

Progress on Small Unmanned Aerial System (sUAS) Noise Characterization

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April 11, 2017

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A Storied Legacy, A Soaring Future

Outline



- Introduction
 - Considerations for sUAS Noise
 - Objectives
- Technical Approach
 - Experimental Setups
 - Noise Prediction Methods
- Results
 - Rotor-Airframe Interaction Noise
 - Facility and Prediction Comparisons
- Upcoming Work

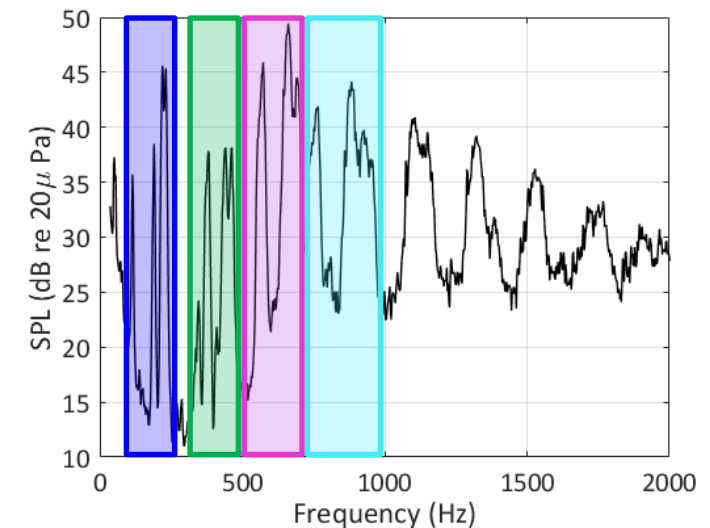
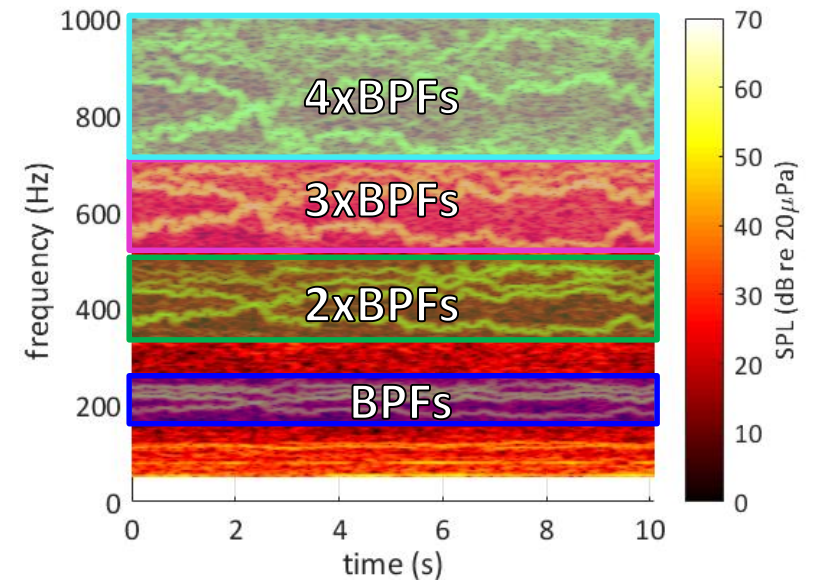


Introduction

sUAS Noise Considerations



- Fundamental rotary-wing sUAS noise sources
 - Rotor
 - Deterministic
 - Broadband
 - Motor
 - Higher-frequency tonality
 - Related to rotor blade passage frequency (BPF)
- Effects of multiple rotors, presence of airframe
 - Multiple BPFs
 - Rotor-airframe interaction effects
 - Roles of rotor blade and airframe surfaces in noise radiation?



Introduction

Objectives



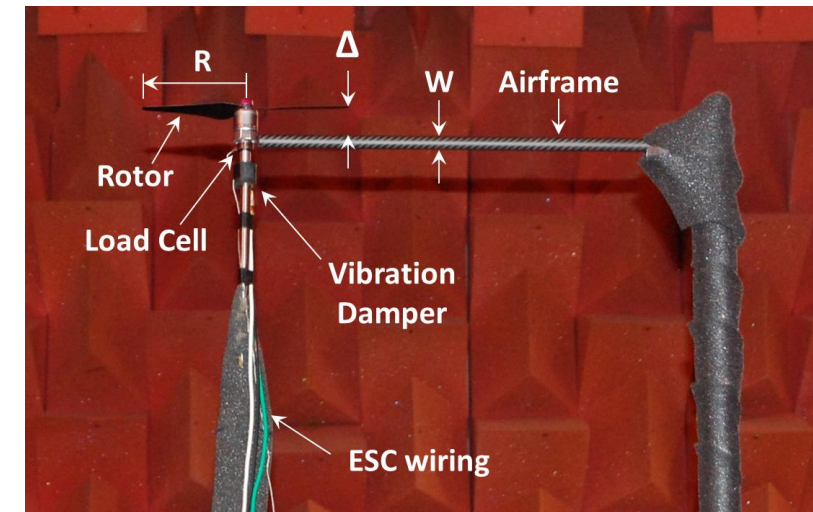
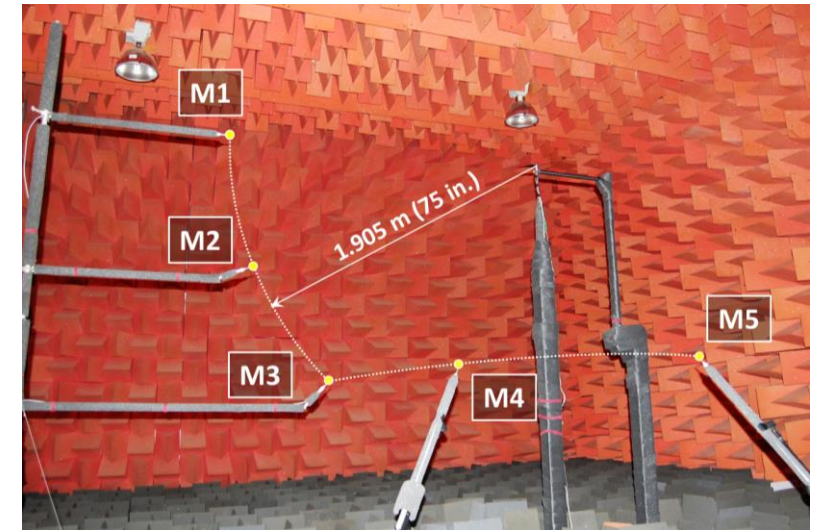
- Assess ability of noise predictions to capture physics responsible for rotor-airframe noise generation
- Determine contributions of rotor and rotor-airframe interactions to radiated noise for simple vehicle configurations
- Verify consistency between experimental facilities to ensure reliable measurement capabilities for more complex vehicle and flight conditions

Technical Approach

Experimental Setups



- SALT anechoic chamber
 - 100 Hz cut-off frequency
 - Arc microphone sub-arrays (elevation and azimuthal variations)
 - Well suited for hover testing small rotors
- Rotor and airframe support stands
 - Physically separate from one another
 - Able to vary rotor tip separation distance (Δ)
 - Airframes of constant and variable cross-section considered



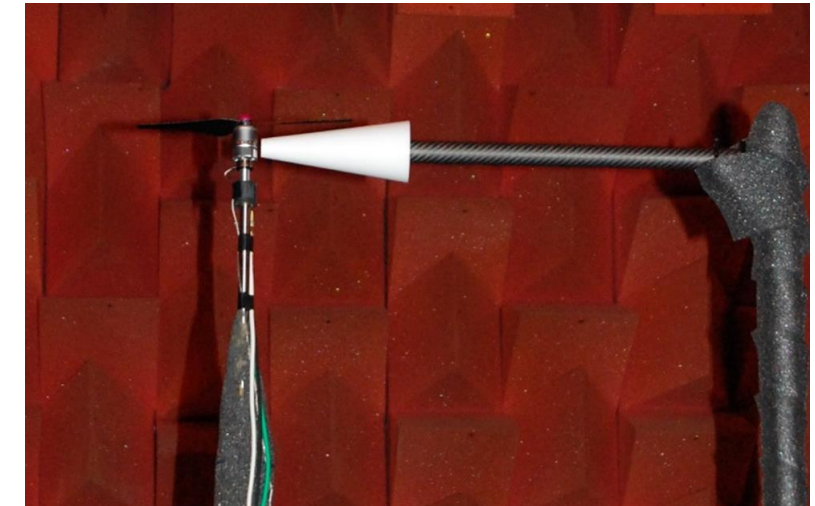
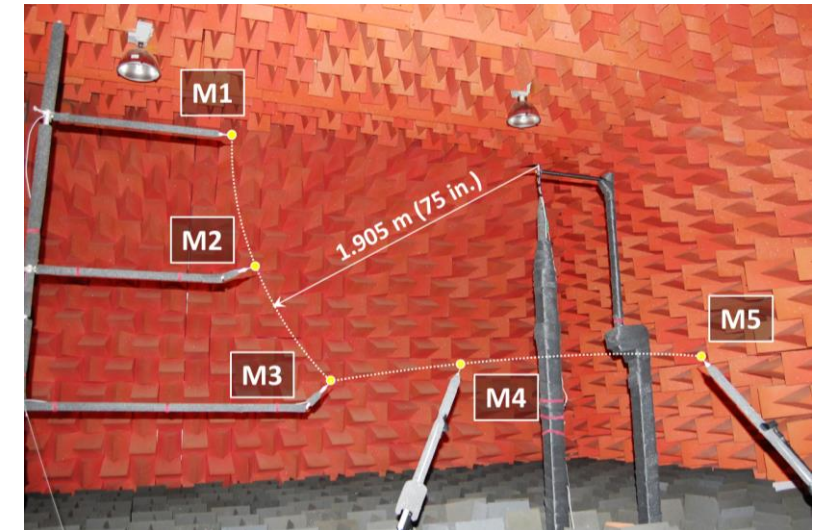
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- Rotors
 - Considering two carbon-fiber rotors of different size, similar geometry and static thrust performance

