TIME-ACCURATE UNSTEADY FLOW SIMULATIONS SUPPORTING THE SRM T+68-SEC PRESSURE "SPIKE" ANOMALY INVESTIGATION (STS-54B)

by

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ABSTRACT

Time-accurate unsteady flow simulations are being performed supporting the SRM T+68-sec pressure "spike" anomaly investigation. The anomaly occurred in the RH SRM during the STS-54 flight (STS-54B) but not in the LH SRM (STS-54A) causing a momentary thrust mismatch approaching the allowable limit at that time into the flight. Full-motor internal flow simulations using the USA-2D axisymmetric code are in progress for the nominal propellant burn-back geometry and flow conditions at T+68-sec--P_C = 630 psi, γ = 1.1381, T_C = 6200 R, perfect gas without aluminum particulate. In a cooperative effort with other investigation team members, CFD-derived pressure loading on the NBR and castable inhibitors was used iteratively to obtain nominal deformed geometry of each inhibitor, and the deformed (bent back) inhibitor geometry was entered into this model. Deformed geometry was computed using structural finite-element models. A solution for the unsteady flow has been obtained for the nominal flow conditions (existing prior to the occurrence of the anomaly) showing sustained standing pressure oscillations at nominally 14.5 Hz in the motor IL acoustic mode that flight and static test data confirm to be normally present at this time. Average mass flow discharged from the nozzle was confirmed to be the nominal expected (9550 lbm/sec). The local inlet boundary condition is being perturbed at the location of the presumed reconstructed anomaly as identified by interior ballistics performance specialist team members. A time variation in local mass flow is used to simulate sudden increase in burning area due to localized propellant grain cracks. The solution will proceed to develop a pressure rise (proportional to total mass flow rate change squared). The volume-filling time constant (equivalent to 0.5 Hz) comes into play in shaping the rise rate of the developing pressure "spike" as it propagates at the speed of sound in both directions to the motor head end and nozzle. The objectives of the present analysis are to: (1) capture the dynamic responses of the motor combustion gas flow to correlate with available low-frequency (< 12.5 sample/sec) data and (2) observe the high-frequency (up to 50 Hz) characteristics of the response to determine any potentials for dynamic coupling.

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STS-54B SRM PRESSURE "SPIKE" ANOMALY INVESTIGATION

OBJECTIVE

- PERFORM TIME-ACCURATE CFD SIMULATIONS OF INTERNAL FLOW RESPONSE TO PRESSURE "SPIKE" ANOMALY ASSUMED TO BE CAUSED BY ALUMINUM OXIDE SLAG EJECTION THROUGH THE NOZZLE TO:

  1) CAPTURE DYNAMIC RESPONSES FOR CORRELATION WITH AVAILABLE 12.5 SAMPLE/SEC FLIGHT DATA, AND

  2) OBSERVE HIGH-FREQUENCY (UP TO 50 HZ) CHARACTERISTICS OF THE RESPONSE TO DETERMINE ANY POTENTIALS FOR DYNAMIC COUPLING

STS-54B SRM PRESSURE "SPIKE" ANOMALY INVESTIGATION

APPROACH

- DEVELOP THE UNSTEADY SOLUTION FOR THE MOTOR/NOZZLE FLOW AT T + 67 SEC
  - BENT-OVER INHIBITORS
- SIMULATE NOZZLE BLOCKAGE OF 39 IN^2 AT THROAT FOR"SPIKE" ANOMALY SCENARIO INITIATION
  - SUDDENLY APPLIED
  - REDUCED SMOOTH NOZZLE CONTOUR (LESS FLOW AREA WITHOUT EXTRANEOUS SHOCKS)
- COMPUTE MOTOR INTERNAL FLOW TRANSIENT UNTIL PEAK PRESSURE REACHED
  - OBSERVE CHARACTERISTICS
- RETURN NOZZLE GEOMETRY TO UNBLOCKED CONFIGURATION
  - BLOCKAGE SUDDENLY REMOVED
- COMPUTE MOTOR INTERNAL FLOW TRANSIENT TO RECOVERY

TIME-ACCURATE CFD ANALYSIS OF RSRM Pc ANOMALY T + 68 SEC

BASIC ASSUMPTIONS:

- PERFECT GAS
- ADIABATIC WALL
- NEGLECTS DAMPING FROM ALUMINUM PARTICULATE
- AXISYMMETRIC FLOW

SIMULATION/ANALYSIS TOOL:

- TIME-ACCURATE USA CODE (DEVELOPED BY ROCKWELL)
- CURRENTLY IN USE BY ED33 FOR RSRM AND ASRM VORTEX SHEDDING/ACOUSTIC INTERACTION STUDIES
- OUTPUTS PLOT 3D FILES IN MSFC STANDARDIZED FORMATS

MODELING APPROACH

BENEFITS

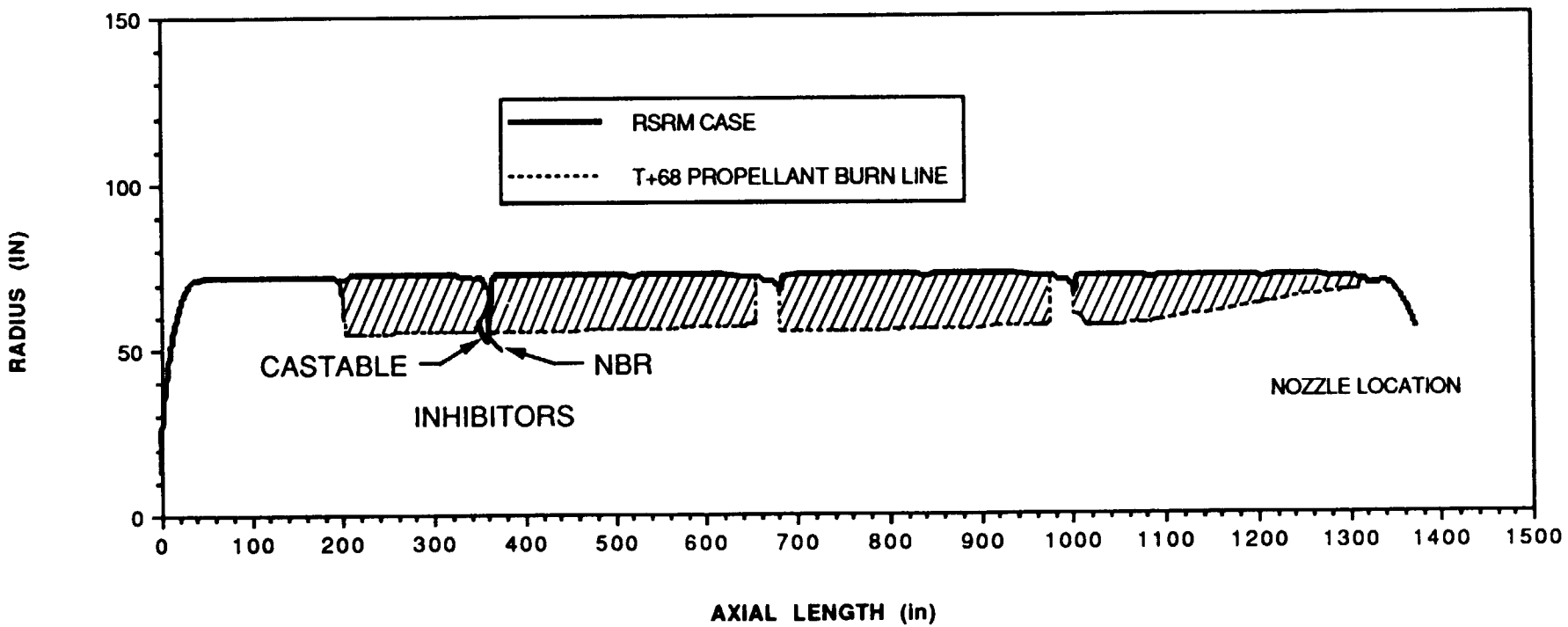
- CAN SHOW POTENTIALS FOR UNSTEADY BEHAVIOR
  - MOTOR ACOUSTIC MODE RESPONSE, INHIBITOR VORTEX SHEDDING, INHIBITOR DYNAMIC PRESSURE DIFFERENTIAL LOADING, MOTOR VOLUME-FILLING TIME CONSTANT, NOZZLE STAGNATION POINT MOVEMENT
- MATCHES 2D STEADY-FLOW CFD (MEAN VALUES)
  - PRESSURE, VELOCITY PROFILES, CALCULATED THRUST BEFORE THE "SPIKE"
- PROVIDES PRESSURE-VS-TIME TRANSIENT OVER FULL MOTOR LENGTH FOR SIMULATED "SPIKE" ANOMALY

AREAS FOR IMPROVEMENT

- REDUCE AFT DOME VOLUME GAS FILLING VOLUME BY THE VOLUME OF SLAG ACCUMULATION, ADD SLOSH MOTION DYNAMICS FOR THE POOLING SLAG
- DEVELOP 2-PHASE, TIME-DEPENDENT MODEL FOR AGGLOMERATED SLAG FLOW THROUGH THE NOZZLE TO INCLUDE SLAG MOMENTUM THRUST INCREMENT

