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UNSTEADY FLOW SIMULATIONS IN SUPPORT OF THE SSME HEX TURNING VANE CRACKING INVESTIGATION WITH THE ATD HPOTP

by

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ABSTRACT

Unsteady flow computations are being performed with the P&W (ATD) and the Rocketdyne baseline configurations of the SSME LO_2 turbine turnaround duct (TAD) and heat exchanger (HEX). The work is in support of the HEX inner turning vane cracking investigation. Fatigue cracking has occurred during hot firings with the P&W configuration on the HEX inner vane, and it appears the fix will involve changes to the TAD splitter vane position and to the TAD inner wall curvature to reduce the dynamic loading on the inner vane. Unsteady flow computations on the P&W baseline and fix and on the Rocketdyne baseline reference follow steady-flow screening computations done by MSFC/ED32 on several trial configurations arriving at the fix.

The P&W TAD inlet velocity profile has a strong radial velocity component that directs the flow toward the inner wall and raises the local velocity a factor of two and the dynamic pressure a factor of four. The fix is intended to redistribute the flow more evenly across the HEX inner and outer vanes like the Rocketdyne baseline reference. Vane buffeting at frequencies around 4,000 Hz is the leading suspected cause of the problem. Our simulations (work in progress) are being done with the USA 2D axisymmetric code approximating the flow as axisymmetric u+v 2D (axial, u, and radial, v, components only). The HEX coils are included in the model to make sure the fix does not adversely affect the HEX environment.

Turbulent kinetic energy, k, levels where $k = 1/2\ v'\ rms^2$ are locally as high as 10,000 ft^2/sec^2 for the P&W baseline at the engine interface (between the TAD and HEX) at the HEX inner vane location. However, k is less than 8,000 on the HEX outer vane and only about 4,500 on the HEX inner vane for the Rocketdyne baseline. Unsteady turbulence intensity, v'rms/v, and pressure, p', are being computed in the present computations to compare with steady-flow Reynolds-averaged computations where p'rms = const (ρk) for overall rms random turbulence from 0.1 to 12,000 Hz frequency. Random overall static, p'rms fluctuations as large as 1.7 psi are estimated from k on the HEX inner vane for the P&W baseline configuration but only about 0.7 psi for the Rocketdyne configuration.

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ENGINE HEX TURNING VANE CRACKING INVESTIGATION UNSTEADY CFD ANALYSIS

OBJECTIVE

- PROVIDE UNSTEADY FLOW SIMULATIONS OF THE ATD HPOTP TURNAROUND DUCT/HEAT EXCHANGER FLOW TO SUPPORT IDENTIFICATION OF A "FIX" THAT:

  1) ELIMINATES HEX INNER VANE CRACKING, AND

  2) DOES NOT ADVERSELY AFFECT THE HEX COIL ENVIRONMENT

ENGINE HEX TURNING VANE CRACKING INVESTIGATION
UNSTEADY CFD ANALYSIS

APPROACH

- DENSITY-BASED TIME-ACCURATE CFD CODE
  - 2ND-ORDER ACCURATE
  - PREVIOUSLY BENCHMARKED ON SIMPLE FLOW
    - RECTANGULAR CAVITY (ROSSITER)
    - EDGETONE (BROWN)
    - CURVED VANE (4 KHZ LO_2 SPLITTER VANE)
  - AXISYMMETRIC u AND v
- GEOMETRY, BOUNDARY CONDITIONS, AND REFERENCE QUANTITIES SAME AS IN STEADY-FLOW CFD ANALYSIS
- RESULTS COMPARED FOR GEOMETRY CHANGE
  - BASELINE CONFIGURATION
  - "FIX" CONFIGURATION

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MODELING APPROACH

BENEFITS

- CAN SHOW POTENTIALS FOR UNSTEADY BEHAVIOR
  – FLOW INSTABILITIES, UNSTEADY SEPARATION, BUFFETING
- MATCHES 2D STEADY-FLOW CFD (MEAN VALUES)
- PROVIDES HEX VANE UNSTEADY LOADING - - p', (t, ℓ)
- CAN PROVIDE p' AT AIRFLOW MEASUREMENT LOCATIONS
- AIDS UNDERSTANDING OF HOT FIRE AND AIRFLOW TEST DATA

AREAS FOR IMPROVEMENT

- 2D (INSTEAD OF 3D) TRUNCATED GEOMETRY CAN ALLOW ACOUSTICS TO DOMINATE
- TURBULENCE TREATMENT IS ALWAYS A QUESTION

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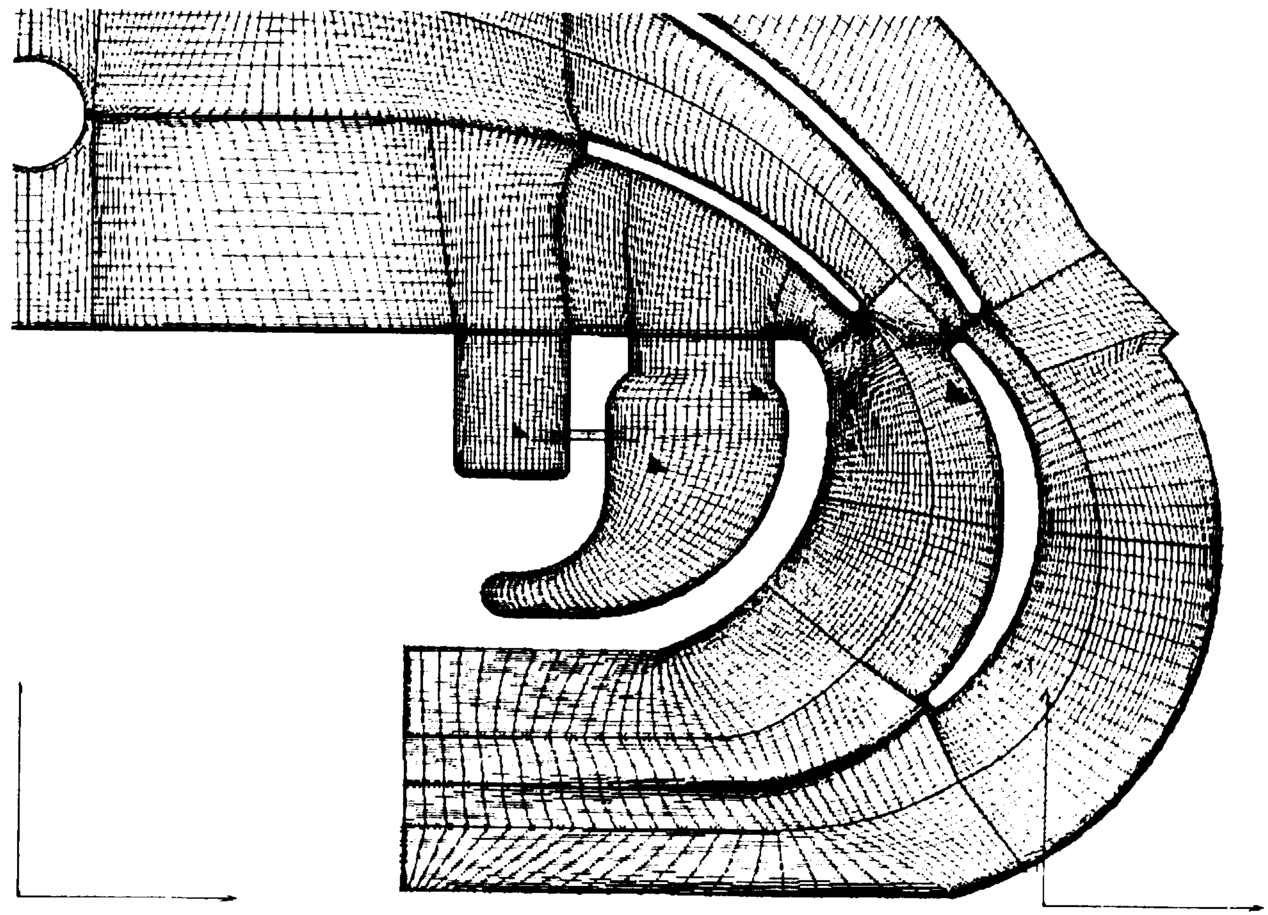
ENGINE HEX TURNING VANE CRACKING INVESTIGATION
UNSTEADY CFD ANALYSIS