Name	R (mm)	Ω range (RPM)	M_{tip} range	$\overline{C_T}$
DJI-CF	119.2	4200-7200	0.15 – 0.26	0.0094
TM-CF	190.5	3000-6000	0.18 – 0.35	0.0097



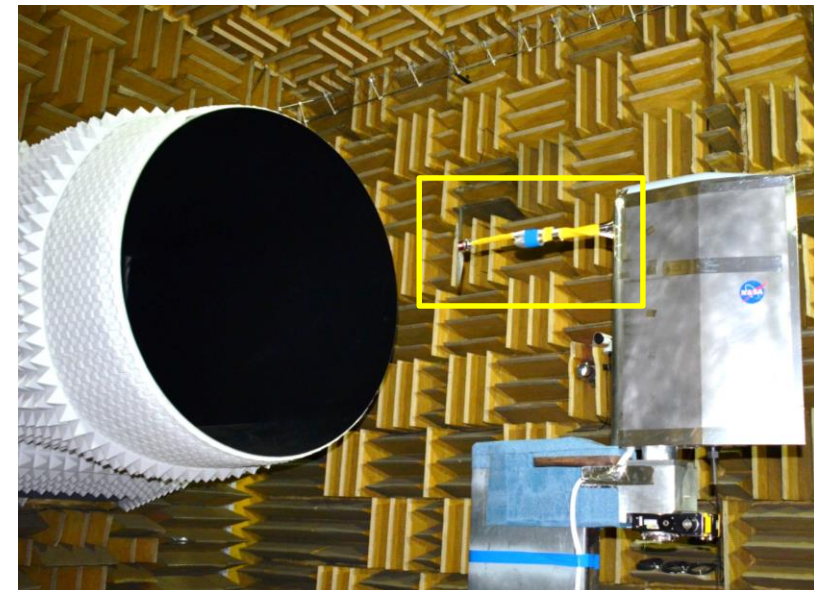
Technical Approach

Experimental Setups (contd.)



- The Low Speed Aeroacoustic Wind Tunnel (LSAWT)
 - Formerly home of the jet engine simulator (JES)
 - Recently outfit with larger, circular inlet nozzle
 - Mobile model test stand (MTS) with pitch, roll, and yaw capabilities
 - Designed for testing sUAS and small propeller platforms

Parameter	Historical	Current
TS length, m	6.12	5.59
Nozzle width, m	1.44	1.93
Mach # range	0.10 – 0.32	0.04 – 0.14
Test articles	JES	MTS

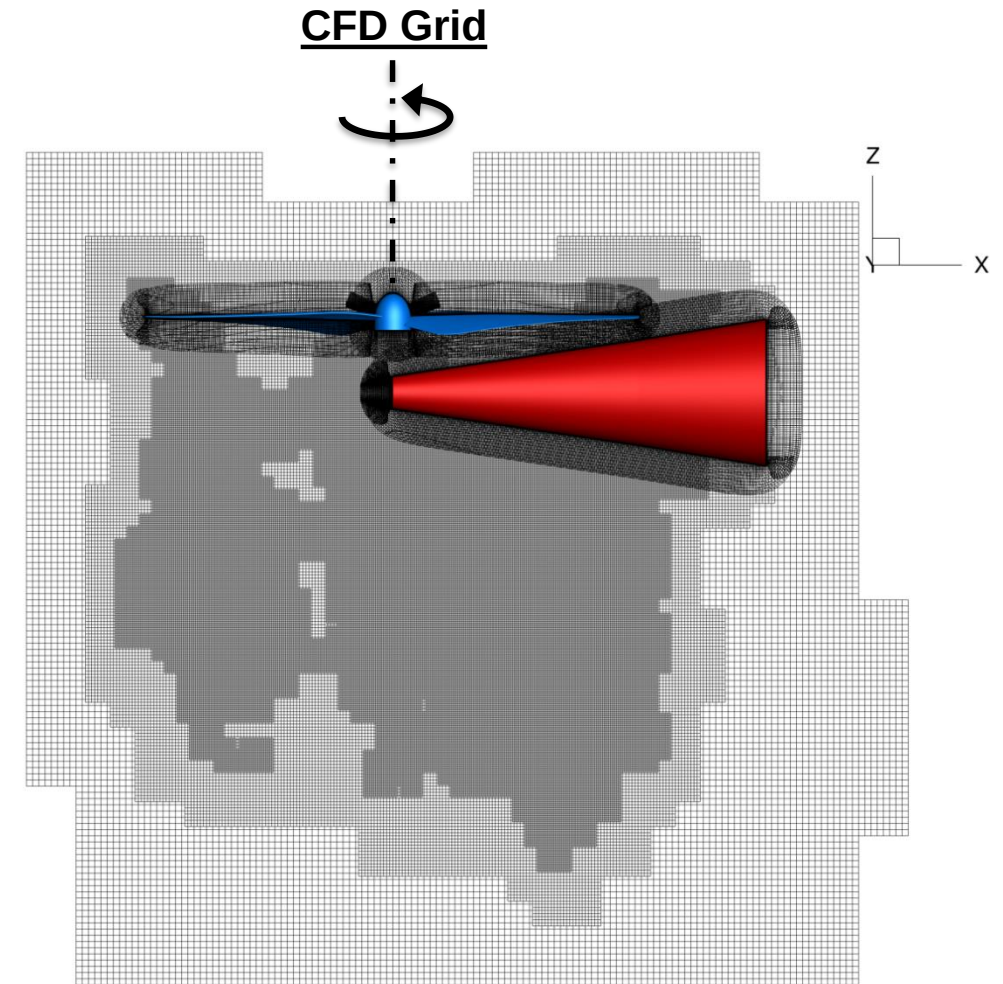


Technical Approach

Noise Prediction Methods



- High-fidelity CFD (**DJI-CF rotor**)
 - OVERFLOW2 uRANS
 - Computes impermeable blade surface loadings
 - Coupled with PSU-WOPWOP (referred to as OF2-PSW)
 - Utilize off-body adaptive mesh refinement (AMR)



