

## COMPARATIVE AERODYNAMIC ANALYSIS OF A MISSILE WITH AN EIGHT-FIN TAIL

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The longitudinal aerodynamic characteristics of a tail-stabilized missile were estimated using the Missile Datcom code and a hybrid method. The tail consists of eight swept fins with a wedge section. The present analysis accounts for the effect of the wedge airfoil on the normal-force curve slope of the fins for all Mach numbers. The results are compared with test data at Mach numbers between 0.6 and 3.6 and with predictions obtained by Moore and Hymer using the 2005 version of their Aeropredicion code.

The Aeropredicion and Missile Datcom codes provide very good agreement between analysis and test data. The hybrid method, that uses the VORLAX code to calculate the contributions of the tail unit, gives good results at subsonic and high supersonic Mach numbers. It overestimates the normal-force curve slopes of the tail unit and of the configuration at moderate supersonic Mach numbers.

### NOMENCLATURE

$b_e$	exposed span
$c$	chord of tail fin
$C_{m\alpha}$	pitching-moment curve slope
$C_{N\alpha}$	normal-force curve slope
$D$	reference length, maximum body diameter
$D_B$	base diameter
$K_{BL}$	masking effect due to body boundary layer
$K_W$	amplification of normal-force curve slope due to wedge cross-section
$M$	Mach number
$Re$	Reynolds number
$S_o$	reference area, $(\pi/4)D^2$
$t$	thickness of tail fin
$X_{CP}$	center of pressure location relative to nose tip

## Notation of the Components

B	body alone
B-T	body-tail combination
TU	tail unit

## INTRODUCTION AND OBJECTIVES

Moore and Hymer [1] developed a semi-empirical method for the estimation of the effects of a blunt trailing-edge on the aerodynamics of lifting surfaces. Their method uses shock expansion analysis for the basic section and approximations for the effects of leading-edge rounding, aspect ratio and number of fins (six or eight). They incorporated the method in the 2005 version of their Aeroprediction code. (AP05 - [2]) As part of the validation of the method, the authors of [1] and [2] analyzed the aerodynamic characteristics of a projectile configuration that features an eight-fin tail, with a wedge section. Schematics of the projectile and the section of the fins are presented in the two parts of Figure 1. The base diameter ratio was obtained from Moore [3] and is  $D_B/D=0.75$ . The data available in [1] is a good benchmark for additional comparisons.

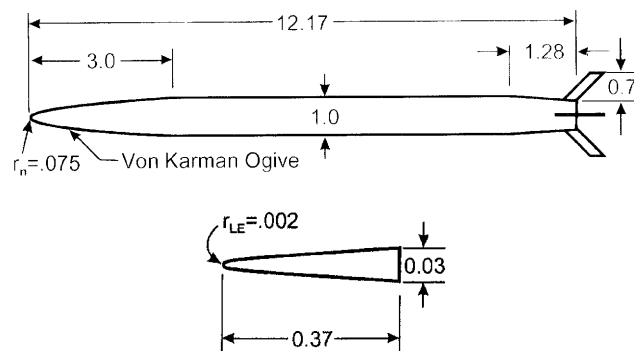


Figure 1: Schematic of the benchmark configuration, from Moore and Hymer [1], [2].

The objectives of the present study are to analyze the benchmark configuration using additional methodologies and code, to compare the results with test data and with predictions by the AP05 code, and to evaluate the capability of the various methods to estimate the longitudinal aerodynamics characteristics of the configuration.

## ANALYSIS

### Wedge Section Effect

The present analysis accounts for the effects of a thick wedge section using a method previously proposed by Sigal [4]. In the subsonic and transonic ranges, the results of slender body theory that were applied by Sacks [5] for thick narrow wings, were used. The governing geometrical parameter in his analysis is thickness to span ratio. In the supersonic range, the McLellan [6] analysis that is based on exact oblique shock wave relationships is used. The amplification of the normal-force curve slope, relative to that of a thin section, depends upon the wedge angle and the Mach number.