BASELINE CONFIGURATION GRID



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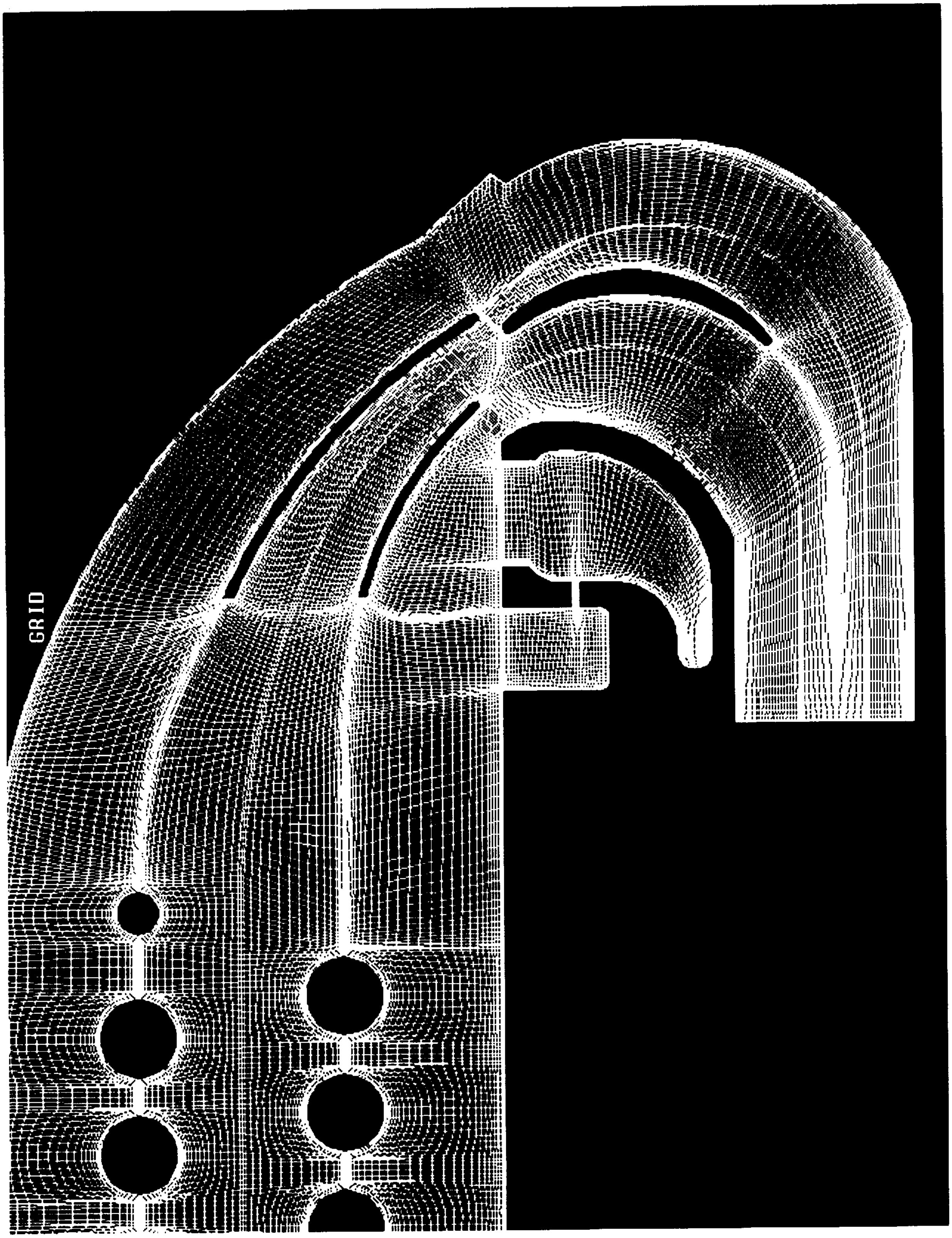
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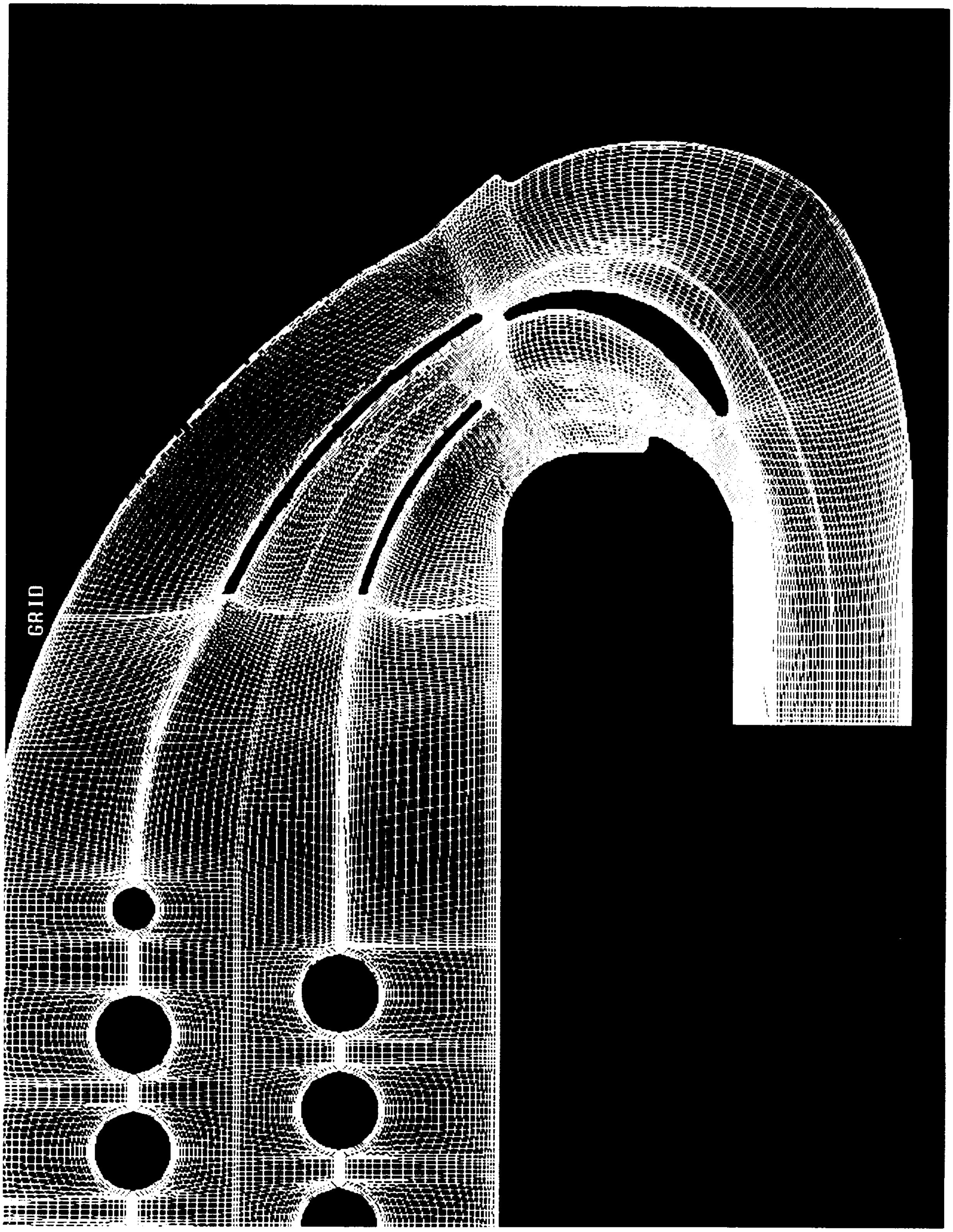
