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Aeroballistic Research Facility Data Analysis System (ARFDAS)

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FINAL REPORT FOR PERIOD OCTOBER 1986-SEPTEMBER 1987

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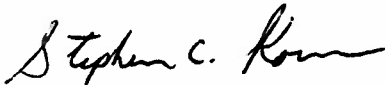
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FOR THE COMMANDER



STEPHEN C. KORN
Chief, Aeromechanics Division

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19. ABSTRACT (Continue on reverse if necessary and identify by block number) This report documents the computerized analysis programs used to examine free-flight, ballistic trajectory data (spatial position, angular orientation, and time) obtained at the United States Air Force Aeroballistic Research Facility (ARF). The Aeroballistic Research Facility Data Analysis System (ARFDAS) is a set of Fortran programs used to extract aerodynamic coefficients from experimental spark range data. This report, essentially a User's Manual, concentrates on how to utilize ARFDAS to conduct the desired analysis. The theory behind the derivation of the six degree of freedom equations of motion is fully explained by the references. The purpose of the report is to enable a person, who possesses a good knowledge of aerodynamics, to utilize the ARFDAS computer codes to analyze experimental data to final coefficient form.						
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PREFACE

This program was conducted by the General Electric Company, Lakeside Avenue, Burlington, Vermont 05401-4985, under Contract F08635-87-C-0005 with the Air Force Armament Laboratory, Eglin Air Force Base, Florida 32542-5434. Lt. Roger Gates (AFATL/FXA) managed the program for the Armament Laboratory. The program was conducted during the period from October 1986 to September 1987.

This manual describes the Aeroballistic Research Facility Data Analysis System (ARFDAS) that is utilized by engineers at the Aeroballistic Research Facility to reduce experimental spark range data to aerodynamic coefficients. The intent herein is to demonstrate ARFDAS capabilities and utilization. The technical methodology is covered by the referenced documents. Extensive use is made of example input menus, and output presentation of results, to aid the user in understanding these complex computer codes.



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SECTION I

INTRODUCTION

The Aeroballistic Research Facility Data Analysis System (ARFDAS) is a set of Fortran programs used for the determination of aerodynamic coefficients from spark range experimental data. These programs are intended for use by engineers at the United States Air Force Aeroballistic Research Facility (ARF), an enclosed spark range used to examine the ballistic trajectories of experimental munitions in free flight (Reference 1). Two of the programs, Projectile Design Analysis System (PRODAS) and Modified Trajectory (MODTRAJ), are designed to estimate the aerodynamics of a projectile and create simulated test data. These programs are used to "design the experiment." The remaining programs use the test data (actual or simulated) to determine the aerodynamic coefficients from a best fit of the theoretical equations to the observed motion. The following menu is a list of program options currently available in ARFDAS.

Enter the number of the desired action

----- Linear Theory -----

- 1 - Input / Analysis
- 2 - Output

----- 6 DOF -----

- 3 - Setup
- 4 - Analysis
- 5 - Output

----- Auxiliary -----

- 6 - Plot Experimental Data Points
- 7 - Delete stored files
- 8 - Run Time - Distance Bias
- 9 - Run MODTRAJ
- 10 - Run PRODAS
- 11 - Breakup Tunnel XYZ files

- 99 - Exit

In a typical analysis, PRODAS would be run first. In PRODAS, a finite element model of the projectile is created from which aerodynamic coefficient estimates of the model are found. These estimates will be used as the starting point for a least squares fit of the test data. An exterior ballistics analysis may be performed to determine the projectile motion. This data would be useful in locating cameras for a test firing. PRODAS may be used to create input data for the program MODTRAJ. In MODTRAJ a Six Degree of Freedom (6 DOF) motion analysis is performed. The motion data is correlated to each of the ARF's camera locations. Typical noise is then superimposed on the motion data. The resulting file may be run through the data reduction codes (linear and 6 DOF) to test for coefficient sensitivity.

After actual test data has been read from the film the Time-Distance Bias program is run. This program adjusts the projectile motion to account for measurement bias as found from a previously conducted range survey (calibration).

The biased experimental data may now be plotted. This visual examination makes it easier to show problems with the data such as points obviously out of position or long gaps between stations.

The first step in data reduction is the linear theory input/analysis. The linear theory analysis program creates input for the 6 DOF program. Plotted or tabulated output may be created from either the linear theory or 6 DOF programs. This report will further explain the theory of the analysis techniques and instructions for using the ARFDAS programs.

ARFDAS is implemented on one of the Eglin AFB VAX computers. The program utilizes the Tektronix graphics library Plot-10.

Throughout all the programs that comprise ARFDAS, common techniques for modifying data are used. The principal method is to display a menu of parameters for modification by the user. This is done by specifying the line number in the menu and the new value:

S87040613 40mm HEDP Tubular

1 - Temperature	(deg C):	0.00
2 - Pressure	(mbars):	0.00
3 - Relative humidity	(40%-.40):	0.00
4 - Projectile mass	(grams):	0.00
5 - Projectile diameter	(inches):	0.00

Key in item number ", " new value

Key in "LIST" to relist "DONE" to continue

: 1,19.6

In the above example, the temperature will be changed from 0 to 19.6 degrees Celcius. The "LIST" option will redisplay the input menu showing any changes that have been made. The "DONE" option signals that modification is complete on this menu. Only the first character of the command is examined, therefore, only an L or D must be entered. The program will recognize either upper or lower case characters.

SECTION II

SIMULATED RANGE DATA (MODTRAJ)

MODTRAJ is a modified 6 DOF trajectory analysis program. Instead of outputting analysis results throughout the trajectory at specified time or distance increments, the data points are output when the horizontal travel matches the location of a camera station in the ARF. Random noise is then superimposed on the six output parameters (X, Y, Z, pitch, yaw, roll) before the analysis results are written to the data file for reading by Linear Theory Input. The probable errors of the noise were determined from the reading accuracy of the ARF range and are hardwired into the code. The only user input into MODTRAJ during program execution is the name of the data file written by PRODAS. The output data file from MODTRAJ will have the same name as the input file and is in the form of a Linear Theory input file.

The input for MODTRAJ is created by the trajectory segment of PRODAS (Section V). Selecting the MODTRAJ option in PRODAS will cause the contents of all trajectory input menus to be written into a data file for reading by MODTRAJ. PRODAS will not perform a trajectory analysis when running the MODTRAJ input option.

Once MODTRAJ has generated a trajectory, the resulting data points may be plotted. The following output menu shows the choices of plotted output:

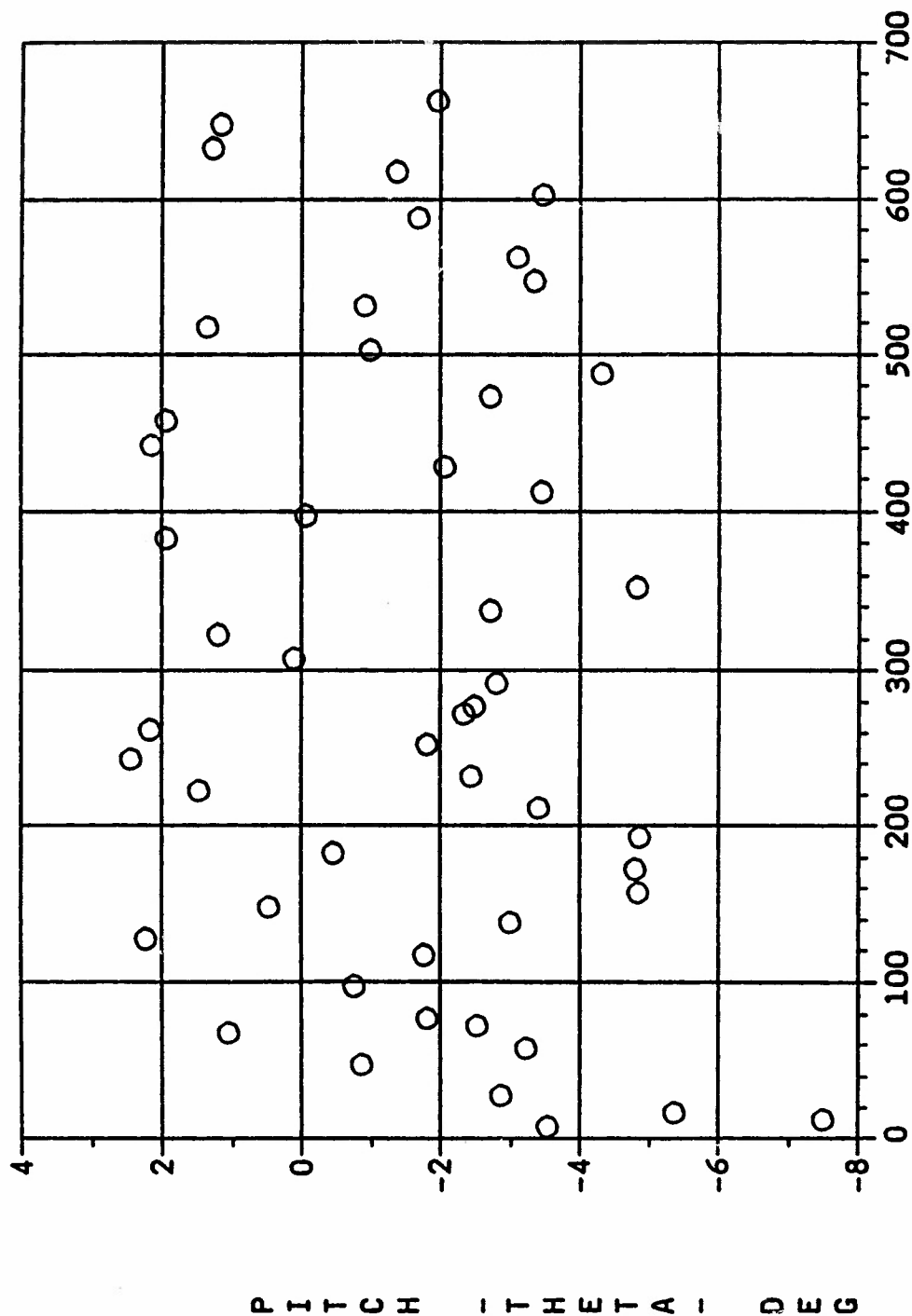
Theoretical Point Plots

vs time	vs travel
1 - Down Range Travel [X]	- 11
2 - Horizontal Motion [Y]	- 12
3 - Vertical Motion [Z]	- 13
4 - Pitch [THETA]	- 14
5 - Yaw [PSI]	- 15
6 - Roll [PHI]	- 16
7 - Pitch/Yaw [THETA-PSI]	
8 - Pitch/Yaw Step Plot	
9 - Done	
: <u>4</u>	

Figure 1 shows a sample plot of pitch data for a 20mm projectile. Tabulated data may also be created by MODTRAJ upon exit. Table 1 shows a partial tabulated output created by the 20mm sample run.

A primary application of MODTRAJ is to generate data for simulated data reduction. This reduction can determine parameter sensitivity. Before performing a 6 DOF reduction on actual test data, the reduction of MODTRAJ data can determine which coefficients can be reduced with acceptable accuracy.

SAMPLE2
20mm TP MODTRAJ test



28-SEP-87
13:16:39

TRAVEL (FT)

Figure 1. MODTRAJ Data Output

TABLE 1. MODTRAJ TABULAR OUTPUT

MODTRAJ Documentation test case

6 Degree of Freedom Trajectory Program

Input Data

Projectile Diameter (in)	Axial Inertia (lbm-in ²)	Y Transverse Inertia (lbm-in ²)	Z Transverse Inertia (lbm-in ²)	Product of Inertia (lbm-in ²)	Projectile Weight (lbm)	Number of Fins	Table Size
0.531	0.00758	0.05857	0.05857	0.00000	0.23048	0	17

Elevation Angle (deg)	Asimuth Angle (deg)	Angle of Attack (deg)	Angle of Sideslip (deg)	Pitch Rate (rad/sec)	Yaw Rate (rad/sec)	Roll Rate (rad/sec)	Muzzle Velocity (ft/sec)	Integration Time Step (sec)
1.000	0.000	0.900	0.000	40.000	40.000	13947.	4350.	0.00020

Initial Conditions

Altitude (ft)	Horizontal Range (ft)	Cross Range (ft)	Time (sec)
0.000	600.000	0.000	0.000

Aerodynamic Coefficient Tables
(For Fixed Plane EOM)
Mach Numbers

COEFF	(CMA=CZA)	0.60	0.90	0.95	1.00	1.05	1.10	1.20	1.35
1		0.01	0.60	0.90	1.00	1.05	1.10	1.20	1.35
		1.50	1.75	2.00	3.00	4.00	5.00		
2 CX0		0.19800	0.19800	0.20040	0.25900	0.37100	0.42700	0.41800	0.39200
		0.34600	0.31300	0.28200	0.19000	0.15200	0.13000		
3 CXa2	(ABAR)	2.43650	2.43650	2.87710	3.74890	4.24410	4.70300	5.20910	5.74050
		4.57610	3.98260	3.39740	2.90580	2.04520	1.62510		

Temperature (Deg F):	59.02
Pressure (psi):	14.692
Density (slug/ft ³):	0.00237692

TABLE 1. MODTRAJ TABULAR OUTPUT (CONCLUDED)

Time (sec)	X (ft)	X (m)	Travel Y (ft)	Z (ft)	Mach Number	Pitch (deg)	Yaw (deg)	Velocity X (ft/sec)	Y (ft/sec)	Z (ft/sec)	Projectile Velocity (ft/sec)	Slant Range (ft)
0.000000	600.00	182.88	0.000	0.000	0.000	0.000	0.000	4349.	0.00	75.52	4350.0	0.000
0.000199	600.87	183.14	0.000	0.015	3.896	0.366	0.529	4349.	0.01	75.90	4349.8	0.868
0.000399	601.73	183.41	0.000	0.030	3.896	0.527	1.161	4349.	0.05	75.87	4349.7	1.735
0.000598	602.60	183.67	0.000	0.045	3.896	0.459	1.827	4349.	0.11	75.84	4349.5	2.603
0.000798	603.47	183.94	0.000	0.061	3.895	0.165	2.457	4349.	0.20	75.81	4349.4	3.470
0.000997	604.34	184.20	0.000	0.076				4349.	0.32	75.80	4349.2	4.338

Time (sec)	X (ft)	X (m)	Roll Rate (rad/sec)	Pitch Rate (rad/sec)	Yaw Rate (rad/sec)	Pitch (deg)	Yaw (deg)	Angle of Attack (deg)
0.000000	600.00	182.88	0.	0.000	0.000	0.000	0.000	0.000
0.000200	600.87	183.14	13946.	3.896	0.366	-0.156	-0.624	0.643
0.000400	601.73	183.41	13946.	3.896	0.527	-0.370	-1.220	1.275
0.000600	602.60	183.67	13946.	3.896	0.459	1.396	-1.266	1.884
0.000800	603.47	183.94	13945.	3.895	0.165	-2.415	-0.483	2.462

Time (sec)	X (ft)	X (m)	Roll Rate (rad/sec)	Pitch Rate (rad/sec)	Yaw Rate (rad/sec)	Pitch (deg)	Yaw (deg)	Gamma (deg)	Delta (deg)	Roll (deg)
0.000000	600.00	182.88	13947.	40.00	40.01	-1.000	0.000	1.00	0.00	0.
0.000200	600.87	183.14	13947.	23.53	51.77	-0.634	0.529	1.00	0.00	159.
0.000400	601.73	183.41	13946.	4.26	57.90	-0.473	1.162	1.00	0.00	319.
0.000600	602.60	183.67	13946.	-15.98	57.84	-0.540	1.829	1.00	0.00	478.
0.000800	603.47	183.94	13946.	-35.28	51.59	-0.835	2.460	1.00	0.00	637.

AERODAS input Tunnel XYZ data (with random noise)

Time (sec)	Y (in)	Z (in)	X (ft)	Pitch (deg)	Yaw (deg)	Roll (deg)
0.0001994	-0.0090	0.1866	600.8658	0.00801	0.01061	158.3
0.0003989	0.0142	0.3367	601.7347	0.02018	0.00456	317.5
0.0005983	-0.0023	0.5505	602.6030	0.03048	0.00913	118.0
0.0007978	-0.0029	0.7260	603.4679	0.04076	0.01408	276.1
0.0009972	0.0095	0.9083	604.3397	0.05257	0.02470	76.6
0.00091746	0.0148	8.5087	639.8701	-0.01910	-0.02424	130.9

SECTION III

TIME-DISTANCE BIAS (TDBIAS)

The Time-Distance Bias (TDBIAS) program serves two objectives: (1) a preliminary fit to the experimental time-distance data to screen for erroneous timing data, and (2) the option of superimposing statistical bias data based on the range calibration. The program will flag the user to potentially suspect data. Corrections to the data may be entered from within the program. Generally the statistical biasing data will be superimposed to improve data quality. For biased data the program will prefix the shot number with the letter B.

The data resulting from the film readings is stored in a file containing multiple shots. The first step in program execution will be to specify the name of this file. The shots from this file will be selected individually for biasing. A LIST option is available to display the name of all shots within the composite file.

The following illustrates the shot selection procedure:

Enter the name of the file containing the raw data: TUNDAT

Key in 10 digit projectile title (or LIST): LIST

Basic range data projectile titles (TUNNELXYZ)

S87040613 40 MM HEDP TUBULAR REREAD

S87040209 40 MM HEDP TUBULAR REREAD

S87080617 20 MM BOOMED/CASED

S87080618 20 MM BOOMED/CASED

S87032490 40 MM HEDP TUBULAR

S87032797 40 MM HEDP TUBULAR

Key in 10 digit projectile title (or LIST): S87040613

For the shot selected, the following physical and atmospheric properties must be entered:

S87040613 40mm HEDP Tubular

1 - Temperature	(deg C):	0.00
2 - Pressure	(mbars):	0.00
3 - Relative humidity	(40%-.40):	0.00
4 - Projectile mass	(grams):	0.00
5 - Projectile diameter	(inches):	0.00

Key in item number ", " new value

Key in "LIST" to relist "DONE" to continue

: 1,19.6

A curvilinear regression fit is performed on the data using the IMSL mathematics library. This curve fit finds a 3rd order time solution. This equation along with the input echo, experimental times, and curve fit times will be printed out:

BS87040716 40 MM HEDP TUBULAR

$$\text{TIME} = -0.3530054\text{E-}10 * X^{**3} + 0.1876861\text{E-}06 * X^{**2} + 0.9585853\text{E-}03 * X + 0.5469398\text{E+}00$$

Temperature (Deg C): 19.60
 (Deg F): 67.28
 (Deg R): 526.92

Pressure (mbar): 1017.000
 (lbf/ft**2): 2124.513
 Humidity : 0.520

Mass (grams): 244.00
 Mass (slugs): 0.016719

Diameter (in): 1.575
 Area (ft**2): 0.01353

PV (lbf/ft-sec): 24.74380
 RHO (slug/ft**3): 0.00233652

DBSQ : 0.00
 TA (deg): 0.00

BS87040716 40 MM HEDP TUBULAR

Distance (ft)	Input Time (sec)	Fit Time (sec)	Delta (sec)	Velocity (ft/sec)	CD
11.9377003	0.5584267	0.5584099	-0.1680851E-04	1038.366	0.409506
17.1982994	0.5634965	0.5634812	-0.1525879E-04	1036.259	0.407454
27.1723995	0.5731447	0.5731248	-0.1990795E-04	1032.304	0.403592
47.2350998	0.5925861	0.5926338	0.4768372E-04	1024.506	0.395938 ***
57.1082993	0.6022863	0.6022886	0.2324581E-05	1020.745	0.392227

Standard Deviation : 0.0000159308
 XR Average : 0.0000000191

Note in the above partial printout that the point at 47.235 feet is flagged with "***." Any point where the error in time exceeds 1.5 standard deviations will be flagged. This flag is only to call attention to the point for possible action by the engineer; no program action is taken.

Once the curve fit has been displayed, the user has the following options:

Enter number of the desired option

- 1 - Edit current data
- 2 - Plot fit results
- 3 - Refit the current data
- 4 - Store the edited/biased data
- 5 - Select a new shot
- 6 - Print tabulated file on exit or new shot
- 7 - Exit

: 1

Editing may be done on the time or roll at each station. Entering a negative time will remove the station from the analysis. A value of -99 for roll will result in the roll data being ignored by the Linear Theory and 6 DOF analyses. The following is a partial listing resulting from entering the edit option:

Tunnel XYZ data for editing

Enter negative time to remove a station

Station Distance (feet)	Time (sec)	Roll (deg)	Station Distance (feet)	Time (sec)	Roll (deg)
11.9377 (1)	0.5584267	(14) -99.	242.0256 (27)	0.7894410	(39) -99.
17.1983 (2)	0.5634965	(15) -99.	252.0643 (28)	0.7999383	(40) -99.
27.1724 (3)	0.5731447	(16) -99.	271.9348 (29)	0.8207810	(41) -99.
47.2351 (4)	0.5925861	(17) -99.	276.9530 (30)	0.8260718	(42) -99.
57.1083 (5)	0.6022863	(18) -99.	291.9944 (31)	0.8419708	(43) -99.
67.0824 (6)	0.6120735	(19) -99.	306.9884 (32)	0.8578804	(44) -99.
72.1105 (7)	0.6170182	(20) -99.	322.0588 (33)	0.8739316	(45) -99.
76.9907 (8)	0.6218238	(21) -99.	352.1425 (34)	0.9062108	(46) -99.
151.9478 (9)	0.6967998	(22) -99.	382.1923 (35)	0.9387400	(47) -99.
181.9187 (10)	0.7273291	(23) -99.	397.1584 (36)	0.9550332	(48) -99.
186.9524 (11)	0.7324781	(24) -99.	412.1839 (37)	0.9714601	(49) -99.
212.0999 (12)	0.7583820	(25) -99.	442.1961 (38)	1.0044963	(50) -99.
222.1359 (13)	0.7687663	(26) -99.			

Key in item number ", " new value

Key in "LIST" to relist "DONE" to continue

: 13,-1

In the above example, the data associated with number 13 (222.1359 feet) was eliminated.

The following plots may be created:

Enter the number for the desired operation

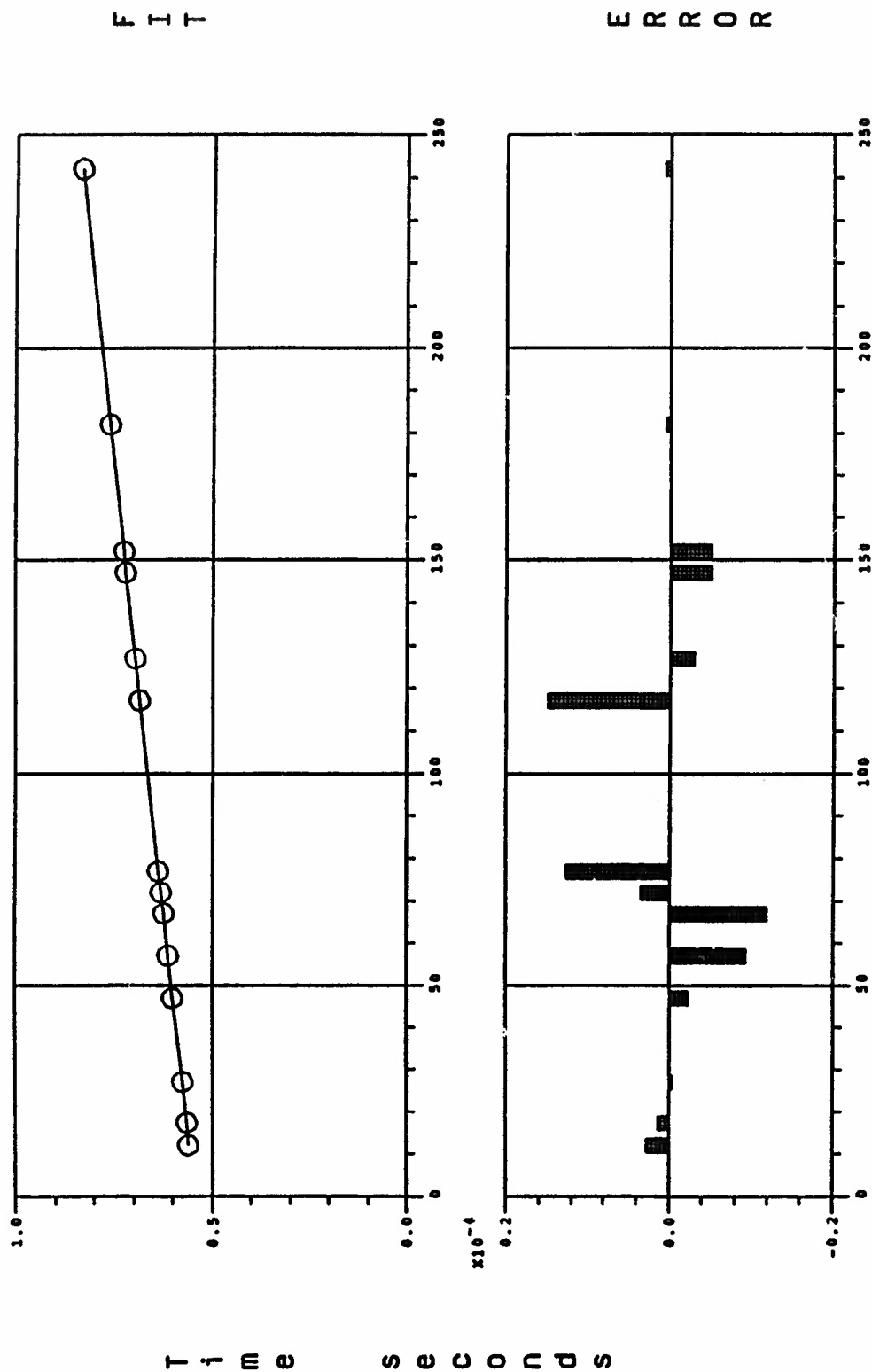
- 1 - Time - fit plot
- 2 - Velocity versus Distance
- 3 - CD versus Distance
- 4 - Done

: 1

The time plot includes both time versus distance and error at each station. The bar graph makes it easy to spot obvious errors such as erroneous input times. See Figure 2 for a sample TDBIAS time fit plot. The other plots are self-explanatory.

When the data is stored it will be written in an individual file by shot number for reading by the Linear Theory input program.

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Distance (ft)

Figure 2. TDBIAS Results

SECTION IV

PLOTTING EXPERIMENTAL POINTS

This program allows the user to read in the experimental data points, as they come from the film readings or TDBIAS program, and create scatter plots. The points are plotted without any reduction or analysis being performed. This allows the user to examine the data prior to attempting to analyze it. One reason the engineer may wish to do this might be to determine the degree of angular motion present during the flight. Large angles could alert the engineer that non-linear aerodynamics might be present, or very small angles could indicate that certain angle dependent coefficients might be difficult to determine. The following menu will be displayed for plot choice:

Linear Theory Experimental Point Plots

- 1 - Horizontal Drift [Y] vs Down-Range Travel [X]
- 2 - Vertical Drop [Z] vs Down-Range Travel [X]
- 3 - Roll [PHI] vs Down-Range Travel [X]
- 4 - Pitch [THETA] vs Down-Range Travel [X]
- 5 - Yaw [PSI] vs Down-Range Travel [X]

99 - Done

:

Figure 3 shows the experimental yaw data for a 40mm projectile.

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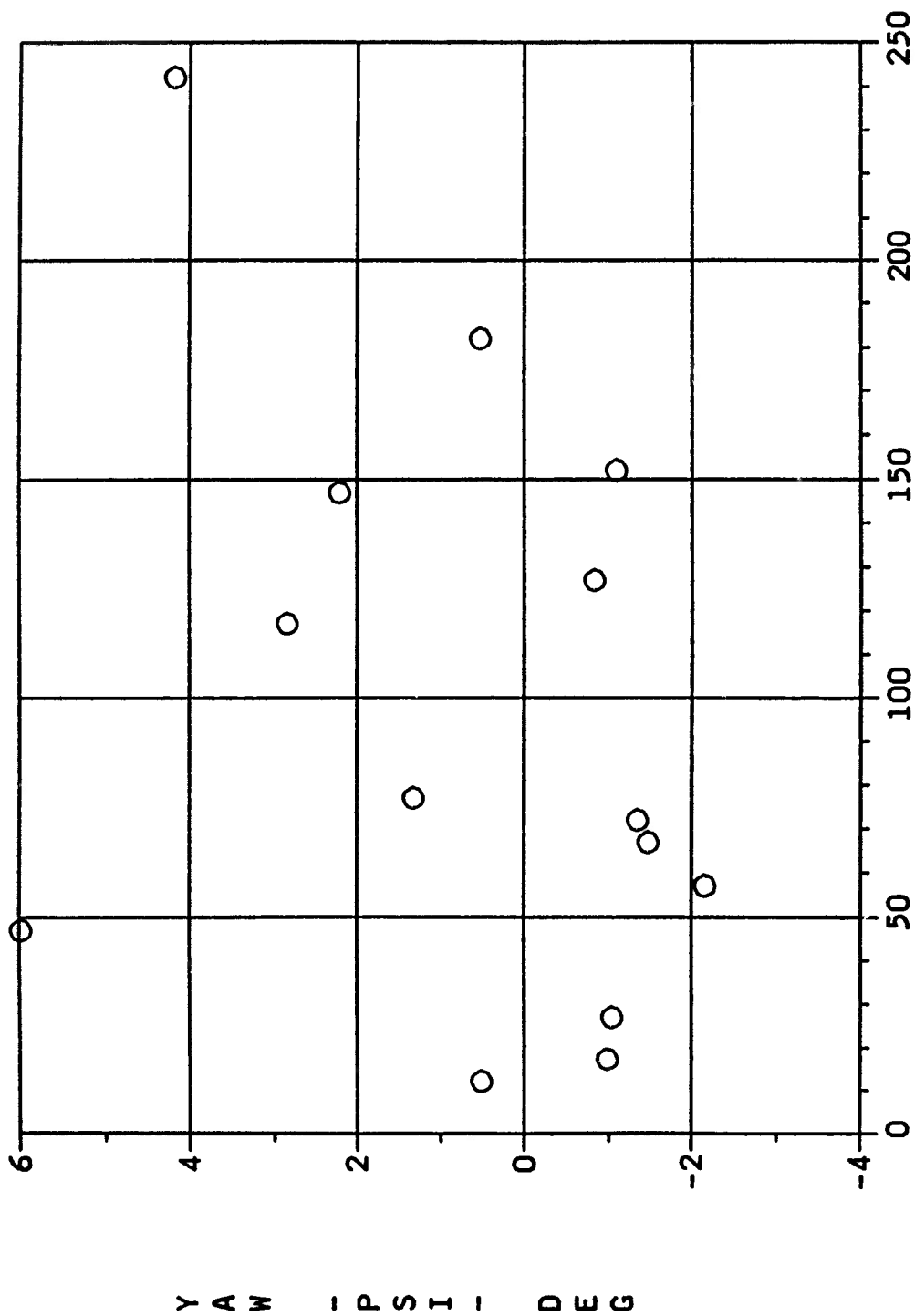


Figure 3. Experimental Points Only Plot

SECTION V

PROJECTILE DESIGN ANALYSIS SYSTEM (PRODAS)

1. GENERAL

PRODAS, as installed at ARF is a Fortran program used to aid the engineer in performing stability and exterior ballistic analyses. The program uses a common data structure to pass information among independent modules to facilitate rapid projectile design and analysis. The program uses interactive menus in combination with Tektronix Plot-10 graphics to provide a user friendly environment. Input/output may be performed in either english or metric units. The program has been used for projectiles from 5.56mm to 8 inches in diameter.

The first step will be to specify the terminal being used:

- 1 - Large Screen
- 2 - Small Screen
- 3 - Large Screen Color (Tek 4105)
- 4 - Small Screen Shaded Color (Tek 4105)

Choosing the large or small screen will determine the number of lines printed on a page and the number of columns in a line. The small screen is limited to 26 lines of 80 columns. The large screen has 55 lines of 132 columns to a page. In the small screen mode, the text is output as Tektronix character size 2. In the large screen mode the text size will be smaller. The large screen mode will take fewer pages than the small screen mode but the small screen mode will be more readable.

PRODAS also supports the Tektronix 4100 series color terminals. Options Three and Four will use these terminals to make color line plots, and use the shaded areas capability to make color shaded drawings of the projectile. For the color shaded drawing to appear correct, the model must be constructed in a specific manner. The rules for model construction are explained in the Edit New (EN) module.

After the terminal type has been specified, the main menu for the program will be displayed. The appearance of this menu is different for the large and small screen modes.

Select code of desired analysis from the following menu

EN Enter new data
EF Read existing data file
EE Edit existing data

M Physical Properties
S Stability Analysis
T 2/6 DOF Trajectory

C Catalog Data
DF Delete Existing File
B Exit PRODAS

Enter code for desired operation:

Each module of PRODAS is accessed by entering a one or two character mnemonic. As each module is completed, the program will return to this menu.

2. PRODAS PROGRAM SEGMENTS

The following paragraphs detail each of the program segments.

When running an analysis, data is passed among the modules. This requires that the analysis be run in a specific order. Once data has been cataloged it will not be necessary to run that module again unless the projectile has been changed.

The Physical Properties (M) module must be run before any other analysis module.

a. EN - Enter New

The first step in running an analysis on PRODAS will be the construction of the projectile model. The projectile model is a finite element representation of the projectile to be analyzed. The model is composed of positive and negative density frustums, each called an element. A model may contain up to 150 elements. Most projectiles can be adequately modeled with 50-75 elements. The elements that make up the model are divided into nine categories, each defined by the physical function of the element. These categories are called component codes. The component codes are:

-2	Boom
-1	Sabot
0	Projectile Body
1	Penetrator
2	Filler
3	Rotating Band
4	Ogive
5	Boattail
6	Fin

When accepting a new model, the program will prompt the user for a file title, description, and input/output units. The program will then accept element data until a <cr> is entered (Table 2). Each element requires eight parameters:

- left diameter
- right diameter
- length
- reference length
- density
- component code
- radius
- color code

All elements, except fins, are assumed to be radially symmetric. The model must be constructed such that the projectile points to the right and all geometry lies within positive space. The reference length is the distance from the origin to the left edge of an element. It is not necessary for the base of the projectile to be at the zero reference length. When entering data, it is not necessary to enter trailing zeros.

The color code is used to create color shaded models on Tektronix 4100 series terminals. The codes signal the program as to which patterns to use in drawing the element. Color codes may run from 1 to 16. If a code is not defined by the user, one will be assigned by the program when the model is read in Enter File Module (EF) based on the component code. For a model to look correct when drawn in color, it is necessary to enter elements in a specific order. Elements will be displayed in numerical order. Negative density elements are drawn with the background color (index 0). The negative elements must be displayed before elements are displayed that fill in this volume. The easiest way to remember the proper sequence is to create the models from the outside in. Create the rotating band and sabot first. Create the fin, then the body, penetrator, and ogive. Any high explosive filler will probably be last. Within the Edit Existing (EE) module is the ability to renumber elements to correct errors.

If a fin element, component code 6, was entered, the program will request the fin details. These are seen at the bottom of Table 2. Under normal operation these will be on a different screen.

After the fin has been defined, the program will proceed to the Edit Existing (EE) module to accept corrections to the model (Figure 4).

TABLE 2. ELEMENT DATA

Enter 9 character file title

: MAFMODEL

Enter descriptive text

: EN DEMONSTRATION

Enter type of units for file

1 - English 2 - Metric

: 1

Enter element parameters seperated by commas

left dia, right dia, length, ref. length, density, code, radius, color code

-2 Boom -1 Sabot 0 Body 1 Penetrator 2 Filler 3 Band

4 Ogive 5 Boattail 6 Fin 7 Tracer

Letters may be used for densities:

S Steel, A Aluminum, T Tungsten, P Plastic, D DU, H HE,

1: 1,1,2,0,.1,0,0,0

2: 1,0,2,2,-1,4,0,0

3: 2, 2, 1, 0, .1, 6, 0, 0

10

Enter fin group information

Fin Types

1 - Rectangular 2 - Delta

3 - Clipped Delta 4 - Swept Rectangular

Number of Fin Groups(<4) : 1

Enter element numbers in fin group 1 separated by commas

: 3

Fin Type : 1

Projectile Diameter at Fin (in): 1.0

Fin Trailing Edge Thickness (in): .05

Fin Leading Edge Thickness (in): .05

Number of Fins in Group : 4

Edit Menu

- 1 File Title
 - 2 Elements
 - 3 Fin Information
 - 4 Scale Model
 - 5 Tabulate Model Data
 - 6 Zoom
 - 7 Change Units
 - 8 Change Ref. Length
 - 9 Change Element #
 - 10 Change Ref. Dia.
 - 11 Change Density
 - 12 Mass Properties
 - 99 Return to Main Menu
- :

Filename: MAFMODEL

EN DEMONSTRATION

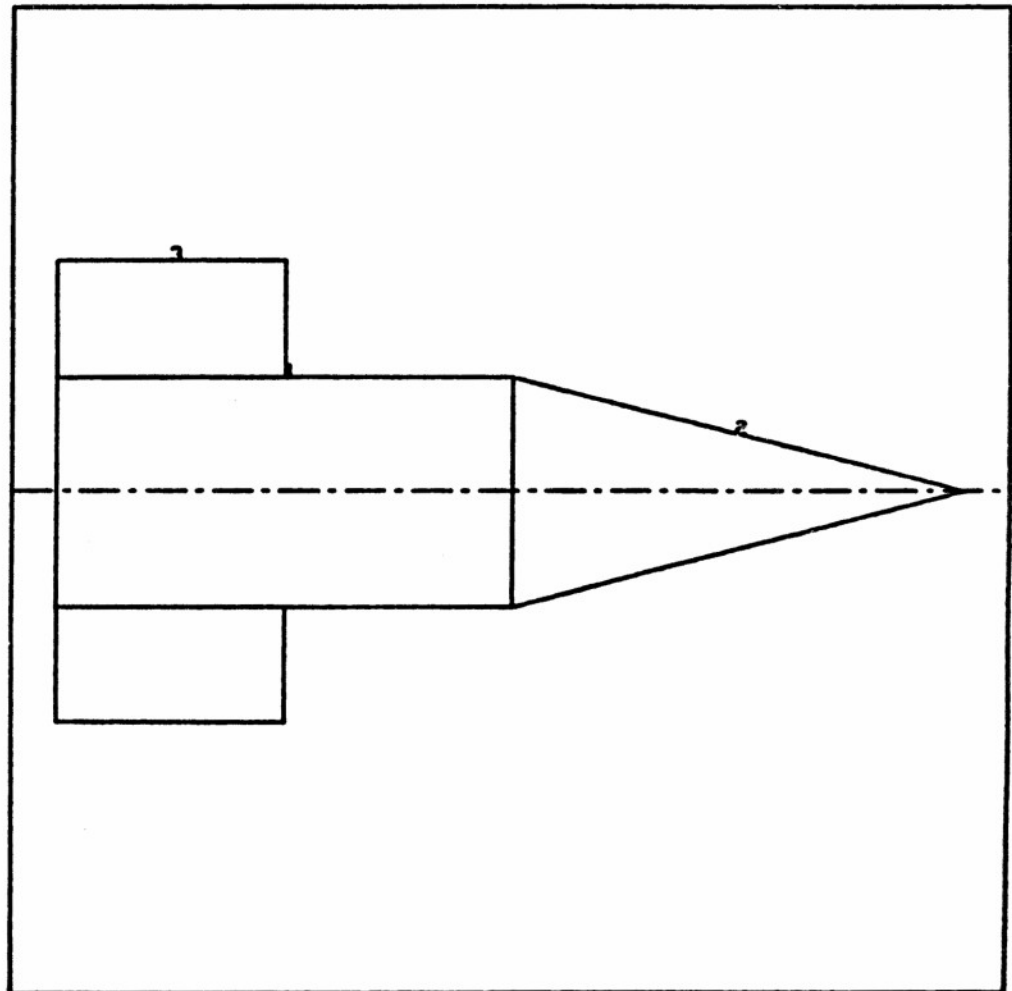


Figure 4. New Model-Finner

b. EF - Enter File

When the Enter Existing File module is selected, the program will prompt the user for a projectile model file name. If the name is not known, a list option is available. After typing EF the following instruction will be displayed:

Key in 9 character projectile title (or "LIST"): LIST

Lists may be formed in one of two methods:

Enter the type of list desired

- 1 - Brief**
- 2 - Full**

In the brief list only the file names are listed. In the full list the file description is printed in addition to the file names. Configurations which have been identified as inventory rounds will be accompanied by an asterisk (*).

