AD-A039 757 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OHIO SCH--ETC F/G 1/2
MANEUVERING TARGET SIMULATION FOR TESTING THE TERMINAL GUIDANCE--ETC(U)
MAR 77 H G PADDON

UNCLASSIFIED AFIT/GE/EE/77-2 NL

1 OF 2
AD
A039757

AD A039757

DDC
RECEIVED
MAY 20 1977
C

COPY AVAILABLE TO DDC DOES NOT
PERMIT FULLY LEGIBLE PRODUCTION

MANEUVERING TARGET SIMULATION FOR TESTING THE TERMINAL GUIDANCE FOR AIR-TO-AIR MISSILES

THESIS

GE/EE/77-2

Harry G. Paddon
Major USAF

AD No.
DDC FILE COPY

Approved for public release; distribution unlimited.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: AFIT/GE/EE/77-2	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE *(and Subtitle)*: MANEUVERING TARGET SIMULATION FOR TESTING THE TERMINAL GUIDANCE OF AIR-TO-AIR MISSILES	5. TYPE OF REPORT & PERIOD COVERED: MS Thesis
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Harry G. Paddon, Major USAF	8. CONTRACT OR GRANT NUMBER(s): Masters thesis,
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Air Force Institute of Technology (AFIT-EN), Wright-Patterson AFB, Ohio 45433	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 12 181 p.
11. CONTROLLING OFFICE NAME AND ADDRESS: AFATL/DLMA, Eglin AFB, FL 32542	12. REPORT DATE: Mar[redacted]977
	13. NUMBER OF PAGES: 180
14. MONITORING AGENCY NAME & ADDRESS *(if different from Controlling Office)*	15. SECURITY CLASS. *(of this report)*: Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*
Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES
Approved for public release; IAW AFR 190-17
JERRAL F. GUESS, Captain, USAF
Director of Information

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*
Air Combat Simulation
Aircraft Simulation
Maneuvering Target

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*
There was a need for a complete maneuvering target for air- to-air combat simulation. A computer program was developed with logic and tactical decisions subroutines. The parameters for these decisions corresponded to the differences in pilots and the relative aircraft states. The decision subroutines provided the desired control inputs to accomplish the required maneuvers. Validation of the simulated target was accomplished by use of five test runs from different initial conditions as well as twenty runs from the same initial conditions.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED 012 225

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

MANEUVERING TARGET SIMULATION FOR TESTING THE TERMINAL GUIDANCE OF AIR-TO-AIR MISSILES

THESIS

Presented to the Faculty of the School of Engineering

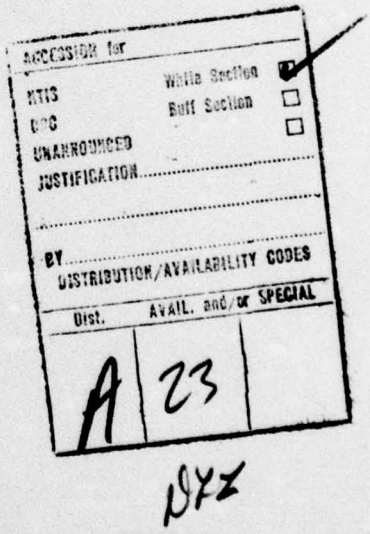
of the Air Force Institute of Technology

Air University

in Partial Fulfillment of the

Requirements for the Degree of

Master of Science



by

Harry G. Paddon, B. S.
Major USAF

Graduate Electrical Engineering

March 1977

Approved for public release; distribution unlimited.

Preface

I became interested in the capability of air-to-air missiles first hand while on the receiving end of some and the giving end of others during my combat tour in Vietnam. When Major Thomas Moriarty suggested the subject, I was more than educationally interested. The need for the development of a maneuvering target came from Dr. Michael Caluda, Armament Development Test Center, Eglin AFB, Florida.

The program was developed using human pilot's observation and logic in making decisions. My background is as a tactical fighter pilot and instructor pilot. As an instructor pilot, I observed pilots make airborne tactical decisions. These observations were incorporated in the development of this thesis.

The assistance provided by my thesis advisor, Major Thomas Moriarity, was invaluable. He provided the initial direction and continued motivation throughout the development.

And most of all, I must express my deepest appreciation to my wife, Pat, and family for their support and patience during the writing of this thesis, without which it is likely I would not have completed the project.

Contents

		Page
Preface		ii
List of Figures		vi
List of Tables		vii
Abstract		viii
I.	Introduction	1
	Background	1
	Objective	2
	Description and Scope	2
	Organization	4
II.	Combat Scenario and Description	6
	Model Description	6
	Decision Logic	10
	Missile Seeker Noise	19
III.	Program Evasion	22
	Data Inputs	23
	Subroutine ANGLESF	23
	Subroutine ANGLESM	
	Subroutine PRINT	23
	Subroutine ATTACKF	25
	Subroutine ATTACKM	
	Subroutine PILOT	25
	Subroutine EVAMANU	26
	Subroutine THRUSTF	28
	Subroutine THRUSTM	
	Subroutine DESINP	29

Page

Subroutine PURSUIT 29

Subroutine INPUTSF 29
Subroutine INPUTSM . . . . . .

Subroutine FORCESF 32
Subroutine FORCESM . . . . . .

Subroutine UPDATEF 33
Subroutine UPDATEM . . . . . .

Subroutine IRNOS 33
Subroutine RADNOS . . . . . .

Subroutine REDUCE 33

Miscellaneous Subroutines and Functions 34

IV. Aircraft Model 37

Validation 37
Initial Conditions 37
Aircraft Characteristics 39
Equations of Motion 40

V. Results 42

Battle 1 and 2 42
Battle 3 44
Battle 4 44
Battle 5 46
Statistical Characteristics 46

VI. Conclusions and Recommendations 58

Conclusions 58
Recommendations 59

Bibliography 61

Appendix A: Fortran Computer Program Listing 62

Page

Appendix B: Test Results 122

Appendix C: Aircraft Aerodynamic Coefficients and Equations 162

Appendix D: Missile Model 166

Appendix E: Entering Data 169

Vita 171

List of Figures

Figure		Page
1	Body Axis System	8
2	Pilot Imposed System	9
3	Angular Maneuver Selection Coordinates	13
4	Missile Azimuth Angle Rate Determination . . .	17
5	Missile Elevation Angle Rate Determination . . .	18
6	Program Evasion - Flow Chart	24
7	Control Rate Model	31
8	Battle 3 Plot	45
9	Battle 4 Plot	47
10	Battle 5 Plot	48

List of Tables

Table		Page
I	Model versus Aircraft Performance	38
II	Test Run Initial Conditions	43
III (1-4)	Parameters of Infra Red Guided Missile Production Runs	50
IV (1-4)	Parameters of Radar Guided Missile Production Runs	54

Abstract

There was a need for a complete maneuvering target for air-to-air combat simulation. A computer program was developed with logic and tactical decisions subroutines. The parameters for these decisions corresponded to the differences in pilots and relative aircraft states. The decision subroutines provided the desired control inputs to accomplish the required maneuvers. Validation of the simulated target was accomplished by use of five test runs from different initial conditions as well as twenty runs from the same initial conditions.

Maneuvering Target Simulation for Testing the Terminal Guidance of Air-to-Air Missiles

I. Introduction

Background

Successful development of accurate air-to-air missiles depends heavily on the results of preproduction simulation testing. For successful simulation testing and to keep the cost down at all levels of development, a comprehensive and realistic simulation of targets must be developed. This will accurately test missile guidance and performance before the costly manufacturing of the prototype missile and live-fire testing is begun. Many maneuvering targets have been developed for this purpose and for use in other simulation fields (Ref. 2:51). However, a maneuvering target that reacts like a recent graduate of the United States Air Force Tactical Fighter Weapons Center (TFWC) to different air-to-air missile combat situations is needed to provide an effective simulation (Ref. 7).

The development of the maneuvering target is dependent on the aircraft and the pilot. Frequently when maneuvering targets are synthesized, the pilot is many times neglected; however, the pilot is too important a factor to the results of an air-to-air battle not to be

included. The outcome of a battle becomes very sensitive to the pilot's judgement of range, relative position, and selection of the proper maneuver; in fact, these factors sometimes affect the outcome of air-to-air combat more than the particular missiles and aircraft involved.

Previous targets have been programmed to follow specific tracks or maneuvers for simulated air battles. This may be satisfactory for initial testing, but before the costly latter stages of testing, a comprehensive air-to-air combat simulation must be available.

Objective

The development of a fully maneuvering target was the objective of this thesis. The requirements of the maneuvering target are:

1. Respond with the desired maneuvers to the attack of the missile.

2. Include a human pilot range-judgement error.

3. Update the desired maneuver and the inputs throughout the simulation.

Description and Scope

The maneuvers incorporated in the simulation should be the latest in evasive tactics. The program must be able to accommodate

additional or new maneuvers with a minimum of programming changes.

The development of the maneuvering target simulation resulted in the program not being limited to any specific aircraft or missile. The program can be easily adapted to accommodate most aircraft and missiles.

The maneuvering target uses decision logic to respond to the given aircraft-missile situation, to determine the finite control inputs to fly the evasive maneuvers, and to continuously update the decision process so as to select an evasive response.

A realistic maneuvering target must not be optimized because a pilot has only one chance at each combat situation. During air-to-air combat and especially in maneuvers against launched missiles, the pilot has a very limited time to estimate the range and closure rate and then choose a maneuver. As a result, there are incidents where the pilot selects other than the optimal maneuver or even the wrong maneuver.

The responsive target was developed in the following manner:

1. The maneuvers were selected for the program.

2. The basic decision logic was developed.

3. The maneuver noise was selected. This was the manner in which the pilot's response was incorporated into the simulation.

4. Control inputs were developed for the maneuvers in step 1.

5. The simulation was then programmed and validated. It was necessary to run tests from different positions as well as numerous runs from the same initial conditions.

Organization

The thesis includes the combat scenario and description, analysis of the computer program, validation of the aircraft model, plus results and conclusions. The program listing, printed results, data input, development of the aerodynamic coefficients, and the missile model are included in the appendices.

The combat scenario, Section II, includes the development of the mathematics of the aircraft model. In addition, the development of the decision logic and missile seeker noise are presented.

Each individual function and subroutine are discussed in Section III, Computer Program. The calling sequence of the routines and the theory behind the development of the main program and subprograms is covered.

In Section IV, the aircraft model is validated as well as the decision logic. The initial conditions, aircraft characteristics and the equations of motion are developed.

The results of the five validation runs and the 20 runs from the same initial conditions are in Section V, Results and Conclusions.

Each validation run is considered individually as well as the total results of the twenty consecutive runs.

II. Combat Scenario and Description

Computer simulation of air-to-air combat is a means of providing for testing and evaluating tactics, maneuvers, and missile hardware. When the simulation is designed to follow pre-selected maneuvers or tracks, the operator in reality dictates the results. The best maneuver or tactic is a result of trial and error by the simulation operator.

The optimal type of simulation is not realistic. Each situation must allow only one selection by the pilot. In addition, maneuvering noise must be introduced for errors in judgement of the pilot. This idea will be developed further in the discussion of Subroutine Pilot.

Combat logic was developed from the relative states of the two vehicles and this logic provides feedback to the decision making process. The feedback continuously updates the decision parameters so that the maneuvering target will react as if controlled by a human pilot.

Model Description

The aircraft is represented by a center of mass model. The aircraft contains a body centered coordinate system, with the origin located at the center of gravity, C. G., of the aircraft. The X_B-axis is directed out the front of the aircraft, the Y_B-axis is directed out the right wing of the aircraft, and the Z_B-axis completes the right handed

orthogonal coordinate system, therefore, is directed out the bottom of the aircraft. The orientation of the body axis is shown in Figure 1.

The missile is described by the same type of body axis coordinate system. The pilot superimposes a spherical coordinate system over the body axis of the aircraft so as to relate the missile to his own frame. This relationship is shown in Figure 2. When range (R) is utilized, it refers to the distance between the aircraft and the missile. Zeta (ζ) is the asimuth angle to the missile from the aircraft. The angle is measured positive right in the X_B-Y_B plane of the aircraft. Eta (η) is the elevation angle from the aircraft to the missile with positive being up from and perpendicular to the X_B-Y_B plane (Ref. 1:9).

The navigation frame has its origin at the C. G. of the aircraft. The Y_N-axis is directed toward east and the Z_N-axis is directed downward along the gravity vector, g. The X_N-axis completes the right hand orthogonal coordinate system. The X_N-axis is directed north.

The wind axis reference frame is also used. The origin of this frame is the C. G. of the aircraft. The X_W-axis is directed along the velocity vector of the aircraft with respect to the atmosphere. The Z_N-axis is in the plane of symmetry of the aircraft and is directed perpendicular to the X_W-axis. The Y_W-axis completes the right-hand orthogonal coordinate system (Ref. 2:109).

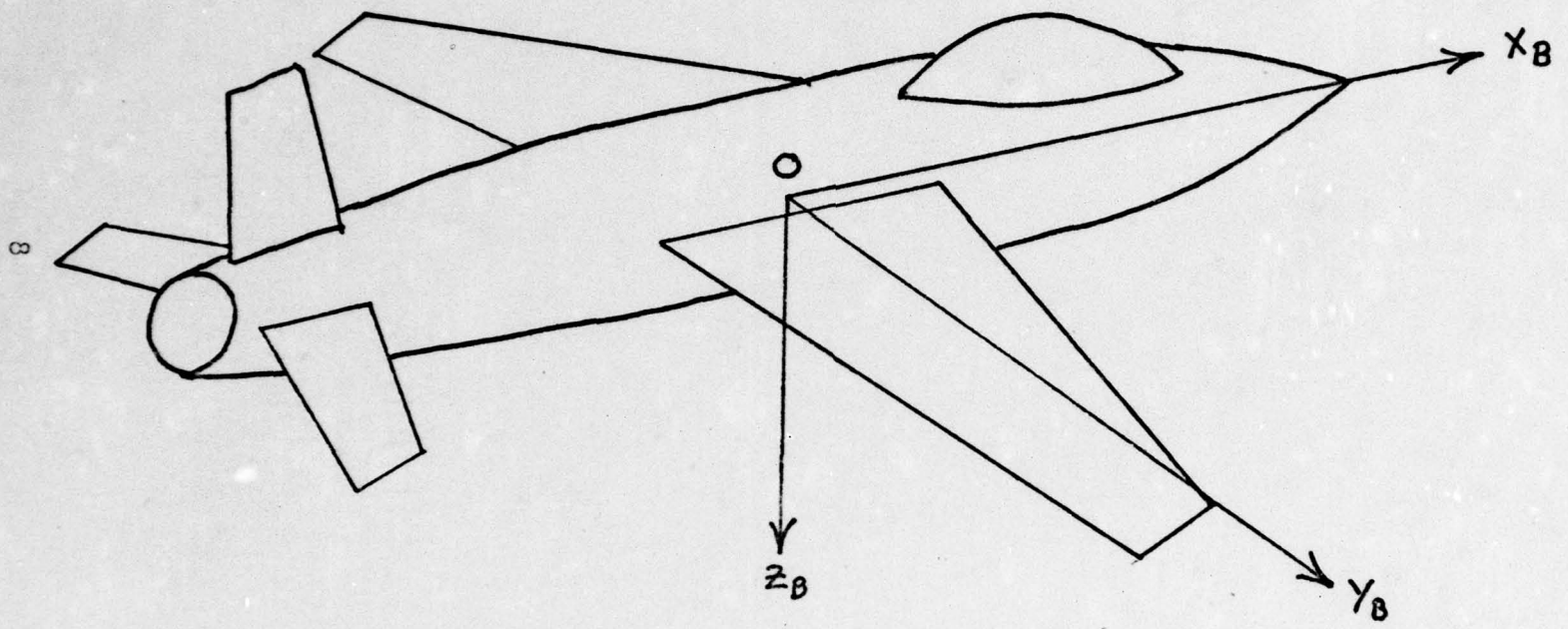


Figure 1 Body Axis System

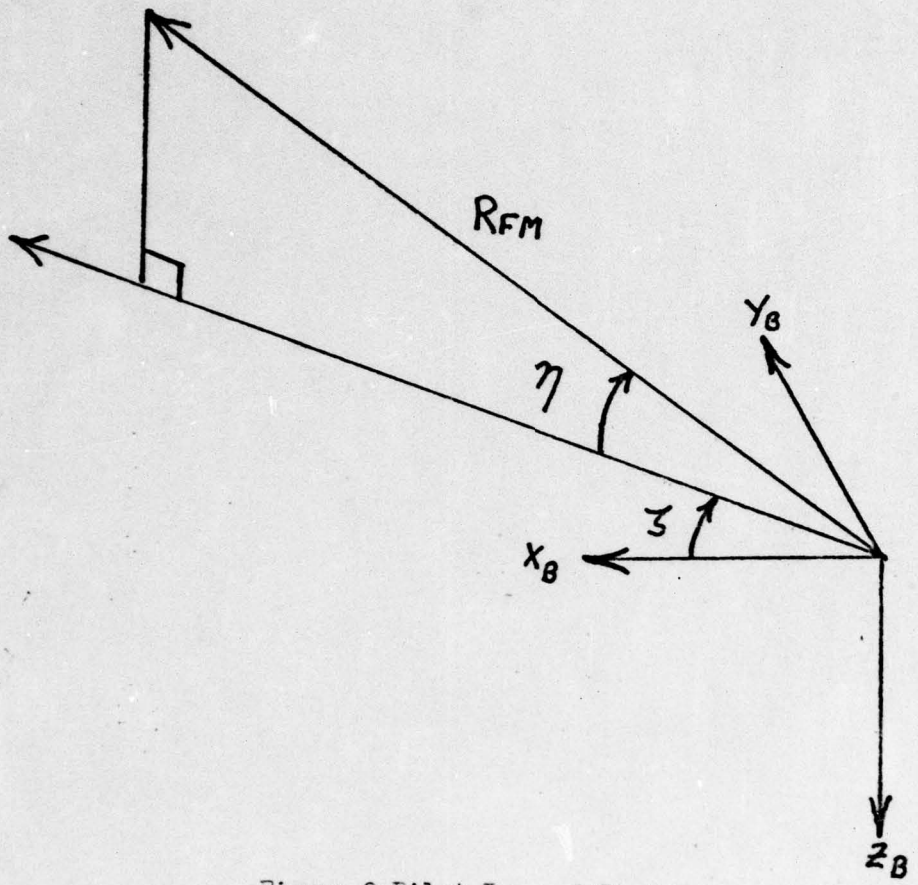


Figure 2 Pilot Imposed System

(Ref. 1:9)

Before describing the final coordinate system that is utilized in the aircraft simulation, a few basic assumptions have to be made:

1. The earth's fixed frame is considered an inertial frame.
2. The earth's rotation is neglected.
3. The earth is assumed to be flat.
4. Gravity is assumed to be constant in direction and magnitude.
5. Air mass movement is assumed to be zero.

With these assumptions included, the earth's surface fixed coordinate frame is introduced. This frame parallels the aircraft navigation frame. The origin of the earth's surface frame is fixed on the earth's surface and is directly below the aircraft C. G. at time zero. At the beginning of each engagement, the aircraft's horizontal coordinates are zero and the vertical coordinate is equal to the negative altitude of the aircraft. It can be seen that at time zero any vector in the navigational frame will have the same orientation in the earth's surface reference frame and vice versa (Ref. 1:10).

Decision Logic

Maneuver selection is based on the instantaneous relative states between the aircraft and missile. The decision logic considered the range between the two vehicles and the closure geometry. To transform the decision logic into the reactions of a human, the

selection parameters used by the pilot are incorporated into the decision logic routine. A pilot will see the missile as two angles and estimated range. The pilot describes the missile as, "Missile, five o'clock high at 5000 feet." Converted into mathematical terms, the position translates as range of 5000 feet, azimuth 150 degrees, and elevation of 45 degrees (Ref. 1:10).

At long ranges, the assumption of point mass is selected due to the inability of the pilot to determine relative sizes. He can estimate range, azimuth, and elevation.

After determining an estimated position, the maneuver selection is based on the relative state vectors. The state vectors are resolved into two two-dimensional angles. First, the aircraft angle-off is considered. The angle-off (φ off) is defined as the angle between the line-of-sight vector and the missile's velocity vector. The cone angle (θ cone) is the angle between the velocity vector and the line sight-of-sight vector of the aircraft.

Over a period of time, the pilot is able to estimate the rate of change in the relative position between the aircraft and the missile. Therefore, the pilot adds the estimated range rate ($\dot{R}$) azimuth rate (ζ) and elevation rate, $\dot{\eta}$, to his knowledge for use in maneuver selection (Ref. 1:11-12).

A pilot is now able to make a logical maneuver selection based on:

R - Range

$\dot{R}$ - Range Rate

ζ - Azimuth

$\dot{\zeta}$ - Azimuth Rate

η - Elevation

$\dot{\eta}$ - Elevation Rate

φ - Angle Off

θ - Cone Angle

The relationship between these variables are shown in Figure 3.

Before the previous eight parameters can be determined, the earth's fixed coordinates have to be transformed into the aircraft body fixed frame. The aircraft states consisted of the following components:

x, y, z - position

u, v, w - velocity

Ψ, θ, φ - Euler angles (heading, flight path angle, and bank angle)

The missle states consisted of the same components.

The missile's relative position is converted in the aircraft's navigation frame. The velocity components are also converted.

$$x_{MF} = x_M - x_F \quad (1)$$

$$y_{MF} = y_M - y_F \quad (2)$$

$$z_{MF} = z_M - z_F \quad (3)$$

$$u_{MF} = u_M - u_F \quad (4)$$

$$v_{MF} = v_M - v_F \quad (5)$$

$$w_{MF} = w_M - w_F \quad (6)$$

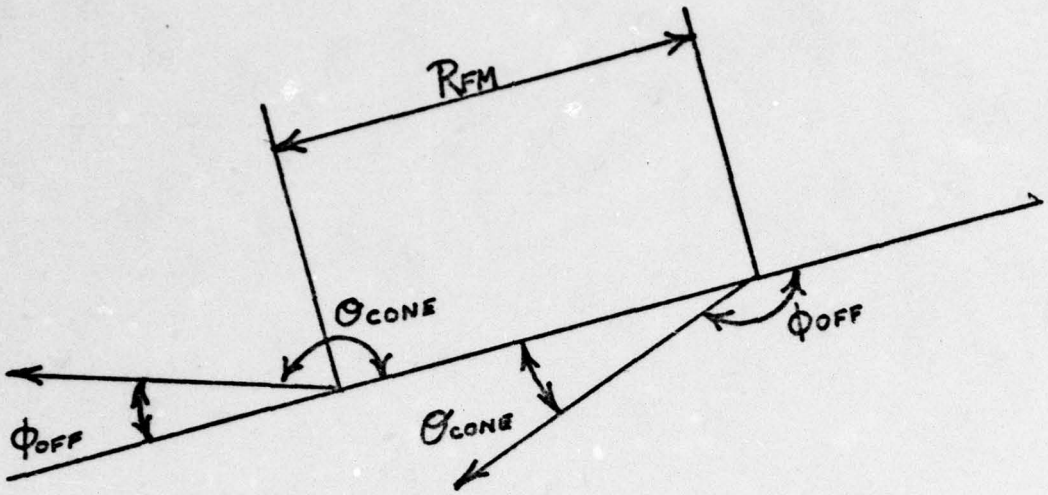


Figure 3 Angular Maneuver Selection Coordinates

(Ref. 4:86)

The missile position and velocity components in the aircraft's navigation frame are converted into the aircraft's body fixed frame by use of the Euler angle transformation.

$$T_{NB} = \begin{bmatrix} c\theta c\Psi & c\theta s\Psi & -s\theta \\ s\varphi s\theta c\Psi - c\varphi s\Psi & s\varphi s\theta s\Psi + c\varphi s\Psi & s\varphi c\theta \\ c\varphi s\theta c\Psi + s\varphi s\Psi & c\varphi s\theta s\Psi - s\varphi c\Psi & c\varphi c\theta \end{bmatrix} \tag{7}$$

where s denotes sine and c denotes cosine.

$$\begin{bmatrix} x_{MB} \\ y_{MB} \\ z_{MB} \end{bmatrix} = T_{NB} \begin{bmatrix} x_{MF} \\ y_{MF} \\ z_{MF} \end{bmatrix} \tag{8}$$

$$\begin{bmatrix} u_{MB} \\ v_{MB} \\ w_{MB} \end{bmatrix} = T_{NB} \begin{bmatrix} u_{MF} \\ v_{MF} \\ w_{MF} \end{bmatrix} \tag{9}$$

The azimuth and elevation of the missile with respect to the aircraft are determined in the following manner:

$$\zeta_{MF} = \sin^{-1}\left(\frac{y_{MB}}{R}\right) \tag{10}$$

$$\eta_{MF} = \sin^{-1}\left(\frac{-z_F}{R}\right) \tag{11}$$

The simplest means of determining the range between the missile and aircraft is to use the position coordinates of each in the earth's surface fixed frame. The range is computed as the square root of the sum of the squares of the differences of the three components of position.

$$R = \sqrt{X^2_{MF} + Y^2_{MF} + Z^2_{MF}} \qquad (12)$$

The closure rate or range rate is computed by use of differences in the relative positions and the differences in the components of velocity. Both velocity and position components are in the aircraft body fixed frame. By use of trigometric substitution, the range rate is determined by use of the velocity differences and two angles, azimuth and elevation. The range rate is computed as the difference of the missile and aircraft velocity components along the line-of-sight.

$$\dot{R} = \frac{u_{MB}\, x_{MB} + v_{MB}\, y_{MB} + w_{MB}\, z_{MB}}{R} \qquad (13)$$

or

$$\dot{R} = u_{MB} \cos \eta_{MF} \cos \zeta_{MF} + v_{MB} \cos \eta_{MF} \sin \zeta_{MF} - w_{MB} \sin \eta_{MF} \qquad (14)$$

The azimuth rate and elevation rate are then determined. To determine these variables, the heading angle of the missile, expressed in the aircraft's body fixed frame, (Ψ_{MF}) is derived first. Ψ_{MF} is the angle between the aircraft's X_B axis and the velocity vector component of the missile in the $X_B Y_B$ plane of the aircraft.

$$\Psi_{MF} = \cos^{-1} \frac{u_{MB}}{[u^2_{MB} + v^2_{MB}]^{\frac{1}{2}}} \qquad (15)$$

If v_{MB} is negative, Ψ_{MF} becomes the negative of the above equation.

$$\Psi_{MF} = - \cos^{-1} \frac{u_{MB}}{[u^2_{MB} + v^2_{MB}]^{\frac{1}{2}}} \qquad (16)$$

Another angle of interest is the flight path angle of the missile in the $X_B Y_B$ plane of the aircraft, θ_{MF}

$$\theta_{MF} = \sin^{-1} \frac{-w_{MB}}{[u^2_{MB} + v^2_{MB} + w^2_{MB}]^{\frac{1}{2}}} \qquad (17)$$

With Ψ_{MF} and θ_{MF} defined, the azimuth rate $\dot{\zeta}$, and elevation rate, $\dot{\eta}_{MF}$, are then determined.

$$\dot{\zeta}_{MF} = \frac{[u^2_{MB} + v^2_{MB}]^{\frac{1}{2}} \cos(\pi/2 + \zeta_{MF} - \Psi_{MF})}{R \cos \eta_{MF}} \qquad (18)$$

$$\dot{\eta}_{MF} = \frac{[u^2_{MB} + v^2_{MB}]^{\frac{1}{2}} \cos(\Psi_{MF} - \zeta_{MF}) \sin \eta_{MF} - w_{MB} \cos \eta_{MF}}{R} \qquad (19)$$

Refer to Figures 4 and 5 for the orientation of $\dot{\zeta}$ and $\dot{\eta}$.

The next angles to be determined are the angle off, φ_{off}, and cone angle, θ_{cone}. The scaler dot product of R and the aircraft's velocity vector, $\bar{V}$, determine the φ_{off}. The mathematical solution:

$$\cos(\varphi_{off}) = \frac{\bar{V} \cdot \bar{R}}{[\bar{V}]\ [\bar{R}]} \qquad (20)$$

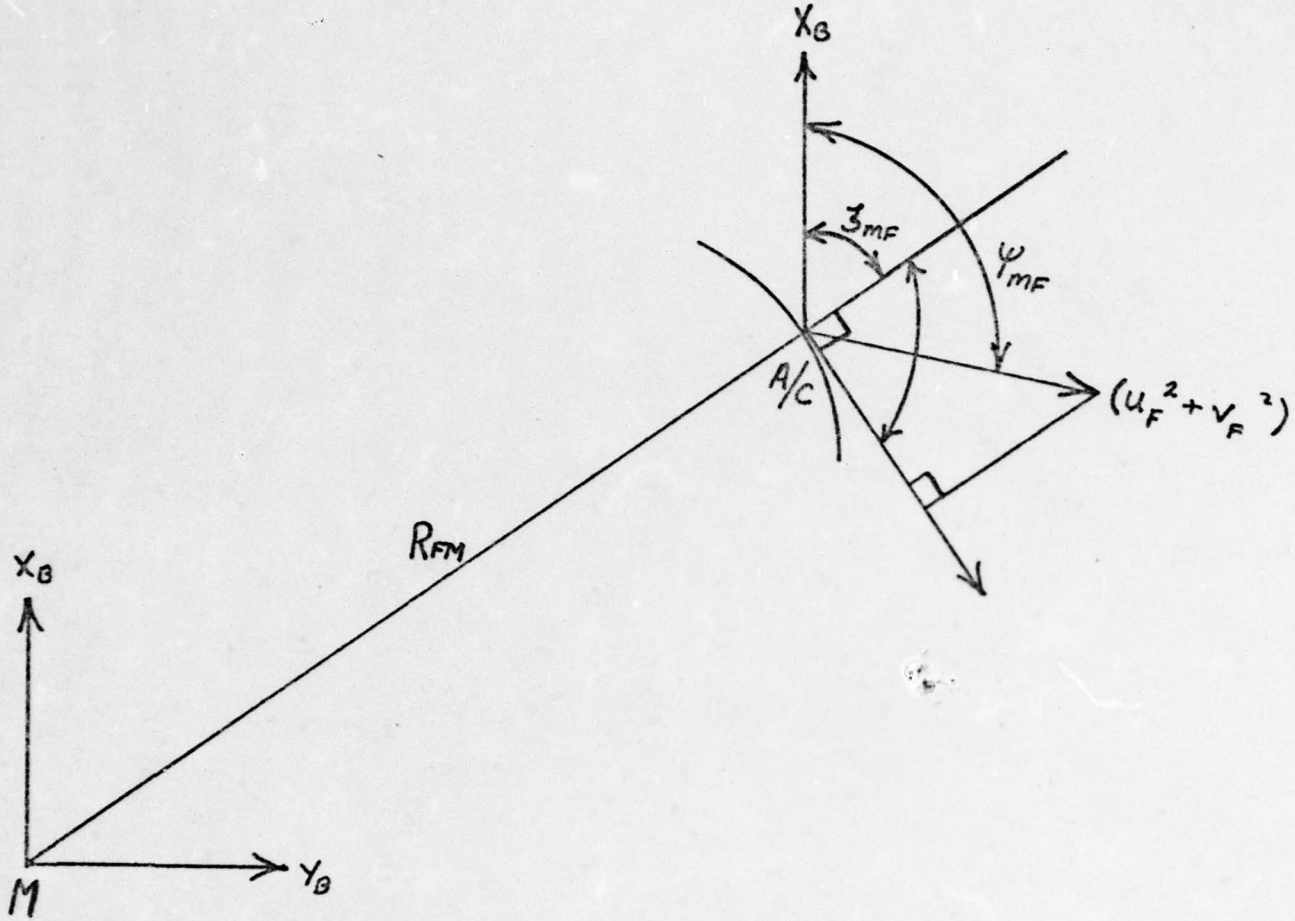


Figure 4 Missile Azimuth Angle Rate Determination

(Ref. 1:16)

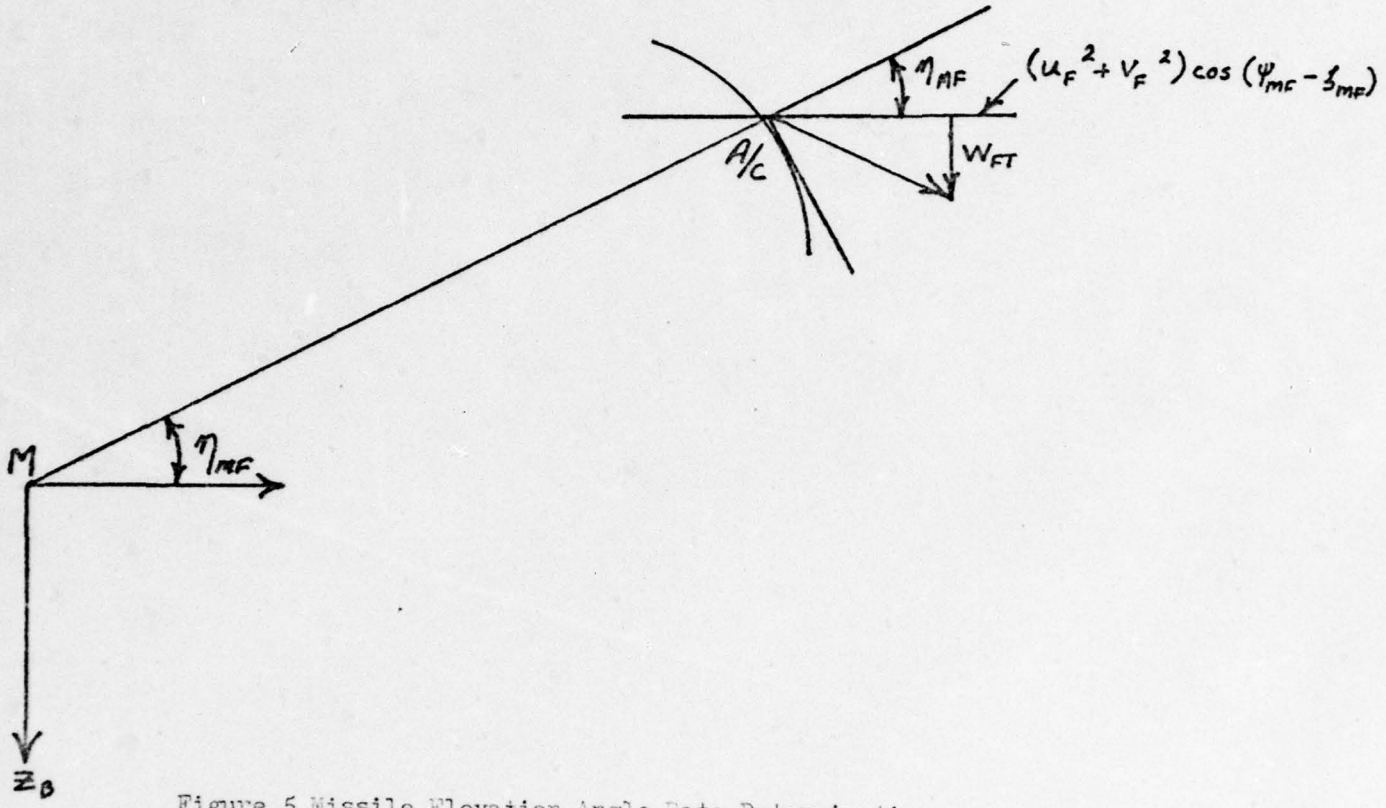


Figure 5 Missile Elevation Angle Rate Determination

(Ref. 1:17)

$$\cos(\varphi_{off}) = \frac{x_{MF}\, u_M + y_{MF}\, v_{MF}\, v_M + z_{MF}\, w_M}{V \quad R} \qquad (21)$$

The angle-off is defined as the angle between the line-of-sight vector and the missile's velocity vector.

