RSRM Chamber Pressure Oscillations:
Transit Time Models and Unsteady CFD

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Abstract

Space Shuttle solid rocket motor (SRM) low frequency internal pressure oscillations have been observed since early testing. The same type of oscillations are also present in the redesigned solid rocket motor (RSRM). The oscillations, which occur during RSRM burn, are predominantly at the first three motor cavity longitudinal acoustic mode frequencies. Broadband flow and combustion noise provide the energy to excite these modes at low levels throughout motor burn, however, at certain times during burn the fluctuating pressure amplitude increases significantly. The increased fluctuations at these times suggests an additional excitation mechanism.

The RSRM has inhibitors on the propellant forward facing surface of each motor segment. The inhibitors are in a slot at the segment field joints to prevent burning at that surface. The aft facing segment surface at a field joint slot burns and forms a cavity of time varying size. Initially the inhibitor is recessed in the field joint cavity. As propellant burns away the inhibitor begins to protrude into the bore flow. Two mechanisms (transit time models) that are considered potential pressure oscillation excitations are cavity edge-tones, and inhibitor hole-tones. Estimates of frequency variation with time of longitudinal acoustic modes, cavity edge-tones, and hole-tones compare favorably with frequencies measured during motor hot firing. It is believed that the highest oscillation amplitudes occur when vortex shedding frequencies coincide with motor longitudinal acoustic modes.

A time accurate CFD analysis was made to replicate the observations from motor firings and to observe the transit time mechanisms in detail. FDNS is the flow solver used to detail the time varying aspects of the flow. The fluid is approximated as a single-phase ideal gas. The CFD model was an axisymmetric representation of the RSRM at 80 seconds into burn. Deformation of the inhibitors by the internal flow was determined through an iterative structural and CFD analysis. The analysis domain ended just upstream of the nozzle throat. This is an acoustic boundary condition that caused the motor to behave as an closed-open organ pipe. This differs from the RSRM which behaves like a closed-closed organ pipe.

The unsteady CFD solution shows RSRM chamber pressure oscillations predominantly at the longitudinal acoustic mode frequencies of a closed-open organ pipe. Vortex shedding in the joint cavities and at the inhibitors contribute disturbances to the flow at the second longitudinal acoustic mode frequency. Further studies are planned using an analysis domain that extends downstream of the nozzle throat.

RSRM - Chamber Pressure Oscillations: Transit Time Models and Unsteady CFD

Workshop for CFD Applications in Rocket Propulsion and Launch Vehicle Technology

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Introduction

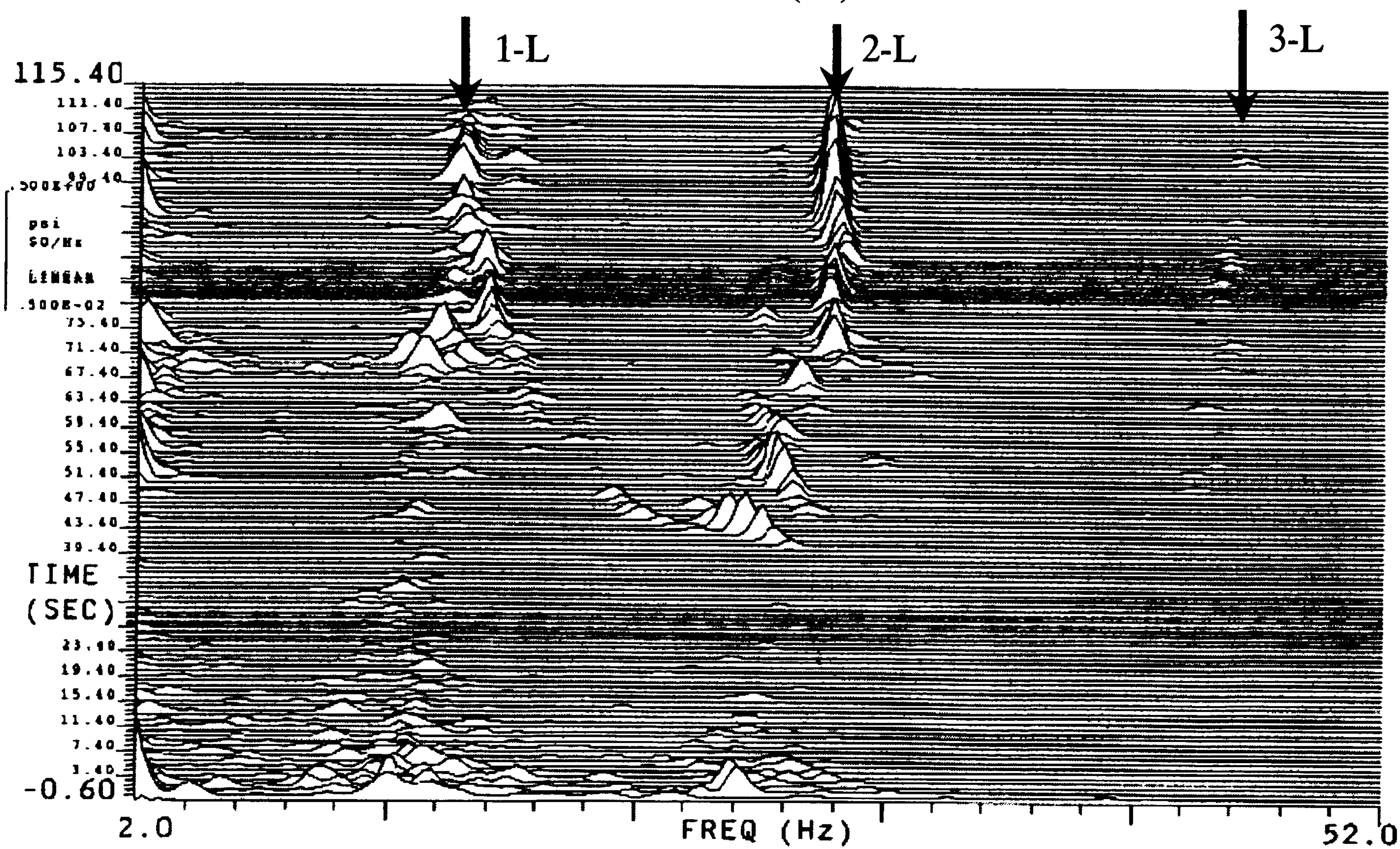
- Space Shuttle SRM Pc oscillations issues have surfaced at various times in past
    - Pre- STS-1 loads analysis
    - Post STS-1 loads evaluation
    - STD to HPM change
    - FWC testing
    - HPM to RSRM change (ASRM)
    - Inhibitor stiffening evaluation (present study)
- SRM Pc oscillation evaluation based primarily on test and flight data
- Mechanisms evaluated empirically
- Unsteady CFD activities initiated in early 1990's (funded thru 1993)
- Unsteady RSRM CFD activities revived for inhibitor stiffening evaluation

