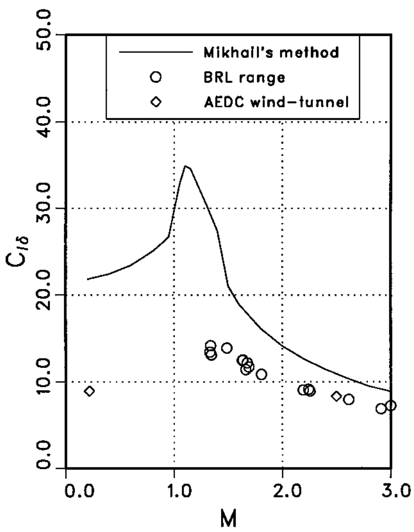

Fig. 1 Roll due to fin cant stability derivative of the basic finner.

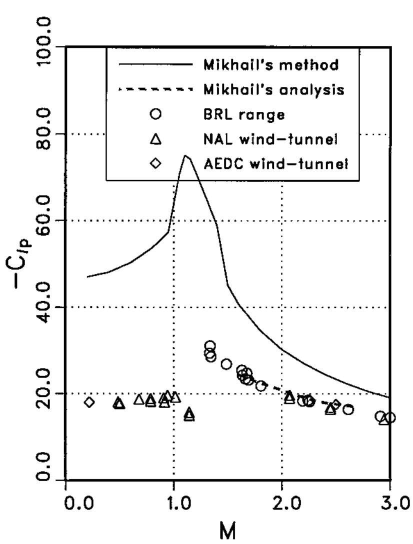

Fig. 2 Roll damping stability derivative of the basic finner.

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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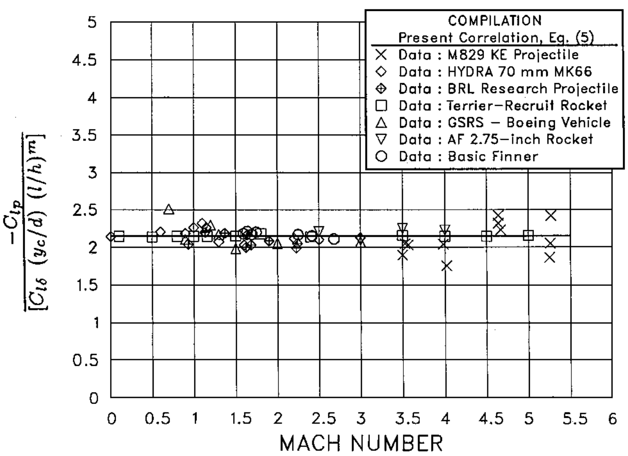

Fig. 1 Compilation of roll data of all seven missile configurations (from Ref. 1).

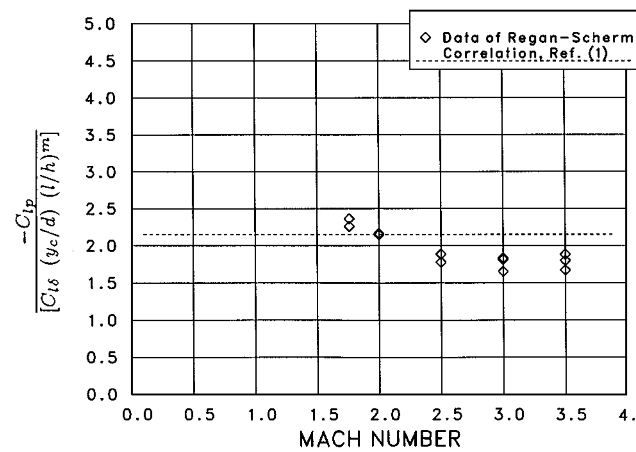

Fig. 2 Correlation result for the case of curved fins of Ref. 4.

sizes and with real finite fin areas and spans must not be exercised in theoretical cases, as in "what if" the fin span goes to zero (i.e., body alone, no fins) or what if the (fin-span)/(body-diameter) ratio goes to infinity (i.e., fin alone, no body). Only theoretically derived formulas may be subjected to these what-if limits to check and extend the range of applicability. The commentator thus in fact misuses the application of said empirical correlation that cannot "identify" an infinite fin span or a zero fin span.

