Mid-Fidelity Aeroacoustic Prediction of Scaled eVTOL Rotors

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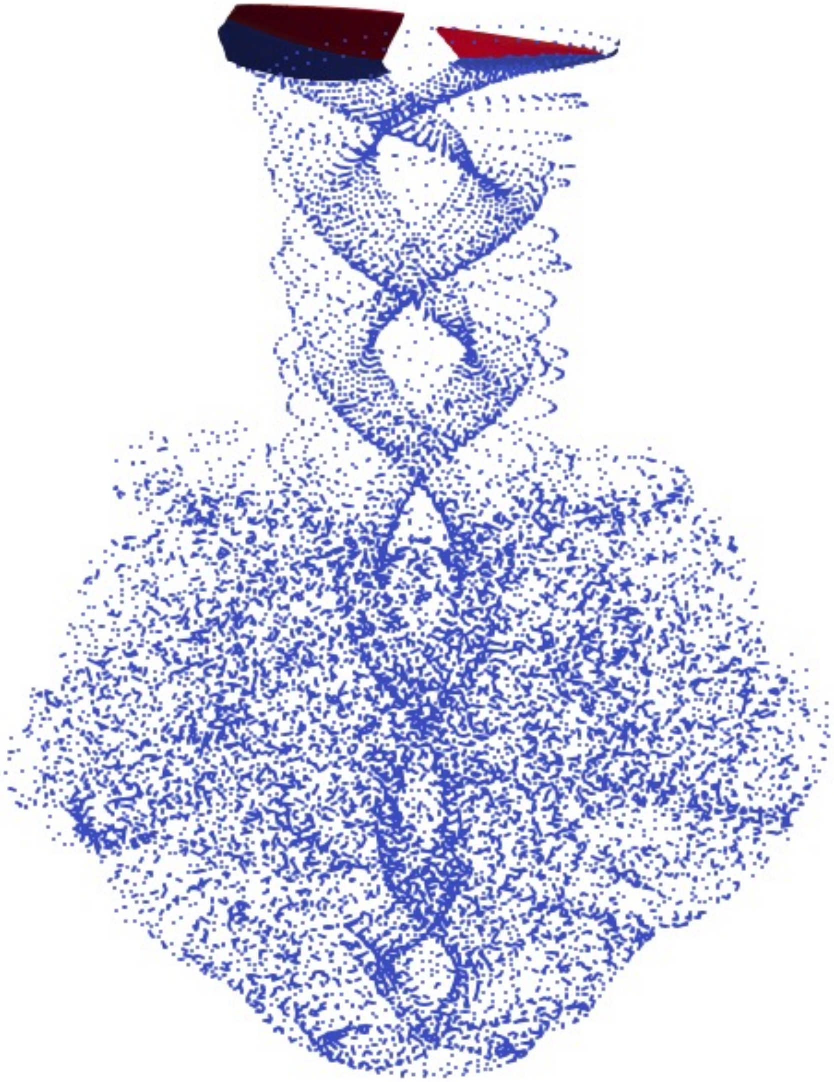
Outline

- Introduction
- Prediction method for tonal simulation
- Prediction method for broadband simulation
- Individual predictions
- Combined prediction
- Conclusion



Visualization of the flow around the propeller in hover computed by DUST simulations