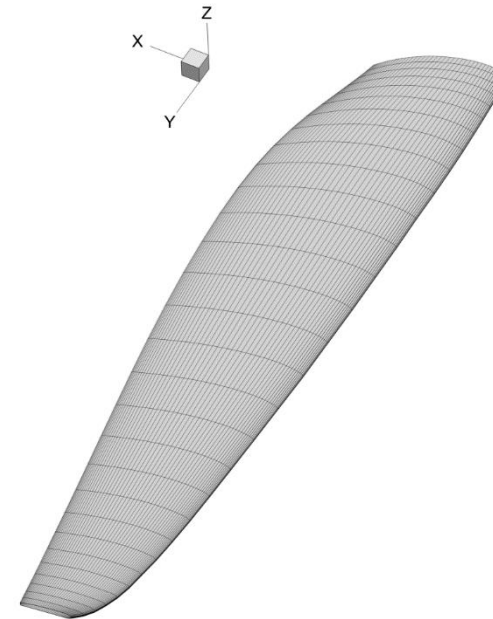
Technical Approach

Noise Prediction Methods

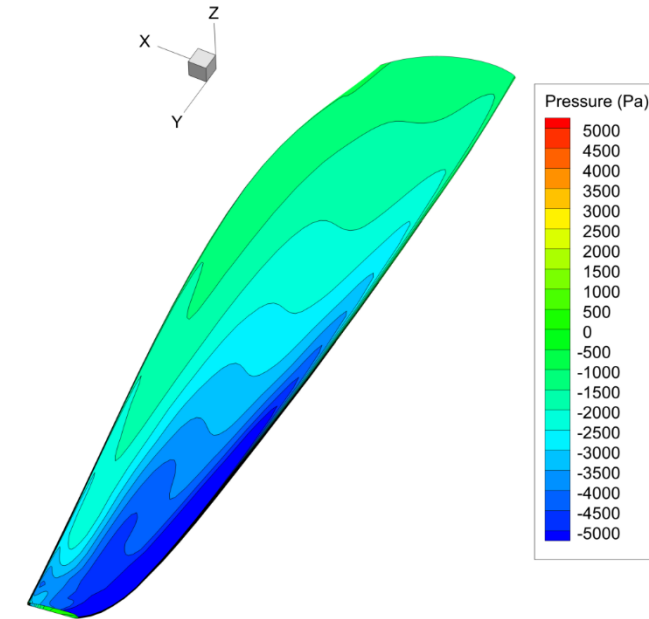


- High-fidelity CFD (**DJI-CF rotor**)
 - OVERFLOW2 uRANS
 - Computes impermeable blade surface loadings
 - Coupled with PSU-WOPWOP (referred to as OF2-PSW)
 - Utilize off-body adaptive mesh refinement (AMR)
- Low-fidelity BEA (**TM-CF rotor**)
 - Propeller Analysis System (PAS) suite of ANOPP
 - Only applicable to cases of isolated rotors/propellers

PAS Blade Grid



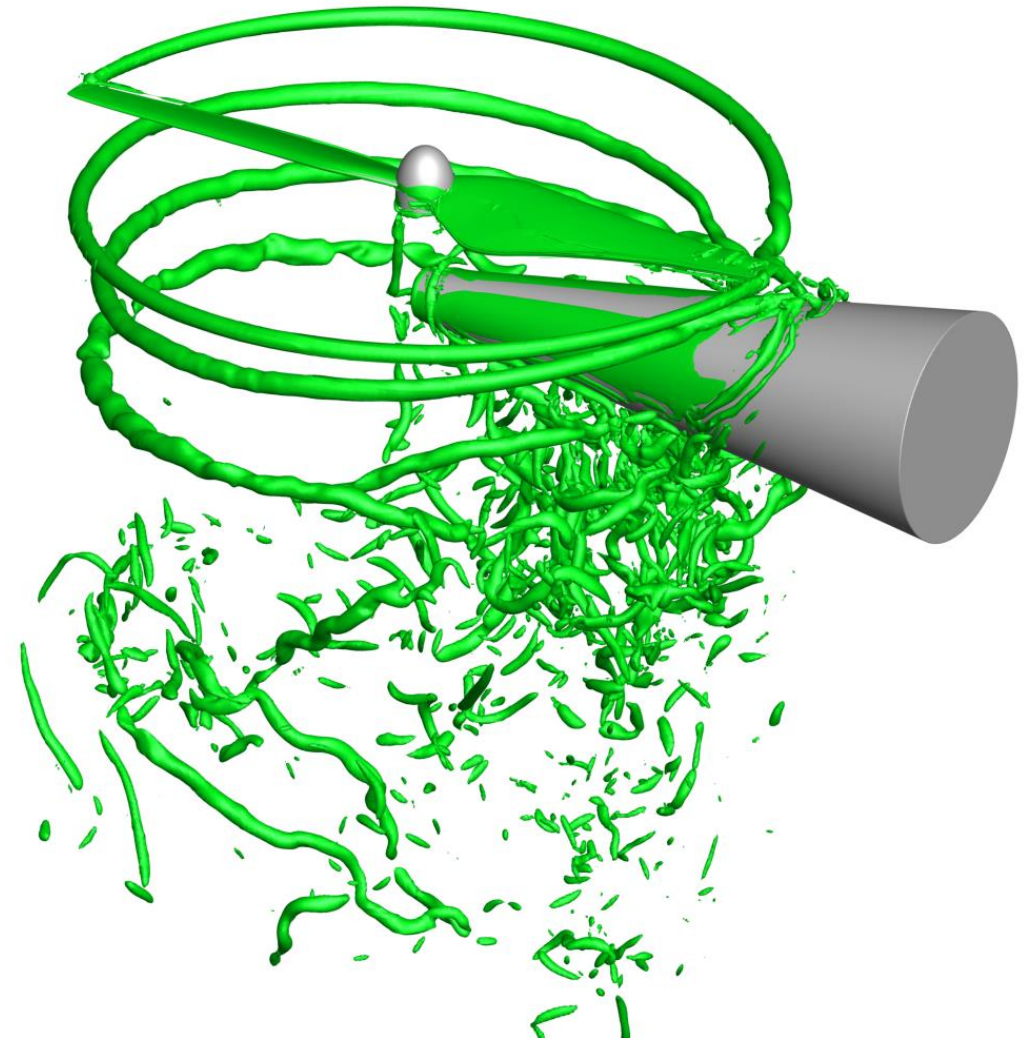
PAS Blade Pressures



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Results

Experimental Trends



- Acoustic Spectra

- Rod:

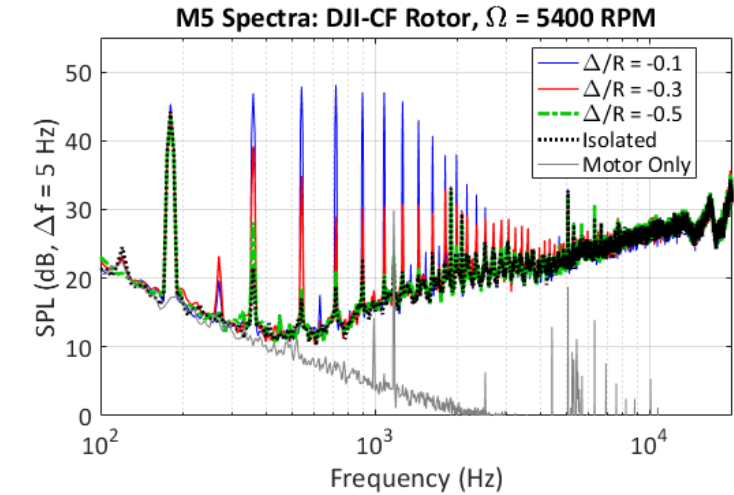
- $W/c_{\text{ref}} \approx 1$
 - Harmonically rich for small rotor tip clearances (Δ)
 - Case of $\Delta/R = -0.5$ nearly identical to case of isolated rotor

- Cone:

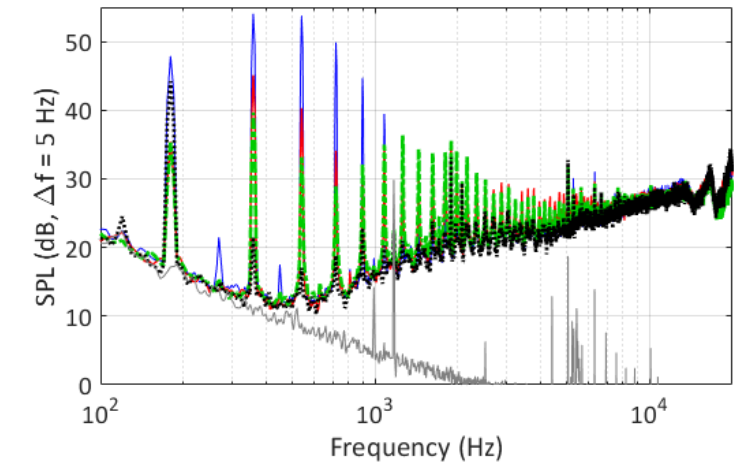
- Variations in BPF acoustic amplitude with tip clearance
 - Faster harmonic roll-off for small Δ
 - Considerably more harmonic content for case of $\Delta/R = -0.5$

- Broadband content does not change with airframe configuration

Rod airframe:



Cone airframe:

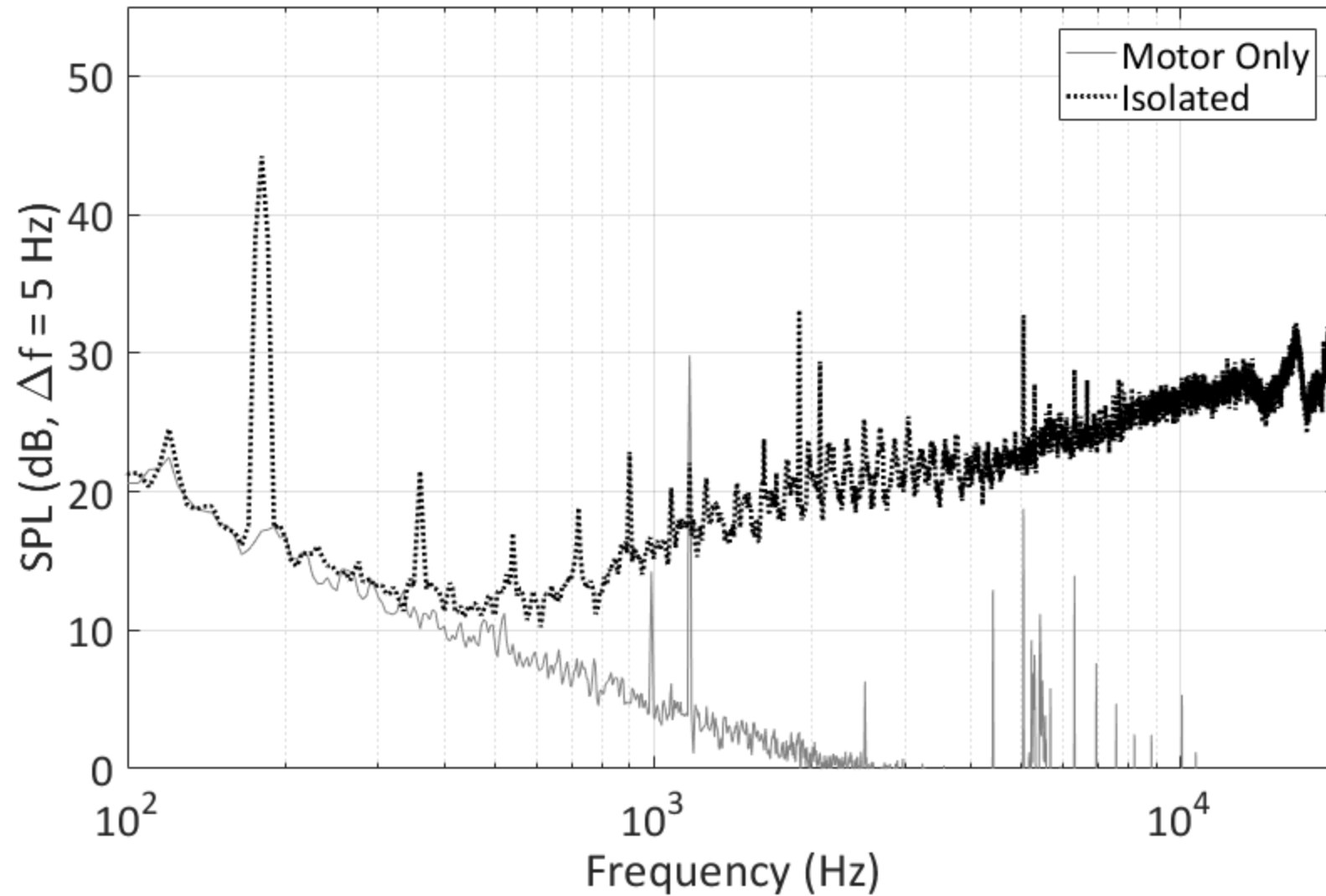


Results

Experimental Trends



M5 Spectra: DJI-CF Rotor, $\Omega = 5400$ RPM

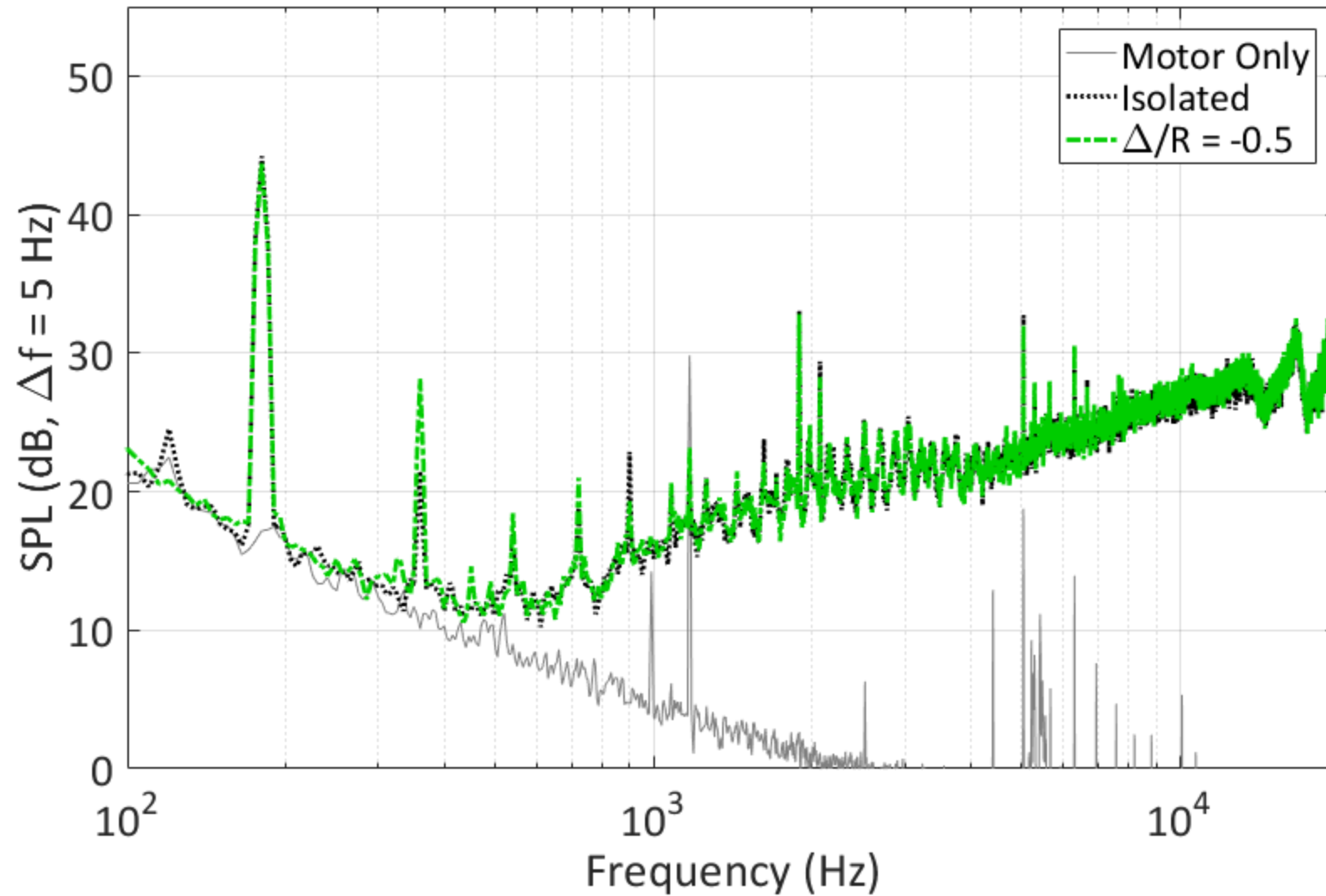


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Experimental Trends



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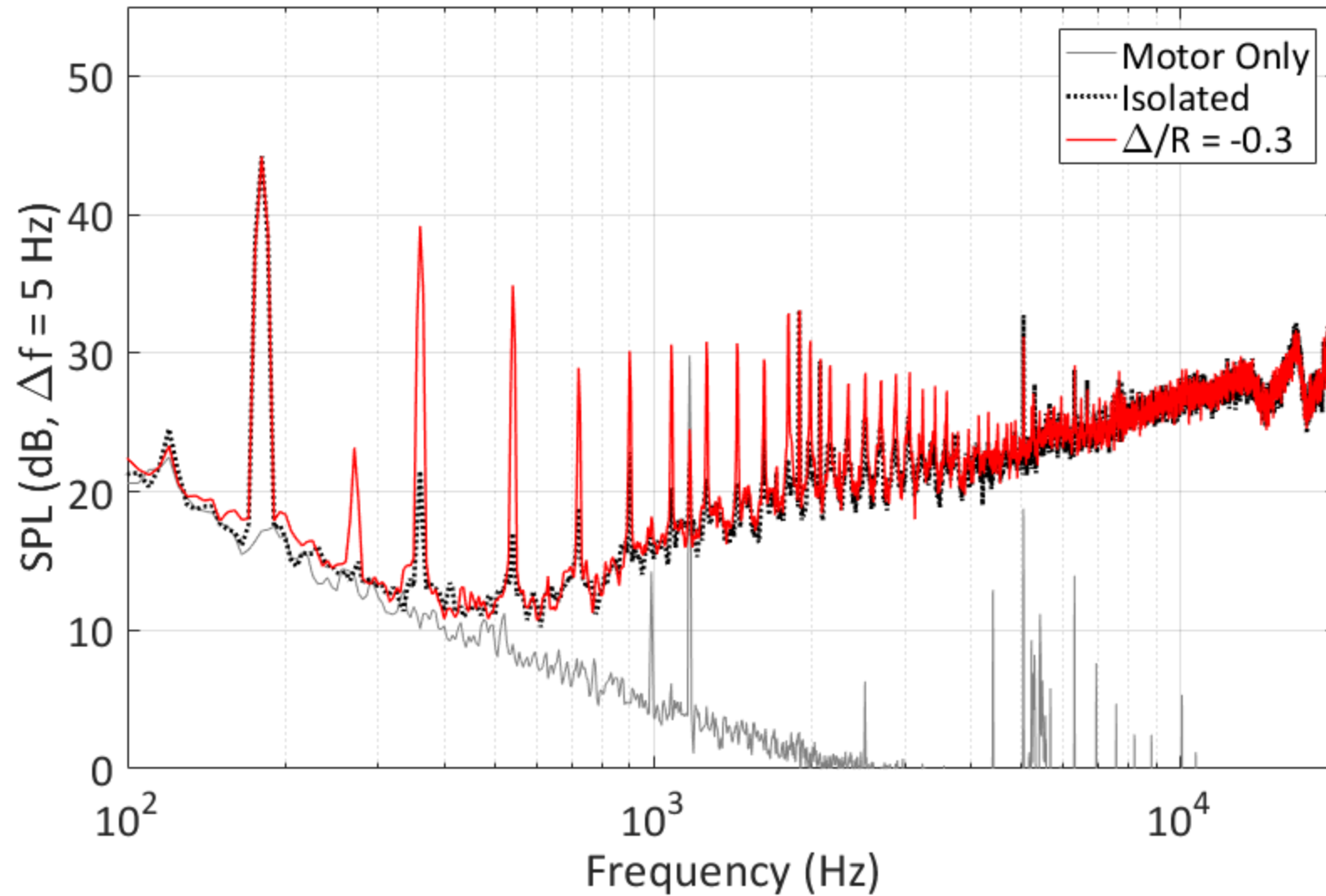


