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- **Abstract** -

Workshop for Computational Fluid Dynamic Applications in Rocket Propulsion

Three-Dimensional Navier-Stokes Analysis and Redesign of an Imbedded Bellmouth Nozzle in a Turbine Cascade Inlet Section

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Verification of proposed turbopump blading performance will involve evaluation of candidate blades in cascade test facilities. It is necessary to be able to predict the flow fields within these cascades for the results to be applicable to actual engine environments. This work presents the results of a study to predict the flow field for the NASA Lewis Transonic Turbine Blade Cascade Facility, which is similar to those used to evaluate rocket propulsion turbines. A pitchwise non-uniform total pressure distribution was observed at the blade row leading edge plane. A CFD analysis was used to show that the cause of the flow non-uniformity was a pair of vortices that originated in an embedded bellmouth inlet. Further CFD analysis was used to verify that a redesigned inlet section resulted in a flow with acceptable uniformity.

A computational analysis was chosen because physical accessibility to the inlet section was limited, and because a computational approach also allows one to examine design changes cheaper and more quickly than an experimental approach would. The PARC code, a general purpose, three-dimensional, Navier-Stokes code with multi-block solution capability, was chosen for the present study. Results are presented detailing the computational requirements needed to accurately predict flows of this nature.

Calculations of the original geometry showed total pressure loss regions consistent in strength and in location to experimental measurements. An examination of the results shows that the distortions are caused by a pair of vortices that originate as a result of the interaction of the flow with the imbedded bellmouth. Computations were performed for an inlet geometry which eliminated the imbedded bellmouth by bridging the region between it and the upstream wall. This analysis indicated that eliminating the imbedded bellmouth eliminates the troublesome pair of vortices, resulting in a flow with much greater pitchwise uniformity.

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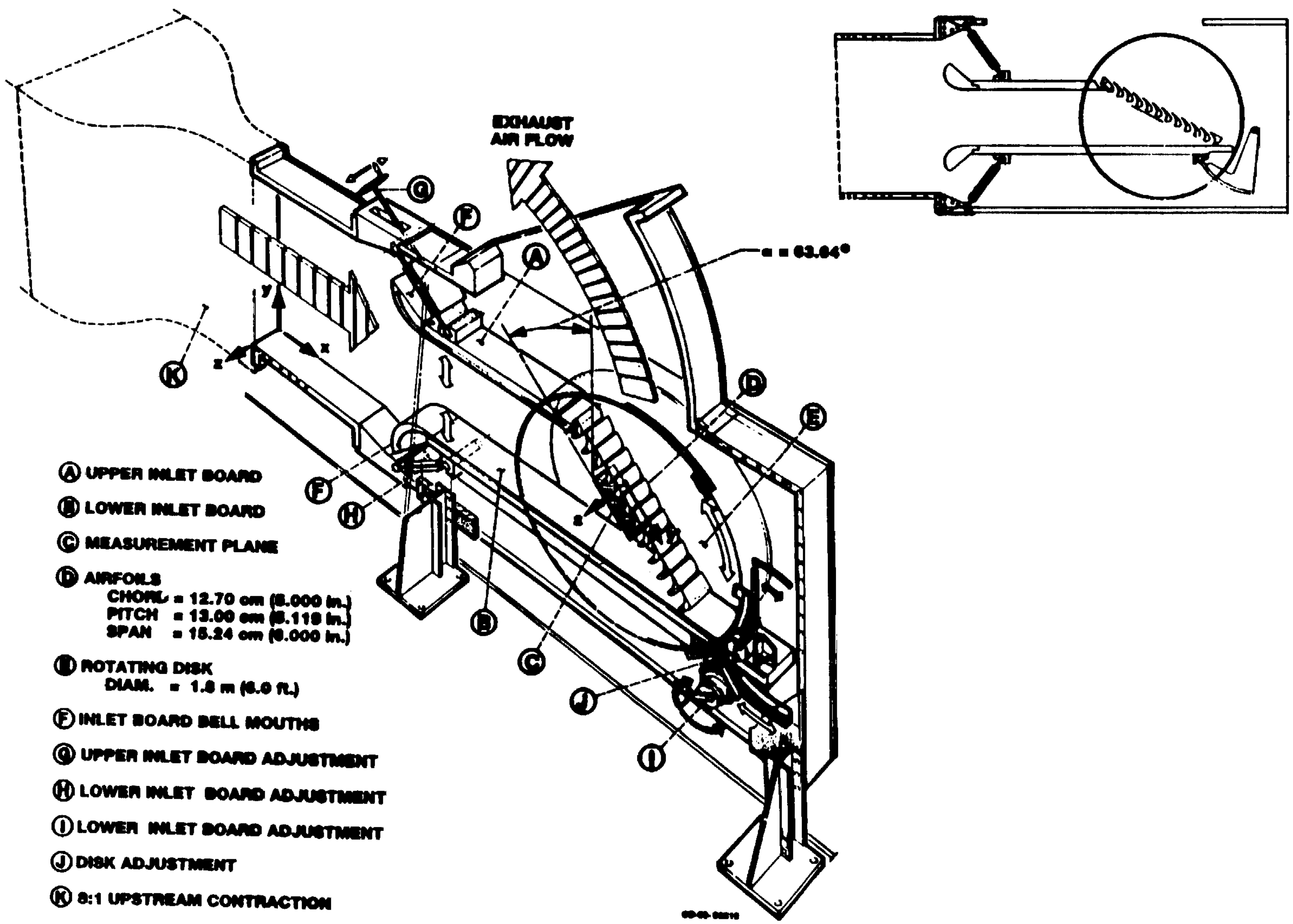
Transonic Turbine Blade Cascade Inlet Analysis – Outline of Presentation

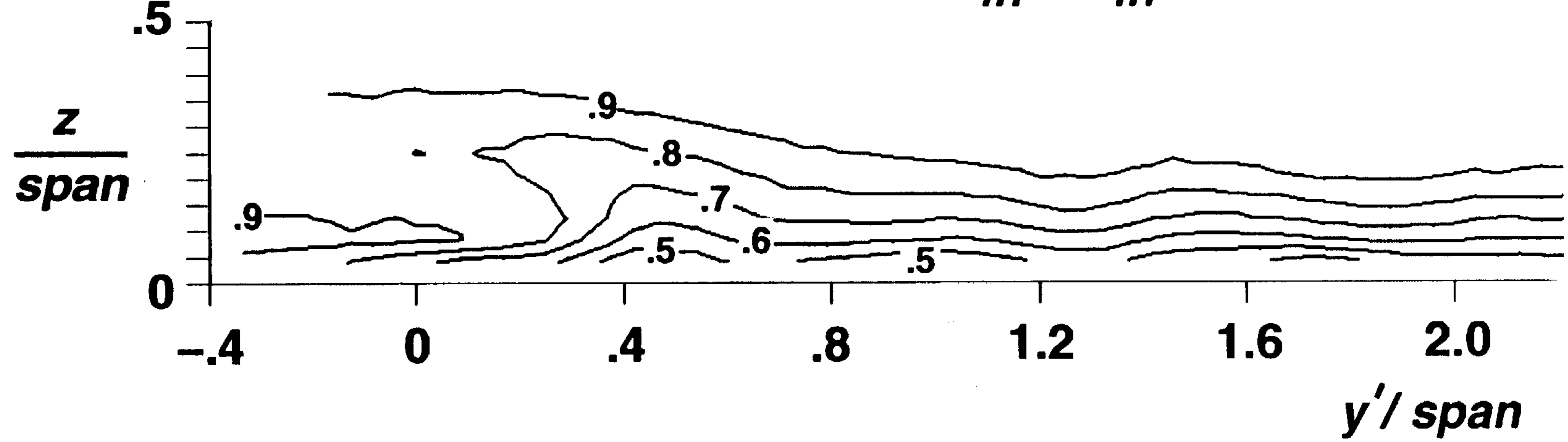
- Motivation and objectives
- Computational methods and models
  - geometry and grids
  - boundary conditions
  - computational time and convergence
- Results of computations
- Proposed geometry modifications
- Ongoing and future work
  - 8:1 upstream contraction section
  - off–design incidence case

