LEESIDE SEPARATION OF HYPERSONIC WEAPONS

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Abstract

A cooperative effort between Hughes Missile Systems Company, NASA Langley Research Center and AF Wright Laboratory was performed to evaluate the adequacy of simplified aerodynamic predictive methods for estimating the leeside separation of weapons from a hypersonic air vehicle. Aerodynamic test results were obtained at the NASA Mach 6 wind tunnel facility (Reference 1), where typical store-shaped test models were traversed in the 'shielding' influence of an inclined flat plate. These data largely verify that aerodynamic predictive methods, based on Newtonian impact 'line-of-sight' approximation methods, yield representative force and moment characteristics acting on stores during their leeside carriage and upward eject launch. Based on these predicted data, simulated leeside launch trajectories of advanced submunition weapons show that they can be safely separated from a carriage vehicle at hypersonic speeds.

Nomenclature

Aerodynamic force and moment coefficient data are presented in the weapon's body-axis coordinate system and selected reference areas and lengths are noted on the appropriate figures.

S	reference area, in^2
C_A	axial-force coefficient, Drag force / qS
C_N	normal-force coefficient, Normal force / qS
C_m	pitching-moment coefficient, Pitching moment / qSl

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• Member

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Z	store separation distance, in.
l	reference length, in.
M_∞	freestream Mach number
Re_∞	freestream unit Reynolds number, per ft
α	angle of attack, degrees

Uncertainties in the force and moment data were based on balance component accuracies and these data were reduced to coefficient form as noted below:

Coefficient uncertainty for--	
Cone cylinder	Roof delta
ΔC_N	ΔC_N
±0.059	±0.0046
ΔC_A	ΔC_A
±0.012	±0.00092
ΔC_m	ΔC_m
±0.040	±0.00089

Table 1. Coefficient Uncertainties

Introduction

Hughes has extensive background and experience in air-launched hypersonic weapon air vehicle technology including flight performance estimates of scramjet powered missiles. Conceptual design studies of high speed air vehicles capable of flying many hundreds of miles in a matter of minutes were performed. Our hypersonic air vehicle designs were sized to accommodate their carriage constraints for launch from a fighter aircraft including their strap-on, yoke-like tandum booster arrangement. In this preliminary study (Reference 2), multiple submunitions were launched from a 'bus-like' hypersonic missile. These submunitions delivered kinetic energy penetrator warheads including blast fragmentations against buried and mobile ground targets.

Flight performance results were based on hypersonic aerodynamic wind tunnel test data taken on a unique blended wing-body carriage air vehicle design. This carriage vehicle is capable of delivering leeward as well as base released submunitions at high speeds.

Background

At hypersonic speeds, the advantages of leeside carriage and safe separation characteristics gained by advanced stores launched from a large aircraft have been evaluated (Reference 3). In this study, a simplified method for predicting the aerodynamic characteristics of launched weapons was taken based on Newtonian impact flow 'line-of sight' approximation. Due to the relatively benign environment of the separated leeside flowfield region (very low air density at subsonic speeds), essentially no carriage drag or heating loads occur and negligible aerodynamic forces and moments are estimated to act on the 'shielded' regions of the launched weapons (see Figure 2). This approach largely avoids intractable/ complex/ interactive flowfield effects typical of weapons released into the windward flowfield as well as extreme heat loading and adverse kinematic behavior of the stores (Reference 4).

At hypersonic speeds, base release from a carriage vehicle is a preferred mode for safe weapon launches due to its relatively benign separated base flow region (Reference 5). The leeside separated flow region of a hypersonic vehicle can be considered as a favorable extension of its benign base flow region. Consequently, the leeside flow region of a high speed carriage air vehicle can equally be used for aiding the safe release of weapons.

Favorable comparison of measured wind tunnel test data at hypersonic speeds to predicted aerodynamic characteristics of advanced weapon shapes launched to the leeside from a parent vehicle at hypersonic speeds was found and these results are presented herein.

Simplified Aerodynamic Prediction Methods

Using Newtonian impact theory and hypersonic 'line-of-sight' approximation methods as depicted in Figure 2, representative aerodynamic characteristics were estimated for a conformal and an axisymmetric missile design undergoing leeside separation from a slender parent vehicle (Reference 1). Based on this predictive approach, the following characteristics and variations of the aerodynamic forces and moments acting on the weapons are made as a function of their vertical displacement in the shielding 'line-of-sight' influence of the aircraft; namely,

1. Within the separated flow region, only null forces and moments are estimated to act on the weapons.
2. For partially emersed weapons in the outer airstream, the unshielded, 'wetted' surfaces of

the displacing weapon by the outer freestream airflow are considered effective in generating transitional aerodynamic forces and moments.

3. Upon full emersion of the weapons in the outer airstream, all external surfaces of the configuration contribute to the vehicle's aerodynamic loading and, at a given attitude, these values remain fixed with further displacement of the weapon from the aircraft.

These factors are largely evident in Orbiter vehicle wind tunnel test data taken at Mach 7.4 and moderate angles of attack (see Figures 3 and 4). In these cases, large leeside separated flowfield regions exist in a manner nominally consistent with Newtonian impact theory 'line-of-sight' approximations. The separated flow region is evidenced by the measured total pressure decay inner region and centerline inner region having reversed subsonic flow. Under these conditions, the vertical stabilizer of the Orbiter vehicle and its rudder control surfaces are 'shielded'. Consequently, these external surfaces become essentially void of aerodynamic input or effectiveness.

Mach 6 Wind Tunnel Test Results

A cooperative wind tunnel experiment to measure the aerodynamic characteristics of two specific weapon designs during leeside separation from a large hypersonic vehicle was performed by NASA Langley at their 20-inch Mach 6 tunnel and supported by Hughes under our advanced vehicle design IR&D program for missiles. In this test, an axisymmetric, cone-cylinder missile-like model (Figure 5) and a conformal, delta planform missile-like model (Figure 6) were tested in various leeside proximities to a flat plate model representative of a carriage aircraft at 15 degrees angle of attack (Figure 7). A water-cooled, six-component force and moment internal balance system was used to measure the aerodynamic force and moment characteristics of the leeside weapon models as they translated through positions of vertical displacement, **Z**, above the inclined flat plate and at pitch attitudes of the store models of zero and +15. degrees (Figure 8).

As a function of launch displacement and for freestream conditions of testing, earlier predictions of aerodynamic lift, drag and pitching moment coefficients for both weapon-like test models are shown herein (Figures 9 thru 12). To permit proper comparisons between measured and predicted aerodynamic data, the predicted coefficients were transformed from wind axis to body axis system and adjusted to reflect corresponding reference lengths and areas as noted.

Comparisons of measured to predicted body axis aerodynamic data for the axisymmetric-like missile model are shown in Figure 13 and similar comparisons for the conformal-like missile model are presented in Figure 14. Normal and axial force and pitching moment data are compared as a function of leeside vertical displacement, **Z,** in inches.

In general, the character of the aerodynamic test results largely agrees with the predicted variations as a function of the test model's leeside displacement and reasonable agreement is found in coefficient magnitudes for corresponding normal and axial forces and pitching moment data; namely,

1. An inner null region for aerodynamic forces and moments for the fully shielded weapon models is largely verified.
2. Aerodynamic characteristics of the partially shielded weapon models and their transitional variations with vertical displacement from the leeside surface are largely verified.
3. Magnitudes of aerodynamic characteristics of the unshielded weapon models (displaced beyond their shielded region) and their nominal invariance with further vertical displacement from the leeside surface are largely verified.
4. Based on the good agreement with the measured test data, our simplified aerodynamic predictive methods and approaches used for leeside separation of weapons from a 'shielding' carriage air vehicle at hypersonic speeds are found to yield representative results.

Estimates of Weapon Leeside Separation Characteristics

Estimates of separation trajectories for leeside weapon launch were simulated and predicted by 3-DOF analyses (see Figure 15). In this case, initial conditions provided by a typical launcher were applied to a submunition. These results show that leeside launches of typical weapons from a hypersonic air vehicle can be safely achieved.

Conclusions

Based on Newtonian impact 'Line-of-Sight' approximation techniques, a simplified aerodynamic prediction method was verified by wind tunnel tests to provide representative force and moment estimates for weapons released leeward from a carriage air vehicle at hypersonic speeds. Predicted separation trajectories indicate that leeside launch of weapons can be safely achieved from a hypersonic air vehicle.

