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Finite-difference Solutions of the Alternate Turbopump Development High-pressure Oxidizer Turbopump Pump-end Ball-bearing Cavity Flows

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by

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These analyses were undertaken to aid in the understandng of flow phenomena in the Alternate Turbopump Development (ATD) High-pressure Oxidizer Turbopump (HPOTP) Pump-end ball bearing (PEBB) cavities and their roles in turbopump vibration initiation and bearing distress. This effort was being performed to provide timely support to the program in a decision as to whether or not the program should be continued.

In the first case, it was determined that a change in bearing throughflow had no significant effect on axial preload. This was a follow-on to a previous study which had resulted in a redesign of the bearing exit cavity which virtually eliminated bearing axial loading.

In the second case, a three-dimensional analysis of the inner-race-guided cage configuration was performed so as to determine the pressure distribution on the outer race when the shaft is 0.0002" off-center. The results indicate that there is virtually no circumferential pressure difference caused by the offset to contribute to bearing tilt.

In the third case, axisymmetric analyses were performed on an outer-race guided cage configuration to determine the magnitude of tangential flow entering the bearing. The removed-shoulder case was analyzed as was the static diverter case. A third analysis where the preload spring was shielded by a sheet of metal for the baseline case was also performed. It was determined that the swirl entering the bearing was acceptable and the project decided to use the outer-race-guided cage configuration.

In the fourth case, more bearing configurations were analyzed. These analyses included thermal modeling so as to determine the added benefit of injecting colder fluid directly onto the bearing inner-race contact area. The results of these analyses contributed to a programmatic decision to include coolant injection in the design.

FINITE-DIFFERENCE SOLUTIONS OF THE ALTERNATE TURBOPUMP HIGH-PRESSURE OXIDIZER TURBOPUMP PUMP-END BALL-BEARING CAVITY FLOWS

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OVERVIEW

- Introduction
- Objective
- Approach
- Results
- Future work

INTRODUCTION

- Distress (increased temperature rise across bearings, high wear rate) observed in pump-end ball bearings in testing at Pratt & Whitney
  - Possible cause is loss of preload on the bearing
  - Second possible cause is loss of solid-film lubricant transfer to bearing contact areas because bearing outer-race tilt causes excessive ball temperature, which inhibits lubricant transfer
    - ◊ One potential agent for bearing tilt is asymmetric pressure loading on bearing
  - Third possible cause is inadequate cooling
- Some design changes implemented to mitigate distress
  - Move bearing cage to outer race to increase throughflow of fluid to inner-race contact areas
  - Remove material from inlet-side inner-race shoulder to increase flow to inner-race contact areas
  - Inject cooler flow near inner-race contact areas to reduce ball temperatures
  - Silicon nitride balls

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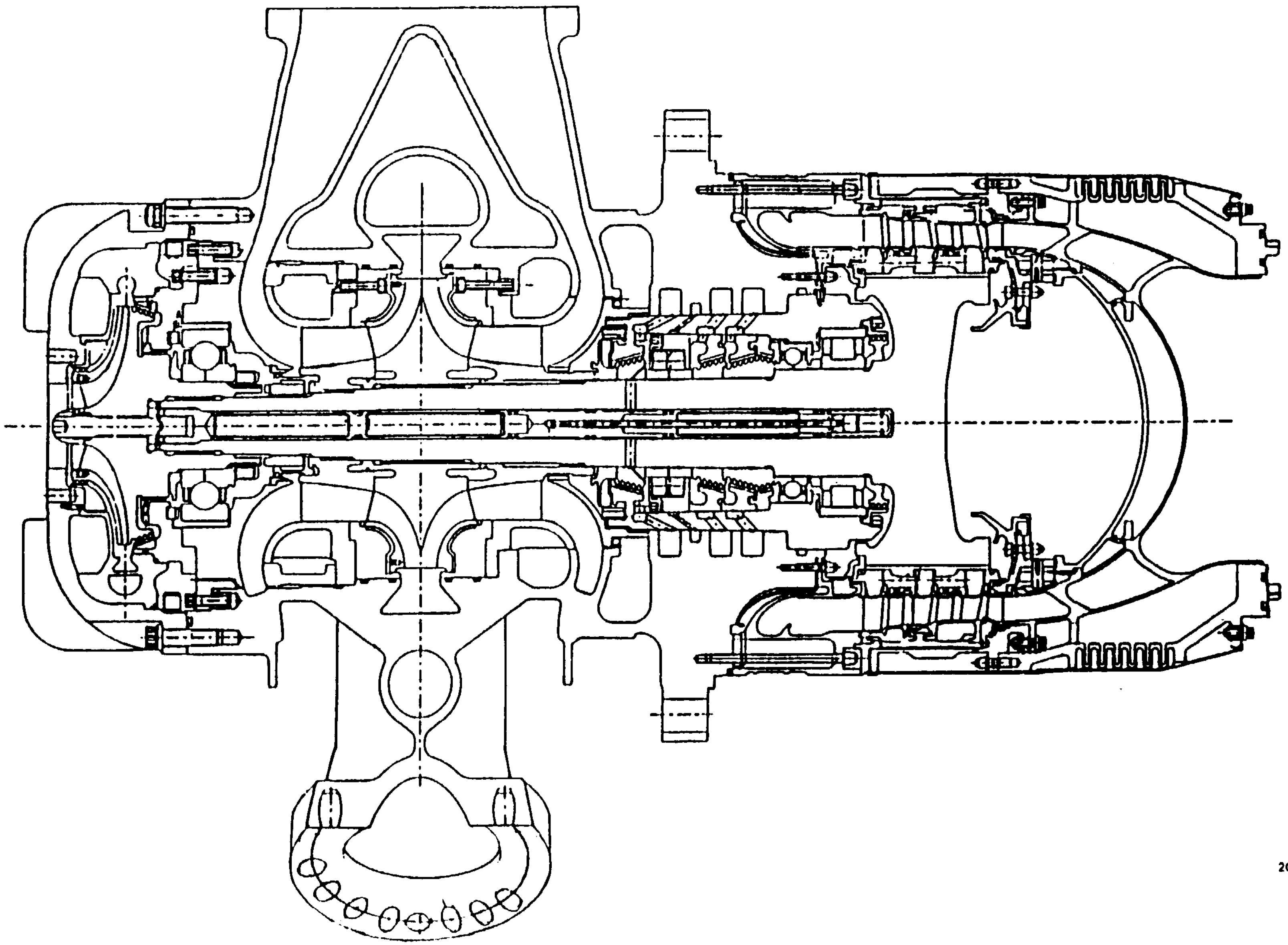
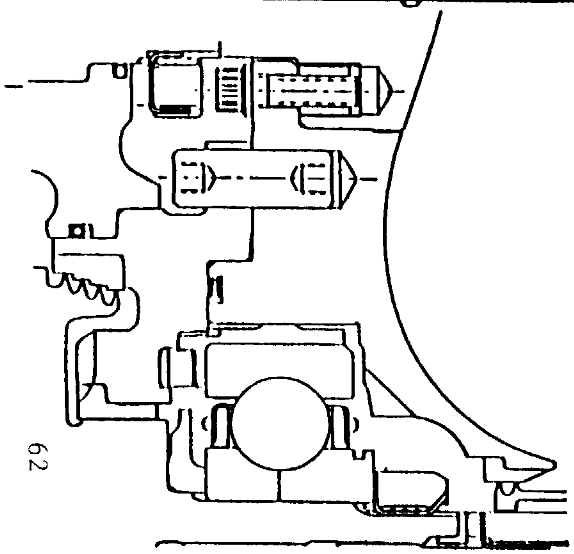
ATD SSME High Pressure Oxidizer Turbopump

