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THE EFFECT OF BOATTAIL SHAPE ON MAGNUS.(U)

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The effects of projectile boattail geometry on the Magnus force and moment were investigated through wind tunnel tests of a 5.2 caliber non-finned projectile. Boattail length varied from 0 to 1.7 calibers and boattail angle varied from 0 to 18 deg with Mach numbers ranging between 0.5 and 2.5. A Reynolds number of 4 million per foot was chosen to ensure fully developed turbulent flow ahead of the boattail. The Magnus force and moment

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coefficient derivatives are shown to correlate well with a non-dimensional variable derived from the Howarth-Mangler transformation. An empirical methodology for calculating the Magnus force and moment coefficient derivatives is developed and shown to compare favorably with the Magnus data of other shells.

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FOREWORD

This work was performed to provide an empirical methodology to predict the Magnus force and moments of spin stabilized projectiles. The work was initiated while the authors were in the Guided Project Division of the Armaments Development Department. It has subsequently been completed while the senior author is at his present duty station, the Weapons Development Division of the Advanced Weapons Department and the junior author at his current duty station, the Exterior Ballistics Division of the Warfare Analysis Department. The work has continuously been supported under SEATASK 35A-501/090-1/URO-302-001. The wind tunnel tests were jointly supported by NAVSEA and Eglin Air Force Base, Florida with the cognizant Air Force engineers, Mr. Ken Cobb and Mr. Ed Sears.

This report, in addition to being reviewed by the authors, was reviewed by Dr. William Chadwick, Research Scientist in the Armaments Development Department and by Mr. Herman Caster, Head of the Exterior Ballistics Division.

R. A. NIEMANN, Head
Warfare Analysis Department

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INTRODUCTION

The aerodynamic coefficients of spin stabilized shells are usually determined by means of tests conducted in either the wind tunnel or the spark range. However, analytical methods are now available for estimating the coefficients of drag, normal force and pitching moment.[1] This note presents the results of parametric wind tunnel tests and outlines an empirical procedure for estimating the Magnus force and moment coefficient derivatives. (Similar work is in progress to determine the pitch and roll damping moments.)

Deviations of cannon fire due to spin were first conjectured by Robins in 1740. They were confirmed experimentally by Magnus in 1853. The influence of the Magnus moment on the dynamic stability of spinning shells is now widely recognized. Indeed, the Magnus moment is mainly responsible for the instabilities encountered by large slender shells, thereby imposing a lower limit to air resistance and an upper limit to range capability. An example of current trends in projectile design is shown in Figure 1.

There have been several attempts to predict the Magnus force and moment analytically on the basis of laminar boundary layer flows about slowly spinning slender cylinders at low incidence.[2,3,4] However, turbulent boundary layers and high spin rates characterize the environments of most shells. The spinning cylinder, and/or ogive with fully developed turbulent boundary layer, has been treated more recently by Vaughn.[5,6]

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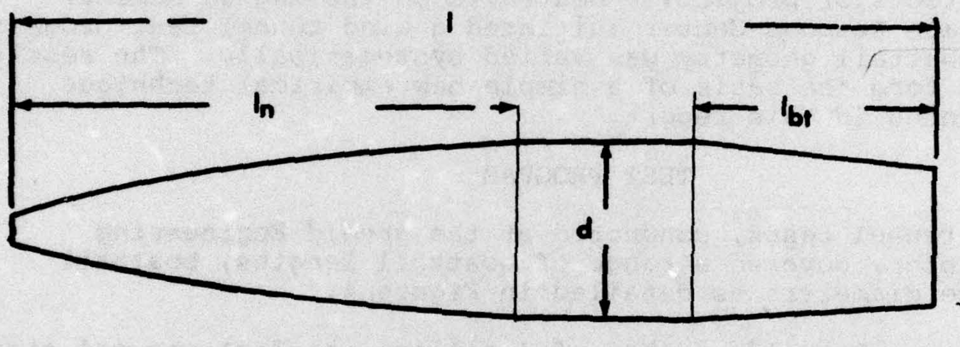
1. Moore, F. G., Aerodynamics of Guided and Unguided Weapons: Part I - Theory and Application, NWL TR - 3018, December 1973.
2. Kelly, H. R., Thacker, R. G., The Effect of High Spin on the Magnus Force on a Cylinder at Small Angles of Attack, NAVORD Report 5036, February 1956.
3. Martin, J. C., On Magnus Effects Caused by the Boundary Layer Displacement Thickness on Bodies of Revolution at Small Angles of Attack, Ballistic Research Laboratory Report 870, June 1955.
4. Sedney, R., Laminar Boundary Layer on a Spinning Cone at Small Angles of Attack, Ballistic Research Laboratory Report 991, September 1956.
5. Vaughn, H. R., Reis, G. E., A Magnus Theory, AIAA Paper 73-124, January 1973.
6. Vaughn, H. R., Reis, G. E., A Magnus Theory for Bodies of Revolution, SC-RR-720537, January 1973.



$$4.5 \leq l/d \leq 6$$

$$2 \leq l_n/d \leq 3.5$$

$$l_{bt}/d \sim 0.6$$

$$\theta_{bt} \sim 7^{\circ}$$

FIG. 1 EXAMPLE OF CURRENT SHELL DESIGN

Attempts have also been made to establish empirical prediction methods for the Magnus moment by correlating experimental data on the basis of projectile boattail length.[7,12] These empirical methods are compared with experimental data in Figure 2. The comparison reveals a need for further refinements in both empirical and theoretical methods.

It is known that the Magnus moment of a spinning shell exhibits a weak dependence on forebody geometry[8] and a strong linear dependence on projectile length[9] as shown in Figure 3. The moment also exhibits a strong dependence on boattail length.[10,11] In view of the poor performance of existing computational methods and the demonstrated first order effects of projectile boattails on the Magnus moment, the Naval Surface Weapons Center initiated a wind tunnel test program in which the boattail geometry was varied systematically. The results of these tests form the basis of a simple new empirical technique which is presented in this report.

TEST PROGRAM

The wind tunnel tests, conducted at the Arnold Engineering Development Center, covered a range of boattail lengths, boattail angles and base diameters as detailed in Figure 4.

A free stream Reynolds number of 4 million per foot was selected for all tests to insure fully developed turbulent flow. Magnus force and moments were measured for angles of attack varying from -2 to 8 degrees. Non-dimensional spin (pd/2V) varied from 0.0 to 0.3. Tests in the Mach number range between 0.5 and 1.5 were conducted in the 4-foot transonic tunnel and for the Mach number range between 1.5 and 2.5 in the 4-foot supersonic tunnel. Full-scale test models were used.

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7. Whyte, R. H., SPINNER - A Computer Program for Predicting the Aerodynamic Coefficients of Spin Stabilized Projectiles, General Electric Class 2 Report, 1969.
8. Platou, A. S., Magnus Characteristics of Finned and Non-finned Projectiles, AIAA Journal, Vol. 3, No. 1, January 1965.
9. Holmes, J. E., Regan, F. J., Falusi, M. E., Supersonic Wind Tunnel Magnus Measurements of the 7-, 8-, 9-, and 10 Caliber Army-Navy Spinner Projectile, Naval Ordnance Laboratory TR - 68-172, 1968.
10. Sokol, C. R., Dynamic Stability of Three Low Drag Projectiles, Naval Weapons Laboratory TR - 3027, August 1973.
11. Platou, A. S., Nielsen, G. I., The Effect of Conical Boattails on the Magnus Characteristics of Projectiles at Subsonic and Transonic Speeds, Ballistic Research Laboratory Report 1720, 1974.
12. Whyte, R. H., SPIN-73, An Updated Version of the Spinner Program, Picatinny Arsenal TR 4588, November 1973.

