A History of the Noise Control & Acoustics Division (NCAD)

Martin L Pollack, PhD.

Engineering Solutions Through Science
Outline of Presentation

- Historical Perspective on NCAD
- Samplers of State of the Art Technology
- View of NCAD into the Future
The Founding of NCAD

- 1978 .... ASME WAM in San Francisco → idea for Division established
- 1979 … Town Meeting at ASME WAM in N.Y.→ NCA National Group
- 1981 …. Division (NCAD) established

First Sessions …. WAM in Chicago
….. “Noise Control Engineering in the 1980’s”

Objective: Noise Control & Acoustics focused on Mechanical Engineering
The Founders of NCAD

D. Mote .... Originator & first Chair
A. Akay .... Originator & first Vice-Chair

H. Scarton, G. Reethof, T. Dear .... first Executive Committee
M. Sevik, G. Koopmann, K. Baumeister .... early “shaping” of Division

M. Sevik → attracted underwater acoustics research community into NCAD
M. Sevik & T. Dear → Per Bruel Gold Medal

K. Uno Ingard .... inaugural Rayleigh lecturer & first recipient of Per Bruel
The Evolution of NCAD

- NCAD → focal point for Acoustics & Noise Control within ASME
  - steer focus of research in Flow Acoustics & Structural Acoustics
  - platform for interaction with researchers other disciplines

- Technical Committees formed to steer technical focus areas
  - meeting content
  - research areas
  - tutorial & special lectures

- Journal of Vibration & Acoustics
  - high quality peer reviewed papers
  - source for state of the art noise control & acoustics with ME relevance

- Tutorials & Workshops
  - focused sessions on special topics
  - opportunity for industry engagement
Broadening of Organization Involvement

- Initially Dominated by Navy & Academic Communities

- Growth of Industry Involvement during mid-1980’s → today
  - Electric Boat
  - Lockheed Martin
  - Bechtel
  - United Technologies

- Industry Focusing Technical Themes, Tutorials, Lectures
Technical Committees & Thrusts

*Core Disciplines:* Flow Induced Noise & Vibration
Structural Acoustics

*Focus Areas:* Turbomachinery Noise, Numerical Techniques in Acoustics
Active Noise Control, Instrumentation
Duct Acoustics & Liners, Biomedical Acoustics
High Intensity Acoustics, Friction-Induced Sound & Vibration
Materials Characterization, Numerical Techniques in Acoustics

Technical Committees focus on themes reflecting emerging industry needs & state-of-the-art technologies
Rayleigh Lecture

Keynote Rayleigh Lectures

- Acoustics in Physics and Mechanical Engineering -- K. Uno Ingard
- Computer Aided Silence-- J. E. Ffowcs Williams
- From the Finite to the Boundless: Acoustics of Very Large Systems-- Miguel C. Junger
- Elements of Flow Noise from Rayleigh to Today -- Alan Powell
- Biomechanics of Hearing Sensitivity -- Sir Michael James Lighthill
- Nonlinear Acoustics -- David T. Blackstock
- Structural Acoustics from Lord Rayleigh to the Present -- David Feit
- Progressive Waves: The Modern Evolution and Refinement of One of the Most Basic Concepts in Acoustics -- Alan D. Pierce
- The High-Speed Many-Bladed Propeller: Asymptotic Theory for its Acoustic Field -- David G. Crighton
- Surprises in Axially Moving Material Dynamics – C. Dan Mote Jr.

State of the Art Acoustics: Physics & Methods
Keynote Rayleigh Lectures

- Information Extraction from the Scattered Acoustic Field of Waterborne Structures -- Maurice Sevik
- Controlled Interference of Acoustic Fields -- P.A. Nelson
- Rayleigh Conductivity -- Michael S. Howe
- Designing Quiet Structures Virtually -- Gary Koopmann
- Acoustics of Friction -- Adnan Akay
- Emerging Design Tools for Quiet Turbomachines -- William Blake
- Variational Solutions: What Rayleigh and Ritz Did Not Tell Us -- Jerry Ginsberg
- The Big Problems Remaining in Tranduction -- Ilene Busch Vishniac
- Fourier Acoustics, Uncovering the Origins of Sound -- Earl G. Williams
- A Systems Approach to Noise Mitigation Strategies -- Donald E. Thompson
- Fluid-Structure Interaction and Acoustics -- H.M. Atassi
- Structural Acoustics from Macro to Micro -- Robert Clark
- Putting it all Together: the Technology Stages in the Design of Propulsion Systems for Noise -- RH Schlinker

State of the Art Acoustics: Physics & Methods
Per Bruel Gold Medal for Noise Control and Acoustics

- Established in 1987, honors Dr. Per Bruel who pioneered the development of sophisticated noise and vibration measuring and processing equipment.