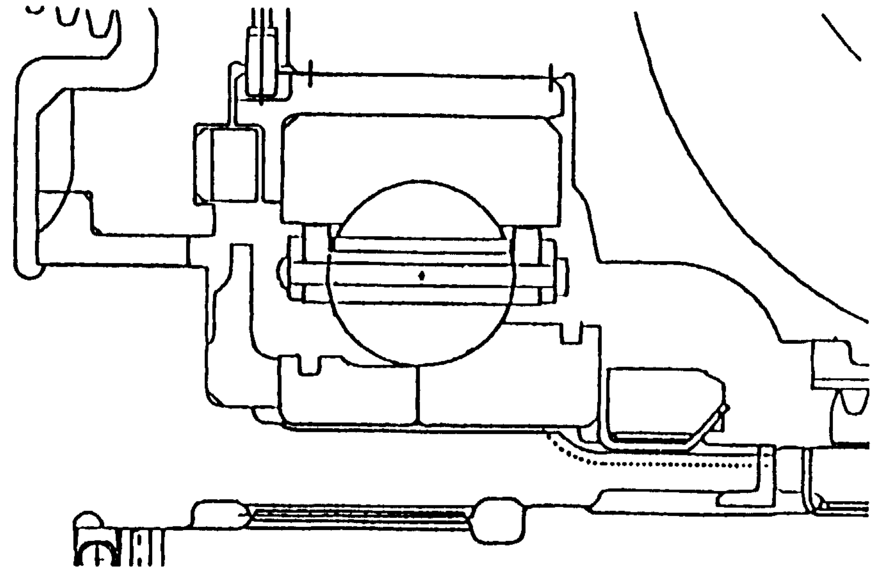


20 April 1993

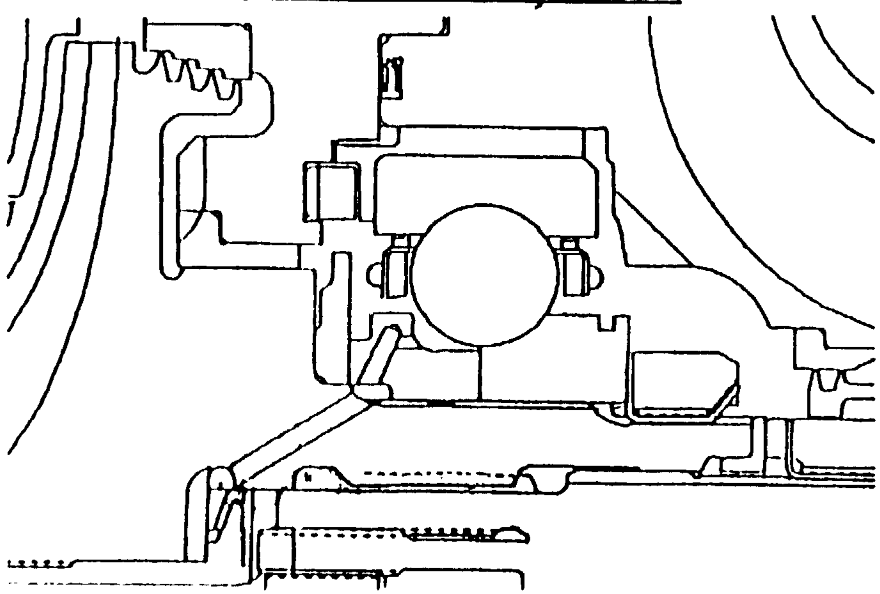
Baseline Configuration



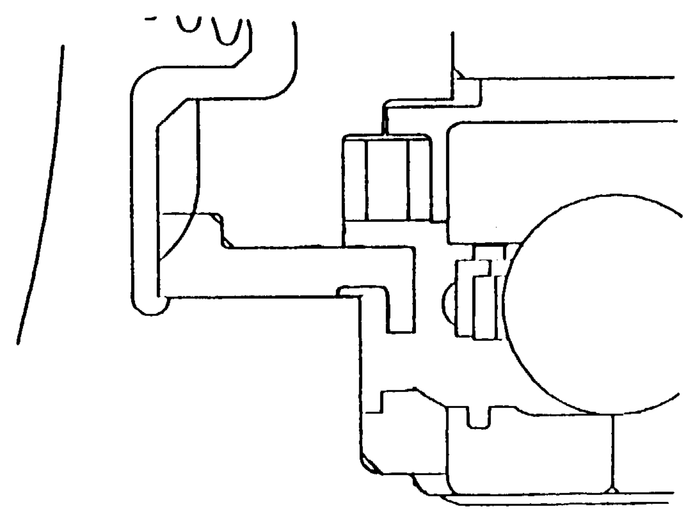
Removed Race Shoulder



Inner Race Injection



Static Diverter



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OBJECTIVE OF CFD ANALYSIS

- Determine effect of flow rate upon axial preload
- Quantify pressure field asymmetry due to rotor offset as cause of bearing tilt
- Determine effect of design changes upon bearing inlet swirl (viscous heating)
- Quantify effectiveness of design changes to enhance cooling

APPROACH

- All analyses
  - K-ε turbulence model with wall functions
  - Neglected ball
  - Incompressible
  - Fixed inlet velocity field
- Effect on axial preload
  - Previous analysis indicated at 9 pps flow rate through bearing, pressure forces on inlet and outlet faces of bearing balanced such that preload was unaffected
  - Analyzed axisymmetrically and isothermally with finite-difference Navier-Stokes code (FDNS) and finite-volume Navier-Stokes co-located code (REFLEQS)
  - Analyzed for 15 pps flow rate to augment previous 9 pps analysis
- Pressure field asymmetry
  - Analysis of inlet cavity with 0.0002" shaft static offset and flow rate of 15 pps
  - Three-dimensional isothermal analysis using FDNS

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APPROACH (continued)

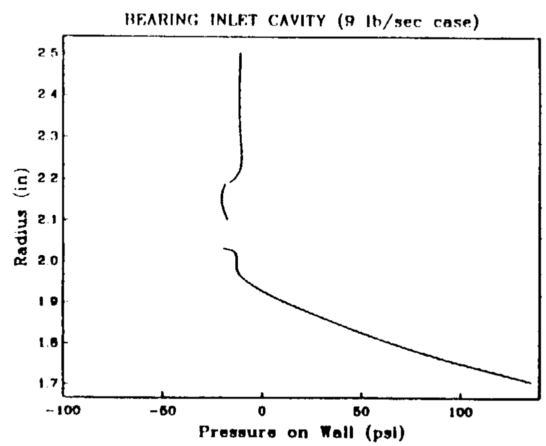
- Asses bearing design effects on bearing inlet swirl
  - Analyses of inlet cavity with outer-race-guided cage with flow rate of 15 pps
  - Utilized three configurations
  - Axisymmetric isothermal analysis using FDNS
- Cooling enhancement
  - Analyses of inlet cavity for outer-race-guided cage configuration
    - ◊ Lowered shoulder analyzed for three different ball/inner-race heat-generation levels with 15 pps through bearing
    - ◊ Injection cases analyzed for three different ball/inner-race heat-generation levels with 7.5 pps entering through seal (230 °R) and 7.5 pps injected through inner race (190 °R)
  - Axisymmetric thermal analyses using REFLEQS
  - Effectiveness determined by maximum temperature in bearing area