References

1) Wilcox, Jr., F.J., 'Separation Characteristics of Generic Stores from Lee Side of an Inclined Flat Plate at Mach 6,' NASA Tech Memo 4652, May 1995.
2) Hughes Missile Systems Company 'Technical Proposal for Time Critical Target Technology,' submitted to Air Force Wright Laboratory, February 1996.
3) August, H., Hughes briefing on 'Weaponization of Hypersonic Aircraft,' September 1988. (SECRET)
4) Newman, G., Fulcher, K., Ray, R. and Pinney, M., 'On the Aerodynamics/ Dynamics of Store Separation from a Hypersonic Aircraft,' AIAA-92-2722, June 1992.
5) Butler, G., King, D., Abate, G. and Stephens, M., 'Ballistic Range Tests of Store Separation at Supersonic to Hypersonic Speeds,' AIAA-91-0199, January 1991.

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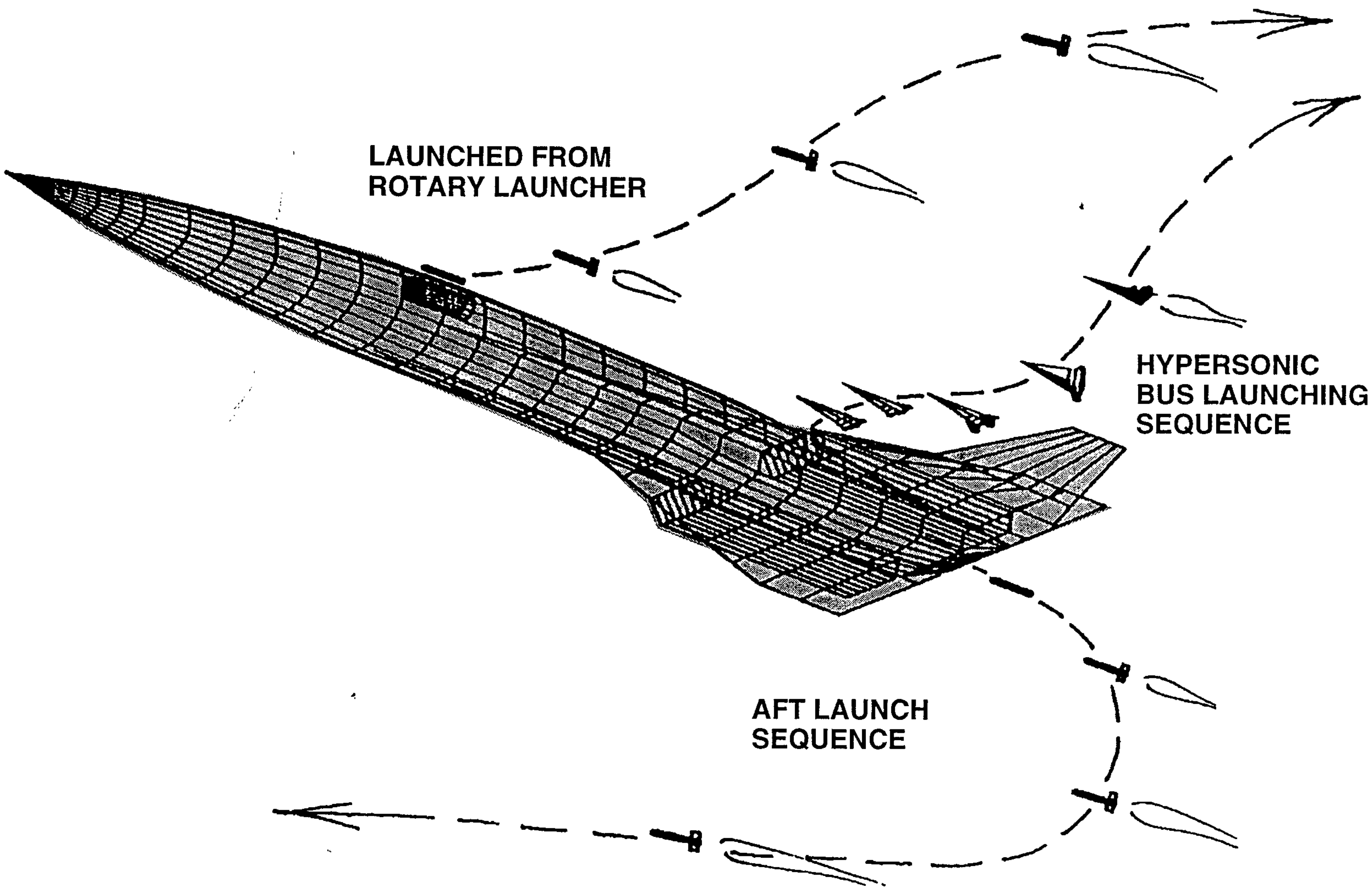

Figure 1. Weaponization of a Hypersonic Aircraft

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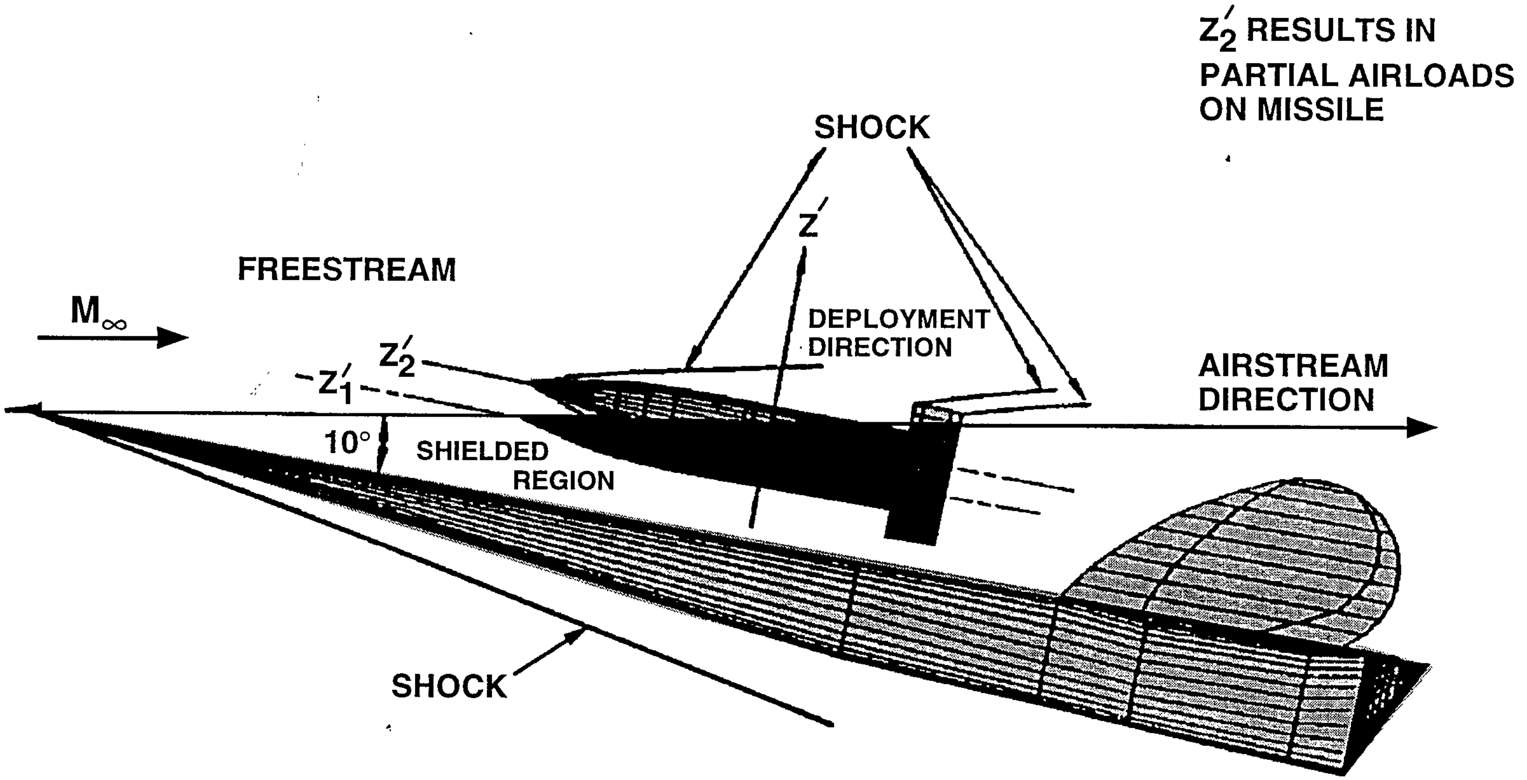

NOTE: DARKENED AREA INDICATES SHIELDED REGIONS IN A LOW DYNAMIC PRESSURE ENVIRONMENT.

