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NAVIER-STOKES ANALYSIS OF AN OXIDIZER TURBINE BLADE WITH TIP CLEARANCE WITH AND WITHOUT A MINI-SHROUD†

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p. 26

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ABSTRACT

The Gas Generator Oxidizer Turbine (GGOT) Blade is being analyzed by various investigators under the NASA MSFC-sponsored Turbine Stage Technology Team design effort. The present work concentrates on the tip clearance region flow and associated losses; however, flow details for the passage region are also obtained in the simulations. The present calculations simulate the rotor blade row in a rotating reference frame with the appropriate coriolis and centrifugal acceleration terms included in the momentum equations. The upstream computational boundary is located about one axial chord from the blade leading edge. The boundary conditions at this location have been determined by Pratt & Whitney using an Euler analysis without the vanes to obtain approximately the same flow profiles at the rotor as were obtained with the Euler stage analysis including the vanes. Inflow boundary layer profiles are then constructed assuming the skin friction coefficient at both the hub and the casing. The downstream computational boundary is located about one axial chord from the blade trailing edge, and the circumferentially averaged static pressure at this location was also obtained from the P&W Euler analysis.

Results obtained for the 3-D baseline GGOT geometry at the full scale design Reynolds number show a region of high loss in the region near the casing. Particle traces in the near tip region show vortical flow behavior of the fluid which passes through the clearance region and exits at the downstream edge of the gap. In an effort to reduce clearance flow losses, the mini-shroud concept was proposed by the Pratt & Whitney design team. Calculations were performed on the GGOT geometry with the mini-shroud. Results of these calculations indicate that the mini-shroud does not significantly affect the flow in the passage region, and although the tip clearance flow is different, the mini-shroud does not seem to prevent the above-mentioned vortical flow behavior. Since both flow distortion and total pressure losses are similar for both geometries, the addition of the mini-shroud does not seem to reduce the tip clearance flow effects.

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† This work was supported by NASA Marshall Space Flight Center under Contract NAS8-38865.

APPROACH

UTILIZE SRA MINT CODE

- GENERAL NON-RECTANGULAR BLOCK STRUCTURE
- SINGLE GRID
- FULL NAVIER-STOKES EQUATIONS
- NO-SLIP WALL BOUNDARY EQUATIONS WITH SUBLAYER RESOLUTION
- ALGEBRAIC MIXING LENGTH TURBULENCE MODEL
- IMPLICIT LINEARIZED BLOCK SOLVER (ADI)

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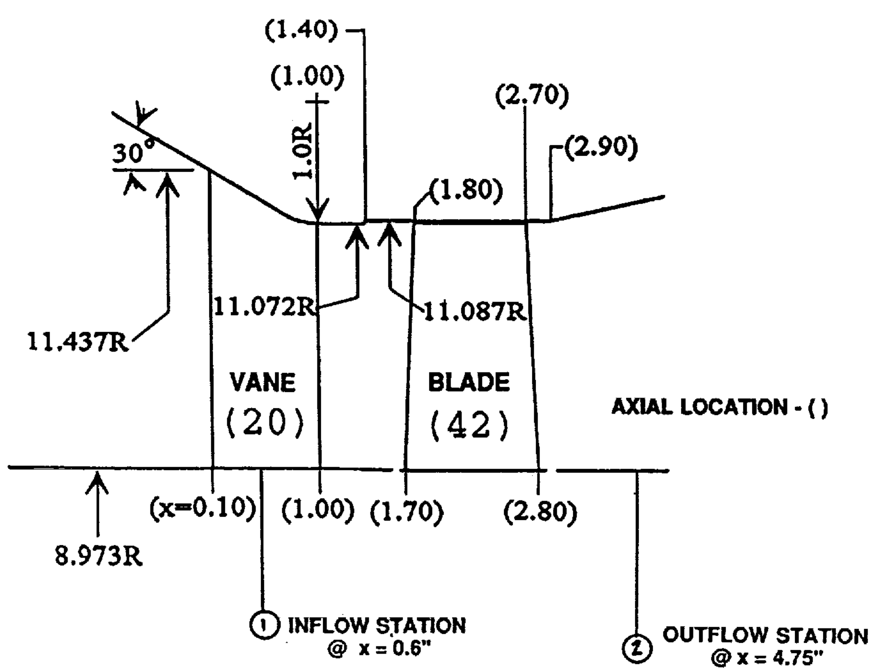
OXIDIZER TURBINE BASELINE DESIGN

FULL SCALE TURBINE FLOWPATH CLOSE-UP



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FLOW PARAMETERS

- SUPPLIED BY P&W DESIGN TEAM
- CIRCUMFERENTIALLY - AVERAGED SPANWISE DISTRIBUTIONS FROM EULER CODE
  - UPSTREAM AXIAL MASS FLUX
  - UPSTREAM TOTAL TEMPERATURE
  - UPSTREAM FLOW ANGLES
  - DOWNSTREAM STATIC PRESSURE
- HUB AND CASING ENDWALL BOUNDARY LAYER PROFILES CONSTRUCTED WITH ASSUMED B. L. THICKNESS $\delta = 0.03$ IN.

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GRID GENERATION

- "FALSE CORNER" GRID STRUCTURE
- 2-D ELLIPTIC GRIDS GENERATED WITH EAGLE

  60 x 90 POINTS IN CROSS-SECTIONAL PLANE
- 3-D GRID CONSTRUCTION

  21 BLADE CROSS-SECTIONAL PLANES

  REDISTRIBUTION IN SPANWISE DIRECTION

  28 POINTS FROM HUB TO TIP

  12 POINTS IN CLEARANCE REGION

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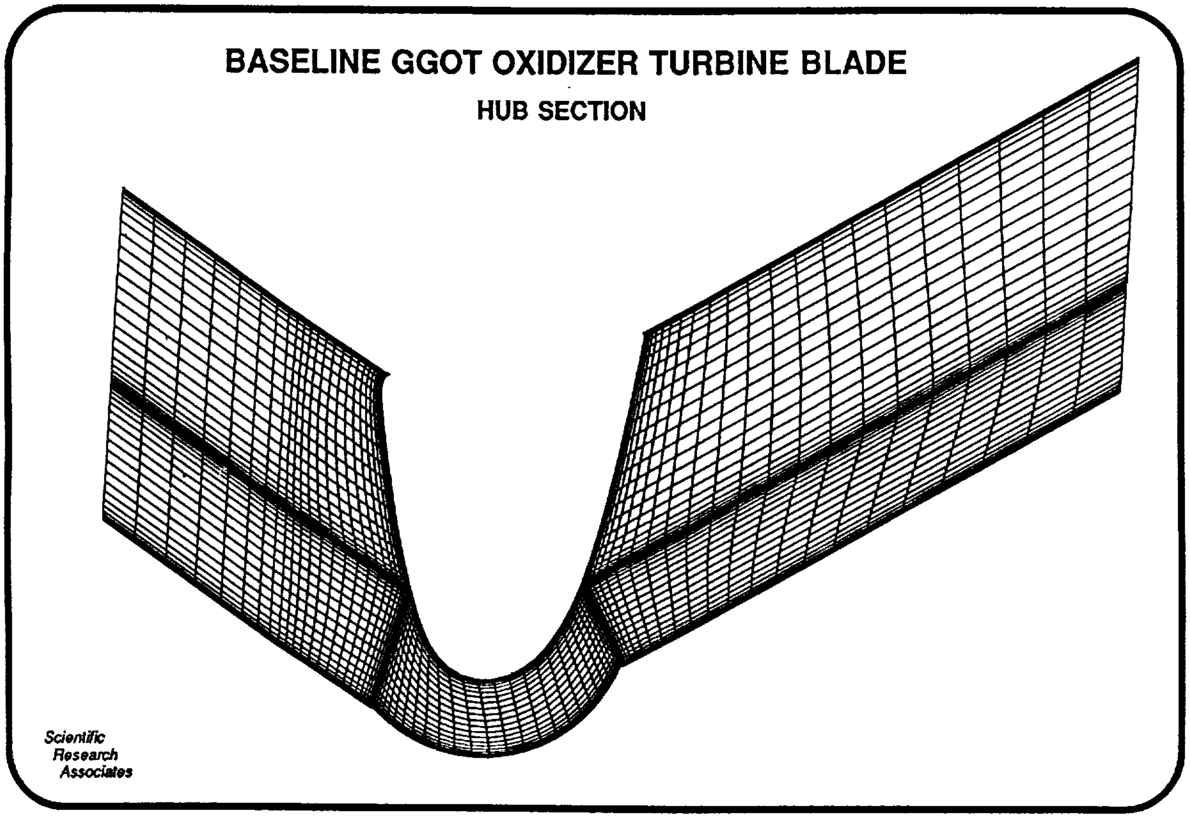
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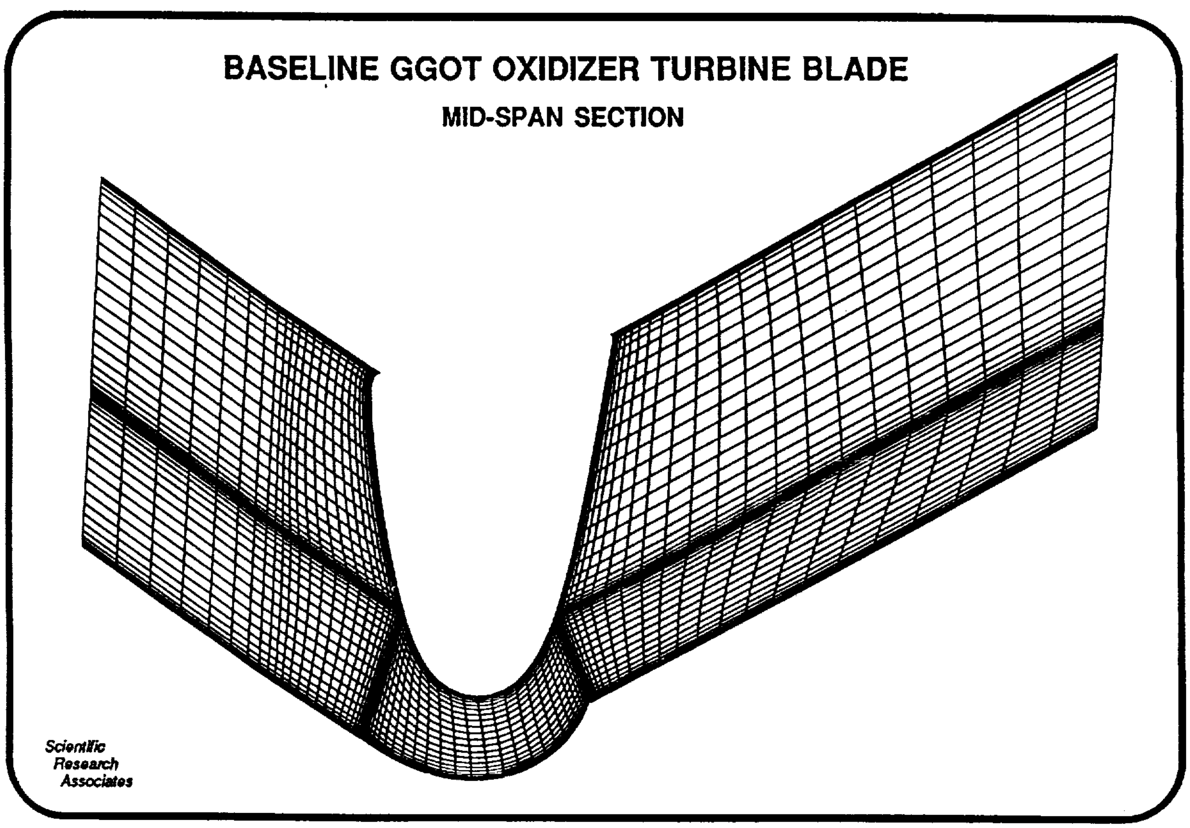
HUB SECTION
Scientific
Research
Associates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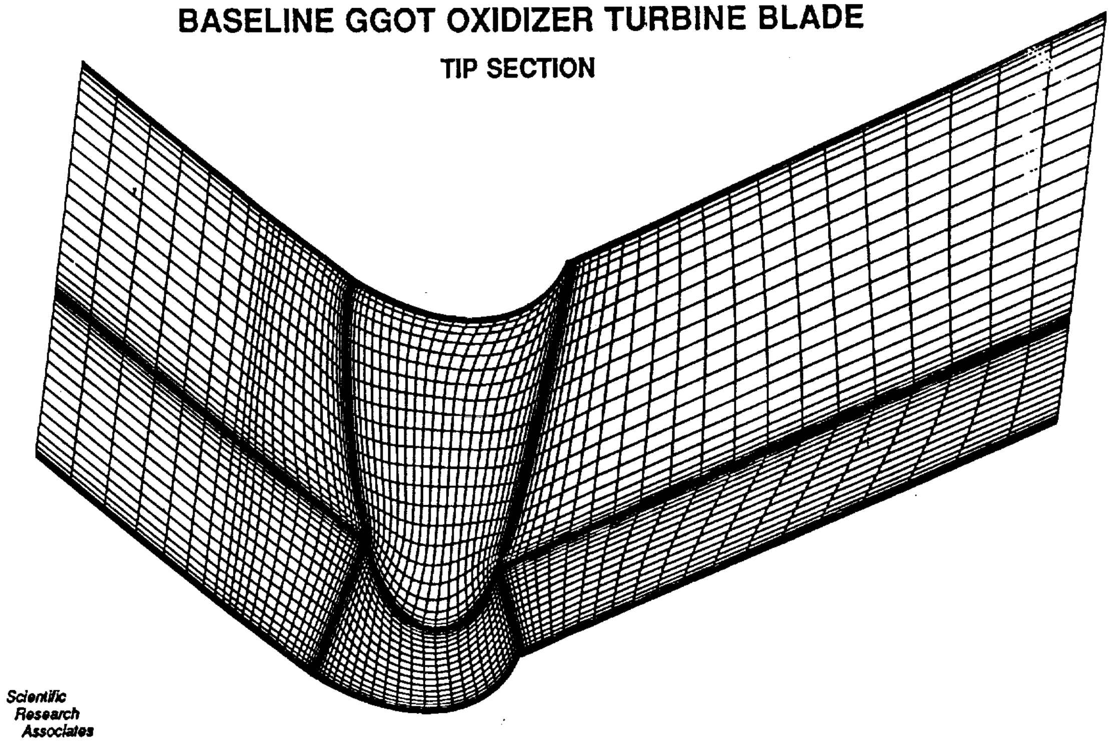
MID-SPAN SECTION
Scientific
Research
Associates

