Program Manual for

ASTOP

An Arbitrary Space Trajectory Optimization Program

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FOREWORD

ASTOP was originally developed in 1970 under Contract NAS5-11193 for the NASA Goddard Space Flight Center. The development work was sponsored by Mr. Kenneth I. Duck. Principal contributors to the program, in addition to this author, were Samuel Pines and Henry Wolf of Analytical Mechanics Associates, Inc.

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The contributions of all of these individuals are gratefully acknowledged.

ABSTRACT

ASTOP, an Arbitrary Space Trajectory Optimization Program, is designed to generate optimum low-thrust trajectories in an N-body field while satisfying selected hardware and operational constraints. The approach consists of dividing the trajectory into a number of segments or arcs over which the control is held constant. This constant control over each arc is optimized using a parameter optimization scheme based on gradient techniques. A modified Encke formulation of the equations of motion is employed. The program provides a wide range of constraint, end conditions, and performance index options. An equally important feature is that the basic approach is conducive to future expansion of features such as the incorporation of new constraints and the addition of new end conditions.

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I. INTRODUCTION

Over the past several years there have been a limited number of attempts to develop a low-thrust, N-body trajectory optimization program. Most, if not all, of these have been calculus of variations programs which basically differ from the widely used two-body program formulations only in the number of attracting bodies included in the gravitational field simulation. That is to say, there has been little or no concerted attempt to incorporate more realistic system and subsystem simulations and/or hardware and operational constraints in the N-body formulations. In fact, the step from two-body to N-body has been a formidable one and has not as yet been successfully completed. The problem appears to be due to the high non-linearities existing in the proximity of a planet which cause extreme convergence difficulties in the solution of the boundary value problem. And, of course, introducing constraints and increasing the complexity of the models will only serve to magnify this problem.

In ASTOP a different approach to the development of a low-thrust, N-body trajectory optimization program is employed. The underlying principle is that the trajectory is divided into a series of segments over which the control is held constant. Thus, over each segment (or arc), the control is represented as a vector of parameters rather than a set of time-varying functions. Consequently, the optimization problem is no longer one of the calculus of variations, but instead is a parameter optimization problem for which a variety of gradient techniques have been developed and successfully employed. An extremely important side benefit of this approach is that constraints may be added and models made more complex without a great amount of re-programming.

The basic philosophy upon which ASTOP is built is that the performance that may be achieved by fully optimizing a trajectory subject to specified constraints is generally insensitive to the control variables in the vicinity of the optimum. Pursuing this thought, one might concede that a slowly varying control variable might be replaced over a time arc by a constant value with only a small loss in performance and, by choosing a sufficiently small time interval, even fairly large control variable rates might be accomodated with small performance penalties. The basic premise of ASTOP is that, for the low thrust interplanetary missions of current interest, the number of constant control arcs which are required to yield a performance near that of the variational optimum is quite small, possibly on the order of five or six. When one further considers the complexity of the hardware required to continually vary the thrust direction relative to the spacecraft, the simplicity of the approximate optimal constant control arcs becomes increasingly more interesting.

ASTOP is designed such that a complete mission trajectory is comprised of a series of constant control arcs. The number of arcs and their durations are input. The spacecraft orientation angles are the control parameters and, along with the arc end times, certain propulsion system and spacecraft design parameters, and selected initial conditions, are available for optimization. The spacecraft design assumes that the solar arrays (if any) are fixed relative to the thrust vector; consequently, a specified spacecraft orientation affects the performance in three ways: (1) the direction of the thrust vector; (2) the direction and magnitude of the solar pressure; and (3) the magnitude of the power generated due to the incidence angle of the sun's rays on the solar arrays.

Operational constraints are provided through an option which permits one to force the spacecraft orientation to follow a specified vector. This constraint may be employed to satisfy a requirement that an antenna point toward the Earth or that a sensor point toward a specified star or the sun. This feature is termed the Constrained Mode. There are two primary hardware constraints incorporated in the program. One is represented by the fact that the orientation of the arrays is expressly related to spacecraft orientation and, therefore, to thrust direction. This, of course, couples the effects of choice of thrust direction and the power generated as a function of array planform area exposed to the sun. The second hardware constraint is the option of imposing the condition that power input to a thruster be held constant even though the power generated by the powerplant may be variable. This is accomplished by assuming that individual thrusters are turned off as needed and that the fraction of a power unit left over is simply radiated in the form of heat.

The program is designed such that thrusting is not permitted during the first arc following departure of the launch parking orbit. Solar pressure forces are also neglected during this arc; consequently, the spacecraft orientation has no effect on the motion and no providions are made for orientation angle inputs on this first arc. The duration of the arc is input and may be made as long or short as desired.

The program will presently accomodate a maximum of 13 arcs, including the first in which no thrust is permitted. The maximum number of independent parameters presently is 19 while the maximum number of dependent parameters is 30. These limitations may be extended in the future by increasing the dimensions of certain arrays.

II. PROGRAM FORMULATION

Equations of Motion. The equations of motion of the spacecraft in the gravitational field of n attracting bodies and subject to other perturbing accelerations such as thrust and radiation pressure, are given by,*

$$\ddot{R}_v = -\sum_{i=1}^{n} \mu_i \frac{R_{vi}}{r_{vi}^3} + A_p + A_{sr} \quad , \tag{1}$$

where $\ddot{R}_v$ is the total acceleration acting on the vehicle, μ_i is the gravitational constant of the i^{th} attracting body, R_{vi} is the position of the vehicle relative to the i^{th} body, $r_{vi} = |R_{vi}|$, and A_p and A_{sr} represents the non-gravitational perturbing acceleration due to thrust and solar pressure, respectively. These equations are put into observable form by referring them to a reference body c. The equations of motion of the reference body are:

$$\ddot{R}_c = -\sum_{\substack{i=1 \\ i \neq c}}^{n} \mu_i \frac{R_{ci}}{r_{ci}^3} \quad , \tag{2}$$

where $r_{ci} = |R_{ci}|$. Subtraction of Equation (2) from Equation (1) results in the equations of motion of the vehicle with respect to the reference body c.

$$\ddot{R}_{vc} = -\mu_c \frac{R_{vc}}{r_{vc}^3} - \sum_{\substack{i=1 \\ i \neq c}}^{n} \mu_i \left[\frac{R_{vi}}{r_{vi}^3} - \frac{R_{ci}}{r_{ci}^3} \right] + A_p + A_{sr} \quad , \tag{3}$$

with $r_{vc} = |R_{vc}|$. This permits uniform computation of the perturbations, regardless of reference origin.

If Equation (3) is integrated directly by some numerical scheme, there results, after a number of step-by-step integrations, an accumulation of error which leads to inaccurate results. To avoid this loss in precision, it is convenient to write Equation (3) in the form:

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*In this section, upper case symbols commonly denote dimensioned vectors, lower case symbols with an over bar denote unit vectors, and other lower case symbols denote scalars.

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$$\ddot{R}_{vc} = \ddot{R}_k + \ddot{\xi} .$$

The velocity and displacement vectors can be written as:

$$\dot{R}_{vc} = \dot{R}_k + \dot{\xi} ,$$

$$R_{vc} = R_k + \xi .$$

The reference body (the one in whose sphere of influence the vehicle travels) is chosen so as to minimize the perturbat ons.

In this method $\ddot{R}_k$ is taken as:

$$\ddot{R}_k = - \mu_c \frac{R_K}{r_k^3} \tag{4}$$

and

$$\ddot{\xi} = - \mu_c \left[\frac{R_{vc}}{r_{vc}^3} - \frac{R_k}{r_k^3} \right] - \sum_{\substack{i=1 \\ i \neq c}}^{n} \mu_i \left[\frac{R_{vi}}{r_{vi}^3} - \frac{R_{ci}}{r_{ci}^3} \right] + A_p + A_{sr} . \tag{5}$$

Equations (4) constitute the equations of motion of the Kepler problem and are solved by subroutine TBDP. The accelerations $\ddot{\xi}$ are known as the Encke perturbations and this formulation of the equations of motion is termed as Encke formulation.

The terms appearing on the right hand side of Equation (5) involve numerous terms of the form $\frac{R}{r^3} - \frac{R_o}{r_o^3}$ where R and R_o may differ only by small amounts.

A computation scheme, which avoids loss of precision due to the subtraction of nearly equal terms and which also is correct when R_{vc} is not small, is employed. Defining the variable u as:

$$u = \frac{2}{r_o^2} (R_o + \frac{1}{2} \Delta R) \cdot \Delta R ,$$

where $\Delta R = R - R_o$, then the difference terms on the right hand side of (5) may be evaluated

$$\frac{R}{r^3} - \frac{R_o}{r_o^3} = \frac{\Delta R}{r_o^3} + \frac{R\left(u^3 + 3u^2 + 3u\right)}{\left(1 + \frac{r^3}{r_o^3}\right)} .$$

The method presented yields accurate trajectories using relatively little computer time. All significant solar system bodies may be included without undue complications. Since the perturbations only are integrated, the allowable integration interval is fairly large over most of the path. Even in the vicinity of Earth or another planet a relatively large interval (compared to other schemes) may be used without limiting the stability and accuracy of the solutions. The perturbations are kept small in two ways. First, the two-body orbit is rectified whenever the perturbations exceed a specified maximum value compared to the corresponding unperturbed values. This limits error build-up with respect to particular reference body. Second, the reference body of the two-body problem is changed from Earth, to sun, to planet accordingly, as that reference body would contribute the largest perturbing force otherwise. This method is referred to as a modified Encke formulation and will handle circular orbits and zero inclination, which are normally singular regions for the standard e formulation. The problem is defined in terms of parameters which have physical significance (namely, the position and velocity vectors) which are direct elatable to measurable quantities.

The acceleration due to the thrust of the propulsion system may be written

$$A_p = \frac{T}{m}$$

for any propulsion system. Here T represents the thrust vector and m is the mass of the spacecraft. For an electric propulsion system, the power output is limited and it is convenient to write the thrust acceleration in terms of parameters more directly related to the propulsion system design. One such parameter is the reference power, p_r, that is generated by the power source. This is related to the thrust magnitude through the equation

$$f = |T| = \frac{2p_r\eta}{c},$$

where η is the propulsion system efficiency factor and c is the jet exhaust speed. The characteristics of the propulsion system parameters will be discussed subsequently.

Considering the total number of photons impinging on the spacecraft in unit time, let us assume that a ratio c $(0 \le c_a \le 1)$ is absorbed by the spacecraft, and that the remainder is reflected with a reflection angle equal to the angle of incidence. Then, we may write the resultant spacecraft acceleration due to solar radiation pressure, assuming that the spacecraft may be approximated as a flat plate of area a;

$$A_{sr} = \frac{k_s a}{mr^2} |\bar{e}_r \cdot \bar{n}| \left[2(1-c_a)(\bar{e}_r \cdot \bar{n})\bar{n} + c_a \bar{e}_r\right],$$

where $\bar{e}_r$ is a unit vector along the heliocentric position vector, r is the solar distance, $\bar{n}$ is a unit vector normal to the assumed flat plate representing the spacecraft, and k_s is a solar constant representing the solar radiation pressure on a flat plate normal to the sun line at unit distance from the sun, assuming all photons are absorbed.

Propulsion System Characteristics. It is essential that the program be capable of simulating the characteristics of either nuclear or solar electric propulsion systems. The mathematical descriptions of the two types of propulsion systems differ primarily in the representation of p_r, the power generated. For a nuclear electric system, p_r, is generally assumed to be constant over a trajectory, while for a solar electric system, p_r will vary with the solar distance and with the angle of incidence of the sun's rays to the solar panels. Let p_o represent the power that can be generated by the solar panels at unit distance from the sun if the panels are normal to the sun line, and let γ denote the ratio of power available at any specific solar distance and incidence angle to that available at unit distance with normal incidence. Furthermore, let $\bar{n}$ be the unit vector normal to the panels with a direction such that the solar cells are facing the sun providing $\bar{e}_r \cdot \bar{n} > 0$. Then we may write, for the power available to the propulsion system, p_a

$$p_a = p_o \gamma - p_x ,$$

where p_x represents a constant increment of power that may be assigned for purposes other than primary propulsion, such as housekeeping. Unless otherwise specified, it will be assumed that $p_r = p_a$. The assumed form of γ is

$$\gamma = d \sum_{i=0}^{4} a_i d^{i/4} .$$

where d is the density of photons incident on a unit area of the arrays and is defined

$$d = (\bar{e}_r \cdot \hat{n})/r^2 ,$$

and $\hat{n}$ is related to $\bar{n}$ as follows:

$$\hat{n} = \begin{cases} \bar{n} & \text{if } \bar{e}_r \cdot \bar{n} > 0 \\ \bar{0} & \text{if } \bar{e}_r \cdot \bar{n} < 0 \end{cases} .$$

The coefficients a_i, $i = 0, 1, ---, 4$, are input constants. Nuclear electric propulsion is simulated by setting

$$\gamma = 1 .$$

For either type of propulsion system, the jet exhaust speed is assumed constant over the trajectory. The efficiency factor is taken to be a function of the jet exhaust speed c of the form,

$$\eta = \frac{b c^2}{c^2 + d^2} ,$$

where b and d are specified constants. (Note that d is distinct from the photon density defined above). The mass flow of the propulsion system is

$$\dot{m} = -\frac{f}{c} .$$

It should be noted that the acceleration due to radiation pressure will generally be a factor of interest only for solar-electric systems. For such systems, the assumption that the spacecraft is a flat plate in the computation of the solar pressure is appropriate since the solar panels comprise the major portion of the spacecraft area exposed to the sun. The area a of the solar panels, which appears in the equation for solar pressure, is related to the power capacity of the panels through the equation

$$a = k_p p_o + \Delta a ,$$

where k_p is a specified quantity representing the area of solar cells required to generate a unit of power at unit distance from the sun, and Δa is a specified constant.

Depending upon the particular propulsion system hardware involved, it may be desirable to force the power input to a thruster to be constant. Since, for a solar electric system, the power generated will not be a constant, it will be necessary to modulate the total power fed to the thrusters and to control the number of thrusters in use at each instant in time. To this end, define a power increment Δp which represents the desired power level of each individual thruster. Then for a given power available to the propulsion system, p_a, the number of thrusters that may be in operation is

$$\ell = \mathrm{mod}\ (p_a, \ \Delta p),$$

where mod (a, b) is the largest integer that is less than or equal to the quotient a/b. This means that a portion of the power available, p_d, given by

$$p_d = p_a - \ell \Delta p$$

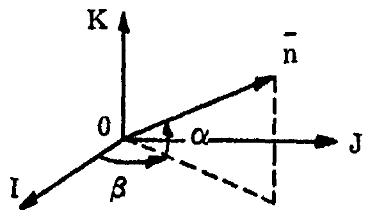
must be discarded. The actual power used by the propulsion system is

$$p_r = \ell \Delta p.$$

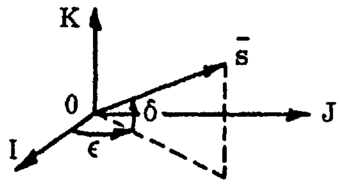
<u>Spacecraft Design Considerations</u>. For reliability reasons, it is desirable to fix the orientation of the solar panels of an electrically propelled spacecraft relative to the central portion of the spacecraft. Consequently, the normal vector, $\bar{n}$, that appears in both the propulsion and the solar pressure terms of the equations of motion must be expressed in a body-fixed coordinate system. For this purpose, introduce the Cartesian frame OIJK which is fixed in the spacecraft. Relative to this system $\bar{n}$ would be written

$$\bar{n} = \cos\alpha \cos\beta I + \cos\alpha \sin\beta J + \sin\alpha K ,$$

where the angles α and β would be design parameters that are specified and held constant throughout the trajectory.



It is also useful to define an additional arbitrary unit vector, say $\bar{s}$, that is fixed in the OIJK system, i.e.,



$$\bar{s} = \cos\delta \cos\epsilon I + \cos\delta \sin\epsilon J + \sin\delta K .$$

The angles δ and ϵ are also specified design parameters that are held constant throughout the trajectory. The purpose of this vector will be discussed subsequently in the section pertaining to flight mode options.

The thrust direction, defined by the unit vector

$$\bar{e}_T = T/|T| ,$$

is assumed fixed in the OIJK coordinate system and directed through the center of gravity. We will, without loss of generality, assume that

$$\bar{e}_T = I.$$

Flight Mode Options. It is desired to provide the capability of generating approximate optimum trajectories for a given mission for a variety of flight modes. For all flight modes, the trajectory is divided into a series of arcs. Over each arc the control parameters are held constant, and we seek the optimum control parameters of each arc. In general, the available control parameters will include certain initial conditions, propulsion system parameters, engine on and off times, and the thrust angles. Two basic flight modes are provided. The first is termed the unconstrained mode for which complete freedom is permitted in selecting the optimum spacecraft orientation for a given arc. The second mode is termed the constrained mode because the body-fixed unit vector, $\bar{s}$, discussed previously, is required to continuously lie within a cone of specified half-angle about a known vector. The orientation of $\bar{s}$ within the cone is arbitrary as is the roll orientation of the spacecraft about $\bar{s}$.

A. Unconstrained Mode. Let XYZ represent the inertial frame of reference in which the trajectory computations (heliocentric) are made. We define the orientation of the spacecraft in terms of the IJK axes, relative to the inertial frame through the angles ξ, ν, ζ. Let ξ denote the nodal angle which is a rotation about the Z axis to the node of the I-J and X-Y planes; ν denotes a rotation about the nodal line and is the inclination of the I-J plane relative to the X-Y plane; ζ denotes a rotation in the I-J plane from the node to the I-axis. The transformation from the XYZ to the IJK system is

$$A(\xi, \nu, \zeta) = \begin{bmatrix} (c\zeta c\xi - s\zeta s\xi c\nu) & (c\zeta s\xi + s\zeta c\xi c\nu) & (s\zeta s\nu) \\ (-s\zeta c\xi - c\zeta s\xi c\nu) & (-s\zeta s\xi + c\zeta c\xi c\nu) & (c\zeta s\nu) \\ (s\xi s\nu) & (-c\xi s\nu) & (c\nu) \end{bmatrix}$$

where s and c denote sine and cosine, respectively. Since the transformation is orthogonal, the inverse of $A(\xi, \nu, \zeta)$ is equal to its transpose, facilitating the transformation from the IJK to the XYZ system. Thus, the vectors $\bar{n}$ and $\bar{e}_T$ in the inertial coordinate system, which are required for the equations of motion, are

$$\bar{n} = A(\xi, \nu, \zeta)^T \begin{bmatrix} \cos\alpha\cos\beta \\ \cos\alpha\sin\beta \\ \sin\alpha \end{bmatrix}$$

$$\bar{e}_T = A(\xi, \nu, \zeta)^T \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

where the superscript T denotes transpose. The choice of the three angles at the start of each arc is completely unconstrained; however, once the choice is made, the angles are held constant throughout the arc.

B. Constrained Mode. A problem of particular interest is that of optimizing the motion of the spacecraft subject to the constraint that the antenna, which is fixed relative to the spacecraft, be continuously pointing in the general direction of the Earth. Other constrained problems of interest include thrusting at a fixed angle to the sun line and thrusting along the velocity vector. All of these problems may be considered within the framework of the following general formulation.

Consider the body-fixed unit vector $\bar{s}$, given by

$$\bar{s} = \cos\delta\cos\epsilon\, I + \cos\delta\sin\epsilon\, J + \sin\delta K ,$$

where, as stated previously, δ and ϵ are specified angles representing spacecraft design factors. $\bar{s}$ is an arbitrary vector that may be used for different purposes in different problems. As an example, it may represent the antenna pointing direction. In the most general constrained case, we require that the spacecraft be continuously oriented such that $\bar{s}$ lies within a cone of specified half angle about a known unit vector $\bar{x}(t)$. This latter vector is determined internally in the program according to an input option flag. The input options permit defining $\bar{x}(t)$ as the direction from the spacecraft to any planet, the sun, or a star, or as the direction of the heliocentric velocity vector. The position of $\bar{s}$ in the cone about $\bar{x}(t)$, which requires two angles for specification, may be specified or optimized. Also the orientation of the pacecraft about $\bar{s}$ is available as a parameter for optimization.

To determine the inertial components of certain body-fixed vectors, e.g., $\bar{e}_T$ and $\bar{n}$, it is necessary to define a series of rigid body rotations and the transformations associated with each. To this end, consider two arbitrary unit vectors $\bar{a}$ and $\bar{b}$ and suppose $\bar{a}$ is rotated about $\bar{b}$ through an angle α to a position $\bar{c}$. In general, $\bar{c}$ is given by

$$\bar{c} = A(\bar{b}, \alpha)\, \bar{a} ,$$

where $A(\bar{b}, \alpha)$ is a transformation matrix of the form

$$A(\bar{b}, \alpha) = U\cos\alpha + B(1 - \cos\alpha) + C\sin\alpha,$$

with U being the 3x3 identity matrix,

$$B = \begin{bmatrix} b_1 b_1 & b_1 b_2 & b_1 b_3 \\ b_2 b_1 & b_2 b_2 & b_2 b_3 \\ b_3 b_1 & b_3 b_2 & b_3 b_3 \end{bmatrix}$$

and

$$C = \begin{bmatrix} 0 & -b_3 & b_2 \\ b_3 & 0 & -b_1 \\ b_2 & b_1 & 0 \end{bmatrix}$$

where b_1, b_2, b_3 are the components of $\bar{b}$. In vector notation, this general transformation may be written

$$\bar{c} = \cos\alpha\, \bar{a} + (1 - \cos\alpha)(\bar{a} \cdot \bar{b})\,\bar{b} + \sin\alpha\,(\bar{b} \times \bar{a})$$

At any instant in time, the spacecraft orientation in inertial space may be defined through the following sequence of rotations. First, consider the body axis system IJK aligned with the inertial frame such that the components of $\bar{s}$ are identical in the body and the inertial coordinate systems. Then rotate the IJK system through an angle σ such that $\bar{s}$ is aligned with $\bar{x}(t)$. The angle σ is given by

$$\sigma = \cos^{-1}(\bar{s} \cdot \bar{x}) \qquad (0 \le \sigma \le \pi)$$

and the rotation is about a unit vector $\bar{m}$ which is normal to both $\bar{s}$ and $\bar{x}$, i.e.,

$$\bar{m} = (\bar{s} \times \bar{x})/\sin\sigma\,.$$

The transformation for this rotation is, of course, $A(\bar{m}, \sigma)$ for which the general form is given above. We now seek two rotations which together uniquely define the location of $\bar{s}$ within the cone about $\bar{x}$. For reasons which will become clear subsequently, we choose first a rotation about $\bar{x}$ through an arbitrary angle ϕ followed by a rotation about a vector normal to $\bar{x}$ through an angle ψ. The particular normal vector about which this latter rotation takes place is entirely arbitrary and we pick, for convenience, one which is easily attainable and which is known to be normal to $\bar{x}$ without checking. This vector is the one which $\bar{m}$ would occupy after rotating through the angle ϕ about $\bar{x}$. Denote this vector $\bar{q}$, then

$$\bar{q} = A(\bar{x}, \phi)\,\bar{m}\,,$$

and the transformation matrix for the third rotation is $A(\bar{q}, \psi)$. This particular choice for the second and third rotations was made because it results in a single control parameter, namely ψ, through which the constraint that $\bar{s}$ lie within a specified cone about $\bar{x}$ may be imposed. Letting ψ_{max} represent the specified half-cone angle, then the constraint is satisfied simply by forcing

$$\psi \leq \psi_{max} .$$

If the value of ψ to be used at a particular time satisfies the inequality constraint, then the solution proceeds as if there were no constraint. If, however, the inequality constraint would be violated, then ψ is set equal to ψ_{max}. Denoting as $\bar{s}_I$ the vector $\bar{s}$ in the inertial system, we then have

$$\bar{s}_I = A(\bar{q}, \psi)\, \bar{x} .$$

The final rotation required is one about $\bar{s}_I$ through an angle θ, for which the transformation matrix is $A(\bar{s}_I, \theta)$. The angle θ defines the roll orientation of the spacecraft about the vector $\bar{s}$ (or $\bar{s}_I$), and is an independent parameter for optimization.

The application of the above-defined transformations permits one to obtain the inertial components of any unit vector, say $\bar{p}$, that is fixed in the IJK system and has the known components p_1, p_2, p_3. Denoting the inertial components of $\bar{p}$ as p_{I_1}, p_{I_2}, p_{I_3} then

$$\begin{bmatrix} p_{I_1} \\ p_{I_2} \\ p_{I_3} \end{bmatrix} = A(\bar{s}_I, \theta)\, A(\bar{q}, \psi)\, A(\bar{x}, \phi)\, A(\bar{m}, \sigma) \begin{bmatrix} p_1 \\ p_2 \\ p_3 \end{bmatrix}$$

Of course, this transformation is valid for both $\bar{p} = \bar{n}$ and for $\bar{p} = \bar{e}_T$.

Two special cases of the above formulation for the constrained mode warrant mention. The first is that by setting ψ_{max} equal to a large number, one may effectively run unconstrained trajectories with the same control parameters used in the constrained mode. The second is that $\bar{s}$ may be forced to coincide with $\bar{x}$ exactly by requiring that

$$\psi = \psi_{max} = 0 .$$

However, if this is done, then ϕ and θ are not independent parameters and it is convenient to set $\phi = 0$. If this is done, then both $A(\bar{x}, \phi)$ and $A(\bar{q}, \psi)$ degenerate to the identity matrix, and θ is the only spacecraft orientation angle remaining to be optimized.

The angles ϕ, ψ, and θ are held constant over each arc of the trajectory, although they are permitted to vary from arc to arc. Also the input angle ψ_{max} is held constant over each arc, but is permitted to change at the start of each arc. This allows the study of cases in which $\bar{s}$ is either little or not at all constrained over some arcs and very tightly constrained over other arcs.

Optimization Parameters. At the user's option, the following parameters are available for optimization.

Initial Conditions

i, Ω, ω - inclination, longitude of ascending node, and argument of perigee of the launch parking orbit,

$x_{p_o}, y_{p_o}, z_{p_o}$ - initial planetocentric position components, and

$\dot{x}_{p_o}, \dot{y}_{p_o}, \dot{z}_{p_o}$ - initial planetocentric velocity components; or

t_o - time at departure of parking orbit, and

v_{p_o} - speed at departure of parking orbit

Propulsion system parameters

p_o - reference power

c - jet exhaust speed

Spacecraft design parameters

α, β - direction angles of solar array normal vector

δ, ϵ - direction angles of constraint vector (e.g., antenna pointing vector)

Arc end times

$t_1, t_2, ---, t_n$ - times at which arcs terminate

Thrust angles (independent set for each arc)

Unconstrained mode

ξ, ν, ζ

Constrained mode

ϕ, ψ, θ

Initial Conditions. The initial position and velocity of the spacecraft at departure of the launch parking orbit are direct inputs. These inputs are in the form of the geocentric ecliptic Cartesian coordinates of the position and velocity x_{po}, y_{po}, z_{po}, $\dot{x}_{po}$, $\dot{y}_{po}$, $\dot{z}_{po}$. The time of launch from the parking orbit is the input launch date t_ℓ. Once the initial position, velocity, and time are defined, the motion of the spacecraft is integrated forward along a coasting arc in the n-body force field (no solar radiation pressure) to an input time t_1, which represents the time at which the electric propulsion system is turned on and solar radiation pressure is included in the perturbations. Typically, t_1 will be several hours past t_o. The introduction of the time interval between the high-thrust phase and the starting of the low-thrust phase serves two purposes. First, it includes in the simulation a phase that will be necessary in a mission to erect solar arrays and/or make other preparations, and check out systems before commencing the interplanetary phase of the mission. Secondly, the time interval permits the vehicle to recede from the proximity of a planet which, inherently, is a region of high non-linearities and which frequently cause considerable difficulty in the trajectory and mission analysis.

Two options are available for optimizing the point of departure from the parking orbit. In one option, the spacecraft is assumed to have a prescribed ephemeris in the given orbit such that the variation of the launch time results in the variation of the point of departure as defined by two-body motion in the parking orbit. In this option the independent parameters are the speed at departure v_{po} and the initial time t_o. Partial derivatives of the state with respect to these parameters are obtained analytically rather than by finite differences over the first arc. These partials are obtained:

$$\frac{\partial R_{p_o}}{\partial v_{p_o}} = 0; \quad \frac{\partial \dot{R}_{p_o}}{\partial v_{p_o}} = \frac{V_{p_o}}{v_{p_o}}$$

$$\frac{\partial R_{p_o}}{\partial t_o} = \sqrt{\frac{\mu_p}{|R_{p_o}|}}\ \frac{V_{p_o}}{v_{p_o}}; \quad \frac{\partial \dot{R}_{p_o}}{\partial t_o} = -\frac{\mu_p}{|R_{p_o}|^3} R_{p_o}$$

$$\frac{\partial m_o}{\partial v_{p_o}} = -\frac{a_1}{a_2} e^{-(v_{p_o}/a_2)}; \quad \frac{\partial m_o}{\partial t_o} = 0 ,$$

where R_{p_o}, $\dot{R}_{p_o}$ are the planetocentric position and velocity at departure of the launch parking orbit. The partials at the end of the first (two-body) arc are then immediately obtained by multiplying these partials by the state transition matrix for that arc. The partials of the initial mass m_o are obtained by differentiating the equation

$$m_o = a_1 e^{-v_{p_o}/a_2} - a_3 ,$$

where a_1, a_2 and a_3 are input constants describing the performance capability of a specific launch vehicle. The second option permits variations in initial position and velocity through variations in the circular launch parking orbit orientation and the speed of departure. As in the previous option, the departure point is assumed to coincide with the periapse of the departure hyperbola. From the input planetocentric position and velocity vectors R_{p_o}, $\dot{R}_{p_o}$, compute the angular momentum

$$H = R_{p_o} \times \dot{R}_{p_o} ,$$

and define

$$\bar{h} = H/|H| ; \quad \bar{\ell} = (\bar{k} \times \bar{h})/\sin i ,$$

where $\bar{k}$ is a unit vector along the North Pole and i is the inclination of the parking orbit relative to the equator. The unit vector $\bar{\ell}$ lies along the ascending node of the parking orbit on the equator. The inclination is obtained from the equation

$$\cos i = \bar{h} \cdot \bar{k} .$$

Letting the independent parameters for this option be the inclination i, the longitude of node Ω, the argument of perigee ω, and the departure speed v_{p_o}, the desired partials are written

$$\frac{\partial X}{\partial i} = \bar{\ell} \times X ,$$

$$\frac{\partial X}{\partial \Omega} = \bar{k} \times X ,$$

$$\frac{\partial X}{\partial \omega} = \bar{h} \times X ,$$

$$\frac{\partial m_o}{\partial i} = \frac{\partial m_o}{\partial \Omega} = \frac{\partial m_o}{\partial \omega} = 0 ,$$

where X denotes either R_{p_o} or $\dot{R}_{p_o}$. The partials with respect to v_{p_o} remain the same as for the first option above. Again, the partials at the end of the first arc are obtained by multiplying the above by the state transition matrix.

Trajectory Integration. A trajectory is generated by numerically integrating the second order differential equations for the Encke perturbations $\ddot{\xi}$ and the first order equation for the mass flow rate $\dot{m}$. The program is designed such that any perturbation trajectories required by the differential corrections scheme for the evaluation of partial derivatives are integrated simultaneously with the nominal trajectory. Consequently, at any one time, the program may be integrating either a single trial trajectory or a total of $(p+1)$ trajectories where p is the number of perturbation trajectories. The number p may differ from arc to arc as explained in the description of subroutine GENMA.

The two-body trajectory that serves as the reference for the Encke perturbation is evaluated in subroutine TBDP. The same two-body reference trajectory is employed for the nominal and all associated perturbation trajectories, thereby saving considerable computational effort. The criteria for rectification of the reference trajectory is applied only to the nominal trajectory, however.

A sixth-order, backward-difference integrator is employed in the program. The difference table is constructed using a fourth-order Runge-Kutta integrator with a step size equal to one-fourth the standard interval. After completing six steps with the Runge-Kutta, integration commences with the backward-difference formulas for 18 additional steps at the reduced interval. After every fourth of the total 24 steps, the results are stored in a separate table such that, after the 24th step, a difference table is available for continuation of the integration with the backward-difference formulas at the full step size.

The independent variable of integration used in ASTOP is the universal variable, β. This variable is related to the change in eccentric along the two-body reference trajectory, as follows:

$$\beta = \sqrt{a_k}\ (E - E_o)\ ,$$

where a_k is the semi-major axis, E is the eccentric anomaly and the subscript o refers to an arbitrary epoch, such as a rectification point. Through differentiation, it is seen that

$$\dot{\beta} = \sqrt{\mu}/r_k ,$$

where μ is the gravitational constant of the reference body and r_k is the magnitude of the position vector on the two-body reference trajectory. Consequently, denoting derivatives with respect to β with the prime, the first and second order derivatives of any variable x with respect to β may be written

$$x' = \dot{x}/\dot{\beta} ,$$

$$x'' = \ddot{x}/\dot{\beta}^2 + x'(R_k \cdot \dot{R}_k)/r_k\sqrt{\mu} ,$$

where R_k and $\dot{R}_k$ are the position and velocity vectors, respectively, on the reference two-body trajectory.

It should be noted that, in the discussions throughout this document, the terminology "trial trajectory" and "nominal trajectory" are generally synonymous when referring to the storage of trajectory data in various arrays. Trial trajectory implies that no perturbation trajectories are currently being evaluated. Trial trajectory data are stored in the storage locations reserved for nominal trajectories when both nominal and perturbation trajectories are generated.

As a final point, it will be noted in various subroutine descriptions that various arrays will be referred to as position vectors or velocity vectors but are actually dimensioned six. The reason for this is that ASTOP frequently requires the magnitude or the square or cube of the magnitude of a vector. To avoid recomputing these quantities, these magnitude related variables are selectively computed and stored in a consistent format for subsequent use. The format of a typical six vector R with components x, y, z and magnitude r is

$$R = [x, y, z, r^3, r, r^2] .$$

Partial Derivative Matrix. The partial derivatives of the performance index and the end conditions with respect to the independent parameters of the problem are required for the parameter optimization and for the solution of the boundary value problem. For the most part, these partials are generated through the use of a differential corrections technique involving the simultaneous generation of the nominal trajectory and several perturbation trajectories. As a means of reducing the number of perturbation trajectories required, each arc is considered separately. Perturbation trajectories are integrated over an arc only for the perturbations actually in effect over the arc. The perturbations include those imposed through the choice of independent parameters (only those applicable over the arc) plus all state variables. At the end of each arc, the partials of the final state with respect to all perturbations (including the initial state) are formed. On subsequent arcs, the partials with respect to independent parameters that were applicable on preceding arcs are propagated by successively applying the state transition matrix for each successive arc to the partials matrix of the preceding arc. A detailed description of this process is given in the discussion of subroutine GENMA.

After the matrix for the final arc is generated as above, the end conditions are formed along with their partials with respect to the final state. Thus, the desired partial derivative matrix required by the iterator is formed by multiplying the matrix of partials of the end conditions by the matrix of partials of the final state. The appropriate equations are given in the description of subroutine FNMAT.

Parameter Optimization and the Boundary Value Problem. A generalized iterator, subroutine MINMX3, is employed to solve the boundary value problem and to perform direct parameter optimization. This routine has two basic modes, known as the "select" and the "optimize" modes. In the select mode, the iterator attempts only to satisfy the specified end conditions. In the optimize mode, an attempt is made to improve the performance index while maintaining satisfaction of the end conditions. The transition from select to optimize mode is automatic. If no performance index is specified, the iteration is terminated upon successful completion of the select mode; i.e., the optimize mode is never entered. Typically the iterator displays quadratic convergence properties in the select mode, but rather slow convergence rate when nearing the solution in the optimize mode. Details of the algorithm are presented in the discussion of subroutine MINMX3.

Planetary Ephemerides. Planetary position and velocity data are obtained as a function of date with the use of an analytic ephemeris routine. Planetary orbital elements are stored as quadratic functions of Julian date. The stored coefficients for eccentricity, inclination, longitude of ascending node and latitude of perihelion are referenced to an epoch of January 0.5, 1900, while the coefficients for mean longitude are referenced to an epoch of January 0.5, 1965. The position and velocity vectors are computed in ecliptic Cartesian coordinates in an Equinox of date frame. The computations are performed in subroutine EPH, and the equations and approach used are described in the discussion of that routine.

Rather than compute the planetary ephemerides by calling EPH each time they are required, a table of planetary positions and velocities is computed once each case at equal intervals in time, and interpolation is used for all subsequent evaluations. This table provides for up to 250 locations for each Cartesian component of each vector. The time interval between tabular entries is determined internally, being a multiple of four days and depending upon the anticipated mission duration. That is, for mission durations less than 1000 days, the interval is four days; for missions of 1000-2000 days, the interval is eight days; etc. The table is constructed in subroutine EPHEM; the interpolation is performed in subroutine INT.

III. PROGRAM INPUTS

Namelist Input Feature. Inputs to ASTOP are given through the namelist feature of the IBM Fortran IV programming language. The input namelist is named MINPUT, and every input required or used in the program is declared by the name in the list. The general form for assigning an input value to a quantity is, simply

NAME = VALUE

where NAME is the name assigned to the variable and is included in the namelist, and VALUE is a numerical or logical quantity consistent in form (i.e., logical, interger, or real) with NAME. All MINPUT names commencing with the letters I-N represent integers, whereas all names commencing with the letters A-H or O-Z are double precision floating point numbers. All input data sets must begin with the characters

&MINPUT

commencing in card column 2 and followed by at least one blank. The data set must end with the characters

&END

preceded by at least one blank. Card column 1 is ignored on all input cards. Multiple data assignments on a single card is permissible if separated by commas. A comma following the last VALUE on a card is optional. The order of the input data assignments is arbitrary; i.e., they need not be in the same order as listed in the namelist. In fact, there is no requirement that any specific input parameter be represented in the input data set. If no value is included in the inputs for a particular parameter, the default value is used. A complete list of non-zero default values of input variables is given later in this section. For other details regarding the namelist feature, the reader is referred to the IBM System/360 Fortran IV Language Manual.

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After reading inputs, the routine MODIF is called and can be used for modifying variables not available as program inputs simply by recompiling the subroutine.

Input Variable Descriptions

Variable	Definition
ALPHA	α - angle, in degrees, between $\bar{n}$ and its projection in the body fixed I-J plane.
AL1 AL2 AL3	a_1, a_2, a_3 - coefficients representing the performance of a particular launch vehicle and used in evaluating the initial spacecraft mass as a function of the departure speed. a_1 and a_3 are in kilograms; a_2 is in meters per second.
AO	Array of up to ten coefficients a_i used in the polynomial for the power variation γ with solar distance. Not used if constant power option is in effect (NOPT(66)=1).
APS	α_{ps} - specific propulsion system and power-plant mass in kilograms per watt.
ARCDTA(1, I)	t_i - time at end of i^{th} arc in hours from the input Julian date.
ARCDTA(2, I)	T_i - trigger with possible settings of ± 1. A positive setting indicates that the i^{th} arc will be a thrusting arc, whereas a negative value indicates a coasting arc.
ARCDTA(3, I) ARCDTA(4, I) ARCDTA(5, I)	ξ, ν, ζ, or θ, ψ, ϕ - the appropriate set of three spacecraft orientation angles in degrees, for the i^{th} arc.
ARCDTA(6, I)	ψ_{max} - maximum permissible value of the angle ψ, in degrees for the i^{th} arc. Used only if operating in the constrained flight mode.

ARCDTA(7, I)	p_x - increment of power, in watts, generated by the power source but not available for primary propulsion, for the i^{th} arc.
	For the first arc, only t_1 is needed or used.
ARRAY	A triply dimensioned array (8, 3, 12) of program integration intervals as a function of radial distance from the current reference body. There can be up to 7 integration intervals as specified by the 8 radial points.
	Define the array as ARRAY (J, K, L), then
	L=1, 12 - corresponding planet reference, as follows:

1 - Earth	7 - Saturn
2 - not used	8 - Uranus
3 - sun	9 - Neptune
4 - Venus	10 - Pluto
5 - Mars	11 - not used
6 - Jupiter	12 - not used

K=1 - radial value, in Earth radii when referring to Earth reference; in AU otherwise.

=2 - integration interval, in (Earth radii)$^{\frac{1}{2}}$ when referring to Earth reference; in (AU)$^{\frac{1}{2}}$ otherwise.

=3 - not used.

J=1, 8 - up to 8 radii or 7 intervals.

The integration interval ARRAY (J, 2, L) applies between the two radial distances defined by ARRAY (J, 1, L) and ARRAY (J+1, 1, L). The distances must be input monotonically increasing with J.

BL	b - dimensionless coefficient used in the expression for electric propulsion system efficiency.

BTA		β-angle, in degrees, between the projection of $\bar{n}$ in the body fixed I-J plane and the I (thrust) axis.

BX — Array dimensioned (4,100), containing the independent parameter information.

BX(1,J)	Trigger indicating whether J^{th} parameter is to be an independent parameter in boundary value problem. BX(1,J) = 0. Not an independent parameter. = 1. Used as independent parameter.
BX(2,J)	Perturbation increment used to compute partial derivatives. Used only if trigger is on. Units are same as that of the parameter.
BX(3,J)	Maximum change to J^{th} parameter permitted in a single iteration. Should be a positive quantity. Used only if trigger is on. Units are same as that of the parameter.
BX(4,J)	Weighting factor. Should be a positive quantity. A guideline for selecting these weights is to estimate the uncertainty in how well you think you know a given independent variable. Then set the weighting factor equal to the inverse square of the uncertainty, where the uncertainty is expressed in the same units as the input units of the variable. The smaller the value of the weighting factor, the more the importance given to the associated variable by the iterator.

The initial values for all independent parameters are input separately as described below. The specific independent parameters associated with the various values of J in the BX array are as follows:

J = 1	t_o - time of departure from Earth parking orbit in hours from the input Julian launch date (XJLD). The input value is assumed to be zero. Since analytic partials with respect to t_o are employed, BX(2, 1), the increment, is ignored.
= 2-5	delta increments in the parameters argument of pericenter (ω), longitude of ascending node (Ω), inclination (i) and speed at pericenter (v_{po}), respectively. The units are degrees for the angles and Earth radii per hour for v_{po}. These are increments to the nominal values obtained from the position and velocity vectors and are therefore zero on all nominal trajectories. No input value is required for these parameters. Since analytic partials are employed for these parameters, the perturbation increments are ignored. These parameters may not be used in conjunction with either J=1 or 6.
= 6	v_{p_o} - speed at departure from Earth parking orbit in Earth radii per hour. This parameter is not input but is computed from the VEL vector. Not used if BX(1, 5) is equal to one.
= 7-9	x, y, and z components, respectively, of the geocentric position at departure from the Earth parking orbit, in Earth radii. May not be used as independent parameters if independent parameters 1-6 are used.
= 10-12	x, y, and z components, respectively, of the geocentric velocity at departure from the Earth parking orbit, in Earth radii per hour. May not be used as independent variables if independent parameters 1-6 are used.

BX (cont)	J = 14	Jet exhause speed c of low thrust propulsion system in m/sec.
	= 15	Reference power p_o of low thrust propulsion system in watts.
	= 16-17	Angles α and β, respectively, in degrees, defining the direction of the unit vector $\bar{n}$, the normal to the solar cell array, relative to the body fixed coordinate system OIJK.
	= 18-19	Angles δ and ϵ, respectively, in degrees, defining the direction of the $\bar{s}$ vector relative to the body fixed coordinate system OIJK.
	= 20	End time of the first arc in hours.

The remaining parameters are in groups of four for each arc commencing with the second arc. i pertains to the arc number where $i \geq 2$.

4i+13 4i+14 4i+15	The first three parameters are the spacecraft orientation angles, in degrees. The orientation angles ξ, ν, ζ (unconstrained mode) or θ, ψ, ϕ (constrained mode) have identification numbers 4i+13, 4i+14, 4i+15, respectively. The mode is determined by option NOPT(65).
4i+16	The last parameter for each arc is the time at the end of the arc in hours.

BY Array, dimensioned (3,50), containing information pertinent to the dependent parameters. For each dependent parameter the iterator requires up to three input quantities. These inputs are:

BY(1,L)	Trigger. If off (i.e., equal to zero), the parameter is ignored and is not considered a dependent parameter. Then the other two inputs pertaining to the L^{th} parameter need not be input. If trigger is on (i.e., not equal to zero), the L^{th} parameter is considered to be a dependent parameter or constraint.

BY (cont)	BY(2, L)	Desired value of the dependent parameter.
	BY(3, L)	Tolerance of convergence to desired value.

The specific dependent parameters associated with the several possible values of L are as follows:

L = 1	Initial mass less low thrust propellant and retro propellant if any, in kilograms.
= 2	Net spacecraft mass m_n in kilograms.
= 3	Reference thrust f_o in newtons.
= 4	Heliocentric distance r in AU.
= 5	Heliocentric speed v in AU/hr.
= 6	Helio. semi-major axis a in AU.
= 7	Helio. flight path angle γ in degrees.
= 8	Helio. eccentricity e.
= 9	Helio. apocenter distance r_a in AU.
= 10	Helio. pericenter distance r_p in AU.
= 11	Planetocentric distance r_T in AU.
= 12	Planetocentric speed v_T in AU/hr.
= 13	Planeto. semi-major axis a_T in AU.
= 14	Planeto. flight path angle γ_T in deg.
= 15	Planeto. eccentricity e_T.
= 16	Planeto. apocenter distance r_{Ta} in AU.
= 17*	Planeto. pericenter distance r_{Tp} in AU.

*When this parameter is designated as an end condition, its trigger is automatically reset to zero as is that of r_T (L=11), and the triggers of the Cartesian coordinates (L=18-20) are set to one. The desired values of r_T and the tolerances of the Cartesian coordinates must be input. A flag is set internally to re-evaluate the desired values of the Cartesian coordinates on each trajectory.

BY (cont)	L = 18	x	Cartesian coordinates of vehicle with respect to target in AU.
	= 19	y	
	= 20	z	
	= 21-50	Not used.	

The notation employed above for the end conditions is consistent with that used in the description of subroutine FNMAT of this report. The reader is referred there for a mathematical description of each end condition.

CA — c_a - fraction of photons incident on the solar arrays that are absorbed ($0 \leq c_a \leq 1$). The remainder of the photons are assumed to be reflected at an angle equal to the incidence angle.

CE — c - jet exhaust speed of electric propulsion system, in meters per second.

CNI — Not presently used.

CR — c_r - jet exhaust speed of the retro stage in m/sec.

DELP — Δp - power of the individual thrusters, in watts. A non-zero value implies discrete steps in power consumed by electric propulsion system as distance from the sun varies.

DLTA — δ - angle, in degrees, between $\bar{s}$ and its projection in the body-fixed I-J plane.

DP — Δa - portion of spacecraft area independent of the reference power, in m^2.

DSQ — d^2 - coefficient used in the expression for electric propulsion system efficiency, in units of m^2/sec^2.

ECI — Not used.

EMUDD — Not used.

ENPLAN	The flag defining the number of attracting bodies to be included in the simulation. Referring to the list of planet numbers in the description of IREFNB, the input number for this flag means that all bodies in the list whose planet number is less than or equal to this flag are included in the simulation. Thus, the input value of this flag should be greater than or equal to the target planet number. If the target is not a planet, the flag must be greater than or equal to 3.
EPSLON	ϵ - angle, in degrees, between the projection of $\bar{s}$ in the body fixed I-J plane and the I (thrust) axis.
ER	Vector containing the x, y, and z components, respectively, of the inertial unit vector along which $\bar{s}$ is to be directed. Used only if NOPT(64) = 2.
IREFNB IREFNT	These two fields are the planet numbers of the launch and target planets, respectively. The code numbers for the individual planets are as follows:

1 - Earth	6 - Jupiter
2 - not presently used	7 - Saturn
3 - Sun	8 - Uranus
4 - Venus	9 - Neptune
5 - Mars	10 - Pluto

ITF	Provides normal termination conditions for runs which require more execution time than is estimated. The value specifies the number of CPU seconds required to execute the summary trajectory.
ITMAX	Maximum number of iterations in each of the two modes, select and optimize, of the iterator.
MOPT	Index defining which of the available end conditions is to be the performance index of the problem. Corresponds to the index L of the BY array.

NARCS — Number of arcs comprising the complete trajectory, including the initial arc commencing at departure from the launch parking orbit during which no thrust is permitted.

NOPT — A 72 element array of ASTOP option flags. Elements 2-13 and 40-46 are used to select or suppress printout of position and velocity information relative to various reference bodies. A non-zero value input for a specific element results in the printing of the associated vector at each print point. Note that for elements 41-46, element 40 must also be set non-zero. The vectors associated with each element are as follows:

2 - Spacecraft position relative to current integration reference body, in km.

3 - Spacecraft velocity relative to current integration reference body, in km/sec.

4 - Spacecraft position relative to Earth, in km.

5 - Spacecraft position relative to Moon, in km.

6 - Moon position relative to Earth, in km.

7 - Spacecraft position relative to Sun, in km.

8 - Spacecraft position relative to Venus, in km.

9 - Spacecraft position relative to Mars, in km.

10 - Spacecraft position relative to Jupiter, in km.

11 - Spacecraft position deviation from reference two body conic, in km.

12 - Spacecraft velocity deviation from reference two body conic, in km/sec.

NOPT (cont)

13 - Non-two body accelerations acting on spacecraft, in km/sec^2.

40&41 - Spacecraft position relative to Saturn, in km.

40&42 - Spacecraft position relative to Uranus, in km.

40&43 - Spacecraft position relative to Neptune, in km.

40&44 - Spacecraft position relative to Pluto, in km.

40&45 - Spacecraft position relative to Earth-Moon barycenter, in km.

40&46 - Spacecraft position relative to Mercury, in km. (Not available)

The remaining elements that are currently used by ASTOP are as follows:

16 - Controls the printing of information at each rectification point.

=0 - information is printed
≠0 - printout is suppressed

33 - Controls the units of printout of the osculating orbital elements semi-major axis a, apoapse distance r_a, and periapse distance r_p.

=0 - a in units of Earth radii and r_p and r_a in kilometers.
≠0 - a, r_p and r_a in units of AU.

50 - Indicates that the orbital elements of the target are input. This option is not currently available. The value should be zero, the default value.

57 - Indicates that a final retro maneuver is to be simulated.

=0 - no retro maneuver.
≠0 - a retro maneuver is to be performed. The parameters RTA and RTP as well as the retro stage structural and performance parameters must be input.

58 - Defines whether the iterator commences in the select or optimize mode.

=0 - start in select mode.
≠0 - start in optimize mode. This option will usually be employed on continuation cases.

60 - Triggers optional printout of trajectory information at arc end points on the final trajectory only or on all trajectories.

=0 - printout requested on final trajectory only.
≠0 - printout requested on all trajectories.

63 - Contains the identification number of the planet toward which $\bar{s}$ is to be directed. The code is the same as for the inputs IREFNB and IREFNT. Used only if NOPT(64) = 1 and NOPT(65) = 2.

64 - Defines the type of constraint placed on the $\bar{s}$ vector, as follows:

=1 - $\bar{s}$ directed toward the planet indicated by NOPT(63).
2 - $\bar{s}$ is directed along the input inertial vector ER.
3 - $\bar{s}$ is directed along the heliocentric velocity vector.
Used only if NOPT(65) = 2.

65 - Defines the steering mode.

=1 - unconstrained mode
2 - constrained mode.

66 - Defines the type of electric propulsion system.

=0 - solar electric
≠0 - nuclear electric

68 - Specifies the orientation constraints of the solar arrays.

=0 - array articulation is restricted to rotation about the longitudinal axis.
≠0 - arrays are forced to be normal to the sun line throughout the trajectory.

NPR — A non-zero value causes the partial derivative matrix to be printed in subroutine MINMX3. This flag need not be set since the matrix is automatically printed elsewhere.

NPWR — Number of coefficients used in polynomial expression for power as a function of solar distance. Not used if constant power option is in effect (NOPT(66) = 1).

OMI — Not used.

POS — Vector containing the geocentrix x, y, and z components, respectively, of the spacecraft position at departure from the Earth's parking orbit, in Earth radii.

POSRCS — Position deviation rectification criteria. Reference two-body trajectory is rectified if $|\xi|^2/r_k^2 >$ POSRCS.

P0 — p_o - reference power in watts.

RBRE	Radius of the Earth's sphere of influence in Earth radii.
REKM	Distance conversion factor. Equal to the number of kilometers in one Earth radius.
RTA RTP	Apocenter and pericenter distances, respectively, of capture orbit about target planet, in planetary radii.
SAI	Not used.
SOI	Not used.
THTS	Maximum change permitted in the osculating eccentric anomaly beyond which rectification of the nominal two body orbit is performed before continuing the integration of the trajectory.
TIMEL	Total time interval in hours from XJLD over which ephemeris table for all planets in simulation is created at start of run.
TPI	Not used.
TSCL	Time conversion factor for input/output purposes. Normally set to 3600.
VEL	Vector containing the geocentrix x, y and z components of the spacecraft velocity at departure of the parking orbit, in Earth radii per hour.
VELRCS	Velocity deviation rectification criteria. Two body reference trajectory is rectified if $\lvert\dot{\xi}\rvert^2/(\dot{R}_k \cdot \dot{R}_k) >$ VELRCS.
WTOPT	Weighting factor for the performance index in the optimize mode. Larger values of WTOPT result in more relative emphasis being placed on the performance index as compared to the end conditions.

XDAR	Array of seven perturbations of state variables x, y, z, $\dot{x}$, $\dot{y}$, $\dot{z}$ and m, respectively, at the start of each arc except first. Used to evaluate state transition matrix for each arc. The appropriate units are AU for position, AU/hr for velocity and kilograms for mass. Only heliocentric position and velocity are used as state variables.
XJLD	Julian date (with leading 244 omitted) which represents the launch date corresponding to the initial conditions input in POS and VEL.
XKP	k_p - surface area of solar arrays per unit reference power, in m^2/watt.
XKR	k_r - tankage factor of the retro stage.
XKS	k_s - solar pressure acting on flat plate at a distance of 1 AU from the sun assuming all photons are absorbed, in newtons/m^2.
XKST	k_{st} - structure factor of the spacecraft.
XKT	k_t - tankage factor of the electric propulsion system.
XMDKM	Conversion factor for distance, equal to the number of kilometers in 1 AU.
YAMBDA	Inhibiting parameter to control the step size in the iterator, MINMX3. The input is used only on continuation cases.

Input Variable Default Values

AL1 = 138726.52

AL2 = 3776.8656

AL3 = 1999.2024

AO = .627
5.3054
-10.0376
7.1073
-2.0021

APS = .03

ARRAY(2,1,I)* = 400.

ARRAY(1,2,I)* = .00390625

BL = .769

CE = 30000.

CR = 2941.995

DSQ = 204490000.

ENPLAN = 6.

ER(3) = 1.

IREFNB = 1

IREFNT = 6

ITF = 10

ITMAX = 50

NARCS = 5

NPWR = 5

POS(1) = 1.025

POSRCS = .0001

P0 = 50000.

RBRE = 123.4

REKM = 6378.165

RTA = 38.

RTP = 2.

SAI = 1.

THTS = 1.5

TIMEL = 15000.

TSCL = 3600.

WTOPT = 1.

VEL(2) = 7.

VELRCS = .0001

XDAR = .1D-8
.1D-8
.1D-8
.1D-9
.1D-9
.1D-9
.1D-2

XKR = .11111110

XKT = .03

XMDXM = 149598000.

YAMBDA = 2^{-28}

Note: All other input variables and arrays are defaulted to zero.

* I = 1-12

IV. PROGRAM OUTPUT

Standard Printout. The printout of ASTOP may be divided conveniently into four groups as follows: (1) the namelist inputs, (2) the iteration summary, (3) the final trajectory summary, and (4) the case summary. The iteration summary is written for each nominal trajectory and contains independent and dependent parameter information, a spacecraft mass breakdown, and the partial derivative matrix. The final trajectory summary includes position and velocity data at the initial time and at the end of each arc. The case summary is a collection of trajectory, spacecraft and mission data that will usually be of interest to the mission analyst and is intended to serve as a brief, one-page description of the salient features of the case. A more detailed description of the ASTOP output is given in the following paragraphs.

To provide a means of verifying the inputs to the program, the input namelist MINPUT is printed at the start of each case. The format is standard namelist format as provided in the Fortran language. All input variables are listed in alphabetical order.

For each trajectory selected as a nominal and for which a partial derivative matrix is evaluated, the iteration summary is printed starting at the top of a new page for each iteration. Following a statement of the iteration number is written a block of parameters preceded with the heading "INDEPENDENT PARAMETERS". The block contains all parameters, each appropriately titled, that are available for selection as independent parameters of the boundary value problem regardless of whether they are actually so designated. Those which are employed as independent parameters in the specific case being considered are indicated with a double asterisk beside the title. The length of the block is variable because that depends on the number of trajectory arcs in the problem. The first line of the block contains seven parameters representing the initial state of the spacecraft (three components each of the initial position and velocity plus the initial mass). The second row contains the jet exhaust speed, c, and reference power p_o, the angles α and β defining the orientation of $\bar{n}$, the angles δ and ϵ defining the orientation of $\bar{s}$, the initial time t_o, and the time of the end of the first (coasting) arc. The next line(s) contains the three thrust angles and the end time for each of the arcs (exclusive of the first) comprising the trajectory. Each line contains information for two arcs. Following the arc data are the four parameters defining changes in the initial orientation of the launch parking orbit and the speed of departure from that orbit. These parameters are titled "DLOMS", "DLOML", "DLINC", and "DLVPO" and represent changes from the previous nominal in argument of perigee, longitude of ascending node, inclination to the equator, and speed at periapse of the launch hyperbola, respectively. The final parameter in the independent parameters block is the speed of periapse of the launch hyperbola.

The next block of data consists of the 20 parameters which are presently available as end conditions. These parameters are all appropriately titled and are preceded by the heading "DEPENDENT PARAMETERS". Again, those parameters which are specified as end conditions of the case are indicated with a double asterisk beside the title. The parameters comprising the 20 available end conditions are the final spacecraft mass; the net spacecraft mass; the reference thrust; the final heliocentric distance and speed; the final heliocentric osculating semi-major axis, flight path angle, eccentricity, apocenter distance and perihelion distance; the target centered final distance and speed; the final planetocentric osculating semi-major axis, flight path angle, eccentricity, apocenter distance and pericenter distance; and the three final planetocentric ecliptic Cartesian components of distance.

Following the block of dependent parameters is a line stating the reference system in which the integration terminated, the value of the inhibitor used by the iterator, and a trajectory counter. This counter is the cumulative number of trajectories integrated exclusive of the nominal trajectories. This is followed by a spacecraft mass breakdown. This includes the initial mass, the low thrust propulsion, propellant, and tankage masses, the structural mass, the retro propellant and structure, and the net spacecraft mass. Finally, the iteration summary print is concluded with the partial derivative matrix. Each row of this matrix represents the partials of one of the specified end conditions with respect to all of the indicated independent parameters. The order of the partials reading across a given row is the same as that in which independent parameters appear in the first block of data of the iteration summary. Likewise, the order reading down the matrix is that in which the dependent parameters as they appear in the second data block. Additional self-explanatory messages from the iterator may follow the partial derivative matrix.

Any particular case may terminate for one of several reasons such as (1) the case is converged, (2) the case will not converge, (3) the maximum number of iterations specified is exceeded, or (4) the case times out. Regardless of the cause of the termination, a final trajectory summary is then printed. This summary consists of standard program print for the initial time and for the final times of the several arcs comprising the trajectory. This includes at each point the position and velocity data as requested through the input flags NOPT(2) - NOPT(16) plus a variety of osculating elements evaluated at the same times. The osculating elements are the true anomaly, semi-major axis, eccentricity, periapse distance, apoapse distance, inclination, argument of periapse, period, mean motion, right ascension of ascending node, mean anomaly, eccentric anomaly, and time since periapse passage. Each data point also includes the ecliptic Cartesian coordinate of a unit vector along the periapse direction and of another unit vector along the angular momentum.

After indicating the launch planet and target of the case mission, the case summary contains a statement as to whether the program is operating in the constrained or unconstrained mode for the case. If in the constrained mode, a message is printed specifying the reference to which $\bar{s}$ is constrained. For the case in which the reference is a star, the input unit vector defining the location of the star is printed. This is followed with a line of data specifying several of the input coefficients used for the case. Included are the coefficients describing the capability of the launch vehicle, the low thrust propulsion system efficiency coefficients, the photon absorption coefficient c_a, and the specific array area k_p. A spacecraft mass breakdown similar to that printed in the iteration summary is then written, followed by the angles α, β, δ, and ϵ which define the orientation of the $\bar{n}$ and $\bar{s}$ vectors in the body fixed coordinate system. The next line of data contains a number of low thrust propulsion system parameters including the reference power, the reference thrust, the jet exhaust speed, the efficiency, the unit thruster power Δp, and the array area. A trajectory schedule is then printed, giving pertinent information from the ARCDTA array relative to each arc. The first line of the block contains the end times of all arcs. Below this are written six lines of data containing the three thrust angles, the power diverted for non-propulsive uses p_x, the maximum allowable half-cone angle ψ_{max} (applicable only for constrained mode cases), and the thrust mode indicator "ON" or "OFF" defining the operational status of the propulsion system for the arc. These six quantities are positioned in separate columns for each arc, and the columns are located below and midway between the two times defining the start and end of the arc. If there are more than eight arcs, the format is repeated until all arcs are accounted for. No information is printed for the first arc since no thrust is permitted on the arc. After the trajectory schedule are written the date, the hyperbolic excess speed, and the energy parameter c_3 at departure of the launch planet and upon arrival at the target. If no retro maneuver is required, the departure and arrival conditions complete the case summary printout. If a retro maneuver is performed, however, then related parameters are printed on a single line. These include the retro stage propellant and structure, the periapse and apoapse distances of the final orbit, the specific impulse of the retro stage, the orbital velocity at periapse of the capture orbit, and the incremental velocity imparted by the retro stage. All units are explicitly indicated on the case summary page. Examples of the above types of printout available with ASTOP are given in the Section VIII, EXAMPLE CASE.

Information and Error Messages. A number of messages can be printed under special circumstances. These messages are listed below. For each one, the subroutine in which the print statement appears is listed, the logical unit on which the message is written is given, the circumstances or cause for the message is explained, the response of the system is described, and some suggested user responses are given when applicable.

Actually all messages are currently written on unit 6 since the logical unit variable IO is set to 6 internally. Note that some messages are coded to unit 6 directly. For a description of the variables printed in the messages, the reader is referred to the description of the appropriate subroutine noted. The description of the messages, in alphabetical order, follows.

1. CASE CONVERGED

Subroutine:	ITMAT
Logical Unit:	IO (=6)
Cause or Reason:	The criterion used by the iterator indicates that the desired solution was achieved.
System Response:	Continues processing.
User Response:	None. The message is for information purposes only.

2. EPHEMERIS TABLE FILLED. CHECK INPUT PARAMETER TIMEL ON FUTURE RUNS FOR POSSIBLE REDUCTION IN EPHEMERIS COMPUTATIONS.

Subroutine:	EPHEM
Logical Unit:	6
Cause or Reason:	All 250 storage locations in the array TBBL of common NORML for each Cartesian coordinate of each planet have been filled.
System Response:	If the input parameter TIMEL significantly exceeds the flight time, in hours, TIMEL should be reduced on future runs to eliminate computations of planetary ephemerides at time points that will not be used.

3. ERROR CONDITION RETURNED FROM MINMX3. RUN TERMINATED IN SUBROUTINE ITMAT

Subroutine:	ITMAT

Logical Unit:	IO (=6)
Cause or Reason:	The iterator, subroutine MINMX3, has detected an uncorrectable error and has transmitted and error condition to the calling routine ITMAT.
System Response:	The job is immediately terminated after writing the above message.
User Response:	Follow the directions given for companion messages generated in MINMX3 at the time the error condition was detected.

4. ERROR IN PARTIAL DERIVATIVE CALCULATION

Subroutine:	MINMX3
Logical Unit:	6
Cause or Reason:	An error condition was detected in subroutine TRAJL while integrating a nominal and perturbation trajectories, and an error flag was returned to the calling routine MINMX3.
System Response:	An error condition flag is set and returned to ITMAT. A return is then executed from MINMX3.
User Response:	Presently, no error conditions are monitored in TRAJL. Therefore, this message will not appear.

5. ERROR TBAR - T0BAR TOO LARGE = (D17.8)
REDUCTION DEN XX ZZ YY DELT IXX
(D25.16) (D25.16) (D25.16) (D25.16) (D25.16) (I4)

Subroutine:	SAMM
Logical Unit:	IO (=6)
Cause or Reason:	The time interval input to subroutine SAMM exceeds the period of the orbit.
System Response:	A set of reduction formulae are automatically invoked to assure accurate computations over the long arc.
User Response:	None. The message is for information purposes only.

6. FIRST GUESSES WILL NOT RUN TRAJECTORY

Subroutine:	MINMX3
Logical Unit:	6
Cause or Reason:	An error condition was detected in subroutine TRAJL while integrating the first trajectory of a case.
System Response:	An error flag is set and returned to subroutine ITMAT.
User Response:	Presently, subroutine TRAJL does not monitor any error conditions. Therefore, this message will never appear.

7. ITERATOR IS GIVING ERROR RETURN

Subroutine:	MINMX3
Logical Unit:	6
Cause or Reason:	An error condition was detected in subroutine TRAJL while integrating a trajectory.
System Response:	An error condition flag is set and returned to subroutine ITMAT. A return to the calling program is then executed.
User Response:	Presently, no error conditions are monitored in subroutine TRAJL. Therefore this message will never appear.

8. ITERATOR IS NOW IN OPTIMIZE MODE

Subroutine:	MINMX3
Logical Unit:	6
Cause or Reason:	All specified end conditions have been satisfied within specified tolerances, thereby completing the objectives of the select mode of the iterator.
System Response:	The iteration continues in the optimize mode.
User Response:	None. Message is for information purposes only.

9. MATRIX INVERSION NOT PERFORMED ON LAST ITERATION

Subroutine: MINMX3

Logical Unit: 6

Cause or Reason: An error condition was detected in subroutine SIMEQ while iterating in the select mode. The inhibitor was moderately large, indicating some convergence difficulty.

System Response: A return to the subroutine ITMAT is executed after printing a message defining the number of trajectories generated.

User Response: The error condition in SIMEQ arises if the simultaneous equations being solved are not all independent. Normally this would suggest an error in defining the independent and/or dependent parameters.

10. MAXIMUM ITER. EXCEEDED I, BETA, BETAM1 = ___(I4)___ ___(E17.8)___(E17.8)___

Subroutine: SAMM

Logical Unit: IO (=6)

Cause or Reason: The iteration for the solution of Kepler's problem did not converge to the required tolerance in 40 iterations.

System Response: Processing continues with the values attained on the last iteration.

User Response: This message is unlikely to appear. However, if it should appear, it would signal either a very unusual orbit or a large time interval. Look for an input error, bad guesses of the independent parameters, or a program error.

11. MAXIMUM NUMBER OF ITERATIONS EXCEEDED

Subroutine: MINMX3

Logical Unit: 6

Cause or Reason: The specified number of iterations, ITMAX, was reached in either the select or optimize mode.

System Response: The last nominal trajectory is integrated once again for print purposes and the case is terminated.

User Response: Resubmit the job with the independent parameters updated to the last iteration.

12. MDC EPH ERROR

Subroutine: EPH

Logical Unit: 6

Cause or Reason: The iterative solution of Kepler's problem failed to converge to prescribed tolerances within 200 iterations.

System Response: The values attained after the limiting number of iterations are used for subsequent calculations.

User Response: This unlikely error condition would most likely occur due to input errors.

13. PARABOLIC ORBIT OSCULATING ELEMENTS SUPPRESSED

Subroutine: ELCO

Logical Unit: IO (=6)

Cause or Reason: The input position and velocity vectors resulted in a value for the inverse of the semi-major axis exactly equal to zero, indicating a parabolic orbit.

System Response: The calculations and printing of the osculating orbital elements are bypassed.

User Response: None. The message is printed for information purposes only.

14. PDATE ERROR

Subroutine: PDATE

Logical Unit: 6

Cause or Reason: The input date corresponds to a calendar year greater than 2100.

System Response: The year is set to 2100 and computation continues.

User Response: Correct inputs or if the date is actually beyond the year 2100, then rewrite subroutine PDATE.

15. RVE EXCEEDS MAX.
IREFNO = ___(I3)___ TIME = ___(D24.15)___ R = ___(D24.15)___

Subroutine: DETDT

Logical Unit: IO (=6)

Cause or Reason: The current radial distance from the reference body exceeds the largest tabular value for that body in ARRAY

System Response: The integration interval is left unchanged and computation continues.

User Response: Correct the input ARRAY table to accomodate the range of distances encountered on the trajectory.

16. RVE LESS THAN MIN.
IREFNO = ___(I3)___ TIME = ___(D24.15)___ R = ___(D24.15)___

Subroutine: DETDT

Logical Unit: IO (=6)

Cause or Reason: The current radial distance from the reference body is less than the first tabular value for that body in ARRAY.

System Response: The integration interval is left unchanged and computation continues.

User Response: Correct the input ARRAY table to accomodate the range of distances encountered on the trajectory.

17. THIS CASE HAS TIMED OUT

Subroutine: TRAJL

Logical Unit: IO (=6)

Cause or Reason: It was determined from subroutine REMTIM that either the CPU or IO time remaining for the job was about to run out.

System Response: A final trajectory is generated for print purposes, the case summary is printed, and the job is terminated.

User Response: Resubmit the job after updating the independent parameters.

18. THIS CASE IS CONVERGED

Subroutine: MINMX3

Logical Unit: 6

Cause or Reason: The criterion used by the iterator indicates that the desired solution was achieved.

System Response: Continues processing.

User Response: None. Message is for information purposes only.

19. THIS CASE WILL NOT CONVERGE

Subroutine: MINMX3

Logical Unit: 6

Cause or Reason: While operating in the select mode, the iterator determines that no further improvement of the dependent parameters can be achieved.

System Response: A flag is set indicating that convergence was not achieved, and a return to ITMAT is executed.

User Response: Analyze the problem to determine if a solution may not exist, i.e., a case where not all end conditions may be satisfied simultaneously. If this appears not to be the case, then the boundary value problem must be altered. For example, selectively remove one or more end conditions to find which condition(s) is causing the problem. A sequence of cases may then be designed to work the end condition toward its desired value.

20. TOO MANY ITERATIONS IN SUBROUTINE TBDP

Subroutine: TBDP

Logical Unit: 6

Cause or Reason: The iterative solution to Keplers problem did not converge to the prescribed tolerance within 20 iterations.

System Response: Processing continues with the values attained on the last iteration.

User Response: Probable input error. Check inputs.

21. TRAJECTORY TERMINATED IN REFERENCE OTHER THAN SUN OR TARGET PLANET. RUN TERMINATED IN SUBROUTINE FNMAT.

Subroutine: FNMAT

Logical Unit: 6

Cause or Reason: At the end of the trajectory, the reference body ID is checked and determined to be other than the sun or the specified target body.

System Response: The job is immediately terminated.

User Response: Check for input errors. This condition is unlikely to occur unless, for some reason, the spacecraft never leaves the reference system of the launch body.

22. nn TRAJECTORIES WITHOUT PARTIAL DERIVATIVES AND nn TRAJECTORIES WITH PARTIAL DERIVATIVES REQUIRED FOR THIS CASE

Subroutine: MINMX3

Logical Unit: 6

Cause or Reason: This message is printed prior to executing a return from MINMX3 except in those cases where an error condition flag is returned from TRAJL.

System Response: Continues processing.

User Response: Follow suggestions given for companion messages.

V. PROGRAM STRUCTURE

In this section, several tables are presented which represent the overall structure of ASTOP. These tables are particularly useful in understanding the organization of the program and in determining the basic relationships among the various subroutines, labelled commons and common variables.

ASTOP is comprised of 39 sub-programs, including MAIN and BLOCK DATA. There are no Function sub-programs within ASTOP. Only one subroutine, DIAG1, contains a secondary entry point. This entry point is named SUMMRY. Since neither DIAG1 nor SUMMRY use calling arguments, the use of the secondary entry point is not expected to require modification when converting to other machines. Subroutine REMTIM is a dummy routine provided for use on systems other than the IBM computers at GSFC. At GSFC, REMTIM is a library subroutine that returns to the calling program the time remaining for the job. ASTOP is coded to use this information to avoid "timing-out", thereby losing valuable information. By properly re-coding REMTIM, other installations may find it possible to duplicate this useful feature.

The first table presented displays the calling sequence of the program subroutines. This "tree" format is useful in determining what sequence of subroutine calls may be invoked when a single call to one subroutine is made. The inverse of this information is presented in the second table. Here, for each subroutine, is listed all other subroutines which call that subroutine. The third table resembles the second, but instead lists all subroutines that contain a specified labelled common. These two tables are listed in the alphabetical order of the referenced subroutine or common name. Note that ASTOP does not contain an unlabelled common.

The final set of tables are particularly useful and unique. Each of the tables represents a specified labelled common and lists each variable that is referenced somewhere in ASTOP. For each variable name there is listed the variable type, the dimension if the name represents an array (a blank denotes a non-dimensioned variable), the relative address (in decimal bytes from the start of the common), and the names of the subroutines that reference the variable or array by the name specified. Note that situations where the same location is referenced by different names in different subroutines are recognized by instances where the relative address is identical for two different names and/or dimensions. If a common block contains a named variable or array that is not referenced in ASTOP, that variable or array will not appear in these tables.

Subroutine Calling Sequence

```
MAIN ─┬─ INPUT ── MODIF ── LAMBRT ── PDATE
      └─ ITMAT ─┬─ MINMX3 ─┐
                │          ├─ XYZ
                │          ├─ TRAJL ──┬─ AMAINT ── DERIV ─┬─ TBDP ── SUBFG
                │          ├─ PMPRNT  │                   ├─ RADII
                │          └─ SIMEQ   │                   └─ SOLENG ─┬─ FINDXB ── INT
                └─ FNPRNT ─┬─ TRAJL (see above)                      ├─ AMAL
                           └─ SUMMRY*                                ├─ MTVT
                                      ├─ REMTIM                      └─ MTMT
                                      ├─ INIT ──── SETI ─┬─ SAMM ──┬─ DCUBIC
                                      │           │      │         └─ SUBFG
                                      │           │      ├─ DIAG1
                                      │           │      ├─ AMAL
                                      │           │      └─ MTVT
                                      │           └─ EPHEM ── EPH
                                      ├─ RECT ── RADII
                                      ├─ DERIV (see above)
                                      ├─ MIIP1 ── ELCO
                                      ├─ DETDT
                                      ├─ CONTRL ─┬─ TBDP ── SUBFG
                                      │          ├─ AMAINT (see above)
                                      │          ├─ GENMA ─┬─ MIIP1 ── ELCO
                                      │          └─ INT    └─ FNMAT ─┬─ INT
                                      └─ SUMMRY*                     ├─ RADII
                                                                     ├─ EPH
                                                                     └─ DIAG1
```

*ENTRY POINTS

SUBROUTINE CROSS REFERENCE TABLE

NAME	SUBROUTINES REFERENCING MEMBER			
AMAINT	CONTRL	TRAJL		
AMAL	SETI	SOLFNG		
CONTRL	TRAJL			
DCUBIC	SAMM			
DERIV	AMAINT	TPAJL		
DETDT	TRAJL			
DIAG1	FNMAT	SETI		
ELCO	MIIP1			
EPH	EPHEM	FNMAT		
EPHEM	INIT			
FINDXB	SOLENG			
FNMAT	GENMA			
FNPRNT	ITMAT			
GENMA	CONTRL			
INIT	TRAJL			
INPUT	MAIN			
INT	CONTRL	DERIV	FINDXB	FNMAT
ITMAT	MAIN			
LAMBRT	MODIF			
MIIP1	GENMA	TRAJL		
MINMX3	ITMAT			
MODIF	INPUT			
MTMT	SOLENG			
MTVT	SETI	SOLENG		
PDATE	LAMBRT			
PMPRNT	MINMX3			
RADII	DERIV	FNMAT	RECT	
RECT	TRAJL			
REMTIM	TRAJL			
SAMM	SETI			
SETI	INIT			
SIMEQ	MINMX3			
SOLENG	DERIV			
SUBFG	SAMM	TBDP		
SUMMRY	FNPRNT	TRAJL		
TBDP	CONTRL	DERIV		
TRAJL	FNPRNT	MINMX3		
XYZ	MINMX3			

COMMON CROSS REFERENCE TABLE

NAME	SUBROUTINES REFERENCING MEMBER					
ALAN	CONTRL	DERIV	DETDT	DIAG1	FINDXB	FNMAT	GENMA
	INIT	LAMBRT	MIIP1	RECT	SETI	SOLENG	TBDP
	TRAJL						
AMI	AMAINT	GENMA	SETI				
AM1	AMAINT	BLK DT	CONTRL	DERIV	DIAG1	FNMAT	GENMA
	MIIP1	RECT	SETI	SOLENG	TBDP	TRAJL	
CONRAD	DIAG1	FNMAT					
CONVRT	RECT	SOLENG					
ENG	GENMA	SOLENG					
FNM	BLK DT	FNMAT	INPUT				
FRAN	BLK DT	DIAG1	INPUT	MIIP1	RECT		
HENRY	BLK DT	CONTRL	DERIV	DETDT	DIAG1	ELCO	EPHEM
	FINDXB	FNMAT	GENMA	INIT	INPUT	LAMBRT	MIIP1
	MODIF	RECT	SETI	SOLENG	TBDP	TRAJL	
HER	BLK DT	CONTRL	DERIV	DIAG1	FNMAT	GENMA	INPUT
	ITMAT	MINMX3	SETI	SOLENG	TRAJL		
HIM	INPUT	ITMAT					
HIS	BLK DT	CONTRL	DIAG1	FNMAT	GENMA	INIT	INPUT
	ITMAT	LAMBRT	MINMX3	SETI			
IEPH	EPH	EPHEM	FNMAT				
ILEF	CONTRL	DERIV	FINDXB	GENMA	INPUT	MIIP1	RECT
	SETI	SOLENG	TRAJL				
INPR	BLK DT	DIAG1	INPUT				
INTEG	BLK DT	CONTRL	DERIV	DETDT	DIAG1	ELCO	FINDXB
	FNMAT	FNPRNT	GENMA	INIT	INPUT	ITMAT	LAMBRT
	MIIP1	RECT	SETI	SOLENG	TRAJL		
JERR	BLK DT	DIAG1	FINDXB	FNMAT	GENMA	INIT	INPUT
	LAMBRT	SETI	SOLENG	TRAJL			
JHW	GENMA	SETI					
KAT	DIAG1	INPUT	MINMX3				
LAMB	BLK DT	DIAG1	EPH	INPUT	LAMBRT		
LEFT	CONTRL	DERIV	DETDT	FINDXB	FNMAT	GENMA	MIIP1
	MODIF	RECT	SETI	SOLENG			
LEON	BLK DT	DERIV	GENMA	RECT	TBDP	TRAJL	
LPPR	DIAG1	INPUT					
MEL	GENMA	SETI	SOLENG				
MINEPS	INPUT	MINMX3					
MINSEC	BLK DT	INPUT	TRAJL				
NOMLL	DIAG1	FNMAT	GENMA	SETI	TRAJL		
NORM	CONTRL	DERIV	EPHEM	FINDXB	FNMAT	INPUT	INT
NORML	EPHEM	INT					
NPNT	BLK DT	INPUT	MINMX3				
ODBALL	BLK DT	EPH	INPUT				
PERAPS	FNMAT	INPUT	MINMX3				
RSCAL	BLK DT	INPUT	LAMBRT	SETI			
SAML1	SAMM	SETI					
STEVE	CONTRL	DERIV	DETDT	GENMA	MODIF	RECT	TBDP
	TRAJL						
TBPR	CONTRL	MODIF	TBDP				
THAD	SAMM	SUBFG	TBDP				
VPLLL	GENMA	LAMBRT	SETI				
XMMM	BLK DT	FNMAT	INPUT	ITMAT	MINMX3	SETI	

COMMON VARIABL= CROSS REFERENCE TABLE

COMMON AMI LENGTH 8

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
NEQN	I*4		0	SETI
				GENMA
				AMAINT

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON AM1 LENGTH 2264

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
T	R*8		8	AMAINT
BETA	R*8		8	RECT
				TBDP
				DERIV
DTI	R*8		16	TBDP
				TRAJL
				CONTRL
DELTI	R*8		16	AMAINT
XI	R*8	80	24	RECT
				AMAINT
XIL	R*8	80	24	SETI
				DERIV
				DIAG1
				FNMAT
				GENMA
				MIIP1
				CONTRL
				SOLENG
XID	R*8	80	664	RECT
				TRAJL
				AMAINT
XIDL	R*8	80	664	SETI
				DERIV
				GENMA
				MIIP1
				CONTRL
D2XI	R*8	80	1304	TRAJL
				AMAINT
D2XIL	R*8	80	1304	DERIV
				GENMA
				MIIP1
				SOLENG
IFST	I*4	80	1944	AMAINT
				BLKDATA

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON ENG LENGTH 2240

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
SNAL	R*8	20	0	GENMA
				SOLENG
CSAL	R*8	20	160	GENMA
				SOLENG
SNBET	R*8	20	320	GENMA
				SOLENG
CSBET	R*8	20	480	GENMA
				SOLENG
SNDL	R*8	20	640	GENMA
				SOLENG
CSDL	R*8	20	800	GENMA
				SOLENG
SNET	R*8	20	960	GENMA
				SOLENG
CSET	R*8	20	1120	GENMA
				SOLENG
SNX	R*8	20	1280	GENMA
				SOLENG
CSX	R*8	20	1440	GENMA
				SOLENG
SNV	R*8	20	1600	GENMA
				SOLENG
CSV	R*8	20	1760	GENMA
				SOLENG
SNZ	R*8	20	1920	GENMA
				SOLENG
CSZ	R*8	20	2080	GENMA
				SOLENG

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON FNM LENGTH 16

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
RTA	R*8		0	FNMAT
				INPUT
				BLKDATA
RTP	R*8		8	FNMAT
				INPUT
				BLKDATA

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON HER LENGTH 576

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
IPS	I*4		0	DIAG1
				FNMAT
				ITMAT
				MINMX3
NDEP	I*4		0	INPUT
NSL	I*4		4	SETI
				DIAG1
				FNMAT
				GENMA
				ITMAT
				MINMX3
NIND	I*4		4	INPUT
NSL1	I*4		8	SETI
				GENMA
IFTRG	I*4		12	SETI
				INPUT
IPOFL	I*4	30	20	DIAG1
				FNMAT
				INPUT
IVAR	I*4	100	140	SETI
				DIAG1
				FNMAT
				GENMA
				INPUT
				ITMAT
ITMAX	I*4		540	INPUT
				ITMAT
				BLKDATA
NTP	I*4		544	SETI
				DERIV
				GENMA
				CONTRL
NTPS	I*4		548	SETI
				DIAG1
				GENMA
				INPUT
				CONTRL
				BLKDATA
NMAX	I*4		552	SOLENG
				BLKDATA
NPWR	I*4		552	INPUT
NJ	I*4		556	SETI
				GENMA
JN	I*4		560	SETI
				GENMA
IPAT	I*4		564	GENMA
				TRAJL
NCT1	I*4		568	SETI

COMMON HER (CONTINUED)

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
				FNMAT
				GENMA
				CONTRL
				SOLENG
NJL	I*4		572	SETI
				GENMA
NVARY	I*4		572	INPUT

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON	HIM	LENGTH	240

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
YCON	R*8	30	0	INPUT
				ITMAT

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON HIS LENGTH 10056

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
PFG	R*8	30,30	0	DIAG1
				FNMAT
				MINMX3
WX	R*8	30	7200	INPUT
				MINMX3
XVAR	R*8	30	7440	SETI
				GENMA
				INPUT
YEPS	R*8	30	7680	INPUT
				ITMAT
				MINMX3
XEPS	R*8	30	7920	INPUT
				MINMX3
CHNS	R*8	100	8160	SETI
				DIAG1
				LAMBRT
CHN	R*8	100	8960	INIT
				SETI
				DIAG1
				FNMAT
				GENMA
				INPUT
				ITMAT
				CONTRL
				LAMBRT
				BLKDATA
PDFL	R*8	30	9760	DIAG1
				FNMAT
XDAR	R*8	7	10000	INPUT
				BLKDATA
XDDR	R*8	7	10000	GENMA

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON	JHW	LENGTH	2072	
VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
PYI	R*8	7,7	0	SETI
				GENMA
CPH	R*8	7,30	392	GENMA

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON KAT LENGTH 16

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
LAMBDA	R*8		0	MINMX3
XAMBDA	R*8		0	DIAG1
				INPUT
KOUNT	I*4		8	DIAG1
				MINMX3
L	I*4		12	MINMX3

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON MEL LENGTH 4

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
ISOL	I*4		0	SETI
				GENMA
				SOLENG

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON ALAN LENGTH 24

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
T	R*8		0	RECT
				TBDP
				DERIV
				DETDT
				DIAG1
				FNMAT
				TRAJL
				CONTRL
				FINDXB
TBET	R*8		0	SETI
				MIIP1
				LAMBRT
RHBR	R*8		8	SETI
				DERIV
				GENMA
				TRAJL
				CONTRL
				SOLENG
DORHO	R*8		16	DERIV
				GENMA
				TRAJL

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON FRAN LENGTH 8

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
XMDKM	R*8		0	RECT
				DIAG1
				INPUT
				MIIP1
				BLKDATA

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON IEPH LENGTH 4

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
NC	I*4		0	EPH
				EPHEM
NCLL	I*4		0	FNMAT

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON ILEF LENGTH 68

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
NEQL	I*4		0	RECT
				SETI
				DERIV
				GENMA
				MIIPI
				CONTRL
				SOLENG
NON	I*4		8	RECT
				SETI
				DERIV
				GENMA
				MIIPI
				SOLENG
NOP65	I*4		12	SETI
				GENMA
				INPUT
				SOLENG
NOP64	I*4		44	INPUT
				FINDXB
NOP63	I*4		48	INPUT
				FINDXB
NS	I*4		52	SETI
				GENMA
N4	I*4		56	SETI
				GENMA
NS1	I*4		60	SETI
				GENMA
NJJ	I*4		64	GENMA
				TRAJL

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON INPR LENGTH 4320

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
ARCDTA	R*8	7,20	0	DIAG1
				INPUT
				BLKDATA
BX	R*8	4,100	1120	INPUT
				BLKDATA

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON JERR LENGTH 4544

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
VBL	R*8	568	0	BLKDATA
VBLDC	R*8	200	0	GENMA
				SOLENG
A	R*8		1600	INPUT
				SOLENG
CA	R*8		1608	DIAG1
				INPUT
				SOLENG
BL	R*8		1616	DIAG1
				FNMAT
				INPUT
				SOLENG
DSQ	R*8		1624	DIAG1
				INPUT
				SOLENG
DELP	R*8		1632	DIAG1
				INPUT
				SOLENG
AO	R*8	10	1540	INPUT
				SOLENG
XKS	R*8		1728	INPUT
				SOLENG
ETV	R*8	3	1736	INIT
				SOLENG
ET	R*8	3	1760	SOLENG
XKP	R*8		1784	DIAG1
				INPUT
ER	R*8	3	1792	DIAG1
				INPUT
				FINDXB
				SOLENG
CP1	R*8	7,30	1816	SETI
				FNMAT
				GENMA
				TRAJL
TBIN	R*8	122	3496	SETI
				FNMAT
				GENMA
				INPUT
				SOLENG
ETA	R*8		4472	DIAG1
				FNMAT
				SOLENG
CR	R*8		4480	DIAG1
				FNMAT
				INPUT
XKR	R*8		4488	DIAG1
				FNMAT

.COMMON JERR (CONTINUED)

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
				INPUT
XKT	R*8		4496	DIAG1
				FNMAT
				INPUT
XKST	R*8		4504	DIAG1
				FNMAT
				INPUT
APS	R*8		4512	DIAG1
				FNMAT
				INPUT
AL1	R*8		4520	SETI
				DIAG1
				INPUT
				LAMBRT
AL2	R*8		4528	SETI
				DIAG1
				FNMAT
				INPUT
				LAMBRT
AL3	R*8		4536	SETI
				DIAG1
				FNMAT
				INPUT
				LAMBRT

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON LAMB LENGTH 28

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
XJLD	R*8		0	EPH
				DIAG1
				INPUT
				LAMBRT
				BLKDATA
RBRE	R*8		16	INPUT
				BLKDATA

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON LEFT LENGTH 13440

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
XRL	R*8	6,20	0	RECT
				SETI
				DERIV
				DETDT
				FNMAT
				GENMA
				MIIP1
				CONTRL
XRDL	R*8	6,20	960	RECT
				SETI
				DERIV
				FNMAT
				GENMA
				MIIP1
				CONTRL
				FINDXB
VCOL	R*8	72,20	1920	DERIV
				MIIP1
				MODIF
				CONTRL
				FINDXB
				SOLENG

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON	LEON	LENGTH	112

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
XRO	R*8	6	0	TBDP
				DERIV
				GENMA
				TRAJL
XRODT	R*8	6	48	TBDP
				DERIV
TMPDP	R*8		96	RECT
				TBDP

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON LPPR LENGTH 4

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
ICT	I*4		0	DIAG1
ITC	I*4		0	INPUT

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON NORM LENGTH 104

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
TREF	R*8		0	INT
				EPHEM
DLEPH	R*8		8	DERIV
				EPHEM
				FNMAT
				INPUT
				CONTRL
				FINDXB
ITBL	I*4	22	16	DERIV
				EPHEM
				FNMAT
				CONTRL
				FINDXB

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON NPNT LENGTH 4

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
NPR	I*4		0	INPUT
				MINMX3
				BLKDATA

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON TBPR LENGTH 4

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
ITB	I*4		0	TBDP
				MODIF
				CONTRL

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON THAD LENGTH 136

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
BETAM1	R*8		0	SAMM
				TBDP
				SUBFG
GG0	R*8		8	TBDP
GG0	R*8		8	SAMM
				SUBFG
G1	R*8		16	SAMM
				TBDP
				SUBFG
G2	R*8		24	SAMM
				TBDP
				SUBFG
G3	R*8		32	SAMM
				TBDP
				SUBFG
G4	R*8		40	SAMM
				SUBFG
G5	R*8		48	SAMM
				SUBFG
F0	R*8		72	SUBFG
F1	R*8		80	SUBFG
F2	R*8		88	SUBFG
F3	R*8		96	SUBFG
F4	R*8		104	SUBFG
F5	R*8		112	SUBFG

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON XMMM LENGTH 972

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
B	R*8	120	0	BLKDATA
B	R*8	30	0	SETI
				ITMAT
				MINMX3
Q	R*8	30	240	FNMAT
				MINMX3
QMIN	R*8	30	480	ITMAT
				MINMX3
QMAX	R*8	30	720	ITMAT
				MINMX3
WTOPT	R*8		960	INPUT
				MINMX3
				BLKDATA
MOPTM	I*4		968	INPUT
				MINMX3

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON HENRY LENGTH 3472

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
ARRAY	R*8	8,3,12	0	DETDT
				INPUT
				BLKDATA
CHIND	R*8		2304	INIT
				DETDT
				TRAJL
INTV	R*8	72	2312	INIT
				DERIV
IN1X	R*8	3	2888	CONTRL
XN1X	R*8	3	2888	FNMAT
				FINDXB
IN2X	R*8	3	2912	CONTRL
XN2X	R*8	3	2912	FNMAT
				FINDXB
KSQQ	R*8	12	2936	RECT
				INPUT
				MIIPI
				CONTRL
				BLKDATA
XSQQ	R*8	12	2936	SETI
				DIAGI
				FNMAT
KM	R*8	12	3032	INIT
				RECT
				DERIV
MDIST	R*8		3128	ELCD
				DERIV
				CONTRL
				BLKDATA
XDIST	R*8		3128	EPHEM
				GENMA
				FINDXB
				SOLENG
MEI	R*8	12	3136	INIT
				MODIF
				CONTRL
				BLKDATA
ME	R*8	12	3232	INIT
				RECT
				MODIF
				CONTRL
POSRCS	R*8		3328	INPUT
				CONTRL
				BLKDATA
PRVDT	R*8		3336	INIT
				DERIV
PDT	R*8		3344	INIT
				DETDT

COMMON HENRY (CONTINUED)

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
PCIN	R*8		3352	INIT
				DETDT
RD	R*8		3360	ELCO
				DIAG1
				ENMAT
				INPUT
				BLKDATA
REKM	R*8		3368	ELCO
				RECT
				DIAG1
				EPHEM
				INPUT
				MIIP1
				BLKDATA
RRM	R*8		3376	MODIF
				CONTRL
				BLKDATA
RRE	R*8		3384	INPUT
				CONTRL
				BLKDATA
RREU	R*8		3392	CONTRL
				BLKDATA
RCIND	R*8		3400	DERIV
				TRAJL
RATIO	R*8		3408	RECT
				CONTRL
TSCL	R*8		3424	DIAG1
				INPUT
				MIIP1
				BLKDATA
THTS	R*8		3432	INPUT
				CONTRL
				BLKDATA
TP1	R*8		3440	INIT
				SETI
				CONTRL
TIMEL	R*8		3448	EPHEM
				INPUT
				BLKDATA
THET	R*8		3456	ELCO
				TBDP
				DERIV
				CONTRL
VELRCS	R*8		3464	INPUT
				CONTRL
				BLKDATA

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON INTEG LENGTH 348

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
DAY	I*4		0	LAMBRT
YEAR	I*4		8	LAMBRT
IDUMMY	I*4		12	INIT
				RECT
				CONTRL
ITRIG	I*4		16	INIT
				TRAJL
				CONTRL
IREFNO	I*4		20	ELCO
				INIT
				RECT
				SETI
				DERIV
				DETDT
				DIAG1
				FNMAT
				GENMA
				MIIP1
				CONTRL
				FINDXB
				SOLENG
				BLKDATA
IREFNB	I*4		24	INIT
				DIAG1
				INPUT
				BLKDATA
IREFNT	I*4		28	DIAG1
				FNMAT
				INPUT
				BLKDATA
IN	I*4		32	INPUT
				BLKDATA
IO	I*4		36	ELCO
				RECT
				DETDT
				DIAG1
				INPUT
				ITMAT
				MIIP1
				TRAJL
				BLKDATA
IJK	I*4		40	FNMAT
				GENMA
				CONTRL
				FINDXB
MONTH	I*4		44	LAMBRT
NOPT	I*4	72	52	ELCO
				RECT

COMMON INTEG (CONTINUED)

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
				DIAG1
				FNMAT
				GENMA
				INPUT
				ITMAT
				BLKDATA
				MIIP1
				TRAJL
				FNPRNT
				SOLENG
NPLAN	I*4		340	INIT
				RECT
				INPUT
				CONTRL
NPLAN3	I*4		344	INIT
				DERIV

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON	NOMLL		LENGTH	4
VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
NOMT	I*4		0	SETI
				DIAGI
				FNMAT
				GENMA
				TRAJL

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON NORML LENGTH 96000

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
TBBL	R*8	12000	0	INT
				EPHEM

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON RSCAL LENGTH 80

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
RLP	R*8		0	SETI
				LAMBRT
				BLKDATA
RPHAT	R*8	3	8	SETI
				LAMBRT
HCR	R*8	3	32	SETI
RDPML	R*8	3	56	SETI
				LAMBRT

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON	SAML1		LENGTH	400
VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
ROTB	R*8	3	0	SAMM
RODTB	R*8	3	24	SAMM
RTB	R*8	3	48	SAMM
RDTB	R*8	3	72	SAMM
AIJ	R*8	3,3	96	SAMM
				SETI
BIJ	R*8	3,3	168	SAMM
				SETI
CIJ	R*8	3,3	240	SAMM
				SETI
DIJ	R*8	3,3	312	SAMM
				SETI
D1AD	R*8		384	SAMM
XMU	R*8		392	SAMK
				SETI

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON STEVE LENGTH 152

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
DEL	R*8		0	RECT
				DETDT
				MODIF
				TRAJL
KSQ	R*8		8	RECT
				CONTRL
XSQ	R*8		8	TBDP
				DERIV
				GENMA
				TRAJL
1AD	R*8		16	RECT
				TBDP
RDOTD	R*8		24	RECT
				TBDP
TI	R*8		32	RECT
				TBDP
				CONTRL
TM2DP	R*8		40	RECT
				TBDP
XRI	R*8	6	48	RECT
				TBDP
				DERIV
XRIDT	R*8	6	96	RECT
				TBDP
				DERIV
SQTMU	R*8		144	RECT
				TBDP
				DERIV

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON VPLLL LENGTH 16

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
VP00	R*8		0	SETI
				LAMBRT
ITD	I*4		8	SETI
				GENMA
ITD1	I*4		12	SETI
				GENMA

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COMMON VARIABLE CROSS REFERENCE TABLE

COMMON	CONRAD		LENGTH	24
VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
VTP	R*8		0	FNMAT
VORB	R*8		0	DIAG1
DELV	R*8		8	FNMAT
DELVEL	R*8		8	DIAG1
VPA	R*8		16	FNMAT
VTP	R*8		16	DIAG1

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON CONVRT LENGTH 16

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
APSCON	R*8		0	RECT
				SOLENG

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON MINEPS LENGTH 240

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
EPS	R*8	30	0	INPUT
				MINMX3

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON MINSEC LENGTH 4

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
ITF	I*4		0	INPUT
				TRAJL
				BLKDATA

COMMON VARIABLE CROSS REFFRENCE TABLE

COMMON OCBALL LENGTH 64

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
SAI	R*8		0	EPH
				INPUT
				BLKDATA
ECI	R*8		8	EPH
				INPUT
CNI	R*8		16	EPH
				INPUT
OMI	R*8		24	EPH
				INPUT
SOI	R*8		32	EPH
				INPUT
TPI	R*8		40	EPH
				INPUT
EMUDD	R*8		48	EPH
				INPUT

COMMON VARIABLE CROSS REFERENCE TABLE

COMMON PERAPS LENGTH 52

VARIABLE	TYPE	DIM	ADDR	SUBROUTINE
RDOT	R*8	3	0	FNMAT
				MINMX3
RM	R*8		24	INPUT
				MINMX3
RP	R*8		32	INPUT
				MINMX3
EMU	R*8		40	INPUT
				MINMX3
IPER	I*4		48	INPUT
				MINMX3

VI. SUBROUTINE DESCRIPTIONS

In this section are presented detailed descriptions of every subroutine of the ASTOP program. The descriptions are given in alphabetic order of the subroutine name. Entry points are not described separately, but are included in the description of the primary subroutine. Each description is comprised of the following sections:

1) Name of subroutine.
2) List of calling arguments.
3) List of sub-programs referenced by the subroutine being described.
4) List of commons referenced by the subroutine.
5) Entry points in the subroutine.
6) List of sub-programs referencing the subroutine being described.
7) Detailed discussion of pertinent equations and logic.
8) Description of printout and messages generated by the subroutine.
9) List of any documents referenced in the Discussion.
10) Table of external variables used by the subroutine.
11) Detailed flow chart.

Items 8 and 9 are included if applicable.

The table of external variables include for each variable listed the Fortran name, the use of the variable, the name of the common array, if any, in which the variable appears, and a definition of the variable. The variables included in this table include only those referenced within the subroutine which are available for use in other routines; e.g., common variables or variables contained in argument lists. Temporary variables which are evaluated in, and not transmitted out of, the subroutine are not listed. For any array included in the table, the dimension of the array is enclosed in parentheses beside the Fortran name. The use of the variable is indicated by one or more of six alphabetic codes, which are defined as follows:

A - the variable appears in the argument list of a sub-program called by the subroutine.

E - the variable is equivalenced to a common variable; the name of the common variable is enclosed in parentheses under the name of the common.

R - the variable is a program input variable; this code appears only in the description of subroutine INPUT.

S - the value of the variable is changed and stored within the subroutine.

U - the value of the variable is used within the subroutine; i.e., the variable name appears on the right hand side of an equation or in an IF test.

X - the variable name appears in the argument list of the subroutine.

If the variable represents a variable used in the Discussion section of the subroutine description, the mathematical symbol of the variable is included in the definition of the variable.

The flow charts included in the subroutine description were prepared by the proprietary system Autoflow-II at the Goddard Space Flight Center. These charts are arranged such that the logic flow proceeds down each column and continues at the top of the next column to the right. Usually 3 or 4 columns will comprise a page. Each page is numbered in the upper right hand corner. Within each column there normally will exist several blocks of code. These blocks are numbered sequentially from 01 through the logic on each page. Thus, any specific block of code is identified by a page number and block number. The block number appears at the upper right of a block. A number shown at the upper left of a block is the statement number appearing in the subroutine listing. A transfer to a remote block is usually indicated by a circle with a number of form xxx.yy inscribed. Occasionally, the number in the circle appears with xxx directly above yy. In either case, xxx represents the page number and yy denotes the block number on that page to which control is transferred. At the end of each page, except the last, a transfer to the top of the next page is indicated with the symbol /xxx.yy. At the point to which the transfer occurs, a horizontal arrow is shown entering the logic flow with a number to the left defining the page and block number from which the transfer took place. A standard convention is employed to indicate selected operations. For example, a diamond denotes an IF test, algebraic code is enclosed in rectangles, a rectangle inscribed in another rectangle denotes the start of a DO loop or a CONTINUE statement, and a rectangle with a border on both sides denotes the call of a subroutine. Within the left border on a call to a subroutine is the page and block number of the start of that routine. The last page(s) of the flow chart contains a listing of the non-executable statements in the subroutine. These statements include type, dimension,common, equivalence, data and format statements.

Name: AMAINT

Calling Arguments: INDS

Referenced Sub-programs: DERIV

Referenced Commons: AMI, AM1

Entry Points: None

Referencing Sub-programs: CONTRL, TRAJL

Discussion: This subroutine performs the numerical integration of a set of second order differential equations. The solution consists of the first and second integrals of the second derivatives. The current second derivatives are stored in the array D2XI, the first derivatives are placed in XID, and the integrated variables are in XI. Each of these arrays are dimensioned 80 which represents the maximum number of equations that may be integrated. The actual number of equations being integrated is specified through the common variable NEQN. If a subset of the equations to be integrated are first order differential equations, the solutions to this subset are efficiently obtained by avoiding the evaluation of the second integral. Only the first integral is obtained and stored in the appropriate elements of XID and also in the corresponding elements of XI. Whether a specific equation is to be treated as a first or second order differential equation is indicated with the common variable array IFST, which is also dimensioned 80. A value of zero in a specific element of IFST indicates that the corresponding element of D2XI is to be treated as a second derivative, and a first and second integral are to be evaluated. A non-zero value, however, indicates that the corresponding element of D2XI is to be treated as a first derivative, and only a first integral is to be evaluated and stored in both XID and XI.

The differential equations are integrated using standard, sixth-order backward-difference predictor formulas. This technique requires that a table of second derivatives be maintained for the current time and the preceding six integration points for each variable to be integrated. Let the vector of variables to be integrated be denoted X, with its first and second derivatives being $\dot{X}$ and $\ddot{X}$. Then denote

$$\ddot{X}_i = \ddot{X}(t_i); \qquad i = 1, ---, 7$$

as the tabular values of the second derivatives at the integration times t_i, where

$$t_{i-1} - t_i = h$$

and h is the constant integration interval. Also, let decreasing values of the subscript i represent the more recent integration points such that t_1 is the current time, t_2 is the preceding integration point, etc. The values of X and $\dot{X}$ at previous points are not required, but are available at the current time t_1. The problem is to evaluate X and $\dot{X}$ for the time $t_1 + h$. The formulas for this purpose are

$$X(t_1 + h) = X(t_1) + h\left[\dot{X}(t_1) + \frac{h}{2k} S_2\right]$$

$$\dot{X}(t_1 + h) = \dot{X}(t_1) + \frac{h}{k} S_1$$

where S_1 and S_2 are two vectors of dimension NEQN, defined as follows:

$$S_1 = \sum_{i=1}^{7} \alpha_i \ddot{X}_i; \quad S_2 = \sum_{i=1}^{7} \beta_i \ddot{X}_i$$

and k, α_i and β_i are a set of constants which may be derived from the st backward difference formulas. The values of these constants are

$$k = 60480$$

i	α_i	β_i
1	198721	139849
2	-447288	-243594
3	705549	369399
4	-688256	-354188
5	407139	207495
6	-134472	- 68106
7	19087	9625

Once the integration to time $t_1 + h$ is completed, the derivative routine DERIV is called to evaluate $\ddot{X}(t_1 + h)$. The tabular second derivatives are then shifted such that $\ddot{X}_{i-1}$ is placed in $\ddot{X}_i$ for $i = 7-2$, sequentially, and $\ddot{X}(t_1 + h)$ is placed in $\ddot{X}_1$. The table is then ready for the next integration step.

The use of this numerical integration technique requires the availability of the second derivatives for the previous six integration points. Obviously, some other method is required to initially construct this table. Additionally, the above algorithm assumes continuity in $\ddot{X}$ and $\dddot{X}$ over the interval t_7 to $t_1 + h$. If this assumption of continuity is violated, it is necessary to discard the tables in use up to the point of discontinuity and once again construct the table to restart the algorithm. For the purpose of developing the new table, this subroutine also contains a fourth-order Runge-Kutta (R-K) integrator. The accuracy required by the backwards difference integrator is maintained by the R-K integrator by using an integration interval h' equal to one quarter of the standard interval h. The procedure is to take six integration steps of length h' using the R-K integrator. The original second derivatives at the initial time (or the time of a discontinuity) and the derivatives at the end of the six steps are loaded into a special derivative array, $\ddot{X}_i'$. This table is then employed by the backward difference integrator to integrate eighteen additional steps of length h'. At the end of each fourth step, the fourth derivatives are also loaded into the array $\ddot{X}_i$ such that, at the end of the 24 steps of length h', the complete table of second derivatives for an integration interval of h is available. The integration interval then continues at the normal interval. It should be noted that only one step of interval h' is executed on a single call to AMAINT. A set of counters are maintained so that the switch from R-K to the backward difference formulas is automatic.

The equations for the fourth-order Runge-Kutta integration of second order differential equations are as follows:

$$K_1 = h'\ddot{X}[t_1, X(t_1), \dot{X}(t_1)]$$

$$K_2 = h'\ddot{X}[t_1 + \frac{h'}{2}, X(t_1) + h'(\dot{X}(t_1)/2 + K_1/8), \dot{X}(t_1) + K_1/2]$$

$$K_3 = h'\ddot{X}[t_1 + \frac{h'}{2},\ X(t_1) + h'(\dot{X}(t_1)/2 + K_1/8), \dot{X}(t_1) + K_2/2]$$

$$K_4 = h'\ddot{X}[t_1 + h',\ X(t_1) + h'(\dot{X}(t_1) + K_3/2),\ \dot{X}(t_1) + K_3]$$

$$X(t_1 + h') = X(t_1) + h'[\dot{X}_1(t_1) + (K_1 + K_2 + K_3)/6]$$

$$\dot{X}(t_1 + h') = \dot{X}(t_1) + (K_1 + 2K_2 + 2K_3 + K_4)/6$$

where K_1, K_2, K_3, and K_4 are arrays dimensioned NEQN.

The R-K integrator is also used for any non-standard integration interval, $h^* < h$. The procedure is to first evaluate the integer n which is the largest integer such that

$$n h' < h^*$$

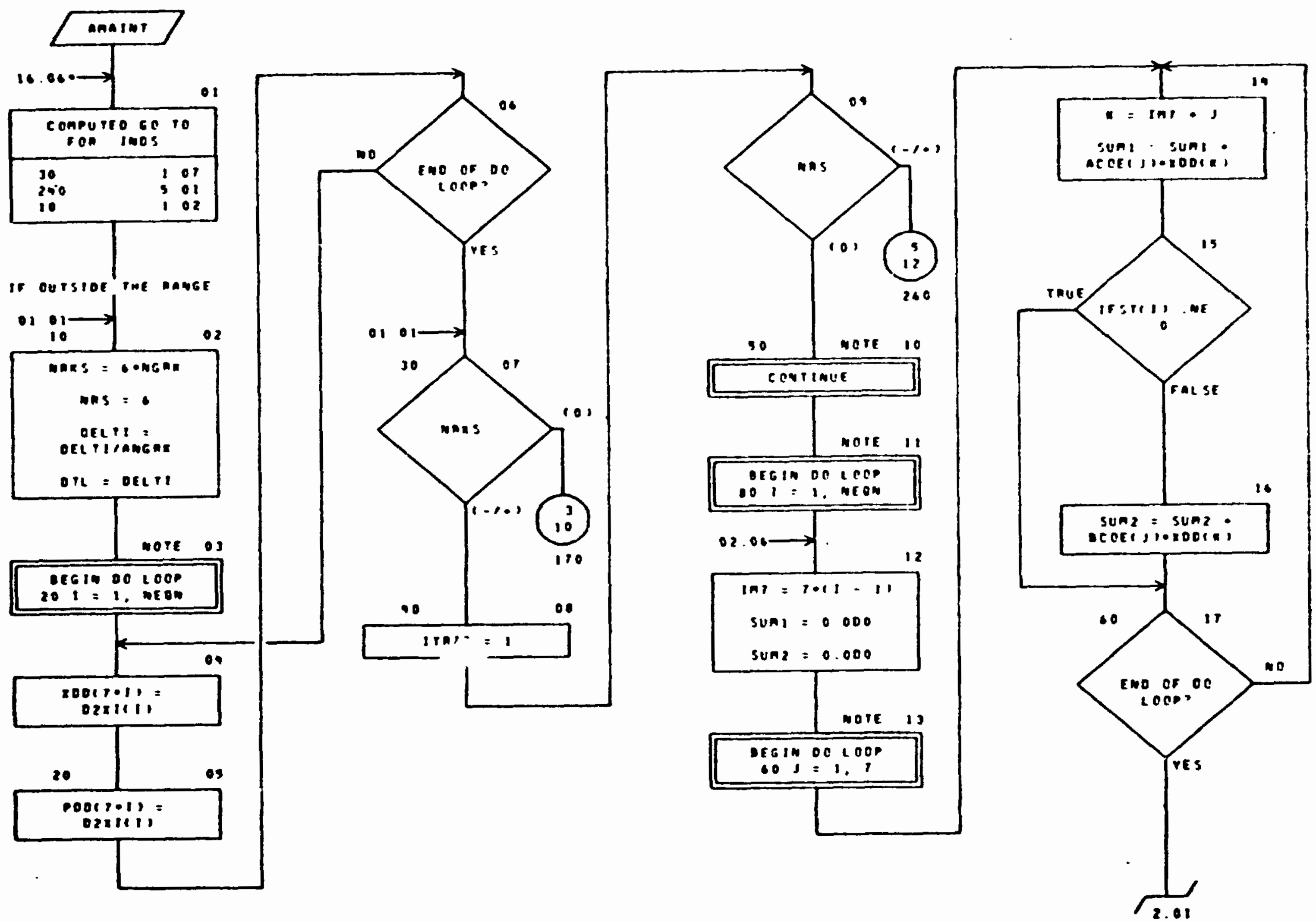
where $h' = h/4$. A total of n steps of interval h' followed by a single step of interval $(h^* - n h')$ are then executed using the R-K algorithm to obtain the desired point. Unlike the procedure employed when constructing the derivative tables, the n+1 steps using the R-K formulas are executed with a single call to AMAINT.

The information as to which procedure to use is passed to subroutine AMAINT through the calling argument INDS. This integer variable may have the value of 1, 2, or 3. A standard integration step is indicated by INDS = 1. For this case, the interval may be either h or h', depending on whether the complete derivative table is available, and the integration technique used may be either the backward difference or the R-K algorithm, depending on the number of steps taken since the table construction was begun. INDS=2 signifies that a non-standard interval h^* is to be integrated. The integration over the total interval is performed before leaving the subroutine. A value of 3 denotes that a new derivative table is to be constructed, and the necessary counters are initialized so that the construction process is begun. A Fortran variable NRKS is initialized to 24 and decremented by one following each integration interval of h', and a variable NRS is initialized to 6 and decremented by one each integration step of h' by the R-K integrator. The R-K integrator is used if NRS > 0, and the integration interval h' = h/4 is used if NRKS > 0. A single integration step is performed on a call to AMAINT if INDS is either 1 or 3.

AMAINT EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
T	SU	AM1	Independent variable of integration, t.
XI(80)	SU	AM1	Array of integrated variables, X.
DTI	SUE	AM1 (DELTI)	Integration interval, h or h' or h*.
XID(80)	SU	AM1	First derivatives of integrated variables, $\dot{X}$.
D2XI(80)	U	AM1	Second derivatives of integrated variables, $\ddot{X}$.
IFST(80)	U	AM1	Array of flags defining which equations are first order differential equations. A value of 0 denotes a second order equation; a value of 1 denotes a first order equation.
INDS	UX		Indicator flag defining the procedure AMAINT is to use. Value of 1 indicates standard call; value of 2 denotes non-standard integration interval; value of 3 signals the need to reconstruct the derivative tables.
NEQN	U	AMI	Number of equations being integrated.
CWLIN (240)	SUE	AM1 (XI)	Array equivalent to XI, but dimensioned to include XID and D2XI.
DELTI	SU	AM1	Integration interval, h or h' or h*.

CHART TITLE - SUBROUTINE AMAINT(INDS)



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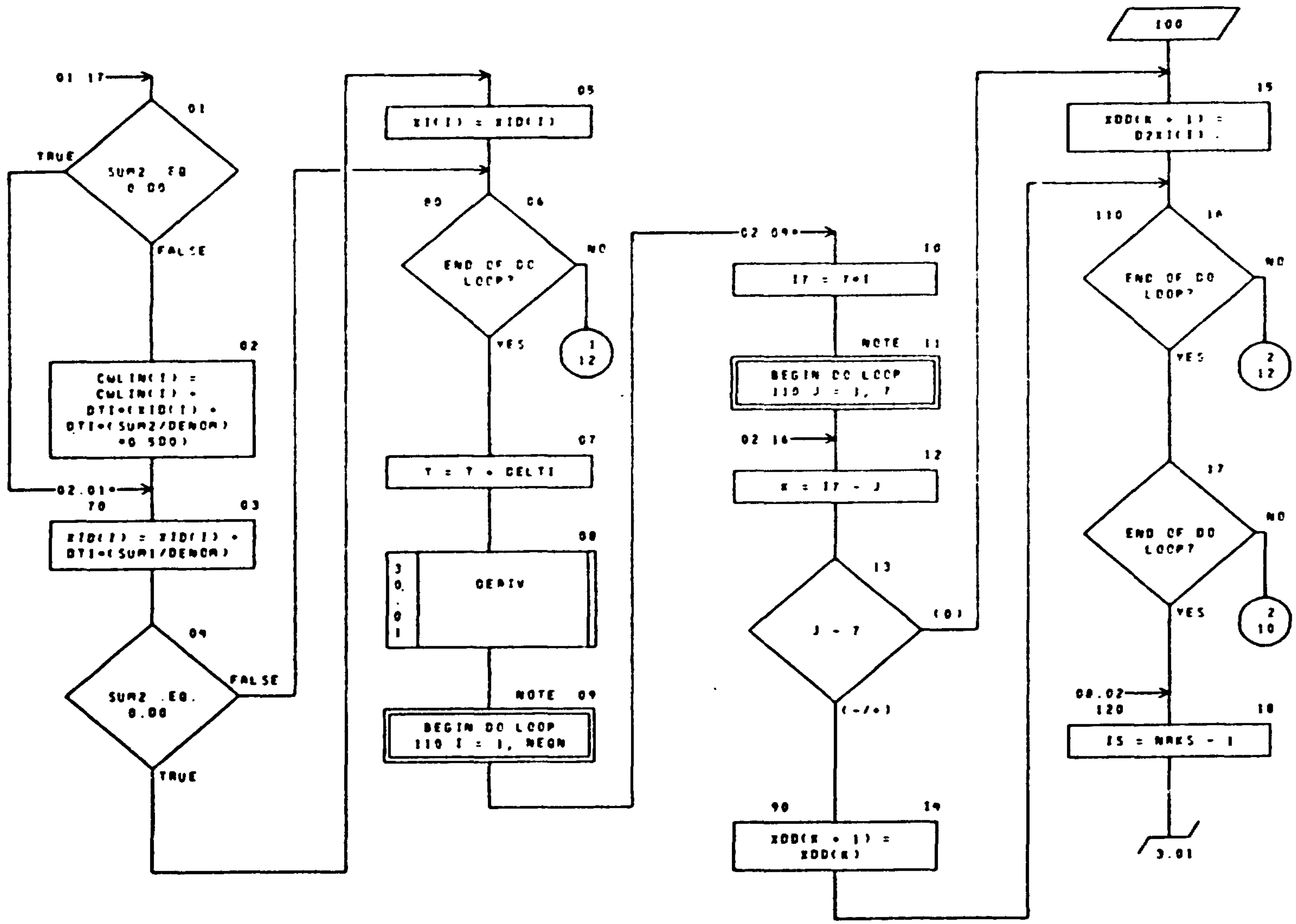

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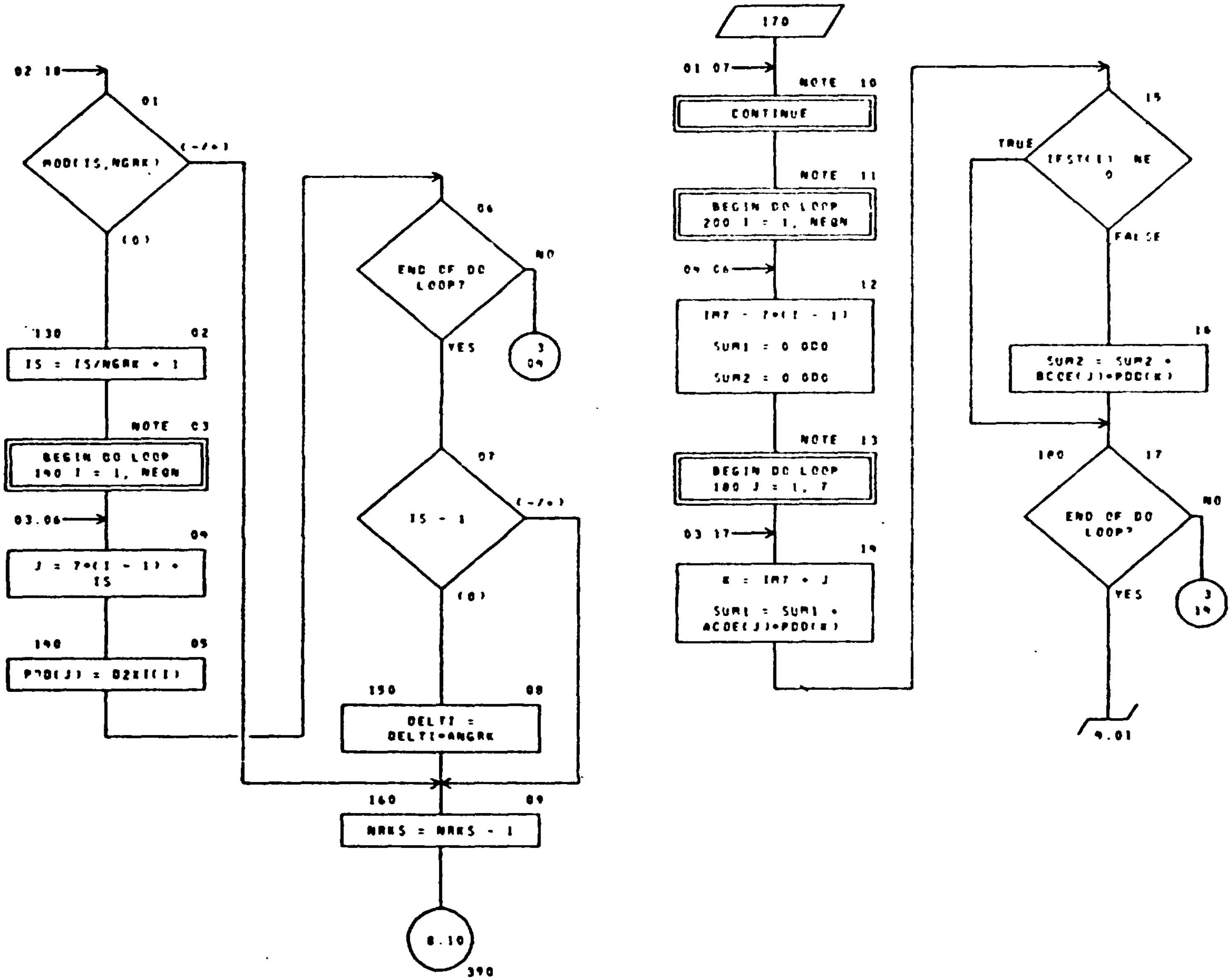

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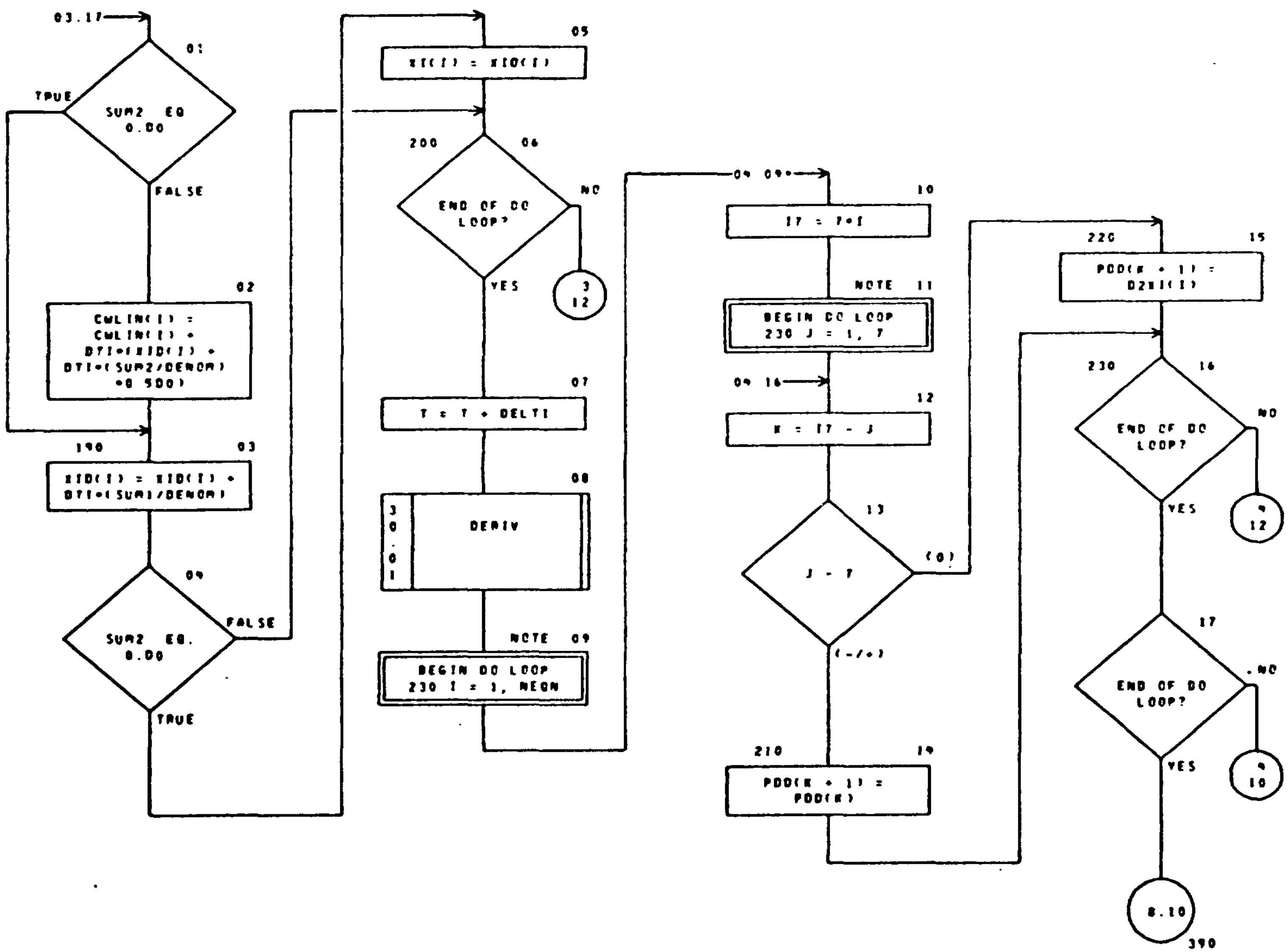
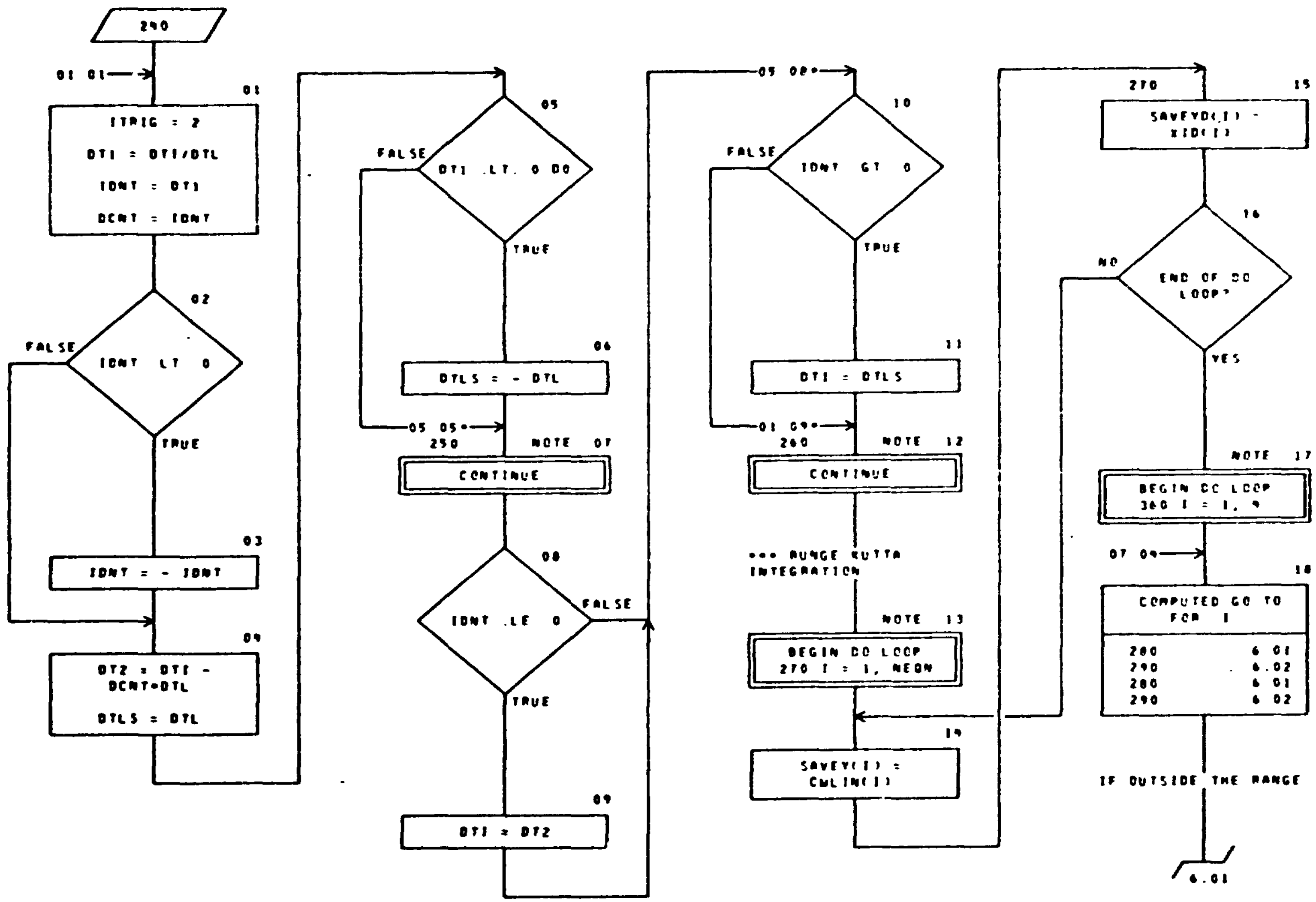


AMAINT-9

CHART TITLE - SUBROUTINE AMAINT(INDS)



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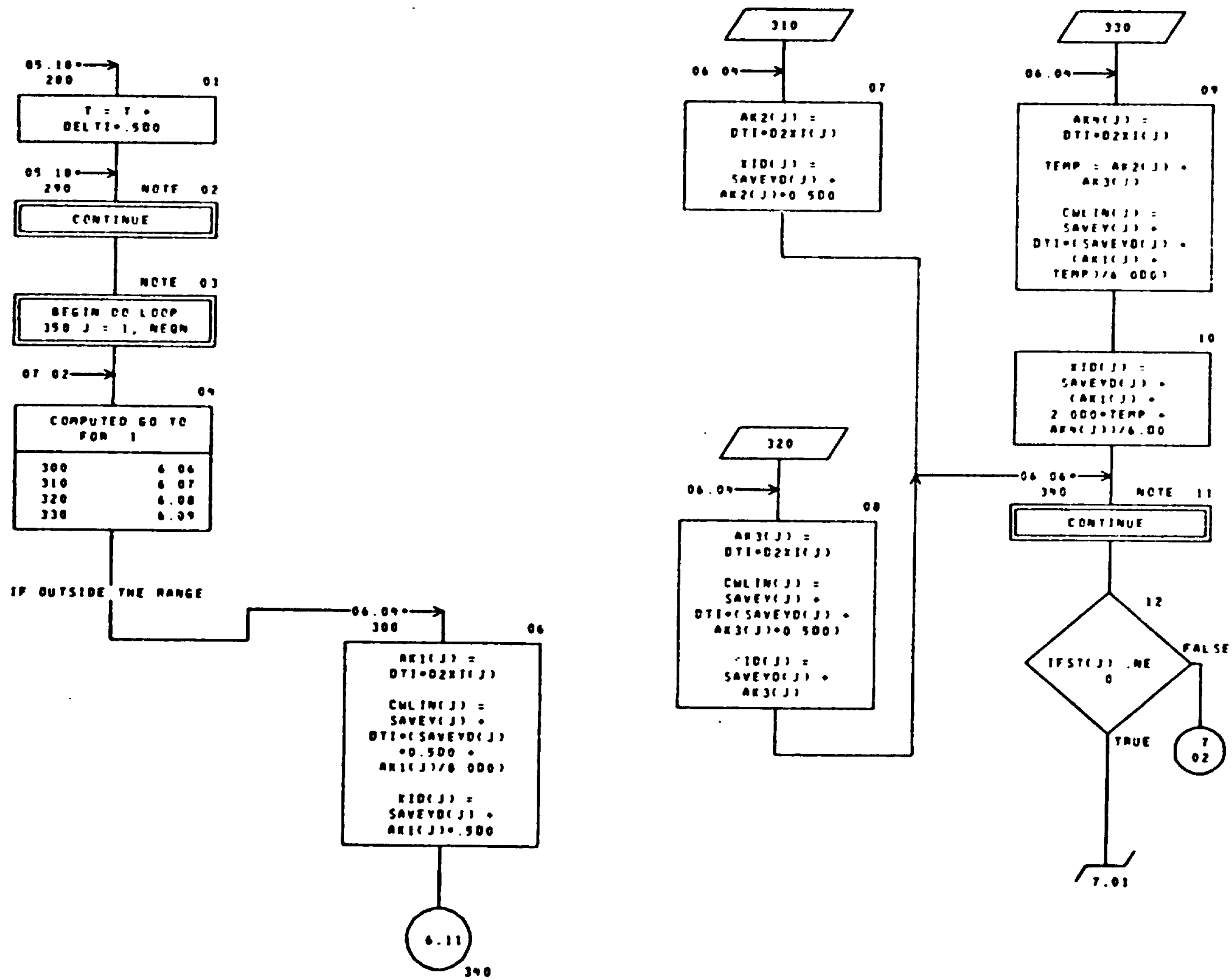
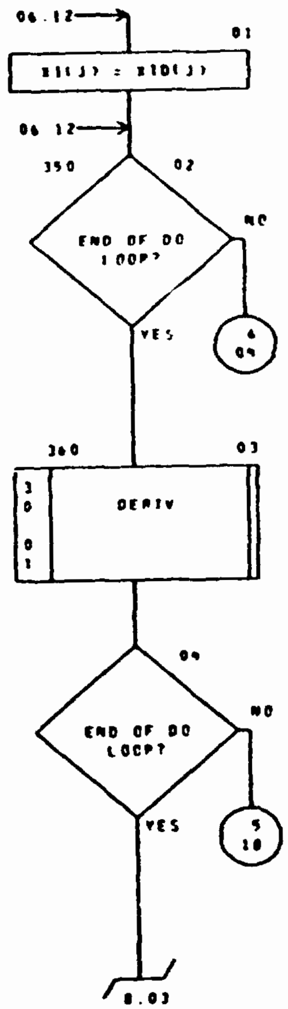


AMAINT-11

CHART TITLE - SUBROUTINE AMAINT(INDS)



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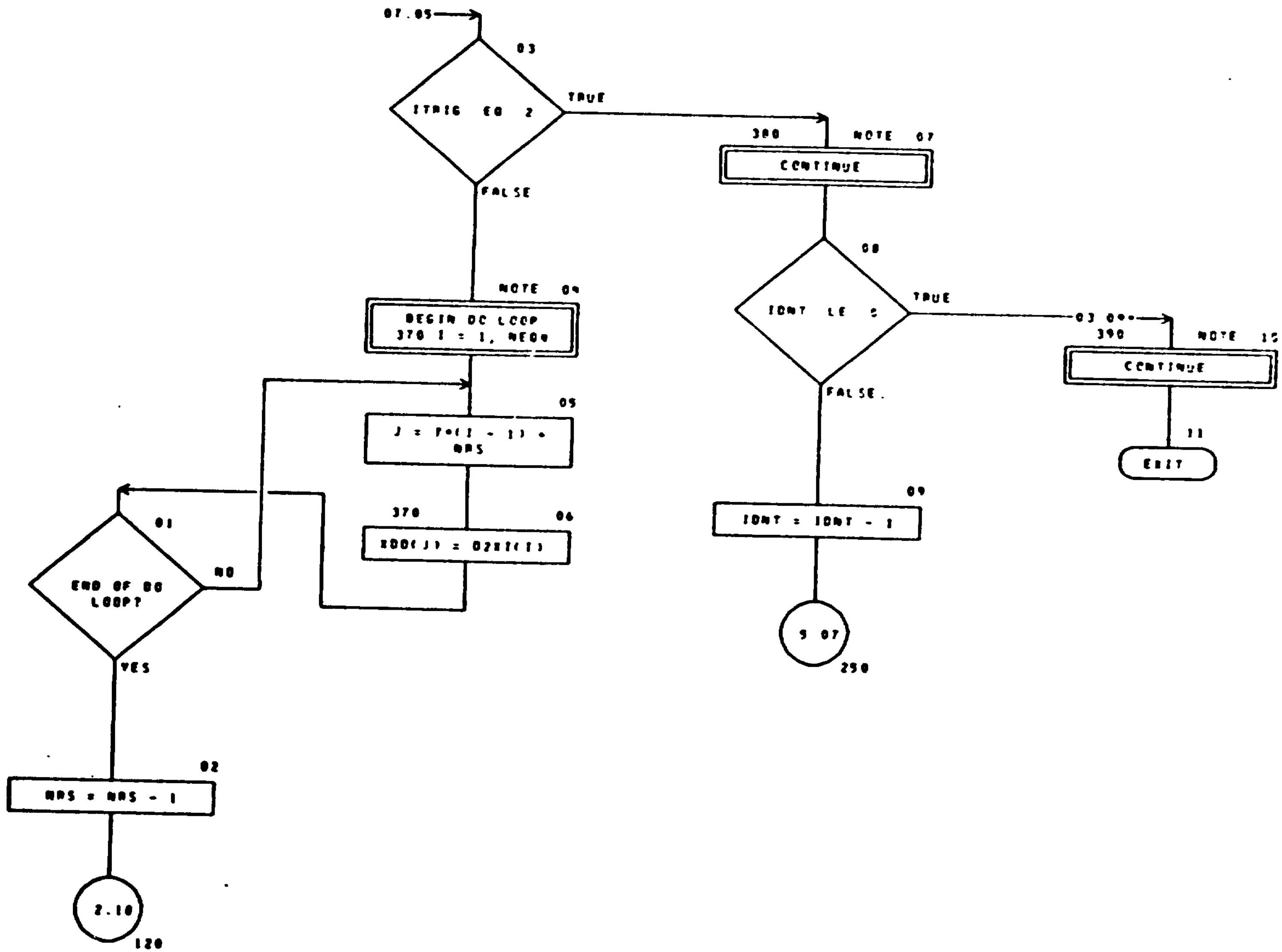


CHART TITLE - NON-PROCEDURAL STATEMENTS

```
IMPLICIT REAL*8 (A-H,O-Z)
DIMENSION SAVEY(80),CWLIN(240),ACOE(7),BCOE(7),
SAVEYD(80),AK1(80),AK2(80),AK3(80),AK4(80),PDD(560),XDD(560)
COMMON/AM1/NEQN,NPT2
COMMON/AM1/DELT,T,DELTI,X1(80),X1D(80),D2X1(80),IFST(80)
EQUIVALENCE(X1(1),CWLIN(1)),(DELTI,DTI)
DATA ACOE/198721 D0,-447288 D0,705549 D0,-688256 D0,
407139 D0,-134472 D0,19087 D0/
DATA BCOE/139849 D0,-293594 D0,369399 D0,-354188 D0,
207495 D0,-68196 D0,9625 D0/
DATA DENOM/60480 D0/
DATA ANGRK,NGRK/4 D0,4/
```

<u>Name:</u> AMAL

<u>Calling Arguments:</u> X, SND, CSD, A

<u>Referenced Sub-programs:</u> None

<u>Referenced Commons:</u> None

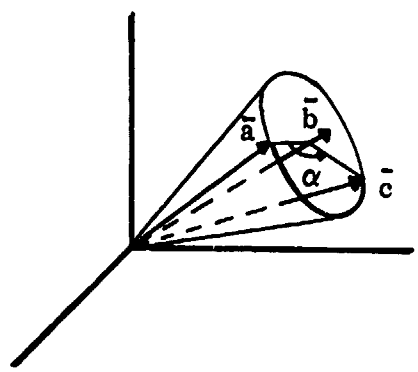
<u>Entry Points:</u> None

<u>Referencing Sub-programs:</u> SETI, SOLENG

<u>Discussion:</u> This subroutine computes the 3 x 3 transformation that applies for the rotation of a unit vector $\bar{a}$ about a second unit vector $\bar{b}$ through a given clock angle α to the position $\bar{c}$. Denoting the transformation matrix as $A(\bar{b}, \alpha)$, the transformation may be mathematically represented:

$$\bar{c} = A(\bar{b}, \alpha)\,\bar{a}.$$

Pictorially, the rotation appears as in the following sketch:



Note that this subroutine computes the transformation matrix A only. The resultant vector $\bar{c}$ is evaluated using the subroutine MTVT. The matrix A is evaluated with the formula (see Reference).

$$A(\bar{b}, \alpha) = I\cos\alpha + B(1 - \cos\alpha) + C\sin\alpha$$

where I is the 3 x 3 identity matrix, B represents the outer product of $\bar{b}$ upon itself, i.e.,

$$
B = \begin{bmatrix} b_1 b_1 & b_1 b_2 & b_1 b_3 \\ b_2 b_1 & b_2 b_2 & b_2 b_3 \\ b_3 b_1 & b_3 b_2 & b_3 b_3 \end{bmatrix}
$$

and C is the cross product operator matrix

$$
C = \begin{bmatrix} 0 & -b_3 & b_2 \\ b_3 & 0 & -b_1 \\ -b_2 & b_1 & 0 \end{bmatrix}
$$

The elements b_1, b_2, and b_3 represent the Cartesian components of $\bar{b}$.

<u>Reference</u>:

S. Pines and B. F. Cockrell, "Partial Derivatives of Matrices Representing Rigid Body Rotations," MSC Internal Note No. 68-FM-231, September 1968.

AMAL EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
A(3, 3)	SX		Transformation matrix, $A(\bar{b}, \alpha)$.
X(3)	UX		Reference unit vector, $\bar{b}$.
CSD	UX		Cosine of clock angle α, $\cos \alpha$.
SND	UX		Sine of clock angle α, $\sin \alpha$.