Transonic Turbine Blade Cascade Inlet Analysis – Overall View of Cascade Inlet Section

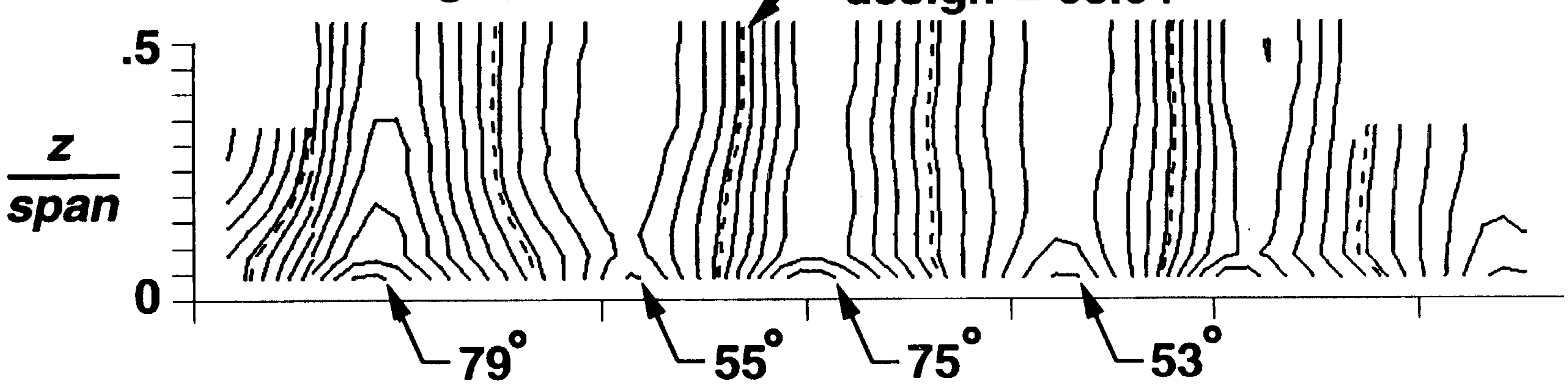


Transonic Turbine Blade Cascade Inlet Analysis – Preliminary Experimental Measurements

Total Pressure Coefficient, $\frac{P' - P_{in}}{P'_{in} - P_{in}}$



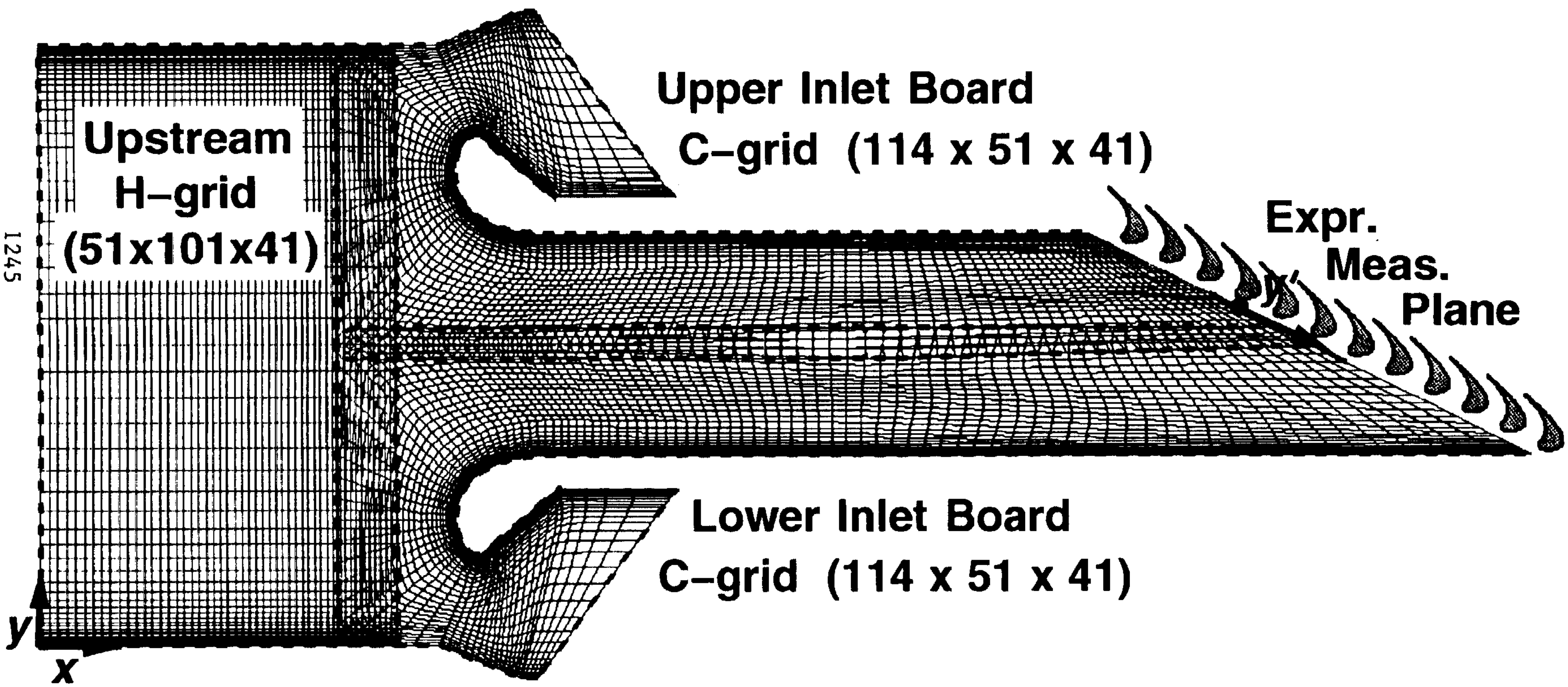
Flow Angle, α



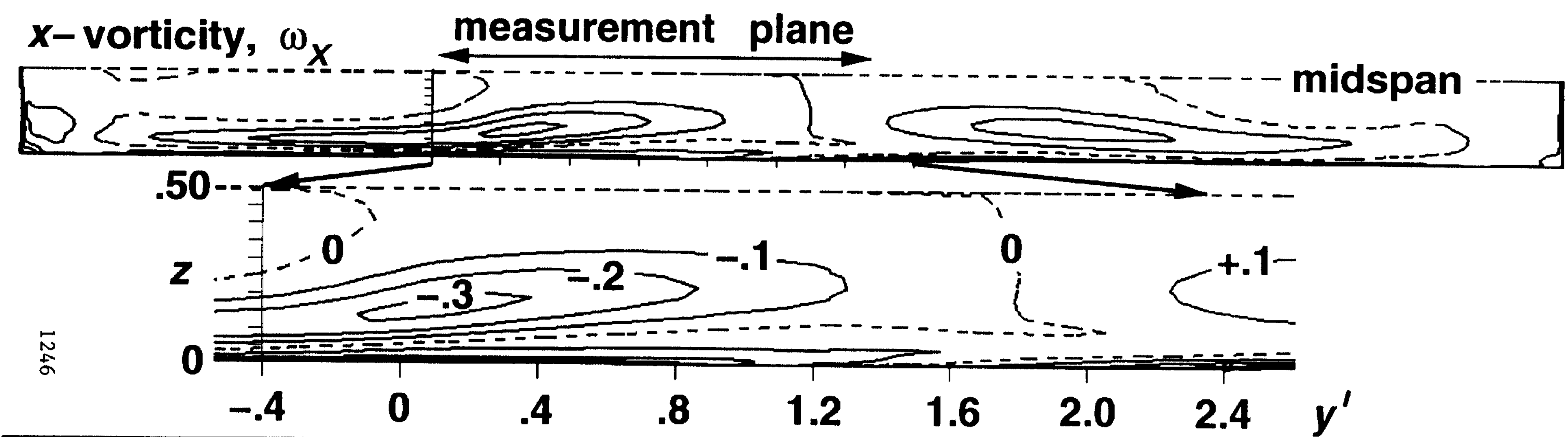
Transonic Turbine Blade Cascade Inlet Analysis – Code Descriptions