Figure 2. Hypersonic Aerodynamic Analyses for Leeside Weapon Separation

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ORBITER WIND TUNNEL DATA

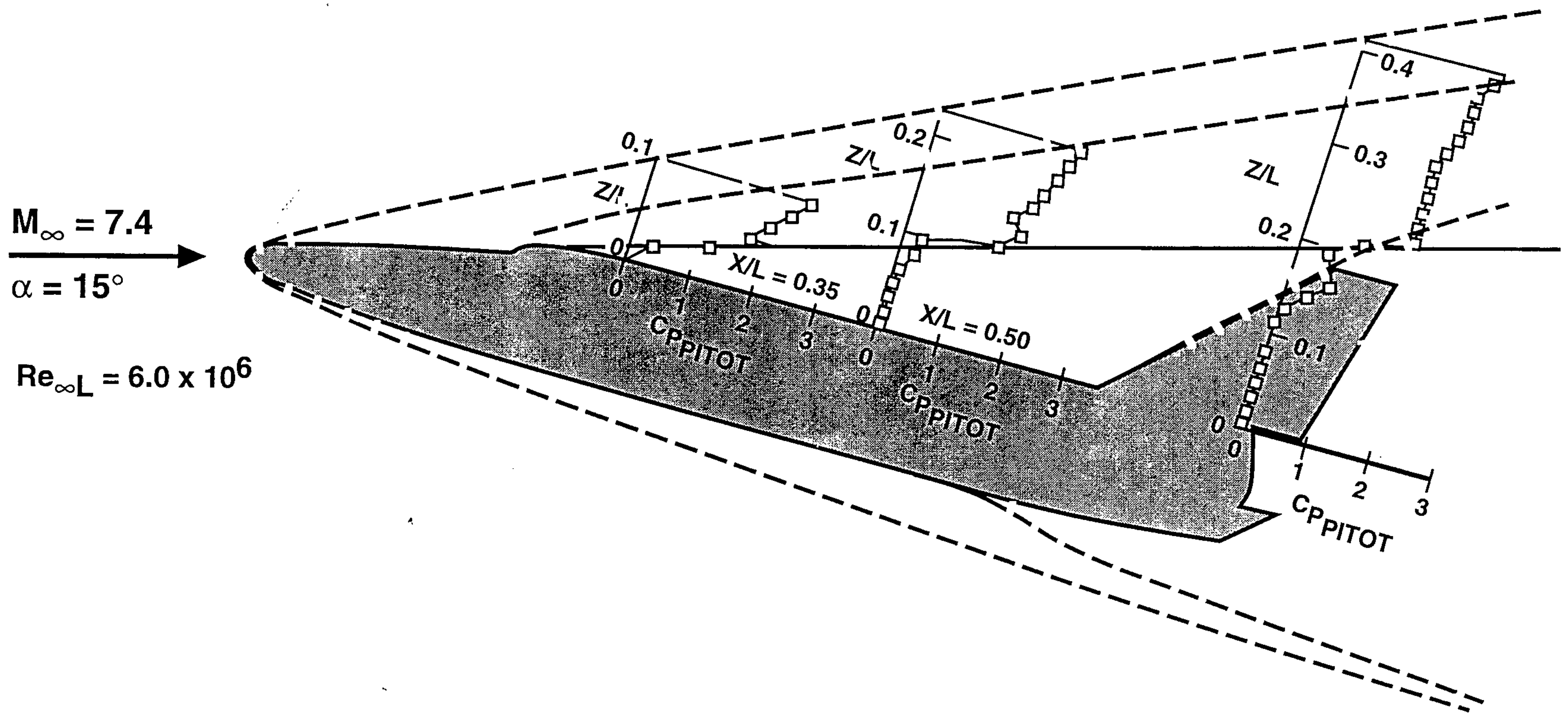

Figure 3. Leeside Centerline Pitot Pressure Distributions at Hypersonic Speeds

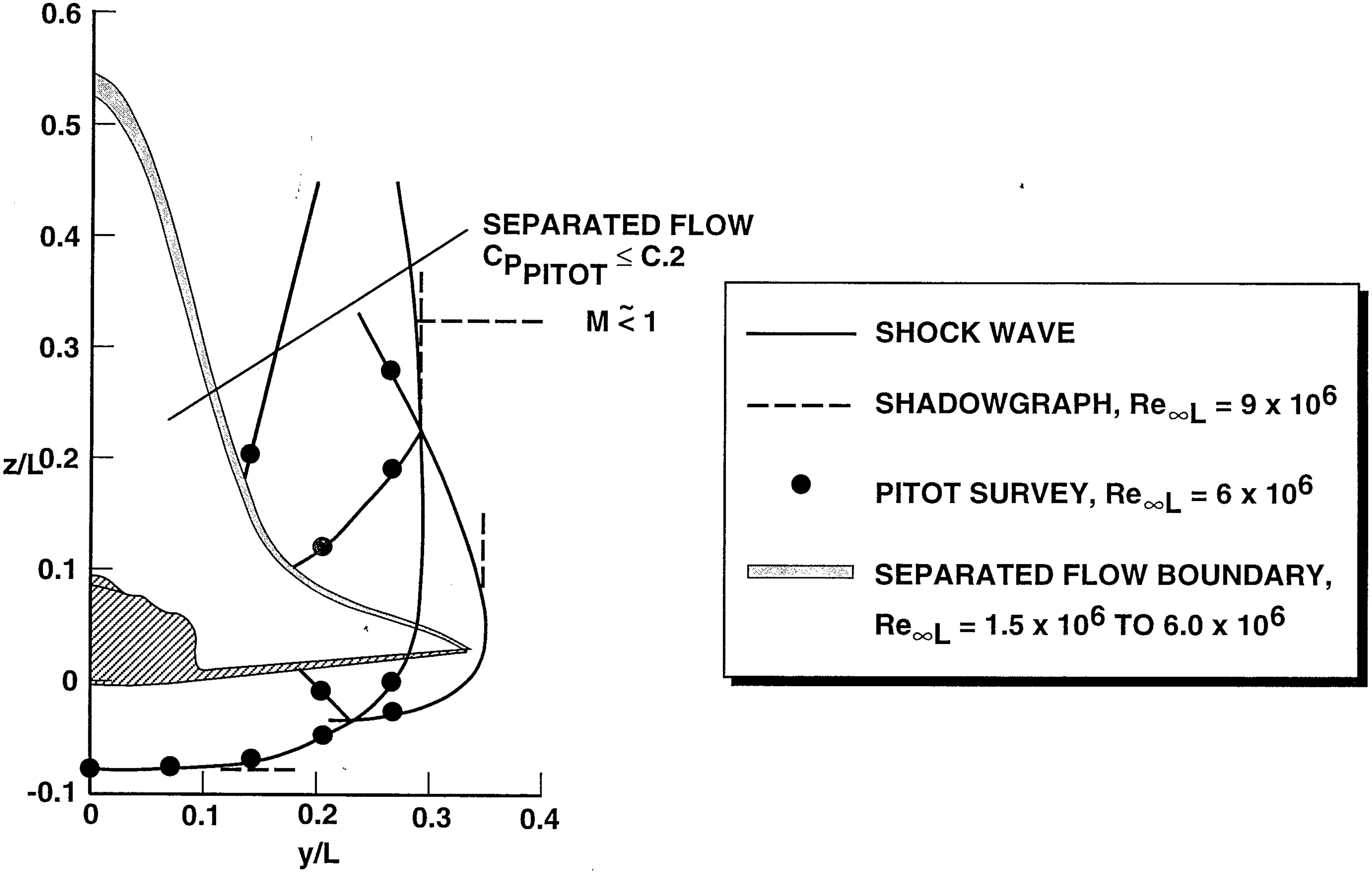

Figure 4. Delta-Wing Orbiter Flow-Field Structure
$M_\infty = 7.4$ $\alpha = 30°$ $x/L = 0.98$

