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Aerodynamic Stability and Heating Analyses for the Aeroassist Flight Experiment Vehicle

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Since ground based flow simulations are presently unable to model flight conditions expected for AOTVs (Aeroassist Orbital Transfer Vehicle) and other hypersonic space vehicles, computer codes are being developed to provide design parameters necessary for structure, guidance, and control aspects. Over the past four years, VRFLO (Viscous Reactive Flow) has been written to model finite-rate chemistry and viscous effects for a variety of aerobrake bodies. VRFLO includes a number of unique features that are summarized as follows:

1. Grid generation is an integral part of the code for several aerobrake configurations which includes the wake flow region.
2. The formulation is valid for three air chemical models.
3. An ADI central difference technique is used to solve the Navier-Stokes and species continuity equations in split groups.
4. Grid density and numerical damping are minimized by shock-fitting and conformal mapping of body points.

Currently, the AFE (Aeroassist Flight Experiment) project requires critical input parameters for the design development, and to aid its progress, aerodynamic forces and heating rates are calculated at a specified trajectory point of maximum heating. The code was calibrated against Mach 10 measurements taken at the Langley Continuous-Flow Hypersonic Tunnel to determine grid sensitivity and reliability estimates for flight calculations. Aerodynamic forces and moment coefficients (lifts, drags, and pitching moments) were calculated at five angles of attack to determine the basic coefficient behavior as a function of angle for stability analysis. Wind tunnel simulations were modeled by calculating the flowfield about the complete body assuming an inviscid, perfect gas which resolved the non-linear behavior in the pitching moment measured from wind tunnel experiments. Inviscid, reacting air calculations, for flight conditions at Mach 32, show a linear pitching moment that agrees with calculations performed at Langley Research Center which considered inviscid, equilibrium air with forebody geometry. Preliminary, not fully converged, viscous, reacting flow calculations at the same flight conditions reveal a slight non-linear relation between pitching moment and angle of attack. In each case, the base pressure contributions are examined by considering the forebody and complete body separately.

Considering that heat-transfer measurements are accurate within ±7% and an equal amount of uncertainty is associated with CFD results, the convective heat flux calculations are in fairly good agreement with the Langley Mach 10 wind tunnel measurements. While the calculated surface pressure distribution demonstrates excellent agreement with measurement, the heat-transfer coefficient exhibits similar surface behavior to the data but varies in value. Incident angle studies show that the maximum heating decreases with increasing attack angle without modifying the overall distribution shape. Calculations for flight conditions show similar trends observed from wind tunnel simulations but have a more pronounced peak at the stagnation region. Fully catalytic calculations indicate that the heat-transfer coefficients are about 25% larger in general than those in the non-catalytic solutions; the actual fluxes expected for flight conditions will be bounded by the two extremes.

