Ideally Twisted Rotor Testing and Predictions

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Presentation Overview

A series of experiments were conducted in an anechoic hover chamber to investigate the noise and performance of an ideally twisted rotor design. The results of this test were compared with those of noise prediction tools.

- Introduction
- Blade Design
- Experiment
- Noise Prediction Comparison
- Final thoughts

Introduction

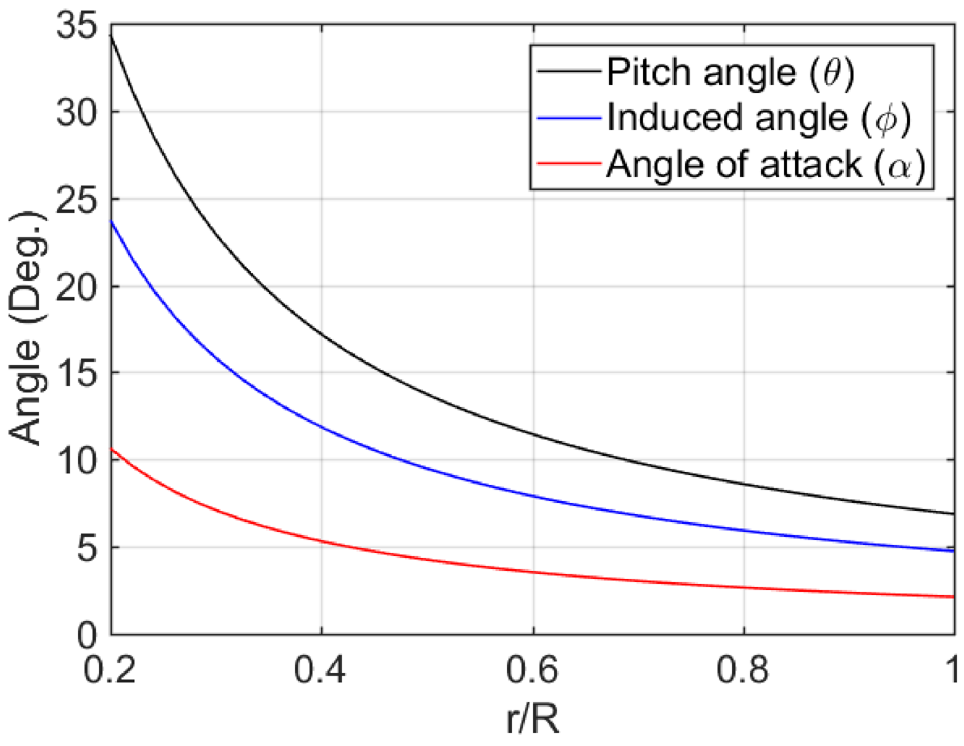
- Hover chamber tests of small rotors are beneficial in ***assessing the noise impact*** of small unmanned aerial vehicles (sUAS)

- With commercial off the shelf (COTS) rotors, it is not always possible to know the **exact geometric properties** or the ***complexity of the inflow***

- A rotor with an ideal twist distribution ***theoretically*** has ***uniform inflow,*** which may be simpler to predict using low fidelity tools

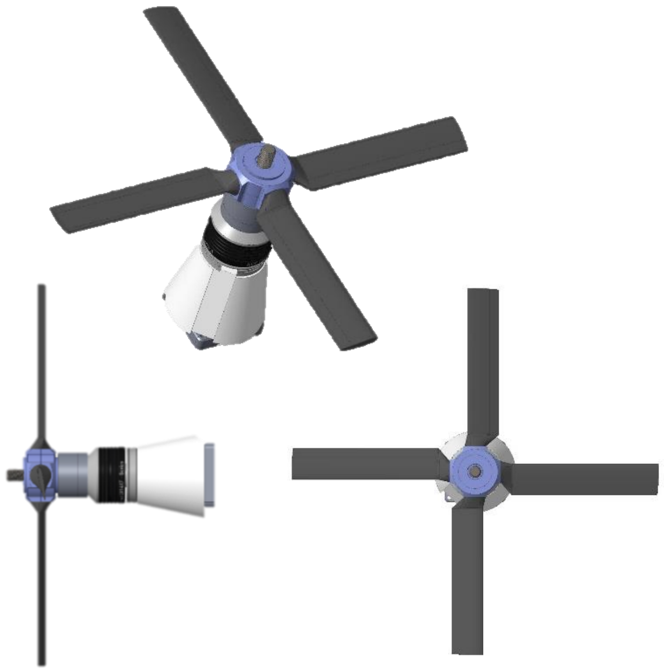
Ideally Twisted Rotor

- Target thrust = 11.12 N
- Blade Design
  - 5500 RPM
  - 4 blades
  - Blade radius $R = 0.1588\,m\ (6.25\ in.)$
- Thrust coefficient $C_T = 0.0137$
- Tip Mach number $M_{tip} = 0.27$
- Tip angles
  - Pitch $\theta = 6.9°$
  - Induced $\phi = 4.7°$
  - Angle of attack $\alpha = 2.1°$

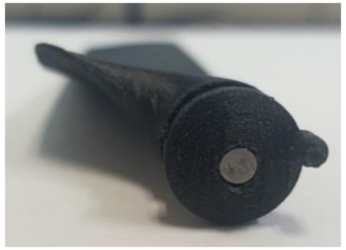


Ideally Twisted Rotor

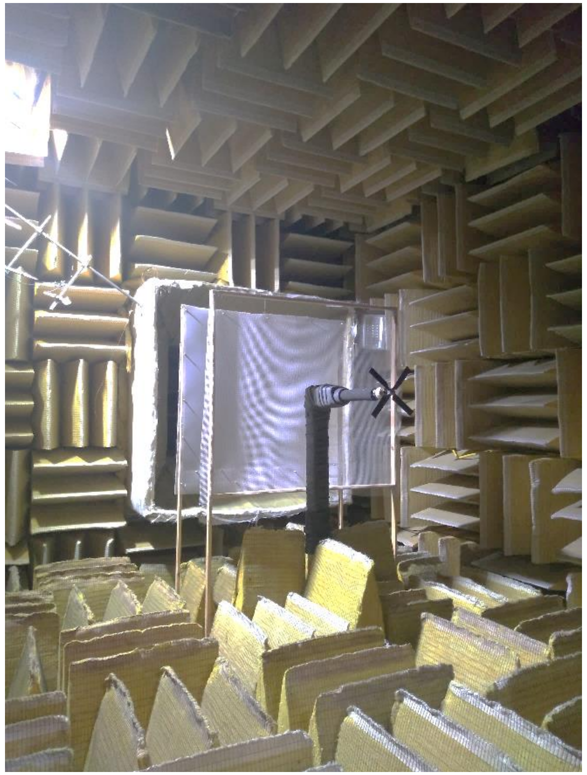
Blade Design



Additive Manufacturing



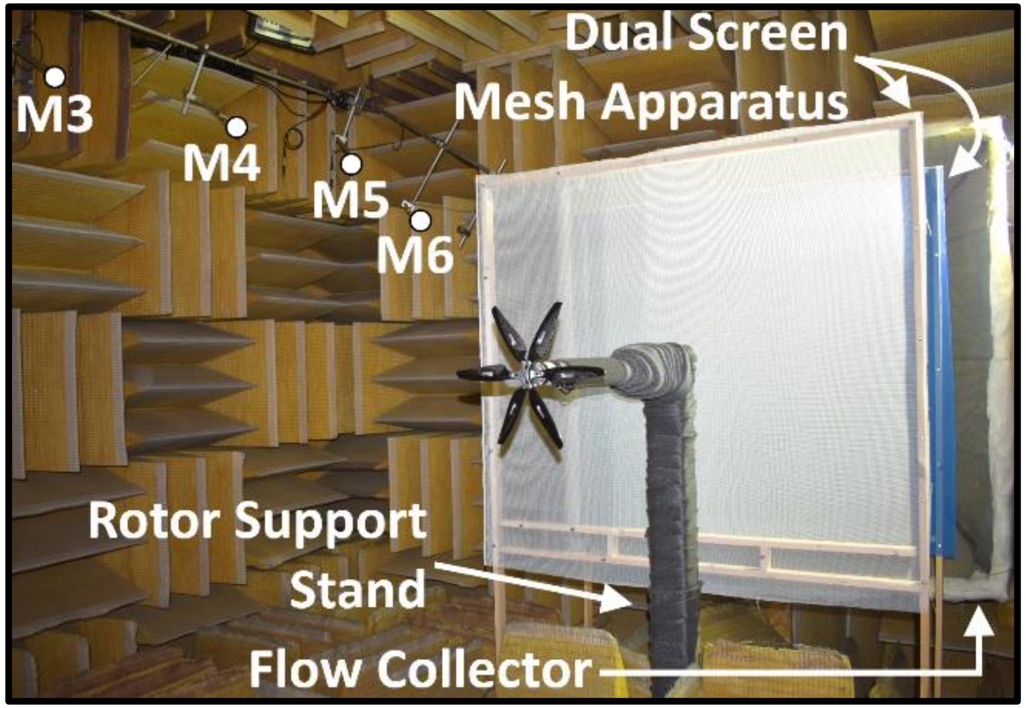
Testing

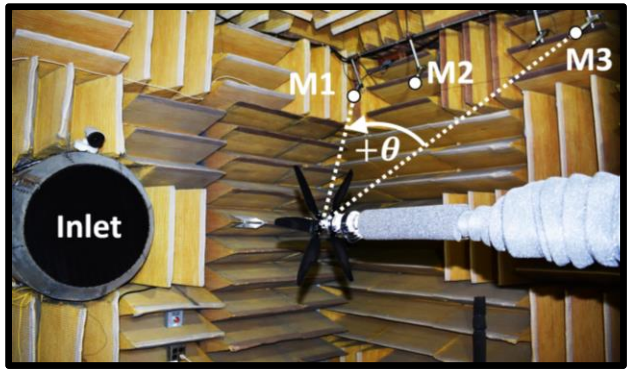


Experiment: Facility and Setup

Small Hover Anechoic Chamber (SHAC)*

- Room dimensions = [3.87 x 2.56 x 3.26] m
- Acoustically treated (cutoff down to 250 Hz)
- DAS: Brüel & Kjær (BK) LAN-XI DAQ and BK Connect Software
    - 6 B&K Type 4939 Free-Field microphones
    - Laser sensor tachometer
    - 6-Component AI-IA mini40 multiaxis load cell
- Scorpion Motor

