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NAVAL POSTGRADUATE SCHOOL
Monterey, California

PODEMS - A POINT DEFENSE MISSILE SIMULATION

by

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ABSTRACT

A Point Defense Missile Simulation has been developed. This report describes the concept of such a missile, the basic features of the simulation program including the integration routine and the jet reaction controllers, and provides a FORTRAN coded source program.

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LIST OF SYMBOLS

c_i	Corrector for state variables at time step i
$C_{l'}$, $C_{m'}$, $C_{n'}$	Moment coefficients of baseline missile expressed in pitch axes
$C_{x'}$, $C_{y'}$, $C_{z'}$	Force coefficients of baseline missile expressed in pitch axes
d	Missile diameter, ft
e_0-e_3	Quaterion parameters
h	Step size for fast integration speed, secs
h_s	Step size for slow integration speed, secs
I_x, I_y	Longitudinal and transverse moments of inertia, slugs-ft^2
K_m, K_n	Moment amplication factors due to JRC's
K_y, K_z	Force amplication factors due to JRC's
m	Missile mass, slugs
m_i	Modified value of state variables at time step i
m'_i	Derivatives of state variables evaluated with m_i
p,q,r	Missile angular rates about body axes, rad/sec
p_i	Predicted value of state variables at time step i
r_{mT}	Range from target to missile, ft
S	Reference area, ft^2
T11-T33	Elements of transformation matrix from inertial axes to body axes
T_r	Thrust of rocket, lbs
T_{JRC}	Thrust of JRC's, lbs
u,v,w	Components of missile's inertial velocity in body axes, ft/sec

u_T, v_T, w_T	Components of total relative wind velocity in body axes, ft/sec
u_w, v_w, w_w	Components of true wind velocity in body axes, ft/sec
V	Magnitude of relative wind velocity, ft/sec
x, y, z	Body axes coordinate system
x_{mT}, y_{mT}, z_{mT}	Target position relative to missile in body axes, ft
x', y', z'	Pitch axes coordinate system
X, Y, Z	Inertial axes coordinate system
X_I, Y_I, HT	North-south, east-west, and height inertial position of missile, ft
X_F, Y_F, Z_F	Total forces along missile body axes, lbs
X_M, Y_M, Z_M	Total moments along missile body axes, lbs-ft
XT_I, YT_I, HTT	North-south, east-west, and height inertial position of target, ft
x_{cg}	Position of missile center of gravity, ft
x_{JRC}	Position of missile JRC thrusters, ft
$\tilde{y}_i, \tilde{z}_i$	Predicted values of state variables at time step i
α	Missile angle of attack, degrees
ϵ	Quaterion orthogonality error
ϵ_B	Angular error between gyro spin axis and target line of sight, rad
ϵ_C	Angular error between coil housing axis and target line of sight, rad
θ, Φ, Ψ	Standard missile Euler angles, deg
θ_4	Angular error associated with seeker gimbal ring, rad
σ_A, σ_B	Target elevation and azimuth angles relative to missile axes
Φ_1	Seeker roll angle, rad
Φ_J	Orientation of relative wind with respect to thruster axes, deg
Φ_w	Orientation of relative wind with respect to missile axes, deg
Ψ_2	Seeker coil housing look angle, rad

Ψ_3	Angular error associated with seeker gimbal ring, rad
Ω_C	Angular rotation rate of coil housing, rad/sec
Ω_{G_y}	Angular rotation rate of gyro spin axis about its y axis, rad/sec
Ω_{G_z}	Angular rotation rate of gyro spin axis about its z axis,
Ω_Y	Angular rotation rate of seeker yoke, rad/sec

LIST OF FIGURES

INTRODUCTION

A POint DEfense Missile Simulation (PODEMS) program has been developed and this report offers a description of its basic features, structure, and requirements. Although rather straight forward in nature, this program provides the basic framework from which further simulations of increased complexity and sophistication can be easily implemented.

The concept of a point defense missile as defined by this effort can be best understood by analyzing a typical flight. The seeker of the missile initially acquires a low-altitude, high speed, incoming target. The surface-to-air missile launches vertically, and then immediately performs a rapid pitch-over maneuver toward the target with a consequent altitude gain of less than 500 feet. The primary controllers for this phase of the flight are two pairs of diametrically opposed jets (jet reaction controllers-JRC) aligned perpendicular to both one another and the missile axis of symmetry. Upon attainment of an approximately horizontal flight path, the primary controller of the missile transfers to typical aerodynamic surfaces (CANARDS) which then guide the missile to intercept. The maneuvers of lift-off and pitch-over, for which the time frame is 1. - 1.5 secs, are of primary interest and therefore are the object of this simulation.

The important features of the simulation are: acceptance of a vertical launch configuration, implementation of JRC controlled maneuvers, a detailed simulation of a large-look angle seeker, and a dual speed integration routine.

The basis of the simulation is a dual speed integration routine using Hamming's predictor-modifier-corrector formulation for the recursion equations. The user has the option of specifying which state variables are integrated with the two different steps size h and h_s . Additionally, because of the singularities evident in the Euler angles, four quaterion parameters are employed to uniquely represent the missile attitude for all possible orientations.

All of the missile parameters, including the aerodynamic data for both the baseline missile and the JRC's, are listed within the report. However, the reader is cautioned against the assumption that a particular missile is being simulated for the data are only representative of this type of missile.

The intention of this effort was to provide a general basic structural program capable of simulating a missile as a rigid body with the specific subroutines for the aerodynamic data, rigid body parameters, etc. to be supplied by the user as required.

A. Definitions of Coordinate Systems

1. Inertial Coordinate System

An inertially fixed coordinate system (X,Y,Z) is attached to the earth with the origin at ground zero, the X axis indicating north, the Y axis indicating east and the Z axis indicating the local vertical (positive downward).

2. Missile Fixed Coordinate System

A body fixed coordinate system (x,y,z) is located with its origin at the missile center of gravity, the x axis as the missile's axis of symmetry (positive pointing forward), the y axis rotated negative 45° from the right-hand pitch canard, and the z axis rotated accordingly. See Figure 1.

3. Pitch Axis Coordinate System

The origin and the x' axis of the pitch axes coordinate system (x',y',z') are coincident with their counterparts in the missile fixed axes system, while the z' axis always coincides with the projection of the relative wind vector onto the y , z plane. The angle Φ_W indicates the relative rotation of (x',y',z') with respect to (x,y,z). See Figure 2.

B. Missile Position and Orientation

The coordinates X , Y , HT locate the missile center of gravity with respect to the inertial coordinate system in the north-south, east-west, and height above ground zero directions respectively.

The orientation of the missile axes with respect to the inertial system is monitored using the standard Euler angles[1] Ψ , Θ , Φ (yaw, pitch, roll) with the order of rotation as given. The resulting transformation matrix from inertial coordinates to missile coordinates is

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} T11 & T12 & T13 \\ T21 & T22 & T23 \\ T31 & T32 & T33 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

where

$T11 = \cos\Psi \cos\theta$

$T12 = \sin\Psi \cos\theta$

$T13 = - \sin\theta$

$T21 = \cos\Psi \sin\theta \sin\Phi - \sin\Psi \cos\Phi$

$T22 = \sin\Psi \sin\theta \sin\Phi + \cos\Psi \cos\Phi$

$T23 = \cos\theta \sin\Phi$

$T31 = \cos\Psi \sin\theta \cos\Phi + \sin\Psi \sin\Phi$

$T32 = \sin\Psi \sin\theta \cos\Phi - \cos\Psi \sin\Phi$

$T33 = \cos\theta \cos\Phi$

In the actual simulation, the Euler angles are not employed because of their singularity at $\theta = \pm 90.$; however they are calculated and outputed to aid the program user in visualization of the missile orientation. The following equalities define the Euler angles when $\theta \neq \pm 90.$:

$\theta = \sin^{-1} (-T13)$

$\Psi = \tan^{-1} (T12/T11)$ (4 quadrant $\tan^{-1}$)

$\Phi = \tan^{-1} (T23/T33)$ (4 quadrant $\tan^{-1}$)

However, when $\theta = \pm 90.$, Ψ and Φ are undefined and the following convention is adopted

$\Psi = 0$

$\Phi = \tan^{-1} (T21, T31)$ (4 quadrant $\tan^{-1}$)

C. Quaterions[2]

To avoid the singularity of the Euler angles at $\theta = \pm 90$. the quaterion system of four coordinates is adopted. The introduction of an extra coordinate into the system removes the singularity but requires the addition of a constraint equation on the four parameters.

The four coordinates are e_0, e_1, e_2, e_3 with the constraint of $e_0^2 + e_1^2 + e_2^2 + e_3^2 = 1$ (orthogonality). The elements of the previously mentioned transformation matrix are functions of these coordinates.

$$T11 = e_0^2 + e_1^2 - e_2^2 - e_3^2$$

$$T12 = 2(e_1e_2 + e_0e_3)$$

$$T13 = 2(e_1e_3 - e_0e_2)$$

$$T21 = 2(e_1e_2 - e_0e_3)$$

$$T22 = e_0^2 + e_2^2 - e_1^2 - e_3^2$$

$$T23 = 2(e_2e_3 + e_0e_1)$$

$$T31 = 2(e_1e_3 + e_0e_2)$$

$$T32 = 2(e_2e_3 - e_0e_1)$$

$$T33 = e_0^2 + e_3^2 - e_1^2 - e_2^2$$

The differential equations for the quaterion parameters as functions of the missile angular rates (p,q,r) are:

$$\dot{e}_0 = -\tfrac{1}{2}(e_1 p + e_2 q + e_3 r)$$

$$\dot{e}_1 = \tfrac{1}{2}(e_0 p - e_3 q + e_2 r)$$

$$\dot{e}_2 = \tfrac{1}{2}(e_3 p + e_0 q - e_1 r)$$

$$\dot{e}_3 = \tfrac{1}{2}(- e_2 p + e_1 q + e_0 r)$$

Mechanization of the constraint equation is achieved by defining an error

$$\epsilon = 1 - (e_0^2 + e_1^2 + e_2^2 + e_3^2)$$

which is a measure of the violation of the constraint and applying a correction factor to each differential equation which reduces the error. With a value of $K = 1$ the equations remain correctly constrained within $|\epsilon| \leq 10^{-6}$.

$$\dot{e}_0 = -\tfrac{1}{2}(e_1 p + e_2 q + e_3 r) + K e_0 \epsilon$$

$$\dot{e}_1 = \tfrac{1}{2}(e_0 p - e_3 q + e_2 r) + K e_1 \epsilon$$

$$\dot{e}_2 = \tfrac{1}{2}(e_3 p + e_0 q - e_1 r) + K e_2 \epsilon$$

$$\dot{e}_3 = \tfrac{1}{2}(- e_2 p + e_1 q + e_0 r) + K e_3 \epsilon$$

The required initial conditions on e_0 , e_1 , e_2 , e_3 are given as functions of the initial Ψ , Θ , Φ by

$$e_0 = \cos(\Psi/2)\cos(\Theta/2)\cos(\Phi/2) + \sin(\Psi/2)\sin(\Theta/2)\sin(\Phi/2)$$

$$e_1 = \cos(\Psi/2)\cos(\Theta/2)\sin(\Phi/2) - \sin(\Psi/2)\sin(\Theta/2)\cos(\Phi/2)$$

$$e_2 = \cos(\Psi/2)\sin(\Theta/2)\cos(\Phi/2) + \sin(\Psi/2)\cos(\Theta/2)\sin(\Phi/2)$$

$$e_3 = -\cos(\Psi/2)\sin(\Theta/2)\sin(\Phi/2) + \sin(\Psi/2)\cos(\Theta/2)\cos(\Phi/2)$$

D. Differential Equations for Rigid Body

With X_F , Y_F , Z_F defined as the total forces on the missile expressed in missile axes x,y,z respectively and X_M , Y_M , Z_M defined as the total moments about the missile center of gravity expressed in the same axis system, the differential equations of motion are:

$$\dot{u} = rv - qw + X_F/m$$

$$\dot{v} = pw - ru + Y_F/m$$

$$\dot{w} = qu - pv + Z_F/m$$

$$\dot{p} = \frac{X_M}{I_x}$$

$$\dot{q} = - \frac{pr\ (I_x - I_y) + Y_M}{I_y}$$

$$\dot{r} = + \frac{pq\ (I_x - I_y) + Z_M}{I_y}$$

$$\begin{bmatrix} \dot{x}_I \\ \dot{y}_I \\ \dot{HT} \end{bmatrix} = \begin{bmatrix} \\ T^{-1} \\ \\ \end{bmatrix} \begin{bmatrix} u \\ v \\ -w \end{bmatrix}$$

$$\dot{e}_0 = - \tfrac{1}{2}\ (e_1 p + e_2 q + e_3 r) + Ke_0 \epsilon$$

$$\dot{e}_2 = \tfrac{1}{2}\ (e_0 p - e_3 q + e_2 r) + Ke_1 \epsilon$$

$$\dot{e}_3 = \tfrac{1}{2}\ (e_3 p + e_0 q - e_1 r) + Ke_2 \epsilon$$

$$\dot{e}_4 = \tfrac{1}{2}\ (- e_2 p + e_1 q + e_0 r) + Ke_3 \epsilon$$

It is assumed that the missile is symmetric about the x axis, no cross products of inertia exist and $I_y = I_z$. $T^{-1} = T^T$ where T is the transformation matrix from (X,Y,Z) to (x,y,z).

E. Definition of the Relative Wind Orientation

Two angles α and Φ_W define the orientation of the relative wind vector with respect to the missile axis system as shown in Figure 3, where u_T, v_T, w_T are the x,y,z components of the resultant wind and $V = (u_T^2 + v_T^2 + w_T^2)^{\frac{1}{2}}$. Along each axis the resultant wind component is the difference of the missile inertial velocity and the true wind for that axis.

$$u_T = u - u_W$$

$$v_T = v - v_W$$

$$w_T = w - w_W$$

Additionally, Φ_J defines the orientation of the resultant wind with respect to each individual JRC (Jet Reaction Controller). Positive Φ_J is defined as shown in Figure 4.

F. Aerodynamic Data

The missile aerodynamics are divided into two distinct categories: (1) aerodynamic coefficients for the baseline missile (no JRC) and (2) amplification factors which represent the effect of the JRC thrusters. Both sets of data are functionally dependent on α and either Φ_W or Φ_J but not on Mach number.

The baseline aerodynamic coefficients $C_{x'}$, $C_{y'}$, $C_{z'}$, $C_{\ell'}$, $C_{m'}$, $C_{n'}$ are given as shown in Figures 5-6. For the present simulation $C_{x'} = C_{y'} = C_{\ell'} = C_{n'} = 0$.

The effects of the JRC thrusters are summarized by amplification factors as follows (y force and moment amplification factors are used as examples)

$$K_y = \frac{Y_F\big|_{\text{JRC on}} - Y_F\big|_{\text{JRC off}}}{T_{\text{JRC}}}$$

$$K_m = \frac{Y_M\big|_{\text{JRC on}} - Y_M\big|_{\text{JRC off}}}{T_{\text{JRC}}\,(x_{\text{JRC}})}$$

The specific values of K_y, K_z, K_m, K_n as programmed are shown in Figures 7-8. For this simulation $K_y = K_n = 0$. Additionally, the effects of the JRC jets are assumed to be independent.

G. Integration Routine[3]

Hamming's predictor, modifier, corrector set of recursion equations are used for the dual speed numerical integration of the problem state variables. The following is a brief explanation of the equations.