The geometrical parameters for the subject configuration are  $t/b_e=0.022$  and  $t/c=0.081$ . The amplification of the normal-force of the fins, relative to that of matching thin fins, is:

$$K_W = \begin{cases} 1.053, & M < 1.82 \\ 0.94 + 0.062 \cdot M, & M \geq 1.82 \end{cases} \quad (1)$$

### Missile Datcom

The 1997 version of the Missile Datcom [7] (M-Datcom) code was used to analyze the benchmark configuration. The computational model that was used is shown in Figure 2. The diameter of the boattail at fins mid-chord location is 0.786 body diameters.

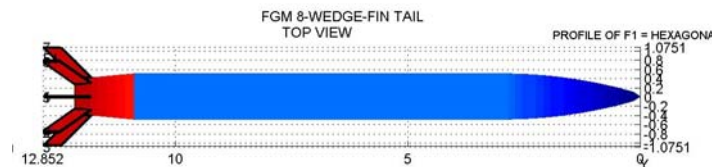


Figure 2: The computational model used for the Missile Datcom code.

The contributions of the tail unit (fins, body-tail mutual interactions, and fin-fin mutual interactions) were obtained by:

$$C_{N_\alpha}(\text{TU}) = C_{N_\alpha}(\text{B-T}) - C_{N_\alpha}(\text{B}) \quad (2a)$$

$$C_{m_\alpha}(\text{TU}) = C_{m_\alpha}(\text{B-T}) - C_{m_\alpha}(\text{B}) \quad (2b)$$

The stability derivatives, including wedge cross-section effect are:

$$C_{N\alpha}(B-T) = C_{N\alpha}(B) + K_W \cdot C_{N\alpha}(TU) \quad (3a)$$

$$C_{m\alpha}(B-T) = C_{m\alpha}(B) + K_W \cdot C_{m\alpha}(TU) \quad (3b)$$

$$X_{CP}/D = - C_{m\alpha}(B-T) / C_{N\alpha}(B-T) \quad (3c)$$

### The Hybrid Method

This method, by Sigal [8], combines two prediction tools. The contribution of the tail unit is evaluated by the VORLAX code, that is a generalized vortex lattice method and code by Miranda et al [9]. The method is based on the linear theory, and is therefore not applicable for transonic Mach numbers. It considers all body-fin and fin-fin interactions. The contribution of the body alone was obtained from databases and methods that were previously reviewed and elected in [10]. The contribution of the main body was based on the empirical database of Barth [11]. The contribution of the boattail was obtained using Amit's effective boattail angle method [12] for the subsonic and transonic regions and Data Sheets S.01.03.03 and S.08.03.03 by the British ESDU for the supersonic range. For details about these Data Sheets see [13].

The computational model used for the VORLAX code is depicted in Figure 3. The diameter of the model body is 0.786 calibers, as mentioned before. The inclusive span matches that of the configuration. The contributions of the tail unit to the normal-force and pitching-moment coefficients were obtained by subtracting the stability derivatives of the body alone from those of the combination, using eq. (2a) and (2b).

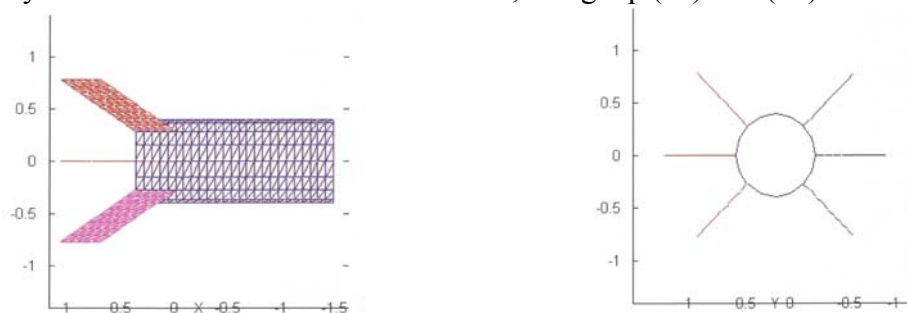


Figure 3: The computational model used for the VORLAX code.