Wind Tunnel Axis System for Aerocoefficients

$\alpha = 0°$

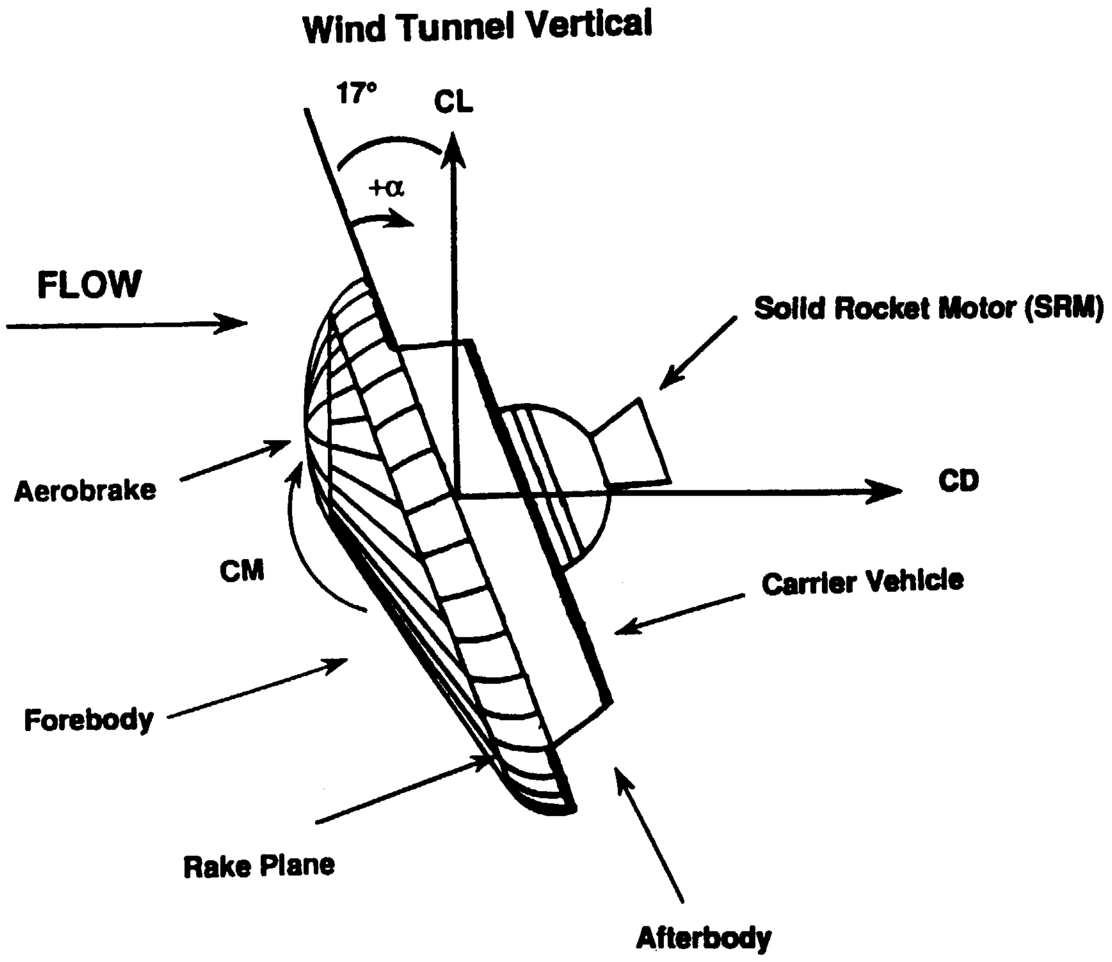
$$C_L = \frac{L}{q\,S}$$

$$C_D = \frac{D}{q\,S}$$

$$C_M = \frac{M}{q\,S\,L'}$$

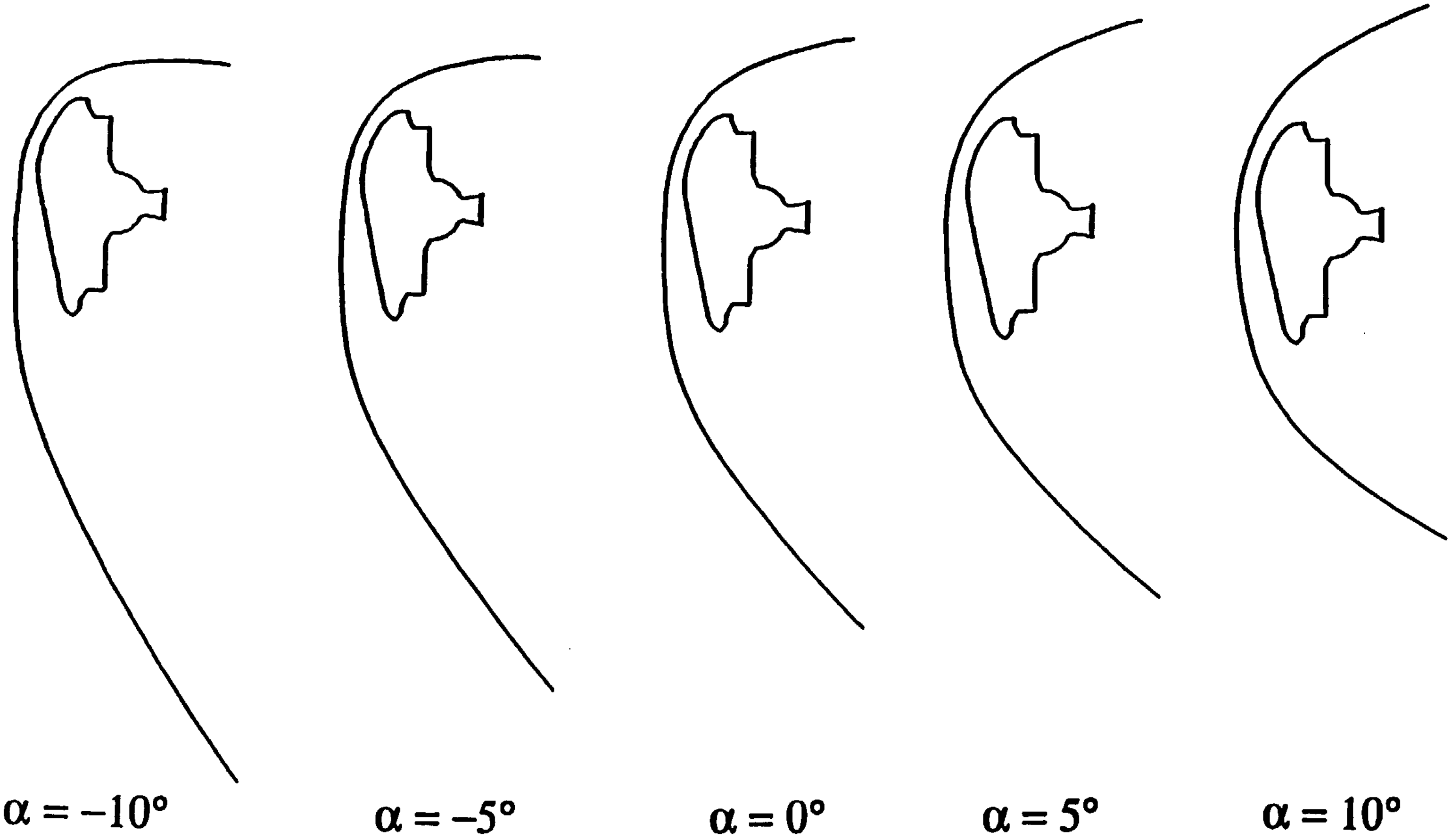
$$S = \frac{\pi\,W\,L'}{4}$$

$$q = \frac{1}{2}\rho_\infty V_\infty^2$$



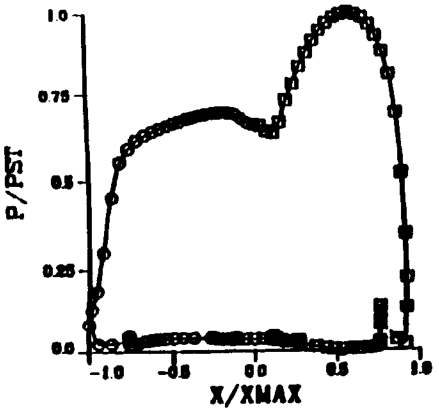
Shock Shape Variations with Angle of Attack

