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Abstract of a proposed presentation at the Workshop for CFD Applications in Rocket Propulsion to be held at NASA Marshall Space Flight Center, AL, April 20-22, 1993.

Three-dimensional unsteady flow calculations in an advanced Gas Generator turbine

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Abstract

This paper deals with the application of a three-dimensional, unsteady Navier-Stokes code for predicting the unsteady flow in a single stage of an advanced gas generator turbine. The numerical method solves the three-dimensional thin-layer Navier-Stokes equations, using a system of overlaid grids, which allow for relative motion between the rotor and stator airfoils. Results in the form of time averaged pressures and pressure amplitudes on the airfoil surfaces will be shown. In addition, instantaneous contours of pressure, mach number etc. will be presented in order to provide a greater understanding of the inviscid as well as the viscous aspects of the flowfield. Also, relevant secondary flow features such as cross-plane velocity vectors and total pressure contours will be presented. Prior work in two-dimensions has indicated that for the advanced designs, the unsteady interactions can play a significant role in turbine performance. These interactions affect not only the stage efficiency but can substantially alter the time-averaged features of the flow. This work is a natural extension of the work done in two-dimensions and hopes to address some of the issues raised by the two-dimensional calculations. These calculations are being performed as an integral part of an actual design process and demonstrate the value of unsteady rotor-stator interaction calculations in the design of turbomachines.

THREE-DIMENSIONAL UNSTEADY FLOW CALCULATIONS FOR AN ADVANCED GAS GENERATOR TURBINE

(PRELIMINARY RESULTS)

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Scope

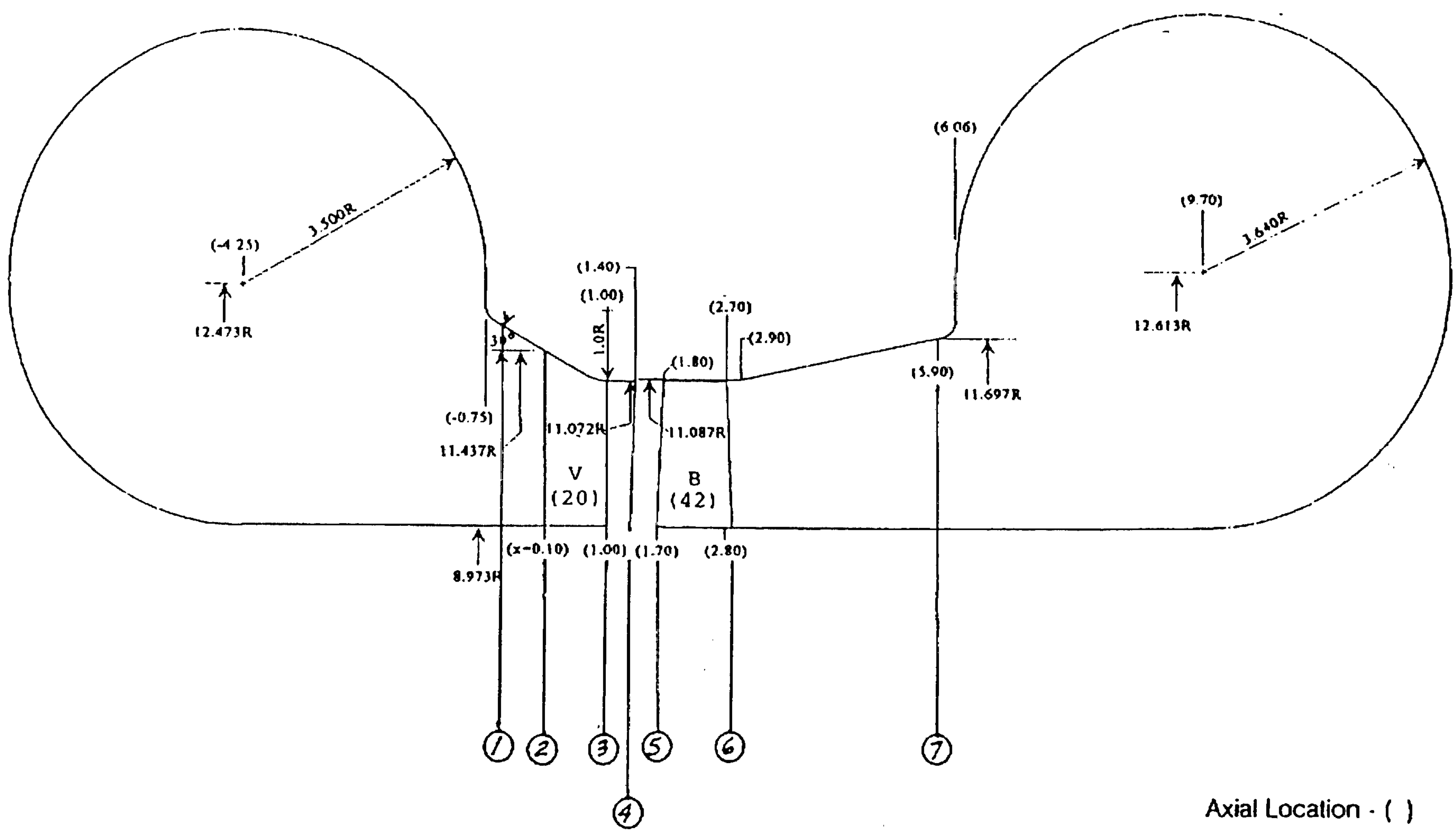
PERFORM THREE-DIMENSIONAL UNSTEADY COMPUTATIONS FOR THE SINGLE STAGE GAS GENERATOR OXIDIZER TURBINE

PROVIDE RESULTS TO THE TURBINE STAGE DESIGN TEAM SUCH AS

- TIME AVERAGED AND UNSTEADY PRESSURE ENVELOPES
- UNSTEADY SECONDARY FLOW FEATURES

OXIDIZER TURBINE BASELINE DESIGN

Full Scale Turbine Flowpath



Axial Location - ( )

① STATION NUMBER

ORIGINAL PAGE IS
OF POOR QUALITY

Background

DESIGN REQUIREMENTS OF NEXT GENERATION TURBINES ARE

- HIGH SPECIFIC WORK PER STAGE
- LOW WEIGHT AND SMALL SIZE
- HIGH EFFICIENCY
- DURABILITY

Background contd...

THESE DESIGN REQUIREMENTS IMPLY

- HIGH TURNING ANGLES PER STAGE
- UNCONVENTIONAL AIRFOIL SHAPES
- SMALL AXIAL GAPS
- LARGE UNSTEADY INTERACTIONS

EFFECTS OF UNSTEADY INTERACTIONS ON TURBINE PERFORMANCE STILL IN THE PROCESS OF EVALUATION

NEED A MORE POWERFUL PREDICTIVE CAPABILITY

- MODEL AS MUCH OF THE FLOW PHYSICS
- ISSUES OF ACCURACY

Background contd...

UNSTEADY ROTOR-STATOR INTERACTION CODES HAVE BEEN DEVELOPED AT NASA AMES

- HAVE DEMONSTRATED THE ABILITY OF PREDICTING FLOW QUANTITIES SUCH AS
  - TIME AVERAGED PRESSURE DISTRIBUTIONS ON AIRFOIL SURFACES.
  - PRESSURE AMPLITUDES AND PHASE ON THE SURFACE OF THE AIRFOILS.
  - TIME AVERAGED TOTAL PRESSURE DEFECTS IN WAKES.

- THESE CODES HAVE ATTAINED A LEVEL OF MATURITY TO WARRANT THEIR USE IN THE DESIGN PROCESS OF A TURBOMACHINE

Computational Details

TIME-ACCURATE SOLUTIONS TO THE 3D THIN-LAYER NAVIER-STOKES EQUATIONS.

HIGH-ORDER, UPWIND, FINITE-DIFFERENCE ALGORITHM USED

ALGORITHM SET IN ITERATIVE, FACTORED AND IMPLICIT FRAMEWORK

FLOWFIELD DISCRETIZED USING A SYSTEM OF OVERLAID GRIDS

ROTOR GRIDS MOVE RELATIVE TO STATOR GRIDS

TURBULENT EDDY VISCOSITY COMPUTED USING BALDWIN-LOMAX MODEL

Boundary conditions

- INLET TOTAL PRESSURE INPUT AS A FUNCTION OF RADIUS
- REIMANN VARIABLE AS A FUNCTION OF RADIUS
- FLOW ANGLES
- EXIT STATIC PRESSURE INPUT AS A FUNCTION OF RADIUS

Study of accuracy

A STUDY OF ACCURACY WAS INITIATED IN TWO-DIMENSIONS

MOTIVATIONS FOR THIS STUDY WERE

- DEVOLOPMENT OF A HYBRID STRUCTURED/UNSTRUCTURED CODE
  - FOR UNSTRUCTURED CODES, INCORPORATING HIGH ORDER TERMS MAY NOT BE STRAIGHTFORWARD
  - GRID ADAPTATION IS SIMPLER FOR UNSTRUCTURED SOLVERS
- NONLINEAR ROTOR-STATOR INTERACTIONS

