Penn State Center for Acoustics and Vibration (CAV)

Structural Vibration and Acoustics Group
Presented as part of the 2013 CAV Spring workshop

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Today's topics

- Quiet rotorcraft roof panels
  - Dr. Steve Hambric

- Martin guitar structural-acoustics
  - Micah Shepherd, ARL and PhD student, Acoustics

- Requalification of CAV's hemi-anechoic room
  - Paul Bauch, MS student, Acoustics

- Sonic fatigue of aircraft panels
  - Matt Shaw, PhD student, Acoustics
Quiet Rotorcraft Roof Panels

Principal Investigators:  Dr. S.A. Hambrick, Dr. K.L. Koudela, M.R. Shepherd (PhD, Acoustics), and D.B. Wess

Sponsor: NASA

Collaborators: Bell Helicopter, 150 Kansas State University
Rotorcraft Cabin Noise

- Strong transmission gear meshing tones excite roof panel

![Graph showing noise levels](image)

- Main rotor Bull gear mesh
- Main rotor Input Pinion gear mesh

10 dB
Baseline Panel

- Manufactured at Bell Helicopter (Textron)
Honeycomb core sandwich panel

• Stiff and lightweight
  – Carbon fiber face sheets
  – Nomex core
Baseline Panel – FE/BE modeling

- All solid quadratic elements, smeared face sheet properties
- BE model of surrounding air
Baseline Panel – FE modeling

- Inner face sheets
- Outer flange
Goals

• Validate vibro-acoustic modeling tools
  – Sound power transmission loss

• Later - use tools to assess optimized panel designs
Baseline Panel – Modes

1. For the mode labeled [1,1], the frequencies are 127 Hz FE and 122 Hz Exp.

2. For the mode labeled [2,1], the frequencies are 251 Hz FE and 247 Hz Exp.

3. For the mode labeled [3,1], the frequencies are 486 Hz FE and 487 Hz Exp.

4. For the mode labeled [2,2], the frequencies are 426 Hz FE and 438 Hz Exp.
Baseline Panel – Modes

![Graph showing FE Frequency (Hz) vs Experimental Frequency (Hz) for different values of n (n=1, n=2, n>2) and error conditions (No error, -10% error, +10% error).]
CHAMP Analysis Tools

Dynamic loads
- Flow turbulence
- Electromagnetic fields (motors, generators)
- Rotating machinery loads (gearsets, bearings)

Mode shapes and modal parameters of base structure(s)
(from in-vacuo FE models and/or measurements)

Acoustic impedances of surrounding and/or entrained fluid
(from BE or FE model)

Joint modal acceptance matrix (includes all cross terms)

Mechanical impedances of connected structures
(from FE models and/or measurements)

Operational Noise and Vibration
- Structural vibration cross-spectral densities,
- acoustic pressure and particle velocity cross-spectral densities,
- power flow distribution
Radiation damping from BE model included in analysis
Center panel dominates transmitted sound power.
Transmission Loss

Simulations within 3 dB of NASA SALT measurements
Next steps

• Split panel optimized design formulated
  – Assessed with analytic tools
• Structural assessments at Bell
• Structural-Acoustic assessments at Penn State
• Build and test at NASA SALT
Martin Guitar Structural-Acoustics

Principal Investigators: M.R. Shepherd, S.A. Hambric, D.C. Swanson

Sponsor: The Martin Guitar Company
CAV Transmission Loss Facility Characterization

Principal Investigators: P. Bauch and A. Barnard

Sponsor: ARL/Penn State Walker Fellowship
Standard Qualification

- **ISO 3745**
  - 12 traverse paths with 70+ discrete points

- **ASTM E90 and E2249**
  - Measurable TL ranges from 40 dB at 400 Hz and 55 dB at 10 kHz.

1/8 in. Hardboard

2 in. Acoustic Felt
Incident Field: Beamformer

- 41 point discrete linear arrays.
- Levels normalized to reference mic and d.i.
- Beam steered in frequency domain (phase shift)
• Beamwidth within tolerances

± 3 dB is diffuse for most frequencies up to 4 kHz.

Normalized One-Third Octave Band Beamformer

Beamwidth within Tolerance (Horizontal) [degrees]

Beamwidth within Tolerance (Vertical) [degrees]
\[ \rho_{12_i}(kx_{1,2_i}) = \Re \left\{ \frac{G_{p_{1}p_{2_i}}(\omega,x)}{G_{p_{1}p_{2}} G_{p_{2_i}p_{2_i}}} \right\} = \frac{\sin(kx_{1,2_i})}{kx_{1,2_i}} \]

- Averaged over \( ka \)
- Agreement up to \( ka=5-15 \)
Incident Field: SCAF

\[ SCAF(k) = \frac{|\rho_{\text{meas}}(kx) \cdot \rho_{\text{theory}}(kx)|^2}{[|\rho_{\text{meas}}(kx) \cdot \rho_{\text{meas}}(kx)|][|\rho_{\text{theory}}(kx) \cdot \rho_{\text{theory}}(kx)|]} \]

- Spatial correlation function summed into one-third octave bands
- Diffuse field up to 4 kHz one-third octave band.
Aircraft Panel Sonic Fatigue

Principal Investigators: Matt Shaw, PhD student, Acoustics
Dr. S.A. Hambric, Dr. R. L. Campbell, Advisors

Sponsor:
Problem statement

- **Supersonic, diffusing flow downstream of nozzle**
  - Complex surface pressure fluctuations on structural panel
    - M. Lurie and Dr. Phil Morris
- **Compute panel stress time histories and spectra**
  - Use to assess fatigue damage and life
Forcing function – space/time

Pressure vs. distance and time

- Time [s]: 0.04 to 0.13
- Position (rel nozzle exit) $x/d_j$: -20 to 40
- Total Pressure [Pa]: $10^4$ to $10^6$

Throat: $x=-0.19842$
Nozzle Exit: $x=0$
Forcing function – frequency

pressure vs frequency and position downstream

Frequency, $f d_i / u_i$

Position (rel nozzle exit), $x / d_i$

Spectral Density [dB re 1 Pa/Hz]

Throat $x=-0.19842$

Nozzle Exit $x=0$
CHAMP calculations

- CHAMP 1D beam response using cross-spectral densities of CFD-based forcing functions
  - (ASD = Auto-spectral density)
  - (CSD = Cross-spectral density)
Next steps

- Time-domain vs. frequency-domain calculations
- Empirical models of turbulent flow through shock cells?
- 3D flow fields, 2D stiffened panel structure
  - Validate against measurements to be made at UTRC/P&W