Inviscid, Mach 10

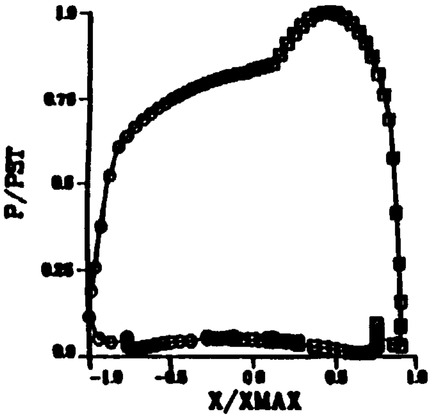


Pressure Distribution Along AFE Body

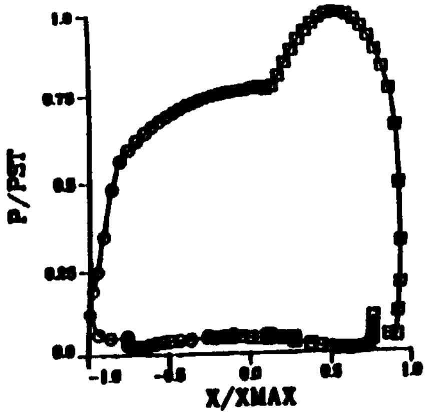
Inviscid, Mach 10



PST= 134.836
α = -10°

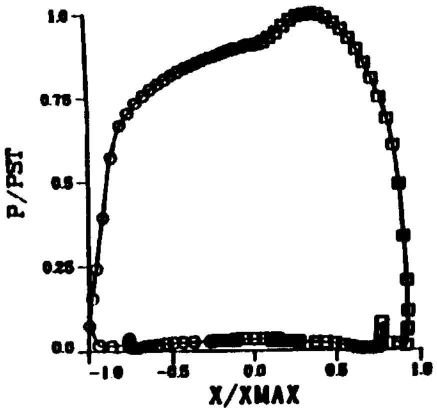


PST= 139.112
α = 0°

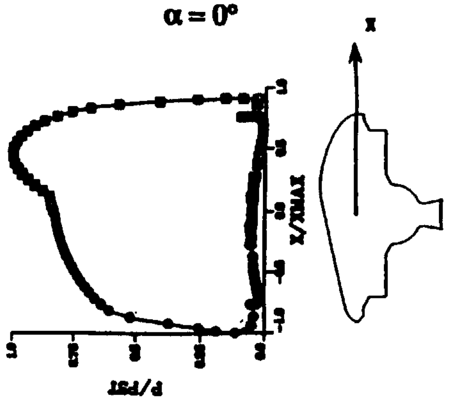


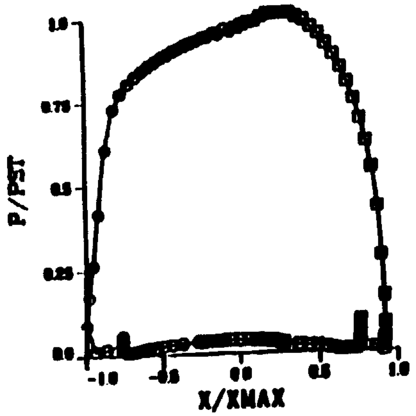
PST= 139.309

α = -5°



PST= 135.179
α = 5°

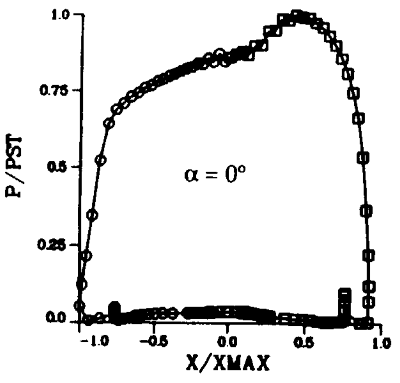




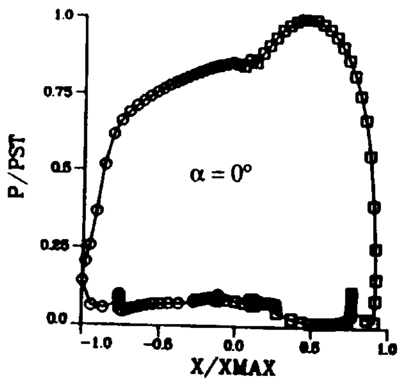
PST= 132.730
α = 10°

Grid Variations

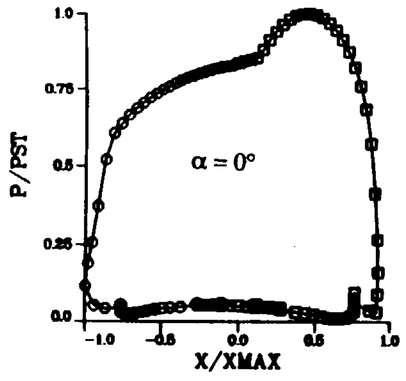
Inviscid, Mach 10



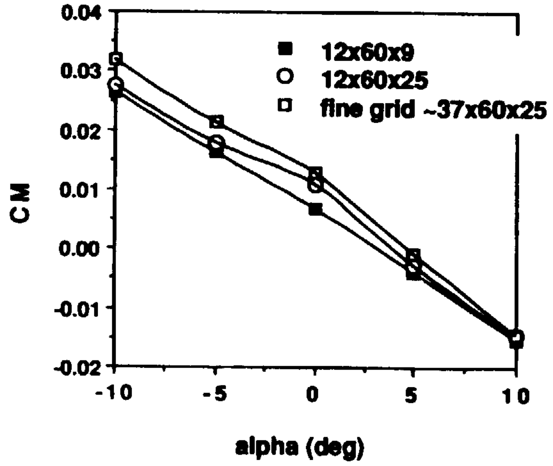
12x60x9 PST= 133.579



12x60x25 PST= 134.846



30x60x25 PST= 139.112



NxMxL , where

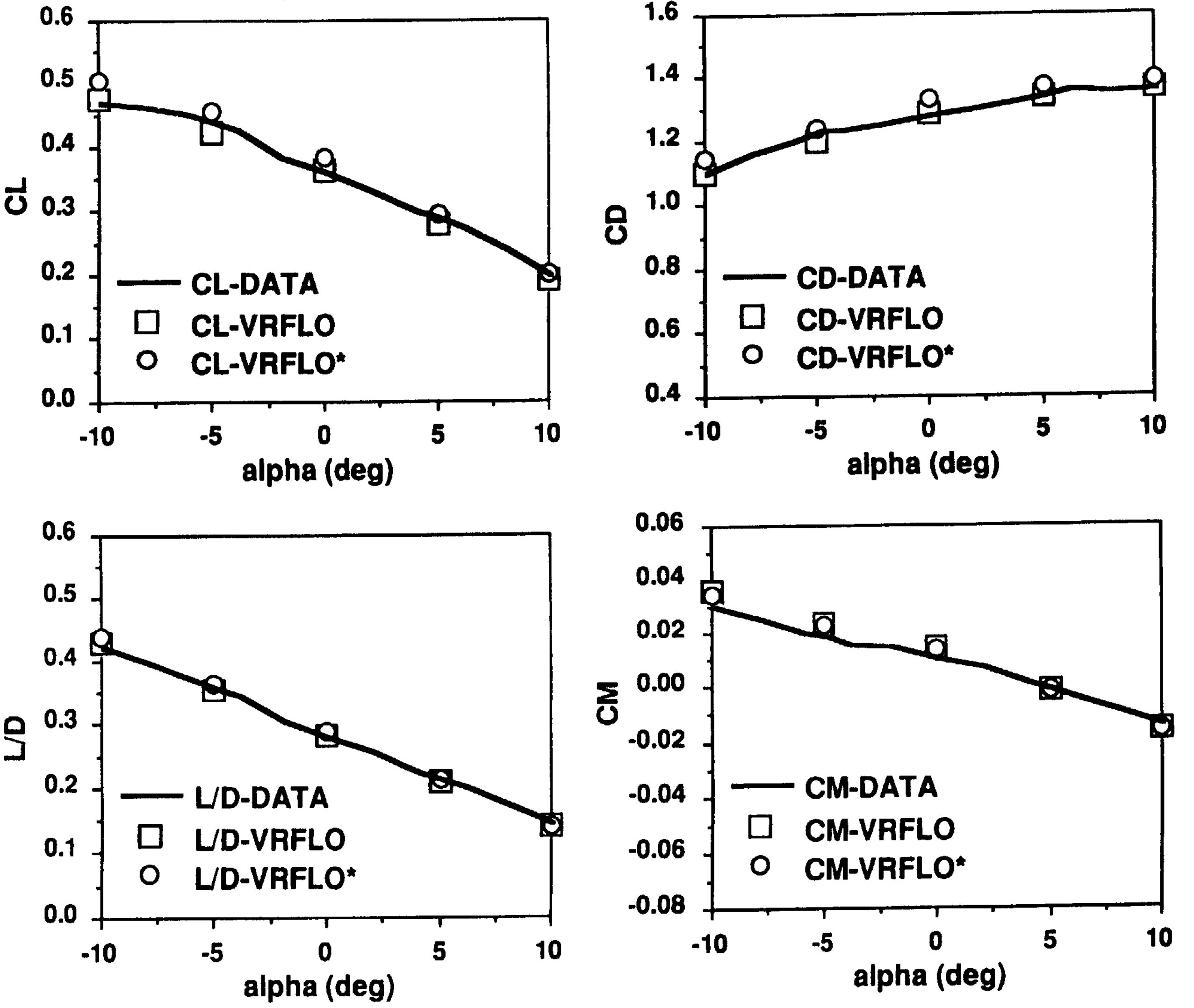
N = number of points from AFE body to boundary

