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**AUTHORITY**

AFAL ltr, 24 Jun 1974

THIS PAGE IS UNCLASSIFIED
CLOSE AIR SUPPORT MISSILE
GUIDANCE AND CONTROL STUDY
VOLUME II. THREE-DEGREE-OF-FREEDOM SIMULATION

DEPARTMENT OF MECHANICAL ENGINEERING
THE UNIVERSITY OF FLORIDA

TECHNICAL REPORT AFATL-TR-71-169, VOLUME II

DECEMBER 1971

Distribution limited to U.S. Government agencies only; this report documents the close air support missile guidance and control study; distribution limitation applied December 1971. Other requests for this document must be referred to the Air Force Armament Laboratory (DLWC), Eglin Air Force Base, Florida 32542.
Close Air Support Missile
Guidance And Control Study

Volume II. Three-Degree-Of-Freedom Simulation

J. Mahig

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FOREWORD

This report was prepared by the Industrial and Experiment Station, Department of Mechanical Engineering, University of Florida, Gainesville, Florida, under Contract No. F08635-71-C-0073 with the Air Force Armament Laboratory, Eglin Air Force Base, Florida, during the period from 9 December 1970 to 9 December 1971. Lieutenant Robert J. Karner (DLWG) monitored the project for the Armament Laboratory.

The principal investigator for the contractor was Dr. J. Mahig.

This report consists of two volumes. Volume I is devoted to the Six-Degree-of-Freedom Simulation while Volume II is concerned with the Three-Degree-of-Freedom Simulation. This is Volume II.

This technical report has been reviewed and is approved.

HEYWARD H. STRONG
Acting Chief, Air-to-Surface Guided Weapons Division
ABSTRACT

This report describes in detail a three-degree-of-freedom program which can be used to determine the trajectory and miss distance of a guided missile system. The options for the program are such as to permit variation of the aerodynamics, seeker, autopilot, actuator, and missile motor performance for the purpose of accurately simulating a given missile design and evaluating the effects of any changes in system parameters. Sufficient detail has been included in the text to minimize the effort needed to update or modify the program presented.

DISTRIBUTION

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</tbody>
</table>

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SECTION I

INTRODUCTION

The purpose of the report is to describe in detail the equations used and the form required for the input data to a three-degree-of-freedom simulation of a laser guided missile system. The primary purpose of a three-degree-of-freedom simulation is to make possible the study of the characteristics of a given missile system quickly and economically. Since cross-coupling effects influence a missile's performance through the seeker, autopilot, and missile dynamics, any results obtained must be considered as preliminary until justified by a six-degree-of-freedom simulation.

Examples of some of the studies which can be usefully made are optimization of the seeker, autopilot gain, and noise sensitivity. The noise sensitivity studies include not only electronic noise but spot motion and signal loss simulation. Once the parameters for a given missile have been entered, it can be used efficiently even on a small computer since the program only requires 17,000 words of core.

The program for a specific missile is given in Appendix I. This program is made up of four parts: the main program and the subroutines DER, MODAMS, and GAUSS. The main program modifies input data to conform to program logic and maintains sole control for batch processing requirements. The subroutine DER retains control only over a given missile flight. The purpose of this routine is to determine the current value of the aerodynamic coefficients and angle of attack; provide limiters (e.g., fin deflection and electronic saturation); and determine the present value of the derivative of the state variables. The subroutine DER then updates the state variables by calling the subroutine MODAMS which integrates the entire system of equations using an Adams-Moulton predictor-corrector method with a Runge-Kutta start. The subroutine GAUSS is used by DER to generate a set of random variables which are used to determine the position of a laser spot and the apparent location of the target with respect to the missile. The routine is also used to determine pulse loss through the variable VLAZRP.
All the aerodynamic coefficients are either a function of Mach number or of the fin deflection. The aerodynamic coefficients used in this program are plotted in Appendix II. These plots are used to develop the aerodynamic coefficients as approximate functions of the dependent variable Mach number and fin deflection. The procedure makes DER compute much faster than would be possible through a table look-up procedure and need not detract from the accuracy.
SECTION II
STATE VARIABLES

A discussion of state variable techniques is given in many control theory books\(^1\),\(^2\),\(^3\). However, a discussion of these techniques is appropriate at this point since they are used in the program to determine the missile's flight path.