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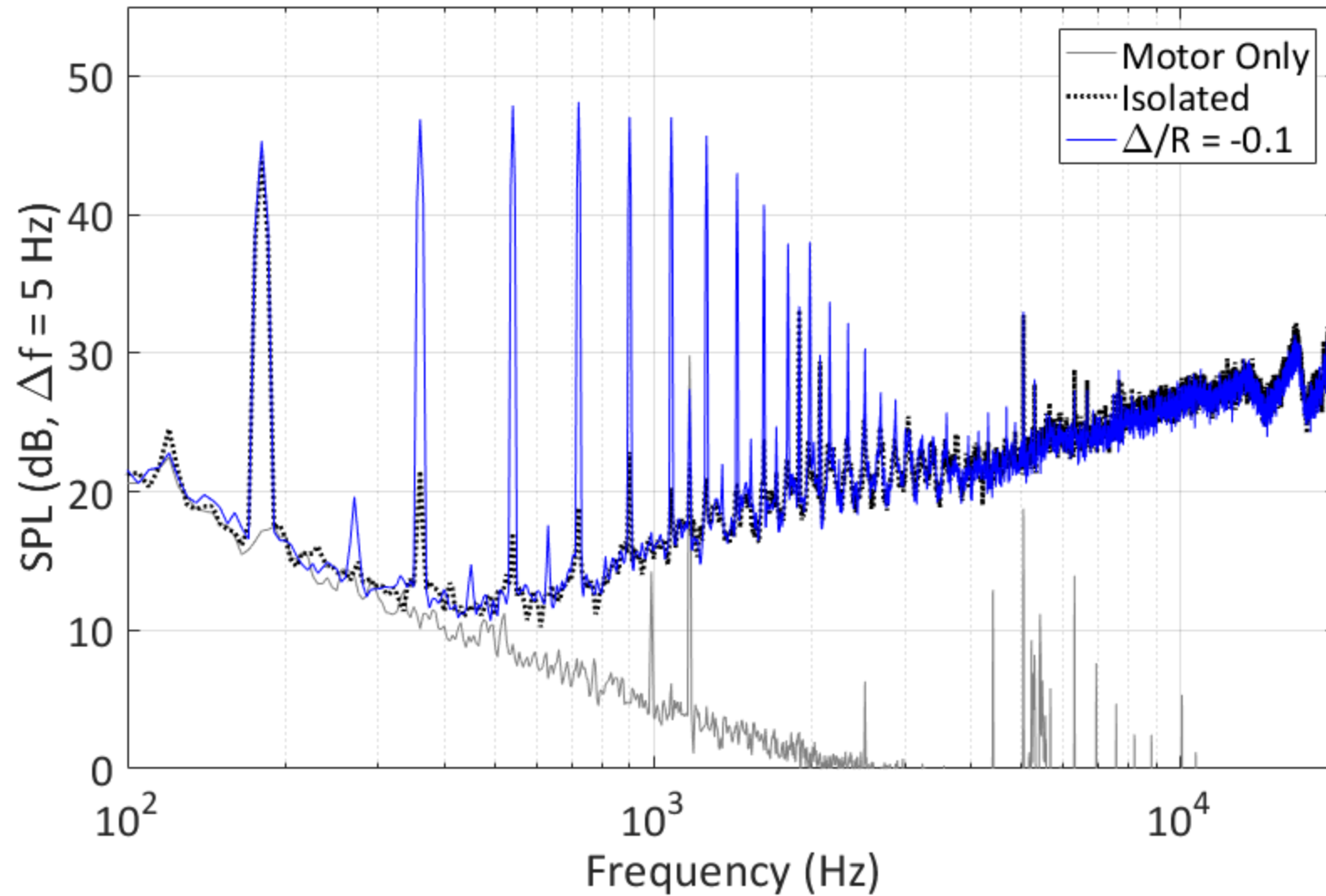


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M5 Spectra: DJI-CF Rotor, $\Omega = 5400$ RPM



Results

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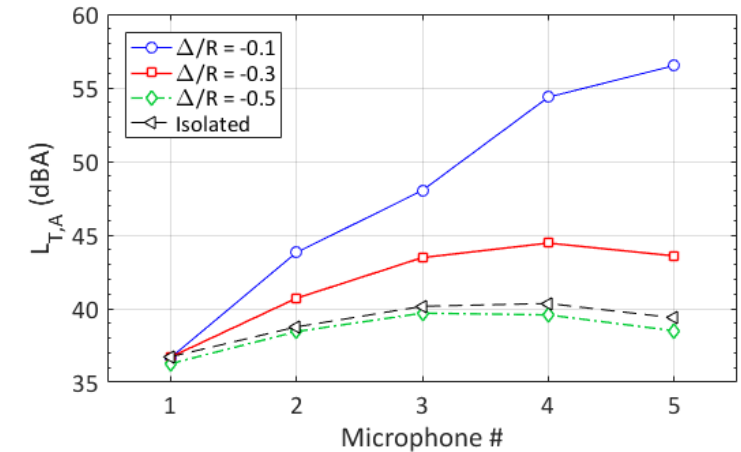
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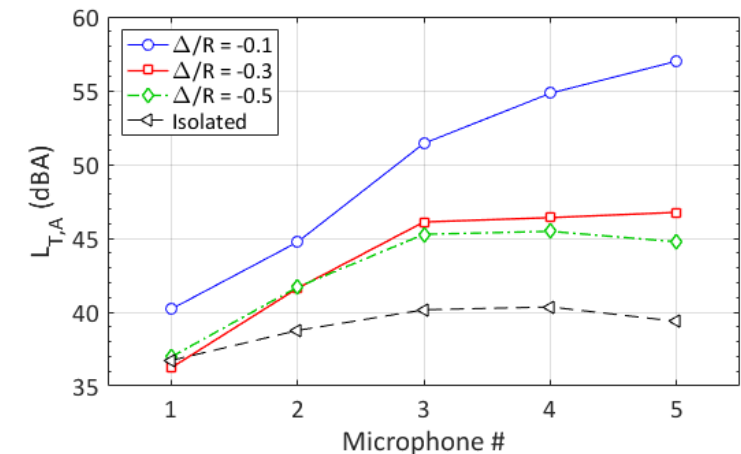
- A-weighted Tonal OASPLs