M = number of points from forebody to afterbody

L = number of points around body in plane normal to pitch plane

INVISCID, MACH 10
AEROCOEFFICIENTS vs ANGLE OF ATTACK

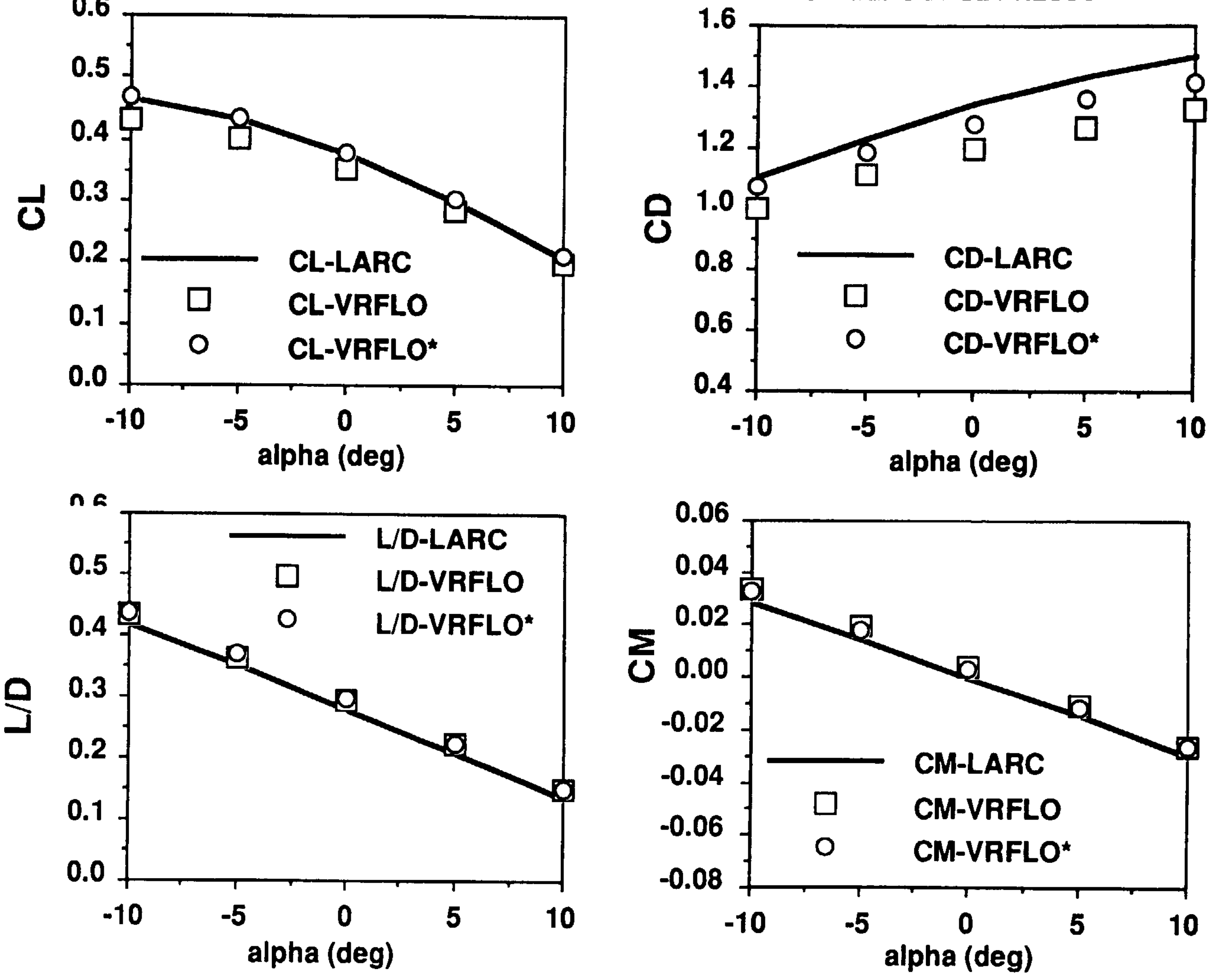
VRFLO*- ZERO BASE PRESSURE DATA - M 10 WIND TUNNEL



MACH 32
INVISCID, REACTING FLOW
