Table 1: Maneuvering Target Simulation for Testing the Terminal Guidance

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Diagram 1: Representation of maneuvering target simulation.

Diagram 2: Graph showing terminal guidance performance.
MANEUVERING TARGET SIMULATION
FOR TESTING THE TERMINAL GUIDANCE
FOR AIR-TO-AIR MISSILES

THESIS

GE/EE/77-2  Harry G. Paddon
Major       USAF

Approved for public release; distribution unlimited.
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.
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

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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.
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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 azimuth 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).
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 (\ddot{R}) azimuth rate (\dot{\zeta}) 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:
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
- $\psi, \theta, \phi$ - Euler angles (heading, flight path angle, and bank angle)

The missile 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.

\[
\begin{align*}
    x_{MF} &= x_M - x_F \\
    y_{MF} &= y_M - y_F \\
    z_{MF} &= z_M - z_F \\
    u_{MF} &= u_M - u_F \\
    v_{MF} &= v_M - v_F \\
    w_{MF} &= w_M - w_F
\end{align*}
\]
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.

\[
T_{NB} = \begin{bmatrix}
    c\theta c\gamma & c\theta s\gamma & -s\theta \\
    s\theta s\gamma - c\gamma c\phi & s\theta c\gamma + c\phi s\gamma & s\theta c\phi \\
    c\theta s\gamma + s\gamma c\phi & c\theta c\gamma - s\phi s\gamma & c\theta c\phi
\end{bmatrix}
\]  

(7)

where \( s \) denotes sine and \( c \) denotes cosine.

\[
\begin{bmatrix}
    x_{MB} \\
    y_{MB} \\
    z_{MB}
\end{bmatrix} = T_{NB} \begin{bmatrix}
    x_{MF} \\
    y_{MF} \\
    z_{MF}
\end{bmatrix}
\]  

(8)

\[
\begin{bmatrix}
    u_{MB} \\
    v_{MB} \\
    w_{MB}
\end{bmatrix} = T_{NB} \begin{bmatrix}
    u_{MF} \\
    v_{MF} \\
    w_{MF}
\end{bmatrix}
\]  

(9)

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

\[
\zeta_{MF} = \sin^{-1} \left( \frac{y_{MB}}{R} \right)
\]  

(10)

\[
\eta_{MF} = \sin^{-1} \left( -\frac{z_F}{R} \right)
\]  

(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.
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 trigonometric 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.

\[ R = \sqrt{X_{MF}^2 + Y_{MF}^2 + Z_{MF}^2} \]  \hspace{1cm} (12)

\[ \dot{R} = \frac{u_{MB} x_{MB} + v_{MB} y_{MB} + w_{MB} z_{MB}}{R} \]  \hspace{1cm} (13)

or

\[ \dot{R} = u_{MB} \cos \eta_{MF} \cos \zeta_{MF} + v_{MB} \cos \eta_{MF} \sin \zeta_{MF} - w_{MB} \sin \eta_{MF} \]  \hspace{1cm} (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, \( \eta_{MF} \) is derived first. \( \eta_{MF} \) is the angle between the aircraft's X axis and the velocity vector component of the missile in the \( X_B Y_B \) plane of the aircraft.

\[ \eta_{MF} = \cos^{-1} \frac{u_{MB}}{\sqrt{u_{MB}^2 + v_{MB}^2}} \]  \hspace{1cm} (15)
If \( v_{MB} \) is negative, \( \psi_{MF} \) becomes the negative of the above equation.

\[
\psi_{MF} = -\cos^{-1} \left( \frac{u_{MB}}{\sqrt{u_{MB}^2 + v_{MB}^2}} \right) \tag{16}
\]

Another angle of interest is the flight path angle of the missile in the \( X_B Y_B \) plane of the aircraft, \( \theta_{MF} \).

\[
\theta_{MF} = \sin^{-1} \left( \frac{-w_{MB}}{\sqrt{u_{MB}^2 + v_{MB}^2 + w_{MB}^2}} \right) \tag{17}
\]

With \( \psi_{MF} \) and \( \theta_{MF} \) defined, the azimuth rate \( \zeta \), and elevation rate, \( \eta_{MF} \), are then determined.

\[
\zeta_{MF} = \frac{\left( u_{MB}^2 + v_{MB}^2 \right)^{\frac{1}{2}} \cos \left( \eta_{MF} - \psi_{MF} \right)}{R \cos \psi_{MF}} \tag{18}
\]

\[
\eta_{MF} = \frac{\left( u_{MB}^2 + v_{MB}^2 \right)^{\frac{1}{2}} \cos \left( \psi_{MF} - \zeta_{MF} \right) \sin \eta_{MF} - w_{MB} \cos \eta_{MF} \cos \eta_{MF}}{R} \tag{19}
\]

Refer to Figures 4 and 5 for the orientation of \( \zeta \) and \( \eta \).

The next angles to be determined are the angle off, \( \varphi_{off} \), and cone angle, \( \theta_{cone} \). The scaler dot product of \( R \) and the aircraft's velocity vector, \( \vec{V} \), determine the \( \varphi_{off} \). The mathematical solution:

\[
\cos \left( \varphi_{off} \right) = \frac{\vec{V} \cdot \vec{R}}{[\vec{V}] [\vec{R}]} \tag{20}
\]
\[
\cos (\phi_{\text{off}}) = \frac{x_{\text{MF}}y_{\text{M}} + y_{\text{MF}}^2v_{\text{M}}^2 + z_{\text{MF}}w_{\text{M}}}{vR}
\]

(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:

\[
\cos (\theta_{\text{cone}}) = \cos \theta_{\text{MF}} \cos \theta_{\text{MF}} \cos \tau_{\text{MF}}
\]

(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, \( \sigma \), 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 affect 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 ANGLESFM**

The angle and angular rate conversion subroutines for both vehicles transform the degree inputs into radians by use of the Function DEGZRAD. ANGLESF and ANGLESFM 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

PRINT

ATTACK ROUTINES

EVAMATU

THRUST ROUTINES

DECISION POINT

DESIGN

PURSUIT

INPUT ROUTINES

INPUT Routines

TEST C-INIT

FORCE ROUTINES

UPDATE ROUTINES

REDUCE

TEST PARAMETERS

STOP

FIGURE 6
24
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 ±1000 feet, while at the 1000 feet point, the distribution is within ±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, \( \varphi_{\text{off}} \), 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 (\( \alpha \)) as an example, the error is determined between the desired angle of attack (\( \alpha_D \)) and the actual \( \alpha \) of the aircraft.

\[
\text{ERROR} \ \alpha = \alpha_D - \alpha
\]

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

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

where:

- \( \dot{\alpha} \) - rate of change of angle of attack
- \( P_1, 2 \) - guidance parameters for aircraft
- \( \dot{\alpha}_{\text{MAX}} \) - max rate of change of angle of attack
- \( \Delta t \) - integration interval

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

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

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

The finite control inputs can be bypassed if the error is zero.

Again using angle of attack as an example, the relationship becomes:

\[
\alpha = \alpha_D \quad \text{(Ref. 4:94)}
\]
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 horizontal 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 differential 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 transforma-
tions. 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. Aero-
dynamic 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 Runge-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

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

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

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

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

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

\[ \dot{\omega} = qw \cos \varphi w - rw \sin \varphi w \] (30)

\[ \dot{\varphi} w = (qw \sin \varphi w + rw \cos \varphi w) \sec \theta w \] (31)

\[ \dot{X}_E = V \cos \theta w \cos \varphi w \] (32)
\[ \dot{Y}_E = V \cos \phi_w \sin \psi_w \]  
\[ \dot{Z}_E = -V \sin \psi_w \]  

(33)  
(34)

The equations for \( \dot{\psi}_w, \dot{\theta}, \dot{\beta} \) (Ref. 2:150) are not used in Subroutine F. The finite control inputs \( \dot{\psi}_w, \dot{\alpha}, \dot{\beta} \) 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.

\[ F_Y = T_{YW} - \text{Sideforce} - mg \cos \theta_W \sin \psi_W \]  
\[ F_Z = T_{ZW} - \text{Lift} + mg \cos \theta_W \cos \psi_W \]  

(35)  
(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 positions 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>
<thead>
<tr>
<th>Test Number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>A/C type</td>
<td>non-responsive</td>
<td>non-responsive</td>
<td>responsive</td>
<td>responsive</td>
<td>responsive</td>
</tr>
<tr>
<td>Position (feet)</td>
<td>X and Y position are zero for all.</td>
<td>Z is -20000 feet altitude for all.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity u (feet/sec)</td>
<td>700</td>
<td>800</td>
<td>900</td>
<td>1000</td>
<td>1100</td>
</tr>
<tr>
<td>v and w velocities are zero for all.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orientation angles (Deg.)</td>
<td>Ŷ, θ, φ are zero for all.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angular body rates (Deg/sec)</td>
<td>p, q and r are zero for all.</td>
<td></td>
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<td>Missile type</td>
<td>IR</td>
<td>RADAR</td>
<td>RADAR</td>
<td>IR</td>
<td>RADAR</td>
</tr>
<tr>
<td>Position x (feet)</td>
<td>-5196</td>
<td>-5196</td>
<td>10392</td>
<td>-6000</td>
<td>-6000</td>
</tr>
<tr>
<td>y</td>
<td>-3000</td>
<td>3000</td>
<td>6000</td>
<td>-6000</td>
<td>-6000</td>
</tr>
<tr>
<td>z</td>
<td>-20000</td>
<td>-20000</td>
<td>-20000</td>
<td>-14000</td>
<td>-14000</td>
</tr>
<tr>
<td>Velocity u (feet/sec)</td>
<td>2694</td>
<td>2694</td>
<td>-2694</td>
<td>1838</td>
<td>1838</td>
</tr>
<tr>
<td>v</td>
<td>1555</td>
<td>-1555</td>
<td>-1555</td>
<td>1838</td>
<td>-1838</td>
</tr>
<tr>
<td>w</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-1838</td>
<td>-1838</td>
</tr>
<tr>
<td>Orientation angles Ŷ (Deg)</td>
<td>30</td>
<td>330</td>
<td>210</td>
<td>45</td>
<td>315</td>
</tr>
<tr>
<td>θ</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Angular rates (Deg/sec)</td>
<td>Ŷ and θ are zero for all.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Results</td>
<td>HIT</td>
<td>HIT</td>
<td>MISS</td>
<td>MISS</td>
<td>HIT</td>
</tr>
</tbody>
</table>
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 an 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.
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 VERTICAL 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 stochastic 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)

Figure 9
RESPONSIVE AIRCRAFT/RADAR GUIDED MISSILE

LEGEND

- FIGHTER
- MISSILE
△ GND TRK(F)
+ GND TRK(M)

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):

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5999.90</td>
<td>629.20</td>
</tr>
<tr>
<td>Minimum</td>
<td>5025.00</td>
<td>Maximum</td>
</tr>
<tr>
<td>Median</td>
<td>6210.00</td>
<td>6950.00</td>
</tr>
</tbody>
</table>

Decision Point 1 Time (Seconds):

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>.90</td>
<td>.29</td>
</tr>
<tr>
<td>Minimum</td>
<td>.47</td>
<td>Maximum</td>
</tr>
<tr>
<td>Median</td>
<td>.81</td>
<td>1.35</td>
</tr>
</tbody>
</table>
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:** 0.15
- **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)

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>2.74</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>.27</td>
</tr>
<tr>
<td>Minimum</td>
<td>2.31</td>
</tr>
<tr>
<td>Maximum</td>
<td>3.13</td>
</tr>
<tr>
<td>Median</td>
<td>2.85</td>
</tr>
</tbody>
</table>

Time to go from decision point 2 (seconds)

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>.50</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>.15</td>
</tr>
<tr>
<td>Minimum</td>
<td>.16</td>
</tr>
<tr>
<td>Maximum</td>
<td>.67</td>
</tr>
<tr>
<td>Median</td>
<td>.55</td>
</tr>
<tr>
<td>Termination Time (seconds)</td>
<td>Time To Go From Point 1 (seconds)</td>
</tr>
<tr>
<td>---------------------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>3.61</td>
<td>3.04</td>
</tr>
<tr>
<td>3.64</td>
<td>2.94</td>
</tr>
<tr>
<td>3.65</td>
<td>2.85</td>
</tr>
<tr>
<td>3.60</td>
<td>3.13</td>
</tr>
<tr>
<td>3.66</td>
<td>2.33</td>
</tr>
<tr>
<td>3.65</td>
<td>2.84</td>
</tr>
<tr>
<td>3.63</td>
<td>2.98</td>
</tr>
<tr>
<td>3.66</td>
<td>2.36</td>
</tr>
<tr>
<td>3.66</td>
<td>2.31</td>
</tr>
<tr>
<td>3.64</td>
<td>2.92</td>
</tr>
<tr>
<td>3.61</td>
<td>3.09</td>
</tr>
<tr>
<td>3.67</td>
<td>2.65</td>
</tr>
<tr>
<td>3.66</td>
<td>2.34</td>
</tr>
<tr>
<td>3.63</td>
<td>2.94</td>
</tr>
<tr>
<td>3.67</td>
<td>2.56</td>
</tr>
<tr>
<td>3.67</td>
<td>2.54</td>
</tr>
<tr>
<td>3.64</td>
<td>2.89</td>
</tr>
<tr>
<td>3.66</td>
<td>2.50</td>
</tr>
<tr>
<td>3.67</td>
<td>2.65</td>
</tr>
<tr>
<td>3.62</td>
<td>3.00</td>
</tr>
</tbody>
</table>

53
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):

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>5952.70</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>668.68</td>
</tr>
<tr>
<td>Minimum</td>
<td>5011.00</td>
</tr>
<tr>
<td>Maximum</td>
<td>6956.00</td>
</tr>
<tr>
<td>Median</td>
<td>5700.00</td>
</tr>
</tbody>
</table>

Decision Point 1 Time (seconds):

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>1.56</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>.17</td>
</tr>
<tr>
<td>Minimum</td>
<td>1.30</td>
</tr>
<tr>
<td>Maximum</td>
<td>1.81</td>
</tr>
<tr>
<td>Median</td>
<td>1.63</td>
</tr>
</tbody>
</table>
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):

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>937.30</td>
<td>297.62</td>
</tr>
<tr>
<td>Minimum</td>
<td>500.00</td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>1427.00</td>
<td></td>
</tr>
<tr>
<td>Median</td>
<td>963.50</td>
<td></td>
</tr>
</tbody>
</table>

Decision Point 2 Time (seconds):

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>2.87</td>
<td>0.08</td>
</tr>
<tr>
<td>Minimum</td>
<td>2.74</td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>3.00</td>
<td></td>
</tr>
<tr>
<td>Median</td>
<td>2.86</td>
<td></td>
</tr>
</tbody>
</table>
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 = 0.18
- Minimum = 1.30
- Maximum = 1.82
- Median = 1.49

Time to go from decision point 2 (seconds):

- Mean = 0.25
- Standard Deviation = 0.08
- Minimum = 0.12
- Maximum = 0.38
- Median = 0.26
<table>
<thead>
<tr>
<th>Termination Time (seconds)</th>
<th>Time To Go From Point 1 (seconds)</th>
<th>Time To Go From Point 2 (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.12</td>
<td>1.76</td>
<td>.38</td>
</tr>
<tr>
<td>3.12</td>
<td>1.57</td>
<td>.25</td>
</tr>
<tr>
<td>3.12</td>
<td>1.71</td>
<td>.29</td>
</tr>
<tr>
<td>3.12</td>
<td>1.68</td>
<td>.14</td>
</tr>
<tr>
<td>3.12</td>
<td>1.79</td>
<td>.13</td>
</tr>
<tr>
<td>3.12</td>
<td>1.81</td>
<td>.36</td>
</tr>
<tr>
<td>3.11</td>
<td>1.40</td>
<td>.13</td>
</tr>
<tr>
<td>3.11</td>
<td>1.32</td>
<td>.29</td>
</tr>
<tr>
<td>3.12</td>
<td>1.82</td>
<td>.24</td>
</tr>
<tr>
<td>3.11</td>
<td>1.35</td>
<td>.16</td>
</tr>
<tr>
<td>3.11</td>
<td>1.47</td>
<td>.14</td>
</tr>
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<td>3.12</td>
<td>1.75</td>
<td>.25</td>
</tr>
<tr>
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<td>1.30</td>
<td>.23</td>
</tr>
<tr>
<td>3.12</td>
<td>1.74</td>
<td>.12</td>
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<tr>
<td>3.11</td>
<td>1.37</td>
<td>.32</td>
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<tr>
<td>3.11</td>
<td>1.47</td>
<td>.29</td>
</tr>
<tr>
<td>3.11</td>
<td>1.40</td>
<td>.33</td>
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<tr>
<td>3.11</td>
<td>1.48</td>
<td>.26</td>
</tr>
<tr>
<td>3.12</td>
<td>1.50</td>
<td>.27</td>
</tr>
<tr>
<td>3.11</td>
<td>1.41</td>
<td>.35</td>
</tr>
</tbody>
</table>

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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


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


Appendix A

Fortran Computer Program Listing
```
PROGRAM Evasion(IVPUT=80, OUTPT=TAPE1, TAPE2, TAPE3)
DIMENSION AC(19), J4(5), DATAF(13), DATAM(16), DINF(+), RANG(2)

* THIS PROGRAM SIMULATES THE LATEST FIGHTER EVASION MANEUVERS AGAINST A *0.00150
* LAUNCHED AIR-TO-AIR MISSILE.*
* ARRAY EQUIVALENCES ARE:
* DATAF (FIGHTER) DATAM (MISSILE) FORF (FIGHTER) FORM (MISSILE)
* 1 X POSITION 1 1 X FORCES 1 VELOCITY 0.00190
* 2 Y POSITION 2 2 Y FORCES 2 VERTICAL G FORCE 0.00200
* 3 Z POSITION 3 3 Z FORCES 3 HORIZONTAL G FORCE 0.00210
* 4 X VELOCITY 4 + X MOMENT 0.00220
* 5 Y VELOCITY 5 5 Y MOMENT 0.00230
* 6 Z VELOCITY 6 5 Z MOMENT 0.00240
* 7 BANK 7 7 YAW RATE 0.00250
* 8 PITCH 7 8 PITCH RATE 0.00260
* 9 HEADING 8 9 ROLL RATE 0.00270
* 10 YAW RATE 9 10 MASS 0.00280
* 11 PITCH RATE 10 11 BANK 0.00290
* 12 ROLL RATE 12 PITCH 0.00300
* TEST 11-16 13 HEADING 0.00310
* CONDITION

VEHICLE DATA
AC(FIGHTER) DM(MISSILE) AFT(FIGHTER) AM(MISSILE) 0.000380
1 WEIGHT 1 PSI MAX 1 ALPHA THRUST 1 PSI MAX 0.000390
2 WING AREA 2 THETA MAX 2 BETA THRUST 2 THETA MAX 0.000400
3 WING SPAN 3 PSI DOT MAX 3 ALPHA 3 PSI DOT MAX 0.000410
4 MEAN CHORD + THETA DOT MAX + BETA 4 THETA DOT MAX 0.000420
5 THRUST DOT MAX + TIME CONSTANT 5 HEADING 3 0.000430
6 PHI DOT MAX 5 GMAX 6 PITCH 5 0.000440
```

