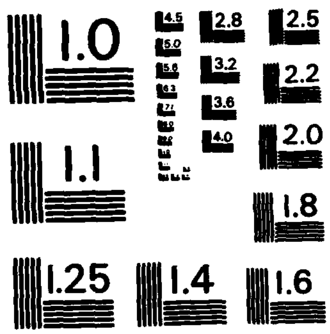
AD-A160 003 ESTIMATING THE MAGNUS MOMENT EFFECT ON STABILITY OF 30-MM BOOMED PROJECTILES(U) AIR FORCE ARMAMENT LAB EGLIN AFB FL R H BYERS ET AL. AUG 85 AFATL-TR-85-69 1/1

UNCLASSIFIED SBI-AD-E801 207 F/G 19/4 NL

END

FILMED

DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AFATL-TR-85-69

Estimating the Magnus Moment Effect on Stability of 30-mm Boomed Projectiles

Richard H Byers, 2 Lt
Ken Cobb

GUNS AND PROJECTILE BRANCH
MUNITIONS DIVISION

AUGUST 1985

FINAL REPORT FOR PERIOD DECEMBER 1984 - FEBRUARY 1985

Approved for public release; distribution unlimited

Air Force Armament Laboratory

AIR FORCE SYSTEMS COMMAND ★ UNITED STATES AIR FORCE ★ EGLIN AIR FORCE BASE, FLORIDA

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

This report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

JOHN A. PALMER, Colonel, USAF
Chief, Munitions Division

Even though this report may contain special release rights held by the controlling office, please do not request copies from the Air Force Armament Laboratory. If you qualify as a recipient, release approval will be obtained from the originating activity by DTIC. Address your request for additional copies to:

Defense Technical Information Center
Cameron Station
Alexandria, Virginia 22314

If your address has changed, if you wish to be removed from our mailing list, or if the addressee is no longer employed by your organization, please notify AFATL/DLJG, Eglin AFB FL 32542.

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

AD-A160 003

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

2b. DECLASSIFICATION/DOWNGRADING SCHEDULE

3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S)

5. MONITORING ORGANIZATION REPORT NUMBER(S): AFATL-TR-85-69

6a. NAME OF PERFORMING ORGANIZATION: Munitions Division

6b. OFFICE SYMBOL *(If applicable)*: DLJ

7a. NAME OF MONITORING ORGANIZATION: Guns and Projectiles Branch (DLJG)

6c. ADDRESS *(City, State and ZIP Code)*: Air Force Armament Laboratory, Eglin AFB, Florida 32542-5000

7b. ADDRESS *(City, State and ZIP Code)*: AFATL, Eglin AFB, FL 32542-5000

8a. NAME OF FUNDING/SPONSORING ORGANIZATION: Munitions Division

8b. OFFICE SYMBOL *(If applicable)*: DLJ

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c. ADDRESS *(City, State and ZIP Code)*: Air Force Armament Laboratory, Eglin AFB, Florida 32542-5000

10. SOURCE OF FUNDING NOS.

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.
62602F	2502	12	11

11. TITLE *(Include Security Classification)*: Estimating the Magnus Moment Effect on Stability of 30mm Boomed Projectiles

12. PERSONAL AUTHOR(S): 2d Lt Richard H. Byers/Ken Cobb

13a. TYPE OF REPORT: Final

13b. TIME COVERED: FROM 3-11-84 TO 1-5-85

14. DATE OF REPORT *(Yr., Mo., Day)*: August 1985

15. PAGE COUNT: 35

16. SUPPLEMENTARY NOTATION: None

17. COSATI CODES

FIELD	GROUP	SUB. GR.

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*: Ammunition Analysis; Boom Effects; Magnus Moment Coefficient

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

This report documents the results obtained from a comparison of free-flight spark range tests and PRODASMAGNUS computer stability results for 30mm spin stabilized projectiles. Two configurations were considered, each with the same boom diameter of 0.5 inch, 1.0 inch and 1.25 inch boom lengths. The results show that PRODASMAGNUS can accurately predict the effects of a boom's presence on projectile stability.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐

21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL: 2d Lt Richard H. Byers

22b. TELEPHONE NUMBER *(Include Area Code)*: (904)882-8195

22c. OFFICE SYMBOL: DLJG

DD FORM 1473, 83 APR   EDITION OF 1 JAN 73 IS OBSOLETE.

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

PREFACE

This test report documents the computer analysis results obtained on 30mm boomed projectiles. This analysis was conducted by the Guns and Projectile Branch, Munitions Division, Air Force Armament Laboratory, Eglin Air Force Base, Florida 32542, during December 1984 through February 1985. The project engineer was Lieutenant Richard H. Byers (DLJG). Technical assistance was provided by Mr. Ken Cobb (DLYS).

(The reverse of this page is blank)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SYMBOLS AND NOMENCLATURE

SYMBOL	DESCRIPTION	UNITS
A	Projectile Cross-Sectional Area	ft^2
C_{lp}	Spin Deceleration Coefficient	$M_{lp}/\bar{q}Ad(pd/2V)$
C_m	Pitching Moment Coefficient	$M_m/\bar{q}Ad$
C_{mq}	Damping Moment Coefficient	$M_{mq}/\bar{q}Ad(qd/2V)$
C_{np}	Magnus Moment Coefficient	$M_{np}/\bar{q}Ad(pd/2V)$
C_N	Normal Force Coefficient	$F_N/\bar{q}A$
C_{Yp}	Magnus Force Coefficient	$F_{Yp}/\bar{q}A(pd/2V)$
C_X	Axial Force Coefficient	$F_X/\bar{q}A$
CG	Center of Gravity, Calibers From Nose	
I_x	Axial Moment of Inertia	$slugs\text{-}ft^2$
I_y	Transverse Moment of Inertia	$slugs\text{-}ft^2$
F_N	Normal Force	lbs
F_{Yp}	Magnus Force	lbs
F_X	Axial Force	lbs
M_{lp}	Spin Damping Moment	ft-lbs
M_m	Pitching Moment About CG	ft-lbs
M_{mq}	Damping Moment About CG	ft-lbs
M_{np}	Magnus Moment About CG	ft-lbs
V	Total Velocity	ft/sec
d	Projectile Diameter	ft
g	Gravity	$32.174\ ft/sec^2$
m	Projectile Mass	slugs
p	Projectile Spin Rate	rad/sec

SYMBOL	DESCRIPTION	UNITS
q	Projectile Pitch Rate	rad/sec
$\bar{q}$	Dynamic Pressure ($\frac{1}{2}\rho V^2$)	lb/ft^2
$\bar{\alpha}$	Total Angle of Attach	radians
ρ	Air Density	$slugs/ft^3$
BMD	Boom Diameter/Projectile Diameter	
BML	Boom Length/Projectile Length	
k_1^{-2}	md^2/I_x	
k_2^{-2}	md^2/I_y	
K	VCG	
M_α	Pitching Moment Derivative with $\bar{\alpha}$	
S_d	Dynamic Stability Factor	
S_g	Gyroscopic Stability Factor	
[illegible]	Axial Spin Rate	
VB	Boattail Length	
VCG	Distance From Nose to CG	
VL	Projectile Length	
VN	Projectile Nose Length	
CNPA	Magnus Moment Coefficient	
CYPA	Magnus Force Coefficient	
CPF	Magnus Force Center of Pressure	
CXCL	VL - VN - VB - 1.5	
CVN	VN - 2.5	
CVB	VB	
CVL	VL	

(The reverse of this page is blank)

SECTION I

INTRODUCTION

Work has been going on for several years in the development of telescoped ammunition. The Guns and Projectiles Branch (DLJG) of the Air Force Armament Laboratory (AFATL) is currently sponsoring an Advanced Gun Technology (AGT) program that will include development of a projectile for 20mm telescoped ammunition. This projectile differs from a conventional projectile in that there is a boom attached to the projectile base. In support of the AGT ammunition development, DLJG conducted an in-house boomed projectile stability program.

Previous interest in the area of boomed projectile stability (Ref 1) provided some useful data on 30mm projectiles with various boom configurations. The primary tool used by DLJG in the design and analysis of spin stabilized projectiles is PRODAS (Ref 2). However, when modeling boomed projectiles, PRODAS does not consider the effects of the boom on the aerodynamic coefficients that influence the dynamic stability.