The cone angle is defined as the angle between the aircraft's velocity vector and its line-of-sight vector. The mathematical value is determined by:

$$\cos(\theta_{cone}) = \cos \zeta_{MF} \cos \eta_{MF} \qquad (22)$$

(Ref. 4:77-83)

Missile Seeker Noise

The calculation of the desired variables for the missile are the same as for the aircraft except the relative positions are reversed. Another area must be introduced at this point. The missile seeker noise is not just a constant Gaussian noise source. A scaling factor is introduced to increase or decrease the standard deviation, 6, of the guidance error of the missile as a factor of the missile's and aircraft's relative orientation.

First, the radar guided missile noise is assumed to be minimized when the missile is directly in front of or behind its target. As the relative line-of-sight rotates around to the side of the aircraft, the azimuth guidance error is assumed to be the largest. The same phenomenon occurs in the elevation errors. The

point of the largest guidance error due to elevation is assumed to be when the missile is directly above or below the aircraft.

The seeker noise for the infra-red guided missile is modeled in the same way except for the position of maximum guidance error. The position of maximum noise is assumed to be directly in front of the missile's target, while the minimum noise is assumed to be when the missile is directly behind the target. The infra-red guided missile tracks the maximum heat point of the plane following the aircraft. As the relative position rotates from directly in front of the target to the rear, the scale factor decreases, therefore, the guidance error decreases.

It was assumed for this simulation that the missile tracks the plume of the aircraft. Therefore, an additional X-axis guidance error is present and it contributes significantly to the X-guidance error.

The angles used to determine relative position are developed in the description for Subroutine ATTACKF. These angles represent the relationship of the missile to the aircraft. The angles determine the actual presentation the missile seeker attempts to track.

The X-axis guidance error is assumed not to be entirely a result of the relative azimuth angle. As the relative elevation angle increases, the X-axis guidance error also increases. The same is true of the Y and Z guidance errors. Therefore, it is assumed

that elevation and azimuth relative angles effect all three of the guidance errors.

To define the scale factor as a non-dimensional variable, the relative angles are divided by the maximum value that the angle could attain. The scale factor is used to compute the standard deviation of the Gaussian distribution. The Gaussian number generator routine is taken from Gordon (Ref. 3:114-115). The actual guidance error is computed so that the deviation from the previously computed error is small. The noise is a high frequency noise that is integrated out by the missile and, therefore, has little effect on the missile guidance. The actual modeling of the missile and associated noise is beyond the scope of this thesis.

III. Computer Program

Program Evasion

The computer program was not only developed for the accuracy of the simulation but also simplicity, size, and modular construction. This led to reasonable memory requirements, compilation and execution times.

Arrays are used for initial conditions, aircraft and missile data, and all variables derived in each subroutine. This provides for ease of transfer between the main program and subroutines and keeps the program variables simple.

The versatility of the program is extended by use of an integer to denote non-responsive or responsive targets and infra-red (IR) or radar guided missiles. Other type guidance systems could be added without a great deal of change to the basic program.

The main program is a series of calls for subroutines. For each run, the initial conditions and aircraft/missile data routines are called once. Subroutines are called once at the beginning to change all angles/angular rates from degrees to radians.

The subroutines called during each integration step will be discussed separately. In general, these subroutines determine and update the parameters, select the desired maneuvers and control inputs and print the desired outputs at regular intervals. At the completion of each integration step, conditions are compared with

maximum values. A flow chart is depicted in Figure 6.

Data Inputs

Subroutines DATAFTR, DATAMIS, INITFT, and INITMIS read in the respective aircraft and missile data, along with the initial conditions of both vehicles. These four subroutines are called once at the beginning of each run by Program EVASION.

Subroutine ANGLESF/Subroutine ANGLESM

The angle and angular rate conversion subroutines for both vehicles transform the degree inputs into radians by use of the Function DEGZRAD. ANGLESF and ANGLESM are called following the data inputs in EVASION.

Subroutine PRINT

Subroutine PRINT performs three tasks. It calls Subroutines ATTACKF and ATTACKM for the respective vehicles, converts desired output variables from radians to degrees, and prints the desired output variables in the proper format (Ref. 1:73).

The printed output provides for easy comparison between the position, velocities, and orientation of the two vehicles plus the relative position of the missile with respect to the aircraft.

Subroutine PRINT converts the desired program outputs from radians to degrees by use of the Function RADZDEG.

Subroutine PRINT calls the Subroutines ATTACKF and ATTACKM for the respective vehicles. These subroutines will be explained later.

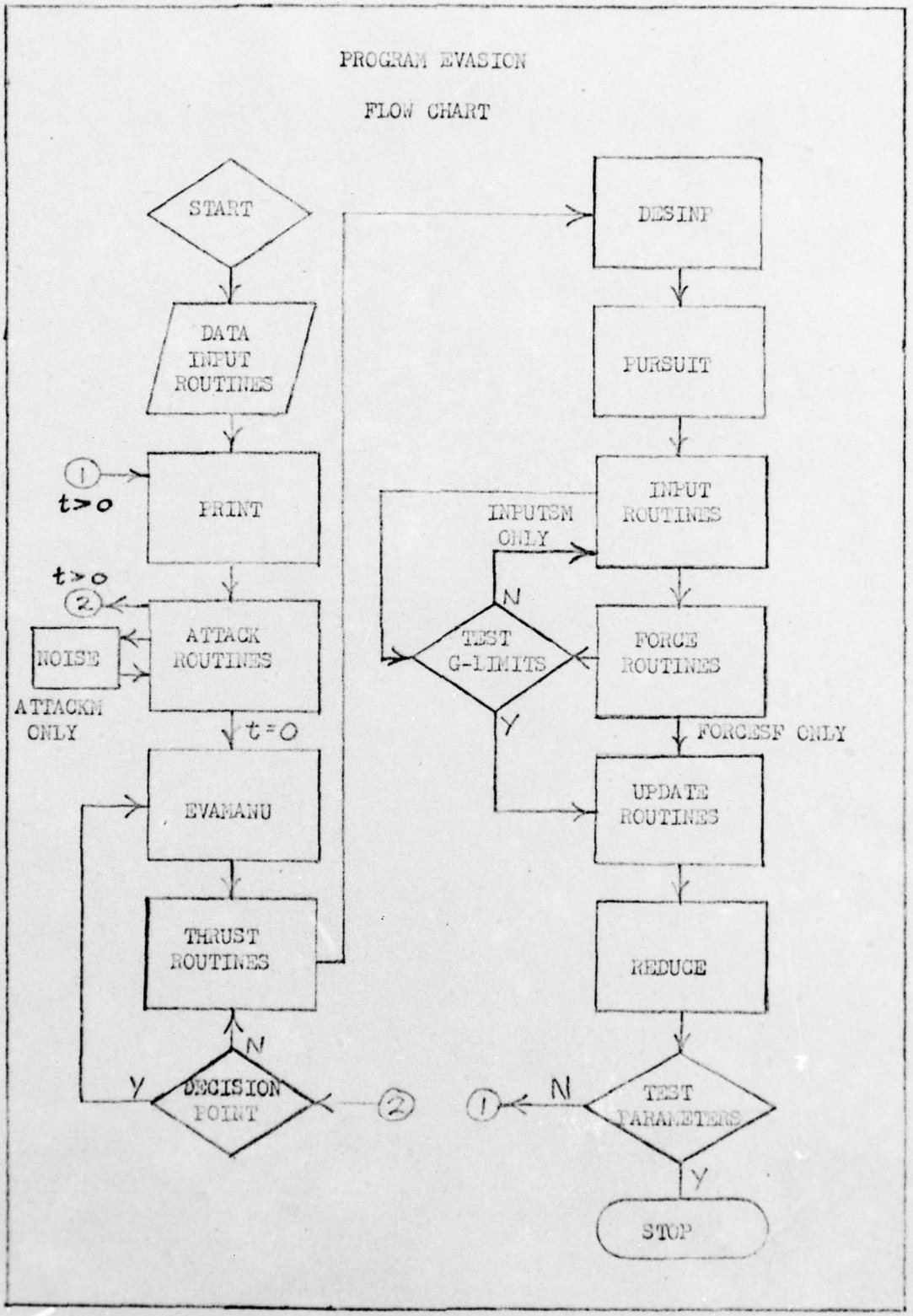

PROGRAM EVASION
FLOW CHART
START
DATA INPUT ROUTINES
1
t>0
PRINT
t>0
2
NOISE
ATTACKM ONLY
ATTACK ROUTINES
t=0
EVAMANU
THRUST ROUTINES
N
Y
DECISION POINT
2
DESINT
PURSUIT
INPUT ROUTINES
INPUTSM ONLY
N
TEST G-LIMITS
Y
FORCE ROUTINES
FORCESF ONLY
UPDATE ROUTINES
REDUCE
N
1
TEST PARAMETERS
Y
STOP

FIGURE 6

Subroutine PRINT is called at three points in the simulation. It is called at time zero to initialize the relative position variables and print out initial conditions. PRINT is called at the completion of each integration, so that the desired outputs will be printed at regular intervals throughout the simulation. At termination, PRINT is called to record the end conditions.

Subroutine ATTACKF/Subroutine ATTACKM

Subroutines ATTACKF and ATTACKM determine the relative position and velocity components of the opposing vehicle in its own navigational frame. These components are then transformed into the respective vehicle's body fixed frame.

The relative angles are computed during each integration upon which the desired maneuvers are selected.

Subroutines ATTACKF and ATTACKM are called in Subroutine PRINT. ATTACKM calls the two seeker noise subroutines, IRNOS and RADNOS, which will be discussed later.

Subroutine PILOT

The maneuvering target must react like a human pilot. It will, therefore, be less than perfect in its judgement and estimation of range. By use of a random number generator, a range judgement error is introduced. The judgement error allows for variation in the pilot's ability to estimate range.

There are two decision points in the simulation; 6000 and 1000 feet are the ranges at which new maneuvers are selected. The range

errors are bounded by specific values which are determined from flying experience. If better values are available, they should be included. At the 6000 feet point, the range errors have a uniform distribution $\pm$ 1000 feet, while at the 1000 feet point, the distribution is within $\pm$ 500 feet. In turn, this range judgement error changes the execution point of the desired maneuvers. The ranges are then used as parameters in Subroutine EVAMANU to select the desired maneuver.

This subroutine is an over-simplification of the judgement of a human pilot but it does provide for a variation in pilot skill. All levels of skill are present in every flying unit.

PILOT is called at the beginning of each run in Program EVASION.

Subroutine EVAMANU

Maneuvers against a launched air-to-air missile must be simple in execution. Generally, the defense against a missile fired in the aft quarter is a maximum turn rate "break" turn into the plane of the missile. As the missile closes to approximately 1000 feet, a rapid roll out of the plane is initiated. Obviously, because of closure rates, the timing of this last portion is very subjective.

The attempt is to initially generate maximum line-of-sight rate for the missile and then to further complicate plane corrections during end game maneuvering. This defense works well against rear hemisphere missiles launched near the heart of the firing envelope.

Long range firings provide another problem. A hard turn into the missile only supplies closure so that the missile is not required to fly a pursuit type curve. Therefore, a hard turning target is hit from the front quarter rather than the tail.

There are two options available against long-range missile firings:

1. Hard turn away to put the aircraft outside maximum range.

2. Turn away enough to force the missile into a "tail chase" and then break hard into it at 6000 feet, hopefully causing an overshoot.

Head-on or beam shots are best handled by a hard pulling turn to put the aircraft outside of range. However, if the pilot does not want to lose sight of the missile, a hard turn away should be initiated to force the missile into a pursuit type curve and proceed with an overshoot.

At any time, breaking downward at high calibrated airspeeds to lower altitudes not only shrinks the missile envelope, but also increases background noise and clutter.

Early turns into radar guided missiles do not help. These turns just present a larger radar return and do not affect the maneuvering required by the missile.

Near the maximum firing range, the aircraft should extend away from infra-red guided missiles. This is extremely hard to judge and the normal response for IR missiles is to turn into the

missile and increase angle off, φ_{off}, the tail to either put it outside source limits or to increase tracking and maneuvering difficulty.

Infra-red guided missiles are very fast and maneuverable. The best way to counter launches from within the heart of the firing envelope is to have the break be in the plane of the attacking aircraft's wings at launch. This turn can be increased to a break after launch, making the initial turn in the plane of the missile.

Subroutine EVAMANU is called in Program EVASION normally one to three times depending on the initial range between missile and aircraft. EVAMANU is called at the 6000 and 1000 feet decision points as well as at the initial point of the simulation.

Subroutine THRUSTF/Subroutine THRUSTM

Subroutines THRUSTF and THRUSTM normally compute the thrust of the respective vehicles by use of Subroutines ATMOS and TBLNOC (Ref. 5). Maximum, Military, and Idle thrust are determined as well as the present thrust of the aircraft. In both thrust subroutines, the total velocity, mach number, and dynamic pressure of each vehicle are determined. The missile is considered a constant thrust and velocity vehicle for the test runs of the simulation. For actual missile testing, THRUSTM would be used to compute the thrust of the missile.

THRUSTF and THRUSTM are called in Program EVASION during each integration.

Subroutine DESINP

Subroutine DESINP provides the desired control inputs for the selected maneuvers from EVAMANU. The inputs are updated during each integration. The control inputs are angle of attack, sideslip angle, angle of bank, and desired thrust. These control inputs correspond to elevator, rudder, aileron, and throttle control (Ref. 4:103-104).

Program EVASION calls Subroutine DESINP during each integration.

Subroutine PURSUIT

Subroutine PURSUIT provides the control inputs for the missile in the same manner as DESINP did for the aircraft. PURSUIT provides the desired heading and pitch for the missile.

If, at any time, the missile goes ballistic, PURSUIT includes a test condition to return to the main program. Therefore, the desired inputs remain the same.

PURSUIT is called during each integration by Program EVASION.

Subroutine INPUTSF/Subroutine INPUTSM

Finite control rates are supplied to the simulation by Subroutines INPUTSF and INPUTSM to their respective vehicles. These instantaneous control rates are required to make the simulation realistic. The control rates are functions of the control errors. In INPUTSF, angle of attack, back angle, sideslip, and thrust are computed. The pitch and heading

angles of the missile are determined in INPUTSM.

Using angle of attack (α) as an example, the error is determined between the desired angle of attack (α_D) and the actual α of the aircraft.

$$\text{ERROR } \alpha = \alpha_D - \alpha \tag{23}$$

The actual control inputs are determined for the simulation by use of the following limits:

$$\frac{\text{ERROR } \alpha}{(\Delta t)} \quad \dot{\alpha} = P_1 \dot{\alpha}_{MAX} \left(\frac{\text{ERROR } \alpha}{P_2 \dot{\alpha}_{MAX}(\Delta t)} \right) \leq P_1 \dot{\alpha}_{MAX} \tag{24}$$

where:

$\dot{\alpha}$ - rate of change of angle of attack

$P_{1,2}$ - guidance parameters for aircraft

$\dot{\alpha}_{MAX}$ - max rate of change of angle of attack

Δt - integration interval

After $\dot{\alpha}$ was determined, the new α for the aircraft is computed:

$$\alpha = \alpha_{OLD} = (\text{SIGN ERROR } \alpha)\, \dot{\alpha}\, (\Delta t) \tag{25}$$

The relation of control rates to control error are illustrated in Figure 7 (Ref. 4:93).

The finite control inputs can be by-passed if the error is zero. Again using angle of attack as an example, the relationship becomes:

$\alpha = \alpha_D$ (Ref. 4:94).

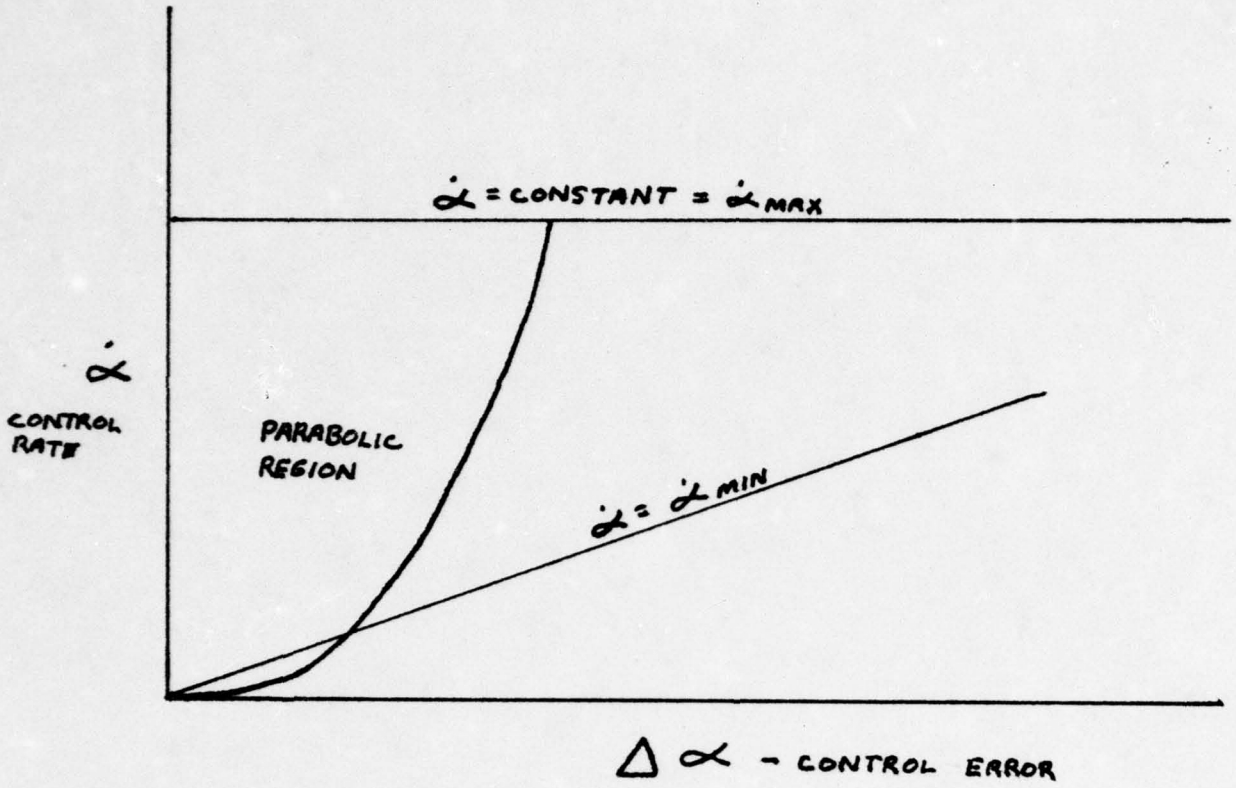


Figure 7 Control Rate Model

(Ref. 4:94)

INPUTSF and INPUTSM are called in Program EVASION during each integration. INPUTSM is also called in FORCESM if either the vertical or hotizontal g forces exceed the maximum for the missile. This call provides for a recomputing of the pitch and heading angles. Reduced angular rates are supplied by FORCESM which maintain the g forces within limits.

Subroutine FORCESF/Subroutine FORCESM

Subroutines FORCESF and FORCESM determine the forces and moments acting on the respective vehicles. By use of Function TBLNDC, the coefficients and derivatives are determined in FORCESF for the aircraft. The total coefficients were computed and the total forces and moments are then determined.

Other parameters defined in FORCESF are the pitch, bank, and sideslip angles in the wind coordinate frame.

In FORCESM, only the vertical and horizontal g forces are computed. This is due to the very simple missile supplied to the simulation. In actual tests, FORCESM should be expanded to the same extent as FORCESF.

FORCESF and FORCESM are called during each integration in Program EVASION. FORCESM calls INPUTSM if either the horizontal or vertical g forces are exceeded. There is further discussion in Appendix D and Section INPUTSM

Subroutine UPDATEF/Subroutine UPDATEM

The actual integration is accomplished by use of Subroutines RKDESF and RKDESM. The deferential equations are supplied to the RKDESF and RKDESM routines by subroutines F and M respectively.

UPDATEF and UPDATEM calls RKDESF and RKDESM respectively during each integration. Program EVASION calls UPDATEF and UPDATEM during each integration.

Subroutine IRNOS/Subroutine RADNOS

Subroutines IRNOS and RADNOS are routines that determined the guidance error for infra-red and radar guided missiles. The basic Gaussian random generator is modified by a scaling factor that changes the dispersion of the noise as a function of the relative orientation between the missile and the aircraft. The scaling factor is combined with the standard deviation to produce a corrected value as a function of the relative orientation. The missile aim point deviation is computed in the standard manner. Further discussion of the methodology in the noise routines is in the section "Missile Seeker Noise" in Chapter II.

IRNOS and RADNOS are called by ATTACKM according to the type missile being simulated. It is called during each integration.

Subroutine REDUCE

Subroutine REDUCE is a simple program to reduce the time rate of change of the range between the two vehicles. When the range covered during one integration interval is equal to or less than the range between the two vehicles, the integration time interval is reduced so

that the range covered in one integration interval is less than one foot. This procedure is a simple means of providing accuracy of less than one foot during the termination phase. REDUCE is called in the Program EVASION.

Miscellaneous Subroutines and Function Subprograms

The previously discussed programs and subroutines are the main solution to the simulation problem. There were several functions and subroutines developed to perform specific calculations or transformations. In addition, two subroutines and a function subprogram are used from the Air Force Institute of Technology (AFIT) Subroutines Library (Ref. 5).

Function TBLNOC

This function is from the AFIT Subroutines Library. It is an n-dimensional table look-up function that is used in THRUSTF and FORCESF for aerodynamic coefficients and thrust parameters. Aerodynamic coefficients are stored as a function of angle of attack and Mach Number. Thrust parameters are stored as a function of Mach number. TBLNDC is from the AFIT Subroutines Library (Ref. 5) and is furnished in Appendix A.

Subroutines RKDESF and RKDESM

These subroutines are taken from the AFIT Subroutines Library. RKDESF and RKDESM are fourth order Runga-Kutta differential equation solvers for the respective vehicle. The subroutines RKDESF

and RKDESM are called in the respective UPDATEF and UPDATEM subroutines (Ref. 5). and is furnished in Appendix A. The differential equations are supplied by subroutines F and M for the respective integration routines.

Subroutine ATMOS

This subroutine is taken from the AFIT Subroutines Library. ATMOS is a tabulation of the 1959 ARDC atmospheric tables. The atmospheric parameters are determined as a function of altitude by linear interpolation. From ATMOS, the speed of sound, the density, and the density ratio are used to calculate many variables in the simulation. ATMOS is called in THRUSTF, THRUSTM and INITMIS (Ref. 5) and is supplied in Appendix A.

Subroutines F and M

These subroutines are called by RKDESF and RKDESM respectively. They contain the differential equations of motion to be solved by RKDESF and RKDESM.

Subroutine TRANN2B

Euler angle transformation equations are used in TRANN2B to change a vector from the vehicle's navigation frame into the vehicle's body frame (Ref. 2:116-117).

Subroutine TRANB2W

By use of the angle of attack and sideslip angles, TRANB2W transforms a vector from the vehicle's body fixed frame into the

vehicle's wind fixed frame (Ref. 2:116-117).

Function DEG2RAD

The angles and angular rates are normally inputed as degrees. DEG2RAD transforms degrees into radians.

Function RAD2DEG

For convenience, the angles/angular rates are printed in degrees. After computations, RAD2DEG transforms radians into degrees.

Others

The general utility functions are taken from the FORTRAN Extended Library (Ref. 6:8.1-8.12). They include:

1) Intrinsic Functions - IFIX, SIGN AMAX 1, AMIN 1, ABS, MOD

2) Basic External Function - SIN, COS, SQRT, ACOS, ASIN

3) Utility Subprograms - EOF, RANP

IV. Aircraft Model

Validation

Validation of the aircraft simulation model was accomplished in basically two ways. The flying experience of the author was used as well as the Technical Order of the F-4C (Ref. 8).

After the complete aircraft model was developed, the simulation was accomplished with a missile with zero closure rate to validate all of the programmed aircraft maneuvers. Using the author's flying experience, the performance of the aircraft was determined to be consistent with present day fighter aircraft.

The simulated performance was compared to published performance data in the F-4C Technical Order (Ref. 8:A9-94, 95). Performance parameters used were rate of turn, angle of bank, and radius of turn as a function of altitude and Mach number. Comparison was very favorable. Deviations were a result of simplification of the total aerodynamic coefficient computations in FORCESF. For comparison, Table I displays some test and technical order results.

The decision logic of the aircraft required validation. During the zero closure rate missile simulations, the maneuver selection and aircraft reaction and maneuvering were compared to tactical flying manuals and the author's combat flying experience. The aircraft performed as if controlled by an average fighter pilot.

Table I

Model versus Aircraft Performance

	Rate of Turn (Deg/Sec)	Acceleration (min)	Dive Recovery (feet)	Time to Climb (min)
Aircraft Model	4.2	1.2	7500	.8
F-4 Specifications	4.3	1.0	7000	.6
Parameters	Altitude - 20000 ft Mach - 1.0 Bank - 70 deg.	Max Power Altitude - 20000 ft Initial Mach - .8 Final Mach - .9	Mach - 1.0 Initial Alt - 20000 Dive Angle-60 Deg	Initial Alt - 10000 Final Alt - 20000 Mach - .9 Mach Power

Initial Conditions

The initial conditions of the aircraft consist of:

1. Position coordinates (x_F, y_F, z_F)
2. Velocity components (u_F, v_F, w_F)
3. Orientation angles (heading, bank, flight path)
4. Angular velocity components (p, q, r)

   p - about X_B axis

   q - about Y_B axis

   r - about Z_B axis

The initial conditions 1 and 2 are in the earth surface fixed reference frame. Number 3 is in the aircraft body fixed reference frame.

The initial conditions are used in the first integration for maneuver selection and computations.

Aircraft Characteristics

The characteristics of the aircraft are required to determine the coefficients for the equations of motions. The aircraft chosen to be simulated was basically the F-4C. The actual aerodynamic coefficient equations and stability derivatives used in FORCESM are in Appendix C. The aerodynamic coefficients consist of the basic coefficients and stability derivatives. They were compiled as functions of the Mach Number and angle of attack. The thrust parameters were compiled as a function of Mach Number alone (Ref. 9).

Equations of Motion

The differential equations of motions used in the simulation are taken from ETKIN (Ref. 2:149-150). These equations were derived with the following assumptions:

1. Rigid body
2. Plane of symmetry in combined wind and body axes.
3. Flat earth
4. Constant mass
5. Constant gravity acceleration
6. Atmosphere is at rest relative to the earth.
7. Centripetal acceleration associated with earth rotation is neglected.

The differential equations of motion of the maneuvering target are:

$$\dot{v} = \frac{1}{m}(T_{XW} - D - mg \sin \theta w) \qquad (26)$$

$$\dot{p} = \frac{1}{I_{XX}} [L - I_{XZ} (\dot{r} + pq) + (I_{YY} - I_{ZZ}) qr] \qquad (27)$$

$$\dot{q} = \frac{1}{I_{YY}} [M - I_{XZ} (r^2 - p^2) + (I_{ZZ} - I_{XX}) rp] \qquad (28)$$

$$\dot{r} = \frac{1}{I_{ZZ}} [N + I_{XZ} (\dot{p} - qr) + (I_{XX} - I_{YY}) pq] \qquad (29)$$

$$\dot{\theta}w = qw \cos \varphi w - rw \sin \varphi w \qquad (30)$$

$$\dot{\Psi}w = (qw \sin \varphi w + rw \cos \varphi w) \sec \theta w \qquad (31)$$

$$\dot{X}_E = V \cos \theta w \cos \psi w \qquad (32)$$

$$\dot{Y}_E = V \cos \theta w \sin \psi w \tag{33}$$

$$\dot{Z}_E = -V \sin \psi w \tag{34}$$

The equations for $\dot{\varphi} w$, $\dot{\alpha}$, $\dot{\beta}$, (Ref. 2:150) are not used in Subroutine F. The finite control inputs φw, α, β, are developed in Subroutine INPUTSF.

Integration of equation 26 produces the force equation in the x direction. The force equations for the y and z directions are not differential equations. Forces in the y and z direction are computed in FORCESF.

$$F_Y = T_{YW} - \text{Sideforce} - mg \cos \theta_W \sin \varphi_W \tag{35}$$

$$F_Z = T_{ZW} - \text{Lift} + mg \cos \theta_W \cos \varphi_W \tag{36}$$

V Results

Five test combat battles were simulated from different initial conditions of the missile, different airspeeds of the aircraft, different types of missiles and aircraft. In addition, production runs were accomplished by repeating the same battle twenty times from the same initial conditions, type missile and aircraft.

