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Technical Comments

Brief discussion of previous investigations in the aerospace sciences and technical comments on papers published in the Journal of Spacecraft and Rockets *are presented in this special department. Entries must be restricted to a maximum of 1000 words, or the equivalent of one* Journal *page including formulas and figures. A discussion will be published as quickly as possible after receipt of the manuscript. Neither the AIAA nor its editors are responsible for the opinions expressed by the correspondents. Authors will be invited to reply promptly.*

Comment on "Roll Damping for Projectiles Including Wraparound, Offset, and Arbitrary Number of Fins"

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Nomenclature

b = inclusive span
C_{lp} = roll damping stability derivative
$C_{l\delta}$ = roll due to differential fin cant stability derivative
c_r = root chord
d = body diameter
E = Eastman's correlation parameter
h = exposed semispan of a fin
l = length of the arc of a curved fin
M = Mach number
m = exponent in Mikhail's correction factor
n = number of fins
y_c = lateral area center of a fin

Superscript

AD = Adams and Dugan

Introduction

IN Ref. 1, Mikhail extends Eastman's correlation[2] of the relationship between the roll damping and the roll due to fin cant stability derivatives, from cruciform tails to various types of tails. Eastman's correlation relates the ratio of the two roll stability derivatives to a single geometrical parameter by

$$C_{lp} = -2.15(y_c/d)C_{l\delta} \tag{1}$$

This relationship was based on test data of several configurations at Mach numbers between 0 and 4.0.

Reference to Adams and Dugan's Analysis

In Sec. II.C (Ref. 1), the author states that the analysis of the roll stability derivatives by Adams and Dugan[3] is based on "supersonic analysis using the linearized perturbation theory." A review of Ref. 3 clearly shows that their analysis is based on slender-wing theory. This is also apparent because the results of Ref. 3 are independent of Mach number, which is typical of slender-wing theory.

The relationship between the ratio of the roll stability derivatives, based on body diameter and cross-sectional area, and those of Adams and Dugan is (see Ref. 4)

$$C_{lp}\big/C_{l\delta} = (b/d)\big[C_{lp}\big/C_{l\delta}\big]^{\mathrm{AD}} \tag{2}$$

The ratio $[C_{lp}/C_{l\delta}]^{\mathrm{AD}}$ depends on d/b and varies between 0.627 for $d/b = 0$ (plain cruciform fins) and 1.0 for $d/b = 1.0$ (diminishing exposed spans). Equation (3) of Ref. 1 is incorrect in two ways: 1) The dependence of the ratio of the stability derivatives on d/b is inverted. 2) It uses the constant 0.627 instead of a function of d/b. The error is apparent because Eq. (3) of Ref. 1 yields zero roll damping for $d/b = 0$. As a result, the comparison of Eqs. (3) and (4), which is discussed in Sec. II.D of Ref. 1, has no meaning.

Extension to Curved Fins

In Sec. II.E of Ref. 1, the author extends Eastman's[2] correlation to configurations that feature canted wraparound fins. This is done by reducing C_{lp} by $(l/h)^m$, where l is the length of the arc of the curved fin, h is the exposed semispan, and $m = 0.1(1 + M + \frac{2}{3}M^2)$. This correction was applied to the data obtained by Regan and Schermerhorn[5] for the Army–Navy 10-caliber spinner equipped with four wraparound fins. In this case $l/h = \pi/(2\sqrt{2}) = 1.11$, and the correction factor is 1.08 at $M = 2.5$ and 1.14 at $M = 3.5$. The average original correlation parameter, $E = (C_{lp}/C_{l\delta})/(y_c/d)$, at Mach numbers 2.5–3.5 is −2.12, which is in very good agreement with the value −2.15 obtained by Eastman.[2] The average extended correlation parameter, based on Eq. (5) of Ref. 1, is −1.90. Thus, in this case the correction degrades the correlation. Note that Ref. 1 used test data for one threeform configuration, the Hydra rocket of Ref. 6, to extend Eastman's correlation to both curved fins and arbitrary number of fins. The fins of the Hydra are mounted in a recess in the afterbody, whereas those of the Army–Navy missile are mounted on a cylindrical afterbody. It is concluded that the extended correlation proposed in Ref. 1 is not a general one.

Evaluation of $C_{l\delta}$

Section II.G of Ref. 1 offers a fast evaluation method for the roll-producing stability derivative $C_{l\delta}$. The text that accompanies Eq. (6) of Ref. 1 states that the normal-force coefficient of the individual fin includes the fin–body and body–fin influence coefficients at angle of attack and considers this an advantage. The opinion of the author of this comment is that both influence coefficients should not be included in the analysis of this stability derivative. From a formal point of view, because the objective is to evaluate the derivative of the left-hand side of Eq. (7) of Ref. 1 with respect to fin deflection angle, one has to evaluate the right-hand side for fin deflection, rather than for angle of attack. From the phenomenological point of view, according to Pitts et al.,[7] the fin–body effect is due to body upwash, which increases the local angles of attack. The body–fin influence coefficient is due to the reflection of the load acting on the fins on the body. The first effect is symmetrical; hence, it does not produce a net rolling moment. The loads acting on the body do not contribute to rolling moments because they are in the directions of the normals to the body surface.