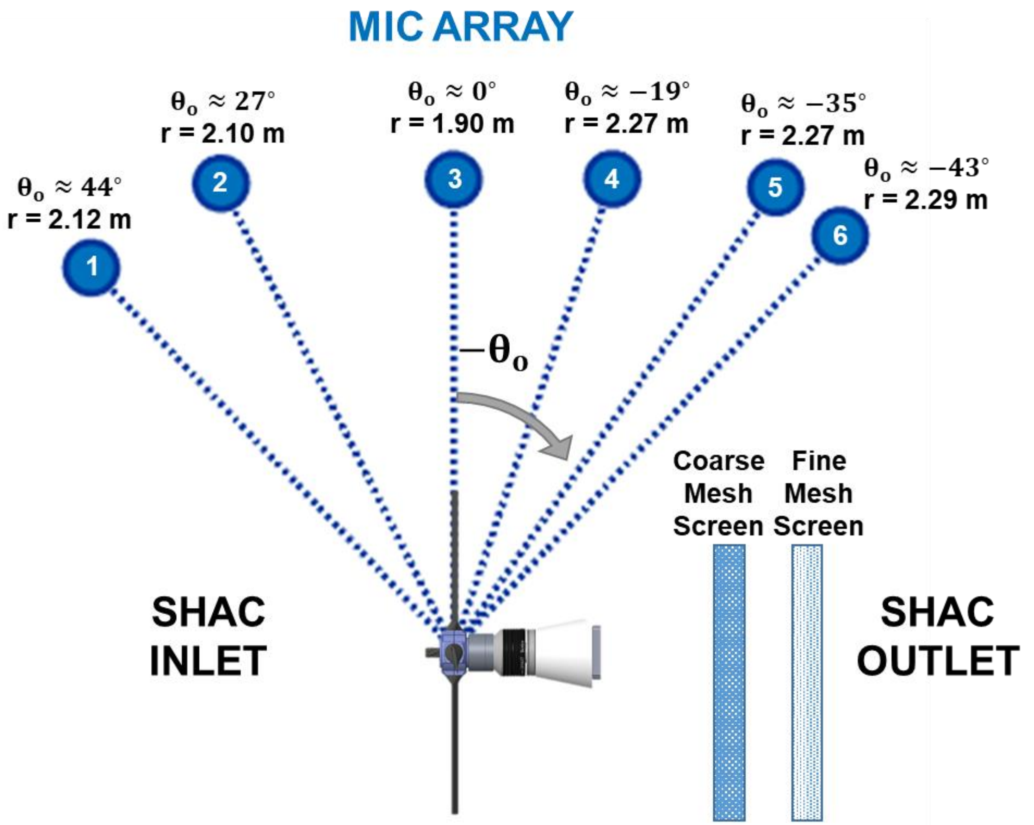


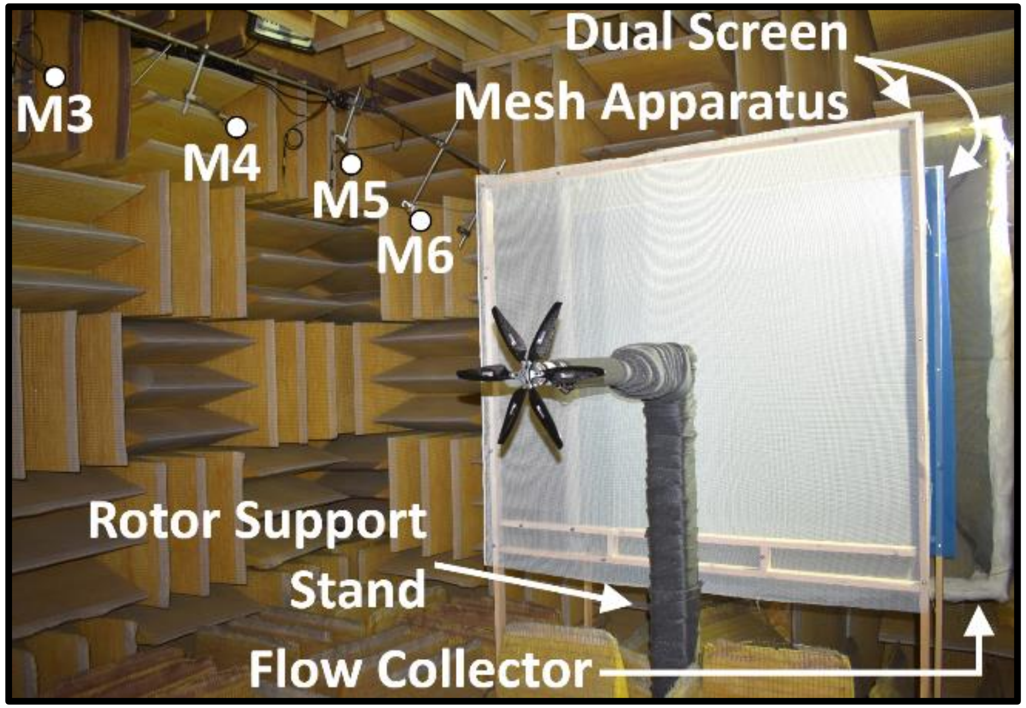


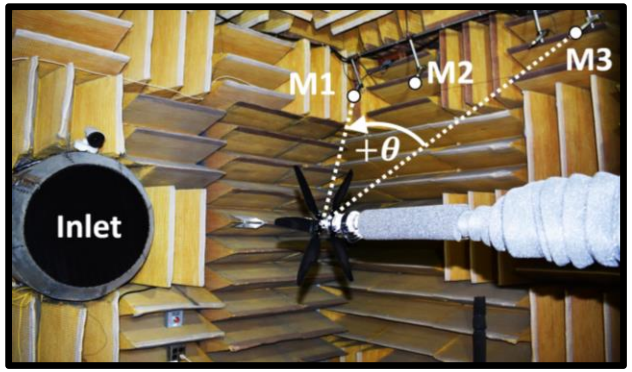
** Whiteside, S. K. S., Zawodny, N. S., Fei, X., Pettingill, N. A., Patterson, M. D., Rothhaar, P. M., "An Exploration of the Performance and Acoustic Characteristics of UAV-Scale Stacked Rotor Configurations", AIAA SciTech 2019, https://doi.org/10.2514/6.2019-1071*

Experiment: Facility and Setup

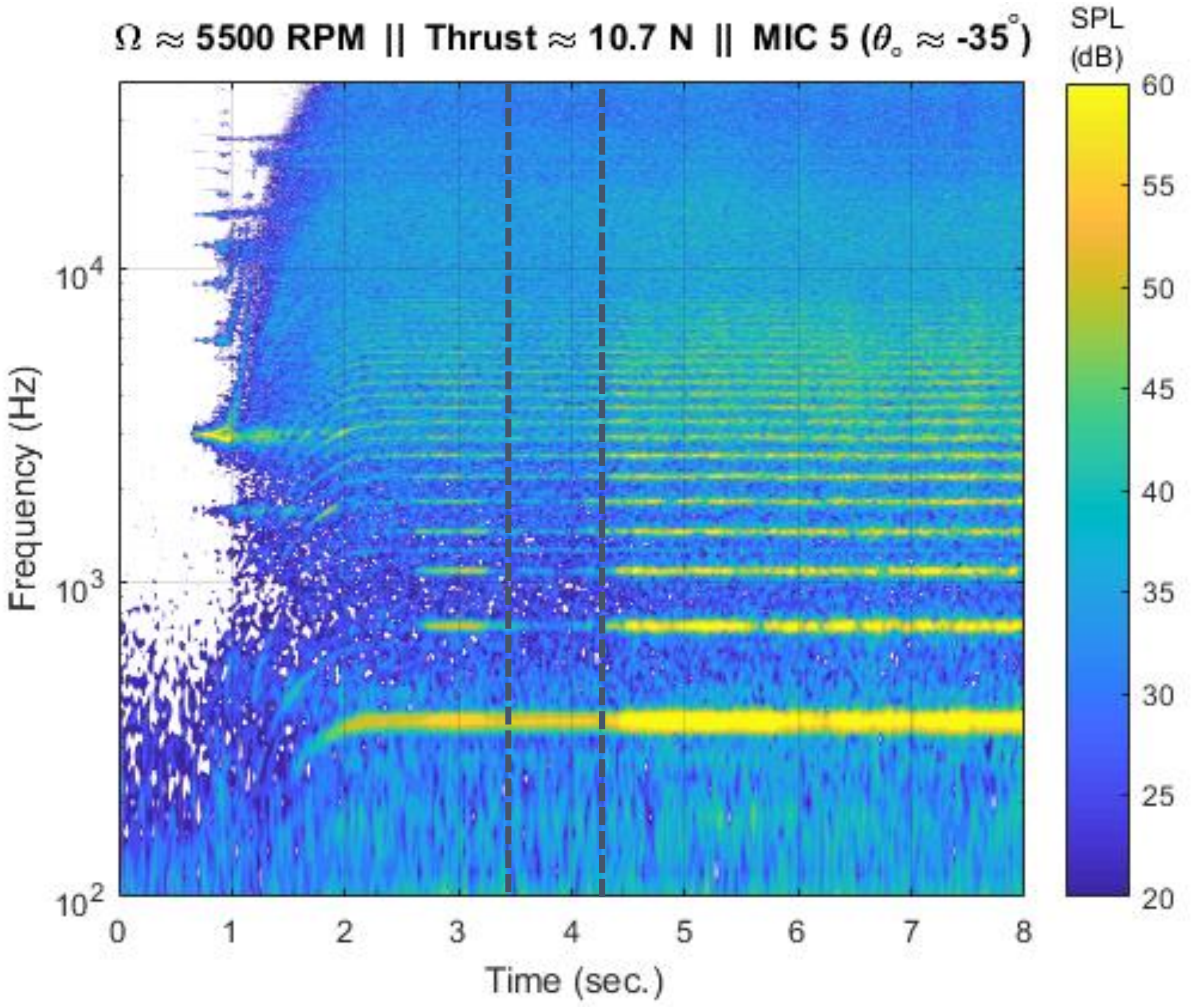
Small Hover Anechoic Chamber (SHAC)