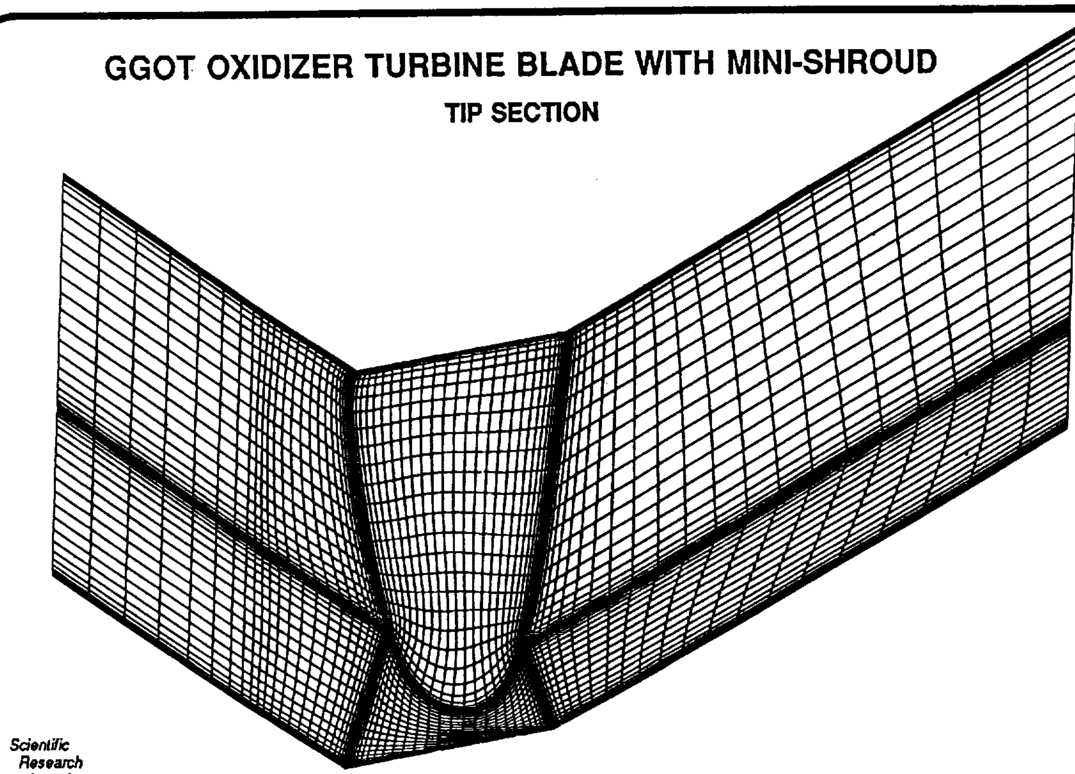
BASELINE GGOT OXIDIZER TURBINE BLADE

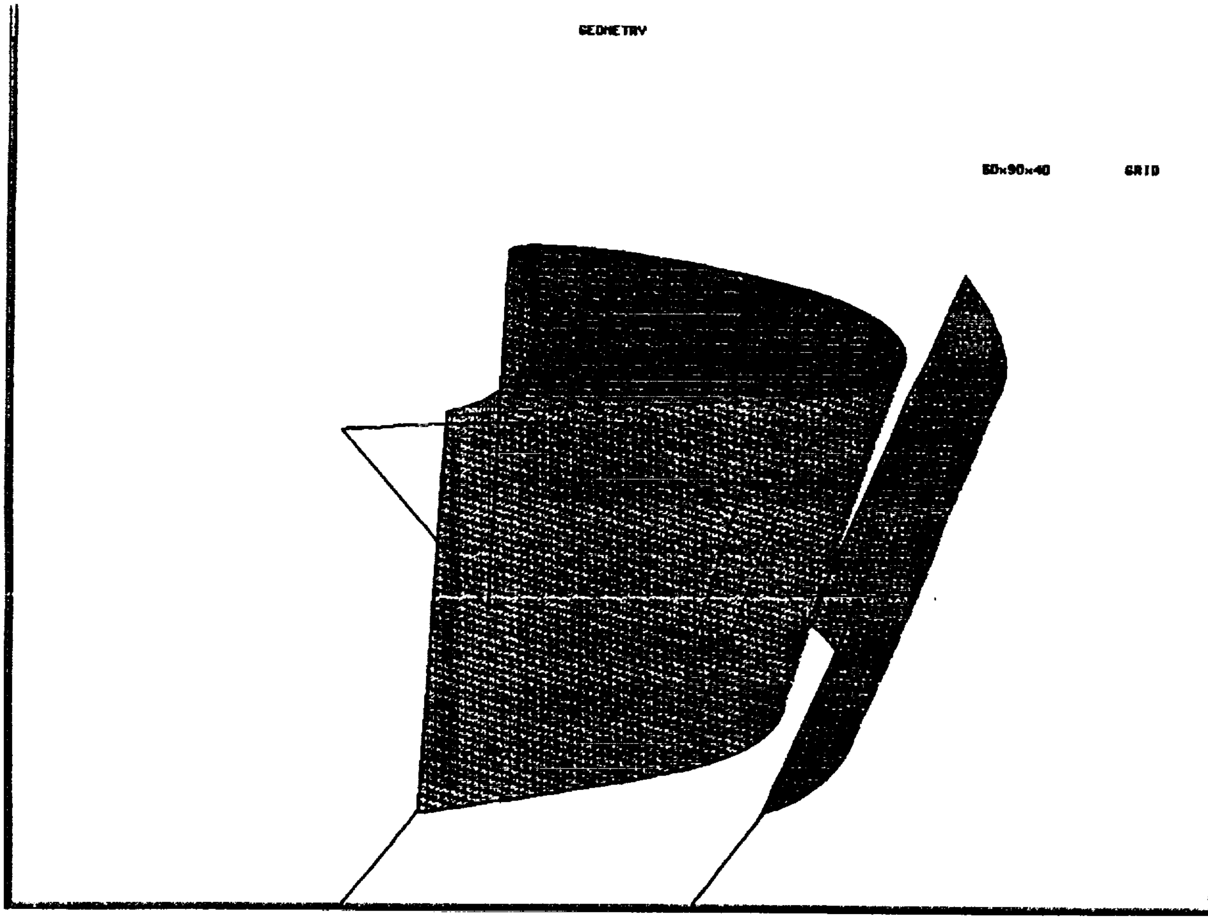
TIP SECTION



GGOT OXIDIZER TURBINE BLADE WITH MINI-SHROUD

TIP SECTION

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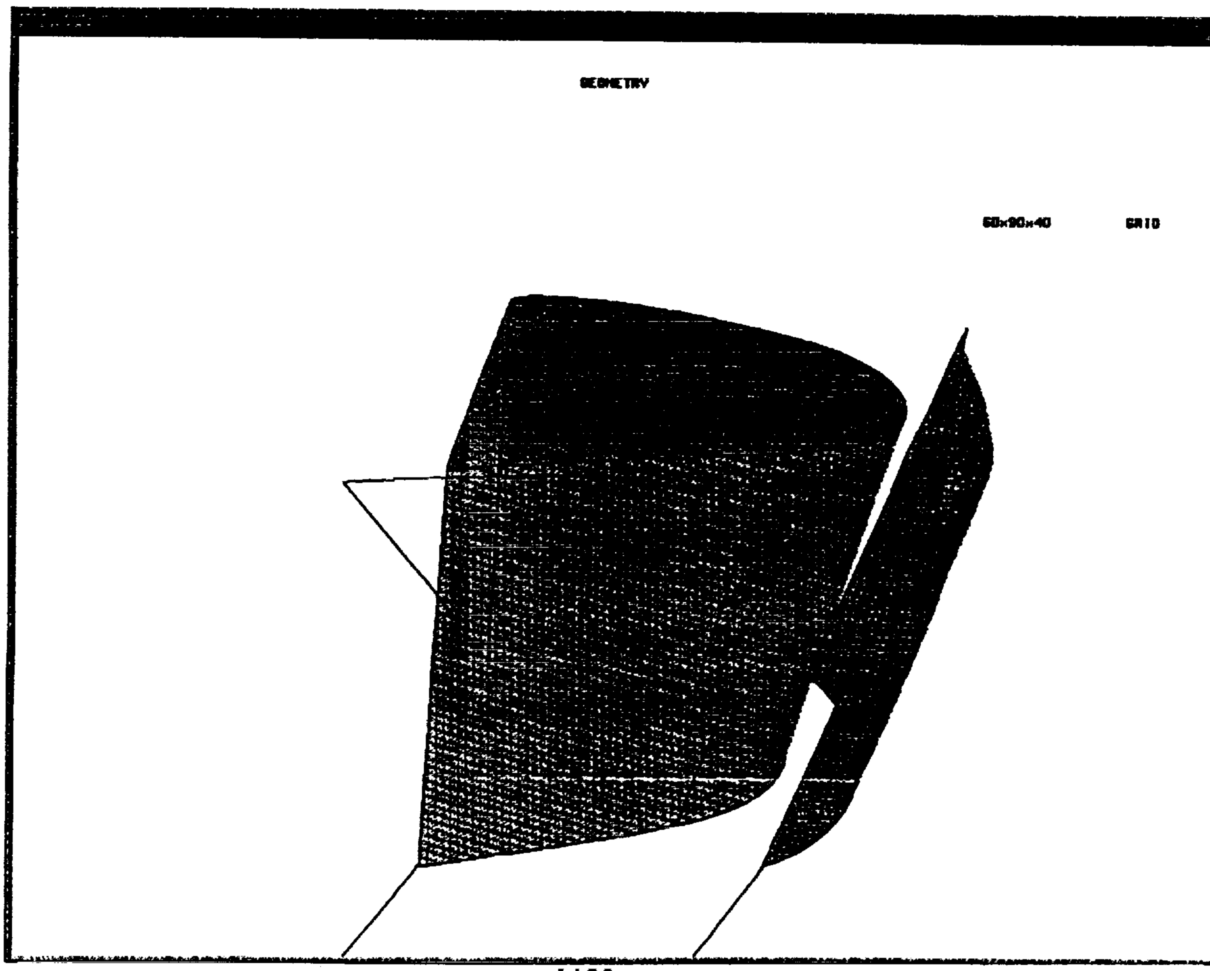
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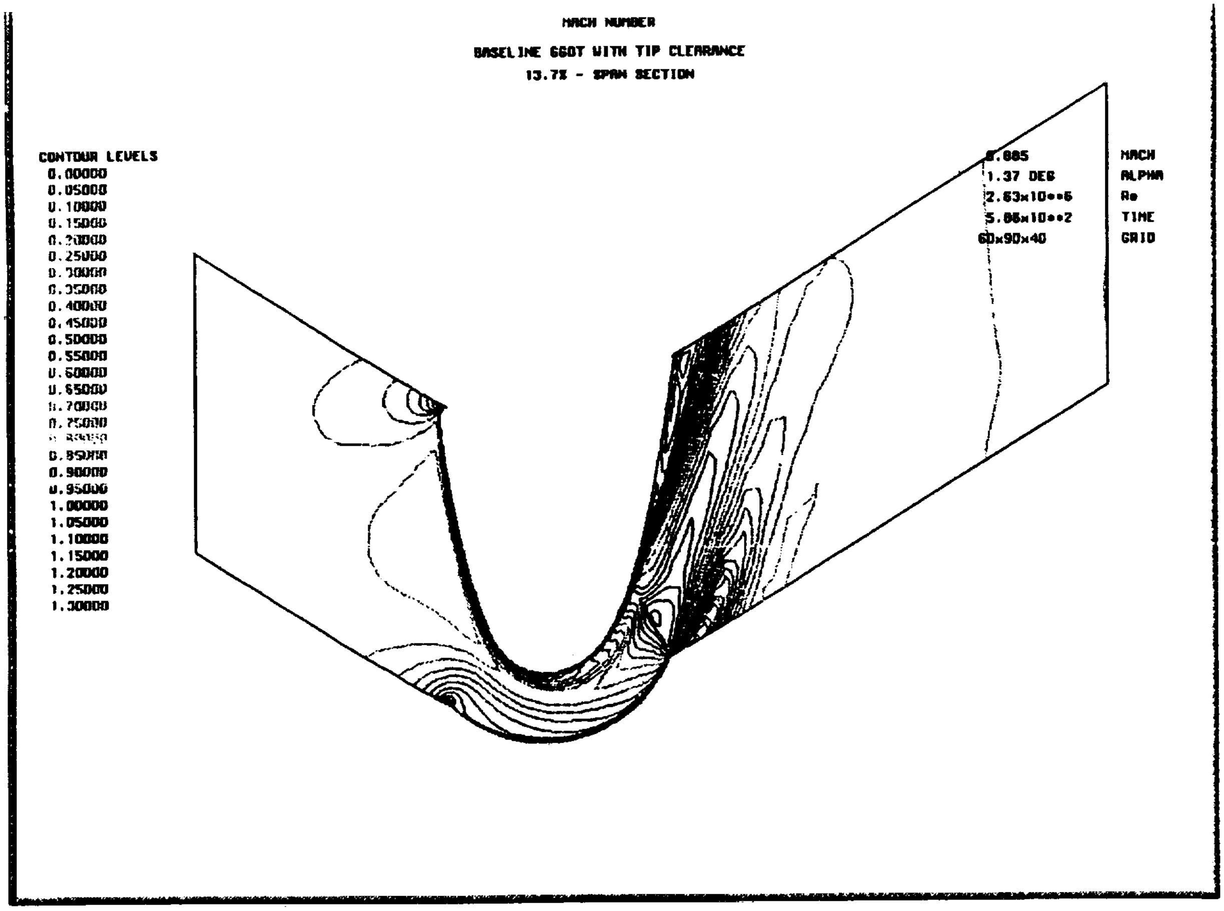
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0.25000
0.30000
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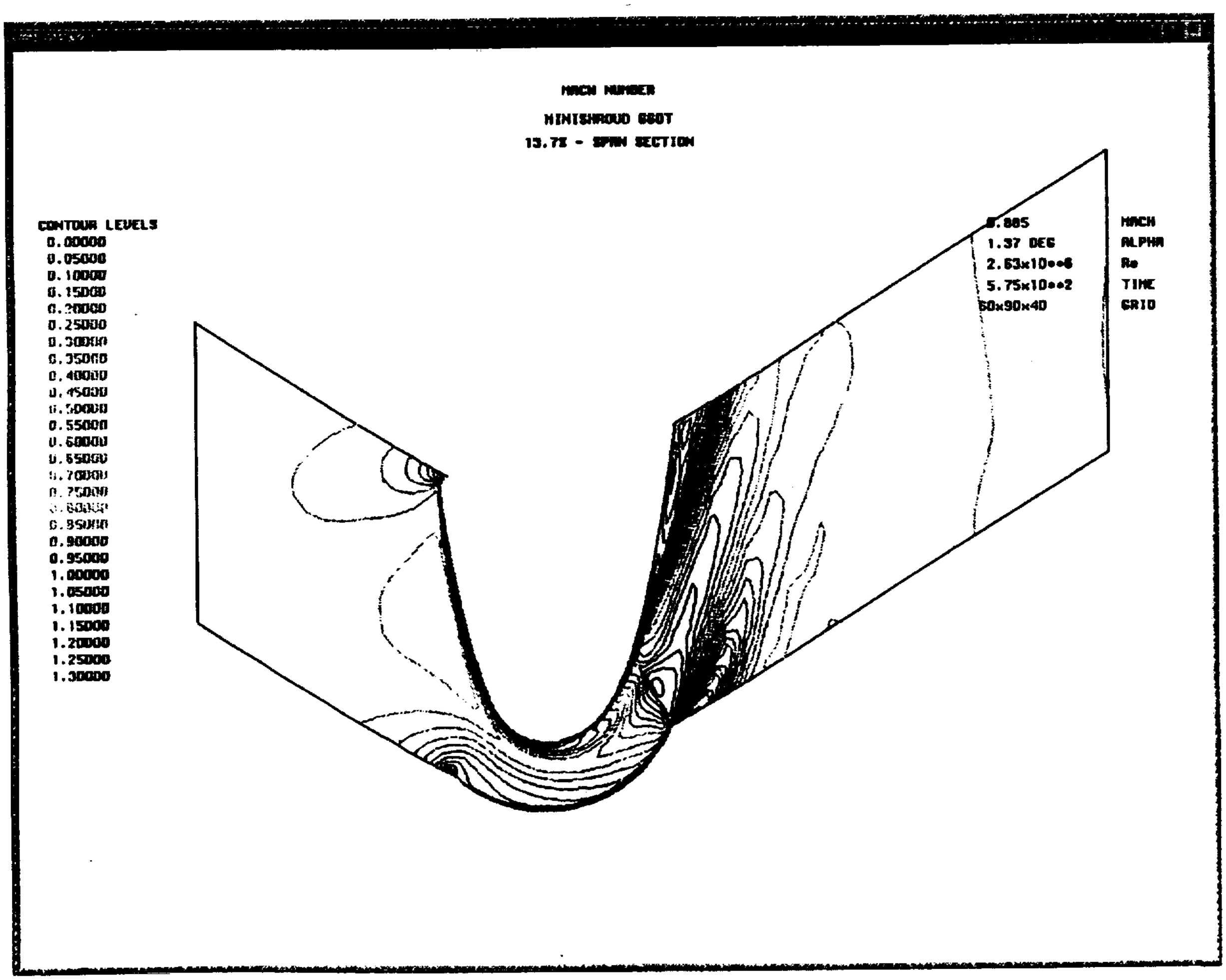
0.885 MACH
1.37 DEG ALPHA
2.63x10**6 Re
5.86x10**2 TIME
60x90x40 GRID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1.10000
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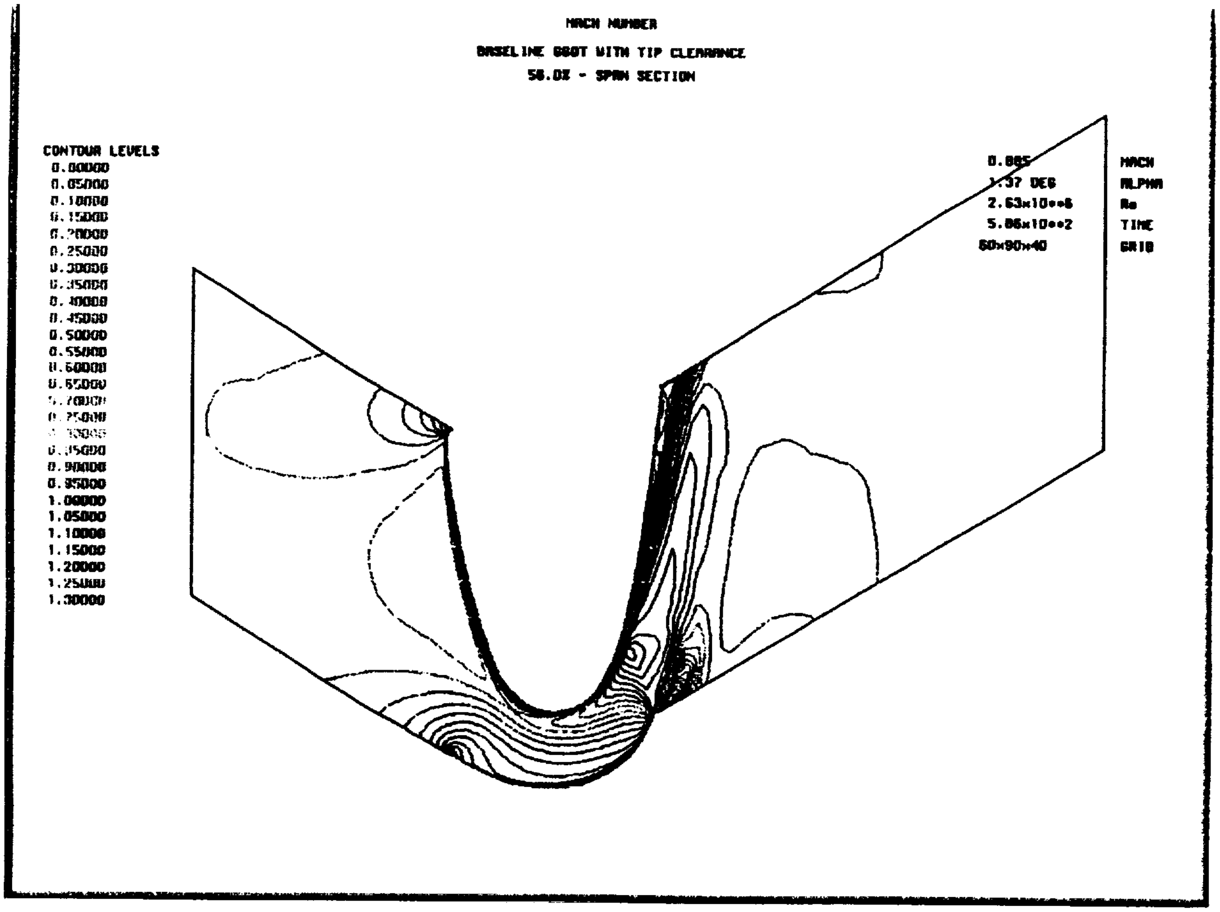
1.37 DEG ALPHA
2.63x10**6 Re
5.75x10**2 TIME
60x90x40 GRID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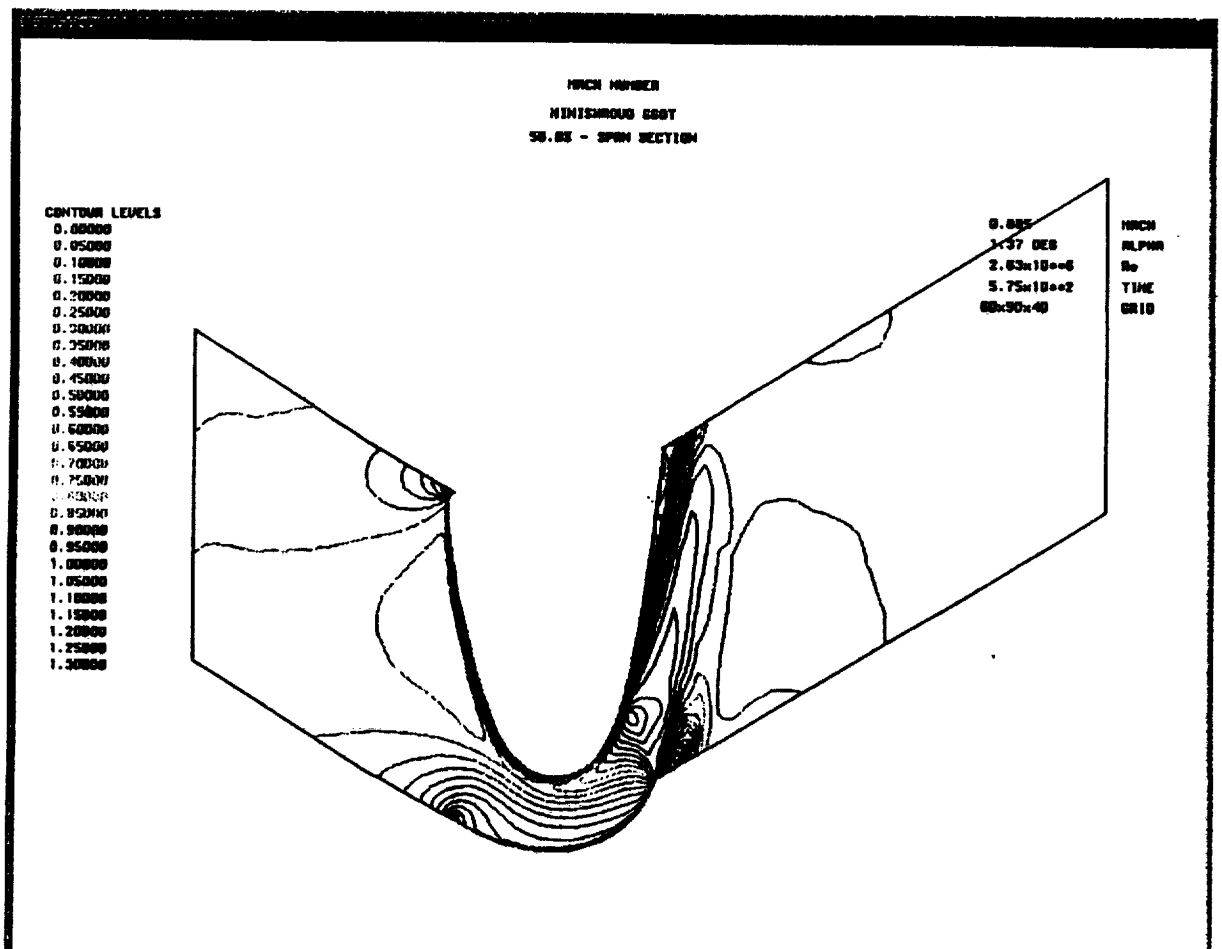
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CONTOUR LEVELS