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CHART TITLE - SUBROUTINE AMAL(X,SND,CSD,A)

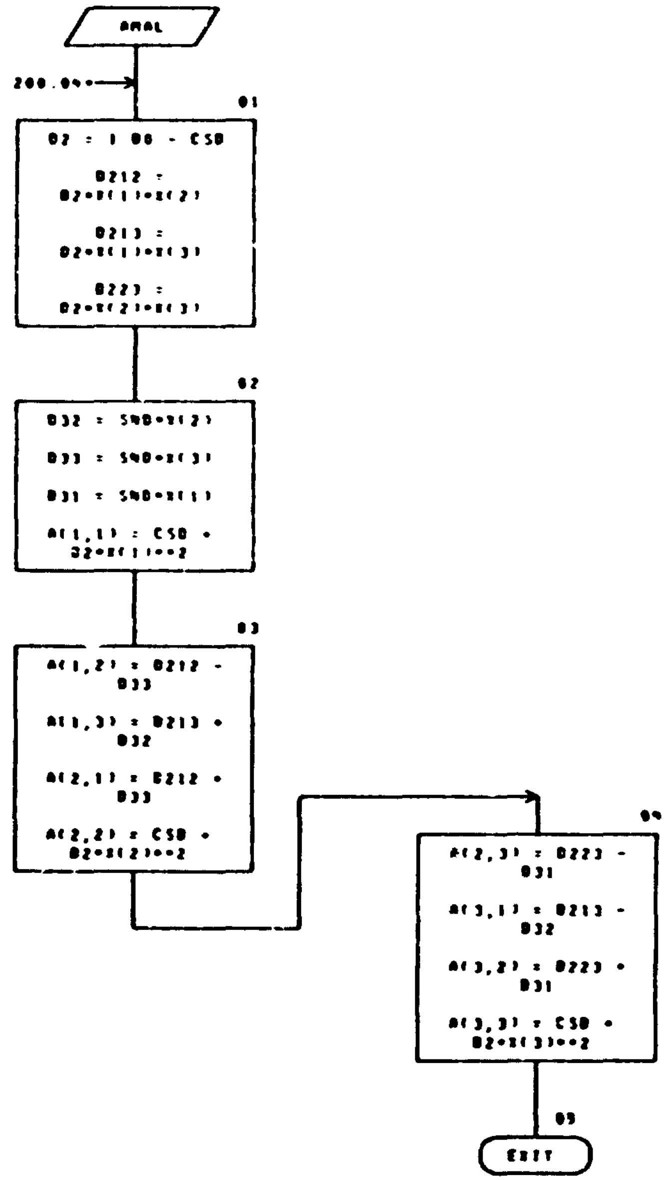


CHART TITLE - NON-PROCEDURAL STATEMENTS

```
IMPLICIT REAL*8(A-H,O-Z)
DIMENSION X(3),A(3,3)
```

Name: CONTRL

Calling Arguments: None

Referenced Sub-programs: AMAINT, GENMA, INT, TBDP

Referenced Commons: ALAN, AM1, HENRY, HER, HIS, ILEF, INTEG, LEFT, NORM, STEVE, TBPR

Entry Points: None

Referencing Sub-programs: TRAJL

Discussion: This subroutine monitors the calculation of the nominal trajectory to determine when two-body trajectory rectifications and reference switches are required and to control the integration of the trajectory to precise arc end times. Upon entry, the current time is compared to the scheduled end time of the current trajectory arc. If this end time is passed, subroutine TBDP is called to evaluate the interval in the universal anomaly required to integrate to the desired end time. Subroutine AMAINT is then called with this interval and the backward integration is performed. A call to subroutine GENMA is performed to store pertinent trajectory arc information and, if perturbation trajectories are being computed simultaneously with the nominal, to update the partial derivative matrix to the end of the arc. The arc counter and next arc end time are updated and a flag ITRIG is set to 1 to indicate that an end of arc has been encountered. A check is then made to determine if the arc just completed is the last arc of the trajectory. If so, the flag ITRIG is set to 3 to indicate end-of-trajectory and a return from the subroutine is immediately executed. Otherwise, the logic flow continues as if no end-of-arc had been encountered.

The next step is to determine if switch of the reference coordinate system should be performed. This determination is made on the basis of the distance of the spacecraft from the various attracting bodies included in the simulation. With each possible attracting body included in the program there is defined a distance which may be considered the radius of the sphere of influence. When the spacecraft is within this sphere, the reference coordinate system is centered at the corresponding body. Switches in the reference coordinate system are performed at the end of the integration interval over which the sphere was crossed. No attempt is made to iterate the actual crossing point.

The current reference coordinate system is identified by the common variable IREFNO. When IREFNO = 1 (Earth), the possibility of passing into the sphere of the moon is first checked; if negative (i.e., the sphere was not crossed) the possibility of passing outside the Earth's sphere is then checked. When IREFNO = 2 (Moon) or IREFNO > 3 (any planet other than Earth), the only check is to see if the sphere of the associated body is exited. When IREFNO = 3 (Sun), the possibility of entering the sphere of each planet included in the simulation is checked. If the result of any of these checks is positive, the variable IREFNO is changed to the new reference body identification number and two calls to subroutine INT are executed to return the position and velocity of the new reference body at the current time. Unless the crossing is from Moon to Earth, from Sun to Earth or from any planet other than Earth to Sun, the sign of each element of these two vectors is immediately reversed. Additionally, if the crossing is from Earth to Sun or vice-versa, the units of distance are converted to AU when going to Sun reference and to ER when going to Earth reference. This conversion of units is performed not only for the position and velocity vectors just returned from subroutine INT, but also for the array of positions and velocities XRL and XRDL, respectively, of the spacecraft relative to all perturbing bodies and of the Encke terms in position and velocity, XIL and XIDL. The position and velocity vectors relative to the current reference body are updated to the new reference body and the factor for converting between time and universal anomaly derivatives is corrected for the new reference body using the formula

$$\dot{\beta} = \sqrt{\mu}/r$$

where β is the universal anomaly, μ is the gravitational constant of the new reference body and r is the new two body distance. Also, the planetary mass array, ME, is defined in terms of Earth masses if the new IREFNO is less than 3 and in terms of Sun masses otherwise, and the flag ITRIG is set to 1 to indicate that a special event has occurred over the integration interval being monitored. A return from CONTRL is then executed.

If no reference switches were required over the integration interval, a final set of checks are made to determine if a rectification of the reference two-body trajectory is appropriate as a result of accumulated deviations from the reference trajectory. Such rectifications can be triggered by the occurrence of any one of three events: (1) the change in eccentric anomaly on the reference two-body orbit since the last rectification exceeding the value of the common variable THTS; (2) the square of the ratio of the position deviation from the reference two-body over the distance from the reference body exceeding the value of the common variable POSRCS; or (3) the square of the ratio of the velocity deviation from the reference trajectory over the speed relative to the reference body exceeding the value of the common variable VELRCS. The three common variables noted are available as inputs to the program. If not input, the following default values are used:

THTS = 1.5 radians
POSRCS = 1.D-4
VELRCS = 1.D-4

If any one of the rectification criteria is satisfied, the integer flag IDUMMY is set to indicate the reason for rectification, the flag ITRIG is set to 1 to indicate a special event has occurred during the integration interval, and a return from the subroutine is executed. If none of the rectification criteria is satisfied, the subroutine is exited with the flags IDUMMY = 4 and ITRIG = 2 except for the case when an end of arc had been encountered for which ITRIG will possess a value of 1.

CONTRL EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
T	UA	ALAN	Current time in hours from start of the trajectory, t.
ME(12)	S	HENRY	Planetary mass array in Earth masses if IREFNO < 3 and in Sun masses otherwise.
TI	U	STEVE	Time of last rectification, in hours. from start of trajectory.
XI(3)	UE	AM1 (XIL)	Positional deviation of nominal trajectory from reference two-body trajectory.
XR(6)	UE	LEFT (XRL)	Position vector of spacecraft relative to current reference body. Same as XRL but limited to nominal trajectory only.
CHN (100)	U	HIS	Array of variables available for use as independent variables in the boundary value problem. Only the arc end times are used in this routine.
DTI	S	AM1	Time interval in hours from last rectification to desired print point. Value is stored just prior to call to TBDP. Upon return from TBDP, DTI contains universal anomaly integration interval from current time to desired print point.
IJK	SUA	INTEG	Index of array ITBL. Values range from 1-8 and correspond to Sun, Jupiter, Mars, Venus, Saturn, Uranus, Neptune and Pluto, respectively.

CONTRL EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
ITB	S	TBPR	Flag set to 1 immediately preceding call to TBDP to force that routine to compute the correct universal anomaly integration interval required to integrate backward to desired arc end time. Reset to zero after call to TBDP.
KSQ	S	STEVE	Gravitational constant of current reference body, in ER^3/hr^2 for IREFNO ≤ 2 and AU^3/hr^2 for IREFNO ≥ 3.
MEI (12)	U	HENRY	Array of planetary masses in units of Earth masses. Index is IREFNO.
NTP	SU	HER	Counter incremented along the trajectory and equal to the current arc number.
RRE	U	HENRY	Distance from Earth in ER beyond which the reference is switched from Earth to Sun.
RRM	U	HENRY	Distance from Moon in ER beyond which the reference is switched from Moon to Earth or vice-versa.
TP1	SU	HENRY	Time in hours from the start of the trajectory to the next scheduled arc completion.
XID(3)	UE	AM1 (XIDL)	Velocity deviation of nominal trajectory from reference two body trajectory.
XIL(80)	SUE	AM1	Second integrals of Encke terms of nominal and perturbation trajectories.

CONTRL EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
XRL (6,20)	SUE	LEFT	Position vectors of spacecraft from reference body on nominal and perturbation trajectories. Dimension of 6 provides for magnitude, square and cube of distance plus the three Cartesian components.
IN1X(3)	SUA	HENRY	Array of planetary position coordinates returned from ephemeris interpolation routine INT.
IN2X(3)	SUA	HENRY	Array of planetary velocity coordinates returned from ephemeris interpolation routine INT.
ITBL(22)	UA	NORM	Table of values defining relative locations of the first ephemeris coordinates for each planetary body. Ephemeris data are stored in the array TBBL of common NORML. First 11 elements of ITBL define position location; last 11 define velocity location. Index is IJK.
KSQQ (12)	UA	HENRY	Array of planetary gravitational constants. Index is IREFNO. Units are ER^3/hr^2 for Earth and Moon and AU^3/hr^2 for all other bodies.
NCT1	S	HER	Index defining the relative location of arc thrust/coast triggers within variable array TBIN. Set equal to 10 (NTP-1)+2.
NEQL	U	ILEF	Total number of trajectories being integrated simultaneously.
NTPS	U	HER	Integer equal to the total number of trajectory arcs minus 1.

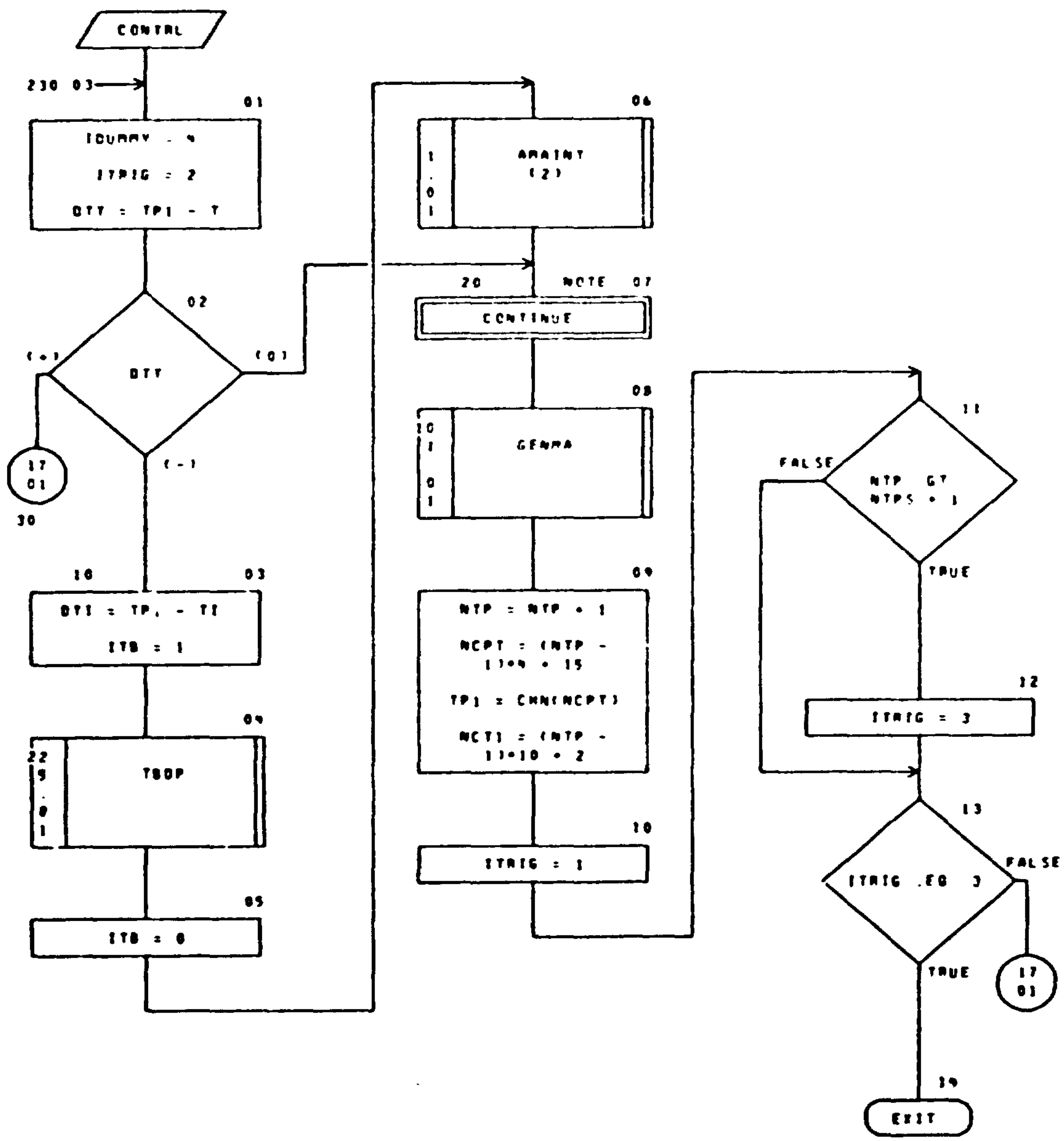
CONTRL EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
RHBR	SU	ALAN	Factor for converting from derivatives with respect to universal anomaly, β, to time derivatives. Equal to $\dot{\beta} = \sqrt{\mu}/r$, where μ is the gravitational constant of the reference body and r is the two-body reference trajectory distance.
RREU	U	HENRY	Distance from Earth, in AU, within which the reference is switched from Sun to Earth.
THET	U	HENRY	Change in the two body reference trajectory eccentric anomaly, in radians, since the last rectification.
THTS	U	HENRY	Maximum change, in radians, of eccentric anomaly permitted without rectification.
VCOL (72,20)	UE	LEFT	Array of spacecraft position vectors relative to all perturbing bodies on nominal and perturbed trajectories. Includes Cartesian coordinates plus magnitude, square and cube of distance.
VCOR (72)	UE	LEFT (VCOL)	Same as VCOL except limited to nominal trajectory only.
XIDL (80)	SUE	AM1	First integral of Encke terms of nominal and perturbation trajectories.
XRDL (6,20)	SUE	LEFT	Velocity vectors of spacecraft relative to reference body on nominal and perturbation trajectories. Dimension of 6 provides for magnitude, square and cube of velocity plus the three Cartesian components.
XRDT (6)	UE	LEFT (XRDL)	Same as XRDL but limited to nominal trajectory only.

CONTRL EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
DLEPH	U	NORM	Time interval, in hours, between tabular entries in ephemeris table.
ITRIG	SU	INTEG	Flag initialized to 2 on entry and subsequently set to 3 if end of trajectory is reached and to 1 if an end of arc or rectification point is reached.
MDIST	U	HENRY	Conversion factor for converting between ER and AU.
NPLAN	U	INTEG	Number of perturbing bodies included in the trajectory simulation.
RATIO	SU	HENRY	Variable containing the value of the position or velocity deviation squared or eccentric anomaly change causing a rectification.
IDUMMY	S	INTEG	Flag initialized to 4 on entry and subsequently set to 1, 2, or 3 if rectification due to velocity deviation, position deviation or eccentric anomaly change is required.
IREFNO	SUA	INTEG	Reference body ID number as follows: 1 Earth; 5 Mars; 9 Neptune 2 not available; 6 Jupiter; 10 Pluto 3 Sun; 7 Saturn 4 Venus; 8 Uranus
POSRCS	U	HENRY	Rectification criterion for position deviation squared.
VELRCS	U	HENRY	Rectification criterion for velocity deviation squared.

CHART TITLE - SUBROUTINE CONTRL



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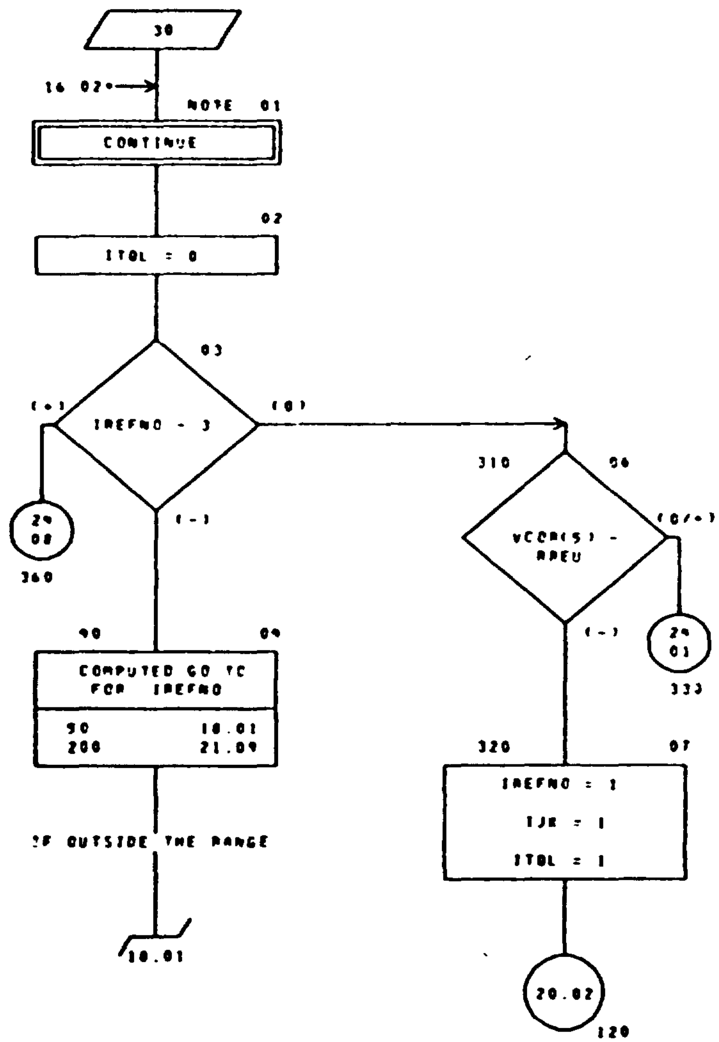

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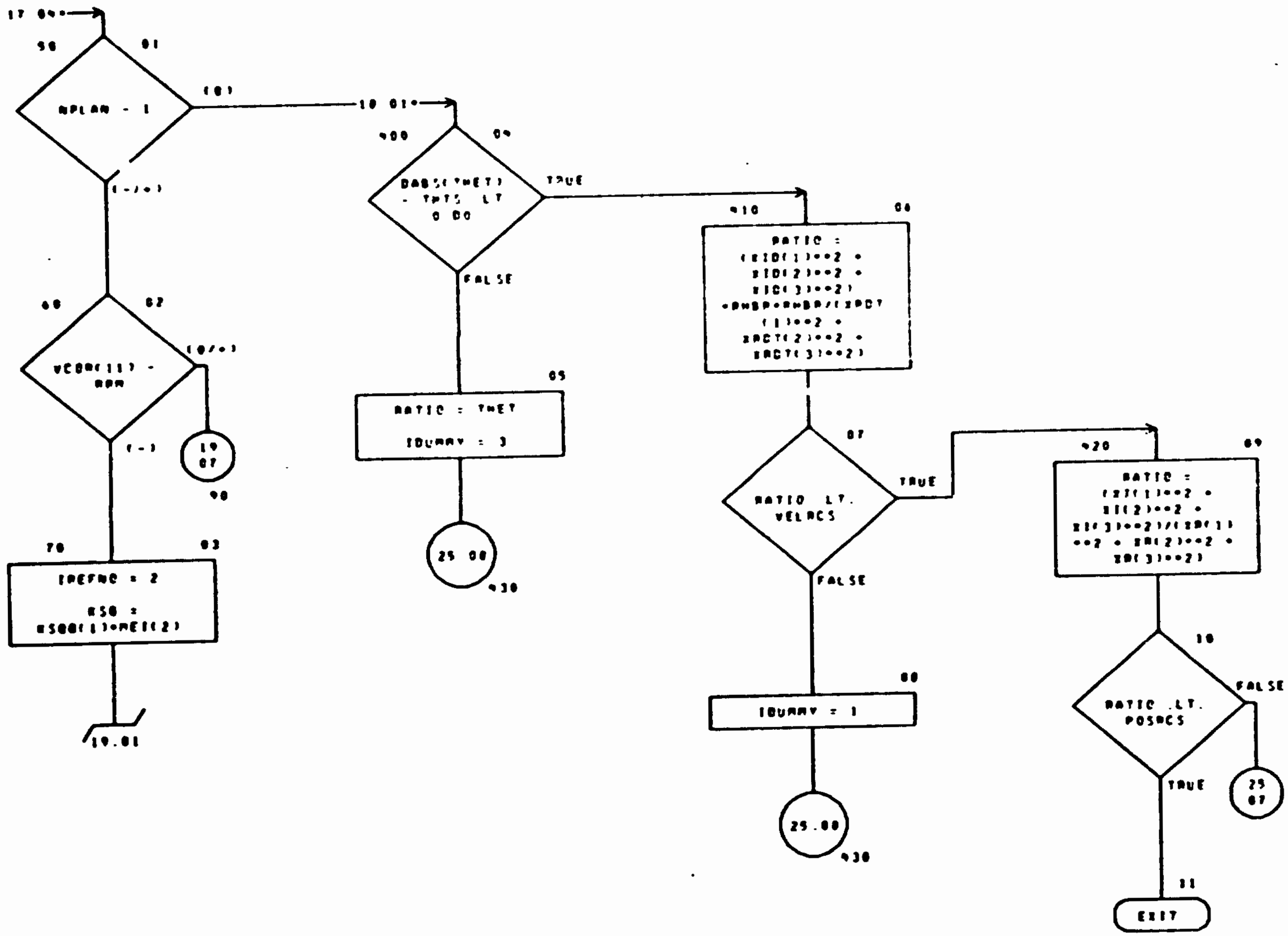
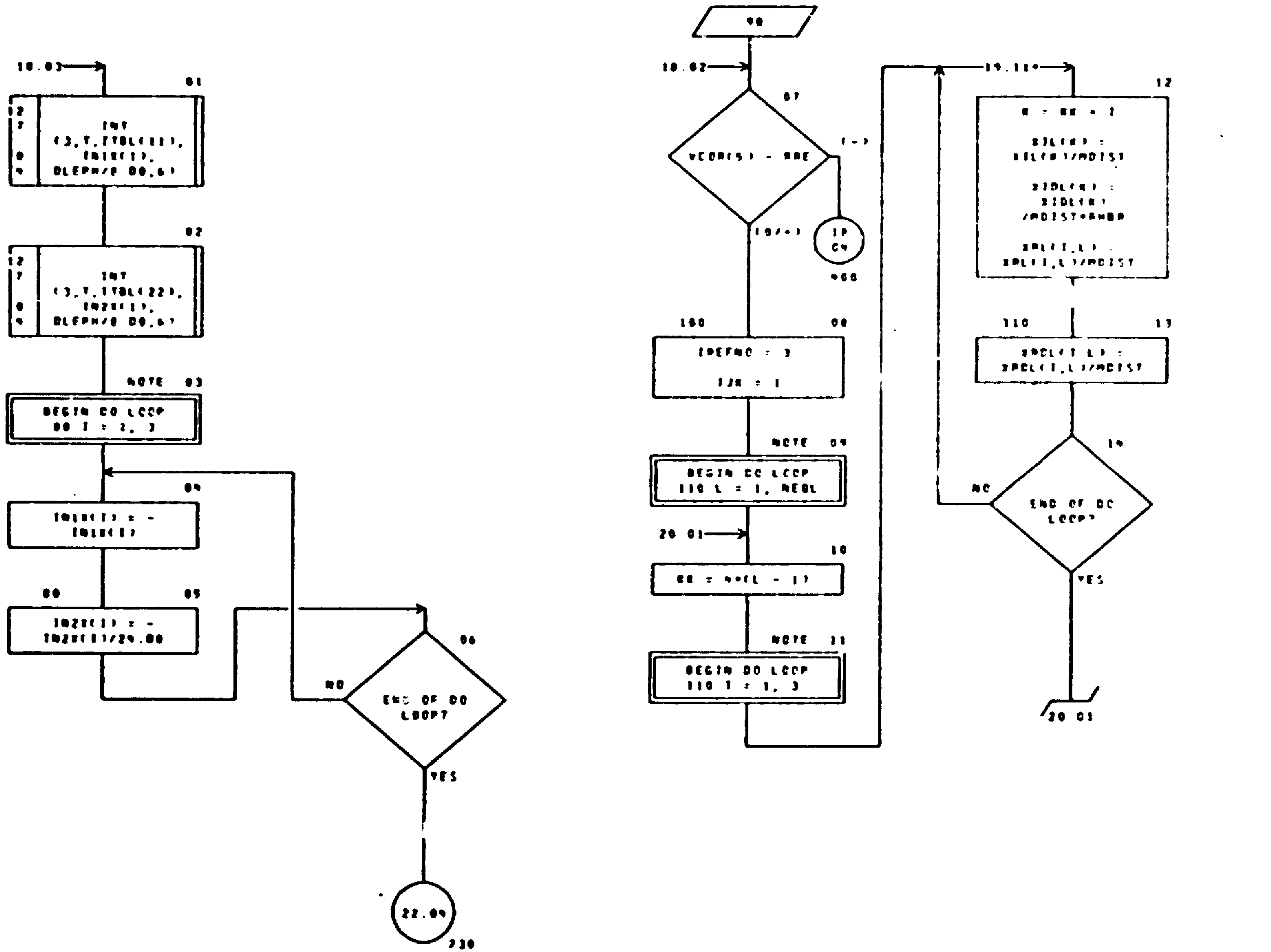


CONTRL-11

CHART TITLE - SUBROUTINE CONTRL



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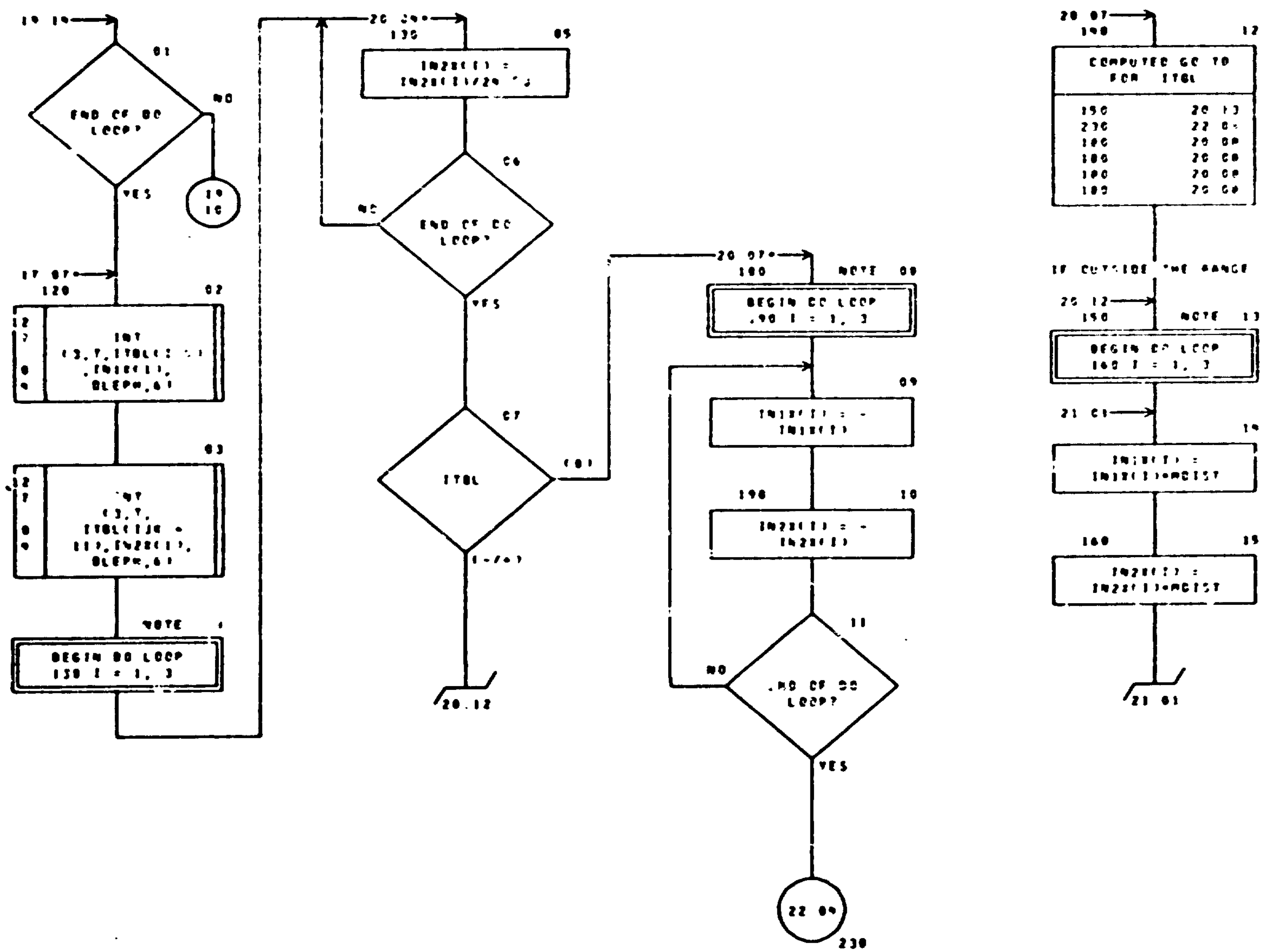


CONTRL-13

CHART TITLE - SUBROUTINE CONTRL

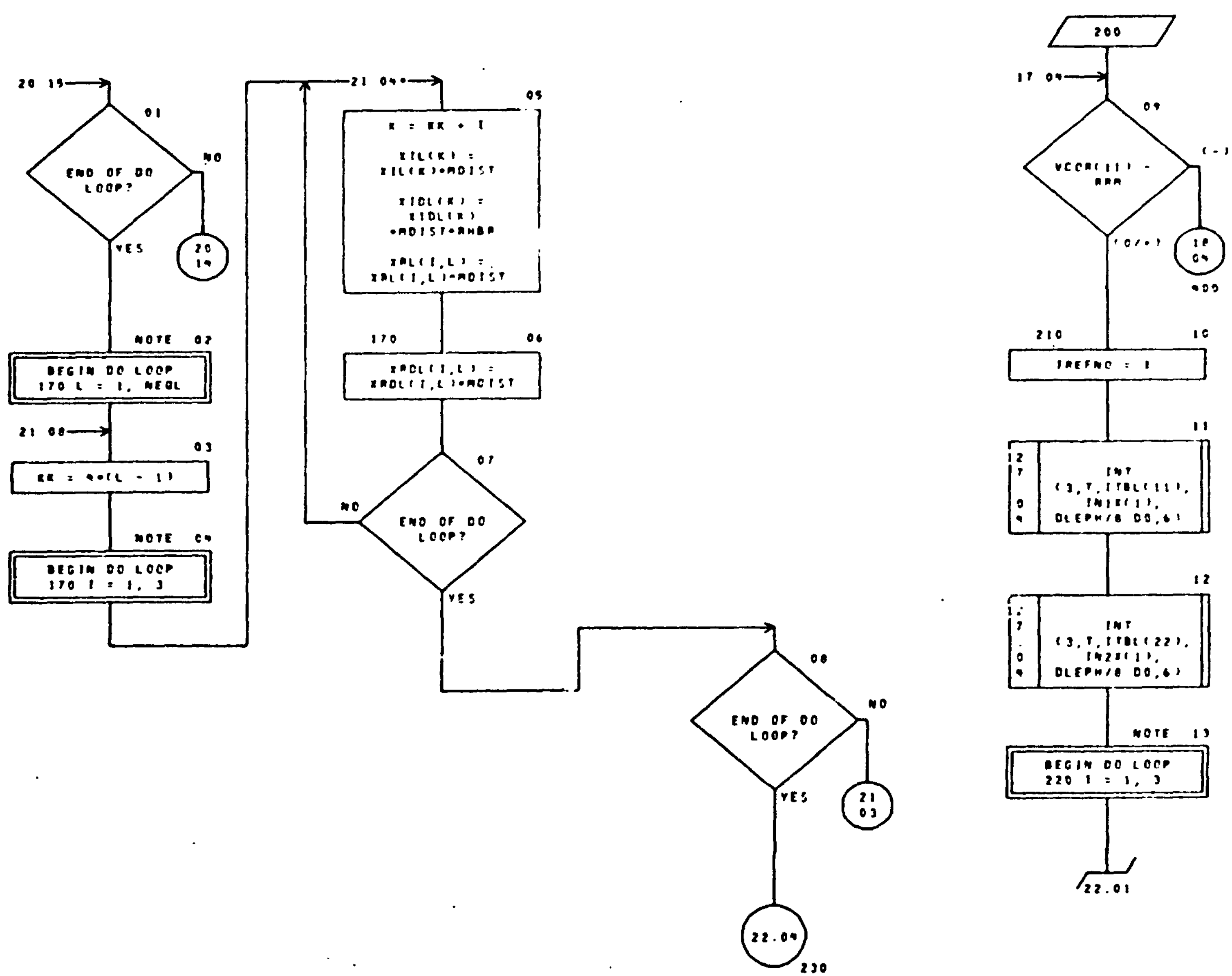


CHART TITLE - SUBROUTINE CONTRL

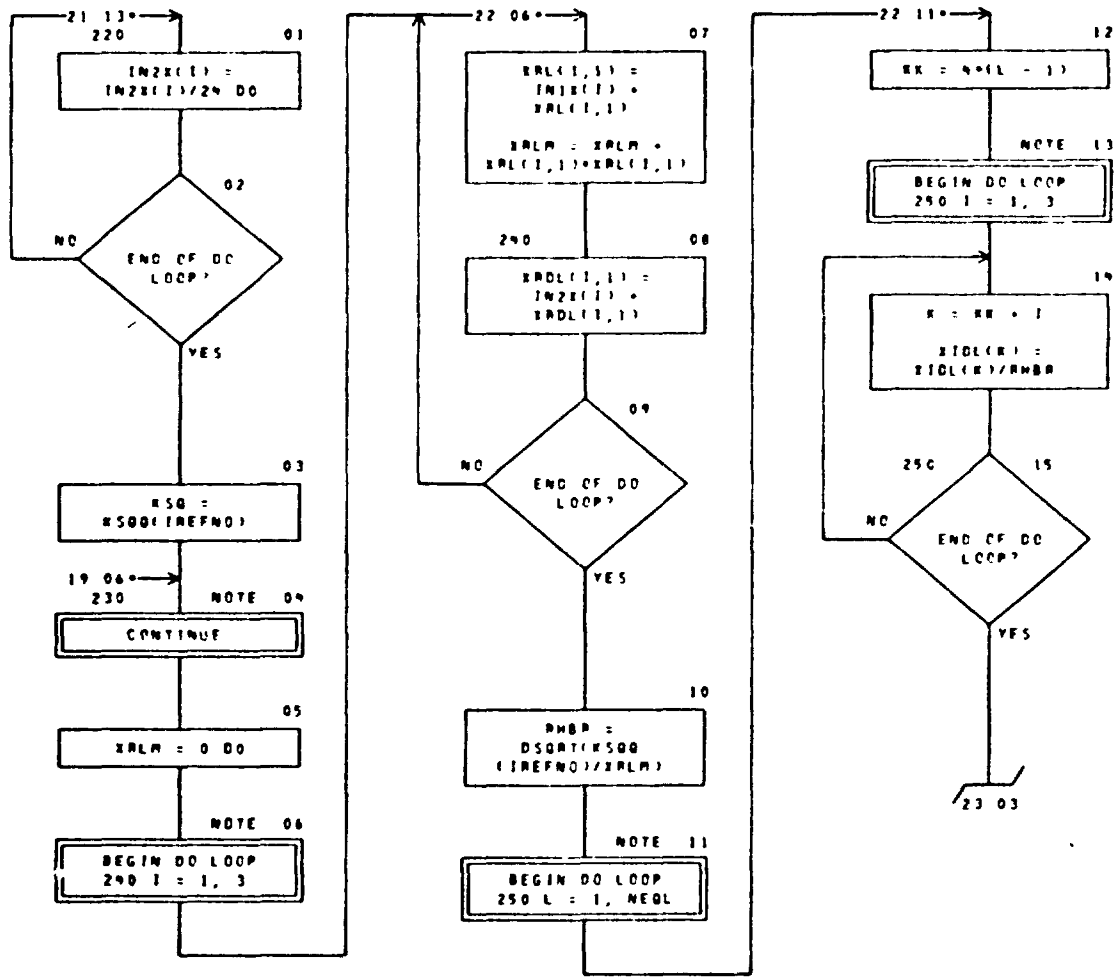


CHART TITLE - SUBROUTINE CONTRL

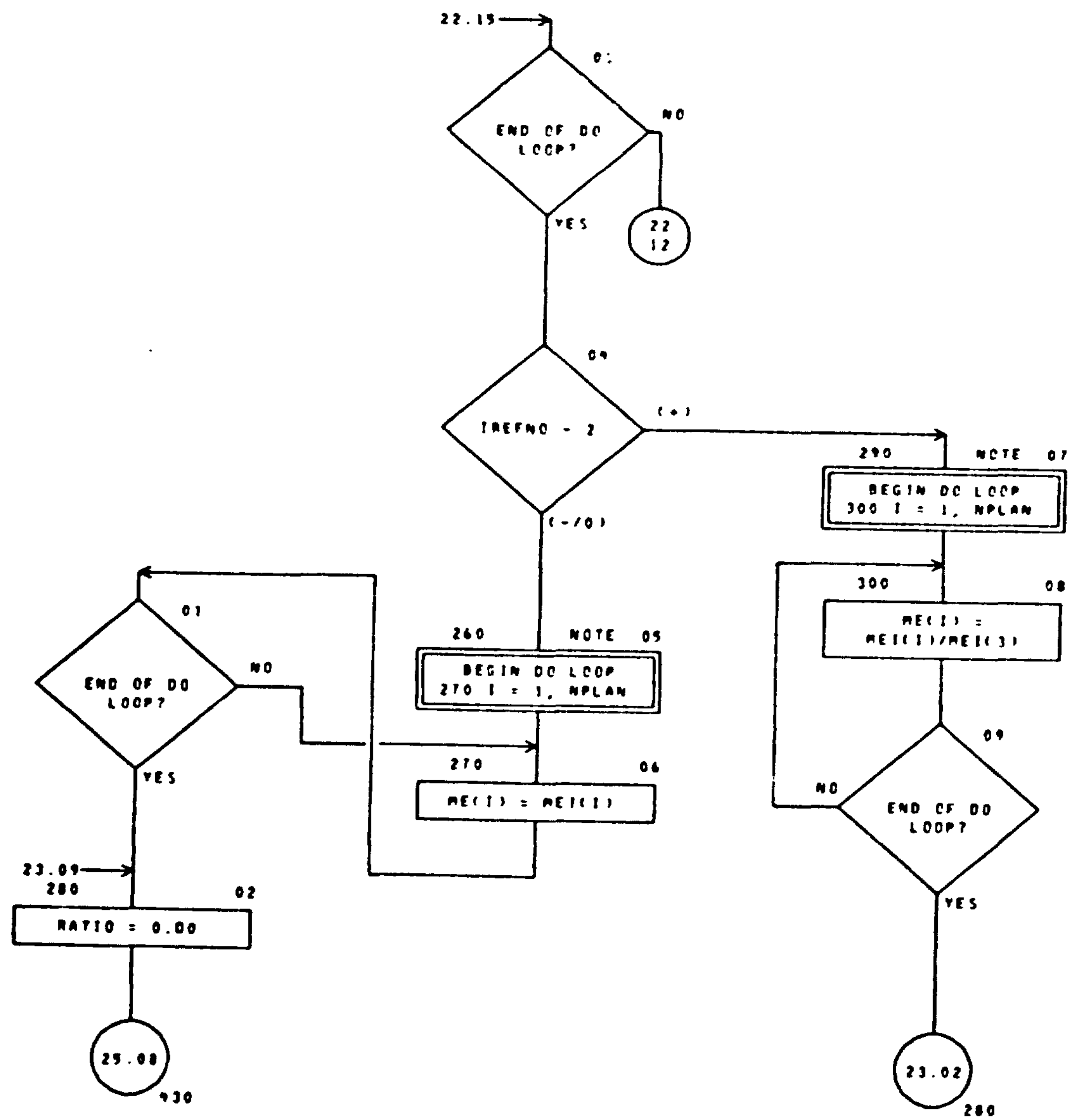


CHART TITLE - SUBROUTINE CONTRL

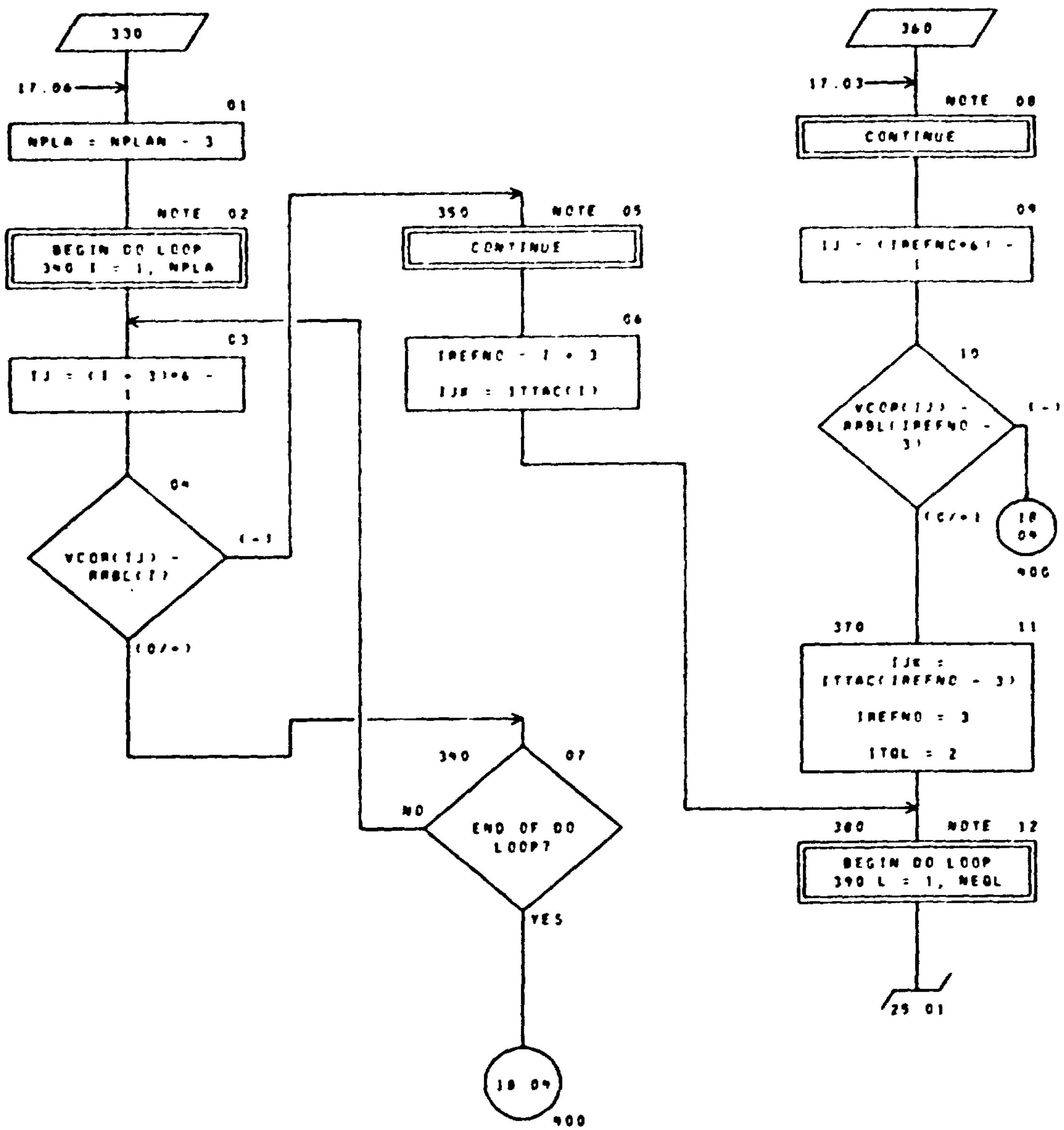


CHART TITLE - SUBROUTINE CONTRL

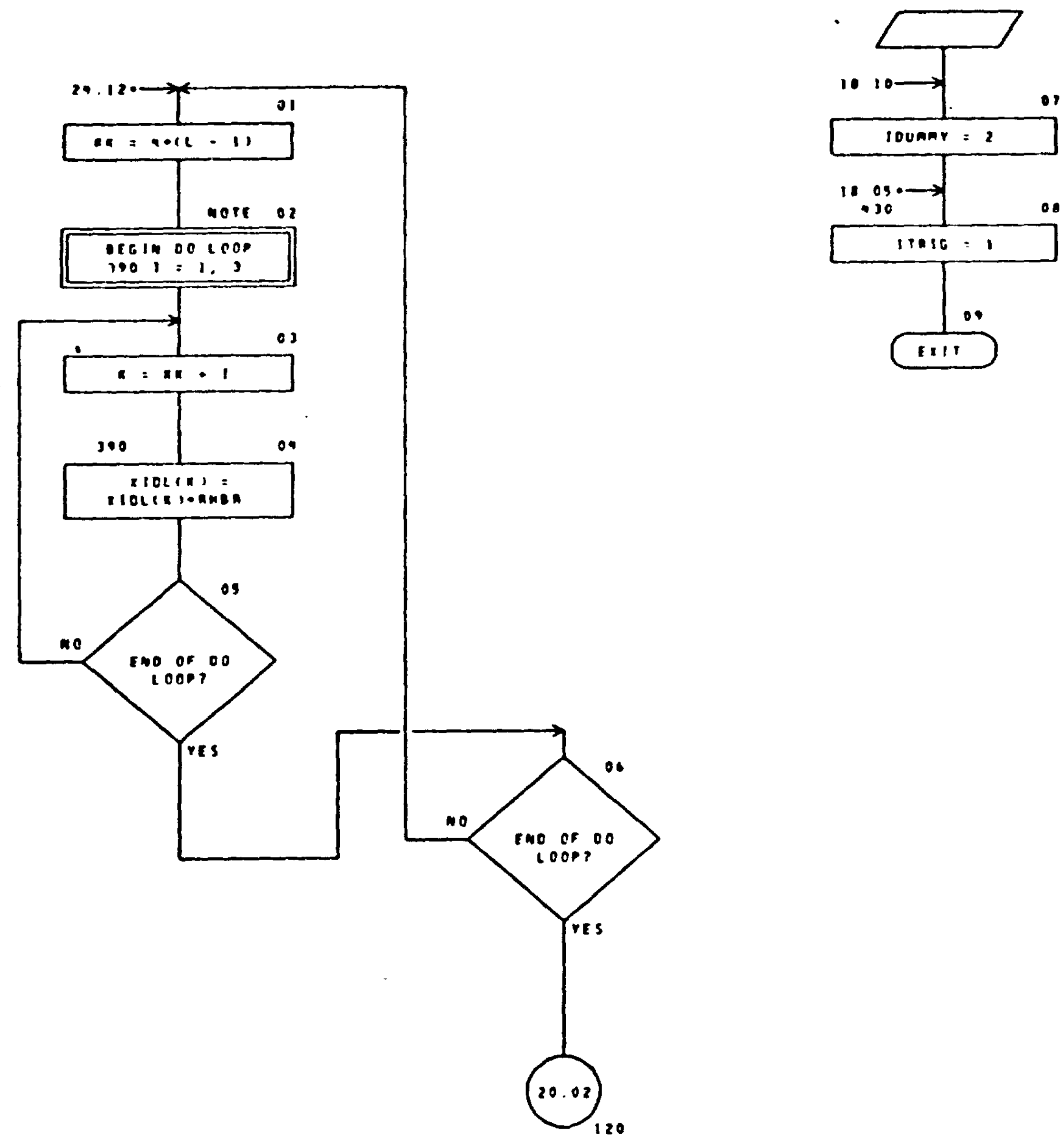


CHART TITLE - NON-PROCEDURAL STATEMENTS

```
IMPLICIT REAL*8 (A-H,O-Z)
INTEGER YEAR,DAY,HOURS
INTEGER DAY,HOURS,YEAR
REAL*8 KSQQ,MEI,ME,KM,MDIST,INTV,IN1X,IN2X,KSQ
DIMENSION XR(6),XRDOT(6),XI(3),XID(3),VCOR(72),RPBL(9)
DIMENSION ITTAC(8)
COMMON/ALAN/T,RHBP,DORHO
COMMON/AMI/DELT,BETA,DTI,XIL(80),XIDL(80),D2XIL(80),IFST(80)
COMMON/HENRY/ARRAY(8,3,12),CHIND,INTV(72),IN1X(3),
IN2X(3),KSQQ(12),KM(12),MDIST,MEI(12),ME(12),POSRCS,PRVDT,
PDT,PCIN,RC,REKM,RRM,RRE,RREU,RCINC,RATIC,SEC,TSCL,TH*S,TPI,
TIMFL,THET,VELRCS
COMMON/HER/IPS,NSL,NSL1,IFTRG,ITCT,IPCFL(30),IVAR(100),ITMAX,NTP,
NTPS,NMAX,NJ,JN,IPAT,NCT1,NJL
COMMON/HIS/PFG(30,30),WX(30),XVAR(30),YEPS(30),YC-S(30),
CHNS(100),CHN(100),PCFL(30),IDAR(7)
COMMON/ILEF/NEQL,NEQ3,NON,NCP65,IDAR(7),NCP64,NCP63,NS,N9,NS1,NJJ
COMMON/INTEG/DAY,HOURS,YEAR,IDUMMY,ITRIG,IREFNO,IREFNB,
IREFNT,IN,IC,IJK,MONTH,MIN,NCPT(72),NPLAN,NPLAN3
COMMON/LEFT/XRL(6,20),XRDL(6,20),VCOL(72,20)
COMMON/NORM/TREF,DLEPH,ITBL(22)
COMMON/STEVE/ZELT,KSQ,DIAD,REYTD,TI,TM2DP,XRI(6),XRIDT(6),SQTMU
COMMON/TBPR/ITB
EQUIVALENCE (XR(1),XRL(1,1)),(XRDT(1),XRDL(1,1)),(XI(1),XIL(1)),
(XID(1),XIDL(1)),(VCOR(1),VCOL(1,1))
```

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
      DATA AABL/ 411950936695817D-2, 385855850380251D-2,
     322250707894409D0, 364676849753055D0, 3457252944597575D0,
     5808906335711736D0, 2366D0,0.D0, 753456619165934D-3/
      DATA ITTAC/4,3,2,5,6,7,8,9/
```

Name: DCUBIC

Calling Arguments: C, R, NRE

Referenced Sub-programs: None

Referenced Commons: None

Entry Points: None

Referencing Sub-programs: SAMM

Discussion: DCUBIC is a general routine for the solution of the cubic equation of the form

$$x^3 + c_1 x^2 + c_2 x + c_3 = 0$$

The approach used is the straightforward application of the solution to cubic equations contained in many references, including the one below. If there exist three real roots to the equation, they are returned in the array R. If there is one real root and two conjugate imaginary roots, the real root is returned in the first element of R, the real portion of the imaginary roots is returned in the second element, and the imaginary portion of the imaginary roots is returned in the third element of R. The number of real roots are returned in NRE.

Reference:

C.R.C. Standard Math Tables, Chemical Rubber Co., Inc. 13th Student Edition, 1964, pp. 366-367.

DCUBIC EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
C(3)	UX		Array of equation coefficients c_i, $i = 1, 2, 3$.
R(3)	SX		Array containing roots of the cubic equation, as defined in the discussion above.
NRE	SX		Number of real roots to the cubic equation.

CHART TITLE - SUBROUTINE DCUBIC(C,R,NRE)

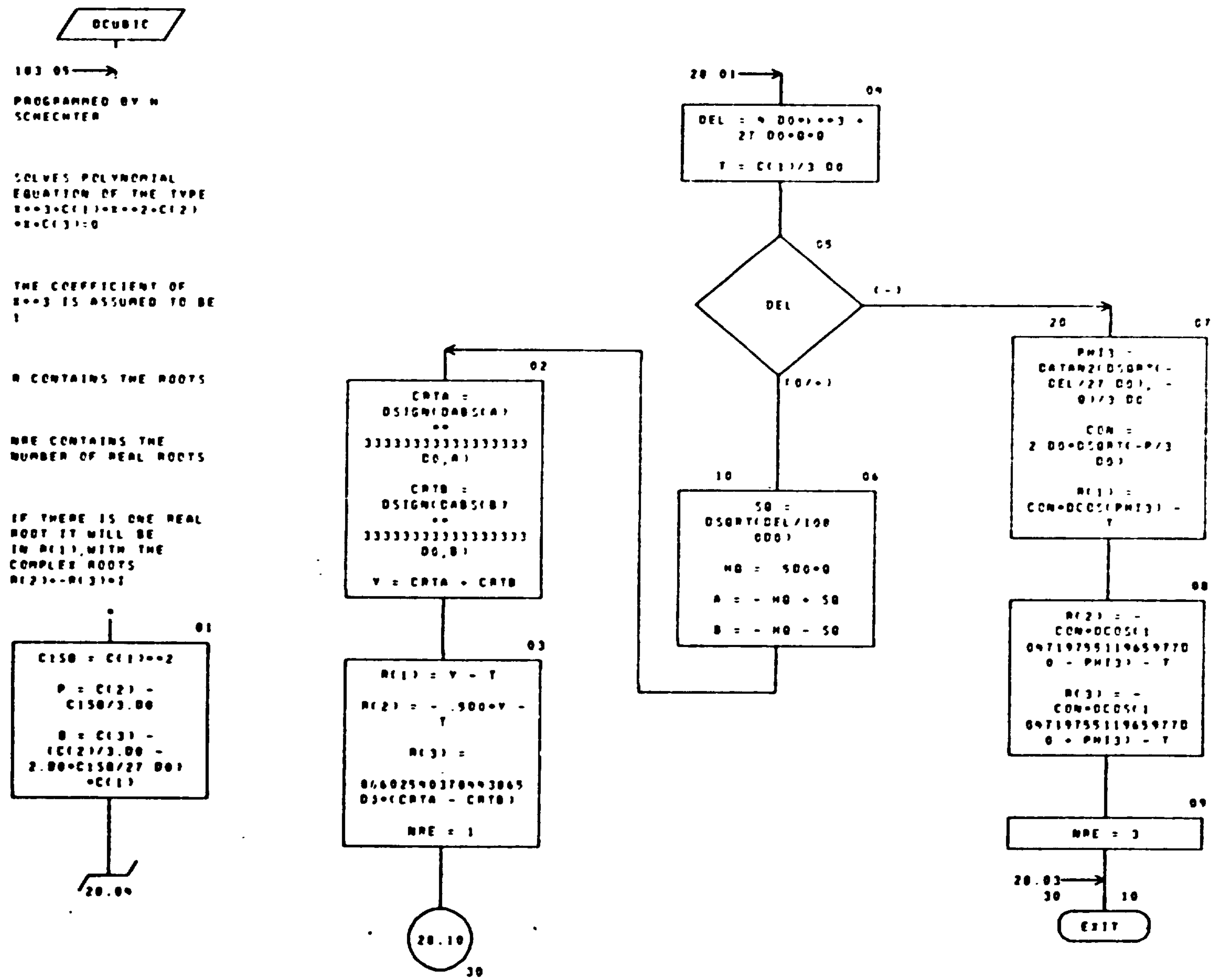


CHART TITLE - NON-PROCEDURAL STATEMENTS

```
IMPLICIT REAL*8 (A-H,O-Z)
DIMENSION C(3),R(3)
```

Name: DERIV

Calling Argument: None

Referenced Sub-programs: INT, RADII, SOLENG, TBDP

Referenced Commons: ALAN, AM1, HENRY, HER, ILEF, INTEG, LEFT, LEON, NORM, STEVE

Entry Points: None

Referencing Sub-programs: AMAINT, TRAJL

Discussion: DERIV evaluates derivatives for numerical integration. The equations of motion of the spacecraft in the gravitational field of n attracting bodies and subject to other perturbing accelerations such as thrust and radiation pressure, are given by,

$$\ddot{R}_v = -\sum_{i=1}^{n} \mu_i \frac{R_{vi}}{r_{vi}^3} + \sum_j F_j , \tag{1}$$

where $\ddot{R}_V$ is the total acceleration acting on the vehicle, μ_i is the gravitational constant of the i^{th} attracting body, R_{vi} is the position of the vehicle relative to the i^{th} body, and F_j represents the non-gravitational perturbing acceleration such as thrust and solar pressure. These equations are put into observable form by referring them to a reference body c. The equations of motion of the reference body are:

$$\ddot{R}_c = -\sum_{\substack{i=1 \\ i \neq c}}^{n} \mu_i \frac{R_{ci}}{r_{ci}^3} . \tag{2}$$

Subtraction of Equation (2) from Equation (1) results in the equations of motion of the vehicle with respect to the reference body c.

$$\ddot{R}_{vc} = -\mu_c \frac{R_{vc}}{r_{vc}^3} - \sum_{\substack{i=1 \\ i \neq c}}^{n} \mu_i \left[\frac{R_{vi}}{r_{vi}^3} - \frac{R_{ci}}{r_{ci}^3} \right] + \sum_j F_j . \tag{3}$$

This permits uniform computation of the perturbations, regardless of reference origin. It should be noted the perturbation arising from the mass of the reference planet corresponds to the Encke acceleration,

$$\Delta\ddot{R}_p = -\sum_i^n \mu_i \left(\frac{R_{vi}}{r_{vi}^3} - \frac{R_{ci}}{r_{ci}^3} \right).$$

R_{ci} is obtained from the ephemeris interpolation routine INT and stored in the COMP array. R_{vi} is stored in the VCOL array.

If Equation (3) is integrated directly by some numerical scheme, there results, after a number of step-by-step integrations, an accumulation of error which leads to inaccurate results. To avoid this loss in precision, it is convenient to write Equation (3) in the form:

$$\ddot{R}_{vc} = \ddot{R}_k + \ddot{\xi} . \tag{4}$$

The velocity and displacement vectors can be written as:

$$\dot{R}_{vc} = \dot{R}_k + \dot{\xi} , \tag{5}$$

$$R_{vc} = R_k + \xi . \tag{6}$$

The reference body (the one in whose sphere of influence the vehicle travels) is chosen so as to minimize the perturbations.

In this method $\ddot{R}_k$ is taken as:

$$\ddot{R}_k = -\mu_c \frac{R_k}{r_k^3} , \tag{7}$$

and

$$\Delta\ddot{R} = -\mu_c \left[\frac{R_{vc}}{r_{vc}^3} - \frac{R_k}{r_k^3} \right] - \sum_{\substack{i=1 \\ i \neq c}}^{n} \mu_i \left[\frac{R_{vi}}{r_{vi}^3} - \frac{R_{ci}}{r_{ci}^3} \right] + \sum_j F_j . \tag{8}$$

Equations (7) constitute the equations of motion of the Kepler problem and are solved by subroutine TBDP.

The terms accounting for the Encke term and the planetary perturbations appearing on the right hand side of Equation (8) involve numerous terms of the form $\frac{R}{r^3} - \frac{R_o}{r_o^3}$ where R and R_o may differ only by small amounts. For the Encke term, for instance, $R - R_o = \Delta R$ which is small, and for the planetary perturbations, the difference is R_{vc} which often is small also.

A computation scheme, which avoids loss of precision due to the subtraction of nearly equal terms and which also is correct when R_{vc} is not small, is employed. Defining the variable u as:

$$u = \frac{2}{r_o^2}(R_o + \frac{1}{2}\Delta R) \cdot \Delta R , \tag{9}$$

where $\Delta R = R - R_o$, then the difference terms on the right hand side of (8) may be evaluated

$$\frac{R}{r^3} - \frac{R_o}{r_o^3} = \frac{\Delta R}{r_o^3} + \frac{R(u^3 + 3u^2 + 3u)}{\left(1 + \frac{r^3}{r_o^3}\right)} .$$

VCOL and COMP are the storage blocks from which the planetary perturbations are computed. Both consist of several 6-vectors whose components are $[x, y, z, r^3, r, r^2]$, respectively. The VCOL block is doubly dimensioned and contains the same vectors, regardless of reference. The position vectors contained in the VCOL (I, J) block are:

I	Vector
1 - 6	vehicle with respect to Earth
7 - 12	vehicle with respect to Moon
13 - 18	vehicle with respect to Sun

I	Vector
19 - 24	vehicle with respect to Venus
25 - 30	vehicle with respect to Mars
31 - 36	vehicle with respect to Jupiter
37 - 42	vehicle with respect to Saturn
43 - 48	vehicle with respect to Uranus
49 - 54	vehicle with respect to Neptune
55 - 60	vehicle with respect to Pluto
67 - 72	vehicle with respect to Mercury

for all J. Vectors for J = 1 correspond to the nominal trajectory while J = 2 to J = NEQL corresponds to perturbation trajecotires. The format of the COMP block is identical to the VCOL format. The contents of the COMP depend on the reference origin. The COMP vectors contain the reference body with respect to the perturbing bodies. Since these vectors are the same for nominal and reference trajectories, the array is singly dimensioned. In this array, one of the vectors would be the reference with respect to itself. This vector is filled with the unperturbed vehicle position (derived from the two-body problem) with respect to the reference.

The method presented yields accurate trajectories using relatively little computer time. All significant solar system bodies may be included without undue complications. All perturbing bodies whose identification number is not greater than the integer NPLAN are included in the simulation. Since the perturbations only are integrated, the allowable integration interval is fairly large over most of the path. Even in the vicinity of Earth or another planet a relatively large interval (compared to other schemes) may be used without limiting the stability and accuracy of the solutions. The perturbations are kept small in two ways. First, the two-body orbit is rectified whenever the perturbations exceed a specified maximum value compared to the corresponding unperturbed values. This limits error build-up with respect to particular reference body. Second, the reference body of the two-body problem is changed from Earth, to Sun, to planet accordingly, as that reference body would contribute the largest perturbing force otherwise. This method is referred to as a modified Encke formulation and will handle circular orbits and zero inclination, which are normally singular regions for the standard Encke formulation. The problem is defined in terms of parameters which have real physical significance (namely, the position and velocity vectors) which are directly relatable to measurable quantities.

The computation of the non-gravitational contributions is performed in subroutine SOLENG. The total accelerations are then converted to second derivatives with respect to the universal variable β through the equations

$$\xi'' = \ddot{\xi} \frac{r_k^{\,2}}{\mu_c} + \xi' \frac{R_k \cdot \dot{R}_k}{\sqrt{\mu_c}\, r_k}$$

where the prime denotes derivatives with respect to β.

DERIV EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
T	U	ALAN	Time in hours from start of trajectory.
KM(12)	U	HENRY	Array of planetary gravitational constants, in ER^3/hr^2 for IREFNO ≤ 2, AU^3/hr^2 for IREFNO ≥ 3. Index is IREFNO.
NQN	U	ILEF	Number of equations integrated on each nominal trajectory.
NTP	U	HER	Counter incremented along the trajectory and equal to the current arc number.
XIL(80)	U	AM1	Second integrals of Encke terms of nominal and perturbation trajectories.

DERIV EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
XRI(6)	U	STEVE	Position vector on reference two-body trajectory at last rectification point. Contents include [x, y, z, r^3, r, r^2].
XRL (6, 20)	SUA	LEFT	Position vectors of spacecraft from reference body on nominal and perturbation trajectories. Dimension of 6 provides for magnitude, square and cube of distance plus the three Cartesian components.
XRO(6)	SUA	LEON	Position vector on reference two-body trajectory at current time. Contents include [x, y, z, r^3, r, r^2].
XSQ	U	STEVE	Gravitational constant of current reference body, in ER^3/hr^2 for IREFNO ≤ 2 and AU^3/hr^2 for IREFNO ≥ 3.
BETA	U	AM1	Universal variable, accumulated from last rectification point.
INTV (72)	SUA	HENRY	Array of planetary heliocentric position vectors returned from subroutine INT. The three Cartesian coordinates of the bodies are stored sequentially in the following order: Earth, Jupiter, Mars, Venus, Saturn, Uranus, Neptune, Pluto. Only the first 24 locations are currently used by the program.
NEQL	U	ILEF	Number of trajectories being integrated simultaneously.
RHBR	SU	ALAN	Factor for converting between time derivatives and universal anomaly derivatives, $\dot{\beta}$.

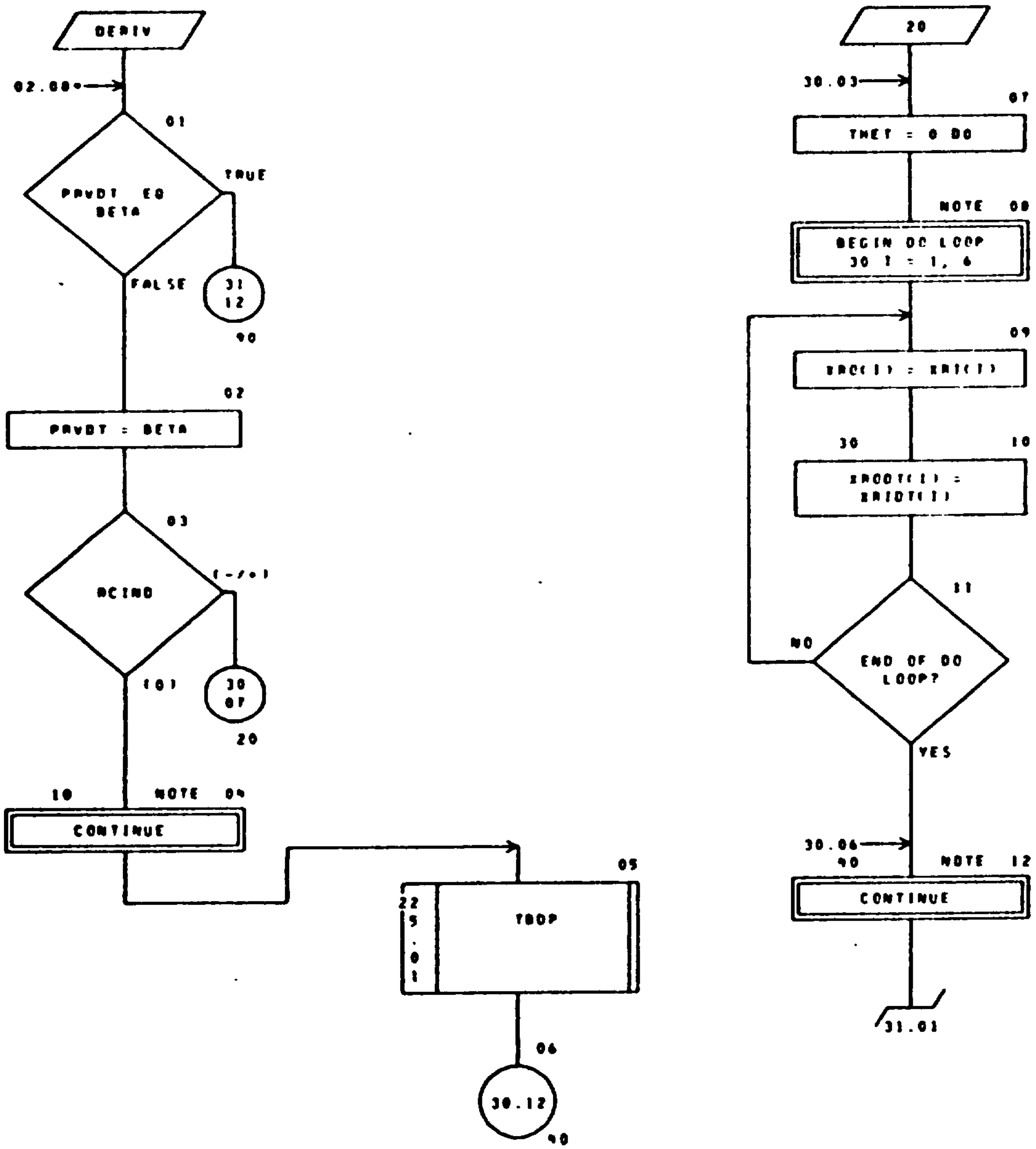
DERIV EXTERNAL VARIABLES TABLE (cont)

Variables	Use	Common	Description
THET	S	HENRY	Change in eccentric anomaly along reference two-body trajectory, measured in radians from last rectification.
VCOL (72,20)	UA	LEFT	Array of spacecraft position vectors relative to all perturbing bodies on nominal and perturbed trajectories. Includes Cartesian coordinates plus magnitude, square and cube of distance.
XIDL (80)	U	AM1	First integral of Encke terms of nominal and perturbation trajectories.
XRDL (6,20)	SUA	LEFT	Velocity vectors of spacecraft relative to reference body on nominal and perturbation trajectories. Dimension of 6 provides for magnitude, square and cube of velocity plus the three Cartesian components.
DELPH	U	NORM	Time interval, in hours, between tabular entries in ephemeris table.
DORHO	SU	ALAN	Factor used in converting between second derivatives with respect to time and universal anomaly, defined $\dot{r}_k/\sqrt{\mu}$.
D2XIL (80)	SU	AM1	Array of second derivatives representing the Encke perturbations for the nominal and perturbation trajectories.
MDIST	U	HENRY	Conversion factor for converting between ER and AU.
PRVDT	SU	HENRY	Value of universal anomaly on previous pass through subroutine DERIV.

DERIV EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
RCIND	U	HENRY	Rectification indicator. Value of 1 denotes that a rectification of the reference two-body trajectory was just performed.
SQTMU	U	STEVE	$\sqrt{\mu}$.
XRIDT (6)	U	STEVE	Velocity vector on reference two-body trajectory at last rectification point. Contents include $[\dot{x}, \dot{y}, \dot{z}, v^3, v, v^2]$.
XRODT (6)	SU	LEON	Velocity vector on reference two-body trajectory at current time. Contents include $[\dot{x}, \dot{y}, \dot{z}, v^3, v, v^2]$.
IREFNO	U	INTEG	Reference body ID number as follows: 1 Earth, 2 not available, 3 Sun, 4 Venus, 5 Mars, 6 Jupiter, 7 Saturn, 8 Uranus, 9 Neptune, 10 Pluto
NPLAN3	UA	INTEG	Number of position coordinates to be returned from the ephemeris interpolation subroutine INT.

CHART TITLE - SUBROUTINE DERIV



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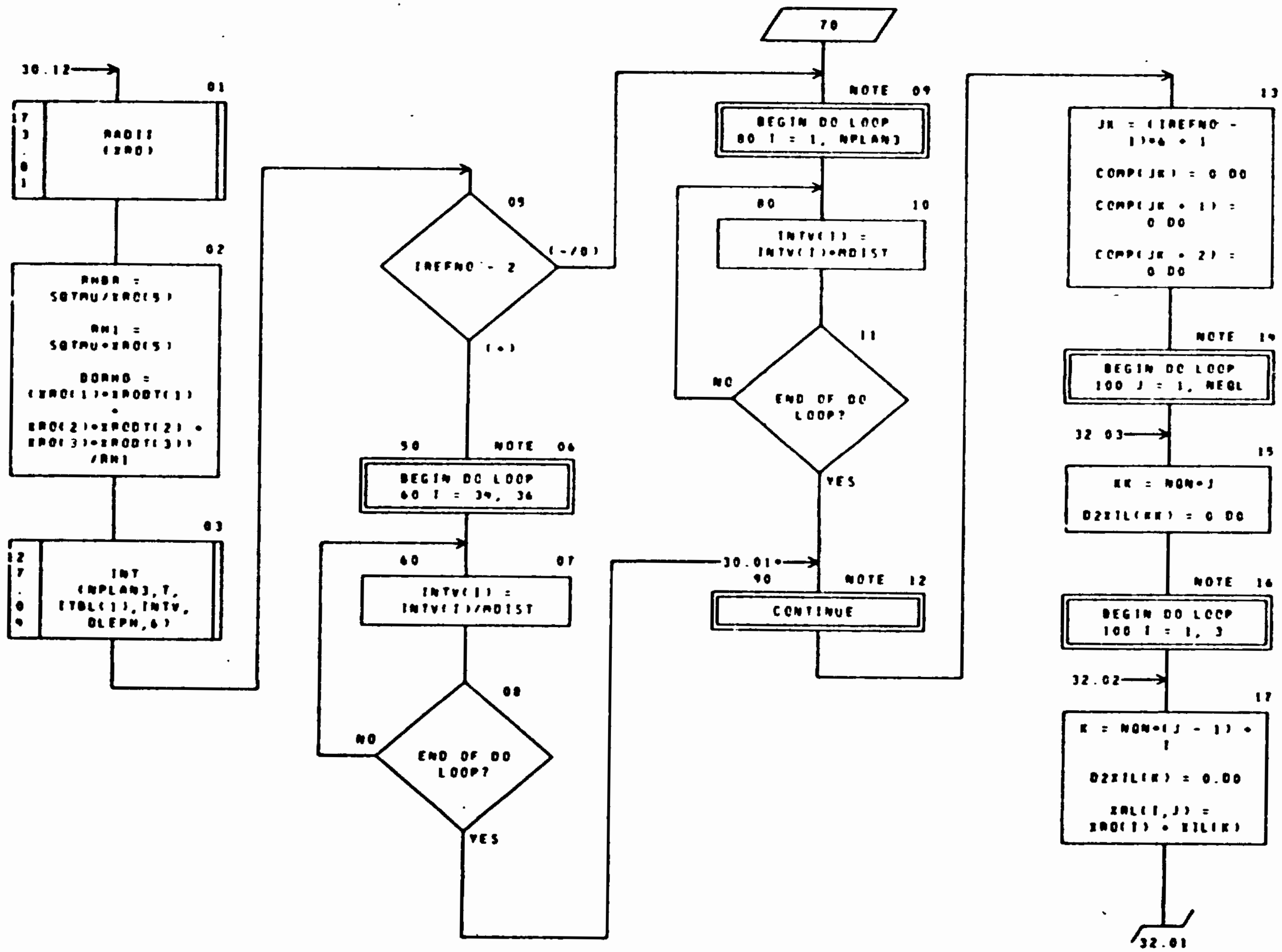

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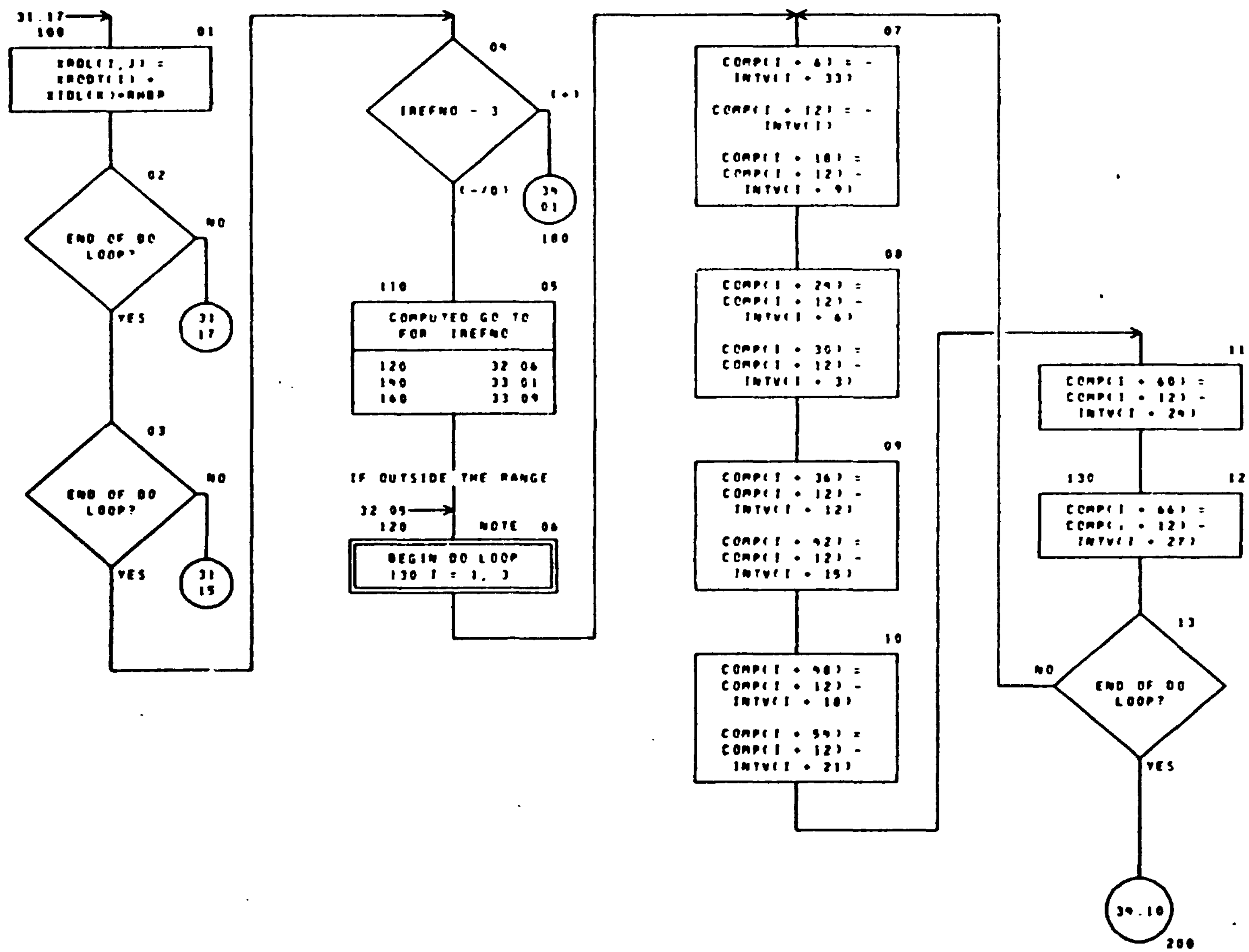

DERIV-11

CHART TITLE - SUBROUTINE DERIV

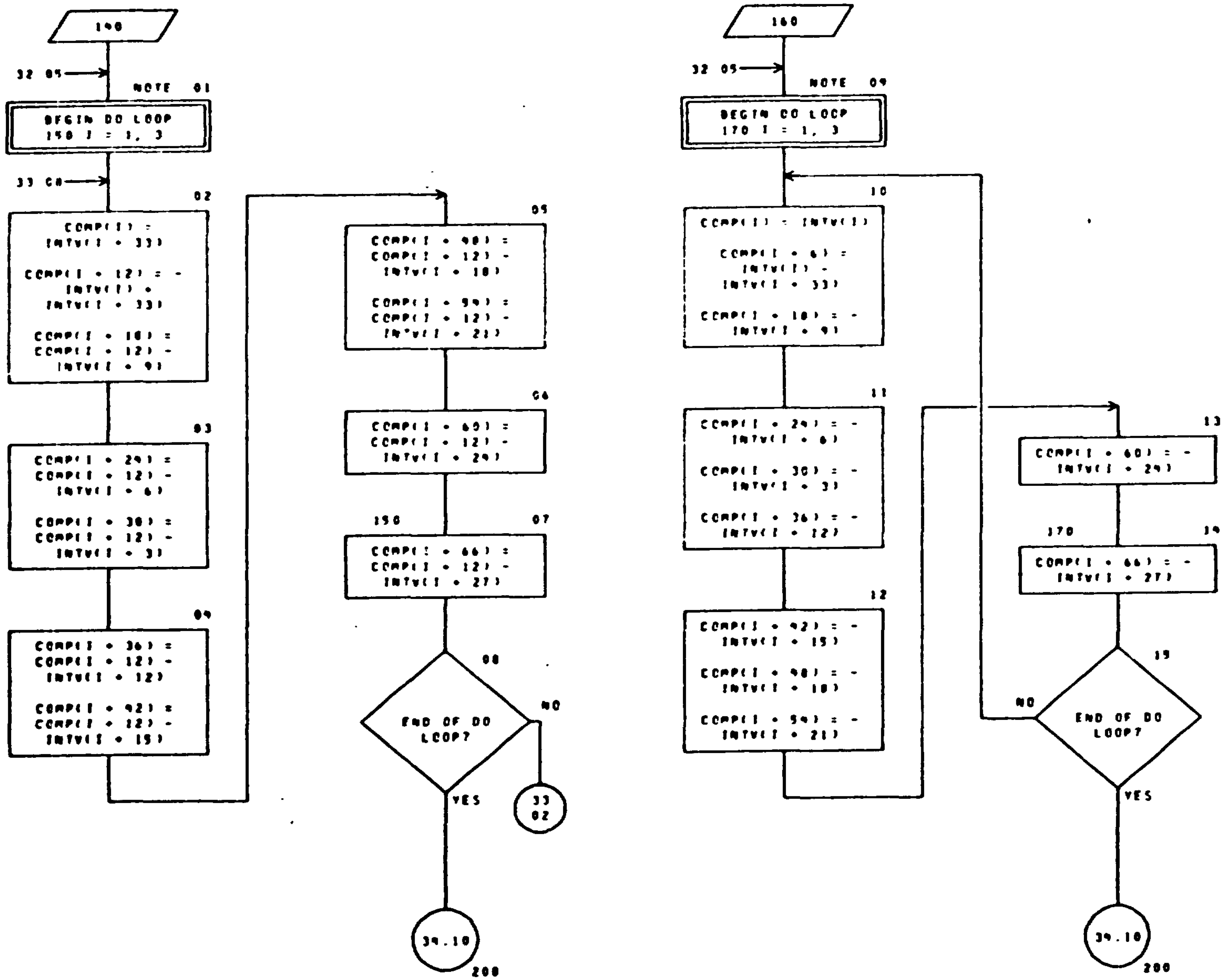

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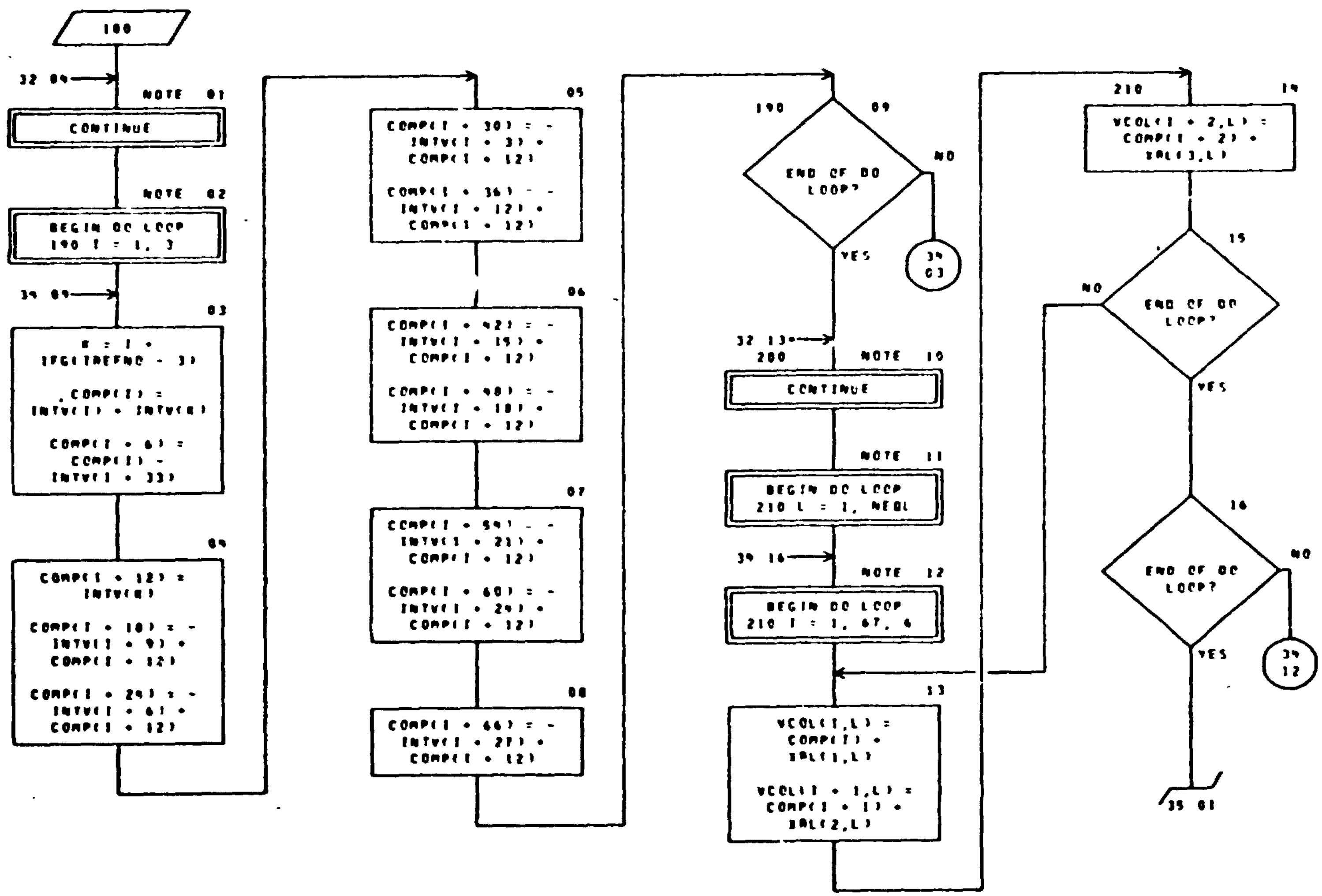
CHART TITLE - SUBROUTINE DERIV



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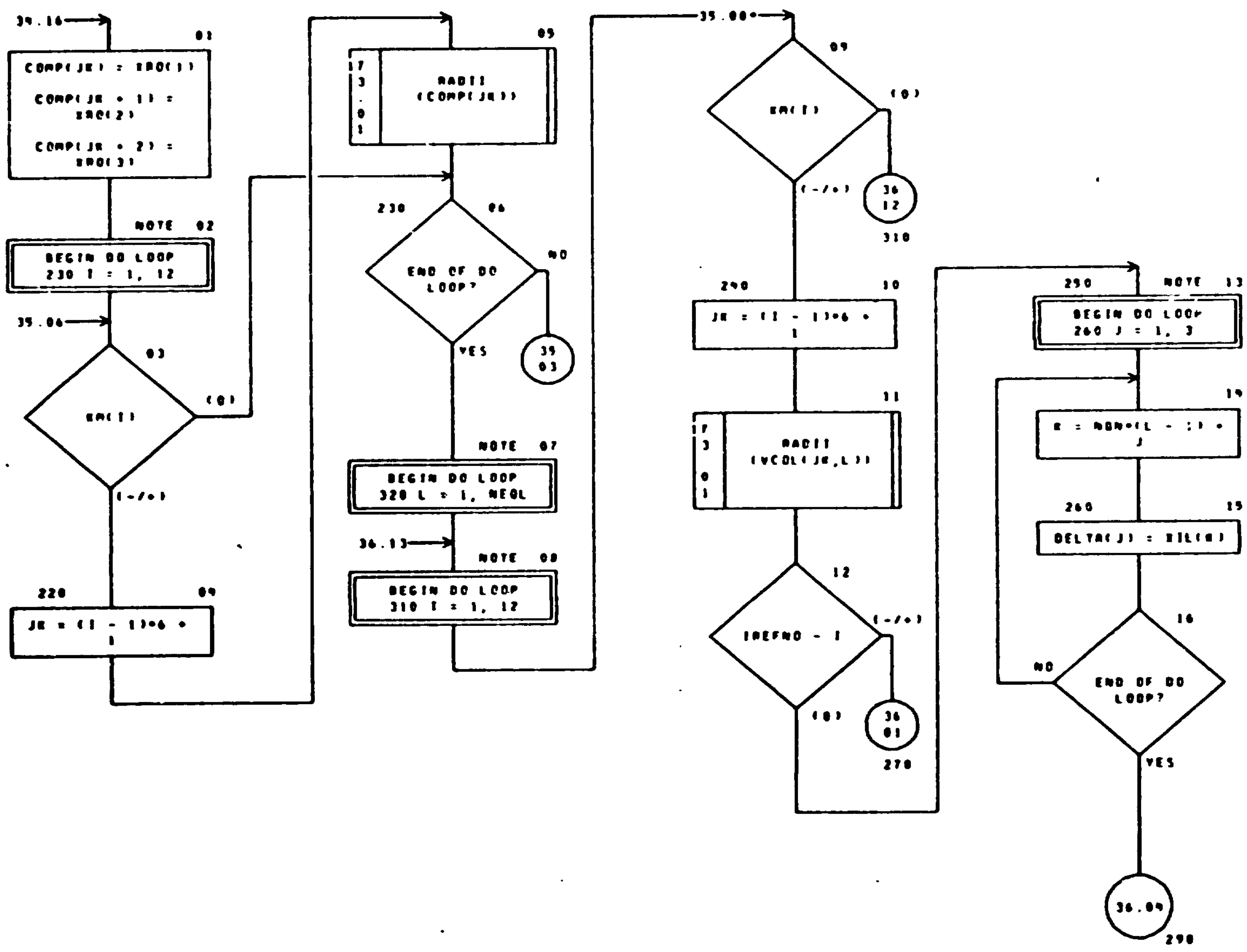
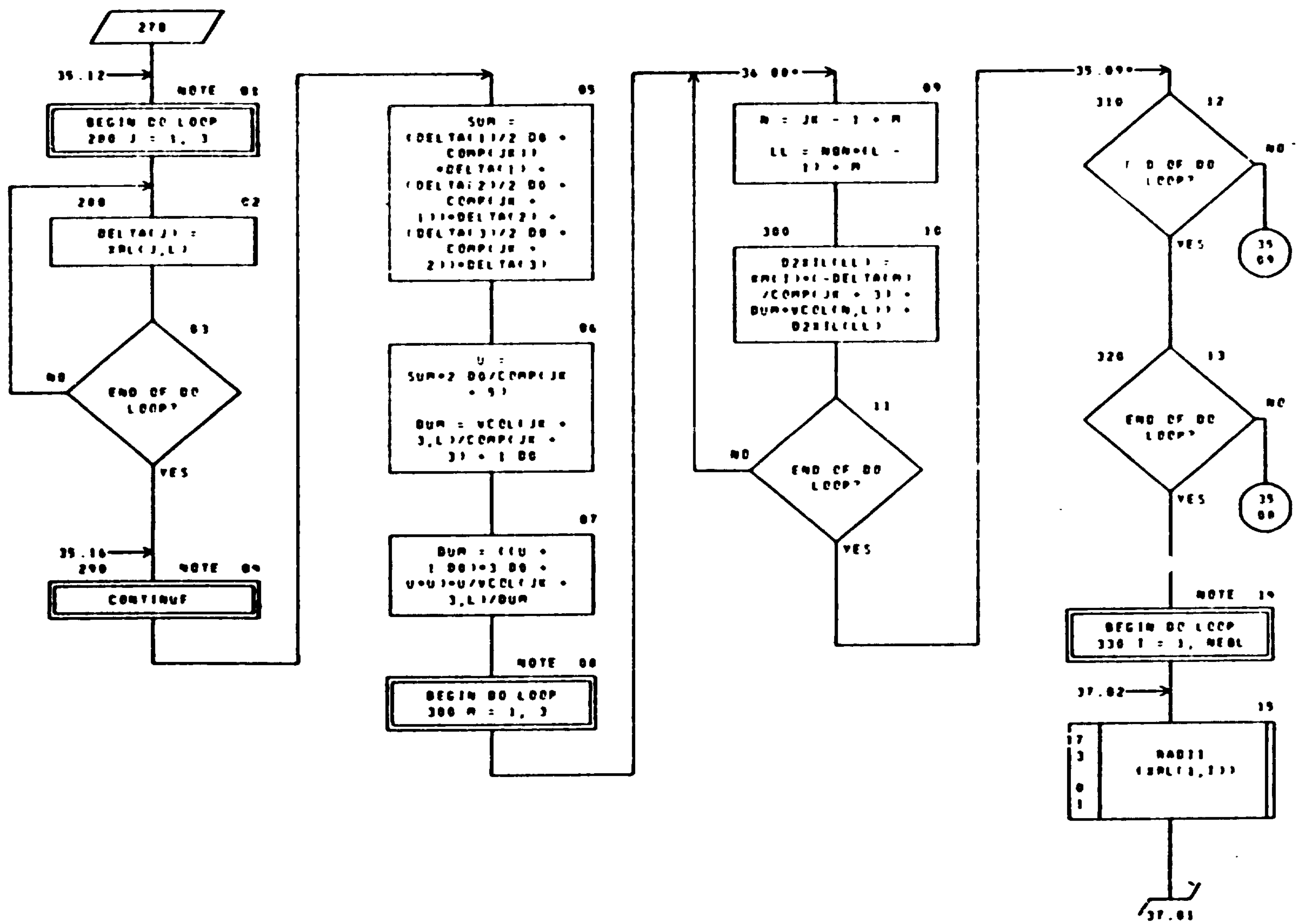


CHART TITLE - SUBROUTINE DERIV



DERIV-15

CHART TITLE - SUBROUTINE DERIV

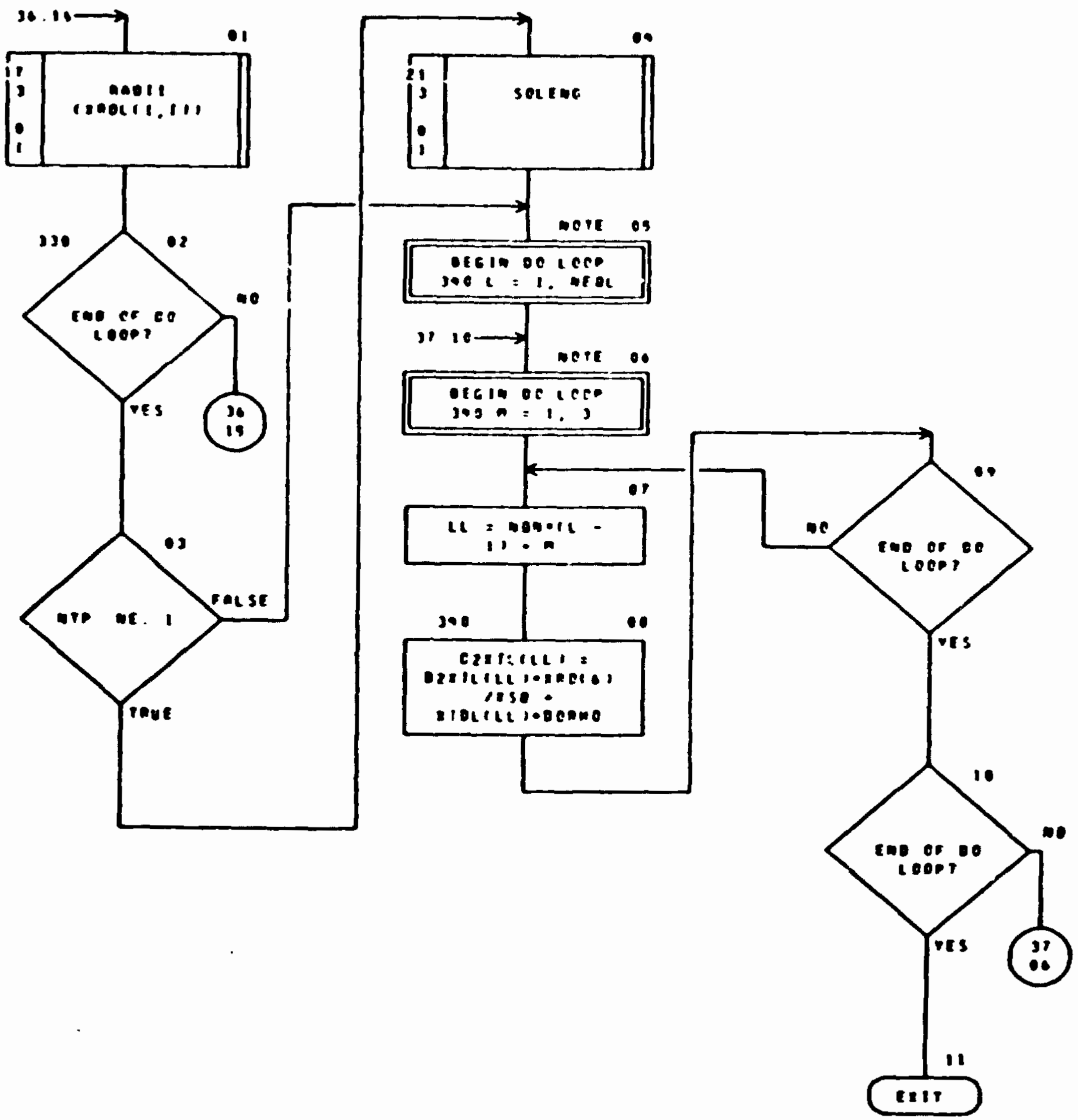


CHART TITLE - NON-PROCEDURAL STATEMENTS

```
IMPLICIT REAL*8 (A-H,O-Z)
INTEGER DAY,HOURS,YEAR
REAL*8 ESOO,MEI,ME,EM,MDIST,INTV,IN1X,IN2X
DIMENSION IFG(9),DELTA(3),COMP(72)
COMMON/ALAN/T , AHDR, OCRHO
COMMON/AMI/DELT,BETA,DTI,XIL(80),XIDL(80),DZXIL(80),IFST(80)
COMMON/HENRY/ARRAY(8,3,12),CHIND,INTV(72),IN1X(3),
IN2X(3),ESOO(12),EM(12),MDIST,MEI(12),ME(12),POSACS,PRVDT,
PDT,PCIN,RD,REAM,RAM,RAE,RREV,RCIND,RATIO,SEC,TSCL,TNTS,TPI,
TIMEL,THET,VELACS
COMMON/HER/IPS,NSL,NSL1,IFTAG,ITCT,IPCFL(30),IVAR(100),ITMAX,NTP,
NTPS,NPAT,NJ,JN,IPAT,NCTI,NJL
COMMON/ILEF/NEQL,NEQ3,NON,NOP65,ICAR(7),NOP60,NOP63,NS,NV,NS1,NJJ
COMMON/INTEG/DAY,HOURS,YEAR,IDUMMY,ITRIG,IREFNC,IREFNO,
IREFNT,IN,IO,IJK,MONTH,MIN,NCPT(72),NPLAN,NPLANJ
COMMON/LEFT/XPL(6,20),XPDL(6,20),VCOL(72,20)
COMMON/LEON/XRO(6),XRODT(6),TMPOP,W
COMMON/NORM/TREF,DLEPS,ITBL(22)
COMMON/STEVE/IFLT,XSO,CIAD,PDCTD,TI,TM2DP,XRI(6),XRIDT(6),SOTMU
DATA IFG/9,6,3,12,15,18,21,24,27/
```

<u>Name:</u> DETDT

<u>Calling Argument:</u> None

<u>Referenced Sub-programs:</u> None

<u>Referenced Commons:</u> ALAN, HENRY, INTEG, LEFT, STEVE

<u>Entry Points:</u> None

<u>Referencing Sub-programs:</u> TRAJL

<u>Discussion:</u> This subroutine is used to define the integration and print intervals throughout the trajectory. The values of the intervals to be used are stored in the array ARRAY(8, 3, 12) as a function of distance from the several planetary bodies. ARRAY contains, for each body, up to eight distances with which are associated seven integration intervals and seven print intervals. Denoting the distance for the current reference body as r_i, $i = 1, 2, ---, 8$, and the instantaneous distance of the spacecraft from the reference body as r, a comparison of r and r_i is made to determine the index j such that

$$r_j \leq r < r_{j+1}.$$

The.. the integration interval, $\Delta\beta$, and the print interval, Δp, are assigned

$$\Delta\beta = \text{ARRAY (j, 2, IREFNO)}$$

$$\Delta p = \text{ARRAY (j, 3, IREFNO)}$$

If $r < r_1$ or $r > r_8$, a warning message is printed and the subroutine is exited without modifying either the integration or print interval. If r is between r_1 and r_8, the new integration interval is compared with the previous value and, if unequal, the integration interval change indicator CHIND is set to 1. Similarly, the new print interval is compared to the previous value and, if unequal, the print interval change indicator is set to 1.

<u>Messages and Printout:</u> If $r < r_1$, the following message is printed:

RVE LESS THAN MIN.

IREFNO = __(I3)__ TIME = __(D24.15)__ R = __(D24.15)__ .

The three variables printed are the reference body number, the current time in hours from the start of the trajectory, and the current distance from the reference body in ER if IREFNO < 3 and in AU otherwise.

If $r > r_8$, the following is printed:

RVE EXCEEDS MAX.

IREFNO = __(I3)__ TIME = __(D24.15)__ R = __(D24.15)__ .

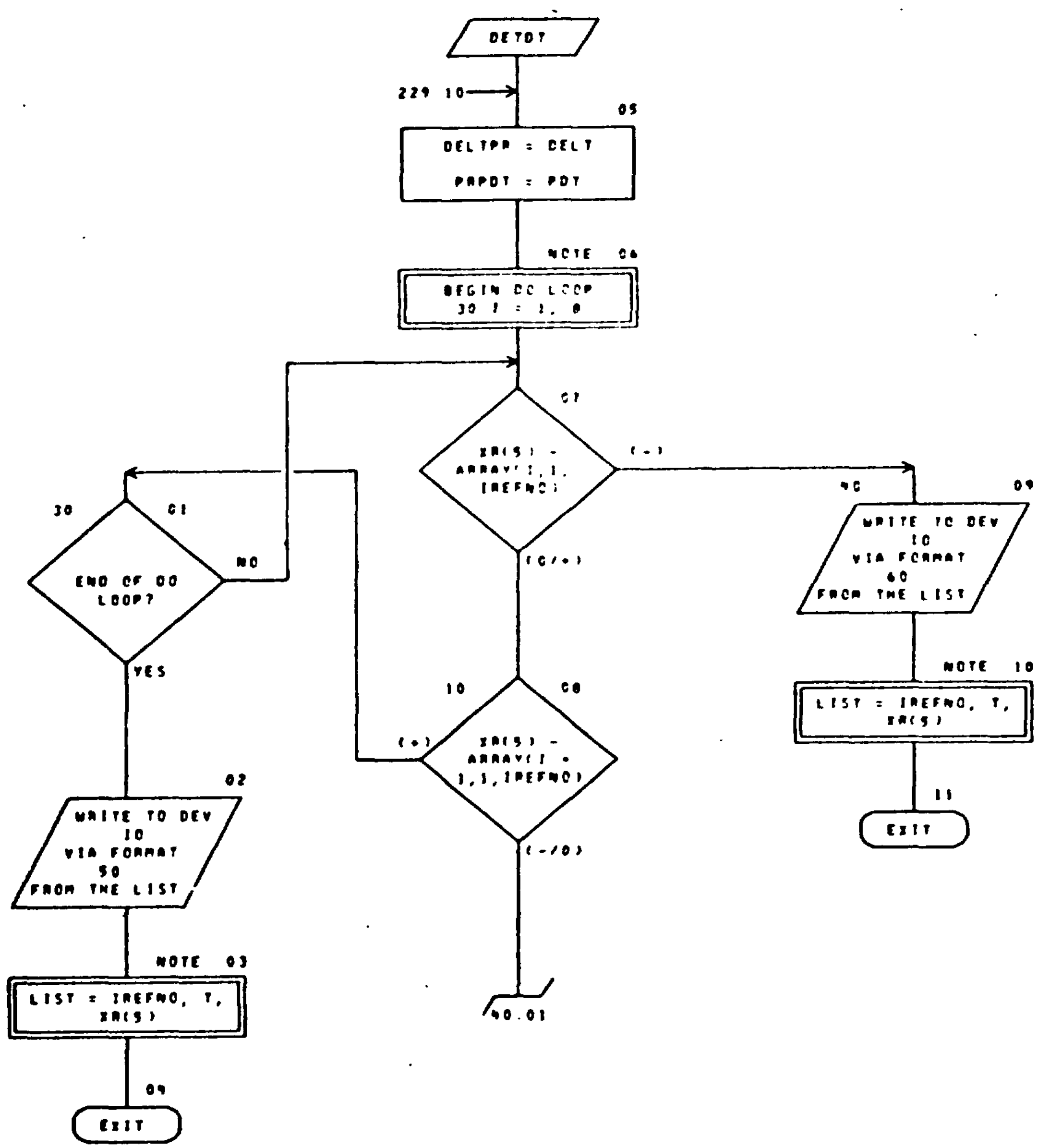
<u>DETDT EXTERNAL VARIABLES TABLE</u>

Variable	Use	Common	Description
T	U	ALAN	Current time in hours from start of trajectory.
XR(6)	UE	LEFT (XRL)	Position of spacecraft relative to reference body. The six elements contain $[x, y, z, r^3, r, r^2]$.
PDT	SU	HENRY	Print interval, Δp, in hours. (Not presently activated in the program).
DELT	SU	STEVE	Integration interval of universal variable, $\Delta\beta$.
PCIN	S	HENRY	Print interval change indicator. Set to 1. if the new print interval differs from the previous interval.

DETDT EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
ARRAY (8, 3, 12)	U	HENRY	Array containing tables of the integration and print (not used) intervals as a function of distance from the several solar system bodies. The third subscript indexes the tables according to the celestial body; the reference body indicator IREFNO is used as the index for this subscript. The second subscript defines the specific tabular parameter; 1 corresponds to distance, 2 to integration interval and 3 to print interval (not used). The first subscript indexes the tabular parameters.
CHIND	S	HENRY	Integration interval change indicator. Set to 1. if the new integration interval differs from the previous interval.
IREFNO	U	INTEG	Reference body ID number as follows: 1 Earth, 2 not available, 3 Sun, 4 Venus, 5 Mars, 6 Jupiter, 7 Saturn, 8 Uranus, 9 Neptune, 10 Pluto

CHART TITLE - SUBROUTINE DETDT



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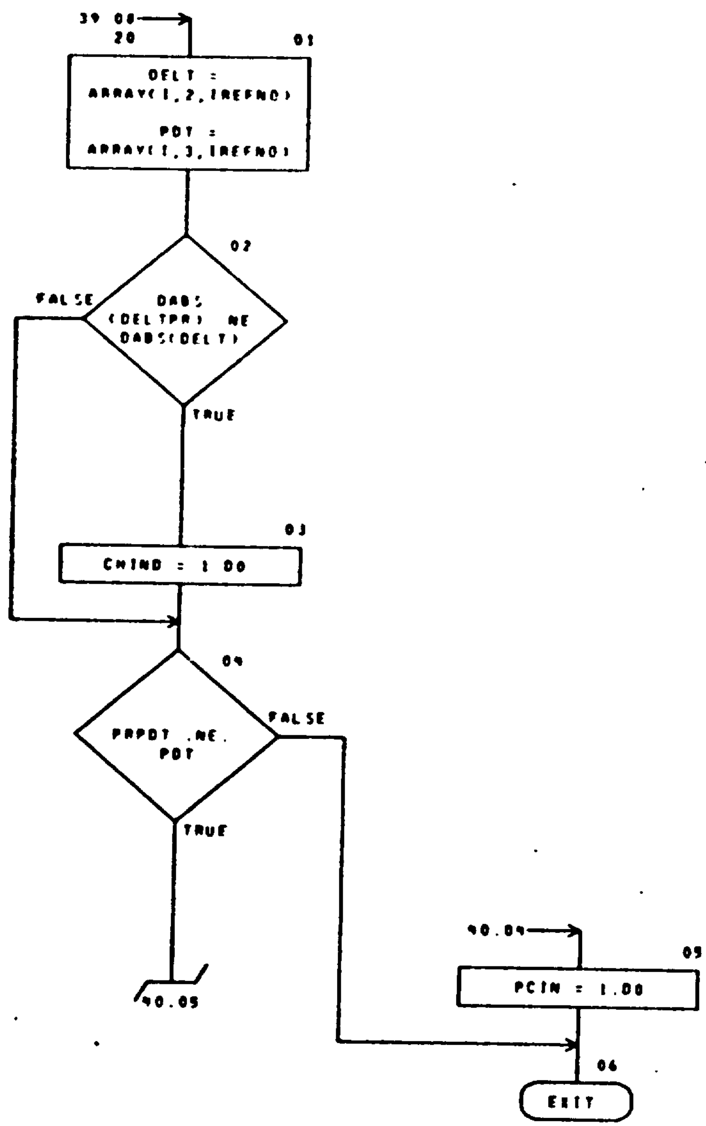

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
            IMPLICIT REAL*8 (A-H,O-Z)
            INTEGER YEAR,DAY,HOURS
            REAL*8 KSQQ,MEI,ME,KM,MDIST,INTV,IN1X,IN2X,KSQ
            DIMENSION XR(6)
            COMMON/ALAN/T,AMBR,DORHO
            COMMON/HENRY/ARRAY(8,3,12),CHIND,INTV(72),IN1X(3),
            IN2X(3),KSQQ(12),KM(12),MDIST,MEI(12),ME(12),POSACS,PAVDT,
            PDT,PCIN,RD,REKM,RRM,RRE,RAEU,ACIND,RATIO,SEC,TSCL,THTS,TPI,
            TIMEL,THET,VELACS
            COMMON/INTEG/DAY,HOURS,YEAR,IDUMMY,ITRIG,IREFNC,IREFNB,
            IREFNT,IN,IO,IJK,MONTH,MIN,NCPT(72),NPLAN,NPLAN3
            COMMON/LEFT/XRL(6,20),XRDL(6,20),VCCL(72,20)
            COMMON/STEVE/DELT,KSQ,DIAD,RDOTD,TT,TM2DP,XRI(6),XRIDT(6),SQTMU
            EQUIVALENCE (XR(1),XRL(1,1))
  50        FORMAT (' AVE EXCEEDS MAX  '///' IREFNO = 'I3,' TIME ='1PD24 15,
            ' R ='D24 15)
  60        FORMAT (' AVE LESS THAN MIN. '///' IREFNO = 'I3,' TIME = '1PD24 15,
            ' R ='D24.15)
```

Name: DIAG1

Calling Argument: None

Referenced Sub-programs: None

Referenced Commons: ALAN, AM1, CONRAD, FRAN, HENRY, HER, HIS, INPR, INTEG, JERR, KAT, LAMB, LPPR, NOMLL

Entry Points: SUMMRY

Referencing Sub-programs: FNMAT, SETI

Discussion: Subroutine DIAG1 performs the printing of the trajectory summary at each iteration. The printout consists of a complete set of independent and dependent parameters for the mission, a spacecraft mass breakdown, and the partial derivative matrix. On the first call to the routine on each case, the headings for the independent and dependent parameters are initialized for the case. On all calls to the routine the current time is compared to the end time of the first arc, and if the current time is less, a return from the subroutine is immediately performed. A return is also performed if the current trajectory is not a nominal (i.e., a partial derivative matrix based on this trajectory has not been generated), providing the flag NOPT(60) is zero. Otherwise, the logic proceeds to print the trajectory summary print after converting all angles from radians to degrees. The masses are printed in kilograms. The initial mass, m_o, is equated to the launch vehicle payload which is assumed to be a function of launch excess speed, i.e.,

$$m_o = a_1 e^{-v_c/a_2} - a_3 ,$$

$$v_c = \sqrt{v_\infty^2 + 2v_o^2} ,$$

where a_1, a_2 and a_3 are coefficients representative of the specific launch vehicle of interest, v_o is the circular satellite speed at 185 km altitude above the earth and v_∞ is the excess speed. The propulsion system mass m_{pp} is

$$m_{pp} = \alpha_{ps} p_o ,$$

where α_{ps} is the specific propulsion system mass in kg/watt and p_o is the reference power in watts. The propellant mass m_p is evaluated as the difference between the initial spacecraft mass and the final integrated mass prior to any retro maneuver. The tankage and structure masses, m_t and m_s, respectively, are defined

$$m_t = k_t m_p ,$$

$$m_s = k_s m_o ,$$

where k_t and k_s are input scaling coefficients. The retro stage propellant and structure are

$$m_{rp} = (m_o - m_p)(1 - e^{-\Delta v/c_r}) ,$$

$$m_{rt} = k_r m_{rp} ,$$

where Δv is the magnitude of the incremental velocity required to brake the spacecraft at periapse of the incoming hyperbola to the desired periapse speed on the desired capture orbit, c_r is the jet exhaust speed of the retro stage and k_r is an input scaling coefficient. The net spacecraft mass is defined as the mass remaining after subtracting from the initial mass all of the above mass components.

A call to SUMMRY results in the printing of the case summary page, consisting of an identification of the launch and target planets; a statement defining the steering mode; a listing of the launch vehicle, efficiency law, photon absorption and specific array area coefficients; a spacecraft mass breakdown; a printout of the angles defining the orientation of the unit vector $\bar{n}$ along the normal to the arrays and the unit constraint vector $\bar{s}$ (see SOLENG); a line of propulsion system parameters including reference power, reference thrust in newtons, exhaust speed, overall efficiency, unit thruster power Δp, and solar array area; a trajectory schedule; a line of departure and arrival conditions; and a line of retro and target orbit conditions (for orbiter missions only).

Messages and Printout: For each trajectory selected as a nominal and for which a partial derivative matrix is evaluated, the iteration summary is printed starting at the top of a new page for each iteration. Following a statement of the iteration number is written a block of parameters preceded with the heading "INDEPENDENT PARAMETERS." The block contains all parameters, each appropriately titled, that are available for selection as independent parameters of the boundary value problem regardless of whether they are actually so designated. Those which are employed as independent parameters in the specific case being considered are indicated with a double asterisk beside the title. The length of the block is variable because that depends on the number of trajectory arcs in the problem. The first line of the block contains seven parameters representing the initial state of the spacecraft (three components each of the initial position and velocity plus the initial mass). The second row contains the jet exhaust speed, c, and the reference power p_o, the angles α and β defining the orientation of $\bar{n}$, the angles δ and ϵ defining the orientation of $\bar{s}$, the initial time t_o, and the time of the end of the first (coasting) arc. The next line(s) contains the three thrust angles and the end time for each of the arcs (exclusive of the first) comprising the trajectory. Each line contains information for two arcs. Following the arc data are the four parameters defining changes in the initial orientation of the launch parking orbit and the speed of departure from that orbit. These parameters are titled "DL OMS", "DL OML", "DL INC", and "DL VP0" and represent changes from the previous nominal in argument of perigee, longitude of ascending node, inclination to the equator, and speed at periapse of the launch hyperbola, respectively. The final parameter in the independent parameters block is the speed at periapse of the launch hyperbola.

The next block of data consists of the 20 parameters which are presently available as end conditions. These parameters are all appropriately titled and are preceded by the heading "DEPENDENT PARAMETERS." Again, those parameters which are specified as end conditions of the case are indicated with a double asterisk beside the title. The parameters comprising the 20 available end conditions are the final spacecraft mass; the net spacecraft mass; the reference thrust; the final heliocentric distance and speed; the final heliocentric osculating semi-major axis, flight path angle, eccentricity, apocenter distance and pericenter distance; the target centered final distance and speed; the final planetocentric osculating semi-major axis, flight path angle, eccentricity, apocenter distance and pericenter distance; and the three final planetocentric ecliptic Cartesian components of distance.

Following the block of dependent parameters is a line stating the reference system in which the integration terminated, the value of the inhibitor used by the iterator, and a trajectory counter. This counter is the cumulative number of trajectories integrated exclusive of the nominal trajectories. This is followed by a spacecraft mass breakdown. This includes the initial mass, the low thrust propulsion, propellant, and tankage masses, the structural mass, the retro propellant and structure, and the net spacecraft mass. Finally, the iteration summary print is concluded with the partial derivative matrix. Each row of this matrix represents the partials of one of the specified end conditions with respect to all of the indicated independent parameters. The order of the partials reading across a given row is the same as that in which independent parameters appear in the first block of data of the iteration summary. Likewise, the order reading down the matrix is that of the dependent parameters as they appear in the second data block. Additional self-explanatory messages from the iterator may follow the partial derivative matrix. An example of the iteration summary printout is presented in Table 1.

After indicating the launch planet and target of the case mission, the case summary contains a statement as to whether the program is operating in the constrained or unconstrained mode for the case. If in the constrained mode, a message is printed specifying the reference to which $\bar{s}$ is constrained. For the case in which the reference is a star, the input unit vector defining the location of the star is printed. This is followed with a line of data specifying several of the input coefficients used for the case. Included are the coefficients describing the capability of the launch vehicle, the low thrust propulsion system efficiency coefficients, the photon absorption coefficient c_a, and the specific array area k_p. A spacecraft mass breakdown similar to that printed in the iteration summary is then written, followed by the angles α, β, δ, and ϵ which define the orientation of the $\bar{n}$ and $\bar{s}$ vectors in the body fixed coordinate system. The next line of data contains a number of low thrust propulsion system parameters including the reference power, the reference thrust, the jet exhaust speed, the efficiency, the unit thruster power Δp, and the array area. A trajectory schedule is then printed, giving pertinent information from the ARCDTA array relative to each arc. The first line of the block contains the end times of all arcs. Below this are written six lines of data containing the three thrust angles, the power diverted for non-propulsive uses p_x, the maximum allowable half-cone angle ψ_{max} (applicable only for constrained mode cases), and the thrust mode indicator "ON" or "OFF" defining the operational status of the propulsion system for the arc. These six quantities are positioned in separate columns for each arc, and the columns are located below and midway between the two times defining the start and end of the arc. If there are more than eight arcs, the format is repeated until all arcs are accounted for. No information is printed for the first arc since no thrust is permitted on the arc. After the trajectory schedule are written the date, the hyperbolic excess speed, and the energy parameter c_3 at departure of the launch planet and upon arrival at the target. If no retro maneuver is required, the departure and arrival conditions complete the case summary printout. If a retro maneuver is performed, however, then related parameters are printed on a single line. These include the retro stage propellant and structure, the periapse and apoapse distances of the final orbit, the specific impulse of the retro stage, the orbital velocity at periapse of the capture orbit, and the incremental velocity imparted by the retro state. All units are explicitly indicated on the case summary page. An example of the case summary printout is shown in Table 2.

Table 1.

```
                              TRAJECTORY SUMMARY ITERATION NO. 16

                                  INDEPENDENT PARAMETERS

      ** NAME APPLIES TO PARAMETERS, USED IN THE ITERATION
X (TO)          Y (TO)          Z (TO)          XDOT            YDOT            ZDOT            M (TO)
6.62475946D-01  3.66761394D-01 -6.90855192D-01 -5.43532632D 00  5.26176059D 00 -2.45099124D 00  3.75881852D 02

C               PO              ALPHA           TO              BETA            DELTA           EPSLON          T1
2.40000000D 04  1.50000000D 03  0.0             0.0             2.70000000D 02  0.0             9.00000000D 01  1.20000000D 01

THETA     **    PSI             PHI             T2        **    THETA           PSI             PHI             T3
-1.55841075D 01 0.0             0.0             5.92193447D 03  0.0             0.0             0.0             1.36500000D 04

DL OMS    **    DL OML    **    DL INC          DL VPC    **    VPGC
-4.41782972D-04 4.38067258D-04  0.0             2.42498311D-06  7.91254975D 00

                                  DEPENDENT PARAMETERS

FINAL MASS      NET S/C   **    THRUST          DST.FR.SUN      VL.WRT.SUN      SM.AXIS SN      FL.P.A.SUN      ECCENT.SUN
3.46065330D 02  3.00170834D 02  7.09400505D-02  5.24100815D 00  3.02634233D-04  4.91814224D 00  5.18770826D 01  7.87731397D-01

APCEN. SUN      PRICEN.SUN      DST.FR.TRG      VL.WRT.TRG      SM.AX.TRGT      FL.P.A.TGT      ECCENT.TRG      APCNT.TRGT
8.79231730D 00  1.04396718D 00  2.00047297D-01  2.66357129D-04 -7.42693048D-03 -8.56336002D 01  2.34896999D 00 -2.48725673D-02

PCENT.TRGT      X TARGET  **    Y TARGET  **    Z TARGET  **
1.90187063D-02  1.88959768D-01  6.53838645D-02 -6.17063622D-03

    TRAJECTORY TERMINATED IN JUPITER REFERENCE      INHIBITOR IS  5.00000000D-01     TRAJ. COUNTER IS   39

                                SPACECRAFT MASS BREAKDOWN (KG)

 INITIAL        PROPULSION      PROPELLANT      TANKAGE         STRUCTURE       RETRO PROP      RETRO STR       NET S/C
3.75881852D 02  4.50000000D 01  2.98165222D 01  8.94495665D-01  0.0             0.0             0.0             3.00170834D 02

                                PARTIAL DERIVATIVE MATRIX BY ROWS

-3.78782D 00 -4.84281D 00 -3.22503D 02  2.57610D-01 -1.78974D-03

 1.40946D 00  1.48953D 00 -3.62117D 00 -2.34916D-01  3.55882D-06

-1.30026D 00 -1.92807D 00  4.95414D-01 -7.14379D-02 -1.56464D-05

 4.05065D-01 -6.23545D-03  4.53021D-02 -2.97899D-01  5.78055D-06
```

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Table 2.

CASE SUMMARY

LAUNCH	TAPGET
EARTH	JUPITER

S-VECTOR RELATIVE TO	CONSTRAINED MODE
	SUN

LAUNCH VEHICLE COEFFICIENTS

A1(KG)	A2(M/SEC)	A3(KG)
153208.C5	2335.1258	53.34

EFFICIENCY LAW COEFFICIENTS

B	DSO(M*M/SEC/SEC)
0.7690	20449C00C.0

PHOTON ABS. COEFF. CA	SPEC. ARRAY AREA XKP(M*M/W)
0.C	0.0

SPACECRAFT MASS BREAKDOWN (KG)

INITIAL	PROPULSION	PROPELLANT	TANKAGE	STRUCTURE	RETRO	NET S/C
3.758602020 02	4.50000000D C1	2.979456050 01	8.934360190-01	C.0	0.0	3.0C1719050 02

SPACECRAFT DESIGN FACTORS

M-VECTOR ALPHA(DEG)	M-VECTOR BETA(DEG)	S-VECTOR DELTA(DEG)	S-VECTOR EPSILON(DEG)
0.0	270.000	0.0	9C.0C0

PROPULSION SYSTEM PARAMETERS

REF POWER(W)	REF THRUST(N)	EXHAUST SPEED(M/SEC)	EFFICIENCY	UNIT THRUSTER POWER(W)	ARRAY ARE.(M**2)
1530.00	0.073940	24000.00	0.56752	0.0	0.0

TRAJECTORY SCHEDULE

TIME (DAYS)	0.500	246.209	568.750
THETA OR XI (DEG)	-15.643	0.0	
PSI OR NU (DEG)	0.0	0.C	
PHI OR ZETA (DEG)	0.0	0.0	
POWER DIVERTED (W)	0.0	0.0	
PSI MAX (DEG)	0.0	0.C	
THRUST	ON	OFF	

DEPARTURE AND ARRIVAL CONDITIONS

DATE	EXCESS SPEED(M/SEC)	C3 (KM**2/SEC**2)	DATE	EXCESS SPEED(M/SEC)	C3 (KM**2/SEC**2)
4570.0CC0	8530.4[illegible]7	74.58775	5132.7500	10679.00.59	114.04107

DIAG1 EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
T	U	ALAN	Time in hours from start of trajectory.
BL	U	JERR	Efficiency coefficient, b.
CA	U	JERR	Photon absorption coefficient. Ratio of number of photons absorbed by solar array to total number of photons incident.
CR	U	JERR	Jet exhaust speed of retro stage, in m/sec.
ER(3)	U	JERR	Unit constraint vector, $\bar{s}$.
IO	U	INTEG	Logical unit on which standard print-out is written.
RD	U	HENRY	Factor for converting from radians to degrees, (= 57.295779513).
AL1, AL2, AL3	U	JERR	Coefficients a_1, a_2, and a_3, respectively, defining launch vehicle performance capability as a function of launch excess speed. AL1 and AL3 are in units of kg and AL2 is in units of m/sec.
APS	U	JERR	Specific propulsion system mass, α_{ps}, in kg/watt.
CHN(100)	U	HIS	Array of variables available for use as independent variables in the boundary value problem.
DSQ	U	JERR	Efficiency coefficient, d^2, in units of m^2/sec^2.
ETA	U	JERR	Overall propulsion system efficiency, $\eta = bc^2/(c^2+d^2)$, where c is electric propulsion system jet exhaust speed.

DIAG1 EXTERNAL VARIABLES TABLE (cont)

Variables	Use	Common	Description
ICT	SU	LPPR	Initialization flag. Non-zero value implies that printout headings for independent parameters have been initialized.
IPS	U	HER	Number of dependent variables in the two point boundary value problem.
NSL	U	HER	Number of independent variables in the two point boundary value problem.
PFG (30, 30)	U	HIS	Partial derivative matrix of dependent variables with respect to independent variables.
VTP	SU	CONRAD	Hyperbolic excess speed upon arrival at the target planet.
XIL(280)	U	AM1	XIL(4), containing the final spacecraft mass, is the only element used.
XKP	U	JERR	Specific array area, k_p, in m^2/watt.
XKR	U	JERR	Retro stage structure factor, k_r.
XKT	U	JERR	Electric propulsion tankage factor, k_t.
CHNS(100)	SU	HIS	Array of variables available for use as independent variables. Same as CHN except units are changed to those used for printout.
DELP	U	JERR	Unit thruster power, Δp, in watts.
IVAR(100)	U	HER	Array containing the indices of the CHN array for those variables of the input BX array having non-zero triggers.

DIAG1 EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
NOMT	U	NOMLL	Nominal trajectory flag. Value of 0 implies the current trajectory is a nominal and partial derivatives are to be generated.
NOPT(72)	U	INTEG	Array of program option flags.
NTPS	U	HER	Total number of trajectory arcs minus 1.
POFL(30)	U	HIS	Array of dependent parameter values for the current trajectory.
REKM	U	HENRY	Number of kilometers in an equatorial Earth radius.
TSCL	U	HENRY	Number of seconds in one hour (= 3600).
VORB	U	CONRAD	Speed in target planet capture orbit at point of insertion, in m/sec.
XJLD	U	LAMB	Julian date of launch - 2440000.
XKST	U	JERR	Structural scaling factor k_s.
XSQQ(12)	U	HENRY	Array of planetary gravitational constants.
IPOFL(30)	U	HER	Array containing the indices of the BY array for those variables having non-zero triggers.
KOUNT	U	KAT	Counter of the non-nominal trajectories.
XMDKM	U	FRAN	Number of Earth radii in one AU.

DIAG1 EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
ARCDTA (7,20)	U	INPR	Array containing input data for each trajectory arc as follows, where I denotes the arc number. ARCDTA(1,I) - arc end time in hours. ARCDTA(2,I) - trigger indicating whether the propulsion system is on (+1.) or off (-1.) over the arc. ARCDTA(3,I) - thrust angle XI or THETA, in degrees. ARCDTA(4,I) - thrust angle NU or PSI, in degrees. ARCDTA(5,I) - thrust angle ZETA or PHI, in degrees. ARCDTA(6,I) - maximum permissible value for PSI. ARCDTA(7,I) - housekeeping power in watts.
DELVEL	U	CONRAD	Retro stage velocity increment, Δv.
IREFNB	U	INTEG	Identification number of launch planet. Code is same as for IREFNO.
IREFNO	U	INTEG	Reference body ID number as follows: 1 Earth, 5 Mars, 9 Neptune 2 not available, 6 Jupiter, 10 Pluto 3 Sun, 7 Saturn 4 Venus, 8 Uranus
IREFNT	U	INTEG	Identification number of target planet. Code is same as for IREFNO.
XAMBDA	U	KAT	Inhibitor, λ, used by iterator. (See MINMX3).