Reference to Adams and Dugan Analysis

Equation (3) in Ref. 1, which was never applied in any of the work of the said paper, shows (d/bo), and it should have shown (bo/d) instead. Nevertheless, the equation was not used in the work to generate any numbers. It was provided, as should be, to relate the prior published art to the work at hand. This must have been an opportune time for the commentator to find a typographical misprint in the unused formula and then analyze the misprinted form regarding what if the wrong fraction (d/bo) approaches zero (i.e., fins alone, no body) and what if (d/bo) approaches 1.0 (i.e., body alone, no fins). Nevertheless, the noting of any typos is always appreciated. In Ref. 1, Eq. (4) was strongly distinguished from Eq. (3) due to their distinct and different origins. The commonality is only in their simplicity and similarity in form. Equation (3) was derived based on slender "wing" theory (incorrectly printed in the paper as slender "body" theory), whereas Eq. (4) is empirical. In Sec. II.D of the paper, the difference was stressed. Therefore, the commentator's remark, "the comparison of Eqs. (3) and (4) has no meaning," is ill-thought.

Extension to Curved Fins

Reference 4, which the commentator referred to for the curved-fins case, was obtained to calculate the case and check on the numbers given in the comment. First, Ref. 4 deals with the measurement of Magnus moment and Magnus force coefficients generated in a wind tunnel at high spin rate (as high as 663 Hz for a 1-in. rod) and does not deal with measurement of either C_{l_p} or C_{l_δ}. The steady-state spin is measured, and then only the ratio of C_{l_p}/C_{l_δ} is deduced. These high spin values were used in the wind-tunnel test, not to duplicate an actual flight spin that the missile (Army–Navy Spinner Projectile with added fins) will fly at but rather to make the usually small Magnus forces large enough to be measurable. All of the missiles for which Eastman used the data for constructing his correlation are low-spin missiles, usually spun within 35 Hz. Even Mikhail's later projectile addition (M829 model of Fig. 1) spins at about 90 Hz. Therefore, at high spin rates, nonlinearities for both C_{l_p} and C_{l_δ} will occur, as clearly cited experimentally by Dupuis[5] in 1987. Second, because missiles or finned projectiles do not fly at these high spin rates, no measured C_{l_p} and C_{l_δ} values are available in the literature for high spin to be compared to the low-spin values for missiles that we deal with in the present correlation. Therefore, applying either the Eastman or Mikhail correlation to these high spin cases is questionable if not a misapplication, to say the least, with both C_{l_p} and C_{l_δ} exhibiting different nonlinear behavior. These two facts should not have escaped the commentator's attention when using and citing said reference.

Additional aspects in the comment are addressed next. First, the value of the diameter for the missile case was not given in the cited Ref. 4. Assuming a value based on other reports of tests for the same Army–Navy Spinner cannot be made because test models can be different. Second, in the development of either Eastman or Mikhail correlation, both C_{l_p} and C_{l_δ} are independently measured values and are given separately, with each having its own error bounds. Reference 4 gives no directly measured C_{l_p} or C_{l_δ} values but rather a "deduced" value of the ratio (C_{l_p}/C_{l_δ}) based on the steady-state spin value. Even the error bars for that deduced ratio are not given in Ref. 4, and the commentator never bothered to investigate. Using a deduced C_{l_p}/C_{l_δ} value may involve different (smaller?) error than having both C_{l_p} and C_{l_δ} measured independently, as they are usually tested at different wind tunnels and with different instrumentation, with each having its own error band. Therefore, comparing results using the ratio (C_{l_p}/C_{l_δ}) values of Ref. 4 to the earlier Mikhail results may be expected to be different and cannot be the basis for indicating an improvement or worsening of the curved-fin prediction using the correction $(l/h)^m$. Third, the "selective" choosing of certain Mach numbers ($M = 2.5$ and 3.5 only) dismays us, whereas the data in Ref. 4 include Mach 1.76, 2.0, and 3.0 as well. It must have suited the commentator numbers to use these two cases only, which correspond to high spin (245–663 Hz, for 1-in. rod diameter) rather than the lower Mach numbers that correspond to lower spin of 123–343 Hz (for a 1-in. rod diameter). When we calculated all cases of Ref. 4 for all Mach numbers, the result of which is given in Fig. 2, the Mikhail correlation constant reasonably averages the results obtained for the data of Ref. 4 with the curvature correction over all of the Mach numbers. If one "selects" only the higher Mach numbers ($M = 2.5$ and higher), as the commentator chose to do, one might think that the Mikhail correction factor $(l/h)^m$ in the correlation was not correct. This selective choosing by the commentator is highly inappropriate, if not unethical. The commentator also cannot claim he was unaware of these data because they are in the same report he used, referenced, and based on which he wrote his comment. Further, the result of Fig. 2 also suggests that the high-spin cases (the high-Mach-number cases) may have nonlinearities not observed for lower-spin cases. On the basis of these factors, the commentator argument that the fin curvature correction factor worsens the correlation for this wraparound fin case is without merit.