The hybrid method also contains an approximate correction due to the masking effect of body boundary layer on the tail. The displacement thickness at the tail location was evaluated using ESDU Item 89008 [14]. It is assumed that this effect reduces the effective area of each fin by the area of a rectangle whose large side is the root chord, and whose narrow side is the displacement thickness. The body boundary layer

displacement thickness was evaluated for  $Re_D=0.5 \cdot 10^6$  that was obtained from [3]. For the present geometry and Re number

$$K_{BL} = \begin{cases} 0.968 - 0.0005 \cdot M - 0.0055 \cdot M^2, & M < 2.0, \\ 0.945 - 0.018 \cdot (M - 2.0), & M \geq 2.0. \end{cases} \quad (4)$$

The dependences of  $K_{BL}$  and of  $K_W$  on Mach number are shown in Figure 4.

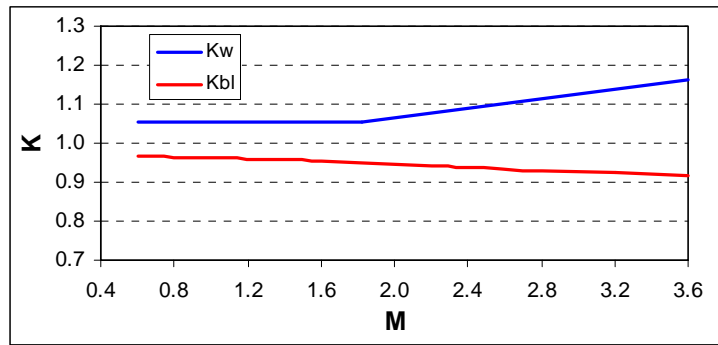


Figure 4: Wedge amplification and body boundary layer correction factors.

The characteristics of the configuration were calculated using

$$C_{N_\alpha}(B-T) = C_{N_\alpha}(B) + K_W \cdot K_{BL} \cdot C_{N_\alpha}(TU) \quad (5a)$$

$$C_{m_\alpha}(B-T) = C_{m_\alpha}(B) + K_W \cdot K_{BL} \cdot C_{m_\alpha}(TU) \quad (5b)$$

$$X_{CP}/D = - C_{m_\alpha}(B-T) / C_{N_\alpha}(B-T) \quad (5c)$$

## RESULTS AND COMPARISONS

### Body Alone

Since the two predictions of the body alone characteristics show large differences, a third method was used for additional comparison. The comparison includes estimates from the following sources:

1. Output of the M-Datcom code. This is based on several methods as described in [7].

2. The present combination of database and methods that was used with the hybrid method.
3. ESDU item 90034 [15]. This code provides two estimates for the stability derivatives: Basic, or inviscid, and a second estimate that considers two effects caused by viscosity: inclination of the friction force at angle of attack and effective flare caused by the growing boundary layer displacement thickness along the body. This code was run for  $Re_D=0.5 \cdot 10^6$  as noted before.

Comparisons of the normal-force curve slope and the center of pressure location of the body are presented in the two parts of Figure 5. It is apparent that the ESDU basic estimate and the present method are in good agreement for both parameters. The M-Datcom code features a dip in the normal-force curve slope around  $M=0.9$ . This is accompanied by a forward shift of the center of pressure. The ESDU estimates, with the viscous effects included, provide a larger normal-force curve slope and a more aft center of pressure location than all other methods. The good match between the basic ESDU output and the present prediction validates the latter.

### **Body-Tail Configuration**

The two parts of Figure 6 present comparisons between predictions and test data for the configuration. Both codes, namely the AP05 and the M-Datcom with wedge effect included provide good estimates of the normal-force curve slope and the center of pressure location. The deviations between predictions and test data are less than 7.0% in  $C_{N_\alpha}$  and 0.7 in  $X_{CP}/D$ , namely 5.8% of body length. The M-Datcom shows a spike in  $C_{N_\alpha}$  and a dip in  $X_{CP}/D$  at  $M=1.0$ . The AP05 code prediction of the center of pressure location in the transonic region is more forward than test data.

The hybrid method provides a good estimate at the subsonic range. It overestimates  $C_{N_\alpha}$  in the moderate supersonic range and provides very good predictions of both stability derivatives at  $M \geq 3.0$ .

