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COMPUTER PROGRAM TRAJECTORY OPTIMIZATION BY EXPLICIT NUMERICAL METHODS

By James W. Hilliard
Computation Laboratory

NASA

George C. Marshall Space Flight Center, Huntsville, Alabama

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ABSTRACT

The details are given of a computer program which calculates the minimum time required for a space vehicle to meet its mission while in an optimum trajectory. Also, the program can maximize an option if the burning time is fixed. The vehicle motion, assumed to be in a plane, is described by two linear differential equations. A precoded subroutine, Runge-Kutta Fourth Order, is used to integrate the equations of motion. Numerical methods are employed to determine the deviation in constraining functions explicitly in terms of first and second order variations in thrust angle. An iteration method is employed which, when computed, provides the effect of first and second order variations in addition to the usual numerical solution to the differential equations.

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James W. Hilliard

DIGITAL PROJECTS BRANCH

COMPUTATION LABORATORY

RESEARCH AND DEVELOPMENT OPERATIONS

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LIST OF ILLUSTRATIONS

DEFINITION OF SYMBOLS

Symbol	Definition
$\ddot{x}$	Horizontal component of acceleration
$\ddot{y}$	Vertical component of acceleration
$\dot{x}$	Horizontal component of velocity
$\dot{y}$	Vertical component of velocity
x	Horizontal component of distance
y	Vertical component of distance
v	Velocity of vehicle
r	Distance of vehicle from center of earth
θ	Angle of velocity vector from the vertical
Φ	Angle of departure
g_o	Gravity acceleration at initial time
r_o	Distance from center of earth at initial time
$\ddot{x}_g$	Horizontal drag component
$\ddot{y}_g$	Vertical drag component
T_i	Staging times
t_k	Integration times
Δt_k	Integration time intervals
ξ_k	$\frac{t_k + t_{k+1}}{2}$
$\Delta \xi_k$	$\xi_k - \xi_{k-1}$

DEFINITION OF SYMBOLS
(Continued)

Symbol	Definition
τ_k	$\frac{t_k - T_i}{100}$
a_i	Constant times force
b_i	Constant times mass
c_i	Constant times rate of change of mass
$\frac{f}{m}$	Thrust acceleration
ψ_k	Thrust angles
ψ_o	Thrust angle at initial time
$\Delta\psi_k$	Deviation of thrust angles
ψ_r	Thrust angle at cutoff
t'_r	$T_{n-1} - \frac{100b_n}{c_n}$
O_v	Orbital velocity
E_v	Escape velocity
E	Angular momentum
E_j	Radius 90^o from perigee

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COMPUTER PROGRAM TRAJECTORY OPTIMIZATION BY EXPLICIT NUMERICAL METHODS

SUMMARY

The details are given of a computer program which calculates the minimum time required for a space vehicle to meet its mission while in an optimum trajectory. Also, the program can maximize an option if the burning time is fixed. The vehicle motion, assumed to be in a plane, is described by two linear differential equations. A precoded subroutine, Runge-Kutta Fourth Order, is used to integrate the equations of motion. Numerical methods are employed to determine the deviation in constraining functions explicitly in terms of first and second order variations in thrust angle. An iteration method is employed which, when computed, provides the effect of first and second order variations in addition to the usual numerical solution to the differential equations.*

*See reference 1.

INTRODUCTION

The purpose of this report is to document a computer program "Trajectory Optimization by Explicit Numerical Methods." The program contains thirteen options with a maximum of eight additional constraints for each option and is applicable to space vehicles with one or more stages. There are three precoded subroutines that must be contained in the source deck.* Three select switches, SS 2, SS 3, and SS 4 are used for additional printed data. SS 2 is turned on if the conditions of power cutoff are desired. If SS 3 is turned on, data throughout the trajectory is printed for all iterations. If it is off, only the last iteration is printed. Turn SS 4 on for the data at every integration interval during the coast period. No disks, drums, or special tapes are used. The program language is FORTRAN IV and the computer is Control Data Corporation's 3200.

"Trajectory Optimization by Explicit Numerical Methods" was conceived and derived by Lyle R. Dickey, Technical and Scientific Staff, Aero-Astrodynamics Laboratory, George C. Marshall Space Flight Center.

* See Appendices I, II, and III.

ANALYSIS AND EQUATIONS

The results desired require the solution to the linearized equations which describe the motion of the vehicle. For analysis, the motion was assumed to be in a plane and described by the following differential equations:

$$\ddot{x} = \frac{f}{m} \sin\psi + \ddot{x}_g \ ,$$

$$\ddot{y} = \frac{f}{m} \cos\psi + \ddot{y}_g$$

where

$$\ddot{x}_g = \frac{x}{r} g \ ,$$

$$\ddot{y}_g = \frac{y}{r} g \ ,$$

$$g = -g_o \frac{r_o}{r^2} \ ,$$

$$g_o = 9.81 \ \frac{\text{meters}}{\text{second}^2} \ ,$$

$$r_o = 6370 \text{ KM} \ ,$$

$$r = \sqrt{x^2 + y^2} \ ,$$

$$v = \sqrt{\dot{x}^2 + \dot{y}^2} \ .$$

The analysis for $\frac{f}{m}$ and ψ are discussed on pages 5 and 6.

At each staging time (T_i) a_i, b_i, and c_i are given for i=1,2,3, ---,N.

The numerical method, Runge-Kutta Fourth Order, is used for integrating the equations of motion. DELT, the integration step size, and T_i are used to compute two tables of time, t_k and Δt_k.

$$t_k = t_{k-1} + \text{DELT},$$

$$\Delta t_k = \text{DELT}$$

for $T_i - t_k \geq \text{DELT}$.

If $T_i - t_k < \text{DELT}$,

then $t_k = T_i$

$$t_{k+1} = T_i \ ,$$

$$\Delta t_k = T_i - t_k,$$

$$\Delta t_{k+1} = 0.0.$$

For the case where $T_i - T_{i-1} \leq \text{DELT}$

then $t_k = T_{i-1} \ ,$

$$t_{k+1} = T_{i-1} \ ,$$

$$t_{k+2} = T_{i-1} + \frac{1}{2} (T_i - T_{i-1}) \ ,$$

$$t_{k+3} = T_i \ ,$$

$$t_{k+4} = T_i \ ,$$

$$\Delta t_k = 0.0 \ ,$$

$$\Delta t_{k+1} = \frac{1}{2} (T_i - T_{i-1}) \ ,$$

$$\Delta t_{k+2} = t_{k+1} \ ,$$

$$\Delta t_{k+3} = 0.0.$$

The end points are required to be the same.

$$t_1 = T_1 \ ,$$

$$t_n = T_N \ .$$

Briefly stated, the t table is discontinuous at each staging time.

An added input value of time, T2, is used for calculating the t table into irrational numbers.*

The thrust angles, ψ_k, are computed as follows:

$$\psi_k = \psi_o + (\psi_n - \psi_o) \left[\frac{t_k - t_1}{t_n - t_1} \right]$$

where

$$\psi_o = \tan^{-1} \left[\frac{\dot{x}_o y_o - \dot{y}_o x_o}{x_o \dot{x}_o + y_o \dot{y}_o} \right] \ ,$$

*See Deck Setup Instructions for choosing a proper value for T2

$$\psi_n = \theta_n \ ,$$

$$t'_n = T_N - \frac{100 b_N}{C_N} \qquad \text{(A)}$$

and x_o, y_o, $\dot{x}_o$ and $\dot{y}_o$ are initial conditions for integration.

Thrust, $\frac{f}{m}$, is described by the following:

$$\frac{f}{m_k} = \frac{a_i}{b_i + C_i \tau_k}$$

where $$\tau_k = \frac{t_k - T_i}{100} \ .$$

Runge-Kutta requires the ψ angles to be computed once at t_k, twice at $t_k + \frac{1}{2}\Delta t_k$, and once at t_{k+1}. Three point interpolation is used to compute ψ at $t_k + \frac{1}{2}\Delta t_k$.

$$t = t_k + \frac{1}{2}\Delta t_k \ ,$$

$$C_1 = \frac{(t-t_{k+1})(t-t_k)}{(t_{k-1}-t_{k+1})(t_{k-1}-t_k)} \ ,$$

$$C_2 = \frac{(t-t_{k+1})(t-t_{k-1})}{(t_k-t_{k+1})(t_k-t_{k-1})} \ ,$$

$$C_3 = \frac{(t-t_k)(t-t_{k-1})}{(t_{k+1}-t_k)(t_{k+1}-t_{k-1})} \ ,$$

then $\psi = C_1\psi_{k-1} + C_2\psi_k + C_3\psi_{k+1}$.

For iteration there are six other tables computed at $t_k + \frac{1}{2}\Delta t_k$.

$$\xi_k = \frac{t_{k-1}+t_k}{2} \quad ,$$

$$\Delta\xi_k = \xi_k - \xi_{k-1} \quad ,$$

$$\bar{h}_1 = -\frac{g_o r_o^2}{r^3}\left[1-3\left(\frac{x}{r}\right)^2\right] \quad ,$$

$$\bar{h}_2 = \frac{g_o r_o^2}{r^3}\left[\frac{3xy}{r^2}\right] \quad ,$$

$$\bar{K}_1 = \bar{h}_2 \quad ,$$

$$\bar{K}_2 = -\frac{g_o r_o^2}{r^3}\left[1-3\left(\frac{y}{r}\right)^2\right] \quad .$$

The following matrix is defined for iteration:

$$U(t_k, t_{k+1}) = I + A(\zeta_k)\Delta t_k \quad ,$$

for $k = 1,2,3,---,n,$

and

$$A(\zeta_k) = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ \bar{h}_1 & \bar{h}_2 & 0 & 0 \\ \bar{K}_1 & \bar{K}_2 & 0 & 0 \end{bmatrix} \quad .$$

The cutoff options and additional constraints are defined and stored in a single array, Z.

Option 1. $Z_1 = \text{Time} = t_k$

2. $Z_2 = x = \int f(\dot{x})dt$

3. $Z_3 = y = \int f(\dot{y})dt$

4. $Z_4 = \dot{x} = \int f(\ddot{x})dt$

5. $Z_5 = \dot{y} = \int f(\ddot{y})dt$

6. $Z_6 = r = \sqrt{x^2+y^2}$

7. $Z_7 = v = \sqrt{\dot{x}^2+\dot{y}^2}$

8. $Z_8 = \theta = \tan^{-1} \frac{\dot{x}y-\dot{y}x}{x\dot{x}+y\dot{y}}$

9. $Z_9 = \Phi = \tan^{-1}\left(\frac{x}{y}\right)$

10. $Z_{10} = O_v = v^2 - \frac{g_o r_o^2}{r}$

11. $Z_{11} = E_v = \frac{1}{2} v^2 - \frac{g_o r_o^2}{r}$

12. $Z_{12} = E = \dot{x}y - \dot{y}x$

13. $Z_{13} = E_j = r - \frac{Z_{12}^2}{g_o r_o^2}$

A 13x4 matrix is defined by placing into its rows

Time $C_1 = [\ 0 \quad 0 \quad 0 \quad 0\ ]$

x $C_2 = [\ 1 \quad 0 \quad 0 \quad 0\ ]$

y $C_3 = [\ 0 \quad 1 \quad 0 \quad 0\ ]$

$\dot{x}$ $\quad C_4 = [\ 0 \quad 0 \quad 1 \quad 0\ ]$

$\dot{y}$ $\quad C_5 = [\ 0 \quad 0 \quad 0 \quad 1\ ]$

r $\quad C_6 = [\ \frac{x}{r} \quad \frac{y}{r} \quad 0 \quad 0\ ]$

v $\quad C_7 = [\ 0 \quad 0 \quad \frac{\dot{x}}{r} \quad \frac{\dot{y}}{r}\ ]$

θ $\quad C_8 = [\ \frac{xv\cos\theta - \dot{x}r}{r^2 v\sin\theta} \quad \frac{yv\cos\theta - xv}{r^2 v\sin\theta} \quad \frac{\dot{x}r\cos\theta - xv}{rv^2\sin\theta} \quad \frac{\dot{y}r\cos\theta - yv}{rv^2\sin\theta}\ ]$

Φ $\quad C_9 = [\ \frac{1}{y}\left(1 - \frac{x^2}{y^2}\right) \quad -\frac{x}{r^2} \quad 0 \quad 0\ ]$

O_v $\quad C_{10} = [\ -\frac{g_o r_o^2 x}{r^3} \quad -\frac{g_o r_o^2 y}{r^3} \quad 2\dot{x} \quad 2\dot{y}\ ]$

E_v $\quad C_{11} = [\ -\frac{g_o r_o^2 x}{r^3} \quad -\frac{g_o r_o^2 y}{r^3} \quad \dot{x} \quad \dot{y}\ ]$

E $\quad C_{12} = [\ -\dot{y} \quad \dot{x} \quad y \quad -x\ ]$

E_j $\quad C_{13} = [\ \frac{x}{r} + \frac{2\dot{y}Z_{12}}{g_o r_o^2} \quad \frac{y}{r} - \frac{2\dot{x}Z_{12}}{g_o r_o^2} \quad -\frac{2yZ_{12}}{g_o r_o^2} \quad \frac{2xZ_{12}}{g_o r_o^2}\ ]$

$$\bar{Z}_{pm} = Z_{pm}$$

and

$$Z^*_{qm} = Z_{qm}$$

where p and q are the numbers that specify power cutoff and coast cutoff options respectively for $m=1,2,3,---,M_2$.

$\overline{K}_{pm}$ and K^*_{pm} are the values of power and coast cutoff limits for each option for $m=1,2,3,---,M_2$.

$\overline{T}$ is defined when $\overline{Z}_{pm} = \overline{K}_{pm}$,

at this time set $\frac{f}{m} = 0.0$ and integrate to

T^*_m , defined when $Z^*_{pm} = K^*_{pm}$.

$\overline{TL}_{pm}$ and TL^*_{pm} are tolerances for the options.

$$P^*_m = \frac{-C_{qm}(T^*_m)}{C_{qm}(T^*_m)\dot{x}(T^*_m)}$$

where $$\dot{x}(T^*_m) = \begin{bmatrix} \dot{x}_n \\ \dot{y}_n \\ \ddot{x}_n \\ \ddot{y}_n \end{bmatrix} .$$

The additional constraints are chosen such that

$$P(r_{mj}) = Cr_{mj}(T^*_m)\left[I + \dot{x}(T^*_m)P^*_m\right]$$

for $j = 1,2,3,---,N_m$

then $$P_m = \begin{bmatrix} P(r_{m1}) \\ P(r_{m2}) \\ P(r_{m3}) \\ \cdot \\ \cdot \\ P(r_{mN_m}) \end{bmatrix} .$$

$$\hat{P} = C_{\hat{q}}(T_m^*) \quad , \tag{B}$$

then $$Q = P_{M_2}^*$$

or $$Q = \hat{P} \quad .$$

If $\hat{P}$ is used, then $\hat{q}$ must be the number which specifies the time option, $q = 1$.

$$h_1(t) = QU(T_{M_2}^*, t)H_1(t) \quad ,$$

$$h_2(t) = QU(T_{M_2}^*, t)H_2(t)$$

where $H_1 = \frac{f}{m}(t)$ $\begin{bmatrix} 0 \\ 0 \\ \cos\psi \\ -\sin\psi \end{bmatrix}$,

and $H_2 = \frac{1}{2}\left(\frac{f}{m}\right)$ $\begin{bmatrix} 0 \\ 0 \\ -\sin\psi \\ -\cos\psi \end{bmatrix}$.

$$F_m(t) = \left\{ \begin{array}{ll} P_m U(T_m^*, t)H_1(t), & t_o \le t \le \overline{T} \\ 0.0 \quad , & \overline{T} \le t \le T_{M_2}^* \end{array} \right\} \quad ,$$

$$G_m(t) = \left\{ \begin{array}{ll} P_m U(T_m^*, t) H_2(t), & t_o \le t \le \bar{T} \\ 0.0\ , & \bar{T} \le t \le T^* \end{array} \right\} ,$$

then $$F(t) = \begin{bmatrix} F_1(t) \\ F_2(t) \\ \cdot \\ \cdot \\ F_{M_2}(t) \end{bmatrix} ,$$

and $$G(t) = \begin{bmatrix} G_1(t) \\ G_2(t) \\ \cdot \\ \cdot \\ G_{M_2}(t) \end{bmatrix} .$$

$$B = \int_{t_o}^{t_n} F(t)F'(t)dt = \sum_{k=0}^{n} F(t)F'(t)\Delta\xi_k ,$$

$$\bar{Q} = -\int_{t_o}^{t_n} F(t)h_1(t)dt = -\sum_{k=0}^{n} F(t)h_1(t)\Delta\xi_k ,$$

$$\lambda = B^{-1}\bar{Q} ,$$

$$\epsilon(t) = h_1(t) + \lambda' F(t),$$

$$h^*(t) = h_2(t) + \lambda' G(t).$$

$$Z = \begin{bmatrix} Zr_{11}(T_1^*) \\ Zr_{12}(T_1^*) \\ \cdot \cdot \cdot \\ Zr_{1N_1}(T_1^*) \\ Zr_{21}(T_2^*) \\ Zr_{22}(T_2^*) \\ \cdot \cdot \cdot \\ Zr_{M_2NM_2}(T_{M_2}^*) \end{bmatrix}$$

then $\Delta Z = K_L - Z$

where $K_L = \begin{bmatrix} K_1 \\ K_2 \\ \cdot \\ \cdot \\ K_{NM} \end{bmatrix}$.

K_L, given by the user, are the limits of the additional constraints.

$$|\epsilon(t_k)| < E_o \quad , \tag{C}$$

$$|\Delta Z| < El_L \tag{D}$$

for $L = 1,2,3,---,N_M$. E_o and El_L are tolerances given by the user.

If conditions C and D are not satisfied, then,

$$\bar{F} = -\frac{F}{2h_2^*} \quad ,$$

$$\epsilon = \frac{\epsilon}{2h_2^*} \quad ,$$

$$\bar{B} = \int_{t_o}^{t_n} F(t)\bar{F}'(t)dt = \sum_{k=1}^{n} F(t_k)\bar{F}'(t_k)\Delta\xi_k \quad ,$$

$$\epsilon_n = \int_{t_o}^{t_n} F(t)\bar{\epsilon}(t)dt = \sum_{k=1}^{n} F(t_k)\bar{\epsilon}(t_k)\Delta\xi_k \quad ,$$

$$\Delta\lambda = \bar{B}^{-1}\left[\epsilon_n + \Delta Z\right] \quad ,$$

$$\Delta\psi = -\bar{\epsilon}(t) + \Delta\lambda'\bar{F}(t) \quad .$$

then $\psi = \psi + \Delta\psi$,

return to integration with all the initial conditions and repeat the iteration until conditions C and D are satisfied.

DOCUMENTATION CHECKLIST

JOB NUMBER 560490

Project:	Have It	Remarks
1125	X	
Program Development Charts	X	
Original Problem from Customer	X	
Correspondence	X	
Check Case	X	
Documentation Checklist	X	
Problem:		
*Abstract	X	
*Technical Description	X	
Equations	X	
Definition of Terms	X	
Special Options	X	
Numerical Methods for Solution	X	
Technical References	X	
Related Projects	X	
Programming:		
Library Subroutines	X	
Program Subroutines	X	
Special Input Form	X	
Special Input Tape Contents		None Used
Special Output Tape Contents		None Used
Plots Generated		None
Method of Verification	X	
*Block Diagram	X	
Flow Charts	X	
*Program Listing	X	
Deck Setup:		
*Computer Configuration	X	
*Estimated Running Time	X	
*Restart Procedure		No Capability
*Deck Sequence	X	
*Required Input Data	X	
*Restrictions & Limitations	X	
*Diagnostics		None Printed
*Normal Output Quantity	X	
*Definition of Output	X	
*Sample Operator Instruction Card	X	
*Sample Save Label		Not Applicable
*Sample Input Form	X	
*Sample Output	X	
*Sample Plots		None Used
Decks:		Location of
Symbolic	X	Bldg. 4200, Rm. G24
Binary	X	Bldg. 4200, Rm. G24
Data	X	Bldg. 4200, Rm. G24

Prepared by: James W. Hilliard — Programmer — Date

Approved by: Joseph Scollard — Programming Mgr. — Date

DECK SETUP INSTRUCTIONS

All the input data must appear sequentially in the data deck as shown in Table 3. The user may not be concerned with T_N that must satisfy Equation A. T_N, A_N, B_N, and C_N must be added for all cases.

$$T_N \leq T_1 + \text{DELT } [175-2(N+NO)] ,$$

$$A_N = A_{N-1} ,$$

$$B_N = B_{N-1} ,$$

$$C_N = C_{N-1} ,$$

Where N=1 + number of stages and 175 is the largest allowable number of storages for each single array variable.

NO is the number of options and NR is the maximum number of constraints being used. NC=0 if Equation B is not used and will equal $\hat{q}$ for all other cases. The value of $\hat{q}$ will be the number of the variable being maximized. IO is the number of the cutoff option for which the weighting functions will be computed. IO=1,2,3,---,8. NRUN=0 for the last case in a stack. EO is the tolerance for $\epsilon(t_k)$.

T2 is the second value of the t table desired to irrationalize all the values.

$$T2 = t_2$$

and

$$T2 - T_1 \leq DELT.$$

The numbers for power cutoff, N6(I), coast cutoff options, N5(I), and the constraints, N2(I,J), can be obtained from the Z array.

Refer to the Example Case and Data Package Card Arrangement, Table 4, for data instructions of all variables.

SAMPLE INPUT

x_o = 236255.46

y_o = 6456667.82

$\dot{x}_o$ = 2800.5746

$\dot{y}_o$ = 635.94317

T_1 = 184.99481

T_2 = 412.5503

T_3 = 523.87973

T_4 = 528.87973

a_1 = 10.787315

a_2 = 8.92405155

a_3 = 10^{-20}

a_4 = 1.96132994

b_1 = 1.2867664

b_2 = 0.69140715

b_3 = 1.0

b_4 = 0.36021199

c_1 = -0.261282644

c_2 = -0.212616813

c_3 = 0.0

c_4 = 0.046948359

Δt = 5.0

Δt_c = 5.0

SAMPLE INPUT
(Continued)

$\hat{q}$ = 7

r_o = 6370000.0

g_o = 9.81

θ_c = 1.5707963

$\overline{K}_1$ = 412.85503 for time (t_k)

$\overline{K}_2$ = 773.599673 for time (t_k)

K_1^* = 6370000.0 for radius (r_k)

K_2^* = 773.599673 for time (t_k)

p_1 = 1

p_2 = 1

g_1 = 6

g_2 = 1

$\overline{TL}_1$ = 0.01

$\overline{TL}_2$ = 0.01

TL_1^* = 0.1

TL_2^* = 0.01

E_o = 10^{-5}

$K_{1,1}$ = 5971137.6 constraint for (y_k)

$K_{2,1}$ = 6552000.0 constraint for (r_k)

$K_{2,2}$ = 1.5707963 constraint for (θ_k)

$EL_{1,1}$ = 0.1

$EL_{2,1}$ = 0.1

$EL_{2,2}$ = 10^{-5}

This is a four stage vehicle, because there are four T points.

$$N = 1 + 4.$$

There are two options for power cutoff and coast cutoff.

$$NO = 2.$$

The maximum number of additional constraints used is two.

$$NR = 2.$$

Equation B is used because $\hat{q}$ is given and NC = $\hat{q}$ if given, otherwise NC = 0.

$$NC = 7$$

The last option is used to compute the weighting functions.

$$IO = 2$$

There is only one case.

$$NRUN = 0.$$

$$EO = 1.0 \times 10^{-5}$$

$$T2 = 185.0.$$

From the Z array the time option is 1 and the radius option is 6.

