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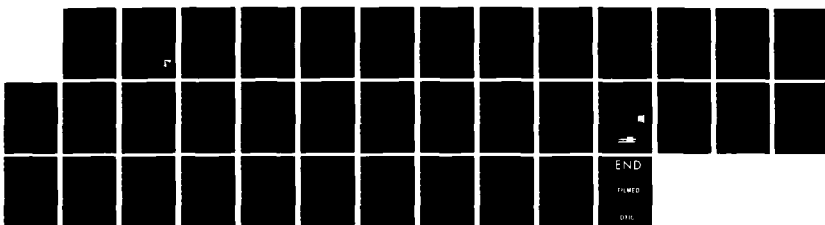
ESTIMATING THE MAGNUS MOMENT EFFECT ON STABILITY OF
30-MM BOOMED PROJECTILES(U) AIR FORCE ARMAMENT LAB
EGLIN AFB FL R H BYERS ET AL. AUG 85 AFATL-TR-85-69
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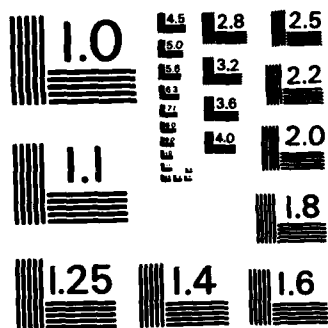
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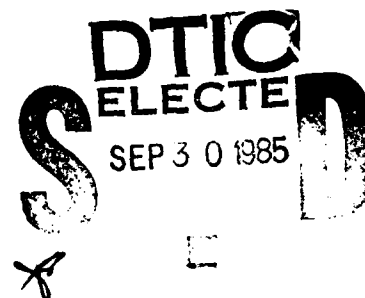
AFATL-TR-85-69**Estimating the Magnus Moment
Effect on Stability of 30-mm
Boomed Projectiles**

Richard H Byers, 2 Lt
Ken Cobb

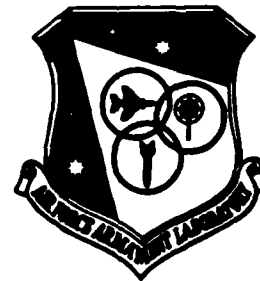
GUNS AND PROJECTILE BRANCH
MUNITIONS DIVISION

AUGUST 1985

FINAL REPORT FOR PERIOD DECEMBER 1984 - FEBRUARY 1985



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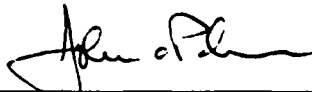
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FOR THE COMMANDER



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

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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.					
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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).

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SYMBOLS AND NOMENCLATURE

<u>SYMBOL</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
A	Projectile Cross-Sectional Area	ft ²
C _{lp}	Spin Deceleration Coefficient	M _{lp} /qAd(pd/2V)
C _m	Pitching Moment Coefficient	M _m /qAd
C _{mq}	Damping Moment Coefficient	M _{mq} /qAd(qd/2V)
C _{np}	Magnus Moment Coefficient	M _{np} /qAd(pd/2V)
C _N	Normal Force Coefficient	F _N /qA
C _{Yp}	Magnus Force Coefficient	F _{Yp} /qA(pd/2V)
C _X	Axial Force Coefficient	F _X /qA
CG	Center of Gravity, Calibers From Nose	
I _x	Axial Moment of Inertia	slugs-ft ²
I _y	Transverse Moment of Inertia	slugs-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

SYMBOLS AND NOMENCLATURE (CONCLUDED)

<u>SYMBOL</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
q	Projectile Pitch Rate	rad/sec
$\bar{q}$	Dynamic Pressure ($\frac{1}{2}\rho V^2$)	lb/ft ²
$\bar{\alpha}$	Total Angle of Attack	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	
$M_{\dot{\alpha}}$	Pitching Moment Derivative with $\bar{\alpha}$	
S_d	Dynamic Stability Factor	
S_g	Gyroscopic Stability Factor	
	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	