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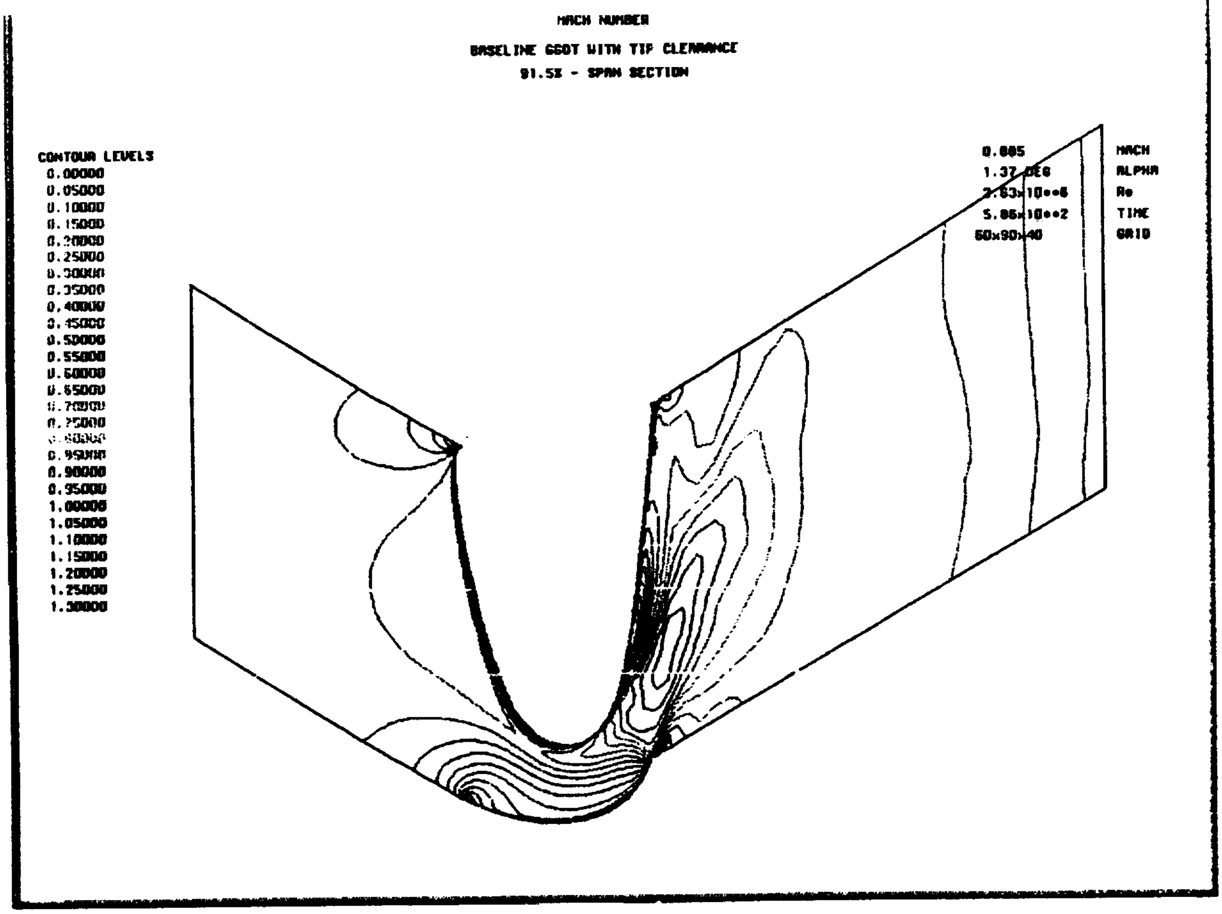
5.75x10**2 TIME
60x90x40 GRID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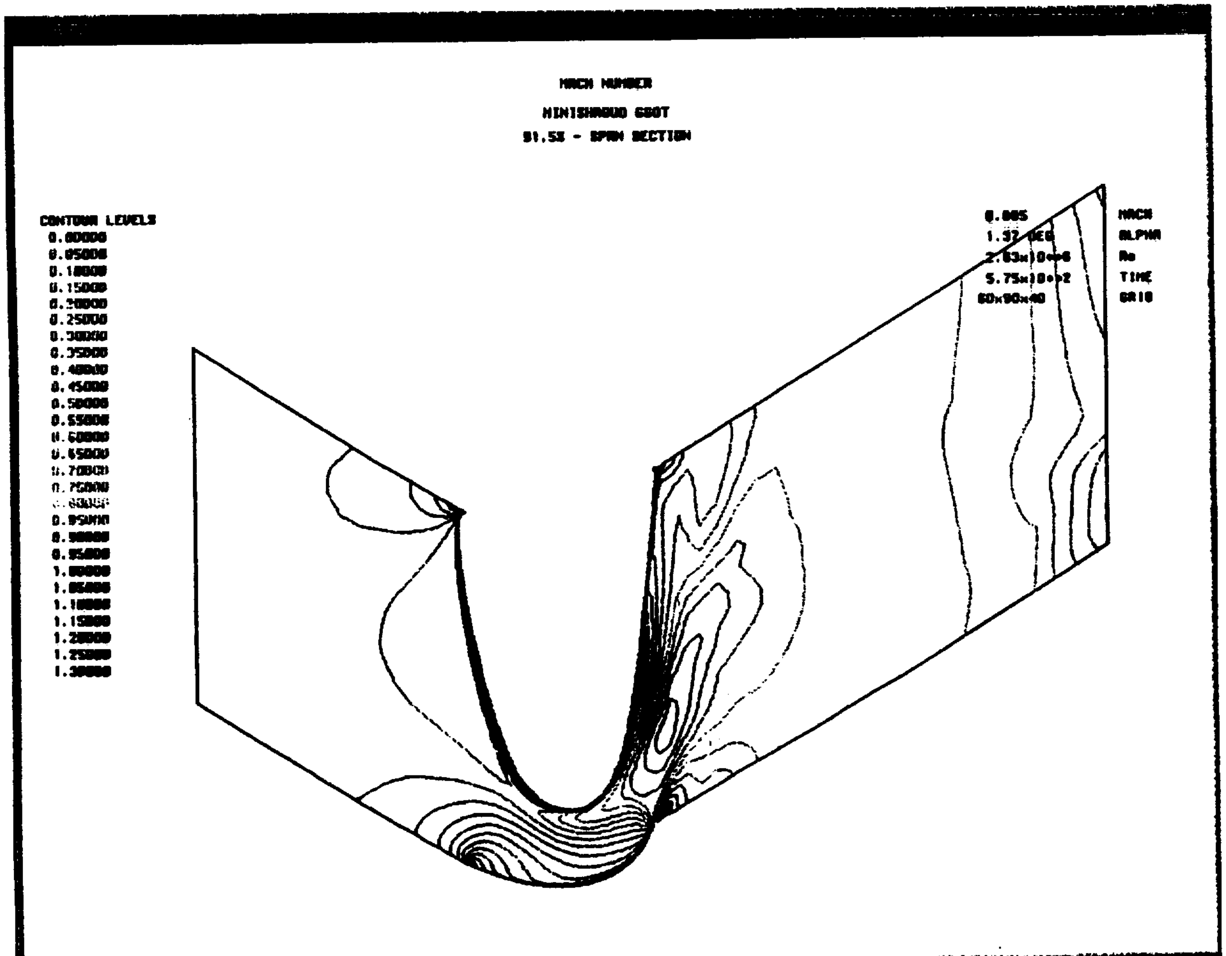
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CONTOUR LEVELS
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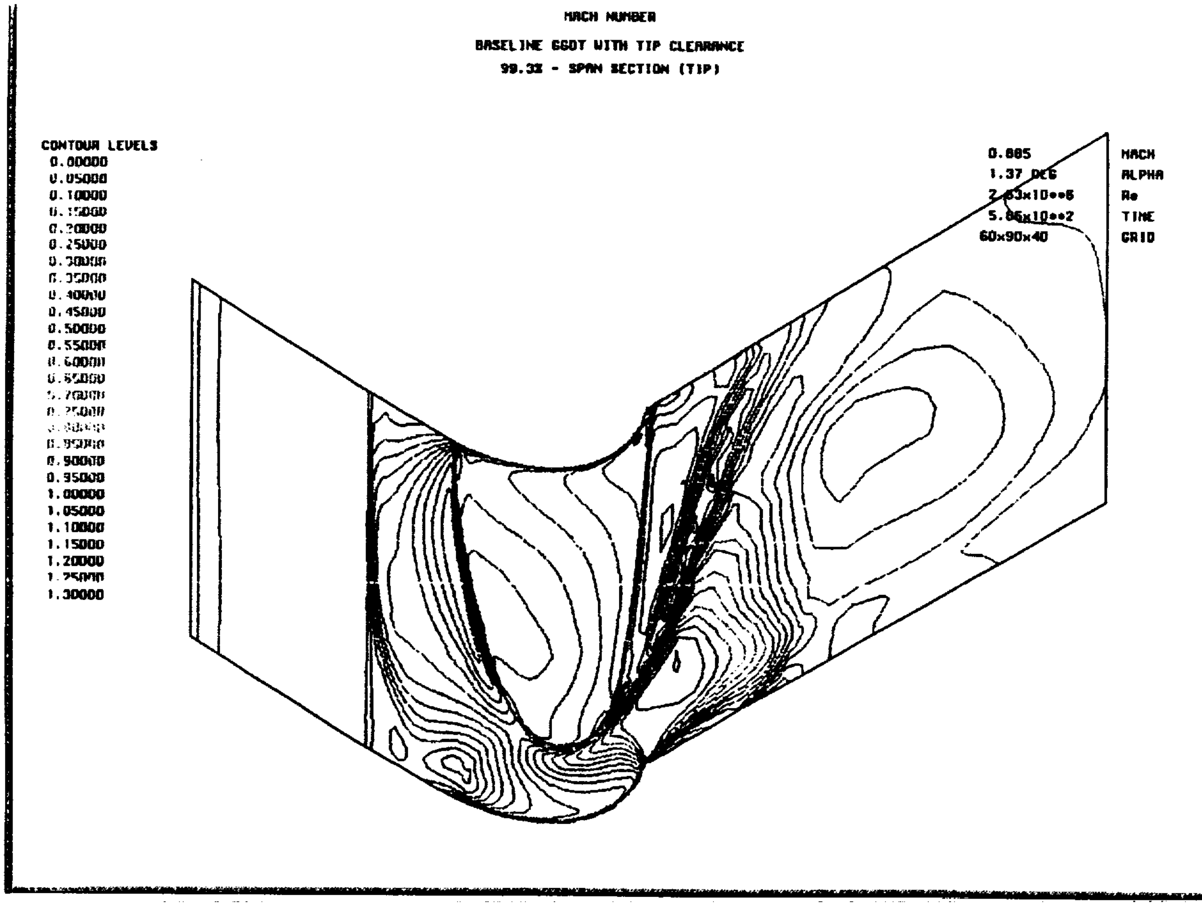
2.63x10**6 Re
5.75x10**2 TIME
60x90x40 GRID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0.885 MACH
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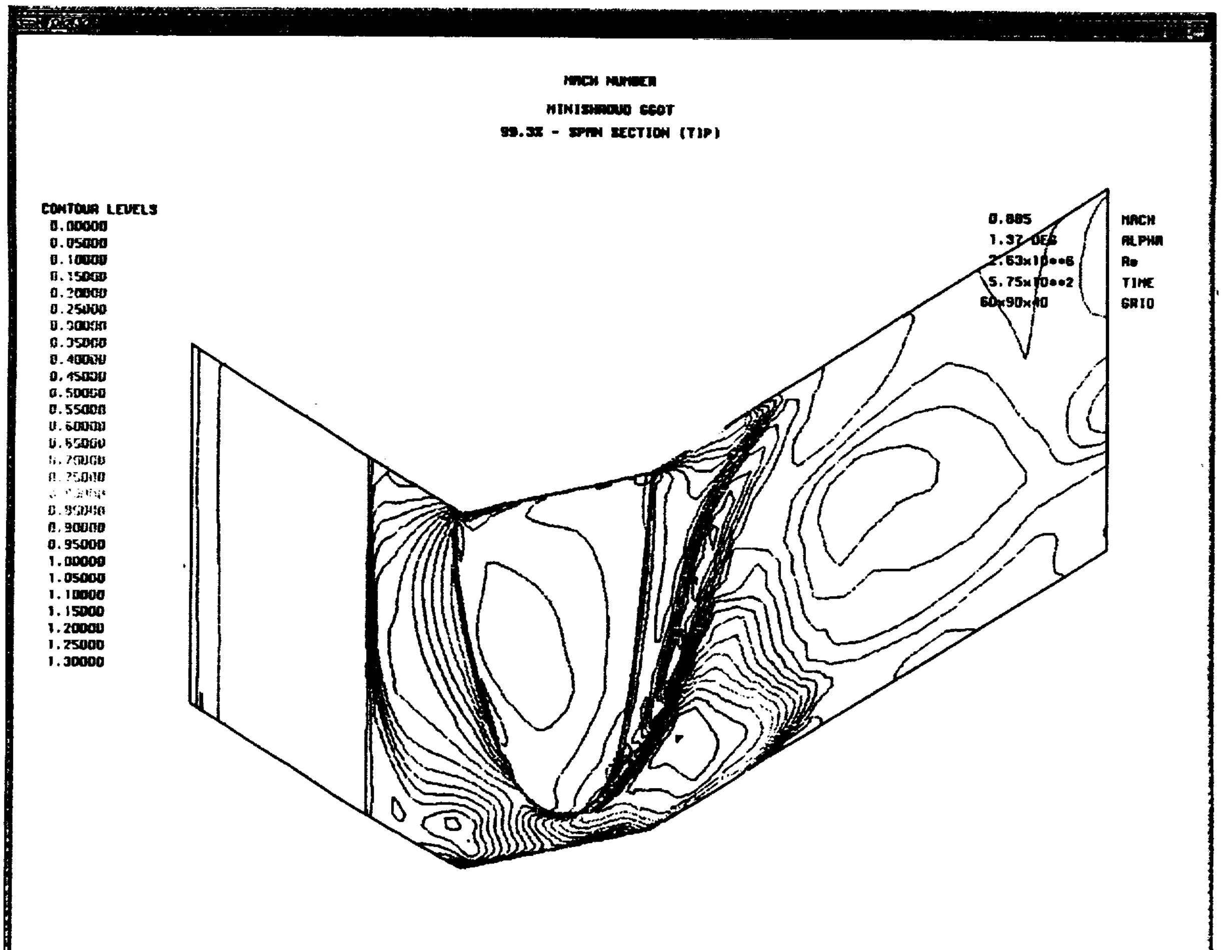
5.86x10**2 TIME
60x90x40 GRID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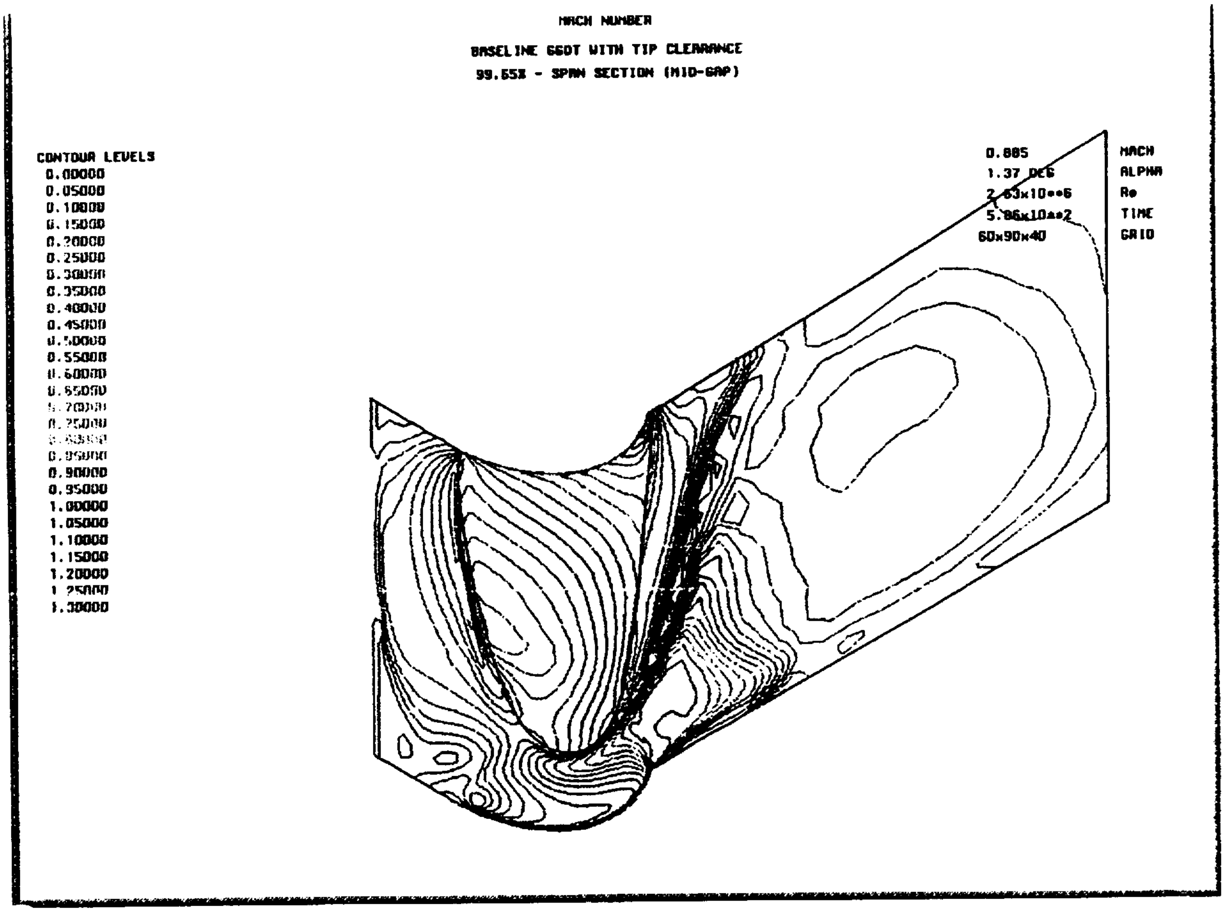
2.63x10**6 Re
5.75x10**2 TIME
60x90x40 GRID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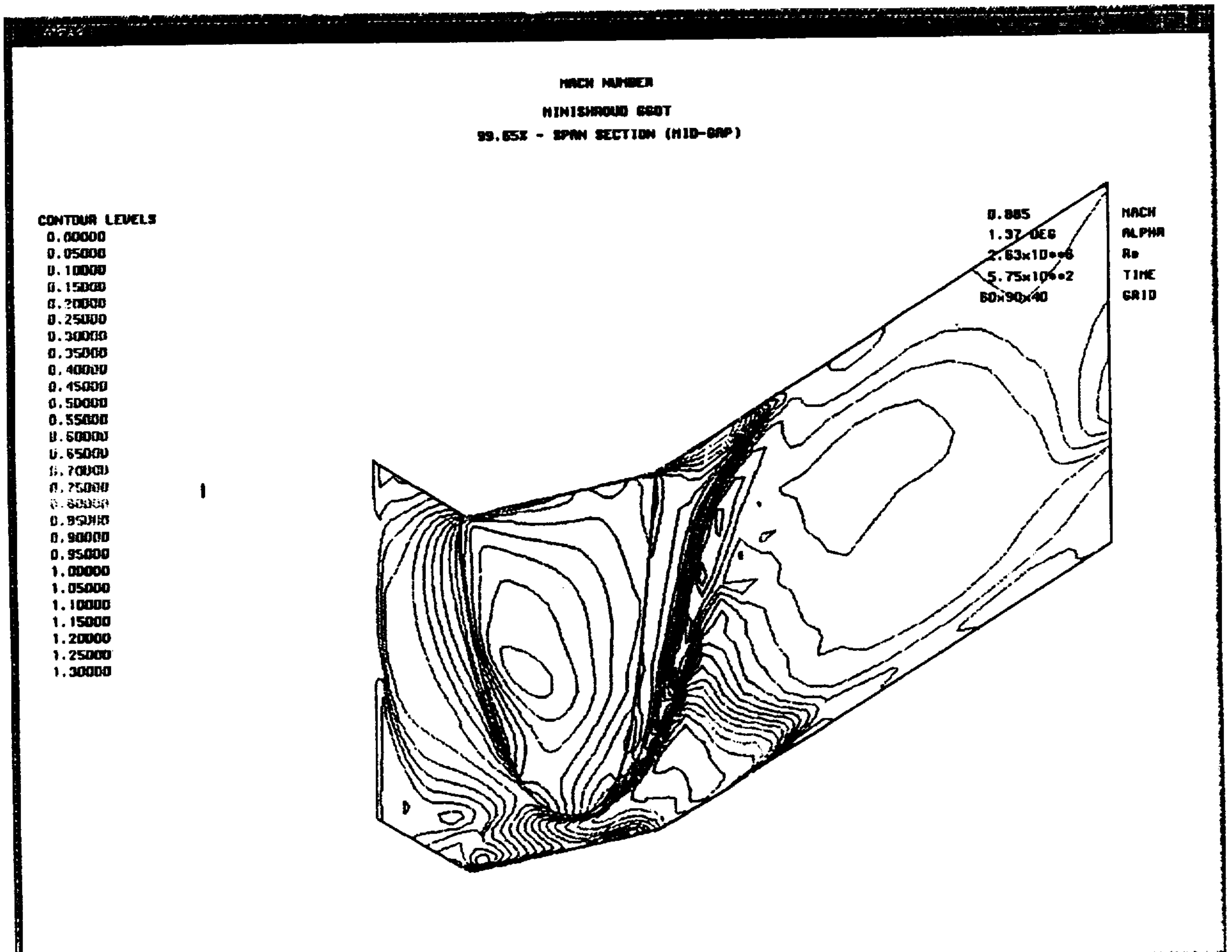
2.63x10**6 Re
5.86x10**2 TIME
60x90x40 GRID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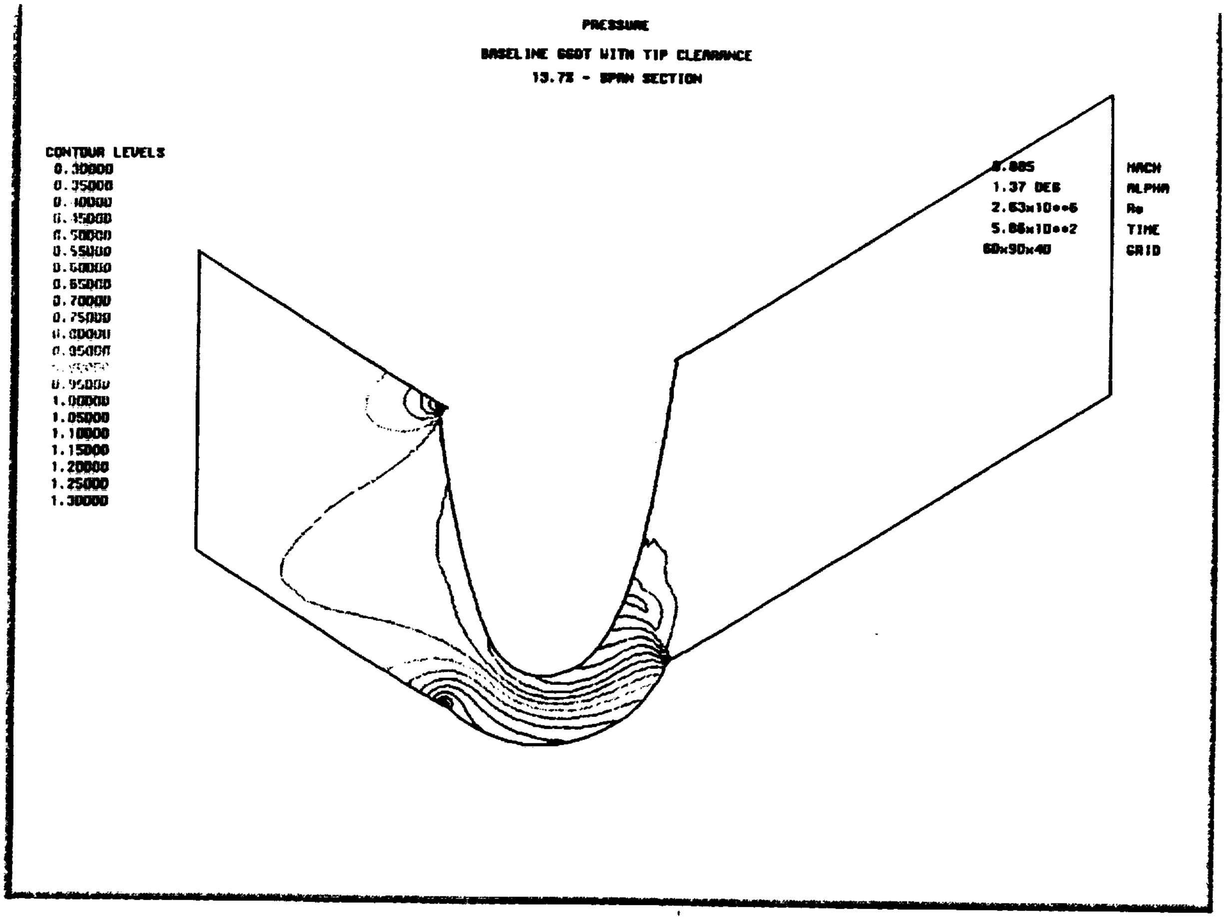
0.885 MACH
1.37 DEG ALPHA
2.63x10**6 Re
5.75x10**2 TIME
60x90x40 GRID