The aircraft started at the same point in each battle; $x = 0$, $y = 0$, $z = -20000$. The velocity of the aircraft increased by 100 feet per second for each battle. The first aircraft had an initial velocity of 700 feet per second. All angles and angular rates are zero including heading which was north.

The two types of missiles, infra-red and radar guided, were simulated. Each type was directed once against a non-responsive aircraft for initial testing. The other three battles were from three different ppsitions to further test the aircraft simulation.

The initial conditions of the missile and aircraft are listed in Table II. Aircraft 3 and 4 were used with missile 3, which was positioned in front and behind respectively, for the production runs. Actual test numbers and results are listed in Appendix B.

Battle 1 and 2

The first two missiles were flown against non-responsive aircraft. Both type missiles scored hits on the target. The guidance errors were small due to the small angle off in azimuth and zero

Table II

Test Run Initial Conditions

Test Number		1	2	3	4	5
A/C type		non-responsive	non-responsive	responsive	responsive	responsive
Position (feet)		X and Y position are zero for all. Z is -20000 feet altitude for all.				
Velocity (feet/sec)	u	700	800	900	1000	1100
		v and w velocities are zero for all.				
Orientation angles (Deg.)		Ψ, θ, φ are zero for all.				
Angular body rates (Deg/sec)		p, q and r are zero for all.				
Missile type		IR	RADAR	RADAR	IR	RADAR
Position (feet)	x	-5196	-5196	10392	-6000	-6000
	y	-3000	3000	6000	-6000	-6000
	z	-20000	-20000	-20000	-14000	-14000
Velocity (feet/sec)	u	2694	2694	-2694	1838	1838
	v	1555	-1555	-1555	1838	-1838
	w	0	0	0	-1838	-1838
Orientation angles (Deg)	Ψ	30	330	210	45	315
	θ	0	0	0	35	35
Angular rates (Deg/sec)	$\dot{\Psi}$ and $\dot{\theta}$ are zero for all.					
Results		HIT	HIT	MISS	MISS	HIT

elevation angle. During actual missile testing this type of run would be used to calibrate and initially test missile systems and simulation.

Battle 3

The radar guided missile was positioned for a 30 degrees off forward pass. The aircraft was a responsive target. Because the range was greater than 6000 feet and the missile was in front of the aircraft, selected a SPLIT S as the first maneuver.

At the 6000 feet range point, EVAMANU updated the maneuver selection to a HARD BREAK so as to force the missile into a aft quarter attack. The turn was then reversed to attempt to force the missile into an overshoot.

A VERTICLE DIVE FOLLOWED BY A HARD PULL UP was selected at the 1000 feet point by EVAMANU. The aircraft was successful in evading the missile. The guidance was again minimal due to zero elevation angle and a small angle off in azimuth. The results are shown in Figure 8.

Battle 4

The infra-red guided missile was flown against a responsive target. The missile was positioned below, behind, and to the left of the aircraft. For this situation, EVAMANU selected a VERTICLE DIVE away from the missile due to the range being greater than 6000 feet.

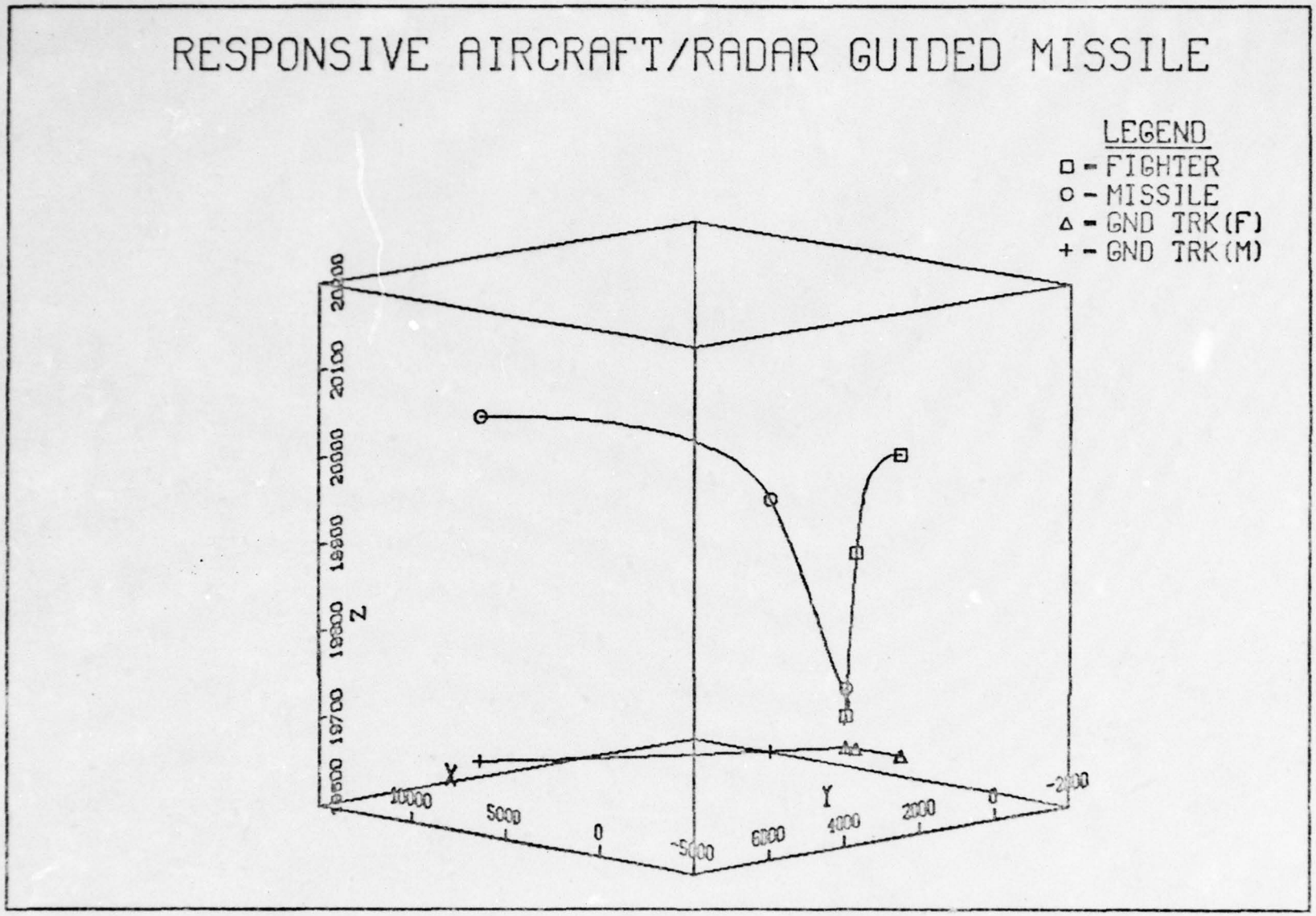

RESPONSIVE AIRCRAFT/RADAR GUIDED MISSILE
LEGEND
□ - FIGHTER
○ - MISSILE
△ - GND TRK(F)
+ - GND TRK(M)
Z
20000
20100
19900
19700
X
10000
5000
0
Y
6000
4000
2000
0

Figure 8

At the 6000 feet decision point, EVAMANU changed the maneuver to a HARD BREAK into the missile. The aircraft attempted to cause an overshoot by trying a SPLIT S at the 1000 feet range point.

The aircraft was successful in evading the missile. The guidance error was relatively large due to large elevation and azimuth angles. The results are plotted in Figure 9.

Battle 5

The radar guided missile was directed against a responsive target. The range was greater than 6000 feet. The missile was below, behind, and to the right of the aircraft. EVAMANU selected a VERTICLE DIVE away from the missile.

EVAMANU updated the selected maneuver at the 6000 feet point to a HARD BREAK into the missile. The break continued until overshoot or 1000 feet range, whichever came first. EVAMANU selected a SPLIT S at the 1000 feet range point. The maneuver was continued until the missile scored a hit. As in battle 4, the guidance error was relatively large for the same reasons. The results are shown in Figure 10.

Statistical Characteristics

Twenty consecutive runs were made from the same initial conditions to test the stocastic properties of the guidance errors and pilot judgement errors developed in the program. The initial conditions are

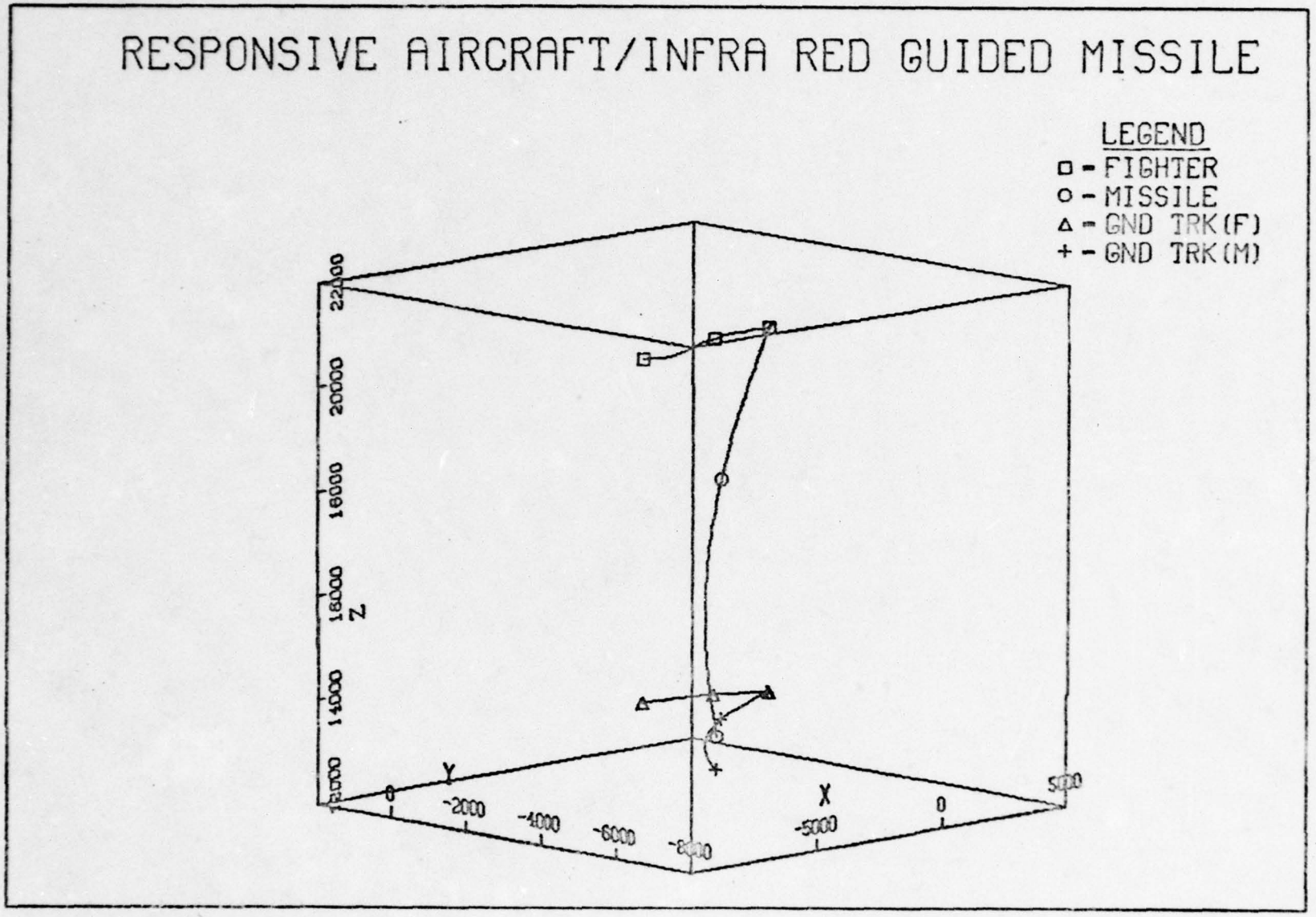

RESPONSIVE AIRCRAFT/INFRA RED GUIDED MISSILE
LEGEND
□ - FIGHTER
○ - MISSILE
△ - GND TRK(F)
+ - GND TRK(M)
Z
22000
20000
18000
16000
14000
12000
Y
0
-2000
-4000
-6000
-8000
X
-5000
0
5000

Figure 9

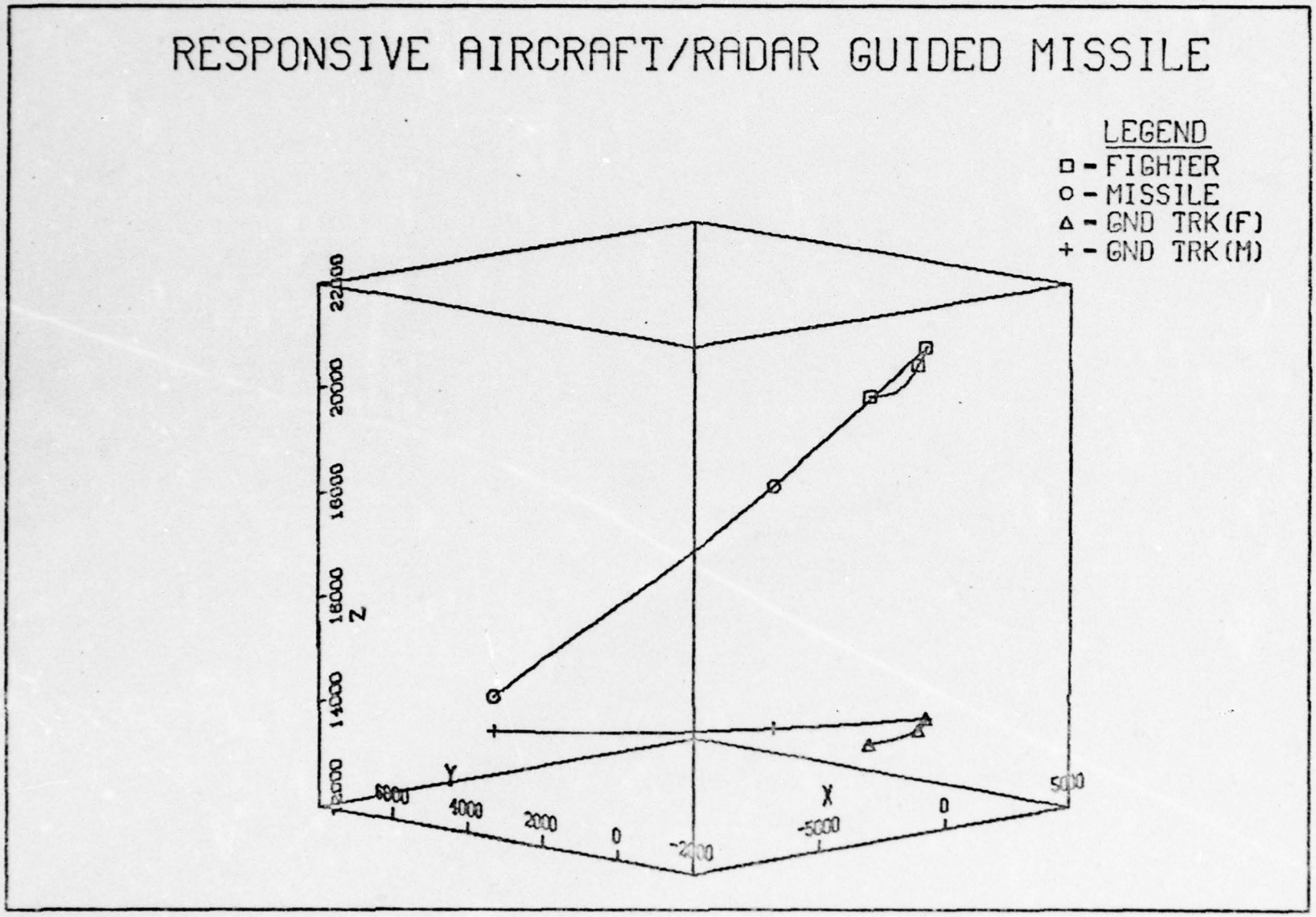

RESPONSIVE AIRCRAFT/RADAR GUIDED MISSILE
LEGEND
□ - FIGHTER
○ - MISSILE
△ - GND TRK(F)
+ - GND TRK(M)
Z
22000
20000
18000
16000
14000
12000
Y
6000
4000
2000
0
-2000
X
-5000
0
5000

Figure 10

from the aircraft in tests three and four. The missile's initial conditions are those of missiles from test battles one and three. The conditions are listed in Table II.

Using the infra-red guided missile from the battle one and aircraft from test four, the resulting statistics are recorded in Table III. The results of the missile and aircraft of battle three are recorded in Table IV.

Table III-1

The statistics of the following parameter are the results of twenty production runs from the same initial conditions.

Decision Point 1 Range (feet):

Mean=	5999.90	Standard Deviation=	629.20
Minimum=	5025.00	Maximum=	6950.00
Median=	6210.00		

Decision Point 1 Time (Seconds):

Mean=	.90	Standard Deviation=	.29
Minimum=	.47	Maximum=	1.35
Median=	.81		

Table III-2

The statistics of the following parameter are the results of twenty production runs from the same initial conditions.

Decision Point 2 Range (feet):

Mean=	1150.90	Standard Deviation=	274.39
Minimum=	592.00	Maximum=	1453.00
Median=	1284.50		

Decision Point 2 Time (seconds):

Mean=	3.14	Standard Deviation=	.15
Minimum=	2.98	Maximum=	3.50
Median=	3.10		

Table III-3

The statistics of the following parameter are the results of twenty production runs from the same initial conditions.

Time to go from decision point 1(seconds)

Mean=	2.74	Standard Deviation=	.27
Minimum=	2.31	Maximum=	3.13
Median=	2.85		

Time to go from decision point 2(seconds)

Mean=	.50	Standard Deviation=	.15
Minimum=	.16	Maximum=	.67
Median=	.55		

Table III-4

Termination Time (seconds)	Time To Go From Point 1 (seconds)	Time To Go From Point 2 (seconds)
3.61	3.04	.63
3.64	2.94	.27
3.65	2.85	.38
3.60	3.13	.59
3.66	2.33	.16
3.65	2.84	.63
3.63	2.98	.64
3.66	2.36	.53
3.66	2.31	.66
3.64	2.92	.65
3.61	3.09	.37
3.67	2.65	.31
3.66	2.34	.67
3.63	2.94	.61
3.67	2.56	.47
3.67	2.54	.60
3.64	2.89	.57
3.66	2.50	.42
3.67	2.65	.45
3.62	3.00	.40

Table IV-1

The statistics of the following parameter are the results of twenty production runs from the same initial conditions.

Decision Point 1 Range (feet):

Mean=	5952.70	Standard Deviation=	668.68
Minimum=	5011.00	Maximum=	6956.00
Median=	5700.00		

Decision Point 1 Time (seconds):

Mean=	1.56	Standard Deviation=	.17
Minimum=	1.30	Maximum=	1.81
Median=	1.63		

Table IV-2

The statistics of the following parameter are the results of twenty production runs from the same initial conditions.

Decision Point 2 Range (feet):

Mean=	937.30	Standard Deviation=	297.62
Minimum=	500.00	Maximum=	1427.00
Median=	963.50		

Decision Point 2 Time (seconds):

Mean=	2.87	Standard Deviation=	.08
Minimum=	2.74	Maximum=	3.00
Median=	2.86		

Table IV-3

The statistics of the following parameter are the results of twenty production runs from the same initial conditions.

Time to go from decision point 1(seconds):

Mean=	1.56	Standard Deviation=	.18
Minimum=	1.30	Maximum=	1.82
Median=	1.49		

Time to go from decision point 2(seconds):

Mean=	.25	Standard Deviation=	.08
Minimum=	.12	Maximum=	.38
Median=	.26		

Table IV-4

Termination Time (seconds)	Time To Go From Point 1 (seconds)	Time To Go From Point 2 (seconds)
3.12	1.76	.38
3.12	1.57	.25
3.12	1.71	.29
3.12	1.68	.14
3.12	1.79	.13
3.12	1.81	.36
3.11	1.40	.13
3.11	1.32	.29
3.12	1.82	.24
3.11	1.35	.16
3.11	1.47	.14
3.12	1.75	.25
3.11	1.30	.23
3.12	1.74	.12
3.11	1.37	.32
3.11	1.47	.29
3.11	1.40	.33
3.11	1.48	.26
3.12	1.50	.27
3.11	1.41	.35

VI. Conclusions and Recommendations

Conclusions

The objectives of the simulation were listed earlier. All objectives were accomplished to varying degrees. Subroutine PRINT produced the results of interest.

The first objective was good aircraft performance. The simulated performance of the aircraft in the selected maneuvers compares well with the actual aircraft performance as determined from the author's flying experience and the F-4C Technical Order. This was a major objective of the simulation.

A second objective was to incorporate pilot judgement into the simulation. As the printed results indicate, the selected maneuvers were initiated at various ranges producing the simulated judgement error of the human pilot. The results indicate that the range at which the pilot executes a maneuver has a strong effect on the success of the missile attack.

The program has the ability to select the desired maneuver at predetermined decision points in the air-to-air combat simulation. The new maneuvers are selected at the ranges determined by the pilot judgement subroutine. The inputs for these maneuvers were updated during each integration interval. The inputs are equivalent to the pilot control inputs to the ailerons, elevators, and rudders. In addition,

the aircraft has the ability to maneuver or fly straight and level Therefore, the third objective was met.

The aircraft model has provisions to incorporate most maneuvers applicable to air-to-air combat. The maneuvers selected for the program are taken from the latest tactical flying manuals and information from the staff of the TFWC.

Recommendations

Further development of complete aerodynamic coefficient equations will more completely simulate the performance of the aircraft. An aeronautical engineer with flying experience in fighter type aircraft should develop a more complete model to produce an authentic maneuvering target.

The maneuvers must be continually changed and updated so that a true test can be made of missile guidance. The latest tactical manuals and the staff of TFWC are the best sources to update the program maneuvers.

All the missile routines must be developed for complete combat simulation. The routines are available in the present program but include only a very basic missile model used just to test the target simulation.

The development of the missile model and missile noise is beyond the scope of this thesis. The missile seeker noise programs

are elementary attempts at modeling noise as a function of relative position. Further study in this area may provide a more realistic simulation.

Bibliography

1. Barrett, Robert P. Development of a Responsive Target for Tracking Tasks in the Dynamic Enviornmental Simulator, Wright-Patterson AFB, Ohio, Air Force Institute Technology, June 1973. Ad-769925/9GA.

2. Etkin, Benard. Dynamics of Atmospheric Flight, New York, New York: John Wiley & Sons, Inc., 1972.

3. Gordon, Geoffrey. System Simulation, Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1969.

4. Hague, D. S., et al. "Combat Optimization and Analysis Program -- COAP." Air-to-Air Combat Analysis and Simulation Symposium. Volumes I-IV. AFFDL-TR-71-52. Wright-Patterson AFB, Ohio: Air Force Flight Dynamics Laboratory, August 1971.

5. ----. Digital Computation Handbook of Available Subroutines for the Control Data 6600 Computer Systems. ASD/VNC Internal Memo 70-003. Wright-Patterson AFB, Ohio: Aeronautical Systems Division, 15 December 1970.

6. ----. Fortram Extended Version 4 Reference Manual. Control Data Corporation, Sunnyvale, California, 1975.

7. ----. Tactical Fighter Weapon Employment. AFM 3-1. DAF, 1970. (SECRET)

8. ----. U.S.A.F. Series F-4C, F-4D and F-4E Aircraft. Technical Order 1F-4C-1, DAF, 15 July 1969, Change 13, 15 August 1973.

9. ----. Aircraft Propulsion Data Book. New York, New York: General Electric Company, 1957.