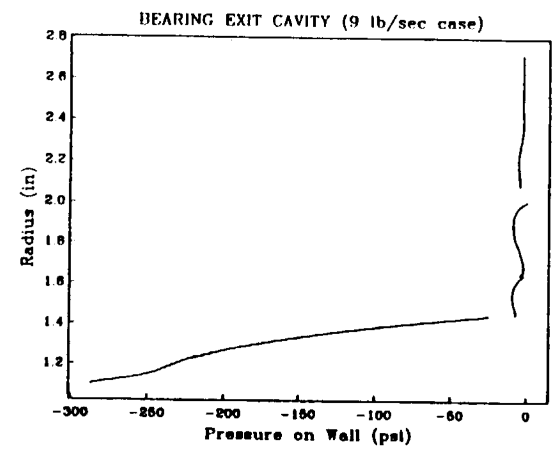
RESULTS

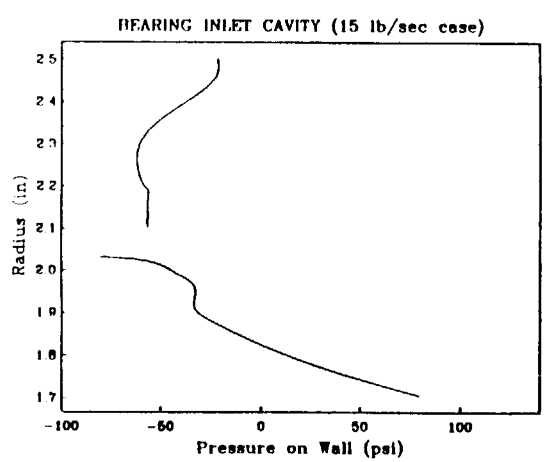
- Change in flow rate does not affect axial preload
- No circumferential pressure field asymmetry due to shaft offset to contribute to bearing tilt
- Moving bearing cage to outer race increases inlet swirl
  - Baseline: bearing inlet swirl = 15 ft/sec
  - Removed race: bearing inlet swirl = 31 ft/sec
  - Shielded preload spring: bearing inlet swirl = 105 ft/sec
  - Static diverter: bearing inlet swirl = 55 ft/sec
- For silicon nitride balls, cooling enhancement keeps ball temperatures in desirable range
  - For inner race guided cage with no EHD, maximum temperature 325 °R
  - For outer race guided cage:

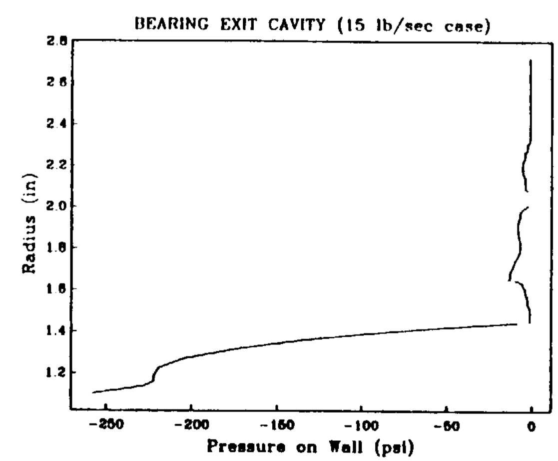
Elastohydrodynamic film (Q)	Lowered shoulder	Coolant injection
None (0.56 Btu/sec)	255 °R	213 °R
Partial (0.23 Btu/sec)	240 °R	204 °R
Full (0.028 Btu/sec)	231 °R	198 °R

