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NUMERICAL STUDY OF BASE PRESSURE CHARACTERISTIC CURVE FOR A FOUR-ENGINE CLUSTERED NOZZLE CONFIGURATION

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Abstract

Excessive base heating has been a problem for many launch vehicles. For certain design such as the direct dump of turbine exhaust in the nozzle section and at the nozzle lip of the Space Transportation Systems Engine (STME), the potential burning of the turbine exhaust in the base region have caused a tremendous concern. Two conventional approaches have been considered for predicting the base environment: (1) empirical approach, and (2) experimental approach. The empirical approach uses a combination of data correlations and semi-theoretical calculations. It works best for linear problems, simple physics and geometry. However, it is highly suspecious when complex geometry and flow physics are involved, especially when the subject is out of historical database. The experimental approach is often used to establish database for engineering analysis. However, it is qualitative at best for base flow problems. Other criticisms include the inability to simulate forebody boundary layer correctly, the interference effect from tunnel wall, and the inability to scale all pertinent parameters. Furthermore, there is a contention that the information extrapolated from subscale tests with combustion is unconservative.

One potential alternative to the conventional methods is the computational fluid dynamics (CFD), which has none of the above restrictions and is becoming more feasible due to maturing algorithms and advancing computer technology. It provides more details of the flowfield and is only limited by the computer resources. However, it has its share of criticism as a predictive tool for base environment. One major concern is that CFD has not been extensively tested for base flow problems. It is therefore imperative that CFD be assessed and benchmarked satisfactorily for base flows.

In this study, the turbulent base flowfield of a experimental investigation for a four-engine clustered nozzle is numerically benchmarked using a pressure based CFD method. Since the cold air was the medium, accurate prediction of the base pressure distributions at high altitudes is the primary goal. Other factors which may influence the numerical results such as the effects of grid density, turbulence model, differencing scheme, and boundary conditions are also being addressed. Preliminary result of the computed base pressure agreed reasonably well with that of the measurement. Basic base flow features such as the reverse jet, wall jet, recompression shock, and static pressure field in plane of impingement have been captured.

Numerical Study of Base Pressure Characteristic Curve for a Four-Engine Clustered Nozzle Configuration

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OBJECTIVE

- ☆ To benchmark a cold flow experiment for a four-engine clustered nozzle base flowfield with a CFD model

Base environment predictive methods

★ The empirical approach

- works best for linear problems, simple physics, and simple geometry
- highly suspicious when complex geometry and complex physics such as base flows are involved
- especially when the subject is out of historical database

★ The experimental approach

- often used to establish a database for engineering analysis
- qualitative at best for base flow applications
- inability to simulate forebody boundary layers
- possible interference effect from tunnel wall
- inability to scale all pertinent parameters
- information extrapolated from subscale test with combustion is unconservative

Base environment predictive methods

☆ The CFD approach

- has none of the above restrictions
- is becoming more feasible due to maturing algorithms and advancing computer technology
- provides subtle details of flow physics
- is only limited by computer resources

CFD Methodology

- Non-Staggered Grid Pressure Based Method
- Curvilinear Transformed Navier-Stokes Equations
- Predictor plus Multi-Corrector Solution Procedure for Efficient Time Marching
- Second and Fourth-Order Central Plus Upwind Dissipation for the Convective Terms
- Two-Equation Turbulence Model