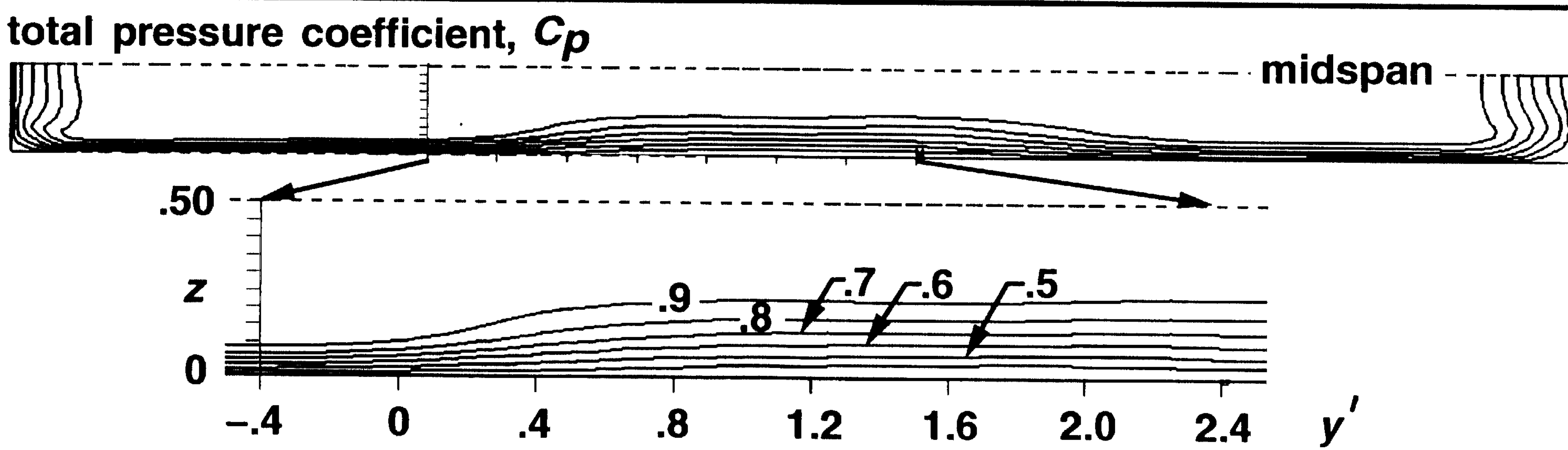
- PARC code, NASA Lewis version 7.2
  - General purpose Reynolds Averaged Navier–Stokes solver
  - Multi–block solution capability
  - Second–order accurate finite–differences
  - Blended second– and fourth–difference artificial dissipation
  - Beam & Warming solution algorithm
  - Baldwin–Lomax algebraic turbulence model used
  - No laminar–to–turbulent transition model used
- RVC3D
  - Turbomachinery Reynolds Averaged Navier–Stokes solver
  - Second–order accurate finite–differences
  - Blended second– and fourth–difference artificial dissipation
  - Four–stage Runge–Kutta solution algorithm
  - Baldwin–Lomax or Cebeci–Smith algebraic turbulence models

Transonic Turbine Blade Cascade Inlet Analysis – Original Geometry and Grids



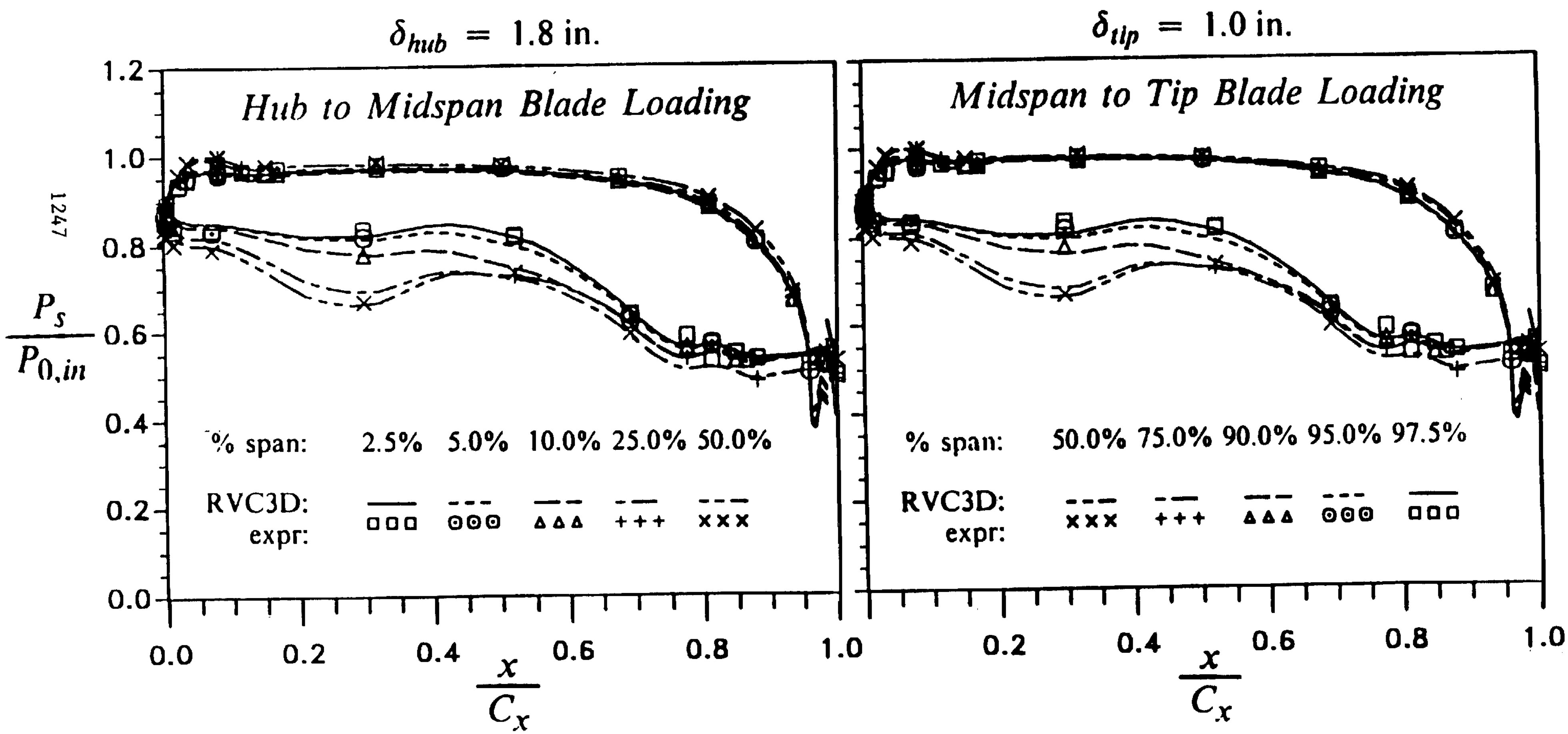
Transonic Turbine Blade Cascade Inlet Analysis – Calculations of Original Geometry (uniform exit)