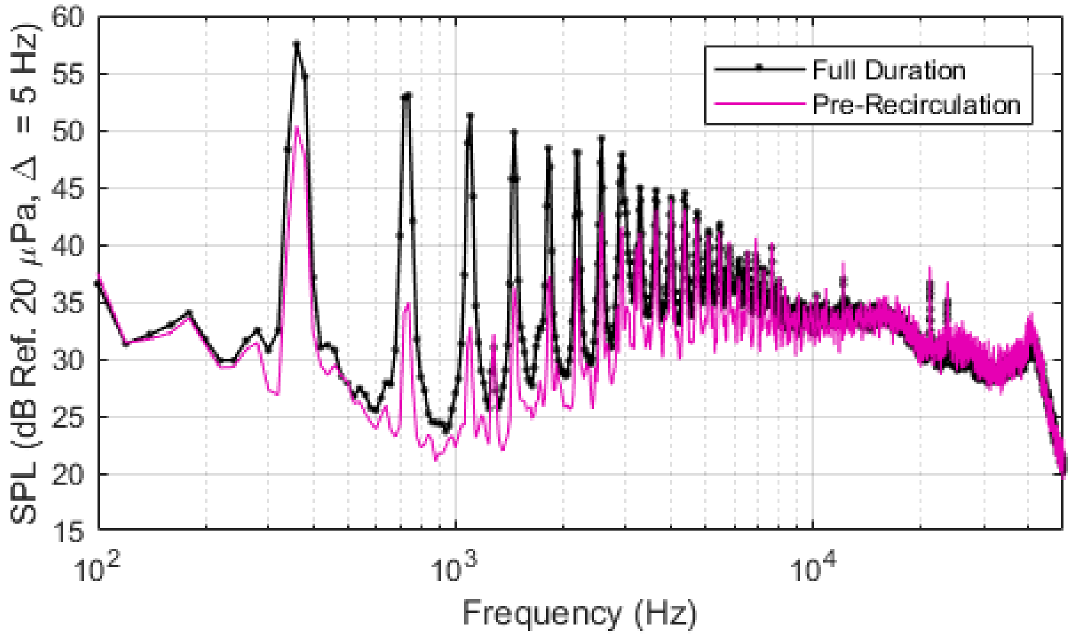






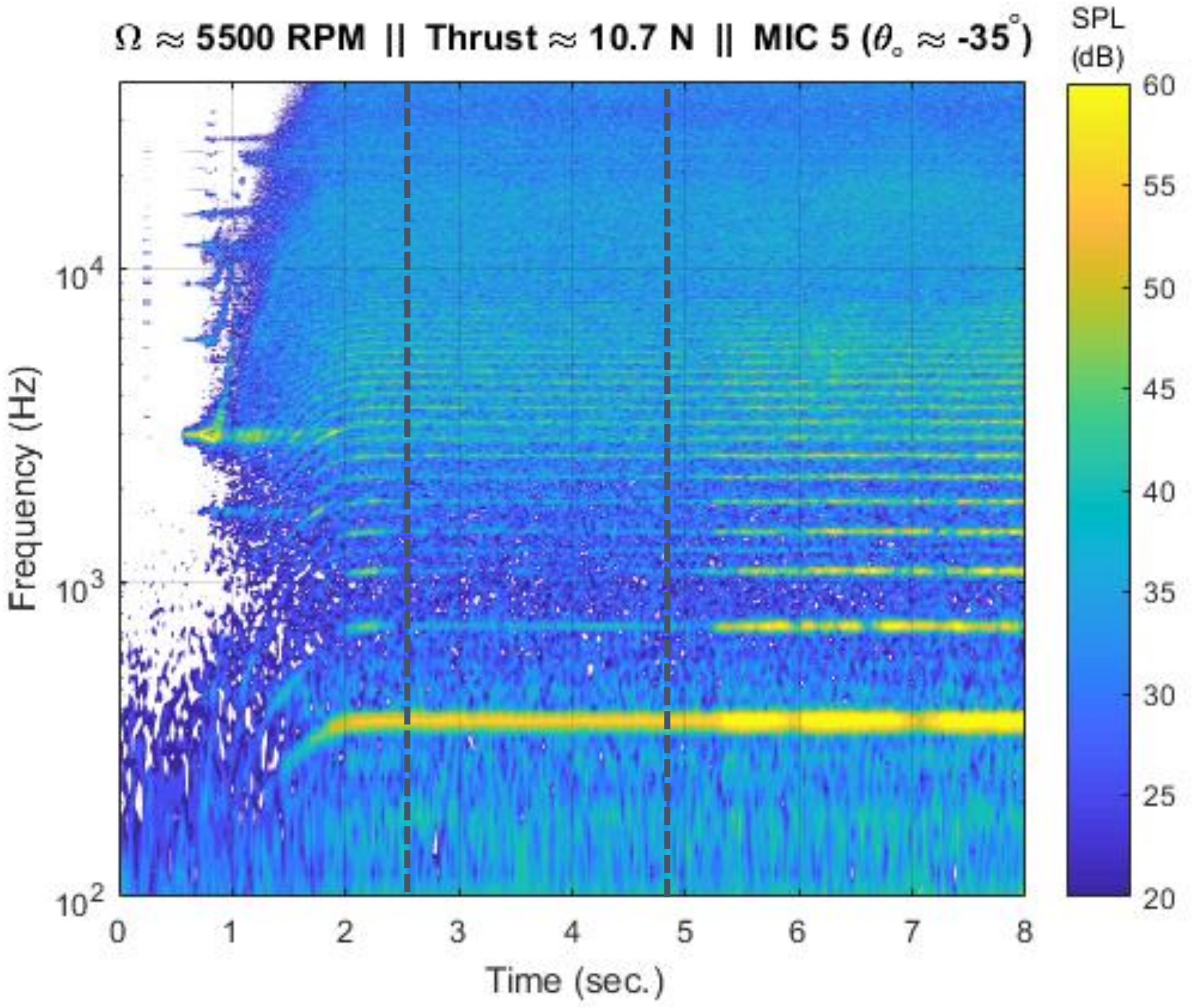
Experiment: Without Mesh Screens

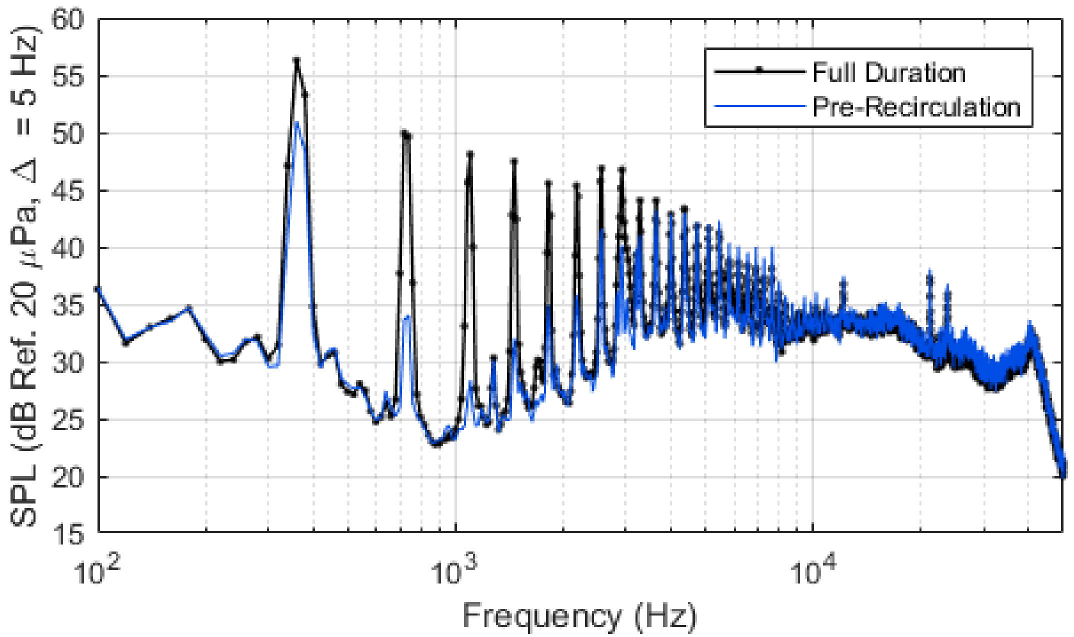




Without mesh screens, “clean data” duration is **< 1 second**

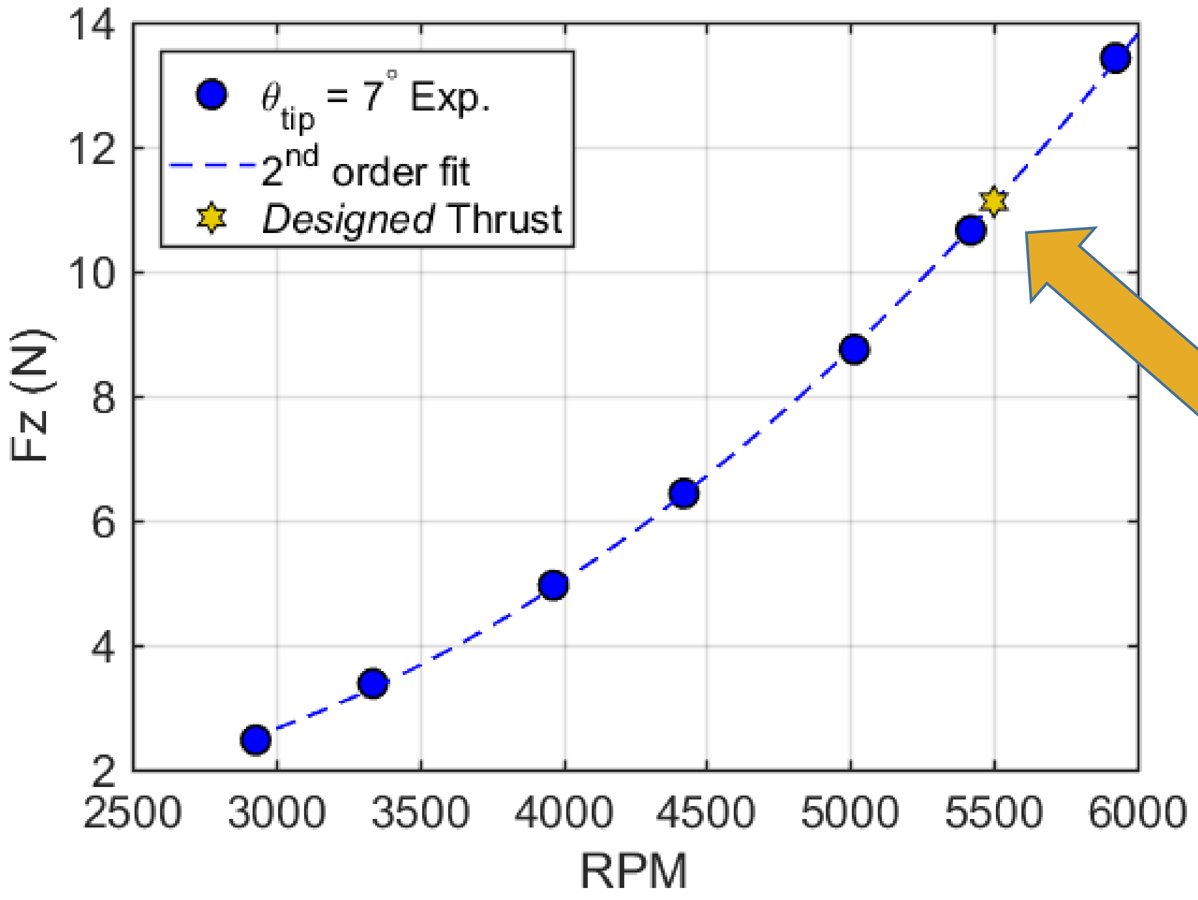
Experiment: With Mesh Screens





With mesh screens, “clean” data duration is **> 2 seconds**

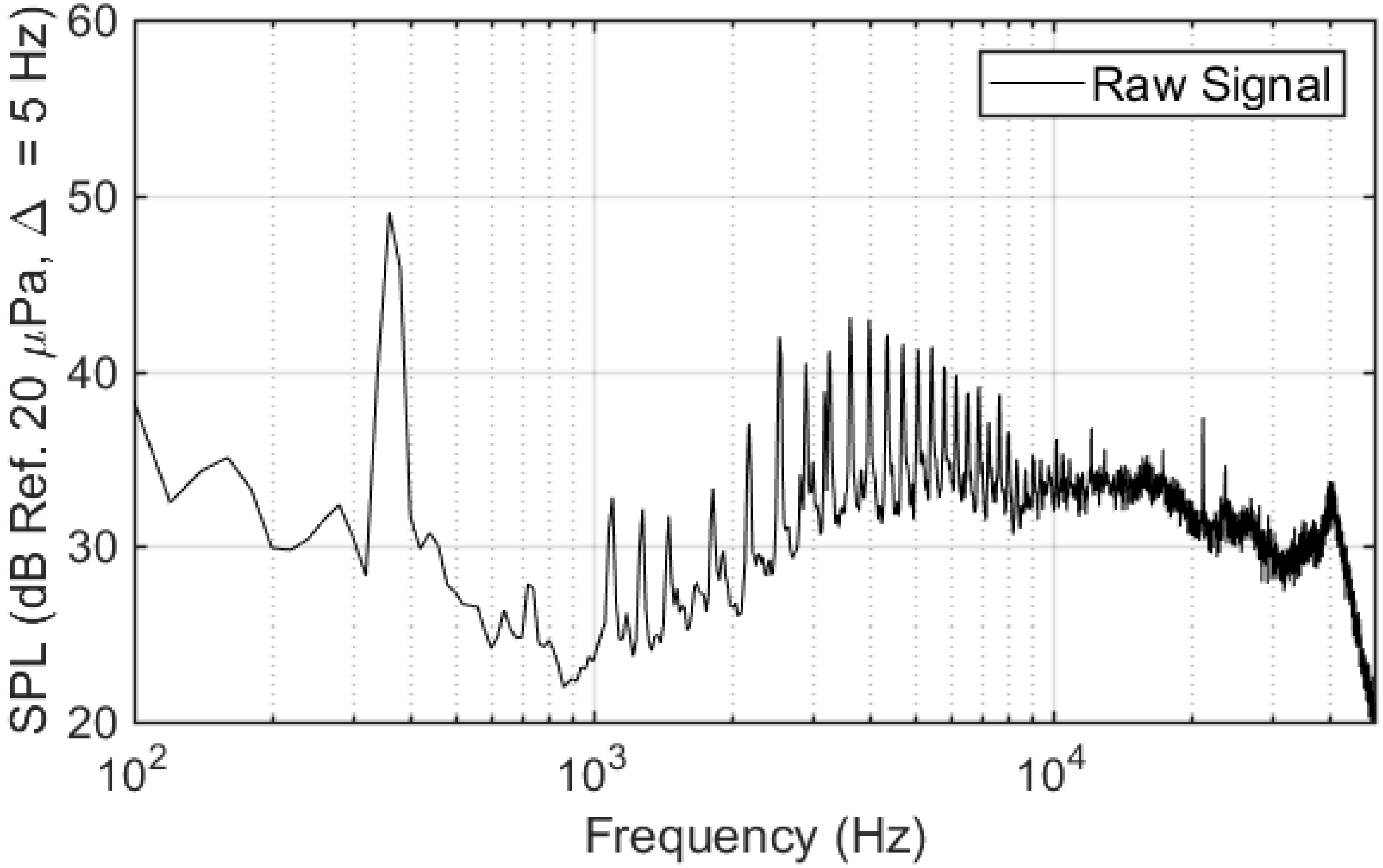
Experiment Results: Thrust Sweep