TIME-ACCURATE CFD ANALYSIS OF RSRM Pc ANOMALY T +68 SEC

POSTULATED INTERNAL GEOMETRY AND SIMULATION CONDITIONS FOR RSRM @ T + 68 SEC

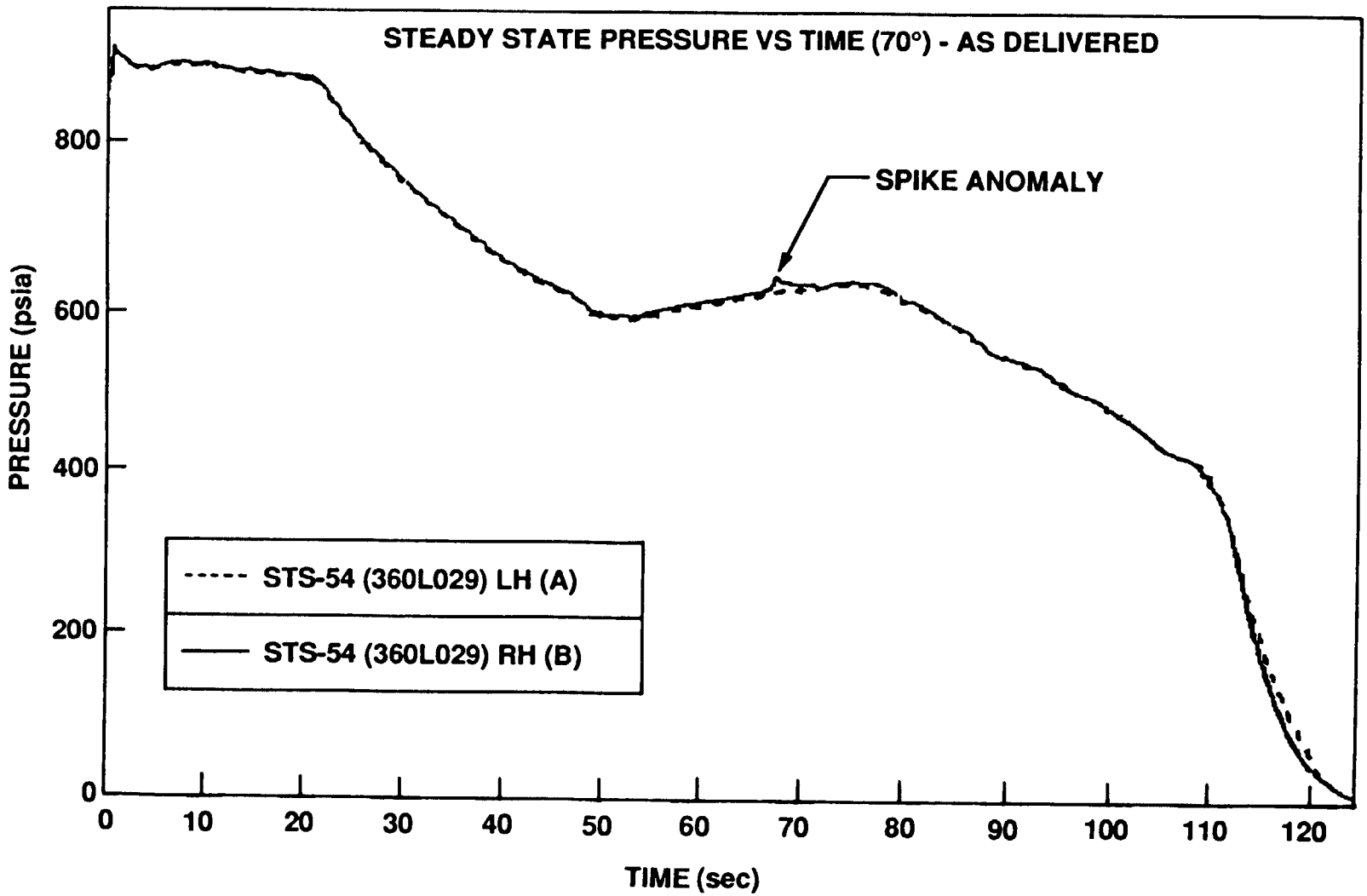


GAMMA 1.1381 (W/OUT ALUMINUM PARTICULATE)
PRESSURE 629.7 PSI
TEMP 3444.5 K (6200 R)

PERFECT GAS
SPEED OF SOUND 3493 FT/SEC
DENSITY (GAS) 1.575E-04 LB/IN^3

STS-54 RH PRESSURE PERTURBATION INVESTIGATION

STEADY STATE PRESSURE VS TIME (70°)



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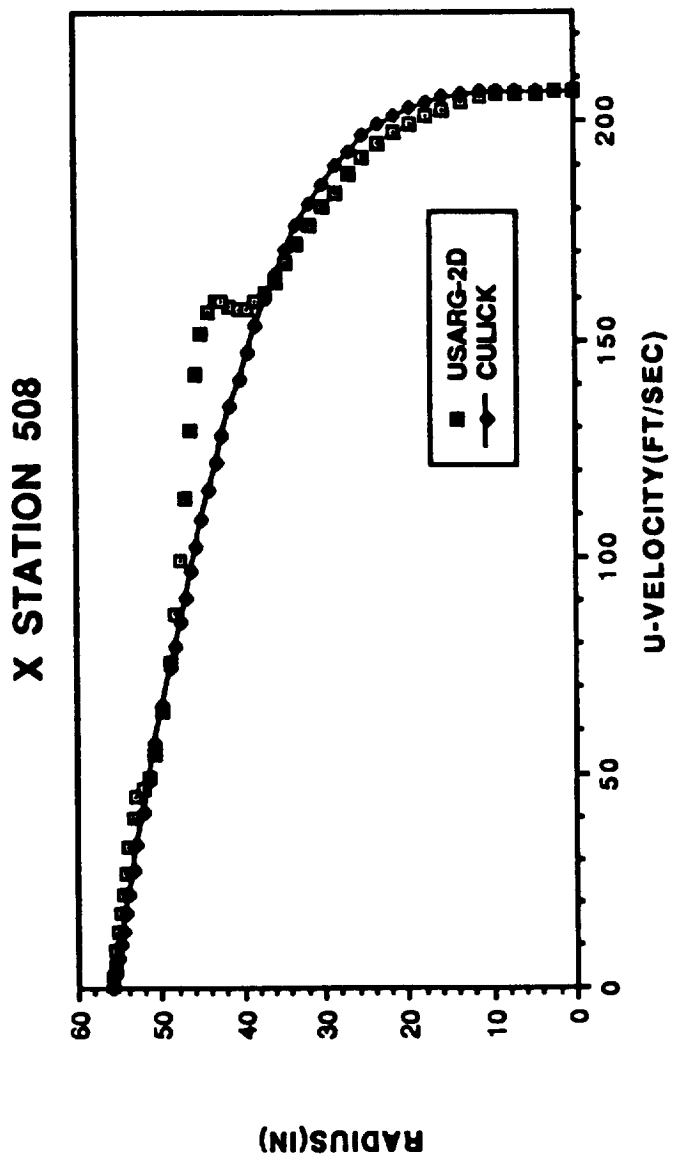
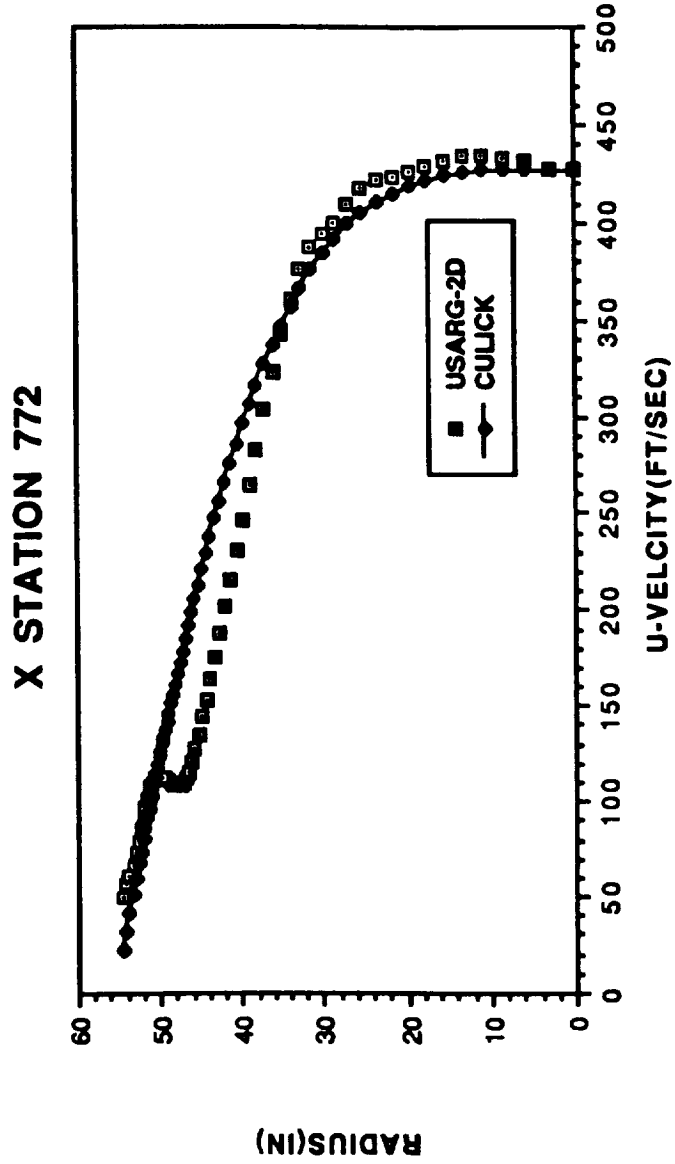
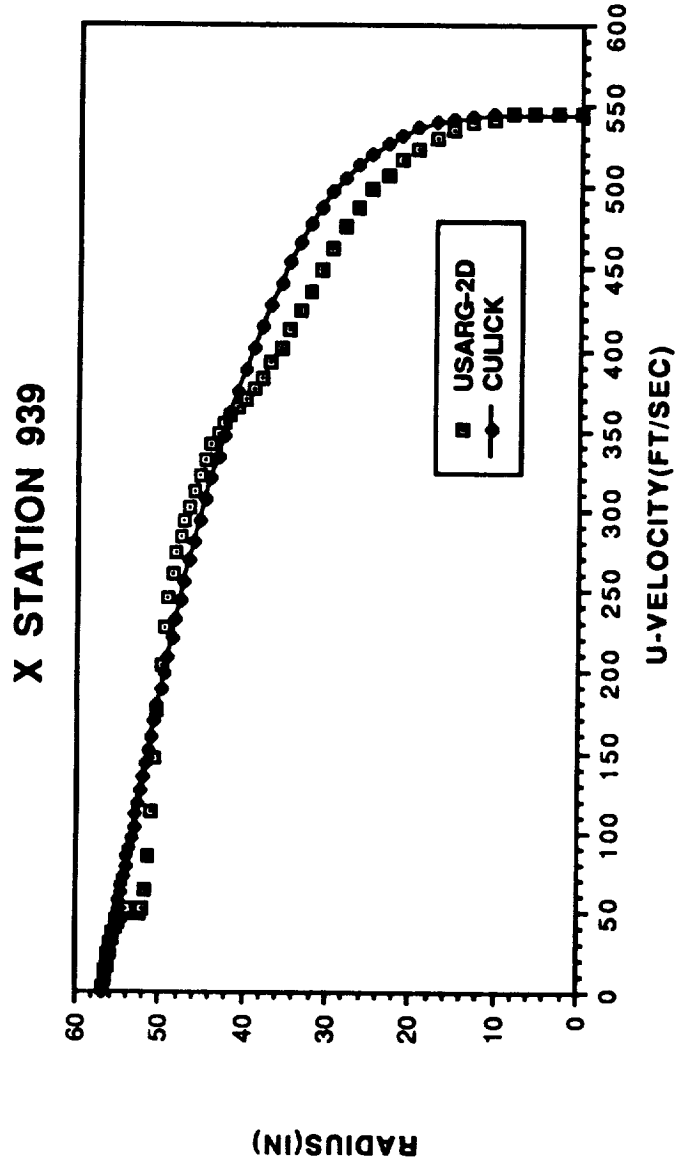

