6-1987

In-Duct Measurement of Turbocharger Noise

William L. Krasson
Purdue University

J Stuart Bolton
Purdue University, bolton@purdue.edu

IN-DUCT MEASUREMENT OF TURBOCHARGER NOISE

W. L. Krasson
J. S. Bolton

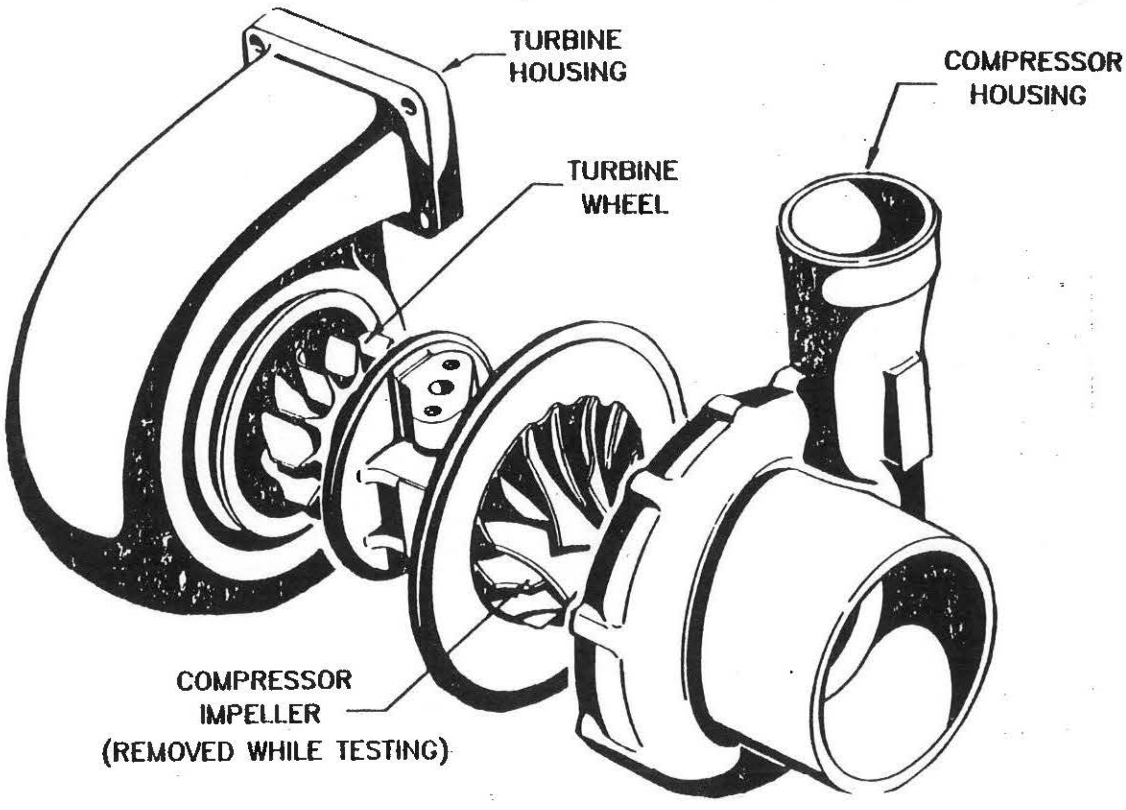
Ray W. Herrick Laboratories,
School of Mechanical Engineering,
Purdue University,
West Lafayette,
IN 47907.

HERRICK LABS / PURDUE UNIVERSITY

INTRODUCTION

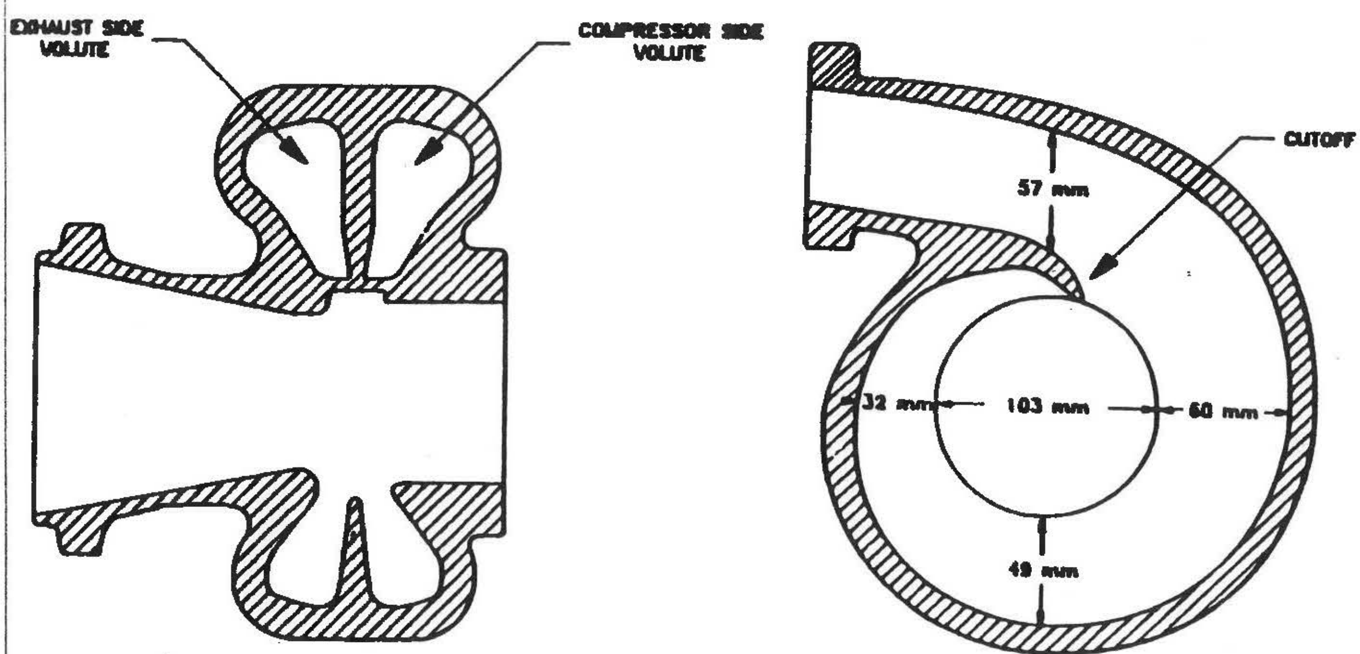
- **Turbocharger**
  - as used on large diesel truck engines
- **Noise Control**
  - noise radiated downstream from turbine side
- **Objective**
  - a measurement technique which indicates effect of modifications and is independent of precise rig geometry
- **Approach**
  - define measurement empirically
  - investigate its character theoretically