The purpose of this report is to document the work done in developing a mathematical expression that accurately models the boom effects on projectile stability, primarily the Magnus moment coefficient. The results generated by the expression, for a specific test model, will be compared to statistical multifit data taken from ballistic range tests.

The model evaluated was constructed from a 30mm Honeywell HE round. The models weighed approximately 4000 grains (259.24 grams) each. This was the suggested weight of 30mm telescoped ammunition (Ref 3). Boom lengths of 1.0 and 1.25 inches were considered, while all projectiles had boom diameters of 0.5 inch. A total of 12 projectiles were fired in the Aeroballistic Range Facility located at Eglin Air Force Base, Florida.

SECTION II

STABILITY ANALYSIS MODEL

1. STABILITY PARAMETERS. The stability analysis model makes use of the spin stabilized projectile analysis segment of PRODAS. The objective of this program was to modify PRODAS to model boomed projectiles to evaluate their dynamic stability. The evaluation would be accomplished by developing a boom projectile prediction equation. The stability parameters of interest were $C_{np\alpha}$, the Magnus moment coefficient with respect to the total angle of attack, $\bar{\alpha}$, and the dynamic stability factor, S_d. The relationship between $C_{np\alpha}$, S_d, and the gyroscopic stability factor, S_g, will be shown later.

The various coefficients used in the stability equations make use of parameters that describe a typical spin stabilized projectile. These parameters can be seen in Figure 1. The method used to develop the boom equation is similar to the empirical techniques employed in References 4 and 5. In general, an equation of the following form was used:

$$CX_i = a_1 + a_2X_{i1} + a_3X_{i2} + \dots + a_nX_{i(n-1)} + b_1X_{i1}X_{i2} + b_2X_{i1}X_{i3} + \dots + b_{(n-1)}X_{i1}X_{in} + c_1X_{i1}^2 + c_2X_{i2}^2 + \dots + c_nX_{in}^2 + \dots \tag{1}$$

where $a_1, \dots a_n$, $b_1 \dots b_{(n-1)}$, and $c_1, \dots c_n$ are coefficients to be determined. The terms $X, \dots X_{mn}$ are dependent upon a particular projectile geometry. Equation 1 is an example of a multiple linear regression fit for n parameters of X. This technique is commonly used when data for many firings of a particular projectile are available. For the case of the boomed projectile reduction equation, we only had two parameters to fit, boom diameter and boom length. The fit was also done for only 11 shots divided into three configurations. When determining the Magnus force coefficient derivative ($C_{Y_{p_\alpha}}$), Magnus moment coefficient derivative ($C_{n_{p_\alpha}}$), and the Magnus Force center of pressure (C_{PF}), the following approach was used: (Many of the following equations are written here as they appear in the computer program.)

$$CVL = VL \tag{2}$$

$$CVB = VB \tag{3}$$

$$CXCL = VL - VN - VB - 1.5 \tag{4}$$

$$CVN = VN - 2.5 \tag{5}$$

$$CYPA = E_1(CVL) - 0.1(CVB) \tag{6}$$

CYPA is the Magnus force coefficient derivative with respect to $\bar{\alpha}$. For $\bar{\alpha} = 1.0^\circ$:

$$CNPAN = -E_1(CVL)[E_2 + 0.55(CXCL) + 0.80(CVN)] + CVB(CVL/4.7) \tag{7}$$

$$CPF_{(\bar{\alpha}=1)} = -CNPAN/CYPA \tag{8}$$

$$C_{Y_{p_\alpha}} = CYPA \tag{9}$$

$$C_{n_{p\alpha}(1)} = (VCG - CPF_{(1)})CYPA \tag{10}$$

Equation 10 is the Magnus moment coefficient derivative with respect to $\bar{\alpha} = 1.0^\circ$. PRODAS code was modified with respect to CNPA for both $\bar{\alpha} = 1.0^\circ$ and $\bar{\alpha} = 5.0^\circ$ calculations.

For $\bar{\alpha} = 5.0^\circ$

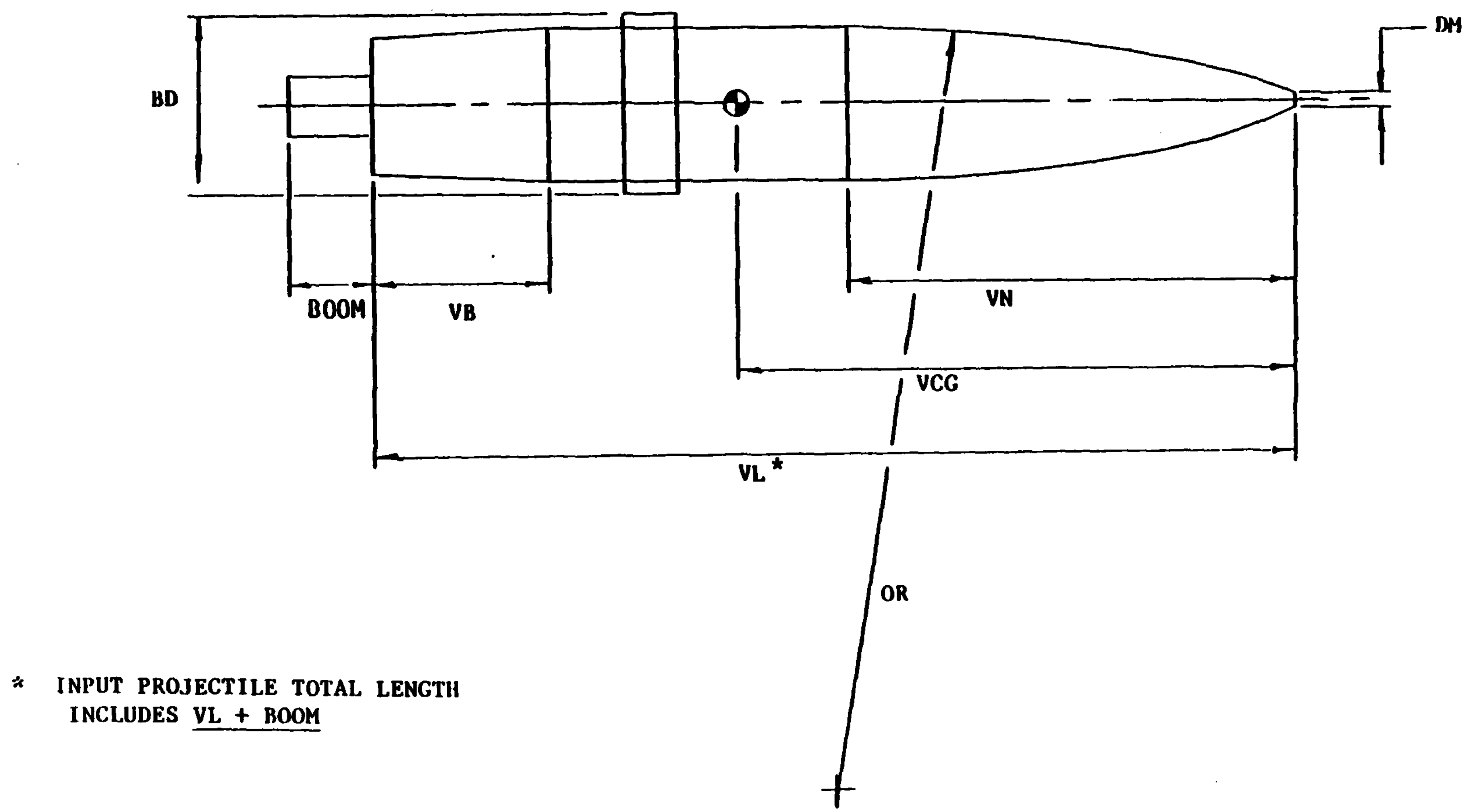


Figure 1. Projectile Parameters

$$CNPAN = -E_1(CVL)[E_4 + 0.55(CXCL) + 0.80(CVN)] + CVB(CVL/4.7) \quad (11)$$

$$CPF_{(\alpha=5)} = -CNPAN/CYPA \quad (12)$$

$$C_{Yp\alpha} = CYPA \quad (13)$$

$$C_{np\alpha_{(5)}} = (VCG - CPF_{(5)})CYPA \quad (14)$$

The best place to start modeling the boom's effects was in the Magnus moment coefficient, $C_{np\alpha}$.

