A study of standing pressure waves within open and closed acoustic resonators.

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The first section of the results presented herein was conducted on an axisymmetric resonator configured with open ventilation ports on either end of the resonator, but otherwise closed and free from obstruction. The remaining section presents the results of a similar resonator shape that was closed, but contained an axisymmetric blockage centrally located through the axis of the resonator. Ambient air was used as the working fluid. In each of the studies, the resonator was oscillated at the resonant frequency of the fluid contained within the cavity while the dynamic pressure, static pressure, and temperature of the fluid were recorded at both ends of the resonator. The baseline results showed a marked reduction in the amplitude of the dynamic pressure waveforms over previous studies due to the use of air instead of refrigerant as the working fluid. A sharp reduction in the amplitude of the acoustic pressure waves was expected and recorded when the configuration of the resonators was modified from closed to open. A change in the resonant frequency was recorded when blockages of differing geometries were used in the closed resonator, while acoustic pressure amplitudes varied little from baseline measurements.
A Study of Standing Pressure Waves Within Open and Closed Acoustic Resonators.

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Presentation Outline

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• Background
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  → Results
• Open Resonator Configuration
  → Experimental Setup
  → Results
• Closed Configuration with Blockages
  → Experimental Setup
  → Results
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Research Objective

- Extend the research of:
  - Lawrenson, et al. (1998)
  - Ilinskii, et al. (1998)
  - Chun, et al. (2000)

- Determine if high-amplitude standing pressure waves can be generated:
  - using air as the working fluid
  - in resonators containing blockages
  - in resonators containing ventilation holes

- Goal is to determine applicability to NASA’s flow control systems
Background

- Dr. Timothy Lucas discovered a method to produce high-amplitude acoustic waves in resonators.

- Previously published work focused mainly on using refrigerant as the working fluid.

- NASA’s need for methods of flow control has driven the research towards applicability of using air as the working fluid.
Dimensionless Variables

Dimensionless Pressure

→ \( \frac{P}{P_0} = \frac{P_{\text{INSTANTANEOUS}}}{P_{\text{AVE QUIET CONDITION}}} \)
→ \( \frac{P_{\text{MAX}}}{P_0} = \frac{P_{\text{CYCLE MAXIMUM}}}{P_{\text{AVE QUIET CONDITION}}} \)

• Dimensionless Frequency

→ \( \Omega = 2 \cdot f \cdot l_{\text{RESONATOR}} / (\gamma \cdot 8314 \cdot T_K / MW)^{1/2} \)

• Dimensionless Time

→ \( \tau = f \cdot t \)
Baseline Configuration
Baseline Configuration: Experimental Setup

- Electrodynamic Shaker Table
  → 500 lbf (2220 N) capacity
- Conical Resonator
  → $r(z) = 0.0056 + 0.2680 \cdot z$ [m]
  → Aluminum 7075T6 with 0.14 inch (3.6x10^{-3} m) wall thickness
  → Containing air (ambient conditions)
- Instrumentation
  Each end of the resonator contains:
  A. Dynamic pressure sensors (2)
  B. Static pressure transducers (2)
  C. Accelerometer (2)
  D. Thermocouples (2)
Baseline Configuration: Experimental Results

- Non-linear frequency shift with increasing acceleration amplitude
- Moderate hysteresis evident (hardening)

- Constant max acceleration: 80g
- \( P_0 = 100.2 \text{ kPa} \)
- No microshocks evident
- \( P_{\text{MAX}} / P_0 = 3.05 \) (306kPa)
- Static Pressure rise of \( \sim 6.5 \text{ kPa} \)
Open Resonator Configuration
Open Resonator Configuration: Experimental Setup

- Identical hardware and instrumentation used in baseline experiments
- End caps
  - Aluminum 7075T6
  - 0.188 inch (4.77 x 10^{-3} m) thickness
- Additionally
  - Wide end cap:
    - one (1) ventilation hole
    - \( \phi 0.100 \text{in} (\phi 2.54 x 10^{-3} \text{m}) \)
  - Narrow end cap:
    - eight (8) ventilation holes
    - \( \phi 0.025 \text{in} (\phi 6.35 x 10^{-4} \text{m}) \)
Open Configuration: Experimental Results

- Max acceleration: 80g
- No apparent hysteresis
- $P_{\text{MAX}} / P_0 = 1.48$ (148 kPa)

- No microshocks evident
- $P_0 = 99.2$ kPa
- Static Pressure rise of $\sim 0.8$ kPa
Closed Resonator Configuration With Blockages
Closed Configuration w/ Blockages: Experimental Setup

- Identical hardware and instrumentation used in Baseline experiments
- Baseline end caps (no ventilation holes)
- Additionally
  - Centrally located cylindrical blockage
    - Ø 0.443 inch (1.356 cm)
    - Ø 0.433 inch (1.331 cm)
    - Ø 0.423 inch (1.306 cm)
    - Ø 0.403 inch (1.255 cm)
Closed Configuration w/ Blockages: Experimental Results

- Blockage Diameter: \( \phi 0.403 \text{ inch} \) \((1.255 \text{ cm})\)
- No apparent hysteresis
- No frequency shift with increasing acceleration amplitude

- No microshocks evident
- \( P_o = 99.8 \text{ kPa} \)
- Static Pressure rise of \( \sim 4.3 \text{ kPa} \)
Closed Configuration w/Blockages: Experimental Results

- Constant maximum sinusoidal acceleration: 80g

- Increasing blockage diameter:
  - Reduces $P_{\text{MAX}}$
    - $P_{\text{MAX}} / P_0 = 1.65$ (φ0.403 inch )
    - $P_{\text{MAX}} / P_0 = 1.57$ (φ0.443 inch )
  - Increases fundamental resonant frequency
    - $\Omega_1 = 1.293$ (φ0.403 inch )
    - $\Omega_1 = 1.299$ (φ0.443 inch )
Comparison of Results

- Maximum Acceleration Amplitude: 80g
- From the baseline configuration:
  - $P_{\text{MAX}}$ reduced 49% with addition of openings
  - $P_{\text{MAX}}$ reduced 54% with addition of blockages
  - $\Omega$ increased 2% with addition of blockages
End of Presentation
Conclusions

1. Standing waves with maximum pressures of 306 kPa have been produced in resonators containing ambient pressure air.

2. While the addition of holes to the resonator does reduce the magnitude of the acoustic waves produced, their addition does not prohibit the generation of large magnitude standing waves.

3. The addition of structures inside the resonator shifts the fundamental frequency and decreases the amplitude of the generated pressure waves.