Parametric Study

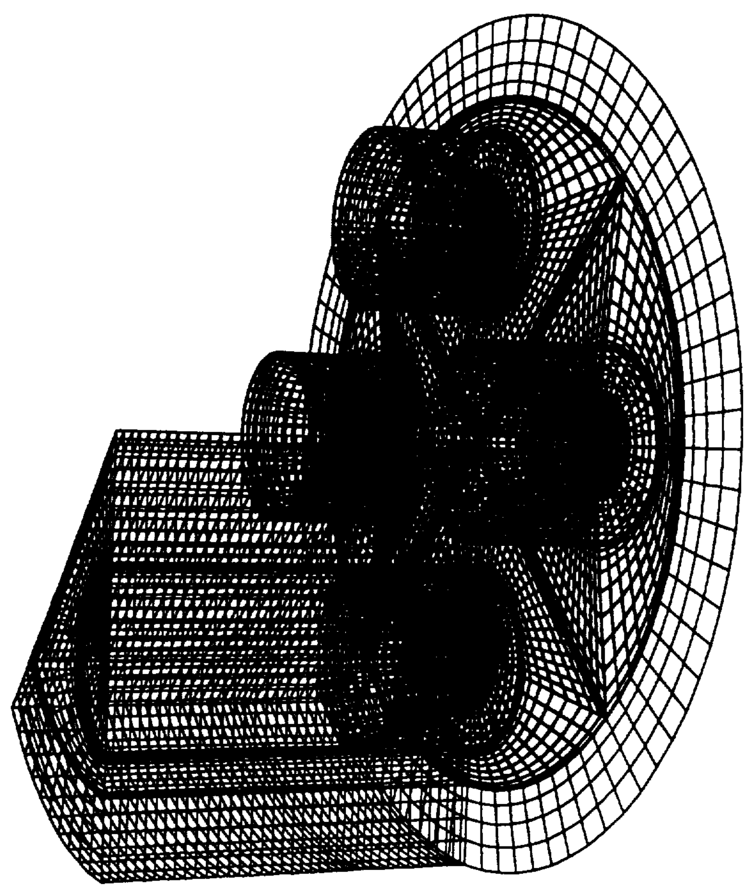
☆ Grid Resolution

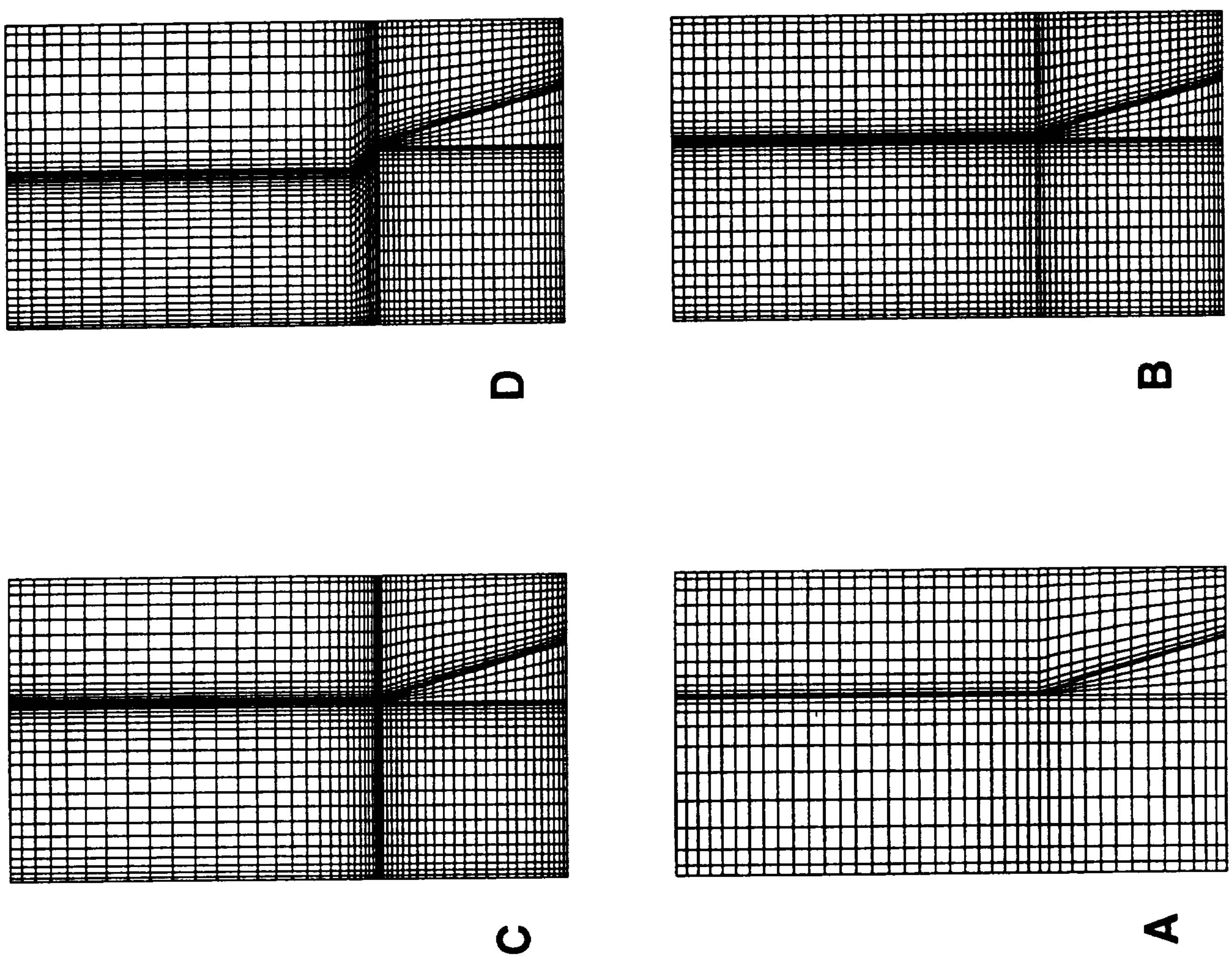
- four 2-zone 3D grid were generated
- Grid A: 34,030 points
- Grid B, C, and D: 113,202 points

☆ Turbulence Model

☆ Inlet boundary condition

☆ Convective dissipation parameter

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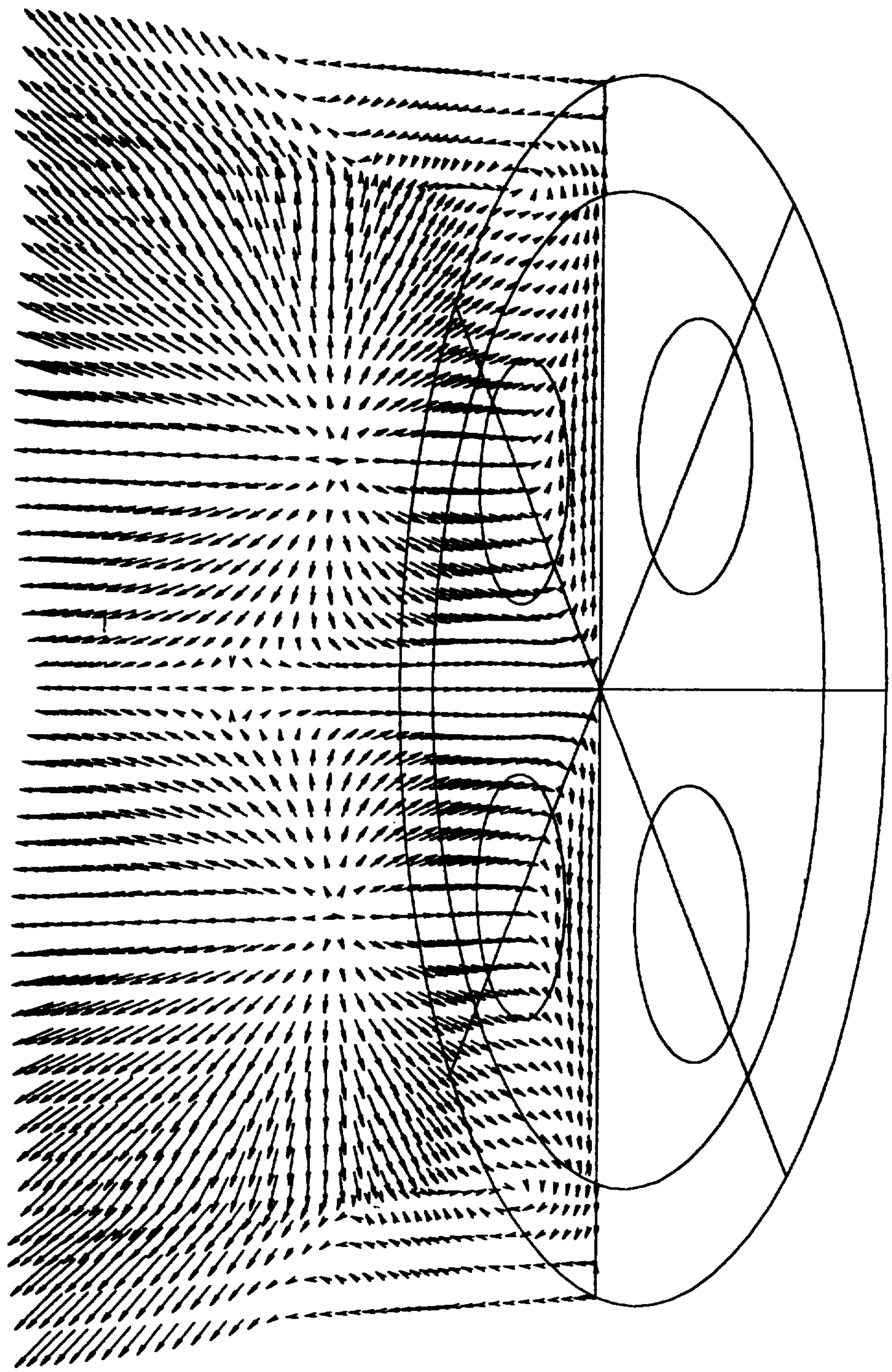
B
C
A