For a system of n ordinary differential equations

$$y' = f(x,y)$$

where

$$y' = dy/dx \ ,$$

a sequence of the solution variables

$$y_i = y\ (x_i) \qquad i = 1, 2, \ldots$$

can be expressed as a function of previous y_i and y_i'. With $h = x_{i+1} - x_i$ Hammings method is:

PREDICT: $$p_{i+1} = y_{i-3} + \frac{4h}{3}\,(2y_i' - y_{i-1}' + 2y_{i-2}')$$

MODIFY: $$m_{i+1} = p_{i+1} - \frac{112}{121}\,(p_i - c_i)$$

$$m_{i+1}' = f\ (x_{i+1}\ ,\ m_{i+1})$$

CORRECT: $$c_{i+1} = \frac{1}{8}\,[9y_i - y_{i-2} + 3h\ (m_{i+1}'$$

$$+ 2y_i' - y_{i-1}')]$$

FINAL VALUE: $$y_{i+1} = c_{i+1} + \frac{9}{121}\,(p_{i+1} - c_{i+1})$$

Each advance of h in the independent variable x requires two evaluations of y', once for the predictor and once for the corrector. The method is numerically stable with truncation errors to the order of h^5.

The values of y and y' from the past three intervals are necessary, thus a starting technique is required. The conventional application of a 4th order Runge-Kutta integration method on the first three steps was discarded in favor of calculating the required state variables by a Euler backstep. Specifically, for $i = 0$,

$$y_{-3} = y_0 - 3hy'_0$$

$$y_{-2} = y_0 - 2hy'_0$$

$$y_{-1} = y_0 - h\,y'_0$$

$$y'_{-2} = y'_{-1} = y'_0$$

This method suffers from inaccuracy when y'_{-2} and y'_{-1} differ appreciably from y'_0. However, in this simulation, no variation in the solution was detected from the application of the less accurate Euler backstep when compared with a Runge-Kutta starter.

An additional complexity was introduced by the requirement of a dual speed integration algorithm because of computational time considerations. Now there are two systems of differential equations:

$$y' = f\,(x,y,z)$$

$$z' = f\,(x,y,z)$$

with the z equations requiring smaller time steps than the y equations for the same accuracy criteria. With h and h_s defined as the smaller and larger step sizes respectively, figure 9 depicts the sequencing of the algorithm for one step of h_s . A ratio of $h_s/h = 5$ is chosen for illustration although this is variable at the operator's option.

H. Other Subroutines

CONTROL SYSTEM

The JRC's were assumed to be the primary controlling elements for the initial missile trajectory and, therefore, the canard deflection are identically zero for this phase of the flight.

Two control equations govern the action of the JRC's, one for each pair of opposing jets. Figure 10 defines the jet numbers and orientations. For illustration the control of jets 1 and 3 is presented. A variable PRMTZ is defined as a function of missile-target relative position and rates. The exact specification for this equation is the operators responsibility. When PRMTZ > 0 jet 3 is on while jet 1 is off. If PRMTZ < 0 the reverse is true, and when PRMTZ $= 0$ both jets are off.

As an example of a possible control equation consider

$$\mathrm{PRMTZ} = \sigma_A + K\,\dot{\sigma}_A$$

where σ_A is defined in Figure 11.

SEEKER

This program incorporates a simulation of a large look angle version of a present day seeker. The simulation was supplied by the manufacturer and was only slightly modified to interface correctly. The system description will not be discussed here, only the inputs and outputs of the subroutine.

The following information is required by subroutine SEEKER: X_I , Y_I , HT , XT_I , YT_I , HTT , [T] , p , q , r , $\dot{p}$, $\dot{q}$, $\dot{r}$. The subroutine returns: Φ_1 , Ψ_2 , Ψ_3 , θ_4 , ϵ_B , ϵ_C , $\dot{\Phi}_1$, $\dot{\Psi}_2$, Ω_y , Ω_C , Ω_{G_y} , Ω_{G_z} for outputting if desired.

RIGID BODY PARAMETERS

All rigid body parameters (mass , I_x , I_y , C.G. position) are linearly interpolated between the initial values at lift-off and the final values when the missile thrust motor is expended. The instantaneous position of the center of gravity x_{cg} is defined relative to the reference point for the aerodynamic data as in Figure 12. The following table indicates the parameters as used in the program.

PARAMETER	LIFT OFF	BURN OUT	
m	6.742	4.710	slug
I_y	65.1	48.1	slug-ft^2
I_x	.420	.245	slug-ft^2
x_{cg}	-.321	.406	ft

S = .13635 ft^2

d = .4167 ft

x_{JRC} = 2.434 ft

T_{JRC} = 400. lbs

T_r = 3000. lbs

ATMOSPHERE[4]

Both the density and acoustical velocity of air as functions of height are generated within ATMOS. A linear interpolation of these parameters is based on data from an ICAO Standard Atmosphere Table at heights of 0. and 1000. ft.

Additionally values for the X and Y components of surface winds maybe entered as constant or functions of altitude depending on the operator's preference.

TARGET

Subroutine target calculates the time history trajectory of the target as a function of its initial inertial position, constant inertial velocity components and time.

THRUST

Missile thrust is assumed to be a constant THR for a duration of burn TBURN, after which THR = 0 .

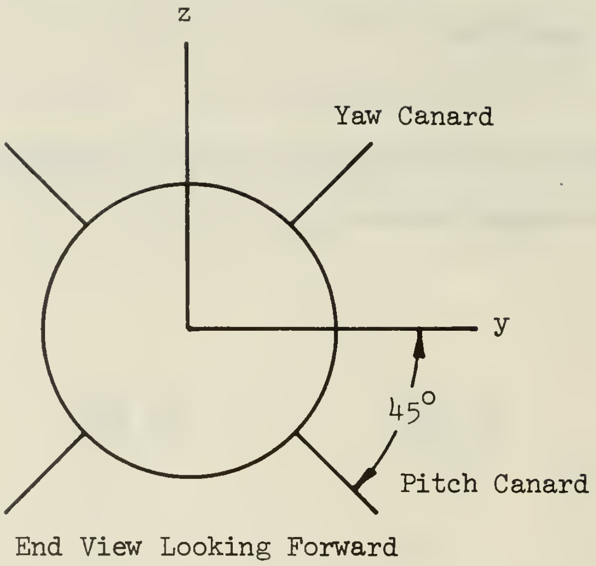


Figure 1. Definition of Missile Fixed Coordinate System

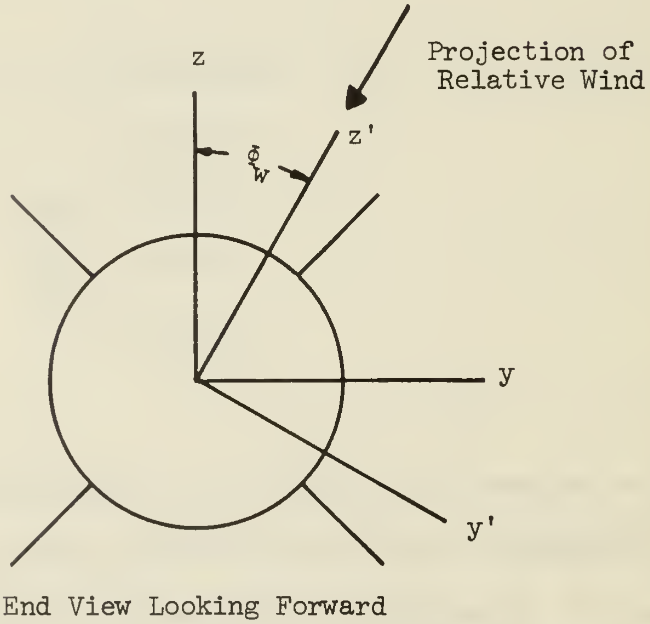
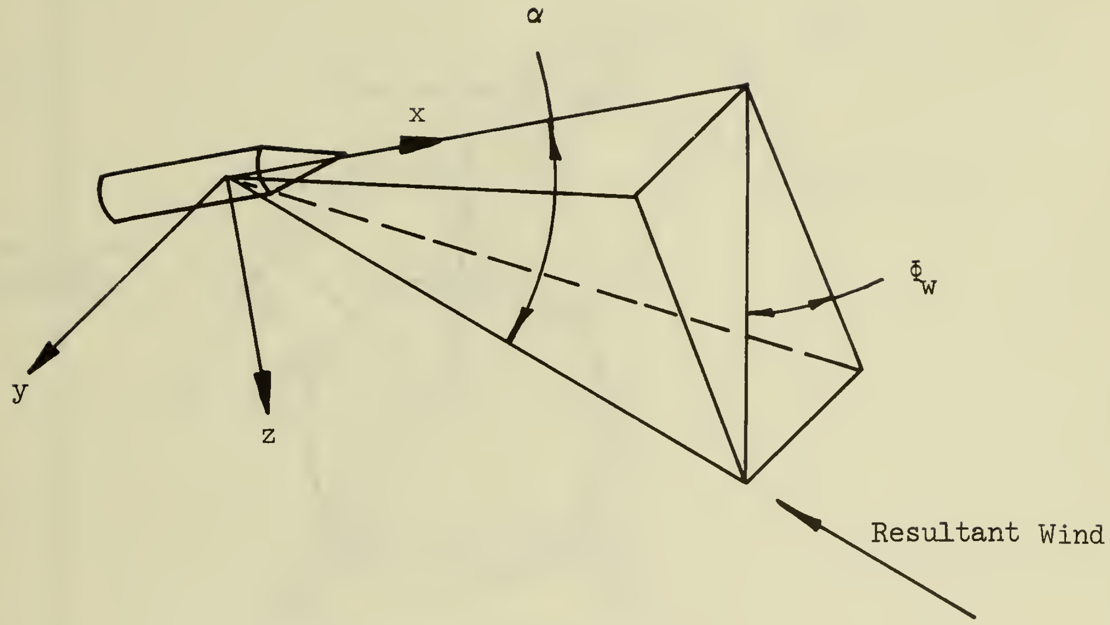


Figure 2. Definition of Pitch Axes Coordinate System



$$\alpha = \cos^{-1}(u_T/V)$$

$$\Phi_W = \cos^{-1}(w_T/(v_T^2 + w_T^2)^{\frac{1}{2}})$$

If $\alpha = 0$, $\Phi_W \equiv 0$

Figure 3. Relative Wind Orientation

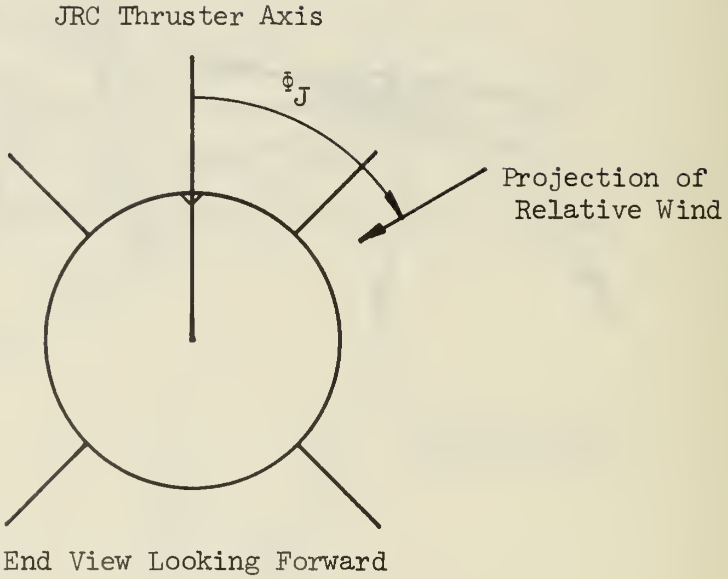


Figure 4. Relative Wind Orientation
With Respect to the JRC Thruster Axis.

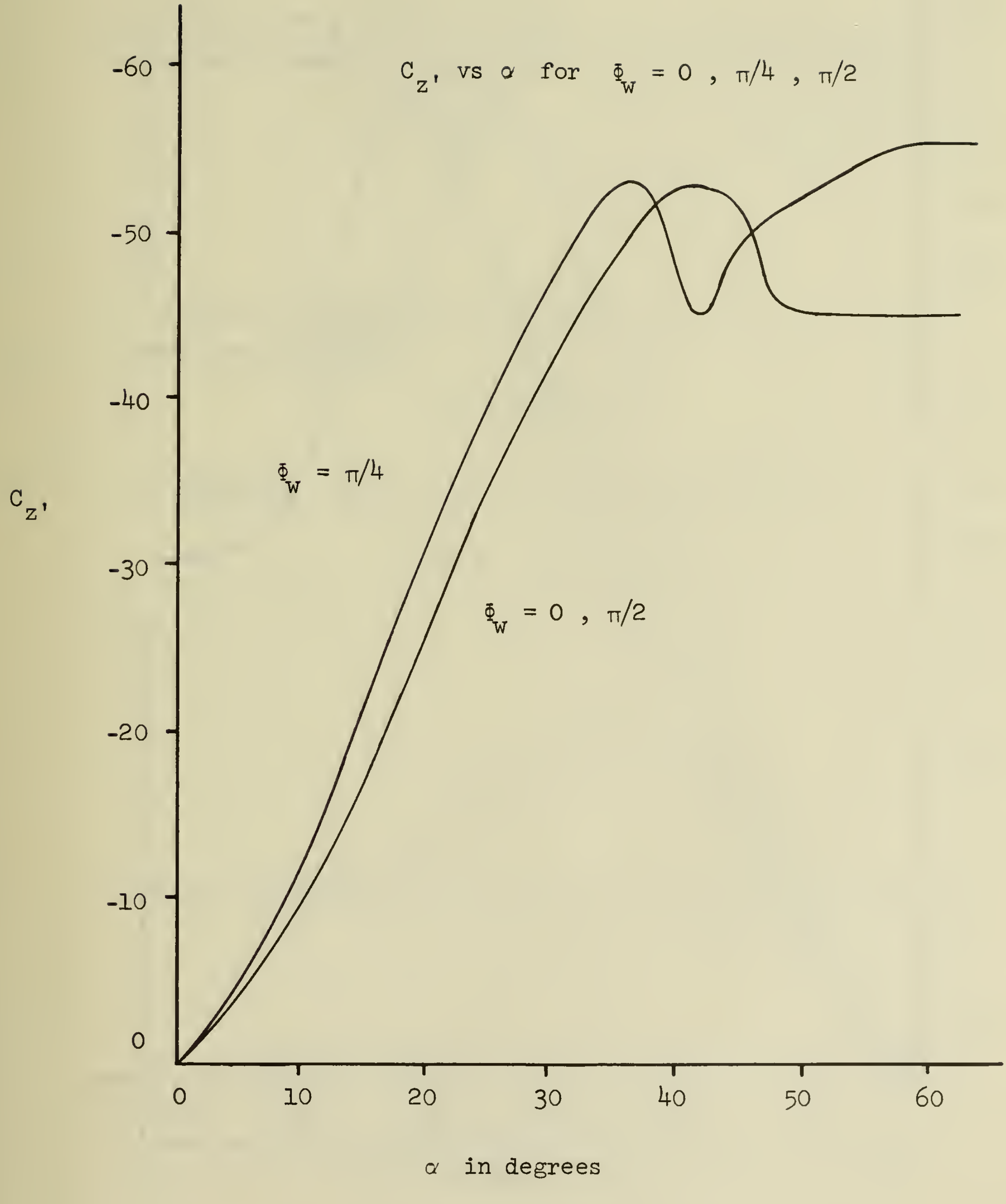


Figure 5. $C_{z'}$ vs α for $\Phi_w = 0$, $\pi/4$, $\pi/2$.