PRESSURE
BASELINE GGOT WITH TIP CLEARANCE
13.7% - SPAN SECTION
CONTOUR LEVELS
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0.40000
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0.50000
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0.885 MACH
1.37 DEG ALPHA
2.63x10**6 Re
5.86x10**2 TIME
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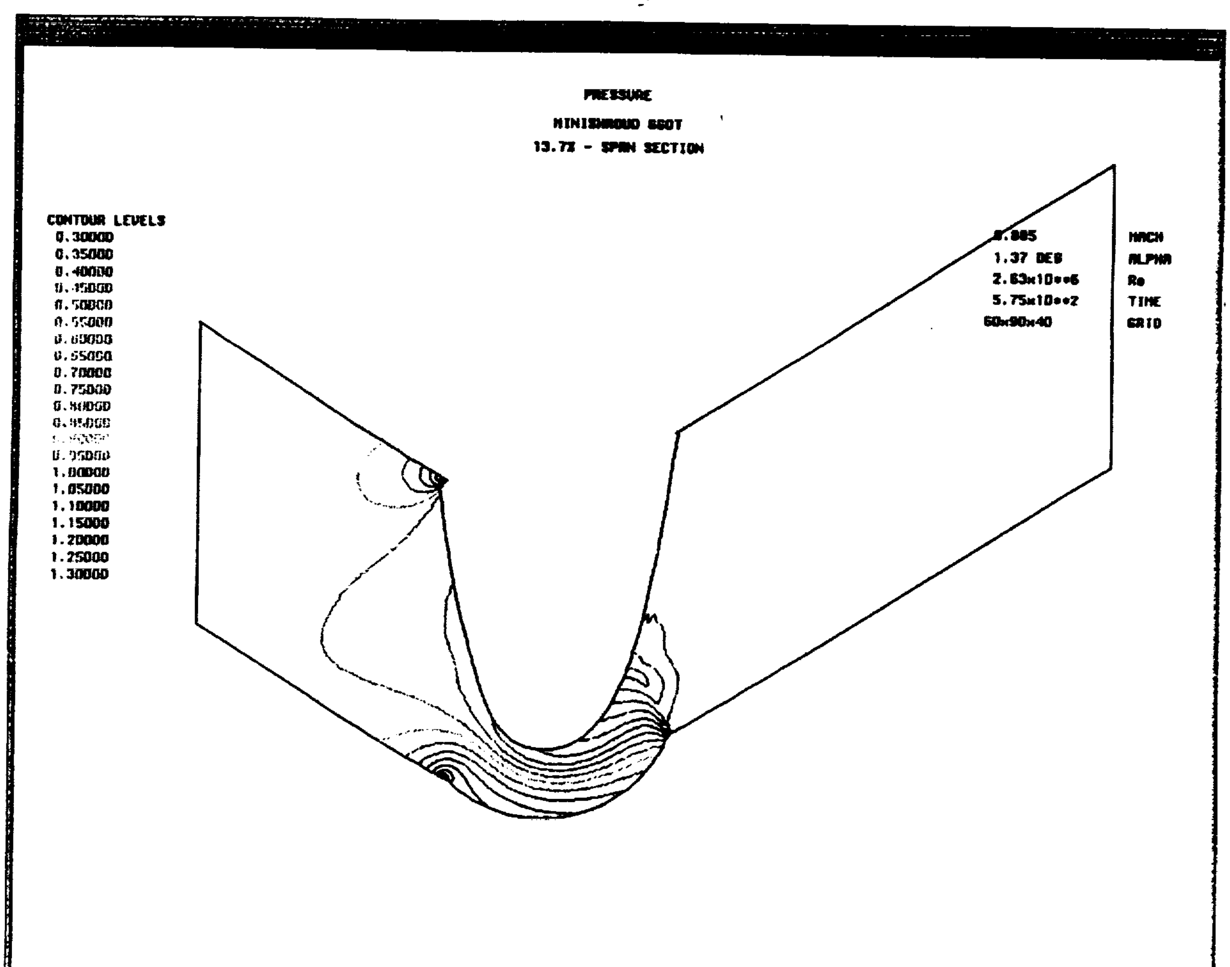
PRESSURE
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13.7% - SPAN SECTION
CONTOUR LEVELS
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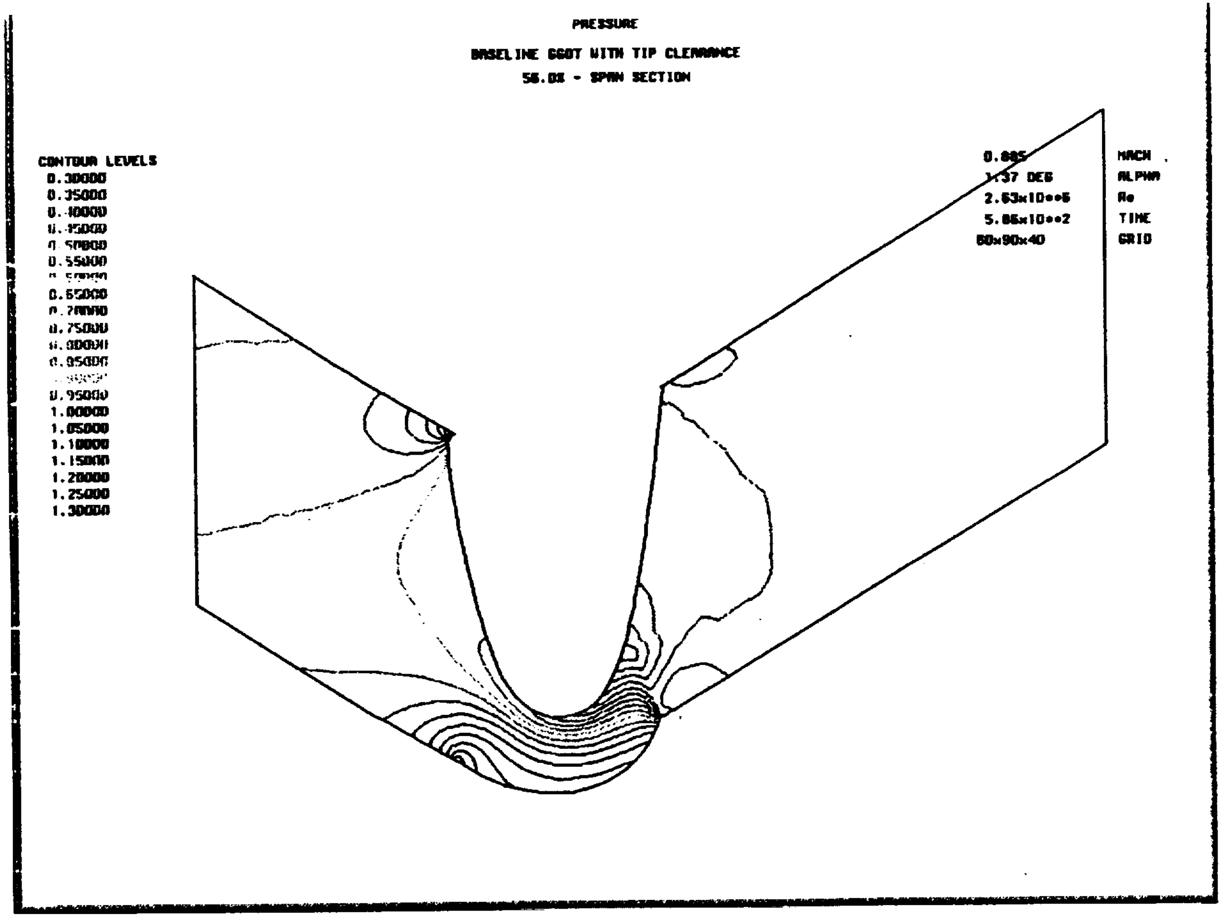
60x90x40 GRID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1.37 DEG
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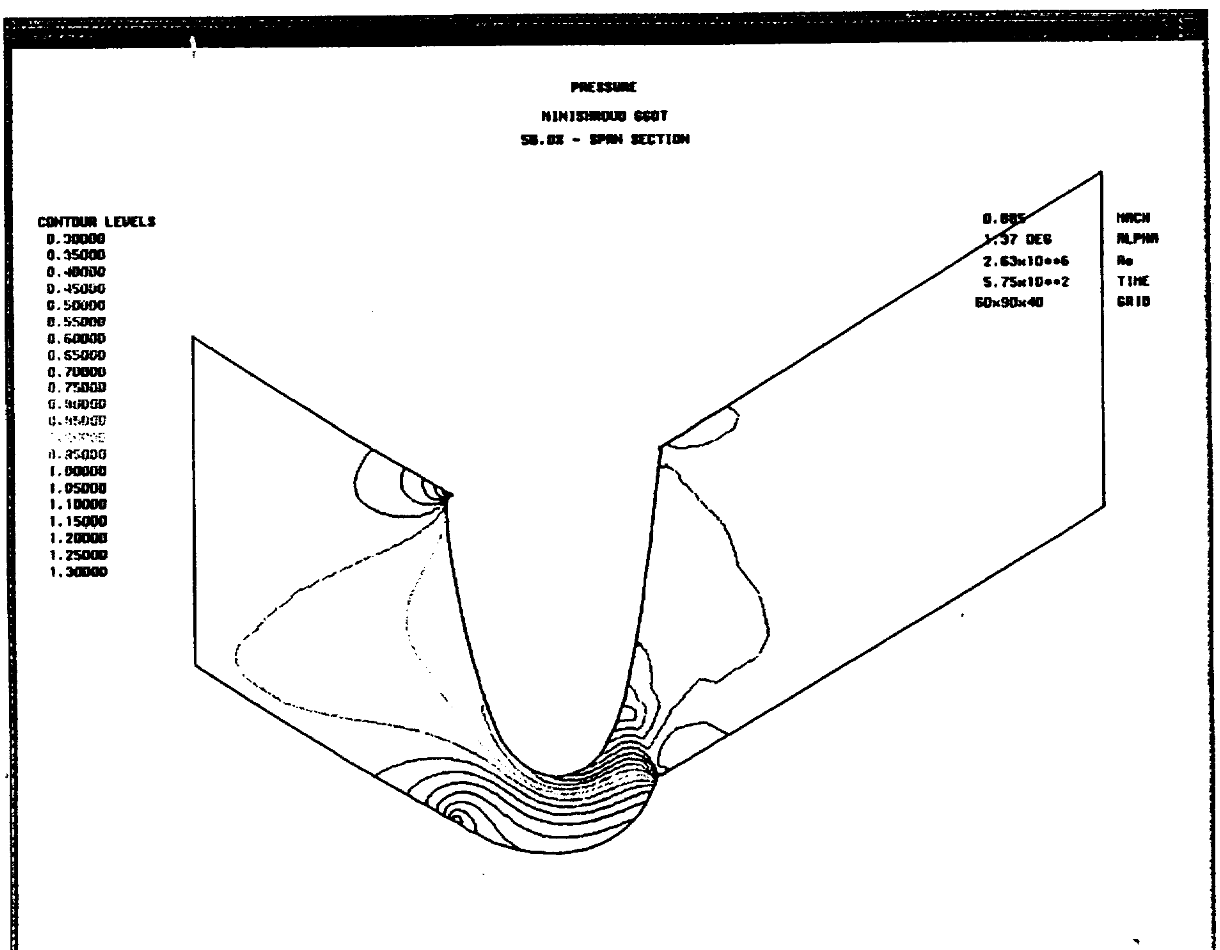
MACH
ALPHA
Re
TIME
GRID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56.0% - SPAN SECTION
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MACH
ALPHA
Re
TIME
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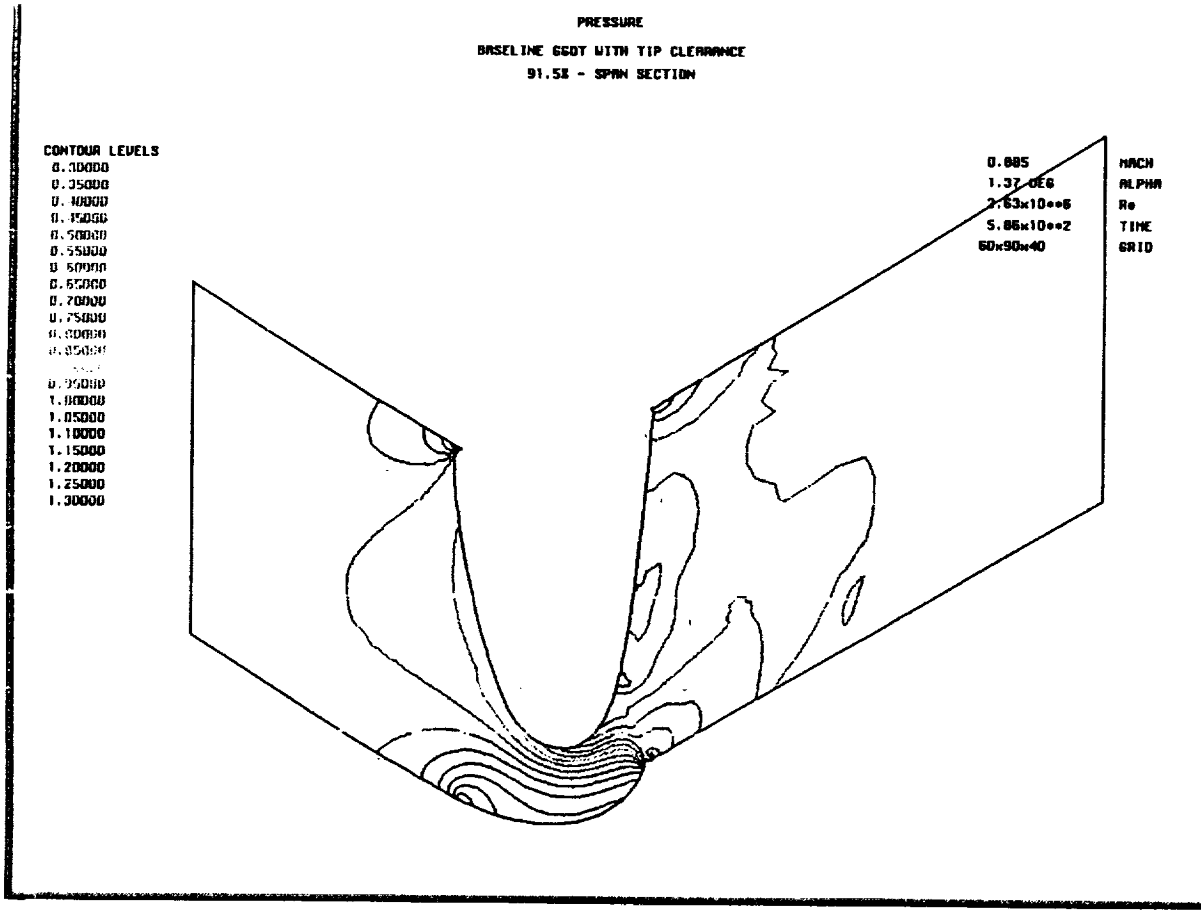
PRESSURE
BASELINE GGOT WITH TIP CLEARANCE
91.5% - SPAN SECTION
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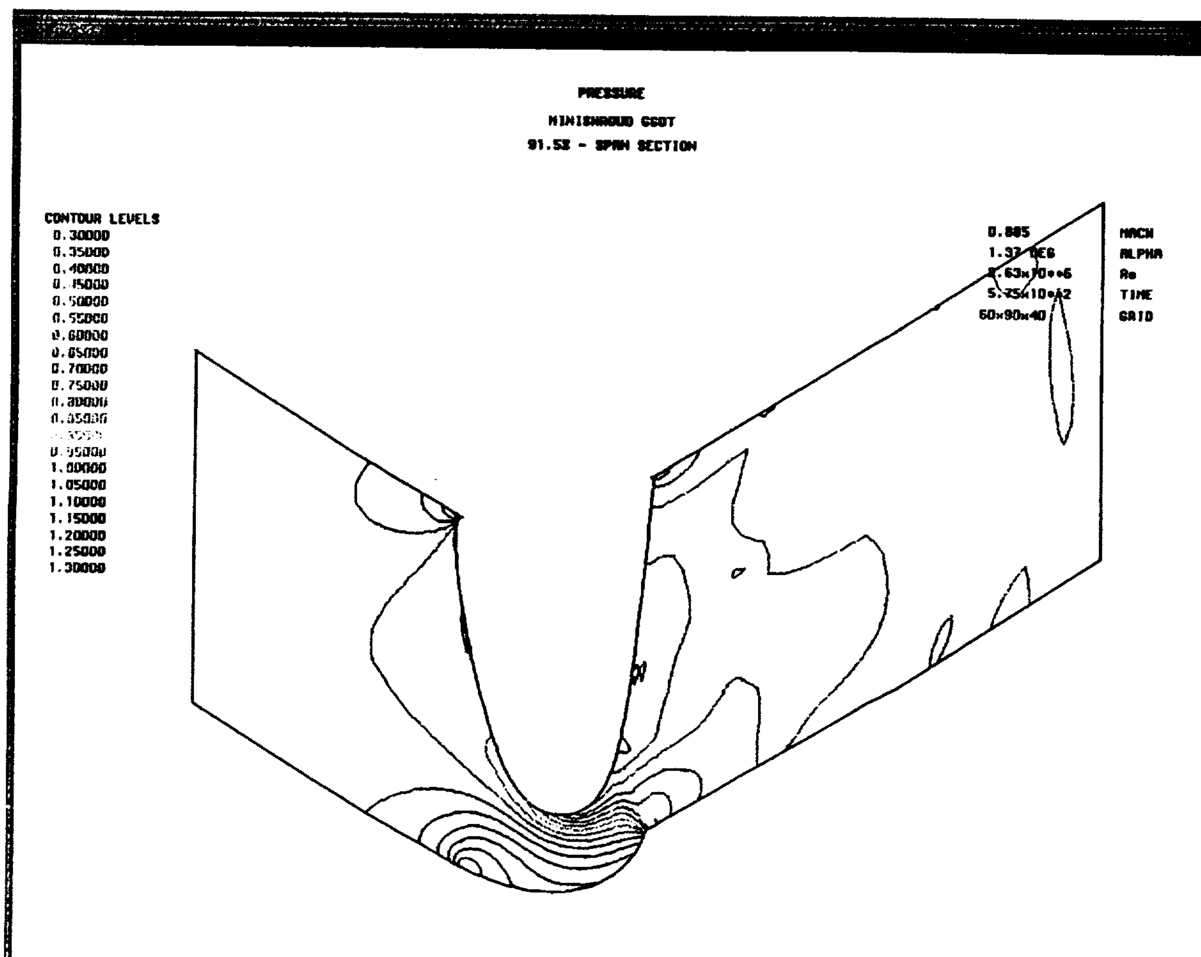
5.86x10**2 TIME
60x90x40 GRID