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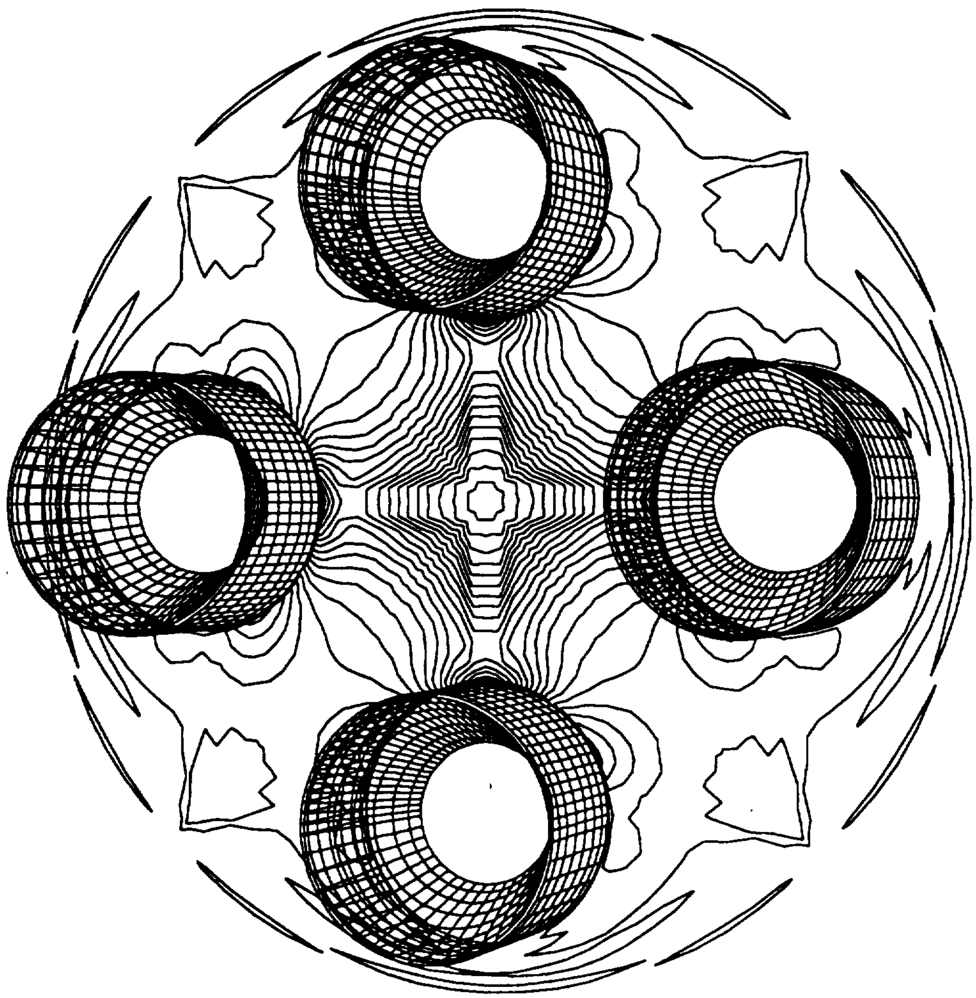