AEROCOEFFICIENTS vs ANGLE OF ATTACK

LARC - EQUILIBRIUM, INVISCID AIR

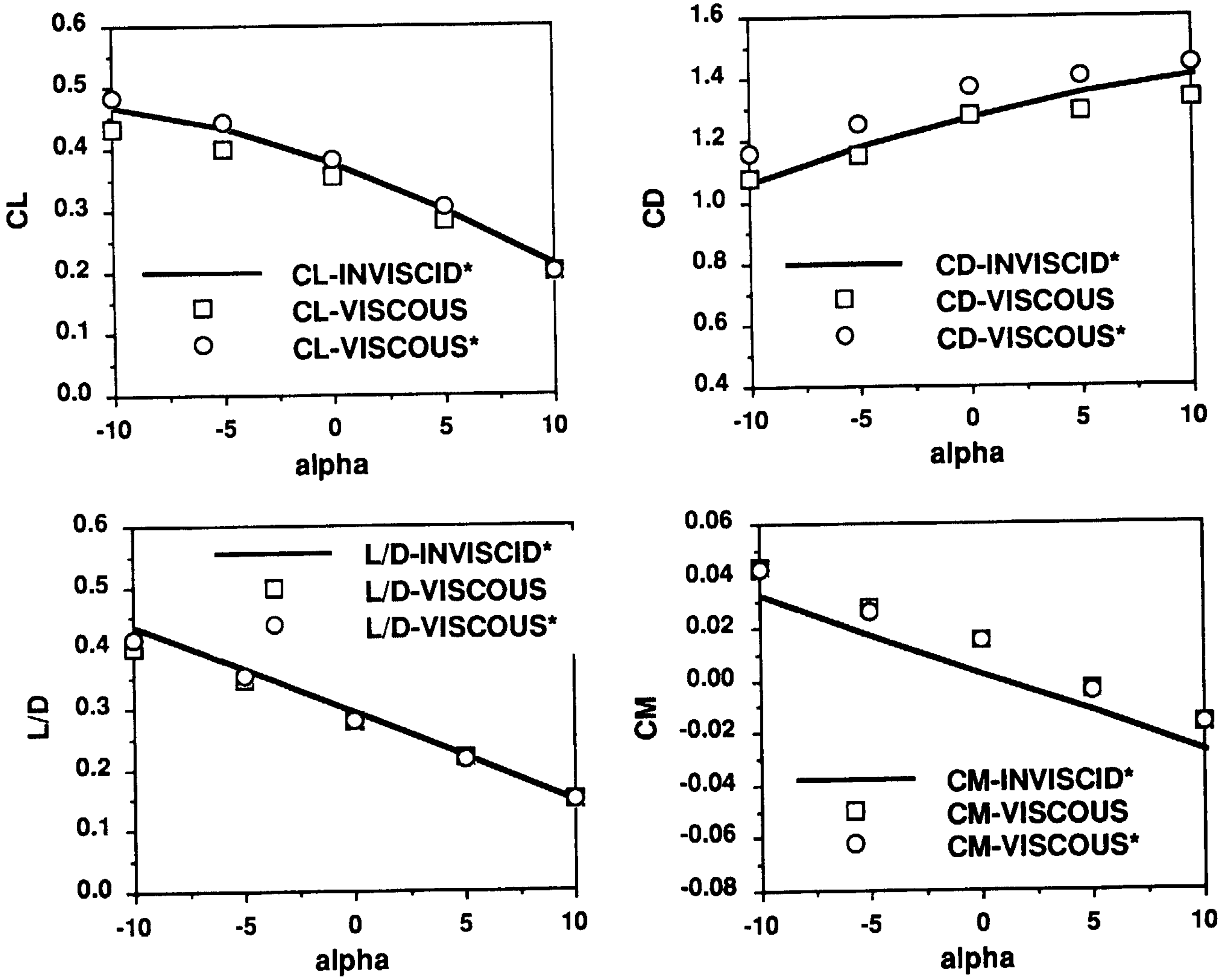
VRFLO* - ZERO BASE PRESSURE



MACH 32
VISCOUS, REACTING FLOW
AEROCOEFFICIENTS vs ANGLE OF ATTACK

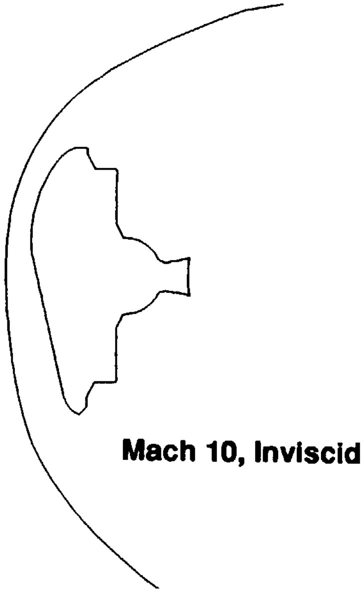
INVISCID* - ZERO BASE PRESSURE

VISCOUS* - ZERO BASE PRESSURE

