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3D FLOW ANALYSIS OF THE ALTERNATE SSME HPOT TAD

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ABSTRACT

This paper describes the results of numerical flow analyses performed in support of design development of the Space Shuttle Main Engine Alternate High Pressure Oxidizer Turbine Turn–around duct (TAD). The flow domain has been modeled using a 3D, Navier–Stokes, general purpose flow solver. The goal of this effort is to achieve an alternate TAD exit flow distribution which closely matches that of the baseline configuration. 3D Navier Stokes CFD analyses were employed to evaluate numerous candidate geometry modifications to the TAD flowpath in order to achieve this goal. The design iterations are summarized, as well as a description of the computational model, numerical results and the conclusions based on these calculations.

Workshop for Computational Fluid Dynamics Applications in Rocket Propulsion, NASA MSFC

3D Flow Analysis of the Alternate SSME HPOT TAD

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April 20, 1993

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Outline

I. Problem Overview

II. Background – Differences Between Rocketdyne Baseline and ATD HPOT TAD

- Geometrical
- Aerodynamic

III. Approach

- Minimize Differences using CFD tools to predict flowfield differences

IV. Status

- Modified ATD TAD Configuration Defined Which Emulates Rocketdyne Baseline

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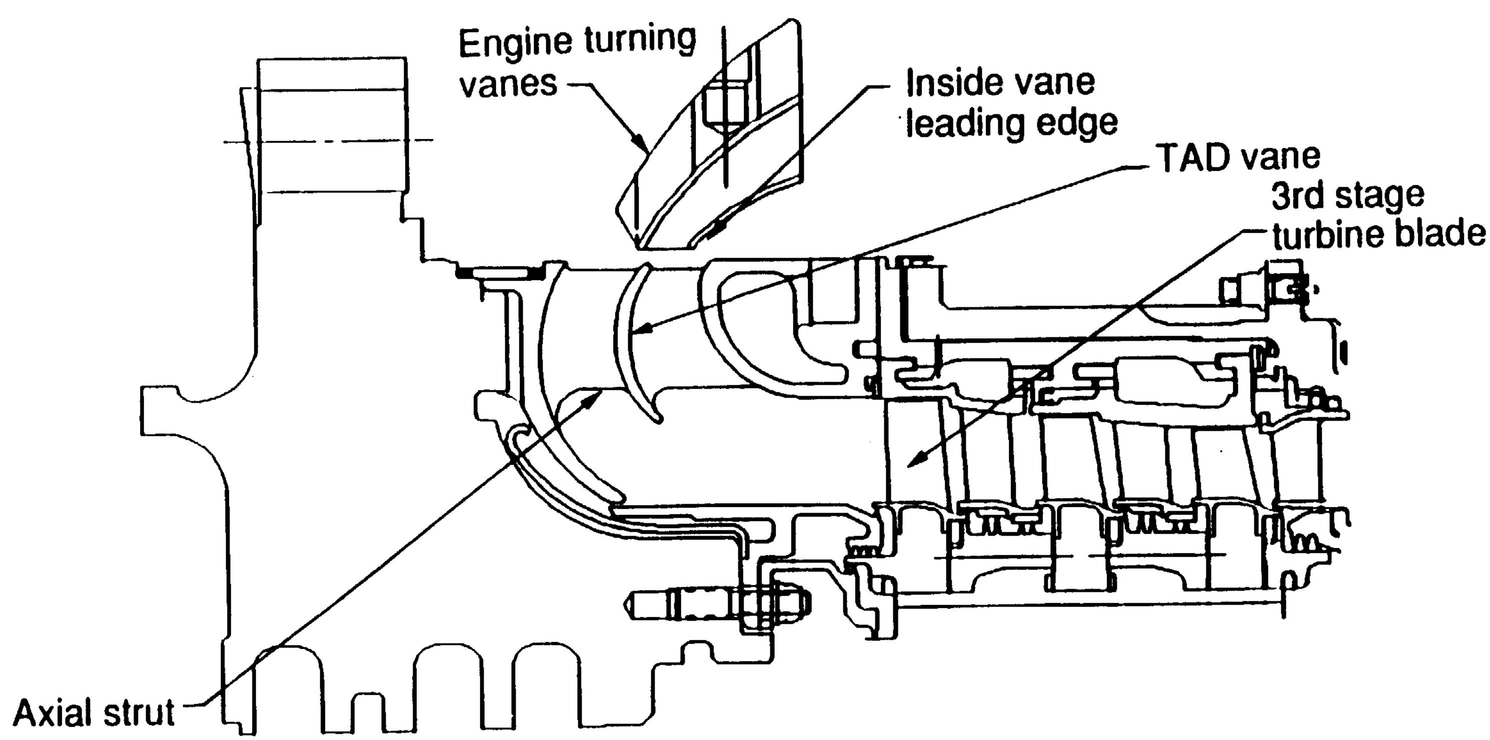
Problem Overview

Engine Turning Vane Cracking Investigation

- Engine turning cracking occurs at inside vane leading edge, pressure and suction side.

Heat Exchanger



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Problem Overview

- Engine turning vane cracking occurs with P&W HPOTP

- Fractography analysis indicates cracking is due to HCF.

- Fault tree failure analysis indicates flow environment induced loads result in HCF incidents.

- Flow environment induced loads may result from:

  - Interface velocity distribution
  - Unsteadiness/turbulence
  - Turbine thermal profiles

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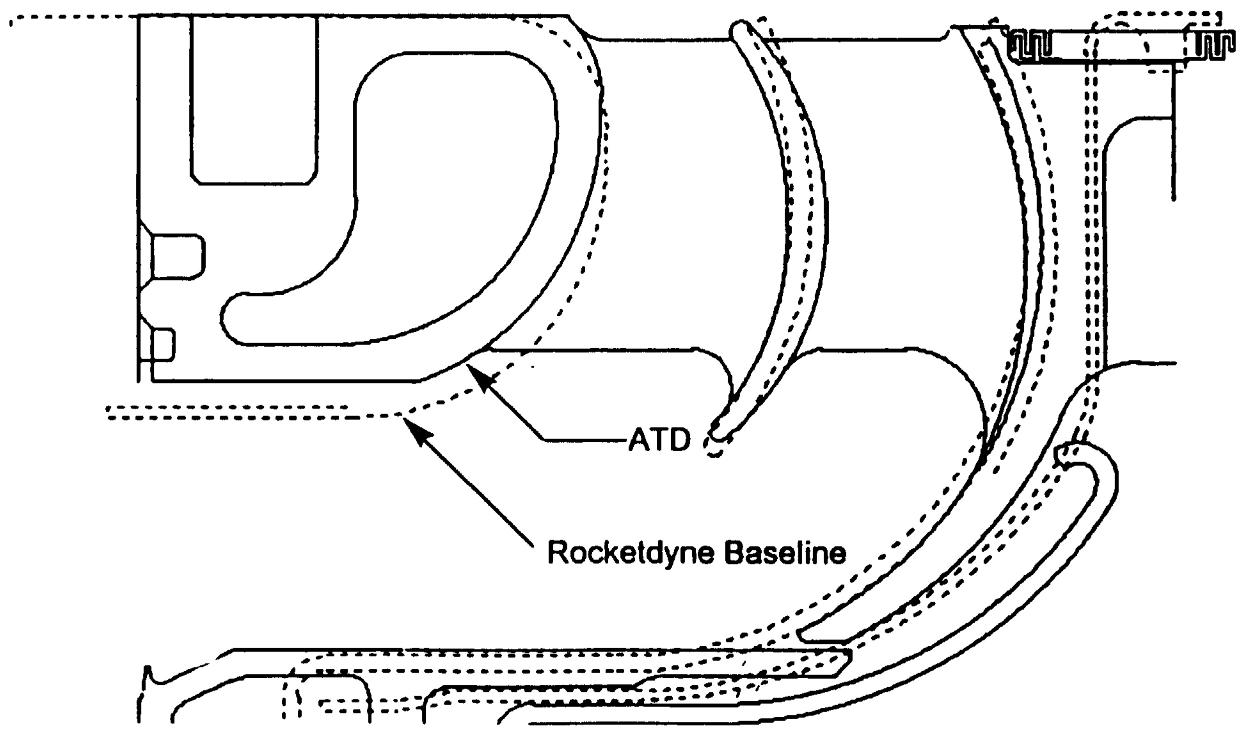
Geometrical Differences