- Computed over first 20 BPF harmonics
 - Very similar levels between airframe configs. for small Δ
 - Cone airframe yields considerably higher levels for $\Delta/R = -0.5$

Rod airframe:



Cone airframe:



Results

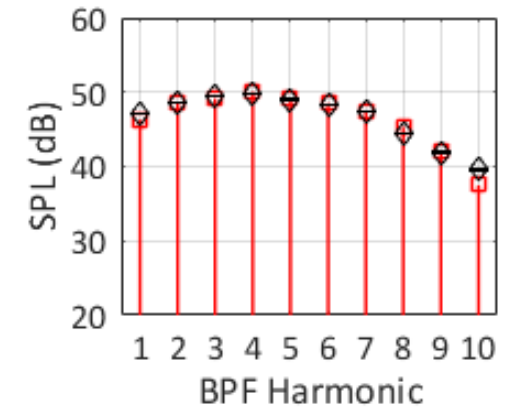
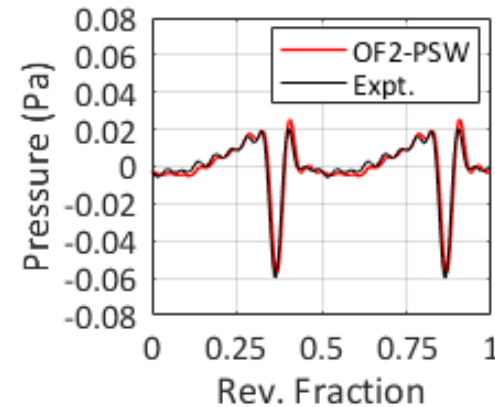
Noise Prediction Comparisons (OF2-PSW)



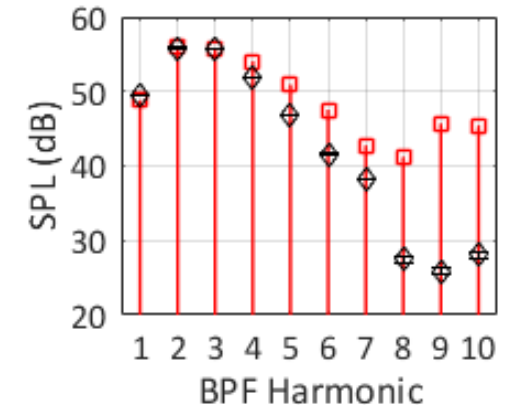
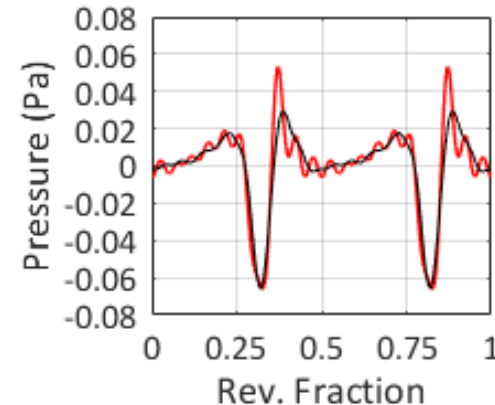
- Experimental data harmonically averaged to yield mean rotor revolution acoustic time histories
 - Common filtering technique applied to measured and prediction data
 - First 10 BPF harmonics considered
- Results show good agreement for both rod and cone airframe cases
 - Cone airframe case predictions yield higher harmonic content than observed in experiments
 - Results provide confidence for analyzing contributions of rotor and airframe surfaces to radiated noise

M5 time history and BPF harmonic spectrum ($\Omega = 5400$ RPM, $\Delta/R = -0.1$)

Rod airframe:



Cone airframe:



Results

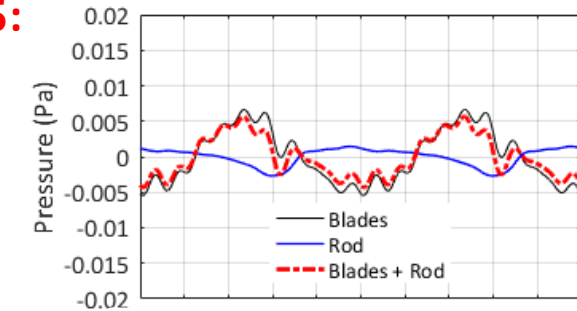
Predicted Rotor/Airframe Noise Contributions



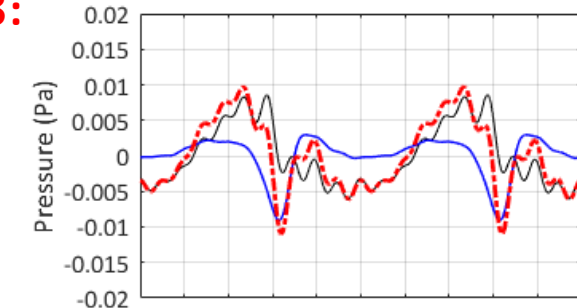
- Case of generic rod airframe
($W/c_{\text{ref}} \approx 1$)
- Both rotor blade and rod surfaces play important noise radiation roles for close airframe proximities
- Rod surfaces seen to contribute very little noise for $\Delta/R = -0.5$

M5 time histories for varying Δ ($\Omega = 5400$ RPM)

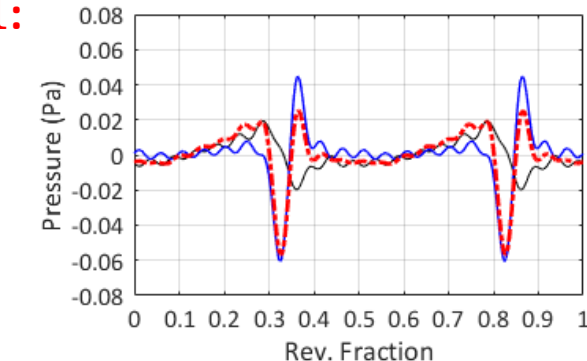
$\Delta/R = -0.5$:



$\Delta/R = -0.3$:



$\Delta/R = -0.1$:

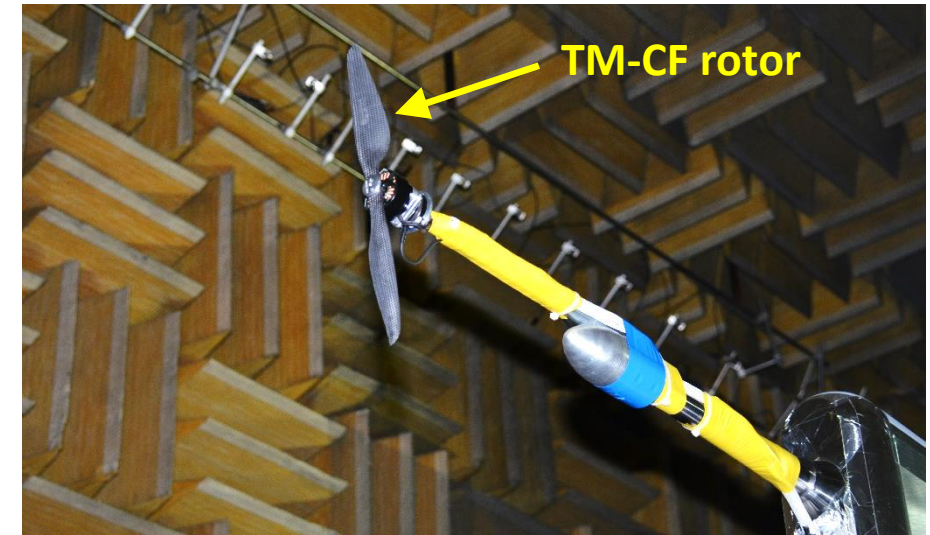


Results

Rotor Measurements in LSAWT



- Hover configuration (**TM-CF rotor**)
 - Intended to emulate isolated rotor SALT facility setup