Evaluation of C_{l_δ}

Section II.G of Ref. 1 offers three possible references for the reader to use to compute C_{l_δ}. None of these methods, as indicated in the paper, is direct, accurate, or valid for all speed regimes. Therefore, the offering in the paper was to provide a direct, fast, zero-order method to estimate C_{l_δ}. In Ref. 1, the intent is to use directly measured data for C_{l_δ} to estimate C_{l_p}. Therefore, a simple engineering method was offered only in case the reader had no other recourse. The emphasis in the method was on simplicity. Further, it was mainly targeted for four-fin configurations, as given in Fig. 3 of Ref. 1, where the fin-to-fin interference is reasonably well established. The NSWC-AP code (Ref. 5 of Mikhail[1]) was used. This code is known to have modified and improved models for fin-body and body-fin interference factors beyond the original formulation of Pitts et al.[6] of 1957. For simplicity and practicality, both factors were left in because many codes do not provide detailed breakdown of the normal force components. (The smaller body-fin contribution factor should be removed because it actually works normal to the body itself rather than normal to the fin surface, as the commentator notes.) Let us remember that this is a last-resort method that the user was offered to use if he had no other C_{l_δ} input. The commentator then uses a company proprietary code[7] that is not available to this author or to the public for application. This code provides some large results for C_{l_δ} and C_{lp} in Figs. 1 and 2 of the Comment. First, the accuracy and validity of such a code are not known or documented by publications in the open literature. Second, its models for the fin-body and body-fin interference may be outdated or identical to those originals of Pitts et al.[6] and thus lack the published improvements of the mentioned NSWC-AP code used in the paper. In fact, the code[7] accuracy for predicting even the basic aerodynamic coefficients (CN_α and CM_α) for missiles is not even known in the open literature, as compared to the NSWC-AP code.

Applications

The original Eastman correlation is for cruciform (four-fin) configurations only, and it assumes that all of the fins are canted and contribute equally to the roll. Adjustment to the roll coefficients has to be made when not all of the fins are canted and also for n-number of fins for Mikhail's correlation. It was thought, based on the writeup of the Rollstin[8] report (p. 65, first line), defining the aerodynamic coefficients, that the C_{l_δ} values given in the report were for two canted fins only (in the pitch plane) out of the four-fin set. The approach used in Ref. 1 for the Terrier-Recruit configuration was to adjust the C_{l_δ} to full four canted fins and then apply the correlation. Because doubling the number of canted fins from two to four does not double the C_{l_δ} (see Adams and Dugan's[2] estimated increase factor of 1.52 for C_{l_δ} [p. 612]). The adjustment factor of $(N/Nc)^{0.44} = 1.357$ was used to multiply the C_{l_δ} to adjust the value required by the correlation, where N is the number of all fins (=4) and Nc is the number of the canted fins (=2). Note that the C_{lp} value is function of the number of fins rather than the cant angle value; thus, it needs no adjustment. Note also that, if all fins are canted in a set of fins of n-fin number, this factor reduces to the value of 1.0. This adjustment was applied to the Terrier-Recruit case discussed in Ref. 1, where the commentator notes that the C_{lp}/C_{l_δ} ratio was 3.015 without this adjustment factor, which unfortunately slipped from being printed in the paper, for which matter this author shoulders the responsibility. With the adjustment factor, the correlation in Fig. 7 of Ref. 1 is consistent with Table 4 in the same paper, since the table provides the data as given from the Rollstin report. However, after reviewing the commentator remark, the Rollstin report was revisited and careful examination of the coefficient definitions indicates that the two-fin case applies only to the CN_α only, where, at the + position, only two fins contribute to the normal force. For this oversight, the commentator is thanked and, thus, his remark on this point is correct. Last, the commentator goes back to the Basic Finner missile and uses his computed large C_{l_δ} values and then plugs them into Eq. (5) to estimate the, not surprisingly, large C_{lp} value in Fig. 2 in the Comment. Figure 11 of Ref. 1 shows the results for C_{lp} for the Basic Finner, where best results are attained only when the experimental C_{l_δ} was used. Less-accurate values are obtained when the simplified method of estimating C_{l_δ} is used, as also indicated in Fig. 11 of Ref. 1.

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