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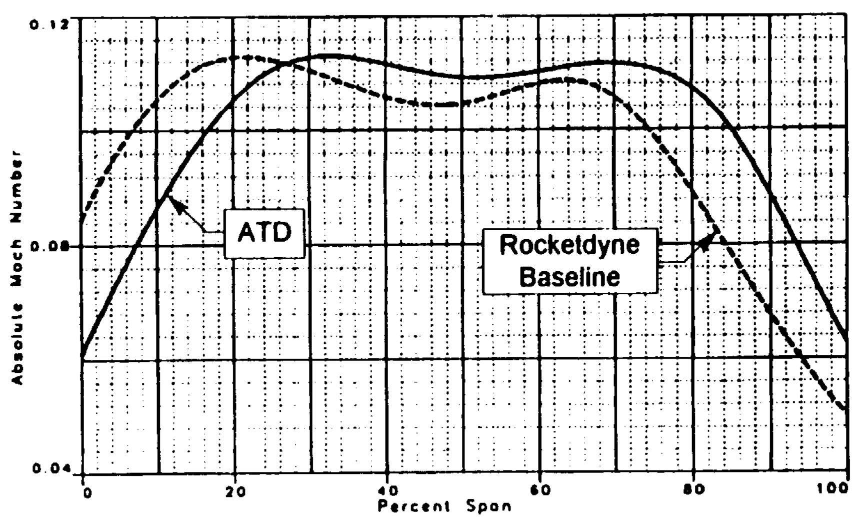
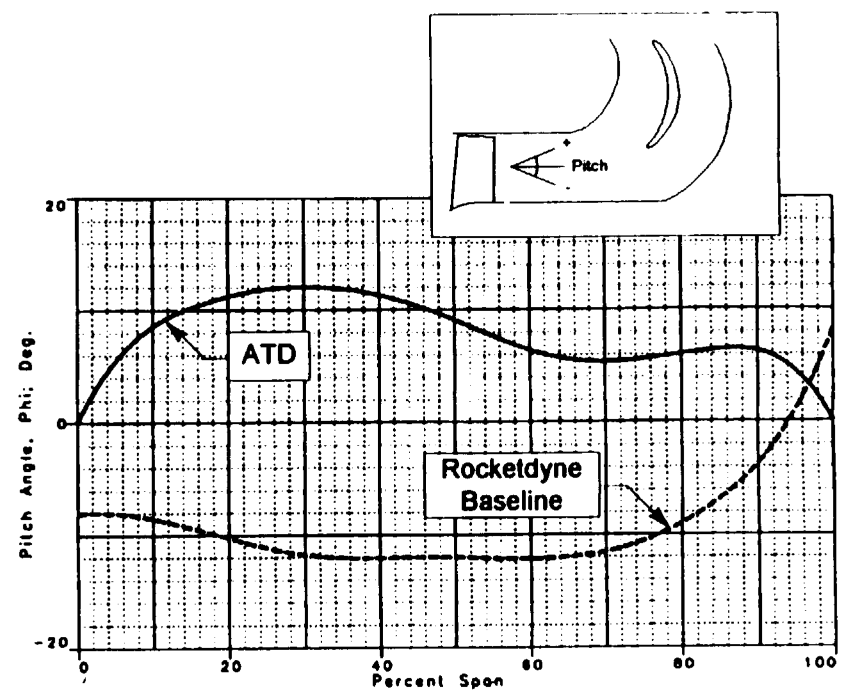
TAD Inlet Gas Profile Differences





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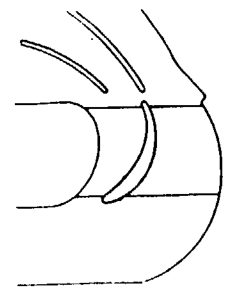
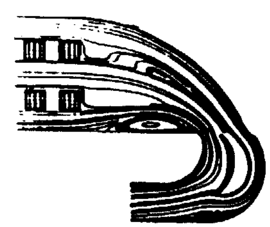
CFD Support for TAD Modification – Design Process

Geometry Definition



CFD Analysis



TAD Modified to Match Baseline Interface Conditions

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Description of STAR–CD

- General Purpose, 3D Navier Stokes Flow Solver
- Body–Fitted, Unstructured Mesh allows for modelling of Complex Geometries
- Rapid Turn–Around
- TAD Calibration Cases
    - Arizona State University Test Case (D.Metzger)
    - NASA–Ames Test Case (D.Monson)

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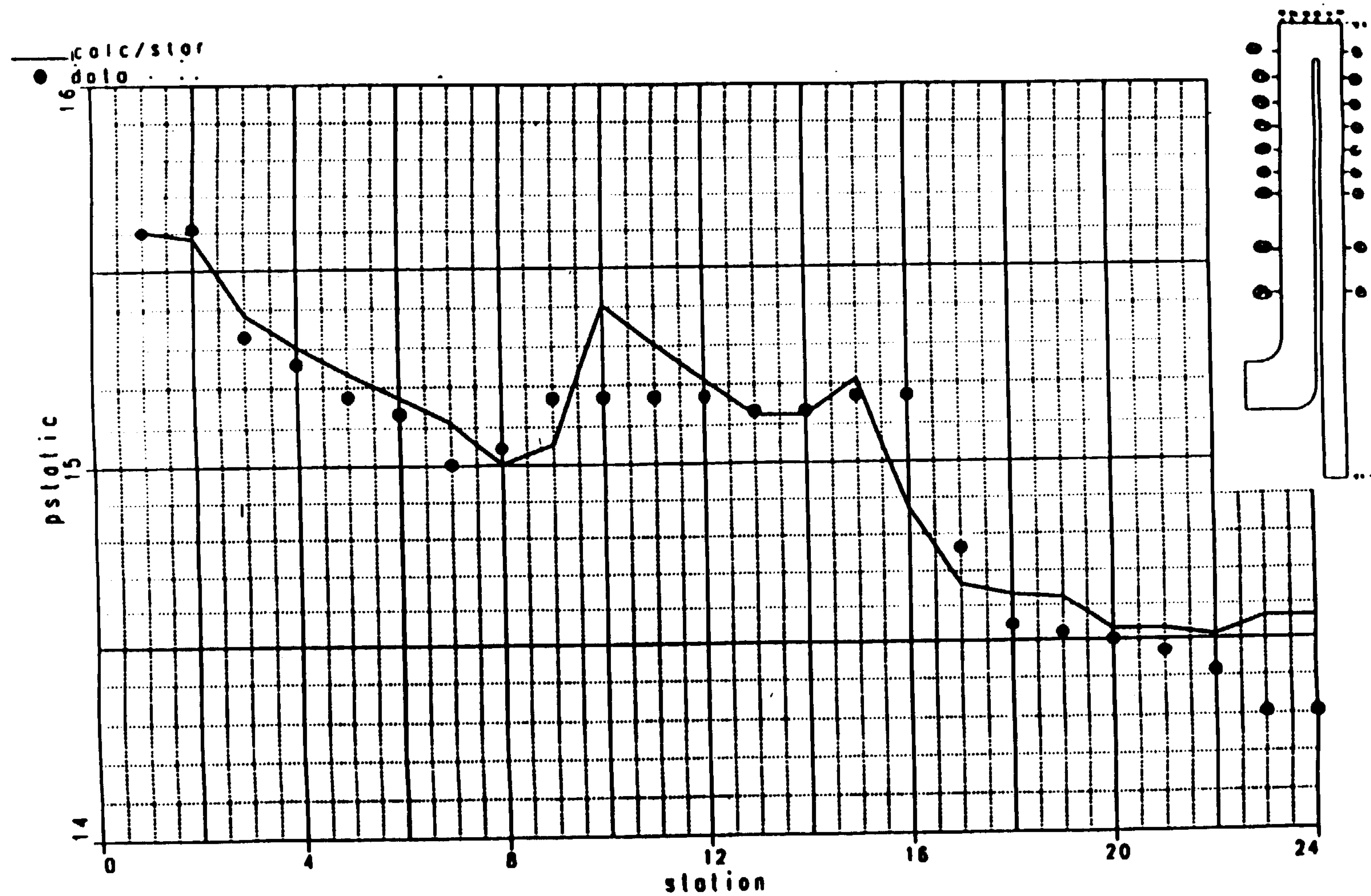
Code Verification



