Preliminary Results of UAS Quadcopter Aeroacoustic Testing

Nicole Pettingill, Nikolas Zawodny, Christopher Thurman
NASA Langley Research Center

October 20, 2021

Acoustics Technical Working Group Meeting

Presentation Outline

- Introduction
- Background
- Facility and hardware set up
- Preliminary results
  - Hover
  - Forward Flight
  - Beamforming
- Conclusions and future work

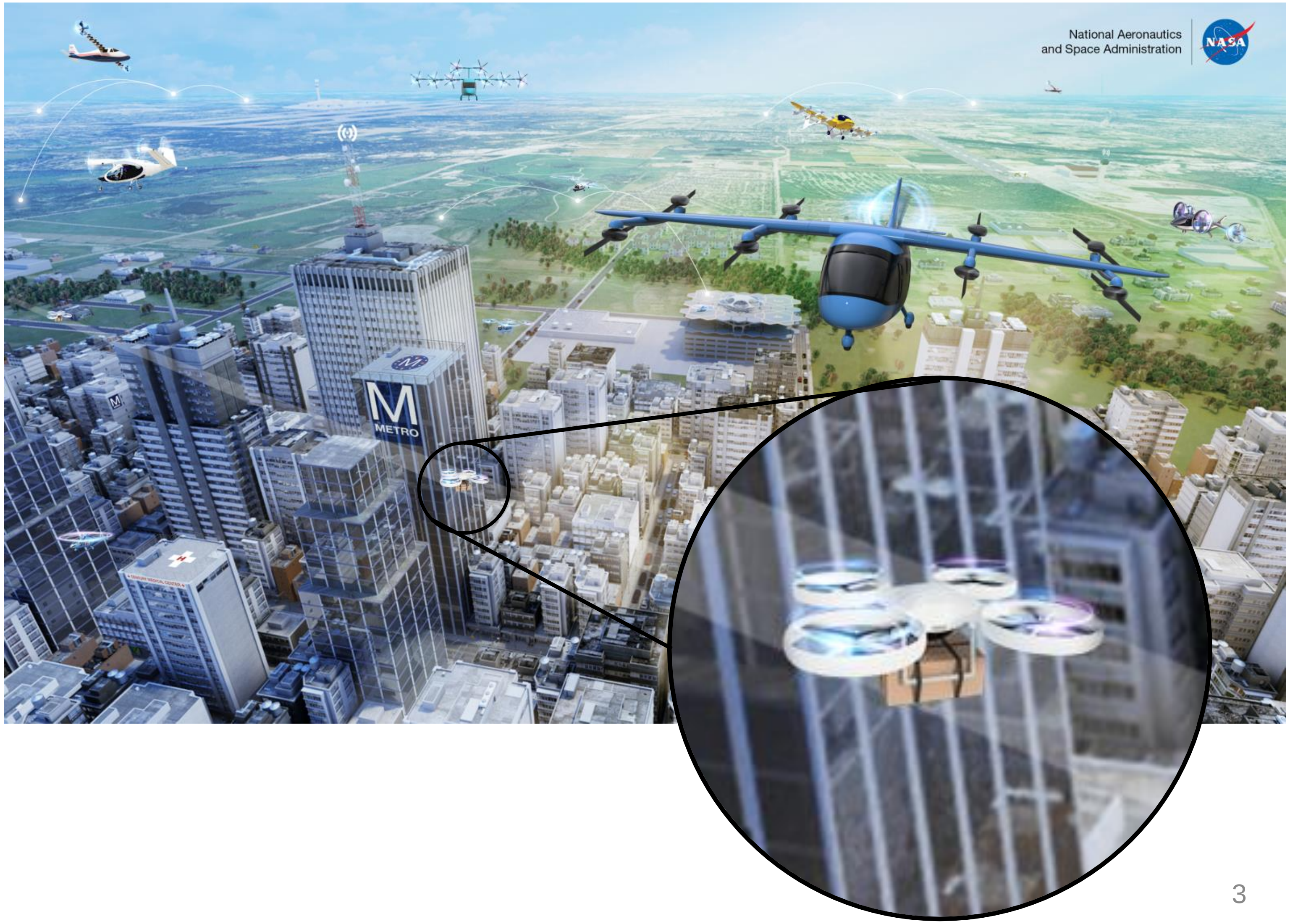
Introduction

- ***Advanced Air Mobility (AAM)*** is working to create ***safe***, ***sustainable***, ***accessible***, *and* ***affordable*** aviation to move ***people*** and ***packages***.

- The AAM industry motivates us to ***characterize noise sources*** to assess the ***community impact*** of these new vehicle concepts.

- ***Noise*** may be a ***key barrier*** for ***community acceptance,*** and ***rotors*** contribute significantly to the noise signature of these vehicles.

- ***Wind tunnel tests*** of small rotors are beneficial in assessing the ***potential noise impact*** of both ***small unmanned aerial vehicles (sUAS)*** and ***larger urban air mobility (UAM) vehicles***

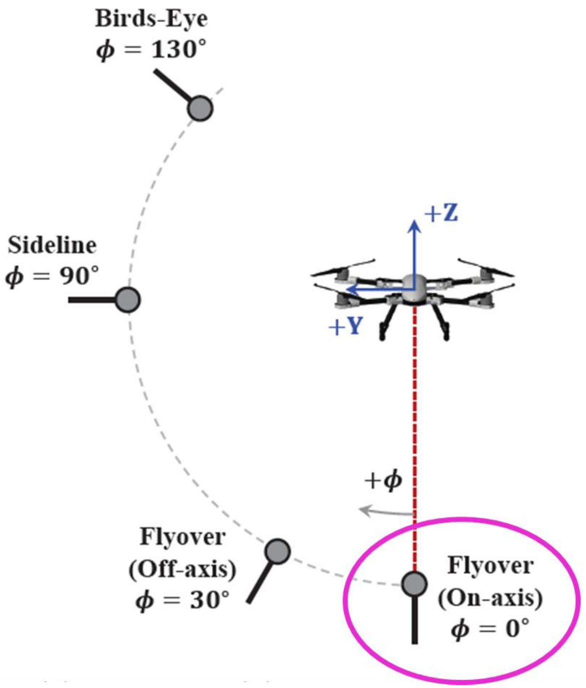


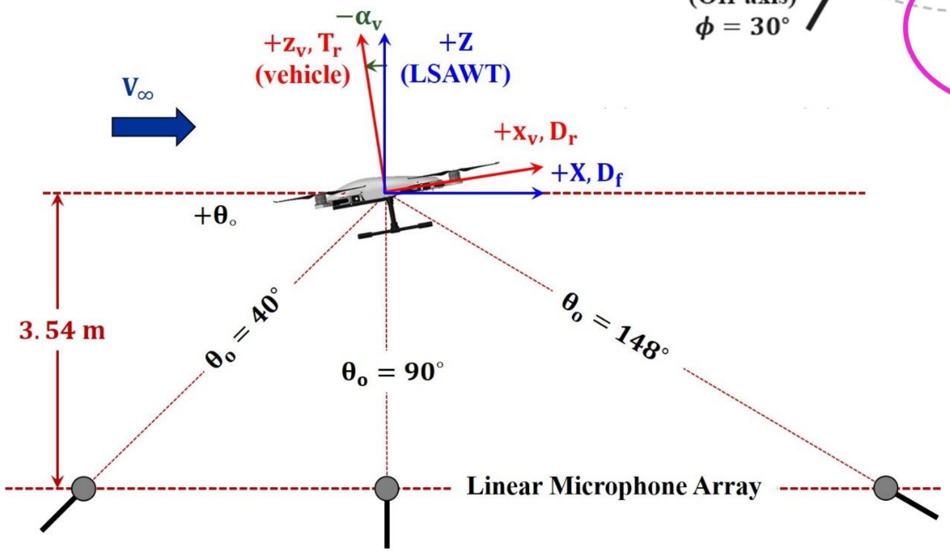
Past Test
LSAWT 2017

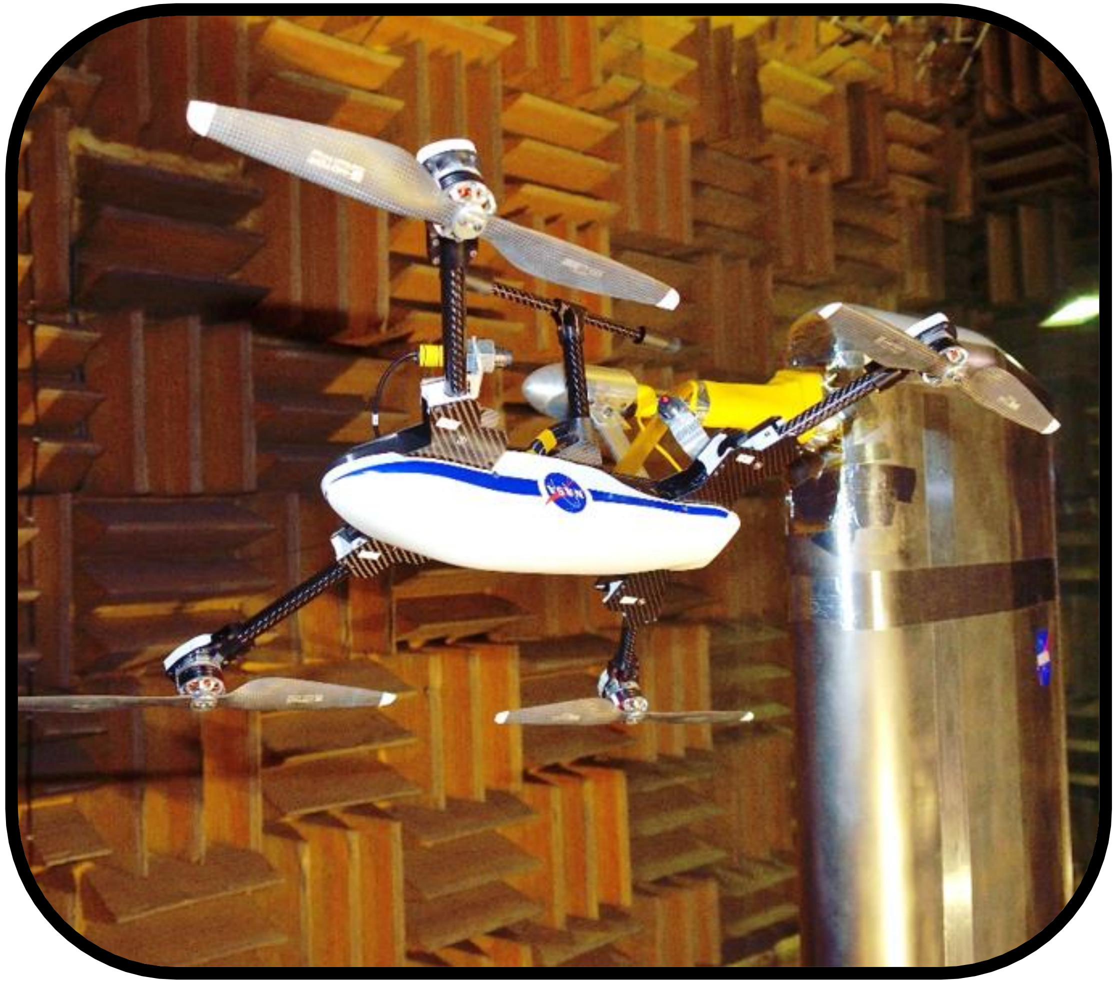
Pettingill, N. A. & Zawodny, N. S. "Identification and Prediction of Broadband Noise for a Small Quadcopter". VFS Forum 75 2019.

Zawodny, N. S. & Pettingill, N. A., "Acoustic Wind Tunnel Measurements of a Quadcopter in Hover and Forward Flight Conditions". 47th InterNoise 2018.