The equation of motion governing pitch of the missile is given below in the familiar form:

\[
I_{yy} \ddot{\theta} = M_2
\]  

(1)

where \(M_2\) is considered a function of time and the state variables. To convert this to state variable notation, the second order equation must first be converted into two first order equations. (This is also true for an \(n^{th}\) order system which, in order to be converted into the state variable form, must first be converted into \(n^{th}\) order systems.) Equation (1) is converted through the following definitions:

\[
\begin{align*}
\dot{\theta} &= \theta_2 \\
\dot{\theta}_2 &= M_2
\end{align*}
\]

Now, since \(M_2\) is a function of \(\theta\) and \(\dot{\theta}\) and \(t\), then the system may be defined in state variable form as

\[
\begin{align*}
\dot{\theta} &= \theta_2 \\
\dot{\theta}_2 &= M_2(\theta, \theta_2, t).
\end{align*}
\]

This same process can be used for an \(n^{th}\) order system.

A list of the state variables and their derivatives in DER is given in Table I.
### TABLE I. PROGRAM VARIABLE AND STATE VARIABLE IDENTIFICATION

<table>
<thead>
<tr>
<th></th>
<th>State Variable</th>
<th>State Variable Derivative</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>X - Y(1,1)</td>
<td>X - YP(1,1)</td>
</tr>
<tr>
<td>2.</td>
<td>X - Y(2,1)</td>
<td>X - YP(2,1)</td>
</tr>
<tr>
<td>3.</td>
<td>Z - Y(3,1)</td>
<td>Z - YP(3,1)</td>
</tr>
<tr>
<td>4.</td>
<td>Z - Y(4,1)</td>
<td>Z - YP(4,1)</td>
</tr>
<tr>
<td>5.</td>
<td>$\lambda_S$ - Y(5,1)</td>
<td>$\dot{\lambda}_S$ - YP(5,1)</td>
</tr>
<tr>
<td>6.</td>
<td>$\lambda$ - Y(6,1)</td>
<td>$\dot{\lambda}$ - YP(6,1)</td>
</tr>
<tr>
<td>7.</td>
<td>$\delta$ - Y(7,1)</td>
<td>$\dot{\delta}$ - YP(7,1)</td>
</tr>
<tr>
<td>8.</td>
<td>$\delta$ - Y(8,1)</td>
<td>$\ddot{\delta}$ - YP(8,1)</td>
</tr>
<tr>
<td>9.</td>
<td>$\delta$ - Y(9,1)</td>
<td>$\dddot{\delta}$ - YP(9,1)</td>
</tr>
<tr>
<td>10.</td>
<td>$\theta$ - Y(10,1)</td>
<td>$\dot{\theta}$ - YP(10,1)</td>
</tr>
<tr>
<td>11.</td>
<td>$\dot{\theta}$ - Y(11,1)</td>
<td>$\ddot{\theta}$ - YP(11,1)</td>
</tr>
<tr>
<td>12.</td>
<td>R - Y(12,1)</td>
<td>$\dot{R}$ - YP(12,1)</td>
</tr>
<tr>
<td>13.</td>
<td>$\phi$ - Y(13,1)</td>
<td>$\dot{\phi}$ - YP(13,1)</td>
</tr>
<tr>
<td>14.</td>
<td>$\phi_M$ - Y(14,1)</td>
<td>$\dot{\phi}_M$ - YP(14,1)</td>
</tr>
</tbody>
</table>

Note: State Variables R, $\phi, \phi_M$ are the results of proportional guidance implementation. The implementation is assumed ideal.
SECTION III
SYSTEM EQUATIONS

3.1 Equations of Motion

The equations of motion for the three-degree-of-freedom simulation used in the program are developed as follows:

The forces in body axes -

\[ F_1 = - (C_A + 2C_{A|\delta|}) qS + TH \]
\[ F_2 = - (C_{N\alpha} a + C_{N\delta}) qS \]
\[ M_2 = (-C_{N\alpha}(X_{cp} - X_{cg}) a + C_{N\delta}(X_{cg} - X_c) \delta) qS d \]
\[ - C_{M\delta}(\rho V_A / 4) S d^2 \]

Table II defines the relationship between the commonly used aerodynamic coefficients, used above, with the variable names used in the fortran program listing shown in Appendix I.