<table>
<thead>
<tr>
<th></th>
<th>RELATIVE VECTORS IN BODY FRAME</th>
<th>THRUST AND ATMOSPHERIC DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X POSITION</td>
<td>TF(FIGHTER)</td>
</tr>
<tr>
<td>2</td>
<td>Y POSITION</td>
<td>TM(MISSILE)</td>
</tr>
<tr>
<td>3</td>
<td>Z POSITION</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>X VELOCITY</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Y VELOCITY</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Z VELOCITY</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>RELATIVE PARAMETERS</th>
<th>DESIRED INPUTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X POSITION</td>
<td>DINF(FIGHTER)</td>
</tr>
<tr>
<td>2</td>
<td>Y POSITION</td>
<td>DINM(MISSILE)</td>
</tr>
<tr>
<td>3</td>
<td>Z POSITION</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>RANGE</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>X VELOCITY</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Y VELOCITY</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Z VELOCITY</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>AZIMUTH (POSITIVE RIGHT)</td>
<td>PILOT REACTION RANGE</td>
</tr>
<tr>
<td>9</td>
<td>ELEVATION (POSITIVE UP)</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>RANGE RATE</td>
<td></td>
</tr>
</tbody>
</table>

| 7     | YAW RATE                         | *000450                      |
| 8     | PITCH RATE                       | *000470                      |
| 9     | ROLL RATE                        | *000480                      |
| 10    | BANK                             | *000490                      |
| 11    | ALPHA MAX                        | *000500                      |
| 12    | BETA MAX                         | *000510                      |
| 13    | ALPHA DOT MAX                    | *000520                      |
| 14    | BETA DOT MAX                     | *000530                      |
| 15    | PHI DOT MAX                      | *000540                      |

| 1     | CURRENT THRU                      | *000550                      |
| 2     | MACH NUMBER                       | *000550                      |
| 3     | DYNAMIC PRESSURE                  | *000550                      |
| 4     | RANGE BETWEEN                     |                               |
| 5     |                                      | *000550                      |
| 6     |                                      | *000550                      |
| 7     |                                      | *000550                      |
| 8     |                                      | *000550                      |
* 11 PSI
* 12 THETA
* 13 PHI(BODY FRAME)
* 14 PSI(BODY FRAME)
* 15 THETA(BODY FRAME)
* 16 AZIMUTH RATE
* 17 ELEVATION RATE
* 18 CONE ANGLE
* 19 ANGLE OF

SUBROUTINES RODES, C3LNDG, AND ATYS ARE FROM THE AFITSJ3ROUTINES
LIBRARY, WRIGHT PATTERSON AFB, OHIO.

* 00030

DATA PI,3.14159,32.17/
REWIND 1
REWIND 2
TIME=0.0
DT=.01
IN=0
LOCK=0
IND: X=0
K=1
READ(1,*) KF
IF(EOF(1),NE.0)STOP" END OF DATA 1"
READ(2,*) KM
IF(EOF(2),NE.0)STOP" END OF DATA 2"
WRITE(3) KF,KM
PRINT," TYPE OF MISSILE ISI"
IF(KM.EQ.2)PRINT," INFRA-RED"
IF(KM.EQ.3)PRINT," RADAR GUIDE"
PRINT*
PRINT," TYPE FIGHTER ISI"
IF(KF.EQ.0)PRINT," NON-RESPONSIVE"
IF(KF.EQ.0)PRINT," RESPONSIVE"
CALL DATAFTR(AC)
CALL DATAMIS(DM)
CALL INITFIT(DATAFT)
CALL INITMIS(DATAM)
CALL ANG_SF(AC,ATF,DATAFT)
CALL ANGLESM(OM,AM,DATAM)
CALL PRINT(DM,DT,KF,KM,AM,ATF,INDEX,PI,TIME,AFT,AM,ATF,DATAFT,DATAM)
+AM,ABF)
CALL PILOT(AFT,RANG)
GO TO 25
10 INDEX=INDEX+1
IF(K.EQ.2) GO TO 2
K=2
20 IF(KF.LE.0) CALL EVAMANJ(TIME,PI,MANUVR,AFT,RANG,DATAFT)
IF(KF.LE.0) MANUVR=0
GO TO 2
1 INDEX=INDEX+1
K=1
2 CALL TRJSF(INDEX,DATAM,TF)
CALL TRJSTM(INDEX,DATAM,TF,FORM)
CALL DESNY(TIME,MANUVR,DINF,DATAFT,AC,TF,AFT,ABF,PI,ATF)
CALL PURSJT(INDEX,DATAM,OM,ATM,DINF,PI,AM)
CALL INPJTSF(DT,AFT,DINF,TF)
CALL INPJTM(LOCK,PI,ATM,DINF,TF)
CALL FORCESF(INDEX,TF,FORF,AC,DATAFT,DINF)
CALL FORCESM(LOCK,OM,FORF,DATAM,ATM,AM)
CALL UPDATE(TF,AFT,FORF,DATAFT,PI,TIME,DT,AC)
TIME=TIME-DT
CALL UPDATE(DATAM,DT,TF,FORM,TIME)
CALL PRINT(DM,DT,KF,KM,AM,ATF,INDEX,PI,TIME,AFT,AM,ATF,DATAFT,DATAM)
+AM,ABF)
IF(DT.EQ.0.1) CALL REDUCE(PI,INDEX,AFT,DT)
25 IF(DT.EQ.0.1) DT=0.0000001
INTER=IFIX(.30000001/DT)
IF(MOD(INDEX,INTER).NE.0) GO TO 109
IN=IN+1
XI(IN)=DATAFT(IN)
YI(IN)=DATAFT(IN+1)
ZI(IN)=DATAFT(IN+2)
XH(IN)=DATAM(1)
YH(IN)=DATAM(2)
ZH(IN)=DATAM(3)

105 IF(TIME.EQ.0.0) GO TO 1

**** TESTING IN-FLIGHT CONDITIONS AGAINST GIVEN PARAMETERS *****

IF(INDEX.EQ.1) TIME=ATF(4)/(ABS(ATF(10)))
IF(ATF(4).EQ.0.0) GO TO 102
IF(ATF(4).LT.0.5) GO TO 103

-1 IF(ATF(3)(2),GE.0.0) GO TO 104
-2 IF(ATF(3)(2),LE.0.0) GO TO 107
-3 IF(ATF(3)(3),GE.0.0) GO TO 108

+5 IF(ROCK.AT.1) GO TO 105
+6 DO 3 J=11,16

IF(IFIX(DATAM(J)) .LT.1) GO TO 75
DATAM(J)=0.0

IF(MOD(INDEX,INTER).EQ.0) PRINT 30

80 FORMAT(’/** MISSILE PARAMETERS ARE WITHIN LIMITS */

90 IF(ATF(10),GT.0.0) GO TO 101
IF(TIME.GT.0.5) GO TO 111
IF(ATF(4),LT.RANGE1.AND.,ATF(4),GT.RANGE1-200.0) GO TO 101
IF(ATF(4),LT.RANGE2.AND.,ATF(4),GT.RANGE2-200.0) GO TO 101
GO TO 1

103 IF(IFIX(DATAM(11)),.LT.1) GO TO 41
PRINT*,"MISSILE EXCEEDED MAXIMUM LATERAL G'S!
PRINT 113, FORM(2), DF(6)

113 FORMAT(’/** MISSILE PULLED*, F6.2, * LATERAL G'S, */
+** MAXIMUM LACAL IS*, F6.2, */

DATAM(11)=1.0
GO TO 41

104 IF(IFIX(DATAM(12)),.LT.2) GO TO 42
PRINT*,"MISSILE EXCEEDED MAXIMUM VERTICAL G'S!
PRINT 114, FORM(3), DF(6)

114 FORMAT(’/** MISSILE PULLED*, F6.2, * VERTICAL G'S, */
+** MAXIMUM VERTICAL IS*, F6.2, */

DATAM(12)=2.0
GO TO 42
107 IF(IFI(XDATAM(13)),EQ,3)GO TO 43
PRINT*,"TARGET OUTSIDE GIMBAL LIMITS!"
PRINT 117,AT4(19),AT4(1)
117 FORMAT(/X,* MISSILE'S CONE ANGLE TO THE FIGHTER IS*,-F6.2,* DEGREES*.0001340
+*,-/X,* MAXIMUM GIMBAL ANGLE OF THE MISSILE IS*,-F5.2,* DEGREES.*.0001330
+*
DATAM(13)=3.0
GO TO 43
108 IF(IFI(XDATAM(14)),EQ,4)GO TO 44
PRINT*,"TARGET OUTSIDE GIMBAL LIMITS!"
PRINT 123,AT4(8),AT4(1)
128 FORMAT(/X,* RELATIVE 12H14TH ANGLE IS*,-F7.2,* DEGREES.*,-/X,* MAX.002000
+*,-/X,* MAXIMUM 12H14TH ANGLE IS*,-F7.2,* DEGREES.*/
PRINT 123,AT4(9),AT4(2)
129 FORMAT(/X,* RELATIVE ELEVATION ANGLE IS*,-F7.2,* DEGREES.*,-/X,* MAX.002030
+*,-/X,* MAXIMUM ELEVATION GIMBAL ANGLE IS*,-F7.2,* DEGREES.*/
DATAM(14)=4.0
GO TO 44
109 IF(IFI(XDATAM(15)),EQ,5)GO TO 45
PRINT*,"MISSILE EXCEEDED MANEUVERING CAPABILITY!"
PRINT 133,AT4(15),AT4(3)
139 FORMAT(/X,* VERTICAL LINE OF SIGHT RATE IS*,-F8.2,* DEGREES/SECOND*.002120
+*,-/X,* MAXIMUM VERTICAL RATE IS*,-F3.2,* DEGREES/SECOND.*/
PRINT 143,AT4(17),AT4(4)
140 FORMAT(/X,* HORIZONTAL LINE OF SIGHT RATE IS*,-F8.2,* DEGREES/SECOND*.002130
+*,-/X,* MAXIMUM HORIZONTAL RATE IS*,-F6.2,* DEGREES/SECOND.*/
DATAM(15)=5.0
GO TO 45
106 IF(IFI(XDATAM(16)),EQ,5)GO TO 113
PRINT*;
PRINT*,"MISSILE IS PULLING MAXIMUM 5!"
PRINT*;
DATAM(16)=6.0
GO TO 46
116 LOCK=0
GO TO 46
110 PRINT*,'"TIME LIMIT!"
101 PRINT*,'"MISSILE HAS MISSED THE AIRCRAFT!"
IN=IN+1
XF(IN)=DATAFT(1)
YF(IN)=DATAFT(2)
ZF(IN)=DATAFT(3)
XM(IN)=DATAM(1)
YM(IN)=DATAM(2)
ZM(IN)=DATAM(3)
WRITE(3)IN
DO 55 I=1,IN
WRITE(3)XF(I),YF(I),ZF(I)
WRITE(3)XM(I),YM(I),ZM(I)
55 CONTINUE
INDEX=0
CALL PRINT(DM,DT,KF,KM,AM,ATM,INDEX,PI,TIME,AFT,AM,ATF,DATAFT,DAT)
+AM,ABF)
GO TO 102
102 PRINT*,'"MISSILE HAS SCORED A HIT ON THE AIRCRAFT!"
IN=IN+1
XF(IN)=DATAFT(1)
YF(IN)=DATAFT(2)
ZF(IN)=DATAFT(3)
XM(IN)=DATAM(1)
YM(IN)=DATAM(2)
ZM(IN)=DATAM(3)
WRITE(3)IN
DO 55 I=1,IN
WRITE(3)XF(I),YF(I),ZF(I)
WRITE(3)XM(I),YM(I),ZM(I)
55 CONTINUE
INDEX=0
CALL PRINT(DM,DT,KF,KM,AM,ATM,INDEX,PI,TIME,AFT,AM,ATF,DATAFT,DAT)
+AM,ABF)
GO TO 102
END
SUBROUTINE DATAFR(AC)  002540
DIMENSION AC(15)  002550

* READ IN AIRCRAFT DATA.  002560
* 002570
00 4 I=1,15  002580
READ (1,*) AC(I)  002590
IF(EOF(I).NE.0) STOP "END OF DATA"  002600
  + CONTINUE  002610
  5 RETURN  002620
END  002630
SUBROUTINE INITFT(DATAFT)
DIMENSION DATAFT(12)

* READ IN INITIAL CONDITIONS FOR THE AIRCRAFT. *

DO 1 I=1,12
READ (1,*) DATAFT(I)
1 CONTINUE
RETURN
END
SUBROUTINE DATAMIS(DM)
DIMENSION DM(5)

* READ IN MISSILE DATA. *

DO 4 I=1,5
READ (2,*) DM(I)
CONTINUE
RETURN
END

002390
002300
002310
002320
002330
002340
002350
002350
002370
002380
002390
SUBROUTINE INITMIS(DATAM)
DIMENSION DATAM(15)

* READ IN INITIAL CONDITIONS FOR THE MISSILE. *

DO 1 I=1,10
READ (2,*) DATAM(I)
CONTINUE
1

Z=-DATAM(3)
CALL ATMOS(Z,TH,SIGMA,RHO,THETA,DELTA,CA,AMU,

DATAM(4)=DATAM(4)*CA
DATAM(5)=DATAM(5)*CA
DATAM(6)=DATAM(6)*CA
DO 2 J=11,16

2

DATAM(J)=0.0
RETURN
END
SUBROUTINE ANGLESF (AC, AFT, DATAFT)
DIMENSION AC(19), AFT(13), DATAFT(12)

* THIS SUBROUTINE CONVERTS INITIAL AND COMPUTED ANGLES
* FROM DEGREES TO RADIANS.

AFT(1) = 0.0
AFT(2) = 0.0
AFT(5) = DEGREES (DATAFT(3), 0., 0., 0.)
AFT(6) = DEGREES (DATAFT(3), 0., 0., 0.)
AFT(10) = DEGREES (DATAFT(7), 0., 0., 0.)
AFT(11) = DEGREES (AC(7), 0., 0., 0.)
AFT(12) = DEGREES (AC(3), 0., 0., 0.)
AFT(13) = DEGREES (AC(3), 0., 0., 0.)
AFT(14) = DEGREES (AC(10), 0., 0., 0.)
AFT(15) = DEGREES (AC(6), 0., 0., 0.)

CALL TRANG30 (DATAFT(4), DATAFT(5), DATAFT(6), AFT(5), AFT(6), AFT(10), J)

RETURN
END

SUBROUTINE ANGLESF (AC, AFT, DATAFT)
DIMENSION AC(19), AFT(13), DATAFT(12)

* THIS SUBROUTINE CONVERTS INITIAL AND COMPUTED ANGLES
* FROM DEGREES TO RADIANS.

AFT(1) = 0.0
AFT(2) = 0.0
AFT(5) = DEGREES (DATAFT(3), 0., 0., 0.)
AFT(6) = DEGREES (DATAFT(3), 0., 0., 0.)
AFT(10) = DEGREES (DATAFT(7), 0., 0., 0.)
AFT(11) = DEGREES (AC(7), 0., 0., 0.)
AFT(12) = DEGREES (AC(3), 0., 0., 0.)
AFT(13) = DEGREES (AC(3), 0., 0., 0.)
AFT(14) = DEGREES (AC(10), 0., 0., 0.)
AFT(15) = DEGREES (AC(6), 0., 0., 0.)