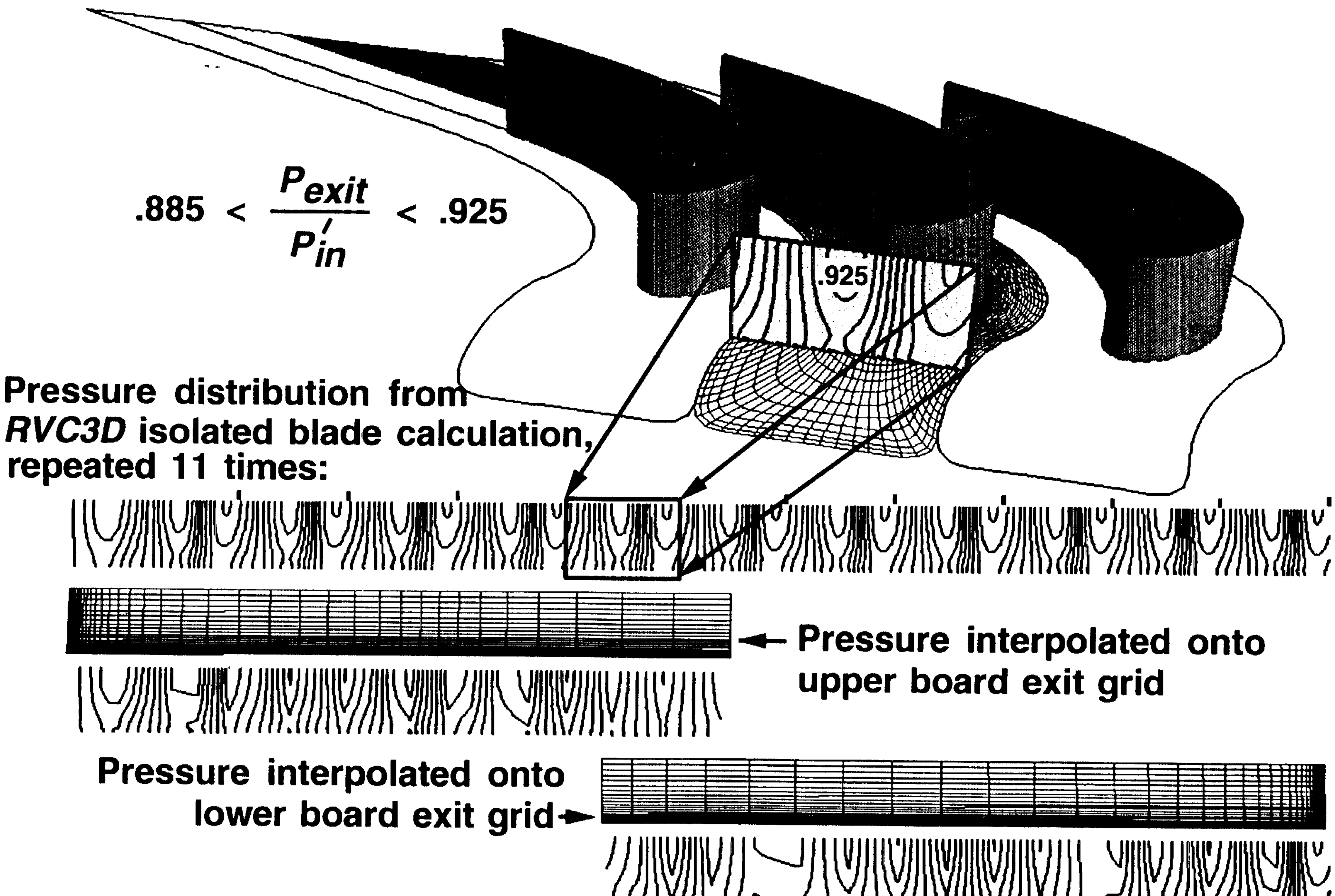


Transonic Turbine Blade Cascade Inlet Analysis – RVC3D Isolated Blade Calculations – Loading

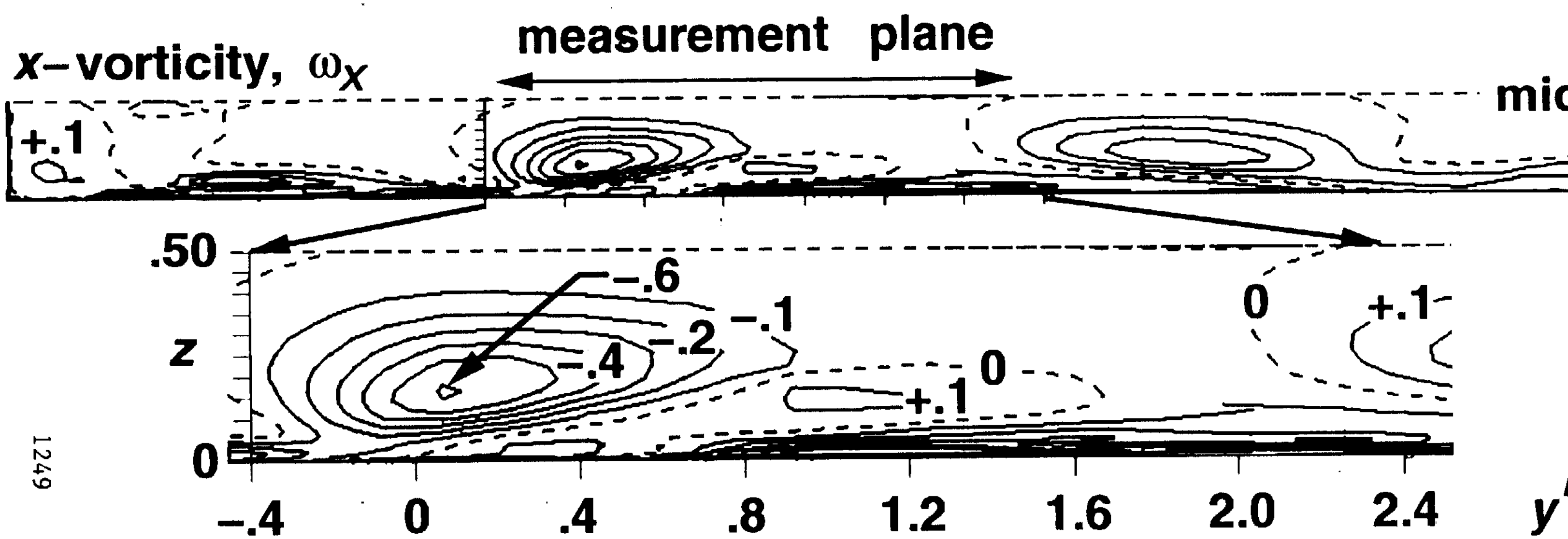
$Re_{C_x} = 0.497 \times 10^6$; $\alpha_{in} = 63.64°$ (design);
$\delta_{hub} = 1.8$ in.; $\delta_{tip} = 1.0$ in.; subsonic exit - $M_{exit} = 0.9$

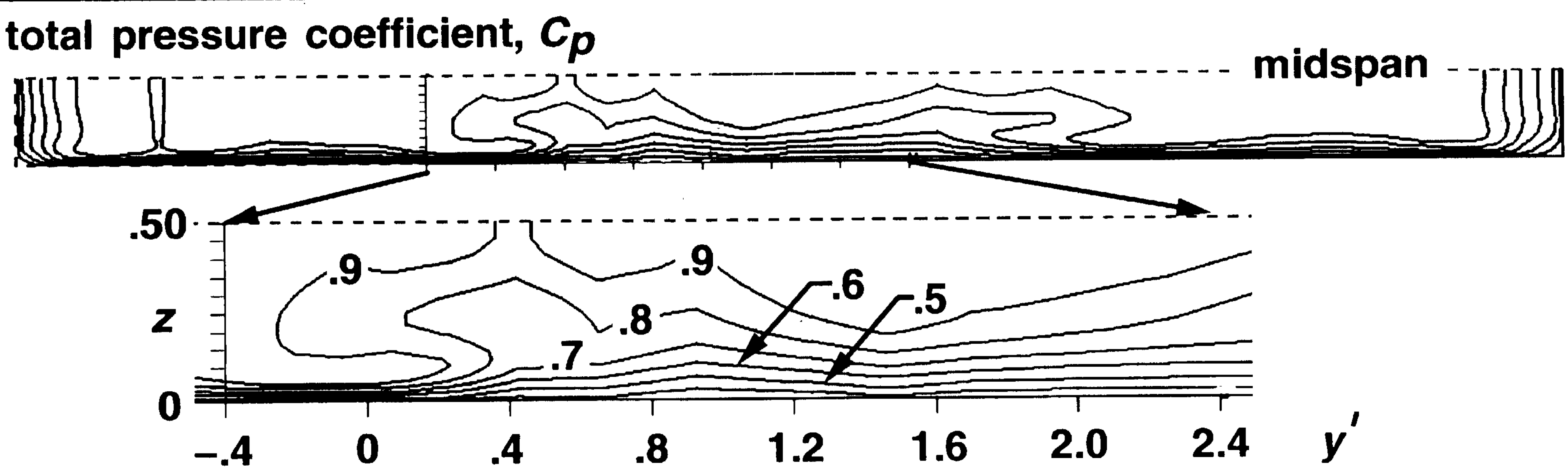


Transonic Turbine Blade Cascade Inlet Analysis – Non-uniform Exit Pressure Boundary Condition