TURBOCHARGER ASSEMBLY



HERRICK LABS / PURDUE UNIVERSITY

TURBINE HOUSING SECTION



HERRICK LABS / PURDUE UNIVERSITY

EXPERIMENTAL PHASE

- **Centrifugal Fans**
  - — single mic with flow noise suppressor
  - — choose radial location so that $W = p_{rms}^2 S/\rho c$ is approximately true
  - — technique adapted to broadband sources (uncorrelated modes)
- **Problems**
  - — frequency response and directivity of suppressor
  - — assumption that "typical point" can be found when noise is predominantly tonal and multi-modal

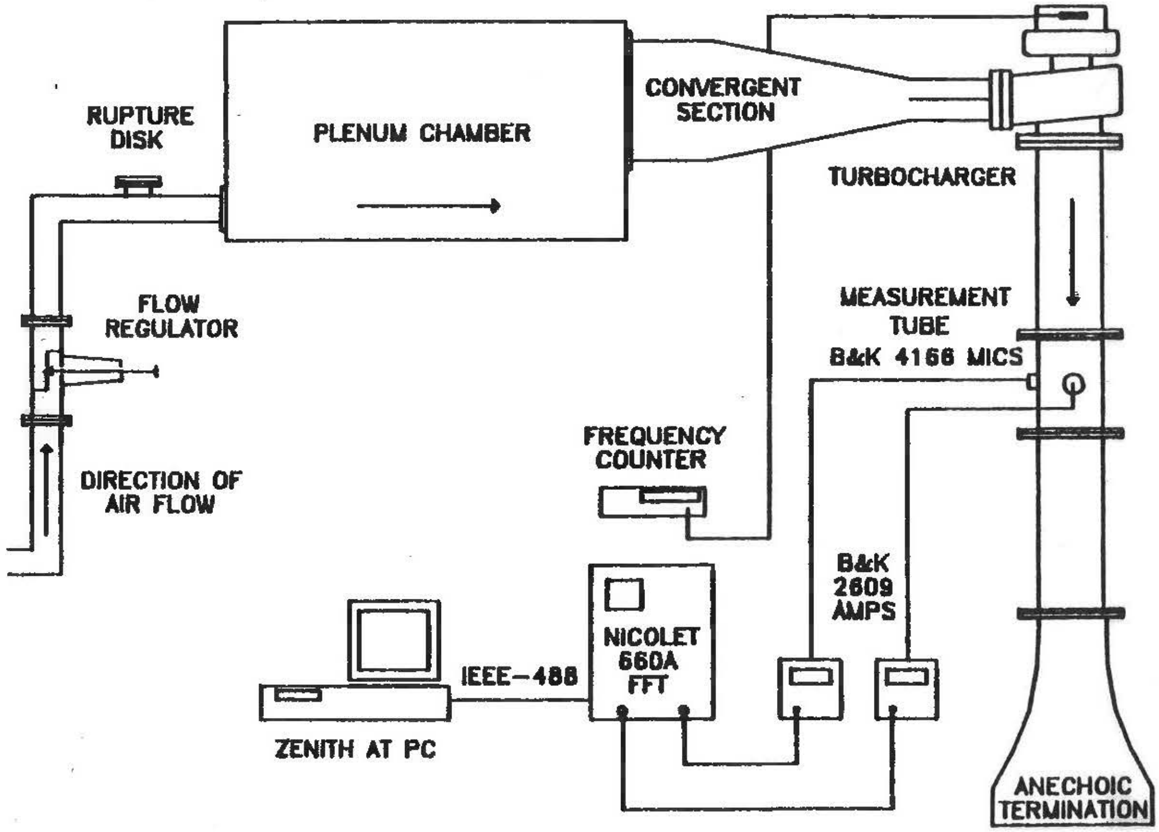
EXPERIMENTAL PHASE

- **Suggested Solution**
  - circumferentially average mean squared pressure measured at duct periphery

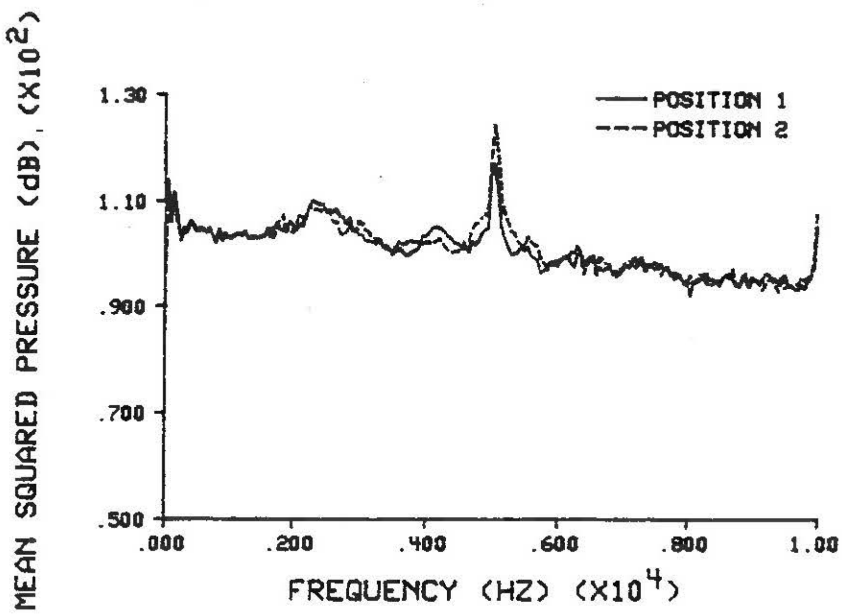
$$(p_{rms}^2)_{av} = \frac{1}{2\pi}\int_0^{2\pi} p_{rms}^2 d\theta$$

  - p_{rms}^2 measured at duct circumference with flush mounted pressure microphone
- **Possible Problem**
  - boundary layer noise

