



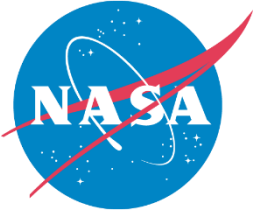
Challenges and Progress in Broadband Noise Prediction for Small Scale Rotors

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Aeroacoustics Branch, NASA Langley Research Center

NASA Acoustics Technical Working Group

October 17, 2018



Outline

- Background: sUAS and rotor noise sources
- SUI Endurance vehicle and experimental setup
- Current prediction tools
- Results and future work

Noise in sUAS

- Small unmanned aircraft system (sUAS) rotors differ greatly from those of conventional helicopter
 - 20-50 times smaller
 - Higher rotation speeds
 - Multiple rotor configurations means rotors may interact with each other aerodynamically
 - Fixed pitch (no collective/trim controls)
- Broadband noise may have comparable amplitudes to BPF harmonic amplitudes



Photo Credit : [Aaron Burden](#) on [Unsplash](#) .

Common Rotor Noise Sources

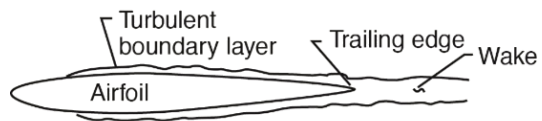
Periodic

- Thickness noise
- Loading noise
- Blade vortex interaction (BVI) noise

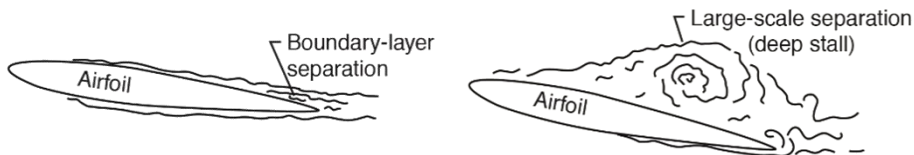
Nondeterministic/Broadband

- Turbulence Ingestion
- Blade-wake interaction (BWI) noise
- **Self-noise**

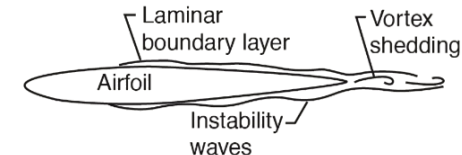
Turbulent boundary layer – trailing edge (TBL-TE) noise



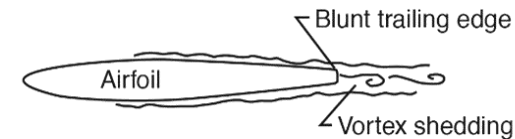
Separation/Stall noise



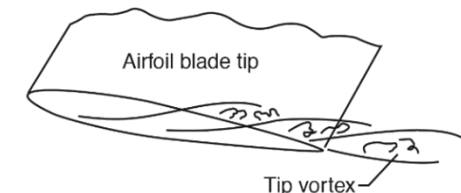
Laminar boundary layer – vortex shedding (LBL-VS) noise



Trailing edge bluntness – vortex shedding (B-VS) noise



Tip vortex formation noise



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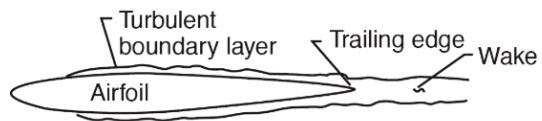
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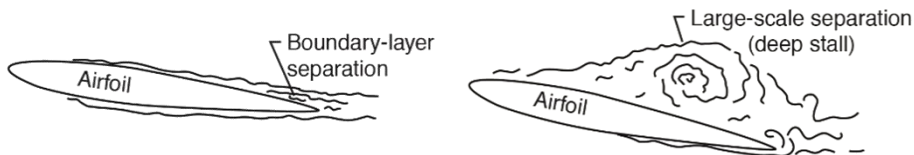
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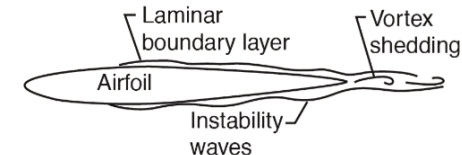
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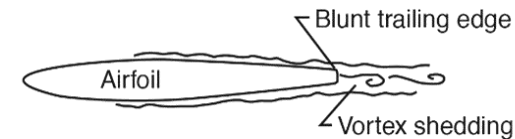
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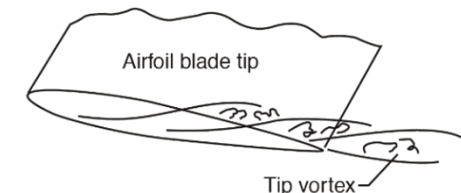
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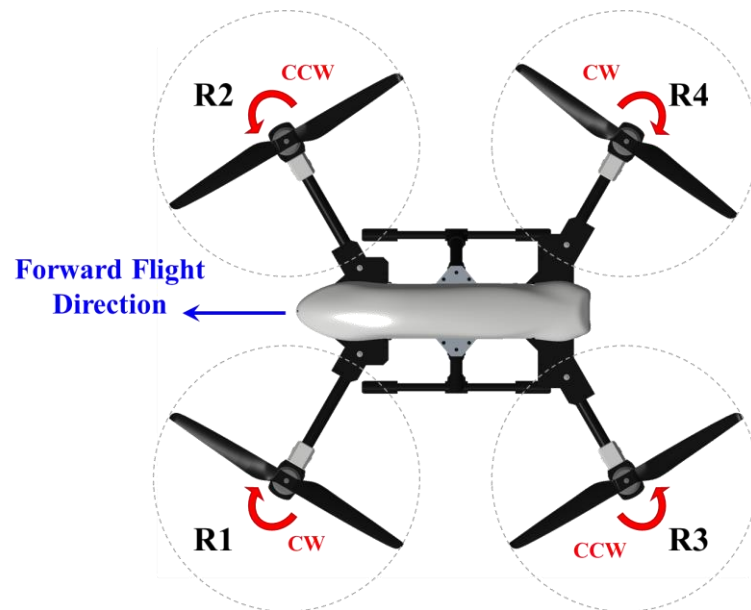
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LSAWT Experiments

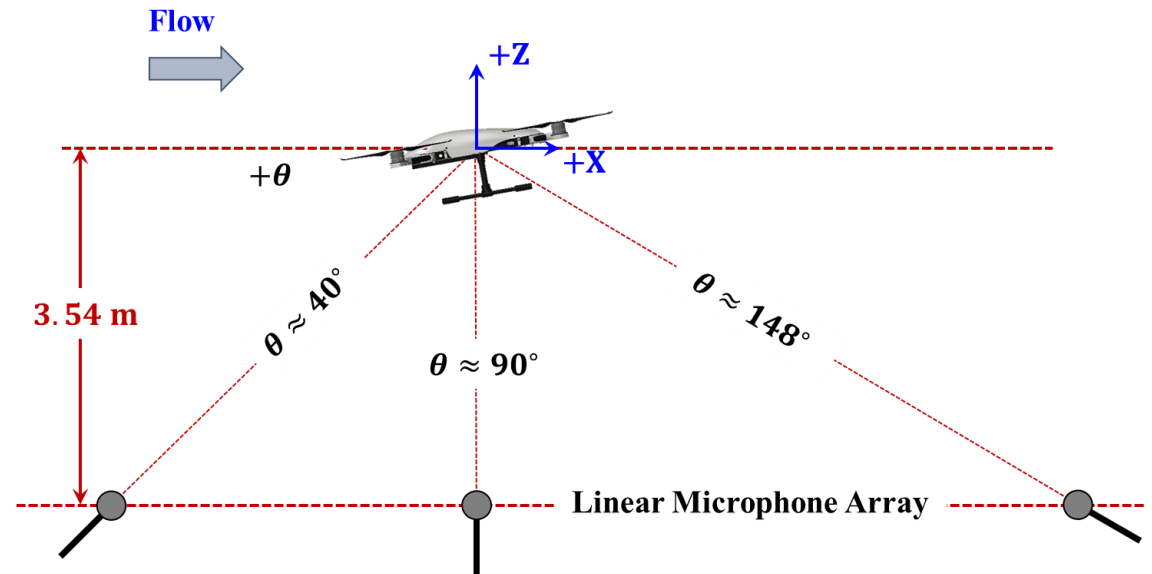
SUI Endurance Vehicle Characteristics

- Tip speeds of $0.2 < M < 0.3$
- Diameter of 0.38 m (15 in)
- Two-bladed rotors
- 0.51 m (20 in) distance away from each other



Flight Conditions

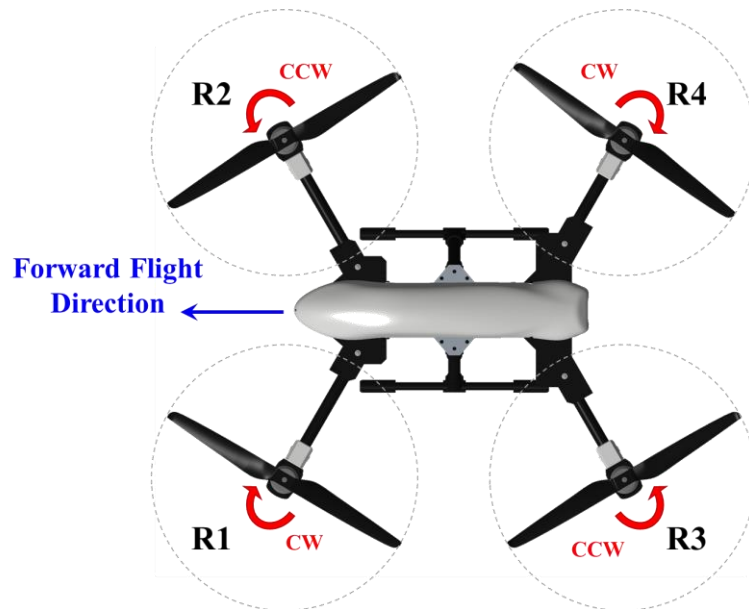
- Hover
- Forward flight at $M 0.045$
 - $\alpha = -10^\circ$
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LSAWT Experiments