After a file is selected the units to be used for the input/output are selected. The file contains a flag to show the units used at the time the file was cataloged. These units will be the default condition:

Enter number for the type of units to use for I/O

- 1 - English**
- 2 - Metric**
- <cr> for default (english)**

A drawing of the projectile (showing some key dimensions) will be created. The program will then accept a main menu option. A carriage return <cr> will return the program to a display of the main menu.

c. EE - Edit Existing

The Edit Existing module allows the user to make changes to the geometric representation of the projectile.

Upon entering this module, a drawing of the projectile identifying each element and the editing menu will be displayed, (Figure 5). A dashed line is drawn down the axis of the projectile. Element numbers that appear above this line have positive densities. The element numbers that appear below the line have negative densities.

Edit Option One allows the user to change the title and description for the model. If a projectile has been declared to be an inventory round, it is necessary to change the title in order to store any changes to the model.

Edit Option Two allows for the addition, deletion, or modification of element data. If this option is selected, the user will be prompted to enter an element number.

Edit Menu

- 1 File Title
 - 2 Elements
 - 3 Fin Information
 - 4 Scale Model
 - 5 Tabulate Model Data
 - 6 Zoom
 - 7 Change Units
 - 8 Change Ref. Length
 - 9 Change Element #
 - 10 Change Ref. Dia.
 - 11 Change Density
 - 12 Mass Properties
 - 99 Return to Main Menu
- :

Filename: MAFSPIN

EE DEMONSTRATION

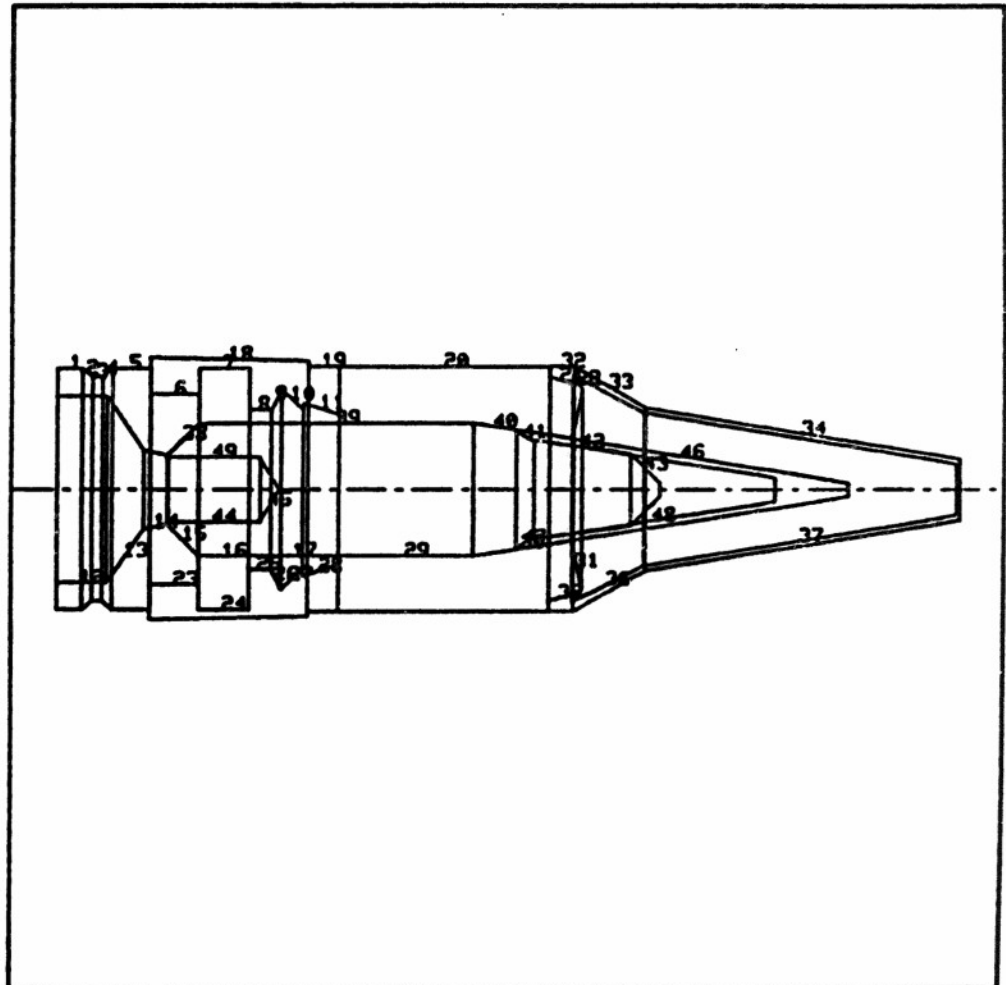


Figure 5. EE Option Menu

To delete an element, enter the element number as a negative. The model will then be redrawn. Be sure to examine the model before making additional changes. Since no gaps are left when numbering elements, some of the element numbers will now be changed.

To add elements enter the word ADD. The program will then display element numbers to be added and accept new geometry until a <cr> is entered with no data. Data is accepted in the same form as when the model was first entered; left diameter, right diameter, length, reference length, density, component code, radius, color code.

To modify an element, enter that element number. A menu will be displayed showing the current data (Figure 6).

Edit Option Three allows for modification of the fin information (Figure 7). Three entry menus are necessary to define fin data. In each case, the program will display the current data. A <cr> will leave the current data unchanged. The first display is the number of fin groups. Remember that the program is limited to three fin groups but stability analysis can only handle one fin group. In the second display, the elements make up the fin group. The program is limited to five elements in a fin group. The third display is the fin geometry. This data includes fin type, thickness of leading and trailing edges, projectile diameter at fin, and the number of fins.

Edit Option Four performs a scaling of all dimensions in the model. The user will be prompted for a scale factor. All lengths and diameters will be multiplied by this factor.

Edit Option Five creates a table of the mass properties of the current model and the element geometry of that model (Table 3). After the table is displayed, a full screen drawing of the projectile will be displayed (Figure 8). If a laser plotter is available, an option to make a print of this screen will be offered after a <cr> is typed.

Edit Option Six allows the user to zoom in on some portion of the screen to make a magnified view of the model. The terminal's cursor is used to locate two points. The first point will be the center of the new screen window. The second point will be the right edge of the screen. See Figures 9 and 10 for an example. Each terminal uses the cursor differently so check terminal instructions if problems occur. With most terminals a point is detected by typing <space bar> or typing <space bar> <cr>. To return to a full scale drawing, type <Z> instead of <space bar>.

Edit Option Seven will toggle the display units between english and metric.

Edit Menu

- 1 File Title
 - 2 Elements
 - 3 Fin Information
 - 4 Scale Model
 - 5 Tabulate Model Data
 - 6 Zoom
 - 7 Change Units
 - 8 Change Ref. Length
 - 9 Change Element #
 - 10 Change Ref. Dia.
 - 11 Change Density
 - 12 Mass Properties
 - 99 Return to Main Menu
- : 2

Model has 49 elements
Enter element number
(Neg. elem. no. to delete)
(Type "ADD" to add element)
: 18
Present values
1. Left Diam (in) 1.055
2. Right Diam (in) 1.025
3. El Length (in) 0.640
4. Ref Length (in) 0.380
5. Density(lbm/in3) 0.050
6. Component Code 3
7. Radius (in) 0.000
8. Color Code 0
Enter variable no. "," value
Enter "DONE" to continue
5,.055
DONE

Filename: MAFSPIN
EE DEMONSTRATION

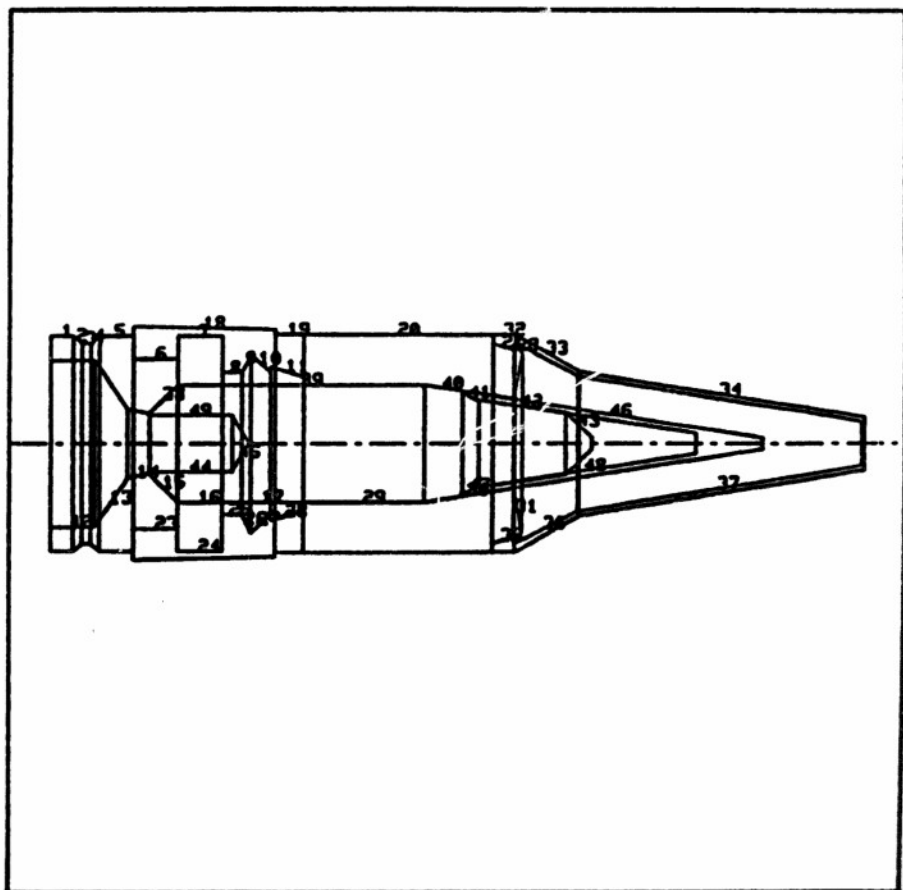


Figure 6. EE Element Modification

Edit Menu

```

1 File Title
2 Elements
3 Fin Information
4 Scale Model
5 Tabulate Model Data
6 Zoom
7 Change Units
8 Change Ref. Length
9 Change Element #
10 Change Ref. Dia.
11 Change Density
12 Mass Properties
99 Return to Main Menu
: 3

```

```

Enter number of fin groups
(current model = 1):
Enter element numbers in fin group 1
(current model 28)
:

```

```

1 Fin Type : 2
2 Proj Dia at Fin (in): 0.793
3 Fin Thickness (in): 0.0970
4 Fin Lead Edge Thk (in): 0.0800
5 Number of Fins : 6
Enter variable no. ",", value
Enter "DONE" to continue
D

```

Filename: MAFFIN

EE TEST

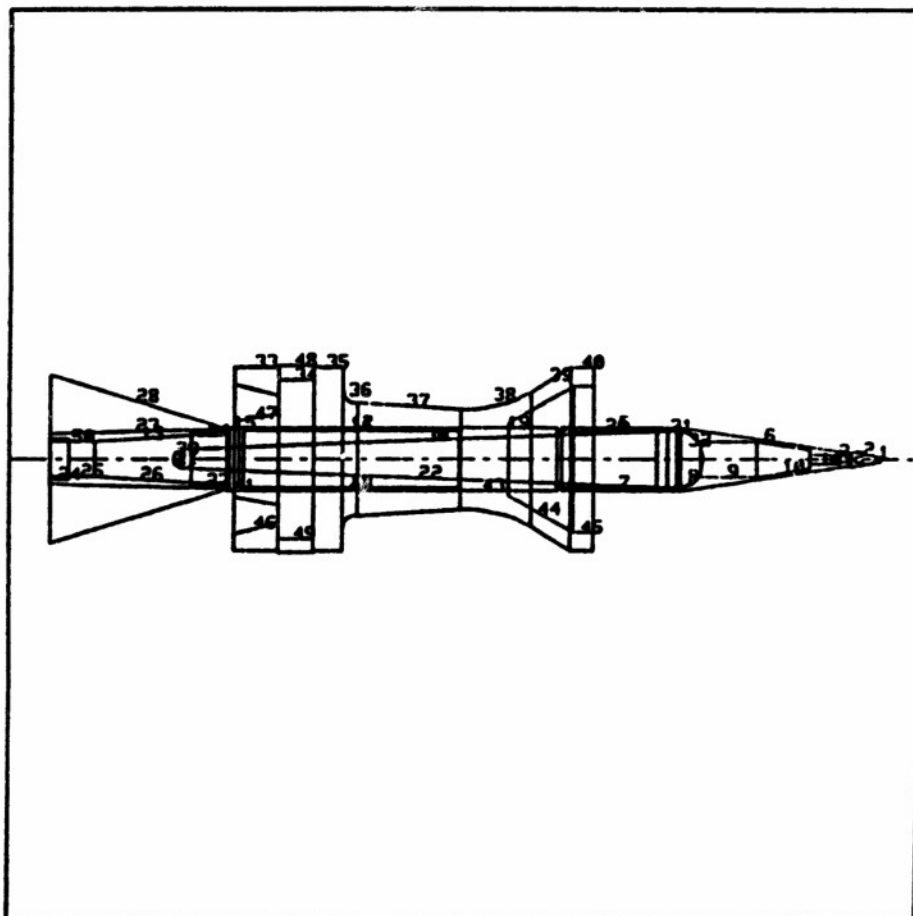


Figure 7. EE Fin Modification

TABLE 3. EE TABULATED OUTPUT

Filename: MAFSPJM		:TEST EE MODEL						
Diameter	(in)	0.531						
Projectile Length	(in)	2.800						
Ogive Length	(in)	1.550						
C.G. from Nose	(in)	1.890						
Axial Moment	(lbm-in ²)	0.00758						
Transverse Moment	(lbm-in ²)	0.05057						
Total Weight	(lbm)	0.298						
Projectile Weight	(lbm)	0.230						
Seabot Weight	(lbm)	0.067						
Penetrator Weight	(lbm)	0.027						
Filler Weight	(lbm)	0.000						
Model Input Segment								
Element No.	Left Diam. (in)	Right Diam. (in)	Elem Length (in)					
1	0.9650	0.9650	0.1000					
2	0.9650	0.9600	0.4000					
3	0.9600	0.9600	0.4000					
4	0.9600	0.9650	0.1600					
5	0.9650	0.9650	0.2000					
6	0.7600	0.7600	0.2000					
7	0.9650	0.9650	0.0900					
8	0.6400	0.6400	0.0900					
9	0.6400	0.6400	0.0900					
10	0.8000	0.8000	0.1500					
11	0.7000	0.7000	0.1500					
12	0.7450	0.7450	0.0940					
13	0.7450	0.3200	0.1300					
14	0.3200	0.5310	0.2000					
15	0.5310	0.5310	0.3700					
16	0.5310	1.0550	0.3800					
17	1.0550	0.9800	0.1300					
18	0.9800	0.9800	0.8700					
19	0.9800	0.9000	0.0900					
20	0.9000	0.9000	0.4500					
21	0.9000	0.7600	0.2000					
22	0.7600	0.9650	0.2000					
23	0.9650	0.6400	0.0900					
24	0.6400	0.6400	0.1500					
25	0.6400	0.7000	0.5500					
26	0.7000	0.5310	0.4050					
27	0.5310	0.4100	0.0450					
28	0.4100	0.9800	0.1000					
29	0.9800	0.9800	0.3000					
30	0.9800	0.2400	1.3000					
31	0.2400	0.5000	0.1750					
32	0.5000	0.4000	0.0750					
33	0.4000	0.3800	0.4000					
34	0.3800	0.2000	0.1950					
35	0.2000	0.0500	2.3550					
36	0.0500	0.2550	0.4500					
37	0.2550	0.2000	0.0500					
38	0.2000	0.4800	1.8000					
39	0.4800	0.4800	1.9550					
40	0.4800	0.4550	0.4550					
41	0.4550	0.0600	0.0600					
42	0.0600	0.0000	0.0000					
43	0.0000	0.0000	0.0000					
44	0.0000	0.0000	0.0000					
45	0.0000	0.0000	0.0000					
46	0.0000	0.0000	0.0000					
47	0.0000	0.0000	0.0000					
48	0.0000	0.0000	0.0000					
49	0.0000	0.0000	0.0000					
Return to continue								
Model Input Segment								
Element No.	Left Diam. (in)	Right Diam. (in)	Elem Length (in)	Reference Pt (in)	Density (lbm/in ³)	Code No.	Element Radius (in)	Color
1	0.9650	0.9650	0.1000	0.0000	0.1000	-1	0.0000	0
2	0.9650	0.9600	0.4000	0.1000	0.1000	-1	0.0000	0
3	0.9600	0.9600	0.4000	0.1400	0.1000	-1	0.0000	0
4	0.9600	0.9650	0.1600	0.1000	0.1000	-1	0.0000	0
5	0.9650	0.9650	0.2000	0.2200	0.1000	-1	0.0000	0
6	0.7600	0.7600	0.2000	0.3800	0.1000	-1	0.0000	0
7	0.9650	0.9650	0.0900	0.5000	0.0800	-1	0.0000	0
8	0.6400	0.6400	0.0900	0.7800	0.0800	-1	0.0000	0
9	0.6400	0.6400	0.0900	0.8700	0.0800	-1	0.0000	0
10	0.8000	0.8000	0.1500	1.0000	0.0800	-1	0.0000	0
11	0.7000	0.7000	0.1500	0.0000	0.1000	-1	0.0000	0
12	0.7450	0.7450	0.0940	0.2000	0.1000	-1	0.0000	0
13	0.7450	0.3200	0.1300	0.3500	0.1000	-1	0.0000	0
14	0.3200	0.5310	0.2000	0.4500	0.1000	-1	0.0000	0
15	0.5310	0.5310	0.3700	0.5800	0.0500	-1	0.0000	0
16	0.5310	1.0550	0.3800	0.7800	0.0500	-1	0.0000	0
17	1.0550	0.9800	0.1300	1.0200	0.0500	3	0.0000	0
18	0.9800	0.9800	0.8700	1.1500	0.0500	-1	0.0000	0
19	0.9800	0.9000	0.0900	2.0200	0.0500	-1	0.0000	0
20	0.9000	0.9000	0.4500	2.1100	0.0500	-1	0.0000	0
21	0.9000	0.7600	0.2000	0.9100	0.0500	-1	0.0000	0
22	0.7600	0.9650	0.2000	2.1100	0.0500	-1	0.0000	0
23	0.9650	0.6400	0.0900	1.0000	0.0500	3	0.0000	0
24	0.6400	0.6400	0.1500	0.3800	0.0500	-1	0.0000	0
25	0.6400	0.7000	0.5500	1.5000	0.0500	-1	0.0000	0
26	0.7000	0.5310	0.4050	1.7650	0.0350	-1	0.0000	0
27	0.5310	0.4100	0.0450	2.1000	0.0400	-1	0.0000	0
28	0.4100	0.9800	0.1000	2.0200	0.0400	-1	0.0000	0
29	0.9800	0.9800	0.3000	2.1200	0.0400	-1	0.0000	0
30	0.9800	0.2400	1.3000	2.4200	0.0400	-1	0.0000	0
31	0.2400	0.5000	0.1750	2.0200	0.0400	-1	0.0000	0
32	0.5000	0.4000	0.0750	2.1100	0.0400	-1	0.0000	0
33	0.4000	0.3800	0.4000	2.4100	0.0400	-1	0.0000	0
34	0.3800	0.2000	0.1950	0.4500	0.0850	1	0.0000	0
35	0.2000	0.0500	2.3550	0.5000	0.0850	1	0.0000	0
36	0.0500	0.2550	0.4500	1.7650	0.0850	4	0.0000	0
37	0.2550	0.2000	0.0500	1.0200	0.0850	1	0.0000	0
38	0.2000	0.4800	1.8000	1.9550	0.0850	1	0.0000	0
39	0.4800	0.4800	1.9550	0.4500	0.0850	1	0.0000	0
40	0.4800	0.4550	0.4550	0.0500	0.0850	1	0.0000	0
41	0.4550	0.0600	0.0600	0.0000	0.0850	1	0.0000	0
42	0.0600	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
43	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
44	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
45	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
46	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
47	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
48	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
49	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
50	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
51	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
52	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
53	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
54	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
55	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
56	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
57	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
58	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
59	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
60	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
61	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
62	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
63	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
64	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
65	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
66	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
67	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
68	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
69	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
70	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
71	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
72	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
73	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
74	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
75	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
76	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
77	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
78	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
79	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
80	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
81	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
82	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
83	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
84	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
85	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
86	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
87	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
88	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
89	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
90	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
91	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
92	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
93	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
94	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
95	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
96	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
97	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
98	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
99	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0
100	0.0000	0.0000	0.0000	0.0000	0.0850	1	0.0000	0

Return to continue

Filename: MAFSPIN

TEST EE MODEL

Total Length • 3.720 (in)

Projectile Length • 2.800 (in)

Sabot Length • 3.720 (in)

Ogive Length • 1.550 (in)

Band Length • 0.640 (in)

Penetrator Length • 2.025 (in)

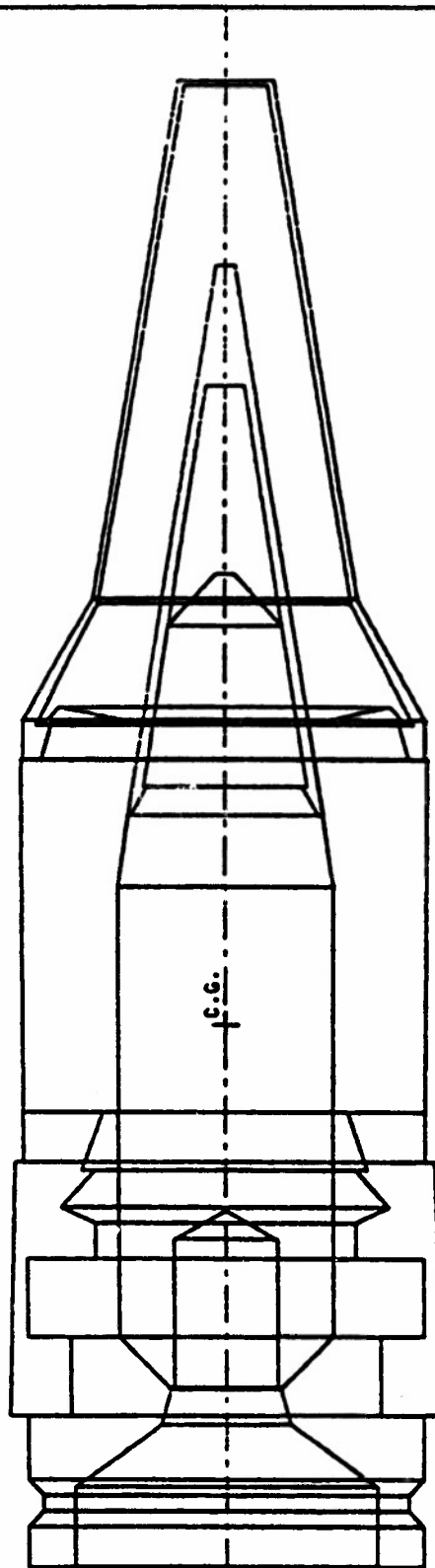


Figure 8. EE Projectile Drawing

Filename: I25MFAPDS
25MM M791 APDS-T

Edit Menu

- 1 File Title
 - 2 Elements
 - 3 Fin Information
 - 4 Scale Model
 - 5 Tabulate Model Data
 - 6 Zoom
 - 7 Change Units
 - 8 Change Ref. Length
 - 9 Change Element #
 - 10 Change Ref. Dia.
 - 11 Change Density
 - 12 Mass Properties
 - 99 Return to Main Menu
- : 6

Please pick center location for the window
Enter "Z" to return to regular display

Now move crosshair to right side of window
Enter "Z" to return to regular display

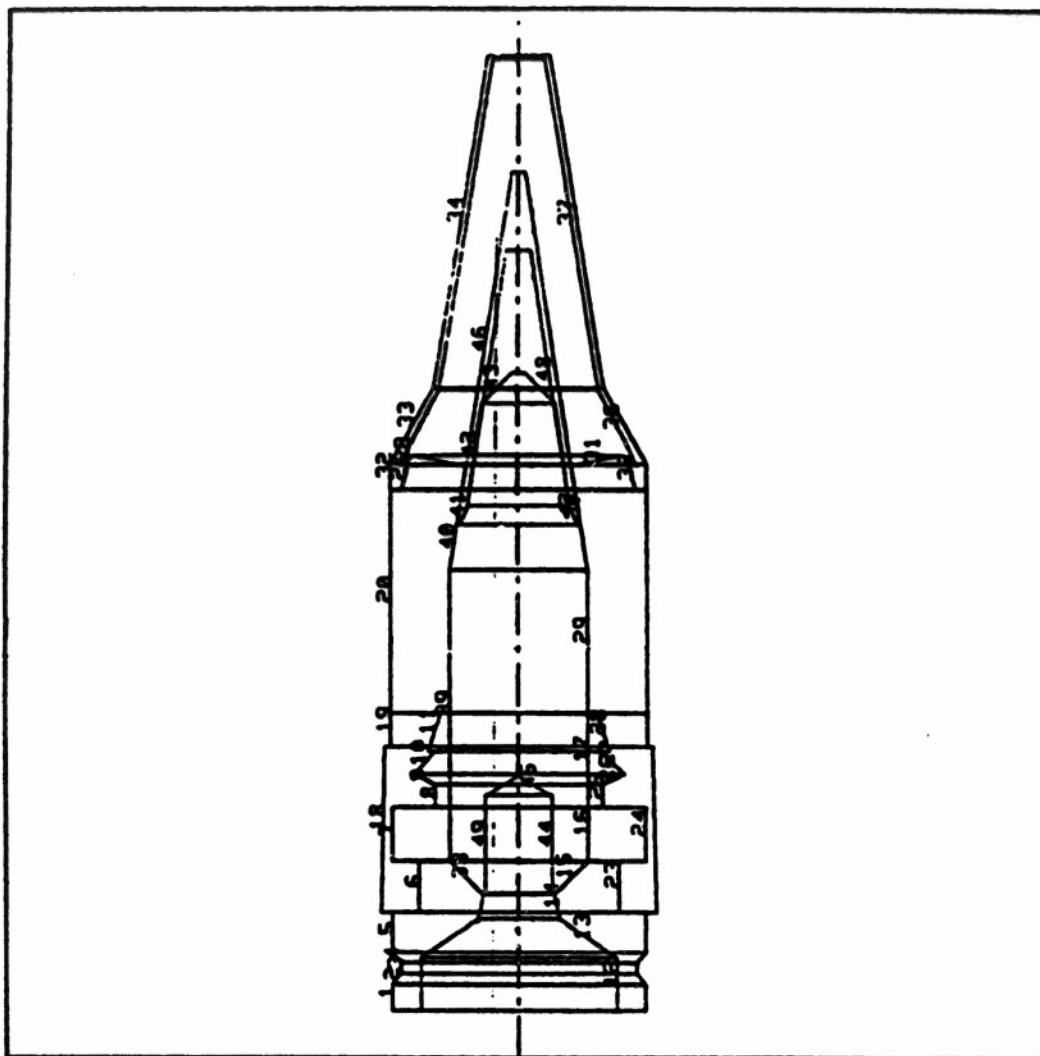


Figure 9. EE Zoom Option

Edit Menu

- 1 File Title
 - 2 Elements
 - 3 Fin Information
 - 4 Scale Model
 - 5 Tabulate Model Data
 - 6 Zoom
 - 7 Change Units
 - 8 Change Ref. Length
 - 9 Change Element #
 - 10 Change Ref. Dia.
 - 11 Change Density
 - 12 Mass Properties
 - 99 Return to Main Menu
- : 8

Enter element method:

- 1 By list
- 2 By element range
- 3 By ref. len range
- 4 Return to edit menu

1

Enter list of elements

<CR> when done

: 1

:

Enter delta (in): 0.0

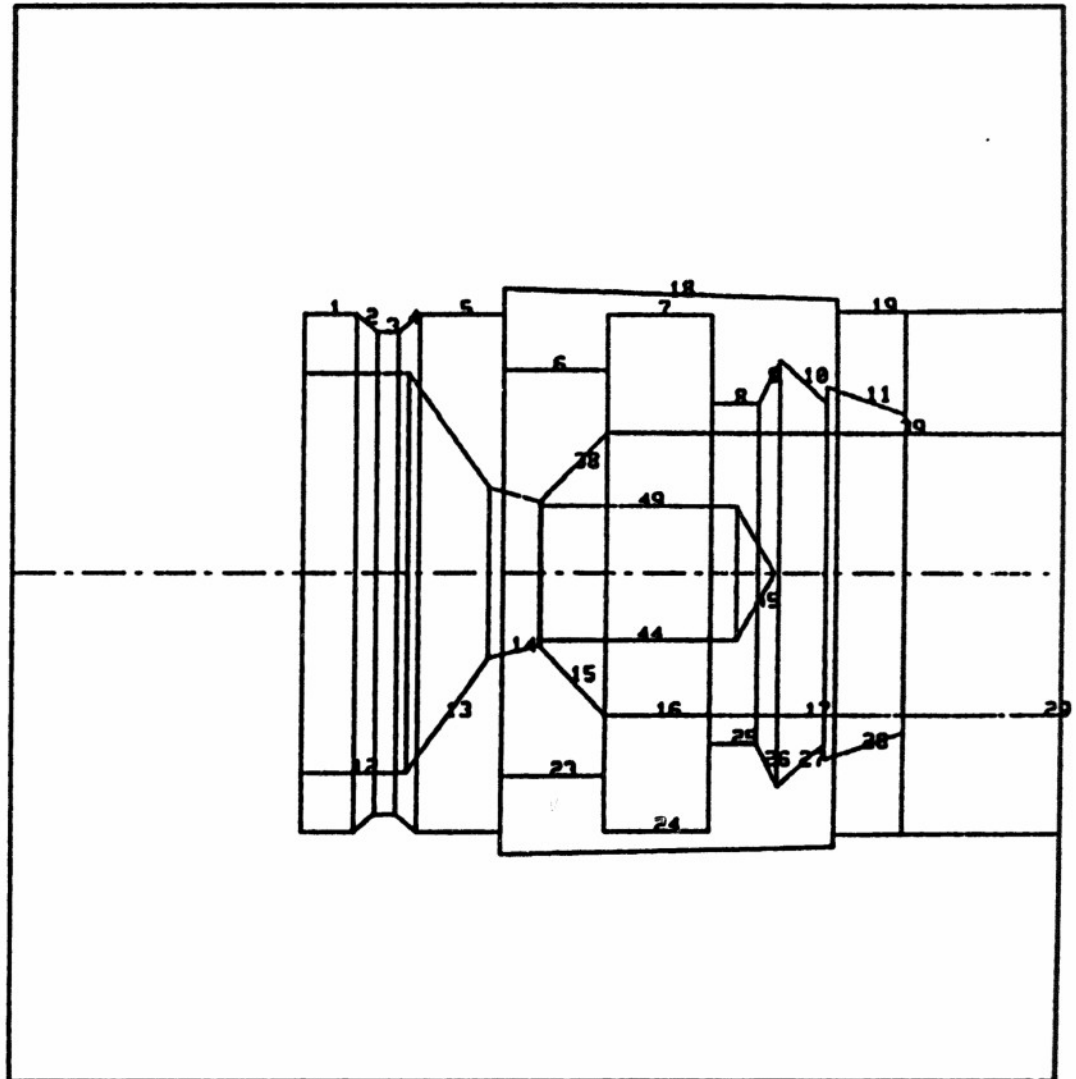


Figure 10. EE Reference Modification

Edit Option Eight allows for the modification of the reference length for a group of elements. Three methods exist for defining the elements to change (Figure 10). The first method is to enter a list of elements separated by commas. Element numbers will be accepted until a <cr> is entered with no elements. Method 2 accepts lower and upper numbers for a continuous range of elements. Again, multiple lines of input may be used, each with a continuous range. Method 3 accepts a range of reference lengths. Any element whose current reference length falls within this range will be modified.

Once the elements have been identified, enter the amount to change the reference length. A positive change will move the model to the right, a negative to the left. Remember that the model must not extend into negative space.

Edit Option Nine is used to swap the numbers of two elements. This is needed only to create a shaded color drawing on a Tektronix 4100 series terminal. Elements are drawn in numerical order. When operating in the color shaded mode, PRODAS draws each element as a color quadrilateral. Elements with a negative density are drawn with the background color. All other elements are drawn with the color selected by the user or assigned by the program. If the elements are not ordered properly, this could cause an element to be displayed before the negative element is displayed that makes room for it, i.e., the penetrator being draw before the sabot. This edit option allows for a quick reordering of elements to make a cleaner color drawing.

Edit Option Ten allows the user to assign a value to the reference diameter for the projectile. This will override any value computed from the geometry.

Edit Option Eleven allows the user to specify an old density and a new density. All occurrences of the old density will be changed to the new density. Note that positive and negative densities are never considered to be the same.

Edit Option Twelve computes and displays the mass properties of the projectile as it is currently defined.

Edit Option Ninety Nine returns the program to the main level.

d. Other Auxiliary Options

(1) C - Catalog

This program option will take the data representing the projectile model and the analysis input parameters and store them in a data file for use in the future. The data file will use the file name specified for the current projectile (see EN and EE options). If a file already exists by this name, the old file will be lost. If the inventory round flag was set for this model file the program will not allow the user to catalog the file without first changing the name (see EE option). The inventory round flag may only be set/cleared by the user using a system editor on the projectile model file. The flag may not be changed from within PRODAS.

When a file is cataloged, the program will examine the LIST.MAF data file. If an entry does not exist for this file name, an entry will be created.

(2) B - Bye (exit PRODAS)

This option is used to terminate a PRODAS session. The program maintains flags for the data that is available for storage. If this data has not been retained, the program will question the user to see if this data is to be saved before exit.

If the projectile model is not an inventoried round and an analysis module has been run that could have changed stored parameters, the user will be prompted to see if a catalog option is desired before exit.

(3) DF - Delete File

This option allows the user to delete projectile model files that have become outdated or surplus. The program will prompt the user to specify the files to be deleted. Continue specifying names until finished deleting files, then enter a <cr>. If the inventory flag has been set for a file, it may not be deleted. The LIST.MAF file will be updated to remove the entry for each file deleted.

e. M - Physical Properties

The physical properties segment calculates the weight, center of gravity, and moments of inertia for each element in the projectile model. Center of gravity locations are measured from the reference length for the element (positive right). These individual properties are then combined to form the properties for the entire composite projectile. Within the weight summaries, total refers to the sum of all elements (interior ballistic weight) and projectile refers to the flying portion of the model (exterior ballistic weight). Inertias do not include sabot elements; therefore, it is an exterior ballistic property. Depending on the projectile configuration, the sabot, penetrator, and HEI weights may be computed and tabulated separately. If fins are present on this model, the fin group information is displayed. Tables 4 and 5 show typical results for a spin and fin stabilized projectile.

The only input required for this segment is the projectile model data. The output from this segment is used by most of the other PRODAS modules.

Once the physical properties have been calculated, the user has the option of overriding the computed properties for individual elements or groups of elements. This is done by selecting the "MOD" option after the output has been displayed. If the "MOD" option is selected, enter the element number(s) to be changed. Then enter the weight, inertias, reference length, and center of gravity for the group of elements. These properties will be displayed as the first element given with the properties for the remaining elements zeroed.

