Team Eberhard Sengpiel

Effects of Altitude on the Speed of Sound

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Project Background

• Mission:
  ○ To observe how variations in temperature and humidity of the air with increasing altitude affects the speed of sound

• Goals:
  ○ To produce meaningful acoustic data for use in acoustic engineering applications
  ○ To maintain chambers of constant temperature or humidity compared to changing exterior conditions

• Hypothesis:
  ○ As the temperature decreases with altitude the speed of sound will decrease
  ○ As the humidity decreases with altitude the speed of sound will decrease
  ○ These effects will be compounded when the air experiences decreases in both temperature and humidity
Speed of Sound Dependency

- Air properties like density are significantly impacted by temperature and humidity
- Increased temperatures and decreased molar masses will cause increases in speed of sound
  - Increased humidity causes decreased molar mass

\[
p = \frac{n \cdot R \cdot T}{V} \quad \rho = \frac{n \cdot M}{V}
\]

\[
c = \sqrt{\frac{\gamma \cdot p}{\rho}} = \sqrt{\frac{\gamma \cdot n \cdot R \cdot T \cdot V}{V \cdot n \cdot M}} = \sqrt{\frac{\gamma \cdot R \cdot T}{M}}
\]

- \( n \) = Number of moles
- \( R \) = Universal gas constant
- \( T \) = Temperature
- \( V \) = Volume
- \( M \) = Molar mass
Chamber Functions

• Chamber #1:
  ○ Relative Humidity ≈ 100%
  ○ Temperature ≈ 25°C

• Chamber #2:
  ○ Ambient Relative Humidity
  ○ Ambient Temperature

• Chamber #3:
  ○ Relative Humidity ≈ 0%
  ○ Temperature ≈ 25°C
Initial Design

Bottom Portion of Chambers:

Top Portion of Chambers:

Note: Holes in Chambers are for the purpose of keeping humidity and temperature constant in each.
Final Design Overview

Eberhard Sengpiel 7
System Testing Overview

Subsystem Testing:

• Sensor operation with Arduino MEGA
• Data acquisition via MicroSD logger with Arduino MEGA
• Sensor precision testing
• Ultrasonic Rangefinder calibration
• Temperature and humidity gradients in each chamber caused by volume
  ○ In room temperature climates
  ○ In refrigerated climates

Structural Testing:

• Drop test (~20 ft.)
• Stair pitch test (~10 stairs)
• Whip test (~12 min.)

Environmental Testing:

• Vacuum test
• Cooler test
Temperature and Humidity Gradients

Temperature Gradient with 1 Heater

Temperature Gradient 2 Heaters vs. No Heater

Humidity Gradient with Humidifier

Eberhard Sengpiel 12
Drop Test

Stair Pitch Test
Predicted Data

Chamber 1: Humid Conditions
- Expected decrease of 8 m/s

Chamber 2: Ambient Conditions
- Expected decrease of 50 m/s

Chamber 3: Dry Conditions
- Expected decrease of 0.1 m/s
Flight Results, Chamber 1

- 100% relative humidity
- 25°C
Flight Results, Chamber 2

- Ambient relative Humidity
- Ambient temperature
Chamber 2 Speed of Sound
Flight Results, Chamber 3

- 0% Relative Humidity
- 25°C
What Worked

• Sensors
  o All but two pressure sensors worked ~45 min. flight time
  o Batteries lasted long enough to provide necessary data

• Water atomizer
  o Water reservoir did not expire
  o Humidity in chamber 1 held consistently, though not as high as desired

• Desiccant
  o Low relative humidity in chamber 3

• Heaters
  o Able to maintain constant temperature in chamber 1 (±12%)

• Data acquisition
  o MicroSD data logger functioned for the entire 45 min. Flight

• Chamber isolation
  o The proximity and insufficient insulation between chambers resulted in expected heat and humidity leaks between chambers
What Didn’t Work

• Data reliability
  ○ Noise caused by sudden payload movements resulted in data that was difficult to post-process
  ○ Parabolic curve in speed of sound adds to post-processing difficulties (excluding outliers)

• Underlying Data Issue: Sensor security
  ○ Sudden payload movements resulted in bumps that caused noise in speed of sound data, which was avoidable with more robust sensor mounting
Lessons Learned and Advice for Future Participants

• Find an experiment early
  o Make sure it is feasible within time and budget constraints
  o Study the theory and expected results of the experiment in depth before pursuing
  o Consider the physical limitations of sensors, transducers and actuators when sourcing

• Testing, testing, testing
  o Do not wait until the last minute to begin full system checks, especially with electrical components
  o Allow an extra full week of testing in the schedule to ensure launch readiness
  o Dedicate more time to testing such systems than anything else!

• Keep systems simple
  o Complexity adds precious testing and programming time requirements as well as weight
  o If the same functionality can be accomplished with a simpler design, it’s likely worth pursuing
Conclusion

• Overall mission success
  ○ Proved that isolating chambers in high altitude environments is feasible when executed carefully
  ○ Collected real data that agrees with predictions/standard compression wave theory
  ○ Survived and logged data throughout a 45 min. flight that reached over 100,000 ft.

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