- Representative quadcopter was tested in the Low Speed Aeroacoustic Wind Tunnel (LSAWT)
- Performance and acoustic data measured
- Acoustic measurements taken by an overhead 28 microphone linear array (overhead flyover observers)
- Results published in two papers*



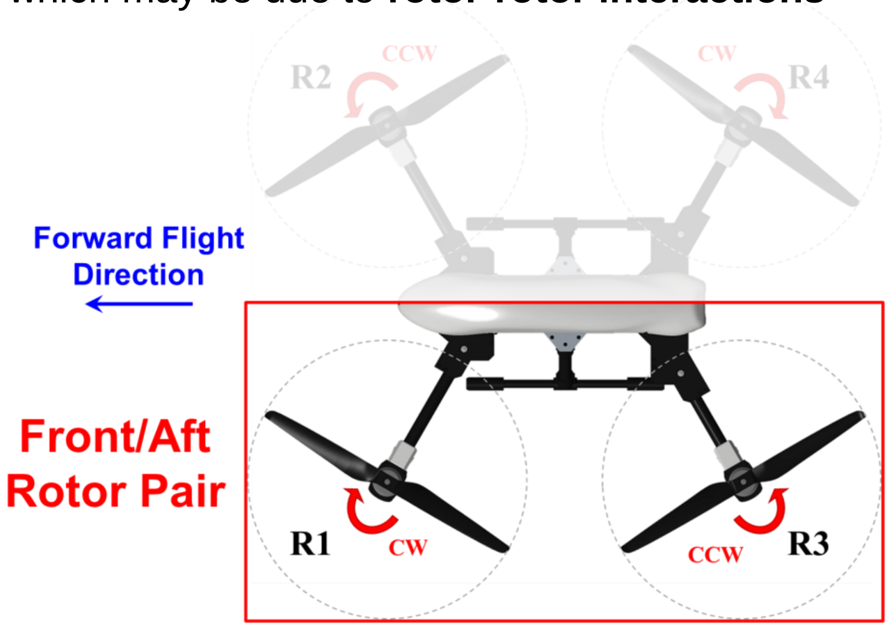




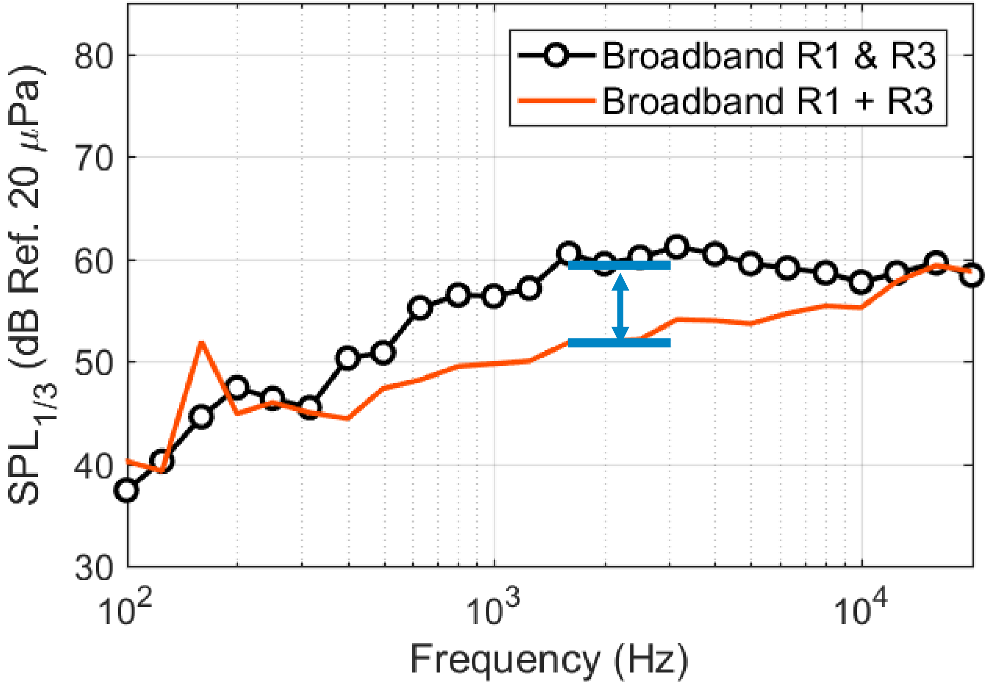
Past Test
LSAWT 2017

- Noise sources investigated were **self-noise**, **rotor-airframe interactions** and possible **rotor-rotor interactions**

- Rotor-rotor interactions in forward flight
  - Compared acoustics of *one* **simultaneous operation** case of front/aft rotor pair (R1 & R3) against superimposed result of *two* **individual operation** cases (R1 + R3)
  - Identified additional broadband noise for R1 & R3 vs. R1 + R3 at high thrust setting, which may be due to **rotor-rotor interactions**



Broadband Noise at 10 lb condition



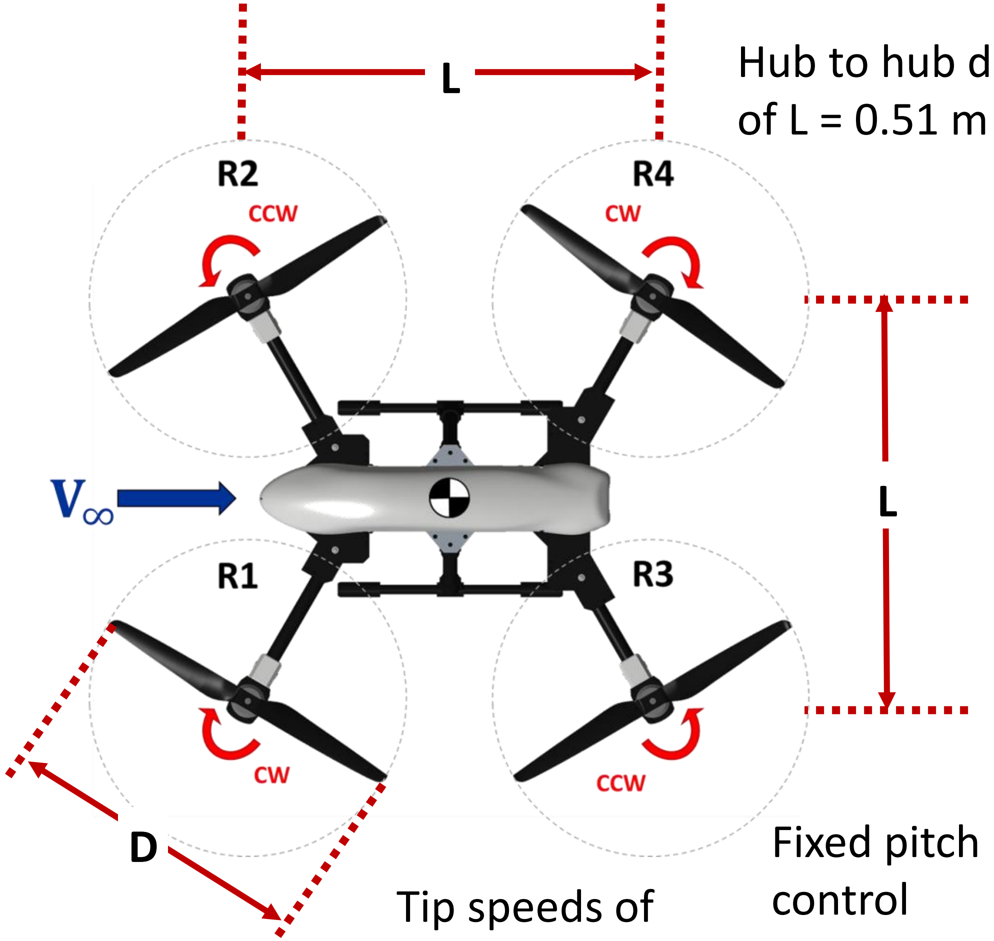
Broadband noise due to multirotor interaction effects between simultaneously operating rotors

Current Test

Vehicle and Hardware

- Quadcopter: SUI Endurance
- Three blade sets
  - T-Motor COTS blade set
  - Optimum blade design:
    - ProtoLabs SLA with glass grit
    - ProtoLabs SLS “rough blade”
- Two hubs
  - COTS
  - SLA in-house hub
- Cylinder Spacers
  - Baseline (0.15R distance from rotor to airframe)
  - 2.5 inch spacer (0.48R)
  - 1.25 inch spacer (0.30R)

Representative Vehicle Characteristics



Hub to hub distance of L = 0.51 m (~20 in)

Rotor diameter of D = 0.38 m (~15 in)

Tip speeds of $0.2 < M < 0.3$

Fixed pitch control

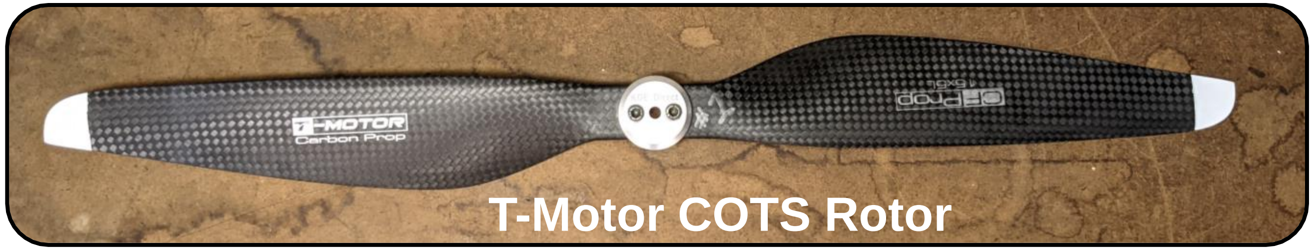
Vehicle and Hardware

- Quadcopter: SUI Endurance

- Three blade sets
  - T-Motor COTS blade set
  - Optimum blade design:
    - ProtoLabs SLA with glass grit
    - ProtoLabs SLS “rough blade”

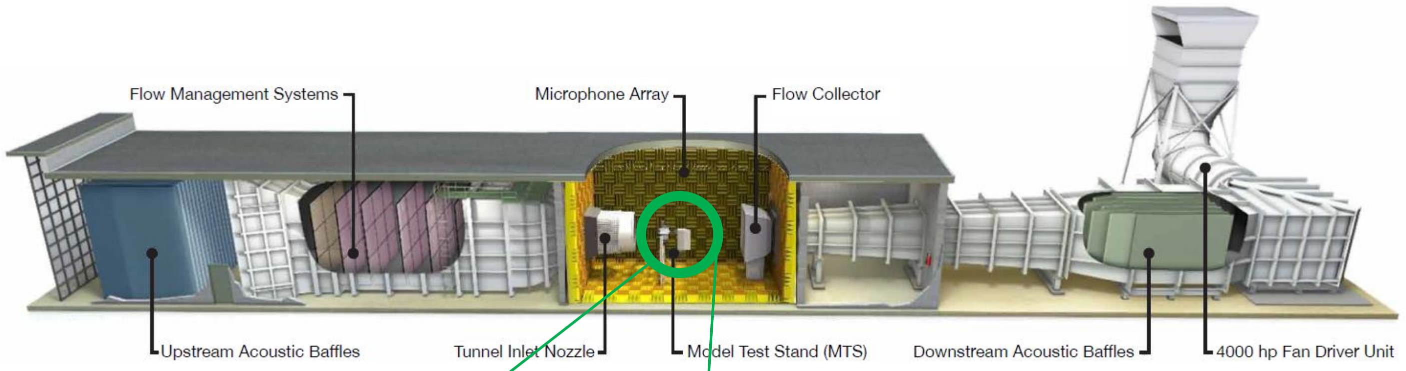
- Two hubs
  - COTS
  - SLA in-house hub

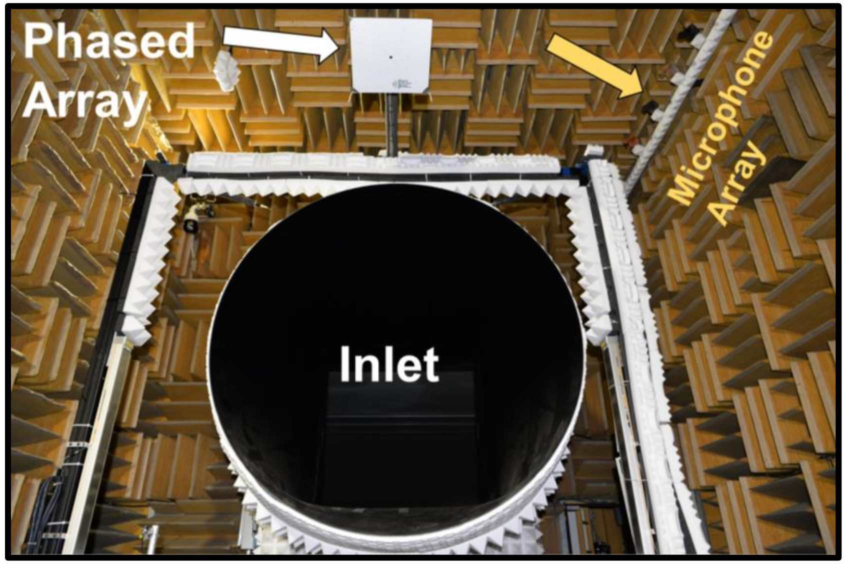
- Cylinder Spacers
  - Baseline (0.15R distance from rotor to airframe)
  - 2.5 inch spacer (0.48R)
  - 1.25 inch spacer (0.30R)