TABLE 4. SPIN STABILIZED MOMENTS

Page Number 1

Filename: I25MUPADS

: 25MM M791 APDS-T

Diameter (in)	I Code	Projectile		Ogive Length (in)	C.G. from Nose (in)	Length (in)	Reference Location (in)	Density (lbm/in ³)	Weight (lbm)	Transverse		Total Projectile		Sabot		Penetrator		Filler	
		Length (in)	Right Diameter (in)							Moment (lbm-in ²)	Moment (lbm-in ²)	Weight	Moment (lbm-in ²)	Weight	Moment (lbm-in ²)	Weight	Moment (lbm-in ²)	Weight	Moment (lbm-in ²)
0.531		2.800		1.550	1.890	0.00758	0.05857		0.298	0.230	0.067	0.227	0.000 lbm						
	1	0.965	0.965	0.965	0.100	0.000	0.100	0.100	0.00731	0.00085	0.00043	0.0500							
	2	0.965	0.900	0.900	0.040	0.100	0.100	0.100	0.00273	0.00030	0.00015	0.0195							
	3	0.900	0.900	0.900	0.040	0.140	0.140	0.100	0.00254	0.00026	0.00013	0.0200							
	4	0.900	0.965	0.965	0.040	0.140	0.140	0.100	0.00273	0.00030	0.00015	0.0205							
	5	0.965	0.965	0.965	0.160	0.220	0.220	0.100	0.01170	0.00136	0.00071	0.0800							
	6	0.760	0.760	0.760	0.200	0.380	0.380	0.100	0.00907	0.00066	0.00036	0.1000							
	7	0.965	0.965	0.965	0.200	0.580	0.580	0.100	0.01463	0.00170	0.00090	0.1000							
	8	0.640	0.640	0.640	0.090	0.780	0.780	0.080	0.00232	0.00012	0.00006	0.0450							
	9	0.640	0.800	0.800	0.040	0.870	0.870	0.080	0.00131	0.00009	0.00004	0.0215							
	10	0.800	0.640	0.640	0.090	0.910	0.910	0.080	0.00294	0.00019	0.00010	0.0417							
	11	0.700	0.600	0.600	0.150	1.000	1.000	0.080	0.00399	0.00021	0.00011	0.0712							
	12	0.745	0.745	0.745	0.200	1.000	1.000	-0.100	-0.00872	-0.00060	-0.00033	0.1000							
	13	0.745	0.320	0.320	0.156	0.200	0.200	-0.100	-0.00366	-0.00016	-0.00009	0.0583							
	14	0.320	0.270	0.270	0.094	0.356	0.356	-0.100	-0.00064	-0.00001	0.00000	0.0444							
	15	0.270	0.531	0.531	0.130	0.450	0.450	-0.100	-0.00170	-0.00004	-0.00002	0.0786							
	16	0.531	0.531	0.531	0.200	0.580	0.580	-0.100	-0.00443	-0.00016	-0.00009	0.1000							
	17	0.531	0.531	0.531	0.370	0.780	0.780	-0.100	-0.00819	-0.00029	-0.00024	0.1850							
	18	1.055	1.025	1.025	0.640	0.380	0.380	0.050	0.02719	0.00368	0.00277	0.3169							
	19	0.980	0.980	0.980	0.130	1.020	1.020	0.050	0.00450	0.00059	0.00030	0.0650							
	20	0.980	0.980	0.980	0.870	1.150	1.150	0.031	0.02051	0.00248	0.00253	0.4362							
	21	0.900	0.850	0.850	0.090	2.020	2.020	0.050	0.00271	0.00026	0.00013	0.0441							
	22	0.890	0.810	0.810	0.045	2.110	2.110	0.050	0.00128	0.00012	0.00006	0.0218							
	23	0.760	0.760	0.760	0.200	0.380	0.380	-0.050	-0.00454	-0.00033	-0.00018	0.1000							
	24	0.965	0.965	0.965	0.200	0.580	0.580	-0.050	-0.00731	-0.00085	-0.00045	0.1000							
	25	0.640	0.640	0.640	0.090	0.780	0.780	-0.050	-0.00145	-0.00007	-0.00004	0.0450							
	26	0.640	0.800	0.800	0.040	0.870	0.870	-0.050	-0.00082	-0.00005	-0.00003	0.0215							
	27	0.800	0.640	0.640	0.090	0.910	0.910	-0.050	-0.00184	-0.00012	-0.00006	0.0417							
	28	0.700	0.600	0.600	0.150	1.000	1.000	-0.050	-0.00249	-0.00013	-0.00007	0.0712							
	29	0.531	0.531	0.531	0.555	1.150	1.150	-0.035	-0.00430	-0.00015	-0.00009	0.2775							
	30	0.531	0.410	0.410	0.405	1.705	1.705	-0.035	-0.00248	-0.00007	-0.00007	0.1852							
	31	0.410	0.810	0.810	0.045	2.110	2.110	-0.050	-0.00068	-0.00004	-0.00002	0.0272							
	32	0.980	0.980	0.980	0.100	2.020	2.020	0.040	0.00302	0.00036	0.00018	0.0500							
	33	0.980	0.650	0.650	0.300	2.120	2.120	0.040	0.00635	0.00056	0.00033	0.1300							
	34	0.650	0.240	0.240	0.300	2.420	2.420	0.040	0.00866	0.00029	0.00113	0.4636							
	35	0.900	0.850	0.850	0.090	2.020	2.020	-0.040	-0.00217	-0.00021	-0.00011	0.0441							
	36	0.920	0.620	0.620	0.300	2.110	2.110	-0.040	-0.00566	-0.00045	-0.00026	0.1308							
	37	0.620	0.210	0.210	1.300	2.410	2.410	-0.040	-0.00761	-0.00023	-0.00015	0.4520							
	38	0.280	0.531	0.531	0.125	0.455	0.455	0.685	0.01111	0.00027	0.00015	0.0750							
	39	0.580	0.531	0.531	1.125	0.580	0.580	0.685	0.17056	0.00601	0.02101	0.5625							
	40	0.531	0.480	0.480	0.175	1.705	1.705	0.685	0.02408	0.00077	0.00045	0.0846							
	41	0.460	0.380	0.380	0.075	1.880	1.880	0.685	0.00714	0.00016	0.00008	0.0351							
	42	0.400	0.280	0.280	0.400	1.955	1.955	0.685	0.02514	0.00038	0.00052	0.1767							

TABLE 4. SPIN STABILIZED MOMENTS (CONCLUDED)

25MM M791 APDS-T

Filename: I25MMAPDS

I Code	Left Diameter (in)	Right Diameter (in)	Length (in)	Reference Location (in)	Density (lbm/in**3)	Weight (lbm)	Axial Moment (lbm-in**2)	Transverse Moment (lbm-in**2)	Center of Gravity (in)	Radius (in)
43	1	0.280	0.050	0.125	2.355	0.685	0.00213	0.00001	0.0375	0.0375
44	1	0.255	0.255	0.375	0.455	-0.685	-0.01312	-0.00021	0.1875	0.1875
45	1	0.250	0.000	0.072	0.830	-0.685	-0.00081	0.00000	0.0180	0.0180
46	4	0.480	0.050	1.375	1.880	0.100	0.00925	0.00016	0.3826	0.3826
47	0	0.460	0.380	0.075	1.880	-0.100	-0.00104	-0.00002	0.0351	0.0351
48	0	0.400	0.100	1.955	1.955	-0.100	-0.00550	-0.00036	0.3214	0.3214
49	0	0.255	0.255	0.375	0.455	0.060	0.00115	0.00001	0.1875	0.1875

Element Codes

-2 - Boom	-1 - Sabot	0 - Projectile Body
1 - Penetrator	2 - HE	3 - Band
4 - Ogive	5 - Boattail	6 - Fins
7 - Tracer		

TABLE 5. FIN STABILIZED MOMENTS

Filename: I120M829												
:120MM M829 APDS-FS												
Diameter		Projectile Length		Ogive Length	C.G. from Nose		Transverse		Total Projectile		Sabot Penetrator	Filler
(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
26.492	613.969	91.618	325.514	3.80783	783.00452	15.751	9.386	6.365	8.862	0.000 lbm	0.000 Grams	
						7144.427	4257.256	2887.171	4019.563			
I Code	Left Diameter (mm)	Right Diameter (mm)	Length (mm)	Reference Location (mm)	Density (gm/cm**3)	Weight (kg)	Axial Moment (kg-cm**2)	Transverse Moment (kg-cm**2)	Center of Gravity (mm)	Radius (mm)		
1	-1	120.802	13.538	381.584	1.384	0.21475	3.91740	1.99150	6.7691			
2	-1	114.300	13.538	381.584	-1.384	-0.19225	-3.13965	-1.59919	6.7691			
3	3	116.510	120.599	215.468	1.384	0.11643	2.04654	1.02890	3.8538			
4	3	120.599	120.599	223.088	1.384	0.05622	1.02206	0.51162	1.7780			
5	3	118.212	118.212	226.644	1.384	0.09645	1.68480	0.84564	3.1750			
6	3	123.165	121.006	232.994	1.384	0.23580	4.39381	2.23853	7.2342			
7	3	121.006	121.006	247.548	1.384	0.56597	10.35902	5.77591	17.7800			
8	3	121.006	119.329	283.108	1.384	0.20971	3.78568	1.92403	6.6491			
9	3	112.141	112.141	215.468	-1.384	-0.53539	-8.41610	-4.89248	19.5834			
10	3	112.141	86.004	254.635	-1.384	-0.03761	-0.47484	-0.23780	1.5994			
11	3	86.004	80.086	258.140	-1.384	-0.06096	-0.52660	-0.26665	3.9675			
12	3	80.086	102.235	266.268	-1.384	-0.01522	-0.16195	-0.08101	0.9058			
13	3	102.235	102.235	267.945	-1.384	-0.03059	-0.39964	-0.20001	1.3462			
14	3	102.235	111.328	270.637	-1.384	-0.09765	-1.39601	-0.70304	4.0487			
15	3	104.318	113.106	278.511	-1.384	-0.09794	-1.45083	-0.73015	3.9126			
16	3	107.645	119.685	286.131	-1.384	-0.14674	-2.38094	-1.20376	5.4038			
17	-1	119.685	119.685	296.570	2.768	0.35436	6.34502	3.21074	5.6896			
18	-1	101.600	114.300	301.015	-2.768	-0.17187	-2.68161	-1.34646	3.2609			6.375
19	-1	114.300	114.300	307.365	-2.768	-0.01659	-0.27096	-0.13549	0.2921			-19.761
20	-1	101.600	70.256	301.015	2.768	3.21985	1.82492	0.95988	7.0482			-40.005
21	-1	70.256	66.777	316.916	2.768	0.11875	0.69760	0.36218	5.7182			
22	-1	66.777	82.829	328.549	2.768	0.33078	2.09263	1.31559	16.4908			
23	-1	82.829	109.322	359.232	2.768	0.34264	4.07813	2.11962	9.2585			
24	-1	109.322	114.300	376.199	2.768	0.03256	0.50023	0.25015	0.6168			-3.150
25	-1	119.380	119.380	377.419	2.768	0.13063	2.32720	1.16553	2.1082			
26	-1	114.300	114.300	381.635	2.768	0.38451	6.27929	3.19838	6.7691			
27	-1	119.380	119.380	395.173	2.768	0.05509	0.98135	0.49082	0.8890			
28	-1	68.986	81.128	367.792	-2.768	-0.03309	-0.24909	-0.12472	1.3216			8.509
29	-1	68.986	52.222	7.849	2.768	0.05399	0.21775	0.11173	3.6324			-8.484
30	-1	52.222	30.480	375.641	2.768	0.26998	0.64258	1.37581	29.4153			
31	-1	81.128	98.044	370.332	-2.768	-0.15068	-1.53404	-0.77624	4.5755			
32	-1	98.044	109.220	378.943	-2.768	-0.33245	-4.66756	-2.38459	7.0625			19.507
33	-1	109.220	109.220	392.608	-2.768	-0.18510	-2.76003	-1.38787	3.5687			
34	-1	30.480	30.480	446.634	2.768	0.00641	0.00745	0.00378	1.5875			
35	-1	119.380	115.468	2.794	2.768	0.08376	1.44432	0.72270	1.3815			
36	-1	24.511	24.511	119.456	-2.768	-0.14554	-0.10930	-1.56056	55.7149			
37	-1	25.730	25.730	230.886	-2.768	-0.31509	-0.26075	-12.71476	109.4613			
38	-1	30.226	34.696	115.011	7.833	0.01484	0.01971	0.00992	1.1954			
39	-1	34.696	34.696	117.297	7.833	0.07939	0.11946	0.06733	5.3594			
40	-1	22.708	28.296	115.011	-7.833	-0.01786	-0.01480	-0.00769	2.3842			
41	-1	29.997	29.997	119.456	-7.833	-0.04739	-0.05330	-0.02954	4.2799			
42	-1	29.489	29.489	119.456	2.768	0.00898	0.00976	0.06505	2.3749			

TABLE 5. FIN STABILIZED MOMENTS (CONCLUDED)

Page Number 4

Filename: I120M829 :120MM M829 APDS-FS

I Code	Left Diameter (mm)	Right Diameter (mm)	Length (mm)	Reference Location (mm)	Density (gm/cm**3)	Weight (kg)	Axial Moment (kg-cm**2)	Transverse Moment (kg-cm**2)	Center of Gravity (mm)	Radius (mm)
43	-1	29.489	64.541	129.870	124.206	2.768	0.65299	2.21028	80.3580	
44	-1	64.541	102.235	16.561	254.076	2.768	0.19764	1.43686	9.3433	-18.999
45	-1	102.235	111.328	7.874	270.637	2.768	0.19330	2.79202	4.0487	
46	-1	104.318	113.106	7.620	278.511	2.768	0.19588	2.90166	3.9126	
47	-1	107.645	119.685	10.439	286.131	2.768	0.29349	4.76187	1.46029	
48	0	26.416	26.416	101.600	12.903	2.768	0.15413	0.13444	2.40751	5.4038
49	6	81.509	81.509	25.146	0.000	2.768	0.03693	0.27648	1.39305	50.8000
50	6	81.509	26.416	89.306	25.146	2.768	0.06992	0.34590	0.15770	12.5730
51	6	41.275	26.416	12.903	0.000	-2.768	-0.00364	-0.00783	31.6196	
52	0	22.225	22.225	11.989	12.903	-2.768	-0.01287	-0.00425	5.0428	
53	0	19.558	19.558	13.157	24.892	-2.768	-0.01094	-0.00552	5.9944	
54	0	21.996	21.996	24.689	64.491	-2.768	-0.02597	-0.00419	6.5786	
55	0	23.012	23.012	25.298	89.179	-2.768	-0.02913	-0.01571	12.3444	
56	1	19.812	21.996	2.997	64.491	18.546	0.01909	-0.02317	12.6492	
57	1	21.996	21.996	25.984	67.488	18.546	0.01048	0.00538	1.5508	
58	1	22.403	22.403	24.994	93.472	18.546	0.18312	0.11075	12.9921	
59	1	24.511	24.511	112.420	118.466	18.546	0.18271	0.11462	12.4968	
60	1	25.730	25.730	219.075	230.886	18.546	0.98378	0.73880	56.2102	
61	1	25.730	24.308	0.711	449.961	18.546	2.11256	1.74826	109.5375	
62	1	24.308	24.308	2.591	450.672	18.546	0.00630	0.00479	0.3503	-0.762
63	1	24.308	21.361	36.881	453.263	18.546	0.02230	0.01647	1.2954	
64	1	21.361	21.361	31.826	490.144	18.546	0.28049	0.18408	17.6484	
65	0	26.492	24.892	72.009	450.342	2.768	0.21153	0.12065	15.9131	
66	4	24.892	11.328	52.426	522.351	2.768	0.10337	0.08513	35.2572	
67	4	11.557	0.762	39.192	574.777	7.833	0.03913	0.01968	19.9610	
68	0	25.019	24.308	0.279	450.342	-2.768	0.01149	0.00115	10.4812	-0.762
69	0	24.308	24.308	2.591	450.672	-2.768	-0.00037	-0.00028	0.1385	
70	0	24.308	21.361	36.881	453.263	-2.768	-0.00333	-0.00246	1.2954	
71	0	21.361	21.361	31.826	490.144	-2.768	-0.04186	-0.02748	17.6484	
72	0	6.756	6.756	32.715	521.970	-2.768	-0.03157	-0.01801	15.9131	
73	0	8.077	8.077	20.091	554.685	-2.768	-0.00325	-0.00019	16.3576	
74	0	8.077	8.077	10.846	557.784	7.833	-0.00285	-0.00023	10.0457	
75	0	6.985	6.985	6.147	568.630	7.833	0.00435	0.00036	5.4229	
							0.00185	0.00011	3.0734	

Fin Information

Fin Group	Element Numbers in Group	Fin Type	Fin Thick (mm)	Lead Thk (mm)	Number of Fins
1	49 50 51	3	2.9972	2.0320	6

Element Codes

-2 - Boom	-1 - Sabot	0 - Projectile Body
1 - Penetrator	2 - HE	3 - Band
4 - Ogive	5 - Boattail	6 - Fins
7 - Tracer		

It must be noted that the weights and inertias given for the composite projectile are for the "flying" portion only. Sabot elements and rotating band elements on a sabot projectile are removed before making these calculations. The total weight is carried separately for use in the internal ballistics segment.

f. S - Stability

The stability segment is broken into three phases:

- 1 - Computation of aerodynamic and stability parameters
- 2 - Empirical interior ballistics
- 3 - Plotted/tabulated output

The form of the input and output menus will be different for spin and fin stabilized projectiles. Physical property data must be available from the "M" segment. The input menu for a spin stabilized projectile is:

Stability Inputs

1 - Projectile Diameter	(inch):	0.531
2 - Meplat Diameter	(inch):	0.050
3 -	(calibers):	0.094
4 - Rotating Band Diameter	(inch):	0.531
5 -	(calibers):	1.000
6 - Ogive Radius	(inch):	531.000
7 -	(calibers):	1000.000
8 - Boom Length	(inch):	0.000
9 -	(calibers):	0.000
10 - Projectile Length	(inch):	2.800
11 -	(calibers):	5.273
12 - Ogive Length	(inch):	1.550
13 -	(calibers):	2.919
14 - Boattail Length	(inch):	0.000
15 -	(calibers):	0.000
16 - CG from Nose	(inch):	1.890
17 -	(calibers):	3.560
18 - Rifling Twist	(inch/rev):	23.504
19 -	(calibers/rev):	23.862
20 - Gun Bore Diameter	(inch):	0.985
21 - Total Weight	(lbm):	0.230
22 - Axial Moment	(lbm-in**2):	0.00758
23 - Transverse Moment	(lbm-in**2):	0.05857
24 - Air Temperature	(Deg F):	59.000

Key in item number ", " new value

Key in "LIST" to relist "DONE" to continue

Key in "PRINT" for a Line printer output

The input menu for a fin stabilized projectile is:

**Finned Projectile Aerodynamic Coefficient and
Stability Determination**

1 - Number of Fins	:	6
2 - Fin Type (1 Rectangular	2 Delta) :	2
(3 Clipped	4 Swept)	
3 - Fin Root Chord	(calibers):	2.867
4 - Fin Tip Chord	(calibers):	0.000
5 - Fin Height	(calibers):	1.078
6 - Fin Thickness	(calibers):	0.070
7 - Fin Lead Thickness	(calibers):	0.057
8 - Boattail Length	(calibers):	2.867
9 - Boom Length	(calibers):	0.000
10 - Boom (or Aft Boattail) Dia	(calibers):	1.000
11 - Nose Radius	(calibers):	30.535
12 - Meplat Diameter	(calibers):	0.043
13 - Nose Length	(calibers):	3.308
14 - Nose to CG Distance	(calibers):	7.204
15 - Projectile Diameter	(inch):	1.395
16 - Projectile Cylindrical Length	(cal):	7.505
17 - Projectile Base to Fin Trailing	:	0.000
Edge Distance (calibers)		
18 - Axial Inertia	(lbm-in**2):	1.64276
19 - Transverse Inertia	(lbm-in**2):	130.69066
20 - Weight	(lbm):	8.206
21 - Projectile Velocity	(ft/sec):	5500.000
22 - Magnus Moment Coefficient	:	5.000
23 - Roll Induced Side Moment Coefficient	:	0.000
24 - Temperature	(Deg F):	59.000
25 - Gun Bore Diameter	(inches):	4.128
26 - Any T Pads on Fins	(0 - no 1 - yes):	0.

Key in item number ", " new value

Key in "LIST" to relist "DONE" to continue

Key in "PRINT" for a Line printer output

Note the SPINNER data may be entered in either length units or calibers but FINNER is limited to calibers only. A default ogive radius of 100 calibers is used if the ogive radius is set to zero. SPINNER requires that an ogive exists in order to run the stability analysis.

Within the "T" segment the aerodynamic coefficients may be modified to reflect any experimental data that becomes available. When this option is exercised a flag is set in PRODAS. If that flag is set when the stability segment is run, the user will be prompted with the message:

This round has previously modified aerodynamic coefficients.
Do you wish to recalculate the aerodynamic coefficients or
proceed directly to the stability analysis?

Enter 0 to recalculate aeros

Enter 1 to proceed directly to stability

If Option One is chosen, the values from the data base will be echoed in the output. If option zero is selected, or the empirical data has not been modified, a display of the flying (no sabot elements) portion of the projectile model together with the stability analysis model will be displayed. The stability analysis model is generated from the geometry as defined in the stability input menu. This drawing is displayed for the user to examine for model verification before running the analysis. Figure 11 shows the verification model for a typical FINNER analysis. In this figure both the projectile as modeled and the aerodynamic representation of that projectile are displayed. If the analysis model does not match the desired configuration, return to the input to correct the model. Once the user is satisfied with the model, the analysis will be run.

For both fin and spin stabilized projectiles, the tabulated output will include an echo of the input values, the table of aerodynamic coefficients, and the stability analysis parameters. For a spin stabilized projectile, a table of McDRAG coefficients will also be printed. Table 6 shows the output for a spin stabilized projectile. The parameters output in this table are:

SPINNER aerodynamic coefficients are:

Mach - Mach number

CX - Zero yaw drag coefficient

CX2 - Yaw drag coefficient per $\sin^2$ -

CNa - Normal force coefficient per $\sin$ -

Cma - Pitching moment coefficient per $\sin$ -

CPN - Normal force center of pressure (calibers from nose)

Cypa - Magnus force coefficient derivative per $\sin$ -

Cnpa - Zero yaw magnus moment coefficient derivative per $\sin$ -

Cnpa3- Cubic magnus moment coefficient derivative per $\sin^3$ -

Cnpa5- Quintic magnus moment coefficient derivative per $\sin^5$ -

CPF1 - Center of pressure of Magnus force at 1 degree of yaw
(calibers from nose)

CPF5 - Center of pressure of Magnus force at 5 degrees of yaw
(calibers from nose)

Cnpa-5- 5 degree secant slope of magnus moment coefficient
derivative (@ 5 deg yaw) per $\sin a$

Cmq - Pitch damping coefficient

Clp - Spin deceleration coefficient

Filename: 1120M829
1120M M829 APDS-75

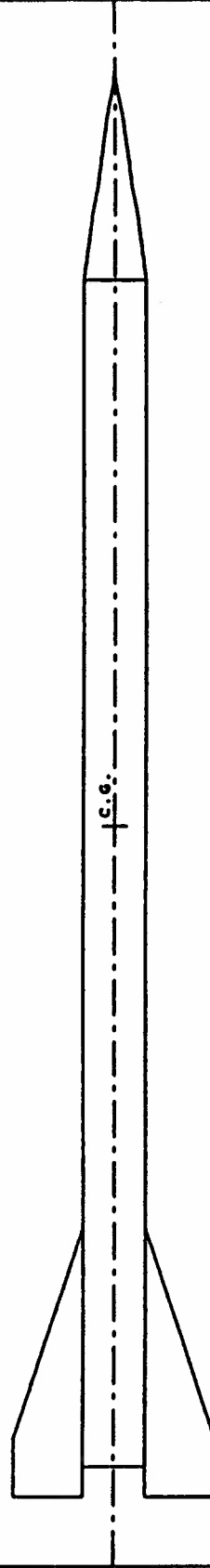
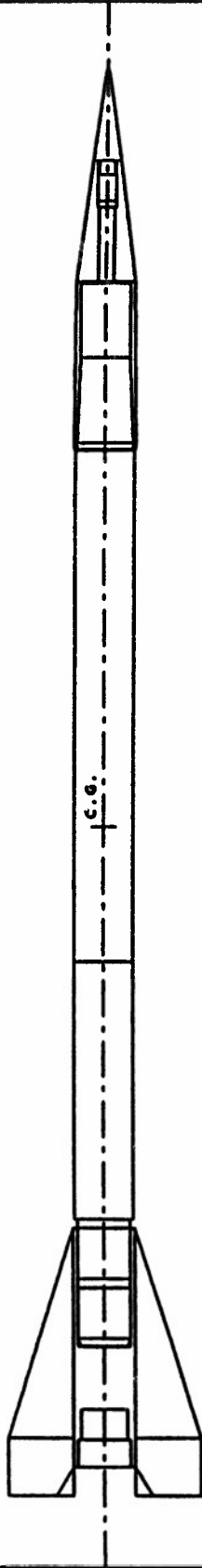


Figure 11. Geometry Validation Model

TABLE 6. SPINNER OUTPUT (CONCLUDED)

Filename: I25MMAPDS 25MM M791 APDS-T

MCDRAG Computed Drag Coefficients

Mach	CD0	CX	DELTA	CDH	CDSF	CDBND	CDBT	CDB
0.010	0.232	0.198	0.034	0.000	0.070	0.000	0.000	0.162
0.600	0.234	0.198	0.036	0.000	0.067	0.000	0.000	0.166
0.800	0.238	0.200	0.037	0.000	0.063	0.000	0.000	0.175
0.900	0.240	0.220	0.020	0.000	0.061	0.000	0.000	0.179
0.950	0.265	0.258	0.006	0.024	0.060	0.000	0.000	0.181
1.000	0.330	0.371	-0.041	0.047	0.059	0.000	0.000	0.224
1.050	0.447	0.427	0.020	0.167	0.058	0.000	0.000	0.222
1.100	0.424	0.418	0.006	0.147	0.057	0.000	0.000	0.220
1.200	0.402	0.392	0.010	0.130	0.056	0.000	0.000	0.216
1.350	0.381	0.367	0.013	0.118	0.053	0.000	0.000	0.209
1.500	0.363	0.346	0.017	0.111	0.051	0.000	0.000	0.201
1.750	0.337	0.313	0.024	0.102	0.048	0.000	0.000	0.187
2.000	0.312	0.283	0.030	0.096	0.046	0.000	0.000	0.171
2.500	0.268	0.230	0.038	0.088	0.041	0.000	0.000	0.140
3.000	0.232	0.190	0.042	0.082	0.037	0.000	0.000	0.113
4.000	0.179	0.152	0.027	0.074	0.031	0.000	0.000	0.074
5.000	0.146	0.130	0.016	0.069	0.026	0.000	0.000	0.051

*** CX is either Spinner or modified drag ***
 *** coefficient as presented in the above table ***

Filename: I25MMAPDS 25MM M791 APDS-T

Stability Parameters

Mach	GYRO	SBAR	RECIP SBAR-5	RECIP-5 Spin	DELT	W1	W2	L1	L2	L1-5	L2-5	DISP
				(rad/sec)	(sec)	(rad/sec)	(rad/sec)	(1/ft)	(1/ft)	(1/ft)	(1/ft)	(mrad)
0.010	2.376	-0.753	-0.482	1.399	1.190	36.0769	4.08	0.55	-0.001584	0.000561	-0.000251	-0.000772
0.600	2.357	-0.753	-0.482	1.399	1.189	2149.0013	244.67	33.56	-0.001587	0.000564	-0.000250	-0.000773
0.800	2.300	-0.350	-1.216	1.594	1.544	2866.0010	324.94	46.03	-0.001351	0.000323	-0.000124	-0.000904
0.900	2.338	0.232	2.435	1.183	1.035	3224.0009	366.54	50.81	-0.001451	-0.000050	-0.000559	-0.000942
0.950	2.338	0.497	1.339	1.076	1.006	3243.0008	386.89	53.64	-0.001545	-0.000379	-0.000844	-0.001080
1.000	2.344	0.453	1.427	0.746	1.069	3582.0008	407.44	56.28	-0.002145	-0.000449	-0.001665	-0.000929
1.050	2.584	0.527	1.288	0.701	1.098	3762.0007	434.07	52.84	-0.002036	-0.000619	-0.001756	-0.000899
1.100	2.514	0.500	1.333	0.609	1.180	3941.0007	452.97	57.12	-0.002356	-0.000626	-0.002156	-0.000826
1.200	2.448	0.457	1.418	0.526	1.290	4299.0006	492.22	64.24	-0.002760	-0.000585	-0.002616	-0.000729
1.350	2.416	0.425	1.493	0.476	1.379	4836.0006	552.65	73.37	-0.003212	-0.000561	-0.003092	-0.000681
1.500	2.390	0.383	1.615	0.422	1.502	5374.0005	613.00	82.58	-0.003860	-0.000504	-0.003751	-0.000613
1.750	2.364	0.400	1.563	0.434	1.471	6269.0004	713.98	97.53	-0.003850	-0.000539	-0.003753	-0.000636
2.000	2.383	0.414	1.522	0.444	1.447	7165.0004	816.98	110.46	-0.003830	-0.000579	-0.003746	-0.000664
2.500	2.369	0.429	1.484	0.454	1.424	8956.0003	1020.27	139.03	-0.003819	-0.000605	-0.003747	-0.000678
3.000	2.347	0.428	1.486	0.449	1.435	10747.0003	1222.56	168.60	-0.003816	-0.000584	-0.003755	-0.000645
4.000	2.367	0.422	1.501	0.444	1.448	14330.0002	1632.28	222.60	-0.003815	-0.000560	-0.003755	-0.000621
5.000	2.393	0.415	1.520	0.436	1.465	17912.0002	2043.77	274.83	-0.003813	-0.000537	-0.003753	-0.000597

McDRAG aerodynamic coefficients are:

MACH - Mach number
CDO - McDRAG computed zero yaw drag coefficient
CX - SPINNER computed zero yaw drag coefficient
DELTA- Difference between McDRAG and SPINNER
CDH - Transonic pressure head drag
CDSF - Skin friction drag
CDBND- Rotating band drag
CDBT - Boattail drag
CDB - Base drag

SPINNER stability analysis parameters are:

MACH - Mach number
GYRO - Gyro stability factor
SBAR - Dynamic stability factor @ 1 degree of yaw
RECIP- Dynamic reciprocal factor @ 1 degree of yaw
SBAR5- Dynamic stability factor @ 5 degrees of yaw
RECIP5- Dynamic reciprocal factor @ 5 degrees of yaw
SPIN - Spin rate (rad/sec)
W1 - Nutation frequency (rad/sec)
W2 - Precession frequency (rad/sec)
L1 - Nutation damping factor @ 1 degree of yaw (1/ft)
L2 - Precession damping factor @ 1 degree of yaw (1/ft)
L1-5 - Nutation damping factor @ 5 degrees of yaw (1/ft)
L2-5 - Precession damping factor @ 5 degrees of yaw (1/ft)
DELT - Integration time step (sec)
DISP - Dispersion factor per .001 inches of barrel clearance (mils)

Table 7 shows the tabulated output from a FINNER analysis. The parameters output are:

FINNER aerodynamic coefficients are:

Mach - Mach number

CD - Zero yaw drag coefficient

CNa - Normal force coefficient per $\sin \bar{\alpha}$

CPN - Normal force center of pressure (calibers from nose)

Cma - Pitching moment coefficient per $\sin \bar{\alpha}$

Cmq - Pitch damping coefficient

CXB - Body alone zero yaw axial force coefficient

CXF - Fin alone zero yaw axial force coefficient

CnaB - Body alone normal force coefficient per $\sin \bar{\alpha}$

CnaF - Fin alone normal force coefficient per $\sin \bar{\alpha}$

CPNB - Body alone normal force center of pressure
(calibers from nose)

CPNF - Fin alone normal force center of pressure
(calibers from nose)

FINNER stability analysis parameters are:

P - Spin rate (rad/sec)

GYRO - Gyro stability factor

SIGMA- Inverse of the gyro stability factor

RATE - $2 \sigma / (1 - \sigma)$ rate of nutation wrt precession divided by
the rate of precession

P/W1 - Spin divided by the nutation frequency

PD/2V- Non-dimensional spin rate

W1 - Nutation frequency (rad/sec)

W2 - Precession frequency (rad/sec)

L1 - Nutation damping factor (1/ft)

TABLE 7. FINNER OUTPUT

Filename I120M829

in mm	Body Length	Ogive Length	Boattail Length	Boom Length	C.G. from Nose	Band Diameter	Meplat Diameter	Ogive Radius
	601.066	91.618	0.000	0.000	325.514	0.000	0.054	0.000
in calibers	22.220	3.387	0.000	0.000	12.033	0.000	0.002	0.000
in mm	Diameter (mm)	Weight (kg)	Gun Bore (mm)	Temperature (Deg C)	Air Density (gm/cm**3)	Axial Mom. (kg-cm**2)	Trans. Mom. (kg-cm**2)	
	27.051	4.257	120.015	15.000	0.631401	3.807829	783.004517	
in mm	Fin Root Chord	Fin Tip Chord	Fin Height	Fin Thickness	Fin Lead Thickness	Base to Trailing Edge Distance		
	114.452	25.146	29.502	2.997	2.032	-12.903		
in calibers	4.231	0.930	1.091	0.111	0.075	-0.477		

Projectile has 6 clipped delta fins

Aerodynamic Coefficients

Mach	CD	Cna	CPN	Cma	Cmq	CXB	CXF	CnaB	Cnaf	CPNB	CPNF
0.010	0.459	20.551	18.363	-130.083	-3384.38	0.300	0.159	2.994	17.557	4.273	20.766
0.400	0.459	20.153	18.199	-124.249	-3242.55	0.300	0.159	2.994	17.160	4.266	20.629
0.800	0.538	24.545	18.615	-161.533	-3886.30	0.303	0.236	3.014	21.531	4.243	20.626
1.000	0.828	25.378	18.678	-168.633	-4020.44	0.480	0.348	3.060	22.319	4.031	20.686
1.100	0.819	26.236	18.997	-182.683	-4303.35	0.506	0.313	2.929	23.306	4.237	20.852
1.200	0.740	26.332	18.991	-183.201	-4353.49	0.477	0.263	2.982	23.350	4.168	20.883
1.300	0.707	26.213	18.970	-181.826	-4380.25	0.464	0.243	3.034	23.179	4.105	20.916
1.500	0.661	25.657	18.872	-175.459	-4384.03	0.438	0.223	3.159	22.498	3.979	20.963
1.800	0.595	25.604	18.811	-173.535	-4441.49	0.400	0.195	3.285	22.319	3.791	21.022
2.000	0.551	24.808	18.693	-165.206	-4348.91	0.376	0.175	3.371	21.437	3.683	21.053
2.500	0.481	23.933	18.521	-155.269	-4260.90	0.326	0.155	3.485	20.448	3.344	21.108
3.000	0.423	22.116	18.294	-138.452	-3980.63	0.288	0.135	3.449	18.667	2.959	21.127
3.500	0.391	20.244	18.080	-122.405	-3667.38	0.269	0.122	3.399	16.845	2.944	21.134
4.000	0.366	18.597	17.860	-108.359	-3389.68	0.250	0.116	3.349	15.248	2.929	21.140
5.000	0.338	16.145	17.473	-87.821	-2953.41	0.229	0.110	3.249	12.896	2.899	21.145

TABLE 7. FINNER OUTPUT (CONCLUDED)

Filename: I120M829

120MM M829 APDS-FS

Stability Parameters of Statistically Stable Missiles

P (rad/sec)	GYRO	SIGMA	RATE	P/W1	PD/2V	W1 (rad/sec)	W2 (rad/sec)	L1 (1/m)	L2 (1/m)	AP	YR (deg)
13.841	0.000	4102.592	-2.000	0.100	0.000	138.110	-138.043	-0.0028	-0.0028	1.009	0.000
69.207	0.000	820.519	-2.002	0.501	0.001	138.245	-137.909	-0.0028	-0.0028	1.330	0.000
110.731	0.000	512.825	-2.004	0.800	0.001	138.346	-137.808	-0.0028	-0.0028	2.739	0.000
124.572	0.000	455.845	-2.004	0.900	0.001	138.380	-137.774	-0.0028	-0.0028	4.986	0.000
131.493	0.000	431.853	-2.005	0.950	0.001	138.397	-137.757	-0.0028	-0.0028	8.498	0.000
138.414	0.000	410.260	-2.005	1.000	0.001	138.414	-137.741	-0.0028	-0.0028	14.802	0.000
145.334	0.000	390.724	-2.005	1.050	0.001	138.431	-137.724	-0.0028	-0.0028	8.083	0.000
152.255	0.000	372.964	-2.005	1.100	0.001	138.448	-137.707	-0.0028	-0.0028	4.511	0.000
166.097	0.000	341.884	-2.006	1.199	0.001	138.481	-137.674	-0.0028	-0.0028	2.241	0.000
207.621	0.000	273.508	-2.007	1.498	0.002	138.583	-137.573	-0.0028	-0.0028	0.798	0.000
276.828	0.000	205.132	-2.010	1.995	0.002	138.752	-137.405	-0.0028	-0.0028	0.333	0.000
415.241	0.000	136.757	-2.015	2.985	0.003	139.090	-137.071	-0.0028	-0.0028	0.125	0.000
692.069	0.000	82.058	-2.025	4.951	0.006	139.770	-136.404	-0.0028	-0.0028	0.042	0.000
1384.138	-0.001	41.038	-2.050	9.783	0.011	141.483	-134.752	-0.0028	-0.0027	0.010	0.000
2768.275	-0.002	20.537	-2.102	19.095	0.022	144.972	-131.510	-0.0029	-0.0027	0.003	0.000
4152.413	-0.005	13.712	-2.157	27.954	0.034	148.542	-128.349	-0.0029	-0.0027	0.001	0.000
8304.825	-0.021	6.910	-2.338	51.990	0.067	159.739	-119.352	-0.0030	-0.0025	0.000	0.001

Stability Analyzed for

Velocity (m/sec)	CD	CMA	CMQ
1670.000	0.442	13.529	-56.233 -2711.642

FINNER stability analysis parameters - (continued)

L2 - Precession damping factor (1/ft)

AF - Amplification factor

YR - Yaw of repose (deg)

Additional outputs on this page include:

For rectangular fins:

AR- Fin aspect ratio

LAMBDA- Body diameter divided by total fin span
(tip to tip)

For delta, clipped delta, or swept fins:

Epsilon - Angle from horizontal to a line between forward
point of root chord to aft point of tip chord

LAMBDA - Body diameter divided by total fin span
(tip to tip)

Once the aerodynamic coefficients and parameters have been printed,
the user will be asked to select a muzzle velocity and aircraft velocity:

1 - Muzzle Velocity (ft/sec): 4350.000
2 - Aircraft Velocity(ft/sec): 0.000

Key in item number ",", new value

Key in "CALC" to calculate

Key in "LIST" to relist "DONE" to continue

Key in "PRINT" for a Line printer output

The aircraft velocity may be zero but the muzzle velocity must be
greater than zero. Since the muzzle velocity is used to compute the
projectile spin, the velocity components must be dealt with separately.