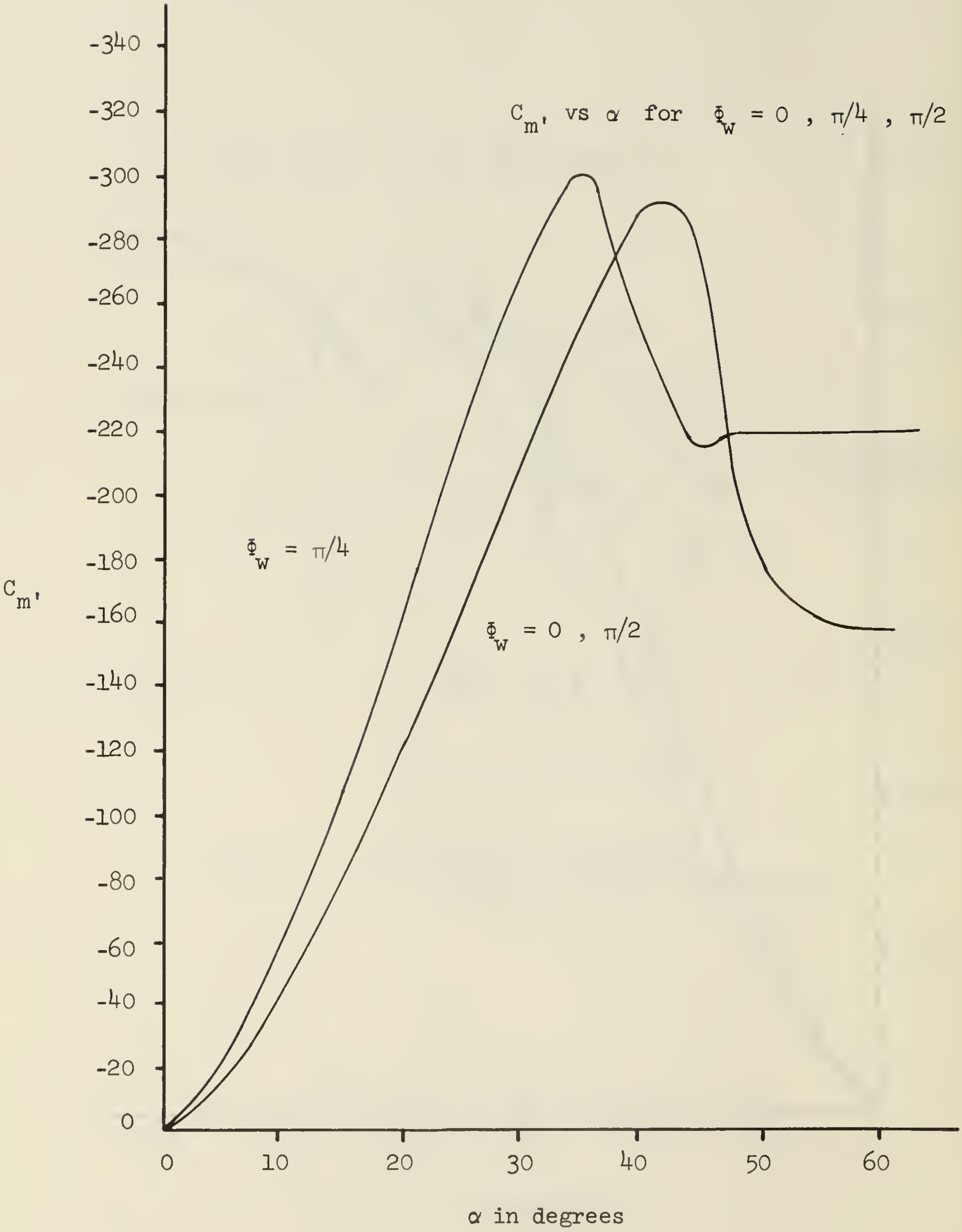


Figure 6. $C_{m'}$ vs α for $\Phi_w = 0$, $\pi/4$, $\pi/2$.

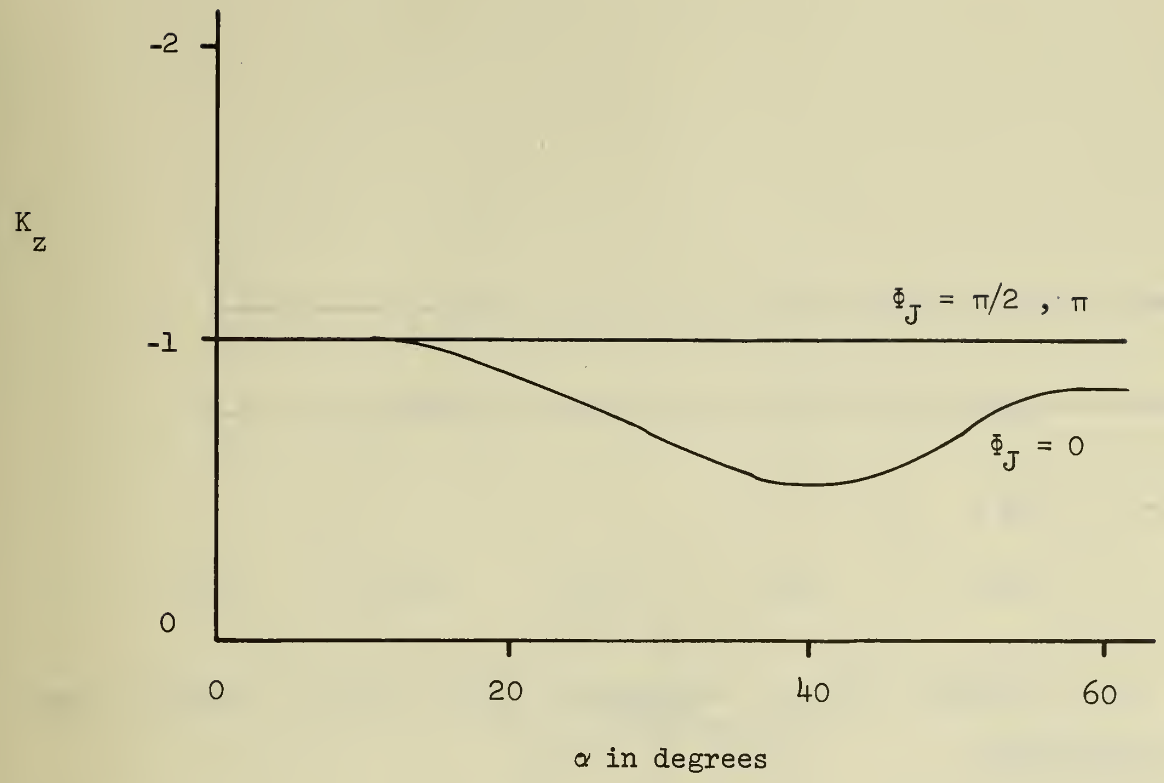


Figure 7. K_z vs α for $\Phi_J = 0$, $\pi/2$, π .

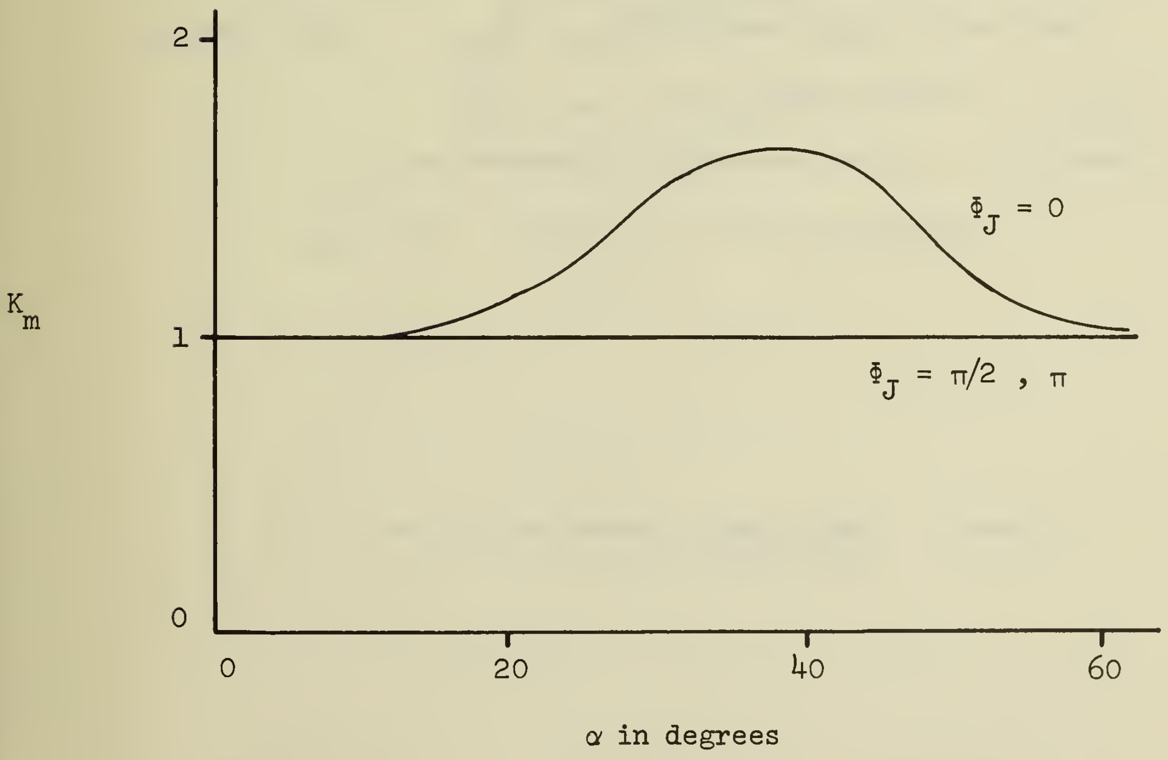
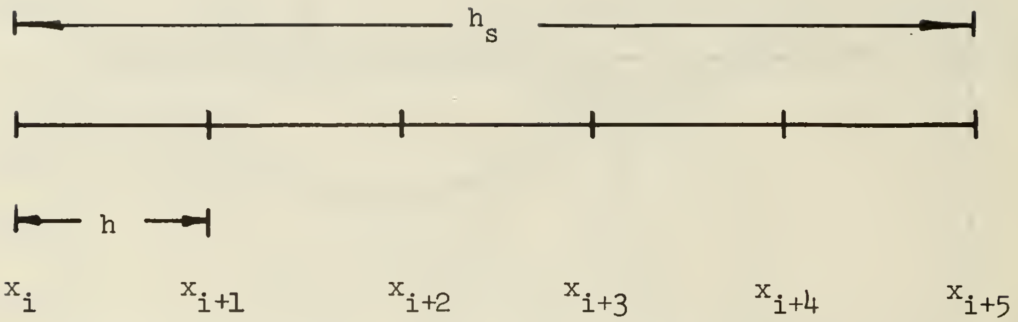
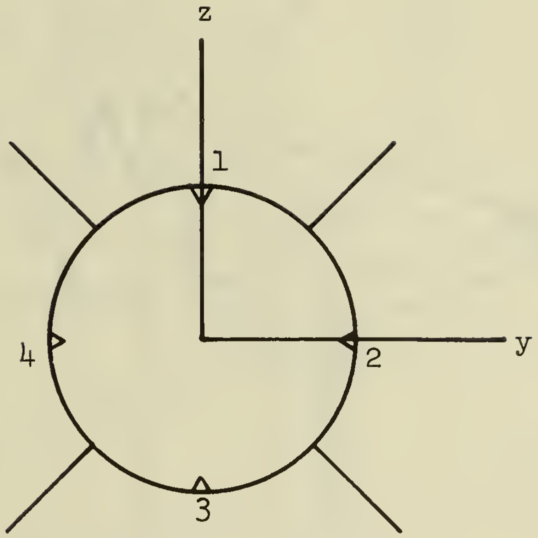


Figure 8. K_m vs α for $\Phi_J = 0$, $\pi/2$, π .



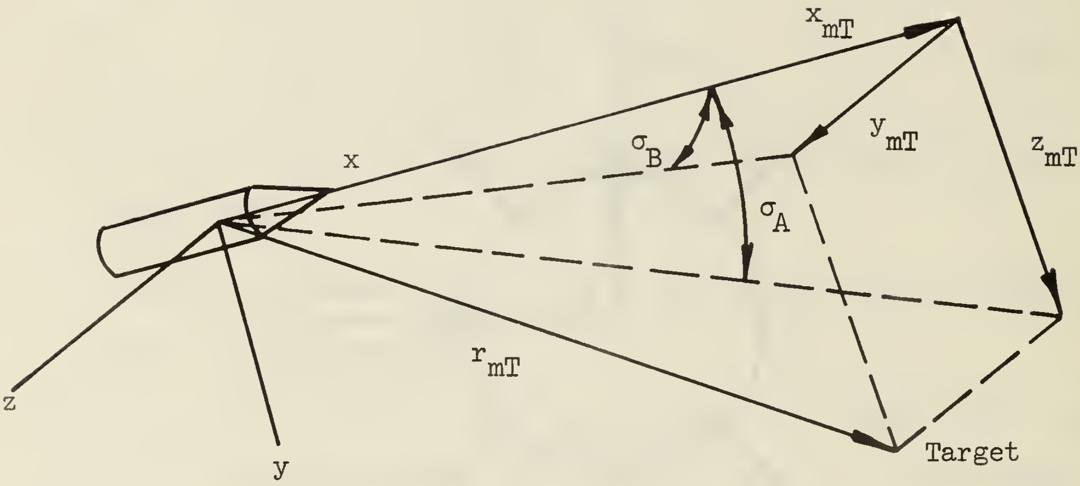
1. At $x = x_i$ evaluate z'_i , y'_i and predict $\tilde{z}_{i+1}$ and $\tilde{y}_{i+5}$ using h and h_s respectively.
2. At $x = x_{i+1}$ evaluate z'_{i+1} , y'_{i+1} and correct z_{i+1} and y_{i+5} using h and h_s respectively.
3. With y_{i+5} now fixed, at $x = x_{i+1}$, x_{i+2} , ... evaluate only z'_{i+1} , z'_{i+2} , ... and sequentially predict $\tilde{z}_{i+2}$, $\tilde{z}_{i+3}$, ... and correct z_{i+2} , z_{i+3} , ... until $x = x_{i+5}$.
4. Repeat steps (1) - (3) for successive increments of h_s .

Figure 9. Dual Speed Integration for One Large Step h_s .



End View Looking Forward

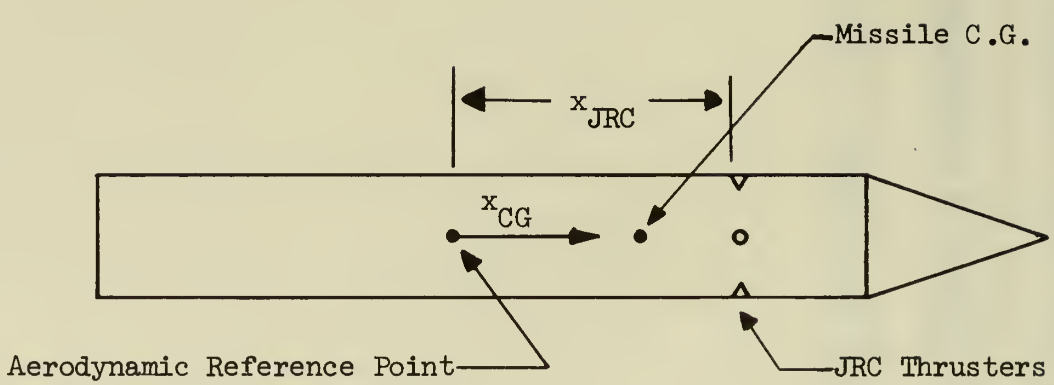
Figure 10. Definition of JRC Orientation.



$$\sigma_A = \tan^{-1} (z_{mT}/x_{mT})$$

$$\sigma_B = \tan^{-1} (y_{mT}/x_{mT})$$

Figure 11. Definition of Target Azimuth and Elevation Angles.



Note: x_{cg} is shown positive

Figure 12. Definition of Missile Parameters.

REFERENCES

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2. Mitchell, E. E. L., and Rogers, A. E., "Quaterion Parameters in the Simulation of a Spinning Rigid Body," Simulation, Vol. 4, No. 6, June, 1965.