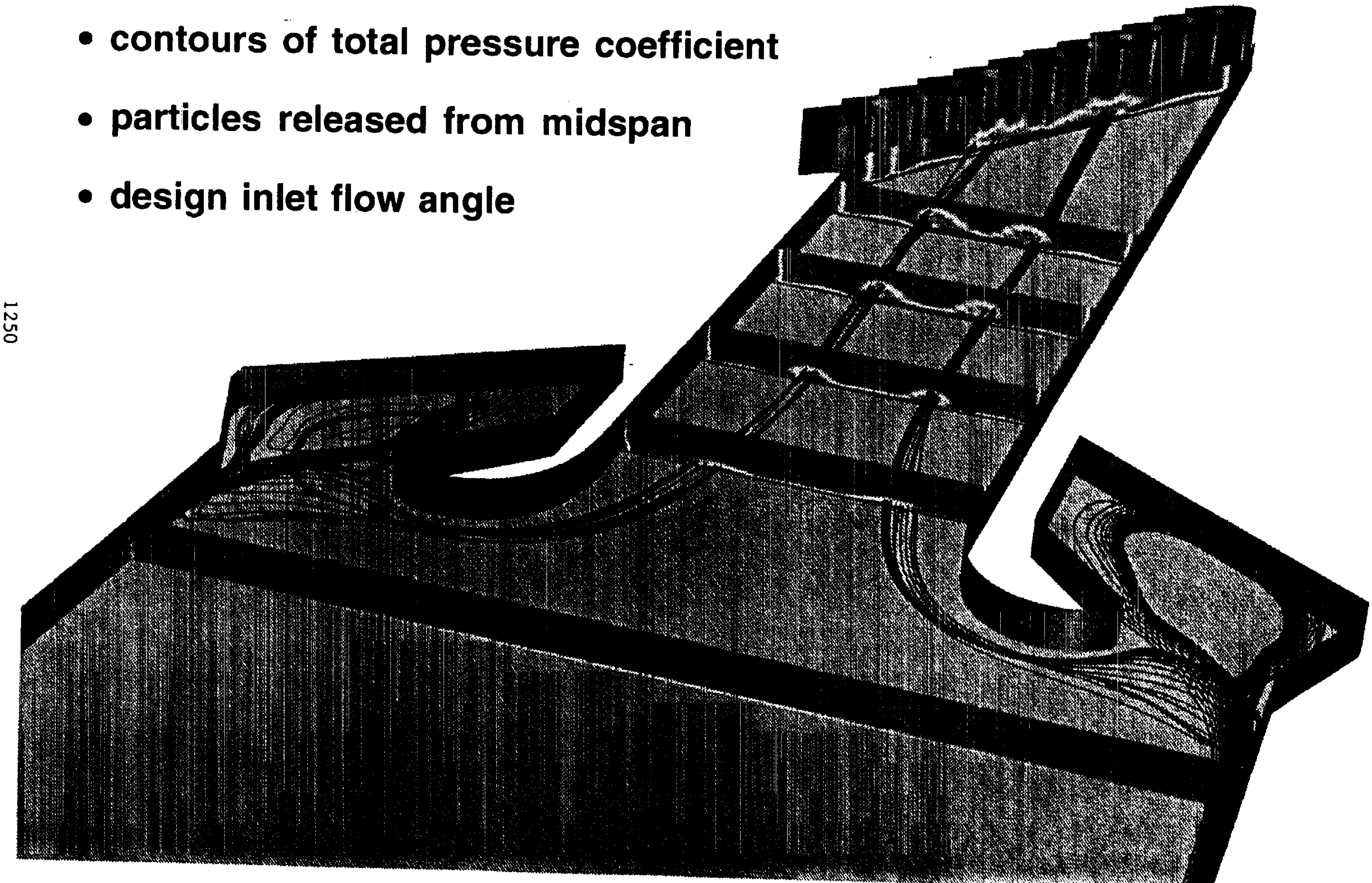
Transonic Turbine Blade Cascade Inlet Analysis – Calculations of Original Geometry (non–uniform exit)



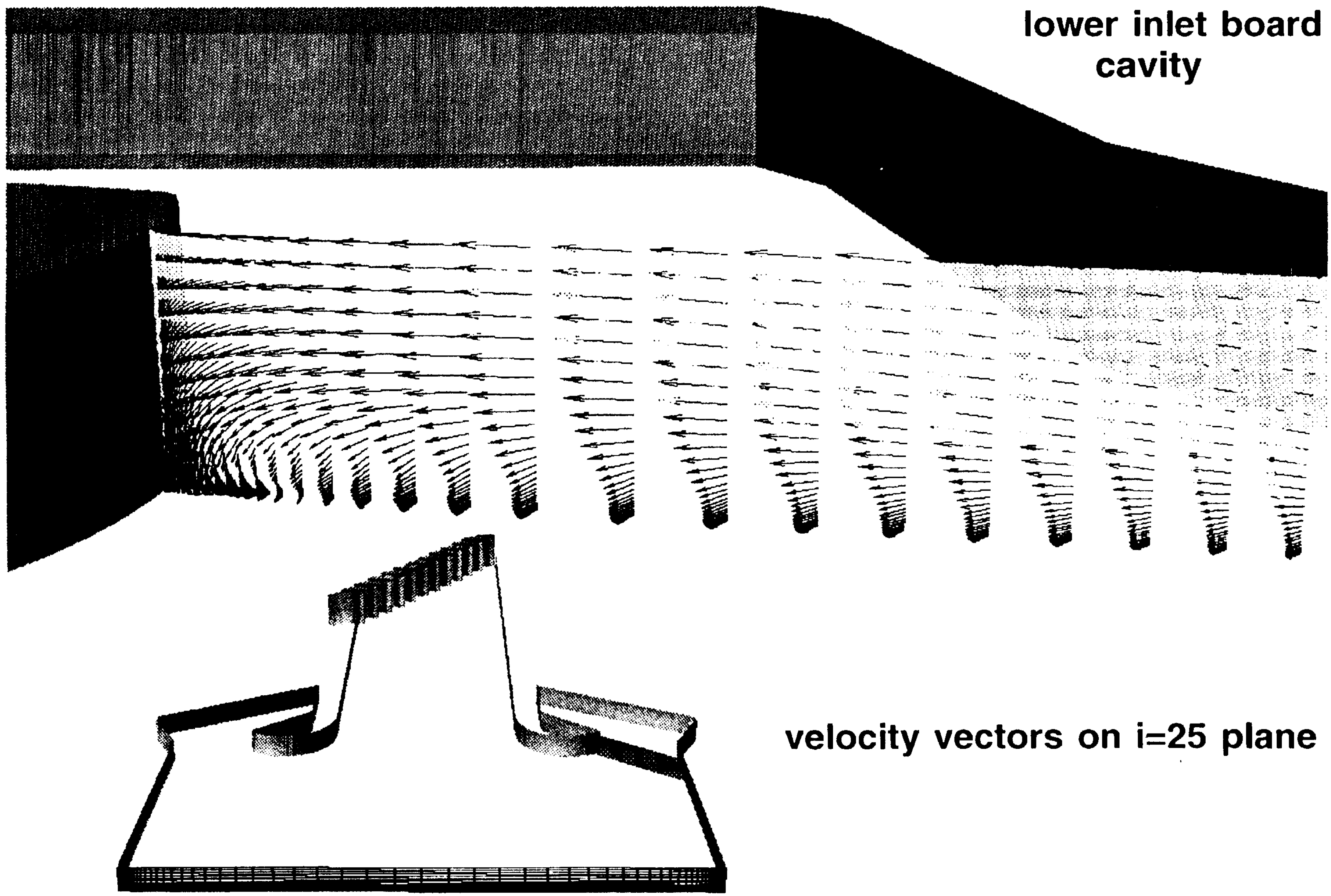


Transonic Turbine Blade Cascade Inlet Analysis – Calculations of Original Geometry (non–uniform exit)