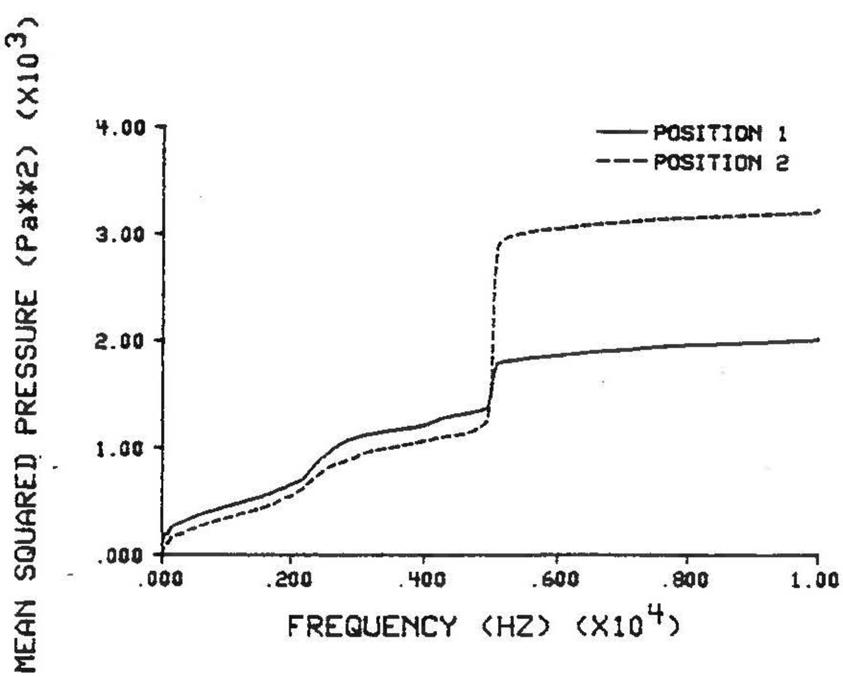
MEASUREMENT RIG



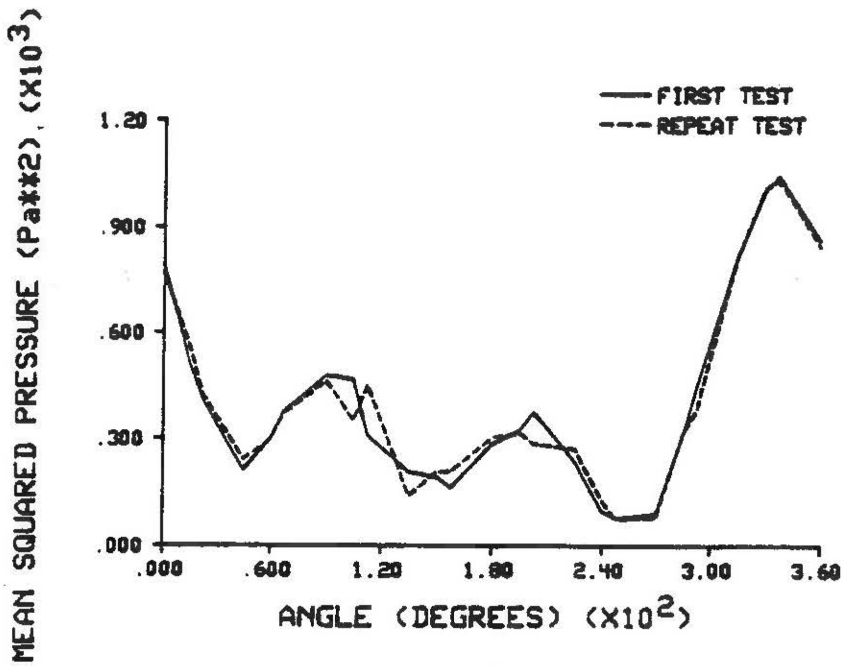
HERRICK LABS / PURDUE UNIVERSITY



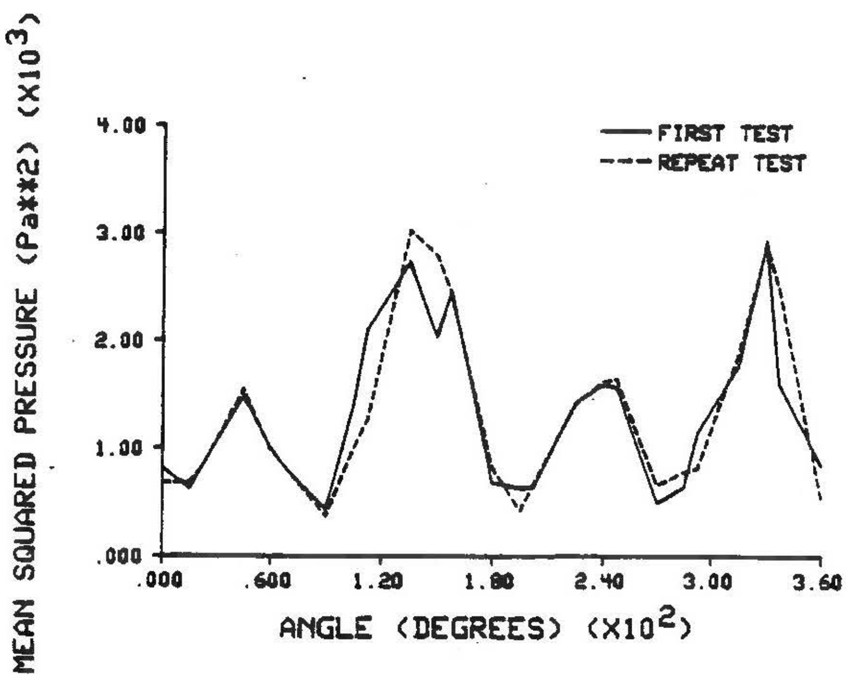
Preliminary 6-Speed Test
Power Spectra at 25000 RPM



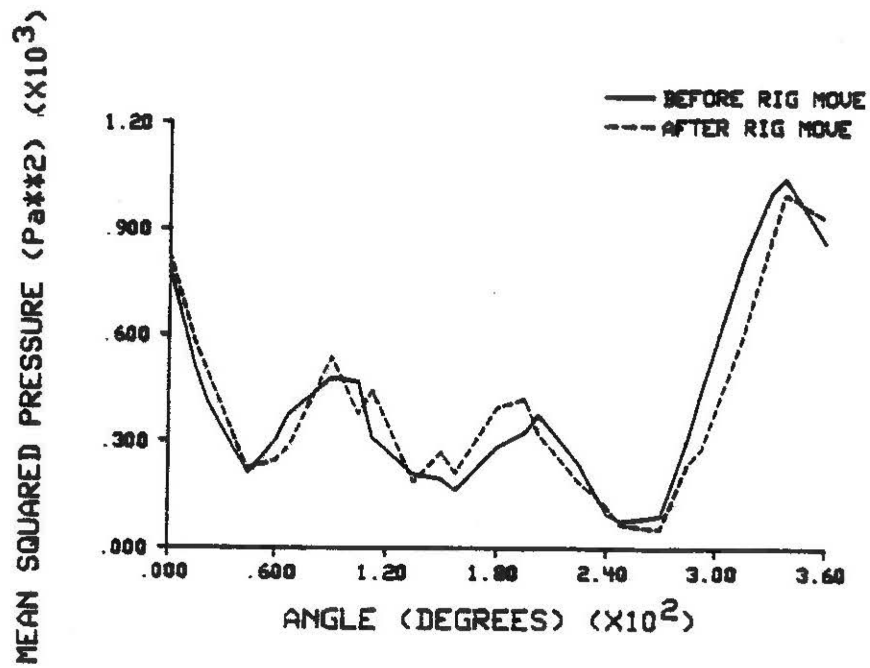
Preliminary 6-Speed Test
Cumulative Pressure Distributions
at 25000 RPM