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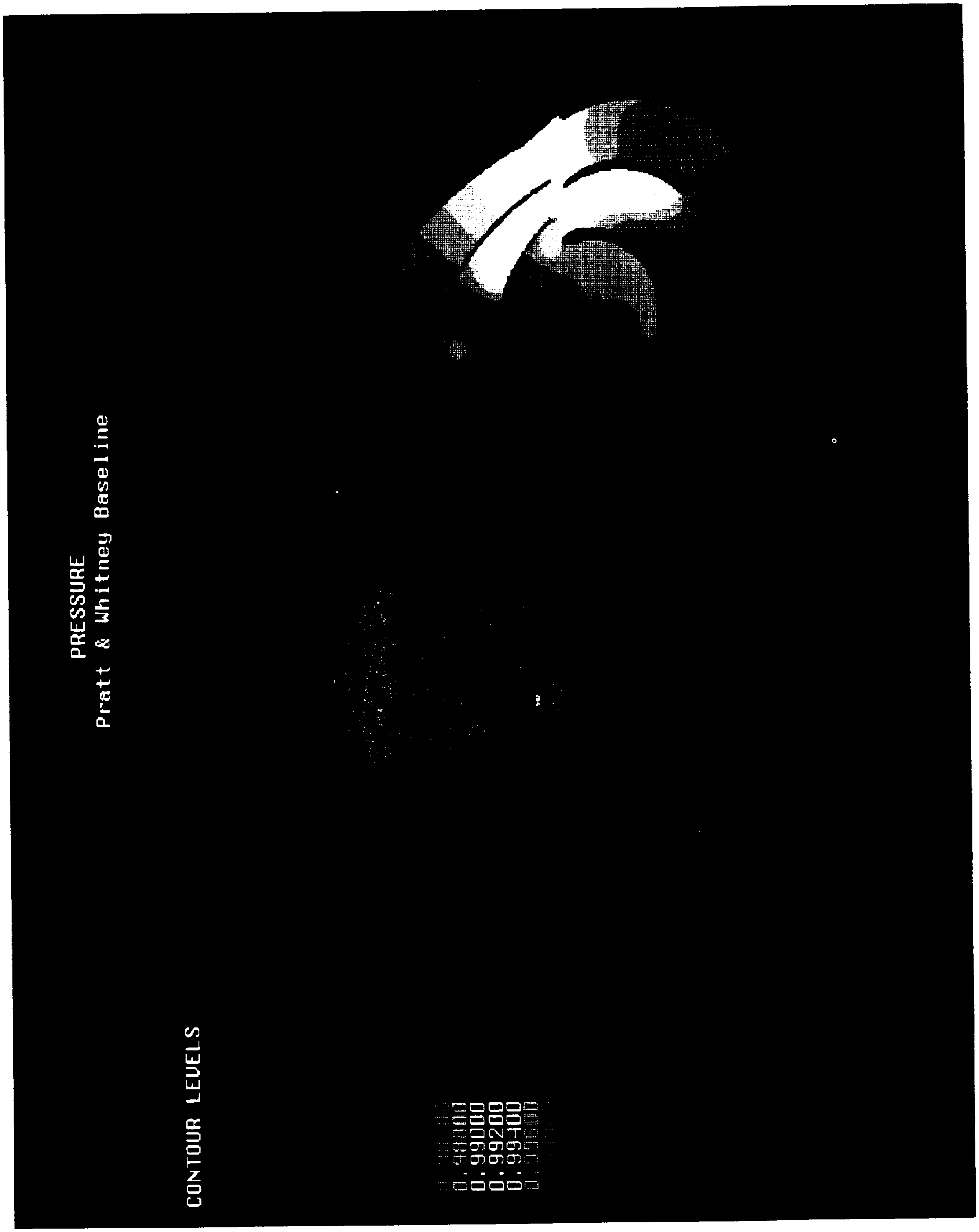
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Pratt & Whitney Baseline
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