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Passive Ultrasonic Deterrents to Reduce Bat Mortality in Wind Farms

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Overview

Idea/Technology:

- Blade-mounted ultrasonic deterrent driven by blade-relative flow

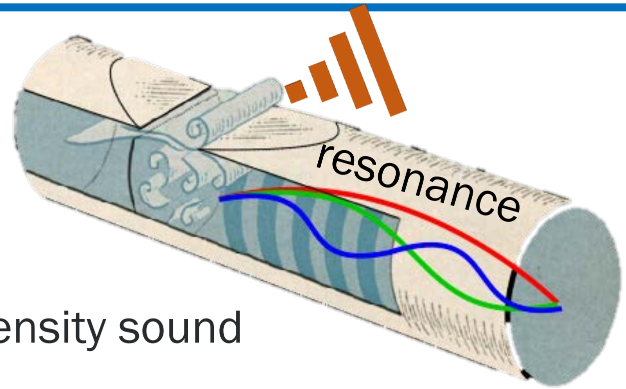
Technology Impact:

- Mitigate bat mortality at wind farms with little-to-no reduction in energy capture
- Cost savings by replacing/supplementing *operational mitigation* with the proposed deterrent

Current status:

- Deterrent tested to generate ultrasound spectrum in labs
- Passive operation looks promising … design optimization pending
- Impact on bats … not yet investigated

Concept and technical merit



- Adaptation of dog (Galton's) whistle
- Working principle:
  Flow instability coupled with a resonator → high-intensity sound
- Multiple resonators for broad spectral coverage (20 - 50 kHz)
- Blade-relative air flow for passive operation
  - no moving parts → less possibility of mechanical failure
- Blade-mounted ultrasonic deterrents need to radiate smaller distance (~5-10 m);
  - Nacelle/tower-mounting requires coverage of the entire rotor disk (50-100 m)

Nacelle v/s blade-mounted ultrasonic deterrents

Hub + tower mounted deterrents

- Blade tips far from deterrent → high source power required
- High-frequencies decay rapidly → full blade coverage nearly impossible
- Adverse impact of ultrasound on other wildlife

Blade-mounted deterrents

- Deterrents place where required
- Travel distance~10 m → low-amplitude at the source

Design

Whistle design, fabrication & testing

- Initial whistle design idea: aerodynamic whistle using Helmholtz/cavity + pipe resonance
- 3D printing (for fabrication) works well
- Experiments with high-pressure air supply (initial testing)

