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Conservation Equations and Physical Models for Hypersonic Air Flows Over the Aeroassist Flight Experiment Vehicle

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Abstract

The code development and application program for the Langley Aerothermodynamic Upwind Relaxation Algorithm (LAURA), with emphasis directed toward support of the Aeroassist Flight Experiment (AFE) in the near term and Aeroassisted Space Transfer Vehicle (ASTV) design in the long term is reviewed. LAURA is an upwind-biased, point-implicit relaxation algorithm for obtaining the numerical solution to the governing equations for three-dimensional, viscous, hypersonic flows in chemical and thermal nonequilibrium. The algorithm is derived using a finite-volume formulation in which the inviscid components of flux across cell walls are described with Roe's averaging and Harten's entropy fix with second-order corrections based on Yee's Symmetric Total Variation Diminishing scheme. Because of the point-implicit relaxation strategy, the algorithm remains stable at large Courant numbers without the necessity of solving large, block tri-diagonal systems. A single relaxation step depends only on information from nearest neighbors. Predictions for pressure distributions, surface heating, and aerodynamic coefficients compare well with experimental data for Mach 10 flow over an AFE wind tunnel model. Predictions for the hypersonic flow of air in chemical and thermal nonequilibrium (velocity = 8917 m/s, altitude = 78 km.) over the full scale AFE configuration obtained on a multi-domain grid are discussed.

SIMULATION CAPABILITIES

PROGRAM LAURA (LANGLEY AEROTHERMODYNAMIC UPWIND RELAXATION ALGORITHM)

I. PHYSICS

Navier -Stokes Or Thin-Layer Navier-Stokes Equations

Steady Or Unsteady

Laminar (Turbulent Boundary Layer)

Chemical Nonequilibrium (11 Species, 2 Chemical Kinetic Models)

Thermal Nonequilibrium (Two-Temperature Model)

Documented In NASA TP 2867

II. NUMERICS

Finite Volume, Roe's Averaging, STVD Limiters

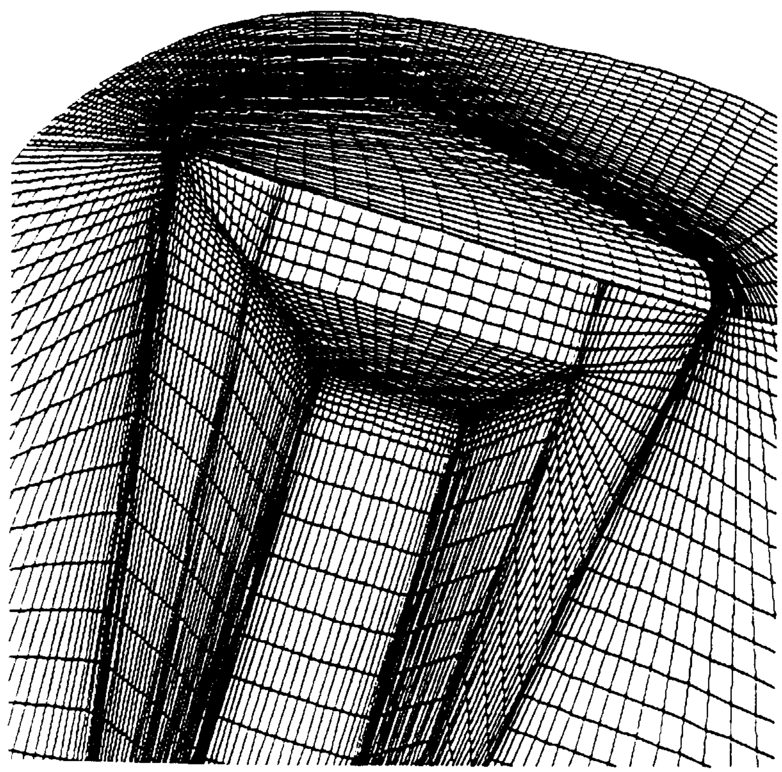
Fluid Mechanics And Chemistry Strongly Coupled