Background

- Space Shuttle solid rocket motor low frequency internal pressure oscillations observed since early testing
- Same type oscillations present in redesigned solid rocket motor (RSRM)
- Predominantly at first three motor internal longitudinal acoustic mode frequencies
- Broadband flow and combustion noise provide energy to excite these modes at low levels throughout motor burn
- At certain times during burn fluctuating pressure amplitude increases significantly
- Increased fluctuations at these times suggests an additional excitation mechanism

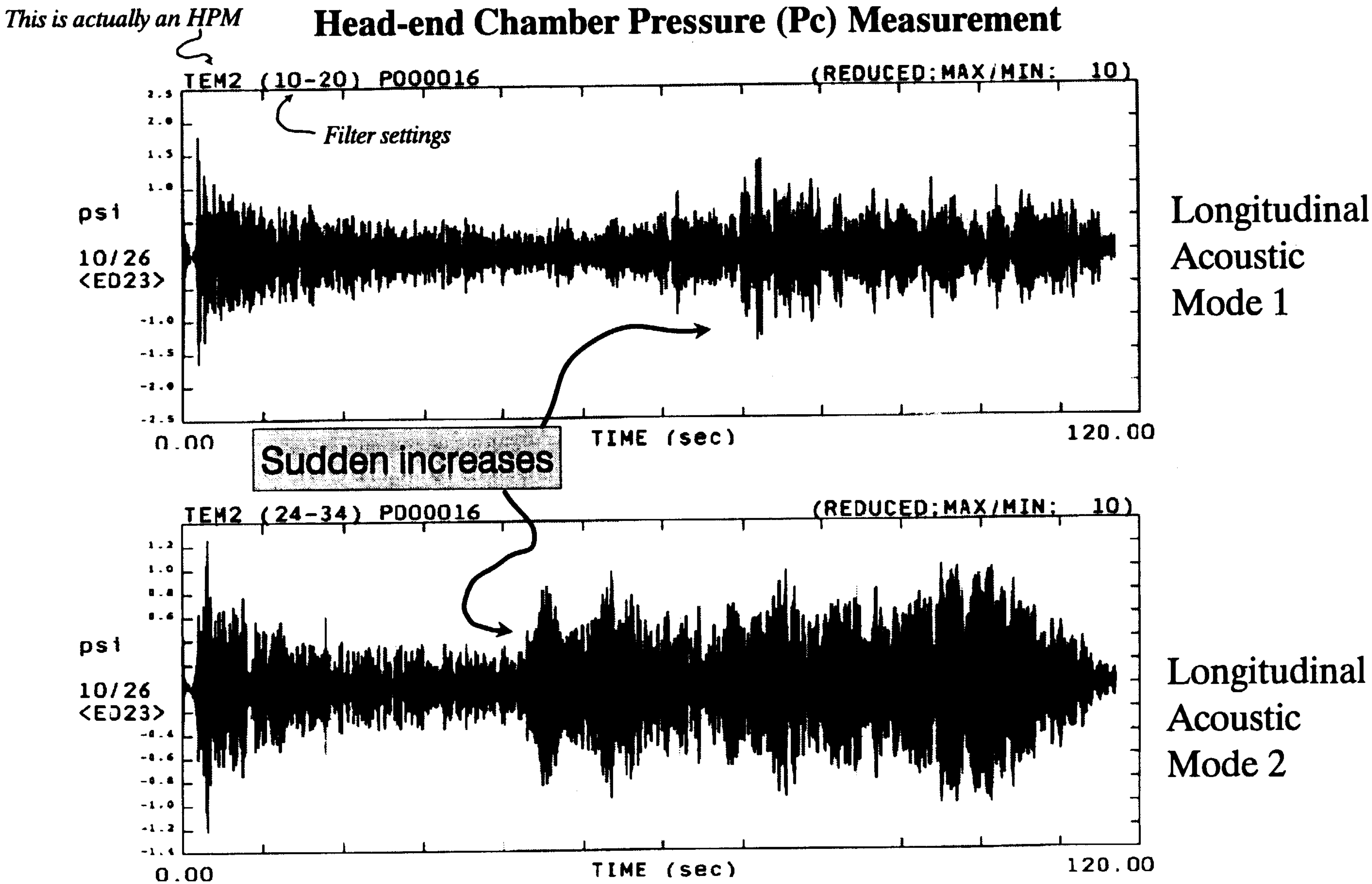
Typical RSRM Pc Isoplot

Head-end Chamber Pressure (Pc) Measurement



Typical RSRM Pc Timehistory (Bandpass Filtered Data)

Head-end Chamber Pressure (Pc) Measurement



General Characteristics

- RSRM inhibitors on propellant forward facing surface of each motor segment
- Inhibitors in slot at segment field joints to prevent burning at forward facing surface
- Aft facing segment surface at field joint slot burns to form cavity of time varying size
- Initially inhibitor recessed in field joint cavity
- As propellant burns away inhibitor protrudes into bore flow
- Two mechanisms considered potential pressure oscillation exciters
  - Feedback transit-time models
  - 1. Cavity edge-tones
  - 2. Inhibitor hole-tones
- Estimates of frequency variation with time of longitudinal acoustic modes, cavity edge-tones, and hole-tones compare favorably with frequencies measured during motor hot firing
- Highest oscillation amplitudes occur when vortex shedding frequencies coincide with motor longitudinal acoustic modes