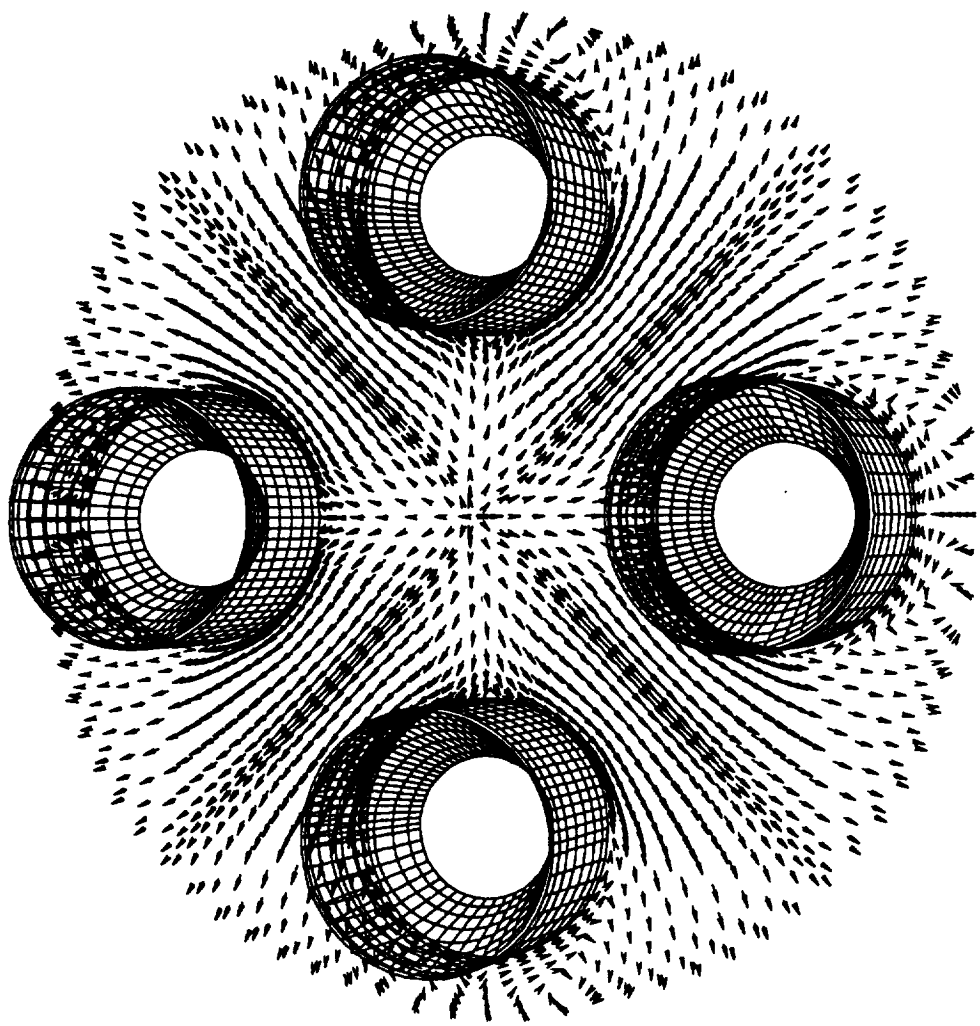

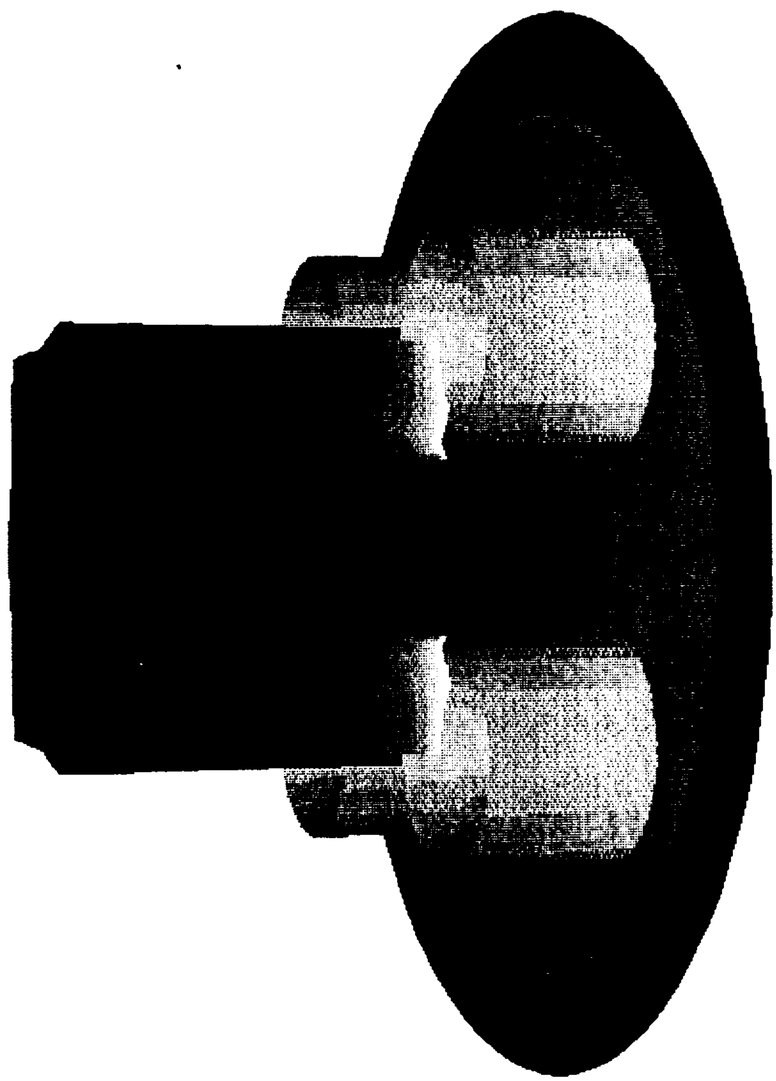

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