PRESSURE
MINISHROUD GGOT
91.5% - SPAN SECTION
CONTOUR LEVELS
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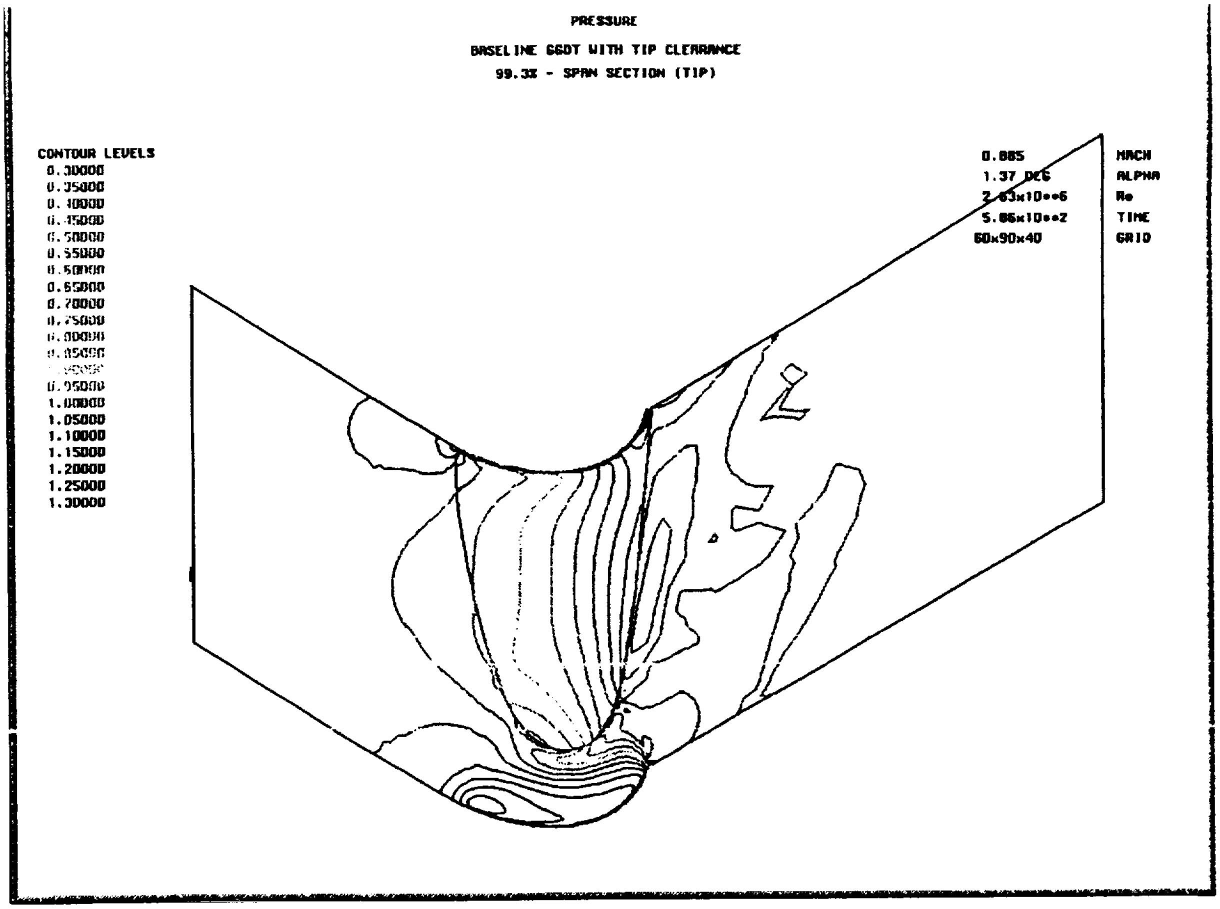
1.37 DEG ALPHA
Re
5.75x10**2 TIME
60x90x40 GRID