Excitation Mechanisms

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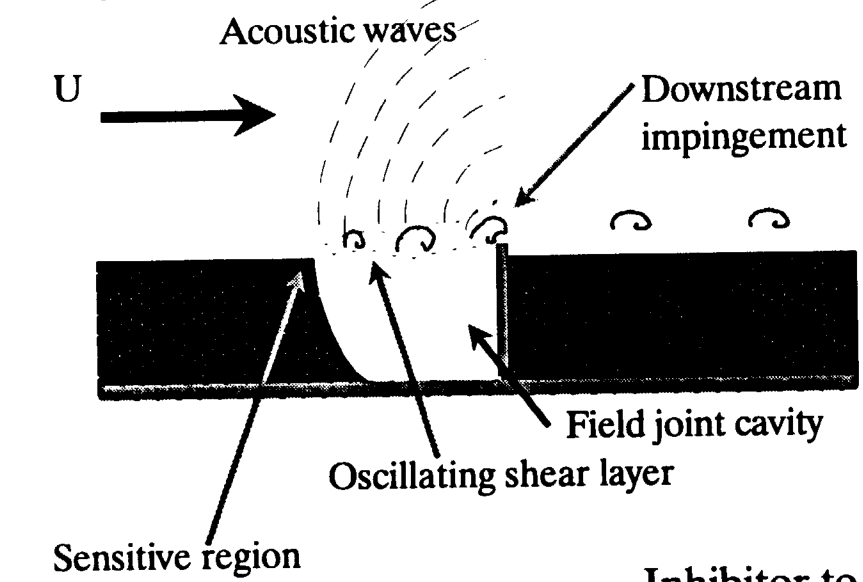
Cavity Edge-Tone Mechanism

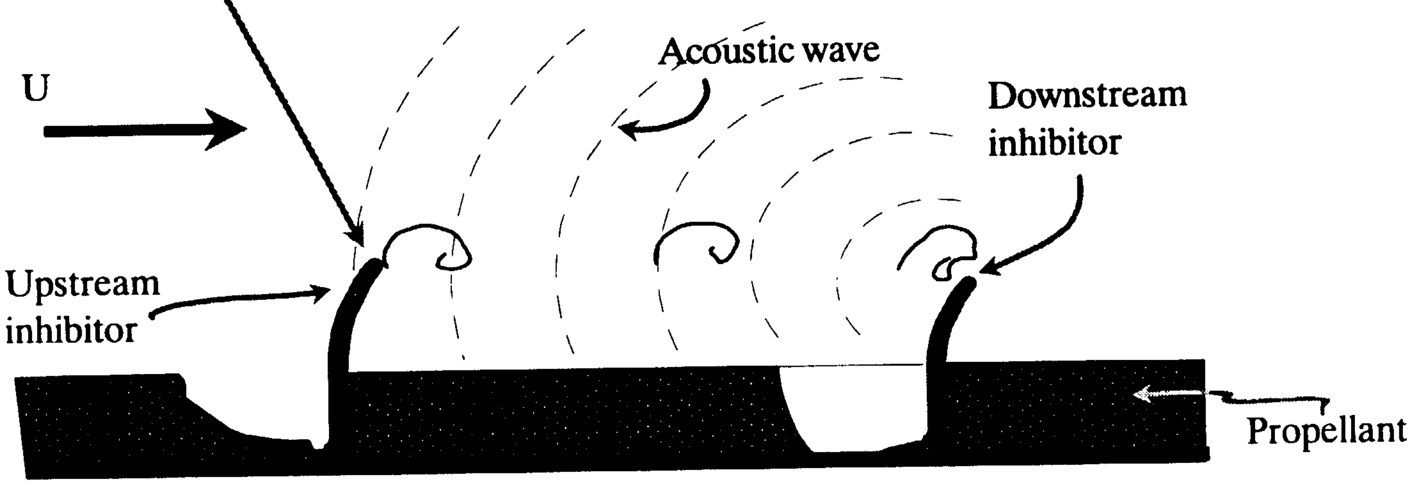


Feedback Transit Time Models

Empirical estimates - time for disturbance to travel downstream plus time for feedback to sensitive region

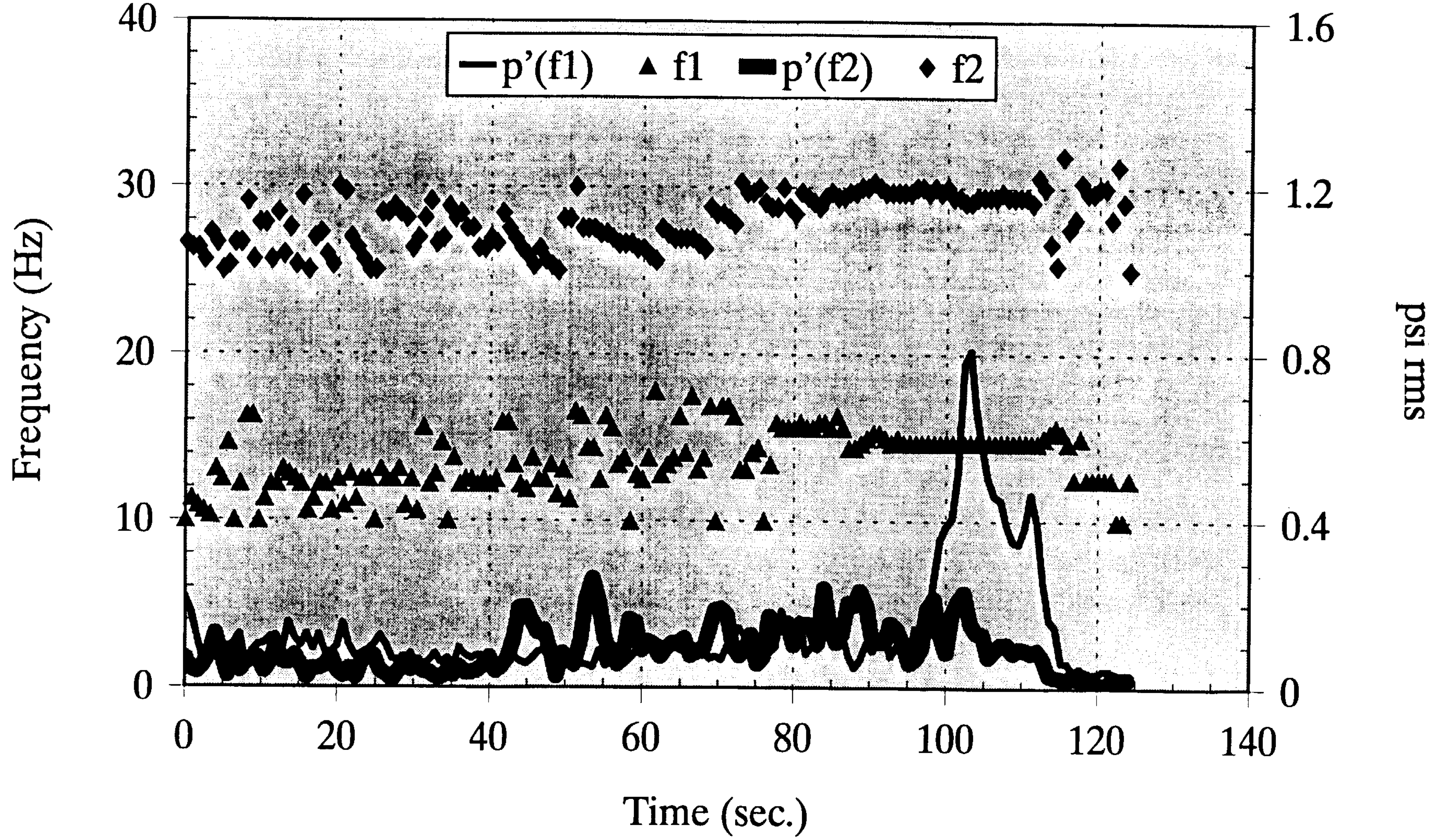
Analytical estimates - sum of phase of downstream traveling wave and phase of upstream traveling acoustic wave

