Rocket Engine Turbine On-Blade Fluctuating Pressure Experimental Work

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Outline

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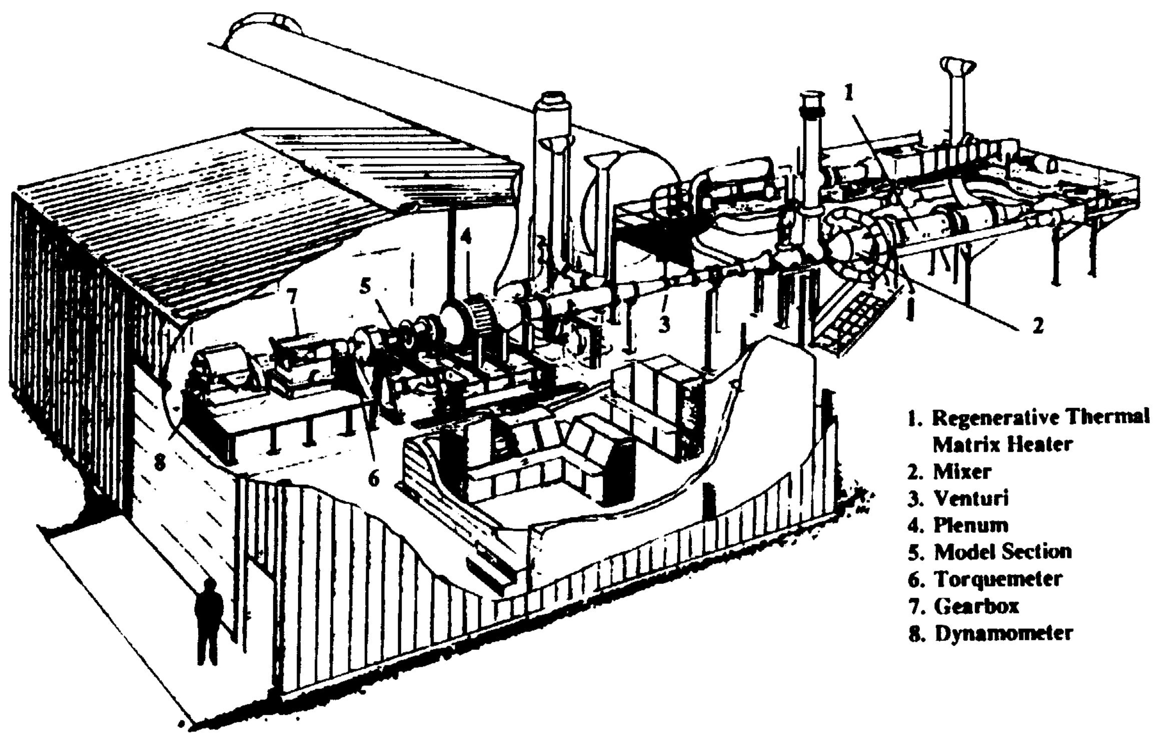
- SSME HPFT On-Blade Effort
  - Model Description
  - Instrumentation
  - Unsteady Data
    - Calibration Issues
    - Signal Analysis
    - Blade Surface Pressure Mappings
- Turbine Performance Optimization Effort
  - Objectives of On-Blade Experimental Work
  - Incorporation of Lessons Learned from SSME HPFT Effort

Background

- Flowfield unsteadiness major factor in turbine performance and life
- Cold-flow testing conducted at NASA MSFC (1998) to increase understanding of unsteady environments for rocket engine turbines
  - SSME HPFT (RKDYN) 1st Stage On-Blade Fluctuating Pressures
  - Unique data set
    - Obtained several minutes of data per setpoint
    - Extensive steady performance database for turbine
- On-blade fluctuating pressure mapping in work supporting Turbine Performance Optimization effort
  - Supersonic turbine
  - Incorporate lessons learned from SSME HPFT effort