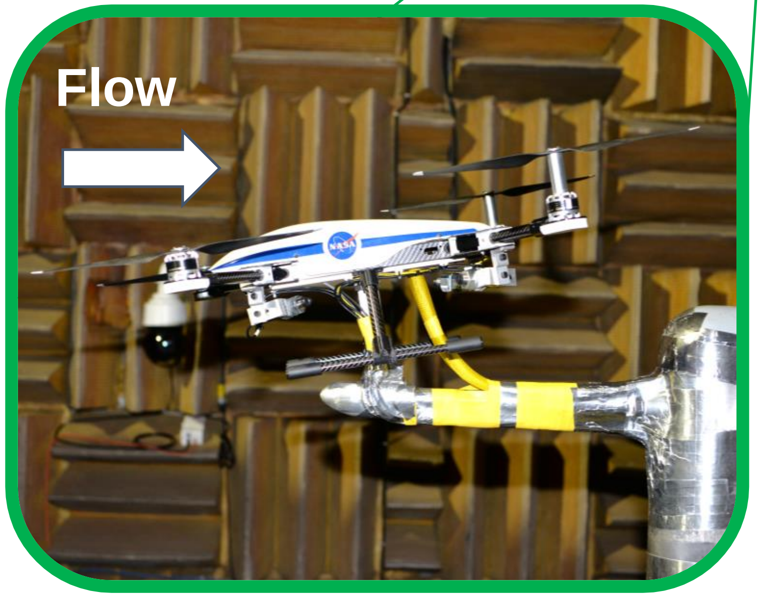


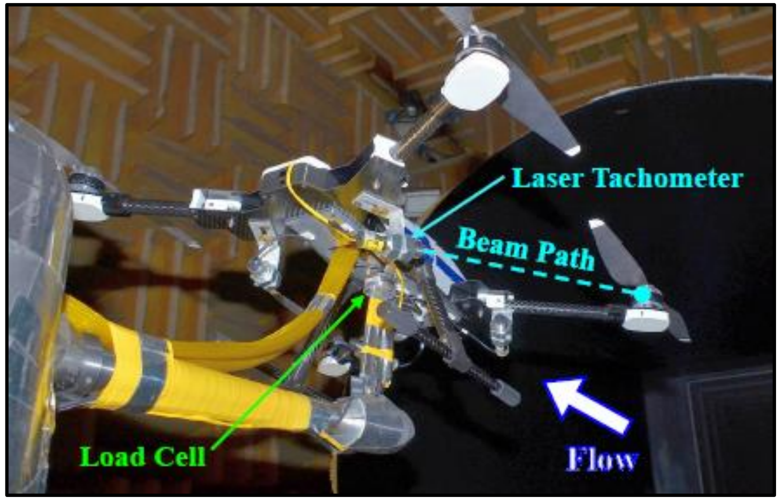
Low Speed Aeroacoustic Tunnel
LSAWT 2021

- LSAWT is an **open-circuit free jet wind tunnel**
- Test section dim: **5.6 m length, 1.93 m inlet** diameter
- Acoustically treated **(cutoff down to 250 Hz)**
- Acoustic measurements taken by a **28 microphone linear array**
- **Phased array** installed **1.25 m away** from the rotor plane



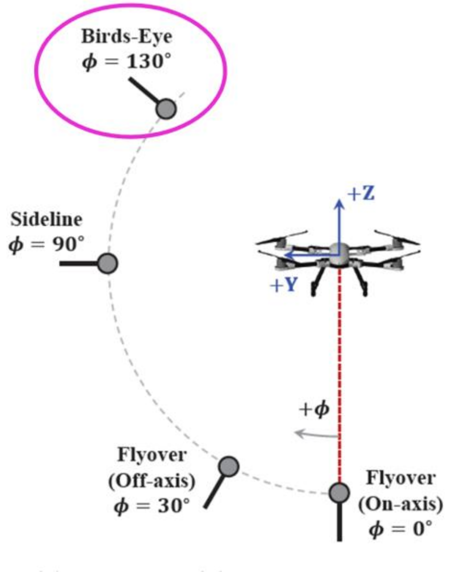


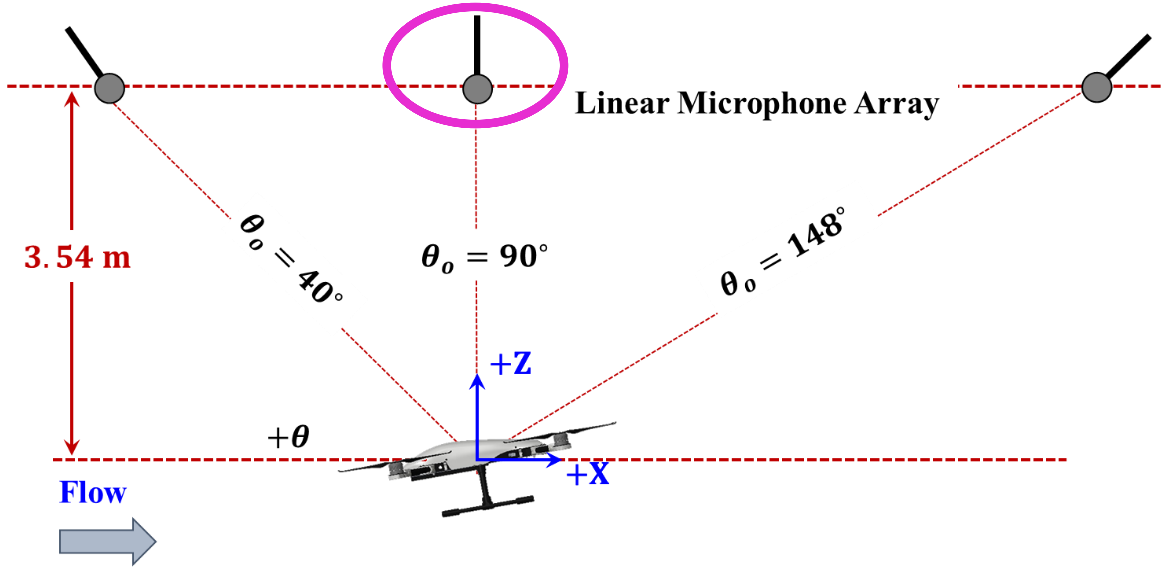


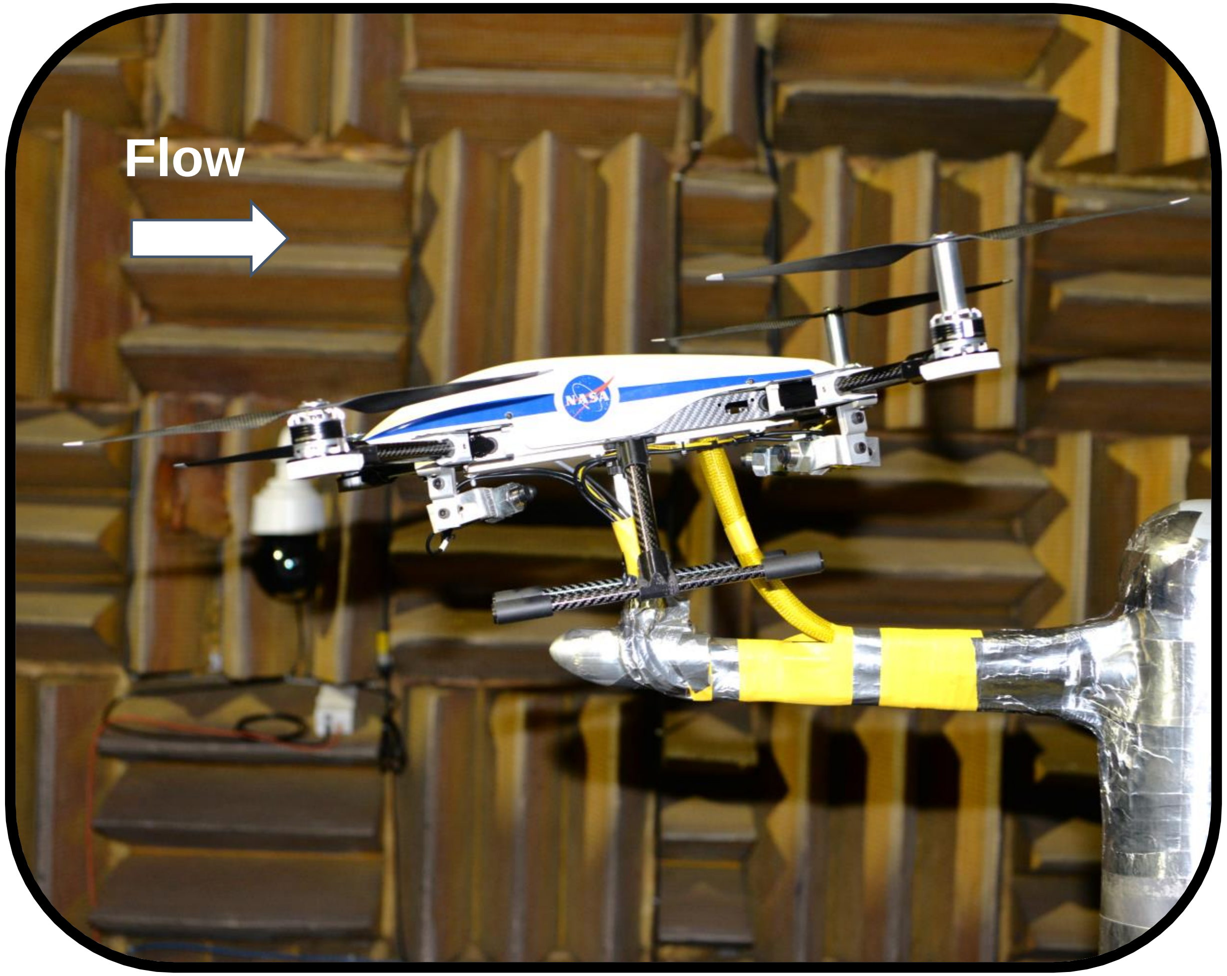


Low Speed Aeroacoustic Tunnel
LSAWT 2021

- Vehicle remained in upright orientation ("Birds-Eye" array location)
- The vehicle pitch angle was changed for the various flight conditions:
  - **hover (0 deg.)**
  - forward flight (4 deg.)
  - **forward flight (10 deg.)**