In order to do this, Equations 10 and 14 must be modified to consider configurations with and without booms attached. The required modification led to the following expression:

$$C_{np\alpha} = (VCG - CPF)CYPA + [VCG - (K + X_1(BML) + X_2(BMD) + X_3(BML \cdot BMD))]CYPA \quad (15)$$

where

$$K = VCG \quad (16)$$

$$BML = (\text{boom length})/(\text{projectile length}) \quad (17)$$

$$BMD = (\text{boom diameter})/(\text{projectile diameter}) \quad (18)$$

X_1, X_2, and X_3 are correlation constants to be determined. Equation 15 was substituted for Equations 10 and 14 in the PRODAS code. The modified computer program was called PRODASMAGNUS and will be referred to as the PM program.

2. STABILITY EQUATIONS. The stability equations are defined by

parameters: C_X, $C_{n\alpha}$, $C_{m\alpha}$, $C_{np\alpha}$, C_{mq}, and $C_{\ell p}$. The gyroscopic stability factor, S_g, is:

$$S_g = \frac{2I_x{}^2p^2}{\pi I_y C_{m\alpha} d^3 V^2 \rho} \tag{19}$$

or

$$S_g = (\omega^2 I_x{}^2)/(4I_y M_\alpha) \tag{20}$$

where

$$M_\alpha = 1/2\,\rho\, AV^2 dC_{m\alpha} \tag{21}$$

The gyroscopic stability factor is basically the ratio of the gyroscopic moment to the static overturning (tumbling) moment. The dynamic stability factor, S_d, is:

$$S_y = \frac{2(C_{n\alpha} - C_X + (k_1{}^{-2}/2)C_{np\alpha})}{(C_{n\alpha} - C_X - (k_2{}^{-2}/2)C_{mq} + (k_1{}^{-2}/2)C_{\ell p})} \tag{22}$$

$$k_1{}^{-2} = md^2/I_x \tag{23}$$

$$k_2{}^{-2} = md^2/I_y \tag{24}$$

The Magnus moment coefficient, $C_{np\alpha}$, and the pitch damping coefficient, C_{mq}, are the aerodynamic coefficients that have the greatest effect on dynamic stability. Mathematically, the gyroscopic-dynamic stability relationship is given by:

$$\frac{1}{S_g} \leq S_d(2 - S_d) \tag{25}$$

The resulting stability regions are illustrated in Figure 2.

3. FORTRAN CODE. The following FORTRAN statements were encoded into the SPINNER Program Overlay of PRODAS:

```
          BML = BOOM
          IF(BML .NE. 0.0) BTEST = 1
          XA8(J) = (VCG - XA7(J))*XA6(J)
          IF (BTEST .NE. 1) GO TO 401
          CNPAT = XA8(J)
          CALL MAGNUS (E)
          CPFB = E(1)*BML + E(2)*BMD + E(3)*BML*BMD + VCG
          XA8(J) = CNPAT + (VCG - CPFB)*XA6(J)
      401 CONTINUE
```

The same procedure was used for $\bar{\alpha} = 5.0^{\circ}$. The following FORTRAN variable equivalence is established:

$$XA6(J) = CYPA \tag{26}$$

$$XA7(J) = CPF \tag{27}$$

$$XA8(J) = CNPA \tag{28}$$

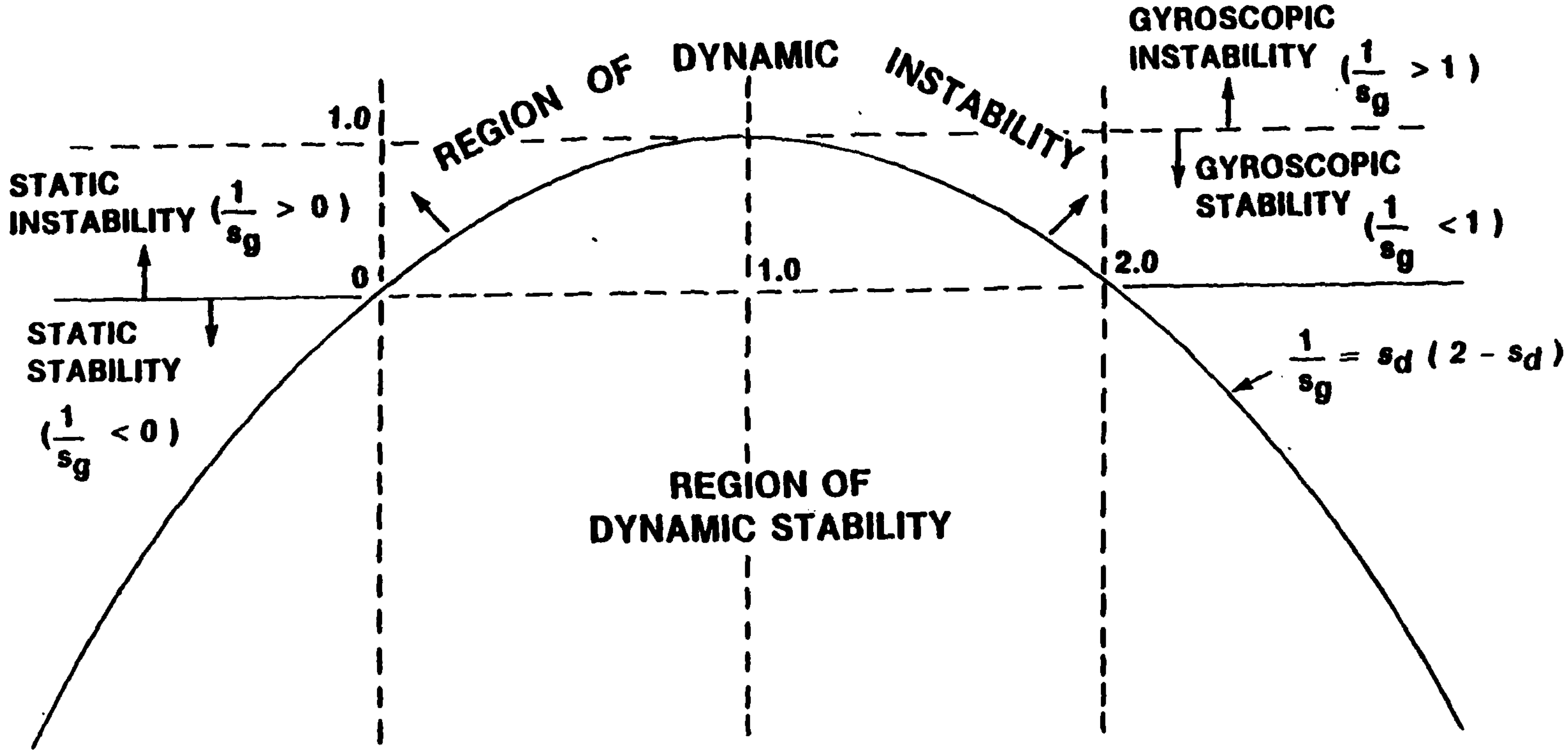


Figure 2. Dynamic Stability

It can be seen that Equation 15 takes on the form of Equation 10, for $\bar{\alpha} = 1.0^\circ$, when the projectile has no boom. In the case of no boom, the logical variable BTEST = 0, and all of the boom coefficients equal zero, leaving the program as it was originally encoded.

4. ALGORITHM COEFFICIENTS. Calculation of the boom algorithm coefficients was dependent upon the results of the work done by Hathaway (Ref 1). The projectile parameters were:

Configuration	Mach No	CNPA	BML (in)	BMD (in)
B	2.886	0.79	1.0	0.375
D	2.817	4.86	2.5	0.75
E	2.892	1.55	1.0	0.75

Values for VCG, CPF, and CYPA in Equation 15 were taken from the multifit data of the previous tests (Ref 1). All boom coefficients were expressed in non-dimensional calibers (see Equations 17 and 18).

Configuration	VCG	BML (cal.)	BMD (cal.)	BMLxBMD
B	3.1243	0.8467	0.3175	0.2688
D	3.3101	2.1169	0.6351	1.3444
E	3.1408	0.8467	0.6351	0.5377

For Mach number approximately equal to 2.9 and $\bar{\alpha} = 1.0^\circ$,

$$CPF = 3.398 \tag{29}$$

$$CYPA = -0.743 \tag{30}$$

Equation 15 was then solved for each projectile configuration used.

For configuration B:

$$0.79 = (3.1243 - 3.398)(-0.743) + .6291X_1 + .2359X_2 + .1997X_3 \quad (31)$$

For configuration D:

$$4.86 = (3.3101 - 3.398)(-0.743) + 1.5728X_1 + .4719X_2 + .9989X_3 \quad (32)$$

For configuration E:

$$1.55 = (3.1408 - 3.398)(-0.743) + .6291X_1 + .4719X_2 + .3995X_3 \quad (33)$$

Combining all three equations, 31, 32, and 33 and expressing in matrix notation:

$$\begin{bmatrix} 0.5866 \\ 1.3589 \\ 4.7947 \end{bmatrix} = \begin{bmatrix} 0.6291 & 0.2359 & 0.1997 \\ 0.6291 & 0.4719 & 0.3995 \\ 1.5728 & 0.4719 & 0.9989 \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \\ X_3 \end{bmatrix} \quad \begin{matrix} (34) \\ (35) \\ (36) \end{matrix}$$

Solving the linear system by a Gauss-Jordan technique yields:

$$X_1 = 0.29491 \quad (37)$$

$$X_2 = -1.972925 \quad (38)$$

$$X_3 = 6.196368 \quad (39)$$

These coefficients, X_1, X_2, and X_3, are similar to $a_1, \ldots a_n$, $b_1, \ldots b_{(n-1)}$, and $c_1, \ldots c_n$ in Equation 1. Since the coefficients were based upon limited experimental data, it was decided not to enter them directly into the PM program. Instead, the coefficients were put into subroutine MAGNUS and called into the main program when needed. This was done to accommodate later changes depending upon availability of additional boom projectile test results.

After calculation of the coefficients and implementation of the algorithm, the program was run using a carefully constructed PRODAS model. This projectile design, as described by the computer model, was then built by the machine shop and fired in the ARF. It was anticipated that the multi-fit data would verify the accuracy of the boom projectile algorithm.

SECTION III

BALLISTIC RANGE TESTS

1. MODELS. The test model is illustrated in Figures 3a and 3b. All models were 30mm Honeywell HE projectiles with PES plastic bands. This particular projectile was chosen because it was readily available due to band tests being conducted by DLJG. All projectiles were cut down 1.0 inch from the forward end and fitted with an aluminum nose cone that conformed to the original ogive plus the M505 fuze assembly. Every effort was made to build a stable boomed projectile that would weigh approximately 4000 grains, the anticipated weight of 30mm telescoped ammunition.

Each projectile was fitted with a solid aluminum boom that was threaded into the base of the projectile. Extreme care was made to center the boom into the base to prevent in-bore balloting and unstable flight after launch. A boom diameter of 0.5 inches was chosen since that dimension was recommended for actual 30mm telescoped ammunition.

A total of 12 projectiles were supplied to the ARF for testing. Six models had boom lengths of 1.0 inch and the remaining six models had boom lengths of 1.25 inches. Once again, it was anticipated that 30mm telescoped ammunition would require a boom length somewhere between 1.0 and 1.25 inches (Ref 3). These boom configurations also filled a data void left by the previous 30mm boomed projectile tests.

2. TEST PROCEDURE AND CONDITIONS. Prior to firing these projectiles in the ARF, several were fired in the Interior Ballistics Laboratory (Bay 10). The purpose of these tests was to insure model integrity during both the internal ballistics phase and the in-flight phase by using witness cards and

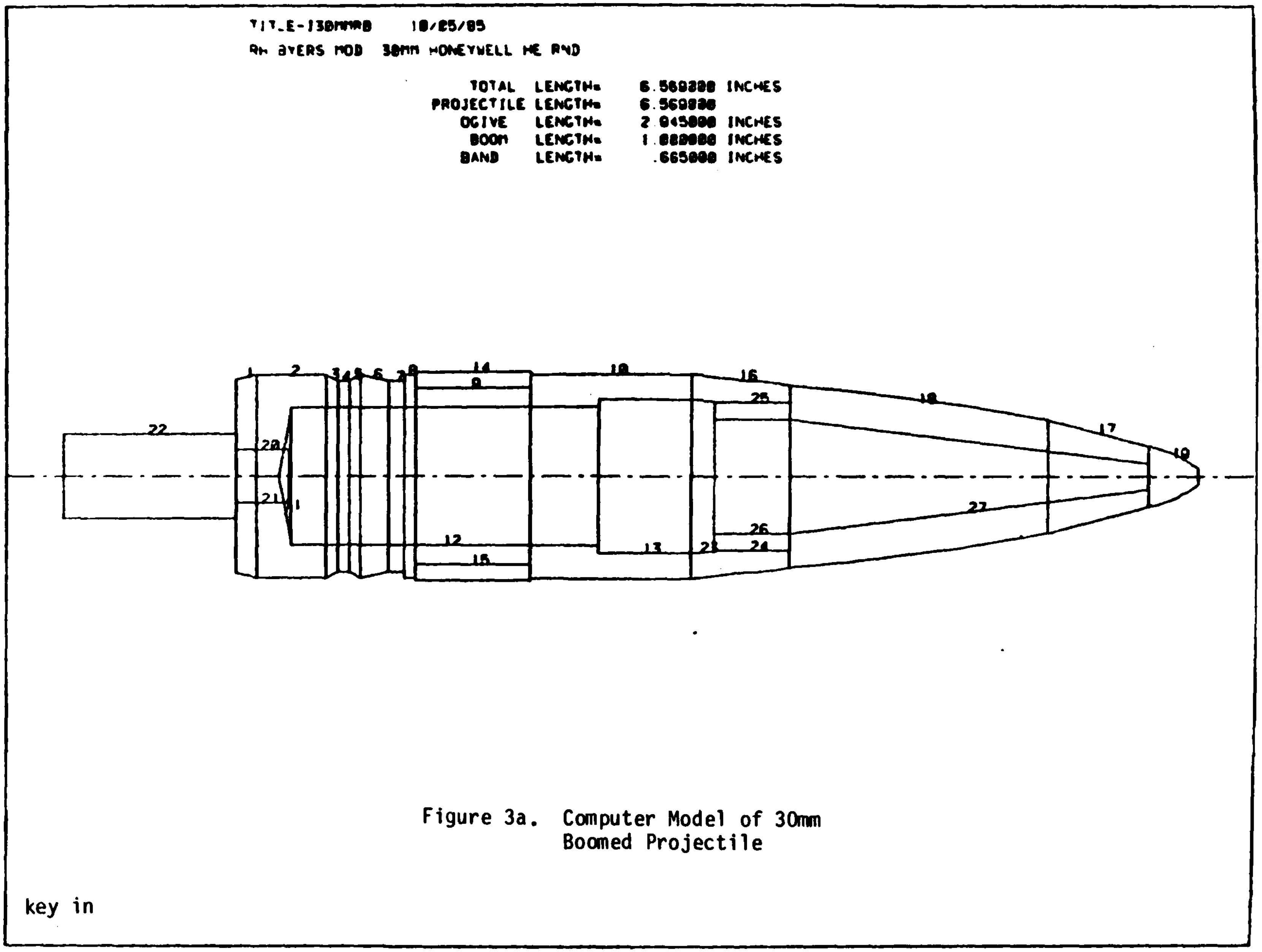


Figure 3a. Computer Model of 30mm Boomed Projectile

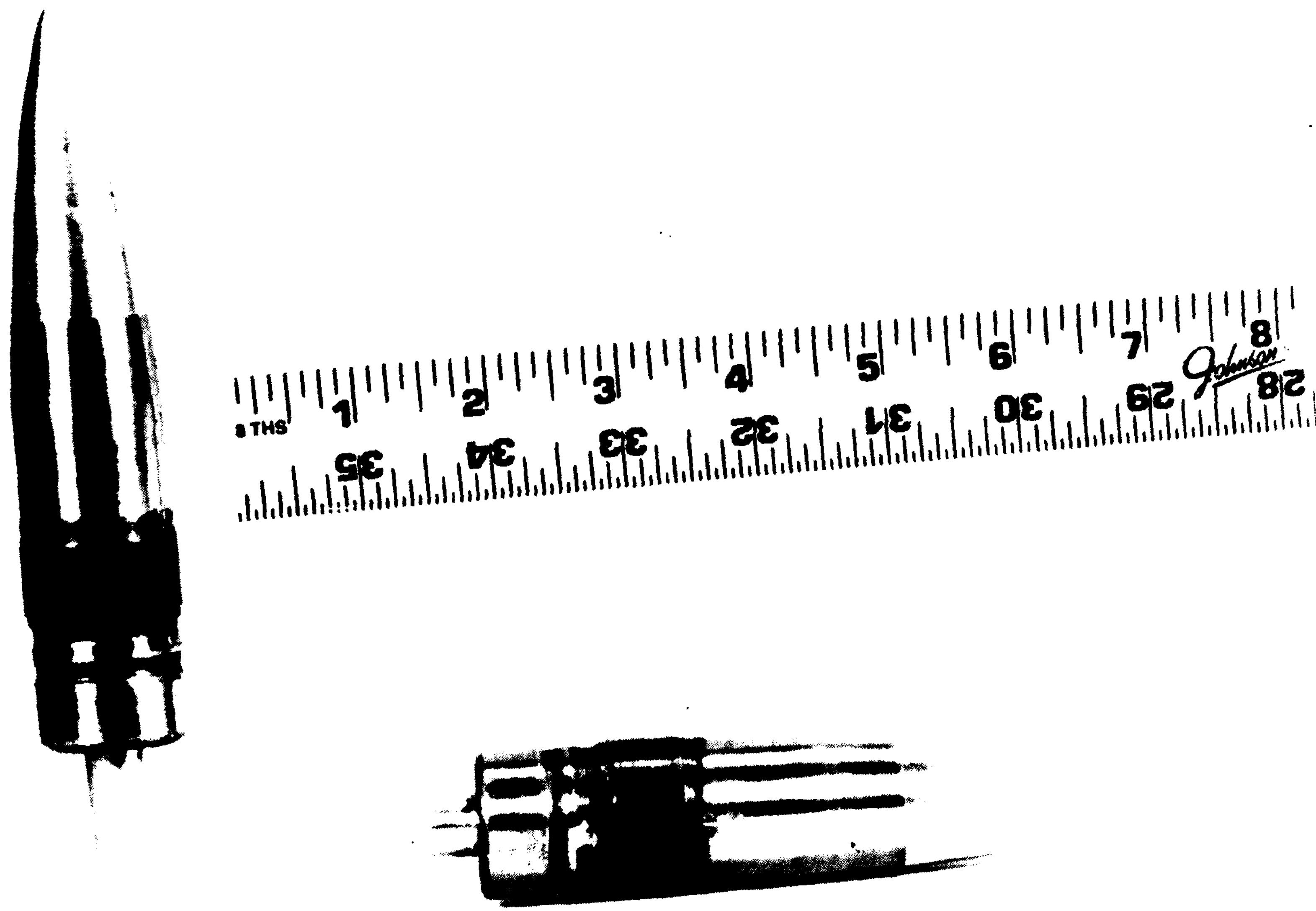


Figure 3b. 30mm Boomed Projectiles

in-flight photography. All but one projectile flew straight with no yaw indication on the cards. The one failure was attributed to a poor fit between the HE body and the aluminum nose cone.

The models were fired from a 30mm rifled barrel with a twist rate of one turn in 18 calibers. All models were launched at atmospheric pressure conditions and at essentially the same Mach number of 3.0.

A test summary of all models fired during the test is contained in Table 1. Mass properties of the free-flight models are presented in Table 2. Ballistic range data was extracted for 11 of the 12 projectiles. Data from one projectile was excluded because the nose cone separated from the body while in flight.

TABLE 1. TEST CONDITIONS SUMMARY

Shot No.	Boom Length, in.	Mach No.	$\bar{\delta}^2$ Deg.^{2}	Temp. °C	Press MBAR	Rel. Hum. %	Freon gms.
BS84112683	1.00	3.15	4.1	21.87	1022.7	0.54	—
BS84112684	1.00	3.03	1.7	21.79	1022.7	0.54	--
BS85011890	1.25	3.01	0.1	21.23	1014.9	0.50	—
BS85011891	1.25	3.00	1.6	21.34	1014.8	0.50	--
BS85011892	1.00	3.03	0.3	21.26	1014.9	0.50	—
BS85011893	1.25	3.03	1.7	21.41	1014.9	0.50	--
BS85031404	1.00	2.97	38.0	22.55	1019.3	0.50	725
BS85031405	1.00	2.95	37.6	22.68	1018.0	0.52	725
BS85031506	1.00	2.98	3.2	22.70	1021.7	0.52	725
BS85031507	1.25	3.00	52.1	22.73	1022.0	0.51	725
BS85031508	1.25	3.00	13.1	19.77	1022.0	0.52	725
BS85031509	1.25	NOSE CAME OFF					

TABLE 2. MASS PROPERTIES DATA

SHOT NO.	DIA CM	MASS GRAMS	IX GM-CM2	IY GM-CM2	IZ GM-CM2	LENGTH CM	CG PERCENT	CG CM FM NOSE	ROLL PINS
BS85031405	2.9947	253.83	369.483	3217.2	3217.2	14.351	.6851	9.832	NO
BS85031404	2.9931	254.00	370.714	3232.4	3232.4	14.342	.6875	9.860	NO
BS85031506	2.9921	254.16	370.116	3220.8	3220.8	14.340	.6864	9.843	YES
BS84112684	2.9931	254.05	370.093	3231.4	3231.4	14.339	.6850	9.822	YES
BS85011892	2.9957	254.33	371.449	3217.2	3217.2	14.343	.6863	9.843	YES
BS84112683	2.9984	254.62	371.065	3224.1	3224.1	14.335	.6861	9.835	YES

1.0-Inch Boom Length

SHOT NO.	DIA CM	MASS GRAMS	IX GM-CM2	IY GM-CM2	IZ GM-CM2	LENGTH CM	CG PERCENT	CG CM FM NOSE	ROLL PINS
BS85031507	2.9921	257.16	371.268	3382.0	3382.0	14.336	.6889	9.876	NO
BS85031508	2.9942	256.75	370.714	3370.3	3370.3	14.353	.6900	9.903	NO
BS85011891	2.9934	256.90	371.697	3355.4	3355.4	14.323	.6895	9.876	YES
BS85011890	2.9952	257.04	371.528	3340.5	3340.5	14.331	.6895	9.881	YES
BS85011893	2.9936	257.12	372.206	3352.2	3352.2	14.336	.6898	9.889	YES

1.25-Inch Boom Length

SECTION IV

RESULTS AND DISCUSSION

The Magnus moment coefficients extracted from the data reduction of the free flight trajectories of the 11 models are compared in Table 3. The flights were all at approximately the same Mach number of 3.0.

1. **ARF DATA.** The results of the in-flight analysis can be seen in Table 4, the Linear Theory Parameter Results, and in Table 5, the 6 DOF Multifit Results. The parameters of primary importance in this test were the values of CNPA, Magnus moment coefficient derivative, for each boom configuration. The following table illustrates the comparison of CNPA for Mach = 3.0 between the PM program, the multifit results, and the original PRODAS program:

TABLE 3. MAGNUS MOMENT COEFFICIENTS

BOOM CONFIGURATION	PM	Multifit	PRODAS
(1.0" x 0.5")			
$C_{npa_{(1^o)}}$	0.998	n/a	0.137
$C_{npa_{(4^o)}}$	1.035	1.02	0.175
(1.25" x 0.5")			
$C_{npa_{(1^o)}}$	1.355	n/a	0.122
$C_{npa_{(4^o)}}$	1.395	1.50	0.162

The PRODASMAGNUS and the Multifit results agree very well. The small difference suggests a good approximation of the actual boomed projectile

TABLE 4. LINEAR THEORY PARAMETER RESULTS

SHOT NO.	MACH	DBSQ	CD	CD0	CDSQ	CNA	CMA	CMQ	CNPA	CLPR	CLPU
BS85031405	2.932	39.3	.314	.247	5.579	3.579	3.838	-21.0	.878	.000	-.025
BS85031404	2.954	42.6	.316	.241	5.795	3.795	3.811	-20.6	.914	.000	-.028
BS85031506	2.979	3.5	.271	.265	5.281	3.051	4.024	-21.8	1.021	-.019	-.031
BS84112684	3.027	1.8	.267	.263	5.504	3.274	4.056	-23.2	1.201	-.019	-.019
BS85011892	3.033	.3	.264	.263	5.440	3.218	4.143	-33.4	2.073	-.020	.003
BS84112683	3.139	1.2	.258	.253	14.061	11.831	3.796	-24.5	.981	-.019	.000

1.0-Inch Boom Length

SHOT NO.	MACH	DBSQ	CD	CD0	CDSQ	CNA	CMA	CMQ	CNPA	CLPR	CLPU
BS85031507	2.982	54.5	.330	.231	5.989	3.759	3.732	-26.3	1.695	.000	-.033
BS85031508	2.988	12.7	.280	.258	5.492	3.262	3.978	-24.3	1.388	.000	-.029
BS85011891	3.001	1.7	.270	.267	4.810	2.580	4.197	-20.5	1.160	-.019	-.052
BS85011890	3.014	.1	.266	.266	6.617	4.387	4.728	-55.2	4.258	-.020	-.006
BS85011893	3.026	2.0	.267	.263	5.816	3.586	4.451	-30.0	1.921	-.024	.019

1.25-Inch Boom Length

TABLE 5. 6 DOF MULTIPLE FIT RESULTS

MULT. FIT No.	SHOT NUMBERS	MACHA	DBSQ ABARM	CX CX2 CX4	CNA CNA3 CNA5	CYPA CYPA3	CMA CMA3 CMA5	CMQ CMQ2 CMQ4	CNPA CNPA3 CNPA5	CLP CXM CMAM	PE-X PE-YZ	PE-A PE-R
1	DS85031404 DS85031405 DS85031506	2.968	26.3 16.4	.268 1.220 .00	3.307 12.754 .00	-1.00 .00	4.068 -13.261 .0	-21.2 .0 0.	.97 7.06 .0	-.0188 -.0700 .000	.0028 .0021	.2860 4.6690
2	DS84112684 DS85031405 DS85031404	2.984	26.3 16.4	.268 1.151 .00	3.266 13.980 .00	-1.00 .00	4.061 -12.861 .0	-21.2 .0 0.	.92 8.65 .0	-.0191 -.0700 .000	.0024 .0022	.2517 3.4490
3	DS85031405 DS85011892 DS85031506 DS84112684 DS85031404	2.994	16.5 16.5	.266 1.224 .00	3.309 12.447 .00	-1.00 .00	4.056 -12.691 .0	-21.8 .0 0.	1.12 1.89 .0	-.0189 -.0700 .000	.0022 .0021	.2279 4.9010

1.0-Inch Boom Length

MULT. FIT No.	SHOT NUMBERS	MACHA	DBSQ ABARM	CX CX2 CX4	CNA CNA3 CNA5	CYPA CYPA3	CMA CMA3 CMA5	CMQ CMQ2 CMQ4	CNPA CNPA3 CNPA5	CLP CXM CMAM	PE-X PE-YZ	PE-A PE-R
4	DS85011893 DS85011891 DS85031507 DS85031508	3.006	16.9 17.6	.265 1.337 .00	3.253 12.000 .00	-.62 .00	4.015 -9.589 .0	-23.5 .0 0.	1.28 2.32 .0	-.0205 -.0700 .000	.0089 .0019	.2642 9.3420
5	DS85011893 DS85011891 DS85031508	3.009	4.9 9.1	.264 2.991 .00	3.405 12.000 .00	- 94 .00	4.218 -26.341 .0	-36.3 .0 0.	1.87 .00 .0	-.0205 -.0700 .000	.0094 .0017	.3164 11.0800
6	DS85011893 DS85011891 DS85031507	3.010	18.4 17.7	.267 1.192 .00	3.177 12.000 .00	-.74 .00	3.926 -7.095 .0	-22.9 .0 0.	1.26 18.11 -394.8	-.0205 -.0700 .000	.0037 .0018	.2675 11.4000
7	DS85011890 DS85011891 DS85011893 DS85031507	3.011	13.7 18.3	.266 .987 .00	4.065 -6.730 .00	-1.00 .00	3.920 -6.624 .0	-26.8 .0 0.	1.74 -3.71 .0	-.0210 -.0700 .000	.0033 .0018	.2421 8.3980

1.25-Inch Boom Length

Magnus moment by the mathematical model. Only values of CNPA for 4-5^{o} were provided by the 6 DOF reduction. The PRODAS values are significantly smaller than PM or Multifit. This outcome was anticipated since PRODAS does not consider the influence of the boom on projectile stability, in particular, CNPA. Smaller values of CNPA, provided by PRODAS, will tend to predict optimistic dynamic stability results of boomed projectiles. For the same boomed projectile configuration PM may predict unstable, or at best, marginally stable dynamic stability. By holding the boom diameter constant and increasing the boom length, the trend is to increase values of S_d for the 30mm model. This trend can best be seen in Figure 4. This figure illustrates the curve generated by a 0.5-inch diameter boom modeled at Mach = 3.0 for the following boom lengths: 1.0, 1.25, 1.5, 2.0, and 2.5 inches. The "no boom" configuration is included as a reference point.

The entire PM stability results for both boom configurations can be seen in Figures 5a and 5b. The results used to generate the boom effects versus boom length curve are included in the Appendix.

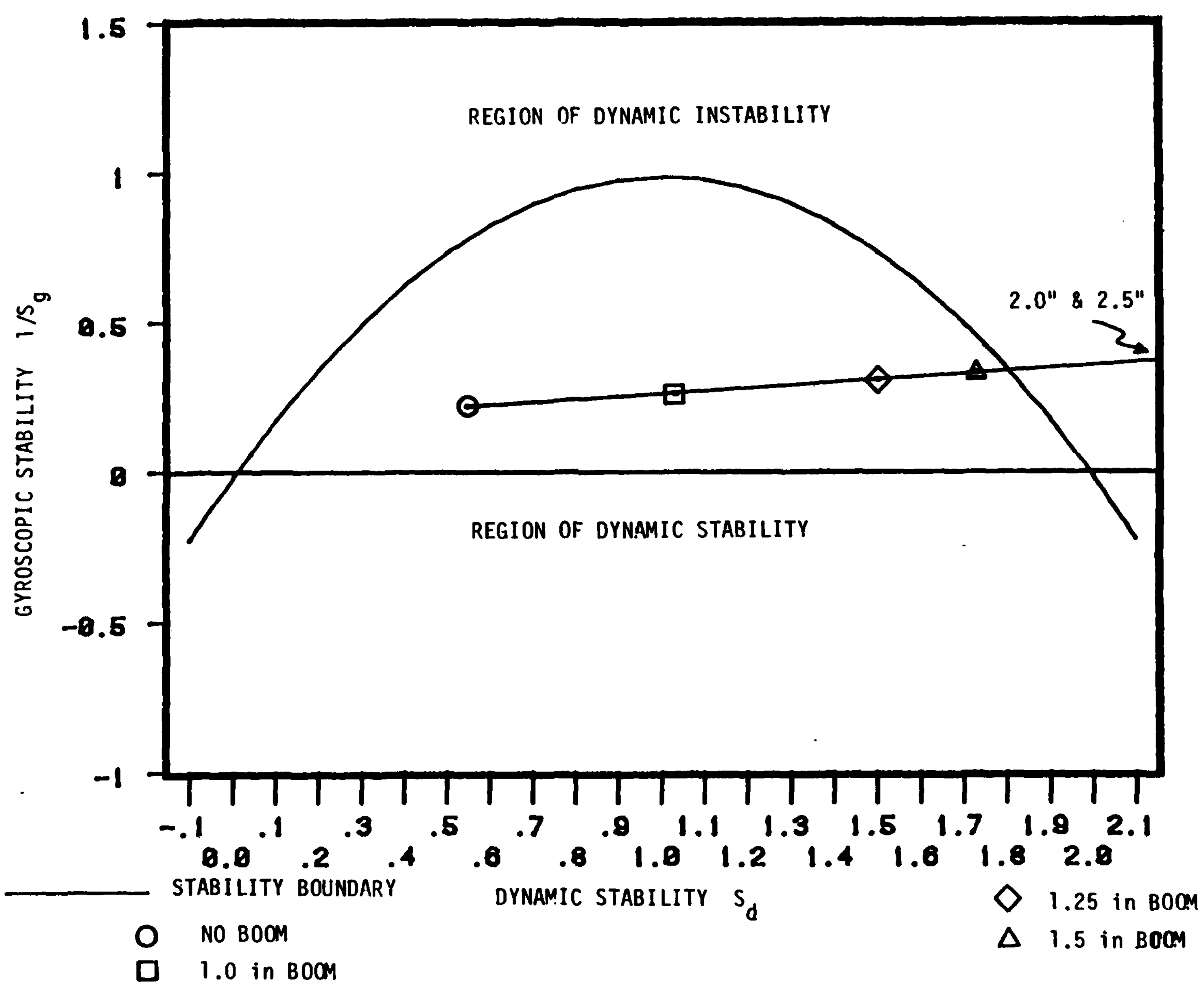


Figure 4. Dynamic Stability Versus Boom Lengths

BALLISTICS TITLE-132MMR9 10/05/85

	TOTAL LENGTH	OGIVE LENGTH	BOATTAIL LENGTH	BOOM LENGTH	C.G. FROM NOSE	BAND DIAMETER	MEPLAT DIAMETER	OGIVE RADIUS	RIFLING TWIST
IN INCHES	6.566000	2.945022	.000200	1.000000	3.840011	1.215000	.284300	15.460006	21.321000/REV
IN CALIBERS	5.566040	2.495763	.000200	.847458	3.262636	1.029661	.241200	13.135560	18.000000/REV

DIAMETER INCHES	WEIGHT POUNDS	GUN BORE INCHES	TEMPERATURE DEG-F	AIR DENSITY SLUGS/FT3	AXIAL MOM. LBS-IN-SQ	TRANS MOM. LBS-IN-SQ	BOOM DIA INCHES	BOOM DIA. CALIBERS
1.180000	.579500	1.184500	59.000000	.002376	.1245	1.2051	.50000	.42373

AERODYNAMIC COEFFICIENTS

MACH	CX	CX2	CNA	CMA	CPN	CYPA	CNPA	CNPA3	CNPA5	CPF-1	CPF-5	CNPA-5	CMO	CLP
.600	.190	2.503	2.201	3.506	1.670	-.755	.054	91.876	-881.256	2.105	3.205	.904	-.715	-.029
.800	.201	2.990	2.221	3.582	1.650	-.755	.205	83.405	-707.354	2.305	3.305	.960	-.715	-.027
.900	.214	3.460	2.250	3.730	1.681	-.850	.570	60.937	-571.067	2.705	3.445	1.122	-3.850	-.026
.950	.270	3.956	2.260	3.830	1.571	-1.005	1.054	47.027	-440.770	3.005	3.405	1.400	-6.776	-.025
1.020	.361	4.475	2.294	3.925	1.551	-.901	1.062	32.620	-280.600	3.105	3.405	1.359	-11.433	-.025
1.050	.402	4.934	2.319	3.999	1.538	-.897	1.050	19.512	-157.601	3.205	3.405	1.230	-11.724	-.024
1.100	.401	5.517	2.339	4.057	1.528	-.850	1.037	13.742	-96.910	3.345	3.405	1.165	-13.633	-.024
1.200	.394	6.037	2.399	4.114	1.547	-.755	.945	9.652	-59.016	3.375	3.405	1.035	-15.635	-.024
1.350	.377	5.440	2.490	4.121	1.606	-.755	.960	7.074	-42.235	3.305	3.405	1.035	-17.781	-.023
1.500	.362	4.838	2.500	4.123	1.676	-.755	.967	7.135	-33.045	3.405	3.405	1.035	-20.424	-.022
1.750	.342	4.237	2.696	4.039	1.766	-.755	.975	6.205	-25.455	3.415	3.405	1.035	-20.424	-.022
2.000	.321	3.637	2.790	3.940	1.855	-.755	.903	5.456	-17.065	3.425	3.405	1.035	-20.424	-.022
2.500	.289	3.022	2.809	3.766	1.963	-.755	.990	4.617	-8.675	3.435	3.405	1.035	-20.424	-.021
3.000	.263	2.529	2.849	3.591	2.022	-.755	.990	3.770	-.284	3.445	3.405	1.035	-20.424	-.021
4.000	.225	2.065	2.749	3.540	1.972	-.755	.990	3.770	-.284	3.445	3.405	1.035	-20.424	-.020
5.000	.203	1.642	2.649	3.400	1.942	-.755	.990	3.770	-.284	3.445	3.405	1.035	-20.424	-.020

STABILITY PARAMETERS

MACH	GYRO	SBAR	RECIP	SBAR-5	RECIP-5	SPIN	DELT	V1	V2	L1	L2	L1-5	L2-5	DISP
.600	3.079	2.003	-142.749	4.481	-.000	2370.	.0013	245.45	24.02	.000070	-.001314	.001720	-.002054	.001
.800	3.013	2.444	-.920	4.673	-.000	3150.	.0010	326.50	32.81	.000384	-.001628	.001883	-.003127	.000
.900	2.887	2.304	-1.428	3.366	-.218	3554.	.0009	365.50	38.71	.000483	-.002321	.001502	-.003420	.007
.950	2.812	2.453	-.890	3.091	-.207	3752.	.0008	384.59	42.09	.000867	-.003254	.001744	-.004131	.003
1.020	2.750	1.771	2.460	2.089	-5.384	3949.	.0008	403.70	45.43	-.000072	-.003107	.000533	-.003791	.070
1.050	2.690	1.728	2.126	1.917	6.252	4147.	.0007	422.87	48.71	-.000146	-.003170	.000221	-.003546	.076
1.100	2.660	1.540	1.411	1.660	1.770	4344.	.0007	442.17	51.87	-.000564	-.003123	-.000302	-.003385	.076
1.200	2.623	1.318	1.112	1.304	1.184	4739.	.0007	481.46	57.49	-.001165	-.002922	-.000970	-.003109	.070
1.350	2.619	1.216	1.049	1.273	1.000	5331.	.0006	541.52	64.80	-.001577	-.002951	-.001421	-.003107	.002
1.500	2.618	1.100	1.012	1.154	1.024	5924.	.0005	601.65	72.04	-.002108	-.002962	-.001968	-.003103	.006
1.750	2.672	1.125	1.016	1.164	1.028	6911.	.0004	703.86	82.11	-.002000	-.003032	-.001964	-.003156	.003
2.000	2.740	1.140	1.020	1.174	1.031	7898.	.0004	807.03	91.23	-.002070	-.003101	-.001962	-.003200	.100
2.500	2.866	1.156	1.025	1.185	1.035	9873.	.0003	1014.41	108.41	-.002055	-.003166	-.001964	-.003257	.110
3.000	3.006	1.158	1.026	1.183	1.035	11848.	.0003	1224.02	123.37	-.002050	-.003146	-.001975	-.003221	.115
4.000	3.043	1.153	1.024	1.178	1.033	15797.	.0002	1634.25	162.27	-.002057	-.003089	-.001982	-.003164	.113
5.000	3.086	1.146	1.022	1.171	1.030	19746.	.0002	2045.65	199.70	-.002064	-.003032	-.001990	-.003126	.111

Figure 5a. PRODASMAGNUS (PM) Stability Results, 1.0" By 0.5"

BALLISTICS TITLE-130MMRB 10/05/85

	TOTAL LENGTH	OGIVE LENGTH	BOATTAIL LENGTH	BOOM LENGTH	C G. FROM NOSE	BAND DIAMETER	MEPLAT DIAMETER	OGIVE RADIUS	RIFLING TWIST
IN INCHES	6 816002	2 945020	.020020	1.250000	3.073706	1 215002	.284300	15.400066	21 321000/REV
IN CALIBERS	5 770814	2 495763	.000220	1.059322	3 262070	1.020661	.241000	13 135562	18 000000/REV

DIAMETER INCHES	WEIGHT POUNDS	GUN BORE INCHES	TEMPERATURE DEG-F	AIR DENSITY SLUGS/FT3	AXIAL MOM LBS-IN-SQ	TRANS MOM LBS-IN-SQ	BOOM DIA. INCHES	BOOM DIA. CALIBERS
1 182000	584460	1 184500	50.000020	002376	1247	1 1346	.50000	.42373

AERODYNAMIC COEFFICIENTS

MACH	CX	CX2	CNA	CMA	CPN	CYPA	CNPA	CNPA3	CNPA5	CPF-1	CPF-5	CNPA-5	CMQ	CLP
.600	.196	2 503	2 201	3 550	1 670	-.755	.411	91 076	-601.256	2.105	3 205	1 242	-.413	-.020
.800	.198	2 960	2.221	3 627	1 650	-.755	.562	83.405	-707.354	2.305	3.395	1.317	-.413	-.027
.900	.212	3 460	2 250	3 785	1 601	-.850	.072	60.037	-571.067	2.705	3.445	1 525	-3 558	-.026
.950	.268	3 956	2 260	3 885	1 571	-1.085	1 560	47.027	-440.770	3.005	3.495	2 002	-6.406	-.025
1.000	.359	4 475	2 294	3 072	1 551	-.081	1 531	32 620	-280.600	3.105	3.495	1 628	-11 145	-.025
1.050	.400	4.964	2 319	4 046	1 530	-.097	1 475	10.510	-157 601	3 205	3.495	1 654	-11 439	-.024
1.100	.339	5.517	2 339	4 105	1 528	-.850	1.440	13.742	-90 010	3.345	3.495	1 567	-13 350	-.024
1.200	.332	6 037	2 306	4 163	1 547	-.755	1 302	9.652	-50.016	3.375	3.405	1 393	-15 362	-.024
1.350	.375	5 440	2 480	4 172	1 606	-.755	1 317	7.074	-42 235	3.305	3.495	1.393	-17 559	-.023
1.500	.360	4 838	2.500	4 176	1 676	-.755	1 325	7.135	-33 845	3.405	3.495	1 303	-20 296	-.022
1.750	.337	4.237	2.609	4 004	1 766	-.755	1 333	6.205	-25 455	3.415	3 495	1 393	-20 206	-.022
2.000	.316	3 637	2 709	3 906	1 855	-.755	1 340	5.456	-17.065	3 425	3.465	1 393	-20 296	-.022
2.500	.286	3 022	2 690	3 825	1 963	-.755	1.348	4 617	-6 675	3.435	3.495	1 393	-20 296	-.021
3.000	.26.	2 529	2 849	3 649	2 022	-.755	1 355	3.770	-.204	3.445	3 405	1.303	-20 236	-.021
4.000	.223	2.005	2 749	3 603	1.972	-.765	1.355	3.770	-.204	3.445	3 495	1.303	-20.206	-.020
5.000	.201	1 642	2.649	3 552	1.942	-.755	1 355	3.770	-.204	3.445	3.495	1.393	-20.296	-.020

STABILITY PARAMETERS

MACH	GYRO	SBAR	RECIP	SBAR-5	RECIP-5	SPIN	DELT	V1	V2	L1	L2	L1-5	L2-5	DISP
.600	2 942	3.251	-.246	5.005	-.044	2370.	.0013	236.00	24 42	.000065	-.002031	.002522	-.003600	.003
.800	2 879	3 706	-.150	6 074	-.040	3150.	.0010	313.08	33.35	.001177	-.002353	.002602	-.003860	.002
.900	2 760	3.227	-.253	4 343	-.008	3554.	.0209	351.28	30 35	.001401	-.003152	.002522	-.004273	.000
.950	2 689	3 354	-.220	4 021	-.123	3752.	.0028	360 56	42 70	.002040	-.004330	.002036	-.005218	.005
1.000	2 630	2 360	-1 145	2 700	-.526	3049.	.0030	387.86	46 18	.001052	-.004177	.001665	-.004780	.000
1.050	2 581	2 266	-1.650	2.463	-.077	4147.	.0020	406 22	40 52	.000093	-.004082	.001265	-.004454	.070
1.100	2.544	1.906	142.000	2 122	-3.077	4344.	.0027	424.70	52 74	.000444	-.003084	.000710	-.004240	.070
1.200	2 500	1.602	1.071	1 762	2.302	4730.	.0207	462.30	50.46	-.000230	-.003689	-.000049	-.003870	.070
1.350	2 504	1.539	1.400	1.500	1.556	5331.	.0006	520.02	65 93	-.000647	-.003716	-.000480	-.003874	.003
1.500	2 501	1.300	1 170	1.437	1.235	5024	.0005	577 71	73.34	-.001101	-.003724	-.001030	-.003866	.000
1.750	2 551	1 402	1 103	1 444	1.245	6011.	.0005	675 02	83 65	-.001167	-.003780	-.001041	-.003014	.005
2.000	2 613	1 415	1.200	1.450	1.254	7800.	.0024	775 07	93 00	-.001154	-.003851	-.001045	-.003960	.102
2.500	2 731	1 427	1.224	1 450	1.265	9873.	.0023	974.47	110 63	-.001150	-.003905	-.001050	-.003907	.112
3.000	2 862	1 431	1.220	1 456	1.262	11840	.0003	1176.2,	125 00	-.001156	-.003874	-.001000	-.003052	.117
4.000	2 800	1 427	1.223	1 452	1 257	15707	.0002	1570.62	165 53	-.001166	-.003014	-.001001	-.003802	.115
5.000	2 941	1.422	1.217	1 448	1 251	19746	.0022	1966.50	203 60	-.001177	-.023754	-.001102	-.003820	.113

Figure 5b. PRODASMAGNUS (PM) Stability Results, 1.25" By 0.5"

SECTION V

CONCLUSION

The formulation of a mathematical expression based upon empirical data for estimating the Magnus moment aerodynamic coefficient has been completed. The method was encoded into PRODAS and the results appear to be very good for projectile configurations within the limits of the PRODAS data base.

The method should be a useful tool in the stability analysis of boomed projectiles within the 20mm to 30mm range. The best approach, however, would have been to include the boomed test data in the PRODAS data base and then solve for X_1, X_2, and X_3 using a multifit linear regression technique.

This empirical method, with some modifications, would be useful in obtaining estimates for the other aerodynamic coefficients influenced by the boom's presence.

REFERENCES

1. Hathaway, W., Buff, R., and Lemmers, P., "Free Flight Range Aerodynamic Test: 30-mm Boomed Projectiles", AFATL-TR-84-77, January 85.

2. Burnett, J., Hathaway, W., Whyte, R., "Projectile Design and Analysis System (PRODAS-81)", AFATL-TR-81-43, April 81.

3. Clarke, S., Hendry, J., LaFeber, C., "Advanced Development of High-Performance Telescoped Ammunition", AFATL-TR-83-22, March 83.

4. Sears, E., "An Empirical Method for Predicting Aerodynamic Coefficients for Projectiles - Drag Coefficients", AFATL-TR-72-173, August 72.

5. Whyte, R., "SPIN-73 An Updated Version of the Spinner Computer Program", AMCMS TR 4588, November 73.

APPENDIX

DYNAMIC STABILITY vs BOOM LENGTH

BML (in)	BMD (in)	Mach #	Dynamic Stability (S_d)	Gyroscopic Stability (S_g)
0.0	0.0	3.00	0.593	0.28877
1.0	0.5	3.00	1.158	0.33267
1.25	0.5	3.00	1.431	0.34941
1.5	0.5	3.00	1.724	0.36873
2.0	0.5	3.00	2.389	0.41684
2.5	0.5	3.00	3.178	0.47916

The curve generated by plotting S_g as a function of S_d has an equation of the form: Y = aX + b. For the data represented above, that equation takes on the form of:

$$1/S_g = 0.24553 + 0.07279 * S_d.$$

(The reverse of this page is blank)

END

FILMED

11-85

DTIC