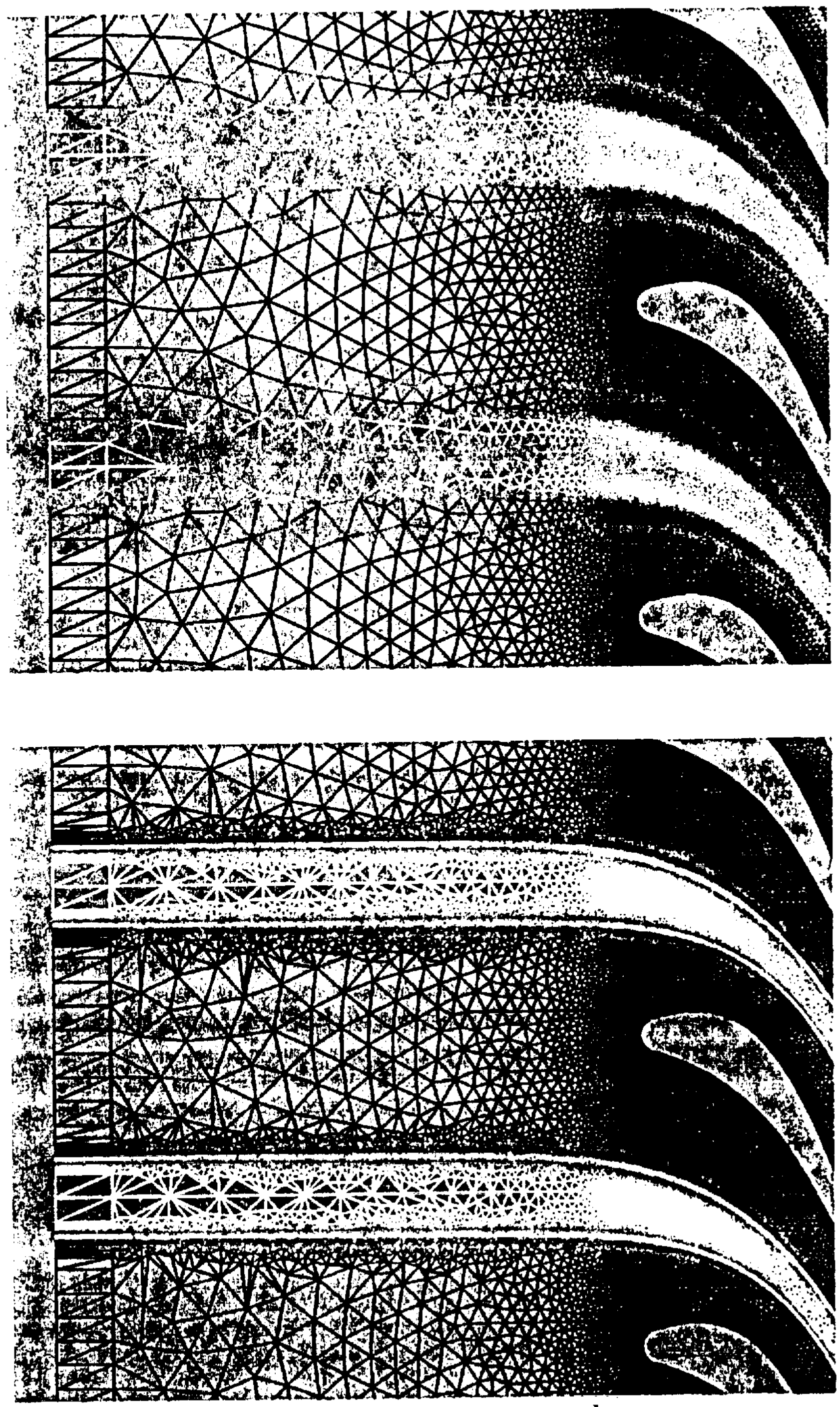


Figure Hot-streak calculation: original and adapted grids for the stator

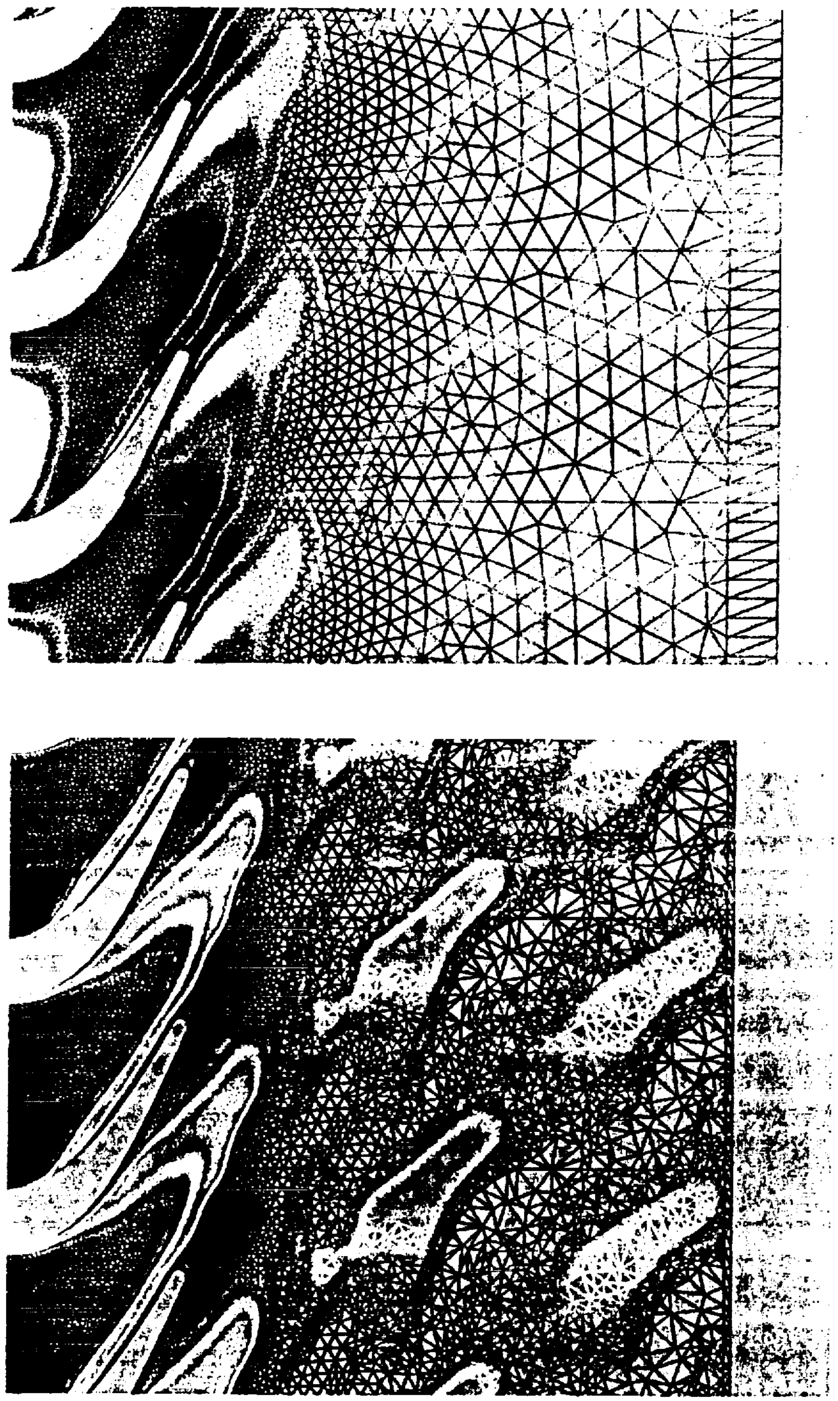
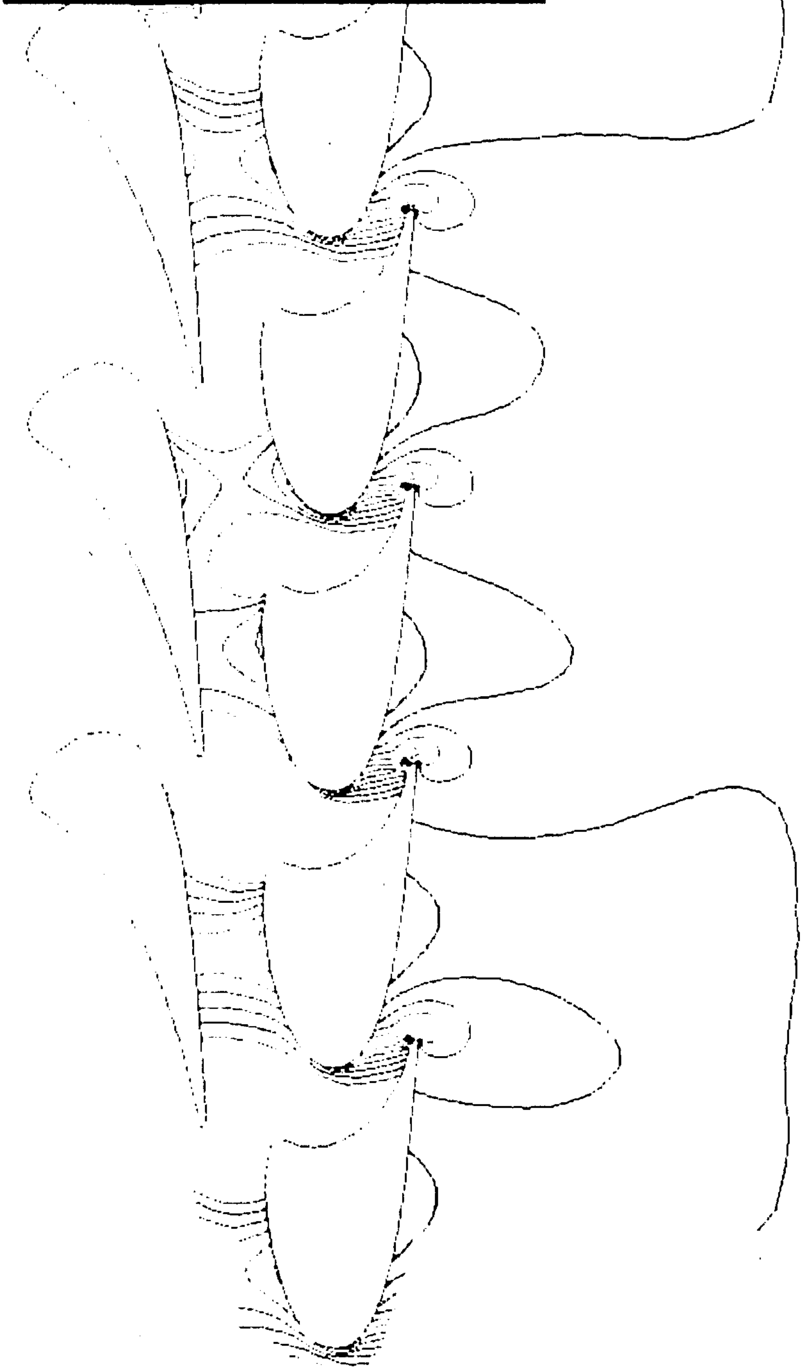


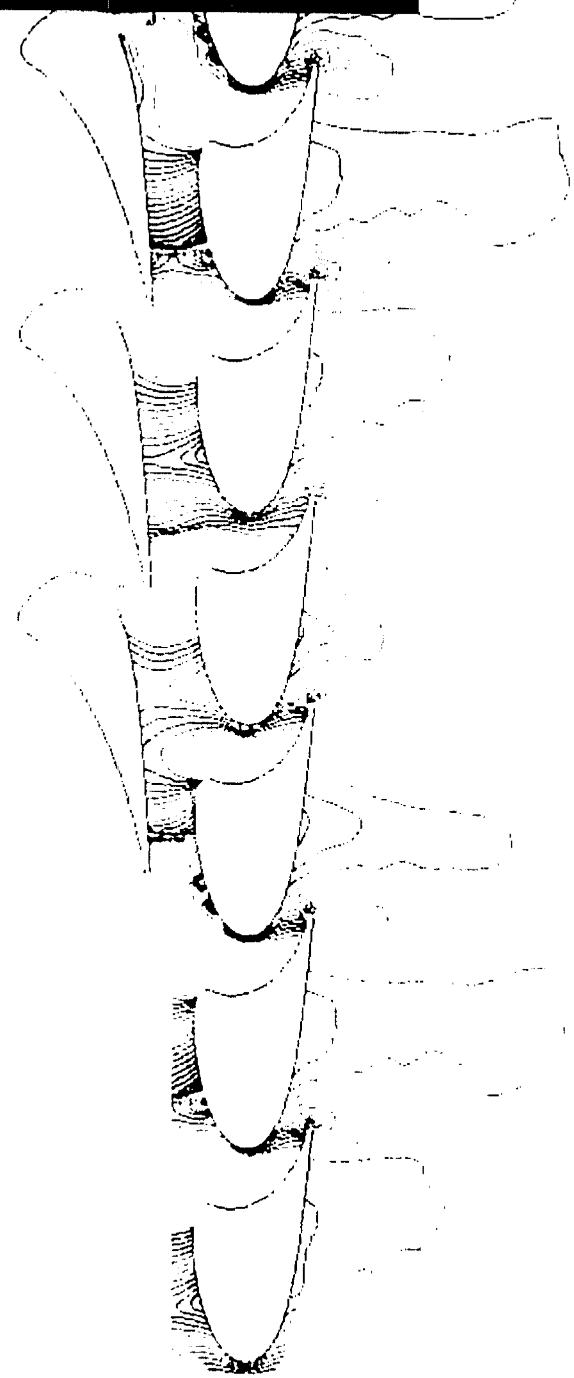
Figure Hot-streak calculation: original and adapted grids for the rotor