- Awarded in recognition of eminent achievement and extraordinary merit in the field of noise control and acoustics.

- Achievement must include useful applications of the principles of noise control and acoustics to the art and science of mechanical engineering.
Recipients of Per Bruel Gold Medal

K. Uno Ingard                                           David Feit
Lothar Cremer                                           Leo L. Beranek
Alan Powell                                             Adnan Akay
Miguel C. Junger                                        Cyril M. Harris
David Crighton                                         Jerry H. Ginsberg
Eric E. Ungar                                           Ira Dyer
Allan D. Pierce                                         Gary H. Koopmann
Maurice M. Sevik                                        Micheal S. Howe
John E. Ffowcs-Williams
Aircraft Noise

- Fan noise sources:
  - (high frequency phenomena)
    - Rotor/stator interaction
    - Boundary layers and ingested turbulence
    - Rotor noise
Typical Fan Sound Power Spectra

Subsonic Tip Speed

Supersonic Tip Speed
Schematic of Rotor Wake Phenomena

- Blade Surface boundary layer
- Tip Corner Vortex
- Secondary Flow
- Hub Corner Vortex
- Blade Wakes
- Rotation
- Flow
Emerging Design Tools for Quiet Turbomachines

William K. Blake

Mechanics of Flow Induced Sound and Vibration, Vols. 1&2, 1986
Structure of Prediction Tools for Engineering Application: Low Mach Number and Structural Vibration

- Geometry Surface / Structure
  - Flow Model
  - Mean Flow Solution:
    - Shear
    - TKE
    - Length Scales
  - Define Spectral Fluid Acoustic Model
    - Models for Surface Dipoles and Forces
  - Structural Model
    - FEM Basis Functions
    - Fluid Impedance
  - Surface Impedance
    - Flow-Induced Vibration
    - “Modal” Radiation Efficiencies
    - Far field Acoustic Transfer Function for Rigid Surfaces
  - Sound
Side Edge Noise of Deployed Wing Flaps

- High lift develops strong side edge vorticity
- Flow separation develops strong side cross flow
- Dipole sound emitted by side edge surface pressures
Fourier Acoustics: Uncovering the Origins of Sound

Earl G. Williams
Senior Scientist for Structural Acoustics
Acoustics Division, Naval Research Laboratory
Washington, D.C.
ASME Winter Meeting
Washington, DC – November 18, 2003

(Fourier Acoustics, E.G. Williams, Academic Press, 1999)
Microphone Array Measurement

Array measurement grid
Above plate source

Measured pressure field
$f(x,y)$

$f(x, y) = \sum_{m=-\infty}^{\infty} \sum_{n=-\infty}^{\infty} F(k_m, k_n) \exp(ik_m x + ik_n y)$

K-Space

$|F(k_m, k_n)|$

2-D Fourier series

- k-space plot indicates dominant wavelengths

Real part color coded
Facilities and Cylindrical NAH

Underwater NAH Facility

Localization of Hull ‘Hot Spots’ using Supersonic Intensity

Pool Dimensions:
Diameter: 55 feet
Depth: 50 feet

Farfield Directivity

Reconstructed nearfield pressure

Typical Cylindrical Holographic Scan

Attachment wires

Measurement points (128x64)

Hydrophone probe

Facilities under direction of
Brian Ruston, NRL
Helmholtz Equation Least Squares Method for NVH Diagnosis

Sean F. Wu, Ph.D.
University Distinguished Professor
Fellow, ASME, ASA
Wayne State University
Detroit, MI 48202
1 – Sound emitted by vibrating object.

2 – Sound is sampled using microphones near the surface.

3 – Sound field is curve-fitted using spherical wave functions.

4 – Pressure, particle velocity and intensity is visualized.
Setup Flexibility

Power Steering Column

Engine Test
Noise Source Identification

Microphone array aligned against a car door

Intensity plot showing noise sources on car door
How is the acoustic energy coming to the inside of the passenger cabin?

Sound Pressure
Noise everywhere

Surface velocity
Few dominant spots

Acoustic Intensity
Radiating in or out?
### Panel Contribution Analysis

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<tr>
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Better Understanding

**Example: Brake Squeal**

- **Sound Pressure**
  - Ambiguous
  - Many possibilities

- **Acoustic Intensity**
  - An accurate picture of sources

- **Normal Velocity**
  - Surface motion of rotor
  - An exact picture of the physical noise generating mechanism

All the information necessary to make good engineering decisions.
Designing Quiet Structures
Dr. Gary Koopmann, Penn State University

Minimizing Sound Power Radiated from Structures
  -- Volume Velocity
  -- Sound Radiation Efficiency

Designing Quiet Structures, A Sound Power Minimization Approach
G.H. Koopmann
  J.B. Fahnline
Optimal Design of Quiet Structures/Cavities Using Tuned Absorbers and/or Mass Modifications

Dr. Gary Koopmann
Distinguished Professor – Mechanical Engineering
Director, Center for Acoustics and Vibration
Penn State University
Approach to Structural - Acoustic Design

- Assess sound quality (noisiness) of machine at early design stages prior to fabrication.

[Diagram]

1. **Design**
2. **Fabricate Virtually**
3. **Assess Noisiness**
   - If no, check if acceptable.
   - If yes, proceed to standard fabrication.
   - Standard fabrication leads to market.

Specialists:
- Elec. Engr.
- Indust. Engr.
- Noise Control Engineer
**Examples of Objective Functions**

- Minimize Kinetic Energy
- Spectrum Shaping
- Minimize Sound Power, $W(f)$

**Design Variables**

- shape
- thickness, $t$
- stiffness, $E$
- density, $\rho$
- external forces (impedances)

**Constraints**

- weight
- cost
- size
- ease of maintenance
Structural - Acoustic Design
Application: Propulsor
Tools for Optimal Structural - Acoustic Design

Structural Model

\[ u(x_r) = i\omega \sum_{n}^{N} \phi_n(x_r) \left\{ \sum_{m}^{M} \phi_n(x_m) F(x_m) \right\} \]

\[ u(x_r) = i\omega \sum_{n}^{N} \frac{\phi_n(x_r)}{\omega^2 - \omega^2_{dn}(1+i\eta_n)} \]

Acoustic Radiation Model

\[ W_T = \frac{1}{2} \sum_{\mu=1}^{N} \sum_{\nu=1}^{N} u^*_\mu u_\nu R_{\mu\nu} \]

Constrained Minimization Algorithm

Minimize \( W \) (design variables) subject to constraints (i.e., dynamic balancing of propulsor, total added mass)
Dynamic Structural Model
(mass, stiffness, and damping)

\[
[M]\dddot{U} + [C]\ddot{U} + [K]U = F
\]

Yields eigenmodes, \( \varphi_n \)
and eigenvalues, \( \omega_n \)
Sound Power Calculation Using the Resistance Matrix $\mathbf{R}$

\[ W_T = \frac{1}{2} \sum_{\mu=1}^{N} \sum_{\nu=1}^{N} u_\mu u_\nu \mathbf{R}_{\mu\nu} \]

\[
\begin{bmatrix}
\frac{p_1}{u_1} & \frac{p_1}{u_2} & \frac{p_1}{u_3} & \cdots & \frac{p_1}{u_N} \\
\frac{p_2}{u_1} & \frac{p_2}{u_2} & \frac{p_2}{u_3} & \cdots & \vdots \\
\frac{p_3}{u_1} & \frac{p_3}{u_2} & \frac{p_3}{u_3} & \cdots & \vdots \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
\frac{p_\mu}{u_1} & \cdots & \cdots & \cdots & \frac{p_\mu}{u_N}
\end{bmatrix} \begin{bmatrix}
u_1 \\
u_2 \\
u_3 \\
\vdots \\
u_N
\end{bmatrix}
\]
Sound Power Optimization
Conclusions

- Overall Sound Power was Reduced:
  - Simulated Annealing Prediction: 71.88 dB to 62.77 dB
  - FEM using Optimal Masses: 71.88 dB to 60.03 dB

- Concentration of Degenerate Modes was reduced:
  - 1st Degenerate Set: frequency range changed from 1.8361 Hz to 69.4205 Hz
  - 2nd Degenerate Set: frequency range changed from 4.0820 Hz to 113.4560 Hz
Quiet Product Design Using Broadband Vibration Absorbers

A Thesis Defense in Mechanical Engineering

Committee:
Distinguished Professor Gary Koopmann, Co-Advisor
Professor Ashok Belegundu, Co-Advisor
Professor Arvind Rangaswamy
Professor Martin Trethewey
Research Objective

- Develop and experimentally validate an optimization tool for applying multiple tuned absorbers to structures
Multiple tuned absorbers, closely spaced in frequency, exhibit broader-band force potential.
Acoustic Model