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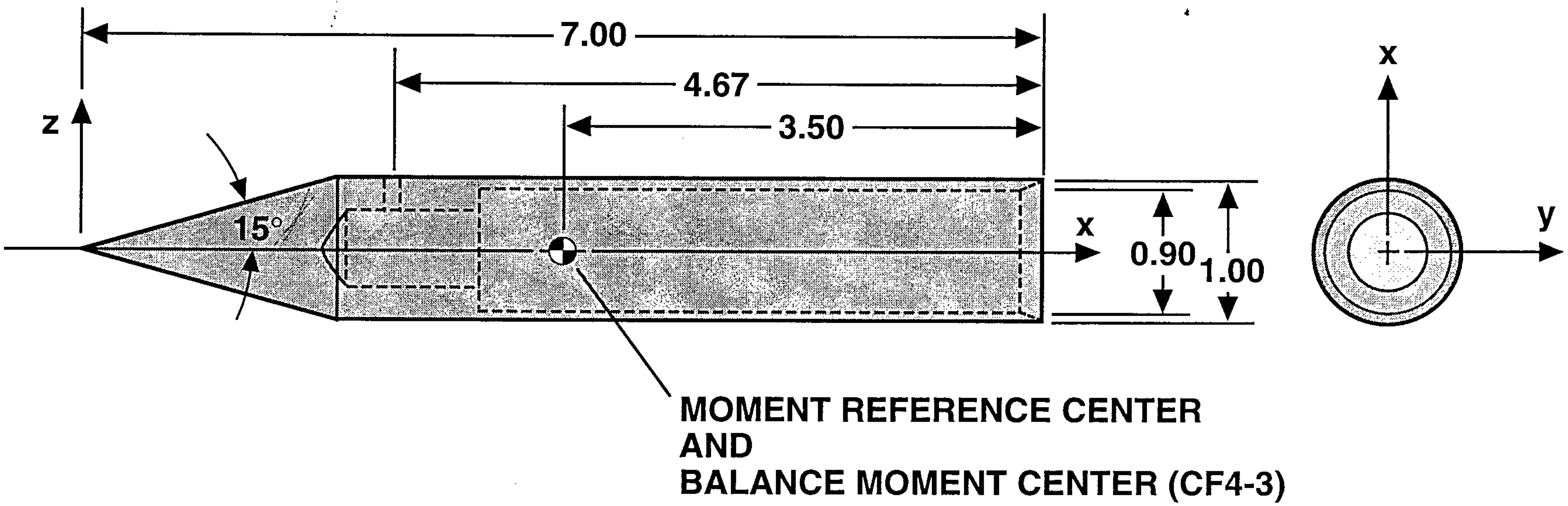

$S_{ref} = 0.79$ in.^{2}
$l_{ref} = 1.00$ in.
MODEL WEIGHT = 220g = 220g (1 lb/453.59g) = 0.49 lb

Figure 5. Axisymmetric Missile Model Cone-Cylinder Configuration

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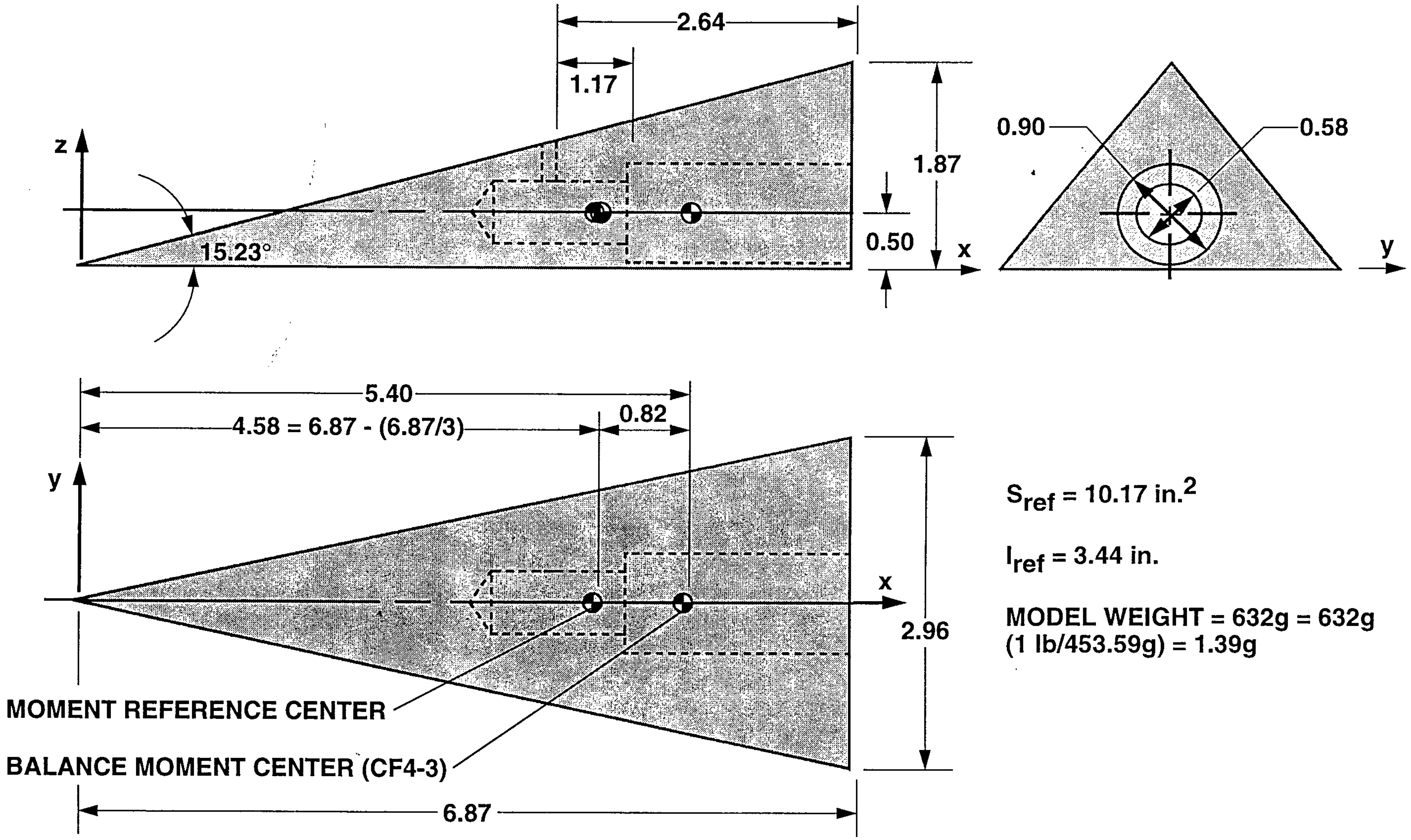

S_{ref} = 10.17 in.^{2}

l_{ref} = 3.44 in.

MODEL WEIGHT = 632g = 632g (1 lb/453.59g) = 1.39g

Figure 6. Conformal Missile Model - Roof Delta Configuration

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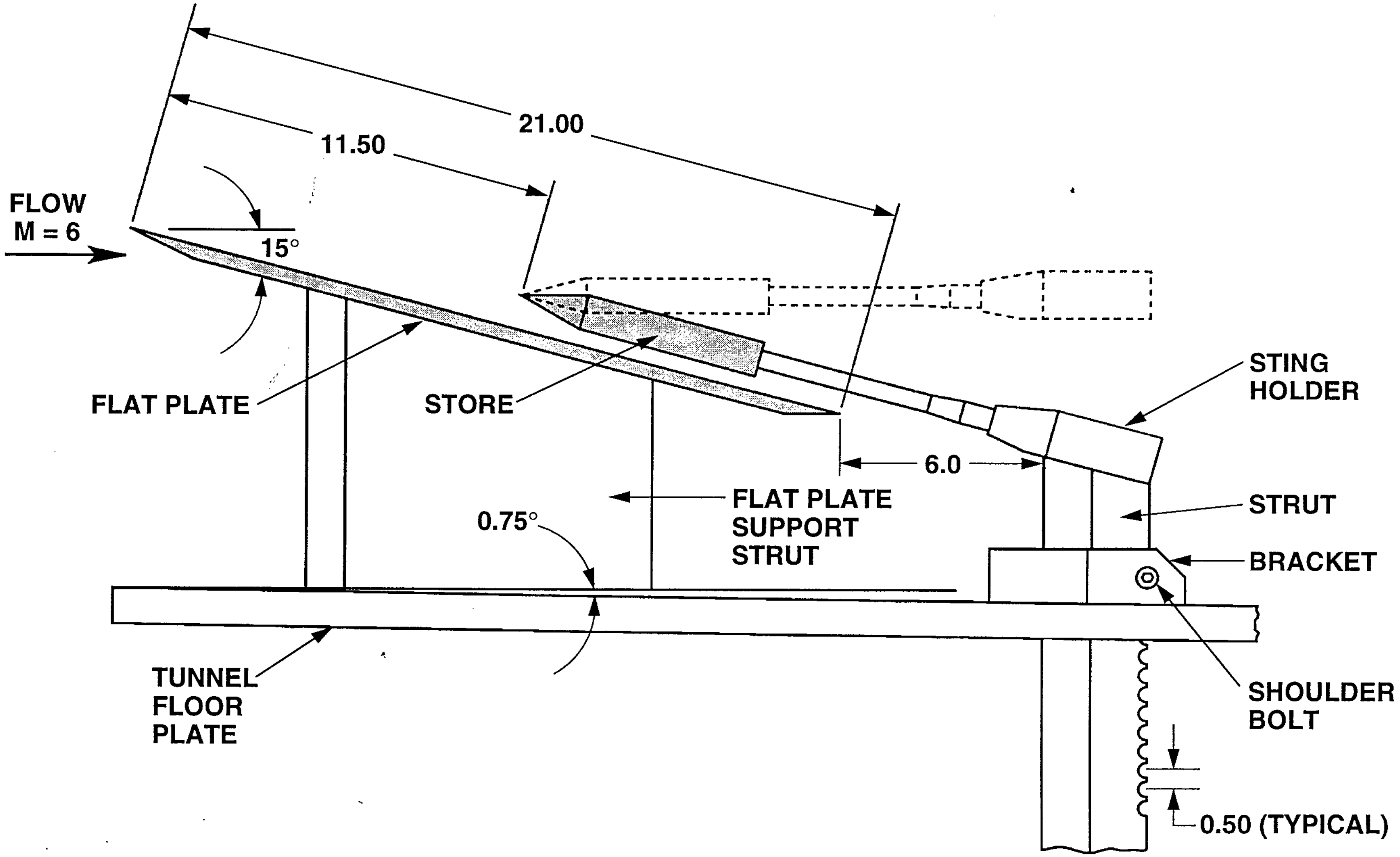