Growth of eVTOL and sUAS

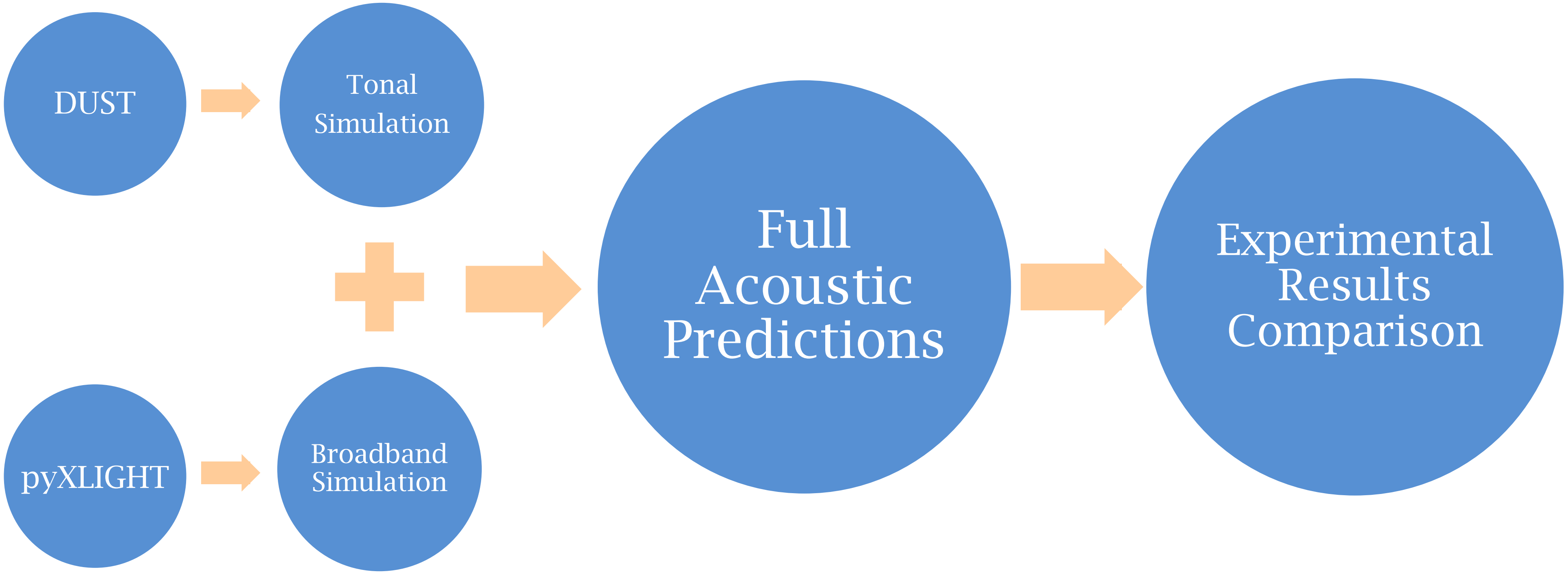
- Increase in demand for the use of electric motors and propellers to drive propulsors across a range of small air vehicle classes
- Applications of eVTOL and sUAS within urban environments
- Concern for increased urban noise pollution
- High demand for a low computational cost method of predicting the tonal and broadband acoustics for electrically driven rotors

AAM in urban environment
(via. appel.nasa.gov)

Archer’s Maker aircraft (via. Archer.com)

Proposed Solution

An affordable and reliable method of acoustic simulation will be developed. Once validated, this tool will provide quick and accurate simulation results to study preliminary designs of electric rotors.



Overview of Tonal Simulation

DUST

- Open-sourced flexible medium-fidelity aerodynamic solver (by Politecnico di Milano and A^3 by Airbus)
- Sets up geometry and flight conditions
- Models aerodynamic flow-field

Ffowcs Williams and Hawkings (FWH) acoustic solver

- Farassat 1A solution is used
- Yields loading pressure, thickness pressure, and total pressure at different observer locations for each time step

Digital Signal Processing for PSD

- Decomposes the pressure fluctuations in the time domain into the frequency domain
- Allows for data comparison with experimental data

Overview of Broadband Simulation

Boundary layer characterizing parameters

- Obtained through pyXLIGHT, a Python implementation of XFOIL by MDO lab
- Found for every section of each blade element

Turbulent boundary layer pressure spectrum at trailing edge

- Utilizes empirical wall pressure spectrum model developed by Dr. Seongkyu Lee
- Function of boundary layer parameters