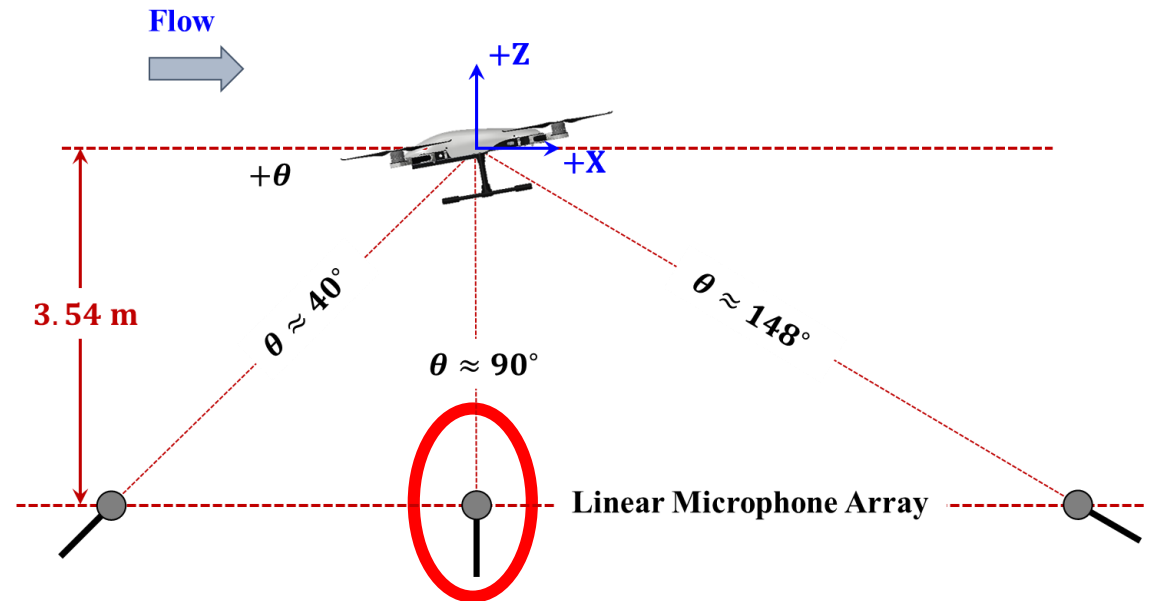
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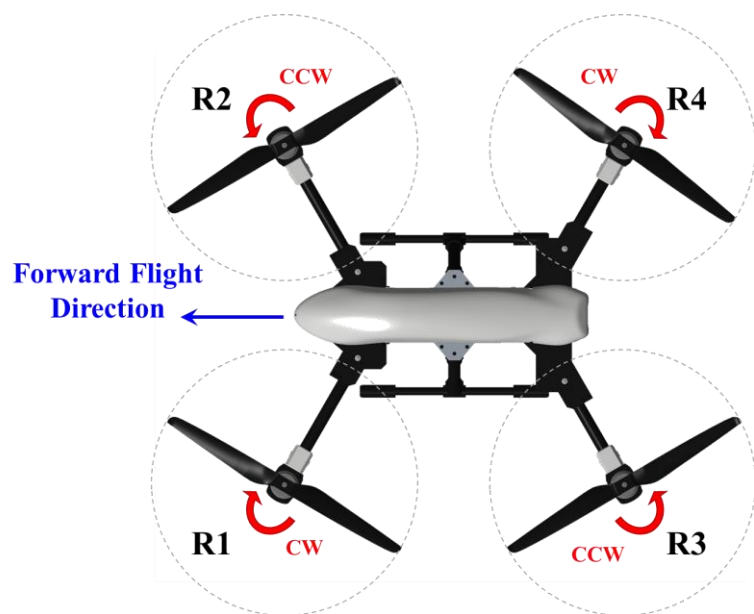
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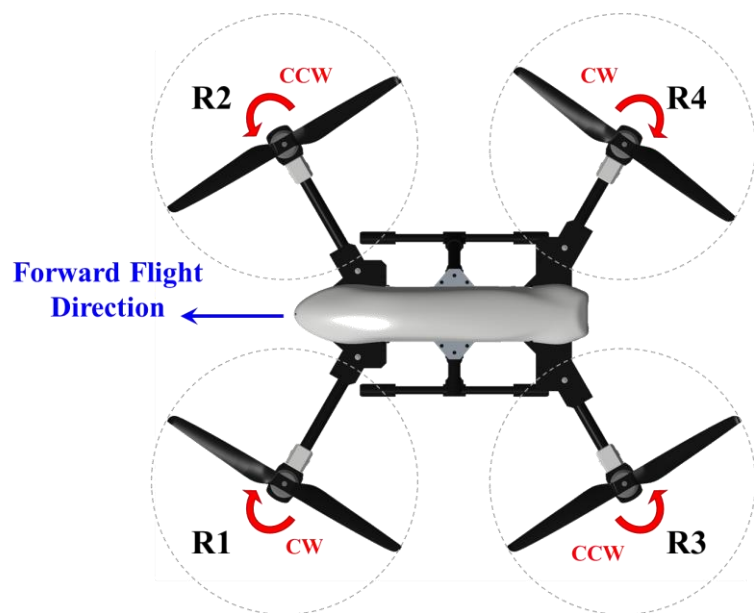
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Vehicle Thrust (N)	R1 Rotation Speed (RPM)	R2 Rotation Speed (RPM)	R3 Rotation Speed (RPM)	R4 Rotation Speed (RPM)
27	3130	3160	3830	3830
36	3610	3640	4430	4410
44	4050	3990	4900	4940

LSAWT Experiments

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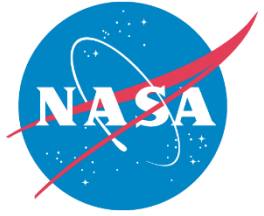
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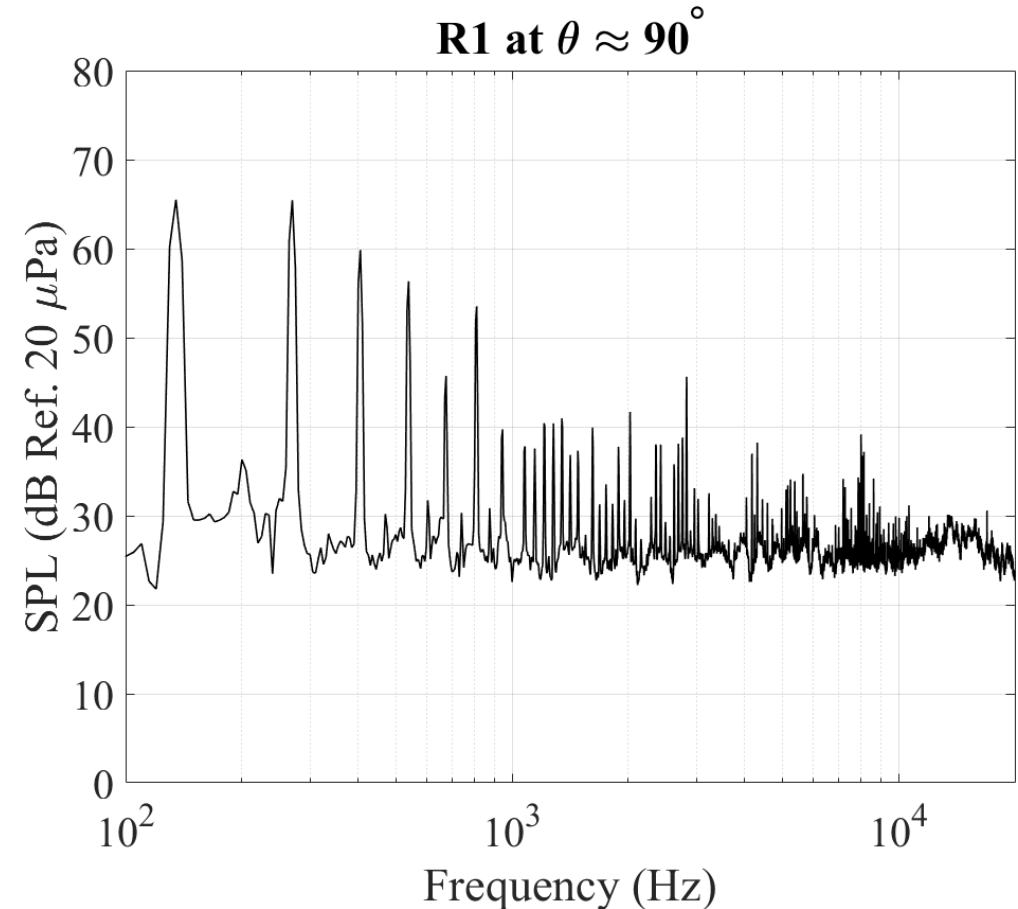
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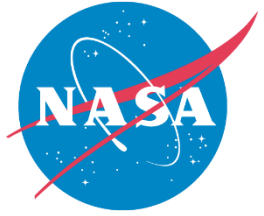
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Experimental Data Processing