3. Ralston, A., and Wilf, H. (Editors), Mathematical Methods for Digital Computers, Vol, I, John Wiley & Sons, Inc., New York, 1967.

4. Dommasch, Daniel O., and others, Airplane Aerodynamics, Pitman Publishing Corporation, New York, 1967.

APPENDIX A

PROGRAM LISTING

The following is a FORTRAN listing of the simulation program designed for compatibility with the United Computing Service, Inc. time sharing system. A typical input/output listing is also included.

```
00100        PROGRAM SXDF(INPUT,OUTPUT,TAPE1,TAPE2,TAPE3)
00110        COMMON Y( 9),DY( 9),X,H,WINDXB,WINDYB,WINDZB,RMACH
00120+       ,CPHIW,XFA,YFA,ZFA,THR,XCG,RMASS,PCAN,YCAN,XM,YM,ZM,XXI,YYI

00130+       ,VSND,SPHIW,HTE,QUE,ALPHA,PHIW,XMAX,TBURN,RHO,VEL,PSI,THT,
00140+       PHI,Z(14),DZ(14)
00150        COMMON NDIM,IPRINT,NSTEP,NPRINT,ICOUNT,IRATE,IRATIO,NDIMF
00160* COMMUNICATIONS BETWEEN SUBROUTINE CTLSYS,AROJRC
00170        COMMON/CTLSYJ/ IJET(4)
00180* COMMUNICATIONS BETWEEN SUBROUTINES TRNSMT,TARGET,SEEKER
00190        COMMON/TRANS/T11,T12,T13,T21,T22,T23,T31,T32,T33
00200* COMMUNICATIONS BETWEEN SUBROUTINES CTLSYS,SEEKER
00210        COMMON/SEEKR/ EPB,SPHI1,CPHI1,EPBC
00220* EQUIVALENCING COMMON MISSILE TERMINOLOGY TO THE STATE VARIABLES
00230* Y(I) AND Z(I) AND THEIR RESPECTIVE DERIVATIVES DY(I) AND DZ(I)
00240        EQUIVALENCE (U,Y(1)),(V,Y(2)),(W,Y(3)),(XI,Y(4)),(YI,Y(5)),

00250+       (HT,Y(6)),(P,Y(7)),(Q,Y(8)),(R,Y(9)),
00260+       (UD,DY(1)),(VD,DY(2)),(WD,DY(3)),
00270+       (XID,DY(4)),(YID,DY(5)),(HTD,DY(6)),(PD,DY(7)),(QD,DY(8)),
00280+       (RD,DY(9))
00290* EQUIVALENCING COMMON MISSILE TERMINOLOGY TO THE STATE VARIABLES
00300* Y(I) AND Z(I) AND THEIR RESPECTIVE DERIVATIVES DY(I) AND DZ(I).
00310        EQUIVALENCE (WYX,Z(3)),(PHI1,Z(4)),(WCZ,Z(5)),(PSI2,Z(6)),
00320+       (WGY,Z(7)),(WGZ,Z(8)),(PSI3,Z(9)),(THT4,Z(10)),
00330+       (E0,Z(11)),(E1,Z(12)),(E2,Z(13)),(E3,Z(14)),(PHI1D,DZ(4)),
00340+       (PSI2D,DZ(6)),(E0D,DZ(11)),(E1D,DZ(12)),(E2D,DZ(13)),
00350+       (E3D,DZ(14))
00360        DATA CON4/57.29577951/,GRAV/32.2/
00370 DATA CON1/1.0/
00380 RETRIEVE(CTLSYS)
00390 RETRIEVE(INIT)
00400 RETRIEVE(THRUST)
00410 RETRIEVE(AERO)
00420 RETRIEVE(TRNSMT)
00430 RETRIEVE(TARGET)
00440 RETRIEVE(RBPRMT)
00450 RETRIEVE(INTEG)
00460 RETRIEVE(AROBSE)
00470 RETRIEVE(SEEKER)
00480 RETRIEVE(ATMOS)
00490 RETRIEVE(AROJRC)
00500 RETRIEVE(INTER2)
00510 RETRIEVE(OUTPUT1)
00520 REWIND 2
00530* INITIALIZE ALL PROGRAM VARIABLES
00540        CALL INIT
00550* THE INTEGRATION ROUTINE REQUIRES TWO EVALUATIONS OF THE STATE
00560* VARIABLE DERIVATIVES FOR EACH TIME STEP. ADDITIONALLY,THE STATE
00570* VARIABLES ARE SEPARATED INTO TWO CATEGORIES; Z(I) FOR VARIABLES
00580* WHICH UPDATE AT EVERY TIME STEP H, AND Y(I) FOR VARIABLES WHICH
00590* UPDATE ONLY EVERY "IRATIO" TIME STEPS.
00600* CALCULATE THE NUMBER OF DERIVATIVE EVALUTIONS NECESSARY FOR
00610* "IRATIO" NUMBER OF TIME STEPS.
00620        IRT2=2*IRATIO
00630      3 DO 2 K=1,IRT2
00640* THE START OF THE DERIVATIVE EVALUATION LOOP.
00650* CALCULATE THE TRANSFORMATION MATRIX BETWEEN THE INERTIAL AXIS
00660* SYSTEM AND THE MISSILE BODY FIXED AXIS SYSTEM.
00670        CALL TRNSMT
00680* CALCULATE THE DERIVATIVES OF THE QUATERION VARIABLES.
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00690        EPS=1.+T11+T22+T33-4.*E0*E0
00700        E0D=-.5*(E1*P+E2*Q+E3*R)+EPS*E0
00710        E1D= .5*(E0*P+E2*R-E3*Q)+EPS*E1
00720        E2D= .5*(E0*Q+E3*P-E1*R)+EPS*E2
00730        E3D= .5*(E0*R+E1*Q-E2*P)+EPS*E3
00740* IT IS NOT NECESSARY TO REEVALUATE ALL OF THE DERIVATIVES WHEN
00750* ONLY THE Z(I), AND NOT THE Y(I), VARIABLES ARE BEING UPDATED.
00760* "IRATE" EQUALS 1 IN THIS SITUATION,OTHERWISE IT EQUALS 0.
00770* WHEN "IRATE" EQUALS 1,PORTIONS OF THE LOOP ARE BYPASSED TO
00780* PREVENT RECOMPUTATION OF NON-UPDATED VARIABLES.
00790        IF (IRATE.EQ.1) GO TO 20
00800* COMPUTE TARGET POSITION.
00810        CALL TARGET
00820* COMPUTE MISSILE THRUST.
00830        CALL THRUST
00840* COMPUTE THE INSTANTANEOUS VALUES OF THE RIGID BODY PARAMETERS.
00850        CALL RBPRMT
00860* COMPUTE THE PERTINENT ATMOSPHERIC PARAMETERS.
00870        CALL ATMOS
00880     20 CONTINUE
00890* SIMULATE THE SEEKER DYNAMICS. THE SEEKER VARIABLES MUST BE
00900* INTEGRATED WITH THE SMALL TIME STEP TO AVOID COMPUTATIONAL
00910* INSTABILITIES, AND HENCE ARE EVALUATED DURING EACH PASS THROUGH
00920* THE LOOP.
00930        CALL SEEKER
00940* BYPASS PORTIONS OF THE LOOP BASED ON "IRATE".
00950        IF (IRATE.EQ.1) GO TO 30
00960* DETERMINE THE MISSILE CONTROL VARIABLES.
00970        CALL CTLSYS
00980* ADD THE EFFECTS OF ATMOSPHERIC WINDS.
00990        UT=U-WINDXB
01000        VT=V-WINDYB
01010        WT=W-WINDZB
01020* CALCULATE MISSILE VELOCITY, MACH NUMBER, AND DYNAMIC PRESSURE.
01030        VEL2=UT*UT+VT*VT+WT*WT
01040        VEL=SQRT(VEL2)
01050        VEL1=SQRT(VEL2-UT*UT)
01060        QUE=.5*RHO*VEL2
01070        RMACH=VEL/VSND
01080* DETERMINE ALPHA AND PHI OF THE WIND. AT THE SINGULARITY OF
01090* ALPHA=0, PHI IS DEFINED AS =0.
01100        PRMT=CON1
01110        IF (VEL.GT.0.) PRMT=UT/VEL
01120        IF (ABS(PRMT).GE.1.0) PRMT=SIGN(CON1,PRMT)
01130        ALPHA=CON4*ACOS(PRMT)
01140        PHIW=0.
01150        SPHIW=0.
01160        CPHIW=1.
01170        IF (VEL1.EQ.0.) GO TO 10
01180        SPHIW=VT/VEL1
01190        CPHIW=WT/VEL1
01200        IF (ABS(SPHIW).GE.1.0) SPHIW=SIGN(CON1,SPHIW)
01210        IF (ABS(CPHIW).GE.1.0) CPHIW=SIGN(CON1,CPHIW)
01220        PHIW=CON4*ACOS(CPHIW)
01230        IF (SPHIW.LT.0.) PHIW=-PHIW
01240* DETERMINE THE AERODYNAMIC FORCES AND MOMENTS.
01250     10 CALL AERO
01260* SUM THE AERO, THRUST, AND GRAVITY FORCES.
01270        XF=XFA+THR+T13*GRAV*RMASS
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01280         YF=YFA+T23*GRAV*RMASS
01290         ZF=ZFA+T33*GRAV*RMASS
01300* EVALUATE THE MISSILE STATE VARIABLE DERIVATIVES.
01310         UD=R*V-Q*W+XF/RMASS
01320         VD=P*W-R*U+YF/RMASS
01330         WD=Q*U-P*V+ZF/RMASS
01340         PD=XM/XXI
01350         PRMT=P*(XXI-YYI)
01360         QD=(-R*PRMT+YM)/YYI
01370         RD=(Q*PRMT+ZM)/YYI
01380         XID=U*T11+V*T21+W*T31
01390         YID=U*T12+V*T22+W*T32
01400         HTD=-(U*T13+V*T23+W*T33)
01410      30 CONTINUE
01420* DETERMINE WHETHER OUTPUT IS DESIRED. "IPRINT"=0 INDICATES
01430* THAT THE INTEGRATION ROUTINE HAS ONLY PREDICTED AND HAS NOT
01440* CORRECTED, THEREFORE THE OUTPUT IS MEANINGLESS. "IPRINT"=1
01450* INDICATES THAT OUTPUTING IS POSSIBLE.
01460         IF (IPRINT.EQ.0) GO TO 6
01470* DETERMINE IF THE DESIRED OUTPUT INTERVAL IS SATISFIED.
01480         IF (MOD(NSTEP,NPRINT).GT.0) GO TO 6
01490* CONVERT THE QUATERIONS TO EULER ANGLES FOR OUTPUTING. AT THE
01500* SINGULARITY OF THETA=+-90, PSI IS DEFINED AS =0 AND PHI
01510* IS CALCULATED.
01520         IF (ABS(T13).GE.1.0) T13=SIGN(CON1,T13)
01530         THT=CON4*ASIN(-T13)
01540         IF (ABS(THT).EQ.90.) GO TO 4
01550         PSI=CON4*ATAN2(T12,T11)
01560         PHI=CON4*ATAN2(T23,T33)
01570         GO TO 5
01580       4 PSI=0.
01590         PHI=CON4*ATAN2(T21,T31)
01600       5 CONTINUE
01610* KEEP TRACK OF THE NUMBER OF TIMES OUTPUTING IS PERFORMED.
01620         ICOUNT=ICOUNT+1
01630* CONVERT RADIANS TO DEGREES FOR OUTPUTING.
01640         PSI20=PSI2*CON4
01650         THT40=THT4*CON4
01660         PHI10=PHI1*CON4
01670         EPBO=EPB*CON4
01680         PSI30=PSI3*CON4
01690         EPBCO=EPBC*CON4
01700* WRITE THE OUTPUT VARIABLES
01710         WRITE(2,)  X,U,V,W,XI,YI,HT,P,Q,R,PSI,THT,PHI,
01720+        ALPHA,PHIW,PHI10,PSI20,PSI30,THT40,EPBO,EPBCO,
01730+        WYX,WCZ,WGY,WGZ,PHI1D,PSI2D,(IJET(I),I=1,4)
01740* DETERMINE WHETHER OR NOT ALL VARIABLES ARE TO BE UPDATED
01750* DURING THE NEXT PASS THROUGH THE LOOP. ALL VARIABLES ARE
01760* EVALUATED ON THE FIRST AND SECOND PASSES AND ONLY THE Z(I)
01770* VARIABLES ARE EVALUATED ON ALL SUBSEQUENT PASSES UNTIL AN
01780* "IRATIO" NUMBER OF STEPS HAVE BEEN TAKEN.
01790       6 IRATE=0
01800         IF (K.GT.2) IRATE=1
01810* CALL THE INTEGRATION ROUTINE.
01820       2 CALL INTEG
01830* STOP THE PROGRAM WHEN THE REQUIRED TIME HAS ELAPSED.
01840         IF (X.LT.(XMAX+H*IRATIO)) GO TO 3
01850* CALL THE PROGRAM TO SORT AND SEQUENCE THE OUTPUT VARIABLES FOR
01860* FOR TTY COMPATIBILITY.
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01870 REWIND 2
01880       CALL OUTPUT1
01890       END
```

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PAGE  1   INIT          03/28/73. 16.53.18


10        SUBROUTINE INIT
20        COMMON Y( 9),DY( 9),X,H,WINDXB,WINDYB,WINDZB,RMACH
30+       ,CPHIW,XFA,YFA,ZFA,THR,XCG,RMASS,PCAN,YCAN,XM,YM,ZM,XXI,YYI
40+       ,VSND,SPHIW,HTE,QUE,ALPHA,PHIW,XMAX,TBURN,RHO,VEL,PSI,THT,
50+       PHI,Z(14),DZ(14)
60        COMMON NDIM,IPRINT,NSTEP,NPRINT,ICOUNT,IRATE,IRATIO,NDIMF
70* COMMUNICATIONS WITH SUBROUTINE TARGET.
80        COMMON/INITL/XT0,YT0,HTT0,XTD,YTD,HTTD
90        EQUIVALENCE (E0,Z(11)),(E1,Z(12)),(E2,Z(13)),(E3,Z(14))
100    100 FORMAT(*INPUT H,XMAX,NPRINT,IRATIO*)
110    110 FORMAT(*INPUT XT0,YT0,HTT0,XTD,YTD,HTTD*)
120* INITIALIZE INTEGRATION ROUTINE CONTROL VARIABLES.
130        IRATE=0
140        ICOUNT=0
150        IPRINT=1
160* SET DIMENSIONS OF Y(I) AND Z(I) RESPECTIVELY. IF DIMENSIONS
170* ARE INCREASED ALSO INCREASE THE STORAGE LOCATION DIMENSIONS
180* SUBROUTINE INTEG.
190        NDIM=9
200        NDIMF=14
210        PRINT   100
220* READ FROM TTY THE STEP SIZE, RUN TIME, OUTPUT INTERVAL,STEP SIZE
230* RATIO.
240        READ    , H,XMAX,NPRINT,IRATIO
250* READ FROM TTY THE TARGET POSITION AND VELOCITY.
260        PRINT   110
270        READ    ,XT0,YT0,HTT0,XTD,YTD,HTTD
280* TIME=0.
290        NSTEP=0
300        X=0.
310* INITIALIZE ALL STATE VARIABLES TO 0.
320        DO 1 I=1,NDIM
330        Y(I)=0.
340      1 DY(I)=0.
350        DO 2 I=1,NDIMF
360        Z(I)=0.
370      2 DZ(I)=0.
380        HTE=6.
390        TBURN=4.5
400* INITIAL EULER ANGLES FOR VERTICAL ORIENTATION.
410        PSI=0.
420        THT=3.141592653/2.
430        PHI=0.
440* COMPUTE INITIAL QUATERION VALUES FROM EULER ANGLES.
450        E0=+COS(PSI/2.)*COS(THT/2.)*COS(PHI/2.)+SIN(PSI/2.)*SIN
460+       (THT/2.)*SIN(PHI/2.)
470        E1=+COS(PSI/2.)*COS(THT/2.)*SIN(PHI/2.)-SIN(PSI/2.)*SIN
480+       (THT/2.)*COS(PHI/2.)
490        E2=+COS(PSI/2.)*SIN(THT/2.)*COS(PHI/2.)+SIN(PSI/2.)*COS
500+       (THT/2.)*SIN(PHI/2.)
510        E3=-COS(PSI/2.)*SIN(THT/2.)*SIN(PHI/2.)+SIN(PSI/2.)*COS
520+       (THT/2.)*COS(PHI/2.)
530        RETURN
540        END
```