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:

$$\begin{aligned}
 CX_1 = & a_1 + a_2X_{i1} + a_3X_{i2} + \dots + a_nX_{i(n-1)} \\
 & + b_1X_{i1}X_{i2} + b_2X_{i1}X_{i3} + \dots + b_{(n-1)}X_{i1}X_{in} \\
 & + c_1X_{i1}^2 + c_2X_{i2}^2 + \dots + c_nX_{in}^2 + \dots \quad (1)
 \end{aligned}$$

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 ($C_{Yp\alpha}$), Magnus moment coefficient derivative ($C_{np\alpha}$), 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.)

$$CVL = VL \quad (2)$$

$$CVB = VB \quad (3)$$

$$CXCL = VL - VN - VB - 1.5 \quad (4)$$

$$CVN = VN - 2.5 \quad (5)$$

$$CYPA = E_1(CVL) - 0.1(CVB) \quad (6)$$

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

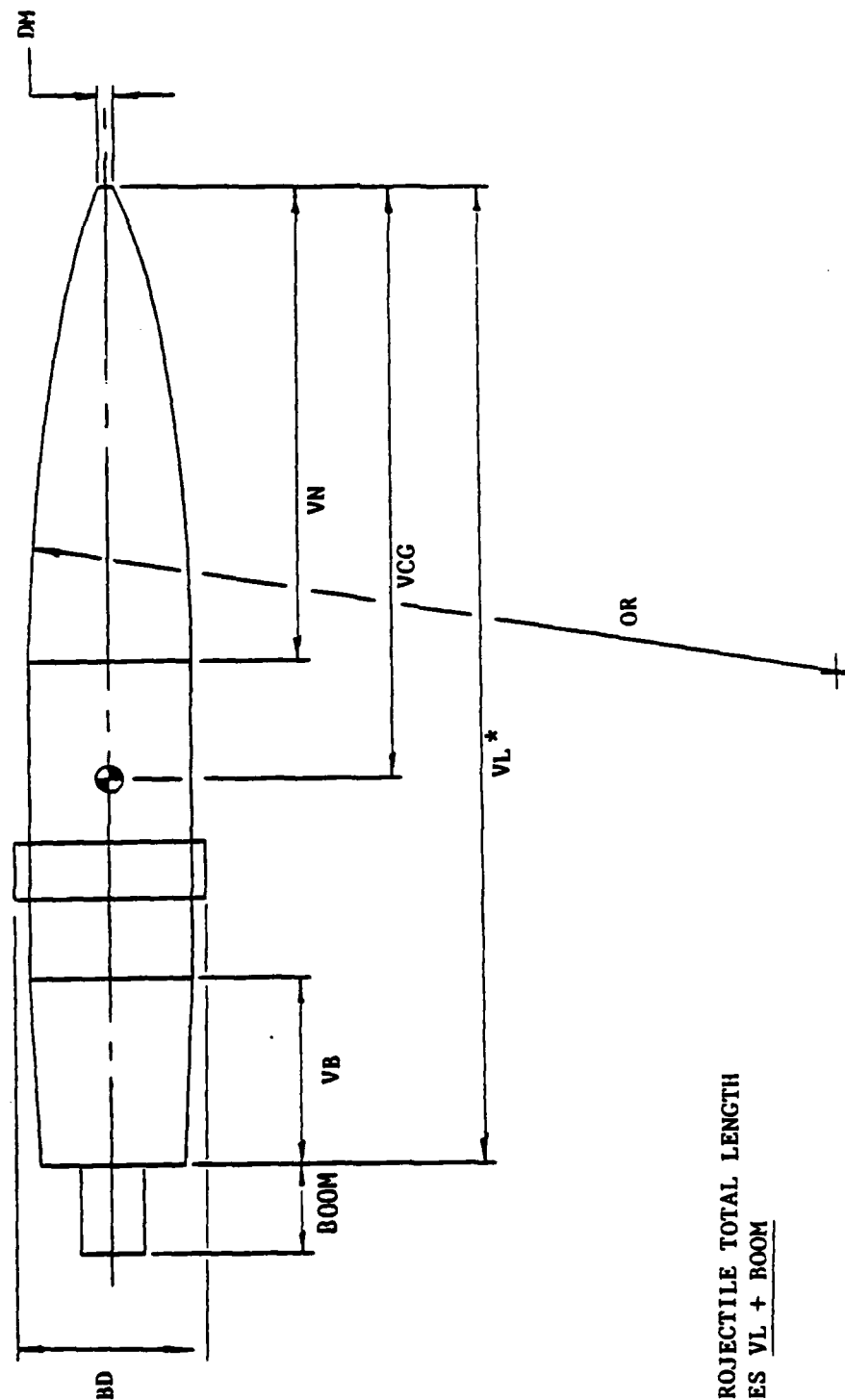
$$CNPAN = -E_1(CVL)[E_2 + 0.55(CXCL) + 0.80(CVN)] + CVB(CVL/4.7) \quad (7)$$