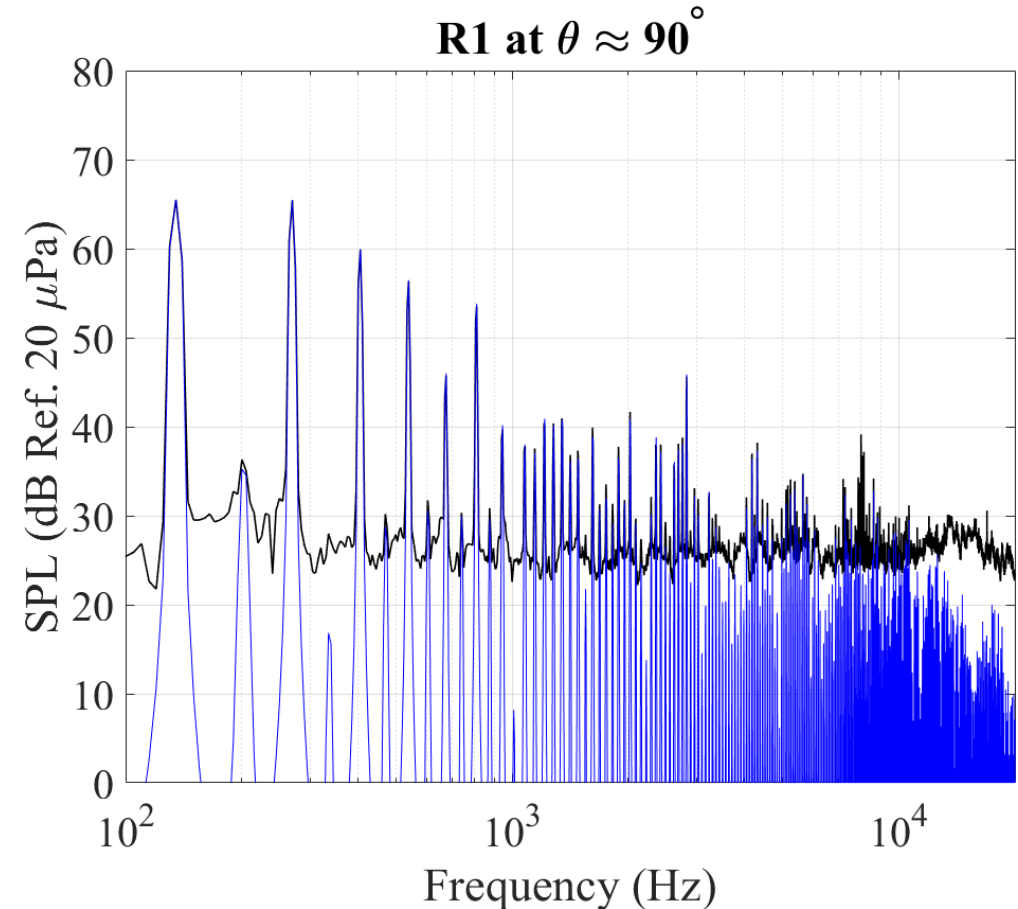
- Data treated as random data sets and narrowband acoustic spectra computed using Fast Fourier Transform
- Extract nonperiodic, broadband noise from microphone signals
 - Compute mean rotor revolution time history
 - Subtract from time record to retain random noise components
- Can compare these spectra to broadband noise predictions

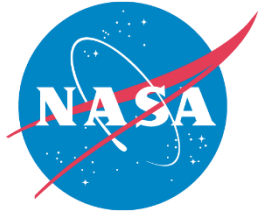




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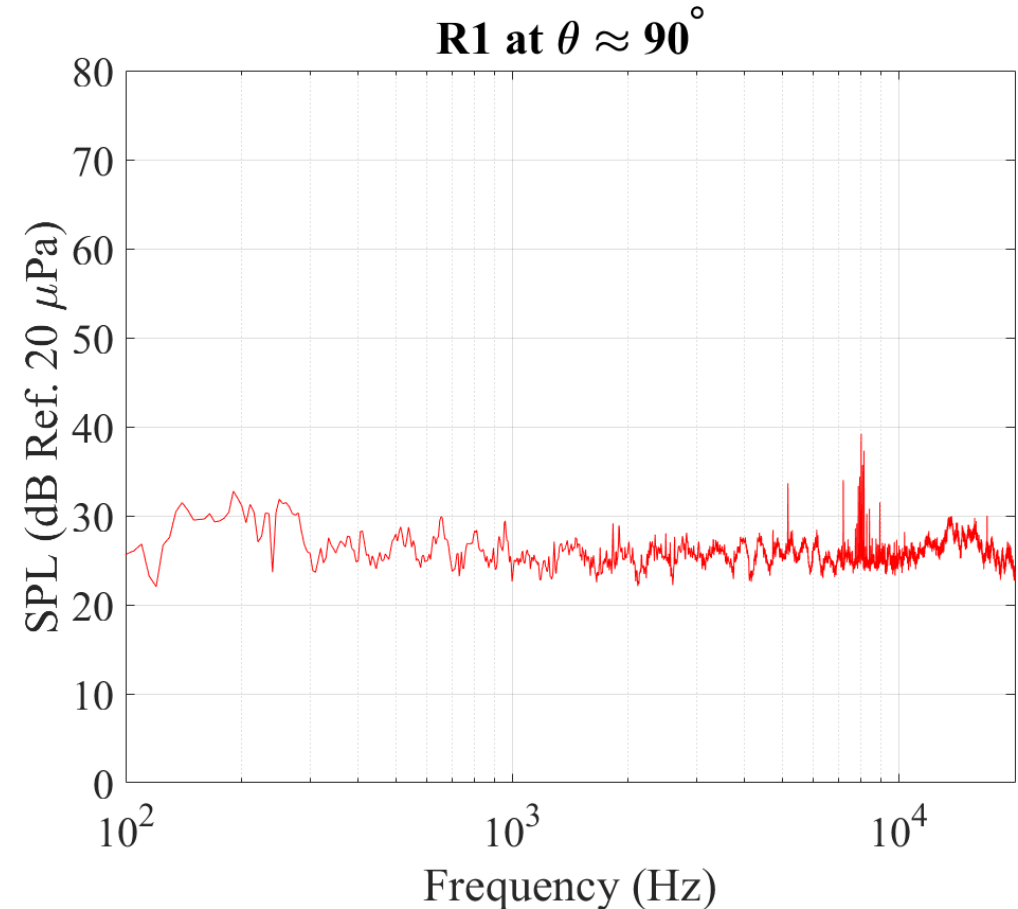
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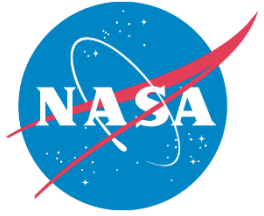




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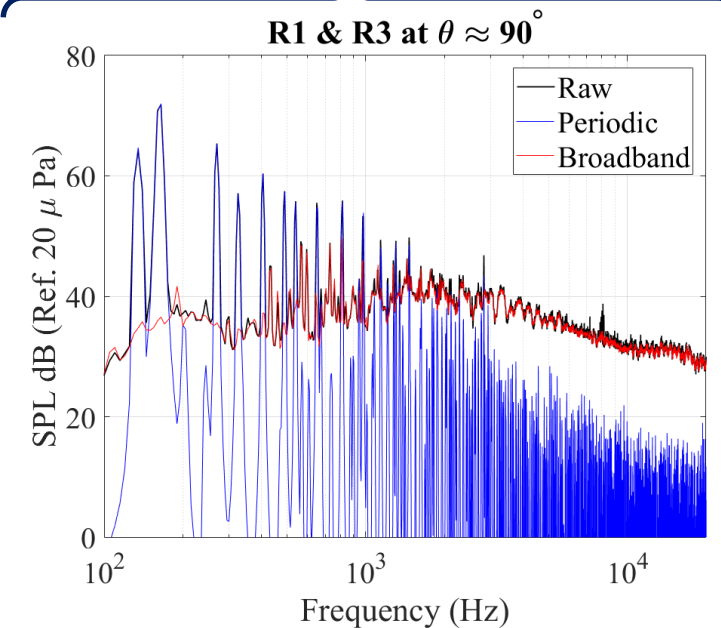
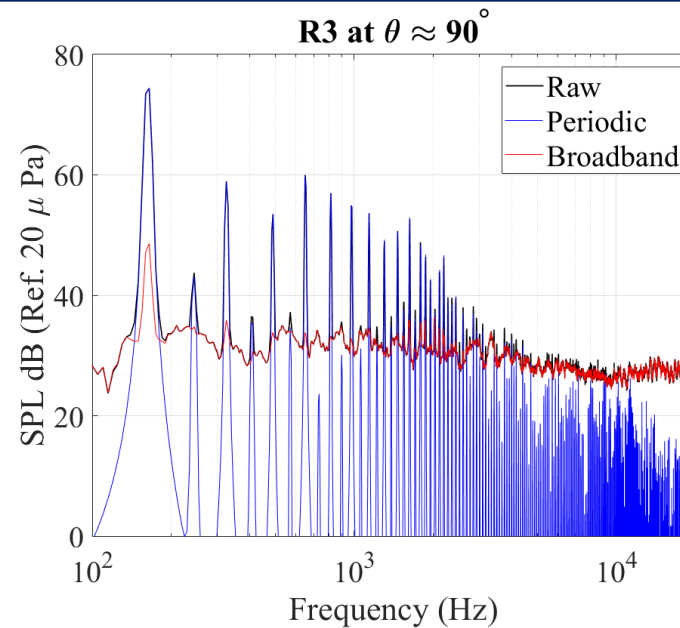
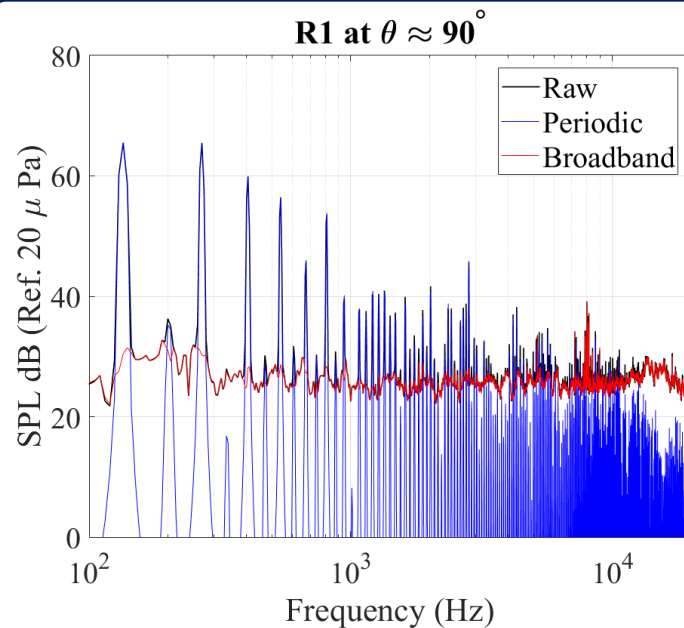