Measured / CFD Predicted Static Pressure With Trip Strips

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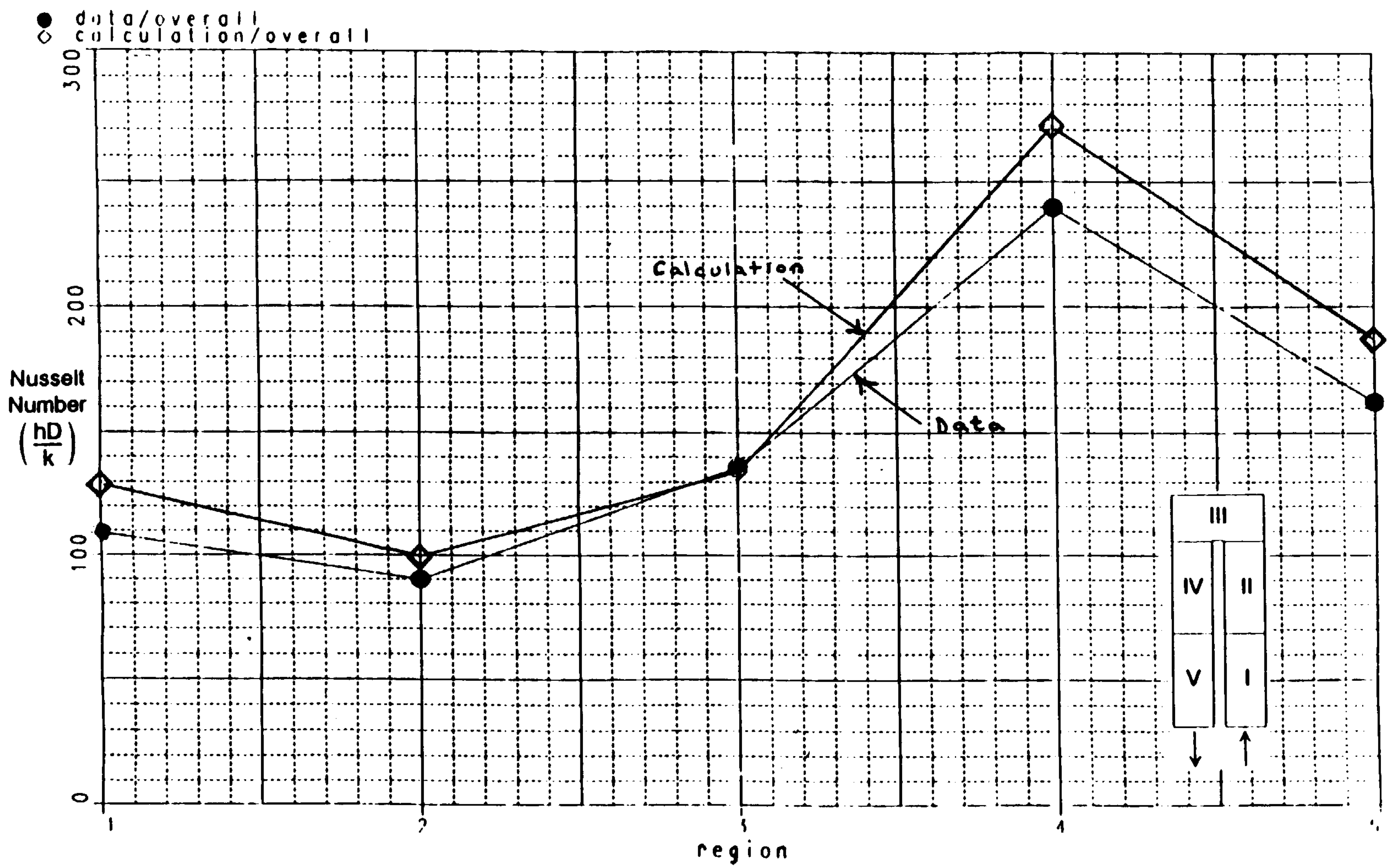
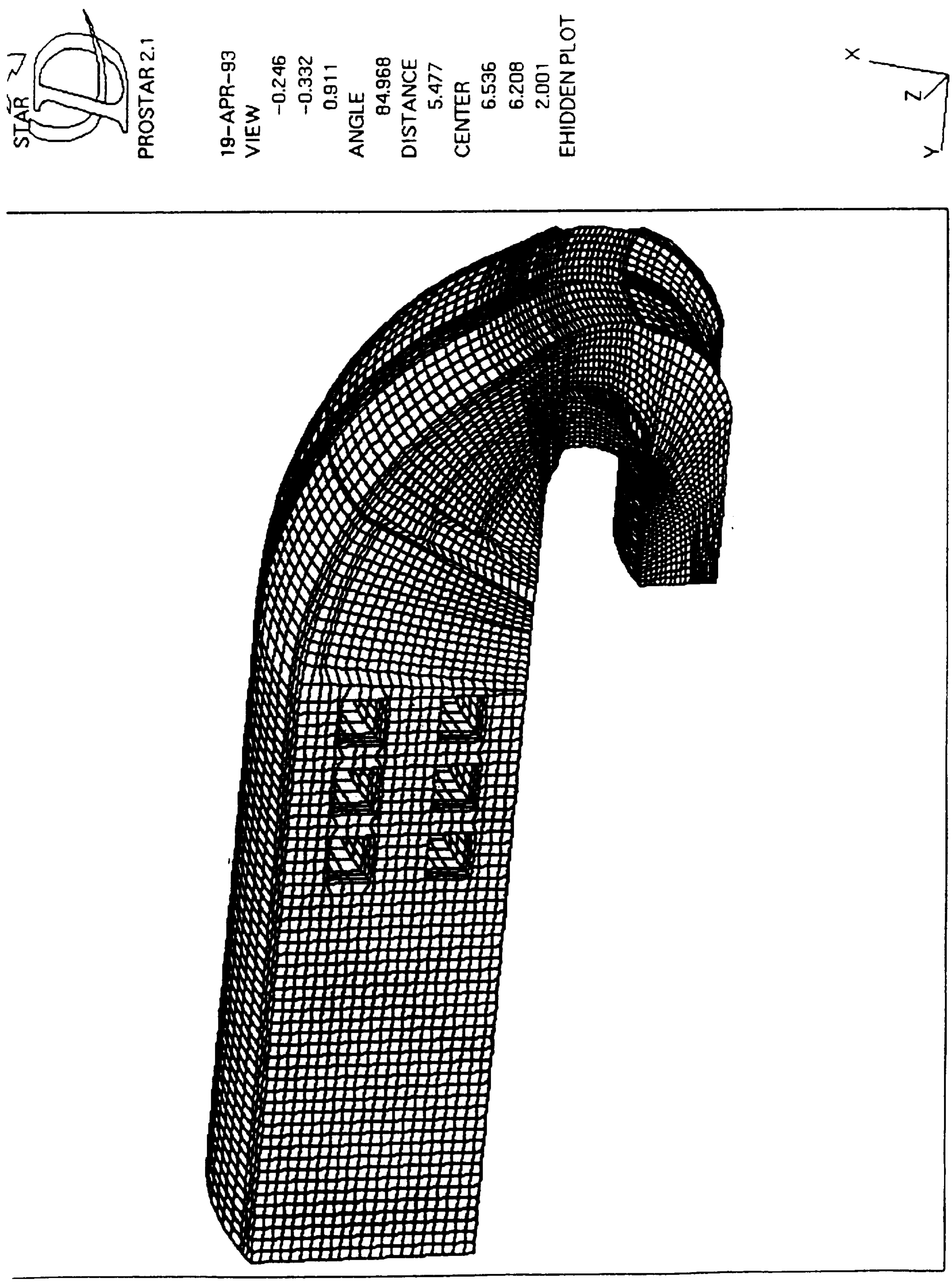
Code Verification



Measured vs Predicted Nusselt Number For Model Without Trip Strips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PROSTAR 2.1
19-APR-93
VIEW
-0.246
-0.332
0.911
ANGLE
84.968
DISTANCE
5.477
CENTER
6.536
6.208
2.001
EHIDDEN PLOT
X
Y
Z