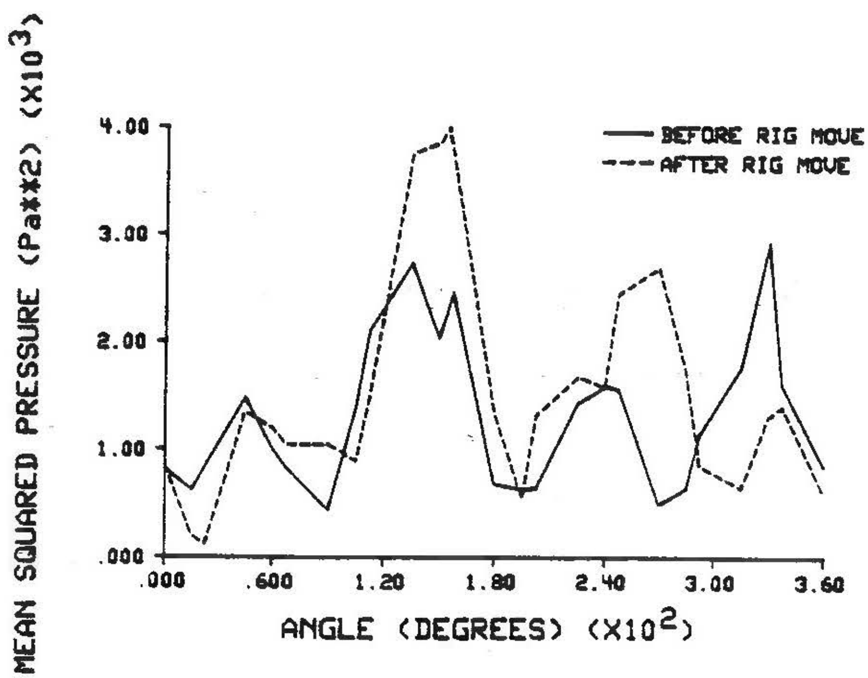
Results of Preliminary and Repeat
25-Point Tests
Circumferential Pressure Distributions
at 20000 RPM



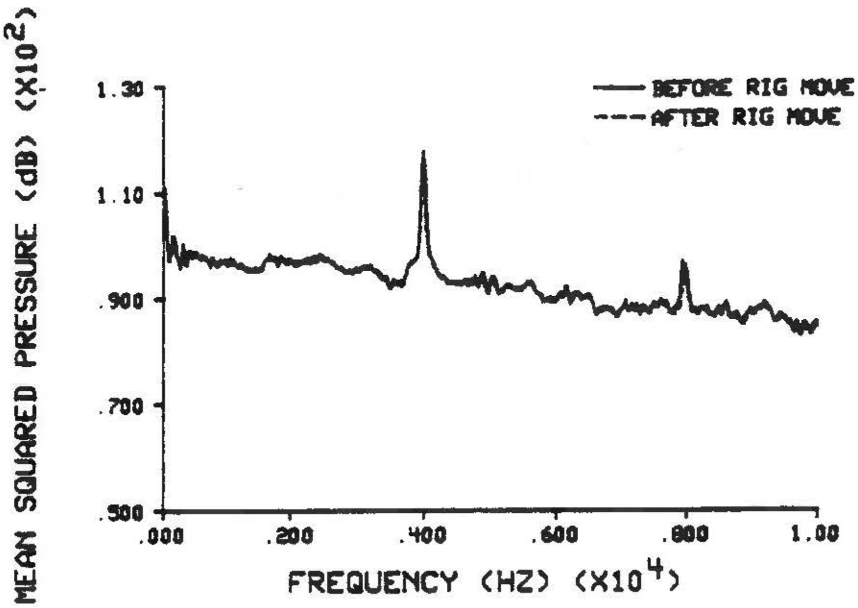
Results of Preliminary and Repeat
25-Point Tests
Circumferential Pressure Distributions
at 25000 RPM



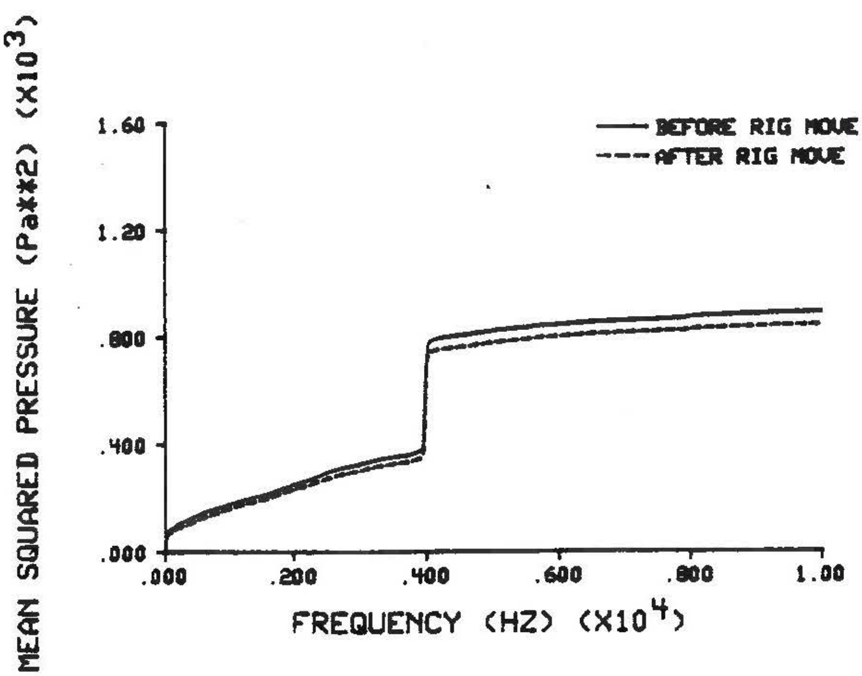
Comparison of 25-Point Tests Before and After Rig Move
Circumferential Pressure Distributions at 20000 RPM



Comparison of 25-Point Tests Before and After Rig Move
Circumferential Pressure Distributions at 25000 RPM