PRESSURE CONTOURS IN THE GGG BY A HYBRID STRUCTURED/UNSTRUCTURED SOLVER (FIRST-ORDER ACCURATE)
THE INTERACTION SHOCK IS NOT PREDICTED

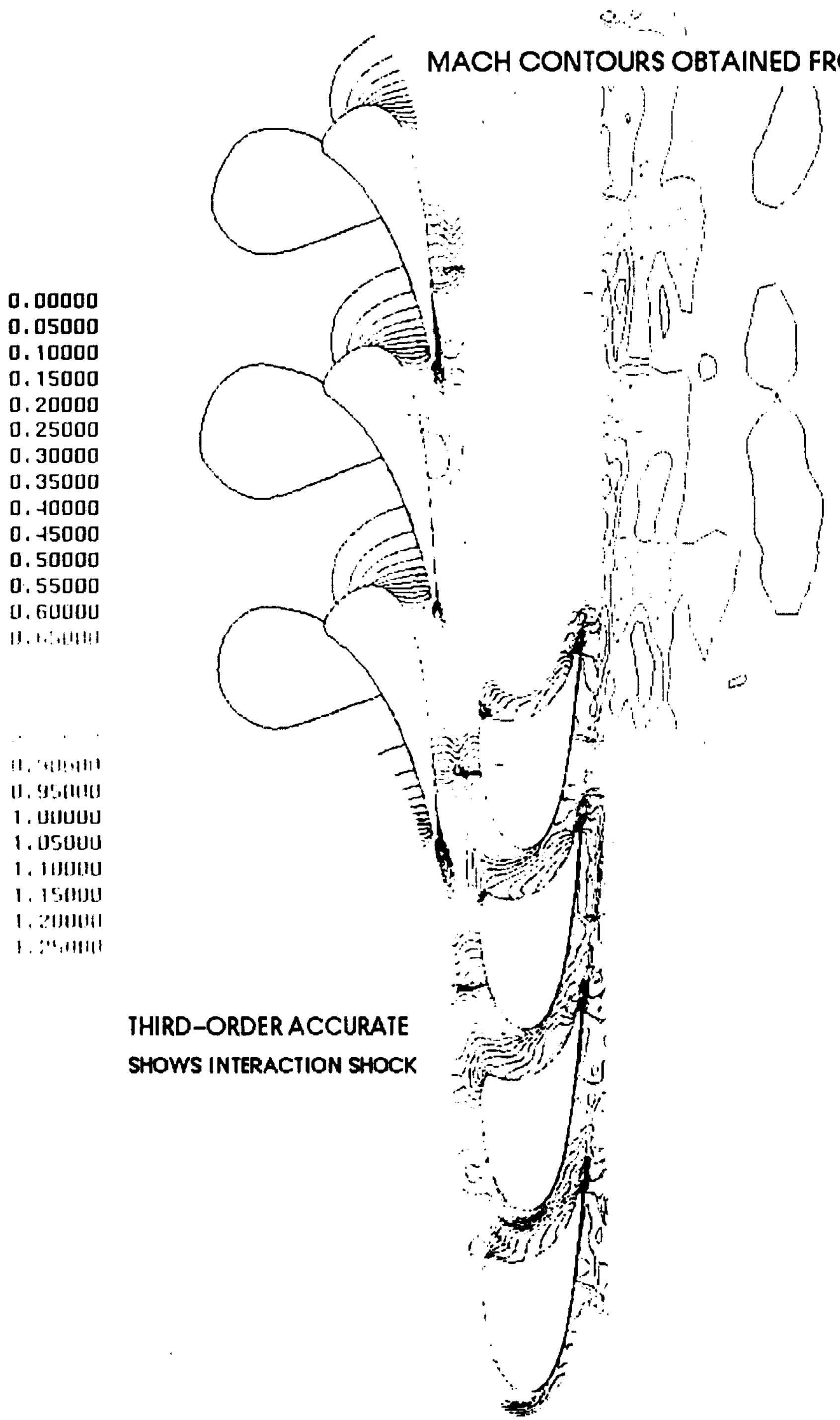


PRESSURE CONTOURS IN THE GGG BY A HYBRID STRUCTURED/UNSTRUCTURED SOLVER (SECOND-ORDER ACCURATE)

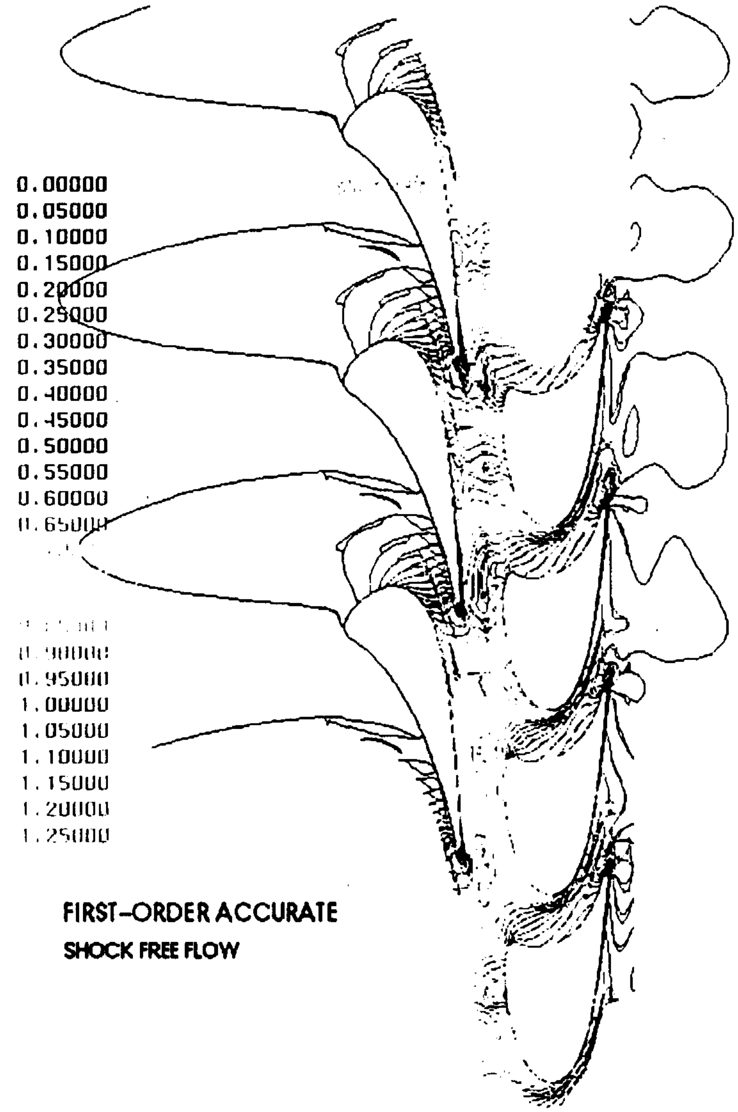
AN INTERACTION SHOCK IS PREDICTED



MACH CONTOURS OBTAINED FROM A STRUCTURED METHOD (STAGE-2)



THIRD-ORDER ACCURATE
SHOWS INTERACTION SHOCK

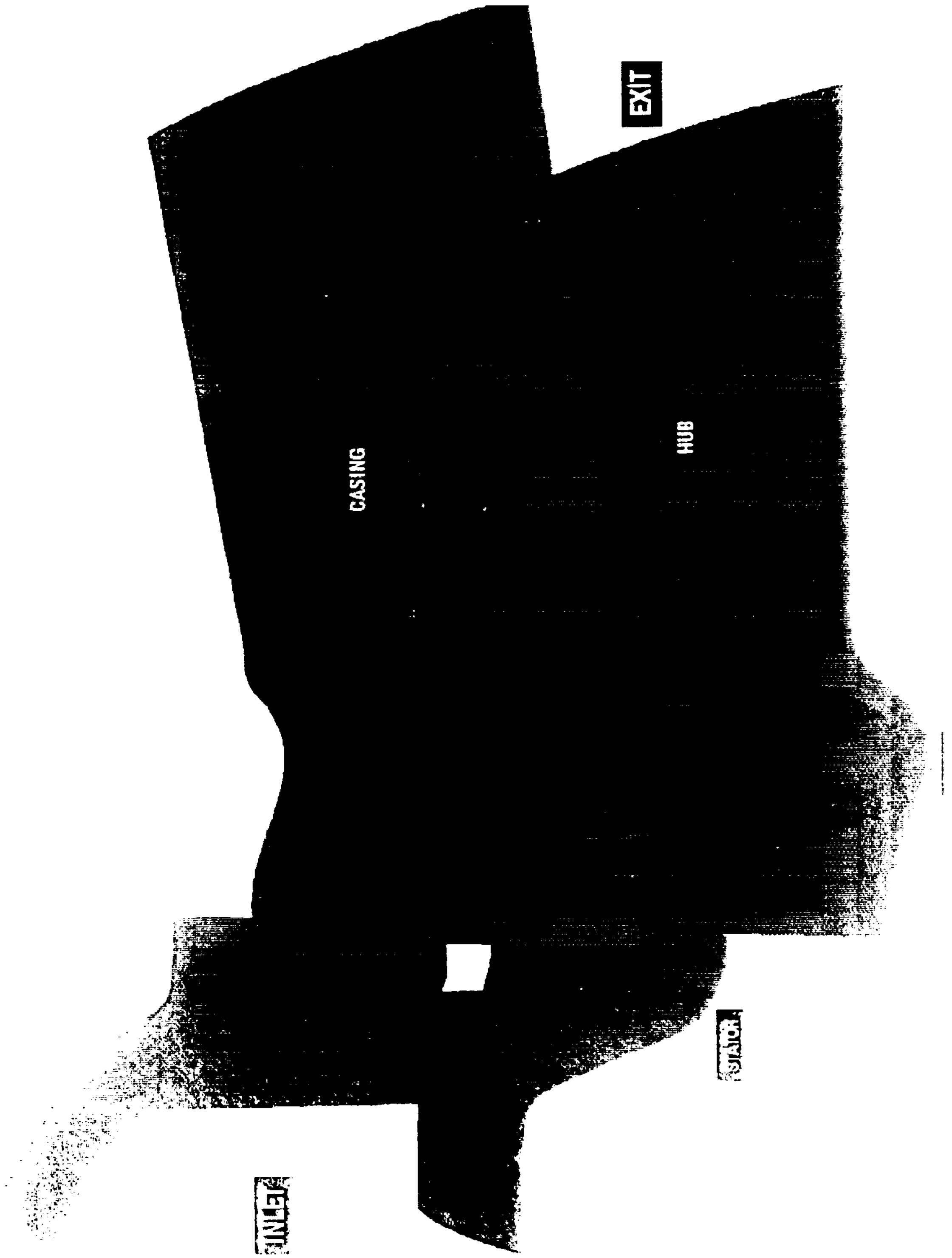


FIRST-ORDER ACCURATE
SHOCK FREE FLOW

Preliminary 3D Results for the GGOT

RESULTS ARE PRELIMINARY BECAUSE

- SOLUTION HAS NOT COMPLETELY CONVERGED TO A TIME PERIODIC STATE
- GRID IS COARSE (IN RADIAL DIRECTION)