θ_{Tip} (Deg.)	Ω_{STD} (RPM)	Thrust (N)
4	5398	6.3788
7	5417	10.655
10	5448	14.457

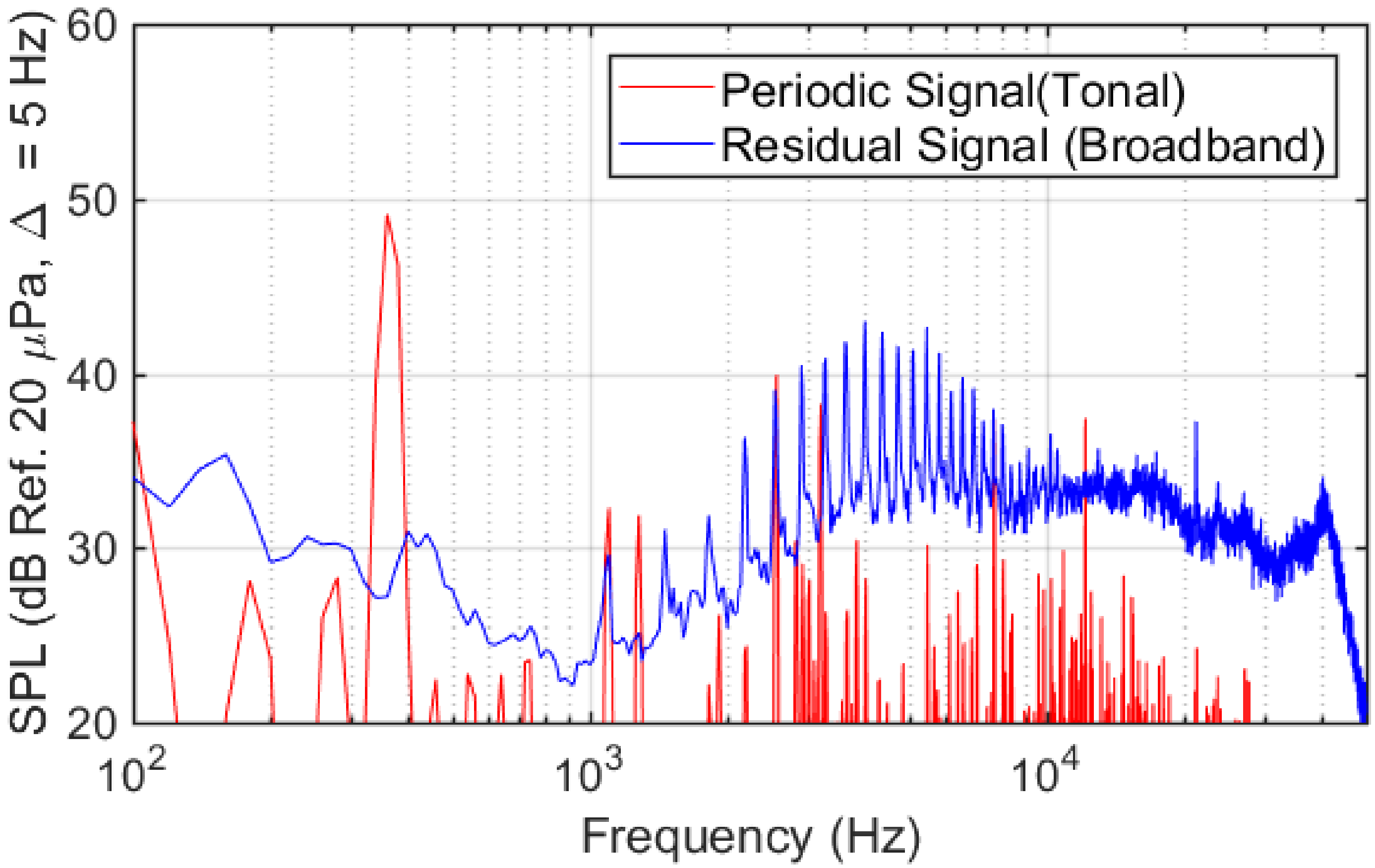
Designed the rotor to reach 11.12 N at 5500 RPM

Broadband Noise Extraction



For more information on extracting broadband noise signal, please see additional slides

Broadband Noise Extraction



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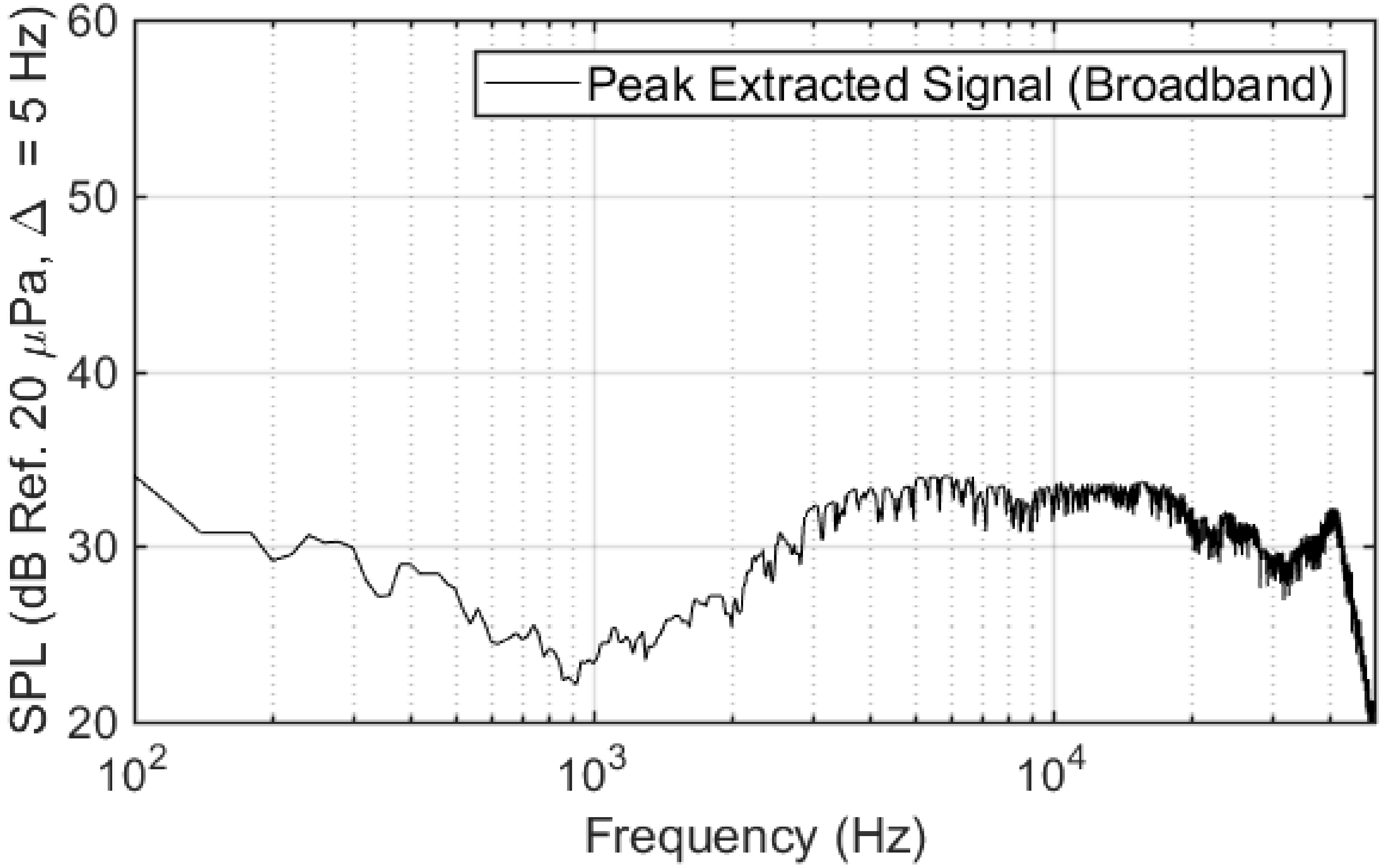
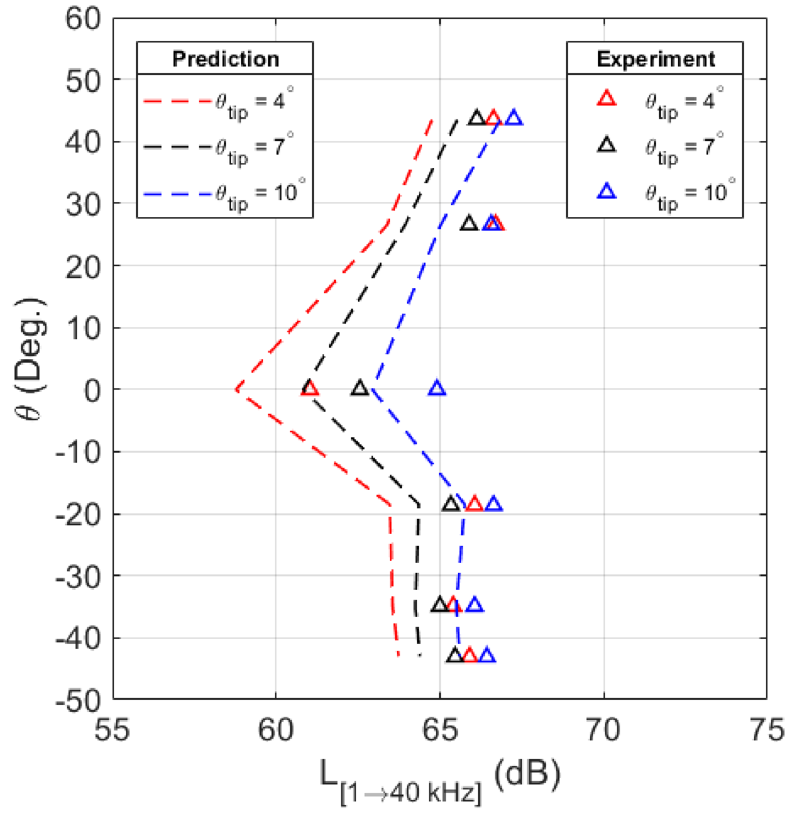