PRESSURE
BASELINE GGOT WITH TIP CLEARANCE
99.3% - SPAN SECTION (TIP)
CONTOUR LEVELS
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0.50000
0.55000
0.60000
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0.885 MACH
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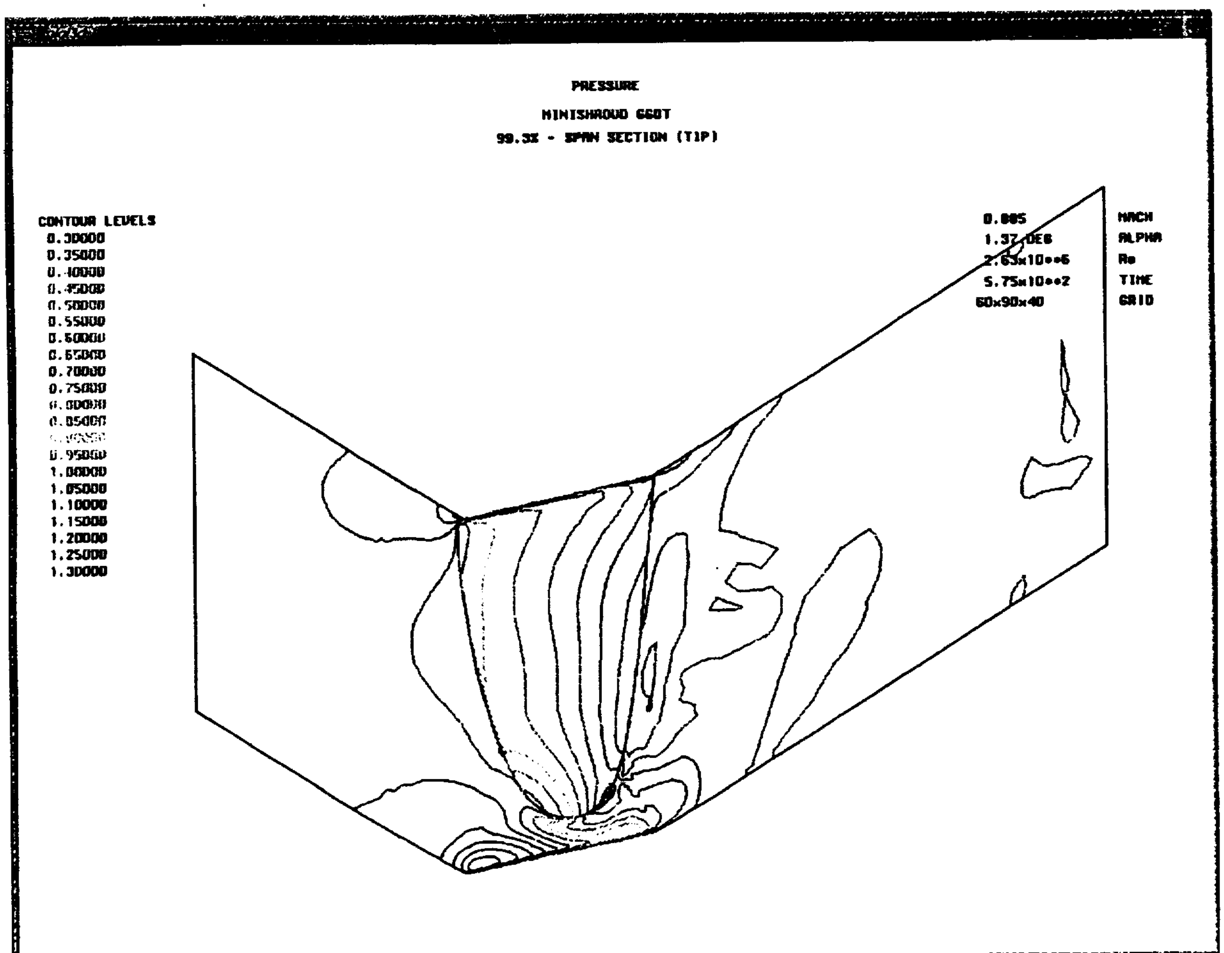
2.63x10**6 Re
5.86x10**2 TIME
60x90x40 GRID


PRESSURE
MINISHROUD GGOT
99.3% - SPAN SECTION (TIP)
CONTOUR LEVELS
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0.55000
0.60000
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0.70000
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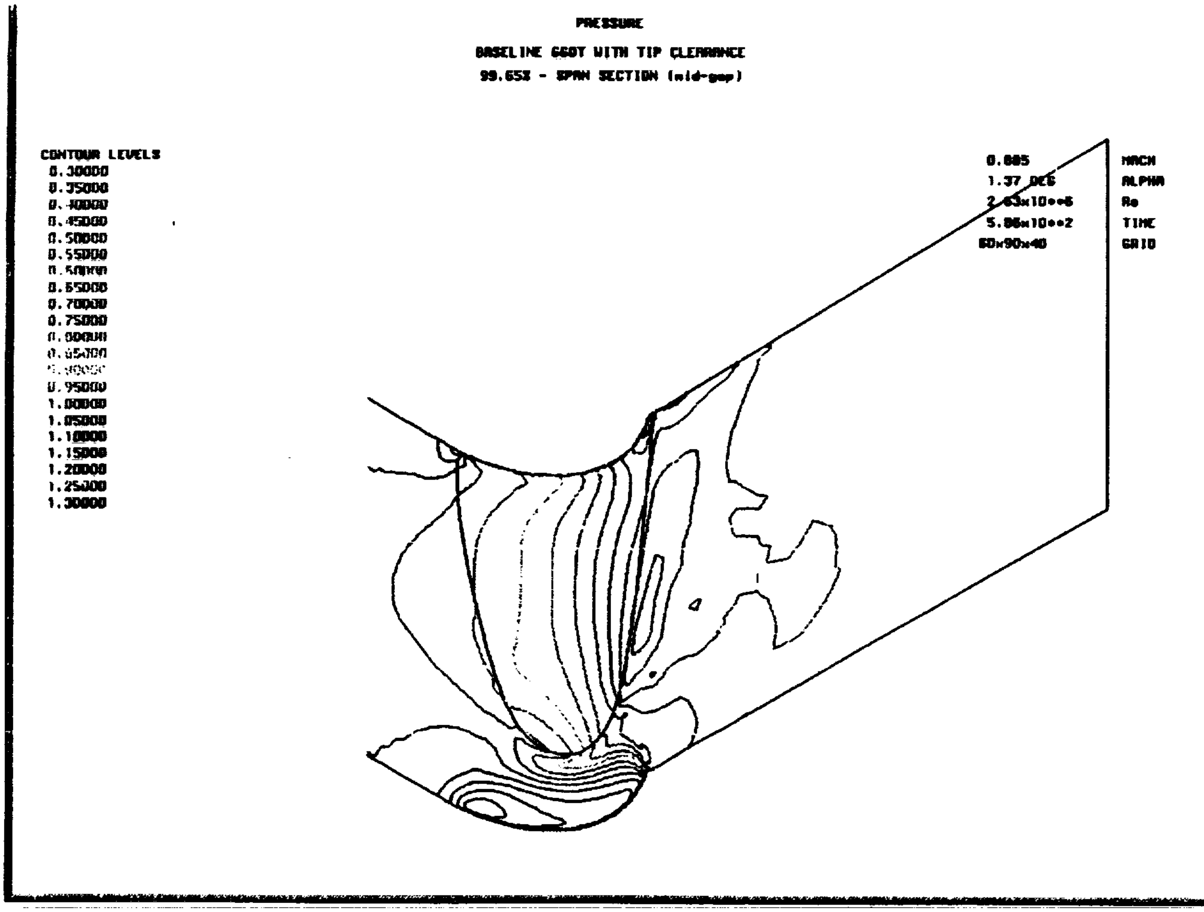
0.885 MACH
1.37 DEG ALPHA
2.63x10**6 Re
5.75x10**2 TIME
60x90x40 GRID


PRESSURE
BASELINE GGOT WITH TIP CLEARANCE
99.65% - SPAN SECTION (mid-gap)
CONTOUR LEVELS
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0.45000
0.50000
0.55000
0.60000
0.65000
0.70000
0.75000
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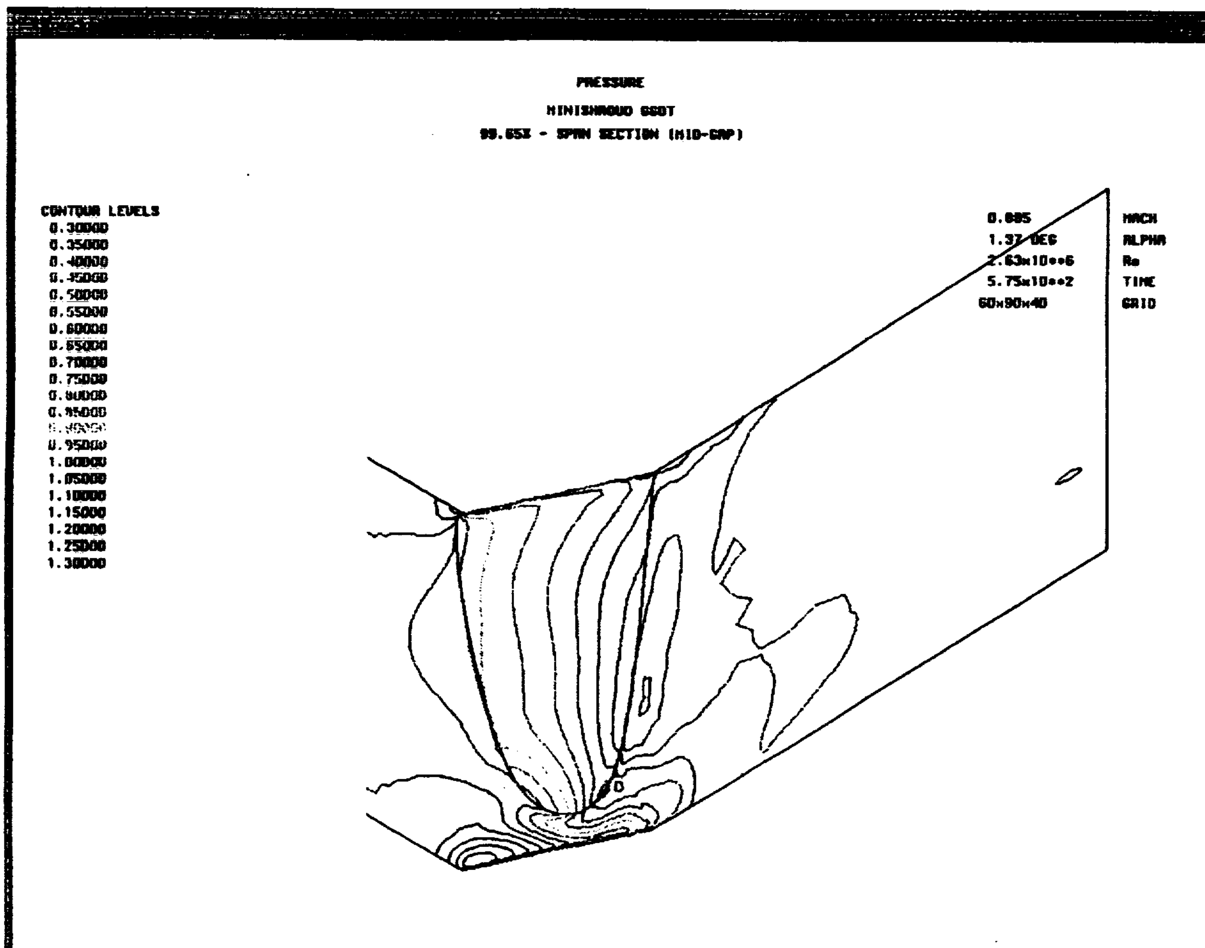
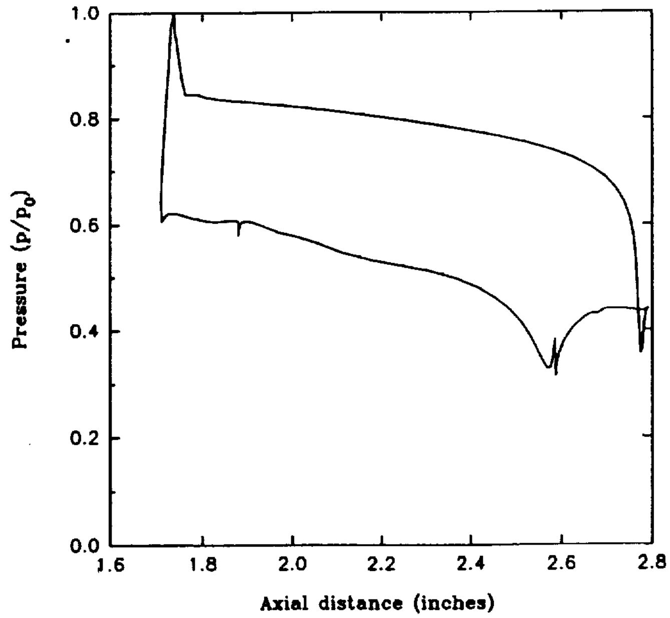
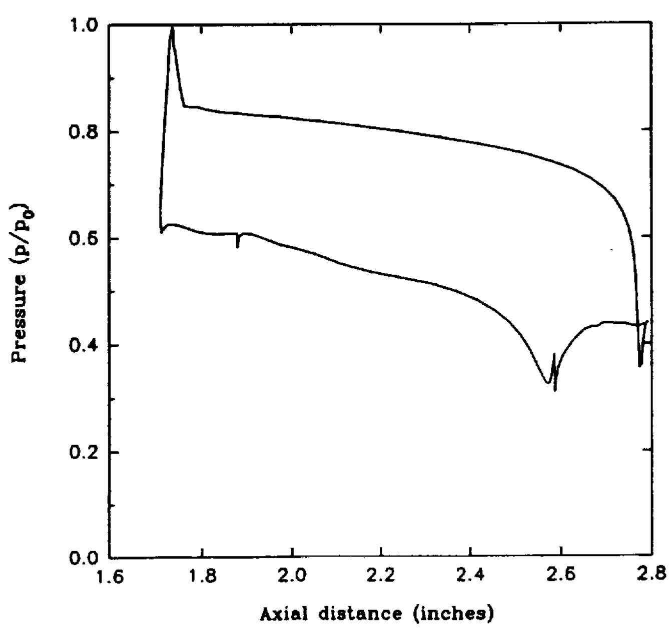
0.885 MACH
1.37 DEG ALPHA
2.63x10**6 Re
5.86x10**2 TIME
60x90x40 GRID