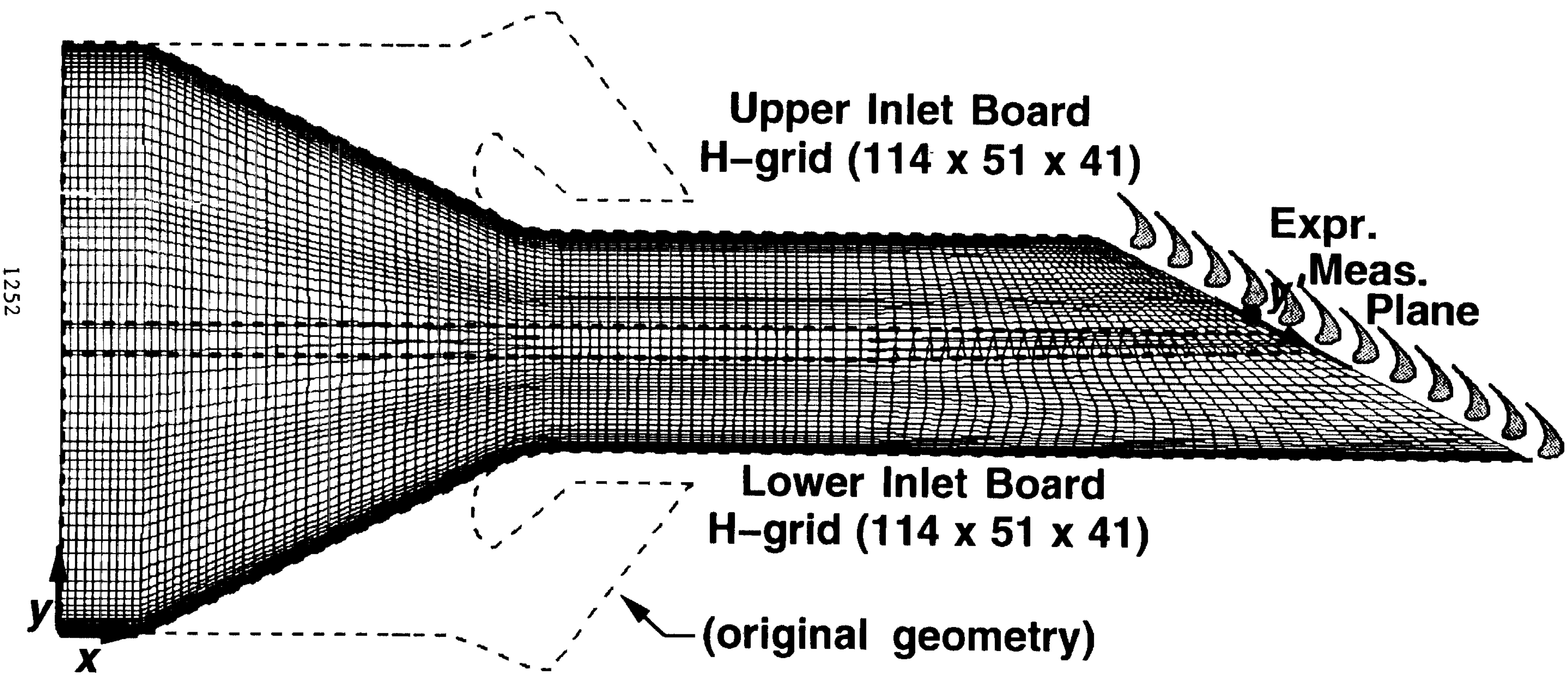
- contours of total pressure coefficient
- particles released from midspan
- design inlet flow angle



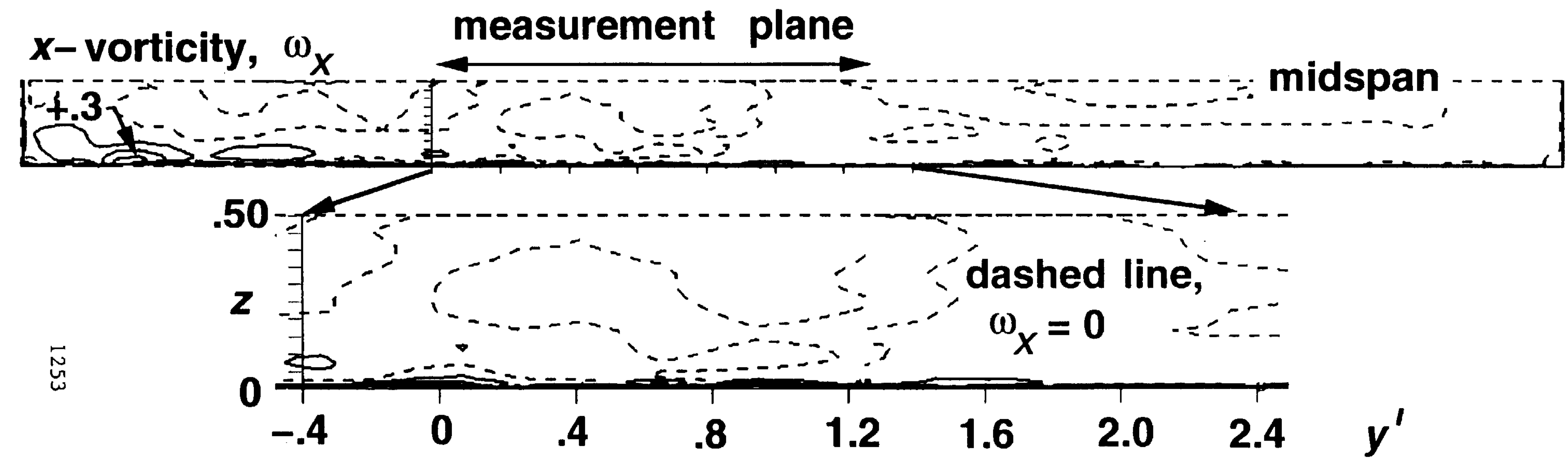
Transonic Turbine Blade Cascade Inlet Analysis – Calculations of Original Geometry (non–uniform exit)