```
PAGE  1   TRNSMT         03/28/73. 16.26.02

10        SUBROUTINE TRNSMT
20        COMMON Y( 9),DY( 9),X,H,WINDXB,WINDYB,WINDZB,RMACH
30+       ,CPHIW,XFA,YFA,ZFA,THR,XCG,RMASS,PCAN,YCAN,XM,YM,ZM,XXI,YYI
40+       ,VSND,SPHIW,HTE,QUE,ALPHA,PHIW,XMAX,TBURN,RHO,VEL,PSI,THT,
50+       PHI,Z(14),DZ(14)
60        COMMON NDIM,IPRINT,NSTEP,NPRINT,ICOUNT,IRATE,IRATIO,NDIMF
70        COMMON/TRANS/T11,T12,T13,T21,T22,T23,T31,T32,T33
80        EQUIVALENCE (E0,Z(11)),(E1,Z(12)),(E2,Z(13)),(E3,Z(14))
90* CALCULATE THE ELEMENTS OF THE TRANSFORMATION MATRIX FROM THE
100* QUATERNION VARIABLES.
110        T11=E0*E0+E1*E1-E2*E2-E3*E3
120        T12=2.*(E1*E2+E0*E3)
130        T13=2.*(E1*E3-E0*E2)
140        T21=T12-4.*E0*E3
150        T22=T11-2.*(E1*E1-E2*E2)
160        T23=2.*(E2*E3+E0*E1)
170        T31=T13+4.*E0*E2
180        T32=T23-4.*E0*E1
190        T33=T11-2.*(E1*E1-E3*E3)
200        RETURN
210        END
```

```
PAGE  1   TARGET        03/28/73. 16.28.59


10        SUBROUTINE TARGET
20        COMMON Y( 9),DY( 9),X,H,WINDXB,WINDYB,WINDZB,RMACH
30+       ,CPHIW,XFA,YFA,ZFA,THR,XCG,RMASS,PCAN,YCAN,XM,YM,ZM,XXI,YYI
40+       ,VSND,SPHIW,HTE,QUE,ALPHA,PHIW,XMAX,TBURN,RHO,VEL,PSI,THT,
50+       PHI,Z(14),DZ(14)
60        COMMON NDIM,IPRINT,NSTEP,NPRINT,ICOUNT,IRATE,IRATIO,NDIMF
70        COMMON/TARG/XTI,YTI,HTTI
80* COMMUNICATIONS WITH SUBROUTINE INIT
90        COMMON/INITL/XT0,YT0,HTT0,XTD,YTD,HTTD
100        COMMON/TRANS/T11,T12,T13,T21,T22,T23,T31,T32,T33
110        COMMON/SEEKR1/SIGA,SIGB,SIGAD,SIGBD
120        EQUIVALENCE (U,Y(1)),(V,Y(2)),(W,Y(3)),(XI,Y(4)),(YI,Y(5)),
130+       (HT,Y(6)),(P,Y(7)),(Q,Y(8)),(R,Y(9))
140        DATA CON1/57.29577951/
150* COMPUTE THE INERTIAL POSITION OF THE TARGET
160        XTI=XT0+X*XTD
170        YTI=YT0+X*YTD
180        HTTI=HTT0+X*HTTD
190* COMPUTE THE TARGET POSITION RELATIVE TO THE MISSILE IN THE
200* INERTIAL AXIS SYSTEM.
210        XIMT=XTI-XI
220        YIMT=YTI-YI
230        HTMT=HTTI-HT
240* TRANSFORM THIS INTO MISSILE BODY COORDINATES.
250        XMT=T11*XIMT+T12*YIMT-T13*HTMT
260        YMT=T21*XIMT+T22*YIMT-T23*HTMT
270        ZMT=T31*XIMT+T32*YIMT-T33*HTMT
280* COMPUTE THE MOTION OF THE TARGET AS VIEWED FROM THE MISSILE
290* AXES USING THE VELOCITIES OF THE TARGET AND THE MISSILE AND
300* THE ROTATIONAL RATES OF THE MISSILE.
310        XMTD=T11*XTD+T12*YTD-T13*HTTD-U-Q*ZMT+R*YMT
320        YMTD=T21*XTD+T22*YTD-T23*HTTD-V-R*XMT+P*ZMT
330        ZMTD=T31*XTD+T32*YTD-T33*HTTD-W-P*YMT+Q*XMT
340* COMPUTE THE AZIMUTH AND ELEVATION ANGLES OF THE TARGET AS
350* SEEN BY THE MISSILE AND THEIR RESPECTIVE RATES.
360        SIGA=ATAN2(ZMT,XMT)*CON1
370        SIGB=ATAN2(YMT,XMT)*CON1
380        SIGAD=CON1*(XMT*ZMTD-XMTD*ZMT)/(XMT*XMT+ZMT*ZMT)
390        SIGBD=CON1*(XMT*YMTD-XMTD*YMT)/(XMT*XMT+YMT*YMT)
400        RETURN
410        END
```

```
PAGE  1   THRUST         03/28/73. 16.16.25


10         SUBROUTINE THRUST
20         COMMON Y( 9),DY( 9),X,H,WINDXB,WINDYB,WINDZB,RMACH
30+        ,CPHIW,XFA,YFA,ZFA,THR,XCG,RMASS,PCAN,YCAN,XM,YM,ZM,XXI,YYI
40+        ,VSND,SPHIW,HTE,QUE,ALPHA,PHIW,XMAX,TBURN,RHO,VEL,PSI,THT,
50+        PHI,Z(14),DZ(14)
60         COMMON NDIM,IPRINT,NSTEP,NPRINT,ICOUNT,IRATE,IRATIO,NDIMF
70         THR=3000.
80         IF (X.GT.TBURN) THR=0.
90         RETURN
100         END
```

```
PAGE  1   RBPRMT          03/28/73. 16.18.29


10        SUBROUTINE RBPRMT
20        COMMON Y( 9),DY( 9),X,H,WINDXB,WINDYB,WINDZB,RMACH
30+       ,CPHIW,XFA,YFA,ZFA,THR,XCG,RMASS,PCAN,YCAN,XM,YM,ZM,XXI,YYI
40+       ,VSND,SPHIW,HTE,QUE,ALPHA,PHIW,XMAX,TBURN,RHO,VEL,PSI,THT,
50+       PHI,Z(14),DZ(14)
60        COMMON NDIM,IPRINT,NSTEP,NPRINT,ICOUNT,IRATE,IRATIO,NDIMF
70        DATA RMASS0/6.742/,YYI0/65.1/,XXI0/.420/,XCG0/-.321/,
80+       RMASSD/-.4506/,YYID/-3.778/,XXID/-.03889/,XCGD/.16152/
90        IF (X.GT.TBURN) GO TO 1
100* IF THE MAIN ROCKET IS STILL ON, THE MISSILE'S MASS,MOMENTS
110* OF INERTIA AND CG POSITION ARE CALCULATED BASED ON THE INITIAL
120* VALUE PLUS AN AVERAGE RATE OF CHANGE TIMES THE ELAPSED TIME.
130        RMASS=RMASS0+X*RMASSD
140        XXI=XXI0+X*XXID
150        YYI=YYI0+X*YYID
160        XCG=XCG0+X*XCGD
170      1 RETURN
180        END
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PAGE  1   ATMOS          03/28/73. 17.02.01

10        SUBROUTINE ATMOS
20        COMMON Y( 9),DY( 9),X,H,WINDXB,WINDYB,WINDZB,RMACH
30+       ,CPHIW,XFA,YFA,ZFA,THR,XCG,RMASS,PCAN,YCAN,XM,YM,ZM,XXI,YYI
40+       ,VSND,SPHIW,HTE,QUE,ALPHA,PHIW,XMAX,TBURN,RHO,VEL,PSI,THT
50+       PHI,Z(14),DZ(14)
60        COMMON NDIM,IPRINT,NSTEP,NPRINT,ICOUNT,IRATE,IRATIO,NDIMF
70        COMMON/TRANS/T11,T12,T13,T21,T22,T23,T31,T32,T33
80        EQUIVALENCE (HT,Y(6))
90        RHO=.0023769-HT*.0000000688
100        VSND=1116.89-HT*.00384
110* SET THE INERTIAL COMPONENTS OF THE WIND.
120        WINDXI=0.
130        WINDYI=0.
140* TRANSFORM INTO MISSILE AXES.
150        WINDXB=WINDXI*T11+WINDYI*T12
160        WINDYB=WINDXI*T21+WINDYI*T22
170        WINDZB=WINDXI*T31+WINDYI*T32
180        RETURN
190        END
```

```
10      SUBROUTINE SEEKER
20      COMMON Y( 9),DY( 9),X,H,WINDXB,WINDYB,WINDZB,RMACH
30+     ,CPHIW,XFA,YFA,ZFA,THR,XCG,RMASS,PCAN,YCAN,XM,YM,ZM,XXI,YYI
40+     ,VSND,SPHIW,HTE,QUE,ALPHA,PHIW,XMAX,TBURN,RHO,VEL,PSI,THT,
50+     PHI,Z(14),DZ(14)
60      COMMON NDIM,IPRINT,NSTEP,NPRINT,ICOUNT,IRATE,IRATIO,NDIMF
70      COMMON/TRANS/T11,T12,T13,T21,T22,T23,T31,T32,T33
80      COMMON/TARG/XTI,YTI,HTTI
90      COMMON/SEEKR/EPB,SPHI1,CPHI1,EPBC
100      EQUIVALENCE (EL,Z(1)),(ER,Z(2)),(WYX,Z(3)),(PHI1,Z(4)),
110+     (WCZ,Z(5)),(PSI2,Z(6)),(WGY,Z(7)),(WGZ,Z(8)),(PSI3,Z(9)),
120+     (THT4,Z(10)),(ELD,DZ(1)),(ERD,DZ(2)),(WYXD,DZ(3)),(PHI1D,DZ
130+     (4)),(WCZD,DZ(5)),(PSI2D,DZ(6)),(WGYD,DZ(7)),(WGZD,DZ(8)),
140+     (PSI3D,DZ(9)),(THT4D,DZ(10)),(P,Y(7)),(Q,Y(8)),(R,Y(9)),
150+     (PD,DY(7)),(QD,DY(8)),(RD,DY(9))
160      EQUIVALENCE (XI,Y(4)),(YI,Y(5)),(HT,Y(6))
170      DATA INIT/0/,T1PSI/.0125/,T2PSI/.0033/,
180+     RKPSI/-960./,EPSIDB/25./,RKBPSI/.046/,RN2/-1./,RPSI/10.5/,
190+     RIPSIB/2.3/,RKTPSI/6.54/,T2PHI/.005/,T1PHI/.025/,RKPHI/300./
200+     ,EPHIDB/25./,RKBPHI/.199/,RPHI/8.8/,RKTPHI/28.1/,RIPHIB/2.84
210+     /,RKTT/350./,RKPTE/.2/,TGYEB/4./,TGZEB/4./,F1,F2,F3,F4/10.,2
220+     .,.5,.5/,PSI2L,PSI3L,THT4L/2.35,.21,.21/,CKSTP2,CKSTP3,CKSTP
230+     4/800.,400.,400./,RIYX,RIYY,RIYZ/.25,.20,.10/,HS,RIGZ,RIGY,R
240+     KHG/3.5,.009,.009,.005/,RICX,RICY,RICZ/.04,.08,.08/,RIDPSI
250+     /.0007/,RKCU2/.8/,TYX2,TYY2,TYZ2/3*0./,TCZ3,TCY3,TCX3/3*0./,
260+      TCXE,TCYE,TCZE/3*0./,TYXU,TYYU,TYZU,TCXU,TCYU,TCZU,TRXU,
270+     TRYU,TRZU,THXU,THYU,THZU,TGYU,TGZU,TGY5,TGZ5/16*0./
280      DATA CON1/3.141592654/,CON2/6.283185308/
290      XMTI=XTI-XI
300      YMTI=YTI-YI
310      ZMTI=-(HTTI-HT)
320      RMT=SQRT(XMTI*XMTI+YMTI*YMTI+ZMTI*ZMTI)
330      RNXI=XMTI/RMT
340      RNYI=YMTI/RMT
350      RNZI=ZMTI/RMT
360      RNMX=T11*RNXI+T12*RNYI+T13*RNZI
370      RNMY=T21*RNXI+T22*RNYI+T23*RNZI
380      RNMZ=T31*RNXI+T32*RNYI+T33*RNZI
390      IF (INIT.EQ.1) GO TO 1
400      INIT=1
410      ISWSZ=0
420      SPSI2=SQRT(RNMY*RNMY+RNMZ*RNMZ)
430      PSI2=ATAN2(SPSI2,RNMX)
440      PHI1=0.
450      IF (SPSI2.NE.0.) PHI1=ATAN2(RNMZ,RNMY)
460    1 CONTINUE
470      SPHI1=SIN(PHI1)
480      CPHI1=COS(PHI1)
490      SPSI2=SIN(PSI2)
500      CPSI2=COS(PSI2)
510      SPSI3=SIN(PSI3)
520      CPSI3=COS(PSI3)
530      STHT4=SIN(THT4)
540      CTHT4=COS(THT4)
550      SPSIT=SPSI2*CPSI3+CPSI2*SPSI3
560      CPSIT=CPSI2*CPSI3-SPSI2*SPSI3
570      EPBPSI=-RNMX*SPSIT+RNMY*CPHI1*CPSIT+RNMZ*SPHI1*CPSIT
580      EPBTHT=-(RNMX*CPSIT*STHT4+RNMY*(CPHI1*STHT4*SPSIT-SPHI1*CTHT
590+     4)+RNMZ*(CPHI1*CTHT4+SPHI1*SPSIT*STHT4))
```