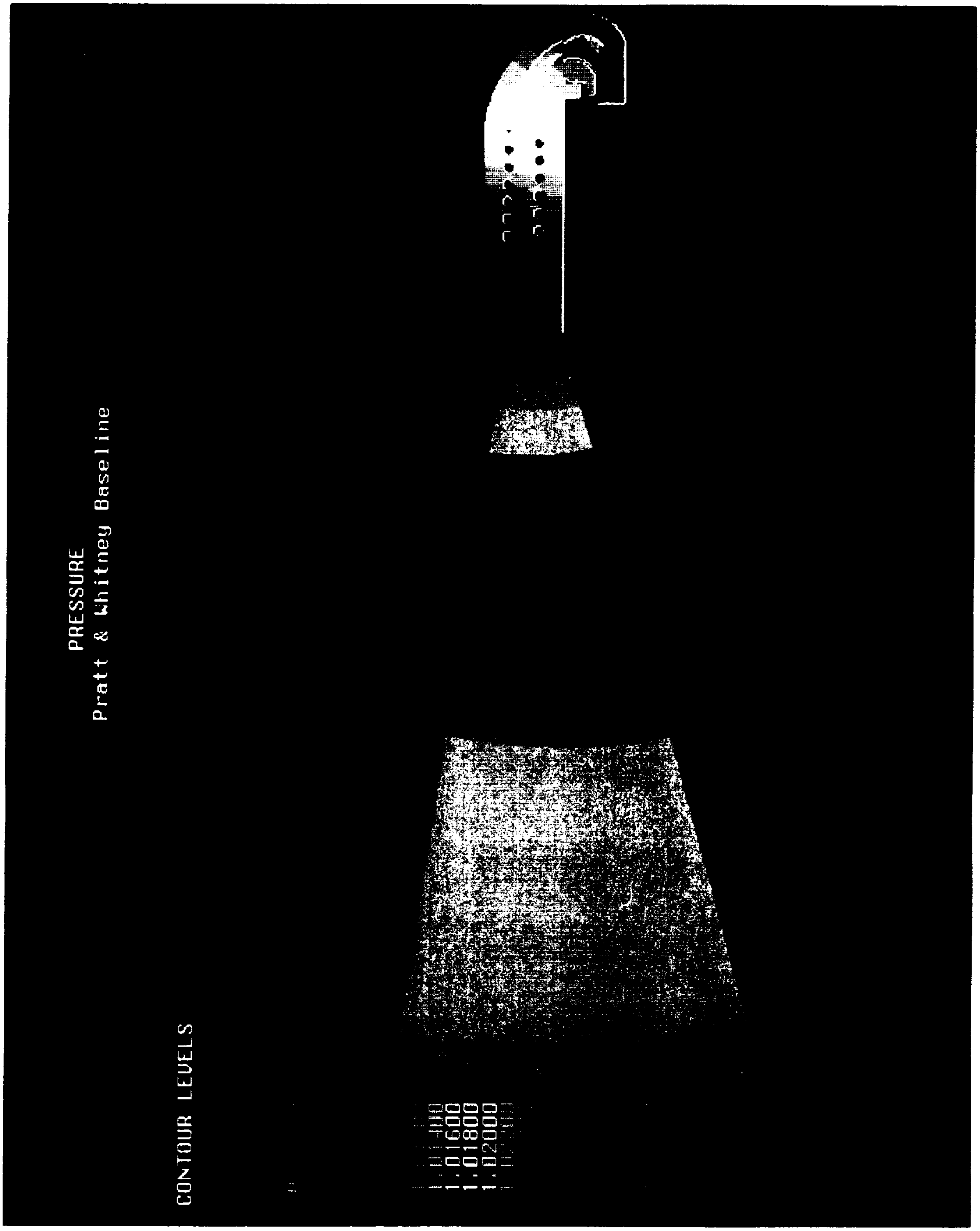
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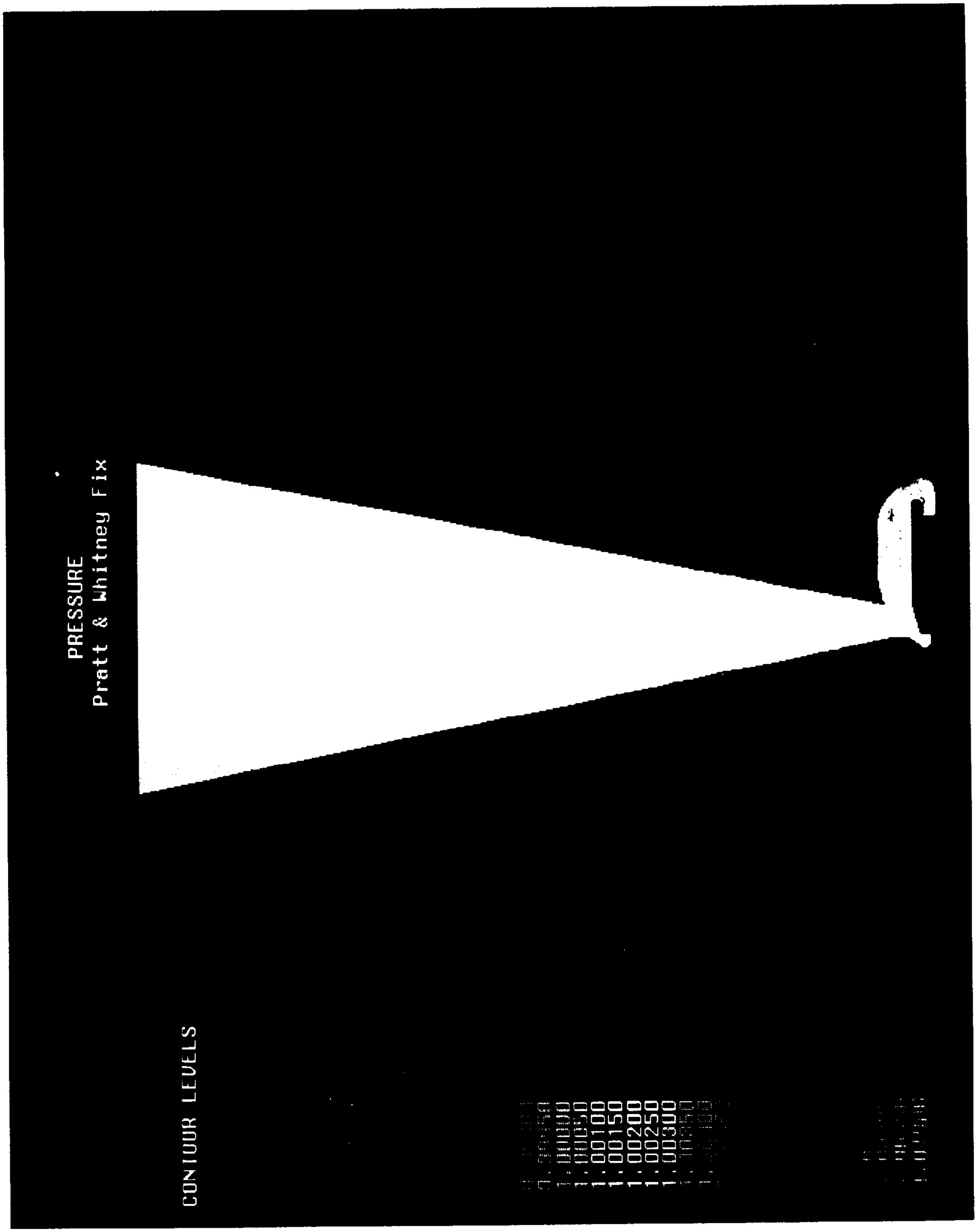
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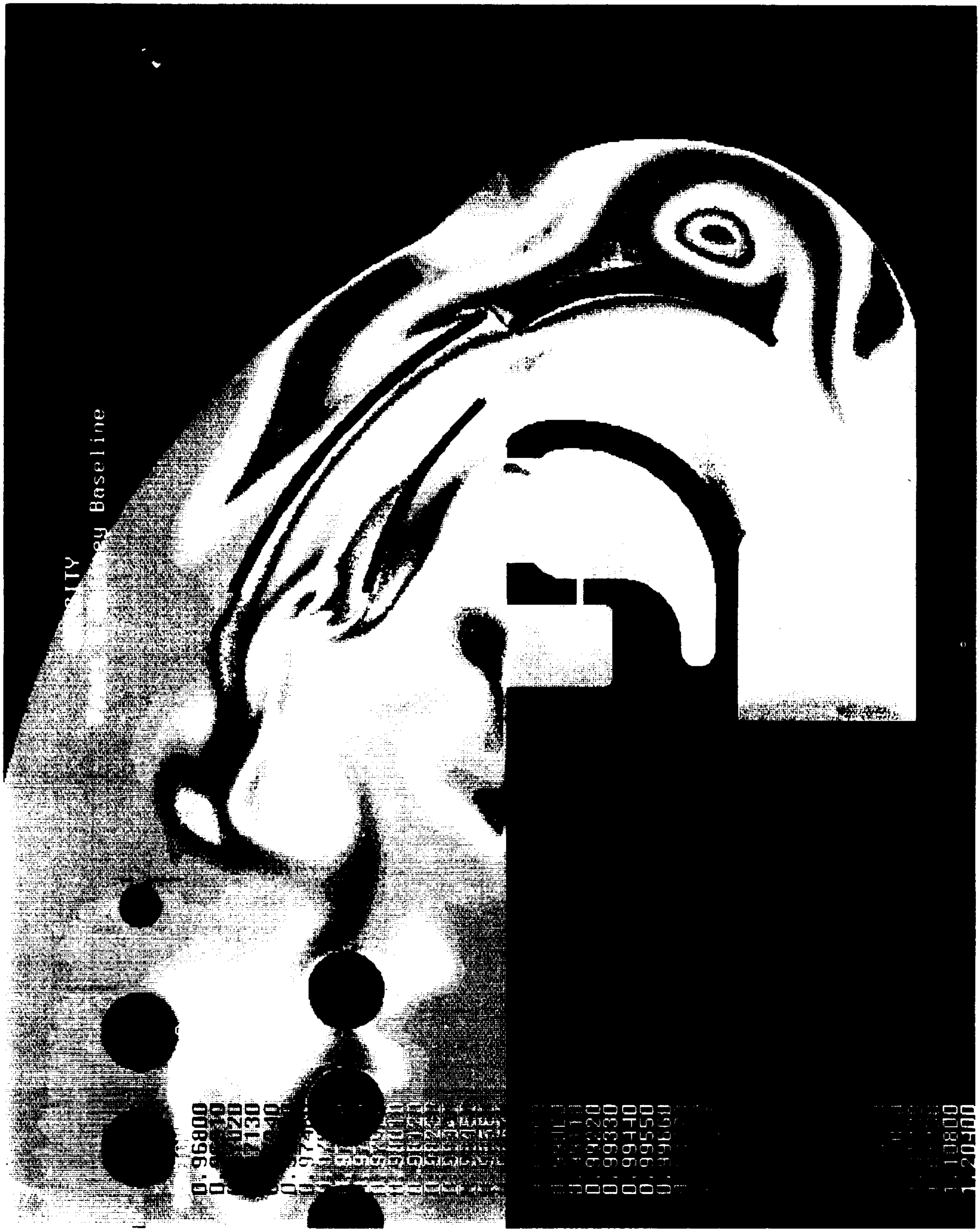