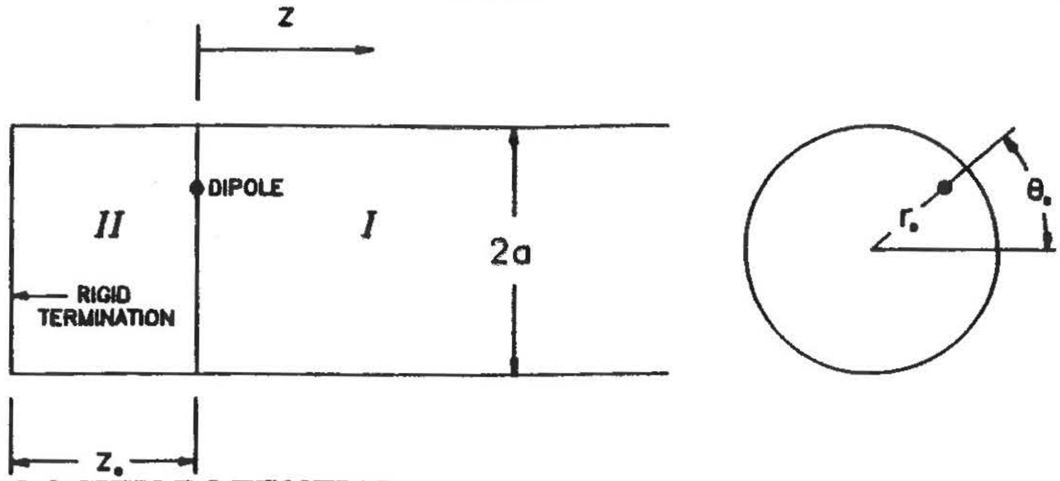
Comparison of Average Power Spectra at 20000 RPM



Comparison of Average Cumulative Pressure Distributions at 20000 RPM

THEORETICAL PHASE

- **Question**
  - — how is circumferentially averaged mean squared pressure related to downstream radiated sound power?
- **Investigate**
  - — sound radiation from an axial dipole located at position of cutoff
  - — for given source strength, calculate:
    - — averaged pressure
    - — sound power
    - — proportionality between them



VELOCITY POTENTIAL

$$\Phi(r,\theta,z,t) = \sum_{m=0}^{\infty} \sum_{n=1}^{\infty} J_m(\gamma_{mn} r)[A_{mn} \cos(m\theta) + B_{mn} \sin(m\theta)] e^{-jk_{mn}z} e^{j\omega t}$$

$$p(r,\theta,z,t) = \rho \frac{\delta\Phi}{\delta t}$$

$$u_z(r,\theta,z,t) = -\frac{\delta\Phi}{\delta z}.$$

$$p(r,\theta,z,t) = j\omega \sum_{m=0}^{\infty} \sum_{n=1}^{\infty} J_m(\gamma_{mn} r) [A_{mn} \cos(m\theta) + B_{mn} \sin(m\theta)] e^{-jk_{mn}z} e^{j\omega t}$$

CASE 2 - DIPOLE NEXT TO RIGID TERMINATION

Boundary Conditions:

$$u_z^{II}(r,\theta,-z_o,t) = 0$$

$$p_1(r,\theta,0,t) - p_2(r,\theta,0,t) = P_0\delta(\underline{R} - \underline{R}_0)e^{j\omega t}$$

Coefficients:

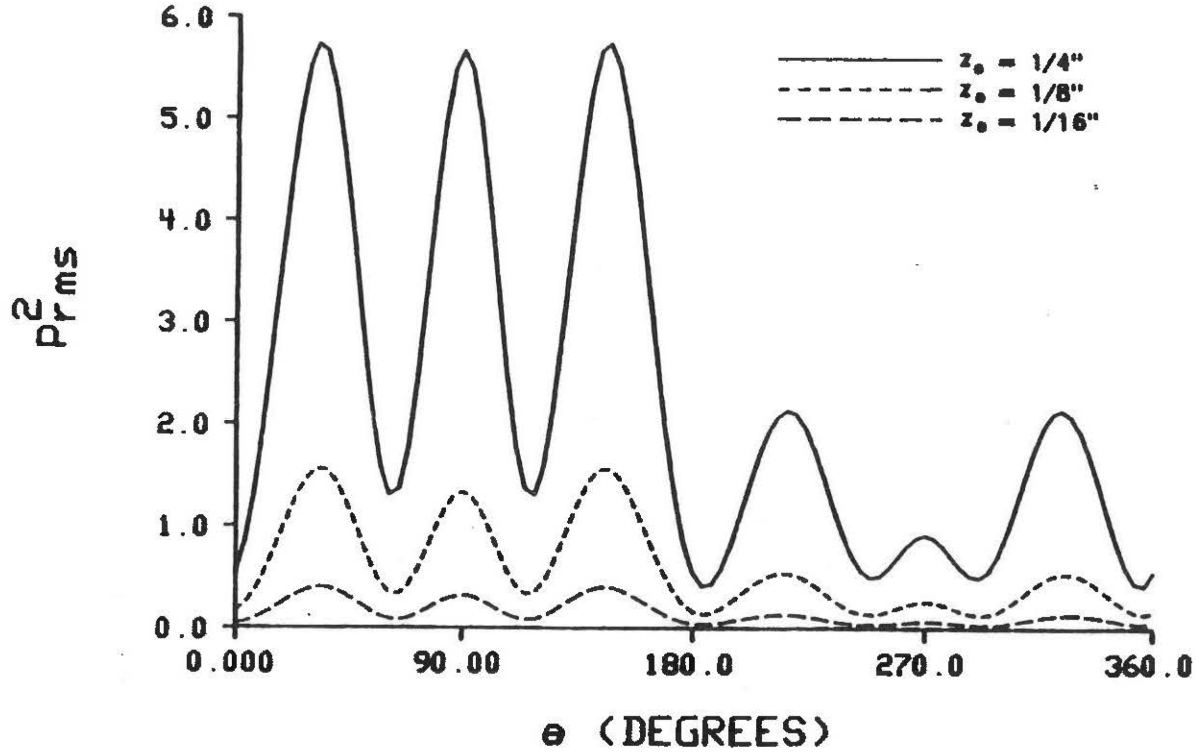
$$A_{mn} = -j\frac{\beta_{mn}}{\omega\rho\Gamma_{mn}} P_0 J_m(\gamma_{mn} r_o)\cos(m\theta_o)$$

$$B_{mn} = -j\frac{\beta_{mn}}{\omega\rho\Gamma_{mn}} P_0 J_m(\gamma_{mn} r_o)\sin(m\theta_o)$$

$$\beta_{mn} = \frac{j\sin(k_{mn} z_o)}{\cos(k_{mn} z_o) + j\sin(k_{mn} z_o)}$$

ANGULAR PRESSURE VARIATION

- **Axial Dipole - Rigid Termination**



HERRICK LABS / PURDUE UNIVERSITY

BASIC EXPRESSIONS: Circumferentially Averaged Mean Squared Pressure

$$\bar{p}^2_{rms} = \frac{1}{2\pi a} \int_0^{2\pi} \frac{1}{2} p(r = a) p^*(r = a) a d\theta$$