```
PAGE  2   SEEKER        03/28/73. 16.33.16


600        RNCY=-RNMX*SPSI2+RNMY*CPSI2*CPHI1+RNMZ*CPSI2*SPHI1
610        RNCZ=-RNMY*SPHI1+RNMZ*CPHI1
620        EPBC=SQRT(RNCY*RNCY+RNCZ*RNCZ)
630        EPB=SQRT(EPBPSI*EPBPSI+ EPBTHT*EPBTHT)
640        RLAMCG=SQRT(THT4*THT4+PSI3*PSI3)
650* CALCULATION OF GAIN COMPENSATION IN ROLL AXIS DRIVE
660        IF (ABS(PSI2).LT..579) GO TO 10
670        VCCOMP=SIGN(1.0,PSI2)
680        GO TO 30
690     10 IF (ABS(PSI2).LT..174) GO TO 20
700        VCCOMP=SIGN(3.3,PSI2)
710        GO TO 30
720     20 VCCOMP=SIGN(10.5,PSI2)
730     30 CONTINUE
740        THRESH=.10
750        IF (ISWSZ.EQ.1) THRESH=.05
760        IF (RLAMCG.GT.THRESH) GO TO 40
770        IF (ABS(PSI2).GE.THRESH ) GO TO 40
780        EPSR=0.
790        ISWSZ=0
800        GO TO 50
810     40 EPSR=-THT4*VCCOMP
820        ISWSZ=1
830     50 CONTINUE
840* ROLL AXIS DRIVE TORQUE MOTOR
850        ERD=(EPSR-ER)/T2PHI
860        EPHID=(T1PHI*ERD+ER)*RKPHI
870        EPHIDL=BOUND(EPHIDB,EPHID)
880        EPHNET=EPHIDL-PHI1D*RKBPHI
890        RIPHI=EPHNET/RPHI
900        TYXMOT=RKTPHI*BOUND(RIPHIB,RIPHI)
910* OUTER LOOK AXIS DRIVE TORQUE MOTOR
920        EPSL=PSI3
930        ELD=(EPSL-EL)/T2PSI
940        EPSID=(T1PSI*ELD+EL)*RKPSI
950        EPSIDL=BOUND(EPSIDB,EPSID)
960        EPSNET=EPSIDL-RKBPSI*RN2*PSI2D
970        RIPSI=EPSNET/RPSI
980        TCZMOT=RKTPSI*BOUND(RIPSIB,RIPSI)
990* GYRO TORQUE CONTROL EQUATIONS
1000        TGYENL=RKTT*EPBPSI-RKPTE*PSI3
1010        TGZENL=-RKTT*EPBTHT+RKPTE*THT4
1020        TGYE=BOUND(TGYEB,TGYENL)
1030        TGZE=BOUND(TGZEB,TGZENL)
1040* SEEKER YOKE DYNAMICS
1050        WYY=Q*CPHI1+R*SPHI1
1060        WYZ=-Q*SPHI1+R*CPHI1
1070        WYYD=QD*CPHI1+RD*SPHI1-PHI1D*(Q*SPHI1-R*CPHI1)
1080        WYZD=-QD*SPHI1+RD*CPHI1-PHI1D*(Q*CPHI1+R*SPHI1)
1090        TYXF1=FRICT(F1,PHI1D)
1100        TYX1=TYXMOT+TYXF1
1110        TYX=TYX2+TYXU+TYX1
1120        TYY=RIYY*WYYD+WYZ*WYX*(RIYX-RIYZ)
1130        TYZ=RIYZ*WYZD+WYX*WYY*(RIYY-RIYX)
1140        TYY1=TYY-TYY2-TYYU
1150        TYZ1=TYZ-TYZ2-TYZU
1160        TMX1=-TYX1
1170        TMY1=-(TYY1*CPHI1-TYZ1*SPHI1)
1180        TMZ1=-(TYY1*SPHI1+TYZ1*CPHI1)
```

```
1190       RICC=RICX*CPHI1*CPHI1+RICY*SPHI1*SPHI1
1200       RIYXE=RIYX+RICC
1210       WYXD=(TYX-WYY*WYZ*(RIYZ-RIYY))/RIYXE
1220       PHI1D=WYX-P
1230* SEEKER COIL HOUSING DYNAMICS
1240       WCX=WYX*CPSI2+WYY*SPSI2
1250       WCY=-WYX*SPSI2+WYY*CPSI2
1260       TCZF2=FRICT(F2,PSI2D)
1270       TCZS2=STOPS(CKSTP2,PSI2L,PSI2)
1280       TCZ2=(TCZMOT-(RN2-1.)*RIDPSI*WYZD)*RN2+TCZF2+TCZS2-RKCU2*
1290+      PSI2
1300       TCZ=TCZ2+TCZU+TCZ3+TCZE
1310       WCZD=(TCZ-WCX*WCY*(RICY-RICX))/(RICZ+RN2*RN2*RIDPSI)
1320       PSI2D=WCZ-WYZ
1330       TCXLI=RICX*(WYYD*SPSI2-PSI2D*(WYX*SPSI2-WYY*CPSI2))+WCY*WCZ
1340+      *(RICZ-RICY)
1350       TCYLI=RICY*(WYYD*CPSI2-PSI2D*(WYX*CPSI2+WYY*SPSI2))+WCZ*WCX
1360+      *(RICX-RICZ)
1370       TCX2=TCXLI-TCX3-TCXE-TCXU
1380       TCY2=TCYLI-TCY3-TCYE-TCYU
1390       TYX2=-(TCX2*CPSI2-TCY2*SPSI2)
1400       TYY2=-(TCX2*SPSI2+TCY2*CPSI2)
1410       TYZ2=-TCZ2
1420* GYRO DYNAMICS
1430       TGY=TGY5+TGYE+TGYU
1440       TGZ=TGZ5+TGZE+TGZU
1450       TGYEFF=TGY-HS*WGZ-(RKHG/RIGZ)*(TGZ+HS*WGY)
1460       TGZEFF=TGZ+HS*WGY+(RKHG/RIGY)*(TGY-HS*WGZ)
1470       WGYD=TGYEFF/(RIGY+RKHG*RKHG/RIGZ)
1480       WGZD=TGZEFF/(RIGZ+RKHG*RKHG/RIGY)
1490* GYRO HOUSING DYNAMICS
1500       WHY=WGY
1510       WHZ=WGZ
1520       WRX=WCX*CPSI3+WCY*SPSI3
1530       WRY=-WCX*SPSI3+WCY*CPSI3
1540       WRZ=(WHZ-WRX*STHT4)/CTHT4
1550       PSI3D=WRZ-WCZ
1560       THT4D=WHY-WRY
1570       TRZF3=FRICT(F3,PSI3D)
1580       TRZS3=STOPS(CKSTP3,PSI3L,PSI3)
1590       TRZ3=TRZS3+TRZF3
1600       TRZ4=-(TRZ3+TRZU)
1610       THYF4=FRICT(F4,THT4D)
1620       THYS4=STOPS(CKSTP4,THT4L,THT4)
1630       THX4=-THXU
1640       THY4=THYF4+THYS4
1650       THZ4=-(TRZ4+THX4*STHT4)/CTHT4
1660       THY5=-(THYU+THY4)
1670       THZ5=-(THZ4+THZU)
1680       TGY5=-THY5
1690       TGZ5=-THZ5
1700       TRX4=-(THX4*CTHT4+THZ4*STHT4)
1710       TRY4=-THY4
1720       TRX3=-(TRX4+TRXU)
1730       TRY3=-(TRY4+TRYU)
1740       TCZ3=-TRZ3
1750       TCX3=-(TRX3*CPSI3-TRY3*SPSI3)
1760       TCY3=-(TRX3*SPSI3+TRY3*CPSI3)
1770       TCYE=-TGYE
```

```
1780       TCZE=-TGZE
1790       RETURN
1800       END
```

```
1810* FUNCTION ROUTINE FOR A LIMITER.
1820        FUNCTION BOUND(XL,X)
1830        BOUND=X
1840        IF (ABS(X).GE.XL) BOUND=SIGN(XL,X)
1850        RETURN
1860        END
```

```
1870* FUNCTION ROUTINE FOR FRICTION.
1880        FUNCTION FRICT(FL,X)
1890        IF (X) 1,2,3
1900      1 FRICT=FL
1910        RETURN
1920      2 FRICT=0.
1930        RETURN
1940      3 FRICT=-FL
1950        RETURN
1960        END
```

```
1970* FUNCTION ROUTINE FOR STOPS WITH COMPLIANCE.
1980        FUNCTION STOPS(SLOPE,XT,X)
1990        STOPS=0.
2000        DEL=ABS(X)-XT
2010        IF (DEL.GE.0.) STOPS=SLOPE*SIGN(DEL,X)
2020        RETURN
2030        END
```

```
INDEX   SEEKER        03/28/73. 16.33.16

10        SUBROUTINE SEEKER
1810* FUNCTION ROUTINE FOR A LIMITER.
1870* FUNCTION ROUTINE FOR FRICTION.
1970* FUNCTION ROUTINE FOR STOPS WITH COMPLIANCE.
```

```
PAGE  1   CTLSYS        03/28/73. 16.21.32

10        SUBROUTINE CTLSYS
20        COMMON Y( 9),DY( 9),X,H,WINDXB,WINDYB,WINDZB,RMACH
30+       ,CPHIW,XFA,YFA,ZFA,THR,XCG,RMASS,PCAN,YCAN,XM,YM,ZM,XXI,YYI
40+       ,VSND,SPHIW,HTE,QUE,ALPHA,PHIW,XMAX,TBURN,RHO,VEL,PSI,THT,
50+       PHI,Z(14),DZ(14)
60        COMMON NDIM,IPRINT,NSTEP,NPRINT,ICOUNT,IRATE,IRATIO,NDIMF
70        COMMON/CTLSYJ/ IJET(4)
80        COMMON/SEEKR/EPB,SPHI1,CPHI1,EPBC
90* COMMUNICATIONS WITH SUBROUTINE TARGET
100        COMMON/SEEKR1/SIGA,SIGB,SIGAD,SIGBD
110        EQUIVALENCE (HT,Y(6)),(PSI2,Z(6)),(PSI2D,DZ(6))
115         EQUIVALENCE (PHI1D,DZ(4))
120        DATA TBJRC/1.2/
130        DATA CON1/.18/
140* ENABLE THE CONTROL SYSTEM AT THE ENABLE HEIGHT.
150        IF (HT-HTE) 1,2,2
160      1 IJRC=0
170        TSJRC=X
180        GO TO 3
190      2 IJRC=1
200* DETERMINE WHETHER THE JRC BURN TIME HAS BEEN EXCEDED, AND IF
210* SO, DISENABLE THE JRC'S.
220        IF ((X-TSJRC).GT.TBJRC) IJRC=0
230      3 IF (IJRC) 4,4,5
240      4 IJET(1)=0
250        IJET(2)=0
260        IJET(3)=0
270        IJET(4)=0
280        GO TO 6
290* DETERMINE THE JRC STATES BASED ON THE CONTROL LAW.
300* PRMTY CONTROLS THE JETS ON THE Y AXIS WHILE PRMTZ CONTROLS
310* THE JETS ON THE Z AXIS. "IJET(1)"=1 SIGNIFIES THAT JET 1 IS ON.
320      5 PRMTY=SIGB+CON1*SIGBD
330        PRMTZ=SIGA+CON1*SIGAD
340        IF (PRMTZ) 7,8,9
350      7 IJET(1)=1
360        IJET(3)=0
370        GO TO 10
380      8 IJET(1)=0
390        IJET(3)=0
400        GO TO 10
410      9 IJET(1)=0
420        IJET(3)=1
430     10 IF (PRMTY) 11,12,13
440     11 IJET(2)=1
450        IJET(4)=0
460        GO TO 6
470     12 IJET(2)=0
480        IJET(4)=0
490        GO TO 6
500     13 IJET(2)=0
510        IJET(4)=1
520      6 CONTINUE
530* THE CANARD DEFLECTIONS ARE SET TO ZERO
540        PCAN=0.
550        YCAN=0.
560        RETURN
570        END
```

```
PAGE  1   AERO          03/28/73. 16.00.38


10        SUBROUTINE AERO
20        COMMON Y( 9),DY( 9),X,H,WINDXB,WINDYB,WINDZB,RMACH
30+       ,CPHIW,XFA,YFA,ZFA,THR,XCG,RMASS,PCAN,YCAN,XM,YM,ZM,XXI,YYI
40+       ,VSND,SPHIW,HTE,QUE,ALPHA,PHIW,XMAX,TBURN,RHO,VEL,PSI,THT,
50+       PHI,Z(14),DZ(14)
60        COMMON NDIM,IPRINT,NSTEP,NPRINT,ICOUNT,IRATE,IRATIO,NDIMF
70* COMMUNICATION WITH AROBSE
80        COMMON/AROB/XFB,YFB,ZFB,XMB,YMB,ZMB
90* COMMUNICATION WITH AROJRC
100        COMMON/AROJ/YFJ,ZFJ,YMJ,ZMJ
110* DETERMINE BASELINE AERODYNAMIC FORCES AND MOMENTS.
120        CALL AROBSE
130* DETERMINE FORCES AND MOMENTS DUE TO THE JRC.
140        CALL AROJRC
150* SUM THE FORCES.
160        XFA=XFB
170        YFA=YFB+YFJ
180        ZFA=ZFB+ZFJ
190* SUM THE MOMENTS AND TRANSFER REFERENCE POINT TO THE
200* MISSILE CG.
210        XM=XMB
220        YM=YMB+YMJ+ZFA*XCG
230        ZM=ZMB+ZMJ-YFA*XCG
240        RETURN
250        END
```

```
      SUBROUTINE AROBSE
      COMMON Y( 9),DY( 9),X,H,WINDXB,WINDYB,WINDZB,RMACH
      ,CPHIW,XFA,YFA,ZFA,THR,XCG,RMASS,PCAN,YCAN,XM,YM,ZM,XXI,YYI
      ,VSND,SPHIW,HTE,GUE,ALPHA,PHIW,XMAX,TBURN,RHO,VEL,PSI,THT,
      PHI,Z(14),DZ(14)
      COMMON NDIM,IPRINT,NSTEP,NPRINT,ICOUNT,IRATE,IRATIO,NDIMF
      COMMON/AERO1/DPHI,DALPHA
      COMMON/AROB/XFB,YFB,ZFB,XMB,YMB,ZMB
      DIMENSION CXB(25,3),CYPB(25,3),CZPB(25,3),CLB(25,3),
       CMPB(25,3),CNPB(25,3)
       DATA CXB /75*0./
       DATA CYPB/75*0./
       DATA CZPB/
       0.,-2.,-4.0,-6.5,-10.0,-13.0,-17.0,-21.0,-25.0,-29.5,
       -34.0,-38.0,-42.0,-45.0,-48.0,-51.0,-52.5,-52.5,-51.0,
       -46.0,-45.0,-45.0,-45.0,-45.0,-45.0,
       0.,-2.,-4.5,-8.0,-12.0,-16.0,-20.5,-25.0,-29.5,-34.5,
       -39.0,-43.0,-47.0,-50.0,-52.5,-52.5,-48.0,-45.0,-49.0,
       -51.0,-52.0,-53.5,-54.5,-55.5,-55.5,
       0.,-2.,-4.0,-6.5,-10.0,-13.0,-17.0,-21.0,-25.0,-29.5,
       -34.0,-38.0,-42.0,-45.0,-48.0,-51.0,-52.5,-52.5,-51.0,
       -46.0,-45.0,-45.0,-45.0,-45.0,-45.0/
       DATA CLB /75*0./
       DATA CMPB/
       0.,-8.,-16.,-26.,-40.,-60.,-80.,-100.,-124.,-142.,
       -164.,-186.,-210.,-230.,-256.,-278.,-290.,-290.,-266.,
       -206.,-178.,-166.,-160.,-158.,-158.,
       0.,-8.,-20.,-36.,-56.,-76.,-100.,-128.,-158.,-184.,
       -214.,-238.,-264.,-282.,-300.,-286.,-250.,-200.,-214.,
       -218.,-218.,-218.,-218.,-220.,-220.,
       0.,-8.,-16.,-26.,-40.,-60.,-80.,-100.,-124.,-142.,
       -164.,-186.,-210.,-230.,-256.,-278.,-290.,-290.,-266.,
       -206.,-178.,-166.,-160.,-158.,-158./
       DATA CNPB/75*0./
       DATA CON1/45./,CON2/2.5/,CON3/90./
       DATA DIA/.4166666667/,S/.1363538470/
       PHIWT=AMOD(ABS(PHIW),CON3)
       PHIWTE=PHIWT/CON1+1.0
       IP=PHIWTE
       DPHI=PHIWTE-IP
       ALPHAE=ALPHA/CON2+1.0
       IA=ALPHAE
       IF (IA.GE.25) IA=24
       DALPHA=ALPHAE-IA
       CALL INTER2(CXB (IA,IP),CXB (IA+1,IP),CXB (IA,IP+1),
       CXB (IA+1,IP+1),CX )
       CALL INTER2(CYPB(IA,IP),CYPB(IA+1,IP),CYPB(IA,IP+1),
       CYPB(IA+1,IP+1),CYP)
       CALL INTER2(CZPB(IA,IP),CZPB(IA+1,IP),CZPB(IA,IP+1),
       CZPB(IA+1,IP+1),CZP)
       CALL INTER2(CLB (IA,IP),CLB (IA+1,IP),CLB (IA,IP+1),
       CLB (IA+1,IP+1),CL )
       CALL INTER2(CMPB(IA,IP),CMPB(IA+1,IP),CMPB(IA,IP+1),
       CMPB(IA+1,IP+1),CMP)
       CALL INTER2(CNPB(IA,IP),CNPB(IA+1,IP),CNPB(IA,IP+1),
       CNPB(IA+1,IP+1),CNP)
       CY=CYP*CPHIW+CZP*SPHIW
       CZ=-CYP*SPHIW+CZP*CPHIW
       CM=CMP*CPHIW+CNP*SPHIW
```