Front/Aft Pair Cases

- Periodic extraction implemented separately for rotor pair
- Resulting in total random noise contribution for simultaneous pair

Individual

Front/Aft Pair

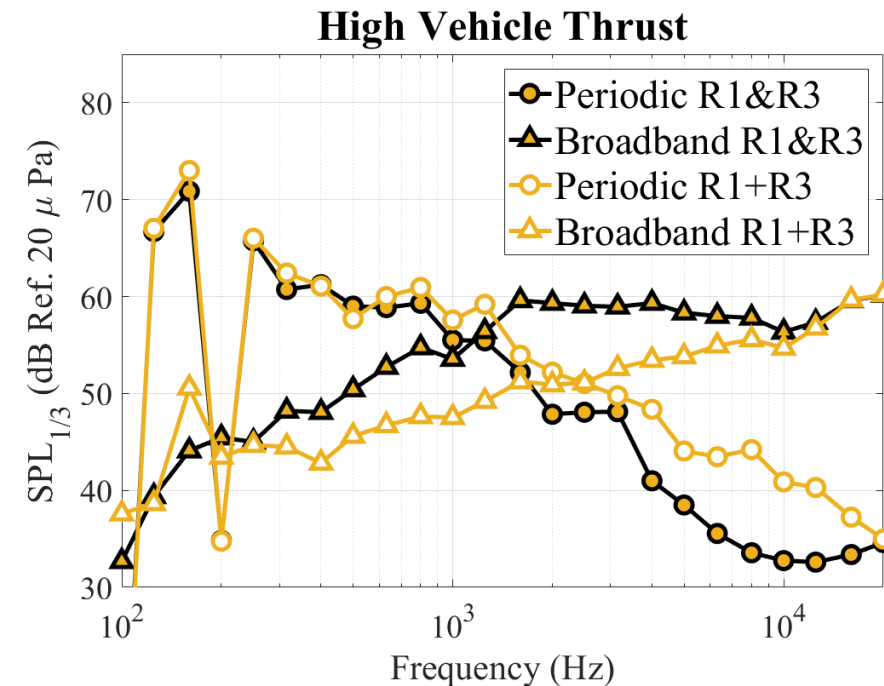
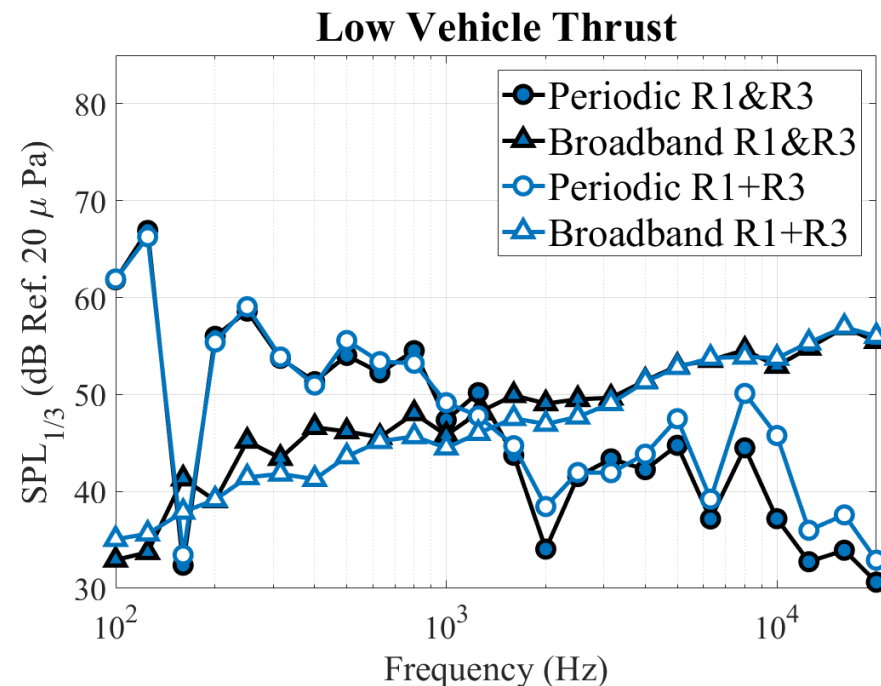


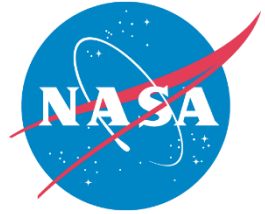


Simultaneous vs. Superimposed

- Comparison
 - One simultaneous pair case (&)
 - Two individual cases superimposed (+)
- Additional broadband noise for R1 & R3 vs. R1 + R3 at high thrust setting

Condition	Vehicle Thrust (N)
Low Thrust	27
Mid Thrust	36
High Thrust	44

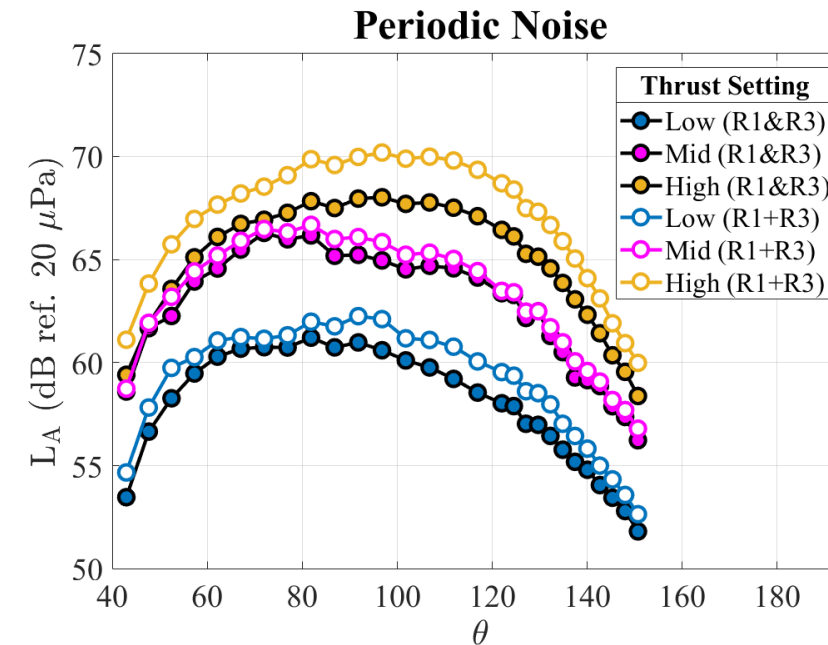
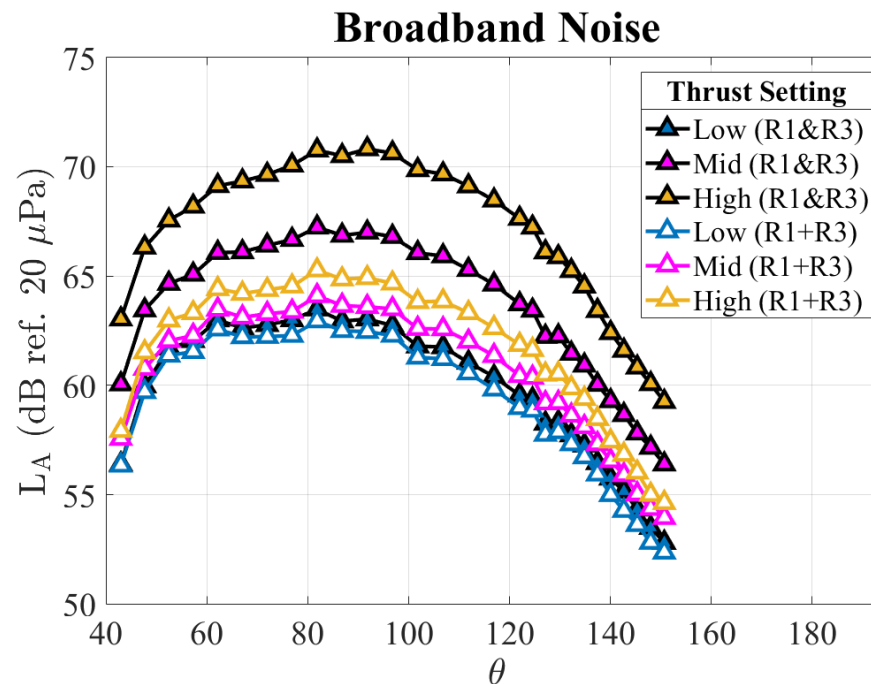