CHART TITLE - SUBROUTINE DIAG1

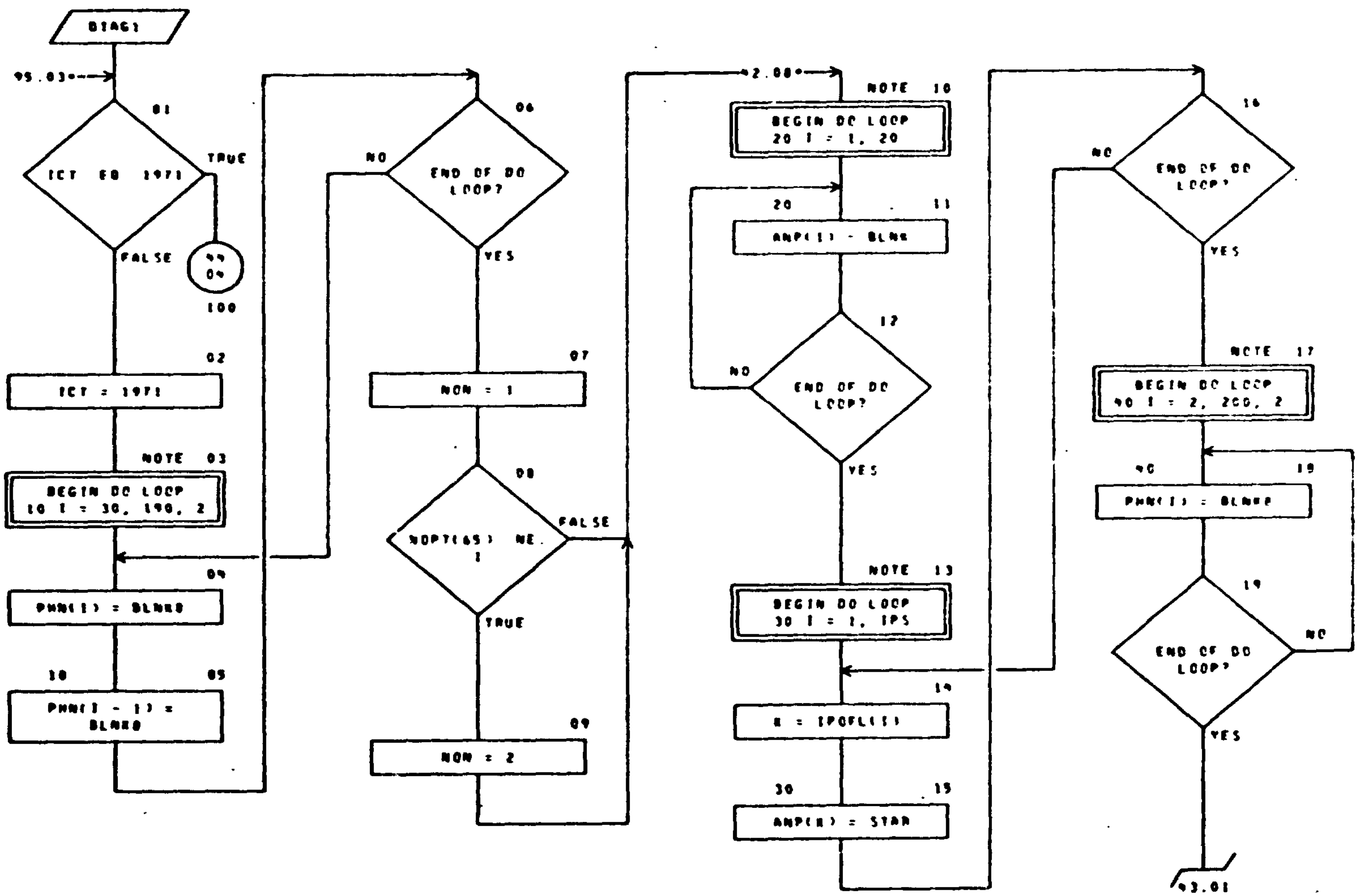


CHART TITLE - SUBROUTINE DIAG1

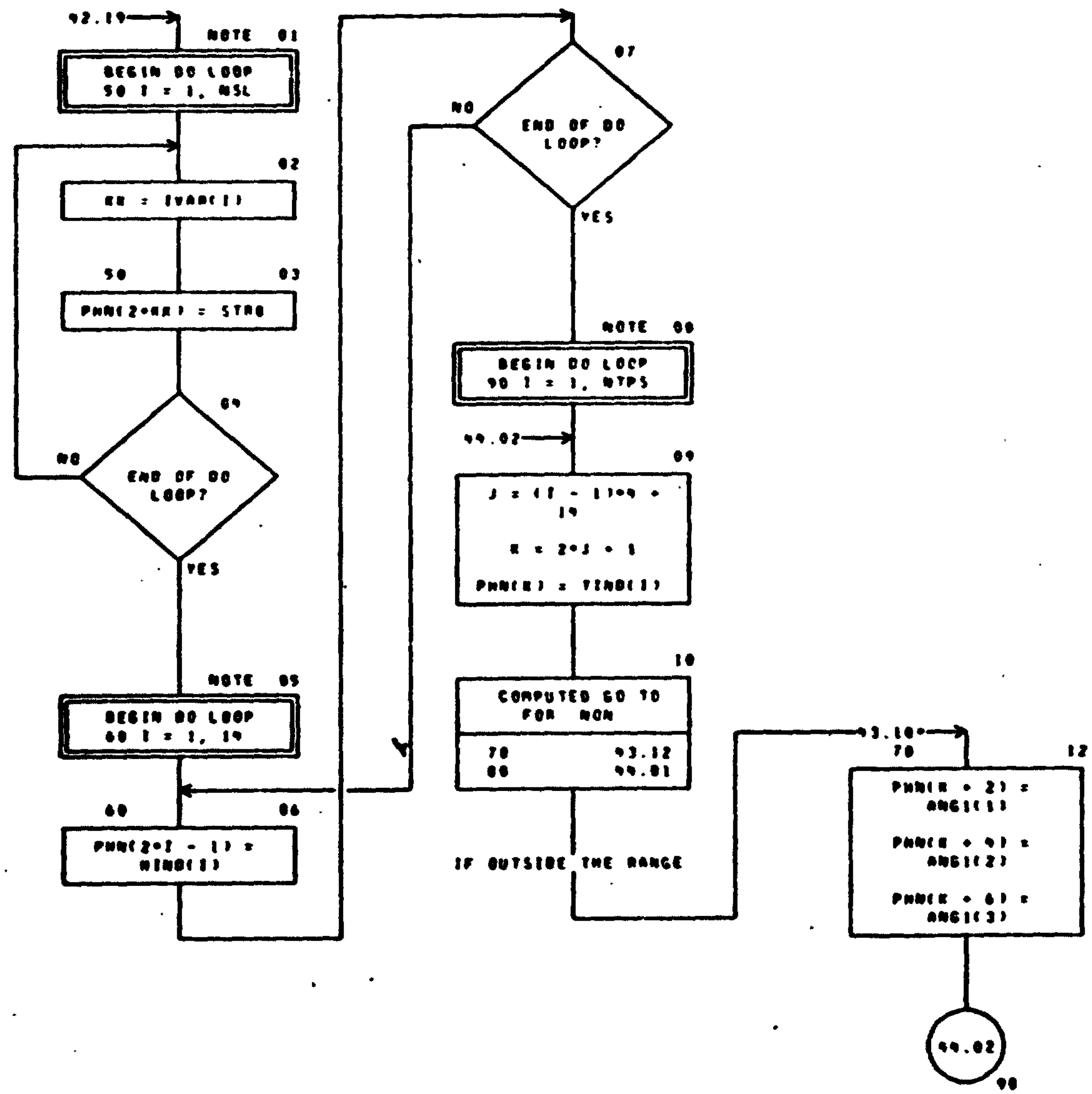
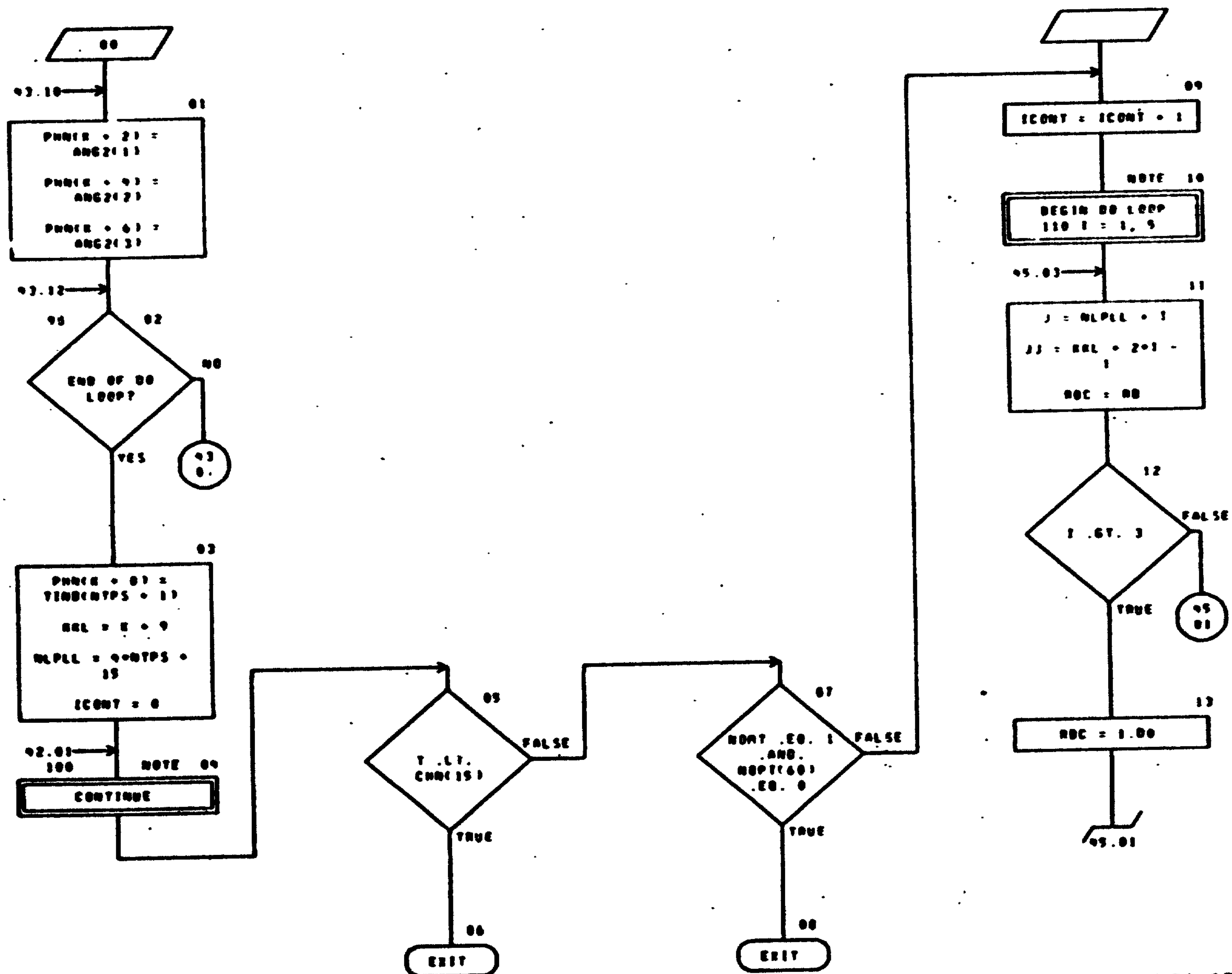


CHART TITLE - SUBROUTINE DIAG1



DIAG1-15

CHART TITLE - SUBROUTINE BIAS1

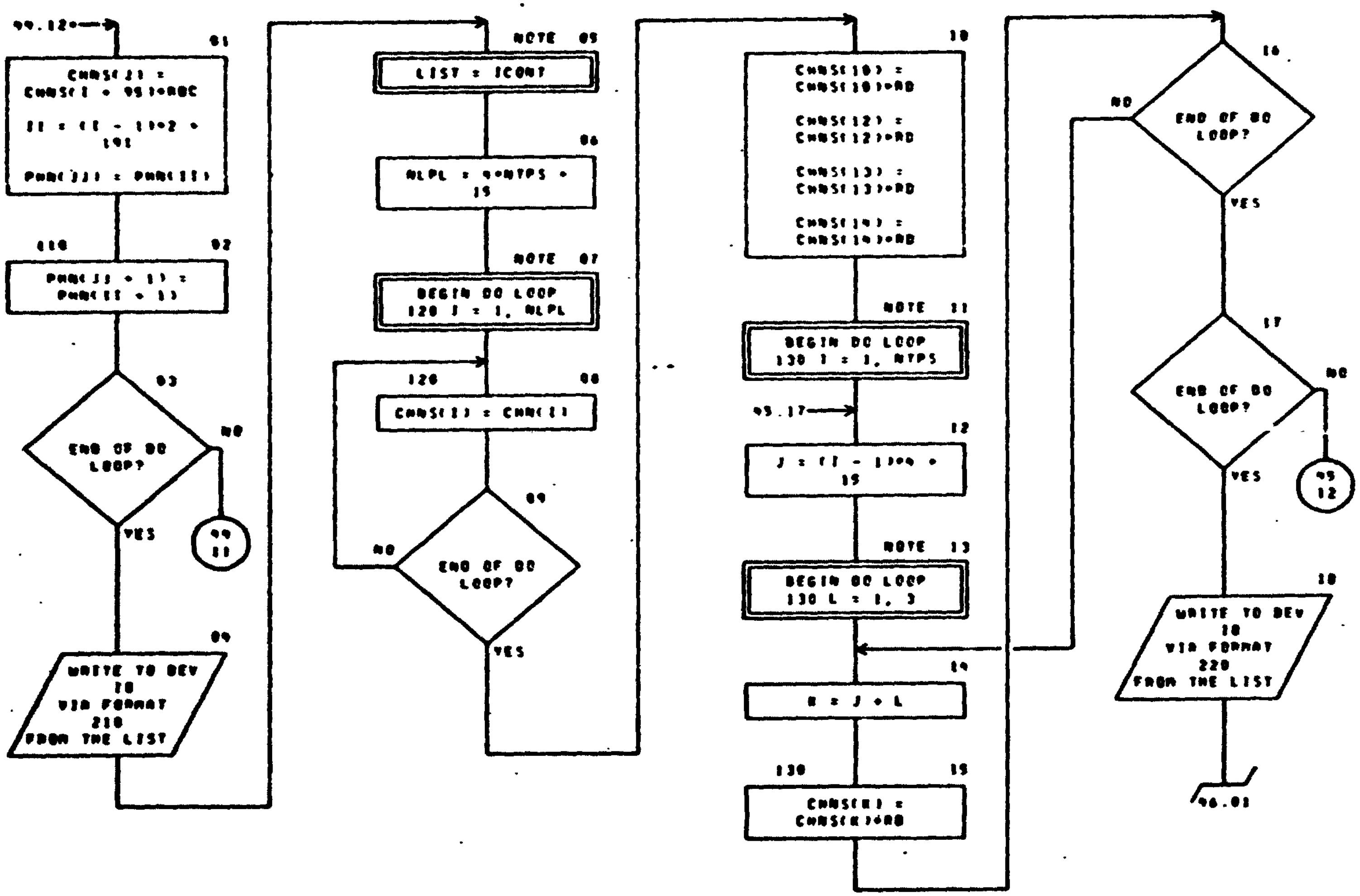
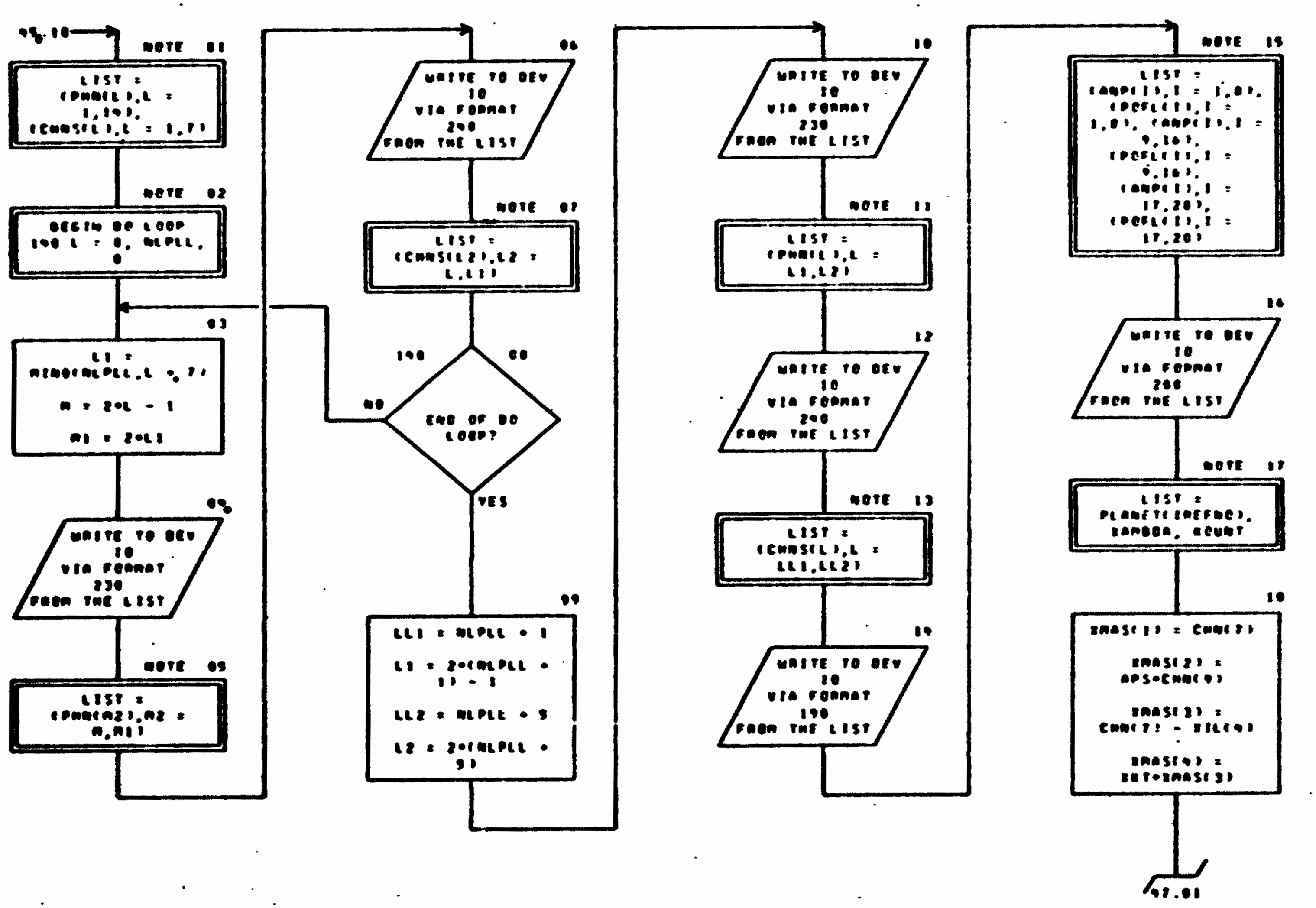


CHART TITLE - SUBROUTINE DIAG1



DIAG1-17

CHART TITLE - SUBROUTINE DIAG1

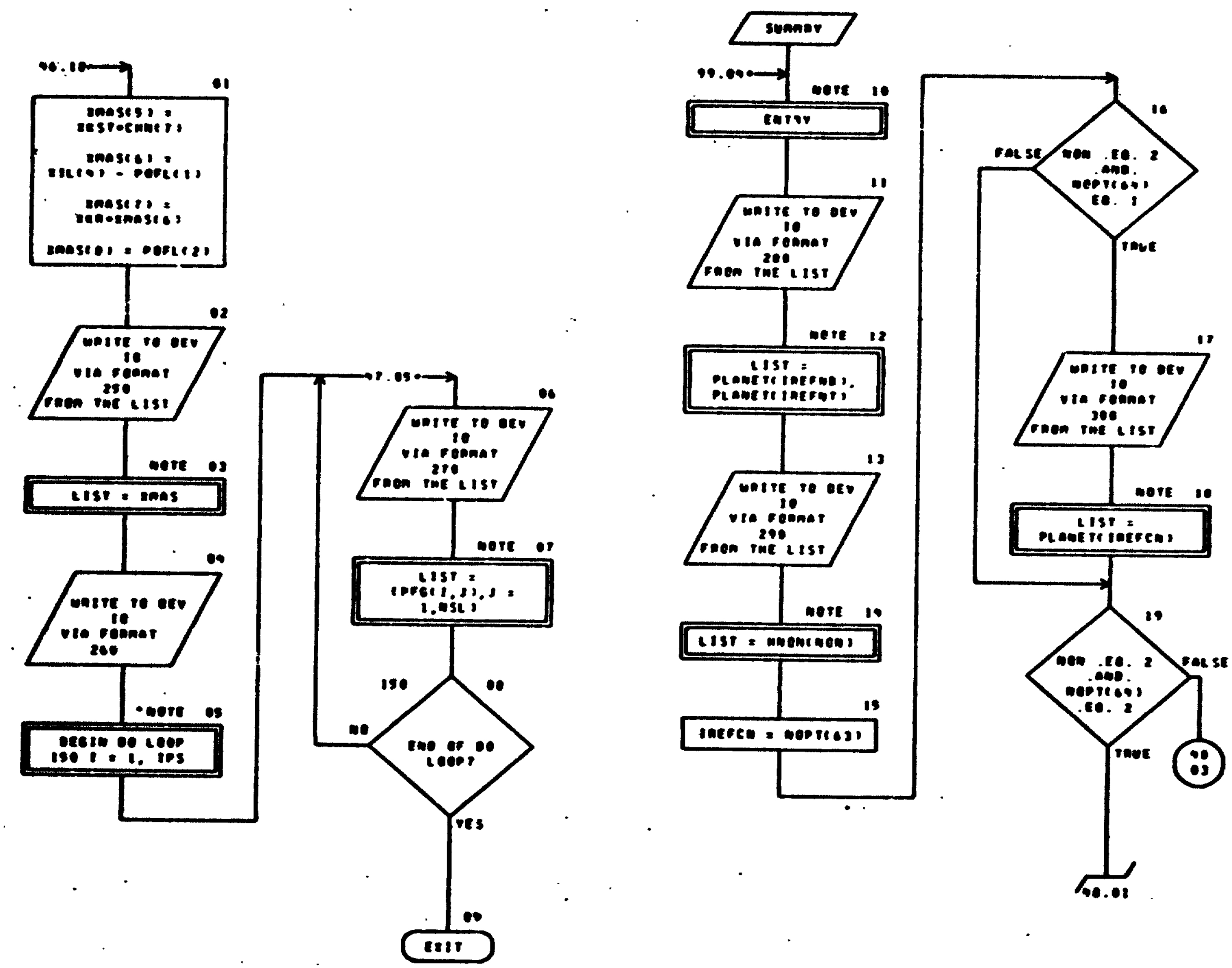
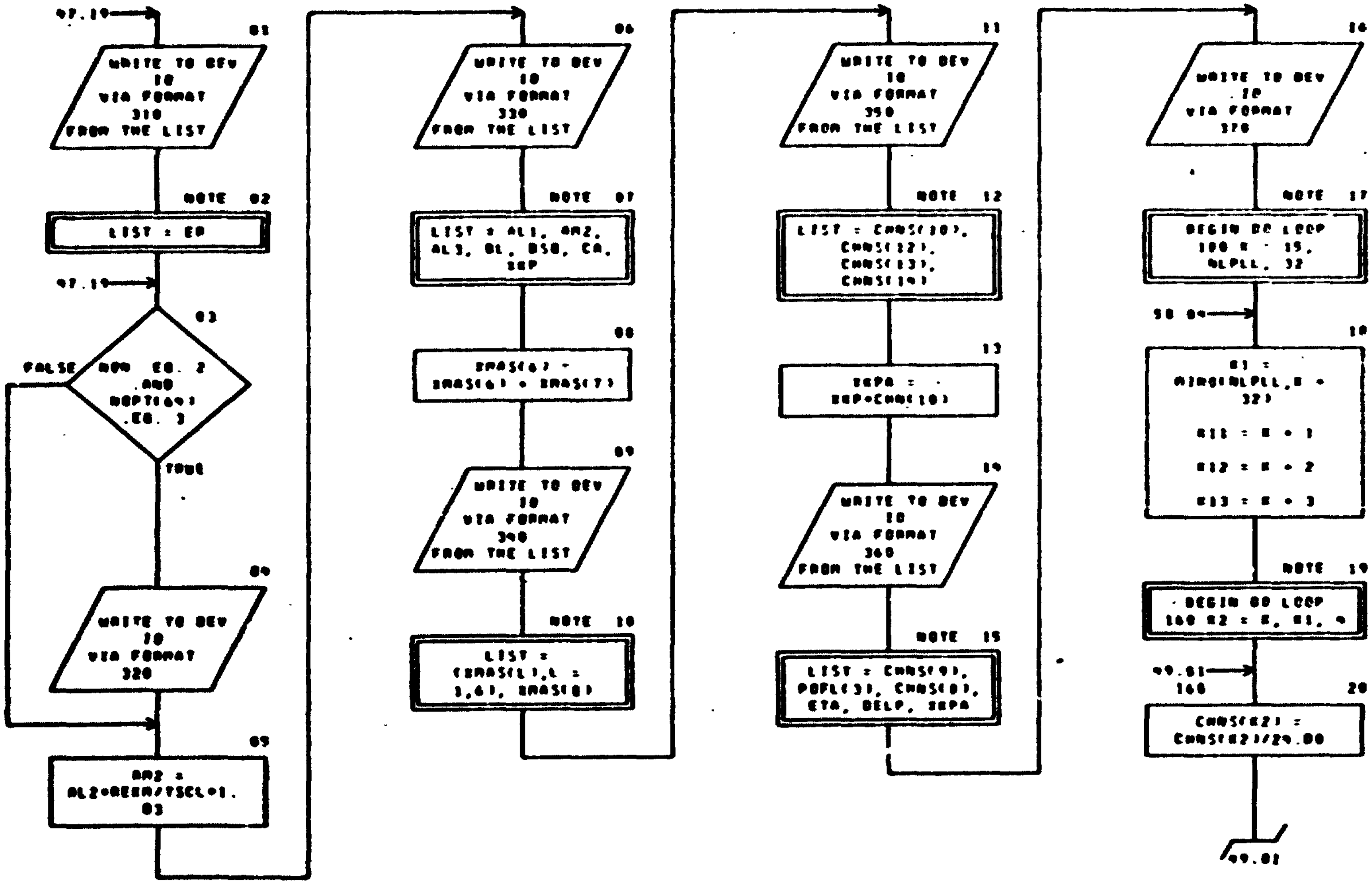


CHART TITLE - SUBROUTINE DIAG1



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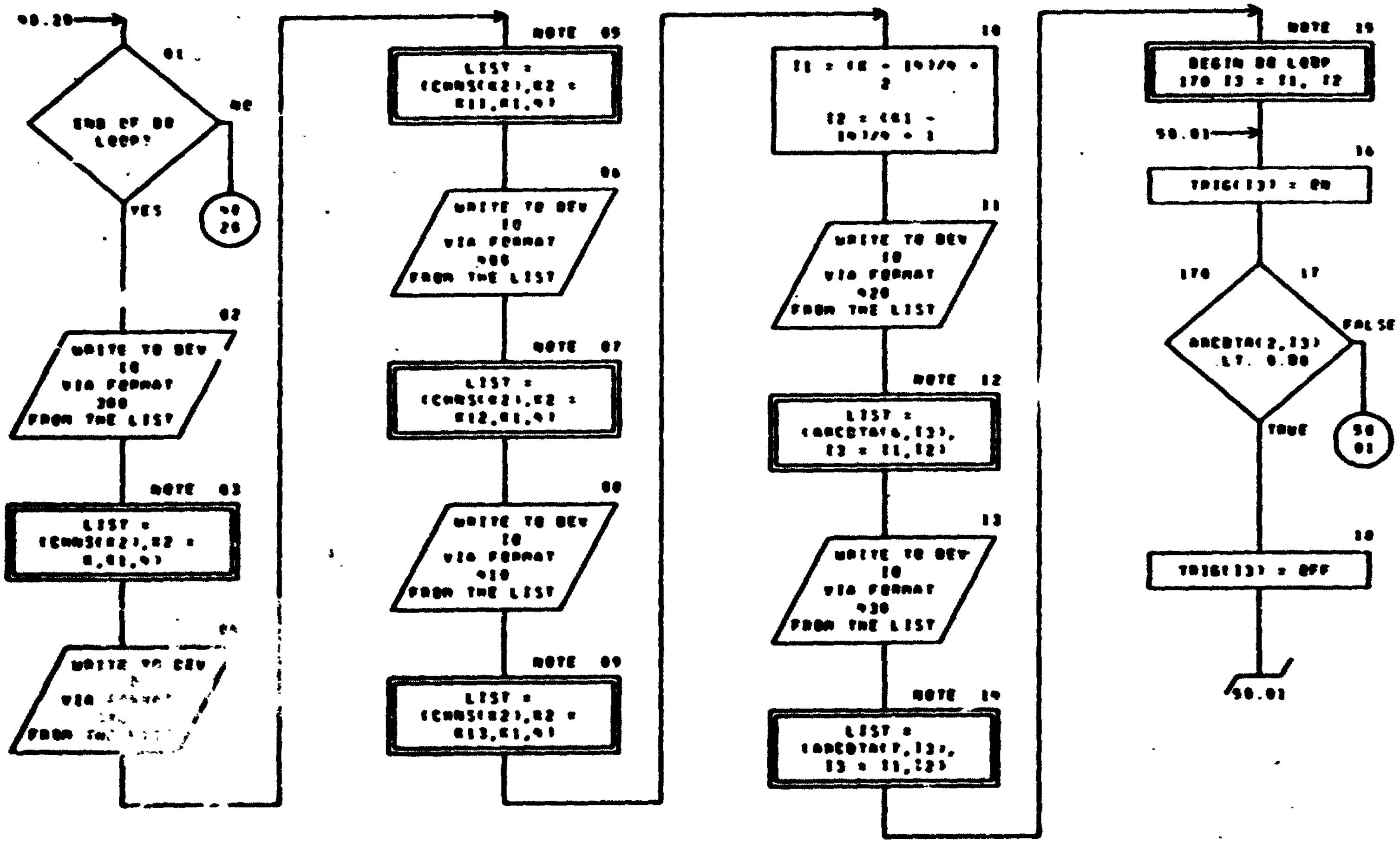
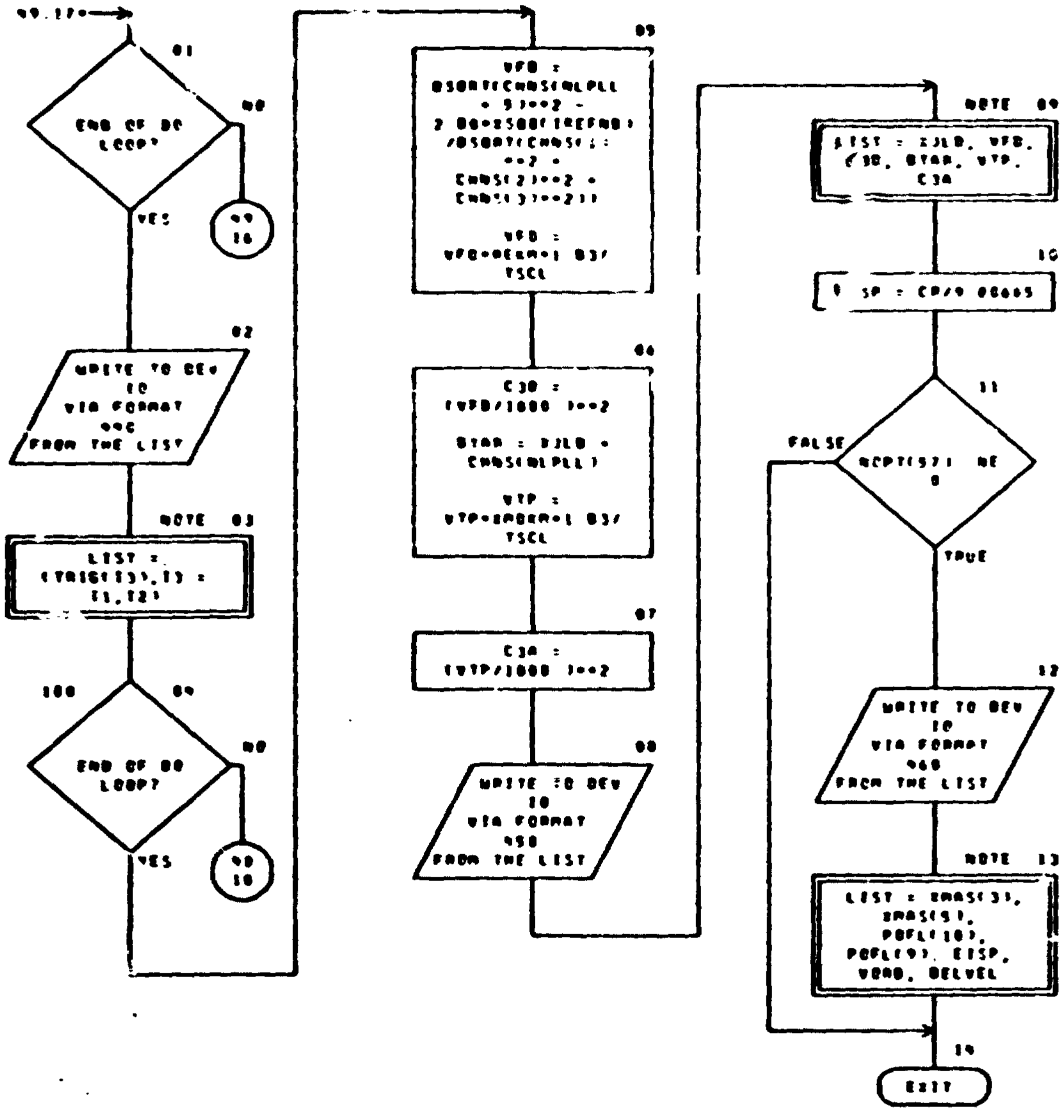


CHART TITLE - SUBROUTINE DIAG1



DIAG1-21

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
IMPLICIT REAL*8(A-H,O-Z)
INTEGER DAY,HOURS,YEAR
REAL*8 ME1,ME,MM,MDIST,INTV,INI1,IN2I
DIMENSION WIND(10),TIND(20),ANG1(3),ANG2(3),P   (3C),PLANET(9)
ANP(20),MNCN(2),ERAS(8),TRIG(20)
COMMON/ALAN/T,AMBP,BCAMC
COMMON/AM1/DEL(3),SIL(200)
COMMON/CONPAC/VCPB,DELVEL VTP
 COMMON /FRAN/ EMSEM
COMMON/HENRY/ARRAY(8,3,12),CHIND,INTV(72),IN1I(3),
IN2I(3),ESBB(12),EM(12),MDIST,ME1(12),ME(12),POSNCS,PRVDT,
PDT,PCIN,PD,PEAM,PDM,PDE,PAEU,PCINB,RATIO,SEC,TSEL,TMTS,TP1,
TIMEL,THET,VELPCS
COMMON/NER/IPS,NSL,NSL1,IFTRG,ITCT,IPOFL(30),IVAP(100),ITMAX,NTP,
NTPS,NMAX,NJ,JN,IPAT,NCT1,NJL
COMMON/NIS/PFG(30,30),WE(30),EVA (30),VEPS(30),EEPS(30),
CHNS(100),CHN(100),POFL(30),XOAR(7)
COMMON/INPR/ARCDTA(7,20),B(9,100)
COMMON INTEG/DAY,HOURS,YEAR,IDUMMY,ITRIG,ILEFNC,IREFNB,
IDEFNT,IN,IO,IJN,MONTH,MIN,NOPT(72),NPLAN,NPLAN3
COMMON/JEPP/VBLOC(260),A,CA,BL,BSO,DELP,AB(10),SUMA,EES,ETV(3),
ET(3),VEP,EA(3),CPI(210),TBIN(122),ETA,CB,BBB,EET,BBST,APS,AL1,
AL2,AL3
COMMON/RAT/LAMBDA,KOUNT,LLL
COMMON/LAMB/EJL9,BINJ,DBRE,LOPT
```

CHART TITLE - NON-PROCEDURAL STATEMENTS

C-3

```
      COMMON/LPPR/ICT
      COMMON/NOMLL/NOMT
      DATA TIND/'  T1    ','  T2    ','  T3    ','  T4    ','  T5    ','
     1  T6    ','  T7    ','  T8    ','  T9    ','  T10   ','  T11   ','
     2  T12   ','  T12   ','  T14   ','  T15   ','  T16   ','  T17   ','
     3  T18   ','  T19   ','  T20   '/
      DATA ANG1/'  XI    ','  NU    ','  ZETA  '/,ANG2/'  THETA ','  PSI
     1 ','  PHI   '/,BLANB/'        '/,STRB/'  **  '/,BLNK/'    '/,
     2STAR/' ** '/
      DATA PHN(191),PHN(193),PHN(195),PHN(197)/'  DL OMS',' DL OML','
     1DL INC',' DL VPO'/,PLANET/' EARTH ',' MOON  ',' SUN   ',' VENU
     2S ',' MARS  ',' JUPITER',' SATURN ',' URANUS ',' PLUTO '/,NNCN/
     3' UN-','     '/,PHN(199)/' VP00  '/
      DATA WIND/'  X (T0)',' Y (T0)',' Z (T0)',' XDOT  ',' YDOT  ','
     1  ZDOT  ',' MSS T0',' C     ',' P0    ',' ALPHA ',' T0    ','
     2  BETA  ',' DELTA ',' EPSLON'/
      DATA ON,OFF/'ON','OFF'/
190   FORMAT ('0'44X,'DEPENDENT PARAMETERS'///' FINAL MASS'A4,' NET S/C
     1  'A4,' THRUST    'A4,' DST.FR.SUN'A4,' VL.WRT.SUN'A4,' SM AX
     2IS SN'A4,' FL.P.A.SUN'A4,' ECCENT.SUN'A4/1PD16 0,7D16.0//' APCE
     3N. SUN'A4,' PRICEN.SUN'A4,' DST.FR.TRG'A4,' VL.WRT.TRG'A4,' SM
     4.AX.TRGT'A4,' FL.P.A.TGT'A4,' ECCENT.TRG'A4,' APCNT.TRGT'A4/1PD
     516.0,7D16.0//' PCENT.TRGT'A4,' X TARGET 'A4,' Y TARGET 'A4,'
     6 Z TARGET 'A4/1PD16.0,3D16.0/)
200   FORMAT ('0'5X,'TRAJECTORY TERMINATED IN'A8,' REFERENCE'5X,' INHIBI
```

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
      TOR IS'1PD16.8,5X,'TRAJ. COUNTER IS'I5)
210   FORMAT ('1'40X,'TRAJECTORY SUMMARY (ITERATION NO.'I3//43X,'INDEPEND
      ENT PARAMETERS'//10X,'** NAME APPLIES TO PARAMETERS, USED IN THE I
      TERATION')
220   FORMAT (14A8/1P7D16.8/)
230   FORMAT (16A8)
240   FORMAT (1P8D16.8/)
250   FORMAT ('0'43X,' SPACECRAFT MASS BREAKDOWN (KG)'//'   INITIAL'6X,'
       PROPULSION'4X,'  PROPELLANT'4X,'  TANKAGE'7X,'  STRUCTURE'5X,'RE
      TRO PROP      RETRO STR       NET S/C      '//1P8D16.8)
260   FORMAT (//44X,'PARTIAL DERIVATIVE MATRIX BY ROWS'/)
270   FORMAT ('0'/(1P10D13.5))
280   FORMAT ('1'51X'CASE SUMMARY'/'0'45X'LAUNCH',11X,'TARGET'/44XA8,10X
      ,A8)
290   FORMAT ('0'40X,A4,'CONSTRAINED MODE')
300   FORMAT (' ',42X,'S-VECTOR RELATIVE TO 'A8)
310   FORMAT (' '42X'S-VECTOR RELATIVE TO STAR   ER = '3F12.7)
320   FORMAT (' '42X'S-VECTOR RELATIVE TO VELOCITY VECTOR')
330   FORMAT (///9X,'LAUNCH VEHICLE COEFFICIENTS',15X,'EFFICIENCY LAW','
       COEFFICIENTS',7X,'PHOTON ABS. COEFF.'7X'SPEC. ARRAY AREA'/12X,'A1
      (KG)',7X,'A2(M/SEC)',4X,'A3(KG)'12X,'B',6X,'DSO(M*M/SEC/SEC)'12X'C
      A',20X'XKP(M*M/W)'/F10.2,F16.4,F10.2,F16.4,F10.)  10.4,F25.4)
340   FORMAT (///43X,' SPACECRAFT MASS BREAKDOWN (KG)'//'  INITIAL '6X,'
       PROPULSION'4X,'  PROPELLANT'4X,'  TANKAGE'7X,'  STRUCTURE'5X,'
      RETRO'9X,'  NET S/C'/1P8D16.8)
```

```
350   FORMAT (///44X'SPACECRAFT DESIGN FACTORS'//30X'N-VECTOR'34X'S-VECT
     OR'/23X'ALPHA(DEG)'3X'BETA(DEG)'22X'DELTA(DEG)'5X'EPSILON(DEG)'/F3
     3.3,F12.3,F32.3,F17.3)
360   FORMAT (///46X'PROPULSION SYSTEM PARAMETERS'//5X'REF POWER(W)'3X'R
     EF THRUST(N)'2X'EXHAUST SPEED(M/SEC)'5X'EFFICIENCY'5X'UNIT THRUSTE
     R POWER(W)'3X'ARRAY AREA(M**2)'/F16.2,F16.4,F17.2,F18.5,F22.2,F21
     2)
370   FORMAT (///50X'TRAJECTORY SCHEDULE'/)
380   FORMAT (' TIME (DAYS)'8X9F12.3)
390   FORMAT (' THETA OR XI (DEG)'9X8F12.3)
400   FORMAT (' PSI OR NU (DEG)'11X8F12.3)
410   FORMAT (' PHI OR ZETA (DEG)'9X8F12.3)
420   FORMAT (' POWER DIVERTED (W)'8X8F12.3)
430   FORMAT (' PSI MAX (DEG)'13X8F12.3)
440   FORMAT (' THRUST'20X,8(8X,A4))
450   FORMAT (///44X'DEPARTURE AND ARRIVAL CONDITIONS'//12X'DATE'6X'EXCE
     SS SPEED(M/SEC)'3X'C3 (KM**2/SEC**2)'8X'DATE'6X'EXCESS SPEED(M/SEC
     )'3X'C3 (KM**2/SEC**2)'/F16.4,F18.5,F20.5,F19.4,F21.5,F17.5)
460   FORMAT ('0'40X'RETRO MANEUVER PARAMETERS'//14X'PROPELLANT(KG)'3X'S
     TRUCTURE(KG)'2X'  PERIAPSE(RADII)'3X'  APOAPSE(RADII)'3X'ISP(SEC)'
     6X'V ORB(M/SEC)'5X'DEL VEL(M/SEC)'/F24.2,F16.2,F18.3,F19.3,F16.2,F
     19.3,F19.3)
```

Name: ELCO

Calling Argument: T, POSIT, VELOC, XMU, IPT

Referenced Sub-programs: None

Referenced Commons: HENRY, INTEG

Entry Points: None

Referencing Sub-programs: MIIP1

Discussion: This subroutine computes a set of osculating orbital elements of the spacecraft trajectory relative to the current reference frame of integration. The principal inputs to the routine are the current time t, the position vector R, the velocity vector $\dot{R}$ and the gravitational constant of the reference body μ. The input units are time in hours and distance in Earth radii if in Earth or moon reference and in AU otherwise. All angles are output in degrees, the mean motion is in radians per hour, the semi-major axis is in Earth radii, except when outside Earth or moon reference and NOPT(33) is non-zero, the units are AU. Apocenter and pericenter distances are in kilometers, except when semi-major axis is expressed in AU, in which case these distances are also in AU. All output times are in hours.

The angular momentum H is evaluated

$$H = R \times \dot{R}, \tag{1}$$

with magnitude

$$h = \sqrt{H \cdot H}\ . \tag{2}$$

Also the distance r and square of the speed are evaluated

$$r = \sqrt{R \cdot R}\ , \tag{3}$$

$$v^2 = \dot{R} \cdot \dot{R}\ , \tag{4}$$

along with

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$$d = R \cdot \dot{R} \ , \tag{5}$$

to obtain the inverse of the semi-major axis

$$\frac{1}{a} = \frac{2}{r} - \frac{v^2}{\mu} \ . \tag{6}$$

If this latter quantity is zero, a message is printed indicating the osculating orbit is parabolic and control is returned to the calling subroutine.

For elliptic orbits (i.e., $\frac{1}{a} > 0$), form the functions

$$e \cos E = \frac{r v^2}{\mu} - 1 \ , \tag{7}$$

$$e \sin E = \frac{d}{\sqrt{\mu a}} \ , \tag{8}$$

$$e = \sqrt{(e \cos E)^2 + (e \sin E)^2} \ , \tag{9}$$

$$E = \tan^{-1}\left(\frac{e \sin E}{e \cos E}\right) , \tag{10}$$

$$M = E - e \sin E \ , \tag{11}$$

where e is eccentricity, E is eccentric anomaly and M is the mean anomaly. For hyperbolic orbits, the hyperbolic anomaly F is employed with the corresponding equations

$$e \cosh F = \frac{r v^2}{\mu} - 1 \ , \tag{12}$$

$$e \sinh F = \frac{d}{\sqrt{\mu |a|}} \ , \tag{13}$$

$$e = \sqrt{(e \cosh F)^2 - (e \sinh F)^2} \ , \tag{14}$$

$$F = \log (\cosh F + \sinh F), \tag{15}$$

$$M = e \sinh F - F. \tag{16}$$

Forming the coefficients

$$c_1 = \frac{1}{e}\left(\frac{v^2}{\mu} - \frac{1}{r}\right), \tag{17}$$

$$c_3 = -\frac{d}{\mu e}, \tag{18}$$

the unit vector in the direction of pericenter is defined

$$\bar{r}_p = c_1 R + c_3 \dot{R}. \tag{19}$$

The unit angular momentum is evaluated

$$\bar{h} = H/h, \tag{20}$$

the mean motion is

$$n = \sqrt{\mu / |a^3|}, \tag{21}$$

and the time of pericenter passage is

$$t_p = t - M/n. \tag{22}$$

The inclination i, longitude of ascending node Ω, and argument of pericenter ω are then evaluated through the following sequence of operations:

$$\sin i = \sqrt{1 - (\bar{h} \cdot \bar{k})^2}, \tag{23}$$

$$i = \tan^{-1}\left(\frac{\sin i}{\bar{h} \cdot \bar{k}}\right), \qquad (0 \le i \le 180) \tag{24}$$

$$\sin \Omega = \begin{cases} \bar{h} \cdot \bar{i}/\sin i & \text{if } \sin i > 0 \\ 0 & \text{if } \sin i = 0 \end{cases}, \tag{25}$$

$$\cos \Omega = \begin{cases} \bar{h} \cdot j/\sin i & \text{if } \sin i > 0 \\ 1 & \text{if } \sin i = 0 \end{cases}, \tag{26}$$

$$\Omega = \tan^{-1}\left(\frac{\sin \Omega}{\cos \Omega}\right), \qquad (-180^\circ \le \Omega \le 180^\circ) \tag{27}$$

$\omega = 0$ if $e = 0$, otherwise

$$\cos \omega = \begin{cases} \dfrac{(\bar{h} \times \bar{r}_p) \cdot \bar{k}}{\sin i} & \text{if } \sin i > 0 \,, \\[2ex] \bar{r}_p \cdot \bar{i} & \text{if } \sin i = 0 \,, \end{cases} \tag{29}$$

$$\sin \omega = \begin{cases} (\bar{r}_p \cdot \bar{k})/\sin i & \text{if } \sin i > 0 \,, \\ \bar{r}_p \cdot \bar{j} & \text{if } \sin i = 0 \,, \end{cases} \tag{30}$$

$$\omega = \tan^{-1}\left(\frac{\sin \omega}{\cos \omega}\right) \,, \qquad (-180^\circ \le \omega \le 180^\circ) \tag{31}$$

where $\bar{i}$, $\bar{j}$, $\bar{k}$ are unit vectors along the x, y; z axes, respectively, of the reference frame in which the vectors R and $\dot{R}$ are input into the subroutine. The true anomaly f is evaluated

$$f = \text{sign}\,(t - t_p) \tan^{-1}\left(\frac{|R \times \bar{r}_p|}{R \cdot \bar{r}_p}\right) \,, \tag{32}$$

providing the eccentricity exceeds 10^{-5}. For eccentricities below this value the true anomaly is equated to the change in eccentric anomaly along the reference two body trajectory since the last rectification and is given the sign of $(t - t_p)$.

In the final portion of the subroutine, the apocenter distance r_a, the pericenter distance, r_p, and the period τ are evaluated:

$$r_a = a(1 + e) \,, \tag{33}$$

$$r_p = a(1 - e) \,, \tag{34}$$

$$\tau = 2\pi/n \,, \tag{35}$$

and all osculating elements are stored in the arrays PBLOC and PBLOC1 in the desired output units. The PBLOC array contains twelve parameters and two unit vectors stored in the following order:

$$a,\ e,\ r_p,\ r_a,\ i,\ \omega,\ \tau,\ n,\ \Omega,\ M,\ E \text{ or } F,\ t_p,\ \bar{r}_p,\ \bar{h} \,.$$

The last twelve elements of the PBLOC array are not modified in ELCO. The PBLOC1 array contains two elements, time t and true anomaly f in that order.

If the print flag IPT is zero, PBLOC1 and the first 18 elements of PBLOC are printed in a format which identifies each element. A return to the calling subroutine is then executed.

Messages and printouts: The computation of $\frac{1}{a} \equiv 0$ leads to the message

PARABOLIC ORBIT OSCULATING ELEMENTS SUPPRESSED

followed by an immediate return from the subroutine. A zero value of the input flag IPT results in the printing of the following block of information:

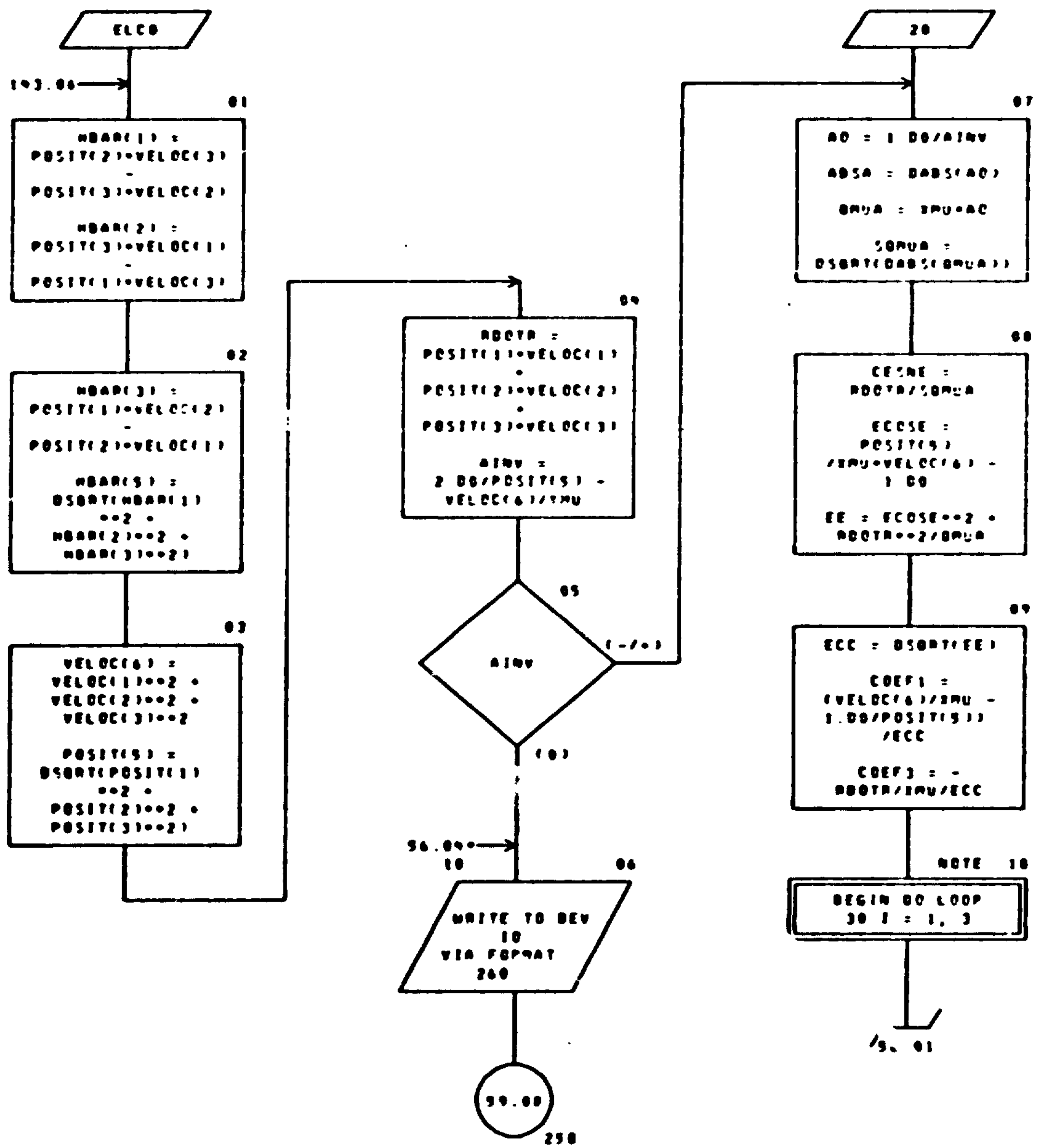
OSCULATING ELEMENTS AT TIME T =		________		TRUE ANOM =	________
SEM MAJ AXIS =	________	ECCENT. =	________	PERICENT. =	________
APOCENT. =	________	INCLINATION=	________	ARG PERIC. =	________
PERIOD =	________	MEAN MOT. =	________	RA ASC NODE =	________
M ANOMALY =	________	E ANOMALY =	________	T PERIC. =	________
UNIT PERICENTER POSITION VECTOR =		________	________	________	
UNIT ANGULAR MOMENTUM VECTOR =		________	________	________	

All values are printed with the format 1PD24.15.

ELCO EXTERNAL VARIABLES TABLE

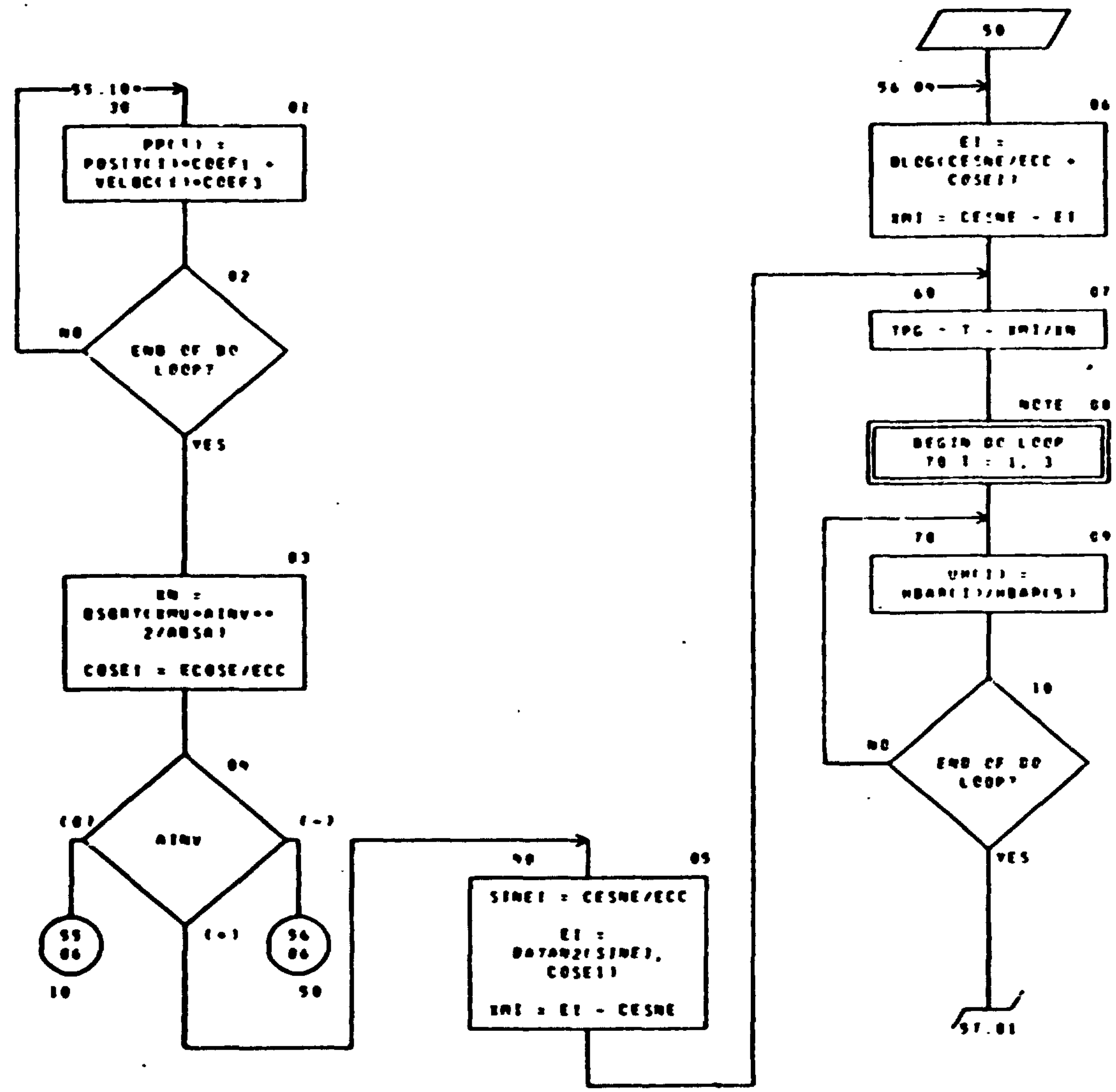
Variable	Use	Common	Description
T	X		Current time, t.
IO	U	INTEG	Logical unit of printer output.
RD	U	HENRY	Radians-to-degrees conversion factor.
IPT	X		Print flag indicating whether osculating elements are to be printed.
XMU	X		Gravitational constant of reference body, μ.
NOPT(72)	U	INTEG	Array of option selector flags.
REKM	U	HENRY	Number of kilometers in one Earth radius.
THET	U	HENRY	Change in eccentric anomaly since last rectification.
MDIST	U	HENRY	Factor for converting from AU to Earth radii.
PBLOC (30)	SU		Array in which osculating elements are stored in the following order: $a, e, r_p, r_a, i, \omega, \tau, n, \Omega$, M, E or F, $t_p, \bar{r}_p, \bar{h}$.
POSIT(3)	UX		Input position vector, R.
VELOC(3)	UX		Input velocity vector, $\dot{R}$.
IREFNO	U	INTEG	Reference body identification number.
PBLOC1(2)	SU		Array containing time t and the true anomaly f, in that order.

CHART TITLE - SUBROUTINE ELCO(T,POSIT,VELOC,XMU,IPT)



ELCO-7

CHART TITLE - SUBROUTINE ELCO(T,POSIT,VELOC,XMU,IPT)



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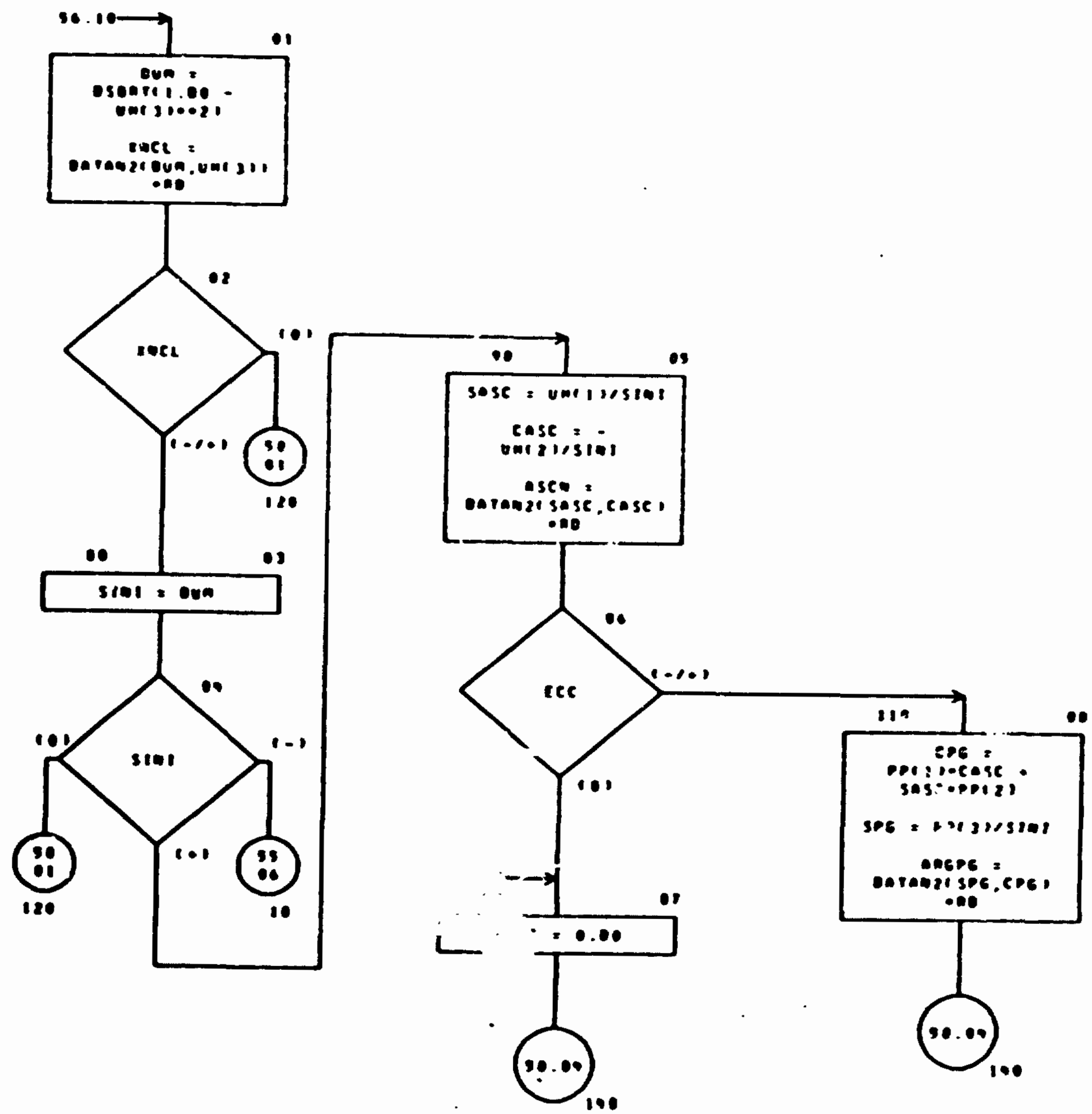

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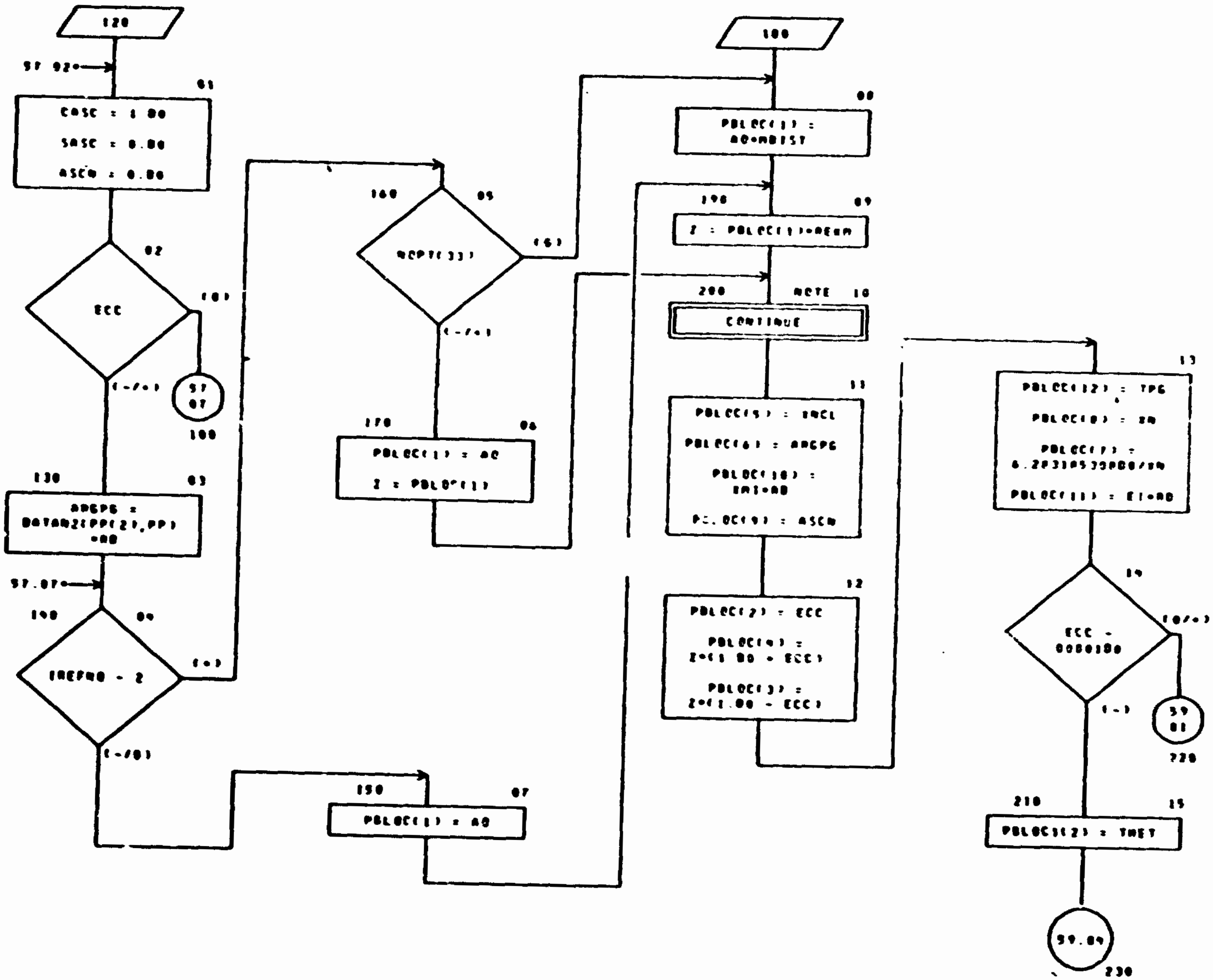


CHART TITLE - SUBROUTINE ELCO(T,POSIT,VELOC,XMU,IPT)

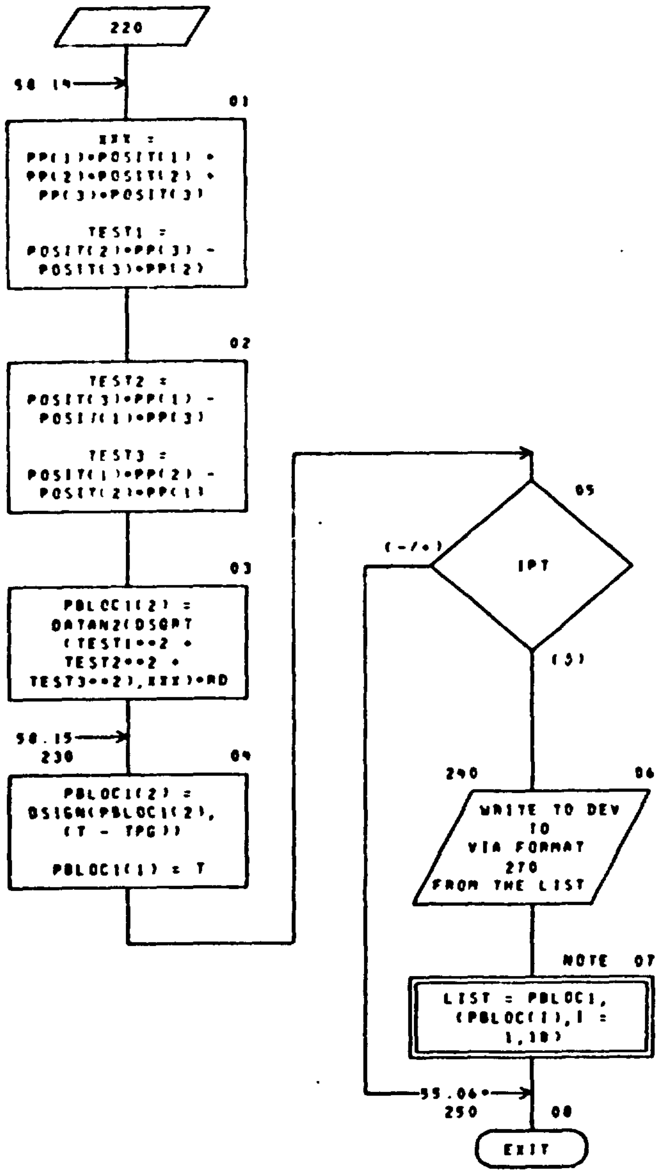


CHART TITLE - NON-PROCEDURAL STATEMENTS

```
          IMPLICIT REAL*8 (A-H,O-Z)
          INTEGER YEAR,DAY,HOURS
          REAL*8 KSOO,MEI,ME,KM,MDIST,INTV,IN1X,IN2X
          DIMENSION PBLOC(30),PBLOC1(2)
          DIMENSION POSIT(6),VELOC(6),HBAR(6),PP(3),UH(3)
          COMMON/HENRY/ARRAY(8,3,12),CHIND,INTV(72),IN1X(3),
          IN2X(3),KSOO(12),KM(12),MDIST,MEI(12),ME(12),POSRCS,PRVDT,
          PDT,PCIN,RD,REKM,RRM,RRE,RREU,RCIND,RATIO,SEC,TSCL,TNTS,TP1,
          TIMEL,THET,VELRCS
          COMMON/INTEG/DAY,HOURS,YEAR,IDUMMY,ITRIG,IREFNC,IREFNB,
          IREFNT,IN,IC,IJK,MONTH,MIN,NOPT(72),NPLAN,NPLAN3
          EQUIVALENCE(PP(1),PBLOC(13)),(UH(1),PBLOC(16))
260       FORMAT (46HOPARABOLIC ORBIT OSCULATING ELEMENTS SUPRESSED)
270       FORMAT ('OOSCULATING ELEMENTS AT TIME T='1PD24 15,' TRUE ANOM='D24
          .15/' SEM MAJ AXIS='D24.15,4X,'ECCENT    ='D24 15,'   PERICENT ='D2
          4.15/3X,'APOCENT.  ='D24 15,'  INCLINATION='D24.15,' ARG PERIC  ='
          D24.15/'   PERIOD    ='D24 15,2X,'MEAN MOT   ='D24.15,' RA ASC NOD
          E='D24.15/'  M ANOMALY  ='D24.15,'  E ANOMALY  ='D24 15,'  T PERIC
          .  ='D24.15/' UNIT PERICENTER POSITION VECTOR ='3D24 15/' UNIT ANG
          ULAR MOMENTUM VECTOR    ='3D24 15)
```

<u>Name:</u> EPH

<u>Calling Arguments:</u> N, TT, X, XD

<u>Referenced Sub-programs:</u> None

<u>Referenced Commons:</u> IEPH, LAMB, ODBALL

<u>Entry Points:</u> None

<u>Referencing Sub-programs:</u> EPHEM, FNMAT

<u>Discussion:</u> Subroutine EPH is an analytical ephemeris routine which computes the heliocentric position and velocity of a planet in the mean equinox and ecliptic frame of date. Mean elements are evaluated as quadratic functions of time for eccentricity e, inclination i, longitude of node Ω, longitude of periapse Π, and mean longitude θ. The sixth element, the semi-major axis a, is assumed constant in time. Coefficients and constants are stored in data arrays for each of the nine planets of the solar system. The values currently in use are listed in the table. The gravitational constant μ for each planet is also stored. Provisions are also available for inputting constant elements for an arbitrary body, referred to as Oddball.

The mean elements are evaluated with the formulas,

$$e = e_1 + e_2\tau + e_3\tau^2 ,$$

$$i = i_1 + i_2\tau + i_3\tau^2 ,$$

$$\Omega = \Omega_1 + \Omega_2\tau + \Omega_3\tau^2 ,$$

$$\Pi = \Pi_1 + \Pi_2\tau + \Pi_3\tau^2 ,$$

$$\theta = \mathrm{mod}\left[\theta_1 + \mathrm{sign}\,(\tau')(\theta_2|\tau'| + \theta_3\tau'^2)\right],$$

where the subscripted characters denote stored coefficients for a given celestial body, τ is the date on which the position and velocity are to be evaluated measured in Julian centuries from January 0.5, 1900, τ' is the same date but measured from January 0.5, 1965, and mod signifies that θ is evaluated modulo 2π (i.e., $0 \leq \theta \leq 2\pi$ radians).

The constant elements for Oddball are input in terms of the semi-major axis, the eccentricity, the inclination, the longitude of ascending node, the argument of perihelion, ω, and the Julian date of perihelion passage, t_p. The eccentricity, inclination, and longitude of ascending node are immediately stored in the locations for e_1, i, and Ω_1, respectively. Π_1 is equated to $\Omega_1 + \omega$; τ' is set to the current date minus the date of perihelion passage; and

$$\theta_1 = \Pi_1 ,$$

$$\theta_2 = 200\pi \sqrt{1/a^3} .$$

The coefficients e_2, e_3, i_2, i_3, Ω_2, Ω_3, Π_2, Π_3 and θ_3 are set to zero, and the quadratic equations defined above are then used to evaluate the current osculating elements for the arbitrary body.

The mean anomaly M is evaluated,

$$M = \theta - \Pi,$$

from which the eccentric anomaly E is calculated by solving the equation

$$M = E - e \sin E,$$

iteratively using Newton's method. A total of 200 iterations are permitted to converge on E to a tolerance of 10^{-15} radians. If this number of iterations is reached, a message is printed and the current value of E is used for all subsequent calculations. The argument of perigee ω is evaluated

$$\omega = \Pi - \Omega,$$

and the position vector is obtained in the orbit plane coordinates

$$x_\omega = a(\cos E - e),$$

$$y_\omega = a\sqrt{1 - e^2}\ \sin E\ ,$$

where x_ω is the component along the perihelion vector and y_ω is the component along the semi-latus rectum, positive in the sense of motion at perihelion.

The transformation matrix A that rotates the position vector in orbit plane coordinates to the ecliptic system used by ASTOP is then evaluated. This matrix is

$$A = \begin{bmatrix} (\cos\Omega\cos\omega - \sin\Omega\sin\omega\cos i) & (-\cos\Omega\sin\omega - \sin\Omega\cos\omega\cos i) \\ (\sin\Omega\cos\omega + \cos\Omega\sin\omega\cos i) & (-\sin\Omega\sin\omega + \cos\Omega\cos\omega\cos i) \\ \sin\omega\sin i & \cos\omega\sin i \end{bmatrix}$$

so that the planetary position vector is defined

$$R = A\begin{bmatrix} x_\omega \\ y_\omega \end{bmatrix}.$$

If the common variable NC is not equal to 1, the planetary velocity is evaluated prior to returning to the calling program. The velocity is first evaluated in orbit plane coordinates as follows:

$$\dot{x}_\omega = -\frac{\sqrt{a(1+\mu/\mu_s)}}{a(1 - e\cos E)}\ \sin E\ ,$$

$$\dot{y}_\omega = \frac{\sqrt{a(1+\mu/\mu_s)(1-e^2)}}{a(1 - e\cos E)}\ \cos E\ ,$$

where μ_s is the sun's gravitational constant ($=1.32718\times10^{20}\ m^3/sec^2$), and then in ecliptic coordinates:

$$\dot{R} = A\begin{bmatrix} \dot{x}_\omega \\ \dot{y}_\omega \end{bmatrix}.$$

PLANETARY GRAVITATIONAL AND ORBITAL CONSTANTS

	Mercury	Venus	Earth	Mars	Jupiter
μ (m^3/sec^2)	2.17562D13	3.248534D14	3.986032D14	4.29778D13	1.267069D17
a (AU)	.3870986	.7233316	1.00000023	1.5236915	5.202561
e_1	.20561421	6.82069D-3	1.675104D-2	9.33129D-2	4.833475D-2
e_2 (1/cent.)	2.046D-5	-4.774D-5	-4.18D-5	9.2064D-5	1.6418D-4
e_3 (1/cent.^{2})	-3.D-8	9.1D-8	-1.26D-7	-7.7D-8	-4.676D-7
i_1 (rad)	.12222565	5.9230124D-2	0	3.2293876D-2	2.2841754D-2
i_2 (rad/cent.)	3.033964D-5	2.1855401D-5	0	-1.1327672D-5	-9.9415893D-5
i_3 (rad/cent.^{2})	-2.7149566D-7	-7.5630934D-8	0	4.5814893D-7	6.7873915D-8
Ω_1 (rad)	.82283029	1.3227513	0	.85148815	1.7356145
Ω_2 (rad/cent.)	2.0677958D-2	1.5952794D-2	0	1.3560239D-2	1.7637076D-2
Ω_3 (rad/cent.^{2})	4.0481942D-6	7.3109903D-6	0	-1.0520457D-5	6.1474375D-6
Π_1 (rad)	1.3246548	2.2713807	1.7666368	5.8332094	.22202207
Π_2 (rad/cent.)	2.7113157D-2	2.3951105D-2	3.0005264D-2	3.2120943D-2	2.8099132D-2
Π_3 (rad/cent.^{2})	5.38628D-6	2.8749451D-5	7.902463D-6	5.8628518D-6	1.8435428D-5
θ_1 (rad)	2.36146727	3.83718291	1.74446001	2.36878283	.90102455
θ_2 (rad/cent.)	2608.8147	1021.35293	628.331958	334.085683	52.9934743
θ_3 (rad/cent.^{2})	5.2552D-6	5.4048D-6	5.279621D-6	5.4222D-6	5.8413262D-6

PLANETARY GRAVITATIONAL AND ORBITAL CONSTANTS (continued)

	Saturn	Uranus	Neptune	Pluto
μ (m^3/sec^2)	3.791794D16	5.786726D15	6.876309D15	3.317819D14
a (AU)	9.554747	19.21814	30.10957	39.537355
e_1	5.589232D-2	4.6344D-2	8.99704D-3	.2515024
e_2 (1/cent.)	-3.455D-4	-2.658D-5	6.33D-6	0
e_3 (1/cent.^{2})	-7.28D-7	7.7D-8	-2.D-9	0
i_1 (rad)	4.3502671D-2	1.3482038D-2	3.1053625D-2	.29959349
i_2 (rad/cent.)	-6.8397514D-5	1.0913156D-5	-1.6656744D-4	0
i_3 (rad/cent.^{2})	-2.7033211D-7	6.8940505D-7	-1.5901889D-7	0
Ω_1 (rad)	1.9685636	1.282417	2.28082	1.9174073
Ω_2 (rad/cent.)	1.524013D-2	8.7033946D-3	1.9180034D-2	0
Ω_3 (rad/cent.^{2})	-2.6560518D-6	2.2892902D-5	4.360996D-6	0
Π_1 (rad)	1.5899628	2.9940888	.81554567	3.9056323
Π_2 (rad/cent.)	3.4180804D-2	2.590824D-2	2.4363514D-2	0
Π_3 (rad/cent.^{2})	1.4422722D-5	4.139824D-6	6.8210376D-6	0
θ_1 (rad)	5.96619116	2.85546276	3.96857273	3.2780198
θ_2 (rad/cent.)	21.3542815	7.50254138	3.837734	2.5273709
θ_3 (rad/cent.^{2})	5.6643206D-6	5.5159192D-6	5.5934894D-6	0

Messages and Printout: If the Newton's iteration for eccentric anomaly fails, the following message is printed:

MDC EPH ERROR

EPH EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
N	UX		Planet identification number N = 1 - Mercury, 2 - Venus, 3 - Earth, 4 - Mars, 5 - Jupiter, 6 - Saturn, 7 - Uranus, 8 - Neptune, 9 - Pluto, 10 - Oddball
X(3)	SX		Ecliptic position vector, R, of planet, in AU.
NC	U	IEPH	Flag defining whether planet's velocity is to be evaluated. NC $\neq$ 1 - position only is computed NC = 1 - position and velocity are computed
TT	UX		Time, in days, measured from the input Julian launch date.
XD(3)	SX		Ecliptic velocity vector, $\dot{R}$, of planet, in units of Earth mean orbital speed.
CNI	U	ODBALL	Ecliptic inclination i of Oddball, in radians.
ECI	U	ODBALL	Eccentricity e of Oddball's orbit.
OMI	U	ODBALL	Longitude of ascending node Ω of Oddball's orbit on ecliptic plane, in radians.

EPH EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
SAI	U	ODBALL	Semi-major axis a of Oddball's orbit, in AU.
SOI	U	ODBALL	Argument of perihelion ω of Oddball's orbit, in radians.
TPI	U	ODBALL	Julian date (minus 2400000) of perihelion passage t_p of Oddball.
XJLD	U	LAMB	Julian date (minus 2440000) of input launch date.
EMUDD	U	ODBALL	Gravitational constant μ of Oddball, in m^3/sec^2.

CHART TITLE - SUBROUTINE EPH(N,TT,X,XD)

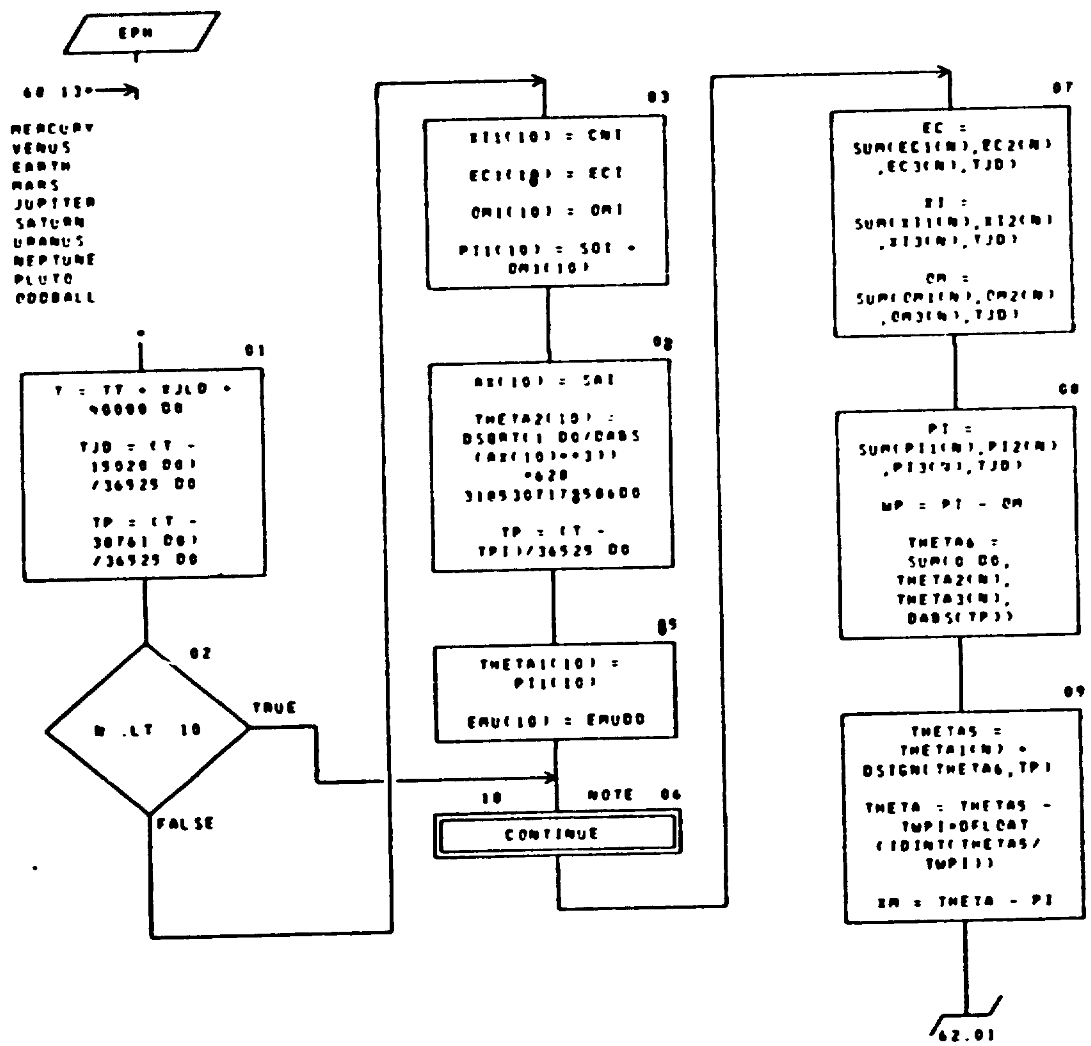


CHART TITLE - SUBROUTINE EPH(N,TT,X,ID)

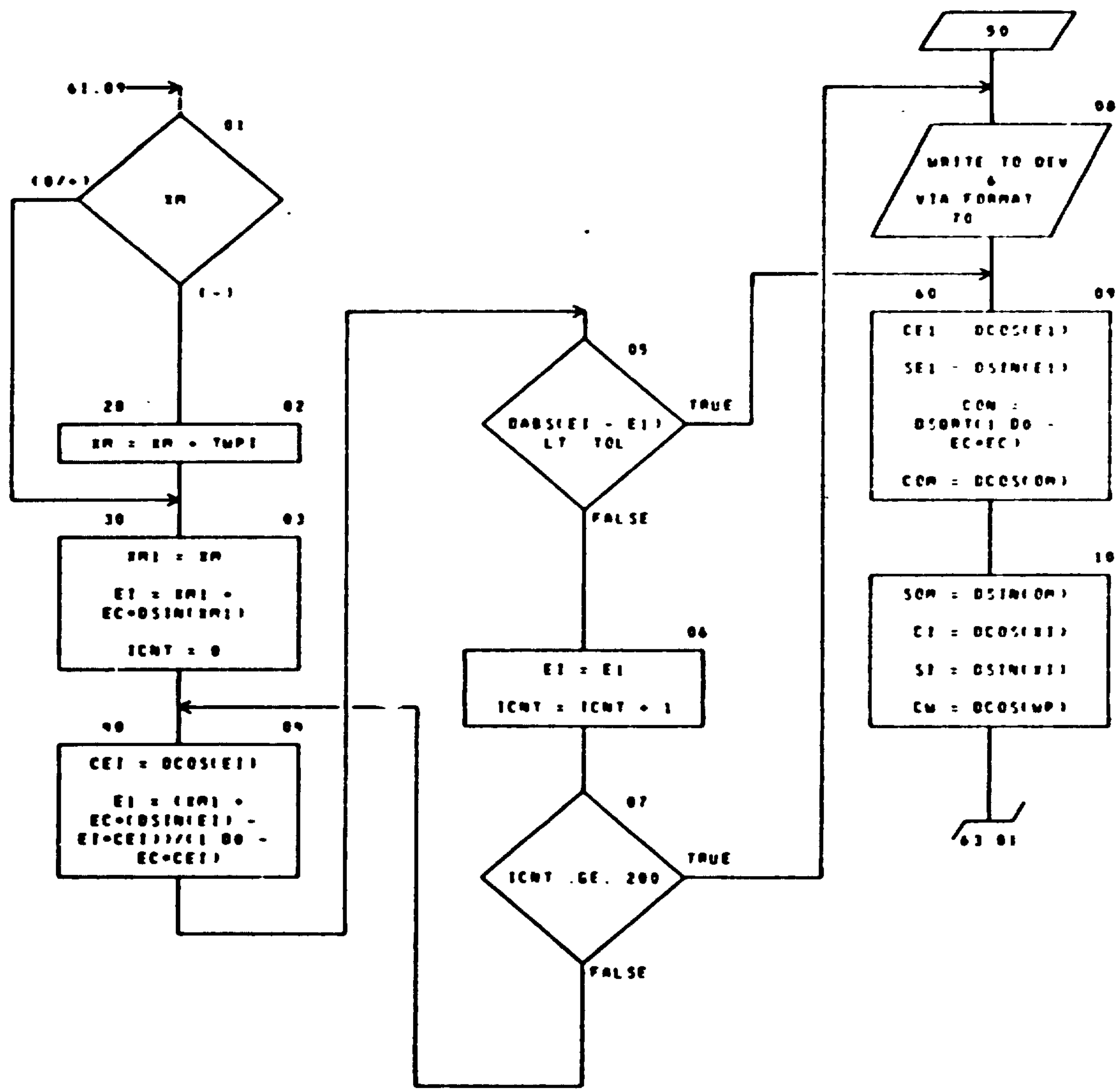


CHART TITLE - SUBROUTINE EPH(N,TT,X,XD)

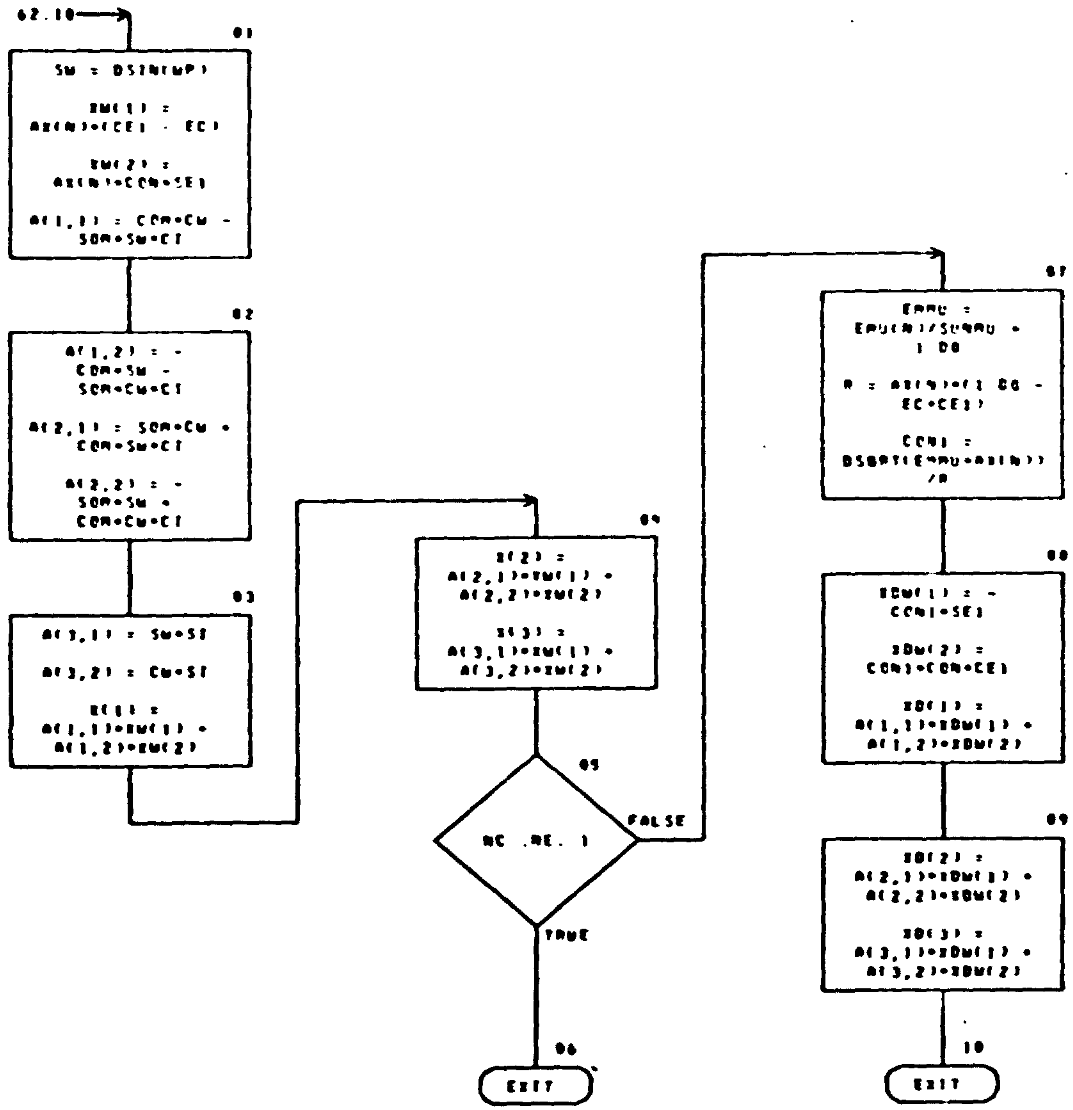


CHART TITLE - NON-PROCEDURAL STATEMENTS

```
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION X(3),XD(3),        XM(2),XDM(2),A(3,2),XI1(10),XI2(10),XI
     3(10),EC1(10),EC2(10),EC3(10),OM1(10),OM2(10),OM3(10),PI1(10),PI2(
     10),PI3(10),THETA1(10),THETA2(10),THETA3(10),AX(10),EMU(10)
      COMMON/IEPH/NC
      COMMON/LAMB/TJLD,XINJ,PBRE,LCPT
      COMMON/CBBALL/SAT,ECI,CAI,OMI,SCI,TPI,EMUDD,AABCDD
      DATA TWPI/6 283185307179586D0/,TOL/1 D-15/,SUMMU/1 32712E20/
       DATA
     XI1(1)/ 1222296SD0/,XI2(1)/3 0339696E-5/,XI3(1)/-2 7169566D-7/,
     EC1(1)/ 2056192ID0/,EC2(1)/2 046D-5/,EC3(1)/-3 D-8/,
     OM1(1)/ 8220302 9D0/,OM2(1)/2 0677950D-2/,OM3(1)/4 0901992E-6/,
     PI1(1)/1 3296590D0/,PI2(1)/2 7113157D-2/,PI3(1)/5 30620E-6/,
     THETA1(1)/2 3614672 7E0/,THETA2(1)/2 6080147D3/,THETA3(1)/5 2552D-6
     /,AX(1)/ 3870986D0/,EMU(1)/2 1756201 3/
       DATA
     XI1(2)/5.9230129D-2/,XI2(2)/2 1055901D-5/,XI3(2)/-7.5638934D-8/,
     EC1(2)/6.820690-3 /,EC2(2)/-4 774D-5/,EC3(2)/9 1E-8/,
     OM1(2)/1.3227513D0/,OM2(2)/1 5952794D-2/,OM3(2)/7 3169903D-6/,
     PI1(2)/2.2713007D0/,PI2(2)/2 3951165D-2/,PI3(2)/2.0749951D-5/,
     THETA1(2)/3 6371029 1D0/,THETA2(2)/1 0213529303/,THETA3(2)/5 9994D-
     6/,AX(2)/.7233316D0/,EMU(2)/3 2485349D14/
       DATA
     XI1(3)/          0.D0/,XI2(3)/          0 D0 /,XI3(3)/          0.D0/,
     EC1(3)/1.675104D-2/,EC2(3)/-4 180D-5/,EC3(3)/-1.26D-7/,
```

```
OM1(3)/        0.D0/,OM2(3)/        0.D0 /,OM3(3)/        0.D0 /,
PI1(3)/1.7666360D0/,PI2(3)/3.0005269D-2/,PI3(3)/7 9029630D-6/,
THETA1(3)/1.7999600100/,THETA2(3)/6 2033195002/,THETA3(3)/5 279621
D-6/,AE(3)/1.0000002300/,EMU(3)/3 986032014/
 DATA
XI1(4)/3.2293076D-2/,XI2(4)/-1 1327672B-5/,XI3(4)/4 5019093D-7/,
EC1(4)/9 33129D-02/,EC2(4)/9 2069D-5/,EC3(4)/-7 7D-08/,
OM1(4)/.0519001500/,OM2(4)/1 3568239D-2/,OM3(4)/-1 0520957D-5/,
PI1(4)/5 0332094D0/,PI2(4)/3 2120993D-2/,PI3(4)/5 0020510D-6/,
THETA1(4)/2 3607020300/,THETA2(4)/3 3960560302/,THETA3(4)/5 42222D
D-6/,AE(4)/1 5236915D0/ ,EMU(4)/4 2977481)
 DATA
XI1(5)/2 2041759D-2/,XI2(5)/-9 9915093D-5/,XI3(5)/6 7873915D-0/,
EC1(5)/4 8334750-2/,EC2(5)/1 641 D-4/,EC3(5)/-4 676D-7/,
OM1(5)/1 7356195D0/,OM2(5)/1 7637076D-2/,OM3(5)/6 1579375D-06/,
PI1(5)/.2220220703/,PI2(5)/2 0899132D-2/,PI3(5)/1 4935420D-5/,
THETA1(5)/.9010245500/,THETA2(5)/52 9934743.6/,THETA3(5)/5 041326
2D-6/,AE(5)/5 20256100/,EMU(5)/1 267069D17/
DATA
XI1(6)/4.3532671D-2/,XI2(6)/-6 0397514D-5/,XI3(6)/-2.7033211D-7/,
EC1(6)/5.5092320-2/,EC2(6)/-3.4550-4/,EC3(6)/-7.28D-7/,
OM1(6)/1.9685636D0/,OM2(6)/1.5240130D-2/,OM3(6)/-2.6560510D-6/,
PI1(6)/1.5099620D0/,PI2(6)/3.4100009D-2/,PI3(6)/1.4922722D-5/,
THETA1(6)/5 9661911D0/,THETA2(6)/21 3542015D6/,THETA3(6)/5 6693.0
6D-6/,AE(6)/9.5597978D0/,EMU(6)/3.791794D16/
```

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
DATA
XI1(7)/1 3982038D-2/,XI2(7)/1 091315600-5/,XI3(7)/6.894050500-7/,
EC1(7)/4 6394000D-2/,EC2(7)/-2 658D-5/,EC3(7)/7 7000-8/,
OM1(7)/1 28241700O/,OM2(7)/8 7033946D-3/,OM3(7)/2 289290200-5/,
PI1(7)/2 9940888000/,PI2(7)/2 5908240D-2/,PI3(7)/4 1398240D-6/,
THETA1(7)/2 85546276DO/,THETA2(7)/7 50254138DO/,THETA3(7)/5 515919
2D-6/,AX(7)/19 2181400/,EMU(7)/5 786726D15/
DATA
XI1(8)/3 1053625D-2/,XI2(8)/-1 6656799D-4/,XI3(8)/-1.5901889D-7/,
EC1(8)/8 997040D-3/,EC2(8)/6 3300D-6/,EC3(8)/-2 000-9/,
OM1(8)/2.2808200DO/,OM2(8)/1 9180034D-2/,OM3(8)/4 360996C0D-6/,
PI1(8)/ 8155456700/,PI2(8)/2 4863514D-2/,PI3(8)/6 8210376D-6/,
THETA1(8)/3 96857273DO/,THETA2(8)/3 83773400DO/,THETA3(8)/5 593489
4D-6/,AX(8)/30.109570O/,EMU(8)/6 876309D15/
DATA
XI1(9)/.299593490O /,XI2(9)/0.00/,XI3(9)/0 DO/,
EC1(9)/ 25150240O/,EC2(9)/0.DO/,EC3(9)/0 DO/,
OM1(9)/1.9174073DO/,OM2(9)/0 DO/,OM3(9)/0 DO/,
PI1(9)/3.905632300/,PI2(9)/0 DO/,PI3(9)/0 DO/,
THETA1(9)/3.27801980DO/,THETA2(9)/2 5273709DOO/,THETA3(9)/
0.DO/,AX(9)/39.5373550O/,EMU(9)/3.317819D14/
DATA XI1(10),XI2(10),XI3(10),EC1(10),EC2(10),EC3(10),OM1(10),OM2(1
0),OM3(10),PI1(10),PI2(10),PI3(10),THETA1(10),THETA2(10),THETA3(10
),AX(10),EMU(10)/17*0.DO/
STATEMENT FUNCTION DEFINITION,  SUM(X9,Y9,Z9,W9)=X9*W9*(Y9*Z9*W9)
```

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
70      FORMAT (1H0,13HMDC EPH ERROR)
```

<u>Name:</u> EPHEM

<u>Calling Arguments:</u> None

<u>Referenced Sub-programs:</u> EPH

<u>Referenced Commons:</u> HENRY, IEPH, NORM, NORML

<u>Entry Points:</u> None

<u>Referencing Sub-programs:</u> INIT

<u>Discussion:</u> This subroutine generates tables of ephemeris data for the eight planets from Venus outward to Pluto. This subroutine, as presently coded, restricts the program to missions having one of these eight planets as the launch planet and one as the final target. The ephemeris data consist of up to 250 entries for each position and velocity coordinate tor each of the eight planets. The data points are equally spaced in time, starting 24 hours prior to the input Julian launch date XJLD. The time interval between points is defined by the variable DLEPH.

Upon entry to EPHEM, the flag NC is set to 1 to assure that all calls to subroutine EPH results in the computation of planetary velocity vectors as well as position vectors. An internal flag is then tested to see if EPHEM has been entered previously during the current run. If so, a return to the calling routine INIT is immediately executed. This assures that the ephemeris tables are loaded only once each run. If there was no previous entry to the subroutine, the internal flag is set for future calls to EPHEM, and the logic to generate the ephemeris tables continues.

A constant is evaluated to convert velocity units from Earth mean orbital speed (as returned by subroutine EPH) to AU/day. The integer array ITBL, which defines the starting location of position and velocity data for each planet in the ephemeris table TBBL, is initialized, the initial time point T for the ephemeris table is set at -24 hours (relative to the input launch date) and stored in the common variable TREF, and the ephemeris table entry counter IT is initialized to zero. A loop is then entered which results in the storing of the desired data in TBBL. The loop begins by incrementing the counter IT by 1, converting the current time from the launch date to days, and calling subroutine EPH a total of eight times to obtain the heliocentric ecliptic position and velocity vectors of the eight planets. The position vectors of all planets at the current time are temporarily stored in the internal array XNTV and the velocities are stored in XNX. The signs of the three position and three velocity components of the Earth are changed so that the array actually contains the position and velocity of the sun relative to Earth and the position and velocity of all other planets relative to the sun. This is the format expected by ASTOP. The ephemeris data are then stored in the appropriate locations of the permanent array TBBL after converting the units of the velocity coordinates. The current time is then incremented DLEPH hours and control is transferred to the top of loop. This loop is cycled until either the current time exceeds an input time limit TIMEL or the limit of 250 time points was entered in the table. In the latter case, a message is printed to inform the user to check the input TIMEL on future runs to see if the number of ephemeris computations may be reduced. TIMEL should be approximately equal to the flight time plus 96 hours, if the flight time is less than 1000 days, and add an additional 96 hours to the flight time for each additional 1000 days of flight time or fraction thereof.

When computed, the TBBL array has the following format:

TBBL(1) -TBBL(250) - x component of sun position w.r.t. Earth for all time points
TBBL(251)-TBBL(500) - y component of sun position w.r.t. Earth for all time points
TBBL(501)-TBBL(750) - z component of sun position w.r.t. Earth for all time points
TBBL(751)-TBBL(1500) - x, y, z components of Jupiter position w.r.t. sun for all time points
TBBL(1501)-TBBL(2250)-x, y, z components of Mars position w.r.t. sun for all time points
TBBL(2251)-TBBL(3000)-x, y, z components of Venus position w.r.t. sun for all time points

TBBL(3001)-TBBL(3750)-x, y, z components of Saturn position w.r.t. sun for all time points
TBBL(3751)-TBBL(4500)-x, y, z components of Uranus position w.r.t. sun for all time points
TBBL(4501)-TBBL(5250)-x, y, z components of Neptune position w.r.t. sun for all time points
TBBL(5251)-TBBL(6000)-x, y, z components of Pluto position w.r.t. sun for all time points

Velocity components are stored 6000 words after the corresponding position components.

Messages and Printout If the full 250 time points are used in constructing the ephemeris table TBBL, the following message is printed for information purposes:

EPHEMERIS TABLE FILLED. CHECK INPUT PARAMETER TIMEL
ON FUTURE RUNS FOR POSSIBLE REDUCTION IN EPHEMERIS
COMPUTATIONS.

EPHEM EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
NC	S	IEPH	Flag defining whether planetary velocity is to be computed by subroutine EPH. $NC \neq 1$ - compute planetary position only $NC = 1$ - compute planetary position and velocity.
TT	SA		Time, in days, from input launch date.
ION(10)	SA		Array of planet ID numbers which correlates the planet ID number used by EPH with the order data are stored in TBBL.
XNX(72)	UA		Velocity vector returned by subroutine EPH. Only first 24 locations are used.

EPHEM EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
ITBL(22)	S	NORM	Table defining the starting locations for the storage of position data and velocity data in TBBL for each planet. The values assigned are the starting locations minus 1, and are as follows: ITBL(1) = 0 - Sun's position ITBL(2) = 750 - Jupiter position ITBL(3) = 1500 - Mars position ITBL(4) = 2250 - Venus position ITBL(5) = 3000 - Saturn position ITBL(6) = 3750 - Uranus position ITBL(7) = 4500 - Neptune position ITBL(8) = 5250 - Pluto position ITBL(12) = 6000 - Sun's velocity ITBL(13) = 6750 - Jupiter velocity ITBL(14) = 7500 - Mars velocity ITBL(15) = 8250 - Venus velocity ITBL(16) = 9000 - Saturn velocity ITBL(17) = 9750 - Uranus velocity ITBL(18) = 10500 - Neptune velocity ITBL(19) = 11250 - Pluto velocity
REKM	U	HENRY	Number of kilometers in one Earth radius.
TBBL (12000)	S	NORML	Array of planetary ephemeris data. See Discussion for format. Only first 12000 words are used.
TREF	S	NORM	Beginning time, in hours from the input launch date, of the ephemeris data table TBBL.
XNTV(72)	UA		Position vector returned by subroutine EPH. Only first 24 locations are used.
DLEPH	U	NORM	Time interval, in hours, between entries in ephemeris data table.

EPHEM EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
TIMEL	U	HENRY	Time limit, in hours from the input launch date, beyond which the construction of the ephemeris data table is discontinued.
XDIST	U	HENRY	Number of Earth radii in one AU.

CHART TITLE - SUBROUTINE EPHEM

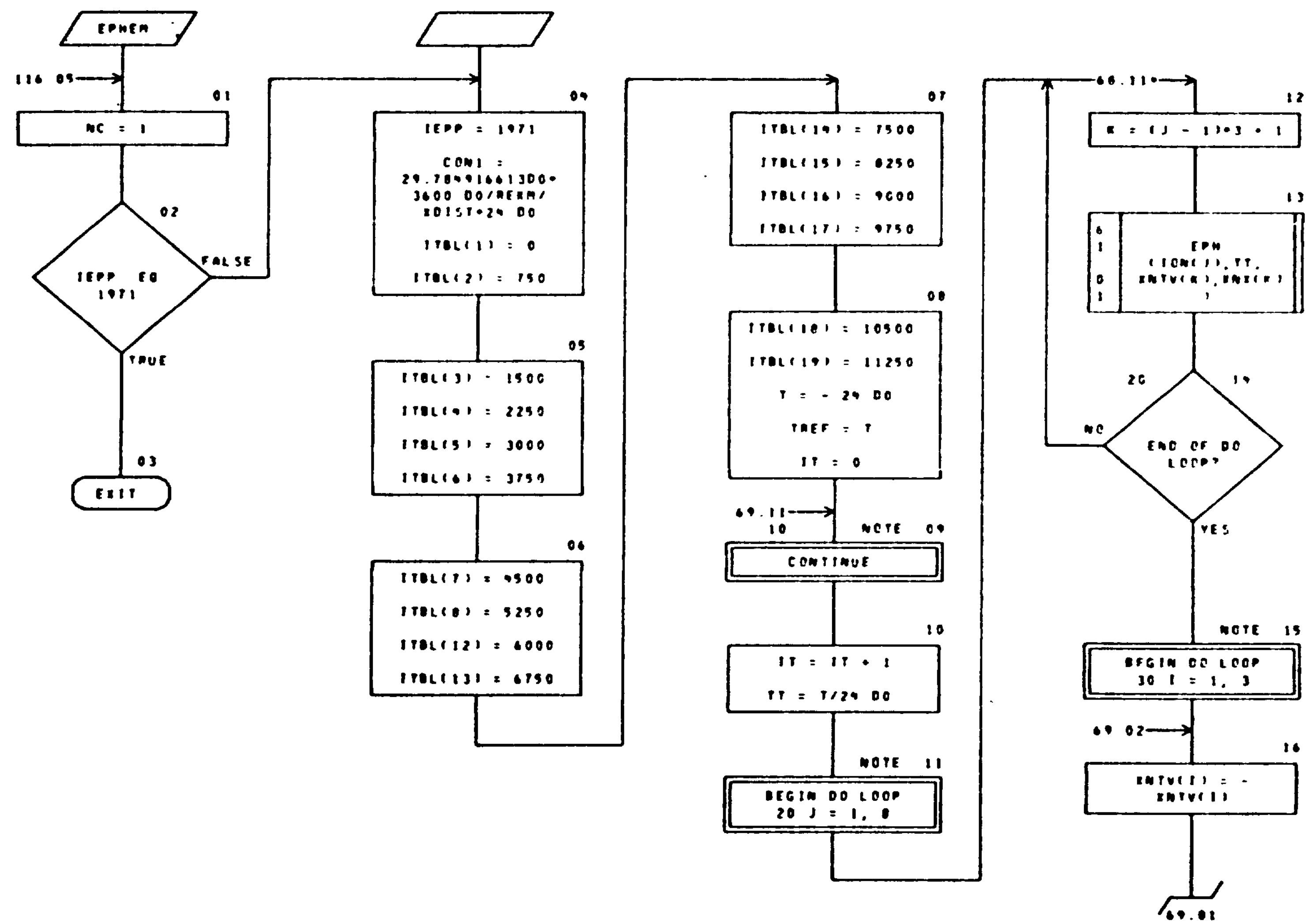


CHART TITLE - SUBROUTINE EPHEM

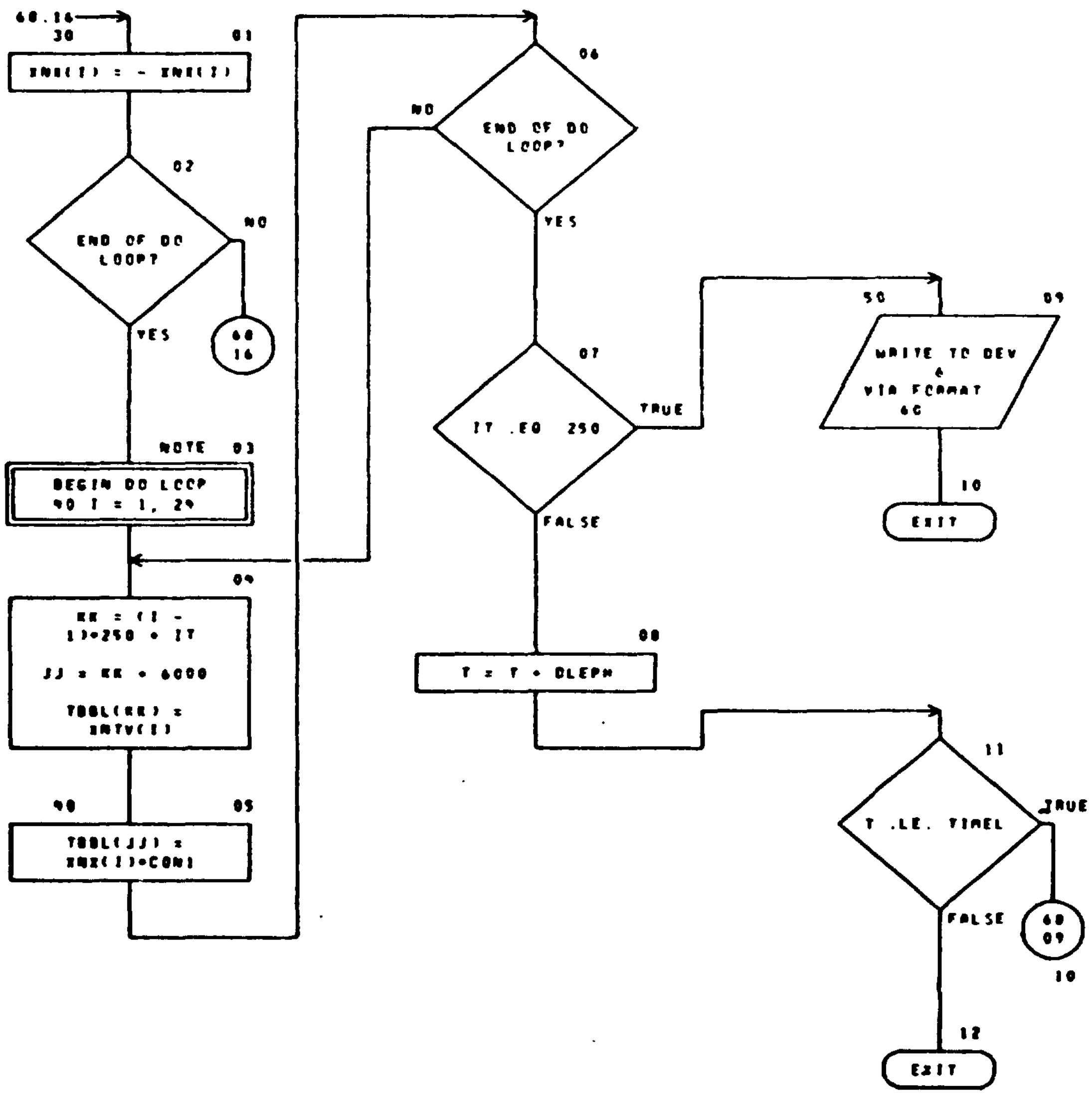


CHART TITLE - NON-PROCEDURAL STATEMENTS

```
      IMPLICIT REAL*8(A-H,O-Z)
      REAL*8 RSQQ,RM,INTV,IN1X,IN2X
      DIMENSION ION(10),XNTV(72),XNX(72)
      COMMON/HENRY/ARRAY(8,3,12),CHIND,INTV(72),IN1X(3),
      IN2X(3),RSQQ(12),RM(12),RDIST,RE1(12),RE(12),POSRCS,PRVDT,
      PDT,PCIN,RO,REKM,RRM,RRE,RPEU,RCIND,RATIO,SEC,TSCL,THTS,TP1,
      TIMEL,THET,VELRCS
      COMMON/IEPH/NC
      COMMON/NORM/TREF,DLEPH,ITBL(22)
      COMMON/NCRML/TBBL(12000)
      DATA ION/3,5,4,2,6,7,8,9/
60    FORMAT ('0EPHEMERIS TABLE FILLED  CHECK INPUT PARAMETER TIMEL ON'
      ' FUTURE RUNS FOR POSSIBLE REDUCTION IN EPHEMERIS COMPUTATIONS ')
```

<u>Name:</u> FINDXB

<u>Calling Arguments:</u> L

<u>Referenced Sub-programs:</u> INT

<u>Referenced Commons:</u> ALAN, HENRY, ILEF, INTEG, JERR, LEFT, NORM

<u>Entry Points:</u> None

<u>Referencing Sub-programs:</u> SOLENG

<u>Discussion:</u> Subroutine FINDXB defines the instantaneous direction of the body fixed unit vector $\bar{s}$ when operating in the constrained mode. If the flag NOP64 is 1, $\bar{s}$ is directed from the spacecraft to the celestial body identified by NOP63; if NOP64 is 3, $\bar{s}$ is directed parallel to the heliocentric velocity vector; if NOP64 is 2, a return from the routine is immediately executed so that the input $\bar{s}$ is preserved.

The computation of $\bar{s}$ for the case in which it is directed toward a prescribed celestial body consists simply of unitizing the negative of the appropriate position vector in the VCOL array. For the case in which $\bar{s}$ is directed along the heliocentric velocity, the computation depends on the current reference frame of integration. If the sun is the current reference body, then the velocity $\dot{R}_c$ relative to the current reference body, contained in the array XRDL, is used directly after dividing by the magnitude. If the reference body is Earth, then

$$\bar{s} = \frac{\dot{R}_c + \dot{R}_{ES}}{|\dot{R}_c + \dot{R}_{ES}|}$$

where $\dot{R}_{ES}$ is the heliocentric velocity of the Earth, obtained by reversing the velocity of the sun relative to Earth, $\dot{R}_{SE}$. $\dot{R}_{SE}$ is obtained by interpolating within the ephemeris data using subroutine INT, and applying a conversion factor to achieve the correct units. If the reference body is the moon*, then

*ASTOP presently does not support the capability of moon reference. However, this subroutine handles the option should it be included in ASTOP later.

$$\bar{s} = \frac{\dot{R}_c + \dot{R}_{ME} + \dot{R}_{ES}}{|\dot{R}_c + \dot{R}_{ME} + \dot{R}_{ES}|}$$

where $\dot{R}_{ME}$ is the velocity of the moon relative to Earth, obtained by interpolating within the ephemeris data table. For any other available reference body

$$\bar{s} = \frac{\dot{R}_c + \dot{R}_{BS}}{|\dot{R}_c + \dot{R}_{BS}|}$$

where $\dot{R}_{BS}$ is the velocity of the reference body relative to the sun, obtained by interpolating within the ephemeris data table.

FINDXB EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
L	UX		Integer index defining the specific perturbation or nominal trajectory for which the computations for $\bar{s}$ are to be made.
T	SUA	ALAN	Time in hours from the start of the trajectory.
ER(3)	SU	JERR	Unit constraint vector, $\bar{s}$.
IJK	SU	INTEG	Index of the VCOL array relating data to specific celestial bodies.
ITBL (22)	U	NORM	Array of indexes identifying location of ephemeris data by planet. (See EPHEM).
VCOL (72,20)	U	LEFT	Array of spacecraft position vectors relative to each celestial body for the nominal and perturbation trajectories.
XNIX (3)	SU	HENRY	Used for temporary storage of a vector.

FINDXB EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
XN2X (3)	SUA	HENRY	Array used to receive velocity vector from subroutine INT.
XRDL (6, 20)	U	LEFT	Array of velocity vectors of spacecraft relative to the current reference body for nominal and all perturbation trajectories.
DLEPH	UA	NORM	Time interval in hours between entries of ephemeris data.
NOP63	U	ILEF	Integer flag defining celestial body to which $\bar{s}$ is to be directed. Options are the same as for the launch reference body number IREFNB.
NOP64	U	ILEF	Integer flag defining the steering constraint mode. =1 - $\bar{s}$ is directed toward the celestial body defined by NOP63. =2 - $\bar{s}$ is directed along an input inertial vector. =3 - $\bar{s}$ is directed along the heliocentric velocity vector.
XDIST	U	HENRY	Number of Earth radii in one AU.
IREFNO	U	INTEG	Reference body ID number as follows: 1 Earth, 5 Mars, 9 Neptune 2 not available, 6 Jupiter, 10 Pluto 3 Sun, 7 Saturn 4 Venus, 8 Uranus

CHART TITLE - SUBROUTINE FINDXB(L)

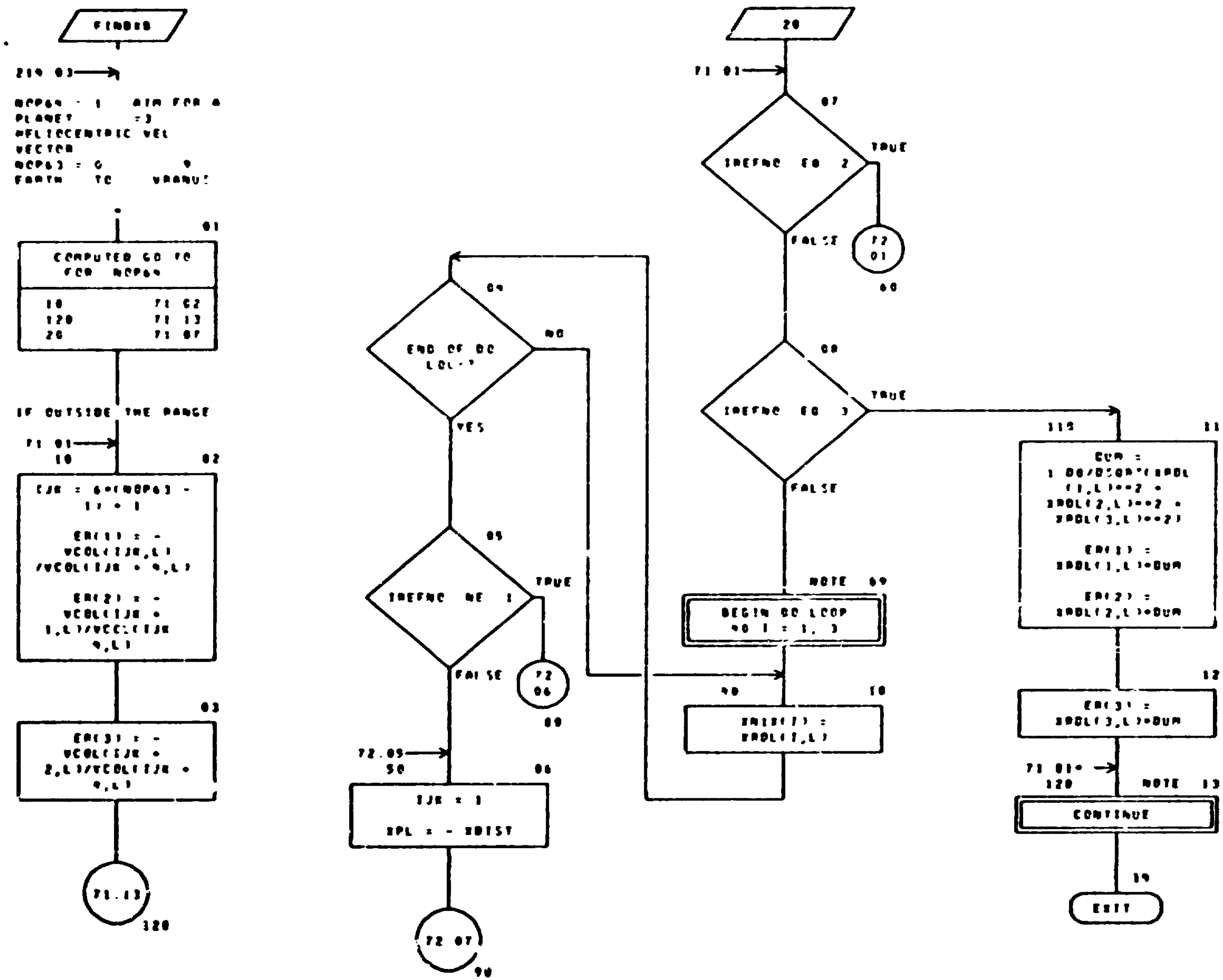
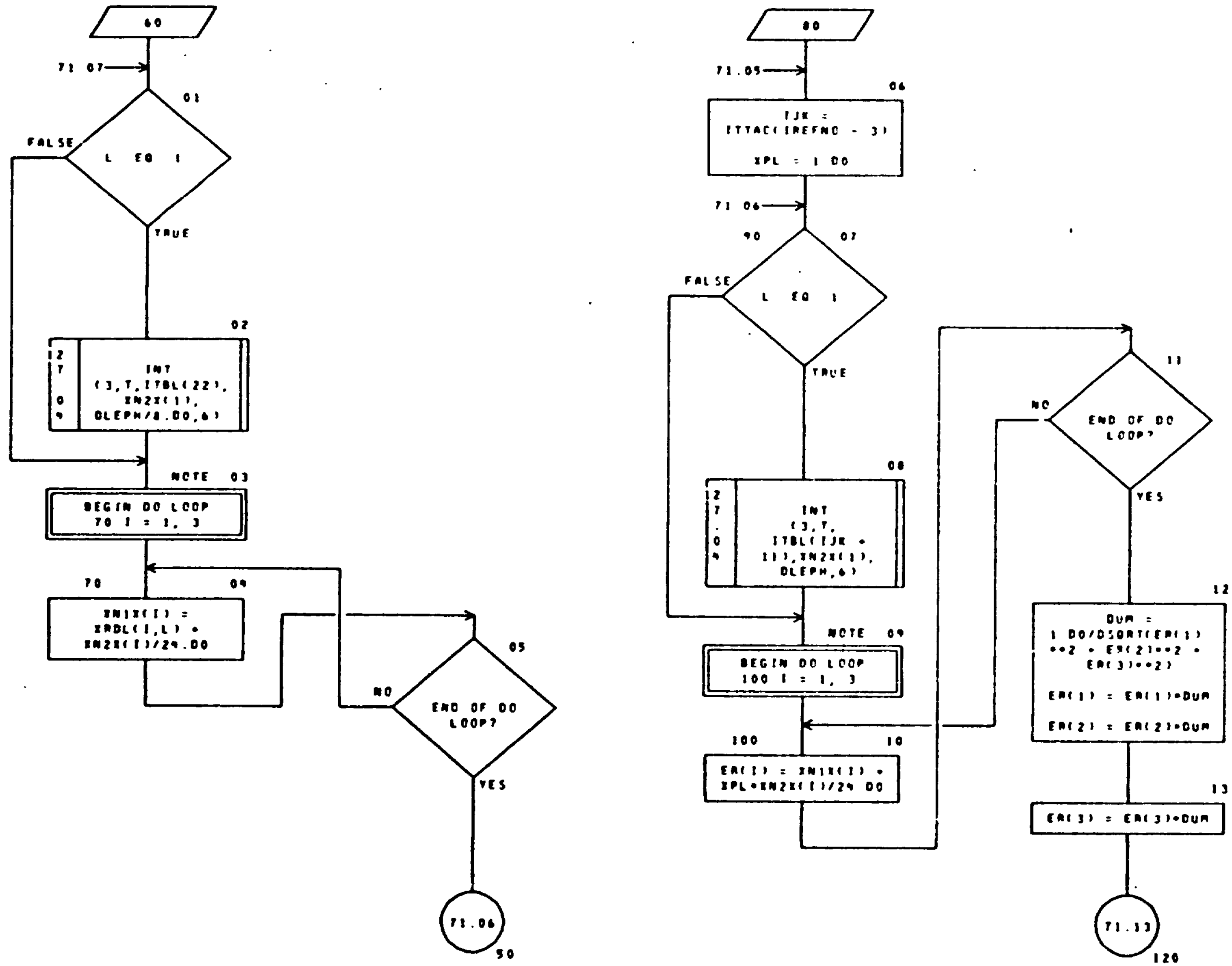


CHART TITLE - SUBROUTINE FINDXB(L)