EXIT
CASING
HUB
STATOR
INLET

Geometry Rescaling

Turbine Geometry

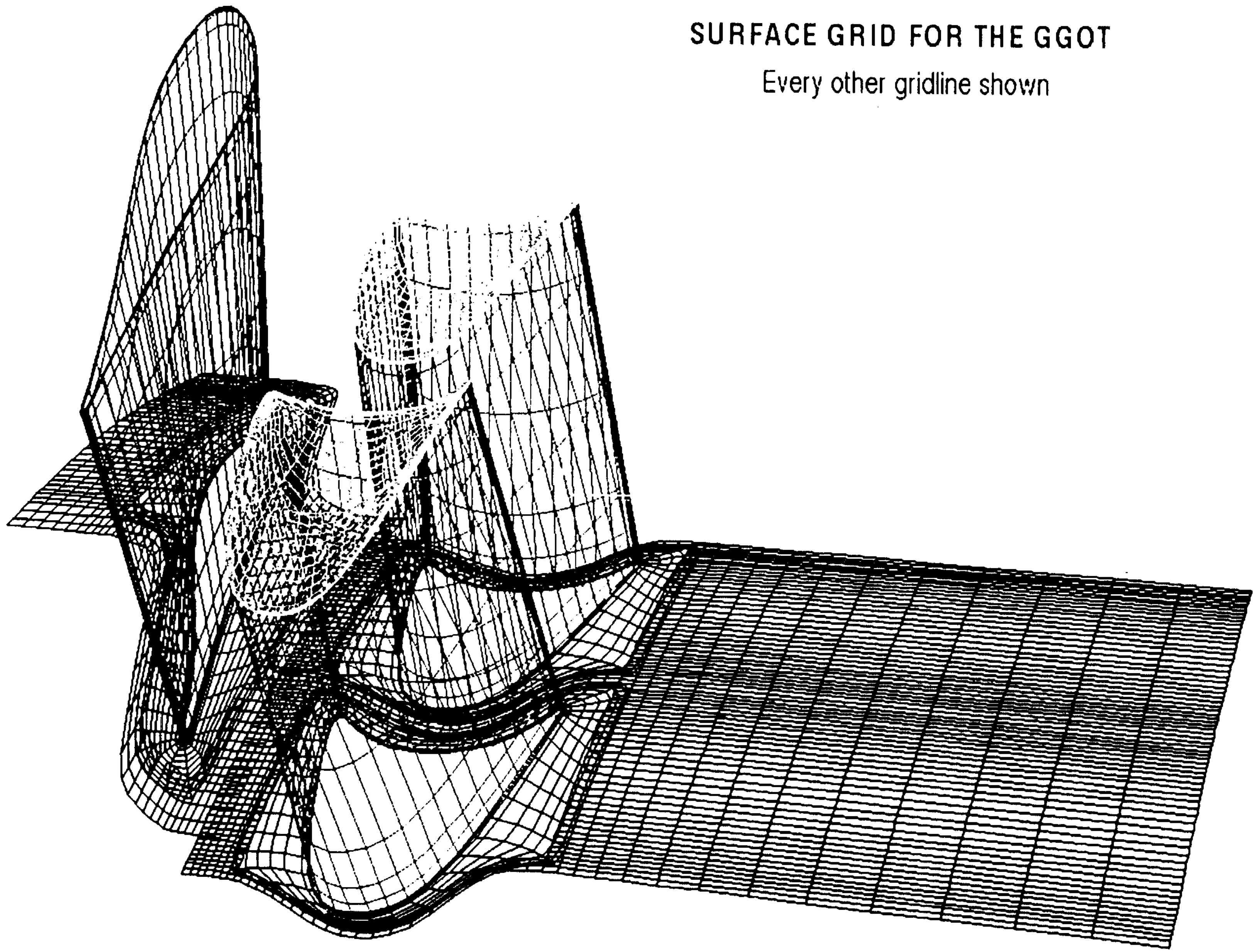
Number of stator blades = 20
Number of rotor blades = 42