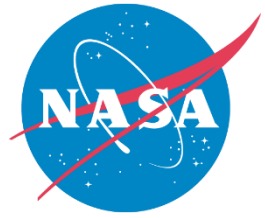


Simultaneous vs. Superimposed

- Comparison
 - One simultaneous pair case (&)
 - Two individual cases superimposed (+)
- L_A plots show this effect same at all observer angles

Condition	Vehicle Thrust (N)
Low Thrust	27
Mid Thrust	36
High Thrust	44





Prediction Tools

ROTONET

- Rotorcraft Noise Prediction System^[1]
- Subsystem of NASA Aircraft Noise Prediction Program (ANOPP)
- Multiple modules, including
 - Improved blade aerodynamics (IBA)
 - Improved blade boundary layer (IBL)
- Trims collective and cyclic pitch
- **Calculates local inflow conditions**

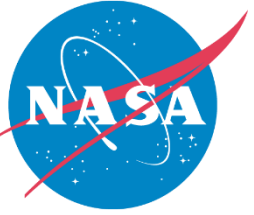
BARC

- Broadband Acoustic Rotor Codes^[2]
- Semi-empirical, blade element method
- NACA 0012 empirical BL-data
- Uses inflow conditions and airfoil geometry as inputs
- **Predicts broadband noise due to self-noise sources and incorporates into a rotational reference frame**

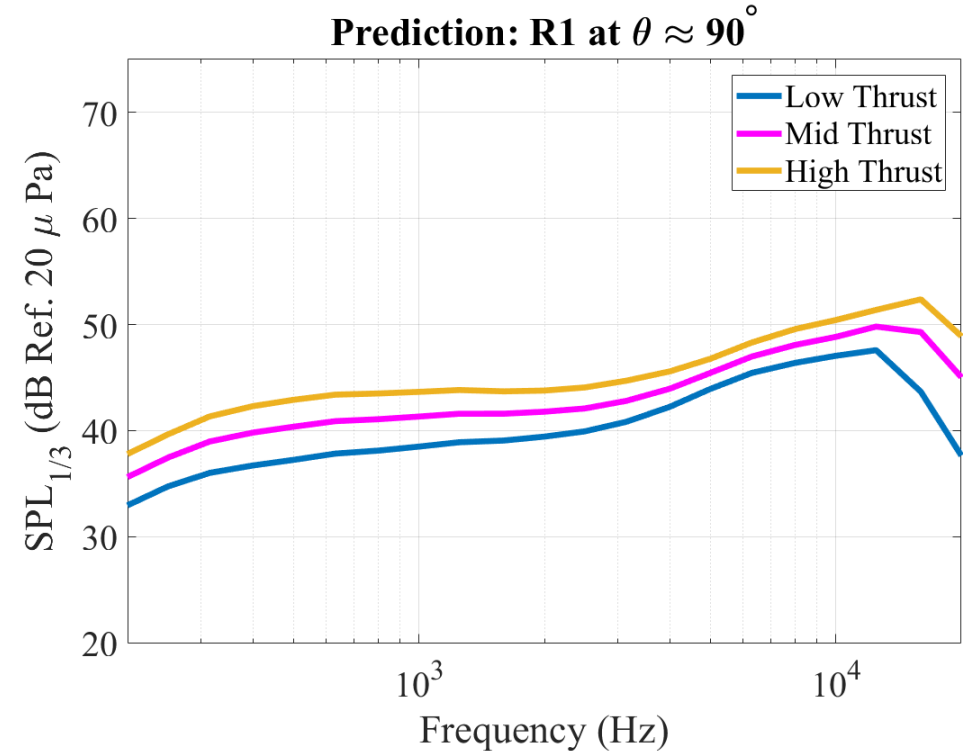
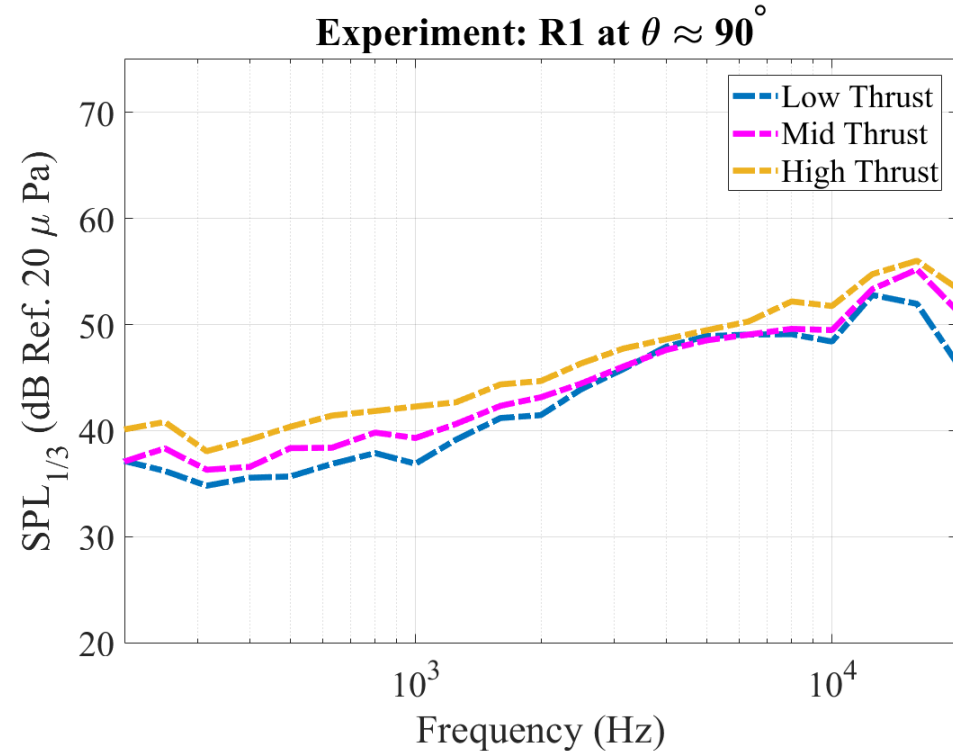
Use ROTONET and BARC together to predict broadband noise due to self-noise mechanisms

[1] Weir, S. D., Jumper, J. S., Burley, C. L., and Golub, A. R., "Aircraft Noise Prediction Program Theoretical Manual: Rotorcraft System Noise Prediction System (ROTONET), Part 4," NASA TM 83199, April 1995.

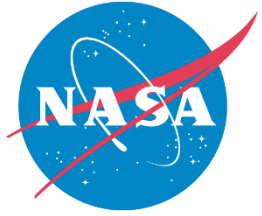
[2] Burley, C. L. and Brooks, T. F., "Rotor Broadband Noise Prediction with Comparison to Model Data," Journal of the American Helicopter Society, Vol. 49, (1), January 2004, pp. 28–42.



LSAWT vs. BARC prediction



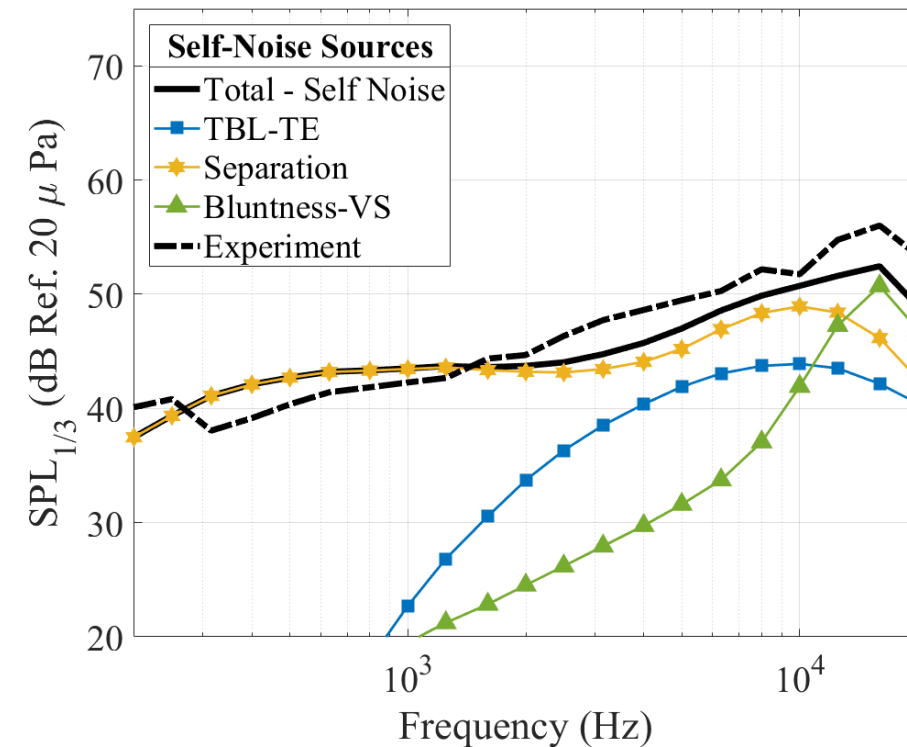
Condition	Vehicle Thrust (N)	R1 Thrust (N)	R1 Rotation Speed (RPM)
Low Thrust	27	7	3130
Mid Thrust	36	9	3610
High Thrust	44	11	4050