CALL TRANG30 (DATAFT(4), DATAFT(5), DATAFT(6), AFT(5), AFT(6), AFT(10), J)

RETURN
END
SUBROUTINE ANGLES (N, AM, JATAM)
DIMENSION DM(5), JM(8), JATAM(15)

THIS SUBROUTINE CONVERTS INITIAL AND COMPUTED ANGLES

FROM RADIANS TO DEGREES

<table>
<thead>
<tr>
<th>AM(0)</th>
<th>AM(1)</th>
<th>AM(2)</th>
<th>AM(3)</th>
<th>AM(4)</th>
<th>AM(5)</th>
<th>AM(6)</th>
<th>AM(7)</th>
<th>AM(8)</th>
<th>AM(9)</th>
<th>AM(10)</th>
<th>AM(11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

RETURN
SUBROUTINE ATTACK(K, PI, AT, DATAM, DATAF, AFT, X, AB)

DIMENSION AT(19), DATAM(12), DATAF(12), AFT(15), AM(8), AB(5)

******************************************************************************

* THIS SUBROUTINE COMPUTES THE RELATIVE POSITIONS, VELOCITIES, 
* AND ANGLES IN THE VEHICLE'S BODY FRAME UPON WHICH THE PILOT 
* USES TO BASE IN-FLIGHT DECISIONS.
******************************************************************************

AT(1) = DATAM(1) - DATAF(1)
AT(2) = DATAM(2) - DATAF(2)
AT(3) = DATAM(3) - DATAF(3)
AT(4) = SQRT(AT(1)**2 + AT(2)**2 + AT(3)**2)
AT(5) = DATAM(4) - DATAF(4)
AT(6) = DATAM(5) - DATAF(5)
AT(7) = DATAM(6) - DATAF(6)

CALL TRAV2B(AT(1), AT(2), AT(3), AFT(5), AFT(5), AFT(10), AB(1),
+ AB(2), AB(3))

AT(8) = ASIN((AB(2) / AT(4)))
IF (AB(1) .GE. 0.0) GO TO 1
IF (AT(3) .GE. 0.0) GO TO 2
AT(6) = PI - AT(3)
GO TO 1

2 AT(8) = PI - AT(3)
AT(9) = ASIN(-AB(3) / AT(4))

CALL TRAV2B(AT(3), AT(5), AT(7), AFT(5), AFT(5), AFT(10), AB(4),
+ AB(5), AB(6))

AT(10) = A3(4) * COS(AT(3)) * COS(AT(9))

* * A3(5) * COS(AT(9)) * SIN(AT(3))
- - AB(6) * SIN(AT(9))
AT(11) = AB(5) - AFT(5)
AT(12) = AB(5) - AFT(5)
AT(13) = 0.0 - AFT(10)
IF (AB(4) ** 2 + AB(5) ** 2, NE, 0.0) GO TO 3
AT(14) = AT(13) + PI
GO TO 4

1 AT(14) = A3(4) / SQRT((AB(4) ** 2 + AB(5) ** 2))
IF (AB(3), LT, 0.0) AT(14) = -AT(14)

GO TO 4

3 AT(14) = A3(4) / SQRT((AB(4) ** 2 + AB(5) ** 2))
IF (AB(3), LT, 0.0) AT(14) = -AT(14)

GO TO 4
4: IF (AB(+)**2 + AB(5) **2 + A3(5) **2 + NE.0,0) GO TO 5
   AT(15) = 0.0
   GO TO 5
5: AT(15) = ASIN(-AB(5)/SQRT(A3(4) **2 + AB(5) **2 + AB(6) **2))
   IF (COS(AT(3)) NE.0,0) GO TO 7
   AT(16) = 0.0
   GO TO 3
7: AT(16) = SQRT(A3(4) **2 + A3(3) **2) * COS(PI/2,0 + AT(8) - AT(14))/
   + AT(4) / COS(AT(9))
   AT(17) = (-SQRT(A3(4) **2 + AB(5) **2) * COS(AT(14) - AT(3)) * SIN(AT(3)))
   + (-AB(6) * COS(AT(9))) / AT(+)
   AT(18) = ACOS(COS(AT(9)) * COS(AT(3)))
   AT(19) = ACOS((AT(1) * DATAM(+) + AT(2) * DATAM(5) + AT(3) * DATAM(5)) /
   + (AT(+) * SQRT(DATAM(+) **2 + DATAM(5) **2 + DATAM(5) **2)))
   RETURN
END
SUBROUTINE ATTACK(OH, r, INDEX, AT, DATAM, DATAF, AM, AFT, AB, 004130
+TIME)
DIMENSION AT(19), DATAM(15), DATAF(12), AM(5), AFT(15), AB(5), AT(19), 004210
+DEL(3), O(4) 004220

* THIS SUBROUTINE COMPUTES THE RELATIVE POSITIONS, VELOCITIES, *
* AND ANGLES IN THE VEHICLE'S BODY FRAME UPON WHICH THE MISSILE *
* USES TO COMPUTE IN-FLIGHT DECISIONS. *
* 004230

IF (I.EQ.2) CALL IRVOS(OM, DT, TIME, AFT, AM, AT, DEL, PI) 004230
IF (I.EQ.3) CALL IRVOS(OM, DT, TIME, AFT, AM, AT, DEL, PI) 004230
DATA XFT=DATAF(1)+DEL(1) 004230
DATA YFT=DATAF(2)+DEL(2) 004230
DATA ZFT=DATAF(3)+DEL(3) 004230
AT(1)=DATAFT-DATAF(1) 004300
AT(2)=DATAFT-DATAF(2) 004300
AT(3)=DATAFT-DATAF(3) 004300
AT(4)=SRT(AT(1)**2+AT(2)**2+AT(3)**2) 004350
AT(5)=DATAF(4)-DATAF(4) 004370
AT(6)=DATAF(5)-DATAF(5) 004390
AT(7)=DATAF(6)-DATAF(6) 004390
CALL TRAV28(AT(1), AT(2), AT(3), AM(5), AM(6), 0, 0, AB(1), 004400
+AB(2), AB(3)) 004410
AT(6)=SIN(AB(2)/AT(4)) 004420
IF (AB(1), GE.0.0) 50 TO 1 004430
IF (AT(3), GE.0.0) 50 TO 2 004440
AT(6)=PI-AT(8) 004450
GO TO 1 004450
2 004460
AT(8)=P1-AT(9) 004470
1 004480
AT(9)=ASIN(-AB(3)/AT(4)) 004490
CALL TRAV28(AT(5), AT(5), AT(7), AM(5), AM(6), 0, 0, AB(4), 004500
+AB(5), AB(6)) 004510
AT(10)=AB(4)*COS(AT(3))**COS(AB(3)) 004520
++AB(5)*COS(AB(3))**SIN(AB(3)) 004530
++AB(5)*SIN(AB(3)) 004540
*AT(11)=AT(5)-AM(5) 004540
AT(12) = AT(6) - AM(3)
AT(13) = AT(10) - 0.0
IF(AB(9)**2 + AB(5)**2 + AB(3)**2) GO TO 3
AT(14) = AT(13) + PI
GO TO 4

3
AT(14) = ACOS((AB(4)/SQR(AB(4)**2 + AB(3)**2))
IF(A9(3) > AT(14) = AT(14)
AT(15) = 0.0
GO TO 5
5
AT(15) = A5IN((AB(3)/SQR(AB(4)**2 + AB(5)**2 + AB(6)**2))
IF(C0S(AT(9)) > NEAT.0.0) GO TO 7
AT(16) = 0.0
GO TO 9
7
AT(16) = SQR(AB(4)**2 + AB(5)**2 + AB(3)**2 + AT(0) - AT(14) +
AT(4)**2 + COS(AB(4)**2 + AT(9)
8
AT(17) = (-SQR(AB(4)**2 + AB(5)**2 + AB(3)**2 + AT(14) + AT(8)**2 + SIN(AB(9))
AT(18) = COS(AB(4)**2 + AT(9))
AT(19) = A515(1) + DATAFT(4) + AT(2) + DATAFT(5) + AT(3) + DATAFT(6)
+ (AT(4) + DATAFT(4)**2 + DATAFT(5)**2 + DATAFT(6)**2)
DELTA = 0.0
DO 100 ID = 1, 3
DELTA = DELTA + DELTA
DELTA = SQR(DELTA)
INTER = 50000001/10
IF(MOD(INDEX, INTER).EQ. 0) PRINT 200, DEL(1), DEL(2), DELTA, DEL(3)
RETURN
END
SUBROUTINE ATMOS(Z,TM,SIGMA,RHO,THETA,DELTA,CA,AMU,K)

**CALLING SEQUENCE**

**CALL ATMOS(Z,TM,SIGMA,RHO,THETA,DELTA,CA,AMU,K)**

- **Z** = GEOMETRIC ALTITUDE (FT)
- **TM** = MOLECULAR SCALE TEMPERATURE (DEGREES RANKIN)
- **SIGMA** = RATIO OF DENSITY TO THAT AT SEA LEVEL
- **RHO** = DENSITY LB-SEC**2-FT**(-4) OR SLUGS-FT**3
- **THETA** = RATIO OF TEMPERATURE TO THAT AT SEA LEVEL
- **DELTA** = RATIO OF PRESSURE TO THAT AT SEA LEVEL
- **CA** = SPEED OF SOUND (FT/SEC)
- **AMU** = VISCOSITY COEFFICIENT (LB-SEC-FT**2)

**K** = 1 NORMAL,
- = 2 ALTITUDE GREATER THAN 300000 FT,
- = 3 ALTITUDE NEGATIVE,

**DIMENSION HPRIMB(11),TM8(11),SIGMAB(11),ALY(11),ARY(11,4)**

**EQUIVALENT** (ARY(1,1),HPRIMB(11),ARY(1,2),TM8(11)),
- (ARY(1,3),SIGMAB(11),ARY(1,4),ALY(11))

**DATA** (ARY(I,J),J=1,4,I=1,11)/

<table>
<thead>
<tr>
<th>X</th>
<th>0.0</th>
<th>518.588</th>
<th>1.0000000E+00</th>
<th>-0.0355555</th>
<th>0.05130</th>
<th>0.05129</th>
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</thead>
<tbody>
<tr>
<td>X</td>
<td>36939.239</td>
<td>339.938</td>
<td>2.3035958E+01</td>
<td>0.0</td>
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<td>X</td>
<td>92020.197</td>
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<td>3.235751E+02</td>
<td>0.00154532</td>
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<tr>
<td>X</td>
<td>154199.450</td>
<td>506.788</td>
<td>1.2117870E+03</td>
<td>0.0</td>
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<tr>
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<td>506.788</td>
<td>5.4977311E+04</td>
<td>-0.0024688</td>
<td>0.05170</td>
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<td>238.188</td>
<td>1.7329156E+05</td>
<td>0.0</td>
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<tr>
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<td>0.0021955</td>
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<td>X</td>
<td>34488.190</td>
<td>436.198</td>
<td>9.3921519E+07</td>
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<tr>
<td>X</td>
<td>52437.360</td>
<td>235.122</td>
<td>7.75658593E+10</td>
<td>0.00586040</td>
<td>0.05210</td>
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</tr>
<tr>
<td>X</td>
<td>557742.780</td>
<td>235.122</td>
<td>5.6324775E+10</td>
<td>0.00274320</td>
<td>0.05220</td>
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<tr>
<td>X</td>
<td>696187.960</td>
<td>233.198</td>
<td>2.7725771E+10</td>
<td>0.00192024</td>
<td>0.05230</td>
<td>0.05230</td>
</tr>
</tbody>
</table>
DATA 1 / 0.018744175 / ; RE / 2.08333531E 07 / , 0.05240
X S / 193.72 / ; PZ / 2116.2 / , 0.05250
X AMUZ / 3.737293E-07 / ; RHOZ / 0.0023763 / , 0.05270
X TMZ / 518.683 / , 0.05280

K=1
IF(Z)>25,19,17
25 K=3
GO TO 13
17 IF(Z.GT.300000.) K=K+1
18 HPRIM=(R/Z/(RE+Z)) * Z
9 DO 10 M=1,11
10 CONTINUE
M=12
11 M=M-1
12 IF(ALM(M))14,15,14
14 TM=TM(M)+ALM(M)*(HPRIM+HPRIMB(M))
SIGMA=EXP((1.0+(1/ALM(M)))*(ALG3(TM3(M)/TM))) * SIGMA3(M)
GO TO 20
20 RHO=R+Z*SIGMA
THETA=TM/TMZ
DELTA=SIGMA*THETA
CA=9.02177*SQRT(TM)
AMU=AMJZ*SQRT((THETA)**3)*((TMZ+S)/(TM+S))
13 RETURN
END
SUBROUTINE THRSTM (INDEX, DATAM, TM, FORM)
DIMENSION DATAM(13), TM(2), FORM(3)

* THIS SUBROUTINE COMPUTES DIFFERENT THUST OUTPUTS AND
* ATMOSPHERIC RELATED NUMBERS.

Z = (-DATAM(3))
CALL ATMOS(Z, TM, SIGMA, RHO, THETA, DELTA, CA, AMJ, K)

FORM(1) = SQRT(DATAM(4)**2 + DATAM(5)**2 + DATAM(6)**2)
TM(1) = FORM(1) / CA
TM(2) = 0.5 * RHO * FORM(1)**2
RETURN
END
SUBROUTINE THRUSTF(INDEX, DATAFT, TT)
DIMENSION DATAFT(12), TT(7)
DIMENSION TABLEX(5)
DIMENSION AMACHF(5), F1T(6), F2T(5), F3T(5), F4T(6), F5T(5)

THIS SUBROUTINE COMPUTES DIFFERENT THRUST OUTPUTS AND ATOMIC NUMBERS.

Z = (-DATAFT(3))
CALL ATMOS(Z, TM, SIGMA, RHO, THETA, DELTA, CA, AMJ, K)
IF (INDEX, ST, 1) GO TO 12

***** READ IN THRUST DATA FOR AIRCRAFT *****
DO 11 I = 1, 5
READ (1,*) AMACHF(I), F1T(I), F2T(I)
READ (1,*) F3T(I), F4T(I), F5T(I)
CONTINUE
11 TT(5) = SQRT(DATAFT(4)**2 + DATAFT(5)**2 + DATAFT(6)**2)
TT(5) = XA = TT(5) / CA
TT(7) = 5 * RHO * TT(5)**2
DO 1 I = 1, 5
1 TABLEX(I) = AMACHF(I)
FTH1 = TANOC(1, 2, F1T, TABLEX, 6, TT(6))
FTH2 = TANOC(1, 2, F2T, TABLEX, 5, TT(5))
FTH3 = TANOC(1, 2, F3T, TABLEX, 5, TT(6))
FTH4 = TANOC(1, 2, F4T, TABLEX, 6, TT(6))
FTH5 = TANOC(1, 2, F5T, TABLEX, 5, TT(6))
IF (DATAFT(3) > 350) GO TO 3
TT(4) = (FTH1 - FTH2) (((3609, + DATAFT(3)) / 1000) * 1000 * DELTA
GO TO +
3 TT(4) = (FTH1 - FTH3 (((DATAFT(3) - 3509, / 1000) * 1000 * DELTA
TT(2) = FTH4 * TT(4)
TT(3) = FTH5 * 1000 * DELTA
IF (INDEX, EQ, 1) TT(1) = TT(2)* 9
RETURN
END
SUBROUTINE PILOT(AT,RANG)
DIMENSION AT(19),RANG(2)

* THIS SUBROUTINE PROVIDES NOISE TO SIMULATE JUDGEMENT ERRORS
* IN RANGE BY THE PILOT.

* TEMP1=RANF(DUMMY)
DERRANG=2000.0*TEMP1-1000.0
RANG(1)=5000.0+DERRANG

TEMP2=RANF(DUMMY)
DERRANG=1000.0*TEMP2-500.0
RANG(2)=1000.0+DERRANG
RETURN
END
SUBROUTINE EVAMNJ(TIME,PI,MANJR,AT,RANG,DATAF)
DIMENSION AT(19),RANG(2),DATAF(13)
IF(TIME.EQ.0.0)N=1
PRINT 100,TIME
100 FORMAT(/4X,* TOTAL ELAPSED TIME IS*,F5.2,* SECONDS.*)
IF(AT(+),.T.,RANG(1))GO TO 101
ESTRAN=6000.0
PRINT 111;ESTRAN,N,AT(+),ESTRAN
111 FORMAT(/4X,* THE PILOT ESTIMATES THE MISSILE TO BE AT A RANGE OF
***,/4X,* MORE THEN *,F3.0,* FEET, THE PILOT EXECUTES MANEUVER NUMBER003030
+R*,I2;/4X,* AT AN ACTUAL RANGE OF*,F3.0,* FEET.*)
N=N+1
003320
GO TO 1
101 IF(N.GT.1)GO TO 121
ESTRAN=6000.0
003320
PRINT 111;ESTRAN,N,AT(+),ESTRAN
121 ESTRAN=6000.0
005490
PRINT 122;ESTRAN,N,AT(+)
122 FORMAT(/4X,* THE PILOT ESTIMATES THE MISSILE TO BE AT A RANGE OF
***,/4X,* LESS THEN *,F3.0,* FEET, THE PILOT EXECUTES MANEUVER NUMBER003030
+R*,I2;/4X,* AT AN ACTUAL RANGE OF*,F3.0,* FEET.*)
N=N+1
005490
GO TO 1
102 ESTRAN=1000.0
005520
PRINT 122;ESTRAN,N,AT(+)
122 FORMAT(/4X,* THE PILOT EXECUTES MANEUVER NUMBER*,I2,* AT AN Actual RANGE OF*,F3.0,* FEET.*)
N=N+1
005520
GO TO 1
*THIS SUBROUTINE SELECTS THE TACTICAL MANEUVER FOR THE
*SITUATION THAT EXISTS.
**---------------------------------------------**
1  IF (ABS (AT (5)) .LT. PI / 2.0) GO TO 3
   IF (AT (4) .LT. RANG (1)) GO TO 2
   PRINT 11
11  FORMAT ('/4X,* MANEUVER IS A VERTICAL DIVE AWAY FROM THE MISSILE,*/')
   MANUVR = 1
   RETURN
2  IF (AT (+) .LT. RANG (2)) GO TO 3
   PRINT 12
12  FORMAT ('/4X,* MANEUVER IS A HARD BREAK,*/')
   MANUVR = 2
   RETURN
3  IF ((-DATAFT (3)) .LT. 15000.0) GO TO 4
   PRINT 13
13  FORMAT ('/4X,* MANEUVER IS A SPLIT S,*/')
   MANUVR = 3
   RETURN
4  PRINT 14
14  FORMAT ('/4X,* THE ALTITUDE OF THE AIRCRAFT IS LESS THAN 15000 FEET.*/')
   MANUVR = 4
   PRINT 15
15  FORMAT ('/4X,* MANEUVER IS A HARD PULL JP,*/')
   RETURN
5  IF (AT (+) .LT. RANG (1)) GO TO 7
   IF ((-DATAFT (3)) .LT. 15000.0) GO TO 6
   PRINT 16
16  FORMAT ('/4X,* MANEUVER IS A SPLIT S,*/')
   MANUVR = 3
   RETURN
6  PRINT 17
17  FORMAT ('/4X,* THE ALTITUDE OF THE AIRCRAFT IS LESS THAN 15000 FEET,*/')
   MANUVR = 5
   RETURN
7  IF (AT (+), LT. RANG (2)) GO TO 8
   PRINT 18
18  FORMAT ('/4X,* MANEUVER IS A HARD BREAK FOLLOWED BY A VERTICAL DIVE,*/')
   MANUVR = 6
   RETURN
8  IF (AT (+), LT. RANG (3)) GO TO 9
   PRINT 19
19  FORMAT ('/4X,* MANEUVER IS A HARD BREAK SO AS TO PUT THE MISSILE')
IN A PURSUIT TYPE CURVE THEY REVERSE DIRECTION OF THE BREA006360

+K.*+/
MANUVR=6
RETURN
5 IF((-DATAFT(3))..T.1003.0) GO TO 9
PRINT 18
18 FORMAT(/'x, MINEJVER IS A VERTICAL DIVE FOLLOWED BY A HARD PULL J007320
+P.*'/
MANUVR=8
RETURN
3 PRINT 19
19 FORMAT(/'x, THE AIRCRAFT IS AT LOW ALTITUDE.*/x, MINEJVER IS A007370
+ HARD PULL UP.+'/
MANUVR=7
RETURN
END
SUBROUTINE PURSUIT(INDEX, JATAM, JM, AT4, DIMM, PI, CM)
DIMENSION AT4(13), JINM(2), AM(8), JM(5), JATAM(16)

* THIS SUBROUTINE COMPUTES THE DESIRED CONTROL INPUTS SO
* THAT THE MISSILE WILL FOLLOW PROPORTIONAL NAVIGATION GUIDANCE.