Rescaled Geometry

Number of stator blades = 21
Number of rotor blades = 42

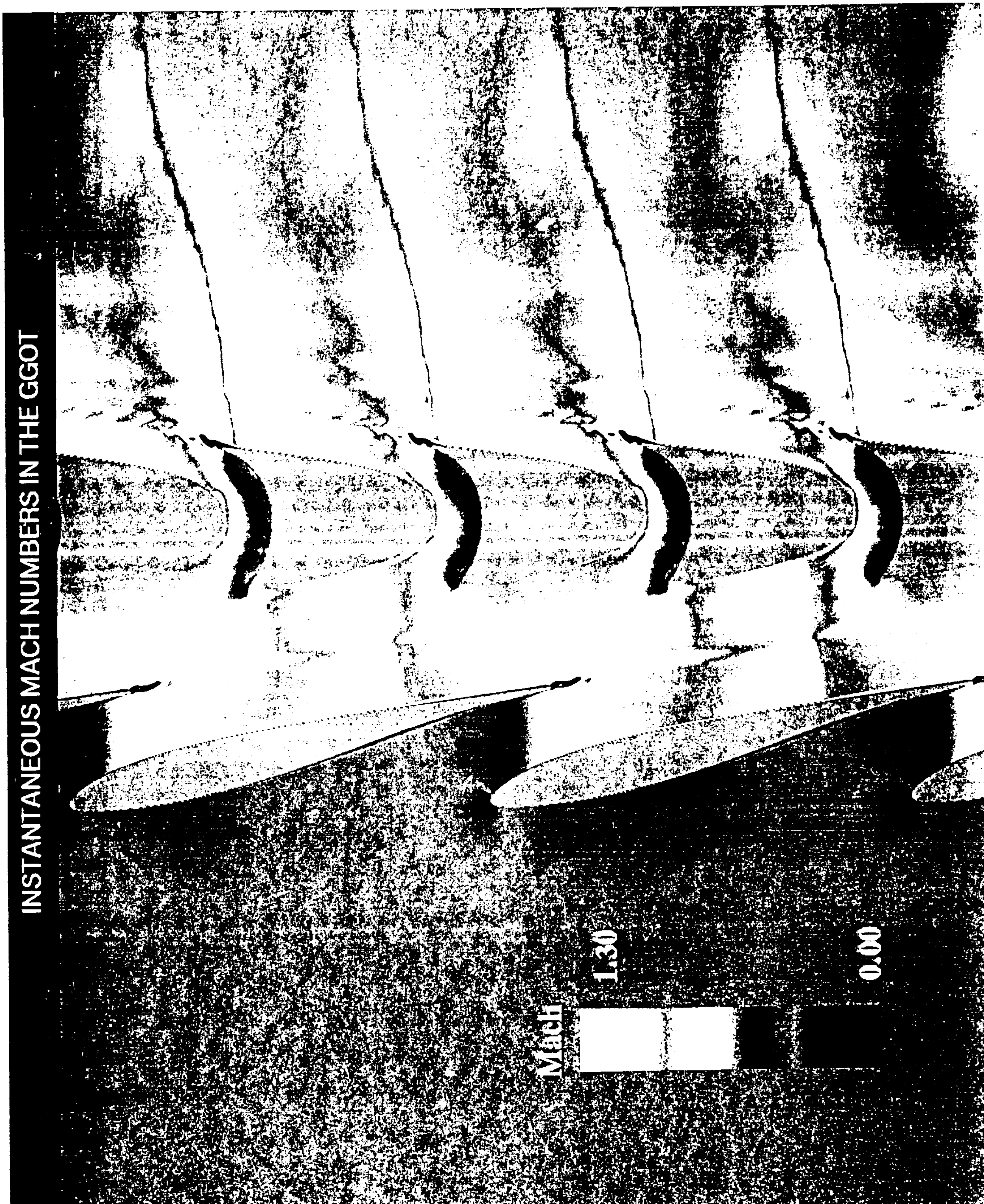
SURFACE GRID FOR THE GGOT

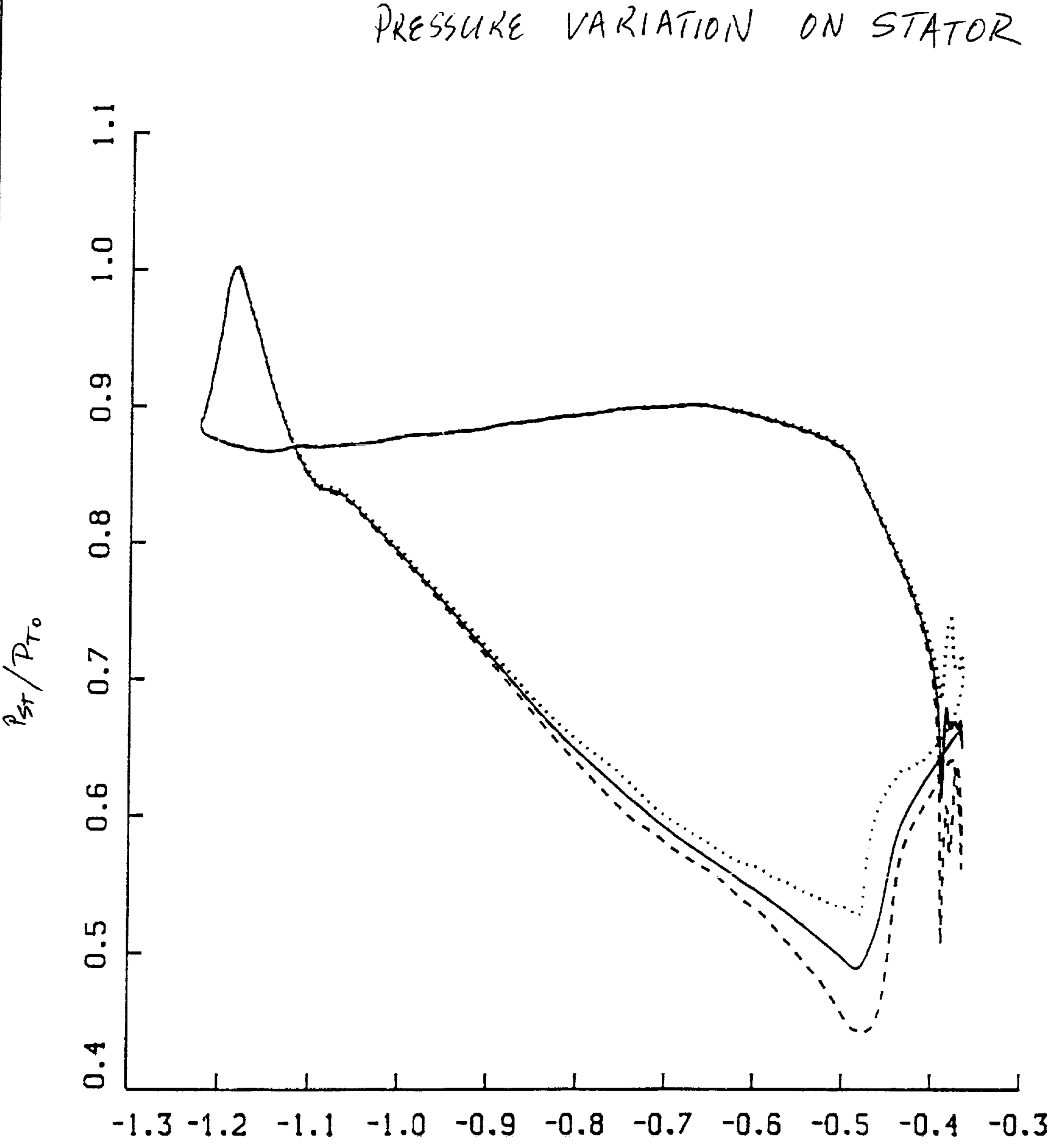
Every other gridline shown

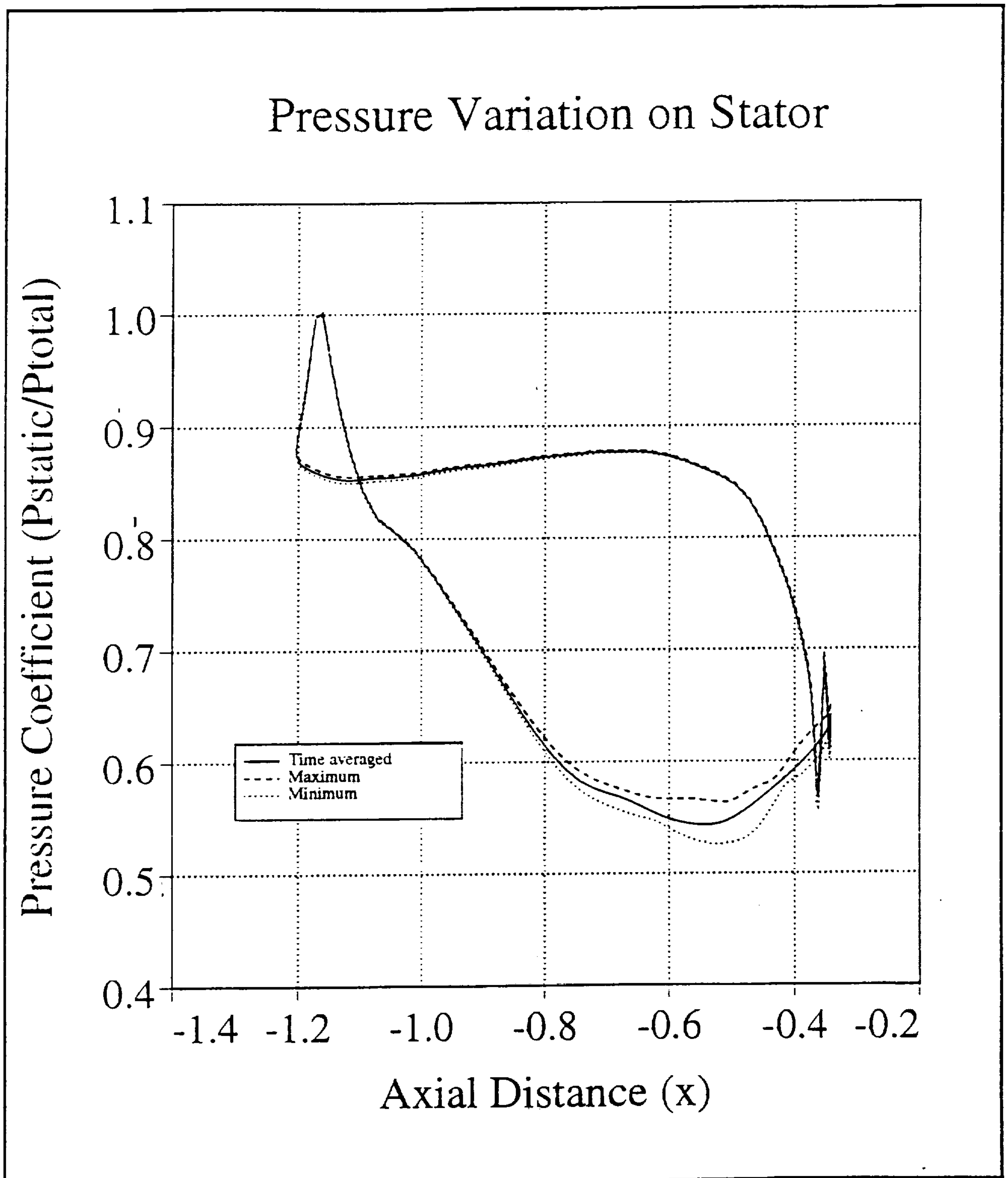


Turbine operating conditions

INLET MACH NO.	0.46
INLET REYNOLDS NO.	2600000/*inch*
RPM	7880
INLET TOTAL PRESSURE	542.77 PSIA
EXIT STATIC PRESSURE	200.00 PSIA
INLET TOTAL TEMPERATURE	1307.02° *R*


INSTANTANEOUS MACH NUMBERS IN THE GGOT
Mach
1.30
0.00

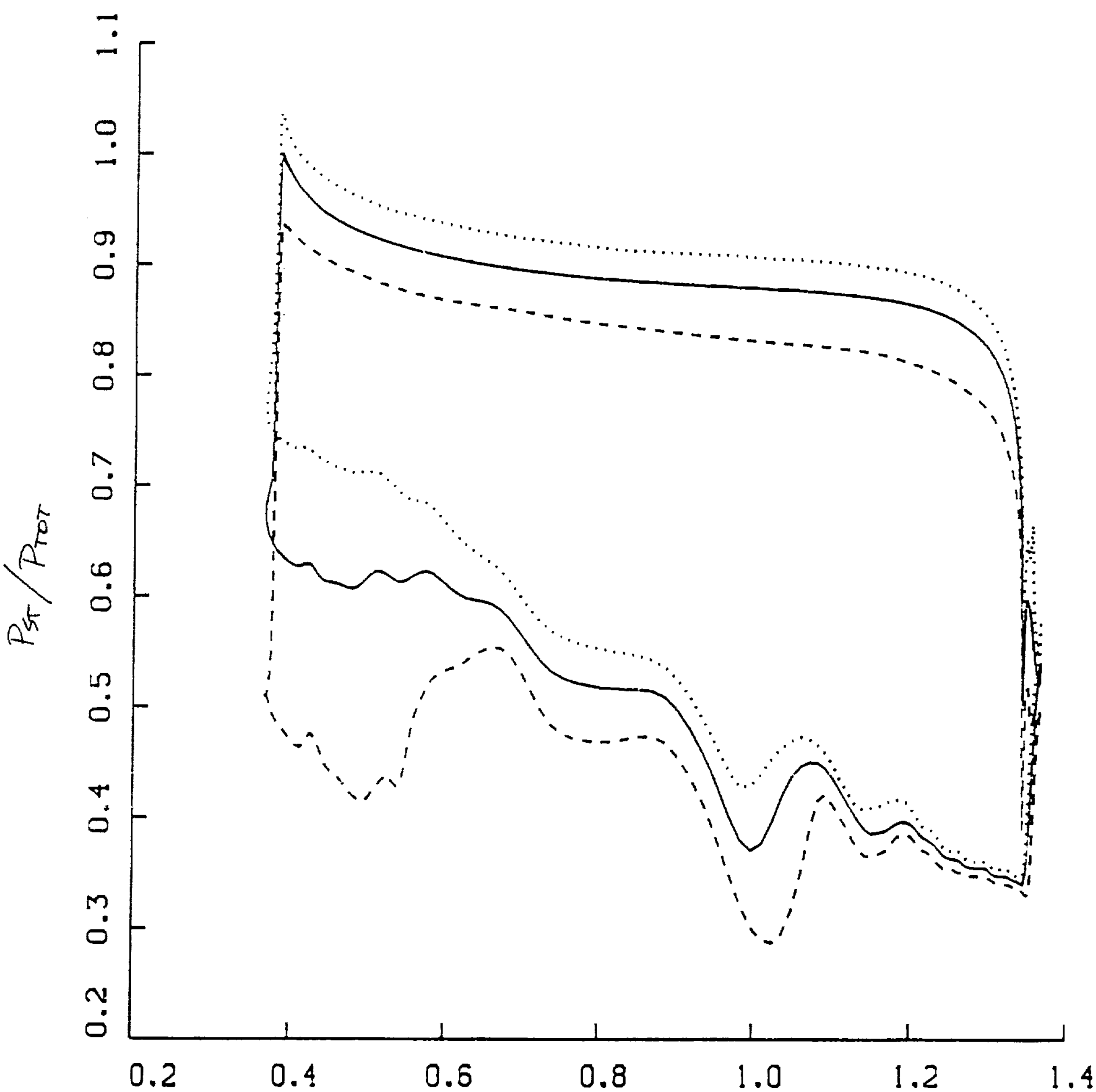

PRESSURE VARIATION ON STATOR
P_{ST}/P_{T_0}
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
-1.3
-1.2
-1.1
-1.0
-0.9
-0.8
-0.7
-0.6
-0.5
-0.4
-0.3

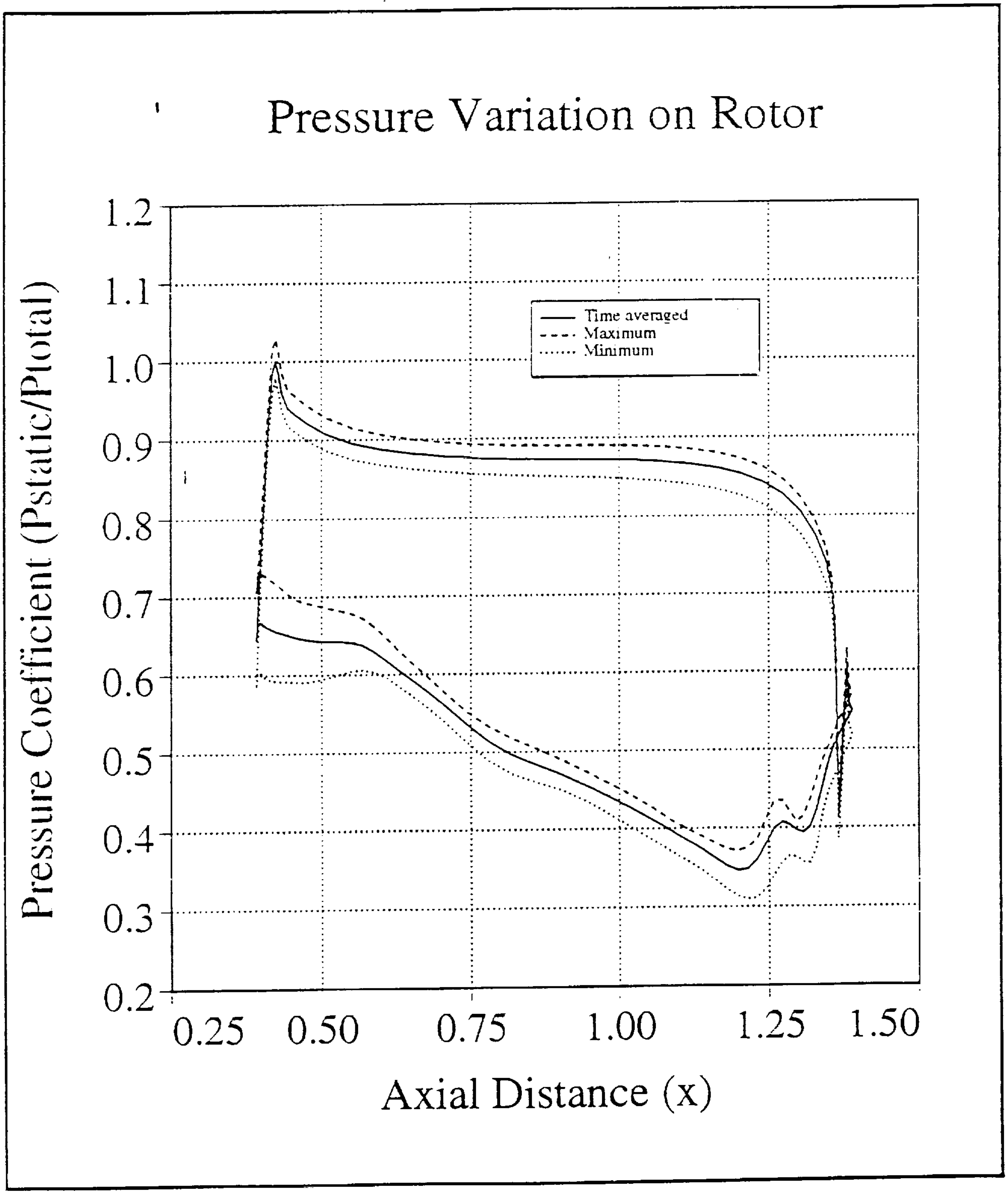


Pressure Variation on Stator
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
Pressure Coefficient (Pstatic/Ptotal)
Time averaged
Maximum
Minimum
-1.4 -1.2 -1.0 -0.8 -0.6 -0.4 -0.2
Axial Distance (x)