N6(1) = 1

N6(2) = 1

N5(1) = 6

N5(2) = 1.

N2(1,1) = 3

N2(2,1) = 6

N2(2,2) = 8

AKB(1) = 412.85503

AKB(2) = 773.599673

AKS(1) = 6370000.0

AKS(2) = 773.599673

TOL1(1) = 0.01

TOL1(2) = 0.01

TOL6(1) = 0.1

TOL6(2) = 0.01

CK(1,1) = 5971137.6

CK(2,1) = 6552000.0

CK(2,2) = 1.5707963

E1(1,1) = 0.1

E1(2,1) = 0.1

E1(2,2) = 10^{-5}

T(I)	A(I)	B(I)	C(I)
184.99481	10.787315	1.2878664	-0.261282644
412.5503	8.92405155	0.69140715	-0.212616813
523.87973	10^{-20}	1.0	0.0
528.87973	1.96132994	0.36021199	-0.046948359
800.0	1.96132994	0.36021199	-0.046948359

XO = 236255.46

YO = 6456667.82

XDO = 2800.5746

YDO = 635.94317

SGO = 9.81

RO = 6370000.0

DELT = 5.0

THC = 1.5707963

This example maximizes the velocity because the burning time is fixed at 773.599673 seconds.

TABLE 1

COMPUTER REQUIREMENTS AND USER INFORMATION

Floating point	Hardware
32,000 storage locations	Hardware
FORTRAN IV compiler	Software
Subroutine library	Software
Job Number	560490
Estimated running time	
SS 2 On	0.176 hours
SS 2 Off	0.075 hour
Restart procedure	No capability
Deck sequence	See computer Listings
Restrictions	See Introduction and Deck Setup Instructions
Printed diagnostics	None
Originator	Lyle R. Dickey, Technical & Scientific Staff, Aero-Astrodynamics Laboratory

TABLE 2

PROGRAM INPUT DATA

Formula Notation	Computer Language Notation	Units of Measurement	Remarks
N	N		Number of staging times
M_2	NO		Number of options
N_{M_2}	NR		Number of max. constraints
q	NC		NC≠0 if equation B is used
	IO		Number for the weighting function option
	NRUN		Number of cases
E_o	EO		Tolerance for $E(t_k)$
	T2	seconds	Desired t_2 value
p	N6(I)		Numbers of power cutoff options
g	N5(I)		Numbers of coast cutoff options
r_{m_j}	N2(I,J)		Numbers of additional constraints
$\bar{k}_{Pm}$	AKB(I)	see Tbl 3	Values of power cutoff limits
k^*_{gm}	AKS(I)	see Tbl 3	Values of coast cutoff limits
t_c	DTA(I)	seconds	Integration increment for coast
$\overline{TL}$	TOL1(I)	see Tbl 3	Tolerance for power cutoff
TL^*	TOL6(I)	see Tbl 3	Tolerance for coast cutoff
K	CK(I,J)	see Tbl 3	Values of cutoff constraint limits

TABLE 2

PROGRAM INPUT DATA
(Continued)

Formula Notation	Computer Language Notation	Units of Measurement	Remarks
EL_L	El(I)	see Tbl 3	Tolerance for ΔZ
T_i	T(I)	seconds	Staging times
a_i	A(I)	Newtons	Constant times force
b_i	B(I)	mass	Constant times mass
c_i	C(I)	mass/seconds	Constant times $\dot{m}$
x_o	XO	meters	Horizontal initial distance
y_o	YO	meters	Vertical initial distance
$\dot{x}_o$	XDO	meters/second	Horizontal initial velocity
$\dot{y}_o$	YDO	meters/second	Vertical initial velocity
g_o	SGO	meters/second^2	Initial gravity acceleration
r_o	RO	meters	Initial distance from center of earth
Δt	DELT	seconds	Power integration increment
θ_c	THC	radians	Velocity vector angle at cutoff

TABLE 3

UNITS OF MEASUREMENT

	$\overline{K}$, K^*, K, El, $\overline{TL}$, and TL^*
t_k	Seconds
x	Meters
y	Meters
$\dot{x}$	Meters/Second
$\dot{y}$	Meters/Second
r	Meters
v	Meters/Second
Θ	Radians
Φ	Radians
O_v	$Meters^2/Second$
E_v	Meters/Second
E	$Mass^2/Seconds$
E_j	Meters

TABLE 4

DATA PACKAGE CARD ARRANGEMENT

Card Number	Variable	Data Field	Remarks
1	N	1-5	Number of stages + 1
1	NO	6-10	Number of options
1	NR	11-15	Number of constraints
1	NC	16-20	0 if equation B is not used
1	NRUN	21-25	0 for last case in a stack
1	IO	26-30	Number of weighting function option
1	EO	31-45	Tolerance for $\mathcal{C}(t_k)$
1	T2	46-60	Value of t_2 desired
2	N6(1)	1-5	
2	N6(2)	6-10	Numbers for power
•	•	•	Cutoff options,
•	•	•	I = 1,2,3,---,NO
2	N6(I)	•	
3	N5(1)	1-5	
3	N5(2)	6-10	Numbers for coast
•	•	•	Cutoff options,
•	•	•	I = 1,2,3,---,NO
3	N5(I)	•	

TABLE 4

DATA PACKAGE CARD ARRANGEMENT
(Continued)

Card Number	Variable	Data Field	Remarks
4	N2(1,1)	1-5	
4	N2(1,2)	6-10	Numbers for
.	.	.	additional constraints
.	.	.	I = 1,2,3,---,NO
4	N2(1,J)	.	
5	N2(2,1)	1-5	J = 1,2,3,---,NR
5	N2(2,2)	6-10	
.	.	.	
.	.	.	
NO+3	N2(I,J)	.	
NO+4	AKB(1)	1-15	First power cutoff value
NO+4	AKS(1)	16-30	First coast cutoff value
NO+4	DTA(1)	31-45	First coast integration increment
NO+4	TOL1(1)	46-60	First power cutoff tolerance
NO+4	TOL6(1)	61-75	First coast cutoff tolerance
NO+5	AKB(2)	1-15	Second power cutoff value
NO+5	AKS(2)	16-30	Second coast cutoff value
.	.	.	.
.	.	.	.

TABLE 4

DATA PACKAGE CARD ARRANGEMENT
(Continued)

Card Number	Variable	Data Field	Remarks
2NO+3	TOL6(I)	61-75	I = 1,2,3,---,NO
2NO+4	CK(1,1)	1-15	First constraint value for first option
2NO+4	E1(1,1)	16-30	Tolerance for first constraint value
2NO+5	CK(1,2)	1-15	Second constraint value for first option
2NO+5	E1(1,2)	16-30	Tolerance for second constraint value
2NO+6	CK(1,J)	1-15	Third constraint value for first option
.	.	.	.
.	.	.	.
2NO+LC*	E1(I,J)	16-30	Tolerance for last constraint value
2NO+LC+1	T(1)	1-15	Initial time
2NO+LC+1	A(1)	16-30	Initial force constant
2NO+LC+1	B(1)	31-45	Initial mass constant
2NO+LC+1	C(1)	46-60	Initial $\dot{m}$ constant
.	.	.	.
	.	.	.
2NO+N+LC	T(N)	1-15	Calculated T(N)
2NO+N+LC	A(N)	16-30	A(N-1)
2NO+N+LC	B(N)	31-45	B(N-1)
2NO+N+LC	C(N)	46-60	C(N-1)

*LC = total number of constraints used for one case.

TABLE 4

DATA PACKAGE CARD ARRANGEMENT
(Continued)

Card Number	Variable	Data Field	Remarks
2NO+N+LC+1	XO	1-15	Initial horizontal distance
2NO+N+LC+1	YO	16-30	Initial vertical distance
2NO+N+LC+1	XDO	31-45	Initial horizontal velocity
2NO+N+LC+1	YDO	46-60	Initial vertical velocity
2NO+N+LC+2	SGO	1-15	Gravity at initial time
2NO+N+LC+2	RO	16-30	Initial radius
2NO+N+LC+2	DELT	31-45	Integration increment
2NO+N+LC+2	THC	46-60	Θ for power cutoff at T(N)

INPUT CARD FORM

CARD NUMBER	Columns 1–15	Columns 16–30	Columns 31–45	Columns 46–60	Columns 61–80
1	5 2 2	7 2 0	0.0001	185.	
2	1 1				
3	6 1				
4	3 0				
5	6 8				
6	412.85503	6370000.0	5.0	0.01	0.1
7	773.599673	773.599673	5.0	0.01	0.01
8	597137.6	0.1			
9	6552000.0	0.1			
10	1.5707963	0.00001			
11	184.99481	10.787315	1.2867664	-0.26128264 4	
12	412.5503	8.92405155	0.69140715	-0.21261681 3	
13	523.87973	1.0E-20	1.0	0.0	
14	528.87973	1.96132994	0.36021199	-0.04694835 9	
15	800.0	1.96132994	0.36021199	-0.04694835 9	
16	236255.46	6456667.82	2800.5746	635.94317	
17	9.81	6370000.0	5.0	1.5707963	

TABLE 5

OUTPUT NOTATION

Notation	Definition	Units
TIME	t_k	Seconds
DELT	Δt_k	Seconds
ETAT	ξ_k	Seconds
DETT	$\Delta\xi_k$	Seconds
CHI	ψ_k	Degrees
DCHI	$\Delta\psi_k$	Degrees
X	x	Meters
Y	y	Meters
XD	$\dot{x}$	Meters/Second
YD	$\dot{y}$	Meters/Second
XDD	$\ddot{x}$	Meters/Second^2
YDD	$\ddot{y}$	Meters/Second^2
RAD	r	Meters
VEL	v	Meters/Second
THETA	θ	Degrees
PHI	Φ	Degrees
OVEL	O_v	(Meters/Second)^2
EVEL	E_v	(Meters/Second)^2

TABLE 5

OUTPUT NOTATION
(Continued)

Notation	Definition	Units
ENEG	E	$Mass^2/Seconds$
ENG	E_j	Meters
HB1	$\bar{h}_1$	$^1/Seconds^2$
HB2	$\bar{h}_2$	$^1/Seconds^2$
KB1	$\bar{k}_1$	$^1/Seconds^2$
KB2	$\bar{k}_2$	$^1/Seconds^2$
FOM	$\frac{f}{m}$	$Meters/Second^2$
HS1	h_1	$^1/Radians$
HS2	h_2	$^1/Radians^2$
H2S	h_2^*	$^1/Radians^2$
EPS	ϵ_k	$^1/Radians$
DRAGX	$\ddot{x}_g$	$Meters/Second^2$
DRAGY	$\ddot{y}_g$	$Meters/Second^2$

APPENDIX I

RUNKUT

Runge-Kutte Integration
INO

WRITTEN BY: C. R. Wallace

PURPOSE: To numerically integrate a set of first and second order differential equations.

DESCRIPTION: This FORTRAN subroutine uses the fourth order Runge-Kutta integration formulas (Hildebrand, page 238) to numerically integrate a set of differential equations which may be solved for the highest order derivatives of each variable. There must be only one independent variable.

USAGE: The subroutine must be called four times for each time step. The calling sequence is:

```
CALL RUNKUT (NEQ,NSO,H,X,F,Y,YP,FK,AY,AYP,SUM1,SUM2,IND)
```

NEQ - Number of equations
NSO - Number of second order equations
H - Step Size
X - Independent variable
F - Highest order derivatives (a block of NEQ values)
Y - Dependent variables (a block of NEQ values)
YP - First derivatives of dependent variables (second order equations only) (NSO values)
FK,AY,AYP,SUM1,SUM2 - Auxiliary block storage (NEQ values of FK,AY, SUM2; NEQ values of AYP and SUM1)
IND - Indicator for which of the four passes is being made through the subroutines; i.e., IND = 1,2,3, or 4.

In order to have all values (including any variables computed from intermediate equations) correct at each time step it is recommended that subroutine RUNKUT be called before the highest order derivatives are computed.

Example: Suppose the equation

$$u'' = g_1\ (u',\ u,\ v,\ w',\ w,\ t)$$
$$v' = g_2\ (u',\ u,\ v,\ w',\ w,\ t)$$
$$w'' = g_3\ (u',\ u,\ v,\ w',\ w,\ t)$$

are to be integrated for 100 steps with a step size of .1. This could be coded as follows:

```
      ⋮
      EQUIVALENCE (u", F(1)), (w", F(2)), (v', F(3)),
                  (u, Y(1)),  (w, Y(2)),  (v, Y(3)),
                 (u', YP(1)),(w', YP(2))
      DIMENSION F(3), Y(3), YP(2), FK(3), AY(3), AYP(3),
                SUM1(3), SUM2(3)
      NEQ = 3
      NSO = 2
      H = .1
      X = 0.
      NP = 101
      DO 1 I = 1, NP
      IF (I-1) 2, 3, 2
3     IND = 4
      GO TO 4
2     IND = 1
5     CALL RUNKUT (NEW,NSO,H,X,F,Y,YP,FK,AY,AYP,SUM1,SUM2,IND)
4     u" = g1
      v' = g2
      w" = g3
      IND = IND + 1
      IF (IND - 4) 5, 5, 6
6     (any desired coding)
1     CONTINUE
      ⋮
```

RESTRICTIONS: Equations may not be higher than second order. If there are both first and second order equations, the variables from the second order equations should be placed first in the blocks. The error is of the order of H^5 times the fifth derivative of the dependent variable.

TIMING: The computation within the subroutine would require less than one second for 4 equations for 100 time steps.

APPENDIX II

SUBROUTINE: Matrix Inverse

WRITTEN BY:

MODIFIED BY: Sylvia Bryant

PURPOSE: Compute the inverse of a matrix

USAGE: CALL MINV (A, AI, DET, M)

Where: A is a (MXM) matrix

AI is the resulting inverse of A

DET is the value of the determinant of A. If A is a singular matrix, DET = 0.

M is the size of A.

There exist two versions of this subroutine. In one case A and AI are two-dimensional arrays (M, M) and must be dimensioned in the user's program and in the subroutine. In the second version A and AI are single arrays and must be dimensioned by the user's program only.

In both cases the array IORD must be dimensioned (M) in the subroutine.

Upon return from the subroutine, A is unchanged.

APPENDIX III

SUBROUTINE: Matrix Multiply

WRITTEN BY: James W. Hilliard and Sylvia Bryant

LANGUAGE: FORTRAN IV

PURPOSE: To compute the product of (single)(single), (double)(double), (single)(double), or (double)(single) array matrices.

USAGE: CALL MATMP(I1, I2, I3, I4, I5, I6, I, J, K, A, B, C)

WHERE:
I1 is the number of dimensioned rows of A
I2 is the number of dimensioned columns of A
I3 is the number of dimensioned rows of B
I4 is the number of dimensioned columns of B
I5 is the number of dimensioned rows of C
I6 is the number of dimensioned columns of C
A is a (I x J) matrix
B is a (J x K) matrix
C is a (I x K) matrix

RESTRICTIONS: (1) I1, I2, I3, I4, I5, and I6 must NOT be zero (0) for single array matrices.

EXAMPLE: DIMENSION A(20), I1 or I2 must = 1.

(2) Neither A nor B may be C.

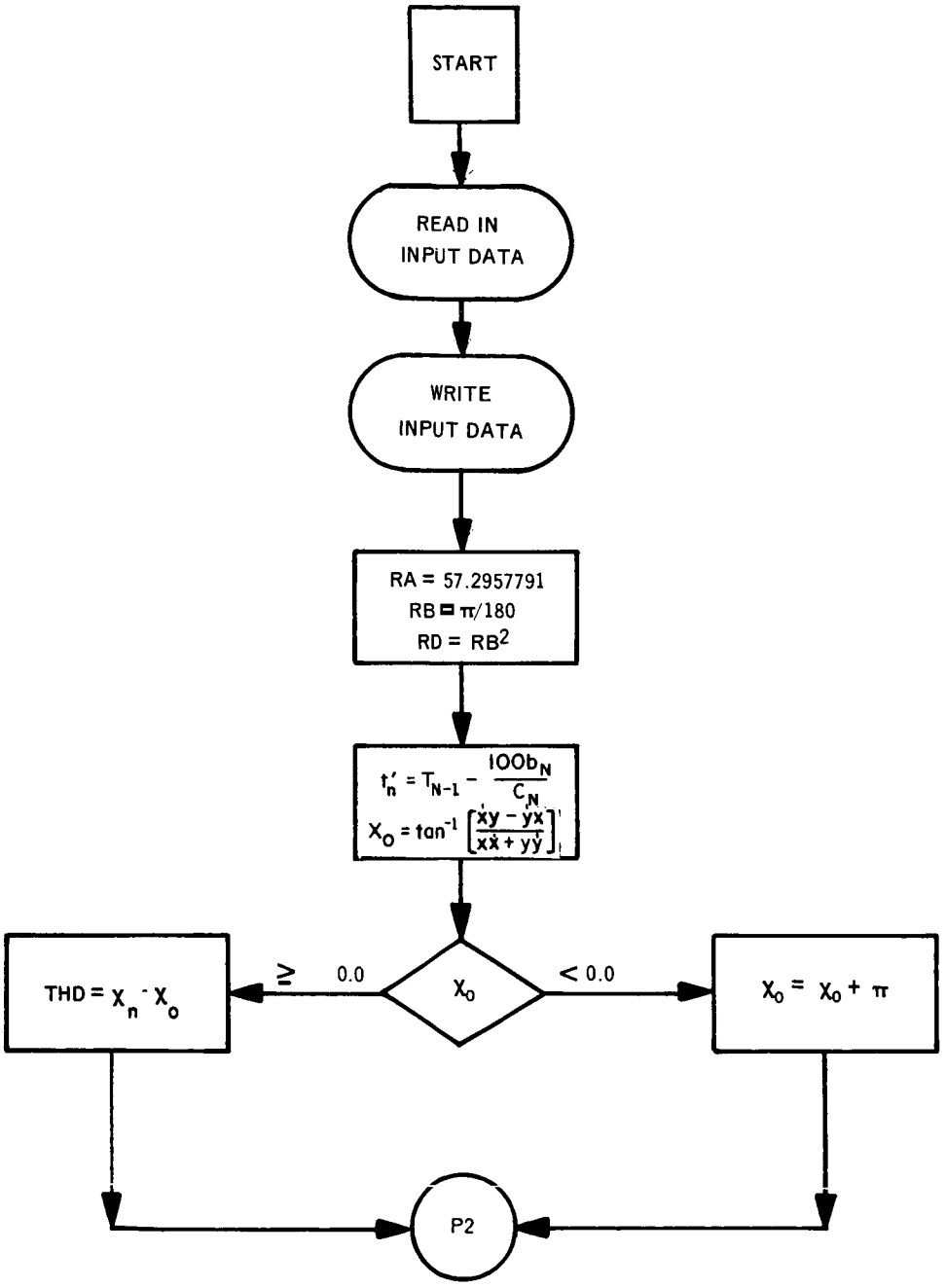
EXAMPLE: CALL MATMP(I1, I2, I3, I4, I5, I6, I, J, K, A, B, A) is illegal.

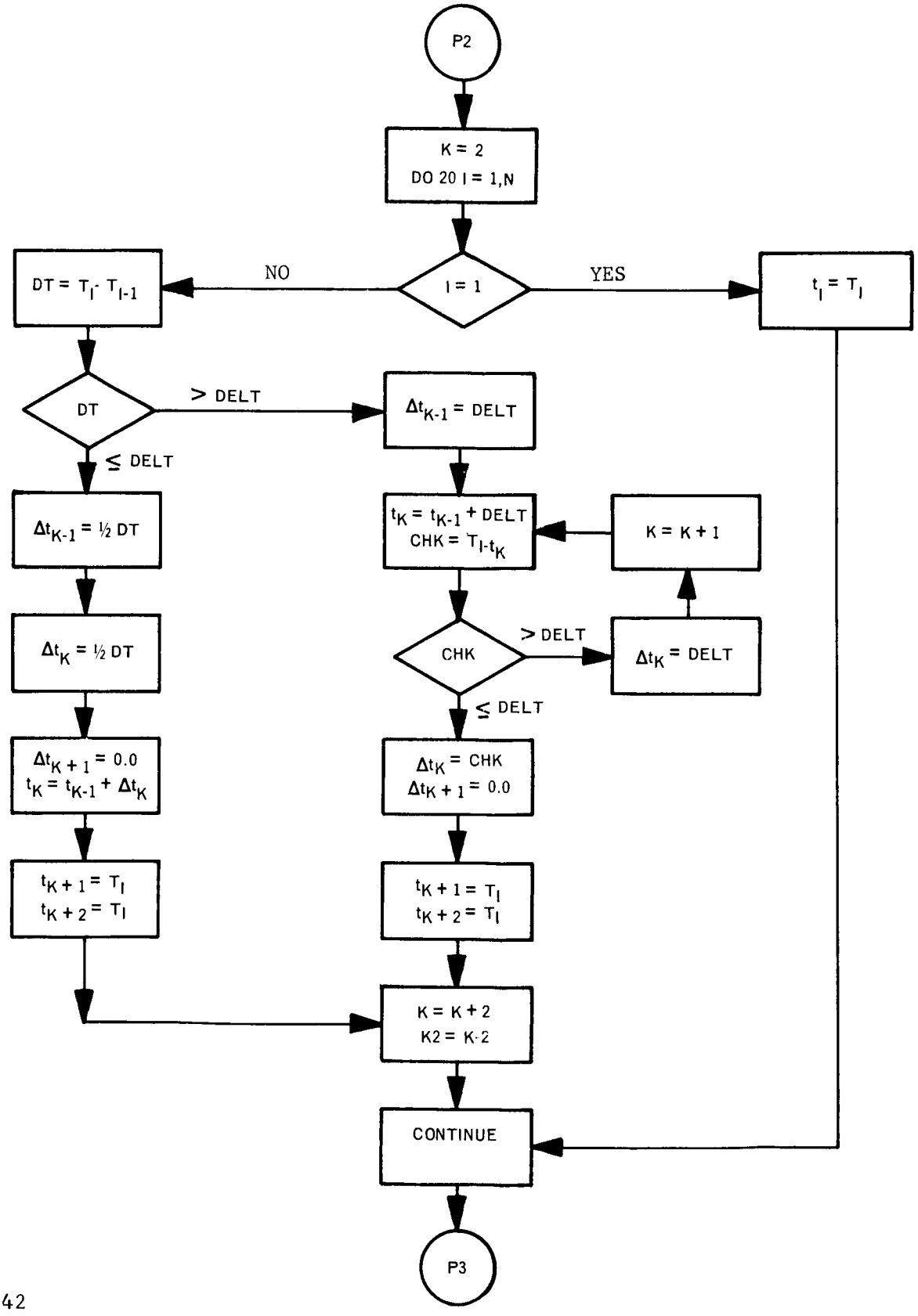
(3) $I \leq I1$ $J \leq I2$ $K \leq I4$
$I \leq I5$ $J \leq I3$ $K \leq I6$