Point Implicit Relaxation, Freeze Inverse Jacobian

Multi-Domain Capability, Structured Grids

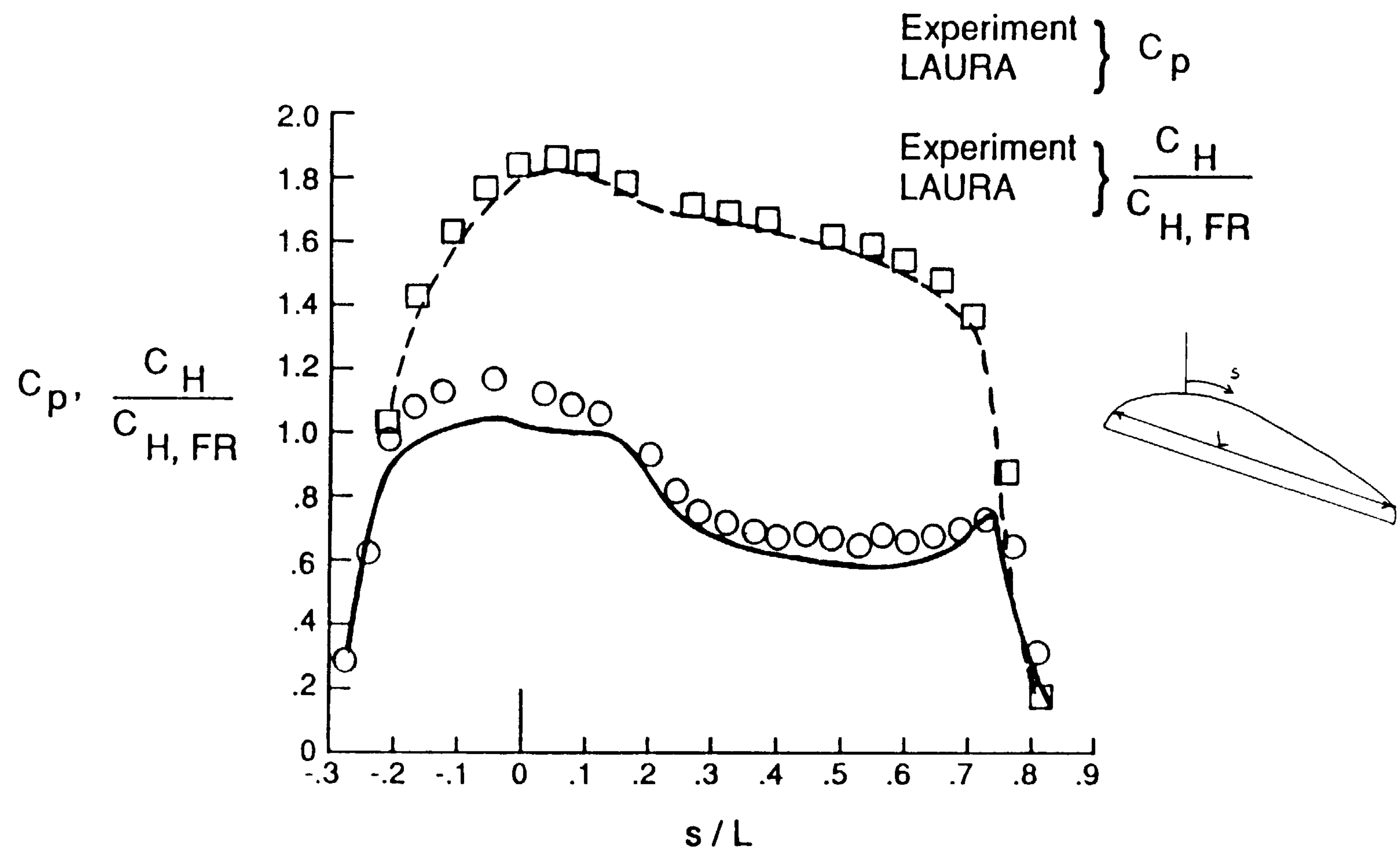
Ideally Suited For Parallel, Asynchronous Iteration Using Unstructured Grids