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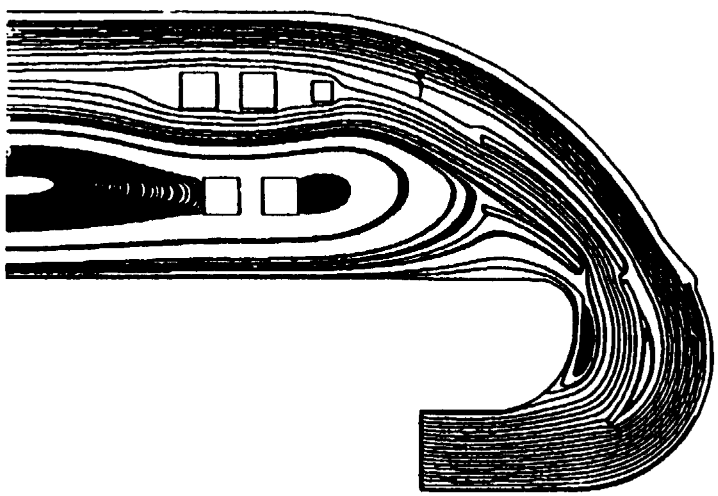
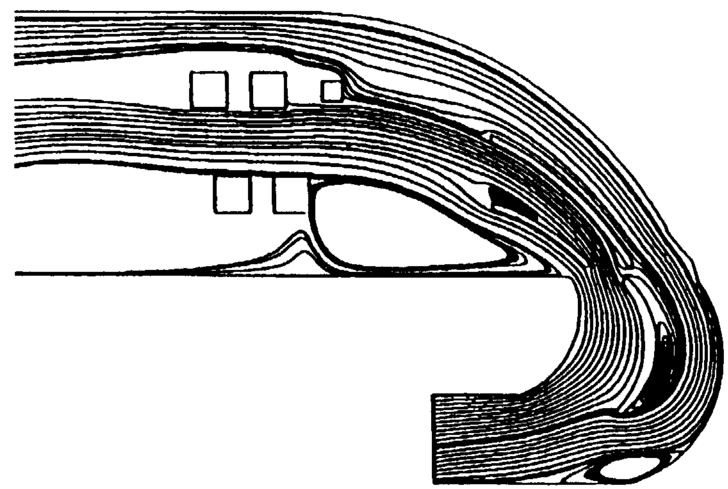
Predicted TAD Flow Pattern Differences

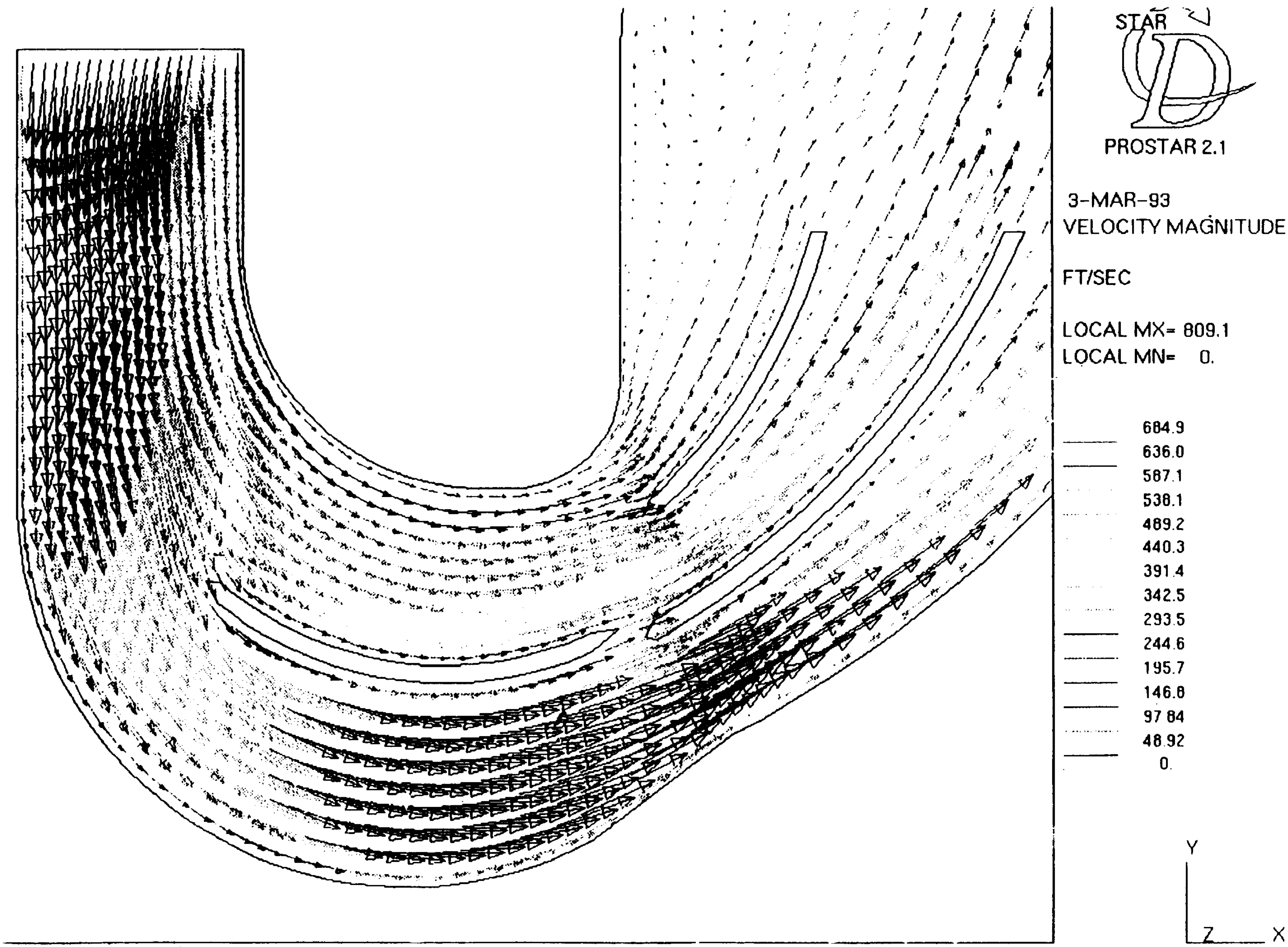
Rocketdyne Baseline



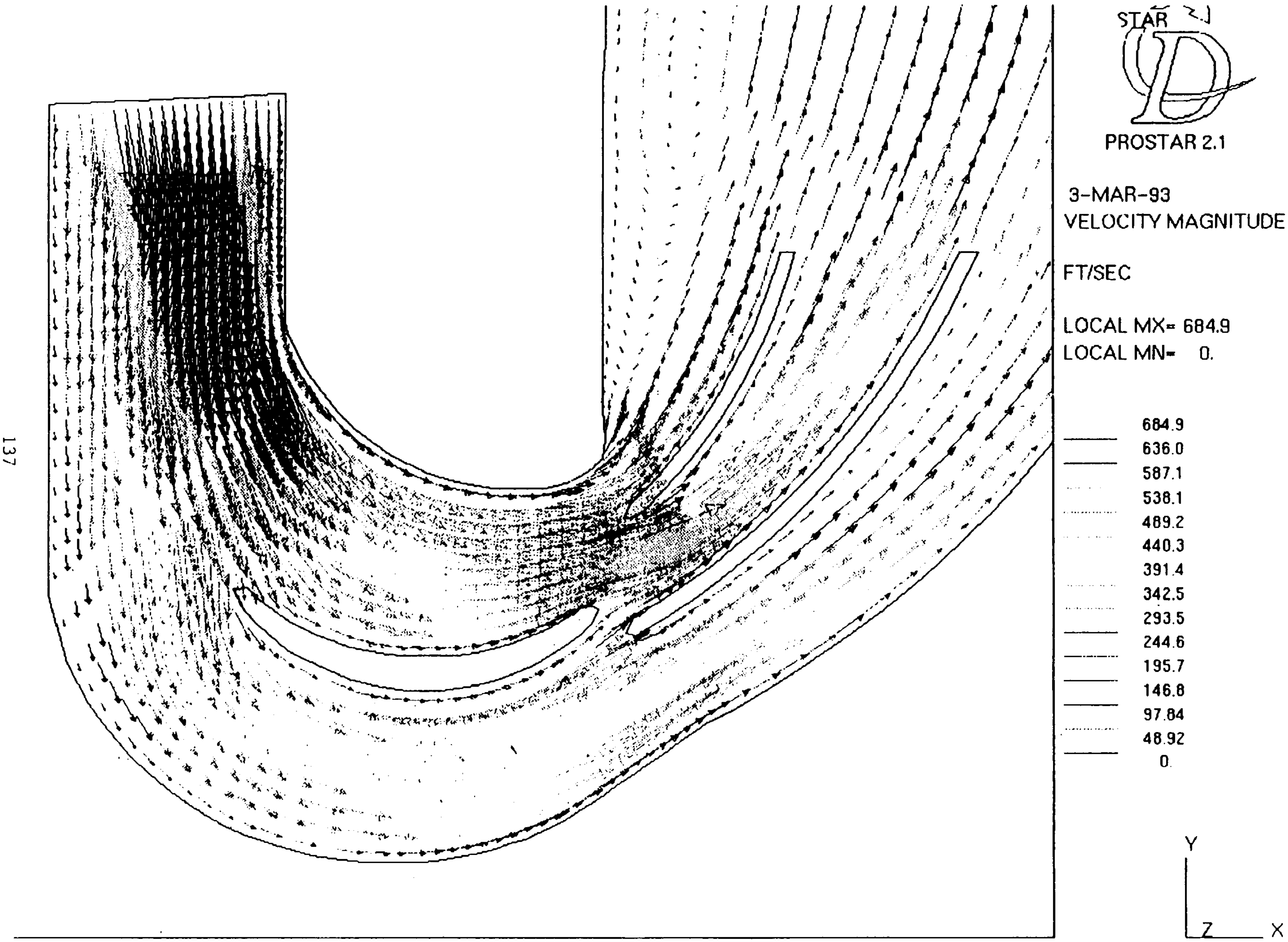
ATD



REFLEQX Axisymmetric Analysis (MSFC)



rocketdyne model..