X STATION 508
USARG-2D
CULICK
U-VELOCITY(FT/SEC)
RADIUS(IN)
0
50
100
150
200
10
20
30
40
60


X STATION 772
USARG-2D
CULICK
U-VELCITY(FT/SEC)
RADIUS(IN)
0
50
100
150
200
250
300
350
400
450
500
10
20
30
40
60


X STATION 939
USARG-2D
CULICK
U-VELOCITY(FT/SEC)
RADIUS(IN)
0
50
100
150
200
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350
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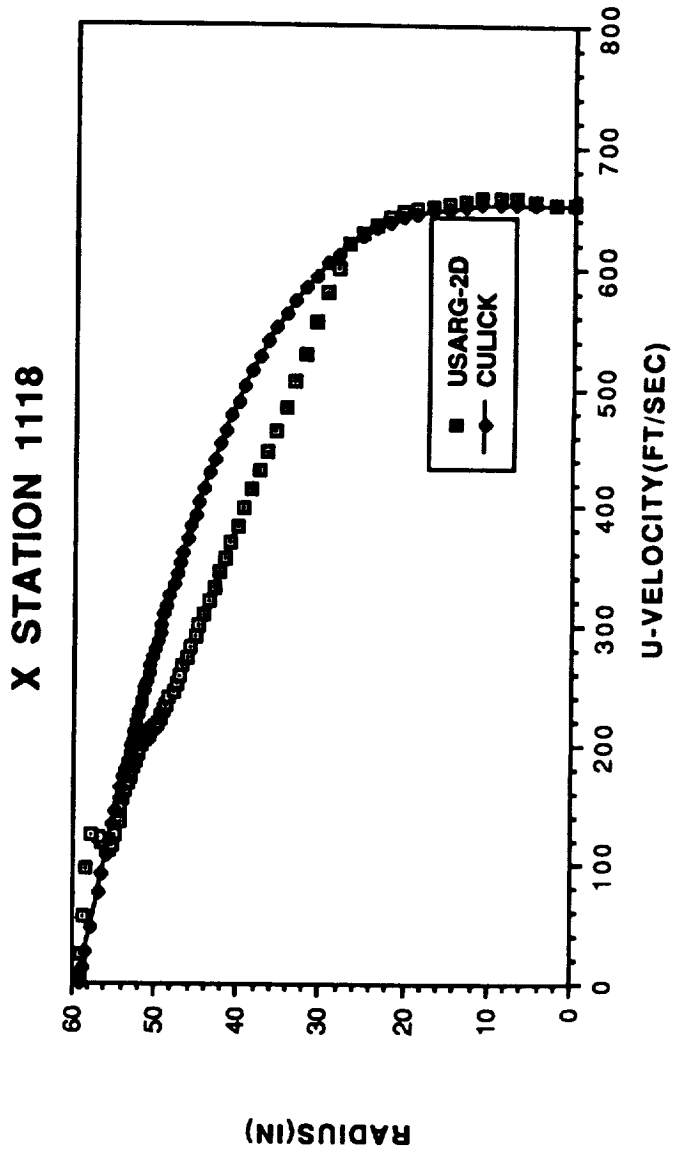
450
500
550
600
10
20
30
40
50
60


X STATION 1118
USARG-2D
CULICK
U-VELOCITY(FT/SEC)
RADIUS(IN)
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300
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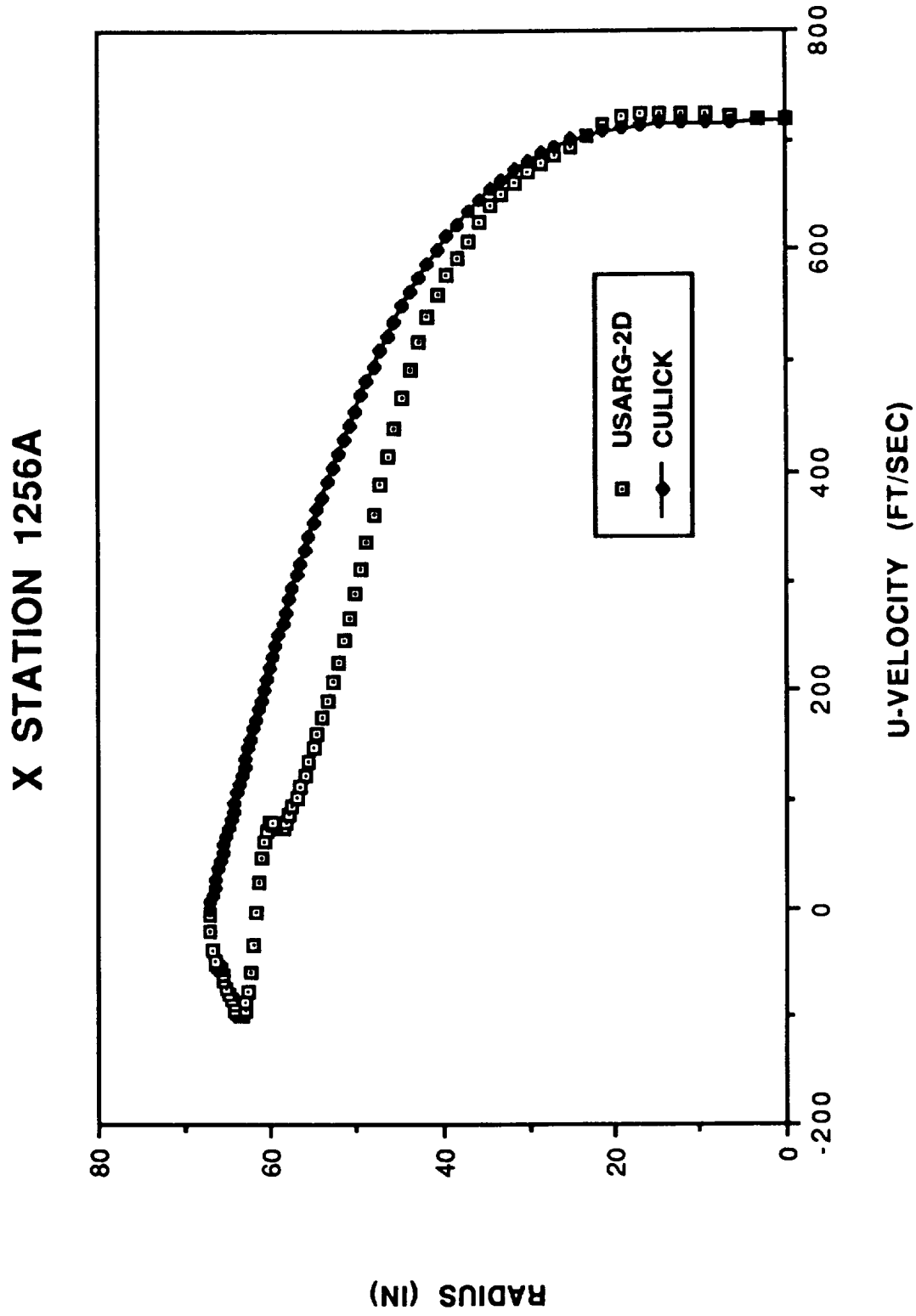
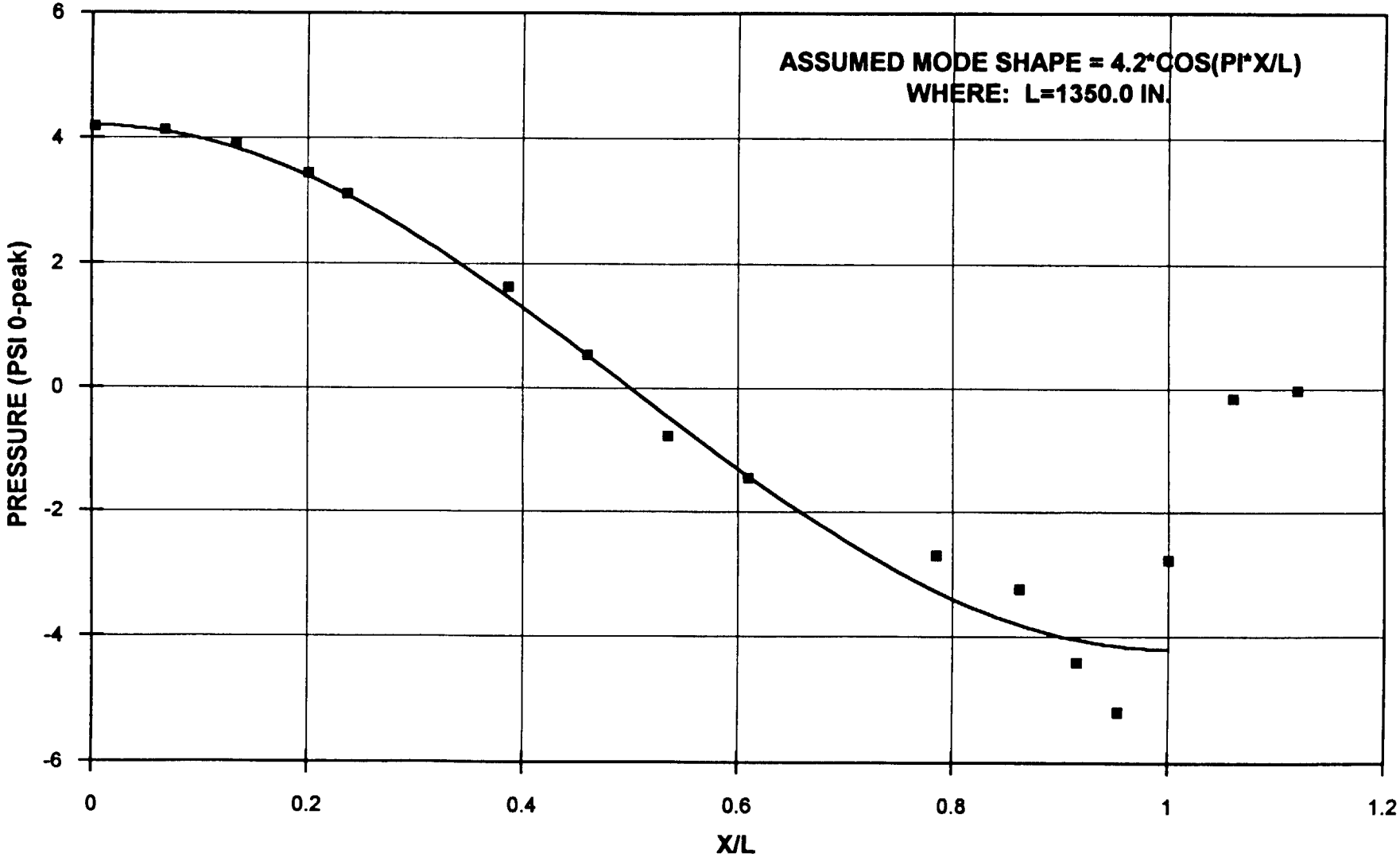
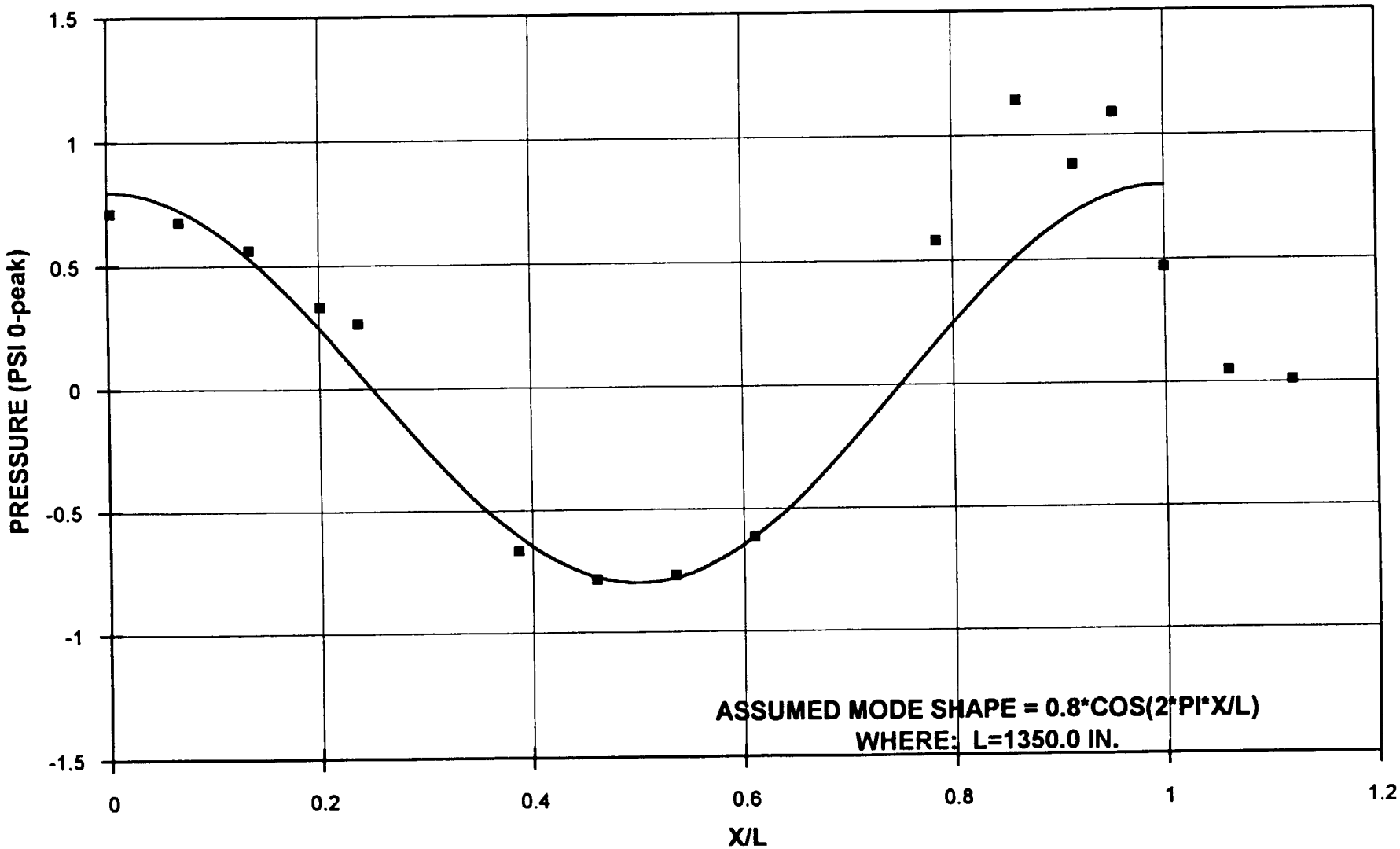
500
600
700
800
10
20
30
40
50
60