Inhibitor to Inhibitor Hole-tone Mechanism



Measured Fluctuating Pressure, p’

RSRM Static Firing Head End Chamber Pressure



Measured p' Comparison

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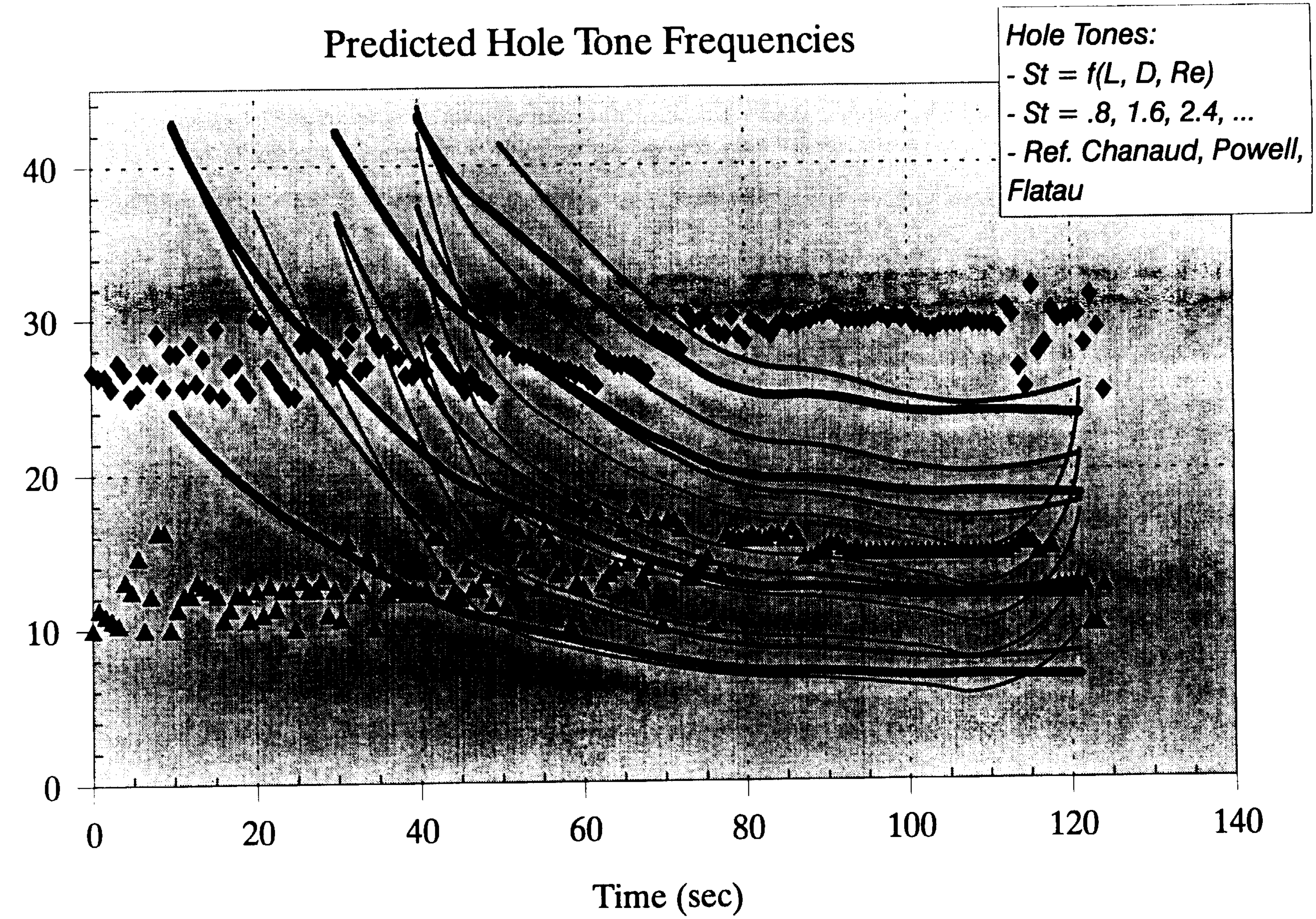
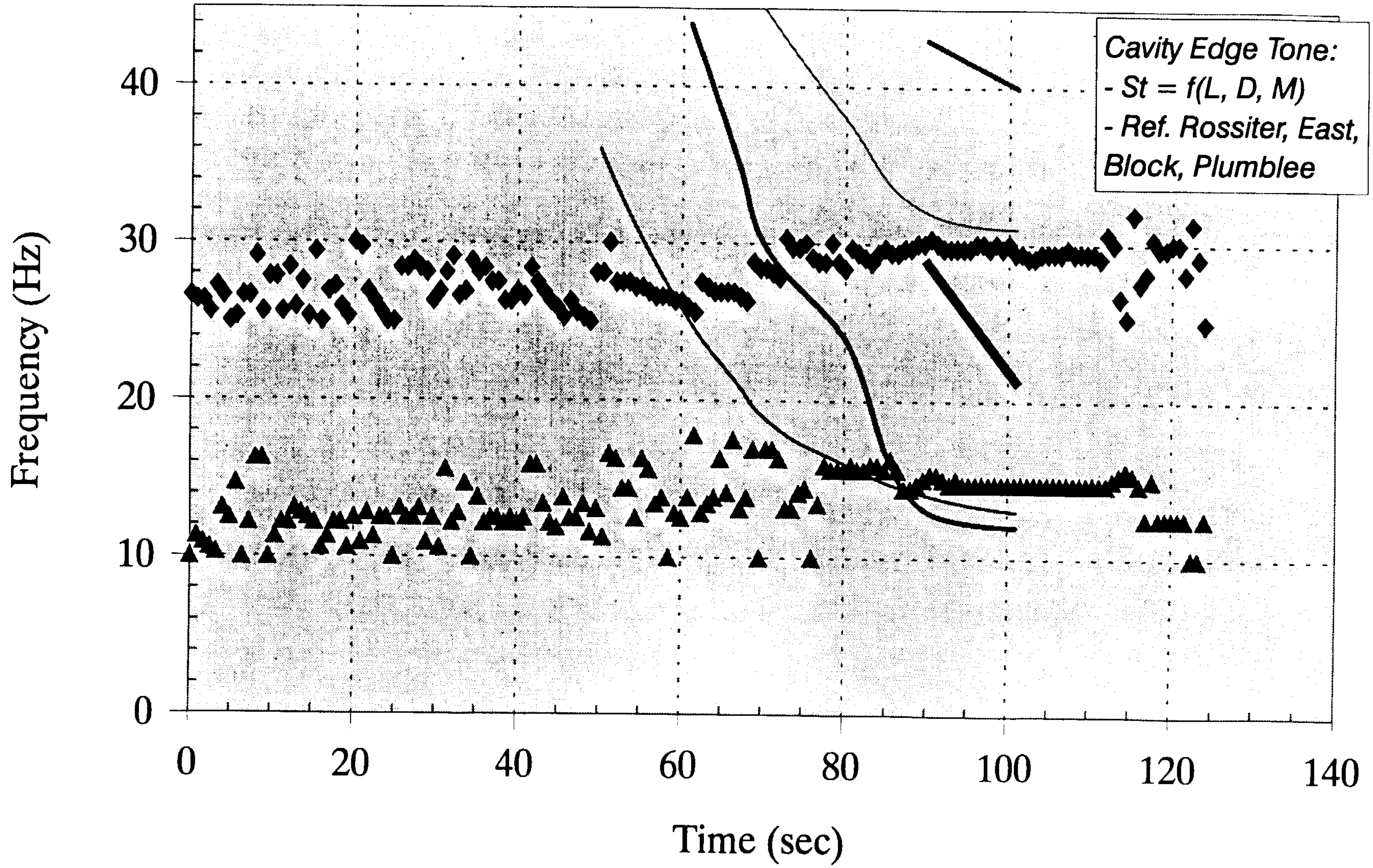