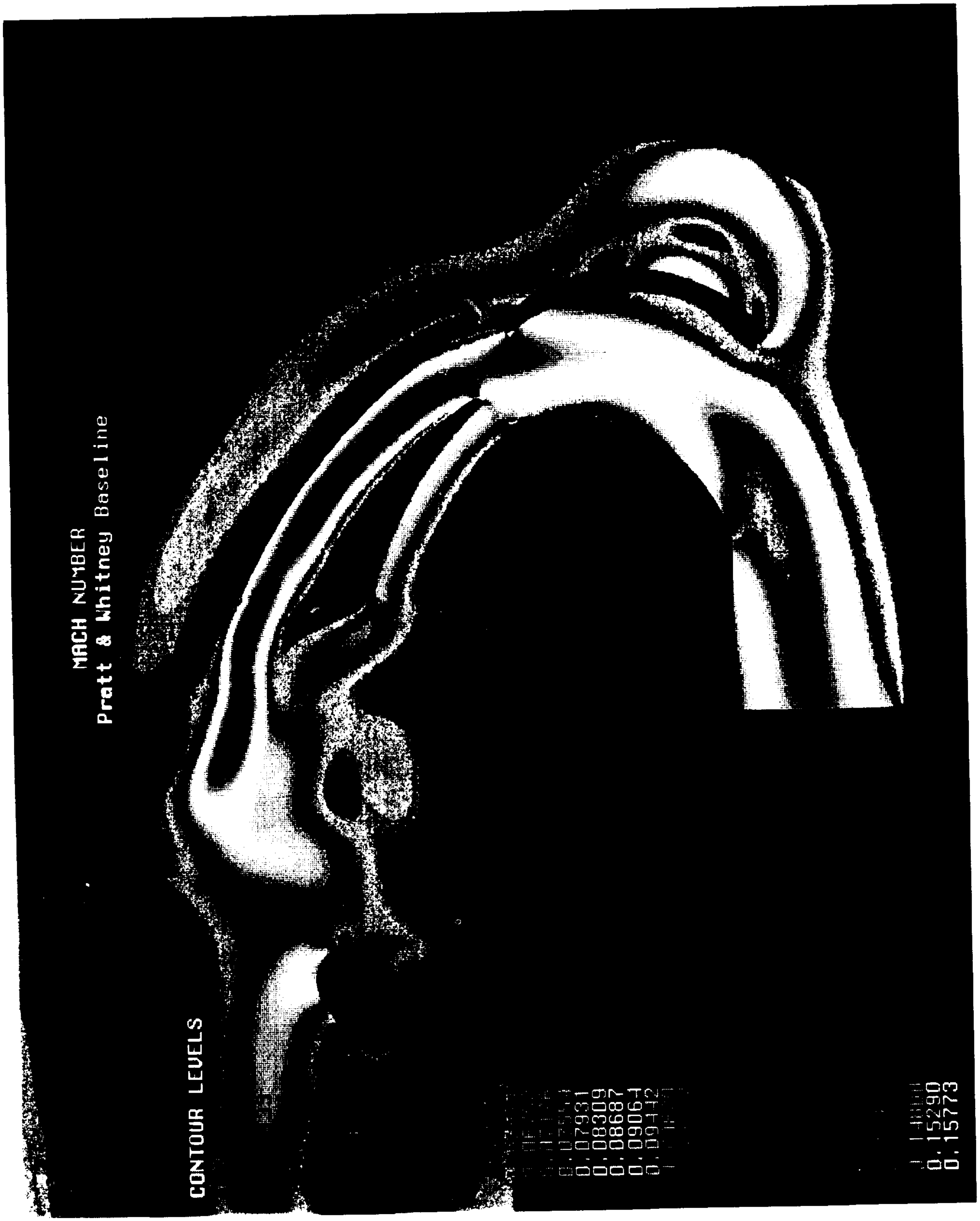
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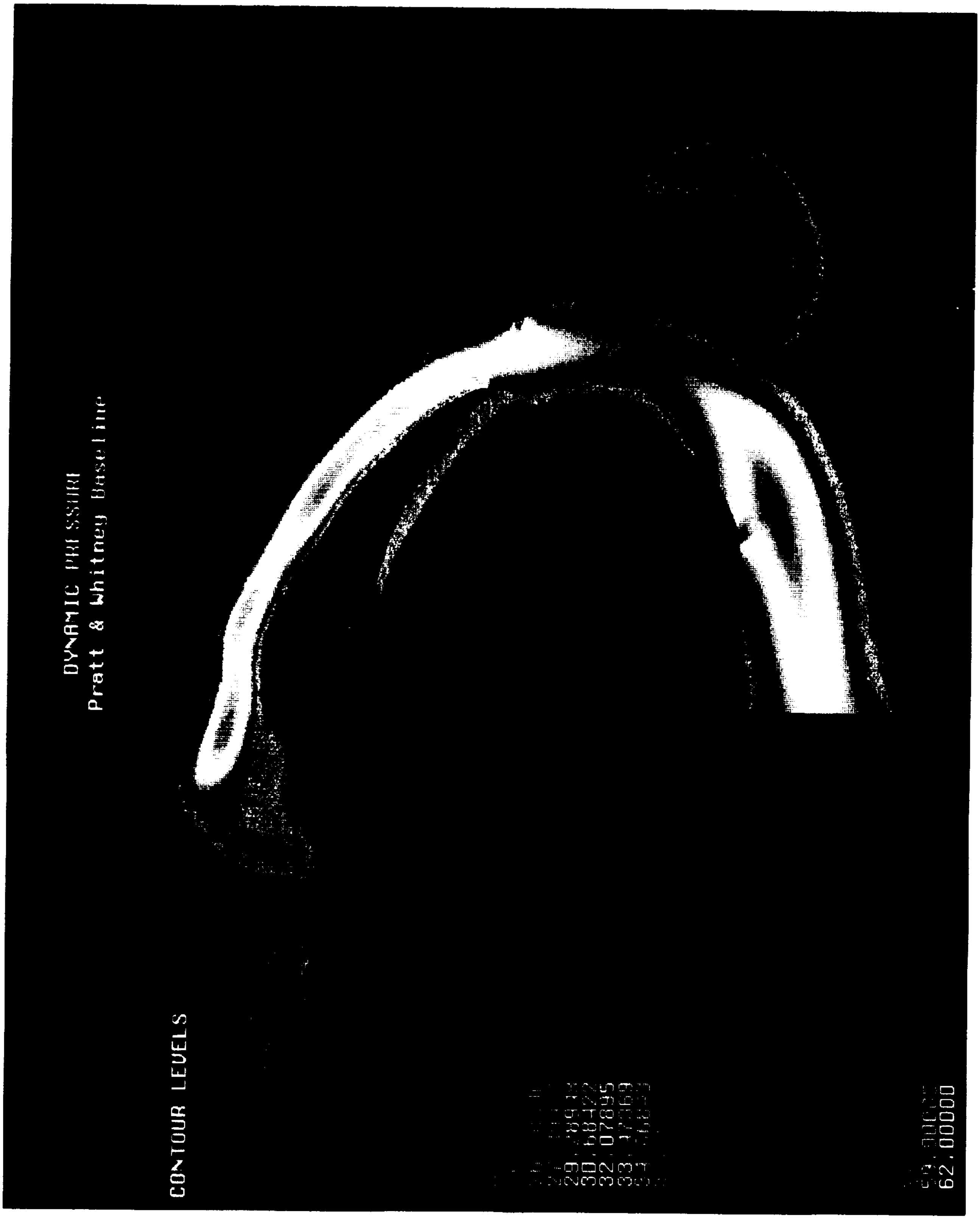