The equations of motion in the earth fixed coordinate system are:

\[ m\ddot{x} = F_1 \cos \theta + F_1 \sin \theta \]
\[ m\ddot{z} = -F_1 \sin \theta + F_1 \cos \theta + mg \]
\[ I_{yy} \dot{\theta} = M_2 \]

where the quantities \( \alpha \), \( V_A \), and \( q \) are defined as follows:

\[ \alpha = V_{ZA} / V_{XA} \quad (\alpha < 15^\circ) \]
\[ V_A = \sqrt{V_{XA}^2 + V_{ZA}^2} \]
\[ q = \frac{1}{2} \rho V_A^2 \]

and the variables \( V_{XA} \) and \( V_{ZA} \) (the velocity along and perpendicular to the missile centerline) are given as:

\[ V_{XA} = \dot{x} \cos \theta - \dot{z} \sin \theta \]
\[ V_{ZA} = \dot{x} \sin \theta + \dot{z} \cos \theta \]
TABLE II. EQUIVALENCE OF AERODYNAMIC COEFFICIENT NOTATION

<table>
<thead>
<tr>
<th>Aerodynamic Coefficient</th>
<th>Program Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_A$</td>
<td>CA</td>
</tr>
<tr>
<td>$C_{A\delta}$</td>
<td>DCA</td>
</tr>
<tr>
<td>$C_{N\alpha}$</td>
<td>CNA</td>
</tr>
<tr>
<td>$C_{N\delta}$</td>
<td>CND</td>
</tr>
<tr>
<td>$C_{M\theta}$</td>
<td>CMT</td>
</tr>
<tr>
<td>$C_{M\delta}$</td>
<td>CMD</td>
</tr>
</tbody>
</table>
Figure 1 and Table III respectively, contain the coordinate system used in the derivation of the equations of motion presented above and define those other terms used as necessary.

![Figure 1. Coordinate System](image)
TABLE III. VARIABLE LISTING

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>Position of missile in X direction</td>
</tr>
<tr>
<td>Z</td>
<td>Position of missile in Z direction</td>
</tr>
<tr>
<td>(\lambda_s)</td>
<td>Line of sight of seeker</td>
</tr>
<tr>
<td>(\lambda)</td>
<td>Line of sight of missile</td>
</tr>
<tr>
<td>(\delta)</td>
<td>Fin Deflection</td>
</tr>
<tr>
<td>(\theta)</td>
<td>Pitch of missile</td>
</tr>
<tr>
<td>(t_g)</td>
<td>Guidance delay</td>
</tr>
<tr>
<td>(m)</td>
<td>Mass of the missile</td>
</tr>
<tr>
<td>(I_{yy})</td>
<td>Moment of inertia</td>
</tr>
<tr>
<td>(q)</td>
<td>Dynamic pressure</td>
</tr>
<tr>
<td>(S)</td>
<td>Reference area</td>
</tr>
<tr>
<td>(d)</td>
<td>Diameter of missile</td>
</tr>
<tr>
<td>(\rho)</td>
<td>Density of air (slugs per cubic feet)</td>
</tr>
<tr>
<td>(T_H)</td>
<td>Thrust force</td>
</tr>
<tr>
<td>(g)</td>
<td>Gravity</td>
</tr>
<tr>
<td>(V_{XA})</td>
<td>Velocity along missile axis</td>
</tr>
<tr>
<td>(V_{ZA})</td>
<td>Velocity perpendicular to missile axis</td>
</tr>
<tr>
<td>(V_A)</td>
<td>Total velocity of the missile</td>
</tr>
<tr>
<td>(\alpha)</td>
<td>Angle of attack of the missile</td>
</tr>
<tr>
<td>(X_{Cq})</td>
<td>Initial location of the center of gravity (calibers) (Equivalent to missile diameters)</td>
</tr>
<tr>
<td>(X_{cp})</td>
<td>Location of center of pressure (calibers)</td>
</tr>
<tr>
<td>(X_C)</td>
<td>Location of fin (calibers)</td>
</tr>
</tbody>
</table>
3.2 Seeker Equations

The position of the target is always assumed to be at the location of the origin of the coordinate system. Thus, the line of sight may be given as

\[ \lambda = \tan^{-1}(Z/X). \]

If the seeker is assumed to be a PLG seeker, then the variation of the seeker axis in terms of the missile orientation may be given as

\[ \lambda_S = -\theta(1 + \tau_S \xi). \]

The angle between the line of sight and the seeker axis may be given as

\[ \epsilon = \lambda - \lambda_S. \]

3.3 Autopilot Equations

The block diagram for the autopilot used in the program is given below in Figure 2.