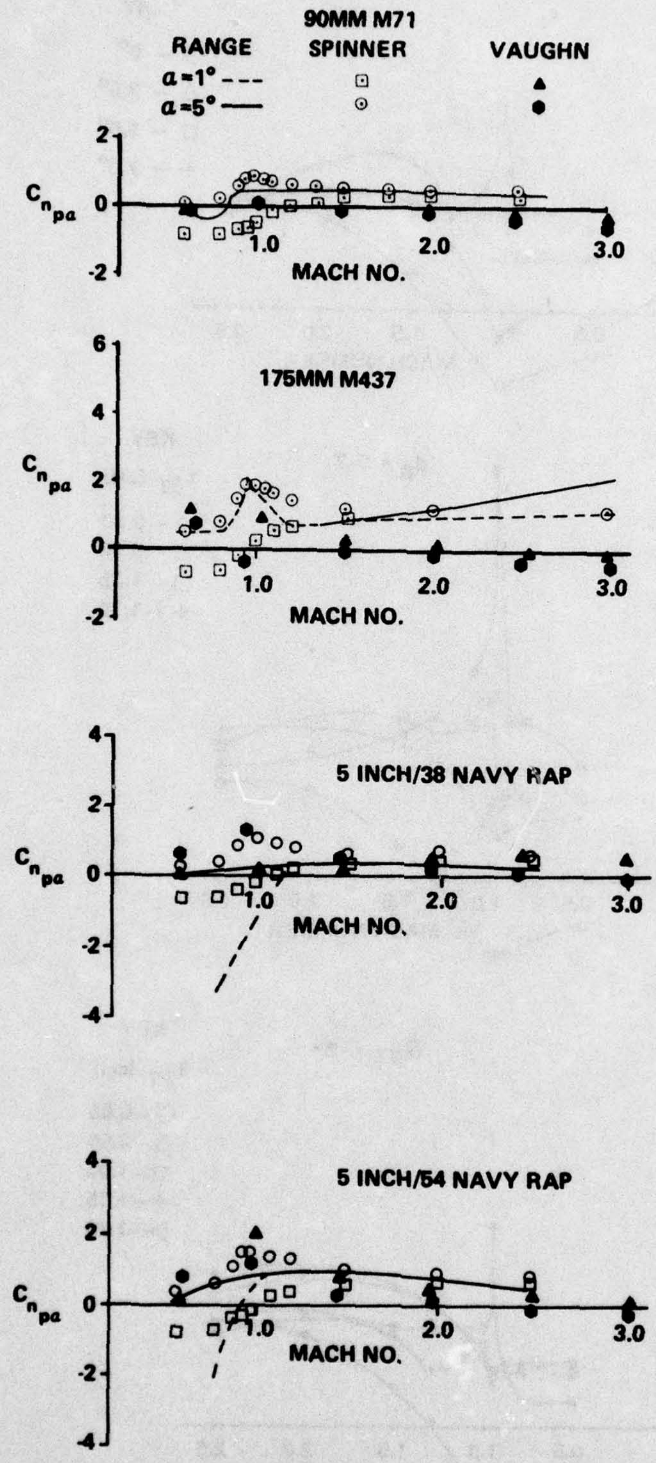


FIG. 2 MAGNUS MOMENT COEFFICIENT DERIVATIVE FOR FOUR PROJECTILES

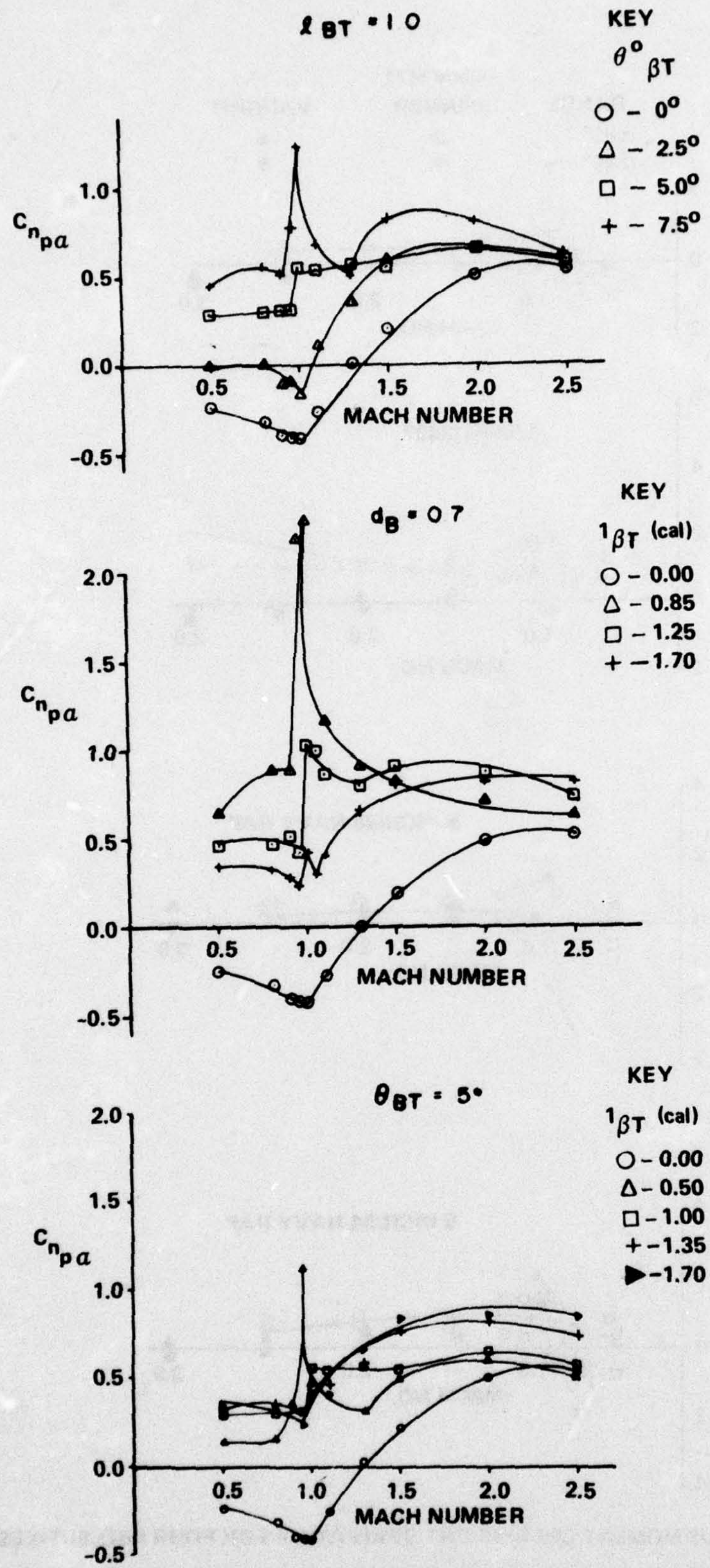
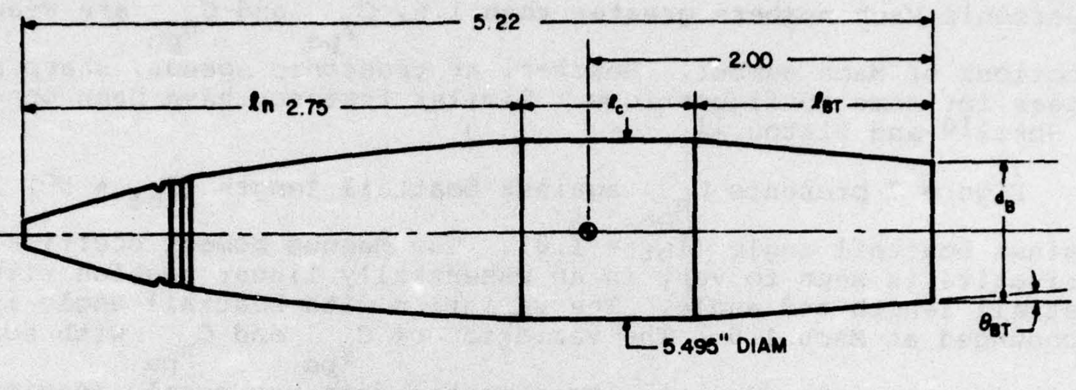


FIG. 3 LINEAR MAGNUS MOMENT COEFFICIENT DERIVATIVE vs MACH NUMBER.



ALL DIMENSIONS IN CALIBERS

CONFIGURATION	l_{bt} CALIBERS	θ_{bt} DEG	d_b CALIBERS	l_c CALIBERS
0	0	0	1.0000	2.460
1	1.00	2.5	0.9126	1.460
2	1.00	3.0	0.8249	1.460
3	1.00	7.5	0.7366	1.460
4	0.50	5.0	0.9124	1.959
5	1.35	5.0	0.7637	1.110
6	1.70	5.0	0.7024	0.759
7	0.45	18.4	0.7000	2.009
8	0.85	10.0	0.7000	1.609
9	1.25	6.9	0.7000	1.205

FIG. 4 VARIATIONS IN BOATTAIL SHAPE USED IN MAGNUS WINDTUNNEL STUDY

TEST RESULTS

The zero yaw derivatives of the Magnus force and moment coefficients are plotted against Mach number for various boattails in Figures 5 and 6. At subsonic Mach numbers less than 0.9 and at supersonic Mach numbers greater than 1.5, $C_{y_{p\alpha}}$ and $C_{n_{p\alpha}}$ are weak functions of Mach number. However, at transonic speeds, sharp spikes appear for some configurations. Similar features have been observed by Sokol[10] and Platou.[11]

Figure 7 presents $C_{n_{p\alpha}}$ against boattail length ($\theta_{bt} = 5^o$) and against boattail angle ($l_{bt} = 1.0$). The Magnus moment coefficient derivative is seen to vary in an essentially linear fashion with both boattail length and angle. The variation with boattail angle is most pronounced at Mach 1.0. The variation of $C_{y_{p\alpha}}$ and $C_{n_{p\alpha}}$ with boattail angle is new since previous experimental data was mostly acquired for shells with boattail angles between 6^o and 8^o.

Figure 8 compares $C_{y_{p\alpha}}$ and $C_{n_{p\alpha}}$ with estimates based on the method of reference 12. For boattail angles less than 5^o, the predictions are essentially incorrect. This is because the SPINNER prediction method does not include boattail angle as an independent variable; it was established using data obtained for a 175mm Army projectile with $\theta_{bt} = 8^o$.