Appendix A

Fortran Computer Program Listing

```
      PROGRAM EVASION(INPUT=/80,OUTPUT,TAPE1,TAPE2,TAPE3)                    000100
      DIMENSION AC(15),DM(5),DATAFT(13),DATAM(16),DINF(4),RANG(2)            000110
     +,AFT(15),AM(8),FORF(13),FORM(3),ATF(19),TF(7),TM(2),ABF(5),DINM(       000120
     +2),ABM(6),ATM(19),XF(100),YF(100),ZF(100),XM(100),YM(100),ZM(100)      000130
*************************************************************************** 000140
*  THIS PROGRAM SIMULATES THE LATEST FIGHTER EVASION MANEUVERS AGAINST A*     000150
*  LAUNCHED AIR-TO-AIR MISSILE.                                         *     000160
*  ARRAY EQUIVALENCES ARE:                                              *     000170
*   DATAFT          DATAM          FORF              FORM              *     000180
*  (FIGHTER)      (MISSILE)     (FIGHTER)        (MISSILE)             *     000190
*    1 X POSITION    1            1  X FORCES      1 VELOCITY          *     000200
*    2 Y POSITION    2            2  Y FORCES      2 VERTICAL G FORCE  *     000210
*    3 Z POSITION    3            3  Z FORCES      3 HORIZONTAL G FORCE*     000220
*    4 X VELOCITY    4            4  X MOMENT                         *     000230
*    5 Y VELOCITY    5            5  Y MOMENT                         *     000240
*    6 Z VELOCITY    6            6  Z MOMENT                         *     000250
*    7   BANK                     7  YAW RATE                         *     000260
*    8   PITCH       7            8  PITCH RATE                       *     000270
*    9   HEADING     8            9  ROLL RATE                        *     000280
*   10  YAW RATE     9           10  MASS                             *     000290
*   11  PITCH RATE  10           11  BANK                             *     000300
*                                    (WIND AXIS)                      *     000310
*   12  ROLL RATE                12  PITCH                            *     000320
*                                    (WIND AXIS)                      *     000330
*         TEST      11-15        13  HEADING                          *     000340
*       CONDITION                    (WIND AXIS)                      *     000350
*                                                                     *     000360
*             VEHICLE DATA                      ANGULAR DATA          *     000370
*  AC(FIGHTER)          DM(MISSILE)       AFT(FIGHTER)    AM(MISSILE) *     000380
*    1 WEIGHT             1 PSI MAX         1 ALPHA THRUST  1 PSI MAX  *     000390
*    2 WING AREA          2 THETA MAX       2 BETA THRUST   2 THETA MAX*     000400
*    3 WING SPAN          3 PSI DOT MAX     3 ALPHA         3 PSI DOT MAX*   000410
*    4 MEAN CHORD         4 THETA DOT MAX   4 BETA          4 THETA DOT*     000420
*                           (DEGREE)*                        MAX(RADIAN)*    000430
*    5 THRUST DOT MAX     5 TIME CONSTANT   5 HEADING       5          *     000440
*    6 PHI DOT MAX        6 GMAX            6 PITCH         6          *     000450
```

```
*    7 ALPHA MAX                          7  YAW RATE       7              *000460
*    8 BETA MAX                           8  PITCH RATE     8              *000470
*    9 ALPHA DOT MAX                      9  ROLL RATE                     *000480
*   10 BETA DOT MAX                      10  BANK                         *000490
*   11 I-XX                              11  ALPHA MAX                     *000500
*   12 I-YY                              12  BETA MAX                      *000510
*   13 I-ZZ                              13  ALPHA DOT MAX1                *000520
*   14 I-XZ                              14  BETA DOT MAX                  *000530
*   15 G MAX                             15  PHI DOT MAX                   *000540
*                                        16  ALPHA DOT                     *000550
*                                                                          *000560
* RELATIVE VECTORS IN BODY FRAME      THRUST AND ATMOSPHERIC DATA          *000570
*  ABF(FIGHTER) AND ABM(MISSILE)      TF(FIGHTER)          TM(MISSILE)     *000580
*    1  X POSITION                      1 ACTUAL THRUST                   *000590
*    2  Y POSITION                      2 MILITARY THRUST                 *000600
*    3  Z POSITION                      3 IDLE THRUST                     *000610
*    4  X VELOCITY                      4 MAXIMUM THRUST                  *000620
*    5  Y VELOCITY                      5 VELOCITY                        *000630
*    6  Z VELOCITY                      6 MACH NUMBER        1            *000640
*                                       7 DYNAMIC PRESSURE   2            *000650
*                                                                         *000660
*                                                                         *000670
* RELATIVE PARAMETERS                                                    *000680
* ATF(FIGHTER TO MISSILE)                                                *000690
*     AND                                 DESIRED INPUTS                 *000700
* ATM(MISSILE TO FIGHTER)             DINF(FIGHTER)          DINM(MISSILE)*000710
*  1  X POSITION                        1  ANGLE OF ATTACK     1  HEADING*000720
*  2  Y POSITION                        2  SIDE SLIP ANGLE     2  PITCH  *000730
*  3  Z POSITION                        3  ANGLE OF BANK                  *000740
*  4  RANGE                             4  THRUST DESIRED                 *000750
*  5  X VELOCITY                                                          *000760
*  6  Y VELOCITY                                                          *000770
*  7  Z VELOCITY                                                          *000780
*  8  AZIMUTH(POSITIVE RIGHT)          PILOT REACTION RANGE               *000790
*  9  ELEVATION(POSITIVE UP)            1  RANGE BETWEEN                 *000800
* 10  RANGE RATE                           5100 AND 5900                 *000810
```

```
*  11  PSI                                        FEET                                *000320
*  12  THETA                                  2   RANGE BETWEEN                       *000330
*  13  PHI(BODY FRAME)                            1100 AND 900                        *000340
*  14  PSI(BODY FRAME)                            FEET                                *000350
*  15  THETA(BODY FRAME)                                                              *000360
*  16  AZIMUTH RATE                                                                   *000370
*  17  ELEVATION RATE                                                                 *000380
*  18  CONE ANGLE                                                                     *000390
*  19  ANGLE OFF                                                                      *000400
*                                                                                     *000410
*   SUBROUTINES RKDES, TBLNDG, AND ATMOS ARE FROM THE AFITSUBROUTINES LIBRARY,        *000420
*   WRIGHT PATTERSON AFB, OHIO.                                                       *000430
************************************************************************************000440
      DATA PI,G/3.14159,32.17/                                                       000450
      REWIND 1                                                                       000460
      REWIND 2                                                                       000470
100   TIME=0.0                                                                       000480
      DT=.01                                                                         000490
      IN=0                                                                           001000
      LOCK=0                                                                         001010
      INDEX=0                                                                        001020
      K=1                                                                            001030
      READ(1,*) KF                                                                   001040
      IF(EOF(1).NE.0)STOP" END OF DATA 1"                                            001050
      READ(2,*) KM                                                                   001060
      IF(EOF(2).NE.0)STOP" END OF DATA 2"                                            001070
      WRITE(3) KF,KM                                                                 001080
      PRINT*," TYPE OF MISSILE IS:"                                                  001090
      IF(KM.EQ.2)PRINT*," INFRA-RED"                                                 001100
      IF(KM.EQ.3)PRINT*," RADAR GUIDED"                                              001110
      PRINT*                                                                         001120
      PRINT*," TYPE FIGHTER IS:"                                                     001130
      IF(KF.EQ.0) PRINT*," NON-RESPONSIVE"                                           001140
      IF(KF.NE.0) PRINT*," RESPONSIVE"                                               001150
      CALL DATAFTR(AC)                                                               001160
      CALL DATAMIS(DM)                                                               001170
```

```
      CALL INITFT(DATAFT)                                                001180
      CALL INITMIS(DATAM)                                                001190
      CALL ANG_ESF(AC,AFT,DATAFT)                                        001200
      CALL ANGLESM(DM,AM,DATAM)                                          001210
      CALL PRINT(DM,DT,KF,KM,ABM,ATM,INDEX,PI,TIME,AFT,AM,ATF,DATAFT,DAT001220
     +AM,ABF)                                                            001230
      CALL PILOT(ATF,RANG)                                               001240
      GO TO 25                                                           001250
10    INDEX=INDEX+1                                                      001260
      IF(K.EQ.2)GO TO 2                                                  001270
      K=2                                                                001280
20    IF(KF.NE.0)CALL EVAMANJ(TIME,PI,MANUVR,ATF,RANG,DATAFT)            001290
      IF(KF.EQ.0)MANUVR=0                                                001300
      GO TO 2                                                            001310
1     INDEX=INDEX+1                                                      001320
      K=1                                                                001330
2     CALL THRUSTF(INDEX,DATAFT,TF)                                      001340
      CALL THRUSTM(INDEX,DATAM,TM,FORM)                                  001350
      CALL DESINP(TIME,MANUVR,DINF,DATAFT,AC,TF,AFT,ABF,PI,ATF)          001360
      CALL PURSUIT(INDEX,DATAM,DM,ATM,DINM,PI,AM)                        001370
      CALL INPUTSF(DT,AFT,DINF,AC,TF)                                    001380
      CALL INPUTSM(LOCK,PI,ATM,DT,AM,DINM,DM)                            001390
      CALL FORCESF(INDEX,TF,AFT,DT,G,FORF,AC,DATAFT,DINF)                001400
      CALL FORCESM(LOCK,DM,FORM,DATAM,G,ATM,AM)                          001410
      CALL UPDATEF(TF,AFT,FORF,DATAFT,PI,TIME,DT,AC)                     001420
      TIME=TIME-DT                                                       001430
      CALL UPDATEM(DATAM,DT,AM,FORM,TIME)                                001440
      CALL PRINT(DM,DT,KF,KM,ABM,ATM,INDEX,PI,TIME,AFT,AM,ATF,DATAFT,DAT001450
     +AM,ABF)                                                            001460
      IF(DT.EQ..01)CALL REDUCE(PI,INDEX,ATF,DT)                          001470
25    INTER=IFIX(.5000001/DT)                                            001480
      IF(MOD(INDEX,INTER).NE.0)GO TO 105                                 001490
      IN=IN+1                                                            001500
      XF(IN)=DATAFT(1)                                                   001510
      YF(IN)=DATAFT(2)                                                   001520
      ZF(IN)=DATAFT(3)                                                   001530
```

```
      XM(IN)=DATAM(1)                                                   001540
      YM(IN)=DATAM(2)                                                   001550
      ZM(IN)=DATAM(3)                                                   001560
105   IF(TIME.EQ.0.0)GO TO 10                                           001570
******TESTING IN-FLIGHT CONDITIONS AGAINST GIVEN PARAMETERS******       001580
      IF(INDEX.EQ.1)TIMED=ATF(4)/(ABS(ATF(10)))                         001590
      IF(ATF(4).LT.5.0)GO TO 102                                        001600
      IF(ABS(FORM(2)).GE.DM(5))GO TO 103                                001610
41    IF(ABS(FORM(3)).GE.DM(5))GO TO 104                                001620
42    IF(ABS(ATM(18)).GT.AM(1).OR.ABS(ATM(18)).GT.AM(2)) GO TO 107      001630
43    IF(ABS(ATM(8)).GT.AM(1).OR.ABS(ATM(9)).GT.AM(2)) GO TO 108        001640
44    IF(ABS(ATM(16)).GT.AM(3).OR.ABS(ATM(17)).GT.AM(4)) GO TO 109      001650
45    IF(LOCK.EQ.1)GO TO 106                                            001660
46    DO 3 J=11,16                                                      001670
      IF(IFIX(DATAM(J)).GE.1)GO TO 75                                   001680
3     DATAM(J)=0.0                                                      001690
      IF(MOD(INDEX,INTER).EQ.0)PRINT 80                                 001700
80    FORMAT(/4X,* MISSILE PARAMETERS ARE WITHIN LIMITS.*/)             001710
75    IF(ATF(10).GT.0.0)GO TO 101                                       001720
      IF(TIME.GT.3.*TIMED)GO TO 110                                     001730
      IF(ATF(4).LT.RANG(1).AND.ATF(4).GT.(RANG(1)-200.0))GO TO 10       001740
      IF(ATF(4).LT.RANG(2).AND.ATF(4).GT.(RANG(2)-200.0))GO TO 10       001750
      GO TO 1                                                           001760
103   IF(IFIX(DATAM(11)).EQ.1)GO TO 41                                  001770
      PRINT*," MISSILE EXCEEDED MAXIMUM LATERAL G!"                     001780
      PRINT 113,FORM(2),DM(5)                                           001790
113   FORMAT(/4X,* MISSILE PULLED*,F5.2,* LATERAL G'S.*,/4X,* MAXIMUM LA001800
     +TERAL G IS*,F6.2,* */)                                            001810
      DATAM(11)=1.0                                                     001820
      GO TO 41                                                          001830
104   IF(IFIX(DATAM(12)).EQ.2)GO TO 42                                  001840
      PRINT*," MISSILE EXCEEDED MAXIMUM VERTICAL G!"                    001850
      PRINT 114,FORM(3),DM(5)                                           001860
114   FORMAT(/4X,* MISSILE PULLED*,F6.2,* VERTICAL G'S.*,/4X,* MAXIMUM V001870
     +ERTICAL G IS*,F5.2,*.*/)                                          001880
      DATAM(12)=2.0                                                     001890
```

```
      GO TO 42                                                          001300
107   IF(IFIX(DATAM(13)).EQ.3)GO TO 43                                  001310
      PRINT*," TARGET OUTSIDE GIMBAL LIMITS!"                           001320
      PRINT 117,ATM(18),AM(1)                                           001330
117   FORMAT(/+X,* MISSILE'S CONE ANGLE TO THE FIGHTER IS*,F6.2,* DEGREE001340
     +S.*,/4X,* MAXIMUM GIMBAL ANGLE OF THE MISSILE IS*,F5.2,* DEGREES.*001350
     +/)                                                                001360
      DATAM(13)=3.0                                                     001370
      GO TO 43                                                          001380
108   IF(IFIX(DATAM(14)).EQ.4)GO TO 44                                  001390
      PRINT*," TARGET OUTSIDE GIMBAL LIMITS!"                           002000
      PRINT 123,ATM(8),AM(1)                                            002010
128   FORMAT(/+X,* RELATIVE AZIMUTH ANGLE IS*,F7.2,* DEGREES.*,/4X,* MAX002020
     +IMUM AZIMUTH ANGLE IS*,F7.2,* DEGREES.*/)                         002030
      PRINT 123,ATM(9),AM(2)                                            002040
129   FORMAT(/+X,* RELATIVE ELEVATION ANGLE IS*,F7.2,* DEGREES.*,/4X,* M002050
     +AXIMUM ELEVATION GIMBAL ANGLE IS*,F7.2,* DEGREES.*/)              002060
      DATAM(14)=4.0                                                     002070
      GO TO 44                                                          002080
109   IF(IFIX(DATAM(15)).EQ.5)GO TO 45                                  002090
      PRINT*," MISSILE EXCEEDED MANEUVERING CAPABILITY!"                002100
      PRINT 139,ATM(16),AM(3)                                           002110
139   FORMAT(/+X,* VERTICAL LINE OF SIGHT RATE IS*,F8.2,* DEGREES/SECOND002120
     +.*,/4X,* MAXIMUM VERTICAL RATE IS*,F8.2,* DEGREES/SECOND.*/)      002130
      PRINT 140,ATM(17),AM(4)                                           002140
140   FORMAT(/+X,* HORIZONTAL LINE OF SIGHT RATE IS*,F8.2,* DEGREES/SECO002150
     +ND.*,/+X,* MAXIMUM HORIZONTAL RATE IS*,F8.2,* DEGREES/SECOND.*/)  002160
      DATAM(15)=5.0                                                     002170
      GO TO 45                                                          002180
106   IF(IFIX(DATAM(16)).EQ.6)GO TO 116                                 002190
      PRINT*                                                            002200
      PRINT*," MISSILE IS PULLING MAXIMUM G!"                           002210
      PRINT*                                                            002220
      DATAM(16)=6.0                                                     002230
116   LOCK=0                                                            002240
      GO TO 46                                                          002250
```

```
110   PRINT*," TIME LIMIT!"                                                  002260
101   PRINT*," MISSILE HAS MISSED THE AIRCRAFT!"                             002270
      IN=IN+1                                                                002280
      XF(IN)=DATAFT(1)                                                       002290
      YF(IN)=DATAFT(2)                                                       002300
      ZF(IN)=DATAFT(3)                                                       002310
      XM(IN)=DATAM(1)                                                        002320
      YM(IN)=DATAM(2)                                                        002330
      ZM(IN)=DATAM(3)                                                        002340
      WRITE(3) IN                                                            002350
      DO 55 I=1,IN                                                           002360
      WRITE(3) XF(I),YF(I),ZF(I)                                             002370
      WRITE(3) XM(I),YM(I),ZM(I)                                             002380
55    CONTINJE                                                               002390
      INDEX=0                                                                002400
      CALL PRINT(DM,DT,KF,KM,ABM,ATM,INDEX,PI,TIME,AFT,AM,ATF,DATAFT,DAT002410
     +AM,ABF)                                                                002420
      GO TO 100                                                              002430
102   PRINT*," MISSILE HAS SCORED A HIT ON THE AIRCRAFT!"                    002440
      IN=IN+1                                                                002450
      XF(IN)=DATAFT(1)                                                       002460
      YF(IN)=DATAFT(2)                                                       002470
      ZF(IN)=DATAFT(3)                                                       002480
      XM(IN)=DATAM(1)                                                        002490
      YM(IN)=DATAM(2)                                                        002500
      ZM(IN)=DATAM(3)                                                        002510
      WRITE(3) IN                                                            002520
      DO 60 I=1,IN                                                           002530
      WRITE(3) XF(I),YF(I),ZF(I)                                             002540
      WRITE(3) XM(I),YM(I),ZM(I)                                             002550
60    CONTINJE                                                               002560
      INDEX=0                                                                002570
      CALL PRINT(DM,DT,KF,KM,ABM,ATM,INDEX,PI,TIME,AFT,AM,ATF,DATAFT,DAT002580
     +AM,ABF)                                                                002590
      GO TO 100                                                              002600
      END                                                                    002610
```

```
      SUBROUTINE DATAFTR(AC)                                                002540
      DIMENSION AC(15)                                                      002550
*************************************************************************002560
*     READ IN AIRCRAFT DATA.                                           *002570
*************************************************************************002580
      DO 4 I=1,15                                                           002590
      READ (1,*) AC(I)                                                      002700
      IF(EOF(1).NE.0)STOP "END OF DATA"                                     002710
4     CONTINUE                                                              002720
5     RETURN                                                                002730
      END                                                                   002740
                                                                            002750
```

```
      SUBROUTINE INITFT(DATAFT)                                          002770
      DIMENSION DATAFT(12)                                               002780
*****************************************************************      002790
*     READ IN INTIAL CONDITIONS FOR THE AIRCRAFT.                *      002800
*****************************************************************      002810
      DO 1 I=1,12                                                        002820
      READ (1,*) DATAFT(I)                                               002830
1     CONTINUE                                                           002840
      RETURN                                                             002850
      END                                                                002860
                                                                         002870
```

```
      SUBROUTINE DATAMIS(DM)                                                002390
      DIMENSION DM(5)                                                       002900
*****************************************************************************002910
*     READ IN MISSILE DATA.                                                 *002920
*****************************************************************************002930
      DO 4 I=1,5                                                            002940
      READ (2,*) D1(I)                                                      002950
+     CONTINJE                                                              002960
      RETURN                                                                002970
      END                                                                   002980
                                                                            002990
```

```
      SUBROUTINE INITMIS(DATAM)                                          003010
      DIMENSION DATAM(15)                                                003020
*****************************************************************      003030
*     READ IN INITIAL CONDITIONS FOR THE MISSILE.                *0030+0
*****************************************************************      003050
      DO 1 I=1,10                                                        003060
      READ (2,*) DATAM(I)                                                003070
1     CONTINUE                                                           003080
      Z=-(DATAM(3))                                                      003090
      CALL ATMOS(Z,TM,SIGMA,RHO,THETA,DELTA,CA,AMU,<)                    003100
      DATAM(4)=DATAM(4)*CA                                               003110
      DATAM(5)=DATAM(5)*CA                                               003120
      DATAM(6)=DATAM(6)*CA                                               003130
      DO 2 J=11,16                                                       003140
2     DATAM(J)=0.0                                                       003150
      RETURN                                                             003160
      END                                                                003170
                                                                         003180
```

```
      SUBROUTINE ANGLESF(AC,AFT,DATAFT)                                 003200
      DIMENSION AC(15),AFT(15),DATAFT(12)                               003210
*****************************************************************     003220
*       THIS SUBROUTINE CONVERTS INITIAL AND COMPUTED ANGLES      *     003230
*       FROM DEGREES TO RADIANS.                                  *     003240
*****************************************************************     003250
      AFT(1)=0.0                                                        003260
      AFT(2)=0.0                                                        003270
      AFT(5)=DEG2RAD(DATAFT(3),0.,0.)                                   003280
      AFT(6)=DEG2RAD(DATAFT(3),0.,0.)                                   003290
      AFT(10)=DEG2RAD(DATAFT(7),0.,0.)                                  003300
      AFT(7)=DEG2RAD(DATAFT(10),0.,0.)                                  003310
      AFT(8)=DEG2RAD(DATAFT(11),0.,0.)                                  003320
      AFT(9)=DEG2RAD(DATAFT(12),0.,0.)                                  003330
      AFT(11)=DEG2RAD(AC(7),0.,0.)                                      003340
      AFT(12)=DEG2RAD(AC(8),0.,0.)                                      003350
      AFT(13)=DEG2RAD(AC(9),0.,0.)                                      003360
      AFT(14)=DEG2RAD(AC(10),0.,0.)                                     003370
      AFT(15)=DEG2RAD(AC(6),0.,0.)                                      003380
      CALL TRANN2B(DATAFT(4),DATAFT(5),DATAFT(6),AFT(5),AFT(6),AFT(10),J003390
     +B,VB,WB)                                                          003400
      AFT(3)=ATAN(WB/UB)                                                003410
      AFT(4)=ASIN(VB/SQRT(UB**2+VB**2+WB**2))                           003420
      RETURN                                                            003430
      END                                                               003440
                                                                        003450
```

```
      SUBROUTINE ANGLESM(DM,AM,DATAM)                                   003470
      DIMENSION DM(6),AM(8),DATAM(15)                                   003480
*****************************************************************     003490
*       THIS SUBROUTINE CONVERTS INITIAL AND COMPUTED ANGLES        *   003500
*       FROM RADIANS TO DEGREES.                                    *   003510
*****************************************************************     003520
      AM(5)=DEG2RAD(DATAM(7),0.,0.)                                     003530
      AM(6)=DEG2RAD(DATAM(8),0.,0.)                                     003540
      AM(7)=DEG2RAD(DATAM(9),0.,0.)                                     003550
      AM(8)=DEG2RAD(DATAM(10),0.,0.)                                    003560
      AM(1)=DEG2RAD(DM(1),0.,0.)                                        003570
      AM(2)=DEG2RAD(DM(2),0.,0.)                                        003580
      AM(3)=DEG2RAD(DM(3),0.,0.)                                        003590
      AM(4)=DEG2RAD(DM(4),0.,0.)                                        003600
      RETURN                                                            003610
      END                                                               003620
                                                                        003630
```

```
      SUBROUTINE ATTACKF(K,PI,AT,DATAFT,DATAM,AFT,AM,AB)                  003350
      DIMENSION AT(19),DATAFT(12),DATAM(16),AFT(16),AM(8),AB(5)           003360
*************************************************************************003370
*      THIS SUBROUTINES COMPUTES THE RELATIVE POSITIONS, VELOCITIES,    *003380
*      AND ANGLES IN THE VEHICLE'S BODY FRAME UPON WHICH THE PILOT      *003390
*      USES TO BASE IN-FLIGHT DECISIONS.                                *003700
*************************************************************************003710
      AT(1)=DATAM(1)-DATAFT(1)                                            003720
      AT(2)=DATAM(2)-DATAFT(2)                                            003730
      AT(3)=DATAM(3)-DATAFT(3)                                            003740
      AT(4)=SQRT(AT(1)**2+AT(2)**2+AT(3)**2)                              003750
      AT(5)=DATAM(4)-DATAFT(4)                                            003760
      AT(6)=DATAM(5)-DATAFT(5)                                            003770
      AT(7)=DATAM(6)-DATAFT(6)                                            003780
      CALL TRANV2B(AT(1),AT(2),AT(3),AFT(5),AFT(5),AFT(10),AB(1),         003790
     +AB(2),AB(3))                                                        003800
      AT(8)=ASIN(AB(2)/AT(4))                                             003810
      IF(AB(1).GE.0.0) GO TO 1                                            003820
      IF(AT(8).GE.0.0) GO TO 2                                            003830
      AT(8)=-PI-AT(8)                                                     003840
      GO TO 1                                                             003850
2     AT(8)=PI-AT(8)                                                      003860
1     AT(9)=ASIN(-AB(3)/AT(4))                                            003870
      CALL TRANV2B(AT(5),AT(6),AT(7),AFT(5),AFT(5),AFT(10),AB(4),         003880
     +AB(5),AB(6))                                                        003890
      AT(10)=AB(4)*COS(AT(8))*COS(AT(8))                                  003900
     ++AB(5)*COS(AT(9))*SIN(AT(8))                                        003910
     +-AB(6)*SIN(AT(9))                                                   003920
      AT(11)=AM(5)-AFT(5)                                                 003930
      AT(12)=AM(6)-AFT(6)                                                 003940
      AT(13)=0.0-AFT(10)                                                  003950
      IF(AB(4)**2+AB(5)**2.NE.0.0)GO TO 3                                 003960
      AT(14)=AT(13)+PI                                                    003970
      GO TO 4                                                             003980
3     AT(14)=ACOS(AB(4)/SQRT(AB(4)**2+AB(5)**2))                          003990
      IF(AB(5).LT.0.0)AT(14)=-AT(14)                                      004000
```

```
4       IF(AB(4)**2+AB(5)**2+AB(6)**2.NE.0.0) GO TO 5                          004010
        AT(15)=0.0                                                             004020
        GO TO 6                                                                004030
5       AT(15)=ASIN(-AB(6)/SQRT(AB(4)**2+AB(5)**2+AB(6)**2))                   004040
6       IF(COS(AT(8)).NE.0.0) GO TO 7                                          004050
        AT(16)=0.0                                                             004060
        GO TO 8                                                                004070
7       AT(16)=SQRT(AB(4)**2+AB(5)**2)*COS(PI/2.0+AT(8)-AT(14))/               004080
       +AT(4)/COS(AT(9))                                                       004090
8       AT(17)=(-SQRT(AB(4)**2+AB(5)**2)*COS(AT(14)-AT(8))*SIN(AT(8))          004100
       +-AB(6)*COS(AT(9)))/AT(4)                                               004110
        AT(18)=ACOS(COS(AT(8))*COS(AT(9)))                                     004120
        AT(19)=ACOS((AT(1)*DATAM(4)+AT(2)*DATAM(5)+AT(3)*DATAM(6))/            004130
       +(AT(4)*SQRT(DATAM(4)**2+DATAM(5)**2+DATAM(5)**2)))                     004140
        RETURN                                                                 004150
        END                                                                    004160
                                                                               004170
```

```
      SUBROUTINE ATTACKM(DM,DT,INDEX,ATF,K,PI,AT,DATAM,DATAFT,AM,AFT,AB,004190
     +TIME)                                                             004200
      DIMENSION AT(19),DATAM(16),DATAFT(12),AM(8),AFT(16),AB(6),ATF(19),004210
     +DEL(3),DM(6)                                                      004220
C*****************************************************************004230
C*      THIS SUBROUTINE COMPUTES THE RELATIVE POSITIONS, VELOCITIES,  *004240
C*      AND ANGLES IN THE VEHICLE'S BODY FRAME UPON WHICH THE MISSILE *004250
C*      USES TO COMPUTE IN-FLIGHT DECISIONS.                          *004260
C*****************************************************************004270
      IF(K.EQ.2)CALL IRNDS(DM,DT,TIME,AFT,AM,ATF,AT,DEL,PI)             004280
      IF(K.EQ.3)CALL RANDS(DM,DT,TIME,AFT,AM,ATF,AT,DEL,PI)             004290
      DATAXFT=DATAFT(1)+DEL(1)                                          004300
      DATAYFT=DATAFT(2)+DEL(2)                                          004310
      DATAZFT=DATAFT(3)+DEL(3)                                          004320
      AT(1)=DATAXFT-DATAM(1)                                            004330
      AT(2)=DATAYFT-DATAM(2)                                            004340
      AT(3)=DATAZFT-DATAM(3)                                            004350
      AT(4)=SQRT(AT(1)**2+AT(2)**2+AT(3)**2)                            004360
      AT(5)=DATAFT(4)-DATAM(4)                                          004370
      AT(6)=DATAFT(5)-DATAM(5)                                          004380
      AT(7)=DATAFT(6)-DATAM(6)                                          004390
      CALL TRANN2B(AT(1),AT(2),AT(3),AM(5),AM(6),0.0,AB(1),             004400
     +AB(2),AB(3))                                                      004410
      AT(8)=ASIN(AB(2)/AT(4))                                           004420
      IF(AB(1).GE.0.0) GO TO 1                                          004430
      IF(AT(8).GE.0.0) GO TO 2                                          004440
      AT(8)=-PI-AT(8)                                                   004450
      GO TO 1                                                           004460
2     AT(8)=PI-AT(8)                                                    004470
1     AT(9)=ASIN(-AB(3)/AT(4))                                          004480
      CALL TRANN2B(AT(5),AT(6),AT(7),AM(5),AM(6),0.0,AB(4),             004490
     +AB(5),AB(6))                                                      004500
      AT(10)=AB(4)*COS(AT(9))*COS(AT(8))                                004510
     ++AB(5)*COS(AT(9))*SIN(AT(8))                                      004520
     +-AB(6)*SIN(AT(9))                                                 004530
      AT(11)=AFT(5)-AM(5)                                               004540
```

```
      AT(12)=AFT(6)-AM(3)                                                    004550
      AT(13)=AFT(10)-0.0                                                     004560
      IF(AB(4)**2+AB(5)**2.NE.0.0)GO TO 3                                    004570
      AT(14)=AT(13)+PI                                                       004580
      GO TO 4                                                                004590
    3 AT(14)=ACOS(AB(4)/SQRT(AB(4)**2+AB(5)**2))                             004600
      IF(AB(5).LT.0.0)AT(14)=-AT(14)                                         004610
    4 IF(AB(4)**2+AB(5)**2+AB(6)**2.NE.0.0) GO TO 5                          004620
      AT(15)=0.0                                                             004630
      GO TO 6                                                                004640
    5 AT(15)=ASIN(-AB(6)/SQRT(AB(4)**2+AB(5)**2+AB(6)**2))                   004650
    6 IF(COS(AT(9)).NE.0.0) GO TO 7                                          004660
      AT(16)=0.0                                                             004670
      GO TO 8                                                                004680
    7 AT(16)=SQRT(AB(4)**2+AB(5)**2)*COS(PI/2.0+AT(8)-AT(14))/               004690
     +AT(4)/COS(AT(9))                                                       004700
    8 AT(17)=(-SQRT(AB(4)**2+AB(5)**2)*COS(AT(14)-AT(8))*SIN(AT(9))          004710
     +-AB(6)*COS(AT(9)))/AT(4)                                               004720
      AT(18)=ACOS(COS(AT(8))*COS(AT(9)))                                     004730
      AT(19)=ACOS((AT(1)*DATAFT(4)+AT(2)*DATAFT(5)+AT(3)*DATAFT(6))/         004740
     +(AT(4)*SQRT(DATAFT(4)**2+DATAFT(5)**2+DATAFT(6)**2)))                  004750
      DELTA=0.0                                                              004760
      DO 100 ID=1,3                                                          004770
  100 DELTA=DEL(ID)**2+DELTA                                                 004780
      DELTA=SQRT(DELTA)                                                      004790
      INTER=.5000001/DT                                                      004800
      IF(MOD(INDEX,INTER).EQ.0)PRINT 200,DEL(1),DEL(2),DELTA,DEL(3)          004810
  200 FORMAT(/14X,* GUIDANCE ERRORS:*,/4X,* X=*,F6.2,* FEET*,/4X,* Y=*,F004820
     +6.2,* FEET*,2X,* TOTAL=*, F7.2,* FEET*,/4X,* Z=*,F6.2,* FEET*/)     004830
      RETURN                                                                 004840
      END                                                                    004850
                                                                             004860
```

```
      SUBROUTINE ATMOS(Z,TM,SIGMA,RHO,THETA,DELTA,CA,AMU,K)                 004380
*****************************************************************************004390
C     CALLING SEQUENCE                                                      004400
C                                                                           004410
C     CALL ATMOS(Z,TM,SIGMA,RHO,THETA,DELTA,CA,AMU,K)                       004420
C                                                                           004430
C     Z     = GEOMETRIC ALTITUDE (FT)                                       004440
C     TM    = MOLECULAR SCALE TEMPERATURE (DEGREES RANKIN)                  004450
C     SIGMA = RATIO OF DENSITY TO THAT AT SEA LEVEL                         004460
C     RHO   = DENSITY LB-SEC**2-FT**(-4) OR SLUGS-FT**3                     004470
C     THETA = RATIO OF TEMPERATURE TO THAT AT SEA LEVEL                     004480
C     DELTA = RATIO OF PRESSURE TO THAT AT SEA LEVEL                        004490
C     CA    = SPEED OF SOUND (FT/SEC)                                       005000
C     AMU   = VISCOSITY COEFFICIENT (LB-SEC-FT**2)                          005010
C                                                                           005020
C     K = 1 NORMAL,                                                         005030
C       = 2 ALTITUDE GREATER THAN 300000. FT.,                              005040
C       = 3 ALTITUDE NEGATIVE,                                              005050
*****************************************************************************005060
C                                                                           005070
      DIMENSION HPRIMB(11),TMB(11),SIGMAB(11),ALM(11),ARAY(11,4)            005080
      EQUIVALENCE (ARAY(1,1),HPRIMB(1)),(ARAY(1,2),TMB(1)),                 005090
     *            (ARAY(1,3),SIGMAB(1)),(ARAY(1,4),ALM(1))                  005100
C                                                                           005110
      DATA ((ARAY(I,J),J=1,4),I=1,11)/                                      005120
     X           0.     ,     518.688 ,   1.0000000E 00 ,   -0.00356515 ,   005130
     X       36089.239 ,     389.988 ,   2.2706958E-01 ,    0.          ,   005140
     X       82020.997 ,     389.988 ,   3.2662751E-02 ,    0.00154532 ,   005150
     X      154199.480 ,     508.788 ,   1.2117870E-03 ,    0.          ,   005160
     X      173884.510 ,     508.788 ,   5.8677311E-04 ,   -0.00246888 ,   005170
     X      259186.350 ,     298.188 ,   1.7329156E-05 ,    0.          ,   005180
     X      295275.590 ,     298.188 ,   1.7328595E-06 ,    0.00219456 ,   005190
     X      344488.190 ,     406.188 ,   9.3921519E-08 ,    0.01097280 ,   005200
     X      524934.380 ,    2386.188 ,   7.7658593E-10 ,    0.00548640 ,   005210
     X      557742.780 ,    2556.188 ,   5.6324877E-10 ,    0.00274320 ,   005220
     X      656167.980 ,    2836.188 ,   2.5726771E-10 ,    0.00132024 /   005230
```

```
      DATA     Q   /  0.018744175     / ,      RE  /  2.0855531E 07     /,
     X         S   /  198.72          / ,      PZ  /  2116.2            /,
     X      AMUZ   /  3.7372998E-07   / ,    RHOZ  /  0.0023769         /,
     X       TMZ   /  518.688         /
      K=1
      IF(Z)26,18,17
   26 K=3
      GO TO 13
   17 IF(Z.GT.300000.)  K=K+1
   18 HPRIM=(RE/(RE+Z))*Z
    9 DO 10 M=1,11
      IF(HPRIM-HPRIMB(M))11,12,10
   10 CONTINJE
      M=12
   11 M=M-1
   12 IF(ALM(M))14,15,14
   14 TM=TMB(M)+ALM(M)*(HPRIM-HPRIMB(M))
      SIGMA=EXP((1.0+(Q/ALM(M)))*(ALOG(TMB(M)/TM)))*SIGMAB(M)
      GO TO 20
   15 TM=TMB(M)
      SIGMA=SIGMAB(M)*EXP(-(Q*(HPRIM-HPRIMB(M)))/TMB(M))
   20 RHO=RHOZ*SIGMA
      THETA=TM/TMZ
      DELTA=SIGMA*THETA
      CA=+9.02177*SQRT(TM)
      AMU=AMUZ*SQRT(THETA**3)*((TMZ+S)/(TM+S))
   13 RETURN
      END
```

```
      SUBROUTINE THRUSTM(INDEX,DATAM,TM,FORM)                          005560
      DIMENSION DATAM(15),TM(2),FORM(3)                                005570
*****************************************************************005580
*       THIS SUBROUTINE COMPUTES DIFFERENT THRUST OUTPUTS AND       *005590
*       ATMOSPHERIC RELATED NUMBERS.                                *005600
*****************************************************************005610
      Z=(-DATAM(3))                                                    005620
      CALL ATMOS(Z,TM,SIGMA,RHO,THETA,DELTA,CA,AMJ,K)                  005630
12    FORM(1)=SQRT(DATAM(4)**2+DATAM(5)**2+DATAM(6)**2)                005640
      TM(1)=FORM(1)/CA                                                 005650
      TM(2)=.5*RHO*FORM(1)**2                                          005660
      RETURN                                                           005670
      END                                                              005680
                                                                       005690
```

```
      SUBROUTINE THRUSTF(INDEX,DATAFT,TT)                                  005710
      DIMENSION DATAFT(12),TT(7)                                           005720
      DIMENSION TABLEXF(5)                                                 005730
      DIMENSION AMACHF(5),F1T(5),F2T(5),F3T(5),F4T(5),F5T(5)               005740
*********************************************************************005750
*       THIS SUBROUTINE COMPUTES DIFFERENT THRUST OUTPUTS AND         *005760
*       ATMOSPHERIC RELATED NUMBERS.                                  *005770
*********************************************************************005780
      Z=(-DATAFT(3))                                                       005790
      CALL ATMOS(Z,TM,SIGMA,RHO,THETA,DELTA,CA,AMU,K)                      005800
      IF(INDEX.GT.1)GO TO 12                                               005810
******READ IN THRUST DATA FOR AIRCRAFT******                             005820
      DO 11 I=1,5                                                          005830
      READ (1,*) AMACHF(I),F1T(I),F2T(I)                                   005840
      READ (1,*) F3T(I),F4T(I),F5T(I)                                      005850
11    CONTINUE                                                             005860
12    TT(5)=SQRT(DATAFT(4)**2+DATAFT(5)**2+DATAFT(6)**2)                   005870
      TT(6)=XA=TT(5)/CA                                                    005880
      TT(7)=.5*RHO*TT(5)**2                                                005890
      DO 1 I=1,5                                                           005900
1     TABLEXF(I)=AMACHF(I)                                                 005910
      FTH1=TBLNDC(1,2,F1T,TABLEXF,5,TT(6))                                 005920
      FTH2=TBLNDC(1,2,F2T,TABLEXF,5,TT(6))                                 005930
      FTH3=TBLNDC(1,2,F3T,TABLEXF,5,TT(6))                                 005940
      FTH4=TBLNDC(1,2,F4T,TABLEXF,5,TT(6))                                 005950
      FTH5=TBLNDC(1,2,F5T,TABLEXF,5,TT(6))                                 005960
      IF(-DATAFT(3).GT.35089)GO TO 3                                       005970
      TT(4)=(FTH1-FTH2*((36089.+DATAFT(3))/1000.))*1000.*DELTA             005980
      GO TO 4                                                              005990
3     TT(4)=(FTH1-FTH3*((-DATAFT(3)-35089.)/1000.))*1000.*DELTA            006000
4     TT(2)=FTH4*TT(4)                                                     006010
      TT(3)=FTH5*1000.*DELTA                                               006020
      IF(INDEX.EQ.1)TT(1)=TT(2)*.9                                         006030
      RETURN                                                               006040
      END                                                                  006050
                                                                           006060
```

```
      SUBROUTINE PILOT(AT,RANG)                                          006080
      DIMENSION AT(19),RANG(2)                                           006090
*************************************************************************006100
*     THIS SUBROUTINE PROVIDES NOISE TO SIMULATE JUDGEMENT ERRORS       *006110
*     IN RANGE BY THE PILOT.                                            *006120
*************************************************************************006130
      TEMP1=RANF(DUMMY)                                                  006140
      DERANG=2000.0*TEMP1-1000.0                                         006150
      RANG(1)=5000.0+DERANG                                              006160
      TEMP2=RANF(DUMMY)                                                  006170
      DERANG=1000.0*TEMP2-500.0                                          006180
      RANG(2)=1000.0+DERANG                                              006190
      RETURN                                                             006200
      END                                                                006210
                                                                         006220
```