```
600       CN=-CMP*SPHIW+CNP*CPHIW
610       XFB=QUE*S*CX
620       YFB=QUE*S*CY
630       ZFB=QUE*S*CZ
640       XMB=QUE*S*DIA*CL
650       YMB=QUE*S*DIA*CM
660       ZMB=QUE*S*DIA*CN
670       RETURN
680       END
```

```
PAGE  1   AROJRC        03/28/73. 16.10.39

      SUBROUTINE AROJRC
      COMMON Y( 9),DY( 9),X,H,WINDXB,WINDYB,WINDZB,RMACH
      ,CPHIW,XFA,YFA,ZFA,THR,XCG,RMASS,PCAN,YCAN,XM,YM,ZM,XXI,YYI
      ,VSND,SPHIW,HTE,QUE,ALPHA,PHIW,XMAX,TBURN,RHO,VEL,PSI,THT,
      PHI,Z(14),DZ(14)
      COMMON NDIM,IPRINT,NSTEP,NPRINT,ICOUNT,IRATE,IRATIO,NDIMF
      COMMON/AERO1/DPHI,DALPHA
      COMMON/CTLSYJ/ IJET(4)
      COMMON/AROJ/YFJ,ZFJ,YMJ,ZMJ
       DIMENSION RKYB(25,3),RKZB(25,3),RKMB(25,3),RKNB(25,3)
       DIMENSION CPE(4),SPE(4)
       DATA RKYB/75*0./
       DATA RKZB/
       -1.0,-1.0,-1.0,-1.0,-1.0,-.99,-.97,-.92,
       -.88,-.86,-.81,-.76,-.70,-.62,-.58,-.53,
       -.52,-.53,-.58,-.66,-.72,-.78,-.80,-.82,-.82,
       50*-1.0/
       DATA RKMB/
       1.0,1.0,1.0,1.0,1.0,1.03,1.06,1.10,
       1.16,1.22,1.29,1.38,1.47,1.54,1.60,1.63,
       1.65,1.60,1.48,1.30,1.18,1.08,1.04,1.04,1.04,
       50*1.0/
       DATA RKNB/75*0./
       DATA TJRC/450./,XJET/2.434/
       DATA CON1/90./,CON2/2.5/,CON3/180./
       DATA PHIE1/0./
       DATA CPE/1.,0.,-1.,0./,SPE/0.,1.,0.,-1./
       ALPHAE=ALPHA/CON2+1.0
       IA=ALPHAE
       IF (IA.GE.25) IA=24
       DALPHA=ALPHAE-IA
       RKY=0.
       RKZ=0.
       RKM=0.
       RKN=0.
       DO 1 I=1,4
       IF (IJET(I).EQ.0) GO TO 1
       PHIJ=PHIW-PHIE1-CON1*(I-1.)
       CP=CPE(I)
       SP=SPE(I)
       IF (ABS(PHIJ).GT.180.) PHIJ=PHIJ-SIGN(360.,PHIJ)
       PHIJT=ABS(PHIJ)
       PHIJTE=PHIJT/CON1+1.0
       IP=PHIJTE
       IF (IP.GE.3) IP=2
       DPHI=PHIJTE-IP
       CALL INTER2(RKYB(IA,IP),RKYB(IA+1,IP),RKYB(IA,IP+1),
       RKYB(IA+1,IP+1),RKYJ)
       CALL INTER2(RKZB(IA,IP),RKZB(IA+1,IP),RKZB(IA,IP+1),
       RKZB(IA+1,IP+1),RKZJ)
       CALL INTER2(RKMB(IA,IP),RKMB(IA+1,IP),RKMB(IA,IP+1),
       RKMB(IA+1,IP+1),RKMJ)
       CALL INTER2(RKNB(IA,IP),RKNB(IA+1,IP),RKNB(IA,IP+1),
       RKNB(IA+1,IP+1),RKNJ)
       IF (PHIJ.GE.0.) GO TO 2
       RKYJ=-RKYJ
       RKNJ=-RKNJ
     2 RKY=RKY+RKYJ*CP +RKZJ*SP
       RKZ=RKZ-RKYJ*SP +RKZJ*CP
```

```
590        RKM=RKM+RKMJ*CP  +RKNJ*SP
600        RKN=RKN-RKMJ*SP  +RKNJ*CP
610      1 CONTINUE
620        YFJ=RKY*TJRC
630        ZFJ=RKZ*TJRC
640        YMJ=RKM*TJRC*XJET
650        ZMJ=RKN*TJRC*XJET
660        RETURN
670        END
```

```
      SUBROUTINE OUTPUT1
      COMMON Y( 9),DY( 9),X,H,WINDXB,WINDYB,WINDZB,RMACH
+     ,CPHIW,XFA,YFA,ZFA,THR,XCG,RMASS,PCAN,YCAN,XM,YM,ZM,XXI,YYI

+     ,VSND,SPHIW,HTE,QUE,ALPHA,PHIW,XMAX,TBURN,RHO,VEL,PSI,THT,
+     PHI,Z(14),DZ(14)
      COMMON NDIM,IPRINT,NSTEP,NPRINT,ICOUNT,IRATE,IRATIO,NDIMF
      DIMENSION OUT(40,30),IOUT(40,4)
  100 FORMAT(F6.3,6F8.2)
  101 FORMAT(F6.3,3F8.2,3F7.2)
  102 FORMAT(F6.3,8F7.2)
  103 FORMAT(//,2X,*TIME*,5X,*U*,7X,*V*,7X,*W*,7X,*XI*,6X,
+     *YI*,6X,*HT*)
  104 FORMAT(//,2X,*TIME*,5X,*P*,7X,*Q*,7X,*R*,5X,*PSI*,4X,*THT*,

+     4X,*PHI*)
  105 FORMAT(//,2X,*TIME*,2X,*ALPHA*,3X,*PHIW*,3X,*PHI1*,
+     3X,*PSI2*,2X,* PSI3*,2X,* THT4*,4X,*EPB*,3X,*EPBC*)
  106 FORMAT(F6.3,4(5X,I1))
  107 FORMAT(//,*JET STATES. 1=ON, 0=OFF*,/)
   108 FORMAT(//,2X,*TIME*,2X,*WYOKE*,2X,*WCOIL*,4X,*WGY*,
+     4X,*WGZ*,2X,*PHI1D*,2X,*PSI2D*)
  200 FORMAT(//,*STEP SIZE=*,F6.4,2X,*IRATIO=*,I2)
      DO 10 I=1,ICOUNT
* READ ALL THE OUTPUTED VARIABLES.
   10 READ(2,) (OUT(I,J),J=1,27),(IOUT(I,J),J=1,4)
* OUTPUT THESE VARIABLES TO THE TTY IN APPROPRIATE COLUMNS WITH
* HEADINGS.
      PRINT   103
      DO 1 I=1,ICOUNT
    1 PRINT   100, (OUT(I,J),J=1,7)
      PRINT   104
      DO 2 I=1,ICOUNT
    2 PRINT   101, OUT(I,1),(OUT(I,J),J=8,13)
      PRINT   105
      DO 3 I=1,ICOUNT
    3 PRINT   102, OUT(I,1),(OUT(I,J),J=14,21)
      PRINT   108
      DO 5 I=1,ICOUNT
    5 PRINT   102, OUT(I,1),(OUT(I,J),J=22,27)
      PRINT   107
      DO 4 I=1,ICOUNT
    4 PRINT   106, OUT(I,1),(IOUT(I,J),J=1,4)
      PRINT   200, H,IRATIO
      STOP
      END
```

```
      SUBROUTINE INTEG
      COMMON Y( 9),DY( 9),X,H,WINDXB,WINDYB,WINDZB,RMACH
+     ,CPHIW,XFA,YFA,ZFA,THR,XCG,RMASS,PCAN,YCAN,XM,YM,ZM,XXI,YYI
+     ,VSND,SPHIW,HTE,QUE,ALPHA,PHIW,XMAX,TBURN,RHO,VEL,PSI,THT,
+     PHI,Z(14),DZ(14)
      COMMON NDIM,IPRINT,NSTEP,NPRINT,ICOUNT,IRATE,IRATIO,NDIMF
* STORAGE LOCATIONS FOR THE REQUIRED PAST STATE VARIABLES AND
* THEIR DERIVATIVES. "AUX" FOR Y(I) AND "BUX" FOR Z(I).
      DIMENSION AUX1( 9),AUX2( 9),AUX3( 9),AUX4( 9),AUX5( 9),
+     AUX6( 9),AUX7( 9),AUX8( 9),BUX1(14),BUX2(14),BUX3(14),
+     BUX4(14),BUX5(14),BUX6(14),BUX7(14),BUX8(14)
      DATA IENTR/1/,IENTRF/2/
      IF (IRATE.EQ.1) GO TO 100
* DECIDE WHETHER TO 1) PREDICT REQUIRED STARTING VALUES BY
* AN EULER BACKSTEP METHOD, 2) PERFORM PREDICTION OF THE Y(I)
* VARIABLES DURING INTEGRATION, OR 3) CORRECT THE Y(I) VARIABLES
* DURING INTEGRATION.
      IF (IENTR-2) 20,21,22
* DETERMINE REQUIRED STARTING VALUES USING AN EULER BACKSTEP, AND
* STORE INTO APPROPRIATE LOCATIONS.
   20 HS=IRATIO*H
      H1=3.*HS
      H3=4./3.*HS
      G1=3.*H
      G3=4./3.*H
      C1=112./121.
      C2=9./121.
      DO 16 I=1,NDIM
      AUX2(I)=Y(I)-HS*DY(I)
      AUX3(I)=Y(I)-2.*HS*DY(I)
      AUX4(I)=Y(I)-3.*HS*DY(I)
      AUX6(I)=DY(I)
      AUX7(I)=DY(I)
   16 AUX8(I)=0.
      DO 26 I=1,NDIMF
      BUX2(I)=Z(I)-H*DZ(I)
      BUX3(I)=Z(I)-2.*H*DZ(I)
      BUX4(I)=Z(I)-3.*H*DZ(I)
      BUX6(I)=DZ(I)
      BUX7(I)=DZ(I)
   26 BUX8(I)=0.
* PREDICT THE Y(I) VARIABLES.
   21 DO 17 I=1,NDIM
      AUX1(I)=Y(I)
      AUX5(I)=DY(I)
      DELT=AUX4(I)+H3*(AUX5(I)+AUX5(I)-AUX6(I)+AUX7(I)+AUX7(I))
      Y(I)=DELT-C1*AUX8(I)
   17 AUX8(I)=DELT
      IENTR=3
      GO TO 100
* CORRECT THE Y(I) VARIABLES.
   22 DO 18 I=1,NDIM
      DELT=.125*(9.*AUX1(I)-AUX3(I)+H1*(DY(I)+AUX5(I)+AUX5(I)
+     -AUX6(I)))
      AUX8(I)=AUX8(I)-DELT
   18 Y(I)=DELT+C2*AUX8(I)
      DO 19 I=1,NDIM
      AUX7(I)=AUX6(I)
      AUX6(I)=AUX5(I)
```

```
00610          AUX4(I)=AUX3(I)
00620          AUX3(I)=AUX2(I)
00630       19 AUX2(I)=AUX1(I)
00640          IENTR=2
00650* NOW TO REPEAT FOR THE Z(I) VARIABLES.
00660* DETERMINE WHETHER TO PREDICT OR CORRECT THE Z(I) VARIABLES.
00670      100 IF (IENTRF.EQ.3) GO TO 32
00680* PREDICT THE Z(I) VARIABLES.
00690          DO 27 I=1,NDIMF
00700          BUX1(I)=Z(I)
00710          BUX5(I)=DZ(I)
00720          DELT=BUX4(I)+G3*(BUX5(I)+BUX5(I)-BUX6(I)+BUX7(I)+BUX7(I))
00730          Z(I)=DELT-C1*BUX8(I)
00740       27 BUX8(I)=DELT
00750* UPDATE THE VARIABLE TIME BY "H" AFTER,EACH PREDICTION.
00760          NSTEP=NSTEP+1
00770          X=NSTEP*H
00780          IPRINT=0
00790          IENTRF=3
00800          RETURN
00810* CORRECT THE Z(I) VARIABLES.
00820       32 DO 28 I=1,NDIMF
00830          DELT=.125*(9.*BUX1(I)-BUX3(I)+G1*(DZ(I)+BUX5(I)+BUX5(I)
00840+         -BUX6(I)))
00850          BUX8(I)=BUX8(I)-DELT
00860       28 Z(I)=DELT+C2*BUX8(I)
00870          DO 29 I=1,NDIMF
00880          BUX7(I)=BUX6(I)
00890          BUX6(I)=BUX5(I)
00900          BUX4(I)=BUX3(I)
00910          BUX3(I)=BUX2(I)
00920       29 BUX2(I)=BUX1(I)
00930          IENTRF=2
00940          IPRINT=1
00950          RETURN
00960          END
```

```
PAGE  1   INTER2        03/28/73. 16.51.23

10        SUBROUTINE INTER2(C00,C10,C01,C11,CB)
20* PERFORMS A TWO DIMENSIONAL INTERPOLATION BETWEEN THE FOUR CORNERS
30* OF THE SQUARE C00-C11 AND RETURNS THE ANSWER BY CB.
40* COMMUNICATIONS WITH SUBROUTINE AERO WHICH CALLS INTER2.
50* DPHI AND DALPHA ARE THE INTERPOLATION INCREMENTS.
60        COMMON/AERO1/DPHI,DALPHA
70        C1=C00+DALPHA*(C10-C00)
80        C2=C01+DALPHA*(C11-C01)
90        CB=C1+DPHI*(C2-C1)
100        RETURN
110        END
```

```
READY.
FORTRAN,OLD,SXDF

READY.
RUN,M=11000

 03/28/73. 17.05.04
PROGRAM   SXDF


INPUT H,XMAX,NPRINT,IRATIO
 ? .0005,2.,200,10
INPUT XT0,YT0,HTT0,XTD,YTD,HTTD
 ? 9000,3000,100,0,0,0


  TIME      U        V         W         XI        YI        HT
 0.        0.       0.        0.        0.        0.        0.
  .100    41.41     0.          .00       .00     0.         2.07
  .200    83.14     1.29      1.29       .02       .02       8.29
  .300   124.61    -9.71     -7.74       .61       .55      18.68
  .400   157.77   -18.84    -47.56      2.57      1.36      33.11
  .500   166.45   -20.10   -114.34      7.15      2.96      50.89
  .600   175.92   -36.26   -150.15     15.35      5.63      71.00
  .700   196.31   -47.88   -166.24     27.98      9.39      91.98
  .800   227.44   -52.29   -169.56     45.23     14.44     112.76
  .900   266.06   -51.83   -162.85     67.10     20.97     132.50
 1.000   308.77   -49.27   -150.62     93.59     29.04     150.66
 1.100   353.54   -45.26   -136.15    124.68     38.69     166.91
 1.200   400.89   -39.66   -118.95    160.36     49.92     181.18
 1.300   449.40   -34.79   -100.35    200.65     62.74     193.53
 1.400   498.01   -30.25    -86.66    245.59     77.18     204.17
 1.500   552.44   -14.23    -36.64    295.19     93.24     213.61
 1.600   601.57    11.12     37.54    349.48    110.87     222.88
 1.700   645.79    27.02     80.41    408.31    129.98     233.29
 1.800   698.37    16.60     45.12    471.48    150.43     245.71
 1.900   749.20   -10.08    -34.29    539.20    172.30     259.58
 2.000   796.43   -23.79    -70.56    611.76    195.74     273.45
```