Figure 7. Sketch of Mach 6 Wind Tunnel Installation

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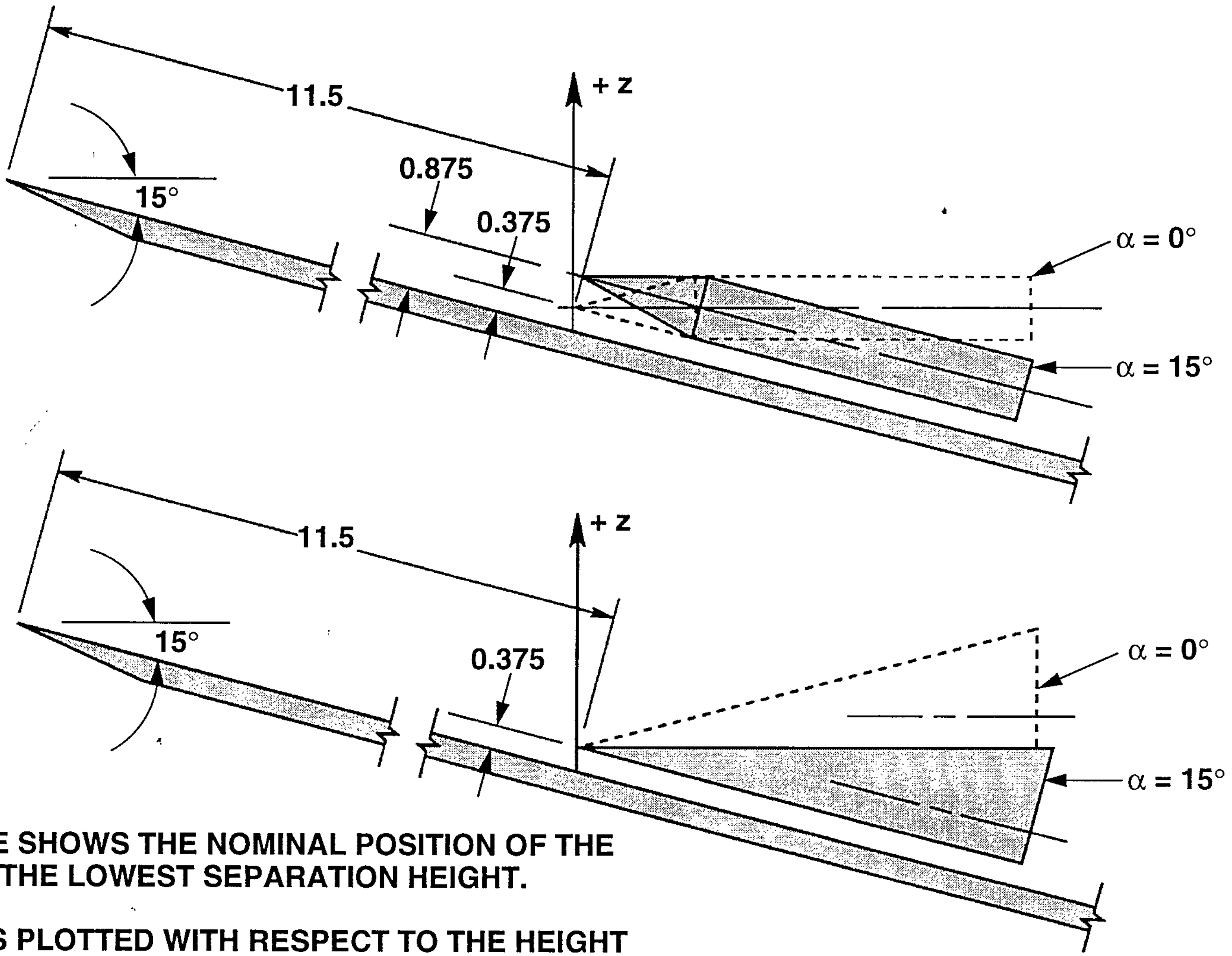

THIS FIGURE SHOWS THE NOMINAL POSITION OF THE STORES AT THE LOWEST SEPARATION HEIGHT.

THE DATA IS PLOTTED WITH RESPECT TO THE HEIGHT IN THE z DIRECTION WITH z = 0 LOCATED ON THE PLATE SURFACE.

ALL LINEAR DIMENSIONS ARE IN INCHES

Figure 8. Sketch of 'Leeside Separation' Vertical Displacement

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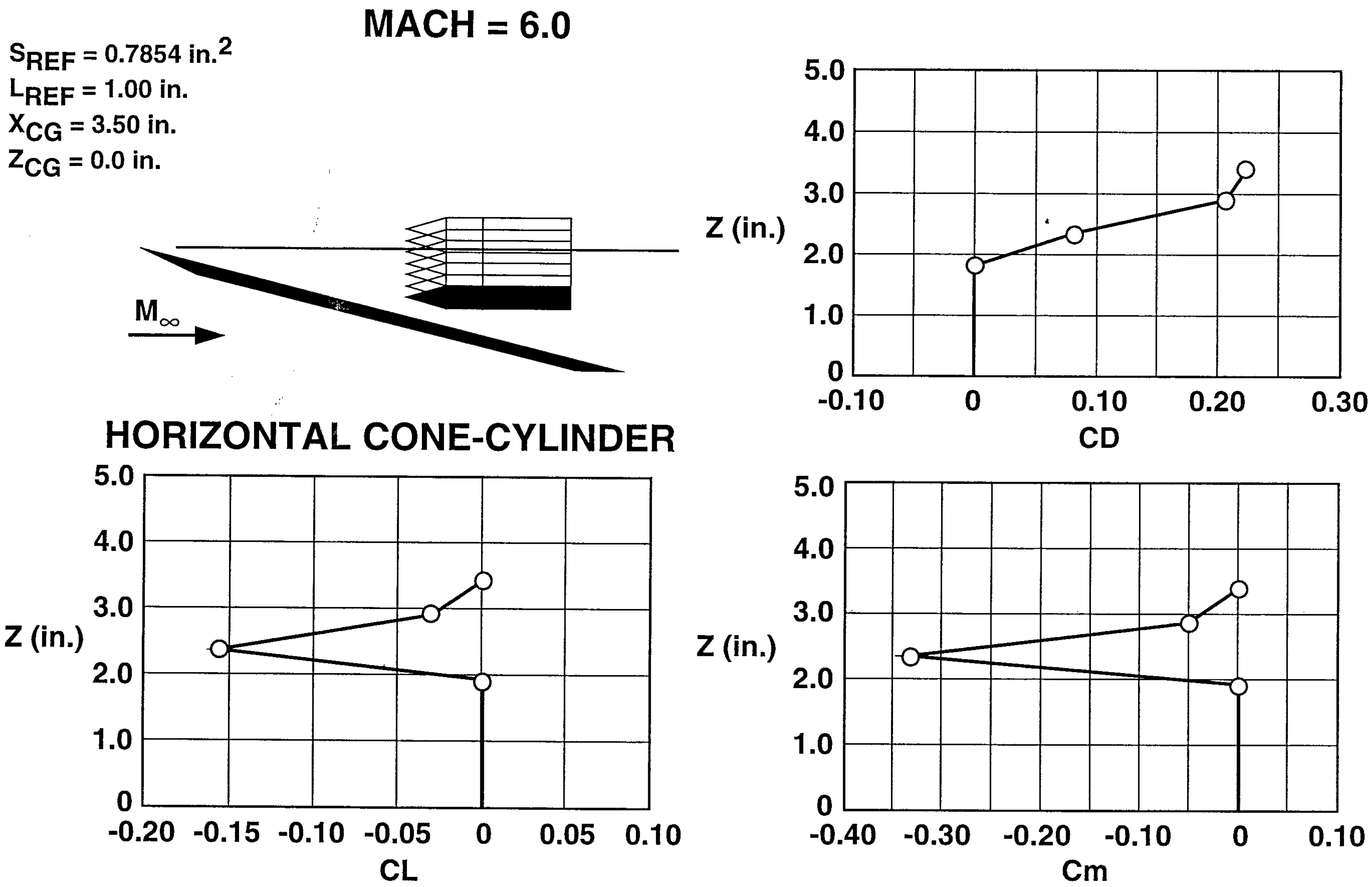