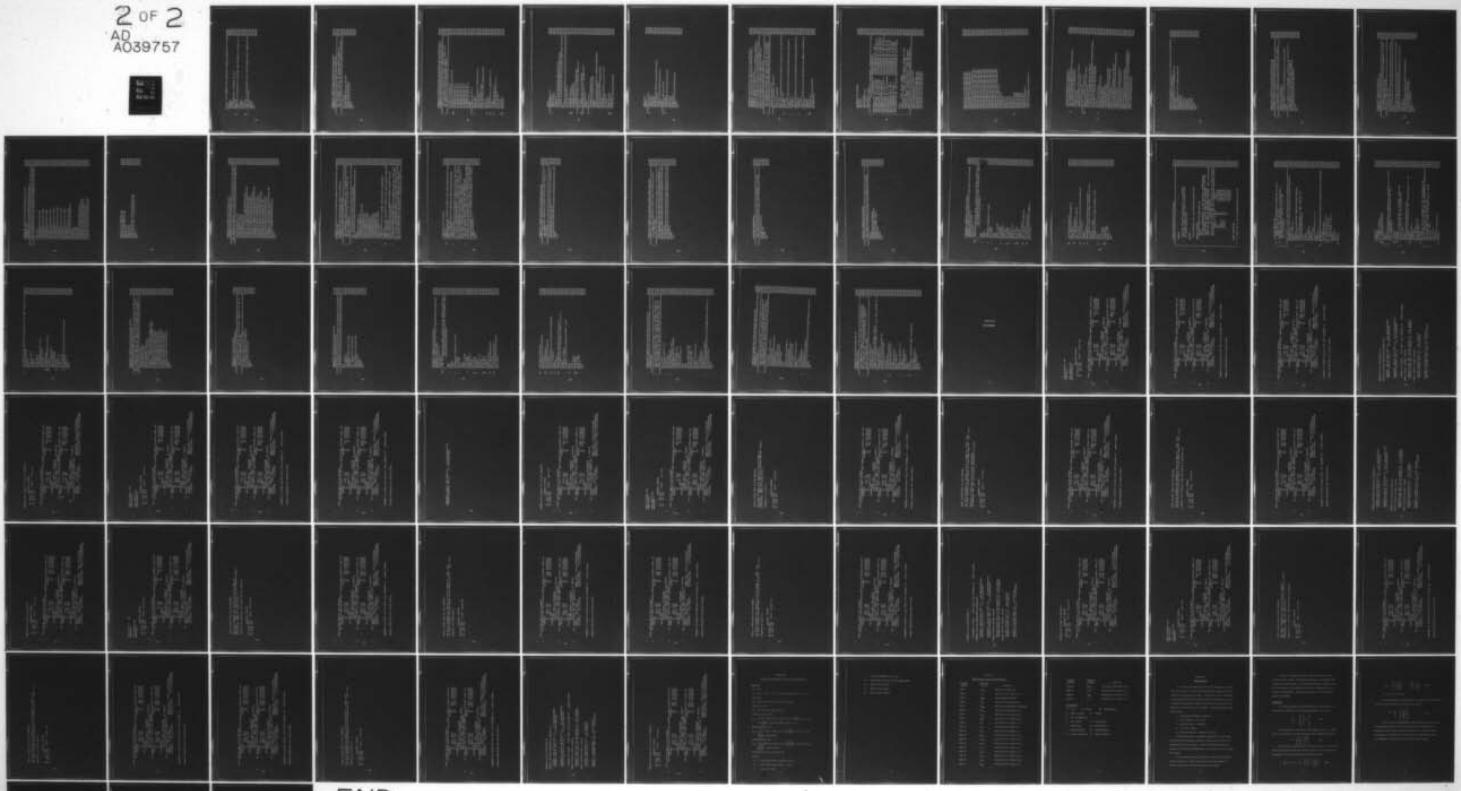
```
      SUBROUTINE EVAMANJ(TIME,PI,MANJ/R,AT,RANG,DATAFT)                 006240
      DIMENSION AT(19),RANG(2),DATAFT(13)                               006250
      IF(TIME.EQ.0.0)N=1                                                006260
      PRINT 100,TIME                                                    006270
100   FORMAT(/4X,* TOTAL ELAPSED TIME IS*,F5.2,* SECONDS.*)             006280
      IF(AT(4).LT.RANG(1))GO TO 101                                     006290
      ESTRAN=6000.0                                                     006300
      PRINT 110,ESTRAN,N,AT(4),ESTRAN,RANG(1)                           006310
110   FORMAT(/4X,* THE PILOT ESTIMATES THE MISSILE TO BE AT A RANGE OF  006320
     +*,/4X,* MORE THEN *,F8.0,* FEET. THE PILOT EXECUTES MANEUVER NUMBE006330
     +R*,I2,/4X,* AT AN ACTUAL RANGE OF*,F8.0,* FEET. THE PILOT ESTIMATE006340
     +S*,/4X,F8.0,* FEET TO BE AT AN ACTUAL RANGE OF*,F8.0,* FEET.*)    006350
      N=N+1                                                             006360
      GO TO 1                                                           006370
101   IF(AT(4).LT.RANG(2))GO TO 102                                     006380
      IF(N.GT.1)GO TO 121                                               006390
      ESTRAN=6000.0                                                     006400
      PRINT 111,ESTRAN,N,AT(4),ESTRAN                                   006410
111   FORMAT(/4X,* THE PILOT ESTIMATES THE MISSILE TO BE AT A RANGE OF  006420
     +*,/4X,* LESS THEN *,F8.0,* FEET. THE PILOT EXECUTES MANEUVER NUMBE006430
     +R*,I2,/4X,* AT AN ACTUAL RANGE OF*,F8.0,* FEET.*)                 006440
      N=N+1                                                             006450
      GO TO 1                                                           006460
121   ESTRAN=6000.0                                                     006470
      PRINT 122,ESTRAN,N,AT(4)                                          006480
122   FORMAT(/4X,* THE PILOT ESTIMATES THE MISSILE TO BE AT A RANGE OF*,006490
     +F8.0,* FEET.*,/4X,* THE PILOT EXECUTES MANEUVER NUMBER*,I2,* AT AN006500
     + ACTUAL RANGE OF*,F8.0,* FEET.*)                                  006510
      N=N+1                                                             006520
      GO TO 1                                                           006530
102   ESTRAN=1000.0                                                     006540
      PRINT 122,ESTRAN,N,AT(4)                                          006550
      N=N+1                                                             006560
*************************************************************************006570
*       THIS SUBROUTINE SELECTS THE TACTICAL MANEUVER FOR THE          *006580
*       SITUATION THAT EXISTS.                                         *006590
```

```
*****************************************************************************006500
1       IF(ABS(AT(8)).LT.PI/2.0) GO TO 5                                        006510
        IF(AT(4).LT.RANG(1))GO TO 2                                             006520
        PRINT 11                                                                006530
11      FORMAT(/+X,* MANEUVER IS A VERTICAL DIVE AWAY FROM THE MISSILE.*/)      006540
        MANUVR=1                                                                006550
        RETURN                                                                  006560
2       IF(AT(4).LT.RANG(2)) GO TO 3                                            006570
        PRINT 12                                                                006580
12      FORMAT(/+X,* MANEUVER IS A HARD BREAK.*/)                               006590
        MANUVR=2                                                                006700
        RETURN                                                                  006710
3       IF((-DATAFT(3)).LT.15000.0)GO TO 4                                      006720
        PRINT 13                                                                006730
13      FORMAT(/+X,* MANEUVER IS A SPLIT S.*/)                                  006740
        MANUVR=3                                                                006750
        RETURN                                                                  006760
4       PRINT 14                                                                006770
14      FORMAT(/+X,* THE ALTITUDE OF THE AIRCRAFT IS LESS THAN 15000 FEET.      006780
       +*,/4X,* MANEUVER IS A HARD PULL UP.*/)                                  006790
        MANUVR=4                                                                006800
        RETURN                                                                  006810
5       IF(AT(4).LT.RANG(1)) GO TO 7                                            006820
        IF((-DATAFT(3)).LT.15000.0)GO TO 6                                      006830
        PRINT 15                                                                006840
15      FORMAT(/+X,* MANEUVER IS A SPLIT S.*/)                                  006850
        MANUVR=3                                                                006860
        RETURN                                                                  006870
6       PRINT 16                                                                006880
16      FORMAT(/+X,* THE ALTITUDE OF THE AIRCRAFT IS LESS THAN 15000 FEET.      006890
       +*,4X/,* MANEUVER IS A HARD BREAK FOLLOWED BY A VERTICAL DIVE.*/)        006900
        MANUVR=5                                                                006910
        RETURN                                                                  006920
7       IF(AT(4).LT.RANG(2)) GO TO 8                                            006930
        PRINT 17                                                                006940
17      FORMAT(/4X,* MANEUVER IS A HARD BREAK SO AS TO PUT THE MISSILE          006950
```

AD-A039 757 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OHIO SCH--ETC F/G 1/2
MANEUVERING TARGET SIMULATION FOR TESTING THE TERMINAL GUIDANCE--ETC(U)
MAR 77 H G PADDON