MAGNUS PREDICTION METHOD

A large number of functionalization procedures were attempted to describe the variation of $C_{y_{p\alpha}}$ and $C_{n_{p\alpha}}$ with boattail geometry and Mach number. The most useful parameter seems to be the Mangler variable.[6]

$$\eta = \left[\frac{\int r^2 dx}{r_{ref}^2 x}\right]^{\frac{1}{2}} \quad (1)$$

which is simply the non-dimensional boattail volume. For conical afterbodies, it reduces to:

$$\eta = \left[\frac{1 + d_b/d_{ref} + (d_b/d_{ref})^2}{3}\right]^{\frac{1}{2}} \quad (2)$$

Plots of the Magnus coefficient derivatives against η are shown in Figures 9 and 10. The linearity of the Mangler correlation is evident (with the exception of $C_{n_{p\alpha}}$ @ $M = 1.0$). The poorness of the Mangler data fit at $M = 1.0$ is unfortunate because it would be

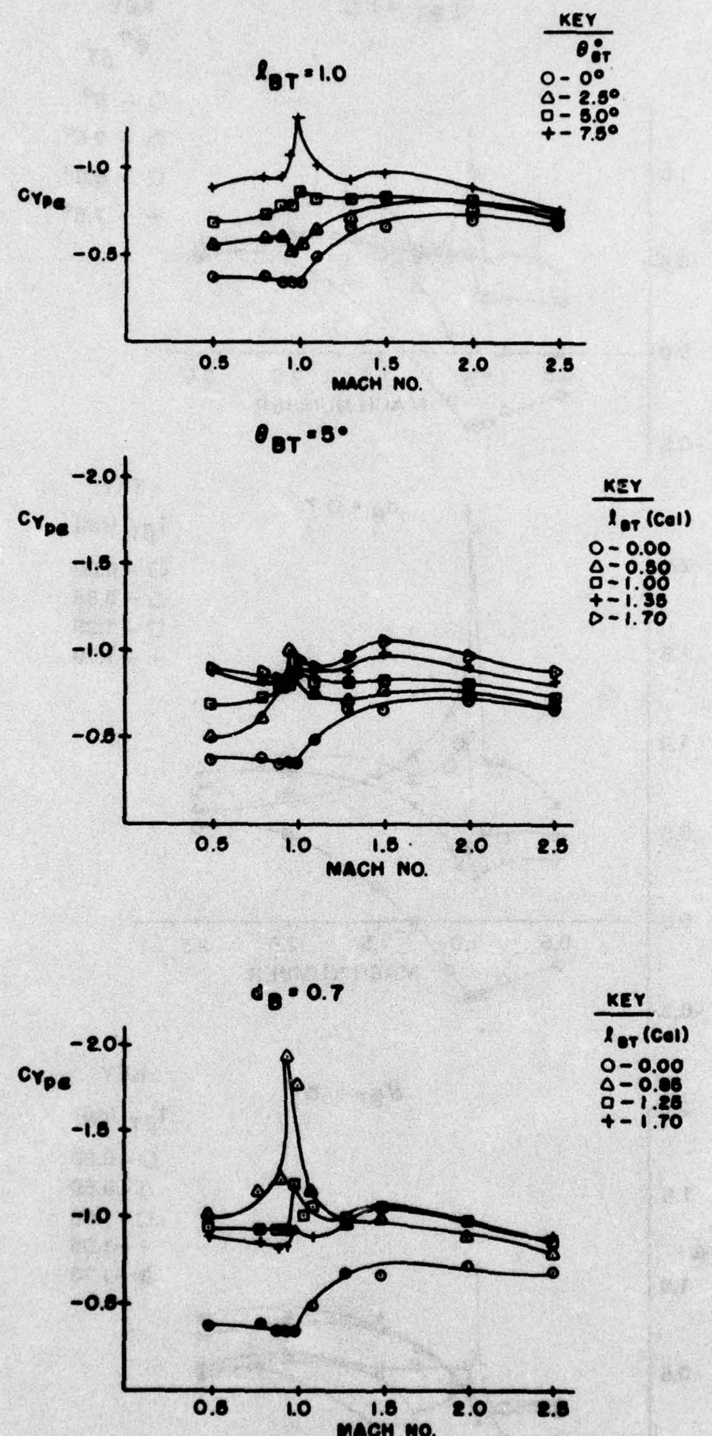


FIG. 5 LINEAR MAGNUS FORCE COEFFICIENT DERIVATIVE vs MACH NUMBER.

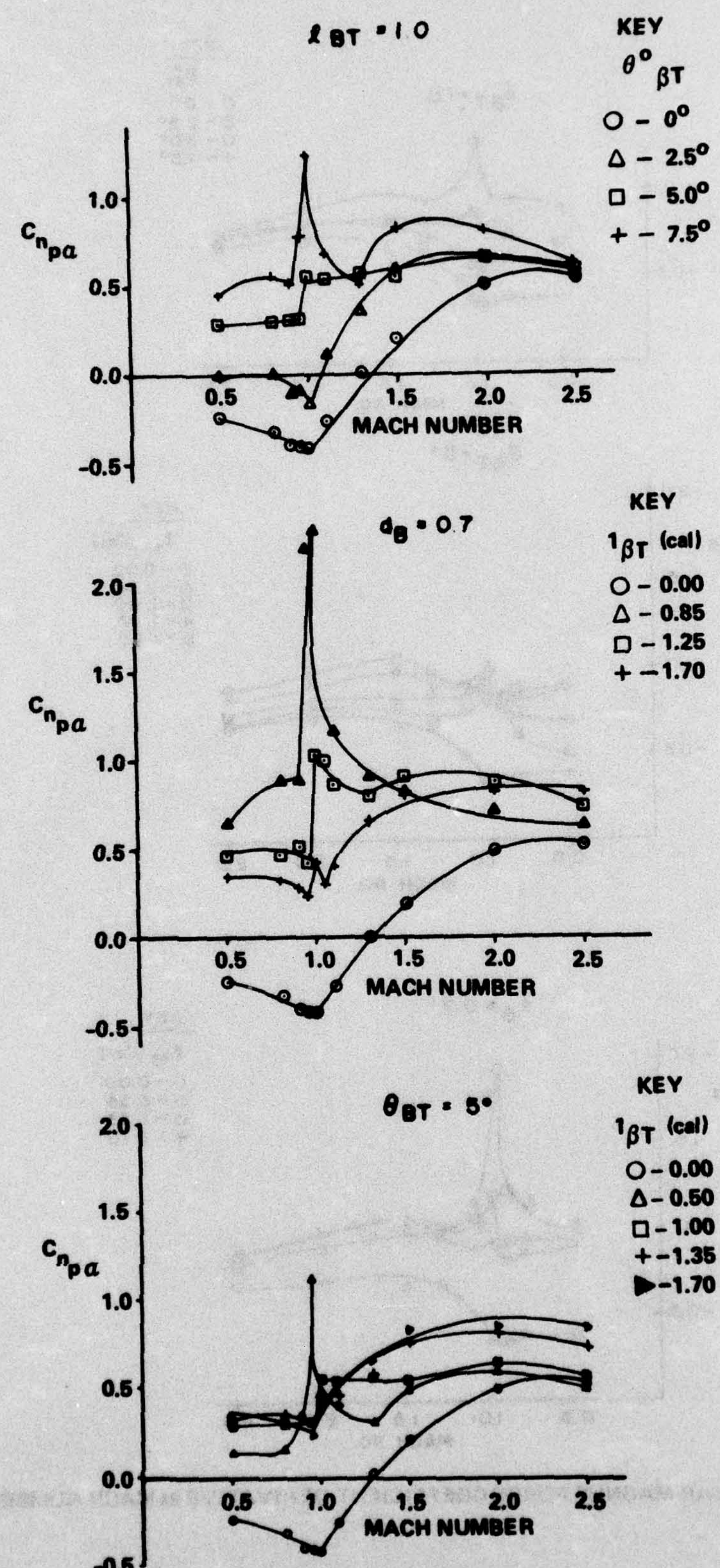


FIG. 6 LINEAR MAGNUS MOMENT COEFFICIENT DERIVATIVE vs MACH NUMBER.