Measured p' Comparison

Predicted Cavity Edge Tone Frequencies



Background

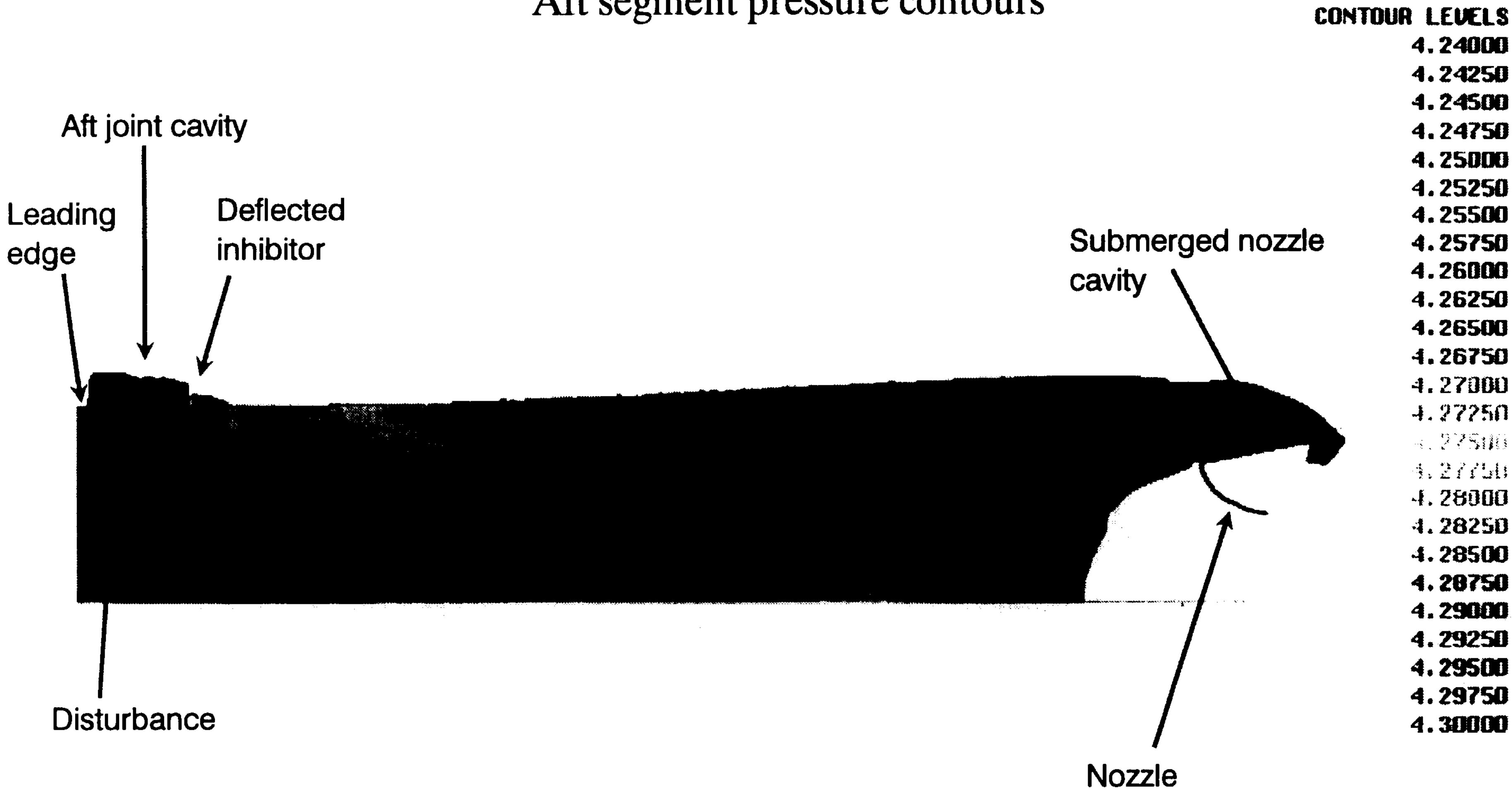
- Numerical simulation of "edge-tone" phenomenon (NASA CR 4581)
  - Performed by Rockwell-Huntsville in 1992 using USA flow solver
  - Solved Navier-Stokes equation for low speed flows
  - Dipole nature of edge-tone
- Numerical simulation of RSRM (NAS8-38550)
  - Performed by Rockwell-Huntsville in 1993 using USA flow solver
  - S+80 sec and S+105 sec burn time geometry and flow
  - Objective: evaluate the effect of inhibitors on Pc oscillations
  - Head-end p' dominated by 1L, 2L, and 3L organ pipe modes
  - Inhibitors generate oscillations , however, head-end p' lower with inhibitor than without inhibitor (not tuned ?)