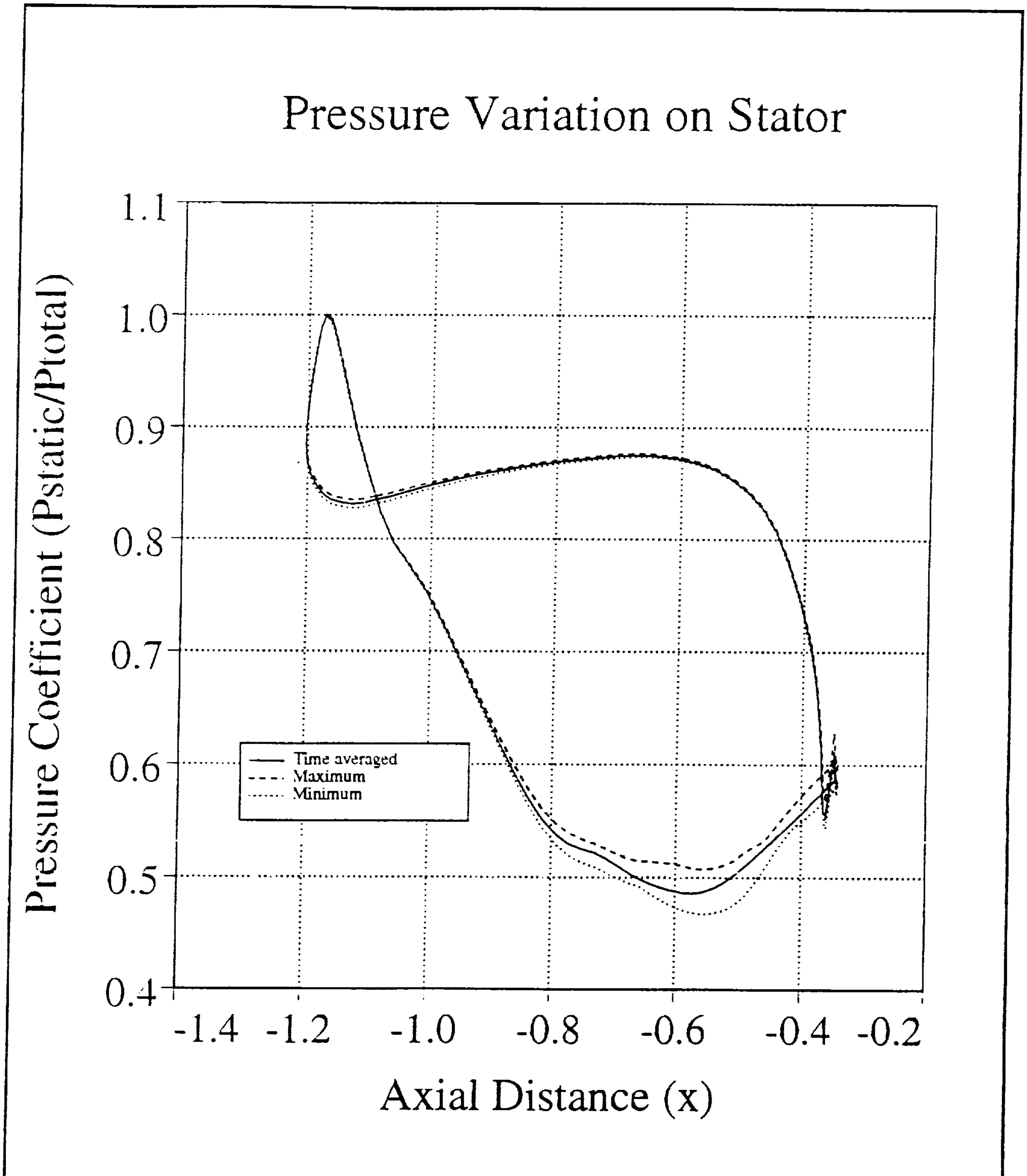
MID PLANE

PRESSURE VARIATION ON ROTOR

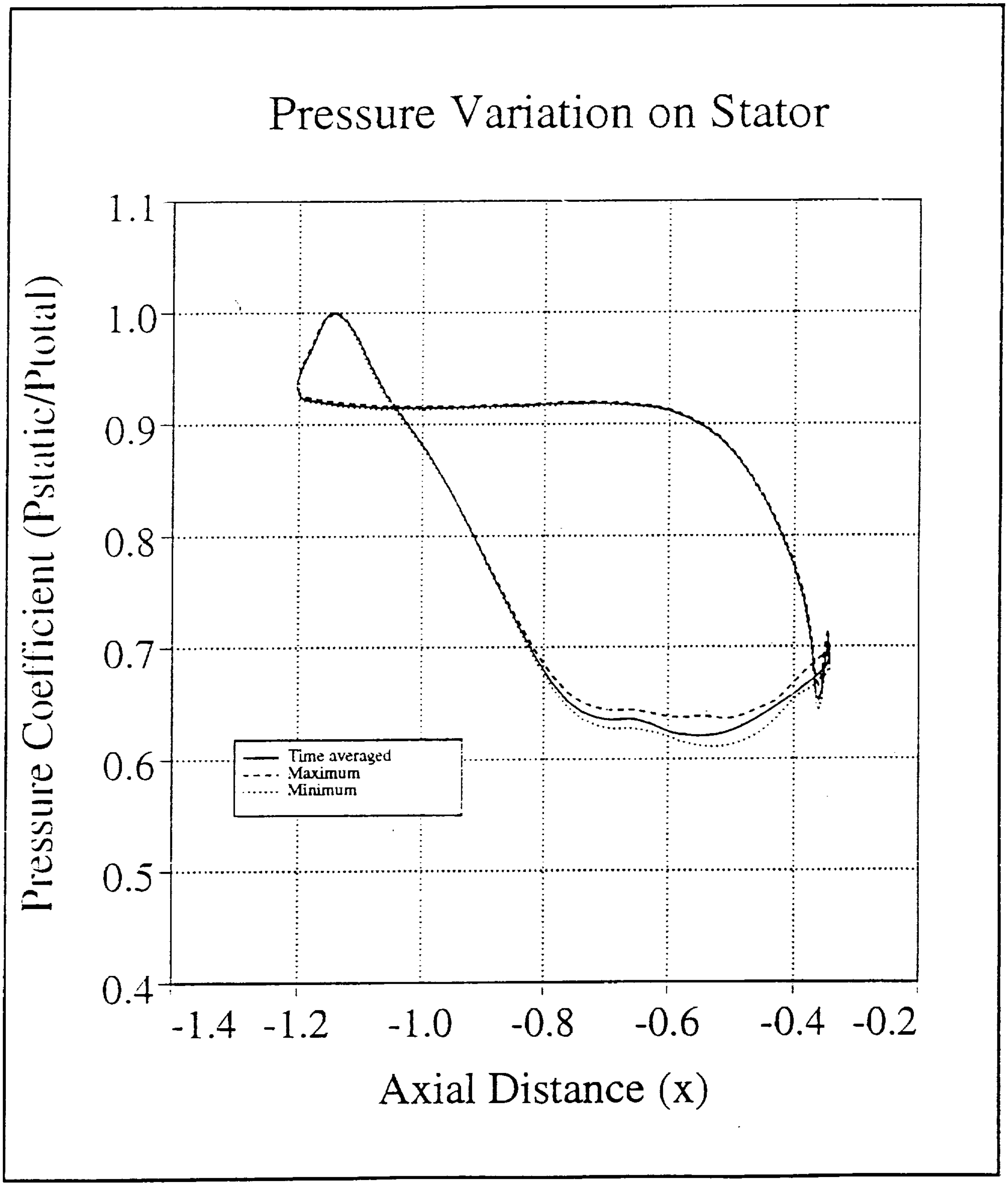



Pressure Variation on Rotor
Pressure Coefficient (Pstatic/Ptotal)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
Time averaged
Maximum
Minimum
0.25
0.50
0.75
1.00
1.25
1.50
Axial Distance (x)