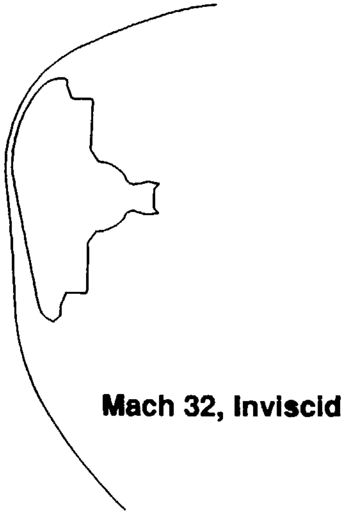


MACH 32
INVISCID / VISCOUS COMPARISONS

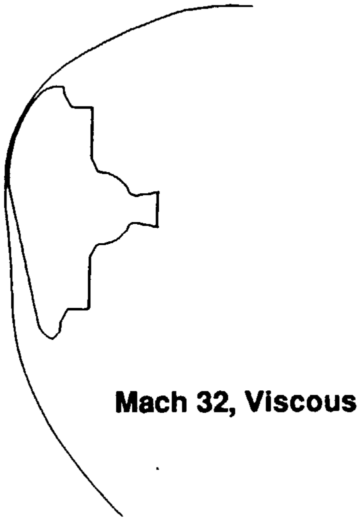
$\alpha = 0°$



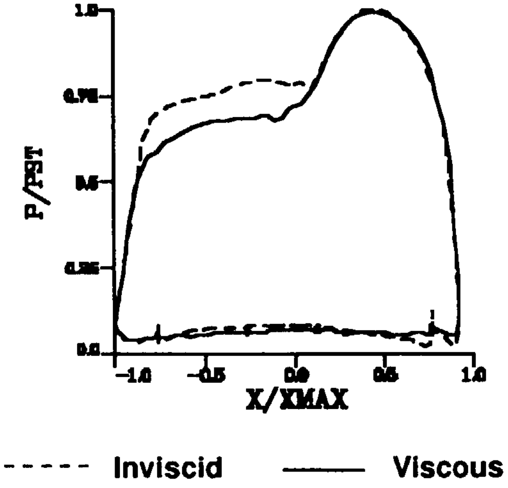
Mach 10, Inviscid

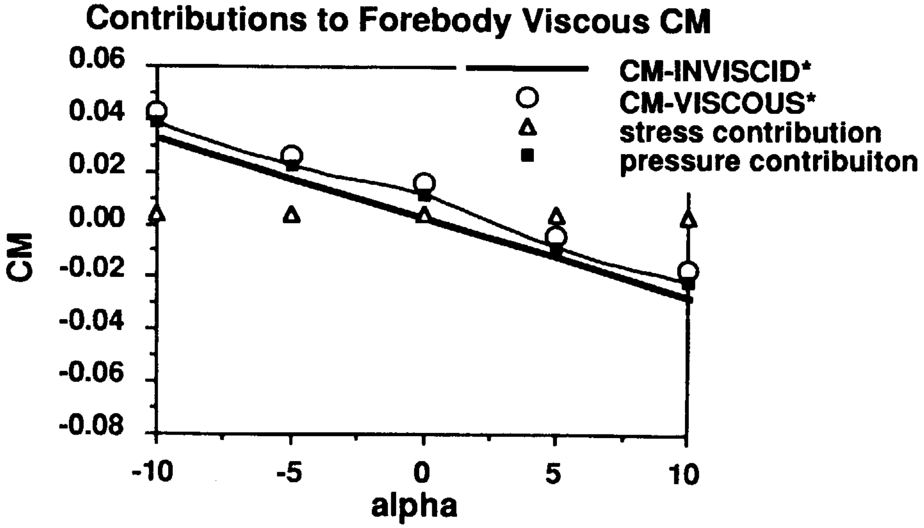


Mach 32, Inviscid

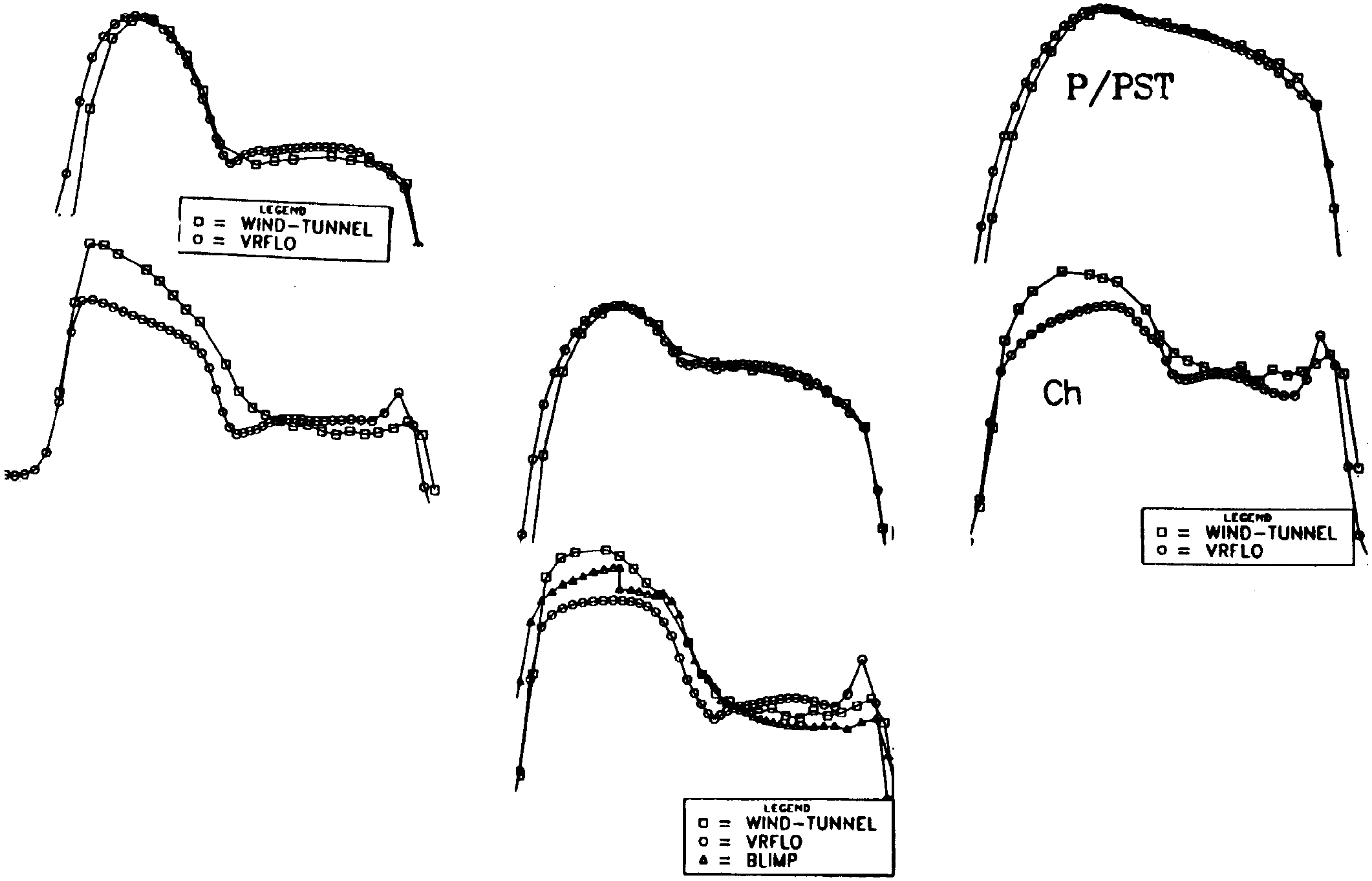