DO 1 J=11,16
1    IF(IFIX(JATAM(J)) .GE. 1) RETURN
    DIMM(1) = AM(5) + 3.*AT4(J13)
    DIMM(2) = AM(6) + 3.*AT4(J17)
    RETURN
END
SUBROUTINE DESIMP(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(13) 007290

* THIS SUBROUTINE COMPUTES THE DESIRED CONTROL INPUTS FOR * 007310
* THE MANJVERS SELECTED IN SUBROUTINE EVAMANU. * 007320

IF (TIME .LE. 0.0) GO TO 0 007340
IF (AFT(3) .GT. AFT(11)) AFT(3) = AFT(11) 007350
100 IF (MANJVR .EQ. 1) GO TO 1 007350
   IF (MANJVR .EQ. 2) GO TO 2 007370
   IF (MANJVR .EQ. 3) GO TO 3 007330
   IF (MANJVR .EQ. 4) GO TO 4 007330
   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 007330
   IF (MANJVR .EQ. 0) GO TO 1 007440
RETURN

VERTICAL DIVE**** 007450

1  007470
   DIN(2) = 0.0 007480
   DIN(4) = TT(4) 007490
   IF (AFT(6) .LE. AFT(11) - PI/2.0) GO TO 11 007490
   DIN(1) = AFT(11) 007500
   DIN(3) = SIGM(PI, AFT(10)) 007510
   IF (AFT(10) .LE. 0.0) DIN(3) = SIGM(PI, AFT(3)) 007520
   GO TO 12 007530
11  007540
   DIN(1) = 0.0 007550
   DIN(3) = 0.0 007560
12  007570
   IF (-DATAFT(3)) .LE. 1300.0) GO TO 13 007580
RETURN 007590
13  007600
   IF (MANJVR .EQ. 8) GO TO 4 007610
   IF (AFT(6) .LE. AFT(11)) GO TO 14 007620
   DIN(1) = AFT(11) 007630
   GO TO 15 007640
14  007650
   DIN(1) = 0.0 007660
15  007670
   DIN(3) = 0.0 007680

007690
RETURN

***** HARD BREAK *****
2  D IN (4) = T T (4)
    D IN (1) = A F T (11)
    D IN (2) = 0.0
    I F (A B (2) . E Q . 0 . 0 , A B (2) , A B (3) , E Q . 0 . 0 ) G O T O 2 1
    D IN (3) = A F T ( 1 0 ) + A S I N ( A B (2) ) / S Q R T ( A B (2) ** 2 + A B (3) ** 2 )
    I F (A B (3) . S T . 0 . 0 ) D IN (3) = A F T ( 1 0 ) + A S I N ( A B (2) ) / S Q R T ( A B (2) ** 2 + A B (3) ** 2 + 2 )
    I F (A B (3) . S T . 0 . 0 ) A N D ( A B (2) . L T . 0 . 0 ) D IN (3) = A F T ( 1 0 ) - A S I N ( A B (2) ) / S Q R T 0 7 3 7 3 0
    + ( A B (2) ** 2 + A B (3) ** 2 )
    G O T O 2 2
2 1  D IN (3) = A F T ( 1 0 ) + 0.3
2 2  I F (M AN J V R . E Q . 0 . 2 ) R E T U R N
    I F (M AN J V R . E Q . 6 . 3 ) G O T O 2 3
    I F (A B S ( A T (1 8 ) ) . L T . 5 * P I / 6 . 0 ) R E T U R N

***** HARD BREAK FOLLOWED BY VERTICAL DIVE *****
    G O T O 1
2 5  I F (A B S ( A T (1 8 ) ) . G E . P I / 2 . 0 ) R E T U R N

***** HARD BREAK FOLLOWED BY A REVERSAL *****
    D IN (3) = - D IN (3)
    R E T U R N

***** SPLIT 5 *****
3  I F (K O U N T . E Q . 0 ) P S I T O P = I F T ( 5 )
    I F (K O U N T . E Q . 0 ) P S I T O P = I F T ( 1 0 )
    K O U N T = 1
    I F (S I G N (1 , A F T (3 ) ) . E Q . S I G N (- 1 , P S I T O P ) ) D IN (3 ) = 0.0
    D IN (3 ) = S I G N ( P S I T O P )
    I F (A F T ( 1 0 ) . E Q . 0 . 0 ) D IN (3 ) = S I G N ( P S I T O P , A T (8 ) )
    D IN (2) = 0.0
    I F (A B S ( A F T (1 0 ) - D IN (3 ) ) . L T . 1 . ) G O T O 3 1
    D IN (1) = A F T (3)
    G O T O 3 2
3 1  D IN (1) = A F T (1 1 )
3 2  D IN (4) = T T ( 4 )
    I F (A F T (6 ) . L T . P I - A F T (1 1 ) ) R E T U R N
DIN(1)=0.0
RETURN

*** PULL UP ***
4    DIN(1)=0.0
    DIN(3)=0.0
    DIN(2)=0.0
    IF(ABS(AFT(10)-DIY(3)) .LE. 0.1) DIY(1)=AFT(11)
    DIN(4)=TT(4)
    IF(AFT(6).GT.PI-AFT(11)) DIY(1)=0.0
RETURN

*** STRAIGHT AND LEVEL ***
10   DIN(1)=0.0
    IF(DATAFT(5).GT.0.0) DIY(1)=AFT(11)
    DIN(2)=0.0
    DIN(3)=0.0
    DIN(4)=TT(2)
    IF(DATAFT(5).GT.0.0) DIY(4)=TT(4)
RETURN
END
SUBROUTINE FORCES(INDEX, TF, AFT, DT, S, FOR, AC, DATA, DIN)
DIMENSION TF(7), AFT(15), FR(13), AC(15), DATA(12), DIN(4)
DIMENSION XAF(2), TAFT(10), NAFT(2)
DIMENSION AMACHF(5), ALPHAF(5), CE1F(5, 4), CE2F(6, 4), CE3F(5, 4),
* CE4F(5, 4), CE5F(5, 4), CE6F(5, 4), CE7F(5, 4), CE8F(6, 4), CE9F(5, 4),
* CE10F(5, 4), CE11F(5, 4), CE12F(6, 4), CE13F(6, 4), CE14F(5, 4), CE15F(6, 4),
* CE16F(5, 4), CE17F(5, 4), CE18F(6, 4), CE19F(6, 4), CE20F(5, 4),
* CE21F(5, 4), CE22F(5, 4), CE23F(6, 4), DSFT(5, 4)
******************************************************************************
* THIS SUBROUTINE COMPUTES THE FORCES ACTING ON THE AIRCRAFT.               *
* THE HEADING, PITCH, AND BANK ANGLES ARE IN THE WIND FRAME.                *
******************************************************************************
IF(INDEX .GT. 1) GO TO 10
****** READ IN AERODYNAMIC DATA******
DO 2 J = 1, 5
   READ (1, *) AMACHF(J)
DO 3 I = 1, 4
   READ (1, *) ALPHAF(I), CE1F(J, I), CE2F(J, I), CE3F(J, I), CE4F(J, I), CE5F(J, I),
          CE6F(J, I), CE7F(J, I), CE8F(J, I), CE9F(J, I), CE10F(J, I), CE11F(J, I),
          CE12F(J, I)
3 CONTINUE
DO 7 I = 1, 4
   READ (1, *) CE13F(J, I), CE14F(J, I), CE15F(J, I), CE16F(J, I), CE17F(J, I),
          CE18F(J, I)
7 CONTINUE
DO 8 I = 1, 4
   READ (1, *) CE19F(J, I), CE20F(J, I), CE21F(J, I), CE22F(J, I), CE23F(J, I),
          DSFT(J, I)
8 CONTINUE
DO 5 I = 1, 4
   READ (1, *) XAF(1) = T(5)
5 CONTINUE
XAF(2) = AFT(3)
IF(INDEX .EQ. 1) IMP = TF(5)
008210
008220
008230
008240
008250
008260
008270
008280
008290
008300
008310
008320
008330
008340
008350
008360
008370
008380
008390
008400
008410
008420
008430
008440
008450
008460
008470
008480
008490
008500
008510
008520
008530
008540
008550
008560
DELMACH = F6 (6) - REALMAC
NAF(1) = 6
NAF(2) = 4
DO 1 I = 1, 5
1 TABF(I) = AMACHF(I)
DO 4 I = 1, 4
TABF(6+I) = ALPHAF(I)

************* TABLE LOOK-UP OF AERODYNAMIC COEFFICIENTS ************

*********** DEFINITION OF COEFFICIENTS ***********

- CEF1 = BASIC LIFT COEFFICIENT
- CEF2 = DERIVATIVE OF L WRT ALPHA
- CEF3 = BASIC DRAG COEFFICIENT
- CEF4 = DERIVATIVE OF D WRT ALPHA
- CEF5 = BASIC PITCHING MOMENT (M)
- CEF6 = DERIVATIVE OF M WRT ALPHA
- CEF7 = DERIVATIVE OF M WRT Q
- CEF8 = DERIVATIVE OF M WRT ALPHADOT
- CEF9 = DERIVATIVE OF L WRT Q
- CEF10 = DERIVATIVE OF L WRT R
- CEF11 = DERIVATIVE OF N WRT Q
- CEF12 = DERIVATIVE OF N WRT R
- CEF13 = DERIVATIVE OF L WRT DELTA S

KEY:
- L = LIFT
- D = DRAG
- M = MOMENT
- N = NAC1 NAC1 NUMBER
- ALPHA = ANGLE OF ATTACK
- ALPHADOT = RATE OF CHANGE OF ALPHA
- P = RATE OF ROLL
- R = RATE OF PITCH
- Q = RATE OF YAW
- M = PITCHING MOMENT
- N = YAWING MOMENT
- LL = ROLLING MOMENT
- DELTA S = ELEVATOR DEFORMATION
- DELTA R = RUDDER DEFORMATION

************** TABLE LOOK-UP OF AERODYNAMIC COEFFICIENTS ************

- CEF1 = BASIC LIFT COEFFICIENT
- CEF2 = DERIVATIVE OF L WRT ALPHA
- CEF3 = BASIC DRAG COEFFICIENT
- CEF4 = DERIVATIVE OF D WRT ALPHA
- CEF5 = BASIC PITCHING MOMENT (M)
- CEF6 = DERIVATIVE OF M WRT ALPHA
- CEF7 = DERIVATIVE OF M WRT Q
- CEF8 = DERIVATIVE OF M WRT ALPHADOT
- CEF9 = DERIVATIVE OF L WRT Q
- CEF10 = DERIVATIVE OF L WRT R
- CEF11 = DERIVATIVE OF N WRT Q
- CEF12 = DERIVATIVE OF N WRT R
- CEF13 = DERIVATIVE OF L WRT DELTA S

************** TABLE LOOK-UP OF AERODYNAMIC COEFFICIENTS ************
TY8=TF(1)*COS(AFT(1))*SIN(AFT(2))
TZ8=-TF(1)*COS(AFT(1))*SIN(AFT(2))
13 CALL TRA482MX9,TY3,TZ8,AFT(3),AFT(4),TXW,TYW,TZW
FOR(12)=AFT(5)*AFT(5)*COS(AFT(10))
FOR(13)=AFT(5)*AFT(4)*SIN(AFT(10))
FOR(11)=AFT(10)
CL=CEF1+CEF2*DA+CEF18*DEL4ACH+CEF13*CD
CLMAX=AC(15)/TF(7)*AC(1)/AC(2)
IF(CL-CL4AX)11,11,12
****TEST OF CL VERS VS CLMAX*****
12 DIN(1)=DL4(1)-(C.-CL4AX)/CLMAX*DIN(1)
ERALPHA=DIN(1)-AFT(3)
AFT(16)=AFT(13)^(ERALPHA/AFT(13)/DT)**2
IF(AFT(15).LE.ABS(ERALPHA/2.0/DT))AFT(16)=ABS(ERALPHA/2.0/DT)
IF(AFT(15).GE.AFT(13))AFT(16)=AFT(13)
AFT(3)=AFT(3)+SIGV(AFT(15)*DT,ERALPHA)
GO TO 13
11 FTLIFT=C_*TF(7)*AC(2)
CD=CEF3+CEF4*DA+CEF13*DEL4ACH
DRAG=CD*TF(7)*AC(2)
CY=CEF23*DB+CEF17*CD
SIDEFOR=CY*TF(7)*AC(2)
CL=CEF21*DB+CEF3*DP*AC(3)/(2.*TF(5))
+CEF10*DR*AC(3)/(2.*TF(5))+CEF15*DB
ROMO=CL*TF(7)*AC(2)
CM=CEF5+CEF6*DA+CEF7*DJ*AC(4)/(2.*TF(5))+
+CEF20*DE*AC(4)/(2.*TF(5))+CEF14*DD
PMO=C*TF(7)*AC(2)
CN=CEF22*DB+CEF11*DF*AC(3)/(2.*TF(5))+
+CEF12*DP*AC(3)/(2.*TF(5))+CEF15*DB
YM0=CN*TF(7)*AC(2)
FOR(1)=TXW-0*AG-FOR(10)*G*SIN(FOR(12))
FOR(2)=TY4-SIDEFOR+FOR(10)*G*COS(FOR(12))*SIN(FOR(11))
FOR(3)=TZM-FTLIFT+FOR(10)*G*COS(FOR(12))*COS(FOR(11))
FOR(7)=FOR(2)/(FOR(11)*TF(5))
FOR(8)=-FOR(3)/(FOR(10)*TF(5))
FOR(9) = AFT(9) * COS(AFT(3)) * COS(AFT(4)) + (AFT(8) - AFT(15)) * SIN(AFT(4))

+ AFT(7) * SIN(AFT(3)) * COS(AFT(4))

FOR(4) = RY*M*COS(AFT(3)) - YOM*SIN(AFT(3))

FOR(5) = RY*M

FOR(6) = RY*M*SIN(AFT(3)) + YOM*COS(AFT(3))

REALMA2 = TF(6)

AOTOLD = AFT(15)

AOLD = AFT(3)

BOLD = AFT(4)

COLD = COSF

POLD = AFT(3)

QOLD = AFT(5)

ROLD = AFT(7)

RETURN

END
SUBROUTINE FORCES4(LOC, DT, FORM, DATAM, G, ATM, AM)
DIMENSION FORM(3), DATAM(15), AT(19), AM(8), DM(6)

* THIS SUBROUTINE COMPUTES THE FORCES ACTING ON THE MISSILE. *

LOCK=1

** TEST OF VERTICAL AND HORIZONTAL G FORCES ON THE MISSILE **
IF(ABS(FORM(2)) .LE. DM(3) .AND. ABS(FORM(3)) .LE. DM(5)) RETURN

1 FORM(2) = AM (7) * FORM (1) / G
FORM (3) = - AM (8) * FORM (1) / G
GO TO 1

END

009920
009930
009940
009950
009960
009970
009980
009990
010000
010010
010020
010030
010040
010050
010060
010070
SUBROUTINE F(F,I,Y,P,FORF,AC)
DIMENSION Y(9),P(3),FORF(13),AC(15)

* THIS SUBROUTINE CONTAINS THE DIFFERENTIAL EQUATIONS OF MOTION *
* FOR USE IN SUBROUTINE RK4SF. *

P(1) = FORF(1)/FORF(10)
P(2) = (FORF(4) + AC(14) * Y(2) * Y(3) + (AC(12) - AC(13)) * Y(3) * Y(4)) / AC(11)
P(3) = (FORF(3) + AC(14) * (Y(4) ** 2 - Y(2) ** 2) + (AC(13) - AC(11)) * Y(4) * Y(2)) / AC(12)
P(4) = (FORF(6) + AC(14) * Y(3) * Y(4) + (AC(11) - AC(12)) * Y(2) * Y(3)) / AC(13)
IF(ABS(Y(5)) < PI/2.0, 0.0, -0.5) GO TO 5
P(6) = (FORF(9) * SIN(FORF(11)) + FORF(7) * COS(FORF(11))) / COS(Y(5))
GO TO 10
5 P(6) = FORF(3)
10 P(5) = FORF(3) * COS(FORF(11)) - FORF(7) * SIN(FORF(11))
P(7) = Y(1) * COS(Y(5)) * COS(Y(6))
P(8) = Y(1) * COS(Y(5)) * SIN(Y(6))
P(9) = -Y(1) * SIN(Y(5))
RETURN
END
SUBROUTINE UPDATEF (TT, AFT, FORF, DATA, PI, T, DT, AC)  
DIMENSION X(9)  
DIMENSION TT(7), AFT(15), FORF(13), DATA(12), AC(15)  

* THIS SUBROUTINE UPDATES THE EQUATION OF MOTIONS FOR THE AIRCRAFT. *  

N=9  
X(1)=TT(3)  
IF (TT(3) .GE. 0.0) X(1)=0.001  
X(2)=AFT(9)  
IF (AFT(9), EQ. 0.0) X(2)=0.001  
X(3)=AFT(3)  
IF (AFT(3), EQ. 0.0) X(3)=0.001  
X(4)=AFT(7)  
IF (AFT(7), EQ. 0.0) X(4)=0.001  
X(5)=FORF(12)  
IF (FORF(12), EQ. 0.0) X(5)=0.001  
X(6)=FORF(13)  
IF (FORF(13), EQ. 0.0) X(6)=0.001  
X(7)=DATA(1)  
IF (DATA(1), EQ. 0.0) X(7)=0.001  
X(8)=DATA(2)  
IF (DATA(2), EQ. 0.0) X(8)=0.001  
X(9)=DATA(3)  
IF (DATA(3), EQ. 0.0) X(9)=0.001  
CALL RODES2 (PI, T, X, N, DT, FORF, AC)  
TT(9)=X(1)  
AFT(9)=X(2)  
AFT(8)=X(3)  
AFT(7)=X(4)  
AFT(6)=X(5)+AFT(3)*COS(AFT(10))  
IF (AFT(6), LT, PI/2.0) AFT(6)=PI-AFT(6)  
IF (AFT(6), LT, -PI/2.0) AFT(6)=-PI-AFT(6)  
AFT(5)=X(5)-AFT(4)*SIN(AFT(10))  
IF (AFT(5), LT, 2.*PI) AFT(5)=AFT(5)-2.*PI  
IF (AFT(5), LT, 0.0) AFT(5)=2.*PI-AFT(5)  

010220  
010300  
010310  
010320  
010330  
010340  
010350  
010360  
010370  
010390  
010390  
010400  
010410  
010420  
010430  
010440  
010450  
010460  
010470  
010470  
010480  
010490  
010500  
010510  
010520  
010530  
010540  
010550  
010560  
010570
DATA(4) = (X(7) - DATA(1)) / DT
DATA(5) = (X(8) - DATA(2)) / DT
DATA(6) = (X(9) - DATA(3)) / DT
DATA(1) = X(7)
DATA(2) = X(8)
DATA(3) = X(9)
IF (AFT(10) .GT. PI) AFT(10) = AFT(10) - 2.*PI
IF (AFT(10) .LT. -PI) AFT(10) = AFT(10) + 2.*PI
RETURN
END
SUBROUTINE INPUTSF(OT, AFT, DINF, AC, TF)

DIMENSION AFT(15), DINF(4), AC(15), TF(7)

* THIS SUBROUTINE PROVIDES THE FINITE CONTROL INPUTS FOR THE AIRCRAFT. *

DELALPH = DINF(1) - AFT(3)
DELBETA = DINF(2) - AFT(+)
DELPHI = DINF(3) - AFT(10)
DELTRST = DINF(4) - TF(1)

AFT(16) = AFT(13) * (DELALPH + (AFT(13) * 4)) ** 2
IF (AFT(15) .LE. ABS(DELPHI)) AFT(15) = ABS(DELPHI)
IF (AFT(15) .GE. AFT(13)) AFT(16) = AFT(13)

BETADOT = AFT(3) + SIG4(AFT(15) * OT, DELALPH)
IF (BETAOT .LE. ABS(DELPHI)) BETAOT = ABS(DELPHI)
IF (BETAOT .GE. AFT(14)) BETADOT = AFT(14)

AFT(+) = AFT(4) * SIG4(BETADOT * OT, DELBETA)

PHIDOT = AFT(15) * (DELPHI) * PHIDOT = AFT(15)

AFT(10) = AFT(10) + SIG4(+IDOT * OT, DELPHI)

TRSTDOT = TF(4) * (DELTRST(+) * AC(3)) ** 2
IF (TRSTDOT .LE. ABS(DELTRST)) TRSTDOT = ABS(DELTRST)
IF (TRSTDOT .GE. AC(3)) TRSTDOT = AC(3)

TF(1) = TF(1) * SIGN(TRSTDOT * OT, DELTRST)
RETURN
END
SUBROUTINE PRINT(J, DT, KFF, AM, AFT, AT, TIME, AFT, AM, ATF, DATA010330
+FT, DATAM, ABF)
DIMENSION AFT(15), AM(8), ATF(19), DATAF(12), DATAM(15)
DIMENSION ATM(19), AFT(5), AFTM(6), AM(3)

* THIS SUBROUTINE PROVIDES A PRINTOUT OF THE NECESSARY INFORMATION
* AND CALLS SUBROUNES ATTACKF AND ATTACKM TO UPDATE THE
* RELATIVE POSITIONS.