X STATION 1256A
USARG-2D
CULICK
RADIUS (IN)
U-VELOCITY (FT/SEC)
0
20
40
60
80
-200
0
200
400
600
800

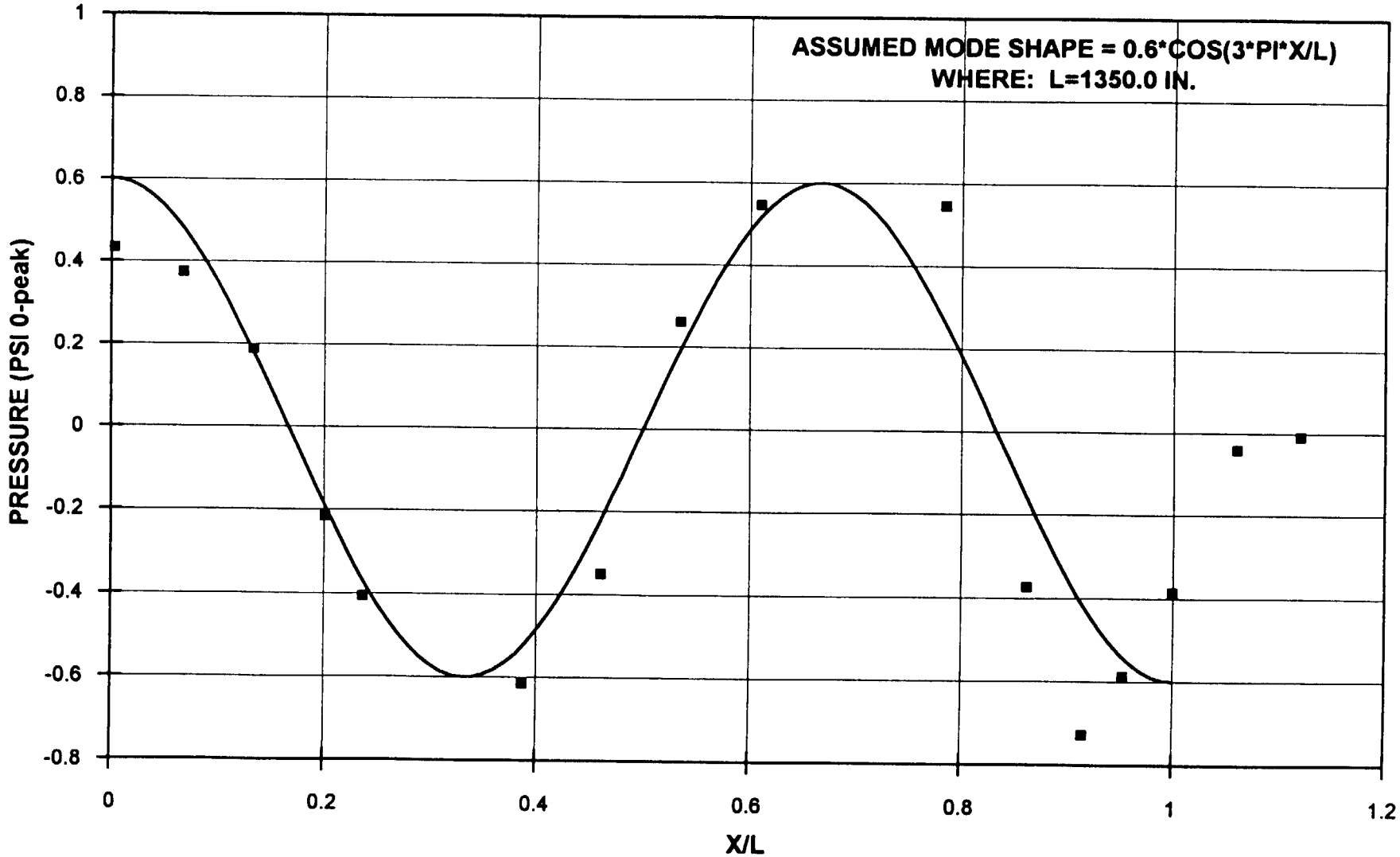
RSRM T+68 CFD SIMULATION
1ST LONGITUDINAL MODE (13.3 Hz)

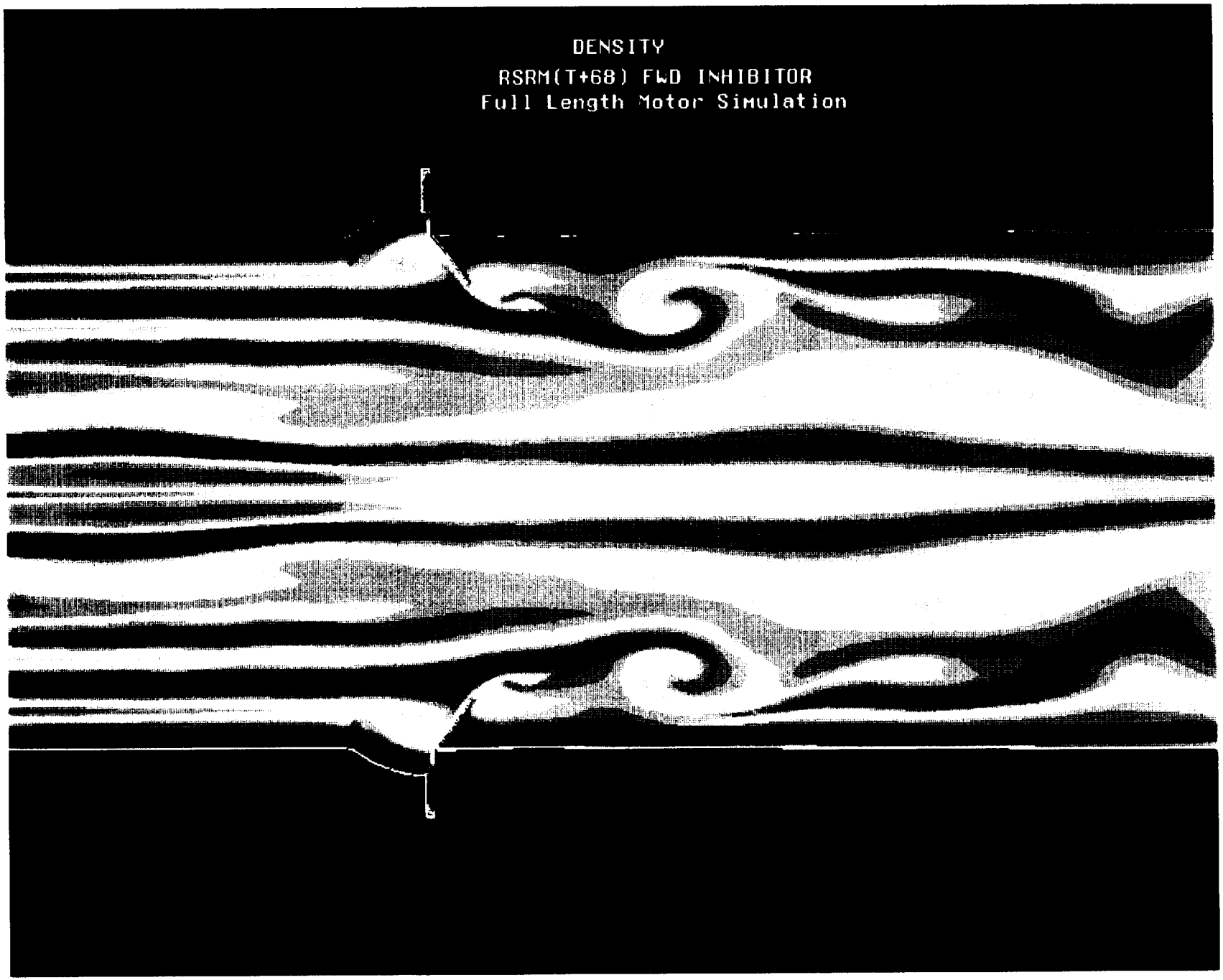


RSRM T+68 CFD SIMULATION
2ND LONGITUDINAL MODE (29.6 Hz)



