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# AERODYNAMIC COEFFICIENTS FOR EXTENDING AND BENDING PROJECTILES

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We address the general problem of calculating the trajectory of a cone-cylinder-flare projectile which extends in flight. The projectile is both pitching and bending. The extension affects the pitching, bending and subsequent flight in significant ways. To facilitate the quick and transparent calculations of the aerodynamic coefficients as they change during extension, we have developed a simple model which agrees well with the results of detailed numerical calculations.

## INTRODUCTION AND SUMMARY

The exterior ballistics of projectiles which are launched in a compact form and then extend in flight and which have the potential for significantly increased terminal performance have been addressed in two recent analytical papers by Subramanian [1] and Reinecke [2]. Their analyses show that extending projectiles have complicated flight characteristics which can potentially either enhance or degrade their performance. In particular, extension during flight can significantly alter maximum angles of attack and bending as well pitch and bending frequencies, which will, in turn, affect potential projectile resonances. Thus, the preliminary design of extending projectiles must be supported by multiple degree of freedom numerical flight calculations to address and resolve these phenomena. These calculations could be carried out using the sophisticated method described by Sahu [3] in which the unsteady Navier-Stokes equations are numerically solved at each time step in the dynamics calculation. This approach seems, however, a bit time consuming for use in extensive preliminary design calculations. To eliminate the necessity of solving the unsteady Navier-Stokes equations at each time step we develop in this paper quasi-steady aerodynamic characteristics for each component of an extending and bending rod-tube projectile. We divide the projectile into a conical nose, an arbitrary number of arbitrarily long circular cylindrical segments (to allow for bending), and a tail fin section. Then using a heuristic regression on the numerical results of Schmidt [4] and the Ames Research Staff [5], we calculate the lift coefficient and center of pressure for each component. The results are shown in Table I and their fidelity of the results to Schmidt's data in Figure 1.

**Table 1: Lift Derivative and Drag Coefficients of Extender Components**

| Component | Length | Reference Area | $C_{L\alpha}$ | Center of Pressure Location | $C_D$ |
|---|---|---|---|---|---|
| Nose | 2.25 Dc | πDc^2)/4 | 1.8 | 1.5 Dc from forward end | 0.1 |
| Body segments | L | $D_C$*L or De*L | 0.03 | 0.5 L from forward end | 0 |
| Tail | 4T | 5T^2 | 2.1 | 2.6 T from forward end | 0.07 |

$C_D$ = drag coefficient

Clα = lift coefficient derivative

Dc = compact body diameter

De = extended body diameter

L = body segment length

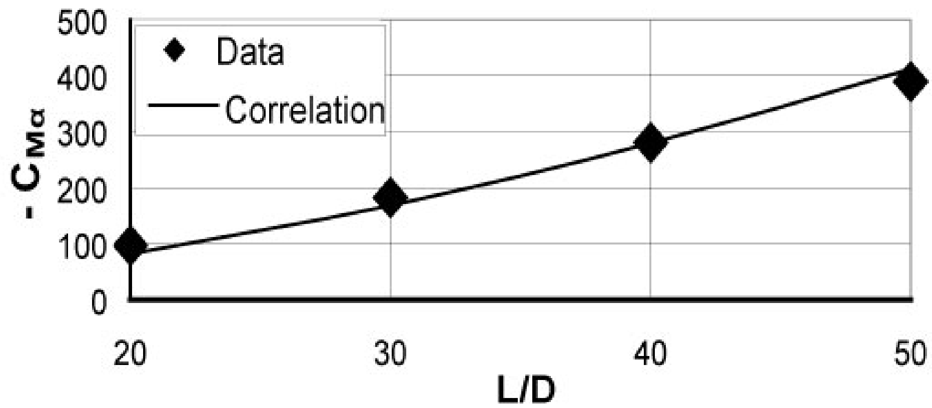


**Figure 1. Moment Coeffiecient Derivative**

## ANALYSIS OF MOMENTS

If the nose has an attached shock (as in the case of a slender cone), the loads on the nose are independent of body length. In addition, for high Reynolds numbers, we may make the approximation that the loads generated by the tail and per unit length by the body are independent of the body length.

We divide the pitching moment of a straight projectile about the projectile center of gravity into three parts corresponding to the three body components. This yields

$$M_T = M_N + M_B + M_F.$$

Assume that the centers of pressure and gravity on the cylindrical body nearly coincide. This yields

$$M_B \approx 0.$$

Now combine these two equations and assume that the centers of pressure of the nose and fins are equidistant from the projectile center of gravity. This gives

$$M_T = \tfrac{1}{2}\, S(L_N - L_F)$$

or

$$L_F = L_N - 2\, M_T/S \qquad (1)$$

We choose as reference areas for the nose and body the body cylindrical cross sectional area

$$A = \pi\, D^2/4.$$

The fins are truncated deltas with a tip chord of T, a root chord of 4T, and a span (or height) of 2T. We take the reference area to be the area of one fin:

$$A_F = 5\, T^2.$$

We note here that adequate static stability can usually be obtained by choosing T to be equal to the compact body [that is, nose base] diameter.