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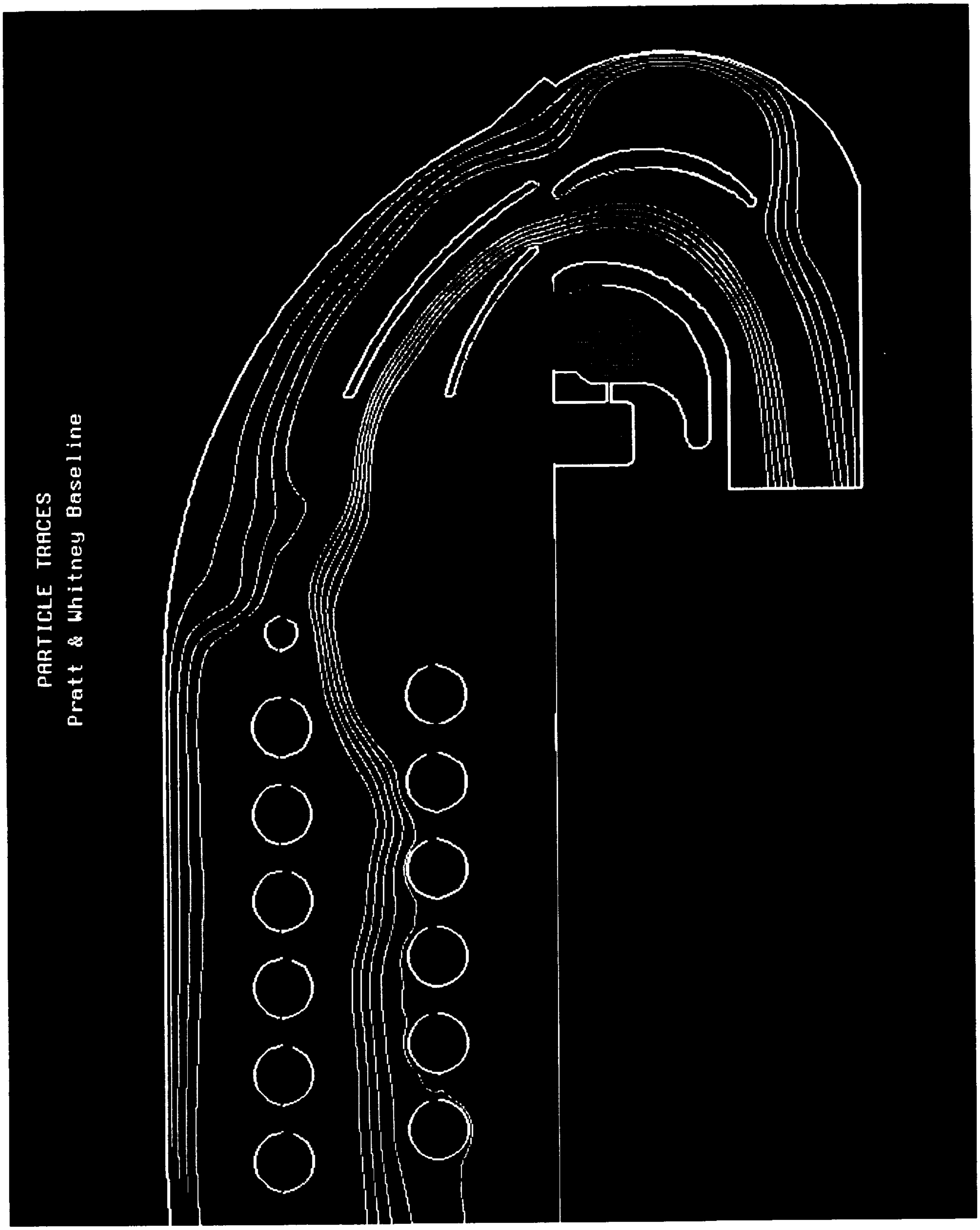
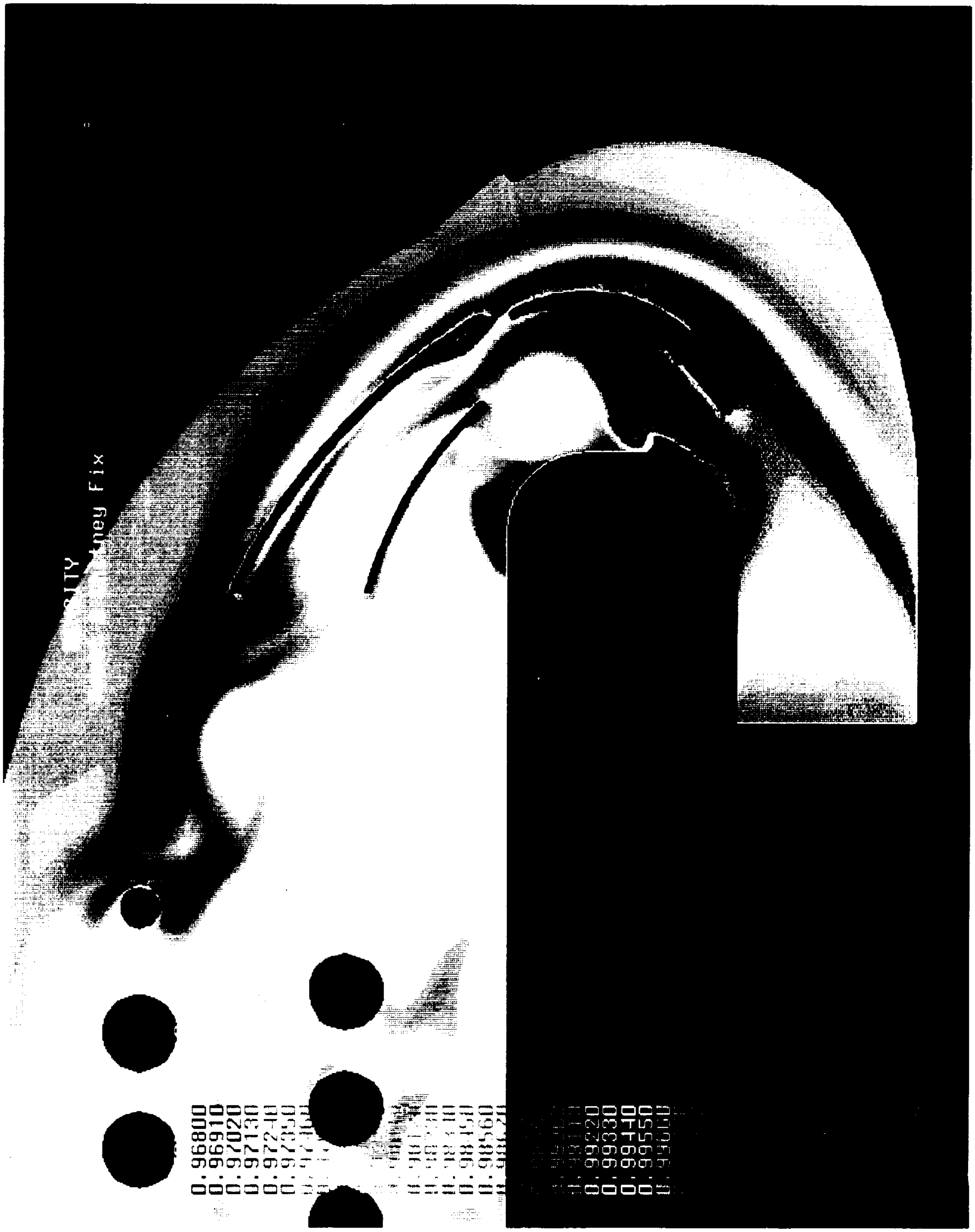
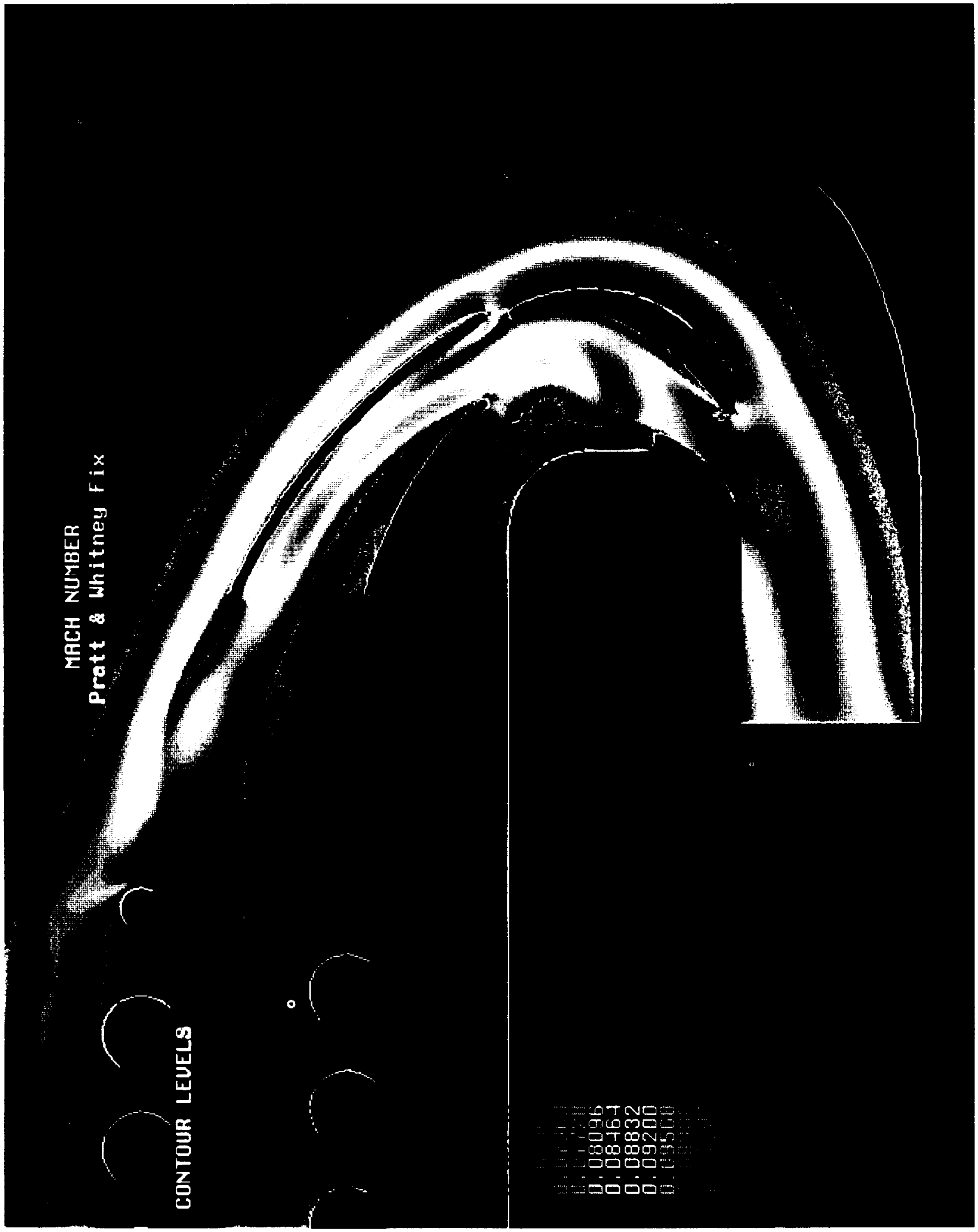