The user may select the option "CALC" which will cause PRODAS to branch into
the Empirical Interior Ballistic program. The Empirical Interior Ballistics
input menu is:

1 - Peak Pressure (psi): 60000.0000
2 - Barrel Length (in): 64.0000
3 - Propellant Weight (grains): 1569.4000
or
4 - Load Density (lbm/in**3): 0.0380
5 - Chamber Volume (in**3): 5.9000

Key in item number ",", new value

Key in "LIST" to relist "DONE" to continue

Key in "PRINT" for a Line printer output

The program will take the values for peak pressure, barrel length, propellant weights, and chamber volume to estimate a muzzle velocity. The results of the analysis will be displayed in tabulated form:

Interior Ballistics Results Gun Parameters

Barrel Length (in): 64.00
Chamber Volume (in**3): 5.900
Bore Area (in**2): 0.7849

Projected Parameters
Projected Weight: 0.297 (lbm) 2084. (grains) 135.0 (grams)
Projected Diameter (in) 0.985

Ballistic Parameters
Charge/mass Ratio 0.7528
Expansion Ratio 9.5139
Propellant Weight - 0.224(lbm) 1569.(grains) 101.65(grams)
Loading Density(lbm/in**3) 0.0380
Muzzle Velocity (ft/sec) 4375.2

If the user selects to send the input menu to the line printer file, the output will also be sent to the line printer file. The program will then return to the point where the muzzle velocity input was displayed. Note that the muzzle velocity has not been changed by the Empirical Interior Ballistic program. If the user wants to use the value computed, it must be entered at this point.

Once the velocities have been established a summary of the stability results, together with a drawing of the flying portion of the projectile model, will be displayed. Additional output options are available at this point (Figure 12).

Option One will cause a return to the stability input menu.

Option Two will cause a return to the muzzle and aircraft velocity input menu.

Option Three will display the menu of plots available for output. The menu available depends on the form of projectile being analyzed. For fin stabilized:

Stability Plot Segment

vs Mach Number	vs Spin/Nut. Freq.
1 CX	11 W1
2 CNa	12 W2
3 CPN	13 L1
4 Cna	14 L2
5 Cmq	15 AF

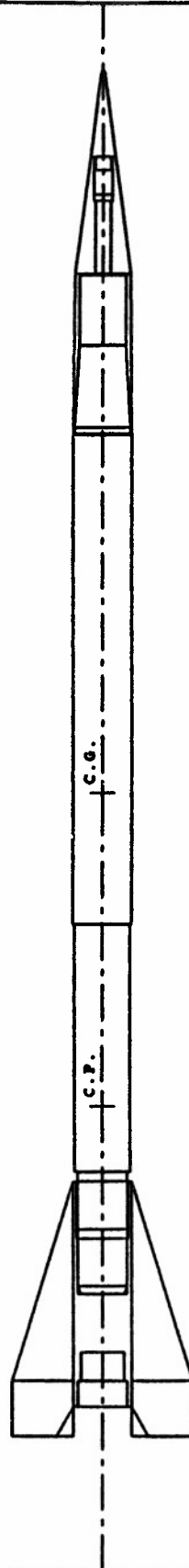
20 Return

:

Filename: 1120M029

120MM M029 APDS-FS

Projectile Length = 613.969 (mm)
 Sebot Length = 334.797 (mm)
 Ogive Length = 91.618 (mm)
 Band Length = 81.102 (mm)
 Penetrator Length = 457.479 (mm)



Stability Results

Rifling Twist	0.0 (mm/rav)	0.0 (cal ibara/rev)
Muzzle Velocity	1670.00 (m/sec)	
Aircraft Velocity	0.00 (m/sec)	
Air Density	.001225 (gram/cm**3)	
Air Temperature	15.0 (Deg C)	
Center of Pressure from Nose	465.696 (mm)	17.579 (cal ibara)
Center of Gravity from Nose	325.514 (mm)	12.287 (cal ibara)
Dynamic Stability Factor	0.000	
Static Margin	140.181 (mm)	5.291 (cal ibara)

Figure 12. Stability Summary

For spin stabilized:

Stability Plot Segment

1 CX	8 CPN
2 CNa	9 Gyro Stability Factor
3 Cma	10 Dynamic Stability Factor (SBAR)
4 Cmq	11 L1
5 Clp	12 L2
6 Cnpa	

20 Return

21 Dynamic Stability Criteria

:

Figure 13 shows the normal force (CNa) curve found by this analysis. The Dynamic Stability Criteria plot (21) shows the projected stability/instability for each of the Mach numbers analyzed and where they fall relative to the stability curve (Figure 14). In this example we see that this projectile will be unstable at subsonic speeds.

Option Four will display the plots available for cross plotting. In stability, unlike the other PRODAS segments, cross plotting will plot the current analysis against data stored in previously cataloged analyses and not against analyses made during this session. If the user selects to enter stability without first entering model geometry, the program will branch to the stability cross plot module. The data available for cross plotting (both spin and fin stabilized) is:

- 1 - CX
- 2 - CNa
- 3 - Cma
- 4 - Cmq
- 5 - Clp
- 6 - Return

Figure 15 shows a cross plot of drag data for spin stabilized projectiles.

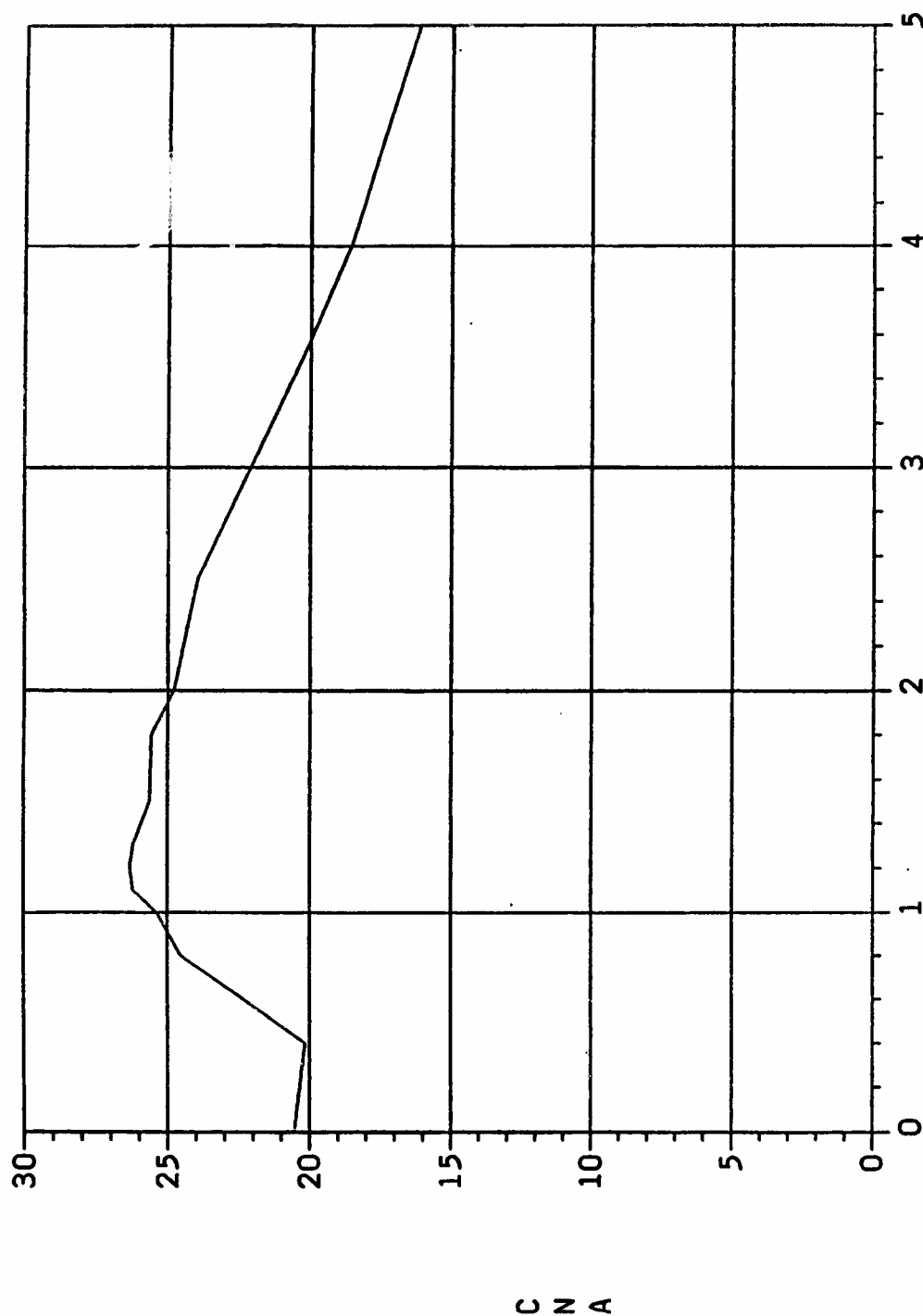
Option Five will return the program to the main PRODAS menu.

Option Six will cause the printed output that has been displayed on the screen to be written into a file for printing on a line printer.

Option Seven is available only if a laser printer is available that supports PLOT-10. This will cause a plot of this stability summary to be made.

If the user enters the stability option without entering a projectile, the program assumes that the user wishes to create cross plots from the cataloged data.

I120M829 :120MM M829 APDS-FS



MACH NUMBER

Figure 13. Stability Output Plot

I25MMAPDS: 25MM M791 APDS-T
DYNAMIC STABILITY CRITERIA

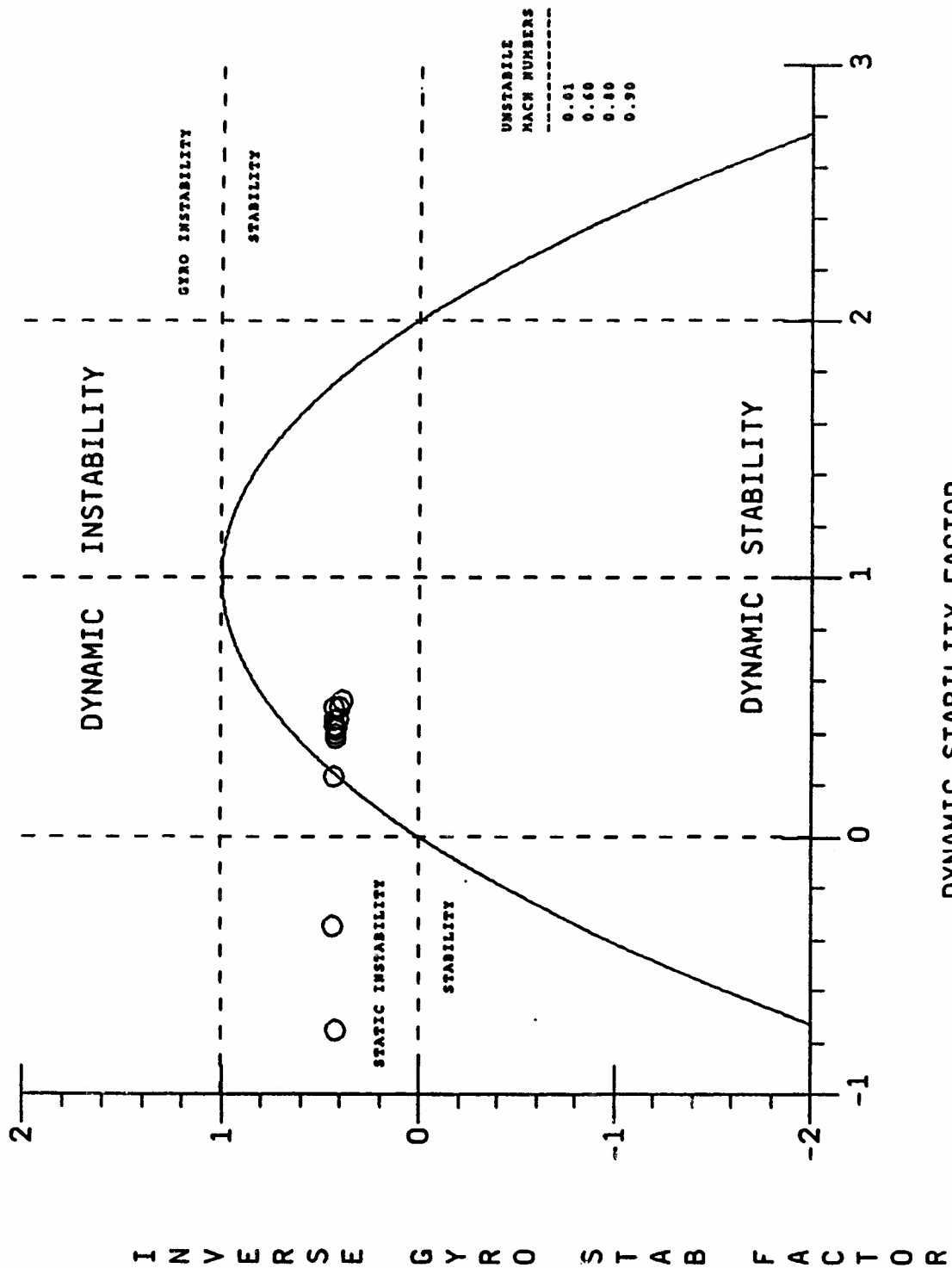


Figure 14. SPINNER Stability Criteria

KEY

125MMAPDS —

125MMSEIT - - -

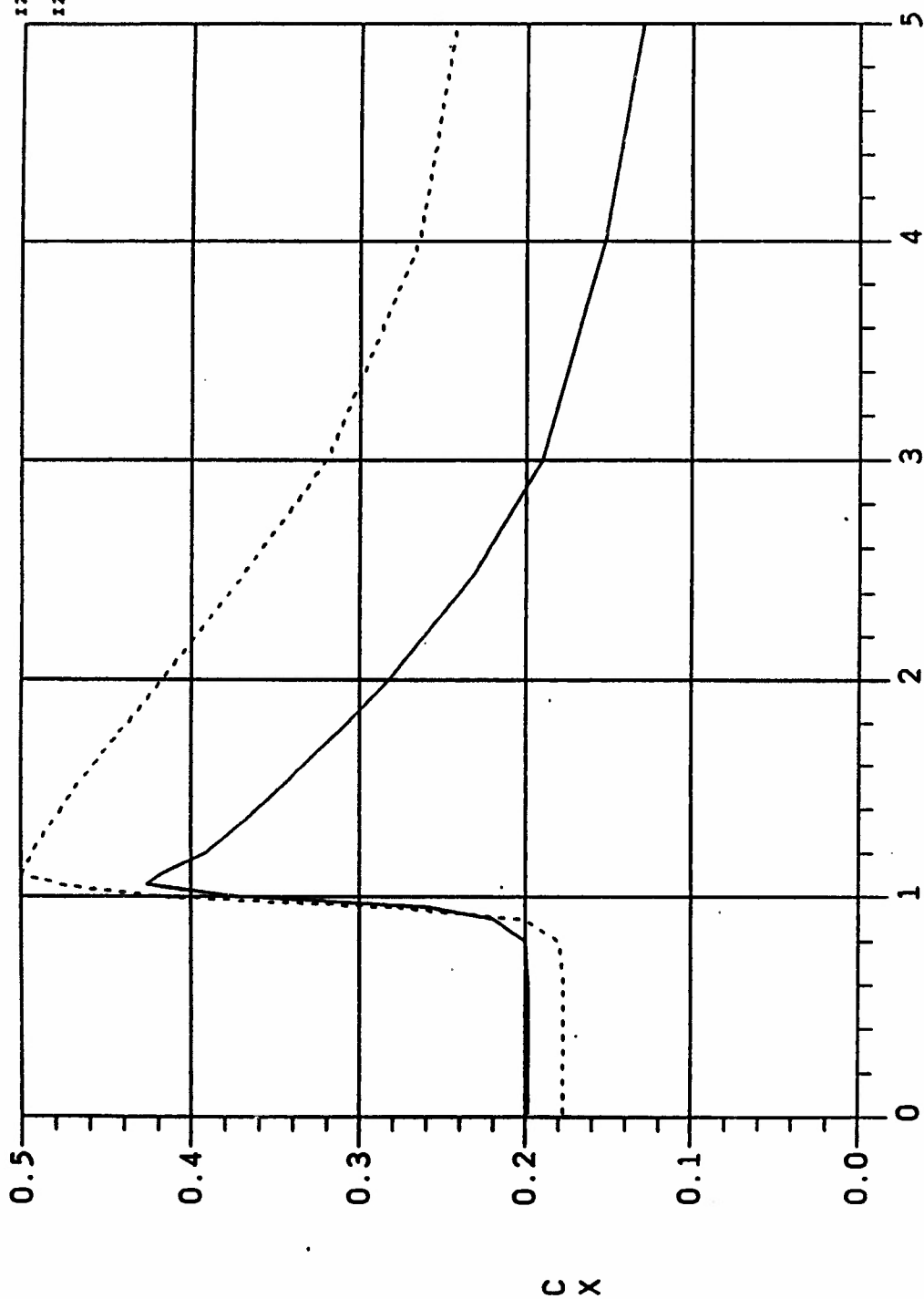


Figure 15. Stability Cross Plot

g. T - 2 / 6 Degree of Freedom Trajectory

This module performs either a 2 or 6 DOF trajectory analysis. If the module is selected without first defining a projectile model, the program will proceed to the cross plot segment.

Three input menus are needed to specify the basic trajectory physical and analysis parameters. The first menu is used to define the overall projectile configuration, which determines the additional input menus needed, and what additional output is desired:

Trajectory Analysis Options Selection

1 - Type of projectile	:	2
(1 - Fin stabilized 2 - Spin stabilized)		
2 - Type of trajectory simulation	:	2
(2 - Two DOF 6 - Six DOF)		
3 - Perform FUMER analysis	:	0
(0 - No 1 - Yes)		
4 - Does the trajectory originate at an aircraft:	:	0
(0 - No 1 - Yes)		
5 - Perform internal ball rotor simulation	:	0
(0 - No 1 - Yes)		
6 - Enter number of barrels in gun	:	1
7 - Examine or modify the aerodynamics	:	0
(0 - No 1 - Yes)		
8 - Generate cross plot file	:	0
(0 - No 1 - Yes)		
9 - Write a QUICK6 or MODTRAJ datafile	:	0
(0 - No file 1 - QUICK6 2 - MODTRAJ)		

Key in item number ", " new value
Key in "LIST" to relist "DONE" to continue
Key in "PRINT" for a Line printer output

Line one specifies the projectile stability configuration, fin or spin. The program will examine the projectile model for fin elements to initialize this parameter.

Line two specifies which equations of motion are to be used for the analysis, 2 or 6 DOF. By default the program will perform a 2 DOF analysis. For the 2 DOF analysis, aerodynamic jump, velocity jump, and yaw of repose effects are taken into account. Aerodynamic and velocity jump effects are the result of firing around an axis that does not match the direction of air flow, i.e., side firing from an aircraft. This causes an angle of attack for the projectile greater than it would normally have for no yaw motion. Yaw of repose is the resistance of a spin stabilized projectile's nose to following the ballistic trajectory, i.e. keeping a nose up orientation as the projectile comes over the apex of the arc in the trajectory.

If tracer burn or rocket effects are to be included, line three (fumer) should be flagged.

For a projectile launched from an aircraft, line four will cause the aircraft parameter menu to be displayed.

Line five will cause the ball rotor fuze input menu to be displayed. This enables the effect of a moving component in the fuze to be included in the equations of motion.

The number of barrels is specified in line six. A multiple barreled gun is assumed to be a gatling gun.

The Stability analysis segment of PRODAS computes aerodynamic coefficients. Line seven allows the user to display and modify these parameters.

Line eight allows the user to flag the program to store trajectory data for the creation of multiple analysis plots. This trajectory data will also be stored for use by other analysis modules within PRODAS (i.e., Target Penetration).

Line nine allows the user to specify that the trajectory input data is to be stored for use by either the QUICK6 or MODTRAJ programs. In either of these cases, trajectory analysis will not be performed. QUICK6 is a batch 6 DOF analysis program. MODTRAJ is a program for simulating a ballistic range. The program creates data points to simulate the camera X-Y-Z-theta-psi data with noise. (See Section II.)

The menus flagged by the above options will be explained in the following pages.

The second and third menus specify the projectile physical properties and basic trajectory analysis parameters:

Trajectory Analysis Conditions (Page 1)

1 - Projectile Diameter	(in):	0.531
2 - Axial Inertia	(lbm-in**2):	0.007581
3 - Transverse Inertia	(lbm-in**2):	0.058568
4 - Center of Gravity	(calibers from nose):	3.560
5 - Drag Form Factor	:	1.000
6 - Fin Cant Angle	(deg):	0.0000
7 - Number of Fins	:	0.
8 - Projectile Weight	(lbm):	0.2305
9 - Switch time from 6 DOF to 2 DOF	:	999.000
10 - Linear theory stability analysis	:	0
(0 - no 1 - yes)		
11 - Aerodynamic jump included	:	0
(0 - no 1 - yes)		
12 - Limiting total angle of attack for which nonlinear coef's are considered	(deg):	10.000
13 - Gun Elevation Angle	(deg +-up):	1.000
(0.0 if aircraft originated)		
14 - Gun Azimuth Angle	(deg +-left):	0.000

Trajectory Analysis Conditions (Page 1) - (Continued)

15 - Missile angle of attack-THETAM : 0.00
(deg +=nose down)
16 - Missile angle of sideslip-PSIM : 0.00
(deg +=nose left)

Key in item number ", " new value
Key in "LIST" to relist "DONE" to continue
Key in "CALC" to calculate
Key in "PRINT" for a Line printer output

Lines one through nine specify the physical parameters. These values are calculated in the Physical Properties segment.

Line ten allows for calculation of the linear theory gyroscopic and dynamic stability factors.

Line eleven causes the aerodynamic jump effects to be included.

Line twelve specifies the upper limit of angle of attack for non-linear coefficients. By default this value is 10 degrees.

Lines thirteen and fourteen define the gun orientation.

Lines fifteen and sixteen define the angular orientation of the projectile at muzzle exit. These parameters do not have an effect in a 2 DOF analysis. The "CALC" option will run the Muzzle Exit segment of PRODAS to assist in the selection of initial pitch and yaw values. After running Muzzle Exit, the program will return to this input menu:

Trajectory Analysis Conditions (Page 2)

1 - Pitch Angular Velocity : 0.00
(rad/sec, +=nose down)
2 - Yaw Angular Velocity : 0.00
(rad/sec, +=nose left)
3 - Initial Axial Spin : 13947.201
(rad/sec, +=right hand twist)
4 - Atmos. Sea Level Temp. (Deg F): 59.00
5 - Wind Range (fps, +=down range): 0.0000
6 - Cross Wind (fps, +=left): 0.0000
7 - Vertical Wind (fps, +=up): 0.0000
8 - Muzzle Velocity (ft/sec): 4350.0000
9 - Initial Altitude (ft): 0.0000
10 - Initial Horizontal Range (ft): 64.4461
11 - Initial Cross Range (ft, +=left): 0.0000
12 - Initial Time (sec): 0.0000
13 - Integration Time Increment (sec): 0.0200000
if 0.0 default = nutation freq./20.
14 - Maximum Time (sec): 70.0000
15 - Maximum Slant Range (ft): 10000.00

Output Increment	Time or Slant Range	
16 - Time	(sec):	0.1000
17 - Slant Range	(ft):	0.00

Key in item number "," new value
Key in "LIST" to relist "DONE" to continue
Key in "CALC" to calculate
Key in "PRINT" for a Line printer output

Lines one and two define the angular velocity of the projectile at the muzzle exit. These parameters do not have an effect in a 2 DOF analysis. The "CALC" option will run the Muzzle Exit segment of PRODA5 to assist in the selection of initial pitch and yaw rate values. After running Muzzle Exit, the program will return to this input menu.

Line three defines the projectile spin. A value of 60 rad/sec is assigned for fin stabilized projectiles. The program cannot handle a projectile with a spin of zero. The spin is computed from the rifling twist as defined in the stability analysis and the muzzle velocity. If the muzzle velocity is changed, a new spin rate will be computed.

Lines four through twelve define the initial atmospheric conditions and gun projectile exit conditions.

Line thirteen is the integration time step. For a 2 DOF analysis the program will default to 0.02 second. For a 6 DOF analysis the program will use the value stored in the projectile data file. For an initial analysis a value of zero should be entered. This will cause the program to compute a value equal to 1/20th the nutation frequency. This will cause an automatic redisplay of the menu. The time step may now be modified to a round value if desired.

The trajectory analysis will run until one of three conditions is reached; the projectile strikes ground ($z \leq 0$), the maximum time is reached (line 14), or the maximum slant range, the distance from the muzzle to the projectile in 3D space, is reached (line 15). If the projectile strikes the ground, the program will interpolate the output data back to $z=0$.

Trajectory output may be created by one of two methods, even increments of time or slant range. The program will allow a maximum of 500 output points to be calculated. Caution should be taken in using slant range output with high angles of attack. As a projectile comes over the top of the trajectory it is possible for the slant range to start decreasing.

If the user selects to examine/modify the aerodynamic coefficients, Table 8 will be displayed. The look of this menu will depend on the type of projectile and terminal being used. For a fin stabilized projectile there are a total of three menus. A spin stabilized projectile has two. In the small screen mode these menus each take two screens to display. To make

TABLE 8. AERODYNAMIC COEFFICIENTS

Aerodynamic Coefficients (Page 1)

Row	Column 1 Mach No.	Column 2 CX0	Column 3 CX2	Column 4 Cma	Column 5 Cma3	Column 6 Cypa	Column 7 Cnpa7	Column 8 Cip	Column 9 Cld
1	0.0100	0.1980	2.4365	2.2427	0.0000	-0.8453	0.0000	-0.0316	0.0000
2	0.6000	0.1980	2.4365	2.2427	0.0000	-0.8453	0.0000	-0.0315	0.0000
3	0.8000	0.2004	2.8771	2.2627	0.0000	-0.8453	0.0000	-0.0299	0.0000
4	0.9000	0.2200	3.3081	2.2925	0.0000	-0.9509	0.0000	-0.0284	0.0000
.									
.									
14	2.5000	0.2300	2.9058	2.8740	0.0000	-0.8453	0.0000	-0.0213	0.0000
15	3.0000	0.1900	2.4653	2.7943	0.0000	-0.8453	0.0000	-0.0202	0.0000
16	4.0000	0.1520	2.0452	2.6943	0.0000	-0.8453	0.0000	-0.0195	0.0000
17	5.0000	0.1300	1.6251	2.5943	0.0000	-0.8453	0.0000	-0.0192	0.0000

Key in column number to modify a column
Enter "s" to populate column with last value entered
Key in "DONE" to continue
Key in "LIST" to relist
Key in "PRINT" for a Line printer output

Aerodynamic Coefficients (Page 2)

Row	Column 1 Mach No.	Column 2 Cma	Column 3 Cma3	Column 4 Cma5	Column 5 Cnpa	Column 6 Cnpa3	Column 7 Cnpa5	Column 8 Cmq	Column 9 Cmq2
1	0.0100	3.2402	0.0000	0.0000	-0.8769	17.3960	-136.4598	-3.1916	0.0000
2	0.6000	3.2626	0.0000	0.0000	-0.8769	17.3960	-136.4598	-3.1916	0.0000
3	0.8000	3.3370	0.0000	0.0000	-0.7078	15.7479	-119.9791	-3.1916	0.0000
4	0.9000	3.3622	0.0000	0.0000	-0.4159	11.3185	-75.6853	-6.4809	0.0000
.									
.									
14	2.5000	3.5789	0.0000	0.0000	0.1713	0.2555	34.9451	-26.2260	0.0000
15	3.0000	3.5858	0.0000	0.0000	0.1797	0.0907	36.5930	-26.2260	0.0000
16	4.0000	3.5384	0.0000	0.0000	0.1797	0.0907	36.5930	-26.2260	0.0000
17	5.0000	3.4849	0.0000	0.0000	0.1797	0.0907	36.5930	-26.2260	0.0000

Key in column number to modify a column
Enter "s" to populate column with last value entered
Key in "DONE" to continue
Key in "LIST" to relist
Key in "PRINT" for a Line printer output

modifications to these tables first enter the column number. Next, enter line numbers and new values for each Mach number to be modified. Enter a <cr> with no line number when modifying a column. If an "S" is entered after the <cr>, all values in the column with Mach numbers higher than the last one modified will be given the values last entered.

If a fumer analysis was selected on menu number 1, the following Fumer Input Menu will be displayed:

Trajectory - FUMER Analysis - Input

```

1 - Axial Inertia at Burnout      (lbm-in**2):      0.007581
2 - Transverse Inertia at Burnout (lbm-in**2):      0.058568
3 - Projectile Weight at Burnout   (lbm):           0.230478
4 - Center of Gravity      (calibers from nose):    3.560222
5 - Multiple Nozzle Cant Angle      (deg):          0.000000
6 - Multiple Nozzle Exit Radius      (in):          0.000000
   (from projectile centerline)
7 - Burn Start Time                (sec):           0.000000
8 - Burn Stop Time                 (sec):           2.400000
9 - Do you wish to input the drag vs time      :      2
   profile or the drag vs Mach no. curve?
(0:Continue 1:Drag & Thrust vs Time 2:Drag vs Mach No.)
Key in item number "," new value
Key in "LIST" to relist "DONE" to continue
Key in "PRINT" for a Line printer output

```

On this menu the physical properties of the projectile after fumer burn out are defined. The Physical Properties segment computes properties with and without the tracer elements. Properties are assumed to vary linearly during the time of the tracer/fumer burn. It is not necessary that tracer elements exist to perform a fumer analysis. If more than one nozzle exists, the radius of the nozzle cluster and cant angle of the nozzles may be specified. The program assumes the nozzles are arranged in a circular pattern. The values entered for thrust are the thrust along the nozzle orientation. The thrust along the projectile axis will be the thrust times the cosine of the cant angle. A rotational force of thrust times the sine of the cant angle is also computed for each nozzle.

Line nine allows for the specification of projectile thrust and/or drag reduction during the projectile burn. An entry of one or two will cause additional input menu(s) to be displayed. An entry of one will display:

Trajectory - FUMER Analysis (Drag & Thrust vs Time) - Input

```

Decrease in Drag Coef. as a Function of Time
Entry #   Burn Time   Delta CX   Thrust
          sec          lbf
Key in "DONE" to continue
Key in "LIST" to relist
Key in "PRINT" for a Line printer output
Key in values separated by commas to modify

```

Up to 20 lines of input may be specified here. Each line must contain a time, delta drag, and thrust entry. Zero may be entered for thrust and drag. Time must be entered in ascending order. The drag reduction entered here is magnitude reduction (negative for increase). During the analysis, the program will perform a linear interpolation from this table.

Option Two in line nine allows for the specification of a reduced drag versus Mach number. A table of drag versus Mach number with and without fumer burn will be displayed. If stability analysis has been run, and this is a spin stabilized projectile, a base drag from McDrag will be displayed. Otherwise the base drag is specified the same as the total drag. The base drag is displayed only for reference purposes. The analysis only uses the total drag:

Trajectory - FUMER Analysis (Drag vs Mach Number) - Input

Mach Number	No Fumer		During Burn	
	Total Drag	Base Drag	Total Drag	Base Drag
0.0100	0.1980	0.1384	1: 0.1822	18: 0.1384
0.6000	0.1980	0.1411	2: 0.1822	19: 0.1411
0.8000	0.2004	0.1477	3: 0.1844	20: 0.1477
0.9000	0.2200	0.1645	4: 0.2024	21: 0.1645
0.9500	0.2590	0.1776	5: 0.2383	22: 0.1776
1.0000	0.3710	0.2518	6: 0.3413	23: 0.2518
1.0500	0.4270	0.2122	7: 0.3928	24: 0.2122
1.1000	0.4180	0.2169	8: 0.3846	25: 0.2169
1.2000	0.3920	0.2108	9: 0.3606	26: 0.2108
1.3500	0.3670	0.2015	10: 0.3376	27: 0.2015
1.5000	0.3460	0.1915	11: 0.3183	28: 0.1915
1.7500	0.3130	0.1733	12: 0.2880	29: 0.1733
2.0000	0.2820	0.1543	13: 0.2594	30: 0.1543
2.5000	0.2300	0.1200	14: 0.2116	31: 0.1200
3.0000	0.1900	0.0927	15: 0.1748	32: 0.0927
4.0000	0.1520	0.0631	16: 0.1398	33: 0.0631
5.0000	0.1300	0.0454	17: 0.1196	34: 0.0454

35 Total burn drag as % of total drag

36 Base burn drag as % of base drag

Key in item number ", " new value

Key in "LIST" to relist "DONE" to continue

Note that modifications will be reflected against each other

Key in "PRINT" for a Line printer output

This table includes four options for modifying the drag. The total drag or base drag during burn may be changed directly. This is done by modifying lines one through thirty-four.

For any change to total drag, the same magnitude change to base drag at that Mach number will be computed. Conversely, changes in base drag are reflected on the total drag. Options Thirty Five and Thirty Six allow for across the board changes by a specified percentage. With Option Thirty Five, a fractional value is specified by which the total drag for all Mach numbers will be multiplied. The magnitude change will then be subtracted from the base drag. Option Thirty Six performs the same operation on the base drag. The fractional value used is stored in the projectile model file and will be displayed when this operation is selected. It is displayed only for reference purposes so it must be reentered.

If Options Thirty Five or Thirty Six are selected the table will be redisplayed in the modified form automatically.

If desired, both the drag versus time and drag versus Mach number tables may be used. For the case of a rocket it will be necessary to use the drag versus time menu to specify the projectile thrust profile. Depending on how the drag reduction data is specified it may be necessary to use either or both menus to define the drag reduction.

If an aircraft-originated trajectory was specified in menu number one, the following menu will be displayed for specification of the aircraft parameters:

Trajectory - Aircraft Originated - Input

Aircraft Inputs

1 - Aircraft Velocity	(ft / sec):	0.000
2 - Aircraft Dive Angle	(deg., +=down):	0.000
3 - Aircraft Dive Azimuth	(deg., +=nose left):	0.000
4 - Aircraft Pitch Angle	(deg., +=nose down):	0.000
5 - Aircraft Yaw Angle	(deg., +=nose left):	0.000
6 - Gun Elevation WRT Aircraft	(deg., +=up):	0.000
7 - Gun Azimuth WRT Aircraft	(deg., +=left):	0.000

Key in item number "," new value

Key in "LIST" to relist "DONE" to continue

Key in "PRINT" for a Line printer output

For an aircraft-originated trajectory, the elevation angle used for the analysis will be the dive angle from this menu. Any other value entered will be ignored.

If a ball rotor simulation was selected on menu number one, the following menu will be displayed:

Trajectory - Ball Rotor Simulation - Input

1 - Ball Weight	(grams):	0.0000
2 - Ball CG from Projectile CG	(in):	0.0000
3 - Ball Clearance	(in):	0.0000

Key in item number "," new value
Key in "LIST" to relist "DONE" to continue
Key in "PRINT" for a Line printer output

If more than one barrel was specified in menu number one, the Multiple Barrel Input menu will be displayed:

Trajectory - Multiple Barrel Gun - Input

Multibarrel Gun Inputs

1 - Gun Half-cone Angle	(deg):	0.000
2 - Muzzle Radius	(in):	0.000
3 - Sear-off Position	(deg, +-ccclu):	0.000
from bottom vertical looking downrange		
4 - Rate of Fire	(SPM):	0.000
5 - Action Time	(msec):	0.000

Key in item number "," new value
Key in "LIST" to relist "DONE" to continue
Key in "PRINT" for a Line printer output

These inputs define the rotational motion of a Gatling gun barrel cluster. This data will determine the angular forces applied to the projectile on exit from the barrel.

This completes the data input for trajectory analysis. The program will perform the analysis and integrate the equations of motion. A fourth order Runge-Kutta integration is used. The results of the last integration step will be printed out followed by the output options:

Terminal Parameters

Velocity	=	690.244 (ft/sec)
X-dist	=	33119.441 (ft)
Y-dist	=	-129.914 (ft)
Z-dist	=	0.000 (ft)
Time	=	24.48492 (sec)

Once the terminal parameters have been displayed, the output option menu will appear:

6 DOF Trajectory Segment Output

Plots		
Time of Flight(sec)		Slant Range(ft)
1	X (ft)	21
2	Y (ft)	22
3	Z (ft)	23
4	Slant Range (ft)	24
5	Velocity (ft/sec)	25
6	Mach Number	26
7	Spin Rate (rad/sec)	27
8	Total Yaw (deg)	28
9	Drop	29
10	Drift	30
11	Gyro. Stability Factor	31
12	Pitch [THETA]-M (deg)	32
13	Yaw [PSI]-M (deg)	33
14	Angular Accel (rad/sec ²)	34
15	Angular Rate (rad/sec)	35
16	Dynamic Stability Factor	36
17	Kinetic Energy	37
38	Y vs X	
39	Z vs X	
40	Theta vs Psi	
50	Return to Input	
51	Cross Plots	
52	Return to Main Menu	
54	Tic mark switch (on)	

Tables

61	Complete Output
62	T vs X,Y,Z,XBAR,V,Spin,Drop,Deflection
63	T vs X,Y,Z,Phi,Theta,Psi,Alpha
64	T vs X,Y,Z for Projectile WRT Barrel C.L. Gun C.L., Aircraft C.L.
65	T vs X,Y,Z,V,RE

Plots are against either time-of-flight or slant range. Tables are computed for time-of-flight and will be sent to the designated output printer.

Gyroscopic and dynamic stability plots are only available if the linear theory option was selected (input menu number two).

Pitch and yaw data is only available if a 6 DOF analysis was run.