UNCLASSIFIED AFIT/GE/EE/77-2 NL

2 OF 2
AD
A039757



END

DATE
FILMED
6-77

```
     +*,/4X,* IN A PURSUIT TYPE CURVE THEN REVERSE DIRECTION OF THE BREA006960
     +K.*/)                                                              006970
      MANUVR=6                                                           006980
      RETURN                                                             006990
5     IF((-DATAFT(3)).LT.1000.0) GO TO 9                                 007000
      PRINT 18                                                           007010
18    FORMAT(/4X,* MANEUVER IS A VERTICAL DIVE FOLLOWED BY A HARD PULL U007020
     +P.*/)                                                              007030
      MANUVR=8                                                           007040
      RETURN                                                             007050
9     PRINT 19                                                           007060
19    FORMAT(/4X,* THE AIRCRAFT IS AT LOW ALTITUDE.*,/4X,* MANEUVER IS A007070
     + HARD PULL UP.*/)                                                  007080
      MANUVR=7                                                           007090
      RETURN                                                             007100
      END                                                                007110
                                                                         007120
```

```
      SUBROUTINE PURSUIT(INDEX,DATAM,DM,ATM,DINM,PI,AM)                  007140
      DIMENSION ATM(19),DINM(2),AM(8),DM(5),DATAM(16)                    007150
*************************************************************************007160
*      THIS SUBROUTINE COMPUTES THE DESIRED CONTROL INPUTS SO           *007170
*      THAT THE MISSILE WILL FOLLOW PROPORTIONAL NAVIGATION GUIDANCE.   *007180
*************************************************************************007190
      DO 1 J=11,16                                                       007200
1     IF(IFIX(DATAM(11)).GE.1)RETURN                                     007210
      DINM(1)=AM(5)+3.*ATM(15)                                           007220
      DINM(2)=AM(6)+3.*ATM(17)                                           007230
      RETURN                                                             007240
      END                                                                007250
                                                                         007260
```

```
      SUBROUTINE DESINP(TIME,MANJVR,DIN,DATAFT,AC,TT,AFT,AB,PI,AT)      007280
      DIMENSION DIN(4),DATAFT(12),AC(15),TT(7),AFT(16),AB(5),AT(19)     007290
*************************************************************************007300
*       THIS SUBROUTINE COMPUTES THE DESIRED CONTROL INPUTS FOR         *007310
*       THE MANJVERS SELECTED IN SUBROUTINE EVAMANU.                    *007320
*************************************************************************007330
      IF(TIME.EQ.0.0)KOUNT=0                                            007340
      IF(AFT(3).GT.AFT(11))AFT(3)=AFT(11)                               007350
100   IF(MANJVR.EQ.1)GO TO 1                                            007360
      IF(MANJVR.EQ.2)GO TO 2                                            007370
      IF(MANJVR.EQ.3)GO TO 3                                            007380
      IF(MANJVR.EQ.4)GO TO 4                                            007390
      IF(MANJVR.EQ.5)GO TO 2                                            007400
      IF(MANJVR.EQ.6)GO TO 2                                            007410
      IF(MANJVR.EQ.7)GO TO 4                                            007420
      IF(MANJVR.EQ.8)GO TO 1                                            007430
      IF(MANJVR.EQ.0)GO TO 10                                           007440
      RETURN                                                            007450
******VERTICAL DIVE******                                              007460
1     DIN(2)=0.0                                                        007470
      DIN(4)=TT(4)                                                      007480
      IF(AFT(6).LE.AFT(11)-PI/2.0)GO TO 11                              007490
      DIN(1)=AFT(11)                                                    007500
      DIN(3)=SIGN(PI,AFT(10))                                           007510
      IF(AFT(10).EQ.0.)DIN(3)=SIGN(PI,AT(3))                            007520
      GO TO 12                                                          007530
11    DIN(1)=0.0                                                        007540
      DIN(3)=0.0                                                        007550
12    IF((-DATAFT(3)).LE.1500.0)GO TO 13                                007560
      RETURN                                                            007570
13    IF(MANJVR.EQ.8)GO TO 4                                            007580
      IF(AFT(6).GE.AFT(11))GO TO 14                                     007590
      DIN(1)=AFT(11)                                                    007600
      GO TO 15                                                          007610
14    DIN(1)=0.0                                                        007620
15    DIN(3)=0.0                                                        007630
```

```
      RETURN                                                                    007340
******HARD BREAK******                                                          007350
2     DIN(4)=TT(4)                                                              007360
      DIN(1)=AFT(11)                                                            007370
      DIN(2)=0.0                                                                007380
      IF(AB(2).EQ.0.0.AND.AB(3).EQ.0.0)GO TO 21                                 007390
      DIN(3)=AFT(10)+ASIN(AB(2)/SQRT(AB(2)**2+AB(3)**2))                        007400
      IF(AB(3).GT.0.0)DIN(3)=AFT(10)+PI-ASIN(AB(2)/SQRT(AB(2)**2+AB(3)**007410
     +2))                                                                       007420
      IF(AB(3).GT.0.0.AND.AB(2).LT.0.0)DIN(3)=AFT(10)-PI-ASIN(AB(2)/SQRT007430
     +(AB(2)**2+AB(3)**2))                                                      007440
      GO TO 22                                                                  007450
21    DIN(3)=AFT(10)+0.5                                                        007460
22    IF(MANJVR.EQ.2)RETURN                                                     007470
      IF(MANJVR.EQ.6)GO TO 25                                                   007480
      IF(ABS(AT(18)).LT.5.*PI/6.0)RETURN                                        007490
******HARD BREAK FOLLOWED BY VERTICAL DIVE******                               007500
      GO TO 1                                                                   007510
25    IF(ABS(AT(18)).GE.PI/2.0)RETURN                                           007520
******HARD BREAK FOLLOWED BY A REVERSAL******                                  007530
      DIN(3)=-DIN(3)                                                            007540
      RETURN                                                                    007550
******SPLIT S******                                                            007560
3     IF(KOUNT.EQ.0)PSISTOP=AFT(5)                                              007570
      IF(KOUNT.EQ.0)PHISTOP=AFT(10)                                             007580
      KOUNT=1                                                                   007590
      IF(SIGN(1.,AFT(5)).EQ.SIGN(-1.,PSISTOP))DIN(3)=0.0                        007600
      DIN(3)=SIGN(PI,PHISTOP)                                                   007610
      IF(AFT(10).EQ.0.)DIN(3)=SIGN(PI,AT(8))                                    007620
      DIN(2)=0.0                                                                007630
      IF(ABS(AFT(10)-DIN(3)).LE..1)GO TO 31                                     007640
      DIN(1)=AFT(3)                                                             007650
      GO TO 32                                                                  007660
31    DIN(1)=AFT(11)                                                            007670
32    DIN(4)=TT(4)                                                              007680
      IF(AFT(6).LT.PI-AFT(11))RETURN                                            007690
```

```
      DIN(1)=0.0                                                        008000
      RETURN                                                            008010
******PULL UP******                                                     008020
4     DIN(1)=0.0                                                        008030
      DIN(3)=0.0                                                        008040
      DIN(2)=0.0                                                        008050
      IF(ABS(AFT(10)-DIN(3)).LE..1)DIN(1)=AFT(11)                       008060
      DIN(4)=TT(4)                                                      008070
      IF(AFT(6).GE.PI-AFT(11))DIN(1)=0.0                                008080
      RETURN                                                            008090
******STRAIGHT AND LEVEL******                                         008100
10    DIN(1)=0.0                                                        008110
      IF(DATAFT(5).GT.0.0)DIN(1)=AFT(11)                                008120
      DIN(2)=0.0                                                        008130
      DIN(3)=0.0                                                        008140
      DIN(4)=TT(2)                                                      008150
      IF(DATAFT(5).GT.0.0)DIN(4)=TT(4)                                  008160
      RETURN                                                            008170
      END                                                               008180
                                                                        008190
```

```
      SUBROUTINE FORCESF(INDEX,TF,AFT,DT,G,FOR,AC,DATA,DIN)                 008210
      DIMENSION TF(7),AFT(15),FOR(13),AC(15),DATA(12),DIN(4)                008220
      DIMENSION XAF(2),TABF(10),WAF(2)                                      008230
      DIMENSION AMACHF(5),ALPHAF(4),CE1F(5,4),CE2F(5,4),CE3F(5,4),          008240
     +CE4F(5,4),CE5F(5,4),CE6F(5,4),CE7F(5,4),CE8F(5,4),CE9F(5,4),          008250
     +CE10F(5,4),CE11F(5,4),CE12F(5,4),CE13F(5,4),CE14F(5,4),CE15F(5,4),    008260
     +CE16F(5,4),CE17F(5,4),CE18F(5,4),CE19F(5,4),CE20F(5,4),               008270
     +CE21F(5,4),CE22F(5,4),CE23F(5,4),DSFT(5,4)                            008280
*************************************************************************008290
*      THIS SUBROUTINE COMPUTES THE FORCES ACTING ON THE AIRCRAFT.      *008300
*      THE HEADING, PITCH, AND BANK ANGLES ARE IN THE WIND FRAME.       *008310
*************************************************************************008320
      IF(INDEX.GT.1)GO TO 10                                                008330
******READ IN AERODYNAMIC DATA******                                       008340
      DO 2 J=1,5                                                            008350
      READ(1,*) AMACHF(J)                                                   008360
      DO 3 I=1,4                                                            008370
      READ (1,*) ALPHAF(I),CE1F(J,I),CE2F(J,I),CE3F(J,I),CE4F(J,I),CE5F(    008380
     +J,I),CE6F(J,I)                                                        008390
3     CONTINUE                                                              008400
      DO 7 I=1,4                                                            008410
      READ(1,*) CE7F(J,I),CE8F(J,I),CE9F(J,I),CE10F(J,I),CE11F(J,I),        008420
     +CE12F(J,I)                                                            008430
7     CONTINUE                                                              008440
      DO 8 I=1,4                                                            008450
      READ(1,*) CE13F(J,I),CE14F(J,I),CE15F(J,I),CE16F(J,I),CE17F(J,I),     008460
     +CE18F(J,I)                                                            008470
8     CONTINUE                                                              008480
      DO 5 I=1,4                                                            008490
      READ(1,*) CE19F(J,I),CE20F(J,I),CE21F(J,I),CE22F(J,I),CE23F(J,I),     008500
     +DSFT(J,I)                                                             008510
5     CONTINUE                                                              008520
2     CONTINUE                                                              008530
10    XAF(1)=TF(6)                                                          008540
      IF(INDEX.EQ.1)REAL_MAC=TF(5)                                          008550
      XAF(2)=AFT(3)                                                         008560
```

```
      DELMACH=TF(6)-REALMAC                                                  008570
      NAF(1)=6                                                               008580
      NAF(2)=4                                                               008590
      DO 1 I=1,5                                                             008600
1     TABF(I)=AMACHF(I)                                                      008610
      DO 4 I=1,4                                                             008620
4     TABF(6+I)=ALPHAF(I)                                                    008630
C************TABLE LOOK-UP OF AERODYNAMIC COEFFICIENTS*********************008640
C              *****DEFINITION OF COEFFICIENTS*******                       008650
C CEF1-BASIC LIFT COEFFICIENT(L)    CEF12O-DERIVATIVE OF M WRT P           008660
C CEF2-DERIVATIVE OF L WRT ALPHA    CEF13-DERIVATIVE OF L WRT DELTA S      008670
C CEF3-BASIC DRAG COEFFICIENT(D)    CEF14-DERIVATIVE OF M WRT DELTA S      008680
C CEF4-DERIVATIVE OF D WRT ALPHA    CEF15-DERIVATIVE OF LL WRT DELTA R     008690
C CEF5-BASIC PITCHING MOMENT(M)     CEF16-DERIVATIVE OF N WRT DELTA R      008700
C CEF6-DERIVATIVE OF M WRT ALPHA    CEF17-DERIVATIVE OF Y WRT TO DELTA R008710
C CEF7-DERIVATIVE OF M WRT Q        CEF18-DERIVATIVE OF L WRT TO MN        008720
C CEF8-DERIVATIVE OF M WRT ALPHADOT CEF19-DERIVATIVE OF D WRT TO MN        008730
C CEF9-DERIVATIVE OF LL WRT P       CEF20-DERIVATIVE OF M WRT TO MN        008740
C CEF10-DERIVATIVE OF LL WRT R      CEF21-DERIVATIVE OF LL WRT BETA        008750
C CEF11-DERIVATIVE OF N WRT R       CEF22-DERIVATIVE OF N WRT BETA         008760
C CEF12-DERIVATIVE OF N WRT P       CEF23-DERIVATIVE OF Y WRT BETA         008770
C CEF13-DERIVATIVE OF L WRT DELTA S DSRFT-DEFLECTION OF THE ELEVATOR       008780
C                                                                          008790
C     KEY:                                                                 008800
C     L-LIFT  D-DRAG  MN-MACH NUMBER                                       008810
C     ALPHA-ANGLE OF ATTACK  ALPHADOT-RATE OF CHANGE OF ALPHA              008820
C     P-RATE OF ROLL  Q-RATE OF PITCH  R-RATE OF YAW                       008830
C     M-PITCHING MOMENT  N-YAWING MOMENT  LL-ROLLING MOMENT                008840
C     DELTA S-ELEVATOR DEFLECTION  DELTA R-RUDDER DEFLECTION               008850
C*************************************************************************008860
      DSRFT=TBLNDC(1,3,DSFT,TABF,NAF,XAF)                                    008870
      DSRFT=DEG2RAD(DSRFT,0.0,0.0)                                           008880
      CEF1=TBLNDC(1,3,CE1F,TABF,NAF,XAF)                                     008890
      CEF2=TBLNDC(1,3,CE2F,TABF,NAF,XAF)                                     008900
      CEF3=TBLNDC(1,3,CE3F,TABF,NAF,XAF)                                     008910
      CEF4=TBLNDC(1,3,CE4F,TABF,NAF,XAF)                                     008920
```

```
      CEF5=TBLNDC(1,3,CE5F,TABF,NAF,XAF)                                  008930
      CEF6=TBLNDC(1,3,CE6F,TABF,NAF,XAF)                                  008940
      CEF7=TBLNDC(1,3,CE7F,TABF,NAF,XAF)                                  008950
      CEF8=TBLNDC(1,3,CE8F,TABF,NAF,XAF)                                  008960
      CEF9=TBLNDC(1,3,CE9F,TABF,NAF,XAF)                                  008970
      CEF10=TB_NDC(1,3,CE10F,TA3F,NAF,XAF)                                008980
      CEF11=TB_NDC(1,3,CE11F,TA3F,NAF,XAF)                                008990
      CEF12=TB_NDC(1,3,CE12F,TA3F,NAF,XAF)                                009000
      CEF13=TB_NDC(1,3,CE13F,TA3F,NAF,XAF)                                009010
      CEF14=TB_NDC(1,3,CE14F,TA3F,NAF,XAF)                                009020
      CEF15=TB_NDC(1,3,CE15F,TA3F,NAF,XAF)                                009030
      CEF16=TB_NDC(1,3,CE16F,TA3F,NAF,XAF)                                009040
      CEF17=TB_NDC(1,3,CE17F,TA3F,NAF,XAF)                                009050
      CEF18=TB_NDC(1,3,CE18F,TA3F,NAF,XAF)                                009060
      CEF19=TB_NDC(1,3,CE19F,TA3F,NAF,XAF)                                009070
      CEF20=TB_NDC(1,3,CE20F,TA3F,NAF,XAF)                                009080
      CEF21=TB_NDC(1,3,CE21F,TA3F,NAF,XAF)                                009090
      CEF22=TB_NDC(1,3,CE22F,TA3F,NAF,XAF)                                009100
      CEF23=TB_NDC(1,3,CE23F,TA3F,NAF,XAF)                                009110
      IF(INDEX.NE.1)GO TO 15                                              009120
      ADTOLD=AFT(16)                                                      009130
      AOLD=AFT(3)                                                         009140
      BOLD=AFT(4)                                                         009150
      POLD=AFT(9)                                                         009160
      QOLD=AFT(8)                                                         009170
      ROLD=AFT(7)                                                         009180
      DOLD=DSRFT                                                          009190
15    DA=AFT(3)-AOLD                                                      009200
      DB=AFT(4)-BOLD                                                      009210
      DP=AFT(9)-POLD                                                      009220
      DQ=AFT(8)-QOLD                                                      009230
      DR=AFT(7)-ROLD                                                      009240
      DD=DSRFT-DOLD                                                       009250
      DADOT=AFT(16)-ADTOLD                                                009260
      FOR(10)=AC(1)/G                                                     009270
      TXB=TF(1)*COS(AFT(1))*COS(AFT(2))                                   009280
```

```
      TYB=TF(1)*COS(AFT(1))*SIN(AFT(2))                                  009290
      TZB=-TF(1)*SIN(AFT(1))*COS(AFT(2))                                 009300
13    CALL TRANB2W(TXB,TYB,TZB,AFT(3),AFT(4),TXW,TYW,TZW)                009310
      FOR(12)=AFT(6)-AFT(3)*COS(AFT(10))                                 009320
      FOR(13)=AFT(5)+AFT(4)*SIN(AFT(10))                                 009330
      FOR(11)=AFT(10)                                                    009340
      CL=CEF1+CEF2*DA+CEF18*DELMACH+CEF13*DD                             009350
      CLMAX=AC(15)/TF(7)*AC(1)/AC(2)                                     009360
      IF(CL-CLMAX)11,11,12                                               009370
******TEST OF CL VERSUS CLMAX******                                      009380
12    DIN(1)=DIN(1)-(CL-CLMAX)/CLMAX*DIN(1)                              009390
      ERALPHA=DIN(1)-AFT(3)                                              009400
      AFT(16)=AFT(13)*(ERALPHA/AFT(13)/DT)**2                            009410
      IF(AFT(16).LE.ABS(ERALPHA/2.0/DT))AFT(16)=ABS(ERALPHA/2.0/DT)      009420
      IF(AFT(16).GE.AFT(13)) AFT(16)=AFT(13)                             009430
      AFT(3)=AFT(3)+SIGN(AFT(16)*DT,ERALPHA)                             009440
      GO TO 13                                                           009450
11    FTLIFT=CL*TF(7)*AC(2)                                              009460
      CD=CEF3+CEF4*DA+CEF19*DELMACH                                      009470
      DRAG=CD*TF(7)*AC(2)                                                009480
      CY=CEF23*DB+CEF17*DR                                               009490
      SIDEFOR=CY*TF(7)*AC(2)                                             009500
      CLL=CEF21*DB+CEF9*DP*AC(3)/(2.*TF(5))                              009510
     ++CEF10*DR*AC(3)/(2.*TF(5))+CEF15*DB                                009520
      RMOM=CLL*TF(7)*AC(2)                                               009530
      CM=CEF5+CEF6*DA+CEF7*DQ*AC(4)/(2.*TF(5))+                          009540
     +CEF20*DELMACH+CEF8*DADDT*AC(4)/(2.*TF(5))+CEF14*DD                 009550
      PMOM=CM*TF(7)*AC(2)                                                009560
      CN=CEF22*DB+CEF11*DR*AC(3)/(2.*TF(5))+                             009570
     +CEF12*DP*AC(3)/(2.*TF(5))+CEF15*DB                                 009580
      YMOM=CN*TF(7)*AC(2)                                                009590
      FOR(1)=TXW-DRAG-FOR(10)*G*SIN(FOR(12))                             009600
      FOR(2)=TYW-SIDEFOR+FOR(10)*G*COS(FOR(12))*SIN(FOR(11))             009610
      FOR(3)=TZW-FTLIFT+FOR(10)*G*COS(FOR(12))*COS(FOR(11))              009620
      FOR(7)=FOR(2)/(FOR(10)*TF(5))                                      009630
      FOR(8)=-FOR(3)/(FOR(10)*TF(5))                                     009640
```

```
 FOR(9)=AFT(9)*COS(AFT(3))*COS(AFT(4))+(AFT(8)-AFT(15))*SIN(AFT(4)  009650
+)+AFT(7)*SIN(AFT(3))*COS(AFT(4))                                   009650
 FOR(4)=R1OM*COS(AFT(3))-Y1OM*SIN(AFT(3))                           009670
 FOR(5)=P1OM                                                        009680
 FOR(6)=R1OM*SIN(AFT(3))+Y1OM*COS(AFT(3))                           009690
 REALMAC=TF(6)                                                      009700
 ADTOLD=AFT(15)                                                     009710
 AOLD=AFT(3)                                                        009720
 BOLD=AFT(4)                                                        009730
 DOLD=DSRFT                                                         009740
 POLD=AFT(9)                                                        009750
 QOLD=AFT(8)                                                        009760
 ROLD=AFT(7)                                                        009770
 RETURN                                                             009780
 END                                                                009790
                                                                    009800
```

```
      SUBROUTINE FORCESM(LOCK,DM,FORM,DATAM,G,ATM,AM)                    009320
      DIMENSION FORM(3),DATAM(15),ATM(19),AM(8),DM(6)                   009330
*****************************************************************     009340
*       THIS SUBROUTINE COMPUTES THE FORCES ACTING ON THE MISSILE.      *009350
*****************************************************************     009360
1     FORM(2)=AM(7)*FORM(1)/G                                           009370
      FORM(3)=-AM(8)*FORM(1)/G                                          009380
      IF(ABS(FORM(2)).LE.DM(6).AND.ABS(FORM(3)).LE.DM(6))RETURN         009390
      LOCK=1                                                            009400
******TEST OF VERTICAL AND HORIZONTAL G FORCES ON THE MISSILE******    009410
      IF(ABS(FORM(2)).GT.DM(6))AM(7)=DM(6)*G/FORM(1)                    009420
      IF(ABS(FORM(3)).GT.DM(6))AM(8)=-DM(6)*G/FORM(1)                   009430
      CALL INPUTSM(LOCK,PI,ATM,DT,AM,DINM,DM)                           009440
      GO TO 1                                                           009450
      END                                                               009460
                                                                        009470
```

```
      SUBROUTINE F(PI,T,Y,P,FORF,AC)                                    009990
      DIMENSION Y(9),P(9),FORF(13),AC(15)                               010000
*********************************************************************010010
*       THIS SUBROUTINE CONTAINS THE DIFFERENTIAL EQUATIONS OF MOTION   *010020
*       FOR USE IN SUBROUTINE RKDESF.                                   *010030
*********************************************************************010040
      P(1)=FORF(1)/FORF(10)                                             010050
      P(2)=(FORF(4)+AC(14)*Y(2)*Y(3)+(AC(12)-AC(13))*Y(3)*Y(4))/AC(11)  010060
      P(3)=(FORF(5)+AC(14)*(Y(4)**2-Y(2)**2)+(AC(13)-AC(11))*Y(4)*Y(2))/010070
     +AC(12)                                                            010080
      P(4)=(FORF(6)+AC(14)*Y(3)*Y(4)+(AC(11)-AC(12))*Y(2)*Y(3))/AC(13)  010090
      IF(ABS(Y(5))-PI/2.0.GT.-.05) GO TO 5                              010100
      P(6)=(FORF(8)*SIN(FORF(11))+FORF(7)*COS(FORF(11)))/COS(Y(5))      010110
      GO TO 10                                                          010120
5     P(6)=FORF(8)                                                      010130
10    P(5)=FORF(8)*COS(FORF(11))-FORF(7)*SIN(FORF(11))                  010140
      P(7)=Y(1)*COS(Y(5))*COS(Y(6))                                     010150
      P(8)=Y(1)*COS(Y(5))*SIN(Y(6))                                     010160
      P(9)=-Y(1)*SIN(Y(5))                                              010170
      RETURN                                                            010180
      END                                                               010190
                                                                        010200
```

```
      SUBROUTINE UPDATEF(TT,AFT,FORF,DATA,PI,T,DT,AC)                    010220
      DIMENSION X(9)                                                     010230
      DIMENSION TT(7),AFT(15),FORF(13),DATA(12),AC(15)                   010240
*****************************************************************      010250
*     THIS SUBROUTINE UPDATES THE EQUATION OF MOTIONS FOR THE AIRCRAFT.*010260
*****************************************************************      010270
      N=9                                                                010280
      X(1)=TT(5)                                                         010290
      IF(TT(5).EQ.0.0)X(1)=.0001                                         010300
      X(2)=AFT(9)                                                        010310
      IF(AFT(9).EQ.0.0)X(2)=.0001                                        010320
      X(3)=AFT(8)                                                        010330
      IF(AFT(8).EQ.0.0)X(3)=.0001                                        010340
      X(4)=AFT(7)                                                        010350
      IF(AFT(7).EQ.0.0)X(4)=.0001                                        010360
      X(5)=FORF(12)                                                      010370
      IF(FORF(12).EQ.0.0)X(5)=.0001                                      010380
      X(6)=FORF(13)                                                      010390
      IF(FORF(13).EQ.0.0)X(6)=.0001                                      010400
      X(7)=DATA(1)                                                       010410
      IF(DATA(1).EQ.0.0)X(7)=.0001                                       010420
      X(8)=DATA(2)                                                       010430
      IF(DATA(2).EQ.0.0)X(8)=.0001                                       010440
      X(9)=DATA(3)                                                       010450
      IF(DATA(3).EQ.0.0)X(9)=.0001                                       010460
      CALL RKDESF(PI,T,X,N,DT,FORF,AC)                                   010470
      TT(5)=X(1)                                                         010480
      AFT(9)=X(2)                                                        010490
      AFT(8)=X(3)                                                        010500
      AFT(7)=X(4)                                                        010510
      AFT(6)=X(5)+AFT(3)*COS(AFT(10))                                    010520
      IF(AFT(6).GT.PI/2.0)AFT(6)=PI-AFT(6)                               010530
      IF(AFT(6).LT.-PI/2.)AFT(6)=-PI-AFT(6)                              010540
      AFT(5)=X(5)-AFT(4)*SIN(AFT(10))                                    010550
      IF(AFT(5).GT.2.*PI)AFT(5)=AFT(5)-2.*PI                             010560
      IF(AFT(5).LT.0.0)AFT(5)=2.*PI+AFT(5)                               010570
```

```
DATA(4)=(X(7)-DATA(1))/DT                                          010580
DATA(5)=(X(8)-DATA(2))/DT                                          010590
DATA(6)=(X(9)-DATA(3))/DT                                          010600
DATA(1)=X(7)                                                       010610
DATA(2)=X(8)                                                       010620
DATA(3)=X(3)                                                       010630
IF(AFT(10).GT.PI) AFT(10)=AFT(10)-2.*PI                            010640
IF(AFT(10).LT.-PI) AFT(10)=AFT(10)+2.*PI                           010650
RETURN                                                             010660
END                                                                010670
                                                                   010680
```

```
      SUBROUTINE INPUTSF(DT,AFT,DINF,AC,TF)                              010700
      DIMENSION AFT(16),DINF(4),AC(15),TF(7)                             010710
*********************************************************************** 010720
*  THIS SUBROUTINE PROVIDES THE FINITE CONTROL INPUTS FOR THE AIRCRAFT.* 010730
*********************************************************************** 010740
      DELALPH=DINF(1)-AFT(3)                                             010750
      DELBETA=DINF(2)-AFT(4)                                             010760
      DELPHI=DINF(3)-AFT(10)                                             010770
      DELTRST=DINF(4)-TF(1)                                              010780
      AFT(16)=AFT(13)*(DELALPH/(AFT(13)*4.))**2                          010790
      IF(AFT(16).LE.ABS(DELALPH))AFT(16)=ABS(DELALPH)                    010800
      IF(AFT(16).GE.AFT(13))AFT(16)=AFT(13)                              010810
      AFT(3)=AFT(3)+SIGN(AFT(16)*DT,DELALPH)                             010820
      BETADOT=AFT(14)*(DELBETA/(AFT(14)*3.))**2                          010830
      IF(BETADOT.LE.ABS(DELBETA))BETADOT=ABS(DELBETA)                    010840
      IF(BETADOT.GE.AFT(14))BETADOT=AFT(14)                              010850
      AFT(4)=AFT(4)+SIGN(BETADOT*DT,DELBETA)                             010860
      PHIDOT=AFT(15)*(DELPHI/(AFT(15)*12.))**2                           010870
      IF(PHIDOT.LE.ABS(DELPHI))PHIDOT=ABS(DELPHI)                        010880
      IF(PHIDOT.GE.AFT(15))PHIDOT=AFT(15)                                010890
      AFT(10)=AFT(10)+SIGN(PHIDOT*DT,DELPHI)                             010900
      TRSTDOT=TF(4)*(DELTRST/(4.*AC(5)))**2                              010910
      IF(TRSTDOT.LE.ABS(DELTRST))TRSTDOT=ABS(DELTRST)                    010920
      IF(TRSTDOT.GE.AC(5))TRSTDOT=AC(5)                                  010930
      TF(1)=TF(1)+SIGN(TRSTDOT*DT,DELTRST)                               010940
      RETURN                                                             010950
      END                                                                010960
                                                                         010970
```

```
      SUBROUTINE PRINT(DM,DT,KF,KM,ABM,ATM,INDEX,PI,TIME,AFT,AM,ATF,DATA010990
     +FT,DATAM,ABF)                                                     011000
      DIMENSION AFT(16),AM(8),ATF(19),DATAFT(12),DATAM(15)              011010
      DIMENSION ATM(19),ABF(5),ABM(6),DM(6)                             011020
C*********************************************************************011030
C*      THIS SUBROUTINE PROVIDES A PRINTOUT OF THE NECESSARY INFORMATION*011040
C*      AND CALLS SUBROUTINES ATTACKF AND ATTACKM TO UPDATE THE         *011050
C*      RELATIVE POSITIONS.                                            *011060
C*********************************************************************011070
      CALL ATTACKF(KF,PI,ATF,DATAFT,DATAM,AFT,AM,ABF)                   011080
      CALL ATTACKM(DM,DT,INDEX,ATF,KM,PI,ATM,DATAM,DATAFT,AM,AFT,ABM,   011090
     +TIME)                                                             011100
      IF(INDEX.EQ.0)GO TO 5                                             011110
      INTER=IFIX(.5000001/DT)                                           011120
      IF(MOD(INDEX,INTER).NE.0)RETURN                                   011130
5     PSIFTED=RAD2DEG(AFT(5))                                           011140
      THEFTED=RAD2DEG(AFT(5))                                           011150
      PHIFTED=RAD2DEG(AFT(10))                                          011160
      PSIMED=RAD2DEG(AM(5))                                             011170
      THEMED=RAD2DEG(AM(5))                                             011180
      ZETF2MD=RAD2DEG(ATF(3))                                           011190
      ETAF2MD=RAD2DEG(ATF(9))                                           011200
      ZETDTMD=RAD2DEG(ATF(16))                                          011210
      ETADTMD=RAD2DEG(ATF(17))                                          011220
      PRINT 1,TIME                                                      011230
1     FORMAT(1H0,//4X,*TOTAL ELAPSED TIME IS*,F5.2,* SECONDS.*)         011240
      PRINT 10                                                          011250
10    FORMAT(1H0,9X,*THE AIRCRAFT'S STATE IN THE EARTH SURFACE FIXED REF011260
     +ERENCE FRAME IS:*)                                                011270
      PRINT 2,DATAFT(1),DATAFT(4),DATAFT(2),DATAFT(5),DATAFT(3),DAT     011280
     +AFT(6),PSIFTED,THEFTED,PHIFTED                                    011290
2     FORMAT(15X,*POSITION*,27X,*VELOCITY*,/20X,*X= *,F7.0,* FEET*,19X, 011300
     +*U= *,F7.0,* FEET/SECOND*,/20X,*Y= *,F7.0,* FEET*,19X,*V= *,F7.   011310
     +0,* FEET/SECOND*,/20X,*Z= *,F7.0,* FEET*,19X,*W= *,F7.0,* FEET/SEC011320
     +OND*,/15X,*ORIENTATION*,/20X,*HEADING (PSI)=*,F5.0,*DEGREES*/     011330
     +20X,*FLIGHT PATH ANGLE (THETA)=*,F5.0,* DEGREES*,/20X,*BANK ANGLE 011340
```

```
     + (PHI)=*,F5.0,* DEGREES*)                                                 011350
      PRINT 20                                                                  011360
20    FORMAT(1H0,9X,*THE MISSILE'S STATE IN THE EARTH SURFACE FIXED REFE        011370
     +RENCE FRAME IS:*)                                                         011380
      PRINT +,DATAM(1),DATAM(4),DATAM(2),DATAM(5),DATAM(3),DATAM(6)             011390
     +,PSIMED,THEMED                                                            011400
4     FORMAT(15X,*POSITION*,27X,*VELOCITY*,/20X,*X= *,F7.0,* FEET*,19X,         011410
     +*U= *,F7.0,* FEET/SECOND*,/20X,*Y= *,F7.0,* FEET*,19X,*V= *,F7.          011420
     +0,* FEET/SECOND*,/20X,*Z= *,F7.0,* FEET*,19X,*W= *,F7.0,* FEET/SEC       011430
     +OND*,/15X,*ORIENTATION*,/20X,*HEADING (PSI)=*,F5.0,*DEGREES*,/           011440
     +20X,*FLIGHT PATH ANGLE (THETA)=*,F5.0,* DEGREES*)                         011450
      PRINT 3,ATF(4),ATF(10),ZETF2MD,ZETDTMD,ETAF2MD,ETADTMD                    011460
3     FORMAT(1H0,9X,*THE FIGHTER PILOT SEES THE MISSILE AT:*,/15X,*RANGE        011470
     += *,F8.1,* FEET*,15X,*RANGE RATE= *,F8.1,* FEET/SECOND*,/15X,*AZIM       011480
     +UTH= *,F7.1,* DEGREES*,11X,*AZIMUTH RATE= *,F8.1,* DEGREES/SECOND        011490
     +*,/15X,*ELEVATION= *,F7.1,* DEGREES*,9X,*ELEVATION RATE= *,F8.1,         011500
     +* DEGREES/SECOND*,//)                                                     011510
      RETURN                                                                    011520
      END                                                                       011530
                                                                                011540
```

```
      SUBROUTINE TRANB2W(XB,YB,ZB,ALPHA,BETA,XW,YW,ZW)                    011550
*************************************************************************011570
*       THIS SUBROUTINE TRANSFERS A VECTOR FROM THE BODY FRAME TO THE   *011580
*       WIND FRAME.                                                     *011590
*************************************************************************011600
      XW=XB*COS(BETA)*COS(ALPHA)+YB*SIN(BETA)*COS(ALPHA)+ZB*SIN(ALPHA)  011610
      YW=-XB*SIN(BETA)+YB*COS(BETA)                                     011620
      ZW=-XB*COS(BETA)*SIN(ALPHA)-YB*SIN(BETA)*SIN(ALPHA)+ZB*COS(ALPHA) 011630
      RETURN                                                            011640
      END                                                               011650
                                                                        011660
```

```
      SUBROUTINE TRANV23(XV,YV,ZV,ALPHA,BETA,GAMMA,XB,YB,ZB)              011580
*************************************************************************011590
*       THIS SUBROUTINE TRANSFERS A VECTOR FROM THE NAVIGATION FRAME     *011700
*       TO THE BODY FRAME.                                               *011710
*************************************************************************011720
      XB=XV*COS(BETA)*COS(ALPHA)+YV*COS(BETA)*SIN(ALPHA)-ZV*SIN(BETA)    011730
      YB=XV*(SIN(GAMMA)*SIN(BETA)*COS(ALPHA)-COS(GAMMA)*SIN(ALPHA))+YV*(011740
     +SIN(GAMMA)*SIN(BETA)*SIN(ALPHA)+COS(GAMMA)*COS(ALPHA))+ZV*SIN(GAMM011750
     +A)*COS(BETA)                                                       011760
      ZB=XV*(COS(GAMMA)*SIN(BETA)*COS(ALPHA)+SIN(GAMMA)*SIN(ALPHA))+YV*(011770
     +COS(GAMMA)*SIN(BETA)*SIN(ALPHA)-SIN(GAMMA)*COS(ALPHA))+ZV*COS(GAMM011780
     +A)*COS(BETA)                                                       011790
      RETURN                                                           011800
      END                                                              011810
                                                                       011820
```

```
      FUNCTION RAD2DEG(RAD)                                                011340
*************************************************************************011350
*       THIS FUNCTION TRANSFERS AN ANGLE FROM RADIANS TO DEGREES.       *011360
*************************************************************************011370
      DEG=RAD*57.2957795131                                                011380
      RAD2DEG=DEG                                                          011390
      RETURN                                                               011400
      END                                                                  011410
                                                                           011420
```

```
      FUNCTION DEG2RAD(DEG,MIN,SEC)                                     011940
*****************************************************************     011950
*       THIS FUNCTION TRANSFERS AN ANGLE FROM DEGREES TO RADIANS.     *011960
*****************************************************************     011970
      RAD=0.                                                            011980
      RAD=RAD+DEG/57.2957795131                                         011990
      RAD=RAD+MIN/3437.7467707849                                       012000
      RAD=RAD+SEC/206264.80625                                          012010
      DEG2RAD=RAD                                                       012020
      RETURN                                                            012030
      END                                                               012040
                                                                        012050
```

```
      SUBROUTINE RKDESF(PI,X,Y,N,DX,FORF,AC)                                    012070
      DIMENSION Y(99),Y0(99),YT(99),YP(99),P0(99),P1(99),P2(99),P3(99)          012080
      DIMENSION FORF(13),AC(15)                                                 012090
      IF(N.LT.100) GO TO 1                                                      012100
      PRINT 100, N                                                              012110
  100 FORMAT(1HA,10X,11HTHE ORDER (,I3,27H) OF THE SYSTEM EXCEEDS 99.,/,        012120
     C          11X,47HCHANGE DIMENSION STATEMENT IN SUBROUTINE RKDES.,        012130
     C         /,11X,18HEXECUTION DELETED.)                                     012140
      STOP                                                                      012150
    1 X0=X                                                                      012160
      X=X+DX                                                                    012170
      H=DX                                                                      012180
    2 IF(ABS(H).GT.ABS(X-X0)) H=X-X0                                            012190
      DO 4 I=1,N                                                                012200
    4 Y0(I)=Y(I)                                                                012210
      HT=H                                                                      012220
      XT=X0                                                                     012230
      RMAXP = 1.E37                                                             012240
      DO 5 I=1,N                                                                012250
    5 YT(I)=Y0(I)                                                               012260
      ASSIGN 6 TO K                                                             012270
      GO TO 20                                                                  012280
    6 DO 7 I=1,N                                                                012290
    7 YP(I)=Y(I)                                                                012300
    8 HT=0.5*H                                                                  012310
      ASSIGN 9 TO K                                                             012320
      GO TO 20                                                                  012330
    9 DO 10 I=1,N                                                               012340
   10 YT(I)=Y(I)                                                                012350
      XT=X0+HT                                                                  012360
      ASSIGN 11 TO K                                                            012370
   20 CALL F(PI,XT,YT,P0,FORF,AC)                                               012380
      DO 21 I=1,N                                                               012390
   21 Y(I)=YT(I)+0.5*HT*P0(I)                                                   012400
      CALL F(PI,XT+0.5*HT,Y,P1,FORF,AC)                                         012410
      DO 22 I=1,N                                                               012420
```

```
22    Y(I)=YT(I)+.5*HT*P1(I)                                                012430
      CALL F(PI,XT+0.5*HT,Y,P2,FORF,AC)                                     012440
      DO 23 I=1,N                                                           012450
23    Y(I)=YT(I)+HT*P2(I)                                                   012460
      CALL F(PI,XT+HT,Y,P3,FORF,AC)                                         012470
      DO 24 I=1,N                                                           012480
24    Y(I)=YT(I)+HT*(P0(I)+2.*(P1(I)+P2(I))+P3(I))/6.                       012490
      GO TO (5,9,11)                                                        012500
11    RMAX=0.                                                               012510
      DO 12 I=1,N                                                           012520
12    RMAX=AMAX1(RMAX,.07*ABS((Y(I)-YP(I))/Y(I)))                           012530
      IF ((RMAX.GT.1.E-05).AND.(RMAX.LT.RMAXP)) GO TO 17                    012540
      X0=X0+H                                                               012550
      IF(X0.EQ.X) RETURN                                                    012560
      IF((RMAX.LT.1.E-7).OR.(RMAX.GT.RMAXP)) H=H+H                          012570
      GO TO 2                                                               012580
17    H=HT                                                                  012590
      XT=X0                                                                 012600
      DO 19 I=1,N                                                           012610
18    YP(I)=YT(I)                                                           012620
19    YT(I)=Y0(I)                                                           012630
      RMAXP = RMAX                                                          012640
      GO TO 8                                                               012650
      END                                                                   012660
                                                                            012670
```

```
      FUNCTION TBLNDC(NEXTR,ND,Z,X,NA,XA)                                012690
*****************************************************************************012700
C                                                                       012710
C     PURPOSE                                                           012720
C                                                                       012730
C       GIVEN THE ARGDATAM(4)NTS,X1,X2,....,XN COMPUTE                  012740
C       Y=F(X1,X2,...,XN) FROM A TABLE OF XCS AND YCS                   012750
C       BY LINEAR INTERPOLATION                                         012760
C                                                                       012770
C     CONTROL                                                           012780
C                                                                       012790
C       REAL FUNCTION, REAL AND INTEGER ARGDATAM(4)NTS                  012800
C                                                                       012810
C     CALLING SEQUENCE                                                  012820
C       Y=TBLNDC(K,M,TABLEY,TABLEX,NA,XA)                               012830
C         WHERE                                                         012840
C         K=0, NO EXTRAPOLATION.  K NOT EQUALTO 0, EXTRAPOLATION.       012850
C         M= DIMENSION OF TABLE LOOK-UP (IF Y=F(X1,X2), THEN M=3)       012860
C         TABLEY IS THE TABLE OF DEPENDENT PARAMETERS                   012870
C         TABLEX IS THE TABLE OF INDEPENDENT VECTORS.  EACH VECTOOR MUST012880
C                BE IN ASCENDING ORDER.                                 012890
C         NA(1),NA(2),...,NA(N) ARE THE LENGTHS OF THE N TABLEX VECTORS.012900
C         XA(1),XA(2),...,XA(N) ARE THE N INDEPENDENT PARAMETERS WHERE N012910
C                EXAMPLE.  TABLEX          TABLEY                       012920
C                N=3          A1        F(A1,B1,C1)                    012930
C                M=4          A2        F(A1,B1,C2)                    012940
C                NA(1)=2      B1        F(A1,B2,C1)                    012950
C                NA(2)=2      B2        F(A1,B2,C2)                    012960
C                NA(3)=2      C1        F(A2,B1,C1)                    012970
C                             C2        F(A2,B1,C2)                    012980
C                                       F(A2,B2,C1)                    012990
C                                       F(A2,B2,C2)                    013000
C                                                                       013010
C     ERROR CONDITIONS                                                  013020
C                                                                       013030
C  1.  AT LEAST ONE OF THE INDEPENDENT VECTORS IS NOT                   013040
```

```
C         IN ASCENDING ORDER.                                                  013050
C   2.  AT LEAST ONE OF THE INDEPENDENT PARAMETERS IS OUT OF                   013060
C         RANGE OF TABLES AND K=0.                                             013070
C   3.  DIMENSION OF TABLE LOOK-UP(M) IS GREATER THAN 6.                       013080
C       AN ERROR MESSAGE IS PRINTED IN EACH CASE                               013090
C       AND A STOP OCCURS.                                                     013100
C                                                                              013110
*******************************************************************************013120
      DIMENSION X(1),NA(1),XA(1),NS(5),WJ(32),RATIO(5),NGROUP(5),              013130
     1ITOT(5),Z(1)                                                             013140
      IF(ND.LE.6)GO TO 1                                                       013150
      PRINT 2                                                                  013160
 2    FORMAT(1H1,10X,23HERROR CONDITION-TBLND ROUTINE)                         013170
      PRINT 5, ND                                                              013180
 5    FORMAT(11X,30HDIMENSION OF TABLE LOOK-UP (M=,                            013190
     1I2,19H) IS GREATER THAN 6)                                               013200
 1    L1=2                                                                     013210
      LF=ND-1                                                                  013220
      DO 3 I=1,LF                                                              013230
      L2=L1+NA(I)-2                                                            013240
      FOUND=0.                                                                 013250
      DO 4 J=L1,L2                                                             013260
      IF(X(J).GT.X(J-1)) GO TO 6                                               013270
      PRINT 2                                                                  013280
      PRINT 40, I                                                              013290
 40   FORMAT(11X,23HINDEPENDENT VECTOR NO. ,I2,20H IS NOT IN ASCENDING         013300
     27H ORDER.)                                                               013310
      CALL SYSTEM(200,0)                                                       013320
    6 IF (FOUND.NE.0.) GO TO 4                                                 013330
      IF (XA(I)-X(J-1))8,4,4                                                   013340
    8 IF (J.GT.L1) GO TO 10                                                    013350
      IF (NEXTR.EQ.0) GO TO 37                                                 013360
      FOUND=1.                                                                 013370
      NS(I)=L1-1                                                               013380
      GO TO 4                                                                  013390
   10 FOUND=1.                                                                 013400
```

```
      NS(I)=J-2                                                          013410
    4 CONTINUE                                                           013420
      IF (FOUND) 11,12,11                                                013430
   12 IF (XA(I)-X(L2))13,13,14                                           013440
   14 IF (NEXTR.NE.0) GO TO 13                                           013450
   37 PRINT 2                                                            013460
      PRINT 41, I                                                        013470
   41 FORMAT(11K,26HINDEPENDENT PARAMETER NO. ,I2,17H IS OUT OF RANGE    013480
     244HOF CORRESPONDING INDEPENDENT VECTOR AND K=0.)                   013490
      CALL SYSTEM(200,0)                                                 013500
   13 NS(I)=L2-1                                                         013510
   11 L1=L2+2                                                            013520
    3 CONTINUE                                                           013530
C     IN NS(I) IS THE SUBSCRIPT IN THE ARRAY X SUCH THAT                 013540
C     X(NS(I)) IS LESS THAN THE ITH ARGDATUM(4)NT                        013550
      DO 15 I=1,LF                                                       013560
      K=NS(I)                                                            013570
      RATIO(I)=(XA(I)-X(K))/(X(K+1)-X(K))                                013580
C     IN RATIO(1) IS THE RATIO OF X ARG, RATIO(2)=RATIO OF Y ETC.        013590
   15 CONTINUE                                                           013600
      NGROUP(1)=NS(1)                                                    013610
      NSUM=NA(1)                                                         013620
      DO 16 I=2,LF                                                       013630
      NGROUP(I)=NS(I)-NSUM                                               013640
      NSUM=NSUM+NA(I)                                                    013650
   16 CONTINUE                                                           013660
C     IN NGROUP(I) IS THE SUBSCRIPT OF THE ITH VARIABLE SUCH             013670
C     THAT THE TABLE VALUE IS LESS THAN THE CORRESPONDING ARGDATUM(4)NT  013680
C     THIS IS IN TERMS OF THIS VARIABLE ONLY                             013690
C     FOR A FUNCTION OF DEGREE ND WE NEED2**(ND-1) VALUES                013700
C     FROM THE Z ARRAY                                                   013710
      ITOT(LF)=1                                                         013720
      DO 17 I=2,LF                                                       013730
      J=LF-I+1                                                           013740
      ITOT(J)=ITOT(J+1)*NA(J+1)                                          013750
   17 CONTINUE                                                           013760
```

```
C     IN ITOT(J) IS THE NUMBER OF LOCATIONS IN THE Z ARRAY NEEDED TO CHA013770
C     THE JTH SUBSCRIPT                                                 013780
      KF=2**LF                                                          013790
      MW=-2                                                             013800
      DO 22 I=1,KF,2                                                    013810
      IFIRST=1                                                          013820
      MW=MW+2                                                           013830
      DO 21 J=1,LF                                                      013840
      MM=2**(J-1)                                                       013850
      IF(AND(MM,MW).EQ.0)GO TO 18                                       013860
      IMON=NGROUP(J)+1                                                  013870
      GO TO 19                                                          013880
   18 IMON=NGROUP(J)                                                    013890
   19 IFIRST=IFIRST+(IMON-1)*ITOT(J)                                    013900
   21 CONTINUE                                                          013910
      ISEC=IFIRST+ITOT(1)                                               013920
      WJ(I)=Z(IFIRST)                                                   013930
      WJ(I+1)=Z(ISEC)                                                   013940
   22 CONTINUE                                                          013950
      DO 24 I=1,LF                                                      013960
      KF=KF/2                                                           013970
      DO 24 J=1,KF                                                      013980
   24 WJ(J)=WJ(2*J-1)+(WJ(2*J)-WJ(2*J-1))*RATIO(I)                      013990
      TBLNDC=WJ(1)                                                      014000
      RETURN                                                            014010
      END                                                               014020
                                                                        014030
```

```
      SUBROUTINE INPUTSM(LOCK,PI,ATM,DT,AM,DINM,DM)                     014050
      DIMENSION AM(8),DINM(2),DM(6),ATM(19)                             014060
*****************************************************************     014070
*  THIS SUBROUTINE PROVIDES THE FINITE CONTROL INPUTS FOR THE MISSILE. *014080
*  IF ANY PARAMETER EXCEEDS THE MAXIMUM, THE MISSILE GOES BALISTIC.    *014090
*****************************************************************     014100
      DELPHI=DINM(1)-AM(5)                                              014110
      DELTHET=DINM(2)-AM(6)                                             014120
      IF(LOCK.EQ.1)GO TO 1                                              014130
      AM(7)=3.*ATM(16)/(DM(5)+1.)                                       014140
      AM(8)=3.*ATM(17)/(DM(5)+1.)                                       014150
      IF(AM(7).LE.ABS(DELPHI))AM(7)=ABS(DELPHI)                         014160
      IF(AM(8).LE.ABS(DELTHET))AM(8)=ABS(DELTHET)                       014170
      IF(ABS(AM(7)).GE.AM(3))AM(7)=AM(3)                                014180
      IF(ABS(AM(8)).GE.AM(4))AM(8)=AM(4)                                014190
1     AM(5)=AM(5)+SIGN(AM(7)*DT,DELPHI)                                 014200
      AM(6)=AM(6)+SIGN(AM(8)*DT,DELTHET)                                014210
      IF(AM(5).GT.2.*PI)AM(5)=AM(5)-2.*PI                               014220
      IF(AM(5).LT.0.0)AM(5)=2.*PI+AM(5)                                 014230
      IF(AM(5).GT.PI/2.)AM(5)=PI-AM(5)                                  014240
      IF(AM(6).LT.-PI/2.)AM(6)=-PI-AM(6)                                014250
      RETURN                                                            014260
      END                                                               014270
                                                                        014280
```

```
      SUBROUTINE M(T,Y,P,FORM,AM)                                       014300
      DIMENSION Y(3),P(3),FORM(3),AM(3)                                 014310
*********************************************************************** 014320
*       THIS SUBROUTINE CONTAINS THE DIFFERENTIAL EQUATIONS OF MOTION   *014330
*       FOR USE IN SUBROUTINE RKDESM.                                   *014340
*********************************************************************** 014350
      P(1)=FORM(1)*COS(AM(6))*COS(AM(5))                                014360
      P(2)=FORM(1)*COS(AM(6))*SIN(AM(5))                                014370
      P(3)=-FORM(1)*SIN(AM(6))                                          014380
      RETURN                                                            014390
      END                                                               014400
                                                                        014410
```

```
      SUBROUTINE UPDATE1(DATAM,DT,AM,FORM,T)                            014430
      DIMENSION X(3),DATAM(15),AM(8)                                    014440
*****************************************************************     014450
*     THIS SUBROUTINE UPDATES THE EQUATIONS OF MOTIONS FOR THE MISSILE.*014460
*****************************************************************     014470
      N=3                                                               014480
      DO 1 I=1,3                                                        014490
      X(I)=DATAM(I)                                                     014500
      IF(DATAM(I).EQ.0.0)X(I)=.0001                                     014510
1     CONTINUE                                                          014520
      CALL RKDESM(T,X,N,DT,FORM,AM)                                     014530
      DO 2 I=1,3                                                        014540
      DATAM(I+3)=(X(I)-DATAM(I))/DT                                     014550
      DATAM(I)=X(I)                                                     014560
2     CONTINUE                                                          014570
      RETURN                                                            014580
      END                                                               014590
                                                                        014600
```

```
      SUBROUTINE RKDESM(X,Y,N,DX,FORM,AM)                                    014320
      DIMENSION Y(99),Y0(99),YT(99),YP(99),P0(99),P1(99),P2(99),P3(99)       014330
      DIMENSION FORM(3),AM(8)                                                014340
      IF(N.LT.100) GO TO 1                                                   014350
      PRINT 100, N                                                           014360
  100 FORMAT(1HA,10X,11HTHE ORDER (,I3,27H) OF THE SYSTEM EXCEEDS 99.,/,     014370
     C          11X,47HCHANGE DIMENSION STATEMENT IN SUBROUTINE RKDES.,      014380
     C        /,11X,18HEXECUTION DELETED.)                                   014390
      STOP                                                                   014400
    1 X0=X                                                                   014410
      X=X+DX                                                                 014420
      H=DX                                                                   014430
    2 IF(ABS(H).GT.ABS(X-X0)) H=X-X0                                         014440
      DO 4 I=1,N                                                             014450
    4 Y0(I)=Y(I)                                                             014460
      HT=H                                                                   014470
      XT=X0                                                                  014480
      RMAXP = 1.E37                                                          014490
      DO 5 I=1,N                                                             014500
    5 YT(I)=Y0(I)                                                            014510
      ASSIGN 6 TO K                                                          014520
      GO TO 20                                                               014530
    6 DO 7 I=1,N                                                             014540
    7 YP(I)=Y(I)                                                             014550
    8 HT=0.5*H                                                               014560
      ASSIGN 9 TO K                                                          014570
      GO TO 20                                                               014580
    9 DO 10 I=1,N                                                            014590
   10 YT(I)=Y(I)                                                             014600
      XT=X0+HT                                                               014610
      ASSIGN 11 TO K                                                         014620
   20 CALL M(XT,YT,P0,FORM,AM)                                               014630
      DO 21 I=1,N                                                            014640
   21 Y(I)=YT(I)+0.5*HT*P0(I)                                                014650
      CALL M(XT+0.5*HT,Y,P1,FORM,AM)                                         014660
      DO 22 I=1,N                                                            014670
```

```
   22   Y(I)=YT(I)+.5*HT*P1(I)                                          014980
        CALL M(XT+0.5*HT,Y,P2,FORM,AM)                                  014990
        DO 23 I=1,N                                                     015000
   23   Y(I)=YT(I)+HT*P2(I)                                             015010
        CALL M(XT+HT,Y,P3,FORM,AM)                                      015020
        DO 24 I=1,N                                                     015030
   24   Y(I)=YT(I)+HT*(P0(I)+2.*(P1(I)+P2(I))+P3(I))/6.                 015040
        GO TO (5,9,11)                                                  015050
   11   RMAX=0.                                                         015060
        DO 12 I=1,N                                                     015070
   12   RMAX=AMAX1(RMAX,.07*ABS((Y(I)-YP(I))/Y(I)))                     015080
        IF ((RMAX.GT.1.E-05).AND.(RMAX.LT.RMAXP)) GO TO 17              015090
        X0=X0+H                                                         015100
        IF(X0.EQ.X) RETURN                                              015110
        IF((RMAX.LT.1.E-7).OR.(RMAX.GT.RMAXP)) H=H+H                    015120
        GO TO 2                                                         015130
   17   H=HT                                                            015140
        XT=X0                                                           015150
        DO 19 I=1,N                                                     015160
   18   YP(I)=YT(I)                                                     015170
   19   YT(I)=Y0(I)                                                     015180
        RMAXP = RMAX                                                    015190
        GO TO 8                                                         015200
        END                                                             015210
                                                                        015220
```

```
      SUBROUTINE IRNOS(DM,DT,TIME,AFT,AM,AFF,AFM,DEL,PI)                    015240
      DIMENSION AFT(16),AM(8),AFF(19),AFM(19),DEL(3),VAR(3),DM(5),DELOLD015250
     +(3),SIGMA(3)                                                          015260
C*********************************************************************** 015270
C     THIS SUBROUTINE PROVIDES NOISE TO INDUCE GUIDANCE ERRORS FOR      * 015280
C     INFRA-RED GUIDED MISSILES. SCALE FACTORS ARE USED TO VARY THE     * 015290
C     ERROR ACCORDING TO THE RELATIVE POSITION OF THE TWO VEHICLES.     * 015300
C*********************************************************************** 015310
      DO 3 I=1,3                                                            015320
      IF(TIME.GT.0.0)GO TO 3                                                015330
      DEL(I)=0.0                                                            015340
      DEL(1)=-10.0                                                          015350
3     DELOLD(I)=DEL(I)                                                      015360
      DELOLD(1)=DELOLD(1)+10.0                                              015370
      UNITY=SQRT((2.*DM(5)+DT)/DT)                                          015380
      X=ABS(AFF(14))                                                        015390
      IF(X.GT.PI)X=2.*PI-X                                                  015400
      Y=ABS(AFF(15))                                                        015410
      IF(X.GT.PI/2.)Y=PI-Y                                                  015420
      XY=Y                                                                  015430
      YX=X                                                                  015440
      Z=X+Y                                                                 015450
      DEL(1)=(X+XY)/(2.*PI)                                                 015460
      DEL(2)=(Y+YX)/(2.*PI)                                                 015470
      DEL(3)=Z/(2.*PI)                                                      015480
      DO 1 I=1,3                                                            015490
      SIGMA(I)=1.0+4.0*DEL(I)                                               015500
      DEV=0.0                                                               015510
      DO 2 J=1,12                                                           015520
      DELTA=RANF(DJMMY)                                                     015530
2     DEV=DEV+DELTA                                                         015540
      VAR(I)=(DEV-6.0)*SIGMA(I)                                             015550
1     DEL(I)=DELOLD(I)*(DM(5)/(DM(5)+DT))+DT*UNITY*VAR(I)/(DM(5)+DT)        015560
      DEL(1)=DEL(1)-10.0                                                    015570
      RETURN                                                                015580
      END                                                                   015590
```

```
      SUBROUTINE RADNOS(DM,DT,TIME,AFT,AM,ATF,ATM,DEL,PI)                015520
      DIMENSION AFT(16),AM(8),ATF(19),ATM(13),DEL(3),VAR(3),DM(5),DELOLD015530
     +(3),SIGMA(3)                                                       015540
*************************************************************************015550
*     THIS SUBROUTINE PROVIDES NOISE TO INDUCE GUIDANCE ERRORS FOR      *015560
*     RADAR GUIDED MISSILES. SCALE FACTORS ARE USED TO VARY THE         *015570
*     ERROR ACCORDING TO THE RELATIVE POSITION OF THE TWO VEHICLES.     *015580
*************************************************************************015590
      DO 3 I=1,3                                                         015700
      IF(TIME.EQ.0.0)DEL(I)=0.0                                          015710
3     DELOLD(I)=DEL(I)                                                   015720
      UNITY=SQRT((2.*DM(5)+DT)/DT)                                       015730
      X=ABS(ATF(14))                                                     015740
      IF(X.GE.PI)X=2.*PI-X                                               015750
      IF(X.GT.PI/2.)X=PI-X                                               015760
      Y=ABS(ATF(15))                                                     015770
      XY=Y                                                               015780
      YX=X                                                               015790
      IF(X.GT.PI/4.)YX=PI/2.-X                                           015800
      DEL(1)=(X+XY)/PI                                                   015810
      DEL(2)=Y/PI+YX/(.5*PI)                                             015820
      DEL(3)=X/PI+Y/(.5*PI)                                              015830
      DO 1 I=1,3                                                         015840
      SIGMA(I)=1.0+4.0*DEL(I)                                            015850
      DEV=0.0                                                            015860
      DO 2 J=1,12                                                        015870
      DELTA=RANF(DUMMY)                                                  015880
2     DEV=DEV+DELTA                                                      015890
      VAR(I)=(DEV-6.0)*SIGMA(I)                                          015900
1     DEL(I)=DELOLD(I)*(DM(5)/(DM(5)+DT))+DT*UNITY*VAR(I)/(DM(5)+DT)     015910
      RETURN                                                             015920
      END                                                                015930
                                                                         015940
```

```
      SUBROUTINE REDUCE(PI,INDEX,ATF,DT)                                015950
      DIMENSION ATF(19)                                                 015970
*****************************************************************     015980
*     THIS SUBROUTINE REDUCES THE STEP SIZE OF THE INTERGRATION     *   015990
*     WHICH REDUCES THE DISTANCE COVERED DURING ONE INTERGRATION    *   016000
*     TO LESS THAN ONE FOOT.  THIS PROVIDES IMPROVED ACCURACY       *   016010
*     DURING THE TERMINATION PHASE.                                 *   016020
*****************************************************************     016030
      INTER=IFIX(.5000001/DT)                                           016040
      ACC=DT*ABS(ATF(10))                                               016050
      IF(MOD(INDEX,INTER).EQ.0)PRINT 4,ACC,DT                           016060
4     FORMAT(/+X,* ACCURACY IS WITHIN *,F7.4,* FEET. STEP INTERVAL IS *,016070
     +F8.5,* SECONDS.*/)                                                016080
      STEP=ABS(ATF(10))*DT                                              016090
      IF(ABS(ATF(14)).LT.PI/2.0)GO TO 5                                 016100
      IF(ATF(4).GT.STEP)RETURN                                          016110
      GO TO 10                                                          016120
5     STEP=STEP*2.0                                                     016130
      IF(ATF(4).GT.STEP)RETURN                                          016140
10    IF(STEP.GE.10.0)GO TO 1                                           016150
      DT=.001                                                           016160
      ACC=DT*ABS(ATF(10))                                               016170
      PRINT 4,ACC,DT                                                    016180
      RETURN                                                            016190
1     IF(STEP.GE.100.0)GO TO 2                                          016200
      DT=.0001                                                          016210
      ACC=DT*ABS(ATF(10))                                               016220
      PRINT 4,ACC,DT                                                    016230
      RETURN                                                            016240
2     PRINT 3                                                           016250
3     FORMAT(/+X,* MAXIMUM DT USED. DT=.00001.*)                        016260
      DT=.00001                                                         016270
      ACC=DT*ABS(ATF(10))                                               016280
      PRINT 4,ACC,DT                                                    016290
      RETURN                                                            016300
      END                                                               016310
```