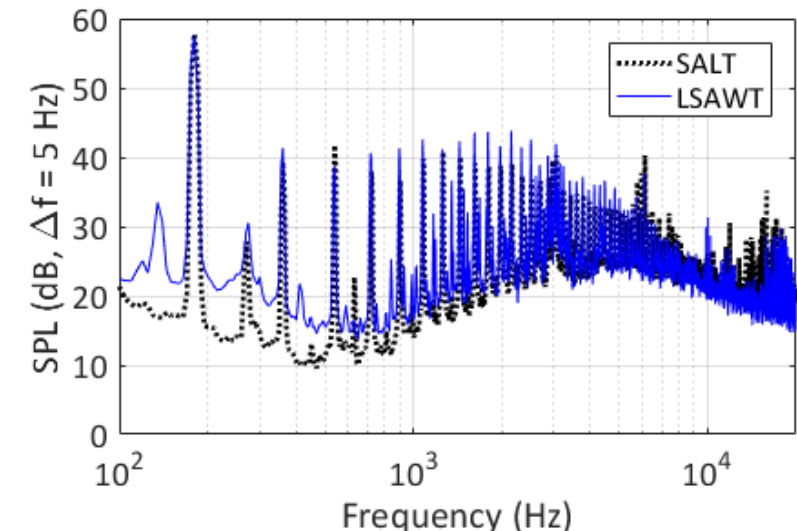
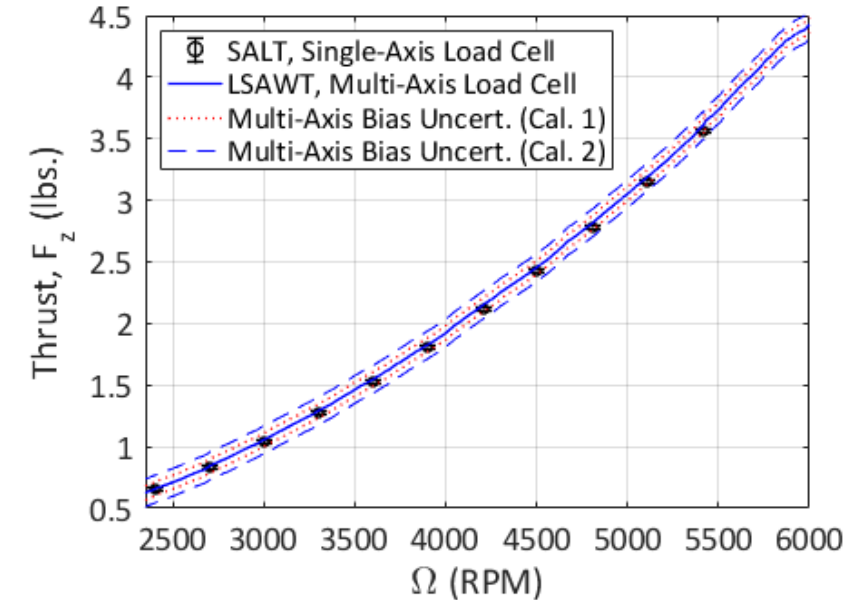


Results

Rotor Measurements in LSAWT



- Hover configuration (**TM-CF rotor**)
 - Intended to emulate isolated rotor SALT facility setup
- Performance and acoustic measurements
 - Thrust data match very well with SALT measurements
 - Acoustic spectra match reasonably well between facilities ($\theta = -45^\circ$)

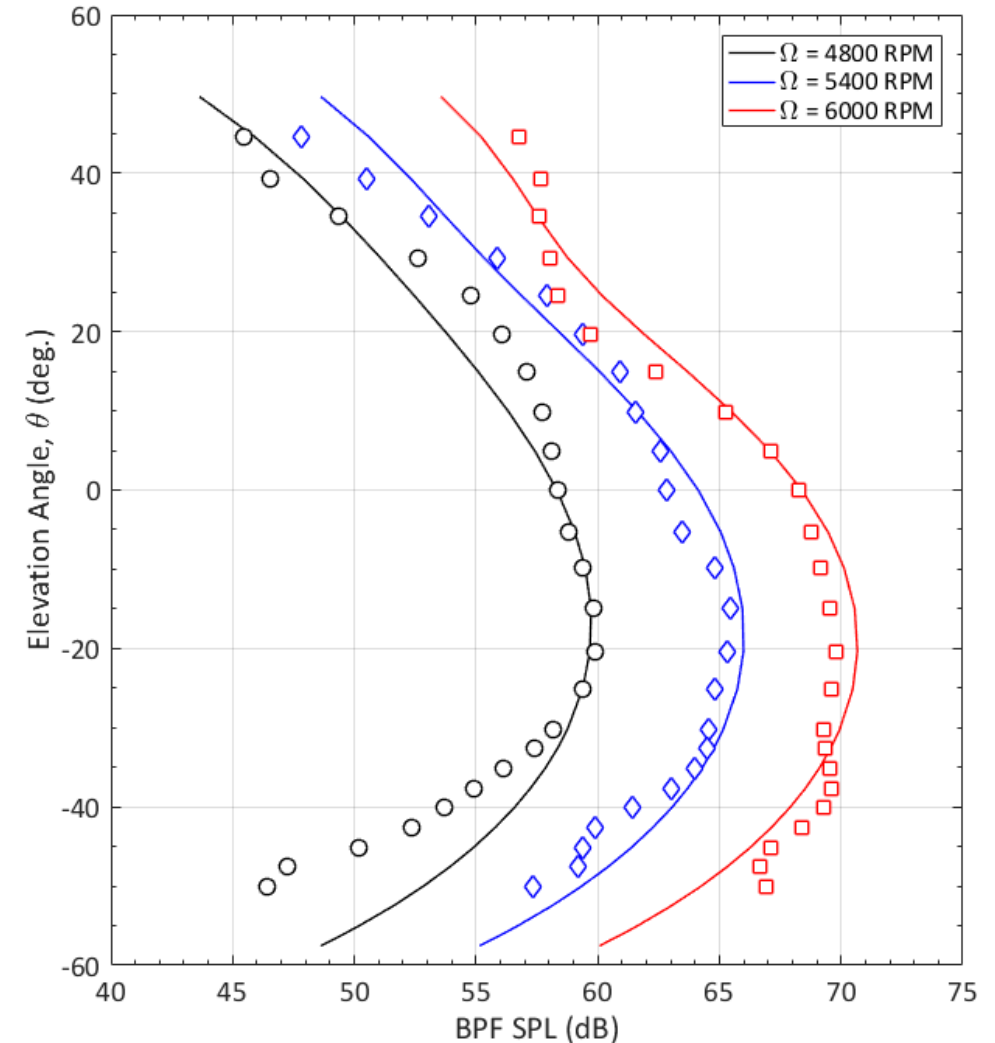


Results

Rotor Measurements in LSAWT (contd.)

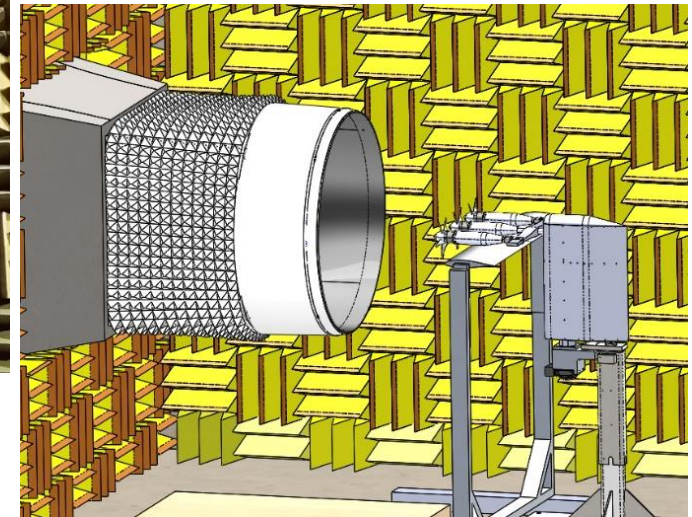
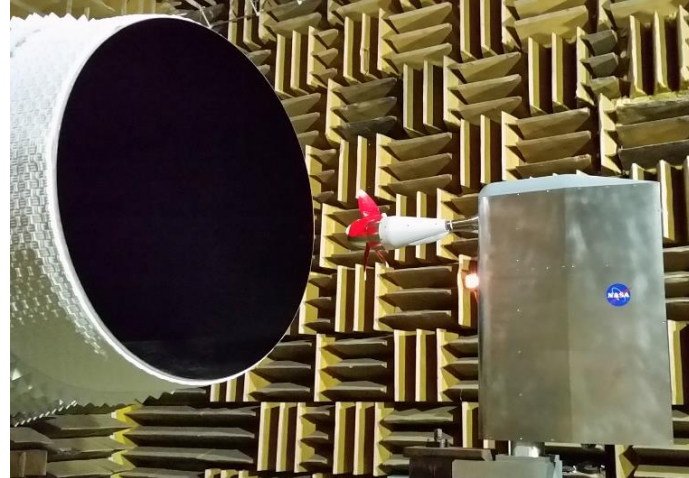
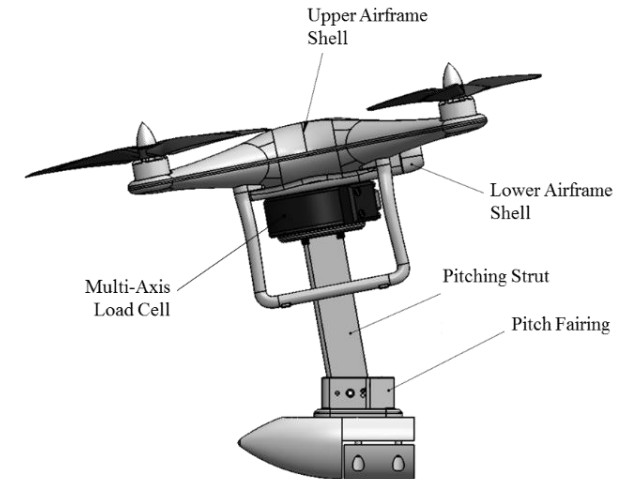