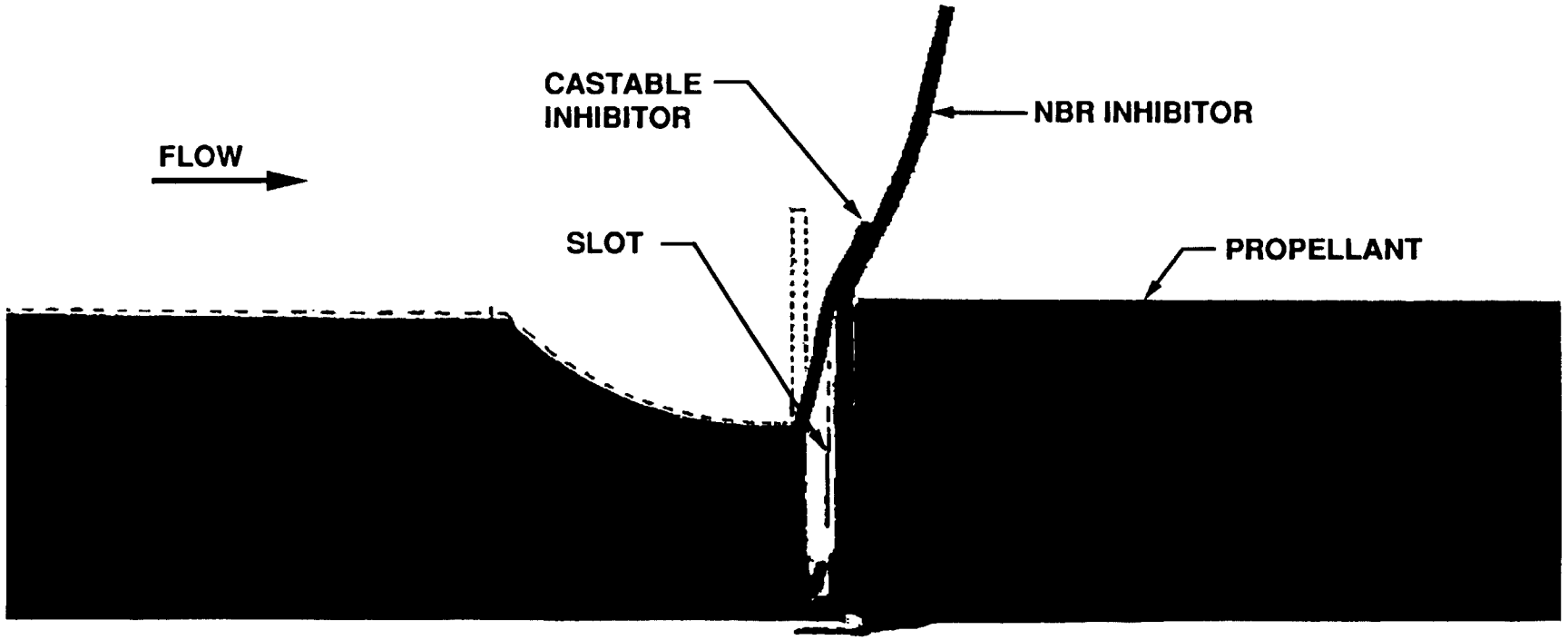
RSRM T+68 CFD SIMULATION
3RD LONGITUDINAL MODE (43.6 Hz)