Self-Noise Prediction

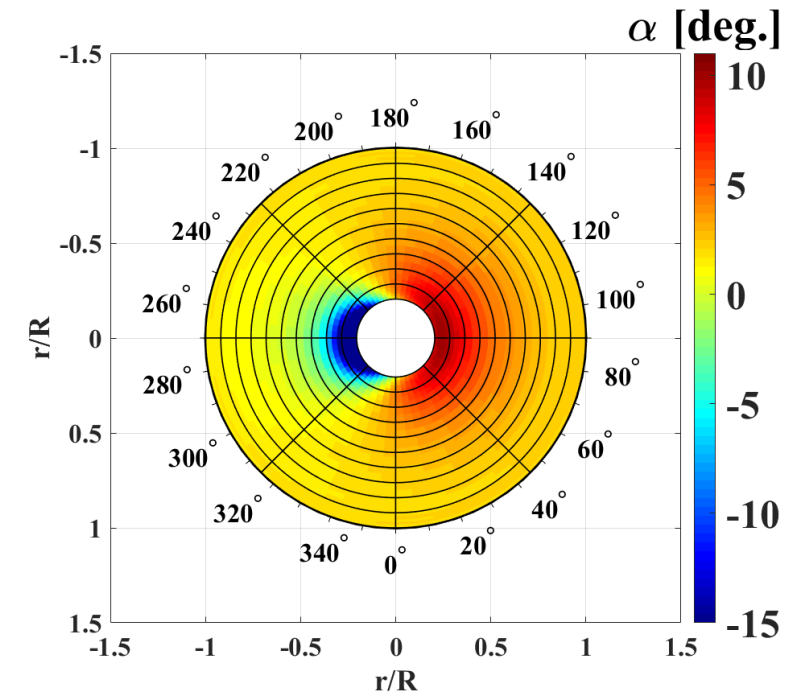
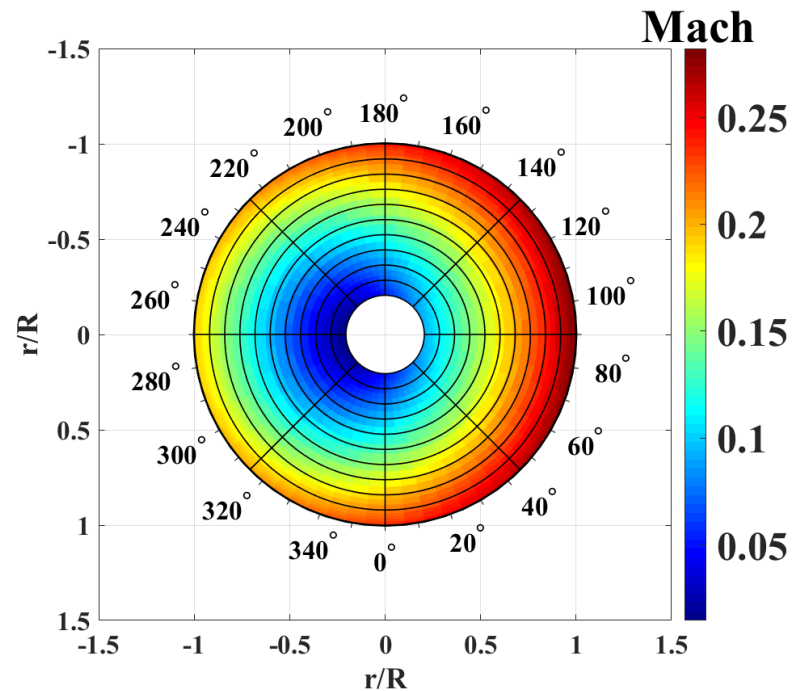
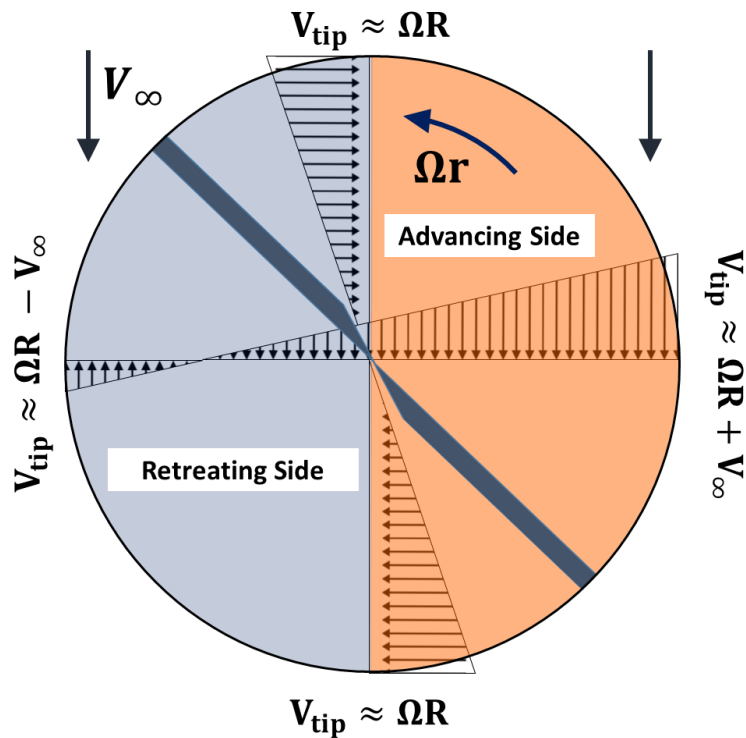
R1 at $\theta \approx 90^\circ$

- Prediction trends well with experiment, under predicting > 1.6 kHz and over predicting < 1.6 kHz
- Separation noise dominates at most frequencies
- Trailing Edge noise (TBL-TE) contributes at mid to high frequency range
- Bluntness – VS noise starts to dominate at 14 kHz
- Both prediction and experiment peak at 16 kHz, with ≈ 3 dB difference



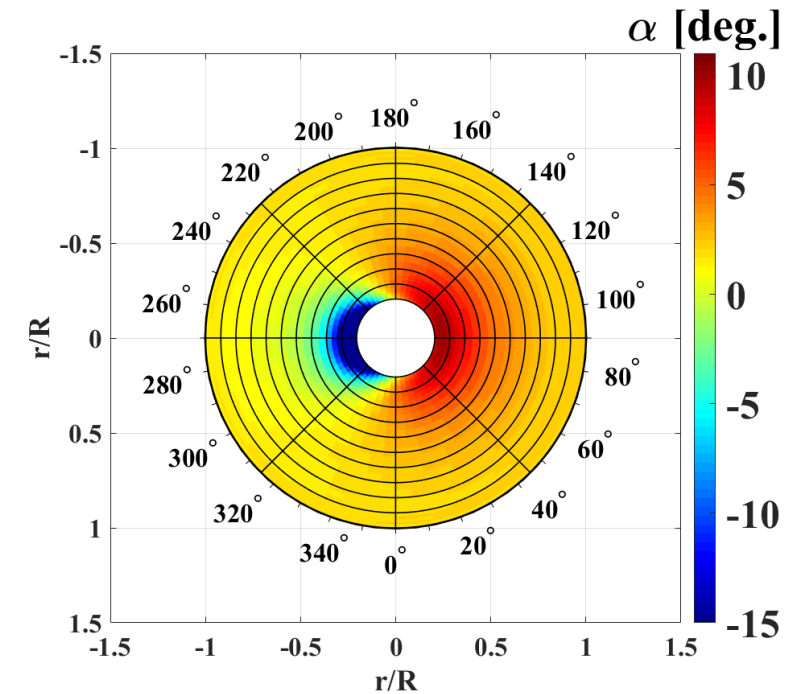
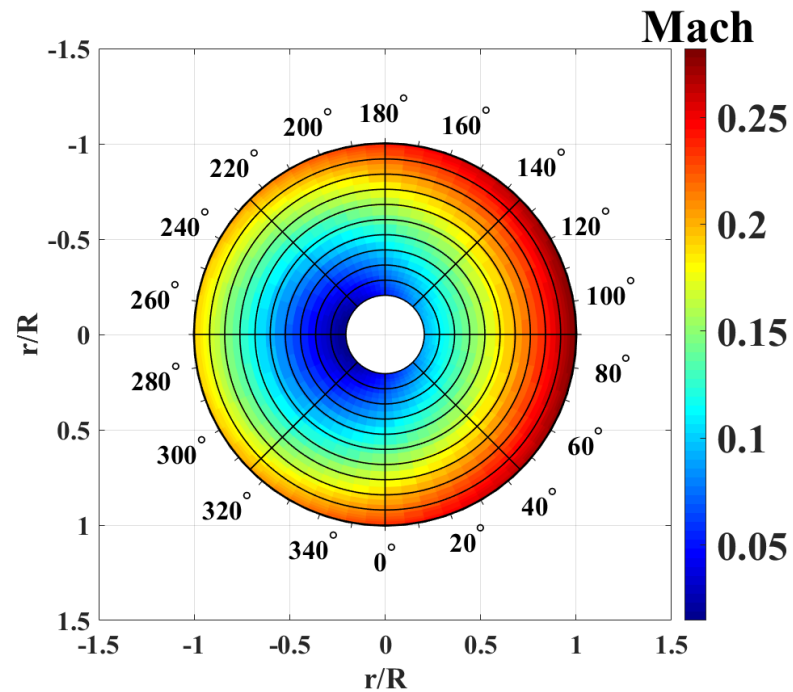
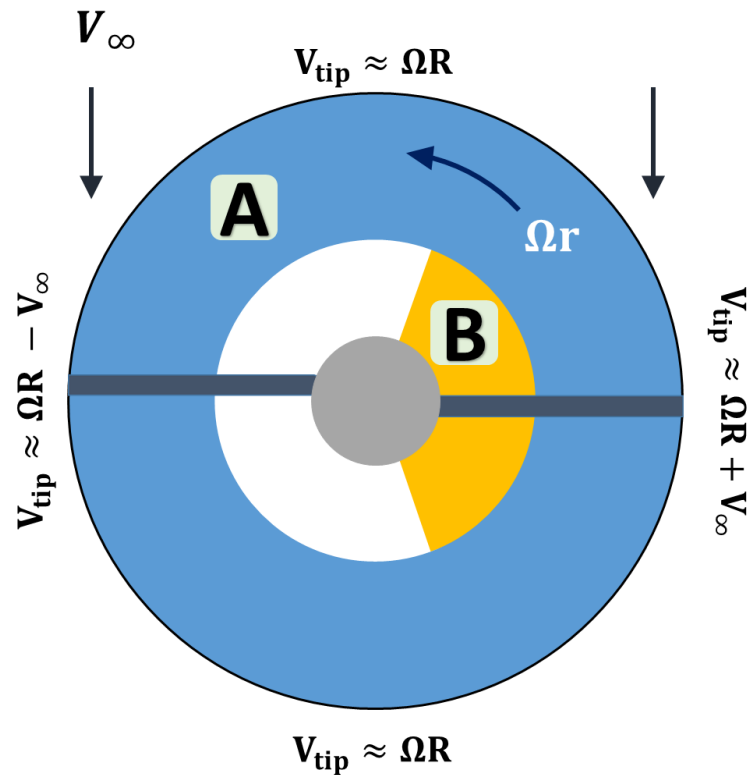
Forward Flight