SSME HPFT On-Blade Effort



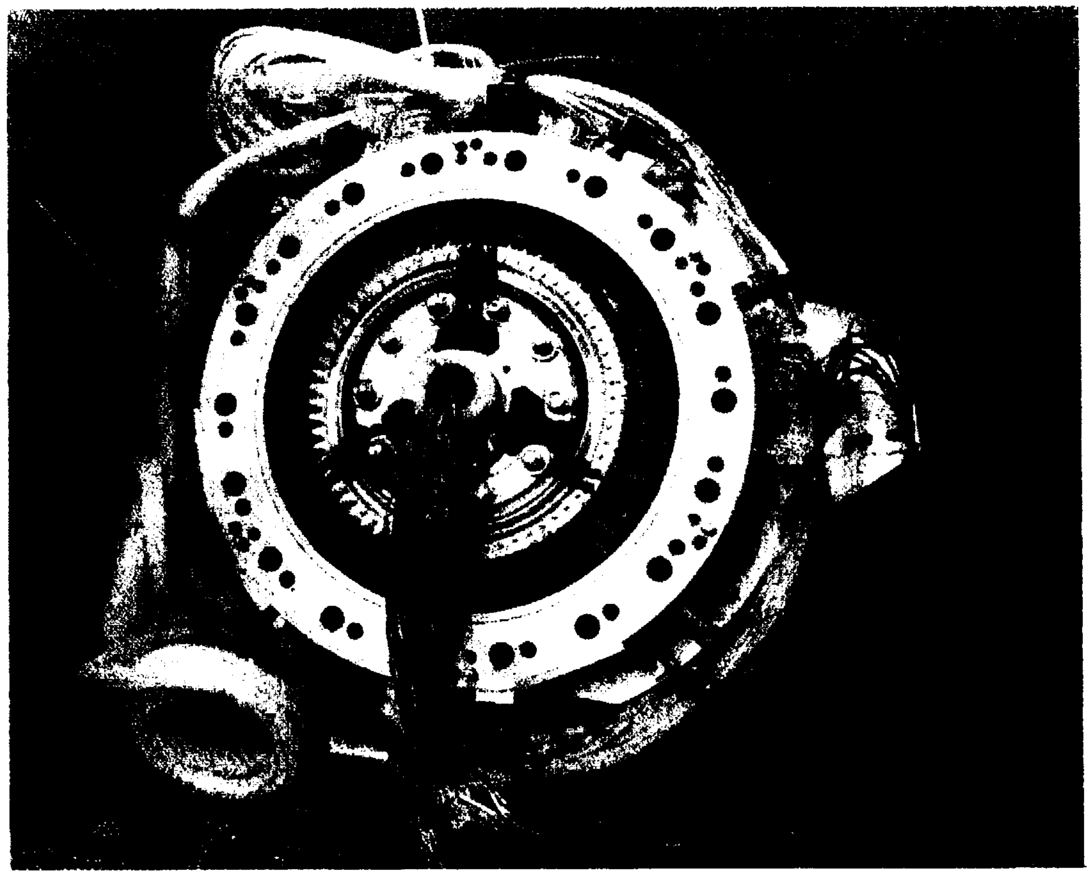
1. Regenerative Thermal Matrix Heater
2. Mixer
3. Venturi
4. Plenum
5. Model Section
6. Torquemeter
7. Gearbox
8. Dynamometer

Schematic of Turbine Test Facility (TTE)

SSME HPFT On-Blade Effort

- Rocketdyne space shuttle main engine (SSME) high pressure fuel turbopump (HPFTP) turbine
- Full-scale
- Inlet struts, stators, and rotors accurately duplicated gas path geometry (engine hardware)
  - 13 inlet struts
  - 41 1st stage stators
  - 63 1st stage rotors
  - 39 2nd stage stators
  - 59 2nd stage rotors

SSME HPFT On-Blade Effort

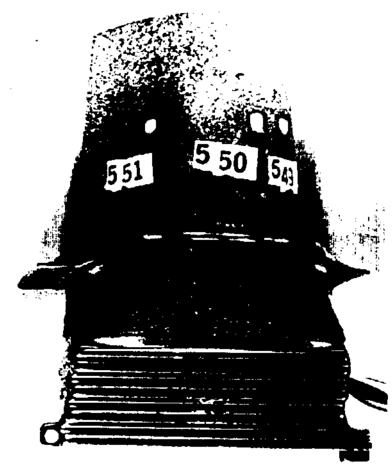


SSME HPFTP Turbine Test Article Instrumented with On-Blade Kulite Pressure Transducers

SSME HPFT On-Blade Effort

- Kulite pressure transducers on 7 of the 1st stage blades

90% Span—3 pressure/3 suction
10% Span—3 pressure/4 suction
50% Span—4 pressure/7 suction



SSME HPFT On-Blade Effort

- Facility Set Points: P_{01}, T_{01}, N, Pr
- Old Design Point (ODP):
  - P_{01}=100 psia
  - T_{01}=550° R
  - N=6982 RPM
  - Pr=1.47
- Calspan Set Point (CSP):
  - P_{01}=50 psia
  - T_{01}=550° R
  - N=6747 RPM
  - Pr=1.61

SSME HPFT On-Blade Effort

- Two unsteady data acquisition and processing platforms used in turbine on-blade characterization
  - Labview driven single-channel transient data recorders
  - 32 channel CADDMAS
    - 100 kHz bandwidth
    - real time display of 32 channels and storage to local disk

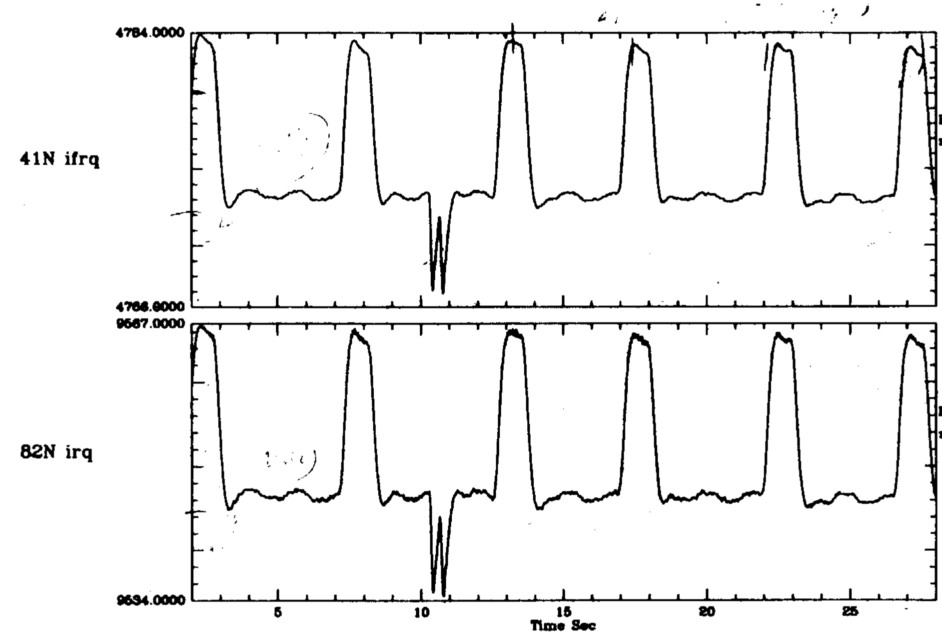
- Fluctuating pressure calibration difficulties encountered during experimental series
  - Bias temperature sensitivity
  - successful calibrations achieved with adequate thermal soak of blades during end-to-end channel cals

SSME HPFT On-Blade Effort

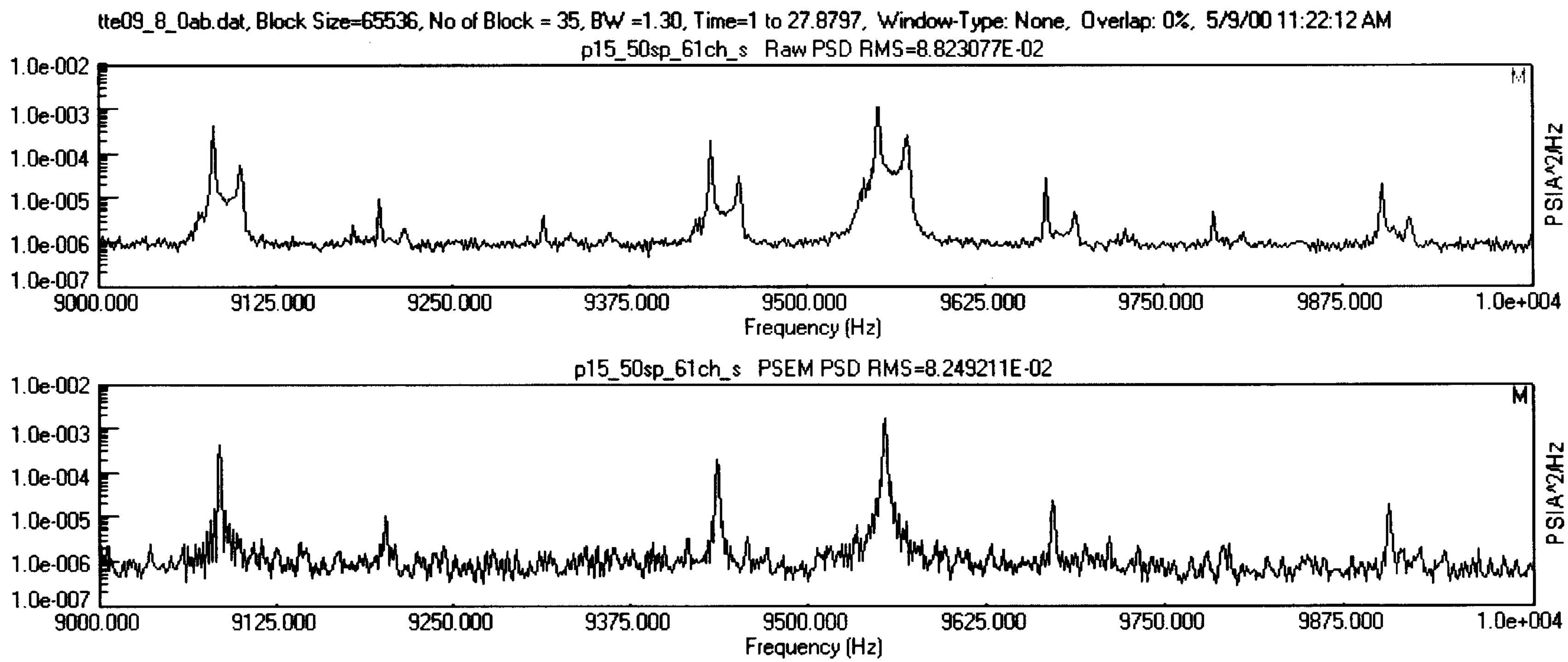
- Rotating machinery diagnostic signal processing tools invaluable in on-blade mapping effort
  - synchronous time average (STA)
  - phase synchronized enhancement method (PSEM)

Instantaneous frequency variation of rotation

18 RPM peak-peak at 0.19Hz



SSME HPFT On-Blade Effort



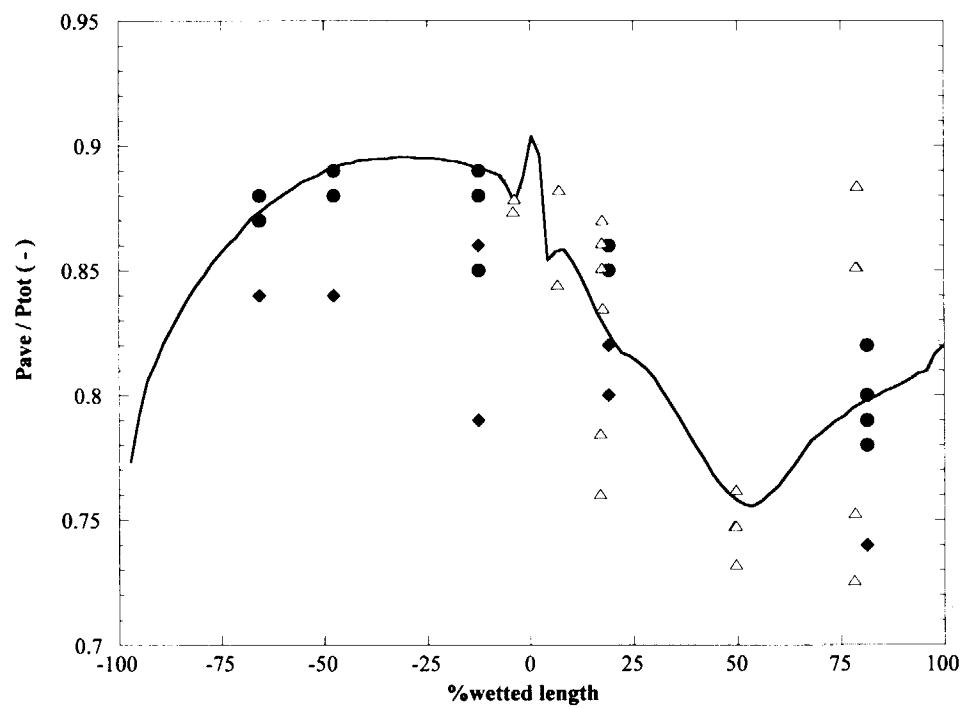
Standard and Enhanced Pressures at 1st Harmonic of 1st Vane Passage Frequency

SSME HPFT On-Blade Effort

- Signal enhancement methods allowed accurate mapping of on-blade environments across chord and span
  - average pressure distributions
  - unsteady envelope
  - vane passing content

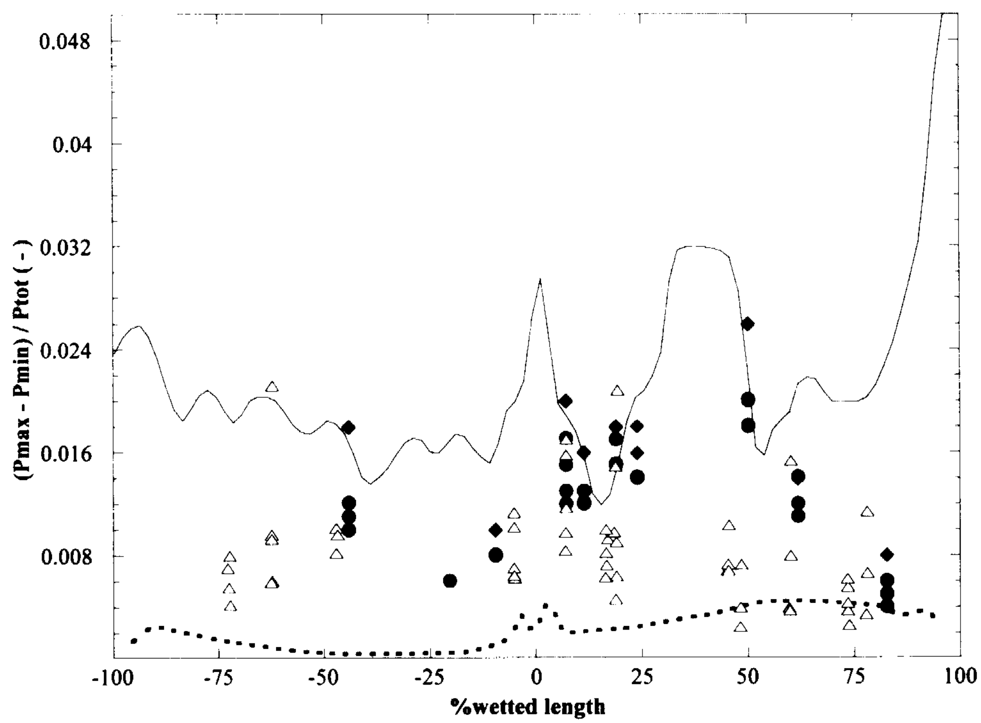
- On-blade pressure waveforms over complete revolution best indicate flow field intricacies of turbine environment
  - understanding phasing and attenuation of wavelets across span and chord will allow us to fill in gaps
  - lots of information to pass on to structures and stress

SSME HPFT On-Blade Effort



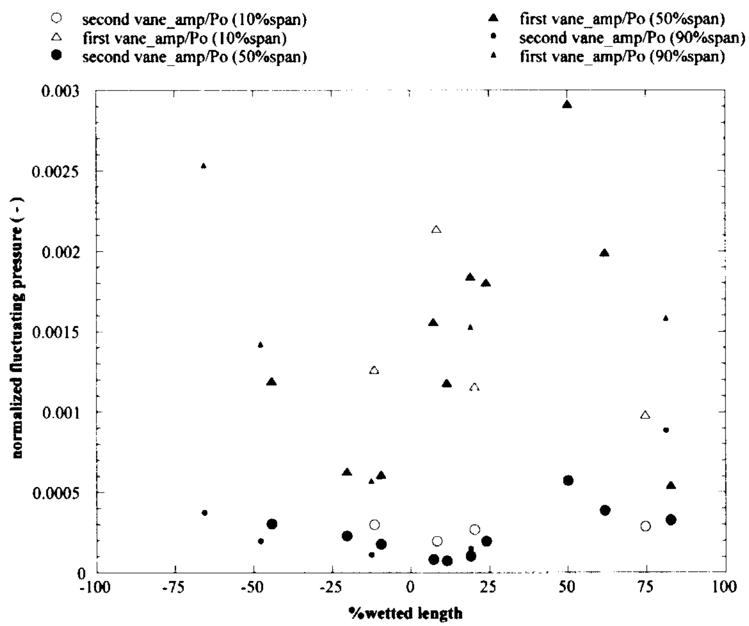
90% Span Normalized Average Pressure versus Wetted Length

SSME HPFT On-Blade Effort

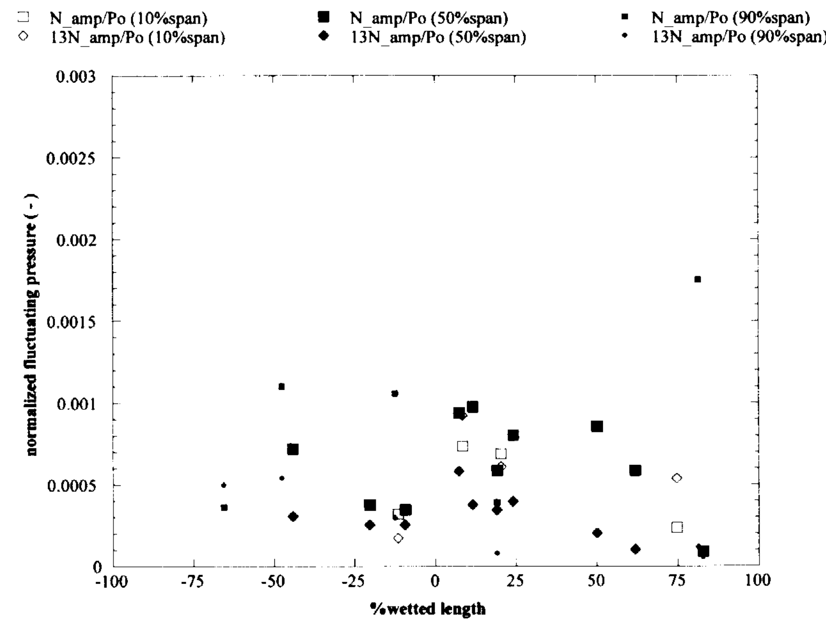


50% Span Normalized Pressure Envelope versus Wetted Length

SSME HPFT On-Blade Effort

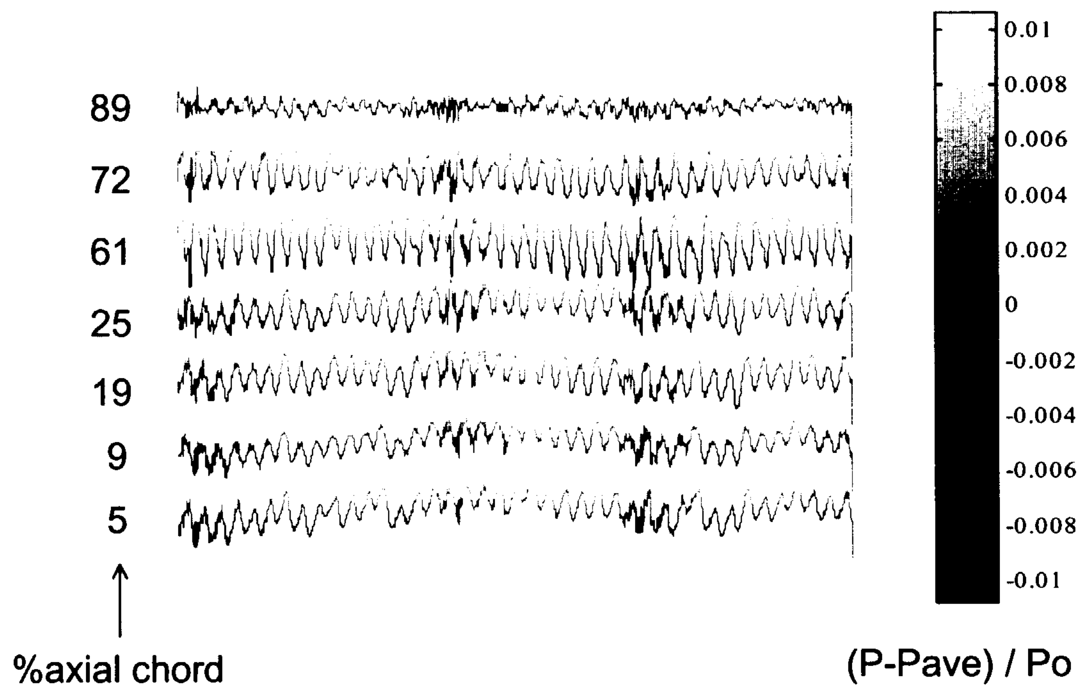


Normalized Vane Passage Response versus Wetted Length



Normalized Synchronous and Inlet Strut Passage Responses versus Wetted Length

SSME HPFT On-Blade Effort



Normalized Time Averaged Surface Pressures at 50% Span Suction Side

Turbine Performance Optimization Effort

- "there exist no unsteady data for design or analysis validation for supersonic turbines"
- Center Director Discretionary Fund: Dynamic Data for Supersonic Turbines
  - running concurrently / in support of Turbine Performance Optimization task
  - provide on-blade pressures for optimized supersonic blade through cold-flow testing
    - identify blade surface pressure steady/unsteady features at both nominal and off-design conditions
    - validate analytical (time-accurate CFD) design methods
    - study inlet flow features across several inlet designs (vanes, nozzles) and characterize potential instabilities

Turbine Performance Optimization Effort

- Applying lessons learned from SSME HPFT effort
  - Kulite / Oxford University providing complete calibration of instrumented blades
    - novel temperature calibration approach
    - acceleration (“g”) sensitivity
    - frequency response
  - perform extensive verification of temperature and acceleration effect compensations
    - dry tare vacuum runs at speed suggested by Air Force Research Laboratory
    - run scaled setpoints at various speeds, temperatures
  - streamline unsteady post-processing focusing on flow features most pertinent to CFD verification and Structures / Stress
    - 100 kHz over 32 channels over 3 minutes over dozens of tests over several builds makes for tired experimentalists and lots of data storage

Turbine Performance Optimization Effort

- Applying lessons learned from SSME HPFT effort (continued)
  - buy most robust sensor for environment
    - lost 9 of 24 on-blade pressure sensors in SSME testing
  - get unsteady data first
    - verify at setpoint and take high frequency data