Using these reference areas and suitably nondimensionalizing Equation 1 yields

$$C_{LF\alpha} = [(\pi/20)\ (D/T)^2][C_{LN\alpha} - 2\ C_{MT\alpha}/(S/D)] \qquad (2)$$

Since $C_{LN\alpha}$ and $C_{MT\alpha}$ are known from the calculations shown respectively in References 5 and 4, we can calculate $C_{LF\alpha}$.

Treating the lift in a like manner yields

$$L_T = L_N + L_B + L_F.$$

Eliminating $L_F$ using Equation 1 gives

$$L_B = L_T - 2\ L_N + 2\ M_T/S,$$

which, again suitably nondimensionalised, yields

$$C_{LB\alpha} = (\pi/4)/(S/D)[C_{LT\alpha} - 2\ C_{LN\alpha} + 2\ C_{MT\alpha}/(S/D)]. \qquad (3)$$

## RESULTS

From Reference 5, we find that 12.5 degree half angle cone has a lift coefficient derivative of 1.8. We are interested in projectiles with fineness ratios S/D of from about 20 to about 60. Thus using the results in Reference 4, we take the best fit to the results for S/D = 30, 40, and 50.

This gives

$$C_{LN\alpha} = 1.8,$$

$$C_{LF\alpha} = 2.1,$$

and

$$C_{LB\alpha} = 0.03.$$

The results of these calculations suggest that these approximations will predict $C_{LT\alpha}$ and $C_{MT\alpha}$ over the fineness ratio range of interest, $20 \leq S/D \leq 60$, with an accuracy of about $\pm$ 20% for the shortest projectiles, S/D = 20, and with increasing accuracy for longer projectiles, $30 \leq S/D \leq 60$.

These results also show that for a projectile with a fineness ratio of 30, the respective contributions of the nose, body and fins to the total lift are 11, 7, and 81%. Their respective contributions to the moment are 12, 0 (by assumption), and 88%. The fins dominate the projectile pitch and heave motion.

Finally, we take the centers of pressure of the projectile components to be their centers of area. The results are summarized in Table 1.

## ANALYSIS OF DRAG

If we assume at the high Reynolds numbers of interest that the profile drag dominates, then the viscous drag on the body is nearly zero and we have (using F rather than D for drag)

$$F_T = F_N + F_F,$$

which nondimensionalized yields

$$C_{DT} = C_{DN} + (20/\pi)(T/D)^2\, C_{DF}. \qquad (4)$$

From Reference 5, we have $C_{DN} = 0.1$ and then fitting the data in Reference 4 gives $C_{DF} = 0.07$. Using $C_{DF} = 0.07$ matches the Reference 4 $C_{DT}$ results within ± 5 % for the fineness ration range $20 \leq L/D \leq 50$.

The results are also summarized in Table 1.

## ACKNOWLEDGMENT

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## REFERENCES

[1] Subramanian, Ravi, Resonance Considerations for Novel Kinetic Energy Projectiles, Proceedings of the 22nd International Symposium on Ballistics, DEStech Publications, Inc, 2005

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[4] Schmidt, E., High L/D Projectile Aerodynamic Consideration, Paper 96-0457, 34th AIAA Aerospace Sciences Meeting & Exhibit, Reno, NV, 1996
[5] Ames Research Staff, Equations Tables And Charts For Compressible Flow, National Advisory Committee For Aeronautics Report 1135, 1953.

## SYMBOLS

| | | |
|---|---|---|
| $A$ | = | cylindrical body cross sectional area = $\pi D^2/4$ |
| $A_R$ | = | reference area |
| | | = A for nose and total projectile |
| | | = SD for cylindrical body or segment |
| | | = $5\,T^2$ for fins |
| $C_L$ | = | $L/qA_R$ |
| $C_{L\alpha}$ | = | $dC_L/d\alpha$ |
| $C_D$ | = | $F/qA_R$ |
| $C_M$ | = | $M/qDA_R$ |
| $C_{M\alpha}$ | = | $dC_M/d\alpha$ |
| $D$ | = | cylindrical body diameter |
| $F$ | = | drag force |
| $L$ | = | lift |
| $M$ | = | pitching moment |
| $q$ | = | dynamic head |
| $S$ | = | body or cylindrical segment length |
| $T$ | = | fin tip chord length |
| $\alpha$ | = | angle of attack |

## SUBSCRIPTS

| | | |
|---|---|---|
| B | = | body |
| F | = | fins |
| N | = | nose |
| R | = | referenc |
| T | = | total |