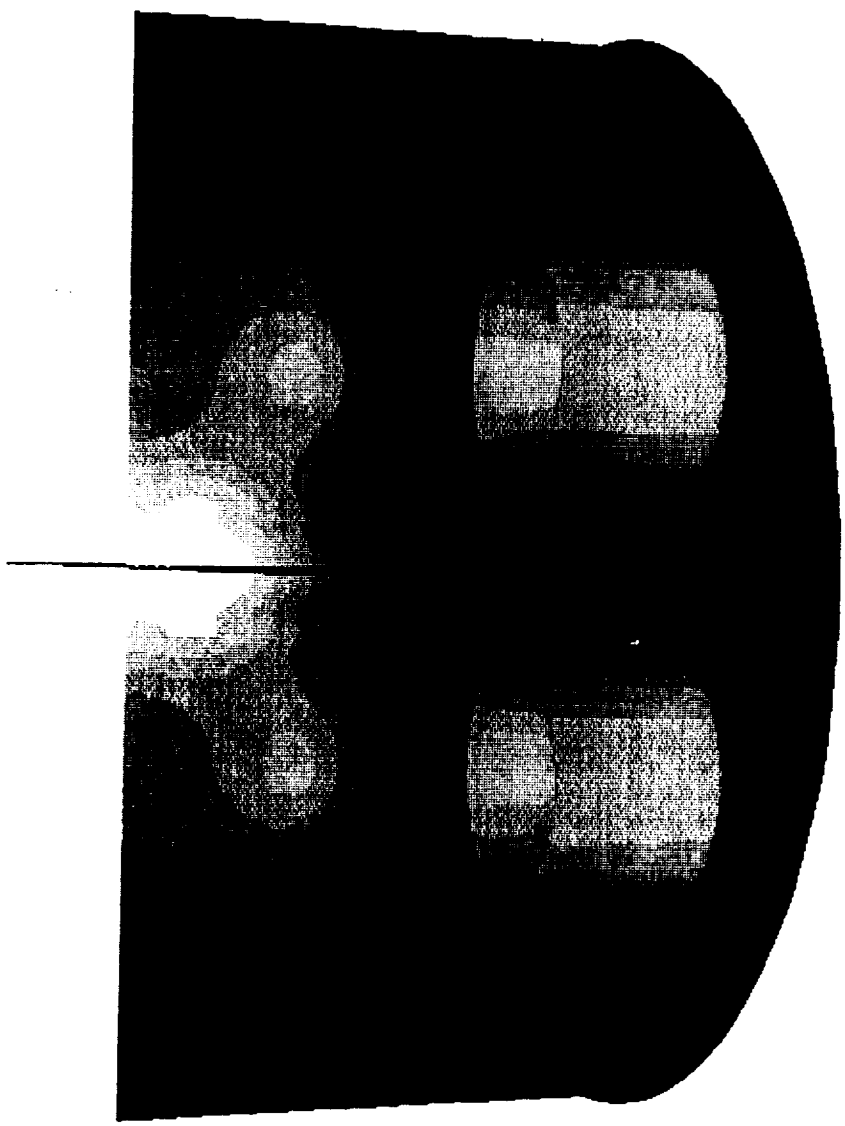

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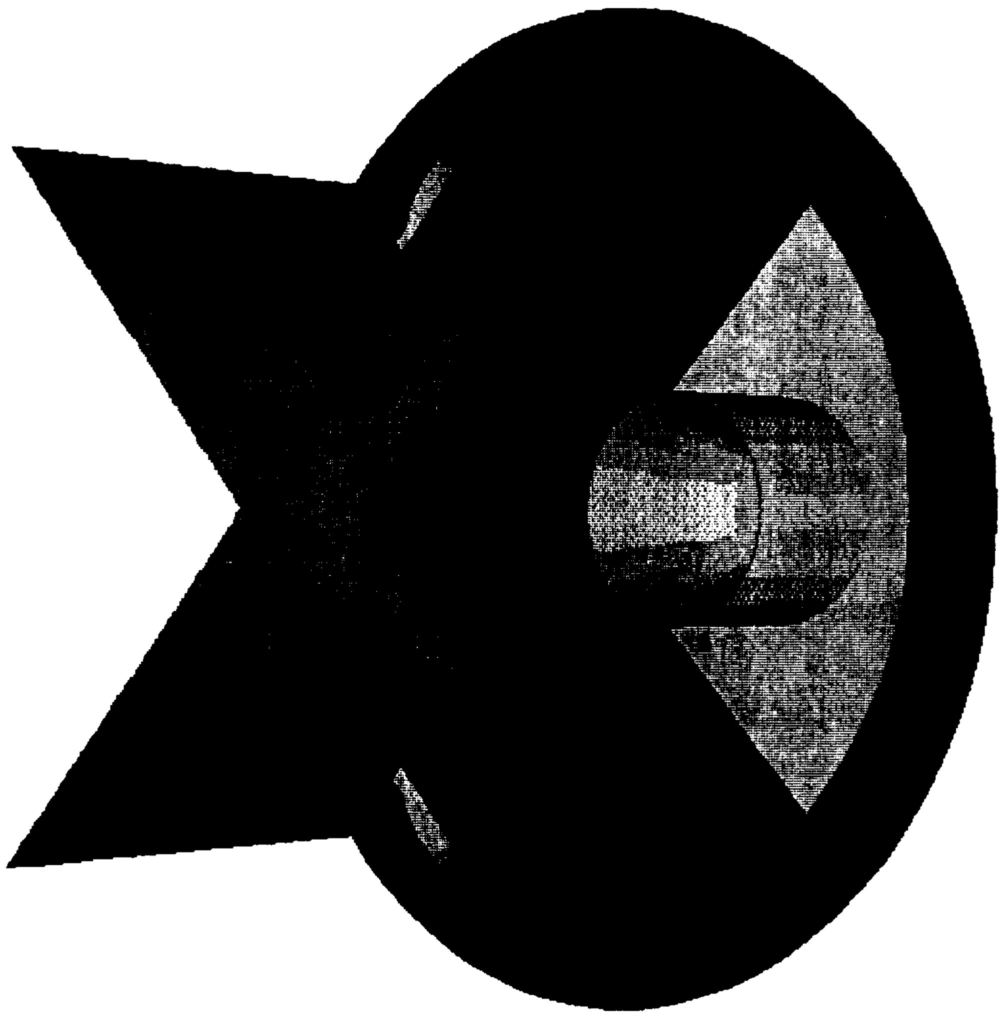