Mach 32, Viscous

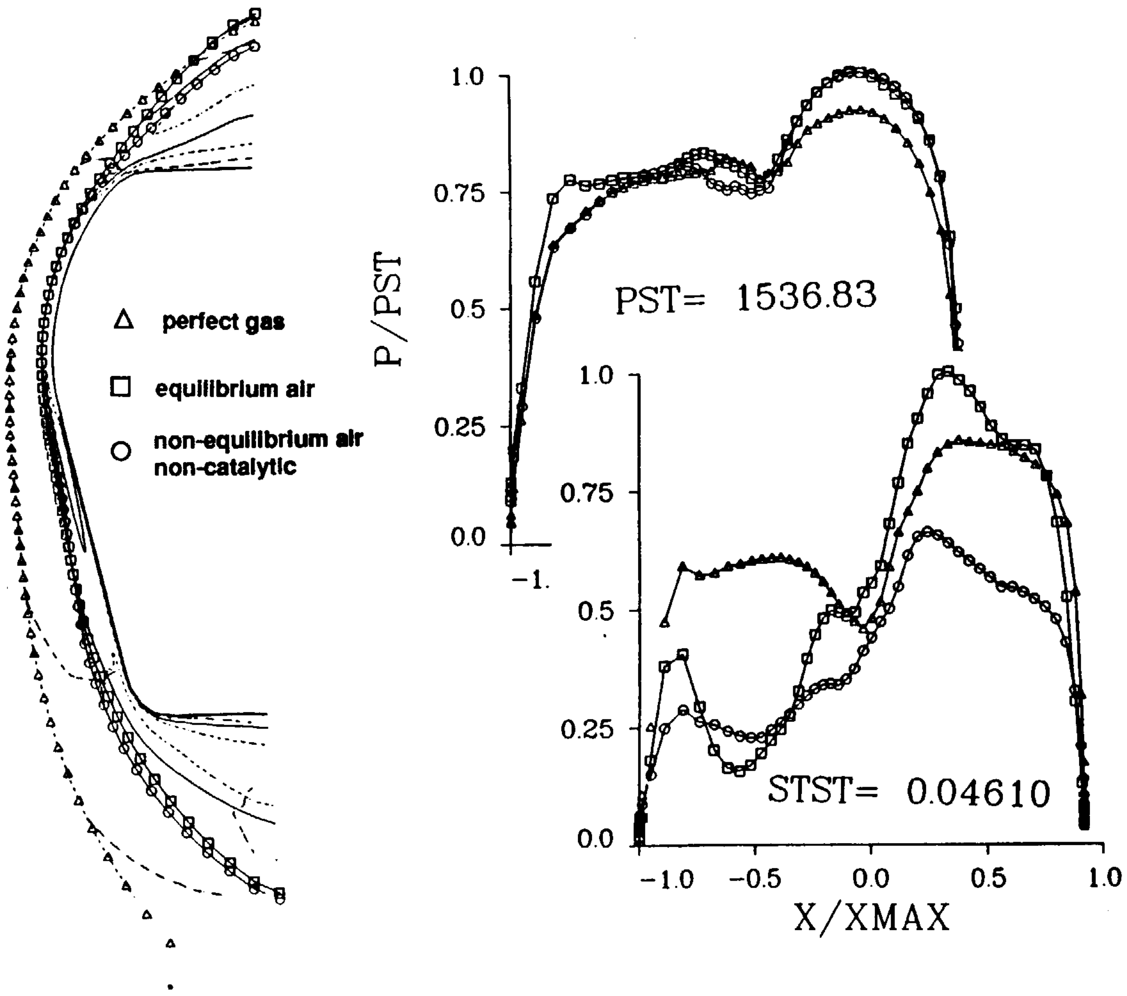




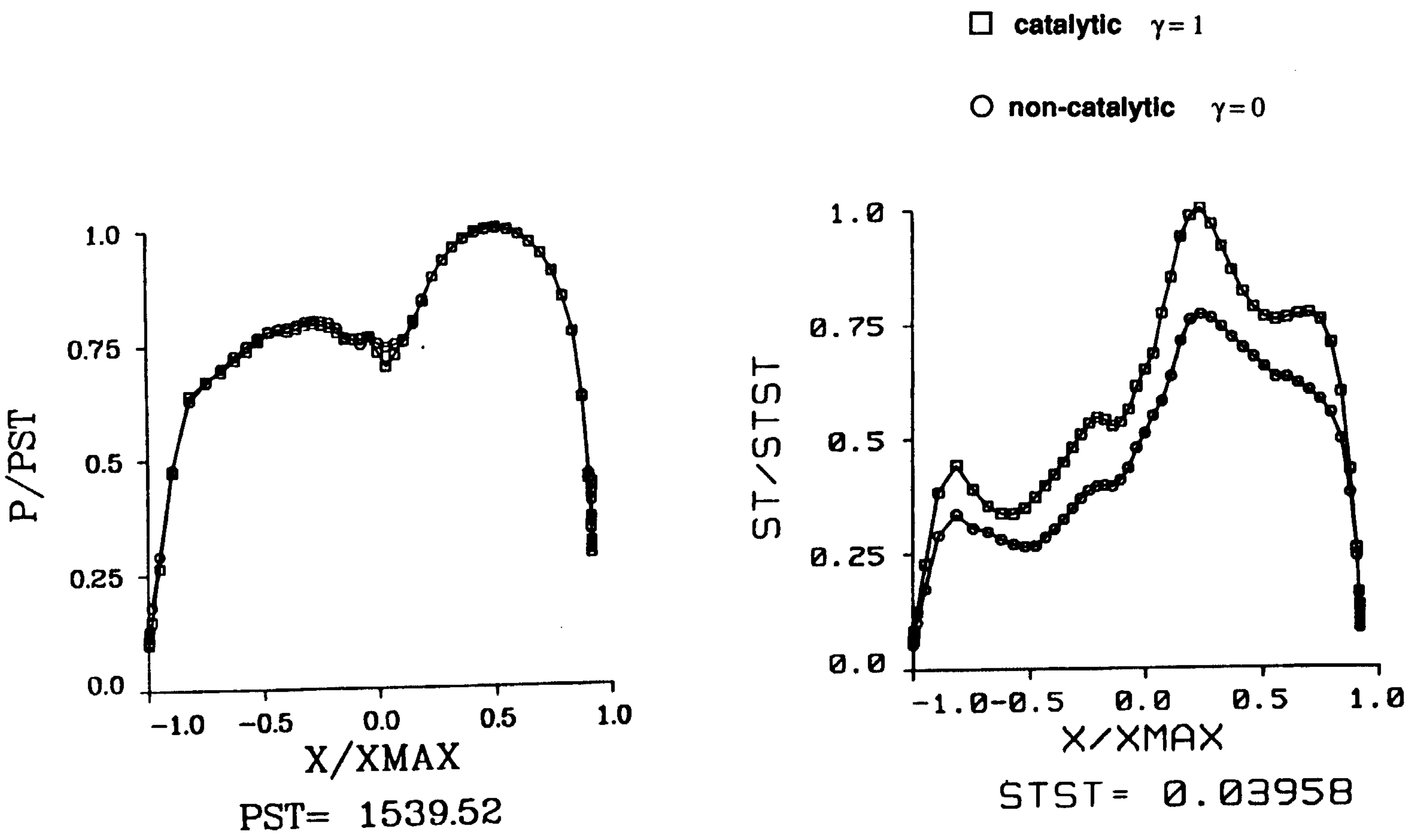
Comparisons of Pressures and Heat Transfer
α = 10°, 0°, -10°
MACH 10



Effects of Gas Models on Pressure and Heating
MACH 35



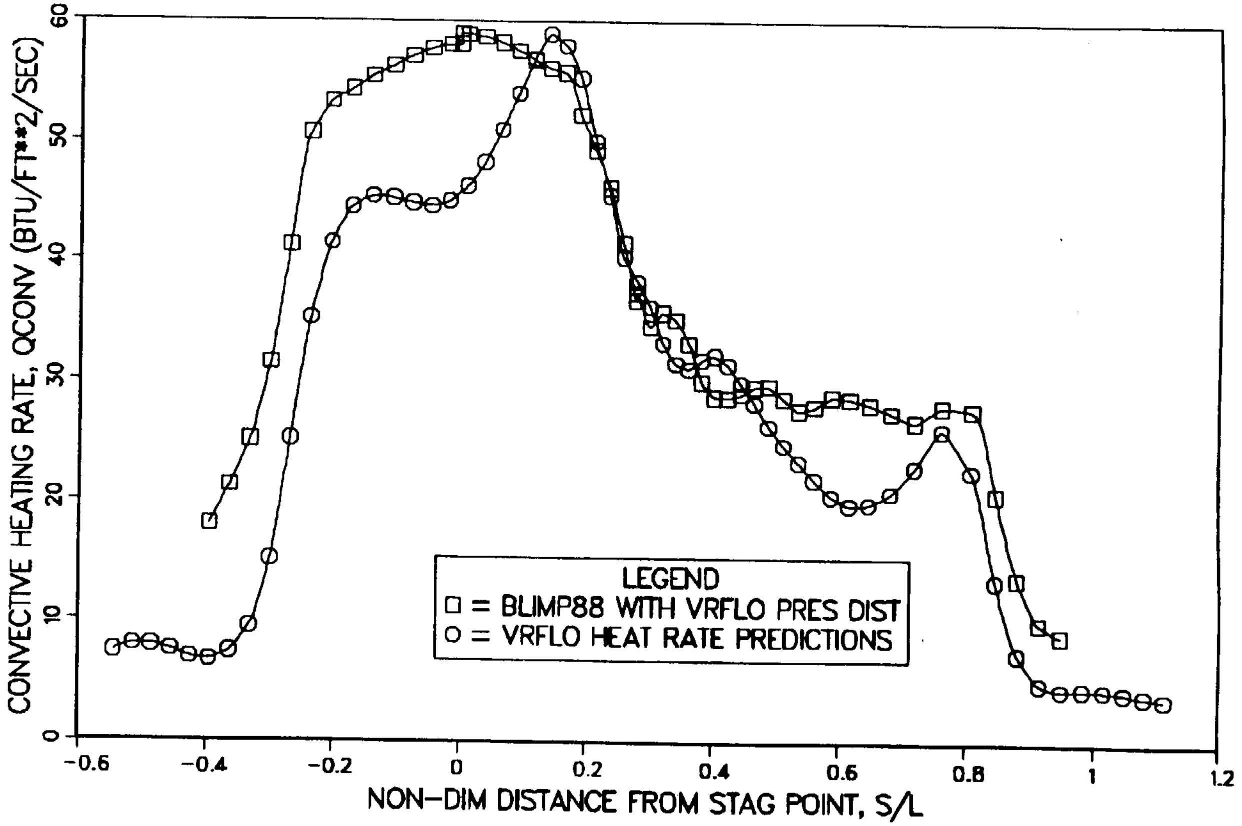
Wall Catalytic Effects on Pressure and Heating
MACH 35



Comparisons of Heating Rates
Boundary Layer and Navier Stokes Codes
MACH 35

4100 LB AFE CONVECTIVE HEATING RATES AROUND AFE PITCH PLANE

CASE 4 – FLIGHT LI–VRFLO CFD & BLIMP88 FULLY CAT TW=5*TINF



Heat Transfer Distribution on AFE Chemically Reactive Computation