COMPUTATIONAL GRID 0N SURFACE AND PLANE OF SYMMETRY FOR AFE WIND TUNNEL MODEL



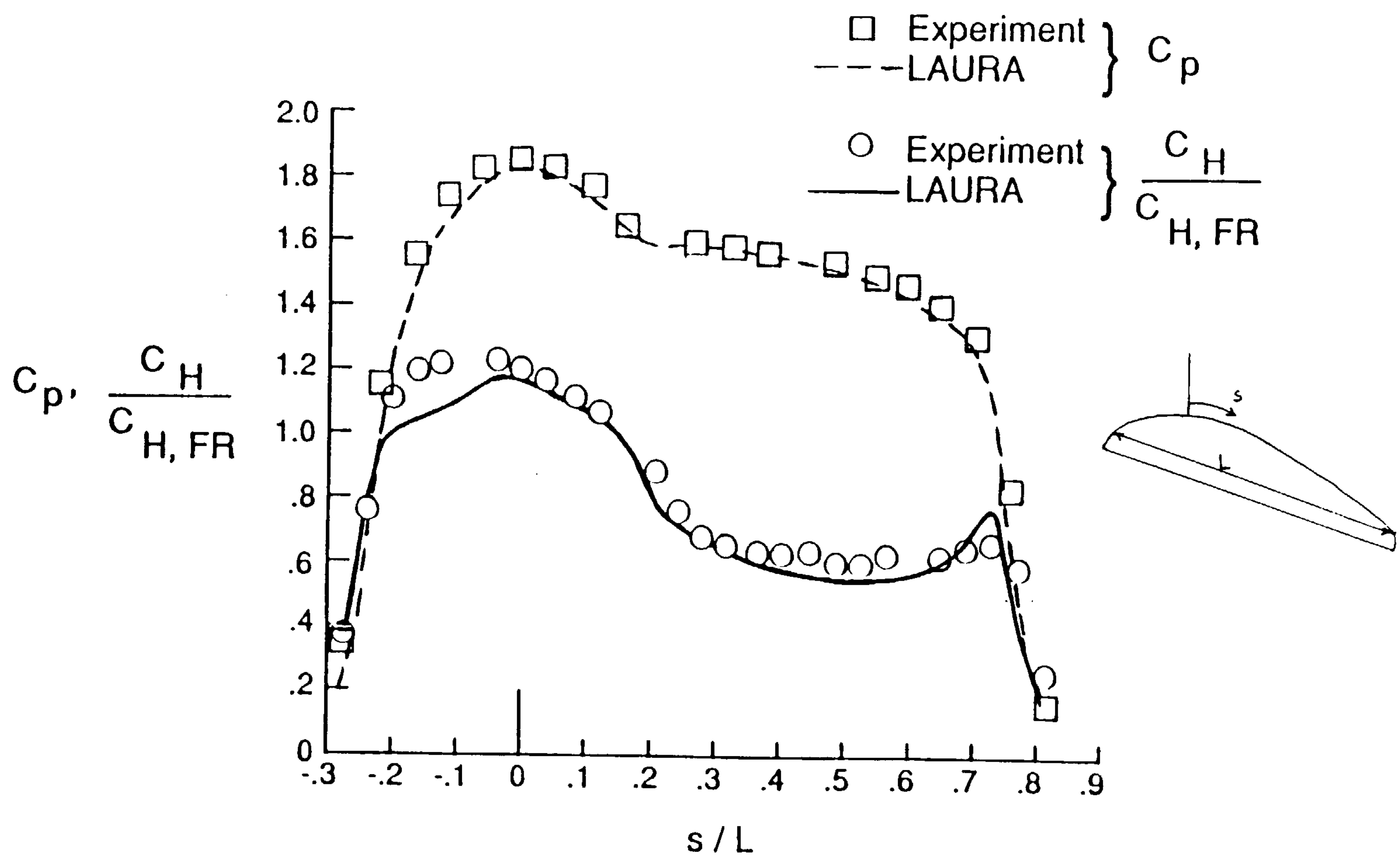
PRESSURE AND HEATING DISTRIBUTION FOR AFE

Mach 10 $\alpha = 5^{\circ}$



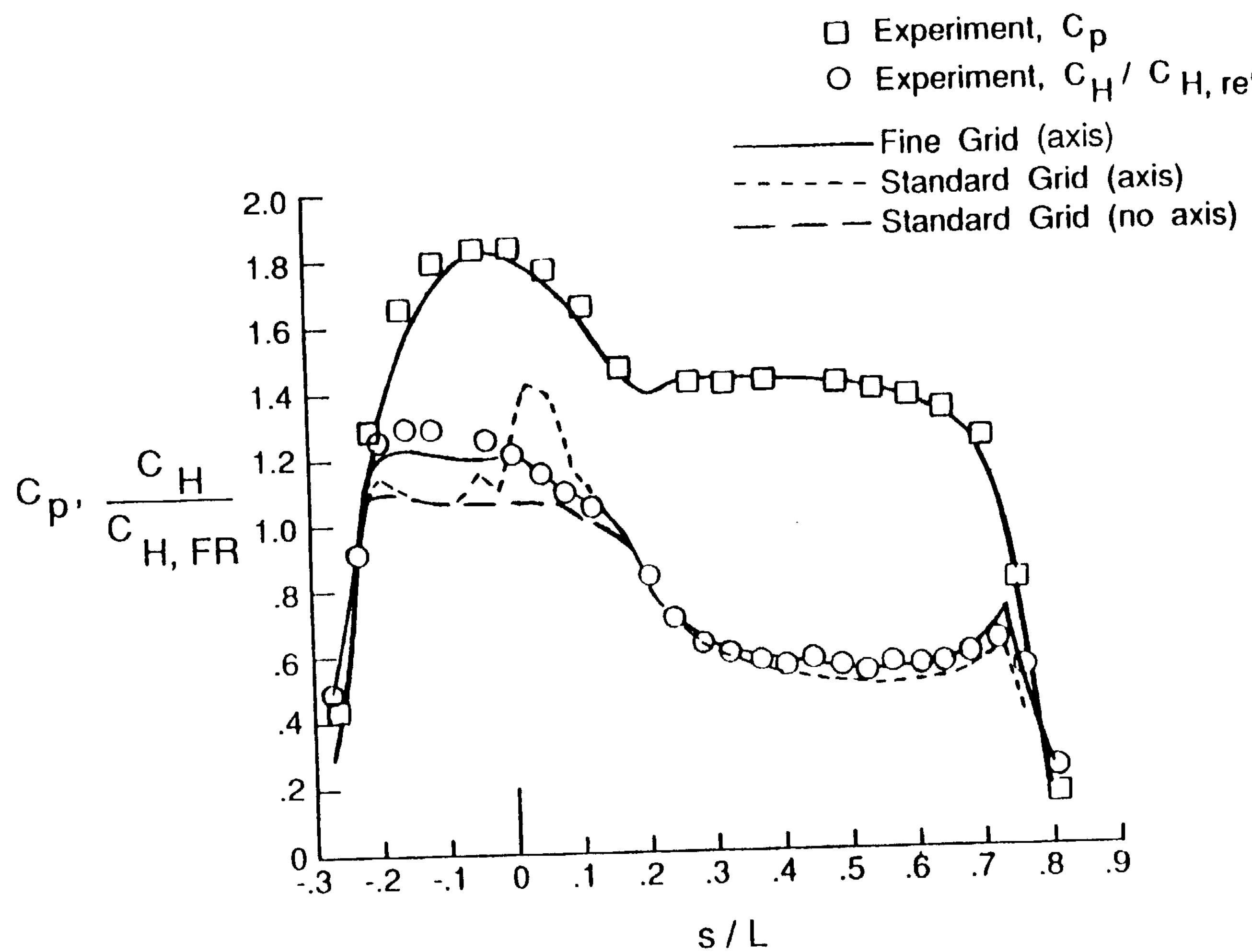
PRESSURE AND HEATING DISTRIBUTION FOR AFE