PARTICLE TRACES
Pratt & Whitney Baseline

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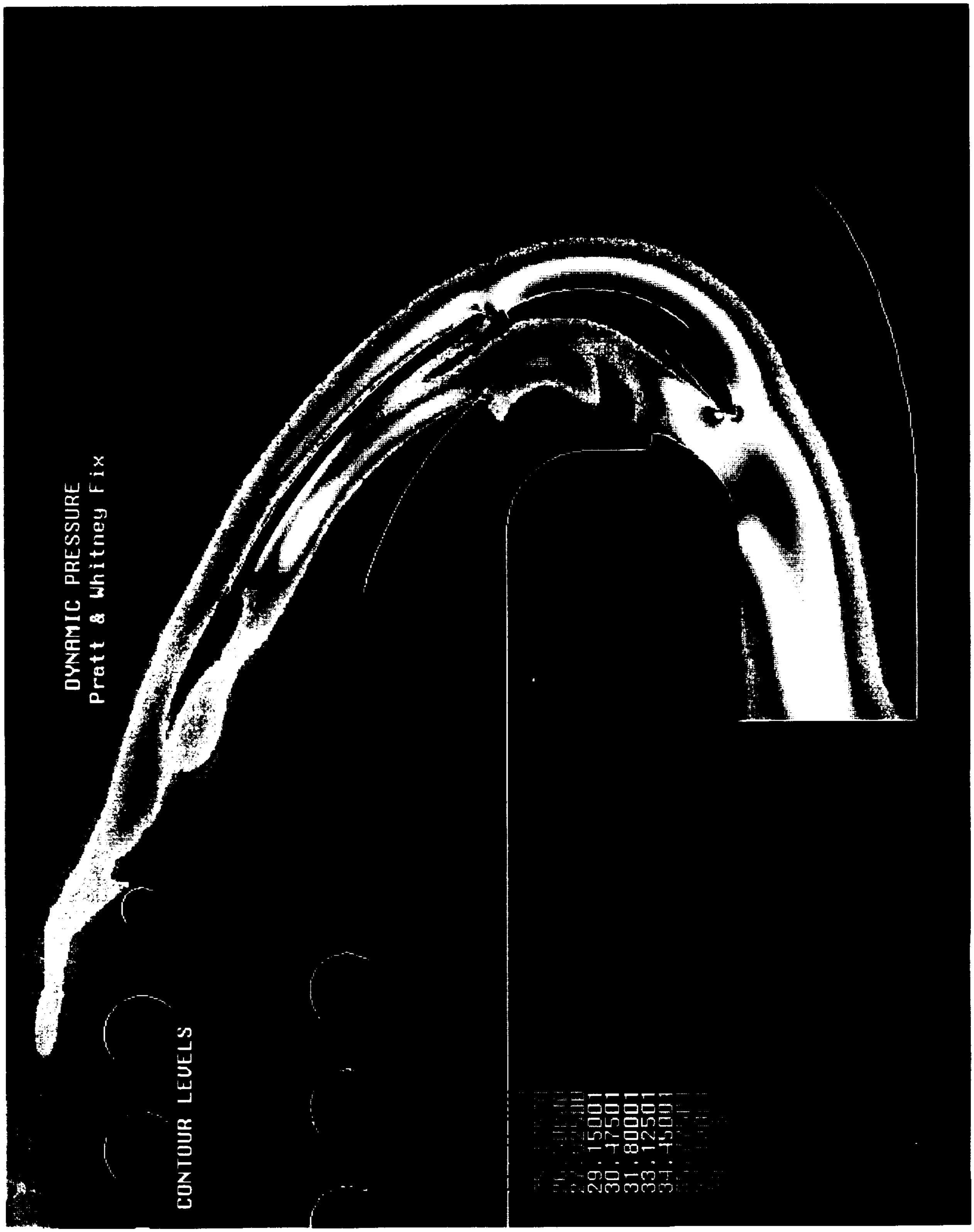
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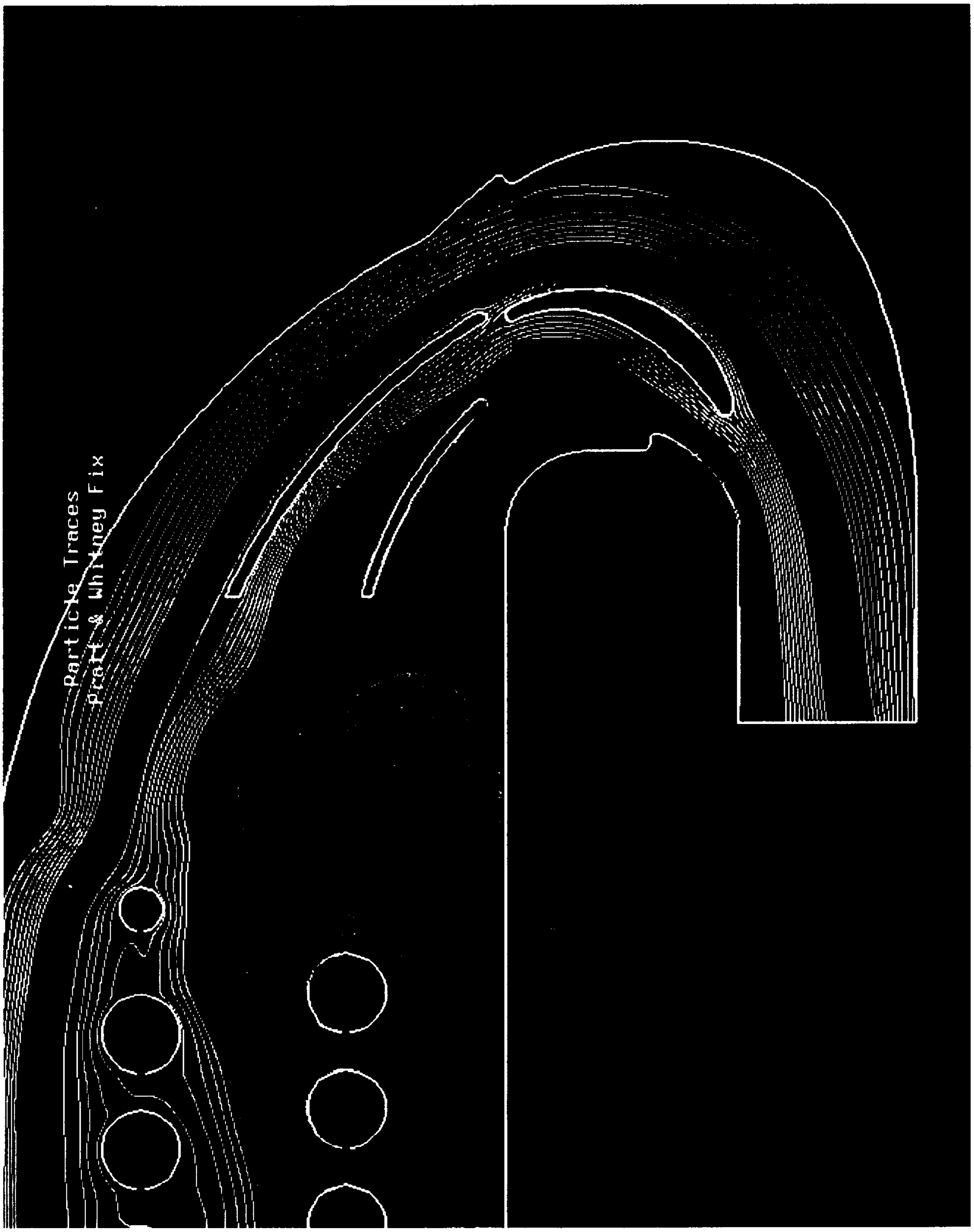
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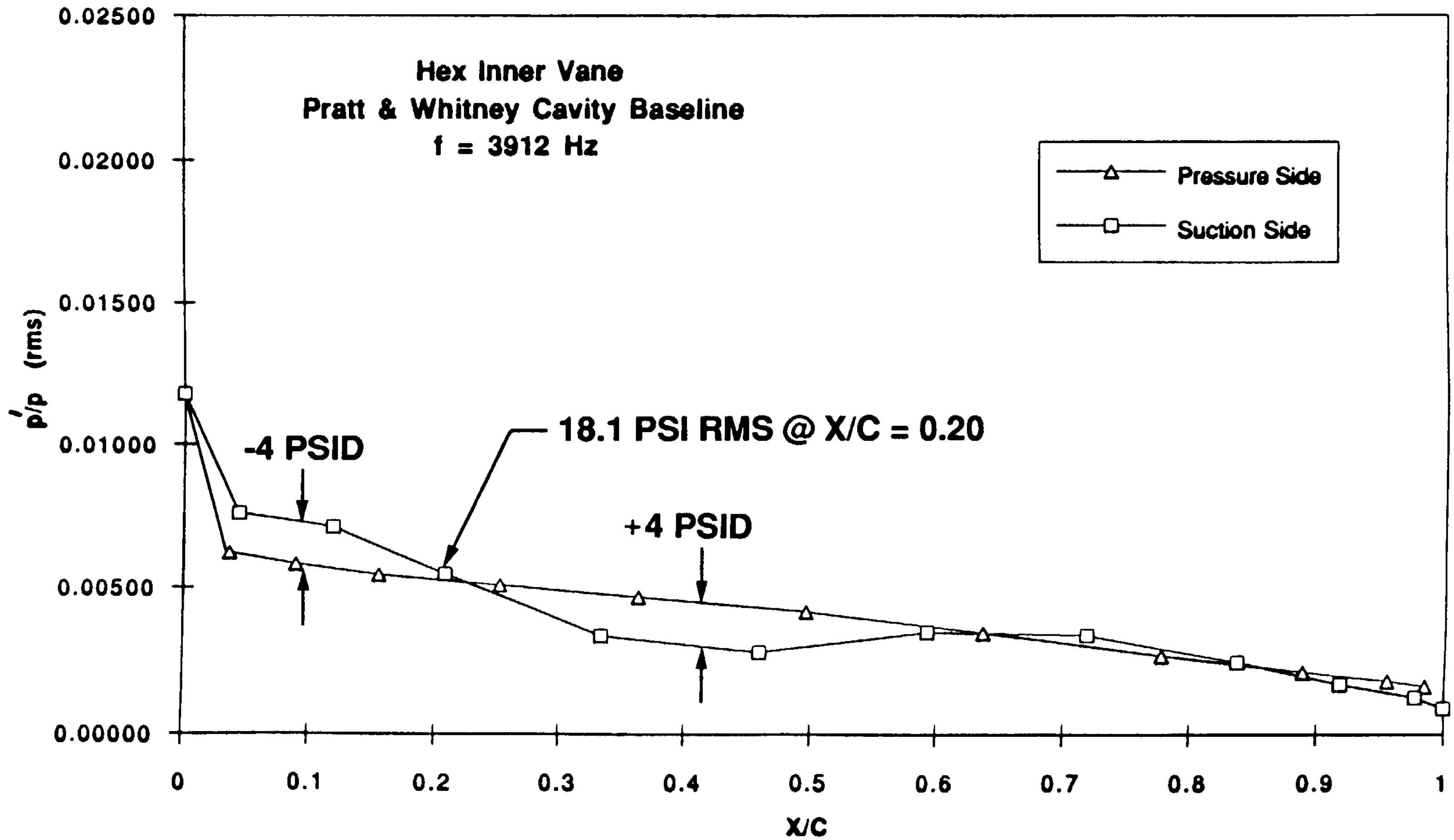
ENGINE HEX TURNING VANE CRACKING INVESTIGATION UNSTEADY CFD ANALYSIS

THE ACOUSTICALLY-TUNED P&W BASELINE WITH CAVITIES CASE GAVE ABSOLUTE AND DIFFERENTIAL LOADINGS ON THE HEX INNER VANE - - AS LARGE AS 4 PSID

P_{REF} = 3625 PSI



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ENGINE HEX TURNING VANE CRACKING INVESTIGATION
UNSTEADY CFD ANALYSIS

PRELIMINARY CONCLUSIONS

1) UNSTEADY PRESSURE DIFFERENTIAL LOADINGS WERE PRODUCED LARGE ENOUGH TO CRACK THE HEX INNER VANE IN THE BASELINE CONFIGURATION. (WITH EXCESSIVE ACOUSTIC TUNING, THEY WERE LARGE ENOUGH TO CRACK THE HEX OUTER VANE ALSO)

2) UNSTEADY PRESSURE DIFFERENTIAL LOADINGS WERE SOMEWHAT REDUCED ON THE HEX INNER VANE FOR THE "FIX" CONFIGURATION BUT THE HEX COIL ENVIRONMENT IS INCREASED

NOTE: ANALYSIS OF COMPUTATIONAL RESULTS STILL IN PROGRESS
DUE: APRIL 26, 1993