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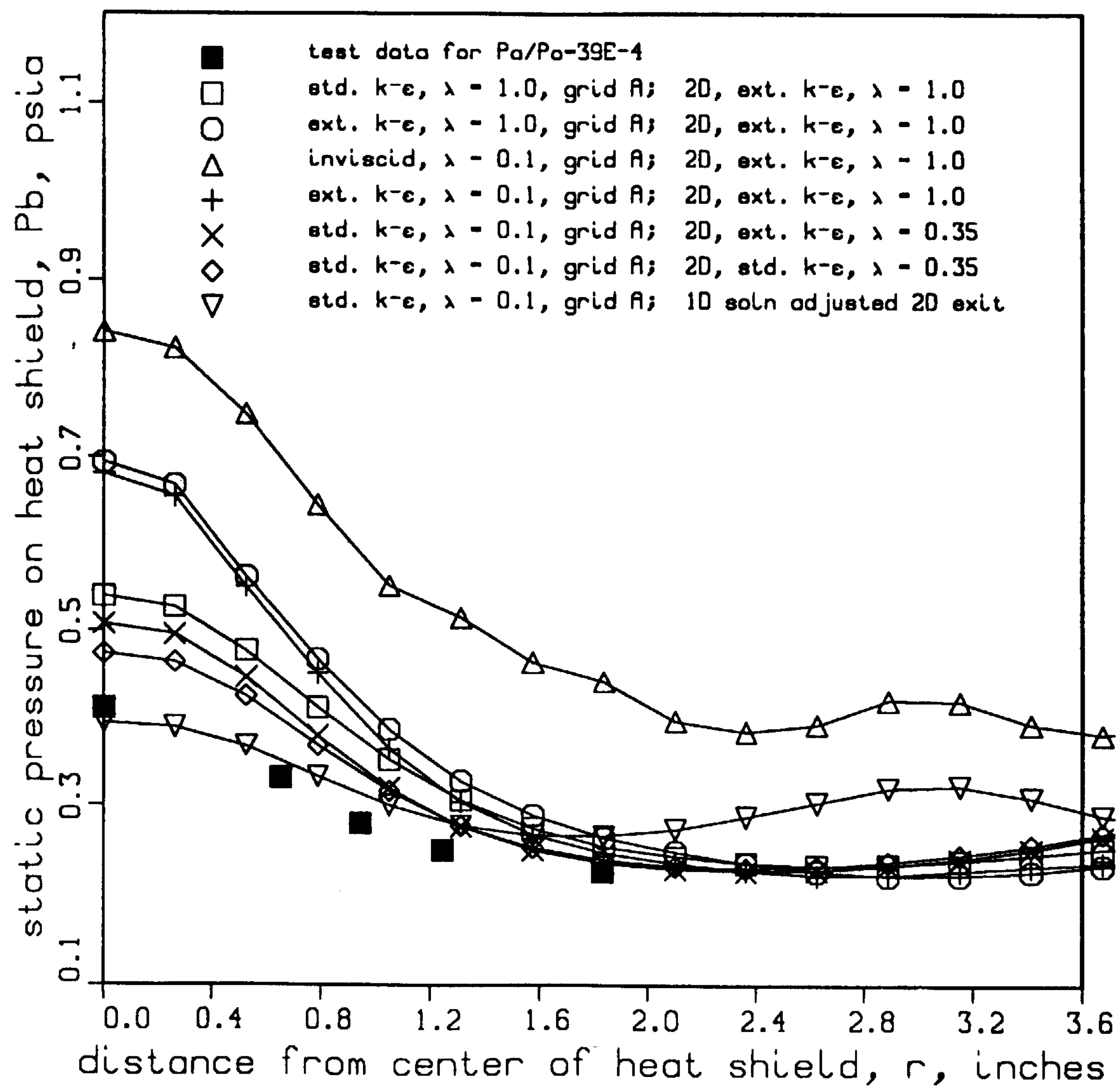
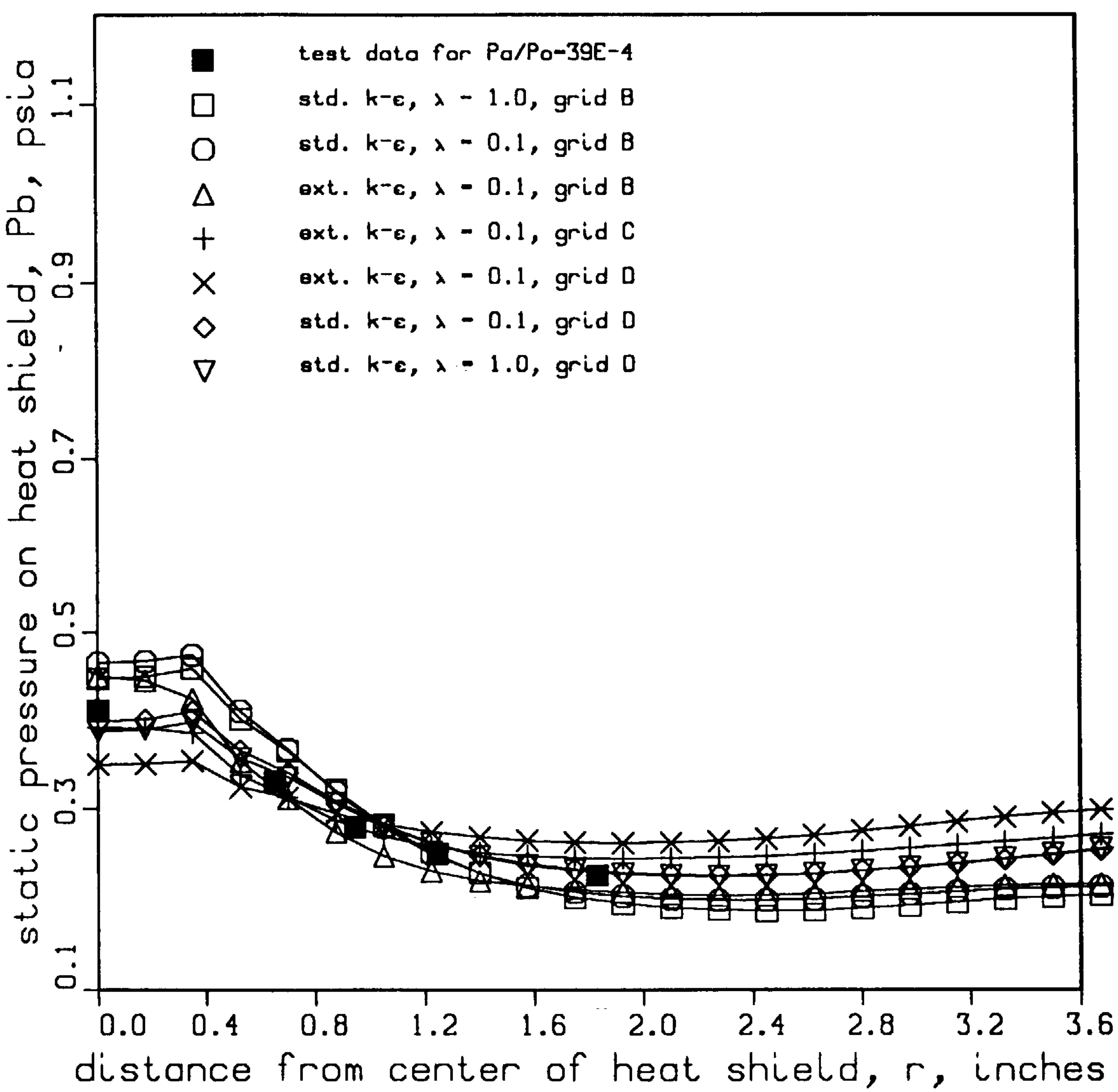
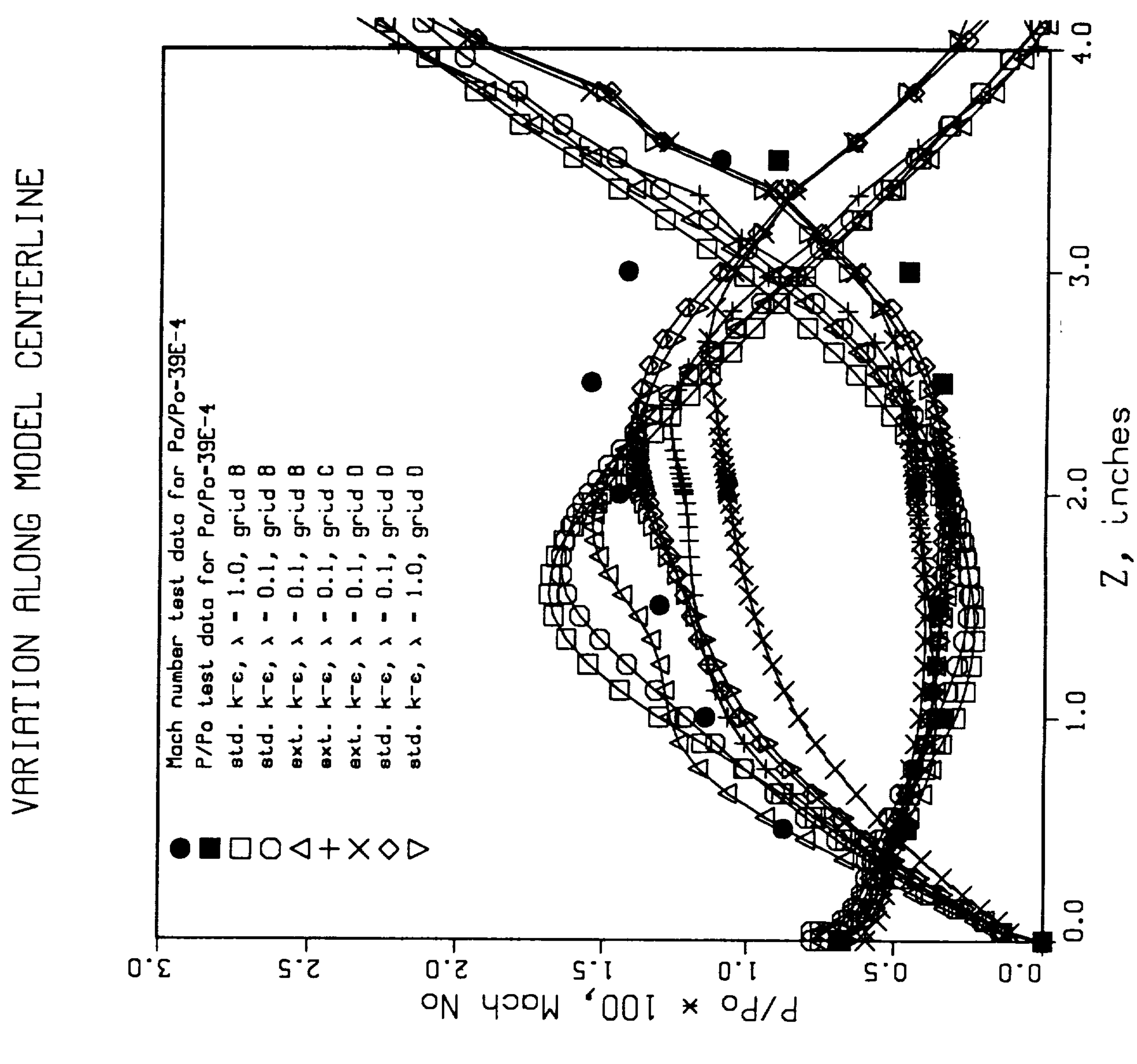
RADIAL BASE PRESSURE DISTRIBUTION