Option Fifty One will send the program to the cross plot menu. The names and descriptions of the trajectories available for plotting will be listed. Up to 10 trajectories may be selected from this list for plotting together. Approximately 500 points will be plotted together. If each curve contains 500 points and three curves are to be plotted together, then every third point will be plotted. The more curves that are plotted together, the fewer points on each curve.

Option Fifty Four will toggle the tick mark flag. The option specifies which way the toggle will go. For a slant range plot the tick marks will show each second of time of flight. For a slant range plot, the tick marks will show each 1000 feet/meters of slant range.

6 DOF Trajectory Cross Plot Segment

Time of Flight		Slant Range(ft)
1	X (ft)	21
2	Y (ft)	22
3	Z (ft)	23
4	Slant Range (ft)	24
5	Velocity (fps)	25
6	Mach No.	26
7	Spin Rate (rad/sec)	27
8	Total Yaw (deg)	28
9	Drop (mrad)	29
10	Drift (mrad)	30
11	Gyroscopic Stability Factor	31
12	Theta-M (deg)	32
13	Psi-M (deg)	33
14	Dynamic Stability Factor	34
15	Kinetic Energy	35

38 Y vs X

39 Z vs X

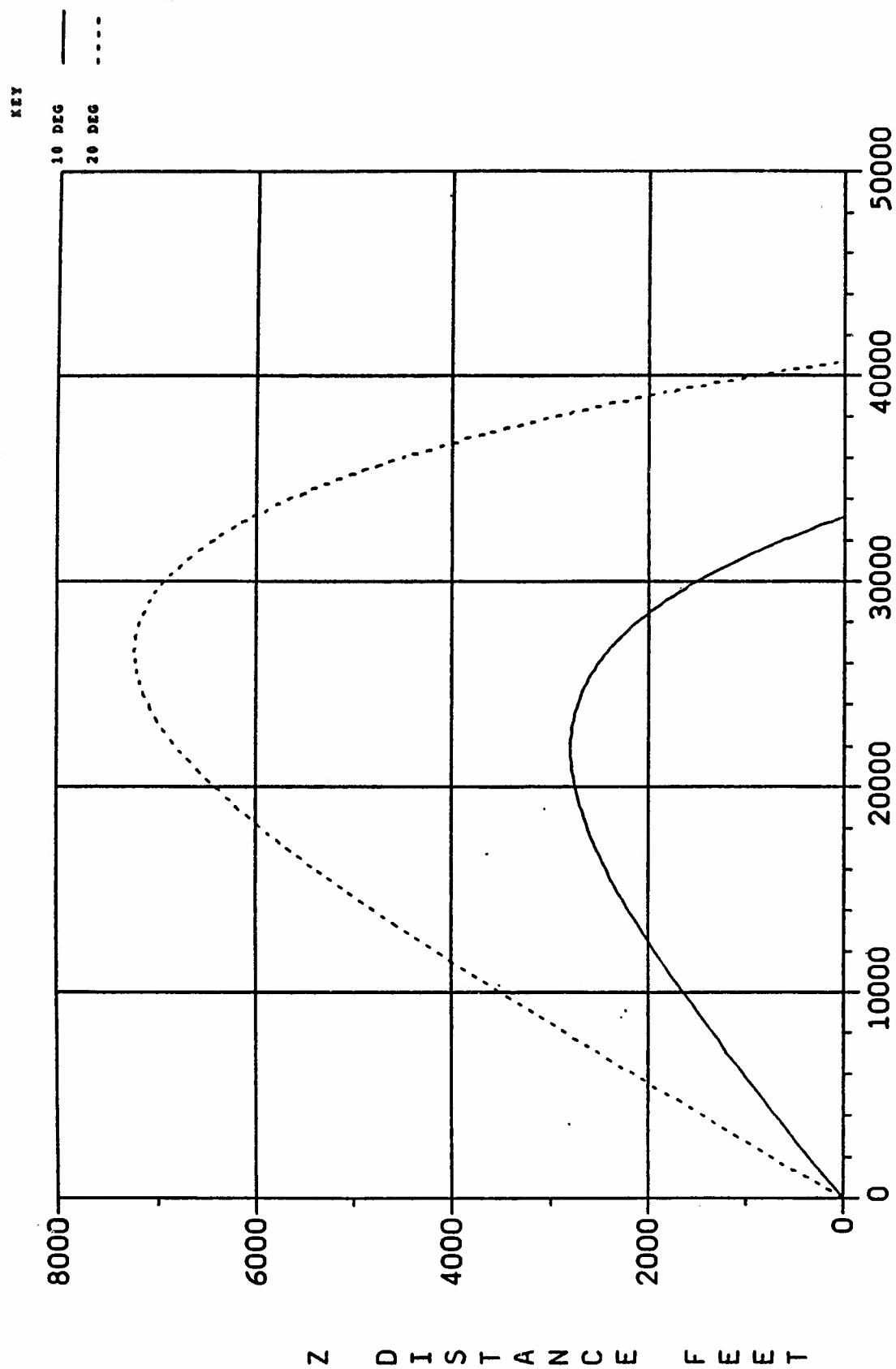
50 Return to Input

52 Return to Main Menu

53 Return to Plot Menu

54 Tic mark switch (on)

Figure 16 shows a cross plot of Z vs X for elevation angle variation.



X DISTANCE FEET

Figure 16. Cross Plotted Trajectory

SECTION VI
LINEAR THEORY

1. GENERAL

Within one executable program both the data input and analysis are performed. Once data has been input it may be stored for future reference. The following options menu will be displayed for data input/analysis:

Enter the number of the desired option

- 1 - Edit Input Data
- 2 - Run Analysis
- 3 - Store Master File Data
- 4 - Exit Linear Theory Program

:

The program will not allow for analysis (Option Two) until data has been returned from the editing module (Option One). Data may be stored (Option Three) before or after the running of an analysis. It is advised that data be stored on exiting the edit module. Storing input at this time will prevent data being lost if a hard crash occurs during the analysis. If the results of the analysis are acceptable, it is advised that the data be stored again. By doing this, the parameters found from the analysis will be the initial estimates for any future reduction of this shot.

2. LINEAR THEORY INPUT

Upon entering the data Edit/Input module, the following menu of options will be displayed:

- 1 - Initialize new data set
- 2 - Retrieve cataloged data set
- 3 - Shot number and description
- 4 - Linear Theory analysis Flags
- 5 - Projectile physical properties
- 6 - Analysis reference data
- 7 - Initial aerodynamic coefficient estimates
- 8 - Initial aerodynamic parameters estimates
- 9 - Aerodynamic fit flags
- 10 - Atmospheric parameters
- 11 - Edit current Tunnel XYZ data
- 12 - Use new data set from Tunnel XYZ file
- 13 - Delete current Tunnel XYZ data
- 14 - Done

Each of the above options will cause a different menu of parameters to be presented for editing. A common procedure for editing has been established. The line number and new value are entered, with one change per line. A "LIST" option will redisplay the data with the changes. "DONE" will terminate the edit session and return to the above menu. "R" will cause the program to step through each entry in the edit menu. The line numbers within the menu will be incremented automatically.

The first step in an editing session is either to retrieve an existing data set or to initialize a new data set. Edit Option One is used to initialize a new data set. Under this option, the program will automatically step through Options Three through Ten and Option Twelve.

To retrieve data stored during a previous data reduction session use Edit Option Two. If the user chooses to retrieve existing data, a question will appear requesting the shot number. A list of available shots may be displayed at this time:

Key in 10 digit projectile title (or LIST): LIST

Enter the shot group number to list: -1

Linear Theory Projectile Titles
Previous Reduction

Shot Group	Shot Number	Date	Time	Description
9	BS87040819	1-SEP-87	13:04:00	40 MM HEDP TUBULAR REREAD
9	BS87040613	1-SEP-87	13:04:00	40 MM HEDP TUBULAR REREAD
9	BS87040209	1-SEP-87	11:57:20	40 MM HEDP TUBULAR REREAD
8	BS87080617	24-AUG-87	15:24:13	20 MM BOOMED/CASED
8	BS87080618	24-AUG-87	15:24:13	20 MM BOOMED/CASED
0	BS87032490	26-JUN-87	10:37:12	40 MM HEDP TUBULAR
0	BS87032797	26-JUN-87	10:37:12	40 MM HEDP TUBULAR
0	BS87042434	15-JUN-87	10:49:38	20 MM BOOMED/CASED
9	BS87042333	15-JUN-87	10:49:38	20 MM BOOMED/CASED

Key in 10 digit projectile title (or LIST): BS87040716

Note that in the above table a negative shot group number was entered. A positive group number will cause only that shot group to be displayed. A negative group number will cause all shot groups to be displayed. Within this table are the date and time that the shot was previously cataloged.

Edit Option Three will allow the user to specify a new shot number and description.

Edit Option Four contains the analysis option flags:

Linear Theory Analysis Flags

1 - Starting point to fit	[LN]: 1
2 - Length of first section to be fit	[NA]: 25
3 - Incremental section increment	[ND]: 0
4 - Summing section increment	[NB]: 2
5 - Frequency guess	[NAUTO]: 0
0: Do not use Cma 1: Use Cma	
6 - Roll Flag	[NROLL]: 0
0: Roll data not available (or do not use)	
1: Roll data available (automatic unwind)	
2: Use roll data as is (already unwound)	
3: Unwind roll data	
7 - Automatic guess routine flag	[NSG]: 0
0: Do not use 1: Use	
8 - Spin Flag	[NSPIN]: 0
0: Spin stabilized (fixed plane)	
1: Fin stabilized (fixed plane)	
2: Fin stabilized (body fixed)	
3: Fin stabilized Cma <> -CNB (body fixed)	
9 - Sections Flag	[NSECT]: 3
0: Use LN, NA, ND, NB	
1: Use automatic sections (Output sectional fits)	
2: Use automatic sections (Output 1 to NT)	
3: Help	
10 - Shot Group Number	[IGRP]: 0

Key in item number ", " new value

Key in "LIST" to relist "DONE" to continue

Key in "R" to step through input

Within this table, LN,NA,ND,NB are used to define the section of range stations to be used in fitting the data and how the data will be incremented.

NROLL is used by the program to flag the routines used to analyze the roll data.

If NSG is set on (set to 1), the program will automatically select the parameters to fit.

NSPIN specifies the type of projectile, fin or spin stabilized, and the coordinate system, fixed plane or body fixed.

If NSECT is set to three, the HELP routines will be called. These routines give the user a chance to control fit curve fitting interactively to help get things started. During the HELP phase only yaw motion is being analyzed. Plotted and tabulated data is available for examination. (See next section on Linear Theory Help.)

The shot group number is initially set by the TDBIAS program and may be modified here if desired.

Edit Option Five contains the physical properties of the projectile to be analyzed:

Projectile Properties

1 - Projectile diameter	[D]	(in):	1.558
2 - Axial moment of inertia	[IX]	(slug-ft-in):	0.0005250
3 - Y axis moment of inertia	[IY]	(slug-ft-in):	0.0010540
4 - Z axis moment of inertia	[IZ]	(slug-ft-in):	0.0010540
5 - Product of inertia	[IXY]	(slug-ft-in):	0.0000000
6 - Projectile weight	[WGT]	(gram):	244.77800
7 - Center of gravity	[XCG]	(from nose):	0.612
8 - Projectile length	[XL]	(in):	3.084

Key in item number "," new value

Key in "LIST" to relist "DONE" to continue

Key in "R" to step through input

Edit Option Six contains the analysis reference parameters:

Analysis Reference Parameters

1 - Initial roll rate	[CA]	(deg/ft):	93.00000
2 - Roll pin orientation	[RBAIS]	(deg):	0.00000
3 - Reference mach number	[MREF]	:	0.60000
4 - Reference diameter	[DIAR]	(in):	1.55764
5 - Reference CG location	[XCGR]	(from nose):	0.61200
6 - Reference length	[XLR]	(in):	3.08440
7 - Number of fins	[XFIN]	(symmetry planes):	1
8 - Roll acceleration	[PH2]	(deg/ft**2):	0.0000E+00

Key in item number "," new value

Key in "LIST" to relist "DONE" to continue

Key in "R" to step through input

Edit Option Seven allows for modification of the aerodynamic coefficient estimates:

Estimates of Aerodynamic Coefficients

1 - C_{Na}	:	2.00000
2 - C_{ma}	:	1.40000
3 - C_{lp}	:	-0.02600
4 - C_{ld}	:	0.00000
5 - C_X Mach	:	0.00000
6 - C_{Xa2}	:	2.30000
7 - Gun Barrel Twist (cal/rev):		29.71000

Key in item number ",", new value

Key in "LIST" to relist "DONE" to continue

Key in "R" to step through input

Within linear theory only the gun barrel twist is used. The twist is used to determine the initial roll rate of the projectile. The other coefficients are just passed through the data file for initial estimates by the 6 DOF program.

Edit Option Eight allows for modification of the initial aerodynamic parameter estimates used by linear theory. The values of these parameters will change during the linear theory reduction. When a good fit is achieved the projectile file should be stored. This will cause the final (fit) values of the estimates to be retained as a future starting point:

Initial Aerodynamic Parameter Estimates

1 - Nutation vector	[K1]	(deg):	0.17710
2 - Precession vector	[K2]	(deg):	0.09820
3 - Nutation damping exponent	[L1]	(1/ft):	0.00070
4 - Precession damping exponent	[L2]	(1/ft):	0.00700
5 - Nutation vector orientation	[P1]	(deg):	299.06381
6 - Precession vector orientation	[P2]	(deg):	273.14471
7 - Nutation frequency	[W1]	(1/ft):	56.48310
8 - Precession frequency	[W2]	(1/ft):	23.84210
9 - Nutation freq. change	[WD1]	(deg/ft**2):	0.00600
10 - Precession freq. change	[WD2]	(deg/ft**2):	0.00340
11 - Trim vector	[K3]	(deg):	0.00000
12 - Trim vector orientation	[P3]	(deg):	0.00000

Key in item number ",", new value

Key in "LIST" to relist "DONE" to continue

Key in "R" to step through input

Edit Option Nine allows for modification of the parameter fit flags. The flags that are set determine which estimates may be modified by the program during the data fitting:

Aerodynamic Modification Fit Flags

1 - Nutation vector	[K1] : 1
2 - Precession vector	[K2] : 1
3 - Nutation damping exponent	[L1] : 0
4 - Precession damping exponent	[L2] : 1
5 - Nutation vector orientation	[P1] : 1
6 - Precession vector orientation	[P2] : 1
7 - Nutation frequency	[W1] : 1
8 - Precession frequency	[W2] : 1
9 - Nutation freq. change	[WD1] : 0
10 - Precession freq. change	[WD2] : 0
11 - Trim vector	[K3] : 0
12 - Trim vector orientation	[P3] : 0
(0 - do not fit : 1 - fit)	
13 - Restart flag	[RES] : 0
(0 - Restart : 1 - No restart)	

Key in item number "," new value

Key in "LIST" to relist "DONE" to continue

Key in "R" to step through input

If the HELP option is to be run, these flags may be changed within that module.

Edit Option Ten allows for modification of the atmospheric parameters. Either relative humidity or air density may be specified. If either value is changed, the other will be computed and displayed:

Atmospheric Conditions

1 - Air temperature	(Deg C):	19.600
2 - Atmospheric pressure	(mbar):	1026.200
3 - Relative humidity	:	0.460
or		
4 - Air density	(slug/ft**3):	0.002361

Key in item number "," new value

Key in "LIST" to relist "DONE" to continue

Edit Option Eleven allows the user to modify time and roll data for any of the stations along the range. A table of the time and roll data for each range station along with the station distances will be displayed. Station distances may not be changed, they are only displayed for reference purposes. Entering a negative time will remove a station from the analysis:

Tunnel XYZ data for editing

Enter negative time to remove a station

Station Distance (feet)	Time (sec)	Roll (deg)	Station Distance (feet)	Time (sec)	Roll (deg)
11.9377 (1)	0.5584267	(14) -99.	242.0256 (27)	0.7894410	(39) -99.
17.1983 (2)	0.5634965	(15) -99.	252.0643 (28)	0.7999383	(40) -99.
27.1724 (3)	0.5731447	(16) -99.	271.9348 (29)	0.8207810	(41) -99.
47.2351 (4)	0.5925861	(17) -99.	276.9530 (30)	0.8260718	(42) -99.
57.1083 (5)	0.6022863	(18) -99.	291.9944 (31)	0.8419708	(43) -99.
67.0824 (6)	0.6120735	(19) -99.	306.9884 (32)	0.8578804	(44) -99.
72.1105 (7)	0.6170182	(20) -99.	322.0588 (33)	0.8739316	(45) -99.
76.9907 (8)	0.6218238	(21) -99.	352.1425 (34)	0.9062108	(46) -99.
151.9478 (9)	0.6967998	(22) -99.	382.1923 (35)	0.9387400	(47) -99.
181.9187 (10)	0.7273291	(23) -99.	397.1584 (36)	0.9550332	(48) -99.
186.9524 (11)	0.7324781	(24) -99.	412.1839 (37)	0.9714601	(49) -99.
212.0999 (12)	0.7583820	(25) -99.	442.1961 (38)	1.0044963	(50) -99.
222.1359 (13)	0.7687663	(26) -99.			

Key in item number ", " new value

Key in "LIST" to relist "DONE" to continue

If a station has been removed a -99 will be displayed for the roll angle.

Edit Option Twelve allows for the replacement of the Tunnel XYZ data set with the data for another shot number. The projectile name and description will be replaced as well, with that of the new Tunnel XYZ data set. All other data will remain the same as it was.

Edit Option Thirteen removes all Tunnel XYZ data but all other data remains.

3. LINEAR THEORY HELP

If the Linear Theory HELP option is selected in the Linear Theory Input (setting flag number nine to three in Edit Option Four), the program will branch into the HELP mode and remain there until directed otherwise. This

module performs a reduction on the yaw data and helps to refine the initial estimates before running the full linear theory reduction. The HELP input menu is:

BS87040716 40mm HEDP Tubular
28-SEP-87 16:18:26

Station Options

1 - Starting Point to Fit : 1 @ 11.94 (ft)
2 - Length Of First Fit Section : 25 @ 442.20 (ft)
3 - Summing Section Increment : 2

Initial Estimates

Fit Flag

11 -	1.0000	Nutation Vector	[K1]	(deg): 1 - 31
12 -	1.0000	Precession Vector	[K2]	(deg): 1 - 32
13 -	0.0007	Nutation Damping Exponent	[L1]	(1/ft): 0 - 33
14 -	0.0070	Precession Damping Exponent	[L2]	(1/ft): 0 - 34
15 -	299.0000	Nutation Vector Orientation	[P1]	(deg): 1 - 35
16 -	273.0000	Precession Vector Orientation	[P2]	(deg): 1 - 36
17 -	44.0000	Nutation Frequency	[W1]	(1/ft): 1 - 37
18 -	25.0000	Precession Frequency	[W2]	(1/ft): 1 - 38
19 -	0.0060	Nutation Frequency Change	[WD1]	(deg/ft**2): 0 - 39
20 -	0.0034	Precession Frequency Change	[WD2]	(deg/ft**2): 0 - 40
21 -	0.0000	Trim	[K3]	(deg): 0 - 41
22 -	0.0000	Trim Orientation	[P3]	(deg): 0 - 42

Key in item number ", " new value

Key in "LIST" to relist "DONE" to continue

The distances shown in lines one and two are station locations and are output for reference purposes. Once the input data is satisfactory, enter DONE to run the analysis.

The HELP output will display the solution for the parameters and the probable error in the yaw:

BS87040716 40mm HEDP Tubular
28-SEP-87 16:18:26

HELP Results

Yaw Error (deg): 0.314
Starting Point to Fit : 1 11.94 (ft)
Length Of First Fit Section : 25 442.20 (ft)
Summing Section Increment : 2
Total Number of Sections : 25 442.20 (ft)

Analysis Parameters

Mutation Vector	[K1]	(deg):	0.39889
Precession Vector	[K2]	(deg):	1.05130
Mutation Damping Exponent	[L1]	(1/ft):	0.00070
Precession Damping Exponent	[L2]	(1/ft):	-0.00308
Mutation Vector Orientation	[P1]	(deg):	288.82666
Precession Vector Orientation	[P2]	(deg):	274.06430
Mutation Frequency	[W1]	(deg/ft):	44.45790
Precession Frequency	[W2]	(deg/ft):	25.36411
Mutation Frequency Change	[WD1]	(deg/ft**2):	-0.00067
Precession Frequency Change	[WD2]	(deg/ft**2):	0.02859
Trim	[K3]	(deg):	0.00000
Trim Orientation	[P3]	(deg):	0.00000

:

At this point, one of the output options may be selected. A <cr> will cause the option menu to be displayed if the number desired is not known.

The following output options exist within the HELP module:

Select desired option

- 1 - Add section increment and continue in Help
- 2 - Edit input parameters
- 3 - Reset estimates to original
- 4 - Reset estimates to previous analysis
- 5 - Display data list (I-NT)
- 6 - Display yaw fit (LN-NA)
- 7 - Exit Help / Resume Linear Theory analysis
- 8 - Exit analysis program
- 9 - Plot Alpha vs X
- 10 - Theta vs X
- 11 - Psi vs X
- 12 - Theta vs Psi
- 13 - Theta & PSI vs X
- 14 - Theta vs Psi (step)

:

Option One will increment the length of the fit by the number specified in the summing section increment. The HELP routine will then be repeated for this set of conditions.

Option Two will return the program to the input menu in HELP. At this point the user may change parameter estimates or fit flags. The program will then analyze the motion for the new set of conditions.

Option Three causes the fit flags and parameter estimates to be returned to what they were when the HELP module was entered. The program will proceed to the input edit menu.

Option Four will reset the estimates to what they were before the last pass through the fitting routines. The program will return to the edit menu for user action.

Option Five will display a table of the motion data as read from the film. The following shows a partial list of this output:

Time (sec)	Down-Range Horizontal Vertical						
	Travel	Motion	Motion	Pitch	Yaw	Roll	Raw Roll
	[X] (ft)	[Y] (feet)	[Z] (feet)	[THETA] (deg)	[PSI] (deg)	[PHI] (deg)	(deg)
0.0000000	11.9377	4.56981	0.91997	-0.04756	-1.02851	0.0	0.0
0.0050698	17.1983	4.59496	0.99552	-0.15527	0.51796	0.0	0.0
0.0147180	27.1724	4.64285	1.10731	-0.23319	-0.29336	0.0	0.0
0.0341594	47.2351	4.80058	1.32640	-0.91906	5.79866	0.0	0.0
0.0438596	57.1083	4.79740	1.43508	-0.60334	0.27905	0.0	0.0
0.0536468	67.0824	4.85454	1.54357	-0.93052	-1.11118	0.0	0.0

Option Six displays a list of the yaw fit together with the pitch and yaw from the film reading. The following shows a partial display from a reduction:

Time (sec)	Travel [X] (feet)	Pitch-Missile		Yaw-Missile	
		Experimental (deg)	Calculated (deg)	Experimental (deg)	Calculated (deg)
0.0000000	11.938	0.775	1.347	-1.302	-1.173
0.0050698	17.198	0.549	0.788	0.243	-0.160
0.0147180	27.172	0.398	0.527	-0.686	-0.251
0.0341594	47.235	-0.292	-0.106	5.503	9.754
0.0438596	57.108	0.024	-1.123	0.123	0.423
0.0536468	67.082	-0.311	-0.656	-1.445	-2.412

Option Seven will terminate the HELP function and continue Linear Theory with the current set of parameter estimates.

Option Eight will terminate the Linear Theory analysis.

Options Nine through Fourteen will create plots of the projectile motion as determined by the last pass through the data reduction. The experimental points will be superimposed on the motion plots for the length of the fit being analyzed. Figure 17 shows pitch and yaw data for travel down the range. Figure 18 shows a Theta versus Psi step plot. On the step plots the points

BS87040716 40 MM HEDP TUBULAR

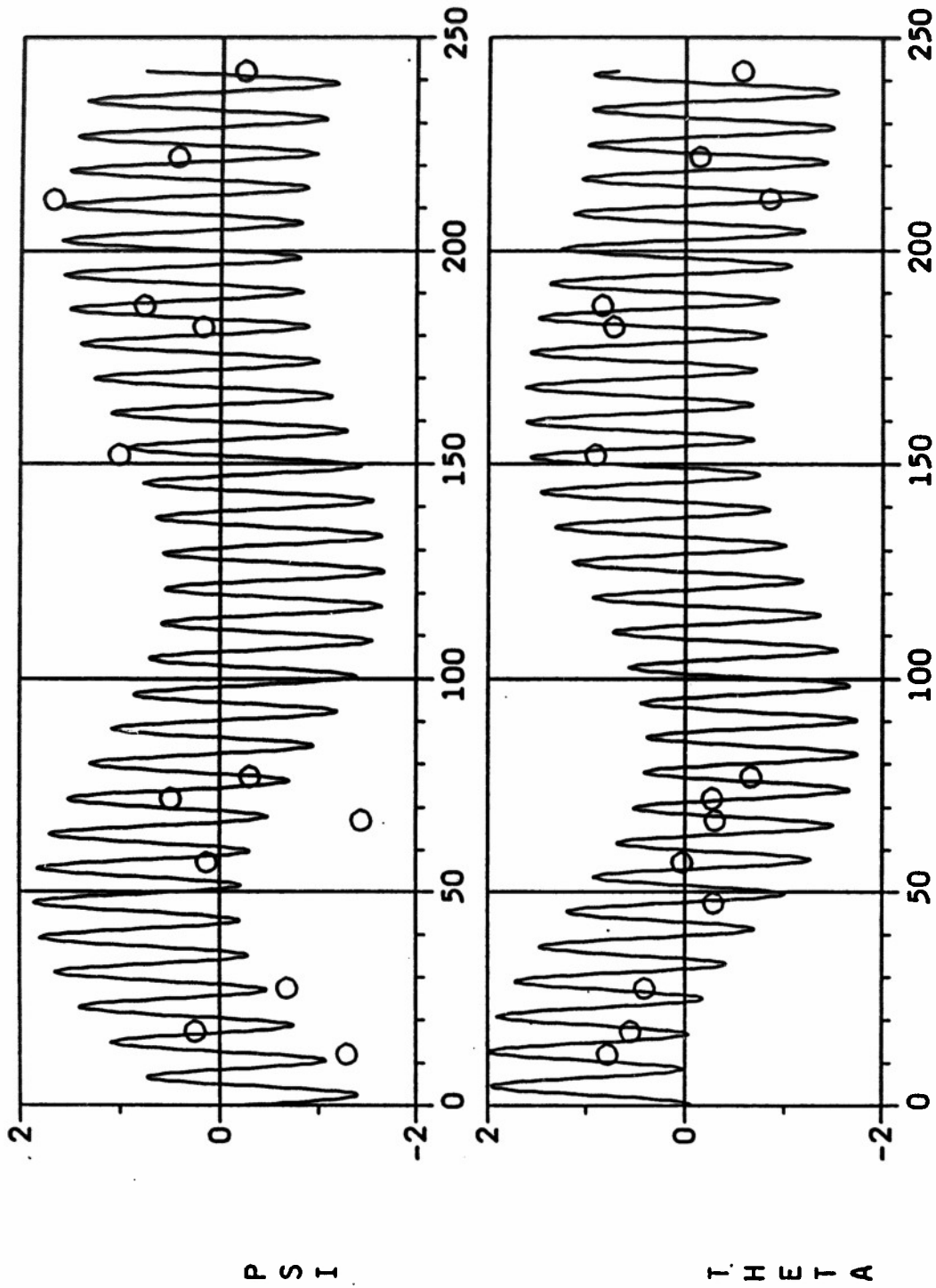
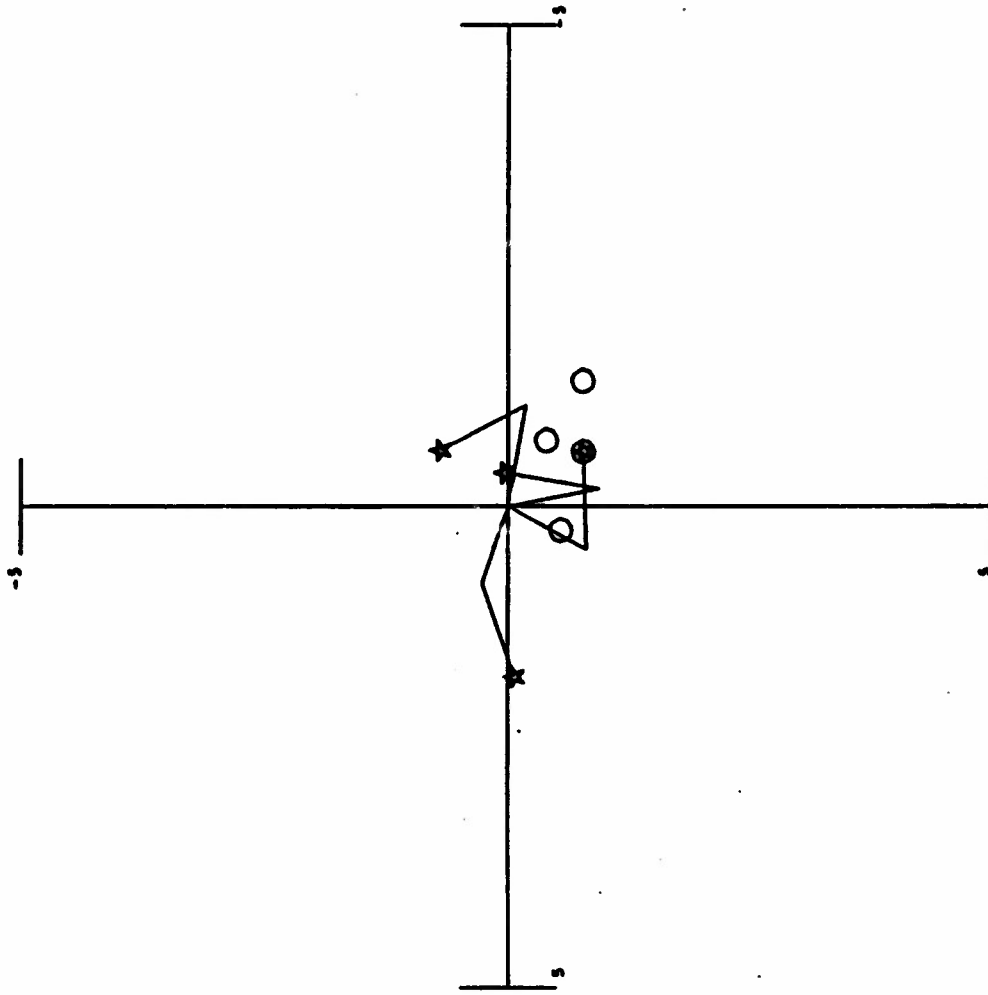


Figure 17. Linear Theory Angular Motion Fit

BS87040716 40 MM HEDP TUBULAR

LINEAR THEORY REDUCTION:



YAW [PSI] (DEG)

Figure 18. Linear Theory Vector Orientation

are displayed one-at-a-time with a pause for the user to type <space bar> between points. Some terminals may also require a <cr>. If any letter is typed other than <space bar> the plot will terminate there. For each point displayed in the step plot the nutation and precession vectors are drawn.

4. LINEAR THEORY ANALYSIS

Linear Theory Analysis may be run either directly from the Input module or after running the HELP module. The user will be prompted for a number of output options.

If roll data exists and the user selected the unwind option, the user has the option of examining this data.

Once the analysis has been performed, the user may examine the analysis summary. It is recommended that this data be examined before cataloging the data.

The user must select whether or not to catalog the data in the summary file. If data already exists for this shot number, it will be overwritten.

The user may choose to use the same output results for plotting. Plot data is maintained by shot number so the output data, once saved, will be available until the user decides to delete the data.

Two forms of tabulated output are available. The full printout and a summary printout. The summary printout is a subset of the full printout and is not offered for printing if the full printout has already been selected. Table 9 shows an abbreviated summary printout.

5. LINEAR THEORY OUTPUT

The output program for linear theory allows the user to create plots of the coefficients, experimental points, or integrated motion. Tabulated summaries may be made of any shot group.

The coefficient plot menu is as follows:

Summary Segment - Linear Theory Reductions

Shot Group 0 - 40mm HEDP

- 1 - CD
- 2 - CD Mach
- 3 - CDO Mach
- 4 - CNa
- 5 - Cma
- 6 - Cnpa
- 7 - Cmq
- 99 - Done

:

TABLE 9. LINEAR THEORY ANALYSIS SUMMARY

Linear Theory Input Summary

Shot Number: TEST25
26-OCT-87 14:29:46

Starting Point to Fit [LM]: 1
Length of First Fit Section [NA]: 15
Incremental Section Increment [ND]: 0
Summing Section Increment [NB]: 10
Frequency Guess [MAUTO]: 0
Roll Flag [MROLL]: 1
Automatic Guess Flag [MSG]: 1
Spin Flag [NSPIN]: 0
Sections Flag [NSECT]: 1
Shot Group Number [IGRP]: 0

Projectile Physical Properties

Diameter (in): 0.9790
Axial Inertia (in-lbf-sec²): 0.0001430
Transverse [Y] Inertia (in-lbf-sec²): 0.0013300
Transverse [Z] Inertia (in-lbf-sec²): 0.0013300
Inertial Cross Product (in-lbf-sec²): 0.0000000
Weight (gram): 185.2911
Center of Gravity (fraction from nose): 0.5613
Length (in): 4.5570

Roll Rate (deg/ft): 183.7148
Air Density (slug/ft³): 0.0023769
Speed of Sound (ft/sec): 1116.53
Reference Mach Number: 2.9100
Reference Center of Gravity (fraction from nose): 0.5613
Reference Length (in): 4.5570
Number of Fins: 1.

CNa : 3.08700
Cma : 2.73530
Clp : 0.00000
Cld : 0.00000
CX Mach : 0.00000
CX2 : 2.75000
Twist (cal/rev): 24.02000

TABLE 9. LINEAR THEORY ANALYSIS SUMMARY (CONTINUED)

Initial Estimates		Parameter		Solve for Flag	
-----		-----		-----	
Nutation Vector		[K1]	(deg):	1.00000	1
Precession Vector		[K2]	(deg):	1.00000	1
Nutation Damping Exp.		[L1]	(1/ft):	-0.00100	1
Precession Damping Exp.		[L2]	(1/ft):	-0.00100	1
Nutation Vector Orientation		[P1]	(deg):	1.00000	1
Precession Vector Orientation		[P2]	(deg):	1.00000	1
Nutation Frequency		[W1]	(deg/ft):	17.38780	1
Precession Frequency		[W2]	(deg/ft):	2.36120	1
Nutation Frequency Change		[WD1]	(deg/ft**2):	0.00000	0
Precession Frequency Change		[WD2]	(deg/ft**2):	0.00000	0
Trim Vector		[K3]	(deg):	0.00000	0
Trim Vector Orientation		[P3]	(deg):	0.00000	0
Tunnel XYZ Input Data (partial list)					

Time	Down-Range Travel	Horizontal Motion	Vertical Motion	Raw Roll	Pitch
(sec)	[X] (ft)	[Y] (ft)	[Z] (ft)	[PHI] (deg)	[THETA] (deg)
0.0000000	7.3086	-0.00068	0.00137	262.1	-2.002
0.0014470	12.5220	0.00261	-0.00019	142.5	-4.708
0.0026045	16.6885	0.00648	0.00232	189.6	-3.380
0.0054985	27.0960	0.01116	0.01264	307.5	-1.692
0.0109970	46.8224	0.01699	0.04528	344.7	-0.070
0.0138910	57.1808	0.01475	0.06754	100.2	-1.693
0.0167850	67.5217	0.00915	0.09079	215.0	1.501
Drag Estimate					

LN = 1 N = 50 NC = 4					

Sum of Residuals		Probable Error			
0.0001576		0.0012485			
0.0000000		0.0000005			
0.0000000		0.0000005			
-----		-----			
Value		Probable Error			
-----		-----			
D1:	-0.101E-05	0.212E-06			
D2:	0.277E-03	0.298E-08			
D3:	0.218E-07	0.111E-10			
D4:	0.147E-11	0.115E-13			

TABLE 9. LINEAR THEORY ANALYSIS SUMMARY (CONTINUED)

J	NP	Weight Factor	Down-range Travel (ft)	Raw Unwound Roll (deg)	Roll Rate (deg/ft)	ADIFF	ERROR	R1	R2	R3	R4	Roll Error (deg)
1	1	1.0	7.31	262.1	183.7	0.6	0.0	36262.	183.71	0.00000E+00	0.00000E+00	0.00000E+00
2	2	1.0	12.52	142.5	183.7	0.5	-2.6	36262.	183.71	0.00000E+00	0.00000E+00	0.00000E+00
3	3	1.0	16.69	189.6	183.7	0.5	-4.3	36262.	183.71	0.00000E+00	0.00000E+00	0.00000E+00
4	4	1.0	27.10	307.5	183.7	0.5	-10.2	36262.	183.71	0.00000E+00	0.00000E+00	0.00000E+00
5	5	1.0	46.82	344.7	183.7	0.6	-23.3	36262.	183.71	0.00000E+00	0.00000E+00	0.00000E+00
6	6	1.0	57.18	100.2	184.3	0.7	-6.9	36261.	184.31	0.00000E+00	0.00000E+00	0.55121

Experimental Trajectory Data Points

Time (sec)	Down-range Travel (ft)	Horizontal Motion [Y] (feet)	Vertical Motion [Z] (feet)	Pitch Missile [THETA] (deg)	Yaw Missile [PSI] (deg)	Unwound Roll [PHI] (deg)	Fixed-Plane [THETA] (deg)	Yaw Fixed-Plane [PSI] (deg)	Roll [PHI] (deg)
0.0000000	7.3086	-0.00068	0.00137	-1.995	3.739	262.1	-2.002	3.751	262.1
0.0014470	12.5220	0.00261	-0.00019	-4.688	1.036	1222.5	-4.708	1.057	142.5
0.0026045	16.6885	0.00648	0.00232	-3.348	-2.129	1989.6	-3.380	-2.104	189.6
0.0054985	27.0960	0.01116	0.01264	-1.630	1.737	3907.5	-1.692	1.765	307.5
0.0109970	46.8224	0.01699	0.04528	0.036	0.374	7544.7	-0.070	0.375	344.7
0.0138910	57.1808	0.01475	0.06754	-1.575	-4.160	9460.2	-1.693	-4.184	100.2

Linear Theory Analysis Final Results

Time (sec)	Time Error (micro sec)	Down-Range Travel [X] (feet)	Horizontal Motion [Y] (feet)	Vertical Motion [Z] (feet)	Y Error (feet)	Z Error (feet)	Velocity (ft/sec)
0.0807414	0.59	291.8115	-0.22228	0.22759	-0.00102	0.00066	3445.3
0.0850823	0.81	306.7485	-0.23489	0.22330	0.00034	-0.00091	3437.1
0.0894232	0.89	321.6506	-0.24307	0.22054	0.00144	-0.00005	3428.9
0.0937641	0.44	336.5192	-0.25129	0.22035	0.00026	0.00188	3420.8
0.0983945	0.77	352.3379	-0.25863	0.21975	-0.00038	-0.00054	3412.2
0.1070763	0.75	381.8923	-0.27452	0.23152	-0.00058	-0.00051	3396.2
0.1117067	0.31	397.5996	-0.28668	0.23761	0.00068	-0.00045	3387.6

Time Error (micro sec)	Down-Range Travel [X] (feet)	Swerve Error [Y-Z] (feet)
0.5297	0.0018	0.0007

TABLE 9. LINEAR THEORY ANALYSIS SUMMARY (CONTINUED)

Linear Theory Analysis Summary : Page 1

Projectile Physical Properties

Diameter	0.979 (in)	24.87 (mm)
Weight	0.408 (lbm)	185.29 (gram)
Axial Inertia	0.055 (lbm-in ²)	161.57 (gm-cm ²)
Transverse [Y] Inertia	0.513 (lbm-in ²)	1502.70 (gm-cm ²)
Transverse [Z] Inertia	0.513 (lbm-in ²)	1502.70 (gm-cm ²)
Inertial Cross product	0.000 (lbm-in ²)	0.00 (gm-cm ²)
Length	4.557 (in)	11.575 (cm)

Center of Gravity (fraction from nose) 0.5613

Air Properties

Density	0.0023769 (slug/ft ³)	0.0012250 (gm/cm ³)
Speed of sound	1116.53 (ft/sec)	340.32 (m/sec)
Reynolds Number	8256479.	
Temperature (Deg C)	14.9989	
Pressure (mbar)	1012.9569	
Relative Humidity	0.0000	

Linear Theory Analysis Summary : Page 2

Starting point to fit	[LN]	:	1.	15.	27.
Number of Stations in Fit	[M]	:	27.	37.	50.
Length of first section to fit	[NA]	:	27.	23.	24.
Total Number of Stations	[NT]	:	50.	50.	50.
Mutation Vector	[K1]	(deg):	2.5328	2.6845	2.5879
Precession Vector	[K2]	(deg):	2.4382	2.0594	2.2071
Mutation Damping Exponent	[L1]	(1/ft):	-0.000660	-0.000790	-0.000678
Precession Damping Exponent	[L2]	(1/ft):	-0.003402	-0.002805	-0.003066
Mutation Vector Orientation	[PH1]	(deg):	84.64	90.62	93.66
Precession Vector Orientation	[PH2]	(deg):	149.34	131.54	168.69
Mutation Frequency	[W1]	(deg/ft):	17.5108833	17.4876423	17.4679527
Precession Frequency	[W2]	(deg/ft):	2.2718909	2.4046700	2.1866343
Mutation Freq. Change	[WD1]	(deg/ft ²):	0.0025113	0.0025483	0.0026129
Precession Freq. Change	[WD2]	(deg/ft ²):	-0.0002248	-0.0006820	-0.0000470
Trim Vector	[K3]	(deg):	0.0000000	0.0000000	0.0000000
Trim Vector Orientation	[PH3]	(deg):	0.0000000	0.0000000	0.0000000

TABLE 9. LINEAR THEORY ANALYSIS SUMMARY (CONCLUDED)

Swerva Constant	[S1]	:	0.0006181	0.0006181	0.0006181	0.0006181	0.0006181
Swerva Constant	[S2]	(1/ft):	0.0375046	0.0389002	0.0327238	0.0339633	0.0339633
Roll Constant	[R1]	:	262.3717	263.4615	249.1992	277.1478	277.1478
Roll Constant	[R2]	(1/ft):	183.9213	183.8760	184.0632	183.8345	183.8345
Roll Constant	[R3]	(1/ft+2):	0.0103441	0.0106711	0.0098738	0.0105046	0.0105046
Probable Error in Distance	[PE-X]	(ft):	0.0016209	0.0016212	0.0012824	0.0017719	0.0017719
Probable Error in Angle	[PE-A]	(deg):	0.0636649	0.0689415	0.0611934	0.0525243	0.0525243
Probable Error in Swerve	[PE-S]	(ft):	0.0009292	0.0008928	0.0007941	0.0006600	0.0006600
Probable Error in Time	[PE-T]	(msec):	0.4737	0.4601	0.3731	0.5297	0.5297
Probable Error in Roll	[PE-R]	(deg):	0.7583	0.7637	0.7953	0.6236	0.6236
Distance to First Fit Station	[X-LM]	(ft):	7.3086	7.3086	156.7715	291.8115	291.8115
Distance to Last Fit Station	[X-M]	(ft):	662.4832	291.8115	457.1191	662.4832	662.4832
Del Bar Squared	[DBSQ]	:	5.7680	8.1690	5.4176	3.9147	3.9147
	[DBEF]	:	9.7690	13.7618	10.2747	7.7839	7.7839
	[DBEP]	:	9.2684	13.2795	9.7676	7.3559	7.3559

 Linear Theory Analysis Summary : Page 3

Mach Number	[MACH]	:	3.0646	3.1562	3.0783	2.9957	2.9957
Cma	[CMA]	:	2.6846	2.6750	2.6750	2.6956	2.6956
Cmq	[CMQ]	:	-13.6765	-14.1923	-11.1757	-11.9708	-11.9708
Cnpe	[CnPA]	:	0.9209	1.0288	0.6213	0.7535	0.7535
CD	[CD]	:	0.3258	0.3237	0.3255	0.3270	0.3270
CD0	[CD0]	:	0.3157	0.3090	0.3159	0.3203	0.3203
CD0 Mech	[CDM]	:	0.3258	0.3237	0.3255	0.3270	0.3270
CD0 Mach	[CDM0]	:	0.3157	0.3090	0.3159	0.3203	0.3203
CMA	[CMA]	:	2.9770	3.1413	3.0694	2.8986	2.8986
Roll Computed Clp	[CLPR]	:	-0.0265	-0.0258	-0.0266	-0.0265	-0.0265
Frequency Computed Clp	[CLPW]	:	-0.0277	-0.0203	-0.0392	-0.0213	-0.0213
Gyro Stability	[GYRO]	:	2.6150	2.5203	2.6038	2.6882	2.6882
Dynamic Weight Factor	[TAU]	:	1.2725	1.2875	1.2742	1.2619	1.2619
Velocity at Mid-Range	[VMID]	(ft/sac):	3421.7085	3523.9824	3436.9805	3344.8425	3344.8425
Mid-Range Distance	[XMID]	(ft):	334.8959	149.5600	306.9453	477.1474	477.1474
Reference Distance	[XREF]	(ft):	7.3086	7.3086	7.3086	7.3086	7.3086
Reference Mach Number	[MREF]	:	2.9100	2.9100	2.9100	2.9100	2.9100
Yaw of Repose	[YREP]	(deg):	0.0045959	0.0042614	0.0045535	0.0048665	0.0048665
Initial Velocity	[VZRO]	(ft/sac):	3604.0483	3604.0483	3604.0483	3604.0483	3604.0483

Figure 19 shows a plot of the linear theory drag coefficients from a reduction of 40mm projectiles.

The following menu is available for experimental point plotting:

Linear Theory Experimental Point Plots

- 1 - Time
- 2 - Horizontal Motion [Y]
- 3 - Vertical Motion [Z]
- 4 - Pitch [THETA]
- 5 - Yaw [PSI]
- 6 - Roll [PHI]
- 7 - Pitch/Yaw [THETA-PSI]
- 8 - Pitch/Yaw Step Plot

99 - Done

:

The experimental points will be superimposed on the motion plots. A plot of experimental data was shown in Figure 3.

The following menu is available for the motion plots:

Enter the number for the desired plot

- 1 - Angle of Attack [ALPHA] vs Travel [X]
- 2 - Pitch [THETA] vs Travel [X]
- 3 - Yaw [PSI] vs Travel [X]
- 4 - Pitch [THETA] vs Yaw [Psi]

5 - Theta & Psi vs X

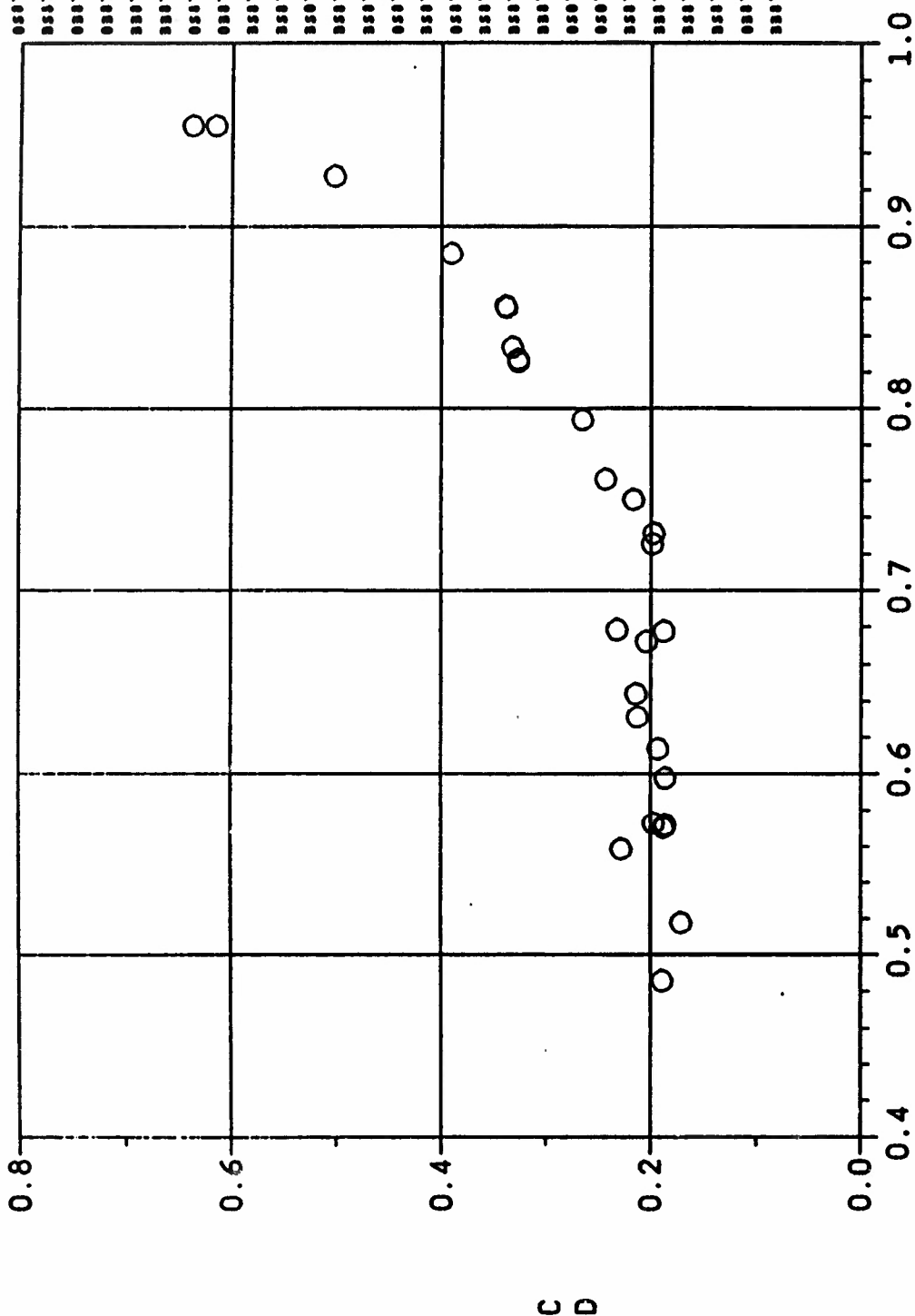
99 - Done

:

Figure 17 in the Linear Theory HELP paragraph shows a plot of the same form as will be created here. The code for plotting in the HELP option is the same as was used for these output plots.

Summary tables are created by shot group number. For the linear theory program the summary tables are sorted by both shot number and Mach number. Table 10 shows part of the Mach number sort of a linear theory summary.

SHOT NUMBERS



Mach Number

Figure 19. Linear Theory Coefficient Plot

TABLE 10. LINEAR THEORY SUMMARY OUTPUT

Linear Theory Summary Output
Shot Group Number 0

Sort by Mach Number

Shot Number	Projectile Diameter (cm)	Mass (grams)	Axial Inertia (gm-cm ²)	Inertia X (gm-cm ²)	Inertia Y (gm-cm ²)	Inertia Z (gm-cm ²)	XY (gm-cm ²)	Length (cm)	CG (percent)	CG (cm from nose)(pins)	Roll
88 87032798	3.9563	244.78	593.170	1190.9	1190.9	1190.9	0.000000	7.834	0.6120	4.795	NO
88 87032490	3.9563	244.78	593.170	1190.9	1190.9	1190.9	0.000000	7.834	0.6120	4.795	NO
88 87032797	3.9563	244.78	593.170	1190.9	1190.9	1190.9	0.000000	7.834	0.6120	4.795	NO
88 87032694	3.9563	244.78	593.170	1190.9	1190.9	1190.9	0.000000	7.834	0.6120	4.795	NO
88 87032693	3.9563	244.78	593.170	1190.9	1190.9	1190.9	0.000000	7.834	0.6120	4.795	NO
88 87032592	3.9563	244.78	593.170	1190.9	1190.9	1190.9	0.000000	7.834	0.6120	4.795	NO

Shot Number	No. of Stations	Observed Distance (m)	Air Density (gm/cm ³)	Speed of Sound (m/sec)	Reynolds Number	X (m)	Probable Error Sverve (m)	Angle (deg)	Roll (deg)
88 87032798	31	131.2	0.0011970	343.02	862168.	0.0014	0.0018	0.29	0.00
88 87032490	32	132.6	0.0011970	343.02	918385.	0.0008	0.0009	0.36	0.00
88 87032797	26	131.2	0.0011970	343.02	1003990.	0.0007	0.0019	0.32	0.00
88 87032694	31	131.2	0.0011980	343.02	1012720.	0.0012	0.0011	0.33	0.00
88 87032693	14	76.2	0.0011980	343.02	1015440.	0.0011	0.0007	0.37	0.00

Shot Number	Mach Number	DBSQ (deg ²)	Mutation Vector [W10]	Precession Vector [K20]	Mutation Damping [L1]	Precession Damping [L2]	Mutation Frequency [W10]	Precession Frequency [W20]	Mutation Change [WD1]	Precession Change [WD2]
88 87032798	0.486	15.5	2.34	3.29	-0.00064	-0.00022	147.387	6.830	0.05738	-0.00460
88 87032490	0.518	2.4	0.84	0.38	-0.00713	0.00574	139.552	5.034	0.05015	0.02478
88 87032797	0.559	53.7	6.84	5.57	-0.00244	-0.00401	148.448	6.824	0.07784	-0.00296
88 87032694	0.570	14.5	3.32	2.43	-0.00084	-0.00205	146.888	7.289	0.05354	-0.00499
88 87032693	0.572	12.3	3.16	1.25	0.00014	0.00448	148.473	6.912	0.07363	0.00519

TABLE 10. LINEAR THEORY SUMMARY OUTPUT (CONCLUDED)

Shot Number	Mach Number	Orientation of Yaw vector (deg)	Yaw of Repose (deg)	Gyro Stability	Roll Fit Spin (deg/m)	Frequency Fit Spin (deg/m)
BS 87032798	0.49	0.00	0.19	6.30	305.12	309.61
BS 87032490	0.52	0.00	0.16	5.86	305.12	290.27
BS 87032797	0.56	0.00	0.14	6.30	305.12	311.73
BS 87032694	0.57	0.00	0.13	5.91	305.12	309.53
BS 87032693	0.57	0.00	0.12	5.83	305.12	311.95

Shot Number	Mach Number	DBSQ	CD	CD0	CDSQ	CME	CMS	Csq	Cmpa	Roll Fit Clp	Frequency Fit Clp
BS 87032798	0.486	15.5	0.188	0.169	4.040	1.740	1.230	1.1	-0.595	0.000	-0.024
BS 87032490	0.518	2.4	0.170	0.167	3.812	1.512	1.189	3.9	-1.217	0.000	-0.001
BS 87032797	0.559	53.7	0.226	0.158	4.178	1.878	1.269	-0.1	-0.213	0.000	-0.022
BS 87032694	0.570	14.5	0.187	0.169	4.018	1.718	1.304	0.6	-0.414	0.000	-0.026
BS 87032693	0.572	12.3	0.185	0.171	3.932	1.632	1.339	2.2	-1.060	0.000	-0.006

Shot Number	Mach Number	Ref Mach Number	DBSQ	CDR	CDR	CDSQ	CDM
BS 87032798	0.486	15.5	0.600	0.188	0.169	4.040	0.000
BS 87032490	0.518	2.4	0.600	0.170	0.167	3.812	0.000
BS 87032797	0.559	53.7	0.600	0.226	0.158	4.178	0.000
BS 87032694	0.570	14.5	0.600	0.187	0.169	4.018	0.000
BS 87032693	0.572	12.3	0.600	0.185	0.171	3.932	0.000

Missile exit values

Shot Number	Mach Number	Location Vector (K10m) (deg)	Procession Vector (K20m) (deg)	Mutation Orientation (P1m) (deg)	Procession Orientation (P2m) (deg)	Mutation Frequency (W10m) (deg/m)	Procession Frequency (W20m) (deg/m)	First Max Yaw From Muzzle (deg)	Distance (m)	Orientation (deg)
BS 87032798	0.486	2.34	3.29	84.097	28.559	147.179	6.847	5.631	0.000	0.000
BS 87032490	0.518	0.83	0.37	278.082	113.095	139.444	4.981	1.214	1.450	120.319
BS 87032797	0.559	6.90	5.65	140.972	98.746	148.169	6.835	12.458	0.000	0.000
BS 87032694	0.570	3.33	2.45	-21.034	253.953	146.694	7.308	5.761	0.000	0.000
BS 87032693	0.572	3.16	1.23	116.267	44.057	148.206	6.893	4.401	2.042	58.533

SECTION VII

SIX DEGREE OF FREEDOM (6 DOF)

1. SIX DOF INPUT

The 6 DOF reduction is split into separate input, analysis, and output programs. The input program creates a named data file for execution by the analysis. The analysis will always run the latest data configuration from the input program.

The first step in setting up the input file for the 6 DOF analysis program is to select the number of shots to be reduced together. Up to five shots may be reduced in a multiple fit:

Enter number of shots in 6 DOF analysis: 1

Next the desired shots are identified:

Key in 10 digit 6 DOF projectile title (or LIST)
: BS87040818

The LIST option will display all of the shot numbers available for a specified shot group. A negative shot group number will display all shots.

An automatic fit option is available on request. This option will allow logic within the program to turn on fit flags based on the reduction and projectile configuration:

Do you want to exercise the automatic fit option (Y/N)? N

If the selected shot(s) have been reduced before, the initial estimates for this reduction may be those used for the previous reduction. If this option is selected, the accuracy of the previous reduction will be displayed and the user prompted on whether or not they shall be used:

Do you want to update initial estimates based on
previous 6 DOF reduction on specified shot(s) (Y/N)? Y

Initial estimate update based on 6 DOF - reduction of:
Date 8-SEP-87 Time 19:35:18

Probable errors of fit to the data were:

X (m)	Y-Z (m)	Theta-Psi (deg)	Phi (deg)
0.003751	0.002992	0.748300	0.000000

Do you want to update (Y/N)? N

Three forms of parameters must be defined for the analysis: the data grouping and update options, initial estimates, and fit flags. Initial estimates and fit flags must be defined for the first fit. Subsequent fits which turn on additional coefficients may also be defined.

The grouping and update menu is:

Fixed Plane Analysis 6-DOF Input

Sectional Fit Options (Single Fit Only)

1 - Data points in first section (NA).....	15
2 - Data points added to each section (NB).....	10

6D Summary / Update Options

3 - Group number code.....	0
4 - 6 DOF - Summary(1, 2, or 3).....	3
5 - 6 DOF - Initial estimate update(1, 2, or 3).....	3

(1 : no update) (2 : fit option selection)
(3 : program criteria)

Miscellaneous

6 - Integration time step (sec) .00043000

Key in item number ", " new value
Key in "LIST to relist "DONE" to continue
: DONE

Options One and Two define how many data points within the range will be reduced together during the fit. Option Three requires the user to specify the group code numbers for cataloging the 6 DOF results. Options Four and Five signal the program for updating the summary file. Criteria One causes no update to be made to the summary file. Criteria Two causes an update based on the setting of two fit flags. Criteria Three causes an update to the summary file if a 10 percent improvement in the probable error occurs. Option Six allows the computed integration time step to be changed.

The next input option allows for changing the initial estimates that were passed to 6 DOF from the linear theory reduction program:

Do you want to change initial estimates (Y/N)? Y

Initial Estimates for Shot Number: BS87040818

1 - Cma : 1.13
2 - Cma3 : 0.000E+00
3 - Cma5 : 0.000E+00
.
.
.
32 - Cnga3 : 0.0000E+00
33 - Cnga : 0.0000E+00
34 - Cnga : 0.0000E+00

Key in item number ", " new value
Key in "LIST to relist "DONE" to continue
: DONE

The above list contains a partial selection of the input parameters. In fact, the coefficient input is split into two menus. An example taken from the second menu is:

1 - Pitch Angle (+ down) [THETA] (deg): -1.87
2 - Pitch Rate (deg/sec): -165.
3 - Yaw (+ left) [PSI] (deg): 0.930
4 - Yaw Rate (deg/sec): -823.
5 - Horizontal Range [X] (feet): 11.9
.
.
.
17 - CNdB : 0.000E+00
18 - CmdA : 0.000E+00
19 - CmdB : 0.000E+00
20 - CX0-unique : 0.000E+00
21 - Clp-unique : 0.000E+00

Key in item number ", " new value
Key in "LIST to relist "DONE" to continue
: DONE

Once the initial estimates are set the initial fit options may be modified:

Do you want to change fit options (Y/N)? Y

Fit Flags for Shot Number: BS87040818
40 MM HEDP TUBULAR

1 - Cma	: 1
2 - Cma3	: 0
3 - Cma5	: 0
.	
.	
.	
32 - Cnga3	: 0
33 - Cnga	: 0
34 - Cnga	: 0

Key in item number "," new value
Key in "LIST to relist "DONE" to continue
: DONE

Here too, the initial fit flag menu takes two pages:

Fit Flags for Shot Number: BS87040818
40 MM HEDP TUBULAR

1 - Pitch Angle (+ down)	[THETA] : 1
2 - Pitch Rate	[THETA-DOT] : 1
3 - Yaw (+ left)	[PSI] : 1
4 - Yaw Rate	[PSI-DOT] : 1
5 - Horizontal Range	[X] : 1
.	
.	
.	
17 - CYg0	: 0
18 - Cmg0	: 0
19 - Cng0	: 0
20 - CX0-unique	: 0
21 - Clp-unique	: 0

Key in item number "," new value
Key in "LIST to relist "DONE" to continue
: DONE

Once the initial fit flags are set the user may define up to 10 subsequent sets of fit flags. The menu for subsequent fits is different from the menu

for the initial fit. Appendix B contains a complete list of the coefficients and the associated line numbers. Here all options appear on one page and not all options are available:

Do you want subsequent fit options (Y/N)?

Fit Option # 2

1 - Cma	: 1
2 - Cma3	: 0
3 - Cma5	: 0
4 - Cmq	: 1
5 - Cmq2	: 0
.	
.	
.	
32 - Cnga3	: 0
33 - Cnga	: 0
34 - Cnga	: 0
35 - Cma-unique	: 0
36 - Inertial Form Factor [IX/IY]	: 1
37 - Cl-DEL fin cant roll moment	: 0
38 - CNdA	: 0
39 - CNdB	: 0
40 - CmdA	: 0
41 - CmdB	: 0
42 - CX0-unique	: 0
43 - Clp-unique	: 0

Key in item number ",", new value

Key in "LIST to relist "DONE" to continue

: DONE

Do you want subsequent fit options (Y/N)? N

The input program is terminated as soon as no further subsequent fits are requested.

2. SIX DOF ANALYSIS

The 6 DOF Analysis program may be run in either interactive or batch mode. When running in a batch mode, the user will be prompted to enter a unique file name. The input data file will be copied to a file with this name. This is necessary to maintain unique file names when multiple processes are running. When running in the interactive mode, the program will run the data as last configured by the input program. The user will see the input data echoed, parameter values input during the analysis, and an analysis summary. The program may be aborted out of the interactive mode by typing <CTRL C>. The user may then restart the analysis in a batch mode.

The interactive analysis mode gives the user the capability of modifying the fit during the analysis. Using the initial estimates and fit options selected in the input program, a reduction is performed and the probable errors printed out:

Probable Errors of Fit — Fit Option: 1

Fit	Pitch-Yaw (deg)	Roll (deg)	Travel [X] (feet)	Swerve [Y-Z] (feet)
1	0.40402	0.00000	0.00531	0.00893
2	0.33277	0.00000	0.01081	0.00549
3	0.32895	0.00000	0.00162	0.00534
4	0.32893	0.00000	0.00161	0.00534

Following the probable errors, the values of the coefficients used for each fit will be printed:

Summary of Aerodynamic Coefficients During Fit

1 Cma	:	1.26880	1.27731	1.27708	1.27707
4 Cmq	:	-0.11800	0.28712	0.27919	0.27675
6 Cnpa	:	-0.23880	-0.42858	-0.43711	-0.43760
17 CX0	:	0.16070	0.15089	0.15072	0.15088
20 CNa	:	1.90340	1.99709	2.00090	2.00133
32 Clp	:	-0.02090	-0.01120	-0.01186	-0.01186
.					
.					
.					

The coefficients should be examined to see if a solution is being converged on. If the values from fit to fit are oscillating, the parameter should be fixed.

After this table is printed, another table of the fit parameters and their associated probable errors will be displayed:

Final Coefficients — Fit Option: 1
At average Mach number unless noted

	Parameter	Probable Error	Fit Flag	
1	Cma :	1.27707	0.01158	1 : 201
4	Cmq :	0.27675	0.29260	1 : 204
6	Cnpa :	-0.43760	0.09651	1 : 206
7	Cnpa3 :	5.54210	0.00000	0 : 207
17	CX0 :	0.15088	0.00208	1 : 217
18	CXa2 :	2.30000	0.00000	0 : 218
20	CNa :	2.00133	0.03661	1 : 220

Final Coefficients -- Fit Option: 1 - (Continued)

23 CYpa	:	-1.00000	0.00000	0 : 223
32 Clp	:	-0.01186	0.00525	1 : 232

146 Fit section : 10
147 Section increment : 5
Total data points : 26

Key in item number ", " new value

"LIST" to relist	"ABORT" to abort
"DONE" to increment fit	"HELPLESS" to end HELP
"RERUN" for same fit length	

:

At this point in the program, parameters may be changed again. Fit options may also be turned on or off. The numbers along the left side allow the user to modify a parameter. The numbers along the right allow the user to change fit flags. All non-zero parameters will be displayed. Values or fit flags other than those displayed may be changed but the user must either know the parameter number or refer to the list in Appendix B. Note the numbers in the right column are the same as the left column with 200 added.

The RERUN option will allow the analysis to be repeated for the same number of tunnel stations with the modified parameters and flags. The DONE option will also use the modified parameters and flags but will increment the number of stations by the summing section increment. The ABORT option will terminate the analysis program. The HELPLESS option will allow the analysis to continue from this point without displaying this change menu again. The program will complete this fit and any subsequent fits as defined by the input program.

The change menu will only appear during the first fit of the data. Fit options during subsequent fits come from the input data file.

3. SIX DOF OUTPUT

The 6 DOF output program allows for the creation of summary tables, motion plots, and coefficient plots. The output menu is:

AERODAS 6 DOF Output Segment

- 1 Summary Tables (Terminal)
 - 2 Summary Tables (Lineprinter)
 - 3 Motion Plots
 - 4 Coefficient Plots
 - 5 Exit Output Program
- :

If summary tables are requested, the shot group to be output must be specified. The summary file will be sorted for the single and multiple

reductions for this group number. The user may select, from the shots, which ones to include in the summary. Table 11 shows a summary of 40mm, spin stabilized, shot reductions.

Coefficient plots are also created by shot group numbers. For the shots selected from the desired shot group, the following menu of plots is available:

Summary Segment - Six Degree of Freedom Reductions

SHOT GROUP 1 - Sample Output

vs Mach Number	vs Angle of Attack
1 - CX0	CX - 11
2 - CNa	CN - 12
3 - Cma	Cm - 13
4 - Cnpa	Cnp - 14
5 - Cmqa	Cmq - 15
6 - Clp	
7 - CXa2	
8 - Cma3	
9 - Cnpa3	
99 - Done	
:	

Plots versus Mach number are for the single shot reductions. Plots versus angle of attack are for multiple shot reductions. Figures 20 and 21 show drag coefficients in both plot modes.

When a motion plot is to be created, the program reads the coefficients for the specified single or multiple shot reduction. These coefficients are then displayed for modification by the user. Each of the shots will be integrated through its trajectory. Probable errors for each shot in the reduction will be displayed prior to the display of the following plot menu:

Plot Segment - Six Degree of Freedom Reductions

SHOT GROUP 1 - Sample Output

Plot #	Description	Plot #	Description
1	Y vs X	8	Residual in X vs X
2	Z vs X	9	Residual in Y vs X
3	Phi vs X	10	Residual in Z vs X
4	Theta vs X	11	Residual in Phi vs X
5	Psi vs X	12	Residual in Theta vs X
6	Alpha vs X	13	Residual in Psi vs X
7	Theta vs Psi	14	Velocity vs X
19	Theta & Psi vs X		
20	Change Shot Number		
21	Print tabulated data on exit		
99	Done		
:			

TABLE 11. 6 DOF SUMMARY

6 DOF Summary Output
Shot Group Number: 0

Shot Number	Date	Time	Ref. CG (cm)	Ref. CG% (cm)	Ref. Length (cm)	Ref. Mach Number	Mach Number	DBSQ (dag2)	Max Angle of Attack (deg)	X (m)	Y-Z (m)	Angle (deg)	Roll (deg)
BS87032798	27-JUL-87	12:25:36	4.80	0.612	7.83	0.49	0.487	15.230	5.7	8.0015	0.0017	0.340	0.00
BS87032490	30-JUL-87	14:47:47	4.80	0.612	7.83	0.52	0.518	2.233	2.3	0.0008	0.0014	0.381	0.00
BS87032797	26-OCT-87	12:02:45	4.80	0.612	7.83	0.56	0.561	52.870	11.6	0.0013	0.0022	0.358	0.00
BS87032694	27-JUL-87	13:35:57	4.80	0.612	7.83	0.57	0.571	14.328	5.7	0.0013	0.0014	0.318	0.00
BS87032693	30-JUL-87	15:04:57	4.80	0.612	7.83	0.57	0.572	12.260	4.8	0.0011	0.0009	0.377	0.00
BS87032592	7-AUG-87	08:03:16	4.80	0.612	7.83	0.57	0.573	14.618	4.7	0.0008	0.0013	0.401	0.00
BS87032696	27-JUL-87	14:24:19	4.80	0.612	7.83	0.60	0.598	1.521	2.4	0.0011	0.0034	0.352	0.00

Shot Number	Mach Number	DBSQ	ABARM	CX	CX2	CMA	CMA3	CYPa	CYPa3	Cma	Cma3	Cmq	Cmq2	Cqpa	Cqpa3	1X/1Y	C1P	CXM	CmaM	Probable Error X(m)	Probable Error Y-Z(m)	Probable Error Angle(deg)	Probable Error Roll(deg)
BS87032798	0.487	15.2	5.7	0.170	2.300	1.761	0.000	-1.00	0.00	1.219	0.000	0.3	0.0	-0.34	0.00	-0.0218	0.00	0.0015	0.0017	0.0015	0.0017	0.340	0.000
BS87032490	0.518	2.2	2.3	0.167	2.300	1.774	0.000	-1.00	0.00	1.125	0.000	1.9	0.0	-0.32	0.00	-0.0202	0.00	0.0008	0.0014	0.0008	0.0014	0.361	0.000
BS87032797	0.561	52.9	11.6	0.161	2.300	1.903	0.000	-1.00	0.00	1.269	0.000	-0.1	0.0	-0.24	0.00	-0.0209	0.00	0.0013	0.0022	0.0013	0.0022	0.358	0.000
BS87032694	0.571	14.3	5.7	0.170	2.300	1.676	0.000	-1.00	0.00	1.302	0.000	0.2	0.0	-0.22	0.00	-0.0238	0.00	0.0013	0.0014	0.0013	0.0014	0.318	0.000
BS87032693	0.572	12.3	4.8	0.170	2.300	1.786	0.000	-1.00	0.00	1.274	0.000	1.5	0.0	-0.66	0.00	-0.0088	0.00	0.0011	0.0009	0.0011	0.0009	0.377	0.000
BS87032592	0.573	14.6	4.7	0.146	9.414	1.818	0.000	-1.00	0.00	1.305	0.000	0.3	0.0	-0.25	0.00	-0.0254	0.00	0.0008	0.0013	0.0008	0.0013	0.401	0.000
BS87032696	0.598	1.5	2.4	0.183	2.300	2.287	0.000	-1.00	0.00	1.272	0.000	5.1	0.0	-2.02	0.00	-0.0014	0.00	0.0011	0.0034	0.0011	0.0034	0.352	0.000

TABLE 11. 6 DOF SUMMARY (CONCLUDED)

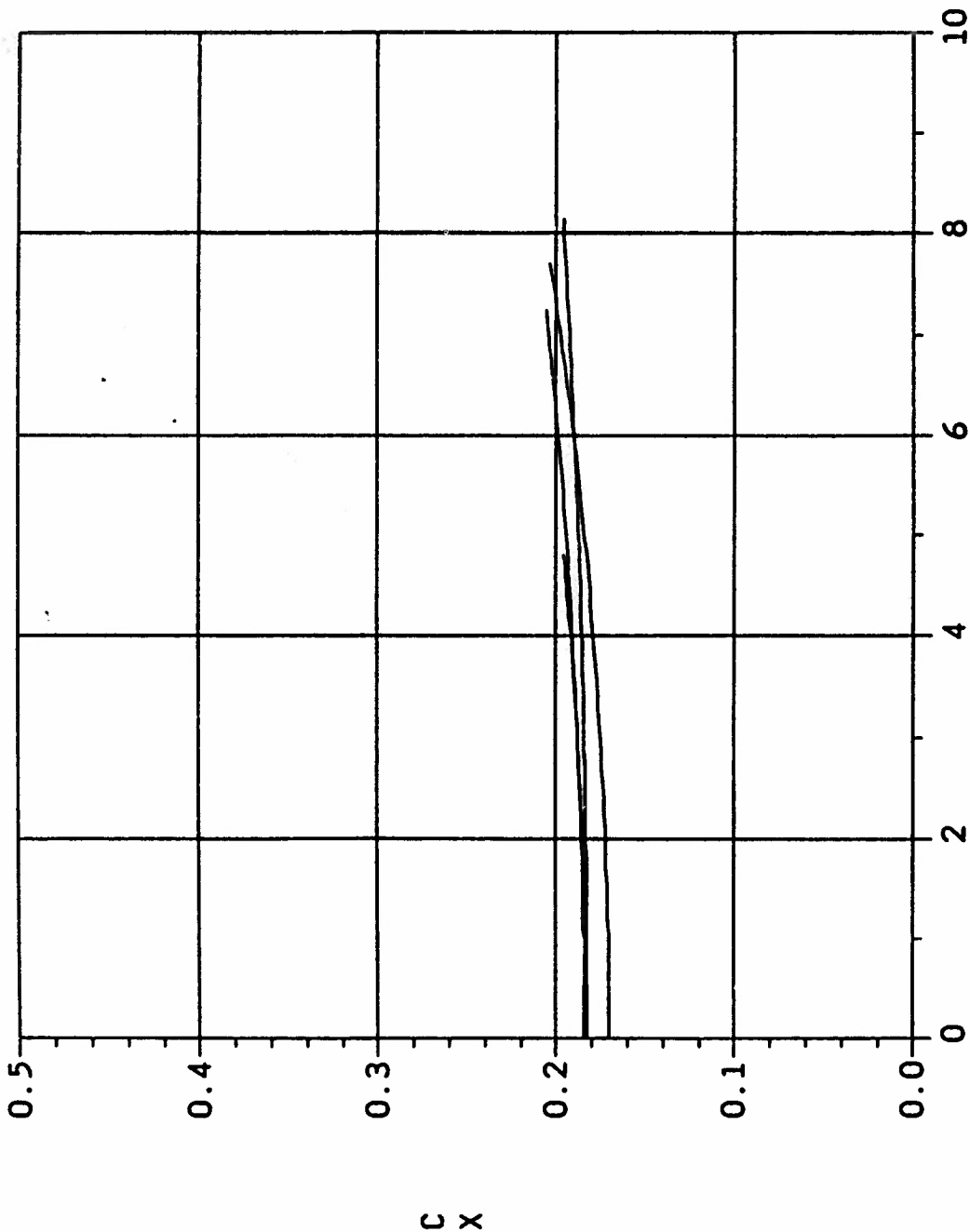
Shot Numbers	Date	Time	Ref. Mach Number	Mach Number	DBSQ (deg2)	Max Angle of Attack (deg)	X (m)	Y-2 (m)	Probable Error Angle (deg)	Roll (deg)
B587032490 B587032797	31-JUL-87	14:45:14	0.522	0.522	23.08	11.57	0.0012	0.0019	0.552	0.000
B587032797 B587032696	28-JUL-87	09:17:52	0.548	0.548	22.82	12.20	0.0028	0.0031	0.473	0.000
B587032797 B587032696	28-JUL-87	08:08:53	0.597	0.597	24.77	11.11	0.0021	0.0032	0.660	0.000
B587040104 B587032696	3-AUG-87	13:17:22	0.601	0.601	12.97	7.20	0.0016	0.0028	0.430	0.000

Shot Numbers	Mach Number	DBSQ	ABARM	CX CX2 CX4	CMA CMA3 CMA5	CYPA CYPa3 CYPa5	Cma Cma3 Cma5	Cmq Cmq2 Cmq4	CmPa CmPa3 CmPa5	Clp Clp3 Clp5	Probable Error X(m) Y-2(m) Angle(deg) Roll(deg)
B587032490 B587032797	0.522	23.1 11.6	0.170 1.844 0.00	1.799 0.000 0.00	-1.00 8.00 0.00	-1.218 1.748 0.0	-0.1 0.0 0.0	-0.26 5.54 8.0	-0.0212 0.0000 0.0000	0.0012 0.0019 0.0000	0.5521 0.0000 0.0000
B587032797 B587032696	0.548	22.8 12.2	0.182 0.686 0.00	2.072 -5.743 0.00	-1.00 0.00 0.00	1.257 0.000 0.0	-0.1 0.0 0.0	-0.67 21.66 0.0	-0.0197 0.0000 0.0000	0.0028 0.0031 0.0000	0.4728 0.0000 0.0000
B587032797 B587032696	0.597	24.8 11.1	0.184 1.310 0.00	1.846 0.000 0.00	-1.00 0.00 0.00	1.270 0.000 0.0	-0.3 0.0 0.0	-0.21 0.00 0.0	-0.0205 0.0000 0.0000	0.0021 0.0032 0.0000	0.6604 0.0000 0.0000
B587040104 B587032696	0.601	13.0 7.2	0.183 1.832 0.00	1.923 0.000 0.00	-1.00 0.00 0.00	1.249 8.504 0.0	-0.1 0.0 0.0	-0.55 40.04 0.0	-0.0249 0.0000 0.0000	0.0016 0.0028 0.0000	0.4301 0.0000 0.0000

6 DOF Reduction - Coefficient Output

Avg. Mach

0.5971
0.5483
0.5217
0.6015



Angle of Attack (deg)

Figure 20. 6 DOF Coefficient Versus Angle of Attack

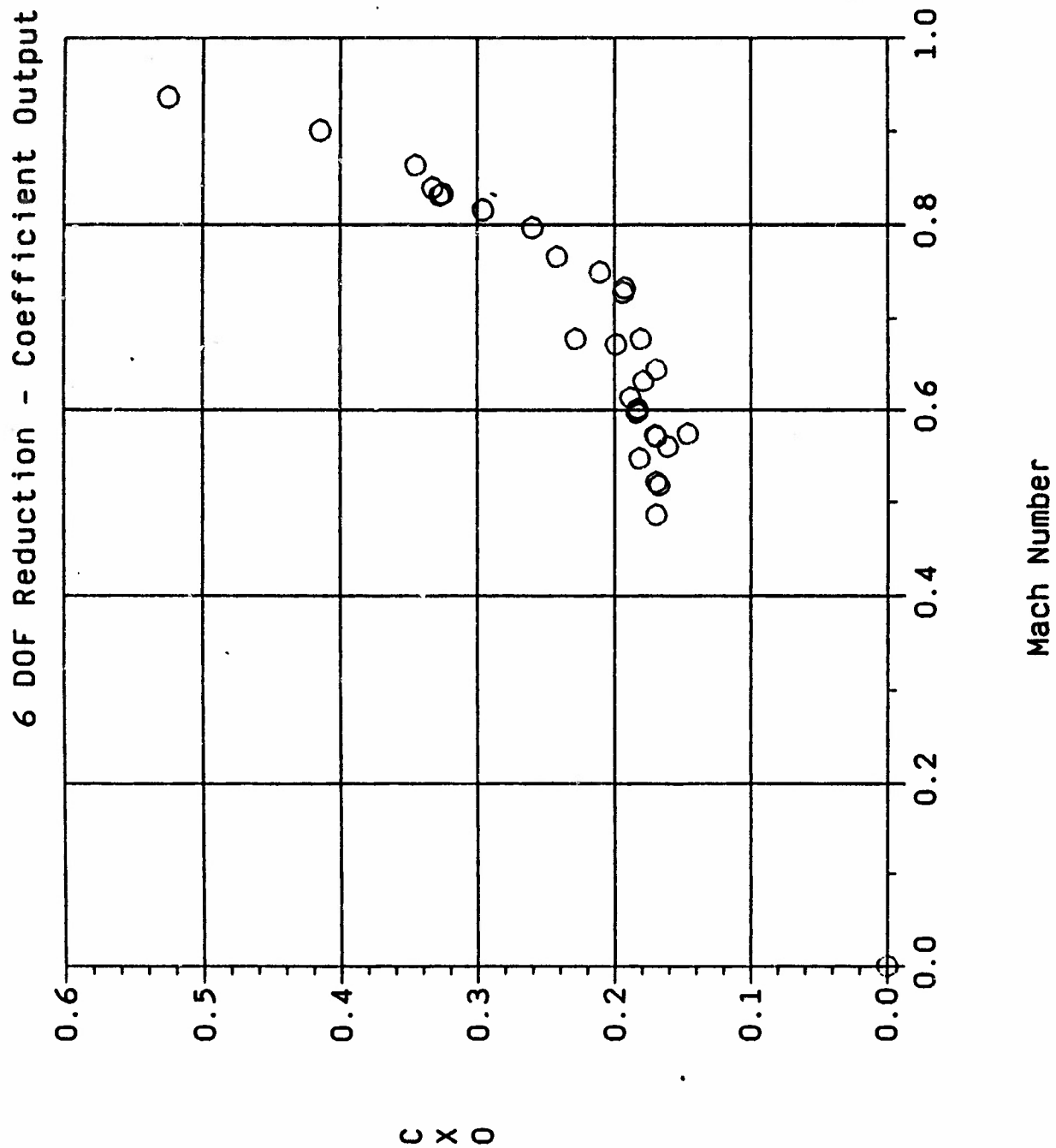


Figure 21. 6 DOF Coefficient Versus Mach Number

From the above menu either motion or residuals may be plotted against the travel down the range. Figure 22 shows a motion plot. Figure 23 shows a residuals plot. For a multiple shot reduction, the data from each shot is available. The program will default to the first shot in the reduction for plotting. Option Twenty enables the user to select other shots for plotting. Option Twenty One enables tabulated data from the motion integration to be printed upon exit from the program.

BS87032797 29-JUL-87 12:12:24 40 MM HEDP TUBLAR
6 DOF Reduction - Motion Plot

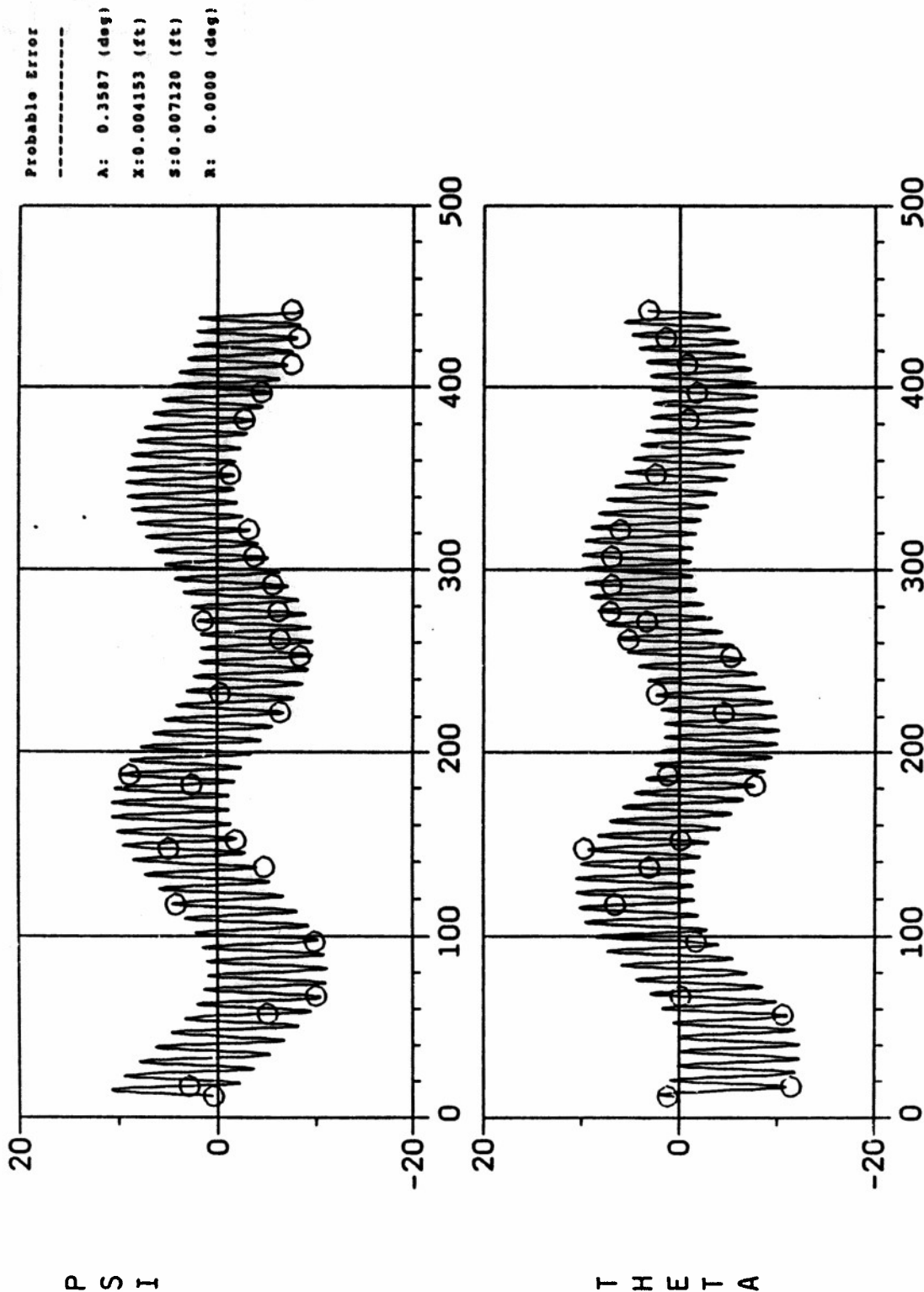


Figure 22. 6 DOF Angular Motion Fit

BS87032797 29-JUL-87 12:12:24 40 MM HEDP TUBLAR
 6 DOF Reduction - Motion Plots

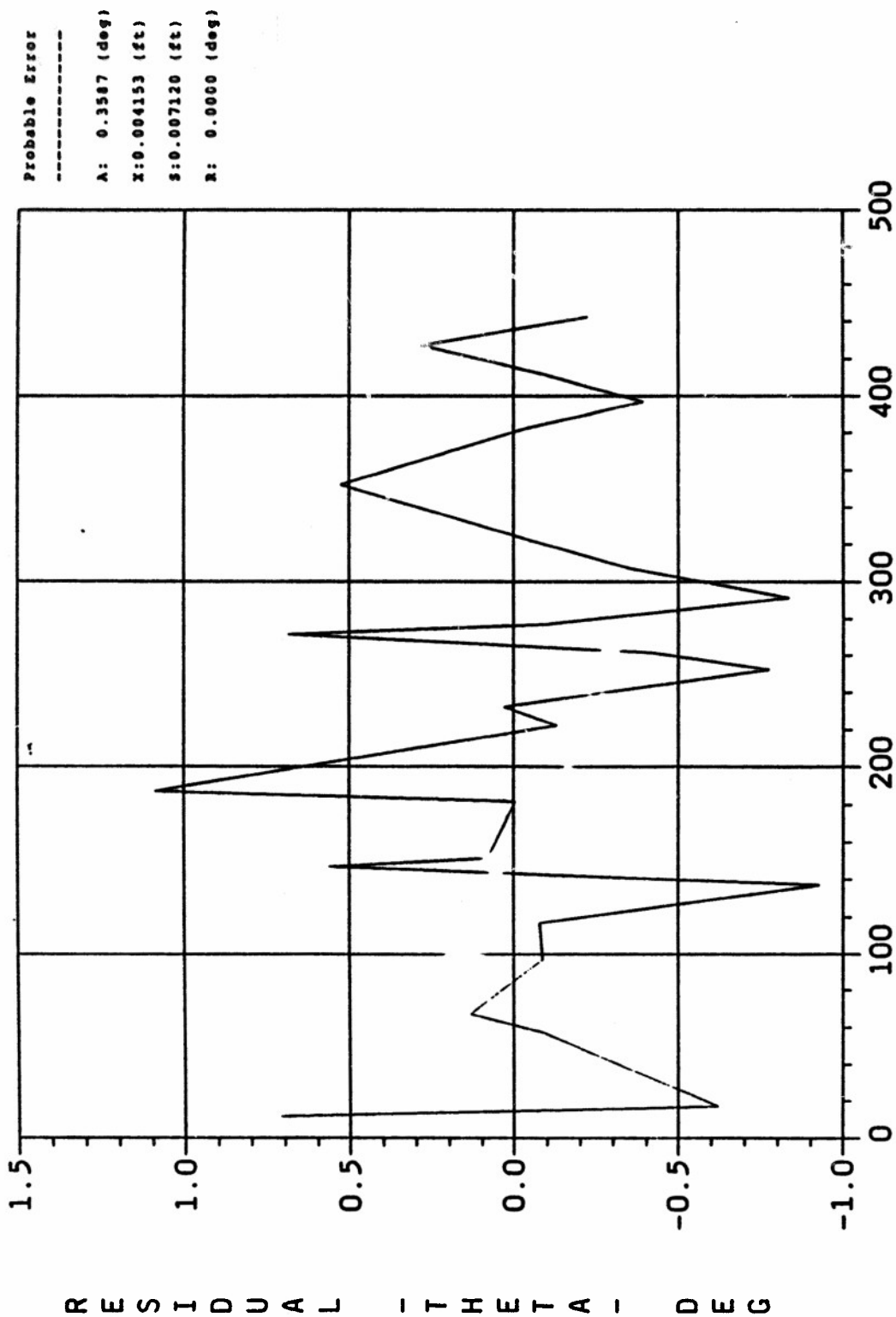


Figure 23. 6 DOF Data Residual

REFERENCES

R.L. Kittyle, J.D. Packard, and G.L. Winchenbach, "Description and Capabilities of the Aeroballistic Research Facility," AFATL-TR-87-08, Air Force Armament Laboratory, Eglin Air Force Base, Florida, 32542-5434, May 1987.

APPENDIX A

TECHNICAL BACKGROUND AND EQUATIONS OF MOTION

APPENDIX A

TECHNICAL BACKGROUND
AND
EQUATIONS OF MOTION

This section provides the equations of motion contained in the linear theory and 6DOF programs in ARFDAS. These mathematical models are directly correlated to the spark range data resulting in a determination of the aerodynamic coefficients and coefficient derivatives that provide the best fit for the experimental data.

Correlation of the data to the linear theory equations of motion is done using a standard least squares method. This analysis provides for preliminary analysis and screening of the data prior to the 6 DOF. Initial estimates for the initial conditions and coefficients are obtained based on this analysis. A more detailed description and derivation, of the equations, is contained in Reference A-1.

Correlation of the data to the 6 DOF equations of motion is performed using the Maximum Likelihood Method. There are two forms of the dynamic equations available in ARFDAS. Selection of the set of equations depends on the configuration being analyzed. For a configuration with both physical and aerodynamic symmetry, the dynamic equations derived in the fixed plane (nonrotating) coordinate system are used (References A-2 and A-3). When either the physical or aerodynamic model contain asymmetries, the dynamic equations derived in the body fixed (rotating) coordinate system are used (Reference A-4). It should be noted that both 6 DOF programs contain a generalized aerodynamic model. The significant coefficients and derivatives to be determined depend on the type of configuration being analyzed.

Solution of the dynamic equations is performed using a fourth order Runge-Kutta integration. Useful transformation identities between various coordinate systems have been included in this appendix. The sign convention for the fixed plane coordinate system is illustrated in Figures A-1 and A-2. Typical forms of the induced aerodynamic coefficients for a four-fin missile are illustrated in Figures A-3 and A-4.

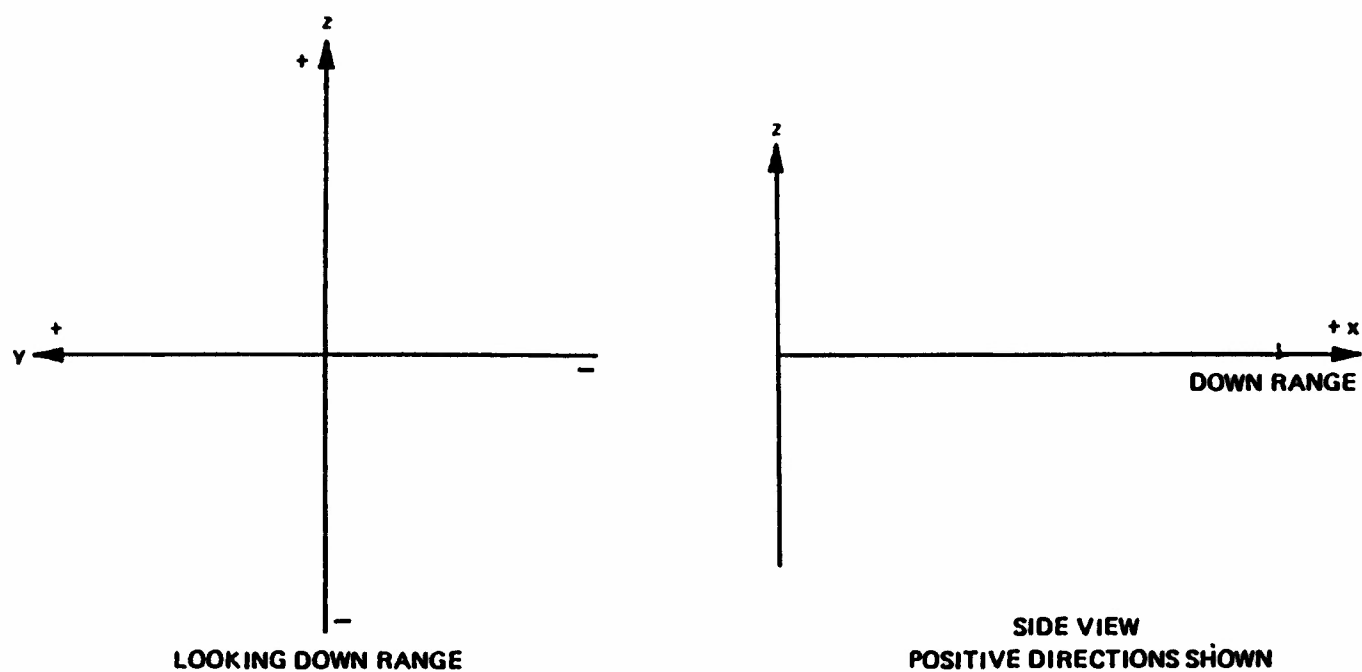


Figure A-1. Coordinate System Fixed Plane (Positions)

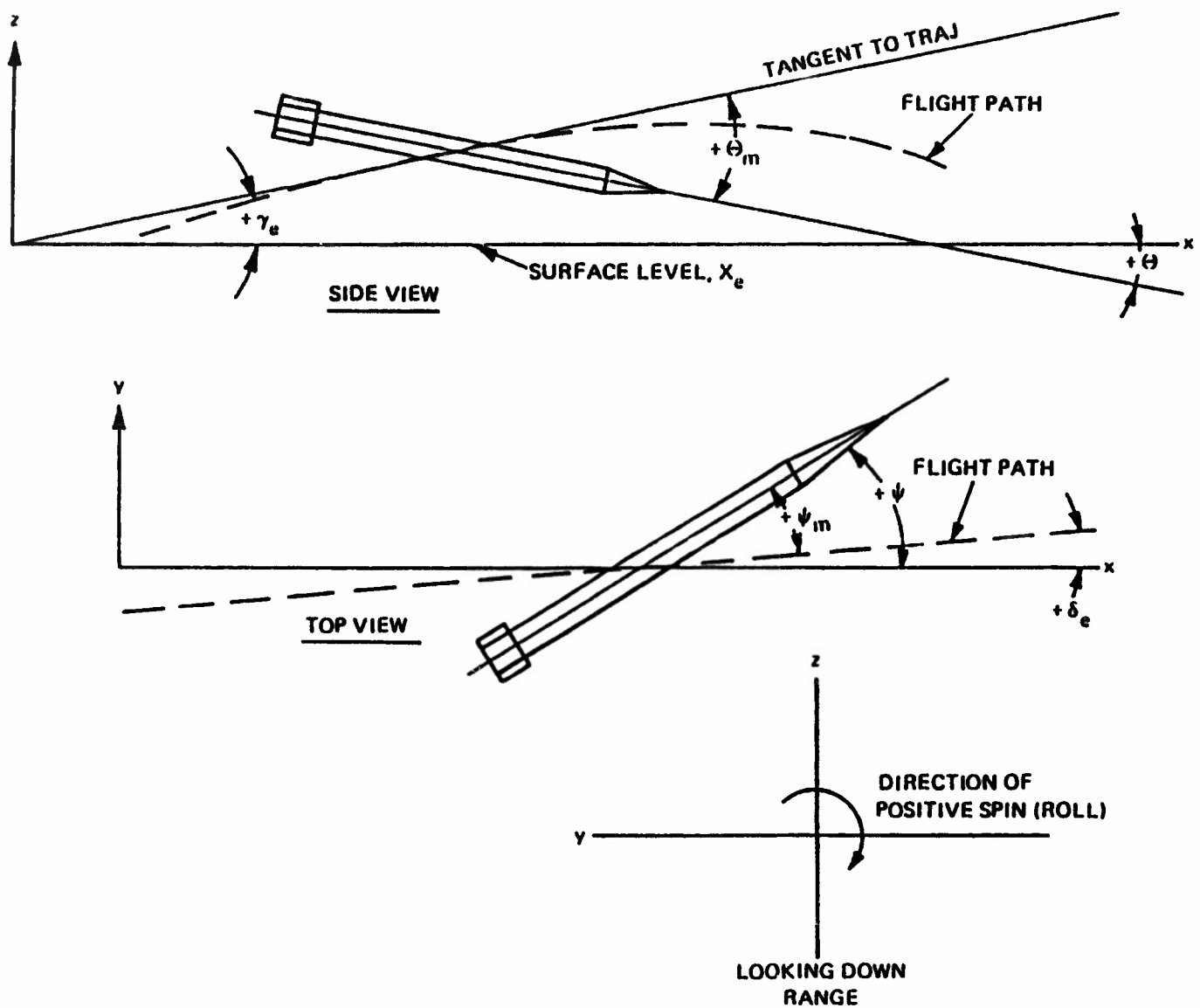


Figure A-2. Coordinate System Fixed Plane (Rotation)

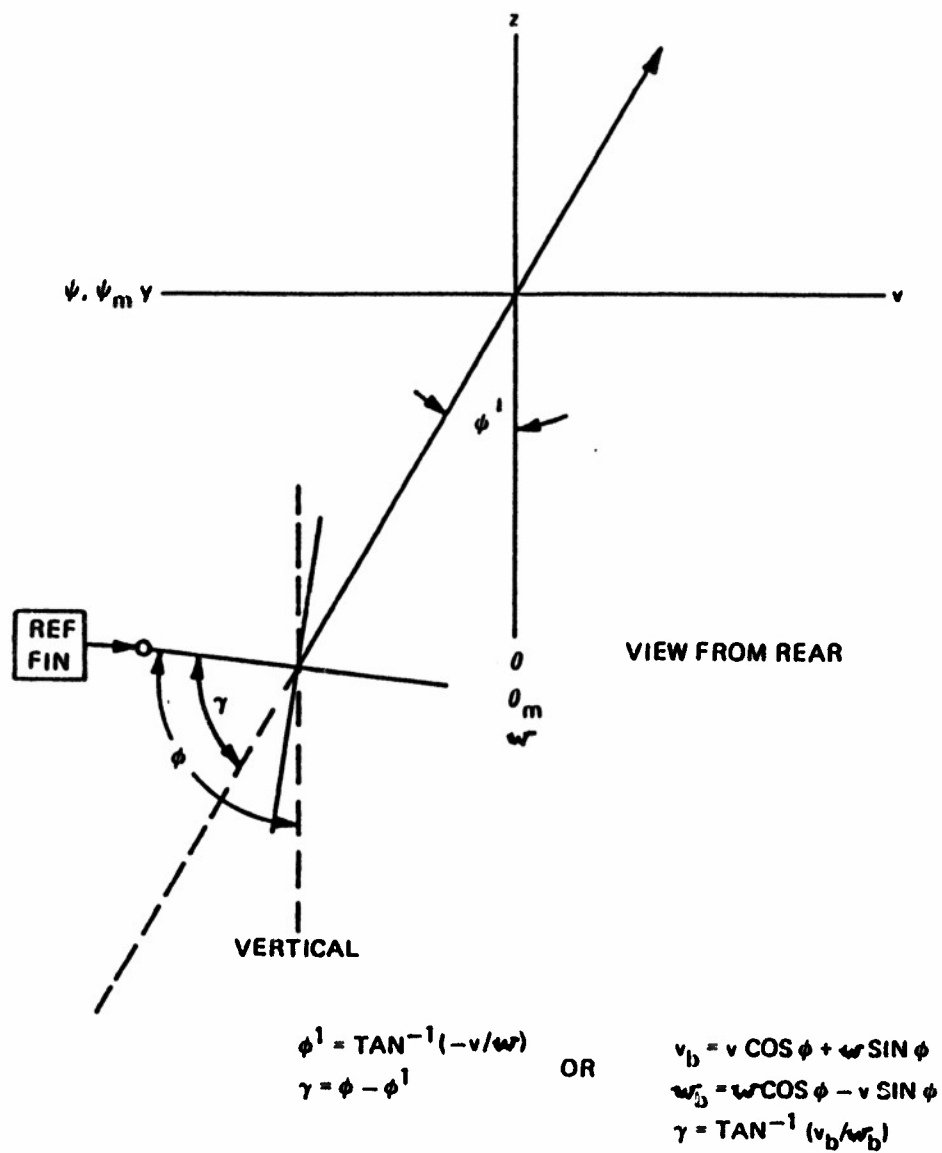
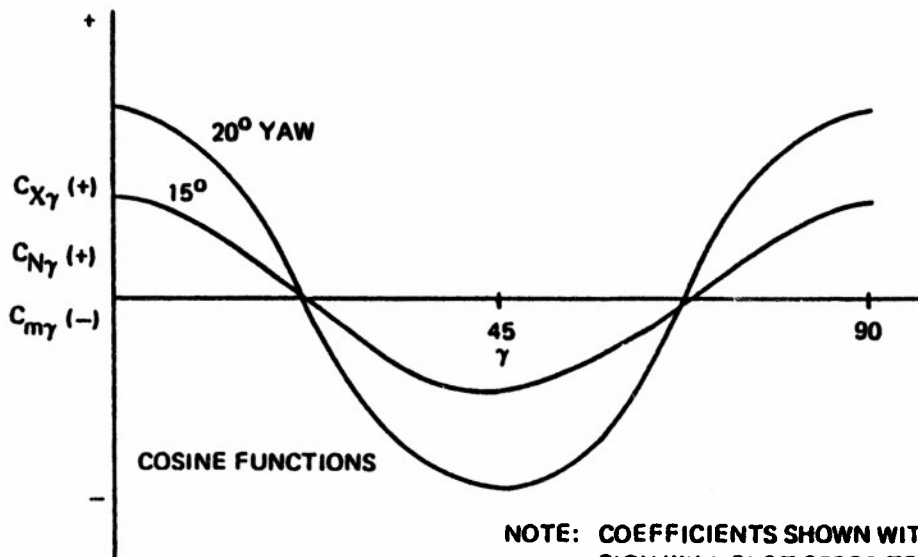
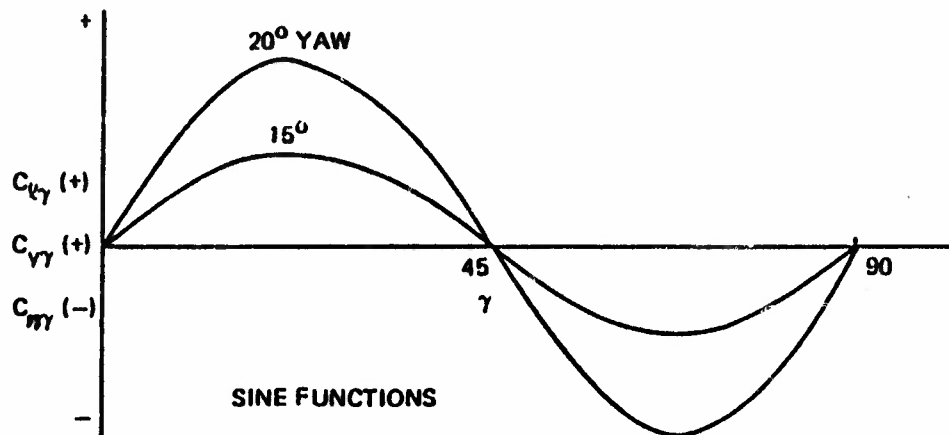


Figure A-3. Roll Angle Orientations



NOTE: COEFFICIENTS SHOWN WITH NEGATIVE (-) SIGN WILL PLOT OPPOSITE TO EXAMPLE

TYPICAL SIGNS FOR DERIVATIVES ARE:

$$C_{L\gamma a_2} + C_{Y\gamma a_3} + C_{N\gamma a_3} +$$

$$C_{X\gamma a_2} + C_{m\gamma a_3} - C_{m\gamma a_3} -$$

Figure A-4. Illustrations of Induced Effects (4 Fin Missile)

1. NOMENCLATURE

Physical Properties

A	Area ($\pi d^2/4$)	ft ²
d	Diameter	ft
I _x	Axial moment of inertia	slug-ft ²
I _y	Transverse moment of inertia (y-axis)	slug-ft ²
I _z	Transverse moment of inertia (z-axis)	slug-ft ²
m	Mass	slugs
CG	Center of gravity	Z from nose
L	Projectile length	ft
m _c	Mass of ball rotor	slugs
r _x	Distance from CG to CG of ball rotor	ft
r _{yz}	Radial clearance of ball rotor	ft
Subscripts		
r	Reference value	

Range Properties

P	Atmospheric pressure	millibars
T	Temperature	Degrees celcius
RH	Relative humidity	Z/100
R _n	Reynolds number	---
M	Mach number	---
a	Speed of sound	ft/sec
ρ	Air density	slugs/ft ³
g	Gravity	32.134 ft/sec ²

Range Properties (continued)

λ_R	Range latitude	30.5 degrees
δ_R	Range azimuth	126.0 degrees
ω_e	Earth rotation rate	
Subscripts		
r	Reference value	

Linear Theory

$d_{1,2,3,4}$	Constants for drag equation
$r_{1,2,3,4}$	Constants for roll equation
K_1	Amplitude nutation vector, degrees
K_2	Amplitude precession vector, degrees
K_3	Amplitude trim vector, degrees
K_4	Amplitude yaw of repose, degrees
ϕ_1	Orientation nutation vector, degrees
ϕ_2	Orientation precession vector, degrees
ϕ_3	Orientation trim vector, degrees
$\dot{\phi}_1$	Angular velocity nutation vector, degrees/ft
$\dot{\phi}_2$	Angular velocity precession vector, degrees/ft
$\dot{\phi}_3$	Angular velocity trim vector, degrees/ft
$\ddot{\phi}_1$	Angular acceleration nutation vector, degrees/ft ²
$\ddot{\phi}_2$	Angular acceleration precession vector, degrees/ft ²
λ_1	Damping factor nutation vector, 1/ft
λ_2	Damping factor precession vector, 1/ft
S_1	Amplitude nutation swerve vector, ft
S_2	Amplitude precession swerve vector, ft
ϕ_{S1}	Orientation nutation swerve vector, degrees
ϕ_{S2}	Orientation precession swerve vector, degrees

Linear Theory (continued)

$z_{1,2,3}^s$

Constants for swerve equation (z-plane)

$y_{1,2,3}^s$

Constants for swerve equation (y-plane)

x_r

Distance from reference station, ft

x_s

Distance from reference station to midpoint of fit, ft

x_m

Midpoint of fit, ft

Subscripts

m

Evaluated at midpoint of fit

6DOF - Fixed Plane

x, y, z

Missile coordinates (fixed plane) ft

u, v, w

Missile velocities (non-rolling) ft/sec

p, q, r

Missile angular velocities (non-rolling) rad/sec

θ, ψ, ϕ

Missile orientation (fixed plane) radians

a_{cx}, a_{cy}, a_{cz}

Components of coriolis acceleration (fixed plane), ft/sec²

a_{cu}, a_{cv}, a_{cw}

Components of coriolis acceleration (non-rolling), ft/sec²

α

Total angle of attack, radians

ϵ

Sine of the total angle of attack $\left[\frac{(v^2 + w^2)}{v^2} \right]^{1/2}$

γ

Aerodynamic roll angle, radians

V

Total missile velocity, ft/sec

F_x, F_y, F_z

Force components (non-rolling), lbs

L, M, N

Moment components (non-rolling), ft-lbs

Superscript

First derivative with respect to time

6DOF - Body Fixed

x, y, z	Missile coordinates (fixed plane), ft
u_b, v_b, w_b	Missile velocities (rolling), ft/sec
p_b, q_b, r_b	Missile angular velocities (rolling), rad/sec
θ, ψ, ϕ	Missile angular orientation (fixed plane), radians
a_{cx}, a_{cy}, a_{cz}	Components of coriolis acceleration (fixed plane), ft/sec ²
$a_{cub}, a_{cvb}, a_{cwb}$	Components of coriolis acceleration (rolling), ft/sec ²
α	Total angle of attack, radians
ϵ	Sine of the total angle of attack $\left[\frac{v_b^2 + w_b^2}{v^2} \right]^{1/2}$
γ	Aerodynamic roll angle, radians
F_{xb}, F_{yb}, F_{zb}	Force components (rolling), lbs
L_b, M_b, N_b	Moment components (rolling), ft-lbs

Superscripts

.	First derivative with respect to time
---	---------------------------------------

Aerodynamic Coefficients

C_D	Drag coefficient
C_X	Axial force coefficient
C_N	Normal force coefficient
C_{Yp}	Magnus force coefficient
$C_{X\gamma}$	Induced axial force coefficient
$C_{N\gamma}$	Induced normal force coefficient
$C_{Y\gamma}$	Induced yaw force coefficient
C_Y	Yaw force coefficients
C_Z	Normal force coefficient
C_{Y0}	Trim yaw force coefficient

Aerodynamic Coefficients (continued)

C_{Z_0}	Trim normal force coefficient
$C_{N\delta_A}, C_{N\delta_B}$	Trim force coefficient components (fixed plane)
C_{Yp}	Magnus force coefficient
$C_{l\delta}$	Roll moment coefficient
C_{lp}	Roll deceleration coefficient
$C_{l\gamma}$	Induced roll coefficient
C_m	Pitching moment coefficient
C_n	Yaw moment coefficient
C_{mq}	Pitching damping coefficient
C_{nr}	Yaw damping coefficient
$C_{m\gamma}$	Induced pitching moment coefficient
$C_{n\gamma}$	Induced yaw moment coefficient
C_{m_0}	Trim pitch moment coefficient
C_{n_0}	Trim yaw moment coefficient
$C_{m\delta_A}, C_{m\delta_B}$	Trim moment coefficient components (fixed plane)

Let:

$$\alpha = w_b/V$$

$$\beta = v_b/V$$

$$\bar{\alpha}, \epsilon = \sin^{-1} \left(\frac{v^2 + w^2}{V^2} \right)^{1/2}$$

Subscripts

α_1 derivative with respect to α^1

β_1 derivative with respect to β^1

$\bar{\alpha}_1$ derivative with respect to ϵ^1

2. LINEAR THEORY

Linear Theory has the following features:

- o Self start (requires only the precession frequency to be reasonably guessed)
- o Elimination of erroneous data points

The equations shown below define the motion for drag, roll, yaw and swerve.

Drag Analysis

$$t = d_1 + d_2 x_r + d_3 x_r^2 + d_4 x_r^3$$

Roll Analysis

$$\phi = r_1 + r_2 x_r + r_3 x_r^2 + r_4 x_r^3$$

Yaw Analysis

$$\begin{aligned}\theta_m &= K_1 e^{\lambda_1 x_r} \cos \left(\phi_1 + \dot{\phi}_1 x_r + \ddot{\phi}_1 \frac{x_r^2}{2} \right) \\ &+ K_2 e^{\lambda_2 x_r} \cos \left(\phi_2 + \dot{\phi}_2 x_r + \ddot{\phi}_2 \frac{x_r^2}{2} \right) \\ &+ K_3 \cos \left(\int_1^1 \dot{\phi}_3 \right) \\ \psi_m &= K_1 e^{\lambda_1 x_r} \sin \left(\phi_1 + \dot{\phi}_1 x_r + \ddot{\phi}_1 \frac{x_r^2}{2} \right) \\ &+ K_2 e^{\lambda_2 x_r} \sin \left(\phi_2 + \dot{\phi}_2 x_r + \ddot{\phi}_2 \frac{x_r^2}{2} \right) \\ &+ K_3 \sin \left(\int_1^1 \dot{\phi}_3 \right) \\ &+ K_4\end{aligned}$$

Swerve Analysis

$$y = y_{s1} + y_{s2}x_r + S_1 e^{\lambda_1 x_r} \sin(\phi_{s1} + \dot{\phi}_1 x_r + \ddot{\phi}_1 \frac{x_r^2}{2}) \\ + S_2 e^{\lambda_2 x_r} \sin(\phi_{s2} + \dot{\phi}_2 x_r + \ddot{\phi}_2 \frac{x_r^2}{2})$$

$$z = z_{s1} + z_{s2}x_r + z_{s3}x_r^2 + S_1 e^{\lambda_1 x_r} \cos(\phi_{s1} + \dot{\phi}_1 x_r + \ddot{\phi}_1 \frac{x_r^2}{2}) \\ + S_2 e^{\lambda_2 x_r} \cos(\phi_{s2} + \dot{\phi}_2 x_r + \ddot{\phi}_2 \frac{x_r^2}{2})$$

The reference station for the analysis is Station 1

Let $x_r = x_i - x_1$ (distance from reference)

Definition of Terms

The unknown coefficients which are solved are:

d_1, d_2, d_3, d_4 - drag analysis

r_1, r_2, r_3, r_4 - roll analysis

$K_1, K_2, \lambda_1, \lambda_2, \phi_1, \phi_2, \dot{\phi}_1, \dot{\phi}_2, \ddot{\phi}_1, \ddot{\phi}_2,$

K_3, ϕ_3 - yaw analysis

$S_1, S_2, \phi_{s1}, \phi_{s2}, y_{s1}, y_{s2}, z_{s1}, z_{s2}, z_{s3}$ - swerve

$\int_1^1 \phi_3$ is set equal to the experimental roll position

$$K_4 = \frac{(\dot{\phi}_1 + \ddot{\phi}_1 x_m + \dot{\phi}_2 + \ddot{\phi}_2 x_m) g}{(\dot{\phi}_1 + \ddot{\phi}_1 x_m)(\dot{\phi}_2 + \ddot{\phi}_2 x_m) V_m^2} \quad (\text{yaw of repose})$$

$$\theta_m = \theta - \frac{\dot{z}}{\dot{x}}$$

$$\psi_m = \psi + \frac{\dot{y}}{\dot{x}}$$

In order to compute the aerodynamic coefficients, the determined constants are shifted to the midrange distance.

$$x_m = (x_{\text{last}} - x_{\text{first}}) \cdot \frac{1}{2}$$

$$x_s = x_m - x_r \quad (\text{distance to be shifted})$$

$$\dot{\phi}_{1m} = \dot{\phi}_1 + \ddot{\phi}_1 x_s$$

$$\dot{\phi}_{2m} = \dot{\phi}_2 + \ddot{\phi}_2 x_s$$

$$\ddot{\phi}_{1m} = \ddot{\phi}_1$$

$$\ddot{\phi}_{2m} = \ddot{\phi}_2$$

$$K_{1m} = K_1 e^{\lambda_1 x_s}$$

$$K_{2m} = K_2 e^{\lambda_2 x_s}$$

$$S_{2m} = S_2 e^{\lambda_2 x_s}$$

$$d_{2m} = d_2 + 2d_3 \cdot x_s + 3d_4 x_s^2$$

$$d_{3m} = d_3 + 3 \cdot d_4 \cdot x_s$$

$$r_{2m} = r_2 + 2r_3 \cdot x_s + 3r_4 x_s^2$$

$$r_{3m} = r_3 + 3 \cdot r_4 \cdot x_s$$

$$C_D = \frac{4m}{\rho A} (d_{3m}/d_{2m})$$

$$C_{lp_r} = 2d (r_{3m}/r_{2m} - d_{3m}/d_{2m}) \left(\frac{\pi \rho d^5}{16 I_x} \right)^{-1} - \text{roll fit}$$

$$C_{lp_\omega} = 2d \left(\frac{\dot{\phi}_{1m} + \dot{\phi}_{2m}}{\dot{\phi}_{1m} + \dot{\phi}_{2m}} \right) \frac{1}{2} - d_{3m}/d_{2m} \left(\frac{\pi \rho d^5}{16 I_x} \right)^{-1} - \text{yaw fit}$$

$$C_{m\alpha} = \frac{8 I_y \dot{\phi}_{1m} \cdot \dot{\phi}_{2m}}{\pi \rho d^3}$$

$$C_{mq} = (\lambda_1 + \lambda_2 + \frac{\rho A C_{Na}}{2m}) \frac{16 I_y}{\pi \rho d^4}$$

$$C_{np\alpha} = (\lambda_1 \frac{4m}{\rho A} - \frac{m d^2}{2 I_y} (1 + \tau) C_{mq} + C_{Na} (1 - \tau)) \frac{I_x}{m d^2 \tau}$$

$$\tau = (\dot{\phi}_{1m} + \dot{\phi}_{2m}) / (\dot{\phi}_{1m} - \dot{\phi}_{2m})$$

$$C_{Na} = C_D + \frac{\dot{\phi}_{2m} d S_{2m}}{(\frac{\pi}{8} \frac{\rho d^3}{m} K_{2m})}$$

No attempt is made during the linear theory analysis to compute $C_{l\delta}$ or $C_{yp\alpha}$ as these will be determined in the 6 DOF analysis. These coefficients are not necessary as estimates for the 6 DOF analysis.

3. SIX DEGREE OF FREEDOM

The data analysis system currently consists of two 6 DOF programs.

- o Fixed plane 6 DOF for symmetric missiles or projectiles including induced forces and moments.
- o Body fixed 6 DOF for configurations such as airplanes or symmetric missiles with or without mass asymmetries.

Both 6 DOF programs can reduce (analyze) up to five sets of experimental data (shots) simultaneously and determine the set of aerodynamic coefficients which best fit all the data.

The equations of motion, force and moment summations, and aerodynamic coefficients will be discussed in this section for each 6 DOF program individually.

6 DOF Fixed Plane

The equations of motion have been derived in a fixed plane coordinate system. The X-axis points downrange, the Y-axis points to the left looking downrange and the Z-axis points up. Coriolis effects have been accounted for.

$$\dot{x} = u \cos \theta \cos \psi - v \sin \psi + w \sin \theta \cos \psi$$

$$\dot{y} = u \cos \theta \sin \psi + v \cos \psi + w \sin \theta \sin \psi$$

$$\dot{z} = -u \sin \theta + w \cos \theta$$

$$a_{cx} = -2\omega_e (\dot{y} \sin \lambda_R + \dot{z} \cos \lambda_R \sin \delta_R)$$

$$a_{cy} = 2\omega_e (\dot{x} \sin \lambda_R - \dot{z} \cos \lambda_R \cos \delta_R)$$

$$a_{cz} = 2\omega_e (\dot{x} \cos \lambda_R \sin \delta_R + \dot{y} \cos \lambda_R \cos \delta_R)$$

$$a_{cu} = \dot{a}_{cx} \cos \theta \cos \psi + a_{cy} \cos \theta \sin \psi - a_{cz} \sin \theta$$

$$a_{cv} = -a_{cx} \sin \psi + a_{cy} \cos \psi$$

$$a_{cw} = a_{cx} \sin \theta \cos \psi + a_{cy} \sin \theta \sin \psi + a_{cz} \cos \theta$$

$$\dot{\theta} = q$$

$$\dot{\psi} = r / \cos \theta$$

$$\dot{\phi} = p + r \tan \theta$$

$$\dot{u} = g \sin \theta - qw + rv - a_{cu} + F_x/m$$

$$\dot{v} = -ru - r \tan \theta - a_{cv} + F_y/m$$

$$\dot{w} = -g \cos \theta + rv \tan \theta + qu - a_{cw} + F_z/m$$

$$\begin{aligned}
\dot{p} &= L/I_x \\
\dot{q} &= -r^2 \tan \theta - I_x/I_y \, rp + M/I_y \\
\dot{r} &= +qr \tan \theta + I_x/I_y \, qp + N/I_y
\end{aligned}$$

Aerodynamic Model

The aerodynamic forces and moments of symmetric spin stabilized projectile and fin stabilized missiles are shown below as they are currently modeled in the MLMFXPL program. For the fin stabilized case, the analysis includes the induced forces and moments. At present, the coefficients are assumed to be functions of Mach number, the sine of the total angle of attack, and the aerodynamic roll angle.

Summation of Forces and Moments

$$F_x = -\bar{q} A \bar{C}_x$$

$$\begin{aligned}
F_y = \bar{q} A \left[-\bar{C}_{N\alpha} \frac{v}{V} + \frac{pd}{2V} \bar{C}_{Ypa} \frac{w}{V} + \bar{C}_{Y\gamma\alpha} \frac{w}{V} \right. \\
\left. + \bar{C}_{N\delta} \delta_A \sin \phi - \bar{C}_{N\delta} \delta_B \cos \phi \right]
\end{aligned}$$

$$\begin{aligned}
F_z = \bar{q} A \left[-\bar{C}_{N\alpha} \frac{w}{V} - \frac{pd}{2V} \bar{C}_{Ypa} \frac{v}{V} - \bar{C}_{Y\gamma\alpha} \frac{v}{V} \right. \\
\left. - \bar{C}_{N\delta} \delta_A \cos \phi - \bar{C}_{N\delta} \delta_B \sin \phi \right]
\end{aligned}$$

$$L = \bar{q} A d \left[\frac{pd}{2V} \bar{C}_{lp} + \bar{C}_l \right]$$

$$\begin{aligned}
M = \bar{q} A d \left[\bar{C}_{m\alpha} \frac{w}{V} + \frac{qd}{2V} \bar{C}_{mq} + \frac{pd}{2V} \bar{C}_{np\alpha} \frac{v}{V} \right. \\
\left. + \bar{C}_{n\gamma\alpha} \frac{v}{V} + \bar{C}_{m\delta} \delta_A \cos \phi - \bar{C}_{m\delta} \delta_B \sin \phi + RMQ \right]
\end{aligned}$$

$$N = \bar{q} Ad \left[-\bar{C}_{ma} \frac{v}{V} + \frac{rd}{2V} \bar{C}_{mq} + \frac{pd}{2V} \bar{C}_{npa} \frac{w}{V} \right. \\ \left. + \bar{C}_{n\gamma\alpha} \frac{w}{V} + C_{m\delta} \delta_A \sin \phi + C_{m\delta} \delta_B \cos \phi + RNQ \right]$$

Aerodynamic Coefficient Expansions

$$\bar{C}_X = C_{X0} + C_{X\alpha_2} \epsilon^2 + C_{X\alpha_4} \epsilon^4 + C_{Xm} (M_1 - M_r) + C_{X\gamma\alpha_2} \epsilon^2 \cos N \gamma$$

$$\bar{C}_{Na} = C_{Na} + C_{Na_3} \epsilon^2 + C_{Na_5} \epsilon^4 + C_{N\gamma\alpha_3} \epsilon^2 \cos N \gamma + C_{Nam} (M_1 - M_r)$$

$$\bar{C}_{N\delta} \delta_A = C_{N\delta} \delta_A$$

$$\bar{C}_{N\delta} \delta_B = C_{N\delta} \delta_B$$

$$\bar{C}_{Ypa} = C_{Ypa} + C_{Ypa_3} \epsilon^2$$

$$\bar{C}_{Y\gamma\alpha} = C_{Y\gamma\alpha_3} \epsilon^2 \sin N \gamma$$

$$\bar{C}_{lp} = C_{lp} + C_{lp\alpha_2} \epsilon^2 + C_{lpm} (M_1 - M_r)$$

$$\bar{C}_l = \bar{C}_{l\delta} \delta + C_{l\gamma\alpha_2} \epsilon^2 \sin N \gamma$$

$$\bar{C}_{ma} = C_{ma} + C_{ma_3} \epsilon^2 + C_{ma_5} \epsilon^4 + C_{ma} (M_1 - M_r) + C_{m\gamma\alpha_3} \epsilon^2 \cos N \gamma \\ + \bar{C}_{Na} (CG - CG_r) + C_{m\gamma\alpha_5} \epsilon^4 \cos N \gamma$$

$$\bar{C}_{mq} = C_{mq} + C_{mq\alpha_2} \epsilon^2 + C_{mq\alpha_4} \epsilon^4$$

$$\bar{C}_{npa} = C_{npa} + C_{npa_3} \epsilon^2 + C_{npa_5} \epsilon^4 + C_{npa_7} \epsilon^6$$

$$\bar{C}_{n\gamma\alpha} = C_{n\gamma\bar{\alpha}_3} \epsilon^2 \sin N \gamma + C_{n\gamma\bar{\alpha}_5} \epsilon^4 \sin N \gamma$$

$$\bar{C}_{m\delta} \delta_A = C_{m\delta} \delta_A$$

$$\bar{C}_{m\delta} \delta_B = C_{m\delta} \delta_B$$

The following terms represent nonplanar damping variations.

$$RMQ = C_{mq2N} \left[\left(\frac{qd}{2V} \right) \left(\frac{w^2}{v^2} \right) - \left(\frac{rd}{2V} \right) \left(\frac{vw}{v^2} \right) \right] + C_{nq2N} \left[\left(\frac{qd}{2V} \right) \left(\frac{v^2}{v^2} \right) + \left(\frac{rd}{2V} \right) \left(\frac{vw}{v^2} \right) \right]$$

$$RNQ = C_{mq2N} \left[\left(\frac{rd}{2V} \right) \left(\frac{v^2}{v^2} \right) - \left(\frac{qd}{2V} \right) \left(\frac{vw}{v^2} \right) \right] + C_{nr2N} \left[\left(\frac{rd}{2V} \right) \left(\frac{w^2}{v^2} \right) + \left(\frac{qd}{2V} \right) \left(\frac{vw}{v^2} \right) \right]$$

The aerodynamic roll angle is computed by transforming the fixed plane velocities into the rolling body coordinate system as follows:

$$v_b = v \cos \phi + w \sin \phi$$

$$w_b = -v \sin \phi + w \cos \phi$$

$$\gamma = \tan^{-1} (v_b / w_b)$$

6 DOF Body Fixed

Since the aerodynamic forces and moments are defined in a body-fixed coordinate system, the equations of motion were derived with respect to a rotating coordinate system. This coordinate system is defined with the x-axis aligned with the longitudinal axis of the missile and points out the nose, the y-axis points out the left wing, and the z-axis points up with respect to the body. The body-fixed coordinate system is rigidly attached to the missile and rotates with the missile about the x-axis. The inertial frame of reference is the Earth. It is assumed that the Earth is fixed in space and flat. Coriolis effects are included in the equations.

$$\begin{aligned}
\dot{x} &= u_b \cos \theta \cos \psi + v_b (\sin \theta \sin \phi \cos \psi - \cos \phi \sin \psi) \\
&\quad + w_b (\sin \theta \cos \phi \cos \psi + \sin \phi \sin \psi) \\
\dot{y} &= u_b \cos \theta \sin \psi + v_b (\sin \theta \sin \phi \sin \psi + \cos \phi \cos \psi) \\
&\quad + w_b (\sin \theta \cos \phi \sin \psi - \sin \phi \cos \psi) \\
\dot{z} &= -u_b \sin \theta + v_b \cos \theta \sin \phi \\
&\quad + w_b \cos \theta \cos \phi \\
a_{cx} &= -2\omega_e (\dot{y} \sin \lambda_R + \dot{z} \cos \lambda_R \sin \delta_R) \\
a_{cy} &= 2\omega_e (\dot{x} \sin \lambda_R - \dot{z} \cos \lambda_R \cos \delta_R) \\
a_{cz} &= 2\omega_e (\dot{x} \cos \lambda_R \sin \delta_R + \dot{y} \cos \lambda_R \cos \delta_R) \\
a_{cub} &= a_{cx} \cos \theta \cos \psi + a_{cy} \cos \theta \sin \psi - a_{cz} \sin \theta \\
a_{cvb} &= a_{cx} (\sin \theta \sin \phi \cos \psi - \cos \phi \sin \psi) \\
&\quad + a_{cy} (\sin \theta \sin \phi \sin \psi + \cos \phi \cos \psi) \\
&\quad + a_{cz} (\sin \phi \cos \theta) \\
a_{cwb} &= a_{cx} (\sin \theta \cos \phi \cos \psi + \sin \phi \sin \psi) \\
&\quad + a_{cy} (\sin \theta \cos \phi \sin \psi - \sin \phi \cos \psi) \\
&\quad + a_{cz} (\cos \phi \cos \theta) \\
\dot{\theta} &= q_b \cos \phi - r_b \sin \phi \\
\dot{\psi} &= (q_b \sin \phi + r_b \cos \phi) / \cos \theta \\
\dot{\phi} &= p_b + \tan \theta (q_b \sin \phi + r_b \cos \phi) \\
\dot{u}_b &= r_b v_b - q_b w_b - a_{cub} + F_{xb}/m + g \sin \theta \\
\dot{v}_b &= p_b w_b - r_b u_b - a_{cvb} + F_{yb}/m - g \sin \phi \cos \theta \\
\dot{w}_b &= q_b u_b - p_b v_b - a_{cwb} + F_{zb}/m - g \cos \phi \cos \theta
\end{aligned}$$

$$\dot{p}_b = \frac{I_y L_b + I_{xy} M_b - (I_x + I_y - I_z) I_{xy} p_b r_b + (I_{xy}^2 + I_y (I_y - I_z)) q_b r_b}{(I_x I_y - I_{xy}^2)}$$

$$\dot{q}_b = \frac{I_x M_b + I_{xy} L_b + (I_x + I_y - I_z) I_{xy} q_b r_b + (I_x (I_z - I_x) - I_{xy}^2) p_b r_b}{(I_x I_y - I_{xy}^2)}$$

$$\dot{r}_b = \frac{N_b + I_{xy} (p_b^2 - q_b^2) + (I_x - I_y) p_b q_b}{I_z}$$

Aerodynamic Model

The aerodynamic forces and moments currently modeled in the body fixed program are given below. Coefficients are assumed to be functions of Mach number, the sine of the pitch and yaw angles, or the total angle of attack and the aerodynamic roll angle.

Summation of Forces and Moments

$$F_{xb} = -\bar{q} A \bar{C}_X$$

$$F_{yb} = \bar{q} A \left(-\bar{C}_{Y0} - \bar{C}_{Y\beta} \frac{v_b}{V} + \bar{C}_{Y\gamma\alpha} \frac{w_b}{V} + \bar{C}_{Yp\alpha} \frac{p_b^d}{2V} \frac{w_b}{V} \right)$$

$$F_{zb} = \bar{q} A \left(-\bar{C}_{Z0} - \bar{C}_{Z\alpha} \frac{w_b}{V} - \bar{C}_{Y\gamma\alpha} \frac{v_b}{V} - \bar{C}_{Yp\alpha} \frac{p_b^d}{2V} \frac{v_b}{V} \right)$$

$$L_b = \bar{q} A d \left(\frac{p_b^d}{2V} \bar{C}_{lp} + \bar{C}_l \right)$$

$$M_b = \bar{q} A d \left(\bar{C}_{m0} + \bar{C}_{m\alpha} \frac{w_b}{V} + \bar{C}_{mq} \frac{q_b^d}{2V} + \bar{C}_{np\alpha} \frac{p_b^d}{2V} \frac{v_b}{V} + \bar{C}_{n\gamma\alpha} \frac{v_b}{V} \right)$$

$$N_b = \bar{q} A d \left(+\bar{C}_{n0} - \bar{C}_{n\beta} \frac{v_b}{V} + \bar{C}_{nr} \frac{r_b^d}{2V} + \bar{C}_{np\alpha} \frac{p_b^d}{2V} \frac{w_b}{V} + \bar{C}_{n\gamma\alpha} \frac{w_b}{V} \right)$$

Aerodynamic Coefficient Expansions

$$\bar{C}_X = C_{X0} + C_{X\alpha} \left(\frac{w_b}{V}\right) + C_{X\alpha_2} \left(\frac{w_b}{V}\right)^2 + C_{X\beta_2} \left(\frac{v_b}{V}\right)^2 + C_{Xm} (M_i - M_r) + C_{X\alpha_2} \epsilon^2$$

$$\bar{C}_{Y0} = C_{Y0}$$

$$\bar{C}_{Z0} = C_{Z0}$$

$$\bar{C}_{Y\beta} = -C_{Y\beta} - C_{Y\beta_3} \left(\frac{v_b}{V}\right)^2 + C_{N\alpha} + C_{N\alpha_3} \epsilon^2 + C_{N\gamma\alpha_3} \epsilon^2 \cos N \gamma$$

$$\bar{C}_{Z\alpha} = C_{Z\alpha} + C_{Z\alpha_2} \left(\frac{w_b}{V}\right) + C_{Z\alpha_3} \left(\frac{w_b}{V}\right)^2 + C_{N\alpha} + C_{N\alpha_3} \epsilon^2 + C_{N\gamma\alpha_3} \epsilon^2 \cos N \gamma$$

$$\bar{C}_{Y\gamma\alpha} = C_{Y\gamma\alpha_3} \epsilon^2 \sin N \gamma$$

$$\bar{C}_{Ypa} = C_{Ypa}$$

$$\bar{C}_{lp} = C_{lp}$$

$$\bar{C}_l = C_{l\delta} \delta + C_{l\gamma\alpha_2} \epsilon^2 \sin N \gamma + C_{l\beta} \left(\frac{v_b}{V}\right)$$

$$\bar{C}_{m0} = C_{m0}$$

$$\bar{C}_{n0} = C_{n0}$$

$$\begin{aligned} \bar{C}_{m\alpha} = & C_{m\alpha} + C_{m\alpha_2} \left(\frac{w_b}{V}\right) + C_{m\alpha_3} \left(\frac{w_b}{V}\right)^2 + C_{m\alpha} + C_{m\alpha_3} \epsilon^2 + C_{m\gamma\alpha_3} \epsilon^2 \cos N \gamma \\ & + \bar{C}_{Z\alpha} (CG - CG_r) \end{aligned}$$

$$\bar{C}_{mq} = C_{mq} + C_{mq\alpha_2} \left(\frac{w_b}{V}\right)^2 + C_{mq} + C_{mq\alpha_2} \epsilon^2$$

$$\begin{aligned}\bar{C}_{n\beta} = & -C_{n\beta} - C_{n\beta_3} \left(\frac{v_b}{V}\right)^2 + C_{m\alpha} + C_{m\alpha_3} \epsilon^2 + C_{m\gamma\alpha_3} \epsilon^2 \cos N \gamma \\ & + \bar{C}_{Y\beta} (CG - CG_r)\end{aligned}$$

$$\bar{C}_{nr} = C_{nr} + C_{nr\beta_2} \left(\frac{v_b}{V}\right)^2 + C_{mq} + C_{mq\alpha_2} \epsilon^2$$

$$\bar{C}_{n\gamma\alpha} = C_{n\gamma\alpha_3} \epsilon^2 \sin N \gamma$$

$$\bar{C}_{np\alpha} = C_{np\alpha}$$

The aerodynamic roll angle is computed as follows:

$$\gamma = \tan^{-1} (v_b/w_b)$$

Transformations (Fixed Plane)

Missile to Earth

$$\begin{aligned}\dot{x} &= u \cos \theta \cos \psi - v \sin \psi + w \sin \theta \cos \psi \\ \dot{y} &= u \cos \theta \sin \psi + v \cos \psi + w \sin \theta \sin \psi \\ \dot{z} &= -u \sin \theta + w \cos \theta\end{aligned}$$

Earth to Missile

$$\begin{aligned}u &= \dot{x} \cos \theta \cos \psi + \dot{y} \cos \theta \sin \psi - \dot{z} \sin \theta \\ v &= -\dot{x} \sin \psi + \dot{y} \cos \psi \\ w &= \dot{x} \sin \theta \cos \psi + \dot{y} \sin \theta \sin \psi + \dot{z} \cos \theta\end{aligned}$$

Transformations (Body Fixed)

Missile to Earth

$$\begin{aligned}\dot{x} &= u_b \cos \theta \cos \psi + v_b (\sin \theta \sin \phi \cos \psi - \cos \phi \sin \psi) \\ &\quad + w_b (\sin \theta \cos \phi \cos \psi + \sin \phi \sin \psi) \\ \dot{y} &= u_b \cos \theta \sin \psi + v_b (\sin \theta \sin \phi \sin \psi + \cos \phi \cos \psi) \\ &\quad + w_b (\sin \theta \cos \phi \sin \psi - \sin \phi \cos \psi) \\ \dot{z} &= -u_b \sin \theta + v_b \cos \theta \sin \phi \\ &\quad + w_b \cos \theta \cos \phi\end{aligned}$$

Transformations (Body Fixed)

Earth to Missile

$$u_b = \dot{x} \cos \theta \cos \psi + \dot{y} \cos \theta \sin \psi - \dot{z} \sin \theta$$

$$\begin{aligned} v_b = & \dot{x} (\sin \theta \sin \phi \cos \psi - \cos \phi \sin \psi) \\ & + \dot{y} (\sin \theta \sin \phi \sin \psi + \cos \phi \cos \psi) \\ & + \dot{z} (\cos \theta \sin \phi) \end{aligned}$$

$$\begin{aligned} w_b = & \dot{x} (\sin \theta \cos \phi \cos \psi + \sin \phi \sin \psi) \\ & + \dot{y} (\sin \theta \cos \phi \sin \psi - \sin \phi \cos \psi) \\ & + \dot{z} (\cos \theta \cos \phi) \end{aligned}$$

Transformations

Body Fixed to Fixed Plane

$$u = u_b$$

$$v = v_b \cos \phi - w_b \sin \phi$$

$$w = v_b \sin \phi + w_b \cos \phi$$

$$p = p_b$$

$$q = q_b \cos \phi - r_b \sin \phi$$

$$r = q_b \sin \phi + r_b \cos \phi$$

Fixed Plane to Body Fixed

$$u_b = u$$

$$v_b = v \cos \phi + w \sin \phi$$

$$w_b = -v \sin \phi + w \cos \phi$$

$$p_b = p$$

$$q_b = q \cos \phi + r \sin \phi$$

$$r_b = -q \sin \phi + r \cos \phi$$

Direction Cosines to Fixed Plane

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

$$\psi = \sin^{-1} (m_e / (m_e^2 + p_e^2)^{1/2})$$

Angular Identities

Missile Angles

$$\sin \bar{\alpha}_m = \sqrt{\sin^2 \psi_m + \cos^2 \psi_m \sin^2 \theta_m}$$

$$\sin \theta_m = \sin \chi_m / \cos \psi_m$$

$$\sin \theta_m = \sin \alpha_m$$

$$\sin \psi_m = -\sin \beta_m \cos \chi_m$$

$$\tan \beta_m = -\tan \psi_m / \cos \theta_m$$

Missile Angles - Earth Angles

$$\theta = \theta_m - \sin^{-1} [\sin \gamma_e / \cos \psi_m]$$

$$\psi = \sin^{-1} [\sin \psi_m / \cos \gamma_e] + \delta_e$$

Angular Identities

Earth Angles

$$\tan \theta = \tan \chi \cos \psi$$

Missile Velocities - Missile Angles

$$v = -V \sin \psi_m$$

$$w = V \cos \psi_m \sin \theta_m$$

$$u = V \cos \psi_m \cos \theta_m$$

Missile Angle - Velocity Relationship

ANGLE	SINE	COSINE	TANGENT
χ_m	$\frac{w}{\sqrt{u^2 + v^2 + w^2}}$	$\frac{\sqrt{u^2 + v^2}}{\sqrt{u^2 + v^2 + w^2}}$	$\frac{w}{\sqrt{u^2 + v^2}}$
ψ_m	$\frac{-v}{\sqrt{u^2 + v^2 + w^2}}$	$\frac{\sqrt{u^2 + w^2}}{\sqrt{u^2 + v^2 + w^2}}$	$\frac{-v}{\sqrt{u^2 + w^2}}$
θ_m	$\frac{w}{\sqrt{u^2 + w^2}}$	$\frac{u}{\sqrt{u^2 + w^2}}$	$\frac{w}{u}$
α_m	$\frac{w}{\sqrt{u^2 + w^2}}$	$\frac{u}{\sqrt{u^2 + w^2}}$	$\frac{w}{u}$
β_m	$\frac{v}{\sqrt{u^2 + v^2}}$	$\frac{u}{\sqrt{u^2 + v^2}}$	$\frac{v}{u}$
α_i	$\frac{\sqrt{v^2 + w^2}}{\sqrt{u^2 + v^2 + w^2}}$	$\frac{u}{\sqrt{u^2 + v^2 + w^2}}$	$\frac{\sqrt{v^2 + w^2}}{u}$

Trajectory Angle - Velocity Relationships

ANGLE

SINE

COSINE

TANGENT

γ_e

$$\frac{\dot{z}}{V}$$

$$\frac{(\dot{x}^2 + \dot{y}^2)^{1/2}}{V}$$

$$\frac{\dot{z}}{(\dot{x}^2 + \dot{y}^2)^{1/2}}$$

δ_e

$$\frac{\dot{y}}{(\dot{x}^2 + \dot{y}^2)^{1/2}}$$

$$\frac{\dot{x}}{(\dot{x}^2 + \dot{y}^2)^{1/2}}$$

$$\frac{\dot{y}}{\dot{x}}$$

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APPENDIX B

**6 DOF COEFFICIENT INPUT LINE NUMBERS
AND
ANALYSIS INDEX NUMBERS**

APPENDIX B

6 DOF Coefficient Input Line Numbers and Analysis Index Numbers

Each coefficient in the 6 DOF programs has an associated input line number and analysis index number. The input line number is used to specify initial conditions at fit flags. These numbers are always sequential for the table currently being displayed. Since initial fit options are different from subsequent fit options, there will be different menus for each. The same is true for fixed plane and body fixed coordinate systems.

Within the analysis program there is one vector of variables for all the coefficients. These numbers are used within the 6 DOF program for specifying parameters and fit flags. A different vector exists for fixed plane and body fixed coordinate systems.

The following pages will define the parameters available within the 6 DOF program and the associated line and index numbers:

1. FIXED PLANE LINE NUMBERS

For each shot in the analysis (up to 5), a menu of aerodynamic coefficients will be displayed. For the last shot in the fit, a menu of physical parameters is displayed. For each shot fit, menus for both aerodynamic coefficients and physical parameters will be displayed.

The aerodynamic coefficient line numbers are:

1 - $Cm\alpha$	2 - $Cm\alpha_3$	3 - $Cm\alpha_5$	4 - Cmq
5 - $Cmq\alpha_2$	6 - $Cnp\alpha$	7 - $Cnp\alpha_3$	8 - $Cnp\alpha_5$
9 - $Cnsm$	10 - $Cm\alpha$ mach	11 - Cx	12 - $Cx\alpha_2$
13 - $Cx\alpha_4$	14 - $CN\alpha$	15 - $CN\alpha_3$	16 - $CN\alpha_5$
17 - $CYp\alpha$	18 - $CYp\alpha_3$	19 - Cx mach	20 - $Cmq\alpha_4$
21 - $Cmq2-N$	22 - $CN\alpha$ mach	23 - $Cnr2-N$	24 - Clp
25 - $Clp\alpha_2$	26 - Clp mach	27 - $CX\gamma\alpha_2$	28 - $CZ\gamma\alpha_3$
29 - $CY\gamma\alpha_3$	30 - $Cl\gamma\alpha_2$	31 - $Cm\gamma\alpha_3$	32 - $Cn\gamma\alpha_3$
33 - $Cm\gamma\alpha$	34 - $Cn\gamma\alpha$		

The physical parameter line numbers are:

1 - Pitch [THETA]	2 - Pitch rate
2 - Yaw [PSI]	4 - Yaw rate
5 - Travel [X]	6 - Velocity
7 - Drift [Y]	8 - Drift rate
9 - Height [Z]	10 - Vertical rate
11 - Roll [PHI]	12 - Roll rate
13 - Cma unique	14 - Inertia ratio [I_x/I_y]
15 - Cl delta	16 - $CZ\gamma 0$
17 - $CY\gamma 0$	18 - $Cm\gamma 0$
19 - $Cn\gamma 0$	20 - $CX 0$ unique
21 - Clp unique	

2. BODY FIXED LINE NUMBERS

For each shot in the analysis (up to 5), a menu of aerodynamic coefficients will be displayed. For the last shot in the fit, a menu of physical parameters is displayed. For each shot fit, menus for both aerodynamic coefficients and physical parameters will be displayed.

1 - $C_{m\alpha}$	2 - $C_{m\alpha_3}$	3 - $C_{N\beta}$	4 - $C_{N\beta_3}$
5 - Dmq	6 - $C_{mq\alpha_2}$	7 - C_{nr}	8 - C_{nr_2}
9 - $C_{m\alpha_2}$	10 - $C_{Z\alpha_2}$	11 - $C_{n\gamma\alpha}$	12 - $C_{m\gamma\alpha}$
13 - $C_{m\alpha}$ -bar	14 - $C_{m\alpha_3}$ -bar	15 - C_{mq} -bar	16 - $C_{mq\alpha_2}$ -bar
17 - $C_{np\alpha}$ -bar	18 - C_{x0}	19 - $C_{x\alpha_2}$	20 - $C_{x\beta_2}$
21 - C_x mach	22 - $C_{Y\beta}$	23 - $C_{Y\beta_3}$	24 - $C_{Z\alpha}$
25 - $C_{Z\alpha_3}$	26 - $C_{Z\gamma\alpha}$	27 - $C_{Y\gamma\alpha}$	28 - $C_{X\alpha}$
29 - $C_{Yp\alpha}$ -bar	30 - $C_{X\alpha_2}$ -bar	31 - $C_{N\alpha}$ -bar	32 - $C_{N\alpha_3}$ -bar
33 - C_{lp}	34 - $C_{l\gamma\alpha}$	35 - $C_{l\beta}$	36 - I_{xy}
37 - I_y/I_z	38 - C_{m0}	39 - C_{N0}	40 - C_{Y0}
41 - C_{Z0}	42 - $C_{l\text{-delta}}$	43 - $C_{ma\text{-unique}}$	

The physical parameter line numbers are:

1 - Pitch [THETA]	2 - Pitch rate
2 - Yaw [PSI]	4 - Yaw rate
5 - Travel [X]	6 - Velocity
7 - Drift [Y]	8 - Drift rate
9 - Height [Z]	10 - Vertical rate
11 - Roll [PHI]	12 - Roll rate
13 - Inertial cross product [I_{xy}]	14 - Inertia form factor [I_x/I_y]
15 - C_{m0}	16 - C_{n0}
17 - C_{Y0}	18 - C_{z0}
19 - $C_{l\text{ delta}}$	20 - $C_{m\alpha\text{-unique}}$

3. FIXED PLANE INDEX NUMBERS

For fixed plane equations of motion, the index numbers in the analysis are:

1 - $Cm\alpha$	2 - $Cm\alpha_3$	3 - $Cm\alpha_5$	4 - Cmq
5 - $Cmq\alpha_2$	6 - $Cnp\alpha$	7 - $Cnp\alpha_3$	8 - $Cnp\alpha_5$
9 - $Cnp\alpha_7$	10 - $Cm\alpha \text{ mach}$	11 - $Cm\gamma\alpha_5$	12 - $Cn\gamma\alpha_5$
17 - Cx	18 - $Cx\alpha_2$	19 - $Cx\alpha_4$	20 - $CN\alpha$
21 - $CN\alpha_3$	22 - $CN\alpha_5$	23 - $CYp\alpha$	24 - $CYp\alpha_3$
25 - $Cx \text{ mach}$	26 - $Cmq\alpha_4$	27 - $Cmq2-N$	28 - $CN\alpha \text{ mach}$
29 - $Cnr2-N$	32 - Clp	33 - $Clp\alpha_2$	34 - $Clp \text{ mach}$
35 - $CX\gamma\alpha_2$	36 - $Cz\gamma\alpha_3$	37 - $CY\gamma\alpha_3$	38 - $Cl\gamma\alpha_2$
39 - $Cm\gamma\alpha_3$	40 - $Cn\gamma\alpha_3$		
41 - Pitch [THETA]		42 - Pitch rate	
43 - Yaw [PSI]		44 - Yaw rate	
45 - Travel [X]		46 - Velocity	
47 - Horizontal motion [Y]		48 - Horizontal rate	
49 - Vertical motion [Z]		50 - Vertical rate	
51 - Roll [PHI]		52 - Roll rate	
53 - $Cma \text{ unique}$		54 - Inertia ratio [I_x/I_y]	
55 - $Cl \text{ delta}$		56 - $CNdA$	
57 - $CNdB$		58 - $CmdA$	
59 - $CmdB$		60 - $CX0 \text{ unique}$	
61 - $Clp \text{ unique}$		62 - Pitch rate [Q]	
63 - Yaw rate [R]		64 - Velocity (missile) [U]	
65 - Hor. rate (missile) [V]		66 - Vertical rate (missile) [W]	
67 - Roll rate [P]			

4. BODY FIXED INDEX NUMBERS

For body fixed equations of motion, the index numbers in the analysis are:

1 - $Cm\alpha$	2 - $Cm\alpha_3$	3 - $CN\beta$	4 - $CN\beta_3$
5 - Cmq	6 - $Cmq\alpha_2$	7 - Cnr	8 - Cnr_2
9 - $Cm\alpha_2$	10 - $Cz\alpha_2$	11 - $Cm\gamma\alpha_3$	12 - $Cn\gamma\alpha_3$
13 - $Cm\alpha$ -bar	14 - $Cm\alpha_3$ -bar	15 - Cmq -bar	16 - $Cmq\alpha_2$ -bar
17 - $Cnp\alpha$ -bar	18 - Cx_0	19 - $Cx\alpha_2$	20 - $Cx\beta_2$
21 - Cx mach	22 - $CY\beta$	23 - $CY\beta_3$	24 - $CZ\alpha$
25 - $CZ\alpha_3$	26 - $CZ\gamma\alpha_3$	27 - $CY\gamma\alpha_3$	28 - $CX\alpha$
29 - $CYp\alpha$ -bar	30 - $CX\alpha_2$ -bar	31 - $CN\alpha$ -bar	32 - $CN\alpha_3$ -bar
33 - Clp	34 - $Cl\gamma\alpha_2$	35 - $Cl\beta$	
41 - Pitch [THETA]	42 - Pitch rate		
43 - Yaw [PSI]	44 - Yaw rate		
45 - Travel [X]	46 - Velocity		
47 - Horizontal motion [Y]	48 - Horizontal rate		
49 - Vertical motion [Z]	50 - Vertical rate		
51 - Roll [PHI]	52 - Roll rate		
53 - Inertial cross product [Ixy]	54 - Axial Inertia [Ix]		
55 - CM_0 -trim	56 - CN_0 -trim		
57 - CY_0 -trim	58 - CZ_0 -trim		
59 - Cl -delta	60 - $Cm\alpha$ -bar		
61 - Not used	62 - Pitch rate [Q]		
63 - Yaw rate [R]	64 - Velocity (missile) [U]		
65 - Drift rate (missile) [V]	66 - Drop rate (missile) [W]		
67 - Roll rate [P]			