For more information on extracting broadband noise signal, please see additional slides

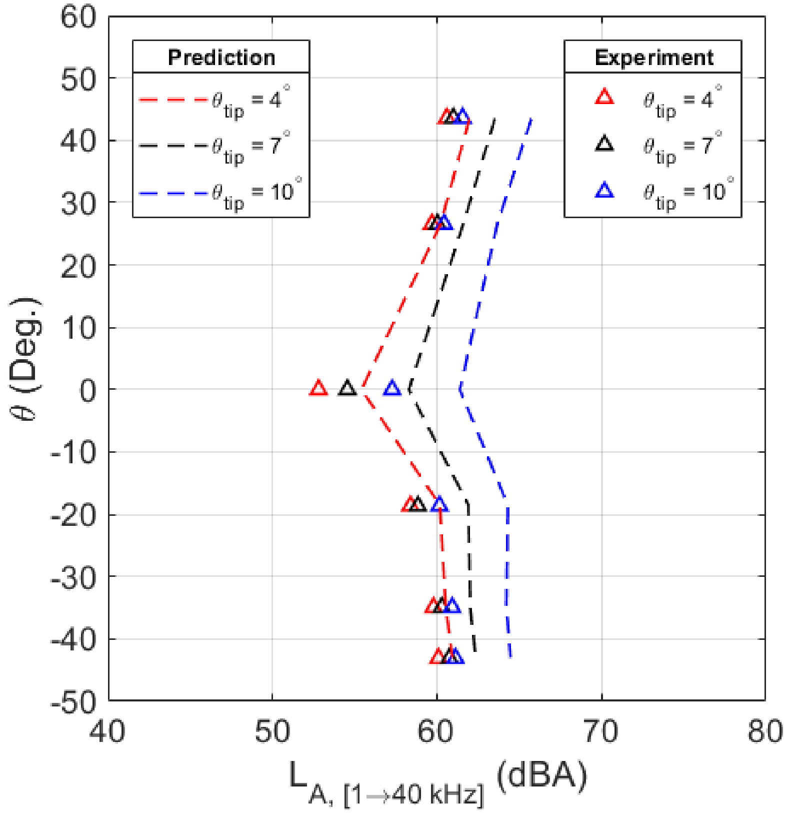
Noise Predictions - Directivity

Broadband noise prediction tool: BARC
BPF Prediction tool: PAS
For more information on these noise prediction tools, please see additional slides

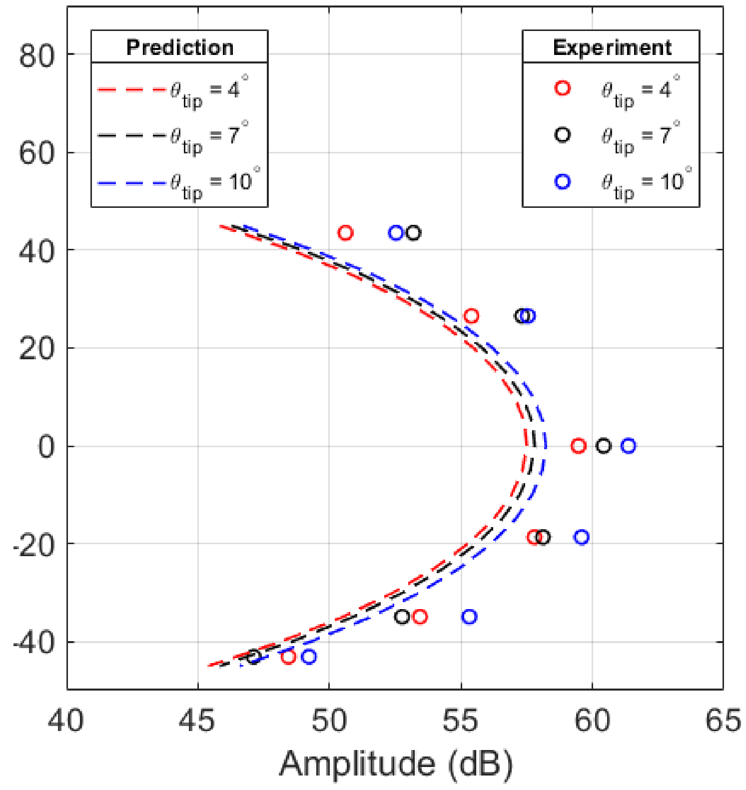
Broadband Noise (Unweighted)



Broadband Noise (A-Weighted)



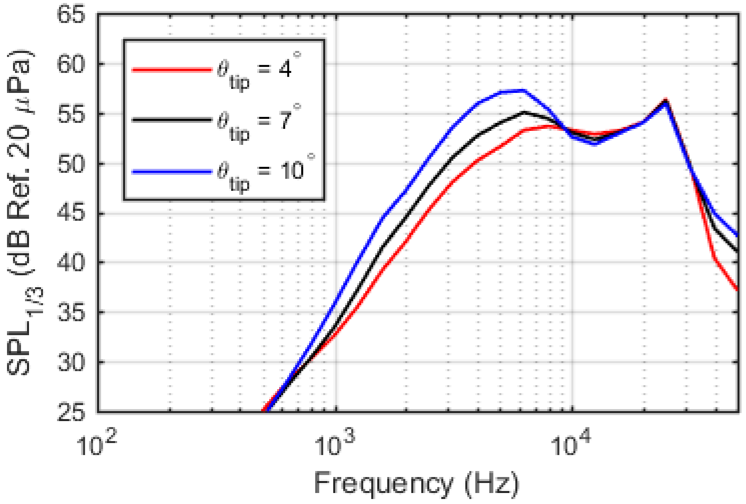
Blade Passage Frequency



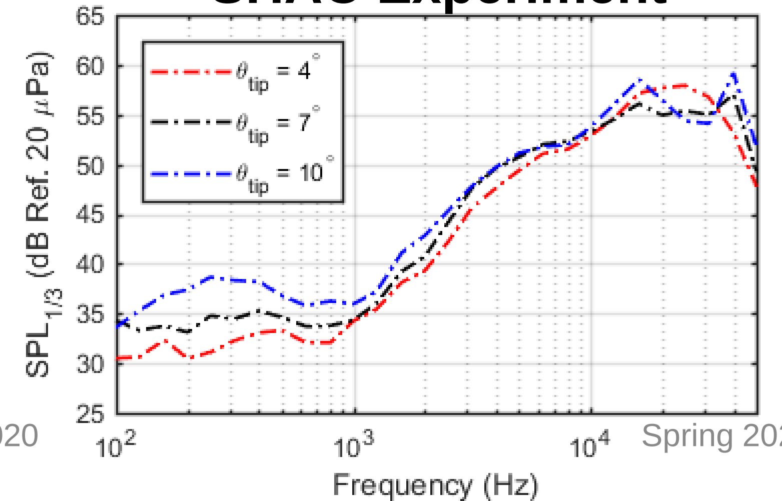
For more information on self-noise sources, please see additional slides

Tripped Broadband Noise Predictions (M5)