$$\bar{p}^2_{rms} = \frac{\omega^2 \rho^2}{2} \sum_{m=0}^{\infty} \sum_{n=1}^{\infty} \sum_{q=1}^{\infty} J_m(\gamma_{mn} a) J_m(\gamma_{mq} a)\ \epsilon_m$$

$$\cdot\ [A_{mn} A^*_{mq} + B_{mn} B^*_{mq}] e^{-j(k_{mn} - k_{mq})z}$$

BASIC EXPRESSIONS: Power

$$I_z(r,\theta,z,t) = \frac{1}{2} \operatorname{Re} (p u_z^*)$$

$$W = \int_{\theta=0}^{2\pi} \int_{r=0}^{a} I_z(r,\theta,z,t) \, r dr d\theta$$

$$W = \frac{\rho\omega}{2} \sum_{m=0}^{\infty} \sum_{n=1}^{\infty} k_{mn} \Gamma_{mn} [A_{mn}^2 + B_{mn}^2]$$

$$A_{mn}^2 = A_{mn} A_{mn}^*$$

$$B_{mn}^2 = B_{mn} B_{mn}^*$$

SOUND POWER

$$W = \eta \, \frac{\overline{p}_{rms}^{2} \cdot S}{\rho c}$$

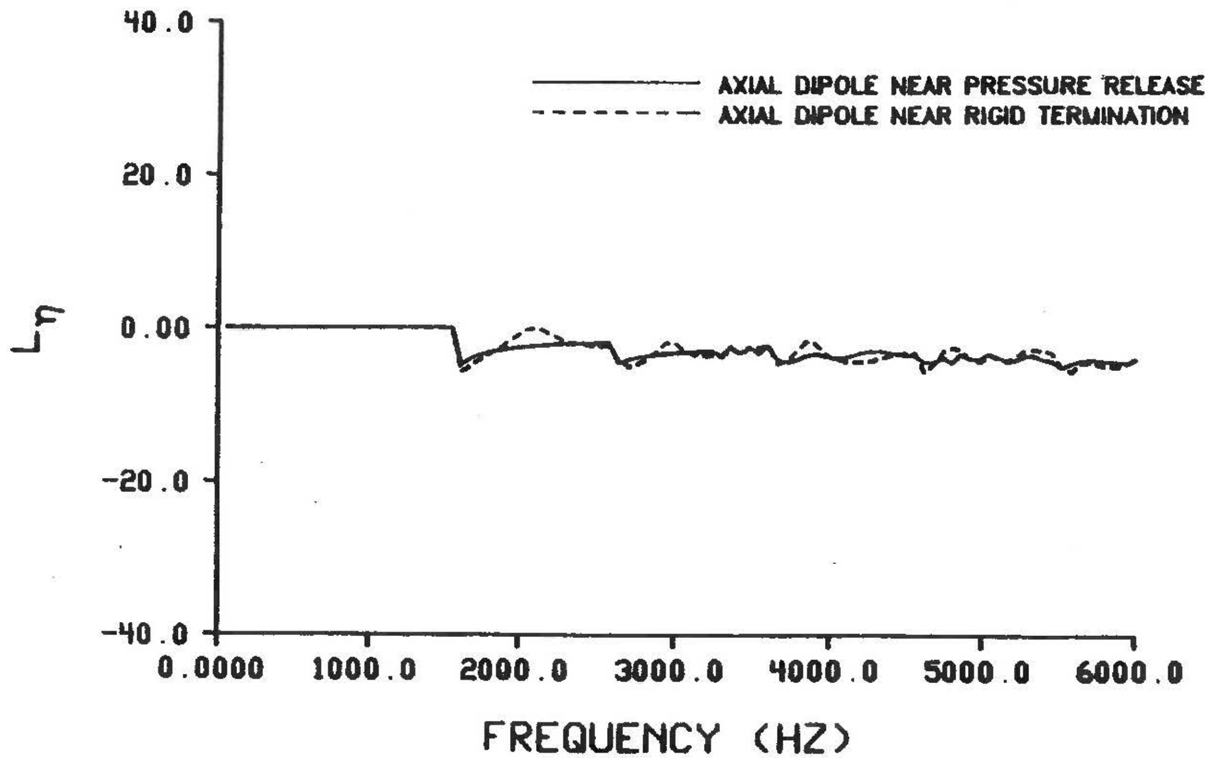
$$10 \log_{10} \left[\frac{W}{W_{ref}} \right] = L_{\eta} + 10 \log_{10} \left[\frac{\overline{p}_{rms}^{2} \cdot S}{\rho c \, W_{ref}} \right]$$

where:

$$L_{\eta} = 10 \log_{10} (\eta)$$

PROPORTIONALITY FACTOR

$$\eta = W\left[\frac{\bar{p}_{rms}^{2} S}{\rho c}\right]^{-1}, \qquad L_\eta = 10 \log_{10}\eta$$