Trailing edge broadband acoustics

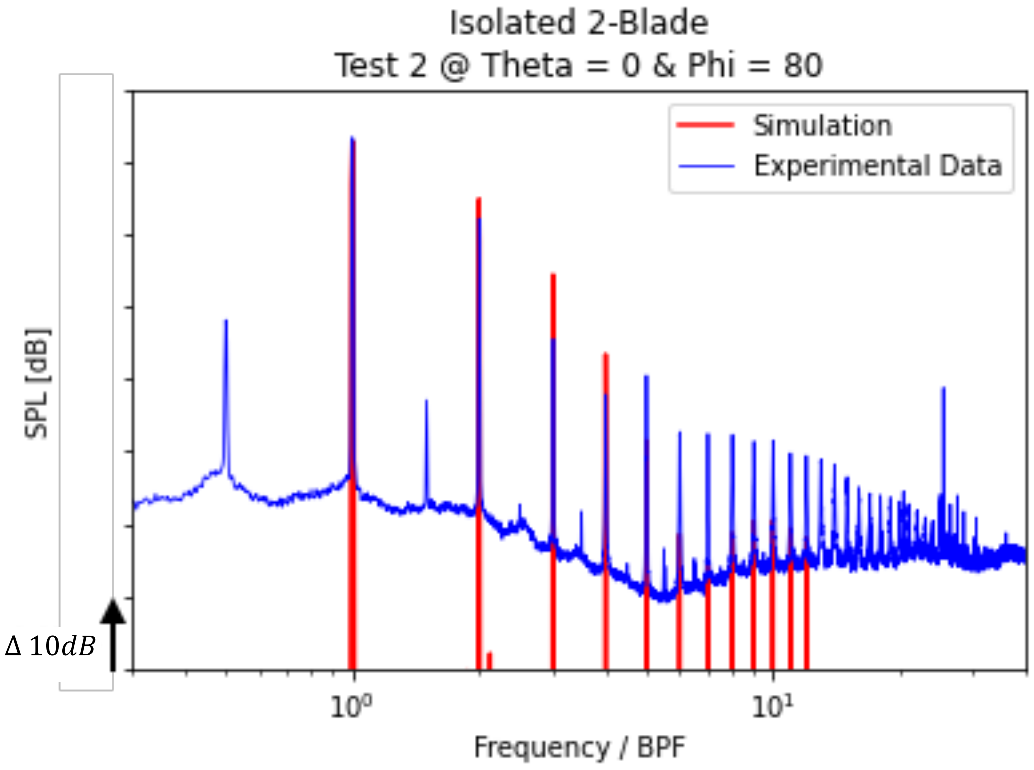
- Formulation by S. Sinayoko et al. for trailing edge acoustics of rotating blades
- Broadband acoustics for elements of a segmented blade are summed

Optimize to match in-house experimental measurements

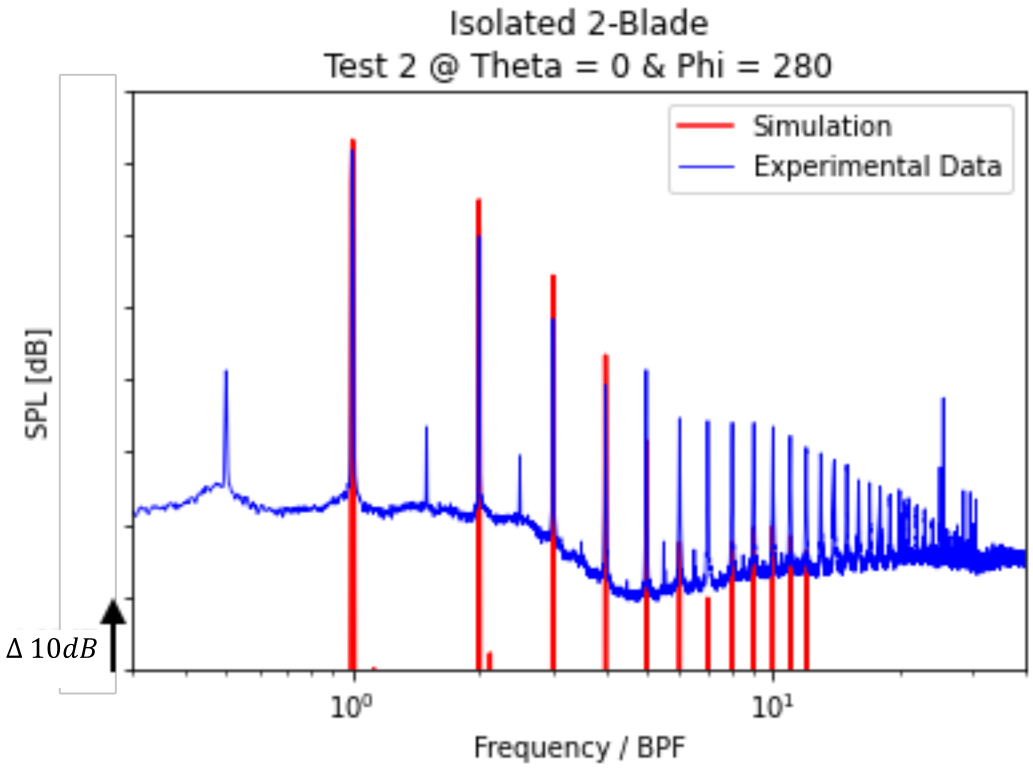
- Optimized scaling of coefficients in wall pressure spectrum model
- Calibrated coefficients to results 10° below rotor plane