Present Study

- Time accurate CFD analysis made to replicate observations from motor firings and observe transit time mechanism details
- CFD model is axisymmetric representation of RSRM at 80 seconds into burn
- Objective: determine effect of stiffer inhibitors on Pc oscillations
- Deformation of inhibitors by internal flow determined through iterative structural and CFD analysis
- FDNS is flow solver used to detail time varying aspects of flow
- Fluid approximated as single-phase ideal gas
- Analysis domain ends upstream of nozzle throat

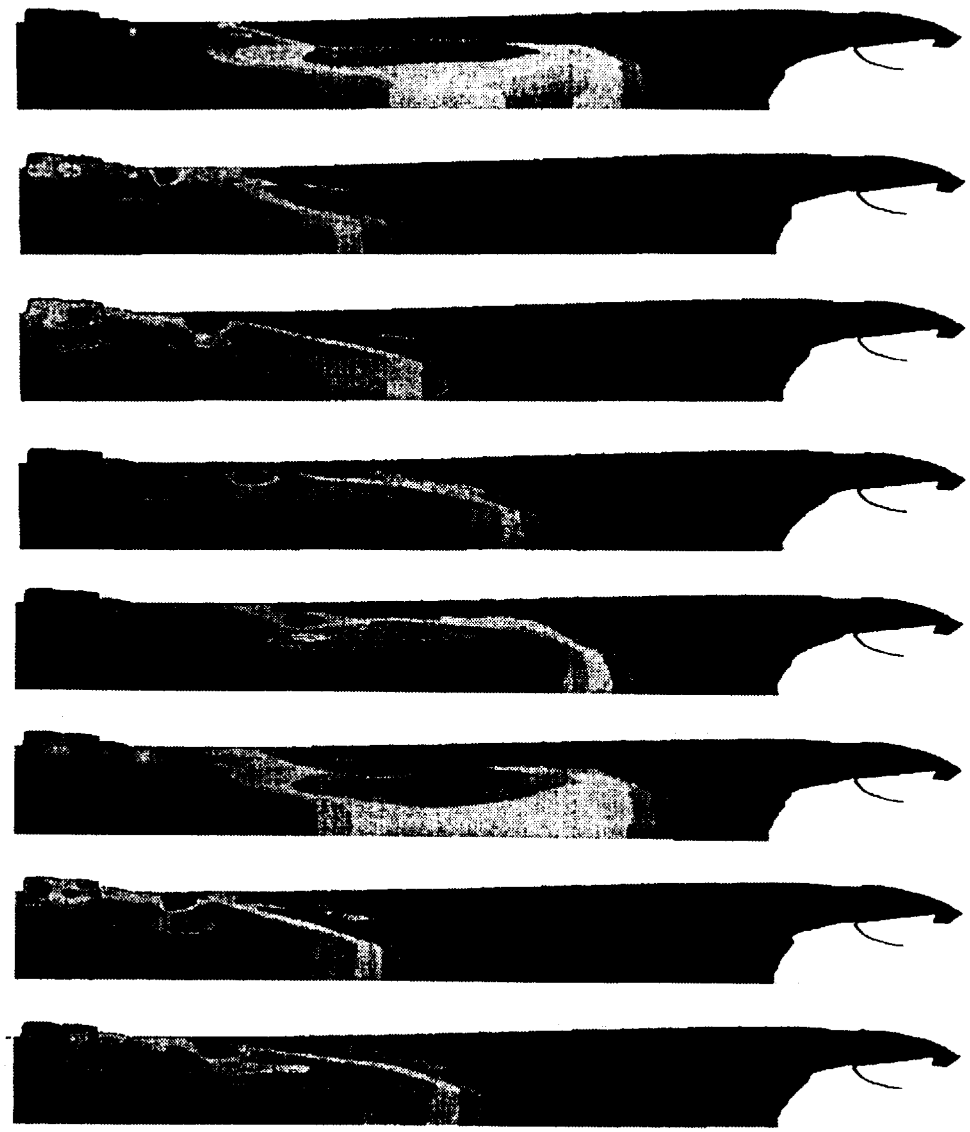
RSRM Unsteady CFD