![Autopilot Block Diagram](image)

- \( K_g = 9.0 \text{ sec} \)
- \( \tau_g = 0.08 \text{ sec} \)
- \( \alpha_g = 10.0 \text{ sec} \)
- \( t_g = 0.25 \text{ sec} \)

Figure 2. Autopilot Block Diagram
3.4 **Nominal Thrust Profile**

The initial thrust is

\[ 7500 \text{ lb; } 0 < t < 0.8 \text{ seconds} \]

which then linearly decreases to zero at 1.3 seconds.

3.5 **Current Input Configuration**

The input data for the missile configuration used is:

- \( d = 0.416 \)
- \( S = 0.136 \)
- \( X_{cg} = 10.6 \text{ (initial)*} [8.75 \text{ at burnout}] \)
- \( X_c = 8.4 \)
- \( M = 4.21 \text{ (initial)*} [3.48 \text{ at burnout}] \)
- \( I_{yy} = 29.56 \text{ (initial)} [25.04 \text{ at burnout}] \)
- \( r_s = 5.0. \)

3.6 **Guidance Laws**

Any guidance law may be simulated by the program; however, for convenience, some guidance implementations are prepackaged into the program. Thus, at the beginning of the subroutine DER is a list of commented cards containing the following statements:

- (a) Pursuit Guidance
- (b) PLG Guidance
- (c) Sidewinder Guidance (PNG).

These statements head the required changes in the program needed to implement that form of guidance. Thus, for example, implementation of PLG guidance only requires the replacement of the current calculation of \( Y_{P(5,1)} \) by the one following the card with the statement PLG GUIDANCE.

*Variation in \( X_{cg} \) and \( M \) during motor burn is assumed proportional to the ratio of the impulse imparted to the total impulse available from the motor.
SECTION IV

PROGRAM DESCRIPTION

4.1 Program Aids

In order to effectively coordinate the variables used in the program with the system equations developed above, Table I is to be used for the identification of the state variables and Table IV will provide definitions for the other variables used by the program. In addition, Figure 3 defines the form in which the input must be prepared and the output format of the program.

A complete listing of the program and its output is given in Appendix I. Appendix II contains the aerodynamic curves for an actual missile. These aerodynamic coefficients are all given as a function of Mach number. Since accurate functional representation of some of these curves are very complex, simple mathematical expressions were chosen which are true only over defined Mach number regimes. The adequacy of the representation may be assessed by the reader by comparing the results obtained from the equations listed in the program with the aerodynamic curves they are intended to represent. These curves are shown in Figure II-1 through Figure II-8.
Input Format

FORMAT (1P6E12.4)

FPT, H, TEN, AR, DVI, VI, DTH, ALP, RANGE, LOS, GBIAS,
VLAZRP, XLASR, DSPEED, TZ

Y(1,1), Y(2,1), Y(3,1), Y(4,1), ..., Y(6,1)
Y(7,1), ..., Y(12,1)
Y(13,1), Y(14,1)

Output Format

FORMAT (1P9E12.4)

Y(1,1), YP(1,1), Y(2,1), YP(2,1), ..., Y(5,1)
YP(5,1), Y(6,1), ..., YP(9,1)
Y(10,1), YP(10,1), ..., YP(13,1), Y(14,1)
YP(14,1)
X, TACC