Baseline ATD...converged

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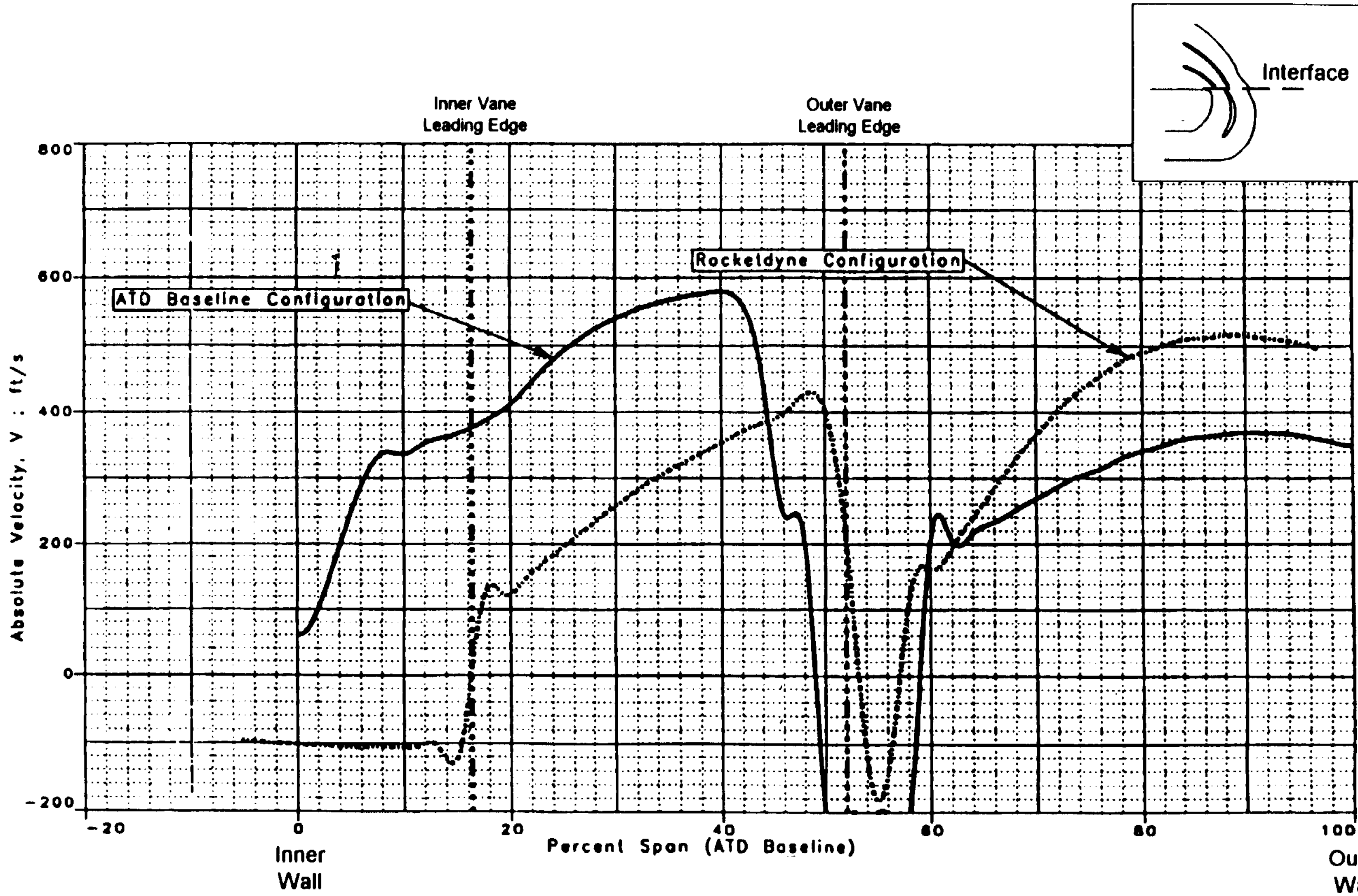
Differences in Velocity Distributions at Interface Plane



REFLEQX Axisymetric Analysis (MSFC)

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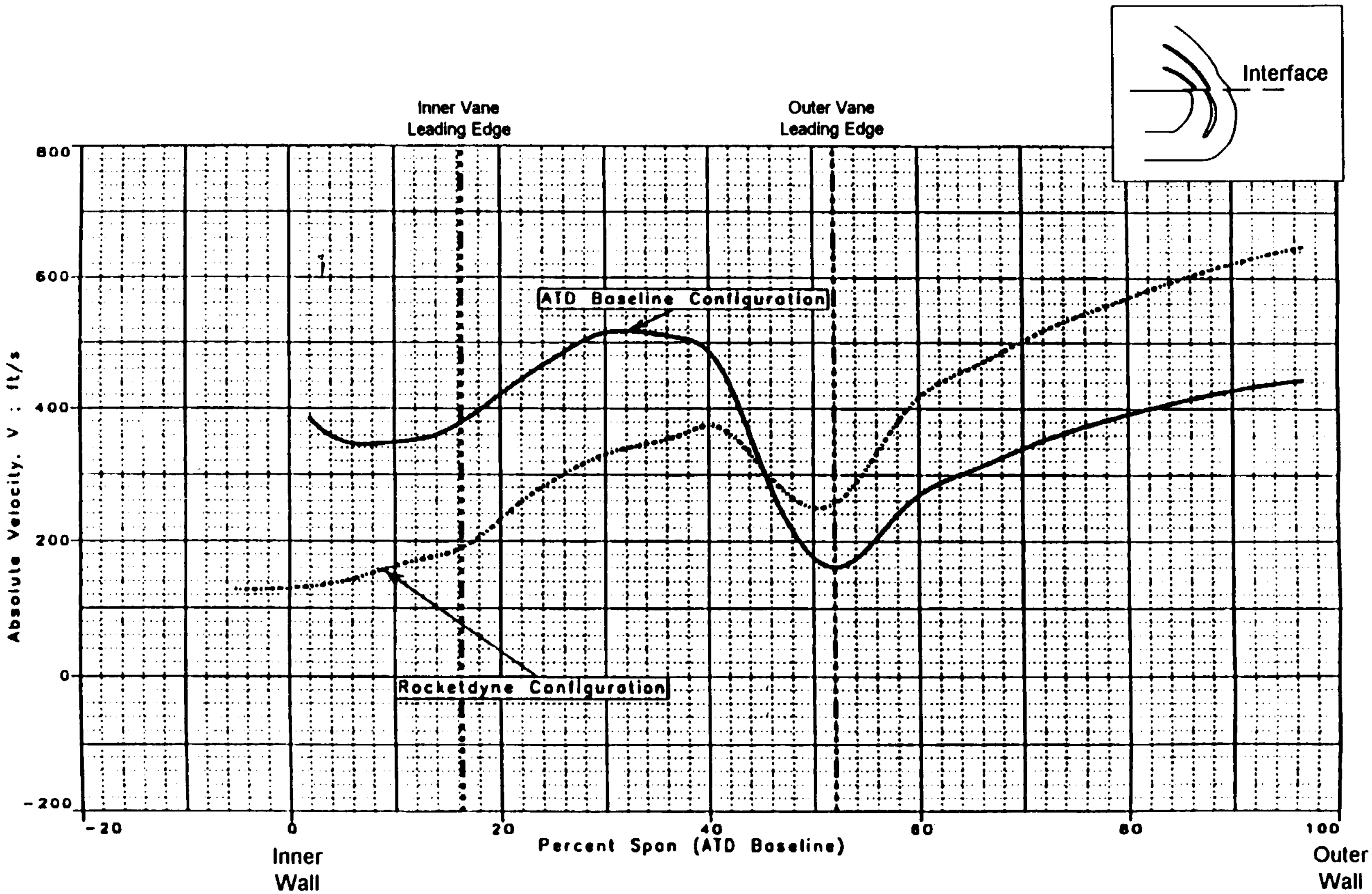
Differences in Velocity Distributions at Interface Plane