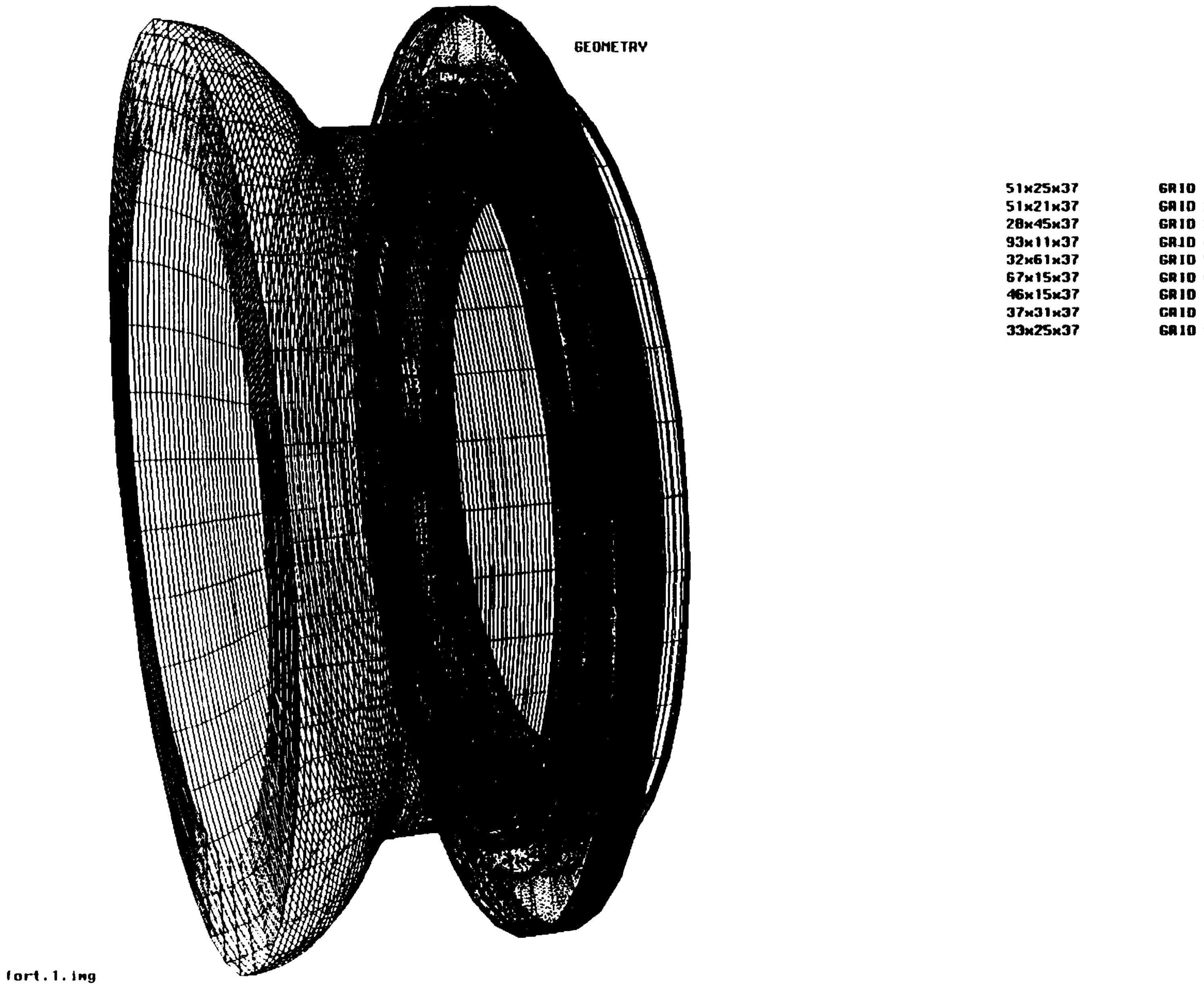
Bearing-face Pressures







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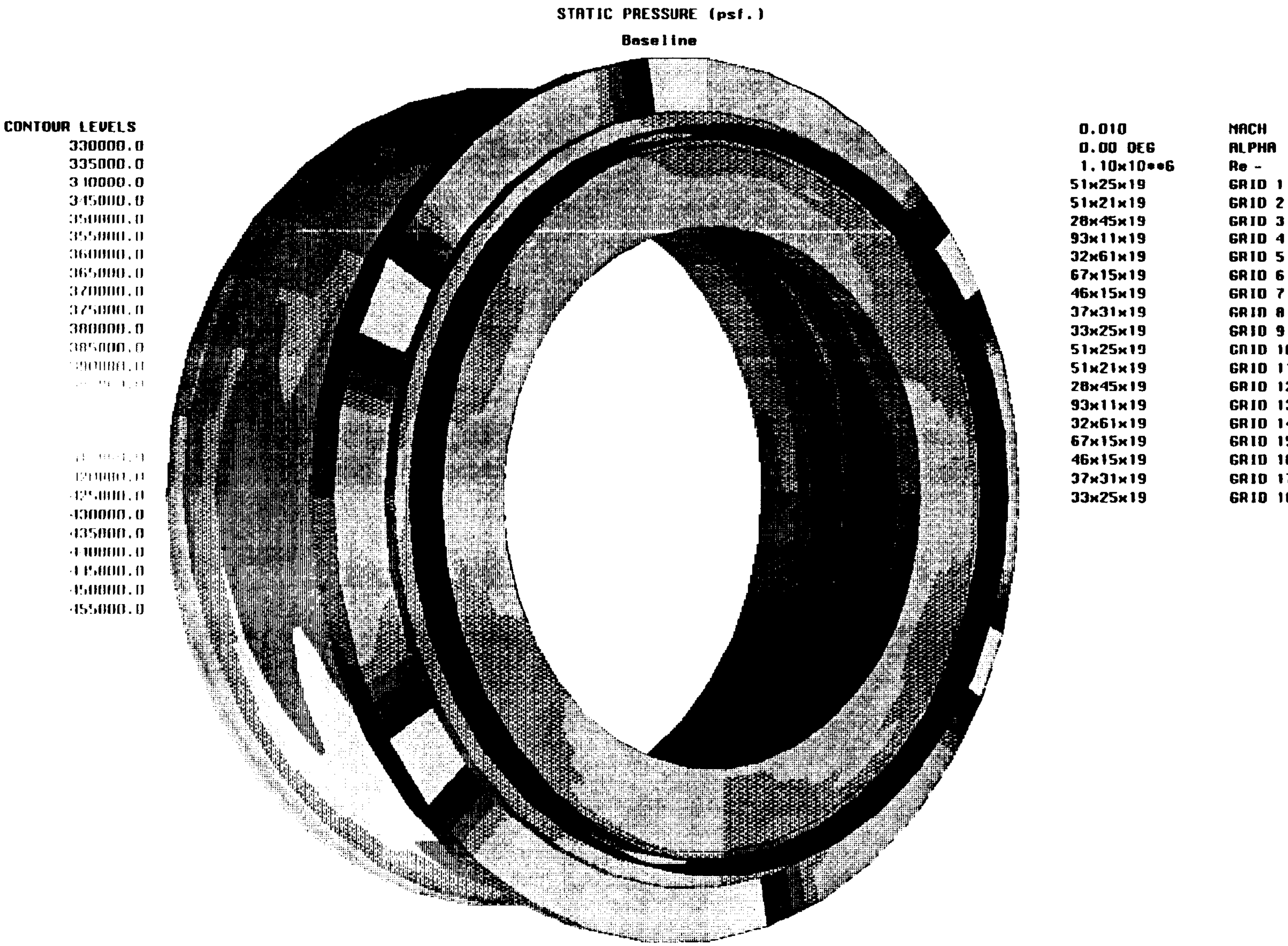
51x21x37 GRID 2
28x45x37 GRID 3
93x11x37 GRID 4
32x61x37 GRID 5
67x15x37 GRID 6
46x15x37 GRID 7
37x31x37 GRID 8
33x25x37 GRID 9
fort.1.img


STATIC PRESSURE (psf.)
Baseline
CONTOUR LEVELS
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335000.0
340000.0
345000.0
350000.0
355000.0
360000.0
365000.0
370000.0
375000.0
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440000.0
445000.0
450000.0
455000.0
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0.00 DEG ALPHA
1.10x10**6 Re -
51x25x19 GRID 1
51x21x19 GRID 2
28x45x19 GRID 3
93x11x19 GRID 4
32x61x19 GRID 5
67x15x19 GRID 6
46x15x19 GRID 7
37x31x19 GRID 8
33x25x19 GRID 9
51x25x19 GRID 10
51x21x19 GRID 11
28x45x19 GRID 12
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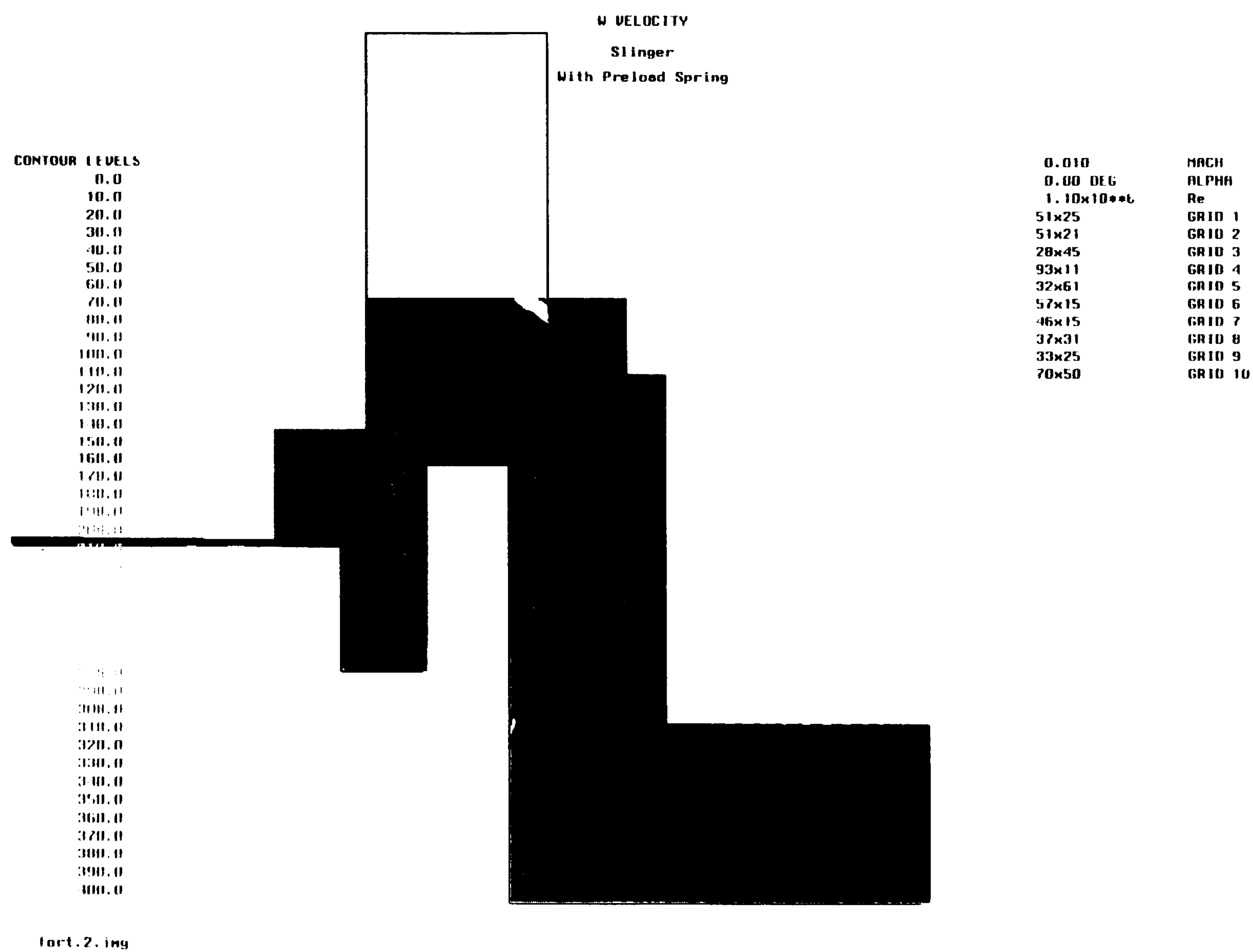
33x25x19 GRID 18


W VELOCITY
Slinger
With Preload Spring
CONTOUR LEVELS
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30.0
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380.0
390.0
400.0
0.010 MACH
0.00 DEG ALPHA
1.10x10**6 Re
51x25 GRID 1
51x21 GRID 2
28x45 GRID 3
93x11 GRID 4
32x61 GRID 5
57x15 GRID 6
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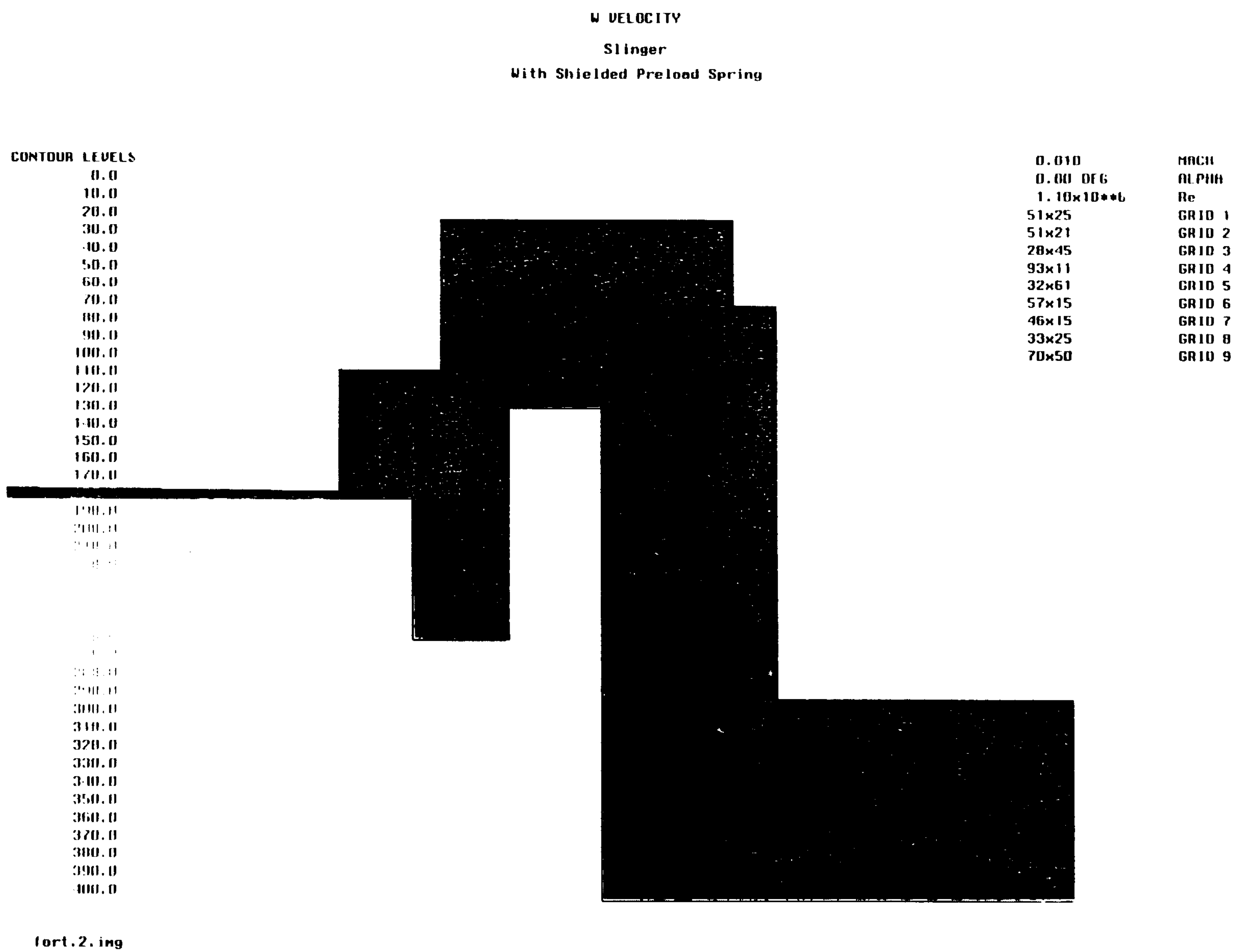
70x50 GRID 10
fort.2.img


W VELOCITY
Slinger
With Shielded Preload Spring
CONTOUR LEVELS
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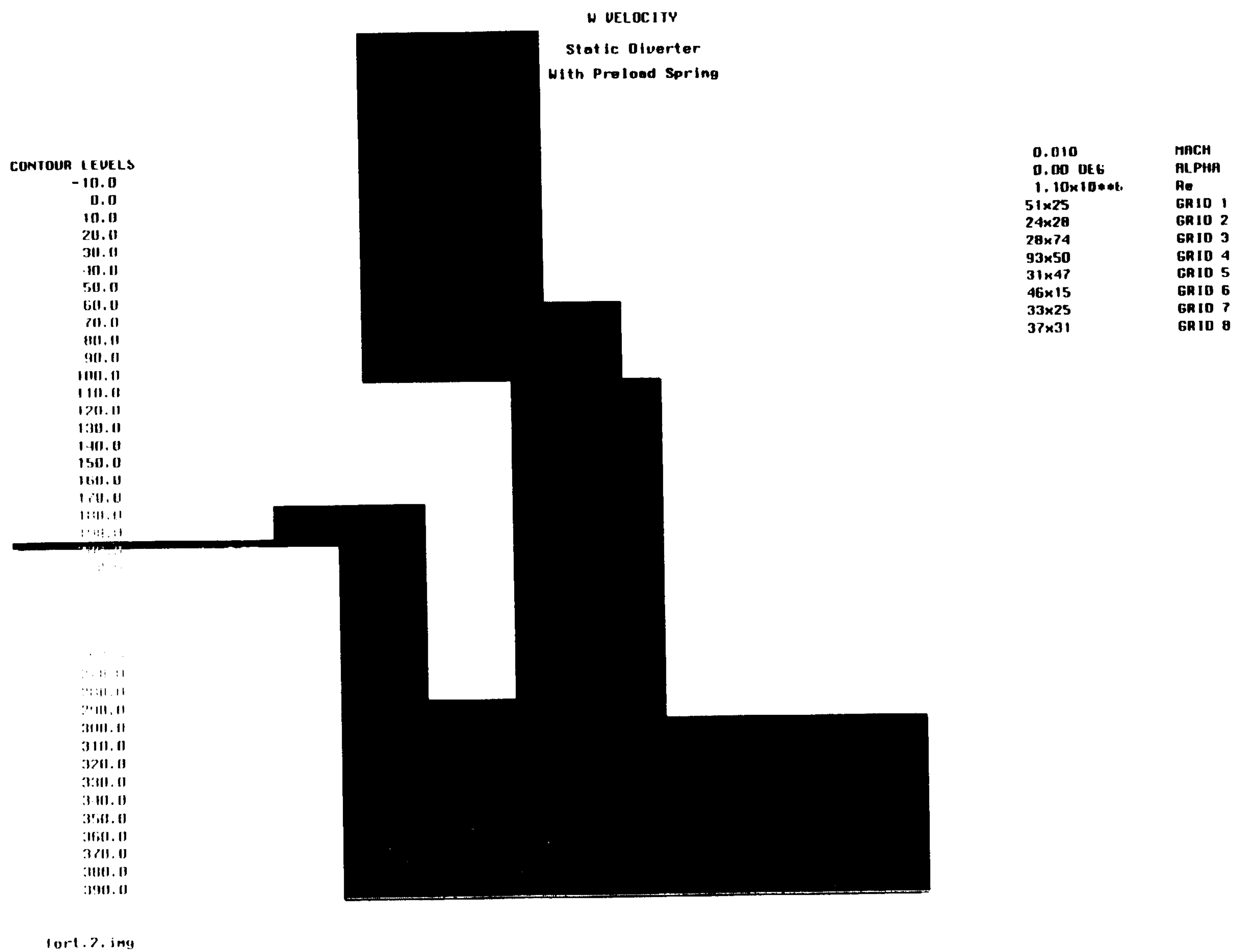
W VELOCITY
Static Diverter
With Preload Spring
CONTOUR LEVELS
-10.0
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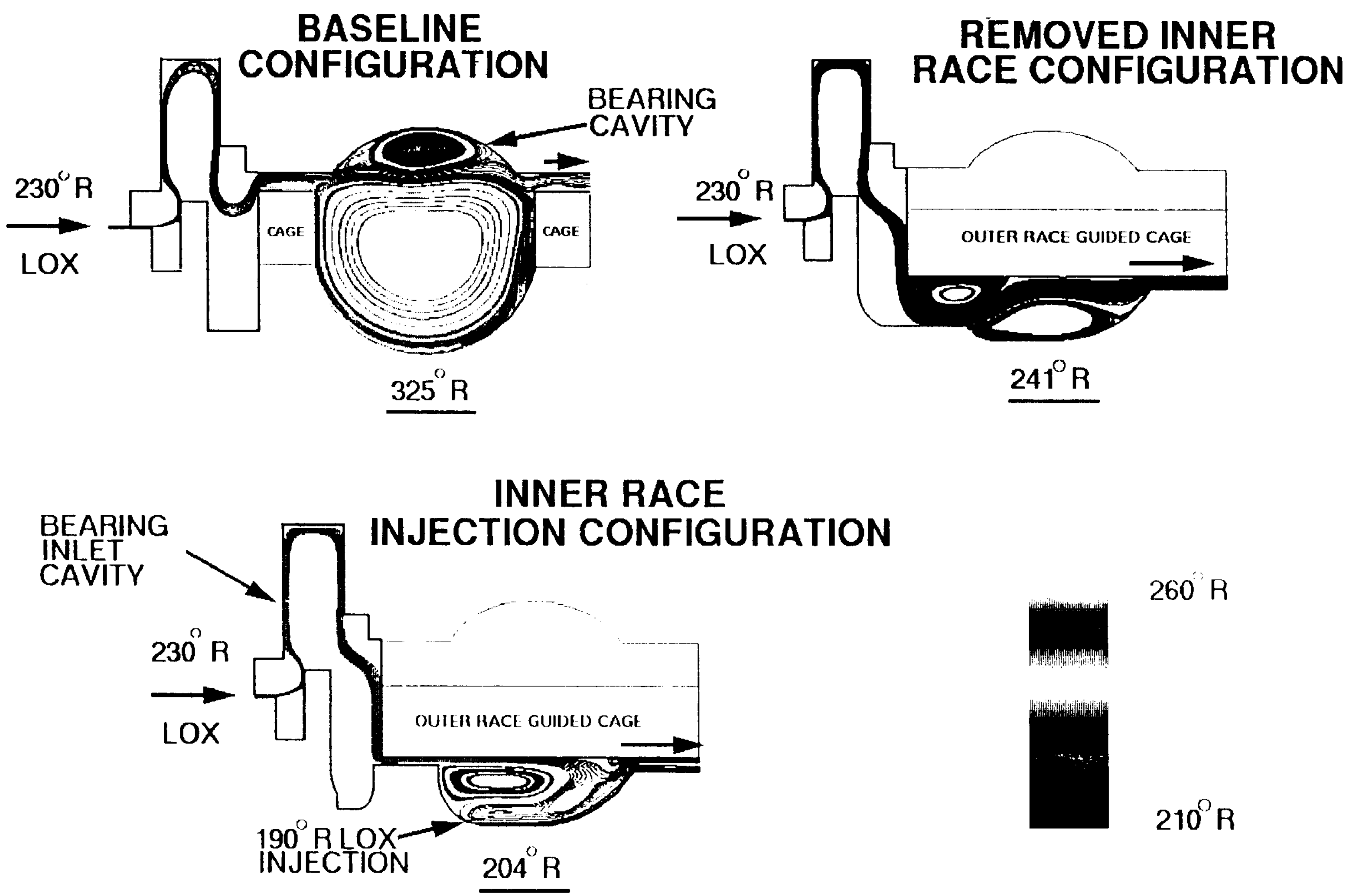
fort.2.img
0.010 MACH
0.00 DEG ALPHA
1.10x10**6 Re
51x25 GRID 1
24x28 GRID 2
28x74 GRID 3
93x50 GRID 4
31x47 GRID 5
46x15 GRID 6
33x25 GRID 7
37x31 GRID 8

CFD ANALYSIS OF ATD BEARING FLOWS
FLOW STREAMLINES COLORED BY FLUID TEMPERATURE



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Future Work

- Optimizing inner-race injection design
  - Sweep angle
  - Injection flow rate
  - Axial flow angle
  - Other possibilities
    - ◊ Shoulder height
    - ◊ Hole location, size, number