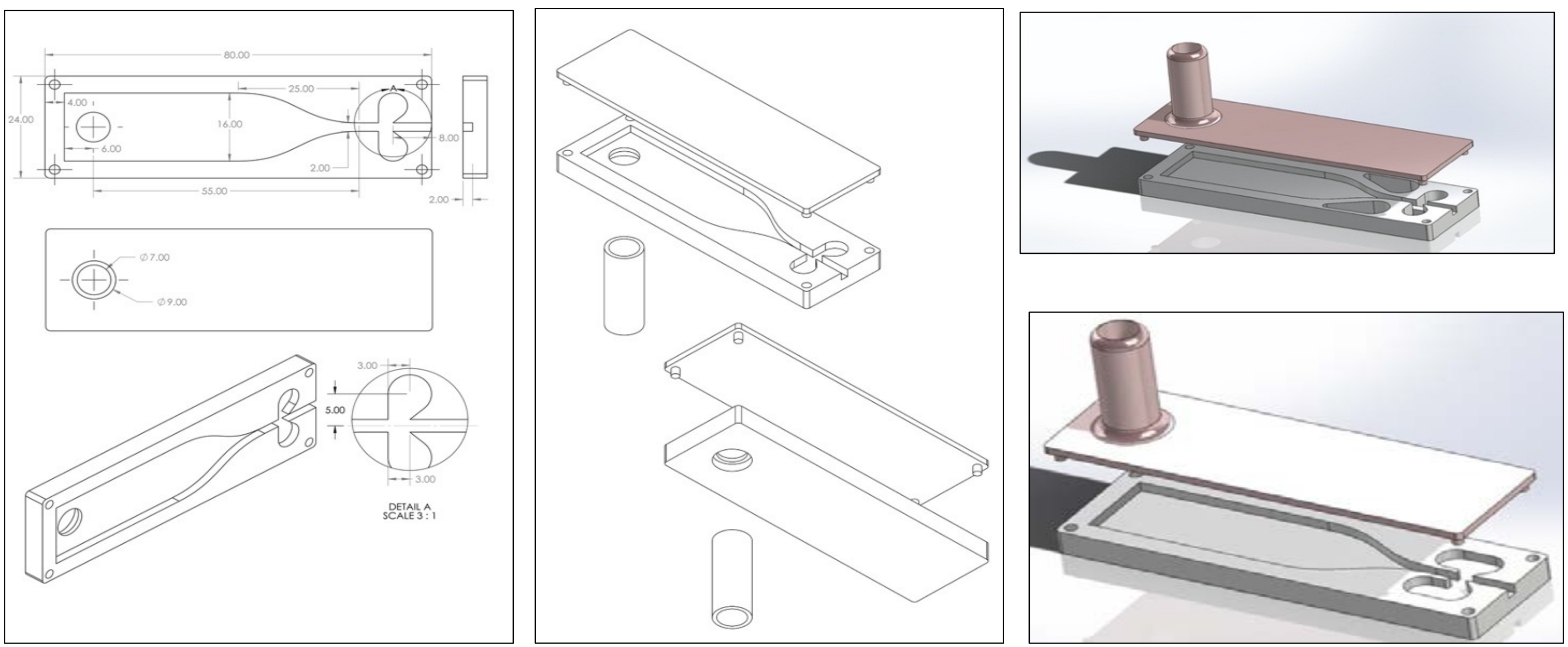


Figure: A CAD design of a conceptual ultrasonic tone generator

Research approach/methods & tasks

Approach

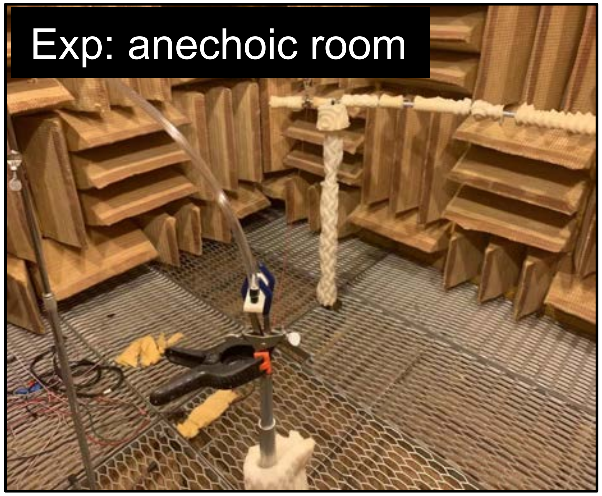
- Adapt Galton's (dog) whistle
- Working principle: fluid flow instability + resonance → high-intensity (ultra)sound
- Mount on rotor blades with an inlet/diffuser assembly that guides flow into the whistle → passive operation

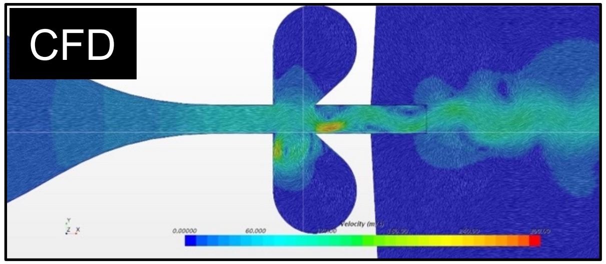
Research tasks/activities

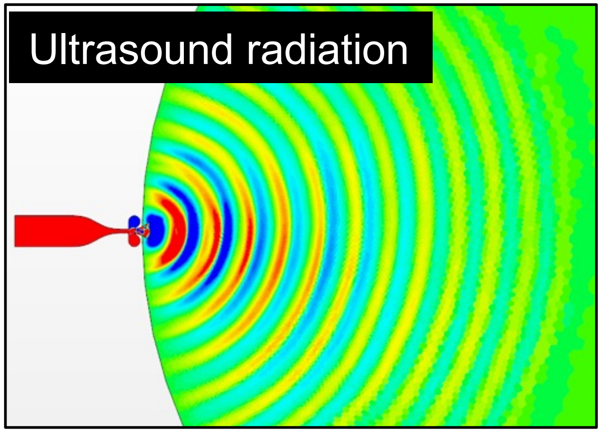
- Demonstrate capability to generate ultrasound using the whistle concept
- Optimize design for high-intensity ultrasound generation
- Verify passive operation numerically & experimentally
- Quantify adverse aero performance impact using section model tests

Methods for design & optimization

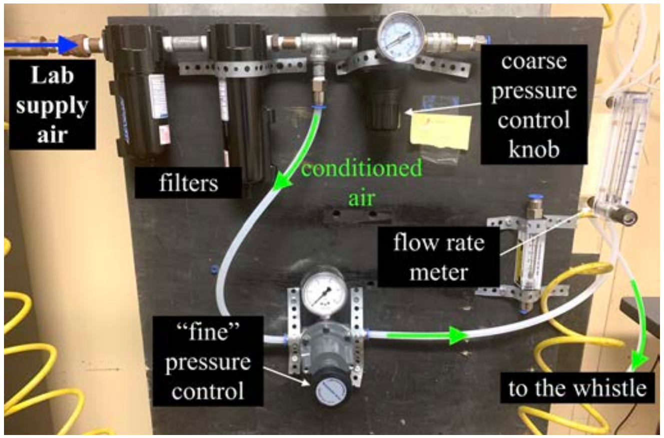
- *Experiments:* using pressurized air in anechoic chamber
- *CFD simulations*: 2-D for design & optimization, 3D for analysis

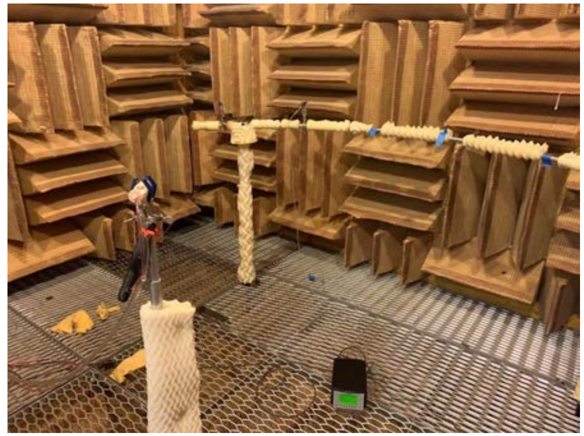


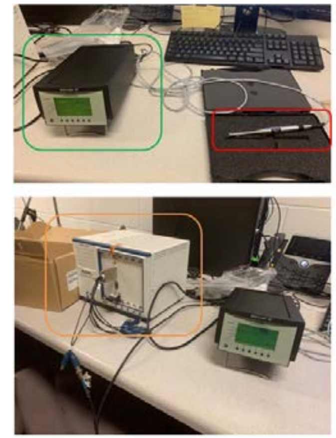


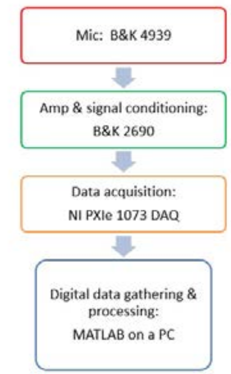


Experimental setup



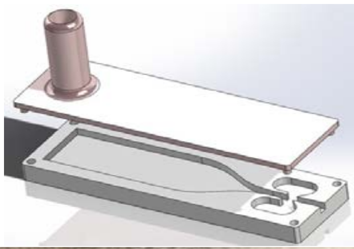


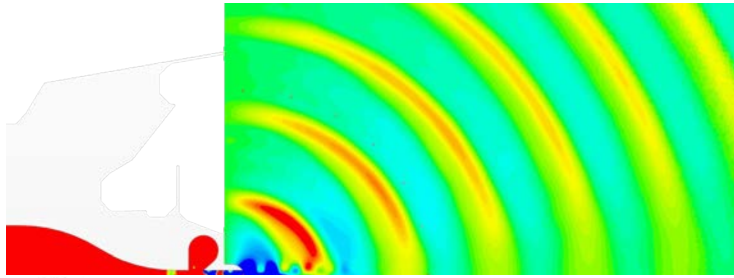


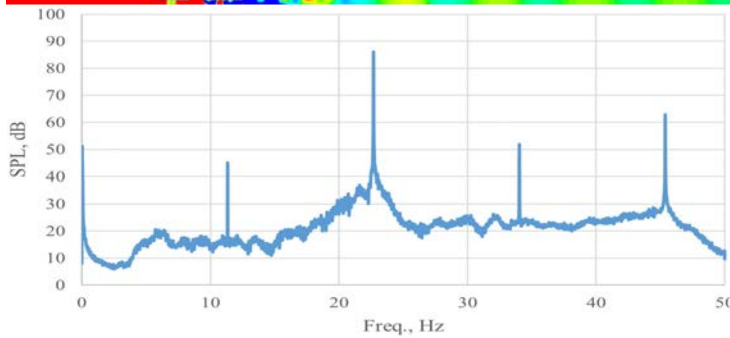


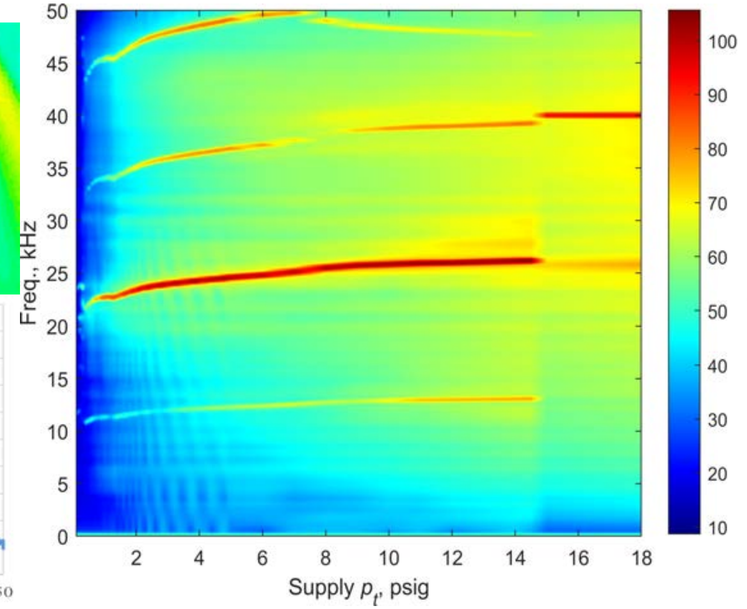
- **Lab air → filters → pressure & flow measurement → to the whistle**
  Flow M ≪ 1 → gauge pressure ≈ p_t
- **Farfield sound measurements on a circular arc**
- **B&K 4939 mic + signal conditioning (B&K 2690) →** $0 < f < 50\ kHz$
- **Directivity:**
  - *Azimuthal* variation small
  - Polar: peak at 30º → single points measurements for further evaluation

Numerical and experimental results







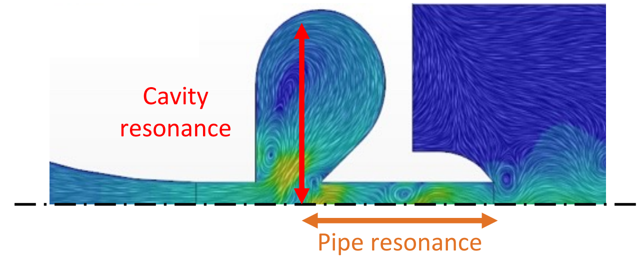


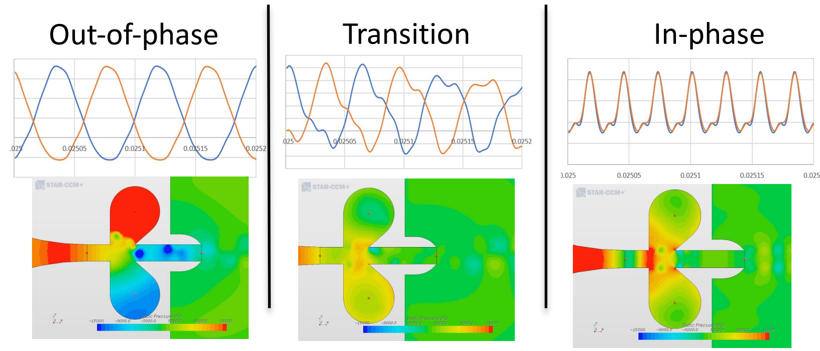
- **Peak $f \sim 22 - 25$ kHz → successful ultrasound generation**
- **Plot sound spectra variation with p_t as a "spectrogram"**
- **Two distinct operating regimes observed:**
  1. ***Low-p_t regime***: $p_t < 14.5$ psig; $f \sim 22 - 25$ kHz; $f\uparrow$ slightly as $p_t\uparrow$; subharmonic observed
  2. ***High-p_t regime:*** $p_t > 14.5$ psig; $f \sim 40$ kHz; subharmonic at 25 kHz; f no variation with p_t

Sound generation & passive operation

Identified sound generation mechanisms → optimization

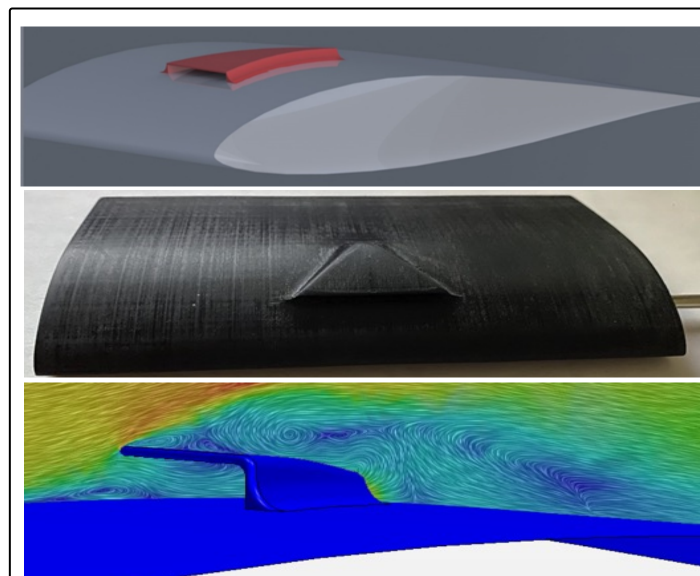
- Cavity resonance enhanced by pipe resonance
- Whistle operates in 3 modes:
  - out-of-phase (low pressure)
  - Transition (med pressure)
  - In-phase (high pressure)
- Enables design of cavity & pipe dimensions





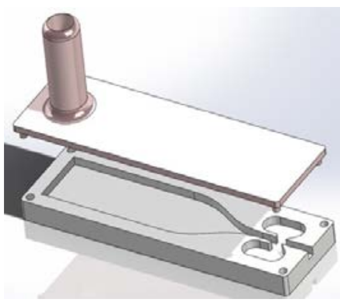
Passive operation

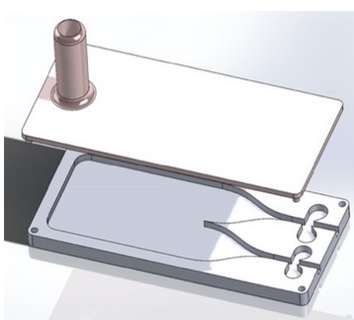
- Initial/preliminary intake designs
- Designed & prototyped
- Prelim analysis and experiments
  - Adverse impact on aero perf negligible (wind tunnel tests)
  - CFD simulations consistent with exp
- Passive ultrasound generation demonstrated numerically

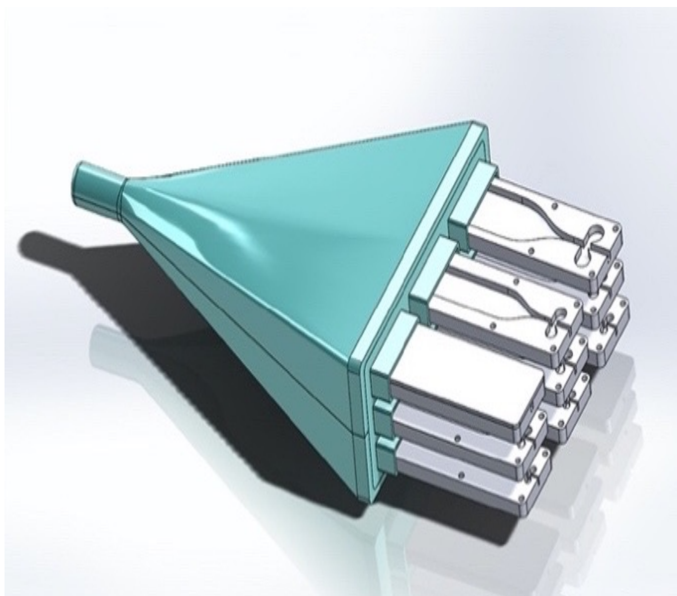


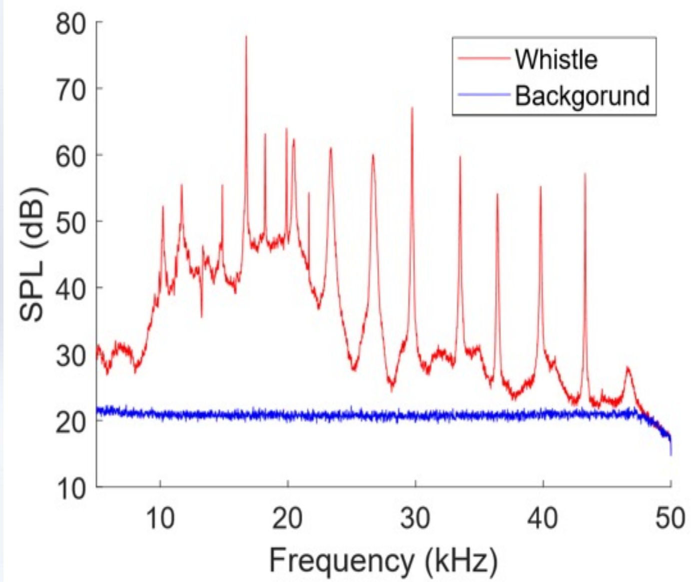
Spectral coverage

- Different bat species use different frequencies for echolocation
- ISU deterrent can be tailored to produce tones in the desired frequency range
- Adding multiple resonators in one whistle and/or adding multiple whistles to cover a broad spectral range









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