Results
Comparison to 2017 Test

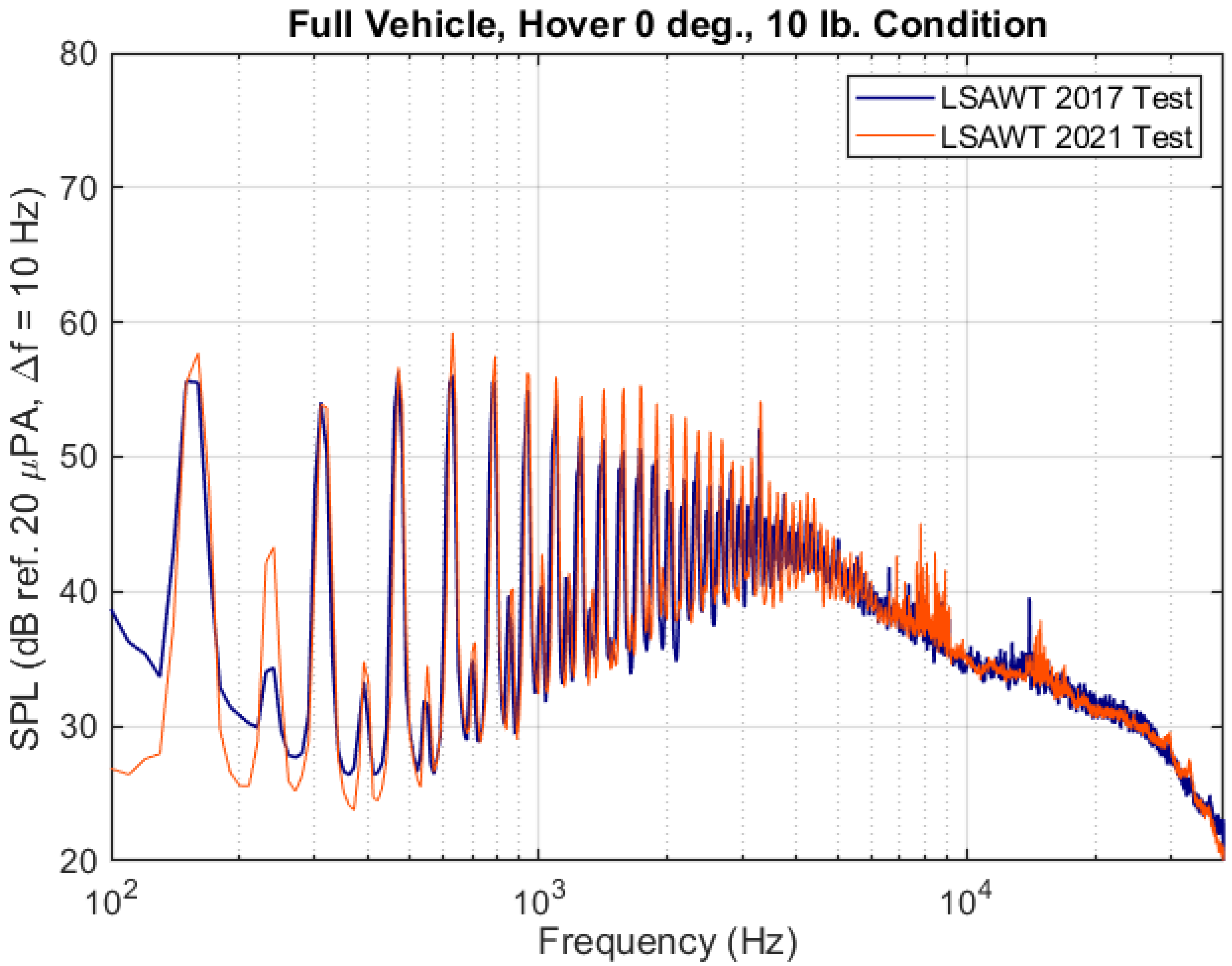
Overhead microphone ($\theta_\circ$ = 90 deg.)

Hover

α_V = 0 deg.

T = 10 lb.

M_∞ = 0.0



Comparison to 2017 Test

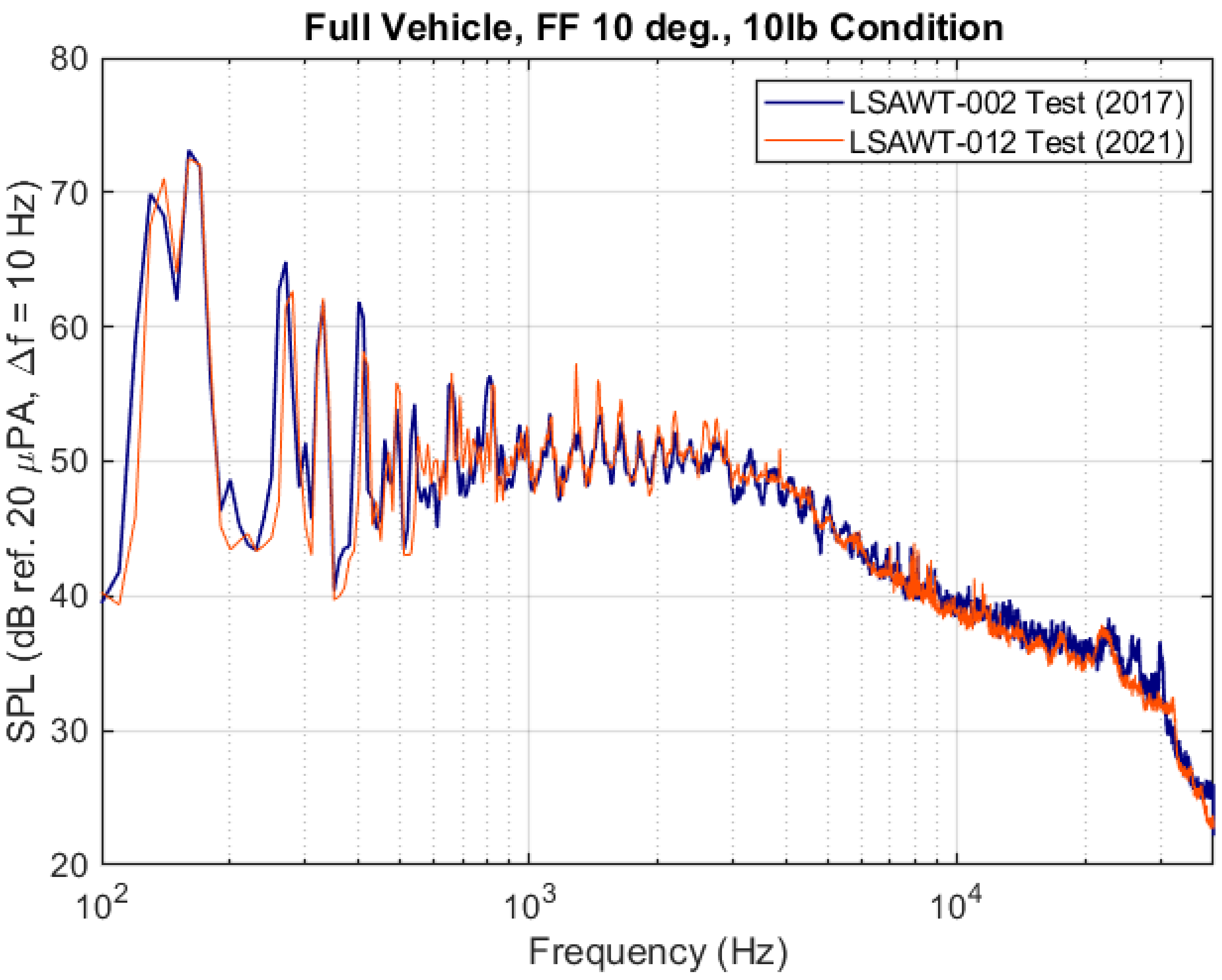
Overhead microphone ($\theta_\circ$ = 90 deg.)

Forward Flight

α_V = -10 deg.

T = 10 lb.

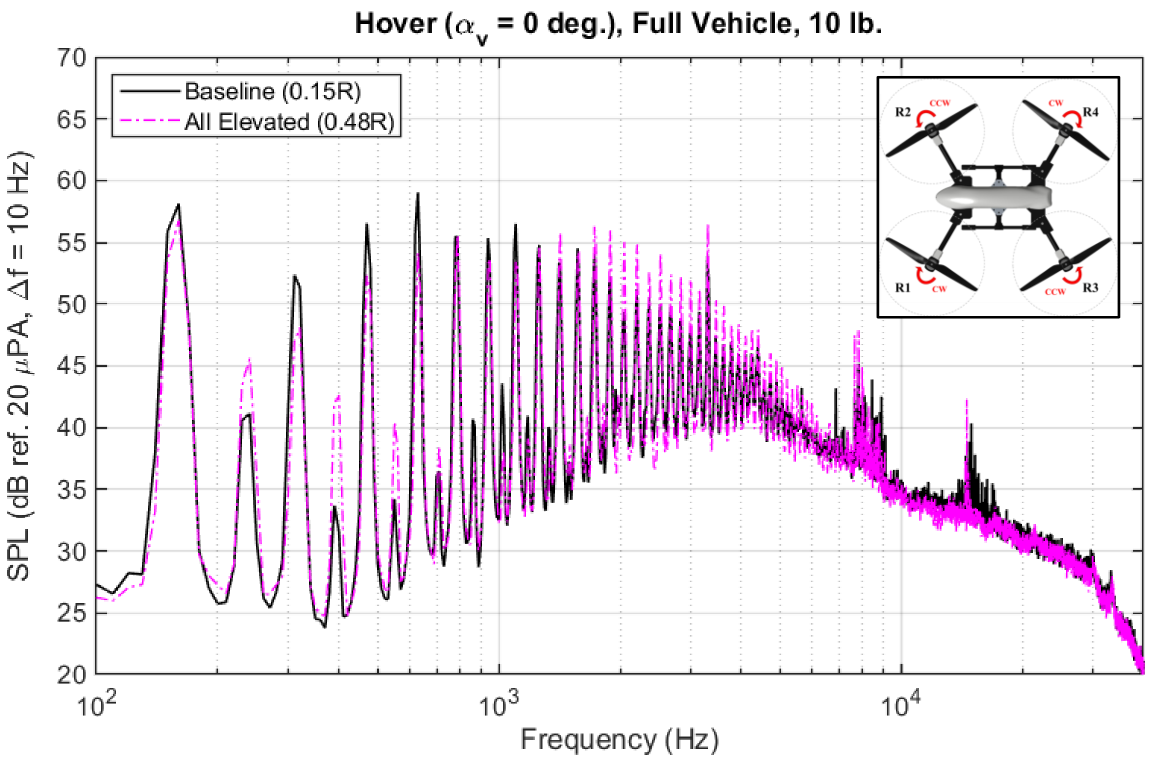
M_∞ = 0.046

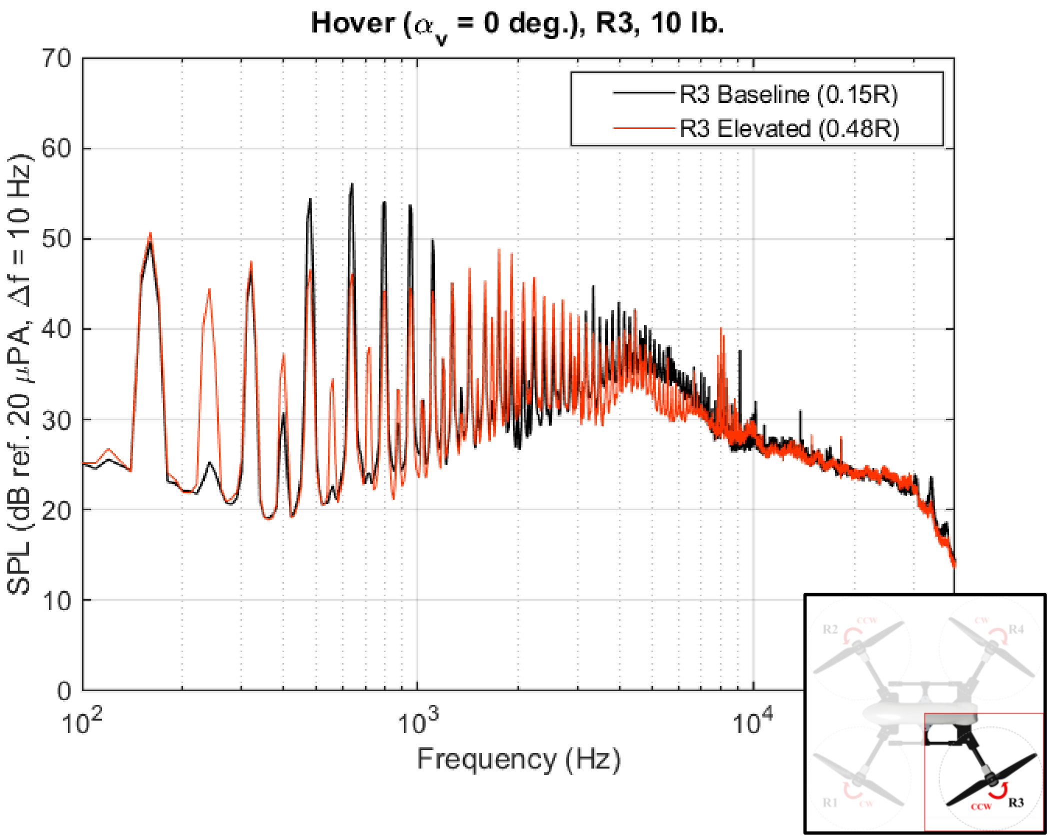


Using the cylinder standoffs in hover

Rotor standoffs were placed on **all rotors** to elevate the rotors from the airframe

There is not a significant noise reduction elevating the rotors in hover, though the amplitudes of 2nd - 4th BPF are reduced