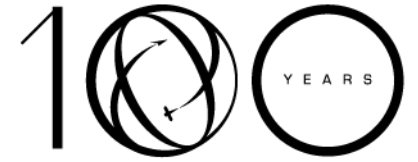
- BPF acoustic directivity measurements and PAS predictions
 - PAS proven to be reliable for simulating rotors of similar size in “near” hover conditions
- LSAWT measurements reflect appropriate directivity trends
 - Increased loading noise below rotor plane for higher rotation rates
 - Levels match better for higher rotation rates (near facility cut-on frequency)
 - Comparisons reasonable, considering possible effects such as diffraction off of inlet nozzle and collector edges



Upcoming Work

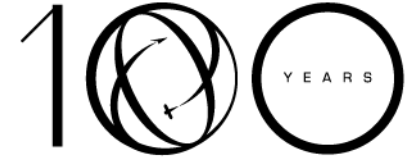
- Forward flight testing of sUAS
 - Single rotor and full quadcopter platforms
- Single and multi-propeller testing
 - Validation of CFD and acoustic predictions
 - Prop-prop, prop-wing interaction studies





Questions?

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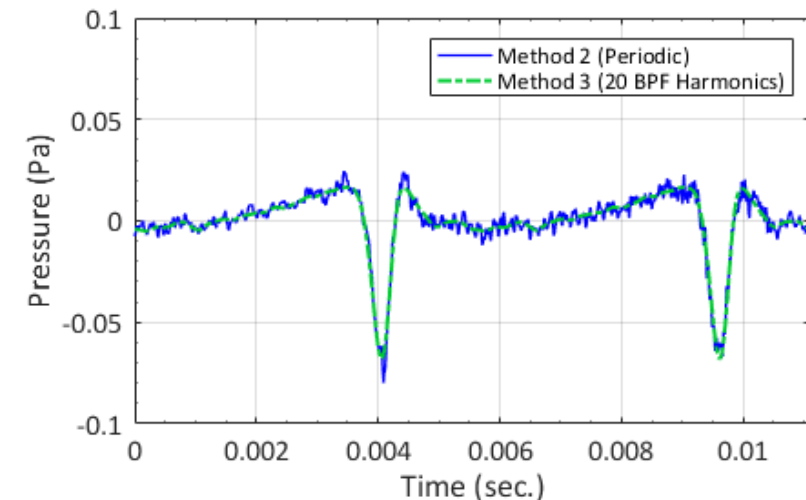
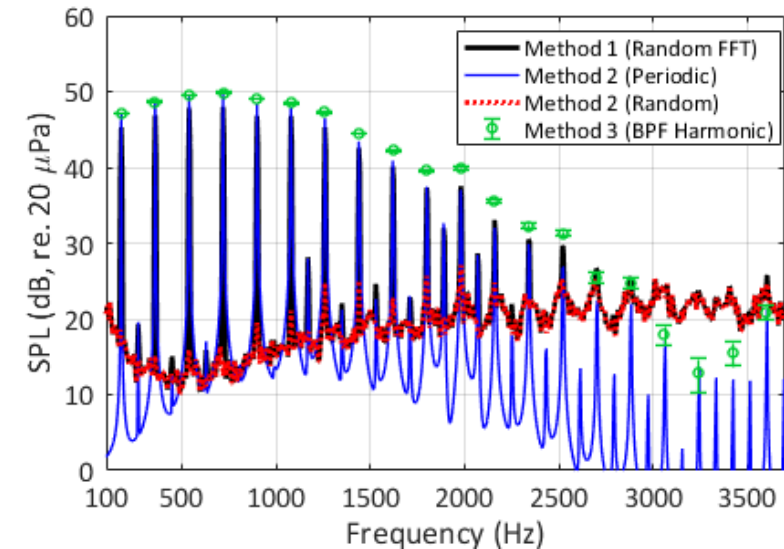


Backup Slides

A Storied Legacy, A Soaring Future

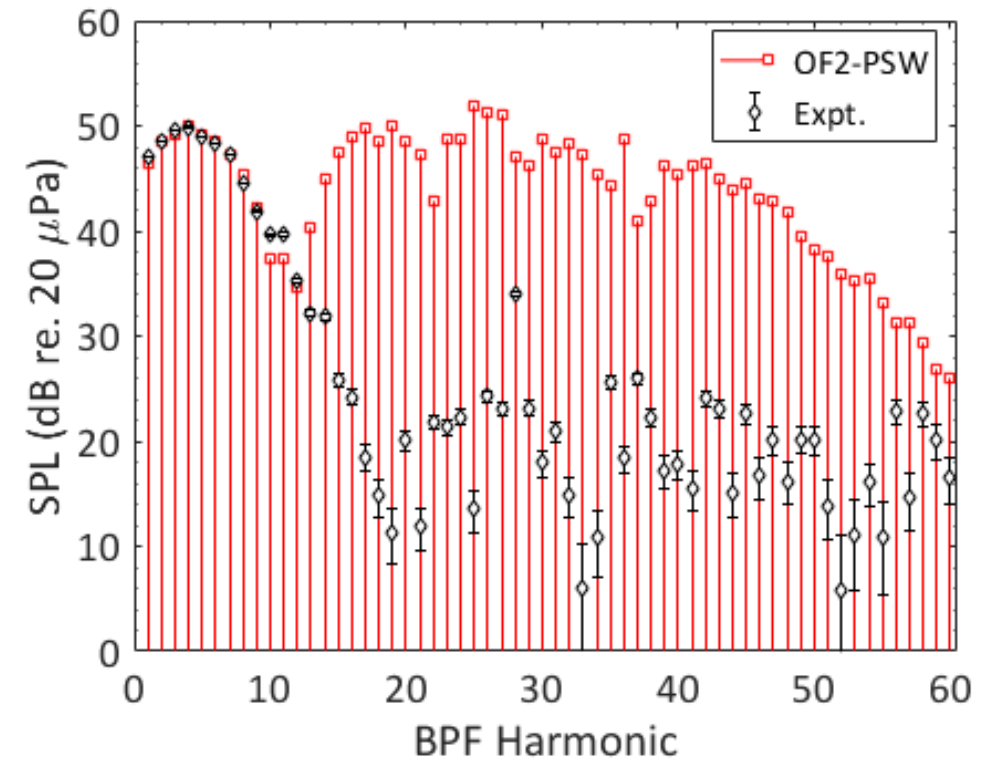
Post-Processing Techniques

- 3 techniques implemented
 - (1) Random FFT
 - (2) Block averaging (per rotor revolution)
 - (3) BPF harmonic filtering
- Method 2 excellent for extracting periodic and random noise components
- Method 3 suitable for comparisons between predictions and measurements



CFD High-Frequency Content

- OF2-PSW observed to over-predict higher frequency (harmonic) content
- Exact cause(s) unknown, currently being investigated
- Comparisons with measurements limited to first 10 BPF harmonics



Results

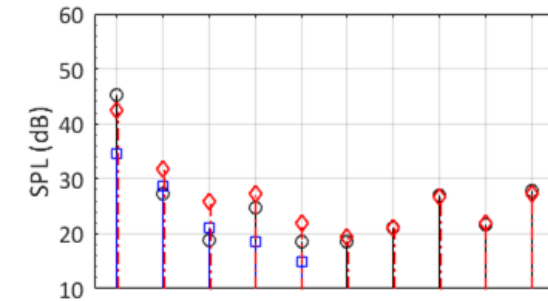
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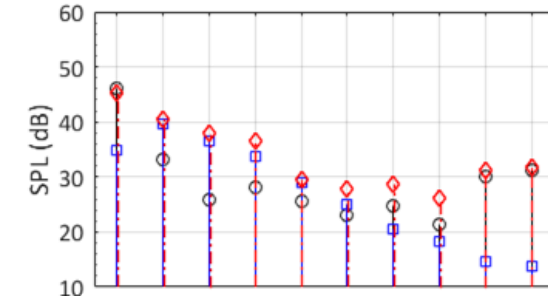
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$\Delta/R = -0.1$:

