Empirical Method for Predicting the Magnus Characteristics of Spinning Shells

Gil Y. Graff*
Naval Surface Weapons Center, White Oak, Md.
and
Frank G. Moore†
Naval Surface Weapons Center, Dahlgren, Va.

Nomenclature

d_b = base diameter, calibers
d_{ref} = reference diameter, calibers
$C_{n_{p\alpha}}$ = zero yaw Magnus moment coefficient derivative $\partial C_n/(\partial\alpha\partial\bar{p})$
$C_{y_{p\alpha}}$ = zero yaw Magnus force coefficient derivative $\partial C_y/(\partial\alpha\partial\bar{p})$
L = total projectile length, calibers
l_{bt} = boattail length, calibers
M = freestream Mach number
p = spin rate
$\bar{p}$ = nondimensional spin $pd_{ref}/(2V)$
r = local body radius
V = freestream velocity
x_{cg} = center of gravity, calibers from nose
α = angle of attack, deg
θ_{bt} = boattail angle, deg
η = Howarth-Mangler variable

Theme

THE effects of projectile boattail geometry (used to increase range) on the Magnus force and moment coefficient derivatives were studied through wind tunnel tests. The derivative coefficients are shown to correlate well with a nondimensional parameter suggested by the Howarth-Mangler transformation. An empirical technique then is developed for the computation of the Magnus coefficient derivatives. Reasonable agreement with experimental data is exhibited with the new techniques.

Contents

The Magnus moments arise due to asymmetries in the flowfield caused by spin and angle of attack. The nature of the moment dependence on p and α is often responsible for the instabilities of long, slender, spin-stabilized shells. There have been several attempts to predict the Magnus force and moment both analytically[1] and empirically.[2] A comparison revealed a need for further refinements.

Previously, experimental work has shown that the Magnus moment is only a weak function of forebody geometry but is strongly dependent on projectile length[3] and on boattail length.[4] Little data existed to determine the effect of boattail angle on the Magnus characteristics.

The Magnus coefficients of the shell geometries (shown in Fig. 1) were, therefore, determined from wind-tunnel tests. Magnus force and moments were measured for angles of attack varying from −2 to 8 deg. Nondimensional spin ($pd/2V$) varied from 0.0 to 0.3. Full-scale test models were used. The zero yaw Magnus moment derivative $C_{n_{p\alpha}}$ is shown as a function of Mach number for various boattail angles (Fig. 2). The boattail effects on the zero yaw Magnus force coefficient derivative $C_{y_{p\alpha}}$ are presented in Ref. 5. Since they are similar to the Magnus moment results, they will not be discussed here.

The most useful correlation of $C_{y_{p\alpha}}$ and $C_{n_{p\alpha}}$ with boattail geometry used the Mangler variable[3]:

$$\eta = [\int r^2 \mathrm{d}x / r^2_{ref} x]^{1/2} \tag{1}$$

which, when applied to the boattail, is the nondimensional boattail volume. For conical boattails, η reduces to

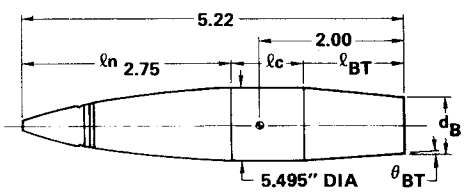
$$\eta = 1/3^{1/2}\{1 + d_b/d_{ref} + (d_b/d_{ref})^2\}^{1/2} \tag{2}$$

Plots of $C_{n_{p\alpha}}$ against η are shown in Fig. 3. Linearity of $C_{y_{p\alpha}}$ against η is just as pronounced.[5] The Mangler plots indicate that the Magnus coefficients decrease with increasing boattail volume. Assuming a linear variation of Magnus with total projectile length, the Magnus coefficient derivatives then are given by

$$C_{y_{p\alpha}} = (L/5.2)(a + b\eta) \tag{3a}$$

$$C_{n_{p\alpha}} = (L/5.2)\{c + d\eta + (3.0 - x_{cg})(a + b\eta)\} \tag{3b}$$

The constants a, b, c, d are the slope and intercepts of the Mangler plots and are functions of Mach number only, as given in Table 1. The constants listed in Table 1 are valid for



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	1.206

Fig. 1 Variations in boattail shape used in Magnus wind-tunnel study.

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*Aerospace Engineer, Advanced Weapons Department, White Oak Laboratory.

†Head, Aeromechanics Branch, Warfare Analysis Dept., Dahlgren Laboratory. Member AIAA.