Tonal Prediction

Hover at nominal RPM for two different observer locations 10° below rotor plane

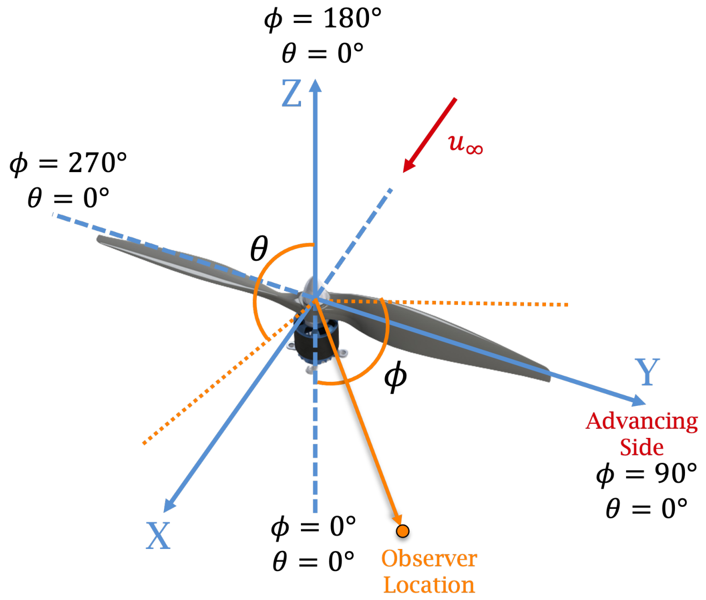


(Advancing Side)



(Retreating Side)

Tonal Prediction



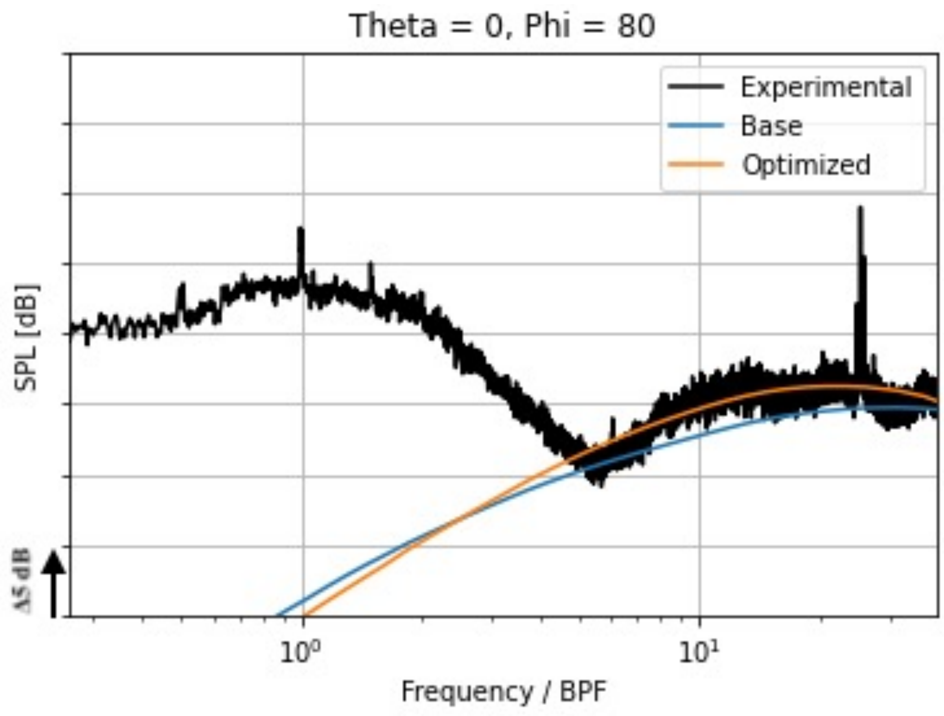
ΔdB at the blade pass frequency (BPF) between experimental data and simulation results:

Legend:
🟩 < ± 5 ΔdB
🟨 < ± 10 ΔdB
🟥 > ± 10 ΔdB

	Observer Location	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Theta	0	0	0	0	0	0	0	0	0	20	0	-20	-20	0	20
	Phi	80	280	70	290	60	300	310	320	330	90	90	90	270	270	270
Test (% RPM wrt nominal)																
Hover (112%)		0.55	0.29	2.77	1.26	4.08	2.05	4.49	5.17	5.13	0.02	0.34	-2.37	-2.71	-0.18	-1.80
Hover (100%)		0.48	-1.42	2.72	-1.65	4.97	-0.59	-0.40	0.34	0.20	-1.76	-0.61	-1.80	0.33	-1.68	-1.35
Hover (88%)		-2.46	-1.99	-1.25	-1.52	0.42	-0.75	-0.48	0.11	-0.10	-2.80	-2.68	-1.61	-1.98	-2.43	-2.11
Hover (76%)		-3.53	-3.56	-2.53	-3.36	-0.94	-3.11	-3.11	-2.95	-2.76	-4.95	-5.10	-5.10	-4.57	-4.30	-5.13
10 m/s (112%)		-1.68	3.65	1.58	4.86	7.56	5.83	6.12	7.11	7.37	-3.73	-0.71	-2.35	1.27	2.51	0.02
10 m/s (100%)		-0.45	2.82	3.20	2.90	7.44	3.34	5.16	5.09	6.83	-5.32	-1.04	1.36	3.95	2.14	2.76
10 m/s (88%)		-3.49	4.69	-2.10	5.90	0.01	7.29	9.30	10.34	12.27	-7.27	-5.58	-3.60	3.61	3.15	1.58
10 m/s (76%)		0.40	1.91	3.80	2.28	6.72	2.82	3.52	3.94	4.75	-7.60	-2.44	-0.31	1.19	1.40	0.57
20 m/s (112%)		0.79	5.26	5.75	5.14	14.81	5.09	5.83	5.78	5.73	-2.79	1.35	0.26	3.56	3.88	0.81
20 m/s (100%)		2.39	3.83	8.90	4.20	17.94	3.98	5.01	4.65	5.37	-2.46	1.58	3.45	4.39	2.58	2.89
20 m/s (88%)		0.76	4.35	6.31	3.87	14.84	4.22	4.77	4.81	5.18	1.63	2.17	1.37	4.95	3.59	1.64
20 m/s (76%)		2.27	3.46	10.45	3.90	16.34	3.54	3.73	3.82	4.89	-1.42	-0.61	2.29	3.57	3.41	2.37
30 m/s (112%)		1.80	8.91	6.51	9.54	17.91	10.24	9.47	10.73	11.66	-2.25	2.74	2.29	7.90	7.36	3.36
30 m/s (100%)		2.01	7.46	10.80	8.57	20.99	8.51	9.30	10.14	10.98	0.24	3.31	5.51	7.96	6.59	6.56
30 m/s (88%)		-0.41	8.11	8.99	9.15	19.75	9.91	10.75	11.25	12.83	4.33	4.55	3.90	8.47	7.42	5.77
30 m/s (76%)		6.39	8.97	15.73	9.56	21.48	10.07	10.21	11.16	12.07	3.64	2.56	5.78	5.02	4.96	4.26