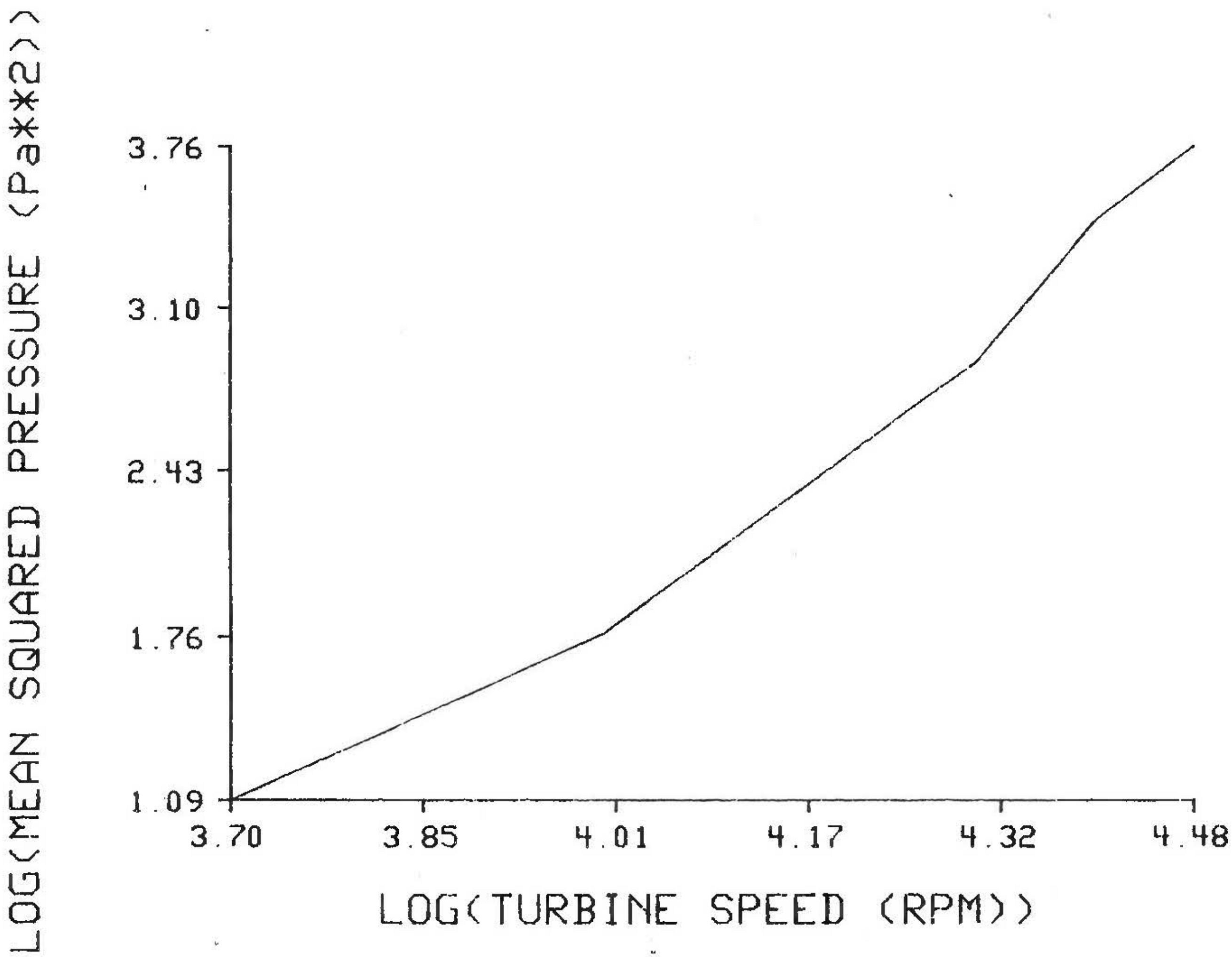


Figure 5.2.14 Logarithmic Total Pressure Distribution of Unmodified, Unsplit Turbocharger

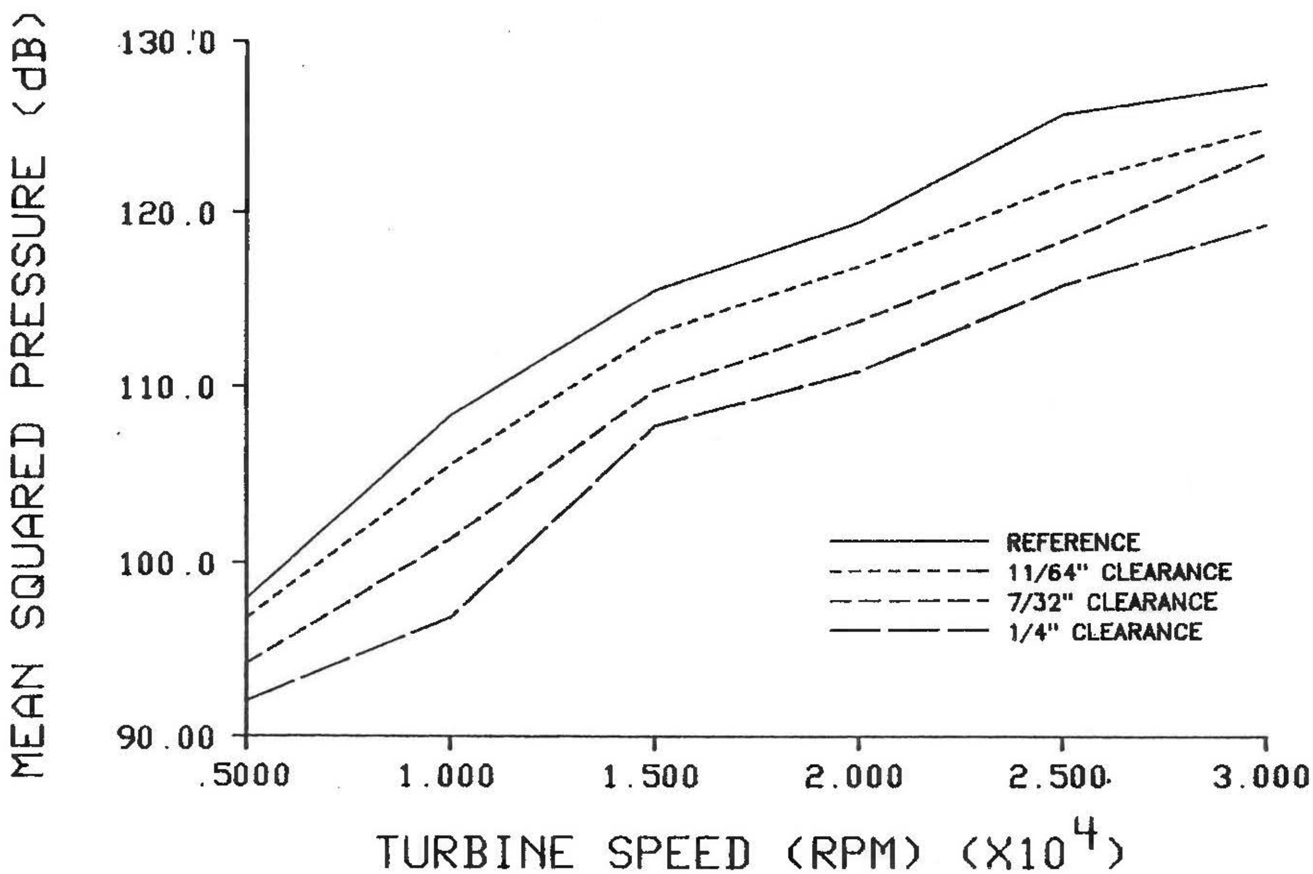
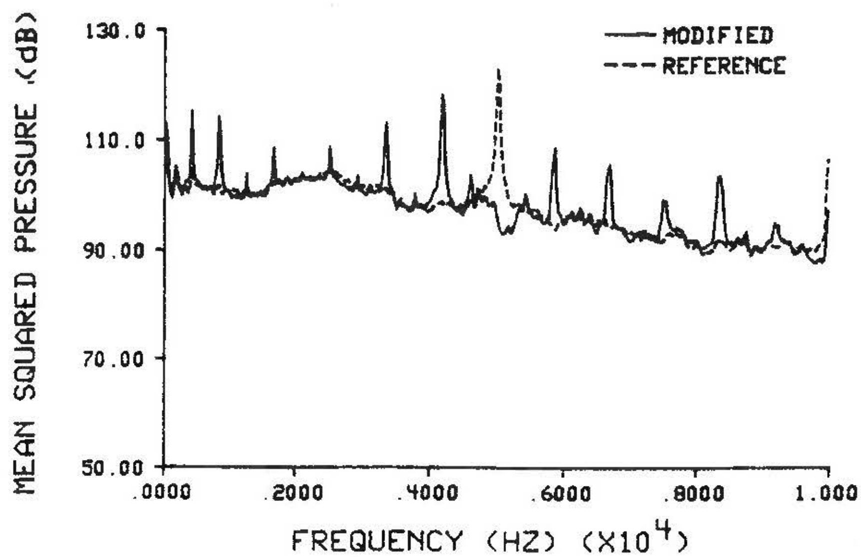
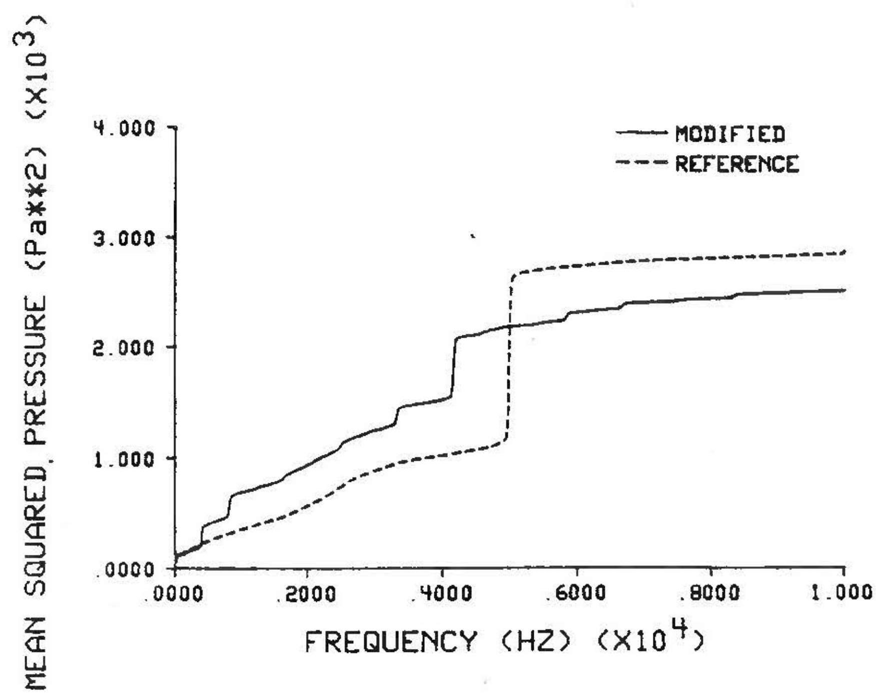