CALL ATTACKF(KF, PI, ATF, DATAF, DATAM, AFT, AM, ABF)
CALL ATTACKM(OM, JT, INDEX, ATM, KF, PI, AM, DATAM, DATAF, AM, AFT, AM, ABM,
+TIME)
IF(INDEX.EQ.0)GO TO 3
INTER=FIX(.30000001/DT)
IF(MOD(INDEX,INTER),NE.0)RETURN

5 PSHIFT=RAD2DEG(AFT(5))
THEFT=RAD2DEG(AF(5))
PMHFT=RAD2DEG(AFT(10))
PSMHD=RAD2DEG(AF(3))
THEMED=RAD2DEG(AM(5))
ZETF24D=RAD2DEG(AF(3))
ZTAF24D=RAD2DEG(AF(3))
ZTEDM=RAD2DEG(AM(15))
ZTMHD=RAD2DEG(AF(7))
PRINT 1, TIME
1 FORMAT(140, /4X, *TOTAL ELLAPSED TIME IS*, F5.2, * SECONDS.*)
PRINT 10
10 FORMAT(140, 3X, *THE AIRCRAFT'S STATE IN THE EARTH SURFACE FIXED REF 011250
+ENCE FRAME IS*)
PRINT 2, DATAF(1), DATAF(2), DATAF(5), DATAF(3), DAT
+AFT(5), PSHIFT, THEFT, PSHIFT
+20X, *FLIGHT PATH ANGLE (THETA)= *, F5.0, * DEGREES*/
011300
011300
011300
011300
011300
011300
011300
011300
+(PHI)=*,F5.0,* DEGREES*)
PRINT 20
FORMAT(1H10,9X,*THE MISSILE'S STATE IN THE EARTH SURFACE REFERENCE FRAME IS*)
+RENGE FRAME IS*)
PRINT *,DATAM(1),DATAM(4),DATAM(2),DATAM(5),DATAM(3),DATAM(6)
+PSMED,TMED
FORMAT(15X,*POSITION*,27X,*VELOCITY*,/20X,*X= *,F7.0,* FEET*,19X, 011370
+0,* FEET/SECOND*,/20X,*Y= *,F7.0,* FEET*,19X,*V= *,F7.0, 011120
+0,* FEET/SECOND*,/20X,*Z= *,F7.1,* FEET*,19X,*W= *,F7.0,* FEET/SECOND, 011430
+ONO*,/15X,*ORIENTATION*,/20X,*EADING (PSI)= *,F5.0,* DEGREES*/* 011440
+20X,*FLIGHT PATH ANGLE (TETA)= *,F5.0,* DEGREES*) 011450
PRINT 3,ATF(10),ATF(10),ZETF2MD,ZETOT4J,ETAF2MO,ETAJ1J
 FORMAT(1H10,9X,*THE FIGHTER PILOT SEES THE MISSILE AT*,/15X,*RANGE=011+70
+*,F8.1,* FEET*,15X,*RANGE RATE= *,F8.1,* FEET/SECOND*,/19X,*AZI=0114+80
+*,F7.1,* DEGREES*,11X,*AZIMUTH RATE= *,F8.1,* DEGREES/SECOND, 011490
+*,F8.1,* ELEVATION= *,F8.1,* DEGREES*,3X,*ELEVATION RATE= *,F8.1, 011500
+* DEGREES/SECOND*,//) 011510
RETURN
END
011520
011530
011540
SUBROUTINE TRANSFERS A VECTOR FROM THE BODY FRAME TO THE MIND FRAME.

\[
\begin{align*}
X &= X_B \cos(\beta) \cos(\alpha) + Y_B \sin(\beta) \cos(\alpha) + Z_B \sin(\alpha) \\
Y &= -X_B \sin(\beta) + Y_B \cos(\alpha) \\
Z &= X_B \cos(\beta) \sin(\alpha) - Y_B \sin(\beta) \cos(\alpha) + Z_B \cos(\alpha)
\end{align*}
\]

RETURN
END
SUBROUTINE TRV23(XV,YV,ZV,ALPHA,BETA,GAMMA,XB,YB,ZB)

* THIS SUBROUTINE TRANSFERS A VECTOR FROM THE NAVIGATION FRAME TO THE BODY FRAME. *

*XB=XV*COS(BETA)*COS(ALPHA)+YV*COS(BETA)*SIN(ALPHA)-ZV*SIN(BETA)
* 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(GAMMA)011730
* +A)*COS(BETA) 011750
* 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(GAMMA)011730
* +A)*COS(BETA) 011790
* RETURN 01100
* END 011320
FUNCTION DEG2RAD(JES,MIN,SEC)  

** THIS FUNCTION TRANSFERS AN ANGLE FROM DEGREES TO RADIANS. **  

RAD=0.  
RAO=RAO+JES/37.2957795131  
RAD=RAD+MIN/3437.7467707349  
RAD=RAD+SEC/206264.80625  
DEG2RAD=RAD  
RETURN  
END
22 \( Y(I)=Y(I)+5*PT(I)*P1(I) \)
23 \( \text{CALL F}(P(I),x+1.5,F) \)
24 \( \text{DO } 25 I=1,N \)
25 \( Y(I)=Y(I)+5*PT(I)*P2(I) \)
26 \( \text{DO } 27 I=1,N \)
27 \( Y(I)=Y(I)-0.5*PT(I)*P3(I) \)
28 \( \text{GO TO } 22 \)
29 \( \text{IF}(T-I\geq P3(I)) \)
30 \( \text{IF}(T-I\geq P3(I)) \)
31 \( \text{IF}(T-I\geq P3(I)) \)
32 \( \text{IF}(T-I\geq P3(I)) \)
33 \( \text{IF}(T-I\geq P3(I)) \)
34 \( \text{IF}(T-I\geq P3(I)) \)
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71 \( \text{IF}(T-I\geq P3(I)) \)
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73 \( \text{IF}(T-I\geq P3(I)) \)
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97 \( \text{IF}(T-I\geq P3(I)) \)
98 \( \text{IF}(T-I\geq P3(I)) \)
99 \( \text{IF}(T-I\geq P3(I)) \)
100 \( \text{IF}(T-I\geq P3(I)) \)
101 \( \text{IF}(T-I\geq P3(I)) \)
102 \( \text{IF}(T-I\geq P3(I)) \)
103 \( \text{IF}(T-I\geq P3(I)) \)
104 \( \text{IF}(T-I\geq P3(I)) \)
105 \( \text{IF}(T-I\geq P3(I)) \)
106 \( \text{IF}(T-I\geq P3(I)) \)
107 \( \text{IF}(T-I\geq P3(I)) \)
108 \( \text{IF}(T-I\geq P3(I)) \)
109 \( \text{IF}(T-I\geq P3(I)) \)
FUNCTION TBLNDC(Y, X, D, Z, XA, NA, KA) 012530

*******************************************************************************/

PURPOSE:

GIVEN THE ARGDATA(4)NTS, X1, X2, ..., XN COMPUTE
Y = F(X1, X2, ..., XN) FOR A TABLE OF X(S) AND Y(S)
BY LINEAR INTERPOLATION

CONTROL

REAL FUNCTION, REAL AND INTEGER ARGDATA(4)NTS

CALLING SEQUENCE

Y = TBLNDC(K, M, TABLEY, TABLEX, NA, KA)
WHERE
K = 0, NO EXTRAPOLATION, K NOT EQUAL TO 0, EXTRAPOLATION.
M = DIMENSION OF TABLE LOOK-UP (IF Y = F(X1, X2), THEN M = 3)
TABLEY IS THE TABLE OF DEPENDENT PARAMETERS
TABLEX IS THE TABLE OF INDEPENDENT VECTORS. EACH VECTOR MUST BE IN ASCENDING ORDER.
NA(1), NA(2), ..., NA(N) ARE THE LENGTHS OF THE N TABLEX VECTORS.
XA(1), XA(2), ..., XA(N) ARE THE N INDEPENDENT PARAMETERS WHERE N = 12310

EXAMPLE: TABLE

<table>
<thead>
<tr>
<th>N</th>
<th>XA1</th>
<th>TABLEY</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>A1</td>
<td>F(A1, B1, C1)</td>
</tr>
<tr>
<td>4</td>
<td>A2</td>
<td>F(A1, B1, C2)</td>
</tr>
<tr>
<td>NA(1) = 2</td>
<td>B1</td>
<td>F(A1, B2, C1)</td>
</tr>
<tr>
<td>NA(2) = 2</td>
<td>B2</td>
<td>F(A1, B2, C2)</td>
</tr>
<tr>
<td>NA(3) = 2</td>
<td>C1</td>
<td>F(A2, B1, C1)</td>
</tr>
<tr>
<td></td>
<td>C2</td>
<td>F(A2, B1, C2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F(A2, B2, C1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F(A2, B2, C2)</td>
</tr>
</tbody>
</table>

ERROR CONDITIONS

1. AT LEAST ONE OF THE INDEPENDENT VECTORS IS NOT
IN ASCENDING ORDER.

2. AT LEAST ONE OF THE INDEPENDENT PARAMETERS IS OUT OF
   RANGE OF TABLES AND \( k=0 \).

3. DIMENSION OF TABLE LOOK-UP \( M \) IS GREATER THAN 5.
   AN ERROR MESSAGE IS PRINTED IN EACH CASE
   AND A STOP OCCURS.

DIMENSION X(1), NA(1), XA(1), NS(5), WJ(32), RATIO(5), NGRJP(5),
1ITOT(5), ?(1).

IF(ND.LE.5) GO TO 1
PRINT 2
2 FORMAT(141, 10X, 23 ERROR CONDITION 3 TABLE LOOK-UP ROUTINE)
PRINT 5, ND
PRINT 11X, 30 DIMENSION OF TABLE LOOK-UP \( M=9 \),
1I2, 19H) IS GREATER THAN 5
1 L1=2
LF=ND-1
DO 3 I=1, LF
L2=L1+NA(I)-2
FOUND=0.
DO 4 J=L1, L2
IF(X(J).LT.X(J-1)) GO TO 5
PRINT 2
PRINT +0, I
5 FORMAT(11X, 23 INDEPENDENT VECTOR NO. , I2, 20H IS NOT IN ASCENDING
   27H ORDER,)
   CALL SYSTEM(200, 0)
6 IF (FOYN(1, NE.0)) GO TO 4
   IF (XA(I)-X(J-1)) \( > 4 \)
8 IF (J,SX-1) GO TO 10
   IF (NEXTR.EQ.0) GO TO 37
   FOUND=1.
   NS(I)=-1-1
   GO TO 4
10 FOUND=1.
NS(I)=J-2
4 CONTINUE
   IF (FOWN(J)) 11,12,11
12 IF (X(A(I))=X(L2)) 13,13,14
14 IF (NEXT2,NE,0) 30 TO 13
37 PRINT 2
   PRINT +1, I
41 FORMAT(11X,26MINDEPENDENT PARAMETER NO.,I2,17H IS OUT OF RANGE
   244HOF CORRESPONDING INDEPENDENT VECTOR AND K=0.)
   CALL SYSTEM(200,0)
13 NS(I)=-2-1
11 L1=L2+2
3 CONTINUE
   IN NS(I) IS THE SUBSCRIPT IN THE ARRAY X SUCH THAT
   X(NS(I)) IS LESS THAN THE ITH ARGDATAM(4)NT
   DO 15 I=1,LF
   K=NS(I)
   RATIO(I)=(X(A(I))-X(K))/(X(K+1)-X(K))
5 IN RATIO(1) IS THE RATIO OF X ARG, RATIO(2)=RATIO OF Y ETC.
15 CONTINUE
   NGROUP(I)=NS(I)
   NSUM=VA(1)
   DO 16 I=2,LF
   NGROUP(I)=NS(I)-NSJM
   NSUM=NSUM+VA(I)
16 CONTINUE
   IN NGROUP(I) IS THE SUBSCRIPT OF THE ITH VARIABLE SUCH
   THAT THE TABLE VALUE IS LESS THAN THE CORRESPONDING ARGDATAM(4)NT
   THIS IS IN TERMS OF THIS VARIABLE ONLY
   FOR A FUNCTION OF DEGREE NO WE NEED2**(NO-1) VALUES
   FROM THE Z ARRAY
   ITOT(LF)=1
   DO 17 I=2,LF
   J=LF-I+1
   ITOT(J)=ITOT(J+1)*VA(J+1)
17 CONTINUE
IN ITOT(J) IS THE NUMBER OF LOCATIONS IN THE Z ARRAY NEEDED TO CHOOSE
THE JTH SUBSCRIPT

KF=2**LF
MW=-2
DO 22 I=1,KF,2
IFIRST=1
MW=MW+2
DO 21 J=1,LF
MM=2**(J-1)
IF(AND(M9,MH),EQ,0)GO TO 18
IMON=NGROUP(J)+1
GO TO 19
18 IMON=NGROUP(J)
19 IFIRST=IFIRST+(IMON-1)*ITOT(J)
CONTINUE
ISCC=IFIRST+ITOT(1)
WJ(I)=Z(IFIRST)
WJ(I+1)=Z(ISCC)
CONTINUE
22 DO 24 I=1,-F
KF=KF/2
DO 24 J=1,-F
24 WJ(J)=WJ(2*J-1)+(WJ(2*J)-WJ(2*J-1))*RATIO(I)
TBLNDC=WJ(1)
RETURN
END
SUBROUTINE M(T,Y,P,FOR1,A1)
DIMENSION Y(9),P(9),FORM(3),AM(3)

* THIS SUBROUTINE CONTAINS THE DIFFERENTIAL EQUATIONS OF MOTION *
* FOR USE IN SUBROUTINE RK4ISM. *

P(1) = FOR1(1) * COS(A1(3)) * COS(AM(3))
P(2) = FOR1(1) * COS(A1(5)) * SIN(AM(3))
P(3) = -FORM(1) * SIN(A1(6))
RETURN
END
SUBROUTINE UPDATE(DATAM, DT, AM, FORM, T)
DIMENSION X(3), DATAM(15), AM(9)

* THIS SUBROUTINE UPDATES THE EQUATIONS OF MOTIONS FOR THE MISSILE. *

N=3
DO 1 I=1, 3
   X(I)=DATAM(I)
   IF(DATAM(I), EQ. 0.0) X(I)=.0001
   CONTINUE
1 CALL R<DES(T, X, N, DT, FORM, AM)
DO 2 I=1, 3
   DATAM(I+3) = (X(I) - DATAM(I)) / DT
   DATAM(I) = X(I)
2 CONTINUE
RETURN
END
SUBROUTINE RODES(X,Y,4,DX,FORM,A4)
DIMENSION Y(39),YO(39),YT(99),PO(99),P1(99),P2(33),P3(33)
DIMENSION FORM(3),A4(3)
IF(N.LT.100) GO TO 1
PRINT 103, N
100 FORMAT(14A,10X,11X,'THE ORDER (,I3,279) OF THE SYSTEM EXCEEDS 39,/',14570
3, 11X,'47 CHANGE DIMENSION STATEMENT IN SUBROUTINE RODES,'14530
3, 11X,18X,'EXECUTION DELETED.)'
STOP
1 X0=X
X=X+DX
H=DX
2 IF(ABS(H),ST. ABS(X-X0)) =X-X0
DO 4 I=1,N
HT=H
XT=X0
RMAXP =1.E37
DO 5 I=1,N
3 YT(I)=Y0(I)
ASSIGN 6 TO K
GO TO 20
5 DO 7 I=1,N
7 YP(I)=Y(I)
8 HT=0.5*H
ASSIGN 9 TO K
GO TO 20
9 DO 10 I=1,N
10 YT(I)=Y(I)
11 XT=X0+4T
ASSIGN 11 TO K
20 CALL M(XT,YT,PO,FORM,A4)
DO 21 I=1,N
21 Y(I)=YT(I)+0.5*HT*PO(I)
CALL M(XT+0.5*HT,Y,P1,FORM,A4)
DO 22 I=1,N
22 END
22  Y(I)=YT(I)+3*HT*P1(I)
    CALL M(XT0,3*HT,Y,P2, FORM, AM)
    DO 23 I=1,N
23  Y(I)=YT(I)+HT*P2(I)
    CALL M(XT+HT,Y,P3, FORM, AM)
    DO 24 I=1,N
24  Y(I)=YT(I)+HT*(P0(I)+2.*(P1(I)+P2(I))+P3(I))/6.
    GO TO <, (5, 9, 11)
11  RMAX=0,
    DO 12 I=1,N
12  RMAX=A1AX1(RMAX,.07*A33((Y(I)-YP(I))/Y(I))
    IF ((RMAX, T.1.E-03). AND. (RMAX, T. RMAXP)) GO TO 17
    X0=X0+.4
    IF (X0.EQ.X) RETURN
    IF ((RMAX, LT.1.E-7). OR. (RMAX, ST. RMAXP)) H=H+.4
    GO TO 2
17  H=HT
    XT=X0
    DO 19 I=1,N
18  YP(I)=YT(I)
19  YT(I)=Y0(I)
    RMAXP = RMAX
    GO TO 8
END
SUBROUTINE IRSOS(I4, DT, TIME, AFT, AM, AT, MY, DEL, PI)
DIMENSION AFT(16), AM(8), AT(19), MY(19), DEL(3), VAR(3), DM(5), DELLD(0)
+(3), SIGMA(3)

* THIS SUBROUTINE PROVIDES NOISE TO INCREASE GUIDANCE ERRORS FOR
* INFRARED GUIDED MISSILES. SCALE FACTORS ARE USED TO VARY THE
* ERROR ACCORDING TO THE RELATIVE POSITION OF THE TWO VEHICLES.