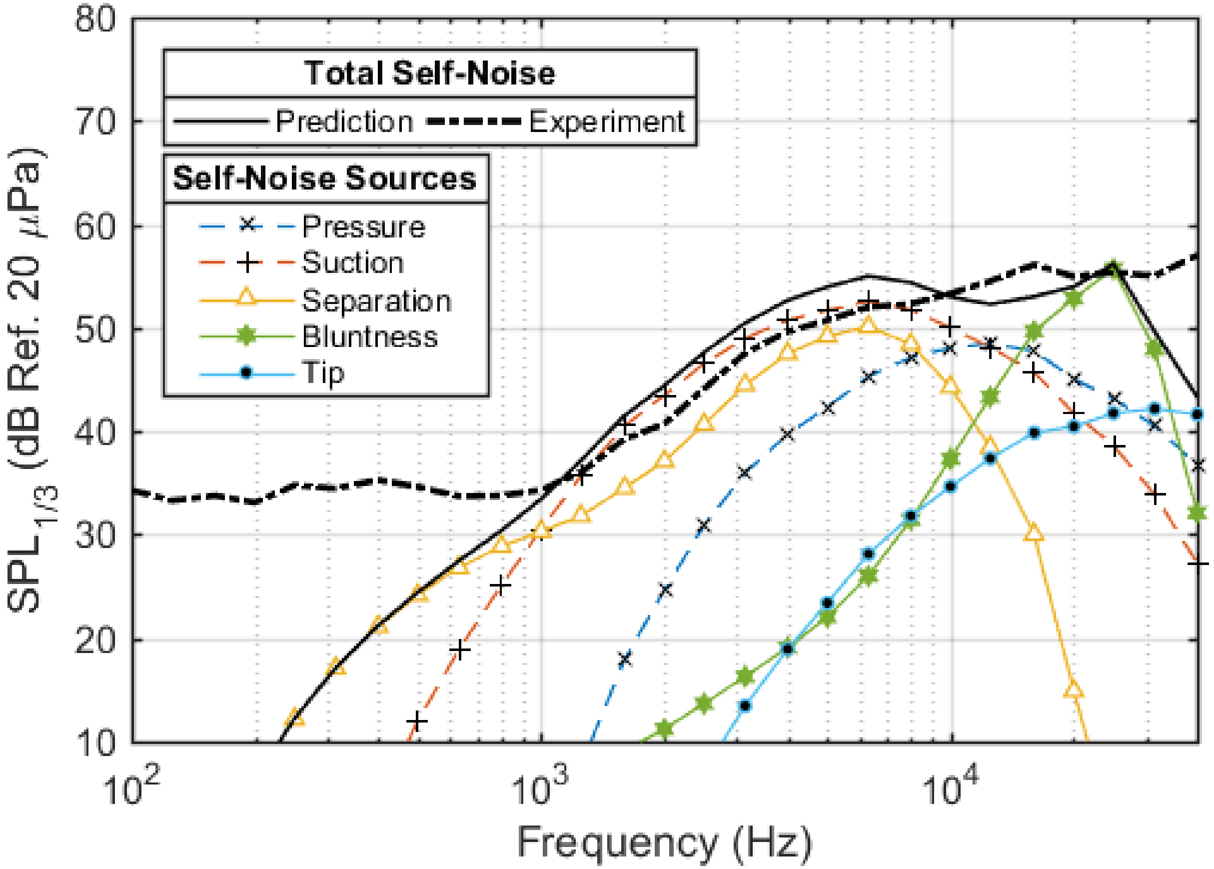
BARC Prediction



SHAC Experiment



7° Pitch (10.7 N) *Tripped* Prediction



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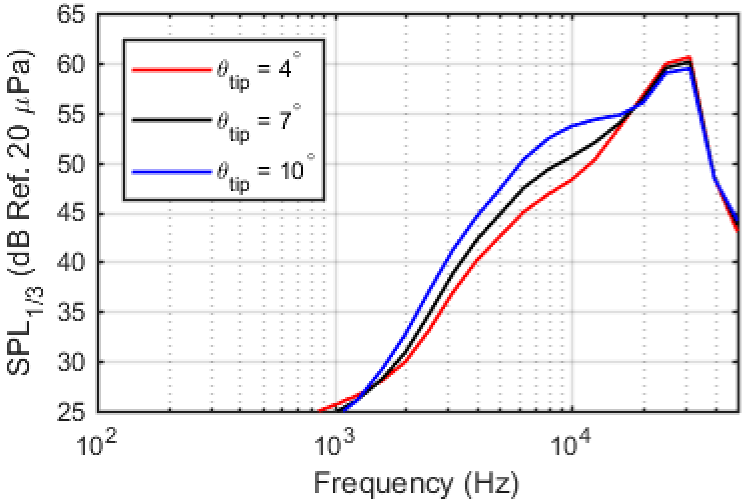
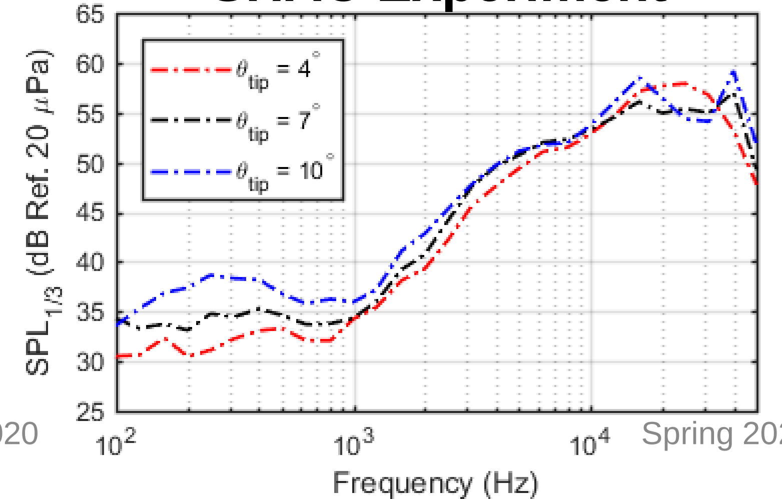
Untripped Broadband Noise Predictions (M5)