Aft segment pressure contours



RSRM Unsteady CFD

Aft segment pressure contour sequence



t=0 sec

t=.01 sec

t=.02 sec

t=.03 sec

t=.04 sec

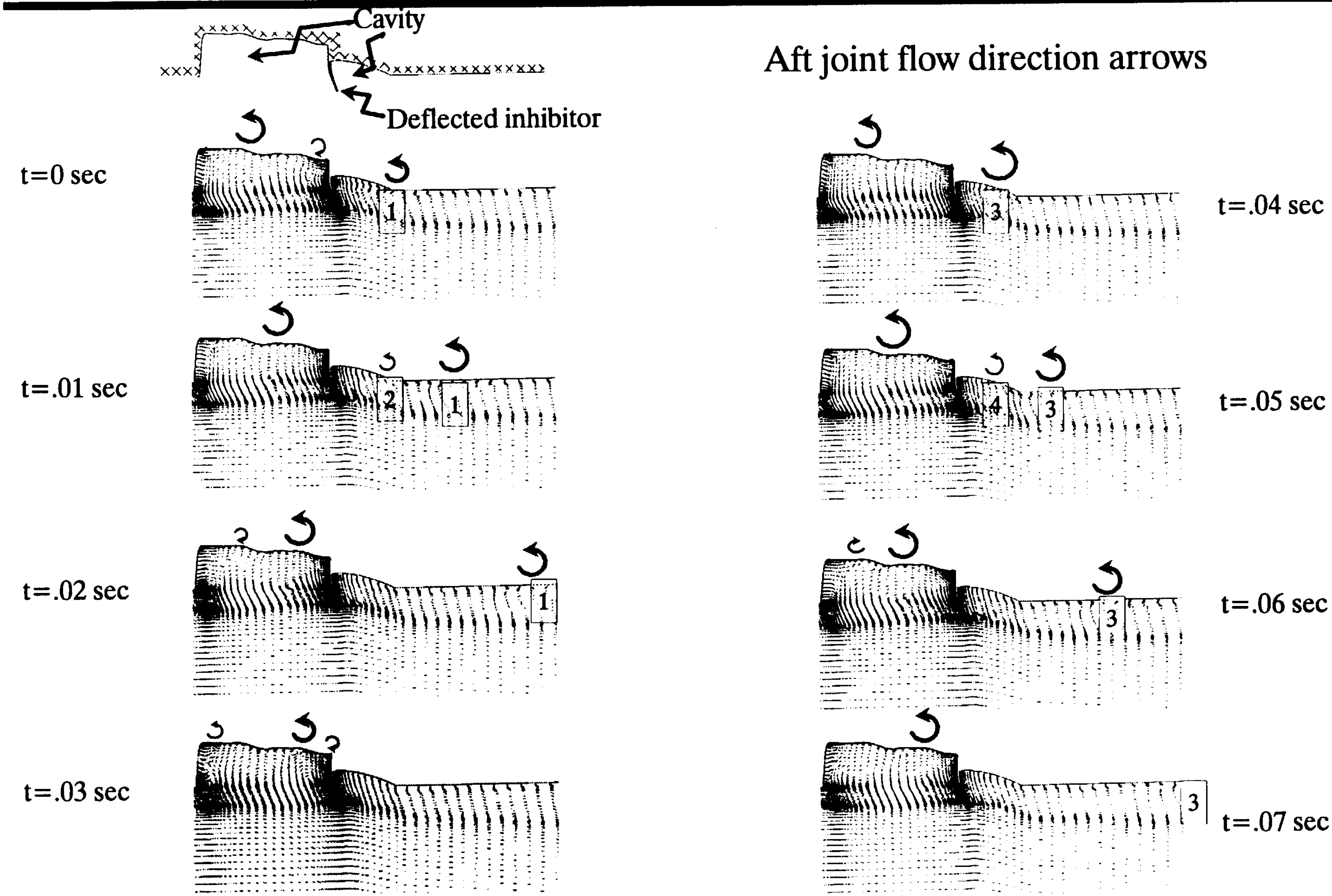
t=.05 sec

t=.06 sec

t=.07 sec

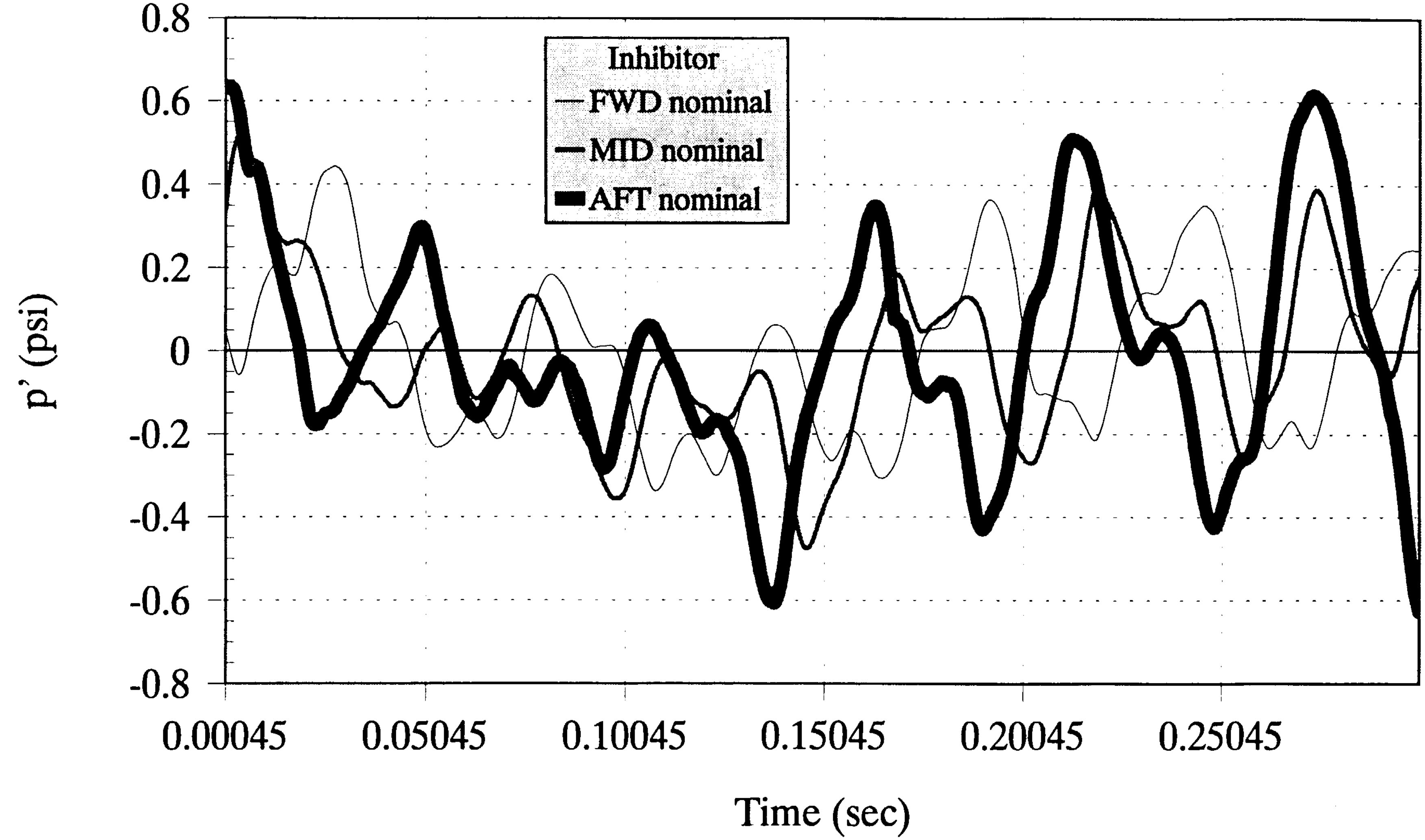
RSRM Unsteady CFD

Aft joint flow direction arrows



RSRM Unsteady CFD Timeplot

Fluctuating Pressure Downstream of Inhibitor Tip



RSRM Unsteady CFD
Power Spectral Density

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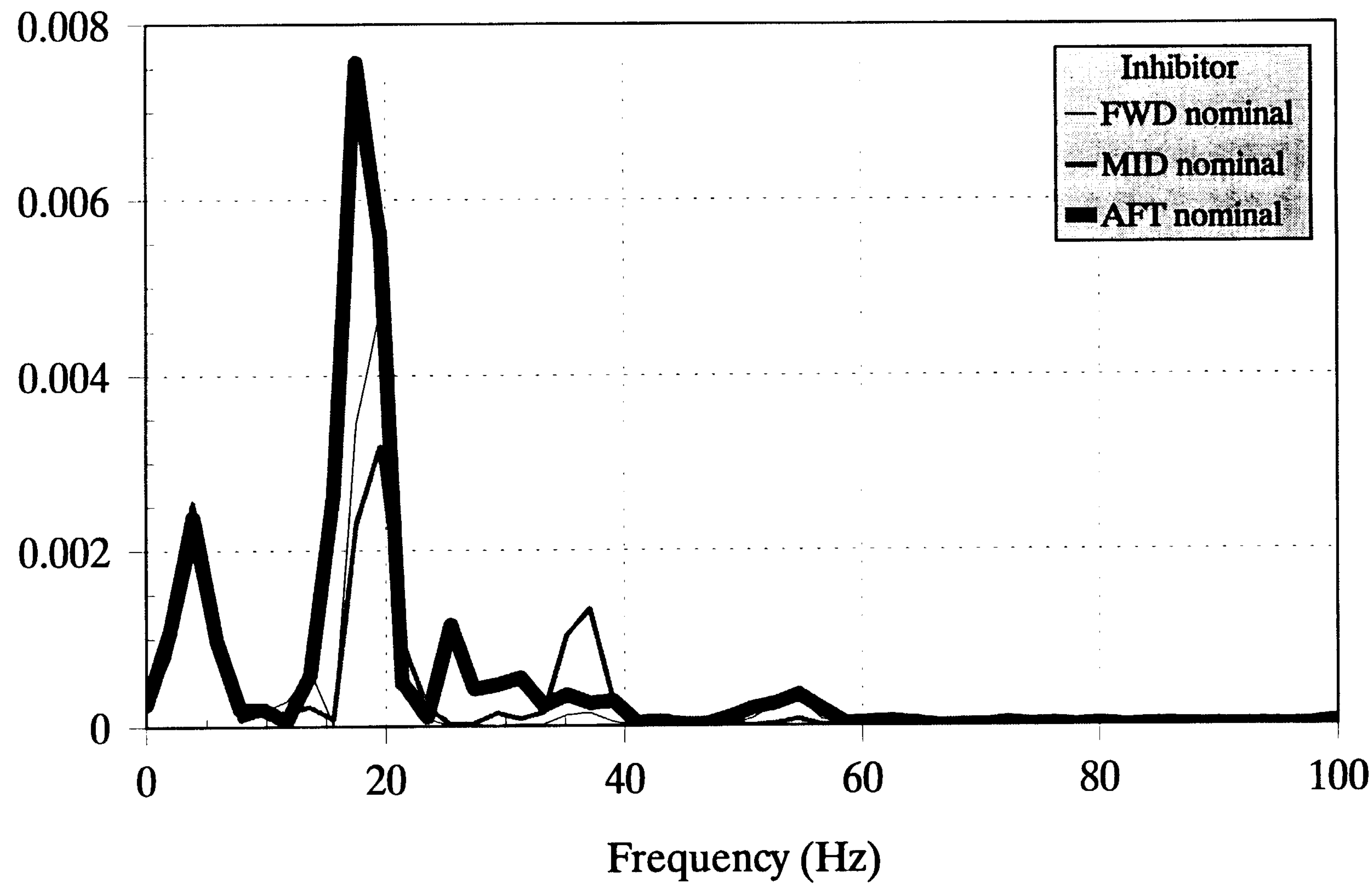
Fluctuating Pressure Downstream of Inhibitor Tip



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Summary of Present Unsteady CFD Results

- RSRM Pc oscillations dominated by organ pipe modes
- These acoustic modes excite or are excited by shedding of vortices within motor
- Vortex shedding in joint cavities and at inhibitors
- Vortex shedding at second open-closed organ pipe frequency
- Essential questions remain unanswered
    - Do vortices gain energy from feedback mechanism?
    - What is the feedback mechanism?
- Further studies planned with this model
    - Extend analysis domain downstream of nozzle throat
    - Evaluate using pressure gradient magnitude