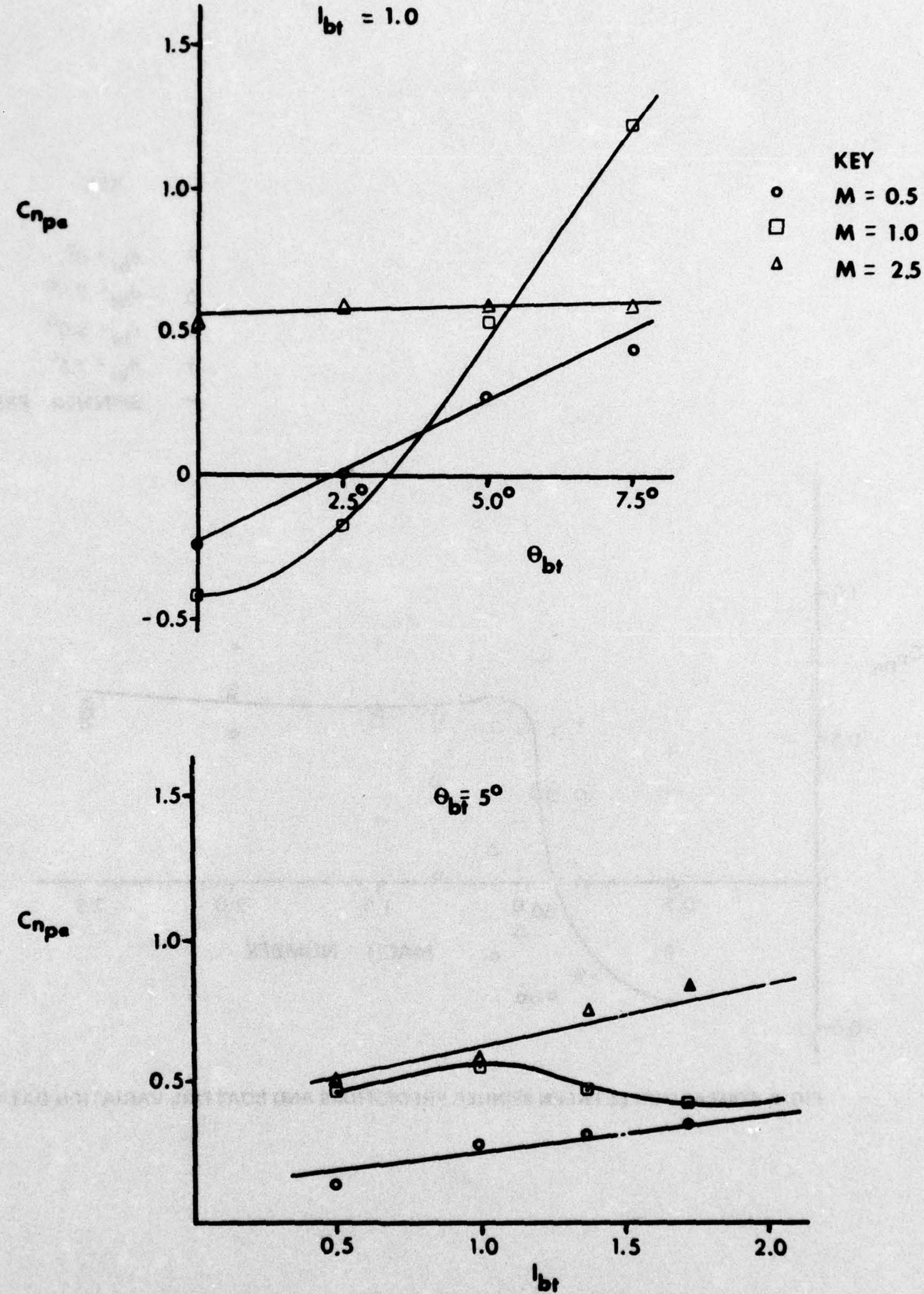


FIG. 7 VARIATION OF $C_{n_{pa}}$ WITH BOATTAIL GEOMETRY

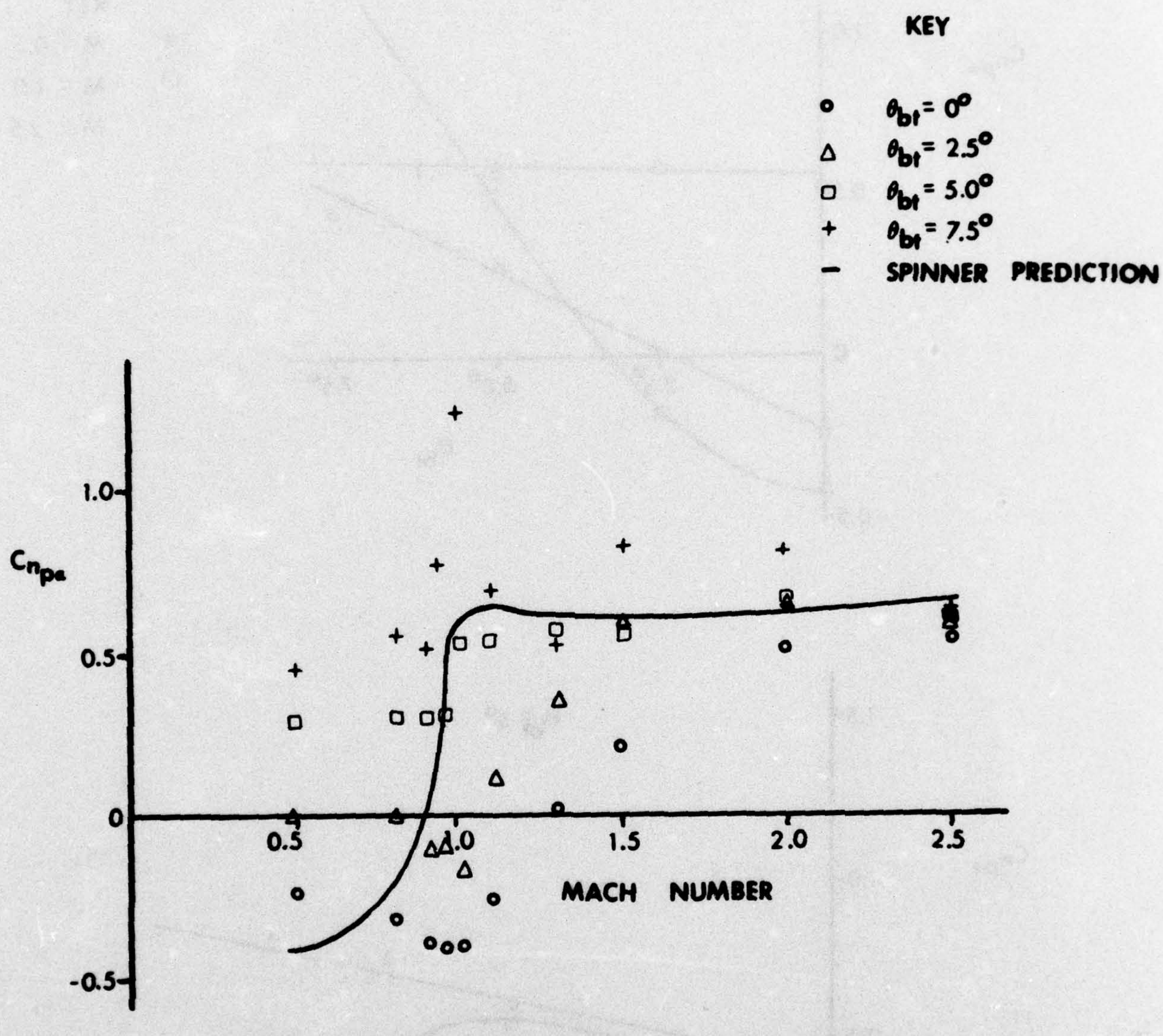


FIG. 8 COMPARISON BETWEEN SPINNER PREDICTIONS AND BOATTAIL VARIATION DATA

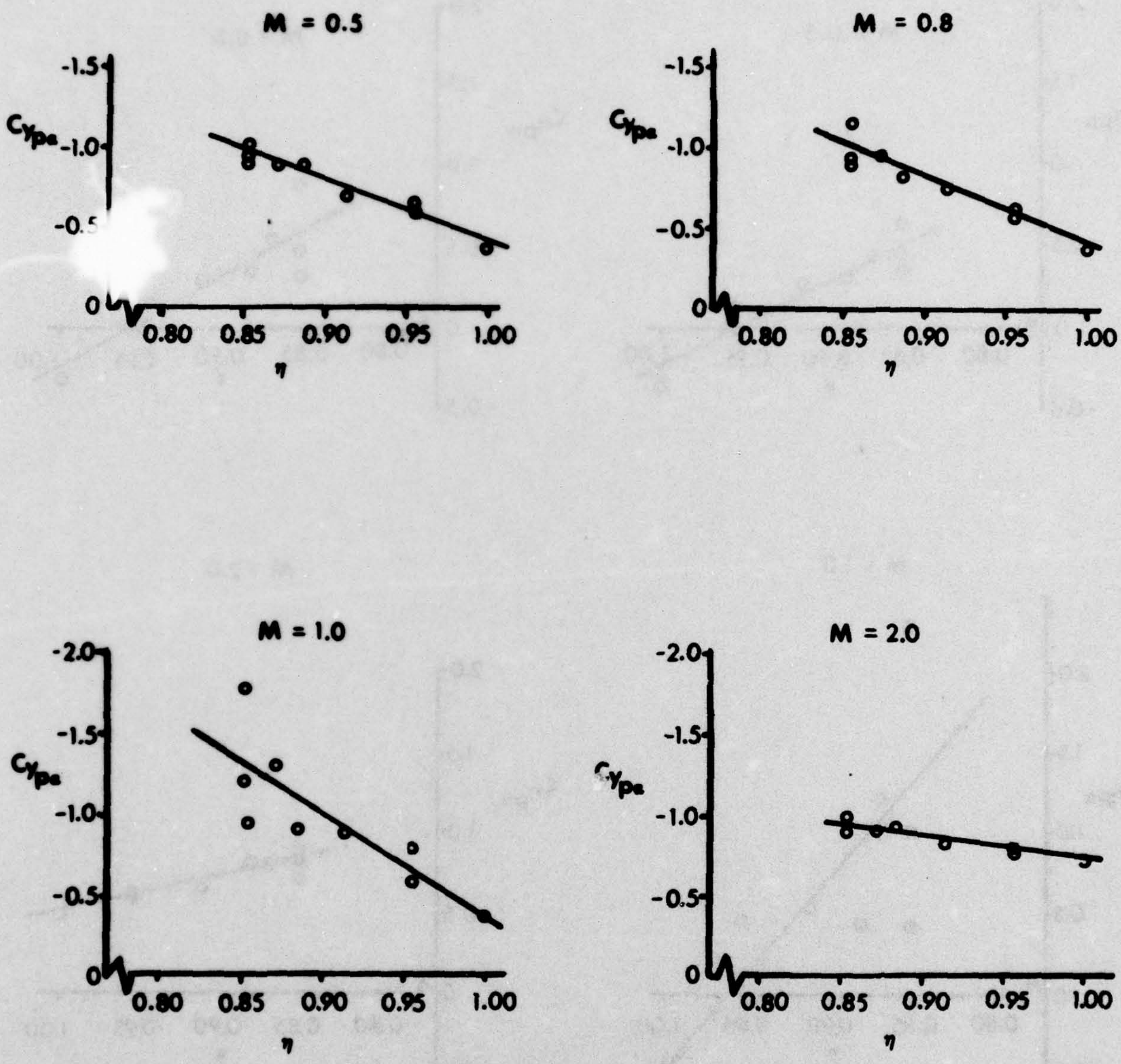


FIG. 9 VARIATION OF $C_{Y_{pa}}$ WITH THE HOWARTH-MANGLER VARIABLE

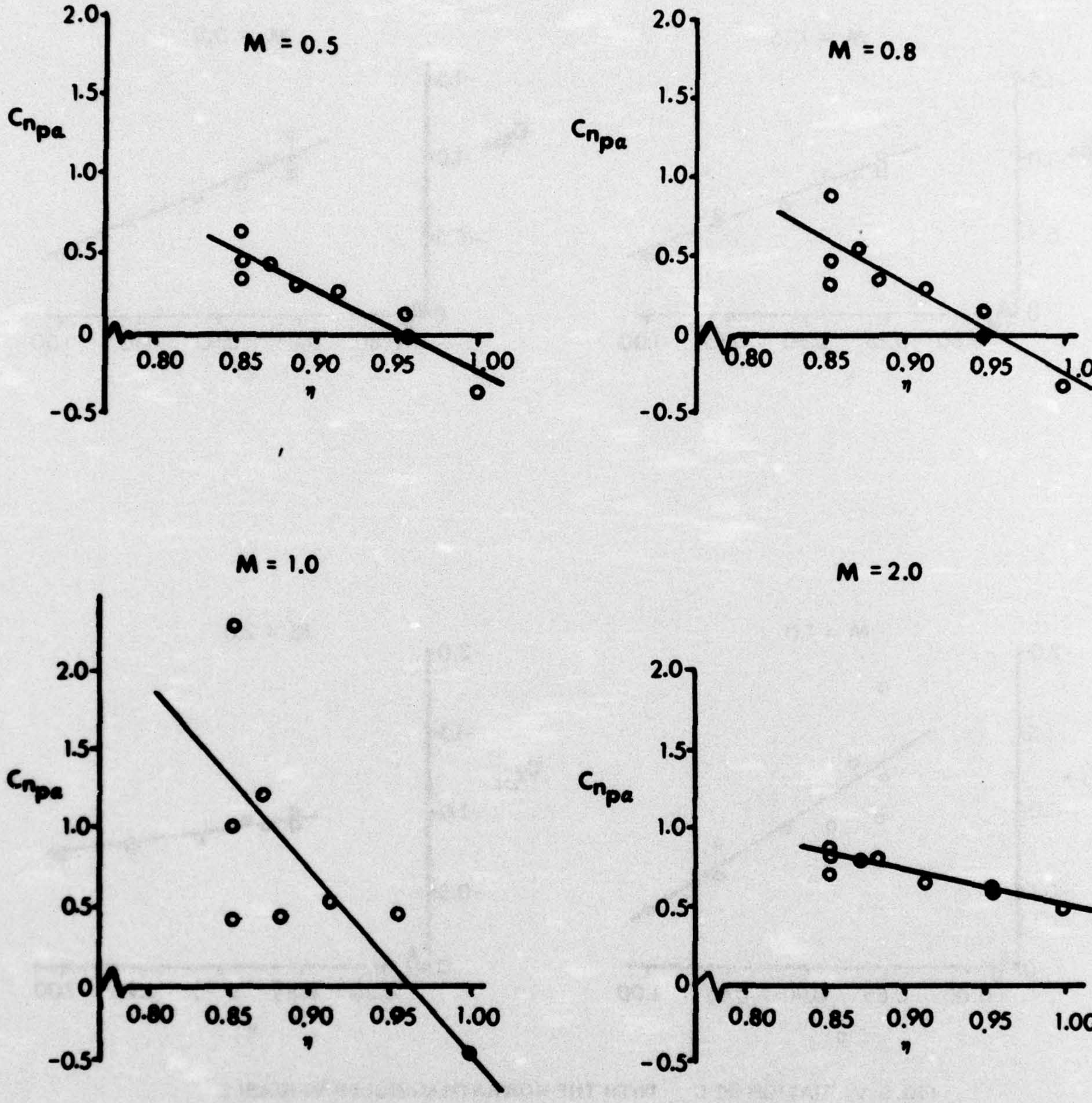


FIG. 10 VARIATION OF $C_{n_{pa}}$ WITH THE HOWARTH-MANGLER VARIABLE

desirable to predict the peak values of the Magnus coefficients. Thus, the wind tunnel data of Platou[11] was examined to see if the Mangler parameter would correlate the Magnus peaks. Data in this study was taken at the transonic Mach numbers: 0.9, 0.94, 0.98 and 1.02. The Mangler correlation of the transonic peaks based on Reference 10 is shown in Figure 11.

The Mangler plots indicate that the Magnus coefficients decrease with increasing boattail volume. The Magnus coefficients may then be written

$$C_{y_{p\alpha}} = a + b\eta$$
$$C_{n_{p\alpha}} = c + d\eta \qquad (3)$$