```
 TIME      P        Q        R      PSI     THT     PHI
0.         0.       0.       0.     0.      90.00   0.
 .100      0.       0.       0.     0.      90.00   0.
 .200      0.       -.52     .52    45.00   89.32   45.00
 .300      0.      -2.43    1.31    41.34   77.76   41.40
 .400      0.      -4.24    -.16    18.61   59.74   20.22
 .500      0.      -3.25    1.12    11.62   35.64   14.61
 .600      0.      -1.80    1.03    14.15   20.65   15.77
 .700      0.      -1.00     .64    16.17   11.83   16.32
 .800      0.       -.53     .19    17.03    6.90   16.46
 .900      0.       -.25     .23    17.59    4.18   16.52
1.000      0.       -.23     .03    17.90    2.58   16.54
1.100      0.       -.15     .11    18.13    1.45   16.55
1.200      0.        .11     .09    18.23    1.12   16.55
1.300      0.       -.10     .07    18.40    1.03   16.55
1.400      0.        .26    -.06    18.39     .92   16.55
1.500      0.       1.16    -.39    18.30    5.77   16.54
1.600      0.       1.15    -.40    17.99   13.22   16.49
1.700      0.        .17    -.09    17.68   17.58   16.41
1.800      0.       -.98     .31    17.66   14.66   16.40
1.900      0.      -1.07     .37    17.90    7.83   16.45
2.000      0.        .02     .01    18.12    4.35   16.47
```

```
 TIME  ALPHA   PHIW   PHI1   PSI2   PSI3   THT4    EPB   EPBC
0.      0.     0.    71.57  89.40  0.     0.       .00    .00
 .100   0.     0.    71.54  89.28    .13    .00    .03    .13
 .200   1.25  45.00  71.57  88.88   -.02   -.04    .05    .04
 .300   5.69-128.55  71.86  78.33   -.10   -.17    .03    .18
 .400  17.96-158.39  70.92  59.40   -.10    .80    .03    .81
 .500  34.90-170.03  64.24  36.08   -.16    .32    .02    .35
 .600  41.28-166.42  62.46  21.07   -.18    .09    .02    .21
 .700  41.39-163.93  62.35  12.18   -.19   -.10    .02    .20
 .800  37.96-162.86  62.43   7.30   -.20    .02    .03    .19
 .900  32.71-162.35  61.75   4.64   -.16   -.04    .03    .19
1.000  27.17-161.89  62.99   3.10   -.17    .02    .01    .16
1.100  22.09-161.61  62.93   2.03   -.16   -.02    .01    .15
1.200  17.37-161.56  62.97   1.59    .06   -.05    .04    .08
1.300  13.30-160.88  63.01   1.67   -.10   -.26    .03    .25
1.400  10.44-160.75  63.05   1.51    .06   -.19    .03    .22
1.500   4.07-158.77  63.43   6.23    .20   -.97    .02    .98
1.600   3.72  16.50  71.49  13.76    .23    .02    .03    .24
1.700   7.48  18.57  71.23  18.22    .21    .02    .02    .22
1.800   3.94  20.20  70.80  15.76   -.16    .09    .02    .17
1.900   2.73-163.62  69.92   9.06   -.17    .04    .03    .19
2.000   5.34-161.37  69.50   5.64   -.15    .00    .03    .15
```

```
  TIME   WYOKE   WCOIL    WGY     WGZ    PHI1D   PSI2D
 0.       0.       0.      0.      0.      0.      0.
  .100    -.02     .03     .02     .03    -.02     .03
  .200     .00     .19    -.06    -.01     .00    -.48
  .300     .10    -.02     .01    -.02     .10   -2.73
  .400    -.81     .06    -.03     .02    -.81   -3.90
  .500    -.70     .02     .01     .04    -.70   -3.39
  .600    -.03     .03     .01     .03    -.03   -2.04
  .700     .20    -.01     .01    -.01     .20   -1.20
  .800    -.03    -.01    -.04    -.02    -.03    -.57
  .900     .21     .06    -.10     .04     .21    -.27
 1.000    -.16     .03    -.09     .00    -.16    -.19
 1.100    -.01     .00     .01     .01    -.01    -.18
 1.200    -.01    -.04    -.04    -.01    -.01     .02
 1.300    -.01    -.01     .02     .01    -.01    -.13
 1.400    -.01    -.07    -.04     .03    -.01     .20
 1.500    1.60     .00    -.01    -.03    1.60    1.22
 1.600    -.08    -.02    -.03     .05    -.08    1.20
 1.700    -.03    -.00    -.04    -.02    -.03     .19
 1.800    -.07     .02    -.06     .01    -.07   -1.01
 1.900    -.54     .05    -.03     .05    -.54   -1.08
 2.000    -.14    -.07    -.03     .05    -.14    -.05

JET STATES. 1=ON, 0=OFF

 0.          0       0       0       0
  .100       0       0       0       0
  .200       0       0       1       1
  .300       0       1       1       0
  .400       0       0       1       1
  .500       1       0       0       1
  .600       0       1       1       0
  .700       0       1       1       0
  .800       0       0       1       1
  .900       0       1       1       0
 1.000       0       0       1       1
 1.100       0       1       1       0
 1.200       0       1       1       0
 1.300       0       1       1       0
 1.400       0       0       0       0
 1.500       0       0       0       0
 1.600       0       0       0       0
 1.700       0       0       0       0
 1.800       0       0       0       0
 1.900       0       0       0       0
 2.000       0       0       0       0

STEP SIZE= .0005  IRATIO=10
 STOP.
```

APPENDIX B

PROGRAM VARIABLES

The following is an alphabetical listing of the computer program variables except for the variables in subroutine SEEKER.

ALPHA	Missile angle of attack
ALPHAE	Angle of attack entry argument for coefficient table lookup
AUX 1 ⋮ AUX 8	Storage locations for integration routine used for HS. Y_i, Y_{i-1}, Y_{i-2}, Y_{i-3}, DY_i, DY_{i-1}, DY_{i-2}, truncation corrector respectively
BUX 1 ⋮ BUX 8	Storage locations for integration routine used for H. Z_i, Z_{i-1}, Z_{i-2}, Z_{i-3}, DZ_i, DZ_{i-1}, DZ_{i-2}, truncation corrector respectively
C1, C2	Intermediate answers for 2-D coefficient lookup
C00, C10 C01, C11	Entry points for 2-D coefficient lookup
CB	Coefficient value return by 2-D coefficient lookup
CL	Aerodynamic total rolling moment coefficient in body fixed axes
CM	Aerodynamic total pitching moment coefficient in body fixed axes
CMP	Aerodynamic total pitching moment coefficient in pitch axes
CMPB	Array of pitching moment coefficient for baseline missile (no JRC) vs α and Φ_W
CN	Aerodynamic total yawing moment coefficient in body fixed axes
CNP	Aerodynamic total yawing moment coefficient in pitch axes
CNPB	Array of yawing moment coefficient for baseline missile (no JRC) vs α and Φ_W
CON1 ⋮ CON4	Program constants
CP	Dummy variable
CPE	Vector of cosines of Φ_E for each engine
CPHI1	Cos (Φ_1)
CPHIW	Cos (Φ_W)
CX	Aerodynamic total X force coefficient in body fixed axes
CXB	Array of X force coefficient for baseline missile (no JRC) vs α and Φ_W
CY	Aerodynamic total Y force coefficient in pitch axes

CYP	Aerodynamic total Y force coefficient in body fixed axes
CYPB	Array of Y force coefficients for baseline missile (no JRC) vs α and Φ_w
CZ	Aerodynamic total Z force coefficient in body fixed axes
CZP	Aerodynamic total Z force coefficient in pitch
CZPB	Array of Z force coefficients for baseline missile (no JRC) vs α and Φ_w
DALPHA	The residule of α required for 2-D coefficient lookup
DELT	Intermediate variable in integration routine
DIA	Missile diameter
DPHI	The residule of Φ_w required for 2-D coefficient lookup
DY	Vector of derivatives of Y
DZ	Vector of derivatives of Z
E0 ⋮ E3	Quaterion variables
E0D ⋮ E3D	Derivatives of E0-E3
EPB	Angular error between gyro spin axis and target line of sight in radians
EPBC	Angular error between coil housing axis and target line of sight in radians
EPBCO	EPBC in degrees for outputting
EPS	Error due to non-orthogonality of E0-E3
G1, G3	Internal constants for integration routine
GRAV	Gravity in ft/sec^2
H1, H3	Internal constants for integration routine
H	Step size for fast integration routine
HS	Step size for slow integration routine
HT	Altitude of missile
HTD	Derivative of HT
HTMT	Altitude difference between missile and target
HTTO	Initial height of target
HTTD	Target climb rate
HTTI	Altitude of target
IA	Entry location on α for 2-D coefficient lookup

ICOUNT	Number of times outputting is performed
IENTR	1--Calculate required starting values, 2--Predict Y(I) for integration, 3--Correct Y(I) for integration
IENTRF	2--Predict Z(1) for integration, 3--Correct Z(I) for integration
IJET	Array for each jet; 0--off, 1--on
IOUT	Array for outputting interger variables
IP	Entry location on Φ_W for 2-D coefficient lookup
IPRINT	0--No outputting permitted, 1--Outputting permitted
IRATE	Controls integration routine; 0--Integrate both Y and Z, 1--Integrate only Z
IRATIO	HS/H
IRT2	2* IRATIO
NDIM	Dimension of Y(I)
NDIMF	Dimension of Z(I)
NPRINT	Outputting interval = NPRINT*H
NSTEP	Counter for number of H integration steps
OUT	Array for outputting real variables
P	Missile roll rate in body axes in rad/sec
PCAN	Pitch canard deflection
PD	Derivative of P
PHI	Φ in degrees
PHI1	Φ_1 in radians
PHI1O	PHI1 in degrees for outputting
PHI1D	Derivative of PHI1
PHIE1	Φ_E for thruster number 1
PHIJ	Φ_J for thruster in degrees
PHIW	Φ_W in degrees
PHIWT	Φ_W reduced to a range of 0 - 90 degrees
PHIWTE	Φ_W entry argument for coefficient table lookup
PRMT	Dummy variable
PRMTY	Control function for JRC's aligned with missile Y axis
PRMTZ	Control function for JRC's aligned with missile Z axis
PSI	Ψ in degrees
PSI2	Ψ_2 in radians
PSI2O	Ψ_2 in degrees for outputting
PSI2D	Derivative of PSI2
PSI3	Ψ_3 in radians

PSI3O	Ψ_3 in degrees for outputting
PSI3D	Derivative of PSI3
Q	Missile pitch rate in body axes in rad/sec
QD	Derivative of Q
QUE	Dynamic pressure $\frac{1}{2}\rho V^2$ in lbs/ft^2
R	Missile yaw rate in body axes in rad/sec
RD	Derivative of R
RHO	ρ in $slugs/ft^3$
RKM	Total moment amplification factor along missile Y axis
RKMB	Array of moment amplification factor vs α and Φ_J
RKN	Total moment amplification factor along missile Z axis
RKNB	Array of moment amplification factor vs α and Φ_J
RKY	Total force amplification factor along missile Y axis
RKYB	Array of forces amplification factor vs α and Φ_J
RKZ	Total force amplification factor along missile Z axis
RKZB	Array of forces amplification factor vs α and Φ_J
RMACH	Mach number of missile
RMASS	Instantaneous missile mass
RMASSO	Initial missile mass
RMASSD	Derivative or RMASS
S	Missile reference area $= \frac{\pi d^2}{4}$
SIGA	σ_A in degrees
SIGAD	Derivative of SIGA
SIGB	σ_B in degrees
SIGBD	Derivative of SIGB
SP	Dummy variable
SPE	Vector of sines of Φ_E for each engine
SPHI1	Sin (Φ_1)
SPHIW	Sin (Φ_W)
T11	Elements of matrix transformation from body to inertial axes
⋮	
T33	
TBJRC	Burn time of JRC's
TBURN	Burn time of missile main thruster
THT	θ in degrees
THT4	θ_4 in radians

THR	Main thruster thrust
THT4O	θ_4 in degrees for outputting
THT4D	Derivative of THT4
TJRC	Thrust of one JRC
TSJRC	Enable time for JRC's
U	U velocity of missile
UD	Derivative of U
UT	U_T
V	V velocity of missile
VD	Derivative of V
VEL	Total missile velocity
VEL1	Dummy variable
VEL2	Dummy variable
VSND	Velocity of sound
VT	V_T
W	W velocity of missile
WCZ	Ω of seeker cage along Z axis
WGY	Ω of seeker gyro along Y axis
WGZ	Ω of seeker gyro along Z axis
WINDXB ⋮ WINDZB	Components of wind along missile body axes
WINDXI ⋮ WINDZI	Components of wind along inertial axes
WT	W_T
X	Time
XCG	Position of missile C.G. relative to aerodynamic reference point
XCGO	Initial XCG
XCGD	Derivative of XCG
XF	Total force along X axis
XFA	Total aerodynamic force along X axis
XFB	Total aerodynamic force along X axis for baseline missile (no JRC
XI	Inertial X position of missile
XID	Derivative of XI
XIMT	Inertial X position of target relative to missile
XJET	Position of JRC's from aerodynamic reference point

XM	Total moment along X axis
XMAX	Total run time
XMB	Total moment along X axis for baseline missile (no JRC)
XMT	X position of target relative to missile in body axes
XMTD	Derivative of XMT
XTO	Initial XTI
XTD	Derivative of XTI
XTI	Inertial X position of target
XXI	I_{XX}
XXIO	Initial XXI
XXID	Derivative of XXI
Y	Vector of slow integration state variables
YCAN	Deflection of yaw canard
YF	Total along Y axis
YFA	Total aerodynamic force along Y axis
YFB	Total aerodynamic force along Y axis for baseline missile (no JRC)
YFJ	Total force along Y axis due to JRC's
YI	Inertial Y position of missile
YID	Derivative of YI
YIMT	Inertial Y position of target relative to missile
YM	Total moment along Y axis
YMB	Total moment along Y axis for baseline missile (no JRC)
YMJ	Total moment along Y axis due to JRC's
YMT	Y position of target relative to missile in body axes
YMTD	Derivative of YMT
YTO	Initial YTI
YTD	Derivative of YTI
YTI	Inertial Y position of target
YYI	I_{YY}
YYIO	Initial YYI
YYID	Derivative of YYI
Z	Vector of fast integration state variables
ZF	Total along Z axis
ZFA	Total aerodynamic force along Z axis

ZFB	Total aerodynamic force along Z axis for baseline missile (no JRC)
ZFJ	Total force along Z axis due to JRC's
ZM	Total moment along Z axis
ZMB	Total moment along Z axis for baseline missile (no JRC)
ZMJ	Total moment along Z axis due to JRC's
ZMT	Z position of target relative to missile in body axes
ZMTD	Derivative of ZMT

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BSTRACT

A Point Defense Missile Simulation has been developed. This report describes the cept of such a missile, the basic features of the simulation program including the egration routine and the jet reaction controllers, and provides a FORTRAN coded rce program.

14 KEY WORDS	LINK A		LINK B		LINK C	
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