- Reverse flow/low flow regions develop on retreating side
- Inflow conditions vary at different element locations
- ROTONET captures this

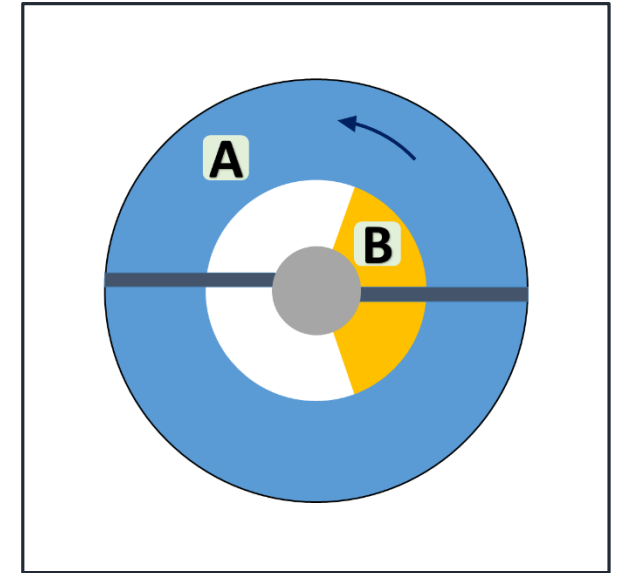
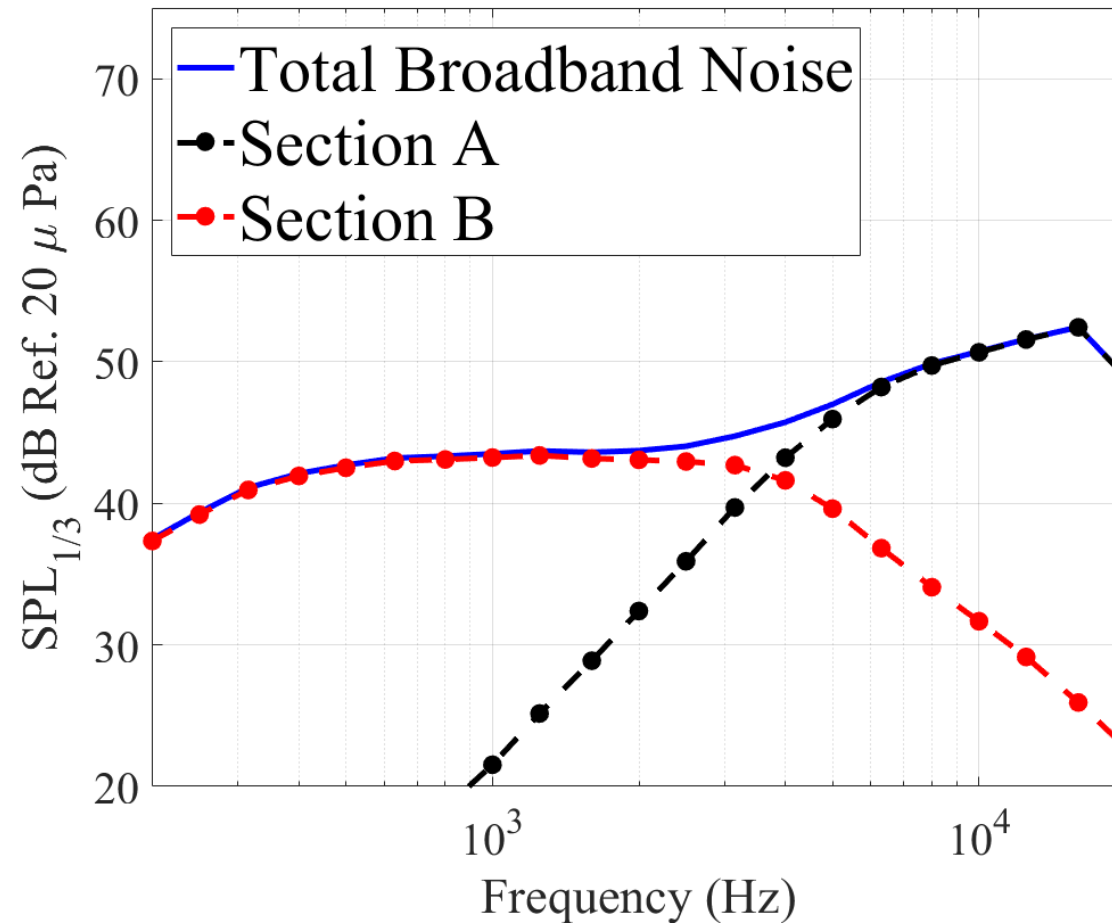


Forward Flight

Split up blade elements into rotor revolution sections



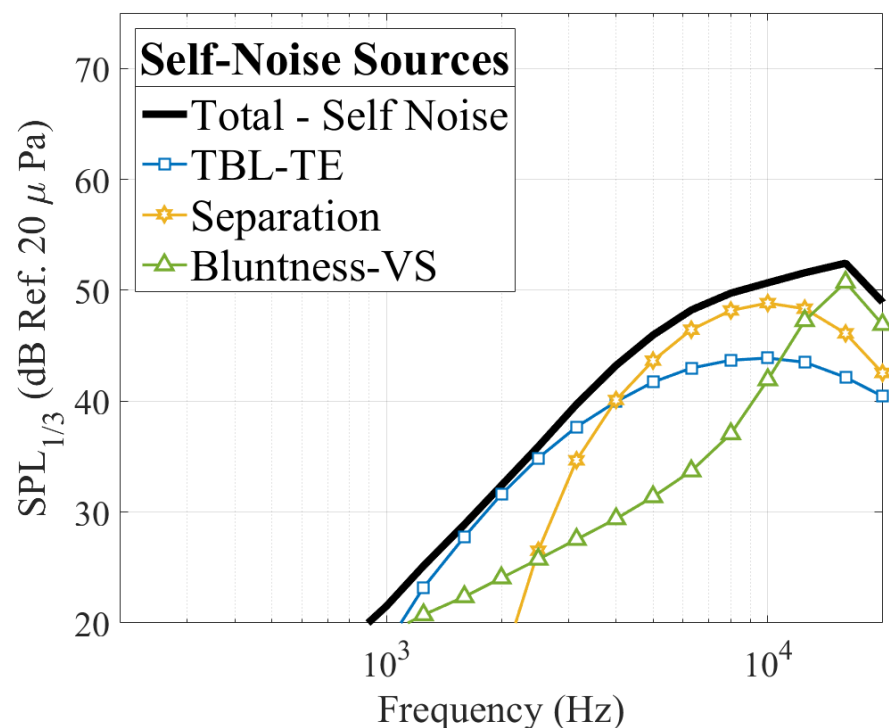
Rotor 1 BARC Prediction



BARC Predictions

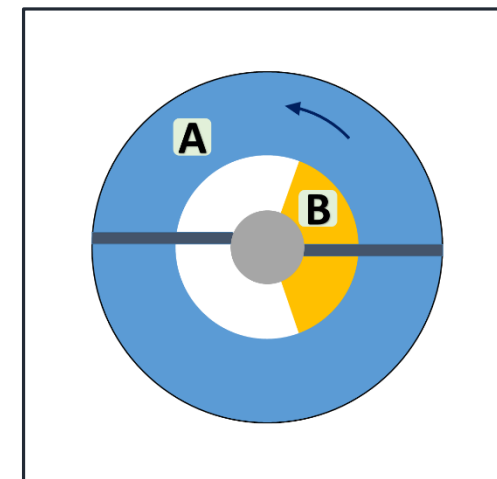
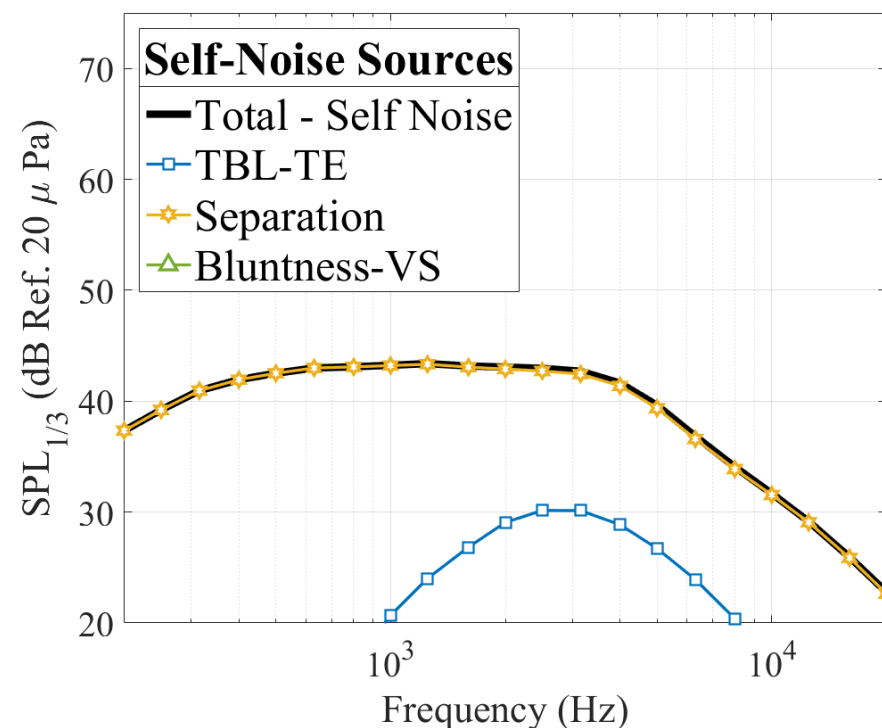
• Portion A