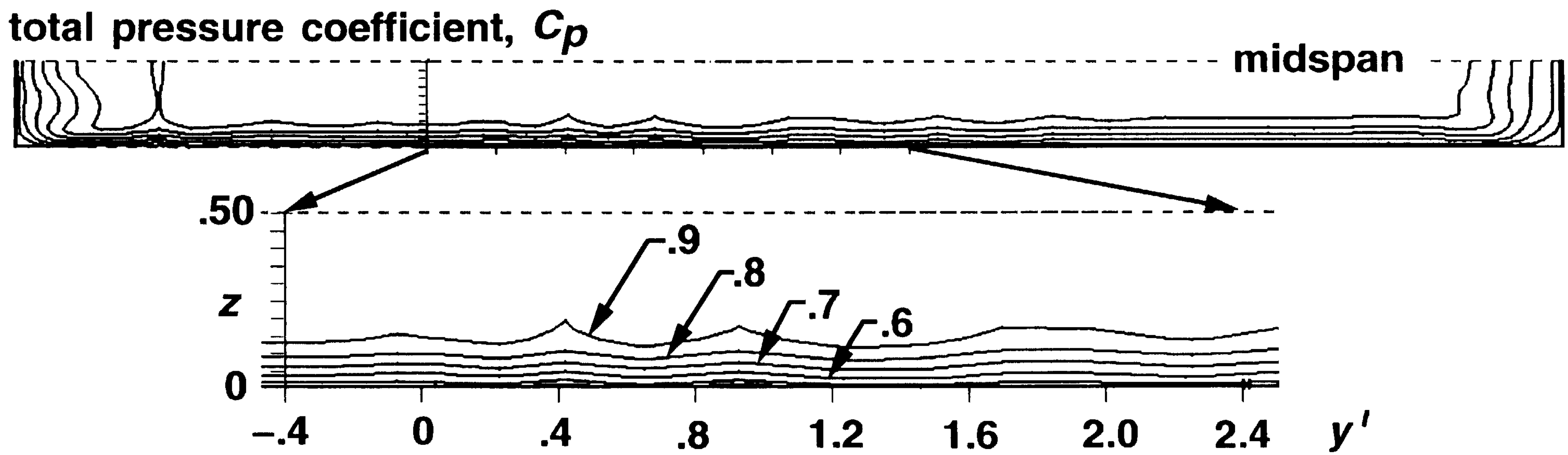


Transonic Turbine Blade Cascade Inlet Analysis - Modified Geometry and Grids

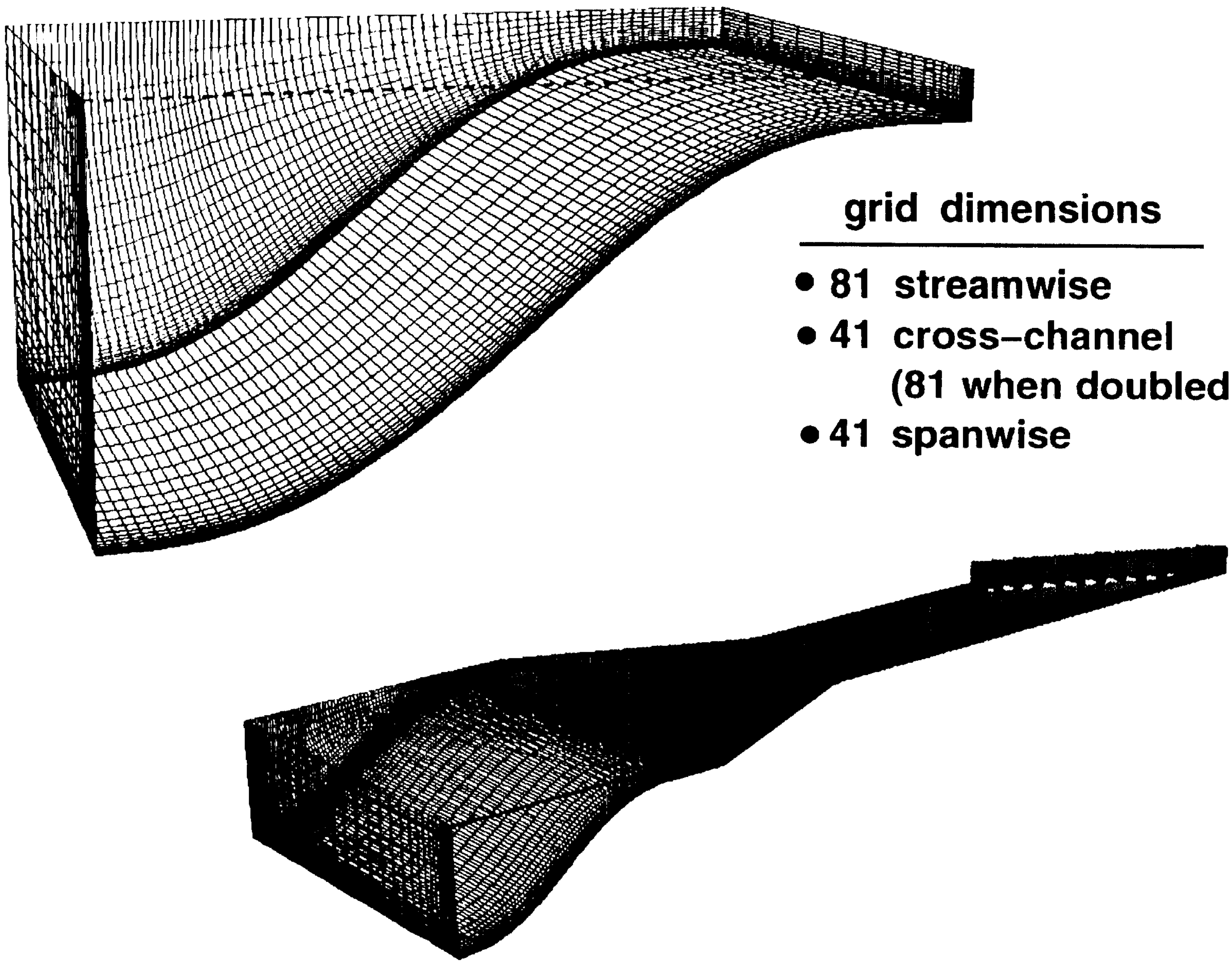


Transonic Turbine Blade Cascade Inlet Analysis – Calculations of Modified Geometry (non–uniform exit)





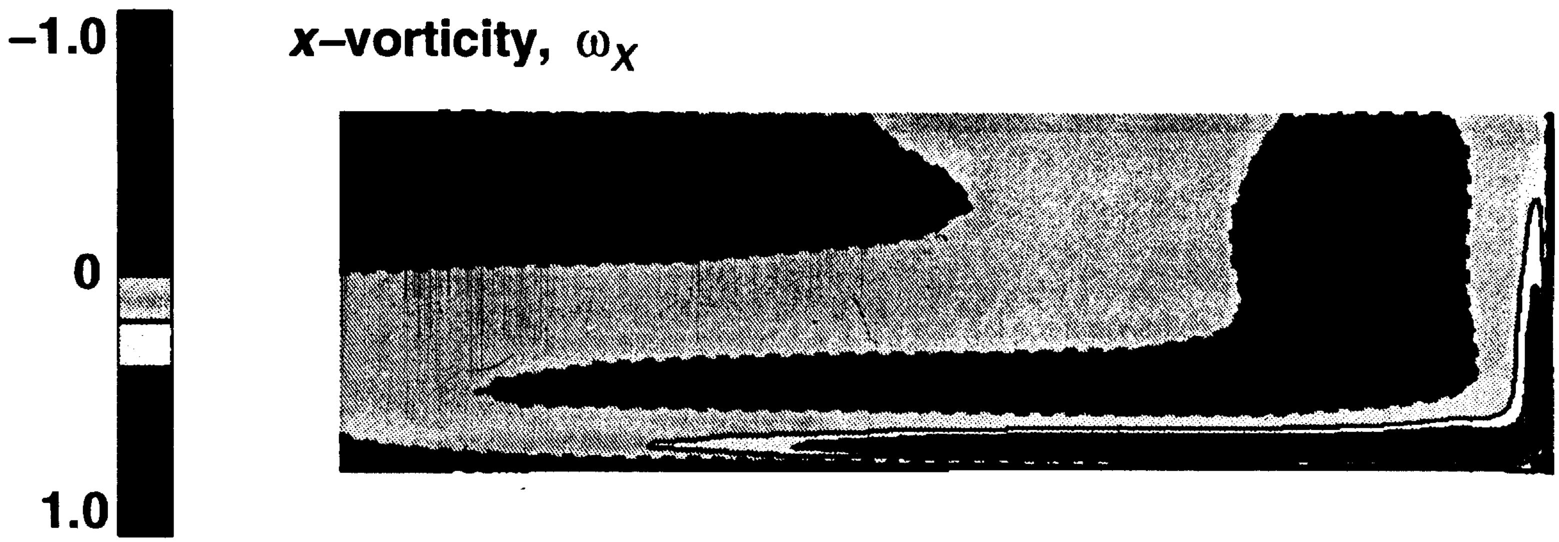
Transonic Turbine Blade Cascade Inlet Analysis - Upstream 8:1 Contraction; geometry and grid