FINDXB-5

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
IMPLICIT  REAL * 8 (A - H,O-Z)
REAL*8 KSQQ,MEI,ME,KM,INTV
INTEGER DAY,HOURS,YEAR
DIMENSION ITTAC(8)
COMMON /ALAN/ T,RHBR,DCRHO
COMMON/HENRY/ARRAY(8,3,12),CHINC,INTV(72),XN1X(3),
XN2X(3),KSQQ(12),KM(12),XDIST,MEI(12),ME(12),POSRCS,PRVDT,
PDT,PCIN,RD,REKM,RRM,RRE,RREU,RCINC,RATIO,SEC,TSCL,THTS,TPI,
TIMEL,THET,VELRCS
COMMON/ILEF/NEQL,NEQ3,NON,NOP65,ICAR(7),NOP64,NOP63,NS,N4,NS1,NJJ
COMMON/INTEG/DAY,HOURS,YEAR,IDUMMY,ITRIG,IREFNC,IREFND,
IREFNT,IN,IO,IJK,MONTH,MIN,NOPT(72),NPLAN,NPLAN3
COMMON/JERR/DUMJ1(224),ER(3),DUMJ2(341)
COMMON/LEFT/XRL(6,20),XRDL(6,20),VCCL(72,20)
COMMON/NORM/TREF,DLEPH,ITBL(22)
DATA ITTAC/4,3,2,5,6,7,8,9/
```

<u>Name:</u> F: . 'AT

<u>Calling Arguments:</u> None

<u>Referenced Sub-programs:</u> DIAG1, EPH, INT, RADII

<u>Referenced Commons:</u> ALAN, AM1, CONRAD, FNM, HENRY, HER, HIS IEPH, INTEG, JERR, LEFT, NOMLL, NORM, PERAPS, XMMM

<u>Entry Points:</u> None

<u>Referencing Sub-programs:</u> GENMA

<u>Discussion:</u> Subroutine FNMAT is called at the end of each trajectory to evaluate the specified end conditions and, if required, the partial derivatives of the end conditions and performance index with respect to the independent parameters. Upon entry, the reference body of integration is checked and, if not the sun or the specified target body, a message is printed and execution is terminated.

The particular iterator being used to perform the parameter optimization, and to solve the boundary value problem, permits the selection of the performance index of the problem from the same list of functions available for specification as final conditions. Regardless of whether a function is specified as the performance index or a final condition that is to be satisfied, the iterator requires as inputs the value of the function on the current nominal trajectory and the partial derivatives of the function with respect to all the independent parameters of the problem.

We permit any specific final condition, f, to be, in its most general form, an explicit function of the final state, y_f, the final time, t_f, the spacecraft design or propulsion system parameters, β, and/or the initial state, y_o

$$f = f(y_f,\ t_f,\ \beta,\ y_o).$$

Then, denoting the independent parameters of the problem as γ, the desired partial derivatives of f are

$$\frac{\partial f}{\partial \gamma} = \frac{\partial f}{\partial y_f} \Phi(o, \ell) + \frac{\partial f}{\partial t_f} \frac{\partial t_f}{\partial \gamma} + \frac{\partial f}{\partial \beta} \frac{\partial \beta}{\partial \gamma} + \frac{\partial f}{\partial y_o} \frac{\partial y_o}{\partial \gamma}$$

where $\Phi(o, \ell)$ is the transition matrix over the entire trajectory which is developed in the calling subroutine GENMA. Clearly the partials $\partial t_f/\partial \gamma$, $\partial \beta/\partial \gamma$, and $\partial y_o/\partial \gamma$ will be either zero or one since t_f, β, and y_o are potential independent parameters. Consequently, the only derivatives that are as yet undefined are those of f with respect to y_f, t_f, β, and y_o. Of course, these depend on the specific form of f and, in order to write them down, it is imperative to list the final conditions to be made available for optional use. This list of conditions, along with the concomitant partial derivatives, follows.

Mass: The mass-related functions that shall be available for end conditions include the final mass, m_f, and the net spacecraft mass, m_n (frequently referred to as payload). For the purpose of this program, the total spacecraft mass, m_o, is assumed to consist of the power plant m_{pp}, propellant m_p, tankage m_t, structure m_{st}, net spacecraft m_n, and when applicable, retro state propellant m_{rp} and structure m_{rt}; i.e.,

$$m_o = m_{pp} + m_p + m_t + m_{st} + m_{rp} + m_{rt} + m_n$$

$$= a_1 e^{-v_{po}/a_2} - a_3$$

where a_1, a_2 and a_3 are performance coefficients representative of the specified launch vehicle, and

$$m_{pp} = \alpha_{ps} P_o$$

$$m_t = k_t m_p$$

$$m_{st} = k_{st} m_o$$

$$m_{rp} = m(t_f)\,(1 - e^{-\Delta v/c_r})$$

$$m_{rt} = k_r m_{pr}$$

with α_{ps} being the specific mass of the propulsion system; k_t, k_{st} and k_r are structural scaling factors; Δv is the retro maneuver velocity increment; and c_r is the jet exhaust speed of the retro stage engine. Of course, $m(t_f)$ is the final spacecraft mass just prior to any retro maneuver. For capture missions, impulsive thrust is assumed for the retro maneuver. Of course, there is no retro maneuver for flyby missions. Capture orbits will be defined in terms of the perifocal and apofocal distances, r_{Tp} and r_{Ta}, relative to the target planet, and the retro maneuver will be assumed to take place at perifocus. Consequently, the incremental velocity, Δv, of the retro maneuver is equal to the difference between the speed at perifocus of the hyperbolic trajectory on which the spacecraft approaches the target planet and at perifocus of the desired elliptic orbit. That is, we define

$$\Delta v = v_{T_p} - \left(\frac{2\mu_T r_{Ta}}{r_{Tp}(r_{Tp} + r_{Ta})} \right)^{\frac{1}{2}}$$

$$v_{T_p} = \left[\mu_T \left(\frac{2}{r_{T_p}} - \frac{1}{a_T} \right) \right]^{\frac{1}{2}}$$

where μ_T is the gravitational constant of the target planet and a_T is the semi-major axis of the planetocentric hyperbolic approach trajectory as evaluated at the final time. Of course, on any specific trial trajectory in the iteration, the planetocentric distance at the end of the trajectory may not be the perifocal distance desired. In fact, depending on the specific condition used to terminate the trajectory, the final position may not even be a perifocal point. Thus, prior to convergence, the Δv will not represent a meaningful quantity, but as the iteration proceeds to the solution, Δv will take on the value desired. The important points are that the definition of Δv remains consistent throughout the iteration, is representative of each trial trajectory, and converges to the desired quantity when the specified end conditions are satisfied.

The final mass is evaluated as follows:

$$m_f = m(t_f) - m_{rp}$$

or

$$m_f = m(t_f)\, e^{-\Delta v/c_r}$$

and the required partial derivatives are

$$\frac{\partial m_f}{\partial y_f} = \frac{\partial m(t_f)}{\partial y_f}\, e^{-\Delta v/c_r} + \frac{m(t_f)}{c_r}\, e^{-\Delta v/c_r}\, \frac{\partial\, |\dot{R}_T(t_f)|}{\partial y_f}$$

$$\frac{\partial m_f}{\partial t_f} = \frac{m(t_f)}{c_r}\, e^{-\Delta v/c_r}\, \frac{\partial\, |\dot{R}_T(t_f)|}{\partial t_f}$$

$$\frac{\partial m_f}{\partial \beta} = \frac{\partial m_f}{\partial y_o} = 0$$

Since $m(t_f)$ is the final value of one of the state variables, $\partial m(t_f)/\partial y_f$ is a matrix of seven elements consisting of 6 zeroes and a one. The partials of $|\dot{R}_T(t_f)|$ will be derived in a subsequent paragraph.

The net spacecraft mass is evaluated

$$m_n = m_f - m_{pp} - m_t - m_{st} - m_{rt}$$

Rewriting in a more suitable form for differentiating

$$m_n = \left[(1+k_r)\, e^{-\Delta v/c_r} + k_t - k_r\right] m(t_f) - (k_t + k_{st})\, m_o - \alpha_{ps}\, p_o$$

then

$$\frac{\partial m_n}{\partial y_f} = \left[(1+k_r)\, e^{-\Delta v/c_r} + k_t - k_r\right] \frac{\partial m(t_f)}{\partial y_f} + \frac{m(t_f)}{c_r}\, (1+k_r)\, e^{-\Delta v/c_r}\, \frac{\partial\, |\dot{R}_T(t_f)|}{\partial y_f}$$

$$\frac{\partial m_n}{\partial t_f} = \frac{m(t_f)}{c_r}\, (1+k_r)\, e^{-\Delta v/c_r}\, \frac{\partial\, |\dot{R}_T(t_f)|}{\partial t_f}$$

$$\frac{\partial m_n}{\partial \beta} = -\alpha_{ps}\, \frac{\partial p_o}{\partial \beta}$$

$$\frac{\partial m_n}{\partial y_o} = (k_t + k_{st}) \frac{(m_o + a_3)}{a_2} \frac{\partial v_{p_o}}{\partial y_o}$$

where v_{p_o} may be one of the y_o's directly or related to the y_o's through the equation

$$v_{p_o}^2 = \dot{x}_{p_o}^2 + \dot{y}_{p_o}^2 + \dot{z}_{p_o}^2 .$$

Of course, p_o is one of the β's and $\dot{x}_{p_o}$, $\dot{y}_{p_o}$, $\dot{z}_{p_o}$ are initial state variables such that their partials are zeroes and ones.

Thrust: To permit the study of specific thruster systems, it may be desirable to fix thrust level while allowing power level and specific impulse to be optimized. Thus, thrust is placed in the list of available end conditions and is evaluated by the equation

$$f_o = 2\, \eta p_o / c$$

where f_o represents a reference thrust level, which is the actual thrust for a nuclear electric propulsion system but is a maximum thrust at 1 AU for a solar electric system, c is the jet exhaust speed and η is the propulsion system efficiency. The required partial derivatives are

$$\frac{\partial f_o}{\partial y_f} = \frac{\partial f_o}{\partial t_f} = \frac{\partial f_o}{\partial y_o} = 0$$

$$\frac{\partial f_o}{\partial \beta} = 2 \frac{\eta}{c} \frac{\partial p_o}{\partial \beta} + 2 \frac{p_o}{c} \left(\frac{d\eta}{dc} - \frac{1}{c} \right) \frac{\partial c}{\partial \beta}$$

with

$$\frac{d\eta}{dc} = 2 \frac{\eta}{c} \left(1 - \frac{\eta}{b} \right) .$$

The derivative of η with respect to c comes from the assumed relationship between η and c given in the description of subroutine SOLENG.

Heliocentric Position and Velocity: The final heliocentric position and velocity may be specified in terms of the Cartesian components of the two vectors or in terms of such position and velocity-related parameters as radial distance r, speed v, flight path angle γ, semi-major axis a, eccentricity e, aphelion distance r_a, and/or perihelion distance r_p. The Cartesian components of position and velocity are the state variables of the problem and are immediately available. The partial derivatives of the components are also immediately available from the matrix $\Phi(o, \ell)$. The other parameters and their derivatives are formed from the state variables as follows:

$$r = (R \cdot R)^{\frac{1}{2}}$$

$$\frac{\partial r}{\partial u} = \frac{u}{r} \quad (u = x, y, z)$$

$$v = (\dot{R} \cdot \dot{R})^{\frac{1}{2}}$$

$$\frac{\partial v}{\partial \dot{u}} = \frac{\dot{u}}{v} \quad (\dot{u} = \dot{x}, \dot{y}, \dot{z})$$

$$a = \frac{r}{2 - rv^2/\mu}$$

$$\frac{\partial a}{\partial u} = \frac{a u}{r^2} \left(1 + \frac{av^2}{\mu}\right); \quad \frac{\partial a}{\partial \dot{u}} = \frac{2 a^2 \dot{u}}{\mu} \quad (u = x, y, z; \dot{u} = \dot{x}, \dot{y}, \dot{z})$$

$$\gamma = \sin^{-1}\left(\frac{R \cdot \dot{R}}{r v}\right)$$

$$\left.\begin{aligned} \frac{\partial \gamma}{\partial u} &= \frac{1}{r \cos \gamma} \left(\frac{\dot{u}}{v} - \frac{u}{r} \sin \gamma\right) \\ \frac{\partial \gamma}{\partial \dot{u}} &= \frac{1}{v \cos \gamma} \left(\frac{u}{r} - \frac{\dot{u}}{v} \sin \gamma\right) \end{aligned}\right\} \quad (u = x, y, z, ; \dot{u} = \dot{x}, \dot{y}, \dot{z})$$

$$e = \left(1 - \frac{r}{a}\left(2 - \frac{r}{a}\right) \cos^2 \gamma\right)^{\frac{1}{2}}$$

$$\frac{\partial e}{\partial u} = \frac{1}{e}\left[\frac{u}{r}\frac{v^2}{\mu}\left(1 - \frac{r}{a}\right)\cos^2\gamma + \frac{\sin \gamma}{a}\left(2 - \frac{r}{a}\right)\left(\frac{\dot{u}}{v} - \frac{u}{r}\sin\gamma\right)\right] \quad \begin{matrix} (u = x, y, z \\ \dot{u} = \dot{x}, \dot{y}, \dot{z}) \end{matrix}$$

$$\frac{\partial e}{\partial \dot{u}} = \frac{1}{e}\left[\frac{2r\dot{u}}{\mu}\left(1-\frac{r}{a}\right)\cos^2\gamma + \frac{r\sin\gamma}{av}\left(2-\frac{r}{a}\right)\left(\frac{u}{r}-\frac{\dot{u}}{v}\sin\gamma\right)\right] \quad \begin{pmatrix} u = x, y, z; \\ \dot{u} = \dot{x}, \dot{y}, \dot{z} \end{pmatrix}$$

$$r_a = a(1+e)$$

$$\frac{\partial r_a}{\partial u} = a\frac{\partial e}{\partial u} + (1+e)\frac{\partial a}{\partial u} \qquad (u = x, y, z, ; \dot{x}, \dot{y}, \dot{z})$$

$$r_p = a(1-e)$$

$$\frac{\partial r_p}{\partial u} = -a\frac{\partial e}{\partial u} + (1-e)\frac{\partial a}{\partial u} \qquad (u = x, y, z; \dot{x}, \dot{y}, \dot{z}) .$$

The partials with respect to the independent parameters are then formed according to the general equation given at the start of this section, with u and $\dot{u}$ representing a portion of y_f. The partials with respect to t_f, β, and y_o are zero.

Planetocentric Position and Velocity: By input option, several planetocentric position and velocity-related parameters are available as end conditions. These include the Cartesian position coordinates x_T, y_T, and z_T, the distance r_T, speed v_T, flight path angle γ_T, semi-major axis a_T, eccentricity e_T, apocenter distance r_{T_a}, and pericenter distance r_{T_p}. Let P_T, $\dot{P}_T$ be the heliocentric position and velocity of the target planet at the final time. Then the planetocentric position and velocity of the spacecraft at the final time are

$$R_T = R - P_T$$
$$\dot{R}_T = \dot{R} - \dot{P}_T$$

with components x_T, y_T, z_T and $\dot{x}_T$, $\dot{y}_T$, $\dot{z}_T$, respectively. Since both P_T and $\dot{P}_T$ are functions only of final time, the partial derivatives of R_T and $\dot{R}_T$ with respect to any independent parameter α are

$$\frac{\partial R_T}{\partial \alpha} = \frac{\partial R}{\partial \alpha} - \dot{P}_T \frac{\partial t_f}{\partial \alpha}$$

and

$$\frac{\partial \dot{R}_T}{\partial \alpha} = \frac{\partial \dot{R}}{\partial \alpha} - \ddot{P}_T \frac{\partial t_f}{\partial \alpha}$$

Consequently, the partials of $\dot{R}_T$ with respect to α will equal those of $\dot{R}$ except when α is the final time; for this latter case, an additional term is added to the heliocentric partials to obtain the planetocentric partials.

Then, employing the standard definitions

$$r_T = (R_T \cdot R_T)^{\frac{1}{2}}$$

$$v_T = (\dot{R}_T \cdot \dot{R}_T)^{\frac{1}{2}} = |\dot{R}_f(t_f)|$$

$$\gamma_T = \sin^{-1}\left(\frac{R_T \cdot \dot{R}_T}{r_T v_T}\right)$$

$$a_T = \frac{r_T}{(2 - r_T v_T^{\,2}/\mu_T)}$$

$$e_T = \left(1 - \frac{r_T}{a_T}\,(2 - \frac{r_T}{a_T}) \cos^2 \gamma_T\right)^{\frac{1}{2}}$$

$$r_{T_a} = a_T\,(1 + e_T)$$

$$r_{T_p} = a_T\,(1 - e_T).$$

The partial derivatives with respect to x_T, y_T, z_T, $\dot{x}_T$, $\dot{y}_T$, $\dot{z}_T$ are identical to those for the heliocentric parameters except a subscript T is added to all symbols.

Due to the large sensitivities inherent in targeting on the planetocentric periapse distance r_{T_p}, it is necessary to transform any problem with this end condition to one with an alternate set of end conditions which are less sensitive. The transformation used here is described in subroutine XYZ and involves the definition of a final planetocentric position vector, which, coupled with the final velocity, yields the desired periapse distance. The partials of these transformed end conditions are given above.

After completing the evaluation of all end conditions and partial derivatives, if required, a call to DIAG1 is made to print the iteration summary, and a return to GENMA is executed.

Messages and Printout: If the reference body at the final time is neither the sun nor the specified target body, the following message is printed:

TRAJECTORY TERMINATED IN REFERENCE OTHER THAN SUN OR TARGET PLANET. RUN TERMINATEDIN SUBROUTINE FNMAT.

FNMAT EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
Q(30)	S	XMMM	Array of dependent variable values for the nominal or trial trajectory.
T	SUA	ALAN	Current time, t, in hours from departure of launch parking orbit.
BL	U	JERR	Efficiency law coefficient, b.
CR	U	JERR	Jet exhaust speed of retro stage, c_r.
RD	U	HENRY	Radians to degrees conversion factor.
RS(6)	SUA		Heliocentric spacecraft position vector at the final time, R.
RT(6)	SUA		Planetocentric spacecraft position vector at the final time, $\dot{R}_T$.
TT	SUA		Final time in days from departure of the launch parking orbit.
XR(6)	UE	LEFT (XRL)	Spacecraft position vector relative to the current reference body.
AL2	U	JERR	Launch vehicle performance coefficient, a_2.

FNMAT EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
AL3	U	JERR	Launch vehicle performance coefficient, a_3.
APS	U	JERR	Specific propulsion system mass, α_{ps}.
CHN(100)	U	HIS	Array of parameters available as independent parameters. (See discussion of subroutine INPUT).
CP1(7,30)	SU	JERR	State transition matrix, Φ.
ETA	U	JERR	Propulsion system efficiency factor, η.
IJK	SUA	INTEG	Index of ITBL array defining the reference body for which the ephemeris data is sought.
IPS	U	HER	Number of dependent parameters specified.
NSL	U	HER	Number of independent parameters specified.
PFG(30,30)	SU	HIS	Partial derivatives of dependent parameters with respect to independent parameters, $\partial f/\partial \gamma$.
RDS(6)	SUA		Heliocentric spacecraft velocity vector at the final time, $\dot{R}$.
RTA	U	FNM	Apoapse distance of specified capture orbit about target planet, r_{T_a}.
RTP	U	FNM	Periapse distance of specified capture orbit about target planet, r_{T_p}.
VPA	S	CONRAD	Hyperbolic excess speed of planetocentric approach trajectory.
VTP	SU	CONRAD	Periapse speed of the planetocentric hyperbolic approach trajectory, v_{T_p}.

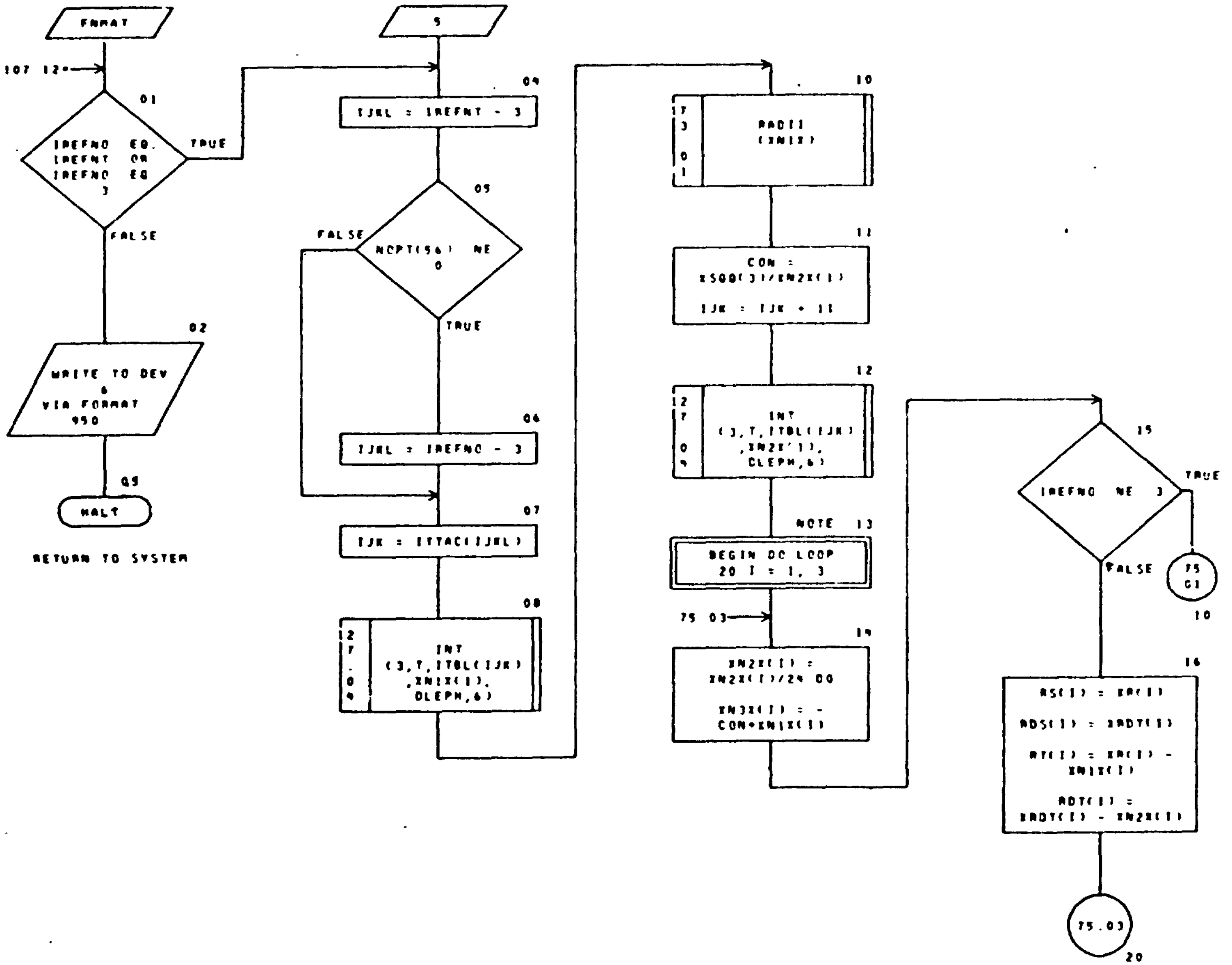
FNMAT EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
XKR	U	JERR	Retro stage tankage factor, k_r.
XKT	U	JERR	Electric propulsion stage tankage factor, k_t .
DELV	SU	CONRAD	Incremental speed required to insert spacecraft into elliptic capture orbit at periapse, Δv.
ITBL(22)	U	NORM	Table defining the starting locations for the storage of position data and velocity data for each planet in the TBBL array. (See discussion of subroutine EPHEM).
IVAR(100)	U	HER	Array of indices defining the correlation between entries in the independent variable arrays and the CHN array.
NCLL	S	IEPH	Flag indicating whether planetary velocity is to be evaluated by subroutine EPH. =1 - compute planetary position and velocity ≠1 - compute planetary position only.
NCT1	U	HER	Index of the location of the thrust/coast trigger of the current arc in the TBIN array.
NOMT	SU	NOMLL	Flag indicating whether perturbation trajectories are currently being integrated. 0 - perturbation trajectories are being integrated. 1 - nominal or trial trajectory only.
NOPT(72)	U	INTEG	Array of program option flags.
POFL(30)	SU	HIS	Array of values of the end conditions. Index is the same as that of the input array BY.

FNMAT EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
RDOT(3)	S	PERAPS	Planetocentric velocity vector at final time.
TBIN(122)	U	JERR	Array of trajectory arc information. (See description of subroutine INPUT).
XKST	U	JERR	Spacecraft structural factor k_{st}.
XN1X(3)	UA	HENRY	Position vector of planet returned from subroutine INT.
XN2X(3)	UA	HENRY	Velocity vector of planet returned from subroutine INT.
XRDT(6)	UE	LEFT (XRDL)	Spacecraft velocity vector relative to the current reference body.
XSQQ(12)	U	HENRY	Array of gravitational constants of the sun, moon and planets.
DLEPH	UA	NORM	Time interval between entries in the ephemeris tables.
IPOFL(30)	U	HER	Array of indices correlating the entries in the Q array and the POFL or input BY arrays.
XMASS	UE	AM1 (XIL)	Current mass of the spacecraft on the nominal or trial trajectory.
IREFNO	U	INTEG	Identification number of the current reference body. Possible values are 1 - Earth 6 - Jupiter 2 - not available 7 - Saturn 3 - sun 8 - Uranus 4 - Venus 9 - Neptune 5 - Mars 10 - Pluto
IREFNT	U	INTEG	Identification number of the specified target body. Options are the same as for IREFNO.

CHART TITLE - SUBROUTINE FNMAT



FNMAT-13

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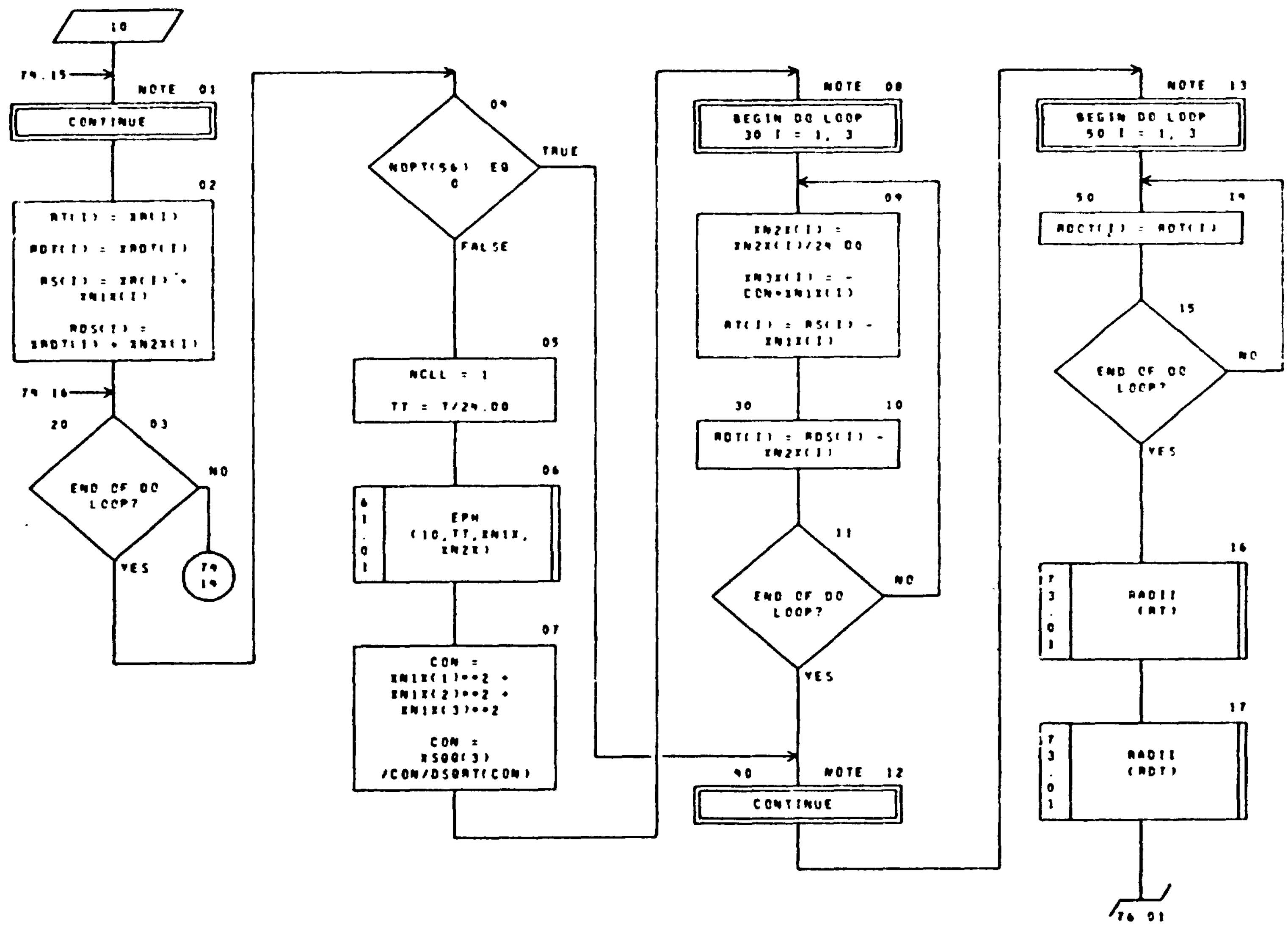

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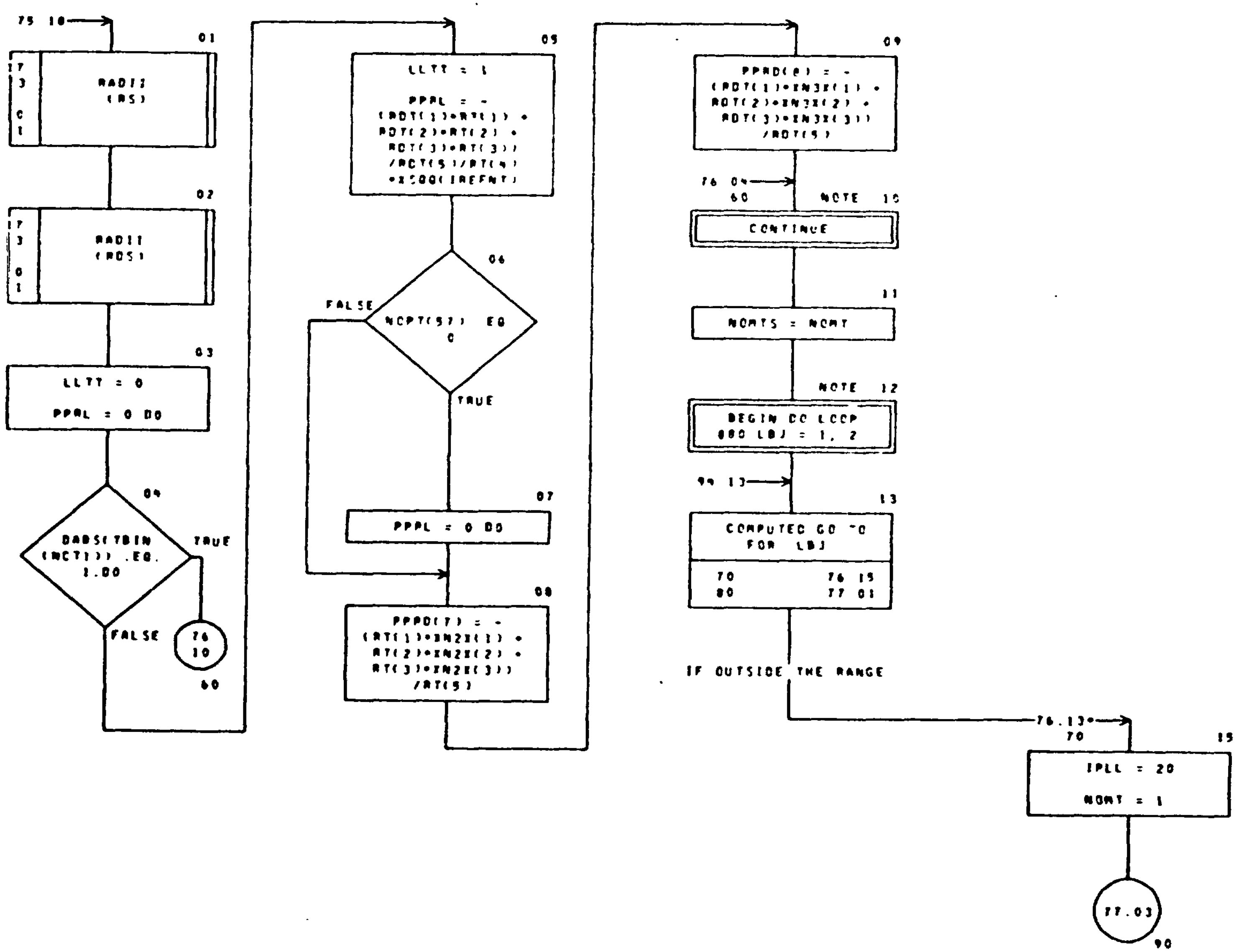

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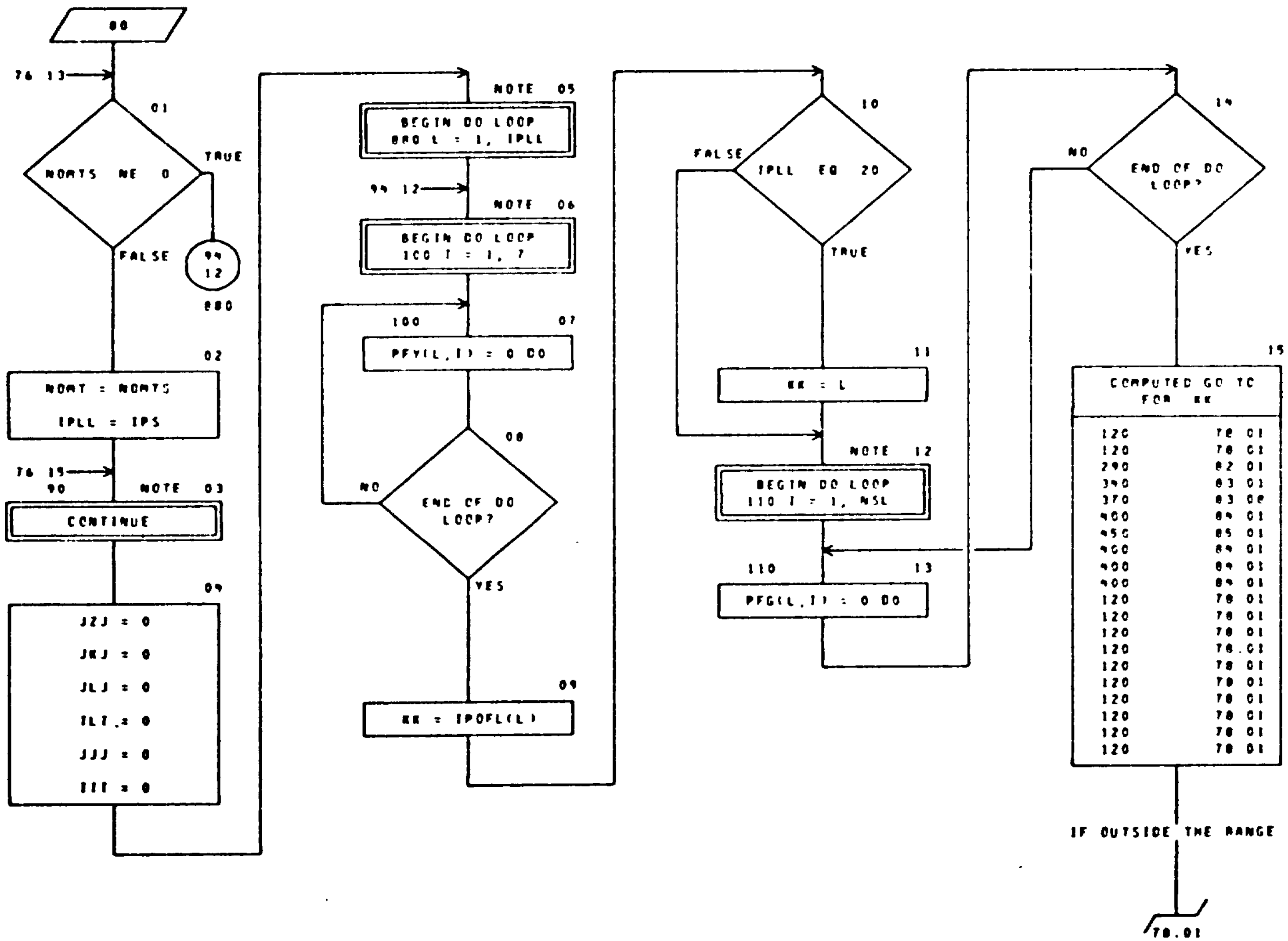

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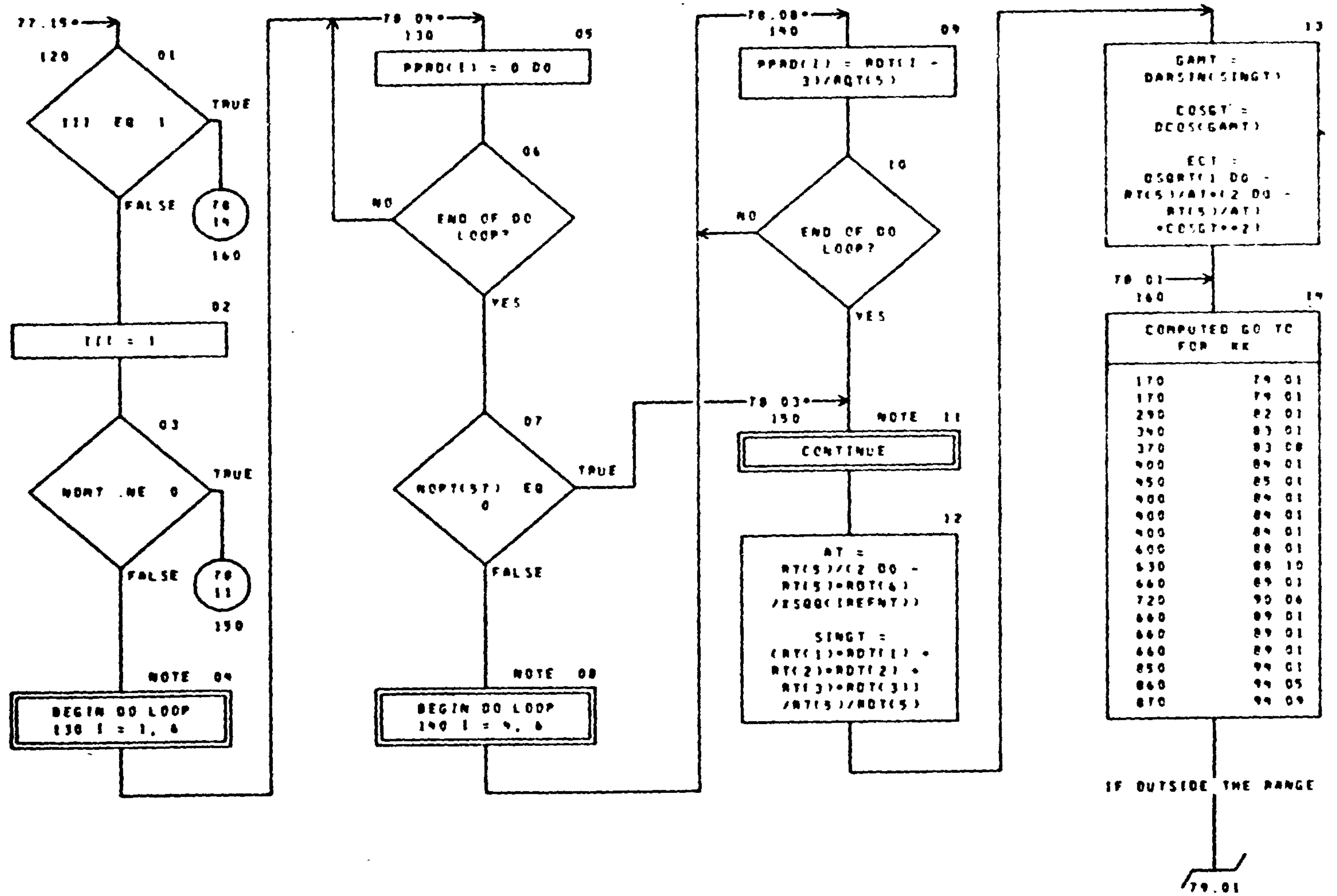

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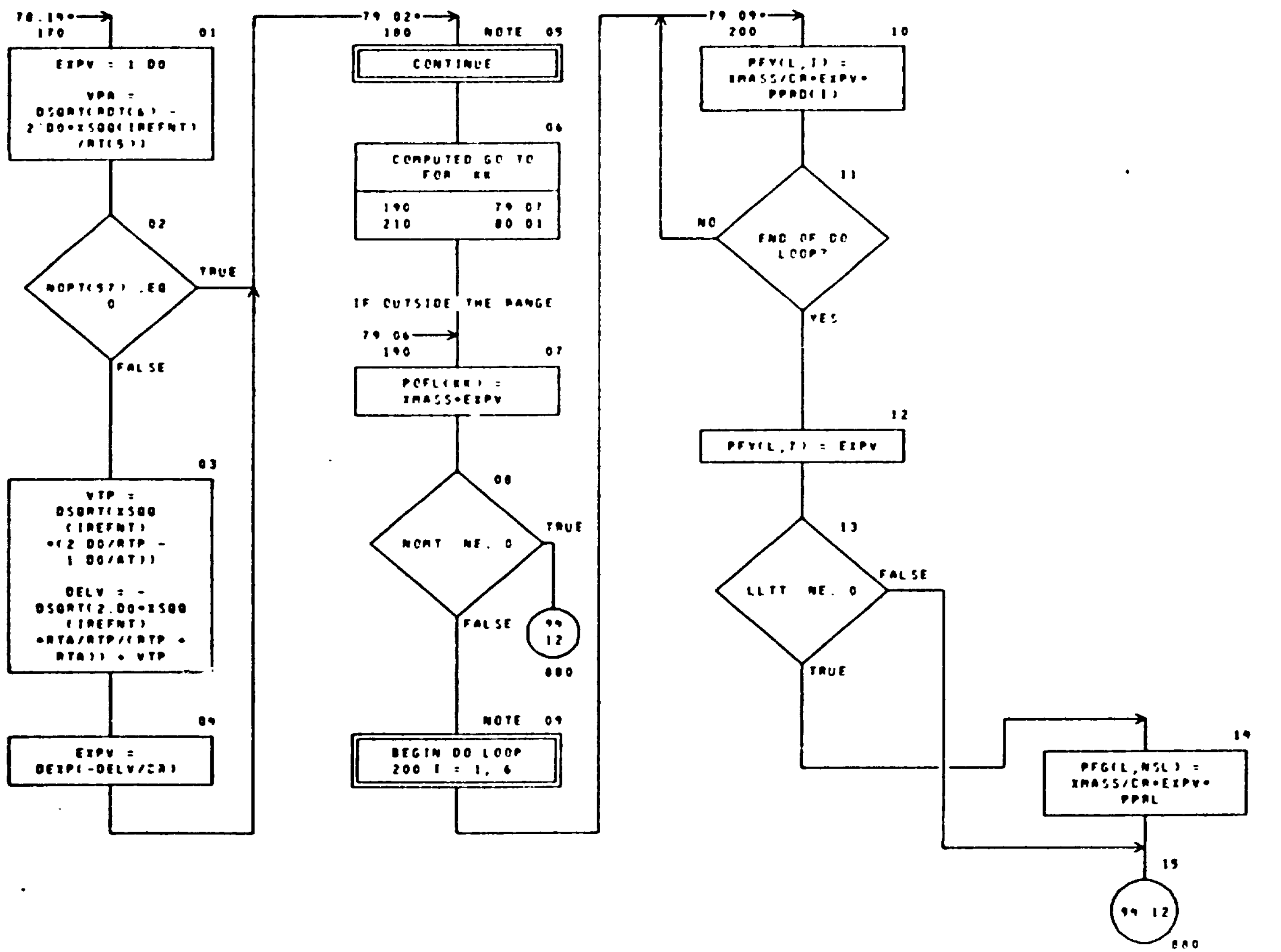

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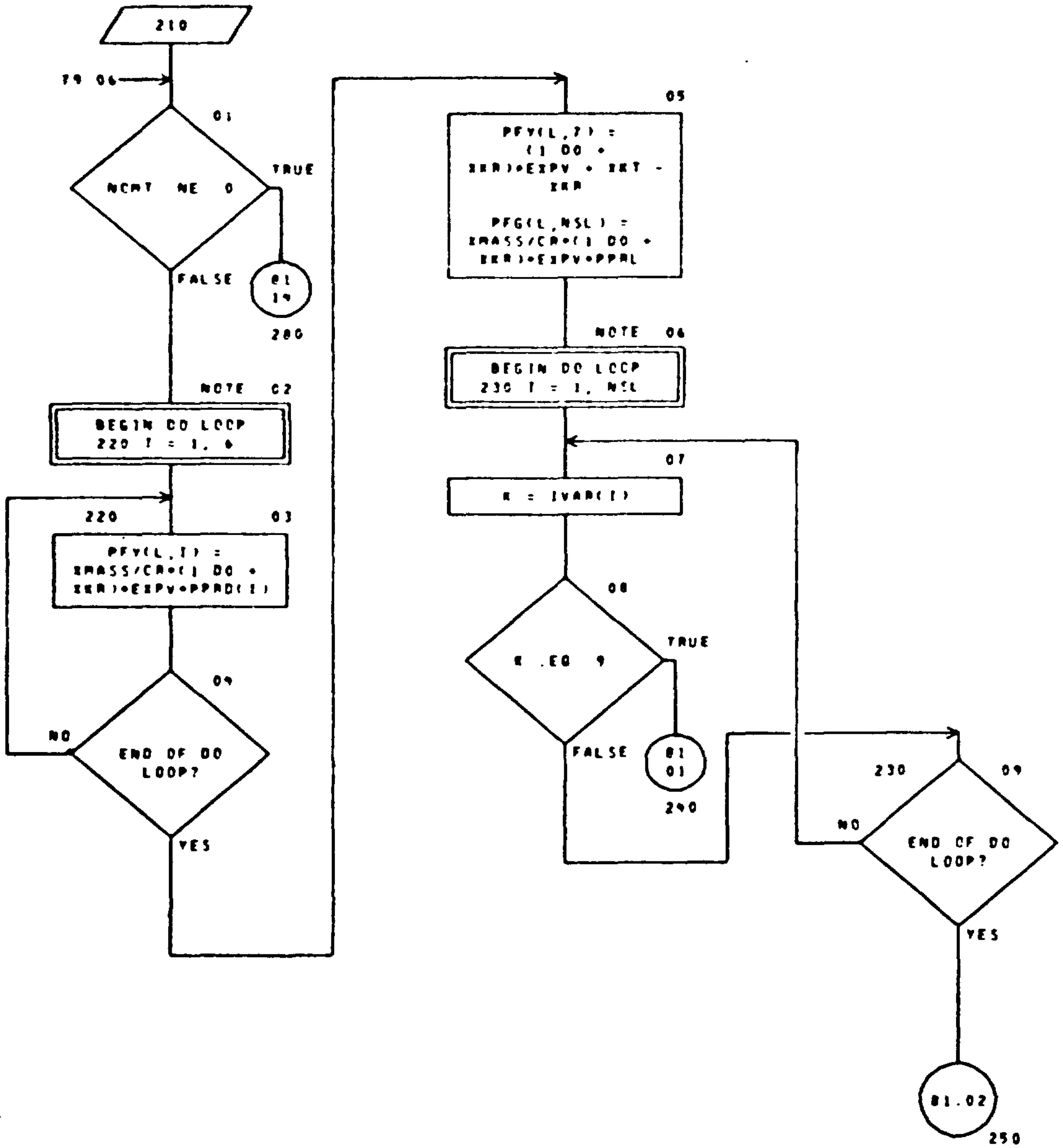

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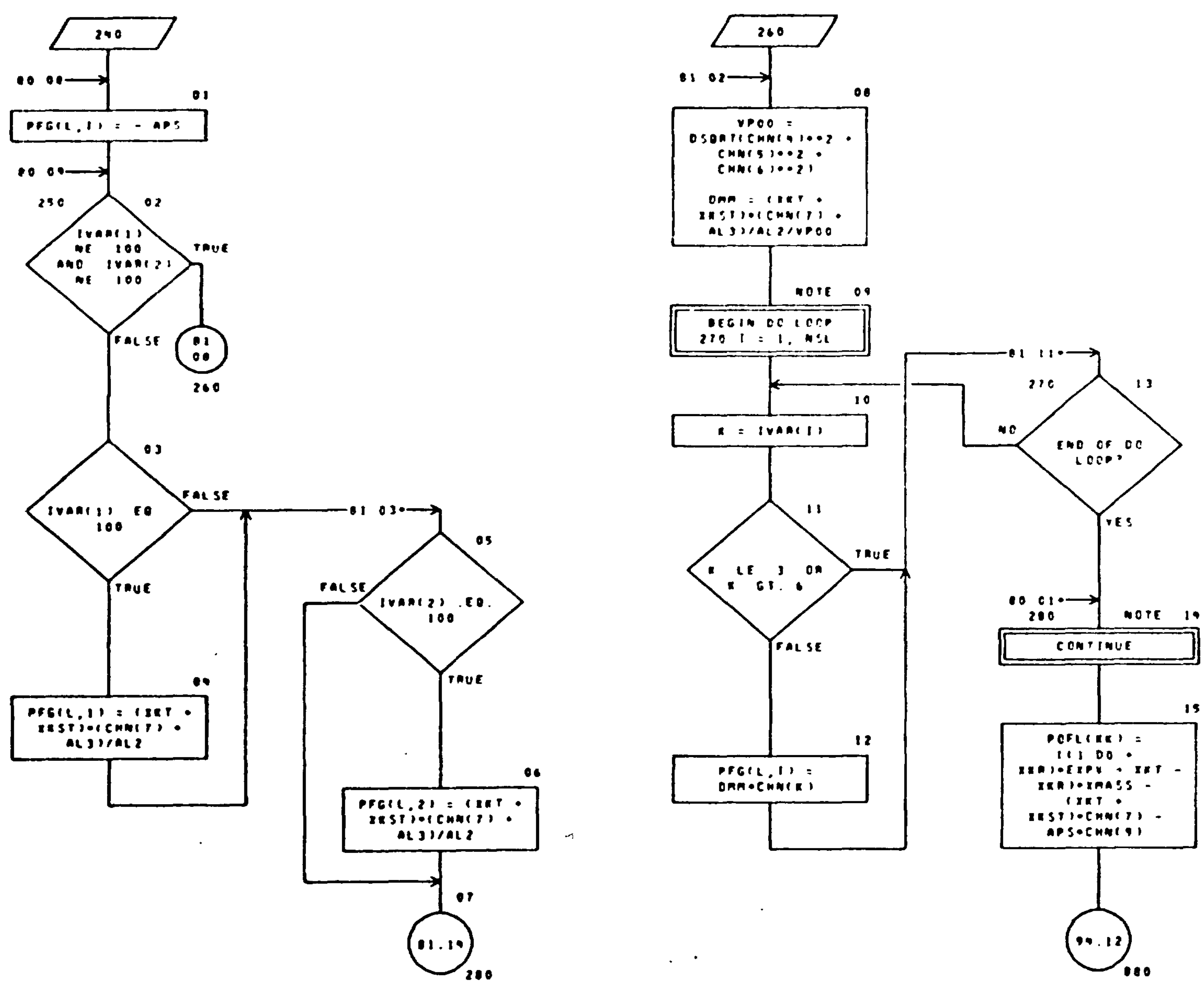

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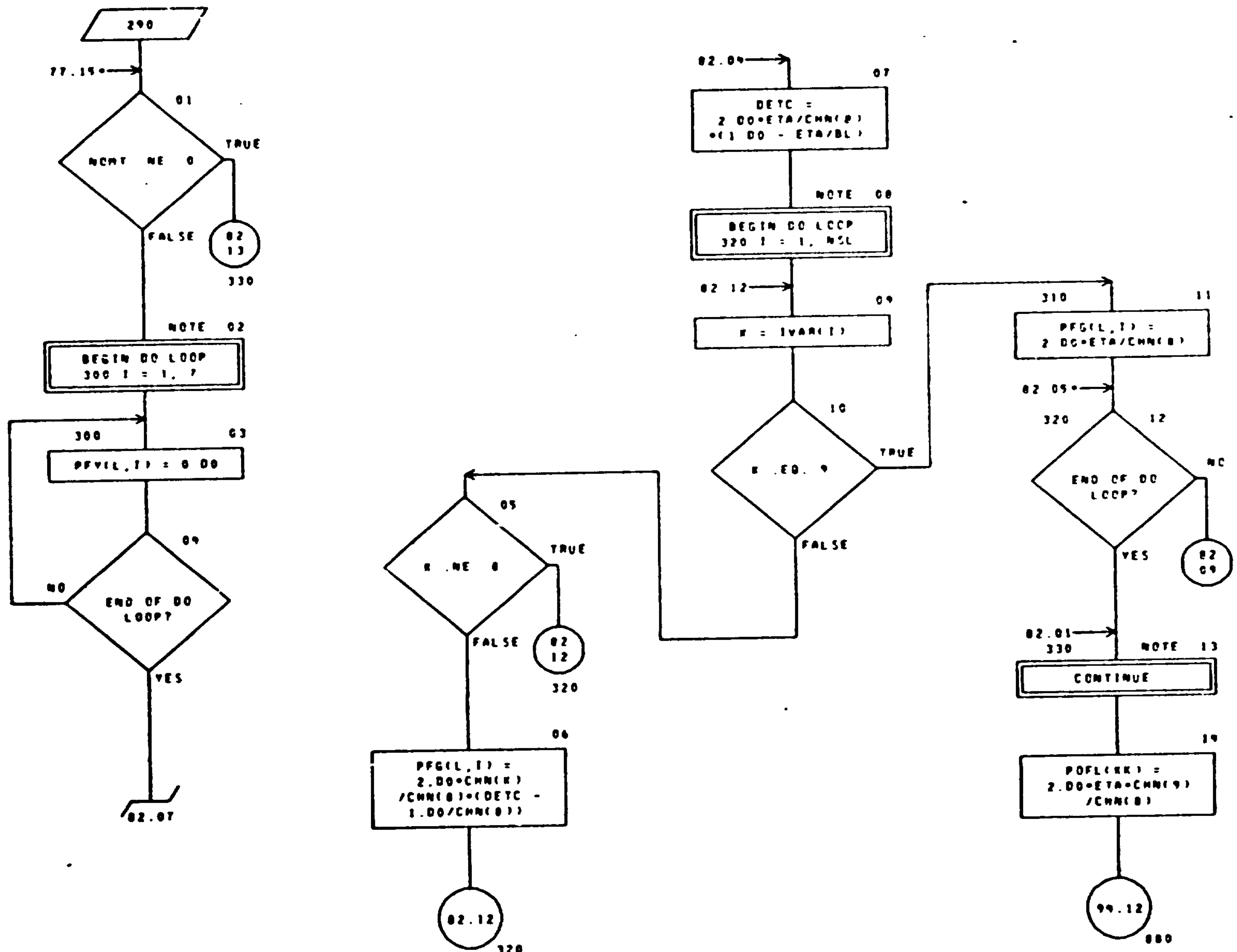

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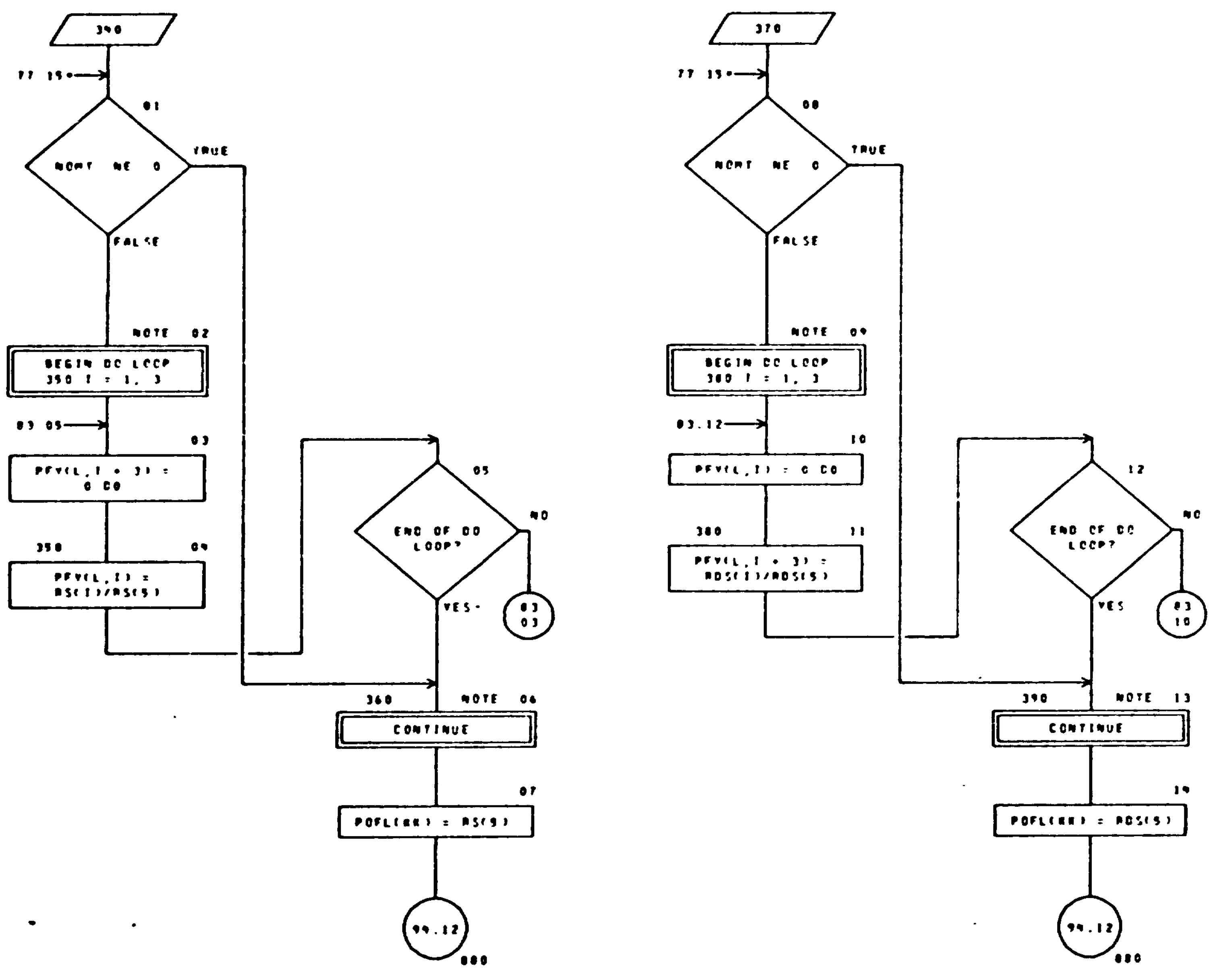

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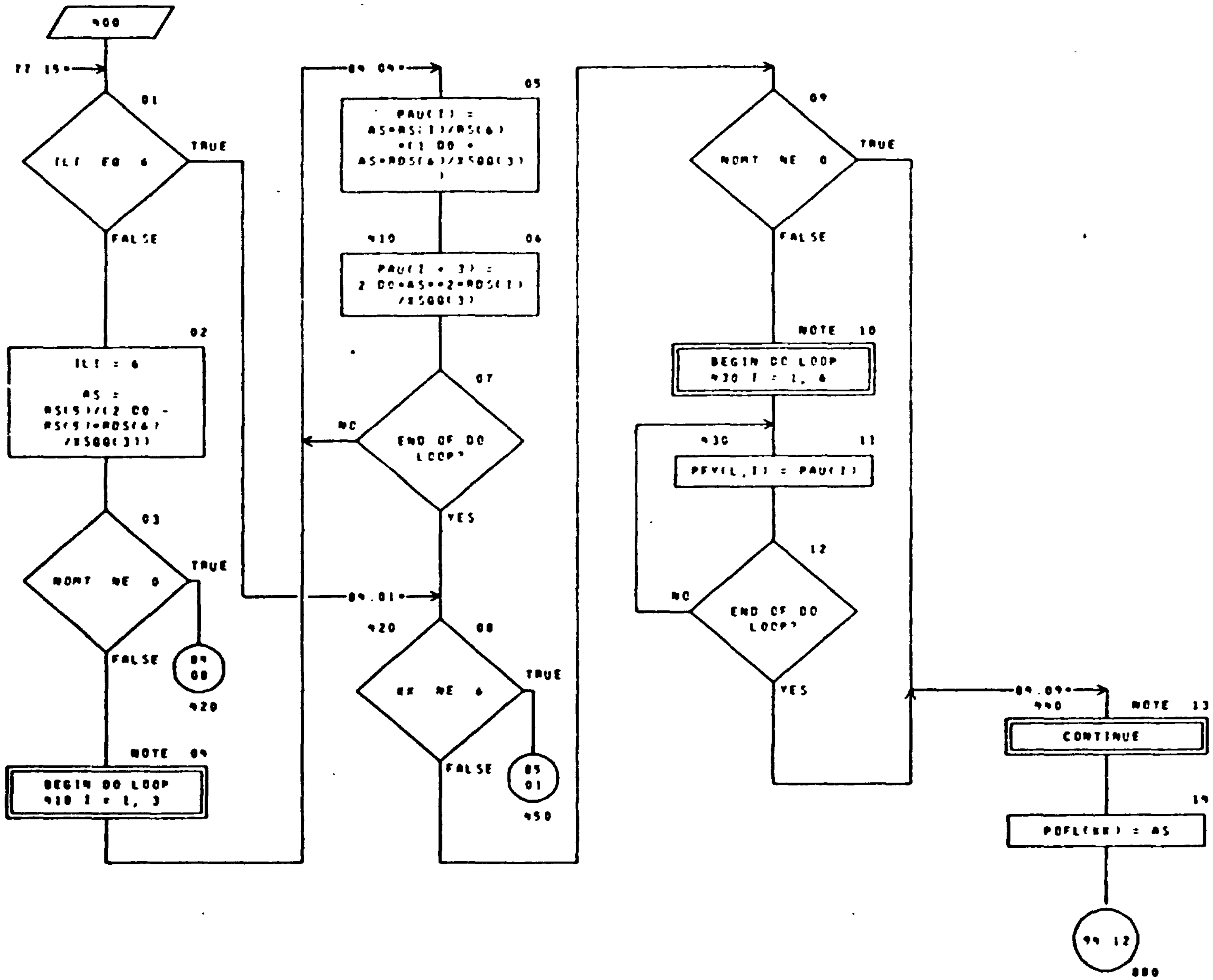

FNMAT-23

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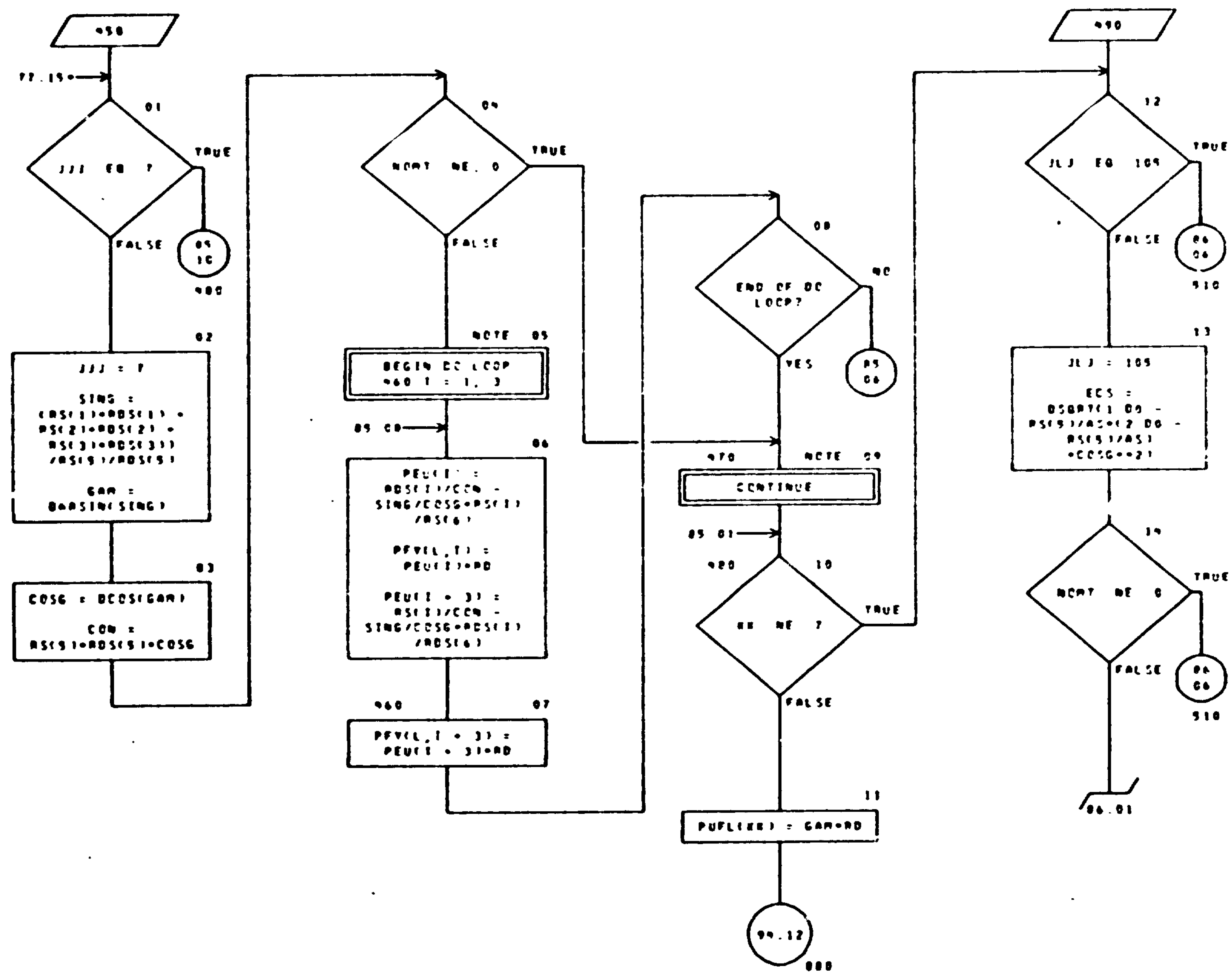

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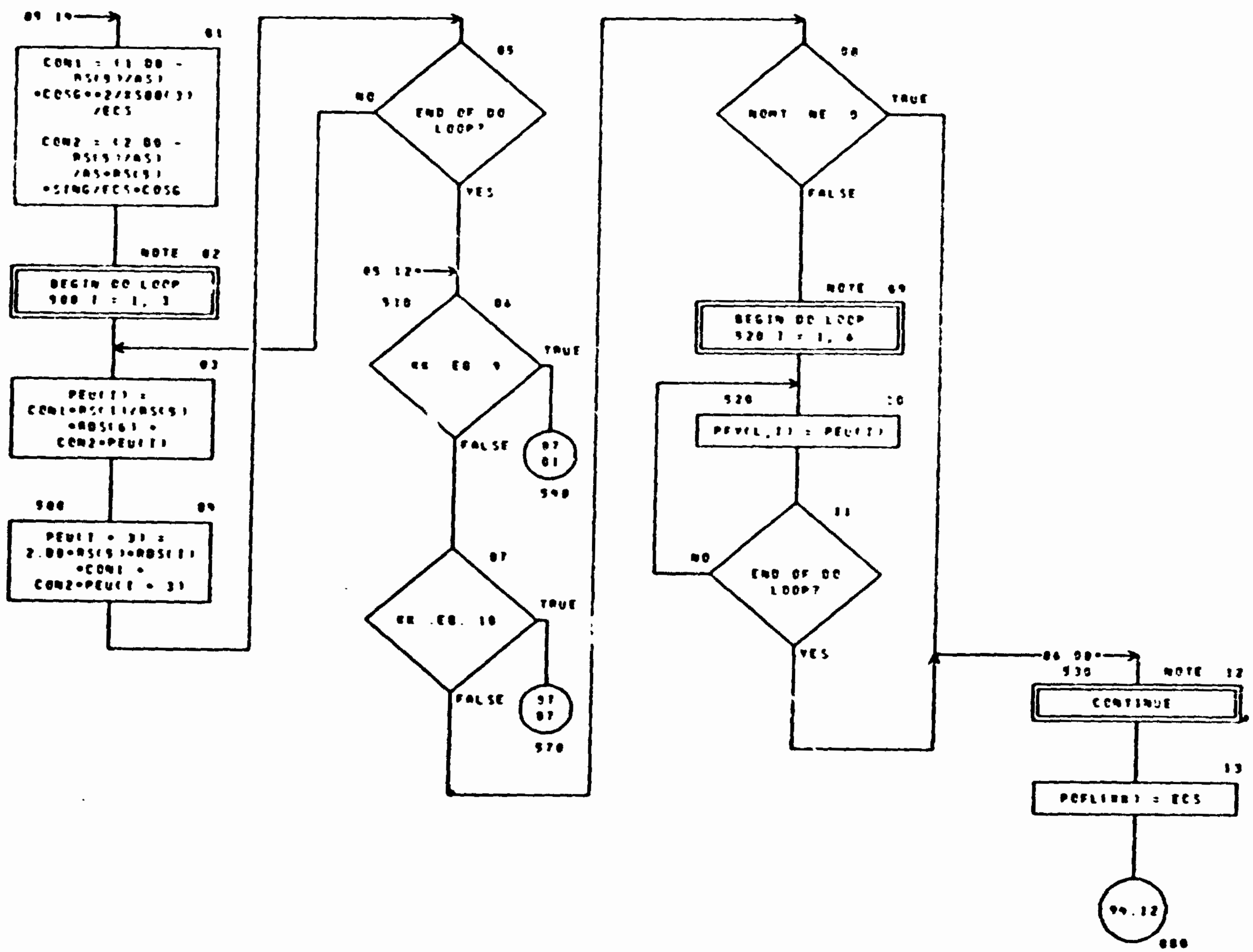

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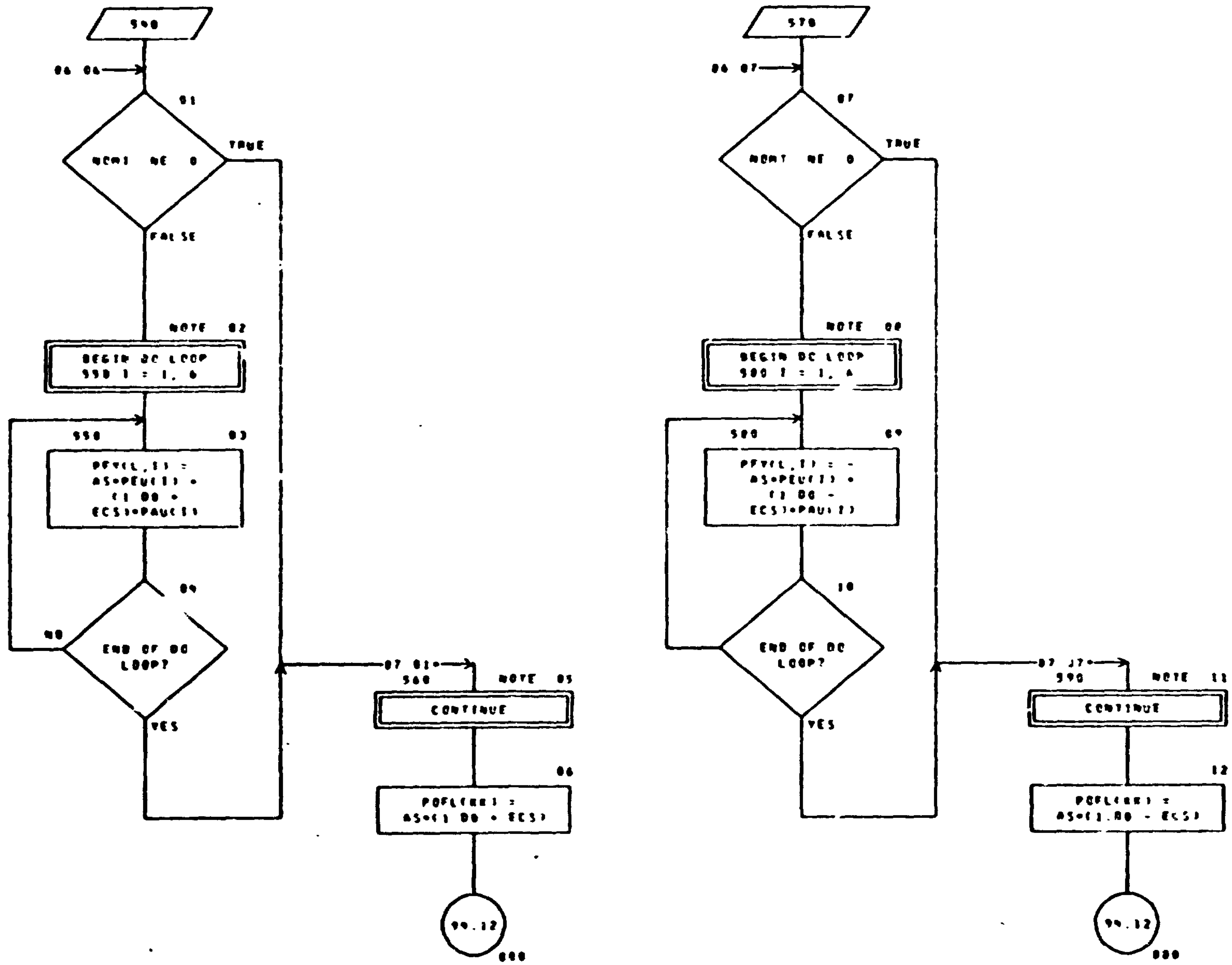

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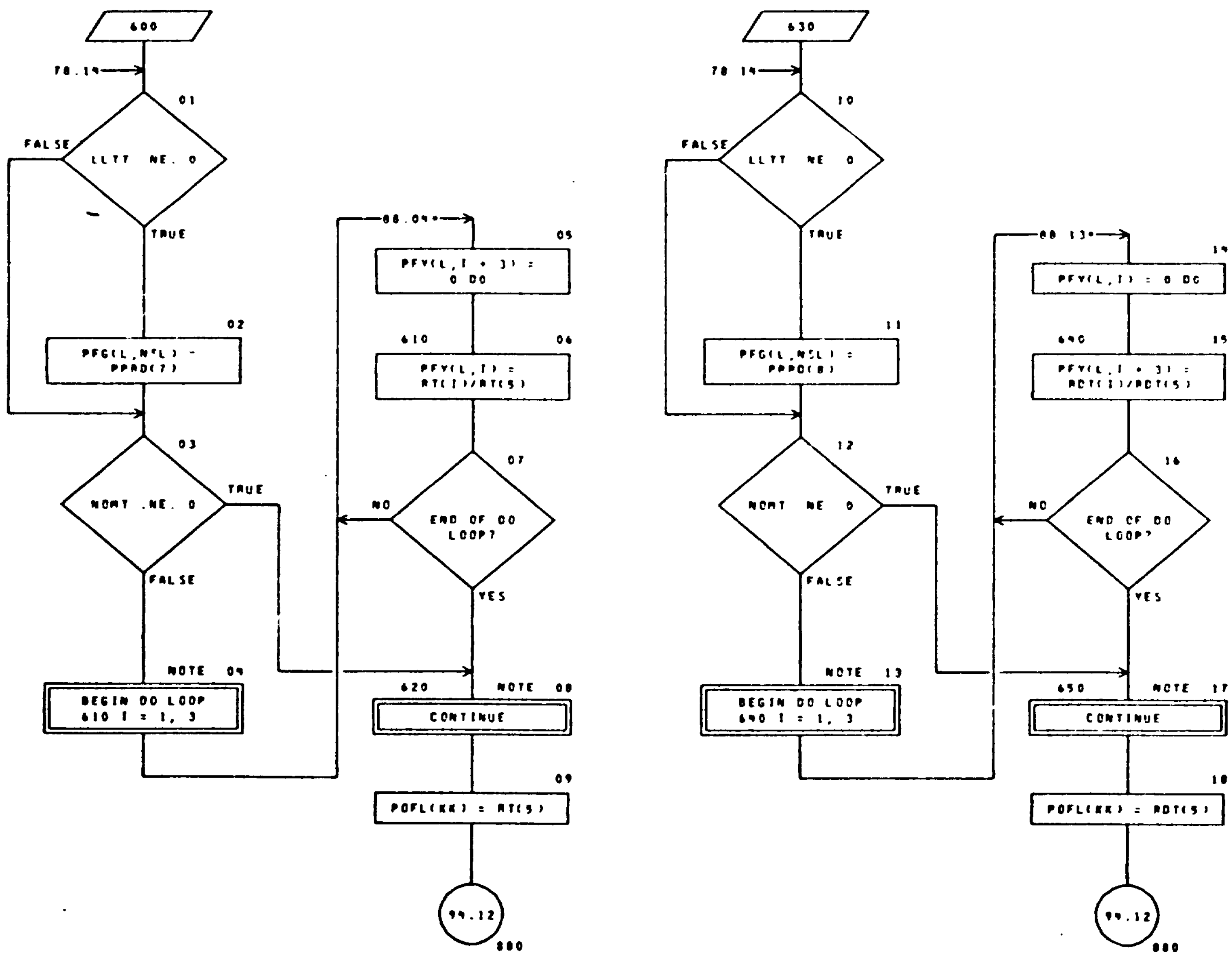

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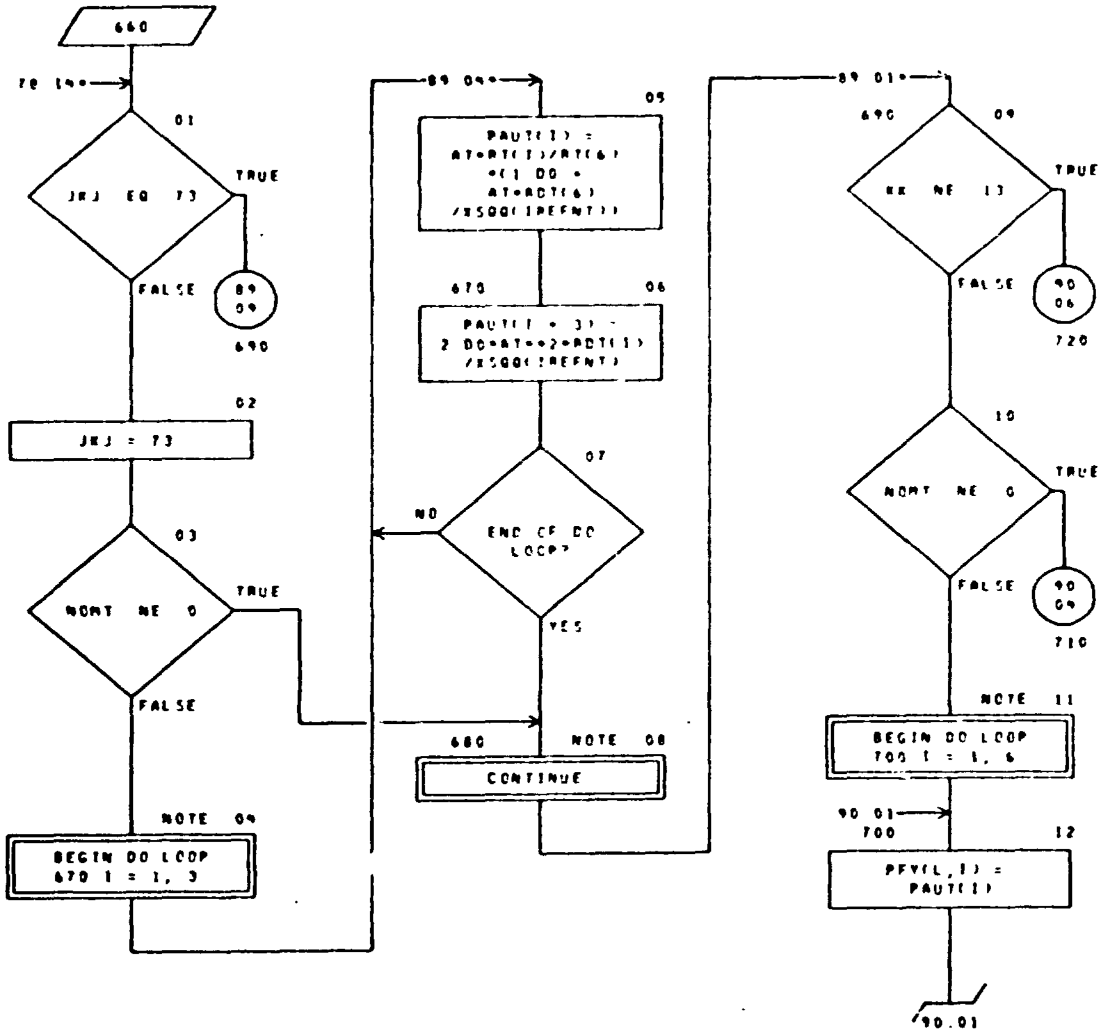

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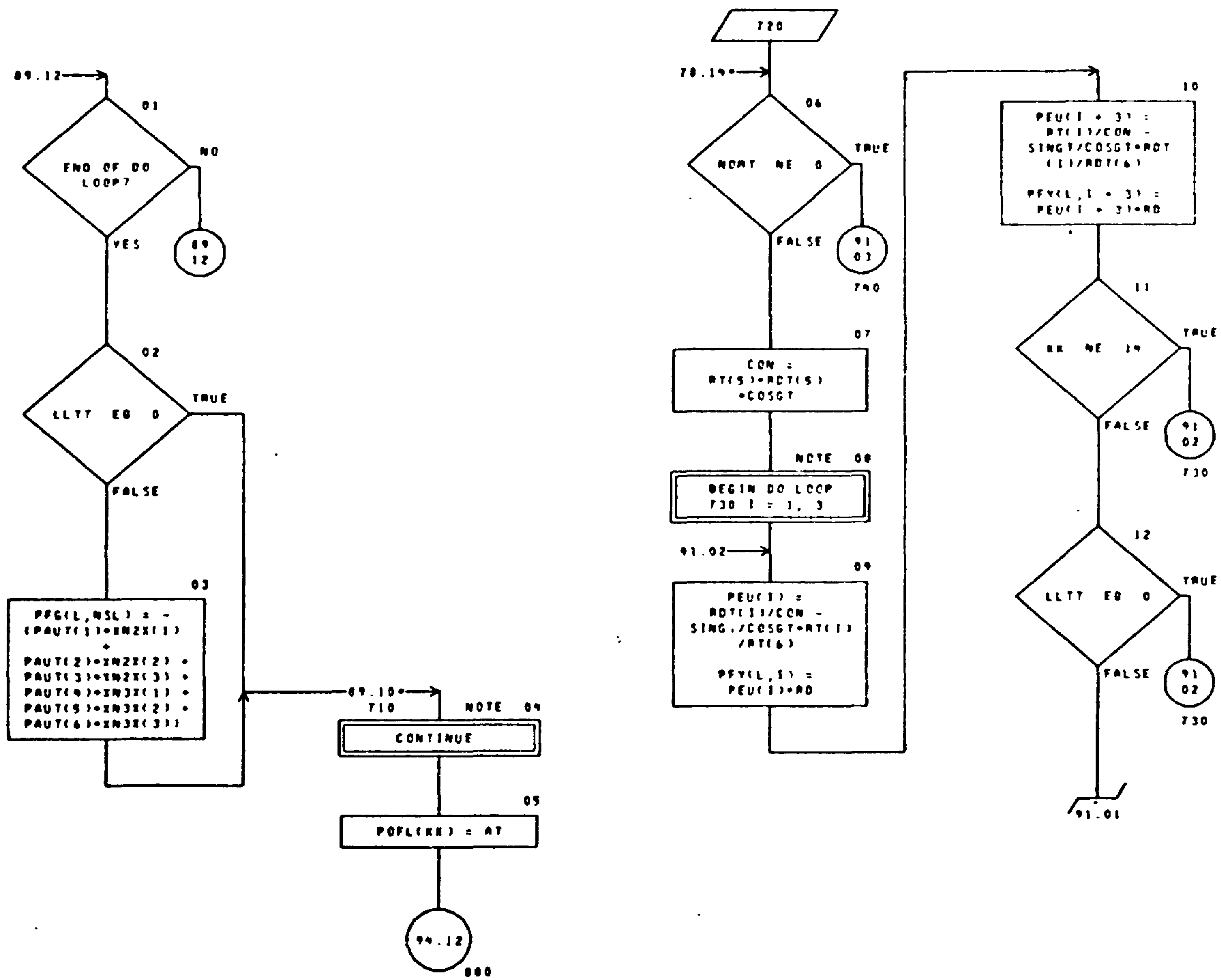

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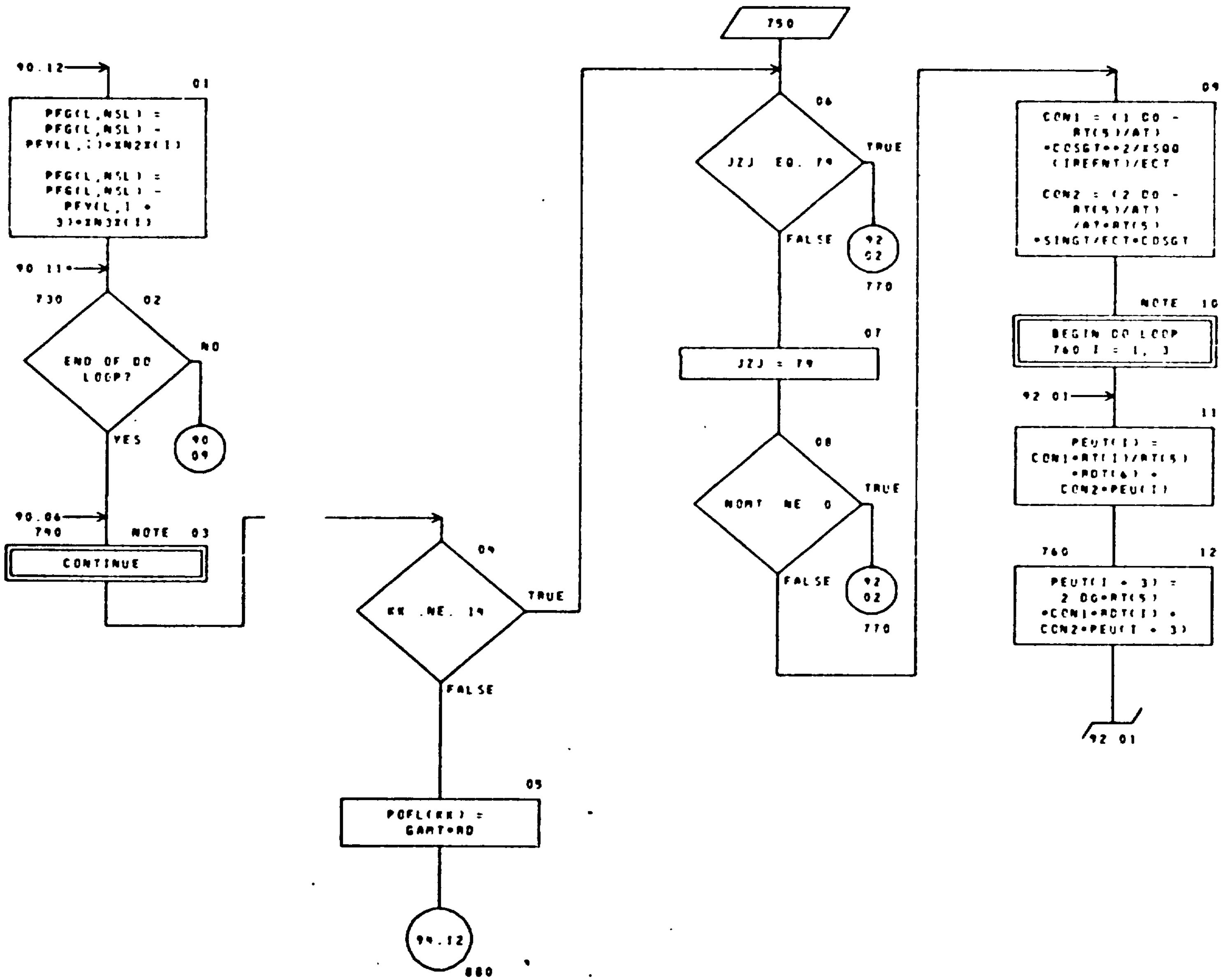

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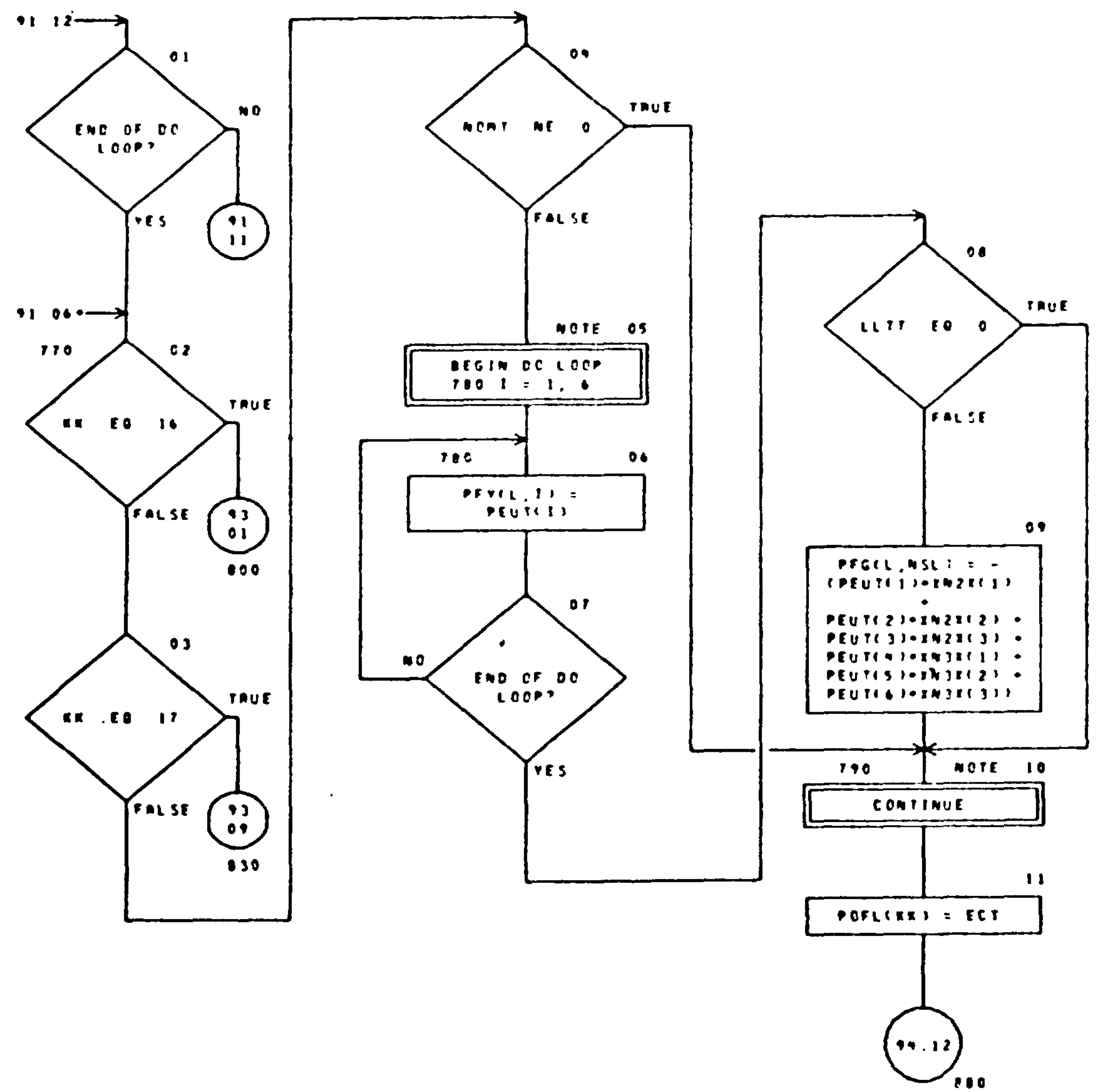

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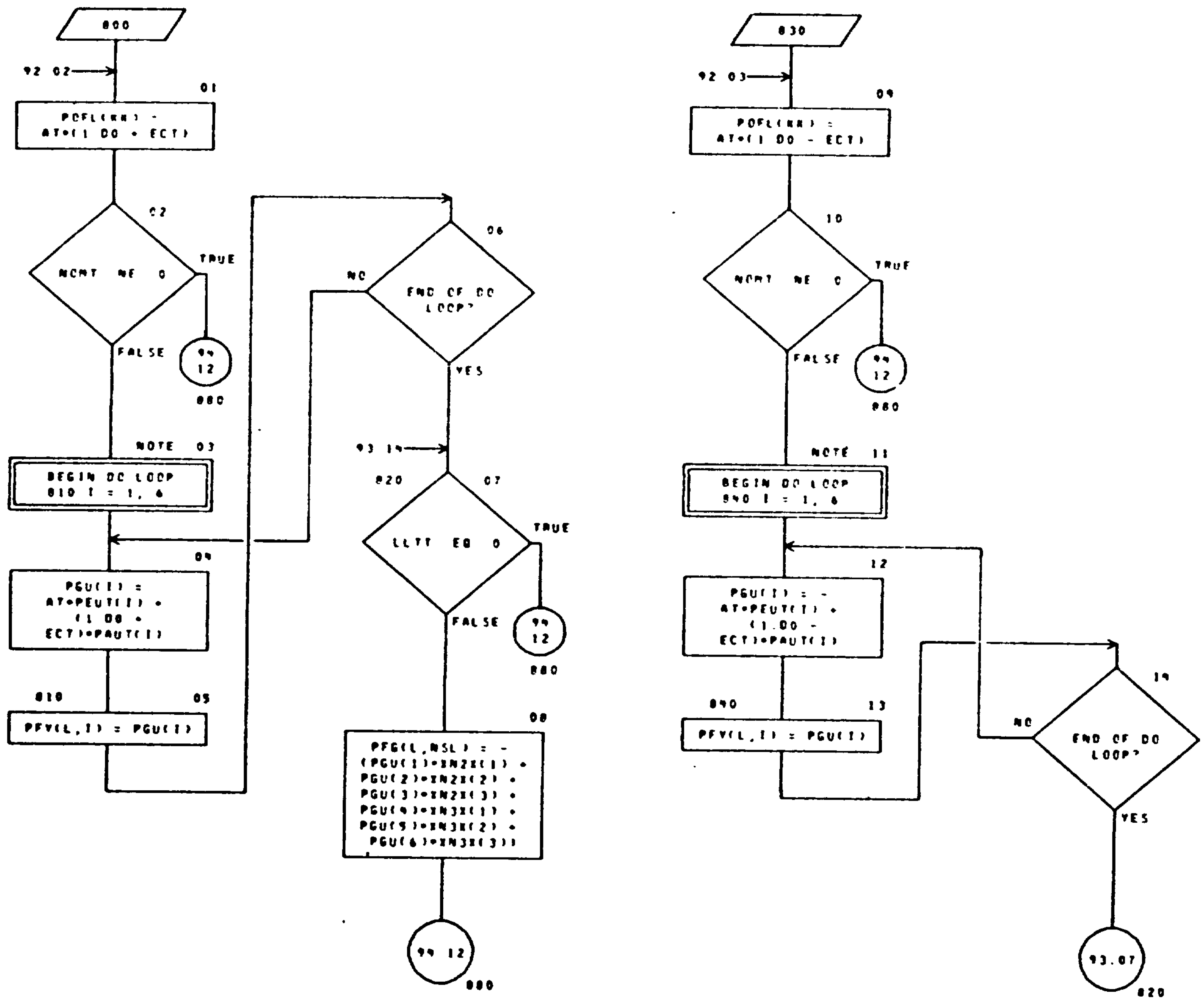

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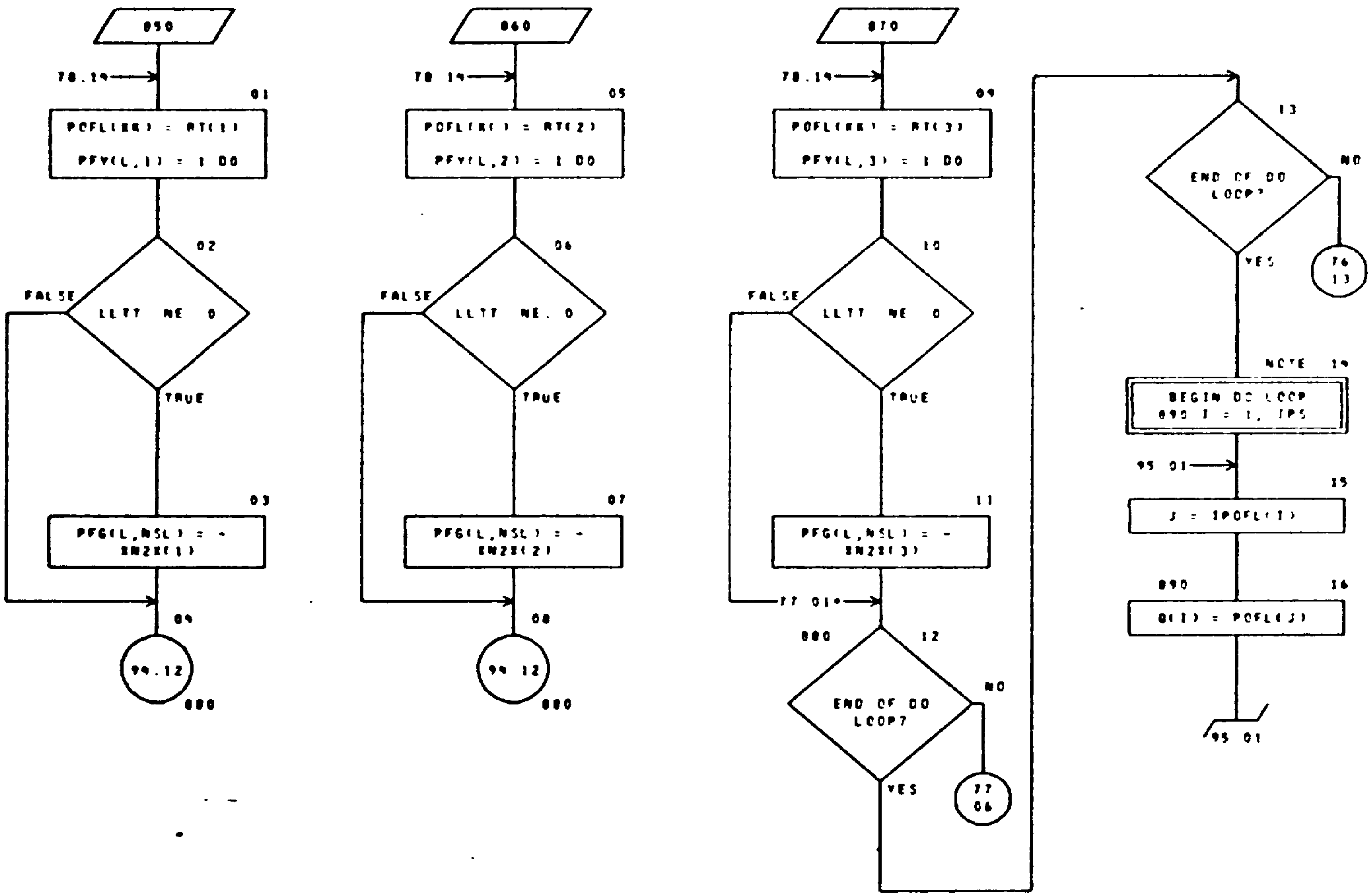

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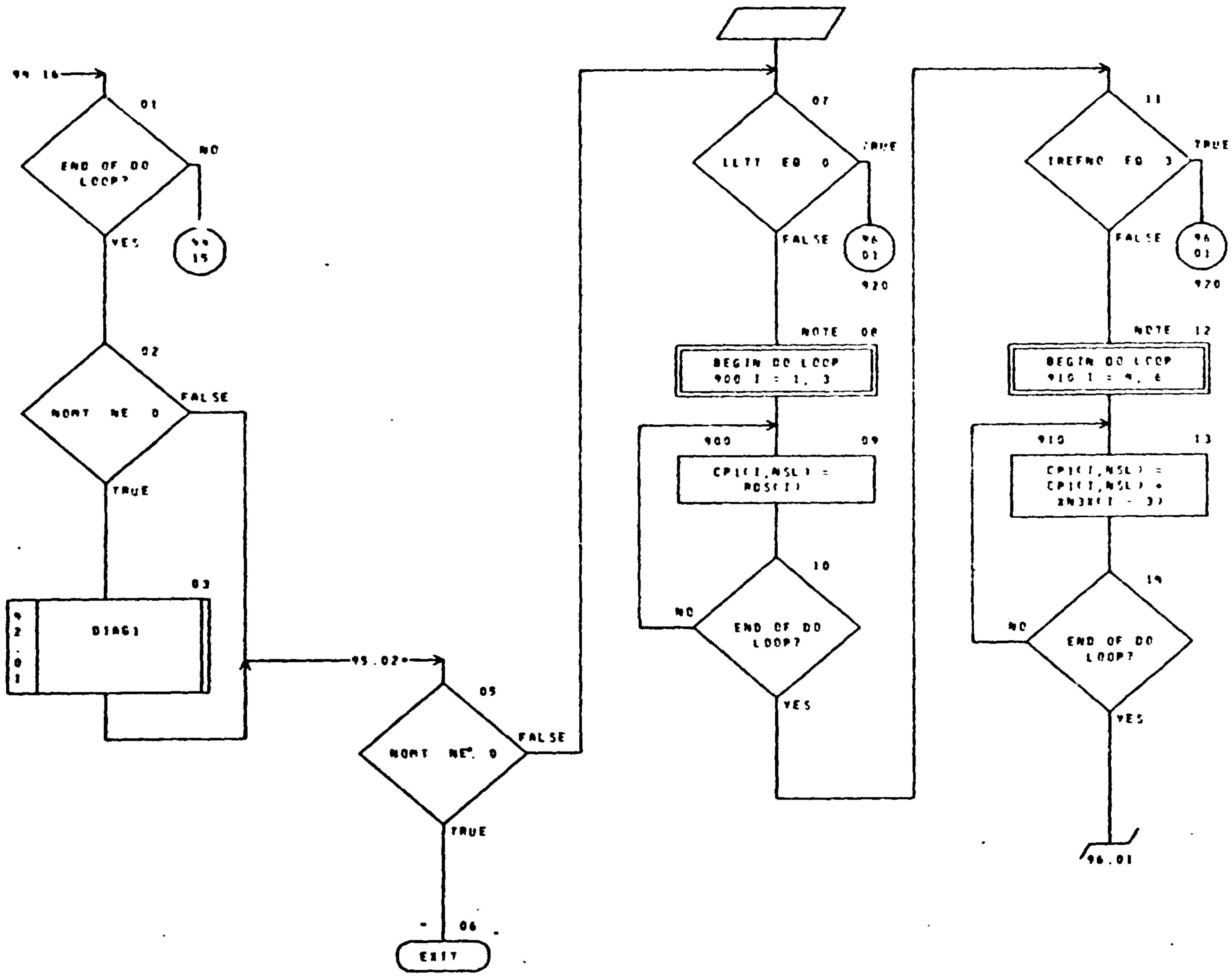

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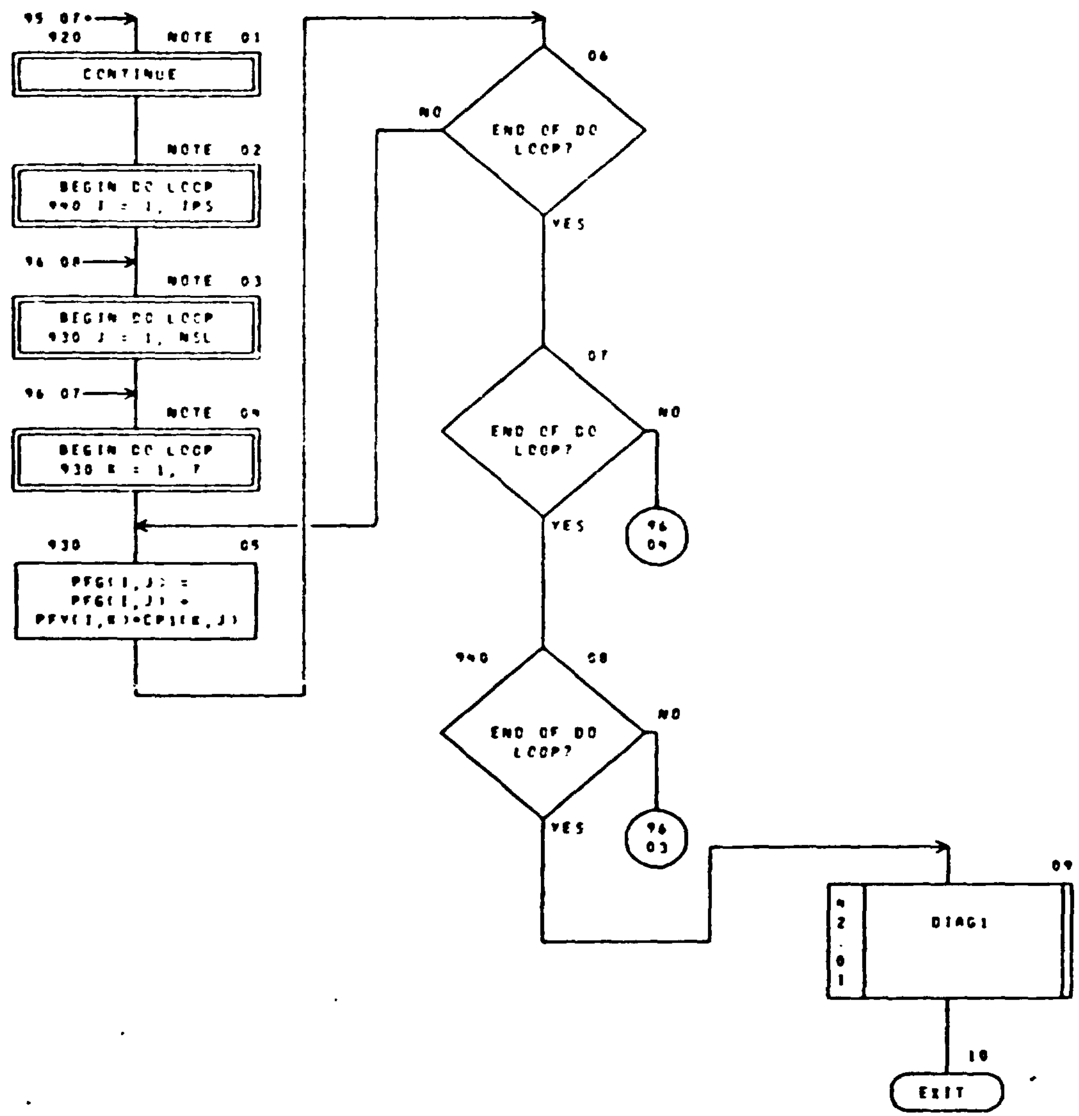

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
IMPLICIT  REAL *8 (A-H,O-Z)
INTEGER DAY,HOURS,YEAR
REAL*8 MEI,ME,KM,MDIST,INTV
DIMENSION XNIX(6),XR(6),XRDT(6),ITTAC(8)
DIMENSION PFV(20,7),PPRD(8),RS(6),RDS(6),PA(6),PEU(6),
XN3X(3),PAUT(6),PEUT(6),PGU(6),RT(6),RDT(6)
COMMON/ALAN/T,RHBP,DCRHD
COMMON/AMI/DELT,BETA,DTI,XIL(80),XIDL(80),D2XIL(80),IFST(80)
COMMON/CONRAD/VTP,DELV,VPA
COMMON/FNM/RTA,RTP
COMMON/HENRY/ARRAY(8,3,12),CHIND,INTV(72),XN1X(3),
XN2X(3),XSOO(12),XM(12),MDIST,MEI(12),ME(12),POSRCS,RAVDT,
PDT,PCIN,RD,REXM,RRM,RRE,RREU,RCIND,RATIO,SEC,TSCL,THTS,TP1,
TIMEL,THET,VELRCS
COMMON/HER/IPS,NSL,NSLI,JFTRG,ITCT,IPCFL(30),IVAR(100),ITMAX,NTP,
NTPS,NMAX,NJ,JN,IPAT,NCT1,NJL
COMMON/HIS/PFG(30,30),WX(30),XVAR(30),VEPS(30),XEPS(30),
CHNS(100),CHN(100),PCFL(30),XDAR(7)
COMMON/IEPH/NCLL
COMMON/INTEG/DAY,HOURS,YEAR,IDUMMY,ITRIG,IREFNO,IREFNB,
IREFNT,IN,IO,IJK,MONTH,MIN,NCPT(72),NPLAN,NPLAN3
COMMON/JERR/VBLOC(200),A,CA,BL,DSQ,DELP,AD (10),SUMA,XKS,ETV(3),
ET(3),XKP,ER(3),CP1(7,30),TBIN(122),ETA,CR,XKR,XKT,XKST,APS,AL1,
AL2,AL3
COMMON/LEFT/XRL(6,20),XRDL(6,20),VCOL(72,20)
```

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
      COMMON/NCALL/NCNT
      COMMON/NORM/TREF,DLEPH,ITBL(22)
      COMMON /PERAPS/ RDCT(3),RA,RP,EMU,IPER
      COMMON/XMMM/D(30),Q(30),QMIN(30),QMAX(30),WTCPT,MOPTM
      EQUIVALENCE (XR(1),XPL(1,1)),(XRDT(1),XRDL(1,1))
      EQUIVALENCE (XMASS,XIL(4))
      DATA ITTAC/4,3,2,5,6,7,8,9/
950   FORMAT ('OTRAJECTORY TERMINATED IN REFERENCE OTHER THAN SUN OR '
      'TARGET PLANET. RUN TERMINATED IN SUBROUTINE FNMAT ')
```

<u>Name:</u> FNPRNT

<u>Calling Arguments:</u> None

<u>Referenced Sub-programs:</u> SUMMRY, TRAJL

<u>Referenced Commons:</u> INTEG

<u>Entry Points:</u> None

<u>Referencing Sub-programs:</u> ITMAT

<u>Discussion:</u> Subroutine FNPRNT initiates the detailed print of the final trajectory and the case summary page. On entry the input option flag NOPT(60) is stored in a temporary location and then set to 1 which results in the detailed trajectory print. Subroutine TRAJL is then called to integrate the final trajectory for printing. NOPT(60) is then reset to its input value and subroutine SUMMRY is called to print the case summary page. A return to the calling program is then executed.

FNPRNT EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
NOPT(72)	SU	INTEG	Array of input option flags. NOPT(60) is used in FNPRNT. When set to 1, NOPT(60) causes the detailed printing of the nominal trajectory.

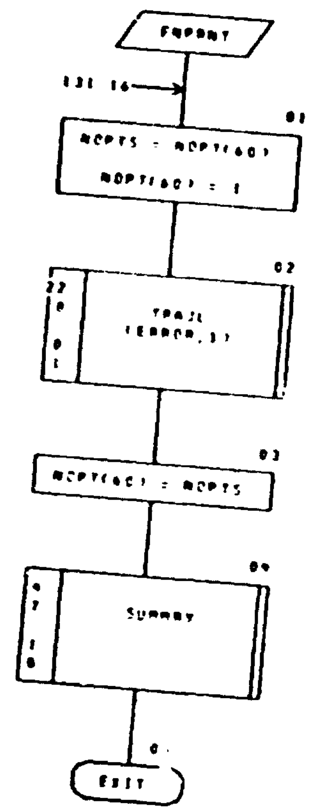
ENPRNT
131 16
01
NCPTS = NOPT(60)
NOPT(60) = 1
02
TRAIL
(ERROR,1)
03
NOPT(60) = NCPTS
04
SUMMARY
EXIT

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
IMPLICIT REAL*8 (A-H,O-Z)
INTEGER DAY,HOURS,YEAR
LOGICAL ERROR
COMMON/INTEG/DAY,HOURS,YEAR,IDUMMY,ITRIG,IREFNC,IREFND,
IREFNT,IN,IC,IJK,MONTH,MIN,NOPT(72),NPLAN,NPLAN3
```


FNPRNT-3

Name: GENMA

Calling Argument: None

Referenced Sub-programs: FNMAT, MIIP1

Referenced Commons: ALAN, AMI, AM1, ENG, HENRY, HER, HIS, ILEF, INTEG, JERR, JHW, LEFT, LEON, MEL, NOMLL, STEVE, VPLLL

Entry Points: None

Referencing Sub-programs: CONTRL

Discussion: Subroutine GENMA is called from CONTRL when the end of the current trajectory arc is detected. The purpose of GENMA is to accumulate the state transition matrix for the nominal trajectory from launch to the current time. The state transition matrix is generated by dividing the numerical differences in the state on perturbed and nominal trajectories by the magnitude of the perturbation. The desired partial derivatives are those of the final position, velocity, and mass with respect to each independent parameter which is to be optimized. With these available, the partials of most functions and end conditions of interest can be formed. Note that this definition is a generalization of the usual definition of state transition matrix. As commonly defined, state transition matrix includes partials of state with respect only to state at an earlier time. Here partials with respect to all independent parameters are included.

A straightforward approach to the evaluation of the transition matrix involves the integration of a perturbation trajectory for each independent parameter to be optimized. For a specific case involving n independent parameters, as many as n+1 trajectories (n perturbed plus 1 nominal) could be required to produce the desired matrix. Because it will, in general, be necessary to generate several matrices before convergence is attained, it is clear that a large number of trajectories must be integrated to yield a solution. It so happens, however, that because of the particular form of the problem, it is possible to generate the transition matrix with fewer than the standard number of perturbation trajectories. This

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circumstance arises because the orientation angles for each arc of the trajectory are treated as individual control parameters which directly affect the motion of the spacecraft only over a portion of the trajectory. For example, consider a trajectory consisting of two arcs. Let y_i, $i = 0, 1, 2$, represent the state at the end of the ith arc (0 denotes the start of the first arc) which occurs at time t_i, let α_1 and α_2 represent the control over the first and second arc, respectively, and let β represent the propulsion system and spacecraft design parameters. The particular matrix that we seek may be written

$$\Phi(0,2) = \left[\frac{\partial y_2}{\partial y_0} \; \vdots \; \frac{\partial y_2}{\partial \beta} \; \vdots \; \frac{\partial y_2}{\partial \alpha_1} \; \vdots \; \frac{\partial y_2}{\partial \alpha_2} \right]$$

Here y_0 is meant to include the time t_0 the speed v_{po} or any of the launch parking orbit orientation angles i, Ω, or ω that are declared as independent variables. Alternatively, it will include only initial state variables that are not fixed. To obtain this matrix, we begin by integrating the nominal and perturbation trajectories over the first arc, stopping the integration at t_1 and forming the transition matrix for that arc, i.e.,

$$\Phi(0,1) = \left[\frac{\partial y_1}{\partial y_0} \; \vdots \; \frac{\partial y_1}{\partial \beta} \; \vdots \; \frac{\partial y_1}{\partial \alpha_1} \right]$$

where the partials are formed by simple finite differencing. This matrix is stored in the locations allotted for the final matrix $\Phi(0,2)$, and the integration of the nominal trajectory is continued over the next arc. The perturbation trajectories are not continued, however. Rather, a new set is begun at time t_1 and integrated over the interval t_1 to t_2. There is a perturbation trajectory over the second arc for each state variable, for each propulsion system and spacecraft design parameter, and for each control parameter in effect over that arc, but none for any control parameters of a previous arc. At the end of the arc, one forms the partials

$$\frac{\partial y_2}{\partial y_1}, \left(\frac{\partial y_2}{\partial \beta}\right)^*, \text{ and } \frac{\partial y_2}{\partial \alpha_2}$$

where $(\partial y_2/\partial\beta)^*$ are the partials in the state at t_2 due to variations in the propulsion system and spacecraft design parameters over the second arc only. Then, form $\Phi(0,2)$ through the operations

$$\Phi(0,2)^* = \left[\frac{\partial y_2}{\partial y_1}\ \Phi(0,1) \;\middle|\; \frac{\partial y_2}{\partial \alpha_2}\right]$$

$$\Phi(0,2) = \Phi(0,2)^* + \left[0 \;\middle|\; \left(\frac{\partial y_2}{\partial \beta}\right)^* \;\middle|\; 0 \;\middle|\; 0\right]$$

$$= \left[\frac{\partial y_2}{\partial y_0} \;\middle|\; \frac{\partial y_2}{\partial \beta} \;\middle|\; \frac{\partial y_2}{\partial \alpha_1} \;\middle|\; \frac{\partial y_2}{\partial \alpha_2}\right]$$

Of course, the extension to more arcs is straightforward. In general, we seek the matrix $\Phi(0,i)$ given by

$$\Phi(0,i) = \left[\frac{\partial y_i}{\partial y_0} \;\middle|\; \frac{\partial y_i}{\partial \beta} \;\middle|\; \frac{\partial y_i}{\partial \alpha_1} \;\middle|\; \frac{\partial y_i}{\partial \alpha_2} \;\middle|\; ---- \;\middle|\; \frac{\partial y_i}{\partial \alpha_i}\right]$$

$$= \Phi(0,i)^* + \left[0 \;\middle|\; \left(\frac{\partial y_i}{\partial \beta}\right)^* \;\middle|\; 0 \;\middle|\; 0 \;\middle|\; --- \;\middle|\; 0\right]$$

with

$$\Phi(0,i)^* = \left[\frac{\partial y_i}{\partial y_{i-1}}\ \Phi(0,i-1) \;\middle|\; \frac{\partial y_i}{\partial \alpha_i}\right]$$

Once the transition matrix is formed for the first arc, each subsequent arc will add to the matrix a number of columns equal to the number of control parameters in effect over that arc. The number of rows remains constant and is equal to the number of state variables.

It should be noted at this point that over the first arc of the trajectory, perturbation trajectories need be run only for those particular state variables for which the initial values will be permitted to vary independently and for any other independent parameters. On all subsequent arcs, however, it is necessary to generate perturbation trajectories for the current independent parameters and for all state variables. Thus, since there are seven state variables, the matrix $(\partial y_i / \partial y_{i-1})$ will be 7x7 for $i \geq 2$ and will be 7xm for $i=1$ where m is the number of independent variations permitted in the state at the start of the first arc. If any propulsion system or spacecraft design parameters are to be optimized, but do not enter into the problem in the first arc, it is convenient to enter a column of zeroes for each such parameter in the transition matrix so that the general form of the matrix is established immediately, and the above formula for $\Phi(0, i)$ is always applicable for $i \geq 2$. As an example, consider the problem of a solar-electric propulsion mission commencing from the vicinity of a low altitude orbit about Earth. Suppose the initial geocentric speed is to be optimized as are the power level and jet exhaust speed of the low-thrust propulsion system and three spacecraft orientation angles over each arc. The first arc consists of coasting on the geocentric hyperbolic trajectory to a specified time t_1 at which the low-thrust system is turned on. The only independent parameter for optimization over this first arc is the geocentric speed at the start of the arc. Consequently, one perturbation trajectory over the first arc must be generated, and the transition matrix will be 7x3. The first column is associated with the initial geocentric speed, and the last two columns are zeroes which are entered in anticipation of future effects of variations in the propulsion system parameters, power and jet exhaust speed. It may be argued that the initial mass is also varying due to its dependence on the velocity, but it is precisely because the variation is not independent that a perturbation trajectory for the initial mass is not required. Over the second arc, a total of twelve perturbation trajectories are required -- seven for the state, two for the propulsion system parameters, power and jet exhaust speed, and three for the orientation angles. Following the procedure indicated above, three columns (associated with the three orientation angles) will be added to the transition matrix such that, at the end of the second arc, the matrix is 7x6. The continuation of this procedure to subsequent arcs is then clear.

It was implicitly assumed above that the time at the end of each arc is fixed. If an arc end time is left open for optimization, then a column must be added to the transition matrix. It is not necessary to integrate a perturbation trajectory for this arc end time as the partials are available in closed form. For example, denote t_i as the end time of the ith arc and let y_i represent the state at t_i. Then, if t_i is to be optimized, form the column matrix

$$\frac{\partial y_i}{\partial t_i} = \dot{y}_i^{\,-} - \dot{y}_i^{\,+}$$

where the minus and plus signs indicate the limits of the time derivative of y_i evaluated just before and just after the end of the arc, respectively. If i is the last arc, the $\dot{y}_i^{\,+} = 0$. This column is added to the transition matrix and subsequently is treated in the identical manner as the partials with respect to the control parameters, α_i, for the ith arc. Note that if the time derivative of a state variable (such as position) is continuous from one arc to the next, the partial is zero. However, for velocity and mass, the switching on or off of an engine, or the change of a thrust angle, can result in a finite partial derivative.

In addition to forming the state transition matrix, GENMA also performs other functions required at the end of each arc. If NOPT(60) is non-zero, subroutine MIIP1 is called to print the trajectory point; the position and velocity vectors, as well as the Encke integrals ξ and $\dot{\xi}$, are reset to the nominal values plus perturbations as appropriate on all perturbation trajectories; the values of the spacecraft, propulsion system and orientation parameters for the next arc are stored in the VBLOC array for the nominal and perturbation trajectories and the sines and cosines of the angles are formed and stored; and, at the end of the final trajectory arc, subroutine FNMAT is called to evaluate the partial derivatives of the specified end conditions and the performance index with respect to all independent parameters.

GENMA EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
V(20)	UE	JERR (VBLOC)	Array of spacecraft orientation angles ν_i or ψ_i for the next arc on nominal and perturbation trajectories.
X(20)	UE	JERR (VBLOC)	Array of spacecraft orientation angles ξ_i or θ_i for the next arc on nominal and perturbation trajectories.
Z(20)	UE	JERR (VBLOC)	Array of spacecraft orientation angles ζ_i or ϕ_i for the next arc on nominal and perturbation trajectories.
JN	SU	HER	Number of spacecraft orientation angles on the next arc that are included in the list of independent parameters.
NJ	U	HER	Counter of the number of the six spacecraft parameters c, p_o, α, β, δ and ϵ that are included in the list of independent parameters.
NS	SU	ILEF	Number of initial state related variables that are included in the list of independent parameters.
N4	SU	ILEF	Index equal to $4(i-2)+1$ where i is the next arc number.
ALP(20)	UE	JERR (VBLOC)	Array of angles α_i between unit array normal vector $\bar{n}$ and its projection in the body fixed I-J plane for the next arc on nominal and perturbation trajectories.
BET(20)	UE	JERR (VBLOC)	Array of angles β_i between projection of $\bar{n}$ in the body fixed I-J plane and the thrust vector for the next arc on nominal and perturbation trajectories.
CHN(100)	U	HIS	Array of values of the variables available as independent parameters. (See description in subroutine INPUT).

GENMA EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
CPH(7,30)	SU	JHW	State transition matrix, Φ. Same as CP1.
CP1(7,30)	SU	JERR	State transition matrix, Φ.
CSV(20)	S	ENG	cos ν_i or cos ψ_i.
CSX(20)	S	ENG	cos ξ_i or cos θ_i.
CSZ(20)	S	ENG	cos ζ_i or cos ϕ_i.
DEL(20)	UE	JERR (VBLOC)	Array of angles δ_i between the unit vector $\bar{s}$ and its projection in the body fixed I-J plane for the next arc on nominal and perturbation trajectories.
ETJ(20)	UE	JERR (VBLOC)	Array of angles ϵ_i between the projection of $\bar{s}$ in the body-fixed I-J plane and the thrust vector for the next arc on nominal and perturbation trajectories.
IJK	SU	INTEG	Temporary storage of index limit.
ITD	U	VPLLL	Flag indicating whether time of departure from launch parking orbit is an independent variable. 0 - not an independent variable 1 - is an independent variable
NJJ	SU	ILEF	Number of columns currently in the state transition matrix.
NJL	U	HER	Number of independent parameters which are functions of the initial position or velocity.
NQN	U	ILEF	Number of equations numerically integrated on each trajectory, sum of first and second order equations.

GENMA EXTERNAL VARIABLES TABLE (cont)

Varible	Use	Common	Description
NSL	U	HER	Number of independent parameters.
NS1	SU	ILEF	NS + 1.
NTP	U	HER	Current trajectory arc number.
PYI(7,7)	SU	JHW	Partial derivatives of the state at the end of the arc with respect to state at the start of the arc, $\partial y_i / \partial y_{i-1}$.
SNV(20)	S	ENG	sin ν_i or sin ψ_i.
SNX(20)	S	ENG	sin ξ_i or sin θ_i.
SNZ(20)	S	ENG	sin ζ_i or sin ϕ_i.
XIL(80)	SU	AM1	Second integral of the Encke perturbations, on nominal and perturbation trajectories.
XRL(6,20)	SU	LEFT	Array of spacecraft position vectors relative to the current reference body on nominal and perturbation trajectories.
XRO(6)	U	LEON	Spacecraft position vector relative to the current reference body on the two-body reference trajectory.
XSQ	U	STEVE	Gravitational constant of the current reference body.
CSAL(20)	S	ENG	cos α_i.
CSDL(20)	S	ENG	cos δ_i.
CSET(20)	S	ENG	cos ϵ_i.
IPAT	SU	HER	Flag indicating whether arc end time is an independent parameter. 1 - arc end time is fixed. 2 - arc end time is variable.

GENMA EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
ISOL	S	MEL	Flag indicating whether trajectory arc is thrust or coast. 1 - thrust arc 2 - coast arc
ITD1	U	VPLLL	Flag indicating whether speed of departure from a fixed parking orbit is an independent parameter. 0 - departure speed is fixed 1 - departure speed is variable.
IVAR(100)	U	HER	Array of indices correlating entries in the CHN array to corresponding entries in the independent parameter arrays.
NCT1	U	HER	Index of the thrust/coast flag of the next arc in the TBIN array.
NEQL	SU	ILEF	Total number of trajectories currently being integrated simultaneously.
NEQN	S	AMI	NQN x NEQL
NOMT	U	NOMLL	Flag indicating whether perturbation trajectories are currently being integrated. 0 - nominal and perturbation trajectories 1 - trial or nominal trajectory only.
NOPT(72)	U	INTEG	Array of program option flags.
NSL1	SU	HEP	Counter equal to NEQL.
NTPS	U	HER	Total number of trajectory arcs minus 1.
RHBR	U	ALAN	$\dot{\beta}$, used in converting between time and universal anomaly derivatives.

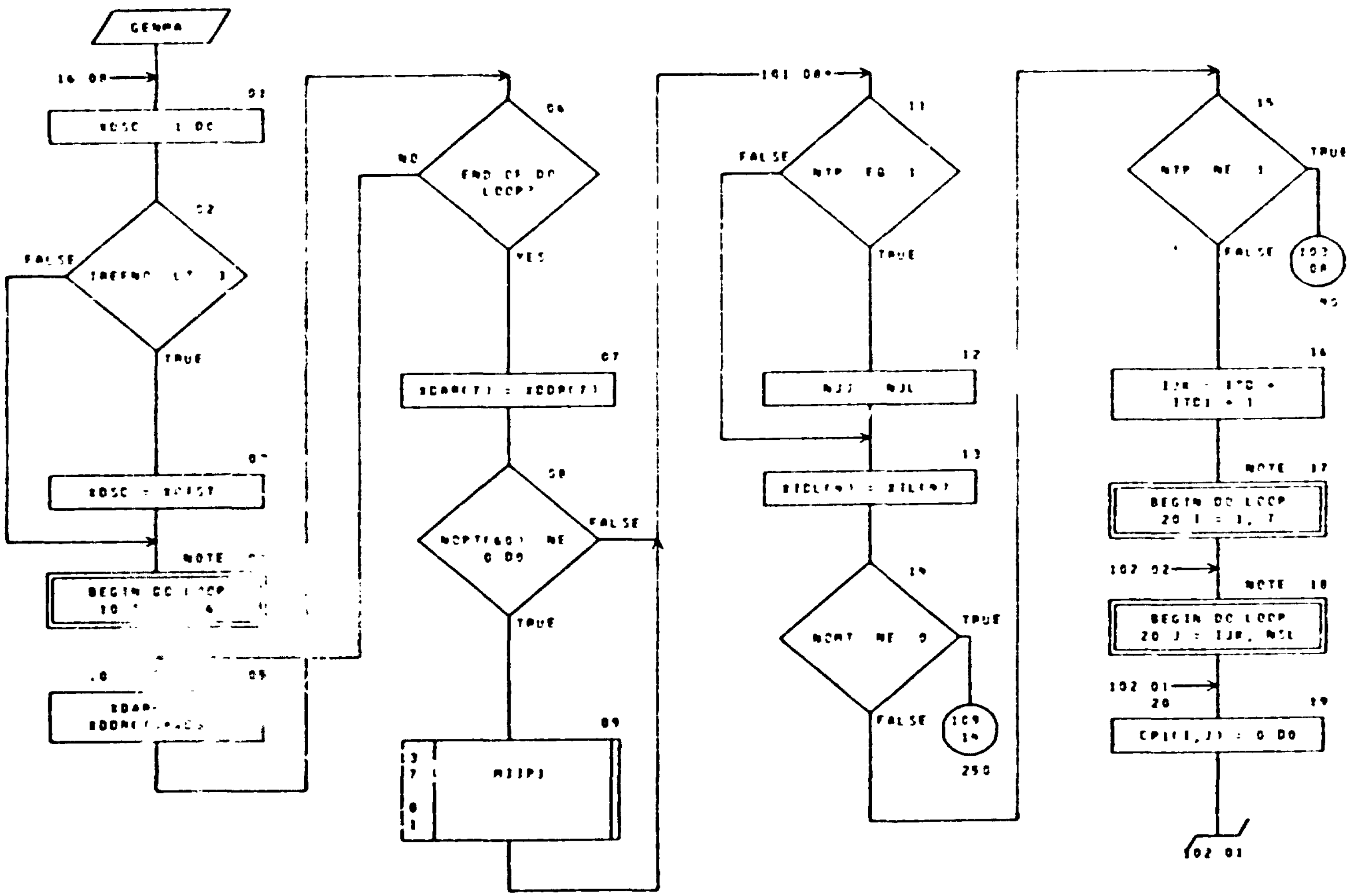
GENMA EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
SNAL(20)	S	ENG	$\sin \alpha_i$.
SNDL(20)	S	ENG	$\sin \delta_i$.
SNET(20)	S	ENG	$\sin \epsilon_i$.
TBIN(122)	U	JERR	Array of trajectory arc information. (See description in subroutine INPUT).
XDDR(7)	U	HIS	State variable perturbation step size.
XIDL(80)	SU	AM1	First integral of the Encke perturbation on the nominal and perturbation trajectories.
XRDL(6,20)	SU	LEFT	Array of spacecraft velocity vectors relative to the reference body on the nominal and perturbation trajectories.
XVAR(30)	U	HIS	Perturbation step sizes for independent parameters.
CSBET(20)	S	ENG	$\cos \beta_i$.
DORHO	U	ALAN	Factor used in converting between time and universal anomaly second derivatives.
D2XIL(80)	U	AM1	Encke perturbations on the nominal and perturbation trajectories.
NOP65	SU	ILEF	Flag indicating whether the constrained or unconstrained steering mode is invoked. 1 - unconstrained mode 2 - constrained mode with $\psi_{max} = 0$ 3 - constrained mode with $\psi_{max_i} \neq 0$.
SNBET(20)	S	ENG	$\sin \beta_i$.

GENMA EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
VBLOC(200)	SUE	JERR	Array containing the values of all spacecraft and orientation variables available as independent parameters. Includes values for nominal and perturbation trajectories on next arc.
XDIST	U	HENRY	Conversion factor equal to the number of ER in one AU.
IREFNO	U	INTEG	Identification number of the current reference body. The possible values are: 1 - Earth 2 - not available 3 - sun 4 - Venus 5 - Mars 6 - Jupiter 7 - Saturn 8 - Uranus 9 - Neptune 10 - Pluto

CHART TITLE - SUBROUTINE GENMA



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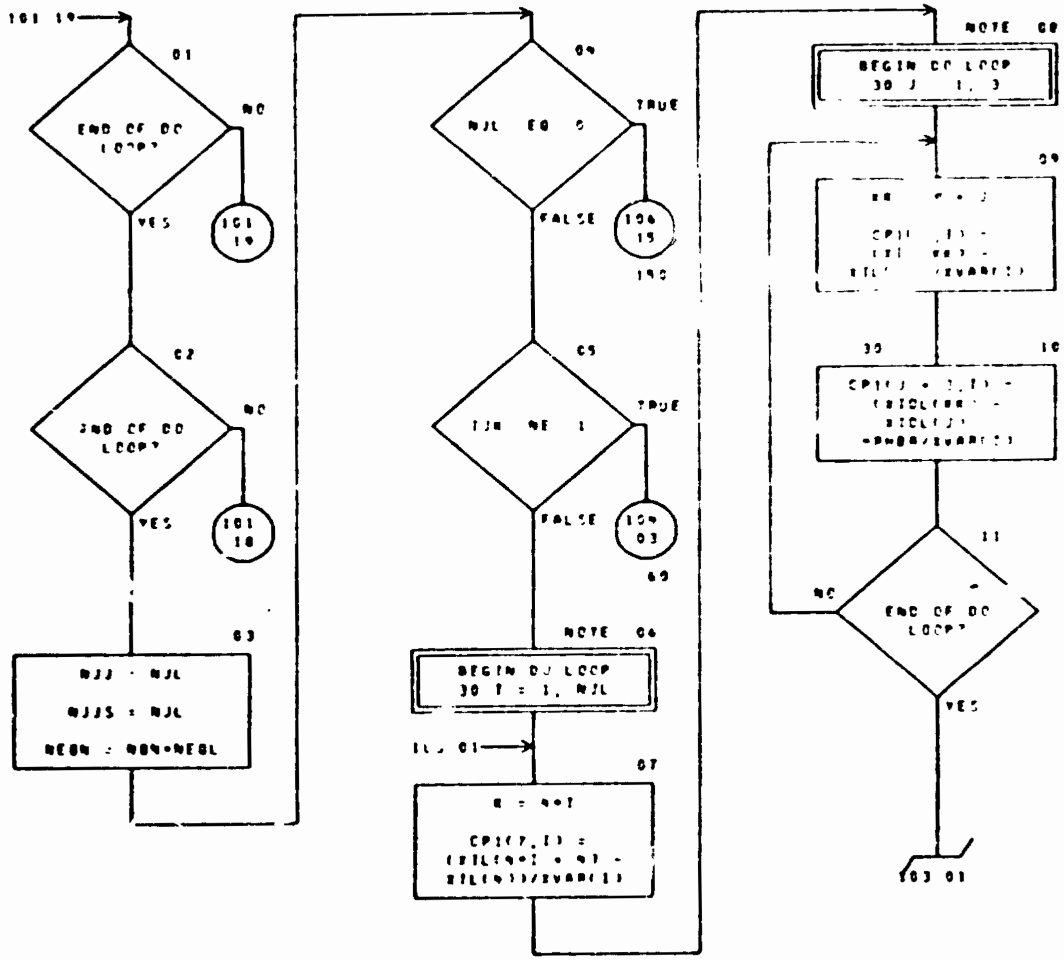


G-ENMA-13

CHART TITLE - SUBROUTINE GENMA

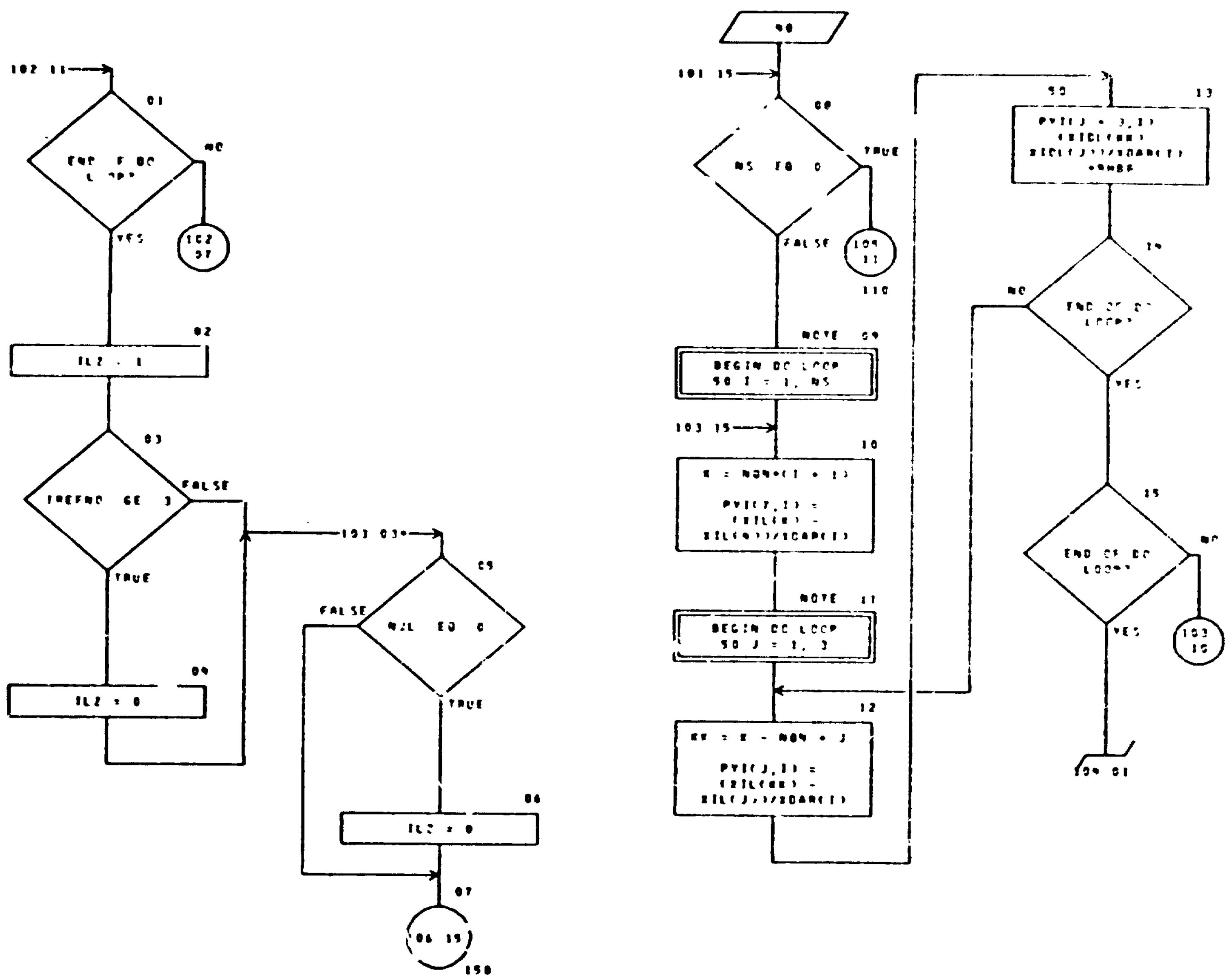
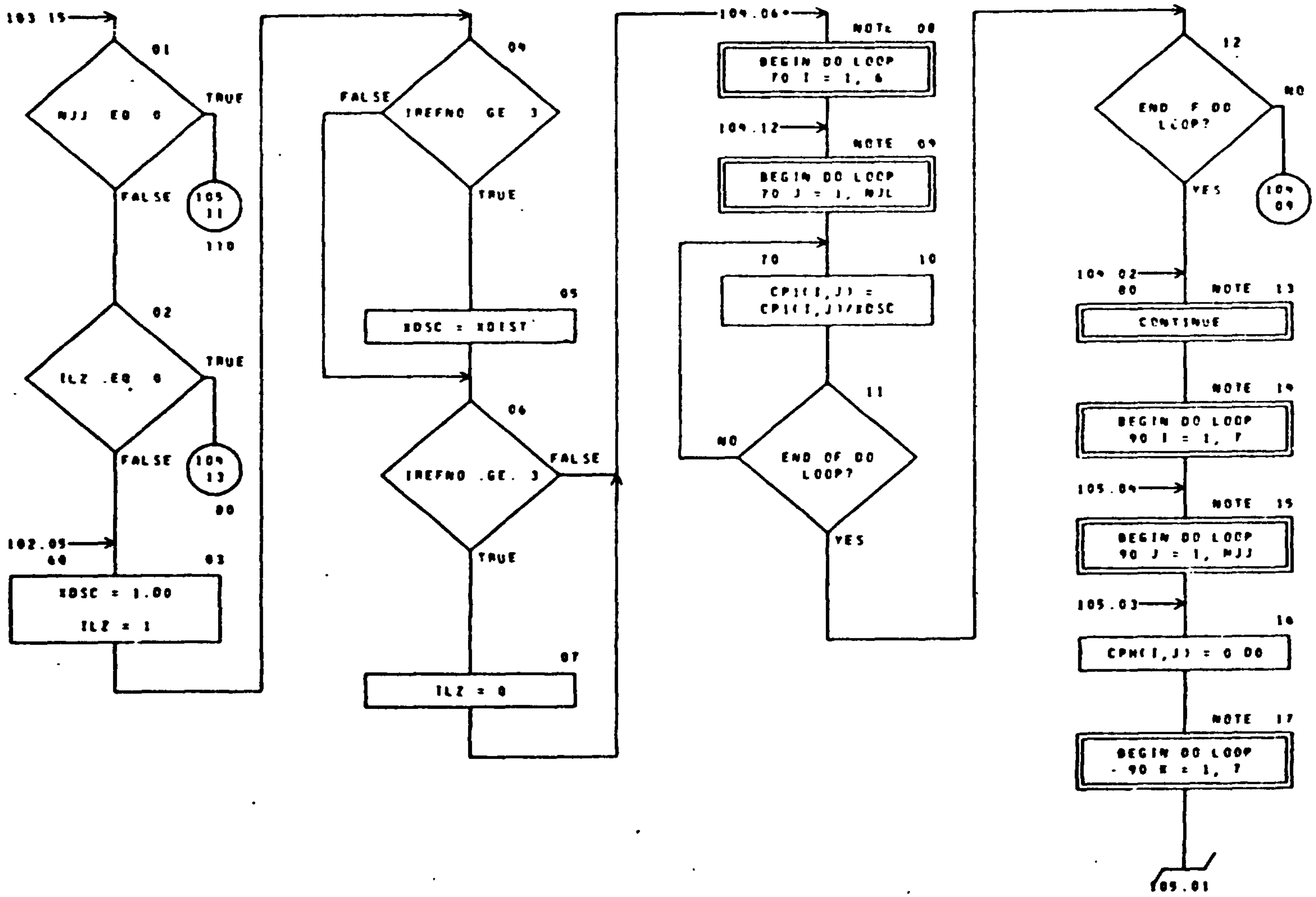


CHART TITLE - SUBROUTINE GENMA

C-4



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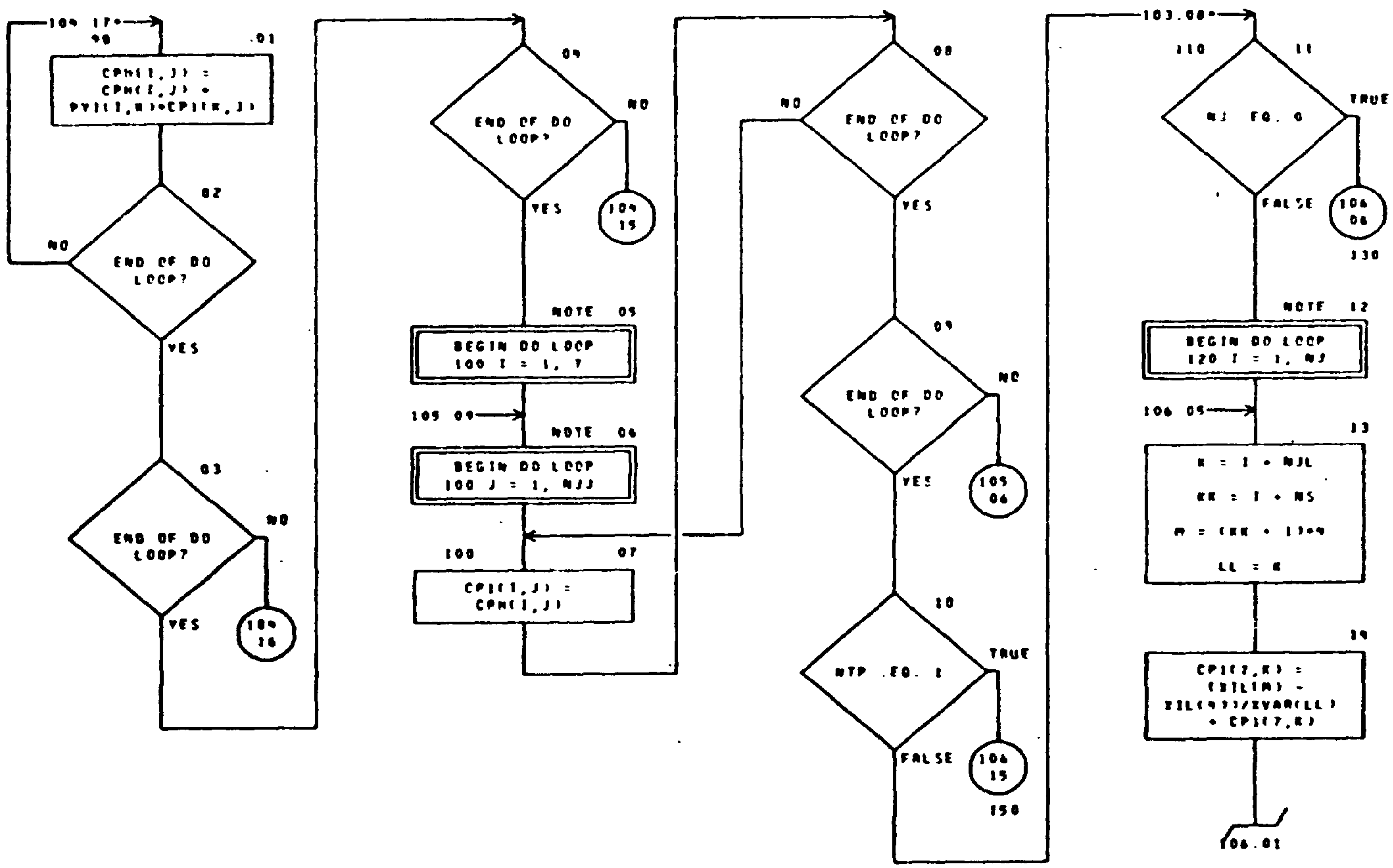

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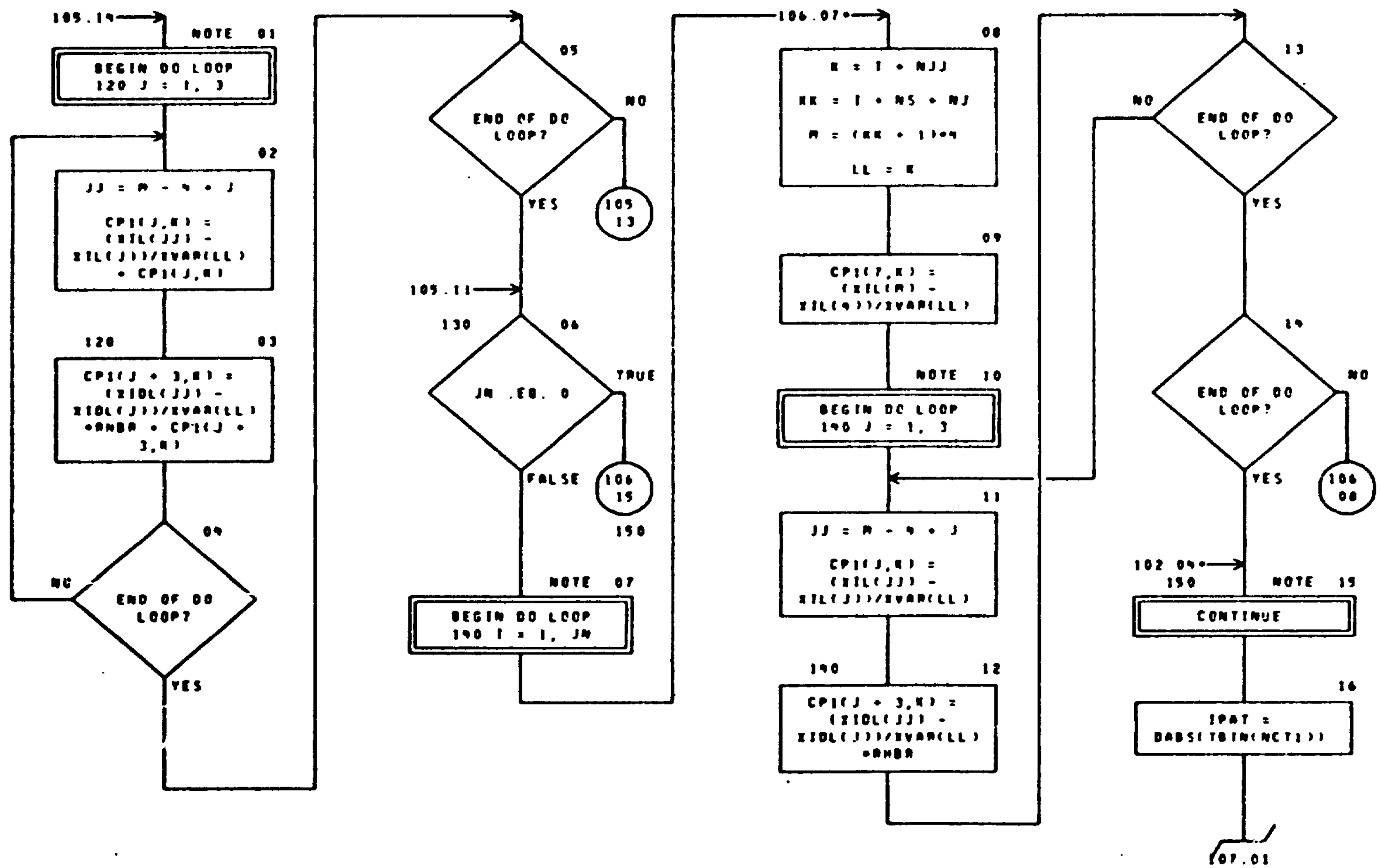

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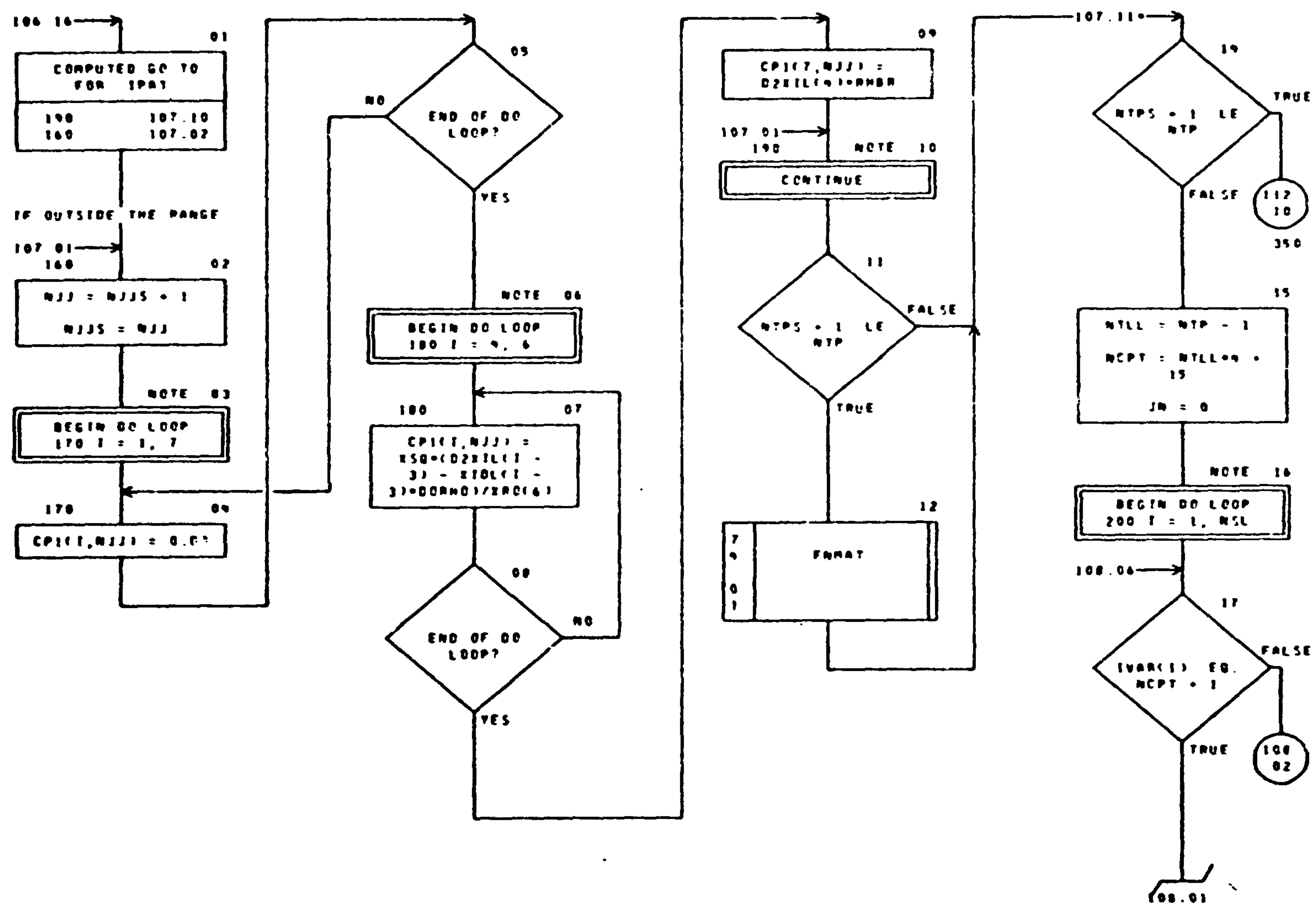

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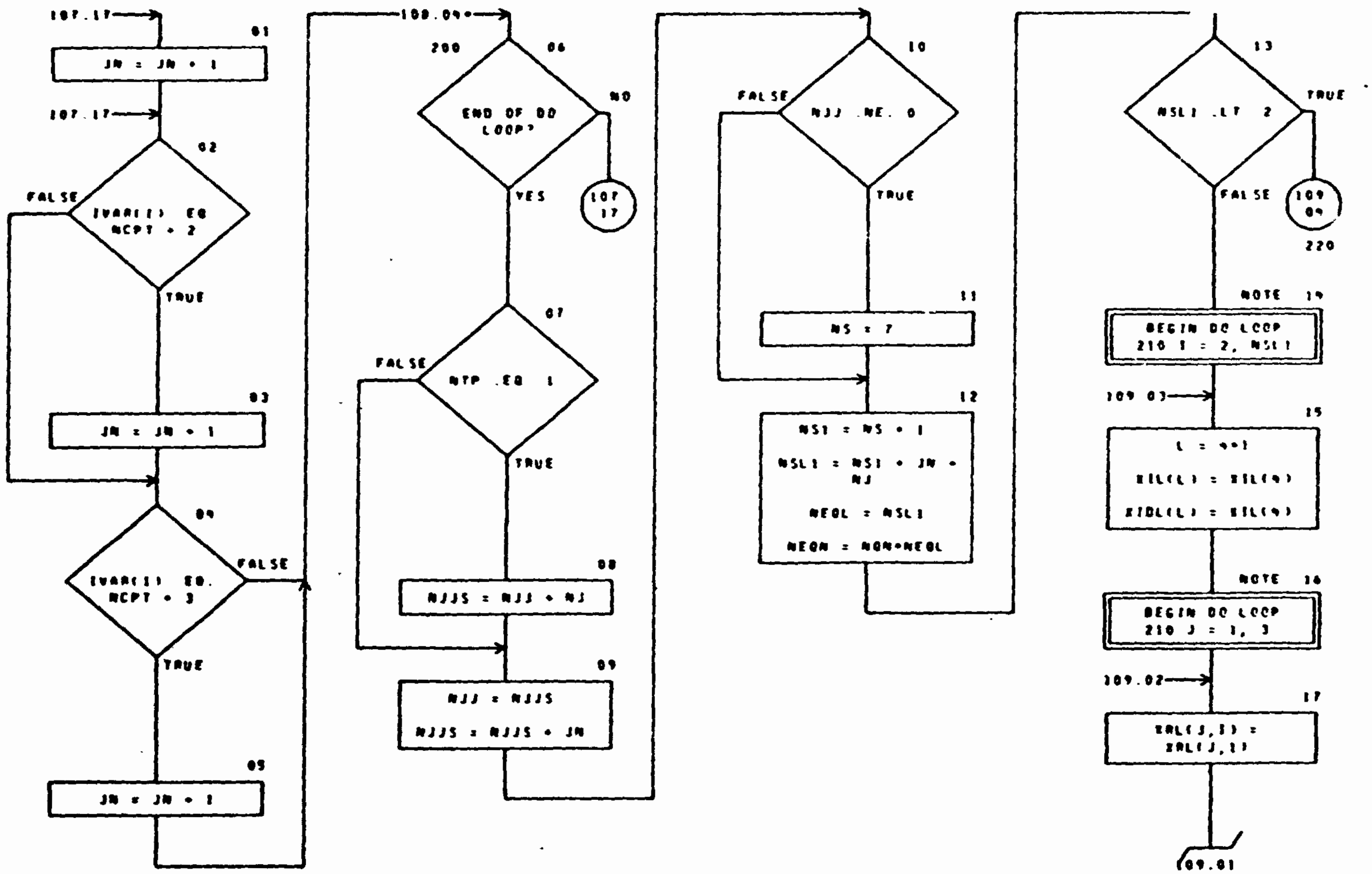

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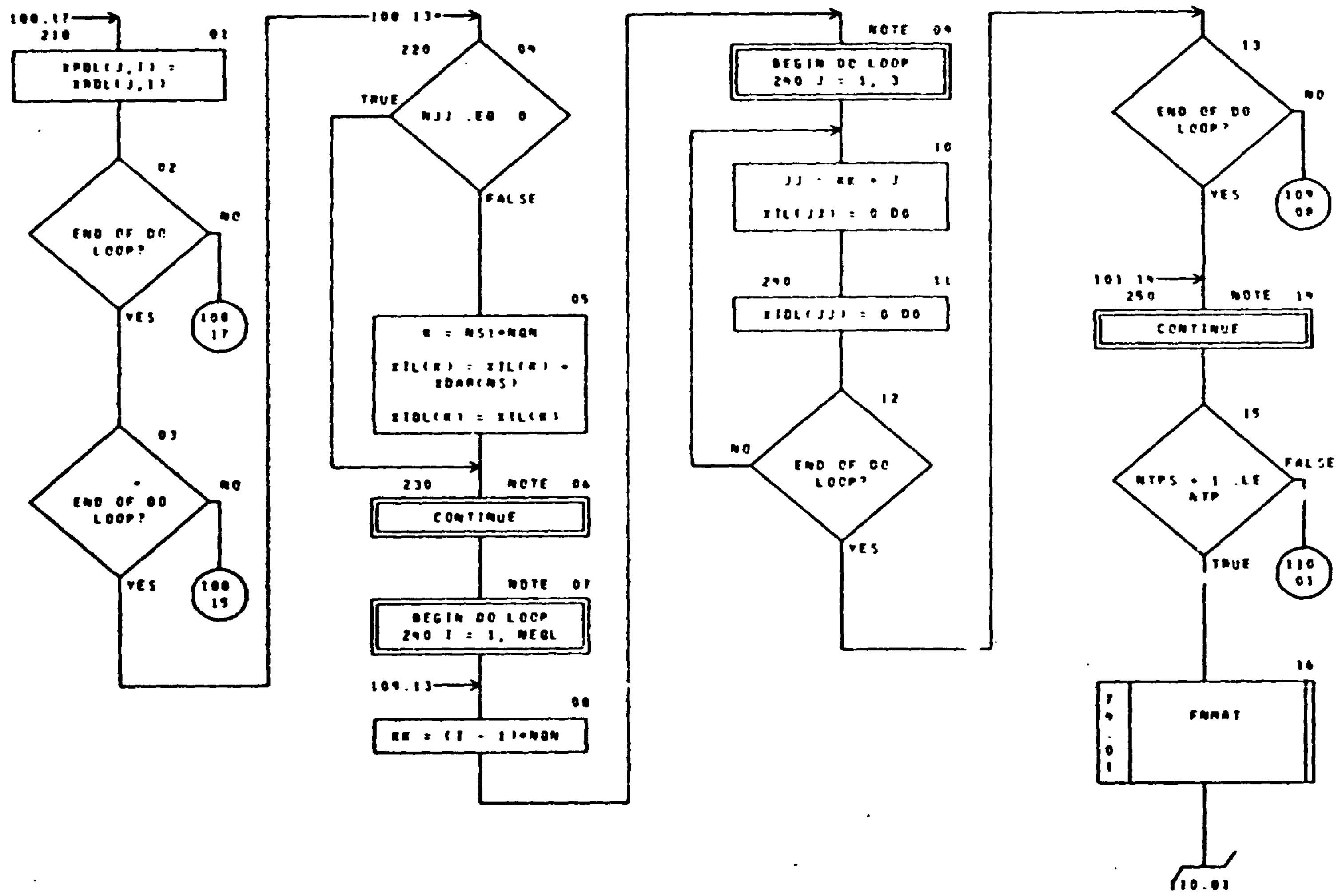

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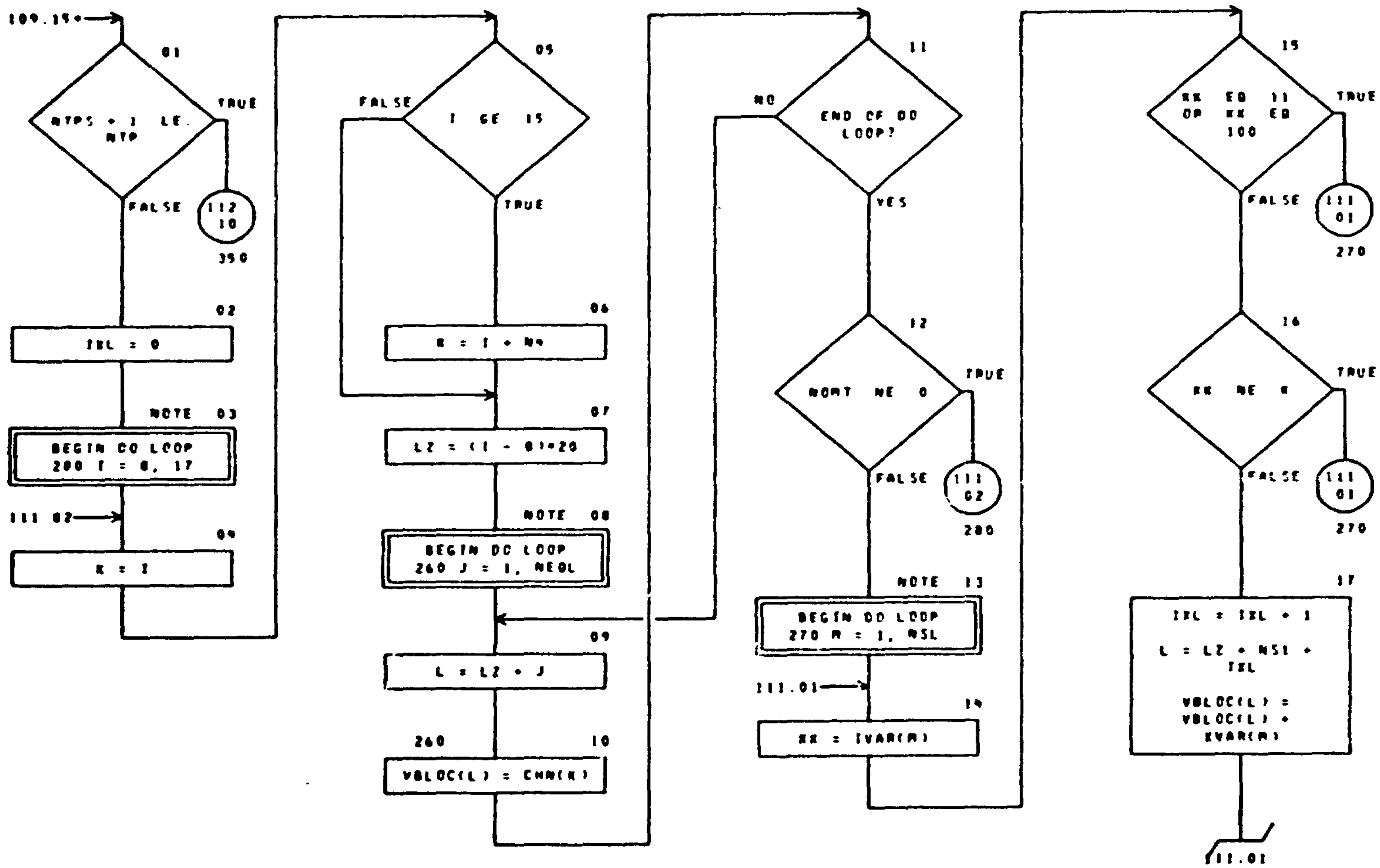

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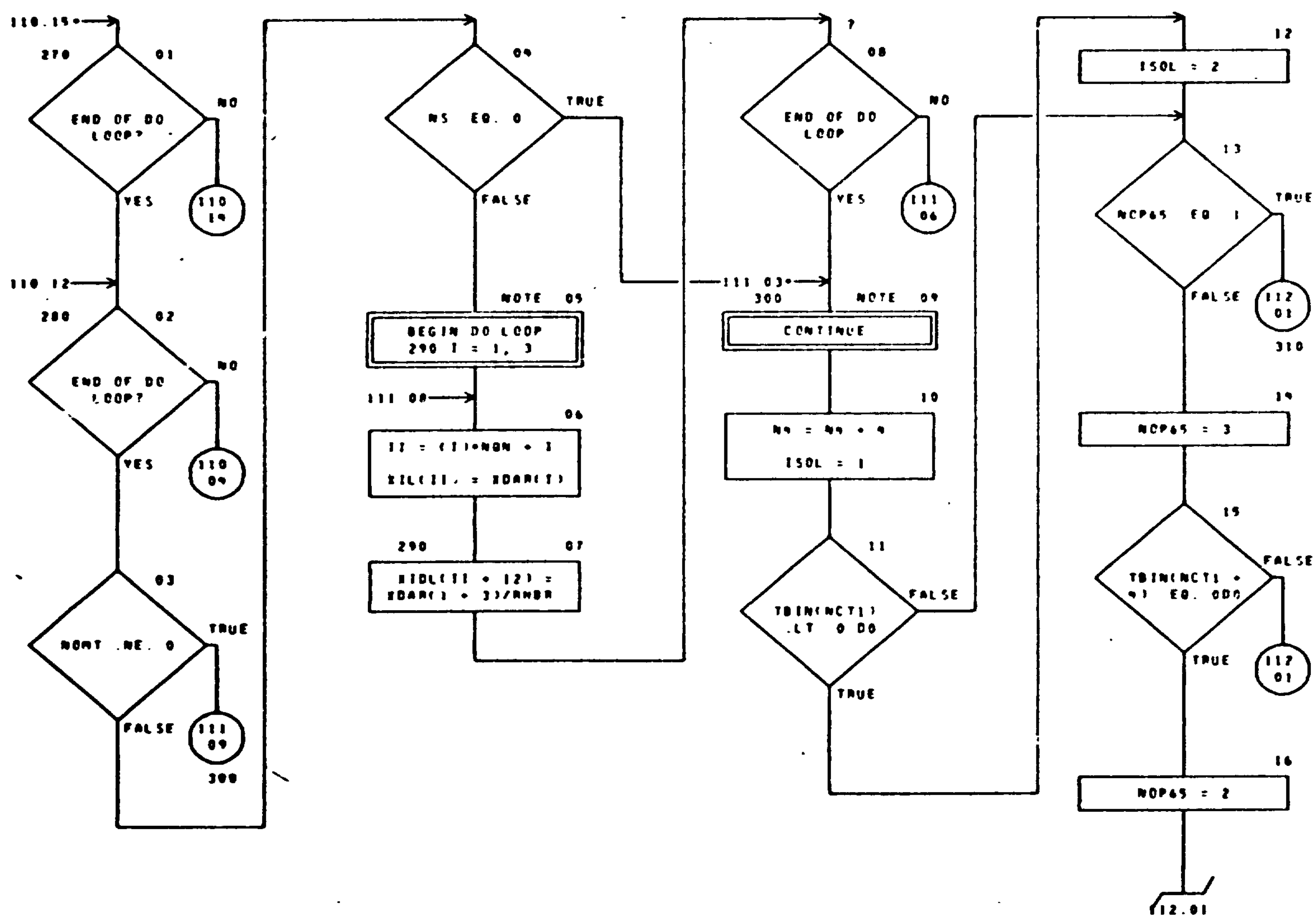

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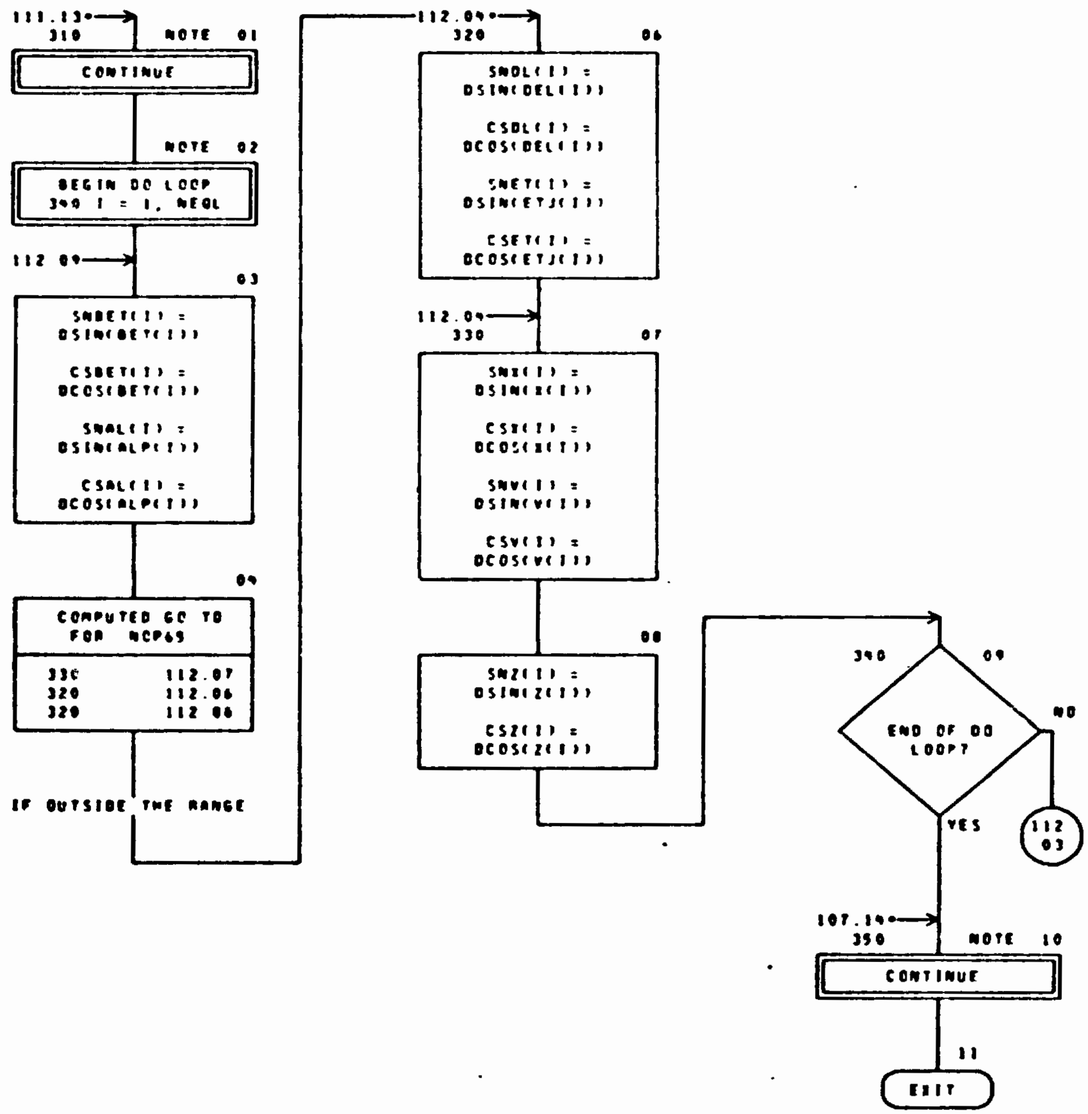

GENMA-23

CHART TITLE - NON-PROCEDURAL STATEMENTS

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INTEGER DAY,HOURS,YEAR
REAL*8 KSQQ,MEI,ME,KM,INTV,IN1X,IN2X
DIMENSION XDAR(7)
DIMENSION ALP(20),BET(20),DEL(20),ETJ(20),X(20),Y(20),Z(20)
COMMON/ALAN/T,ANBR,DORMO
COMMON/AMI/NEQN,NP12
COMMON/AMI/DELT,BETA,DTI,XIL(80),XIDL(80),D2XIL(80),"FST(80)
COMMON/ENG/SNAL(20),CSAL(20),SNBET(20),CSBET(20),SNDL(20),CSDL(20)
,SNET(20),CSET(20),SNX(20),CSX(20),SNY(20),CSY(20),SNZ(20),CSZ(20)
COMMON/HENRY/ARRAY(8,3,12),CHIND,INTV(72),IN1X(3),
IN2X(3),KSQQ(12),KM(12),XDIS(,MEI(12),ME(12),PCSRCS,PRVCT,
PDT,PCIN,RD,REKM,RRM,RRE,RREU,RCIND,RATIO,SEC,TSCL,THTS,TP1,
TIMEL,THET,VELRCS
COMMON/HEP/IPS,NSL,NSL1,IFTRG,ITCT,IPCFL(30),IVAR(100),ITMAX,NTP,
NTPS,NMAX,NJ,JN,IPAT,NCT1,NJL
COMMON/HIS/PFG(30,30),WT(30),XVAR(30),YEPS(30),XEPS(30),
CHNS(100),CHN(100),PCFL(30),XDDR(7)
COMMON/ILEF/NEQL,NEQ3,NQN,NCP45,ICAR(7),NOP44,NCP63,NS,N4,NS1,NJJ
COMMON/INTEG/DAY,HOURS,YEAR,IDUMMY,ITRIG,IREFND,IREFNB,
IREFNT,IN,IO,IJK,MONTH,MIN,NCPT(72),NPLAN,NPLAN3
COMMON/JERR/VBLOC(200),A,CA,BL,DSQ,DELP,AO (10),SUMA,XKS,ETV(3),
ET(3),XKP,ER(3),CP1(7,30),TBIN(122),ETA,CR,XKK,XKT,XKST,APS,AL1,
AL2,AL3
COMMON/JHW/PYI( 7,7),CPH(7,30)
```

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
COMMON/LEFT/XAL(6,20),XADL(6,20),VCCL(72,20)
COMMON/LF.N/XRO(6),XRODT(6),TMPL ,W
COMMON/MEL/ISCL
COMMON/NCALL/NOMT
COMMON/STEVE/ZELT,XSO,C1AD,RDOTD,TI,TM2DP,  I(6),XRTDT(6),SQTMU
COMMON/VPLLL/VPOO,ITD,ITD1
EQUIVALENCE(ALP(1),VBLCC(41)),(BET(1),VBLOC(81)),(DEL(1)),VBLCC(101
)),(ETJ(1)),VBLOC(121)),(X(1)),VBLCC(141)),(V(1)),VBLCC(161)),(Z(1)),
VBLOC(181))
```

<u>Name:</u> INIT

<u>Calling Arguments:</u> None

<u>Referenced Sub-programs:</u> EPHEM, SETI

<u>Referenced Commons:</u> ALAN, HENRY, HIS, INTEG, JERR

<u>Entry Points:</u> None

<u>Referencing Sub-programs:</u> TRAJL

<u>Discussion:</u> This subroutine initializes selected variables at the start of each nominal trajectory. The values of those variables initialized to integer or real constants are shown in parentheses in the descriptions of the external variables below. Other initiatizations include setting the current reference body ID to that of the input launch body, the time of the first print point to the end of the first trajectory arc (CHN(15)), and an index limit, NPLAN3, is set to 3(NPLAN-2). Additionally, the planetary mass array ME is initialized to units of Earth masses if IREFNO is 1 or 2 and to units of sun masses, otherwise. If NPLAN, the number of planets included in the simulation, is greater than 1, additional initialization of propulsion system parameters is accomplished by calling subroutine SETI and the ephemeris data table is constructed by calling EPHEM. A return to the calling program is then executed.