Figure 9. Predicted Aerodynamic Characteristics of Cone-Cylinder Store During Hypersonic Separation

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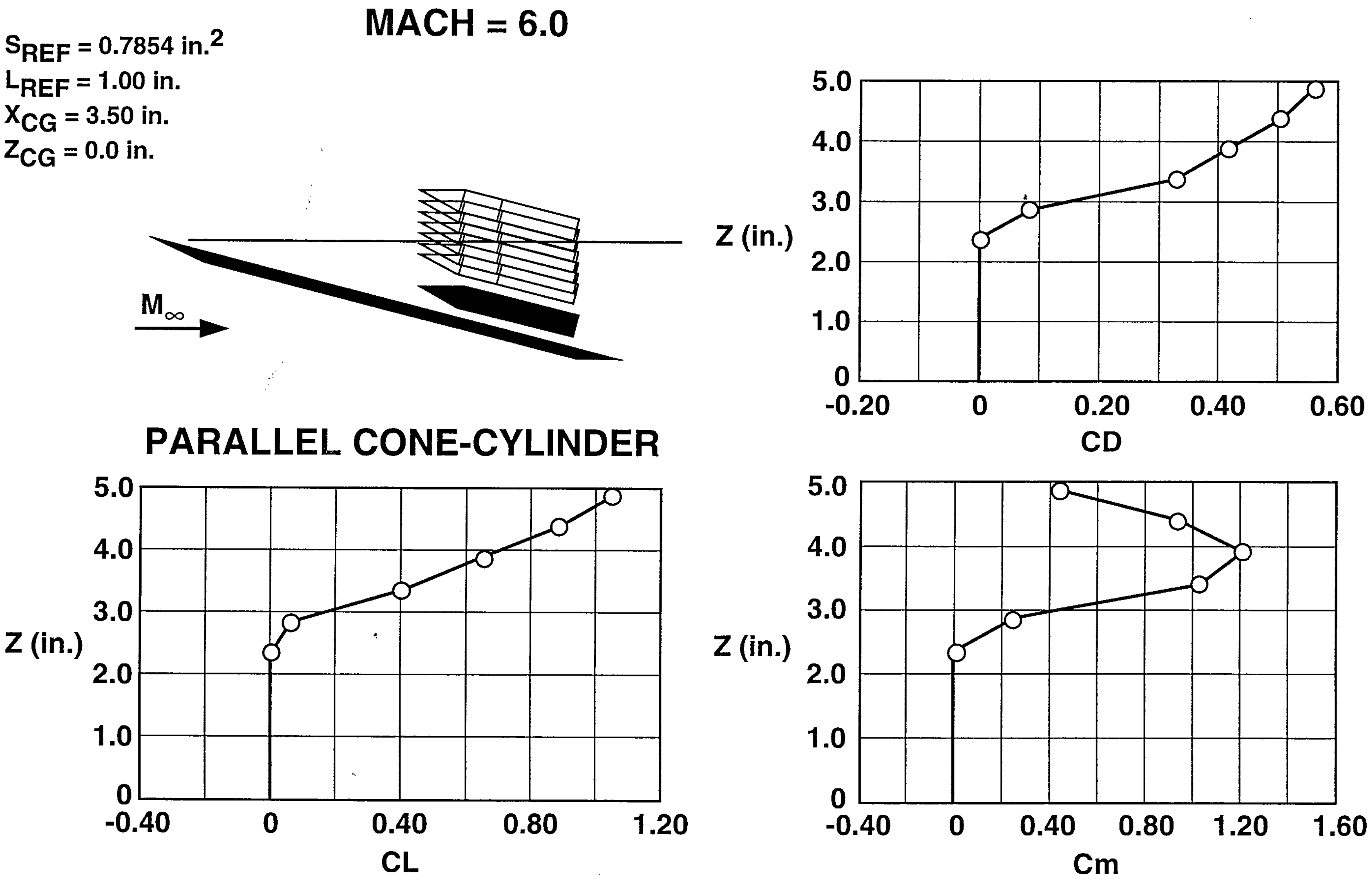

Figure 10. Predicted Aerodynamic Characteristics of Cone-Cylinder Store During Hypersonic Separation

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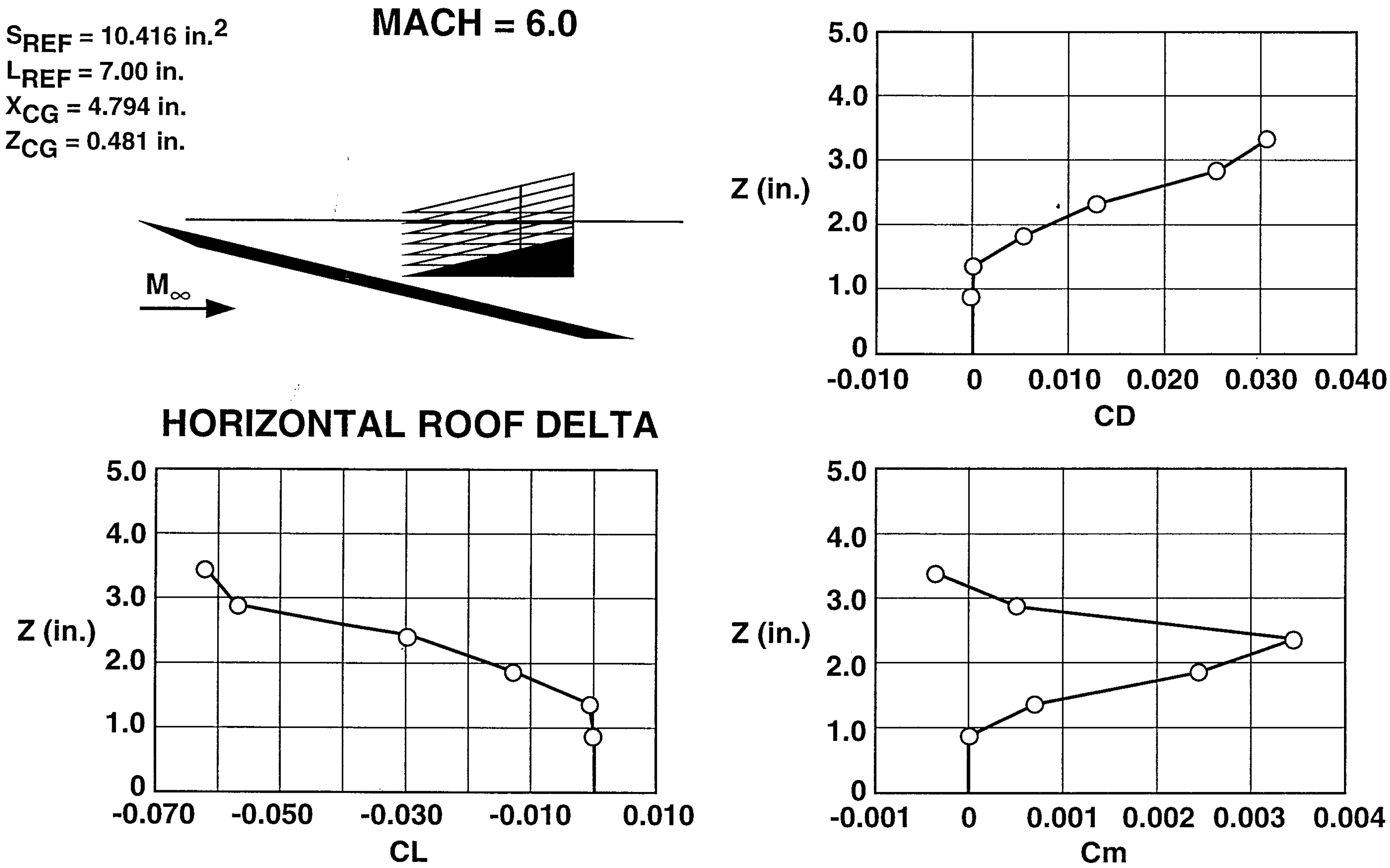