DO 3 I=1,3
  IF(TIME - T, 0.0) 50 TO 3
  DEL(I) = 0.0
  DEL(I) = -10.0
  DELD(I) = DEL(I)
  DELD(I) = DELD(I) + 10.0
  UNITY = SQRT((2.*DM(3)+DT)/3)
  X = ABS(AT(I) - 1)
  IF(X .GE. PI) X = 2.*PI - X
  Y = ABS(AT(I) - 15)
  IF(X .GE. PI/2.) Y = PI - Y
  XY = Y
  YX = X
  Z = X + Y
  DEL(I) = (X + XY)/(2.*PI)
  DEL(2) = (Y + XY)/(2.*PI)
  DEL(3) = Z/(2.*PI)
  DO 1 I=1,3
    SIGMA(I) = 1.0 + 4.0*DEL(I)
    OEV = 0.0
    DO 2 J=1,12
      DELTA = XSF(DJMMY)
    2DEV = OEV + DELTA
      VAR(I) = (OEV - 3.0)*SIGMA(I)
  1DEL(I) = DELD(I) + (CM(5)/(CM(5) + DT) + DT*UNITY*VAR(I)/(CM(5) + DT))
  DEL(I) = DEL(I) - 10.0
RETURN
END
SUBROUTINE RADNOS(JM,JF,TIME,AFT,AM,ATF,ATM,DEL,PI)  
DIMENSION AFT(15),AM(8),ATF(19),ATM(13),DEL(3),VAR(3),OM(5),DELLO  
+(3),SIGMA(3)  
*****************************************************************************  
** THIS SUBROUTINE PROVIDES NOISE TO INJECT GUIDANCE ERRORS FOR *015530  
** RADAR GUIDED MISSILES. SCALE FACTORS ARE USED TO VARY THE *015570  
** ERROR ACCORDING TO THE RELATIVE POSITION OF THE TWO VEHICLES. *015590  
*****************************************************************************  
DO 3 I=1,3  
IF(TIME.EQ.0.0)OM(I)=0.0  
DELOLD(I) = DEL(I)  
UNITY=SQRT((2.*OM(5)+DT)/DT)  
X=ABS(AT=(14))  
IF(XS.4PI)X=2.*PI-X  
IF(XS.2PI)X=PI-X  
Y=ABS(AT=(15))  
XY=Y  
YX=X  
IF(XS.4PI)XY=PI/2.-X  
DEL(1) = (X*XY)/PI  
DEL(2) = Y/PI+XY/(.5*PI)  
DEL(3) = X/PI+Y/(.5*PI)  
DO 1 I=1,3  
SIGMA(I) = 1.0+4.0*DEL(I)  
DEV=0.0  
DO 2 J=1,12  
DELTAT=2*DEV*(DUMMY)  
QV=DEV+DELTAT  
VAR(I) = (QV-3.0)*SIGMA(I)  
3  
DEL(I) = DELLD(I) + (OM(5)/(OM(5)+DT)) + DT*UNITY*VAR(I)/(OM(5)+DT)  
RETURN  
END
SUBROUTINE REDUCE(IINDEX,ATF,DT)
DIMENSION ATF(13)

* THIS SUBROUTINE REDUCES THE STEP SIZE OF THE INTEGRATION
* WHICH REDUCES THE DISTANCE COVERED DURING ONE INTEGRATION
* TO LESS THAN ONE FOOT. THIS PROVIDES IMPROVED ACCURACY
* DURING THE TERMINATION PHASE.

INTER=IFIX(.5000001/DT)
ACC=DT*A3S(ATF(10))
IF(MOD(INDEX,INTER).EQ.0)PRINT 4,ACC,DT
FORMAT(1/4",* ACCURACY IS WITHIN *,F7.4,* FEET, STEP INTERVAL IS *
+F8.5,* SECONDS,*/)
STEP=A3S(ATF(10))*DT
IF(ABS(ATF(14)).LT.PI/2.)GO TO 5
IF(ATF(4).GT.STEP)RETURN
GO TO 10
STEP=STEP*2.0
IF(ATF(4).GT.STEP)RETURN
IF(STEP*.5E-10,.0)GO TO 1
DT=.001
ACC=DT*A3S(ATF(1))
PRINT 4,ACC,DT
RETURN
IF(STEP*.1E-10,.0)GO TO 2
DT=.0001
ACC=DT*A3S(ATF(10))
PRINT 4,ACC,DT
RETURN
2 PRINT 3
3 FORMAT(1/x,* MAXIMUM DT JSEDS. DT=.00001.*)
DT=.00001
ACC=DT*A3S(ATF(10))
PRINT 4,ACC,DT
RETURN
END
Appendix B

Test Results
TYPE OF MISSILE IS:
INFRA-RED

TYPE FIGHTER IS:
NON-RESPONSIVE

GUIDANCE ERRORS:
X= -10.03 FEET
Y= +1.13 FEET TOTAL= 10.09 FEET
Z= +0.27 FEET

TOTAL ELAPSED TIME IS 0.00 SECONDS.

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

POSITION
X= +1.0 FEET
Y= +1.0 FEET
Z= +2000.0 FEET

VELOCITY
U= 700.0 FEET/SECOND
V= 0.0 FEET/SECOND
W= 0.0 FEET/SECOND

ORIENTATION

HEADING (PSI)= 0. DEGREES
FLIGHT PATH ANGLE (THETA)= 0. DEGREES
BANK ANGLE (PHI)= 0. DEGREES

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

POSITION
X= -313.3 FEET
Y= -300.0 FEET
Z= -2005.0 FEET

VELOCITY
U= 2694.0 FEET/SECOND
V= 1553.0 FEET/SECOND
W= 0.0 FEET/SECOND

ORIENTATION

HEADING (PSI)= 30. DEGREES
FLIGHT PATH ANGLE (THETA)= 0. DEGREES

THE FIGHTER PILOT SEES THE MISSILE AT:

RANGE= 6000.2 FEET
AZIMUTH= -150.0 DEGREES
ELEVATION= +5.0 DEGREES

RANGE RATE= -2503.9 FEET/SECOND
AZIMUTH RATE= -3.3 DEGREES/SECOND
ELEVATION RATE= +2.0 DEGREES/SECOND
TOTAL ELAPSED TIME IS 1.00 SECONDS.

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

POSITION
X = 701.0 FEET
Y = 0.0 FEET
Z = -20000.0 FEET

VELOCITY
U = 702.0 FEET/SECOND
V = 0.0 FEET/SECOND
W = 0.0 FEET/SECOND

ORIENTATION
HEADING (PSI) = 0 DEGREES
FLIGHT PATH ANGLE (THETA) = 0 DEGREES
BANK ANGLE (PHI) = 0 DEGREES

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

POSITION
X = -240.0 FEET
Y = -153.4 FEET
Z = -20037.8 FEET

VELOCITY
U = 2838.0 FEET/SECOND
V = 1227.0 FEET/SECOND
W = 23.0 FEET/SECOND

ORIENTATION
HEADING (PSI) = 23 DEGREES
FLIGHT PATH ANGLE (THETA) = 0 DEGREES

THE FIGHTER PILOT SEES THE MISSILE AT:

RANGE = 3509.1 FEET
AZIMUTH = -152.3 DEGREES
ELEVATION = 0.6 DEGREES

RANGE RATE = -2473.0 FEET/SECOND
AZIMUTH RATE = -1.3 DEGREES/SECOND
ELEVATION RATE = 0.1 DEGREES/SECOND

ACCURACY IS WITHIN 24.7393 FEET. STEP INTERVAL IS 0.00000 SECONDS.

MISSILE PARAMETERS ARE WITHIN LIMITS.
TOTAL ELAPSED TIME IS 2.00 SECONDS.

THE AIRCRAFT'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
POSITION
X = 1405. FEET
Y = 3. FEET
Z = -2000. FEET
VELOCITY
U = 705. FEET/SECOND
V = 0. FEET/SECOND
W = 0. FEET/SECOND

ORIENTATION
HEADING (PSI) = 0. DEGREES
FLIGHT PATH ANGLE (THETA) = 0. DEGREES
BANK ANGLE (PHI) = 0. DEGREES

THE MISSILE'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
POSITION
X = 431. FEET
Y = -471. FEET
Z = -20011. FEET
VELOCITY
U = 2838. FEET/SECOND
V = 1129. FEET/SECOND
W = 27. FEET/SECOND

ORIENTATION
HEADING (PSI) = 21. DEGREES
FLIGHT PATH ANGLE (THETA) = 0. DEGREES

THE FIGHTER PILOT SEES THE MISSILE AT:
RANGE = 1037.7 FEET
AZIMUTH = 195.0 DEGREES
ELEVATION = 0.5 DEGREES

RANGE RATE = -2466.7 FEET/SECOND
AZIMUTH RATE = -0.9 DEGREES/SECOND
ELEVATION RATE = -0.8 DEGREES/SECOND

ACCURACY IS WITHIN 24.5370 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 -0.33 Degrees/Second
Maximum Vertical Rate is 0.52 Degrees/Second.

Horizontal Line of Sight Rate is -1.14 Degrees/Second.
Maximum Horizontal Rate is 0.52 Degrees/Second.

Accuracy is within 0.2440 feet. Step interval is 0.0010 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 -0.37 Degrees.
Maximum Elevation Gimbal Angle is 1.05 Degrees.
MISSILE HAS SCORED A HIT ON THE AIRCRAFT!

GUIDANCE ERRORS:

\[ x = -9.55 \text{ FEET} \]
\[ y = -0.31 \text{ FEET} \quad \text{TOTAL:} \quad 9.76 \text{ FEET} \]
\[ z = -1.75 \text{ FEET} \]

TOTAL ELAPSED TIME IS 2.2 SECONDS.

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

<table>
<thead>
<tr>
<th>POSITION</th>
<th>VELOCITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>x = 1701. FEET</td>
<td>u = 706. FEET/SECOND</td>
</tr>
<tr>
<td>y = 0. FEET</td>
<td>v = 0. FEET/SECOND</td>
</tr>
<tr>
<td>z = -2003. FEET</td>
<td>w = 0. FEET/SECOND</td>
</tr>
</tbody>
</table>

ORIENTATION

- HEADING (PSI) = 0. DEGREES
- FLIGHT PATH ANGLE (THETA) = 0. DEGREES
- BANK ANGLE (PHI) = 0. DEGREES

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

<table>
<thead>
<tr>
<th>POSITION</th>
<th>VELOCITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>x = 1697. FEET</td>
<td>u = 2396. FEET/SECOND</td>
</tr>
<tr>
<td>y = 1. FEET</td>
<td>v = 1134. FEET/SECOND</td>
</tr>
<tr>
<td>z = -2003. FEET</td>
<td>w = -4. FEET/SECOND</td>
</tr>
</tbody>
</table>

ORIENTATION

- HEADING (PSI) = 21. DEGREES
- FLIGHT PATH ANGLE (THETA) = 0. DEGREES

THE FIGHTER PILOT SEES THE MISSILE AT:

<table>
<thead>
<tr>
<th>RANGE</th>
<th>RANGE RATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>+4.3 FEET</td>
<td>-1571.3 FEET/SECOND</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>AZIMUTH</th>
<th>AZIMUTH RATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>165.3 DEGREES</td>
<td>-22534.8 DEGREES/SECOND</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ELEVATION</th>
<th>ELEVATION RATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>32.2 DEGREES</td>
<td>11639.5 DEGREES/SECOND</td>
</tr>
</tbody>
</table>
TYPE OF MISSILE IS:
RADAR GUIDED

TYPE FIGHTER IS:
NON-RESPONSIVE

GUIDANCE ERRORS:
x = -0.28 FEET
y = 0.20 FEET  TOTAL = 0.37 FEET
z = -0.14 FEET

TOTAL ELAPSED TIME IS 0.00 SECONDS.

THE AIRCRAFT'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
POSITION
x = 0.0 FEET
y = 0.0 FEET
z = -20000.0 FEET

VELOCITY
u = 800.0 FEET/SECOND
v = 0.0 FEET/SECOND
w = 0.0 FEET/SECOND

ORIENTATION
heading (psi) = 0.0 DEGREES
flight path angle (theta) = 0.0 DEGREES
bank angle (phi) = 0.0 DEGREES

THE MISSILE'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
POSITION
x = -3195.0 FEET
y = 3003.0 FEET
z = -20050.0 FEET

VELOCITY
u = 2594.0 FEET/SECOND
v = -1553.0 FEET/SECOND
w = 0.0 FEET/SECOND

ORIENTATION
heading (psi) = 330.0 DEGREES
flight path angle (theta) = 0.0 DEGREES

THE FIGHTER PILOT SEES THE MISSILE AT:
RANGE = 5000.2 FEET
AZIMUTH = 150.0 DEGREES
ELEVATION = 0.3 DEGREES

RANGE RATE = -2417.3 FEET/SECOND
AZIMUTH RATE = 3.8 DEGREES/SECOND
ELEVATION RATE = 0.2 DEGREES/SECOND
TOTAL ELASPED TIME IS 1.00 SECONDS.

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

POSITION
X = 301. FEET
Y = 3. FEET
Z = -20033. FEET

VELOCITY
U = 901. FEET/SECOND
V = 0. FEET/SECOND
W = 0. FEET/SECOND

ORIENTATION
HEADING (PSI) = 0.0 DEGREES
FLIGHT PATH ANGLE (THETA) = -0.0 DEGREES
BANK ANGLE (PHI) = 0.0 DEGREES

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

POSITION
X = -2392. FEET
Y = 1631. FEET
Z = -20033. FEET

VELOCITY
U = 2877. FEET/SECOND
V = -1131. FEET/SECOND
W = 20. FEET/SECOND

ORIENTATION
HEADING (PSI) = 333.0 DEGREES
FLIGHT PATH ANGLE (THETA) = -0.0 DEGREES

THE FIGHTER PILOT SEES THE MISSILE AT:

RANGE = 3333.5 FEET
RANGE RATE = -2396.7 FEET/SECOND
AZIMUTH = 132.5 DEGREES
AZIMUTH RATE = 1.4 DEGREES/SECOND
ELEVATION = 0.5 DEGREES
ELEVATION RATE = 0.1 DEGREES/SECOND

ACCURACY IS WITHIN 23.9573 FEET. STEP INTERVAL IS .01000 SECONDS.

MISSILE PARAMETERS ARE WITHIN LIMITS.
TOTAL ELAPSED TIME IS 2.10 SECONDS.

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

POSITION
X = 1503. FEET
Y = 0. FEET
Z = -2000. FEET

VELOCITY
U = 803. FEET/SECOND
V = 0. FEET/SECOND
W = 0. FEET/SECOND

ORIENTATION
HEADING (PSI) = 3. DEGREES
FLIGHT PATH ANGLE (THETA) = -0. DEGREES
BANK ANGLE (PHI) = 0. DEGREES

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

POSITION
X = 513. FEET
Y = 551. FEET
Z = -20014. FEET

VELOCITY
U = 2913. FEET/SECOND
V = -1073. FEET/SECOND
W = 26. FEET/SECOND

ORIENTATION
HEADING (PSI) = 343. DEGREES
FLIGHT PATH ANGLE (THETA) = -0. DEGREES

THE FIGHTER PILOT SEES THE MISSILE AT:

RANGE = 1220.7 FEET
RANGE RATE = -2372.9 FEET/SECOND
AZIMUTH = 133.2 DEGREES
AZIMUTH RATE = 0.2 DEGREES/SECOND
ELEVATION = 5 DEGREES
ELEVATION RATE = 0.0 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 = -0.01 FEET
Y = -2.83 FEET TOTAL = 3.90 FEET
Z = -1.93 FEET

TOTAL ELAPSED TIME IS 2.51 SECONDS.

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

POSITION
X = 2015. FEET
Y = 0. FEET
Z = -2000. FEET

VELOCITY
U = 804. FEET/SECOND
V = 0. FEET/SECOND
W = 0. FEET/SECOND

ORIENTATION
HEADING (PSI) = 0 DEGREES
FLIGHT PATH ANGLE (THETA) = 0 DEGREES
BANK ANGLE (PHI) = 0 DEGREES

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

POSITION
X = 2010. FEET
Y = -10. FEET
Z = -20002. FEET

VELOCITY
U = 2315. FEET/SECOND
V = -1085. FEET/SECOND
W = -8. FEET/SECOND

ORIENTATION
HEADING (PSI) = 349 DEGREES
FLIGHT PATH ANGLE (THETA) = 0 DEGREES

THE FIGHTER PILOT SEES THE MISSILE AT:
RANGE = 49.8 FEET RANGE RATE = -1854.1 FEET/SECOND
AZIMUTH = -174.1 DEGREES AZIMUTH RATE = 15503.5 DEGREES/SECOND
ELEVATION = 22.4 DEGREES ELEVATION RATE = 9053.7 DEGREES/SECOND
TYPE OF MISSILE IS:
RADAR GUIDED

TYPE FIGHTER IS:
RESPONSIVE

GUIDANCE ERRORS:

\[ \begin{align*}
X &= -0.25 \text{ FEET} \\
Y &= -0.03 \text{ FEET} \\
Z &= -0.03 \text{ FEET}
\end{align*} \]

TOTAL ELAPSED TIME IS 0.10 SECONDS.