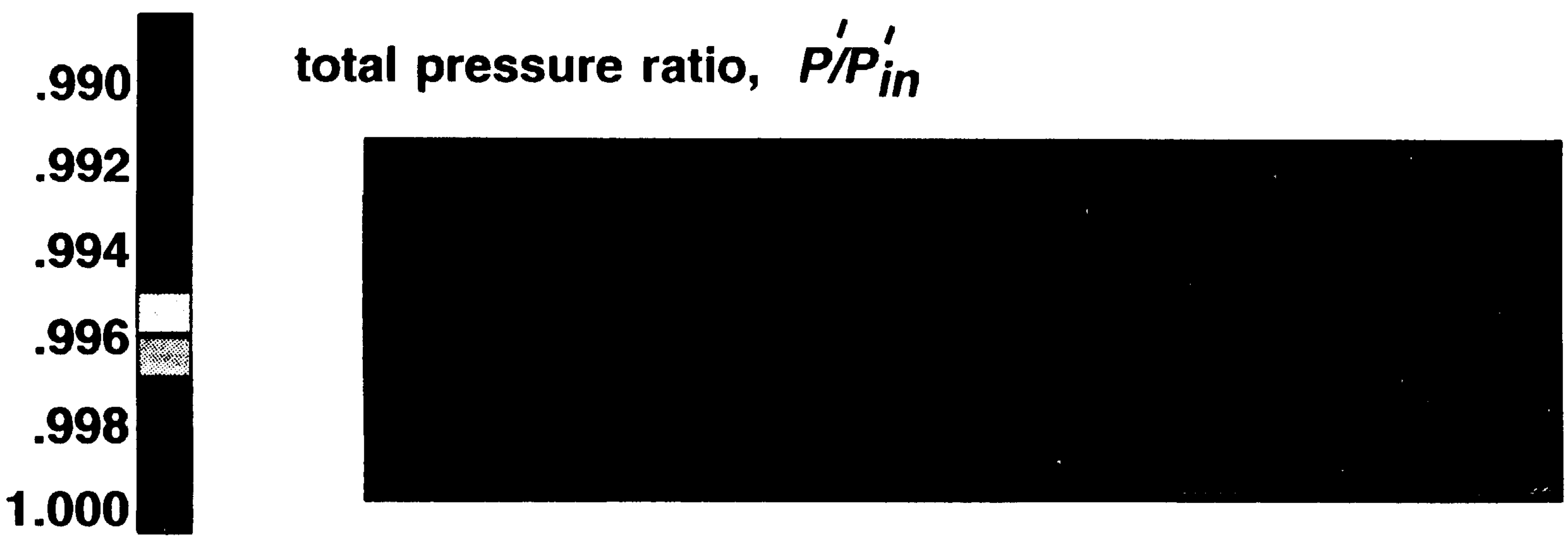
grid dimensions

- 81 streamwise
- 41 cross–channel
  (81 when doubled)
- 41 spanwise

Transonic Turbine Blade Cascade Inlet Analysis – Upstream 8:1 Contraction; preliminary results

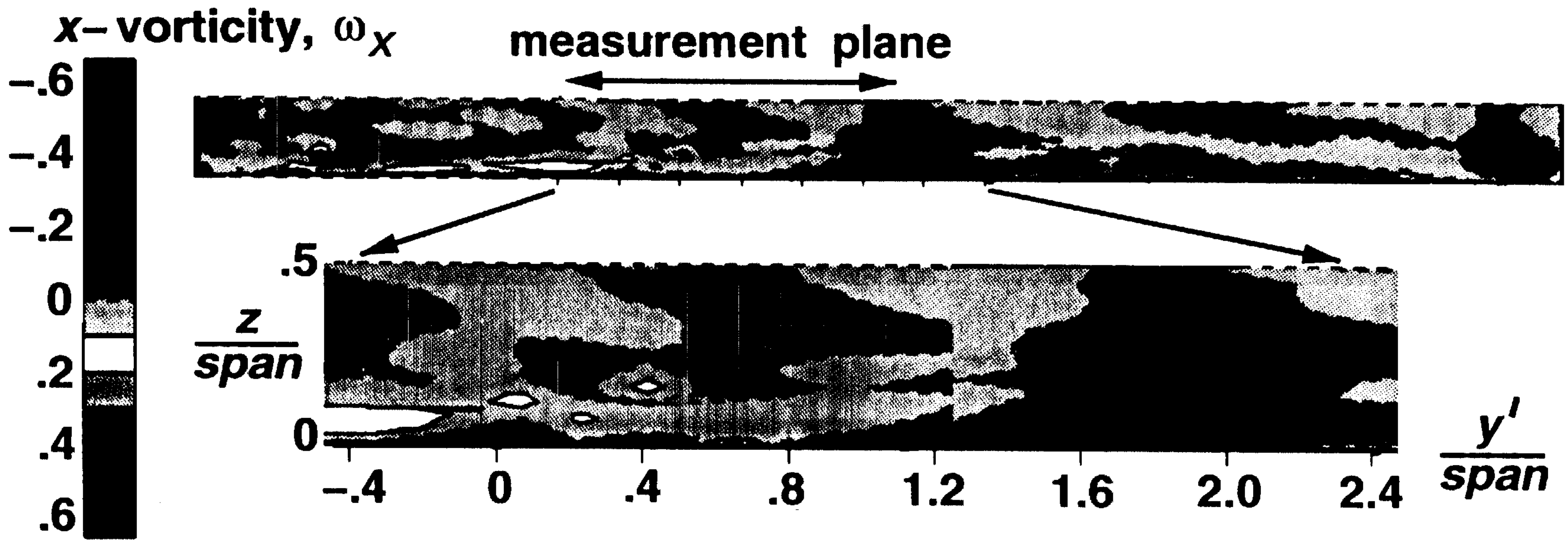


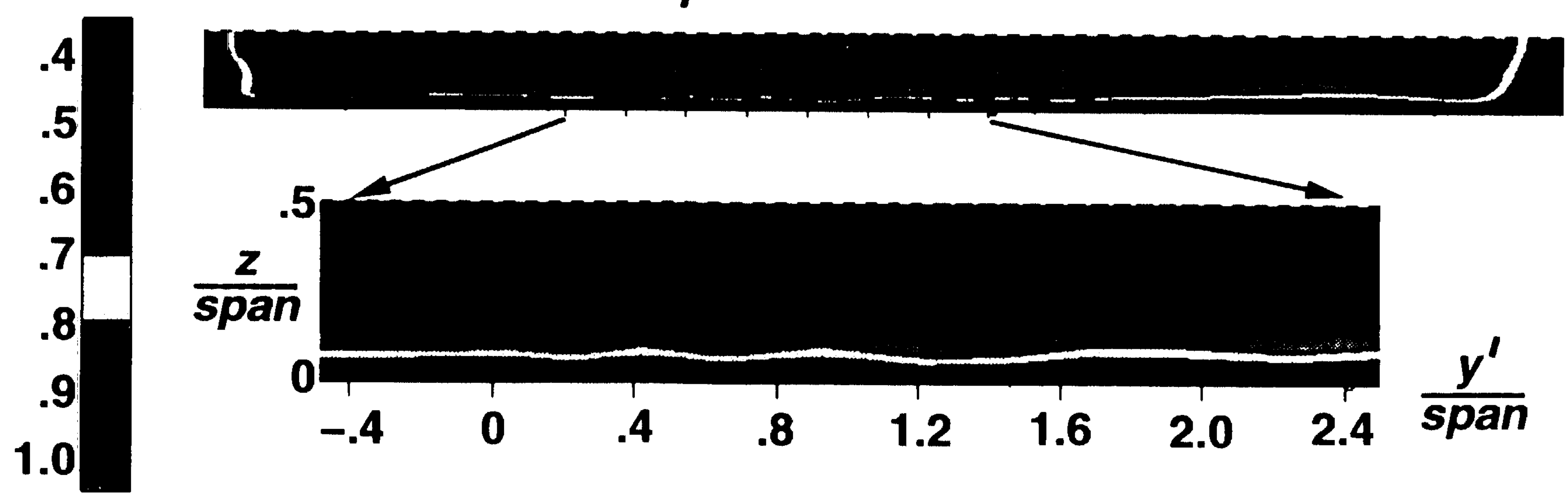
x–vorticity, ω_x



total pressure ratio, P'/P'_{in}

Transonic Turbine Blade Cascade Inlet Analysis – Calculations of Modified Geometry with Upstream 8:1 Contraction (non–uniform exit)





Transonic Turbine Blade Cascade Inlet Analysis –

Summary of Results

total pressure coefficient,

$$\frac{P' - P_{in}}{P'_{in} - P_{in}}$$