MID PLANE

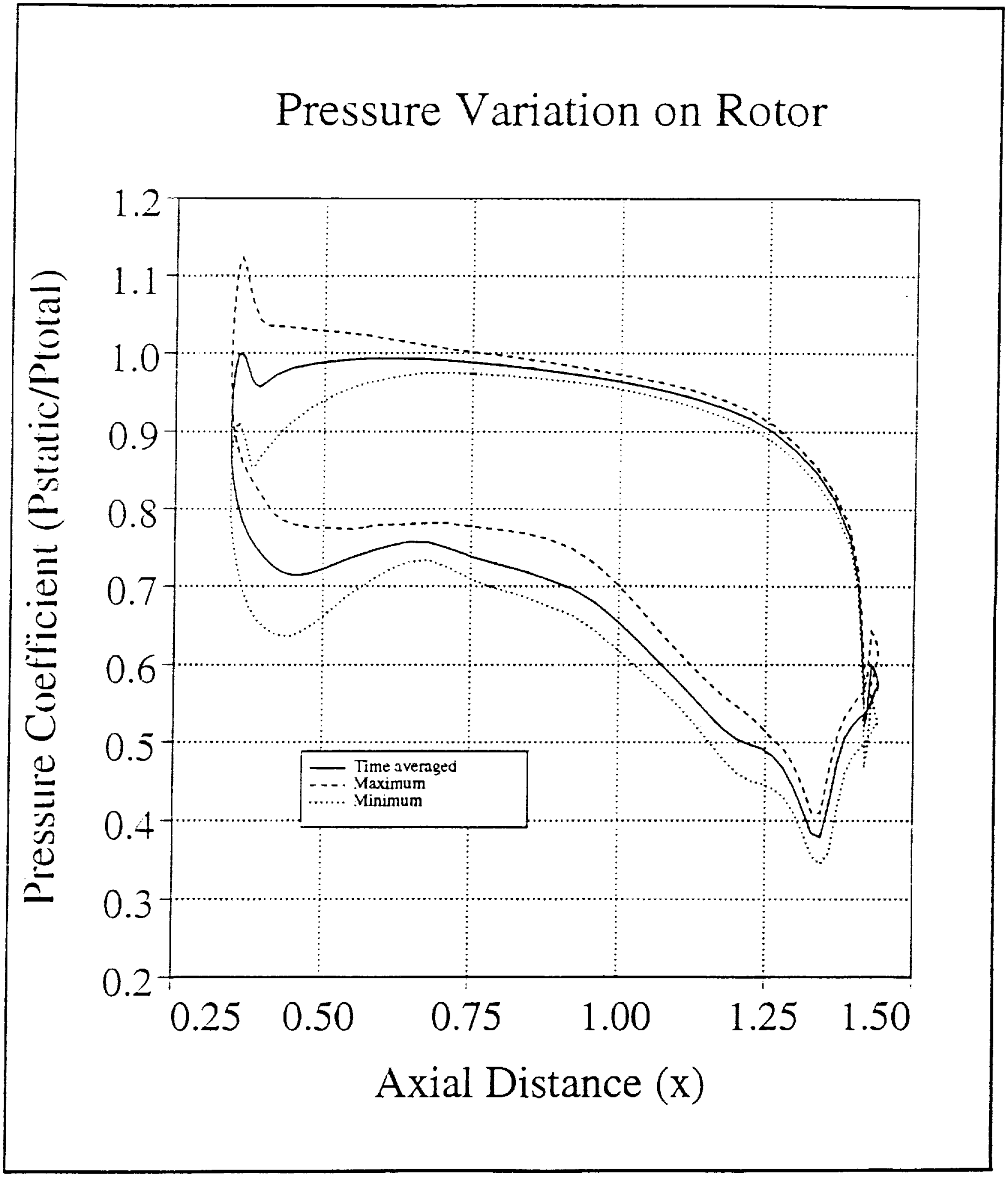

Pressure Variation on Stator
Pressure Coefficient (Pstatic/Ptotal)
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
Time averaged
Maximum
Minimum
-1.4 -1.2 -1.0 -0.8 -0.6 -0.4 -0.2
Axial Distance (x)

HUB

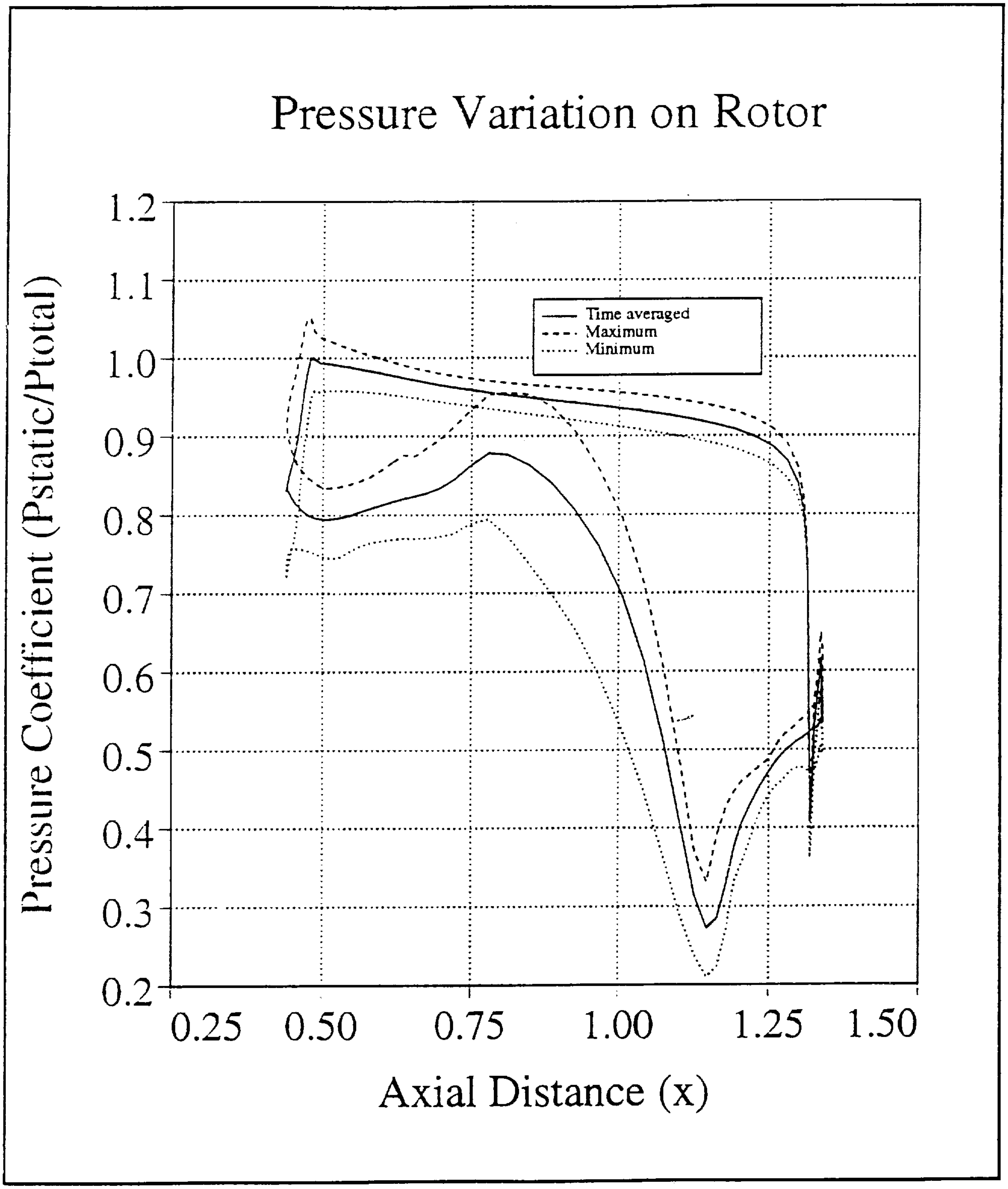


Pressure Variation on Stator
Pressure Coefficient (Pstatic/Ptotal)
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
-1.4 -1.2 -1.0 -0.8 -0.6 -0.4 -0.2
Axial Distance (x)
Time averaged
Maximum
Minimum

CASING


Pressure Variation on Rotor
Pressure Coefficient (Pstatic/Ptotal)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.25
0.50
0.75
1.00
1.25
1.50
Axial Distance (x)
Time averaged
Maximum
Minimum