Figure 3. Input - Output Format.
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>Time increment, DT</td>
</tr>
<tr>
<td>TEN</td>
<td>Angular orientation of thrust vector</td>
</tr>
<tr>
<td>AR</td>
<td>Offset of rocket motor from center line of missile</td>
</tr>
<tr>
<td>DVI</td>
<td>Change in missile velocity in feet/second (initial condition)</td>
</tr>
<tr>
<td>VI</td>
<td>Initial velocity of missile</td>
</tr>
<tr>
<td>DTH</td>
<td>Increment in the line of sight (for next run)</td>
</tr>
<tr>
<td>ALP</td>
<td>Angle of attack (in degrees)</td>
</tr>
<tr>
<td>RANGE</td>
<td>Range of target along line of sight (feet)</td>
</tr>
<tr>
<td>LOS</td>
<td>Line of sight, angle in degrees (always positive)</td>
</tr>
<tr>
<td>GBIAS</td>
<td>Gravity bias term</td>
</tr>
<tr>
<td>FPT</td>
<td>Number of time increments not to be exceeded</td>
</tr>
<tr>
<td>X</td>
<td>Current time, initial time</td>
</tr>
<tr>
<td>TIM</td>
<td>Time of next laser pulse</td>
</tr>
<tr>
<td>THF</td>
<td>Thrust factor (not implemented)</td>
</tr>
<tr>
<td>MAC</td>
<td>Mach No.</td>
</tr>
<tr>
<td>ES</td>
<td>Surface area</td>
</tr>
<tr>
<td>XCP</td>
<td>Location of c.g. in missile diameters</td>
</tr>
<tr>
<td>D</td>
<td>Missile diameter</td>
</tr>
<tr>
<td>TACC</td>
<td>Total acceleration magnitude</td>
</tr>
<tr>
<td>AL</td>
<td>Angle of attack α</td>
</tr>
<tr>
<td>Variable</td>
<td>Description</td>
</tr>
<tr>
<td>----------</td>
<td>-------------</td>
</tr>
<tr>
<td>IXX</td>
<td>Moment of inertia in X direction</td>
</tr>
<tr>
<td>IYY</td>
<td>Moment of inertia in Y direction</td>
</tr>
<tr>
<td>IZZ</td>
<td>Moment of inertia in Z direction</td>
</tr>
<tr>
<td>CA</td>
<td>Drag coefficient</td>
</tr>
<tr>
<td>DCA</td>
<td>Induced drag</td>
</tr>
<tr>
<td>CND</td>
<td>Control vane normal force</td>
</tr>
<tr>
<td>CNA</td>
<td>Body normal force</td>
</tr>
<tr>
<td>CMD</td>
<td>Tail misalignment coefficient</td>
</tr>
<tr>
<td>XCP</td>
<td>CP location – diameters from nose</td>
</tr>
<tr>
<td>CMT</td>
<td>Pitch damping coefficient</td>
</tr>
<tr>
<td>IC</td>
<td>Total number of increments of initial condition DTH</td>
</tr>
<tr>
<td>IK</td>
<td>Printout occurs every Ikth increment of H</td>
</tr>
<tr>
<td>N</td>
<td>Number of state variables</td>
</tr>
<tr>
<td>XLASR</td>
<td>Standard deviation of laser spot in X direction</td>
</tr>
<tr>
<td>VLAZRP</td>
<td>Percent of time laser pulse acquired by seeker/100 (used in pulse loss logic)</td>
</tr>
<tr>
<td>TZ</td>
<td>Length of time for which seeker is caged (pursuit guidance)</td>
</tr>
<tr>
<td>TACC</td>
<td>Total acceleration of missile</td>
</tr>
<tr>
<td>DSPEED</td>
<td>Counter (if greater than one, aircraft speed is incremented by DVI for next launch</td>
</tr>
<tr>
<td>DTH</td>
<td>Increment by which initial orientation is changed for next launch</td>
</tr>
</tbody>
</table>
EP=0.
COPCRA/VAR/TEN,AR,TIM,THF,TTK,TACC,GBIAS
*YFL,VLAZRP,XLSR
*EP,FS,ER,TZ
CPENSI,CRY(14,6),YP(14,6),V(14)
EXTERNAL,ALCER
REALOS
1 CONTINUE
X=0.
TIP=0.
IC=10
IT=0
K=0
A=14
REAC(5,900)FPT,H,TEN,AR,TV1,V1,OTH,ALP,RANGE,LOS,GBIAS
*VLAZRP,XLSR
*DSPEED,TZ
WRITE(6,900)FPT,H,TEN,AR,TV1,V1,OTH,ALP,RANGE,LOS,GBIAS
*VLAZRP,XLSR
*DSPEED,TZ
900 FC=AT (P8E12.4)
PT=FPT
CIT=FCT/57.6
CIL=1,14
4 Y(1,1)=0
Y(12,1)=1000
BBC=IC/2+CIP
2 CONTINUE
V1=V1+CV1
PV=CSC/57.6
Y(1,1)=-RANGE+CSC(PV)
Y(3,1)=-RANGE+SPV(PV)
Y(6,1)=PV
Y(5,1)=Y(6,1)
Y(10,1)=Y(6,1)+BBC
BBC=0.
PT=-Y(10,1)+ALP/57.6
Y(2,1)=V1+CSC(PT)
Y(4,1)=V1+SIN(PT)
FS=0.
ER=0.
EP=0.
WRITE(6,920)Y1(K,1),K=1,N
CSC=1,14
5 V(1)=Y(1,1)
6 CONTINUE
CALL=GCAMS($M,PT,N,Y,YP,CER,IK)
X=0.
TIP=0.
IF(CT=1.1)GOTO2
IT=IT+1
10 Y(1,1)=V(1)
Y(10,1)=Y(10,1)+CIT+IT
Y(5,1)=Y(10,1)
Y(15,1)=Y(10,1)
IF(2,GT,0.0)GOTO12
Y(5,1)=Y(6,1)
12 CONTINUE
V2=V1
Y(2,1)=V2+CSC(Y 10,11)
Y(4,1)=V2+SIN(Y1C,11)
EP=0.

