National Aeronautics and Space Administration

Electric Motor Noise from Small Quadcopters
Part I – Acoustic Measurements





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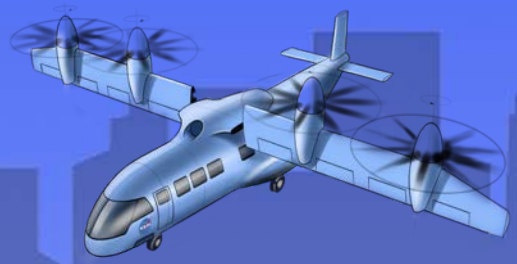
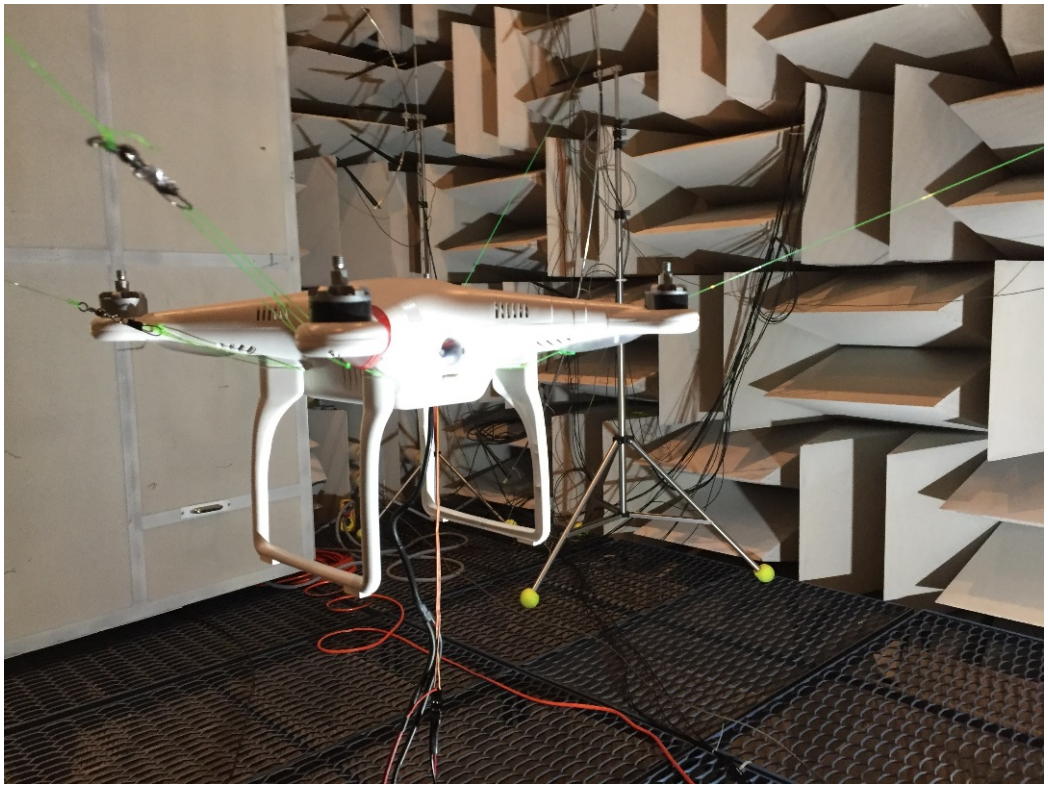



Motivation

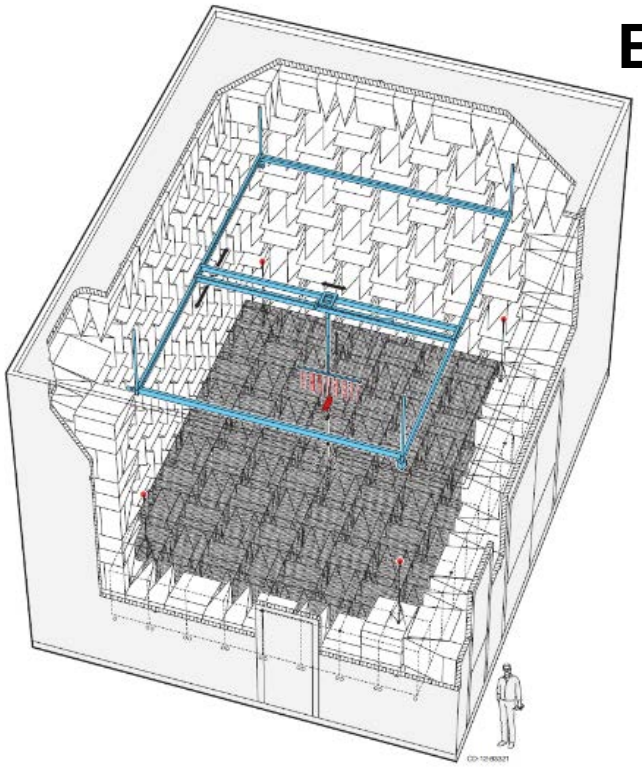
- **Electric motors driving small Unmanned Aircraft Systems (sUAS) propulsors.**
- **Noise expected to be problem, especially for Urban Air Mobility (UAM) missions.**
- **Noise sources need to be understood (propeller, motor, etc.).**
- **Need noise prediction methods for electric motors.**

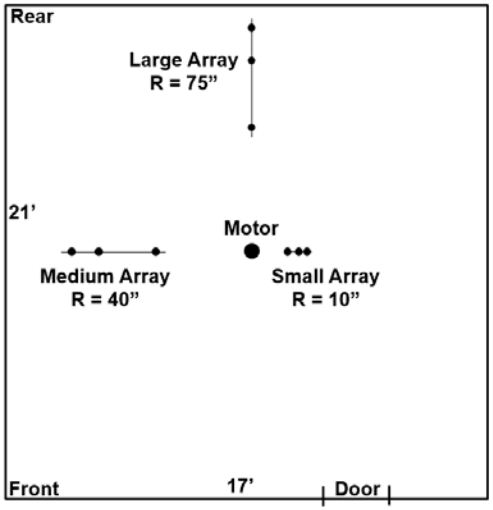


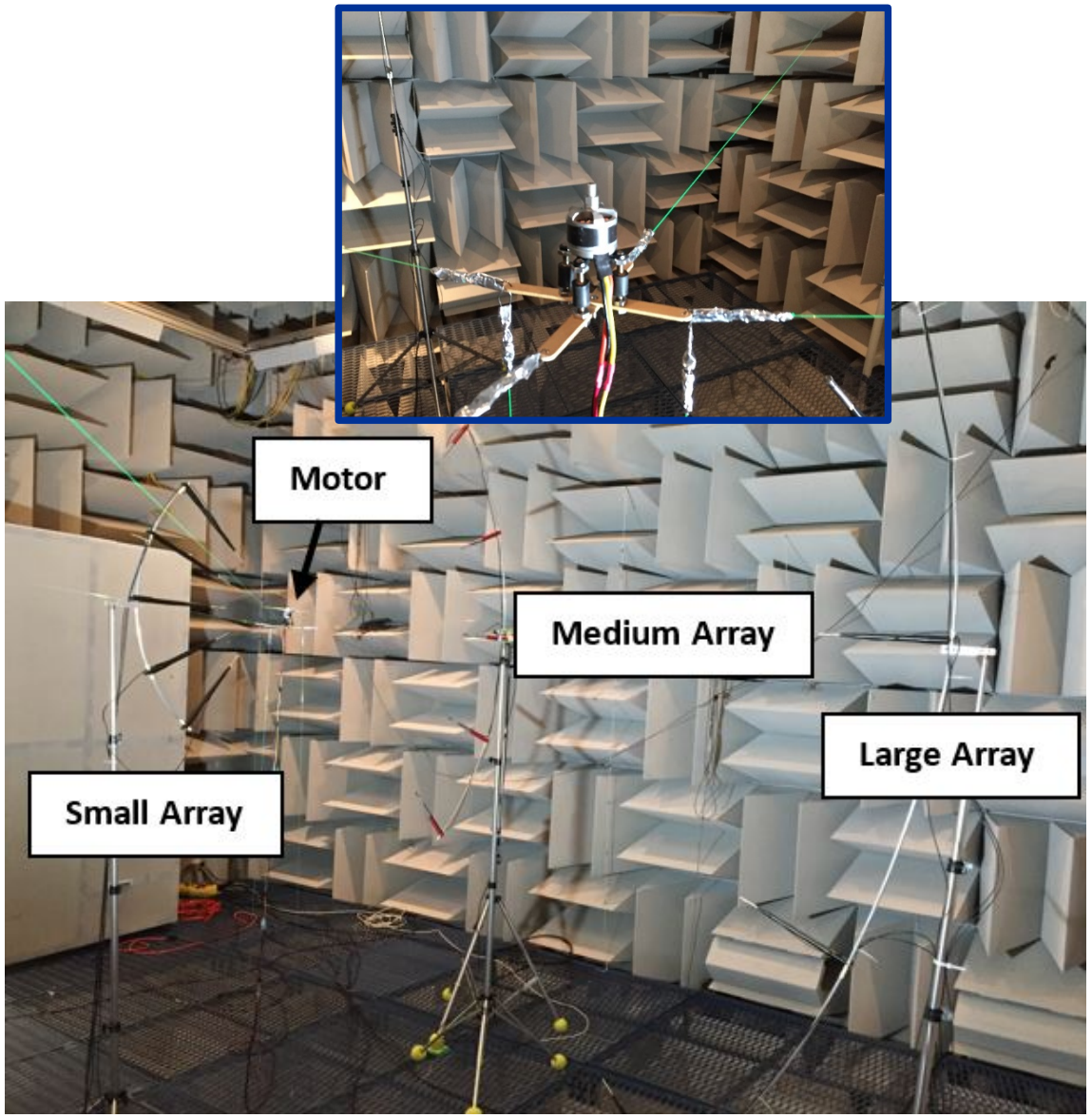
Companion paper in this session will present source characteristics.

Future work will focus on larger motors.

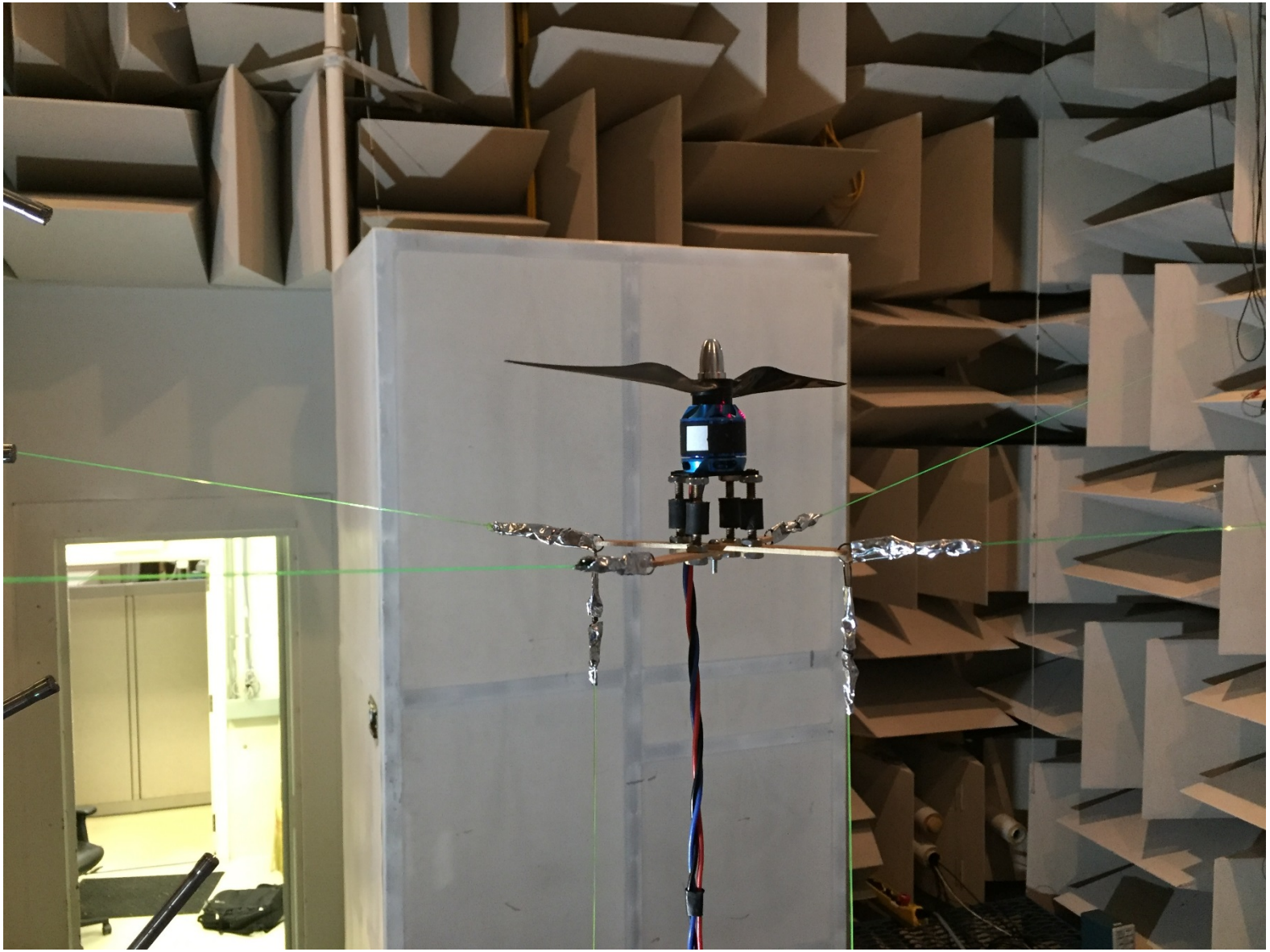
Experimental Setup







Motor & Propeller With Tether

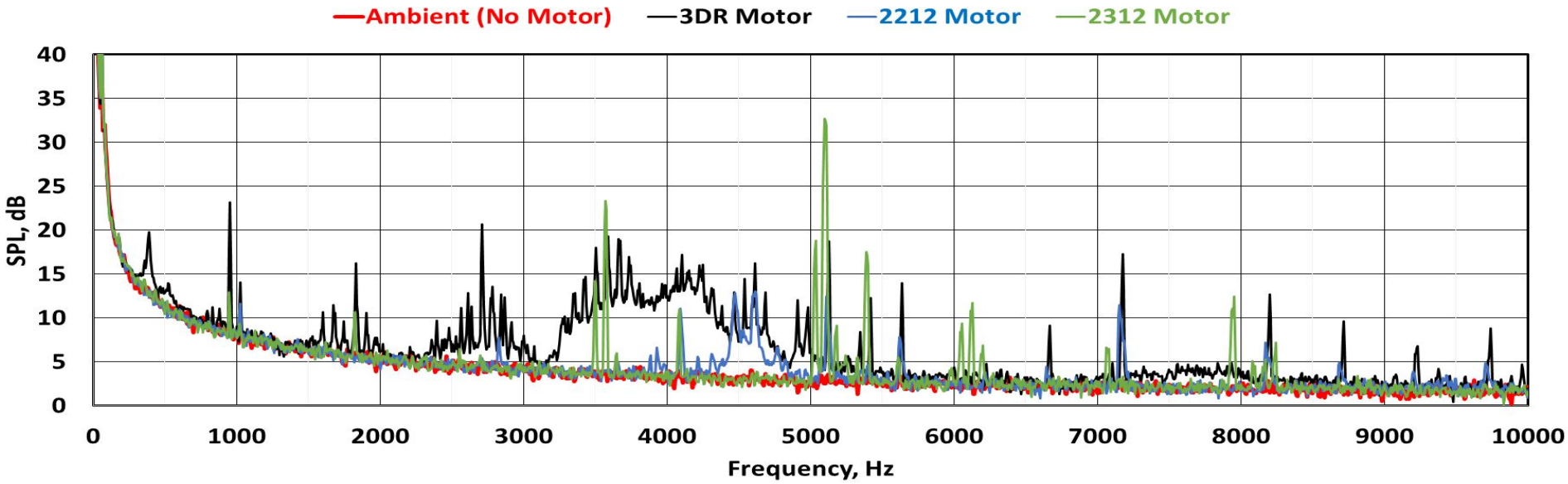


Motor Only With Tether

Test Matrix

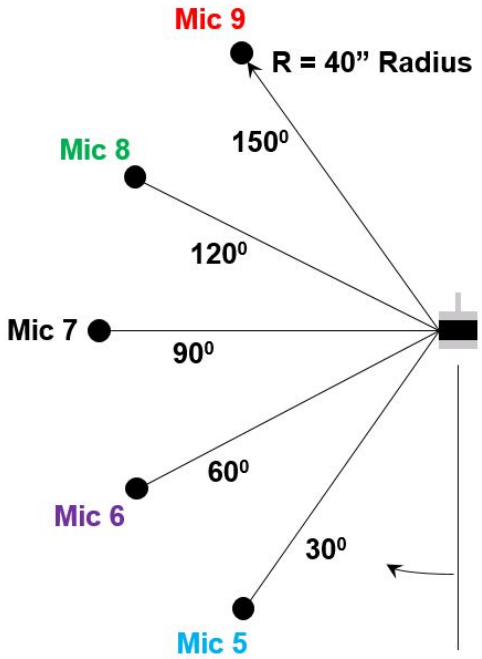
	3DR "Blue"	2212	2312
Speed Variation (RPM)	4380, 5370, 6260	4380, 5370, 6260, 4773	4380, 5370, 6260, 4773
Acoustics (Small, Medium, Large Arrays)	X	X	X
Speed Controllers			
E300	X	X	X
3DR	X	X	-
420S	-	X	X
Load			
Motor Only	X	X	X
2-Bladed	X	X	X
3-Bladed	-	-	X
Phased Array	X (location study)	X	X
Current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

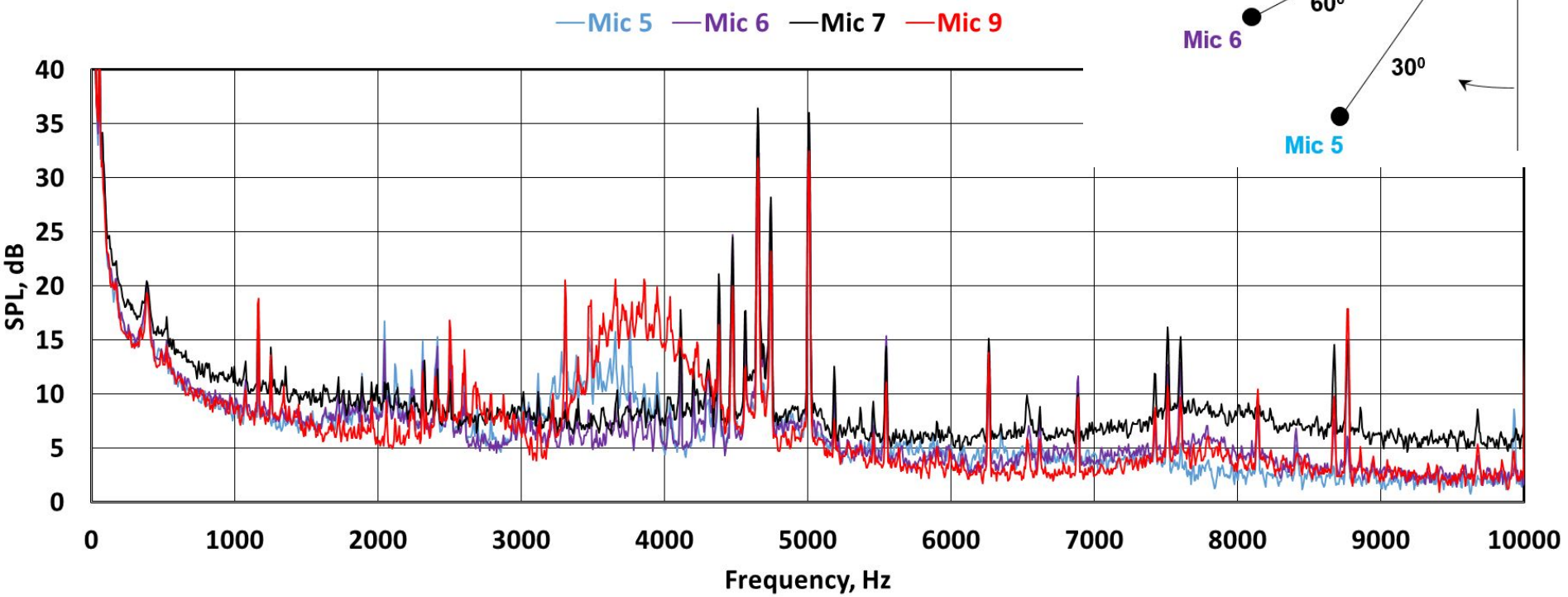
Background Noise



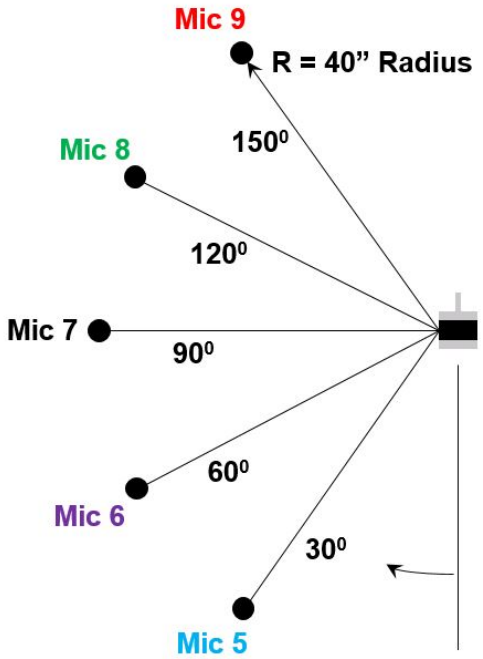
- **Motor-only SPL comparisons for three motors, microphone 9 on medium array, 4380 RPM.**
- **Noise floor from ¼-inch microphones, not chamber**

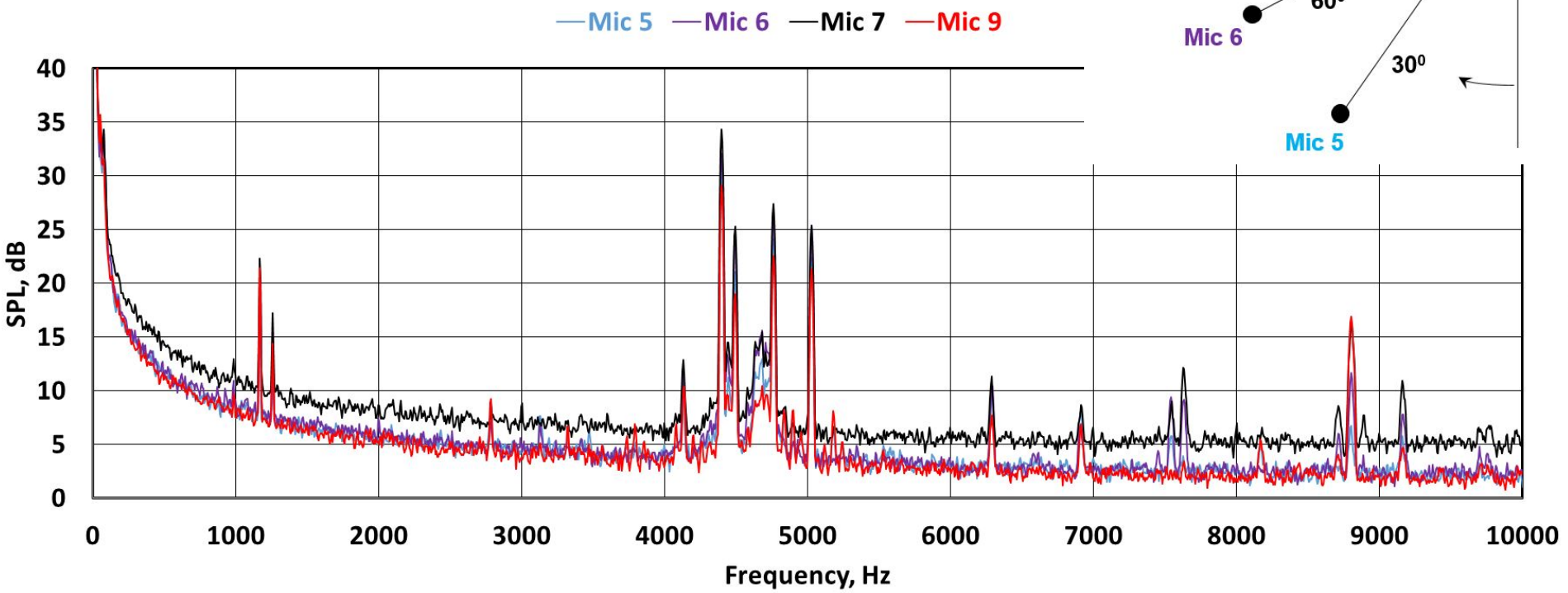
3DR Motor Spectra, 5370 RPM



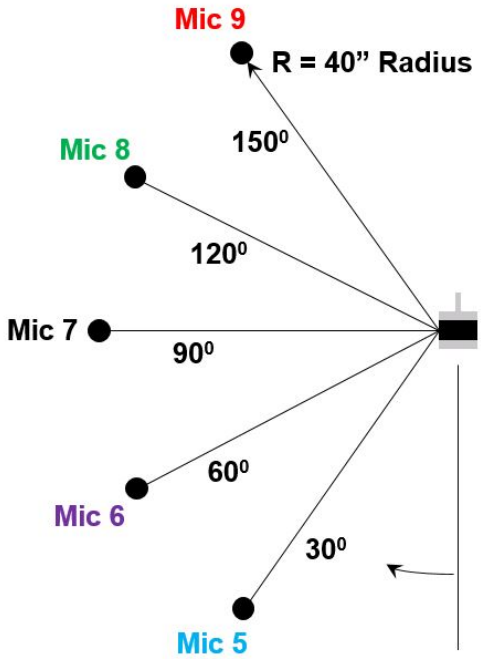


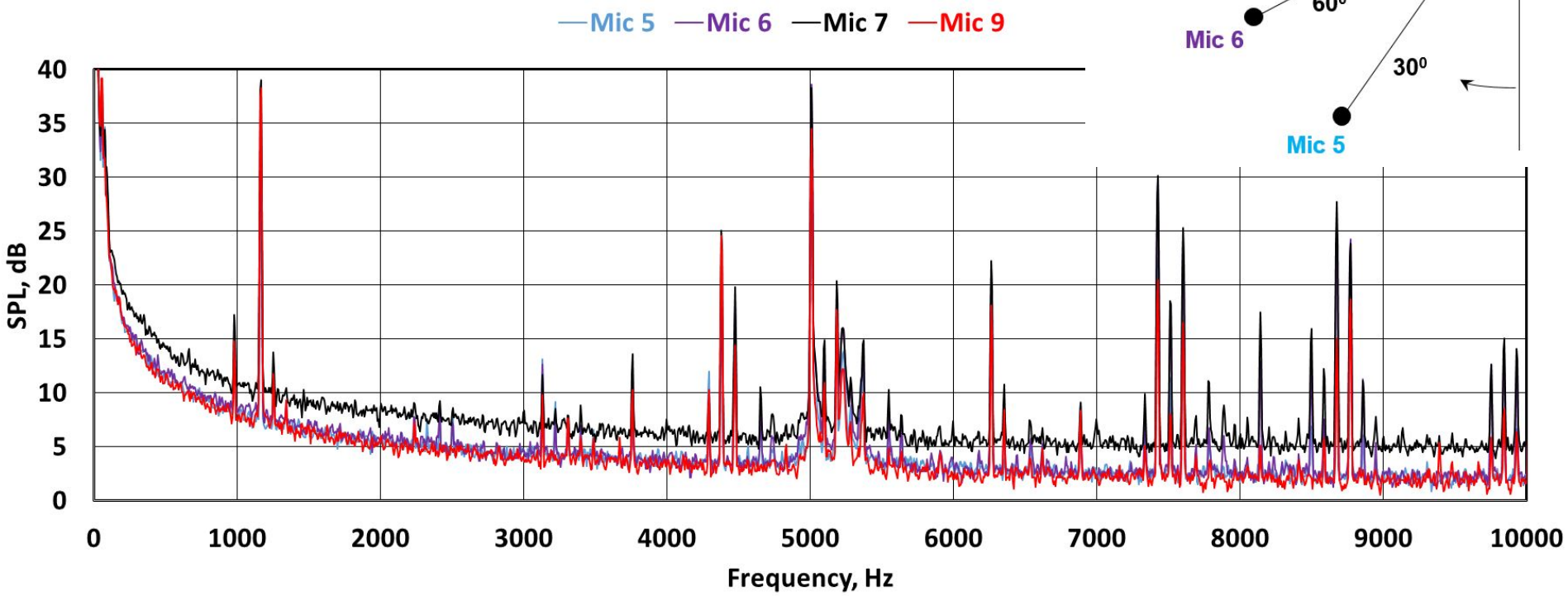
2212 Motor Spectra, 5370 RPM



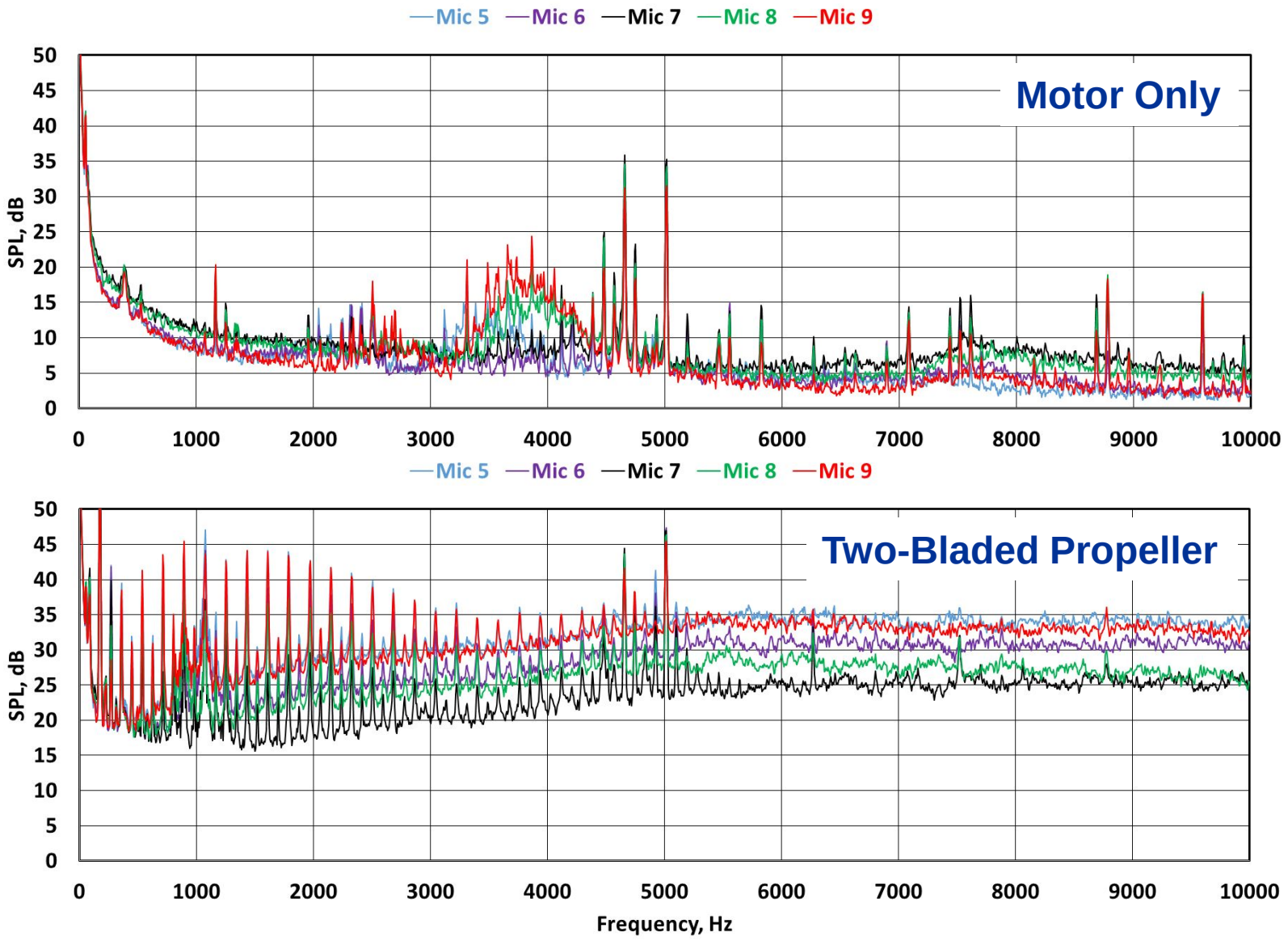


2312 Motor Spectra, 5370 RPM

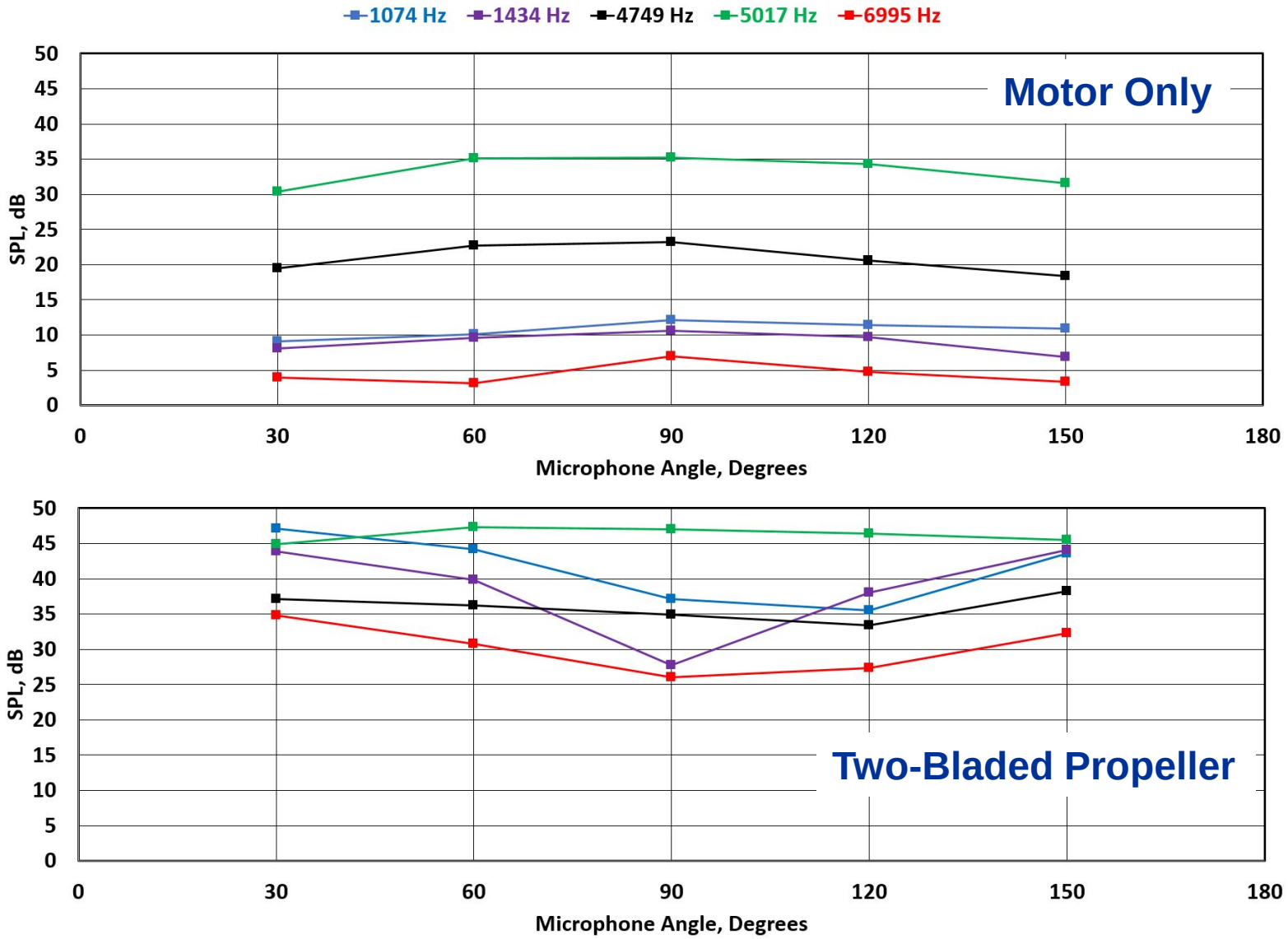




3DR Motor Only vs With Propeller, 5370 RPM

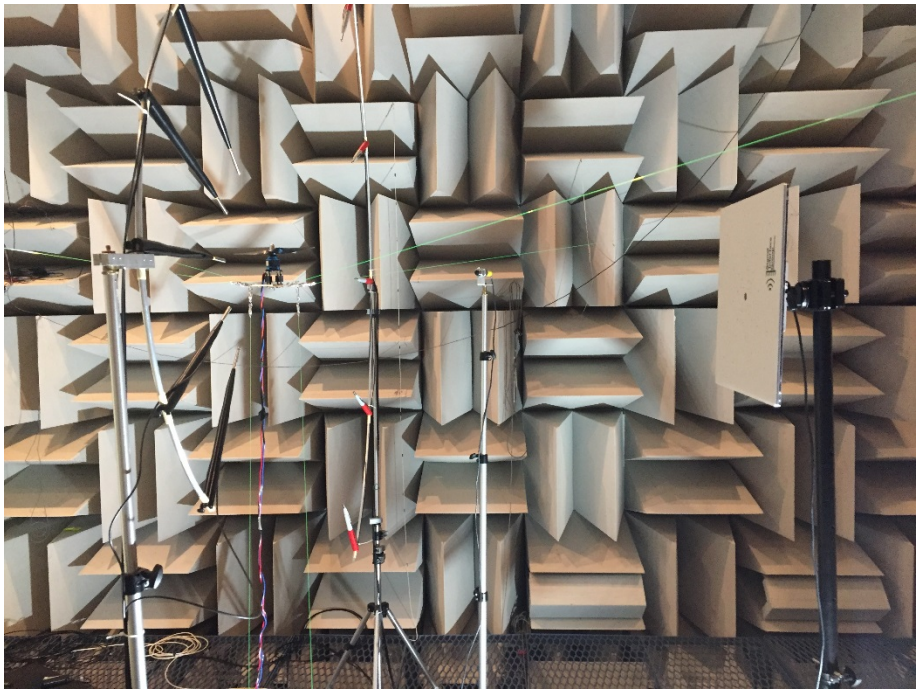


SPL Directivity, 5370 RPM

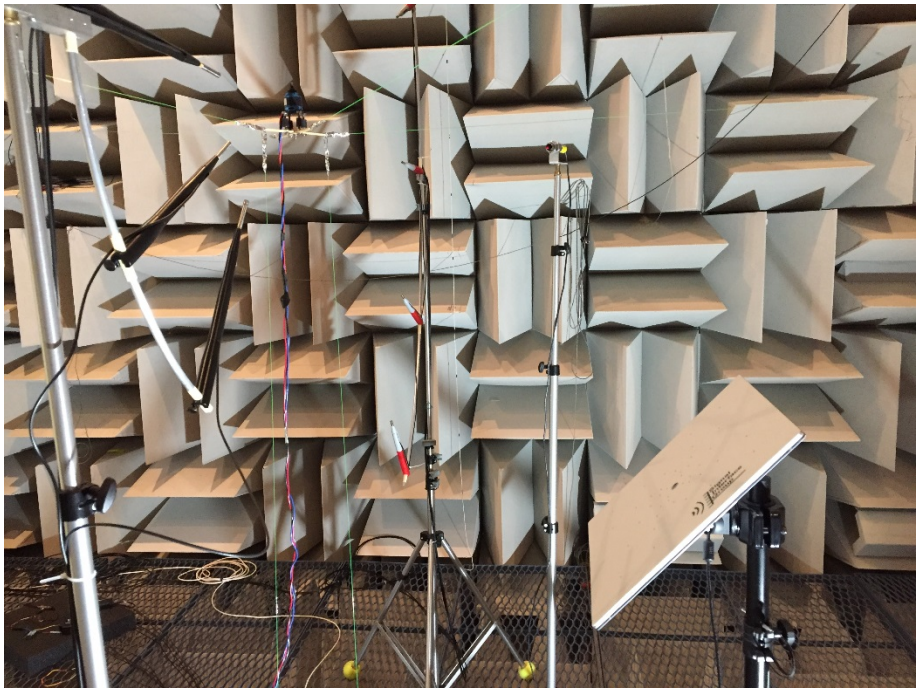


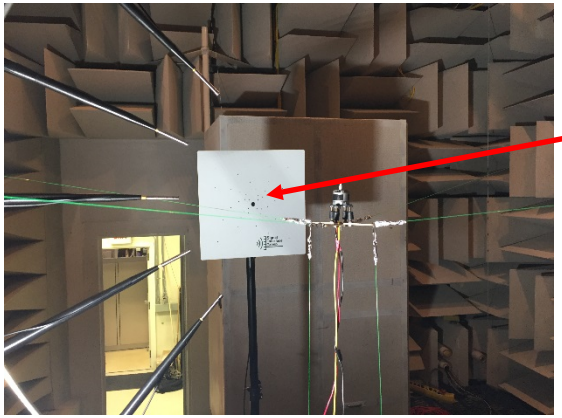
Phased Microphone Array

Normal to Motor



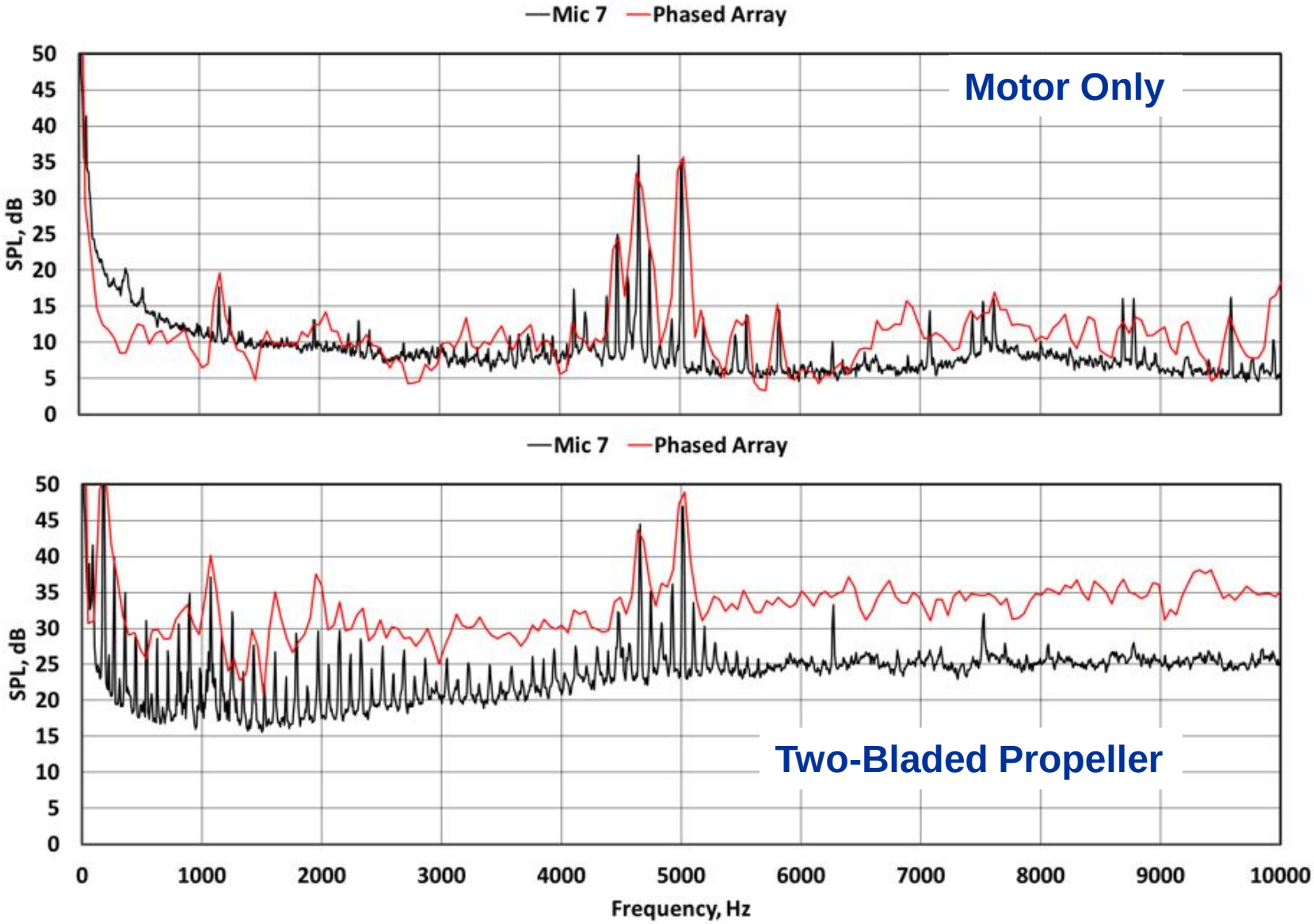
Below Motor



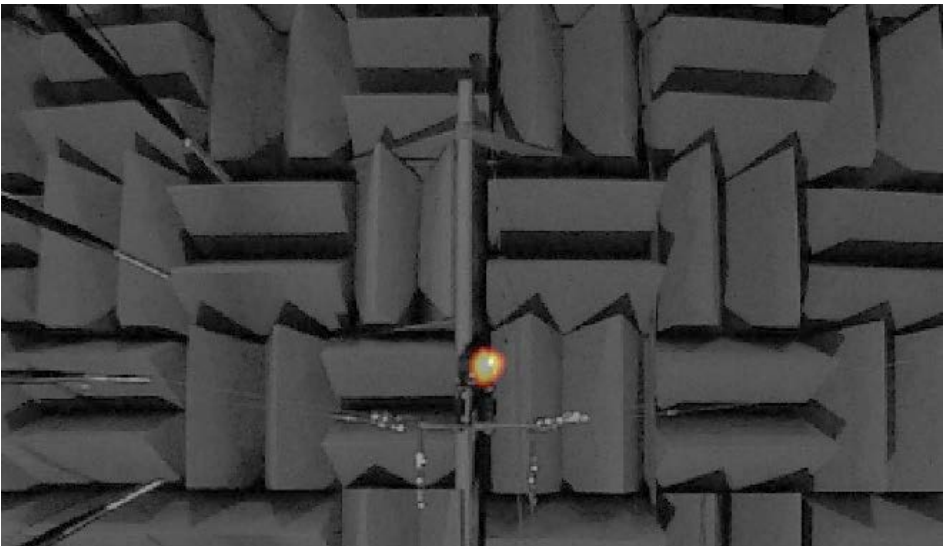


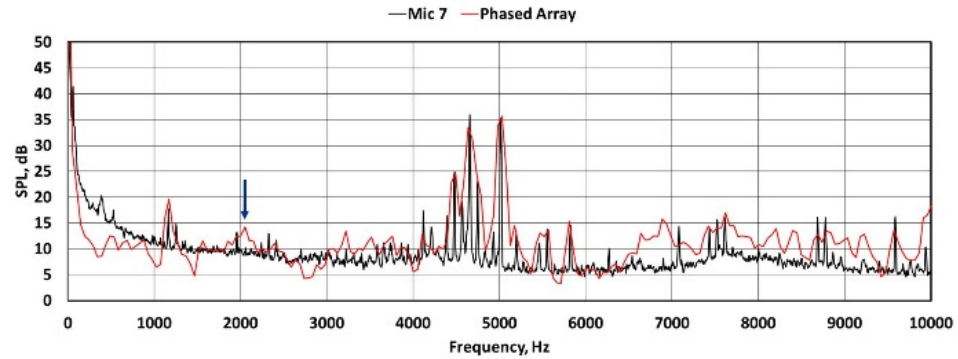
Microphone 2 used for phased array acoustic spectra is located toward the center

3DR Motor Only vs With Propeller, 5370 RPM

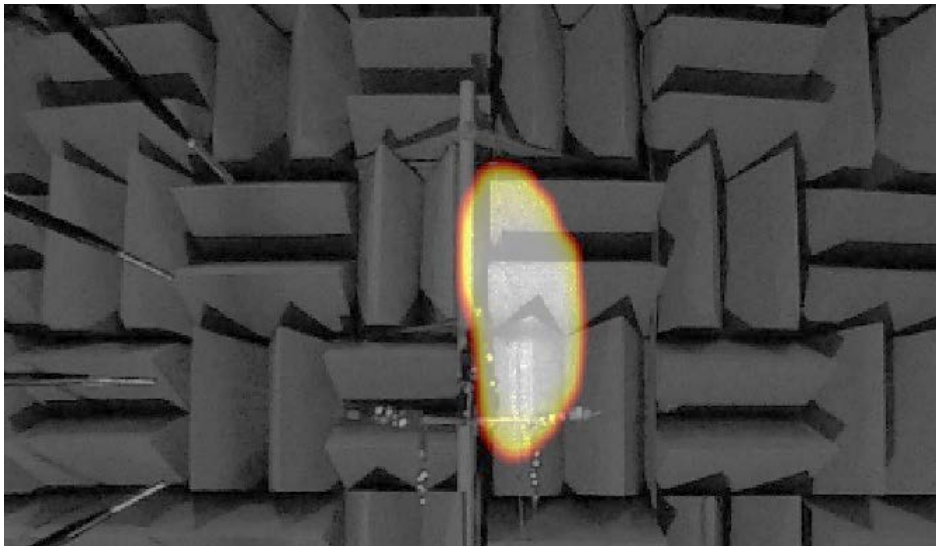


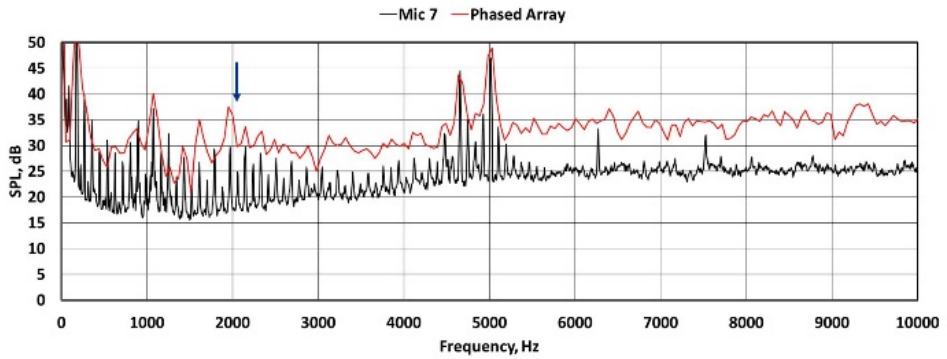
3DR Motor Only vs With Propeller, 5370 RPM Phased Array, 2050 Hz





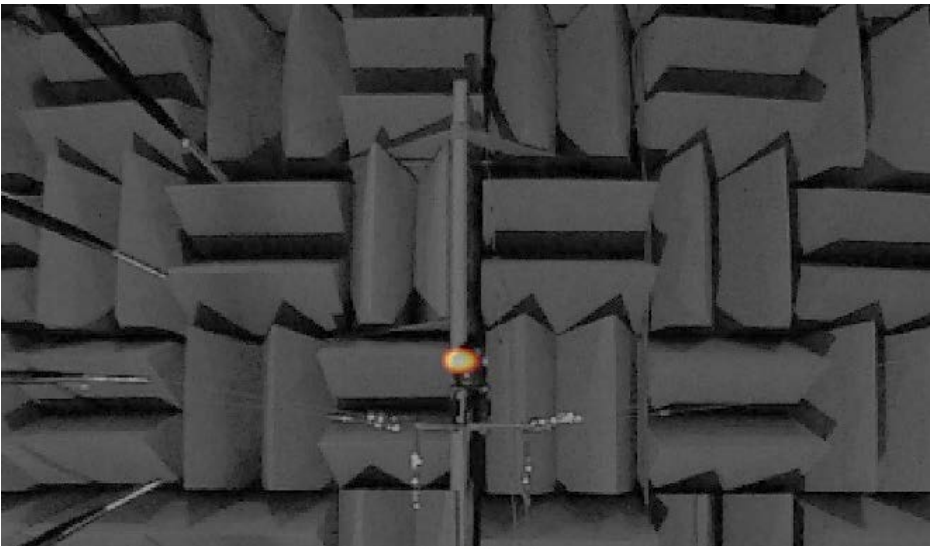
Motor Only

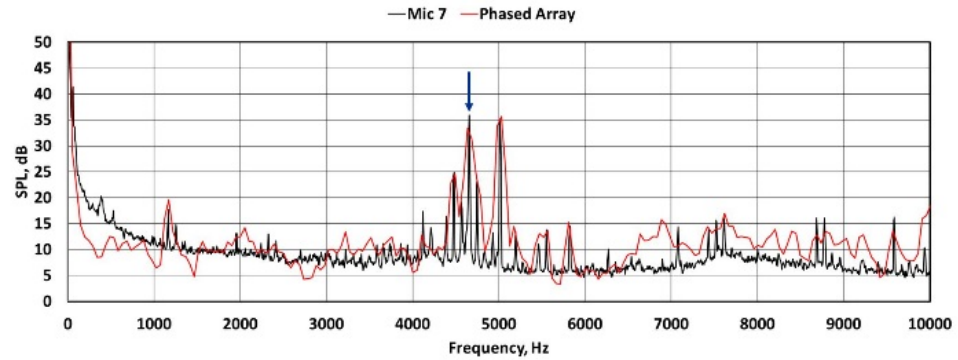


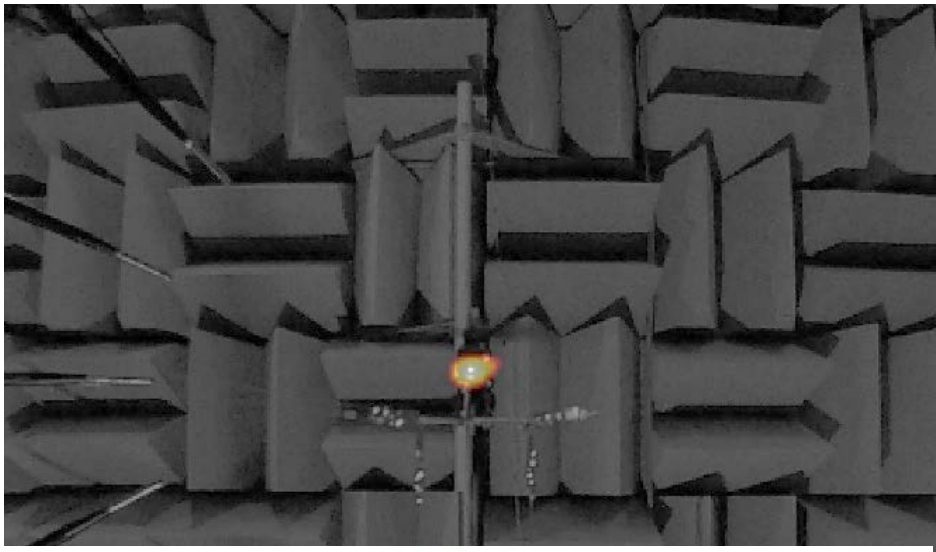


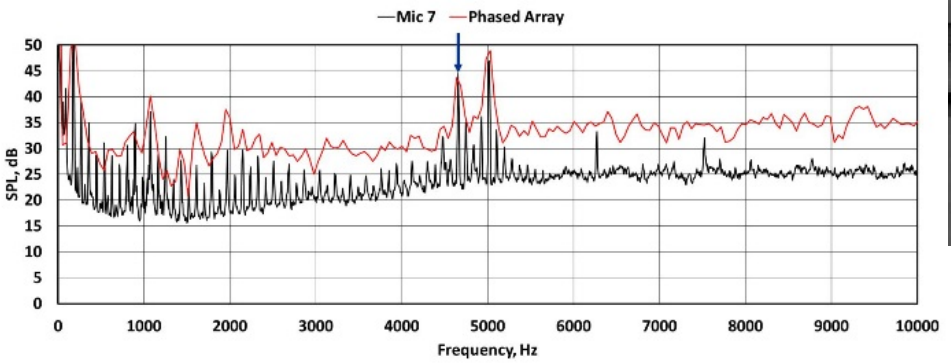
Two-Bladed Propeller

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





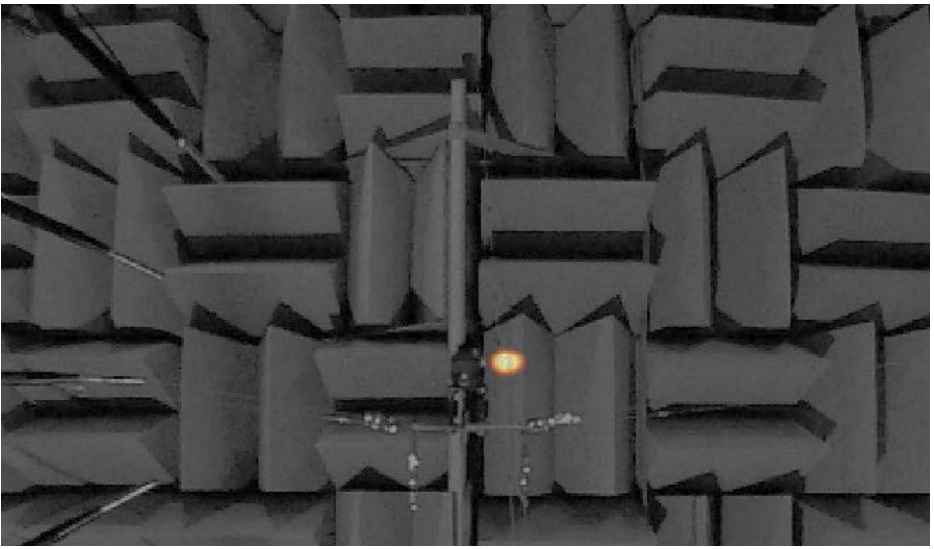


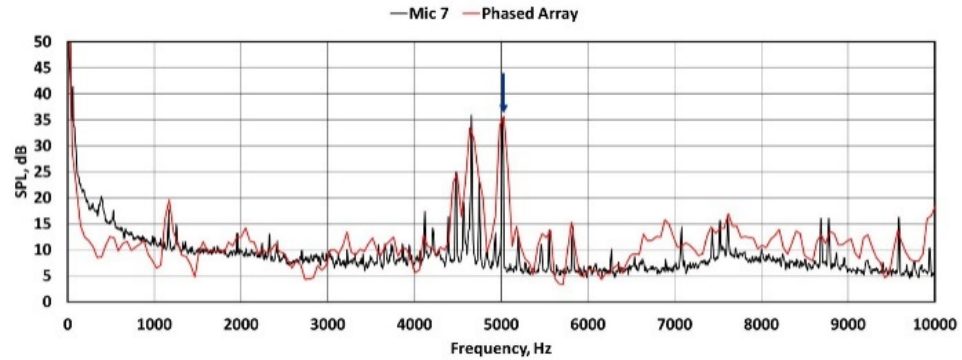


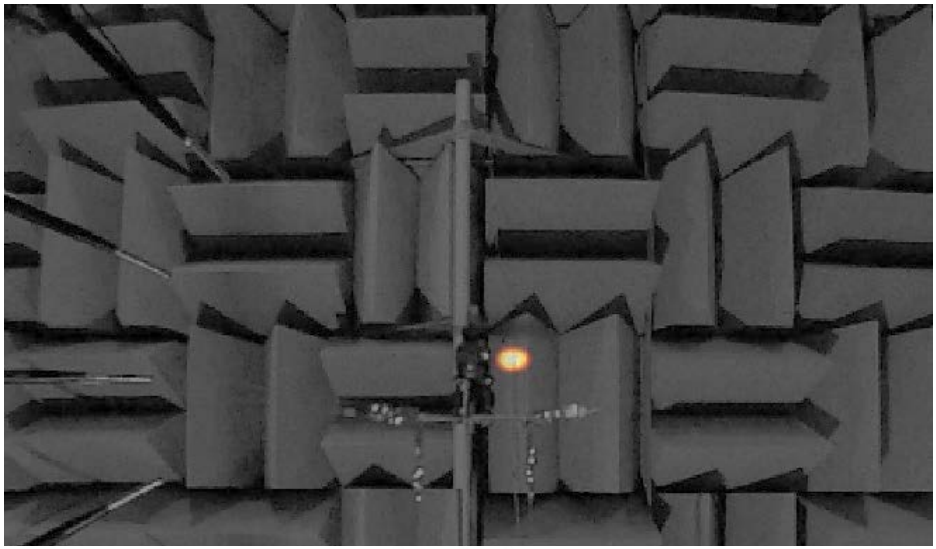
Motor Only

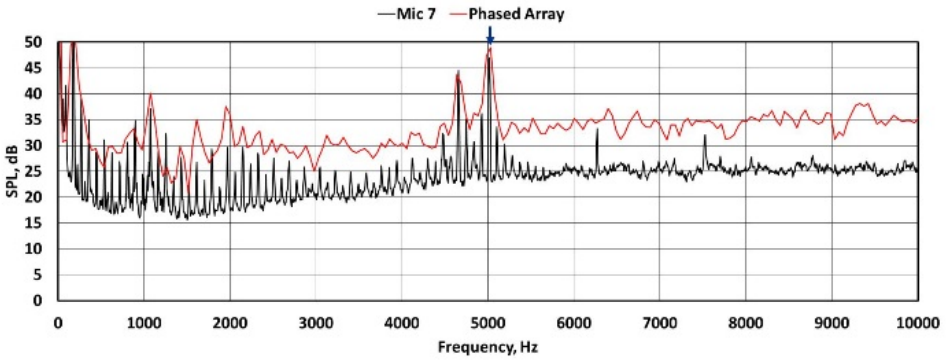
Two-Bladed Propeller

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





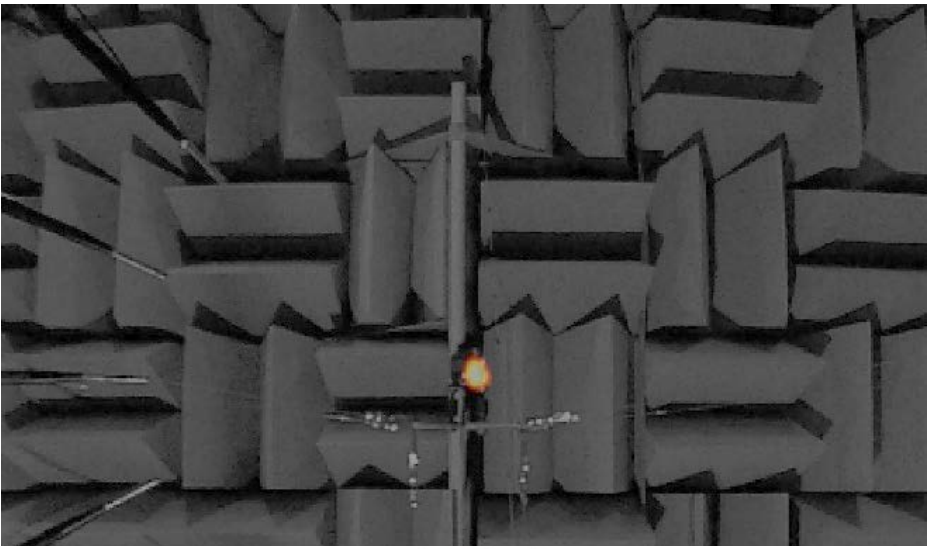


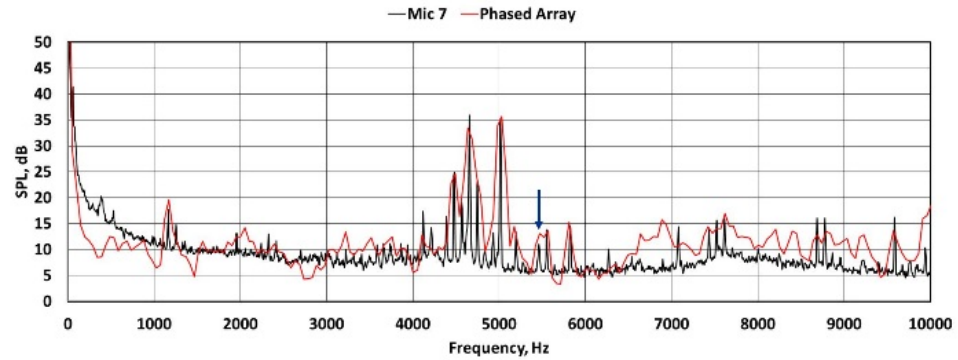


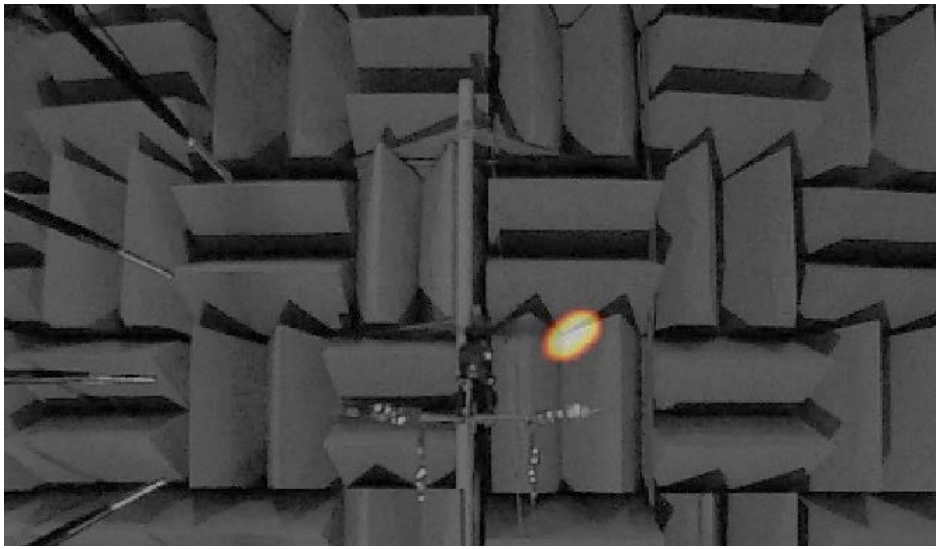
Motor Only

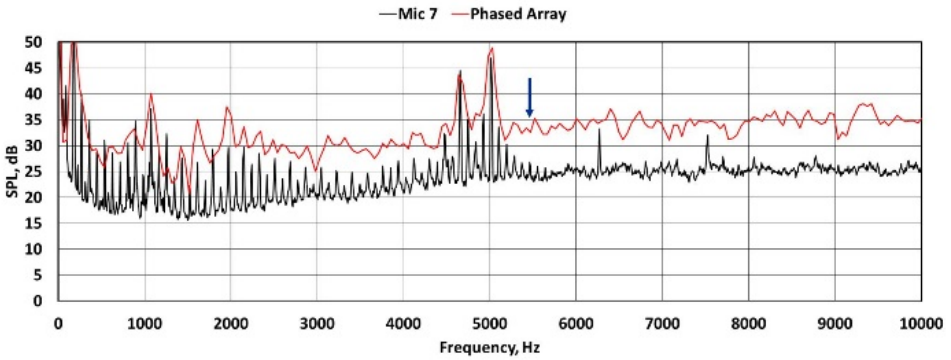
Two-Bladed Propeller

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





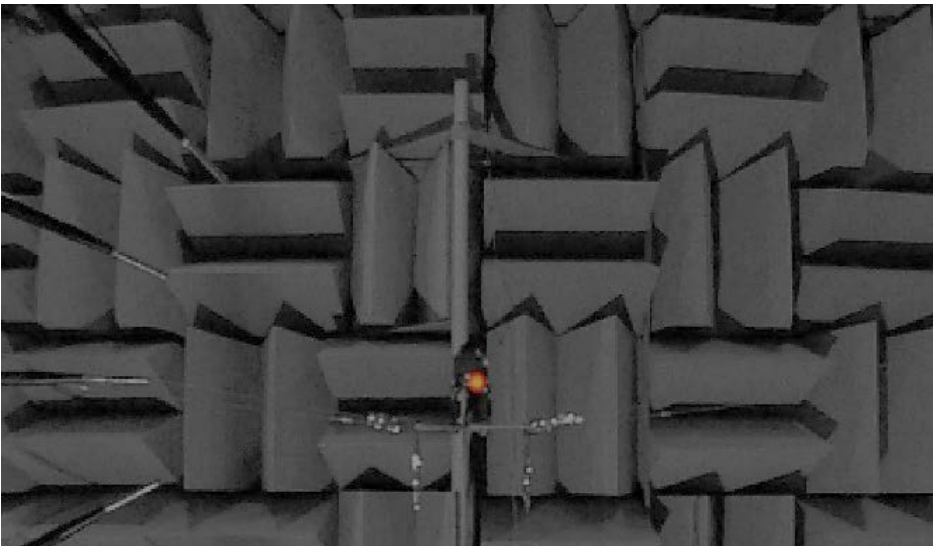


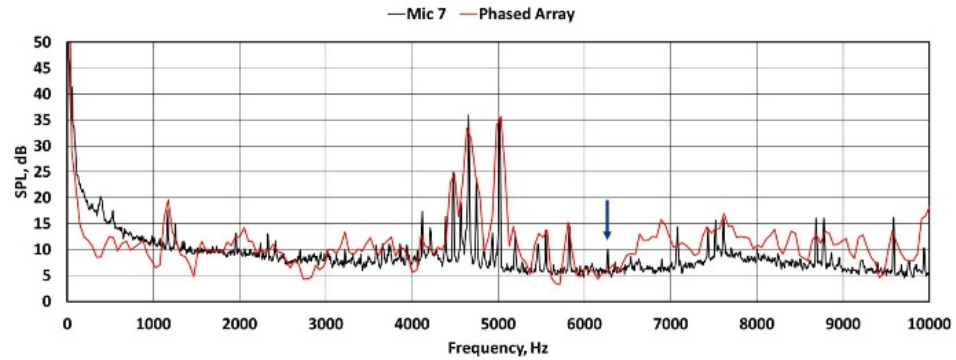


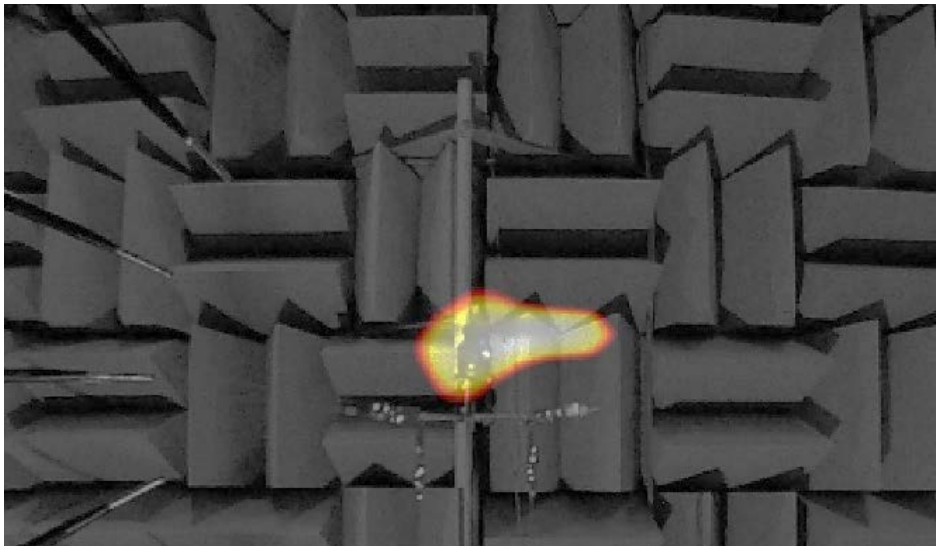
Motor Only

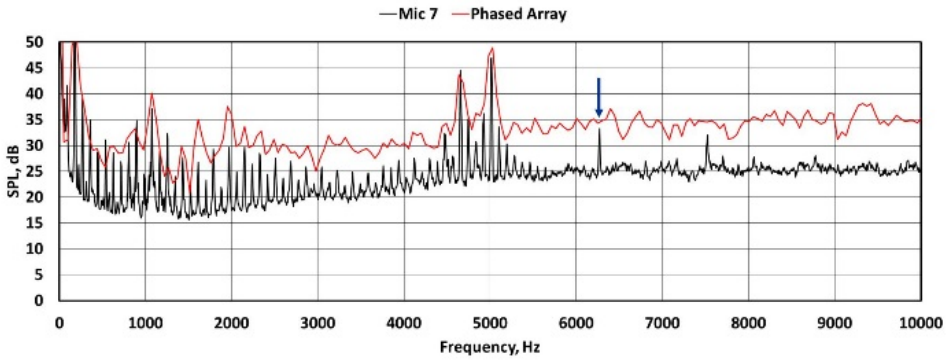
Two-Bladed Propeller

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





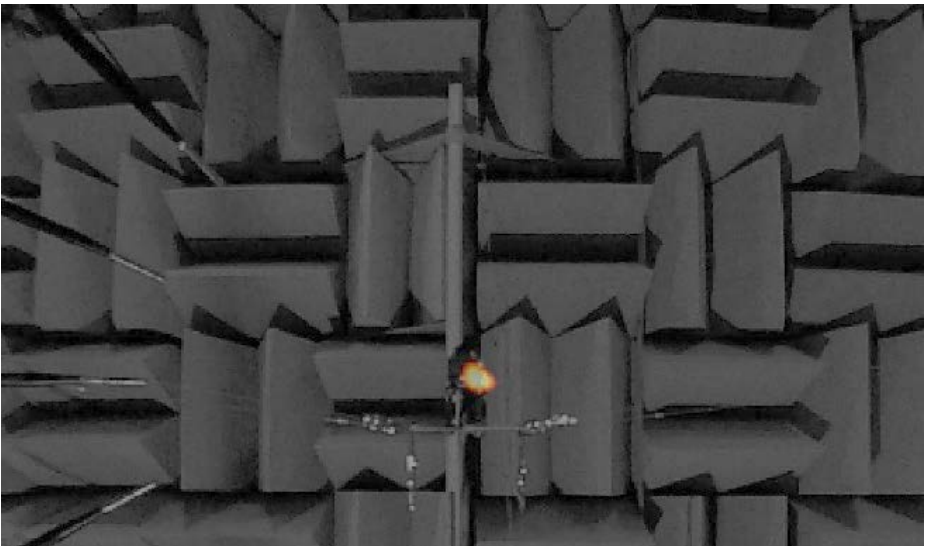


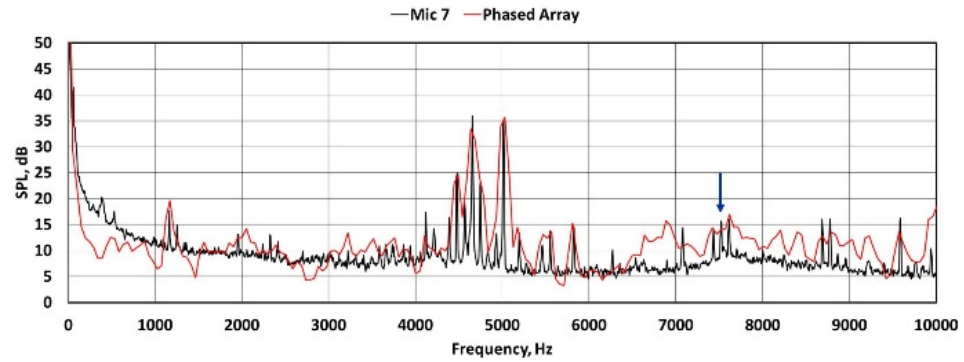


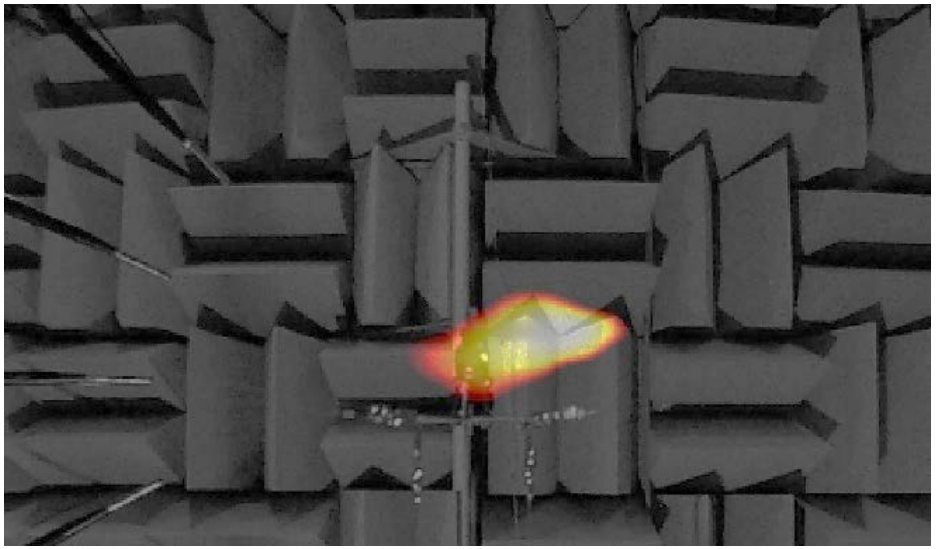
Motor Only

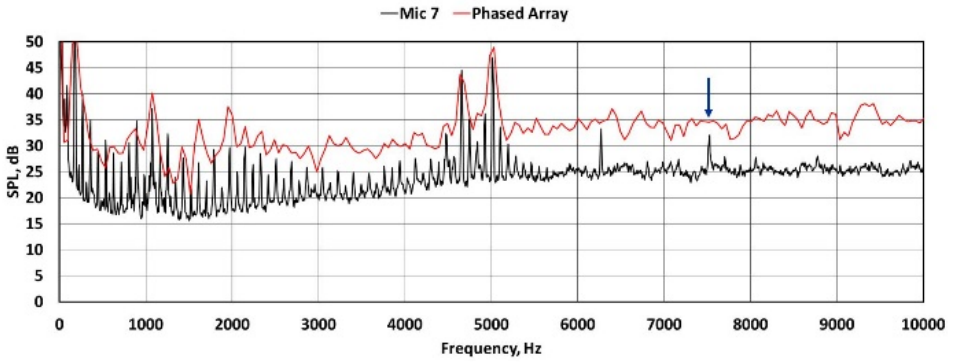
Two-Bladed Propeller

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





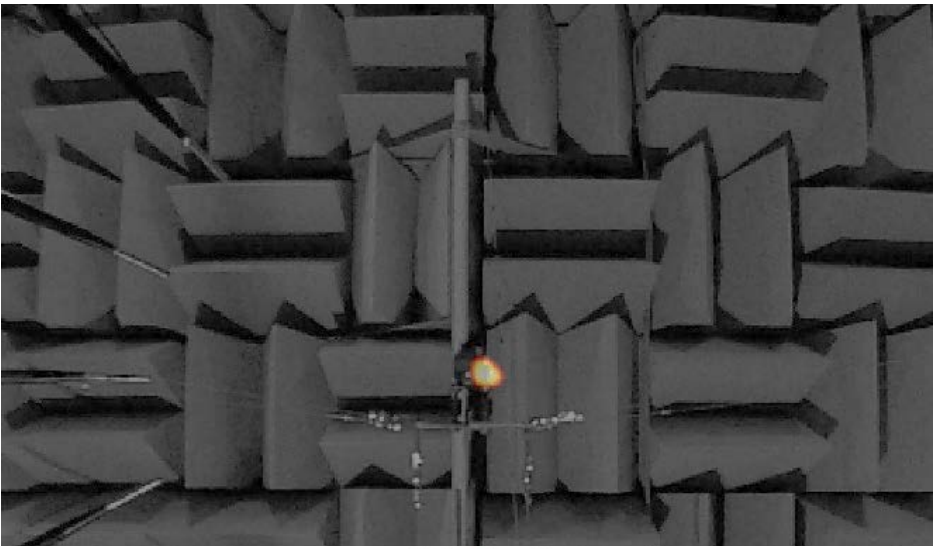


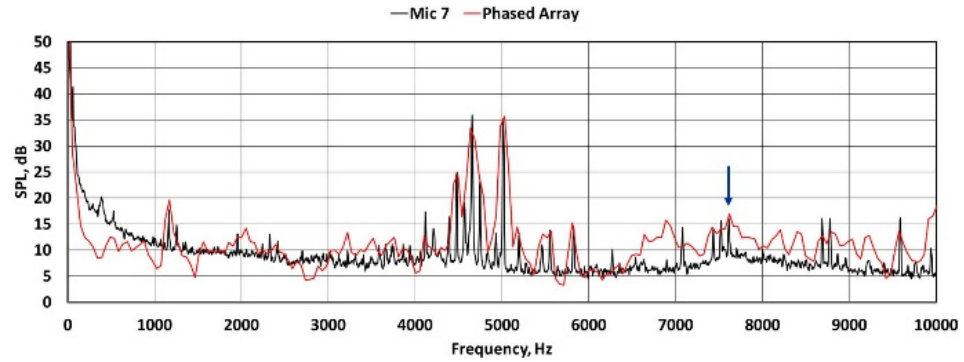


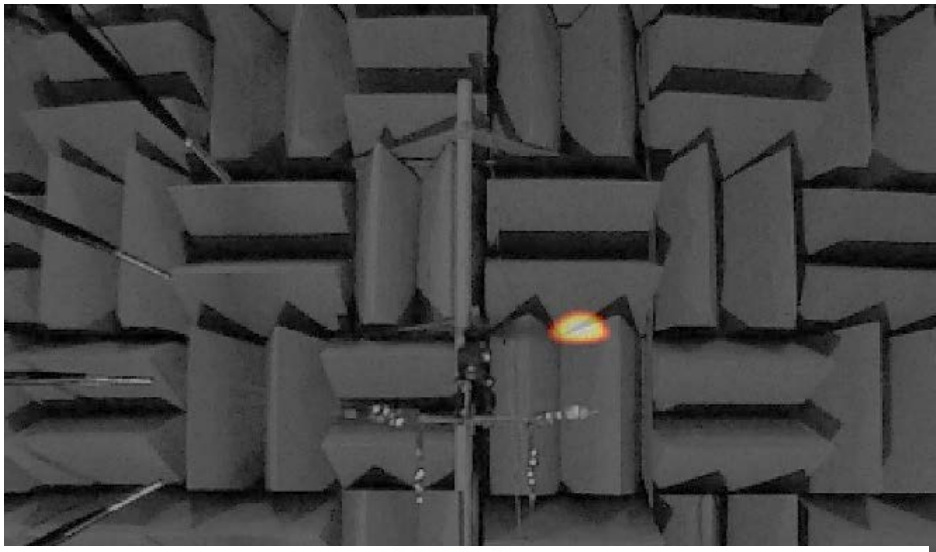
Motor Only

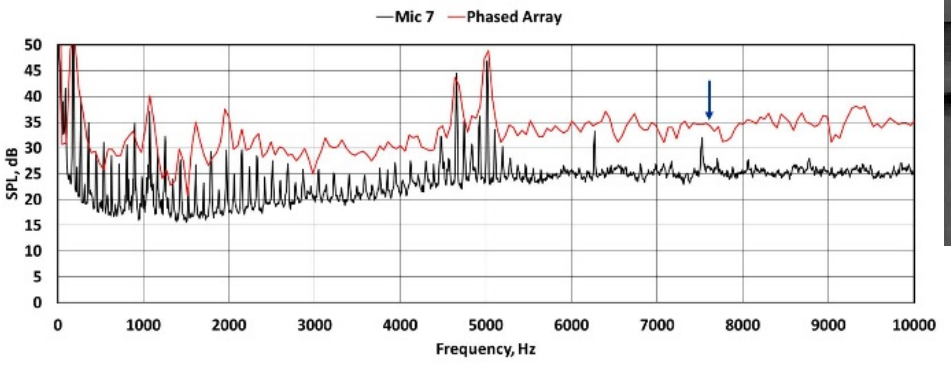
Two-Bladed Propeller

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





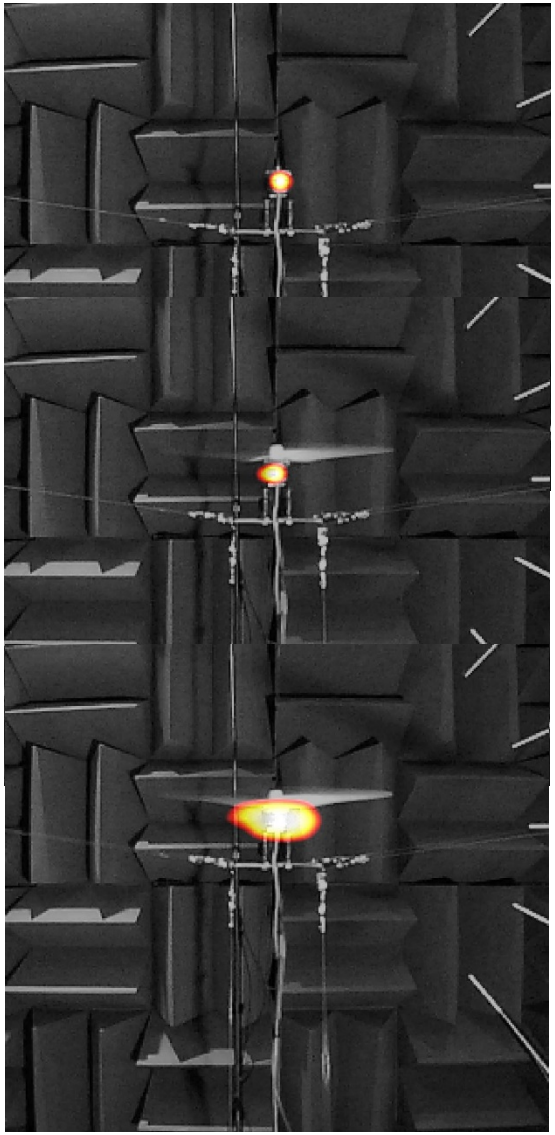




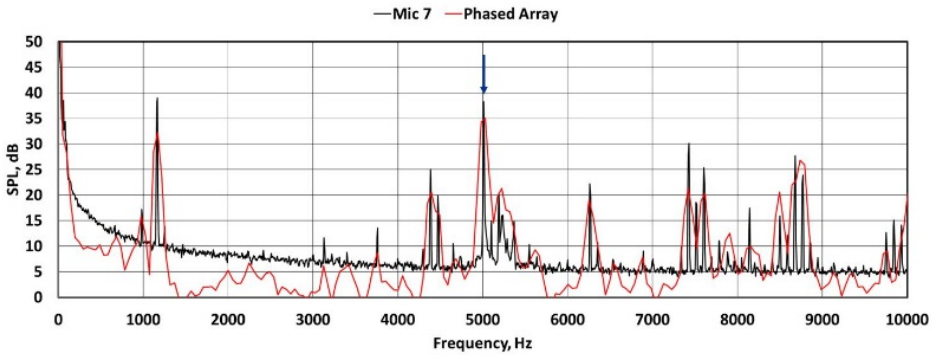
Motor Only

Two-Bladed Propeller

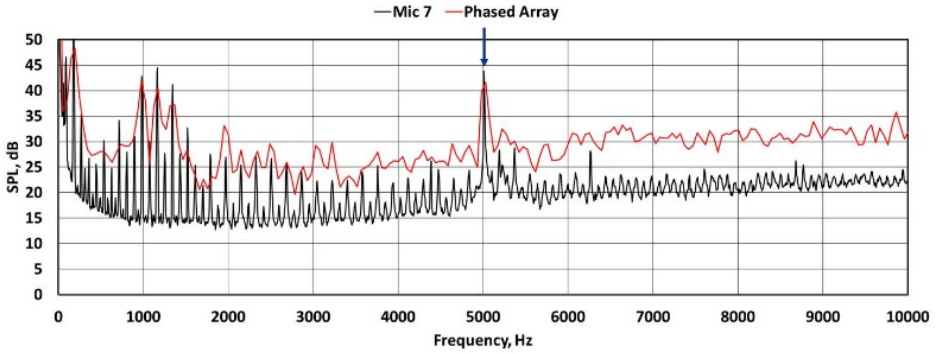
2312 Motor Only vs With Propellers, 5370 RPM Phased Array, 5029 Hz



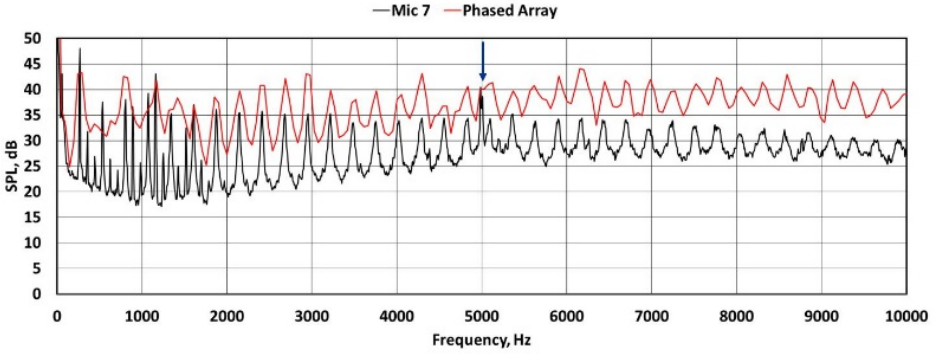
Motor Only



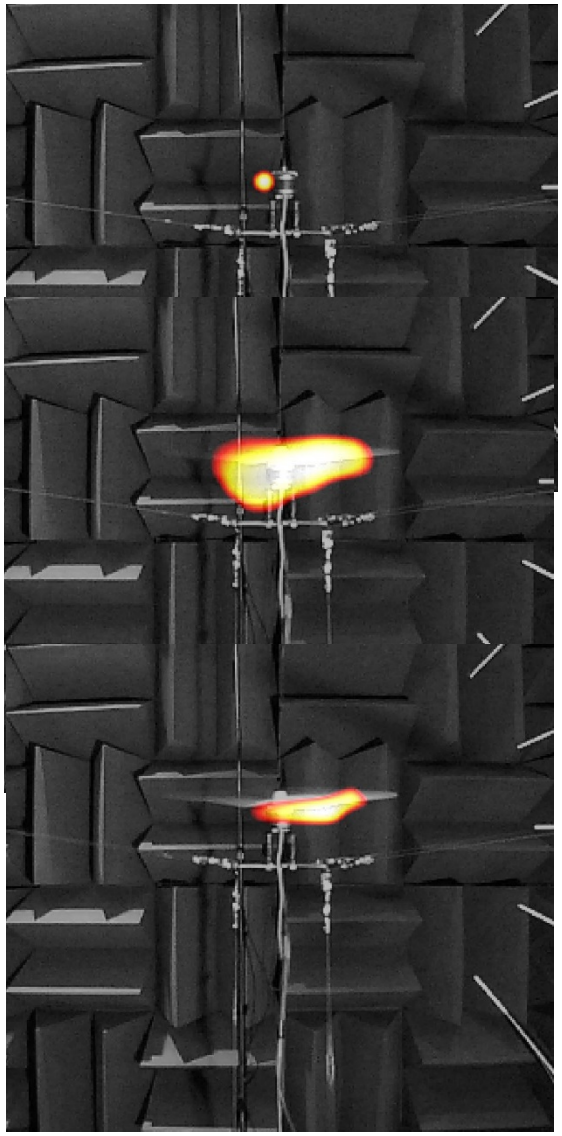
Two-Bladed Propeller



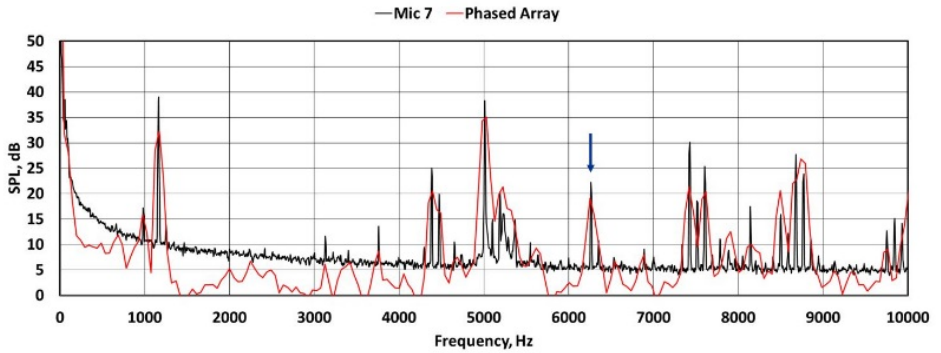
Three-Bladed Propeller



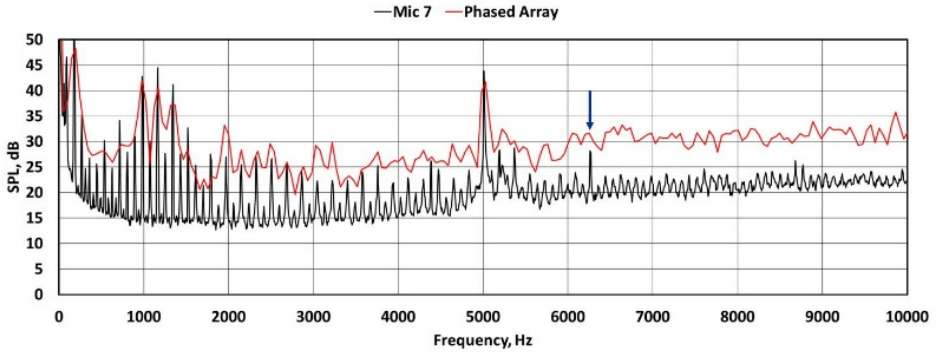
2312 Motor Only vs With Propellers, 5370 RPM Phased Array, 6250 Hz



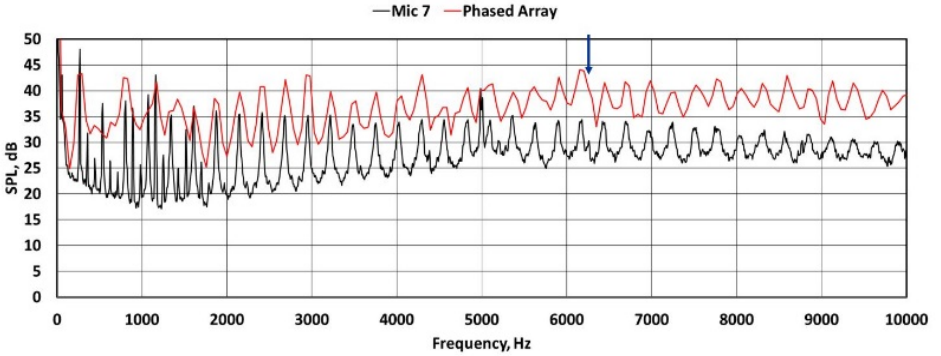
Motor Only



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.