Appendix B

Test Results

```
TYPE OF MISSILE IS:
INFRA-RED

TYPE FIGHTER IS:
NON-RESPONSIVE

          GUIDANCE ERRORS:
   X=-10.09 FEET
   Y=   .13 FEET    TOTAL=  10.09 FEET
   Z=   .27 FEET

0

  TOTAL ELAPSED TIME IS 0.00 SECONDS.
0       THE AIRCRAFT'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
            POSITION                                VELOCITY
                 X=       0. FEET                       U=    700. FEET/SECOND
                 Y=       0. FEET                       V=      0. FEET/SECOND
                 Z= -20000. FEET                        W=      0. FEET/SECOND
            ORIENTATION
                 HEADING (PSI)=    0.DEGREES
                 FLIGHT PATH ANGLE (THETA)=    0. DEGREES
                 BANK ANGLE  (PHI)=    0. DEGREES
0       THE MISSILE'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
            POSITION                                VELOCITY
                 X=  -3196. FEET                        U=   2694. FEET/SECOND
                 Y=  -3000. FEET                        V=   1555. FEET/SECOND
                 Z= -20060. FEET                        W=      0. FEET/SECOND
            ORIENTATION
                 HEADING (PSI)=   30.DEGREES
                 FLIGHT PATH ANGLE (THETA)=    0. DEGREES
0       THE FIGHTER PILOT SEES THE MISSILE AT:
            RANGE=    6000.2 FEET                   RANGE RATE=  -2503.9 FEET/SECOND
            AZIMUTH=  -150.0 DEGREES                AZIMUTH RATE=     -3.3 DEGREES/SECOND
            ELEVATION=      .5 DEGREES              ELEVATION RATE=       .2 DEGREES/SECOND
```

```
0

     TOTAL ELAPSED TIME IS 1.00 SECONDS.
0         THE AIRCRAFT'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                  VELOCITY
                    X=     701. FEET                        U=     702. FEET/SECOND
                    Y=       0. FEET                        V=       0. FEET/SECOND
                    Z= -20000. FEET                         W=       0. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)=    0.DEGREES
                    FLIGHT PATH ANGLE (THETA)=  -0. DEGREES
                    BANK ANGLE  (PHI)=    0. DEGREES
0         THE MISSILE'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:.
               POSITION                                  VELOCITY
                    X=  -2404. FEET                         U=    2858. FEET/SECOND
                    Y=  -1634. FEET                         V=    1227. FEET/SECOND
                    Z= -20037. FEET                         W=      23. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)=   23.DEGREES
                    FLIGHT PATH ANGLE (THETA)=  -0. DEGREES
0         THE FIGHTER PILOT SEES THE MISSILE AT:
               RANGE=    3509.1 FEET                     RANGE RATE=  -2479.0 FEET/SECOND
               AZIMUTH=  -152.3 DEGREES                  AZIMUTH RATE=     -1.3 DEGREES/SECOND
               ELEVATION=      .6 DEGREES                ELEVATION RATE=       .1 DEGREES/SECOND


     ACCURACY IS WITHIN 24.7398 FEET. STEP INTERVAL IS    .01000 SECONDS.


     MISSILE PARAMETERS ARE WITHIN LIMITS.
```

```
0

     TOTAL ELAPSED TIME IS 2.00 SECONDS.
0         THE AIRCRAFT'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                VELOCITY
                    X=    1405. FEET                       U=     705. FEET/SECOND
                    Y=       0. FEET                       V=       0. FEET/SECOND
                    Z= -20000. FEET                        W=       0. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)=    0.DEGREES
                    FLIGHT PATH ANGLE (THETA)=   -0. DEGREES
                    BANK ANGLE  (PHI)=    0. DEGREES
0         THE MISSILE'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                VELOCITY
                    X=     480. FEET                       U=    2898. FEET/SECOND
                    Y=    -471. FEET                       V=    1129. FEET/SECOND
                    Z= -20011. FEET                        W=      27. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)=   21.DEGREES
                    FLIGHT PATH ANGLE (THETA)=   -0. DEGREES
0         THE FIGHTER PILOT SEES THE MISSILE AT:
               RANGE=    1037.7 FEET                  RANGE RATE=   -2466.7 FEET/SECOND
               AZIMUTH=   -153.0 DEGREES              AZIMUTH RATE=       -.6 DEGREES/SECOND
               ELEVATION=       .6 DEGREES            ELEVATION RATE=       -.0 DEGREES/SECOND


     ACCURACY IS WITHIN 24.6570 FEET. STEP INTERVAL IS    .01000 SECONDS.


     MISSILE PARAMETERS ARE WITHIN LIMITS.
```

```
MISSILE IS PULLING MAXIMUM G!

MISSILE EXCEEDED MANEUVERING CAPABILITY!

   VERTICAL LINE OF SIGHT RATE IS    -.35 DEGREES/SECOND
   MAXIMUM VERTICAL RATE IS     .52 DEGREES/SECOND.


   HORIZONTAL LINE OF SIGHT RATE IS   -1.14 DEGREES/SECOND.
   MAXIMUM HORIZONTAL RATE IS     .52 DEGREES/SECOND.


   ACCURACY IS WITHIN   .2440 FEET. STEP INTERVAL IS   .00010 SECONDS.

TARGET OUTSIDE GIMBAL LIMITS!

   MISSILE'S CONE ANGLE TO THE FIGHTER IS  2.09 DEGREES.
   MAXIMUM GIMBAL ANGLE OF THE MISSILE IS  1.05 DEGREES.

TARGET OUTSIDE GIMBAL LIMITS!

   RELATIVE AZIMUTH ANGLE IS   2.44 DEGREES.
   MAXIMUM AZIMUTH ANGLE IS   1.05 DEGREES.


   RELATIVE ELEVATION ANGLE IS   -.87 DEGREES.
   MAXIMUM ELEVATION GIMBAL ANGLE IS   1.05 DEGREES.
```

```
 MISSILE HAS SCORED A HIT ON THE AIRCRAFT!

              GUIDANCE ERRORS:
     X= -9.55 FEET
     Y=  -.91 FEET    TOTAL=    9.76 FEET
     Z= -1.78 FEET

0

    TOTAL ELAPSED TIME IS 2.+2 SECONDS.
0         THE AIRCRAFT'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                  VELOCITY
                    X=    1701. FEET                       U=     706. FEET/SECOND
                    Y=       0. FEET                       V=       0. FEET/SECOND
                    Z= -20000. FEET                       W=       0. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)=    0.DEGREES
                    FLIGHT PATH ANGLE (THETA)=    0. DEGREES
                    BANK ANGLE  (PHI)=    0. DEGREES
0         THE MISSILE'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                  VELOCITY
                    X=    1697. FEET                       U=    2896. FEET/SECOND
                    Y=       1. FEET                       V=    1134. FEET/SECOND
                    Z= -20003. FEET                       W=      -4. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)=   21.DEGREES
                    FLIGHT PATH ANGLE (THETA)=    0. DEGREES
0         THE FIGHTER PILOT SEES THE MISSILE AT:
               RANGE=       +.9 FEET                  RANGE RATE=  -1571.3 FEET/SECOND
               AZIMUTH=    165.3 DEGREES              AZIMUTH RATE= -22534.8 DEGREES/SECOND
               ELEVATION=    32.2 DEGREES             ELEVATION RATE=  11689.5 DEGREES/SECOND
```

```
TYPE OF MISSILE IS:
RADAR GUIDED

TYPE FIGHTER IS:
NON-RESPONSIVE

          GUIDANCE ERRORS:
   X=  -.28 FEET
   Y=   .20 FEET   TOTAL=    .37 FEET
   Z=  -.14 FEET

0

 TOTAL ELAPSED TIME IS 0.00 SECONDS.
0       THE AIRCRAFT'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
            POSITION                                VELOCITY
                 X=       0. FEET                       U=     800. FEET/SECOND
                 Y=       0. FEET                       V=       0. FEET/SECOND
                 Z= -20000. FEET                        W=       0. FEET/SECOND
            ORIENTATION
                 HEADING (PSI)=    0.DEGREES
                 FLIGHT PATH ANGLE (THETA)=    0. DEGREES
                 BANK ANGLE  (PHI)=    0. DEGREES
0       THE MISSILE'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
            POSITION                                VELOCITY
                 X=  -5195. FEET                        U=    2594. FEET/SECOND
                 Y=   3000. FEET                        V=   -1555. FEET/SECOND
                 Z= -20050. FEET                        W=       0. FEET/SECOND
            ORIENTATION
                 HEADING (PSI)= 330.DEGREES
                 FLIGHT PATH ANGLE (THETA)=    0. DEGREES
0       THE FIGHTER PILOT SEES THE MISSILE AT:
            RANGE=    6000.2 FEET                   RANGE RATE=  -2417.3 FEET/SECOND
            AZIMUTH=   150.0 DEGREES                AZIMUTH RATE=       3.8 DEGREES/SECOND
            ELEVATION=      .5 DEGREES              ELEVATION RATE=       .2 DEGREES/SECOND
```

0

TOTAL ELAPSED TIME IS 1.00 SECONDS.

0 THE AIRCRAFT'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:

POSITION		VELOCITY	
X=	801. FEET	U=	801. FEET/SECOND
Y=	0. FEET	V=	0. FEET/SECOND
Z=	-20000. FEET	W=	0. FEET/SECOND

ORIENTATION

HEADING (PSI)= 0.DEGREES

FLIGHT PATH ANGLE (THETA)= -0. DEGREES

BANK ANGLE (PHI)= 0. DEGREES

0 THE MISSILE'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:

POSITION		VELOCITY	
X=	-2392. FEET	U=	2877. FEET/SECOND
Y=	1651. FEET	V=	-1181. FEET/SECOND
Z=	-20038. FEET	W=	20. FEET/SECOND

ORIENTATION

HEADING (PSI)= 338.DEGREES

FLIGHT PATH ANGLE (THETA)= -0. DEGREES

0 THE FIGHTER PILOT SEES THE MISSILE AT:

RANGE=	3598.6 FEET	RANGE RATE=	-2386.7 FEET/SECOND
AZIMUTH=	152.5 DEGREES	AZIMUTH RATE=	1.4 DEGREES/SECOND
ELEVATION=	.6 DEGREES	ELEVATION RATE=	.1 DEGREES/SECOND

ACCURACY IS WITHIN 23.8573 FEET. STEP INTERVAL IS .01000 SECONDS.

MISSILE PARAMETERS ARE WITHIN LIMITS.

```
0

     TOTAL ELAPSED TIME IS 2.00 SECONDS.
0         THE AIRCRAFT'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                  VELOCITY
                    X=    1503. FEET                       U=     803. FEET/SECOND
                    Y=       0. FEET                       V=       0. FEET/SECOND
                    Z= -20000. FEET                       W=       0. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)=    0.DEGREES
                    FLIGHT PATH ANGLE (THETA)=  -0. DEGREES
                    BANK ANGLE  (PHI)=    0. DEGREES
0         THE MISSILE'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                  VELOCITY
                    X=     513. FEET                       U=    2919. FEET/SECOND
                    Y=     551. FEET                       V=   -1073. FEET/SECOND
                    Z= -20014. FEET                       W=      26. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)= 340.DEGREES
                    FLIGHT PATH ANGLE (THETA)=  -0. DEGREES
0         THE FIGHTER PILOT SEES THE MISSILE AT:
               RANGE=    1220.7 FEET                  RANGE RATE=  -2372.9 FEET/SECOND
               AZIMUTH=   153.2 DEGREES               AZIMUTH RATE=        .2 DEGREES/SECOND
               ELEVATION=      .6 DEGREES             ELEVATION RATE=       .0 DEGREES/SECOND


     ACCURACY IS WITHIN 23.7293 FEET. STEP INTERVAL IS    .01000 SECONDS.


     MISSILE PARAMETERS ARE WITHIN LIMITS.
```

HORIZONTAL LINE OF SIGHT RATE IS -.51 DEGREES/SECOND.
MAXIMUM HORIZONTAL RATE IS .52 DEGREES/SECOND.

```
 MISSILE HAS SCORED A HIT ON THE AIRCRAFT!

              GUIDANCE ERRORS:
     X=    .01 FEET
     Y= -2.83 FEET    TOTAL=    3.50 FEET
     Z= -1.98 FEET

0

     TOTAL ELAPSED TIME IS 2.51 SECONDS.
0         THE AIRCRAFT'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                  VELOCITY
                    X=    2015. FEET                       U=     804. FEET/SECOND
                    Y=       0. FEET                       V=       0. FEET/SECOND
                    Z= -20000. FEET                       W=       0. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)=    0.DEGREES
                    FLIGHT PATH ANGLE (THETA)=    0. DEGREES
                    BANK ANGLE  (PHI)=    0. DEGREES
0         THE MISSILE'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                  VELOCITY
                    X=    2010. FEET                       U=    2915. FEET/SECOND
                    Y=      -1. FEET                       V=   -1085. FEET/SECOND
                    Z= -20002. FEET                       W=      -8. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)= 340.DEGREES
                    FLIGHT PATH ANGLE (THETA)=    0. DEGREES
0         THE FIGHTER PILOT SEES THE MISSILE AT:
               RANGE=       4.8 FEET                    RANGE RATE=  -1834.1 FEET/SECOND
               AZIMUTH=  -174.1 DEGREES                 AZIMUTH RATE=  16603.5 DEGREES/SECOND
               ELEVATION=    22.4 DEGREES               ELEVATION RATE=   9058.7 DEGREES/SECOND
```

```
TYPE OF MISSILE IS:
RADAR GUIDED

TYPE FIGHTER IS:
RESPONSIVE

          GUIDANCE ERRORS:
   X=  -.25 FEET
   Y=   .03 FEET   TOTAL=    .27 FEET
   Z=   .01 FEET

0

  TOTAL ELAPSED TIME IS 0.00 SECONDS.
0       THE AIRCRAFT'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
            POSITION                                VELOCITY
                 X=       0. FEET                       U=    300. FEET/SECOND
                 Y=       0. FEET                       V=      0. FEET/SECOND
                 Z= -20000. FEET                        W=      0. FEET/SECOND
            ORIENTATION
                 HEADING (PSI)=    0.DEGREES
                 FLIGHT PATH ANGLE (THETA)=   0. DEGREES
                 BANK ANGLE  (PHI)=   0. DEGREES
0       THE MISSILE'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
            POSITION                                VELOCITY
                 X=  10392. FEET                       U=  -2694. FEET/SECOND
                 Y=   6000. FEET                       V=  -1555. FEET/SECOND
                 Z= -20050. FEET                       W=      0. FEET/SECOND
            ORIENTATION
                 HEADING (PSI)= 210.DEGREES
                 FLIGHT PATH ANGLE (THETA)=   0. DEGREES
0       THE FIGHTER PILOT SEES THE MISSILE AT:
            RANGE=  12000.1 FEET                    RANGE RATE=  -3889.6 FEET/SECOND
            AZIMUTH=    30.0 DEGREES                AZIMUTH RATE=      2.1 DEGREES/SECOND
            ELEVATION=      .2 DEGREES              ELEVATION RATE=       .1 DEGREES/SECOND
```

```
TOTAL ELAPSED TIME IS 0.00 SECONDS.

THE PILOT ESTIMATES THE MISSILE TO BE AT A RANGE OF
MORE THEN     6000. FEET. THE PILOT EXECUTES MANEUVER NUMBER 1
AT AN ACTUAL RANGE OF  12000. FEET.

MANEUVER IS A SPLIT S


          GUIDANCE ERRORS:
X= -1.03 FEET
Y= -4.22 FEET    TOTAL=    4.35 FEET
Z=  -.35 FEET
```

```
0

     TOTAL ELAPSED TIME IS 1.00 SECONDS.
0         THE AIRCRAFT'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                  VELOCITY
                    X=     900. FEET                        U=     900. FEET/SECOND
                    Y=       5. FEET                        V=      13. FEET/SECOND
                    Z= -13333. FEET                        W=      18. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)=    1.DEGREES
                    FLIGHT PATH ANGLE (THETA)=   -1. DEGREES
                    BANK ANGLE  (PHI)=   85. DEGREES
0         THE MISSILE'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                  VELOCITY
                    X=    7783. FEET                       U=  -2518. FEET/SECOND
                    Y=    4303. FEET                       V=  -1825. FEET/SECOND
                    Z= -20042. FEET                        W=      18. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)= 216.DEGREES
                    FLIGHT PATH ANGLE (THETA)=   -0. DEGREES
0         THE FIGHTER PILOT SEES THE MISSILE AT:
               RANGE=    8118.7 FEET                    RANGE RATE=  -3873.4 FEET/SECOND
               AZIMUTH=      1.3 DEGREES                AZIMUTH RATE=       -.1 DEGREES/SECOND
               ELEVATION=     31.1 DEGREES              ELEVATION RATE=       1.8 DEGREES/SECOND


     ACCURACY IS WITHIN 38.7344 FEET. STEP INTERVAL IS    .01000 SECONDS.


     MISSILE PARAMETERS ARE WITHIN LIMITS.
```

TOTAL ELAPSED TIME IS 1.50 SECONDS.

THE PILOT ESTIMATES THE MISSILE TO BE AT A RANGE OF 6000. FEET.
THE PILOT EXECUTES MANEUVER NUMBER 2 AT AN ACTUAL RANGE OF 6184. FEET.

MANEUVER IS A HARD BREAK SO AS TO PUT THE MISSILE
IN A PURSUIT TYPE CURVE THEN REVERSE DIRECTION OF THE BREAK.

GUIDANCE ERRORS:
X= -2.35 FEET
Y= 3.54 FEET TOTAL= 4.49 FEET
Z= -1.15 FEET

```
0

     TOTAL ELAPSED TIME IS 2.00 SECONDS.
0         THE AIRCRAFT'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                  VELOCITY
                    X=    1801. FEET                       U=     899. FEET/SECOND
                    Y=      29. FEET                       V=      36. FEET/SECOND
                    Z= -19953. FEET                        W=      75. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)=    2.DEGREES
                    FLIGHT PATH ANGLE (THETA)=  -3. DEGREES
                    BANK ANGLE  (PHI)=  80. DEGREES
0         THE MISSILE'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                  VELOCITY
                    X=    5349. FEET                       U=  -2357. FEET/SECOND
                    Y=    2374. FEET                       V=  -2015. FEET/SECOND
                    Z= -20005. FEET                        W=     64. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)= 220.DEGREES
                    FLIGHT PATH ANGLE (THETA)=  -1. DEGREES
0         THE FIGHTER PILOT SEES THE MISSILE AT:
               RANGE=    4253.7 FEET                    RANGE RATE=  -3855.6 FEET/SECOND
               AZIMUTH=     1.8 DEGREES                 AZIMUTH RATE=      -.8 DEGREES/SECOND
               ELEVATION=    31.4 DEGREES               ELEVATION RATE=     1.3 DEGREES/SECOND


     ACCURACY IS WITHIN 38.5557 FEET, STEP INTERVAL IS   .01000 SECONDS.


     MISSILE PARAMETERS ARE WITHIN LIMITS.
```

TOTAL ELAPSED TIME IS 2.83 SECONDS.

THE PILOT ESTIMATES THE MISSILE TO BE AT A RANGE OF 1000. FEET.
THE PILOT EXECUTES MANEUVER NUMBER 3 AT AN ACTUAL RANGE OF 1079. FEET.

MANEUVER IS A VERTICAL DIVE FOLLOWED BY A HARD PULL UP.

GUIDANCE ERRORS:

X= -.76 FEET
Y= -.04 FEET TOTAL= 2.10 FEET
Z= -1.97 FEET

```
0

     TOTAL ELAPSED TIME IS 3.00 SECONDS.
0         THE AIRCRAFT'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                  VELOCITY
                    X=   2571. FEET                          U=    847. FEET/SECOND
                    Y=     73. FEET                          V=     49. FEET/SECOND
                    Z= -19723. FEET                          W=    326. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)=   3.DEGREES
                    FLIGHT PATH ANGLE (THETA)=  -4. DEGREES
                    BANK ANGLE  (PHI)=  24. DEGREES
0         THE MISSILE'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                  VELOCITY
                    X=   3034. FEET                          U=  -2259. FEET/SECOND
                    Y=    313. FEET                          V=  -2057. FEET/SECOND
                    Z= -19756. FEET                          W=    539. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)= 222.DEGREES
                    FLIGHT PATH ANGLE (THETA)= -10. DEGREES
0         THE FIGHTER PILOT SEES THE MISSILE AT:
               RANGE=    438.4 FEET                     RANGE RATE=  -3765.6 FEET/SECOND
               AZIMUTH=    24.6 DEGREES                 AZIMUTH RATE=    -14.6 DEGREES/SECOND
               ELEVATION=    18.5 DEGREES               ELEVATION RATE=      3.1 DEGREES/SECOND


     ACCURACY IS WITHIN 37.6562 FEET. STEP INTERVAL IS   .01000 SECONDS.


     MISSILE PARAMETERS ARE WITHIN LIMITS.
```

```
MISSILE EXCEEDED MANEUVERING CAPABILITY!

   VERTICAL LINE OF SIGHT RATE IS      .27 DEGREES/SECOND.
   MAXIMUM VERTICAL RATE IS      .52 DEGREES/SECOND.


   HORIZONTAL LINE OF SIGHT RATE IS  -27.25 DEGREES/SECOND.
   MAXIMUM HORIZONTAL RATE IS      .52 DEGREES/SECOND.


MISSILE IS PULLING MAXIMUM G!

TARGET OUTSIDE GIMBAL LIMITS!

   MISSILE'S CONE ANGLE TO THE FIGHTER IS  2.14 DEGREES.
   MAXIMUM GIMBAL ANGLE OF THE MISSILE IS  1.05 DEGREES.

TARGET OUTSIDE GIMBAL LIMITS!

   RELATIVE AZIMUTH ANGLE IS   3.07 DEGREES.
   MAXIMUM AZIMUTH ANGLE IS   1.05 DEGREES.


   RELATIVE ELEVATION ANGLE IS  -1.00 DEGREES.
   MAXIMUM ELEVATION GIMBAL ANGLE IS   1.05 DEGREES.
```

```
 MISSILE HAS MISSED THE AIRCRAFT!

              GUIDANCE ERRORS:
      X=  -.75 FEET
      Y=  -.90 FEET    TOTAL=   1.21 FEET
      Z=   .29 FEET

0

    TOTAL ELAPSED TIME IS 3.12 SECONDS.
0         THE AIRCRAFT'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                VELOCITY
                    X=   2773. FEET                        U=    853. FEET/SECOND
                    Y=     73. FEET                        V=     51. FEET/SECOND
                    Z= -19690. FEET                        W=    314. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)=   3.DEGREES
                    FLIGHT PATH ANGLE (THETA)=  -4. DEGREES
                    BANK ANGLE  (PHI)=  34. DEGREES
0         THE MISSILE'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                VELOCITY
                    X=   2761. FEET                        U=  -2251. FEET/SECOND
                    Y=     72. FEET                        V=  -2059. FEET/SECOND
                    Z= -19722. FEET                        W=   -533. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)= 222.DEGREES
                    FLIGHT PATH ANGLE (THETA)=  10. DEGREES
0         THE FIGHTER PILOT SEES THE MISSILE AT:
               RANGE=     35.3 FEET                   RANGE RATE=   2535.4 FEET/SECOND
               AZIMUTH=  -139.9 DEGREES               AZIMUTH RATE=  -1341.2 DEGREES/SECOND
               ELEVATION=    39.7 DEGREES             ELEVATION RATE=  -4613.0 DEGREES/SECOND
```

```
 TYPE OF MISSILE IS:
 INFRA-RED

 TYPE FIGHTER IS:
 RESPONSIVE

              GUIDANCE ERRORS:
     X=-10.10 FEET
     Y=  -.15 FEET    TOTAL=  10.10 FEET
     Z=  -.29 FEET

0

    TOTAL ELAPSED TIME IS 0.00 SECONDS.
0         THE AIRCRAFT'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                VELOCITY
                    X=       0. FEET                      U=   1000. FEET/SECOND
                    Y=       0. FEET                      V=      0. FEET/SECOND
                    Z= -20000. FEET                      W=      0. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)=    0.DEGREES
                    FLIGHT PATH ANGLE (THETA)=   0. DEGREES
                    BANK ANGLE  (PHI)=   0. DEGREES
0         THE MISSILE'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                VELOCITY
                    X=  -6000. FEET                      U=   1838. FEET/SECOND
                    Y=  -6000. FEET                      V=   1838. FEET/SECOND
                    Z= -14000. FEET                      W=  -1838. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)=  45.DEGREES
                    FLIGHT PATH ANGLE (THETA)=  35. DEGREES
0         THE FIGHTER PILOT SEES THE MISSILE AT:
               RANGE=  10392.3 FEET                    RANGE RATE=  -2487.0 FEET/SECOND
               AZIMUTH=  -144.7 DEGREES                AZIMUTH RATE=     -6.9 DEGREES/SECOND
               ELEVATION=   -35.3 DEGREES              ELEVATION RATE=      2.7 DEGREES/SECOND
```

TOTAL ELAPSED TIME IS 0.00 SECONDS.

