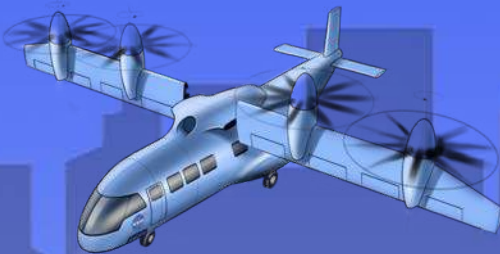


# Electric Motor Noise from Small Quadcopters

## Part I – Acoustic Measurements



**AIAA/CEAS Aeroacoustics Conference**  
**June 25-29, 2018**  
**Atlanta, Georgia**

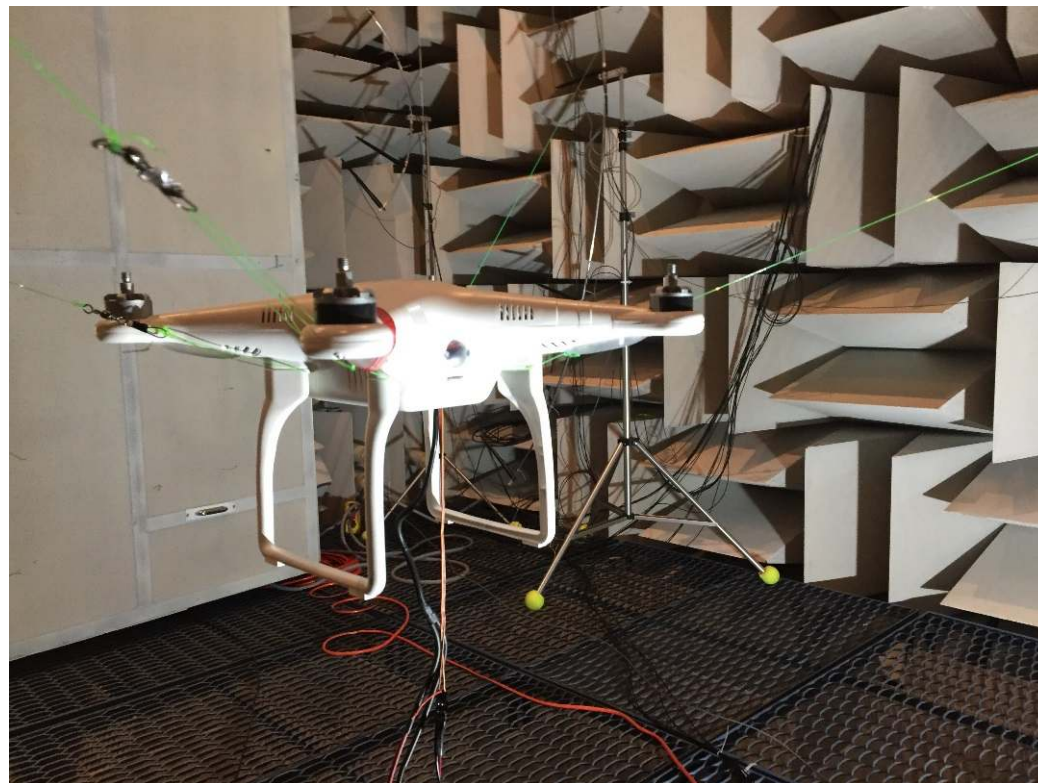


**Dennis L. Huff**  
**Brenda S. Henderson**  
**NASA Glenn Research Center**



# Motivation

- **Electric motors driving small Unmanned Aircraft Systems (sUAS) propulsors.**
- **Noise expected to be problem, especially for Urban Air Mobility (UAM) missions.**
- **Noise sources need to be understood (propeller, motor, etc.).**
- **Need noise prediction methods for electric motors.**

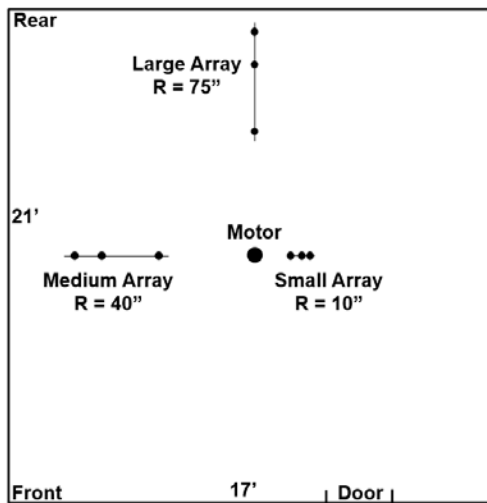
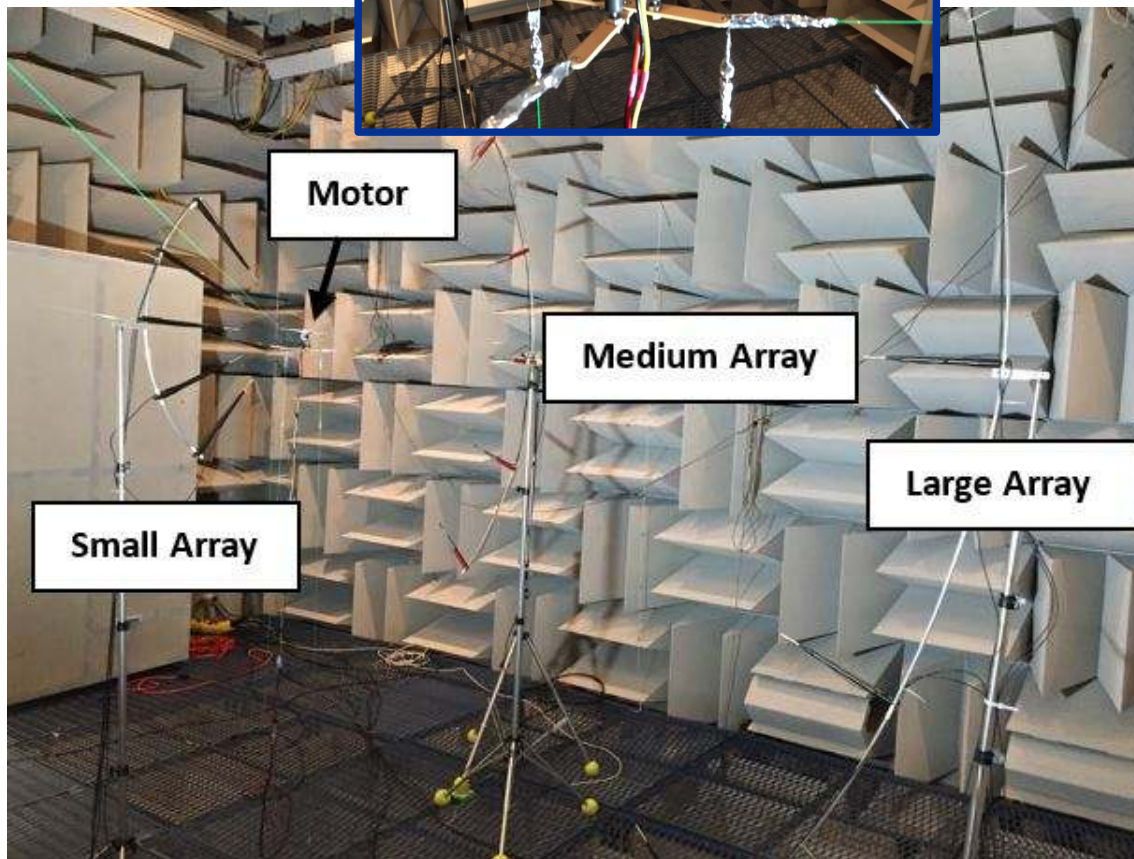
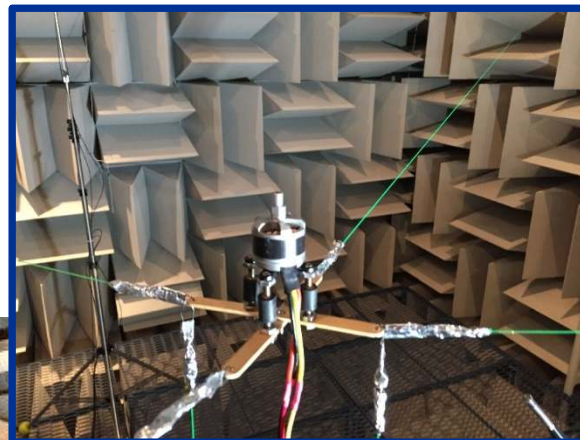
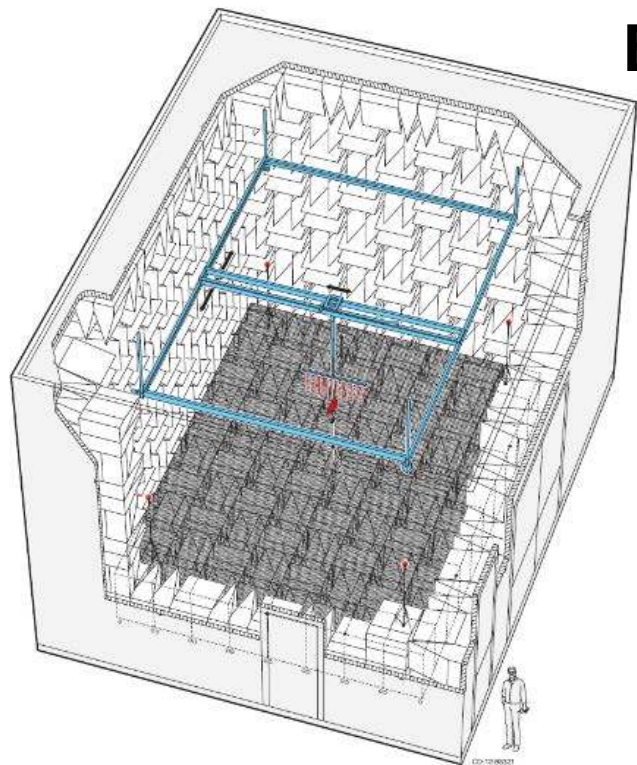


***Companion paper in this session will present source characteristics.***

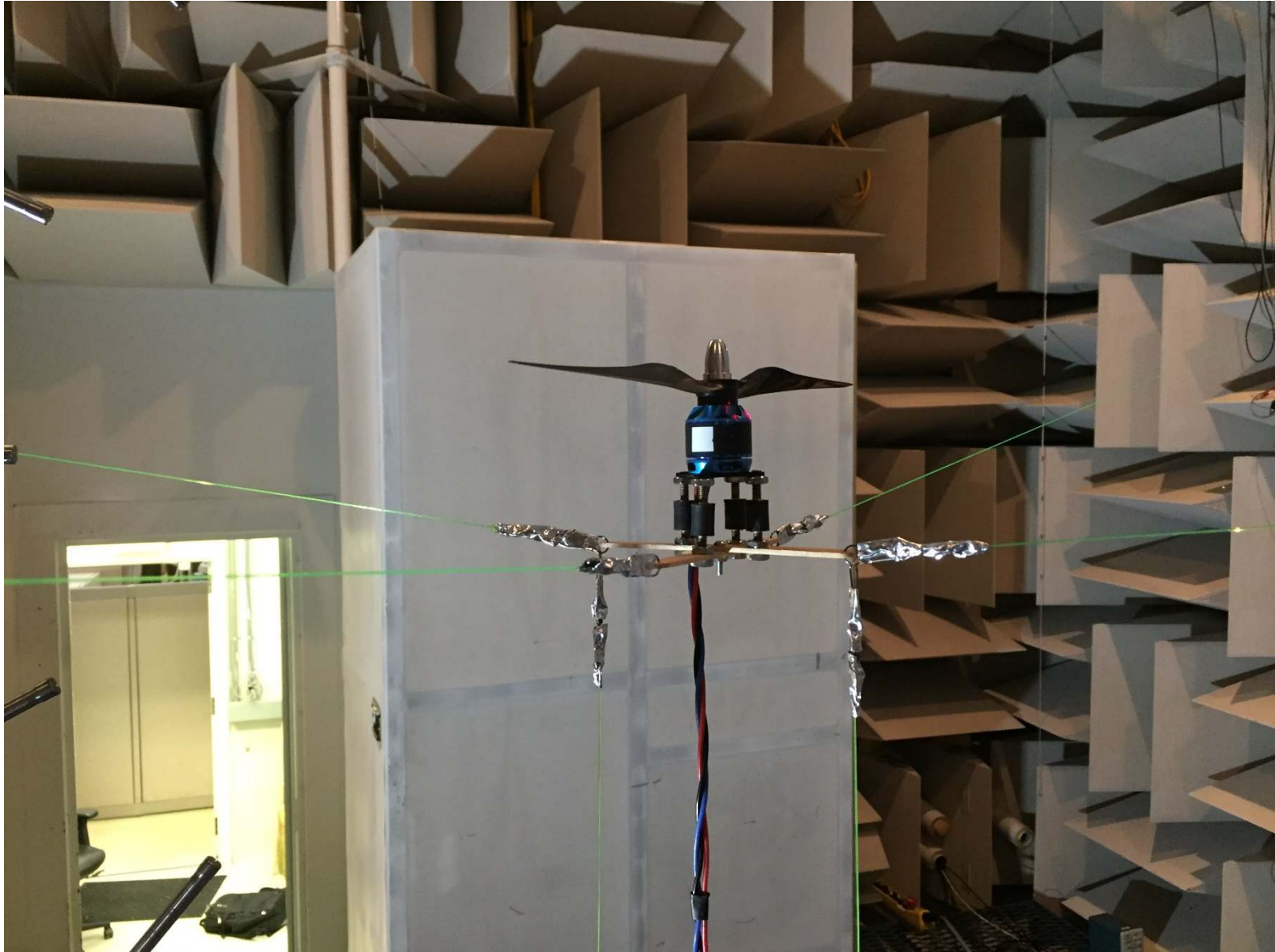
***Future work will focus on larger motors.***



# Experimental Setup



# Motor & Propeller With Tether









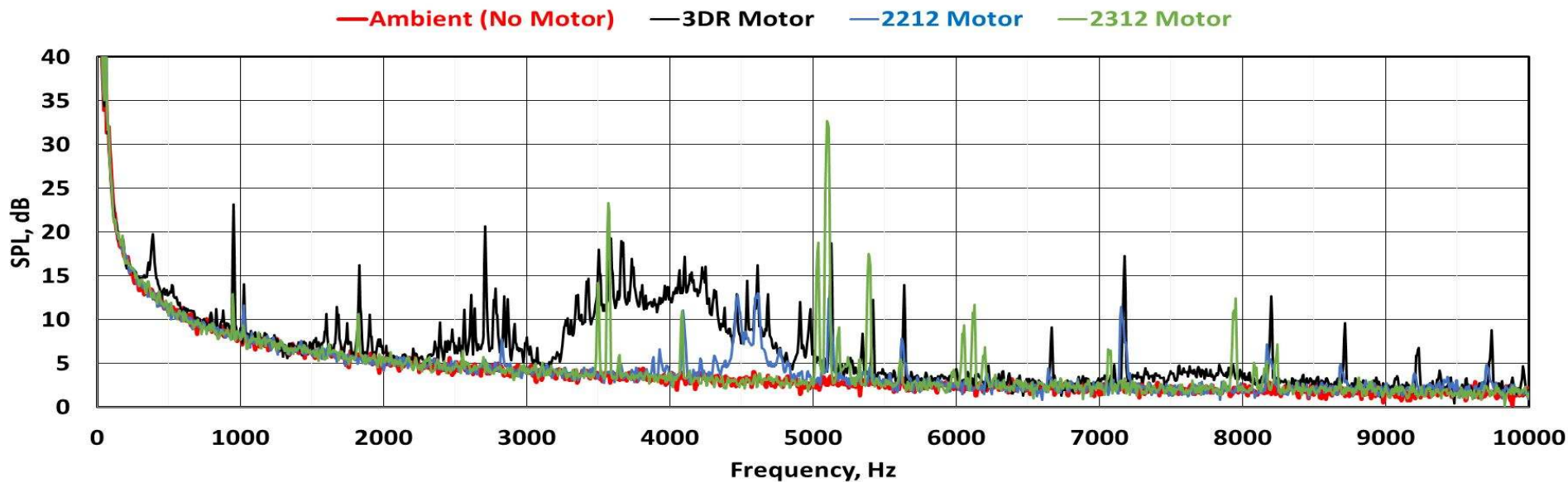
# Test Matrix

	3DR "Blue"	2212	2312
Speed Variation (RPM)	4380, 5370, 6260	4380, 5370, 6260, 4773	4380, 5370, 6260, 4773
Acoustics (Small, Medium, Large Arrays)	X	X	X
Speed Controllers			
E300	X	X	X
3DR	X	X	-
420S	-	X	X
Load			
Motor Only	X	X	X
2-Bladed	X	X	X
3-Bladed	-	-	X
Phased Array	X (location study)	X	X
Current Probe	2 loops	1 loop	1 loop
Ping Test	X	X	X
Motor kV Constant (RPM/Volt)	850	920	960





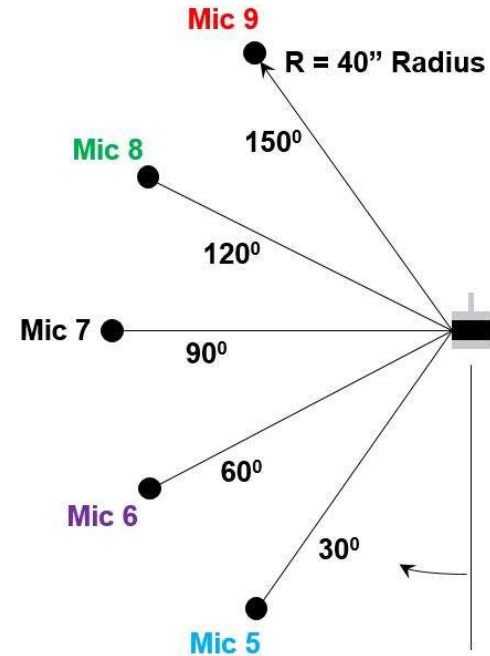
# Background Noise



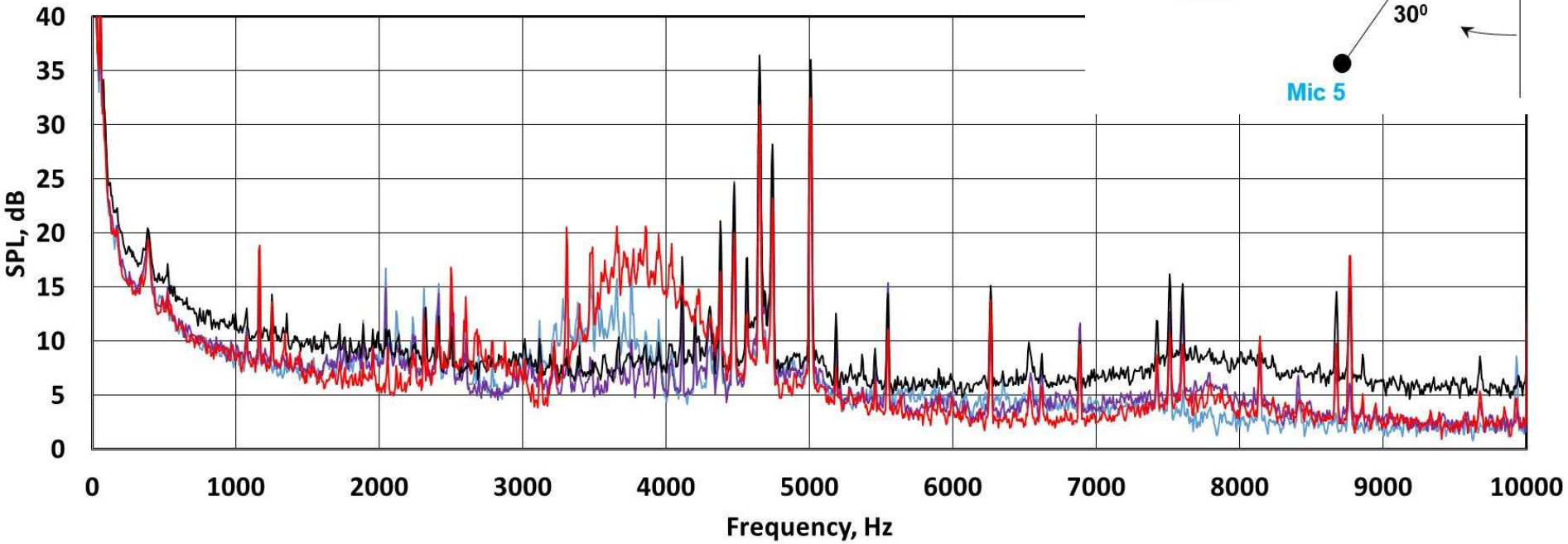
- **Motor-only SPL comparisons for three motors, microphone 9 on medium array, 4380 RPM.**
- **Noise floor from 1/4-inch microphones, not chamber**



# 3DR Motor Spectra, 5370 RPM



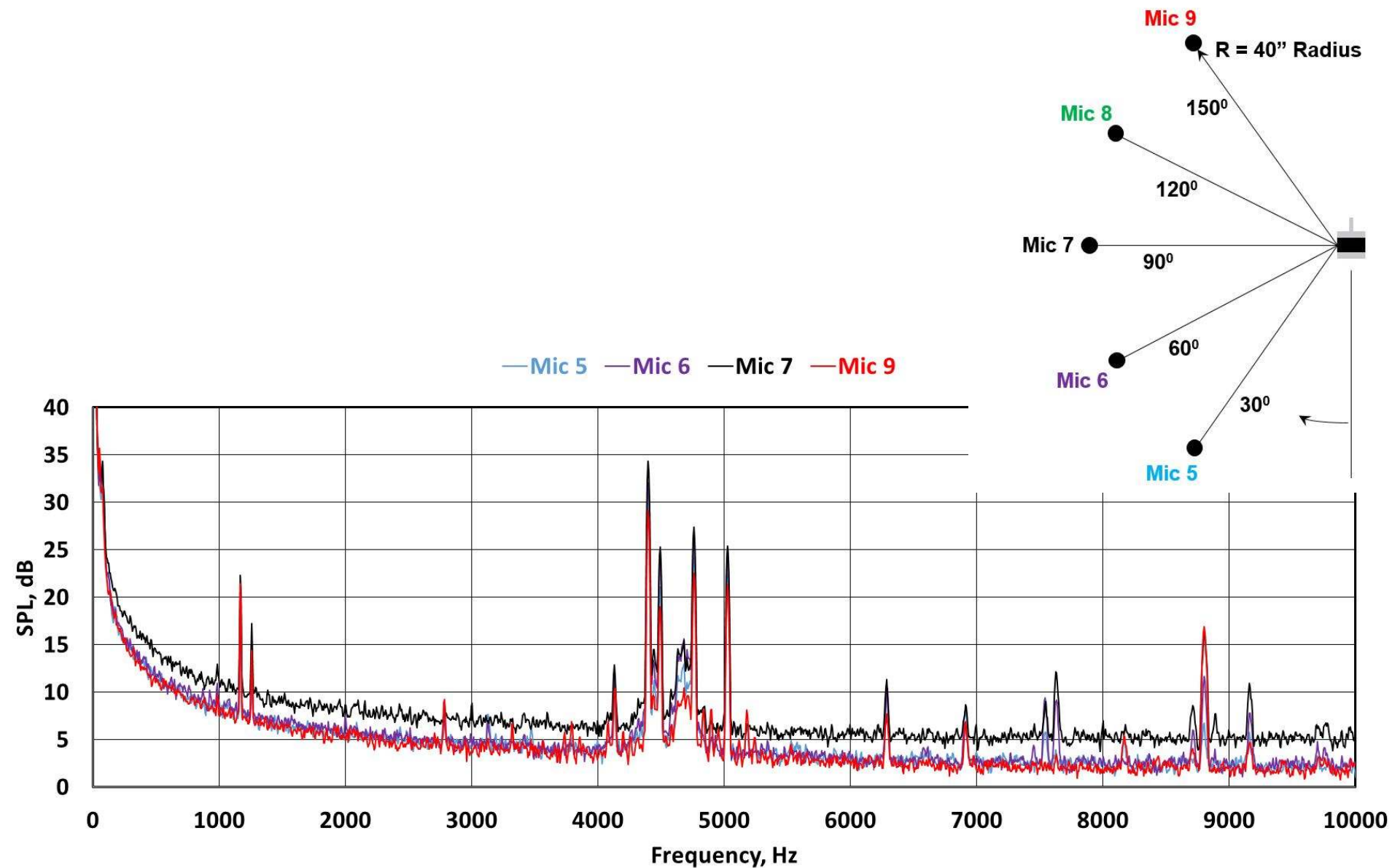
— Mic 5 — Mic 6 — Mic 7 — Mic 9





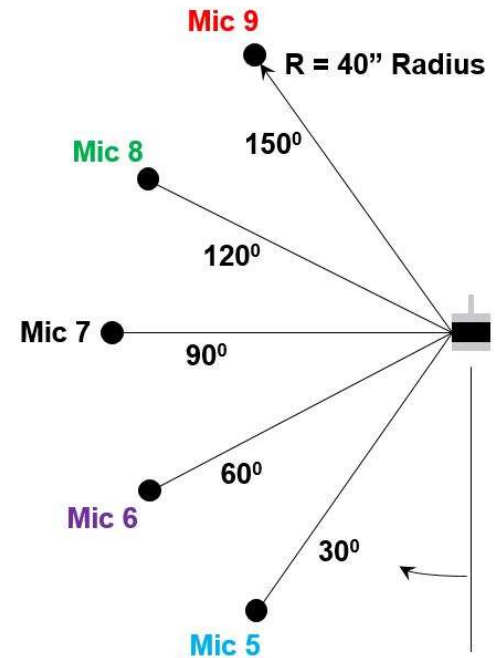


# 2212 Motor Spectra, 5370 RPM

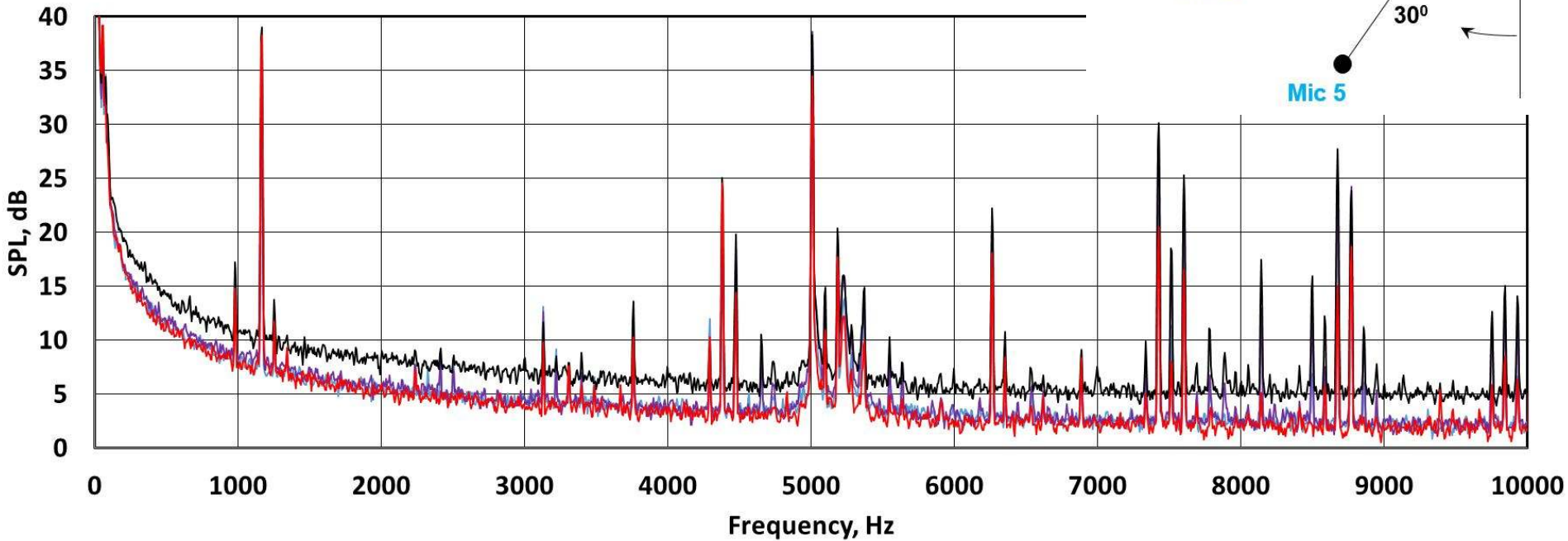




# 2312 Motor Spectra, 5370 RPM

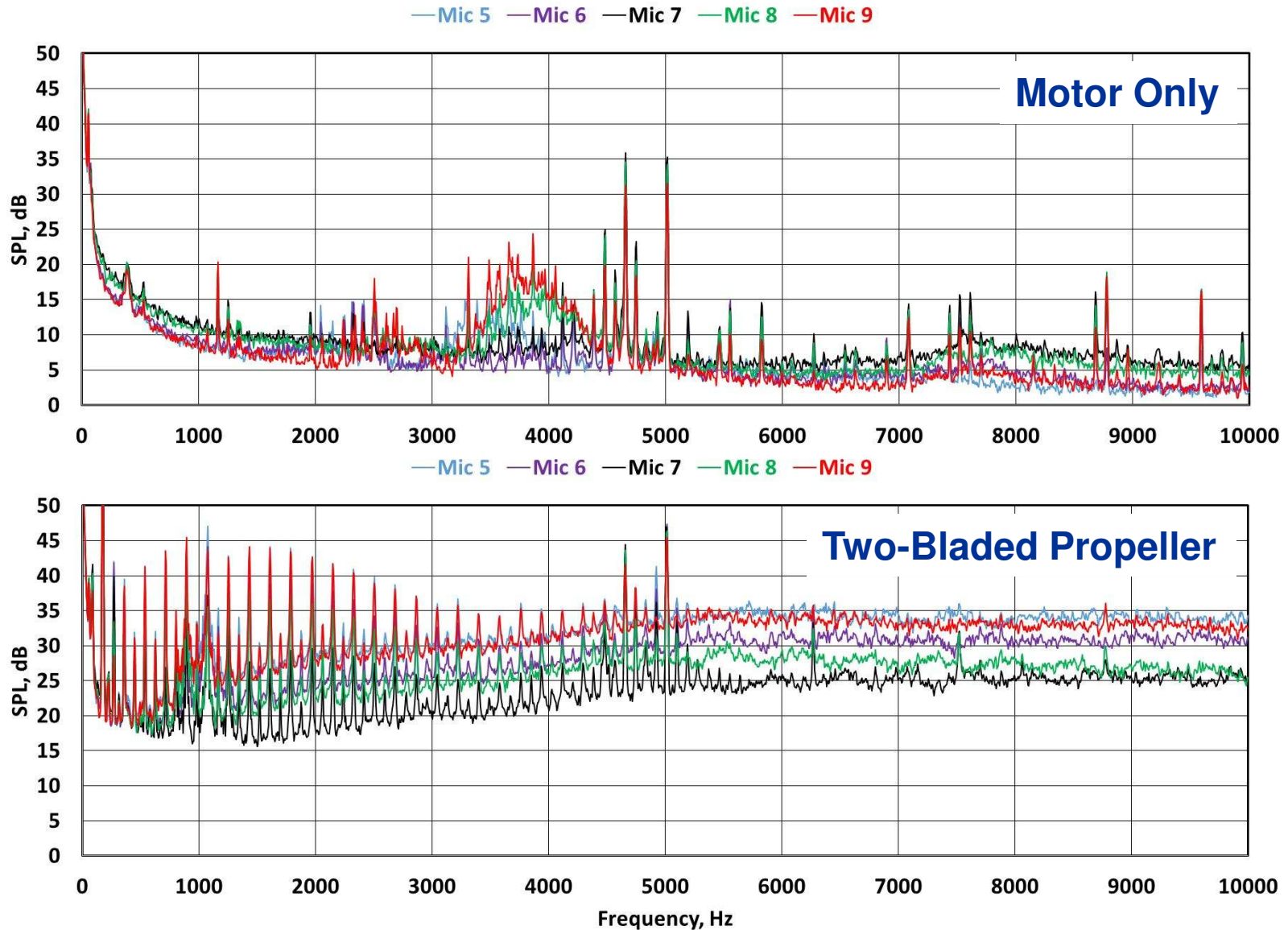


— Mic 5 — Mic 6 — Mic 7 — Mic 9





# 3DR Motor Only vs With Propeller, 5370 RPM

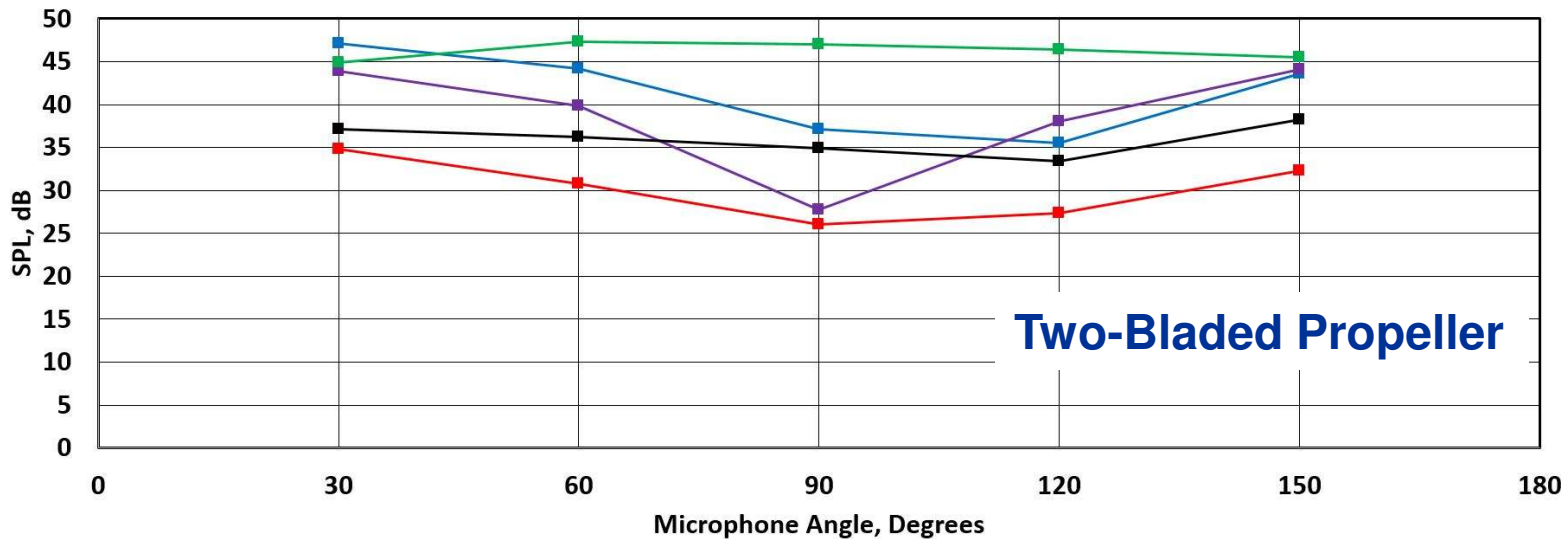
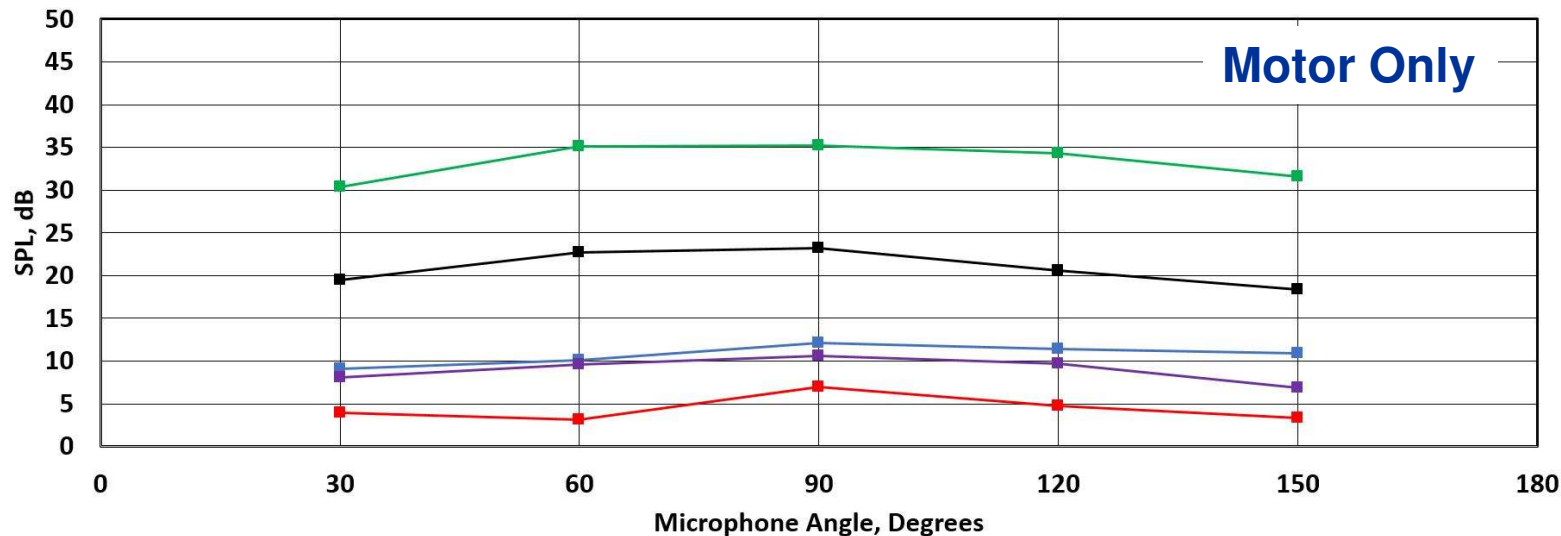






# SPL Directivity, 5370 RPM

■ 1074 Hz ■ 1434 Hz ■ 4749 Hz ■ 5017 Hz ■ 6995 Hz

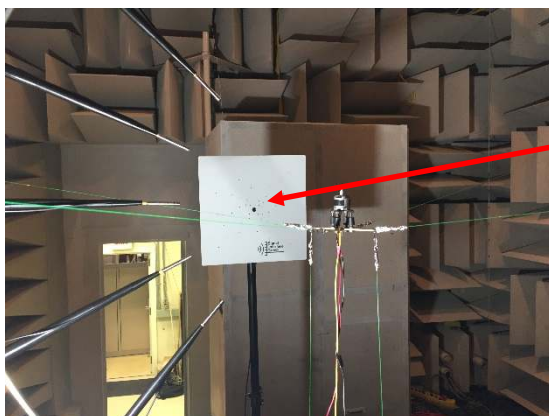
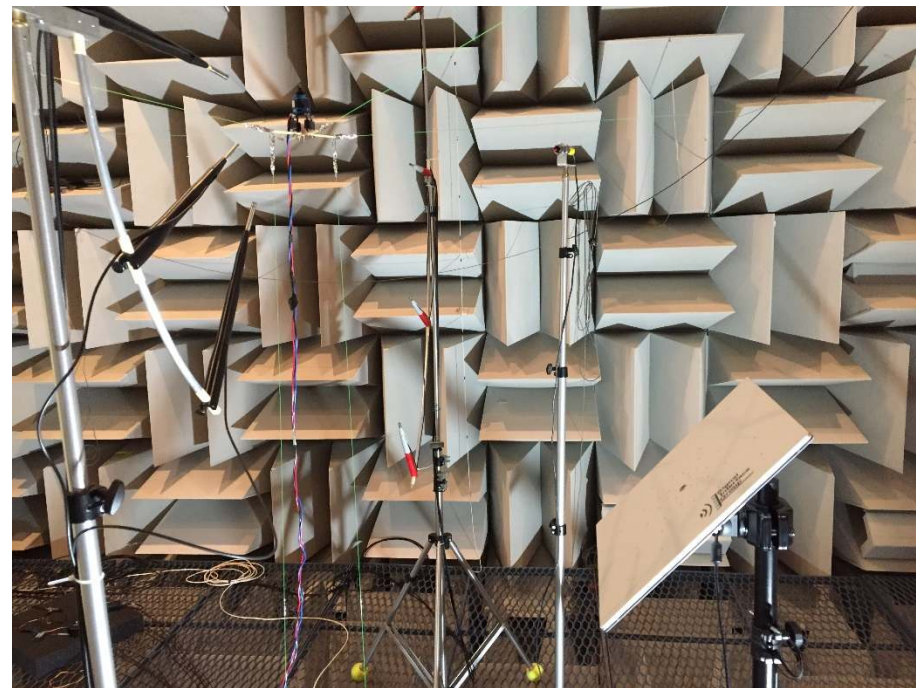


# Phased Microphone Array

## Normal to Motor



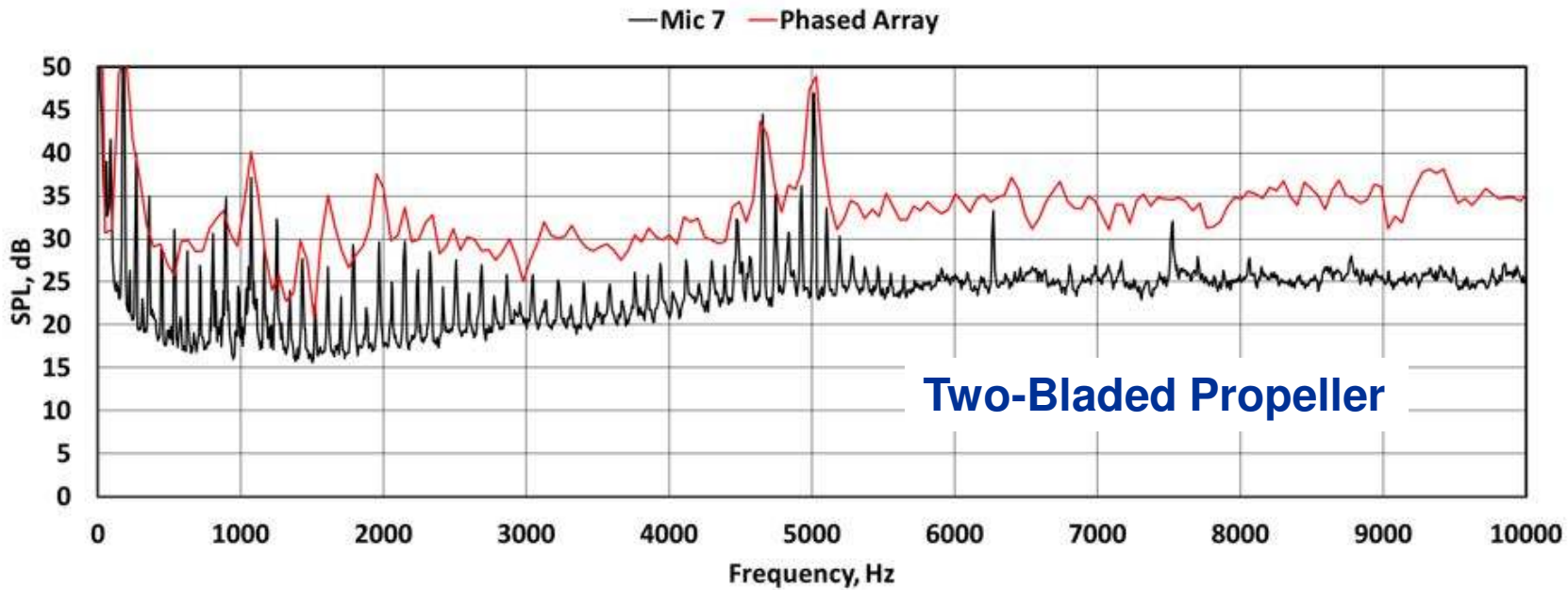
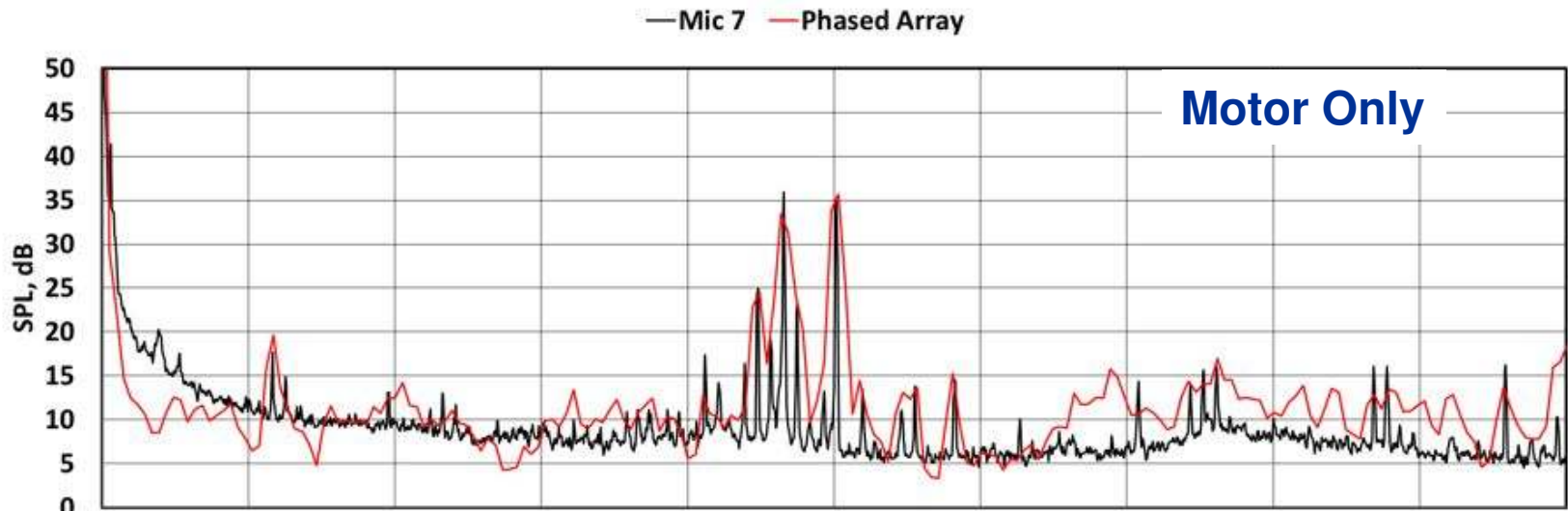
## Below Motor



***Microphone 2 used for phased array acoustic spectra is located toward the center***

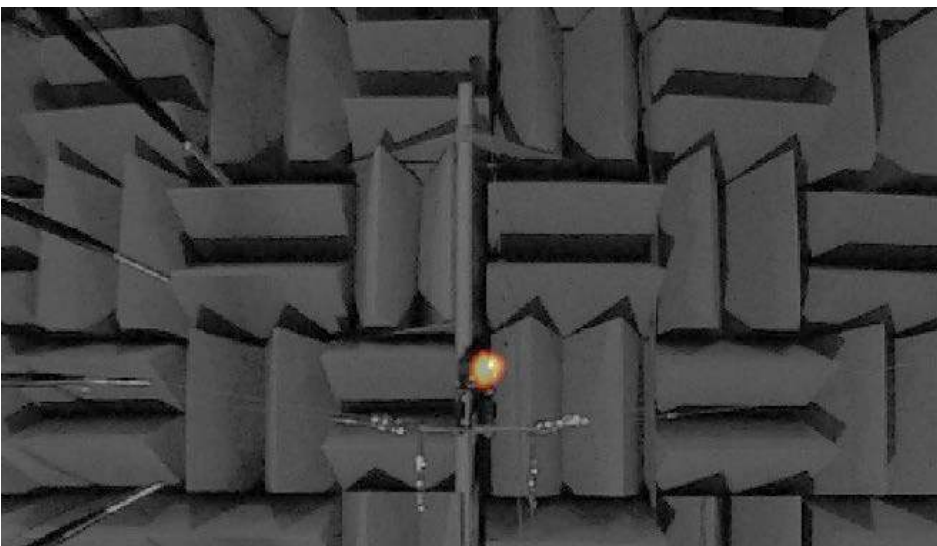


# 3DR Motor Only vs With Propeller, 5370 RPM

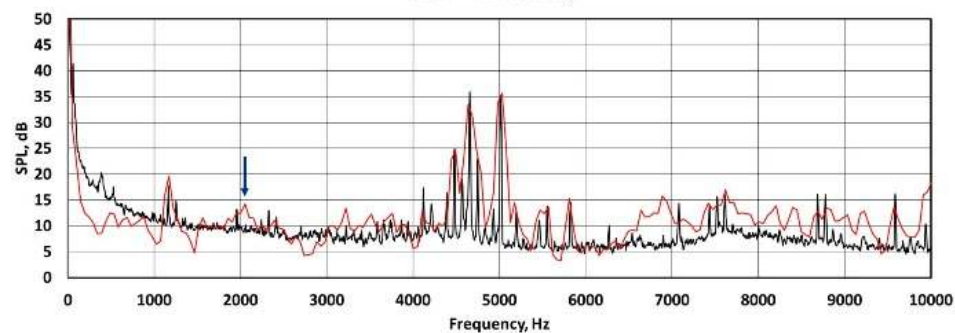
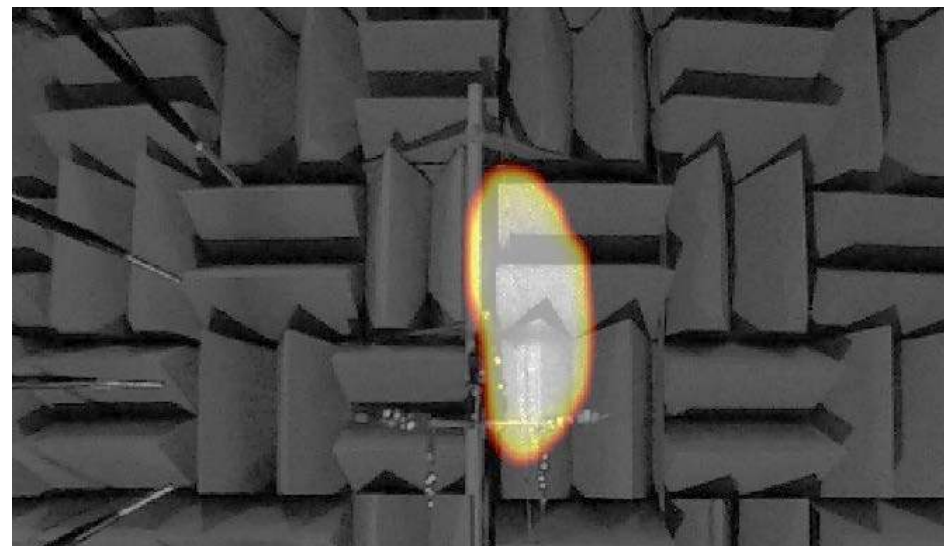




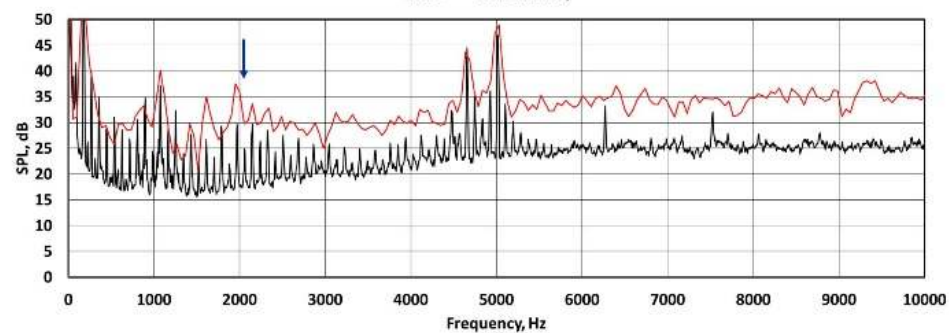
# 3DR Motor Only vs With Propeller, 5370 RPM Phased Array, 2050 Hz



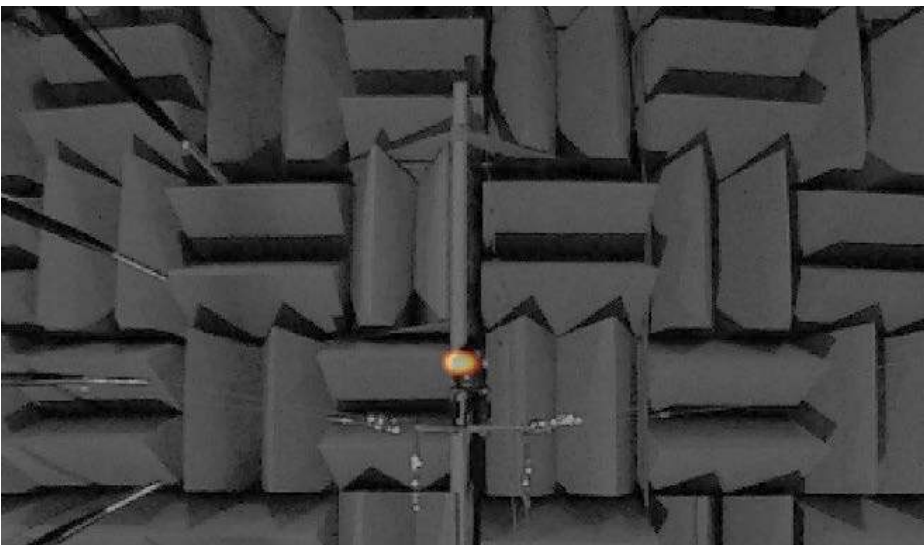
— Mic 7 — Phased Array

**Motor Only**

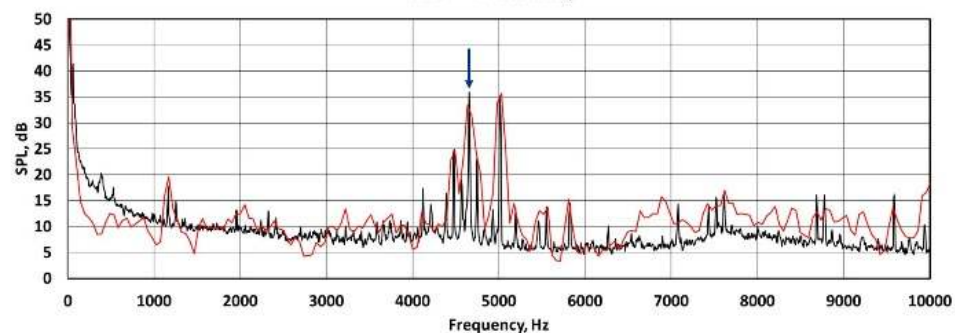
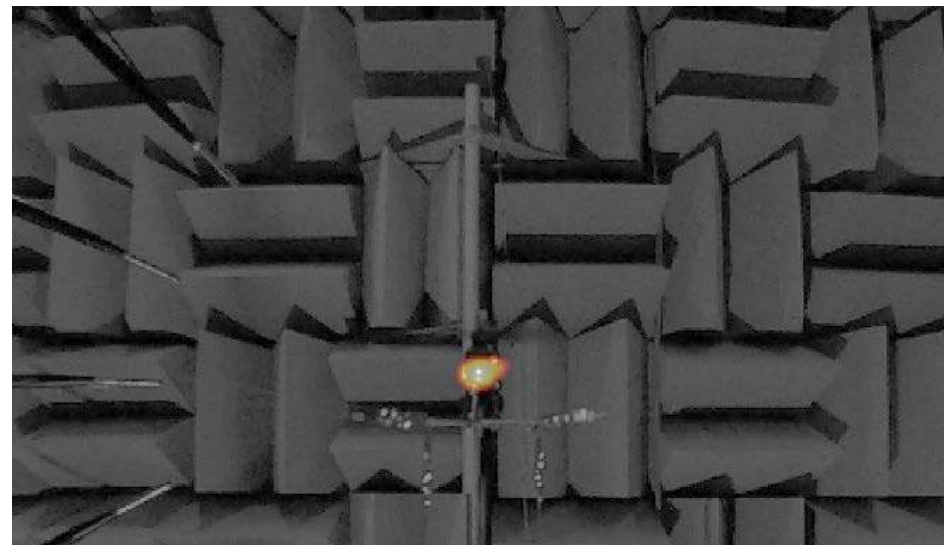
— Mic 7 — Phased Array

**Two-Bladed Propeller**

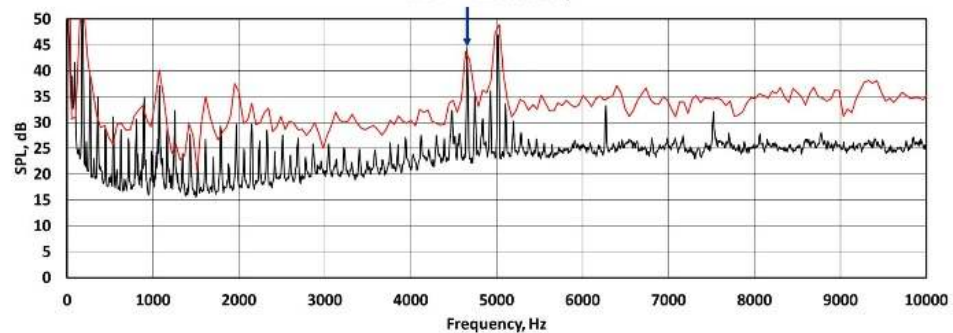
# 3DR Motor Only vs With Propeller, 5370 RPM Phased Array, 4638 Hz



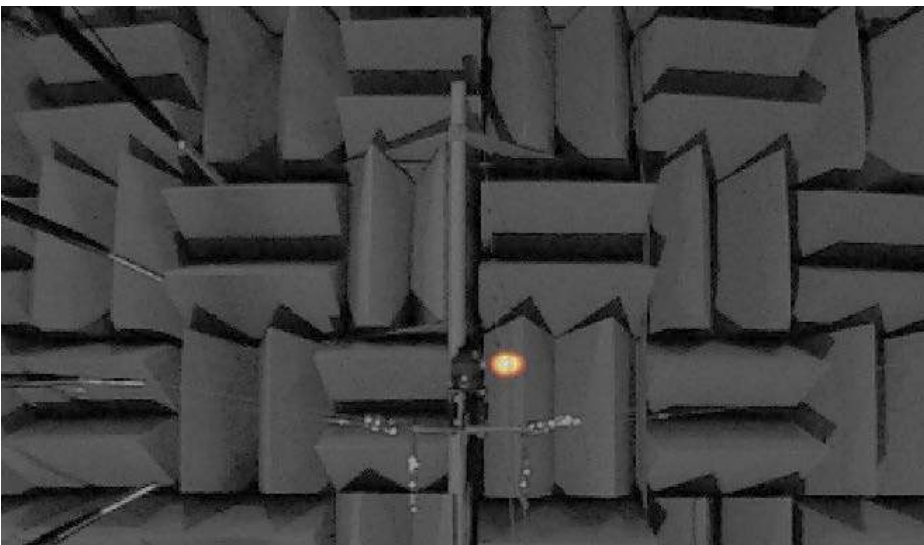
— Mic 7 — Phased Array

**Motor Only**

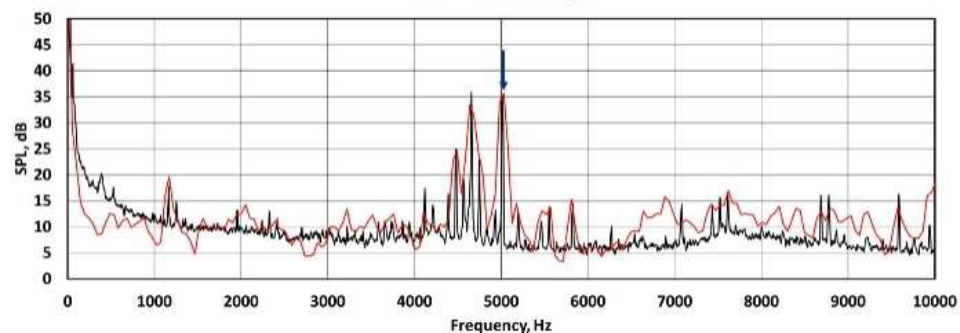
— Mic 7 — Phased Array

**Two-Bladed Propeller**

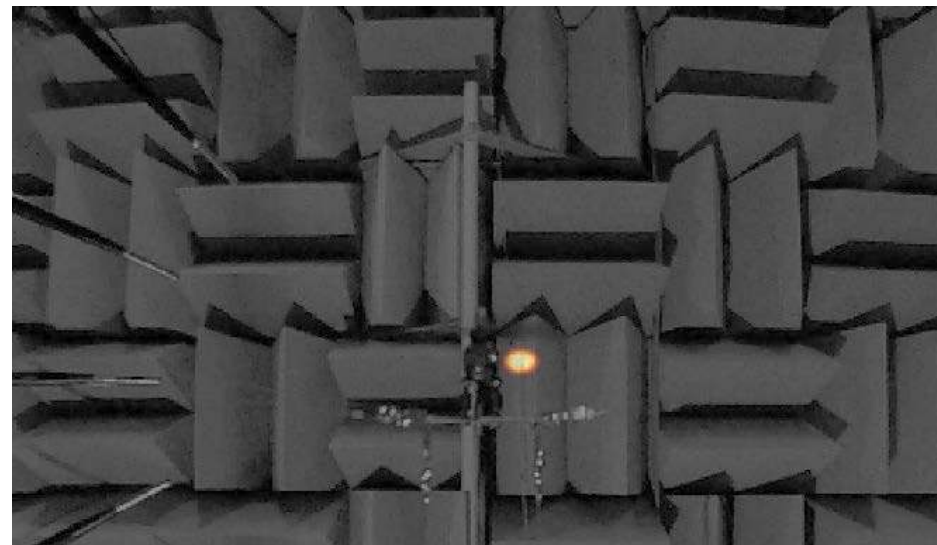
# 3DR Motor Only vs With Propeller, 5370 RPM Phased Array, 5029 Hz



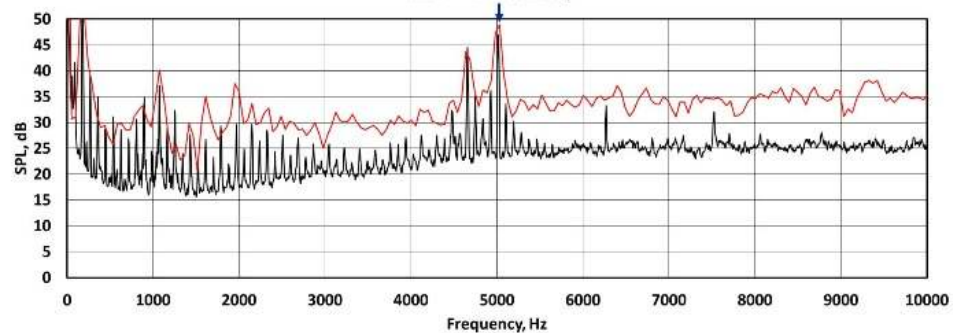
— Mic 7 — Phased Array



**Motor Only**



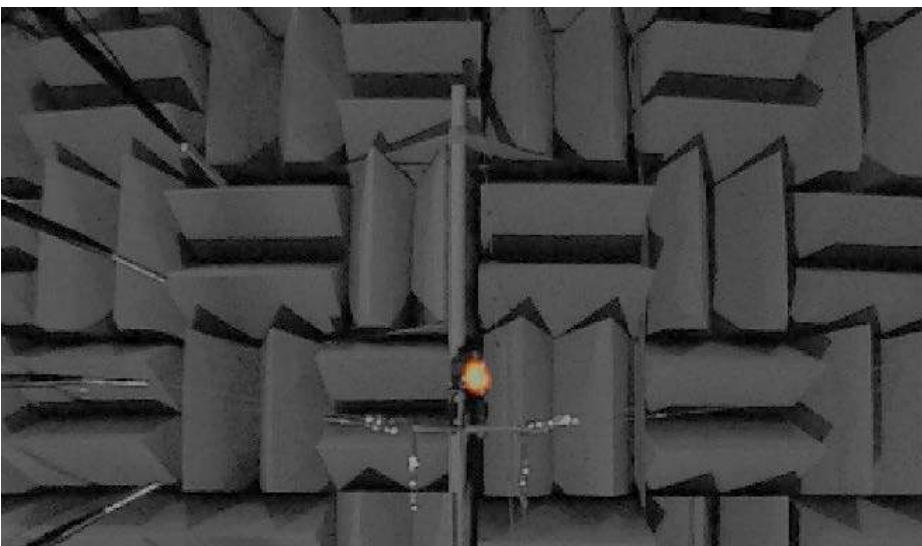
— Mic 7 — Phased Array



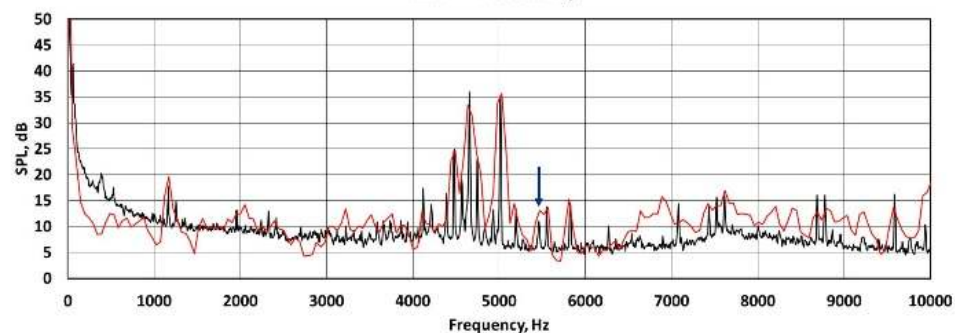
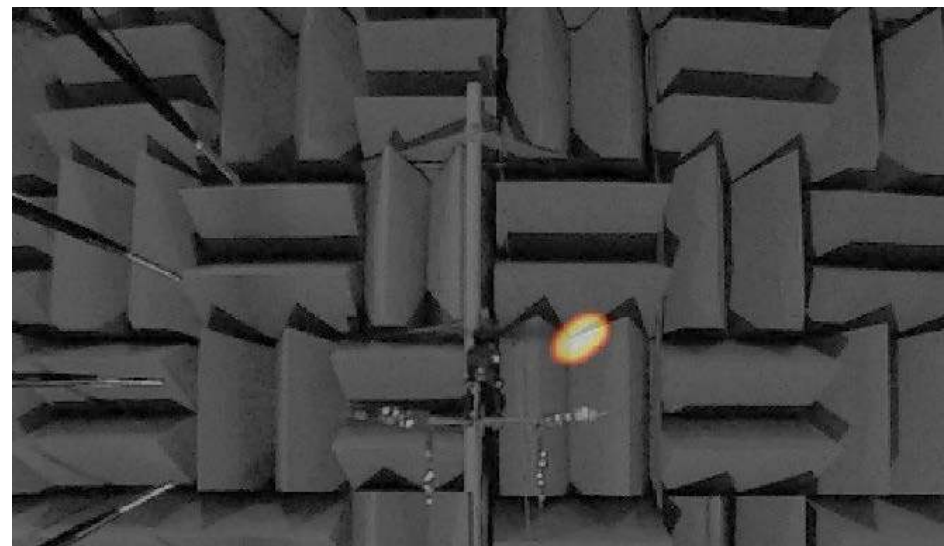
**Two-Bladed Propeller**



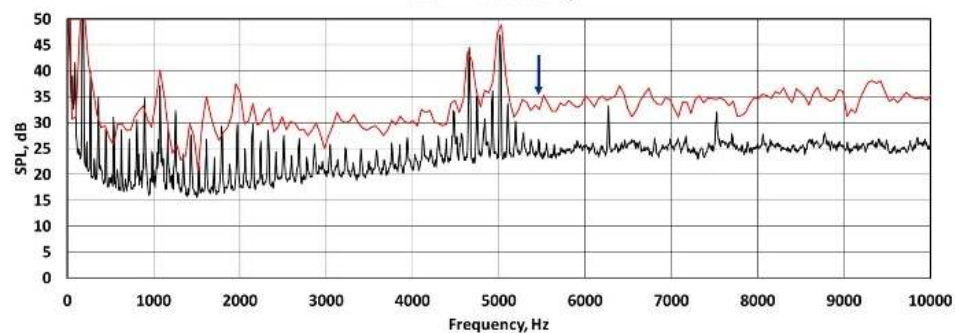
# 3DR Motor Only vs With Propeller, 5370 RPM Phased Array, 5469 Hz



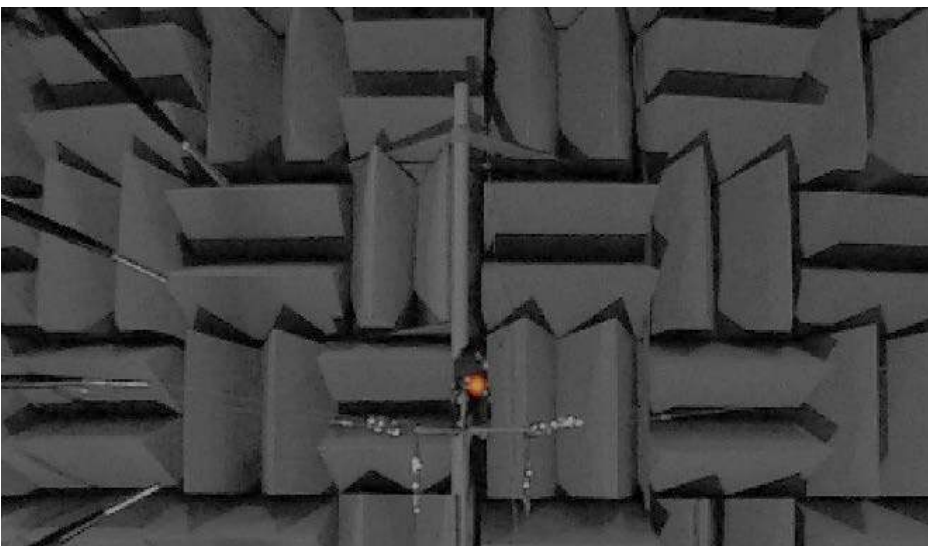
— Mic 7 — Phased Array

**Motor Only**

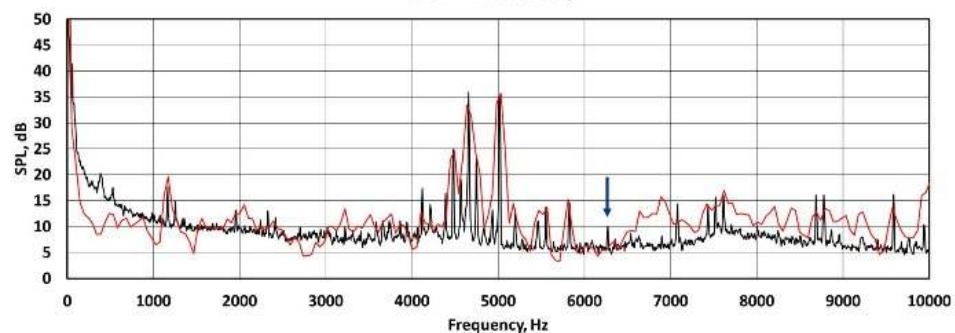
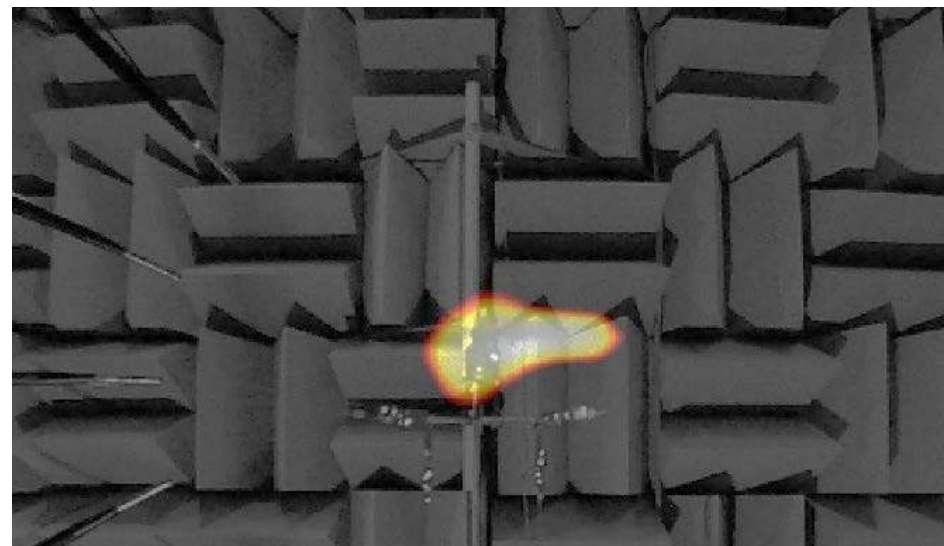
— Mic 7 — Phased Array

**Two-Bladed Propeller**

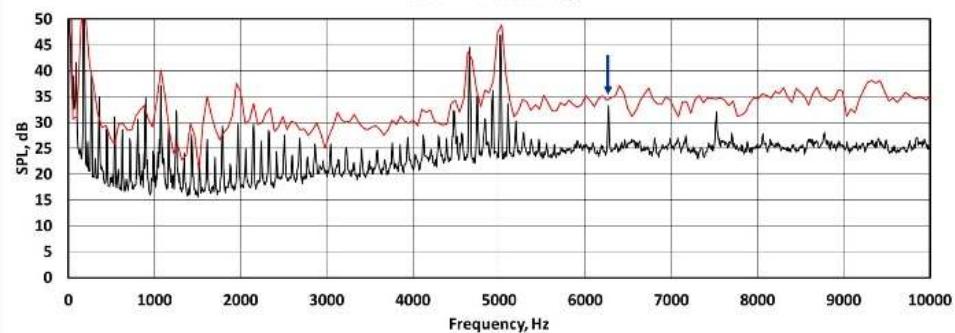
# 3DR Motor Only vs With Propeller, 5370 RPM Phased Array, 6250 Hz



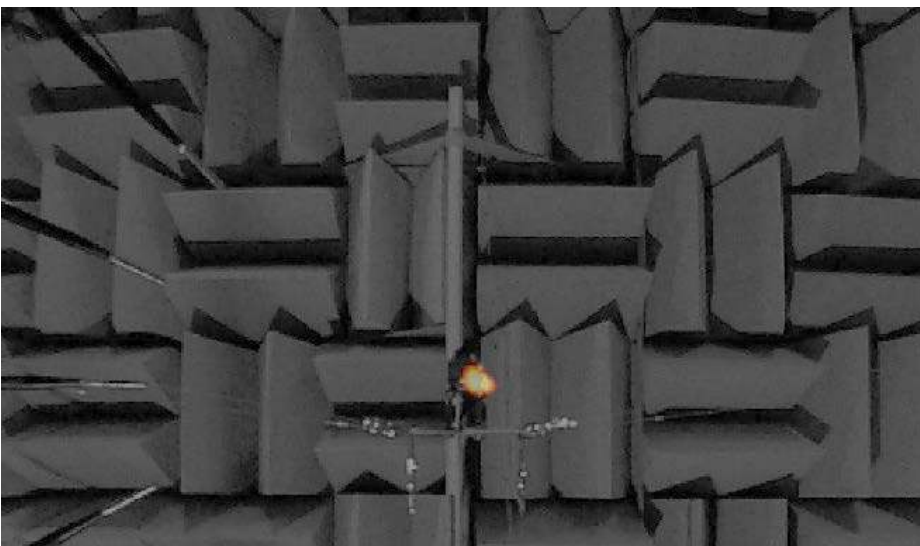
— Mic 7 — Phased Array

**Motor Only**

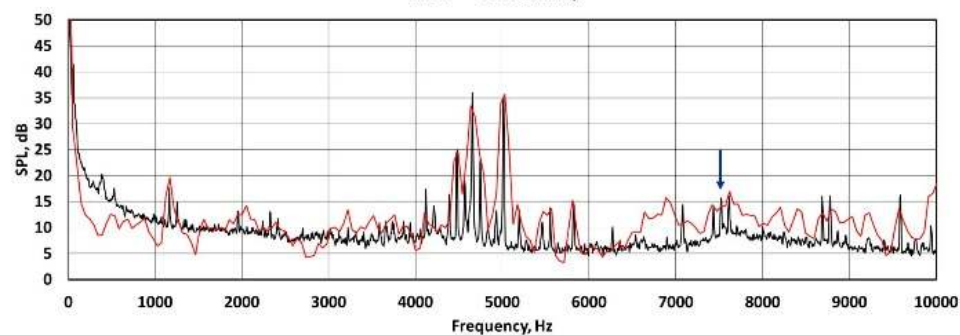
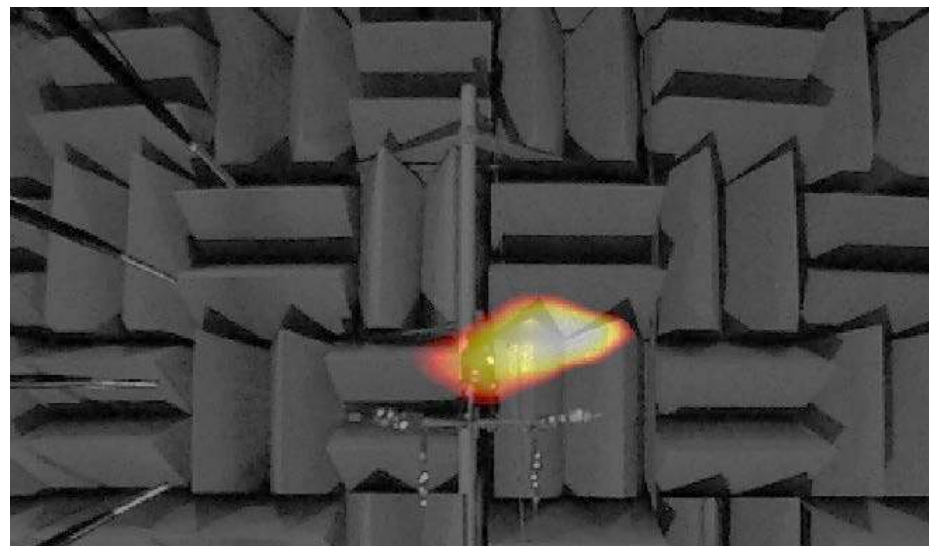
— Mic 7 — Phased Array

**Two-Bladed Propeller**

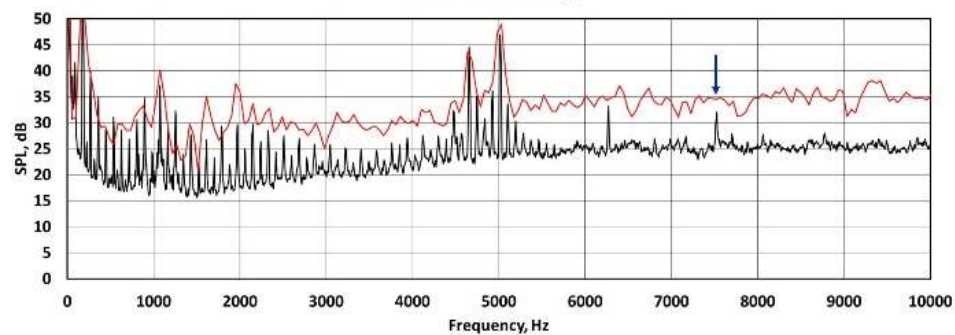
# 3DR Motor Only vs With Propeller, 5370 RPM Phased Array, 7520 Hz



— Mic 7 — Phased Array

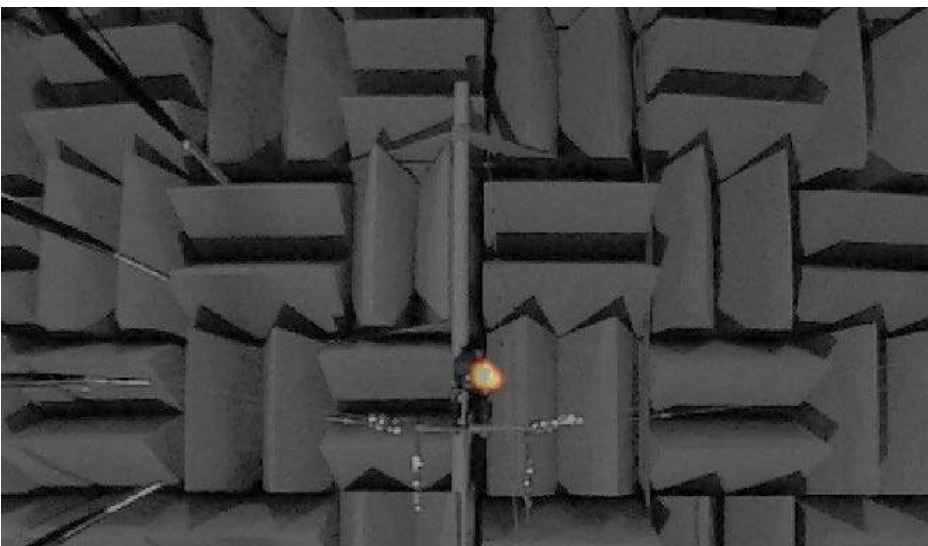
**Motor Only**

— Mic 7 — Phased Array

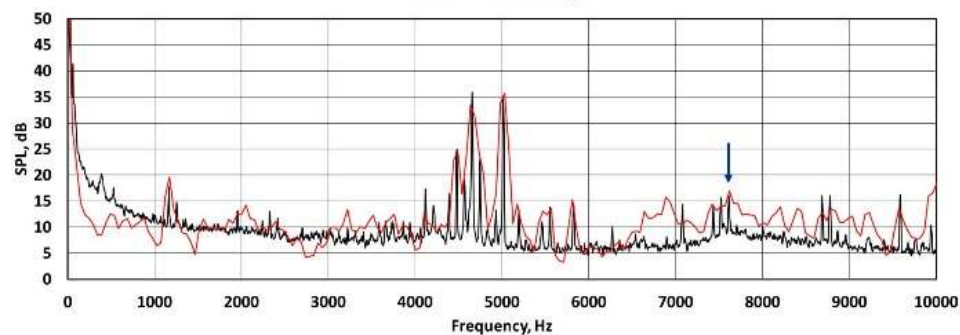
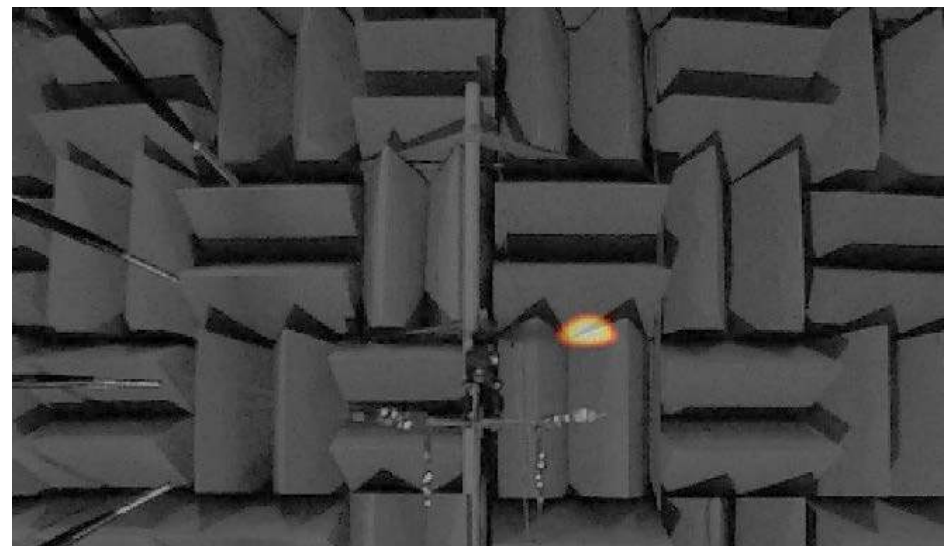
**Two-Bladed Propeller**



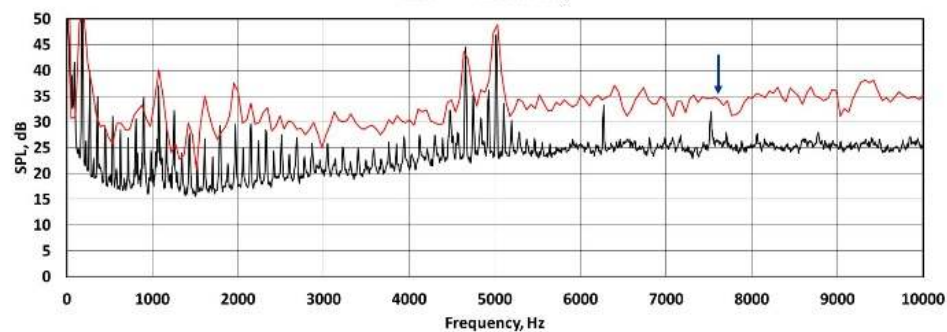
# 3DR Motor Only vs With Propeller, 5370 RPM Phased Array, 7617 Hz



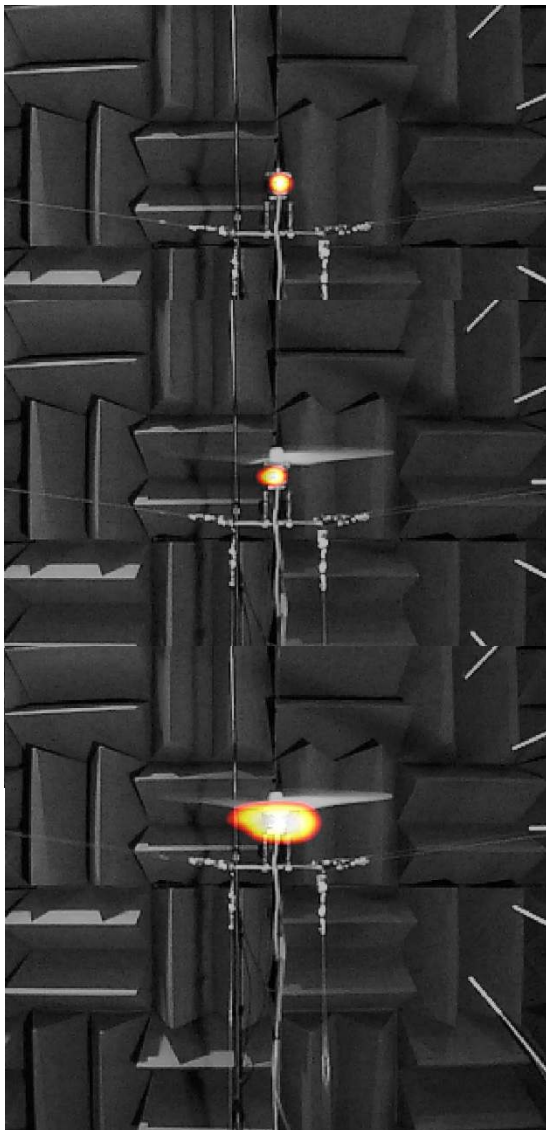
— Mic 7 — Phased Array

**Motor Only**

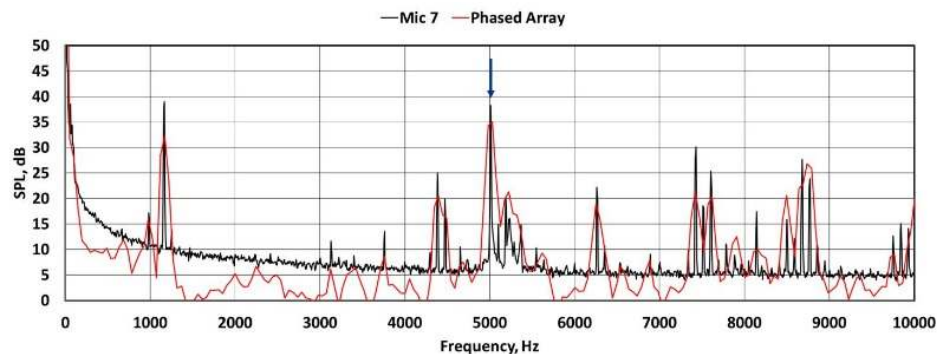
— Mic 7 — Phased Array

**Two-Bladed Propeller**

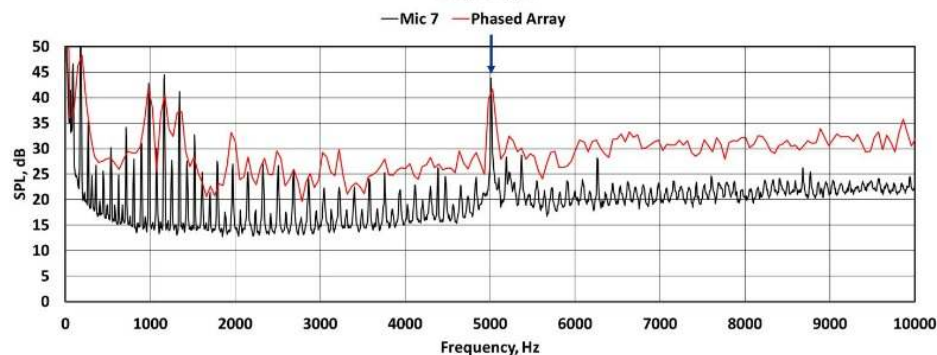
# 2312 Motor Only vs With Propellers, 5370 RPM Phased Array, 5029 Hz



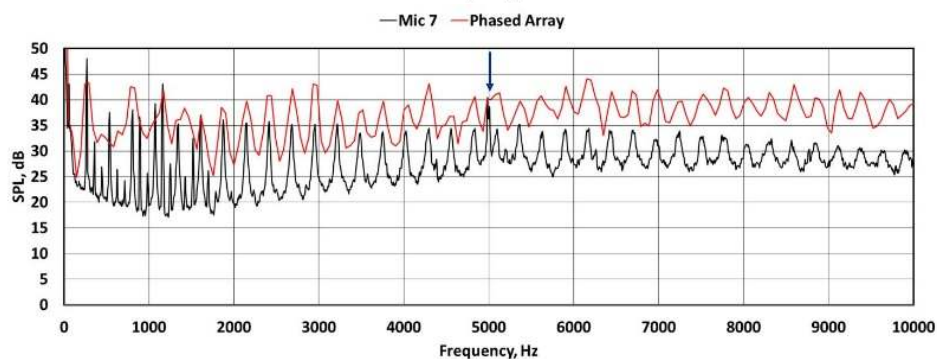
Motor Only



Two-Bladed  
Propeller

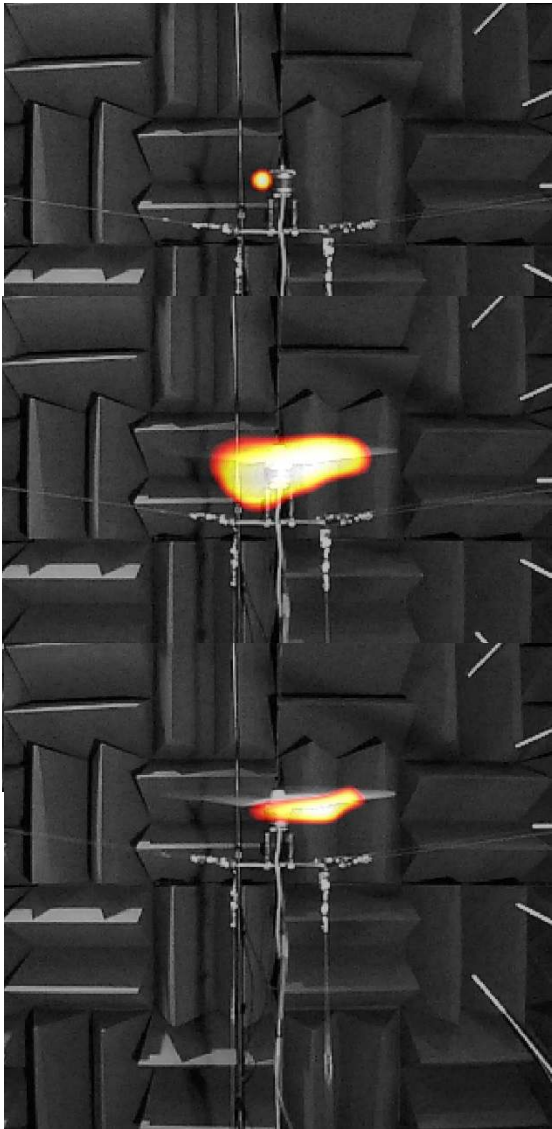


Three-Bladed  
Propeller

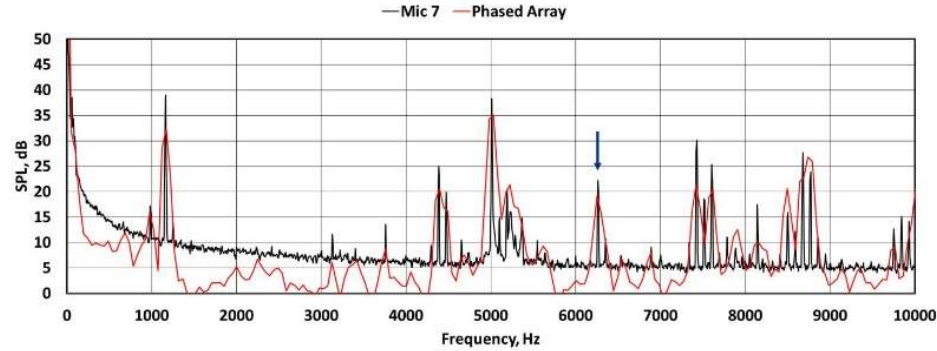




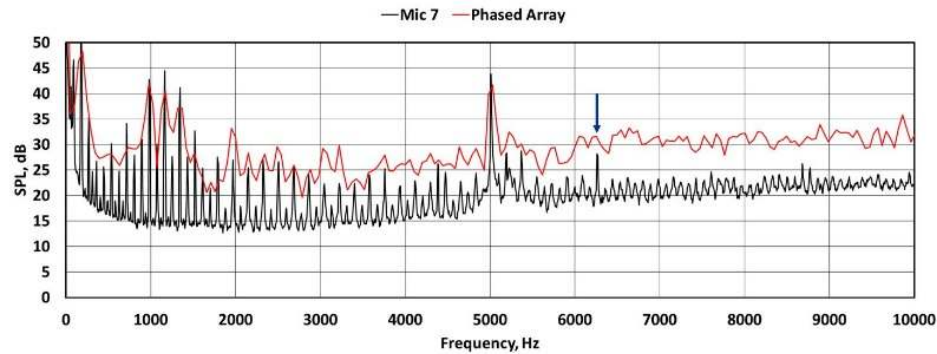
# 2312 Motor Only vs With Propellers, 5370 RPM Phased Array, 6250 Hz



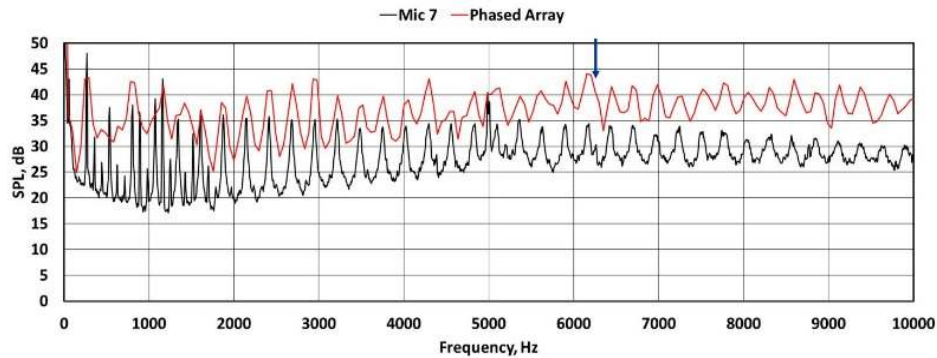
**Motor Only**



**Two-Bladed Propeller**



**Three-Bladed Propeller**





# Conclusions

- **Tones are most important noise source.**
- **Motor noise peaks in a direction normal to the motor rotor axis.**
- **Adding a propeller introduces shaft order/blade passing frequency tones, and higher harmonics that are evident up to about 4000 Hz.**
- **Propeller increases the broadband noise across the entire spectra.**
- **Strong motor tones can be amplified by the propeller loading by 5 to 15 dB and can exceed the propeller noise levels.**
- **A phased microphone array provides acoustic spectra that are in good agreement with far field microphone data.**
- **Beamform images successfully distinguish motor and propeller noise contributions.**





***This work was supported by NASA's Revolutionary Vertical Lift Technology (RVLT) project in the Advanced Air Vehicles Program.***