3D Analysis

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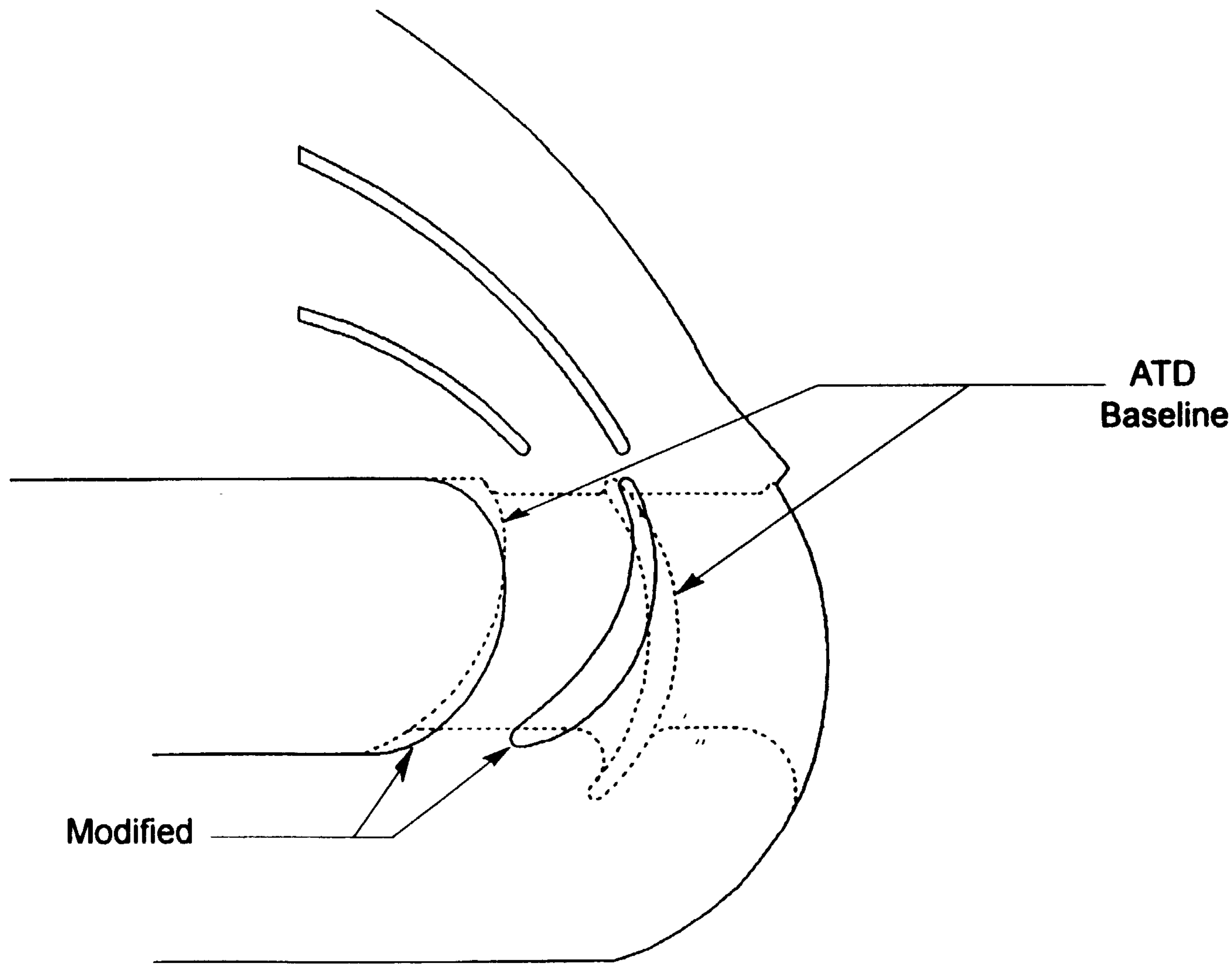
Splitter and Inner Tum Contours Modified to Reduce Velocity Near Inner Vane



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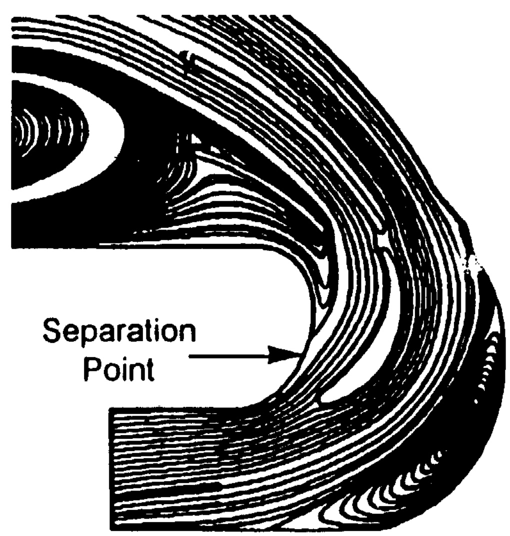
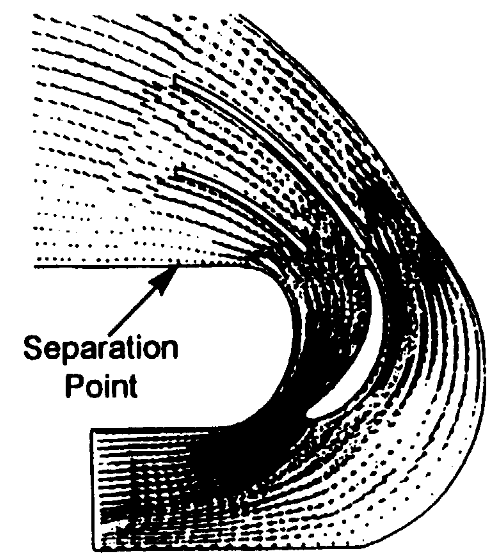
CFD Models Differ in Prediction of Flow Separation For Modified TAD

Axisymmetric Model



3D Model



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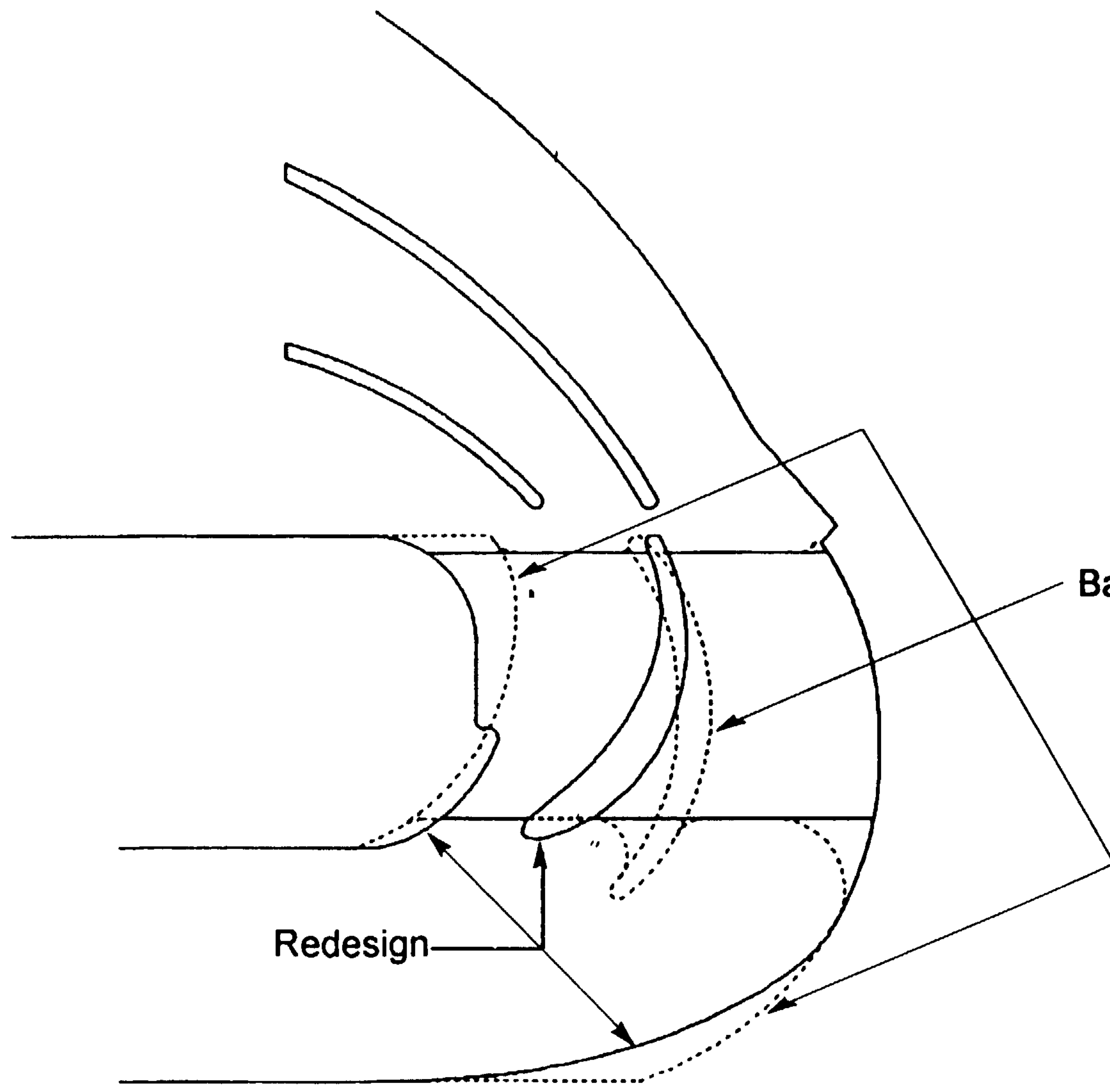
ATD TAD Redesign Configuration