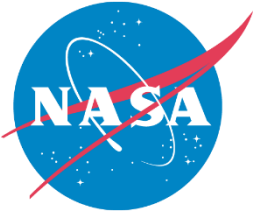
- Higher local Mach
- Bluntness-VS noise



• Portion B

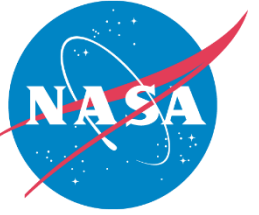
- Highest local AOA
- Separation noise





Future Work

- Predictions for additional flight conditions
- Modify parameters in ROTONET to improve inflow conditions for BARC
- Experimentally, SUI Endurance data for isolated rotor (with no airframe)
- Computationally, CFD predictions for isolated rotor



Acknowledgments

- Funding for this work provided by the following projects: NASA Design Environment for Novel Vertical Lift Vehicles (DELIVER) and Revolutionary Vertical Lift Technology (RVLT)
- Special thanks to LSAWT crew: John Swartzbaugh, Stan Mason, Jeff Collins, Bryan Lamb

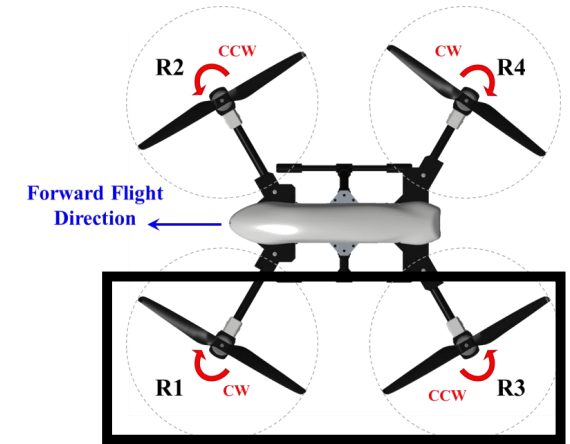
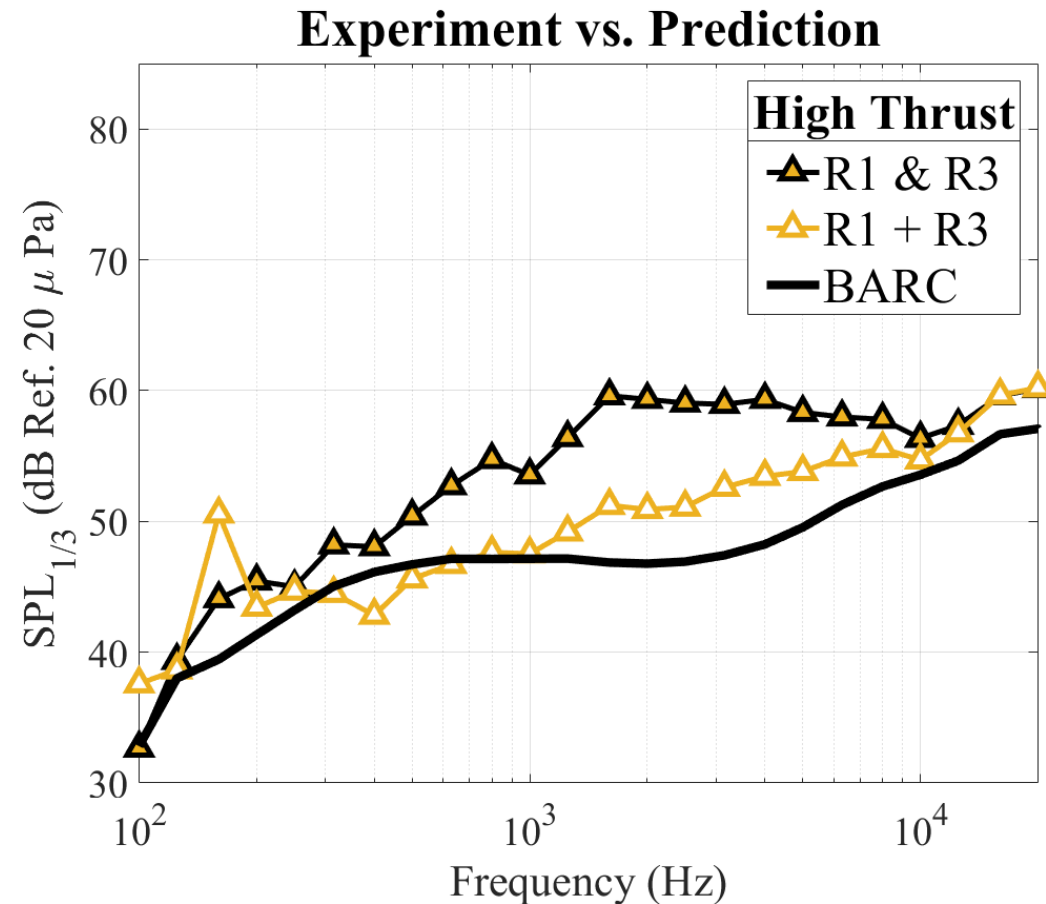
Thank you



Extra Slides



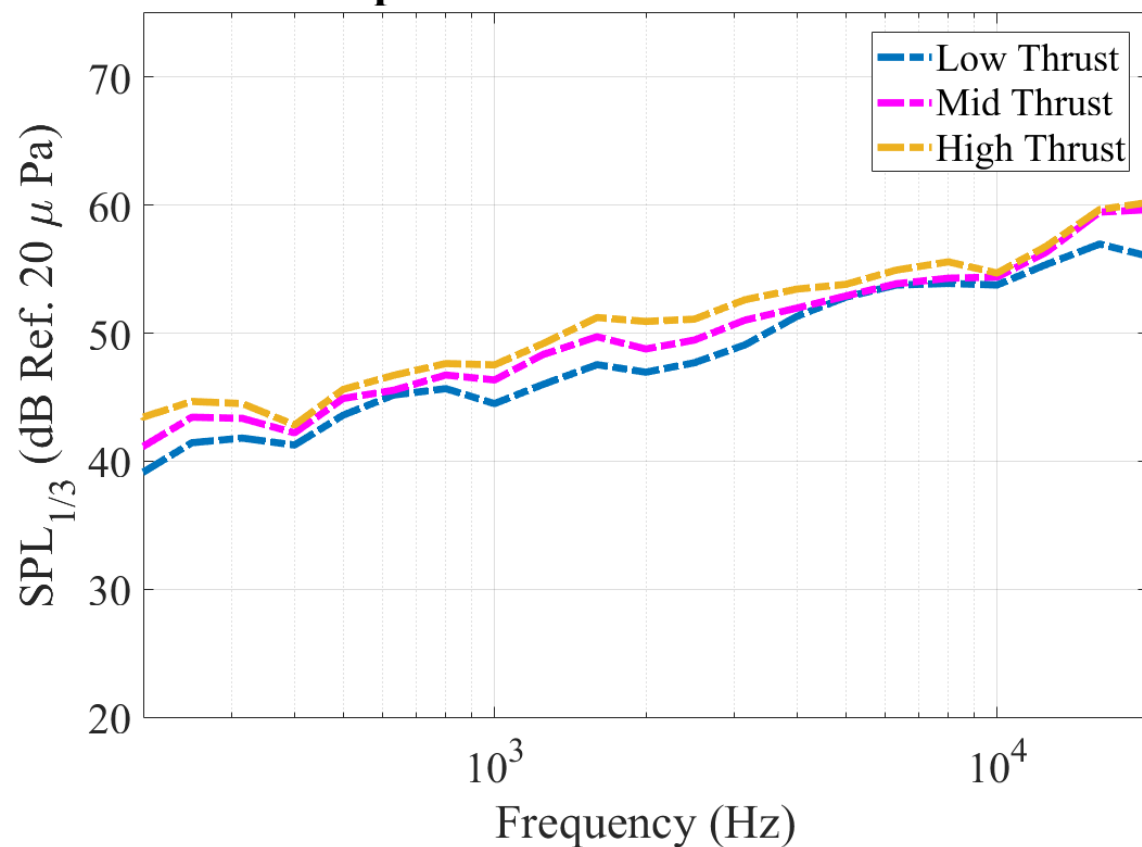
Front Aft Rotor Pair: R1 and R3





Front Aft Rotor Pair: R1 and R3

Experiment: R1 + R3 at $\theta \approx 90^\circ$



Prediction: R1 + R3 at $\theta \approx 90^\circ$