Figure 11. Predicted Aerodynamic Characteristics of Roof Delta Store During Hypersonic Separation

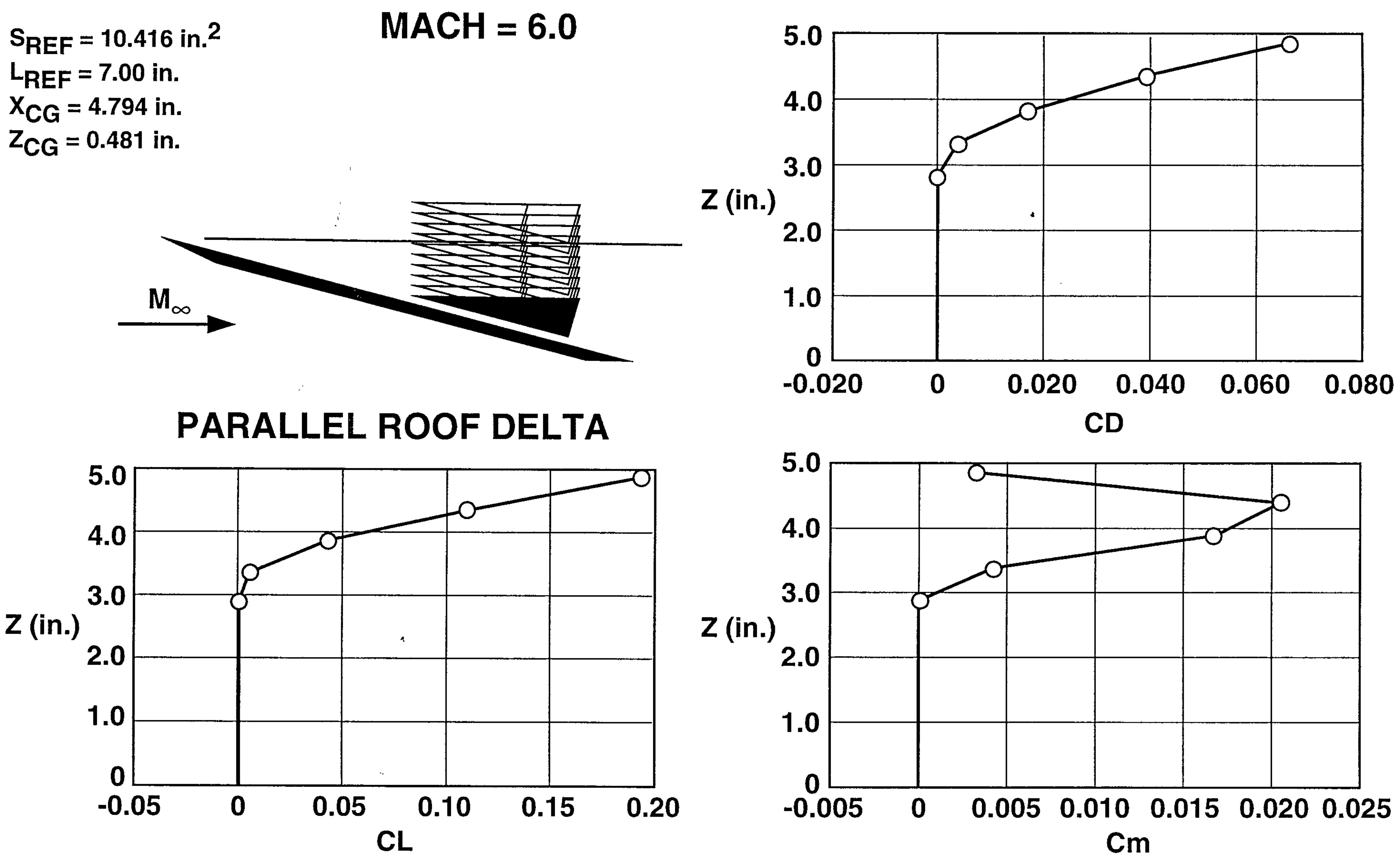

Figure 12. Predicted Aerodynamic Characteristics of Roof Delta Store During Hypersonic Separation

AXISYMMETRIC MISSILE MODEL

CONE-CYLINDER CONFIGURATION

$S_{REF} = 0.79$ sq. in. $L_{REF.} = 1.0$ in.

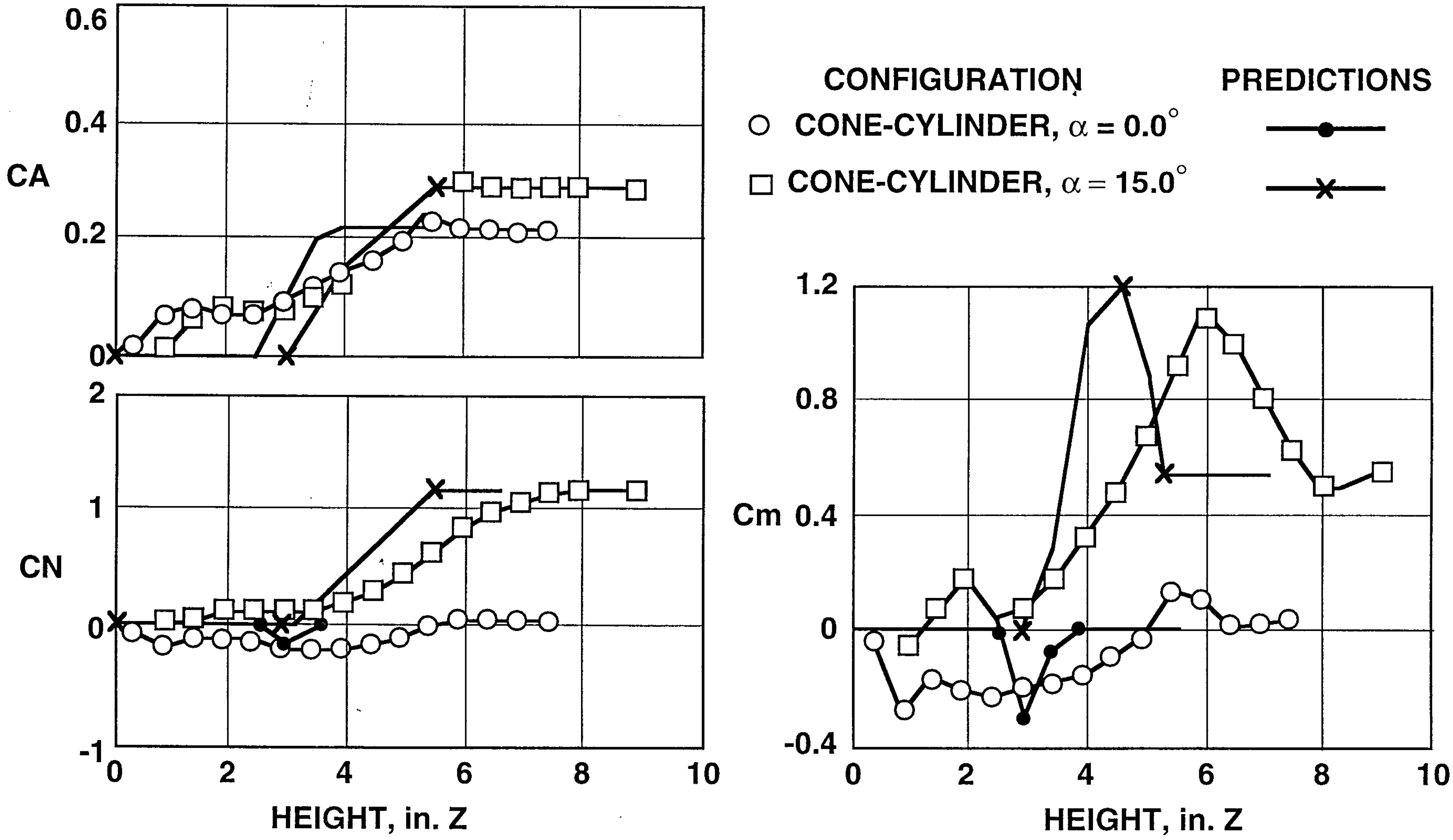

Figure 13. Hypersonic Leeside Separation Aerodynamic Data @ Mach 6

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CONFORMAL MISSILE MODEL

ROOF-DELTA CONFIGURATION

S_{REF} = 10.17 sq. in. L_{REF} = 3.44 in.