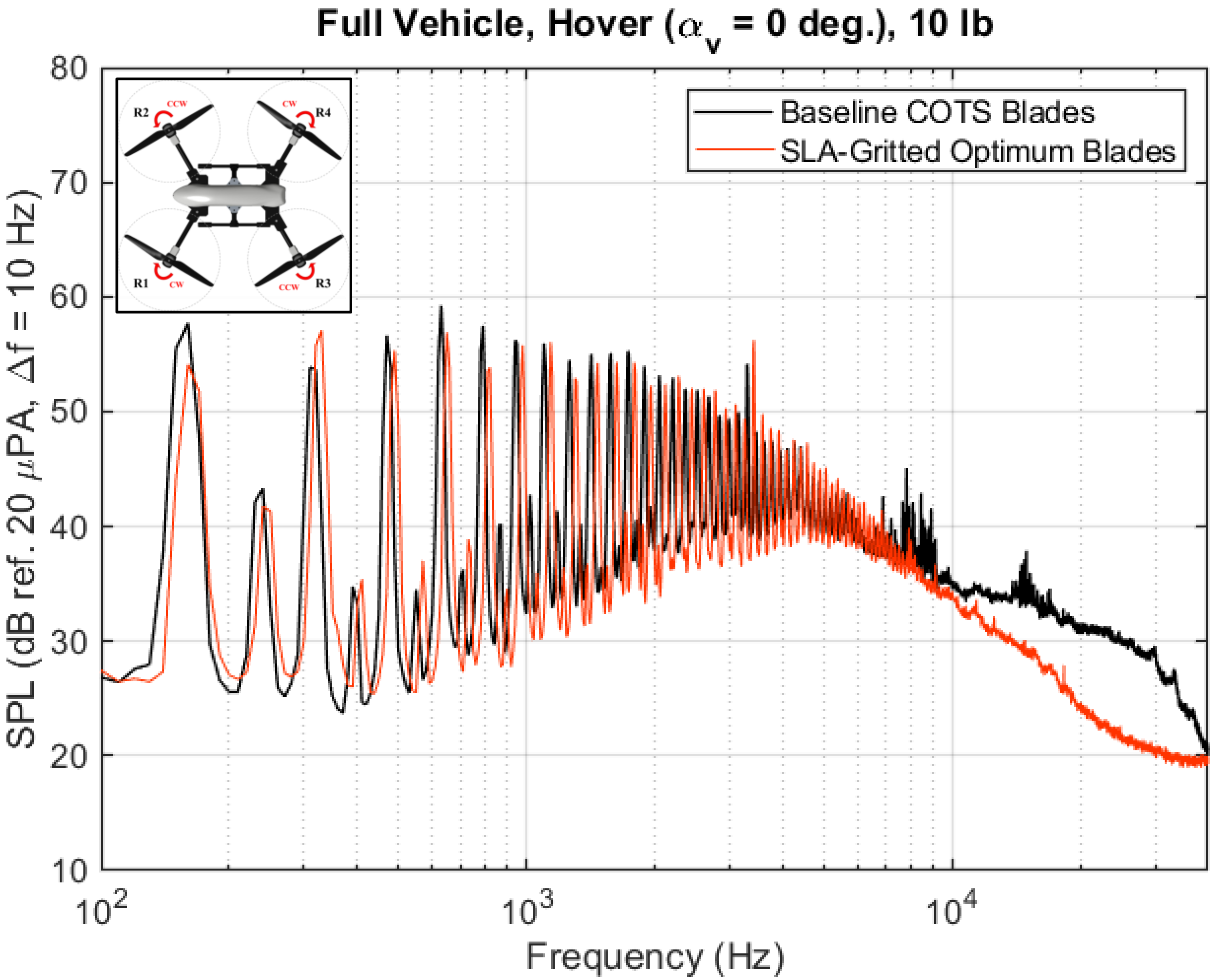
A rotor standoff was placed on **R3** to elevate it from the airframe

Individual rotor better shows possible improvement on rotor airframe noise for 3rd-6th BPF harmonics (between 480 -1 kHz)

Replacing the blades with SLA – gritted blades

T-motor COTS blades were replaced with **optimum design blades**

These SLA blades were gritted with a glass grit to create a “trip” to prevent laminar boundary layer vortex shedding behavior



SLA-Gritted blades provide broadband noise reduction at frequencies higher than **10 kHz**

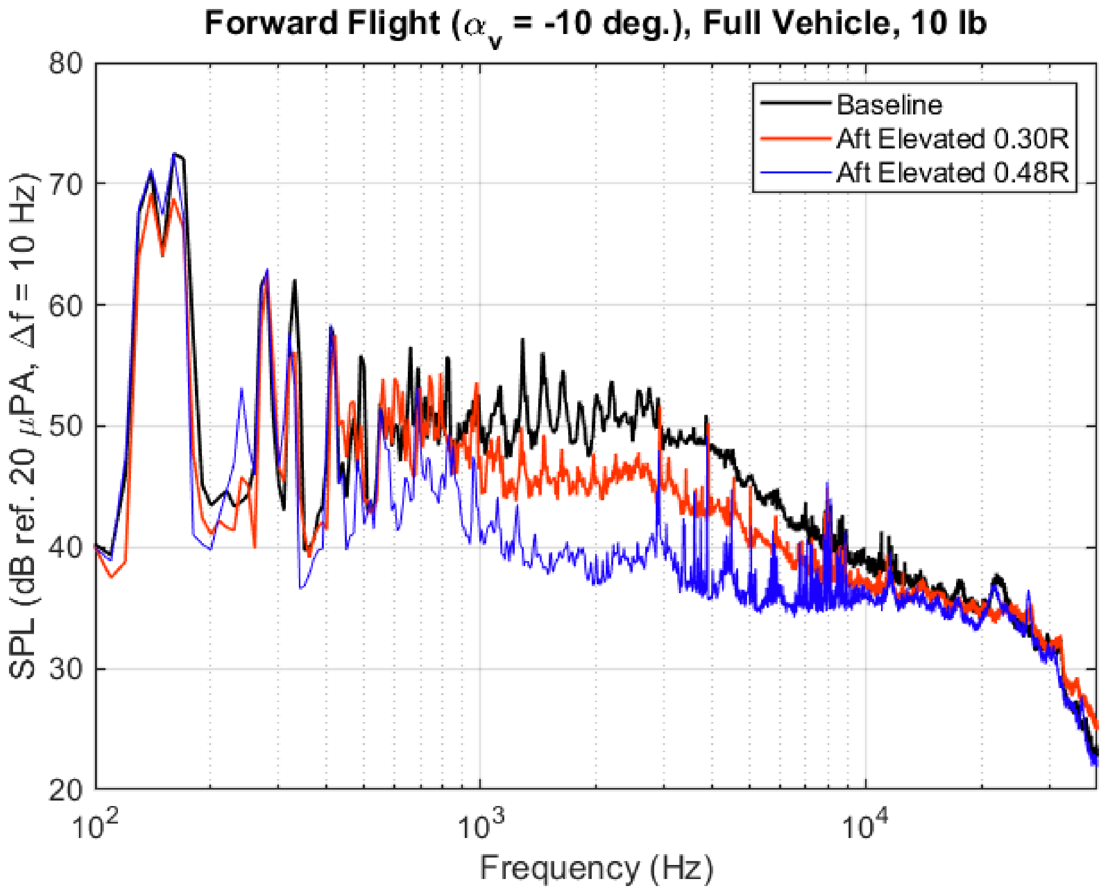
However, these blades were difficult to trim in the full vehicle configuration

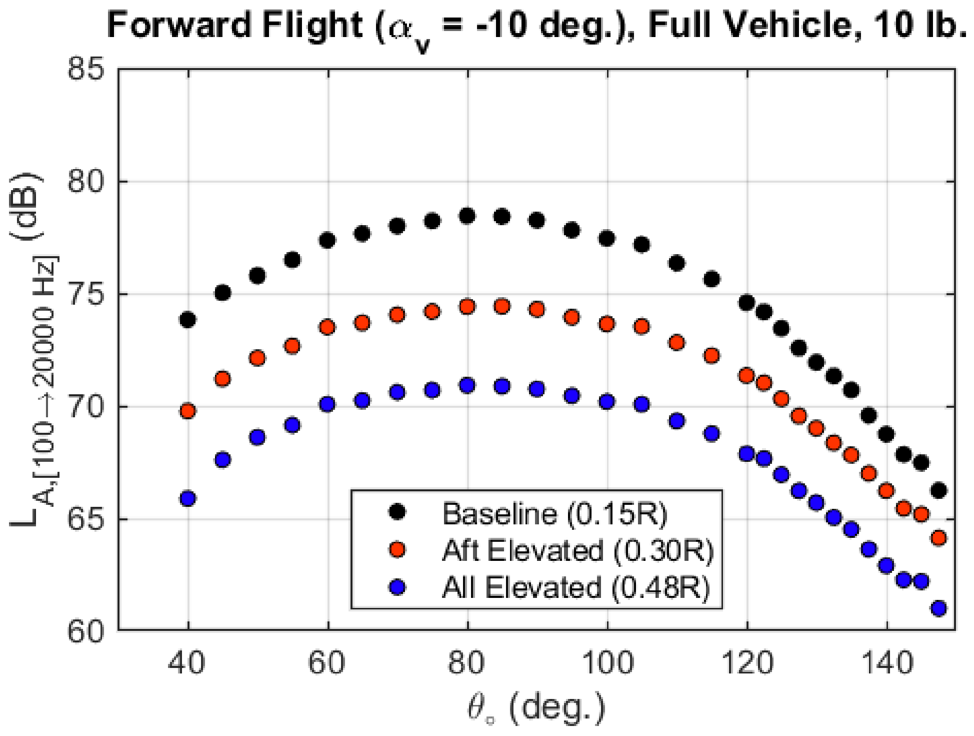
Forward Flight Results

Using the cylinder standoffs in forward flight

Rotor standoffs were placed on **aft rotors (R3 & R4)** to elevate the rotors from the airframe

Between **1 and 9 kHz** there is a decrease of broadband noise content **(up to ~10 dB)**