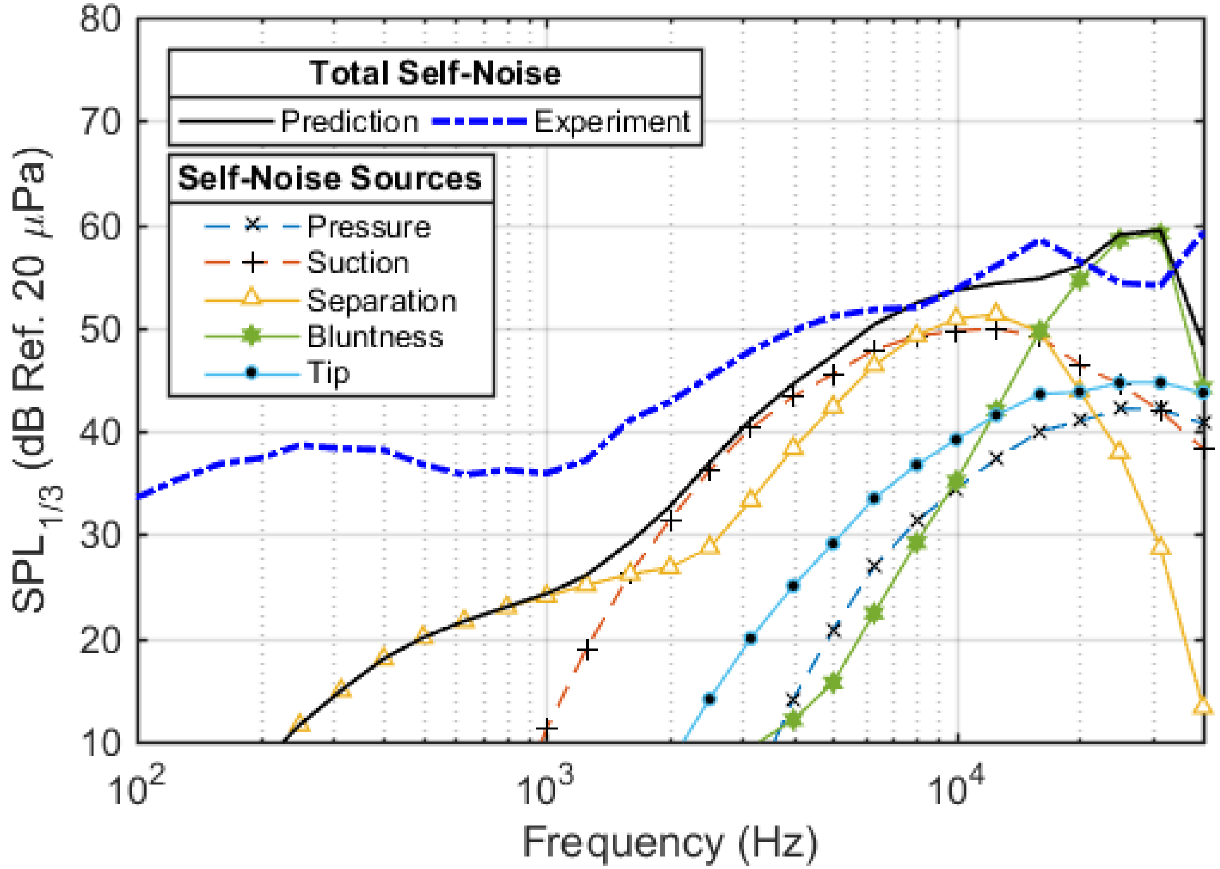
BARC Prediction



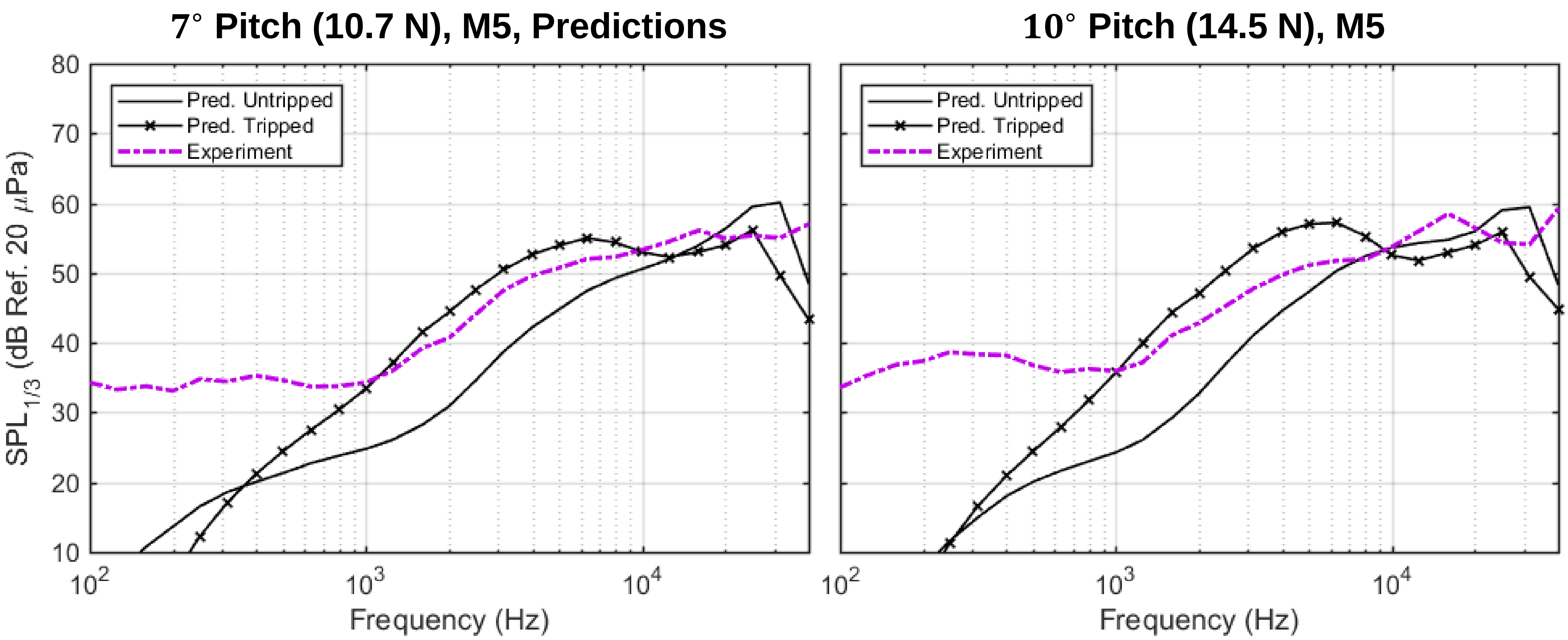
SHAC Experiment



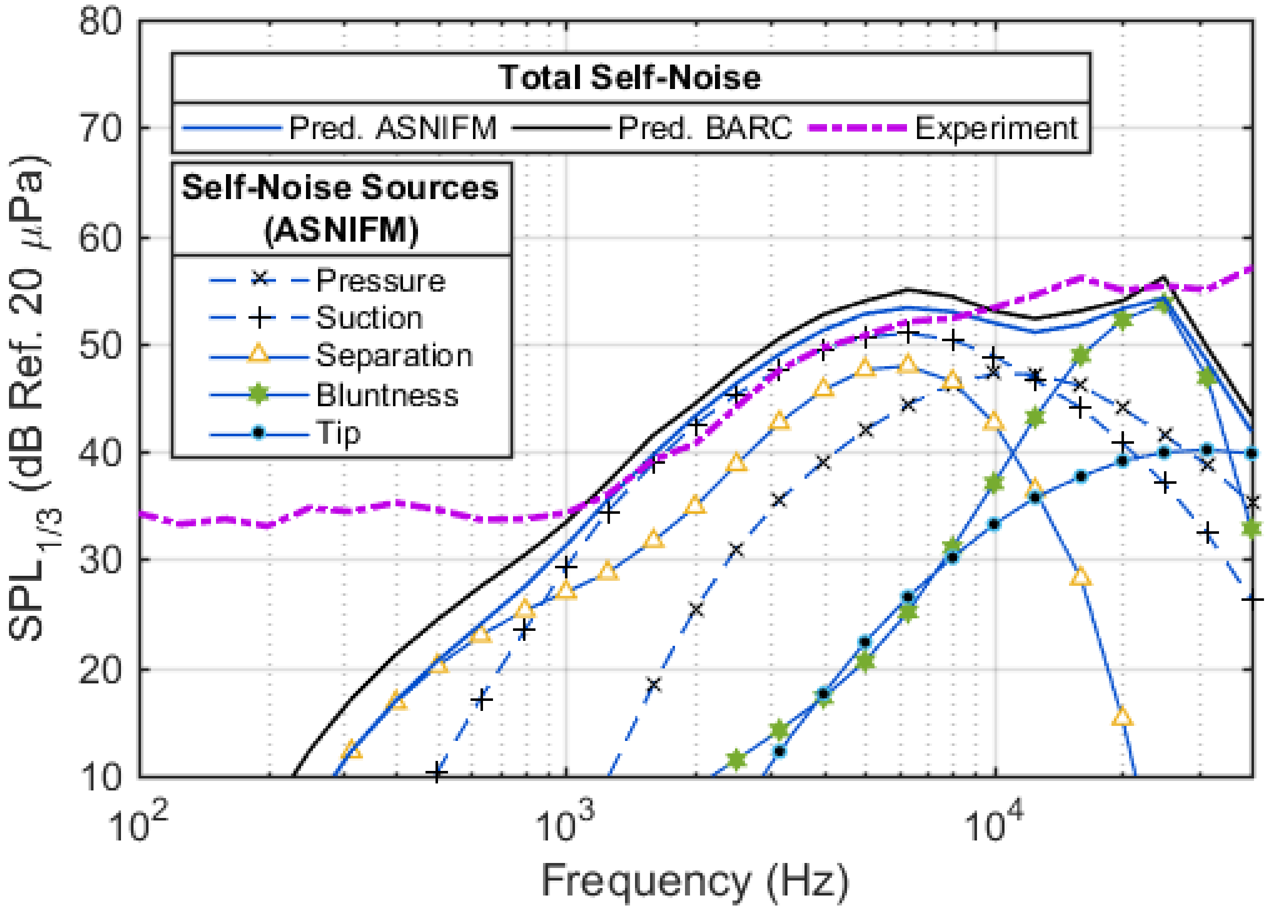
10° Pitch (14.5 N) *Untripped* Prediction



Comparing Untripped and Tripped Predictions



ASNIFM Results



Final Thoughts and Future Work

- The 3-D printed ideally twisted rotor **matched performance expectations** when tested in the SHAC
- Low fidelity tools are able to predict some of the **tonal and broadband noise characteristics** of this tested rotor
- **Higher fidelity inflow modeling** may be necessary for off-design conditions
- An **experimental flow field survey** may provide insight into **nonuniform inflow** that may be occurring at the off-design test conditions
- Examining acoustic data for different RPM sweep at design blade tip pitch (7°) would identify how **noise trends with performance**

Acknowledgments

Funding

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Thank you, any questions?

Extra Slides

Experimental Data Processing

Extracting Broadband Noise

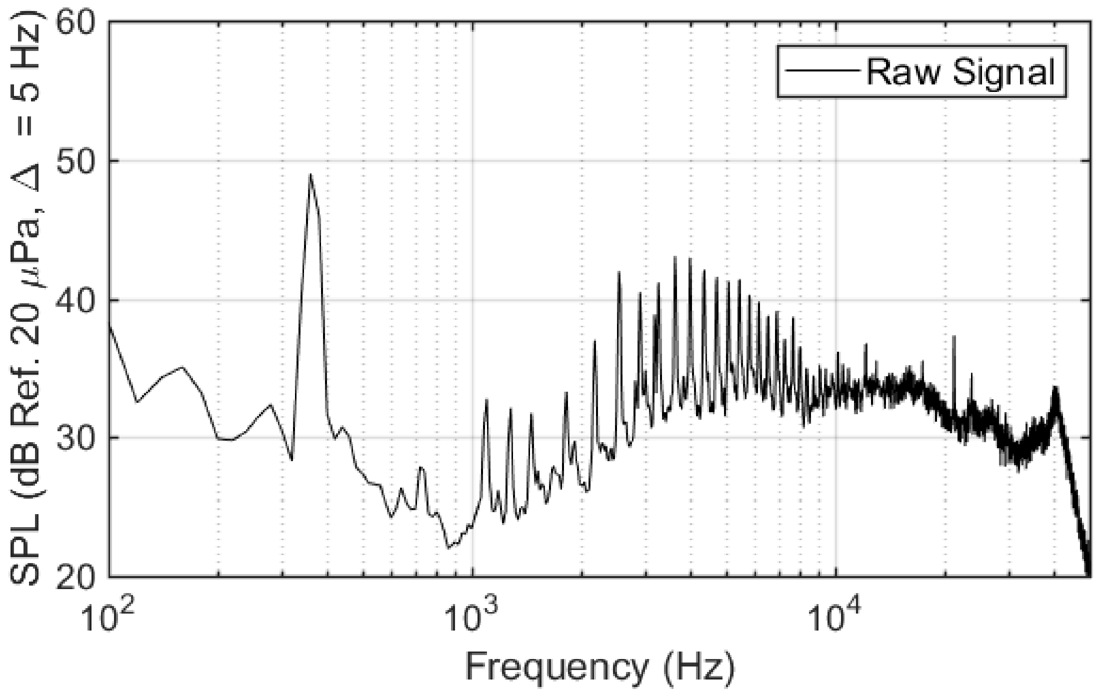
1. **Data treated as random data sets**
   - **Narrowband acoustic spectra computed using fast Fourier Transform (FFT)**

2. Separate periodic and random noise components in the time domain
   - Compute mean rotor revolution time history
   - Subtract from time record to retain random noise components
   - Use FFT to compute periodic and broadband spectra from the mean and residual time series

3. Remove signal peaks that remain in broadband spectra

Resultant broadband noise spectra are compared to broadband noise predictions

Raw Noise Spectra



Additional Resources:

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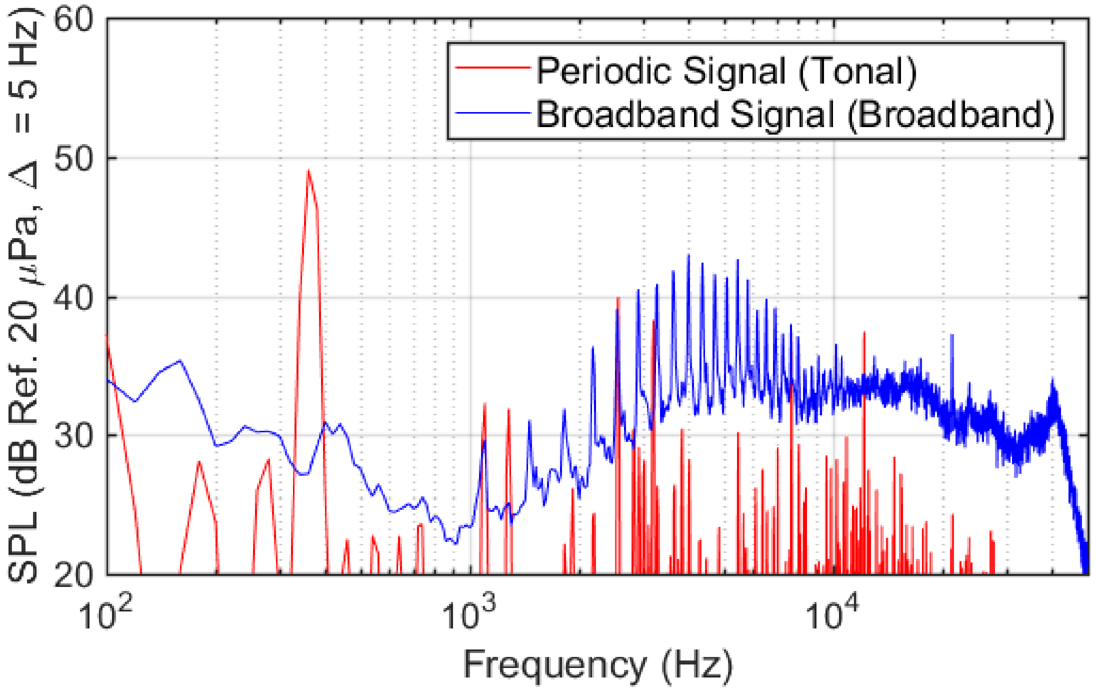
Periodic and Broadband Noise Spectra



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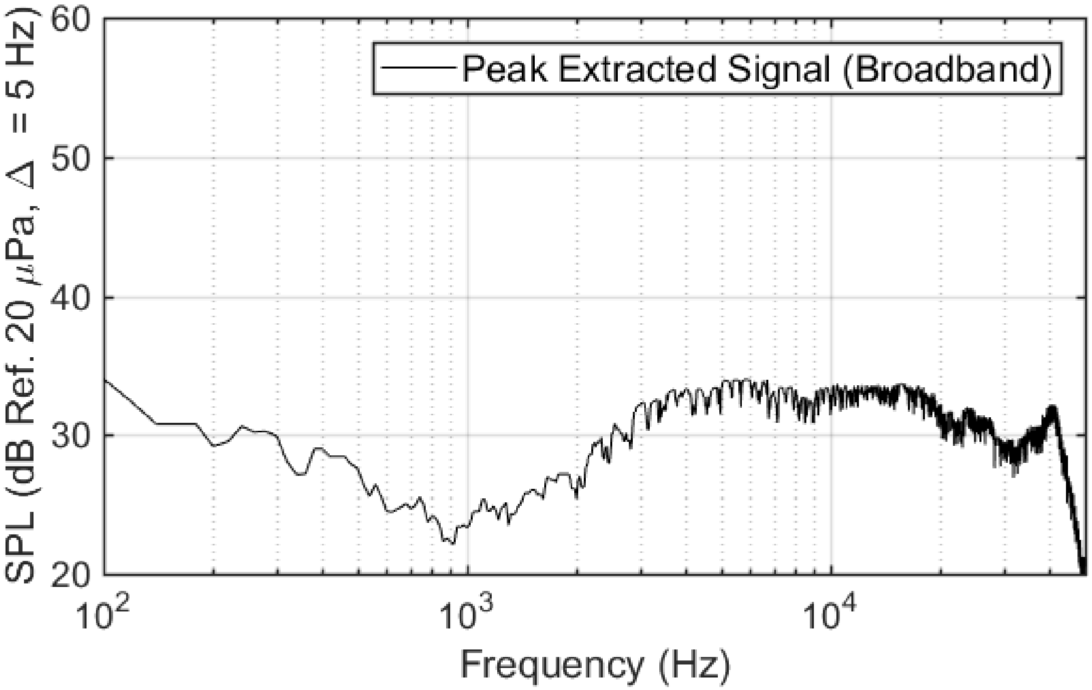
Broadband Noise Spectra