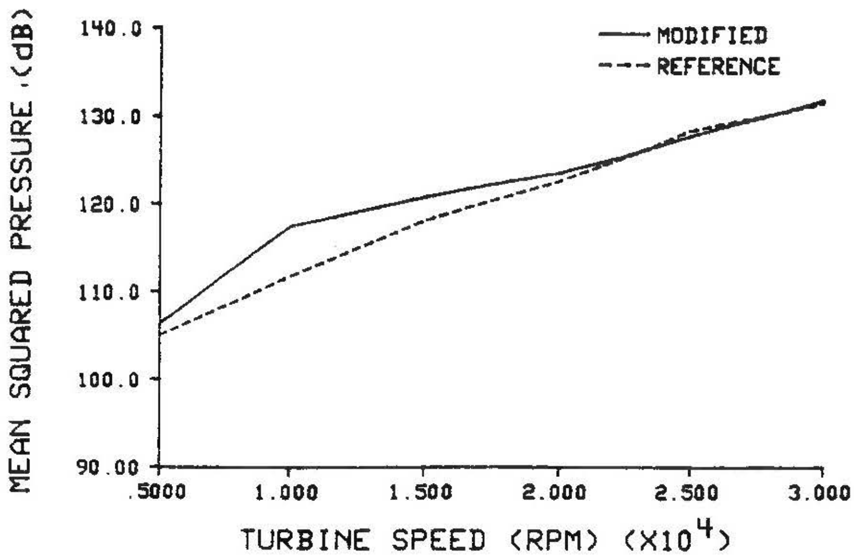
Figure 5.3.2 Fundamental Pressure Distributions Resulting From Increased Blade/Cutoff Clearance



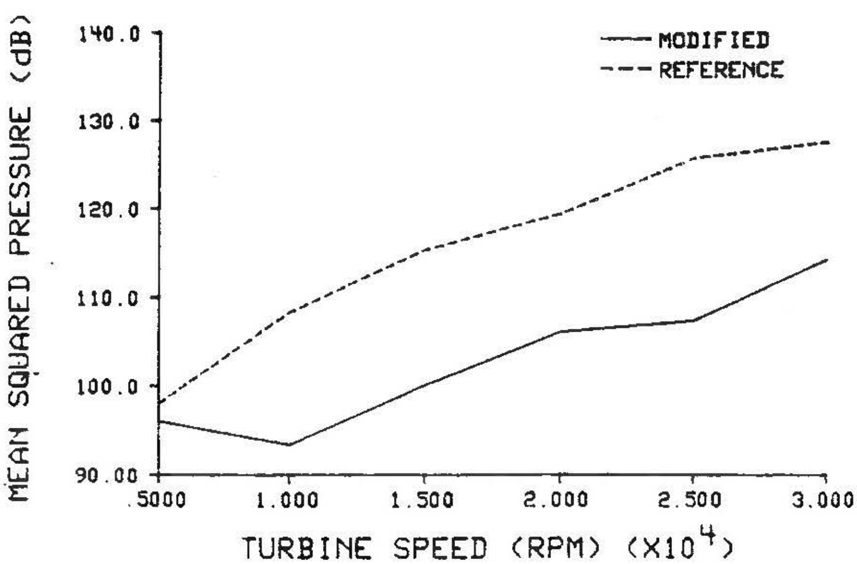
Average Power Spectrum at 25000 RPM Resulting from Modulated Blade Spacing ($\Delta\theta = 11^\circ$)



Average Cumulative Pressure Distribution at 25000 RPM Resulting from Modulated Blade Spacing ($\Delta\theta = 11^\circ$)



Total Pressure Distribution Resulting from Modulated Blade Spacing ($\Delta\theta=11^{o}$)



Fundamental Pressure Distribution Resulting from Modulated Blade Spacing ($\Delta\theta=11^{o}$)

CONCLUSIONS

- Circumferential variation of downstream radiated sound pressure is significant
- Experimentally it has been shown that the circumferentially averaged mean squared pressure is independent of small rig changes
- Theory indicates that averaged pressure may be used to calculate sound power to accuracy of several decibels
- Circumferentially averaged mean squared pressure may be used to judge success of noise control modifications