THE PILOT ESTIMATES THE MISSILE TO BE AT A RANGE OF
MORE THEN 6000. FEET. THE PILOT EXECUTES MANEUVER NUMBER 1
AT AN ACTUAL RANGE OF 10392. FEET.

MANEUVER IS A VERTICAL DIVE AWAY FROM THE MISSILE.

GUIDANCE ERRORS:
X=-10.05 FEET
Y= .39 FEET TOTAL= 10.36 FEET
Z= -2.45 FEET

```
0

     TOTAL ELAPSED TIME IS 1.00 SECONDS.
0          THE AIRCRAFT'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                  VELOCITY
                    X=     995. FEET                         U=     931. FEET/SECOND
                    Y=     -30. FEET                         V=     -83. FEET/SECOND
                    Z= -19973. FEET                          W=     -37. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)= 355.DEGREES
                    FLIGHT PATH ANGLE (THETA)=   3. DEGREES
                    BANK ANGLE  (PHI)= -85. DEGREES
0          THE MISSILE'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                  VELOCITY
                    X=  -3923. FEET                          U=    2279. FEET/SECOND
                    Y=  -4233. FEET                          V=    1585. FEET/SECOND
                    Z= -15687. FEET                          W=   -1550. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)=  35.DEGREES
                    FLIGHT PATH ANGLE (THETA)=  29. DEGREES
0          THE FIGHTER PILOT SEES THE MISSILE AT:
               RANGE=   7787.7 FEET                      RANGE RATE=  -2504.3 FEET/SECOND
               AZIMUTH=  -145.6 DEGREES                  AZIMUTH RATE=     -5.5 DEGREES/SECOND
               ELEVATION=    33.4 DEGREES                ELEVATION RATE=     -2.3 DEGREES/SECOND


     ACCURACY IS WITHIN 25.0427 FEET. STEP INTERVAL IS    .01000 SECONDS.

     MISSILE PARAMETERS ARE WITHIN LIMITS.
```

TOTAL ELAPSED TIME IS 1.66 SECONDS.

THE PILOT ESTIMATES THE MISSILE TO BE AT A RANGE OF 6000. FEET.
THE PILOT EXECUTES MANEUVER NUMBER 2 AT AN ACTUAL RANGE OF 6129. FEET.

MANEUVER IS A HARD BREAK.

GUIDANCE ERRORS:
X=-10.80 FEET
Y= .24 FEET TOTAL= 10.85 FEET
Z= 1.03 FEET

```
0

     TOTAL ELAPSED TIME IS 2.00 SECONDS.
0          THE AIRCRAFT'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                  VELOCITY
                    X=    1952. FEET                       U=     948. FEET/SECOND
                    Y=    -172. FEET                       V=    -133. FEET/SECOND
                    Z= -20141. FEET                        W=    -205. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)= 348.DEGREES
                    FLIGHT PATH ANGLE (THETA)=  -2. DEGREES
                    BANK ANGLE (PHI)=-131. DEGREES
0          THE MISSILE'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                  VELOCITY
                    X=  -1524. FEET                        U=    2482. FEET/SECOND
                    Y=  -2855. FEET                        V=    1255. FEET/SECOND
                    Z= -17225. FEET                        W=   -1551. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)=  27.DEGREES
                    FLIGHT PATH ANGLE (THETA)=  29. DEGREES
0          THE FIGHTER PILOT SEES THE MISSILE AT:
               RANGE=    5282.9 FEET                  RANGE RATE=  -2493.9 FEET/SECOND
               AZIMUTH=  -179.1 DEGREES               AZIMUTH RATE=       2.2 DEGREES/SECOND
               ELEVATION=    58.3 DEGREES             ELEVATION RATE=     -1.9 DEGREES/SECOND


     ACCURACY IS WITHIN 24.9385 FEET. STEP INTERVAL IS   .01000 SECONDS.


     MISSILE PARAMETERS ARE WITHIN LIMITS.
```

```
0

     TOTAL ELAPSED TIME IS 3.00 SECONDS.
0         THE AIRCRAFT'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                  VELOCITY
                    X=    2303. FEET                       U=     933. FEET/SECOND
                    Y=    -414. FEET                       V=    -289. FEET/SECOND
                    Z= -20307. FEET                        W=    -122. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)= 343.DEGREES
                    FLIGHT PATH ANGLE (THETA)=  -9. DEGREES
                    BANK ANGLE  (PHI)=-132. DEGREES
0         THE MISSILE'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                  VELOCITY
                    X=    1021. FEET                       U=    2504. FEET/SECOND
                    Y=   -1743. FEET                       V=     937. FEET/SECOND
                    Z= -18775. FEET                        W=   -1539. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)=  21.DEGREES
                    FLIGHT PATH ANGLE (THETA)=  29. DEGREES
0         THE FIGHTER PILOT SEES THE MISSILE AT:
               RANGE=    2768.5 FEET                    RANGE RATE=  -2538.4 FEET/SECOND
               AZIMUTH=   -179.0 DEGREES                AZIMUTH RATE=        .1 DEGREES/SECOND
               ELEVATION=    65.4 DEGREES               ELEVATION RATE=     -1.7 DEGREES/SECOND


     ACCURACY IS WITHIN 25.3335 FEET. STEP INTERVAL IS   .01000 SECONDS.


     MISSILE PARAMETERS ARE WITHIN LIMITS.
```

```
TOTAL ELAPSED TIME IS 3.81 SECONDS.

THE PILOT ESTIMATES THE MISSILE TO BE AT A RANGE OF   1000. FEET.
THE PILOT EXECUTES MANEUVER NUMBER 3 AT AN ACTUAL RANGE OF    693. FEET.

MANEUVER IS A SPLIT S.


          GUIDANCE ERRORS:
X=-10.73 FEET
Y=  2.37 FEET    TOTAL=  11.09 FEET
Z= -1.44 FEET
```

```
0

     TOTAL ELAPSED TIME IS 4.00 SECONDS.
0         THE AIRCRAFT'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                  VELOCITY
                    X=    3824. FEET                       U=     906. FEET/SECOND
                    Y=    -749. FEET                       V=    -377. FEET/SECOND
                    Z= -20381. FEET                        W=     -56. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)= 337. DEGREES
                    FLIGHT PATH ANGLE (THETA)= -16. DEGREES
                    BANK ANGLE  (PHI)=-141. DEGREES
0         THE MISSILE'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                  VELOCITY
                    X=    3679. FEET                       U=    2687. FEET/SECOND
                    Y=    -340. FEET                       V=     845. FEET/SECOND
                    Z= -20275. FEET                        W=   -1485. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)=  17. DEGREES
                    FLIGHT PATH ANGLE (THETA)=  28. DEGREES
0         THE FIGHTER PILOT SEES THE MISSILE AT:
               RANGE=     201.6 FEET                    RANGE RATE=  -2575.2 FEET/SECOND
               AZIMUTH=   172.4 DEGREES                 AZIMUTH RATE=    194.1 DEGREES/SECOND
               ELEVATION=    69.3 DEGREES               ELEVATION RATE=    -39.1 DEGREES/SECOND


     ACCURACY IS WITHIN 25.7521 FEET. STEP INTERVAL IS   .01000 SECONDS.


     MISSILE PARAMETERS ARE WITHIN LIMITS.
```

MISSILE IS PULLING MAXIMUM G!

ACCURACY IS WITHIN .2525 FEET. STEP INTERVAL IS .00010 SECONDS.

MISSILE EXCEEDED MANEUVERING CAPABILITY!

VERTICAL LINE OF SIGHT RATE IS .71 DEGREES/SECOND.
MAXIMUM VERTICAL RATE IS .52 DEGREES/SECOND.

HORIZONTAL LINE OF SIGHT RATE IS .35 DEGREES/SECOND.
MAXIMUM HORIZONTAL RATE IS .52 DEGREES/SECOND.

TARGET OUTSIDE GIMBAL LIMITS!

MISSILE'S CONE ANGLE TO THE FIGHTER IS 1.17 DEGREES.
MAXIMUM GIMBAL ANGLE OF THE MISSILE IS 1.05 DEGREES.

TARGET OUTSIDE GIMBAL LIMITS!

RELATIVE AZIMUTH ANGLE IS 1.13 DEGREES.
MAXIMUM AZIMUTH ANGLE IS 1.05 DEGREES.

RELATIVE ELEVATION ANGLE IS .39 DEGREES.
MAXIMUM ELEVATION GIMBAL ANGLE IS 1.05 DEGREES.

```
 MISSILE HAS MISSED THE AIRCRAFT!

                GUIDANCE ERRORS:
      X=-10.85 FEET
      Y=    .93 FEET    TOTAL=  10.93 FEET
      Z=   -.83 FEET

0

    TOTAL ELAPSED TIME IS 4.08 SECONDS.
0         THE AIRCRAFT'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                VELOCITY
                    X=    3894. FEET                     U=     903. FEET/SECOND
                    Y=    -779. FEET                     V=    -383. FEET/SECOND
                    Z= -20386. FEET                      W=     -56. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)= 337.DEGREES
                    FLIGHT PATH ANGLE (THETA)= -16. DEGREES
                    BANK ANGLE  (PHI)=-144. DEGREES
0         THE MISSILE'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                VELOCITY
                    X=    3883. FEET                     U=    2692. FEET/SECOND
                    Y=    -775. FEET                     V=     841. FEET/SECOND
                    Z= -20390. FEET                      W=   -1479. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)=  17.DEGREES
                    FLIGHT PATH ANGLE (THETA)=  28. DEGREES
0         THE FIGHTER PILOT SEES THE MISSILE AT:
               RANGE=       8.3 FEET                   RANGE RATE=       2.1 FEET/SECOND
               AZIMUTH=   177.2 DEGREES                AZIMUTH RATE=   3181.7 DEGREES/SECOND
               ELEVATION=   -17.0 DEGREES              ELEVATION RATE= -17547.1 DEGREES/SECOND
```

```
TYPE OF MISSILE IS:
RADAR GUIDED

TYPE FIGHTER IS:
RESPONSIVE

          GUIDANCE ERRORS:
   X= -1.15 FEET
   Y=  -.45 FEET   TOTAL=   1.33 FEET
   Z=   .43 FEET

0

   TOTAL ELAPSED TIME IS 0.00 SECONDS.
0       THE AIRCRAFT'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
            POSITION                                VELOCITY
                 X=      0. FEET                        U=   1100. FEET/SECOND
                 Y=      0. FEET                        V=      0. FEET/SECOND
                 Z= -20000. FEET                        W=      0. FEET/SECOND
            ORIENTATION
                 HEADING (PSI)=   0.DEGREES
                 FLIGHT PATH ANGLE (THETA)=   0. DEGREES
                 BANK ANGLE  (PHI)=   0. DEGREES
0       THE MISSILE'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
            POSITION                                VELOCITY
                 X=  -6000. FEET                        U=   1838. FEET/SECOND
                 Y=    600. FEET                        V=  -1838. FEET/SECOND
                 Z= -14000. FEET                        W=  -1838. FEET/SECOND
            ORIENTATION
                 HEADING (PSI)= 315.DEGREES
                 FLIGHT PATH ANGLE (THETA)=  35. DEGREES
0       THE FIGHTER PILOT SEES THE MISSILE AT:
            RANGE=  10392.3 FEET                    RANGE RATE=  -2420.3 FEET/SECOND
            AZIMUTH=   144.7 DEGREES                AZIMUTH RATE=      7.3 DEGREES/SECOND
            ELEVATION=   -35.3 DEGREES              ELEVATION RATE=      3.0 DEGREES/SECOND
```

TOTAL ELAPSED TIME IS 0.00 SECONDS.

THE PILOT ESTIMATES THE MISSILE TO BE AT A RANGE OF
MORE THEN 6000. FEET. THE PILOT EXECUTES MANEUVER NUMBER 1
AT AN ACTUAL RANGE OF 10392. FEET.

MANEUVER IS A VERTICAL DIVE AWAY FROM THE MISSILE.

GUIDANCE ERRORS:
X= -3.63 FEET
Y= -1.46 FEET TOTAL= 5.14 FEET
Z= 3.28 FEET

```
0

     TOTAL ELAPSED TIME IS 1.00 SECONDS.
0          THE AIRCRAFT'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                  VELOCITY
                    X=   1091. FEET                          U=   1072. FEET/SECOND
                    Y=     50. FEET                          V=    134. FEET/SECOND
                    Z= -20004. FEET                          W=    -93. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)=   7.DEGREES
                    FLIGHT PATH ANGLE (THETA)=   6. DEGREES
                    BANK ANGLE  (PHI)=  85. DEGREES
0          THE MISSILE'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                  VELOCITY
                    X=  -3903. FEET                          U=   2311. FEET/SECOND
                    Y=   4301. FEET                          V=  -1542. FEET/SECOND
                    Z= -15680. FEET                          W=  -1556. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)= 326.DEGREES
                    FLIGHT PATH ANGLE (THETA)=  29. DEGREES
0          THE FIGHTER PILOT SEES THE MISSILE AT:
               RANGE=   7854.6 FEET                     RANGE RATE=  -2439.7 FEET/SECOND
               AZIMUTH=   147.4 DEGREES                 AZIMUTH RATE=       5.6 DEGREES/SECOND
               ELEVATION=    34.9 DEGREES               ELEVATION RATE=     -2.7 DEGREES/SECOND


     ACCURACY IS WITHIN 24.3970 FEET. STEP INTERVAL IS   .01000 SECONDS.


     MISSILE PARAMETERS ARE WITHIN LIMITS.
```

TOTAL ELAPSED TIME IS 1.69 SECONDS.

THE PILOT ESTIMATES THE MISSILE TO BE AT A RANGE OF 6000. FEET.
THE PILOT EXECUTES MANEUVER NUMBER 2 AT AN ACTUAL RANGE OF 6154. FEET.

MANEUVER IS A HARD BREAK.

GUIDANCE ERRORS:
X= .1+ FEET
Y= -2.24 FEET TOTAL= 11.95 FEET
Z= 11.74 FEET

```
0

     TOTAL ELAPSED TIME IS 2.00 SECONDS.
0         THE AIRCRAFT'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                  VELOCITY
                    X=    2115. FEET                        U=     995. FEET/SECOND
                    Y=     275. FEET                        V=     302. FEET/SECOND
                    Z= -20231. FEET                        W=    -250. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)=  17.DEGREES
                    FLIGHT PATH ANGLE (THETA)=  -0. DEGREES
                    BANK ANGLE  (PHI)= 131. DEGREES
0         THE MISSILE'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                  VELOCITY
                    X=   -1471. FEET                       U=    2515. FEET/SECOND
                    Y=    2353. FEET                       V=   -1148. FEET/SECOND
                    Z= -17231. FEET                        W=   -1578. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)= 335.DEGREES
                    FLIGHT PATH ANGLE (THETA)=  30. DEGREES
0         THE FIGHTER PILOT SEES THE MISSILE AT:
               RANGE=    5391.3 FEET                  RANGE RATE=  -2470.4 FEET/SECOND
               AZIMUTH=  -173.7 DEGREES               AZIMUTH RATE=     -4.1 DEGREES/SECOND
               ELEVATION=    60.8 DEGREES             ELEVATION RATE=     -2.1 DEGREES/SECOND


     ACCURACY IS WITHIN 24.7043 FEET. STEP INTERVAL IS    .01000 SECONDS.


     MISSILE PARAMETERS ARE WITHIN LIMITS.
```

```
0
     TOTAL ELAPSED TIME IS 3.00 SECONDS.
0         THE AIRCRAFT'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                  VELOCITY
                    X=    3091. FEET                       U=     953. FEET/SECOND
                    Y=     649. FEET                       V=     442. FEET/SECOND
                    Z= -20417. FEET                       W=    -119. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)=  25.DEGREES
                    FLIGHT PATH ANGLE (THETA)=   -9. DEGREES
                    BANK ANGLE  (PHI)= 131. DEGREES
0         THE MISSILE'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                  VELOCITY
                    X=    1114. FEET                       U=    2651. FEET/SECOND
                    Y=    1951. FEET                       V=    -825. FEET/SECOND
                    Z= -18803. FEET                       W=   -1559. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)= 343.DEGREES
                    FLIGHT PATH ANGLE (THETA)=  29. DEGREES
0         THE FIGHTER PILOT SEES THE MISSILE AT:
               RANGE=    2875.0 FEET                    RANGE RATE=  -2560.3 FEET/SECOND
               AZIMUTH=   179.9 DEGREES                 AZIMUTH RATE=     -2.0 DEGREES/SECOND
               ELEVATION=    70.5 DEGREES               ELEVATION RATE=     -1.9 DEGREES/SECOND


     ACCURACY IS WITHIN 25.6025 FEET. STEP INTERVAL IS   .01000 SECONDS.


     MISSILE PARAMETERS ARE WITHIN LIMITS.
```

TOTAL ELAPSED TIME IS 3.84 SECONDS.

THE PILOT ESTIMATES THE MISSILE TO BE AT A RANGE OF 1000. FEET.
THE PILOT EXECUTES MANEUVER NUMBER 3 AT AN ACTUAL RANGE OF 689. FEET.

MANEUVER IS A SPLIT S.

GUIDANCE ERRORS:
X= -.28 FEET
Y= 3.18 FEET TOTAL= 8.41 FEET
Z= 7.77 FEET

```
0

     TOTAL ELAPSED TIME IS 4.00 SECONDS.
0          THE AIRCRAFT'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                  VELOCITY
                    X=    4011. FEET                       U=     885. FEET/SECOND
                    Y=    1154. FEET                       V=     563. FEET/SECOND
                    Z= -20467. FEET                        W=     -13. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)=  33.DEGREES
                    FLIGHT PATH ANGLE (THETA)= -18. DEGREES
                    BANK ANGLE  (PHI)= 138. DEGREES
0          THE MISSILE'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                  VELOCITY
                    X=    3827. FEET                       U=    2758. FEET/SECOND
                    Y=    1273. FEET                       V=    -520. FEET/SECOND
                    Z= -20317. FEET                        W=   -1466. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)= 347.DEGREES
                    FLIGHT PATH ANGLE (THETA)=  27. DEGREES
0          THE FIGHTER PILOT SEES THE MISSILE AT:
               RANGE=     265.3 FEET                  RANGE RATE=  -2630.5 FEET/SECOND
               AZIMUTH=  -172.4 DEGREES               AZIMUTH RATE=    -329.6 DEGREES/SECOND
               ELEVATION=    78.0 DEGREES             ELEVATION RATE=      -8.1 DEGREES/SECOND


     ACCURACY IS WITHIN 26.3047 FEET. STEP INTERVAL IS   .01000 SECONDS.


     MISSILE PARAMETERS ARE WITHIN LIMITS.
```

MISSILE IS PULLING MAXIMUM G!

MISSILE EXCEEDED MANEUVERING CAPABILITY!

VERTICAL LINE OF SIGHT RATE IS .40 DEGREES/SECOND.
MAXIMUM VERTICAL RATE IS .52 DEGREES/SECOND.

HORIZONTAL LINE OF SIGHT RATE IS .75 DEGREES/SECOND.
MAXIMUM HORIZONTAL RATE IS .52 DEGREES/SECOND.

ACCURACY IS WITHIN .2528 FEET. STEP INTERVAL IS .00010 SECONDS.

TARGET OUTSIDE GIMBAL LIMITS!

MISSILE'S CONE ANGLE TO THE FIGHTER IS 1.09 DEGREES.
MAXIMUM GIMBAL ANGLE OF THE MISSILE IS 1.05 DEGREES.

TARGET OUTSIDE GIMBAL LIMITS!

RELATIVE AZIMUTH ANGLE IS -.24 DEGREES.
MAXIMUM AZIMUTH ANGLE IS 1.05 DEGREES.

RELATIVE ELEVATION ANGLE IS 1.07 DEGREES.
MAXIMUM ELEVATION GIMBAL ANGLE IS 1.05 DEGREES.

```
 MISSILE HAS SCORED A HIT ON THE AIRCRAFT!

              GUIDANCE ERRORS:
     X= -1.05 FEET
     Y=  3.84 FEET    TOTAL=    4.10 FEET
     Z=  -.99 FEET

0

    TOTAL ELAPSED TIME IS 4.10 SECONDS.
0         THE AIRCRAFT'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                  VELOCITY
                    X=    4093. FEET                       U=     878. FEET/SECOND
                    Y=    1210. FEET                       V=     573. FEET/SECOND
                    Z= -20463. FEET                        W=     -14. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)=  33.DEGREES
                    FLIGHT PATH ANGLE (THETA)= -18. DEGREES
                    BANK ANGLE  (PHI)= 142. DEGREES
0         THE MISSILE'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
               POSITION                                  VELOCITY
                    X=    4097. FEET                       U=    2716. FEET/SECOND
                    Y=    1215. FEET                       V=    -548. FEET/SECOND
                    Z= -20465. FEET                        W=   -1556. FEET/SECOND
               ORIENTATION
                    HEADING (PSI)= 349.DEGREES
                    FLIGHT PATH ANGLE (THETA)=  30. DEGREES
0         THE FIGHTER PILOT SEES THE MISSILE AT:
               RANGE=       4.9 FEET                  RANGE RATE=  -1752.6 FEET/SECOND
               AZIMUTH=   -23.4 DEGREES               AZIMUTH RATE=   9758.7 DEGREES/SECOND
               ELEVATION=    45.6 DEGREES             ELEVATION RATE= -22334.1 DEGREES/SECOND
```

Appendix C

Aircraft Aerodynamic Coefficients and Equations

Equations

Lift: (37)

$$C_L = CEF\ 1 + CEF\ 2\ (\Delta\alpha) + CEF\ 18\ (\Delta\ MN) + CEF\ 13\ (\delta\ s)$$

Drag: (38)

$$C_D = CEF\ 3 + CEF\ 4\ (\Delta\alpha) + CEF\ 19\ (\Delta\ MN)$$

Sideforce: (39)

$$C_Y = CEF\ 23\ (\Delta\beta) + CEF\ 17\ (\Delta\beta)$$

Pitching Moment: (40)

$$C_m = CEF\ 5 + CEF\ 6\ (\Delta\alpha) + CEF\ 7\ (\Delta q)\ (\tfrac{1}{2})\left(\frac{C}{\rho V 2}\right) + CEF\ 8\ (\Delta\dot{\alpha})\ (\tfrac{1}{2})\left(\frac{C}{\rho V^2}\right) + CEF\ 20\ (\Delta\ MN) + CEF\ 14\ (\delta\ s)$$

Rolling Moment: (41)

$$C_{LL} = CEF\ 21\ (\Delta\beta) + CEF\ 9\ (\Delta\ \rho)\ (\tfrac{1}{2})\left(\frac{b}{\rho V^2}\right) + CEF\ 10\ (\Delta\ r)\ (\tfrac{1}{2})\left(\frac{b}{\rho V^2}\right) + CEF\ 15\ (\Delta\beta)$$

Yawing Moment: (42)

$$C_N = CEF\ 22\ (\Delta\beta) + CEF\ 11\ (\Delta\ r)\ (\tfrac{1}{2})\left(\frac{b}{\rho V^2}\right) + CEF\ 12\ (\Delta\ p)\ (\tfrac{1}{2})\left(\frac{b}{\rho V^2}\right) + CEF\ 16\ (\Delta\beta)$$

Coefficients are listed in Table III.

Symbols:

$\Delta\alpha$ - delta alpha (angle of attack) - degrees

$\Delta\beta$ - delta beta (sideslip angle) - degrees

b - wing span - feet

c - mean aerodynamic cord - feet

$\Delta\dot{\alpha}$ - delta alpha dot (time rate of change alpha)

Δp - delta p (rate of roll)

Δr - delta r (rate of yaw)

Δq - delta q (rate of pitch)

Table V

Stability Derivatives and Coefficients

Program Symbol	Standard Notation	Definition
CEF 1	C_{LO}	Basic Lift Coefficient
CEF 2	$C_{L\alpha}$	Derivative of L respect to α
CEF 3	C_{DO}	Basic Drag Coefficient
CEF 4	$C_{D\alpha}$	Derivative of D respect to α
CEF 5	C_{MO}	Basic Pitching Moment Coefficient
CEF 6	$C_{m\alpha}$	Derivative of m respect to α
CEF 7	C_{mq}	Derivative of m respect to q
CEF 8	$C_{m\dot{\alpha}}$	Derivative of m respect to $\dot{\alpha}$
CEF 9	C_{lp}	Derivative of l respect to p
CEF 10	C_{lr}	Derivative of l respect to r
CEF 11	C_{Nr}	Derivative of N respect to r
CEF 12	C_{Np}	Derivative of N respect to p
CEF 13	$C_{L\delta s}$	Derivative of L respect to δs
CEF 14	$C_{m\delta s}$	Derivative of m respect to δs
CEF 15	$C_{l\delta r}$	Derivative of l respect to δr
CEF 16	$C_{N\delta r}$	Derivative of N respect to δr
CEF 17	$C_{Y\delta r}$	Derivative of Y respect to δr
CEF 18	C_{LM}	Derivative of L respect to M
CEF 19	C_{Dm}	Derivative of D respect to m

Program Symbol	Standard Notation	Definition
CEF 20	C_{Mm}	Derivative of M respect to m
CEF 21	$C_{l\beta}$	Derivative of l respect to β
CEF 22	$C_{N\beta}$	Derivative of N respect to β
CEF 23	$C_{Y\beta}$	Derivative of Y respect to β

Key Symbols

L - Lift D - Drag M - Mach Number

α - angle of attack β - sideslip

$\dot{\alpha}$ - rate of change of α

p - rate of roll q - rate of pitch

r - rate of yaw m - pitch moment

l - rolling moment N - yawing moment

δs - elevator deflection δr - rudder deflection

Appendix D

Missile Model

To test the performance of the aircraft simulation, a missile model was required. The model included in the program was a very simplified and generalized missile. The missile was a proportional-navigated-guided model with constant velocity, constant mass, and it was unaffected by gravity. Missile specifications were generalized from state-of-the-art air-to-air missiles. The specifications of the missile were:

1. Proportional navigation constant - 3
2. Time constant - .5 seconds
3. Gimbals limits - 30 degrees
4. "G" force - 20 g's.
5. Line-of-sight rate - 30 degrees/second.

During actual missile simulations using the aircraft model, the missile model should be developed along the same modular construction as the aircraft model. All the required subroutines are present in the Program EVASION but are very basic due to the simplified missile.

The missile model was constructed so that any type guidance could be simulated. If other than infra-red or radar guided are desired, noise source subroutines should be developed.

Additional complete subroutines must be developed for an accurate missile model. Differential equations are required for the equations of motion routine. The missile model can be made as complete as desired by the complexity of the total coefficient and force equations in FORCESM. Additional parameters can be put into the model in DATAMIS.

FORCESM

In the development of the missile model, the total velocity of the missile is assumed to be along the longitudinal axis, X-axis.

$$\overline{V}_B = \begin{bmatrix} V_{B_X} \\ O \\ O \end{bmatrix} \qquad (43)$$

This assumption in turn leads to the angular velocity, ω, being equal to vector sum of the rate of change in the azimuth and elevation.

$$\overline{\omega} = \begin{bmatrix} O \\ \omega_y \\ \omega_z \end{bmatrix} = \begin{bmatrix} O \\ \dot{\lambda} \\ \dot{\Psi} \end{bmatrix} \qquad (44)$$

The missile is assumed to be of constant velocity. The acceleration in the aircraft navigation is therefore equal to the cross product of the angular velocity and velocity in the body fixed frame.

$$\dot{\overline{V}}_N = O + \overline{\omega} \times \overline{V}_B = \begin{bmatrix} O \\ \dot{\lambda} \\ \dot{\Psi} \end{bmatrix} \times \begin{bmatrix} V_X \\ O \\ O \end{bmatrix} \qquad (45)$$

$$\dot{\bar{V}}_N = \begin{bmatrix} i & j & k \\ O & \dot{\lambda} & \dot{\Psi} \\ V & O & O \end{bmatrix} = \begin{bmatrix} O & i \\ \dot{\Psi} & Vj \\ -\dot{\lambda} & Vk \end{bmatrix} \qquad (46)$$

(i, j, k) - unit vectors

To determine the acceleration forces in terms of g's, the lateral and vertical acceleration are divided by the gravity.

$$\bar{g} = \frac{\dot{\bar{V}}_N}{\bar{g}} = \begin{bmatrix} O \\ \frac{\dot{\Psi} V}{g} \\ \frac{-\dot{\lambda} V}{g} \end{bmatrix} \qquad (47)$$

A test is needed in FORCESM so that the missile will not exceed its maximum g forces. If the computed g forces are greater than specifications, the rate of change of azimuth and/or elevation will be recomputed to bring the g forces within limits. INPUTSM is called in FORCESM to recompute the azimuth and elevation angles.

Appendix E

Entering Data

Aircraft and missile data are stored in arrays for ease of programming. The data must be read into the program in a specific order for proper operation. The data for the aircraft is put in a file called TAPEI and the missile's data is on TAPE 2. In this manner, selection of one vehicle is not dependent on the other.

After the initial integer which indicates the type missile and target, the vehicle data is stored in arrays AC (aircraft) and DM (missile).

The data is entered one value per card in free format in the following order for the aircraft:

1. Weight
2. Wing Area
3. Wing Span
4. Mean Chord
5. Maximum Rate of Change of Thrust
6. Maximum Rate of Change of Bank
7. Maximum Angle of Attack
8. Maximum Sideslip Angle
9. Maximum Rate of Change of Angle of Attack
10. Maximum Rate of Change of Sideslip

11. Product of Inertia XX

12. Product of Inertia YY

13. Product of Inertia ZZ

14. Product of Inertia XZ

The next information to be entered is the initial conditions which are stored in arrays DATAFT (aircraft) and DATAMIS (missile). The initial conditions are entered one value to a card in free format in the following sequence:

1.	x - position	7.	bank
2.	y - position	8.	pitch
3.	z - position	9.	heading
4.	u - velocity	10.	yaw rate
5.	v - velocity	11.	pitch rate
6.	w - velocity	12.	roll rate

The thrust coefficients are entered in free format, three values per card, as a function of Mach number while the aerodynamic coefficients are entered, six values to a card in free format as a function of angle of attack as well as Mach number. Interpolation is used by the table look-up routine to select the proper coefficients for the given parameters.

The missile model and its parameters will determine the order of entry of its data. The arrays are specified in the program.

Vita

Harry G. Paddon was born 27 April 1939 in Silver Spring, Maryland where he graduated from Montgomery Blair High School in June, 1957. He attended one year at North Carolina State University before entering the United States Air Force Academy. He graduated from the Academy in June 1962 with a Bachelor of Science Degree and a major in Engineering Science. He completed pilot training at Williams AFB, Arizona in August 1963. He has served as a tactical fighter pilot and instructor pilot at Webb AFB, Moody AFB, Nellis AFB and Korat Royal Thai Air Base in T-37, T-38 and F-105 aircraft. He reported to AFIT from Spangdahlem AB, Germany where he served as Chief, Air Traffic Control Operations.

Permanent address: 808 Stonington Road
Silver Spring, Maryland 20902

This thesis typed by Mrs. Carolyn A. Paddon.