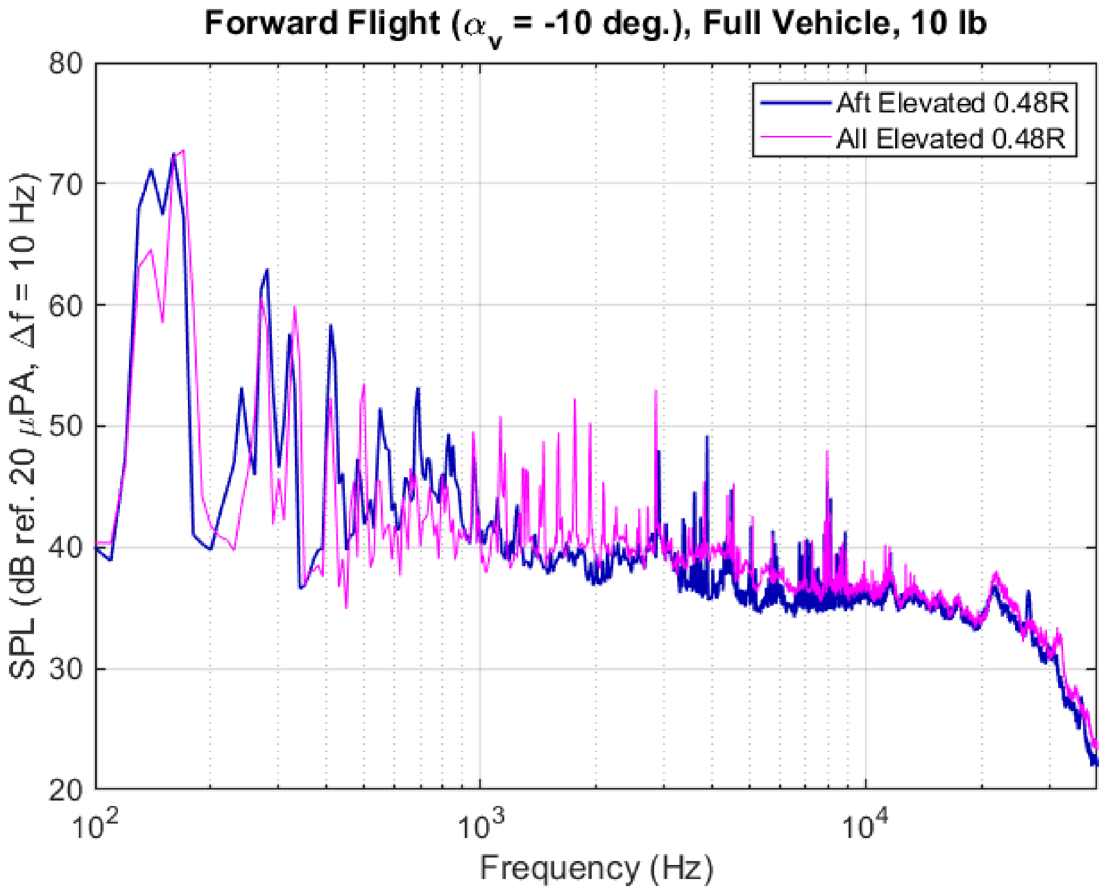


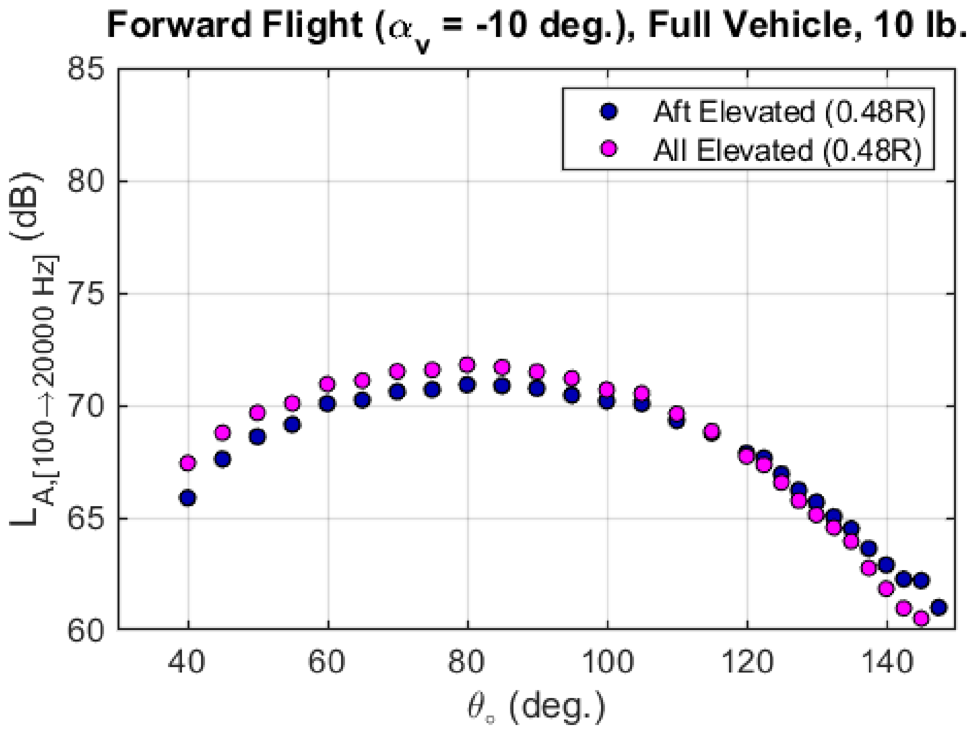
A-weighted integrated levels show a reduction of up to **8 dB**, when including all content between **0.1 and 20 kHz**

Forward Flight Results

Using the cylinder standoffs in forward flight

Rotor standoffs were placed on **all rotors** to elevate the rotors from the airframe

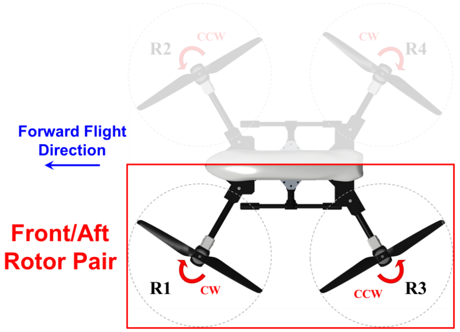


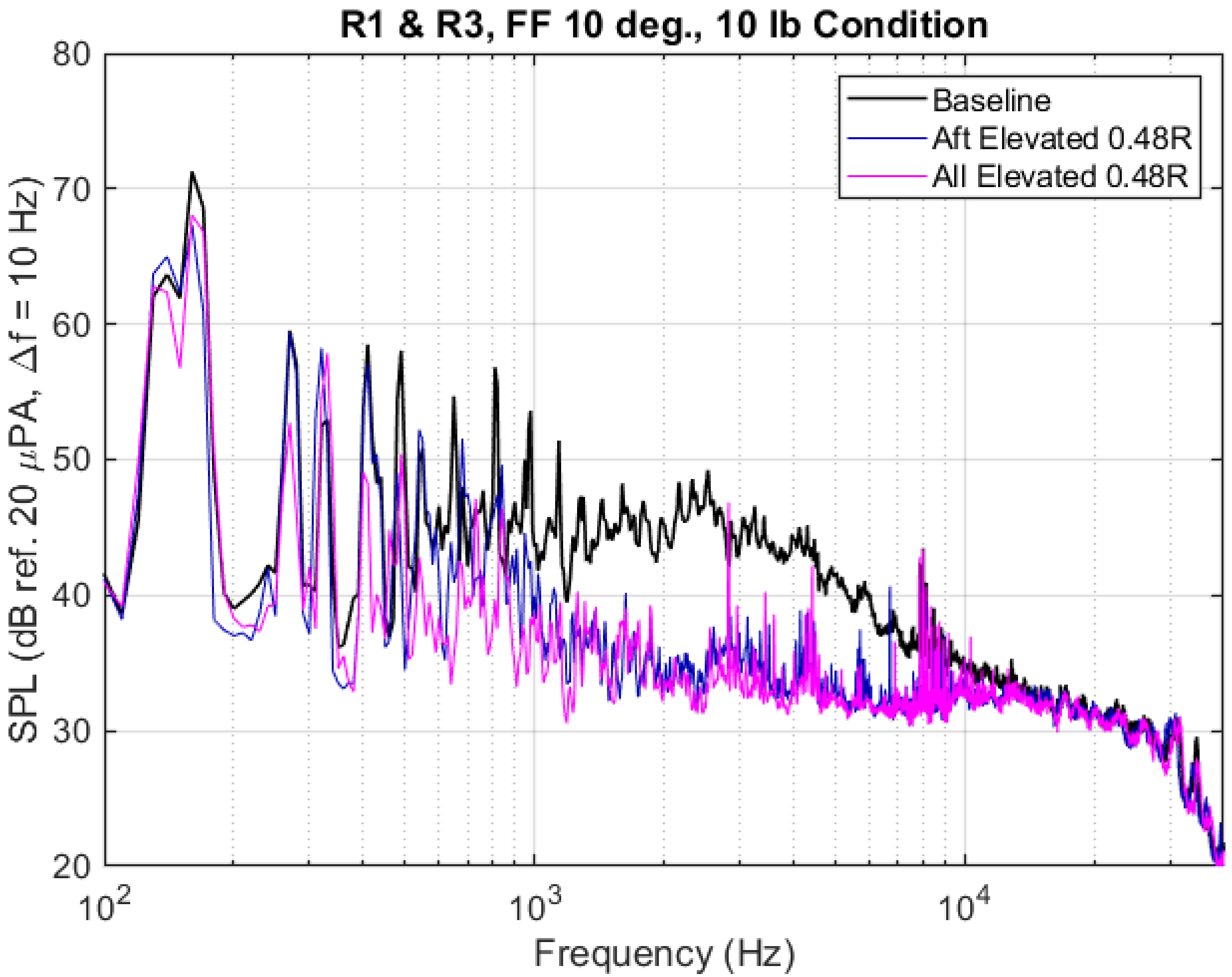


Broadband noise levels between **1 and 9 kHz** have minimal difference when comparing spectra

Additional harmonics present at mid-frequencies could be due to cylinders oscillating

Forward Flight Results
Using the cylinder standoffs (R1 & R3)



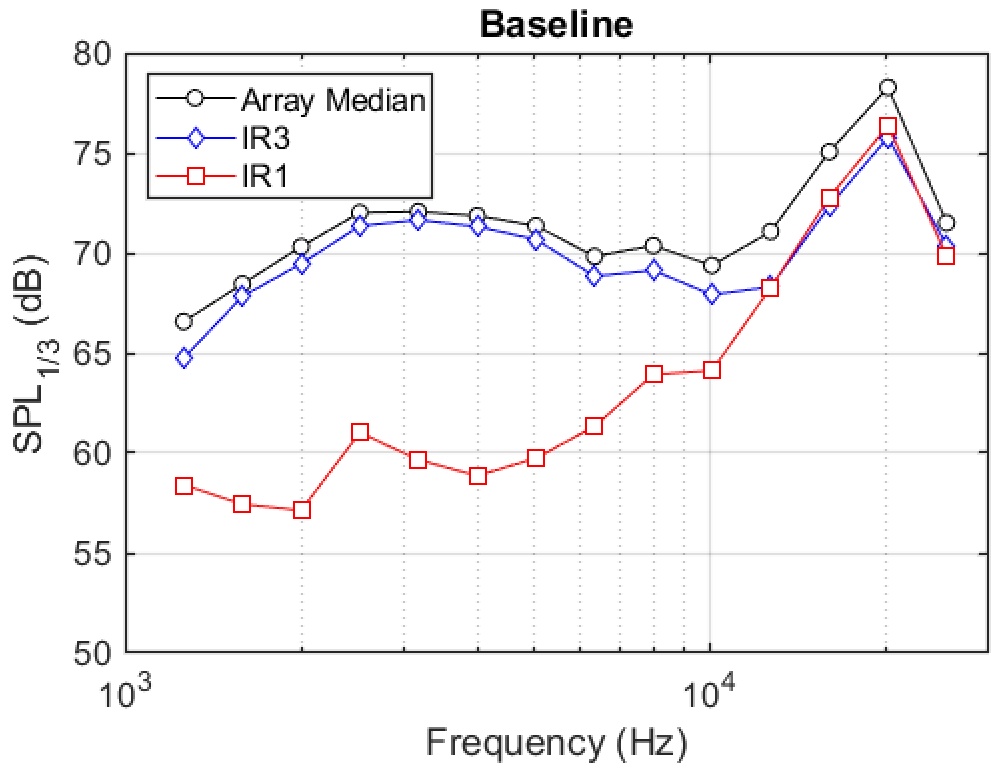


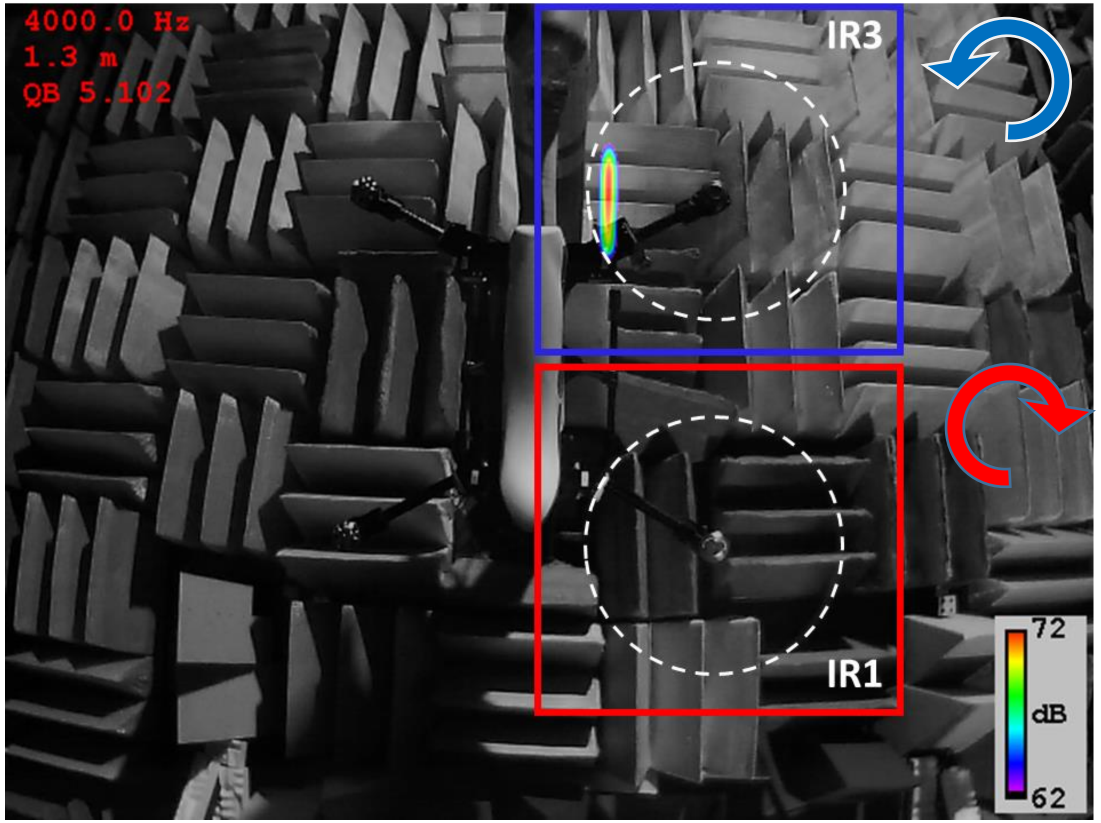
Spectral trend is similar to full vehicle configuration