PRESSURE
MINISHROUD GGOT
99.65% - SPAN SECTION (MID-GAP)
CONTOUR LEVELS
0.30000
0.35000
0.40000
0.45000
0.50000
0.55000
0.60000
0.65000
0.70000
0.75000
0.80000
0.85000
0.90000
0.95000
1.00000
1.05000
1.10000
1.15000
1.20000
1.25000
1.30000
0.885 MACH
1.37 DEG ALPHA
2.63x10**6 Re
5.75x10**2 TIME
60x90x40 GRID

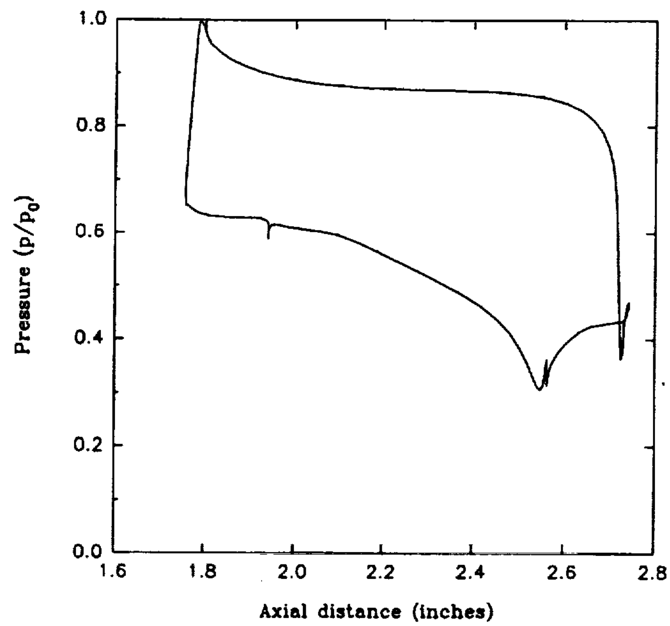
Baseline GGOT with Clearance
Blade Surface Pressure (8.1% span)
Reduced Dissipation – 60 x 90 x 40 grid



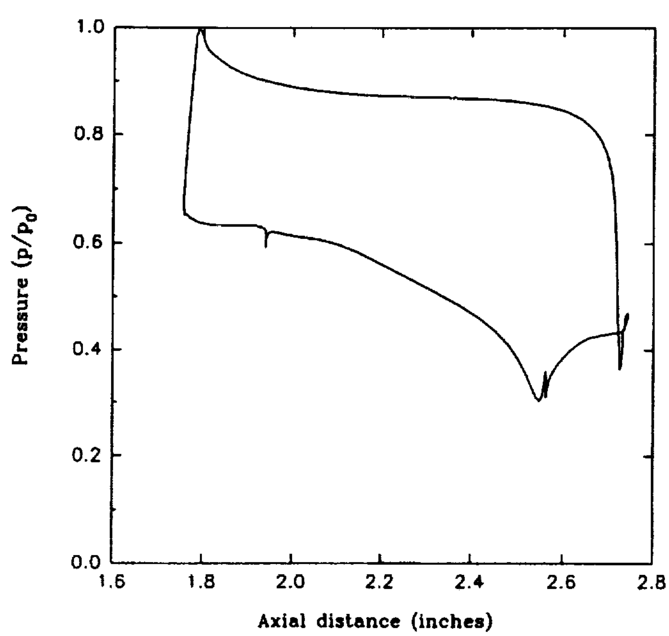
Minishroud GGOT
Blade Surface Pressure (8.1% span)
Reduced Dissipation – 60 x 90 x 40 grid



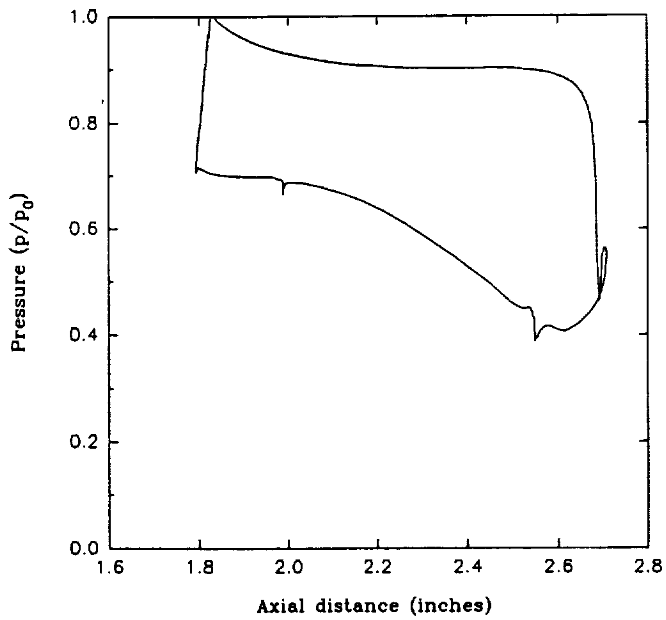
Baseline GGOT with Clearance
Blade Surface Pressure (56.4% span)
Reduced Dissipation – 60 x 90 x 40 grid



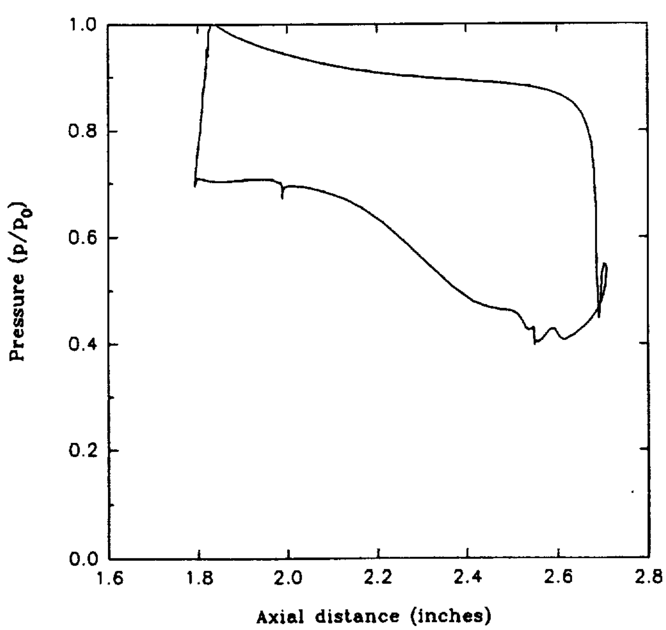
Minishroud GGOT
Blade Surface Pressure (56.4% span)
Reduced Dissipation – 60 x 90 x 40 grid



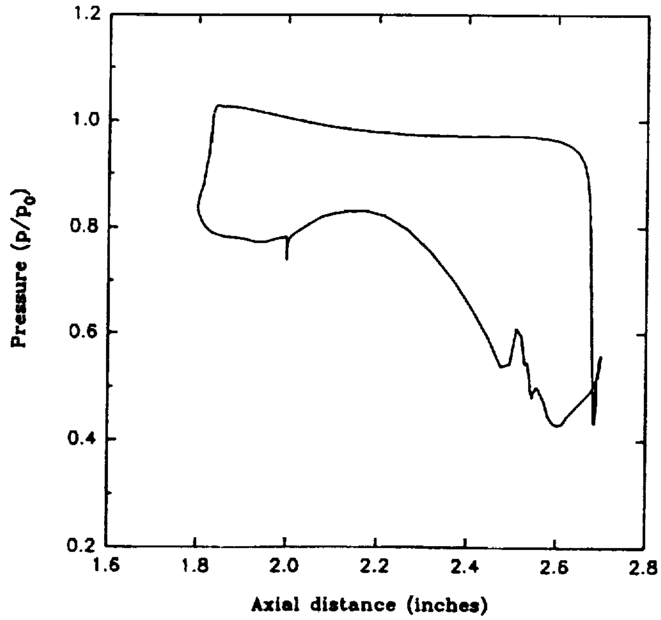
Baseline GGOT with Clearance
Blade Surface Pressure (92.2% span)
Reduced Dissipation - 60 x 90 x 40 grid



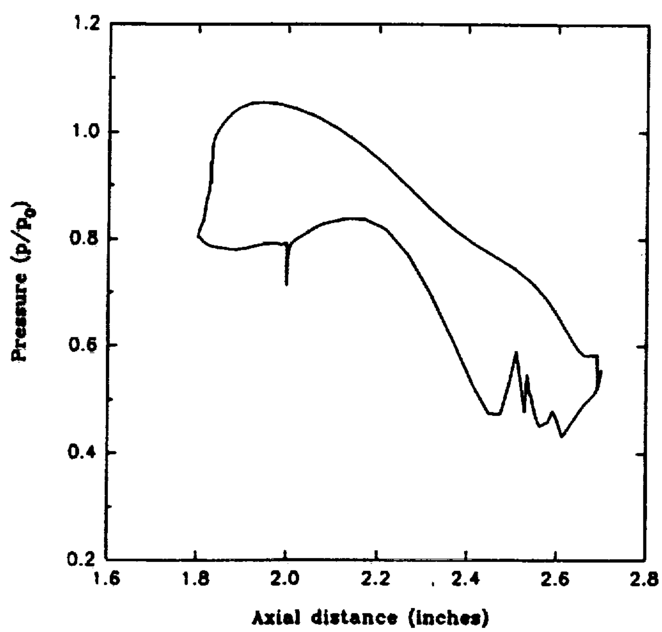
Minishroud GGOT
Blade Surface Pressure (92.2% span)
Reduced Dissipation - 60 x 90 x 40 grid



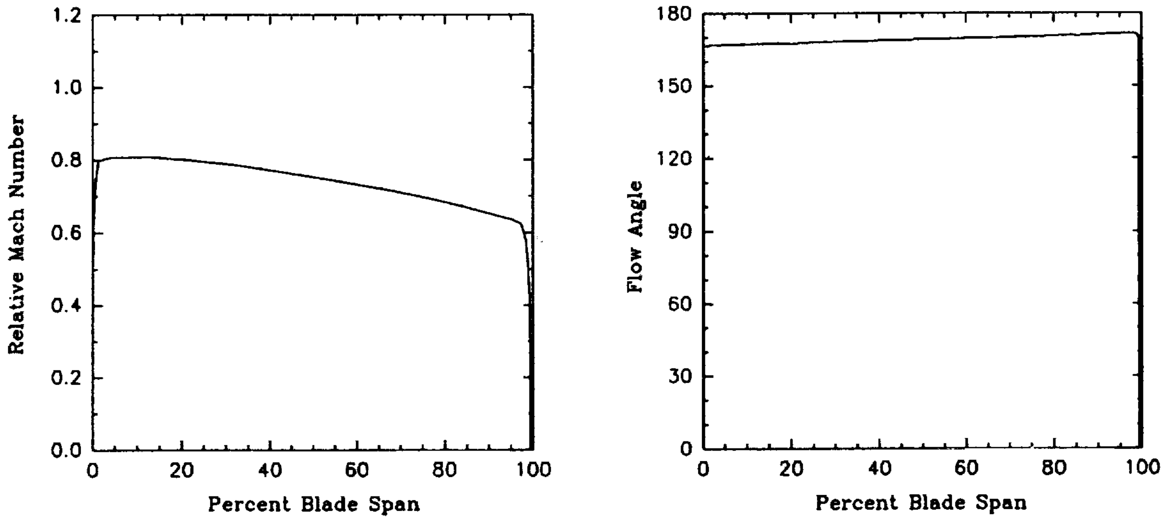
Baseline GGOT with Clearance
Blade Surface Pressure (99.6% span)
Reduced Dissipation - 60 x 90 x 40 grid



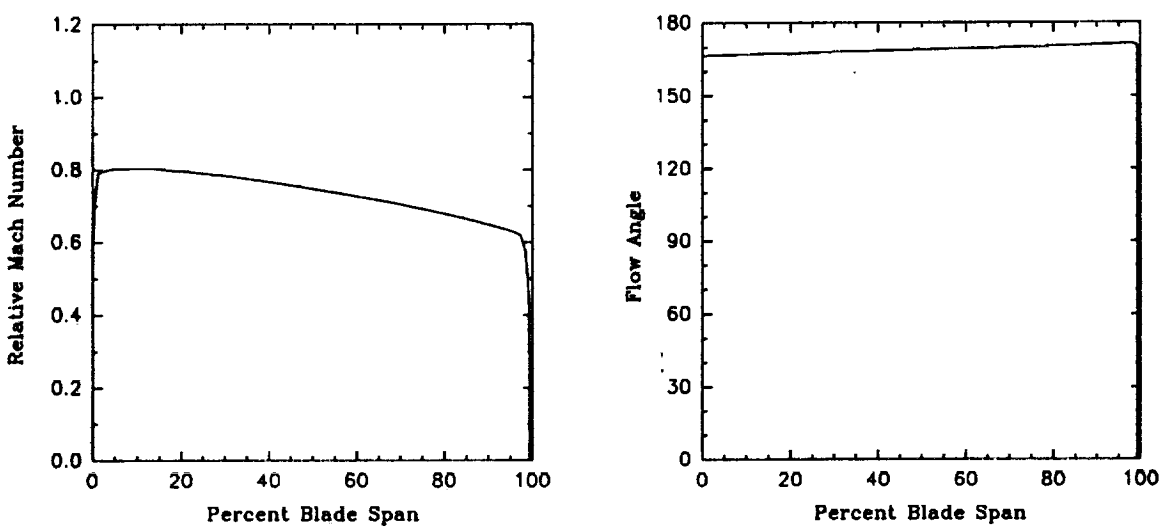
Minishroud GGOT
Blade Surface Pressure (99.6% span)
Reduced Dissipation - 60 x 90 x 40 grid



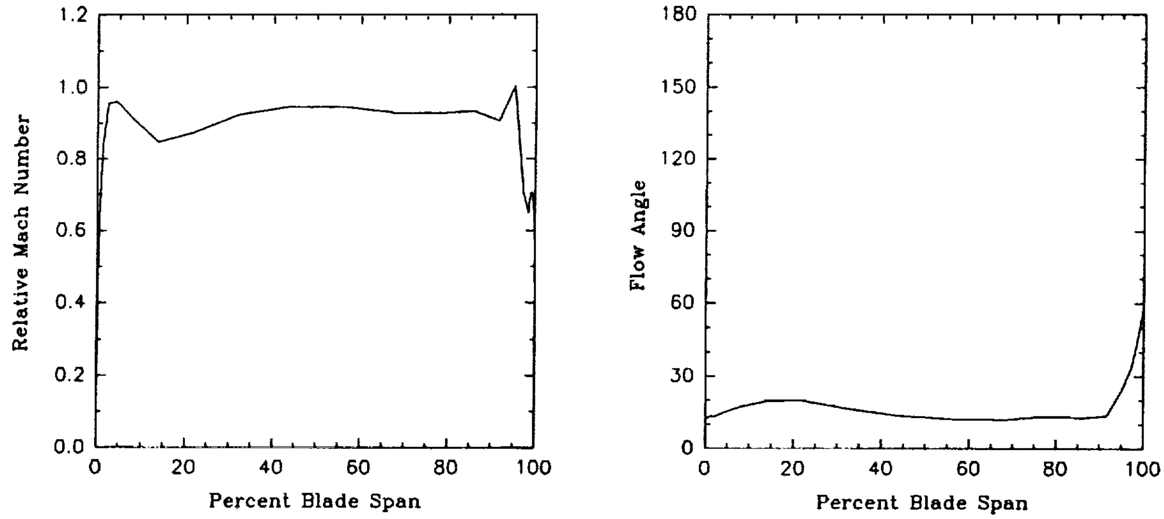
Circumferential Mass Averages
Inflow Boundary (0.6 in.)