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

$$C_{Yp\alpha} = CYPA \quad (9)$$

$$C_{np\alpha}_{(1)} = (VCG - CPF_{(1)})CYPA \quad (10)$$

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



* INPUT PROJECTILE TOTAL LENGTH
INCLUDES VL + BOOM

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:

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

$$\text{where} \quad K = VCG \quad (16)$$

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

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

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_{lp} . The gyroscopic stability factor, S_g , is:

$$S_g = \frac{2I_x^2 p^2}{\pi I_y C_{m\alpha} d^3 v^2 \rho} \quad (19)$$

or

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

where

$$M_\alpha = 1/2 \rho A V^2 d C_{m\alpha} \quad (21)$$

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:

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

$$k_1^{-2} = md^2/I_x \quad (23)$$

$$k_2^{-2} = md^2/I_y \quad (24)$$

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:

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

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:

$$XA6(J) = CYPA \quad (26)$$

$$XA7(J) = CPF \quad (27)$$

$$XA8(J) = CNPA \quad (28)$$

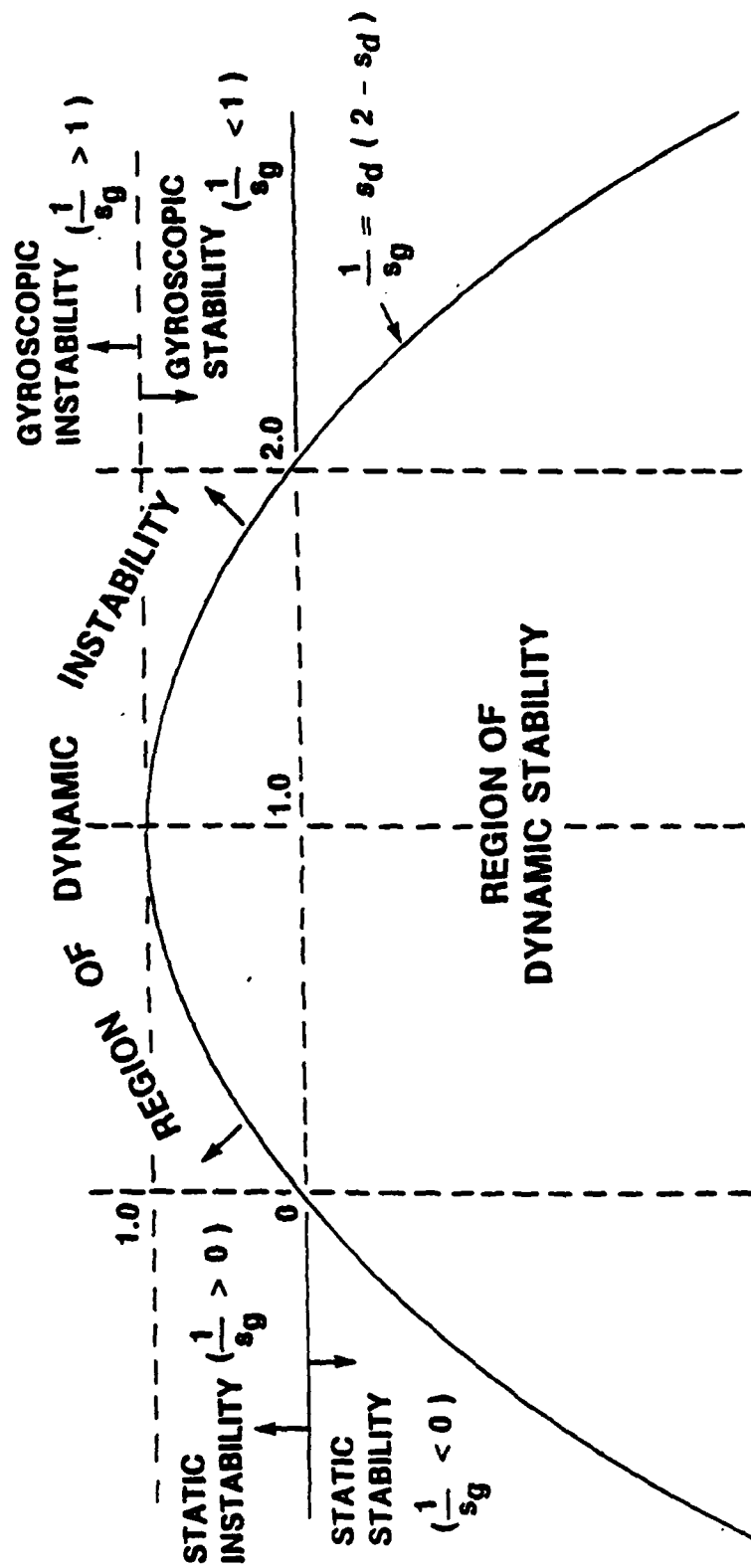


Figure 2. Dynamic Stability

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:

<u>Configuration</u>	<u>Mach No</u>	<u>CNPA</u>	<u>BML (in)</u>	<u>BMD (in)</u>
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).

<u>Configuration</u>	<u>VCG</u>	<u>BML (cal.)</u>	<u>BMD (cal.)</u>	<u>BMLxBMD</u>
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 $\bar{\alpha} = 1.0^\circ$,

$$CPF = 3.398 \quad (29)$$

$$CYPA = -0.743 \quad (30)$$

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:

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

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

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

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 $a_1, \dots, a_n$,

$b_1, \dots, b_{(n-1)}$, and $c_1, \dots, c_n$ 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

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94 BYERS MOD 30MM HONEYWELL HE AND

TOTAL LENGTH=	6.560000 INCHES
PROJECTILE LENGTH=	6.560000
OGIVE LENGTH=	2.845000 INCHES
BOON LENGTH=	1.880000 INCHES
BAND LENGTH=	.665000 INCHES