where the constants (a,b,c,d) are functions of Mach number only and are derived from the data presented herein using the method of least squares.

The constants are listed in Table 1 and are valid for conditions which insure (a) attached flow over the projectile afterbody, and (b) linearity of the force and moment coefficients with respect to yaw level and spin rate. The prediction method is then valid for the approximate range of the variables below:

$\theta_{bt} \leq 8^{\circ}$ $(1.1 < M < 2.5$ and $0.5 \leq M \leq 0.95)$

$\theta_{bt} \leq 6^{\circ}$ $(0.95 < M < 1.1)$

$pd/2V \leq 0.2$

$\alpha \leq 1^{\circ}$

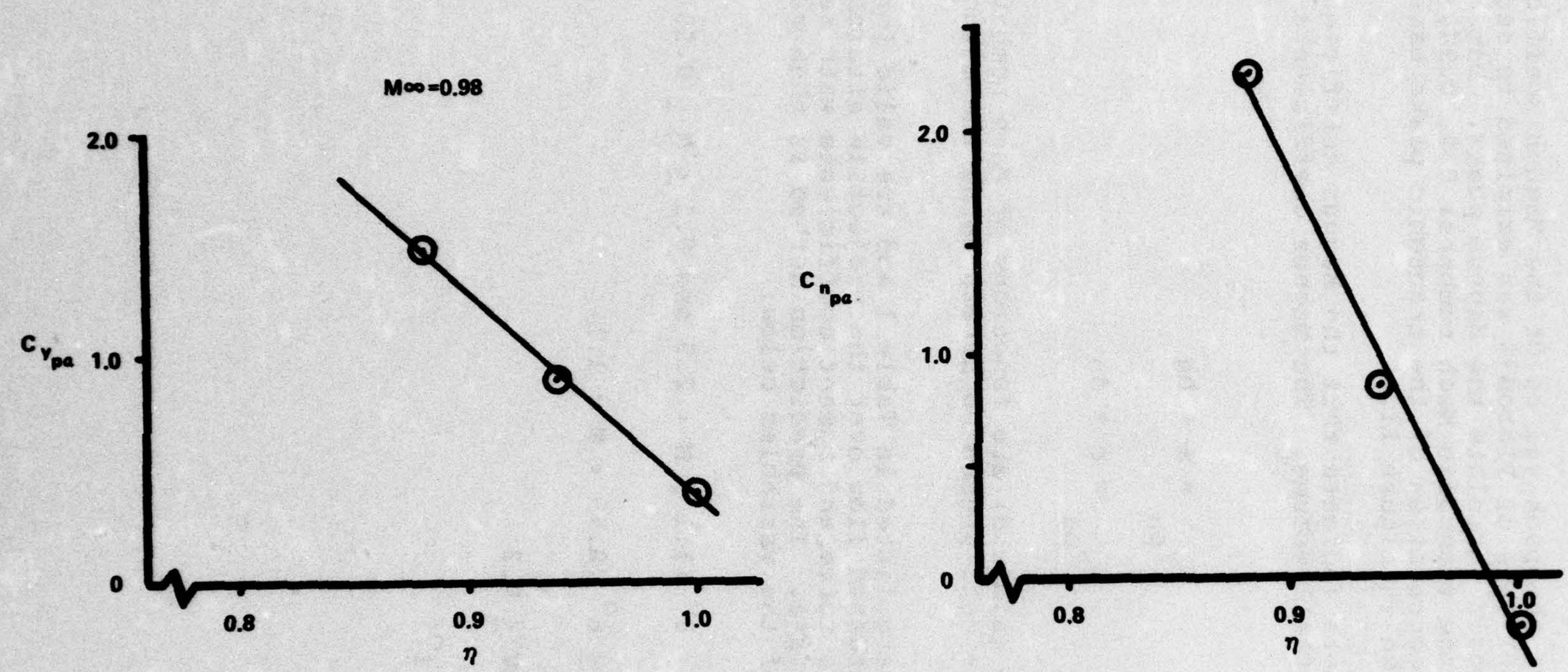


FIG. 11 PLOTS OF EXPERIMENTAL MAGNUS DATA VS. NONDIMENSIONAL MANGLER VARIABLE

Table 1

M	a	b	c	d
0.5	-4.411	4.134	4.475	-4.650
0.8	-4.410	4.001	5.412	-5.644
0.9	-4.268	3.820	5.479	-5.721
Peak*	-9.400	9.000	23.980	-24.000
1.0	-6.766	6.409	10.710	-11.108
1.5	-3.125	2.446	4.107	-4.066
2.0	-2.362	1.658	2.650	-2.133
2.5	-1.889	1.228	2.020	-1.526