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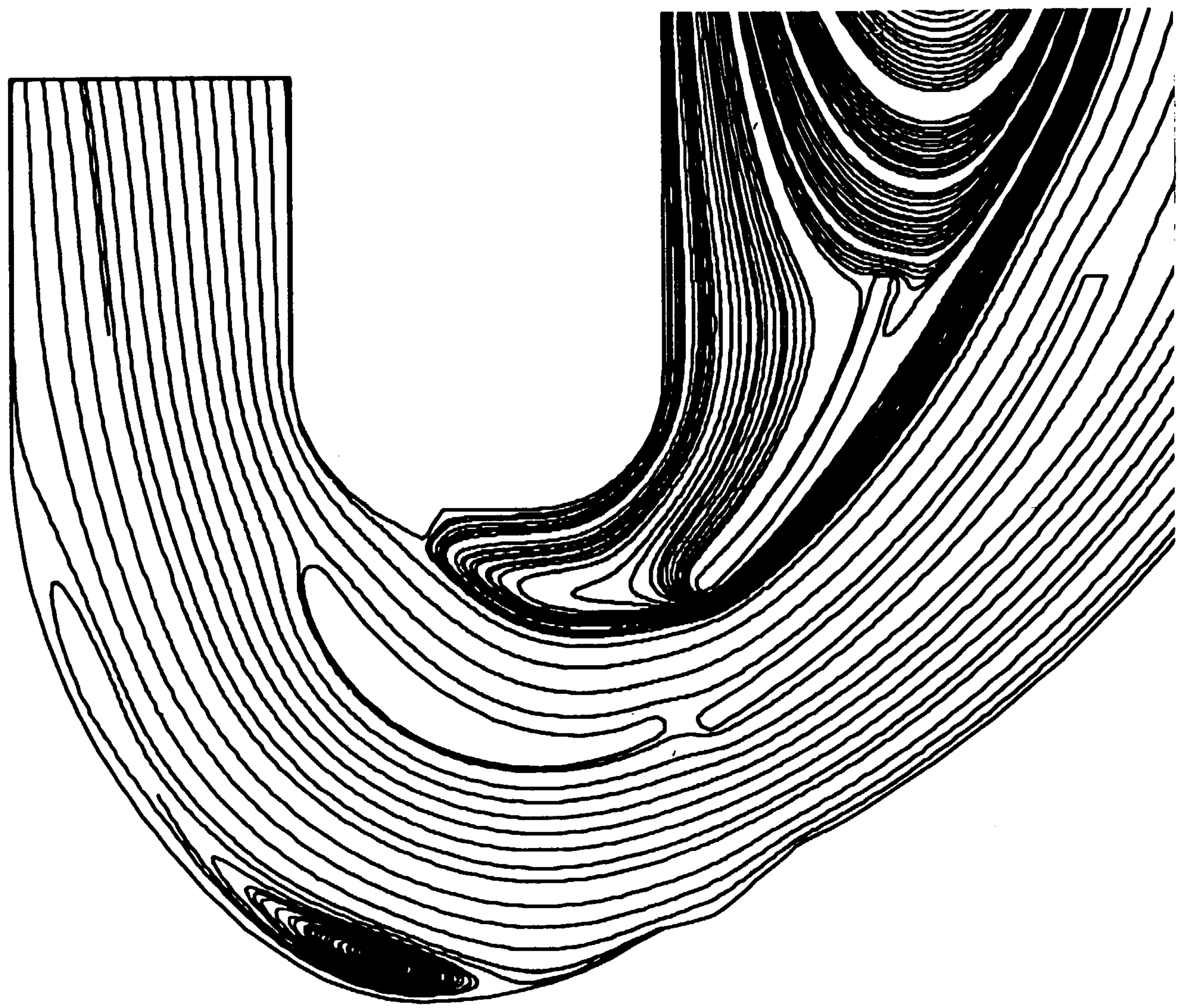
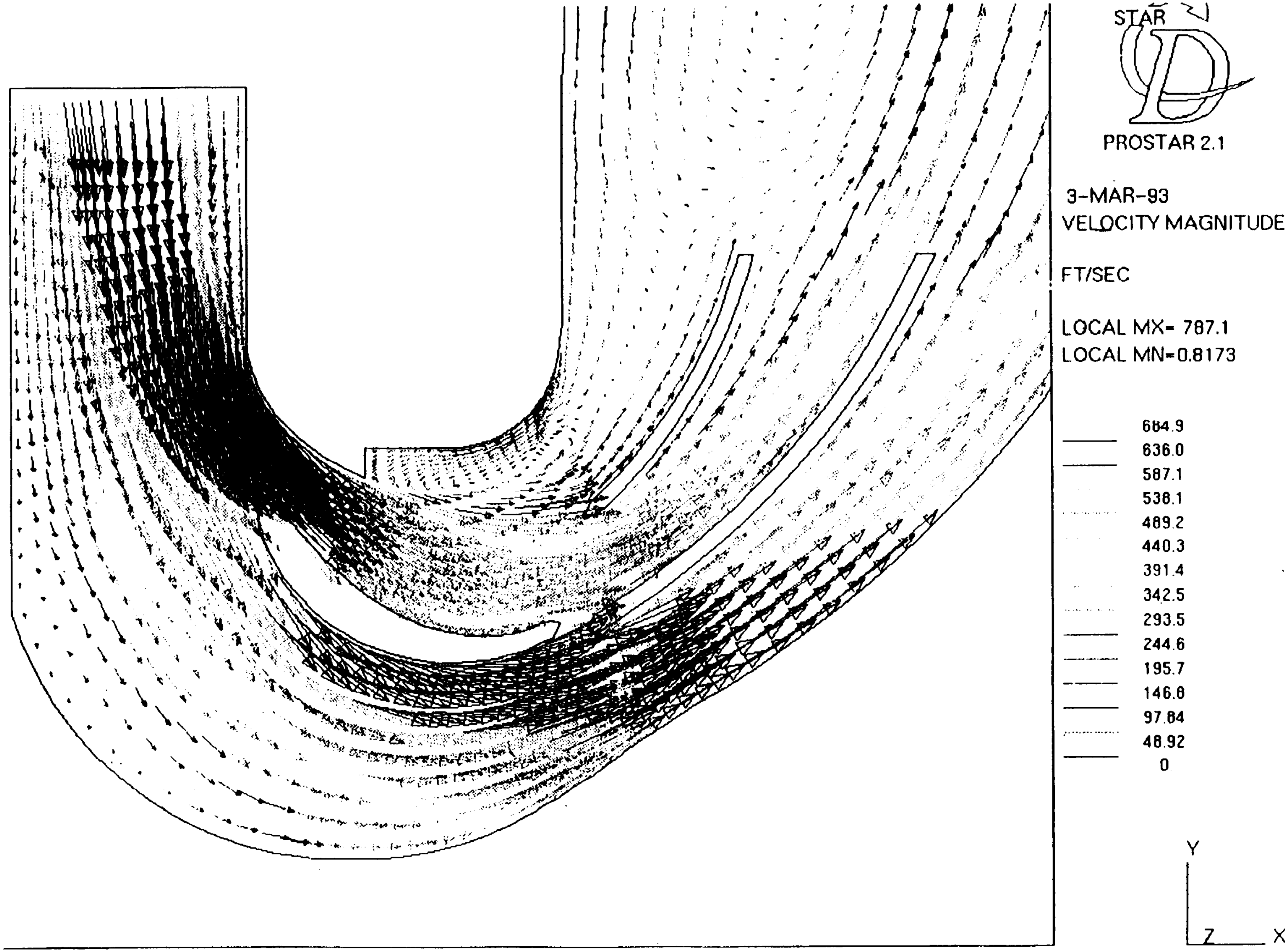
ATD Redesign – 2D Axisymmetric Analysis