<u>INIT EXTERNAL VARIABLES TABLE</u>

Variable	Use	Common	Description
KM(12)	S	HENRY	Array of planetary gravitational constants. (12*0.D0)
ME(12)	S	HENRY	Array of planetary masses, relative to Earth mass if IREFNO is 1 or 2 and to the sun mass otherwise.

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INIT EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
CHN (100)	U	HIS	Array of variables available for use as independent variables in the boundary value problem. Only the arc end times are used in this routine.
ETV(3)	S	JERR	Unit vector along nominal thrust vector in body coordinates. (1.D0, 0.D0, 0.D0)
MEI(12)	U	HENRY	Array of planetary masses in terms of Earth masses.
PDT	S	HENRY	Standard print interval, in hours. (0.D0)
TP1	D	HENRY	Time of next print point, in hours.
INTV(72)	S	HENRY	Array of position vectors of celestial bodies. (72*0.D0)
PCIN	S	HENRY	Print interval change indicator. (\[illegible\].D0)
CHIND	S	HENRY	Integration interval change indicator. (0.D0)
ITRIG	S	INTEG	Flag indicating whether an end-of-arc, a reference switch or a trajectory rectification was required on the last compute interval. (0)
NPLAN	U	INTEG	Number of planets included in simulation.
PRVDT	S	HENRY	Integration interval on previous step. (10^{33})
IDUMMY	S	INTEG	Flag indicating reason that a trajectory rectification is required. (4)

INIT EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
IREFNB	U	INTEG	Launch body identification number 1 - Earth 6 - Jupiter 2 - Not used 7 - Saturn 3 - Sun 8 - Uranus 4 - Venus 9 - Neptune 5 - Mars 10 - Pluto
IREFNO	S	INTEG	Current reference body identification number. Same numbering system as for IREFNB above.
NPLAN3	S	INTEG	Index limit defined as 3(NPLAN-2).

CHART TITLE - SUBROUTINE INIT

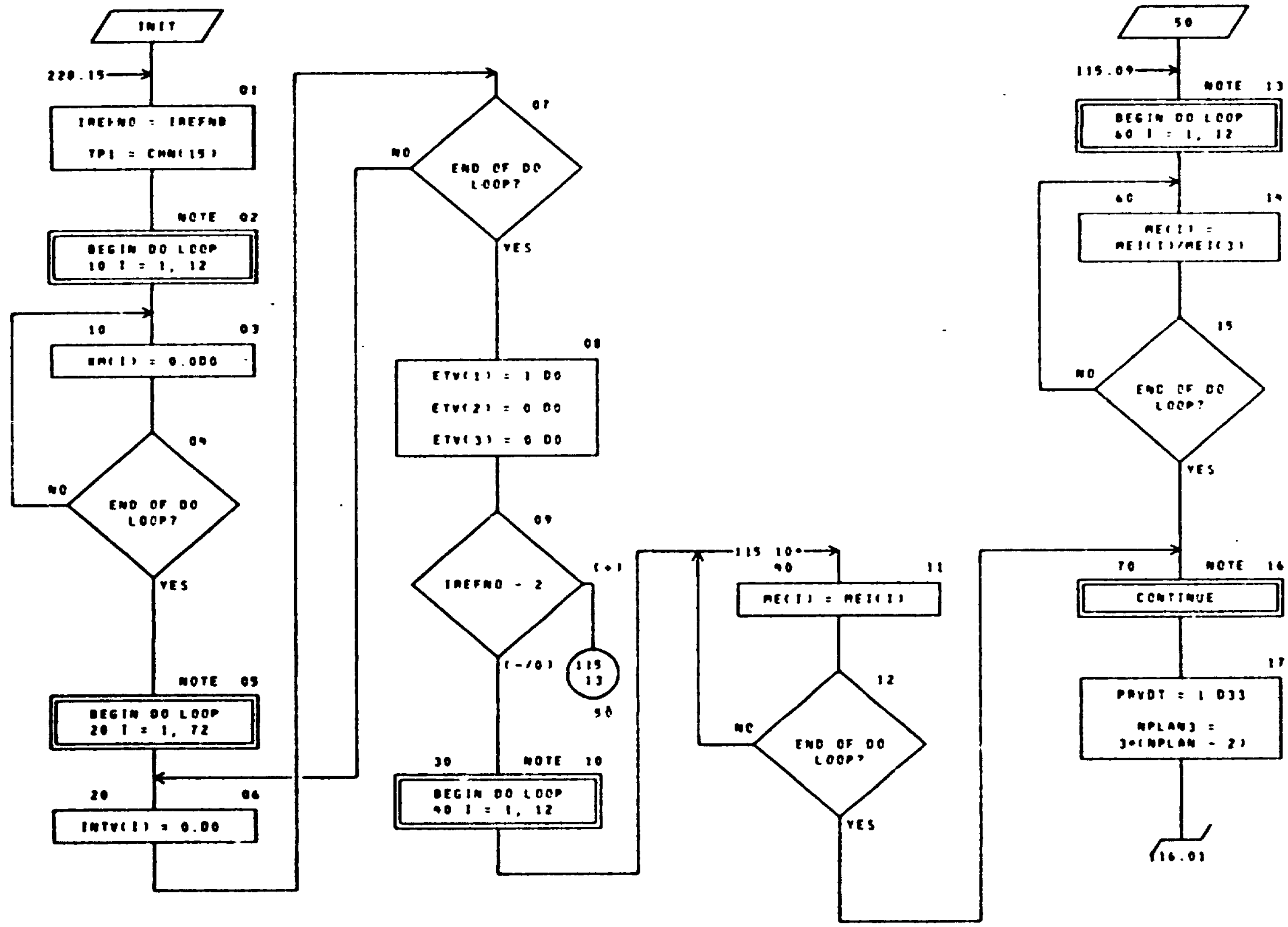


CHART TITLE - SUBROUTINE INIT

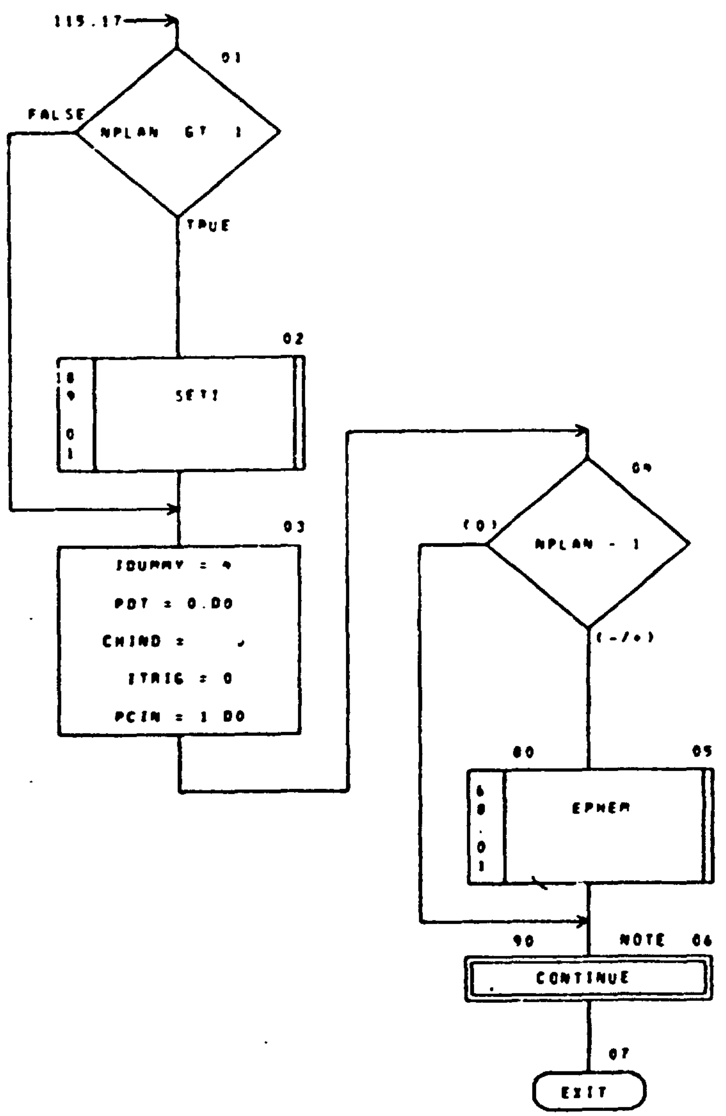


CHART TITLE - NON-PROCEDURAL STATEMENTS

```
IMPLICIT REAL*8(A-H,O-Z)
INTEGER YEAR,DAY,HOURS
REAL*8 KSQQ,MEI,ME,KM,MDIST,INTV,IN1X,IN2X
COMMON/ALAN/T,AMBR,DDRHO
COMMON/HENRY/ARRAY(8,3,12),CHIND,INTV(72),IN1X(3),
IN2X(3),KSQQ(12),KM(12),MDIST,MEI(12),ME(12),POSRCS,PRVDT,
PDT,PCIN,RD,REKM,RRM,RRE,RREU,RCIND,RATIO,SEC,TSCL,THTS,TP1,
TIMEL,THET,VELRCS
COMMON/HIS/PFG(30,30),WX(30),XVAR(30),YEPS(30),XEPS(30),
CHNS(100),CHN(100),POFL(30),XDAR(7)
COMMON/INTEG/DAY,HOURS,YEAR,IDUMMY,ITRIG,IREFNO,IREFNB,
IREFNT,IN,IC,IJR,MONTH,MIN,NCPT(72),NPLAN,NP,AN3
COMMON/JERR/VBLOC(200),A,CA,BL,DSQ,DELP,AC (10),SUMA,XKS,ETV(3),
ET(3),XKP,ER(3),CP1(7,30),TBIN(122),ETA,CR,XKK,X/T,XKST,APS,AL1,
AL2,AL3
```

<u>Name:</u> INPUT

<u>Calling Argument:</u> None

<u>Referenced Sub-programs:</u> MODIF

<u>Referenced Commons:</u> FNM, FRAN, HENRY, HER, HIM, HIS, ILEF, INPR, INTEG, JERR, KAT, LAMB, LPPR, MINEPS, MINSEC, NORM, NPNT, ODBALL, PERAPS, RADPRE, RSCAL, XMMM

<u>Entry Points:</u> None

<u>Referencing Sub-programs:</u> MAIN

<u>Discussion:</u> Subroutine INPUT reads the namelist input data for each case and performs selected array and variable initialization. On the first case only, the following input variables are initialized: MOPT, DP and ALS are set to zero, YAMBDA is set to 2^{-28}, and ENPLAN is set to six. In addition, certain elements of the input array ARRAY are initialized such that the integration interval is set to 0.00390625 (in units of the universal anomaly β) in all reference coordinate systems. Prior to reading the namelist inputs, the variables MOPTM and IPER are initialized to zero on all cases.

The inputs are read in under the namelist name MINPUT. If an end-of-file is encountered while reading the inputs, the run is immediately terminated. After completing the reading of one case of input data, all namelist input variables are immediately printed using the standard namelist print feature of the FORTRAN language. The working value of the iterator inhibitor, XAMBDA, is then equated to the input value YAMBDA.

The input array BX is inspected to determine the number and identity of the independent variables of the case to be run. For each independent variable for which the trigger is set non-zero, an independent variable counter is incremented by one, and the perturbation step size, the maximum step size, and the weight for the variable, all obtained from the input array BX, are stored in the arrays XVAR, XEPS, and WX. Data are stored sequentially in these arrays in the order of the second subscript of the BX array. A table of indices of the three arrays is also constructed which correlates each entry to a specific word in the CHN array. This table is stored in the array IVAR. The order of data in CHN is uniquely related to that of the second subscript of BX, but is not one-to-one. Specifically, for BX(I, J) and CHN(K), the relationship between J and K is as follows:

J	K
1	11
2-6	96-100
7-16	1-10
17-74	12-69

Finally, a tolerance representing a minimum step in the independent variable below which convergence is assumed is stored in the array EPS. All input variables in the BX array which are in units of degrees are converted to radians prior to storing in the condensed arrays. While cycling through the input BX array, the counter NVARY is accumulated which defines the number of independent variables which are functions of the initial position and velocity.

A similar inspection is then performed on the input BY array to identify the dependent variables, or end conditions, of the problem by cycling through BY with respect to its second subscript (see Inputs). If the trigger associated with a specific end condition is zero, all other information relating to that end condition is ignored. If the trigger is non-zero, then the desired value of the end condition is stored in the YCON array, the tolerance to which the end condition must be satisfied is stored in the YEPS array, the second subscript of the BY array, defining the identity of the end condition, is stored in the IPOFL array, and the dependent variable counter NDEP is incremented by one. The current value of the second subscript is compared to the input MOPT and, if equal, the common variable MOPTM is equated to the current value of NDEP. If the trigger BY(1,17), associated with target planet pericenter distance, is non-zero, special steps are taken because pericenter distance is a very sensitive end condition and a poor choice as a dependent variable. Instead of attempting to drive the solution to the desired pericenter distance, the program automatically transforms to a different set of end conditions which produces the same desired result, but which is much less sensitive. The pericenter distance trigger is set to zero and, in its place, the triggers associated with the Cartesian coordinates of the final position in target reference are set to 1. These triggers are BY(1,18), BY(1,19), and BY(1,20). The desired values of the Cartesian coordinates are evaluated internally for each trajectory using the specified pericenter distance and a specified final distance, input in BY(2,11). A flag IPER is set to 1 to indicate that the transformation has been performed.

The next function performed by INPUT is to transfer trajectory arc information from the doubly subscripted input array ARCDTA to the singly subscripted array TBIN after converting the angle ψ_{max} from degrees to radians. In the first word of TBIN is stored the end time of the first arc. In words 2-11 of TBIN is stored information pertaining to the second arc, the third arc data are stored in words 12-21, and so on. The information from ARCDTA for the second arc is stored as follows in TBIN:

TBIN(2)	-	trigger defining whether arc is thrust or coast
TBIN(3)	-	s/c orientation angle ξ or θ
TBIN(4)	-	s/c orientation angle ν or ψ
TBIN(5)	-	s/c orientation angle ζ or ϕ
TBIN(6)	-	maximum permissible value of ψ
TBIN(7)	-	housekeeping power, p_x
TBIN(11)	-	arc end time

The index of a specific element of TBIN for subsequent arcs is obtained by adding 10 for each arc to the index of the same element for the second arc as given above. The thrust/coast trigger of each arc for which the end time is treated as an independent variable of the boundary value problem is set to ±2, where the sign is the same as that input for the trigger. The end time t_f of the last arc is used to define the time interval DLEPH of the ephemeris tables, as follows:

$$DLEPH = 96(t_f/24000)$$

where both t_f and DLEPH are expressed in hours.

The input program option flags are printed and several variables are initialized from input paramters, including NOP63, NOP64, NOP65, RRE, NPLAN and NTPS. The last, NTPS, is set to one less than the number of trajectory arcs. If NTPS is greater than 12, the program is immediately terminated because several arrays are dimensioned to accomodate no more than 13 trajectory arcs. Additionally, the launch vehicle performance coefficient AL2 is converted from units of m/sec to ER/hr, and the angles ALPHA, BTA, DLTA, and EPSLON are converted from degrees to radians. The start time of each arc and the three spacecraft orientation angles associated with that arc are transferred from the TBIN array to the CHN array. For the second arc, the data are stored as follows:

CHN(15)	-	arc start time
CHN(16)	-	s/c orientation angle ξ or θ
CHN(17)	-	s/c orientation angle ν or ψ
CHN(18)	-	s/c orientation angle ζ or ϕ

The angles are in degrees in the TBIN array and are converted to radians prior to storing in CHN. The four parameters for the third arc are stored in CHN beginning in the 19th word, the fourth arc in the 23rd word, and so on. After storing the data for the last arc, the final time is then stored in the next word of CHN.

The solar array area a is evaluated with the formula

$$a = k_p p_o + \Delta a,$$

where k_p is the specific array area per unit reference power, p_o is the input

reference power and Δa is an input constant. The triggers IFTRG and ITC are set to 1 and 0, respectively, and subroutine MODIF is called to perform additional initialization. If the input option flag NOPT(56) is zero, a return from INPUT is executed. If NOPT(56) is non-zero, the input ephemeris osculating elements OMI, SOI, and CNI are converted to radians prior to executing the return.
Note: NOPT(56) should not be entered non-zero as the subroutine EPHEM is not presently capable of handling the ephemeris data for an arbitrary body.

Messages and Printouts: The only print from subroutine INPUT is that of the input namelist MINPUT in standard namelist format, and the formatted print of the program option flag array NOPT. The format is as follows:

```
OPTIONS NOPT(I)

 1   2   3   4  - - - - - - - - - - - - - - - - - - 36
                - - - - - - - - - - - - - - - - - -
__  __  __  __                                      __

37  38  39  40  - - - - - - - - - - - - - - - - - - 72
                - - - - - - - - - - - - - - - - - -
__  __  __  __                                      __
```

where the value of the NOPT flag is printed in place of the underscore.

INPUT EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
A	S	JERR	Solar array area, in m^2.
AO(10)	R	JERR	Solar array power law coefficients, a_i.
BL	R	JERR	Efficiency law coefficient, b.
BX(4,100)	RU	INPR	Array of independent variable information. For each available independent parameter, four pieces of information are required by the iterator. The first subscript, I, relates to these four

INPUT EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
BX(4,100) (cont)	RU	INPR	items; the second subscript, J, relates to the individual independent parameters. The four items are: I — Description 1 — Trigger defining whether variable is to be treated as an independent parameter. 2 — Perturbation step size used to compute partial derivatives. 3 — Maximum change in value of parameter allowed in a single iteration. 4 — Weighting factor. The index J uniquely identifies the independent variable as follows: J — Variable 1 — t_0-time of departure from Earth parking orbit, in hours. 2 — $\Delta\omega$-increment in initial argument of perigee, in degrees. 3 — $\Delta\Omega$-increment in initial longitude of ascending node, in degrees. 4 — Δi-increment in launch parking orbit inclination, in degrees. 5 — Δv_{po}-increment in geocentric speed at launch, in km/sec. 6 — v_{po}-geocentric speed at launch, in degrees. 7-9 — Cartesian coordinates of spacecraft position at launch from Earth parking orbit, in ER. 10-12 — Cartesian coordinates of spacecraft velocity at launch from Earth parking orbit, in ER/hr.

INPUT EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
BX(4,100) (cont)	RU	INPR	14 c-jet exhaust speed of electric propulsion system, in m/sec. 15 p_o-reference power, in watts. 16-17 α, β-angles defining direction of $\bar{n}$ relative to body fixed coordinate system, in degrees. 18-19 δ, ϵ-angles defining direction of $\bar{s}$ relative to body fixed coordinate system, in degrees. 20 End time of first arc, in hours. 4(i-2)+21 Orientation angle ξ or θ for ith arc, in degrees. 4(i-2)+22 Orientation angle ν or ψ for ith arc, in degrees. 4(i-2)+23 Orientation angle ζ or ϕ for ith arc, in degrees. 4(i-2)+24 End time of ith arc, in hours.
BY(3,30)	RU		Array of dependent variable information. For each a ilable dependent variable, corresponding to a specific value of the second subscript, L, the iterator requires three input quantities, one associated with each value of the first subscript, K. The three quantities are: K — Description 1 Trigger indicating whether the associated variable is to be treated as an end condition of the problem. 2 Desired value of the end condition. 3 Convergence tolerance. The possible end conditions and their codes are as follows:

INPUT EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
BY(3, 30) (cont)	RU		**L** — **Variable** 1 Initial mass less electric propulsion system propellant and retro propellant, in kg. 2 Net spacecraft mass, in kg. 3 Reference thrust $\lvert T\rvert_o$, in newtons. 4 Heliocentric distance r, in AU. 5 Heliocentric speed, v, in AU/hr. 6 Heliocentric semi-major axis, a, in AU. 7 Heliocentric flight path angle, γ, in degrees. 8 Heliocentric eccentricity, e. 9 Heliocentric apoapse distance, r_a, in AU. 10 Heliocentric periapse distance, r_p, in AU. 11 Planetocentric distance, r_T, in AU. 12 Planetocentric speed, v_T, in AU/hr. 13 Planetocentric semi-major axis, a_T, in AU. 14 Planetocentric flight path angle, γ_T, in degrees. 15 Planetocentric eccentricity, e_T. 16 Planetocentric apoapse distance, r_{T_a}, in AU. 17 Planetocentric periapse distance, r_{T_p}, in AU. When this perameter is flagged as an end condition, its trigger is automatically reset to zero as is that of r_T (L = 11), and the triggers of the Cartesian coordinates (L = 18 - 20) are set to one. The

INPUT EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
BY(3, 30) (cont)	RU		desired values of r_T and the tolerances of the Cartesian coordinates must be input. IPER is set internally to re-evaluate the desired values of the Cartesian coordinates on each trajectory. 18-20 Cartesian coordinates of vehicle position with respect to the target, in AU. 21-30 Not used. Available for expansion.
CA	R	JERR	Coefficient of absorption, c_a, of the solar arrays.
CE	RE	HIS (CHN(8))	Jet exhaust speed, c, of electric propulsion stage, in m/sec.
CR	R	JERR	Jet exhaust speed, c_r, of the retro stage, in m/sec.
DP	RU		Input incremental solar array area, Δa, in m^2.
ER(3)	R	JERR	Cartesian components of the constrained $\bar{s}$ vector.
IN	U	INTEG	Logical unit on which input data is read.
IO	U	INTEG	Logical unit on which principal program output is written.
P0	RUE	HIS (CHN(9))	Solar array reference power, p_o, in watts.
RM	S	PERAPS	Desired final distance from target planet, in AU.
RP	S	PERAPS	Desired periapse distance of target approach trajectory, in AU.
WX(30)	S	HIS	Independent variable weight array, W_x.

Variable	Use	Common	Description
CHN(100) (cont)	SUE	HIS	The next several words are grouped in sets of four, with each set pertaining to a trajectory arc. Let i denote the trajectory arc number, with $2 \leq i \leq 13$, then the data stored in the next several locations of CHN are as follows: 4(i-2) +16 - s/c orientation angle ξ or θ 4(i-2) +17 - s/c orientation angle ν or ψ 4(i-2) +18 - s/c orientation angle ζ or ϕ 4(i-2) +19 - arc end time The last five words in CHN are as follows: 96 - increment in initial argument of periapse, $\Delta\omega$. 97 - increment in initial longitude of ascending node, $\Delta\Omega$. 98 - increment in equatorial inclination, Δi. 99 - increment in speed at periapse, Δv_{po}. 100 - speed at departure from Earth parking orbit, v_{po}.
CNI	RSU	ODBALL	Ecliptic inclination of input celestial body, in degrees. (Not presently available).
DSQ	R	JERR	Efficiency law coefficent, d^2, in m^2/sec^2.
ECI	R	ODBALL	Orbital eccentricity of input celestial body. (Not presently available).

INPUT EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
AL1	R	JERR	Launch vehicle performance coefficient, a_1, in kg.
AL2	RSU	JERR	Launch vehicle performance coefficient, a_2, in m/sec.
AL3	R	JERR	Launch vehicle performance coefficient, a_3, in kg.
APS	R	JERR	Specific propulsion system mass, α_{ps}, in kg/watt.
BTA	RSUE	HIS (CHN(12))	Angle β between the projection of $\bar{n}$ in the I - J body fixed plane and the I-axis, positive in the direction of J, in deg.
CHN(100)	SUE	HIS	Array containing the values, in internal units, of all variables available as independent variables. The variables associated with each index value are: 1-3 - initial spacecraft position vector 4-6 - initial spacecraft velocity vector 7 - initial spacecraft mass 8 - jet exhaust speed of electric propulsion system 9 - reference power 10 - angle α defining orientation of $\bar{n}$ 11 - initial time 12 - angle β defining orientation of $\bar{n}$ 13 - angle δ defining orientation of $\bar{s}$ 14 - angle ϵ defining orientation of $\bar{s}$ 15 - time at end of first trajectory arc

INPUT EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
EMU	S	PERAPS	Gravitational constant of target planet, in AU^3/hr^2, except when the target is Earth the units are in ER^3/hr^2.
EPS(30)	S	MINEPS	Array of minimum independent variable step sizes below which convergence is assumed.
ITC	S	LPPR	Flag used to indicate whether headings for trajectory summary print have been initialized.
ITF	R	MINSEC	Time, in seconds, to be reserved for calculating the final trajectory.
NPR	R	NPNT	Flag used to indicate whether partial derivative matrix is to be printed.
OMI	R	ODBALL	Longitude of ascending node of input celestial body, in degrees. (Not presently available).
POS(3)	RE	HIS (CHN(1))	Cartesian coordinates of the initial spacecraft position in geocentric ecliptic coordinates, in ER.
RRE	S	HENRY	Radial distance from Earth at which the reference coordinate system is switched between Earth and sun, in ER.
RTA	R	FNM	Apocenter distance of capture orbit about target planet, in planetary radii.
RTP	R	FNM	Pericenter distance of capture orbit about target planet, in planetary radii.
SAI	R	ODBALL	Semi-major axis of input celestial body orbit, in AU. (Not presently available).
SOI	RSU	ODBALL	Argument of periapse of input celestial body, in degrees. (Not presently available.

INPUT EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
TPI	R	ODBALL	Julian date of perihelion passage (with leading 244 omitted) of input celestial body. (Not presently available).
VEL(3)	RE	HIS (CHN(4))	Cartesian coordinates of the initial spacecraft velocity in geocentric ecliptic coordinates, in ER/hr.
XKP	RU	JERR	Specific area of solar arrays, k_p, in m^2/watt.
XKR	R	JERR	Tankage factor of the retro stage, k_r.
XKS	R	JERR	Solar pressure, k_s, acting on a flat plate at a distance of 1 AU from the sun assuming all photons are absorbed, in newtons/m^2.
XKT	R	JERR	Tankage factor of the electric propulsion system, k_t.
DELP	R	JERR	Reference power of an individual thruster, in watts.
DLTA	RUE	HIS (CHN(13))	Angle between $\bar{s}$ and its projection in the I-J body fixed plane, in degrees.
IPER	S	PERAPS	Flag which, when non-zero, indicates that an internal transformation was performed to change from an end condition specifying periapse distance to a set of 3 end conditions specifying final position.
IVAR(100)	SU	HER	Array of indexes which relates entries in the independent variable arrays XVAR, XEPS, EPS, and WX to entries in the array CHN.
KSQQ(12)	U	HENRY	Array of planetary gravitational constants, in AU^3/hr^2 except for Earth and moon (KSQQ(1) and KSQQ(2)) which are in units of ER^3/hr^2.

INPUT EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
MOPT	RU		Index defining which of the available end conditions is to be the performance index of the direct optimization procedure. The correlation with specific end conditions is the same as the second subscript of the BY array.
NDEP	SU	HER	Number of dependent variables for the current case.
NIND	SU	HER	Number of independent variables for the current case.
NOPT(72)	RU	INTEG	Array of program option flags. The flags 2-13 and 40-46 control the printing of spacecraft position, in km, or velocity, in km/sec, relative to various reference frames, except as noted: 2 - position relative to current reference body. 3 - velocity relative to current reference body. 4 - position relative to Earth 5 - position relative to moon (not available). 6 - moon position relative to Earth, in km (not available). 7 - position relative to sun. 8 - position relative to Venus. 9 - position relative to Mars. 10 - position relative to Jupiter. 11 - position deviation from reference two-body, in km. 12 - velocity deviation from reference two-body, in km/sec. 13 - non-two body accelerations on s/c, in km/sec^2.

INPUT EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
NOPT(72) (cont)	RU	INTEG	40 & 41 - position relative to Saturn. 40 & 42 - position relative to Uranus. 40 & 43 - position relative to Neptune. 40 & 44 - position relative to Pluto. 40 & 45 - position relative to E-M bary-center (not available). 40 & 46 - position relative to Mercury (not available). Other flags used in the program are: Index — Purpose 16 — Rectification print 33 — Changes units of semi-major axis in printout of osculating elements. 56 — Signifies orbital elements of target are input. (Not presently available). 57 — Indicates a retro maneuver is required. 58 — Iterator commences in optimize mode. 60 — The printout flagged by the NOPT flags described above is provided for all trajectories rather than just the final. 63 — ID number of planet toward which $\bar{s}$ is directed. 64 — Indicates type of constraint placed on $\bar{s}$ 65 — Defines constrained or unconstrained mode.

INPUT EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
NOPT(72) (cont)	RU	INTEG	66 Indicates solar or nuclear electric propulsion system. 68 Forces arrays to be oriented normal to sun; ignores fixed s/c-array orientation constraint.
NPWR	RU	HER	Number of terms in the series expression for the power curve.
NTPS	SU	HER	Index equal to the number of trajectory arcs minus 1.
RBRE	RU	LAMB	Radial distance from Earth at which the reference coordinate system is switched between Earth and sun, in ER.
REKM	R	HENRY	Conversion factor, equal to the number of kilometers on one ER.
TBIN(122)	SU	JERR	Array of trajectory arc information. The first location contains the end time of the first arc, in hours. Thereafter, ten sequential array locations are reserved for each trajectory arc. Data are stored in the same sequence for all trajectory arcs after the first arc. The order is as shown below for the second arc. Index — Variable 2 Thrust/coast flag. 3 Orientation angle ξ or θ, in degrees. 4 Orientation angle ν or ψ, in degrees. 5 Orientation angle ζ or ϕ, in degrees. 6 ψ_{max}, in radians. 7 Housekeeping power, p_x, in watts.

INPUT EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
TBIN(122) (cont)	SU	JERR	8-10 Not used. 11 Arc end time, in hours. Data for the third arc are stored in locations 12-21, and so on. After the arc end time of the last arc, the number 1. is stored in the next location.
THTS	R	HENRY	Eccentric anomaly change criteria for rectifying the reference two-body trajectory, in radians.
TSCL	R	HENRY	Time conversion factor for input/output. Defaulted to 3600.
XDAR(7)	R	HIS	Perturbation step sizes for position, velocity and mass to be used at start of each trajectory arc for generating state transition matrix. Units are AU, AU/hr and kg.
XEPS(30)	S	HIS	Array of maximum changes permitted in independent parameters. Angles are in radians; all other units are the same as those of the BX array.
XJLD	R	LAMB	Julian date of launch with leading 244 omitted.
XKST	R	JERR	Structure factor of the spacecraft, k_{st}.
XVAR(30)	S	HIS	Array of perturbation step sizes, of the independent variables, used to compute partial derivatives. Angles are in radians; all other units are the same as those of the BX array.
YCON(30)	S	HIM	Array of desired values of dependent variables. Units are the same as those of the BY array.

INPUT EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
YEPS(30)	S	HIS	Array of allowable tolerances to which end conditions must be satisfied. Units are the same as those of the BY array.
ALPHA	RSUE	HIS (CHN(10))	Angle α between $\bar{n}$ and its projection in the body fixed I-J plane, in degrees. Positive in the sense of K.
DLEPH	S	NORM	Time interval, in hours, between successive entries in the ephemeris tables.
EMUDD	R	ODBALL	Gravitational constant of the input celestial body, in AU^3/hr^2. (Not presently available.)
IFTRG	S	HER	First trajectory flag. A value of 1 indicates the current trajectory is the first trajectory of a case.
IPOFL(30)	S	HER	Array of indices correlating elements of the dependent variable arrays YCON and YEPS to associated elements of the BY array.
ITMAX	R	HER	Maximum number of iterations permitted in MINMX3 in either the select or optimize mode.
MOPTM	S	YMMM	Index of the YCON array defining the performance index.
NARCS	RU		Total number of trajectory arcs.
NOPT63	S	ILEF	NOPT(63).
NOPT64	S	ILEF	NOPT(64).
NOPT65	S	ILEF	NOPT(65).
NPLAN	S	INTEG	Integer equal to the input variable ENPLAN.

INPUT EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
NVARY	SU	HER	Number of independent variables that are functions of the initial position or velocity.
TIMEL	R	HENRY	Maximum time, in hours from launch, for which ephemeris data is stored in the tables.
WTOPT	R	XMMM	Weighting parameter associated with the performance index. Used only when the iterator is in the optimize mode. Increasing the magnitude of WTOPT results in the iterator placing more importance on improving the performance index and less on meeting the specified end conditions.
XMDKM	R	FRAN	Conversion factor for distance. Defaulted to the number of kilometers in one AU.
ARCDTA (7, 20)	RU	INPR	Array of data pertaining to the various trajectory arcs. The second subscript corresponds to the arc number. The data associated with the 7 values of the first subscript are as follows: 1 - arc end time, in hours. 2 - thrust/coast flag 3 - orientation angle ξ or θ, in degrees. 4 - orientation angle ν or ψ, in degrees. 5 - orientation angle ζ or ϕ, in degrees. 6 - ψ_{max}, in degrees. 7 - housekeeping power, p_x, in watts.
ENPLAN	RU		Defines which planets are included in the trajectory simulation. All bodies whose ID number (see IREFNB below) is less than or equal to ENPLAN are included in the simulation.

INPUT EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
EPSLON	RSUE	HIS / (CHN(14))	Angle ϵ, in degrees, between the projection of $\bar{s}$ in the body fixed I-J plane and the I-axis, positive in the sense of J.
IREFNB	R	INTEG	Identification number of the launch planet. 1 - Earth 5 - Mars 9 - Neptune 2 - not available 6 - Jupiter 10 - Pluto 3 - Sun 7 - Saturn 4 - Venus 8 - Uranus
IREFNT	R	INTEG	Identification number of the target planet. Same options as for IREFNB.
POSRCS	R	HENRY	Rectification criterion for position deviation from the reference two-body trajectory.
VELRCS	R	HENRY	Rectification criterion for velocity deviation from the reference two-body trajectory.
XAMBDA	S	KAT	Iterator inhibitor, λ.
YAMBDA	RU		Starting value of iterator inhibitor. If not input, a value of 2^{-28} is used.

CHART TITLE - SUBROUTINE INPUT

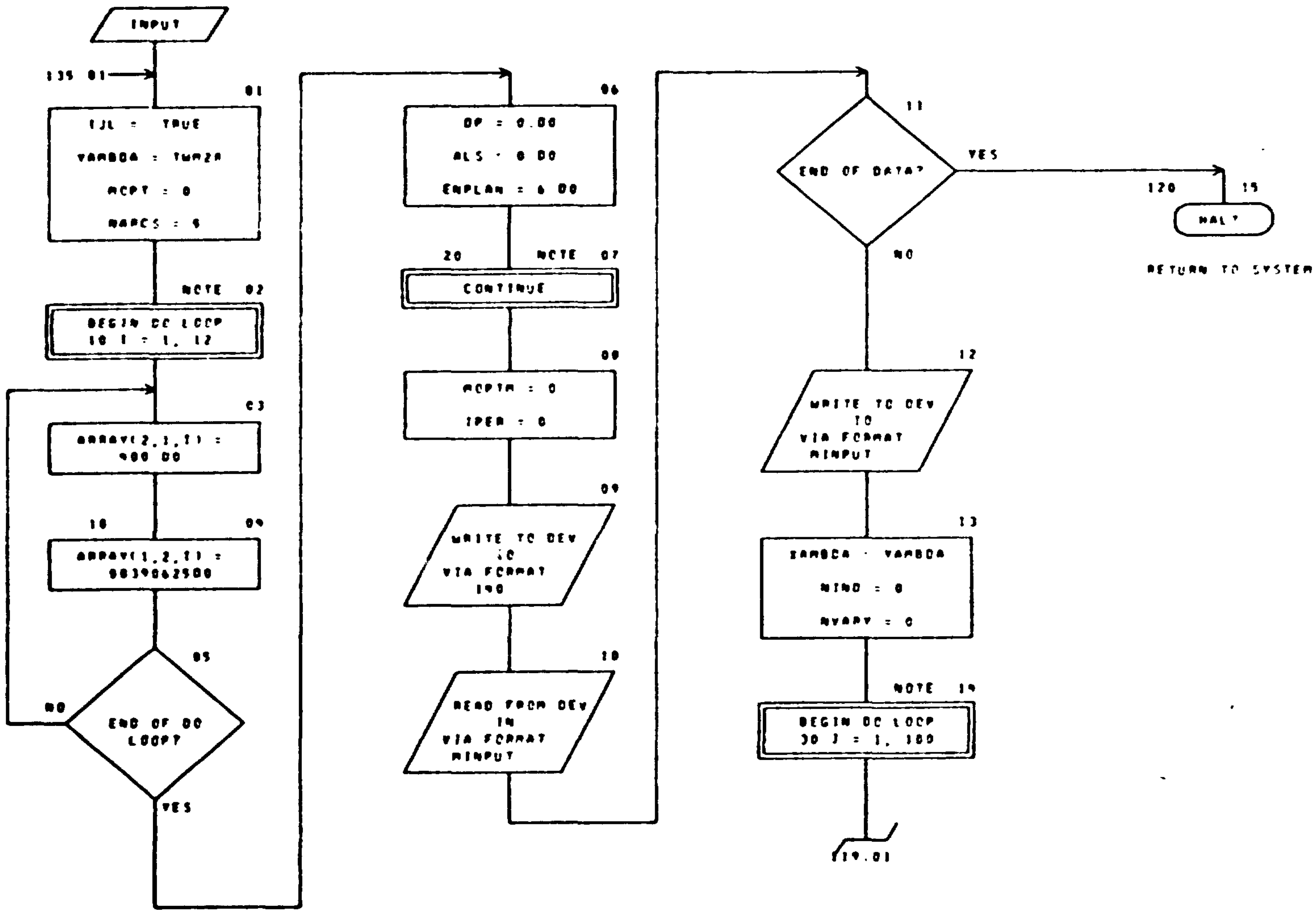
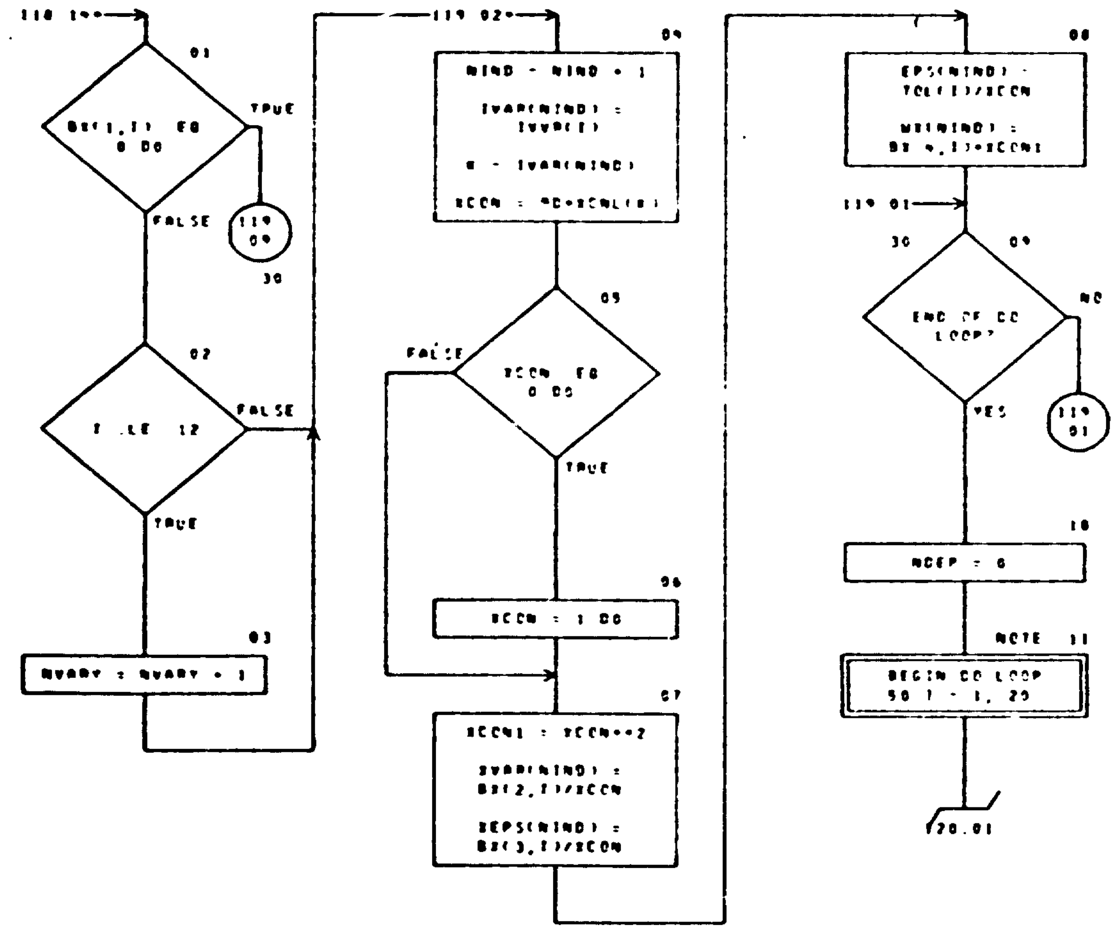


CHART TITLE - SUBROUTINE INPUT



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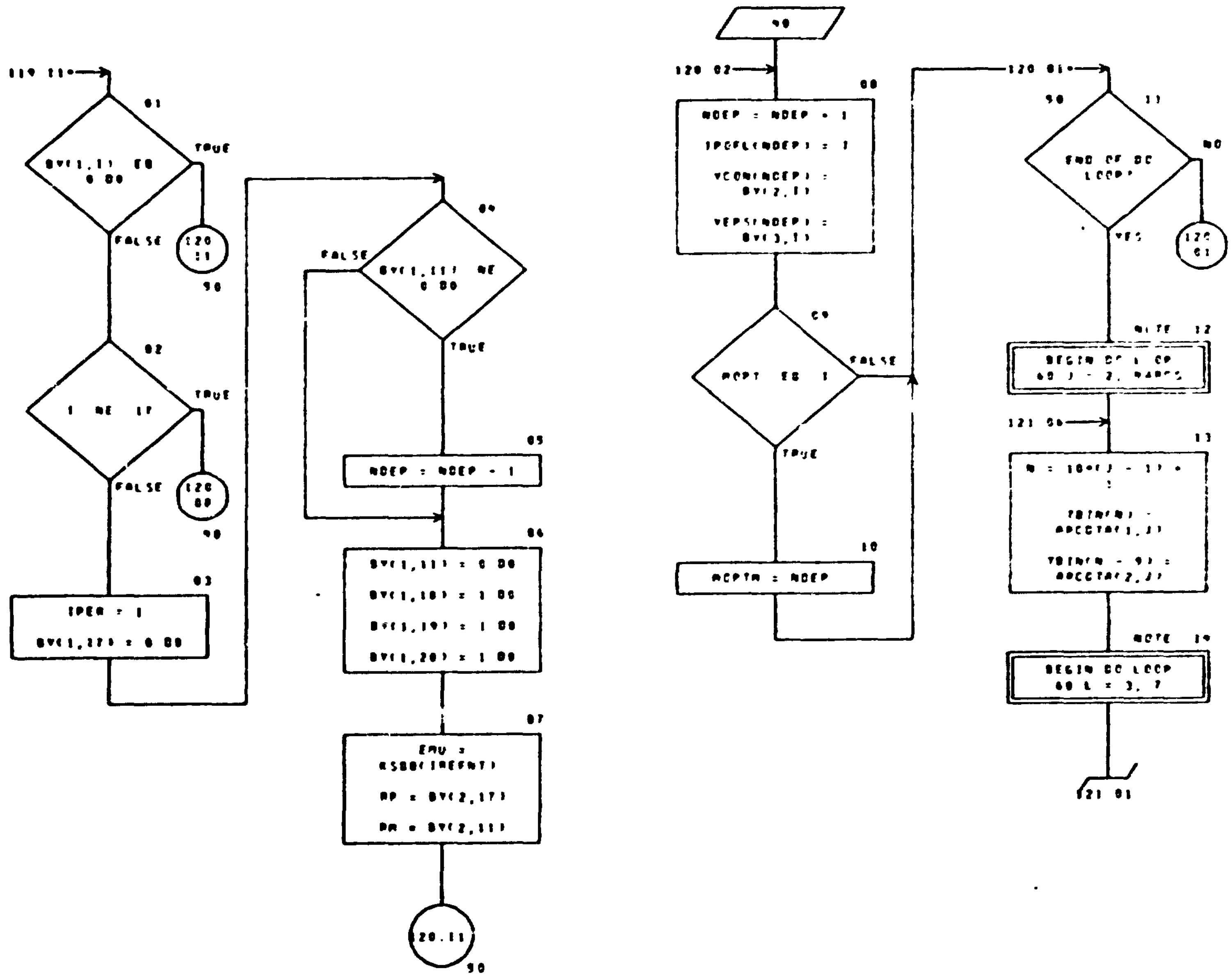

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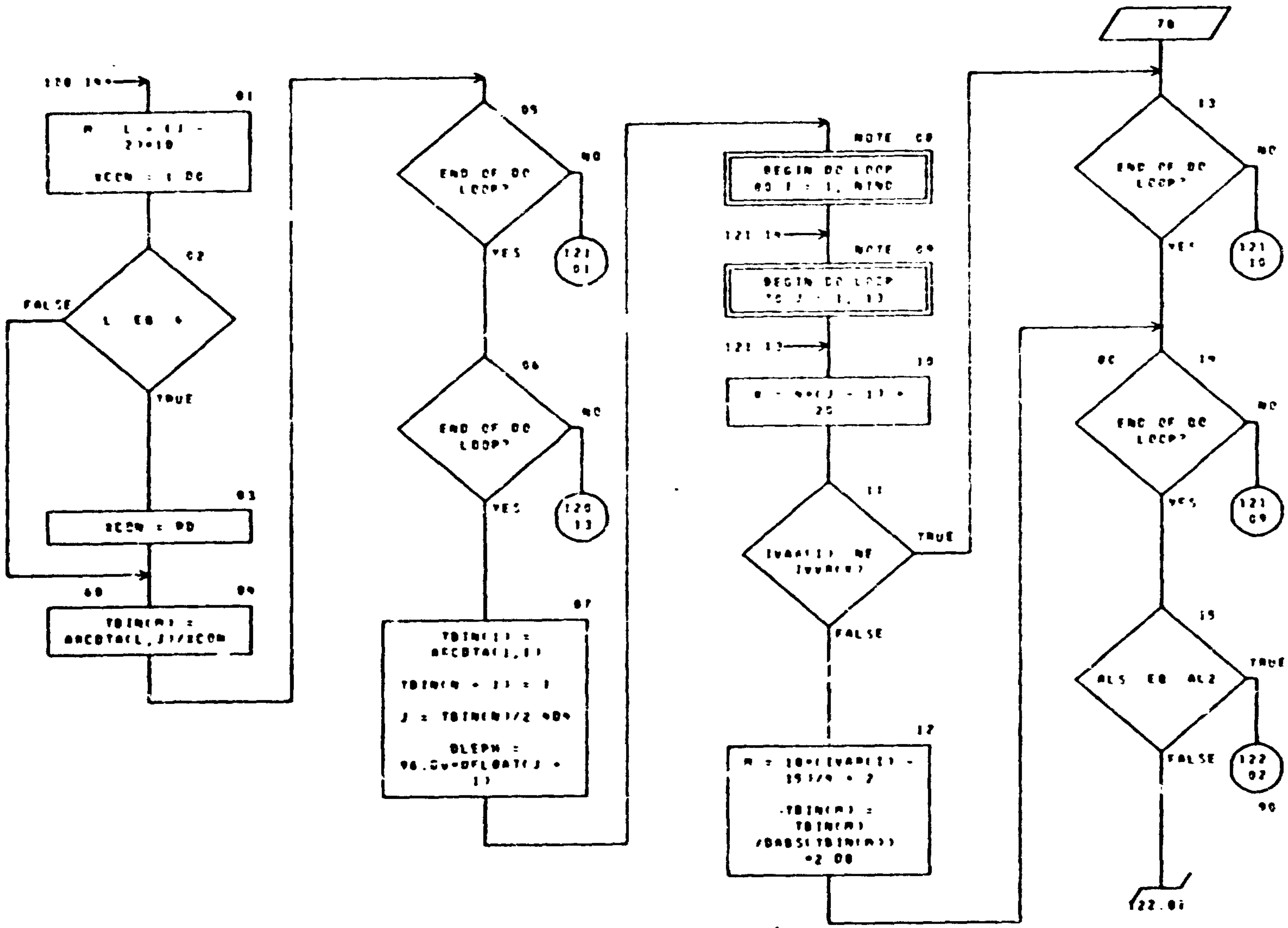
CHART TITLE - SUBROUTINE INPUT



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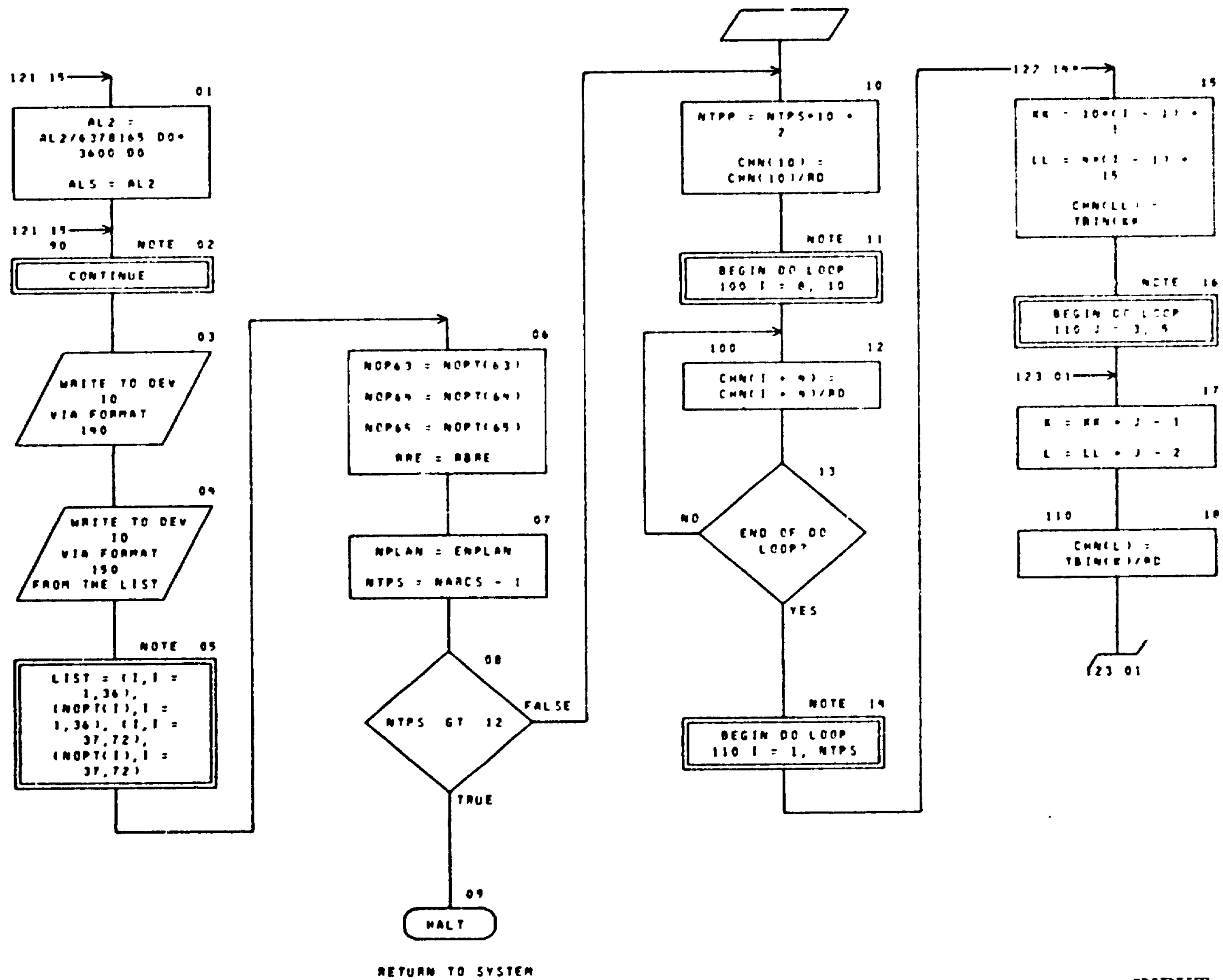

CHART TITLE - SUBROUTINE INPUT

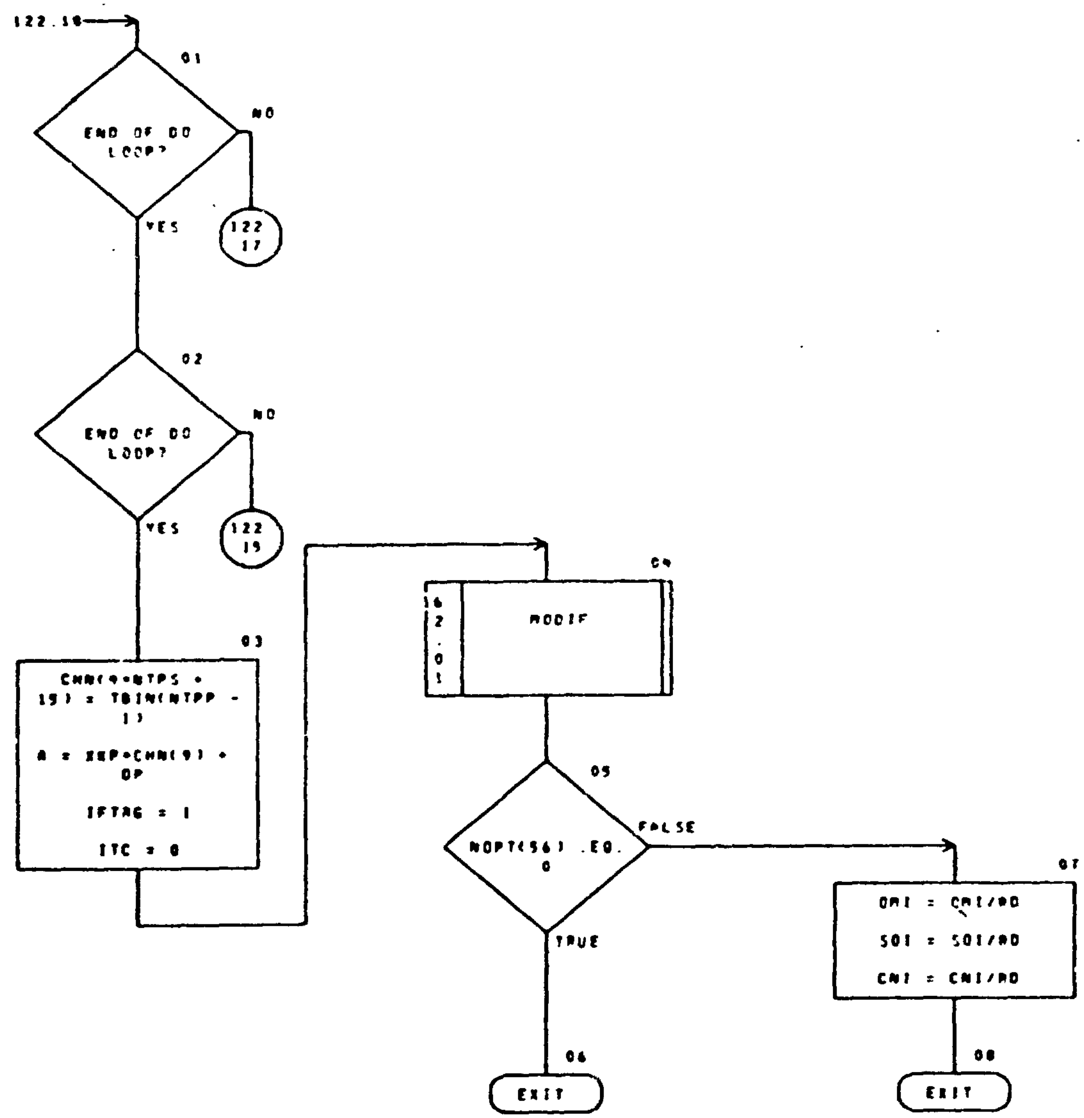

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
IMPLICIT REAL*8 (A-H,O-Z)
INTEGER YEAR,DAY,HOURS
LOGICAL IJL
REAL*8 KSQQ,MEI,ME,KM,MDIST,INTV,IN1X,IN2X
DIMENSION XCNL(100),POS(3),VEL(3),TOL(50),IVVR(75),BV(3,30)
COMMON/FNP/RTA,RTP
COMMON/FRAN/XMDRP
COMMON/HENRY/ARRAY(8,3,12),CHIND,INTV(72),IN1X(3),
IN2X(3),KSQQ(12),KM(12),MDIST,MEI(12),ME(12),POSRCS,PRVCT,
PDT,PCIN,RD,REKM,RRM,RRE,RREU,RCIND,RATIO,SEC,TSCL,THTS,TP1,
TIMEL,THET,VELRCS
COMMON/HER/NDEP,NIND,NSL1,IFTAG,ITCT,IPOFL(30),IVAR(100),ITMAX,NTP
,NTPS,NPWR,NJ,JN,IPAT,NCT1,NVARY
COMMON/HIM/YCON(30)
COMMON/HIS/PFG(30,30),WX(30),XVAR(30),YEPS(30),XEPS(30),
CHNS(100),CHN(100),PCFL(30),XDAR(7)
COMMON/ILEF/NEQL,NEQ3,NON,NCP65,IOAR(7),NCP64,NCP63,NS,N4,NS1,NJJ
COMMON/INPR/ ARCDTA(7,20),BX(4,100)
COMMON/INTEG/DAY,HOURS,YEAR,IDUMMY,ITRIG,IREFNC,IREFNB,
IREFNT,IN,IO,IJK,MONTH,MIN,NOPT(72),NPLAN,NPLAN3
COMMON/JERR/VBLOC(200),A,CA,BL,DSQ,DELP,AC (10),SUMA,XKS,ETV(3),
ET(3),XKP,ER(3),CP1(7,30),TBIN(122),ETA,CR,XER,XET,XKST,RPS,AL1,
AL2,AL3
COMMON/KAT/XAMBDA,KOUNT,LKAT
COMMON/LAMB/XJLD,XINJ,RBRE,LOPT
```

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
      COMMON/LPPR/ITC
      COMMON/MINEPS/EPS(30)
      COMMON/MINSEC/ITF
      COMMON/NORM/TREF,DLEPH,ITBL(22)
      COMMON/NPNT/NPR
      COMMON           /ODBALL/SAI,ECI,CNI,OMI,SOI,TPI,EMUDD,RADOOD
      COMMON /PERAPS/ RDOT(3),RM,RP,EMU,IPER
      COMMON/RSCAL/RLP,RPHAT(3),HCP(3),RCPML(3)
      COMMON/XMMM/E(30),Q(30),QMIN(30),QMAX(30),WTOPT,ROPTM
      EQUIVALENCE (POS(1),CHN(1)),(VEL(1),CHN(4)),
     (CE,CHN(8)),(PO,CHN(9)),(ALPHA,CHN(10)),( BTA,CHN(12)),
     ( DLTA,CHN(13)),(EPSLON ,CHN(14))
      DATA IVVP/11,96,97,9  9,100,1,2,3,4,5,6,7,8,9,10,12,13,14,15,
     16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,
     37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,
     58,59,60,61,62,63,64,65,66,67,68,69/
      DATA XCNL/9*0 D0,1 D0,0 D0,3*1 D0,0 D0,3*1 D0,0 D0,3*1.D0,0 D0,
     3*1 D0,0 D0,3*1.D0,0 D0,3*1 D0,0 D0,3*1 D0,0 D0,3*1 D0,0 D0,
     3*1 D0,0 D0,3*1.D0,0.D0,3*1 D0,0 D0,3*1 D0,0 D0,3*1 D0,0 D0,
     3*1.D0,0 D0,3*1 D0,0 D0,3*1 D0,0 D0,3*1 D0,0 D0,3*1 D0,0 D0,
     3*1.D0,0.D0,3*1.D0,0 D0,3*1 D0,0 D0,3*1 D0,2*0 D0/
      DATA TOL/4*5.D-8,8*1 D-10,3*1 D-6,35*5.D-8/
      DATA BY/90*0.D0/
      DATA TWM28/Z3A10000000000000/
      DATA IJL/.FALSE./
```

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
          NAMELIST/MINPUT/ALPHA,AL1,AL2,AL3,AC,APS,ARCCTA,ARRAY,BL,BTA,BX,
          BY,CA,CE,CNT,CR,DELP,DLTA,DP,DSQ,ECI,EMUDD,ENPLAN,EPSLON,ER,
          IREFNB,IREFNT,ITF,ITMAX,MCPT,NARCS,NCPT,NPR,NPWR,OMI,PCS,PCSPCS,
          PS,PSPE,PTEM,RTA,RTP,SAI,SCI,THTS,TIMEL,TPI,TSCL,WTOPT,VEL,
          VELOCY,XBAR,XJLC,XKP,XKR,XKS,XR??,XXT,XMCHP,YARBCA
140       FORMAT (1H1)
150       FORMAT (1H0 OPTIONS  NOPT(I) //(36I3/))
```

Name: INT

Calling Arguments: NN, X, JZ, ANS, DTL, IR1

Referenced Sub-programs: None

Referenced Commons: NORM, NORML

Entry Points: None

Referencing Sub-programs: CONTRL, DERIV, FINDXB, FNMAT

Discussion: This subroutine is a multi-function, variable order Lagrange interpolation routine. It assumes the functions to be interpolated are stored in the array TBBL at a constant interval DTL in the independent variable. It assumes that a total of 250 tabular points are stored for each function. The number of functions to be interpolated is NN. The tabulations of these NN functions are stored in contiguous 250 word segments of TBBL, the first segment starting in location JZ + 1. The number of points employed in the interpolation is given by IR1, which is one greater than the order of the interpolation. The current value of the independent variable is X, and the interpolated values are output in the array ANS. Provisions are made to avoid interpolation if the current value of the independent variable is at a tabular point, in which case the tabular values of the functions are used.

In ASTOP, the order of interpolation used is always five; i.e., IR1 is always 6. Providing the current value of the independent variable is not near either end of the 250 point tabular entries, the six points used for interpolation are selected such that three points lie on each side of the current value. If three points on either side are not available because the current time lies near one end, then the first six points or last six points of the table, whichever is appropriate, are used. If the current value of the independent variable lies outside the range of the tables, a return to the calling program is executed. Denoting the tabular values of the function to be interpolated as y_i, $i = 1-6$; the corresponding values

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of the independent variable as x_i, and the current value of the independent variable as x, then the interpolated value of the function, y, is evaluated

$$y = \frac{\frac{y_1}{(x-x_1)} - \frac{5y_2}{(x-x_2)} + \frac{10y_3}{(x-x_3)} - \frac{10y_4}{(x-x_4)} + \frac{5y_5}{(x-x_5)} - \frac{y_6}{(x-x_6)}}{\frac{1}{(x-x_1)} - \frac{5}{(x-x_2)} + \frac{10}{(x-x_3)} - \frac{10}{(x-x_4)} + \frac{5}{(x-x_5)} - \frac{1}{(x-x_6)}}$$

INT EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
X	UX		Current value of independent variable.
JZ	UX		Starting location minus 1 of the tabular values in TBBL of the first function to be interpolated.
NN	UX		Number of functions to be interpolated.
ANS(NN)	SX		Array of interpolated values.
DTL	UX		Interval between tabulated points.
IR1	UX		Number of points used in interpolation, $3 \le$ IR1 ≤ 7.
TBBL (12000)	U	NORML	Table of dependent variable values.
TREF	U	NORM	Value of independent variable associated with the first entries in TBBL for all dependent variables.

CHART TITLE - SUBROUTINE INT(NN,X,JZ,ANS,DTL,IRI)

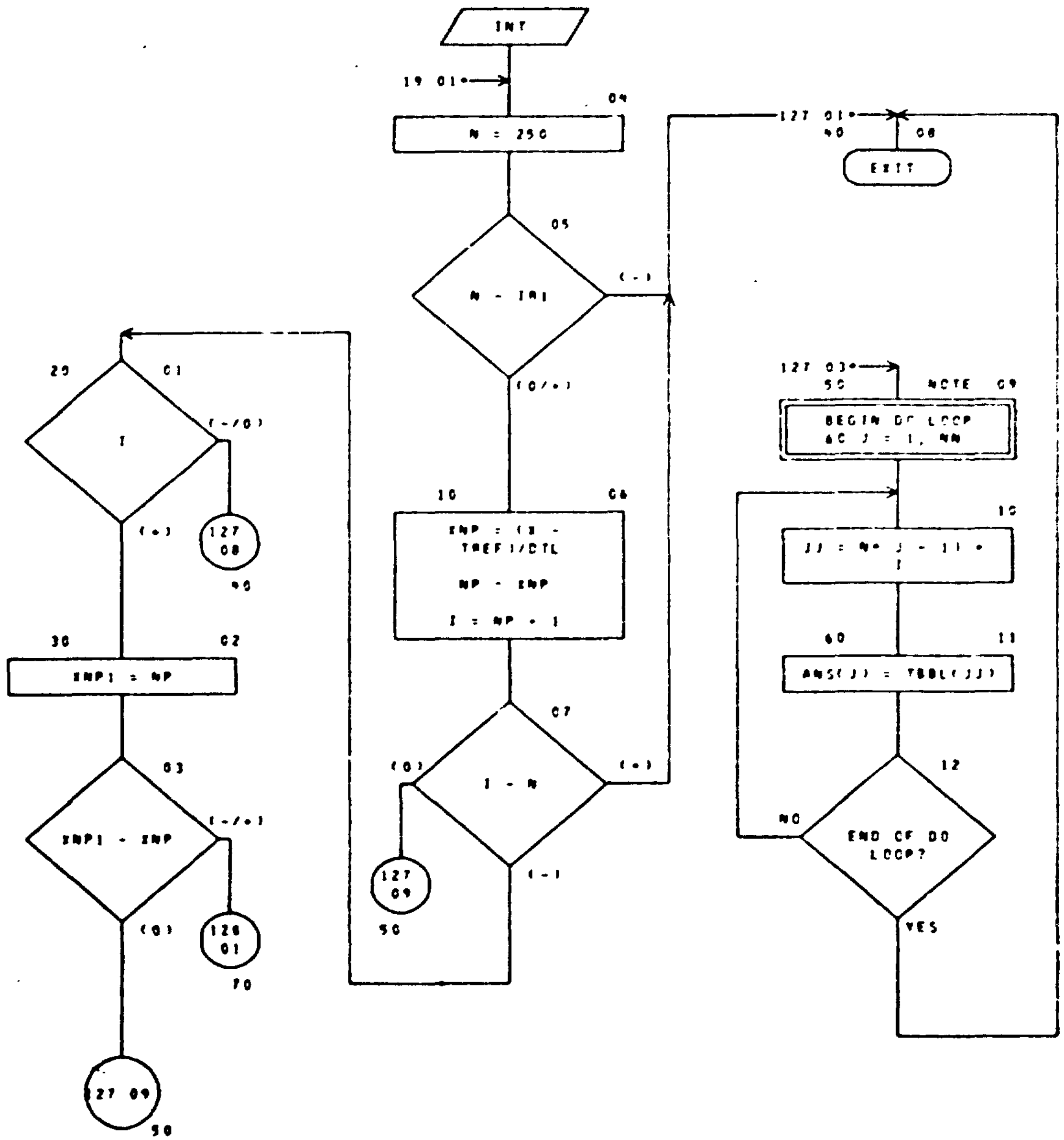

CHART TITLE - SUBROUTINE INT(NN,X,JZ,ANS,DTL,IR1)

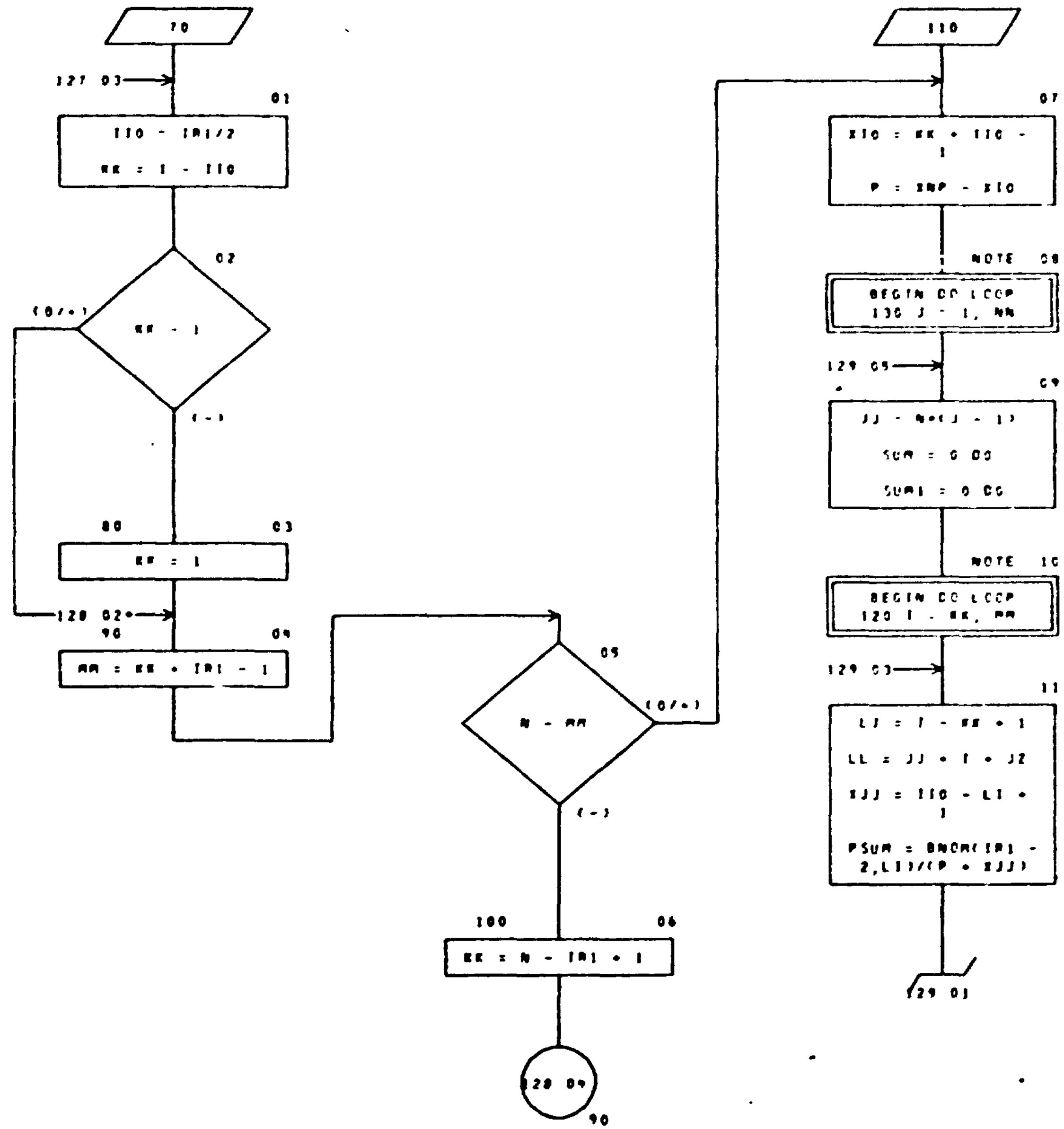

CHART TITLE - SUBROUTINE INT(NN,X,JZ,ANS,DTL,IRI)

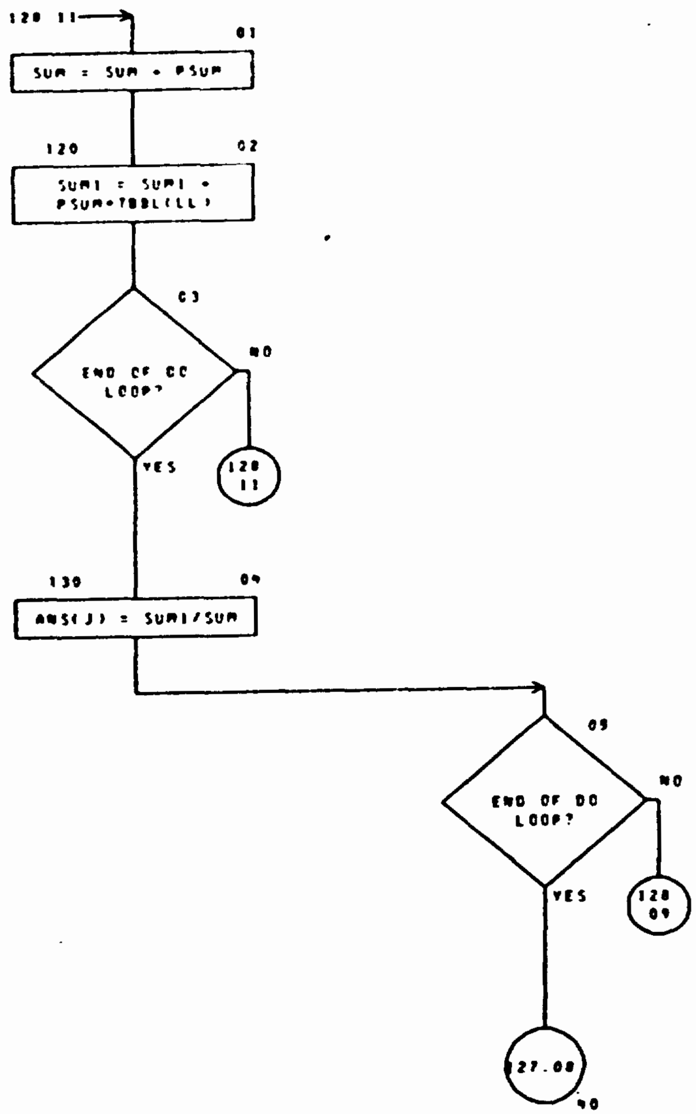

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
IMPLICIT REAL*8(A-H,O-Z)
DIMENSION BNCM(5,7),ANS(1)
COMMON/NCAM/TREF,DLEPH,ITBL(22)
COMMON/NCAML/TBBL(12000)
DATA BNCM/1 D0,1 D0,1 D0,1 D0,1 D0,
-2 D0,-3 D0,-4 D0,-5 D0,-6 D0,
1 D0,3 D0,6 D0,10 D0,15 D0,
0 D0,-1 D0,-4 D0,-10 D0,-20 D0,
0 D0,0 D0,1 D0,5 D0,15 D0,
0 D0,0 D0,0 D0,-1 D0,-6 D0,
0 D0,0 D0,0 D0,0 D0,1 D0/
```

Name: ITMAT

Calling Argument: None

Referenced Sub-programs: MINMX3, FNPRNT

Referenced Commons: HER, HIM, HIS, INTEG, YMMM

Entry Points: None

Referencing Sub-programs: MAIN

Discussion: This subroutine performs the final initialization required before entering the iterator, and then activates the iterator MINMX3 and the printing of the final trajectory. The arrays initialized are MSET, B, QMIN and QMAX. The iterator is then called. Upon return from MINMX3, an error flag is checked and if an error condition was detected, a message is printed and the case is terminated. If there were no error conditions, a convergence indicator is checked. If convergence is indicated, a message is printed. In either case, a call to FNPRNT is then executed to print the final trajectory. A return to MAIN is then executed.

Messages and Printout: If convergence is indicated upon return from MINMX3, the following message is printed:

CASE CONVERGED

prior to printing the final trajectory. If an error condition was detected in MINMX3, the message

ERROR CONDITION RETURNED FROM MINMX3. RUN TERMINATED IN SUBROUTINE ITMAT

is printed.

ITMAT EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
B(30)	S	XMMM	Array of independent variable values, obtained from the CHN array.
IO	U	INTEG	Logical unit used for printout.
CHN(100)	U	HIS	Array of variables available as independent parameters of the boundary value problem. Detailed description provided in subroutine INPUT.
IPS	U	HER	Number of dependent variables.
NSL	U	HER	Number of independent variables.
IVAR(100)	U	HER	Array of indexes relating the independent variables in B to the corresponding elements of CHN.
MSET(5)	SA		Array of counters and triggers used by MINMX3. The five elements are: 1 - number of independent variables, NSL 2 - number of dependent variables, IPS 3 - maximum number of iterations permitted in the select mode, ITMAX 4 - flag indicating whether iterator commences in select or optimize mode, NOPT(58) 5 - maximum number of iterations permitted in the optimize mode, ITMAX
NOPT(72)	U	INTEG	Array of program option flags.
QMAX(30)	S	XMMM	Array of upper allowable limits of dependent variables on converged trajectory.
QMIN(30)	S	XMMM	Array of lower allowable limits of dependent variables on converged trajectory.

ITMAT EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
YCON(30)	U	HIM	Array of desired values of dependent variables.
YEPS(30)	U	HIS	Array of allowable end condition tolerances.
ITMAX	U	HER	Maximum number of iterations permitted.
XCONVG	UA		Trajectory convergence indicator.
XERROR	UA		MINMX3 error condition indicator.

CHART TITLE - SUBROUTINE ITMAT

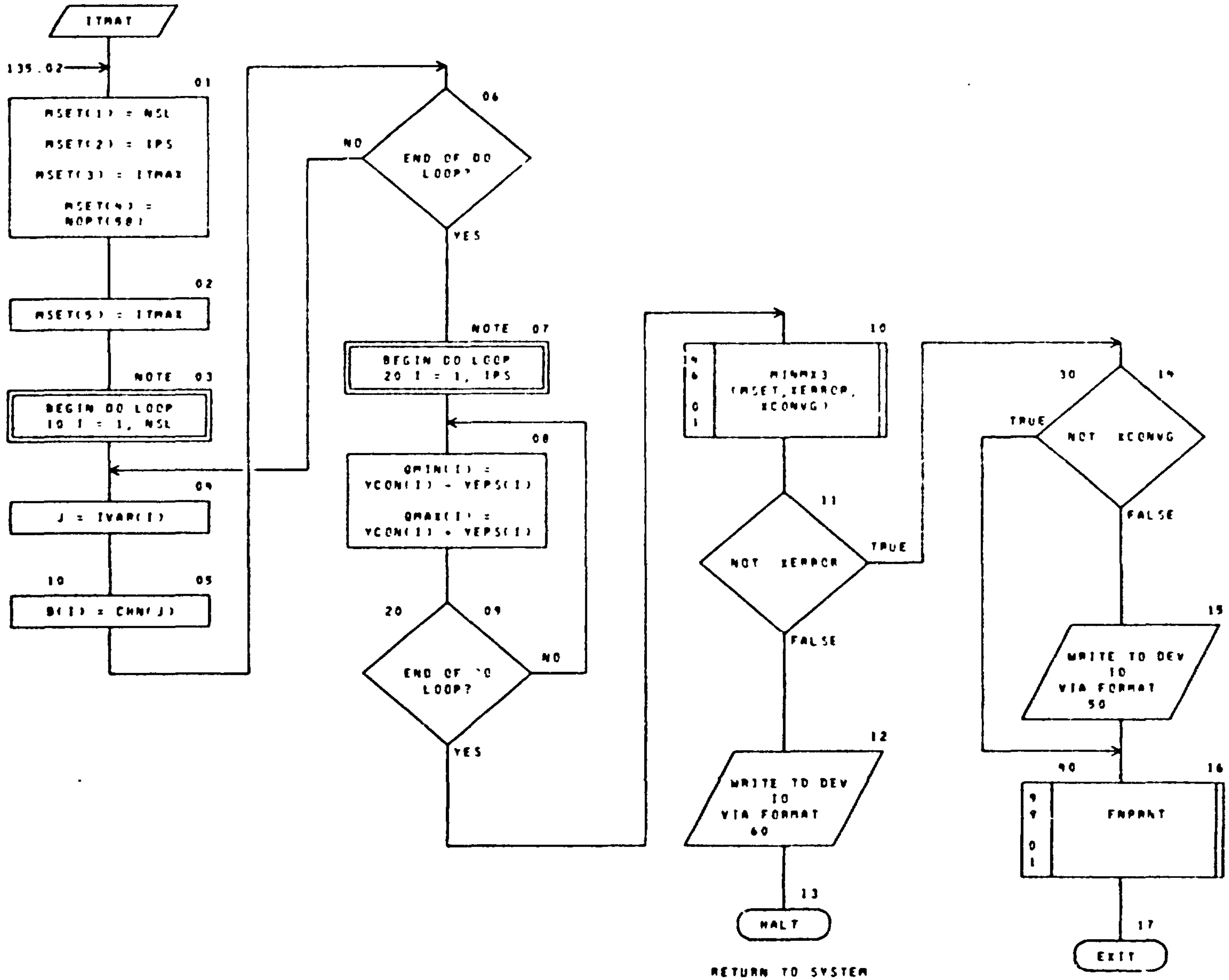

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
          IMPLICIT REAL*8 (A-H,O-Z)
          INTEGER DAY,HOURS,YEAR
          LOGICAL XERROR,XCONVG
          DIMENSION MSET(5)
          COMMON/MER/IPS,NSL,NSL1,IFTRG,ITCT,IPOFL(30),IVAR(100),ITMAX,NTP,
          NTPS,NMAX,NJ,JN,IPAT,NCT1,NJL
          COMMON/MIM/YCON(30)
          COMMON/MIS/PEG(30,30),MX(30),XVAR(30),VEPS(30),XEPS(30),
          CHNS(100),CHN(100),POFL(30),XDAR(7)
          COMMON/INTEG/DAY,HOURS,YEAR,IDUMMY,ITRIG,IREFNC,IREFNB,
          IREFNT,IN,IC,IJK,MONTH,MIN,NOPT(72),NPLAN,NPLAN2
          COMMON/XMMM/B(30),Q(30),QMIN(30),QMAX(30),WTOPT,MOPTM
 50       FORMAT ('   CASE CONVERGED')
 60       FORMAT ('0ERROR CONDITION RETURNED FROM MINMX3  RUN TERMINATED '
          'IN SUBROUTINE ITMAT ')
```

Name: LAMBRT

Calling Argument: None

Referenced Sub-programs: PDATE

Referenced Commons: ALAN, HENRY, HIS, INTEG, JERR, LAMB, RSCAL, VPLLL

Entry Points: None

Referencing Sub-programs: MODIF

Discussion: LAMBRT performs additional case initialization as an extension of subroutine MODIF. Subroutine PDATE is called to determine the calendar date of launch from the input Julian date and the current time, t, is set to zero. The speed v_{po} at departure from the Earth's parking orbit is calculated from the input velocity and stored in the CHN and CHNS arrays (location 100 in each). The radial distance at departure from the launch parking orbit is computed from the input position vector. A unit vector along the initial geocentric velocity is computed and stored in the array RDPML. The launch vehicle payload m_ℓ is computed using the formula

$$m_\ell = a_1 e^{-v_{po}/a_2} - a_3$$

where a_1, a_2, and a_3 are the input launch vehicle coefficients. This mass is equated to the initial spacecraft mass and stored in CHN(7). The initial geocentric position vector is stored in the array RPHAT and CHN(11), the initial time in hours from the input Julian date, is set to zero.

LAMBRT FXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
AL1	U	JERR	Launch vehicle coefficient, a_1, in kg.
AL2	U	JERR	Launch vehicle coefficient, a_2, in ER/hr.
AL3	U	JERR	Launch vehicle coefficient, a_3, in kg.
CHN(100)	SU	HIS	Array of available independent variables.
DAY	A	INTEG	Day of the month of launch.
RLP	S	RSCAL	Radial distance from Earth at launch, in ER.
CHNS(100)	S	HIS	Same as CHN, with units changed for printout purposes.
HOUR	A		Hour of the day of launch.
TBET	S	ALAN	Current time in hours from launch.
VP00	SU	VPLLL	Geocentric speed at departure of parking orbit, in ER/hr.
XJLD	U	LAMB	Julian date of launch with leading 244 omitted.
XJLM	SA		Julian date of launch with leading 24 omitted.
YEAR	A	INTEG	Calendar year of launch.
MONTH	A	INTEG	Calendar month of launch.
RDPML(3)	S	RSCAL	Unit vector along initial geocentric velocity.
RPHAT(3)	S	RSCAL	Initial geocentric position vector, in ER.

CHART TITLE - SUBROUTINE LAMBRT

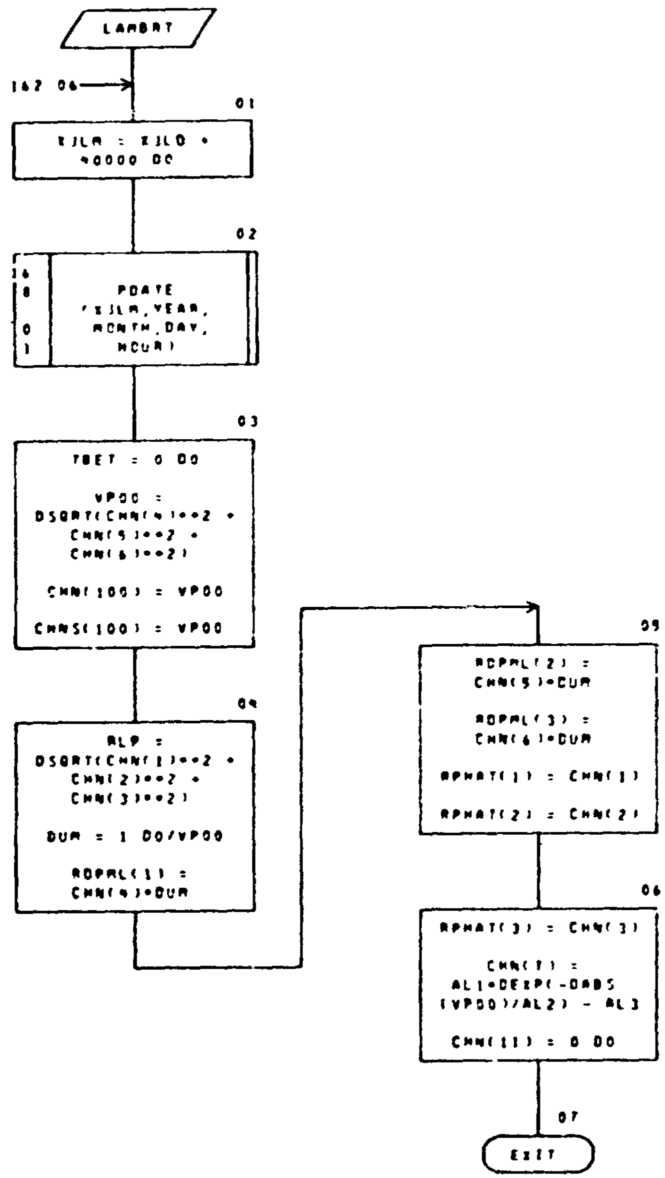

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
IMPLICIT REAL*8(A-H,O-Z)
INTEGER YEAR,DAY,HOURS
REAL*8 KSQQ,MEI,ME,KM,MDIST,INTV,IN1X,IN2X
COMMON/ALAN/TBET,RHBP,DORHC
COMMON/HENRY/ARRAY(8,3,12),CHIND,INTV(72),IN1X(3),
IN2X(3),KSQQ(12),KM(12),MDIST,MEI(12),ME(12),PCSACS,PFVOT,
POT,PCIN,PO,REKM,RAM,RRE,RREU,RCIND,RATIO,SEC,TSCL,THTS,TP1,
TIMEL,THET,VELPCS
COMMON/HIS/PFG(30,30),WX(30),XVAR(30),VEPS(30),XEPS(30),
CHNT(100),CHN(100),PCFL(30),XDAR(7)
COMMON/INTEG/DAY,HOURS,YEAR,IDUMMY,ITRIG,IREFNC,IREFNB,
IREFNT,IN,IC,IJK,MONTH,MIN,NCPT(72),NPLAN,NPLAN3
COMMON/JERR/VBLCC(200),A,CA,BI,DSQ,DELP,AC(10),SUPA,XKS,ETV(3),
ET(3),XKP,ER(3),CP1(7,30),TBIN(122),ETA,CR,XKK,XKT,XKST,APS,AL1,
AL2,AL3
COMMON/LAMB/KJLO,XINJ,RBRE,LCPT
COMMON/RSCAL/RLP,PPHAT(3),HCR(3),PCPAL(3)
COMMON/VPLLL/VPOO,ITD,ITC1
```

<u>Name:</u> MAIN

<u>Calling Arguments:</u> Not applicable

<u>Referenced Sub-programs:</u> INPUT, ITMAT

<u>Referenced Commons:</u> None

<u>Entry Points:</u> Not applicable

<u>Referencing Sub-programs:</u> Not applicable

<u>Discussion:</u> The only purposes of the MAIN program are to call subroutines INPUT and ITMAT, in that order. Upon returning from ITMAT, execution is terminated.

11/23/74

CHART TITLE - PROCEDURES

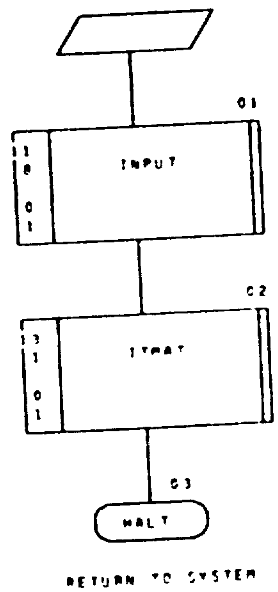

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
IMPLICIT  REAL * 8 (A-H,O-Z)
```

Name: MIIP1

Calling Arguments: None

Referenced Sub-programs: ELCO

Referenced Commons: ALAN, AM1, FRAN, HENRY, ILEF, INTEG, LEFT

Entry Points: None

Referencing Sub-programs: GENMA, TRAJL

Discussion: Subroutine MIIP1 prints spacecraft position, velocity, and/or acceleration vectors relative to selected planets and calls ELCO to print osculating orbital elements. This print is executed at the current time point. If MIIP1 is called while integrating the nominal and perturbation trajectories simultaneously, the print is executed at the current time point for each of the trajectories.

Upon entry to the routine the current time is evaluated in terms of days, hours, minutes and seconds from departure of the launch parking orbit. This time is printed and a conversion factor is defined to convert distances from the current internal units, ER or AU, to kilometers. The NOPT flags, 2-13 and 40-46, are then checked for the desired printout vectors. (See discussion of NOPT array in subroutine INPUT). If the NOPT flag is non-zero, the corresponding position, velocity or acceleration vector is printed in the form of its Cartesian components and its magnitude. After checking all appropriate NOPT flags, subroutine ELCO is called to print the osculating orbital elements at the current time.

Messages and Printout: The current time is printed

TIME IN DAYS, HRS., MINS., SECS. (I8) (I8) (I8) (F10.3)

where the numbers in parentheses denote the Fortran format code of the field represented by the underline. The following optional lines of printout* are obtained, depending on the NOPT flags:

*For the definition of the vector printed, see the definition of the associated NOPT flag in subroutine INPUT.

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If NOPT(2) $\neq 0$,

XR= ______	YR= ______	ZR= ______	RR= ______

If NOPT(3) $\neq 0$,

XRDT= ______	YRDT= ______	ZRDT= ______	RRDT= ______

If NOPT(4) $\neq 0$,

XVE= ______	YVE= ______	ZVE= ______	RVE= ______

If NOPT(5) $\neq 0$,

XVM= ______	YVM= ______	ZVM= ______	RVM= ______

If NOPT(7) $\neq 0$,

XVS= ______	YVS= ______	ZVS= ______	RVS= ______

If NOPT(8) $\neq 0$,

XVVN= ______	YVVN= ______	ZVVN= ______	RVVN= ______

If NOPT(9) $\neq 0$,

XVMR= ______	YVMR= ______	ZVMR= ______	RVMR= ______

If NOPT(10) $\neq 0$,

XVJP= ______	YVJP= ______	ZVJP= ______	RVJP= ______

If NOPT(11) $\neq 0$,

XI= ______	ETA= ______	ZETA= ______	PERT= ______

If NOPT(12) $\neq 0$,

XIDT= ______	ETADT= ______	ZETADT= ______	VPERT= ______

If NOPT(13) $\neq 0$,

D2XI= ______	D2ETA= ______	D2ZETA= ______	APERT= ______

If NOPT(40) and NOPT(41) ≠ 0,

XVP1= ______ YVP1= ______ ZVP1= ______ RVP1= ______

If NOPT(40) and NOPT(42) ≠ 0,

XVP2= ______ YVP2= ______ ZVP2= ______ RVP2= ______

If NOPT(40) and NOPT(43) ≠ 0,

XVP3= ______ YVP3= ______ ZVP3= ______ RVP3= ______

If NOPT(40) and NOPT(44) ≠ 0,

XVP4= ______ YVP4= ______ ZVP4= ______ RVP4= ______

If NOPT(40) and NOPT(45) ≠ 0,

XVP5= ______ YVP5= ______ ZVP5= ______ RVP5= ______

If NOPT(40) and NOPT(46) ≠ 0,

XVP6= ______ YVP6= ______ ZVP6= ______ RVP6= ______

MIIP1 EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
IO	U	INTEG	Logical unit on which standard printout is written.
NQN	U	ILEF	Number of state equations integrated on each trajectory, including second order and first order.
XIL(80)	U	AM1	Second integrals of Encke terms of nominal and perturbation trajectories.

MHP1 EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
XRL(6,20)	UA	LEFT	Position vectors of spacecraft from reference body on nominal and perturbation trajectories. The dimension of six provides for the magnitude, square and cube of the distance as well as the three Cartesian components.
KSQQ(12)	UA	HENRY	Array of planetary gravitational constants.
NEQL	U	ILEF	Number of trajectories being integrated simultaneously, nominal plus perturbed.
NOPT(72)	U	INTEG	Array of program option flags.
REKM	U	HENRY	Conversion factor for distance, equal to the number of kilometers in one ER.
TBET	U	ALAN	Current time in hours from departure of the launch parking orbit.
TSCL	U	HENRY	Conversion factor for time, defaulted to 3600.
VCOL(72,20)	U	LEFT	Array of spacecraft position vectors relative to all perturbing bodies on nominal and perturbed trajectories. Includes Cartesian coordinates plus magnitude, square and cube of distance.
XIDL(80)	U	AM1	First integral of Encke terms of nominal and perturbation trajectories.
XRDL(6,20)	UA	LEFT	Velocity vectors of spacecraft relative to the reference body on nominal and perturbation trajectories. Includes Cartesian coordinates plus magnitude, square and cube of speed.
D2XIL(80)	U	AM1	Array of second derivatives representing the Encke perturbations for the nominal and perturbation trajectories.

MHP1 EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
MPRNT	SUA		Current time, equal to TBLT.
XMDKM	U	FRAN	Conversion factor for distance, equal to the number of kilometers in 1 AU.
IREFNO	UA	INTEG	Identification number of current reference body.

CHART TITLE - SUBROUTINE MIIP1

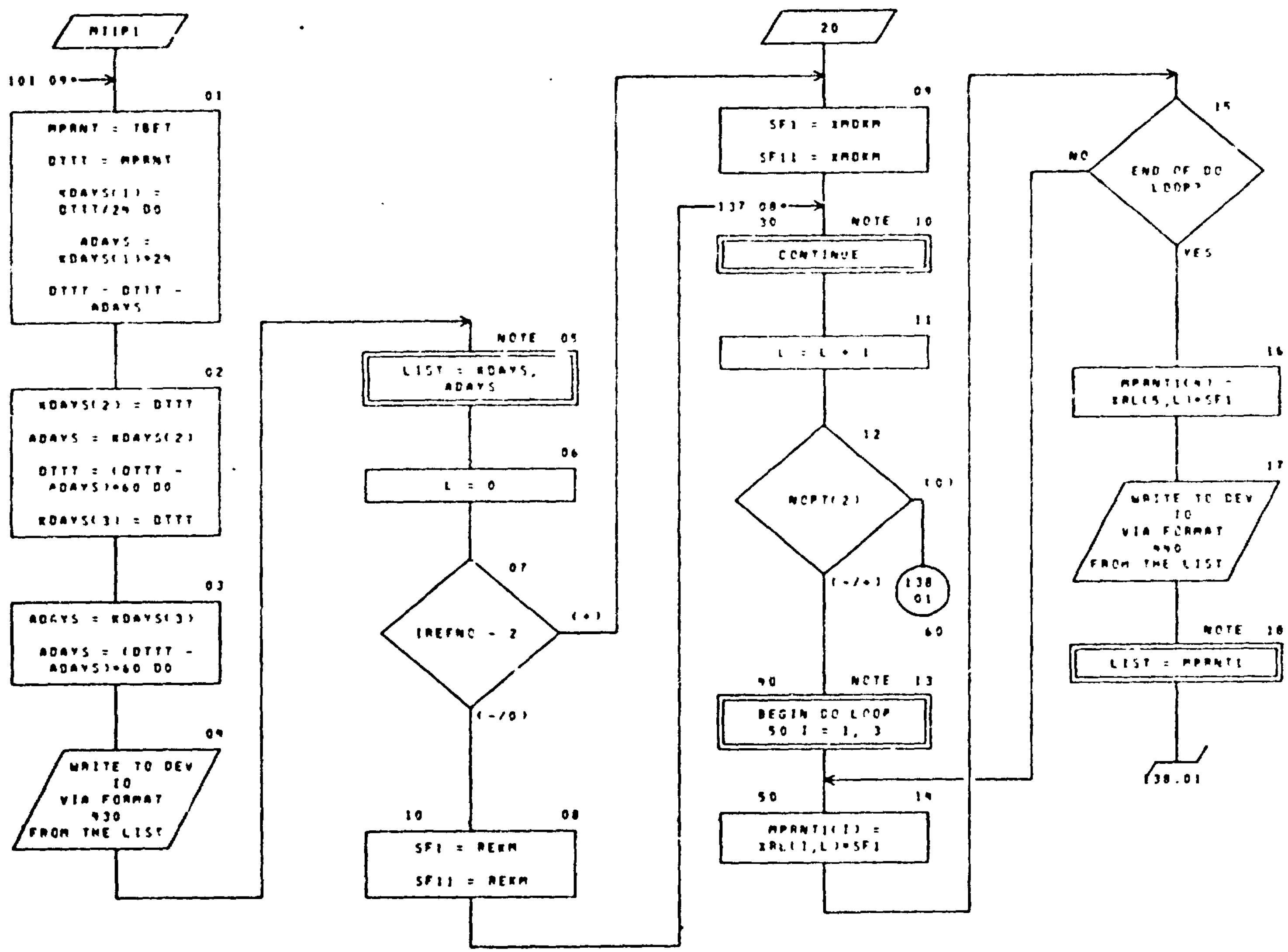
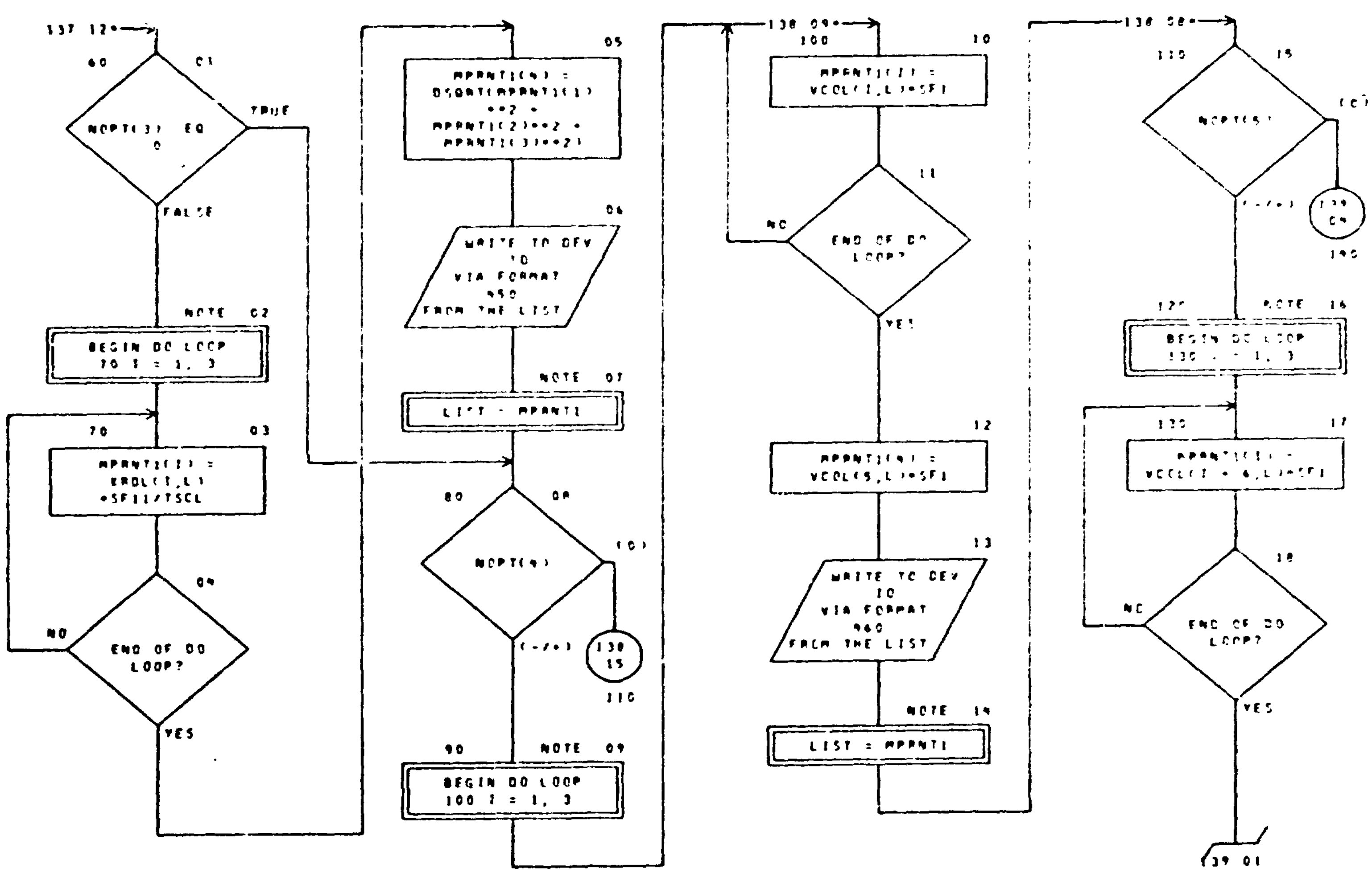


CHART TITLE - SUBROUTINE MIIP1



MIIP1-7

CHART TITLE - SUBROUTINE MIIPI

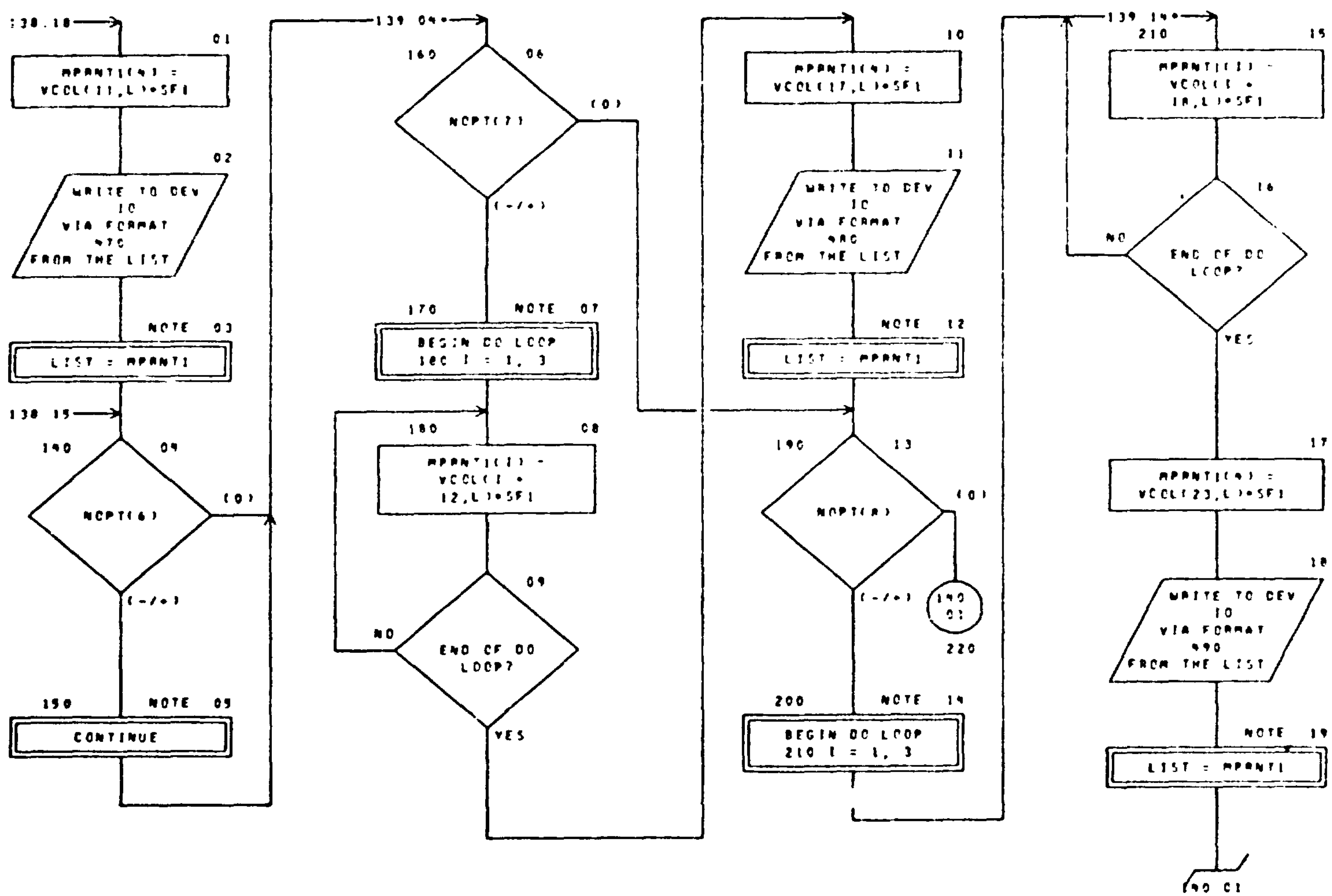
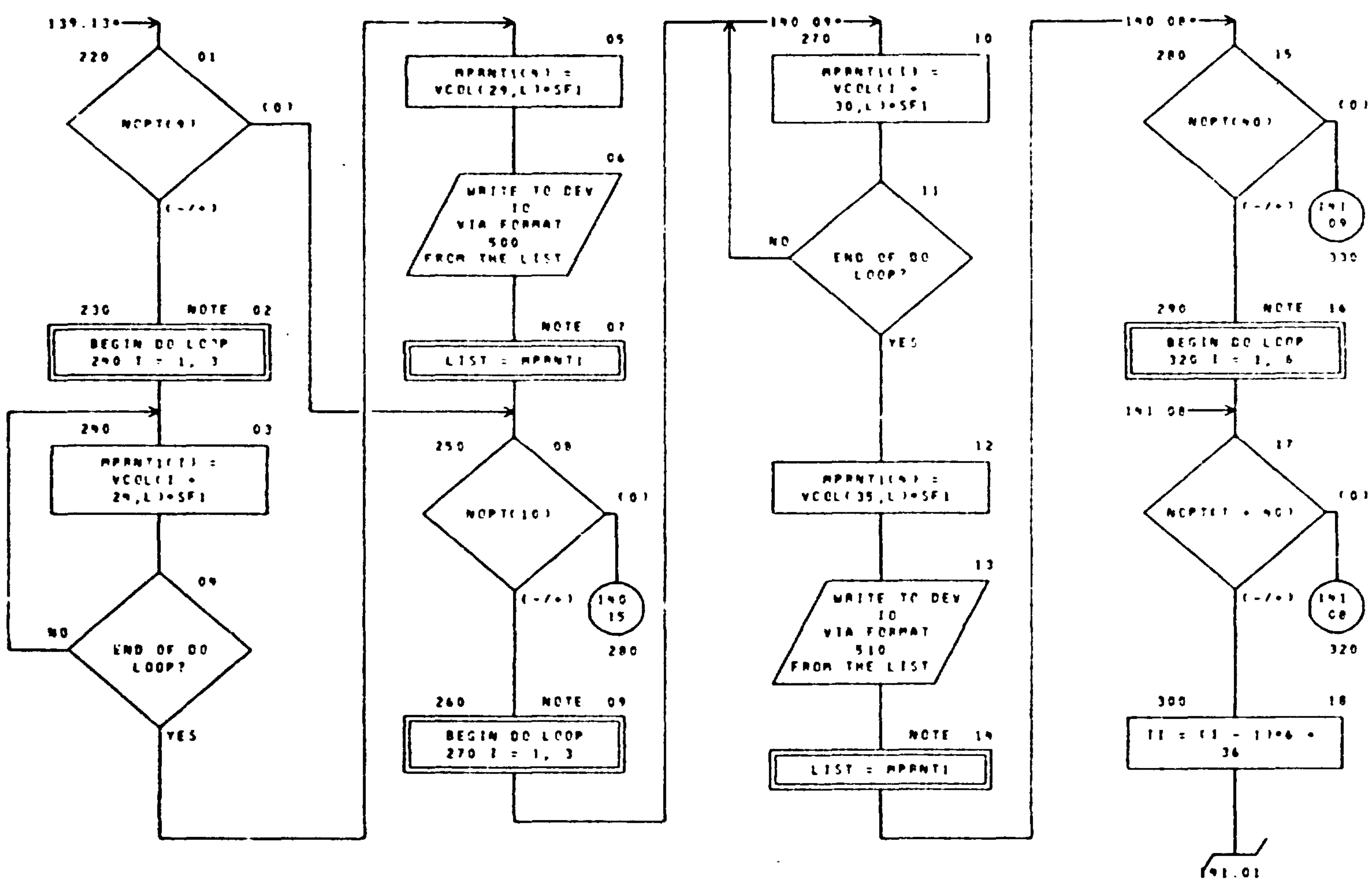


CHART TITLE - SUBROUTINE MIIP1



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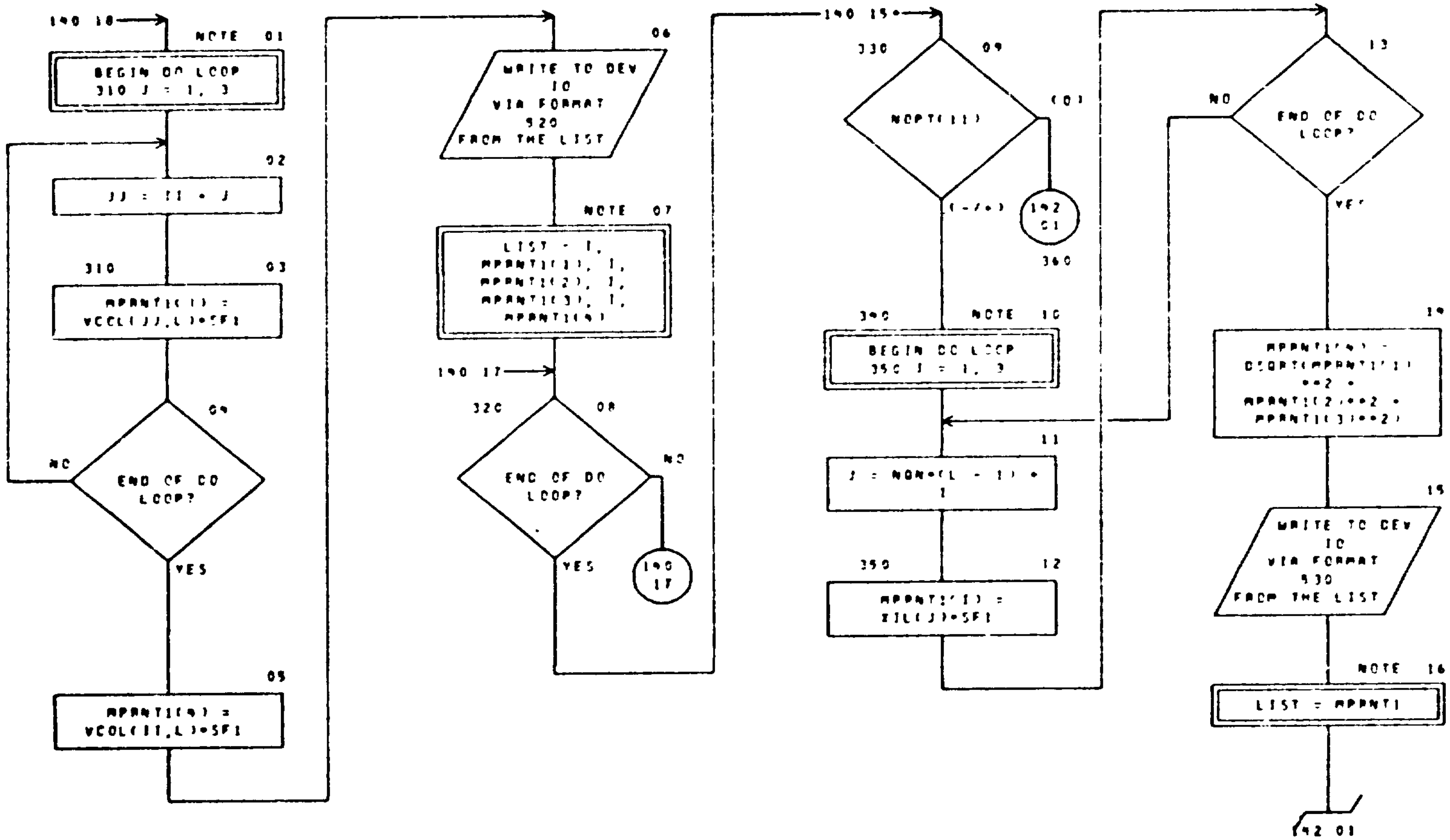

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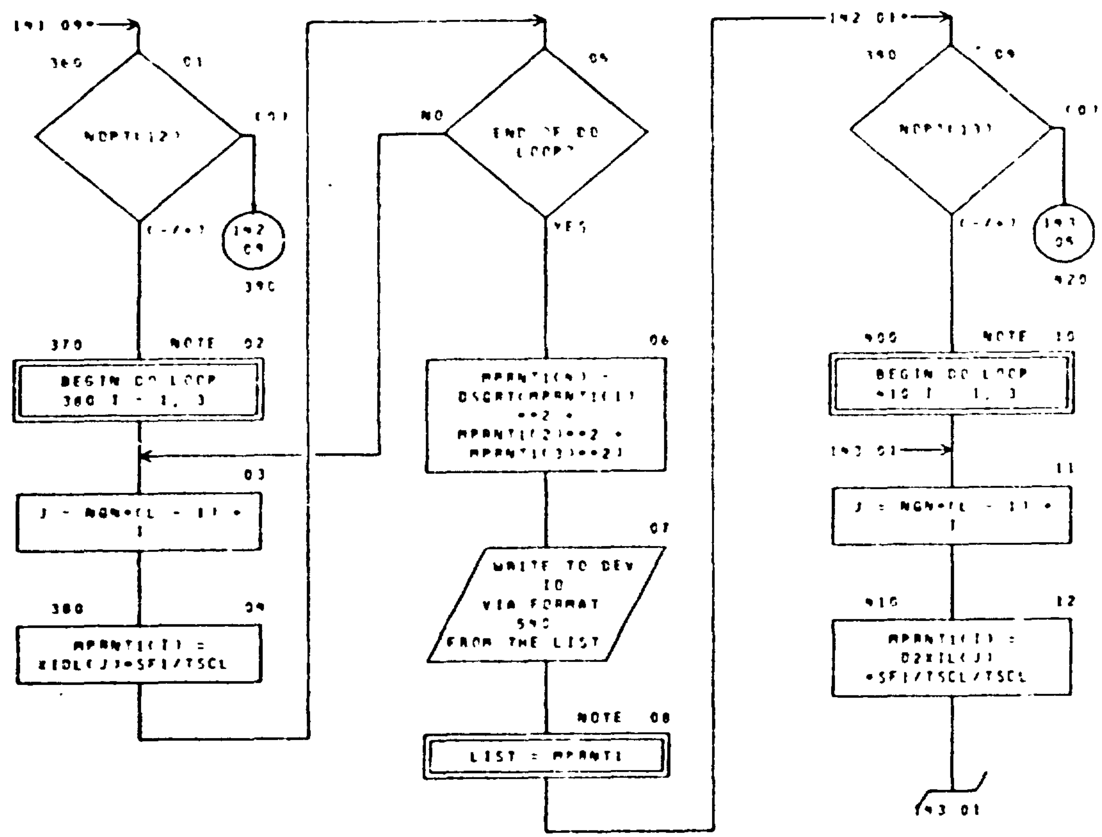


CHART TITLE - SUBROUTINE MIIP1

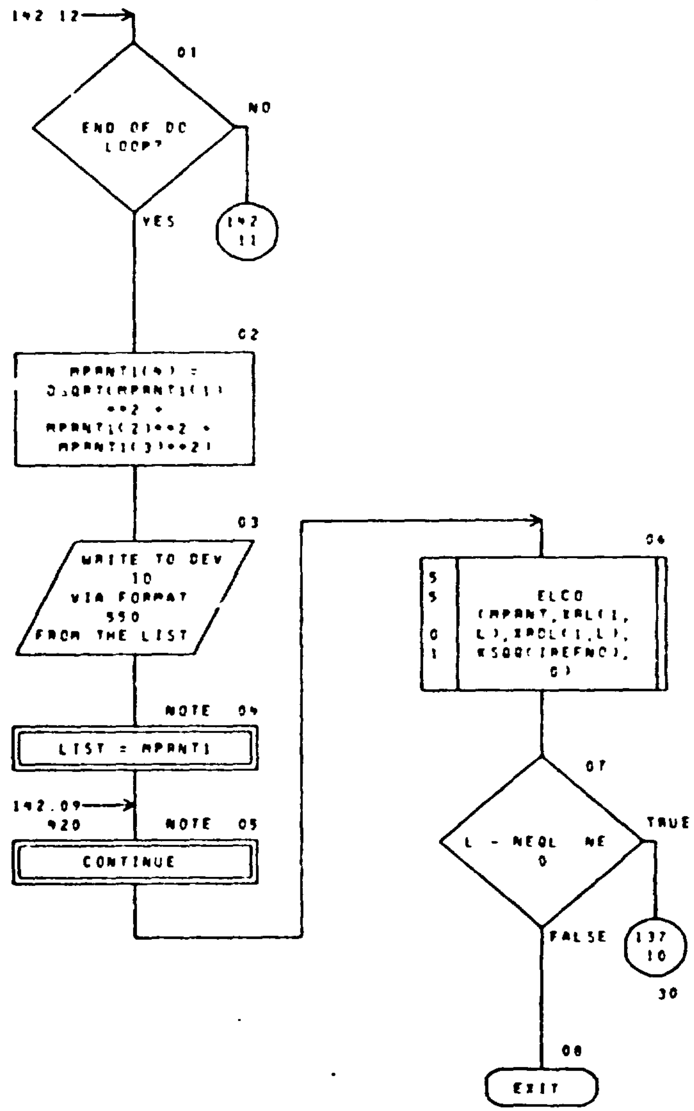


CHART TITLE - NON-PROCEDURAL STATEMENTS

```
          IMPLICIT REAL*8 (A-H,O-Z)
          INTEGER DAY,HOURS,YEAR
          REAL*8 MPRNT,MPRNT1,KSQQ,MEI,MF,KM,MDIST,INTV,INIX,IN2X
          DIMENSION KDAYS(3),MPRNT1(4)
          COMMON/ALAN/TBET,RHBR,DORHC
          COMMON/AMI/DELT,BETA,DTI,XIL(80),XIDL(80),D2XIL(80),IFST(80)
          COMMON/FRAN/XMDKM
          COMMON/HENRY/ARRAY(8,3,12),CHINC,INTV(72),INIX(3),
          IN2X(3),KSQQ(12),KM(12),MDIST,MEI(12),MF(12),POSRCS,PRVDT,
          PCT,PCIN,RC,RFKM,RRM,RRE,RREU,RCIND,RATIC,SEC,TSCL,THTS,TP1,
          TIMEL,THET,VELRCS
          COMMON/ILEF/NEQL,NEQ3,NQN,NCP65,IDAR(7),NCP64 NCP63,N1,N4,NS1,NJJ
          COMMON/INTEG/DAY,HOURS,YEAR,IDUMMY,ITRIG,IREFNC,IREFNB,
          IREFNT,IN,IO,IJK,MONTH,MIN,NCPT(72),NPLAN,NPLAN3
          COMMON/LEFT/XRL(6,20),XRDL(6,20),VCOL(72,20)
430       FORMAT (36HOTIME IN DAYS, HRS , MINS , SECS    I8,I8,I8,F10 3)
440       FORMAT ('    XR='1PD24 15,'    YR='D24 15,'    ZR='D24 15,'    RR=
          'D24 15)
450       FORMAT ('  XRDT='1PD24 15,'  YRDT='D24 15,'  ZRDT='D24 15,'  RRDT=
          'D24 15)
460       FORMAT ('   XVE='1PD24 15,'   YVE='D24 15,'   ZVE='D24 15,'   RVE=
          'D24 15)
470       FORMAT ('   XVM='1PD24.15,'   YVM='D24 15,'   ZVM='D24 15,'   RVM=
          'D24.15)
480       FORMAT ('   XVS='1PD24 15,'   YVS='D24.15,'   ZVS='D24 15,'   RVS=
```

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
              'D24 15)
490        FORMAT (' XVVN='1PD24 15,' YVVN='D24 15,' ZVVN='D24 15,' RVVN=
              'D24 15)
500        FORMAT (' XVMR='1PD24 15,' YVMR='D24 15,' ZVMR='D24 15,' RVMR=
              'D24 15)
510        FORMAT (' XVJP='1PD24 15,' YVJP='D24 15,' ZVJP='D24 15,' RVJP=
              'D24 15)
520        FORMAT (' XVP'I1,'='1PD24 15,' YVP'I1,'='D24 15,' ZVP'I1,'='D24
              15,' RVP'I1,'='D24 15)
530        FORMAT ('   XI='1PD24 15,' ETA='D24 15,' ZETA='D24 15,' PERT=
              'D24 15)
540        FORMAT (' XIDT='1PD24 15,' ETADT='D24 15,'ZETADT='D24 15,' VPERT=
              'D24 15)
550        FORMAT (' D2XI '1PD24 15,' D2ETA='D24 15,'D2ZETA='D24 15,' APERT=
              'D24 15)
```

<u>Name:</u> MINMX3

<u>Calling Arguments:</u> NSET, XERROR, XCONVG

<u>Referenced Sub-programs:</u> PMPRNT, SIMEQ, TRAJL, XYZ

<u>Referenced Commons:</u> HER, HIS, KAT, MINEPS, NPNT, PERAPS, XMMM

<u>Entry Points:</u> None

<u>Referencing Sub-programs:</u> ITMAT

<u>Discussion:</u> MINMX3 is the subroutine which drives the two-point boundary value problem to a solution. The iterator's underlying mathematical analysis if formulated as follows. Let X denote the vector of independent variables and let Y denote the vector of dependent variables. The relationship between these two vectors is given by

$$Y = F(X).$$

The vector function, F, is evaluated by integrating the trajectory; that is, given a complete set of control parameters and initial conditions, the corresponding values of the end conditions Y can be determined. Subroutine TRAJL, supplemented with subroutine XYZ, maps X onto Y and is therefore the software package which generates the function F. The problem is to find the vector X* which will result in specified values of the dependent variables Y*, that is, to solve

$$Y^* = F(X^*),$$

where Y* is known. This is formulated as a minimization problem. The weighted sum of the residuals q_i is given by

$$q_i = \left[Y^* - F(X_i)\right]^T W_y \left[Y^* - F(X_i)\right],$$

where X_i is the current estimate of the independent variables and W_y is a diagonal, positive definite weighting matrix.

The problem is to choose a new value X_{i+1} to minimize q_{i+1}. If X_{i+1} is close to X_i, then

$$F(X_{i+1}) = F(X_i) + P\Delta X,$$

where $\Delta X = X_{i+1} - X_i$ and the partial derivative matrix, P, is given by

$$P = \frac{\partial Y}{\partial X} .$$

Evaluating q_{i+1} with this approximation leads to the expression,

$$q_{i+1} = (\Delta Y - P\Delta X)^T W_y (\Delta Y - P\Delta X),$$

where ΔY, the residual vector, is given by

$$\Delta Y = Y^* - F(X_i) .$$

The problem is then to choose ΔX to minimize q_{i+1}.

For nonlinear functions F, linear approximations work only if ΔX is small. Therefore, the following constraint is imposed,

$$\Delta X^T W_x \Delta X \leq \ell ,$$

where W_x is the input diagonal, positive definite weighting matrix associated with the independent parameters.

Attaching the constraint with a positive scalar inhibitor, λ, the quantity to be minimized is given by

$$q = (\Delta Y - P\Delta X)^T W_y (\Delta Y - P\Delta X) + \lambda (\Delta X^T W_x \Delta X).$$

Finding the minimum of the function yields the solution,

$$\Delta X = (P^T W_y P + \lambda W_x)^{-1} P^T W_y \Delta Y$$

This equation is solved by subroutine SIMEQ. It can be shown that as λ increases, ℓ decreases monotonically. Therefore, λ can always be chosen large enough to satisfy the above inequality. Moreover, if λ is sufficiently large, the correction is approximately

$$\Delta X = \frac{1}{\lambda} W_x^{-1} (P^T W_y) \Delta Y .$$

For ΔX small enough, or λ large enough, we are guaranteed that

$$q_{i+1} \leq q_i .$$

It is advantageous to take as large a step toward satisfying $Y^* - F(X^*)$ as possible. The procedure is initiated with a relatively small value of λ. The idea is to make a correction, determine if any improvement is made, and, if not, cut back on the correction. The following iteration scheme is utilized. Given X_i, the mapping F is executed again to produce Y_{i+1} starting with the values $X_{i+1} = X_i + \Delta X$, and q_{i+1} is calculated. q_{i+1} is then compared with q_i. If there is no improvement, λ is increased. ΔX is recalculated and a new mapping is executed. This is repeated until an improvement results. When this happens, the mapping is executed again, and the partial derivative matrix is computed. λ is reduced by a factor of 64. The iteration continues until the end conditions are satisfied within the prescribed tolerance or no significant improvement can be made or the maximum number of iterations is exceeded.

The constraints, Y, are divided into two types, parameters that are driven to a given value (point constraints) and parameters to be maximized or minimized (performance indices).

For a well-posed problem, there is only one performance index. For each dependent variable, y_i, two values must be specified, y_{min} and y_{max}. These values indicate the acceptable range. If a dependent variable is a point constraint, y_{min} and y_{max} are chosen close together

$$y_{min} = y^* - \delta; \quad y_{max} = y^* + \delta,$$

where y^* is the desired value and δ is a tolerance utilized for weighting purposes. For the performance index, the interval is chosen so that it cannot possibly be attained if the other constraints are satisfied. For instance, if y is to be minimized, y_{min} and y_{max} are taken smaller than attainable, conversely if y is to be maximized, y_{min} and y_{max} are taken larger than attainable. In this way the iteration procedure drives the variable to be optimized in the correct direction until no significant improvement is possible or the input maximum number of iterations is exceeded.

Two modes of solution are available, the select mode and the optimize mode. In the select mode, the iterator attempts only to satisfy the point constraints. The optimize mode adds the performance index to the end conditions and through proper weighting, generates trajectories with an improved performance index while maintaining satisfaction, or near satisfaction,of the point constraints

The scale matrices W_x and W_y are used to make elements of the vectors X and Y con atible for the iteration procedure. The relative importance of the variables is represented in this way. Differing magnitudes are compensated for through the weighting matrixes. W_x is input to the program, W_y is computed internally using the input tolerances and importance factors. For point constraint variables, the elements of W_y are given by the following relation:

$$W_y = \frac{2^{-40}}{\delta_y^2},$$

where δ_y is the corresponding tolerance. The weighting factor for the performance index is computed from

$$W_y = \frac{n}{r^2} 2^{-40}$$

where r is the performance index residual and n is 10^{-n} when the iterator is operating in the select mode and 256 WTOPT when in the optimize mode. This balances the residual in the parameter being optimized against the weighted residuals in the other variables, to satisfy the constraints as the optimization proceeds.

<u>Messages and Printout:</u> Several diagnostic and information messages are provided to inform the user as to the progress made by the iterator or any problems encountered. In all cases, upon exiting the routine, the trajectory counters, KOUNT and L, are printed in the following message:

____ TRAJECTORIES WITHOUT PARTIAL DERIVATIVES AND ___ TRAJECTORIES WITH PARTIAL DERIVATIVES REQUIRED FOR THIS CASE.

If the problem does not involve a performance index and all point constraints are satisfied or if a performance index is being optimized and no further improvement is possible, the following message is printed:

THIS CASE IS CONVERGED.

Upon attainment of convergence in the select mode and just prior to starting the optimize mode, the message

ITERATOR IS NOW IN OPTIMIZE MODE.

is printed.

If the point constraints can not be satisfied in the select mode, one gets the message:

THIS CASE WILL NOT CONVERGE.

If the number of iterations in either the select or optimize mode exceeds the input limit ITMAX, the following message is printed:

MAXIMUM NUMBER OF ITERATIONS EXCEEDED.

If an error condition is detected in TRAJL on the first trajectory (usually resulting from input errors), the following message is printed:

FIRST GUESSES WILL NOT RUN TRAJECTORY.

If an error condition is detected in TRAJL while generating the nominal and perturbation trajectories, the following message is printed:

ERROR IN PARTIAL DERIVATIVE CALCULATION.

Any one of the last four messages above will also generate the message:

ITERATOR IS GIVING ERROR RETURN.

and flags an error condition to be returned from MINMX3 through the calling argument XERROR.

If an error condition occurred in SIMEQ while operating in the optimize mode and recovery is not likely, the following message:

MATRIX INVERSION NOT PERFORMED ON LAST ITERATION.

is printed and the error condition flag XERROR is set.

MINMX3 EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
B(30)	SUA	XMMM	Array of independent variable values, X.
L	SU	KAT	Nominal trajectory counter, incremented each time a partial derivative matrix is evaluated.
Q(30)	SU	XMMM	Array of dependent variable values, Y.
W(30)	SUA		Array of dependent variable weights, W_y.
B2(30)	SUA		B array of preceding trial trajectory.

MINMX3 EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
DB(30)	SUA		Array of independent variable changes, ΔX.
KB	SUA		Number of independent variables.
KQ	SUA		Number of dependent variables.
PM(900)	SUA		Array containing the negative of the partial derivative matrix.
RM	UA	PERAPS	Desired final distance relative to target planet.
RP	UA	PERAPS	Desired periapse distance of osculating orbit at the target planet.
WX(30)	U	HIS	Array of independent variable weights, W_x.
EMU	UA	PERAPS	Gravitational constant of target planet.
EPS(30)	U	MINEPS	Limiting step size for independent variables below which convergence is assumed in the optimize mode.
IPS	UA	HER	Number of dependent variables.
NPR	U	NPNT	Partial derivative matrix print flag.
NSL	U	HER	Number of independent variables.
PFG(30,30)	U	HIS	Partial derivative matrix, P.
DXPM(930)	SUA		Array containing the matrix $(P^T W_y P + \lambda W_x)$ in the first KB^2 locations. The next KB locations contain the array $P^T W_y \Delta Y$.
IPER	U	PERAPS	Flag indicating whether the transformation from periapse distance to Cartesian coordinates was performed.

MINMX3 EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
NSET(5)	UX		Array of counters and flags input to MINMX3: 1 - number of independent variables 2 - number of dependent variables 3 - maximum number of iterations permitted in the select mode 4 - trigger indicating whether to start in select (=0) or optimize (≠0) mode 5 - maximum number of iterations permitted in optimize mode
QMAX(30)	UA	XMMM	Array of upper allowable values of the end conditions.
QMIN(30)	UA	XMMM	Array of lower allowable values of the end conditions.
RDOT(3)	A	PERAPS	Velocity relative to the target planet at the final time.
XEPS(30)	U	HIS	Array of maximum independent variable step sizes permitted in a single iteration.
YEPS(30)	A	HIS	Array of tolerances to which end conditions must be satisfied.
KOUNT	SU	KAT	Counter of trial trajectories.
LSOLU	SUA		Error condition flag returned from SIMEQ.
MOPTM	U	XMMM	Index parameter defining which of the dependent variables is the performance index.
QAVRG(30)	SUA		Array of desired values of the end conditions.

MINMX3 EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
WTOPT	U	XMMM	Weight factor applied to the performance index in the optimize mode.
LAMBDA	SU	KAT	Inhibitor, λ.
LERROR	UA		Error flag returned from subroutine TRAJL.
XCONVG	SX		Convergence indicator returned from MINMX3.
XERROR	SX		Error flag returned from MINMX3.

CHART TITLE - SUBROUTINE MINMX3(NSET,XERROR,XCONVG)

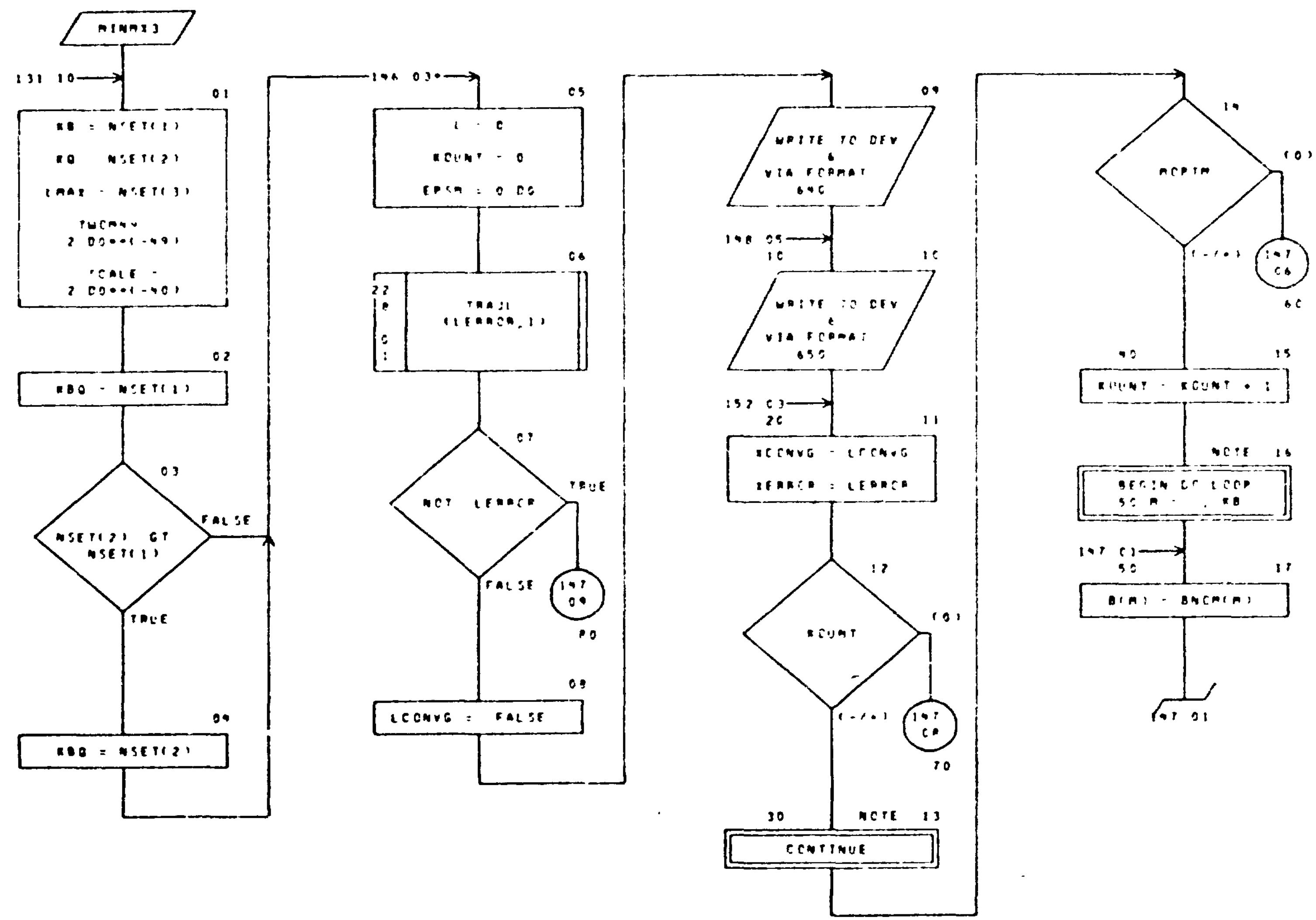
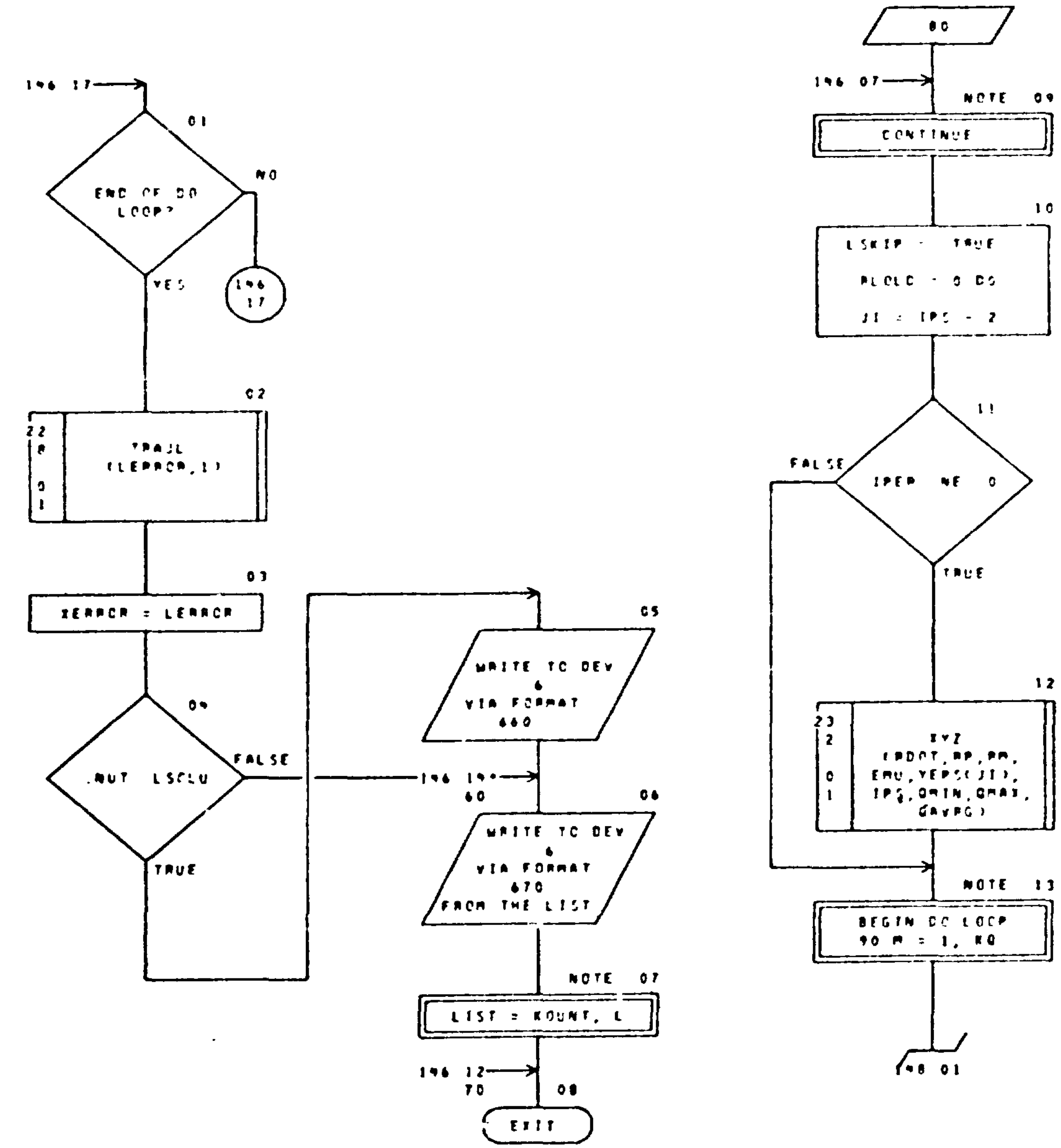


CHART TITLE - SUBROUTINE MINMX3(NSET,XERROR,XCONVG)



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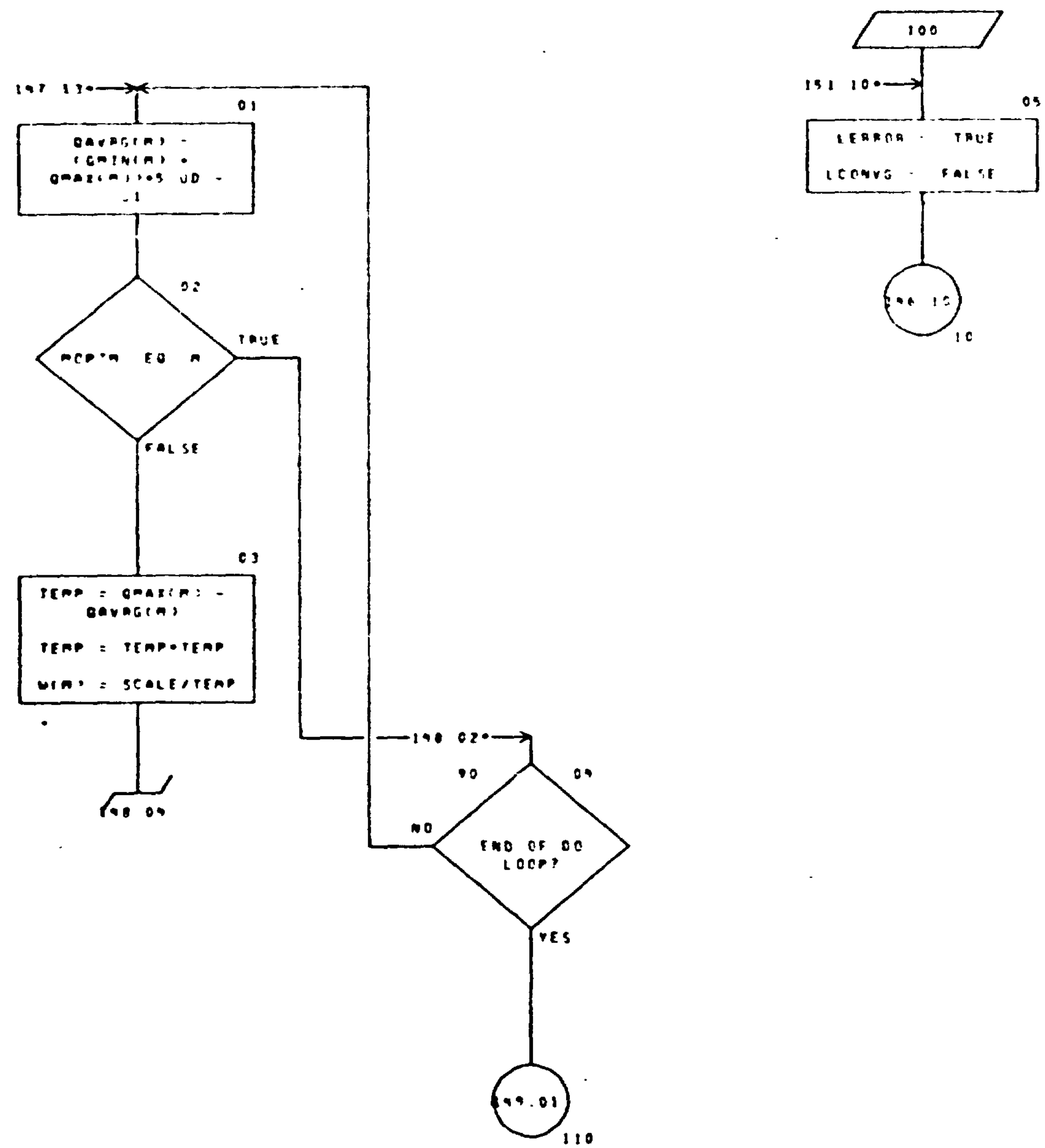

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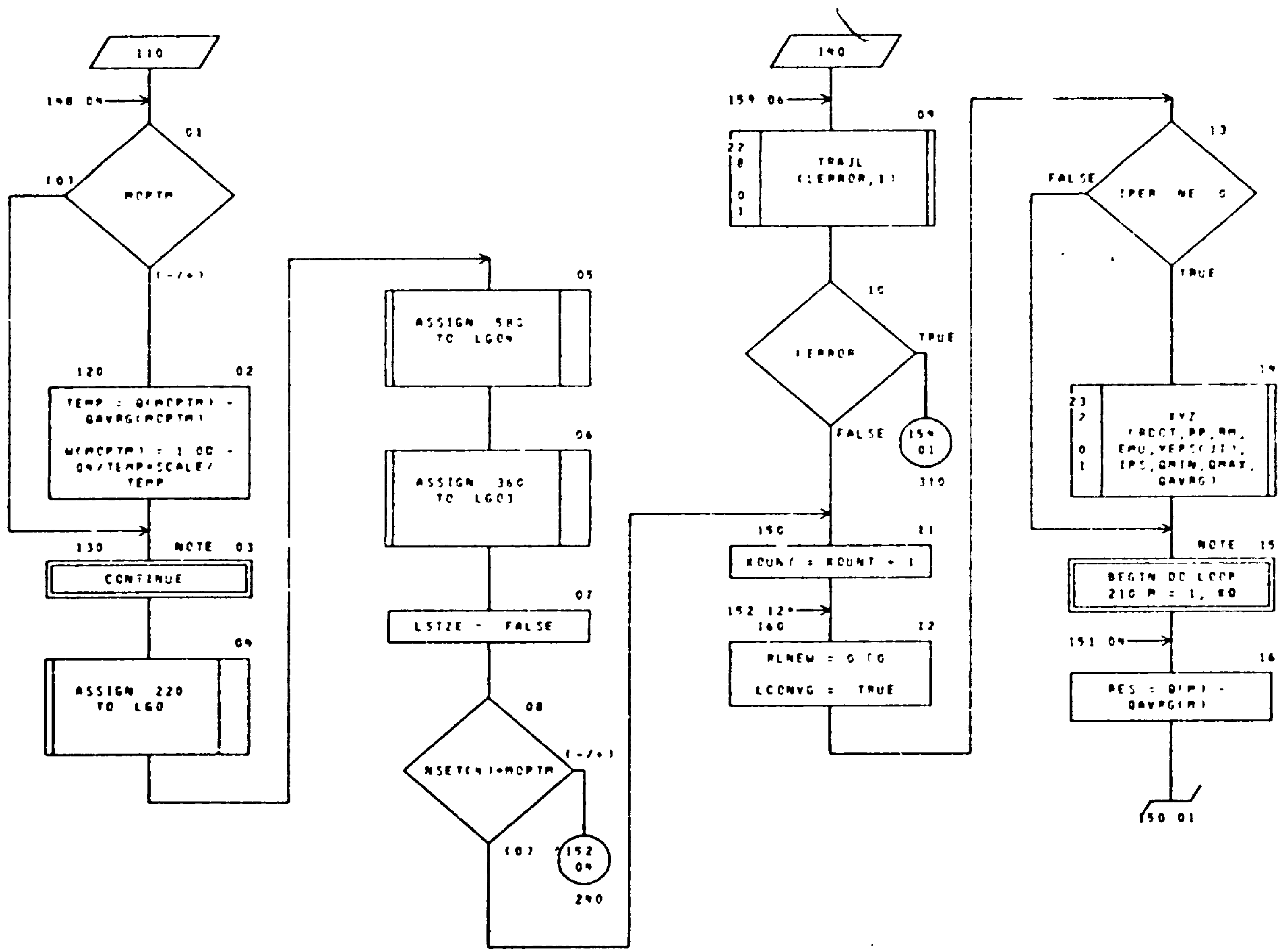

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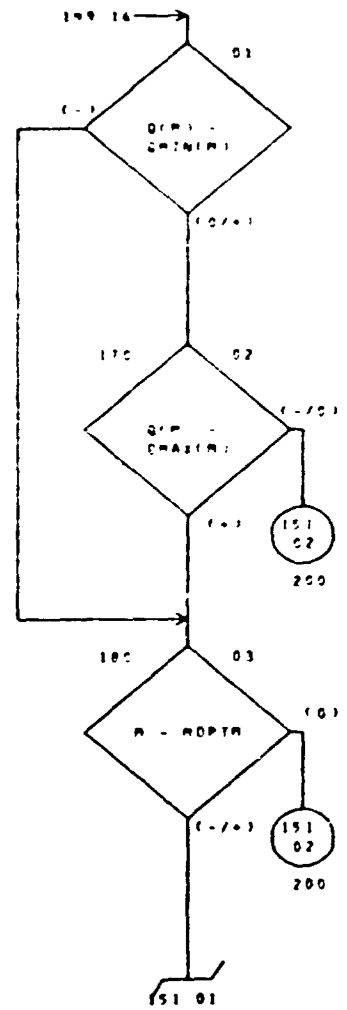

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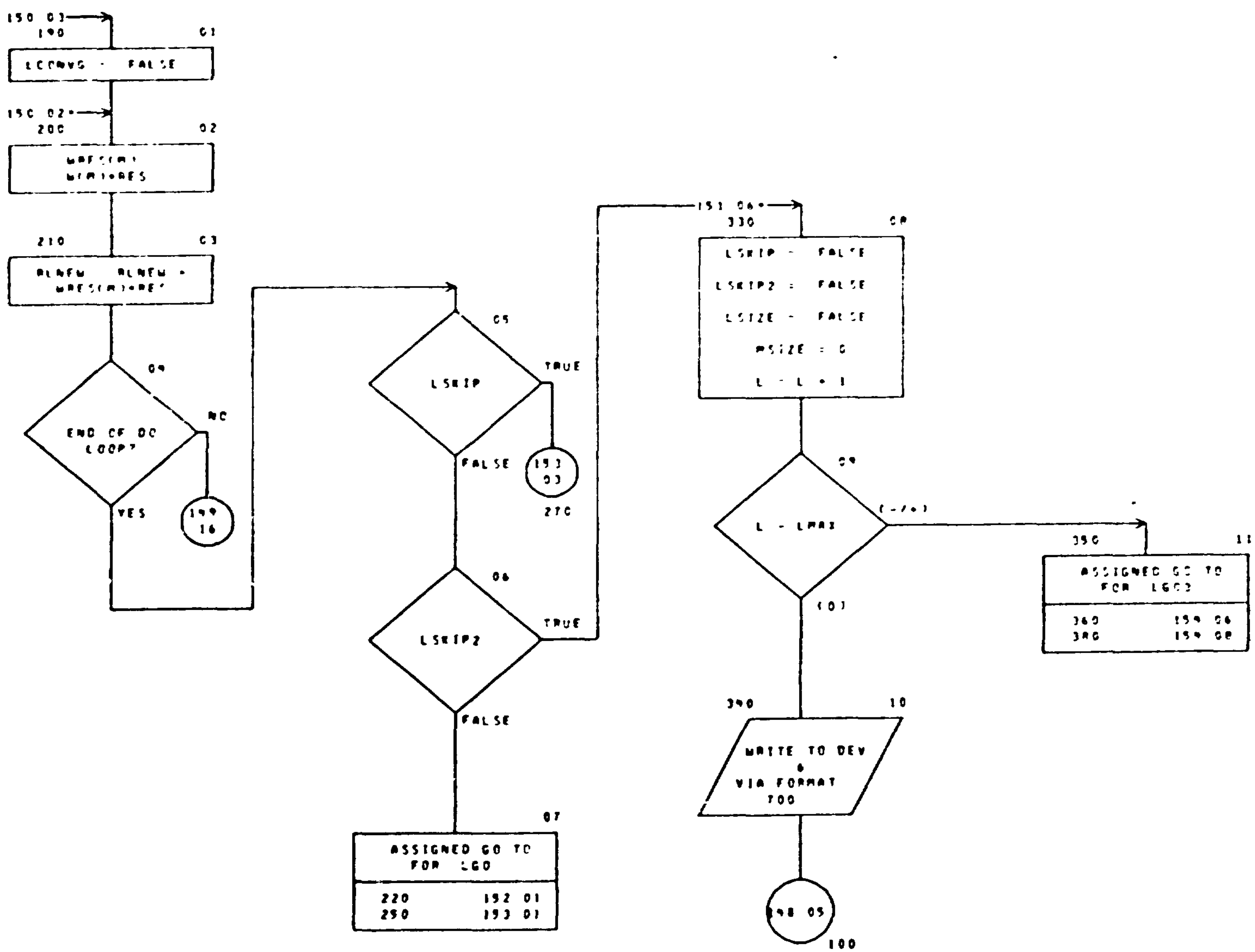

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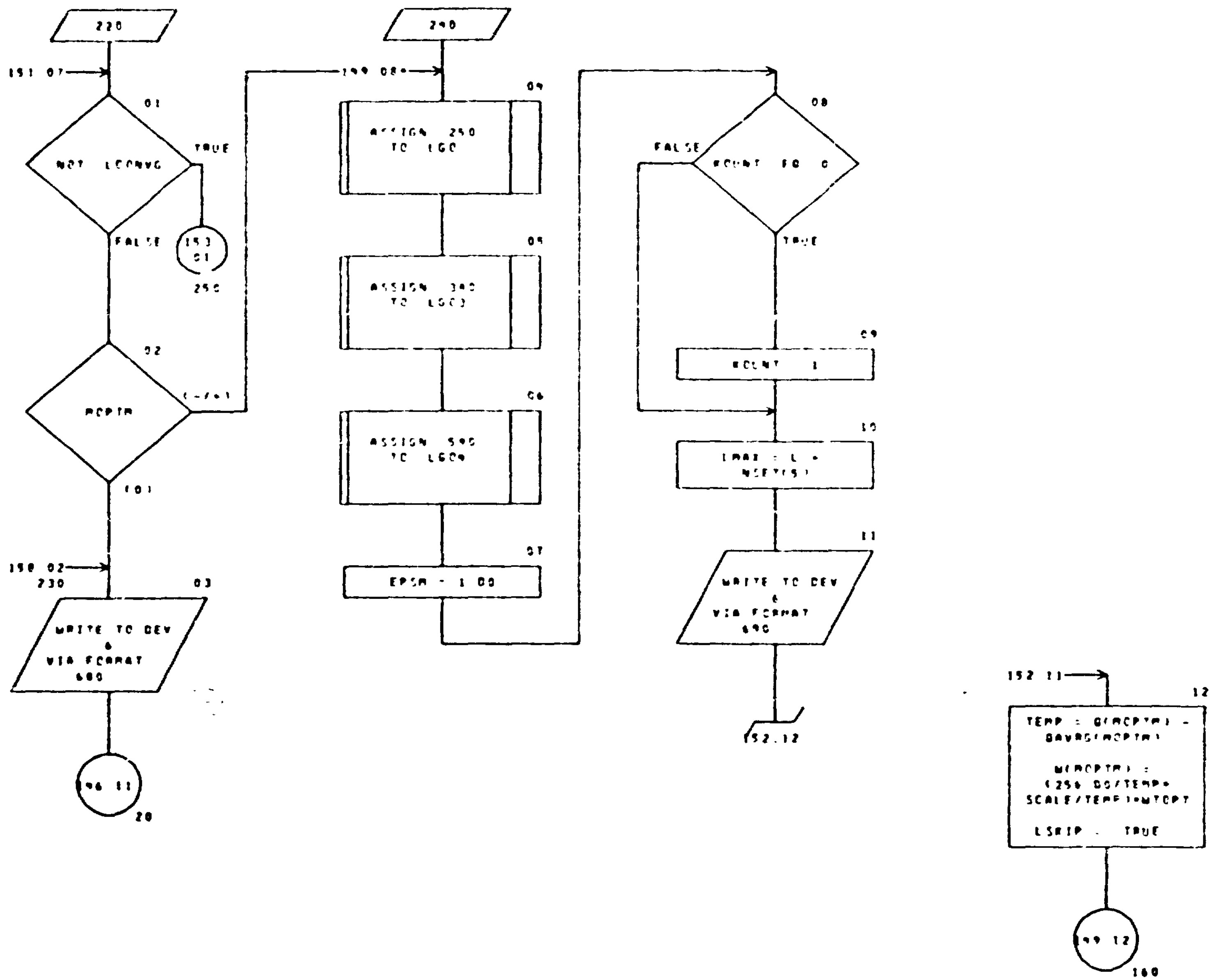

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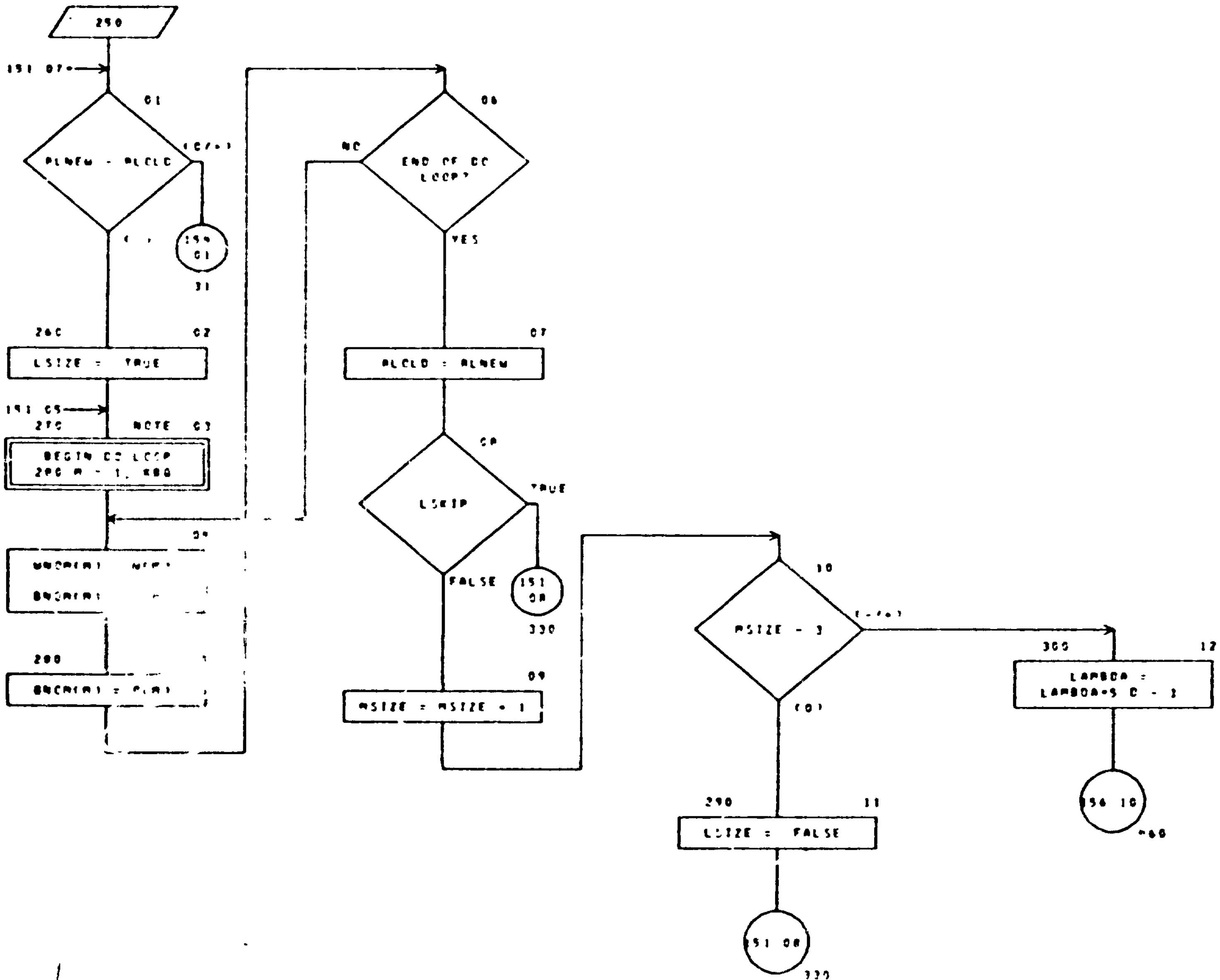


CHART TITLE - SUBROUTINE MINMAX(NSET,KERROR,ICC)

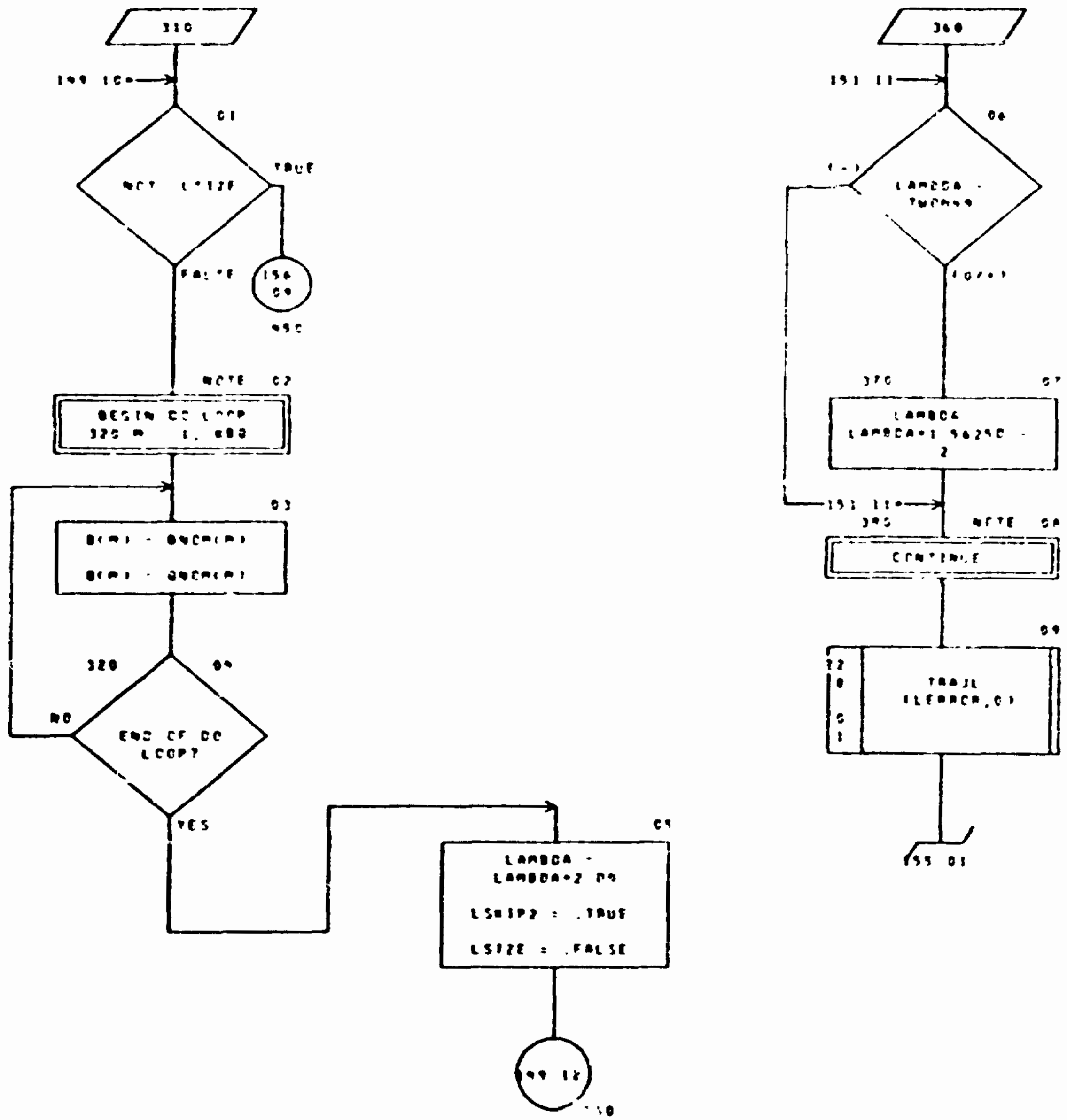


CHART TITLE - SUBROUTINE MINMN3(NSET,KERROR,ICONVG)

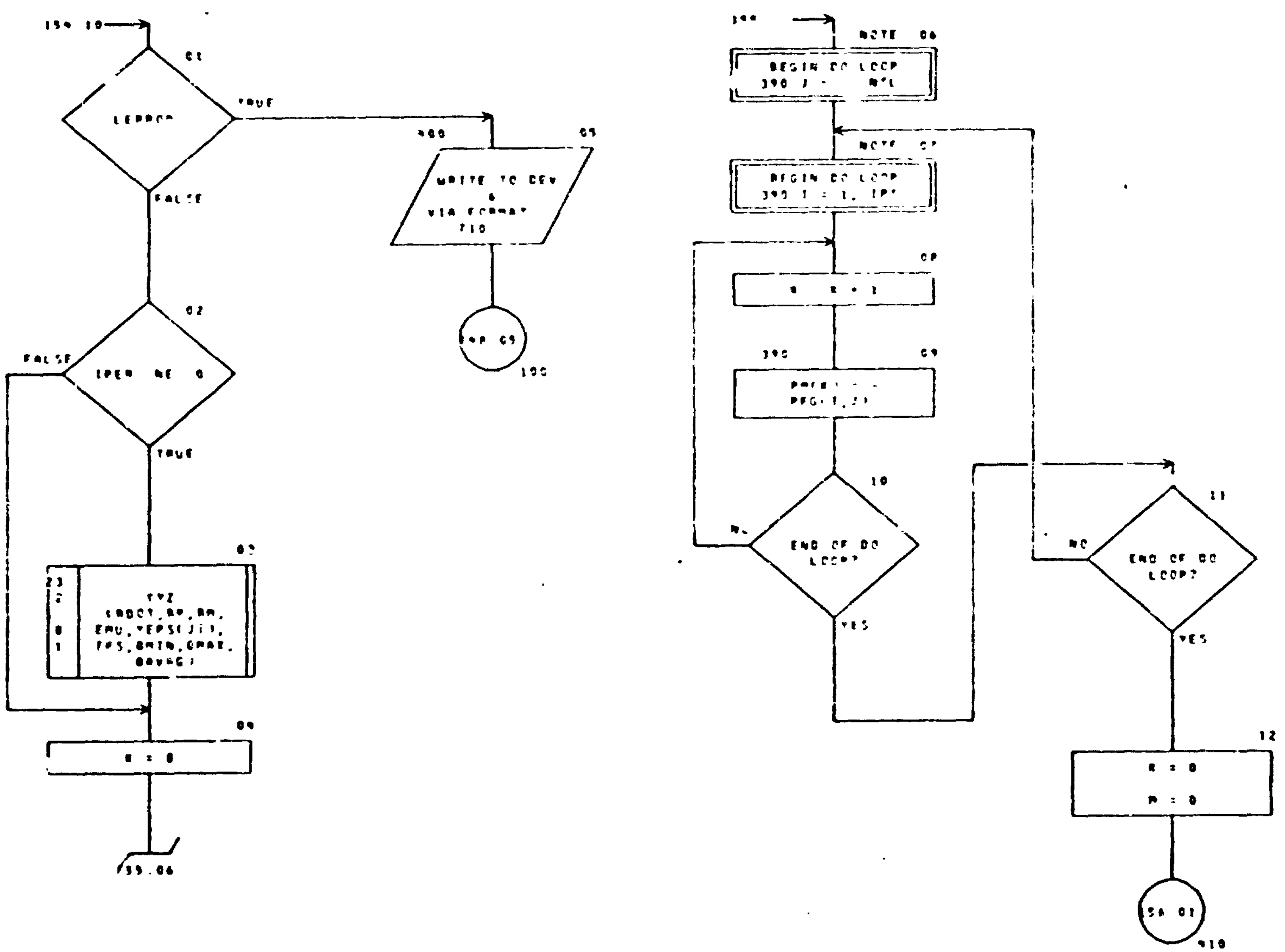


CHART TITLE - SUBROUTINE MINMX(NSET,XERROR,XCONVG)

C-5

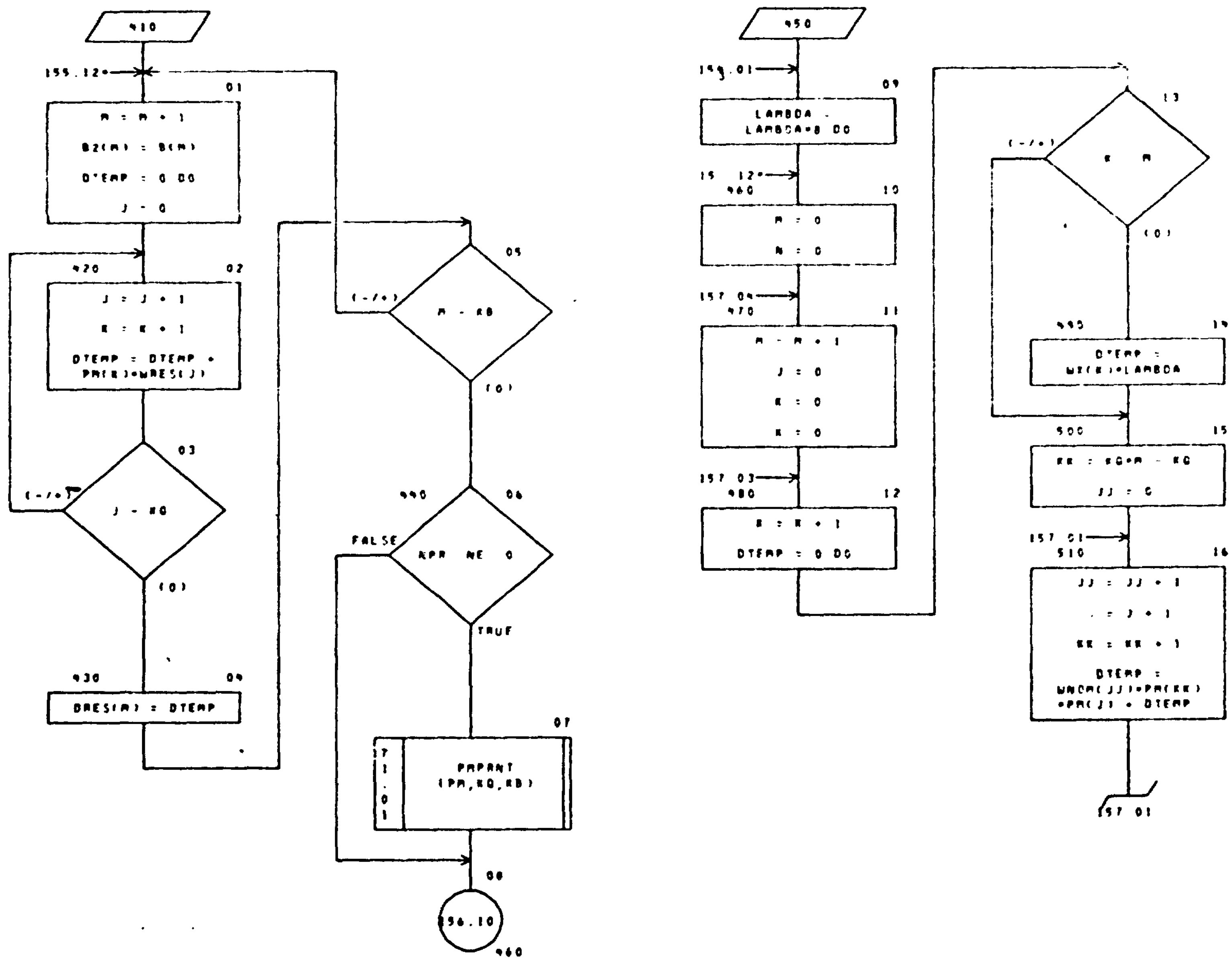
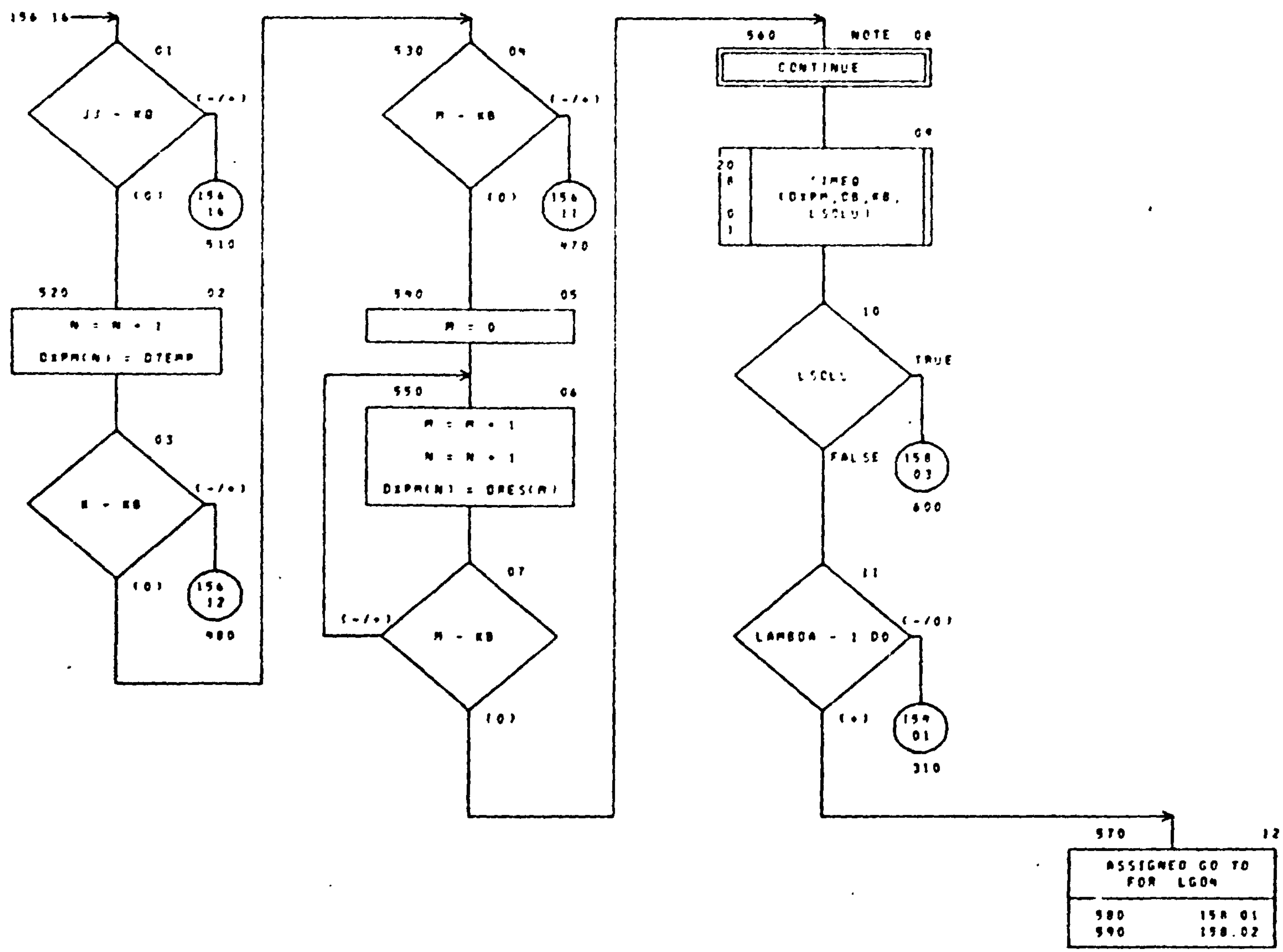


CHART TITLE - SUBROUTINE MINMX3(NSET,XERROR,XCONVG)



MINMX3-21

CHART TITLE - SUBROUTINE MINMX3(NSET,XERROR,XCONVG)

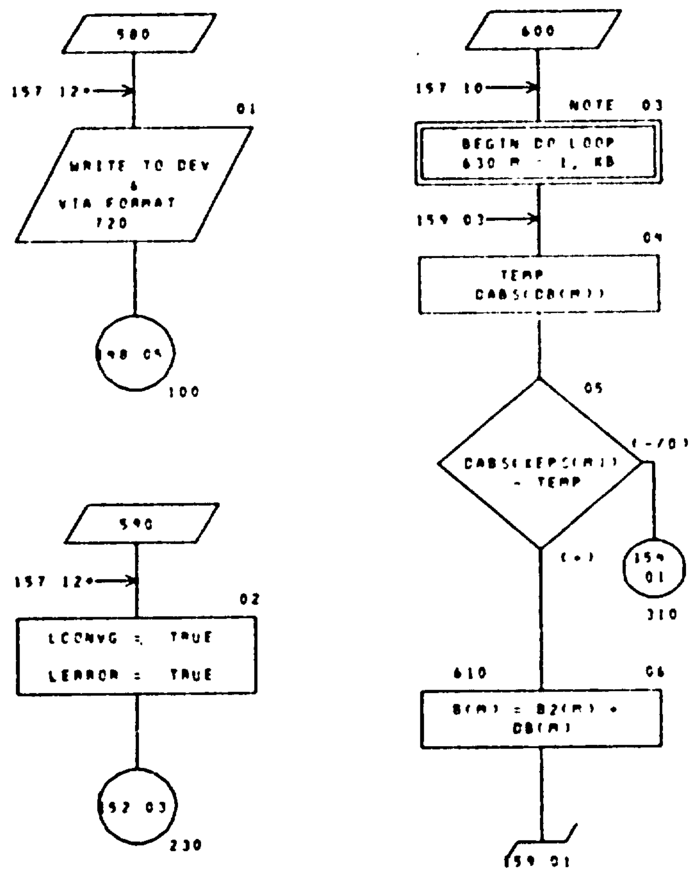
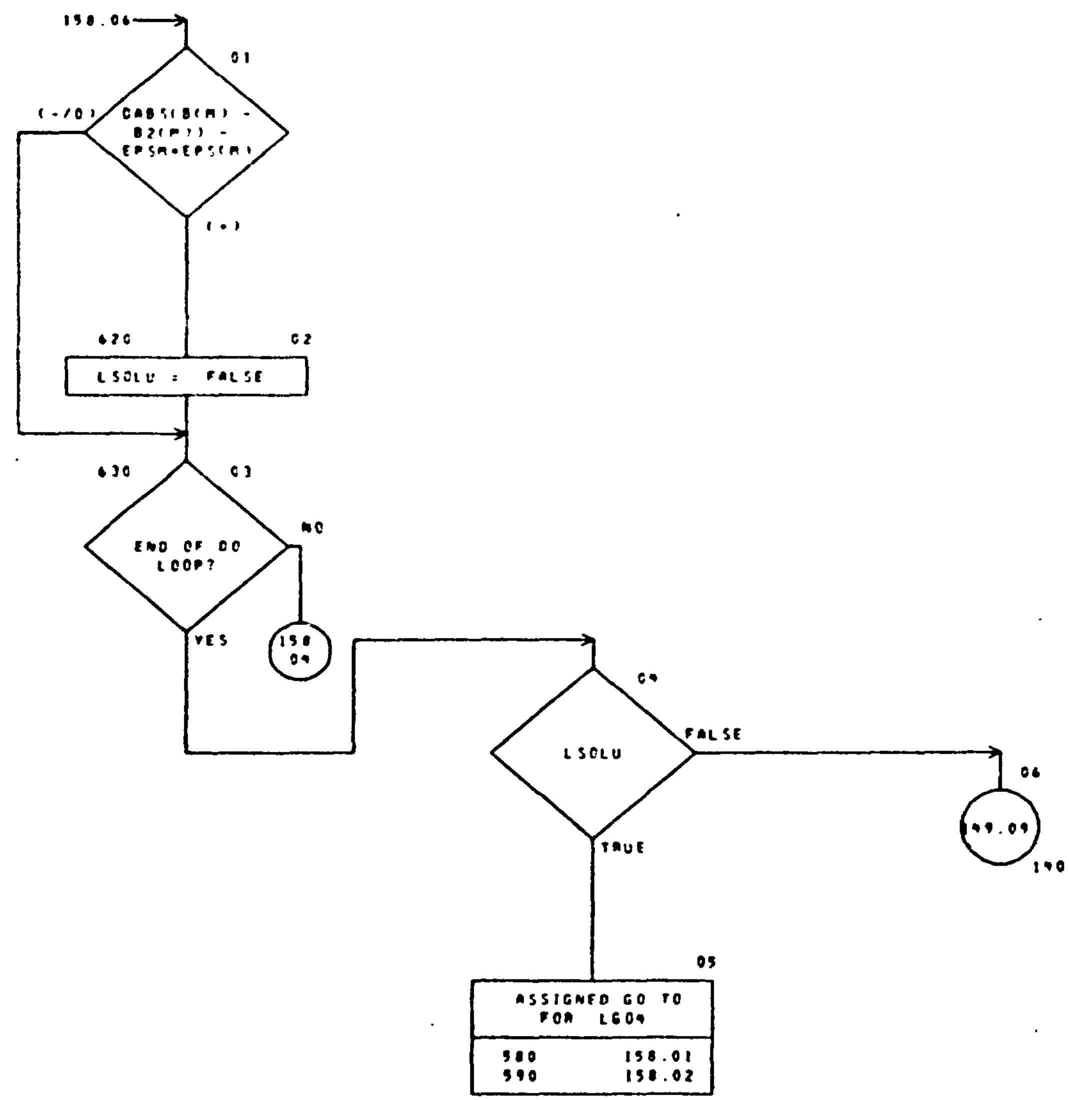


CHART TITLE - SUBROUTINE MINMX3(NSET,XERROR,XCONVG)



MINMX3-23

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
          IMPLICIT REAL*8 ( A-H, O-Z)
          LOGICAL LERROR,LCONVG,LSIZE,LSOLU,LSKIP
          LOGICAL LSKIP2,XCONVG, XERROR
          REAL*8 LAMBDA
          DIMENSION NSET(5)
          DIMENSION DXPM(930),DB(30)
          DIMENSION PM(900),BNOM(30),QNOM(30),PNOM(30),QAVRG(30),
          WRES(30),DRES(30),
           W(30),B2(30) ,WNOM(30)
          COMMON/HER/IPS,NSL,NSL1,IFTRG,ITCT,IPCFL(30),IVAR(100),ITMAX,NTP,
          NTPS,NMAX,NJ,JN,IPAT,NCT1,NJL
          COMMON/HIS/PFG(30,30),WX(30),XVAR(30),YEPS(30),XEPS(30),
          CHNS(100),CHN(100),PCFL(30),XDAR(7)
          COMMON/KAT/LAMBDA,KOUNT,L
          COMMON/MINEPS/EPS(30)
          COMMON/NPNT/NPR
          COMMON /PERAPS/ RDOT(3),RM,RP,EMU,IPER
          COMMON/XMMM/B(30),Q(30),QMIN(30),QMAX(30),WTOPT,MCPTM
640       FORMAT (39H1FIRST GUESSES WILL NOT RUN TRAJECTORY )
650       FORMAT (33H0ITERATOR IS GIVING ERROR RETURN )
660       FORMAT (' MATRIX INVERSION NOT PERFORMED ON LAST ITERATION')
670       FORMAT (1H0,I6,45H TRAJECTORIES WITHOUT PARTIAL DERIVATIVES AND,I4
          ,62H TRAJECTORIES WITH PARTIAL DERIVATIVES REQUIRED FOR THIS CASE.
          )
680       FORMAT (24H0THIS CASE IS CONVERGED )
```

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
690     FORMAT (34H0ITERATOR IS NOW IN OPTIMIZE MODE )
700     FORMAT (39H0MAXIMUM NUMBER OF ITERATIONS EXCEEDED )
710     FORMAT (41H0ERROR IN PARTIAL DERIVATIVE CALCULATION )
720     FORMAT (29H0THIS CASE WILL NOT CONVERGE )
```

<u>Name:</u> MODIF

<u>Calling Arguments:</u> None

<u>Referenced Sub-programs:</u> LAMBRT

<u>Referenced Commons:</u> HENRY, LEFT, STEVE, TBPR

<u>Entry Points:</u> None

<u>Referencing Sub-programs:</u> INPUT

<u>Discussion:</u> The principal purpose of subroutine MODIF is to provide a means of altering program constants that are not available through normal input means. MODIF is called from INPUT after completing all other reading of inputs and initializations. The present code performs the following assignments. The masses of the moon, Earth-moon barycenter, Mercury, Saturn, Uranus, Neptune, and Pluto are set to zero; the spacecraft distance from the moon is set to zero in the VCOL array, the radius of the moon's sphere of influence, RRM, is set to a large negative number, the integration interval is set to a large value and the two-body flag ITB is set to zero. Just prior to executing a return to the calling program INPUT, a call is made to subroutine LAMBRT.

<u>MODIF EXTERNAL VARIABLES TABLE</u>

Variable	Use	Common	Description
ME(12)	S	HENRY	Array of planetary masses in units of Earth masses for index values < 3 (Earth and moon), and in sun masses otherwise.
ITB	S	TBPR	Flag indicating whether time or universal anomaly is the independent variable input to TBDP.

MODIF EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
MEI(12)	S	HENRY	Array of planetary masses, in units of Earth masses.
RRM	S	HENRY	Radius of the moon's sphere of influence, in ER.
DELT	S	STEVE	Integration interval of the universal anomaly, $\Delta\beta$.
VCOL(72, 20)	S	LEFT	Array of spacecraft position vectors relative to all planets for nominal and perturbed trajectories.

CHART TITLE - SUBROUTINE MODIF

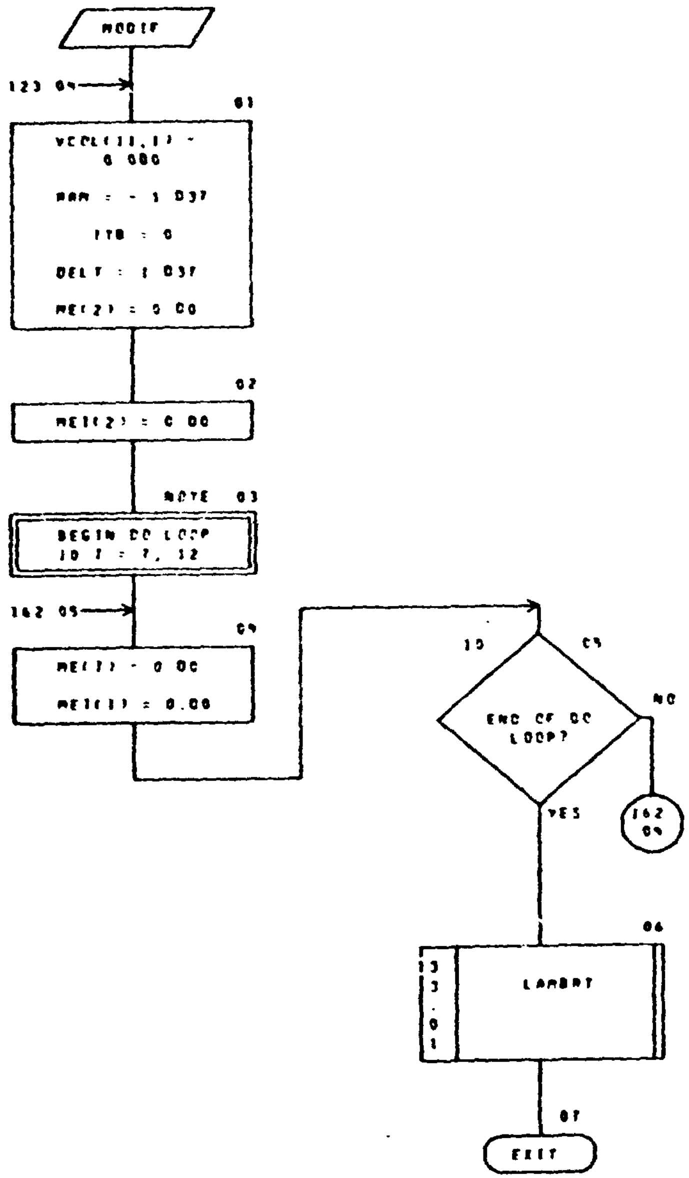


CHART TITLE - NON-PROCEDURAL STATEMENTS

```
 IMPLICIT REAL*8(A-H,O-Z)
REAL*8 RSQQ,ME1,ME,RM,MDIST,INTV,IN1X,IN2X
COMMON/HENRY/ARRAY(8,3,12),CHIND,INTV(72),IN1X(3),
IN2X(3),RSQQ(12),RM(12),MDIST,ME1(12),ME(12),POSPCS,PRVDT,
PDT,PCIN,PC,REFM,RRM,RRE,RREU,PCIND,RATIO,SFC,TSCL,THTS,TP1,
TIMEL,THET,VELRCS
COMMON/LEFT/EPL(240),VCPL(72,20)
COMMON/STEVE/DELT,STV(10)
COMMON/TBPR/ITB
```

<u>Name</u>: MTMT

<u>Calling Arguments</u>: A, B, C

<u>Referenced Sub-programs</u>: None

<u>Referenced Commons</u>: None

<u>Entry Points</u>: None

<u>Referencing Sub-programs</u>: SOLENG

<u>Discussion</u>: This subroutine computes the product of two 3x3 matrices. The input matrices are A and B and the product is returned in the array C. The equation for each element of C is

$$C_{ij} = \sum_{k=1}^{3} A_{ik} B_{kj} \; ; \quad i, j = 1, 2, 3.$$

MTMT EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
A(3,3)	UX		Input 3x3 array.
B(3,3)	UX		Input 3x3 array. .
C(3,3)	SX		Output 3x3 array containing the product of A and B.

CHART TITLE - SUBROUTINE MTMT(A,B,C)

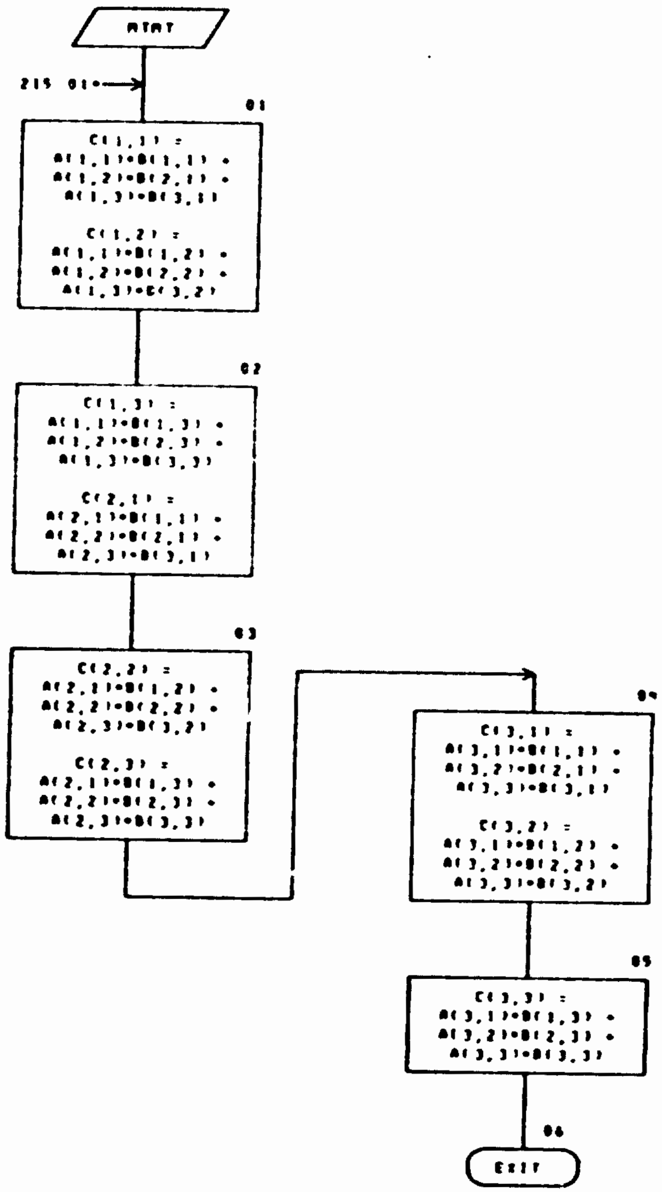


CHART TITLE - NON-PROCEDURAL STATEMENTS

```
IMPLICIT  REAL * 8 (A-H,O-Z)
DIMENSION A(3,3),B(3,3),C(3,3)
```

<u>Name:</u> MTVT

<u>Calling Arguments:</u> A, B, C

<u>Referenced Sub-programs:</u> None

<u>Referenced Commons:</u> None

<u>Entry Points:</u> None

<u>Referencing Sub-programs:</u> SETI, SOLENG

<u>Discussion:</u> This subroutine computes the product of a 3x3 matrix A operating on a 3-dimensional vector B. The result is returned in the 3-dimensional array C. Each element of C is calculated

$$C_i = \sum_{j=1}^{3} A_{ij} B_j \; ; \quad i = 1, 2, 3.$$

MTVT EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
A(3,3)	UX		Input matrix.
B(3)	UX		Input vector.
C(3)	SX		Output vector containing the product of A operating on B.

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CHART TITLE - SUBROUTINE MTVT(A,B,C)

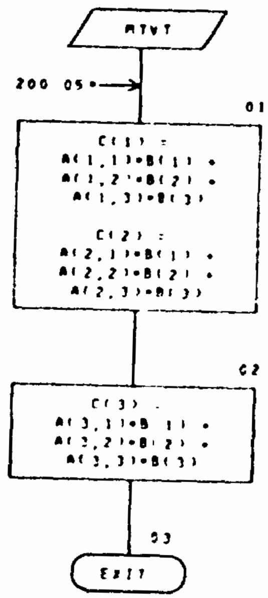

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
IMPLICIT REAL*8 (A-H,O-Z)
DIMENSION A(3,3),B(1),C(1)
```

Name: PDATE

Calling Arguments: TDATE, IY, IM, ID, HOUR

Referenced Sub-programs: None

Referenced Commons: None

Entry Points: None

Referencing Sub-programs: LAMBRT

Discussion: Subroutine PDATE evaluates the calendar date, given the Julian date. The procedure is to first subtract the Julian date (with leading 24 omitted) of 15020.5 from the input date to obtain the number of days from January 1.0, 1900. The year of the input date is then determined by entering a loop and accumulating the sum of days in all years from 1900 until the sum exceeds the number of days first determined on entry to PDATE. The number of days from the start of that year is then determined and used, with the aid of a data table, to define the month and day. Any fraction of a day remaining is then converted to hours and a return to the calling program is executed. The subroutine will not work correctly for input dates later than the year 2100.

Messages and Printout: If a date later than the year 2100 or earlier than the year 1900 is input, the following message is printed:

PDATE ERROR

PDATE EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
ID	SX		Calendar day of the month.
IM	SUX		Calendar month.
IY	SUX		Calendar year.
HOUR	SX		Hour of the day.
TDATE	UX		Input Julian date, with leading 24 omitted.

CHART TITLE - SUBROUTINE PDATE(TDATE,IY,IM,ID,HOUR)

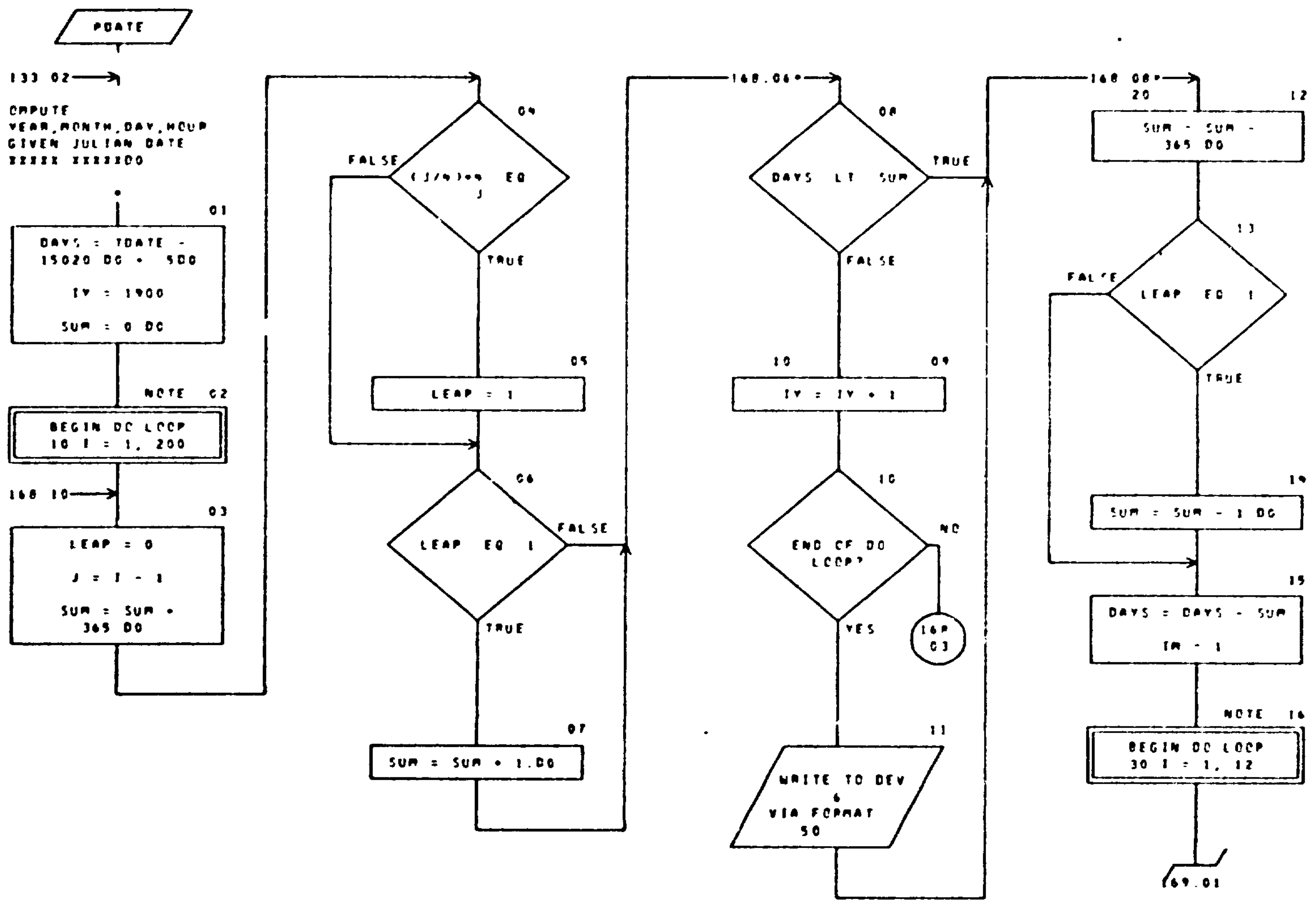

CHART TITLE - SUBROUTINE PDATE(TDATE,IY,IM,ID,HOUR)

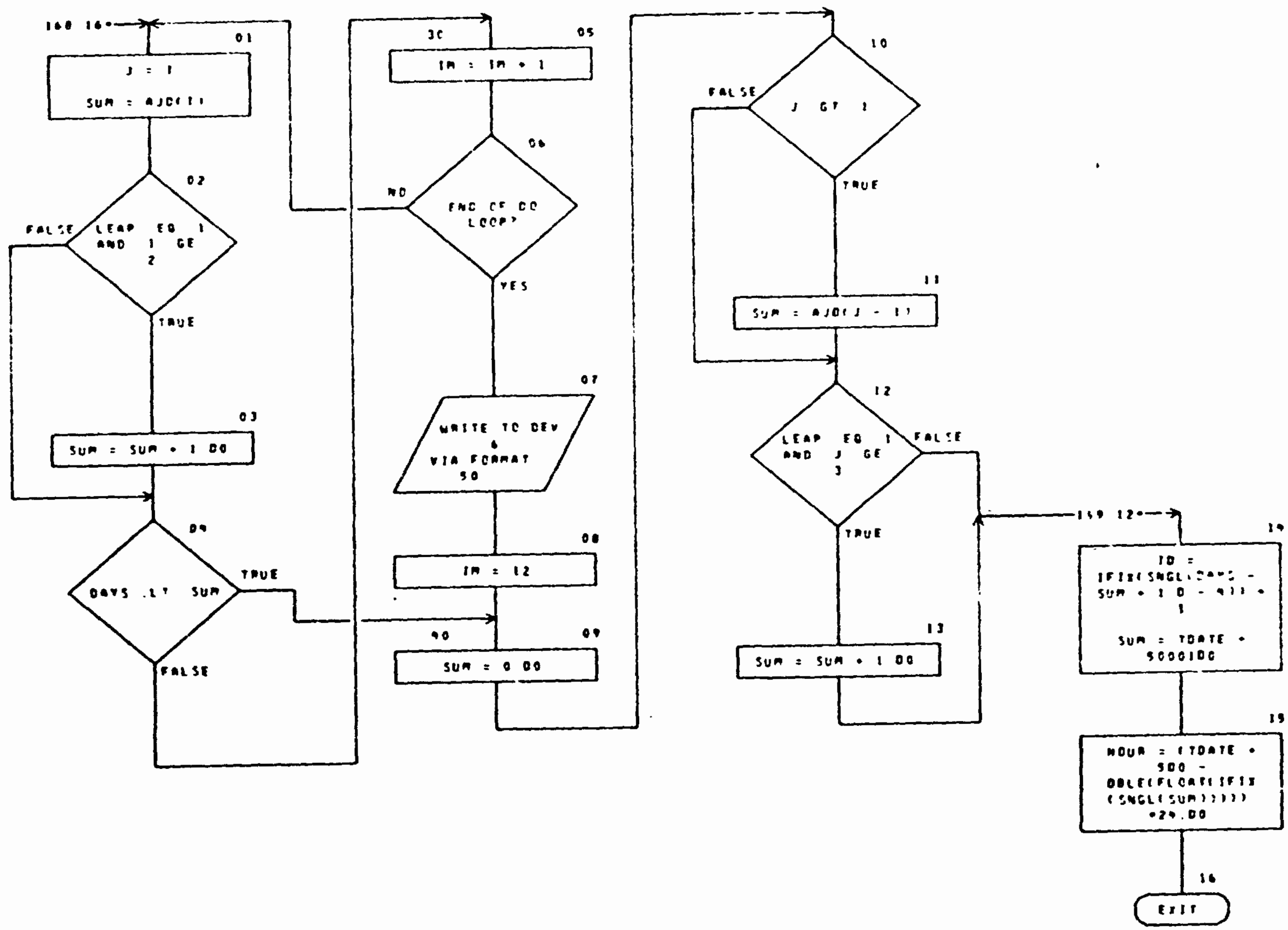

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION AJD(12)
      DATA AJD /31.D0,59 D0,90 D0,120 D0,151 D0,181 D0,212 D0,243 D0.
      273 D0,304 D0,334 D0,365 D0/
50    FORMAT (1H0,11HPDATE ERROR)
```

Name: PMPRNT

Calling Arguments: PM, MQ, MB

Referenced Sub-programs: None

Referenced Commons: None

Entry Points: None

Referencing Sub-programs: MINMX3

Discussion: This subroutine prints the partial derivative matrix used in the solution of the two point boundary value and parameter optimization problem. The matrix is input in the array PM; the number of dependent variables is MQ and the number of independent variables is MB. Denoting the vector of dependent variables as Y, with elements y_i, and the vector of independent variables as X, with elements x_j, then the first line of printout is $\partial y_i / \partial x_j$, $j = 1$, ---, MB; the second line is $\partial y_2 / \partial x_j$, $j = 1$, ---, MB; and so on. Each line may comprise more than one printer line, as each printer line will accomodate a maximum of ten values. If there are more than ten independent variables, the format is repeated. A blank line separates the derivatives of two different end conditions.

Messages and Printout: The format of the printed matrix simply comprises lines of up to ten values with field format of 1PD13.5. The lines of printout are single spaced for partials of the same dependent variable and double spaced between partials of different dependent variables.

PMPRNT EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
MB	UX		Number of independent variables.
MQ	UX		Number of dependent variables.
PM(MQ, MB)	UX		Partial derivative matrix.

CHART TITLE - SUBROUTINE PMPRNT(PM,MQ,MB)

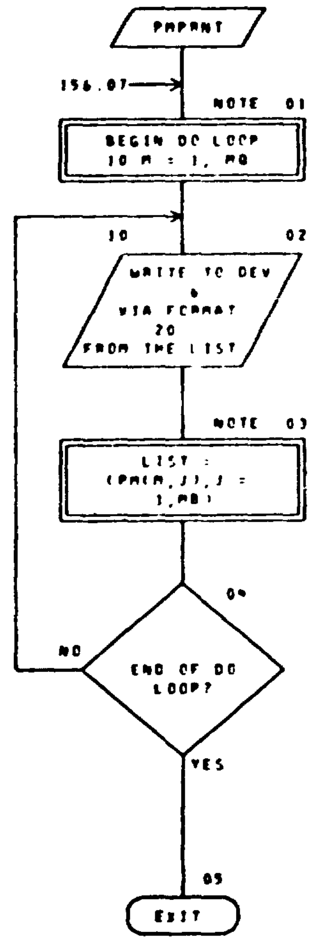

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
          IMPLICIT REAL*8 (A-H,O-Z)
          DIMENSION PMIMG(MB)
 20       FORMAT (1H ,10(/1H ,1P10D13.5))
```

Name: RADII

Calling Argument: XW

Referenced Sub-programs: None

Referenced Commons: None

Entry Points: None

Referencing Sub-programs: DERIV, FNMAT, RECT

Discussion: Given any 3-vector R, RADII computes the magnitude, magnitude squared, and magnitude cubed of that vector. Denoting the Cartesian components of R to be x, y, z and its magnitude to be r, the contents of XW are x, y, z, r^3, r, r^2 in elements 1-6, respectively. Upon entering RADII, the contents of XW(6) are stored in a temporary location, and the magnitude squared of the incoming vector is evaluated

$$XW(6) = r^2 = x^2 + y^2 + z^2$$

If this value equals the saved value of r^2, then further computations are bypassed, as it is assumed that R has not changed and therefore r and r^3 need not be recomputed. Otherwise, the magnitude of R is computed,

$$XW(5) = r = \sqrt{r^2}$$

and the magnitude cubed is obtained,

$$XW(4) = r^3 = r\,r^2.$$

RADII EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
XW(6)	SUX		A vector and the first three powers of its magnitude.

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CHART TITLE - SUBROUTINE RADII(XW)

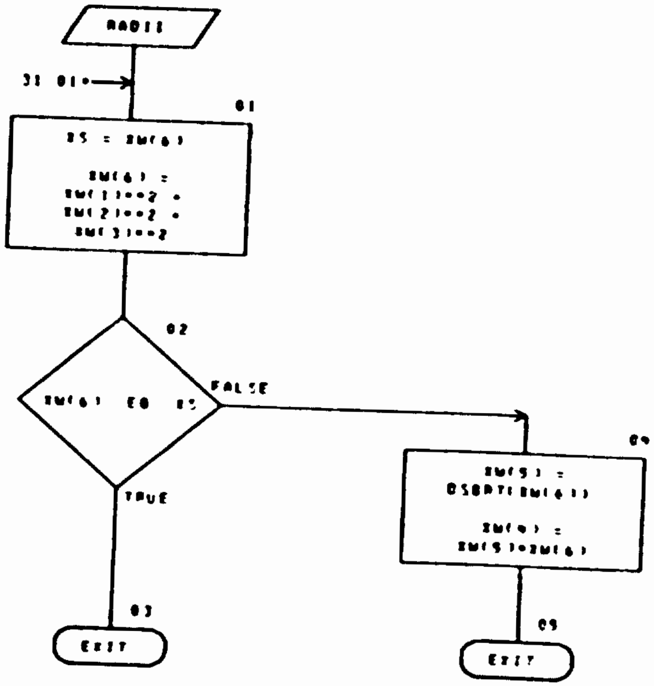


CHART TITLE - NON-PROCEDURAL STATEMENTS

```
IMPLICIT REAL*8 (A-H,O-Z)
DIMENSION XM(6)
```

<u>Name</u>: RECT

<u>Calling Argument</u>: None

<u>Referenced Sub-programs</u>: RADII

<u>Referenced Commons</u>: ALAN, AM1, CONVRT, FRAN, HENRY, ILEF, INTEG, LEFT, LEON, STEVE

<u>Entry Points</u>: None

<u>Referencing Sub-Programs</u>: TRAJL

<u>Discussion</u>: The purpose of this subroutine is to rectify the two body reference trajectory to the current position and velocity and to compute and/or initialize selected parameters to the new reference. Rectifications of the reference trajectory may be initiated for any of a number of reasons, such as the ratio of deviations in position or velocity from the reference to the corresponding two body parameter exceeding a specified value, the change in eccentric anomaly since the last rectification exceeding a specified value, the switching from one reference body to another, or the start of a new trajectory arc. The criteria for rectification due to position or velocity deviations is defaulted to a value of 0.01 for the ratio of the magnitude of the deviation to the magnitude of the corresponding position or velocity. These defaults may be changed by the input parameters POSRCS and/or VELRCS which represent the square of the maximum allowable ratios in position and velocity, respectively. The default value for change in eccentric anomaly is 1.5 radians and may be changed with the input parameter THTS.

The rectification involves redefining the current two body position and velocity vectors

$$R_k = R$$

$$\dot{R}_k = \dot{R}$$

$$d_k = R \cdot \dot{R}$$

$$\frac{1}{a_k} = \frac{2}{r^2} - \frac{\dot{R} \cdot \dot{R}}{\mu}$$

where R denotes the current position vector in the current reference frame of integration, $r = |R|$, μ is the gravitational constant of the reference body, a is the semi-major axis, and the subscript k denotes the reference two body trajectory. The integrated Encke terms ξ and $\dot{\xi}$ are adjusted as follows

$$\xi_i = \xi_i - \xi_n ; \quad \dot{\xi}_i = \dot{\xi}_i - \dot{\xi}_n$$

$$\xi_n = 0; \qquad \dot{\xi}_n = 0,$$

where the subscript i refers to the i^{th} perturbation trajectory and n denotes the nominal trajectory. In addition the universal variable β is set to zero and the gravitational constant is reset in case the reference body of integration just changed. The gravitational constant array KM is reset in case a switch in reference body has occurred which would require a change in units of the KM array. The computation is

$KM(I) = \mu_{\oplus} \; m_{\oplus}(I)$ if in Earth or moon reference

$KM(I) = \mu_{\odot} \; m_{\odot}(I)$ if not in Earth or moon reference

$\mu_{\oplus}$ and $\mu_{\odot}$ are the gravitational constants of the Earth in ER^3/hr^2 and sun in AU^3/hr^2, respectively, $m_{\oplus}(I)$ is the mass of the I^{th} body in Earth masses and $m_{\odot}(I)$ is the mass of the I^{th} body in sun masses. The rectification print is then executed unless excluded by the input flag NOPT(16). Control is then returned to the calling subroutine.

Messages and printouts: If NOPT(16) is input zero, selected information is printed at each rectification point. The format is as follows:

___(Reason)___ RECTIFICATION PRINT ___(Body)___ REFERENCE

PERT OVER UNPERT=__________ TIME=__________ DELTA T=__________

The "reason" for the rectification is printed as one of the following four possibilities:

VEL, POS, TH or blank

corresponding to velocity, position, change in eccentric anomaly, or other, respectively. The "body" printed is the name of the reference body of integration in which the rectification occurred. If the rectification occurred because of a reference switch, the name of the new reference body will be printed here. On the second line the quantity TIME denotes the time of rectification and DELTA T is the integration interval. The quantity denoted as PERT OVER UNPERT will be non-zero only if the "reason" for rectification is non-blank. If POS is printed for the reason, then the quantity PERT OVER UNPERT is

$$\xi \cdot \xi / (R_k \cdot R_k),$$

if the reason is printed VEL, the quantity is evaluated

$$\dot{\xi} \cdot \dot{\xi} / (\dot{R}_k \cdot \dot{R}_k) \; ,$$

and if the reason is printed TH, the quantity is evaluated

$$TH = \theta = E - E_o \; ,$$

where E is the eccentric anomaly and the subscript o refers to the preceding rectification point. All numbers are printed with the format D17.8.

RECT EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
T	U	ALAN	Current time, t, in hours from departure of the launch parking orbit.
IO	U	INTEG	Logical unit on which principal program output is printed.
KM(12)	S	HENRY	Array of gravitational constants of sun, moon and planets.

RECT EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
ME(12)	SU	HENRY	Planetary mass array, scaled according to the reference.
TI	S	STEVE	Time of rectification, t_k, in hours from departure of the launch parking orbit.
XI(80)	SE	AM1	Position deviation from two body reference trajectory, ξ, on nominal and perturbation trajectories.
KSQ	SU	STEVE	Gravitational parameter of reference planet, μ.
NQN	U	ILEF	Number of equations being integrated on each trajectory, including first and second order.
XID(80)	SE	AM1	Velocity deviation from two body reference trajectory, $\dot{\xi}$, on nominal and perturbation trajectories.
XRI(6)	SUA	STEVE	Spacecraft position vector at rectification relative to reference body of integration, R_k.
XRL(6, 20)	U	LEFT	Cartesian position vector of spacecraft relative to reference body of integration, R, on nominal and perturbed trajectories.
BETA	S	AM1	Universal anomaly, β.
DELT	U	STEVE	Normal integration step-size.
KSQQ(12)	U	HENRY	Array of reference body gravitational factors for planets, sun and moon.
NEQL	U	ILEF	Number of trajectories being integrated simultaneously, nominal plus perturbed.
NOPT(72)	U	INTEG	Array of program option flags

RECT EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
O1AD	S	STEVE	Inverse of semi-major axis, $1/a_k$.
REKM	U	HENRY	Conversion factor for distance; equal to the number of kilometers in 1 ER.
XRDL(6, 20)	U	LEFT	Spacecraft velocity vector relative to the reference body of integration, Ṙ. Includes nominal and perturbation trajectories.
NPLAN	U	INTEG	Number of planets included in the simulation.
RATIO	U	HENRY	State deviation criteria used in conjunction with rectification criteria.
RDOTD	SU	STEVE	$d_k = R \cdot \dot{R}$.
SQTMU	SU	STEVE	Square root of reference body gravitational factor, $\sqrt{\mu}$.
TMPDP	S	LEON	β^2.
TM2DP	S	STEVE	$d_k/\sqrt{\mu}$.
XMDKM	U	FRAN	Conversion factor for distance; equal to the number of kilometers in 1 AU.
XRIDT(6)	SUA	STEVE	Spacecraft velocity vector at rectification relative to reference body of integration, $\dot{R}_k$.
APSCON	S	CONVRT	Factor for converting units of acceleration from m/sec^2 to ER/hr^2 or AU/hr^2.
IDUMMY	U	INTEG	Flag equal to 1, 2, 3 or 4 which defines whether rectification was required because of velocity deviation, position deviation, change in eccentricity anomaly or other, respectively.
IREFNO	U	INTEG	Reference body identification number.

CHART TITLE - SUBROUTINE RECT

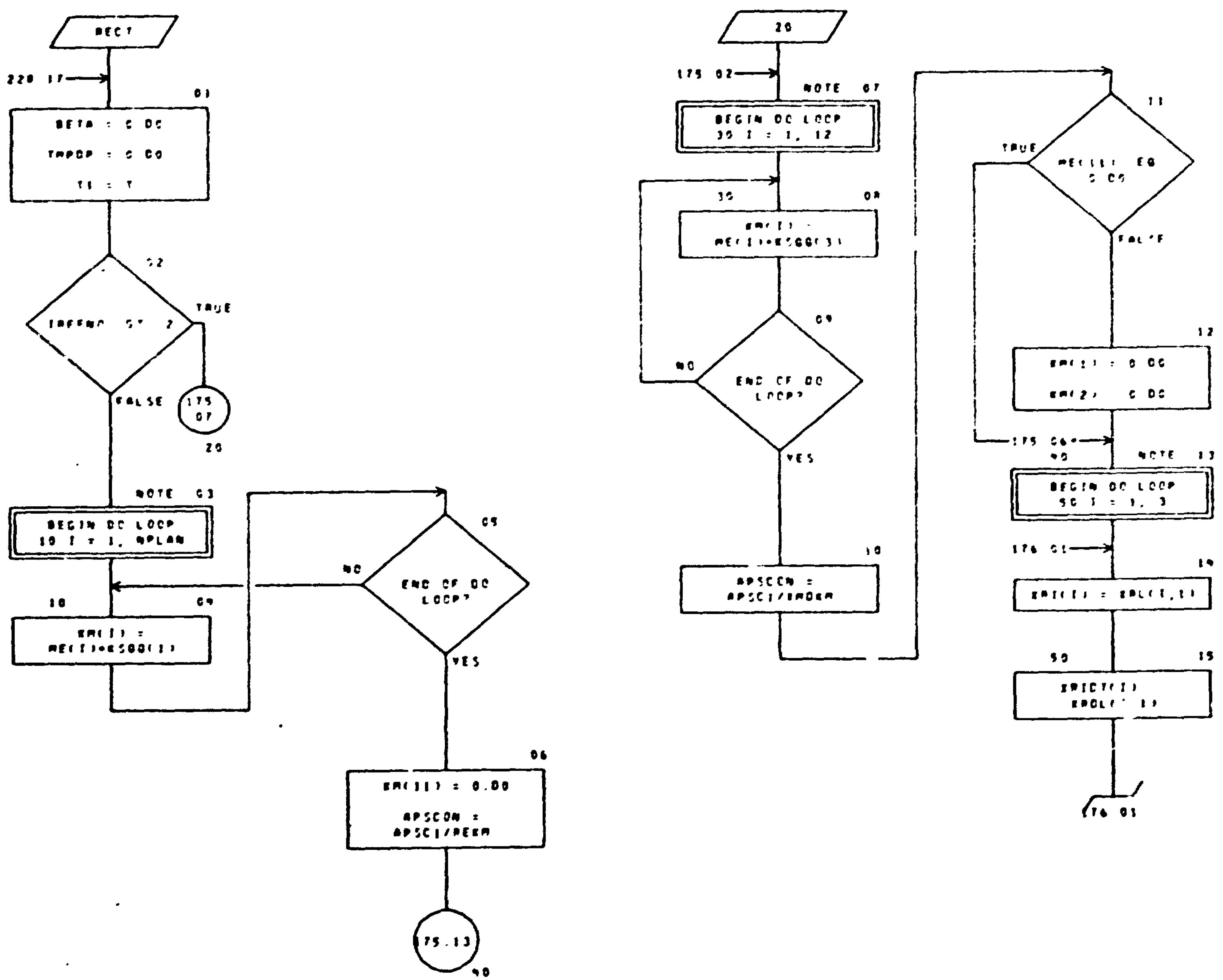
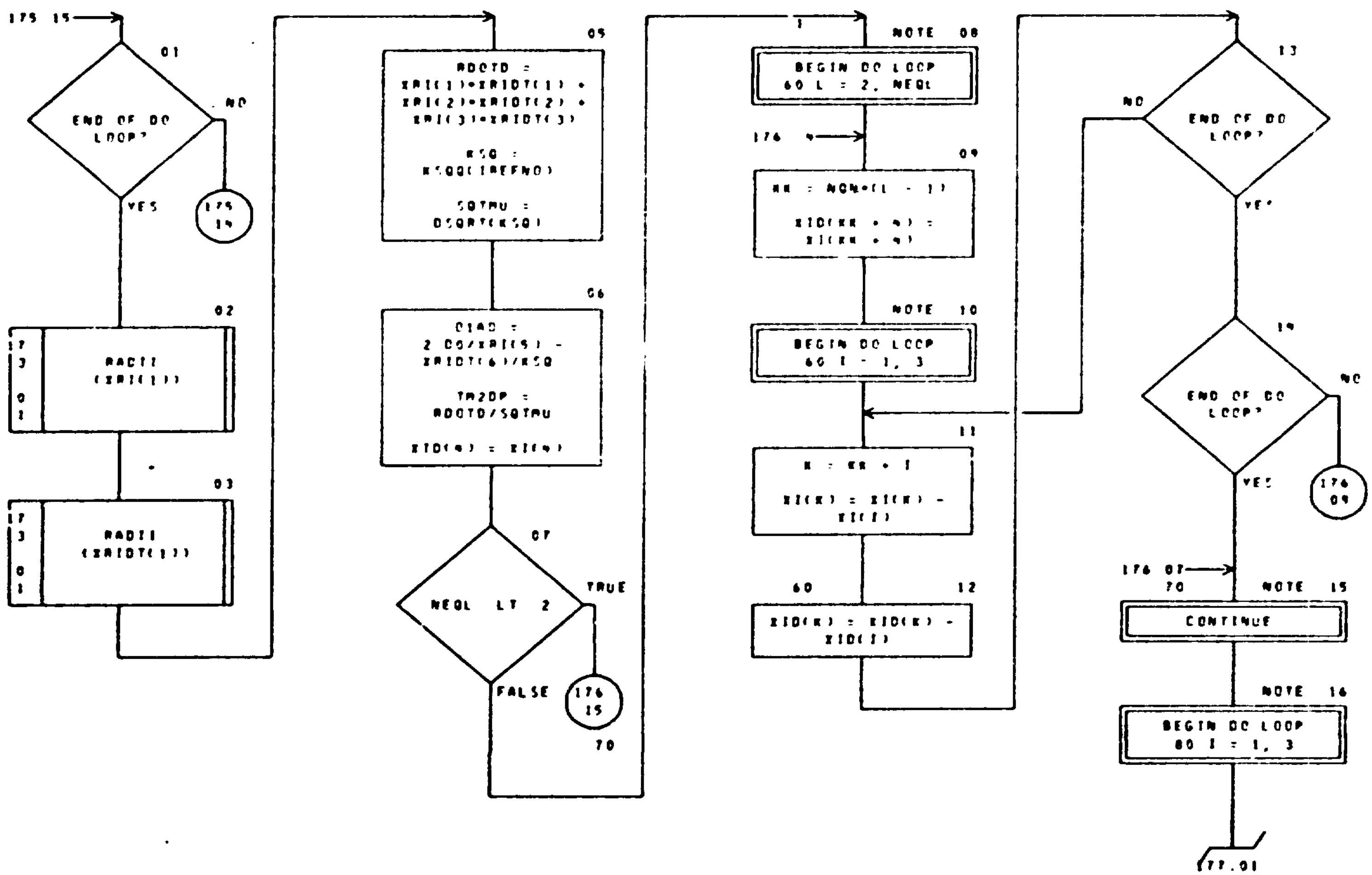


CHART TITLE - SUBROUTINE RECT



RECT-7

CHART TITLE - SUBROUTINE RECT

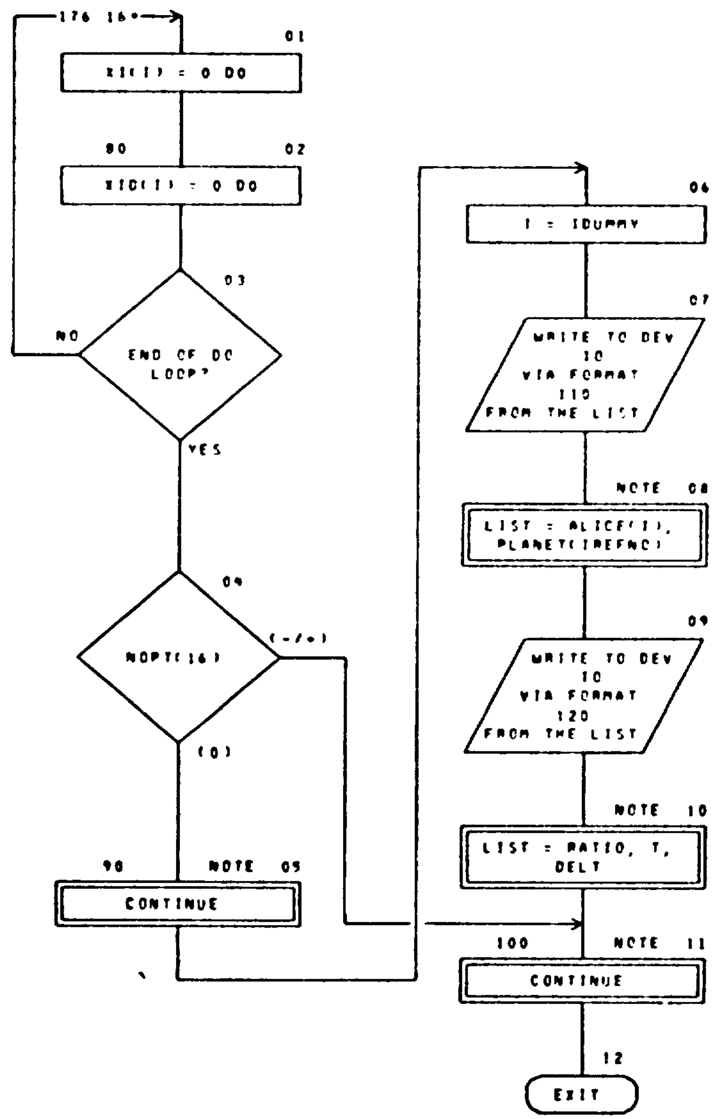


CHART TITLE - NON-PROCEDURAL STATEMENTS

```
          IMPLICIT REAL*8 (A-H,O-Z)
          INTEGER DAY,HOURS,YEAR
          REAL*8 KSQQ,MEI,ME,KM,MDIST,INTV,IN1X,IN2X,KSQ
          DIMENSION PLANET(6)
          DIMENSION ALICE(4)
          COMMON/ALAN/T,RHBR,DORHO
          COMMON/AM1/ZELT,BETA,DTT,XI(80),XID(80),D2XI(80),IFST(80)
          COMMON/CONVRT/APSCON,APSC2
          COMMON/FRAN/XMDKM
          COMMON/HENRY/ARRAY(8,3,12),CHIND,INTV(72),IN1X(3),
          IN2X(3),KSQQ(12),KM(12),MDIST,MEI(12),ME(12),PCSRCS,PRVDT,
          PDT,PCIN,RD,REKM,RRM,RRE,RREV,RCIND,RATIO,SEC,TSCL,THTS,TP1,
          TIMEL,THET,VELRCS
          COMMON/ILEF/NEQL,NEQ3,NON,NOP65,IOAP(7),NOP64,NOP63,NS,N4,NS1,NIJ
          COMMON/INTEG/DAY,HOURS,YEAR,IDUMMY,ITRIG,IREFNO,IREFNB,
          IREFNT,IN,IO,IJK,MONTH,MIN,NOPT(72),NPLAN,NPLAN3
          COMMON/LEFT/XPL(6,20),XPDL(6,20),VCOL(72,20)
          COMMON/LEON/XRO(6),XRDOT(6),TMPOP,W
          COMMON/STEVE/DELT,KSQ,DIAD,RDCTD,TI,TM2DP,XRI(6),XRIDT(6),SQTMU
          DATA PLANET
          /' EARTH',' MOON',' SUN',' VENUS','MARS',' JUPITER'/
          DATA ALICE
          /' VEL',' POS',' TH ','    '/
          DATA APSC1/12960 D0/
110       FORMAT (1A4,21H RECTIFICATION PRINT 1A8,10H REFERENCE//)
```

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
120       FORMAT (20H PERT OVER UNPERT = E17 8,8H TIME = E17 8,19H DELTA BET
          A = ,E17.8//)
```

Name: REMTIM

Calling Arguments: I, J

Referenced Sub-programs: None

Referenced Commons: None

Entry Points: None

Referencing Sub-programs: TRAJL

Discussion: REMTIM is delivered as a dummy routine, but should be recoded as appropriate at each installation to return to the program the amount of time remaining for the job. The first argument I should contain the amount of CPU time; the second argument J should contain the amount of I/O time remaining. In the dummy routine provided, both arguments are set to 9999. This permits ASTOP to execute and effectively ignores the job time-out feature.

REMTIM EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
I	SX		Job CPU time remaining, in seconds.
J	SX		Job I/O time remaining, in seconds.

CHART TITLE - SUBROUTINE REMTIM(I,J)

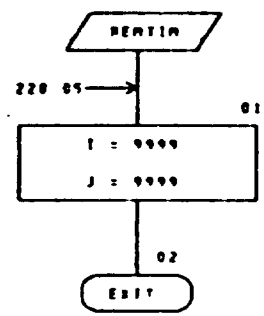


CHART TITLE - NON-PROCEDURAL STATEMENTS

```
IMPLICIT REAL*8 (A-H,O-Z)
```

Name: SAMM

Calling Arguments: TBAR, T0BAR, RXTB, RXDTB, RTX, RDTX, IOPT

Referenced Sub-programs: DCUBIC, SUBFG

Referenced Commons: SAML1, THAD

Entry Points: None

Referencing Sub-programs: SETI

Discussion: Subroutine SAMM solves the two-body conic equations for position R and velocity $\dot{R}$ at a time t, given position R_o and velocity $\dot{R}_o$ at an earlier time t_o. On option, the subroutine also evaluates the state transition matrix $\Phi(t_o, t)$ for the transfer from time t_o to t. To commence the procedure, the following two-body variables are evaluated

$$r_o = \sqrt{R_o \cdot R_o} \quad ,$$

$$v_o^2 = \dot{R}_o \cdot \dot{R}_o \quad ,$$

$$d_o = R_o \cdot \dot{R}_o \quad ,$$

$$\frac{1}{a} = \frac{2}{r_o} - \frac{v_o^2}{\mu} \quad ,$$

where a is the semi-major axis and μ is the gravitational constant of the reference body. If a is greater than zero (i.e., the conic is elliptical), the time interval, $\Delta t = t - t_o$, is compared to the period of the orbit

$$\tau = 2\pi \sqrt{a^3/\mu} \quad .$$

If $\Delta t > \tau$, then Δt is reset to the fractional portion of the period, the integral number of revolutions, n, is saved, a flag is set to denote the reduction in Δt has occurred, and a message is printed.

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An iteration loop is then entered to determine the increment $\Delta\beta$ in the universal anomaly which corresponds to the given time interval Δt. The first guess of $\Delta\beta$ is evaluated

$$\Delta\beta_o = \sqrt{\mu}\ \Delta t/r_o ,$$

and the corresponding increment squared in eccentric anomaly is formed

$$\theta^2 = (E - E_o)^2 = \Delta\beta^2/a .$$

If $|\theta^2| > 1$, an improved first guess for $\Delta\beta_o$ is evaluated by solving the cubic equation

$$\Delta\beta_o^3 + 3d_o\ \Delta\beta_o^2/\sqrt{\mu} + 6\,r_o\ \Delta\beta_o - 6\sqrt{\mu}\ \Delta t = 0 ,$$

for $\Delta\beta_o$. The loop commences with a call to SUBFG to evaluate the series functions G_i. The distance r at the time t may then be calculated

$$r = G_2 + r_o G_o + d_o G_1/\sqrt{\mu} ,$$

and the improved estimate of $\Delta\beta$ becomes

$$\Delta\beta_{i+1} = \Delta\beta_i + \sqrt{\mu}\ \Delta t/r - (G_3 + r_o G_1 + d_o G_2/\sqrt{\mu})/r.$$

The iteration is terminated when either of the two tests

$$\Delta\beta_{i+1} - \Delta\beta_i < \Delta\beta_{i+1}\ \epsilon$$

or

$$\Delta\beta_{i+1} - \Delta\beta_i < \sqrt{\mu}\ \Delta t\ \epsilon/r ,$$

is satisfied, where $\epsilon = 5 \times 10^{-15}$. For elliptic orbits, provisions are made to force β_{i+1} to remain in the interval

$$-\delta < \beta_{i+1} < \delta \ ; \quad \delta = 2\pi/\sqrt{a} .$$

If β_{i+1} is less than the lower bound, it is redefined

$$\beta_{i+1} = (\beta_i - \delta)/2;$$

or if β_{i+1} exceeds the upper bound, then

$$\beta_{i+1} = (\beta_i + \delta)/2 .$$

If the iteration has not converged, an iteration counter is incremented and control is transferred to the top of the loop. A maximum of 40 iterations is permitted. If this limit is reached, a message is printed and the last value of $\Delta\beta_{i+1}$ is used for all subsequent calculations. The flag indicating whether a reduction in Δt was performed for multiple revolutions is checked and, if appropriate, the $\Delta\beta$ is adjusted as follows:

$$\Delta\beta = \Delta\beta + 2\pi n/\sqrt{a} .$$

The two-body f and g functions are then evaluated

$$f = 1 - G_2/r_o ,$$

$$g = \Delta t - G_3/\sqrt{\mu} ,$$

$$\dot{f} = -\sqrt{\mu}\ G_1/r\,r_o ,$$

$$\dot{g} = 1 - G_2/r ,$$

and the desired position and velocity vectors are

$$R = fR_o + g\dot{R}_o ,$$

$$\dot{R} = \dot{f}\,R_o + \dot{g}\dot{R}_o .$$

If the transition matrix for the transfer is desired, its computation then begins. Otherwise, a return to the calling subroutine is executed.

The transition matrix is computed in four partitions as follows:

$$\Phi(t_o, t) = \left[\begin{array}{c|c} A & B \\ \hline C & D \end{array}\right]$$

where

$$A = \partial R/\partial R_o \; ; \qquad B = \partial R/\partial \dot{R}_o \, ,$$

$$C = \partial \dot{R}/\partial R_o \; ; \qquad D = \partial \dot{R}/\partial \dot{R}_o \, .$$

From the equations above for R and $\dot{R}$,

$$A = f I + R_o \frac{\partial f}{\partial R_o} + \dot{R}_o \frac{\partial g}{\partial R_o} ,$$

$$B = g I + R_o \frac{\partial f}{\partial \dot{R}_o} + \dot{R}_o \frac{\partial g}{\partial \dot{R}_o} ,$$

$$C = \dot{f} I + R_o \frac{\partial \dot{f}}{\partial R_o} + \dot{R}_o \frac{\partial \dot{g}}{\partial R_o} ,$$

$$D = \dot{g} I + R_o \frac{\partial \dot{f}}{\partial \dot{R}_o} + \dot{R}_o \frac{\partial \dot{g}}{\partial \dot{R}_o} ,$$

where I denotes the 3x3 identity matrix. The calculation of the partials of f, g, $\dot{f}$, and $\dot{g}$ with respect to the initial position and velocity is facilitated by first forming the auxiliary functions

$$y_1 = 3 G_5 - \Delta\beta G_4 ,$$

$$y_2 = 2 G_4 - \Delta\beta G_3 ,$$

$$y_3 = G_3 - \Delta\beta G_2 ,$$

$$y_4 = y_1 + r_o y_3 + d_o y_2/\sqrt{\mu} ,$$

$$y_5 = \sqrt{\mu}\; y_3/r r_o^2 - \dot{f} .$$

Then the required partial derivatives are evaluated as follows:

$$\frac{\partial f}{\partial R_o} = \left[\frac{(y_2 + G\ )}{r_o^3} - \frac{G_1}{r_o r} \left(\frac{y_4}{r_o^3} - \frac{G_1}{r_o} \right) \right] R_o + \frac{G_1 G_2}{r_o r \sqrt{\mu}} \dot{R}_o \, ,$$

$$\frac{\partial g}{\partial R_o} = \left[\frac{y_1}{r_o^3 \sqrt{\mu}} - \frac{G_2}{r \sqrt{\mu}} \left(\frac{y_4}{r_o^3} - \frac{G_1}{r_o} \right) \right] R_o + \frac{G_2^2}{r \mu} \dot{R}_o \, ,$$

$$\frac{\partial f}{\partial \dot{R}_o} = \frac{G_1 G_2}{r_o r \sqrt{\mu}} R_o + \frac{1}{r_o \mu} \left(y_2 - \frac{G_1 y_4}{r} \right) \dot{R}_o \, ,$$

$$\frac{\partial g}{\partial \dot{R}_o} = \frac{G_2^2}{r \mu} R_o + \frac{1}{\mu^{3/2}} \left(y_1 - \frac{G_2 y_4}{r} \right) \dot{R}_o \, ,$$

$$\frac{\partial \dot{f}}{\partial R_o} = \left[\frac{y_5}{r_o^2} - \frac{\sqrt{\mu}\, G_o}{r_o^2 r^2} \left(\frac{y_4}{r_o^2} - G_1 \right) \right] R_o + \frac{G_o G_2}{r_o r^2} \dot{R}_o - \frac{\dot{f}}{r^2} A^T R \, ,$$

$$\frac{\partial \dot{g}}{\partial R_o} = \left[\frac{y_2}{r_o^3 r} - \frac{G_1}{r_o r^2} \left(\frac{y_4}{r_o^2} - G_1 \right) \right] R_o + \frac{G_1 G_2}{\sqrt{\mu}\, r^2} \dot{R}_o + \frac{G_2}{r^2} A^T R \, ,$$

$$\frac{\partial \dot{f}}{\partial \dot{R}_o} = \frac{G_o G_2}{r_o r^2} R_o + \left(\frac{y_3}{r_o r \sqrt{\mu}} - \frac{G_o y_4}{r_o r^2 \sqrt{\mu}} \right) \dot{R}_o - \frac{\dot{f}}{r^2} B^T R \, ,$$

$$\frac{\partial \dot{g}}{\partial \dot{R}_o} = \frac{G_1 G_2}{r^2 \sqrt{\mu}} R_o + \left(\frac{y_2}{r \mu} - \frac{G_1 y_4}{r^2 \mu} \right) \dot{R}_o + \frac{G_2}{r^2} B^T R \, .$$

<u>Messages and Printout:</u> If the maximum number of iterations in solving for $\Delta\beta$ is exceeded, the following message is printed:

MAXIMUM ITER. EXCEEDED I, BETA, BETAM1 = <u>(I4)</u> <u>(E17.8)</u> <u>(E17.8)</u>

where I denotes the number of iterations, BETA is $\Delta\beta_{i+1}$ and BETAM1 is $\Delta\beta_i$. The quantities in parentheses define the Fortran field format under which the values are printed.

SAMM-5

If the time interval $t - t_o$ exceeds the period of the elliptic orbit, the following messages are printed:

ERROR TBAR - TOBAR TOO LARGE = (D17.8)

REDUCTION DEN XX ZZ YY DELT IXX

(D25.16) (D25.16) (D25.16) (D25.16) (D25.16) (I4)

where DEN is the period in hours, XX is the time interval $t - t_o$ expressed in orbital periods, ZZ is the whole part of XX, YY is fractional part of XX, DELT is the fractional part of XX expressed in hours, and IXX is the integral number of periods (=ZZ).

SAMM EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
G1	U	THAD	Universal anomaly function, G_1, evaluated in SUBFG.
G2	U	THAD	Universal anomaly function, G_2, evaluated in SUBFG.
G3	U	THAD	Universal anomaly function, G_3, evaluated in SUBFG.
G4	U	THAD	Universal anomaly function, G_4, evaluated in SUBFG.
G5	U	THAD	Universal anomaly function, G_5, evaluated in SUBFG.
AIJ(3,3)	SU	SAML1	Matrix of partials of the position at time t with respect to the position at time t_o.
BIJ(3,3)	SU	SAML1	Matrix of partials of the position at time t with respect to the velocity at time t_o.

SAMM EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
CIJ(3,3)	S	SAML1	Matrix of partials of the velocity at time t with respect to the position at time t_o.
DIJ(3,3)	S	SAML1	Matrix of partials of the velocity at time t with respect to the velocity at time t_o.
GG0	U	THAD	Universal anomaly function, G_o, evaluated in SUBFG.
NRE	A		Number of real roots to the cubic equation solved in DCUBIC.
RES(3)	UA		Array of solutions to the cubic equation solved in DCUBIC.
RTB(3)	SU	SAML1	Position vector at time t.
RTX(3)	SX		Position vector at time t, equal to RTB.
SEA(3)	SA		Array of coefficients of the cubic equation solved in DCUBIC.
XMU	U	SAML1	Gravitational constant of central body.
IOPT	UX		Flag indicating whether the state transition matrix is desired. = 1 - matrix is to be evaluated ≠ 1 - matrix is not wanted
O1AD	SU	SAML1	Inverse of semi-major axis, 1/a.
RDTB(3)	SU	SAML1	Velocity vector at time t.
RDTX(3)	SX		Velocity vector at time t, equal to RDTB.
RXTB(3)	UX		Position vector at time t_o, equal to R0TB.

SAMM EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
R0TB(3)	SU	SAML1	Position vector at time t_o.
TBAR	UX		Time t.
RXDTB(3)	UX		Velocity vector at time t_o, equal to R0DTB.
R0DTB(3)	SU	SAML1	Velocity vector at time t_o.
T0BAR	UX		Time t_o.
BETAM1	SU	THAD	Increment in universal anomaly, $\Delta\beta$, between t_o and t.
THETA2	SUA		Square of the difference in eccentric anomaly between t_o and t, θ^2.

CHART TITLE - SUBROUTINE SAMM(TBAR,TOBAR,RXTB,RXDTB,RTX,RDTX,IOPT)

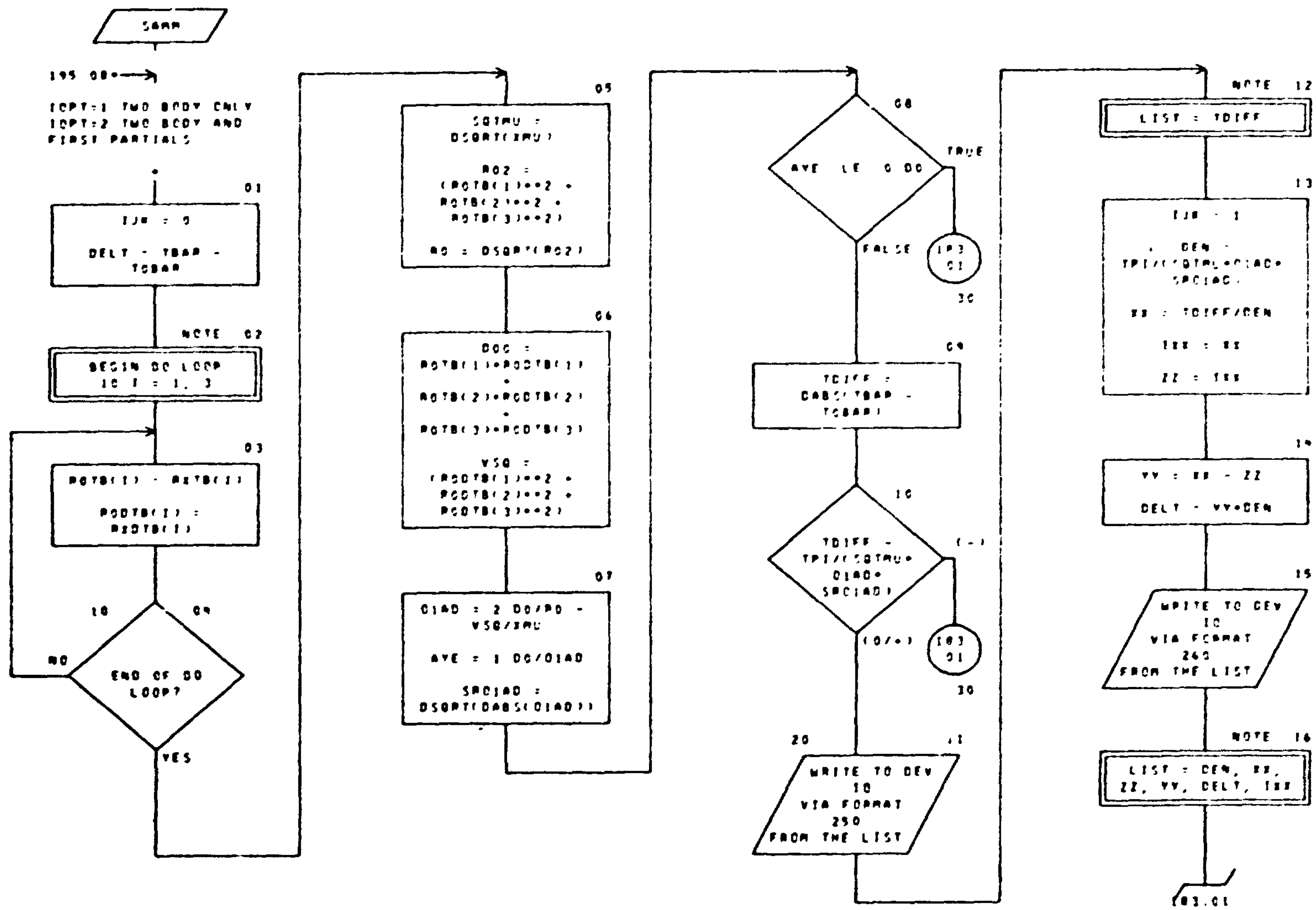


CHART TITLE - SUBROUTINE SAMM(TBAR,TOBAR,RXTB,RXDTB,RTX,RDTX,IOPT)

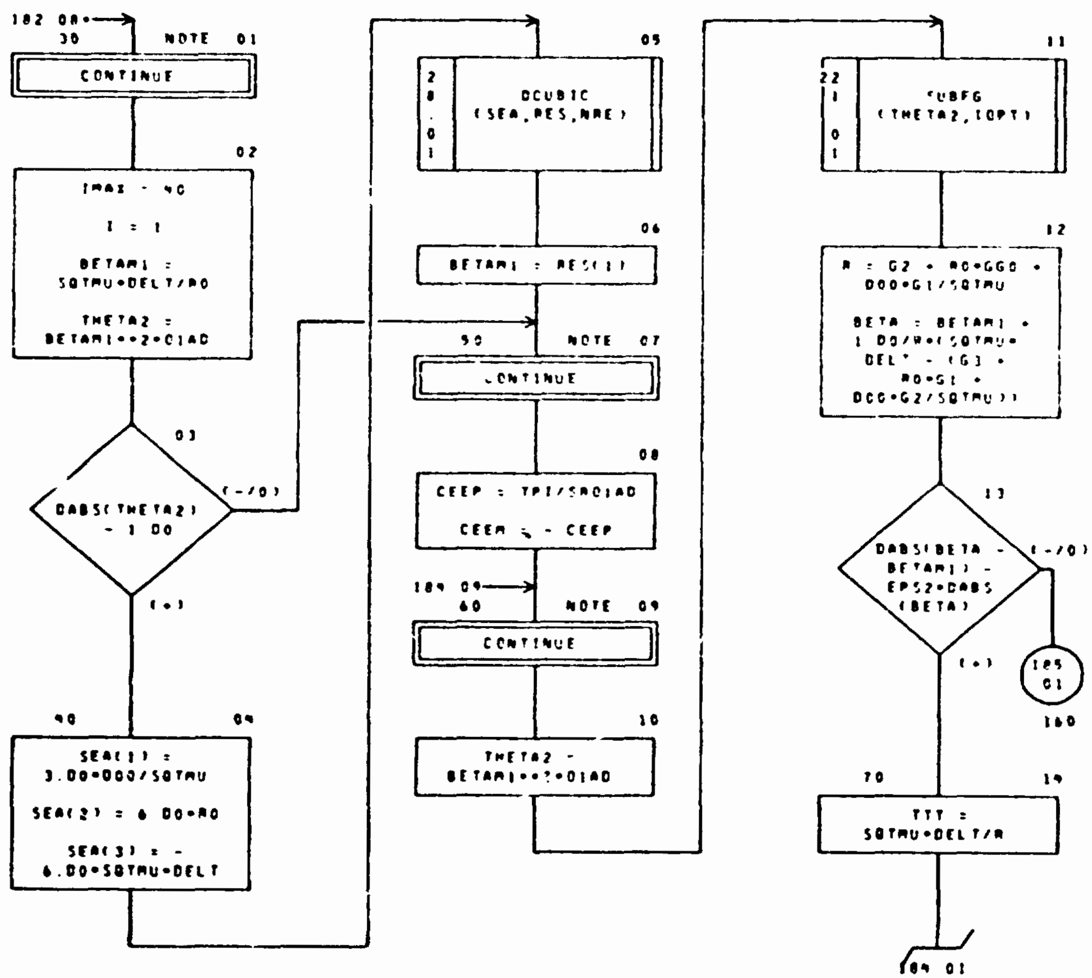
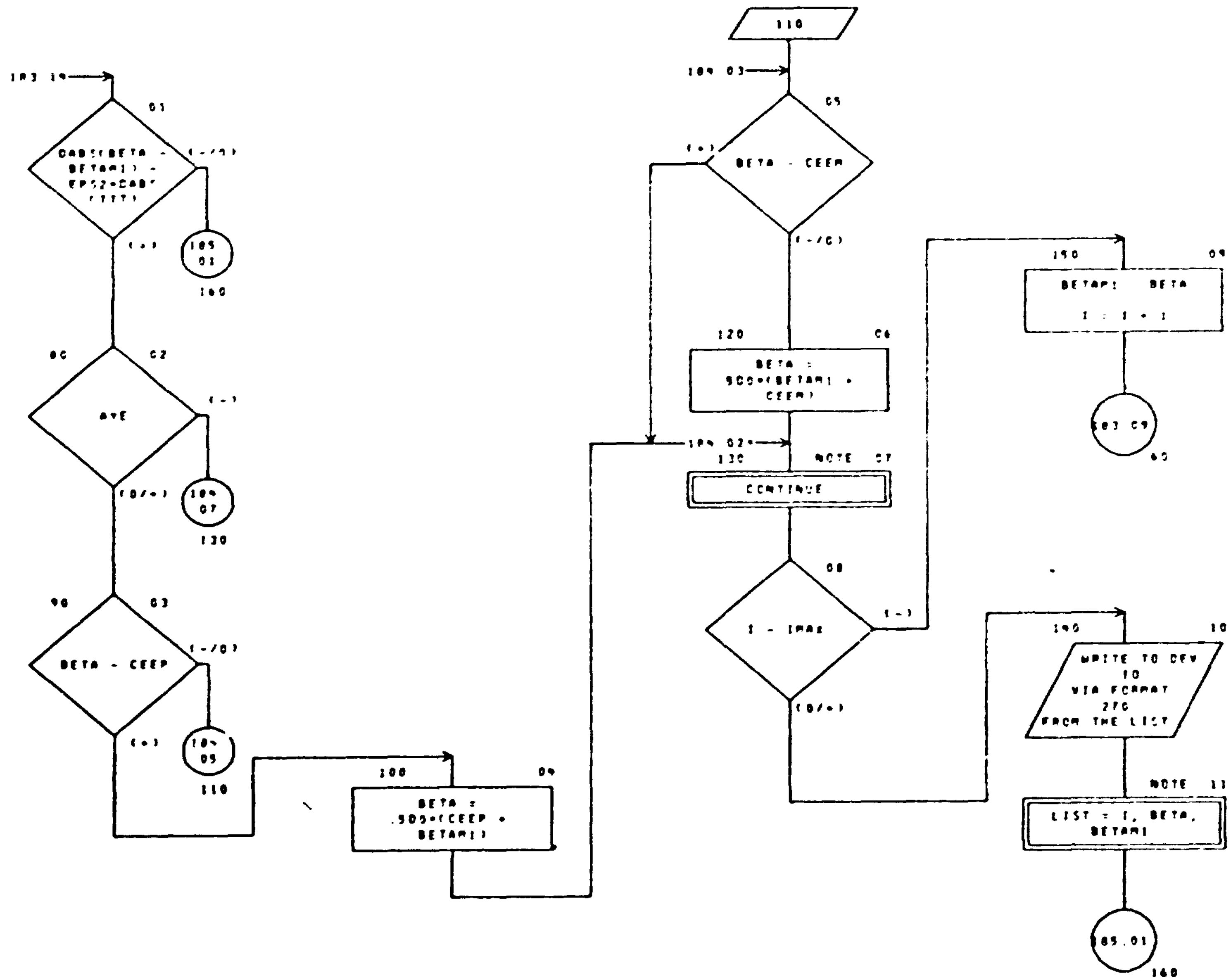


CHART TITLE - SUBROUTINE SAMM(TBAR,TOBAR,RXTB,RXDTB,RTX,RDTX,IOPT)



SAMM-11

CHART TITLE - SUBROUTINE SAMM(TBAR,TDBAR,RETB,REDTB,RTB,RDTB,IOPT)

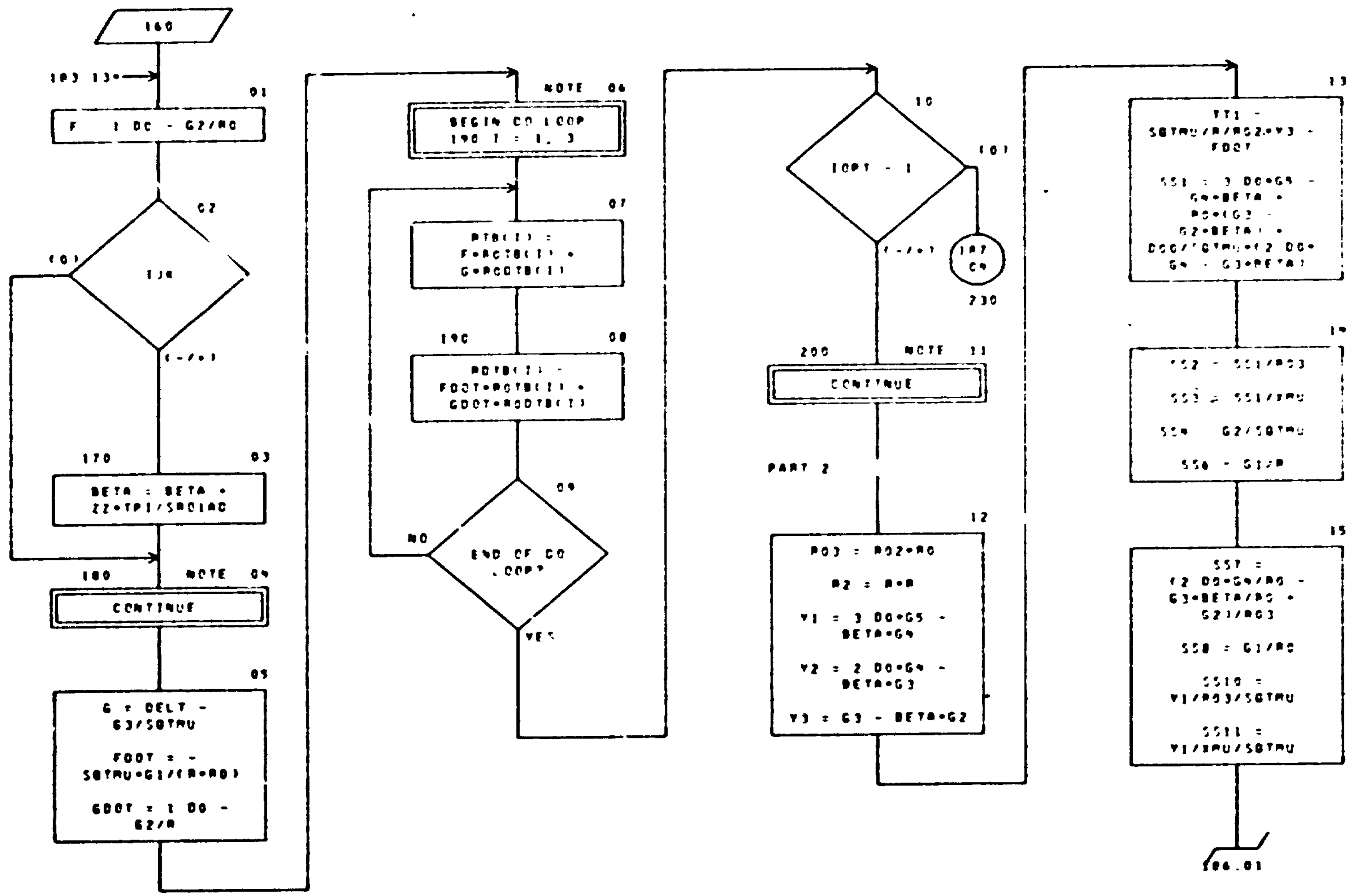


CHART TITLE - SUBROUTINE SAMM(TBAR,TOBAR,RRTB,RRDTB,RTZ,RDTZ,ICPT)

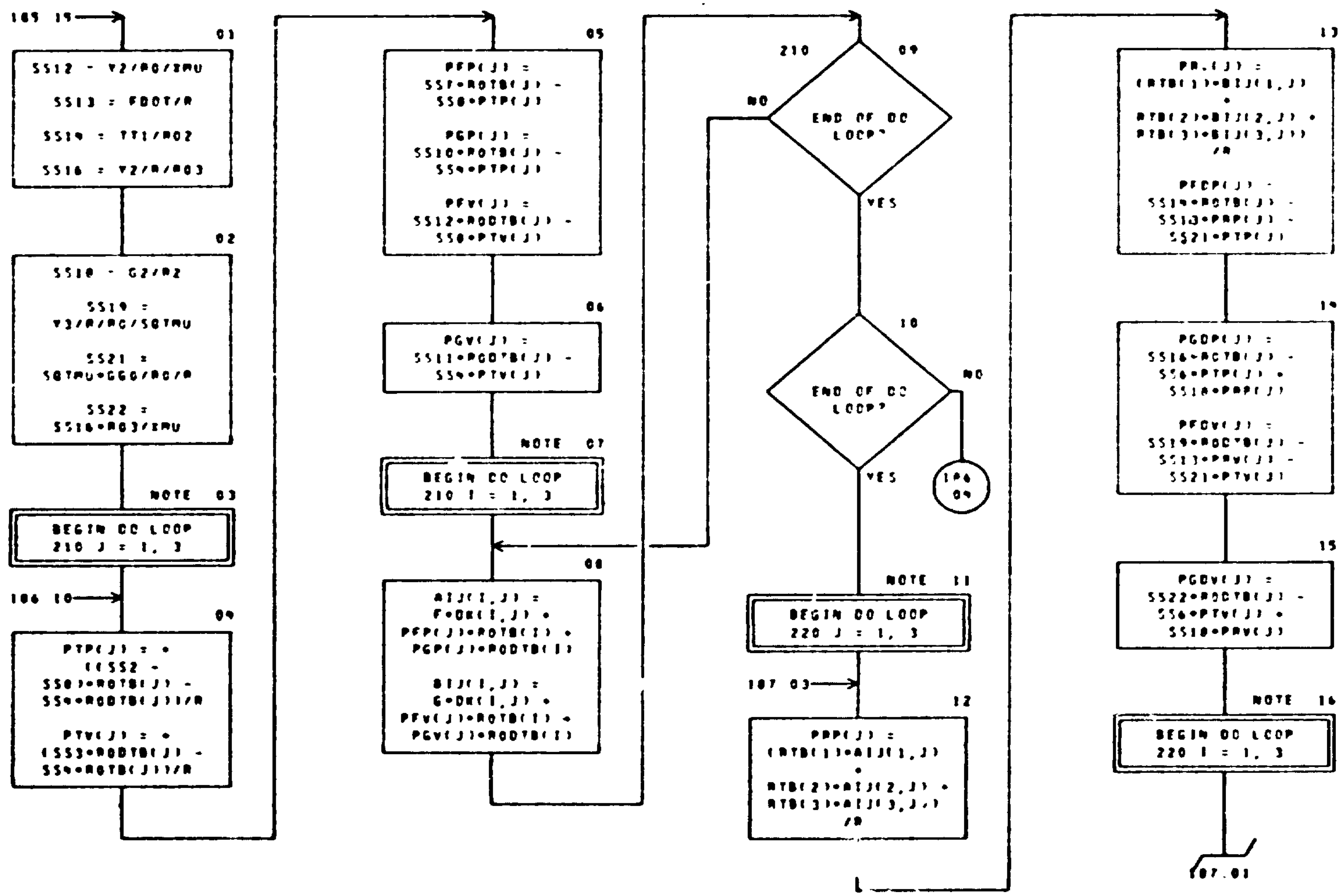


CHART TITLE - SUBROUTINE SAMM(TBAR,TOBAR,RXTB,RXDTB,RTX,RDTX,IOPT)

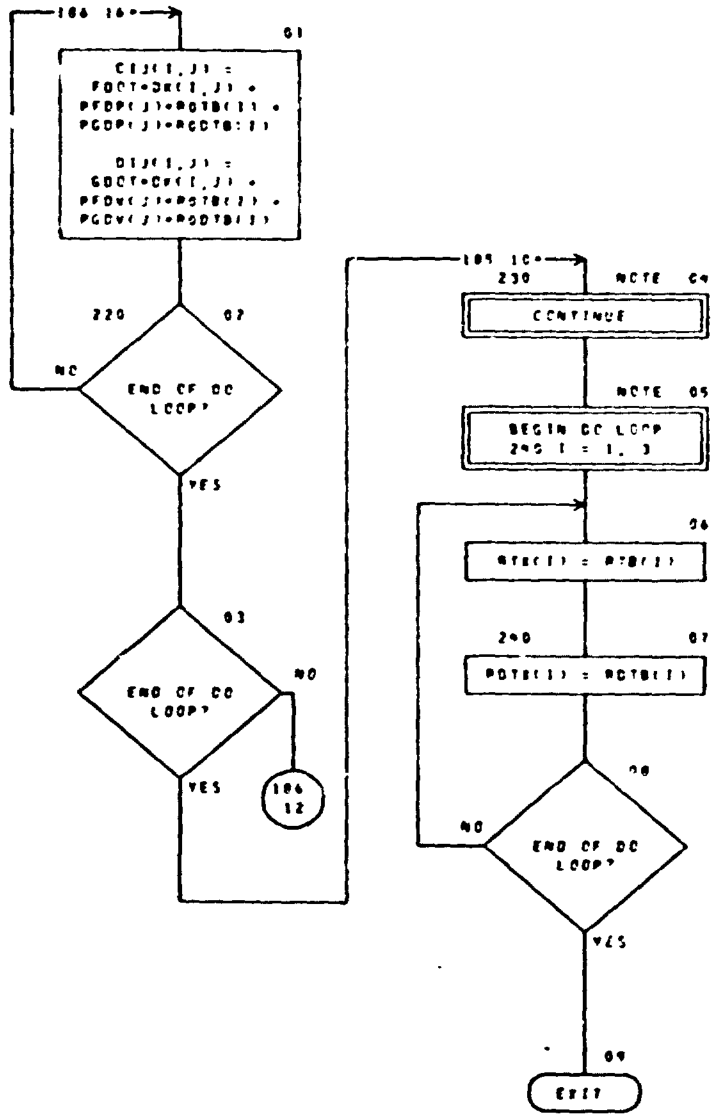


CHART TITLE - NON-PROCEDURAL STATEMENTS

```
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION RETB(3),REDTB(3),RTX(3),RDTX(3)
      DIMENSION PTP(3),PTV(3),PFP(3),PGP(3),PFV(3),PGV(3),PRP(3),PRV(3),
     PFDP(3),PGDP(3),PFDV(3),PGDV(3)
      DIMENSION SEA(3),RES(3)
      DIMENSION DR(3,3)
      COMMON/SAML1/RCTB(3),RSCTB(3),RTB(3),RDTB(3),AIJ(3,3),BIJ(3,3),
     CIJ(3,3),DIJ(3,3),DIAC,XMU
      COMMON/TWAD/BETAM1,GGS,G1,G2,G3,G4,G5,G6,G7,F0,F1,F2,F3,F4,F5,
     F6,F7
      DATA DR/1.D0,3*0.D0,1.D0,3*0.D0,1.D0/
      DATA TPI,EPS2,IC/6.283185307179586D0,5.D-19,6/
250   FORMAT (31H0 ERROR TBAR-TCBAR TOO LARGE = D17.8///)
260   FORMAT (32H0REDUCTION GEN XX ZZ YY DELT 1X8/5D25.16///)
270   FORMAT (40H0 MAXIMUM ITER  EXCEEDED I,BETA,BETAM1 =I4,2E17.8///)
```

Name: SETI

Calling Argument: None

Referenced Sub-programs: AMAL, DIAG1, MTVT, SAMM

Referenced Commons: ALAN, AMI, AM1, HENRY, HER, HIS, ILEF, INTEG, JERR, JHW, LEFT, MEL, NOMLL, RSCAL, SAML1, VPLLL, XMMM

Entry Points: None

Referencing Sub-programs: INIT

Discussion: Subroutine SETI performs the initialization of selected trajectory and partial derivative matrix counters, flags and variables. Upon each entry, the counters JN, NTP, NCT1, NQN, NS, N4, and NS1, the flag ISOL, the variable TP1, and the arrays XIL and XIDL are initialized. On the first entry only of a case the counter NJ; the flags ISP, ITD, ITD1, and ISPT; the variable TBET, the last five elements of CHN and CHNS (corresponding to $\Delta\omega$, $\Delta\Omega$, Δi, Δv_{po} and v_{po}, respectively, in each array); the first seven elements of CHNG (corresponding to the initial state); and the unit vectors $\bar{h}$ and $\bar{\ell}$ are initialized, where

$$\bar{h} = (R_o \times \dot{R}_o)/ |R_o \times \dot{R}_o| ,$$

$$\bar{\ell} = (\bar{k} \times \bar{h})/ |\bar{k} \times \bar{h}| .$$

R_o is the initial geocentric spacecraft position and $\bar{k}$ is along the North Pole. Thus, $\bar{h}$ is along the angular momentum vector and $\bar{\ell}$ is in the direction of the ascending node of the departure hyperbola on the equator. Subroutine DIAG1 is called to initialize the headings for the trajectory summary printout.

On each entry to SETI, except the first, the CHN and CHNS arrays are updated using the independent variable array B. Also the initial time t_o is updated and, if operating in the constrained mode, the spacecraft orientation

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angles ψ_i for all arcs are compared to the input maximum permissible values $(\psi_{max})_i$ and, if appropriate, are scaled to the maximum permissible values. If any one or more of the incremental departure orbit parameters $\Delta\omega$, $\Delta\Omega$, Δ_i or Δv_{po} are independent variables, the new initial position and velocity vectors are updated and stored in the CHN array. Denoting as R_o^*, $\dot{R}_o^*$ the initial position and velocity on the last reference trajectory, then the new initial position and velocity vectors are evaluated

$$R_o = M(\bar{\ell}', \Delta i)\, M(\bar{k}, \Delta\Omega)\, M(\bar{h}, \Delta\omega)\, R_o^* ,$$

$$\dot{R}_o = (1 + \frac{\Delta v_{po}}{v_{po}})\, M(\bar{\ell}', \Delta i)\, M(\bar{k}, \Delta\Omega)\, M(\bar{h}, \Delta\omega)\, \dot{R}_o^* ,$$

where

$$\bar{\ell}' = M(\bar{k}, \Delta\Omega)\, \bar{\ell} ,$$

and $M(\bar{a}, \alpha)$ denotes a general rotation matrix operation. This matrix is evaluated in subroutine AMAT. If the initial time and/or speed of departure from a fixed orbit are specified as independent variables, then the new initial position and velocity are computed for each trajectory and stored in the CHN array. If t_o is a variable, then subroutine SAMM is called to rotate the initial position and velocity vectors to the new launch time. If v_{po} is a variable, the initial mass is computed for the new departure speed, and the departure velocity is evaluated

$$\dot{R}_o = v_{po}\, \bar{v} ,$$

where $\bar{v}$ is a unit vector along the parking orbit velocity.

After determining the initial state, as above, $\dot{\beta} = \sqrt{\mu r_o}$ is stored in RHBR and the counters NSL1, NEQL and NEQN are initialized assuming perturbation trajectories will not be required. If none of the incremental orbital parameters nor the initial time or speed at departure are specified as independent variables, the XIDL, XRL and XRDL arrays are initialized to the initial state for the nominal and perturbation (if applicable) trajectories and a return to the calling subroutine is executed. If any one or more of the incremental orbit parameters or the initial time and/or speed at departure are specified as independent variables, then the first and second integrals, $\dot{\xi}$ and ξ, of the Encke perturbations are set to zero, and the XRL and XRDL arrays are initialized. If no perturbation trajectories are required, a return to the calling program is executed. Otherwise, two partial derivative matrices are evaluated as follows. The state transition matrix for the first (coast) arc is

$$\Phi(t_o, t_1) = \left[\begin{array}{c|c|c} A & B & \begin{matrix}0\\0\\0\end{matrix} \\ \hline C & D & \begin{matrix}0\\0\\0\end{matrix} \\ \hline 000 & 000 & 1 \end{array}\right] ,$$

where

$$A = \frac{\partial R_1}{\partial R_o} \; ; \; B = \frac{\partial R_1}{\partial \dot{R}_o} ; \; C = \frac{\partial \dot{R}_1}{\partial R_o} ; \; D = \frac{\partial \dot{R}_1}{\partial \dot{R}_o} ,$$

are obtained from subroutine SAMM. The subscript 1 refers to the end of the first arc. If any of the incremental orbital parameters are independent variables, then the partials of the initial state with respect to those parameters which are independent variables are evaluated with the equations

$$\frac{\partial R_o}{\partial \Delta\omega} = \bar{h} \times R_o ; \quad \frac{\partial \dot{R}_o}{\partial \Delta\omega} = \bar{h} \times \dot{R}_o ; \quad \frac{\partial m_o}{\partial \Delta\omega} = 0 ,$$

$$\frac{\partial R_o}{\partial \Delta\Omega} = \bar{k} \times R_o ; \quad \frac{\partial \dot{R}_o}{\partial \Delta\Omega} = \bar{k} \times \dot{R}_o ; \quad \frac{\partial m_o}{\partial \Delta\Omega} = 0 ,$$

$$\frac{\partial R_o}{\partial \Delta i} = \bar{\ell} \times R_o ; \quad \frac{\partial \dot{R}_o}{\partial \Delta i} = \bar{\ell} \times \dot{R}_o ; \quad \frac{\partial m_o}{\partial \Delta i} = 0 ,$$

$$\frac{\partial R_o}{\partial \Delta v_{po}} = 0; \quad \frac{\partial \dot{R}_o}{\partial \Delta v_{po}} = \dot{R}_o / |\dot{R}_o| \; ; \quad \frac{\partial m_o}{\partial \Delta v_{po}} = \frac{-(m_o + a_3)}{a_2} \; .$$

The counter NJL and the flag ITD1 are set equal to the number of these four variables specified as independent variables and a return is executed. If the initial time and/or speed are specified as independent variables, then the partials of the initial state with respect to one or both of these variables are developed

$$\frac{\partial R_o}{\partial t_o} = \left(\frac{v_c}{v_{po}} - 1\right) \dot{R}_o \; ,$$

$$\frac{\partial \dot{R}_o}{\partial t_o} = -\frac{\mu}{r_o^3}\left(\frac{v_{po}}{v_c} - 1\right) R_o ,$$

$$\frac{\partial m_o}{\partial t_o} = 0 \; ,$$

$$\frac{\partial R_o}{\partial v_{po}} = 0,$$

$$\frac{\partial \dot{R}_o}{\partial v_{po}} = \dot{R}_o / |\dot{R}_o| \; ,$$

$$\frac{\partial m_o}{\partial v_{po}} = -\frac{(m_o + a_3)}{a_2} \, .$$

A return to the calling program is then executed.

SETI EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
B(30)	SU	XMMM	Array of independent variable values.
JN	S	HER	Number of spacecraft orientation angles on the next arc that are included in the list of independent variables.
NJ	SU	HER	Counter of the number of the six spacecraft parameters c, p_o, α, β, δ and ϵ that are included in the list of independent variables.
NS	S	ILEF	Number of initial state related perturbation trajectories required over next arc.
N4	SU	ILEF	Index equal to $4(i-2) + 1$, where i is the next arc number.
AIJ(3,3)	U	SAML1	Partial derivative matrix of position at the end of the first arc with respect to position at the start of the arc.
AL1	U	JERR	Launch vehicle performance coefficient, a_1.
AL2	U	JERR	Launch vehicle performance coefficient, a_2.
AL3	U	JERR	Launch vehicle performance coefficient, a_3.
BIJ(3,3)	U	SAML1	Partial derivative matrix of position at the end of the first arc with respect to velocity at the start of the arc.
CHN(100)	SUA	HIS	Array of values of all variables available as potential independent variables. (See description of subroutine INPUT).
CIJ(3,3)	U	SAML1	Partial derivative matrix of velocity at the end of the first arc with respect to position at the start of the arc.

SETI EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
CP1(7,30)	S	JERR	Matrix containing the partial derivatives of the state vector (position, velocity and mass) with respect to the independent variables of the arc.
DIJ(3,3)	U	SAML1	Partial derivative matrix of velocity at the end of the first arc with respect to velocity at the start of the arc.
HCR(3)	SUA	RSCAL	Array used for temporary storage of various vectors related to initial velocity.
ITD	S	VPLLL	Flag indicating whether time of departure from launch parking orbit is an independent variable. = 0 - not an independent variable = 1 - is an independent variable
NJL	SU	HER	Number of independent parameters which are functions of the initial position or velocity.
NQN	SU	ILEF	Number of equations numerically integrated on each trajectory, sum of first and second order equations.
NSL	U	HER	Number of independent variables.
NS1	S	ILEF	NS + 1.
NTP	S	HER	Counter incremented along the trajectory and equal to the current arc number.
PYI(7,7)	S	JHW	Partial derivatives of the current state with respect to the state at the start of the arc.
RLP	U	RSCAL	Radius of the circular launch parking orbit, in ER.

SETI EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
TP1	S	HENRY	End time of the current trajectory arc.
XIL(80)	S	AM1	Second integral of the Encke perturbations on the nominal and perturbed trajectories.
XMU	SU	SAML1	Gravitational constant of the reference body.
XRL(6, 20)	S	LEFT	Array of spacecraft position vectors relative to the reference body on nominal and perturbed trajectories. Contains Cartesian coordinates plus the magnitude, square and cube of distance.
CHNS(100)	S	HIS	Same as CHN, with units changed for printout purposes.
ISOL	S	MEL	Flag indicating whether thrust is on or off on current arc. = 1 - thrust on = 2 - thrust off
ITD1	S	VPLLL	Flag indicating whether speed at departure from launch parking orbit is an independent variable. = 0 - not an independent variable ≠ 0 - is an independent variable
IVAR(100)	U	HER	Array of indexes correlating the independent variable array elements to associated elements in the CHN array.
NCT1	S	HER	Index defining the relative location of the arc thrust/coast trigger in the TBIN array.

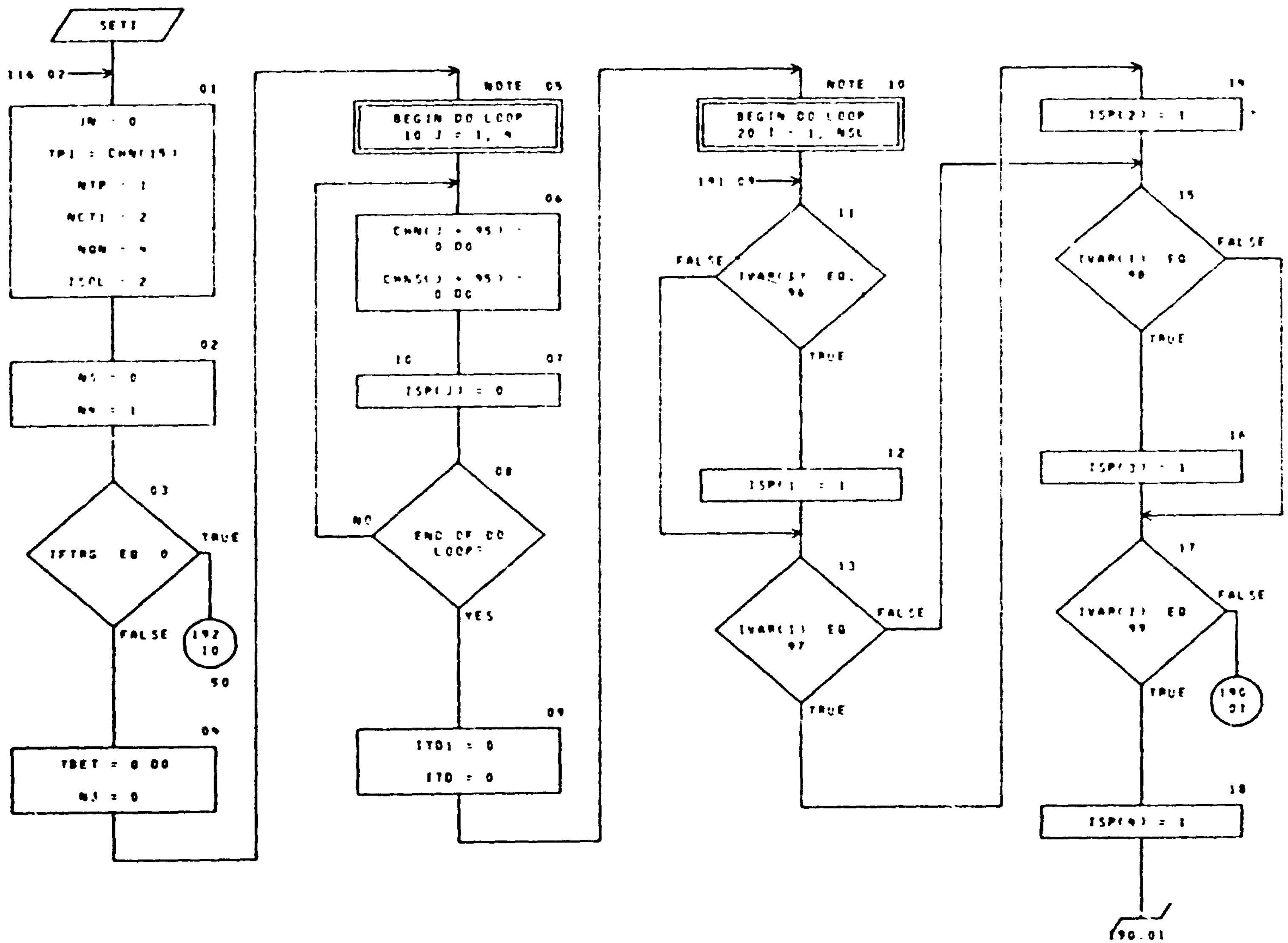
SETI EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
NEQL	S	ILEF	Number of trajectories being integrated simultaneously, nominal plus perturbed.
NEQN	S	AMI	Total number of equations being integrated simultaneously, including first and second order on both nominal and perturbed trajectories.
NOMT	U	NOMLL	Nominal trajectory flag. = 0 - nominal and perturbed trajectories are being integrated simultaneously. ≠ 0 - trial trajectory only is being integrated.
NSL1	SU	HER	Counter, equal to NEQL.
NTPS	U	HER	Number of trajectory arcs minus 1.
RHBR	SU	ALAN	Factor for converting between time and universal anomaly derivatives, $\dot{\beta}$ $(= \sqrt{\mu}/r)$.
TBET	S	ALAN	Current time, in hours from departure of the launch parking orbit.
TBIN(122)	U	JERR	Array of trajectory arc information. (See description in subroutine INPUT).
VP00	SU	VPLLL	Speed at departure of the launch parking orbit, v_{po}.
XIDL(80)	S	AM1	First integral of the Encke perturbations on the nominal and perturbed trajectories.
XRDL(6,20)	SU	LEFT	Array of spacecraft velocity vectors relative to the reference body on nominal and perturbed trajectories. Contains Cartesian coordinates plus the magnitude, square and cube of the distance.

SETI EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
XSQQ(12)	U	HENRY	Array of gravitational constants of the sun, moon and planets.
XVAR(30)	U	HIS	Array of perturbation step sizes of the independent variables, used to compute partial derivatives.
IFTRG	SU	HER	First trajectory flag. A value of 1 indicates the current trajectory is the first trajectory of the case.
NOP65	U	ILEF	Flag indicating whether the program is operating in the constrained or unconstrained mode. Same as the program input NOPT(65).
RDPML(3)	U	RSCAL	Unit vector along initial geocentric velocity.
RPHAT(3)	SUA	RSCAL	Initial geocentric position vector.
IREFNO	U	INTEG	Identification number of the current reference body.

CHART TITLE - SUBROUTINE SETI



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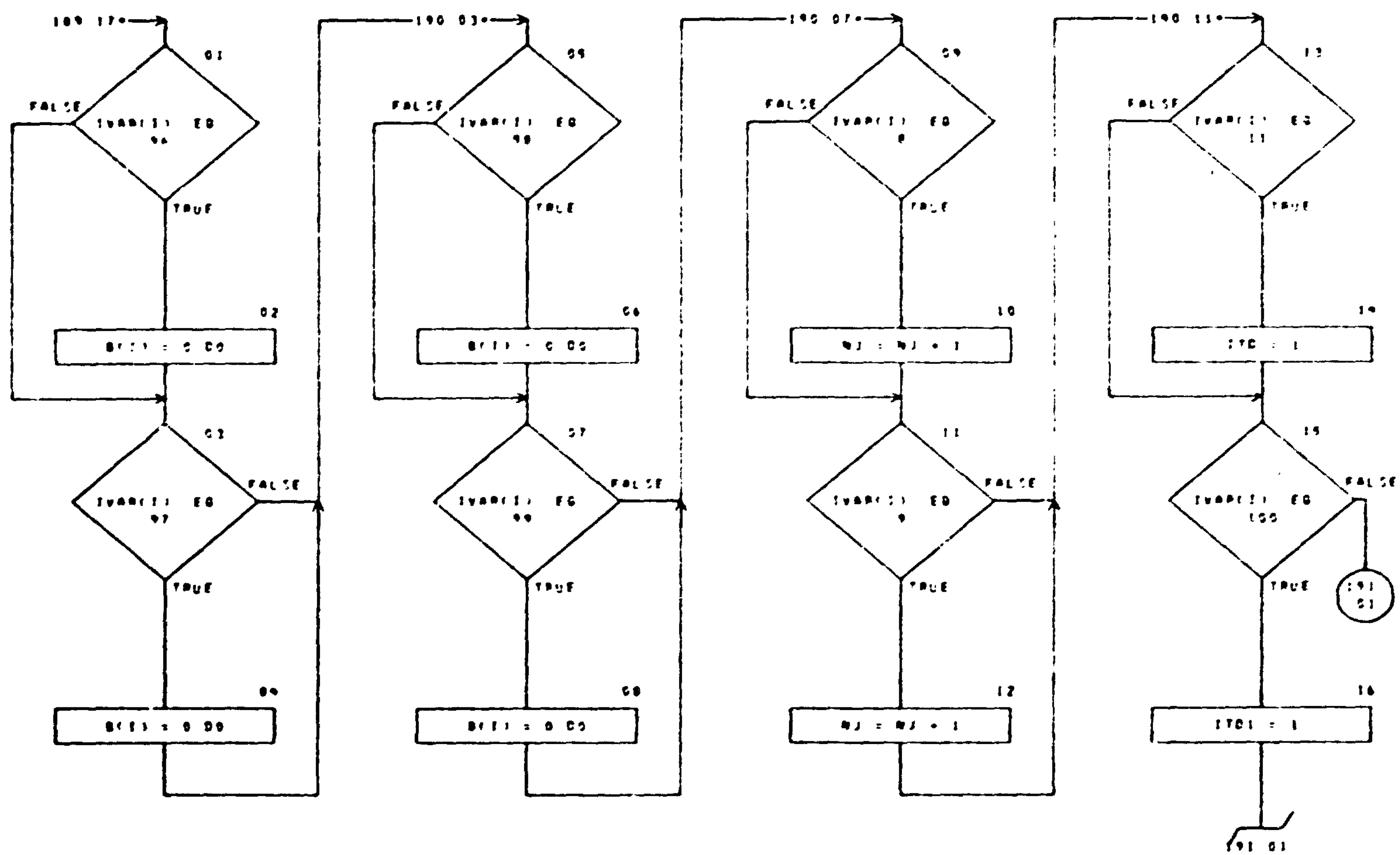

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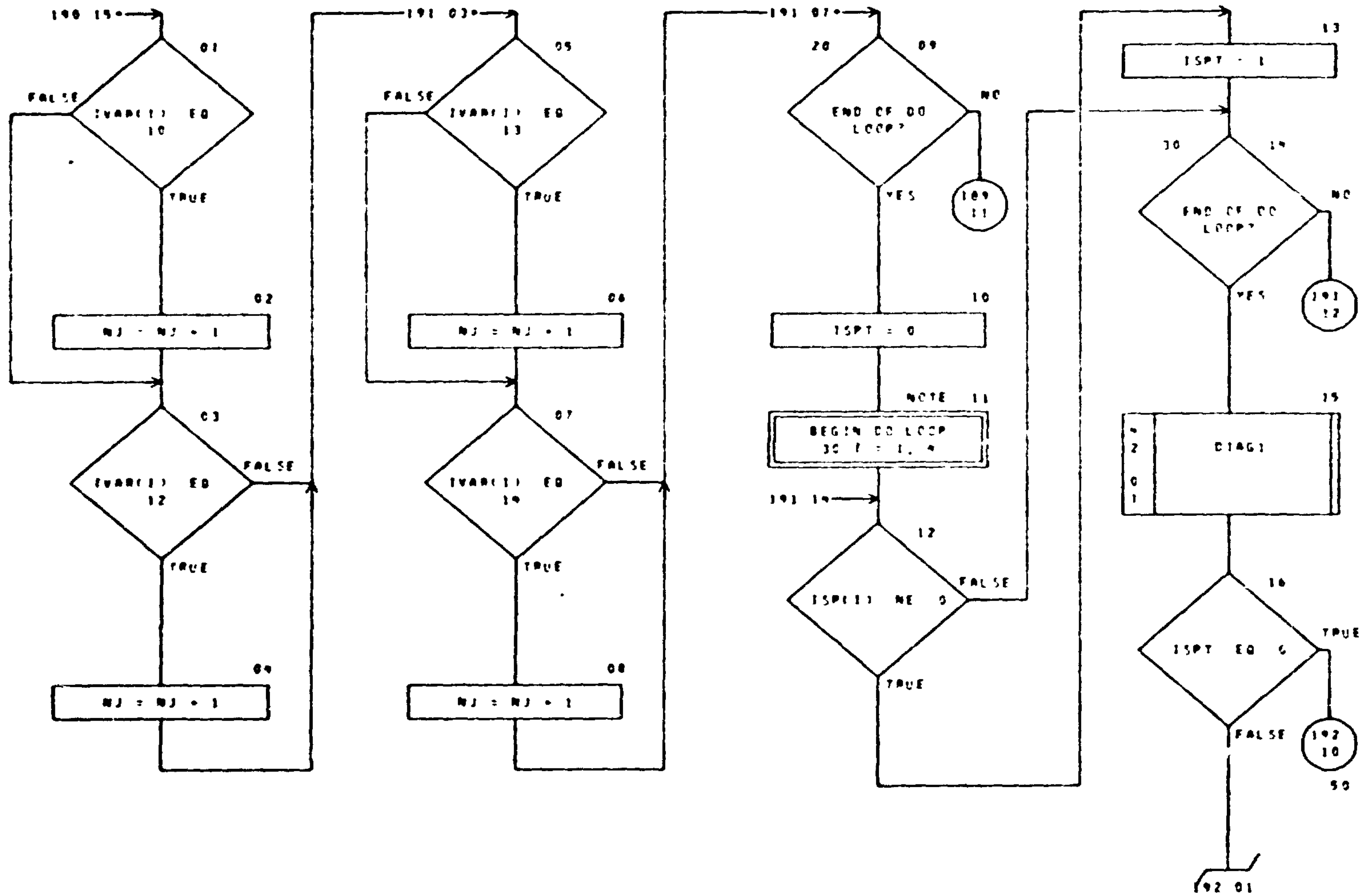

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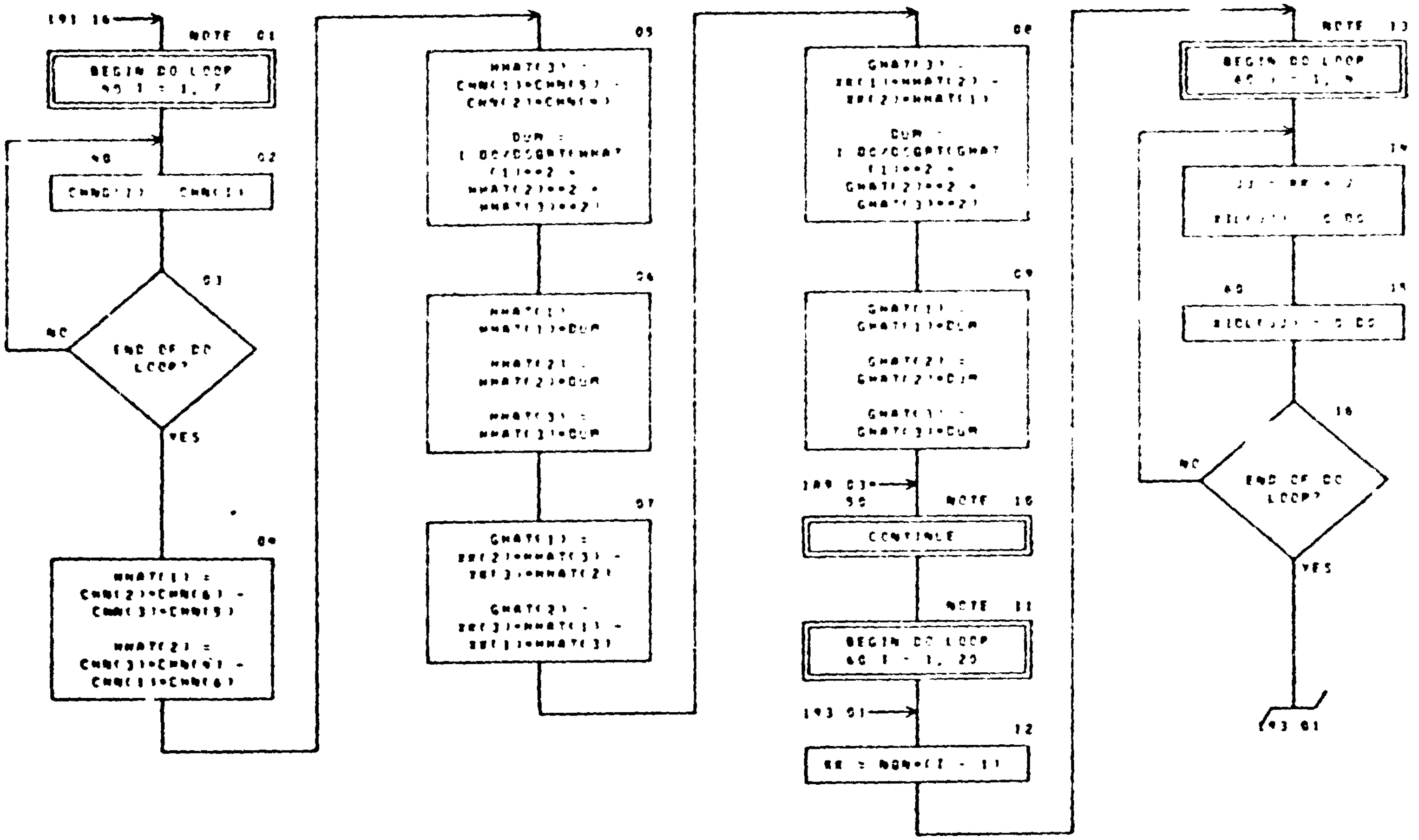

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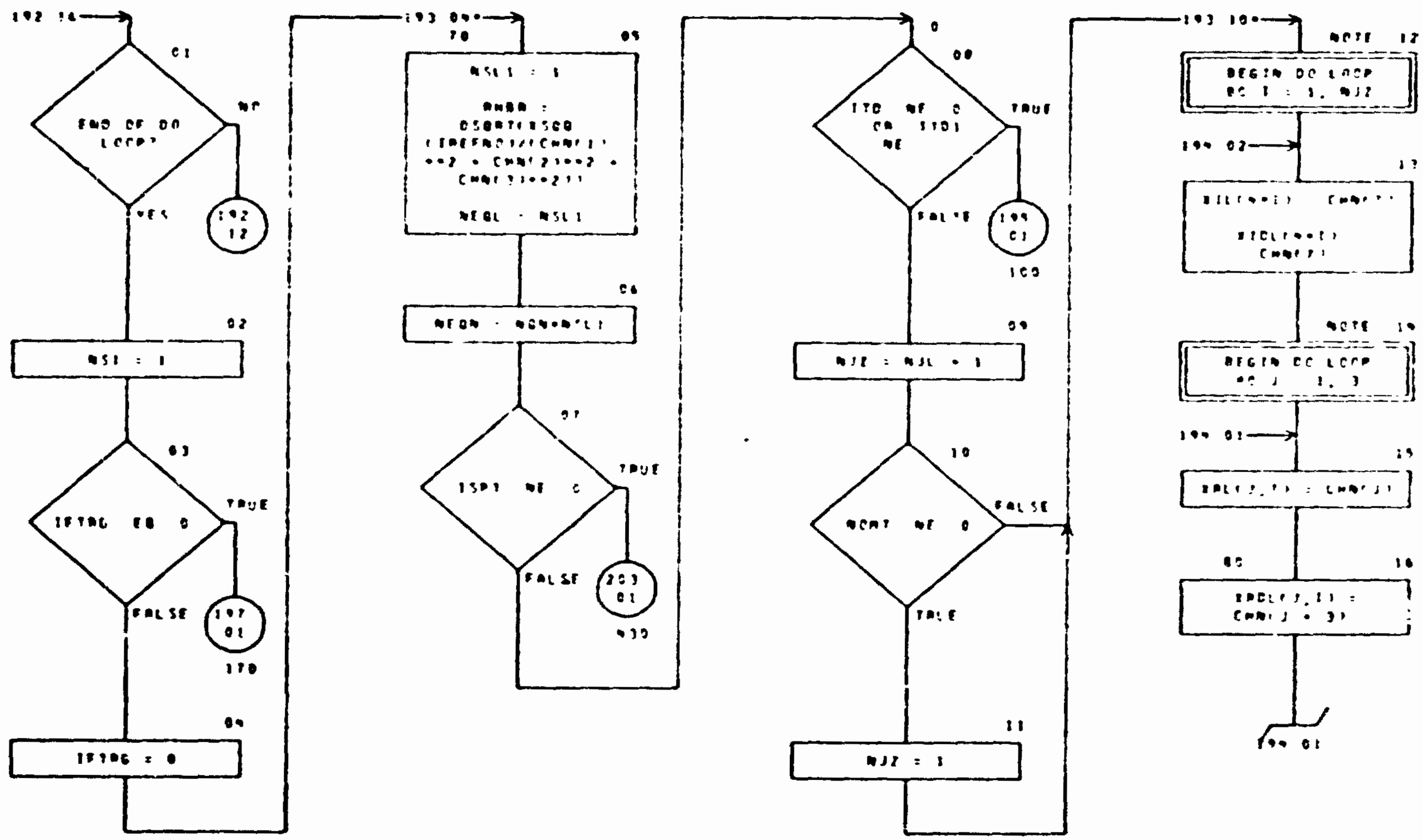

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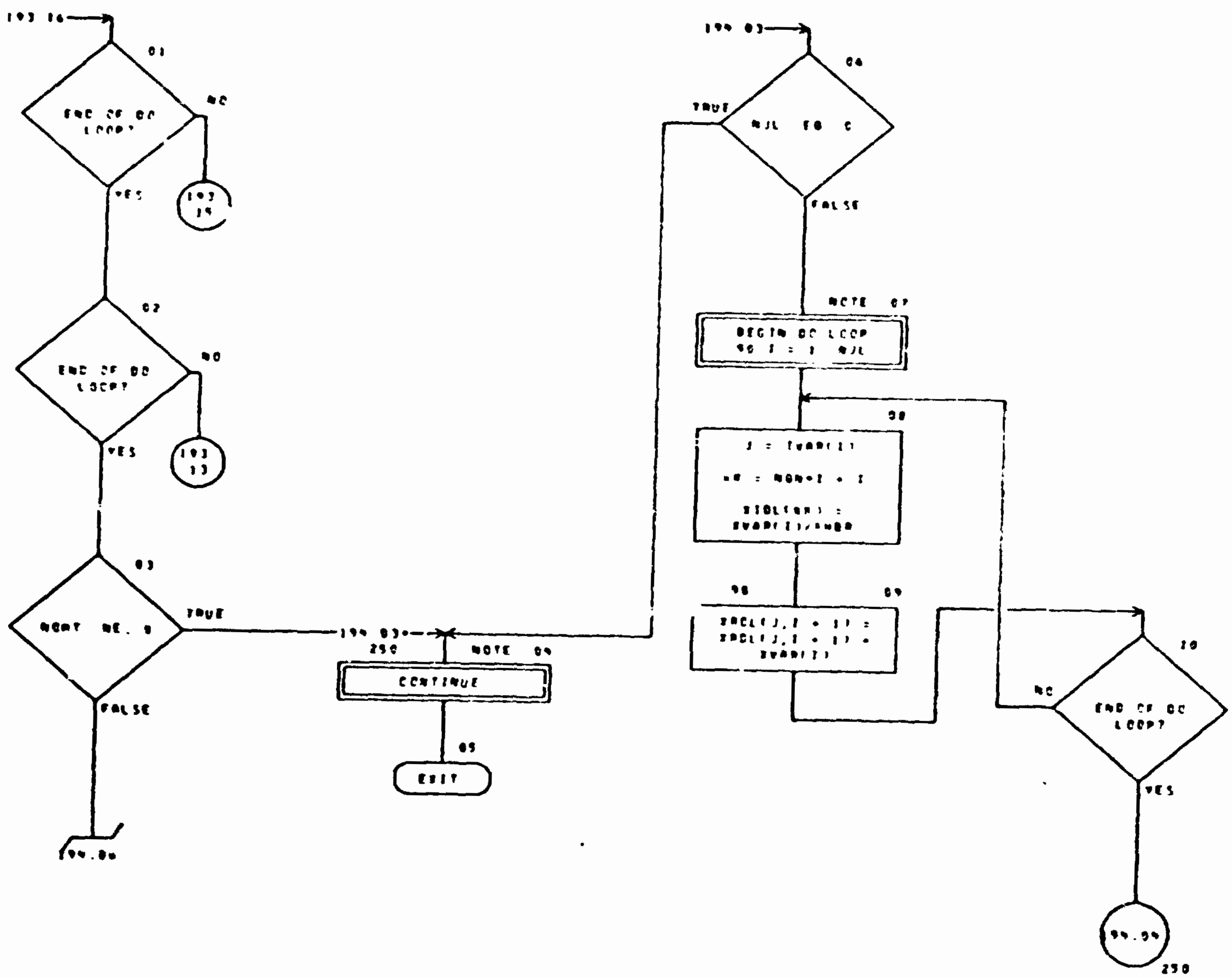

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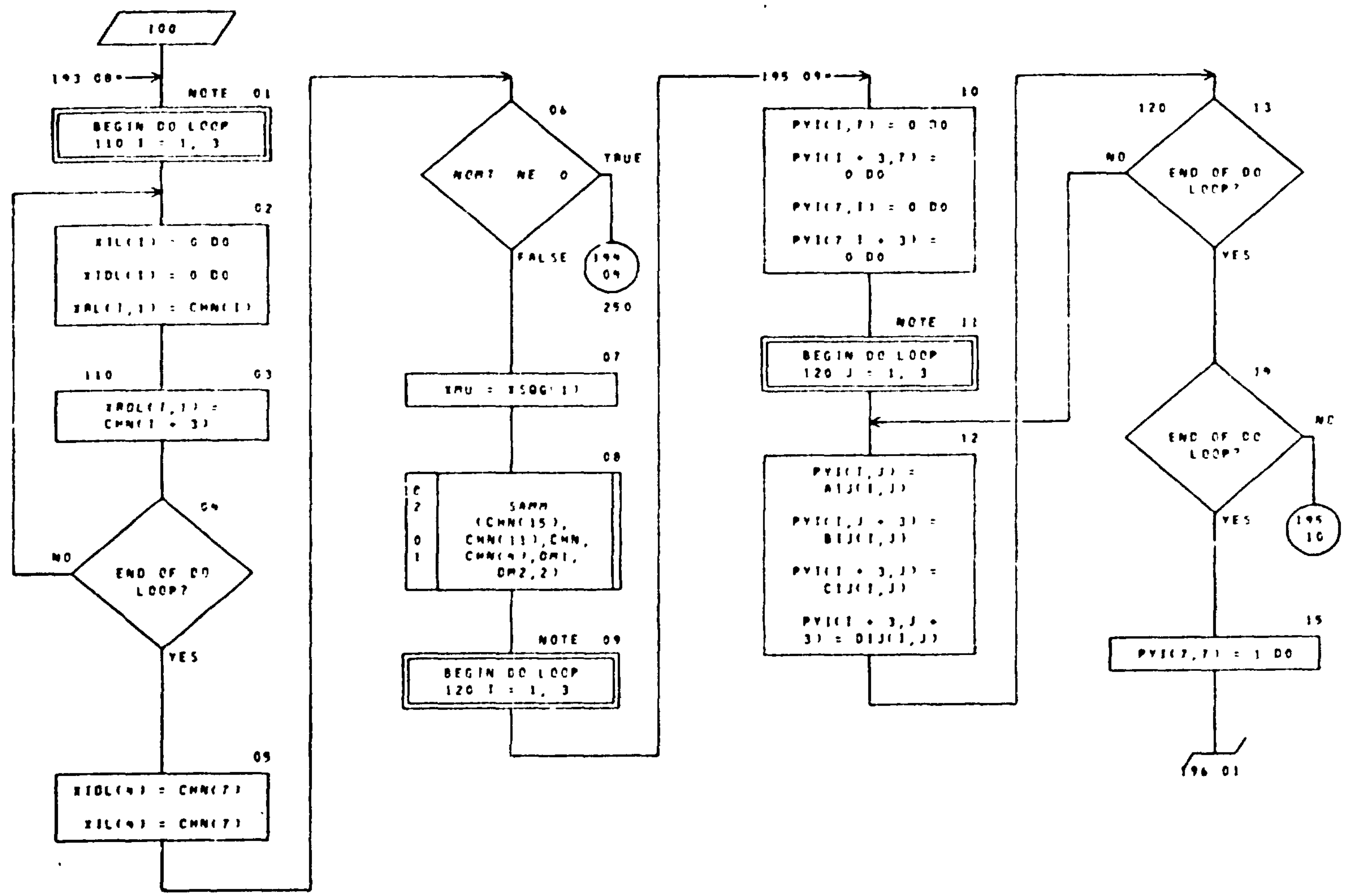

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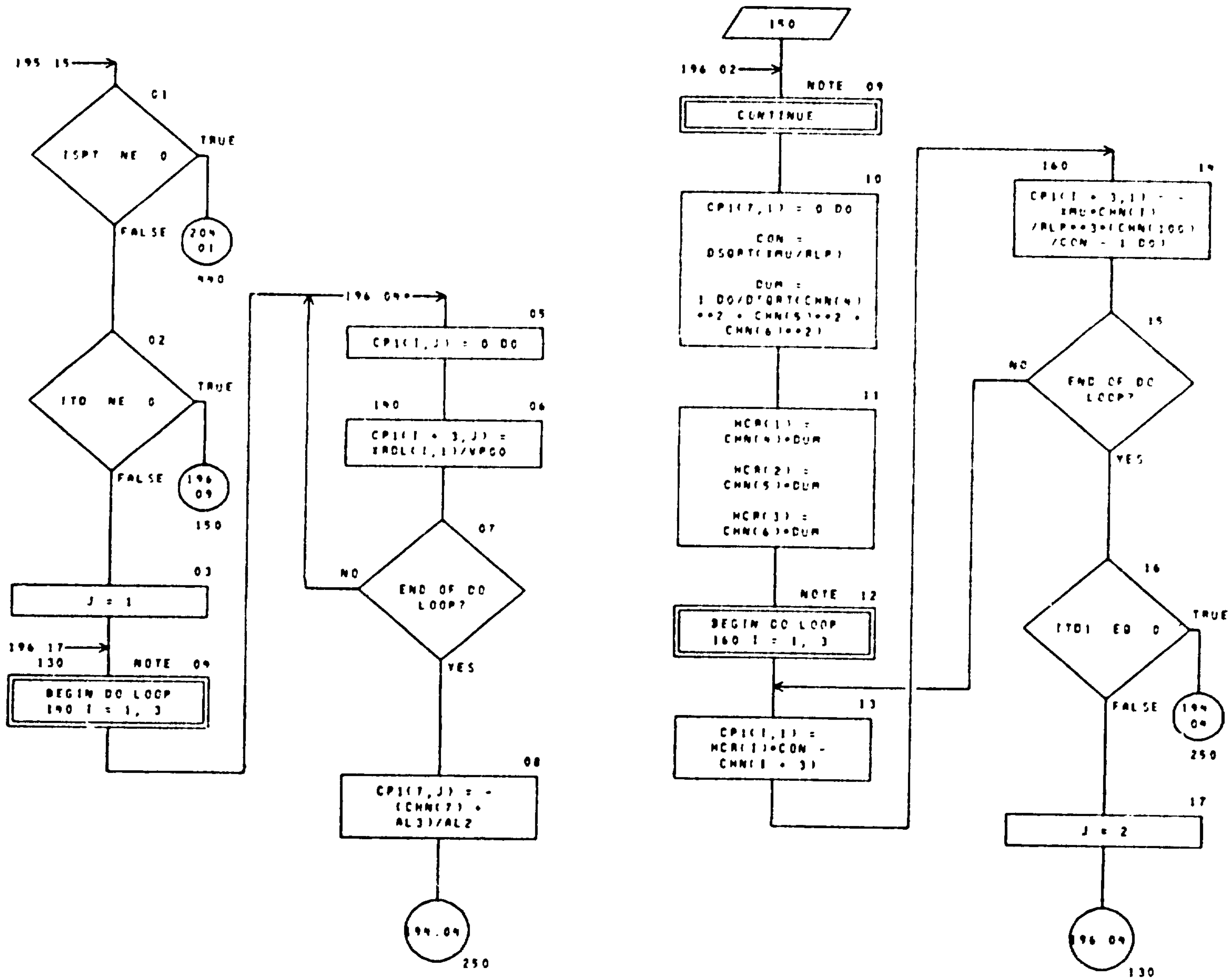

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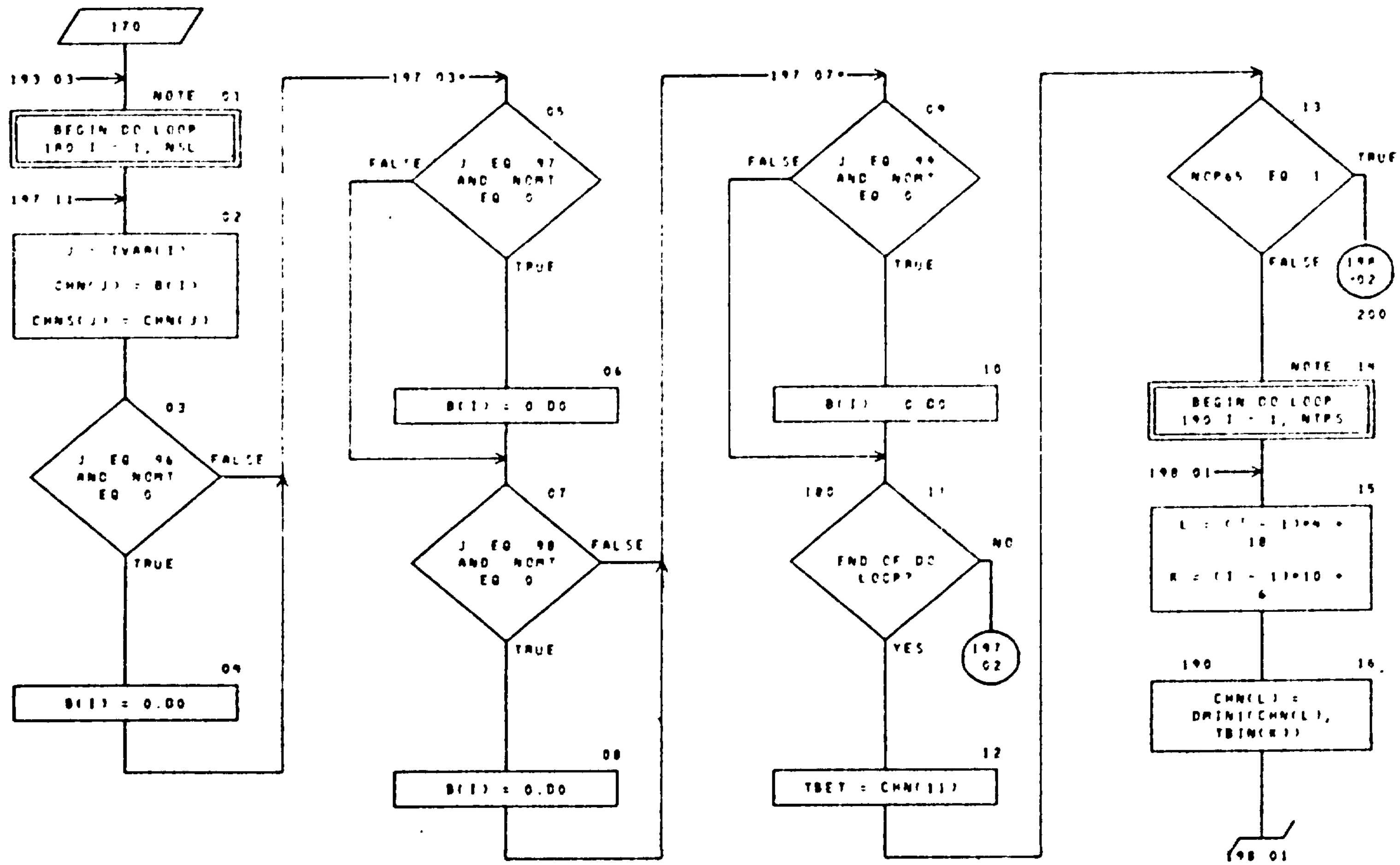

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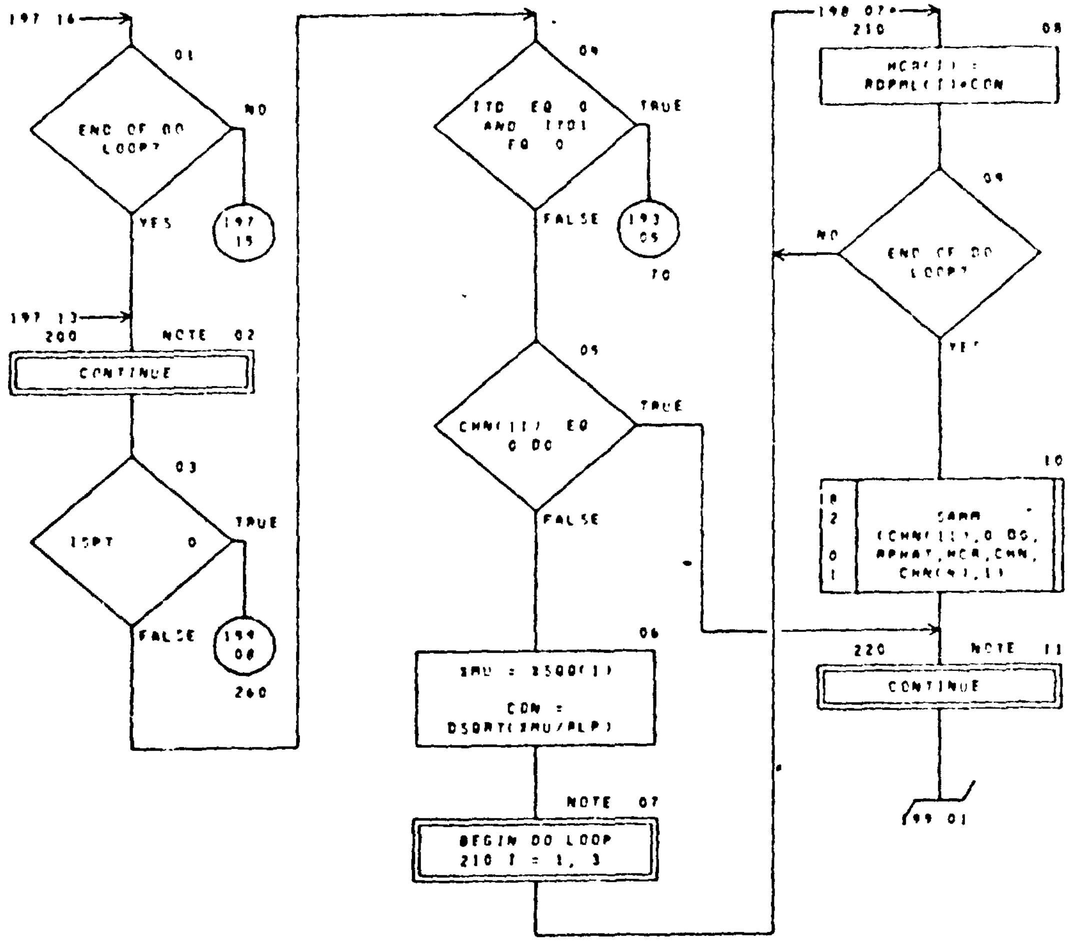
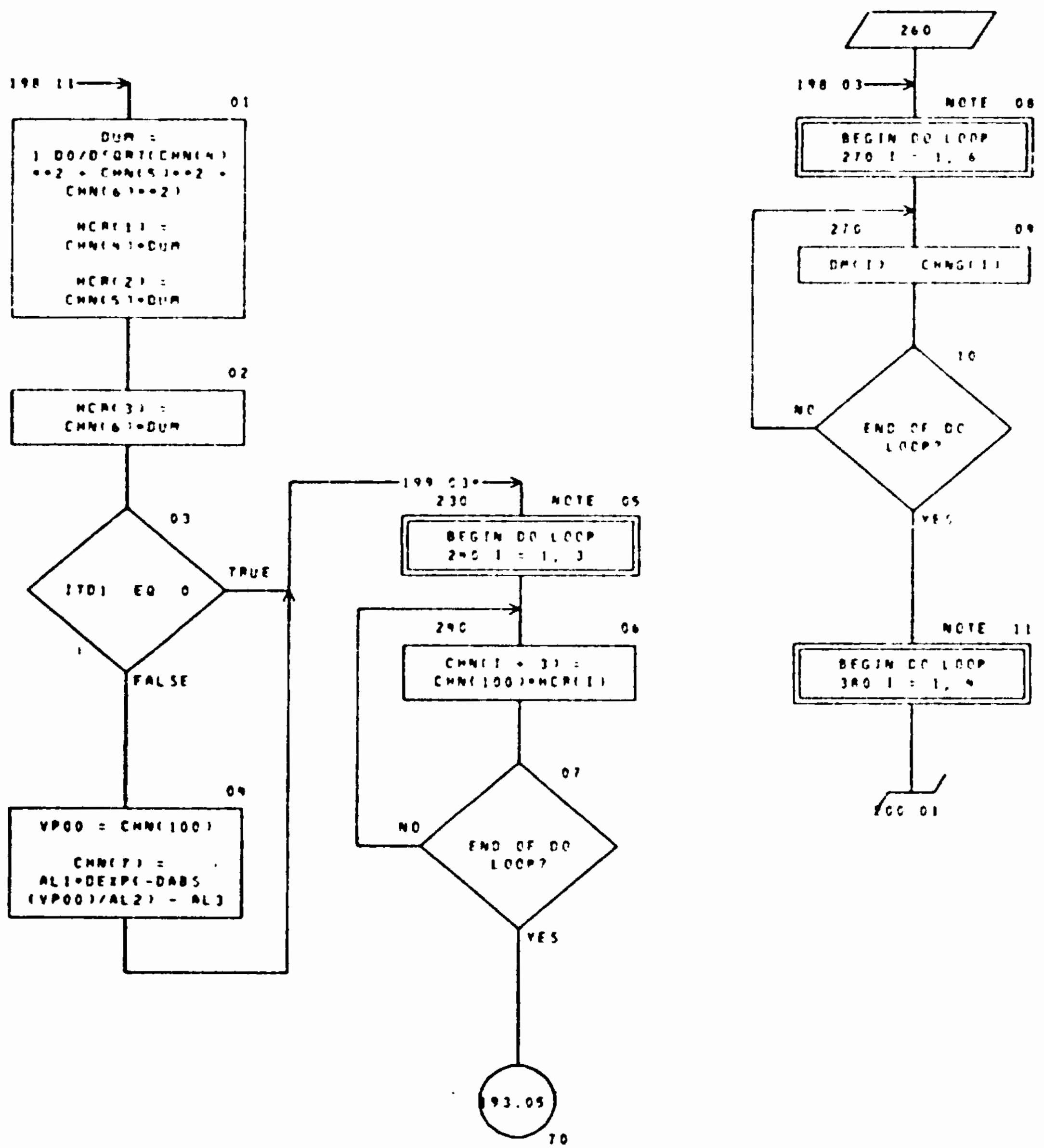


SETI 10

CHART TITLE - SUBROUTINE SETI



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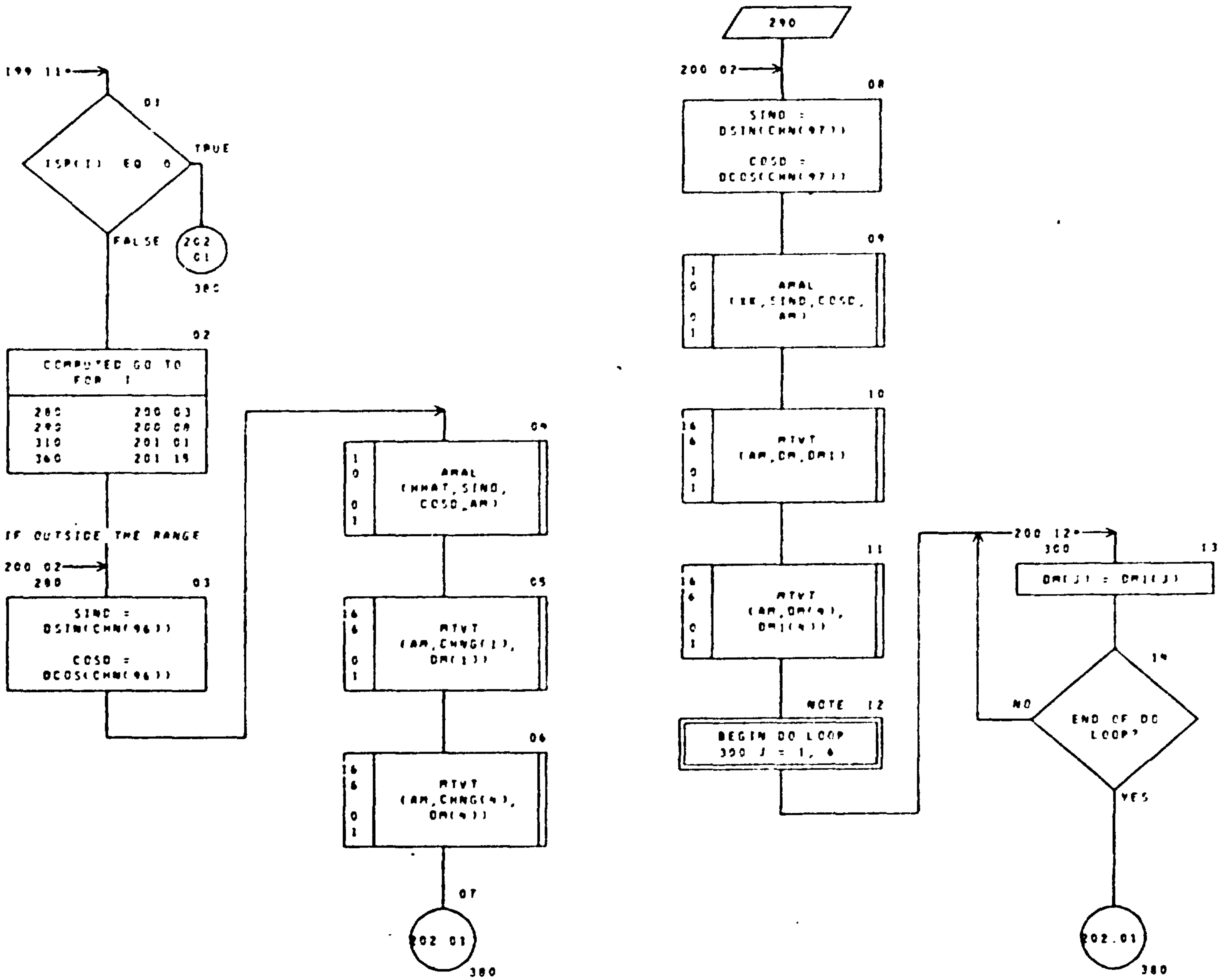

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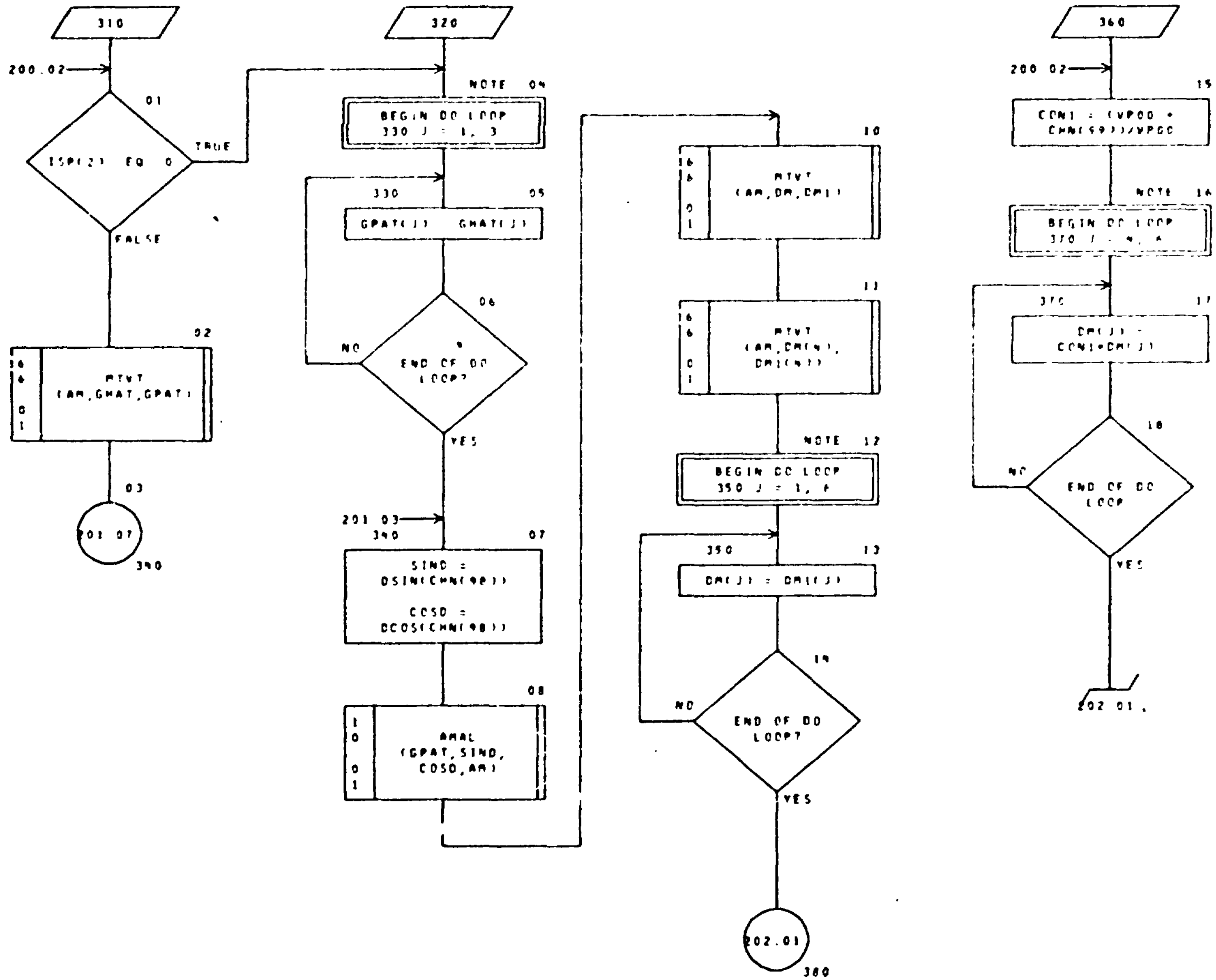

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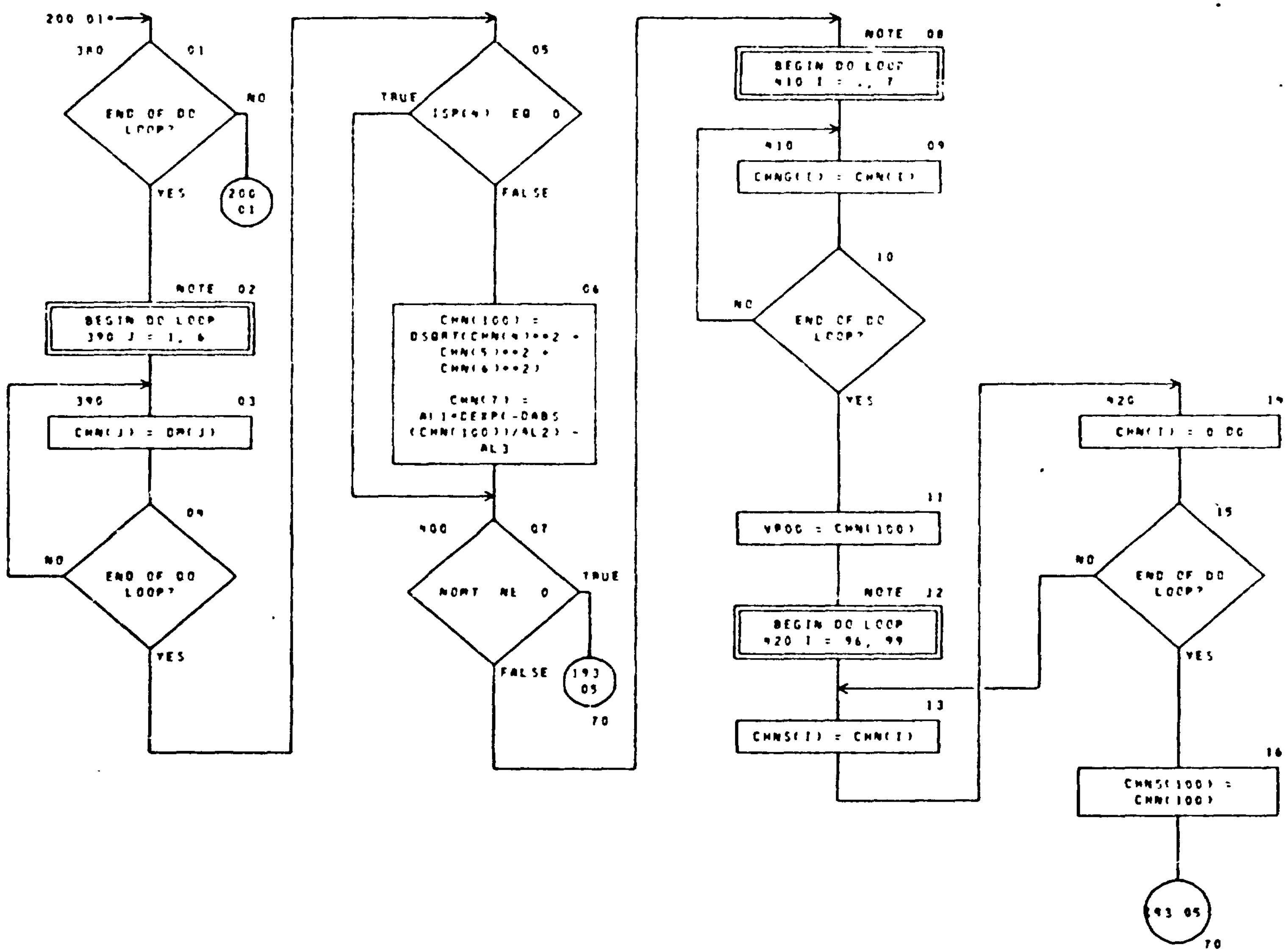

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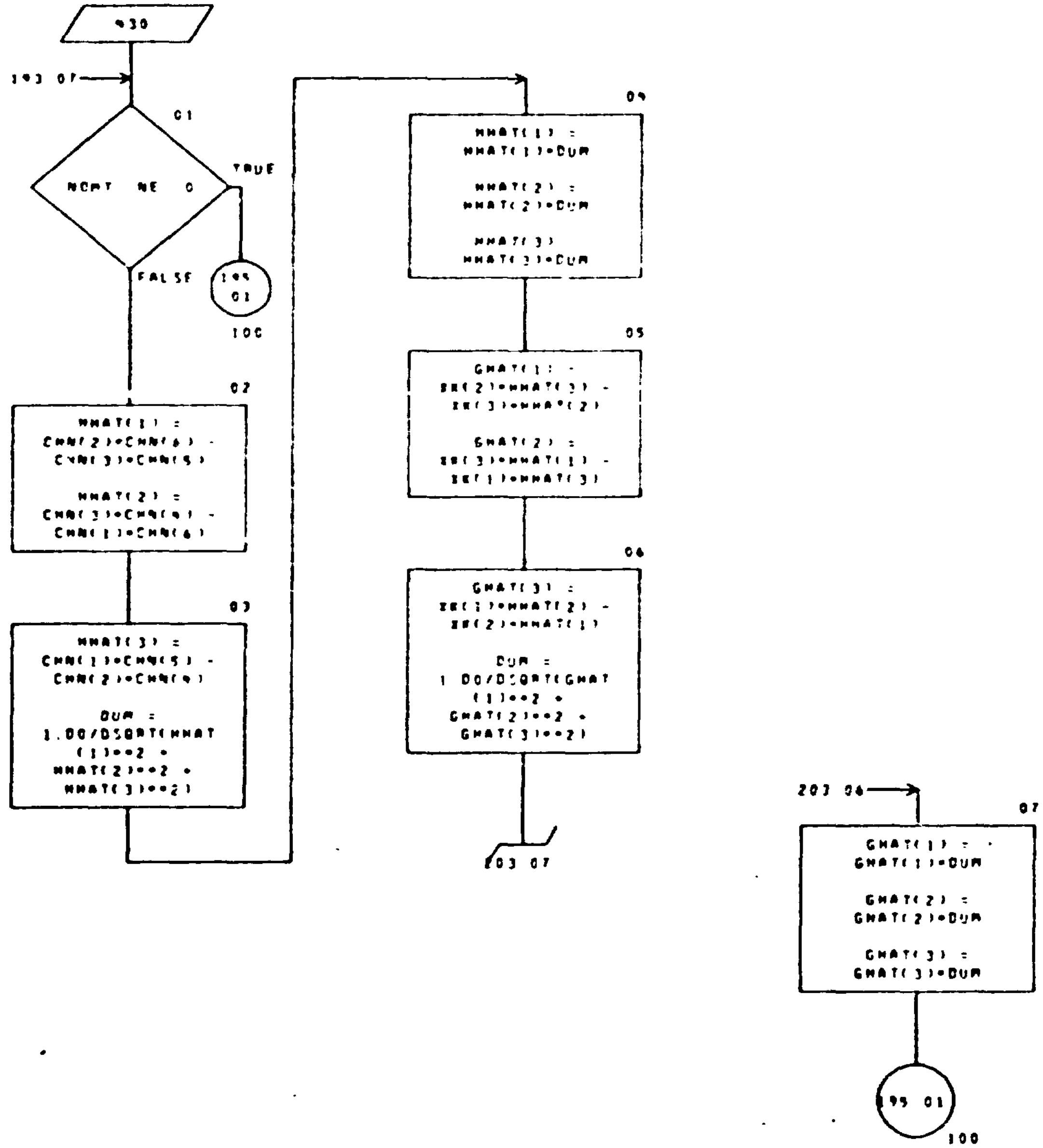

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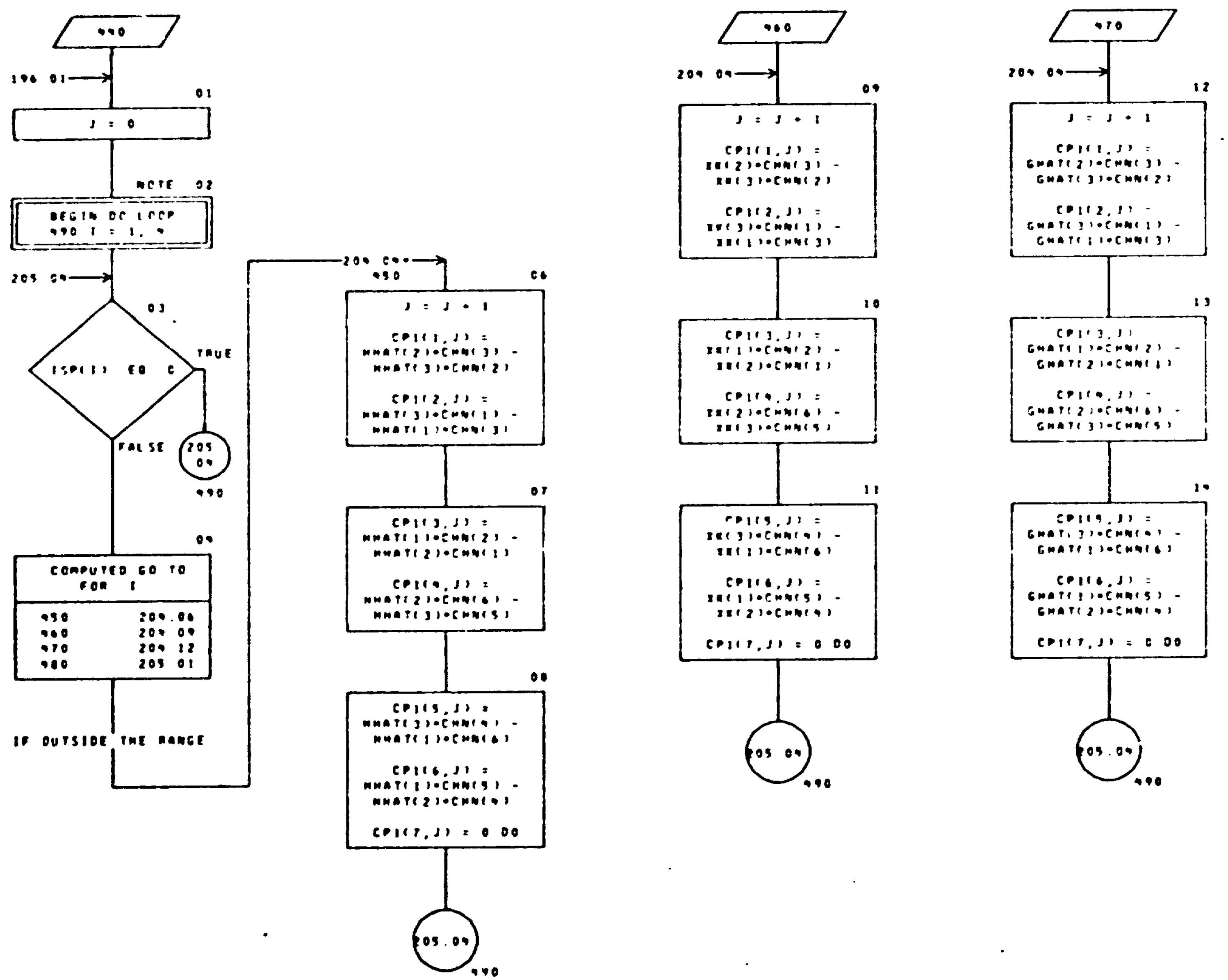

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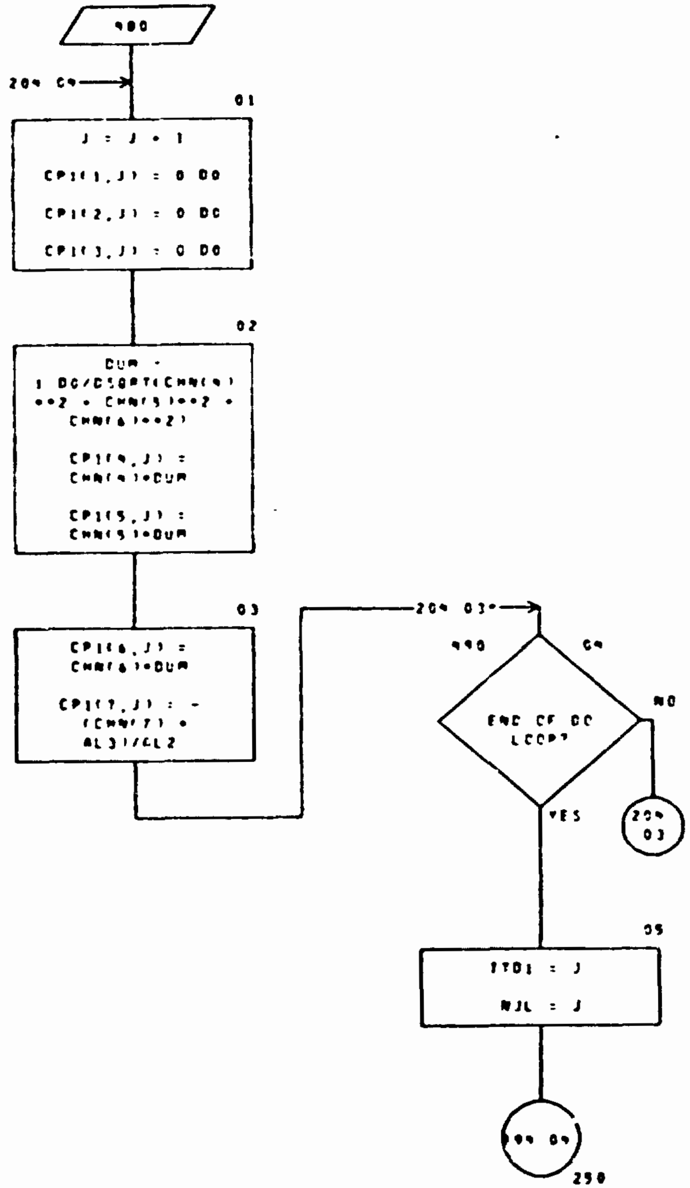

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
IMPLICIT REAL *8 (A-H,O-Z)
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REAL*8 MEI,ME,MM,MDIST,IN2V,IN1X,IN2X
 DIMENSION DM(6),DMI(6),CHNG(7),HHAT(3),AM(3,3),RR(3),GHAT(3),
GPAT(3),ISP(4),DM2(3)
COMMON/ALAN/TBET,RHBR,DCR*C
COMMON/AMI/NEON,NPT2
COMMON/AYL/DELT,T,DTI,XILF(8),XIOL(8),DZXIL(8),IFST(8)
COMMON/HENRY/ARRAY(8,3,12),CHINC,INTV(72),IN1X(3),
IN2X(3),XSOO(12),RM(12),MDIST,MEI(12),ME(12),PCSPCS,PPVCT,
POT,PC,N,PD,PERM,PRM,PPE,PREV,PCINC,RATIO,SEC,TSCL,THTS,TP1,
TIMEL,THET,VFLPCS
COMMON/HER/IPS,NSL,NSL1,IFTRS,ITCT,IPCFL(30),IVAR(100),ITMAX,NTP,
NTPS,NMAX,NJ,JN,IPAT,NCT1,NJL
COMMON/HIS/PFS(30,30),WT(30),XVAR(30),YEPS(30),XEPS(30),
CHNS(100),CHN(100),PCFL(30),ECAR(7)
COMMON/ILEF/NEOL,NEG3,NGN,NCP65,IOAR(7),NCP64,NCP43,NC,NN,NS1,NJJ
COMMON/INTEG/DAY,HOURS,YEAR,IDUMMY,ITRIG,IREFNO,IREFNB,
IREFNT,IN,IO,IJK,MONTH,MIN,NCPT(72),NPLAN,NPLANJ
COMMON/JERR/VBLCC(205),A,CA,BL,DSQ,DELP,AO (10),SUMA,XKS,ETV(3),
ET(3),XEP,ER(3),CP(7,30),TBIN(122),ETA,CR,XRR,XET,XEST,APS,AL1,
AL2,AL3
COMMON/JHW/PVI(7,7),CPH(7,30)
COMMON/LEFT/XPL(6,20),XPDL(6,20),VCCL(72,20)
COMMON/MEL/ISOL
```

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
COMMON/NCALL/NCNT
COMMON/RSCAL/ALP,RPHAT(3),HCP(3),RCPPL(3)
COMMON/SAML1/RCTB(3),RCDTB(3),RTB(3),RDTB(3),AIJ(3,3),BIJ(3,3),
CIJ(3,3),DIJ(3,3),CIAX,IMU
COMMON/VPLLL/MPCO ITC,ITC1
COMMON/EMMM/B(30),Q(30),QMIN(30),QMAX(30),MTCPT,MCPTR
DATA XX/0.D0,0.D0,1.D0/
```

Name: SIMEQ

Calling Argument: C, A, IN, SOLUTN

Referenced Sub-programs: None

Referenced Commons: None

Entry Points: None

Referencing Sub-programs: MINMX3

Discussion: SIMEQ solves a set of simultaneous linear equations of the form

$$CA = B$$

for the n-dimensional column matrix A where C is a known square nxn matrix and B is a known n-dimensional column matrix.

SIMEQ employs the Gauss' method of elimination to solve a set of simultaneous linear equations. Basically, this method involves the solution of one of the n equations for one of the unknown elements of A in terms of the other elements of A, substituting this result into the remaining equations and deriving the new coefficients for the reduced set of equations of order (n-1). By successively repeating this procedure, one eventually obtains a single equation in one unknown. The solution of this equation yields one element of A in terms of the known coefficients of B and C. Using this solution and proceeding backwards successively through the equations of two unknowns, three unknowns, etc., one obtains the unique solution vector A. A detailed description of this method is given in the reference.

Upon successfully solving for the A matrix, the argument SOLUTN is set to .TRUE., and a return to the calling routine is executed. This flag is set to .FALSE. if it is found that all of the equations are not linearly independent.

The coding of SIMEQ assumes that the B array is stored immediately behind the C matrix such that, in effect, C is dimensioned nx(n+1), and B is addressed as the (n+1)th column of C. Both B and C are destroyed in the computations. Note that the inverse of C is not explicitly formed.

Reference:

Pipes, Louis A. and Shahen A. Hovanessian, Matrix Computer Methods in Engineering, John Wiley & Sons, Inc., New York, 1969, pp. 15, 16.

SIMEQ EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
A(IN)	SUX		Array containing the solution vector A.
C(IN, IN+1)	UX		Array containing the matrix C in the first IN columns and the matrix B in the (IN+1)th column.
IN	UX		Order n of the problem, equal to the number of simultaneous equations.
SOLUTN	SX		Logical flag indicating whether the solution matrix A was successfully obtained. .TRUE. - solution successfully obtained .FALSE. - solution not obtained because equations are not linearly independent.

CHART TITLE - SUBROUTIN SIMEQ(C,A,IN,SOLUTN)

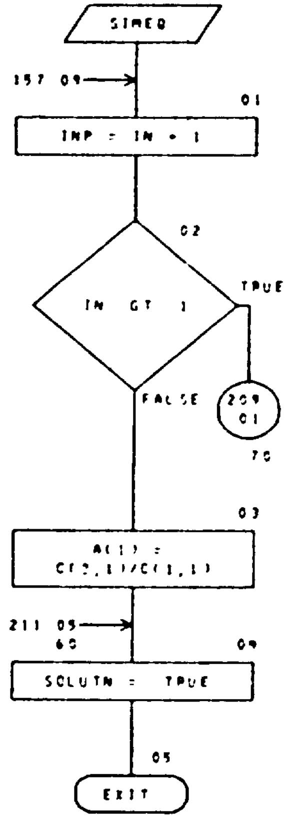

CHART TITLE - SUBROUTINE SIMEQ(C,A,IN,SOLUTN)

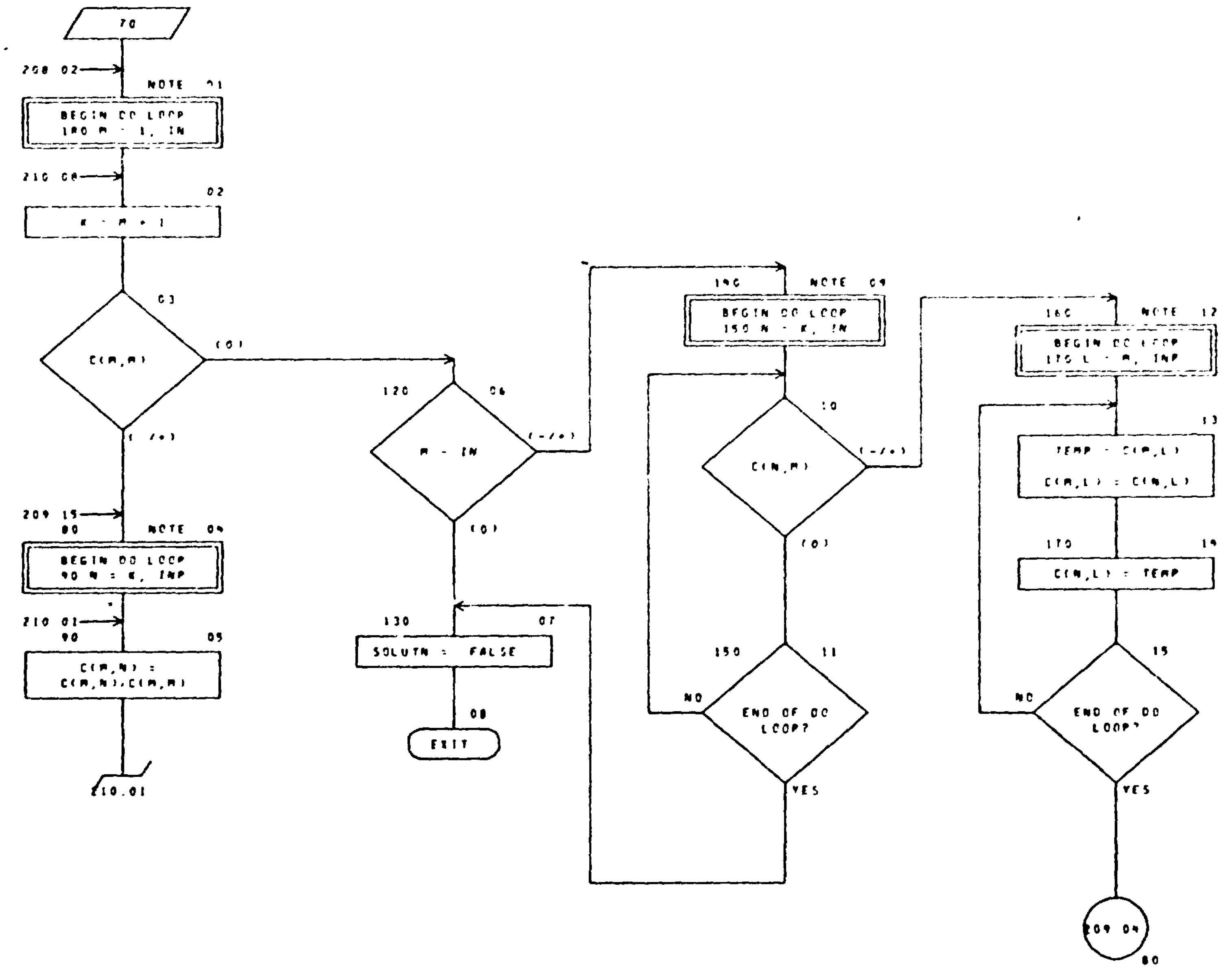

CHART TITLE - SUBROUTINE SIMEQ(C,A,IN,SOLUTN)

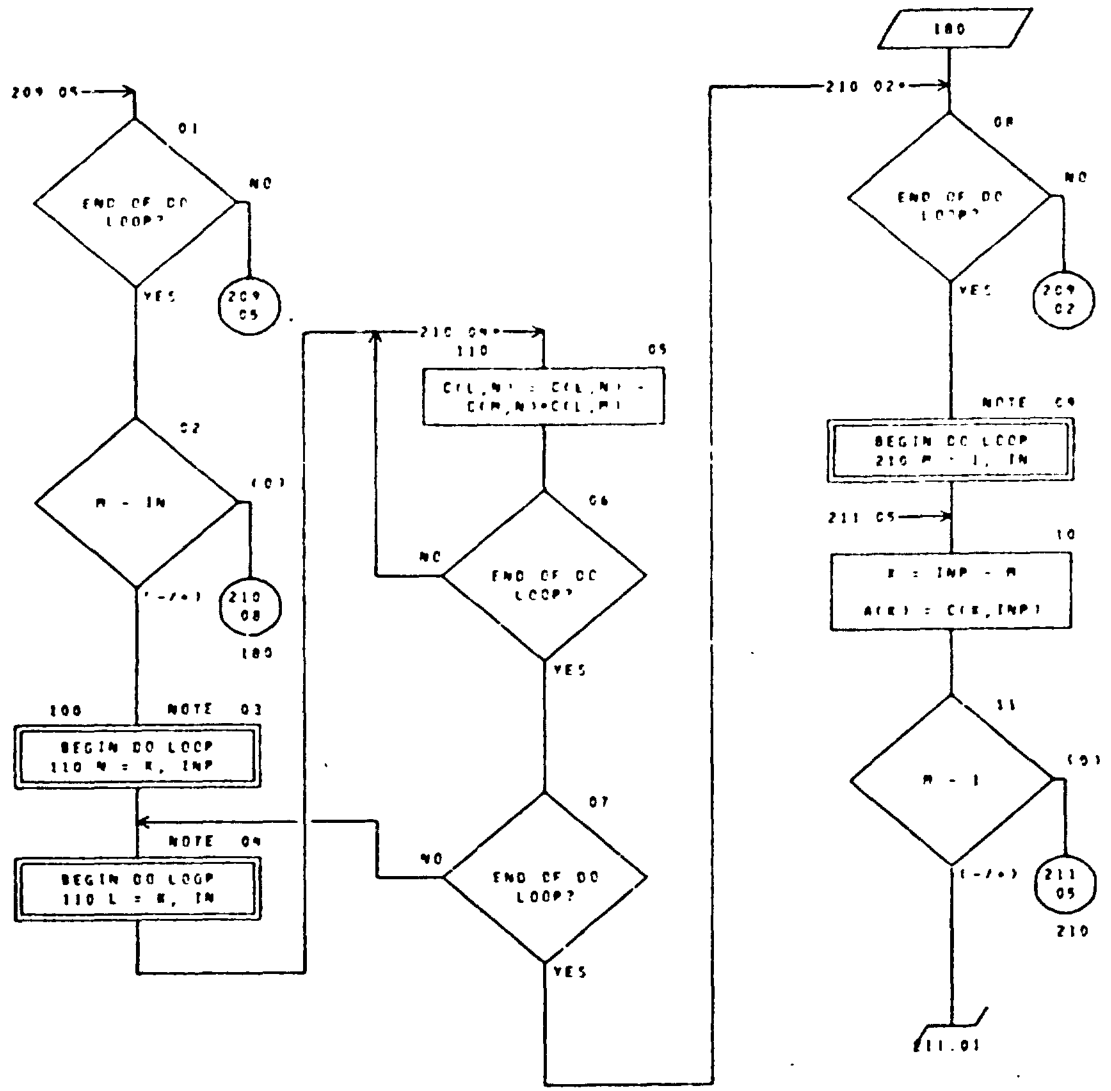

CHART TITLE - SUBROUTINE SIMEQ(C,A,IN,SOLUTN)

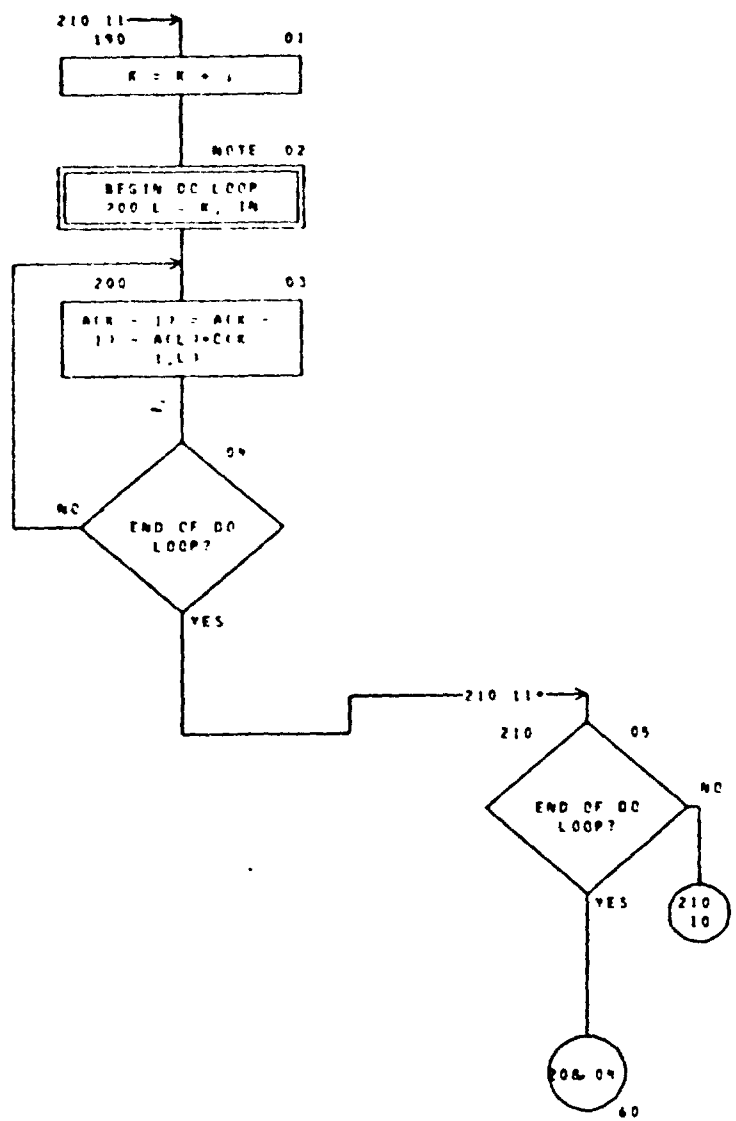

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
IMPLICIT REAL*8 ( A-H, O-Z)
LOGICAL SOLUTN
DIMENSION C(IN,IN), A(IN)
```

Na SOLENG

C g Arguments: None

Referenced Sub-programs: AMAL, FINDXB, MTMT, MTVT

Referenced Commons: ALAN, AM1, CONVRT, ENG, HENRY, HER, ILEF, INTEG, JERR, LEFT, MEL

Entry Points: None

Referencing Sub-programs: DERIV

Discussion: Subroutine SOLENG acts as an extension to subroutine DERIV by computing the perturbations due to thrust and solar pressure and adding these perturbations to the Encke terms in the array D2XIL. Upon entry, a check is made to determine if the current arc is a coast arc and the product $k_s a$, where k_s is the solar constant and a is the total spacecraft area including solar arrays, is zero. If so, no further computations are made, and a return to DERIV is executed. Otherwise, the computation of thrust perturbations continues.

All remaining computation in this subroutine are performed in a loop which is executed a total of NEQL times, where NEQL is the total number of trajectories that are currently being integrated simultaneously. That is, the perturbations are computed first for the nominal or trial trajectory and then for each perturbation trajectory, if any. The subscript i in the equations to follow denotes the variable evaluated for the ith trajectory, where i = 1, 2, ..., NEQL.

The unit vectors $\bar{e}_r$ along the radius vector R_s of the spacecraft relative to the sun

$$\bar{e}_r = R_{si} / |R_{si}|$$

and $\bar{n}$ along the normal to the plane of the arrays in the body fixed coordinate system

$$\bar{n} = \cos\alpha_i \cos\beta_i I + \cos\alpha_i \sin\beta_i J + \sin\alpha_i K$$

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are evaluated. If the unconstrained mode is indicated (NOP65 = 1), the matrix A which rotates a vector expressed in the inertial coordinate system to the body coordinate system is evaluated as follows:

$$A = \begin{bmatrix} (c\zeta_i c\xi_i - s\zeta_i s\xi_i c\nu_i) & (c\zeta_i s\xi_i + s\zeta_i c\xi_i c\nu_i) & (s\zeta_i s\nu_i) \\ -(s\zeta_i c\xi_i + c\zeta_i s\xi_i c\nu_i) & -(s\zeta_i s\xi_i - c\zeta_i c\xi_i c\nu_i) & (c\zeta_i s\nu_i) \\ (s\xi_i s\nu_i) & -(c\xi_i s\nu_i) & (c\nu_i) \end{bmatrix}$$

where c and s denote cosine and sine, respectively, and ζ, ν, ξ are the spacecraft orientation angles. The assignment of A is not performed for the perturbation trajectories unless one or more of the three angles is different from those of the (i-1)th trajectory. If the constrained mode is flagged, the transformation matrix is evaluated in a different manner. First the unit constraint vector $\bar{x}_i$, along which the body fixed vector

$$\bar{s} = \cos\delta_i \cos\epsilon_i I + \cos\delta_i \sin\epsilon_i J + \sin\delta_i K$$

is to be directed, is evaluated by calling subroutine FINDXB. The unit vector

$$\bar{m} = (\bar{s} \times \bar{x}_i) / |\bar{s} \times \bar{x}_i|$$

is evaluated and used to obtain the transformation matrix $M(\bar{m}, \sigma)$ by calling subroutine AMAL, where σ is the angle between $\bar{s}$ and $\bar{x}_i$. If the input value of ψ_{max} for the current arc is input zero, then the transformation matrix $M(\bar{x}_i, \theta_i)$ is evaluated in AMAL, and the desired matrix A is computed

$$A = M(\bar{x}_i, \theta_i)\, M(\bar{m}, \sigma).$$

If ψ_{max} for the current arc is non-zero, then the following operations are performed

$$\bar{q} = M(\bar{x}_i, \phi_i)\, \bar{m}$$

$$\bar{s}_I = M(\bar{q}, \psi_i)\, \bar{x}_i$$

and A is formed

$$A = M(\bar{s}_I, \theta_i)\, M(\bar{q}, \psi_i)\, M(\bar{x}_i, \phi_i)\, M(\bar{m}, \sigma)$$

where each transformation matrix M is obtained by calling subroutine AMAL with the appropriate calling arguments. The vector $\bar{q}$ is simply $\bar{m}$ rotated about $\bar{x}_i$ through the angle ϕ_i and $\bar{s}_I$ is $\bar{x}_i$ rotated about $\bar{q}$ through the angle ψ_i. $\bar{s}_I$ represents the unit vector $\bar{s}$ expressed in inertial coordinates. Since the thrust vector is assumed to lie along the body fixed axis I, the thrust vector, in inertial coordinates, becomes

$$\bar{e}_t = A \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

and the array normal vector, in inertial coordinates, is

$$\bar{n}_I = A\bar{n}.$$

The next step is to evaluate the magnitude of the thrust and solar pressure perturbations and apply the accelerations in the correct direction. If the current arc is a coast arc, the logic proceeds to the computation of solar pressure. For thrust arcs the following computations are made. The density of photons impinging on the arrays is

$$d = (\bar{e}_r \cdot \bar{n}_I)/(R_s \cdot R_s)$$

where R_s is expressed in AU, and the power factor γ is evaluated

$$\gamma = d \sum_{j=0}^{n} a_j d^{j/4}$$

where n is the number of terms of the series (specified by input) and a_j, $j=1,2,\ldots,n$, are the input coefficients. For nuclear electric propulsion systems (specified through the flag NOPT(66)), γ is set to 1 and the above computations are bypassed. If the flag NOPT(68) is non-zero, the dot product

$\bar{e}_r \cdot \bar{n}_I$ is replaced with the constant 1, corresponding to the ease in which the arrays are always oriented normal to the sun line. The power available for propulsive purposes is evaluated

$$p_a = p_{oi}\,\gamma - p_{xi}$$

where p_{oi} is the reference power at 1 AU and p_{xi} is the housekeeping power for the current arc. p_a is set to zero if the computed value is negative. The propulsion system efficiency is

$$\eta = \frac{b\,c_i^2}{c_i^2 + d^2}$$

where b and d^2 are input efficiency coefficients and c_i is the jet exhaust speed. (Note that d is distinct from the same symbol used above for photon density). If the unit thruster power Δp in input zero, the power used by the propulsion system is equated to the power available. Otherwise, the number of operating thrusters n_t is set equal to the integral portion of the ratio $p_a/\Delta p$, and the power used is

$$p_r = n_t\,\Delta p\,.$$

The thrust magnitude is evaluated in newtons

$$f = 2\,p_r\,\eta/c_i,$$

the derivative of mass with respect to the universal anomaly β is

$$m' = -3600\,f/(\dot{\beta}\,c_i)$$

and the thrust acceleration magnitude, in units of ER/hr^2 or AU/hr^2

$$a_p = k(f/m)$$

where k is the conversion constant. The Encke terms are then modified to include the thrust terms

$$\ddot{\xi} = \ddot{\xi} + a_p \bar{e}_t .$$

If the solar pressure term k_s a is zero, the logic transfers to the end of the loop of computations for the current trajectory. Otherwise, the acceleration due to solar pressure is computed

$$A_{sp} = \frac{k k_s a}{m r_s} (\bar{e}_r \cdot \bar{n}_I)[2(1-c_a)(\bar{e}_r \cdot \bar{n}_I)\bar{n}_I + c_a \bar{e}_r]$$

where c_a is the coefficient of absorption. A_{sp} is then added to $\ddot{\xi}$ to obtain the total Encke perturbations.

SOLENG EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
A	U	JERR	Area of the spacecraft, including the solar arrays.
AO(10)	U	JERR	Coefficients, a_j, of the solar power law.
BL	U	JERR	Efficiency law coefficient, b.
CA	U	JERR	Photon absorption coefficient, c_a, equal to the ratio of photons absorbed by the panels to the total number incident.
CL(20)	UE	JERR (VBLOC)	Array of jet exhaust speeds for the nominal and perturbation trajectories, c_i.
ER(3)	SUA	JERR	Body fixed constraint vector, $\bar{s}$.
ET(3)	SU	JERR	Unit vector in the direction of thrust in inertial coordinates.
PW(20)	UE	JERR (VBLOC)	Array of reference powers for the nominal and perturbation trajectories, p_{oi}.

SOLENG EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
QB(3)	SUA		Unit vector, $\bar{q}$.
SB(3)	SUA		Unit vector, $\bar{m}$.
SI(3)	SUA		Unit vector, $\bar{s}_I$.
AAM(3, 3)	SUA		Transformation matrix A.
AMS(3, 3)	UA		Transformation matrix $M(\bar{m}, \sigma)$.
AXT(3, 3)	UA		Matrix product $M(\bar{s}_I, \theta_i)$ $M(\bar{q}, \psi)$ $M(\bar{x}_i, \phi)$.
CSG	SUA		$\cos \sigma$.
CSV(20)	UA	ENG	$\cos \psi_i$ or $\cos \nu_i$.
CSX(20)	UA	ENG	$\cos \theta_i$ or $\cos \xi_i$.
CSZ(20)	UA	ENG	$\cos \phi_i$ or $\cos \zeta_i$.
DSQ	U	JERR	Efficiency law coefficient, d^2, in m^2/sec^2.
ETA	SU	JERR	Efficiency factor, η.
ETV(3)	U	JERR	Unit thrust vector in body fixed coordinates.
NQN	U	ILEF	Numb[illegible] [illegible]ations integrated simu[illegible]y on each trajectory, incluc[illegible] [illegible]st a[illegible] [illegible]econd order.
SNV(20)	UA	ENG	$\sin \psi_i$ o[illegible]
SNX(20)	UA	ENG	$\sin \theta_i$ or [illegible]$_i$.
SNZ(20)	UA	ENG	$\sin \phi_i$ or $\sin \zeta_i$.
XIL(80)	U	AM1	Second integral of the Encke perturbations on the nominal and perturbed trajectories.

SOLENG EXTERNAL VARIABLES TABLE (cont)

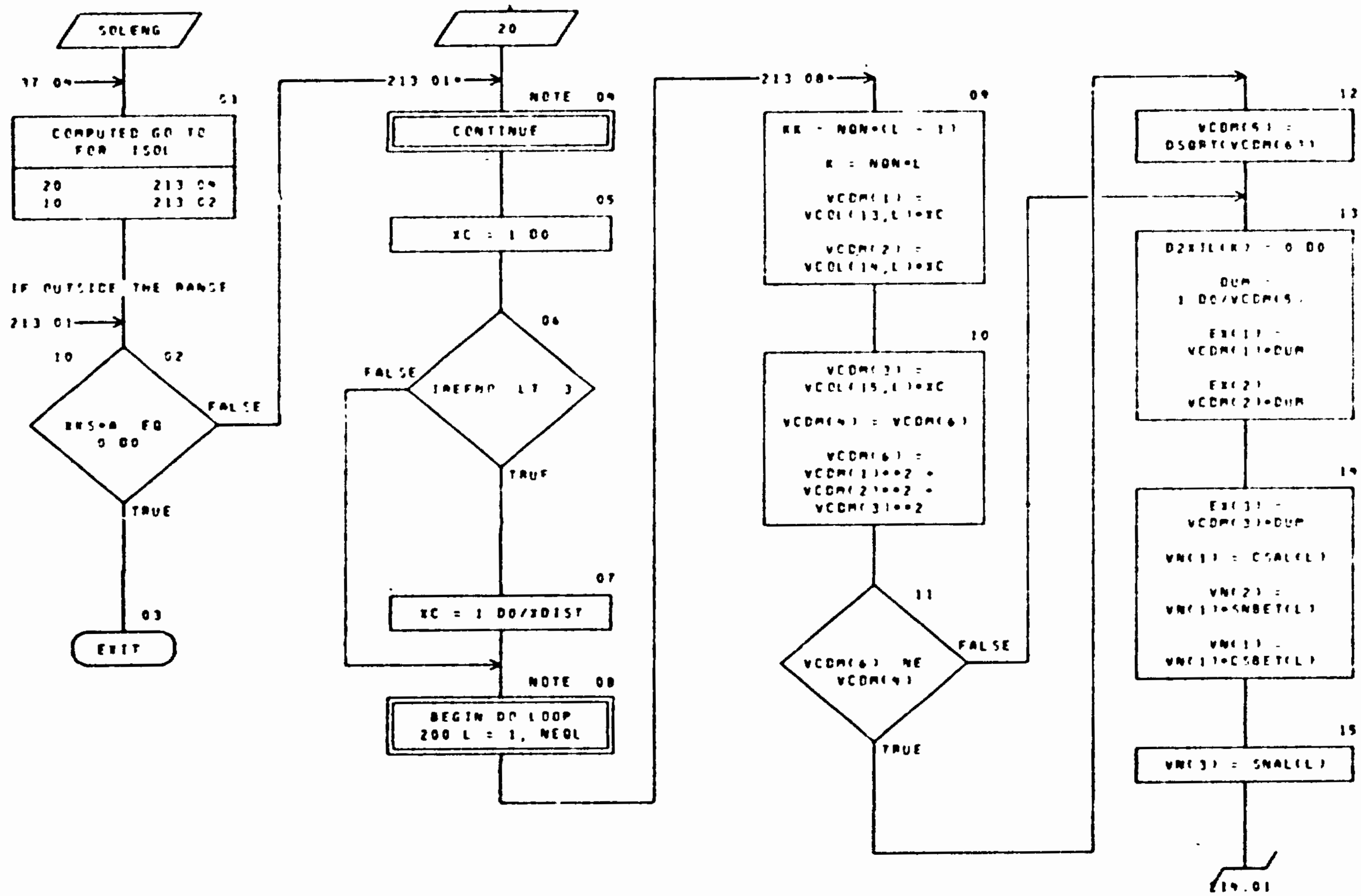
Variable	Use	Common	Description
XKS	U	JERR	Solar pressure, k_s, acting on a flat plate at a distance of 1 AU from the sun assuming all photons are absorbed, in newtons/m^2.
AXT1(3,3)	UA		Transformation matrix $M(\bar{x}_i, \phi_i)$.
AXT2(3,3)	UA		Transformation matrix $M(\bar{q}, \psi_i)$.
AXT3(3,3)	UA		Transformation matrix $M(\bar{s}_I, \theta_i)$.
AXT4(3,3)	UA		Matrix product $M(\bar{q}, \psi_i)$ $M(\bar{x}_i, \phi_i)$.
CSAL(20)	U	ENG	$\cos \alpha_i$.
CSDL(20)	U	ENG	$\cos \delta_i$.
CSET(20)	U	ENG	$\cos \epsilon_i$.
DELP	U	JERR	Unit thruster reference power, Δp.
ISOL	U	MEL	Arc thrust/coast flag. =1 - thrust arc =2 - coast arc
NCT1	U	HER	Index of ψ_{max} for current arc in TBIN array.
NEQL	U	ILEF	Number of trajectories currently being integrated simultaneously.
NMAX	U	HER	Number of coefficients in the solar power law (=n+1).
NOPT(72)	U	INTEG	Array of program option flags.
RHBR	U	ALAN	Factor for converting between time and β derivatives ($=\dot{\beta}$).

SOLENG EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
SNAL(20)	U	ENG	sin α_i.
SNDL(20)	U	ENG	sin δ_i.
SNET(20)	U	ENG	sin ϵ_i.
SSIG	SUA		sin σ.
TBIN(122)	U	JERP	Array of trajectory arc information. (See description in subroutine INPUT).
VCOL (72,20)	U	LEFT	Array of spacecraft position vectors relative to all perturbing bodies. Includes both nominal and perturbed trajectories.
CSBET (20)	U	ENG	cos β_i.
D2XIL (80)	SU	AM1	Array of Encke perturbations, $\ddot{\xi}$, for nominal and perturbed trajectories.
NOP65	U	ILEF	Constraint mode indicator. =1 - unconstrained mode =2 - constrained mode, $\psi_{max} = 0$ =3 - constrained mode, $\psi_{max} \neq 0$.
SNBET (20)	U	ENG	sin β_i.
XDIST	U	HENRY	Conversion factor, equal to the number of ER in 1 AU.
APSCON	U	CONVRT	Factor for converting units of acceleration from m/sec^2 to ER/hr^2 or AU/hr^2.
IREFNO	U	INTEG	Identification number of current reference body.

CHART TITLE - SUBROUTINE SOLENG

C-C



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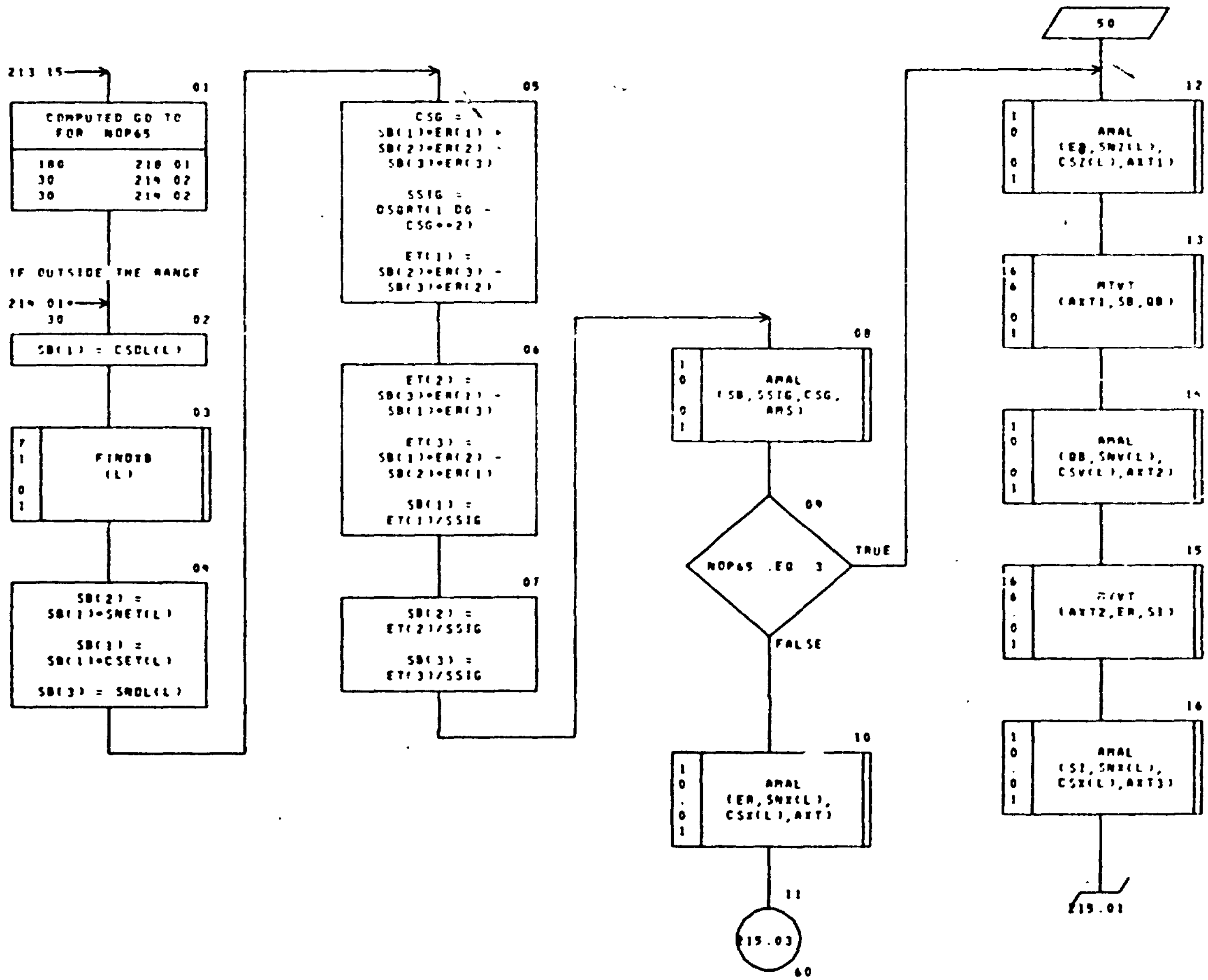

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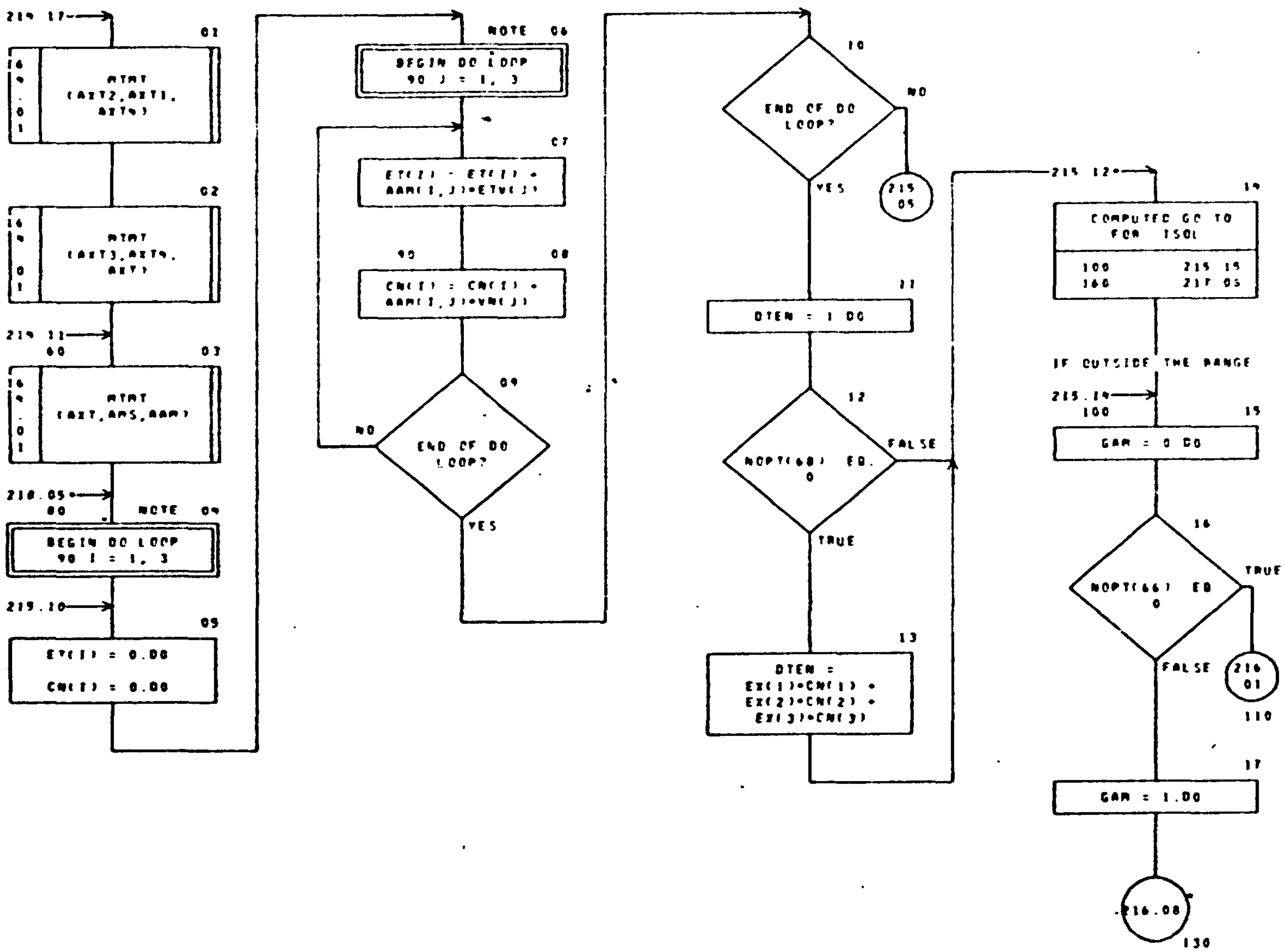

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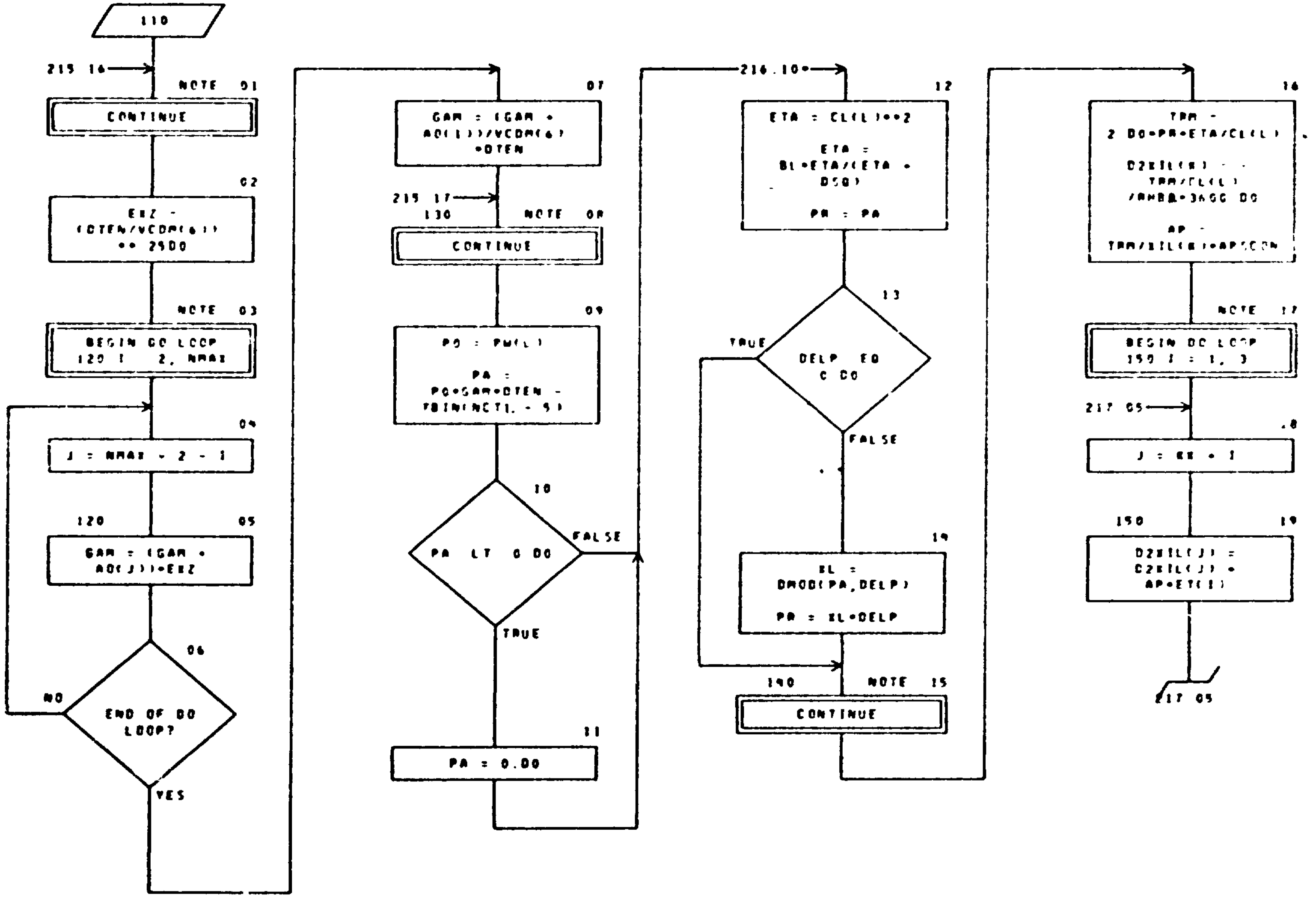

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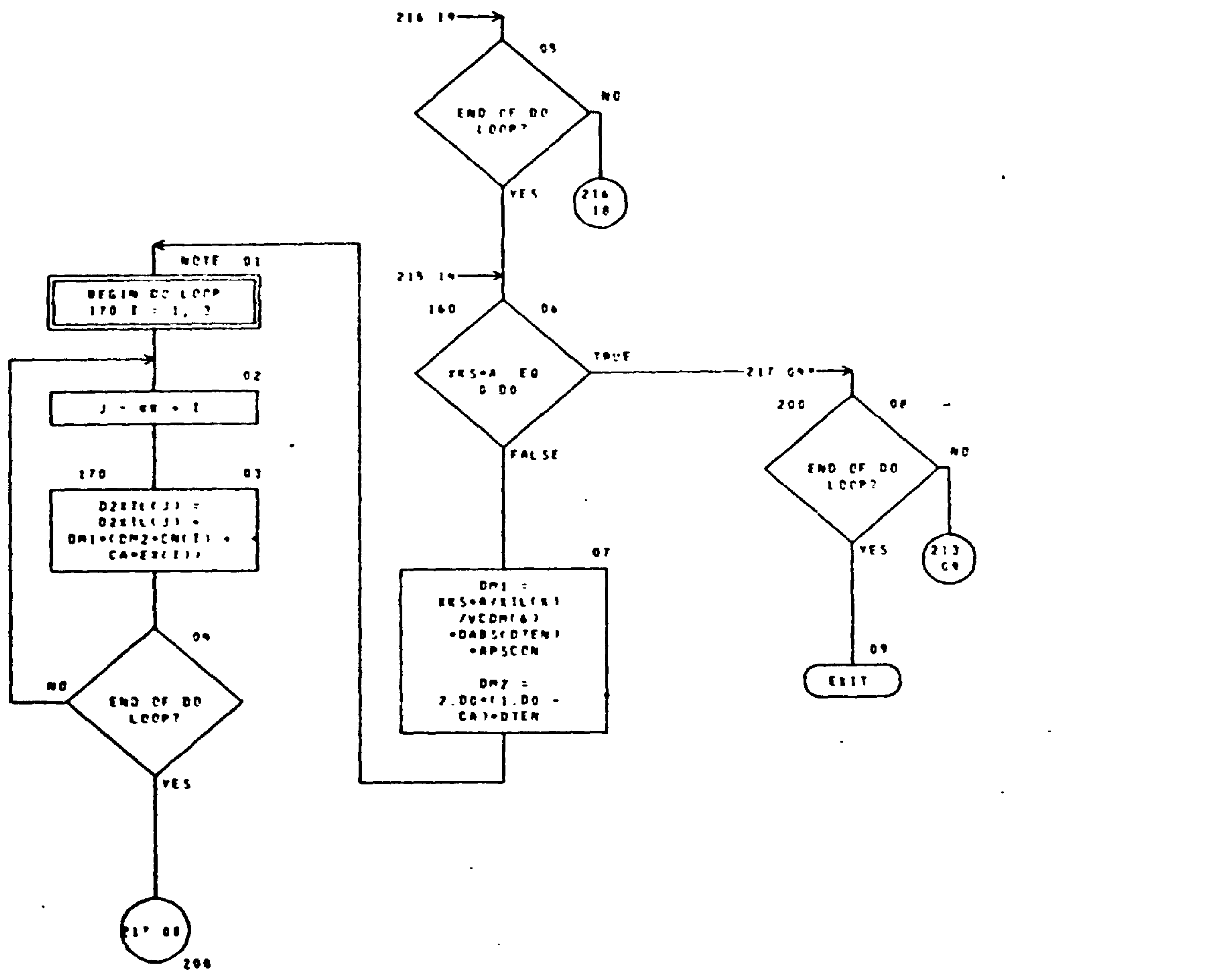

SOLENG-13

CHART TITLE - SUBROUTINE SOLENG

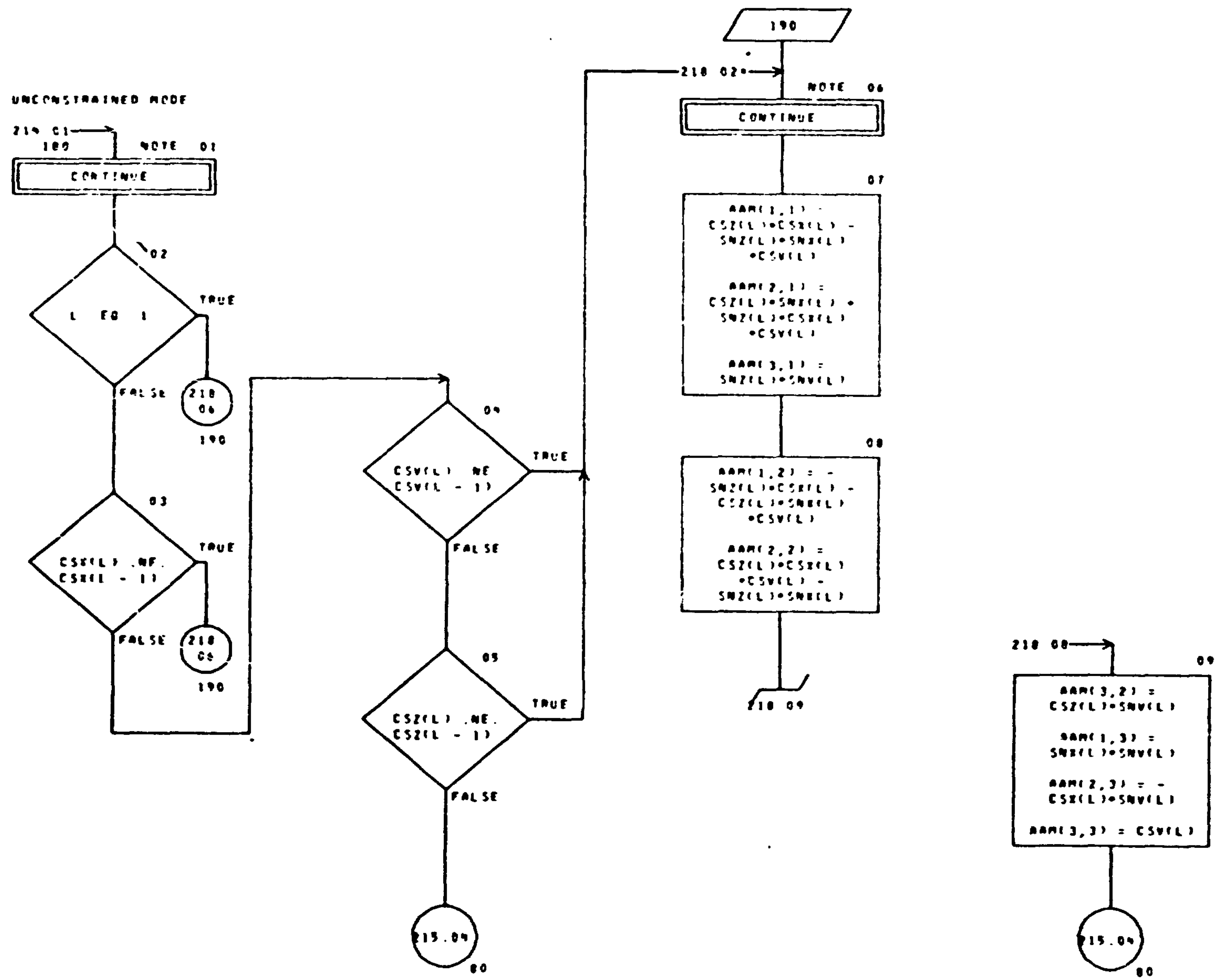

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
IMPLICIT REAL *8 (A-H,O-Z)
INTEGER DAY,HOURS,YEAR
REAL*8 KSOO,MEI,ME,KM,INTV,INIX,IN2X
DIMENSION AXT1(3,3),AXT2(3,3),AXT3(3,3),GB(3),SI(3),AXT4(3,3)
DIMENSION CL(20),PW(20),VCOM(6),EX(3),VN(3),TB(3),CN(3),AAM(3,3)
DIMENSION AMS(3,3),AXT(3,3)
COMMON/ALAN/ T,RHBA,DCRHO
COMMON/AMI/DELT,BETA,DTI,XIL(80),XIDL(80),D2XIL(80),IFST(80)
COMMON/CONVRT/APICON,APSCI
COMMON/ENG/TNAL(20),CSAL(20),SNBET(20),CSBET(20),SNDL(20),CSDL(20)
,SNET(20),CSET(20),SNX(20),CSX(20),SNV(20),CSV(20),SNZ(20),CSZ(20)
COMMON/HENRY/ARRAY(8,3,12),CHIND,INTV(72),INIX(3),
IN2X(3),KSOO(12),KM(12),XDIST,MEI(12),ME(12),POSPCS,PAVDT,
PDT,PCIN,RD,REKM,RAM,RRE,RREU,RCIND,RATIO,SEC,TSCL,THTS,TPI,
TIMEL,THET,VELPCS
COMMON/HER/IPS,NSL,NSL1,IFIRS,ITCT,IPOFL(30),IVAR(100),ITMAX,NTP,
NTPS,NMAX,NJ,JN,IPAT,NCTI,NJL
COMMON/ILEF/NEOL,NEOJ,NON,NOP65,IOAR(7),NOP64,NOP63,NS,N4,NS1,NJJ
COMMON/INTEG/DAY,HOURS,YEAR,IDUMMY,ITRIG,IREFNO,IREFNB,
IREFNT,IN,IO,IJK,MONTH,MIN,NOPT(72),NPLAN,NPLAN1
COMMON/JERR/VBLOC(200),A,CA,BL,DSQ,DFLP,AO (10),SUMA,XKS,ETV(3),
ET(3),XKP,EN(3),CPI(7,30),TBIN(122),ETA,CR,XKK,XKT,XEST,APS,AL1,
AL2,AL3
COMMON/LEFT/XRL(6,20),XRDL(6,20),VCOL(72,20)
COMMON/REL/ISOL
```

SOLENG-15

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
EQUIVALENCE (CL(1),VBLOC(1)),(PW(1),VBLOC(2))
```

<u>Name:</u> SUBFG

<u>Calling Argument:</u> THETA2, IOPT

<u>Referenced Sub-programs:</u> None

<u>Referenced Commons:</u> THAD

<u>Entry Points:</u> None

<u>Referencing Sub-programs:</u> SAMM, TBDP

<u>Discussion:</u> This subroutine evaluates the functions $G_i(\theta^2)$ required for the solution of the two-body Kepler problem. The range of the subscript i depends on the argument IOPT. IOPT=1 denotes that only the trajectory variables are required, in which case i ranges from 0 to 3. IOPT=2 indicates that partial derivatives are desired which requires G_i for $i = 0$-5. The parameter θ is related to the universal anomaly β through the formula

$$\theta^2 = \beta^2/a \tag{1}$$

where a is the semi-major axis. Thus, for elliptic orbits, θ represents the change in eccentric anomaly from the reference position. Denoting

$$\alpha = -\theta^2 \tag{2}$$

then the functions G_i are defined

$$F_i = \sum_{j=0}^{\infty} \frac{\alpha^j}{(2j+i)!} \tag{3}$$

$$G_i = \beta^i F_i \,. \tag{4}$$

Inspection of equation (3) will verify that the F_i satisfy the following recursion formula

$$F_i = \frac{1}{i!} + \alpha F_{i+2} \,. \tag{5}$$

Thus the series expression (3) need only be solved for the two highest order terms F_i after which the lower order terms are obtained with (5). The number of terms required in (3) to maintain the desired accuracy is dependent upon the magnitude of α. It has been determined that ten terms yield 16 digits of accuracy for $|\alpha| \leq 1$. For larger values of $|\alpha|$, reduction formulae exist which permit the accurate computation of the F_i with 10 terms of the series. The procedure is to divide the input α by 4 a number of times n until the result is less than 1. Denote this result α', then the equations for $F_i(4\alpha')$ in terms of $F_i(\alpha')$ are, for IOPT=1

$$F_3(4\alpha') = \left[F_2(\alpha') + F_0(\alpha')\ F_3(\alpha')\right]/4$$

$$F_2(4\alpha') = F_1(\alpha')^2/2 \tag{6}$$

or, for IOPT=2,

$$F_5(4\alpha') = \left[F_4(\alpha') + F_2(\alpha')/6 + F_0(\alpha')\ F_5(\alpha')\right]/16$$

$$F_4(4\alpha') = \left[F_3(\alpha') + F_1(\alpha')\ F_3(\alpha')\right]/8. \tag{7}$$

The lower order terms in either case are obtained from the recursion formula (5). The equations (6) or (7) are cycled n times where the α' of each cycle is the $4\alpha'$ of the preceding cycle. The desired functions G_i are then obtained from (4).

SUBFG EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
F0	SU	THAD	F_0.
F1	SU	THAD	F_1.
F2	SU	THAD	F_2.
F3	SU	THAD	F_3.
F4	SU	THAD	F_4.
F5	SU	THAD	F_5.
G1	S	THAD	G_1.
G2	S	THAD	G_2.
G3	S	THAD	G_3.
G4	S	THAD	G_4.
G5	S	THAD	G_5.
GG0	S	THAD	G_0.
IOPT	UX		Flag indicating whether trajectory only or trajectory and partial derivative variables are needed. 1 - trajectory only 2 - trajectory and partials
BETAM1	U	THAD	Universal anomaly, β.
THETA2	SUX		θ^2.

CHART TITLE - SUBROUTINE SUBFG(THETA2,ICPT)

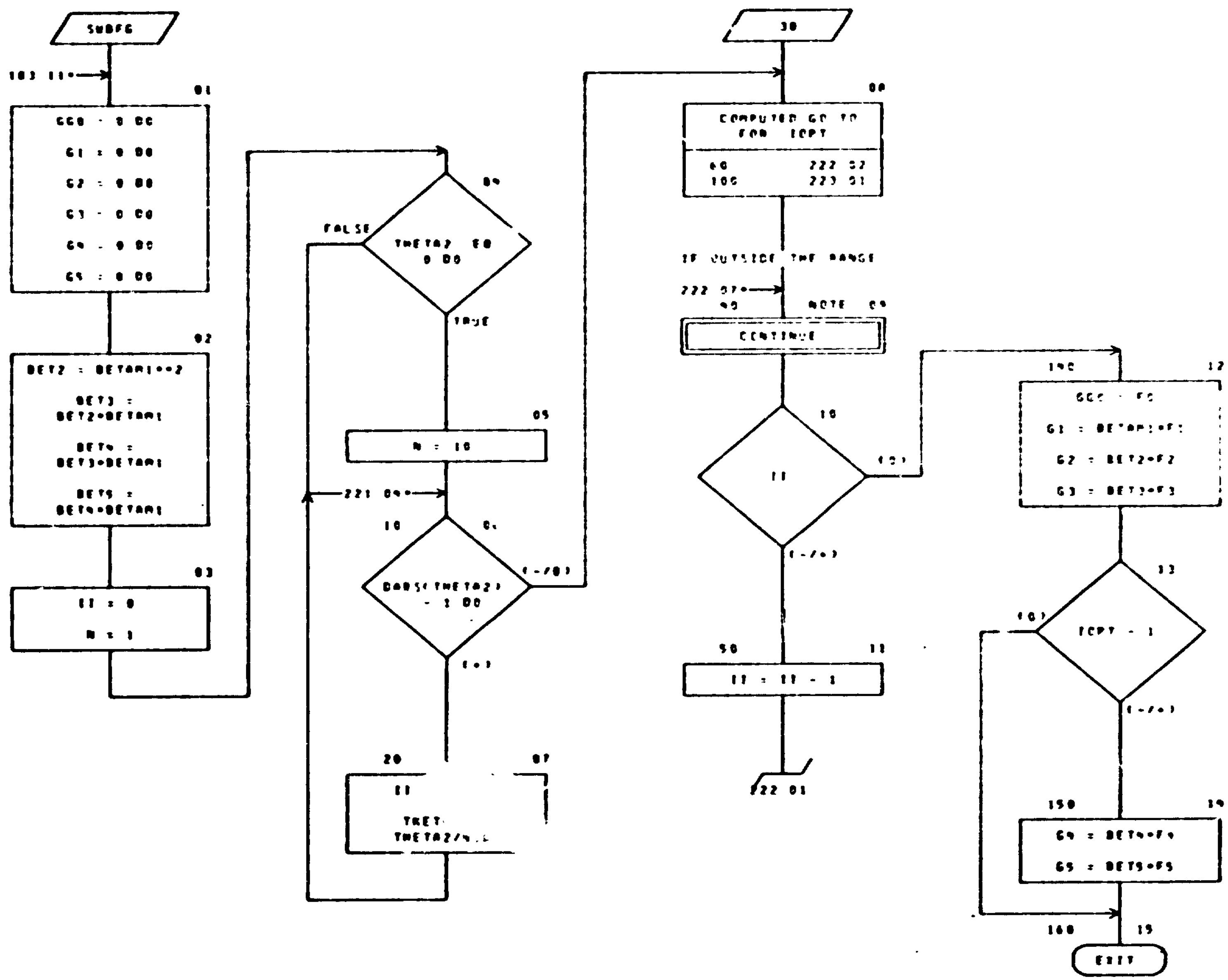

CHART TITLE - SUBROUTINE SUBFG(THETA2,IOPT)

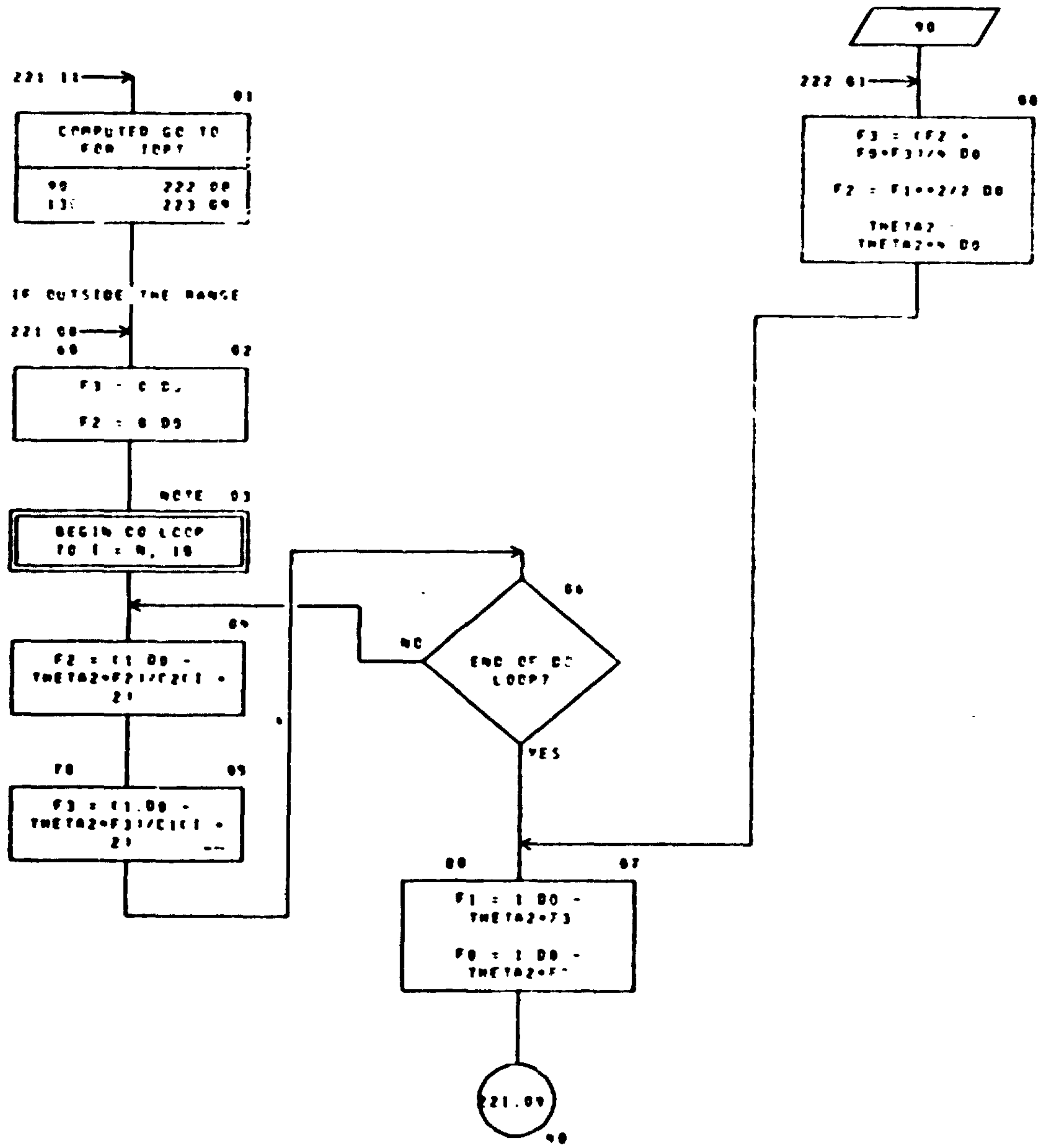

CHART TITLE - SUBROUTINE SUBFG(THETA2,IOPT)

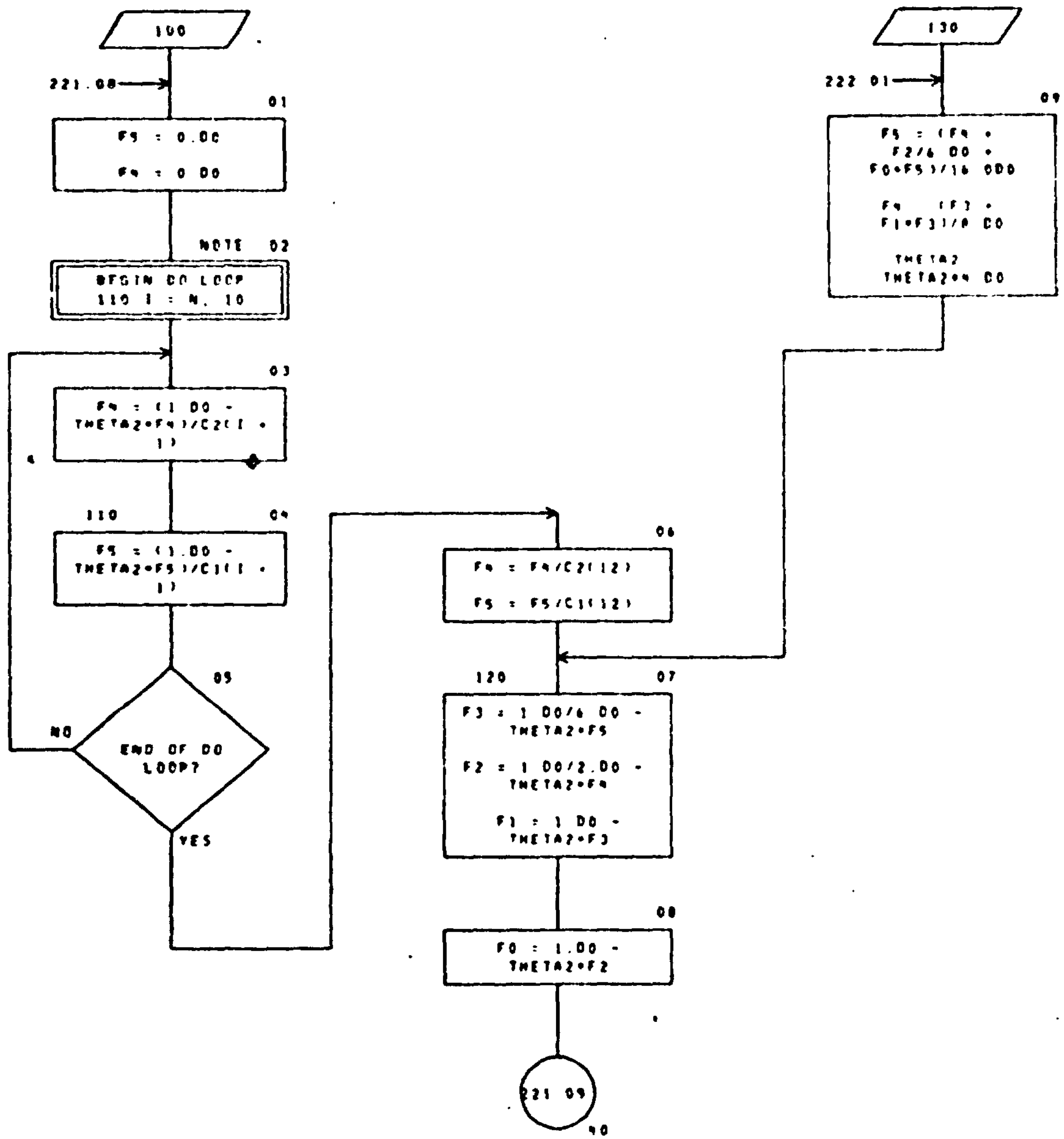

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
IMPLICIT REAL*8 (A-H,O-Z)
DIMENSION C1(12),C2(12)
COMMON/THAD/BETAM1,GG0,G1,G2,G3,G4,G5,G6,G7,F0,F1,F2,F3,F4,F5,
F6,F7
DATA C1/600 D0,506 D0,420 D0,342 D0,272 D0,210 D0,156 D0,110 D0,
72 D0,42 D0,20 D0,6 D0/
DATA C2/552 D0,462 D0,380 D0,306 D0,240 D0,182 D0,132 D0,90 D0,
56 D0,30 D0,12 D0,2 D0/
```

<u>Name:</u> TBDP

<u>Calling Arguments:</u> None

<u>Referenced Sub-programs:</u> SUBFG

<u>Referenced Commons:</u> ALAN, AM1, HENRY, LEON, STEVE, TBPR, THAD

<u>Entry Points:</u> None

<u>Referencing Sub-programs:</u> CONTRL, DERIV

<u>Discussion:</u> This subroutine performs selected two-body computations using the series solutions of universal variable functions G_i, $i = 0,1,2,3$, which are evaluated in SUBFG. When called from CONTRL, TBDP evaluates the increment in the universal anomaly corresponding to a specified time interval referenced from the last rectification point. This essentially involves the iterative solution of Keplers problem as follows. At the top of the loop, define

$$\alpha = \beta^2/a$$

where β is the current value of the universal anomaly and a is the semi-major axis. The functions G_i are then evaluated by calling SUBFG and used in the equations

$$\phi = r_o G_1 + G_3 + d_o G_2/\sqrt{\mu} - \sqrt{\mu}\ \Delta t$$

$$\phi' = r_o G_o + G_2 + d_o G_1/\sqrt{\mu}$$

where r_o is the distance at the last rectification point, $d_o = R_o \cdot \dot{R}_o$, μ is the gravitational constant and Δt is the specified time interval. The change in universal anomaly $\delta\beta$ is evaluated

$$\delta\beta = \phi/\phi'$$

and the current value of β is updated

$$\beta = \beta - \delta\beta .$$

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The magnitude of $\delta\beta/\beta$ is checked and, if less than 10^{-14}, convergence is assumed. The incremental universal anomaly is then defined

$$\Delta\beta = \beta - \beta_s$$

where β_s is the value of β on entry to TBDP, and β is set to β_s. Thus the $\Delta\beta$ corresponds to the increment in β required to proceed backwards from the incoming point on the conic to the point corresponding to the desired time. If convergence was not achieved, i.e., $|\delta\beta/\beta| > 10^{-14}$, an iteration counter is checked and, if less than 20, the logic proceeds to the top of the loop to commence another iteration. If convergence is not achieved in 20 iterations, a warning message is printed, and the universal anomaly increment is defined using the current value of β prior to exiting.

When TBDP is called from DERIV (ITB=0), the principal objective is to evaluate the two-body position and velocity vectors, R and $\dot{R}$, for a given value of β. After forming α and the G_i as above, the time and radial distance from the reference body at the given value of β are evaluated

$$t = t_o + (r_o G_1 + G_3 + d_o G_2/\sqrt{\mu})/\sqrt{\mu}$$

$$r = r_o G_o + G_2 + d_o G_1/\sqrt{\mu}$$

where t_o is the time at the last rectification point. The auxiliary functions f, g, $\dot{f}$, and $\dot{g}$ are formed

$$f = 1 - G_2/r_o; \quad g = r_o G_1/\sqrt{\mu} + d_o G_2/\mu$$

$$\dot{f} = -\sqrt{\mu} G_1/r_o r; \quad \dot{g} = 1 - G_2/r$$

which lead to the familiar equations for R and $\dot{R}$

$$R = f R_o + g \dot{R}_o$$

$$\dot{R} = \dot{f} R_o + \dot{g} \dot{R}_o,$$

where R_o and $\dot{R}_o$ are the position and velocity, respectively, at the last rectification point. Prior to exiting, the change in eccentric anomaly since the last rectification point is evaluated

$$\theta = E - E_o = \sqrt{\alpha} .$$

Messages and Printout: If convergence to the solution of the Kepler problem is not achieved within 20 iterations, the time t, the rectification time t_o, the function $\sqrt{\mu}\ \Delta t$, the change in universal anomaly $\delta\beta$, and the current value of β are printed as follows

TOO MANY ITERATIONS IN SUBROUTINE TBDP.

________ ________ ________ ________ ________

Each value is printed with a field format of D20.14.

TBDP EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
T	SU	ALAN	Current time, t.
G1	U	THAD	G_1.
G2	U	THAD	G_2.
G3	U	THAD	G_3.
TI	U	STEVE	Time t_o at the last rectification point.
DTI	SU	AM1	When called from CONTRL, DTI on entry contains the specified time interval in hours from the last rectification point. On exit, it contains $\Delta\beta$.
GGO	U	THAD	G_o.

TBDP EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
ITB	U	TBPR	Flag indication the type of solution desired. 0 - position and velocity, given β 1 - $\Delta\beta$ given Δt.
XRI(6)	U	STEVE	Position vector R_o relative to the reference body, evaluated at the last rectification point.
XRO(6)	S	LEON	Two body position vector R at current time.
XSQ	U	STEVE	Gravitational constant μ of reference body.
BETA	SU	AM1	Universal anomaly β.
O1AD	U	STEVE	Inverse of the semi-major axis, 1/a.
THET	S	HENRY	Change in eccentric anomaly, $\theta = E - E_o$.
ALPHA	SUA		$\theta^2 = \beta^2/a$.
RDOTD	U	STEVE	$d_o = R_o \cdot \dot{R}_o$.
SQTMU	U	STEVE	$\sqrt{\mu}$.
TMPDP	SU	LEON	β^2.
TM2DP	U	STEVE	$d_o/\sqrt{\mu}$.
XRIDT(6)	U	STEVE	Velocity vector $\dot{R}_o$ relative to the reference body, evaluated at the last rectification point.
XRODT(6)	S	LEON	Two-body velocity vector $\dot{R}$ at current time.
BETAM1	S	THAD	β.