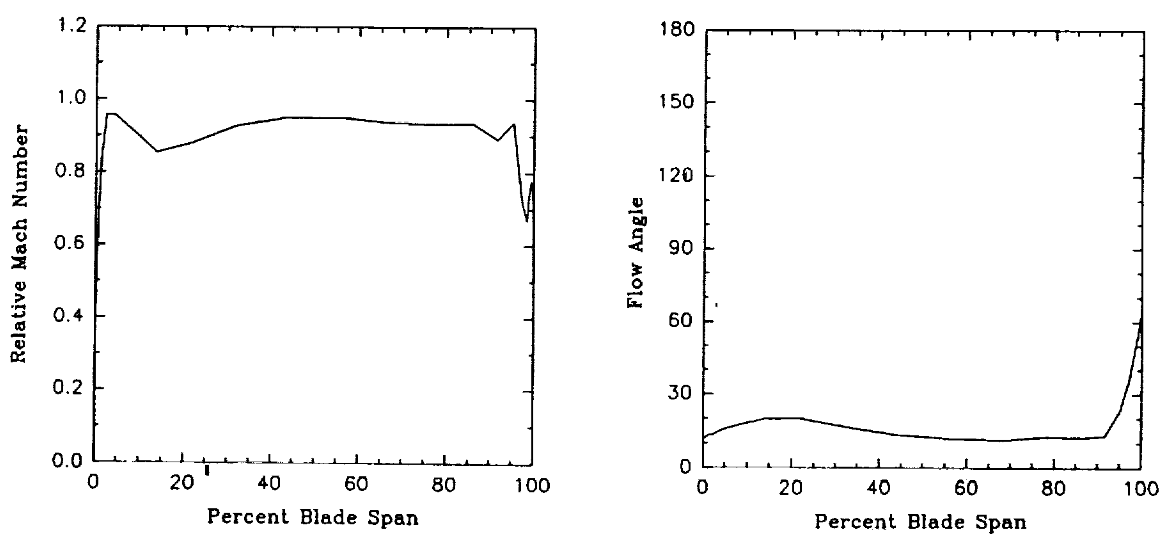
Circumferential Mass Averages
Inflow Boundary (0.6 in.)
Minishroud



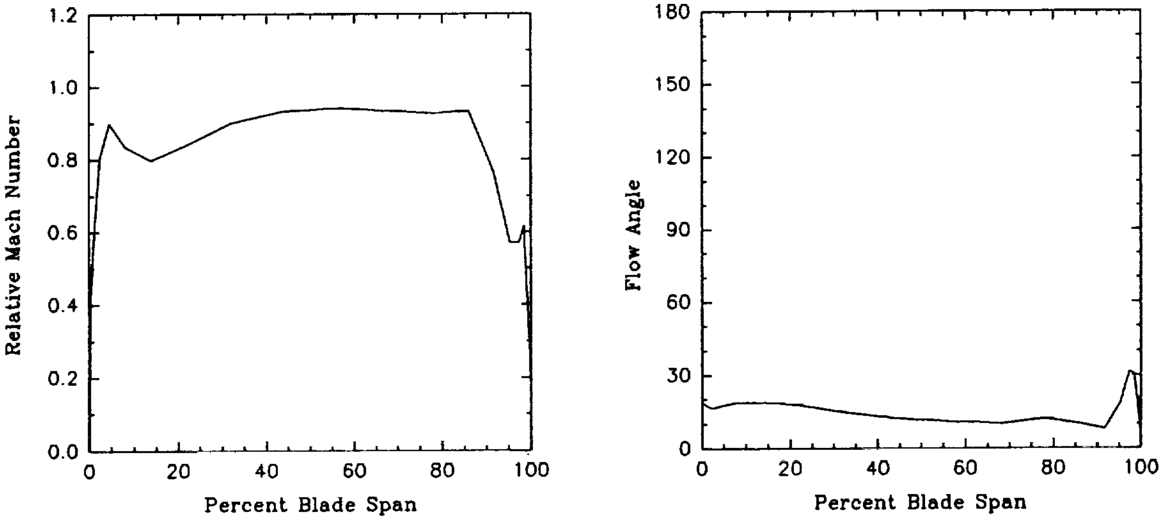
Circumferential Mass Averages Diffuser Start Boundary (2.9 in.)



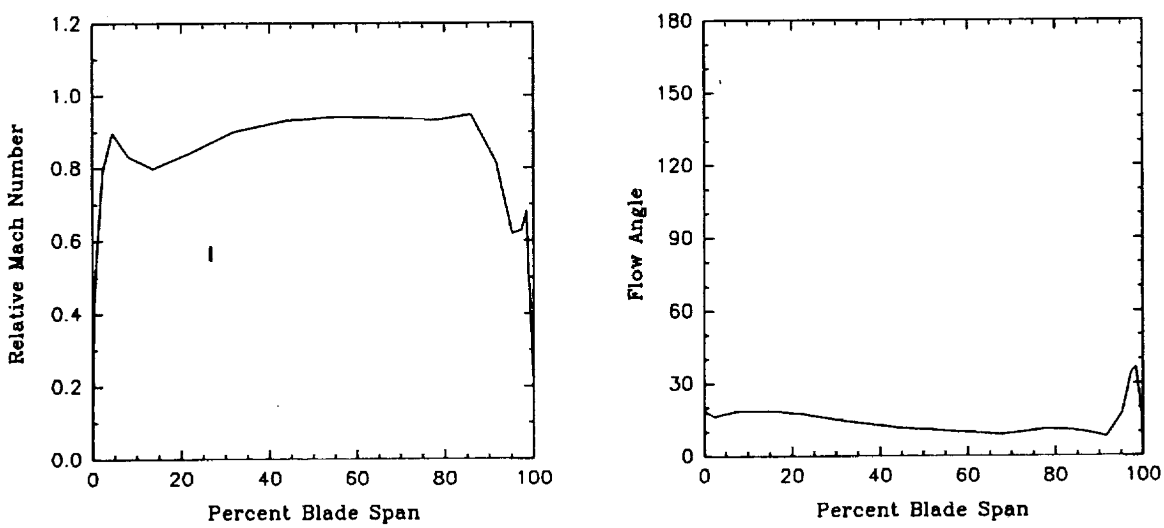
Circumferential Mass Averages Diffuser Start Boundary (2.9 in.) Minishroud



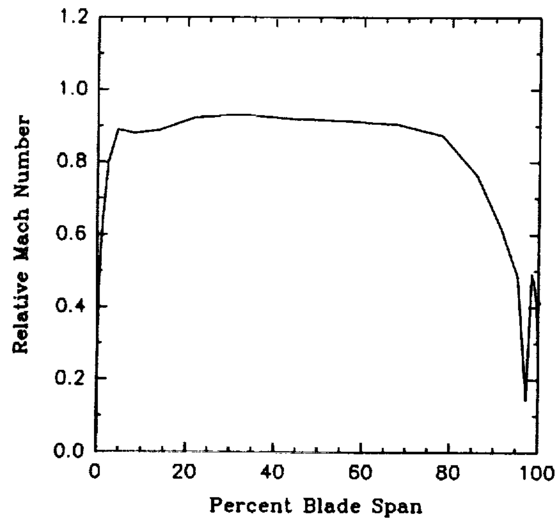
Circumferential Mass Averages
(x = 3.8 in.)

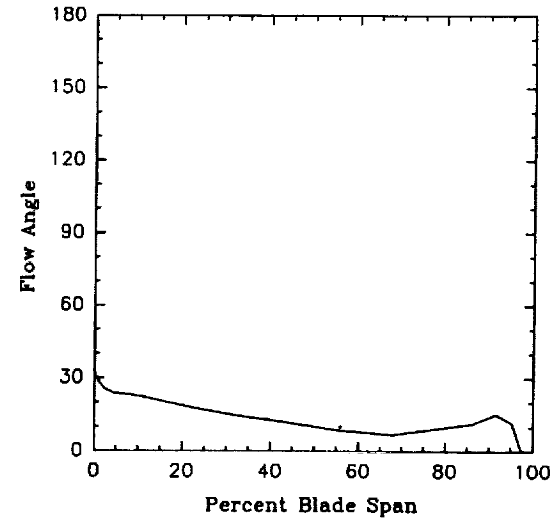


Circumferential Mass Averages
(x = 3.8 in.)
Minishroud

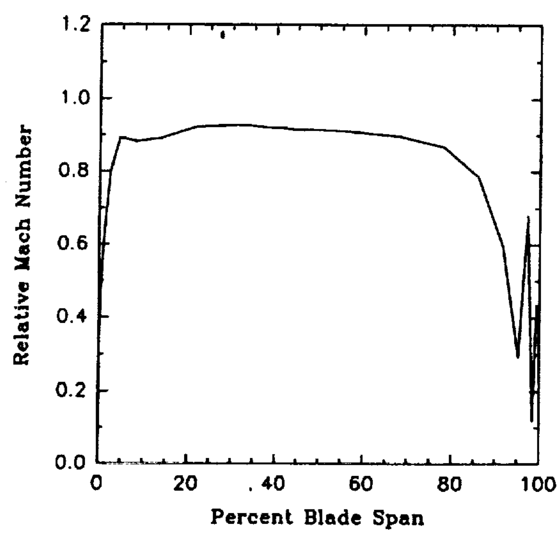


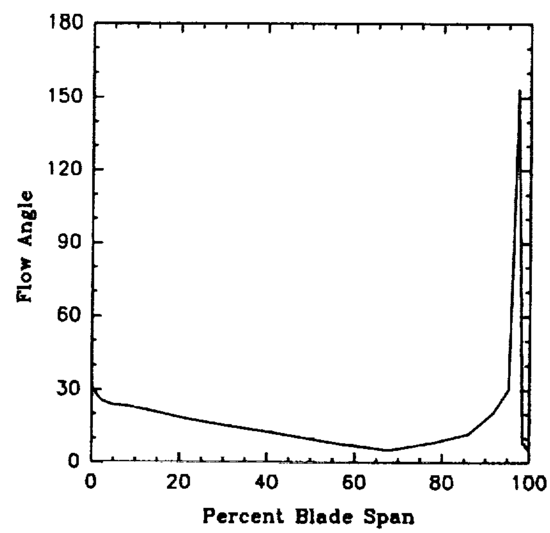
Circumferential Mass Averages
Outflow Boundary (x = 4.75 in.)



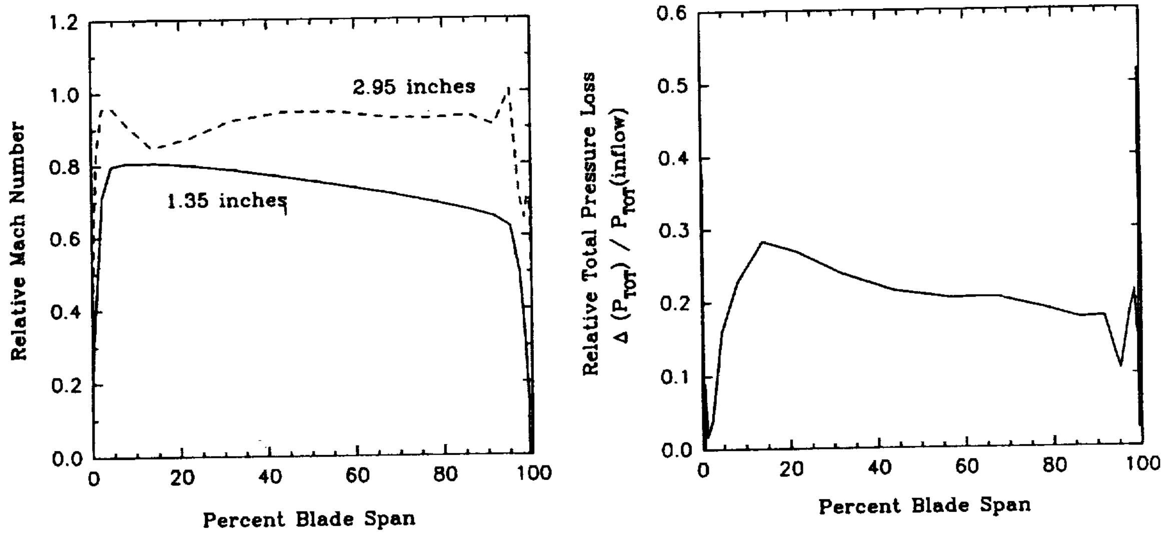


Circumferential Mass Averages
Outflow Boundary (x = 4.75 in.)
Minishroud

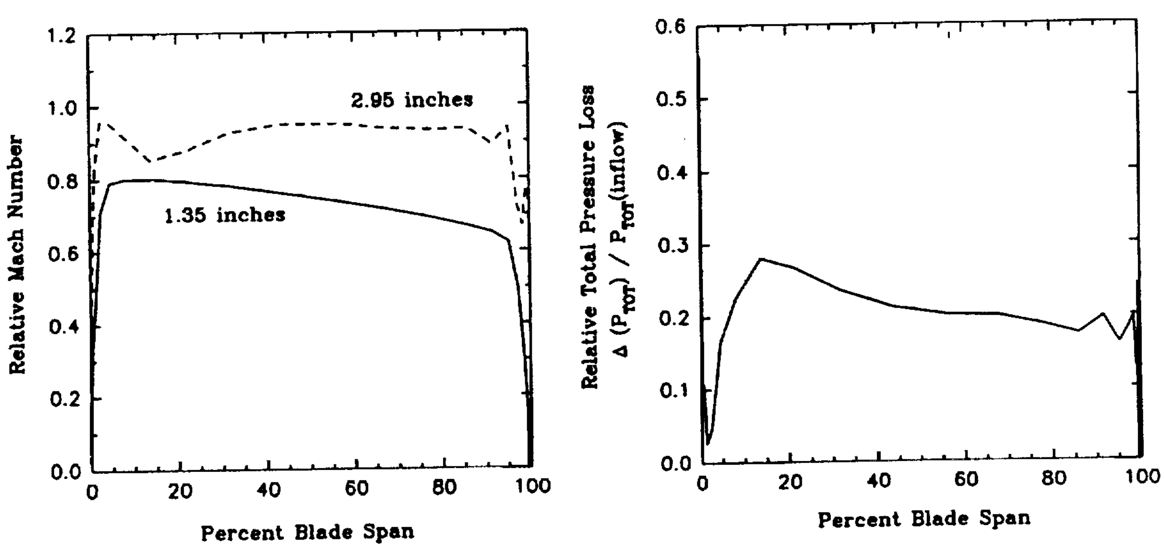




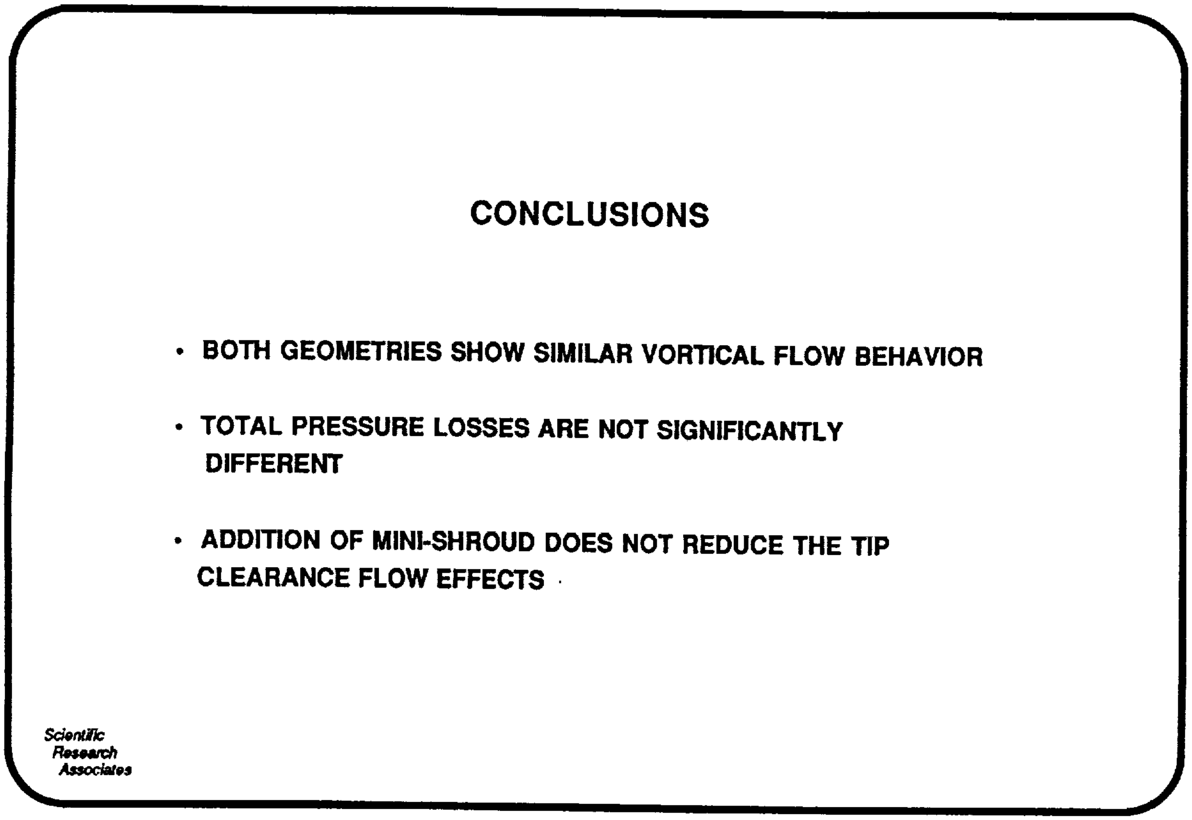
Circumferentially Mass Averaged Total Pressure Loss Across Blade



Circumferentially Mass Averaged Total Pressure Loss Across Blade



Minishroud


CONCLUSIONS
• BOTH GEOMETRIES SHOW SIMILAR VORTICAL FLOW BEHAVIOR
• TOTAL PRESSURE LOSSES ARE NOT SIGNIFICANTLY DIFFERENT
• ADDITION OF MINI-SHROUD DOES NOT REDUCE THE TIP CLEARANCE FLOW EFFECTS
Scientific Research Associates