DENSITY
RSRM(T+68) FWD INHIBITOR
Full Length Motor Simulation

STS-54 RH PRESSURE PERTURBATION INVESTIGATION

CASTABLE INHIBITOR AND NBR INHIBITOR CONTACT



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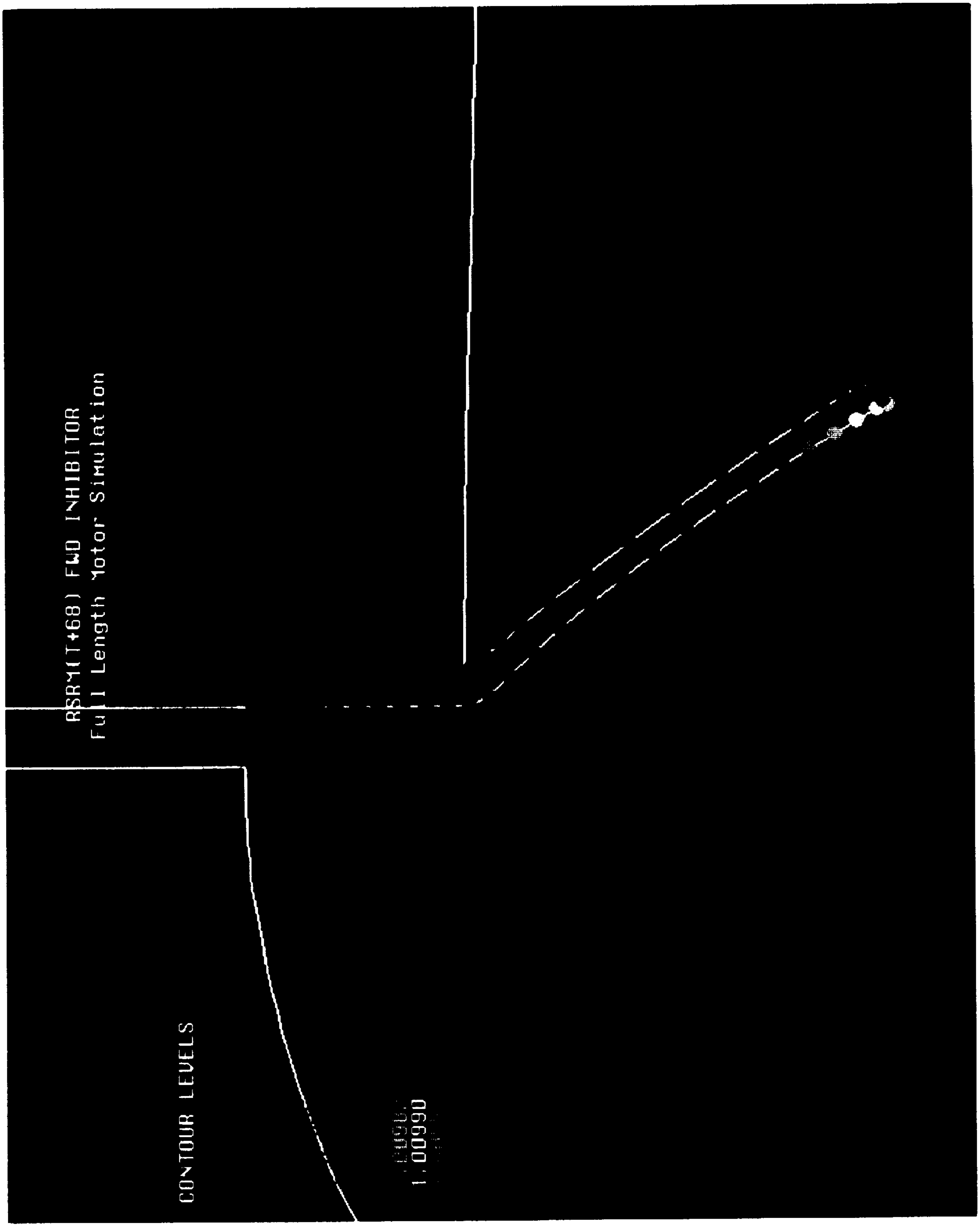
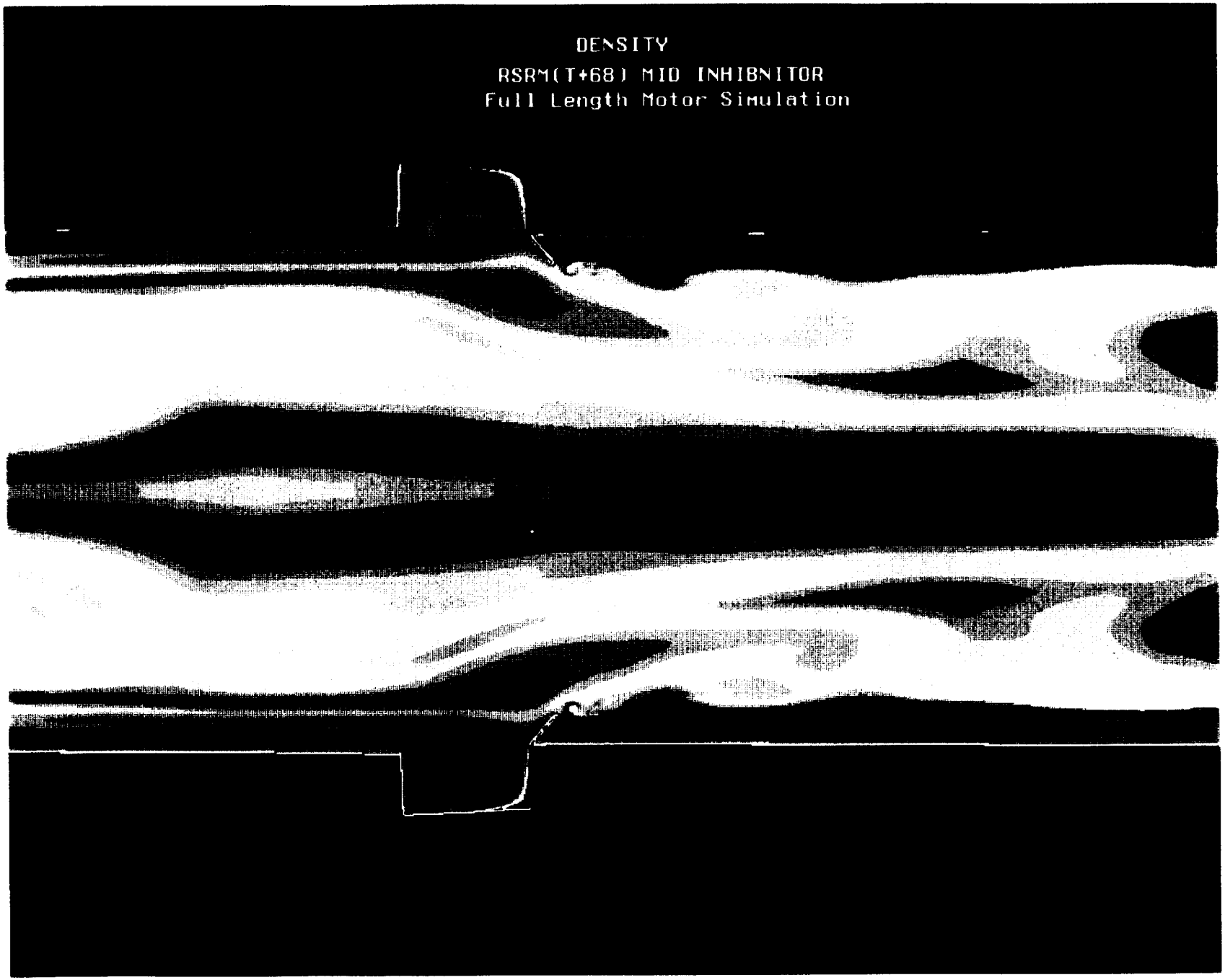
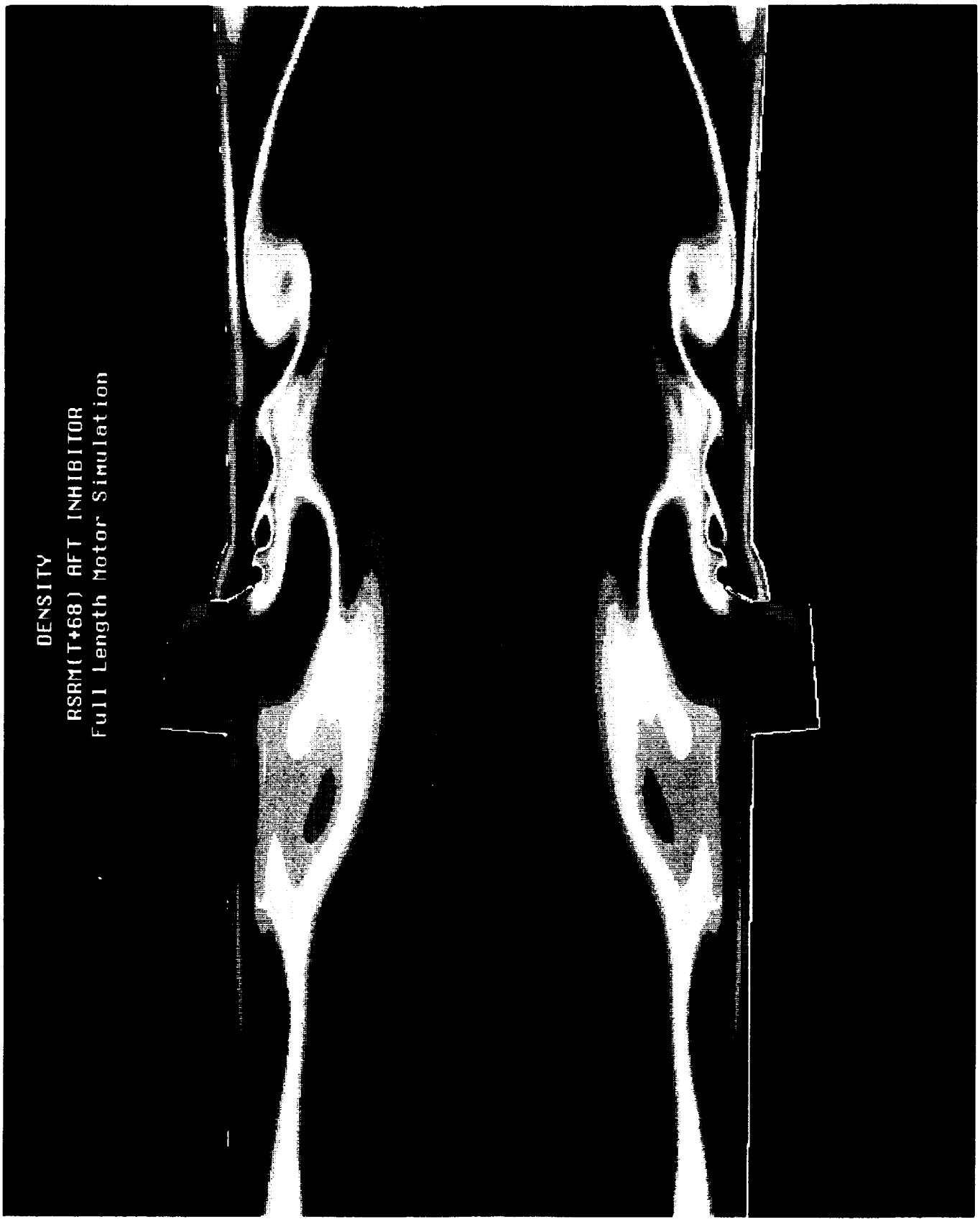
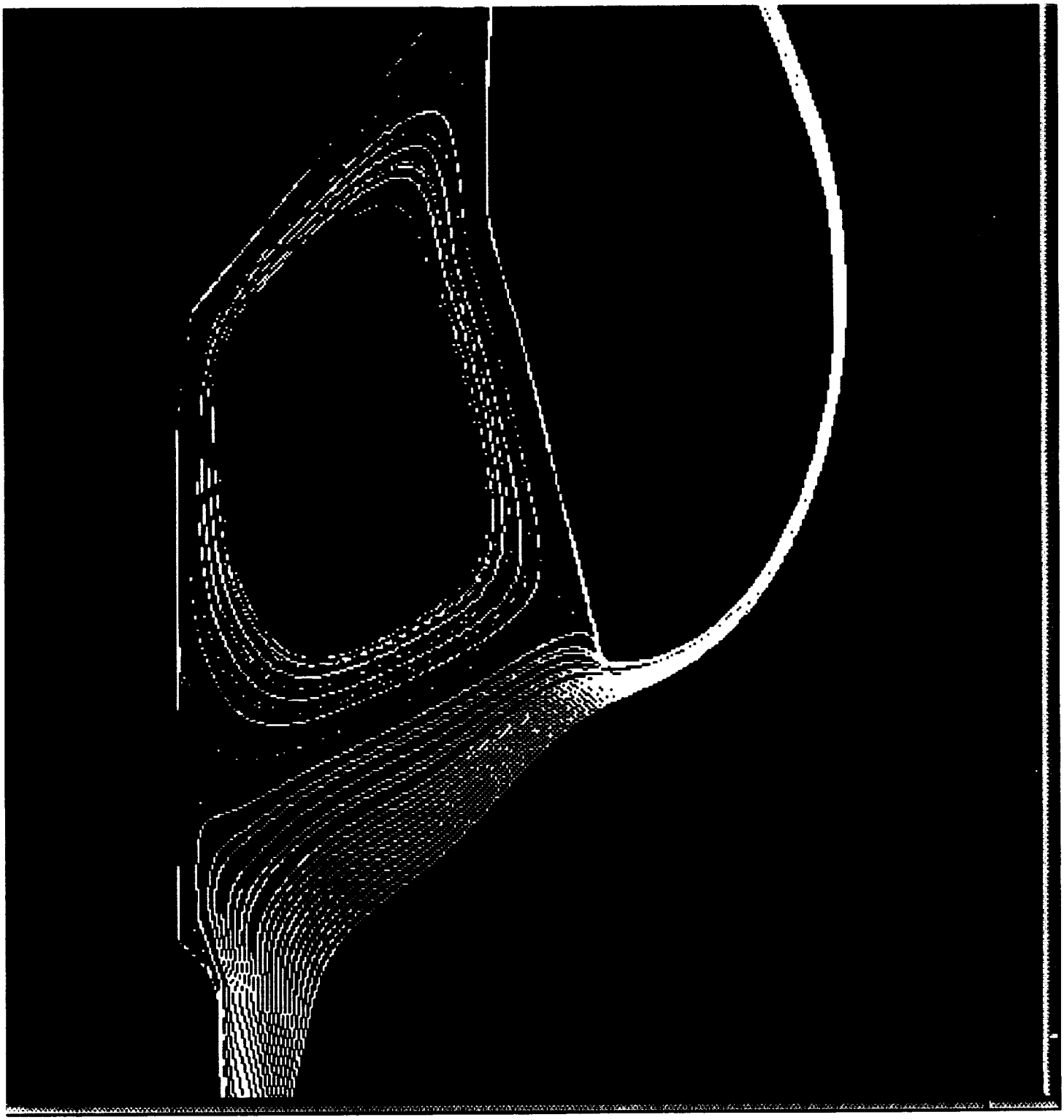
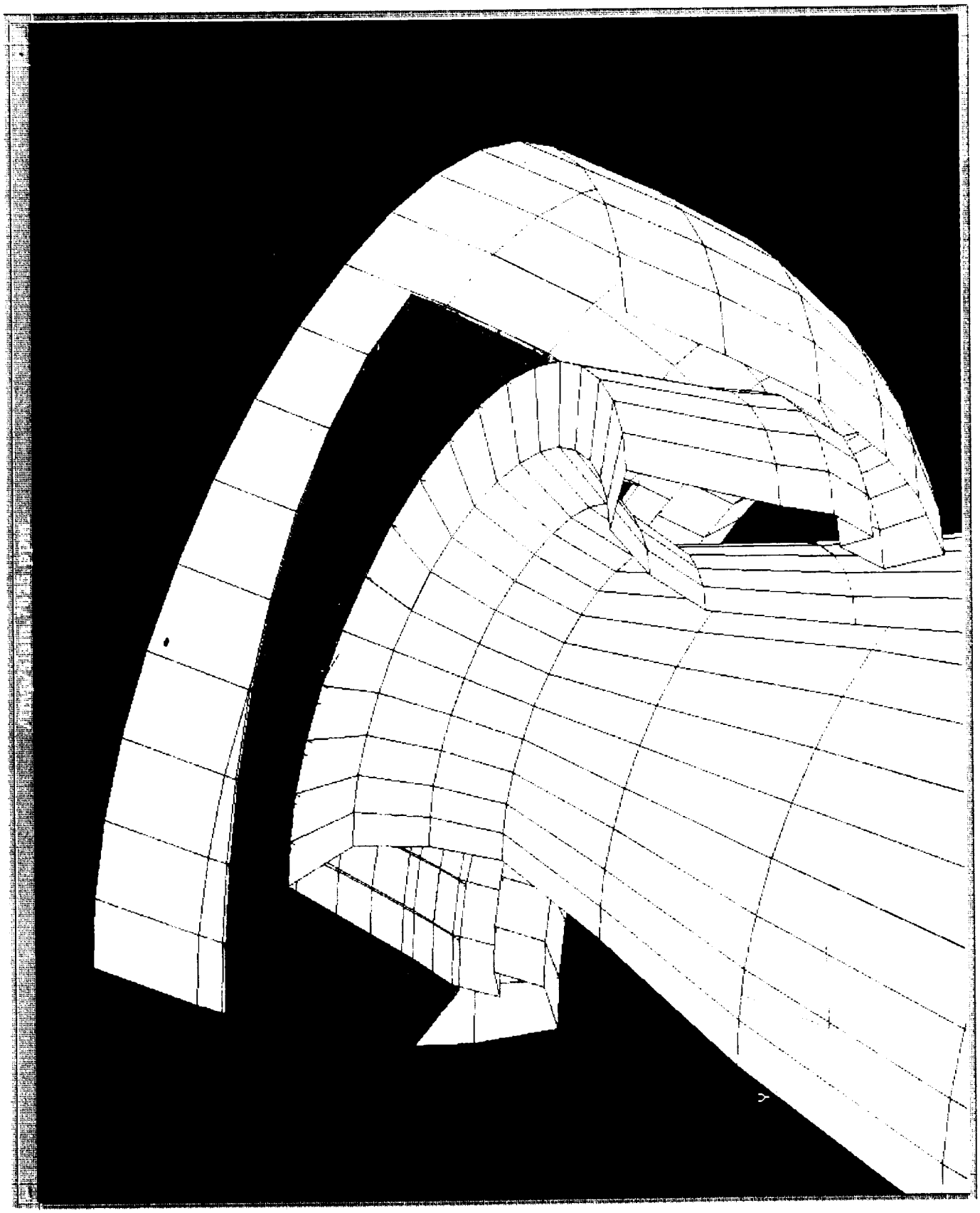
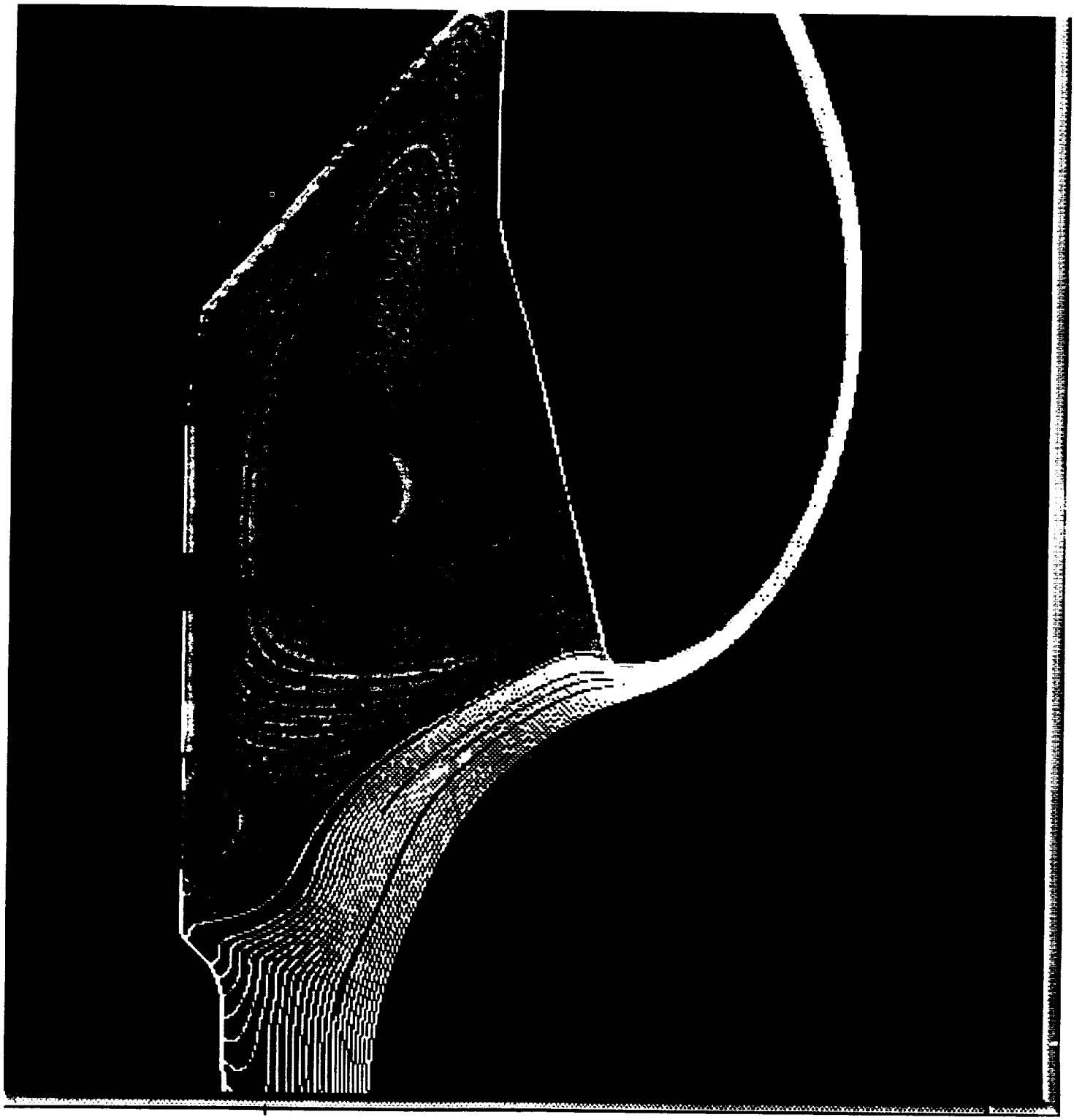