Beamforming Results

Using the cylinder standoffs (R1 & R3)

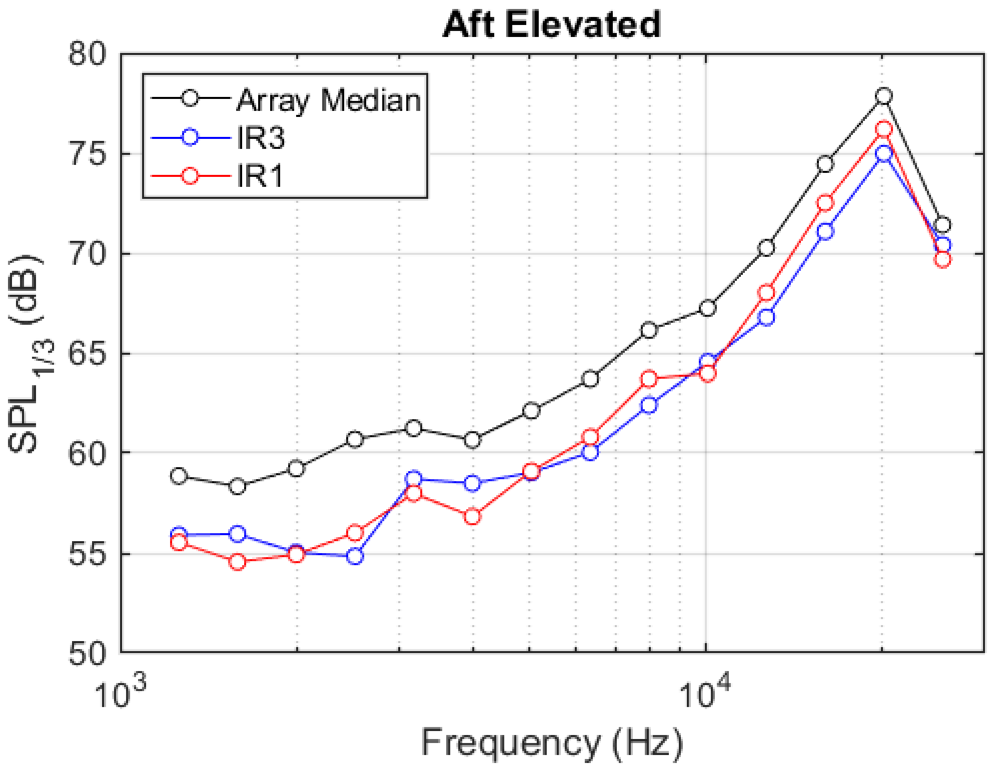
Baseline: 4 kHz



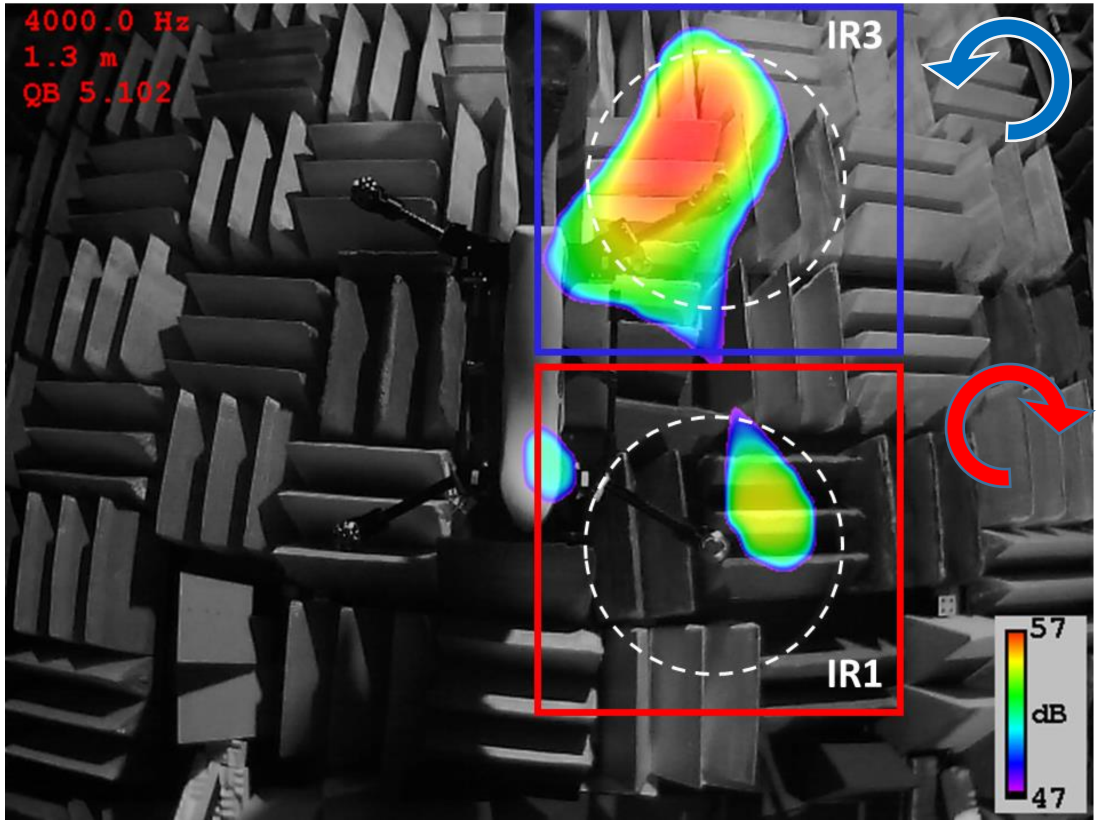


Beamforming Results

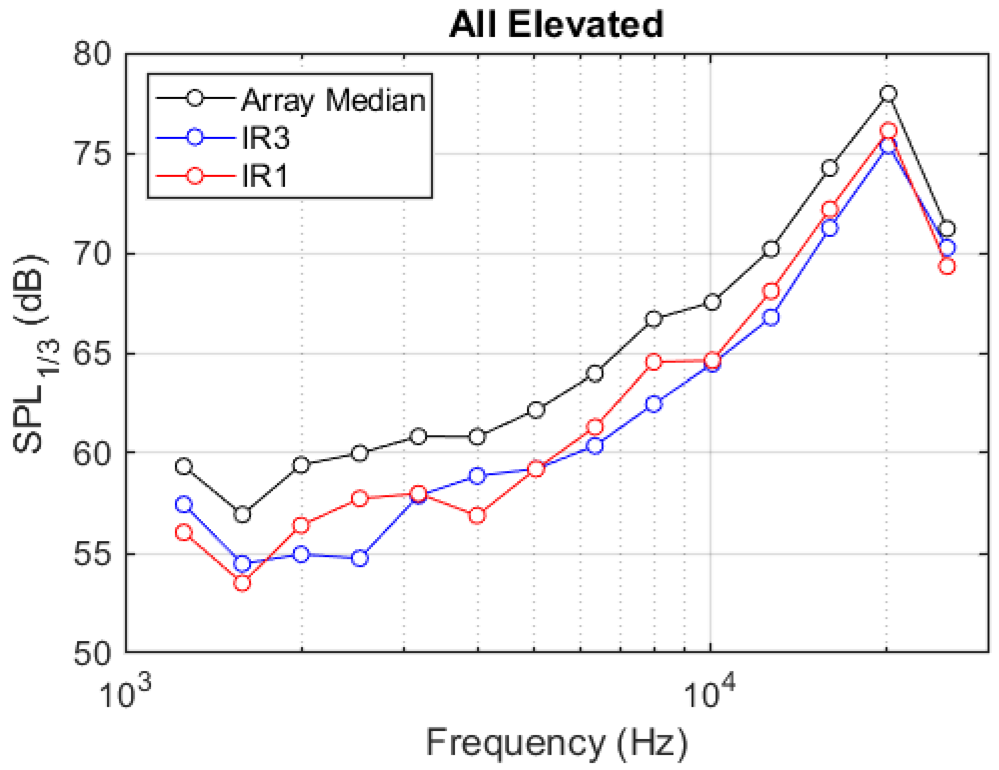
Using the cylinder standoffs (R1 & R3)



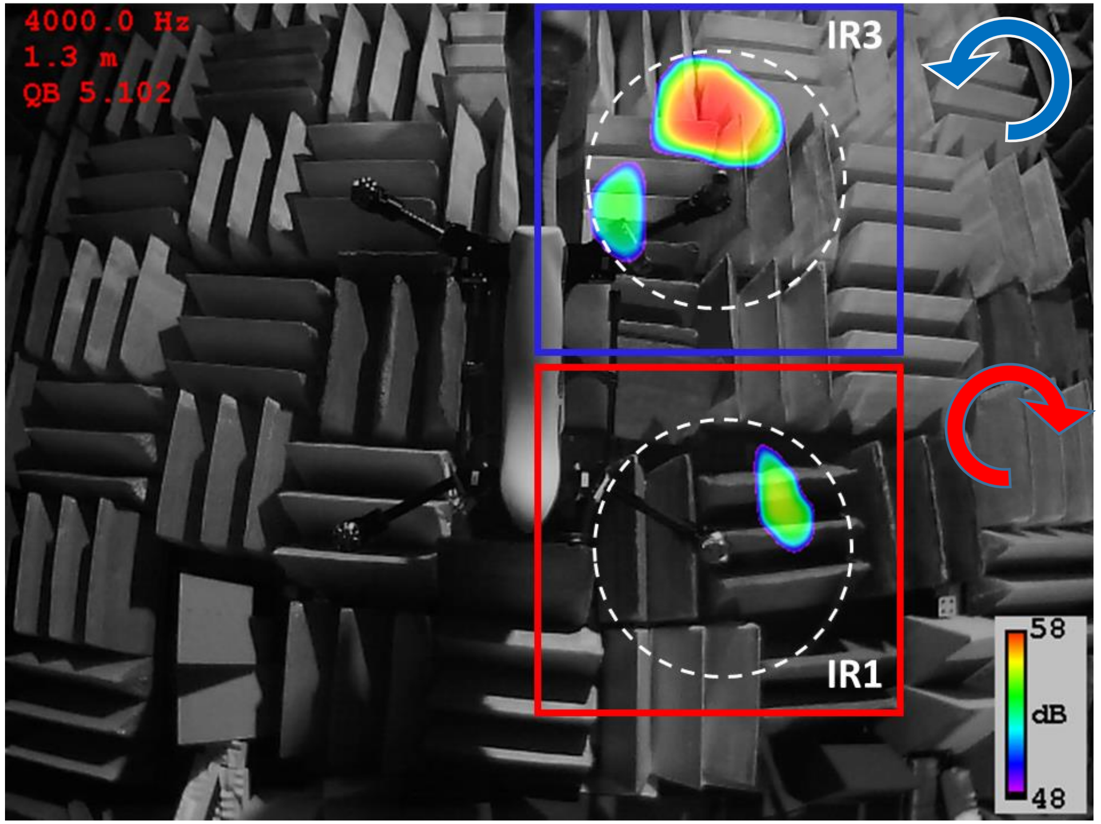
Aft Elevated: 4 kHz



Beamforming Results
Using the cylinder standoffs (R1 & R3)