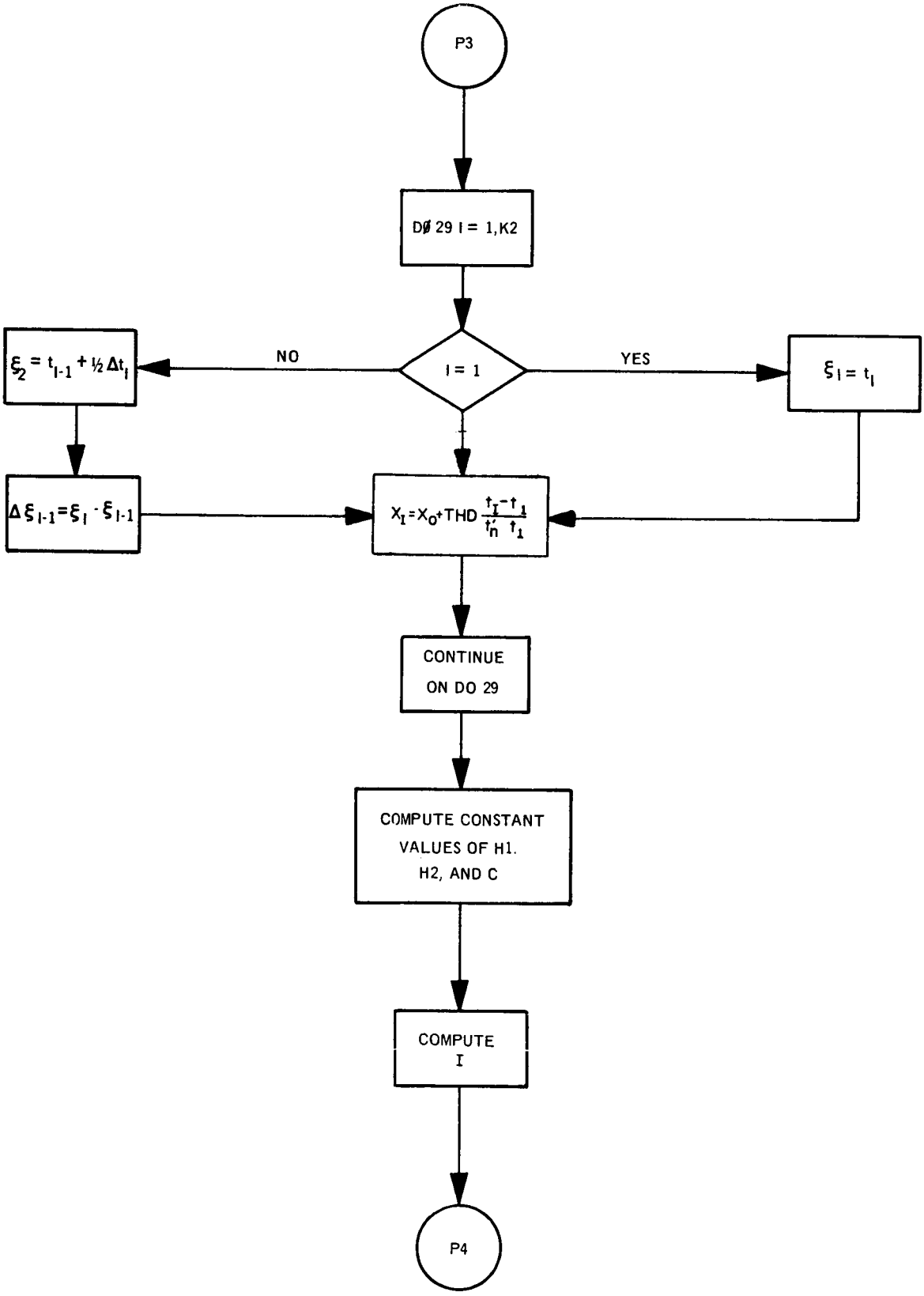
STORAGE: $263_8 = 179_{10}$ locations.

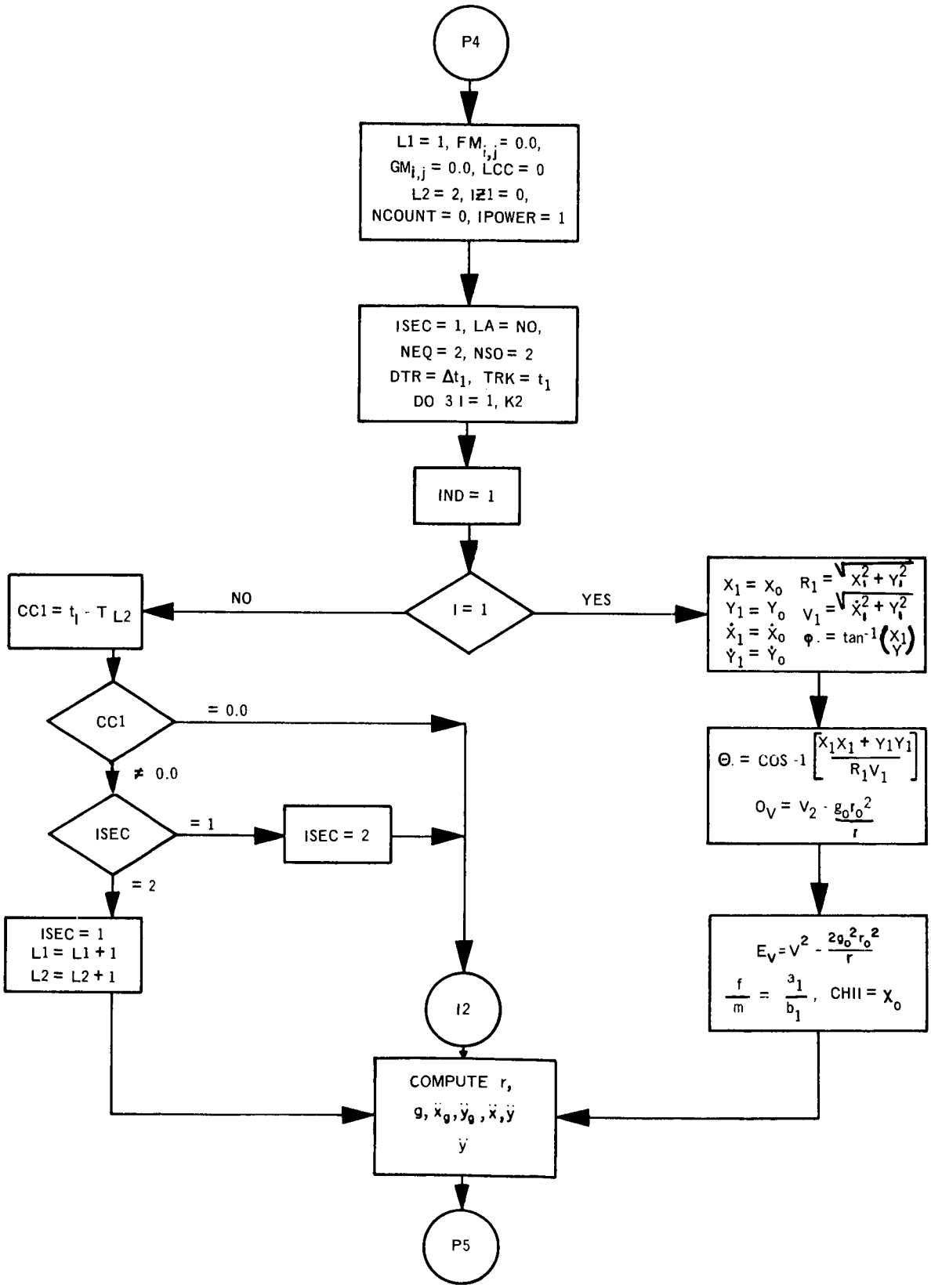
FLOW CHART

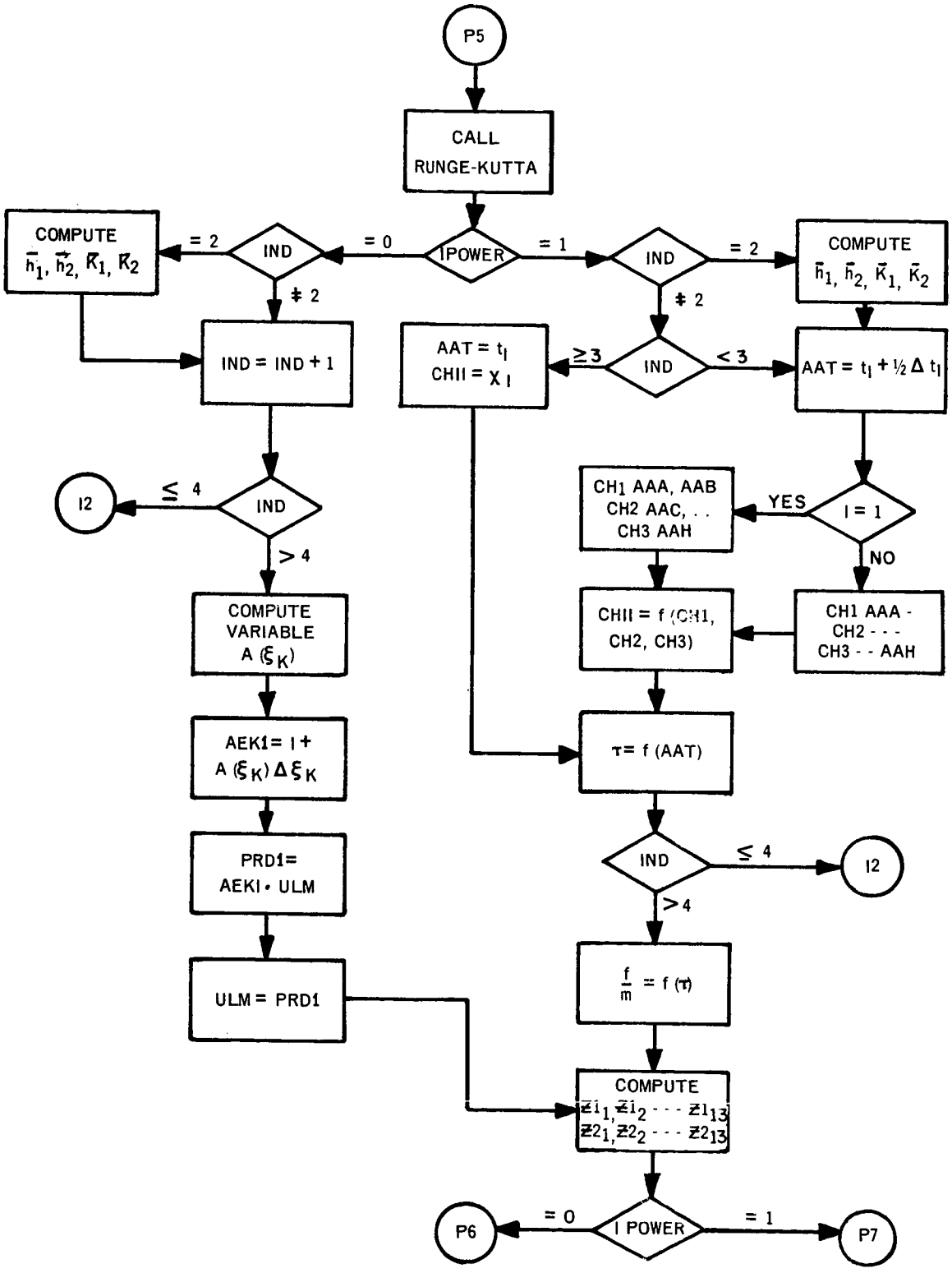
FOR COMPUTER PROGRAM

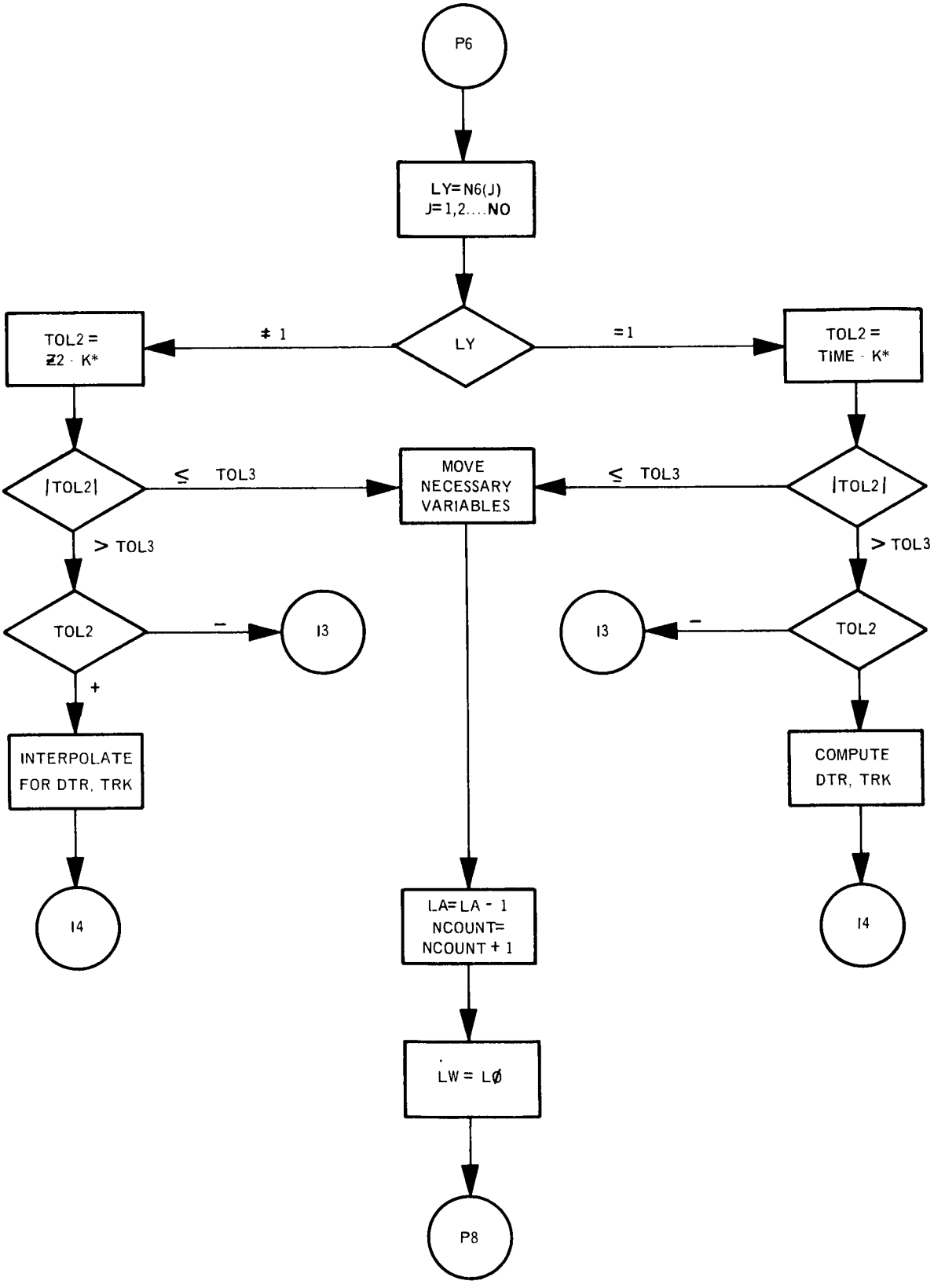

START
READ IN INPUT DATA
WRITE INPUT DATA
RA = 57.2957791
RB = π/180
RD = RB²
$t'_n = T_{N-1} - \frac{100b_N}{C_N}$
$X_O = \tan^{-1}\left[\frac{\dot{x}y - y\dot{x}}{x\dot{x} + y\dot{y}}\right]$
X_O
≥ 0.0
< 0.0
THD = $X_n - X_o$
$X_o = X_o + \pi$
P2

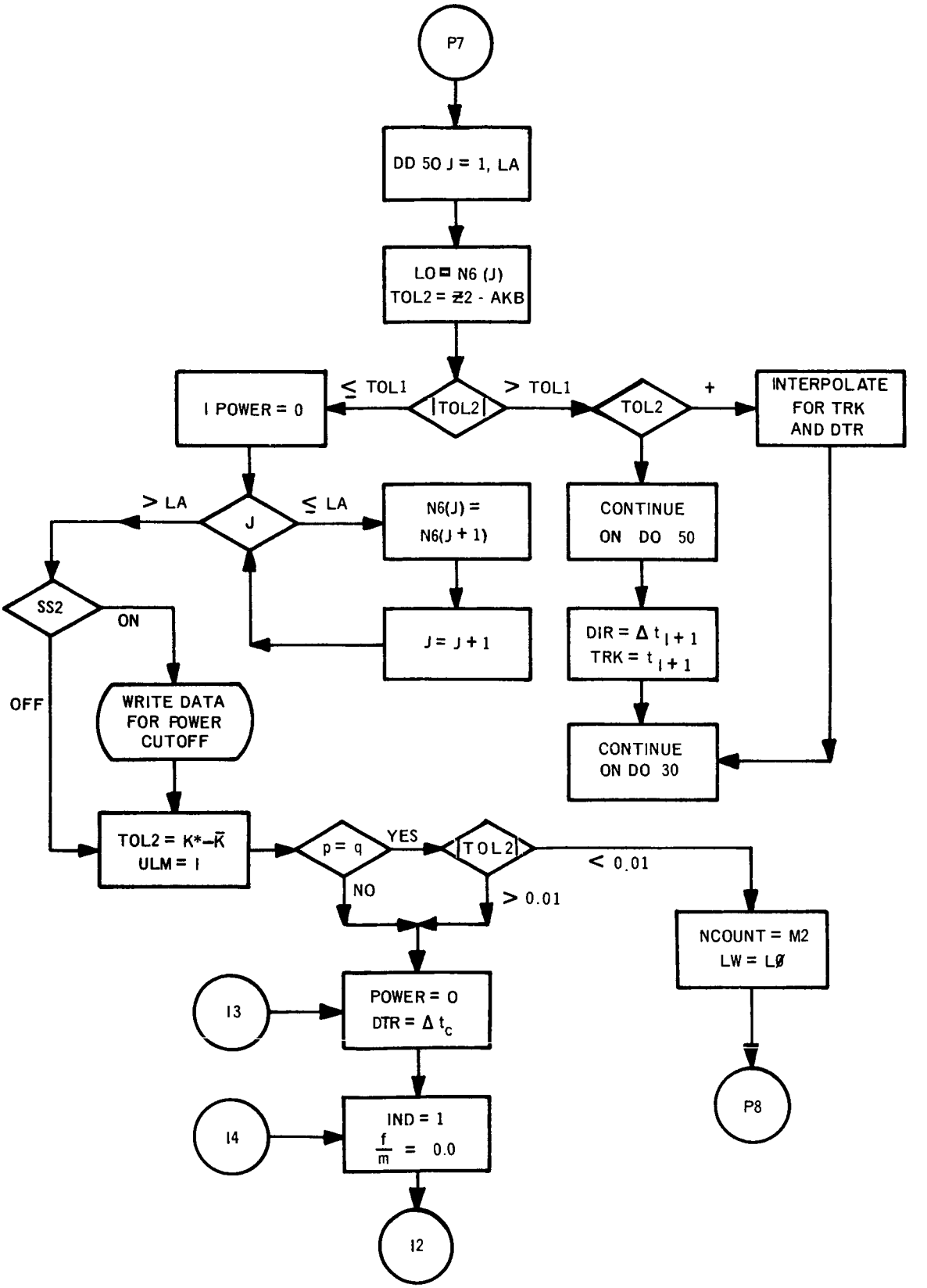

P2
K = 2
DO 20 I = 1,N
I = 1
NO
YES
DT = $T_I - T_{I-1}$
$t_I = T_I$
DT
> DELT
Δt_{K-1} = DELT
≤ DELT
Δt_{K-1} = ½ DT
$t_K = t_{K-1}$ + DELT
CHK = $T_I - t_K$
K = K + 1
Δt_K = ½ DT
CHK
> DELT
Δt_K = DELT
≤ DELT
Δt_{K+1} = 0.0
$t_K = t_{K-1} + \Delta t_K$
Δt_K = CHK
Δt_{K+1} = 0.0
$t_{K+1} = T_I$
$t_{K+2} = T_I$
$t_{K+1} = T_I$
$t_{K+2} = T_I$
K = K + 2
K2 = K-2
CONTINUE
P3

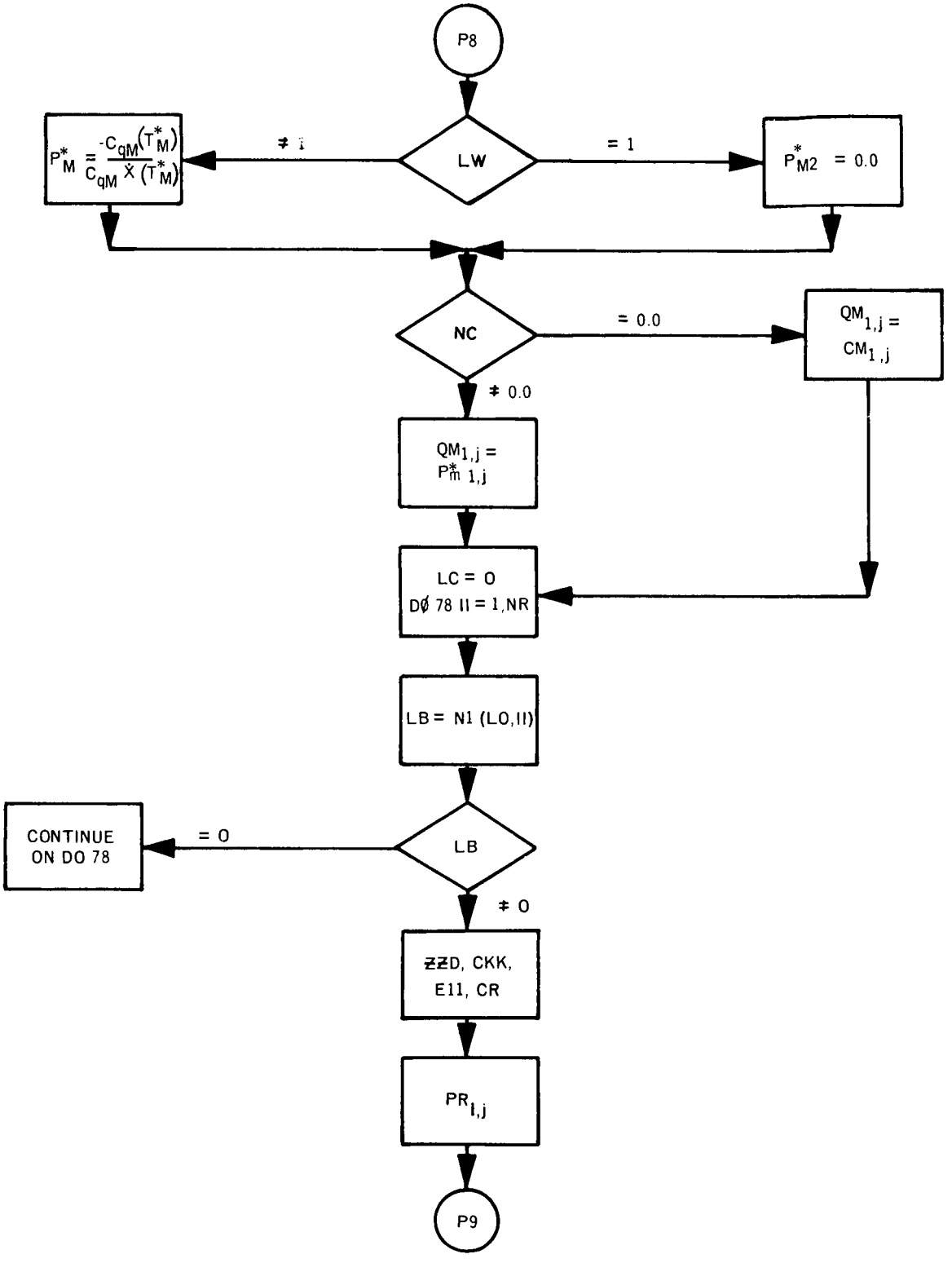

P3
DØ 29 I = 1,K2
I = 1
NO
YES
ξ2 = t I-1 + ½ Δt I
ξ1 = t 1
Δ ξ I-1 = ξ I - ξ I-1
X I = X 0 + THD t I - t 1 / t n t 1
CONTINUE
ON DO 29
COMPUTE CONSTANT
VALUES OF H1.
H2, AND C
COMPUTE
I
P4