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

\[ \begin{align*}
\text{POSITION} & \quad \text{VELOCITY} \\
X &= 0 \text{ FEET} & U &= 300 \text{ FEET/SECOND} \\
Y &= 0 \text{ FEET} & V &= 0 \text{ FEET/SECOND} \\
Z &= -2000 \text{ FEET} & W &= 0 \text{ FEET/SECOND}
\end{align*} \]

ORIENTATION

HEADING (PSI) = 0 DEGREES
FLIGHT PATH ANGLE (THETA) = 0 DEGREES
BANK ANGLE (PHI) = 0 DEGREES

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

\[ \begin{align*}
\text{POSITION} & \quad \text{VELOCITY} \\
X &= 10332 \text{ FEET} & U &= -2634 \text{ FEET/SECOND} \\
Y &= 600 \text{ FEET} & V &= -1505 \text{ FEET/SECOND} \\
Z &= -2000 \text{ FEET} & W &= 0 \text{ FEET/SECOND}
\end{align*} \]

ORIENTATION

HEADING (PSI) = 211 DEGREES
FLIGHT PATH ANGLE (THETA) = 0 DEGREES

THE FIGHTER PILOT SEES THE MISSILE AT:

\[ \begin{align*}
\text{RANGE} &= 12000.1 \text{ FEET} & \text{RANGE RATE} &= -3848.5 \text{ FEET/SECOND} \\
\text{AZIMUTH} &= 330.0 \text{ DEGREES} & \text{AZIMUTH RATE} &= 2.1 \text{ DEGREES/SECOND} \\
\text{ELEVATION} &= 0.2 \text{ DEGREES} & \text{ELEVATION RATE} &= 0.1 \text{ DEGREES/SECOND}
\end{align*} \]
TOTAL ELAPSED TIME IS 0.00 SECONDS.

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

MANEUVER IS A SPIT S.

GUIDANCE ERRORS:

X = -1.03 FEET
Y = -4.22 FEET  TOTAL = 4.35 FEET
Z = -0.35 FEET
TOTAL ELAPSED TIME IS 1.00 SECONDS.

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

<table>
<thead>
<tr>
<th>POSITION</th>
<th>VELOCITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>X = 300, FEET</td>
<td>U = 900, FEET/SECOND</td>
</tr>
<tr>
<td>Y = 5, FEET</td>
<td>V = 13, FEET/SECOND</td>
</tr>
<tr>
<td>Z = -13333, FEET</td>
<td>W = 18, FEET/SECOND</td>
</tr>
</tbody>
</table>

ORIENTATION
- HEADING (PSI) = 1.0 DEGREES
- FLIGHT PATH ANGLE (THETA) = -1.0 DEGREES
- BANK ANGLE (PHI) = 85.0 DEGREES

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

<table>
<thead>
<tr>
<th>POSITION</th>
<th>VELOCITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>X = 7783, FEET</td>
<td>U = -2518, FEET/SECOND</td>
</tr>
<tr>
<td>Y = 4303, FEET</td>
<td>V = -1825, FEET/SECOND</td>
</tr>
<tr>
<td>Z = -20042, FEET</td>
<td>W = 18, FEET/SECOND</td>
</tr>
</tbody>
</table>

ORIENTATION
- HEADING (PSI) = 215.0 DEGREES
- FLIGHT PATH ANGLE (THETA) = -0.0 DEGREES

THE FIGHTER PILOT SEES THE MISSILE AT:

<table>
<thead>
<tr>
<th>RANGE</th>
<th>RANGE RATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>8119.7 FEET</td>
<td>-3873.4 FEET/SECOND</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>AZIMUTH</th>
<th>AZIMUTH RATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.3 DEGREES</td>
<td>-1.0 DEGREES/SECOND</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ELEVATION</th>
<th>ELEVATION RATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>31.1 DEGREES</td>
<td>1.3 DEGREES/SECOND</td>
</tr>
</tbody>
</table>

ACCURACY IS WITHIN 38.734 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 5134 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:

\[ X = -2.35 \text{ FEET} \]
\[ Y = 3.54 \text{ FEET} \quad \text{TOTAL} = 4.49 \text{ FEET} \]
\[ Z = -1.13 \text{ FEET} \]
TOTAL ELAPSED TIME IS 2.00 SECONDS.

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

POSITION
\[ \begin{align*}
X &= 1300. \text{ FEET} \\
Y &= 29. \text{ FEET} \\
Z &= -1933. \text{ FEET}
\end{align*} \]

VELOCITY
\[ \begin{align*}
U &= 899. \text{ FEET/SECOND} \\
V &= 36. \text{ FEET/SECOND} \\
W &= 75. \text{ FEET/SECOND}
\end{align*} \]

ORIENTATION

HEADING (PSI) = 2 DEGREES

FLIGHT PATH ANGLE (THETA) = -3 DEGREES

BANK ANGLE (PHI) = 80 DEGREES

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

POSITION
\[ \begin{align*}
X &= 5343. \text{ FEET} \\
Y &= 2374. \text{ FEET} \\
Z &= -20003. \text{ FEET}
\end{align*} \]

VELOCITY
\[ \begin{align*}
U &= -2337. \text{ FEET/SECOND} \\
V &= -2015. \text{ FEET/SECOND} \\
W &= 64. \text{ FEET/SECOND}
\end{align*} \]

ORIENTATION

HEADING (PSI) = 22.5 DEGREES

FLIGHT PATH ANGLE (THETA) = -1 DEGREES

THE FIGHTER PILOT SEES THE MISSILE AT:

RANGE = 4253.7 FEET

RANGE RATE = -3355.6 FEET/SECOND

AZIMUTH = 1.3 DEGREES

AZIMUTH RATE = -0.8 DEGREES/SECOND

ELEVATION = 31.4 DEGREES

ELEVATION RATE = 1.3 DEGREES/SECOND

ACCURACY IS WITHIN 38.5937 FEET, STEP INTERVAL IS 0.0000 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 = -.75 FEET
y = -.01 FEET TOTAL = 2.10 FEET
z = -1.97 FEET
Total elapsed time is 3.10 seconds.

The aircraft's state in the earth surface fixed reference frame is:

<table>
<thead>
<tr>
<th>POSITION</th>
<th>VELOCITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>X = 2571. FEET</td>
<td>U = 647, FEET/SECOND</td>
</tr>
<tr>
<td>Y = 73. FEET</td>
<td>V = 49, FEET/SECOND</td>
</tr>
<tr>
<td>Z = -19723. FEET</td>
<td>W = 326, FEET/SECOND</td>
</tr>
</tbody>
</table>

Orientation:
- Heading (PSI) = 3. DEGREES
- Flight Path Angle (Theta) = -4. DEGREES
- Bank Angle (Phi) = 24. DEGREES

The missile's state in the earth surface fixed reference frame is:

<table>
<thead>
<tr>
<th>POSITION</th>
<th>VELOCITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>X = 303+. FEET</td>
<td>U = -2259, FEET/SECOND</td>
</tr>
<tr>
<td>Y = 313. FEET</td>
<td>V = -2037, FEET/SECOND</td>
</tr>
<tr>
<td>Z = -19735. FEET</td>
<td>W = 539, FEET/SECOND</td>
</tr>
</tbody>
</table>

Orientation:
- Heading (PSI) = 222. DEGREES
- Flight Path Angle (Theta) = -10. DEGREES

The fighter pilot sees the missile at:

- Range = 439.4 FEET
- Range Rate = -3753.6 FEET/SECOND
- Azimuth = 24.6 DEGREES
- Azimuth Rate = -14.5 DEGREES/SECOND
- Elevation = 15.5 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 2.14 DEGREES/SECOND.
MAXIMUM VERTICAL RATE IS 3.2 DEGREES/SECOND.

HORIZONTAL LINE OF SIGHT RATE IS -27.23 DEGREES/SECOND.
MAXIMUM HORIZONTAL RATE IS 3.2 DEGREES/SECOND.

MISSILE'S DOME ANGLE TO THE FIGHTER IS 2.14 DEGREES.
TARGET OUTSIDE GIMBAL LIMITS!

MAXIMUM GIMBAL ANGLE OF THE MISSILE IS 1.05 DEGREES.
RELATIVE AZIMUTH ANGLE IS 3.07 DEGREES.
MAXIMUM ELEVATION ANGLE IS 1.05 DEGREES.

TARGET OUTSIDE GIMBAL LIMITS!
MISSILE HAS MISSED THE AIRCRAFT!

GUIDANCE ERRORS:

X = -0.75 FEET
Y = -0.30 FEET TOTAL = 1.21 FEET
Z = 0.29 FEET

TOTAL ELAPSED TIME IS 3.12 SECONDS.

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

POSITION
X = 2773. FEET
Y = 73. FEET
Z = -1939. FEET

VELOCITY
U = 853. FEET/SECOND
V = 51. FEET/SECOND
W = 314. FEET/SECOND

ORIENTATION
HEADING (PSI) = 3. DEGREES
FLIGHT PATH ANGLE (THETA) = -4. DEGREES
BANK ANGLE (PHI) = 34. DEGREES

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

POSITION
X = 2761. FEET
Y = 72. FEET
Z = -19722. FEET

VELOCITY
U = -2231. FEET/SECOND
V = -2059. FEET/SECOND
W = -533. FEET/SECOND

ORIENTATION
HEADING (PSI) = 222. DEGREES
FLIGHT PATH ANGLE (THETA) = 10. DEGREES

THE FIGHTER PILOT SEES THE MISSILE AT:

RANGE = 35.3 FEET RANGE RATE = 2335.4 FEET/SECOND
AZIMUTH = -139.9 DEGREES AZIMUTH RATE = -1341.2 DEGREES/SECOND
ELEVATION = 33.7 DEGREES ELEVATION RATE = -4613.0 DEGREES/SECOND
TYPE OF MISSILE IS: INFRA-RED

TYPE FIGHTER IS: RESPONSIVE

GUIDANCE ERRORS:
\[ X = -10.10 \text{ FEET} \]
\[ Y = -0.15 \text{ FEET} \]
\[ Z = -0.29 \text{ FEET} \]

TOTAL ELAPSED TIME IS 0.00 SECONDS.

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

**POSITION**

| X      | 0.00 FEET | U  | 1000.0 FEET/SECOND |
| Y      | 0.00 FEET | V  | 0.00 FEET/SECOND   |
| Z      | -2000.0 FEET | W  | 0.00 FEET/SECOND   |

**ORIENTATION**

HEADING (PSI) = 0. DEGREES

FLIGHT PATH ANGLE (THETA) = 0. DEGREES

BANK ANGLE (PHI) = 0. DEGREES

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

**POSITION**

| X      | -6.000 FEET | U  | 1838.0 FEET/SECOND |
| Y      | -6.000 FEET | V  | 1838.0 FEET/SECOND |
| Z      | -14.000 FEET | W  | -1838.0 FEET/SECOND |

**ORIENTATION**

HEADING (PSI) = 45. DEGREES

FLIGHT PATH ANGLE (THETA) = 35. DEGREES

THE FIGHTER PILOT SEES THE MISSILE AT:

RANGE = 10392.3 FEET

AZIMUTH = -14.7 DEGREES

ELEVATION = -35.3 DEGREES

RANGE RATE = -2437.0 FEET/SECOND

AZIMUTH RATE = -8.9 DEGREES/SECOND

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 THAN 5000 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:

\[ \begin{align*}
X &= -10.05 \text{ FEET} \\
Y &= +0.33 \text{ FEET} \quad \text{TOTAL} = 10.36 \text{ FEET} \\
Z &= -2.49 \text{ FEET}
\end{align*} \]
TOTAL ELAPSED TIME IS 1.00 SECONDS.

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

<table>
<thead>
<tr>
<th>POSITION</th>
<th>VELOCITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>X= 335. FEET</td>
<td>U= 931. FEET/SECOND</td>
</tr>
<tr>
<td>Y= -30. FEET</td>
<td>V= -93. FEET/SECOND</td>
</tr>
<tr>
<td>Z= -19373. FEET</td>
<td>W= -37. FEET/SECOND</td>
</tr>
</tbody>
</table>

ORIENTATION

HEADING (PSI) = 353, DEGREES
FLIGHT PATH ANGLE (THETA) = 3, DEGREES
BANK ANGLE (PHI) = -83, DEGREES

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

<table>
<thead>
<tr>
<th>POSITION</th>
<th>VELOCITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>X= -3923. FEET</td>
<td>U= 2273. FEET/SECOND</td>
</tr>
<tr>
<td>Y= -4833. FEET</td>
<td>V= 1235. FEET/SECOND</td>
</tr>
<tr>
<td>Z= -15687. FEET</td>
<td>W= -1530. FEET/SECOND</td>
</tr>
</tbody>
</table>

ORIENTATION

HEADING (PSI) = 35, DEGREES
FLIGHT PATH ANGLE (THETA) = 29, DEGREES

THE FIGHTER PILOT SEES THE MISSILE AT:

| RANGE= 77877.7 FEET | RANGE RATE= -2304.3 FEET/SECOND |
| AZIMUT= -143.6 DEGREES | AZIMUT RATE= -5.5 DEGREES/SECOND |
| ELEVATION= 33.4 DEGREES | ELEVATION RATE= -2.3 DEGREES/SECOND |

ACCURACY IS WITHIN 23.0427 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 3129 FEET.
MANEUVER IS A HARD BREAK.

GUIDANCE ERRORS:

x = -10.80 FEET
y = 0.24 FEET TOTAL = 10.85 FEET
z = 1.03 FEET
TOTAL ELAPSED TIME IS 2.00 SECONDS.

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

POSITION
X = 1362. FEET
Y = -172. FEET
Z = -2014. FEET

VELOCITY
U = 948. FEET/SECOND
V = -133. FEET/SECOND
W = -205. FEET/SECOND

ORIENTATION
HEADING (PSI) = 349. DEGREES
FLIGHT PATH ANGLE (THETA) = -2. DEGREES
BANK ANGLE (PHI) = -131. DEGREES

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

POSITION
X = -152. FEET
Y = -2353. FEET
Z = -1723. FEET

VELOCITY
U = 2482. FEET/SECOND
V = 1255. FEET/SECOND
W = -1331. FEET/SECOND

ORIENTATION
HEADING (PSI) = 27. DEGREES
FLIGHT PATH ANGLE (THETA) = 23. DEGREES

THE FIGHTER PILOT SEES THE MISSILE AT:

RANGE = 5252.9 FEET
AZIMUTH = -179.1 DEGREES
ELEVATION = 59.3 DEGREES

RANGE RATE = -2493.9 FEET/SECOND
AZIMUTH RATE = 2.2 DEGREES/SECOND
ELEVATION RATE = -1.9 DEGREES/SECOND

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

MISSILE PARAMETERS ARE WITHIN LIMITS.
TOTAL ELAPSED TIME IS 3.00 SECONDS.

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

<table>
<thead>
<tr>
<th>POSITION</th>
<th>VELOCITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>X = 2303. FEET</td>
<td>U = 333. FEET/SECOND</td>
</tr>
<tr>
<td>Y = -41. FEET</td>
<td>V = -259. FEET/SECOND</td>
</tr>
<tr>
<td>Z = -20307. FEET</td>
<td>W = -122. FEET/SECOND</td>
</tr>
</tbody>
</table>

ORIENTATION

HEADING (PSI) = 343. DEGREES
FLIGHT PATH ANGLE (THETA) = -9. DEGREES
BANK ANGLE (PHI) = -132. DEGREES

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

<table>
<thead>
<tr>
<th>POSITION</th>
<th>VELOCITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>X = 1021. FEET</td>
<td>U = 2504. FEET/SECOND</td>
</tr>
<tr>
<td>Y = -1743. FEET</td>
<td>V = 937. FEET/SECOND</td>
</tr>
<tr>
<td>Z = -13773. FEET</td>
<td>W = -1539. FEET/SECOND</td>
</tr>
</tbody>
</table>

ORIENTATION

HEADING (PSI) = 21. DEGREES
FLIGHT PATH ANGLE (THETA) = 29. DEGREES

THE FIGHTER PILOT SEES THE MISSILE AT:

<table>
<thead>
<tr>
<th>RANGE</th>
<th>RANGE RATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2763.5 FEET</td>
<td>-2538.4 FEET/SECOND</td>
</tr>
</tbody>
</table>

AZIMUTH = -179.0 DEGREES
AZIMUTH RATE = -1 DEGREES/SECOND
ELEVATION = 69.4 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:

\[ x = -10.73 \text{ FEET} \]
\[ y = 2.37 \text{ FEET} \quad \text{TOTAL = 11.09 FEET} \]
\[ z = -1.44 \text{ FEET} \]
TOTAL ELAPSED TIME IS 4.10 SECONDS.

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

**POSITION**
- X = 3824.5 FEET
- Y = -749.3 FEET
- Z = -20331.4 FEET

**VELOCITY**
- U = 905.4 FEET/SECOND
- V = -377.6 FEET/SECOND
- W = -95.7 FEET/SECOND

**ORIENTATION**
- HEADING (PSI) = 337.5 DEGREES
- FLIGHT PATH ANGLE (THETA) = -15.5 DEGREES
- BANK ANGLE (PHI) = 141.4 DEGREES

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

**POSITION**
- X = 3573.2 FEET
- Y = -343.7 FEET
- Z = -20273.0 FEET

**VELOCITY**
- U = 2697.5 FEET/SECOND
- V = 645.7 FEET/SECOND
- W = -1439.5 FEET/SECOND

**ORIENTATION**
- HEADING (PSI) = 17.6 DEGREES
- FLIGHT PATH ANGLE (THETA) = 28.2 DEGREES

THE FIGHTER PILOT SEES THE MISSILE AT:

**RANGE** = 201.6 FEET
**RANGE RATE** = -2573.2 FEET/SECOND
**AZIMUTH** = 172.4 DEGREES
**AZIMUTH RATE** = 134.1 DEGREES/SECOND
**ELEVATION** = 69.3 DEGREES
**ELEVATION RATE** = -39.1 DEGREES/SECOND

ACCURACY IS WITHIN 25.7521 FEET. STEP INTERVAL IS 0.01000 SECONDS.

MISSILE PARAMETERS ARE WITHIN LIMITS.
MISSILE IS PULLING MAXIMUM G!

ACCURACY IS WITHIN \(0.2325\) FEET, STEP INTERVAL IS \(0.00010\) SECONDS.

MISSILE EXCEEDED MANEUVERING CAPABILITY!

VERTICAL LINE OF SIGHT RATE IS \(0.71\) DEGREES/SECOND.
MAXIMUM VERTICAL RATE IS \(0.52\) DEGREES/SECOND.

HORIZONTAL LINE OF SIGHT RATE IS \(0.35\) DEGREES/SECOND.
MAXIMUM HORIZONTAL RATE IS \(0.32\) 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 \(0.39\) DEGREES.
MAXIMUM ELEVATION GIMBAL ANGLE IS \(1.05\) DEGREES.
MISSILE HAS MISSED THE AIRCRAFT!