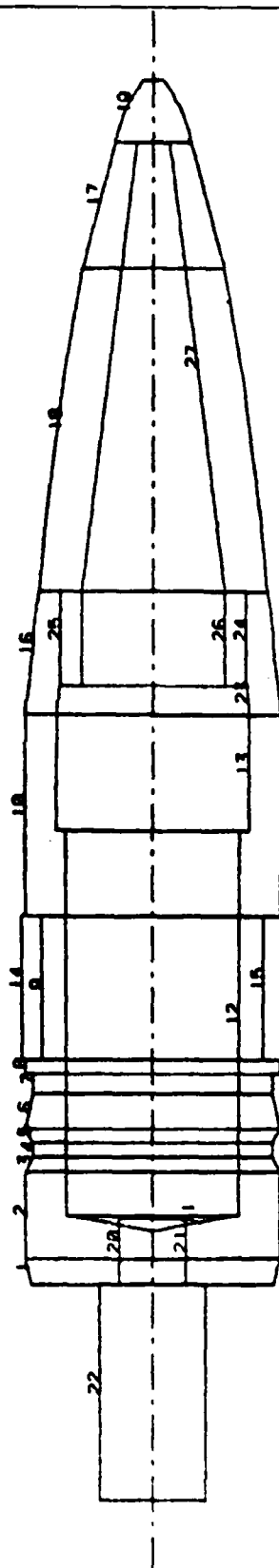


Figure 3a. Computer Model of 30mm Boomed Projectile

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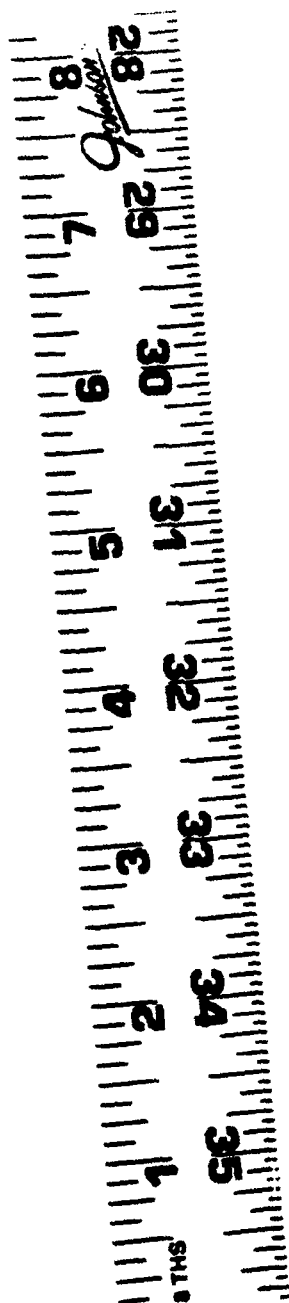


Figure 3b. 30mm Boomed Projectiles

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.	δ^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	IV GM-CM2	I2 GM-CM2	LENGTH CM	CG PERCENT	CM FM NOSE	ROLL PINS
B585031405	2.9947	253.83	369.483	3217.2	3217.2	14.351	.6851	9.832	NO
B585031404	2.9931	254.86	370.714	3232.4	3232.4	14.342	.6875	9.868	NO
B585031506	2.9921	254.16	370.116	3220.8	3220.8	14.340	.6864	9.843	YES
B584112584	2.9931	254.05	370.093	3231.4	3231.4	14.339	.6850	9.822	YES
B585011892	2.9957	254.33	371.449	3217.2	3217.2	14.343	.6863	9.843	YES
B584112683	2.9924	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	IV GM-CM2	I2 GM-CM2	LENGTH CM	CG PERCENT	CM FM NOSE	ROLL PINS
B585031507	2.9921	257.16	371.268	3382.0	3382.0	14.336	.6889	9.876	NO
B585031508	2.9942	256.75	370.714	3370.3	3370.3	14.353	.6900	9.903	NO
B585011891	2.9934	256.90	371.697	3355.4	3355.4	14.323	.6895	9.876	YES
B585011890	2.9952	257.04	371.528	3340.5	3340.5	14.331	.6895	9.881	YES
B585011893	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

<u>BOOM CONFIGURATION</u>	<u>PM</u>	<u>Multifit</u>	<u>PRODAS</u>
(1.0" x 0.5")			
$C_{npa}_{(10)}$	0.998	n/a	0.137
$C_{npa}_{(40)}$	1.035	1.02	0.175
(1.25" x 0.5")			
$C_{npa}_{(10)}$	1.355	n/a	0.122
$C_{npa}_{(40)}$	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.	PACH	DBSO	CD	CDO	CDSO	CMA	CMA	CNO	CMFA	CLPR	CLPU
9585031405	2.932	39.3	.314	.247	5.579	3.579	3.838	-21.0	.878	.000	-.025
9585031404	2.954	42.6	.316	.241	5.795	3.795	3.811	-20.6	.914	.000	-.028
9585031506	2.979	3.5	.271	.255	5.281	3.051	4.024	-21.8	1.021	-.019	-.031
9584112684	3.027	1.8	.267	.263	5.504	3.274	4.056	-23.2	1.201	-.019	-.019
9585011892	3.033	.3	.264	.263	5.448	3.218	4.143	-33.4	2.073	-.020	.003
9584112683	3.139	1.2	.258	.253	4.061	11.831	3.796	-24.5	.981	-.019	.000

1.0-Inch Boom Length

SHOT NO.	PACH	DBSO	CD	CDO	CDSO	CMA	CMA	CNO	CMFA	CLPR	CLPU
9585031507	2.982	54.5	.330	.231	5.989	3.759	3.732	-26.3	1.695	.000	-.033
9585031508	2.988	12.7	.280	.258	5.492	3.262	3.978	-24.3	1.388	.000	-.029
9585011891	3.001	1.7	.270	.267	4.810	2.580	4.197	-20.5	1.160	-.019	-.052
9585011890	3.014	.1	.266	.266	6.617	4.387	4.728	-55.2	4.258	-.020	-.005
9585011893	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

[illegible]

1.0-Inch Boom Length

SHOT NUMBERS			FACEA	DISQ	CX	CH2	CH3	CH4	CYPA	CYPAJ	CMA	CH01	CH02	CH03	CH04	CNPA	CNPAJ	CLP	FE-X	FE-A	FE-VZ	FE-R
4	B585011893	B585011891	3.006	16.9	.265	3.253	-.62	4.015					-23.5	1.28	-.0205				.0089	.2642		
	B585031507	B585031508		17.6	1.337	12.000	-.00	-9.589					.0	2.32	-.0700				.0019	9.3420		
5	B585011893	B585011891	3.009	4.9	.264	3.405	-.34	4.218					-36.3	1.87	-.0205				.0094	.3164		
	B585031508	B585031509		9.1	2.991	12.000	.00	-26.341					.0	.00	-.0700				.001711	.0800		
6	B585011893	B585011891	3.010	18.4	.267	3.177	-.74	3.926					-22.9	1.26	-.0205				.0037	.2675		
	B585031507	B585031508		17.7	1.182	12.000	.00	-7.095					.0	12.11	-.0700				.001811	.4000		
7	B585011893	B585011891	3.011	13.7	.266	4.065	-1.00	3.920					-26.8	1.74	-.0210				.0033	.2421		
	B585011893	B585031507		18.3	.987	-8.730	.00	-6.624					.0	.0	.0000				.0018	8.3900		

1.25-Inch Boom Length

Magnus moment by the mathematical model. Only values of CNPA for $4-5^\circ$ 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.

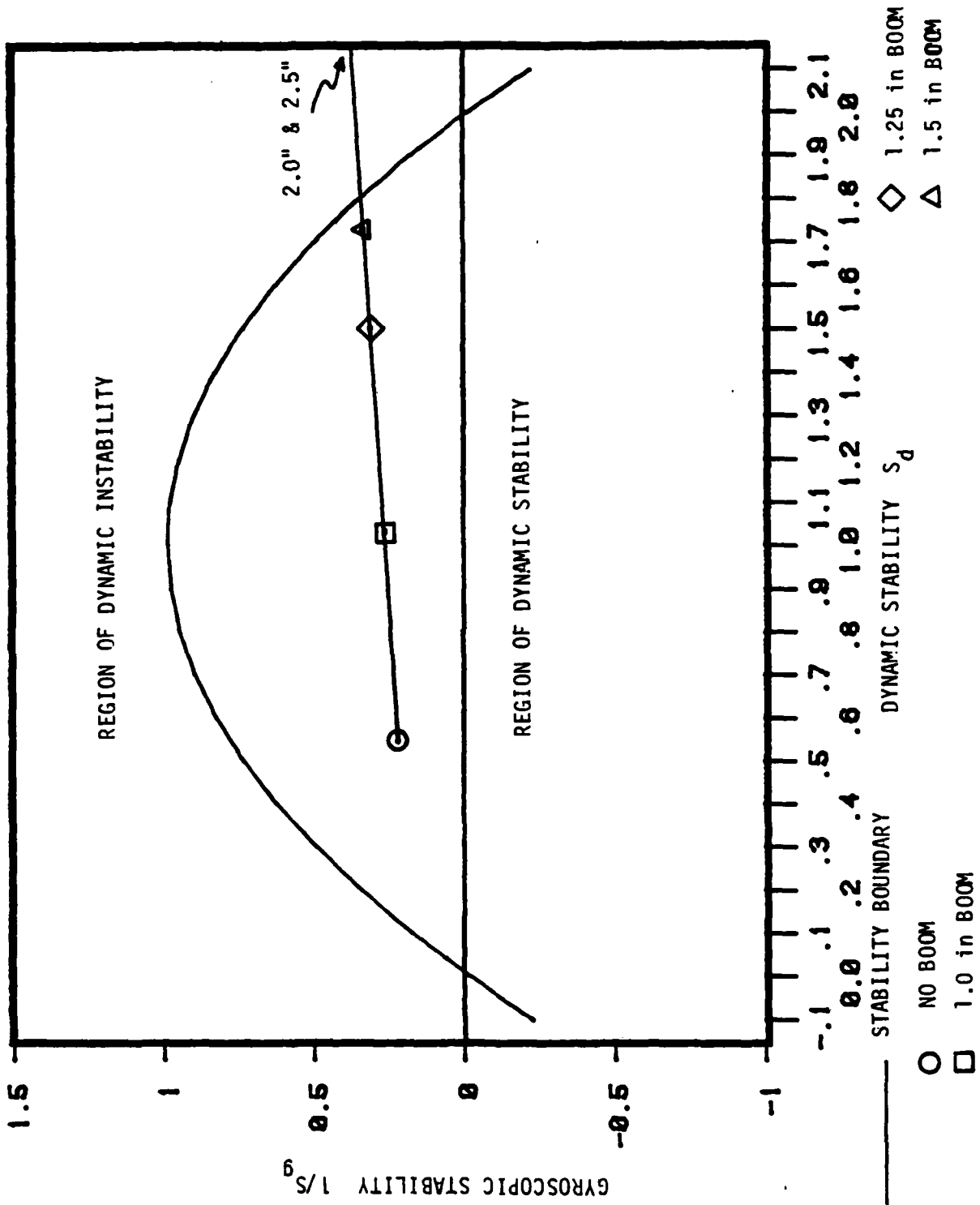


Figure 4. Dynamic Stability Versus Boom Lengths

BALLISTICS TITLE-130MRB 10/05/85

IN INCHES	5 810002	TOTAL LENGTH	2 045020	BOAT TAIL LENGTH	0.00020	BOOM LENGTH	1.250000	C.G. FROM NOSE	3.073706	BAND DIAMETER	1.250000	REPLAT DIAMETER	2.04300	OCIVE RADIUS	15.400000	RIFLING TWIST	21 321000/REV
IN CALIBERS	5 770014	WEIGHT	2 405763	CUN BORE INCHES	0.00020	TEMPERATURE DEG-F	1.000322	AIR DENSITY SLUGS/FT3	3.262078	AXIAL MOM LBS-IN-50	1.020061	TRANS MOM LBS-IN-50	241000	BOOM DIA. INCHES	13.135503	BOOM DIA. CALIBERS	10 000000/REV
		PCUNDS	584468			50.000000			0.02376								

AERODYNAMIC COEFFICIENTS

MACH	CA	CX2	CNA	CMA	CPN	CYPA	CNPA	CNPAS	CPF-1	CPF-5	CNPA-5	CNO	CLP
0.20	1.06	2.503	2.201	3.550	1.670	755	411	91.876	2.106	3.205	1.242	413	0.20
0.40	1.98	2.960	2.221	3.627	1.650	755	562	83.405	2.305	3.305	1.317	413	0.27
0.60	2.72	3.468	2.250	3.785	1.601	755	072	68.037	2.705	3.445	1.525	3.558	0.26
0.80	3.28	3.956	2.260	3.885	1.571	755	1568	47.027	3.005	3.405	2.002	6.486	0.25
1.00	3.50	4.475	2.204	3.072	1.551	755	1531	32.620	3.195	3.405	1.628	1.145	0.25
1.20	4.00	4.954	2.310	4.046	1.538	755	1475	10.510	3.205	3.405	1.654	1.145	0.24
1.40	4.60	5.517	2.339	4.105	1.528	755	1400	13.742	3.345	3.405	1.567	1.330	0.24
1.60	5.35	6.037	2.306	4.163	1.547	755	1302	0.652	3.375	3.405	1.393	15.362	0.24
1.80	6.10	6.448	2.480	4.172	1.626	755	1317	7.074	3.305	3.405	1.393	17.550	0.22
2.00	6.80	6.838	2.508	4.176	1.676	755	1325	7.135	3.405	3.405	1.303	20.206	0.22
2.20	7.40	7.237	2.635	4.004	1.766	755	1333	6.205	3.415	3.405	1.303	20.206	0.22
2.40	8.10	7.637	2.706	3.906	1.855	755	1340	5.456	3.425	3.405	1.303	20.206	0.22
2.60	8.80	8.022	2.800	3.825	1.963	755	1348	4.617	3.435	3.405	1.303	20.206	0.21
2.80	9.50	8.399	2.846	3.649	2.022	755	1355	3.778	3.445	3.405	1.303	20.206	0.20
3.00	10.20	8.765	2.748	3.603	1.972	755	1355	3.778	3.445	3.405	1.303	20.206	0.20
3.20	10.90	9.122	2.646	3.552	1.942	755	1355	3.778	3.445	3.405	1.303	20.206	0.20

STABILITY PARAMETERS

MACH	CYRO	SBAR	RECIP	SBAR-5	RECIP-5	SPIN	DELT	V1	V2	L1	L2	L1-5	L2-5	DISP
0.20	2.042	3.251	2.416	5.005	0.044	2370	0.013	236.00	24.42	0.00655	0.02031	0.02522	0.03600	0.03
0.40	2.070	3.706	1.50	6.074	0.040	3150	0.010	313.00	33.35	0.01177	0.02353	0.02602	0.03060	0.02
0.60	2.760	3.227	2.53	4.343	0.08	3554	0.000	351.20	30.35	0.01401	0.02152	0.02522	0.0273	0.00
0.80	2.680	3.354	2.20	4.021	1.23	3752	0.008	360.56	42.78	0.02048	0.01330	0.02036	0.02218	0.00
1.00	2.630	2.360	1.145	2.780	5.20	3040	0.008	387.66	46.18	0.01052	0.01177	0.01665	0.01700	0.00
1.20	2.581	2.266	1.653	2.463	0.77	4147	0.008	406.22	40.52	0.00803	0.01082	0.01265	0.01454	0.00
1.40	2.544	1.906	1.42	2.122	3.077	4344	0.007	424.76	52.74	0.00444	0.00580	0.00710	0.00870	0.00
1.60	2.500	1.682	1.071	1.762	2.302	4730	0.007	452.30	50.45	0.00238	0.00376	0.00480	0.00574	0.00
1.80	2.504	1.530	1.400	1.508	1.556	5331	0.006	528.02	65.93	0.00047	0.00376	0.00480	0.00574	0.00
2.00	2.501	1.390	1.170	1.444	1.235	5924	0.005	577.71	73.34	0.01101	0.00376	0.00480	0.00574	0.00
2.20	2.551	1.432	1.103	1.437	1.245	6011	0.005	675.07	83.65	0.01167	0.00376	0.00480	0.00574	0.00
2.40	2.613	1.415	1.200	1.453	1.254	7008	0.004	775.07	93.00	0.01154	0.00376	0.00480	0.00574	0.00
2.60	2.731	1.427	1.224	1.458	1.265	8073	0.003	874.47	110.60	0.01150	0.00376	0.00480	0.00574	0.00
2.80	2.862	1.431	1.250	1.456	1.262	1040	0.003	1176.21	125.00	0.01156	0.00376	0.00480	0.00574	0.00
3.00	2.800	1.427	1.223	1.452	1.257	15707	0.002	1578.62	165.53	0.01166	0.00376	0.00480	0.00574	0.00
3.20	2.941	1.422	1.217	1.448	1.251	10746	0.002	1665.58	203.68	0.01177	0.00376	0.00480	0.00574	0.00

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.

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

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

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