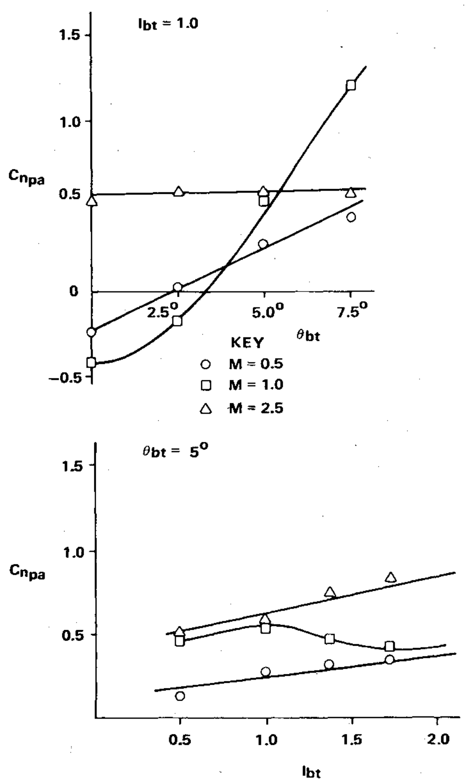

Fig. 2 Variation of $C_{n_{p\alpha}}$ with boattail geometry.

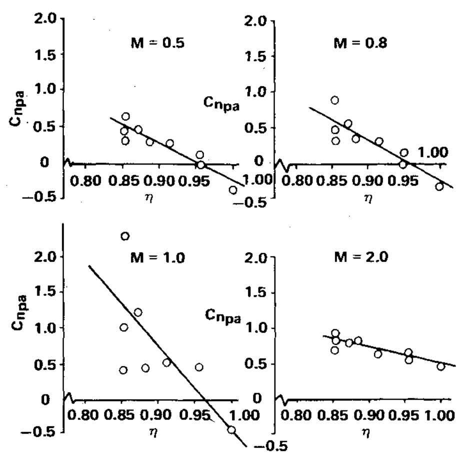

Fig. 3 Variation of $C_{n_{p\alpha}}$ with the Howarth-Mangler variable.

Table 1 Constants as functions of Mach number

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
Transonic 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

conditions that insure 1) attached flow over the projectile afterbody, and 2) linearity of the force and moment coefficients with respect to yaw angle and spin rate. The prediction method then is valid for the approximate range of the variables following:

$$\theta_{bt} \leq 8 \text{ deg for subsonic and supersonic Mach numbers} \quad (4a)$$

$$\theta_{bt} \leq 6 \text{ deg } (0.95 < M < 1.1) \quad (4b)$$

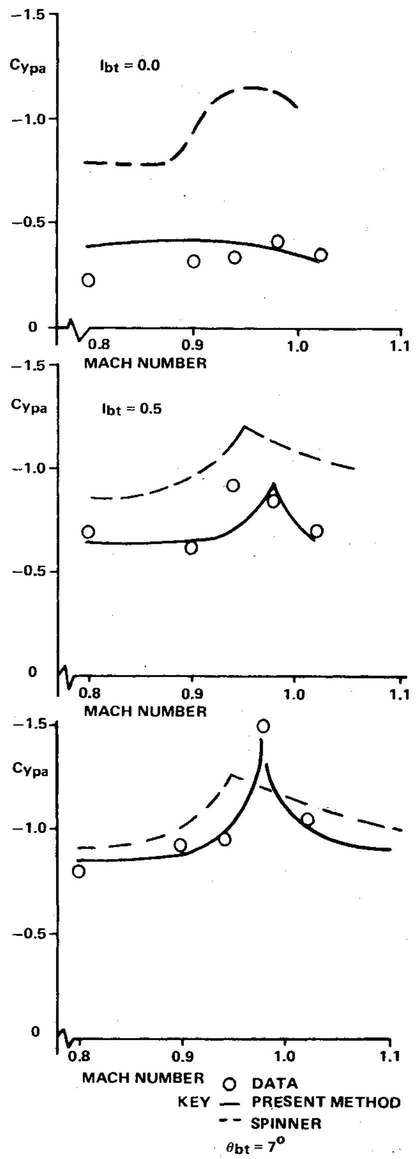

Fig. 4 Comparison between Magnus data and prediction methods (5-caliber Army-Navy spinner).

$$pd/2V \leq 0.2, \quad \alpha \leq 1 \text{ deg} \quad (4c,4d)$$

Results of the Mangler-derived method are shown to compare favorably with experimental data[4] in Fig. 4.

In summary, a new empirical method for predicting Magnus has been developed. The method works reasonably well for projectiles that have discarding rotating bands and at low angles of attack. Further work needs to be done to incorporate the band and nonlinear angle-of-attack effects, as well as to improve the prediction scheme in transonic flow.

References

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[5] Graff, G.Y. and Moore, F.G., "The Effect of Boattail Shape on Magnus," Naval Surface Weapons Center, Dahlgren, Va., TR-3581, 1976.