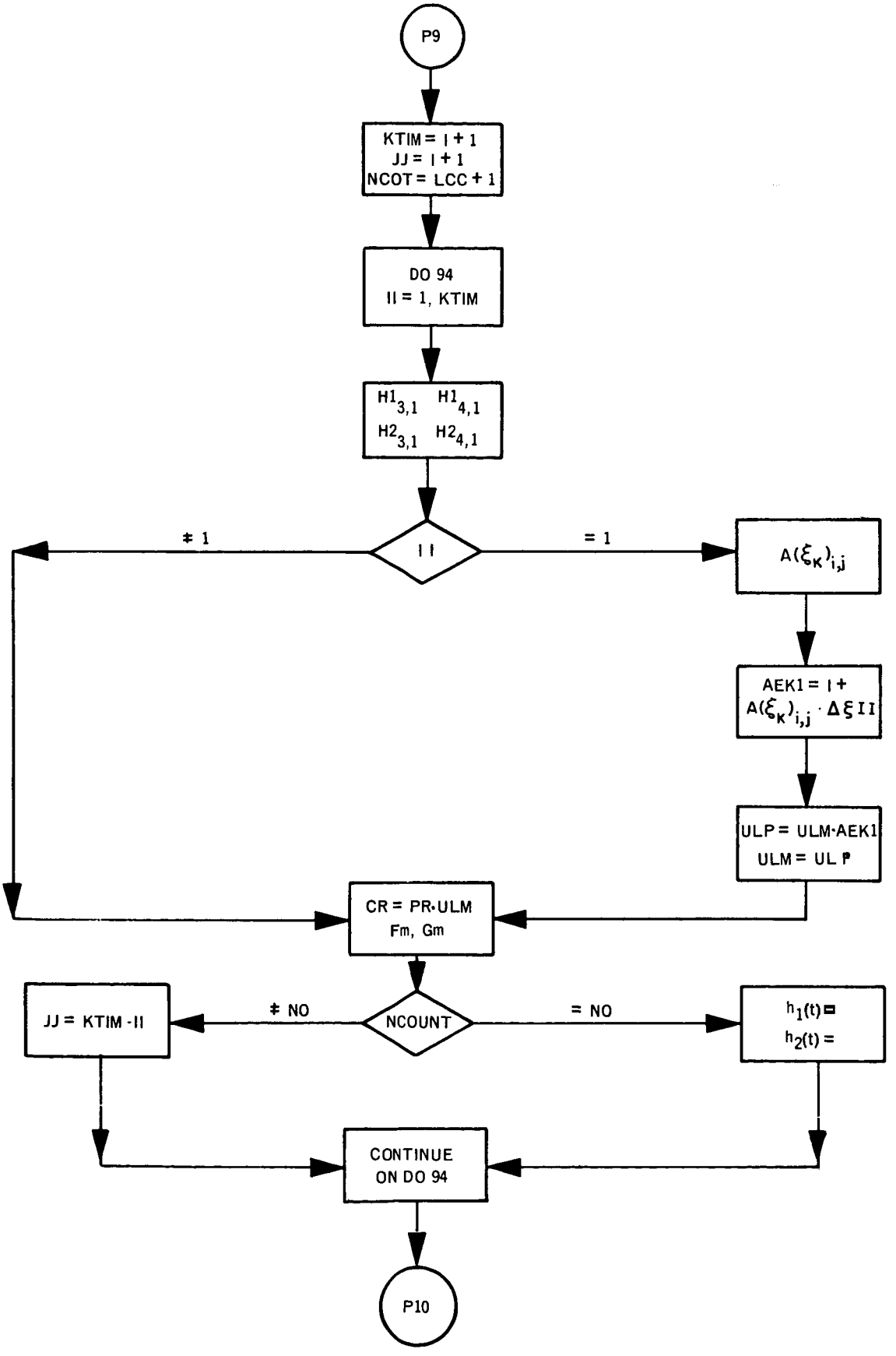

P4
L1 = 1, FM$_{i,j}$ = 0.0,
GM$_{i,j}$ = 0.0, LCC = 0
L2 = 2, IZ1 = 0,
NCOUNT = 0, IPOWER = 1
ISEC = 1, LA = NO,
NEQ = 2, NSO = 2
DTR = Δt_1, TRK = t_1
DO 3 I = 1, K2
IND = 1
I = 1
NO
YES
CC1 = t_1 - T L2
$X_1 = X_o$ $R_1 = \sqrt{X_1^2 + Y_1^2}$
$Y_1 = Y_o$ $V_1 = \sqrt{\dot{X}_1^2 + Y_1^2}$
$\dot{X}_1 = \dot{X}_o$ $\varphi_. = \tan^{-1}\left(\frac{X_1}{Y}\right)$
$\dot{Y}_1 = \dot{Y}_o$
CC1
= 0.0
≠ 0.0
ISEC
= 1
ISEC = 2
= 2
ISEC = 1
L1 = L1 + 1
L2 = L2 + 1
$\Theta_. = \cos^{-1}\left[\frac{X_1X_1 + Y_1Y_1}{R_1V_1}\right]$
$O_V = V_2 - \frac{g_o r_o^2}{r}$
$E_V = V^2 - \frac{2g_o^2 r_o^2}{r}$
$\frac{f}{m} = \frac{^3l}{b_1}$, CHII = X_o
I2
COMPUTE r,
g, $\ddot{x}_g$, $\ddot{y}_g$, $\ddot{x}$, $\ddot{y}$
$\ddot{y}$
P5

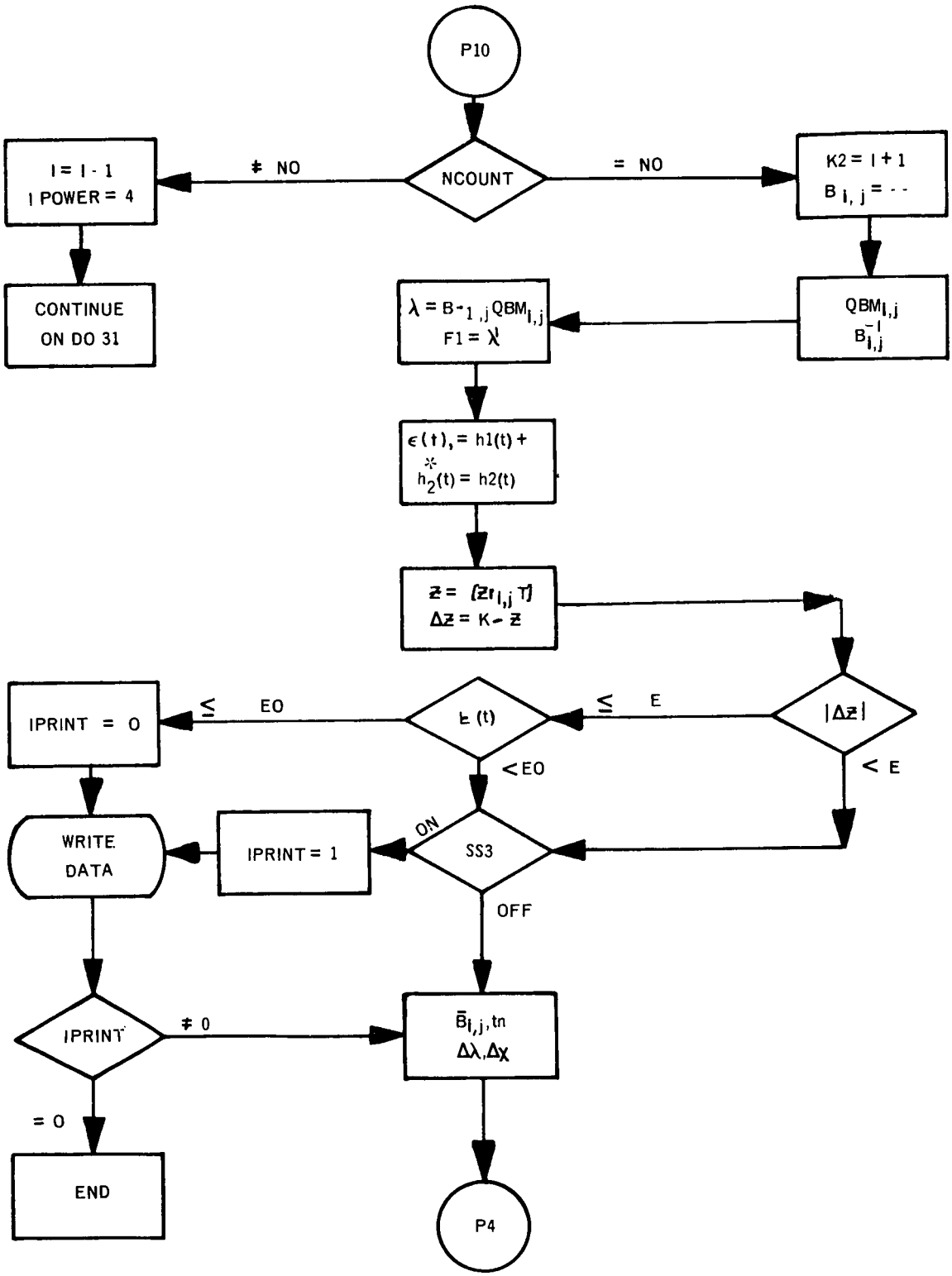

P5
CALL RUNGE-KUTTA
IPOWER
= 0
= 1
IND
= 2
≠ 2
COMPUTE $\bar{h}_1, \bar{h}_2, \bar{K}_1, \bar{K}_2$
IND = IND + 1
IND
= 2
≠ 2
COMPUTE $\bar{h}_1, \bar{h}_2, \bar{K}_1, \bar{K}_2$
AAT = t_I
CHII = X_I
IND
≥ 3
< 3
AAT = $t_I + \frac{1}{2}\Delta t_I$
I2
≤ 4
IND
> 4
CH1 AAA, AAB
CH2 AAC, . .
CH3 AAH
YES
I = 1
NO
CH1 AAA -
CH2 - - -
CH3 - - AAH
CHII = f (CH1, CH2, CH3)
COMPUTE VARIABLE A (ξ_K)
AEK1 = 1 + A (ξ_K) $\Delta \xi_K$
PRD1 = AEKI • ULM
ULM = PRD1
τ = f (AAT)
IND
≤ 4
I2
> 4
$\frac{f}{m}$ = f (τ)
COMPUTE
$\bar{z}i_1, \bar{z}i_2 - - - \bar{z}1_{13}$
$\bar{z}2_1, \bar{z}2_2 - - - \bar{z}2_{13}$
P6
= 0
I POWER
= 1
P7


P6
LY=N6(J)
J=1,2....NO
LY
≠ 1
=1
TOL2 =
Z2 · K*
TOL2 =
TIME · K*
|TOL2|
≤ TOL3
MOVE
NECESSARY
VARIABLES
≤ TOL3
|TOL2|
> TOL3
> TOL3
TOL2
–
I3
I3
–
TOL2
+
INTERPOLATE
FOR DTR, TRK
COMPUTE
DTR, TRK
I4
I4
LA=LA - 1
NCOUNT=
NCOUNT + 1
LW = LØ
P8


P7
DD 50 J = 1, LA
LO = N6 (J)
TOL2 = Z2 - AKB
|TOL2|
≤ TOL1
> TOL1
TOL2
+
INTERPOLATE FOR TRK AND DTR
I POWER = 0
J
> LA
≤ LA
N6(J) = N6(J + 1)
J = J + 1
CONTINUE ON DO 50
DIR = Δ t I + 1
TRK = t I + 1
CONTINUE ON DO 30
SS2
ON
OFF
WRITE DATA FOR POWER CUTOFF
TOL2 = K* - K̄
ULM = I
p = q
YES
NO
|TOL2|
< 0.01
> 0.01
NCOUNT = M2
LW = LØ
P8
I3
POWER = 0
DTR = Δ t c
I4
IND = 1
f/m = 0.0
I2


P8
LW
≠ 1
= 1
$P^*_M = \frac{-C_{qM}(T^*_M)}{C_{qM}\,\bar{X}(T^*_M)}$
$P^*_{M2} = 0.0$
NC
= 0.0
$QM_{1,j} = CM_{1,j}$
≠ 0.0
$QM_{1,j} = P^*_{m\ 1,j}$
LC = 0
DØ 78 II = 1,NR
LB = N1 (LO,II)
LB
= 0
CONTINUE
ON DO 78
≠ 0
ZZD, CKK,
E11, CR
$PR_{I,j}$
P9


P9
KTIM = I + 1
JJ = I + 1
NCOT = LCC + 1
DO 94
II = 1, KTIM
H1 3,1 H1 4,1
H2 3,1 H2 4,1
II
≠ 1
= 1
A(ξK)i,j
AEK1 = I +
A(ξK)i,j · ΔξII
ULP = ULM·AEK1
ULM = ULP
CR = PR·ULM
Fm, Gm
JJ = KTIM - II
≠ NO
NCOUNT
= NO
h1(t) =
h2(t) =
CONTINUE
ON DO 94
P10


P10
NCOUNT
≠ NO
= NO
I = I - 1
I POWER = 4
CONTINUE
ON DO 31
K2 = I + 1
B I, j = - -
QBM I,j
B⁻¹ I,j
λ = B⁻¹ I,j QBM I,j
F1 = λ
ε(t), = h1(t) +
h*2(t) = h2(t)
z̄ = (z̄ I,j T)
Δz̄ = K - z̄
|Δz̄|
≤ E
< E
E (t)
≤ EO
< EO
IPRINT = 0
WRITE
DATA
IPRINT = 1
ON
SS3
OFF
IPRINT
≠ 0
= 0
END
B̄ I,j,tn
Δλ,Δχ
P4

OUTPUT DATA OF THE COMPUTER PROGRAM

*** OPTIMUM GUIDANCE ***

VEHICLE HAS 4 STAGES
AND 2 OPTION(S)

K BAR	K STAR	TL BAR	TL STAR
4.12855030E 02	6.37000000E 06	1.00000000E-02	1.00000000E-01
7.73599673E 02	7.73599673E 02	1.00000000E-02	1.00000000E-02

STAGING TIME	A(I)	B(I)	C(I)
1.84994810E 02	1.07873150E 01	1.28676640E 00	-2.61282644E-01
4.12855030E 02	8.92405155E 00	6.91407150E-01	-2.12616813E-01
5.23879730E 02	1.00000000E-20	1.00000000E 00	0
5.28879730E 02	1.96132994E 00	3.60211990E-01	-4.69483590E-02
8.00000000E 02	1.96132994E 00	3.60211990E-01	-4.69483590E-02

XO=	2.36255460E 05	YO=	6.45666782E 06	XDO=	2.80057460E 03	YDO=	6.35943170E 02
GO=	9.81000000E 00	RO=	6.37000000E 06	THC=	1.57079630E 00	DELT=	5.00000000E 00

CONSTRAINT NUMBERS	CONSTRAINT VALUES	CONSTRAINT TOLERANCES
3	5.97113760E 06	1.00000000E-01
6	6.55520000E 06	1.00000000E-01
8	1.57079630E 00	1.00000000E-05

CONDITIONS FOR POWER CUTOFF, ITERATION 1

TIME	4.12855030E 02	DELT	2.85502999E 00	ETAT	4.10000000E 02	DETT	3.92751500E 00
CHI	7.75653021E 01	X=	1.11046575E 06	Y=	6.42076774E 06	XD=	5.08628094E 03
YD=	-8.96766173E 02	RAD	6.51608721E 06	VEL	5.16473072E 03	THETA	9.01869113E 01
PHI	9.67138210E 00	OVEL	-3.44142708E 07	EVEL	-9.55029850E 07	ENEG	3.36536567E 10
ENG	3.67086200E 06	FOM	1.56019710E 01	DRAGX	-1.59768960E 00	DRAGY	-9.23791926E 00

CONDITIONS FOR COAST CUTOFF, ITERATION 1

TIME	6.44352789E 02	DELT	1.49775909E 00	X=	2.22951292E 06	Y=	5.96709071E 06
XD=	4.51116560E 03	YD=	-3.02089404E 03	RAD	6.36999995E 06	VEL	5.42921872E 03
THETA	1.03320732E 02	PHI	2.04874392E 01	OVEL	-3.30132845E 07	EVEL	-9.55029850E 07
ENEG	3.36536567E 10	ENG	3.67086200E 06	DRAGX	-3.43351997E 00	DRAGY	-9.18950724E 00

CONDITIONS FOR POWER CUTOFF, ITERATION 1

TIME	7.73599673E 02	DELT	3.59967299E 00	ETAT	7.71799837E 02	DETT	1.79983650E 00
CHI	8.14510987E 01	X=	3.47319953E 06	Y=	5.65806078E 06	XD=	7.24809835E 03
YD=	-3.39039321E 03	RAD	6.63903357E 06	VEL	8.00185578E 03	THETA	8.35247838E 01
PHI	2.76162413E 01	OVEL	4.07226613E 06	EVEL	-5.58851636E 07	ENEG	5.27856931E 10
ENG	-3.60749569E 05	FOM	8.01646939E 00	DRAGX	-4.72457782E 00	DRAGY	-7.69663509E 00

CONDITIONS FOR POWER CUTOFF, ITERATION 2

TIME	4.12855030E 02	DELT	2.85502999E 00	ETAT	4.10000000E 02	DETT	3.92751500E 00
CHI	8.81851891E 01	X=	1.10659784E 06	Y=	6.43100556E 06	XD=	5.08548507E 03
YD=	-9.57937867E 02	RAD	6.52551847E 06	VEL	5.17492061E 03	THETA	9.09042343E 01
PHI	9.62465886E 00	OVEL	-3.42206200E 07	EVEL	-9.52210433E 07	ENEG	3.37648347E 10
ENG	3.66146327E 06	FOM	1.56019710E 01	DRAGX	-1.58523140E 00	DRAGY	-9.21258888E 00

CONDITIONS FOR COAST CUTOFF, ITERATION 2

TIME	6.40719740E 02	DELT	2.86470976E 00	X=	2.20930218E 06	Y=	5.97460325E 06
XD=	4.52446063E 03	YD=	-3.04755845E 03	RAD	6.37000000E 06	VEL	5.45512205E 03
THETA	1.03669678E 02	PHI	2.02934985E 01	OVEL	-3.27313435E 07	EVEL	-9.52210435E 07
ENEG	3.37648347E 10	ENG	3.66146327E 06	DRAGX	-3.40239469E 00	DRAGY	-9.20107659E 00

CONDITIONS FOR POWER CUTOFF, ITERATION 2

TIME	7.73599673E 02	DELT	3.59967299E 00	ETAT	7.71799837E 02	DETT	1.79983650E 00
CHI	1.48044177E 02	X=	3.45584482E 06	Y=	5.55017661E 06	XD=	6.99719212E 03
YD=	-4.52207398E 03	RAD	6.53814376E 06	VEL	8.33125745E 03	THETA	9.09647037E 01
PHI	2.78594370E 01	OVEL	8.52722050E 06	EVEL	-5.23554097E 07	ENEG	5.44632380E 10
ENG	-9.13619414E 05	FOM	8.01646939E 00	DRAGX	-4.92196706E 00	DRAGY	-7.90480756E 00

CONDITIONS FOR POWER CUTOFF, ITERATION 3

TIME	4.12855030E 02	DELT	2.85502999E 00	ETAT	4.10000000E 02	DETT	3.92751500E 00
CHI	8.87367056E 01	X=	1.10568690E 06	Y=	6.43328340E 06	XD=	5.08126423E 03
YD=	-9.51237279E 02	RAD	6.52760897E 06	VEL	5.16953562E 03	THETA	9.08511829E 01
PHI	9.61386167E 00	OVEL	-3.42567891E 07	EVEL	-9.52376767E 07	ENEG	3.37409834E 10
ENG	3.66759864E 06	FOM	1.56019710E 01	DRAGX	-1.58240517E 00	DRAGY	-9.20700051E 00

CONDITIONS FOR COAST CUTOFF, ITERATION 3

TIME	6.43128105E 02	DELT	2.73075008E-01	X=	2.21841925E 06	Y=	5.97122399E 06
XD=	4.51319140E 03	YD=	-3.06150727E 03	RAD	6.37000000E 06	VEL	5.45359729E 03
THETA	1.03769910E 02	PHI	2.03809550E 01	OVEL	-3.27479767E 07	EVEL	-9.52376767E 07
ENEG	3.37409834E 10	ENG	3.66759864E 06	DRAGX	-3.41643530E 00	DRAGY	-9.19587244E 00

CONDITIONS FOR POWER CUTOFF, ITERATION 3

TIME	7.73599673E 02	DELT	3.59967299E 00	ETAT	7.71799837E 02	DETT	1.79983650E 00
CHI	1.37809636E 02	X=	3.45808785E 06	Y=	5.56850909E 06	XD=	7.06902920E 03
YD=	-4.39031628E 03	RAD	6.55489627E 06	VEL	8.32142120E 03	THETA	9.00023016E 01
PHI	2.78142456E 01	OVEL	8.51901980E 06	EVEL	-5.22080112E 07	ENEG	5.45460527E 10
ENG	-9.19545867E 05	FOM	8.01646939E 00	DRAGX	-4.88749605E 00	DRAGY	-7.87026495E 00

CONDITIONS FOR POWER CUTOFF, ITERATION 4

TIME	4.12855030E 02	DELT	2.85502999E 00	ETAT	4.10000000E 02	DETT	3.92751500E 00
CHI	8.87307598E 01	X=	1.10565827E 06	Y=	6.43334217E 06	XD=	5.08115114E 03
YD=	-9.51054724E 02	RAD	6.52766203E 06	VEL	5.16939088E 03	THETA	9.08497598E 01
PHI	9.61354067E 00	OVEL	-3.42577898E 07	EVEL	-9.52381817E 07	ENEG	3.37403254E 10
ENG	3.66776326E 06	FOM	1.56019710E 01	DRAGX	-1.58232560E 00	DRAGY	-9.20686007E 00

CONDITIONS FOR COAST CUTOFF, ITERATION 4

TIME	6.43190095E 02	DELT	3.35065168E-01	X=	2.21864746E 06	Y=	5.97113921E 06
XD=	4.51289852E 03	YD=	-3.06185651E 03	RAD	6.37000000E 06	VEL	5.45355098E 03
THETA	1.03772484E 02	PHI	2.03831447E 01	OVEL	-3.27484817E 07	EVEL	-9.52381817E 07
ENEG	3.37403254E 10	ENG	3.66776326E 06	DRAGX	-3.41678675E 00	DRAGY	-9.19574187E 00

CONDITIONS FOR POWER CUTOFF, ITERATION 4

TIME	7.73599673E 02	DELT	3.59967299E 00	ETAT	7.71799837E 02	DETT	1.79983650E 00
CHI	1.37421071E 02	X=	3.45776115E 06	Y=	5.56909200E 06	XD=	7.06884604E 03
YD=	-4.38888666E 03	RAD	6.55521914E 06	VEL	8.32051143E 03	THETA	8.99997178E 01
PHI	2.78108470E 01	OVEL	8.50687050E 06	EVEL	-5.22171695E 07	ENEG	5.45427758E 10
ENG	-9.18324938E 05	FOM	8.01646939E 00	DRAGX	-4.88631223E 00	DRAGY	-7.86992582E 00

CONDITIONS FOR POWER CUTOFF, ITERATION 5

TIME	4.12855030E 02	DELT	2.85502999E 00	ETAT	4.10000000E 02	DETT	3.92751500E 00
CHI	8.87357035E 01	X=	1.10565480E 06	Y=	6.43334977E 06	XD=	5.08113720E 03
YD=	-9.51062735E 02	RAD	6.52766894E 06	VEL	5.16937864E 03	THETA	9.08499169E 01
PHI	9.61350103E 00	OVEL	-3.42578519E 07	EVEL	-9.52381793E 07	ENEG	3.37402799E 10
ENG	3.66777788E 06	FOM	1.56019710E 01	DRAGX	-1.58231561E 00	DRAGY	-9.20684175E 00

CONDITIONS FOR COAST CUTOFF, ITERATION 5

TIME	6.43192816E 02	DELT	3.37786316E-01	X=	2.21865337E 06	Y=	5.97113701E 06
XD=	4.51287829E 03	YD=	-3.06188672E 03	RAD	6.37000000E 06	VEL	5.45355121E 03
THETA	1.03772810E 02	PHI	2.03832014E 01	OVEL	-3.27484793E 07	EVEL	-9.52381793E 07
ENEG	3.37402799E 10	ENG	3.66777788E 06	DRAGX	-3.41679586E 00	DRAGY	-9.19573849E 00

CONDITIONS FOR POWER CUTOFF, ITERATION 5

TIME	7.73599673E 02	DELT	3.59967299E 00	ETAT	7.71799837E 02	DETT	1.79983650E 00
CHI	1.37416181E 02	X=	3.45775818E 06	Y=	5.56907200E 06	XD=	7.06886955E 03
YD=	-4.38895902E 03	RAD	6.55520057E 06	VEL	8.32056957E 03	THETA	8.99999856E 01
PHI	2.78108937E 01	OVEL	8.50766600E 06	EVEL	-5.22165460E 07	ENEG	5.45430024E 10
ENG	-9.18405613E 05	FOM	8.01646939E 00	DRAGX	-4.88634954E 00	DRAGY	-7.86996442E 00

CONDITIONS FOR POWER CUTOFF, ITERATION 6

TIME	4.12855030E 02	DELT	2.85502999E 00	ETAT	4.10000000E 02	DETT	3.92751500E 00
CHI	8.87359094E 01	X=	1.10565474E 06	Y=	6.43334983E 06	XD=	5.08113713E 03
YD=	-9.51064757E 02	RAD	6.52766899E 06	VEL	5.16937895E 03	THETA	9.08499396E 01
PHI	9.61350049E 00	OVEL	-3.42578483E 07	EVEL	-9.52381752E 07	ENEG	3.37402819E 10
ENG	3.66777758E 06	FOM	1.56019710E 01	DRAGX	-1.58231549E 00	DRAGY	-9.20684162E 00

CONDITIONS FOR COAST CUTOFF, ITERATION 6

TIME	6.43192499E 02	DELT	3.37468693E-01	X=	2.21865187E 06	Y=	5.97113757E 06
XD=	4.51287927E 03	YD=	-3.06188594E 03	RAD	6.37000000E 06	VEL	5.45355158E 03
THETA	1.03772812E 02	PHI	2.03831870E 01	OVEL	-3.27484752E 07	EVEL	-9.52381752E 07
ENEG	3.37402819E 10	ENG	3.66777758E 06	DRAGX	-3.41679354E 00	DRAGY	-9.19573935E 00

CONDITIONS FOR POWER CUTOFF, ITERATION 6

TIME	7.73599673E 02	DELT	3.59967299E 00	ETAT	7.71799837E 02	DETT	1.79983650E 00
CHI	1.37416226E 02	X=	3.45775808E 06	Y=	5.56907141E 06	XD=	7.06886919E 03
YD=	-4.38896098E 03	RAD	6.55520002E 06	VEL	8.32057030E 03	THETA	8.99999964E 01
PHI	2.78108950E 01	OVEL	8.50767298E 06	EVEL	-5.22165441E 07	ENEG	5.45430026E 10
ENG	-9.18406211E 05	FOM	8.01646939E 00	DRAGX	-4.88635064E 00	DRAGY	-7.86996557E 00

A DELT of 5.0 seconds was used for the power and coast flights of this trajectory. Because of the excessive amount of output data, this report will show prints at every 20.0 seconds. The coast flight data is not printed because SS 4 was not turned on.

LAST ITERATION ** NUMBER 6

ALL TOLERANCES CHECK

TIME	1.84994810E 02	DELT	5.18999994E-03	ETAT	1.84994810E 02	DETT	2.50000000E 00
CHI	6.40125793E 01	DCHI	-1.12976268E-04	X=	2.36255460E 05	Y=	6.45666782E 06
XD=	2.80057460E 03	YD=	6.35943170E 02	XDD	-2.25283975E 06	YDD	-6.15684636E 07
RAD	6.46098878E 06	VEL	2.87187078E 03	THETA	7.51108828E 01	PHI	2.09557075E 00
OVEL	-5.33620286E 07	EVEL	-1.14971699E 08	ENEG	1.79321349E 10	ENG	6.46098878E 06
HB1	-1.46995765E-06	HB2	1.61799553E-07	KB1	1.61799553E-07	KB2	2.94583588E-06
FOM	8.38327376E 00	HS1	8.12458924E-03	HS2	-1.64473911E-03	H2S	-5.19610551E-03
EPS	3.81783138E-09						

TIME	1.85000000E 02	DELT	5.00000000E 00	ETAT	1.87494810E 02	DETT	5.18999994E-03
CHI	6.40131446E 01	DCHI	-1.12971519E-04	X=	2.36269995E 05	Y=	6.45667112E 06
XD=	2.80061190E 03	YD=	6.35912778E 02	XDD	7.18705346E 00	YDD	-5.85595658E 00
RAD	6.46099261E 06	VEL	2.87190043E 03	THETA	7.51115112E 01	PHI	2.09429801E 00
OVEL	-5.33618218E 07	EVEL	-1.14971456E 08	ENEG	1.79323829E 10	ENG	5.65314744E 06
HB1	-1.46834051E-06	HB2	1.66431806E-07	KB1	1.66431806E-07	KB2	2.94290366E-06
FOM	8.38336211E 00	HS1	8.12464599E-03	HS2	-1.64481960E-03	H2S	-5.19614456E-03
EPS	3.81692189E-09						

TIME	1.90000000E 02	DELT	5.00000000E 00	ETAT	1.87500000E 02	DETT	5.00000000E 00
CHI	6.45567075E 01	DCHI	-1.08658862E-04	X=	2.50363275E 05	Y=	6.45977739E 06
XD=	2.83677659E 03	YD=	6.06575367E 02	XDD	7.27903259E 00	YDD	-5.87918328E 00
RAD	6.46462727E 06	VEL	2.90090246E 03	THETA	7.57109348E 01	PHI	2.21785309E 00
OVEL	-5.31597595E 07	EVEL	-1.14734754E 08	ENEG	1.81730811E 10	ENG	5.63494987E 06
HB1	-1.46515977E-06	HB2	1.75729504E-07	KB1	1.75729504E-07	KB2	2.93727521E-06
FOM	8.46934964E 00	HS1	8.17940414E-03	HS2	-1.72282116E-03	H2S	-5.23432702E-03
EPS	3.75257514E-09						

TIME	1.95000000E 02	DELT	5.00000000E 00	ETAT	1.92500000E 02	DETT	5.00000000E 00
CHI	6.51007984E 01	DCHI	-1.04197507E-04	X=	2.64638533E 05	Y=	6.46273667E 06
XD=	2.87340470E 03	YD=	5.77118456E 02	XDD	7.37245559E 00	YDD	-5.90381799E 00
RAD	6.46815266E 06	VEL	2.93078834E 03	THETA	7.62984807E 01	PHI	2.34289752E 00
OVEL	-5.29519135E 07	EVEL	-1.14493347E 08	ENEG	1.84173302E 10	ENG	5.61602341E 06
HB1	-1.46200924E-06	HB2	1.85119923E-07	KB1	1.85119923E-07	KB2	2.93175662E-06
FOM	8.55711939E 00	HS1	8.23392095E-03	HS2	-1.80214300E-03	H2S	-5.27370698E-03
EPS	3.68072506E-09						

TIME	2.00000000E 02	DELT	5.00000000E 00	ETAT	1.97500000E 02	DETT	5.00000000E 00
CHI	6.56453762E 01	DCHI	-9.96003333E-05	X=	2.79098106E 05	Y=	6.46554836E 06
XD=	2.91050362E 03	YD=	5.47534813E 02	XDD	7.46736137E 00	YDD	-5.92987933E 00
RAD	6.47156947E 06	VEL	2.96155799E 03	THETA	7.68740736E 01	PHI	2.46945358E 00
OVEL	-5.27381160E 07	EVEL	-1.14247058E 08	ENEG	1.86651860E 10	ENG	5.59635040E 06
HB1	-1.45888639E-06	HB2	1.94605596E-07	KB1	1.94605596E-07	KB2	2.92634440E-06
FOM	8.64672735E 00	HS1	8.28819798E-03	HS2	-1.88281690E-03	H2S	-5.31431845E-03
EPS	3.60569175E-09						

TIME	2.20000000E 02	DELT	5.00000000E 00	ETAT	2.17500000E 02	DETT	5.00000000E 00
CHI	6.78277322E 01	DCHI	-7.98300396E-05	X=	3.38827576E 05	Y=	6.47530555E 06
XD=	3.06376091E 03	YD=	4.27787781E 02	XDD	7.86267081E 00	YDD	-6.04879190E 00
RAD	6.48416426E 06	VEL	3.09348239E 03	THETA	7.90559424E 01	PHI	2.99124889E 00
OVEL	-5.18198339E 07	EVEL	-1.13209301E 08	ENEG	1.96938417E 10	ENG	5.50981869E 06
HB1	-1.44661958E-06	HB2	2.33552176E-07	KB1	2.33552176E-07	KB2	2.90568867E-06
FOM	9.02474666E 00	HS1	8.50295947E-03	HS2	-2.21971876E-03	H2S	-5.48981204E-03
EPS	3.26099325E-09						

TIME	2.40000000E 02	DELT	5.00000000E 00	ETAT	2.37500000E 02	DETT	5.00000000E 00
CHI	7.00145894E 01	DCHI	-5.79044491E-05	X=	4.01703029E 05	Y=	6.48264241E 06
XD=	3.22519331E 03	YD=	3.05419571E 02	XDD	8.28543063E 00	YDD	-6.19225124E 00
RAD	6.49507643E 06	VEL	3.23962235E 03	THETA	8.10444788E 01	PHI	3.53908217E 00
OVEL	-5.07911757E 07	EVEL	-1.12077504E 08	ENEG	2.07850869E 10	ENG	5.40976140E 06
HB1	-1.43458075E-06	HB2	2.74230731E-07	KB1	2.74230731E-07	KB2	2.88644838E-06
FOM	9.43732967E 00	HS1	8.71416825E-03	HS2	-2.58119359E-03	H2S	-5.68814465E-03
EPS	2.83807822E-09						

TIME	2.60000000E 02	DELT	5.00000000E 00	ETAT	2.57500000E 02	DETT	5.00000000E 00
CHI	7.22033411E 01	DCHI	-3.38932116E-05	X=	4.67893691E 05	Y=	6.48750149E 06
XD=	3.39538582E 03	YD=	1.79922990E 02	XDD	8.73937106E 00	YDD	-6.36193636E 00
RAD	6.50435239E 06	VEL	3.40014957E 03	THETA	8.28415452E 01	PHI	4.11451182E 00
OVEL	-4.96379101E 07	EVEL	-1.10836837E 08	ENEG	2.19433857E 10	ENG	5.29470331E 06
HB1	-1.42258225E-06	HB2	3.16813428E-07	KB1	3.16813428E-07	KB2	2.86838199E-06
FOM	9.88944392E 00	HS1	8.92224696E-03	HS2	-2.97010252E-03	H2S	-5.91234580E-03
EPS	2.32466846E-09						

TIME	2.80000000E 02	DELT	5.00000000E 00	ETAT	2.77500000E 02	DETT	5.00000000E 00
CHI	7.43914236E 01	DCHI	-7.86385692E-06	X=	5.37581294E 05	Y=	6.48981485E 06
XD=	3.57500660E 03	YD=	5.07537788E 01	XDD	9.22911493E 00	YDD	-6.55989033E 00
RAD	6.51204196E 06	VEL	3.57536686E 03	THETA	8.44513720E 01	PHI	4.71917349E 00
OVEL	-4.83434141E 07	EVEL	-1.09470076E 08	ENEG	2.31738467E 10	ENG	5.16292878E 06
HB1	-1.41041780E-06	HB2	3.61478092E-07	KB1	3.61478092E-07	KB2	2.85123131E-06
FOM	1.03870568E 01	HS1	9.12783763E-03	HS2	-3.38991709E-03	H2S	-6.16606115E-03
EPS	1.70598469E-09						

TIME	3.00000000E 02	DELT	5.00000000E 00	ETAT	2.97500000E 02	DETT	5.00000000E 00
CHI	7.65763350E 01	DCHI	2.00470495E-05	X=	6.10961925E 05	Y=	6.48950324E 06
XD=	3.76482718E 03	YD=	-8.26776714E 01	XDD	9.76041994E 00	YDD	-6.78862470E 00
RAD	6.51819965E 06	VEL	3.76573489E 03	THETA	8.58797178E 01	PHI	5.35478554E 00
OVEL	-4.68881570E 07	EVEL	-1.07957073E 08	ENEG	2.44823711E 10	ENG	5.01242813E 06
HB1	-1.39785822E-06	HB2	4.08408070E-07	KB1	4.08408070E-07	KB2	2.83471600E-06
FOM	1.09374002E 01	HS1	9.33184553E-03	HS2	-3.84488875E-03	H2S	-6.45371524E-03
EPS	9.74978320E-10						

TIME	3.20000000E 02	DELT	5.00000000E 00	ETAT	3.17500000E 02	DETT	5.00000000E 00
CHI	7.87556527E 01	DCHI	4.97056324E-05	X=	6.88248348E 05	Y=	6.48647504E 06
XD=	3.96574817E 03	YD=	-2.21017022E 02	XDD	1.03405011E 01	YDD	-7.05126060E 00
RAD	6.52288619E 06	VEL	3.97190220E 03	THETA	8.71331627E 01	PHI	6.02315538E 00
OVEL	-4.52490327E 07	EVEL	-1.06274072E 08	ENEG	2.58758411E 10	ENG	4.84082775E 06
HB1	-1.38464653E-06	HB2	4.57791733E-07	KB1	4.57791733E-07	KB2	2.81852726E-06
FOM	1.15493248E 01	HS1	9.53549592E-03	HS2	-4.34027402E-03	H2S	-6.78072899E-03
EPS	1.11413101E-10						

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TIME	3.40000000E 02	DELT	5.00000000E 00	ETAT	3.37500000E 02	DETT	5.00000000E 00
CHI	8.09270475E 01	DCHI	8.09836252E-05	X=	7.69672896E 05	Y=	6.48062508E 06
XD=	4.17883259E 03	YD=	-3.64980003E 02	XDD	1.09784670E 01	YDD	-7.35172122E 00
RAD	6.52617023E 06	VEL	4.19474102E 03	THETA	8.82185360E 01	PHI	6.72618682E 00
OVEL	-4.33984791E 07	EVEL	-1.04392810E 08	ENEG	2.73623625E 10	ENG	4.64529792E 06
HB1	-1.37049227E-06	HB2	5.09821480E-07	KB1	5.09821480E-07	KB2	2.80232069E-06
FOM	1.22337790E 01	HS1	9.74040926E-03	HS2	-4.88263820E-03	H2S	-7.15381469E-03
EPS	-9.03810360E-10						

TIME	3.60000000E 02	DELT	5.00000000E 00	ETAT	3.57500000E 02	DETT	5.00000000E 00
CHI	8.30882964E 01	DCHI	1.13719172E-04	X=	8.55491142E 05	Y=	6.47183301E 06
XD=	4.40534939E 03	YD=	-5.15370975E 02	XDD	1.16859198E 01	YDD	-7.69499852E 00
RAD	6.52813049E 06	VEL	4.43539293E 03	THETA	8.91424692E 01	PHI	7.46588921E 00
OVEL	-4.13033055E 07	EVEL	-1.02279322E 08	ENEG	2.89515809E 10	ENG	4.42242953E 06
HB1	-1.35506499E-06	HB2	5.64692088E-07	KB1	5.64692088E-07	KB2	2.78570787E-06
FOM	1.30044704E 01	HS1	9.94870404E-03	HS2	-5.48027231E-03	H2S	-7.58138235E-03
EPS	-2.09433892E-09						

TIME	3.80000000E 02	DELT	5.00000000E 00	ETAT	3.77500000E 02	DETT	5.00000000E 00
CHI	8.52372914E 01	DCHI	1.47726768E-04	X=	9.45986564E 05	Y=	6.45996130E 06
XD=	4.64683125E 03	YD=	-6.73107839E 02	XDD	1.24777974E 01	YDD	-8.08752897E 00
RAD	6.52885829E 06	VEL	4.69532904E 03	THETA	8.99110524E 01	PHI	8.24438868E 00
OVEL	-3.89231039E 07	EVEL	-9.98923225E 07	ENEG	3.06551010E 10	ENG	4.16806681E 06
HB1	-1.33798653E-06	HB2	6.22598216E-07	KB1	6.22598216E-07	KB2	2.76824659E-06
FOM	1.38787927E 01	HS1	1.01631403E-02	HS2	-6.14377645E-03	H2S	-8.07411025E-03
EPS	-3.49291440E-09						

TIME	4.00000000E 02	DELT	5.00000000E 00	ETAT	3.97500000E 02	DETT	5.00000000E 00
CHI	8.73720458E 01	DCHI	1.82837333E-04	X=	1.04147656E 06	Y=	6.44485267E 06
XD=	4.90515262E 03	YD=	-8.39255998E 02	XDD	1.33735787E 01	YDD	-8.53773389E 00
RAD	6.52846072E 06	VEL	4.97643174E 03	THETA	9.05295722E 01	PHI	9.06394294E 00
OVEL	-3.62080588E 07	EVEL	-9.71809904E 07	ENEG	3.24870514E 10	ENG	3.87707618E 06
HB1	-1.31882197E-06	HB2	6.83730772E-07	KB1	6.83730772E-07	KB2	2.74942927E-06
FOM	1.48791546E 01	HS1	1.03873255E-02	HS2	-6.88689367E-03	H2S	-8.64576203E-03
EPS	-5.14410203E-09						

TIME	4.10000000E 02	DELT	2.85502999E 00	ETAT	4.06427515E 02	DETT	3.57248500E 00
CHI	8.84334958E 01	DCHI	2.00749892E-04	X=	1.09120486E 06	Y=	6.43602913E 06
XD=	5.04133296E 03	YD=	-9.25868814E 02	XDD	1.38681807E 01	YDD	-8.78782686E 00
RAD	6.52787860E 06	VEL	5.12564835E 03	THETA	9.07839395E 01	PHI	9.48986185E 00
OVEL	-3.47060978E 07	EVEL	-9.56844667E 07	ENEG	3.34564783E 10	ENG	3.71589634E 06
HB1	-1.30947841E-06	HB2	7.12099343E-07	KB1	7.12099343E-07	KB2	2.74049833E-06
FOM	1.54354358E 01	HS1	1.05045046E-02	HS2	-7.29375048E-03	H2S	-8.96661298E-03
EPS	-6.07997208E-09						

TIME	4.12855030E 02	DELT	0	ETAT	4.10000000E 02	DETT	3.92751500E 00
CHI	8.87359094E 01	DCHI	2.05897008E-04	X=	1.10565474E 06	Y=	6.43334983E 06
XD=	5.08113713E 03	YD=	-9.51064757E 02	XDD	1.40158585E 01	YDD	-8.86265056E 00
RAD	6.52766899E 06	VEL	5.16937895E 03	THETA	9.08499396E 01	PHI	9.61350049E 00
OVEL	-3.42578483E 07	EVEL	-9.52381752E 07	ENEG	3.37402819E 10	ENG	3.66777758E 06
HB1	-1.30793802E-06	HB2	7.16696378E-07	KB1	7.16696378E-07	KB2	2.73904961E-06
FOM	1.56019710E 01	HS1	1.05386341E-02	HS2	-7.41480871E-03	H2S	-9.06306104E-03
EPS	-6.36237019E-09						

TIME	4.12855030E 02	DELT	2.14497001E 00	ETAT	4.13927515E 02	DETT	1.42751499E 00
CHI	7.00440656E 01	DCHI	6.72604553E-06	X=	1.10565474E 06	Y=	6.43334983E 06
XD=	5.08113713E 03	YD=	-9.51064757E 02	XDD	1.05497697E 01	YDD	-4.80168761E 00
RAD	6.52766899E 06	VEL	5.16937895E 03	THETA	9.08499396E 01	PHI	9.61350049E 00
OVEL	-3.42578483E 07	EVEL	-9.52381752E 07	ENEG	3.37402819E 10	ENG	3.66777758E 06
HB1	-1.30676307E-06	HB2	7.20165881E-07	KB1	7.20165881E-07	KB2	2.73792276E-06
FOM	1.29070860E 01	HS1	1.21901555E-02	HS2	-4.41351715E-03	H2S	-1.03438006E-02
EPS	8.52878657E-10						

TIME	4.15000000E 02	DELT	5.00000000E 00	ETAT	4.15355030E 02	DETT	2.14497001E 00
CHI	7.03311450E 01	DCHI	6.12898643E-06	X=	1.11657796E 06	Y=	6.43129875E 06
XD=	5.10385904E 03	YD=	-9.61395991E 02	XDD	1.06366390E 01	YDD	-4.83143376E 00
RAD	6.52750718E 06	VEL	5.19361717E 03	THETA	9.08183063E 01	PHI	9.70691400E 00
OVEL	-3.40081792E 07	EVEL	-9.49900178E 07	ENEG	3.38979158E 10	ENG	3.64083065E 06
HB1	-1.30277667E-06	HB2	7.31767969E-07	KB1	7.31767969E-07	KB2	2.73408419E-06
FOM	1.29927873E 01	HS1	1.22314238E-02	HS2	-4.48214657E-03	H2S	-1.03725274E-02
EPS	8.39918357E-10						

TIME	4.20000000E 02	DELT	5.00000000E 00	ETAT	4.17500000E 02	DETT	5.00000000E 00
CHI	7.10063411E 01	DCHI	4.74283798E-06	X=	1.14223107E 06	Y=	6.42643108E 06
XD=	5.15755677E 03	YD=	-9.85732608E 02	XDD	1.08434799E 01	YDD	-4.90396987E 00
RAD	6.52715162E 06	VEL	5.25091046E 03	THETA	9.07416312E 01	PHI	9.92607116E 00
OVEL	-3.34130998E 07	EVEL	-9.43982603E 07	ENEG	3.42706176E 10	ENG	3.57664911E 06
HB1	-1.29702736E-06	HB2	7.48097873E-07	KB1	7.48097873E-07	KB2	2.72855849E-06
FOM	1.31970479E 01	HS1	1.23270662E-02	HS2	-4.64568701E-03	H2S	-1.04419242E-02
EPS	8.08540790E-10						

TIME	4.40000000E 02	DELT	5.00000000E 00	ETAT	4.37500000E 02	DETT	5.00000000E 00
CHI	7.38038048E 01	DCHI	-6.87438888E-07	X=	1.24760865E 06	Y=	6.40571428E 06
XD=	5.38317785E 03	YD=	-1.08708609E 03	XDD	1.17369423E 01	YDD	-5.24596693E 00
RAD	6.52607867E 06	VEL	5.49184485E 03	THETA	9.03956087E 01	PHI	1.08228075E 01
OVEL	-3.08348271E 07	EVEL	-9.18300141E 07	ENEG	3.58393572E 10	ENG	3.29927493E 06
HB1	-1.27175316E-06	HB2	8.14664267E-07	KB1	8.14664267E-07	KB2	2.70394045E-06
FOM	1.40826241E 01	HS1	1.26971166E-02	HS2	-5.35632221E-03	H2S	-1.07575350E-02
EPS	6.73026079E-10						

TIME	4.60000000E 02	DELT	5.00000000E 00	ETAT	4.57500000E 02	DETT	5.00000000E 00
CHI	7.67613146E 01	DCHI	-5.84288275E-06	X=	1.35768496E 06	Y=	6.38289584E 06
XD=	5.62782858E 03	YD=	-1.19622323E 03	XDD	1.27496626E 01	YDD	-5.68592158E 00
RAD	6.52569290E 06	VEL	5.75355581E 03	THETA	8.99916822E 01	PHI	1.17528520E 01
OVEL	-2.78953883E 07	EVEL	-8.88941811E 07	ENEG	3.75459379E 10	ENG	2.98426794E 06
HB1	-1.24249664E-06	HB2	8.83168239E-07	KB1	8.83168239E-07	KB2	2.67487322E-06
FOM	1.50956009E 01	HS1	1.30391774E-02	HS2	-6.17004481E-03	H2S	-1.11451209E-02
EPS	5.20458343E-10						

TIME	4.80000000E 02	DELT	5.00000000E 00	ETAT	4.77500000E 02	DETT	5.00000000E 00
CHI	7.98845203E 01	DCHI	-1.05856079E-05	X=	1.47286584E 06	Y=	6.35779897E 06
XD=	5.89410363E 03	YD=	-1.31533697E 03	XDD	1.39034794E 01	YDD	-6.24820478E 00
RAD	6.52617357E 06	VEL	6.03908676E 03	THETA	8.95368611E 01	PHI	1.27177875E 01
OVEL	-2.45237312E 07	EVEL	-8.55180312E 07	ENEG	3.94108408E 10	ENG	2.62420714E 06
HB1	-1.20877338E-06	HB2	9.53500468E-07	KB1	9.53500468E-07	KB2	2.64075317E-06
FOM	1.62656014E 01	HS1	1.33403381E-02	HS2	-7.10738829E-03	H2S	-1.16234299E-02
EPS	3.46517481E-10						

TIME	5.00000000E 02	DELT	5.00000000E 00	ETAT	4.97500000E 02	DETT	5.00000000E 00
CHI	8.31765784E 01	DCHI	-1.47352352E-05	X=	1.59361374E 06	Y=	6.33019770E 06
XD=	6.18509518E 03	YD=	-1.44717383E 03	XDD	1.52267190E 01	YDD	-6.96416611E 00
RAD	6.52771075E 06	VEL	6.35214251E 03	THETA	8.90385661E 01	PHI	1.37192972E 01
OVEL	-2.06302223E 07	EVEL	-8.16101590E 07	ENEG	4.14591114E 10	ENG	2.20961661E 06
HB1	-1.17005613E-06	HB2	1.02550534E-06	KB1	1.02550534E-06	KB2	2.60092769E-06
FOM	1.76322041E 01	HS1	1.35843118E-02	HS2	-8.19475049E-03	H2S	-1.22176967E-02
EPS	1.43472789E-10						

TIME	5.20000000E 02	DELT	3.87972999E 00	ETAT	5.16939865E 02	DETT	3.06013501E 00
CHI	8.66373089E 01	DCHI	-1.81309612E-05	X=	1.72045922E 06	Y=	6.29980430E 06
XD=	6.50455215E 03	YD=	-1.59519882E 03	XDD	1.67574027E 01	YDD	-7.87487120E 00
RAD	6.53050643E 06	VEL	6.69730229E 03	THETA	8.85046104E 01	PHI	1.47591919E 01
OVEL	-1.60999737E 07	EVEL	-7.70538053E 07	ENEG	4.37218801E 10	ENG	1.72820090E 06
HB1	-1.12710058E-06	HB2	1.09689015E-06	KB1	1.09689015E-06	KB2	2.55610098E-06
FOM	1.92495085E 01	HS1	1.37506081E-02	HS2	-9.46703469E-03	H2S	-1.29625718E-02
EPS	-9.14042175E-11						

TIME	5.23879730E 02	DELT	0	ETAT	5.20000000E 02	DETT	5.12972999E 00
CHI	8.73280381E 01	DCHI	-1.86834768E-05	X=	1.74582206E 06	Y=	6.29355559E 06
XD=	6.57019381E 03	YD=	-1.62614310E 03	XDD	1.70825162E 01	YDD	-8.07850605E 00
RAD	6.53121249E 06	VEL	6.76844059E 03	THETA	8.83975875E 01	PHI	1.49655270E 01
OVEL	-1.51354541E 07	EVEL	-7.60826962E 07	ENEG	4.41888364E 10	ENG	1.62578048E 06
HB1	-1.12251665E-06	HB2	1.10406872E-06	KB1	1.10406872E-06	KB2	2.55130017E-06
FOM	1.95982258E 01	HS1	1.37717176E-02	HS2	-9.73907340E-03	H2S	-1.31283557E-02
EPS	-1.40516931E-10						

TIME	5.23879730E 02	DELT	2.50000000E 00	ETAT	5.25129730E 02	DETT	0
CHI	8.73280381E 01	DCHI	-1.86869339E-05	X=	1.74582206E 06	Y=	6.29355559E 06
XD=	6.57019381E 03	YD=	-1.62614310E 03	XDD	1.70825170E 01	YDD	-8.07850585E 00
RAD	6.53121249E 06	VEL	6.76844059E 03	THETA	8.83975875E 01	PHI	1.49655270E 01
OVEL	-1.51354541E 07	EVEL	-7.60826962E 07	ENEG	4.41888364E 10	ENG	1.62578048E 06
HB1	-1.11952818E-06	HB2	1.10869383E-06	KB1	1.10869383E-06	KB2	2.54813371E-06
FOM	1.00000000E-20	HS1	7.02702263E-24	HS2	-4.96936483E-24	H2S	-6.69874702E-24
EPS	-7.18371869E-32						

TIME	5.26379730E 02	DELT	2.50000000E 00	ETAT	5.25129730E 02	DETT	1.25000000E 00
CHI	8.77765007E 01	DCHI	-1.90217116E-05	X=	1.76223972E 06	Y=	6.28946214E 06
XD=	6.56392915E 03	YD=	-1.64861371E 03	XDD	-2.51732028E 00	YDD	-8.98435694E 00
RAD	6.53167841E 06	VEL	6.76779825E 03	THETA	8.84466194E 01	PHI	1.50988358E 01
OVEL	-1.51398015E 07	EVEL	-7.60826962E 07	ENEG	4.41888364E 10	ENG	1.62624640E 06
HB1	-1.11352726E-06	HB2	1.11794052E-06	KB1	1.11794052E-06	KB2	2.54183187E-06
FOM	1.00000000E-20	HS1	6.95073854E-24	HS2	-5.00220179E-24	H2S	-6.67652403E-24
EPS	-8.76298125E-32						

TIME	5.28879730E 02	DELT	0	ETAT	5.26379730E 02	DETT	3.06013501E 00
CHI	8.82274908E 01	DCHI	-1.93406897E-05	X=	1.77864165E 06	Y=	6.28531254E 06
XD=	6.55760722E 03	YD=	-1.67106487E 03	XDD	-2.54022338E 00	YDD	-8.97656811E 00
RAD	6.53212981E 06	VEL	6.76717594E 03	THETA	8.84956674E 01	PHI	1.52318622E 01
OVEL	-1.51440130E 07	EVEL	-7.60826962E 07	ENEG	4.41888364E 10	ENG	1.62669780E 06
HB1	-1.11051473E-06	HB2	1.12256224E-06	KB1	1.12256224E-06	KB2	2.53869639E-06
FOM	1.00000000E-20	HS1	6.87344132E-24	HS2	-5.03483824E-24	H2S	-6.65466950E-24
EPS	-1.03615031E-31						

TIME	5.28879730E 02	DELT	1.12027001E 00	ETAT	5.29439865E 02	DETT	1.93986499E 00
CHI	8.82274908E 01	DCHI	-1.93412101E-05	X=	1.77864165E 06	Y=	6.28531254E 06
XD=	6.55760722E 03	YD=	-1.67106487E 03	XDD	-2.54022340E 00	YDD	-8.97656811E 00
RAD	6.53212981E 06	VEL	6.76717594E 03	THETA	8.84956674E 01	PHI	1.52318622E 01
OVEL	-1.51440130E 07	EVEL	-7.60826962E 07	ENEG	4.41888364E 10	ENG	1.62669780E 06
HB1	-1.10915957E-06	HB2	1.12462644E-06	KB1	1.12462644E-06	KB2	2.53727208E-06
FOM	5.44493241E 00	HS1	3.74254234E-03	HS2	-2.74143539E-03	H2S	-3.62342256E-03
EPS	-5.64455149E-11						

TIME	5.30000000E 02	DELT	5.00000000E 00	ETAT	5.31379730E 02	DETT	1.12027001E 00
CHI	8.84304518E 01	DCHI	-1.94822649E-05	X=	1.78598977E 06	Y=	6.28343496E 06
XD=	6.56085739E 03	YD=	-1.68094109E 03	XDD	2.90036318E 00	YDD	-8.82371149E 00
RAD	6.53232840E 06	VEL	6.77276994E 03	THETA	8.85033404E 01	PHI	1.52914061E 01
OVEL	-1.50664179E 07	EVEL	-7.60032485E 07	ENEG	4.42268643E 10	ENG	1.61844978E 06
HB1	-1.10169870E-06	HB2	1.13587656E-06	KB1	1.13587656E-06	KB2	2.52938279E-06
FOM	5.45289423E 00	HS1	3.72894123E-03	HS2	-2.75338772E-03	H2S	-3.62344930E-03
EPS	-6.06519279E-11						

TIME	7.00000000E 02	DELT	5.00000000E 00	ETAT	6.97500000E 02	DETT	5.00000000E 00
CHI	1.22935267E 02	DCHI	8.61413354E-06	X=	2.94007595E 06	Y=	5.85633090E 06
XD=	6.98394733E 03	YD=	-3.43750519E 03	XDD	1.72249547E 00	YDD	-1.20947170E 01
RAD	6.55291220E 06	VEL	7.78408390E 03	THETA	8.95482549E 01	PHI	2.41642033E 01
OVEL	-1.53455559E 05	EVEL	-6.08988733E 07	ENEG	5.10068329E 10	ENG	1.69603376E 04
HB1	-5.50147385E-07	HB2	1.70903434E-06	KB1	1.70903434E-06	KB2	1.96458463E-06
FOM	7.00790757E 00	HS1	-1.67299770E-04	HS2	-4.43099270E-03	H2S	-4.31706118E-03
EPS	-5.38022960E-10						

TIME	7.20000000E 02	DELT	5.00000000E 00	ETAT	7.17500000E 02	DETT	5.00000000E 00
CHI	1.27029503E 02	DCHI	1.79168597E-05	X=	3.08008066E 06	Y=	5.78513176E 06
XD=	7.01556122E 03	YD=	-3.68391593E 03	XDD	1.43373738E 00	YDD	-1.25467133E 01
RAD	6.55397943E 06	VEL	7.92397222E 03	THETA	8.96728219E 01	PHI	2.51714501E 01
OVEL	2.05380967E 06	EVEL	-5.86817165E 07	ENEG	5.19327042E 10	ENG	-2.21405965E 05
HB1	-4.66405622E-07	HB2	1.76661175E-06	KB1	1.76661175E-06	KB2	1.88017451E-06
FOM	7.25118226E 00	HS1	-8.30598195E-04	HS2	-4.57471274E-03	H2S	-4.52494774E-03
EPS	-5.57918156E-10						

TIME	7.40000000E 02	DELT	5.00000000E 00	ETAT	7.37500000E 02	DETT	5.00000000E 00
CHI	1.31018038E 02	DCHI	2.78327190E-05	X=	3.22065789E 06	Y=	5.70891391E 06
XD=	7.04110021E 03	YD=	-3.93937819E 03	XDD	1.11549766E 00	YDD	-1.29994335E 01
RAD	6.55471855E 06	VEL	8.06819637E 03	THETA	8.97969636E 01	PHI	2.61671723E 01
OVEL	4.36711517E 06	EVEL	-5.63615623E 07	ENEG	5.28844244E 10	ENG	-4.71274099E 05
HB1	-3.78519900E-07	HB2	1.82127327E-06	KB1	1.82127327E-06	KB2	1.79183382E-06
FOM	7.51195461E 00	HS1	-1.52029827E-03	HS2	-4.70320903E-03	H2S	-4.76869285E-03
EPS	-5.66387826E-10						

TIME	7.60000000E 02	DELT	5.00000000E 00	ETAT	7.57500000E 02	DETT	5.00000000E 00
CHI	1.34876840E 02	DCHI	3.80978074E-05	X=	3.36168043E 06	Y=	5.62749633E 06
XD=	7.06000597E 03	YD=	-4.20388432E 03	XDD	7.70985957E-01	YDD	-1.34508662E 01
RAD	6.55512092E 06	VEL	8.21683197E 03	THETA	8.99190050E 01	PHI	2.71502349E 01
OVEL	6.79137791E 06	EVEL	-5.39335719E 07	ENEG	5.38622734E 10	ENG	-7.33099314E 05
HB1	-2.86468407E-07	HB2	1.87272271E-06	KB1	1.87272271E-06	KB2	1.69954575E-06
FOM	7.79218281E 00	HS1	-2.23165853E-03	HS2	-4.81737601E-03	H2S	-5.05139890E-03
EPS	-5.62067726E-10						

TIME	7.65000000E 02	DELT	5.00000000E 00	ETAT	7.62500000E 02	DETT	5.00000000E 00
CHI	1.35818993E 02	DCHI	4.06958827E-05	X=	3.39698973E 06	Y=	5.60630831E 06
XD=	7.06363693E 03	YD=	-4.27142005E 03	XDD	6.81163070E-01	YDD	-1.35634071E 01
RAD	6.55516835E 06	VEL	8.25469539E 03	THETA	8.99489573E 01	PHI	2.73938899E 01
OVEL	7.41548547E 06	EVEL	-5.33090250E 07	ENEG	5.41108965E 10	ENG	-8.00490622E 05
HB1	-2.62803382E-07	HB2	1.88504624E-06	KB1	1.88504624E-06	KB2	1.67585599E-06
FOM	7.86553740E 00	HS1	-2.41243367E-03	HS2	-4.84384162E-03	H2S	-5.12855629E-03
EPS	-5.59225555E-10						

TIME	7.70000000E 02	DELT	3.59967299E 00	ETAT	7.67500000E 02	DETT	4.29983650E 00
CHI	1.36751634E 02	DCHI	4.32882450E-05	X=	3.43231605E 06	Y=	5.58478120E 06
XD=	7.06681534E 03	YD=	-4.33951815E 03	XDD	5.89974187E-01	YDD	-1.36758156E 01
RAD	6.55519446E 06	VEL	8.29284612E 03	THETA	8.99786196E 01	PHI	2.76366655E 01
OVEL	8.04702830E 06	EVEL	-5.26772402E 07	ENEG	5.43612152E 10	ENG	-8.68676955E 05
HB1	-2.42239921E-07	HB2	1.89549472E-06	KB1	1.89549472E-06	KB2	1.65533713E-06
FOM	7.94028622E 00	HS1	-2.59428923E-03	HS2	-4.86952998E-03	H2S	-5.20841853E-03
EPS	-5.55189672E-10						

TIME	7.73599673E 02	DELT	0	ETAT	7.71799837E 02	DETT	1.79983650E 00
CHI	1.37416226E 02	DCHI	7.20521199E-04	X=	3.45775808E 06	Y=	5.56907141E 06
XD=	7.06886919E 03	YD=	-4.38896098E 03	XDD	5.38133412E-01	YDD	-1.37724019E 01
RAD	6.55520002E 06	VEL	8.32057030E 03	THETA	8.99999964E 01	PHI	2.78108950E 01
OVEL	8.50767298E 06	EVEL	-5.22165441E 07	ENEG	5.45430026E 10	ENG	-9.18406211E 05
HB1	2.46022185-292	HB2	2.46022185-292	KB1	2.46022185-292	KB2	2.46022185-292
FOM	8.01646939E 00	HS1	-2.73305180E-03	HS2	-4.90073000E-03	H2S	-5.28179115E-03
EPS	1.23962877E-07						

At time 773.599673, HB1, HB2, KB1, and KB2 have no meaning since they are computed at the midpoint of the integration increment.

TIME	5.40000000E 02	DELT	5.00000000E 00	ETAT	5.37500000E 02	DETT	5.00000000E 00
CHI	9.02629644E 01	DCHI	-2.05785362E-05	X=	1.85174308E 06	Y=	5.26618201E 06
XD=	6.58977588E 03	YD=	-1.76988673E 03	XDD	2.88267368E 00	YDD	-8.96666005E 00
RAD	6.53406378E 06	VEL	6.82331629E 03	THETA	8.85706178E 01	PHI	1.58226436E 01
OVEL	-1.43630012E 07	EVEL	-7.52836476E 07	ENEG	4.45701106E 10	ENG	1.54361558E 06
HB1	-1.07678277E-06	HB2	1.17253942E-06	KB1	1.17253942E-06	KB2	2.50333975E-06
FOM	5.52500994E 00	HS1	3.60095811E-03	HS2	-2.86040983E-03	H2S	-3.62546258E-03
EPS	-9.48148227E-11						

TIME	5.60000000E 02	DELT	5.00000000E 00	ETAT	5.57500000E 02	DETT	5.00000000E 00
CHI	9.40427429E 01	DCHI	-2.18933283E-05	X=	1.98411221E 06	Y=	6.22897089E 06
XD=	6.64697520E 03	YD=	-1.95225337E 03	XDD	2.83409164E 00	YDD	-9.27495951E 00
RAD	6.53733735E 06	VEL	6.92773935E 03	THETA	8.86995823E 01	PHI	1.68832870E 01
OVEL	-1.28965679E 07	EVEL	-7.37867083E 07	ENEG	4.52773048E 10	ENG	1.38726582E 06
HB1	-1.02426820E-06	HB2	1.24506081E-06	KB1	1.24506081E-06	KB2	2.44870257E-06
FOM	5.67511931E 00	HS1	3.30741862E-03	HS2	-3.07610862E-03	H2S	-3.64019997E-03
EPS	-1.63709046E-10						

TIME	5.80000000E 02	DELT	5.00000000E 00	ETAT	5.77500000E 02	DETT	5.00000000E 00
CHI	9.79625045E 01	DCHI	-2.19064808E-05	X=	2.11761427E 06	Y=	6.18804881E 06
XD=	6.70299899E 03	YD=	-2.14107995E 03	XDD	2.76442821E 00	YDD	-9.61246043E 00
RAD	6.54035460E 06	VEL	7.03664827E 03	THETA	8.88231062E 01	PHI	1.79407435E 01
OVEL	-1.13476312E 07	EVEL	-7.22096813E 07	ENEG	4.60124664E 10	ENG	1.22168326E 06
HB1	-9.68103509E-07	HB2	1.31638252E-06	KB1	1.31638252E-06	KB2	2.39058598E-06
FOM	5.83361315E 00	HS1	2.96185357E-03	HS2	-3.29187084E-03	H2S	-3.67088844E-03
EPS	-2.31693775E-10						

TIME	6.00000000E 02	DELT	5.00000000E 00	ETAT	5.97500000E 02	DETT	5.00000000E 00
CHI	1.02001563E 02	DCHI	-2.04791880E-05	X=	2.25222126E 06	Y=	6.14328082E 06
XD=	6.75738473E 03	YD=	-2.33693535E 03	XDD	2.66963666E 00	YDD	-9.97747401E 00
RAD	6.54311851E 06	VEL	7.15007099E 03	THETA	8.89434259E 01	PHI	1.89940882E 01
OVEL	-9.71282577E 06	EVEL	-7.05491667E 07	ENEG	4.67758075E 10	ENG	1.04651115E 06
HB1	-9.08204817E-07	HB2	1.38634109E-06	KB1	1.38634109E-06	KB2	2.32890368E-06
FOM	6.00121411E 00	HS1	2.56305786E-03	HS2	-3.50486329E-03	H2S	-3.71965910E-03
EPS	-2.97404767E-10						

TIME	6.20000000E 02	DELT	5.00000000E 00	ETAT	6.17500000E 02	DETT	5.00000000E 00
CHI	1.06133713E 02	DCHI	-1.75310815E-05	X=	2.38789515E 06	Y=	6.09452102E 06
XD=	6.80959262E 03	YD=	-2.54034442E 03	XDD	2.54609052E 00	YDD	-1.03672970E 01
RAD	6.54562676E 06	VEL	7.26800533E 03	THETA	8.90624707E 01	PHI	2.00423596E 01
OVEL	-7.98912737E 06	EVEL	-6.88021562E 07	ENEG	4.75672815E 10	ENG	8.61434074E 05
HB1	-8.44493208E-07	HB2	1.45476036E-06	KB1	1.45476036E-06	KB2	2.26357786E-06
FOM	6.17873036E 00	HS1	2.11130081E-03	HS2	-3.71210480E-03	H2S	-3.78876910E-03
EPS	-3.59705155E-10						

TIME	6.40000000E 02	DELT	5.00000000E 00	ETAT	6.37500000E 02	DETT	5.00000000E 00
CHI	1.10328034E 02	DCHI	-1.30496223E-05	X=	2.52458642E 06	Y=	6.04161359E 06
XD=	6.85901717E 03	YD=	-2.75176862E 03	XDD	2.39089653E 00	YDD	-1.07783222E 01
RAD	6.54787228E 06	VEL	7.39042266E 03	THETA	8.91817546E 01	PHI	2.10845585E 01
OVEL	-6.17362655E 06	EVEL	-6.69660002E 07	ENEG	4.83866091E 10	ENG	6.66177228E 05
HB1	-7.76895332E-07	HB2	1.52145086E-06	KB1	1.52145086E-06	KB2	2.19453935E-06
FOM	6.36706861E 00	HS1	1.60843396E-03	HS2	-3.91067837E-03	H2S	-3.88057941E-03
EPS	-4.15809609E-10						

TIME	6.60000000E 02	DELT	5.00000000E 00	ETAT	6.57500000E 02	DETT	5.00000000E 00
CHI	1.14550243E 02	DCHI	-7.09095069E-06	X=	2.66223293E 06	Y=	5.98439427E 06
XD=	6.90500468E 03	YD=	-2.97159013E 03	XDD	2.20216574E 00	YDD	-1.12062778E 01
RAD	6.54984420E 06	VEL	7.51727594E 03	THETA	8.93022850E 01	PHI	2.21196494E 01
OVEL	-4.26443384E 06	EVEL	-6.50383052E 07	ENEG	4.92333356E 10	ENG	4.60498235E 05
HB1	-7.05344003E-07	HB2	1.58620887E-06	KB1	1.58620887E-06	KB2	2.12172762E-06
FOM	6.56724959E 00	HS1	1.05782374E-03	HS2	-4.09796622E-03	H2S	-3.99753620E-03
EPS	-4.65490757E-10						

TIME	6.80000000E 02	DELT	5.00000000E 00	ETAT	6.77500000E 02	DETT	5.00000000E 00
CHI	1.18764474E 02	DCHI	1.94708154E-07	X=	2.80075917E 06	Y=	5.92269203E 06
XD=	6.94687529E 03	YD=	-3.20010186E 03	XDD	1.97919121E 00	YDD	-1.16465748E 01
RAD	6.55152905E 06	VEL	7.64851150E 03	THETA	8.94245018E 01	PHI	2.31465635E 01
OVEL	-2.25851404E 06	EVEL	-6.30167563E 07	ENEG	5.01069176E 10	ENG	2.44170753E 05
HB1	-6.29778895E-07	HB2	1.64881531E-06	KB1	1.64881531E-06	KB2	2.04509060E-06
FOM	6.78042656E 00	HS1	4.64093707E-04	HS2	-4.27187198E-03	H2S	-4.14216184E-03
EPS	-5.06474862E-10						

LISTINGS FOR THE COMPUTER

PROGRAM AND THE THREE SUBPROGRAMS

```
      DIMENSION CM(13,4),PSM(1,4),CXDM(4,1),PR(8,4),CR(8,4),AID(4,4),
     1QM(1,4),ULM(4,4),H1(4,1),H2(4,1),FM(8,175),GM(8,175),CAP(8,1),
     2BM(8,8),FK(2),AY(2),AYP(2),SM1(2),SM2(2),AEK(4,4),AEK1(4,4),PRD1
     3(4,4),PRD2(4,4),ZZD(8,1),ULP(4,4),QBM(8,1),F1(8,1),F2(8,1),CQ(1,4)
     4,FT(1,8),EN(8,1),CK(13,8),E1(13,8),CKK(13),E11(13),N5(13),JPP(8)
      COMMON N2(13,8),AKB(8),AKS(8),DTA(8),T(10),A(10),B(10),C(10),
     1ST(175),SDT(175),ET(175),DET(175),CHI(175),DCHI(175),R1(175),V1(17
     25),PHI(175),OV(175),EV(175),FOM(175),HB1(175),HB2(175),AK1(175),
     3AK2(175),THET(175),X1(175),Y1(175),XD1(175),YD1(175),XDD1(175),
     4YDD1(175),Z1(13),Z2(13),N6(13),TOL1(13),TOL6(13),EP(1,175),H2S(1,1
     575),W1(2),W2(2),W3(2),ENG(175),ENJ(175),IWAS(8),IT(8),HS1(175),
     6HS2(175)
      COMMON TOL3(13),TOL7(13),AKS1(8),AKB1(8),N3(8),N7(8),DTC(8),
     1N1(13,8)
      EQUIVALENCE (XDD,W1(1)),(YDD,W1(2)),(X,W2(1)),(Y,W2(2)),
     1(XD,W3(1)),(YD,W3(2))
    1 READ(60,2)N,NO,NR,NC,IR,IO,NRUN,EO,T2
    2 FORMAT(7I5,2F15.0)
      READ(60,201)(N6(J),J=1,13)
  201 FORMAT(13I5)
      READ(60,201)(N5(J),J=1,13)
      DO 300 I=1,NO
  300 READ(60,3)(N2(I,J),J=1,8)
    3 FORMAT(8I5)
      DO 4 I=1,NO
    4 READ(60,5)AKB(I),AKS(I),DTA(I),TOL1(I),TOL6(I)
    5 FORMAT(5E15.0)
      DO 255 I=1,8
      JPP(I)=0
      DO 255 J=1,13
  255 CK(J,I)=0.0
      DO 253 J=1,NO
      K=1
      DO 253 I=1,13
      IF(I-N2(J,K))253,254,253
  254 READ(60,501)ADC1,ETL1
      CK(I,J)=ADC1
      E1(I,J)=ETL1
      K=K+1
  253 CONTINUE
  501 FORMAT(2E15.0)
      DO 6 I=1,N
    6 READ(60,599)T(I),A(I),B(I),C(I)
  599 FORMAT(4E15.0)
      READ(60,7)XO,YO,XDO,YDO,SGO,RO,DELT,THC
    7 FORMAT(4E15.0/4E15.0)
      NN1=N-1
      WRITE(61,11)NN1,NO
   11 FORMAT(1H1,////46X,24H*** OPTIMUM GUIDANCE ***//48X,12HVEHICLE HAS
     1 I2,7H STAGES/50X,4HAND I2,10H OPTION(S))
      WRITE(61,12)
   12 FORMAT(11X,15H     K BAR       11X,15H     K STAR      11X,15H     TL B
     1AR      11X,15H     TL STAR     )
      DO 13 I=1,NO
   13 WRITE(61,14)AKB(I),AKS(I),TOL1(I),TOL6(I)
```

```
 14 FORMAT(4(11X,E15.8))
    WRITE(61,15)
 15 FORMAT(//11X,15H  STAGING TIME 11X,15H       A(I)      11X,15H
   1B(I)      11X,15H       C(I)      )
    DO 16 I=1,N
 16 WRITE(61,14)T(I),A(I),B(I),C(I)
    WRITE(61,17)XO,YO,XDO,YDO,SGO,RO,THC,DELT
 17 FORMAT(//5X,6HXO=    E15.8,5X,6HYO=    E15.8,5X,6HXDO=  E15.8,5X,6HY
   1DO=  E15.8/5X,6HGO=    E15.8,5X,6HRO=    E15.8,5X,6HTHC=  E15.8,5X,6
   2HDELT= E15.8)
    WRITE(61,124)
124 FORMAT(//16X,10HCONSTRAINT11X,15H  CONSTRAINT   11X,15H  CONSTRAIN
   1T   /16X,10H NUMBERS  11X,15H     VALUES      11X,12H  TOLERANCES)
    DO 125 J=1,8
    NADD=0
    DO 125 I=1,13
    NADD=NADD+1
    IF(CK(I,J))126,125,126
126 WRITE(61,127)NADD,CK(I,J),E1(I,J)
125 CONTINUE
127 FORMAT(16X,I5,5X,2(11X,E15.8))
    RA=57.2957791
    GO1=-SGO*RO**2
    TPN=T(N)-(100.0*B(N))/C(N)
    CON=(XDO*YO-YDO*XO)/(XO*XDO+YO*YDO)
    CHIO=ATAN(CON)
    IF(CHIO)18,19,19
 18 CHIO=CHIO+3.1415926
 19 THD=THC-CHIO
    K=2
    IFST=4
    DO 20 I=1,N
    IF(I.EQ.1)21,22
 21 ST(1)=T(1)
    DT=T(2)-T(1)
    TLT=T2-T(1)
    IF(DT-TLT)23,24,25
 23 ST(5)=T2
    SDT(4)=T2-T(2)
    GO TO 26
 24 ST(5)=T(2)+DELT
    SDT(4)=DELT
    GO TO 26
 25 IF(DT.LE.DELT)27,28
 27 ST(5)=T2+DELT
    SDT(4)=ST(5)-T(2)
 26 K=K+3
    CHK=0.0
    ST(2)=ST(1)+0.5*DT
    ST(3)=T(2)
    ST(4)=T(2)
    SDT(1)=0.5*DT
    SDT(2)=SDT(1)
    SDT(3)=0.0
    IFST=0
```

```
      GO TO 137
   28 ST(2)=T2
      SDT(1)=TLT
      GO TO 137
   22 DT=T(I)-T(I-1)
      IF(IFST.EQ.0)138,139
  138 IFST=4
      GO TO 20
  139 IF(I.EQ.2)140,141
  141 IF(DT.LE.DELT)142,143
  143 SDT(K)=DELT-CHK
      ST(K+1)=ST(K)+SDT(K)
      GO TO 144
  140 SDT(K)=DELT
      ST(K+1)=ST(K)+DELT
  144 CHK=T(I)-ST(K+1)
      IF(CHK-DELT)145,225,146
  146 K=K+1
      GO TO 140
  145 SDT(K+1)=CHK
  226 SDT(K+2)=0.0
      ST(K+2)=T(I)
      ST(K+3)=T(I)
      K=K+3
      GO TO 137
  225 SDT(K+1)=CHK
      CHK=0.0
      GO TO 226
  142 DOT=DT+CHK
      IF(DOT-DELT)147,148,149
  147 CHK=T(I)-ST(K-2)
      GO TO 150
  148 CHK=0.0
      GO TO 150
  149 CHK=T(I)-(ST(K-2)+DELT)
  150 K=K+3
      ST(K-2)=ST(K-3)+0.5*DT
      ST(K-1)=T(I)
      ST(K)=T(I)
      SDT(K-3)=0.5*DT
      SDT(K-2)=SDT(K-3)
      SDT(K-1)=0.0
  137 K2=K
      K3=K2+1
   20 CONTINUE
      WRITE(61,269)K,K2
  269 FORMAT(2(5X,I4))
      DO 29 I=1,K2
      IF(I.EQ.1)60,81
   60 ET(I)=ST(I)
      GO TO 62
   81 ET(I)=ST(I-1)+0.5*SDT(I)
      DET(I-1)=ET(I)-ET(I-1)
   62 CHI(I)=CHIO+THD*((ST(I)-ST(1))/(TPN-ST(1)))
      DCHI(I)=0.0
```

```
 29 CONTINUE
    DO 202 II=1,4
    DO 202 JJ=1,4
    IF(II.EQ.JJ)203,204
203 AID(II,JJ)=1.0
    GO TO 202
204 AID(II,JJ)=0.0
202 CONTINUE
    H1(1,1)=0.0
    H1(2,1)=0.0
    H2(1,1)=0.0
    H2(2,1)=0.0
    AEK(1,1)=0.0
    AEK(1,2)=0.0
    AEK(1,3)=1.0
    AEK(1,4)=0.0
    AEK(2,1)=0.0
    AEK(2,2)=0.0
    AEK(2,3)=0.0
    AEK(2,4)=1.0
    AEK(3,3)=0.0
    AEK(3,4)=0.0
    AEK(4,3)=0.0
    AEK(4,4)=0.0
    CM(1,1)=0.0
    CM(1,2)=0.0
    CM(1,3)=0.0
    CM(1,4)=0.0
    DO 75 II=2,5
    DO 75 JJ=1,4
 75 GM(II,JJ)=AID(II-1,JJ)
    I[illegible]=0
    DO 170 MO=1,NO
170 IWAS(MO)=K2
 30 L1=1
    ITER=ITER+1
    IDEL=0
    NCOUTT=1
    NSEC=0
    DO 808 II=1,8
    JPP(II)=0
    TOL3(II)=TOL1(II)
    TOL7(II)=TOL6(II)
    DTC(II)=DTA(II)
    N3(II)=N5(II)
    AKS1(II)=AKS(II)
    AKB1(II)=AKB(II)
808 N7(II)=N6(II)
    DO 131 II=1,NO
    DO 131 JJ=1,NR
131 N1(II,JJ)=N2(II,JJ)
    DO 215 II=1,8
    DO 215 JJ=1,175
    FM(II,JJ)=0.0
215 GM(II,JJ)=0.0
```

```
      LCC=0
      L2=2
      IZ1=0
      NCOUNT=0
      IPOWER=1
      ISEC=1
      LA=NO
      NEQ=2
      NSO=2
      DTR=SDT(1)
      TRK=ST(1)
      DO 31 I=1,K
      IND=1
      IF(I.EQ.1)33,34
   33 X=XO
      Y=YO
      XD=XDO
      YD=YDO
      X1(I)=XO
      Y1(I)=YO
      XD1(I)=XDO
      YD1(I)=YDO
      R1(I)=SQRT(X**2+Y**2)
      V1(I)=SQRT(XD**2+YD**2)
      CON1=(X*XD+Y*YD)/(R1(I)*V1(I))
      THET(I)=ACOS(CON1)
      CON1=X/Y
      PHI(I)=ATAN(CON1)
      OV(I)=V1**2+GO1/R1
      EV(I)=V1**2+2.*GO1/R1
      ENG(I)=XD*Y-YD*X
      ENJ(I)=R1(I)-ENG(I)/(-GO1)
      FMM=A(I)/B(I)
      FOM(I)=FMM
      CHII=CHI(I)
      XDD1(I)=FMM*SIN(CHII)+X*GO1/(R1(I)*R1(I))
      YDD1(I)=FMM*COS(CHII)+Y*GO1/(R1(I)*R1(I))
   34 R=SQRT(X**2+Y**2)
      G=GO1/R**2
      DRAGX=X*G/R
      DRAGY=Y*G/R
      XDD=FMM*SIN(CHII)+DRAGX
      YDD=FMM*COS(CHII)+DRAGY
      CALL RUNKUT(NEQ,NSO,DTR,TRK,W1,W2,W3,FK,AY,AYP,SM1,SM2,IND)
      IF(IPOWER)38,39,38
   38 IF(IND.EQ.2)40,41
   40 HB1(I)=(GO1/R**3)*(1.-3.*(X/R)**2)
      HB2(I)=(-GO1/R**3)*(3.*X*Y/R**2)
      AK1(I)=HB2(I)
      AK2(I)=(GO1/R**3)*(1.-3.*(Y/R)**2)
      GO TO 47
   41 IF(IND.LT.3)47,48
   47 AAT=ST(I)+0.5*SDT(I)
      IF(I.EQ.1)42,241
  241 IF(SDT(I-1).EQ.0.0)42,267
```

```
267 IF(SDT(I).EQ.0.0)46,43
 42 CH1=CHI(I)
    CH2=CHI(I+1)
    CH3=CHI(I+2)
    AAA=AAT-ST(I+2)
    AAB=AAT-ST(I+1)
    AAC=ST(I)-ST(I+2)
    AAD=ST(I)-ST(I+1)
    AAE=AAT-ST(I)
    AAF=ST(I+1)-ST(I+2)
    AAG=ST(I+1)-ST(I)
    AAH=ST(I+2)-ST(I+1)
    AAI=ST(I+2)-ST(I)
    GO TO 44
 43 CH1=CHI(I-1)
    CH2=CHI(I)
    CH3=CHI(I+1)
    AAA=AAT-ST(I+1)
    AAB=AAT-ST(I)
    AAC=ST(I-1)-ST(I+1)
    AAD=ST(I-1)-ST(I)
    AAE=AAT-ST(I-1)
    AAF=ST(I)-ST(I+1)
    AAG=ST(I)-ST(I-1)
    AAH=ST(I+1)-ST(I)
    AAI=ST(I+1)-ST(I-1)
 44 CHII=CH1*((AAA*AAB)/(AAC*AAD))+CH2*((AAA*AAE)/(AAF*AAG))+CH3*((AAB
   1*AAE)/(AAH*AAI))
 45 TAU=(AAT-T(L1))/100.0
    FMM=A(L1)/(B(L1)+C(L1)*TAU)
    GO TO 46
 48 AAT=ST(I+1)
    CHII=CHI(I+1)
    CC1=ST(I)-T(L2)
    IF(CC1.EQ.0.0)35,45
 35 IF(ISEC.EQ.1)37,36
 36 ISEC=1
    GO TO 45
 37 ISEC=2
    L1=L1+1
    L2=L2+1
    GO TO 45
 46 IND=IND+1
    IF(IND.LE.4)34,49
 49 FOM(I+1)=FMM
    R=SQRT(X**2+Y**2)
    V=SQRT(XD**2+YD**2)
    XDD1(I+1)=XDD
    YDD1(I+1)=YDD
    X1(I+1)=X
    Y1(I+1)=Y
    XD1(I+1)=XD
    YD1(I+1)=YD
    R1(I+1)=R
    V1(I+1)=V
```

```
      CON1=(X*XD+Y*YD)/(R*V)
      THET(I+1)=ACOS(CON1)
      CON1=X/R
      PHI(I+1)=ATAN(CON1)
      OV(I+1)=V**2+GO1/R
      EV(I+1)=V**2+2.*GO1/R
      ENG(I+1)=XD*Y-YD*X
      ENJ(I+1)=R-(ENG(I+1)**2)/(-GO1)
      Z1(1)=ST(I)
      Z1(2)=X1(I)
      Z1(3)=Y1(I)
      Z1(4)=XD1(I)
      Z1(5)=YD1(I)
      Z1(6)=R1(I)
      Z1(7)=V1(I)
      Z1(8)=THET(I)
      Z1(9)=PHI(I)
      Z1(10)=OV(I)
      Z1(11)=EV(I)
      Z1(12)=ENG(I)
      Z1(13)=ENJ(I)
      GO TO 113
  200 IF(NSEC)113,128,113
  128 Z1(LY)=Z2(LY)
  113 Z2(1)=TRK
      Z2(2)=X
      Z2(3)=Y
      Z2(4)=XD
      Z2(5)=YD
      Z2(6)=R
      Z2(7)=SQRT(XD*XD+YD*YD)
      V=Z2(7)
      CON1=(X*XD+Y*YD)/(R*V)
      Z2(8)=ACOS(CON1)
      CON1=X/Y
      Z2(9)=ATAN(CON1)
      Z2(10)=V**2+GO1/R
      Z2(11)=V**2+2.*GO1/R
      Z2(12)=XD*Y-YD*X
      Z2(13)=ENJ(I+1)
      CM(6,1)=X/R
      CM(6,2)=Y/R
      CM(6,3)=0.0
      CM(6,4)=0.0
      CM(7,1)=0.0
      CM(7,2)=0.0
      CM(7,3)=XD/R
      CM(7,4)=YD/R
      DMM=R*R*V*SIN(Z2(8))
      DMN=R*V*V*SIN(Z2(8))
      CM(8,1)=(X*V*COS(Z2(8))-XD*R)/DMM
      CM(8,2)=(Y*V*COS(Z2(8))-YD*R)/DMM
      CM(8,3)=(XD*R*COS(Z2(8))-X*V)/DMN
      CM(8,4)=(YD*R*COS(Z2(8))-Y*V)/DMN
      CM(9,1)=Y/R**2
```

```
      CM(9,2)=X/R**2
      CM(9,3)=0.0
      CM(9,4)=0.0
      CM(10,1)=GO1*X/R**3
      CM(10,2)=GO1*Y/R**3
      CM(10,3)=2.*XD
      CM(10,4)=2.*YD
      CM(11,1)=CM(10,1)
      CM(11,2)=CM(10,2)
      CM(11,3)=XD
      CM(11,4)=YD
      CM(12,1)=-YD
      CM(12,2)=XD
      CM(12,3)=Y
      CM(12,4)=-X
      CM(13,1)=X/R+(2.*Z2(12)*YD)/(-GO1)
      CM(13,2)=Y/R-(2.*Z2(12)*XD)/(-GO1)
      CM(13,3)=(-2.*Z2(12)*Y)/(-GO1)
      CM(13,4)=(2.*Z2(12)*X)/(-GO1)
      CXDM(1,1)=XD
      CXDM(2,1)=YD
      CXDM(3,1)=XDD
      CXDM(4,1)=YDD
      IF(IPOWER)71,70,71
   71 DO 50 J=1,LA
      IF(JPP(J)-J)256,50,256
  256 JP=J
      LO=N7(JP)
      TOL2=Z2(LO)-AKB1(JP)
      IF(ABS(TOL2).LE.TOL3(JP))51,52
   52 DLTC=ABS(Z1(LO)-Z2(LO))
      DLTK=ABS(Z1(LO)-AKB(JP))
      IF(DLTC.LT.DLTK)83,54
   54 IF(NSEC.EQ.0)161,164
  161 IG=K3
      IT(NCOUTT)=I+2
  165 SDT(IG)=SDT(IG-2)
      ST(IG)=ST(IG-2)
      ET(IG)=ET(IG-2)
      DET(IG)=DET(IG-2)
      CHI(IG)=CHI(IG-2)
      IG=IG-1
      IF(IG.EQ.IT(NCOUTT))164,165
  164 IDEL=JP
      NSEC=4
  151 DZ1=Z2(LO)-Z1(LO)
      DZ2=AKB1(JP)-Z1(LO)
      CHI(I+1)=(DZ2*(CHI(I+1)-CHI(I)))/DZ1+CHI(I)
      CHII=CHI(I)
      DTR=(DZ2*(TRK-ST(I)))/DZ1
      TRK=ST(I)
      W2(1)=AY(1)
      W2(2)=AY(2)
      W3(1)=AYP(1)
      W3(2)=AYP(2)
```

```
      I=I-1
      GO TO 31
   83 IF(NSEC.EQ.0)188,82
  188 DTR=SDT(I+1)
      GO TO 50
   82 IF(JP.EQ.IDEL)151,50
   50 CONTINUE
      GO TO 31
   51 DO 154 MO1=1,N
      IF(TRK.EQ.T(MO1))155,154
  154 CONTINUE
      IF(SDT(I+1).EQ.0.0)155,242
  242 IF(NCOUTT-1)227,156,227
  227 IF(AKB(NCOUTT)-AKB(NCOUTT-1))156,229,156
  229 IF(N6(NCOUTT)-N6(NCOUTT-1))156,155,156
  156 IWAS(NCOUTT)=I
      CHI(I+2)=CHI(I+1)
      ST(I+1)=TRK
      ST(I+2)=TRK
      SDT(I)=DTR
      SDT(I+1)=0.0
      SDT(I+2)=ST(I+3)-ST(I+2)
      ET(I+1)=ST(I)+0.5*SDT(I)
      ET(I+3)=ST(I+1)+0.5*SDT(I+2)
      ET(I+2)=ST(I+1)
      DET(I)=ET(I+1)-ET(I)
      DET(I+1)=ET(I+2)-ET(I+1)
      DET(I+2)=ET(I+3)-ET(I+2)
      DET(I+3)=ET(I+4)-ET(I+3)
  155 NSEC=0
      JPP(JP)=JP
      IDEL=0
      GO TO(58,59)SSWTCHF(2)
   58 TH=THET(I+1)*RA
      PH=PHI(I+1)*RA
      CH=CHII*RA
      WRITE(61,80)ITER,TRK,DTR,ET(I+1),DET(I+1),CH,Z2(2),Z2(3),Z2(4),Z2(
     15),Z2(6),Z2(7),TH,PH,Z2(10),Z2(11),Z2(12),Z2(13),FOM(I+1),DRAGX,DR
     2AGY
   80 FORMAT(///32X,39HCONDITIONS FOR POWER CUTOFF, ITERATION I2///5X,
     16HTIME  E15.8,5X,6HDELT  E15.8,5X,6HETAT  E15.8,5X,6HDETT  E15.8/5
     2X,6HCHI   E15.8,5X,6HX=     E15.8,5X,6HY=     E15.8,5X,6HXD=   E15.8
     3/5X,6HYD=   E15.8,5X,6HRAD   E15.8,5X,6HVEL   E15.8,5X,6HTHETA E15
     4.8/5X,6HPHI   E15.8,5X,6HQVEL  E15.8,5X,6HEVEL  E15.8,5X,6HENEG  E
     515.8/5X,6HENG   E15.8,5X,6HFOM   E15.8,5X,6HDRAGX E15.8,5X,6HDRAGY
     6 E15.8)
   59 TOL2=AKS1(JP)-AKB1(JP)
      DO 68 II=1,4
      DO 68 JJ=1,4
   68 ULM(II,JJ)=AID(II,JJ)
      IF(N7(JP).EQ.N3(JP))304,86
  304 IF(ABS(TOL2).LE.0.01)61,86
   86 IF(LO-1)244,245,244
  245 DO 246 II=1,4
  246 PSM(1,II)=0.0
```

```
      GO TO 247
  244 DO 238 II=1,4
  238 CQ(1,II)=CM(LO,II)
      CALL MATMP(1,4,4,1,4,4,1,4,1,CQ,CXDM,PRD1)
      DO 239 II=1,4
  239 PSM(1,II)=-CQ(1,II)/PRD1
  247 CALL MATMP(4,1,1,4,4,4,4,1,4,CXDM,PSM,PRD1)
      DO 240 II=1,4
      DO 240 JJ=1,4
  240 ULM(II,JJ)=AID(II,JJ)+PRD1(II,JJ)
      GO TO(53,67)SSWTCHF(4)
   53 WRITE(61,110)
  110 FORMAT(///36X,20HCONDITIONS FOR COAST)
   67 IPOWER=0
      DTR=DTC(JP)
  313 IND=1
      FMM=0.0
      GO TO 34
   39 IF(IND.EQ.2)63,64
   63 HBA=(GO1/R**3)*(1.-3.*(X/R)**2)
      HBB=(-GO1/R**3)*(3.*X*Y/R**2)
      HBC=HBB
      HBD=(GO1/R**3)*(1.-3.*(Y/R)**2)
   64 IND=IND+1
      IF(IND.GT.4)65,34
   65 AEK(3,1)=HBA
      AEK(3,2)=HBB
      AEK(4,1)=HBC
      AEK(4,2)=HBD
      DO 66 II=1,4
      DO 66 JJ=1,4
   66 AEK1(II,JJ)=AID(II,JJ)+AEK(II,JJ)*DTR
      CALL MATMP(4,4,4,4,4,4,4,4,4,AEK1,ULM,PRD1)
      DO 69 II=1,4
      DO 69 JJ=1,4
   69 ULM(II,JJ)=PRD1(II,JJ)
      LY=N3(JP)
      GO TO 200
   70 IF(LY.EQ.1)305,306
  305 TOL2=TRK-AKS1(JP)
      IF(ABS(TOL2).LE.TOL7(JP))91,311
  311 IF(TOL2)67,67,312
  312 DTR=DTC(JP)-(TRK-AKS1(JP))
      TRK=TRK-DTC(JP)
      GO TO 307
  306 TOL2=Z2(LY)-AKS1(JP)
      IF(ABS(TOL2).LE.TOL7(JP))91,73
   73 DLTC=ABS(Z1(LY)-Z2(LY))
      DLTK=ABS(Z1(LY)-AKS(LY))
      IF(DLTC.LT.DLTK)89,74
   89 GO TO(103,111)SSWTCHF(4)
  103 TH=Z2(8)*RA
      PH=Z2(9)*RA
      WRITE(61,114)TRK,DTR,Z2(2),Z2(3),Z2(4),Z2(5),Z2(6),Z2(7),TH,PH,
     1Z2(10),Z2(11),Z2(12),Z2(13),DRAGX,DRAGY
```

```
114 FORMAT(//5X,6HTIME  E15.8,5X,6HDELT  E15.8,5X,6HX=    E15.8,5X,6HY
   1=    E15.8/5X,6HXD=   E15.8,5X,6HYD=   E15.8,5X,6HRAD   E15.8,5X,6
   1HVEL   E15.8/5X,6HTHETA E15.8,5X,6HPHI   E15.8,5X,6HOVEL  E15.8,5X
   2,6HEVEL  E15.8/5X,6HENEG  E15.8,5X,6HENG   E15.8,5X,6HDRAGX E15.8,
   35X,6HDRAGY E15.8)
111 IF(NSEC)90,67,90
 74 NSEC=4
 90 DZ1=Z2(LY)-Z1(LY)
    DZ2=AKS1(JP)-Z1(LY)
    TRK=TRK-DTR
    DTR=DZ2*DTR/DZ1
307 W2(1)=AY(1)
    W2(2)=AY(2)
    W3(1)=AYP(1)
    W3(2)=AYP(2)
    GO TO 313
 91 WRITE(61,112)ITER
112 FORMAT(///32X,39HCONDITIONS FOR COAST CUTOFF, ITERATION I2)
    TH=Z2(8)*RA
    PH=Z2(9)*RA
    WRITE(61,114)TRK,DTR,Z2(2),Z2(3),Z2(4),Z2(5),Z2(6),Z2(7),TH,PH,
   1Z2(10),Z2(11),Z2(12),Z2(13),DRAGX,DRAGY
    NSEC=0
    GO TO 92
 61 NCOUNT=NO
    LW=LO
    GO TO 72
 92 NCOUNT=NCOUNT+1
    NCOUTT=NCOUTT+1
    LW=LY
 72 IF(LW-1)330,331,330
331 DO 332 II=1,4
332 PSM(1,II)=0.0
    GO TO 333
330 DO 76 II=1,4
 76 CQ(1,II)=CM(LW,II)
    CALL MATMP(1,4,4,1,4,4,1,4,1,CQ,CXDM,PRD2)
    DO 77 II=1,4
 77 PSM(1,II)=-CQ(1,II)/PRD2
333 IF(NC-1)206,207,206
206 DO 208 II=1,4
208 QM(1,II)=PSM(1,II)
    GO TO 205
207 DO 210 II=1,4
210 QM(1,II)=CM(7,II)
205 LC=0
    DO 78 II=1,NR
    LB=N1(JP,II)
    IF(LB)79,78,79
 79 LC=LC+1
    IZ1=IZ1+1
    ZZD(IZ1)=Z2(LB)
    CKK(IZ1)=CK(LB,JP)
    E11(IZ1)=E1(LB,JP
    DO 790 MI=1,4
```

```
790 CR(LC,MI)=CM(LB,MI)
 78 CONTINUE
    CALL MATMP(4,1,1,4,4,4,4,1,4,CXDM,PSM,PRD1)
    DO 87 II=1,4
    DO 87 MJ=1,4
 87 PRD1(II,MJ)=AID(II,MJ)+PRD1(II,MJ)
    CALL MATMP(8,4,4,4,8,4,LC,4,4,CR,PRD1,PR)
    KTIM=I+1
    JJ=I+1
    NCOT=LCC+1
    LCC=NCOT+LC-1
    WRITE(61,257)JPP(JP),JP,LC,LCC,NCOT,JJ,KTIM,IZ1
257 FORMAT(//5X,6HJPP=  I4,5X,6HJP=   I4,5X,6HLC=   I4,5X,6HLCC=  I4/5
   1X,6HNCOT= I4,5X,6HJJ=   I4,5X,6HKTIM= I4,5X,6HIZ1=  I4)
    DO 94 II=1,KTIM
    H1(3,1)=COS(CHI(JJ))*FOM(JJ)
    H1(4,1)=-SIN(CHI(JJ))*FOM(JJ)
    H2(3,1)=-SIN(CHI(JJ))*FOM(JJ)*0.5
    H2(4,1)=-COS(CHI(JJ))*FOM(JJ)*0.5
    IF(II-1)216,221,216
216 AEK(3,1)=HB1(JJ)
    AEK(3,2)=HB2(JJ)
    AEK(4,1)=AK1(JJ)
    AEK(4,2)=AK2(JJ)
    DO 218 I1=1,4
    DO 218 J1=1,4
218 AEK1(I1,J1)=AID(I1,J1)+AEK(I1,J1)*SDT(JJ)
    CALL MATMP(4,4,4,4,4,4,4,4,4,ULM,AEK1,ULP)
    DO 219 I1=1,4
    DO 219 J1=1,4
219 ULM(I1,J1)=ULP(I1,J1)
221 CALL MATMP(8,4,4,4,8,4,LC,4,4,PR,ULM,CR)
    CALL MATMP(8,4,4,1,8,1,LC,4,1,CR,H1,F1)
    CALL MATMP(8,4,4,1,8,1,LC,4,1,CR,H2,F2)
    LF=0
    DO 88 I1=NCOT,LCC
    LF=LF+1
    FM(I1,JJ)=F1(LF,1)
    GM(I1,JJ)=F2(LF,1)
 88 GM(I1,JJ)=F2(LF,1)
    IF(JP.EQ.IO)85,84
 85 CALL MATMP(1,4,4,4,1,4,1,4,4,QM,ULM,PSM)
    CALL MATMP(1,4,4,1,8,1,1,4,1,PSM,H1,F1)
    CALL MATMP(1,4,4,1,8,1,1,4,1,PSM,H2,F2)
    HS1(JJ)=F1(1,1)
    HS2(JJ)=F2(1,1)
 84 JJ=KTIM-II
 94 CONTINUE
    IF(NCOUNT.EQ.NO)222,223
223 IPOWER=4
    TRK=ST(I+1)
    DTR=SDT(I+1)
    X=X1(I+1)
    Y=Y1(I+1)
    XD=XD1(I+1)
```

```
    YD=YD1(I+1)
 31 CONTINUE
222 K2=KTIM
    WRITE(61,259)
259 FORMAT(//5X,6HBM MAT)
    DO 93 II=1,LCC
    DO 95 JJ=1,LCC
    BM(II,JJ)=0.0
    DO 96 KK=1,K2
 96 BM(II,JJ)=BM(II,JJ)+FM(II,KK)*FM(JJ,KK)*DET(KK)
    WRITE(61,260)BM(II,JJ)
260 FORMAT(5X,E15.8)
 95 CONTINUE
 93 CONTINUE
    DO 97 II=1,LCC
    QBM(II,1)=0.0
    DO 99 JJ=1,K2
 99 QBM(II,1)=QBM(II,1)-FM(II,JJ)*HS1(JJ)*DET(JJ)
 97 CONTINUE
    CALL MINV(BM,BM,TSST,LCC)
    CALL MATMP(8,8,8,1,8,1,LCC,LCC,1,BM,QBM,F1)
    DO 98 II=1,LCC
 98 FT(1,II)=F1(II,1)
    CALL MATMP(1,8,8,175,1,175,1,LCC,K2,FT,FM,EP)
    CALL MATMP(1,8,8,175,1,175,1,LCC,K2,FT,GM,H2S)
    DO 186 II=1,K2
    EP(II)=EP(II)+HS1(II)
186 H2S(II)=H2S(II)+HS2(II)
    DO 100 II=1,LCC
100 ZZD(II)=CKK(II)-ZZD(II)
    DO 889 II=1,LCC
    IF(ABS(ZZD(II)).LT.E11(II))889,102
889 CONTINUE
302 DO 101 JJ=1,K2
    IF(ABS(EP(JJ)).LT.E0)101,102
101 CONTINUE
    WRITE(61,129)ITER
129 FORMAT(1H1,////39X,25HLAST ITERATION -- NUMBER I2//41X,20HALL TOLE
   1RANCES CHECK)
104 IPRINT=0
    GO TO 105
102 GO TO(106,107)SSWTCHF(3)
106 IPRINT=1
    WRITE(61,108)ITER
108 FORMAT(1H1,////32X,39HCONDITIONS FOR POWER FLIGHT, ITERATION I2)
105 DO 659 IP=1,K2
    TH=THET(IP)*RA
    PH=PHI(IP)*RA
    CH=CHI(IP)*RA
    DH=DCHI(IP)*RA
    WRITE(61,660)ST(IP),SDT(IP),ET(IP),DET(IP),CH,DH,X1(IP),Y1(IP),
   1XD1(IP),YD1(IP),XDD1(IP),YDD1(IP),R1(IP),V1(IP),TH,PH,OV(IP),
   1EV(IP),ENG(IP),ENJ(IP),HB1(IP),HB2(IP),AK1(IP),AK2(IP),FOM(IP),
   3HS1(IP),HS2(IP),H2S(IP),EP(IP)
659 CONTINUE
```

```
660 FORMAT(//5X,6HTIME  E15.8,5X,6HDELT  E15.8,5X,6HETAT  E15.8,5X,6HD
   1ETT  E15.8/5X,6HCHI   E15.8,5X,6HDCHI  E15.8,5X,6HX=    E15.8,5X,6
   2HY=    E15.8/5X,6HXD=   E15.8,5X,6HYD=   E15.8,5X,6HXDD   E15.8,5X
   3,6HYDD   E15.8/5X,6HRAD   E15.8,5X,6HVEL   E15.8,5X,6HTHETA E15.8,
   45X,6HPHI   E15.8/5X,6HOVEL  E15.8,5X,6HEVEL  E15.8,5X,6HENEG  E15.
   58,5X,6HENG   E15.8/5X,6HHB1   E15.8,5X,6HHB2   E15.8,5X,6HKB1   E1
   65.8,5X,6HKB2   E15.8/5X,6HFOM   E15.8,5X,6HHS1   E15.8,5X,6HHS2
   7E15.8,5X,6HH2S   E15.8/5X,6HEPS   E15.8)
    WRITE(61,663)
663 FORMAT(//50X,12HETA K MATRIX//)
    DO 664 II=1,4
664 WRITE(61,665)(ULM(II,JJ),JJ=1,4)
665 FORMAT(4(5X,E15.8))
    IF(IPRINT)107,109,107
107 DO 115 II=1,LCC
    DO 116 JJ=1,LCC
    BM(II,JJ)=0.0
    DO 117 KK=1,K2
117 BM(II,JJ)=BM(II,JJ)+FM(II,KK)*(-FM(JJ,KK)*DET(KK)/(2.*H2S(KK)))
116 CONTINUE
115 CONTINUE
    DO 118 II=1,LCC
    EN(II,1)=0.0
    DO 119 KK=1,K2
119 EN(II,1)=EN(II,1)+(FM(II,KK)*EP(KK)*DET(KK)/(2.*H2S(KK)))
118 CONTINUE
    CALL MINV(BM,BM,TSST,LCC)
    DO 120 II=1,LCC
120 EN(II,1)=EN(II,1)+ZZD(II,1)
    CALL MATMP(8,8,8,1,8,1,LCC,LCC,1,BM,EN,ZZD)
    DO 121 II=1,LCC
121 FT(1,II)=ZZD(II,1)
    DO 122 II=1,LCC
    DO 122 KK=1,K2
122 FM(II,KK)=-FM(II,KK)/(2.*H2S(KK))
    CALL MATMP(1,8,8,175,1,175,1,LCC,K2,FT,FM,DCHI)
    DO 187 II=1,K2
187 DCHI(II)=DCHI(II)-EP(II)/(2.*H2S(II))
    DO 123 KK=1,K2
123 CHI(KK)=CHI(KK)+DCHI(KK)
    MOVE=2
    DO 159 MO2=1,K
    IF(MO2.EQ.IWAS(MOVE))157,159
157 IG=MO2+1
    DO 158 MO1=IG,K
    ST(MO1)=ST(MO1+2)
    CHI(MO1)=CHI(MO1+2)
    SDT(MO1-1)=ST(MO1)-ST(MO1-1)
    ET(MO1-1)=ST(MO1-2)+0.5*SDT(MO1-2)
    DET(MO1-1)=ST(MO1-1)+0.5*SDT(MO1-1)-ET(MO1-1)
158 CONTINUE
    MOVE=MOVE+1
159 CONTINUE
    K4=I
    DO 168 MO=K4,K3
```

```
168 CHI(MO+1)=3.*CHI(MO)-3.*CHI(MO-1)+CHI(MO-2)
    GO TO 30
109 IF(NRUN)1,252,1
252 STOP
    END

    SUBROUTINE MATMP(I1,I2,I3,I4,I5,I6,I,J,K,A,B,C)
    DIMENSION A(1),B(1),C(1)
    L1=0
    DO 1 L=1,K
    DO 2 N=1,I
    IC=I5*I6-(I5*(I6-L1)-N)
    C(IC)=0.0
    L2=0
    DO 3 M=1,J
    IA=I1*I2-(I1*(I2-L2)-N)
    IB=I3*I4-(I3*(I4-L1)-M)
    C(IC)=C(IC)+A(IA)*B(IB)
    L2=L2+1
  3 CONTINUE
  2 CONTINUE
    L1=L1+1
  1 CONTINUE
    RETURN
    END

    SUBROUTINE MINV(A,AI,DET,M)
    DIMENSION A(8,8),AI(8,8),IORD(8)
    N=M
    DO 100 I=1,N
    DO 100 J=1,N
100 AI(I,J)=A(I,J)
    DO 51 I=1,N
 51 IORD(I)=I
    DET=1.
    DO 1 K=1,N
    KP1=K+1
    TEST=ABS(AI(K,K))
    IND=K
    IF(K-N)21,22,21
 21 DO 23 L=KP1,N
    TEST1=ABS(AI(L,K))
    IF(TEST-TEST1)24,23,23
 24 TEST=TEST1
    IND=L
 23 CONTINUE
    IF(IND-K)25,22,25
 25 DO 26 J=1,N
    TEST1=AI(IND,J)
    AI(IND,J)=AI(K,J)
 26 AI(K,J)=TEST1
    DET=-DET
    LL=IORD(K)
    IORD(K)=IORD(IND)
    IORD(IND)=LL
```

```
22 CONTINUE
   IF(AI(K,K))31,32,31
31 AI(K,K)=1./AI(K,K)
   DO 2 J=1,N
   IF(J-K)3,2,3
 3 QUOT=AI(K,J)*AI(K,K)
   AI(K,J)=QUOT
   IF(QUOT)42,2,42
42 DO 4 I=1,N
   IF(I-K)5,4,5
 5 TEST=AI(I,J)-AI(I,K)*QUOT
   IF(ABS(TEST)-ABS(AI(I,J))*1.0E-5)70,71,71
70 AI(I,J)=0.
   GO TO 4
71 AI(I,J)=TEST
 4 CONTINUE
 2 CONTINUE
   DO 11 I=1,N
   IF(I-K)12,11,12
12 AI(I,K)=-AI(I,K)*AI(K,K)
11 CONTINUE
   DET=DET/AI(K,K)
 1 CONTINUE
55 DO 52 I=1,N
   IND=IORD(I)
   IF(IND-I)53,52,53
53 LL=IORD(I)
   IORD(I)=IORD(IND)
   IORD(IND)=LL
   DO 54 K=1,N
   TEST=AI(K,IND)
   AI(K,IND)=AI(K,I)
54 AI(K,I)=TEST
   GO TO 55
52 CONTINUE
33 RETURN
32 DET=0.
   RETURN
   END

   SUBROUTINE RUNKUT(NEQ,NSO,H,X,F,Y,YP,FK,AY,AYP,SUM1,SUM2,INDT)
   DIMENSION F(100),Y(100),YP(100),AY(100),AYP(100),SUM1(100)
   DIMENSION SUM2(100),FK(100)
   IF(INDT-2) 1,2,5
 1 AL1=H/2.
   AL2=0.
   AL3=.5
   AL4=1.
   DO 6 I=1,NEQ
   AY(I)=Y(I)
   AYP(I)=YP(I)
   SUM1(I)=0.
 6 SUM2(I)=0.
   GO TO 7
 2 AL1=H/2.
```

```
      X=X+H/2.
      AL2=H/4.
      AL3=.5
      AL4=2.
      GO TO 7
    5 IF (INDT-3) 3,3,4
    3 AL1=H
      AL2=H/2.
      AL3=1.
      AL4=2.
    7 DO 8 I=1,NEQ
      IF (I  -NSO) 9,9,10
    9 Y(I)=AY(I)+AL1*AYP(I)+AL2*FK(I)
      FK(I)=H*F(I)
      YP(I)=AYP(I)+AL3*FK(I)
      SUM1(I)=SUM1(I)+FK(I)
      GO TO 11
   10 FK(I)=H*F(I)
      Y(I)=AY(I)+AL3*FK(I)
   11 SUM2(I)=SUM2(I)+AL4*FK(I)
    8 CONTINUE
      RETURN
    4 X=X+H/2.
      DO 12 I=1,NEQ
      FK(I)=H*F(I)
      SUM2(I)=(SUM2(I)+FK(I))/6.
      IF (I-NSO) 13,13,14
   13 Y(I)=AY(I)+H*AYP(I)+H* SUM1(I)/6.
      YP(I)=AYP(I)+SUM2(I)
      GO TO 12
   14 Y(I)=AY(I)+SUM2(I)
   12 CONTINUE
      RETURN
      END
```

REFERENCES

1. Dickey, Lyle R., "Trajectory Optimization by Explicit Numerical Methods," NASA TM X-53464, George C. Marshall Space Flight Center, May 25, 1966, unclassified.

2. Dickey, Lyle R., "Near-Optimum Guidance - An Analysis of Fuel Penalty," NASA TM X-53249, George C. Marshall Space Flight Center, April 23, 1965, unclassified.

3. Dickey, Lyle R., "Guidance Applications of Linear Analysis," NASA TM X-53166, George C. Marshall Space Flight Center, November 27, 1964, unclassified.

COMPUTER PROGRAM TRAJECTORY OPTIMIZATION BY EXPLICIT NUMERICAL METHODS

By

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