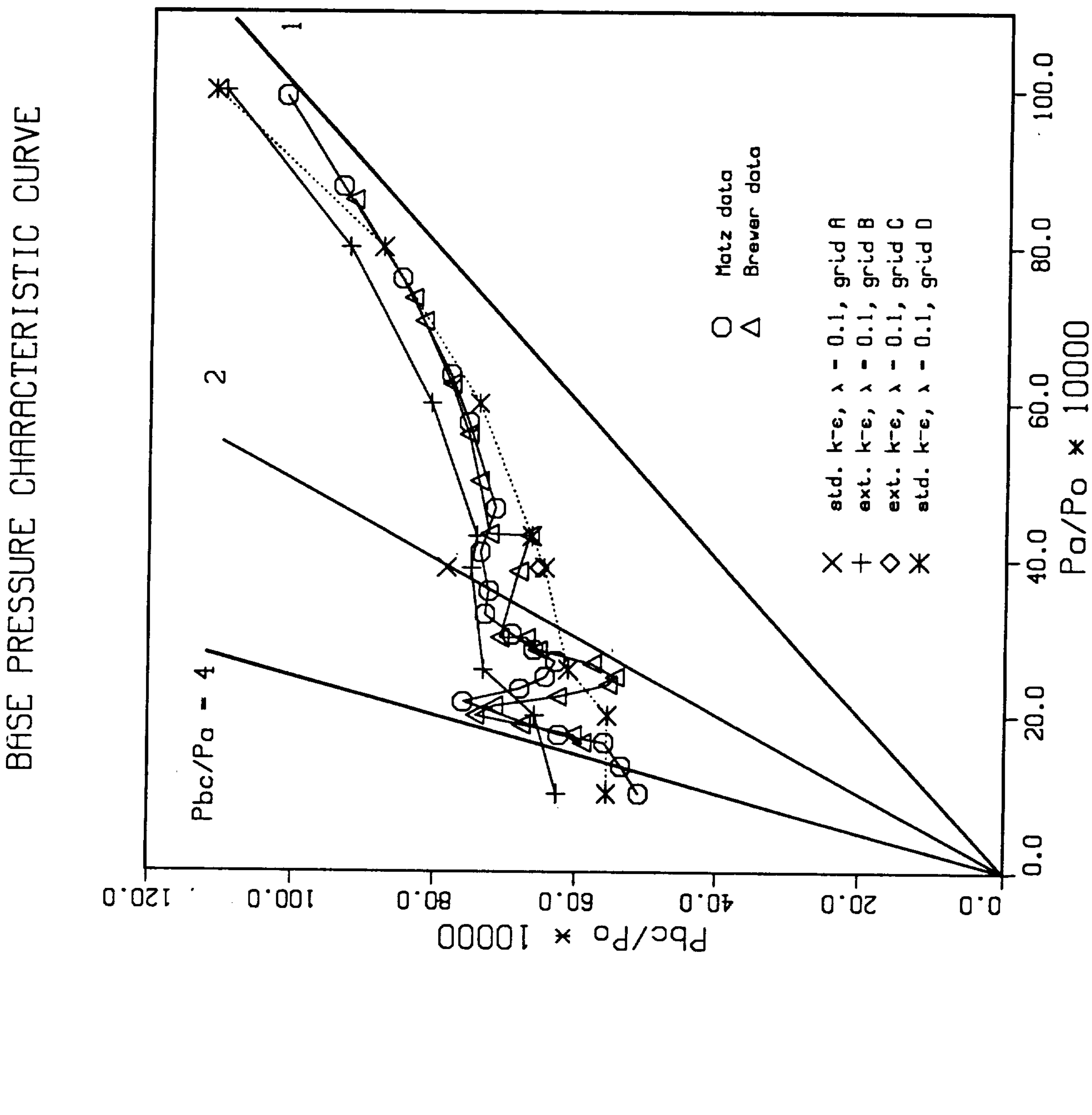


RADIAL BASE PRESSURE DISTRIBUTION





VARIATION ALONG MODEL CENTERLINE
Mach number test data for Pa/Po-39E-4
P/Po test data for Pa/Po-39E-4
std. k-ε, λ - 1.0, grid B
std. k-ε, λ - 0.1, grid B
ext. k-ε, λ - 0.1, grid B
ext. k-ε, λ - 0.1, grid C
ext. k-ε, λ - 0.1, grid D
std. k-ε, λ - 0.1, grid D
std. k-ε, λ - 1.0, grid D
P/Po × 100, Mach No
Z, inches
0.0
0.5
1.0
1.5
2.0
2.5
3.0
4.0



BASE PRESSURE CHARACTERISTIC CURVE
Pbc/Pa = 4
2
1
Matz data
Brewer data
std. k-ε, λ = 0.1, grid A
ext. k-ε, λ = 0.1, grid B
ext. k-ε, λ = 0.1, grid C
std. k-ε, λ = 0.1, grid D
Pa/Po * 10000
Pbc/Po * 10000
0.0
20.0
40.0
60.0
80.0
100.0
120.0

SUMMARY

- ☆ Qualitative base flow features such as the reverse jet, wall jet, recompression shock, and plume-plume impingement have been captured.
- ☆ Quantitative results such as the radial base flow distribution, Mach number and static pressure variations along model center line, and the base pressure characteristic curve agreed reasonable well with those of the experiment
- ☆ Parametric study indicated that the grid resolution and turbulence model are two important parameters which determine the accuracy of a base flow solution
- ☆ The potential of using CFD as a predictive tool for base environment prediction is demonstrated

Future work

- ☆ Grid adapted flowfield solution
- ☆ Hot flow multi-engine base flowfield benchmarking
- ☆ Combustion flow multi-engine base flowfield benchmarking
- ☆ Flight vehicle forbody and base environment simulation

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