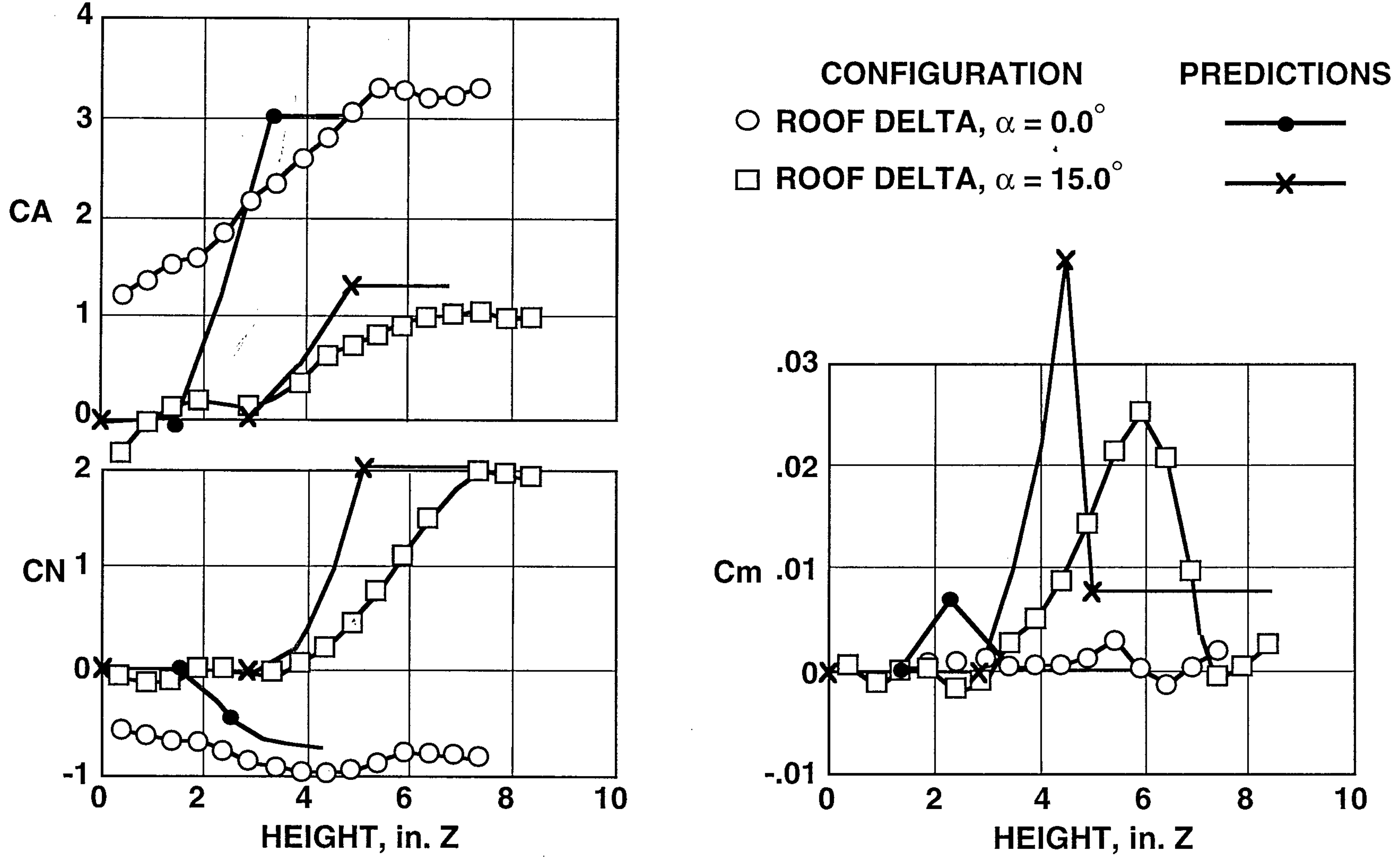
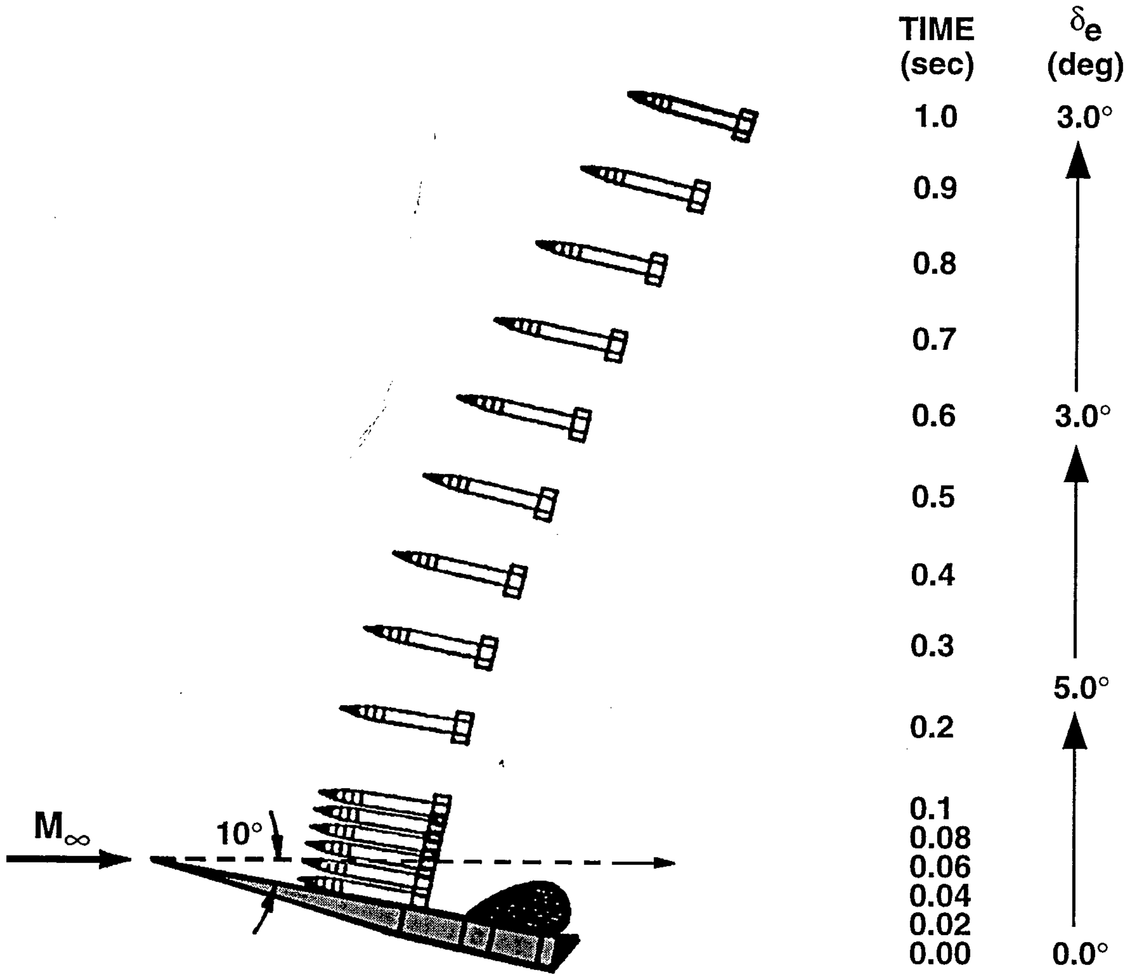


Figure 14. Hypersonic Leeside Separation Aerodynamic Data @ Mach 6



LAUNCH CONDITIONS

- $M_\infty = 10.0$
- ALTITUDE = 125,000 ft
- $V_{eject} = 30$ ft/sec
- $\dot{\theta} = 0.050$ rad/sec (nose down)

δ_e = ELEVATOR DEFLECTION ANGLE

Figure 15. Launch Dynamics for Leeside Separation of the Ring Wing Submissile

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