GUIDANCE ERRORS:
X = -10.35 FEET
Y = +.33 FEET  TOTAL = 10.33 FEET
Z = -+.03 FEET

TOTAL ELAPSED TIME IS 4.18 SECONDS.

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

POSITION
X = 3834. FEET  U = 903. FEET/SECOND
Y = -773. FEET  V = -383. FEET/SECOND
Z = -20335. FEET  W = -38. FEET/SECOND

ORIENTATION
HEADING (PSI) = 337. DEGREES
FLIGHT PATH ANGLE (THETA) = -18. DEGREES
BANK ANGLE (PHI) = 144. DEGREES

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

POSITION
X = 3834. FEET  U = 2632. FEET/SECOND
Y = -773. FEET  V = 841. FEET/SECOND
Z = -20335. FEET  W = -1473. FEET/SECOND

ORIENTATION
HEADING (PSI) = 17. DEGREES
FLIGHT PATH ANGLE (THETA) = 23. DEGREES

0 THE FIGHTER PILOT SEES THE MISSILE AT:

RANGE = 3.3 FEET  RANGE RATE = 2.1 FEET/SECOND
AZIMUTH = 177.2 DEGREES  AZIMUTH RATE = 3181.7 DEGREES/SECOND
ELEVATION = -17.0 DEGREES  ELEVATION RATE = -17947.1 DEGREES/SECOND
TYPE OF MISSILE IS:
RADAR GUIDED

TYPE FIGHTER IS:
RESPONSIVE

GUIDANCE ERRORS:
\[ \begin{align*}
X &= -1.13 \text{ FEET} \\
Y &= -0.43 \text{ FEET} \quad \text{TOTAL}= 1.33 \text{ FEET} \\
Z &= +.49 \text{ FEET}
\end{align*} \]

TOTAL ELAPSED TIME IS 0.30 SECONDS.

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

\[
\begin{align*}
\text{POSITION} & \\
X &= 0 \text{ FEET} \\
Y &= 0 \text{ FEET} \\
Z &= -2000 \text{ FEET}
\end{align*}
\]

\[
\begin{align*}
\text{VELOCITY} & \\
U &= 1100 \text{ FEET/SECOND} \\
V &= 0 \text{ FEET/SECOND} \\
W &= 0 \text{ FEET/SECOND}
\end{align*}
\]

ORIENTATION

\[
\begin{align*}
\text{HEADING (PSI)} &= 0 \text{ DEGREES} \\
\text{FLIGHT PATH ANGLE (THETA)} &= 0 \text{ DEGREES} \\
\text{BANK ANGLE (PHI)} &= 0 \text{ DEGREES}
\end{align*}
\]

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

\[
\begin{align*}
\text{POSITION} & \\
X &= -5000 \text{ FEET} \\
Y &= 5000 \text{ FEET} \\
Z &= -1000 \text{ FEET}
\end{align*}
\]

\[
\begin{align*}
\text{VELOCITY} & \\
U &= 1839 \text{ FEET/SECOND} \\
V &= -1839 \text{ FEET/SECOND} \\
W &= -1839 \text{ FEET/SECOND}
\end{align*}
\]

ORIENTATION

\[
\begin{align*}
\text{HEADING (PSI)} &= 315 \text{ DEGREES} \\
\text{FLIGHT PATH ANGLE (THETA)} &= 35 \text{ DEGREES}
\end{align*}
\]

THE FIGHTER PILOT SEES THE MISSILE AT:

\[
\begin{align*}
\text{RANGE} &= 10322.3 \text{ FEET} \quad \text{RANGE RATE}= -2420.3 \text{ FEET/SECOND} \\
\text{AZIMUTH} &= 144.7 \text{ DEGREES} \quad \text{AZIMUTH RATE}= 7.3 \text{ DEGREES/SECOND} \\
\text{ELEVATION} &= -35.3 \text{ DEGREES} \quad \text{ELEVATION RATE}= 3.0 \text{ DEGREES/SECOND}
\end{align*}
\]
TOTAL ELAPSED TIME IS 0.00 SECONDS.

THE PILOT ESTIMATES THE MISSILE TO BE AT A RANGE OF MORE THAN 6000 FEET, THE PILOT EXECUTES MANEUVER NUMBER 1 AT AN ACTUAL RANGE OF 10332 FEET.

MANEUVER IS A VERTICAL DIVE AWAY FROM THE MISSILE.

GUIDANCE ERRORS:

X = -3.63 FEET
Y = -1.45 FEET TOTAL = 5.14 FEET
Z = 3.23 FEET
TOTAL ELAPSED TIME IS 1.00 SECONDS.

THE AIRCRAFT'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
POSITION
X = 1091. FEET
Y = 53. FEET
Z = -2004. FEET

VELOCITY
U = 1072. FEET/SECOND
V = 134. FEET/SECOND
W = -33. FEET/SECOND

ORIENTATION
HEADING (PSI) = 7 DEGREES
FLIGHT PATH ANGLE (THETA) = 9 DEGREES
BANK ANGLE (PHI) = 85 DEGREES

THE MISSILE'S STATE IN THE EARTH SURFACE FIXED REFERENCE FRAME IS:
POSITION
X = -3903. FEET
Y = 4301. FEET
Z = -15693. FEET

VELOCITY
U = 2311. FEET/SECOND
V = -1542. FEET/SECOND
W = -1536. FEET/SECOND

ORIENTATION
HEADING (PSI) = 325 DEGREES
FLIGHT PATH ANGLE (THETA) = 29 DEGREES

THE FIGHTER PILOT SEES THE MISSILE AT:
RANGE = 73524.6 FEET
AZIMUTH = 147.4 DEGREES
ELEVATION = 34.9 DEGREES

RANGE RATE = -2439.7 FEET/SECOND
AZIMUTH RATE = 5.6 DEGREES/SECOND
ELEVATION RATE = -2.7 DEGREES/SECOND

ACCURACY IS WITHIN 24 3370 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 5000 FEET.
THE PILOT EXECUTES MANEUVER NUMBER 2 AT AN ACTUAL RANGE OF 5194 FEET.

MANEUVER IS A HARD BREAK.

GUIDANCE ERRORS:
X = -0.14 FEET
Y = -2.24 FEET  TOTAL = 11.95 FEET
Z = 11.74 FEET
TOTAL ELAPSED TIME IS 2.00 SECONDS.

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

**POSITION**

<table>
<thead>
<tr>
<th>X</th>
<th>Feet</th>
<th>Y</th>
<th>Feet</th>
<th>Z</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>2113</td>
<td></td>
<td>275</td>
<td></td>
<td>-2023</td>
<td></td>
</tr>
</tbody>
</table>

**VELOCITY**

<table>
<thead>
<tr>
<th>U</th>
<th>Feet/Second</th>
<th>V</th>
<th>Feet/Second</th>
<th>W</th>
<th>Feet/Second</th>
</tr>
</thead>
<tbody>
<tr>
<td>935</td>
<td></td>
<td>302</td>
<td></td>
<td>-250</td>
<td></td>
</tr>
</tbody>
</table>

**ORIENTATION**

HEADING (PSI) = 17, DEGREES
FLIGHT PATH ANGLE (THETA) = -0, DEGREES
BANK ANGLE (PHI) = 131, DEGREES

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

**POSITION**

<table>
<thead>
<tr>
<th>X</th>
<th>Feet</th>
<th>Y</th>
<th>Feet</th>
<th>Z</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1471</td>
<td></td>
<td>2353</td>
<td></td>
<td>-1723</td>
<td></td>
</tr>
</tbody>
</table>

**VELOCITY**

<table>
<thead>
<tr>
<th>U</th>
<th>Feet/Second</th>
<th>V</th>
<th>Feet/Second</th>
<th>W</th>
<th>Feet/Second</th>
</tr>
</thead>
<tbody>
<tr>
<td>2518</td>
<td></td>
<td>-118</td>
<td></td>
<td>-197</td>
<td></td>
</tr>
</tbody>
</table>

**ORIENTATION**

HEADING (PSI) = 335, DEGREES
FLIGHT PATH ANGLE (THETA) = 30, DEGREES

THE FIGHTER PILOT SEES THE MISSILE AT:

RANGE = 5391.3 FEET
AZIMUTH = -173.7 DEGREES
ELEVATION = 66.8 DEGREES

RANGE RATE = -2470.4 FEET/SECOND
AZIMUTH RATE = -4.1 DEGREES/SECOND
ELEVATION RATE = -2.1 DEGREES/SECOND

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

MISSILE PARAMETERS ARE WITHIN LIMITS.
TOTAL ELAPSED TIME IS 3.30 SECONDS.

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

<table>
<thead>
<tr>
<th>POSITION</th>
<th>VELOCITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>x= 3031.0 ft</td>
<td>u= 953.0 ft/s</td>
</tr>
<tr>
<td>y= 89.0 ft</td>
<td>v= 442.0 ft/s</td>
</tr>
<tr>
<td>z= -2047.0 ft</td>
<td>w= -119.0 ft/s</td>
</tr>
</tbody>
</table>

ORIENTATION

HEADING (PSI) = 23.0 DEGREES
FLIGHT PATH ANGLE (THETA) = -3.0 DEGREES
BANK ANGLE (PHI) = 131.0 DEGREES

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

<table>
<thead>
<tr>
<th>POSITION</th>
<th>VELOCITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>x= 111.0 ft</td>
<td>u= 2631.0 ft/s</td>
</tr>
<tr>
<td>y= 1951.0 ft</td>
<td>v= -625.0 ft/s</td>
</tr>
<tr>
<td>z= -13503.0 ft</td>
<td>w= -1559.0 ft/s</td>
</tr>
</tbody>
</table>

ORIENTATION

HEADING (PSI) = 343.0 DEGREES
FLIGHT PATH ANGLE (THETA) = 29.0 DEGREES

THE FIGHTER PILOT SEES THE MISSILE AT:

<table>
<thead>
<tr>
<th>RANGE= 2375.0 ft</th>
<th>RANGE RATE= -2560.3 ft/second</th>
</tr>
</thead>
<tbody>
<tr>
<td>AZIMUTH= 179.3 DEGREES</td>
<td>AZIMUTH RATE= -2.0 DEGREES/second</td>
</tr>
<tr>
<td>ELEVATION= 70.3 DEGREES</td>
<td>ELEVATION RATE= -1.3 DEGREES/second</td>
</tr>
</tbody>
</table>

ACCURACY IS WITHIN 25.5026 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 = -0.23 FEET
Y = 3.13 FEET  TOTAL = 8.41 FEET
Z = 7.77 FEET
TOTAL ELAPSED TIME IS 4.00 SECONDS.

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

POSITION
- \( X = 401.1 \) FEET
- \( Y = 113.4 \) FEET
- \( Z = -2043.7 \) FEET

VELOCITY
- \( U = 835.0 \) FEET/SECOND
- \( V = 563.0 \) FEET/SECOND
- \( W = -13.0 \) FEET/SECOND

ORIENTATION
- HEADING (PSI) = 33.0 DEGREES
- FLIGHT PATH ANGLE (THETA) = -18.0 DEGREES
- BANK ANGLE (PHI) = 138.0 DEGREES

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

POSITION
- \( X = 3927.0 \) FEET
- \( Y = 1273.0 \) FEET
- \( Z = -20317.0 \) FEET

VELOCITY
- \( U = 2758.0 \) FEET/SECOND
- \( V = -520.0 \) FEET/SECOND
- \( W = -1466.0 \) FEET/SECOND

ORIENTATION
- HEADING (PSI) = 347.0 DEGREES
- FLIGHT PATH ANGLE (THETA) = 27.0 DEGREES

THE FIGHTER PILOT SEES THE MISSILE AT:

- RANGE = 255.3 FEET
- RANGE RATE = -2530.5 FEET/SECOND
- AZIMUTH = -172.4 DEGREES
- AZIMUTH RATE = -329.5 DEGREES/SECOND
- ELEVATION = 79.0 DEGREES
- ELEVATION RATE = -3.1 DEGREES/SECOND

ACCURACY IS WITHIN 25.3047 FEET. STEP INTERVAL IS 0.01000 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 .2525 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 = 3.8+ FEET  TOTAL = 4.10 FEET
Z = -0.93 FEET

TOTAL ELAPSED TIME IS 4.10 SECONDS.

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

POSITION
X = 4093. FEET
Y = 1210. FEET
Z = -2043. FEET

VELOCITY
U = 878. FEET/SECOND
V = 573. FEET/SECOND
W = -11+. FEET/SECOND

ORIENTATION
HEADING (PSI) = 33. DEGREES
FLIGHT PATH ANGLE (THETA) = -18. DEGREES
BANK ANGLE (PHI) = 142. DEGREES

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

POSITION
X = 4937. FEET
Y = 1213. FEET
Z = -2045. FEET

VELOCITY
U = 2716. FEET/SECOND
V = -548. FEET/SECOND
W = -1556. FEET/SECOND

ORIENTATION
HEADING (PSI) = 343. DEGREES
FLIGHT PATH ANGLE (THETA) = 30. DEGREES

THE FIGHTER PILOT SEES THE MISSILE AT:

RANGE = 4.9 FEET
AZIMUTH = -23.1 DEGREES
ELEVATION = 45.5 DEGREES

RANGE RATE = -1732.6 FEET/SECOND
AZIMUTH RATE = 3758.7 DEGREES/SECOND
ELEVATION RATE = -22334.1 DEGREES/SECOND
Appendix C

Aircraft Aerodynamic Coefficients and Equations

Equations

Lift: (37)

\[ C_L = \text{CEF} 1 + \text{CEF} 2 (\Delta \alpha) + \text{CEF} 18 (\Delta MN) + \text{CEF} 13 (\Delta s) \]

Drag: (38)

\[ C_D = \text{CEF} 3 + \text{CEF} 4 (\Delta \alpha) + \text{CEF} 19 (\Delta MN) \]

Sideforce: (39)

\[ C_Y = \text{CEF} 23 (\Delta \beta) + \text{CEF} 17 (\Delta \beta) \]

Pitching Moment: (40)

\[ C_m = \text{CEF} 5 + \text{CEF} 6 (\Delta \alpha) + \text{CEF} 7 (\Delta q) \left( \frac{1}{2} \right) \left( \frac{\rho V^2}{\beta} \right) + \text{CEF} 8 (\Delta \dot{\alpha}) \]

\[ (\frac{1}{2}) \left( \frac{\rho V^2}{\beta} \right) + \text{CEF} 20 (\Delta MN) + \text{CEF} 14 (\Delta s) \]

Rolling Moment: (41)

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

\[ \left( \frac{b}{\rho V^2} \right) + \text{CEF} 15 (\Delta \beta) \]

Yawing Moment: (42)

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

\[ \left( \frac{b}{\rho V^2} \right) + \text{CEF} 16 (\Delta \beta) \]

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

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c - mean aerodynamic cord - feet

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

$\Delta p$ - delta p (rate of roll)

$\Delta r$ - delta r (rate of yaw)

$\Delta q$ - delta q (rate of pitch)
<table>
<thead>
<tr>
<th>Program Symbol</th>
<th>Standard Notation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEF 1</td>
<td>$C_{LO}$</td>
<td>Basic Lift Coefficient</td>
</tr>
<tr>
<td>CEF 2</td>
<td>$C_{L\alpha}$</td>
<td>Derivative of $L$ respect to $\alpha$</td>
</tr>
<tr>
<td>CEF 3</td>
<td>$C_{DO}$</td>
<td>Basic Drag Coefficient</td>
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<tr>
<td>CEF 4</td>
<td>$C_{D\alpha}$</td>
<td>Derivative of $D$ respect to $\alpha$</td>
</tr>
<tr>
<td>CEF 5</td>
<td>$C_{MO}$</td>
<td>Basic Pitching Moment Coefficient</td>
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<td>CEF 6</td>
<td>$C_{m\alpha}$</td>
<td>Derivative of $m$ respect to $\alpha$</td>
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<td>CEF 7</td>
<td>$C_{mq}$</td>
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<td>CEF 9</td>
<td>$C_{1p}$</td>
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<td>CEF 10</td>
<td>$C_{1r}$</td>
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<td>$C_{Nr}$</td>
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<td>CEF 13</td>
<td>$C_{L\delta s}$</td>
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<td>CEF 14</td>
<td>$C_{m\delta s}$</td>
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<td>CEF 15</td>
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<td>CEF 16</td>
<td>$C_{N\delta r}$</td>
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<td>CEF 17</td>
<td>$C_{Y\delta r}$</td>
<td>Derivative of $Y$ respect to $\delta r$</td>
</tr>
<tr>
<td>CEF 18</td>
<td>$C_{LM}$</td>
<td>Derivative of $L$ respect to $M$</td>
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<tr>
<td>CEF 19</td>
<td>$C_{Dm}$</td>
<td>Derivative of $D$ respect to $m$</td>
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<tr>
<td>CEF 23</td>
<td>$C_{Y\beta}$</td>
<td>Derivative of $Y$ respect to $\beta$</td>
</tr>
</tbody>
</table>

**Key Symbols**

- **L** - Lift
- **D** - Drag
- **M** - Mach Number

- $\alpha$ - angle of attack
- $\beta$ - sideslip
- $\dot{\alpha}$ - rate of change of $\alpha$
- $p$ - rate of roll
- $q$ - rate of pitch
- $r$ - rate of yaw
- $m$ - pitch moment
- $l$ - rolling moment
- $N$ - yawing moment
- $\delta s$ - elevator deflection
- $\delta r$ - 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.

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.

\[
\overrightarrow{V}_B = \begin{bmatrix} V_B \\ X \\ O \\ O \end{bmatrix}
\]

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

\[
\overrightarrow{\omega} = \begin{bmatrix} 0 \\ \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = \begin{bmatrix} 0 \\ \dot{\chi} \\ \dot{\psi} \end{bmatrix}
\]

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.

\[
\dot{\overrightarrow{V}}_N = \overrightarrow{O} + \overrightarrow{\omega} \times \overrightarrow{V}_B = \begin{bmatrix} 0 \\ \dot{\chi} \\ \dot{\psi} \end{bmatrix} \times \begin{bmatrix} V_B X \\ O \\ O \end{bmatrix}
\]
\[ \dot{V}_N = \begin{bmatrix} i & j & k \\ O & \lambda V & \psi V \\ V & 0 & 0 \end{bmatrix} = \begin{bmatrix} O \\ \psi V \\ -\lambda V \end{bmatrix} \] (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.

\[ \ddot{g} = \frac{\ddot{V}_N}{g} = \begin{bmatrix} O \\ \psi V \\ -\lambda V \end{bmatrix} \] (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  
2. y - position  
3. z - position  
4. u - velocity  
5. v - velocity  
6. w - velocity  
7. bank  
8. pitch  
9. heading  
10. yaw rate  
11. pitch rate  
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.