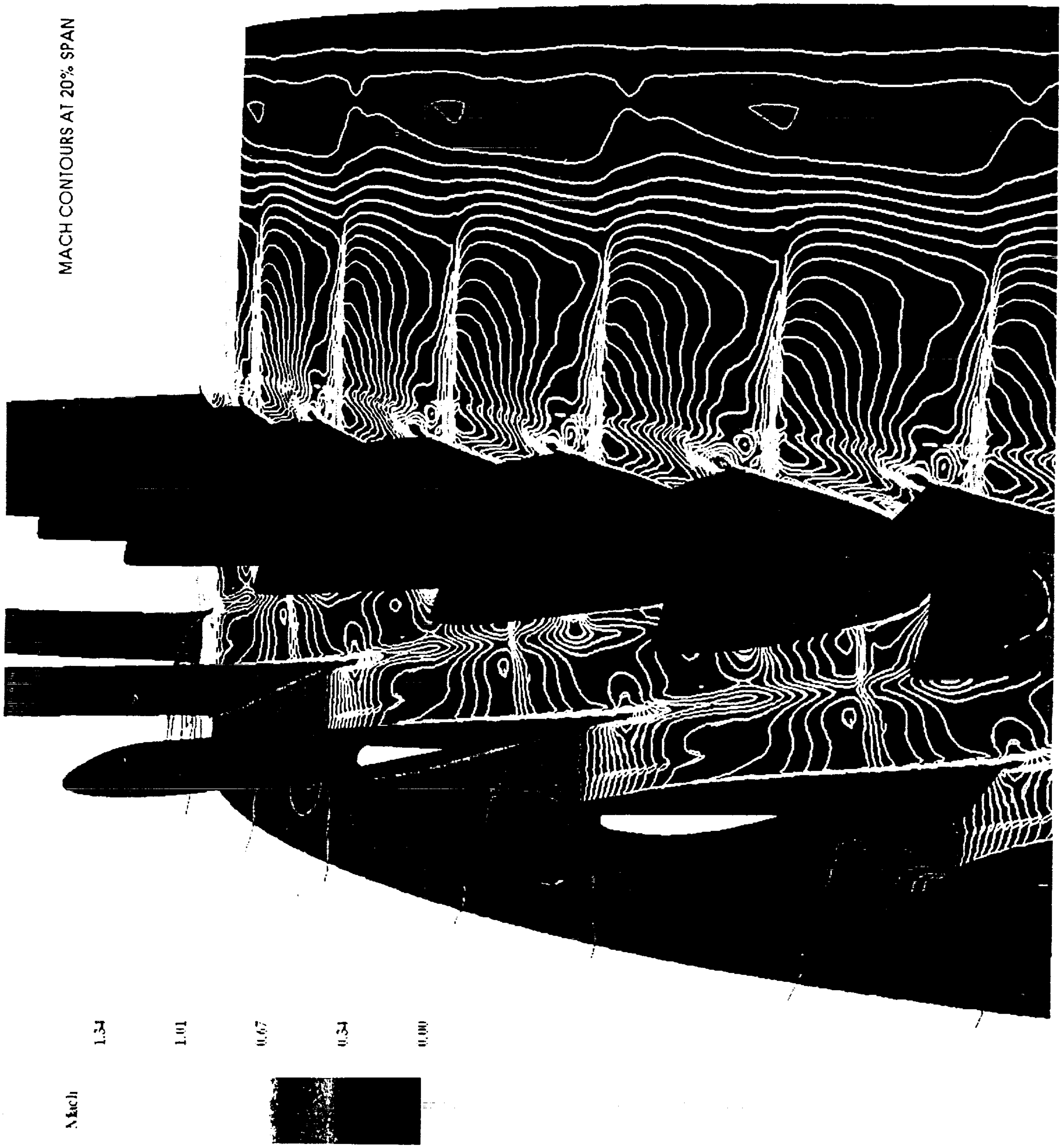
HUB

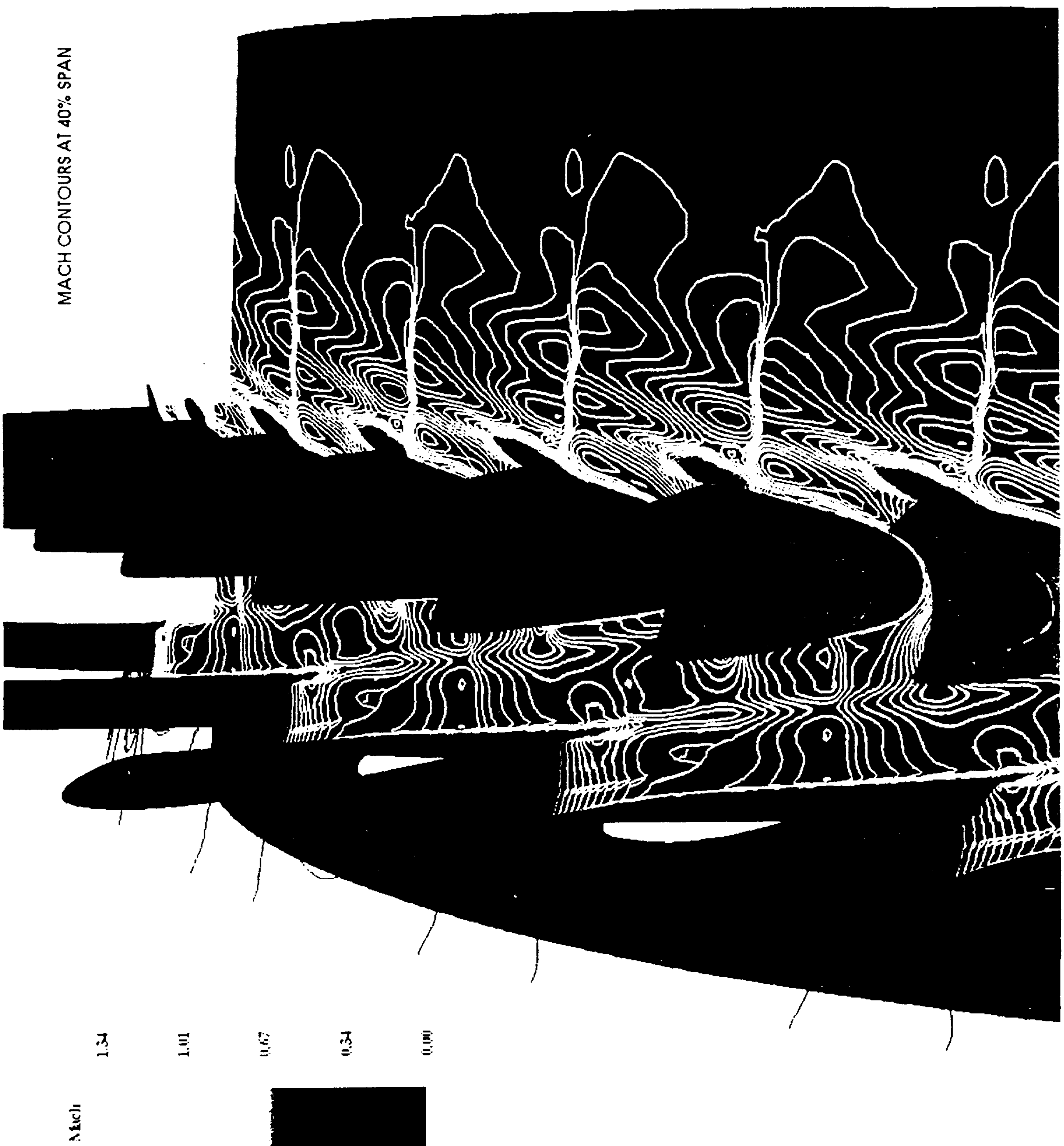


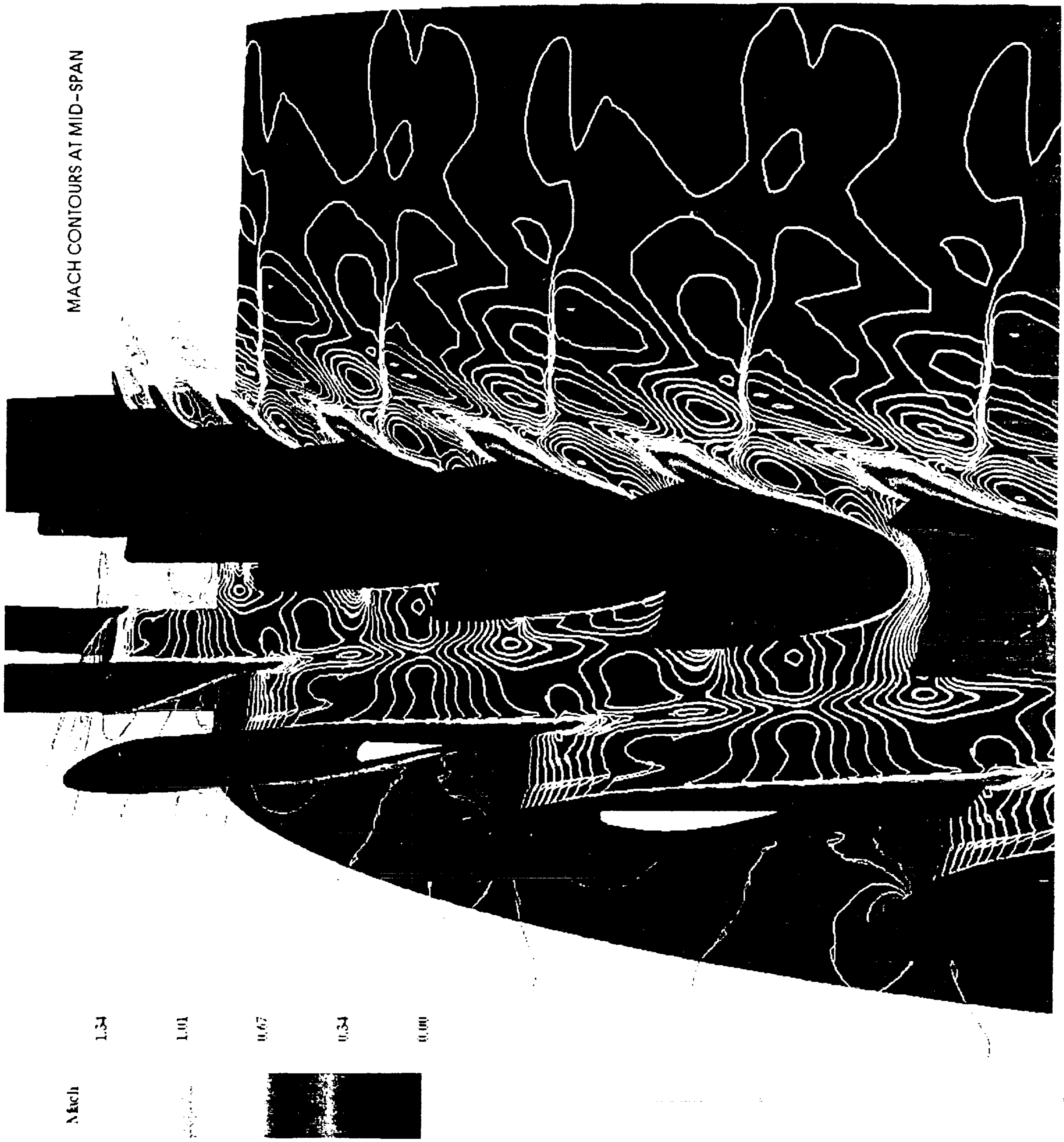
Pressure Variation on Rotor
Time averaged
Maximum
Minimum
Pressure Coefficient (Pstatic/Ptotal)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.25
0.50
0.75
1.00
1.25
1.50
Axial Distance (x)

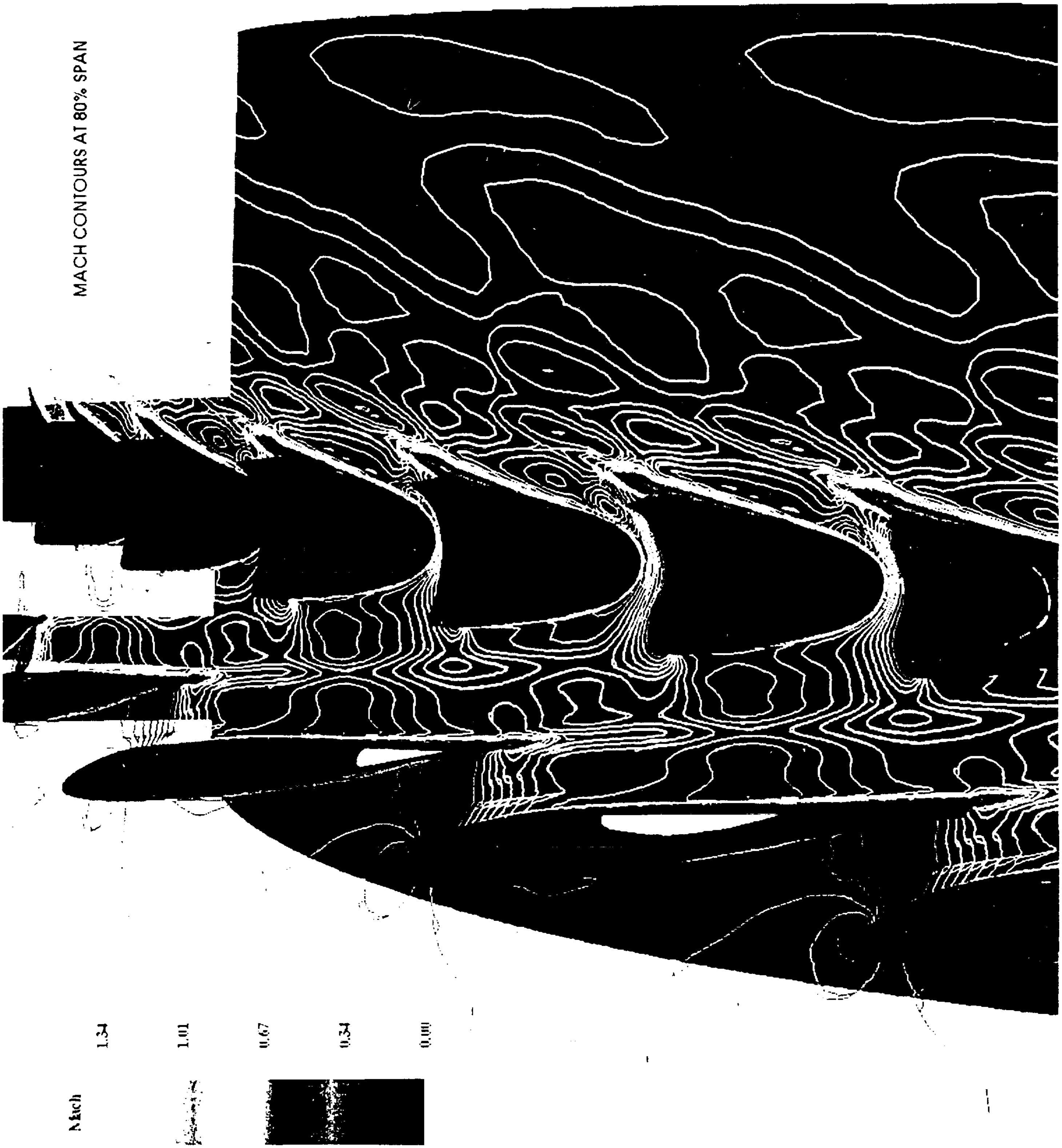
TIP

MACH CONTOURS AT 20% SPAN




MACH CONTOURS AT 40% SPAN
Mach
1.34
1.01
0.67
0.34
0.00


MACH CONTOURS AT MID-SPAN
Mach
1.34
1.01
0.67
0.34
0.00


MACH CONTOURS AT 80% SPAN
Mach
1.34
1.01
0.67
0.34
0.00

Summary and conclusion

A COARSE GRID CALCULATION FOR THE GGOT IS NEARING COMPLETION

- THERE ARE SIMILARITIES AS WELL AS DIFFERENCES WITH THE CORRESPONDING TWO-DIMENSIONAL SOLUTIONS
  - ISSUES OF ACCURACY
  - TWO-DIMENSIONAL MODELLING (STREAM-TUBE CONTRACTION)
- FLOW FIELD SOLUTIONS WILL SERVE AS A GOOD STARTING SOLUTION FOR A FINER GRID CALCULATION ON THE C-90
- INPUT FROM THE DESIGN TEAM AS TO WHAT ASPECT OF THE FLOW FIELD NEEDS TO BE INVESTIGATED FURTHER