- Lumped parameter response:

\[
\hat{p}_\mu \approx -\frac{ik\rho c}{4\pi S_\mu} \sum_{v=1}^{N} \hat{u}_v \iint_{S_\mu} \left( \iint_{S_v} \hat{G}(x / x_S) dS(x_S) \right) dS(x)
\]

\[
\hat{p}_\mu \approx \sum_{v=1}^{N} Z_{\mu\nu} \hat{u}_v
\]

- Each element vibrates as a piston
- Lumped parameter approximation is accurate in the far field
Acoustic Control in Enclosures Using Optimally Designed Helmholtz Resonators

by

Patricia Driesch

Thesis Committee:

Dr. Gary Koopmann, advisor

Dr. Martin Trethewey

Dr. Victor Sparrow

Dr. Mary Frecker

PhD Defense

Mechanical Engineering
Project Summary

Overall Goal: To develop a virtual design methodology to optimize Helmholtz resonator performance coupled to an enclosure

Motivation

- Alleviate low frequency noise for driver
- Structural modifications inhibited
Development of Design Methodology

Optimization

- Objective function: \( f(Q,a,V,L_{eq}) = \sum \sum p^2(\omega_j, x_i) \)
- Design variables: \( Q, V, L_{eq}, \) and \( S \)
- Constraints: limits on HR size
  subject to \( g(Q,a,V,L_{eq}) = f_n = \frac{c}{2\pi} \sqrt{\frac{\pi a^2}{V \cdot L_{eq}}} \)
  \( 300 \text{ Hz} \leq g \leq 700 \text{ Hz} \)

- Sequential quadratic programming (SQP) gradient based technique, \textit{fmincon}, will optimize multiple design variables
Tractor Cabin Acoustic Modes

Mode 1, 114 Hz
Mode 2, 122 Hz
Mode 3, 166 Hz

Mode 4, 237 Hz
Mode 5, 249 Hz
Mode 6, 256 Hz
Research Conclusions

- Reduced the sound by 6.4 and 20.8 dB SPL at 1\textsuperscript{st} and 3\textsuperscript{rd} resonance, respectively, using optimally predicted resonators
- Optimization is necessary to best design a system of resonators for both performance and use of resources
- Decoupling rigid body modes from modified pressure response created numerically efficient acoustic model for optimization

- Especially useful tool for comparing design modifications
- Method provides a valuable tool to virtually evaluate use of Helmholtz resonators
Acoustics of Friction

Adnan Akay

- Principles
- Applications
Rubbing a Wine Glass

- Frequency response
- Finger excitation along edge
- Dry finger excitation radially
- Violin bow excitations

Graphs showing frequency responses and excitation patterns for rubbing a wine glass.
Different brake noises and their approximate spectral contents.
Tutorials & Panel Discussions/ Forums

- **Tutorials:**
  - *Computational Methods for Aeroacoustics*, Sheryl Grace
  - *Adaptive Filtering with Applications to Active Control*, J.S. Vipperman
  - *Phononic Crystals: Towards the Full control of Elastic Waves Propagation*, Jose Sanchez-Dehesa

- **Panel Discussions/ Forums:**
  - *Enjoying Vibroacoustics through Engineering*, W. O. Hughes
  - *NSF Dynamic Systems and Control Program and Sensors Initiative*, M. Tomizuka
  - *Active Noise Control*, J.S. Vipperman
Today’s NCAD

Executive Committee:
Mike Jonson (Penn State/ARL) – Chair
Ted Farabee (NSWCCD) – Vice Chair
Stephen Hambric (Penn State/ARL) – Program Chair 2008
Jeff Vipperman (Univ. of Pittsburgh) – Program Chair 2009
Bob Tomko (Bechtel Bettis Atomic Power Lab)

Technical Committees:
Flow Acoustics – Brent Paul (Alion Sciences)
Structural Acoustics – Liang-Wu Cai (Kansas State Univ.)
Active Control – Jeff Vipperman (Univ. of Pittsburgh)

Journal of Vibration & Acoustics:
Associate Editors – Stephen Hambric & Jeff Vipperman

Membership: ~ 4000 (~ 650 primary, ~ 650 secondary, ~ 2700 other)
Today’s NCAD Themes

- Collaboration with Parallel Noise Control & Acoustics Professional Societies
- Expanded involvement by Industry Partners
- Relevant Technical Sessions & Tutorials of High Quality

Promulgation of State of the Art Noise Control & Acoustics Methods