Mach 10 $\alpha = 0^{\circ}$

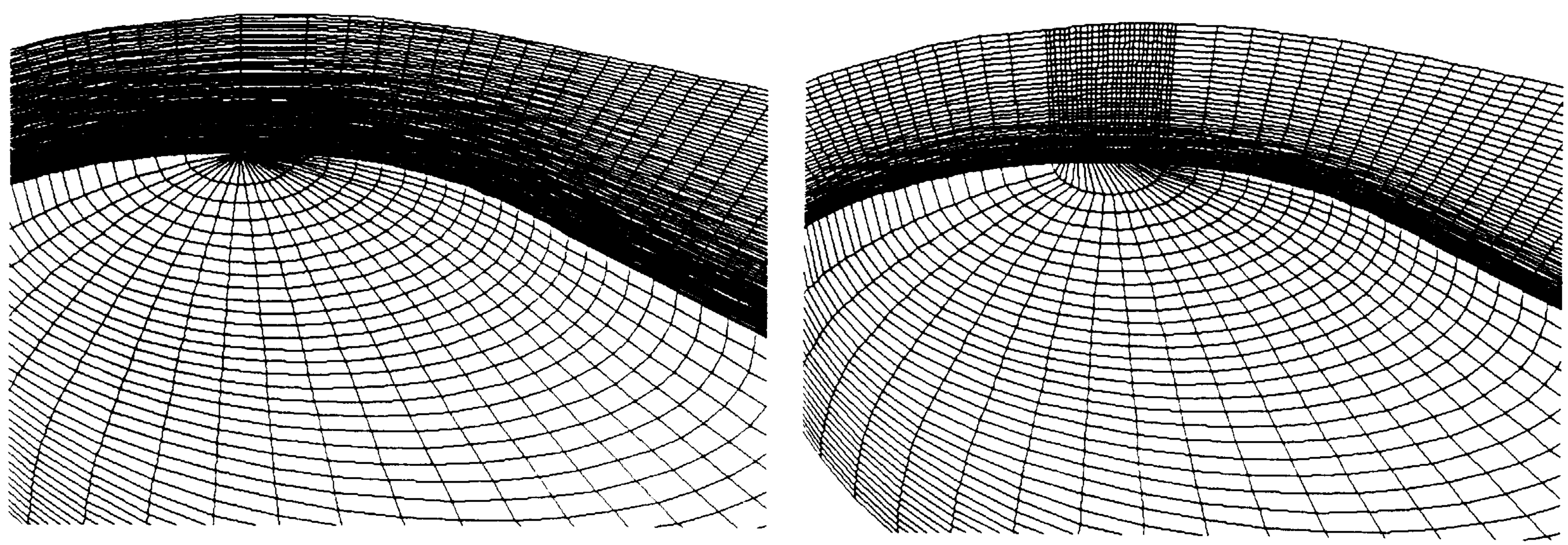


PRESSURE AND HEATING DISTRIBUTION FOR AFE

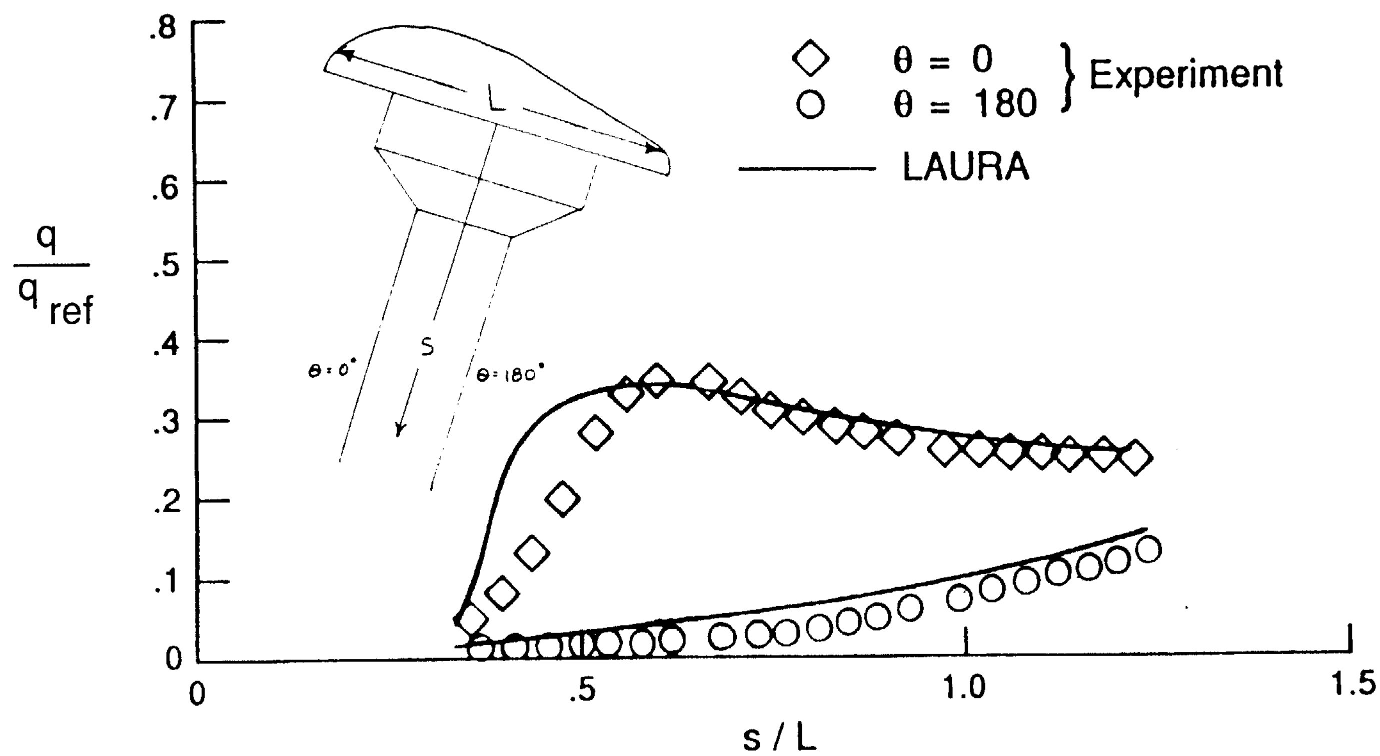
Mach 10 $\alpha = -5°$



DETAIL OF AXIS AND NO AXIS GRIDS

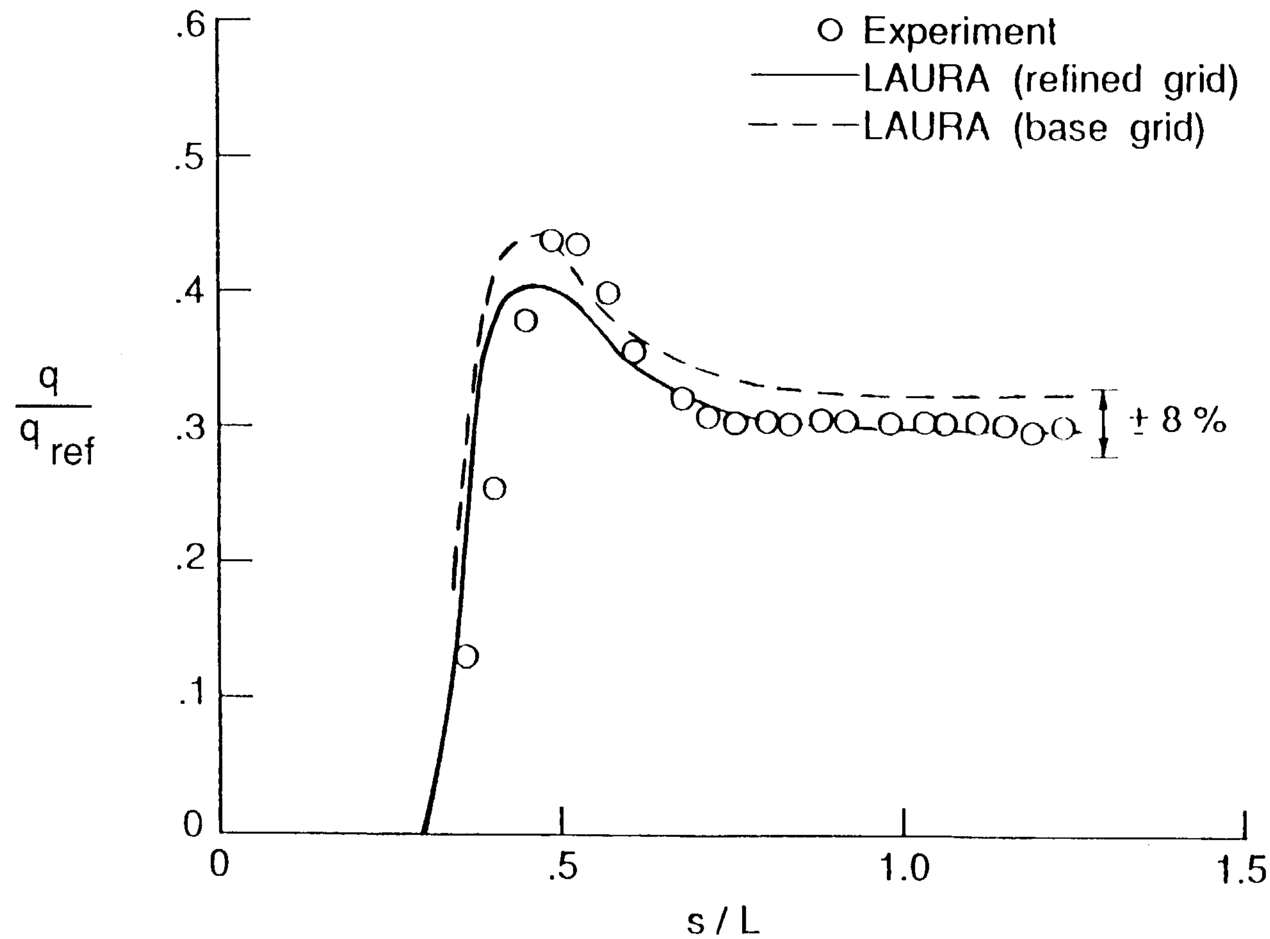


HEATING DISTRIBUTIONS FOR AFE STING
Mach 10 $\alpha = 0^\circ$



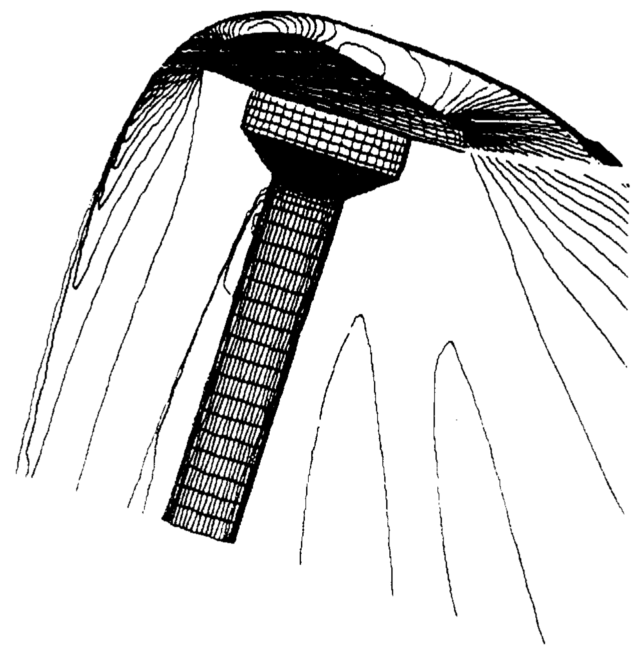
HEATING DISTRIBUTIONS FOR AFE STING

Mach 10 $\alpha = -5^\circ$



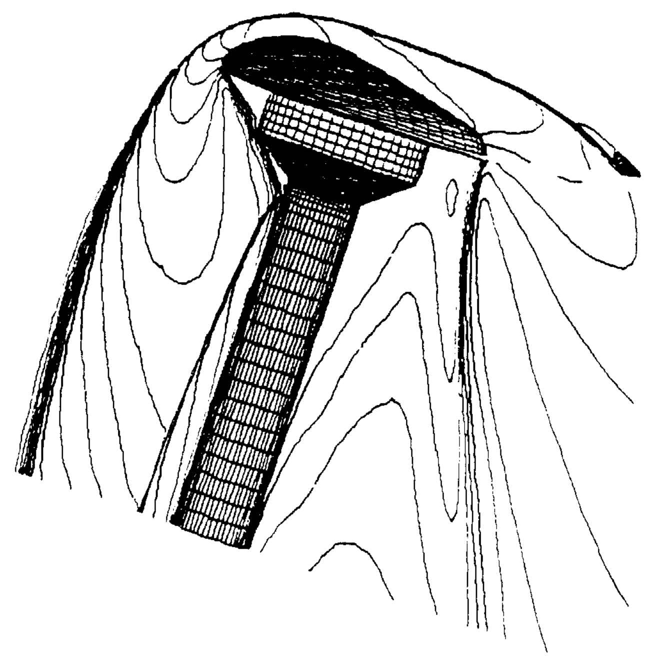
PRESSURE CONTOURS IN THE PLANE OF SYMMETRY