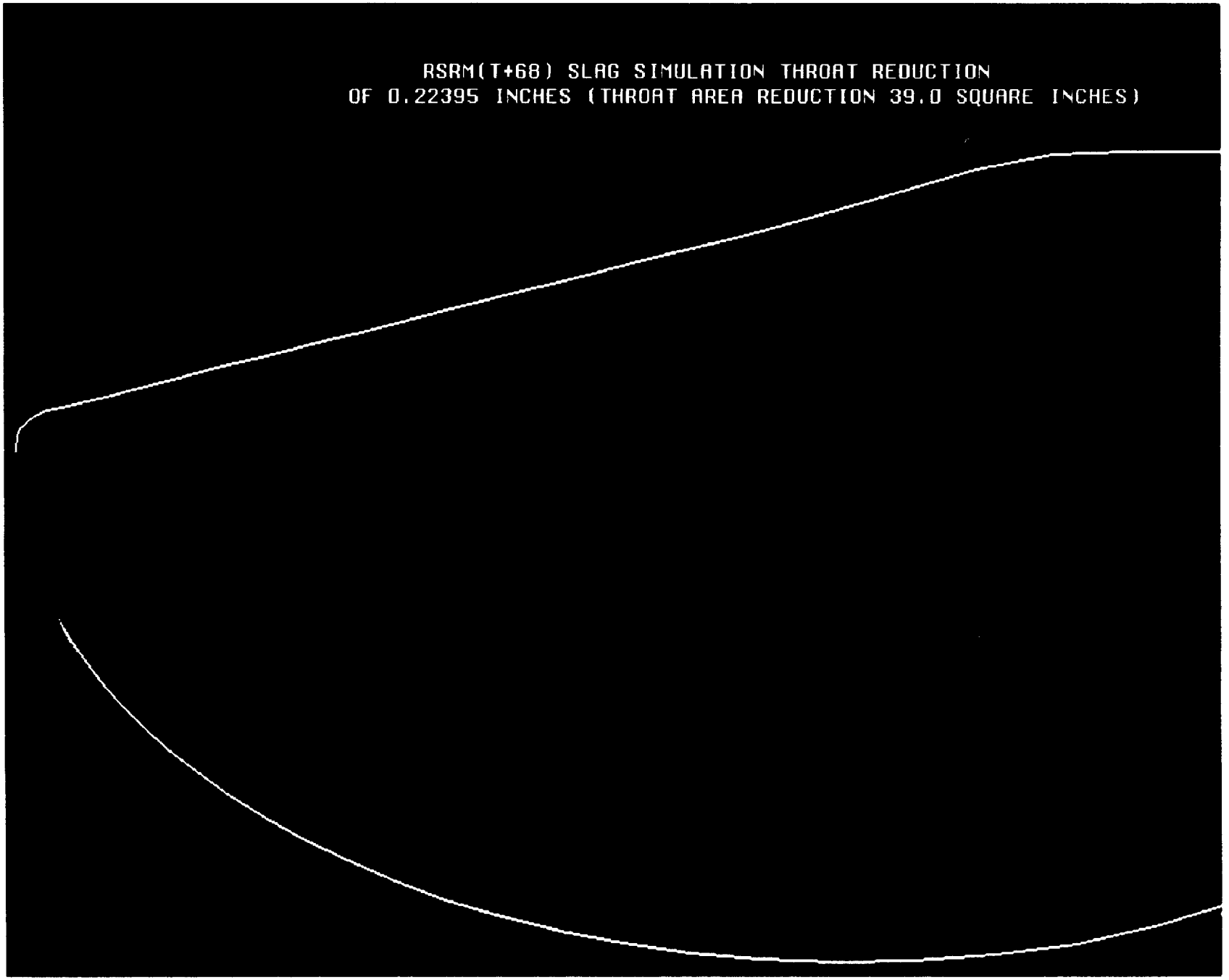

DENSITY
RSRM(T+68) MID INHIBNITOR
Full Length Motor Simulation


DENSITY
RSRM(T+68) AFT INHIBITOR
Full Length Motor Simulation







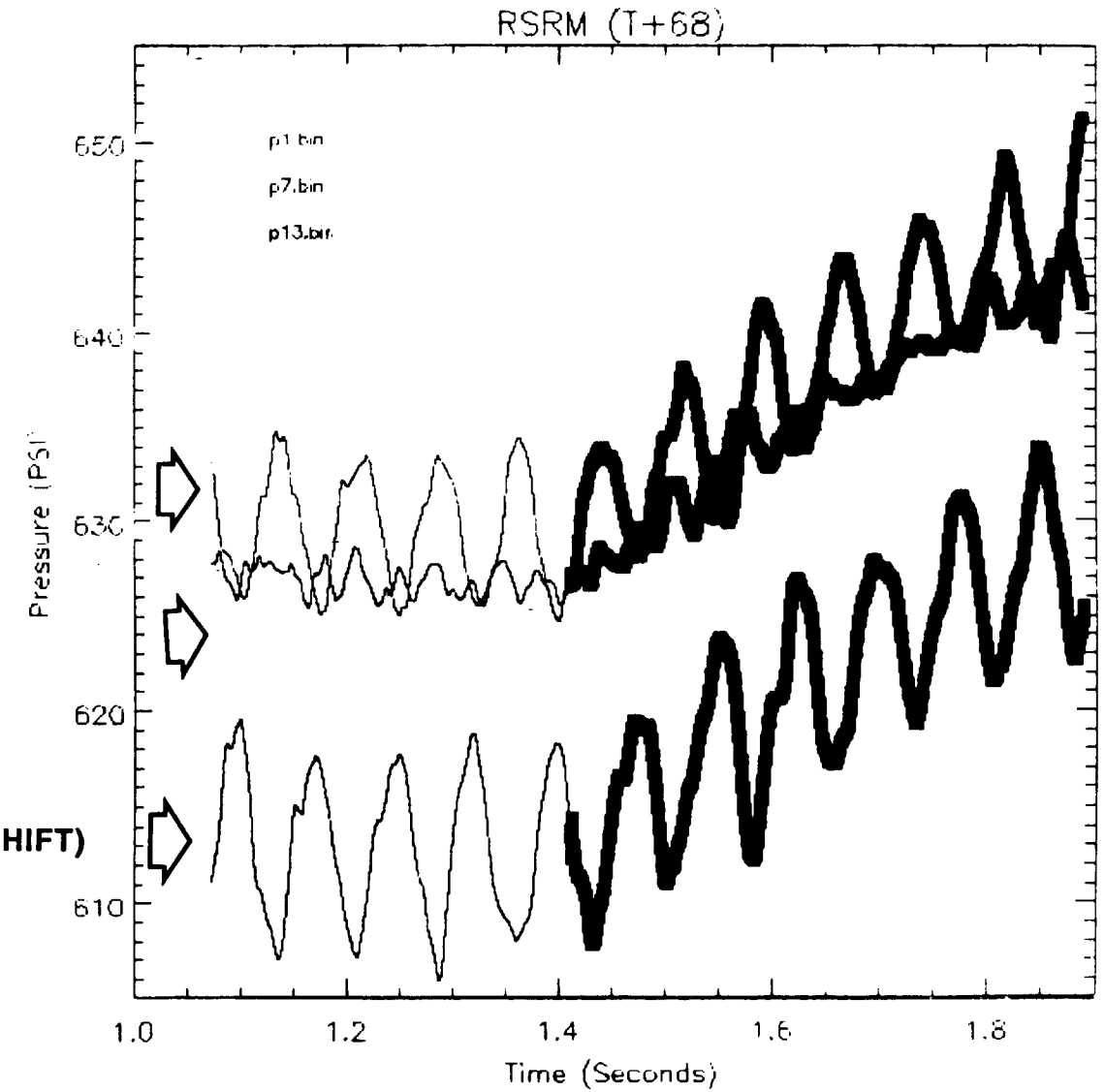

RSRM(T+68) SLAG SIMULATION THROAT REDUCTION
OF 0.22395 INCHES (THROAT AREA REDUCTION 39.0 SQUARE INCHES)