16
32 TH=0.
TTCC11.
GCTC33
31 TH=500.*((TF-X)/(TF-TR))
TTCC=(TTCT-Tx+1TF-X)*.5)/TTGT
33 TTCC1=TTG
XCG=(8.75*10.6-8.75)*TTO
P=x=(3.68+4.21-3.48)*TTO
IX=(1.066+1.094-.0686)*TTO
IVY+25.04*(29.56-25.04)*TTO
I/2+IVY
MAC=Y/1.150.
IF (MAC .GT. 2.1) MAC=2.
IF (MAC .GT. .75) GOTO10
CA=4.
GCTC12
10 IF (MAC .GT. 1.2) GOTO11
CA=(MAC-.561)*.6/.24
GCTC12
11 CA=1.44-MAC+.22/2.8
12 IF (TH.EQ.0) GOTO13
CA=.93*CA
GCTC12
13 CCNTINUE
IF (MAC .GT. .92) GOTO16
GCA=(2.92MAC+3.63)*(ABS(Y7.1)*2.88)*2.2
GCTC17
16 CCNA=-(MAC-2.8)*3.0375*(MAC-2.8)*12*.4*(*ABS(Y7.1)*2.88)*12.1
17 CCNTINUE
CNA=3.9-CCS*MAC+3.14159/2.8)*.7
FF=MAC-.75) GOTO18
CA=*15.8
GCTC21
18 IF (MAC .GT. 1.) GOTO19
CA=15.8+.9/.36*(MAC-.75)
GCTC21
19 IF (MAC .GT. 1.5) GOTO20
CA=21.3
GCTC21
20 CA=-(MAC-2.8)*2.71*20.1
21 IF (MAC .GT. 1.) GOTO23
CCP=(MAC)**315*10.3*4.3
GCTC24
23 CCP=EXP(-MAC-1.4)*14.6*(MAC-1.4)*4.18
24 XCP=-(MAC-6.6)**2+.632+.02*(MAC-6)**4.102*.418
IF (MAC .GT. 1.4) GOTO26
CMT=MAC**2+550+.3700.
GCTC28
26 CMT=EXP(-MAC-1.4)*5600.+(MAC-1.4)*2150.
28 CCNTINUE
F2=(CA+2*CCS*(Y7.11)+.655*TM
F3=(CA+2*AL*(CND))Y(7.1)+.5*ESTI+SIINTEN
A1=10.
A2=8.
A3=10.
A4=4.
A5=2.57.6
A6=TC
A7=5.
A8=60.
A9=20.
A9=1.
TACC=SCRTYP(12,11)*2*YP(4,1)*2)
RETURN
EAC
SUN=SCRTYNCCAS(X,T,P,MPT,N,L,F,DER,IK)
CIP=ASINH(U1,4,1,F(1,4,6)
CC=CN/VAR/THF,IK,THF,ITT,TACC,GBIA
+TF,L,VARP,R,VAR
+EF,F,S,E.T,Z
DATA PREC1, PREC2, PREC3, PREC4
+ /55.0, -59.0, 37.0, -9.0/
+ /9.0, -3.0, -5.0, 1.0/
+ P24 = M / 24.0
+ P1 = PREC1 + M24
+ P2 = PREC2 + M24
+ P3 = PREC3 + M24
+ P4 = PREC4 + M24
+ C1 = CORR1 + M24
+ C2 = CORR2 + M24
+ C3 = CORR3 + M24
+ C4 = CORR4 + M24
DATA ALPHA2, ALPHA3
+ /4.4, 4.45772725/
+ /4.4, 2.5697761, 1.5875564, 2.181004, 3.05096516, 3.83288476 /
+ /OMEQ4, OMEQ2, OMEQA4, OMEQ4 /
+ /1.7476028, -55148086, 1.2259356, 1.1718478/
CALLECR(X,N,U(1,1),F(1,1),P,L,1)
IF (MPT .LE. 1) RETURN
A2 = ALPHA2 + M
+ B21 = BETA21 + M
+ B31 = BETA31 + M
+ B32 = BETA32 + M
+ B41 = BETA41 + M
+ B42 = BETA42 + M
+ B43 = BETA43 + M
+ C1 = OMEGA1 + M
+ C2 = OMEGA2 + M
+ C3 = OMEGA3 + M
+ C4 = OMEGA4 + M
+ C5 = OMEGA5 + M
+ C6 = OMEGA6 + M
+ C7 = OMEGA7 + M
+ C8 = OMEGA8 + M
+ C9 = OMEGA9 + M
+ C10 = OMEGA10 + M
1 CONTINUE
A = X + A2
CALLECR(A,N,U(1,1),F(1,1),P,L,1)
CC 1 = 1,1
U(1,5) = U(1,1) + B21 * F(1,1)
CC 1 = 1,4
1 CONTINUE
A = X + A2
CALLECR(A,N,U(1,1),F(1,1),P,L,1)
CC 2 = 1,4
U(1,5) = U(1,1) + B31 * F(1,1) + B32 * F(1,5)
CC 2 = 1,5
1 CONTINUE
A = X + A3
CALLECR(A,N,U(1,1),F(1,1),P,L,1)
CC 2 = 1,5