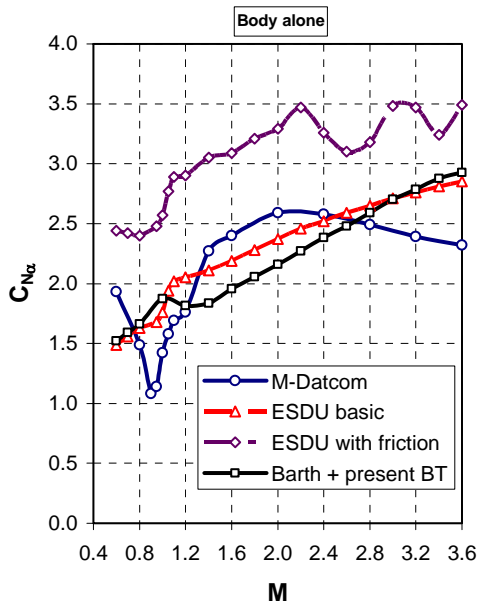


Figure 5a: Comparison of body alone normal-force curve slope.

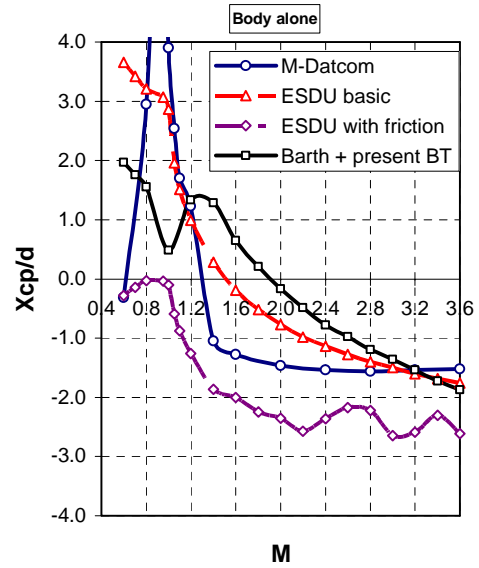


Figure 5b: Comparison of body alone Center of pressure location.

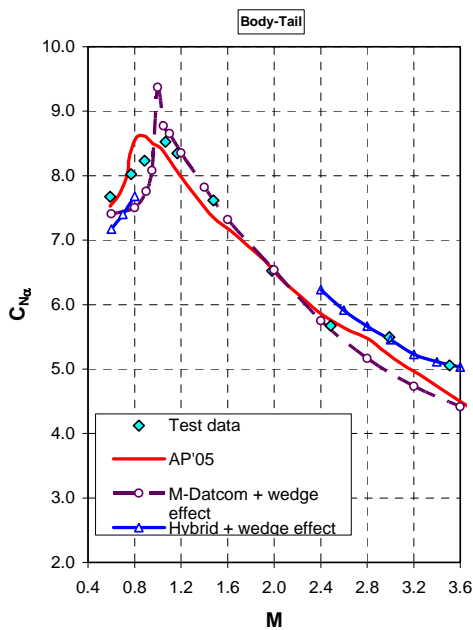


Figure 6a: Comparison of body-tail normal-force curve slope.

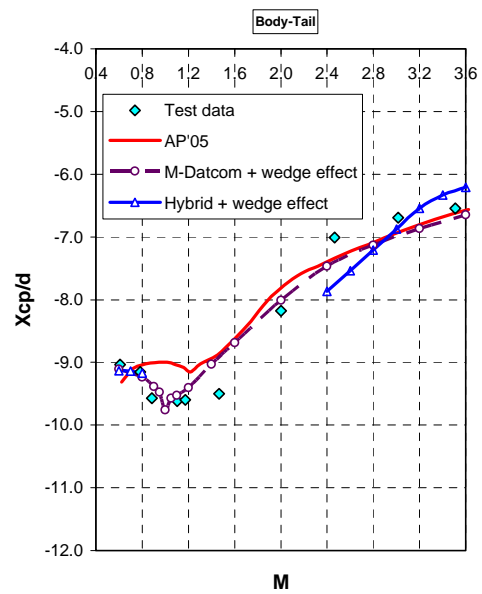


Figure 6b: Comparison of body-tail center of pressure location

## ACKNOWLEDGMENTS

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