$M_\infty = 10 \qquad \alpha = -5^\circ$

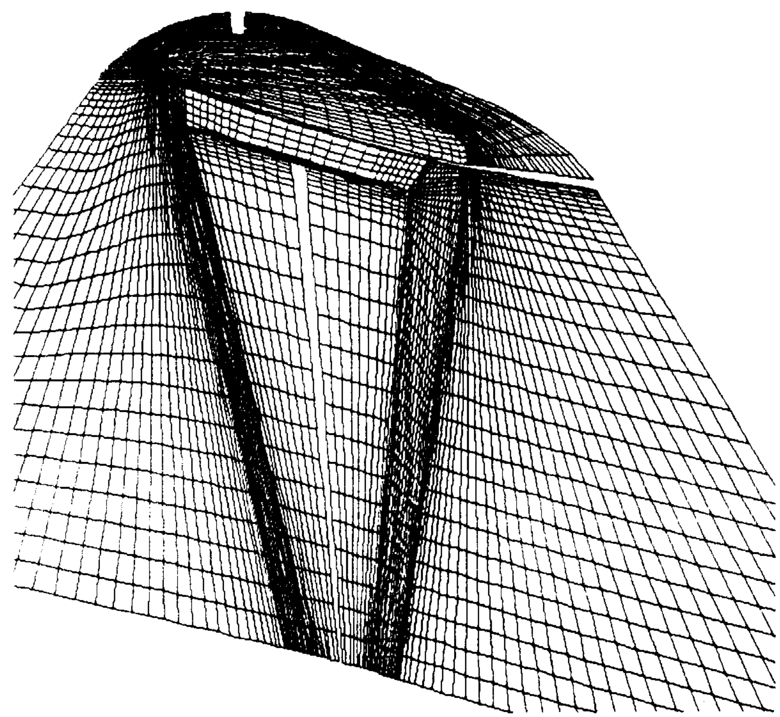


MACH NUMBER CONTOURS IN THE PLANE OF SYMMETRY

$M_{\infty} = 10 \qquad \alpha = -5^{\circ}$

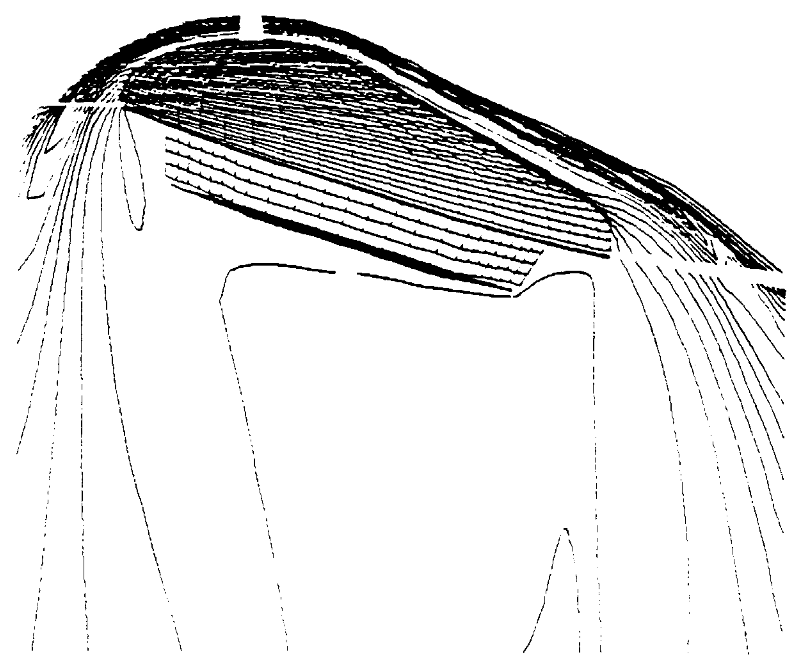


COMPUTATIONAL GRID ON SURFACE AND PLANE OF SYMMETRY FOR AFE



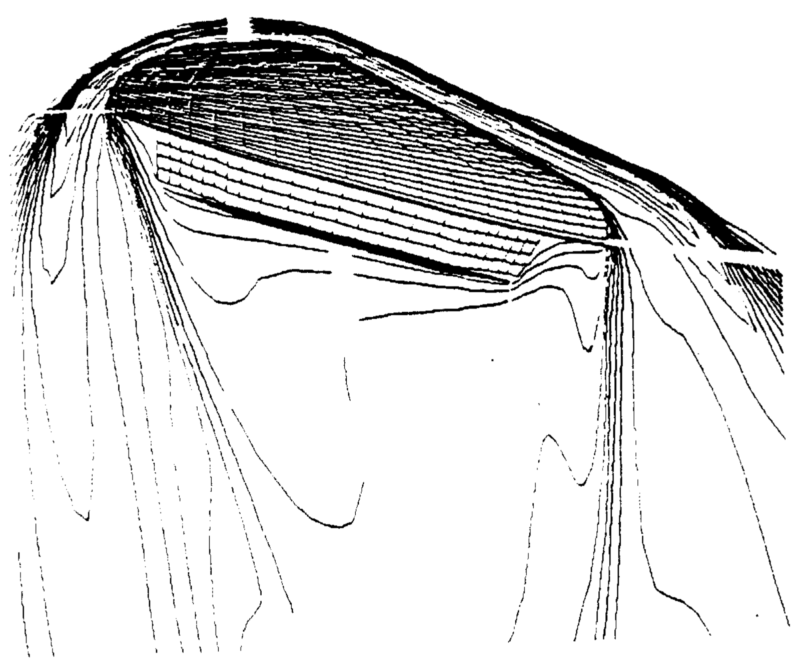
TRANSLATIONAL TEMPERATURE CONTOURS IN THE PLANE OF SYMMETRY

$M_\infty = 32 \qquad h = 78$ km



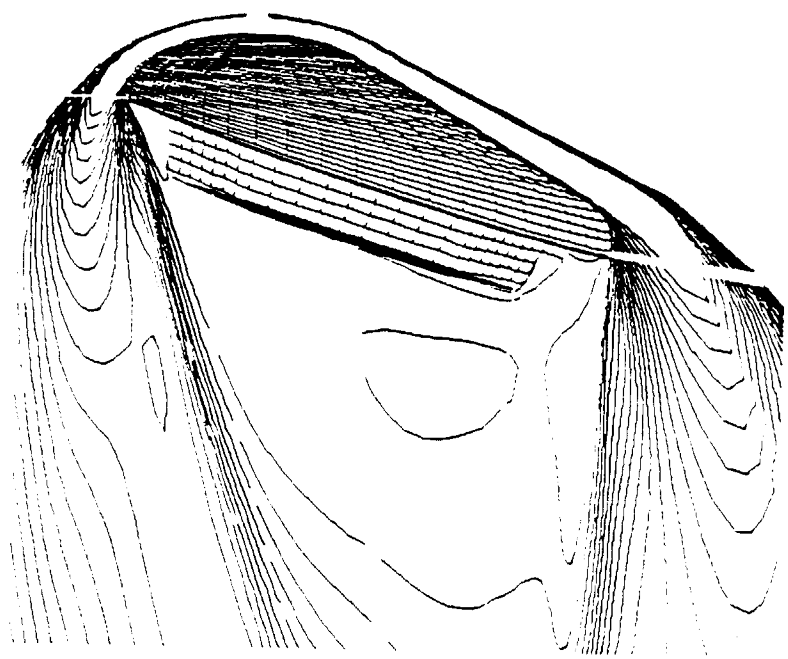
VIBRATIONAL TEMPERATURE CONTOURS
IN THE PLANE OF SYMMETRY