U(1,5) = U(1,1) + B41 * F(1,1) + B42 * F(1,5) + B43 * F(1,6)
CC 2 = 1,6
1 CONTINUE
A = X + A4
CALLECR(A,N,U(1,1),F(1,1),P,L,1)
CC 3 = 1,6
U(1,5) = U(1,1) + B51 * F(1,1) + B52 * F(1,5) + B53 * F(1,6)
CC 3 = 1,5
1 CONTINUE
A = X + A5
CALLECR(A,N,U(1,1),F(1,1),P,L,1)
CC 4 = 1,5
U(1,5) = U(1,1) + B61 * F(1,1) + B62 * F(1,5) + B63 * F(1,6)
CC 4 = 1,4
1 CONTINUE
A = X + A6
CALLECR(A,N,U(1,1),F(1,1),P,L,1)
CC 5 = 1,4
U(1,5) = U(1,1) + B71 * F(1,1) + B72 * F(1,5) + B73 * F(1,6)
CC 5 = 1,3
1 CONTINUE
A = X + A7
CALLECR(A,N,U(1,1),F(1,1),P,L,1)
CC 6 = 1,3
U(1,5) = U(1,1) + B81 * F(1,1) + B82 * F(1,5) + B83 * F(1,6)
CC 6 = 1,2
1 CONTINUE
A = X + A8
CALLECR(A,N,U(1,1),F(1,1),P,L,1)
CC 7 = 1,2
U(1,5) = U(1,1) + B91 * F(1,1) + B92 * F(1,5) + B93 * F(1,6)
CC 7 = 1,1
1 CONTINUE
A = X + A9
CALLECR(A,N,U(1,1),F(1,1),P,L,1)
CC 8 = 1,1
U(1,5) = U(1,1) + B10 * F(1,1) + B10 * F(1,5) + B10 * F(1,6)
CC 8 = 1,0
1 CONTINUE
A = X + A10
CALLECR(A,N,U(1,1),F(1,1),P,L,1)
CC 9 = 1,0
U(1,5) = U(1,1) + B11 * F(1,1) + B11 * F(1,5) + B11 * F(1,6)
CC 9 = 1,1
1 CONTINUE
A = X + A11
CALLECR(A,N,U(1,1),F(1,1),P,L,1)
CC 10 = 1,1
U(1,5) = U(1,1) + B12 * F(1,1) + B12 * F(1,5) + B12 * F(1,6)
LC*+L
CALLER(X,N,UL1,X+1,F(L,K+1),F,LO,LO)
10 CCNTINUE
IF (PFT .LT. 5) RETURN
K=1
KT=0
JK=1K
CC40K=5%MPI
CC 20 J = 1,N
U(J,K) = U(J,K-11 + P1 = F(J,K-1) + P2 + F(J,K-2)
+ P3 + F(J,K-3) + P4 + F(J,K-4)
20 CCNTINUE
X = X + P
CALLER(X,N,UL1,K),F(I,K),I,K,K)
DC 30 J = 1,N
U(J,K) = U(J,K-1) + C1 = F(J,K) + C2 * F(J,K-1)
+ C3 * F(J,K-2) + C4 * F(J,K-3)
30 CCNTINUE
CALLER(X,N,UL1,K),F(I,K),I,K,K)
IF (*613233,33
32 K=6
GCTC37
33 DC3=IT=11S
DC3=IT=11N
U(IJT,T) = U(IJT,IT+1)
34 F(IJT,T) = F(IJT,IT+1)
37 IF (JK=0) 36, 39
42 JK=JK+1K
36 WRITE(6,11) (U(JJ,JK),F(JJ,JK)),JJ=1,N
WRITE(6,11)x,TACC
IF (JK+1K 42, 42, 43
43 JK=JK+1
39 JK=JK-1
40 IF (JS,5) 40, 40, 12
40 CCNTINUE
12 CCNTINUE
JK=JK-1K
WRITE(6,11) (U(JJ,JK),F(JJ,JN)),JJ=1,N
WRITE(6,11)x,TACC
11 PECMP(JX,1PE12.6)
RETURN
ENC
SUBRUTINEGAUSS(S,AM,F,T1)
CCV=EN/VAR/TEN,AR,TIM,THK,TACC,GBIAS
+F,YL,F,LER,X,LSR
+F,EP,F,ER,TZ
CATA (X = 377777777777777778)
CATA (E = 777777777777777778)
C S=THE REQUIRED STANDARD DEVIATION
C AP=IS THE REQUIRED MEAN
C V-VALUE COMPUTE NORMALLY DISTRIBUTED RANDOM NUMBER
IF (T.GE.0.) GOTO4
2 IF (IX) 7, 8, 10
7 IX=IX
8 IF (IX.GT.999) GOTO3
IX=IX*241
A=O
GCTC4
3 IX=IX/10
GCTC2
4 CC501=1.12
IF (I.GT.11) IX*1Y
J=1
I=J
I=(I,J,K)
J=(I,J,H,N)
B=(FLAT1/12)/3.4359739E10
YFL=2.CH &D,8
IX=1
50
A=A+YFL
V=(J-6.145+91
RETURN
END

