Fluctuating Pressure Analysis of a 2-D SSME Nozzle Air Flow Test

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Abstract

To better understand the SSME startup/shutdown transients, an airflow test of a 2-D nozzle was conducted at MSFC's Trisonic wind tunnel. Photographic and other instrumentation show during a SSME start large nozzle shell distortions occur as the Mach disk is passing through the nozzle. During the earlier development of the SSME, this startup transient resulted in a low cycle fatigue failure of one of the LH_2 feedlines. The 2-D SSME nozzle test was designed to measure the static and fluctuating pressure environment and color schlieren video during the startup and shutdown phases of the run profile.

The model consisted of two identical blocks having the same inner contour of the SSME nozzle. The sides of the nozzle were made of glass for schlieren photography. The upper block was instrumented for static pressure measurements. The lower block was instrumented with thirteen Entron fluctuating pressure transducers. Steady state and slow sweep flows were tested for three back pressure conditions (0.5-2.0 psi, 7 psi, 14 psi.) The static pressure data was acquired by a scanning pressure system. The fluctuating pressure data was recorded onto a VHS analog tape recorder. The video, static pressure, and fluctuating pressure data were time synchronized for data correlation.

The shlieren video clearly shows a lambda (λ) shock foot moving down the throat during the slow sweep. The fluctuating pressure RMS time histories show the levels increase as the downstream foot of the lambda shock approaches. When the shock foot is directly above the transducer, levels decrease about 50%. When the upstream leg of the lambda shock approaches the transducer the level quickly jumps up to twice the downstream leg values. After the upstream leg of the lambda shock passes the transducer, the level falls down to the noise floor of the measurement.

Schlieren video, model configuration, fluctuating pressure time histories, power spectrum densities of the test will be shown. Future 2-D nozzle tests and plans for a 3-D nozzle facility will be addressed.

Fluctuating Pressure Analysis of a 2-D Space Shuttle Main Engine (SSME) Nozzle Air Flow Test

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Workshop for Computational Fluid Dynamic Applications
in Rocket Propulsion and Launch Vehicle Technology
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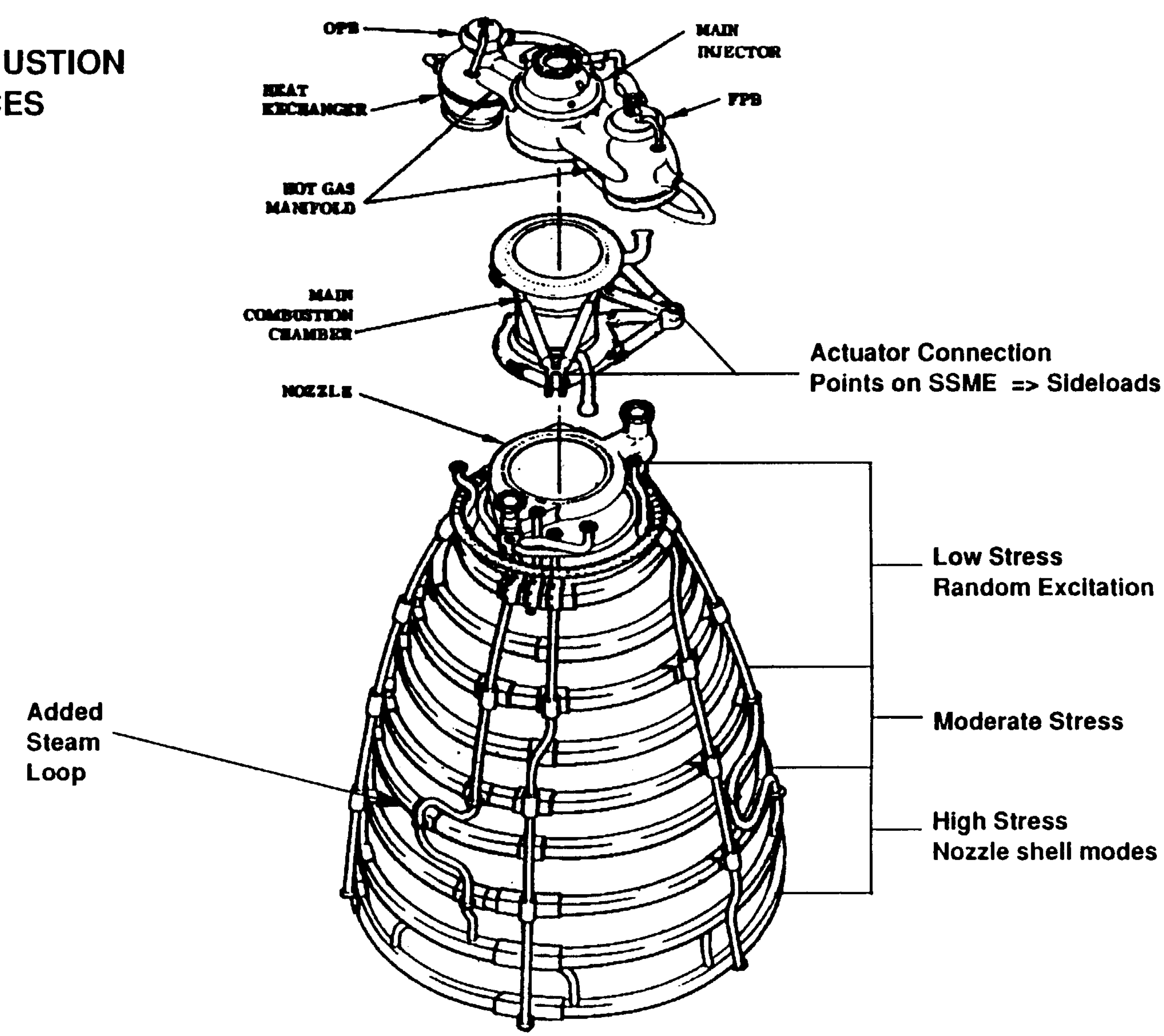
Introduction / History

- SSME Nozzles are subjected to significant unsteady aerodynamic forces during engine start and shutdown transients
- High loads are associated with the start / shutdown nozzle transients
  - » High Stress in Nozzle Aft Region (Excitation of nozzle flexural modes)
  - » Actuator Sideloads
- These transients were severe enough to cause two major test failures of the large coolant supply tubes, downcomers (steerhorn failures)
  - » First failure: Test 750-041 (14 May 1979) Engine E0201
    - – fatigue load failure
    - – resolved by increasing steerhorn thickness
  - » Second failure: Test SF6-03 (4 Nov 1979) Engine E2002
    - – incorrect weld material
    - – resolved by adding nickel plating to tee weld joints, added steam loop to coolant line

SSME COMBUSTION DEVICES



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Test Objectives

- To better understand the unsteady nozzle flows, a wind tunnel experiment using a scaled 2-D (planar) contour model of the SSME nozzle was run
- Tests were conducted at MSFC's 14 inch Trisonic Wind Tunnel facility
- Model was instrumented to measure static, fluctuating pressures, and coloured schlieren videotapes
  - » Recording schlieren video of the shock structure as it move out of the nozzle during startup and back in during shutdown was one of the main objectives
  - » The static pressure ports would help define the relative strength of the shocks
  - » The fluctuating pressure transducers were used to measure the unsteady levels and the show the spectrum shape

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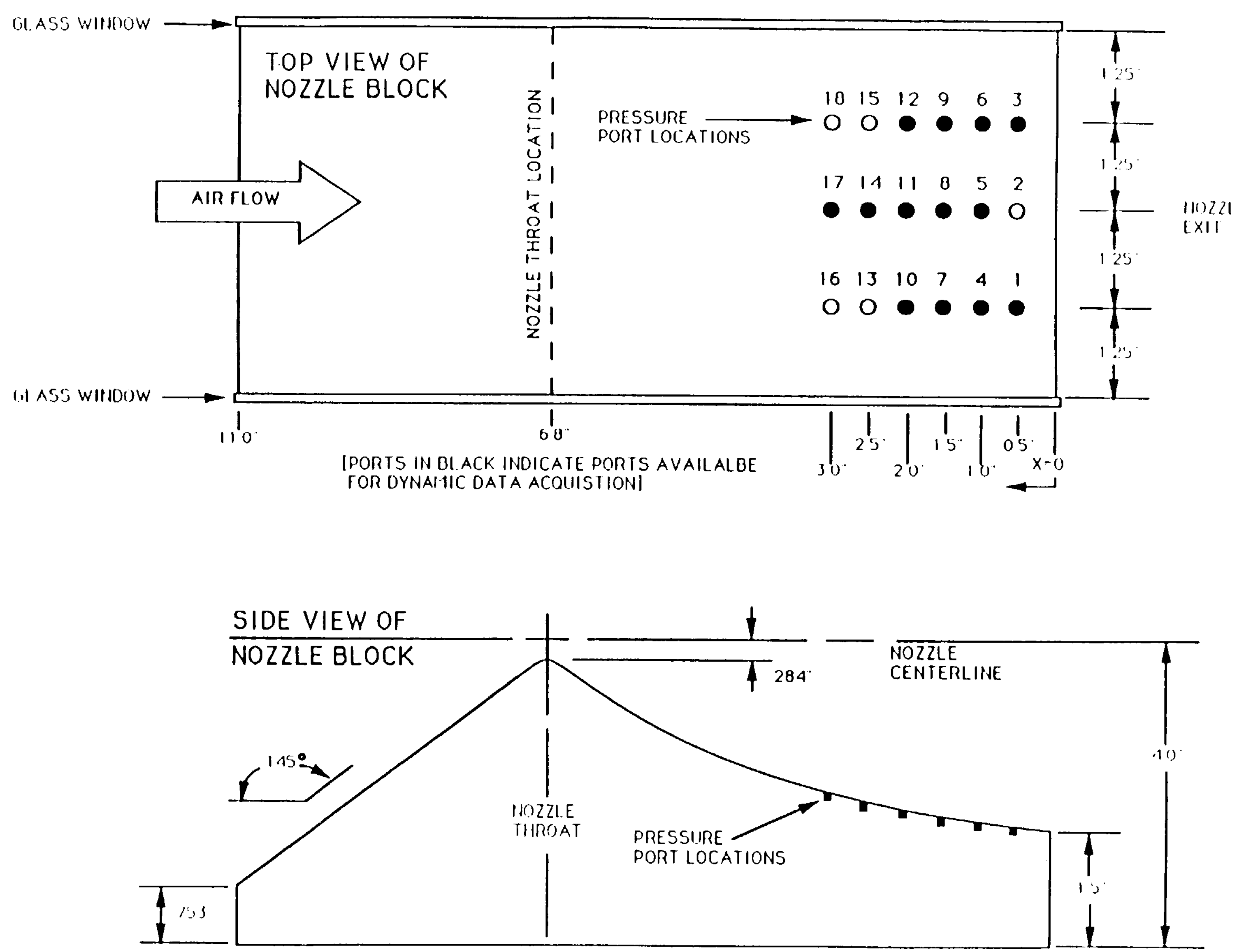
Model and Test Descriptions

- 2-D SSME contour shape
  - » Area Ratio = 8.8:1
  - » Nozzle Length = 11 inches (6.8 inches from throat to exit)
  - » Nozzle Width = 5.0 inches
  - » Nozzle Exit Height = 5.0 inches
  - » Throat Height = 0.568 inches
- Model Instrumentation
  - » 18 Ports - 12 Fluctuating Pressure Transducers Recorded (Lower Block)
  - » 18 Static Pressure Ports (Top Block)
- Facility Measurements
  - » Total Pressure, Total Temperature, and Static Pressure at Nozzle Exit
  - » Schlieren Video
- Test Conditions
  - » 3 Nozzle exit pressure conditions (2 psia, 7 psia, and atmospheric)
  - » Slow sweep runs
  - » 5 steady state runs at predetermined shock locations

NOZZLE BLOCK MODEL AND PRESSURE PORT LOCATIONS



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Structures and Dynamics Laboratory
Aerophysics Division
Induced Environments Branch ED33

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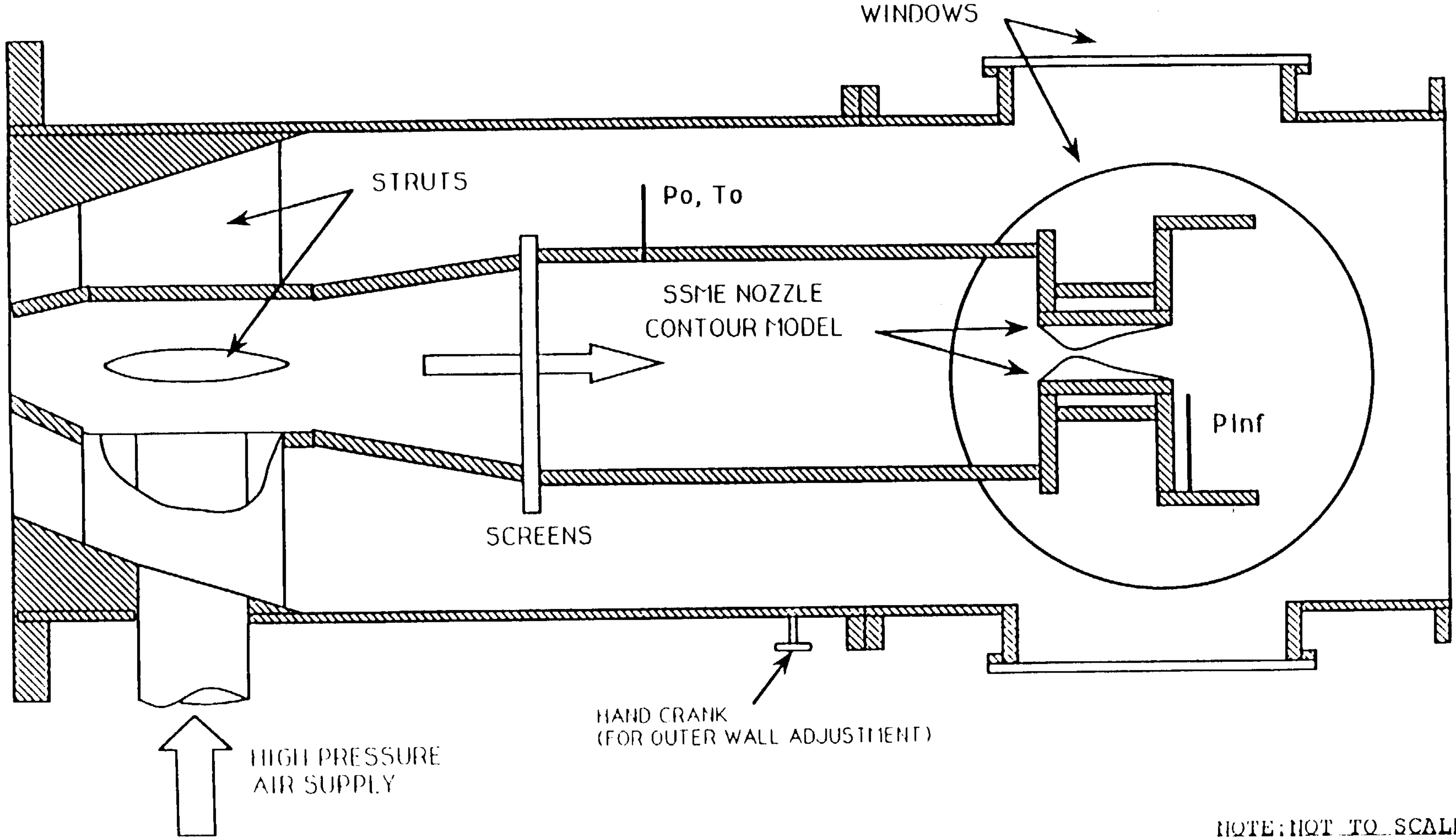
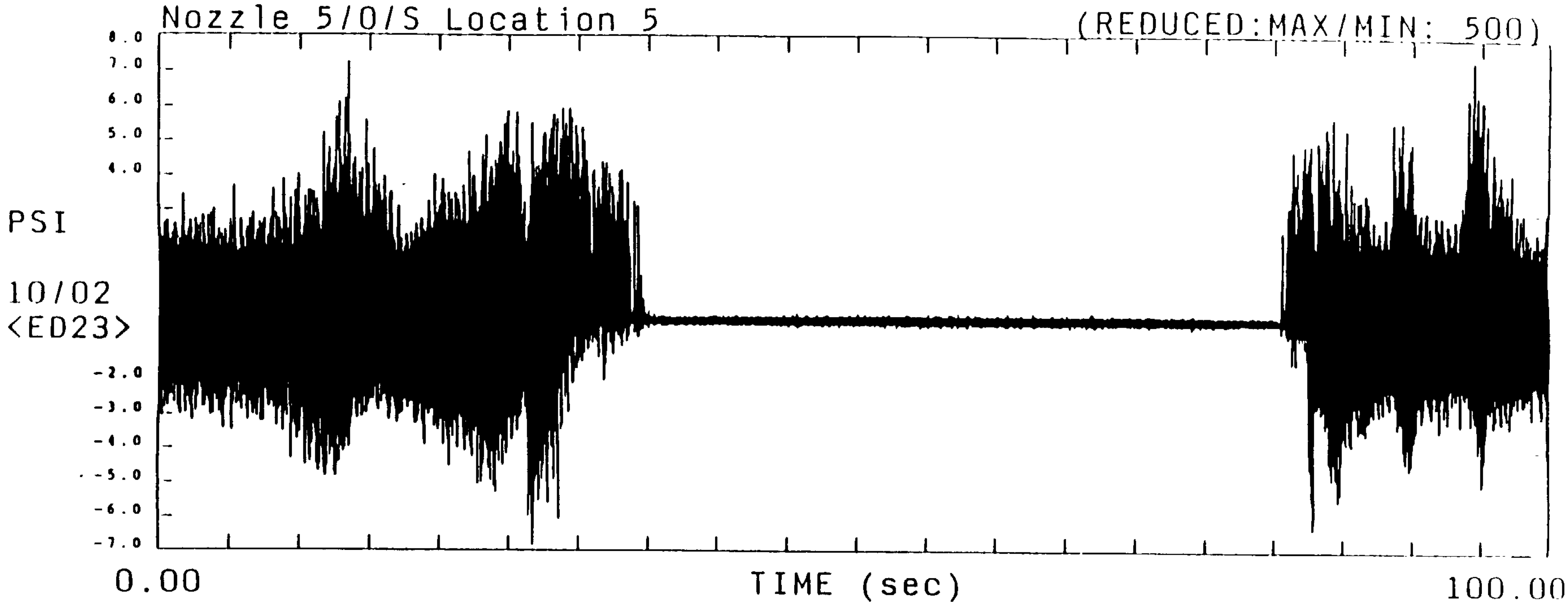
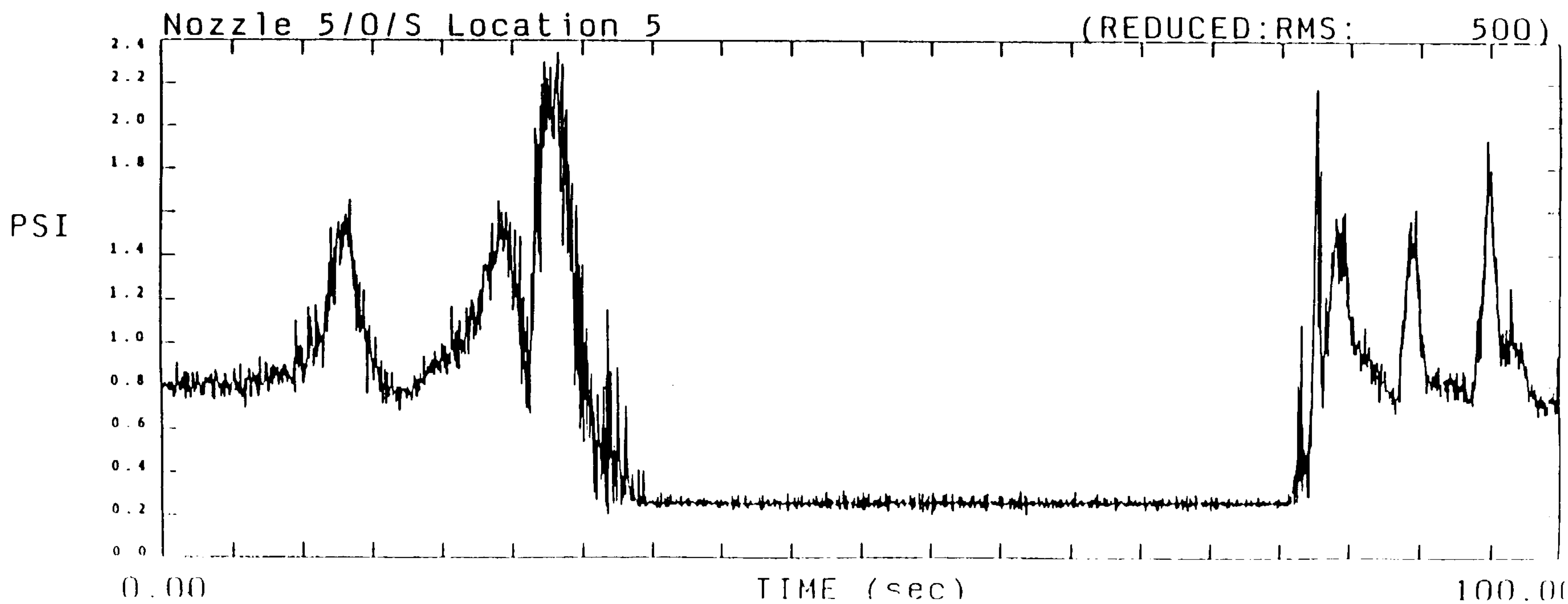
Space Administration

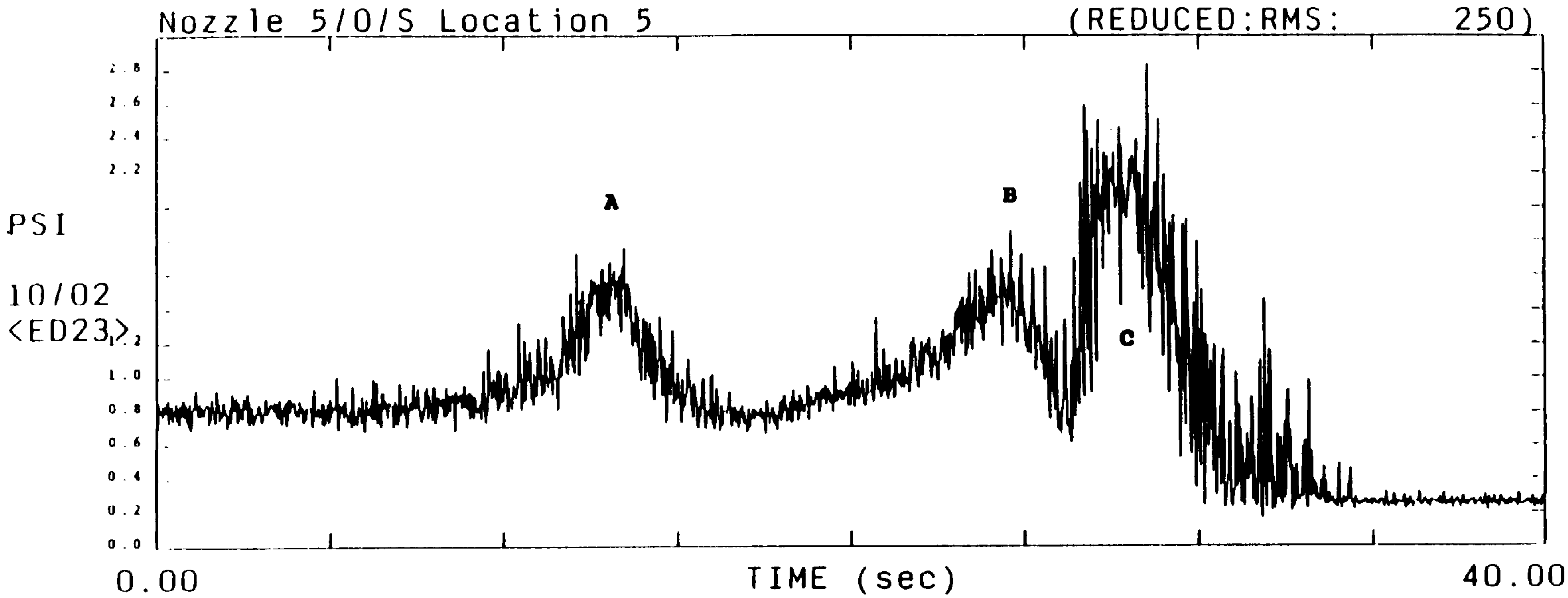
Test Section With 2-D SSME Nozzle Contour Model Installed

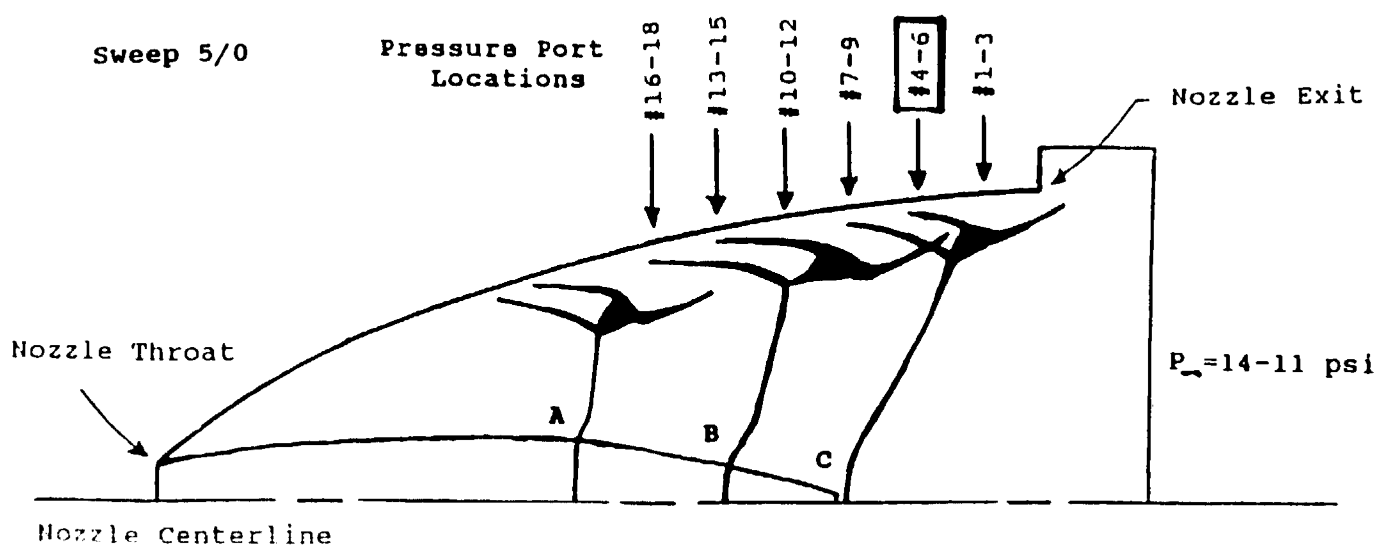


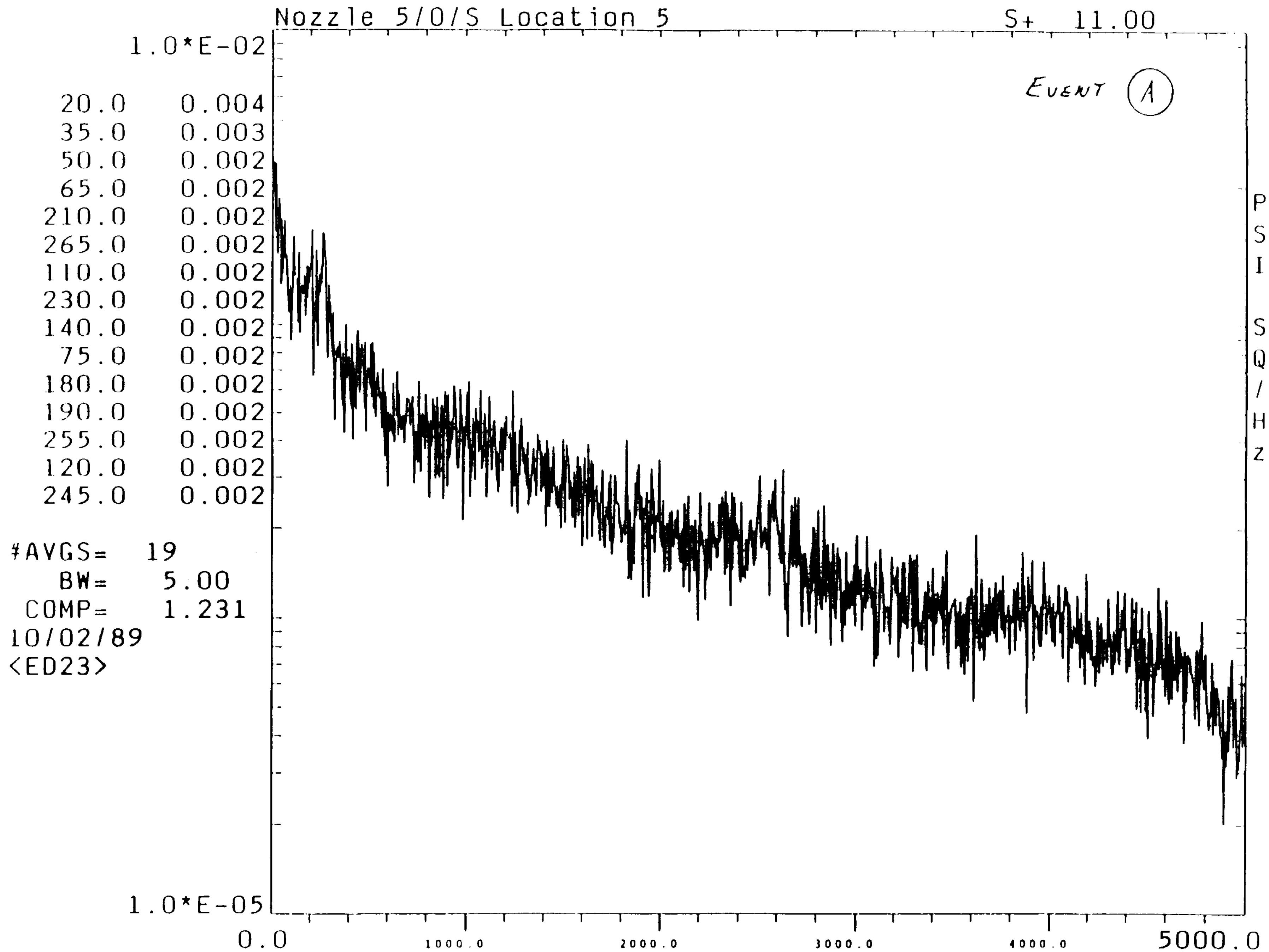
NOTE: NOT TO SCALE


Nozzle 5/O/S Location 5
(REDUCED:MAX/MIN: 500)
PSI
10/02
<ED23>
8.0
7.0
6.0
5.0
4.0
-2.0
-3.0
-4.0
-5.0
-6.0
-7.0
0.00
TIME (sec)
100.00

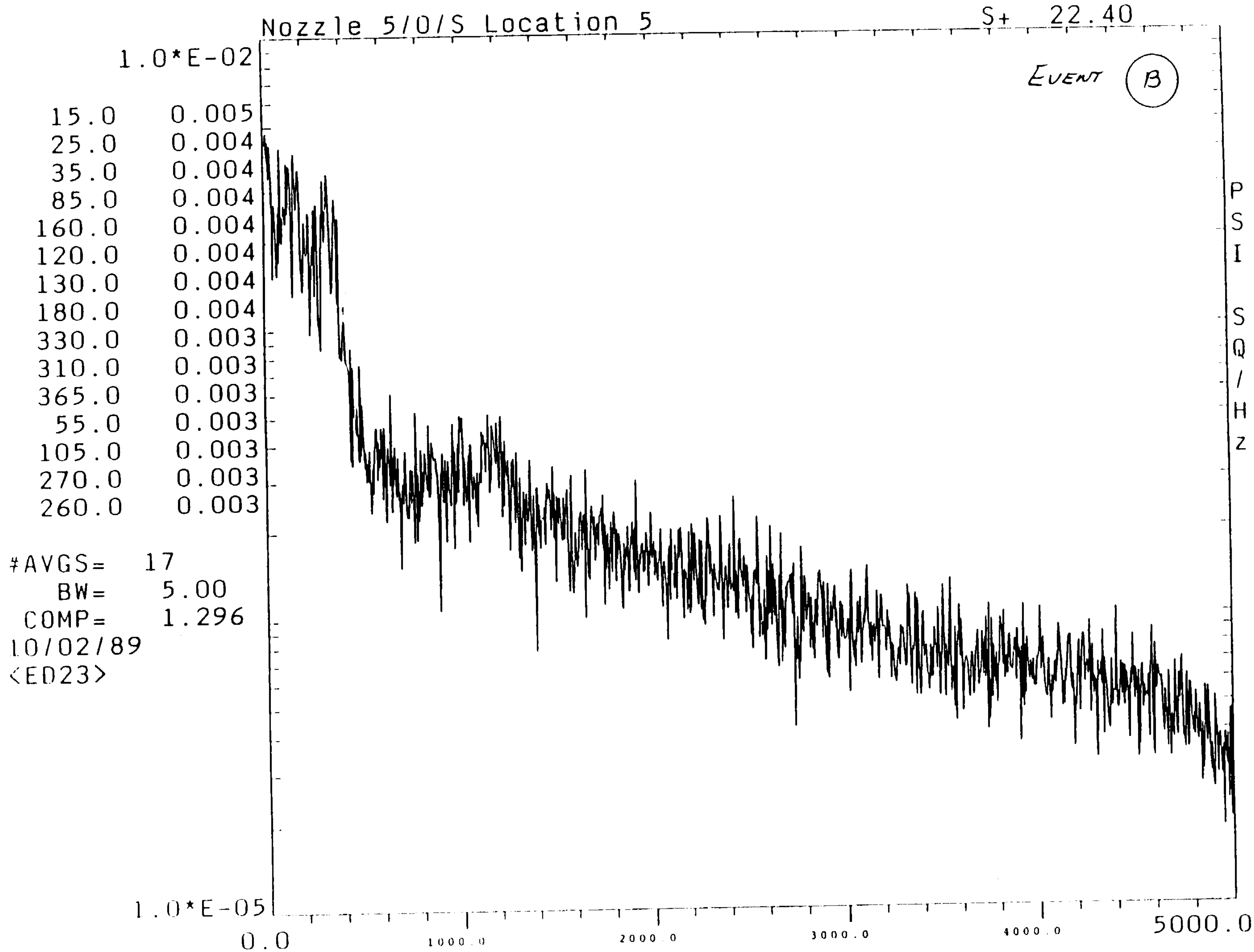

Nozzle 5/O/S Location 5
(REDUCED:RMS: 500)
PSI
2.4
2.2
2.0
1.8
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.00
TIME (sec)
100.00

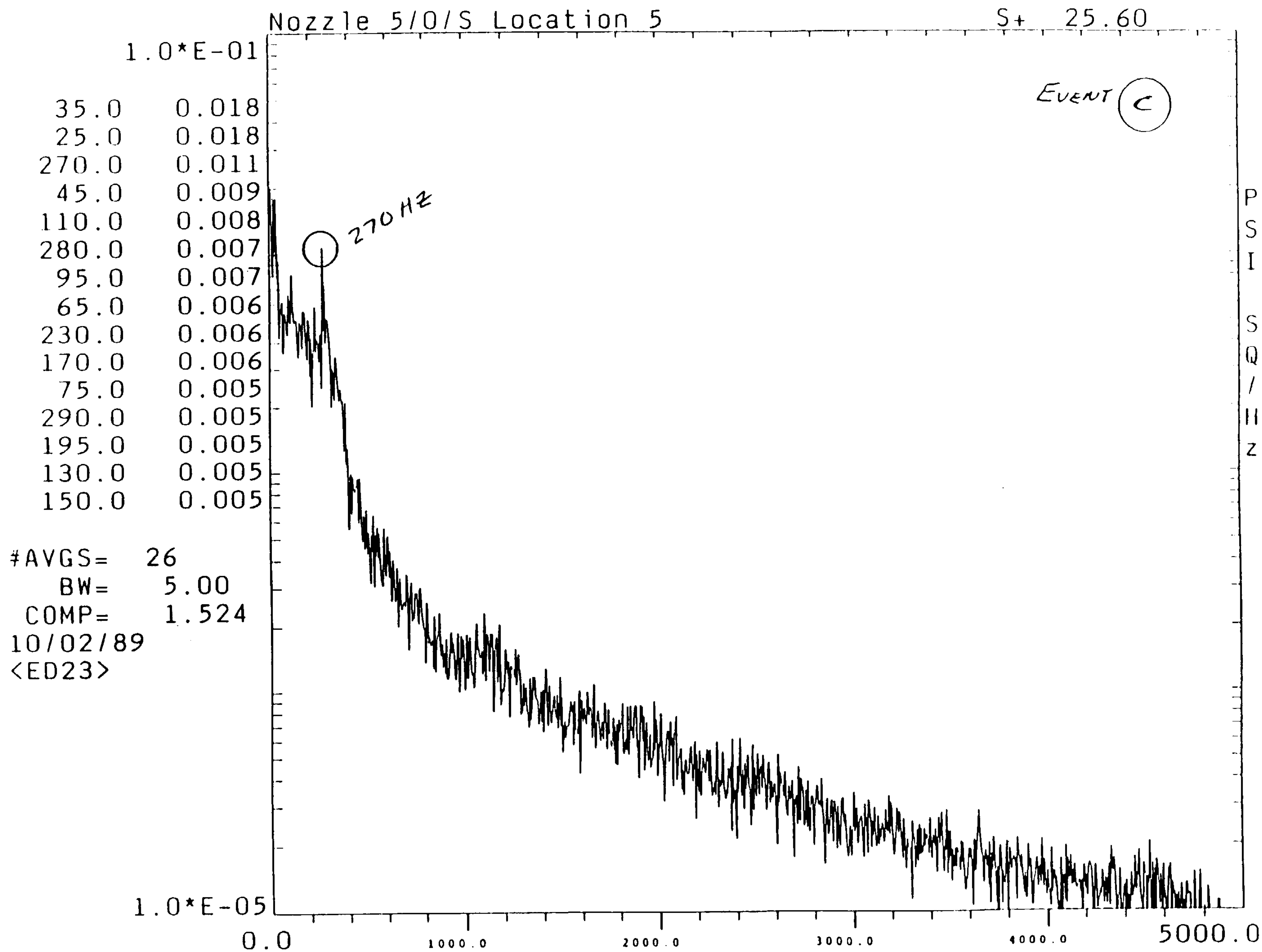

Nozzle 5/0/S Location 5
(REDUCED:RMS: 250)
PSI
10/02
<ED23>
0.0
0.2
0.4
0.6
0.8
1.0
2.2
2.4
2.6
2.8
A
B
C
0.00
TIME (sec)
40.00

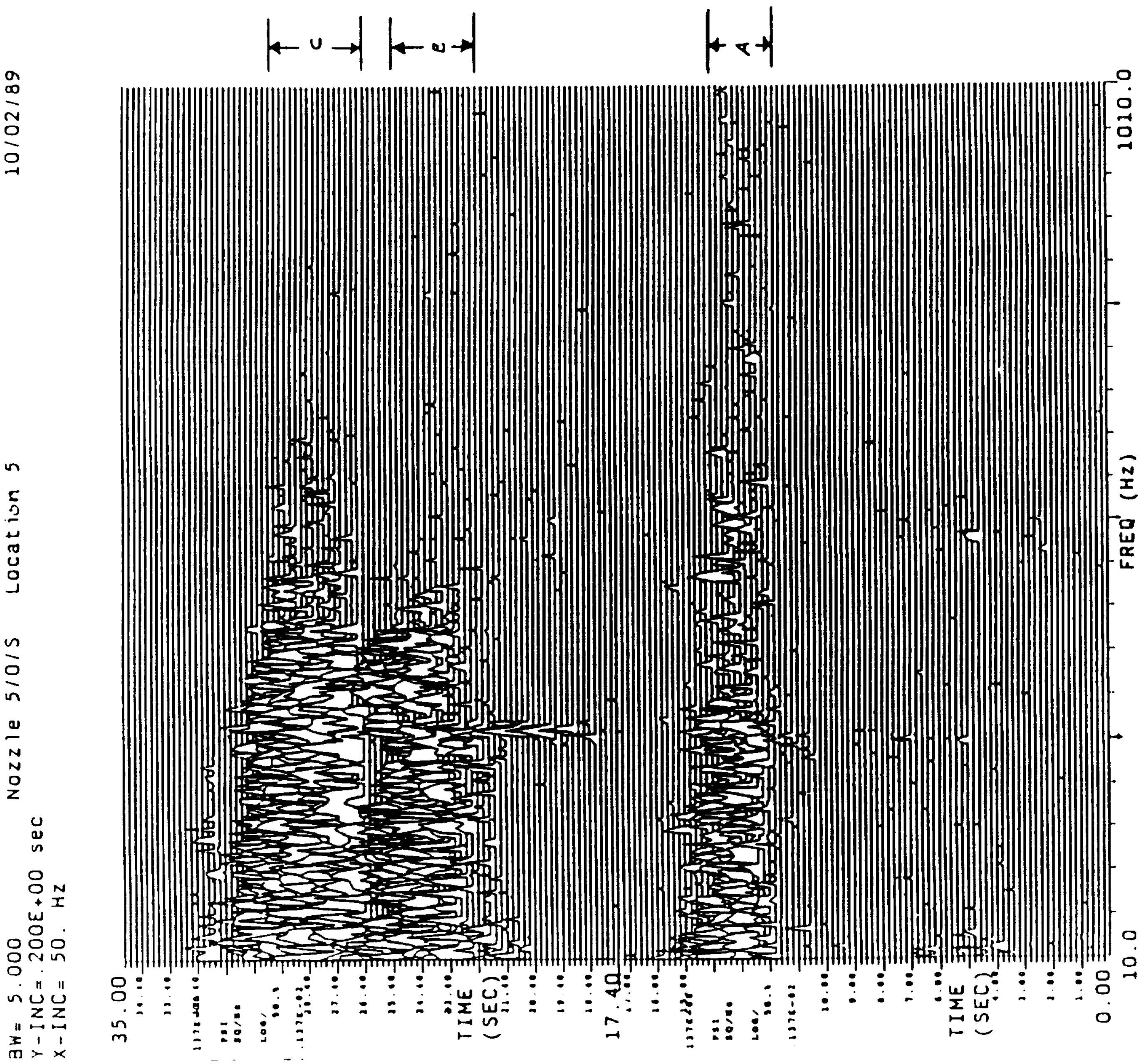

Sweep 5/0
Pressure Port Locations
#16-18
#13-15
#10-12
#7-9
#4-6
#1-3
Nozzle Exit
Nozzle Throat
P_∞=14-11 psi
A
B
C
Nozzle Centerline



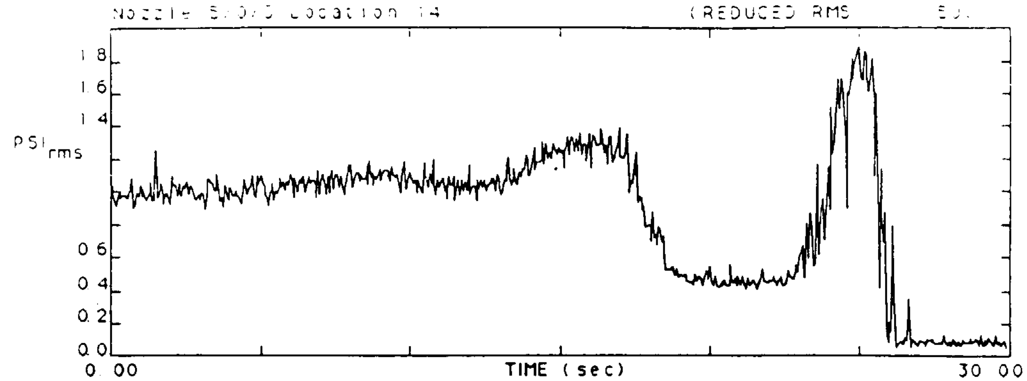
Nozzle 5/0/S Location 5
S+ 11.00
EVENT A
1.0*E-02
20.0 0.004
35.0 0.003
50.0 0.002
65.0 0.002
210.0 0.002
265.0 0.002
110.0 0.002
230.0 0.002
140.0 0.002
75.0 0.002
180.0 0.002
190.0 0.002
255.0 0.002
120.0 0.002
245.0 0.002
#AVGS= 19
BW= 5.00
COMP= 1.231
10/02/89
<ED23>
1.0*E-05
0.0
1000.0
2000.0
3000.0
4000.0
5000.0
PSI SQ/HZ


Nozzle 5/0/S Location 5
S+ 22.40
Event
B
1.0*E-02
1.0*E-05
0.0
1000.0
2000.0
3000.0
4000.0
5000.0
PSI SQ/HZ
15.0 0.005
25.0 0.004
35.0 0.004
85.0 0.004
160.0 0.004
120.0 0.004
130.0 0.004
180.0 0.004
330.0 0.003
310.0 0.003
365.0 0.003
55.0 0.003
105.0 0.003
270.0 0.003
260.0 0.003
#AVGS= 17
BW= 5.00
COMP= 1.296
10/02/89
<ED23>

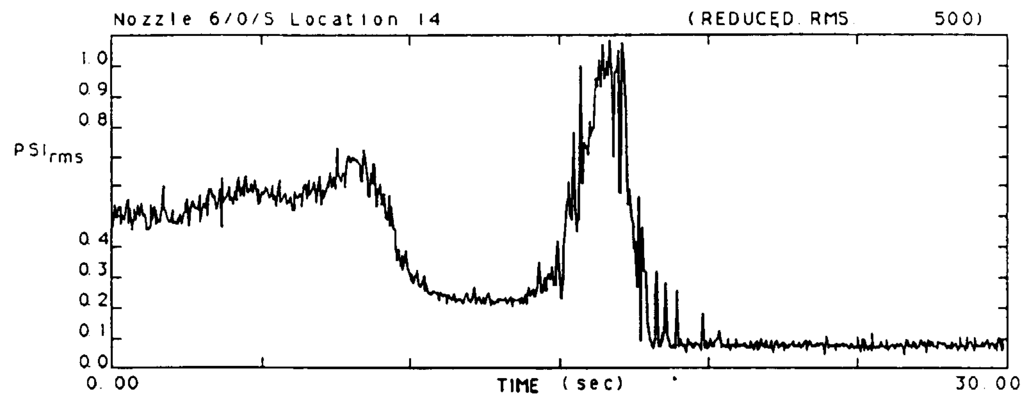

Nozzle 5/0/S Location 5
S+ 25.60
1.0*E-01
35.0 0.018
25.0 0.018
270.0 0.011
45.0 0.009
110.0 0.008
280.0 0.007
95.0 0.007
65.0 0.006
230.0 0.006
170.0 0.006
75.0 0.005
290.0 0.005
195.0 0.005
130.0 0.005
150.0 0.005
#AVGS= 26
BW= 5.00
COMP= 1.524
10/02/89
<ED23>
1.0*E-05
0.0
1000.0
2000.0
3000.0
4000.0
5000.0
PSI SQ/Hz
EVENT C
270 HZ


BW= 5.000
Y-INC= .200E+00 sec
X-INC= 50. Hz
Nozzle 5/0/S
Location 5
10/02/89
35.00
17.40
0.00
TIME (SEC)
TIME (SEC)
10.0
1010.0
FREQ (Hz)
C
B
A

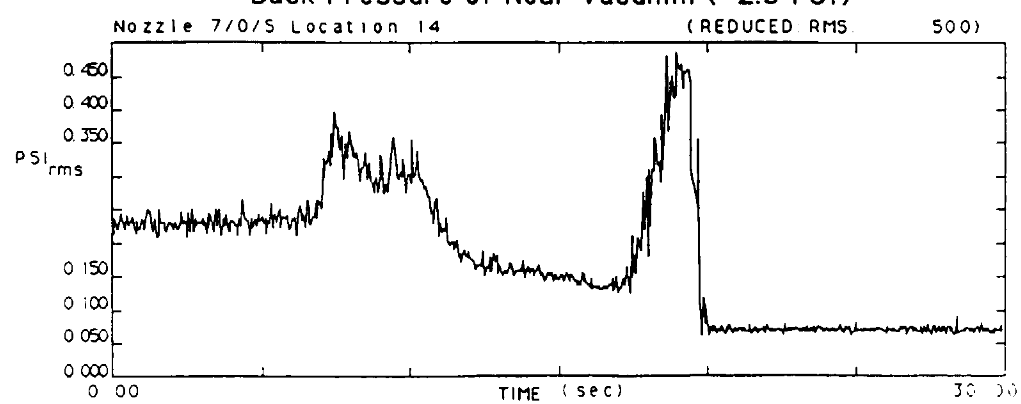
Back Pressure of Atmospheric (~14 PSI)



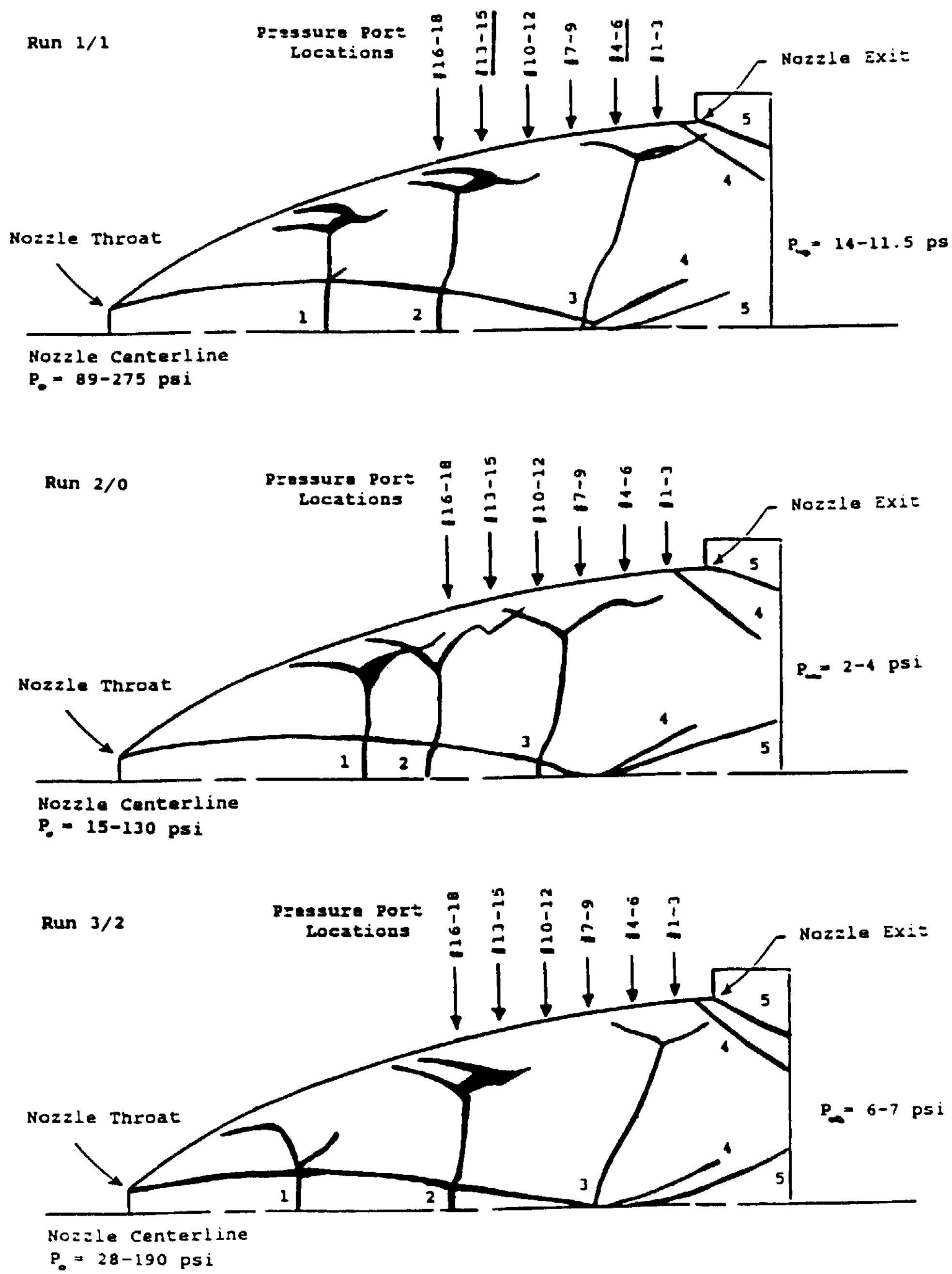
Back Pressure of half Atmospheric (~7 PSI)



Back Pressure of Near Vacumm (~2.5 PSI)



<u>SSME NOZZLE SHELL</u>
<u>SHOCK WAVE LOCATION</u>



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Conclusions

- Fluctuating Pressures are highest at the upstream edge of the lambda shock
- Fluctuating pressure levels decrease "inside" the shock foot
- Spectrum shapes show mostly low frequency energy - this is consistent with similar flow conditions (external bow shock impingement)
- Nondimensional amplitude, ΔCp, levels are similar to external flow conditions
- The plane flow nozzle with side windows is a good method to observe the shock wave patterns
- Data from this experiment have helped describe the unsteady aerodynamic forces a nozzle experiences during startup and shutdown

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Future Fluctuating Pressure Analyses of Nozzle Transients

- The Fluid Dynamics Division has developed plans for 3-D subscale nozzles with the following capabilities:

» Maximum test pressure		350 psi (nitrogen)
» Maximum flow rate	primary	12 lb/s @ 810 °
	secondary	50 lb/s
» Minimum back pressure		0.05 psia
» Maximum run duration		360 sec. @ 12 lb/s
» Maximum supply temperature		350 °F
» Maximum testable area ratio		230
» Test Cabin Size		3 ft diameter x 5 ft

- Two different nozzle contours are to be tested in the Trisonic wind tunnel special test section this July
- The new nozzles will be instrumented and tested similar to the SSME nozzle

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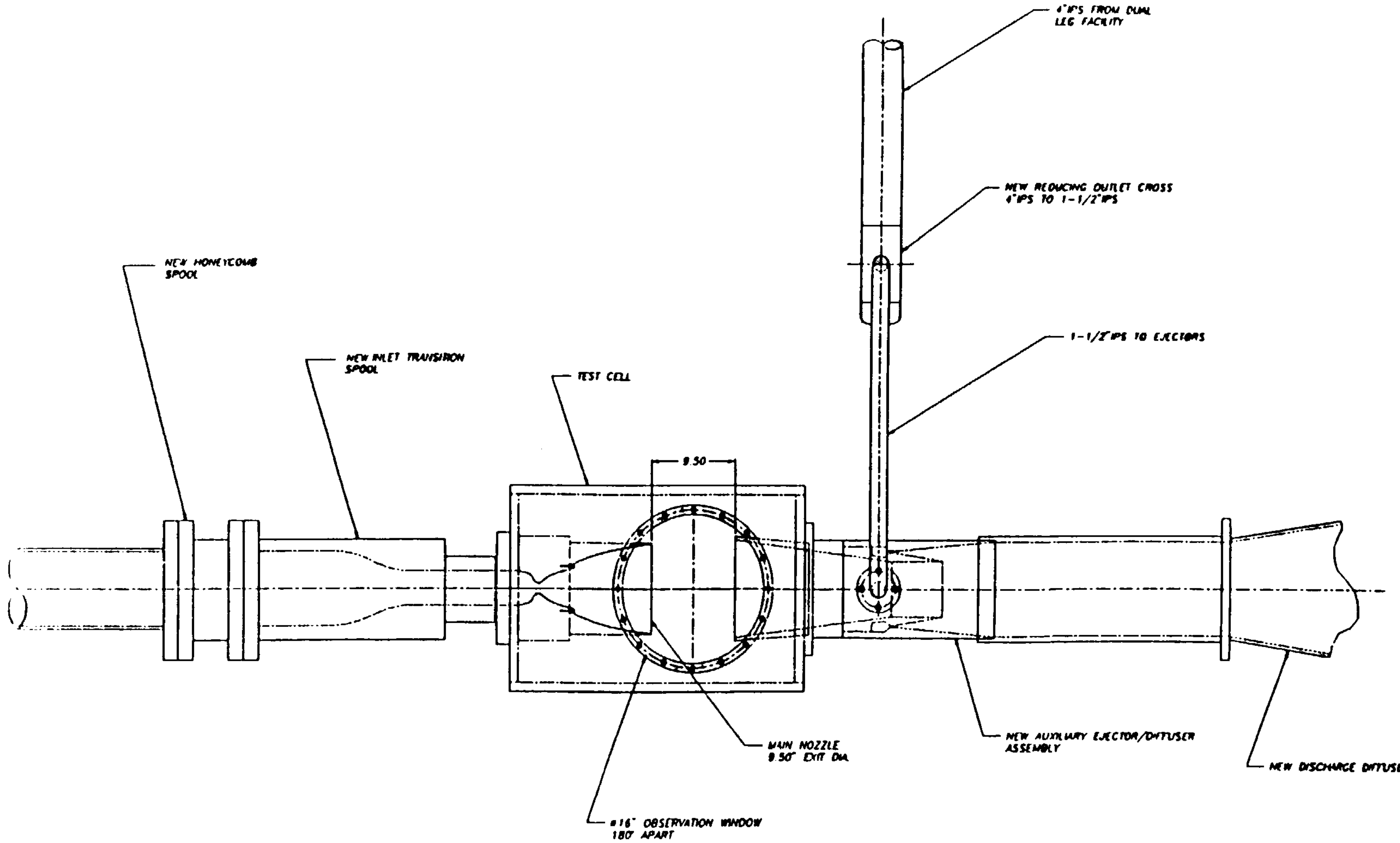
Fluid Dynamics Division's 3-D Nozzle Test Facility



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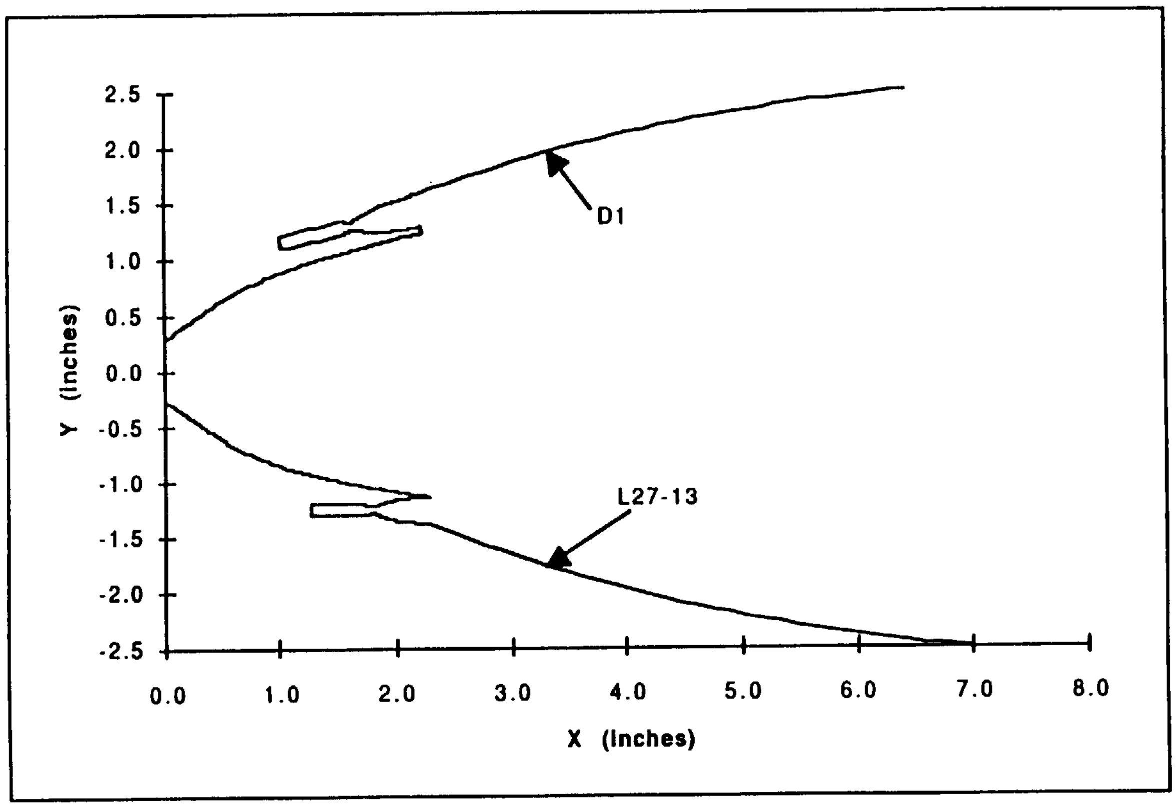
Rocketdyne Tripropellant Nozzle Contour



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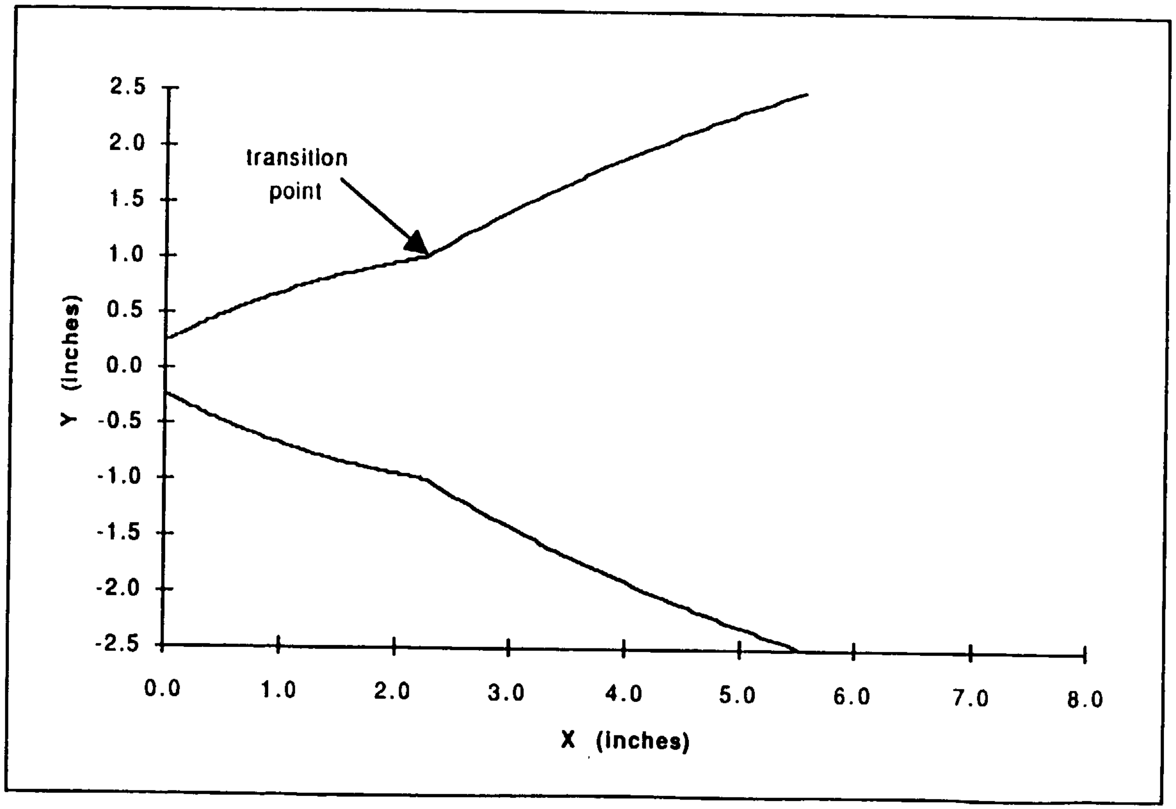
Dual Bell Concept Nozzle Contour



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