Broadband Predictions

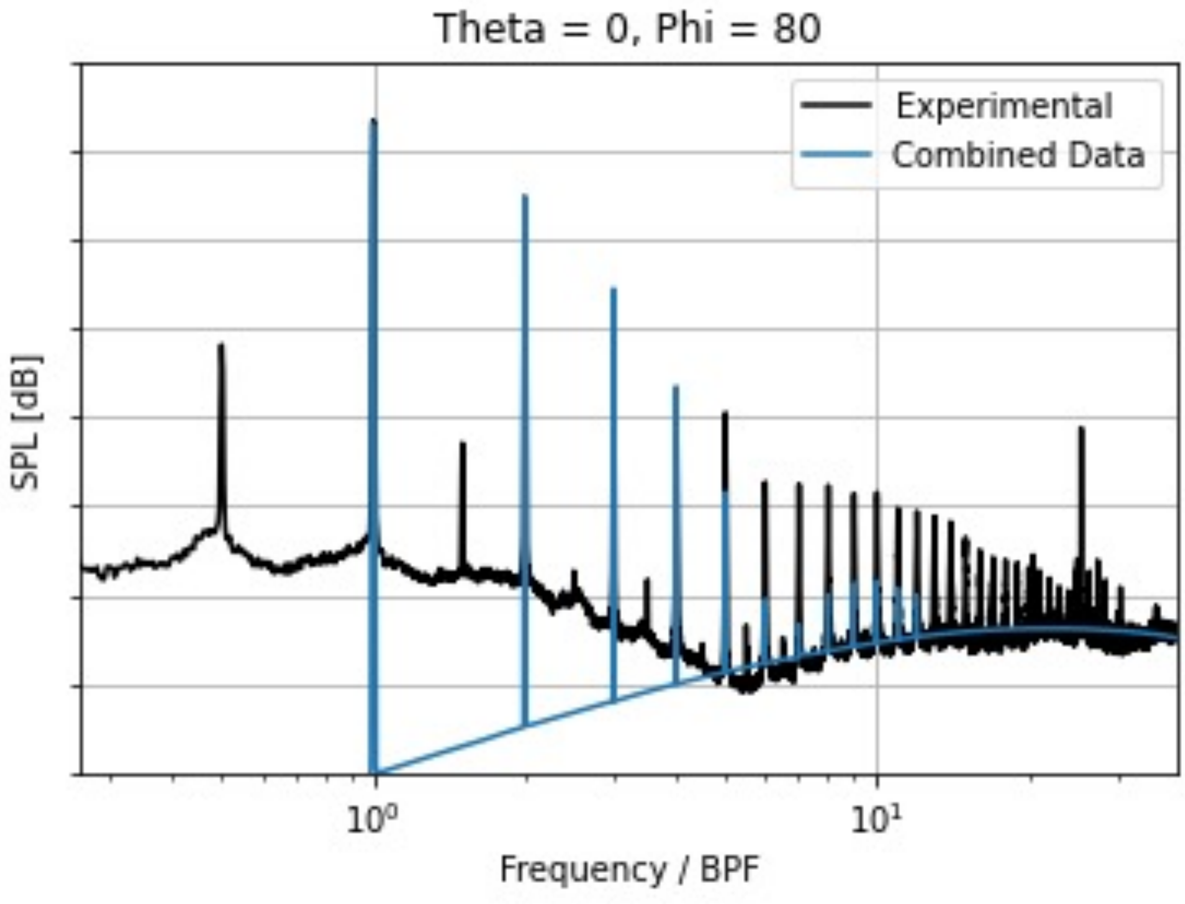
- Comparison Points
  - Worst: 1.3 ΔdB
  - SPL amplitude predictions improved at all additional observer locations



- Residual (sum of squares)
  - Lee Base: 35.1 ΔdB^2
  - Optimized scaling: 3.7 ΔdB^2

Frequency / BPF	Optimized Delta dB
5.2	0.5
7.8	-0.1
10.5	-0.6
13.1	-0.7
15.7	0.4
18.3	0.4
20.9	-0.3
23.6	0.1
26.2	-0.6
31.4	1.3
36.6	-0.3
41.8	-0.2

Combined Prediction



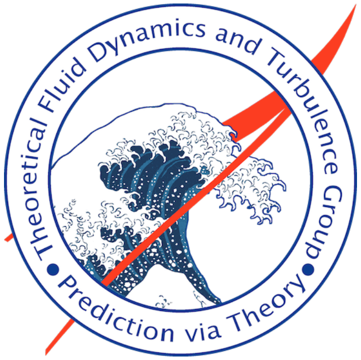
Note: Broadband model only predicts high frequency due to capturing only the trailing edge component.

Summary and Conclusion

- Effective and fast way to predict noise
- Tonal simulation
    - Predicts BPF acoustic radiation within 2.8% at the nominal RPM at hover condition
    - DUST predicts rotor's C_T within 2% of experimental data
    - Less accurate at higher speed flight conditions
    - RPM does not affect tonal model
- Broadband simulation
    - Empirical coefficients set by optimization algorithm for one setpoint at the observer location $\Phi = 80$ & $\theta = 0$, reduced error residuals by 89% at that location for the optimized case
    - Future work: expand optimization to improve results at additional observer locations

Thank you.

Questions?



Extra Slides

Coordinate System