All Elevated: 4 kHz



Conclusions

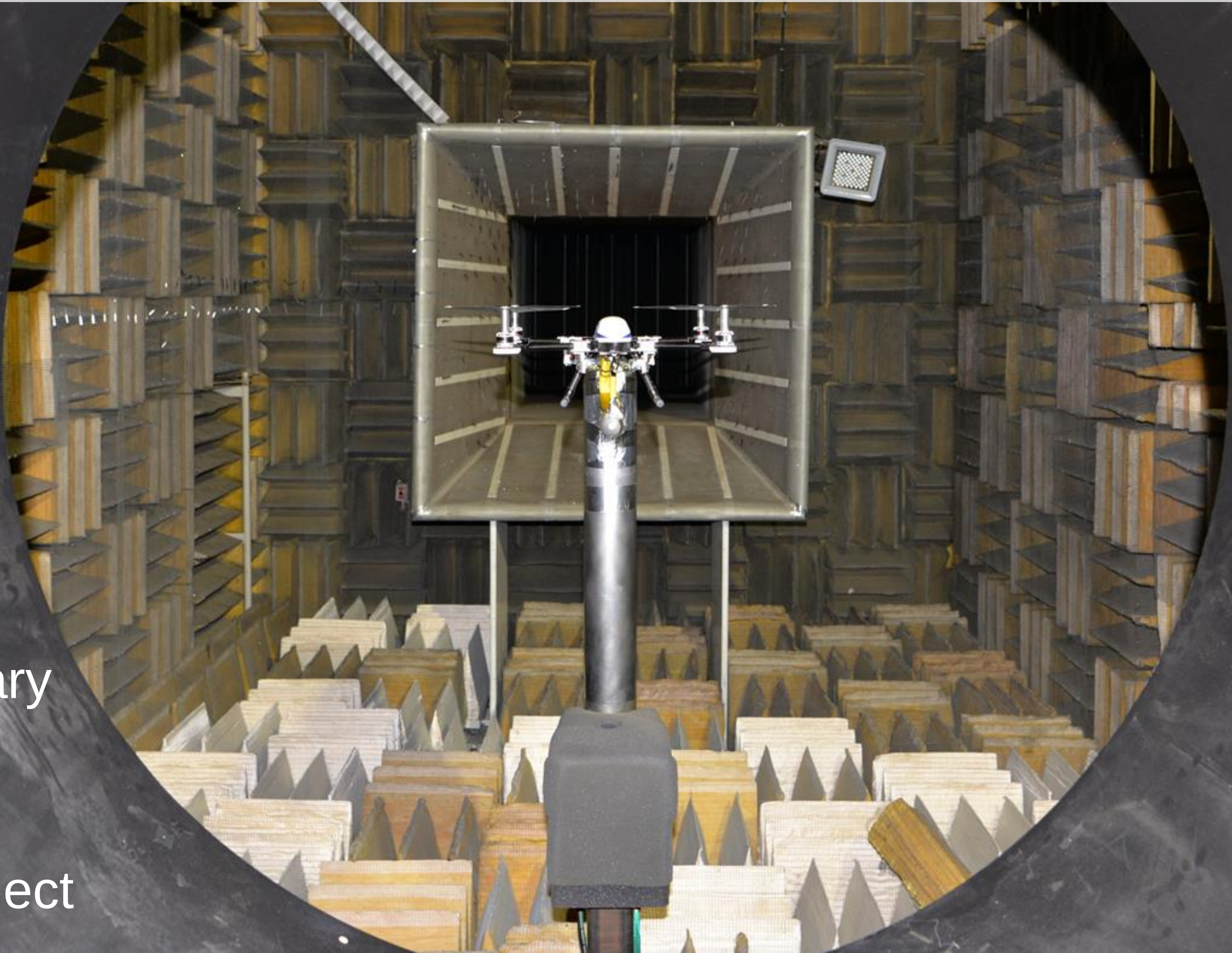
- Hover
  - Elevating rotors did not show a significant noise reduction in full vehicle hover flight conditions
  - When examining single R3 elevated case, elevating the rotor reduced the amplitude of the 4th-6th BPF harmonics

- Forward Flight
  - Elevating rotors (both aft-elevated and all-elevated) reduced mid-frequency broadband noise around 1-9 kHz
  - By elevating rotors could be reducing noise related to:
    - Rotor-airframe interaction noise
    - Rotor-rotor interaction noise
    - Rotor-airframe-rotor interaction noise
    - Individual aft rotor noise contribution

Future Work

- Periodic and broadband noise extraction using TTL signal
- Interrogate additional thrust and flight conditions
- Use low-fidelity tools to help identify noise sources
- Planning to submit papers to future conferences

Acknowledgments



Special Thanks

<u>LSAWT Crew</u>

John Swartzbaugh

Stanley Mason

Bryan Lamb

Scott Parks

Jarrett Braxton

Funding

Revolutionary Vertical Lift Technology (RVLT) Project

Contact Information
Niki Pettingill
nicole.a.pettingill@nasa.gov
757-864-7912

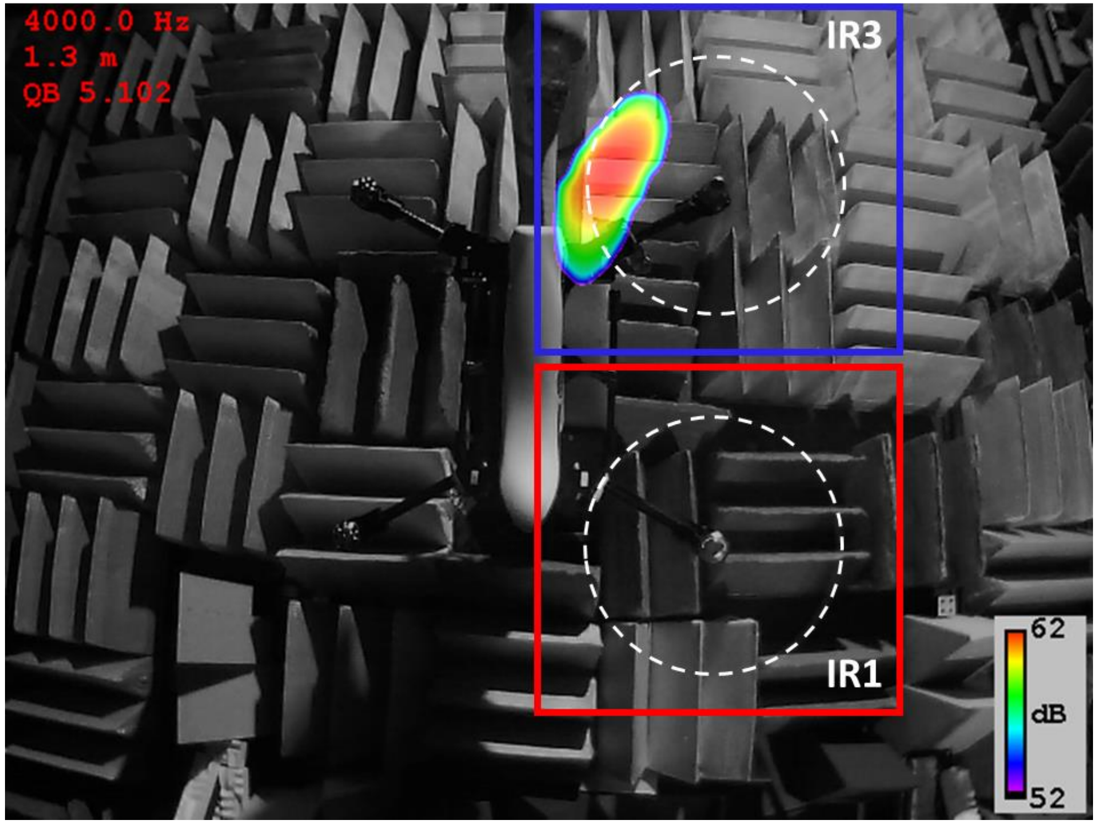
Thank you, any questions?

Extra Slides

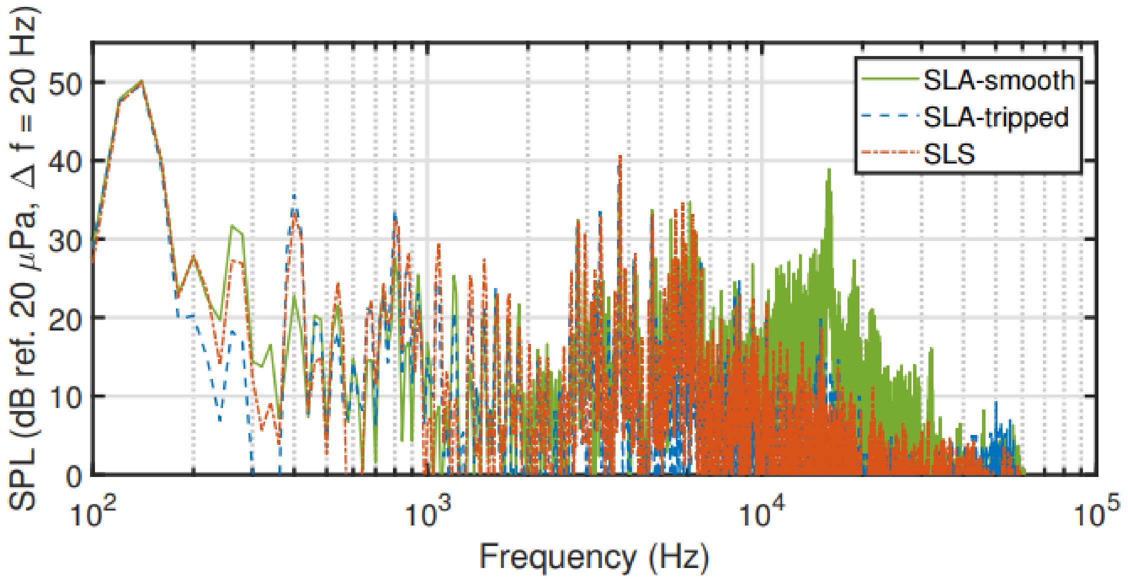
Beamforming Results

Using the cylinder standoffs (R1 & R3)

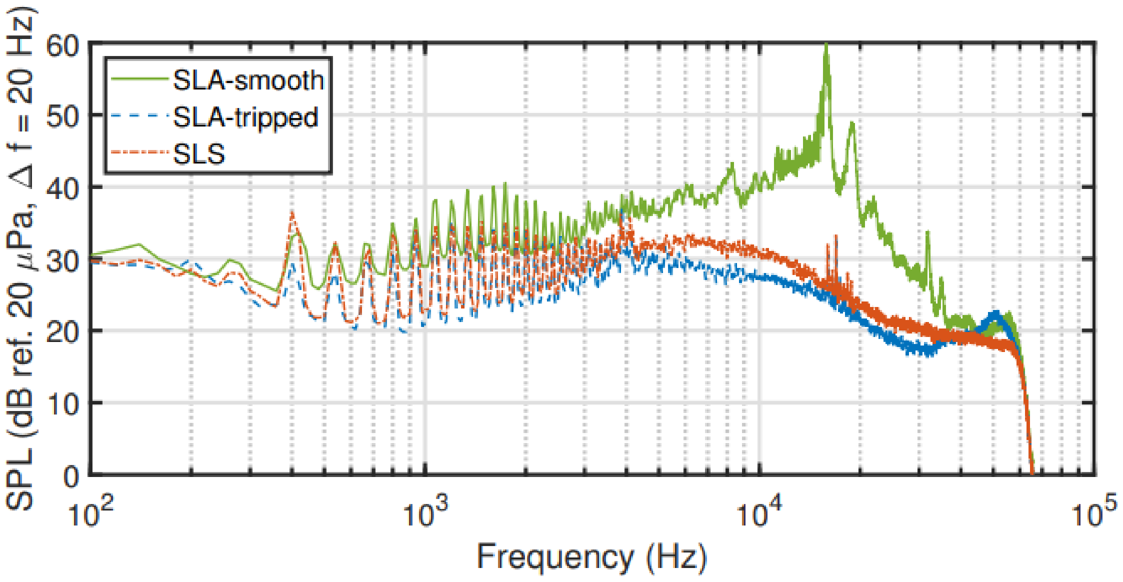
Aft Elevated (med. cyl) : 4 kHz



Blade Set Comparison



(a) Tonal noise.



(b) Broadband noise.

Blade sets were tested in the Small Hover Anechoic Chamber (SHAC) prior to being placed on vehicle

SLA blades had a glass grit applied to them (and referred to as “SLA-tripped”), as it was found to reduce laminar boundary layer vortex shedding (LBLVS) broadband noise between **4 and 30 kHz**

Forward Flight Results

Using the cylinder standoffs in forward flight

Unweighted integrated levels of various elevation configurations: