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 LH2 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 schlieren video clearly shows a lambda ($\lambda$) 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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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
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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
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

TOP VIEW OF NOZZLE BLOCK

PRESSURE PORT LOCATIONS

PORTS IN BLACK INDICATE PORTS AVAILABLE FOR DYNAMIC DATA ACQUISITION

SIDE VIEW OF NOZZLE BLOCK

NOZZLE CENTERLINE

PRESSURE PORT LOCATIONS

NOZZLE THROAT

GLASS WINDOW

AIR FLOW

GLASS WINDOW
Test Section With 2-D SSME Nozzle Contour Model Installed

- STRUTS
- SCREENS
- SSME NOZZLE CONTOUR MODEL
- WINDOWS
- Po, To
- P
- HAND CRANK (FOR OUTER WALL ADJUSTMENT)
- HIGH PRESSURE AIR SUPPLY

NOTE: NOT TO SCALE
Nozzle 5/0/S Location 5

S+ 11.00

Event A

PSI

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
**SSKE Nozzle Shell**

**Shock Wave Location**

Run 1/1

- Pressure Port Locations
- Nozzle Throat
- Nozzle Centerline
  - $P_e = 89-275$ psi
- $P_m = 14-11.5$ psi

Run 2/0

- Pressure Port Locations
- Nozzle Throat
- Nozzle Centerline
  - $P_e = 15-130$ psi
- $P_m = 2-4$ psi

Run 3/2

- Pressure Port Locations
- Nozzle Throat
- Nozzle Centerline
  - $P_e = 28-190$ psi
- $P_m = 6-7$ psi
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, $\Delta C_p$, 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
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
Fluid Dynamics Division’s 3-D Nozzle Test Facility
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Rocketdyne Tripropellant Nozzle Contour

Diagram with axes labeled X (Inches) and Y (Inches)
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Dual Bell Concept Nozzle Contour