Rockwell International
Space Systems Division

TIME-ACCURATE CFD ANALYSIS OF RSRM Pc ANOMALY T + 68 SEC

Huntsville Operations

MOTOR RESPONSE TO SUDDEN 39 IN^2 THROAT AREA REDUCTION



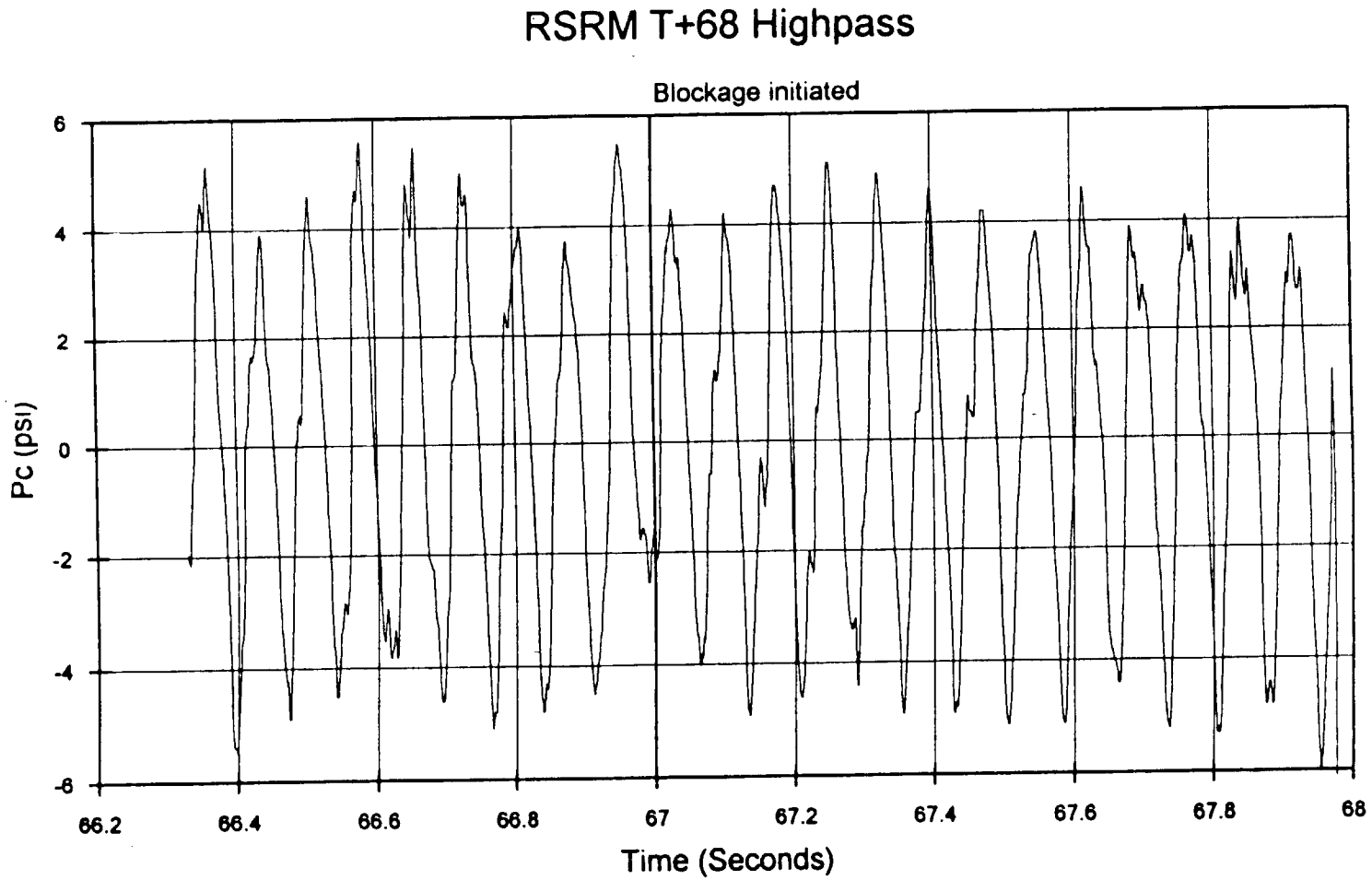
HEAD END

MIDDLE (NODE)

NOZZLE END (180 DEG PHASE SHIFT)

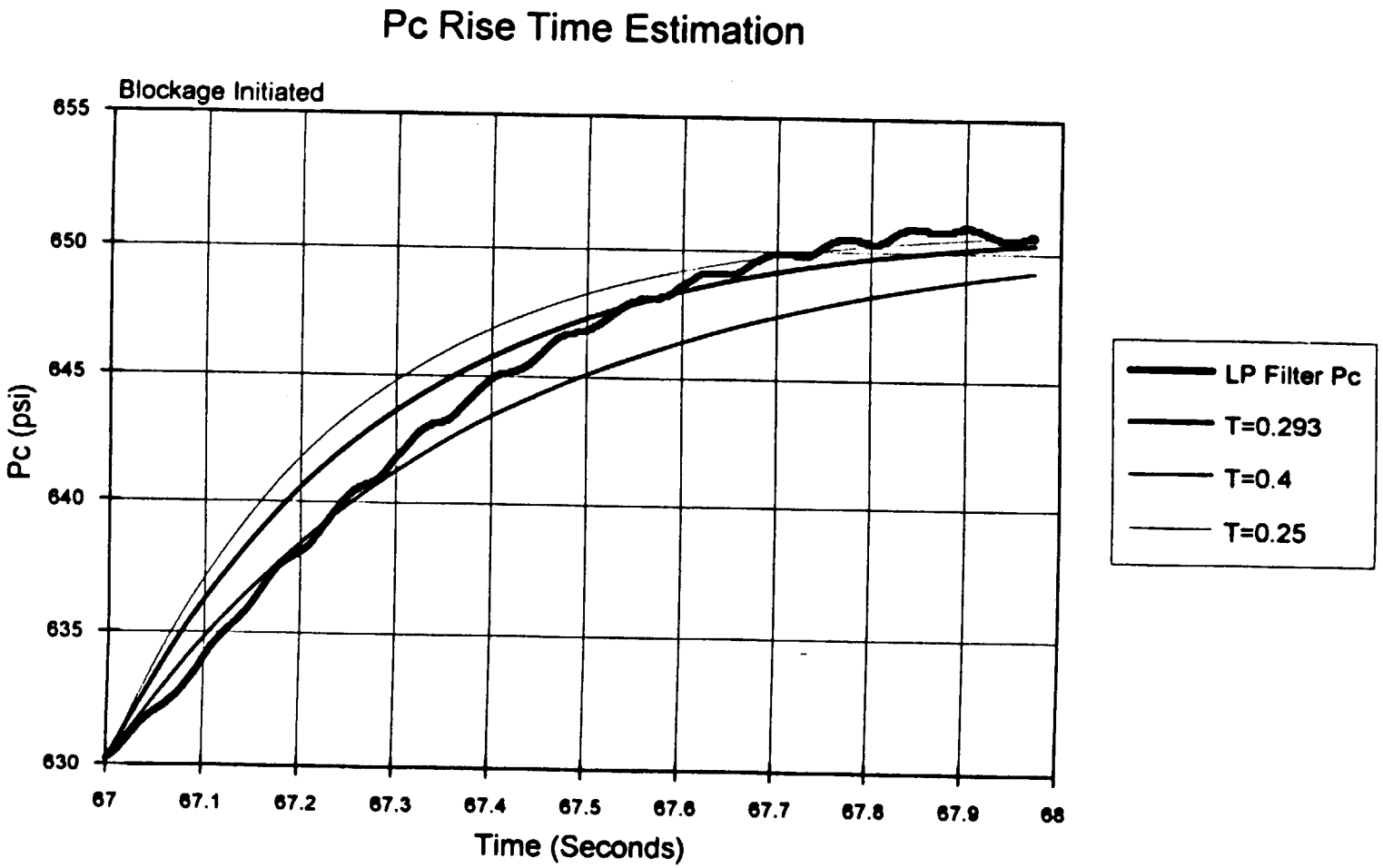
TIME-ACCURATE CFD ANALYSIS OF RSRM Pc ANOMALY T + 68 SEC

HIGH-PASS FILTERED HEAD END PRESSURE SHOWS ESSENTIALLY NO CHANGE IN LONGITUDINAL ACOUSTIC OSCILLATIONS AFTER BLOCKAGE IS INITIATED



TIME-ACCURATE CFD ANALYSIS OF RSRM Pc ANOMALY T + 68 SEC

LOW-PASS FILTERED HEAD END PRESSURE RISE SHOWS CRITICALLY DAMPED RESPONSE (NO OVERSHOOT) AND T=0.293



STS-54B SRM PRESSURE "SPIKE" ANOMALY INVESTIGATION

CONCLUSIONS

- FOR SUDDEN NOZZLE AREA REDUCTION, THEN RETURN TO NORMAL, WITH INHIBITOR AND SLAG POOLING GEOMETRY FIXED THERE IS NO APPARENT COUPLING WITH THE MOTOR 1L, 2L, OR 3L ACOUSTIC MODES IN THE "SPIKE" TRANSIENT

- THE "SPIKE" REACHES AN ASYMPTOTIC MAXIMUM PRESSURE AT THE HEAD END MEASUREMENT LOCATION IN 800 MSEC WITH A 300 MSEC TIME CONSTANT AND NO OVERSHOOT
  - GAS VOLUME-FILLING TIME

- FLIGHT ACCELERATION LOADS AND LARGE NOZZLE GIMBAL (>4.5 DEG) EFFECTS CAN BE ADDED FOR SIMULATING
  - SLAG SLOSHING MOTION DYNAMIC EFFECT
  - 3-D SLAG MIGRATION AS THE NOZZLE INLET MOVES DURING LARGE GIMBAL