The values in Table 1 define $C_{y_{p\alpha}}$ and $C_{n_{p\alpha}}$ for shells with a slenderness ratio of 5.2. Since, as shown in Figure 3, Magnus is a linear function of total projectile length, the new empirical methodology to correlate Magnus as a function of projectile length (L), Mach number (M), and boattail shape (η) is given by equations (4) where $C_{y_{p\alpha}}$ and $C_{n_{p\alpha}}$ of equations (4) are first computed using equations (3).

$$C_{y_{p\alpha}}(L) = (L/5.2)C_{y_{p\alpha}} \tag{4}$$

$$C_{n_{p\alpha}}(L) = (L/5.2)(C_{y_{p\alpha}}(C_{n_{p\alpha}}/C_{y_{p\alpha}}+(3.0 - x_{cg})))$$

The results of equations 3 and 4 in modelling the experimental data are compared with the SPINNER model in Figure 12. These figures reveal that the present model yields a better representation of the data due to the allowance of the effects of boattail angle.

COMPARISON WITH OTHER EXPERIMENTAL DATA

Comparisons between wind tunnel data and predictions based on the Mangler correlation are shown in Figures 13 through 15. Figures 13a and 13b show agreement with the data of Platou[11] for the 5 caliber Army-Navy Spinner boattail variation study. Although the agreement between the present empirical Magnus method and Reference 11 is good, the agreement is not sufficient to validate the approach. The shapes tested by Platou are very similar to those used in the boattail length variation (θ_{bt} = 7.5°) of this study.

*Peak values were taken from Reference 10. The Mangler fit is shown in Figure 11.