1.0000E+03 2.0000E-02 0.0000E+00 0.0000E+00 0.0000E+00 5.0000E+02
2.5000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
2.5000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
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*Note: The table is a placeholder and does not represent the actual content of the image.*
APPENDIX II

AERODYNAMIC CURVES
Figure II-1. Aero Pitch Damping Curve
Figure II-2. Aero Roll Damping Curve

\[ M_\phi = \frac{C_{M_\phi} q S d^2 \dot{\phi}}{2V} \text{ lb-ft} \]

\[ \phi \approx \text{rad/sec} \]
Figure II-3. Center of Pressure Location
Figure II-4. Tail Misalignment Coefficient

\[ M_\Delta = C_{M\Delta} \Delta q Sd \text{ lb-ft} \]

\[ \Delta = \text{radians} \]
Figure 11-5. Body Normal Force
Figure 11-6. Control Vane Normal Force
Figure II-7. Induced Drag
REDUCE .07 FOR POWER ON

Figure II-8. Drag Force
REFERENCES


This report describes in detail a three-degree-of-freedom program which can be used to determine the trajectory and miss distance of a guided missile system. The options for the program are such as to permit variation of the aerodynamics, seeker, autopilot, actuator, and missile motor performance for the purpose of accurately simulating a given missile design and evaluating the effects of any changes in system parameters. Sufficient detail has been included in the text to minimize the effort needed to update or modify the program presented.
Guided Missile
Missile Simulation System
Three-Degree-of-Freedom Simulation