According to Eq. (7) of Ref. 1, the rolling-moment coefficient is proportional to the number of fins. This is valid only when there are no fin-on-fin influences. This condition is met only at supersonic Mach numbers larger than a critical value given by

$$M_{\mathrm{cr}} = \sqrt{\left[1 + (nc_R/\pi d)^2\right]} \tag{3}$$

To substantiate these arguments, the basic finner that was tested by Nicolaides and Bolz[8] and by Jenke[9] was analyzed. The component buildup code of Ref. 10 was used to evaluate the configuration and the body-alone normal-force curve slopes. The rest of the analysis follows Eqs. (6) and (7) of Ref. 1. The results are presented in Fig. 1, in comparison with test data. It is apparent that the method of Ref. 1 greatly overestimates the data.

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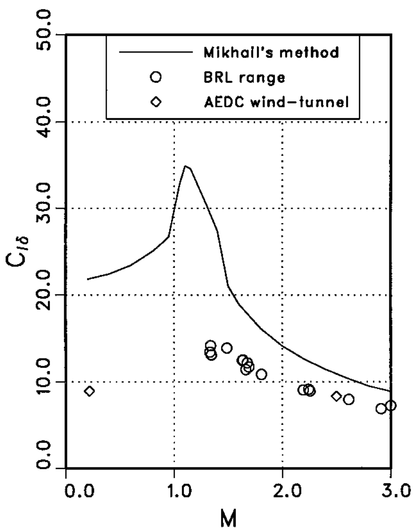

Fig. 1 Roll due to fin cant stability derivative of the basic finner.

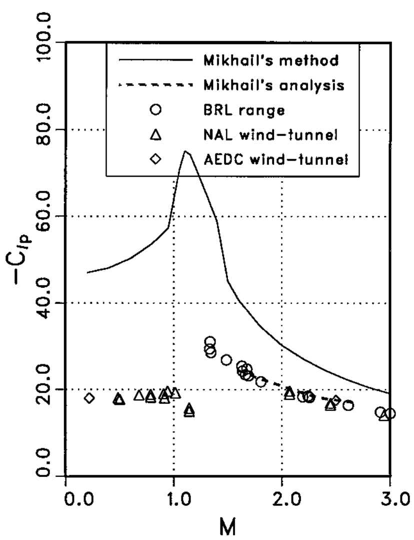

Fig. 2 Roll damping stability derivative of the basic finner.

Applications

In Sec. III.D of Ref. 1, the author analyzes the roll characteristics of the Terrier–Recruit that was studied by Rollstin.[11] The ratio of the roll stability derivatives for this rocket, according to Table 4 of Ref. 1, is 3.015. The shape parameter is $y_c/d = 1.037$, yielding Eastman's correlation parameter, $E = (C_{lp}/C_{l\delta})/(y_c/d) = -2.91$. Thus, the correlation presented in Fig. 7 (Ref. 1) is not consistent with the data given in Table 4 (Ref. 1).

A study of Rollstin's report[11] yielded that the roll stability derivatives given by him were calculated using a strip method (see Appendix C of Ref. 10). Hence, they should not be used as an experimental benchmark. According to Rollstin's analysis,[11] both stability derivatives are proportional to the fin's normal-force curve slope. The expression for C_{lp} in the analysis includes the wing in the presence of a body influence coefficient, whereas $C_{l\delta}$ does not include it. The value of this influence coefficient for the subject configuration is 1.25. If C_{lp} is reduced by this factor, as just argued, the analytically obtained correlation parameter would be $E = -2.33$, namely, much closer to Eastman's empirical value of -2.15 (Ref. 2).

Figure 11 of Ref. 1 presents a multiple comparison for the roll damping stability derivative of the basic finner. It shows very good agreement between analysis based on the fast prediction method and test data. The analysis was repeated by the author of this comment, based on the fast prediction method of Ref. 1 and using the results of the present calculations of $C_{l\delta}$ (Fig. 1) and Eq. (5) of Ref. 1. The present results are shown in Fig. 2, in comparison with test data of Refs. 8 and 9 and with the predictions of Ref. 1. The results of the present analysis are much larger, in absolute value, than those presented by Mikhail[1] and the test data. It is concluded that the calculated results presented in Fig. 11 of Ref. 1 are incorrect.

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Reply by the Author to A. Sigal

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I WOULD like to thank the commentator, A. Sigal, for reading and paying attention to the paper of reference.[1] The commentator, however, missed the main point of the whole paper in three different ways. First, the paper is not about the Adams and Dugan[2] analysis but rather about an empirical correlation devised by Eastman[3] through line fit of experimental data. Second, being declared empirical by its author, Eastman, makes it less subject to analysis of how it was formed. However, its extreme simplicity and generality over all Mach regimes make it highly appealing for providing estimates for C_{lp} if $C_{l\delta}$ is known, or vice versa. Figure 1, shown here from Ref. 1, provides seven different data sets for remarkably different missile configurations; fin numbers; fin types (planner and wraparound); and wide-Mach-number regime covering subsonic, transonic, and supersonic speeds. For a practicing engineer, the correlation is attractively good. In the eyes of a critic, some data points (the x symbols and one triangle symbol in Fig. 1) are not good enough for this one line's worth of calculation. The commentator apparently falls in this latter category. Third, a correlation based on actual measured data for actual real missiles of different shapes and

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