CHART TITLE - SUBROUTINE TBDP

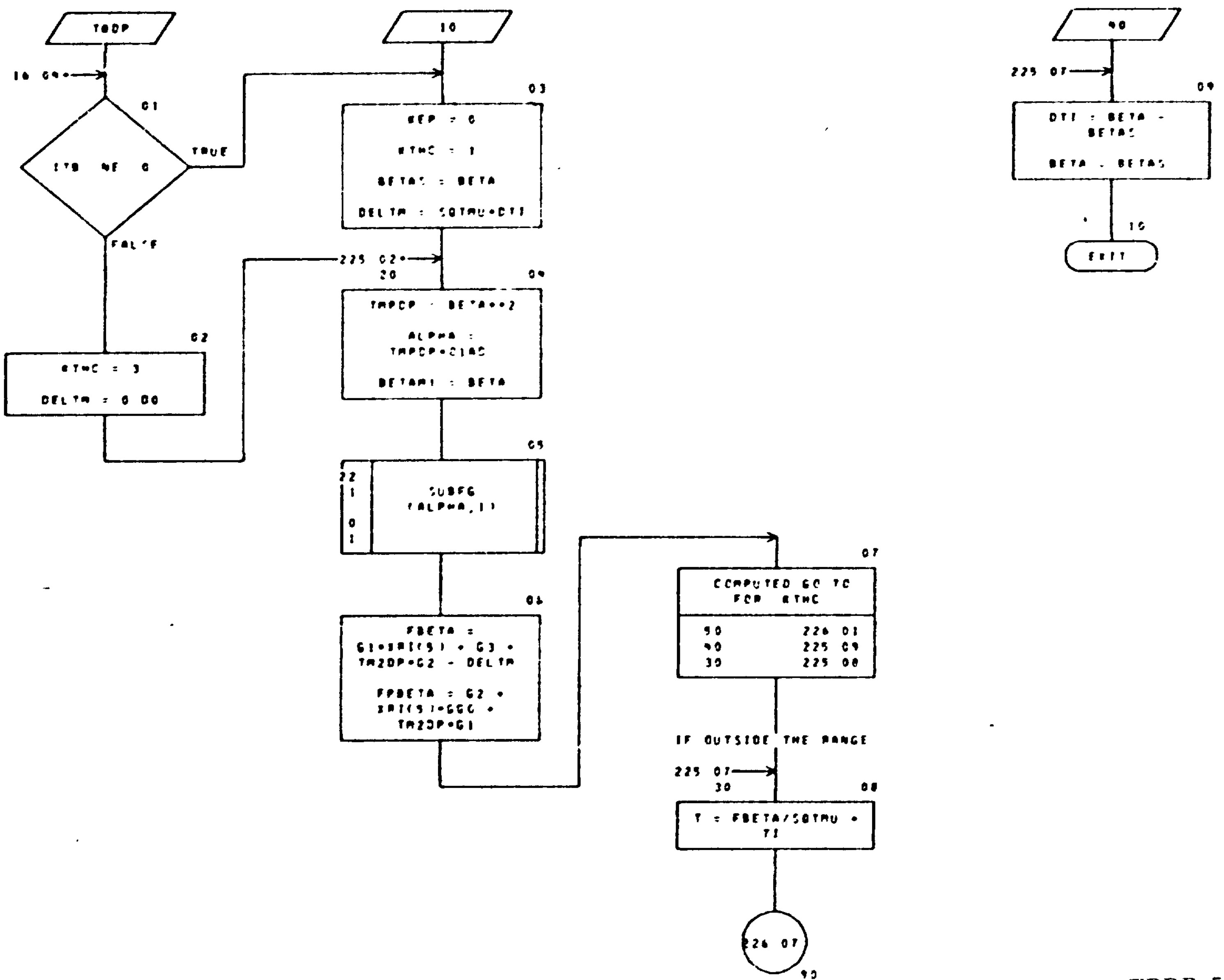

CHART TITLE - SUBROUTINE TBOP

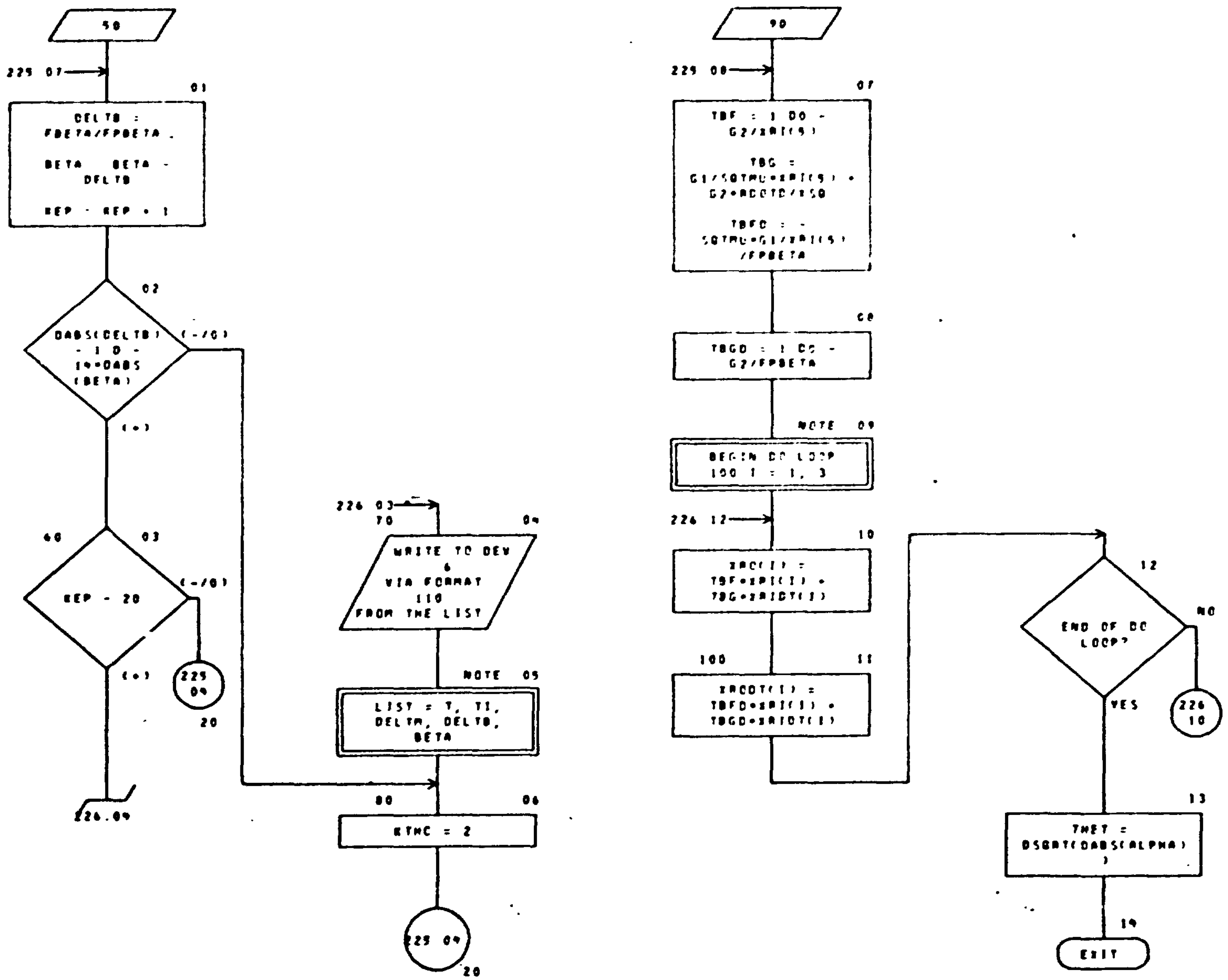

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
      IMPLICIT REAL*8(A-H,O-Z)
      REAL*8 KSQQ,MEI,ME,KM,MDIST,INTV,IN1X,IN2X
      COMMON/ALAN/T,RHBR,DDRHO
      COMMON/AMI/DELT,BETA,DTI,XI(80),XID(80),D2XI(80),IFST(80)
      COMMON/HENRY/ARRAY(8,3,12),CHIND,INTV(12),IN1X(3),
      IN2X(3),KSQQ(12),KM(12),MDIST,MEI(12),ME(12),POSRCS,PRVDT,
      PDT,PCIN,RD,REKM,RRM,RRE,RREU,RCIND,RATIO,SEC,TSCL,THTS,TP1,
      TIMEL,THET,VELRCS
      COMMON/LEON/XRC(6),XRCDT(6),TMPOP,W
      COMMON/STEVE/ZELT,XSQ,DIAD,RDOTC,TI,TM2DP,XRI(6),XRIDT(6),SQTMU
      COMMON/TBPP/ITB
      COMMON/THAD/BETAM1,GGC,G1,G2,G3,G4(4),FC,F1,F2,F3,F4(4)
110   FORMAT (' TOO MANY ITERATIONS IN SUBROUTINE TBDP '/(5D20.14))
```

<u>Name:</u> TRAJL

<u>Calling Arguments:</u> LERROR, NZZ

<u>Referenced Sub-programs:</u> AMAINT, CONTRL, DERIV, DETDT, INIT, MIIP1, RECT, REMTIM, SUMMRY

<u>Referenced Commons:</u> ALAN, AM1, HENRY, HER, ILEF, INTEG, JERR, LEON, MINSEC, NOMLL, STEVE

<u>Entry Points:</u> None

<u>Referencing Sub-programs:</u> FNPRNT, MINMX3

<u>Discussion:</u> Subroutine TRAJL governs the integration of either a single trial trajectory or of a nominal and perturbation trajectories simultaneously. The calling argument NZZ equal to one indicates a trial trajectory is to be generated, while NZZ equal to zero denotes a nominal with perturbations are to be run. The logical flag error condition indicator LERROR is initialized to .FALSE. on entry and is not subsequently modified. Therefore, TRAJL does not return any error conditions to the calling routines.

Upon entry, DELT is set to an arbitrarily large value, NOMT is equated to NZZ, and the time-out flag ITV is set to 1 if sufficient time remains to continue iteration or to 2 if the estimated time for the job is about to run out. The time remaining for the job, in CPU and I/O seconds, is obtained with a call to subroutine REMTIM. The CPU time remaining in seconds must exceed the input integer ITF for a trial trajectory or twice ITF for a nominal and perturbation trajectories, and the I/O time remaining in seconds must exceed half of ITF. Otherwise, ITV is set to 2. If ITV is equal to 2, the flag NOPT(60) is set to 1 to assure that the final trajectory is printed and NOMT is set to 1 so that no perturbation trajectories will be integrated. A message is also printed to indicate that time has run out.

After performing trajectory initialization by calling INIT, a trajectory rectification is performed in subroutine RECT to define the two body reference trajectory from which all Encke perturbations are measured and subroutine DERIV is called to define the derivatives relative to the new reference trajectory. If the current time t is zero and NOPT(60) is non-zero, the initial trajectory point is printed in subroutine MIIP1. If the time is equal to an arc end time on a nominal trajectory, and the arc end time is an independent variable, then the partials of the velocity and mass with respect to that end time are evaluated analytically and stored in the array CP1. The equations are

$$\frac{\partial \dot{R}}{\partial t_i} = - \frac{\mu}{r_k^2} \left(\xi'' - \xi' \frac{R_k \cdot \dot{R}_k}{r_k \sqrt{\mu}} \right)$$

$$\frac{\partial m}{\partial t_i} = - \dot{\beta}\, m'$$

where the prime indicates derivatives with respect to β and the subscript k denotes evaluation on the reference two-body trajectory.

The basic point-by-point integration loop is then entered. The integration interval is defined by calling DETDT. If the interval is different from that of the last integration step, the logic transfers to the rectification logic described above. Otherwise, a single integration step is taken by calling AMAINT. Subroutine CONTRL is then called to determine if any remarkable points or conditions occurred in the interval. The flag ITRIG returned from CONTRL defines the appropriate action to be taken in TRAJL. If ITRIG equals 1, a trajectory rectification is required, and a transfer to the call of RECT is effected. A value of 2 for ITRIG indicates that no special condition was encountered, so another step is integrated after determining the integration interval, and so on. A value of 3 for ITRIG means that the end of the trajectory was encountered. In this case, if ITV is 1, a return to the calling routine is executed. However, if ITV is 2, the case summary page is printed by calling SUMMRY, and execution of the program is terminated.

Messages and Printout: If the time-out flag ITV is 2, the following message is printed:

THIS CASE HAS TIMED OUT.

If NOPT(60) is non-zero, the following heading is printed at the top of the trajectory summary:

FINAL TRAJECTORY

TRAJECTORY ARC DATA

TRAJL EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
T	U	ALAN	Current time, t.
IO	U	INTEG	Logical unit of standard program printout.
CP1(7,30)	SU	JERR	Matrix of partials of state with respect to the independent variables.
DTI	S	AM1	Current integration interval.
ITF	U	MINSEC	Input integral number of seconds that must remain at the start of a trial trajectory to continue iteration.
NJJ	U	ILEF	Index of the second subscript of CP1 defining where to store the partials with respect to arc end time.
NZZ	UX		Flag defining whether perturbations trajectories are to be integrated. 0 - nominal and perturbation trajectories are required 1 - trial trajectory only is required.
XID(80)	U	AM1	Second integrals of the Encke perturbations.

TRAJL EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
XRO(6)	U	LEON	Position vector R_k at the current time on the two body reference trajectory.
XSQ	U	STEVE	Gravitational constant μ of the reference body.
DELT	U	STEVE	Standard integration interval.
D2XI(80)	U	AM1	Encke perturbations.
IPAT	SU	HER	Flag indicating whether analytic partials of current state with respect to time are to be evaluated. 1 - do not evaluate partials 2 - do evaluate partials.
NOMT	SU	NOMLL	Same as NZZ.
NOPT(72)	SU	INTEG	Array of program option flags.
RHBR	U	ALAN	$\dot{\beta}$, used in converting between time and β derivatives.
CHIND	S	HENRY	Flag indicating whether a change in the integration interval has occurred. 0 - no change $\neq$1 - a change has occurred.
DORHO	U	ALAN	Factor used in converting between time and β second derivatives. $(=R_k \cdot \dot{R}_k/r_k\sqrt{\mu})$
ITRIG	U	INTEG	Flag returned from CONTRL indicating whether any remarkable points or conditions were encountered. 1 - trajectory must be rectified 2 - no special conditions encountered 3 - end of trajectory encountered

TRAJL EXTERNAL VARIABLES TABLE (cont)

Variable	Use	Common	Description
RCIND	SU	HENRY	Rectification indicator. 0 - trajectory was not rectified 1 - trajectory was just rectified.
LERROR	SX		Error condition indicator. Always returned as .FALSE.

CHART TITLE - SUBROUTINE TRAJL(LERROR,NZZ)

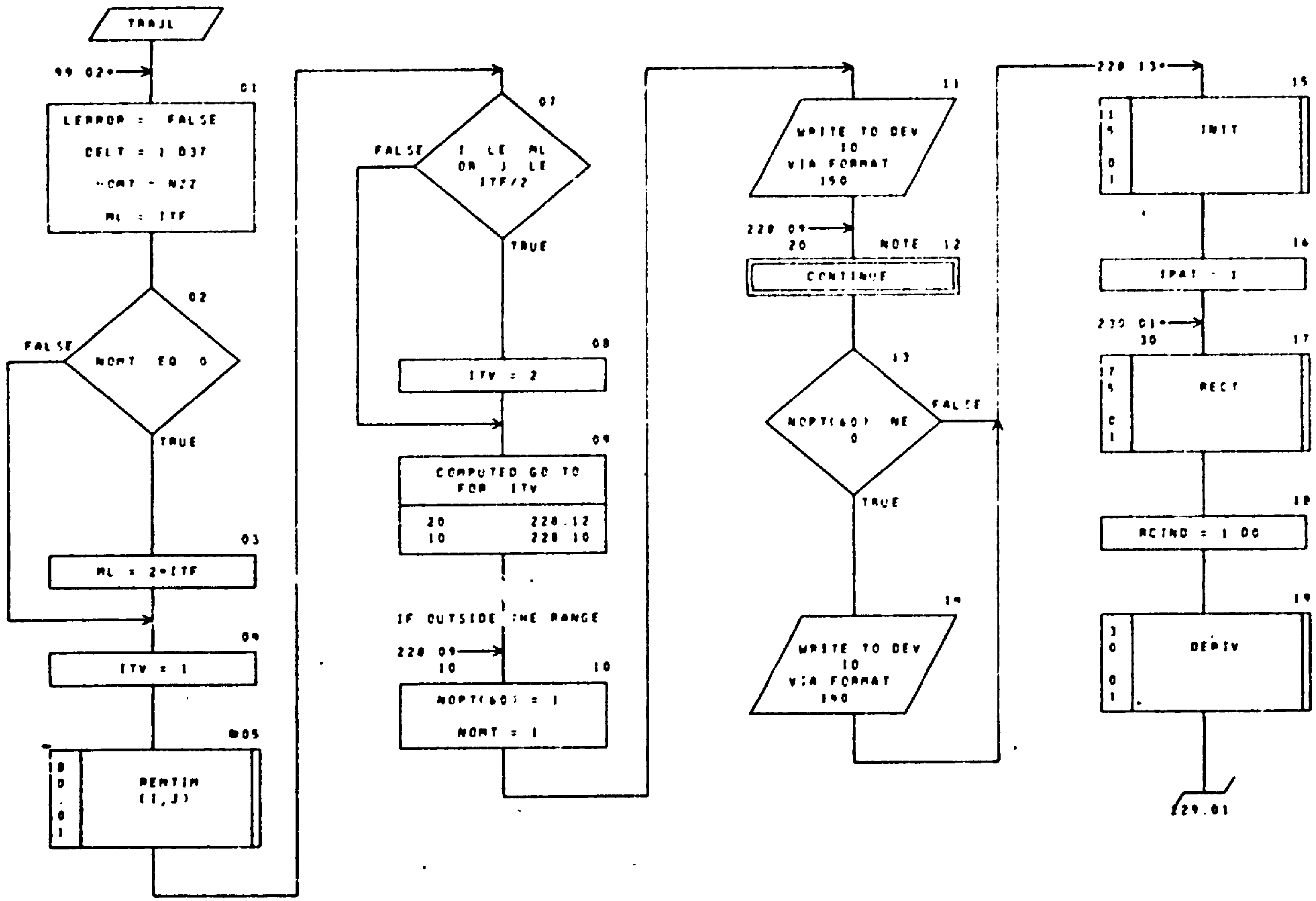

CHART TITLE - SUBROUTINE TRAJL(LERROR,NZZ)

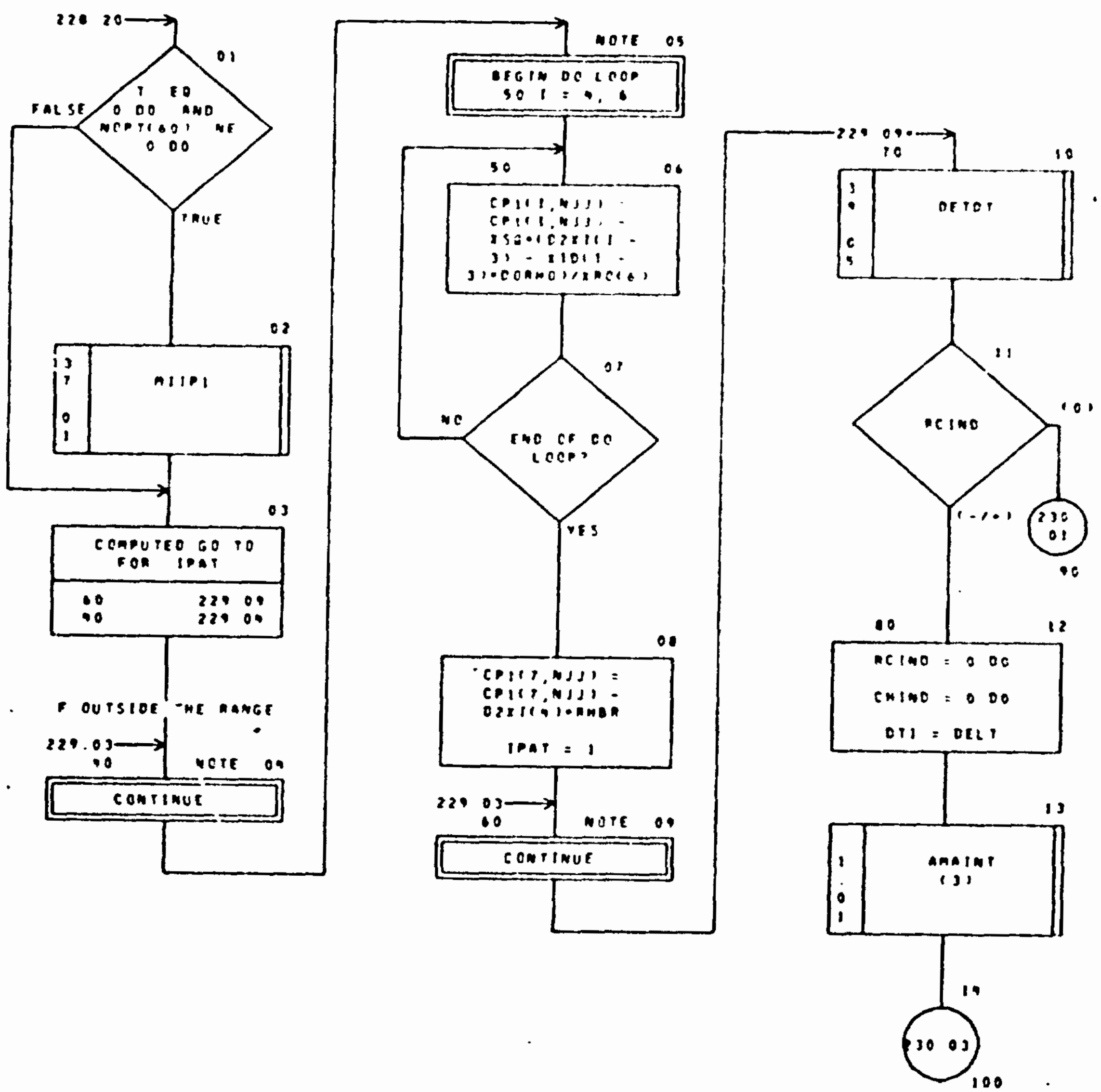

CHART TITLE - SUBROUTINE TRAJL(LERROR,NZZ)

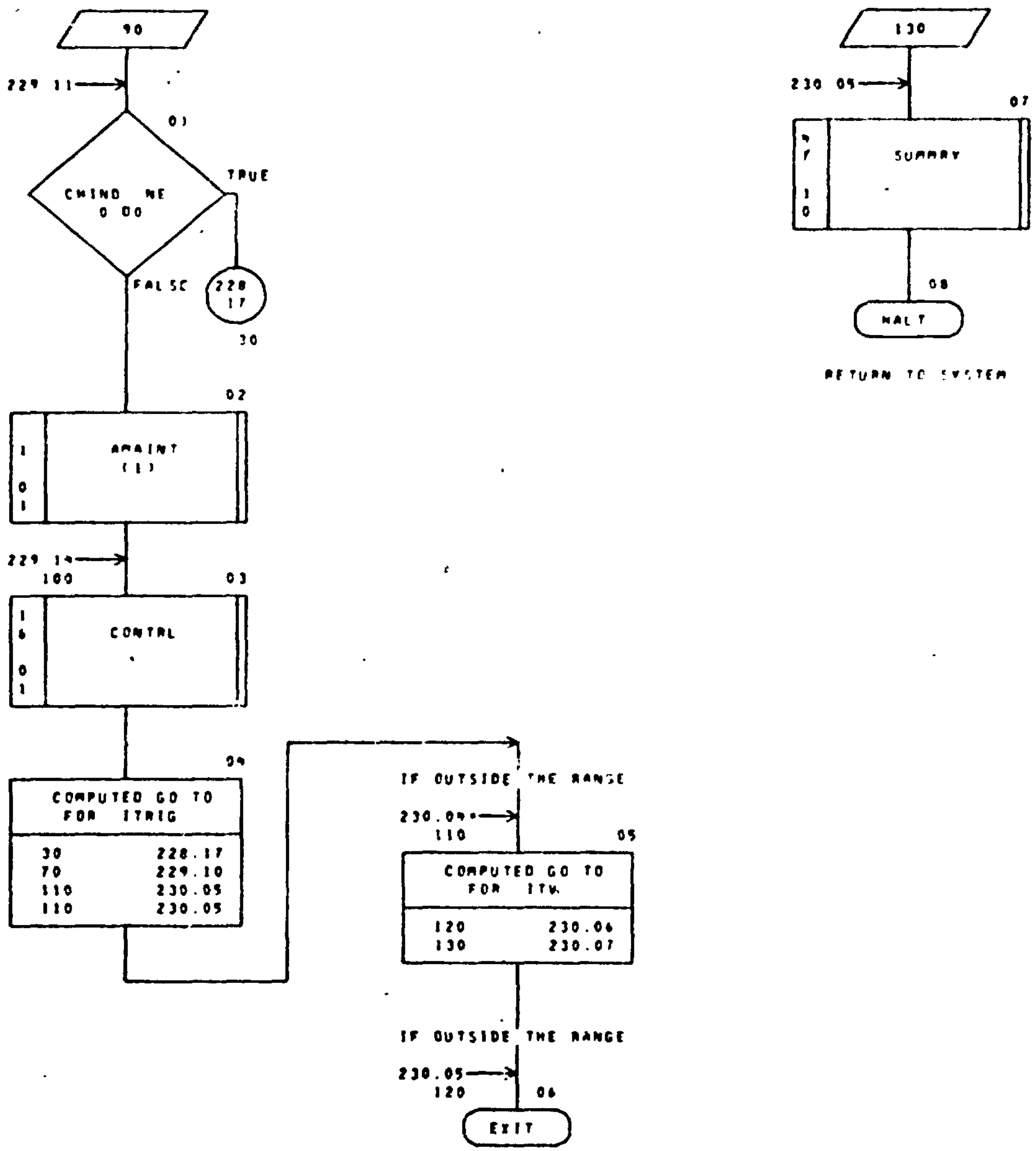

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
         IMPLICIT REAL*8(A-H,O-Z)
         REAL*8 KSOO,MEI,ME,KM,MDIST,INTV,IN1X,IN2X
         INTEGER DAY,HOURS,YEAR
         LOGICAL LERROR
         COMMON/ALAN/T,RHOR,DCPHO
         COMMON/AMI/ZELT,BETA,DTI,XI(80),XID(80),D2XI(80),IFST(80)
         COMMON/HENRY/ARRAY(8,3,12),CHIND,INTV(72),IN1X(3),
         IN2X(3),KSOO(12),KM(12),MDIST,MEI(12),ME(12),PCTRCS,PRVDT,
         PDT,PCIN,RO,REHM,RRM,RRE,RREV,RCINC,RATIO,SEC,TSCL,THTS,TP1,
         TIMEL,THET,VELRCS
         COMMON/HER/IPS,NSL,NTL1,IFTAG,ITCT,IPOFL(30),IVAR(100),ITMAX,NTP,
         NTPS,NMAX,NJ,JN,IPAT,NCT1,NJL
         COMMON/ILEF/IC(16),NJJ
         COMMON/INTEG/DAY,HOURS,YEAR,IDUMMY,ITRIG,IREFNC,IREFNB,
         IREFNT,IN,IO,IJK,MONTH,MIN,NCPT(72),NPLAN,NPLAN3
         COMMON/JERR/VBLCC(200),A,CA,BL,DSQ,DELP,AC (10),SUMA,XKS,ETV(3),
         ET(3),XXP,ER(3),CPI(7,30),TBIN(124),ETA,CR,XKK,XPT,XKST,APS,AL1,
         AL2,AL3
         @COMMON/LEON/XRO(6),XROOT(6),TMPDP,W
         COMMON/MINSEC/ITF
         COMMON/NCALL/NCMT
         COMMON/STEVE/CELT,XSQ,OIAD,ROOTD,T1,TM2DP,XRI(6),XRIDT(6),SQTMU
140      FORMAT ('1'40X,'FINAL TRAJECTORY'///39X,'TRAJECTORY ARC DATA'//)
140      FORMAT (1HO,'THIS CASE HAS TIMED OUT ')
```

<u>Name:</u> XYZ

<u>Calling Arguments:</u> RDOT, RP, RM, EMU, PEPS, IPS, QMIN, QMAX, QAVRG

<u>Referenced Sub-programs:</u> None

<u>Referenced Commons:</u> None

<u>Entry Points:</u> None

<u>Referencing Sub-programs:</u> MINMX3

<u>Discussion:</u> When periapse distance relative to the target planet r_{T_P} is specified as an end condition, a transformation is made internally in the program to convert to an equivalent set of end conditions that is more stable in the solution to the two point boundary value problem. Rather than attempt to terminate the trajectory at periapse, a final specified distance of r_T is assumed, and a specific set of Cartesian position coordinates are determined which have a magnitude of r_T and which, when combined with the velocity $\dot{R}_T$, yield a periapse distance, based on two-body computations, which is equal to the desired value r_{T_P}. Subroutine XYZ performs the computations for these Cartesian coordinates.

By forming the cross product of the velocity $\dot{R}_T$ and the angular momentum of the two body arc possessing the desired periapse distance, one may, after re-organizing the equation, obtain the following equation for R_T

$$R_T = \frac{1}{v_T^2}\left[(R_T \cdot \dot{R}_T)\dot{R}_T + \dot{R}_T \times H\right]$$

where $v_T = |\dot{R}_T|$ and H is the angular momentum vector $R_T \times \dot{R}_T$. The angular momentum vector is not uniquely specified at this point because only five of the required six conditions are given, namely the components of the velocity vector $\dot{R}_T$, the final distance r_T and the periapse distance r_{T_P}. Therefore, we arbitrarily choose H such that the direction $\dot{R}_T \times H$ will be directed along the vector $\dot{R}_T \times \bar{k}$, where $\bar{k}$ is directed along the ecliptic North

Pole. This results in a posigrade approach trajectory with an ecliptic inclination equal to the declination of the velocity vector $\dot{R}_T$. Thus, the desired position vector may be written

$$R_T = \frac{d}{v_T^2} \dot{R}_T - \frac{h}{v_T |\bar{k} \times \dot{R}_T|} (\bar{k} \times \dot{R}_T)$$

where

$$h = |H| = \sqrt{r_{T_P}^2 v_T^2 - 2\mu_T r_{T_P} (1 - r_{T_P}/r_T)}$$

and

$$d = R_T \cdot \dot{R}_T = -\sqrt{r_T^2 v_T^2 - h^2} .$$

XYZ EXTERNAL VARIABLES TABLE

Variable	Use	Common	Description
RM	UX		Final planetocentric distance, r_T.
RP	UX		Planetocentric periapse distance, r_{T_P}.
EMU	UX		Gravitational constant of target planet, μ_T.
IPS	UX		Total number of dependent parameters.
PEPS(3)	UX		Array of tolerances for the three Cartesian coordinates.
QMIN (30)	SX		Array of lowest permissible values of the dependent parameters.
QMAX (30)	SX		Array of largest permissible values of the dependent parameters.
RDOT(3)	UX		Final planetocentric velocity, $\dot{R}_T$.
QAVRG(30)	SX		Array of desired values of the dependent variables. The Cartesian coordinates are stored in locations IPS-2 through IPS of QAVRG.

CHART TITLE - SUBROUTINE XYZ(ROOT,RP,RM,EMU,PEPS,IPS,QMIN,QMAX,QAVRG)

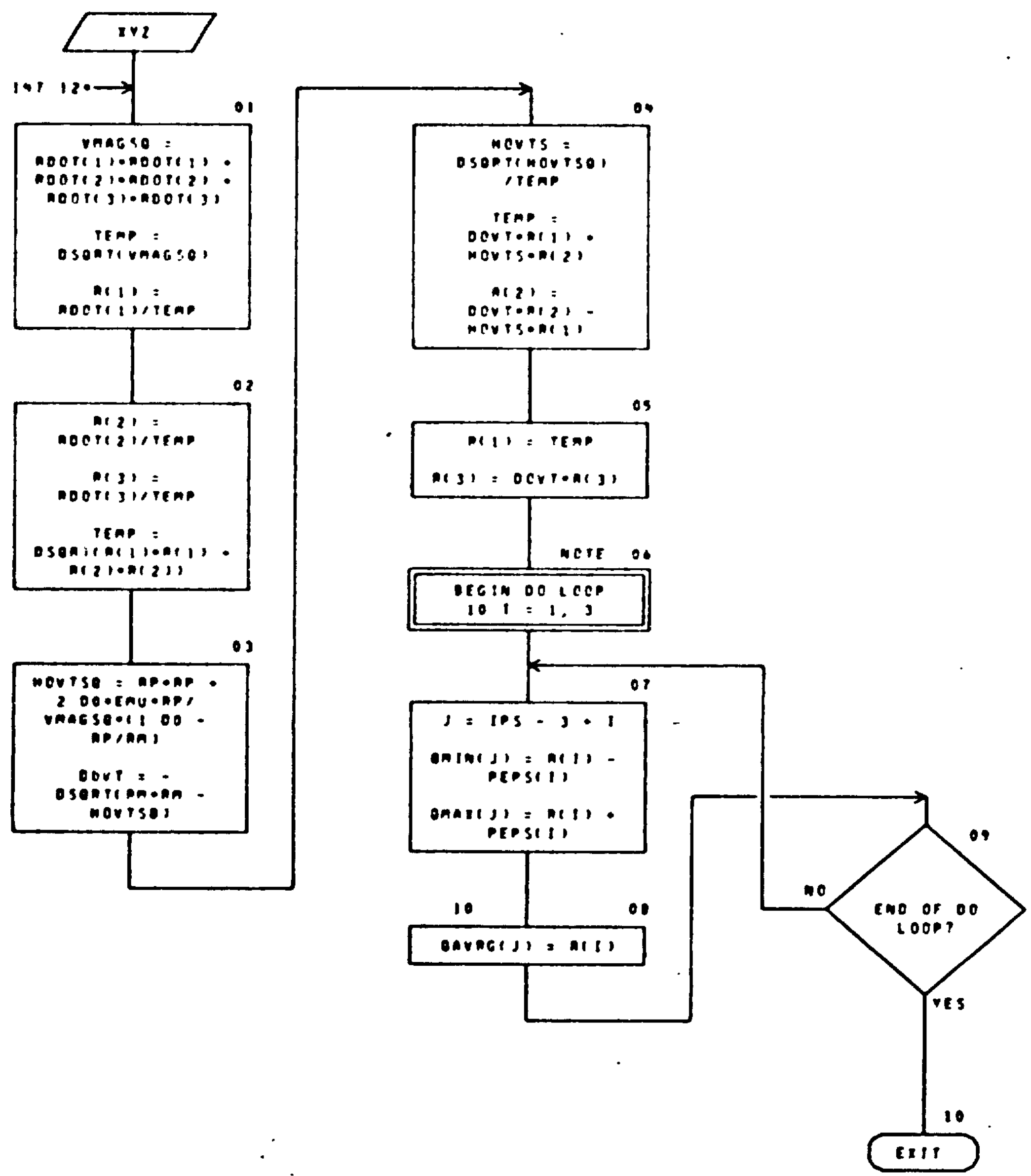

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
IMPLICIT REAL*8 (A-H,O-Z)
DIMENSION ROOT(3),PEPS(3),QMIN(30),QMAX(30),QAVRG(30),R(3)
```

```
      BLOCK DATA
      IMPLICIT REAL*8 (A-H,O-Z)
      INTEGER YEAR,DAY,HOURS
      INTEGER DAY,HOURS,YEAR
      REAL*8 KSQQ,MEI,ME,KM,MDIST,INTV,IN1X,IN2X
      COMMON/AM1/DE(243),IFST(80)
      COMMON/FNM/RTA,RTP
      COMMON/FRAN/XMDKM
      COMMON/HENRY/ARRAY(8,3,12),CHIND,INTV(72),IN1X(3),
     1IN2X(3),KSQQ(12),KM(12),MDIST,MEI(12),ME(12),POSRCS,PRVDT,
     2PDT,PCIN,RD,REKM,RRM,RRE,RREU,RCIND,RATIO,SEC,TSCL,THTS,TP1,
     3TIMEL,THET,VELRCS
      COMMON/HER/IPS,NSL,NSLI,IFTRG,ITCT,IPOFL(30),IVAR(100),ITMAX,
     1NTP,NTPS,NMAX,NJ,JN,IPAT,NCT1,NJL
      COMMON/HIS/PFG(30,30),WX(30),XVAR(30),YEPS(30),XEPS(30),
     1CHNS(100),CHN(100),POFL(30),XDAR(7)
      COMMON/INPR/ARCDTA(7,20),BX(4,100)
      COMMON/INTEG/
     1DAY,HOURS,YEAR,IDUMMY,ITRIG,IREFNO,IREFNB,IREFNT,IN,IO,
     2IJK,MONTH,MIN,NOPT(72),NPLAN,NPLAN3
      COMMON/JERR/VBL(568)
      COMMON/LAMB/XJLD,XINJ,RBRE,LOPT
      COMMON/LEON/XRO(6),XRODT(6),TMPDP,T
      COMMON/MINSEC/ITF
      COMMON/NPNT/NPR
      COMMON/ODBALL/SAI(8)
      COMMON/RSCAL/RLP,RPHAT(3),HCR(3),RDPML(3)
      COMMON/XMMM/B(120),WTOPT,MOPTM
      DATA BX/400*0.D0/,NPR/0/,WTOPT/1.D0/
      DATA TSCL/3600.D0/,REKM/6378.165D0/,MDIST/23454.87D0/,THTS/1.5D0/,
     1VELRCS/1.D-4/,POSRCS/1.D-4/,RRM/9.D0/,
     2RRE/123.3D0/,RREU/.00525690400330510D0/
      DATA MEI/
     11.0D0,0.12299971710C651D-1,0.3329513000D6,0.81501436887119900,
     20.107448704295350D0,0.317886408778844D3,0.951506915856434D2,
     30.145203358046228D2,0.172871910695742D2,0.163747958057395D0,
     40.304043689862058D-5,0.556495570783888D-1/
      DATA KSQQ/
     1.19909416500D2,0.244885259713903D0,0.513736472743055D-5,
     20.125749522569444D-11,0.166365434027778D-12,0.490492013838889D-9,
     30.146781857638889D-9,0.224643229166667D-10,0.271976562500000D-10,
     40.128435677083333D-11,0.518038265857472D-6,0.839438715277778D-13/
      DATA RTA,RTP/36.D0,2.D0/,SAI/1.D0,7*0.D0/,VBL/202*0.D0,
     1.769D0,2.04490B,0.D0,.627DC,5.3054D0,-10.0376D0,7.1073D0,
     2-2.0021D0,16*0.D0,1.D0,333*0.D0,2941.995D0,.1111111D0,.03D0,0.D0,
     3 .03D0,    138726.52D0,3776.8656D0,1999.2024D0/,IREFNB/1/,IREFNT/6/
     4,CHN(1),CHN(2),CHN(3)/
     51.025D0,0.D0,0.D0/,CHN(4),CHN(5),CHN(6)/0.D0,7.D0,0.D0/,XDAR/
     6.1D-8,.1D-8,.1D-8,.1D-9,.1D-9,.1D-9,.1D-2/,TIMEL/15000.D0/,XJLD/
     70.D0/,RBRE/123.4D0/
      DATA CHN(8),CHN(9),CHN(10),CHN(12),CHN(13),CHN(14)
     1      /3.D4,5.D4,4*0.D0/
      DATA RD/57.2957795130823200/,IN/5/,ITMAX/50/,NTPS/1/,NMAX/5/,
     1IO/6/,NOPT/72*0/,ARRAY/288*0.D0/,B/120*0.D0/,ITF/10/
      DATA XMDKM/14.9598D7/,RLP/1.025D0/
      DATA IFST/3*0,1,3*0,1,3*0,1,3*0,1,3*0,1,3*0,1,3*0,1,3*0,1,3*0,1,
     13*0,1,3*0,1,3*0,1,3*0,1,3*0,1,3*0,1,3*0,1,3*0,1,3*0,1,3*0,1,3*0,1/
      DATA ARCDTA/140*0.D0/
      END
```

VII. PROGRAM EXECUTION

ASTOP Program Machine Requirements. When compiled by the IBM 360/Model 91 computer at the Goddard Space Flight Center under their Fortran H, Level 21 compiler with compiler optimization level equal to two, the ASTOP program occupies about 290K (decimal) bytes in core. This includes the core requirements for the following IBM library subroutine which must be accessible to the program:

IHCLASCN	IHCEFNTH
IHCLATN2	IHCLEXP
IHCLSCN	IHCLLOG
IHCLSQRT	IHCEFIOS
IHCFDXPD	IHCERRM
IHCNAMEL	IHCUOPT
IHCECOMH	IHCETRCH
IHCCOMH2	IHCUATBL
IHCFCVTH	IHCFIOS2

The program is written entirely in double precision Fortran IV using the Fortran statement IMPLICIT REAL *8 (A-H, O-Z). This results in the assignment of an 8-byte word location to each real variable name commencing with the letters A-H or O-Z, unless the name is specifically declared to be of another type. An 8-byte word contains 15 hexadecimal digits. As in standard Fortran IV, names commencing with the letters I-N represent integer variables of 4-byte word length, unless specifically declared otherwise through type statements.

The only peripheral equipment referenced by the ASTOP program are the card reader, assigned to UNIT 5, and the high-speed printer, assigned to UNIT 6. No magnetic tapes are employed by the program for either input or output. Of course, temporary data storage assignments are made as required on the disk and drum storage areas. The region size required to execute the program is 312K bytes if the linkage editor is used and 336K bytes if the loader is used.

Deck Set-up. The organization and job control cards of the deck for a batch submittal of an ASTOP run is very simple. Basically all that is required is the linkage editor or loader job control cards, the program object deck, and the input data. A typical deck organization for the IBM 360/91 at GSFC is, using the linkage editor:

```
// JOB CARD
// EXEC LINKGO, REGION.GO=312K
//LINK.SYSLIN DD *
        .
        .
        .
        .
  object deck
        .
        .
        .
        .
  ENTRY MAIN
/*
//GO.DATA5 DD *
        .
        .
        .
        .
  Input Data
        .
        .
        .
        .
/*
```

If the loader is used (which is recommended), the ENTRY MAIN card is removed and the EXEC LINKGO card is replaced with

```
// EXEC LOADER,PARM='EP=MAIN,SIZE=312K',REGION.GO=336K
```

The control cards will change somewhat at different IMB 360/370 installations.

VIII. EXAMPLE CASE

The example case presented here is a 600 day (approximate) Earth-Jupiter flyby mission launched from a 1.025 Earth radii circular parking orbit inclined 28.5 degrees to the equator at 12 noon on November 26, 1980, using the SLV3C/Centaur/TE364-4 launch vehicle. A small solar electric propulsion system with a reference power of 1500 watts and a jet exhaust speed of 24000 m/sec is assumed. In addition, a tankage factor of 0.03 and a specific propulsion system mass of 0.03 kg/watt are specified. The constrained mode option is invoked such that the solar array is continuously oriented normal to the sun-spacecraft line with the thrust vector normal to the heliocentric radius vector (i.e., circumferential thrust). The trajectory is divided into three arcs - a 12-hour coasting arc following the assumed impulsive launch vehicle Earth departure maneuver, a long duration low thrust arc, and a final coast arc to the target. The required end conditions are that, at 13650 hours into the mission (568.75 days), the distance of the spacecraft from Jupiter must be 0.2 AU and the predicted (two-body) perijove distance at that time is to be 0.01 AU (about 21.4 Jupiter radii). A total of five parameters are left unspecified. These include the longitude of ascending node of the launch parking orbit, the argument of perigee of the escape hyperbola, the speed at departure of the launch parking orbit, the angle between the thrust vector and its projection in the ecliptic plane, and the end time of the low thrust arc. The performance index of the problem is net spacecraft mass.

The use of an iterative trajectory optimization program such as ASTOP is facilitated by good first guesses of the independent parameters. To obtain such guesses for this sample case, an optimum 600 day Earth-Jupiter flyby trajectory was generated using an available heliocentric two-body low thrust trajectory optimization program. This latter program has the capability of generating optimal trajectories subject to the fixed thrust angle constraint; therefore, the heliocentric two-body low thrust solution may be expected to possess most of the salient features of the n-body solution. The two-body program solution yields directly the burn time, a (variable) out-of-plane thrust angle, and the hyperbolic excess velocity. The burn time from this solution was about

5993 hours; therefore, the estimated input burn time for the check case was 6,000 hours. The optimal out-of-plane thrust angle varied over the range of -2 degrees at the initial time to -39 degrees at engine shutdown. The estimated constant value required by ASTOP was obtained simply by "eyeballing" a time-average value of the variable angle and slightly biasing that value to a smaller absolute value to account for the greater propulsive force at the smaller heliocentric distances. The value chosen for input was -10 degrees. The geocentric position and velocity at launch was computed using the hyperbolic excess velocity from the heliocentric two-body solution and the specified launch parking orbit radius and inclination, assuming the departure point coincides with perigee of the escape hyperbola. To do this requires the use of the vis-viva integral and conic equation for a hyperbolic trajectory in conjunction with standard spherical trigonometry equations. There will generally exist two equally valid solutions, one with a northerly heading and one with a sourtherly heading. One of these was arbitrarily selected and is represented by the two vectors POS and VEL contained in the input data set presented below. Using these inputs, a trajectory was integrated with ASTOP for the 600 day flight. This trajectory terminated surprisingly close to Jupiter, slightly past the perijove point. The perijove distance was about 0.023 AU (the sphere of influence radius is 0.3 AU) compared to the desired value of 0.01 AU. Since the problem was to terminate at about 0.2 AU from Jupiter, the flight time was reduced from 600 days by an amount equal to the time spent on this trajectory from a distance of 0.2 AU on the approach leg to the final time. This time interval was found to be about 750 hours. Hence, the final flight time selected is 13650 hours. Note that this is not the time to closest approach.

The namelist data set required to generate the example case are reproduced below. The data set contains all input data, exclusive of the default data, that are required to run the example case. The necessary control information for the independent parameters is contained in the BX array and for the dependent parameters in the BY array. The weights for the independent parameters were obtained as suggested in the Section III using uncertainties of 5 degrees each for the longitude of node and argument of perigee, 0.01 km/sec for departure speed, 10 degrees for out-of-plane thrust angle and 1000 hours for burn time. Of the five independent parameters, only one - the out-of-plane thrust angle - uses the specified perturbation step size to form partial derivatives. The othér four employ analytic partials in conjunction with the state transition matrix which is formed by finite differences using the perturbation step sizes input through XDAR. Note that the portion of the BY array pertaining to the final planetocentric Cartesian position coordinate are initialized in anticipation of the automatic transformation of end conditions from the periapse distance to the final position vector. The settings of BTA, EPSLON, and NOPT (63) - NOPT (65) force the program to operate in the constrained mode with the arrays continually facing the sun squarely and the thrusters pointing normal to the sun-spacecraft line.

From the output, it is seen that the first nominal trajectory results in a perijove distance of about .023 AU which is very close to the desired value considering the approximate nature of the method used to obtain the first guesses. After five iterations, the message "ITERATOR IS NOW IN THE OPTIMIZE MODE" is printed. This signifies that a trajectory satisfying the end conditions to the specified tolerances has been found. At this point the iterator commences trying to improve the performance index. After 28 more iterations, the converged case is printed. The machine time (CPU) required to generate this example case was 14 minutes on the IBM 360/91.

```
&MINPUT
BX(1,2)=3*1.D0,4.D-2,BX(1,3)=3*1.D0,4.D-2,BX(1,5)=2*1.D0,.1D0,1.D4
BX(1,21)=1.D0,1.D-3,3.D0,1.D-2,BX(1,24)=1.D0,1.D0,2.4D2,1.D-6
BY(1,2)=1.D0,5.D2,1.D0,BY(1,11)=1.D0,.2D0,1.D-6
BY(1,17)=1.D0,1.D-2,1.D-6,BY(1,18)=0.D0,.1D0,1.D-8
BY(1,19)=0.D0,.1D0,1.D-8,BY(1,20)=0.D0,.1D0,1.D-8
ARCDTA(1,1)=12.D0,ARCDTA(1,2)=6.D3,1.D0,-1.D1,ARCDTA(1,3)=1.365D4,-1.D0
POS= .6469314278D0, .380630192 2D0,-.69801531D0
VEL=-5.54040599D0,5.14887785D0,-2.32723 32D0
XDAR=3*1.D-9,3*1.D-10,1.D-3,CF=2.4D4,P0=1.5D3,BTA=270.D0,EPSLON=90.D0
ARRAY(2,1,3)=1.D1,ARRAY(2,1,6)=2.D0
AL1=153208.05D0,AL2=2385.1258D0,AL3=53.34D0,XJLD=4570.D0
NOPT=2,1,1,NOPT(6)=1,NOPT(10)=1,1,1,NOPT(16)=1,NOPT(63)=3,1,2,NARCS=3
MOPT=2,WTOPT=1.D9,NPR=0
&END
```

```
&MINPUT
ALPHA= 0.0               ,AL1=  153208.0500000000    ,AL2=  2385.125800000000    ,AL3=  53.34000000000000    ,AD=
 0.6270000000000000     , 5.305400000000000       , -10.03760000000000      , 7.107300000000000       , -2.002100000000000      ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,APS=
 0.2999999999999999D-01,ARCOTA=  12.00000000000000 , 0.0                  , 0.0                  , 0.0                  ,
 0.0                    , 0.0                     , 0.0                     , 6000.000000000000       , 1.000000000000000       ,
 -10.00000000000000     , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 13650.00000000000      , -1.000000000000000      , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    ,ARRAY= 0.0                  , 400.0000000000000      , 0.0                  , 0.0                  ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.3906250000000000D-02,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 400.0000000000000       , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.3906250000000000D-02, 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 10.00000000000000      , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.3906250000000000D-02, 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 400.0000000000000       ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.3906250000000000D-02, 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 400.0000000000000       , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.3906250000000000D-02, 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 2.000000000000000       , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.3906250000000000D-02,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    , 0.0                     , 0.0                     , 0.0                     , 0.0                     ,
 0.0                    ,
```

0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
400.0000000000000	0.0	0.0	0.0	0.0
0.0	0.0	0.3905250000000000D-02	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	400.0000000000000
0.0	0.0	0.0	0.0	0.0
0.0	0.3906250000000000D-02	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	400.0000000000000	0.0
0.0	0.0	0.0	0.0	0.0
0.3906250000000000D-02	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	400.0000000000000	0.0	0.0
0.0	0.0	0.0	0.0	0.3906250000000000D-02
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	400.0000000000000	0.0	0.0	0.0
0.0	0.0	0.0	0.3906250000000000D-02	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	BL= 0.7690000000000000 ,BTA=
270.0000000000000	BX= 0.0	0.0	0.0	0.0
1.000000000000000	1.000000000000000	1.000000000000000	0.3999999999999999D-01	1.000000000000000
1.000000000000000	1.000000000000000	0.3999999999999999D-01	0.0	0.0
0.0	0.0	1.000000000000000	1.000000000000000	0.1000000000000000D 00
10000.00000000000	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	1.000000000000000	0.9999999999999999D-03	3.000000000000000	0.9999999999999999D-02
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	1.000000000000000	1.000000000000000
240.0000000000000	0.9999999999999999D-06	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0

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0.0                   , 0.0                   , 0.0                   , 0.0                   , 0.0                   ,
0.0                   , 0.0                   , 0.0                   , 0.0                   , 0.0                   ,
0.0                   , 0.0                   , 0.0                   , 0.0                   , 0.0                   ,
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OPTIONS NOPT(I)

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2	1	1	0	0	1	0	0	0	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
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TRAJECTORY SUMMARY ITERATION NO. 1

INDEPENDENT PARAMETERS

** NAME APPLIES TO PARAMETERS, USED IN THE ITERATION

X (TO)	Y (TO)	Z (TO)	XDOT	YDOT	ZDOT	MSS TO	
6.469314280-01	3.806301920-01	-6.980153100-01	-5.540405990 00	5.148877850 00	-2.327233200 00	3.755875690 02	
C	PO	ALPHA	TO	BETA	DELTA	EPSLON	T1
2.400000000D 04	1.500000000D 03	0.0	0.0	2.700000000D 02	0.0	9.000000000D 01	1.200000000D 01
THETA **	PSI	PHI	T2 **	THETA	PSI	PHI	T3
-1.000000000D 01	0.0	0.0	6.000000000D 03	0.0	0.0	0.0	1.365000000D 04
DL OMS **	DL OML **	DL INC	DL VPO **	VPO0			
0.0	0.0	0.0	0.0	7.913473070 00			

DEPENDENT PARAMETERS

FINAL MASS	NET S/C **	THRUST	DST.FR.SUN	VL.WRT.SUN	SM.AXIS SN	FL.P.A.SUN	ECCENT.SUN
3.455855530 02	2.996854930 02	7.024005050-02	5.255303180 00	3.034182530-04	4.966084270 00	5.217940810 01	7.907414990-01
APCEN. SUN	PRICEN.SUN	DST.FR.TRG	VL.WRT.TRG	SM.AX.TRGT	FL.P.A.TGT	ECCENT.TRG	APCNT.TRGT
8.892973190 00	1.039195350 00	2.019225220-01	2.665389250-04	-7.410948870-03	-9.190946020 01	4.096780510 00	-3.777197980-02
PCENT.TRGT	X TARGET **	Y TARGET **	Z TARGET **				
2.295008200-02	1.975834910-01	3.255871050-02	-2.594993730-02				

TRAJECTORY TERMINATED IN JUPITER REFERENCE   INHIBITOR IS 5.820766090-11   TRAJ. COUNTER IS 1

SPACECRAFT MASS BREAKDOWN (KG)

INITIAL	PROPULSION	PROPELLANT	TANKAGE	STRUCTURE	RETRO PROP	RETRO STR	NET S/C
3.755875690 02	4.500000000D 01	3.000201580 01	9.000604740-01	0.0	0.0	0.0	2.996854930 02

PARTIAL DERIVATIVE MATRIX BY ROWS

-4.070080 00	-5.018960 00	-3.221790 02	1.756670-01	-1.759290-03
1.572570 00	1.605220 00	-3.646560 00	-1.598080-01	3.910290-06
-1.331120 00	-1.941240 00	4.831490-01	-4.929960-02	-1.953520-05
3.979710-01	-2.245440-02	3.377440-02	-3.074170-01	3.727270-06

TRAJECTORY SUMMARY ITERATION NO. 2

INDEPENDENT PARAMETERS

** NAME APPLIES TO PARAMETERS, USED IN THE ITERATION

X (TO)	Y (TO)	Z (TO)	XDOT	YDOT	ZDOT	MSS TO	
6.50039625D-01	3.72732141D-01	-6.99377807D-01	-5.47537400D 00	5.22821770D 00	-2.30259055D 00	3.75731574D 02	
C	PO	ALPHA	TO	BETA	DELTA	EPSLON	T1
2.40000000D 04	1.50000000D 03	0.0	0.0	2.70000000D 02	0.0	9.00000000D 01	1.20000000D 01
THETA **	PSI	PHI	T2 **	THETA	PSI	PHI	T3
-1.24222479D 01	0.0	0.0	5.97130092D 03	0.0	0.0	0.0	1.36500000D 04
DL OMS **	DL OML **	DL INC	DL VPO **	VP00			
2.60347703D-01	-9.65859400D-01	0.0	-4.51896719D-04	7.91302117D 00			

DEPENDENT PARAMETERS

FINAL MASS	NET S/C **	THRUST	DST.FR.SUN	VL.WRT.SUN	SM.AXIS SN	FL.P.A.SUN	ECCENT.SUN
3.45831317D 02	2.99934309D 02	7.09400505D-02	5.24437931D 00	3.03082555D-04	4.93693379D 00	5.19456664D 01	7.88361667D-01
APCEN. SUN	PRICEN.SUN	DST.FR.TRG	VL.WRT.TRG	SM.AX.TRGT	FL.P.A.TGT	ECCENT.TRG	APCNT.TRGT
8.82902315D 00	1.04484444D 00	1.97651545D-01	2.66782895D-04	-7.43813555D-03	-8.61427123D 01	2.11255424D 00	-2.30582236D-02
PCENT.TRGT	X TARGET **	Y TARGET **	Z TARGET **				
8.24195258D-03	1.87397965D-01	6.18644818D-02	-1.09961108D-02				

TRAJECTORY TERMINATED IN JUPITER REFERENCE   INHIBITOR IS 2.50000000D-01   TRAJ. COUNTER IS 3

SPACECRAFT MASS BREAKDOWN (KG)

INITIAL	PROPULSION	PROPELLANT	TANKAGE	STRUCTURE	RETRO PROP	RETRO STR	NET S/C
3.75731574D 02	4.50000000D 01	2.99002571D 01	8.97007714D-01	0.0	0.0	0.0	2.99934309D 02

PARTIAL DERIVATIVE MATRIX BY ROWS

-3.98652D 00	-4.86339D 00	-3.22332D 02	2.11270D-01	-1.77029D-03
1.52445D 00	1.50408D 00	-3.62823D 00	-1.94194D-01	3.68891D-06
-1.32319D 00	-1.92761D 00	4.97183D-01	-5.99277D-02	-1.95675D-05
3.99825D-01	-2.08270D-02	4.70561D-02	-3.02346D-01	4.63978D-06

TRAJECTORY SUMMARY ITERATION NO. 3

INDEPENDENT PARAMETERS

** NAME APPLIES TO PARAMETERS, USED IN THE ITERATION

X (TO)	Y (TO)	Z (TO)	XDOT	YDOT	ZDOT	MSS TO	
6.49485312D-01	3.72347175D-01	-7.00106134D-01	-5.47109660D 00	5.23865974D 00	-2.28935597D 00	3.75697329D 02	
C	PO	ALPHA	TO	BETA	DELTA	EPSLON	T1
2.40000000D 04	1.50000000D 03	0.0	0.0	2.70000000D 02	0.0	9.00000000D 01	1.20000000D 01
THETA **	PSI	PHI	T2 **	THETA	PSI	PHI	T3
-1.32764469D 01	0.0	0.0	5.97896835D 03	0.0	0.0	0.0	1.36500000D 04
DL OMS **	DL OML **	DL INC	DL VPO **	VPOC			
1.40700163D-01	-1.82502851D-01	0.0	1.07449765D-04	7.91312862D 00			

DEPENDENT PARAMETERS

FINAL MASS	NET S/C **	THRUST	DST.FR.SUN	VL.WRT.SUN	SM.AXIS SN	FL.P.A.SUN	ECCENT.SUN
3.45786875D 02	2.99889561D 02	7.09400505D-02	5.24086135D 00	3.02319912D-04	4.92318187D 00	5.18623242D 01	7.87537925D-01
APCEN. SUN	PRICEN.SUN	DST.FR.TRG	VL.WRT.TRG	SM.AX.TRGT	FL.P.A.TGT	ECCENT.TRG	APCNT.TRGT
8.80037431D 00	1.04598943D 00	2.00128970D-01	2.65357271D-04	-7.42509790D-03	-8.56251455D 01	2.35365556D 00	-2.49045145D-02
PCENT.TRGT	X TARGET **	Y TARGET **	Z TARGET **				
1.00523787D-02	1.83998845D-01	6.55687204D-02	-5.40007721D-03				

551

TRAJECTORY TERMINATED IN JUPITER REFERENCE   INHIBITOR IS 3.90625000D-03   TRAJ. COUNTER IS 5

SPACECRAFT MASS BREAKDOWN (KG)

INITIAL	PROPULSION	PROPELLANT	TANKAGE	STRUCTURE	RETRO PROP	RETRO STR	NET S/C
3.75697329D 02	4.50000000D 01	2.99104542D 01	8.97313627D-01	0.0	0.0	0.0	2.99889561D 02

PARTIAL DERIVATIVE MATRIX BY ROWS

-3.99303D 00	-4.84922D 00	-3.22301D 02	2.24669D-01	-1.76915D-03
1.52843D 00	1.49365D 00	-3.62496D 00	-2.06410D-01	3.68293D-06
-1.32262D 00	-1.92572D 00	4.99118D-01	-6.38873D-02	-1.94715D-05
3.98808D-01	-2.10283D-02	5.23979D-02	-5.00916D-01	4.93738D-06

TRAJECTORY SUMMARY ITERATION NO. 4

INDEPENDENT PARAMETERS

** NAME APPLIES TO PARAMETERS, USED IN THE ITERATION

X (TO)	Y (TO)	Z (TO)	XDOT	YDOT	ZDOT	MSS TO	
6.49505119D-01	3.72352753D-01	-7.00086792D-01	-5.47119703D 00	5.23842978D 00	-2.28975430D 00	3.75686984D 02	
C	PO	ALPHA	TO	BETA	DELTA	EPSLON	T1
2.40000000D 04	1.50000000D 03	0.0	0.0	2.70000000D 02	0.0	9.00000000D 01	1.20000000D 01
THETA **	PSI	PHI	T2 **	THETA	PSI	PHI	T3
-1.32732917D 01	0.0	0.0	5.99063541D 03	0.0	0.0	0.0	1.36500000D 04
DL OMS **	DL OML **	DL INC	DL VPO **	VPOO			
-4.12310876D-03	4.79958350D-03	0.0	3.24608275D-05	7.91316108D 00			

DEPENDENT PARAMETERS

FINAL MASS	NET S/C **	THRUST	DST.FR.SUN	VL.WRT.SUN	SM.AXIS SN	FL.P.A.SUN	ECCENT.SUN
3.45773753D 02	2.99876356D 02	7.09400505D-02	5.24099865D 00	3.02334051D-04	4.92382831D 00	5.18653576D 01	7.87566950D-01
APCEN. SUN	PRICEN.SUN	DST.FR.TRG	VL.WRT.TRG	SM.AX.TRGT	FL.P.A.TGT	ECCENT.TRG	APCNT.TRGT
8.80167275D 00	1.04598387D 00	1.99999692D-01	2.66388133D-04	-7.42526438D-03	-8.56394450D 01	2.34639011D 00	-2.48476[illegible]C5D-02
PCENT.TRGT	X TARGET **	Y TARGET **	Z TARGET **				
9.99722174D-03	1.88890704D-01	6.55027836D-02	-5.43726959D-03				

TRAJECTORY TERMINATED IN JUPITER REFERENCE INHIBITOR IS 6.10351563D-05 TRAJ. COUNTER IS 7

SPACECRAFT MASS BREAKDOWN (KG)

INITIAL	PROPULSION	PROPELLANT	TANKAGE	STRUCTURE	RETRO PROP	RETRO STR	NET S/C
3.75686984D 02	4.50000000D 01	2.99132310D 01	8.97396930D-01	0.0	0.0	0.0	2.99876356D 02

PARTIAL DERIVATIVE MATRIX BY ROWS

-3.99313D 00	-4.84975D 00	-3.22292D 02	2.24912D-01	-1.76749D-03
1.52831D 00	1.49388D 00	-3.62498D 00	-2.06362D-01	3.68559D-06
-1.32262D 00	-1.92579D 00	4.99063D-01	-6.38770D-02	-1.94600D-05
3.98851D-01	-2.10064D-02	5.23393D-02	-3.00970D-01	4.93336D-06

TRAJECTORY SUMMARY ITERATION NO. 5

INDEPENDENT PARAMETERS

** NAME APPLIES TO PARAMETERS, USED IN THE ITERATION

X (TO)	Y (TO)	Z (TO)	XDOT	YDOT	ZDOT	MSS TO	
6.495055800-01	3.723518740-01	-7.090868320-01	-5.471189570 00	5.238437260 00	-2.289753440 00	3.756871310 02	
C	**PO**	**ALPHA**	**TO**	**BETA**	**DELTA**	**EPSLON**	**T1**
2.40000000D 04	1.50000000D 03	0.0	0.0	2.70000000D 02	0.0	9.00000000D 01	1.20000000D 01
THETA **	**PSI**	**PHI**	**T2 ****	**THETA**	**PSI**	**PHI**	**T3**
-1.327322630 01	0.0	0.0	5.980610280 03	0.0	0.0	0.0	1.36500000D 04
DL OMS **	**DL OML ****	**DL INC**	**DL VPO ****	**VPOO**			
7.678832430-06	-8.555972640-05	0.0	-4.602622430-07	7.913160620 00			

DEPENDENT PARAMETERS

FINAL MASS	NET S/C **	THRUST	DST.FR.SUN	VL.WRT.SUN	SM.AXIS SN	FL.P.A.SUN	ECCENT.SUN
3.457739470 02	2.998765520 02	7.094005050-02	5.240997340 00	3.028339580-04	4.923823260 00	5.186532760 01	7.975666540-01
APCEN. SUN	**PRICEN.SUN**	**DST.FR.TRG**	**VL.W.T.TRG**	**SM.AX.TRGT**	**FL.P.A.TGT**	**ECCENT.TRG**	**APCNT.TRGT**
8.801662270 00	1.045984250 00	2.000000030-01	2.663880910-04	-7.425206320-03	-8.553858230 01	2.346772130 00	-2.485047350-02
PCENT.TRGT	**X TARGET ****	**Y TARGET ****	**Z TARGET ****				
1.000006090-02	1.888900200-01	6.550567360-02	-5.437576990-03				

TRAJECTORY TERMINATED IN JUPITER REFERENCE   INHIBITOR IS 9.536743160-07   TRAJ. COUNTER IS 9

SPACECRAFT MASS BREAKDOWN (KG)

INITIAL	PROPULSION	PROPELLANT	TANKAGE	STRUCTURE	RETRO PROP	RETRO STR	NET S/C
3.756871310 02	4.50000000D 01	2.991318380 01	8.973955130-01	0.0	0.0	0.0	2.998765520 02

PARTIAL DERIVATIVE MATRIX BY ROWS

-3.993110 00	-4.849730 00	-3.222920 02	2.249090-01	-1.767500-03
1.528300 00	1.493870 00	-3.624980 00	-2.063010-01	3.685530-06
-1.322610 00	-1.925780 00	4.990640-01	-6.387660-02	-1.946010-05
3.988520-01	-2.100640-02	5.233900-02	-3.009700-01	4.933400-06

ITERATOR IS NOW IN OPTIMIZE MODE.

TRAJECTORY SUMMARY ITERATION NO. 6

INDEPENDENT PARAMETERS

** NAME APPLIES TO PARAMETERS USED IN THE ITERATION

X (TO)	Y (TO)	Z (TO)	XDOT	YDOT	ZDOT	MSS TO	
6.49505568D-01	3.72351894D-01	-7.00086832D-01	-5.47118974D 00	5.23843710D 00	-2.28975344D 00	3.75687127D 02	
C	PC	ALPHA	TO	BETA	DELTA	EPSLON	T1
2.40000000D 04	1.50000000D 03	0.0	0.0 **	2.70000000D 02	0.0	9.00000000D 01	1.20000000D 01
THETA **	PSI	PHI	T2 **	THETA	PSI	PHI	T3
-1.32732301D 01	0.0	0.0	5.98061035D 03	0.0	0.0	0.0	1.36500000D 04
DL OMS **	DL OML **	DL INC	DL VPO **	VPDD			
9.19198102D-08	1.70624049D-06	0.0	1.21754374D-03	7.91316263D 00			

DEPENDENT PARAMETERS

FINAL MASS	NET S/C **	THRUST	DST.FR.SUN	VL.WRT.SUN	SM.AXIS SN	FL.P.A.SUN	ECCENT.SUN
3.45773942D 02	2.99876546D 02	7.09400505D-02	5.24099735D 00	3.02833960D-04	4.92382336D 00	5.18653282D 01	7.87566660D-01
APCEN. SUN	PRICEN.SUN	DST.FR.TRG	VL.WRT.TRG	SM.AX.TRGT	FL.P.A.TGT	ECCENT.TRG	APCNT.TRGT
8.80166247D 00	1.04598424D 00	2.00000000D-01	2.66388091D-04	-7.42520630D-03	-8.55386013D 01	2.34676374D 00	-2.48554112D-02
PCENT.TRGT	X TARGET **	Y TARGET **	Z TARGET **				
9.99999862D-03	1.88890039D-01	6.55056114D-02	-5.43765333D-03				

TRAJECTORY TERMINATED IN JUPITER REFERENCE INHIBITOR IS 9.53574316D-07 TRAJ. COUNTER IS 10

SPACECRAFT MASS BREAKDOWN (KG)

INITIAL	PROPULSION	PROPELLANT	TANKAGE	STRUCTURE	RETRO PRUP	RETRO STR	NET S/C
3.75687127D 02	4.50000000D 01	2.99131850D 01	8.97395553D-01	0.0	0.0	0.0	2.99876546D 02

PARTIAL DERIVATIVE MATRIX BY ROWS

-3.99312D 00	-4.84973D 00	-3.22292D 02	2.24909D-01	-1.76750D-03
1.52830D 00	1.49387D 00	-3.62498D 00	-2.06361D-01	3.68553D-06
-1.32261D 00	-1.92578D 00	4.99064D-01	-6.38766D-02	-1.94601D-05
3.98852D-01	-2.10064D-02	5.23390D-02	-3.00970D-01	4.93340D-06

TRAJECTORY SUMMARY ITERATION NO. 7

INDEPENDENT PARAMETERS

** NAME APPLIES TO PARAMETERS, USED IN THE ITERATION

X (TO)	Y (TO)	Z (TO)	XDOT	YDOT	ZDOT	MSS TO	
6.511941060-01	3.716034310-01	-6.985149560-01	-5.466797090 03	5.233502580 00	-2.310951160 00	3.757313290 02	
C	PO	ALPHA	TO	BETA	DELTA	EPSLON	T1
2.400000000 04	1.500000000 03	0.0	0.0	2.700000000 02	0.0	9.000000000 01	1.200000000 01
THETA **	PSI	PHI	T2 **	THETA	PSI	PHI	T3
-1.359268040 01	0.0	0.0	5.970146040 03	0.0	0.0	0.0	1.365000000 04
DL DMS **	DL DML **	DL INC	DL VPO **	VPOO			
-2.253367440-01	1.690561450-01	0.0	-1.386930230-04	7.913021940 00			

DEPENDENT PARAMETERS

FINAL MASS	NET S/C **	THRUST	DST.FR.SUN	VL.WRT.SUN	SM.AXIS SN	FL.P.A.SUN	ECCENT.SUN
3.458353960 02	2.999385180 02	7.094005050-02	5.240954510 00	3.027986970-04	4.922740110 00	5.186621510 01	7.875832130-01
APCEN. SUN	PRICEN.SUN	DST.FR.TRG	VL.WRT.TRG	SM.AX.TRGT	FL.P.A.TGT	ECCENT.TRG	APCNT.TRGT
8.799807590 00	1.045672640 00	2.000453330-01	2.663762040-04	-7.425782240-03	-8.553383260 01	2.349173820 00	-2.487023550-02
PCENT.TRGT	X TARGET **	Y TARGET **	Z TARGET **				
1.008867100-02	1.839390590-01	6.551340280-02	-5.455425570-03				

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TRAJECTORY TERMINATED IN JUPITER REFERENCE INHIBITOR IS 1.562500000-02 TRAJ. COUNTER IS 14

SPACECRAFT MASS BREAKDOWN (KG)

INITIAL	PROPULSION	PROPELLANT	TANKAGE	STRUCTURE	RETRO PROP	RETRO STR	NET S/C
3.757313250 02	4.500000000 01	2.589559270 01	8.968779800-01	0.0	0.0	0.0	2.999385180 02

PARTIAL DERIVATIVE MATRIX BY ROWS

-3.968760 00	-4.851350 00	-3.223370 00	2.292870-01	-1.771450-03
1.515210 00	1.495300 00	-3.623760 00	-2.102840-01	3.664180-06
-1.319670 00	-1.926180 00	4.985850-01	-6.493550-02	-1.950060-05
3.998790-01	-1.949630-02	5.133520-02	-3.004890-01	5.052940-06

TRAJECTORY SUMMARY ITERATION NO. 8

INDEPENDENT PARAMETERS

** NAME APPLIES TO PARAMETERS, USED IN THE ITERATION

X (TO)	Y (TO)	Z (TO)	XDOT	YDOT	ZDOT	MSS TO	
6.527172960-01	3.709371670-01	-6.978472170-01	-5.462799910 00	5.229009070 00	-2.330066170 00	3.757713930 02	
C	PO	ALPHA	TO	BETA	DELTA	EPSLON	T1
2.400000000D 04	1.500000000D 03	0.0	0.0	2.700000000D 02	0.0	9.000000000D 01	1.200000000D 01
THETA **	PSI	PHI	T2 **	THETA	PSI	PHI	T3
-1.384945880 01	0.0	0.0	5.960835730 03	0.0	0.0	0.0	1.365000000D 04
DL OMS **	DL OML **	DL INC	DL VPO **	VPOO			
-2.035255650-01	1.529864080-01	0.0	-1.256749380-04	7.912396230 00			

DEPENDENT PARAMETERS

FINAL MASS	NET S/C **	THRUST	DST.FR.SUN	VL.WRT.SUN	SM.AXIS SN	FL.P.A.SUN	ECCENT.SUN
3.458908280 02	2.999944110 02	7.694005050D-02	5.240979610 00	3.027730510-04	4.922051910 00	5.186846650 01	7.976121670-01
APCEN. SUN	PRICEN.SUN	DST.FR.TRG	VL.WRT.TRG	SM.AX.TRGT	FL.P.A.TGT	ECCENT.TRG	APCNT.TRGT
8.798719080 00	1.045383940 00	2.006425970-01	2.663741350-04	-7.425924730-03	-8.554213220 01	2.345427240 00	-2.484289090-02
PCENT.TRGT	X TARGET **	Y TARGET **	Z TARGET **				
9.991041430-03	1.849439740-01	6.546300000-02	-5.640135050-03				

556 TRAJECTORY TERMINATED IN JUPITER REFERENCE INHIBITOR IS 1.562500000-02 TRAJ. COUNTER IS 16

SPACECRAFT MASS BREAKDOWN (KG)

INITIAL	PROPULSION	PROPELLANT	TANKAGE	STRUCTURE	RETRO PROP	RETRO STR	NET S/C
3.757713930 02	4.500000000 01	2.988056450 01	8.964169350-01	0.0	0.0	0.0	2.999944110 02

PARTIAL DERIVATIVE MATRIX BY ROWS

-3.946340 00	-4.852430 00	-3.223780 02	2.327460-01	-1.774970-03
1.502950 00	1.496380 00	-3.622700 00	-2.133910-01	3.647140-06
-1.317040 00	-1.926510 00	4.981350-01	-6.575040-02	-1.954280-05
4.067700-01	-1.812230-02	5.031260-02	-3.001060-01	5.150840-06

TRAJECTORY SUMMARY ITERATION NO. 9

INDEPENDENT PARAMETERS

** NAME APPLIES TO PARAMETERS, USED IN THE ITERATION

X (TO)	Y (TO)	Z (TO)	XDOT	YDOT	ZDOT	MSS TO	
6.540620500D-01	3.703455870D-01	-6.969016930-01	-5.459173077D 00	5.225165250D 00	-2.345846150D 00	3.757979330D 02	
C	PO	ALPHA	TO	BETA	DELTA	EPSLON	T1
2.400000000 04	1.500000000D 03	0.0	0.0	2.730000000D 02	0.0	9.000000000D 01	1.200000000D 01
THETA **	PSI	PHI	T2 **	THETA	PSI	PHI	T3
-1.409144960D 01	0.0	0.0	5.954237730D 03	0.0	0.0	0.0	1.365000COD 04
DL ONS **	DL OHL **	DL INC	DL VPD **	VP00			
-1.788441970-01	1.334574180D-01	0.0	-8.326142370-05	7.912812990 00			

DEPENDENT PARAMETERS

FINAL MASS	NET S/C **	THRUST	DST.FR.SUN	VL.WRT.SUN	SM.AXIS SN	FL.P.A.SUN	ECCENT.SUN
3.459282600 02	3.000321700 02	7.094005050-02	5.240989330 00	3.027522530-04	4.921475520 00	5.186995710 01	7.876321200-01
APCEN. SUN	PRICEN.SUN	DST.FR.TRG	VL.WRT.TRG	SM.AX.TRGT	FL.P.A.TGT	ECCENT.TRG	APCNT.TRGT
8.797787710 00	1.045163320 00	2.000304320-01	2.653724830-04	-7.425043700-03	-8.554012230 01	2.346224570 00	-2.484919980-02
PCENT.TRGT	X TARGET **	Y TARGET **	Z TARGET **				
9.997118440-03	1.839395000-01	6.545116000-02	-5.708348930-03				

TRAJECTORY TERMINATED IN JUPITER REFERENCE   INHIBITOR IS 1.562500000D-02   TRAJ. COUNTER IS 18

SPACECRAFT MASS BREAKDOWN (KG)

INITIAL	PROPULSION	PROPELLANT	TANKAGE	STRUCTURE	RETRO PROP	RETRO STR	NET S/C
3.757979330 02	4.000003000 01	2.995967270 01	8.960901810-01	0.0	0.0	0.0	3.000321700 02

PARTIAL DERIVATIVE MATRIX BY ROWS

-3.926390 00	-4.853030 00	-3.224060 02	2.361240-01	-1.777460-03
[illegible]91770 00	1.496930 00	-3.621850 00	-2.162580-01	3.634100-06
-1.314710 00	-1.924770 00	4.977450-01	-6.654420-02	-1.956720-05
4.015200-01	-1.587600-02	4.951360-02	-2.997770-01	5.240440-06

TRAJECTORY SUMMARY ITERATION NO. 10

INDEPENDENT PARAMETERS

** NAME APPLIES TO PARAMETERS, USED IN THE ITERATION

X (T0)	Y (T0)	Z (T0)	XDOT	YDOT	ZDOT	MSS T0	
6.55244744D-01	3.69327034D-01	-6.96065560D-01	-5.45593733D 00	5.22181269D 00	-2.36155879D 00	3.75818514D 02	
C	P0	ALPHA	T0	BETA	DELTA	EPSLON	T1
2.40000000D 04	1.50000000D 03	0.0	0.0	2.70000000D 02	0.0	9.00000000D 01	1.20000000D 01
THETA **	PSI	PHI	T2 **	THETA	PSI	PHI	T3
-1.43031013D 01	0.0	0.0	5.94896373D 03	0.0	0.0	0.0	1.36500000D 04
DL ONS **	DL OML **	DL INC	DL VP0 **	VP0			
-1.57093500D-01	1.16986273D-01	0.0	-6.45625175D-05	7.91274842D 00			

DEPENDENT PARAMETERS

FINAL MASS	NET S/C **	THRUST	DST.FR.SUN	VL.WRT.SUN	SM.AXIS SN	FL.P.A.SUN	ECCENT.SUN
3.45957531D 02	3.00061702D 02	7.09400505D-02	5.24099825D 00	3.02734751D-04	4.92099139D 00	5.18712111D 01	7.87648911D-01
APCEN. SUN	PRICEN.SUN	DST.FR.TRG	VL.WRT.TRG	SM.AX.TRGT	FL.P.A.TGT	ECCENT.TRG	APCNT.TRGT
8.79700490D 00	1.04497788D 00	2.00032914D-01	2.66370835D-04	-7.42514908D-03	-8.55402490D 01	2.34610927D 00	-2.48487063D-02
PCENT.TRGT	X TARGET **	Y TARGET **	Z TARGET **				
9.99640810D-03	1.88939211D-01	6.54357642D-02	-5.77081704D-03				

TRAJECTORY TERMINATED IN JUPITER REFERENCE INHIBITOR IS 1.56250000D-02 TRAJ. COUNTER IS 20

SPACECRAFT MASS BREAKDOWN (KG)

INITIAL	PROPULSION	PROPELLANT	TANKAGE	STRUCTURE	RETRO PROP	RETRO STR	NET S/C
3.75818514D 02	4.50000000D 01	2.98605983D 01	8.95829489D-01	0.0	0.0	0.0	3.00061702D 02

PARTIAL DERIVATIVE MATRIX BY ROWS

-3.90852D 00	-4.85323D 00	-3.22427D 02	2.39107D-01	-1.77945D-03
1.48159D 00	1.49715D 00	-3.62121D 00	-2.18958D-01	3.62330D-06
-1.31267D 00	-1.92699D 00	4.97404D-01	- .72388D-02	-1.95849D-05
4.02149D-01	-1.57566D-02	4.08310D-02	-2.93499D-01	5.31815D-06

TRAJECTORY SUMMARY ITERATION NO. 11

INDEPENDENT PARAMETERS

** NAME APPLIES TO PARAMETERS, USED IN THE ITERATION

X (TO)	Y (TO)	Z (TO)	XDOT	YDOT	ZDOT	MSS TO	
6.573070560D-01	3.689260290D-01	-6.945977310D-01	-5.450187140 00	5.216038230 00	-2.387157530 00	3.758481630 02	
C	**PO**	**ALPHA**	**TO**	**BETA**	**DELTA**	**EPSLON**	**T1**
2.400000000 04	1.500000000D 03	0.0	0.0	2.700000000D 02	0.0	9.000000000D 01	1.200000000 01
THETA **	**PSI**	**PHI**	**T2 ****	**THETA**	**PSI**	**PHI**	**T3**
-1.468024210 01	0.0	0.0	5.940857670 03	0.0	0.0	0.0	1.365000000 04
DL OMS **	**DL OML ****	**DL INC**	**DL VPO ****	**VPOJ**			
-2.734331260-01	2.030093540-01	0.0	-9.300176470-05	7.912655420 00			

DEPENDENT PARAMETERS

FINAL MASS	NET S/C **	THRUST	DST.FR.SUN	VL.WRT.SUN	SM.AXIS SN	FL.P.A.SUN	ECCENT.SUN
3.460004570 02	3.001050250 02	7.094005050-02	5.240973320 00	3.027020980-04	4.920015310 00	5.187233340 01	7.870674310-01
APCEN. SUN	**PRICEN.SUN**	**DST.FR.TRG**	**VL.WRT.TRG**	**SM.AX.TRGT**	**FL.P.A.TGT**	**ECCENT.TRG**	**APCNT.TRGT**
8.795353820 00	1.044679810 00	2.009702510-01	2.663611420-01	-7.425626750-03	-8.564151590 01	2.345779380 00	-2.484785470-02
PCENT.TRGT	**X TARGET ****	**Y TARGET ****	**Z TARGET ****				
9.994601180-03	1.889821890-01	6.542076700-02	-5.828617750-03				

TRAJECTORY TERMINATED IN JUPITER REFERENCE   INHIBITOR IS 7.812500000-03   TRAJ. COUNTER IS 23

SPACECRAFT MASS BREAKDOWN (KG)

INITIAL	PROPULSION	PROPELLANT	TANKAGE	STRUCTURE	RETRO PROP	RETRO STR	NET S/C
3.758481630 02	4.500000000 01	2.984770650 01	8.954311940-01	0.0	0.0	0.0	3.001050250 02

PARTIAL DERIVATIVE MATRIX BY ROWS

-3.876460 00	-4.852650 00	-3.224590 02	2.445050-01	-1.782540-03
1.462950 00	1.496750 00	-3.620390 00	-2.236260-01	3.603580-06
-1.309120 00	-1.927360 00	4.968290-01	-6.848910-02	-1.960250-05
4.031650-01	-1.373560-02	4.774420-02	-2.990210-01	5.453750-06

TRAJECTORY SUMMARY ITERATION NO. 12

INDEPENDENT PARAMETERS

** NAME APPLIES TO PARAMETERS, USED IN THE ITERATION

X (TO)	Y (TO)	Z (TO)	XDOT	YDOT	ZDOT	MSS TO	
6.58853540D-01	3.68253748D-01	-6.93488412D-01	-5.44578742D 00	5.21175213D 00	-2.40628256D 00	3.75867485D 02	
C	PO	ALPHA	TO	BETA	DELTA	EPSLON	T1
2.40000000D 04	1.50000000D 03	0.0	0.0	2.70000000D 02	0.0	9.00000000D 01	1.20000000D 01
THETA **	PSI	PHI	T2 **	THETA	PSI	PHI	T3
-1.49403623D 01	0.0	0.0	5.93499834D 03	0.0	0.0	0.0	1.36500000D 04
DL OMS **	DL OML **	DL INC	DL VPO **	VPOO			
-2.04718872D-01	1.51576833D-01	0.0	-6.06062439D-05	7.91259481D 00			

DEPENDENT PARAMETERS

FINAL MASS	NET S/C **	THRUST	DST.FR.SUN	VL.WRT.SUN	SM.AXIS SN	FL.P.A.SUN	ECCENT.SUN
3.46029432D 02	3.00134290D 02	7.09400505D-02	5.24100561D 00	3.02683562D-04	4.91954403D 00	5.18742733D 01	7.87691658D-01
APCEN. SUN	PRICEN.SUN	DST.FR.TRG	VL.WRT.TRG	SM.AX.TRGT	FL.P.A.TGT	ECCENT.TRG	APCNT.TRGT
8.79462782D 00	1.04446024D 00	2.00344751D-01	2.66352950D-04	-7.42558879D-03	-8.55421930D 01	2.34525610D 00	-2.48438415D-02
PCENT.TRGT	X TARGET **	Y TARGET **	Z TARGET **				
9.99066389D-03	1.88959643D-01	6.53934945D-02	-5.98722388D-03				

TRAJECTORY TERMINATED IN JUPITER REFERENCE   INHIBITOR IS 7.81250000D-03   TRAJ. COUNTER IS 25

SPACECRAFT MASS BREAKDOWN (KG)

INITIAL	PROPULSION	PROPELLANT	TANKAGE	STRUCTURE	RETRO PROP	RETRO STR	NET S/C
3.75867485D 02	4.50000000D 01	2.98380534D 01	8.95141601D-01	0.0	0.0	0.0	3.00134290D 02

PARTIAL DERIVATIVE MATRIX BY ROWS

-3.85127D 00	-4.85110D 00	-3.22480D 02	2.48225D-01	-1.78475D-03
1.44801D 00	1.49565D 00	-3.62013D 00	-2.26828D-01	3.59083D-06
-1.30647D 00	-1.92759D 00	4.96393D-01	-6.93265D-02	-1.96193D-05
4.03847D-01	-1.21717D-02	4.68921D-02	-2.98700D-01	5.54829D-06

TRAJECTORY SUMMARY ITERATION NO. 13

INDEPENDENT PARAMETERS

** NAME APPLIES TO PARAMETERS, USED IN THE ITERATION

X (TO)	Y (TO)	Z (TO)	XDOT	YDOT	ZDOT	MSS TO	
6.59970944D-01	3.67770546D-01	-6.92681666D-01	-5.44258055D 00	5.20868030D 00	-2.42008045D 00	3.75874210D 02	
C	PO	ALPHA	TO	BETA	DELTA	EPSLON	T1
2.40000000D 04	1.50000000D 03	0.0	0.0	2.70000000D 02	0.0	9.00000000D 01	1.20000000D 01
THETA **	PSI	PHI	T2 **	THETA	PSI	PHI	T3
-1.51395843D 01	0.0	0.0	5.93146943D 03	0.0	0.0	0.0	1.36500000D 04
DL CMS **	DL OML **	DL INC	DL VPO **	VPOO			
-1.47827900D-01	1.09322514D-01	0.0	-2.10923999D-05	7.91257372D 00			

DEPENDENT PARAMETERS

FINAL MASS	NET S/C **	THRUST	DST.FR.SUN	VL.WRT.SUN	SM.AXIS SN	FL.P.A.SUN	ECCENT.SUN
3.46041947D 02	3.00146980D 02	7.09400505D-02	5.24101945D 00	3.02670204D-04	4.91918745D 00	5.18753884D 01	7.87706133D-01
APCEN. SUN	PRICEN.SUN	DST.FR.TRG	VL.WRT.TRG	SM.AX.TRGT	FL.P.A.TGT	ECCENT.TRG	APCNT.TRGT
8.79406159D 00	1.04431330D 00	2.00032543D-01	2.65353223D-04	-7.42550506D-03	-8.56405403D 01	2.34586375D 00	-2.48484120D-02
PCENT.TRGT	X TARGET **	Y TARGET **	Z TARGET **				
9.99519991D-03	1.83948478D-01	6.53837961D-02	-6.03738386D-03				

TRAJECTORY TERMINATED IN JUPITER REFERENCE   INHIBITOR IS 7.81250000D-03   TRAJ. COUNTER IS 27

SPACECRAFT MASS BREAKDOWN (KG)

INITIAL	PROPULSION	PROPELLANT	TANKAGE	STRUCTURE	RETRO PROP	RETRO STR	NET S/C
3.75874210D 02	4.50000000D 01	2.98322626D 01	8.94967879D-01	0.0	0.0	0.0	3.00146980D 02

PARTIAL DERIVATIVE MATRIX BY ROWS

-3.83250D 00	-4.54937D 00	-3.22469D 02	2.51141D-01	-1.78610D-03
1.43669D 00	1.49436D 00	-3.62014D 00	-2.29314D-01	3.58247D-06
-1.30455D 00	-1.92774D 00	4.96082D-01	-6.99841D-02	-1.96255D-05
4.[illegible]0D-01	-1.09965D-02	4.63663D-02	-2.98464D-01	5.61953D-05

TRAJECTORY SUMMARY ITERATION NO. 14

INDEPENDENT PARAMETERS

** NAME APPLIES TO PARAMETERS, USED IN THE ITERATION

X (TO)	Y (TO)	Z (TO)	XDOT	YDOT	ZDOT	MSS TO	
6.61569377D-01	3.67088324D-01	-6.91517975D-01	-5.43798485D 00	5.20424413D 00	-2.45983102D 00	3.75878467D 02	
C	**PO**	**ALPHA**	**TO**	**BETA**	**DELTA**	**EPSLON**	**T1**
2.40000000D 04	1.50000000D 03	0.0	0.0	2.70000000D 02	0.0	9.00000000D 01	1.20000000D 01
THETA **	**PSI**	**PHI**	**T2 ****	**THETA**	**PSI**	**PHI**	**T3**
-1.54316549D 01	0.0	0.0	5.92601688D 03	0.0	0.0	0.0	1.36500000D 04
DL OMS **	**DL OML ****	**DL INC**	**DL VPO ****	**VPOO**			
-2.11850474D-01	1.57080306D-01	0.0	-1.33518815D-05	7.91256037D 00			

DEPENDENT PARAMETERS

FINAL MASS	NET S/C **	THRUST	DST.FR.SUN	VL.WRT.SUN	SM.AXIS SN	FL.P.A.SUN	ECCENT.SUN
3.46055137D 02	3.00160437D 02	7.09400505D-02	5.24100773D 00	3.02547180D-04	4.91551043D 00	5.18763086D 01	7.87720570D-01
APCEN. SUN	**PRICEN.SUN**	**DST.FR.TRG**	**VL.WRT.TRG**	**SM.AX.TRGT**	**FL.P.A.TGT**	**ECCENT.TRG**	**APCNT.TRGT**
8.79292227D 00	1.04409559D 00	2.00051327D-01	2.66357719D-04	-7.42588400D-03	-8.56399534D 01	2.34622636D 00	-2.48520350D-02
PCENT.TRGT	**X TARGET ****	**Y TARGET ****	**Z TARGET ****				
9.99826702D-03	1.88970109D-01	6.53751452D-02	-6.07534301D-03				

TRAJECTORY TERMINATED IN JUPITER REFERENCE   INHIBITOR IS 3.90625000D-03   TRAJ. COUNTER IS 30

SPACECRAFT MASS BREAKDOWN (KG)

INITIAL	PROPULSION	PROPELLANT	TANKAGE	STRUCTURE	RETRO PROP	RETRO STR	NET S/C
3.75878467D 02	4.50000000D 01	2.98233298D 01	8.94699895D-01	0.0	0.0	0.0	3.00160437D 02

PARTIAL DERIVATIVE MATRIX BY ROWS

-3.80451D 00	-4.94578D 00	-3.22497D 02	2.55427D-01	-1.78818D-03
1.41965D 00	1.49165D 00	-3.62061D 00	-2.32997D-01	3.56762D-06
-1.30181D 00	-1.92798D 00	4.95650D-01	-7.09525D-02	-1.96319D-05
4.04819D-01	-9.24950D-03	4.57021D-02	-2.98105D-01	5.72355D-06

```
TRAJECTORY SUMMARY ITERATION NO. 15

INDEPENDENT PARAMETERS

** NAME APPLIES TO PARAMETERS, USED IN THE ITERATION
X (TO)          Y (TO)          Z (TO)          XDOT            YDOT            ZDOT            MSS TO
6.629346270-01  3.665368440-01 -6.905022880-01 -5.434244990 00  5.230135260 00 -2.456913750 00  3.758731610 02

C               PO              ALPHA           TO              BETA            DELTA           EPSLON          T1
2.400000000 04  1.500000000 03  0.0             0.0             2.700000000 02  0.0             9.000000000 01  1.200000000 01

THETA   **      PSI             PHI             T2      **      THETA           PSI             PHI             T3
-1.567407890 01 0.0             0.0             5.916771740 03  0.0             0.0             0.0             1.365000000 04

DL OMS   **     DL OML   **     DL INC          DL VPO   **     VPOO
-1.834937730-01 1.389975440-01  0.0             1.664343860-03  7.912577010 00

DEPENDENT PARAMETERS

FINAL MASS      NET S/C   **    THRUST          DST.FR.SUN      VL.WRT.SUN      SM.AXIS SN      FL.P.A.SUN      ECCENT.SUN
3.460653130 02  3.001710780 02  7.094005050-02  5.241023130 00  3.026225580-04  4.917830150 00  5.187825010 01  7.877461110-01

APCEN. SUN      PRICEN.SUN      DST.FR.TRG      VL.WRT.TRG      SM.AX.TRGT      FL.P.A.TGT      ECCENT.TRG      APCNT.TRGT
8.791842450 00  1.043829850 00  2.000421380-01  2.663566700-04 -7.426972170-03 -8.563879130 01  2.346629930 00 -2.485532730-02

PCENT.TRGT      X TARGET  **    Y TARGET  **    Z TARGET  **
1.000138300-02  1.859633950-01  6.535576800-02 -6.189975810-03

TRAJECTORY TERMINATED IN JUPITER REFERENCE     INHIBITOR IS 1.953125000-03     TRAJ. COUNTER IS  33

SPACECRAFT MASS BREAKDOWN (KG)

INITIAL         PROPULSION      PROPELLANT      TANKAGE         STRUCTURE       RETRO PRUP      RETRO STR       NET S/C
3.758731610 02  4.500000000 01  2.980784720 01  8.942354170-01  0.0             0.0             0.0             3.001710780 02

PARTIAL DERIVATIVE MATRIX BY ROWS

-3.778760 00 -4.841240 00 -3.225010 02  2.587470-01 -1.791730-03

 1.404250 00  1.488570 00 -3.621600 00 -2.360780-01  3.549770-06

-1.299470 00 -1.928190 00  4.952540-01 -7.172210-02 -1.967520-05

 4.051420-01 -7.697790-03  4.513440-02 -2.977210-01  5.820100-06
```

TRAJECTORY SUMMARY ITERATION NO. 16

INDEPENDENT PARAMETERS

** NAME APPLIES TO PARAMETERS, USED IN THE ITERATION

X (TO)	Y (TO)	Z (TO)	XDOT	YDOT	ZDOT	MSS TO	
6.62935820D-01	3.65536247D-01	-6.90501461D-01	-5.43424080D 00	5.20013322D 00	-2.45593254D 00	3.75873130D 02	
C	PO	ALPHA	TO	BETA	DELTA	EPSLON	T1
2.40000000D 04	1.50000000D 03	0.0	0.0	2.70000000D 02	0.0	9.00000000D 01	1.20000000D 01
THETA **	PSI	PHI	T2 **	THETA	PSI	PHI	T3
-1.56734360D 01	0.0	0.0	5.91677260D 03	0.0	0.0	0.0	1.36500000D 04
DL OMS **	DL OML **	DL INC	DL VPO **	VPOO			
-1.49036037D-04	9.98167869D-05	0.0	9.62876740D-08	7.91257711D 00			

DEPENDENT PARAMETERS

FINAL MASS	NET S/C **	THRUST	DST.FR.SUN	VL.WRT.SUN	SM.AXIS SN	FL.P.A.SUN	ECCENT.SUN
3.46065286D 02	3.00171051D 02	7.09400505D-02	5.24102664D 00	3.02522924D-04	4.91765248D 00	5.18783309D 01	7.87746886D-01
APCEN. SUN	PRICEN.SUN	DST.FR.TRG	VL.WRT.TRG	SM.AX.TRGT	FL.P.A.T.T	ECCENT.TRG	APCNT..RGT
8.79187546D 00	1.04382950D 00	2.00038191D-01	2.66357315D-03	-7.42594438D-03	-8.55336316D 01	2.34667047D 00	-2.48555355D-02
PCENT.TRGT	X TARGET **	Y TARGET **	Z TARGET **				
1.00016467D-02	1.88959333D-01	6.53555150D-02	-6.19438252D-03				

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TRAJECTORY TERMINATED IN JUPITER REFERENCE   INHIBITOR IS 5.12000000D 02   TRAJ. COUNTER IS 41

SPACECRAFT MASS BREAKDOWN (KG)

INITIAL	PROPULSION	PROPELLANT	TANKAGE	STRUCTURE	RETRO PROP	RETRO STR	NET S/C
3.75873130D 02	4.50000000D 01	2.98078440D 01	8.94235320D-01	0.0	0.0	0.0	3.00171051D 02

PARTIAL DERIVATIVE MATRIX BY ROWS

-3.77874D 00	-4.84124D 00	-3.22501D 02	2.58737D-01	-1.79173D-03
1.46424D 00	1.48856D 00	-3.62161D 00	-2.36069D-01	3.54977D-06
-1.29947D 00	-1.92819D 00	4.95254D-01	-7.17191D-02	-1.96753D-05
4.65143D-01	-7.69695D-03	4.51301D-02	-2.97722D-01	5.81936D-06

TRAJECTORY SUMMARY ITERATION NO. 17

INDEPENDENT PARAMETERS

** NAME APPLIES TO PARAMETERS, USED IN THE ITERATION

X (TO)	Y (TO)	Z (TO)	XDOT	YDOT	ZDOT	MSS TO	
6.629377270-01	3.665333130-01	-6.905011860-01	-5.434218200 00	5.200155200 00	-2.455937360 00	3.758730060 02	
C	**PO**	**ALPHA**	**TO**	**BETA**	**DELTA**	**EPSLON**	**T1**
2.400000000 04	1.500000000 03	0.0	0.0	2.700000000 02	0.0	9.000000000 01	1.200000000 01
THETA **	**PSI**	**PHI**	**T2 ****	**THETA**	**PSI**	**PHI**	**T3**
-1.567371680 01	0.0	0.0	5.916790510 03	0.0	0.0	0.0	1.365000000 04
DL DMS **	**DL OML ****	**DL INC**	**DL VPO ****	**VPOO**			
-4.938322650-05	-2.033627080-04	0.0	3.900292450-07	7.912577500 00			

DEPENDENT PARAMETERS

FINAL MASS	NET S/C **	THRUST	DST.FR.SUN	VL.WRT.SUN	SM.AXIS SN	FL.P.A.SUN	ECCENT.SUN
3.463651510 02	3.001709160 02	7.094005050-02	5.241026530 00	3.025231580-04	4.917855990 00	5.187832240 01	7.877467500-01
APCEN. SUN	**PRICEN.SUN**	**DST.FR.TRG**	**VL.WRT.TRG**	**SM.AX.TRGT**	**FL.P.A.TGT**	**ECCENT.TRG**	**APCNT.TRGT**
8.791886420 00	1.043831550 00	2.000344490-01	2.663579290-04	-7.425917960-03	-8.553577540 01	2.347397740 00	-2.486456180-02
PCENT.TRGT	**X TARGET ****	**Y TARGET ****	**Z TARGET ****				
1.001072590-02	1.859525830-01	6.535319610-02	-6.193116910-03				

TRAJECTORY TERMINATED IN JUPITER REFERENCE   INHIBITOR IS 1.280000000 02   TRAJ. COUNTER IS 44

SPACECRAFT MASS BREAKDOWN (KG)

INITIAL	PROPULSION	PROPELLANT	TANKAGE	STRUCTURE	RETRO PROP	RETRO STR	NET S/C
3.758730060 02	4.500000000 01	2.980785420 01	8.942356270-01	0.0	0.0	0.0	3.001709160 02

PARTIAL DERIVATIVE MATRIX BY ROWS

-3.778700 00	-4.841200 00	-3.225000 02	2.587420-01	-1.791720-03
1.404210 00	1.488500 00	-3.621600 00	-2.360720-01	3.549740-06
-1.299460 00	-1.928180 00	4.952580-01	-7.172020-02	-1.967310-05
4.051460-01	-7.695600-03	4.513090-02	-2.977220-01	5.813920-06

TRAJECTORY SUMMARY ITERATION NO. 18

INDEPENDENT PARAMETERS

** NAME APPLIES TO PARAMETERS, USED IN THE ITERATION

X (TO)	Y (TO)	Z (TO)	XDOT	YDOT	ZDOT	MSS TO	
6.62936915D-01	3.66533426D-01	-6.90501907D-01	-5.43421961D 00	5.20016125D 00	-2.45692569D 00	3.75872584D 02	
C	PO	ALPHA	TO	BETA	DELTA	EPSLON	T1
2.40000000D 04	1.53000000D 03	0.0	0.0	2.70000000D 02	0.0	9.00000000D 01	1.20000000D 01
THETA **	PSI	PHI	T2 **	THETA	PSI	PHI	T3
-1.56743361D 01	0.0	0.0	5.91686351D 03	0.0	0.0	0.0	1.36500000D 04
DL OMS **	DL OML **	DL INC	DL VPO **	VPOO			
1.29776355D-04	-1.22172721D-04	0.0	1.32333979D-05	7.91257882D 00			

DEPENDENT PARAMETERS

FINAL MASS	NET S/C **	THRUST	DST.FR.SUN	VL.WRT.SUN	SM.AXIS SN	FL.P.A.SUN	ECCENT.SUN
3.46064609D 02	3.00170370D 02	7.09400505D-02	5.24102742D 00	3.02623370D-04	4.91736655D 00	5.18763340D 01	7.87746828D-01
APCEN. SUN	PRICEN.SUN	DST.FR.TRG	VL.WRT.TRG	SM.AX.TRGT	FL.P.A.TGT	ECCENT.TRG	APCNT.TRGT
8.79190033D 00	1.04383278D 00	2.00032799D-01	2.66358193D-03	-7.42590571D-03	-8.56552929D 01	2.34809733D 00	-2.48660066D-02
PCENT.TRGT	X TARGET **	Y TARGET **	Z TARGET **				
1.00121931D-02	1.84950582D-01	6.53643691D-02	-6.18846377D-03				

TRAJECTORY TERMINATED IN JUPITER REFERENCE INHIBITOR IS 3.20000000D 01 TRAJ. COUNTER IS 47

SPACECRAFT MASS BREAKDOWN (KG)

INITIAL	PROPULSION	PROPELLANT	TANKAGE	STRUCTURE	RETRO PROP	RETRO STR	NET S/C
3.75872584D 02	4.50000000D 01	2.98079746D 01	8.94239239D-01	0.0	0.0	0.0	3.00170370D 02

PARTIAL DERIVATIVE MATRIX BY ROWS

-3.77873D 00	-4.84121D 00	-3.22500D 02	2.56756D-01	-1.79159D-03
1.40422D 00	1.48953D 00	-3.62160D 00	-2.36081D-01	3.54984D-06
-1.29946D 00	-1.92918D 00	4.95258D-01	-7.17235D-02	-1.96746D-05
4.05146D-01	-7.69630D-03	4.51348D-02	-2.97723D-01	5.82001D-06

TRAJECTORY SUMMARY ITERATION NO. 19

INDEPENDENT PARAMETERS

** NAME APPLIES TO PARAMETERS, USED IN THE ITERATION

X (TO)	Y (TO)	Z (TO)	XDOT	YDOT	ZDOT	MSS TO	
6.62934547D-01	3.66535193D-01	-6.90503242D-01	-5.43423515D 00	5.20016332D 00	-2.45590441D 00	3.75871484D 02	
C	PO	ALPHA	TO	BETA	DELTA	EPSLON	T1
2.40000000D 04	1.50000000D 03	0.0	0.0	2.70000000D 02	0.0	9.00000000D 01	1.20000000D 01
THETA **	PSI	PHI	T2 **	THETA	PSI	PHI	T3
-1.56751765D 01	0.0	0.0	5.91705092D 03	0.0	0.0	0.0	1.36500000D 04
DL OMS **	DL OML **	DL INC	DL VPO **	VPOC			
2.40270158D-04	-9.13932964D-05	0.0	3.44851901D-05	7.91258227D 00			

DEPENDENT PARAMETERS

FINAL MASS	NET S/C **	THRUST	DST.FR.SUN	VL.WRT.SUN	SM.AXIS SN	FL.P.A.SUN	ECCENT.SUN
3.46063192D 02	3.00168943D 02	7.09400505D-02	5.24103341D 00	3.02524149D-04	4.91789930D 00	5.18784539D 01	7.87747925D-01
APCEN. SUN	PRICEN.SUN	DST.FR.TRG	VL.WRT.TRG	SM.AX.TRGT	FL.P.A.TGT	ECCENT.TRG	APCNT.TRGT
8.79196427D 00	1.04383433D 00	2.00028886D-01	2.66359142D-04	-7.42536616D-03	-6.55358103D 01	2.34782519D 00	-2.48638496D-02
PCENT.TRGT	X TARGET **	Y TARGET **	Z TARGET **				
1.00101173D-02	1.86945702D-01	6.53610797D-02	-6.13112591D-03				

TRAJECTORY TERMINATED IN JUPITER REFERENCE   INHIBITOR IS 8.00000000D 00   TRAJ. COUNTER IS 50

SPACECRAFT MASS BREAKDOWN (KG)

INITIAL	PROPULSION	PROPELLANT	TANKAGE	STRUCTURE	RETRO PROP	RETRO STR	NET S/C
3.75871484D 02	4.50000000D 01	2.98062924D 01	8.94248773D-01	0.0	0.0	0.0	3.00168943D 02

PARTIAL DERIVATIVE MATRIX BY ROWS

-3.77891D 00	-4.84124D 00	-3.22499D 02	2.58781D-01	-1.79162D-03
1.40425D 00	1.48854D 00	-3.62159D 00	-2.30094D-01	3.55015D-06
-1.29947D 00	-1.92819D 00	4.95256D-01	-7.17286D-02	-1.96731D-05
4.05146D-01	-7.69810D-03	4.51407D-02	-2.97725D-01	5.81997D-06

TRAJECTORY SUMMARY ITERATION NO. 20

INDEPENDENT PARAMETERS

** NAME APPLIES TO PARAMETERS, USED IN THE ITERATION

X (TO)	Y (TO)	Z (TO)	XDOT	YDOT	ZDOT	MSS TO	
6.629318030-01	3.665374150-01	-6.905046970-01	-5.434254610 00	5.230157110 00	-2.455881320 00	3.758701720 02	
C	**PO**	**ALPHA**	**TO**	**BETA**	**DELTA**	**EPSLON**	**T1**
2.400000000 04	1.500000000 03	0.0	0.0	2.700000000 02	0.0	9.000000000 01	1.200000000 01
THETA **	**PSI**	**PHI**	**T2 ****	**THETA**	**PSI**	**PHI**	**T3**
-1.567593620 01	0.0	0.0	5.917266580 03	0.0	0.0	0.0	1.365000000 04
DL OMS **	**DL OML ****	**DL INC**	**DL VPO ****	**VPOO**			
2.619354270-04	-7.410372690-05	0.0	4.116375050-06	7.912586390 00			

DEPENDENT PARAMETERS

FINAL MASS	NET S/C **	THRUST	DST.FR.SUN	VL.WRT.SUN	SM.AXIS SN	FL.P.A.SUN	ELCENT.SUN
3.460615140 02	3.001672540 02	7.094005050-02	5.241341530 00	3.026251550-04	4.917942390 00	5.187862170 01	7.877494800-01
APCEN. SUN	**PRICEN.SUN**	**DST.FR.TRG**	**VL.WRT.TRG**	**SM.AX.TRGT**	**FL.P.A.TGT**	**ECCENT.TRG**	**APCNT.TRGT**
8.792048940 00	1.043835830 00	2.000189390-01	2.663504230-04	-7.426811520-03	-8.555556850 01	2.347431870 00	-2.486074560-02
PCENT.TRGT	**X TARGET ****	**Y TARGET ****	**Z TARGET ****				
1.000712260-02	1.889391480-01	6.535439100-02	-6.173856050-03				

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TRAJECTORY TERMINATED IN JUPITER REFERENCE INHIBITOR IS 2.000000000 00 TRAJ. COUNTER IS 53

SPACECRAFT MASS BREAKDOWN (KG)

INITIAL	PROPULSION	PROPELLANT	TANKAGE	STRUCTURE	RETRO PROP	RETRO STR	NET S/C
3.758701720 02	4.500000000 01	2.980865800 01	8.942597410-01	0.0	0.0	0.0	3.001672540 02

PARTIAL DERIVATIVE MATRIX BY ROWS

-3.776900 00	-4.841290 00	-3.224980 02	2.588060-01	-1.791530-03
1.404290 00	1.488560 00	-3.621590 00	-2.361060-01	3.550510-06
-1.295470 00	-1.928190 00	4.952530-01	-7.173360-02	-1.967150-05
4.051450-01	-7.700300-03	4.514640-02	-2.977300-01	5.819850-06

TRAJECTORY SUMMARY ITERATION NO. 21

INDEPENDENT PARAMETERS

** NAME APPLIES TO PARAMETERS, USED IN THE ITERATION

X (TO)	Y (TO)	Z (TO)	XDOT	YDOT	ZDOT	MSS TO	
6.62929969D-01	3.66538732D-01	-6.90505758D-01	-5.43426555D 00	5.23015639D 00	-2.45586466D 00	3.75869645D 02	
C	**PO**	**ALPHA**	**TO**	**BETA**	**DELTA**	**EPSLON**	**T1**
2.40000000D 04	1.50000000D 03	0.0	0.0	2.70000000D 02	0.0	9.00000000D 01	1.20000000D 01
THETA **	**PSI**	**PHI**	**T2 ****	**THETA**	**PSI**	**PHI**	**T3**
-1.56760966D 01	0.0	0.0	5.91731757D 03	0.0	0.0	0.0	1.36500000D 04
DL OMS **	**DL OML ****	**EL INC**	**DL VPO ****	**VPOO**			
1.91098097D-04	-8.03646003D-05	0.0	1.65312283D-05	7.01258804D 00			

DEPENDENT PARAMETERS

FINAL MASS	NET S/C **	THRUST	DST.FR.SUN	VL.WRT.SUN	SM.AXIS SN	FL.P.A.SUN	ECCENT.SUN
3.46050901D 02	3.00166639D 02	7.09400505D-02	5.24104463D 00	3.02625491D-04	4.91795731D 00	5.18786876D 01	7.87750103D-01
APCEN. SUN	**PRICEN.SUN**	**DST.FR.TRG**	**VL.WRT.TRG**	**SM.AX.TRGT**	**FL.P.A.TGT**	**ECCENT.TRG**	**APCNT.TRGT**
8.79207869D 00	1.04383594D 00	2.00015916D-01	2.56350903D-03	-7.42579093D-03	-8.55367931D 01	2.34731027D 00	-2.48597736D-02
PCENT.TRGT	**X TARGET ****	**Y TARGET ****	**Z TARGET ****				
1.00061917D-02	1.88936589D-01	6.53547794D-02	-6.17128123D-03				

TRAJECTORY TERMINATED IN JUPITER REFERENCE   INHIBITOR IS 5.00000000D-01   TRAJ. COUNTER IS 56

SPACECRAFT MASS BREAKDOWN (KG)

INITIAL	PROPULSION	PROPELLANT	TANKAGE	STRUCTURE	RETRO PRUP	RETRO STR	NET S/C
3.75869645D 02	4.50000000D 01	2.98087436D 01	8.94252309D-01	0.0	0.0	0.0	3.00166639D 02

PARTIAL DERIVATIVE MATRIX BY ROWS

-3.77894D 00	-4.84130D 00	-3.22497D 02	2.58812D-01	-1.79131D-03
1.40431D 00	1.48857D 00	-3.62159D 00	-2.36109D-01	3.55050D-06
-1.29948D 00	-1.92819D 00	4.95253D-01	-7.17349D-02	-1.96712D-05
4.05145D-01	-7.70200D-03	4.51487D-02	-2.97731D-01	5.81992D-06

TRAJECTORY SUMMARY ITERATION NO. 22

INDEPENDENT PARAMETERS

** NAME APPLIES TO PARAMETERS, USED IN THE ITERATION

X (TO)	Y (TO)	Z (TO)	XDOT	YDOT	ZDOT	MSS TO	
6.62929813D-01	3.65538828D-01	-6.90505657D-01	-5.43426632D 00	5.20015656D 00	-2.45586244D 00	3.75869613D 02	
C	PO	ALPHA	TO	BETA	DELTA	EPSLON	T1
2.40000000D 04	1.50000000D 03	0.0	0.0	2.70000000D 02	0.0	9.00000000D 01	1.20000000D 01
THETA **	PSI	PHI	T2 **	THETA	PSI	PHI	T3
-1.56760991D 01	0.0	0.0	5.91731603D 03	0.0	0.0	0.0	1.36500000D 04
DL OMS **	DL OML **	DL INC	DL VPO **	VPOO			
1.77538678D-05	-9.71500149D-06	0.0	9.36999543D-08	7.91258814D 00			

DEPENDENT PARAMETERS

FINAL MASS	NET S/C **	THRUST	DST.FR.SUN	VL.WRT.SUN	SM.AXIS SN	FL.P.A.SUN	ECCENT.SUN
3.46060869D 02	3.00166507D 02	7.09400505D-02	5.24104478D 00	3.02625506D-04	4.91795799D 00	5.18706911D 01	7.87750176D-01
APCEN. SUN	PRICEN.SUN	DST.FR.TRG	VL.WRT.TRG	SM.AX.TRGT	FL.P.A.TGT	ECCENT.TRG	APCNT.TRGT
8.79208006D 00	1.04383592D 00	2.00015746D-01	2.65360929D-04	-7.42578979D-03	-8.55367873D 01	2.34731156D 00	-2.48597793D-02
PCENT.TRGT	X TARGET **	Y TARGET **	Z TARGET **				
1.00061997D-02	1.83935426D-01	6.53547466D-02	-6.17113403D-03				

570 TRAJECTORY TERMINATED IN JUPITER REFERENCE   INHIBITOR IS 4.00000000D 00   TRAJ. COUNTER IS 59

SPACECRAFT MASS BREAKDOWN (KG)

INITIAL	PROPULSION	PROPELLANT	TANKAGE	STRUCTURE	RETRO PROP	RETRO STR	NET S/C
3.75869613D 02	4.50000000D 01	2.98087442D 01	8.94262325D-01	0.0	0.0	0.0	3.00166607D 02

PARTIAL DERIVATIVE MATRIX BY ROWS

-3.77834D 00	-4.34130D 00	-3.22497D 02	2.58812D-01	-1.79131D-03
1.40432D 00	1.48857D 00	-3.62155D 00	-2.36109D-01	3.55050D-06
-1.29948D 00	-1.92819D 00	4.95252D-01	-7.17349D-02	[illegible]
4.05145D-01	-7.70212D-03	4.51488D-02	-2.97731D-01	5.81982D-06

TRAJECTORY SUMMARY RATION NO. 23

INDEPENDENT PARAMETERS

** NAME APPLIES TO PARAMETERS, USED IN THE ITERATION

X (TO)	Y (TO)	Z (TO)	XDOT	YDOT	ZDOT	MSS TO	
6.629296680D-01	3.665389250D-01	-6.905059450D-01	-5.434267090 00	5.200156490 00	-2.453860970 00	3.758695950 02	
C	PO	ALPHA	TO	BETA	DELTA	EPSLON	T1
2.400000000D 04	1.500000000D 03	0.0	0.0	2.730000000D 02	0.0	9.000000000D 01	1.200000000D 01
THETA **	PSI	PHI	T2 **	THETA	PSI	PHI	T3
-1.567609230 01	0.0	0.0	5.917316240 03	0.0	0.0	0.0	1.365000000D 04
DL OMS **	DL OML **	DL INC	DL VPO **	VPOO			
1.590880420-05	-7.804289550-06	0.0	5.719514710-03	7.912598200 00			

DEPENDENT PARAMETERS

FINAL MASS	NET S/C **	THRUST	DST.FR.SUN	VL.WRT.SUN	SM.AXIS SN	FL.P.A.SUN	ECCENT.SUN
3.460608540 02	3.001665920 02	7.094005050-02	5.241041850 00	3.026255090-04	4.917958200 00	5.187069300 01	7.877501550-01
APCEN. SUN	PRICEN.SUN	DST.FR.TRG	VL.WRT.TRG	SM.AX.TRGT	FL.P.A.TGT	ECCENT.TRG	APCNT.TRGT
8.792085540 00	1.043335870 00	2.000156790-01	2.663609400-04	-7.435789360-03	-8.553679360 01	2.387308260 00	-2.485975340-02
PCENT.TRGT	X TARGET **	Y TARGET **	Z TARGET **				
1.000617460-02	1.889363720-01	6.535470320-02	-6.171063250-03				

TRAJECTORY TERMINATED IN JUPITER REFERENCE   INHIBITOR IS 4.000000000D 00   TRAJ. COUNTER IS 61

SPACECRAFT MASS BREAKDOWN (KG)

INITIAL	PROPULSION	PROPELLANT	TANKAGE	STRUCTURE	RETRO PROP	RETRO STR	NET S/C
3.758695950 02	4.500000000D 01	2.980874110 01	8.942622330-01	0.0	0.0	0.0	3.001665920 02

PARTIAL DERIVATIVE MATRIX BY ROWS

-3.778950 00	-4.841310 00	-3.224970 02	2.588120-01	-1.791510-03
1.404320 00	1.488570 00	-3.621590 00	-2.361090-01	3.550500-06
-1.299480 00	-1.928190 00	4.952520-01	-7.173490-02	-1.967120-05
4.051450-01	-7.702300-03	4.514850-02	-2.977310-01	5.814820-06

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TRAJECTORY SUMMARY IT.   0. 24

INDEPENDENT PARAMETERS

     ** NAME APPLIES TO PARAMETERS, USED IN THE ITERATION
X (TO)          Y (TO)          Z (TO)          XDOT            YDOT            ZDOT            MSS TO
6.629296490-01  3.665389380-01  -6.905059570-01 -5.434267170 00 5.200156480 00  -2.453300790 00 3.758695930 02

C               PO              ALPHA           TO              BETA            DELTA           EPSLON          T1
2.400000000 04  1.500000000 03  0.0             0.0             2.700000000 02  0.0             9.000000000 01  1.200000000 01

THETA     **    PSI             PHI             T2        **    THETA           PSI             PHI             T3
-1.567609160 01 0.0             0.0             5.917316050 03  0.0             0.0             0.0             1.365000000 04

DL OMS    **    DL OML    **    DL INC          DL VPO    **    VPOO
2.018945860-06  -9.756402810-07 0.0             6.707721800-09  7.912588200 00

DEPENDENT PARAMETERS

FINAL MASS      NET S/C   **    THRUST          DST.FR.SUN      VL.WRT.SUN      SM.AXIS SN      FL.P.A.SUN      ECCENT.SUN
3.460608520 02  3.001665900 02  7.094005050-02  5.241044350 00  3.026255090-04  4.917953220 00  5.187869320 01  7.877501570-01

APCEN. SUN      PRICLN.SUN      DST.FR.TRG      VL.WRT.TRG      SM.AX.TRGT      FL.P.A.TGT      ECCENT.TRG      APCNT.TRGT
8.792080580 00  1.043835860 00  2.000156730-01  2.663509410-04  -7.425789320-03 -8.553679470 01  2.347307720 00  -2.485974920-02

PCENT.TRGT      X TARGET  **    Y TARGET  **    Z TARGET  **
1.000617060-02  1.889363680-01  6.535469740-02  -6.171053830-03

   TRAJECTORY TERMINATED IN JUPITER REFERENCE     INHIBITOR IS  3.200000000 01    TRAJ. COUNTER IS   64

SPACECRAFT MASS BREAKDOWN (KG)

 INITIAL        PROPULSION      PROPELLANT      TANKAGE         STRUCTURE       RETRO PROP      RETRO STR       NET S/C

3.758695930 02  4.500000000 01  2.980874070 01  8.942622210-01  0.0             0.0             0.0             3.001665900 02

PARTIAL DERIVATIVE MATRIX BY ROWS

-3.778950 00 -4.841310 00 -3.224970 02  2.588120-01 -1.791510-03

 1.404320 00  1.488570 00 -3.621590 00 -2.361 90-01  3.550600-06

-1.299480 00 -1.928190 00  4.952520-01 -7.173490-02 -1.967120-05

 4.051450-01 -7.702340-03  4.514900-02 -2.977310-01  5.819920-06
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TRAJECTORY SUMMARY ITERATION NO. 25

INDEPENDENT PARAMETERS

** NAME APPLIES TO PARAMETERS, USED IN THE ITERATION

X (TO)	Y (TO)	Z (TO)	XDOT	YDOT	ZDOT	MSS TO	
6.62929645D-01	3.66533894OD-01	-6.90505959D-01	-5.43426719D 00	5.23015649D 00	-2.45586075D 00	3.75869592D 02	
C	PO	ALPHA	TO	BETA	DELTA	EPSLON	T1
2.400000 0D 04	1.50000000D 03	0.0	0.0	2.70000000D 02	0.0	9.00000000D 01	1.20000000D 01
THETA **	PSI	PHI	T2 **	THETA	PSI	PHI	T3
-1.56760912D 01	0.0	0.0	5.91731593D 03	0.0	0.0	0.0	1.36500000D 04
DL CMS **	DL OML **	DL INC	DL VPO **	VP00			
4.40837343D-07	-2.66979284D-07	0.0	1.62224724D-09	7.91258821D 00			

DEPENDENT PARAMETERS

FINAL MASS	NET S/C **	THRUST	DST.FR.SUN	VL.WRT.SUN	SM.AXIS SN	FL.P.A.SUN	ECCENT.SUN
3.46060852D 02	3.00166590D 02	7.09400505D-02	5.24104485D 00	3.02625509D-04	4.91795323D 00	5.18786932D 01	7.87750158D-01
APCEN. SUN	PRICEN.SUN	DST.FR.TRG	VL.WRT.TRG	SM.AX.TRGT	FL.P.A.TGT	ECCENT.TRG	APCNT.TRGT
8.79208060D 00	1.04383588D 00	2.00015670D-01	2.66360941D-04	-7.42578730D-03	-8.56367742D 01	2.34730793D 00	-2.48597507D-02
PCENT.TRGT	X TARGET **	Y TARGET **	Z TARGET **				
1.00061721D-02	1.88936364D-01	6.53546981D-02	-6.17105265D-03				

TRAJECTORY TERMINATED IN JUPITER REFERENCE   INHIBITOR IS 1.28000000D 02   TRAJ. COUNTER IS 68

SPACECRAFT MASS BREAKDOWN (KG)

INITIAL	PROPULSION	PROPELLANT	TANKAGE	STRUCTURE	RETRO PROP	RETRO STR	NET S/C
3.75869592D 02	4.50000000D 01	2.98087406D 01	8.94262217D-01	0.0	0.0	0.0	3.00166590D 02

PARTIAL DERIVATIVE MATRIX BY ROWS

-3.77895D 00	-4.84131D 00	-3.22497D 02	2.58812D-01	-1.79151D-03
1.40432D 00	1.48857D 00	-3.62159D 00	-2.36109D-01	3.55060D-06
-1.29948D 00	-1.92815D 00	4.95252D-01	-7.17349D-02	-1.96712D-05
4.05145D-01	-7.70233D-03	4.51490D-02	-2.97731D-01	5.81982D-06

TRAJECTORY SUMMARY ITERATION NO. 26

INDEPENDENT PARAMETERS

** NAME APPLIES TO PARAMETERS, USED IN THE ITERATION

X (TO)	Y (TO)	Z (TO)	XDOT	YDOT	ZDOT	MSS TO	
6.62929641D-01	3.66538542D-01	-6.90505962D-01	-5.43426721D 00	5.20015649D 00	-2.45586070D 00	3.75869592D 02	
C	**PO**	**ALPHA**	**TO**	**BETA**	**DELTA**	**EPSLON**	**T1**
2.40000000D 04	1.50000000D 03	0.0	0.0	2.70000000D 02	0.0	9.00000000D 01	1.20000000D 01
THETA **	**PSI**	**PHI**	**T2 ****	**THETA**	**PSI**	**PHI**	**T3**
-1.56760909D 01	0.0	0.0	5.91731585D 03	0.0	0.0	0.0	1.36500000D 04
DL OMS **	**DL OML ****	**DL INC**	**DL VPO ****	**VPOO**			
4.64252273D-07	-2.36428542D-07	0.0	1.57474168D-09	7.91258821D 00			

DEPENDENT PARAMETERS

FINAL MASS	NET S/C **	THRUST	DST.FR.SUN	VL.WRT.SUN	SM.AXIS SN	FL.P.A.SUN	ECCENT.SUN
3.46060851D 02	3.00166589D 02	7.09400505D-02	5.24104485D 00	3.02625510D-04	4.91795824D 00	5.18786933D 01	7.87750158D-01
APCEN. SUN	**PRICEN.SUN**	**DST.FR.TRG**	**VL.WRT.TRG**	**SM.AX.TRGT**	**FL.P.A.TGT**	**ECCENT.TRG**	**APCNT.TRGT**
8.79208061D 00	1.04383586D 00	2.00015668D-01	2.66360941D-04	-7.42578929D-03	-8.55367942D 01	2.34730790D 00	-2.48597505D-02
PCENT.TRGT	**X TARGET ****	**Y TARGET ****	**Z TARGET ****				
1.00061719D-02	1.89336362D-01	6.53546972D-02	-6.17105132D-03				

TRAJECTORY TERMINATED IN JUPITER REFERENCE   INHIBITOR IS 1.29000000D 02   TRAJ. COUNTER IS 70

SPACECRAFT MASS BREAKDOWN (KG)

INITIAL	PROPULSION	PROPELLANT	TANKAGE	STRUCTURE	RETRO PRUP	RETRO STR	NET S/C
3.75869592D 02	4.50000000D 01	2.98087405D 01	8.94262214D-01	0.0	0.0	0.0	3.00166589D 02

PARTIAL DERIVATIVE MATRIX BY ROWS

-3.77895D 00	-4.84131D 00	-3.22497D 02	2.58812D-01	-1.79131D-03
1.40432D 00	1.48857D 00	-3.62159D 00	-2.36109D-01	3.55050D-06
-1.29548D 00	-1.92819D 00	4.95252D-01	-7.17349D-02	-1.96712D-05
4.05145D-01	-7.70232D-03	4.51490D-02	-2.97731D-01	5.81932D-06

TRAJECTORY SUMMARY ITERATION NO. 27

INDEPENDENT PARAMETERS

** NAME APPLIES TO PARAMETERS, USED IN THE ITERATION

X (TO)	Y (TO)	Z (TO)	XDOT	YDOT	ZDOT	MSS TO	
6.62929640D-01	3.66538943D-01	-6.90505962D-01	-5.43426722D 00	5.20015549D 00	-2.45586069D 00	3.75869592D 02	
C	PO	ALPHA	TO	BETA	DELTA	EPSLON	T1
2.40000000D 04	1.50000000D 03	0.0	0.0	2.70000000D 02	0.0	9.00000000D 01	1.20000000D 01
THETA **	PSI	PHI	T2 **	THETA	PSI	PHI	T3
-1.56760908D 01	0.0	0.0	5.91731585D 03	0.0	0.0	0.0	1.36500000D 04
DL OMS **	DL OML **	DL INC	DL VPO **	VPOO			
1.17772348D-07	-5.77709922D-08	0.0	3.91117628D-10	7.91258821D 00			

DEPENDENT PARAMETERS

FINAL MASS	NET S/C **	THRUST	DST.FR.SUN	VL.WRT.SUN	SM.AXIS SN	FL.P.A.SUN	ECCENT.SUN
3.46060851D 02	3.00166589D 02	7.09400505D-02	5.24104465D 00	3.02625510D-04	4.91795824D 00	5.18786933D 01	7.87750158D-01
APCEN. SUN	PRICEN.SUN	DST.FR.TRG	VL.WRT.TRG	SM.AX.TRGT	FL.P.A.TGT	ECCENT.TRG	APCNT.TRGT
8.79208062D 00	1.04333586D 00	2.00015667D-01	2.66360942D-04	-7.42678928D-03	-8.55367943D 01	2.34730788D 00	-2.43597503D-02
PCENT.TRGT	X TARGET **	Y TARGET **	Z TARGET **				
1.00061717D-02	1.88936362D-01	6.53540969D-02	-6.17105037D-03				

TRAJECTORY TERMINATED IN JUPITER REFERENCE   INHIBITOR IS 5.12000000D 02   TRAJ. COUNTER IS 74

SPACECRAFT MASS BREAKDOWN (KG)

INITIAL	PROPULSION	PROPELLANT	TANKAGE	STRUCTURE	RETRO PROP	RETRO STR	NET S/C
3.75869592D 02	4.50000000D 01	2.99087404D 01	6.94262213D-01	0.0	0.0	0.0	3.00166589D 02

PARTIAL DERIVATIVE MATRIX BY ROWS

-3.77895D 00	-4.84131D 00	-3.22497D 02	2.58812D-01	-1.79151D-03
1.40432D 00	1.48857D 00	-3.62159D 00	-2.36109D-01	3.55050D-06
-1.29948D 00	-1.92819D 00	4.95252D-01	-7.17349D-02	-1.96712D-05
4.05145D-01	-7.70232D-03	4.51490D-02	-2.97731D-01	5.81982D-06

TRAJECTORY SUMMARY ITERATION NO. 28

INDEPENDENT PARAMETERS

** NAME APPLIES TO PARAMETERS, USED IN THE ITERATION

X (T0)	Y (T0)	Z (T0)	XDOT	YDOT	ZDOT	MSS T0	
6.62929639D-01	3.66538944D-01	-6.90605963D-01	-5.43426722D 00	5.20015649D 00	-2.45536068D 00	3.75869592D 02	
C	P0	ALPHA	T0	BETA	DELTA	EPSLON	T1
2.40000000D 04	1.50000000D 03	0.0	0.0	2.70000000D 02	0.0	9.00000000D 01	1.20000000D 01
THETA **	PSI	PHI	T2 **	THETA	PSI	PHI	T3
-1.56760908D 01	0.0	0.0	5.91731583D 03	0.0	0.0	0.0	1.36500000D 04
DL OMS **	DL OML **	DL INC	DL VPO **	VP00			
1.17497330D-07	-5.78225938D-08	0.0	3.88818854D-10	7.91258821D 00			

DEPENDENT PARAMETERS

FINAL MASS	NET S/C **	THRUST	DST.FR.SUN	VL.WRT.SUN	SM.AXIS SN	FL.P.A.SUN	ECCENT.SUN
3.46060851D 02	3.00166589D 02	7.09400565D-02	5.24104485D 00	3.02625510D-04	4.91758824D 00	5.18786933D 01	7.87750158D-01
APCEN. SUN	PRICEN.SUN	DST.FR.TRG	VL.WRT.TRG	SM.AX.TRGT	FL.P.A.TGT	ECCENT.TRG	APCNT.TRGT
8.79208062D 00	1.04383586D 00	2.00015667D-01	2.66350942D-04	-7.42578928D-03	-8.56307943D 01	2.34730786D 00	-2.48597501D-02
PCENT.TRGT	X TARGET **	Y TARGET **	Z TARGET **				
1.00061716D-02	1.88936362D-01	6.53546956D-02	-6.17105062D-03				

TRAJECTORY TERMINATED IN JUPITER REFERENCE   INHIBITOR IS 5.12000000D 02   TRAJ. COUNTER IS 76

SPACECRAFT MASS BREAKDOWN (KG)

INITIAL	PROPULSION	PROPELLANT	TANKAGE	STRUCTURE	RETRO PROP	RETRO STR	NET S/C
3.75869592D 02	4.50000000D 01	2.98087404D 01	6.94262212D-01	0.0	0.0	0.0	3.00166589D 02

PARTIAL DERIVATIVE MATRIX BY ROWS

-3.77895D 00	-4.84130D 00	-3.22497D 02	2.58812D-01	-1.70151D-03
1.40432D 00	1.48857D 00	-3.62159D 00	-2.36109D-01	3.55056D-06
-1.29948D 00	-1.92919D 00	4.95252D-01	-7.17349D-02	-1.96712D-05
4.05145D-01	-7.70229D-03	4.51490D-02	-2.97731D-01	5.81982D-06

THIS CASE IS CONVERGED.

80 TRAJECTORIES WITHOUT PARTIAL DERIVATIVES AND 28 TRAJECTORIES WITH PARTIAL DERIVATIVES REQUIRED FOR THIS CASE.
CASE CONVERGED

FINAL TRAJECTORY

TRAJECTORY ARC DATA

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TIME IN DAYS, HRS.. MINS.. SECS.          0          0          0       0.0
    XR=   4.2282746145361220D 03    YR=   2.3376458669772420 03    ZR=  -4.4041609969061902D 03    RR=   6.5376190891701120 03
  XRDT=  -9.6279591730554260D 00  YRDT=   9.2131822541031430 00  ZRDT=  -4.3528507634801160 00  RRDT=   1.4018831436837830 01
  XVJP=   8.7591022759281660D 08  YVJP=   8.0238624942055810 07  ZVJP=  -1.7982533009304690 07  RVJP=   8.7976152178315020 08
    XI=   0.0                      ETA=   0.0                    ZETA=   0.0                       PERT=   0.0
  XIDT=   0.0                    ETADT=   0.0                  ZETADT=   0.0                      VPERT=   0.0

OSCULATING ELEMENTS AT TIME T=   0.0                          TRUE ANOM=   1.1774592449607860D-07
SEM MAJ AXIS=  -8.3798858177814990-01    ECCENT.    =   2.2233123535921830 00   PERICENT.=   6.5376190891701100 03
  APOCENT.  =  -1.7226003617197170 04   INCLINATION=   4.7883054732243070 01 ARG PERIC. =  -1.1474556218697400 02
  PERIOD    =   1.0300157437557130 00   MEAN MOT.  =   5.8176733396195370 03 RA ASC NODE=   1.5343798040605060 02
 M ANOMALY  =   8.9735244773175980-08   E ANOMALY  =   7.2537651074567450-08   T PERIC.  =  -2.6621261618877280-13
UNIT PERICENTER POSITION VECTOR =   6.4676062739225210-01   3.5759697085731640-01  -6.7356435774546580-01
UNIT ANGULAR MOMENTUM VECTOR    =   3.3169794312941980-01   6.5346364807411090-01   6.7054590055579680-01

TIME IN DAYS, HRS.. MINS.. SECS.          0         11         59      60.000
    XR=  -3.5003661732285440D 05    YR=   1.7276510592515030 05    ZR=   2.2070554858376450 03    RR=   3.9035561443123250 05
  XRDT=  -7.9152446530777830 00  YRDT=   3.7310991595374290 00  ZRDT=   2.2362576535205010-01  RRDT=   8.7534112256335520 00
  XVJP=   8.7441592141938290 06  YVJP=   8.1492777444080610 07  ZVJP=  -1.7979065434730140 07  RVJP=   8.7838826793924990 08
    XI=   3.9944370771033370 03    ETA=  -1.5382246063280650 00  ZETA=   4.5127453950670770-02  PERT=   4.1853035610916020 00
  XIDT=   4.1668193140263840-03 ETADT=  -1.6785705720557950-03ZETADT=   2.2504250014845450-05 VPERT=   4.4922735581042420-03

OSCULATING ELEMENTS AT TIME T=   1.2000000000000000 01 TRUE ANOM=   1.1518453764700270 02
SEM MAJ AXIS=  -8.3749936011360530-01    ECCENT.    =   2.2231358262769390 00   PERICENT.=   6.5372289724219740 03
  APOCENT.  =  -1.7226515620966760 04   INCLINATION=   4.7835537311704450 01 ARG PERIC. =  -1.1174783890101830 02
  PERIOD    =   1.0871532119649170 00   MEAN MOT.  =   5.8159443513615440 00 RA ASC NODE=   1.5343796757936060 02
 M ANOMALY  =   3.3970534461336460 03   E ANOMALY  =   2.4055019154042750 02   T PERIC.  =  -2.9373996364348710-04
UNIT PERICENTER POSITION VECTOR =   6.4675932262446970-01   3.5753393082029490-01  -6.7559053104824940-01
UNIT ANGULAR MOMENTUM VECTOR    =   3.3171774930299030-01   5.5352115734576550-01   6.7059899266359520-01

TIME IN DAYS, HRS.. MINS.. SECS.        246         13         18      56.985
    XR=  -4.3952319935958950D 08    YR=  -1.0435749374276370 08    ZR=   7.7315737298804500 06    RR=   4.5180034174298290 08
  XRDT=  -1.1121393377150600 01  YRDT=  -1.6485108492304630 01  ZRDT=   3.7487029548372770-01  RRDT=   2.0057391609606030 01
  XVJP=   3.4473325434816510 08  YVJP=   1.0533750170919930 08  ZVJP=  -1.0728348017051630 07  RVJP=   3.6459774350991400 08
    XI=   2.1827342012417940 04    ETA=  -1.3435260418041460 05  ZETA=   4.0243937769884760 04  PERT=   1.4194036171383000 05
  XIDT=   7.0279156225853680 01 ETADT=  -3.9312600154724700 02ZETADT=   1.1983339668315660 02 VPERT=   4.2261183734056730 02

OSCULATING ELEMENTS AT TIME T=   5.9173158292029250 03 TRUE ANOM=   1.1805191445564260 02
SEM MAJ AXIS=   1.1237977711943290 03    ECCENT.    =   7.7401754576030500-01   PERICENT.=   1.5197694275525910 08
  APOCENT.  =   1.2715743243404580 09   INCLINATION=   1.1115931822074550 00 ARG PERIC. =  -5.5454048897510240 01
  PERIOD    =   9.1937408334036070 04   MEAN MOT.  =   6.6341935553430870-05 RA ASC NODE=   1.3076214783399980 02
 M ANOMALY  =   2.2534465751252740 01   E ANOMALY  =   6.1472074950020680 01   T PERIC.  =   1.5931473487653580 02
UNIT PERICENTER POSITION VECTOR =   2.5346692498565800-01   9.5723602767612600-01  -1.5979091275749180-02
UNIT ANGULAR MOMENTUM VECTOR    =   1.4693726482164220-02   1.2665801150085930-02   9.9961180555677340-01

TIME IN DAYS, HRS.. MINS.. SECS.        563         18          0       0.0
    XR=   2.1264501301703420D 07    YR=   9.7769318300400020 05    ZR=  -9.2317570152103840 05    RR=   2.9921943678508690 07
  XRDT=  -1.0700354363095230 01  YRDT=  -2.3103361772600690 00  ZRDT=   3.4181947205400110-01  RRDT=   1.1068528723955550 01
  XVJP=   2.5263501304704200 07  YVJP=   9.7769318300400020 05  ZVJP=  -9.2317570152103840 05  RVJP=   2.9921943678508690 07
    XI=   1.7353187210723380 04    ETA=   2.0528962938019240 04  ZETA=  -3.4532066573173250 02  PERT=   2.6882913339849280 04
  XIDT=   1.8165237143306490 01 ETADT=   2.1543196256038800 02ZETADT=  -3.6343519817040000 00 VPERT=   2.8181732253648330 02

OSCULATING ELEMENTS AT TIME T=   1.3650000000000000 04 TRUE ANOM=  -1.1077365732214372D 02
SEM MAJ AXIS=  -1.7419437705335670 02    ECCENT.    =   2.3473077970132310 00   PERICENT.=   1.4969135007155600 06
  APOCENT.  =  -3.7132934585313300 05   INCLINATION=   1.7702331926755140 00 ARG PERIC. =   2.3559614292035880 01
  PERIOD    =   1.3137497104339970 02   MEAN MOT.  =   3.4503045007034000-02 RA ASC NODE=   1.0619351665410930 02
  M ANOMALY  =
```

INDEPENDENT PARAMETERS

** NAME APPLIES TO PARAMETERS, USED IN THE ITERATION

X (TO)	Y (TO)	Z (TO)	XDOT	YDOT	ZDOT	MSS TO	
6.62929638D-01	3.66538945D-01	-6.90505964D-01	-5.43426723D 00	5.20015649D 00	-2.45686667D 00	3.75869591D 02	
C	PO	ALPHA	TO	BETA	DELTA	EPSLON	T1
2.40000000D 04	1.50000000D 03	0.0	0.0	2.70000000D 02	0.0	9.00000000D 01	1.20000000D 01
THETA **	PSI	PHI	T2 **	THETA	PSI	PHI	T3
-1.56760908D 01	0.0	0.0	5.91731583D 03	0.0	0.0	0.0	1.36500000D 04
DL OMS **	DL OML **	DL INC	DL VPO **	VPOO			
1.17497330D-07	-5.78225938D-08	0.0	3.88818854D-10	7.91258821D 00			

DEPENDENT PARAMETERS

FINAL MASS	NET S/C **	THRUST	DST.FR.SUN	VL.WRT.SUN	SM.AXIS SN	FL.P.A.SUN	ECCENT.SUN
3.46060951D 02	3.00166589D 02	7.59400505D-02	5.24104485D 00	3.02625510D-04	4.91795524D 00	5.18786933D 01	7.87750159D-01
APCEN. SUN	PRICEN.SUN	DST.FR.TRG	VL.WRT.TRG	SM.AX.TRGT	FL.P.A.TGT	ECCENT.TRG	APCNT.TRGT
8.79208062D 00	1.04383586D 00	2.00015667D-01	2.66360942D-04	-7.42578328D-03	-9.56367944D 01	2.34720780D 00	-2.49597497D-02
PCENT.TRGT	X TARGET **	Y TARGET **	Z TARGET **				
1.00061711D-02	1.83935361D-01	6.53546961D-02	-6.17104975D-03				

TRAJECTORY TERMINATED IN JUPITER REFERENCE   INHIBITOR IS 2.62144000D 05   TRAJ. COUNTER IS 80

SPACECRAFT MASS BREAKDOWN (KG)

INITIAL	PROPULSION	PROPELLANT	TANKAGE	STRUCTURE	RETRO PROP	RETRO STR	NET S/C
3.75869591D 02	4.50000000D 01	2.98087404D 01	8.94262212D-01	0.0	0.0	0.0	3.00166589D 02

PARTIAL DERIVATIVE MATRIX BY ROWS

0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0

CASE SUMMARY

LAUNCH	TARGET
EARTH	JUPITER

CONSTRAINED MODE
S-VECTOR RELATIVE TO SUN

LAUNCH VEHICLE COEFFICIENTS			EFFICIENCY LAW COEFFICIENTS		PHOTON ABS. COEFF.	SPEC. ARRAY AREA
A1(KG)	A2(M/SEC)	A3(KG)	B	DSQ(M*M/SEC/SEC)	CA	XKP(M*M/W)
153208.05	2565.1258	53.34	0.7690	204490000.0	0.0	0.0

SPACECRAFT MASS BREAKDOWN (KG)

INITIAL	PROPULSION	PROPELLANT	TANKAGE	STRUCTURE	RETRO	NET S/C
3.758695910 02	4.500000000 01	2.980874040 01	8.94252212D-01	0.0	0.0	3.001665890 02

SPACECRAFT DESIGN FACTORS

N-VECTOR		S-VECTOR	
ALPHA(DEG)	BETA(DEG)	DELTA(DEG)	EPSILON(DEG)
0.0	270.000	0.0	90.000

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PROPULSION SYSTEM PARAMETERS

REF POWER(W)	REF THRUST(N)	EXHAUST SPEED(M/SEC)	EFFICIENCY	UNIT THRUSTER POWER(W)	ARRAY AREA(M**2)
1500.00	0.070940	24000.00	0.55752	0.0	0.0

TRAJECTORY SCHEDULE

TIME (DAYS)	0.500	246.555	568.752
THETA OR XI (DEG)	-15.676	0.0	
PSI OR NU (DEG)	0.0	0.0	
PHI OR ZETA (DEG)	0.0	0.0	
POWER DIVERTED (W)	0.0	0.0	
PSI MAX (DEG)	0.0	0.0	
THRUST	ON	OFF	

DEPARTURE AND ARRIVAL CONDITIONS

DATE	EXCESS SPEED(M/SEC)	C3 (KM**2/SEC**2)	DATE	EXCESS SPEED(M/SEC)	C3 (KM**2/SEC**2)
4570.0000	8636.33248	74.58624	5138.7500	10573.19966	114.04531