$M_\infty = 32$ $h = 78$ km



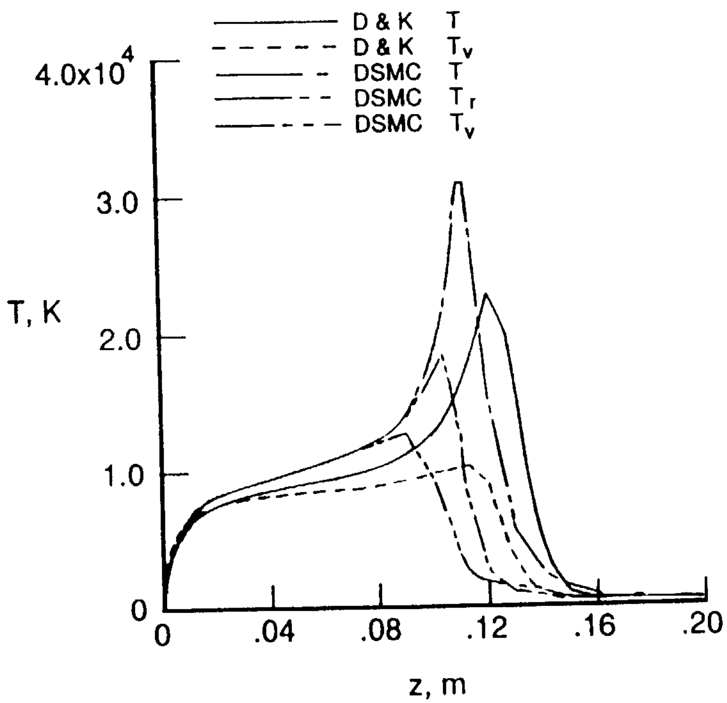
ELECTRON NUMBER DENSITY CONTOURS IN THE PLANE OF SYMMETRY

$M_\infty = 32 \qquad h = 78$ km



TEMPERATURE DISTRIBUTION ACROSS THE SHOCK LAYER

COMPARISON TO DSMC



GRID REFINEMENT STUDY