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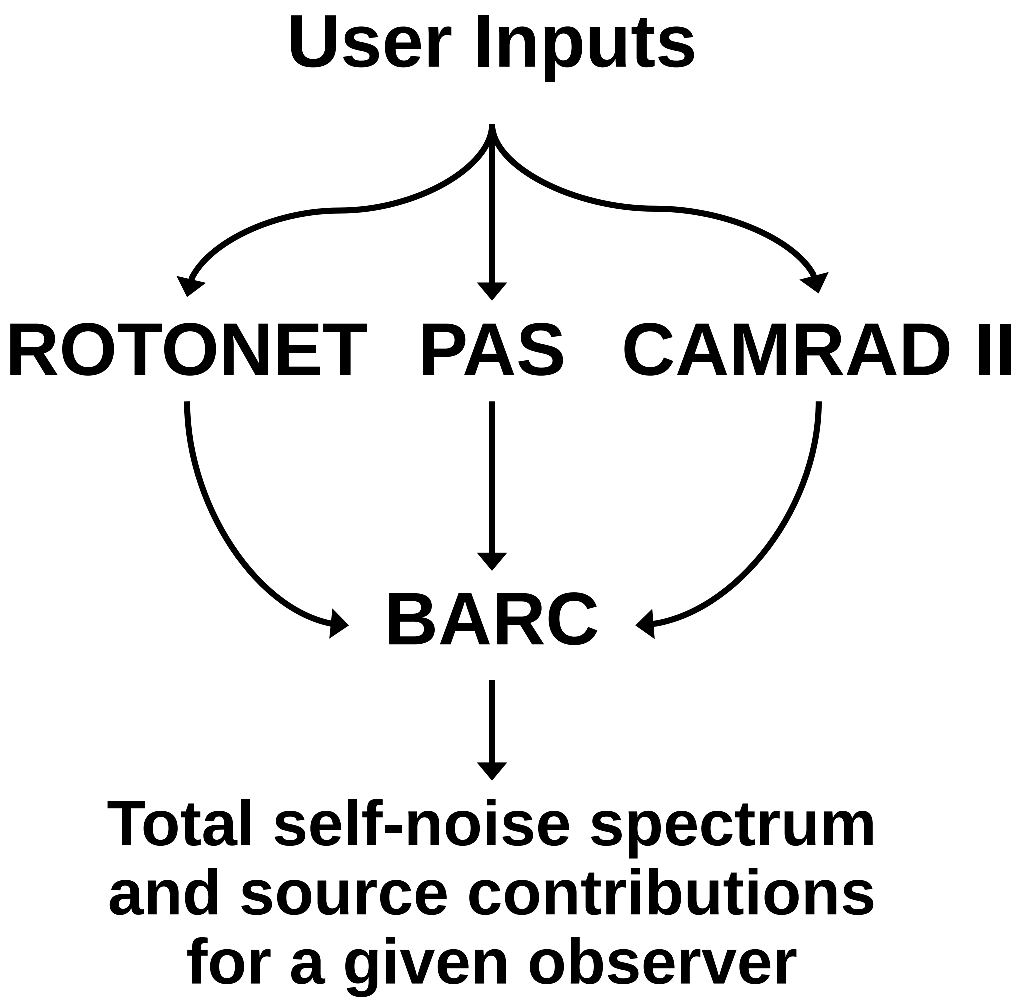
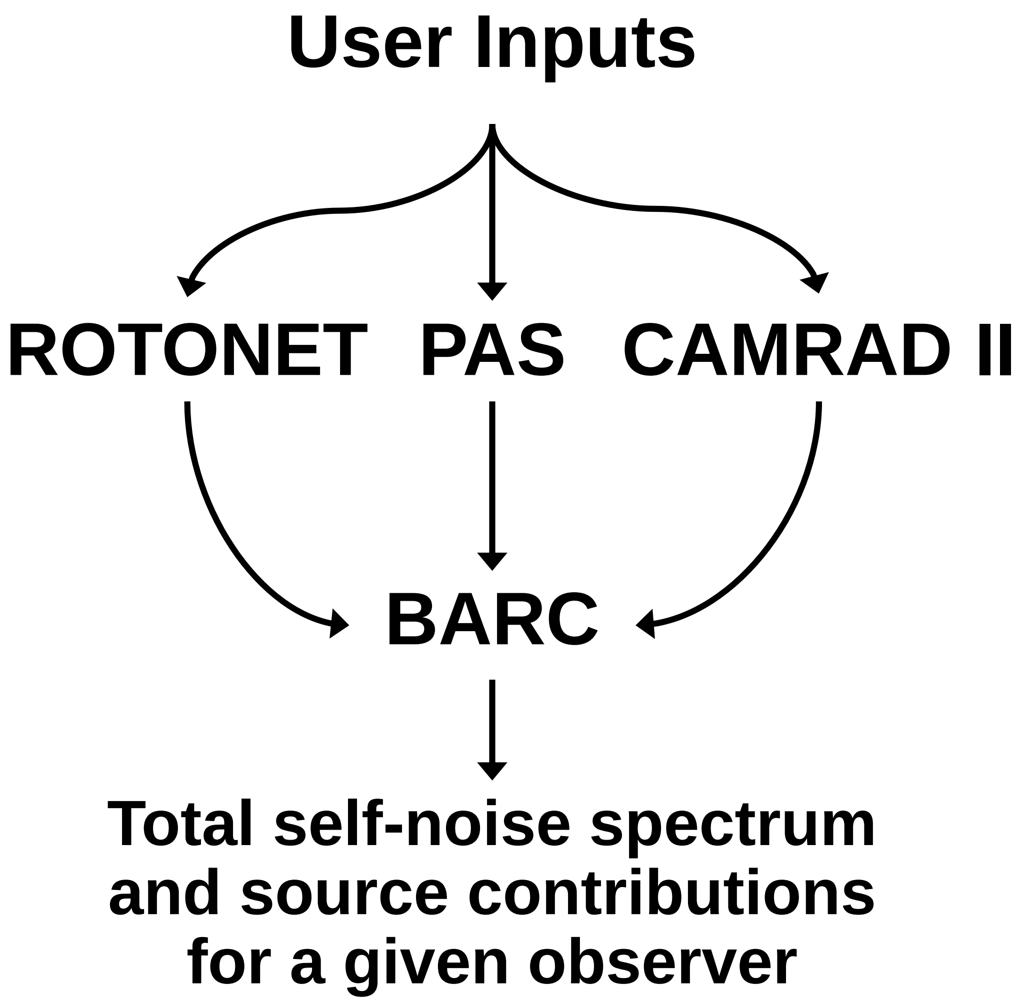
Self-Noise Prediction Methodology



- ***BARC*** (Broadband Acoustic Rotor Codes[1]) is a semiempirical, blade element method for predicting self-noise
- Uses inflow conditions and airfoil geometry as inputs, and NACA0012 empirical BL data
- **Predicts broadband noise due to self-noise sources and incorporates into a rotational reference frame**

[1] 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.

Self-Noise Prediction Methodology



- ***ROTONET*** (Rotorcraft Noise Prediction System[1]) and ***PAS*** (Propeller Analysis System[2]) are subsystems of NASA Aircraft Noise Prediction Program (ANOPP) and are lower fidelity tools with simple inflow models

- ***CAMRAD II*** *(*Comprehensive Analytical Model of Rotorcraft Aerodynamics and Dynamics[3]) is a higher fidelity tool with multiple inflow models

- **Use either ROTONET, PAS or CAMRAD II to calculate local inflow conditions**

[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] Nguyen, L. C. (1991). *The NASA Aircraft Noise Prediction Program Improved Propeller Analysis System*. Hampton.

[3] Johnson, W., Technology Drivers in the Development of CAMRAD II. American Helicopter Society Aeromechanics Specialists Conference, 1994.

*Source: Brooks, T. F., Pope, D. S., and Marcolini, M. A., “Airfoil Self-Noise and Prediction,” NASA RP 1218, 1989.

What is self-noise?

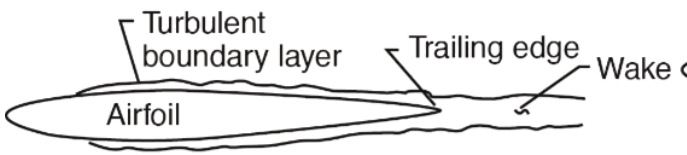
- *Self* generated noise of an airfoil blade encountering smooth flow

- This is a *nondeterministic, broadband* noise source

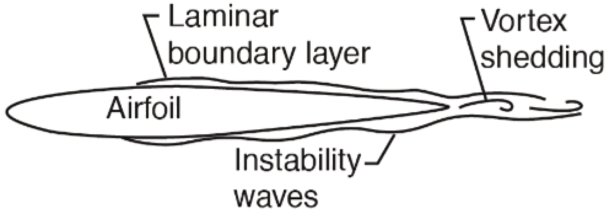
- In 1989, a NASA Reference Publication (RP1218) was published on the topic of self-noise and a prediction method*

6 Self-Noise Source Mechanisms*

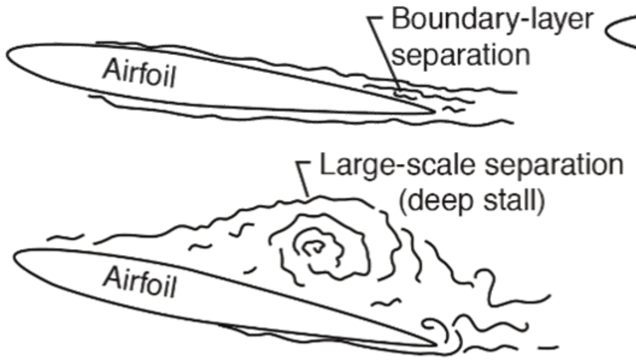
Turbulent boundary layer trailing edge (TBLTE) on: *Pressure* and *Suction* Side



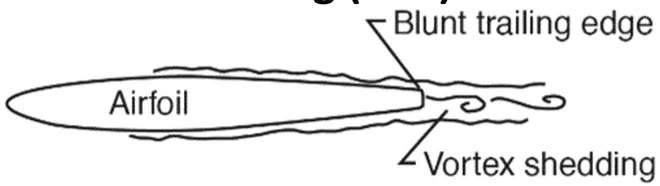
Laminar boundary layer vortex shedding (LBLVS)



Trailing Edge *Separation*/Stall



***Bluntness* vortex shedding (BVS)**



***Tip* vortex formation**