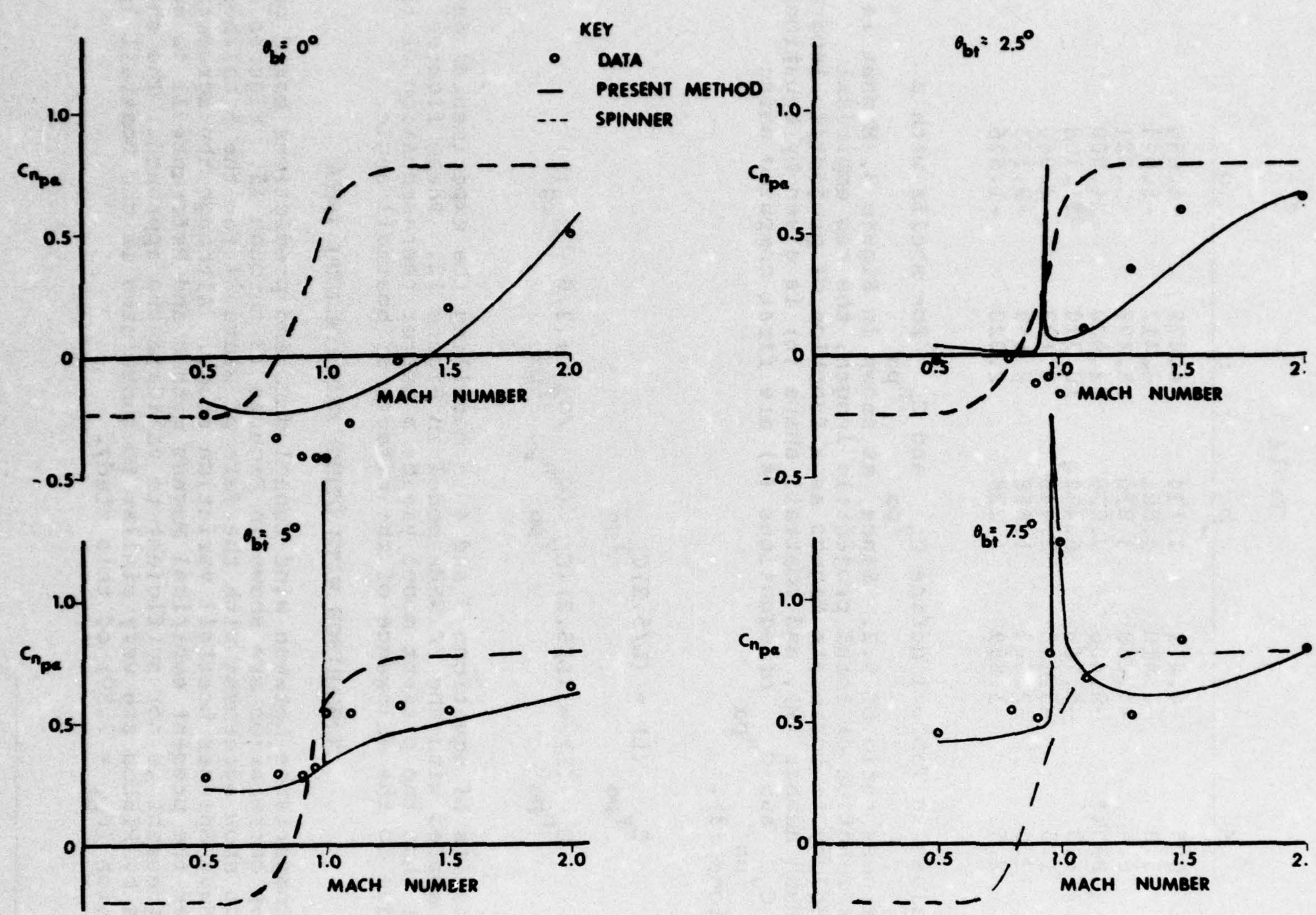


FIG. 12 COMPARISON BETWEEN PREDICTIONS AND BOATTAIL VARIATION DATA

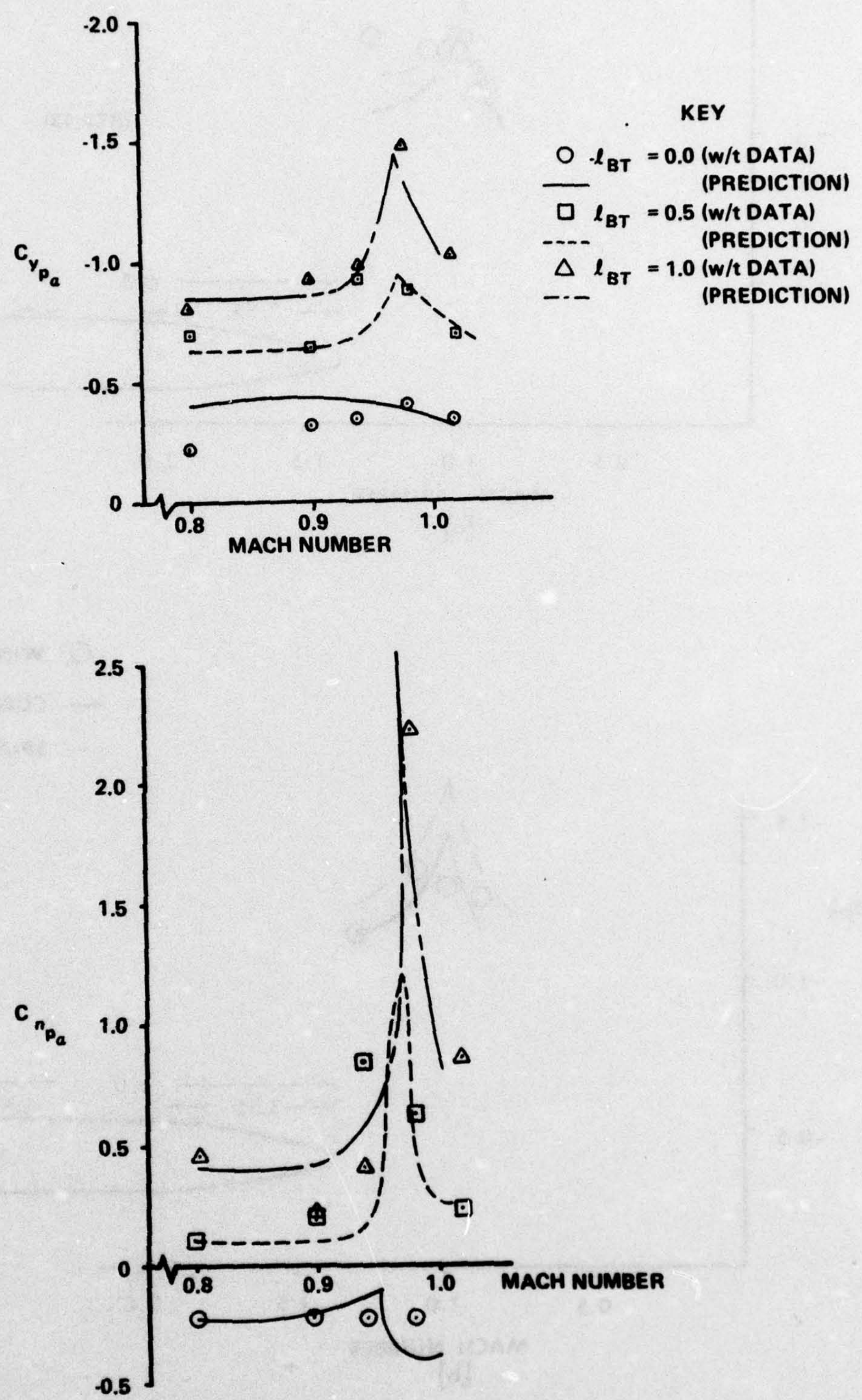


FIG. 13 COMPARISON BETWEEN PREDICTION AND EXPERIMENTAL DATA 5 CALIBER A-N SPINNER

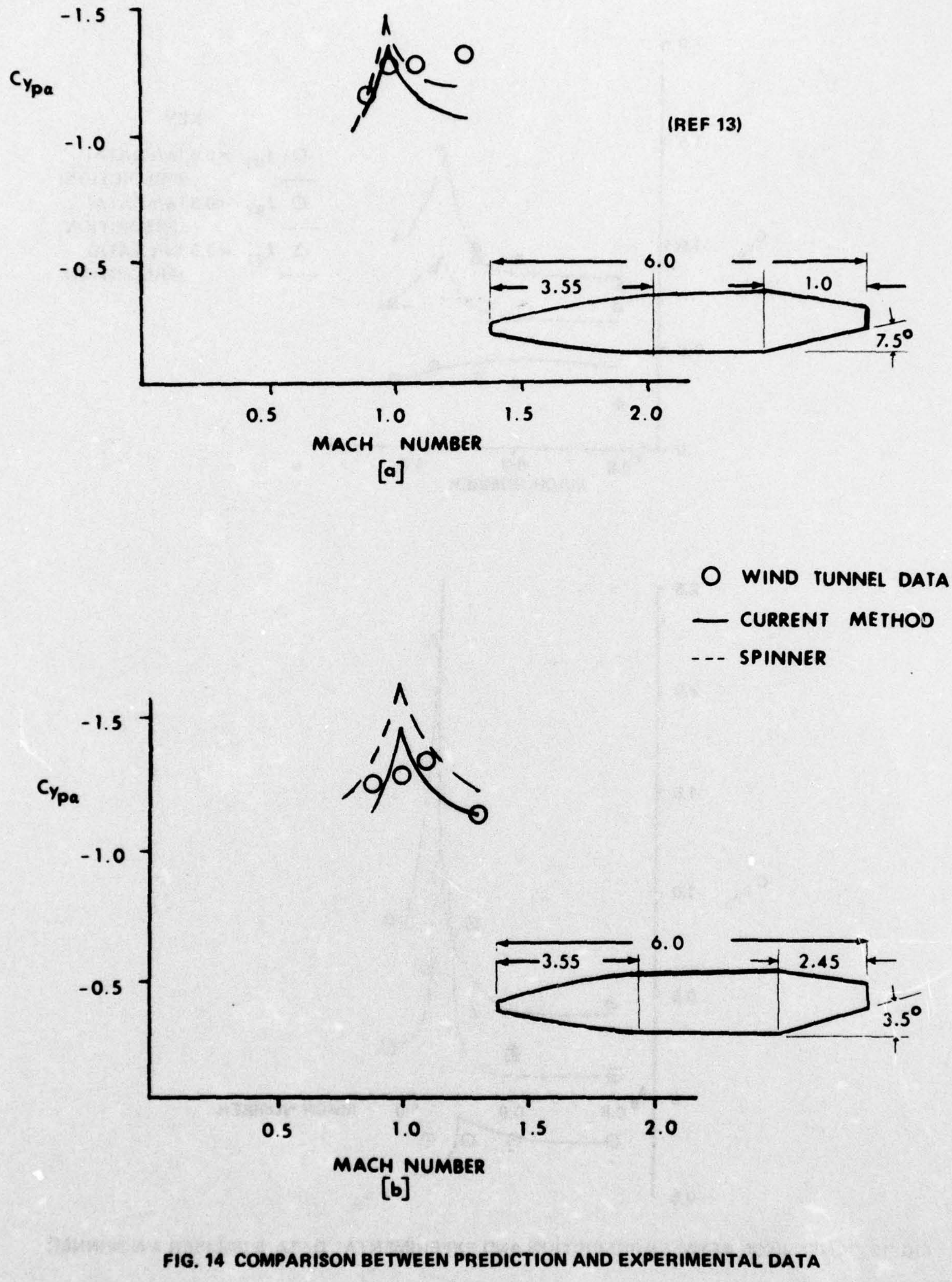


FIG. 14 COMPARISON BETWEEN PREDICTION AND EXPERIMENTAL DATA

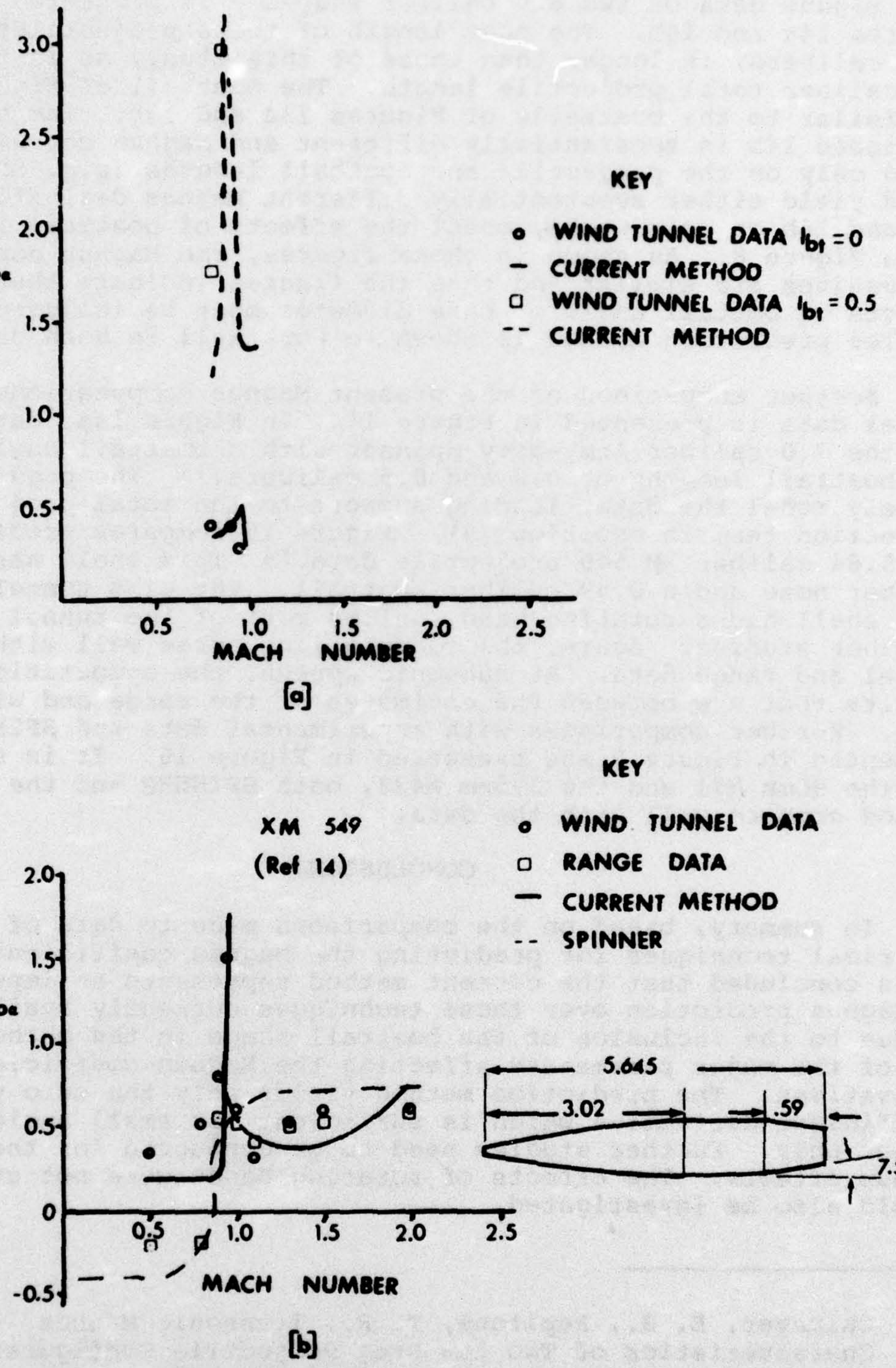


FIG. 15 COMPARISON BETWEEN PREDICTION AND EXPERIMENTAL DATA 7 CALIBER A-N SPINNER

Magnus data of two 6.0 caliber shapes[13] is presented in Figures 14a and 14b. The nose length of these projectiles, 3.55 calibers, is longer than those of this study, as is the 6.0 caliber total projectile length. The boattail of Figure 14a is similar to the boattails of Figures 13a and 13b. The boattail of Figure 14b is substantially different and Magnus correlations based only on the projectile and boattail lengths (e.g. SPINNER) would yield either substantially different Magnus derivatives for 14a and 14b or only weakly model the effects of boattail in general, as in Figure 8. As shown in those figures, the Magnus coefficient derivatives are similar and thus the figures indicate that the effects of bottail angle or base diameter must be included. The Mangler prediction method is shown to work well in both cases.

Further comparison of the present Magnus computations and wind tunnel data is presented in Figure 14. In Figure 14a, data is shown for the 7.0 caliber Army-Navy Spinner with a boattail angle of 7° and boattail lengths of 0.0 and 0.5 calibers.[11] The predictions closely model the data, lending support to the total projectile length correction term in equation (4). Figure 15 compares predictions with the 5.64 caliber XM 549 projectile data.[14] This shell has a 3.0 caliber nose and a 0.59 caliber boattail. The wind tunnel model of this shell had a rotating band, unlike most of the tunnel models used in other studies. Again, the computations agree well with the wind tunnel and range data. At subsonic speeds, the computations give results that are between the estimates of the range and wind tunnel data. Further comparisons with experimental data and SPINNER for data presented in Figure 2 are presented in Figure 16. It is seen that for the 90mm M71 and the 175mm M437, both SPINNER and the present method compare well with the data.

CONCLUSIONS

In summary, based on the comparisons made to date of the current empirical techniques for predicting the Magnus coefficient derivatives, it is concluded that the current method represents an improvement in Magnus prediction over those techniques currently available. This is due to the inclusion of the boattail shape in the methodology as one of the major parameters affecting the Magnus coefficient derivatives. The prediction method yields only the zero yaw Magnus coefficient derivative which is sufficient for small angles of attack only. Further studies need to be conducted for the non-linear Magnus effects. The effects of rotating bands were not studied and should also be investigated.

---

13. Ohlmeyer, E. J., Pepitone, T. R., Transonic Magnus Characteristics of Two Low Drag Projectile Configurations, Naval Weapons Laboratory TR - 2586, November 1971.
14. Platou, A. S., Nielson, G. I., Some Aerodynamic Characteristics of the Artillery Projectile XM 549, Ballistic Research Laboratory MR - 2284, April 1973.

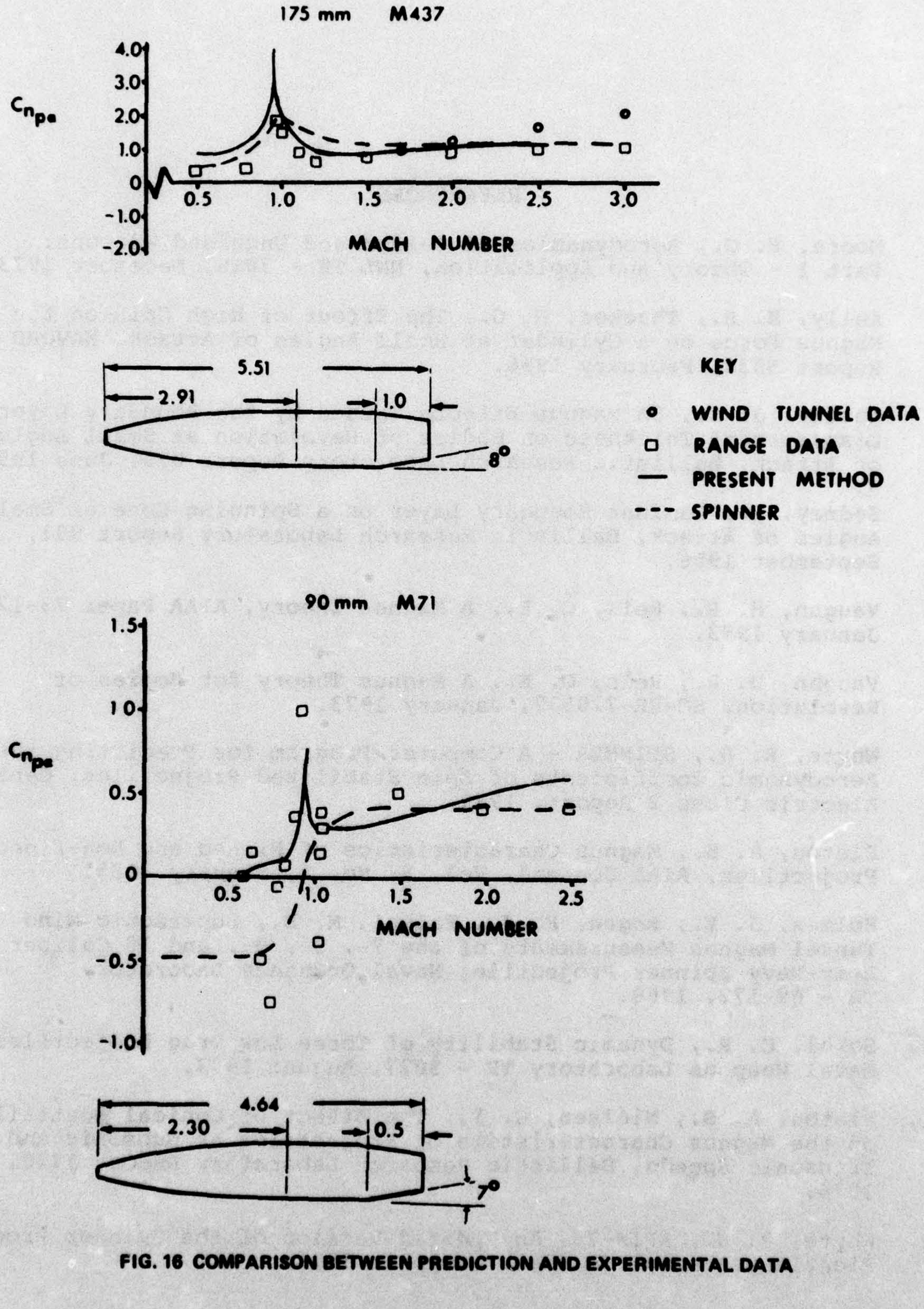


FIG. 16 COMPARISON BETWEEN PREDICTION AND EXPERIMENTAL DATA

REFERENCES

1. Moore, F. G., Aerodynamics of Guided and Unguided Weapons: Part I - Theory and Application, NWL TR - 3018, December 1973.

2. Kelly, H. R., Thacker, R. G., The Effect of High Spin on the Magnus Force on a Cylinder at Small Angles of Attack, NAVORD Report 5036, February 1956.

3. Martin, J. C., On Magnus Effects Caused by the Boundary Layer Displacement Thickness on Bodies of Revolution at Small Angles of Attack, Ballistic Research Laboratory Report 870, June 1955.

4. Sedney, R., Laminar Boundary Layer on a Spinning Cone at Small Angles of Attack, Ballistic Research Laboratory Report 991, September 1956.

5. Vaughn, H. R., Reis, G. E., A Magnus Theory, AIAA Paper 73-124, January 1973.

6. Vaughn, H. R., Reis, G. E., A Magnus Theory for Bodies of Revolution, SC-RR-720537, January 1973.

7. Whyte, R. H., SPINNER - A Computer Program for Predicting the Aerodynamic Coefficients of Spin Stabilized Projectiles, General Electric Class 2 Report, 1969.

8. Platou, A. S., Magnus Characteristics of Finned and Non-fined Projectiles, AIAA Journal, Vol. 3, No. 1, January 1965.

9. Holmes, J. E., Regan, F. J., Falusi, M. E., Supersonic Wind Tunnel Magnus Measurements of the 7-, 8-, 9-, and 10 Caliber Army-Navy Spinner Projectile, Naval Ordnance Laboratory TR - 68-172, 1968.

10. Sokol, C. R., Dynamic Stability of Three Low Drag Projectiles, Naval Weapons Laboratory TR - 3027, August 1973.

11. Platou, A. S., Nielsen, G. I., The Effect of Conical Boattails on the Magnus Characteristics of Projectiles at Subsonic and Transonic Speeds, Ballistic Research Laboratory Report 1720, 1974.

12. Whyte, R. H., SPIN-73, An Updated Version of the Spinner Program, Picatinny Arsenal TR 4588, November 1973.

REFERENCES (Continued)

13. Ohlmeyer, E. J., Pepitone, T. R., Transonic Magnus Characteristics of Two Low Drag Projectile Configurations, Naval Weapons Laboratory TR - 2586, November 1971.

14. Platou, A. S., Nielson, G. I., Some Aerodynamic Characteristics of the Artillery Projectile XM 549, Ballistic Research Laboratory MR - 2284, April 1973.

A. GLOSSARY

a	Mangler force coefficient derivative correlation constant
b	Mangler force coefficient derivative correlation constant
c	Mangler moment coefficient derivative correlation constant
d	Mangler moment coefficient derivative correlation constant
d_b	Base diameter (calibers)
d_{ref}	Reference diameter (calibers)
$C_{n_{p\alpha}}$	Linear Magnus moment coefficient derivative $(\partial^2 C_n/(\partial\alpha\partial\bar{p}))_{\alpha=o}$
$C_{y_{p\alpha}}$	Linear Magnus force coefficient derivative $(\partial^2 C_y/(\partial\alpha\partial\bar{p}))_{\alpha=o}$
L	Total projectile length (calibers)
l_{bt}	Boattail length (calibers)
l_n	Nose length (calibers)
M	Free stream Mach number
p	Spin rate (rad/sec)
$\bar{p}$	Non-dimensional spin rate $(pd_{ref}/(2V))$
r	Body radius
V	Free stream velocity
x_{cg}	Center of gravity (calibers from the nose)
α	Angle of attack
θ_{bt}	Boattail angle (degrees)
η	Howarth-Mangler variable

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