ATD Redesign

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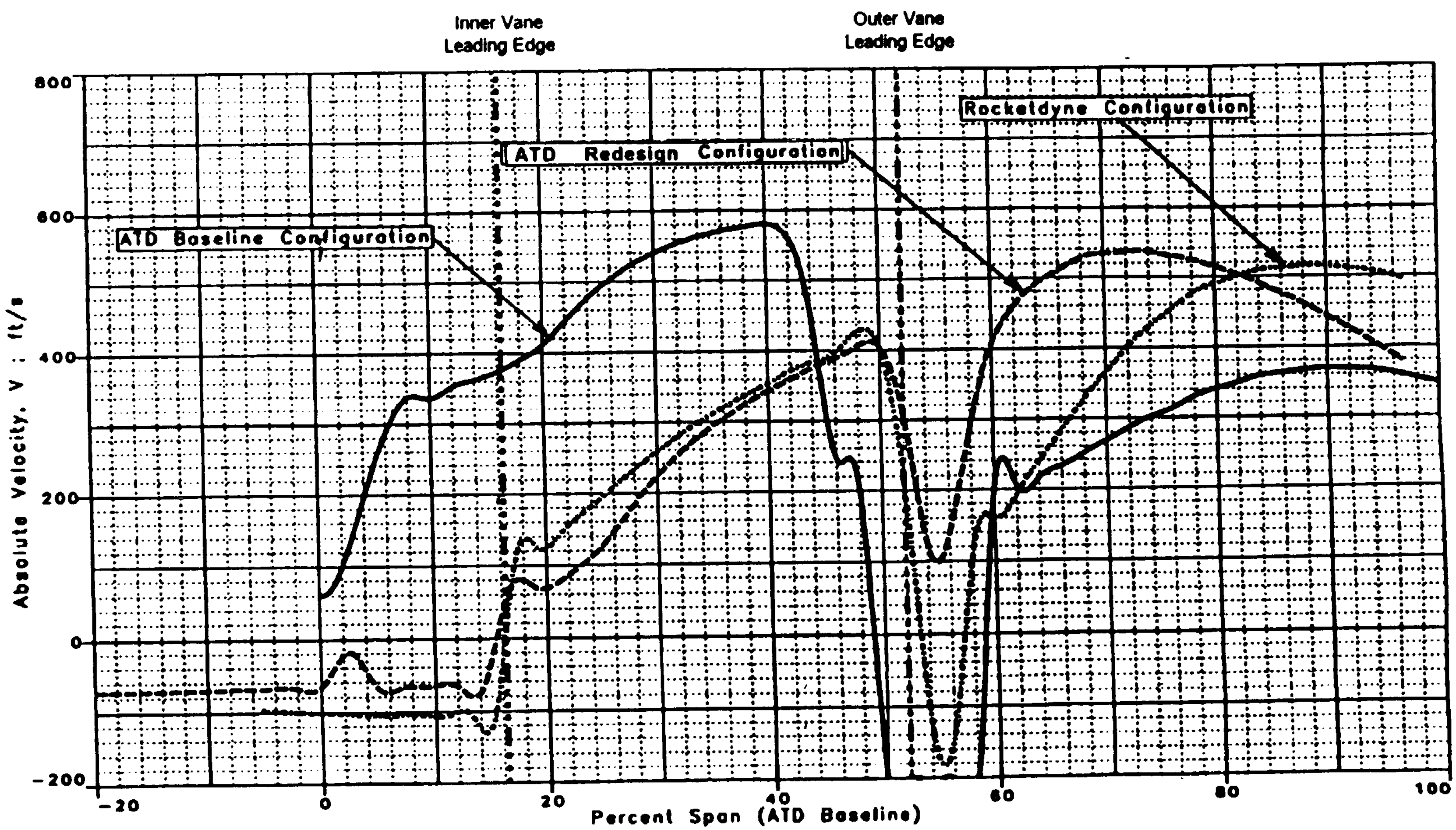
Axisymmetric Analysis Indicates Velocity Near Inner Vane Still At Goal Level



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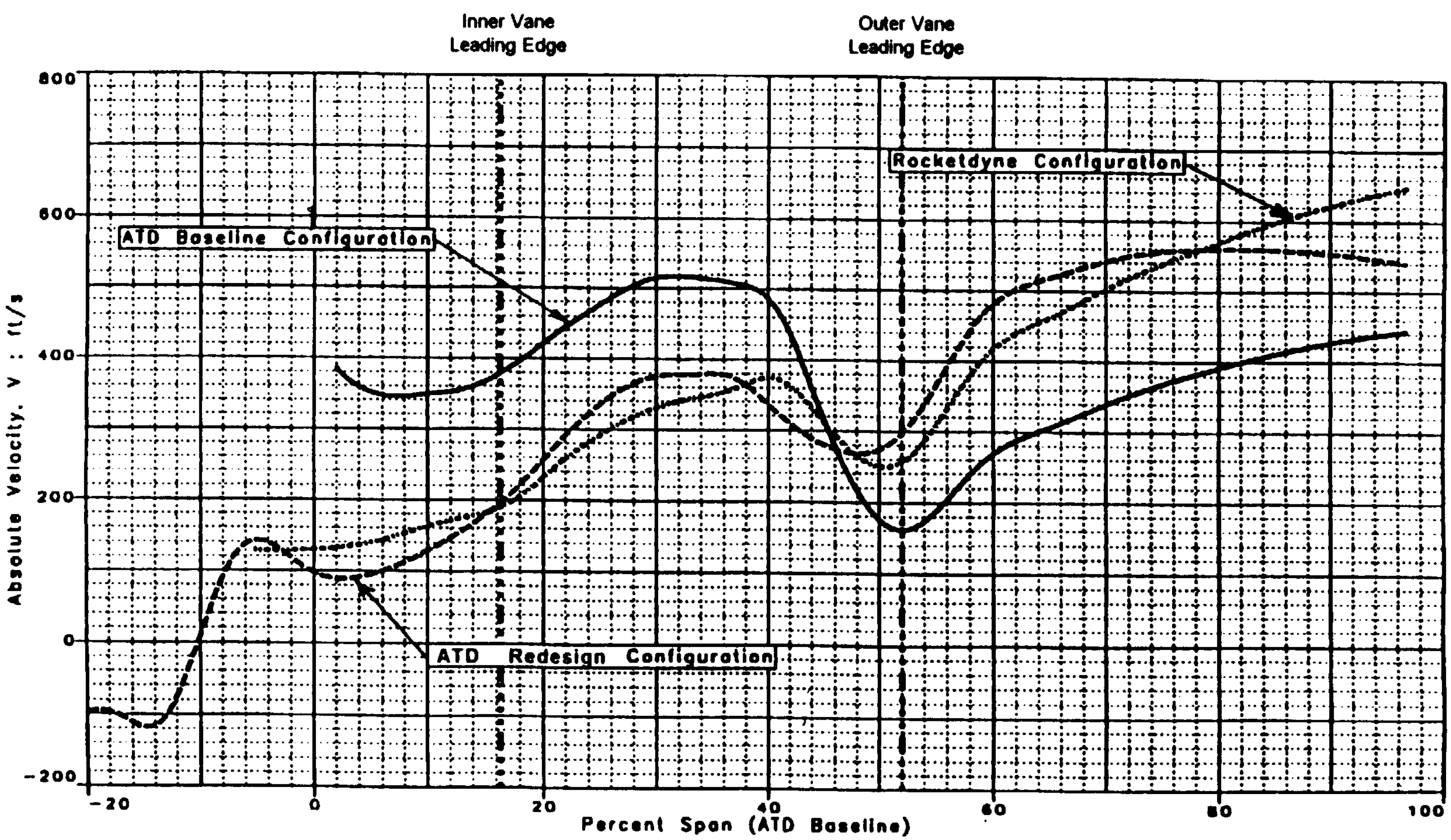
3D Analysis of ATD Redesign TAD Indicates Velocity Near Inner Vane At Goal Level



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Summary

- Major Differences Between the Rocketdyne and ATD TAD's Have Been Identified and Addressed
  - Interface Velocity Distribution
  - TAD Mass Flow Split
  - Fluctuating Pressures Along GOX Hex Vanes
  - Engine–Side Cavities
- Modified ATD TAD Recommended for Incorporation Into the ATD HPOT – Supported By:
  - Axisymmetric CFD Results
  - 3D CFD Results