Initial testing of 10” ducted propeller in hover

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In collaboration with ONERA

Spring 2021 Acoustics Technical Working Group VIRTUAL Meeting
April 14, 2021

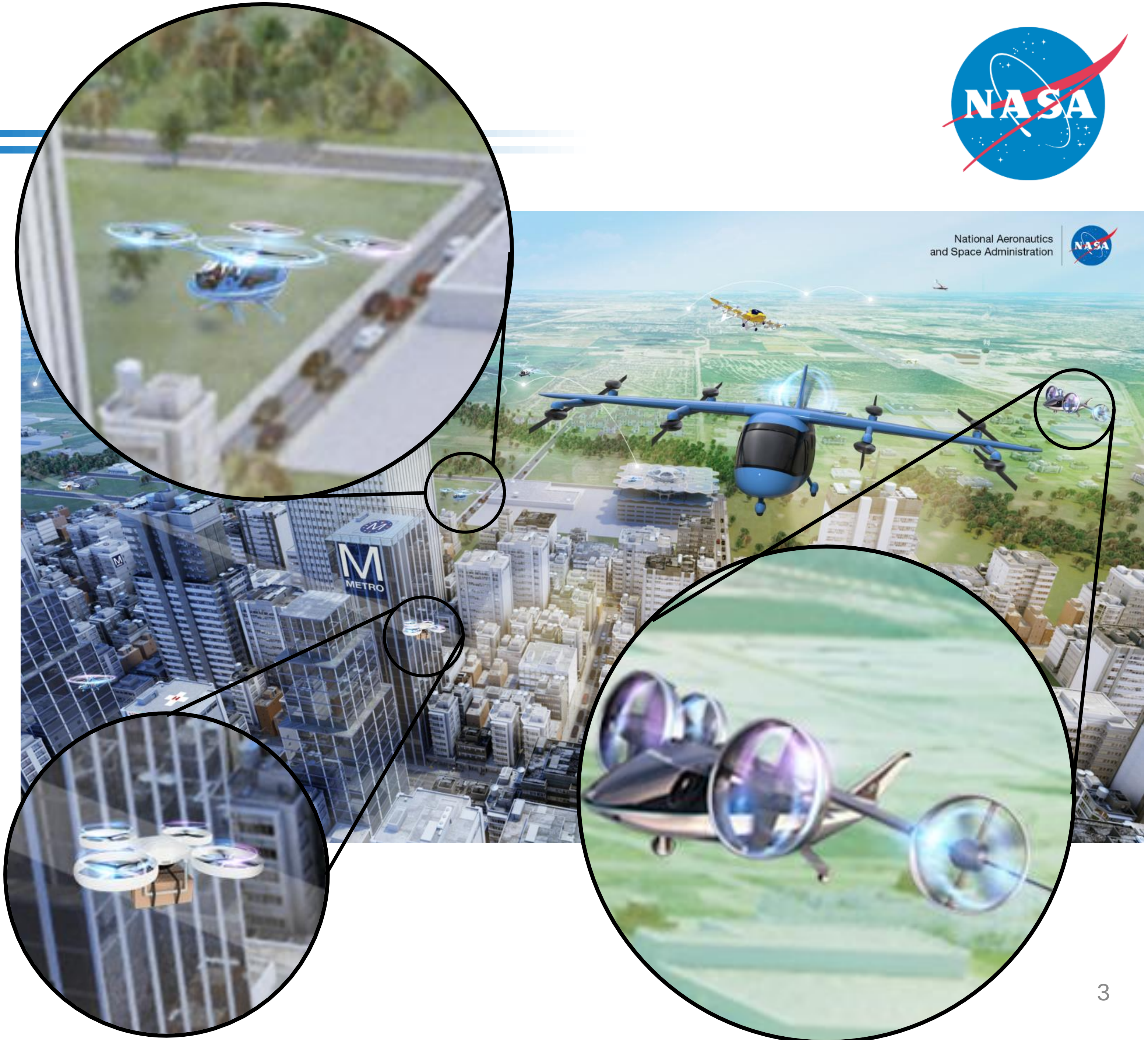
Outline

- Introduction
- Duct design and printing
- Facility and hardware set up
- Preliminary performance and acoustic data
- Future Work

Introduction

Objective: to help assess benefits of acoustic liners installed in a scaled duct

- Many AAM aircraft configurations are being considered, some of which have ducted propulsors
- Previous work on liner design and prediction have been done*
- This presentation will focus on the test setup and initial results



* *Simon, F. and Schiller, N., "ONERA/NASA Collaboration on Noise Reduction for Ducted Rotors," NASA Acoustics Technical Working Group Meeting, Apr 8, 2020.*

Design and set up

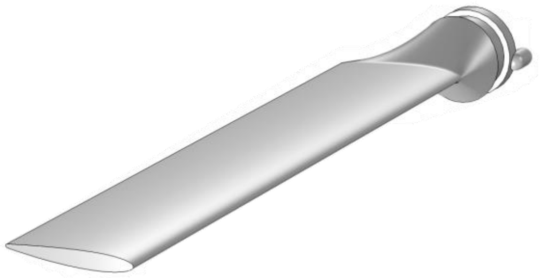
- Blade(s)
  - 9.6” diameter, 3-bladed rotor at 9,000 RPM
  - Target design thrust = 1.9 lbs
  - Tip pitch angle $\theta = 10°$
  - NACA 0012 airfoil, no twist
  - Blades manufactured via Stereolithography (SLA)

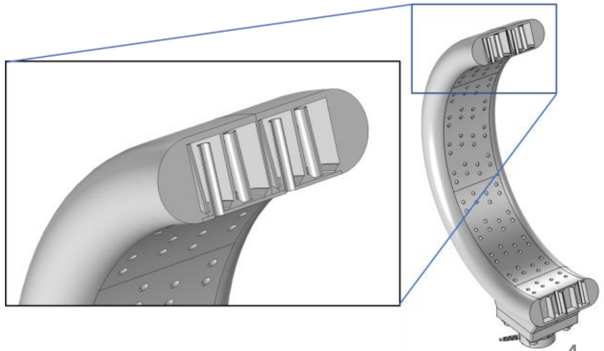
- Ducts
  - Two ducts
    - Untreated hardwall duct
    - Low resistance LEONAR lined duct (L02)
  - Straight ducts, 10” inner diameter,1.2” thick, 0.6” inlet and exhaust lip radius, 2.4” axial extent (of the straight duct section), blade tip clearance 4% of duct inner radius
  - Ducts manufactured via stereolithography (SLA)

L02 Duct

Hardwall Duct

Propeller Blade

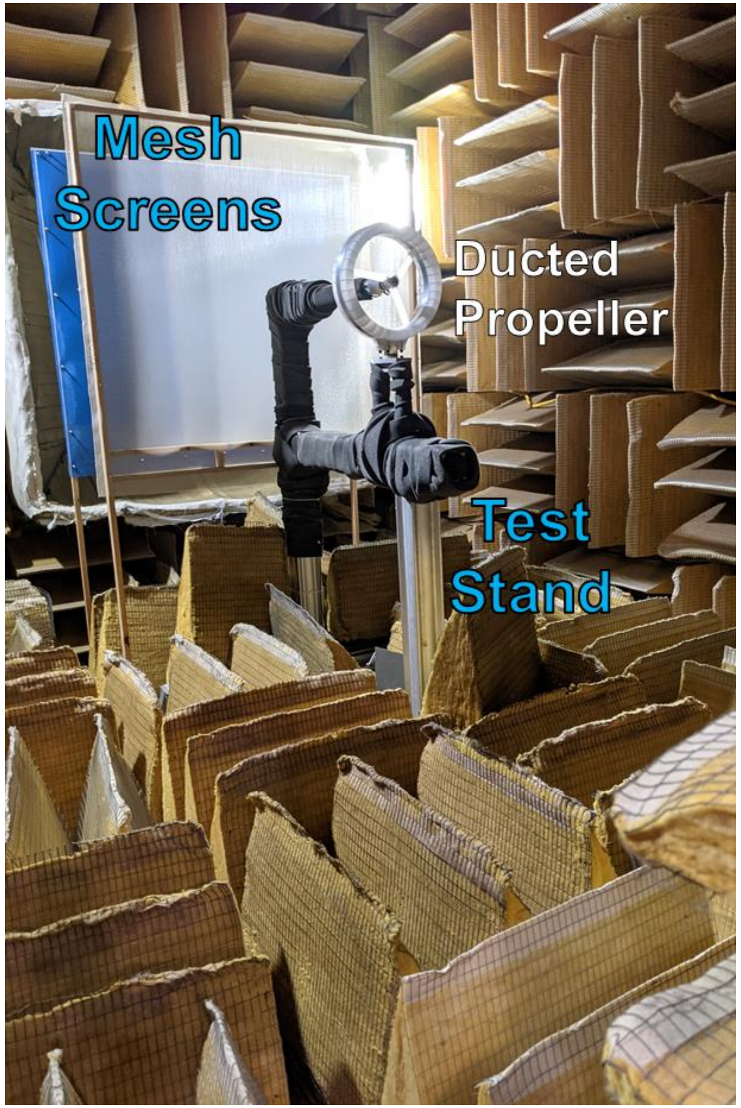




Experiment: Facility and Setup

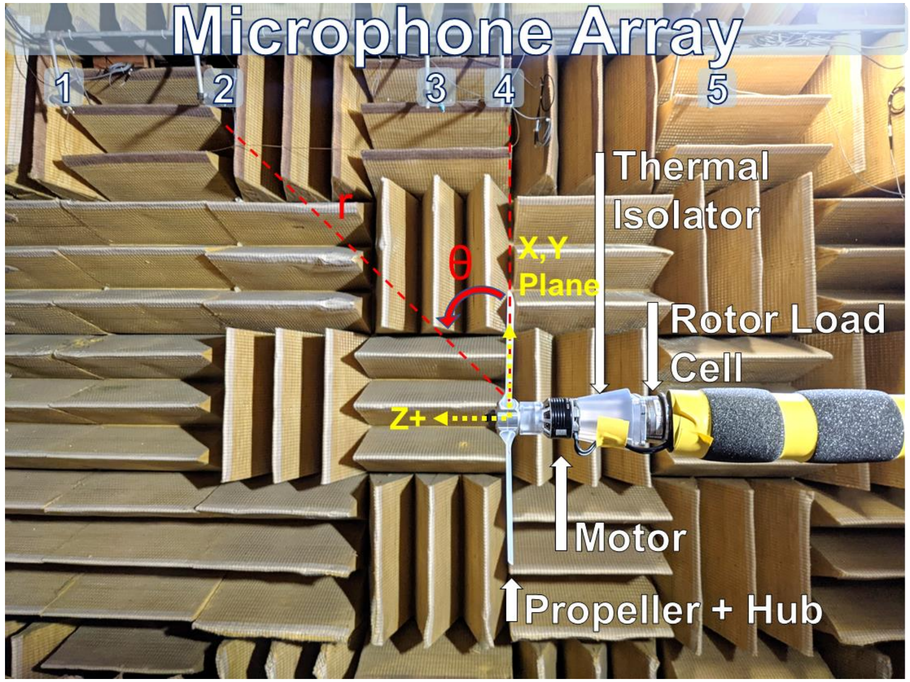
* Whiteside, S. K. S., Zawodny, N. S., Fei, X., Pettingill, N. A., Patterson, M. D., Rothhaar, P. M., "An Exploration of the Performance and Acoustic Characteristics of UAV-Scale Stacked Rotor Configurations", AIAA SciTech 2019, https://doi.org/10.2514/6.2019-1071

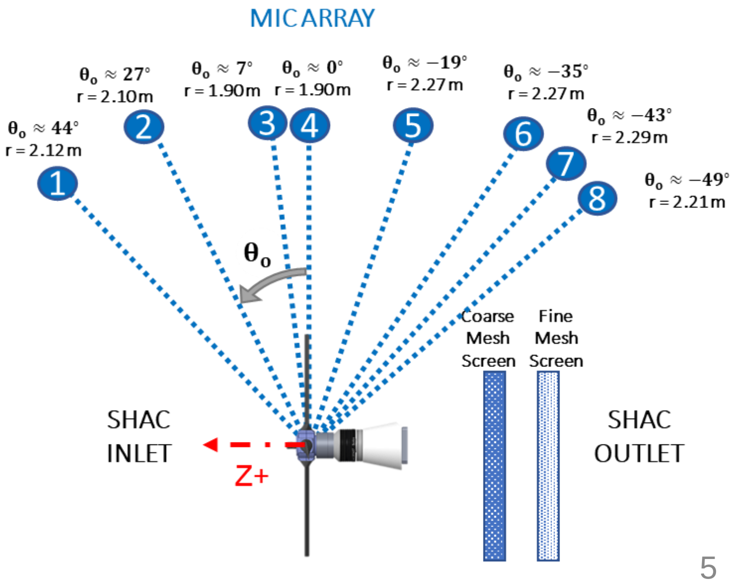
Small Hover Anechoic Chamber (SHAC)*



- Room dimensions = [3.87 x 2.56 x 3.26] m
  - Acoustically treated (cutoff down to 250 Hz)
  - Mesh screens reduce the onset of recirculation
- Hardware
  - KDE 2814XF-515 motor
  - Duct mounted on 1" 8020 axial track (~6" below rotor loadcell)

- DAS: Brüel & Kjær (BK) LAN-XI DAQ and BK Connect Software
  - 6 B&K Type 4939 Free-Field microphones + 2 B&K Type 4954B microphones
  - Laser sensor tachometer
  - 2x 6-Component AI-IA mini40 multiaxis load cell
  - Hot Wire Probe + Thermistor





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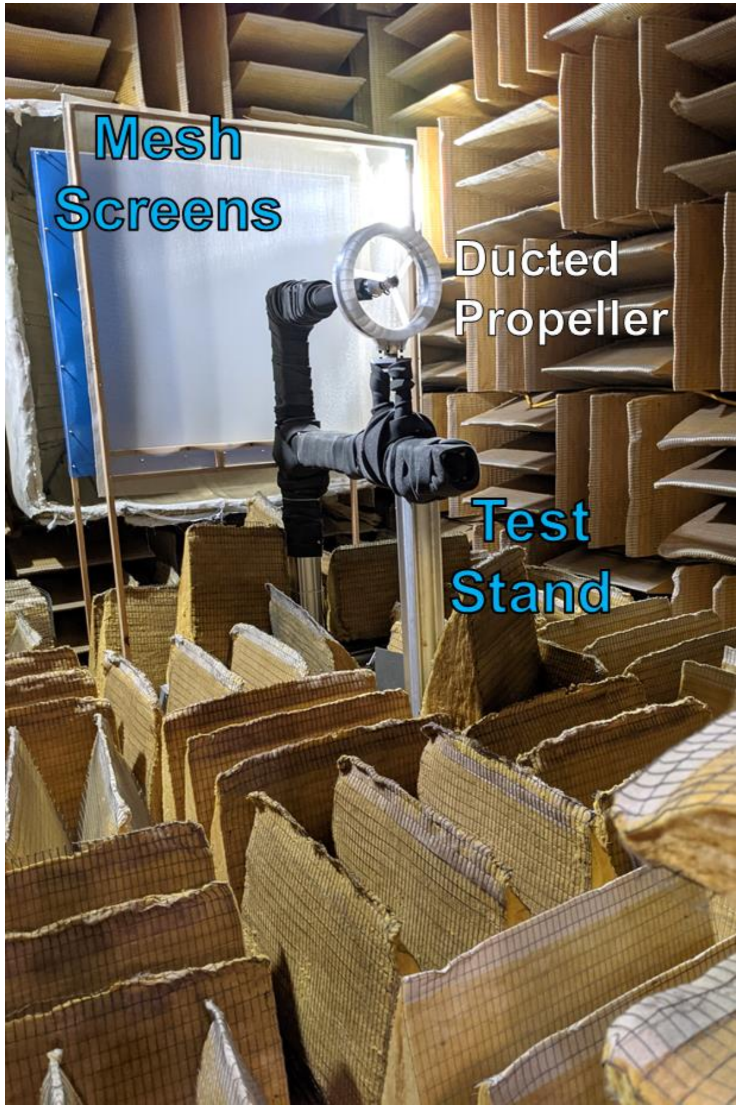

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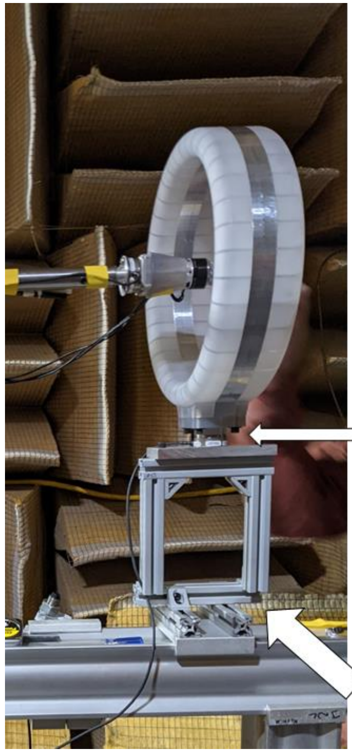
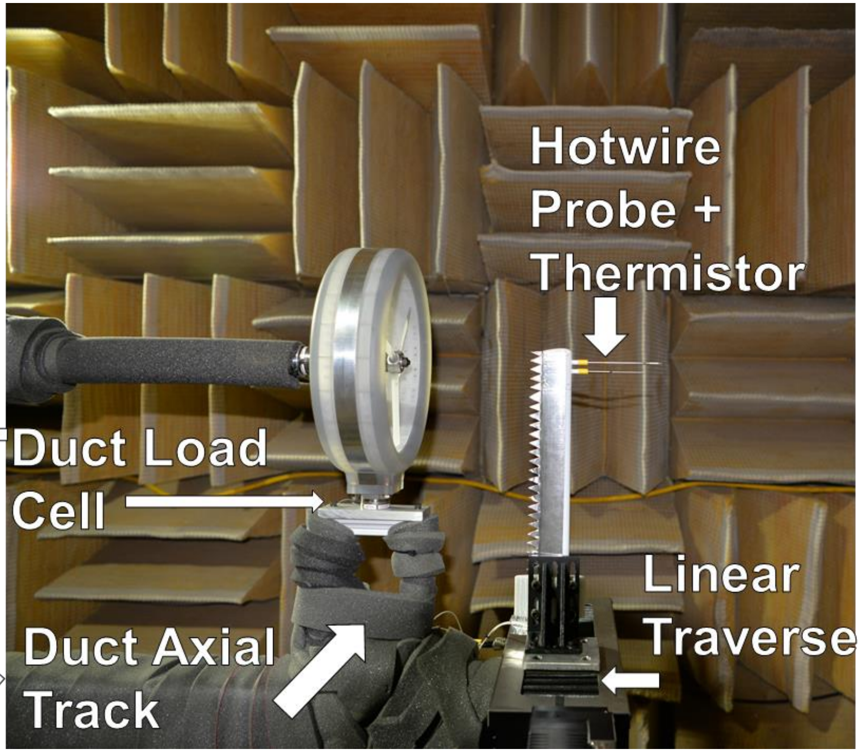




Testing configurations

Three propeller configurations

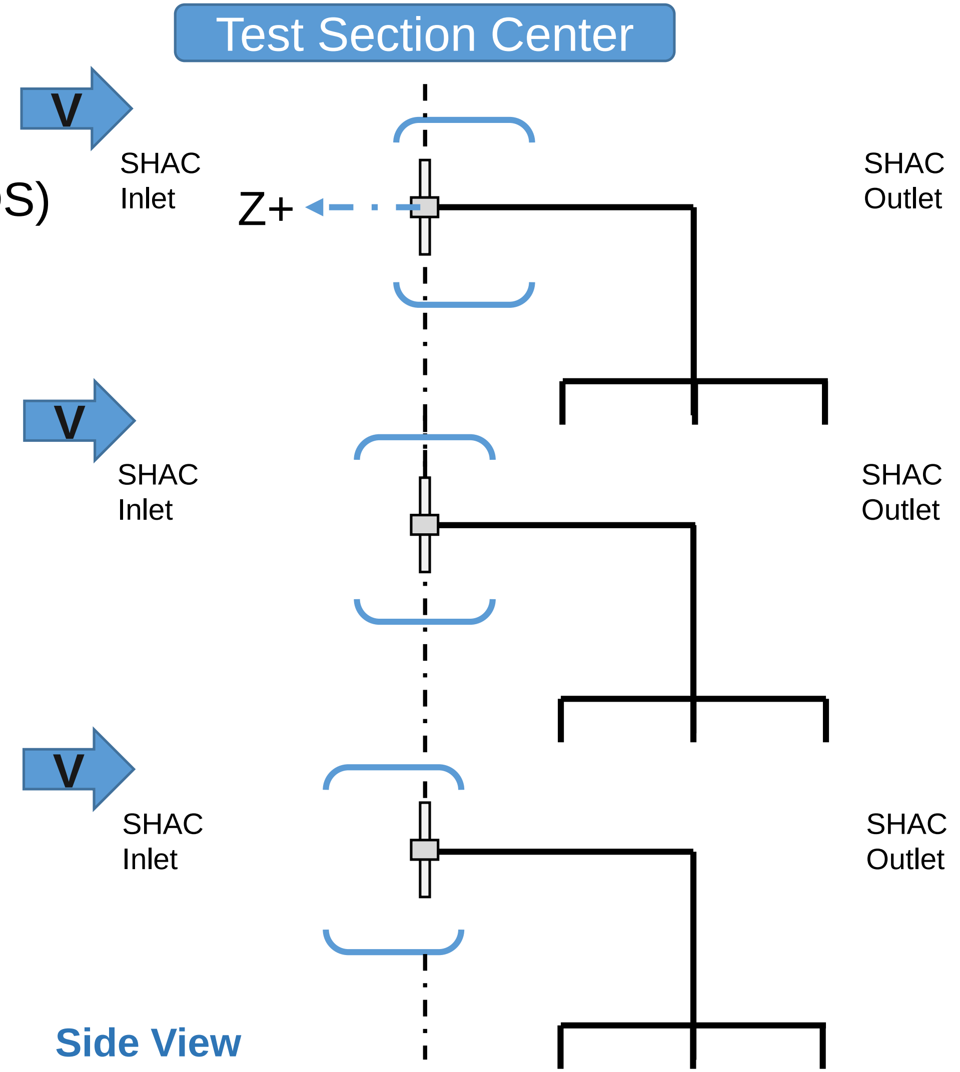
- Isolated propeller (no duct)
- Hardwall untreated ducted propeller
- L02 treated ducted propeller

Two flow conditions

- Background flow on (V ~5 m/s)
- Background flow off (V = 0 m/s)

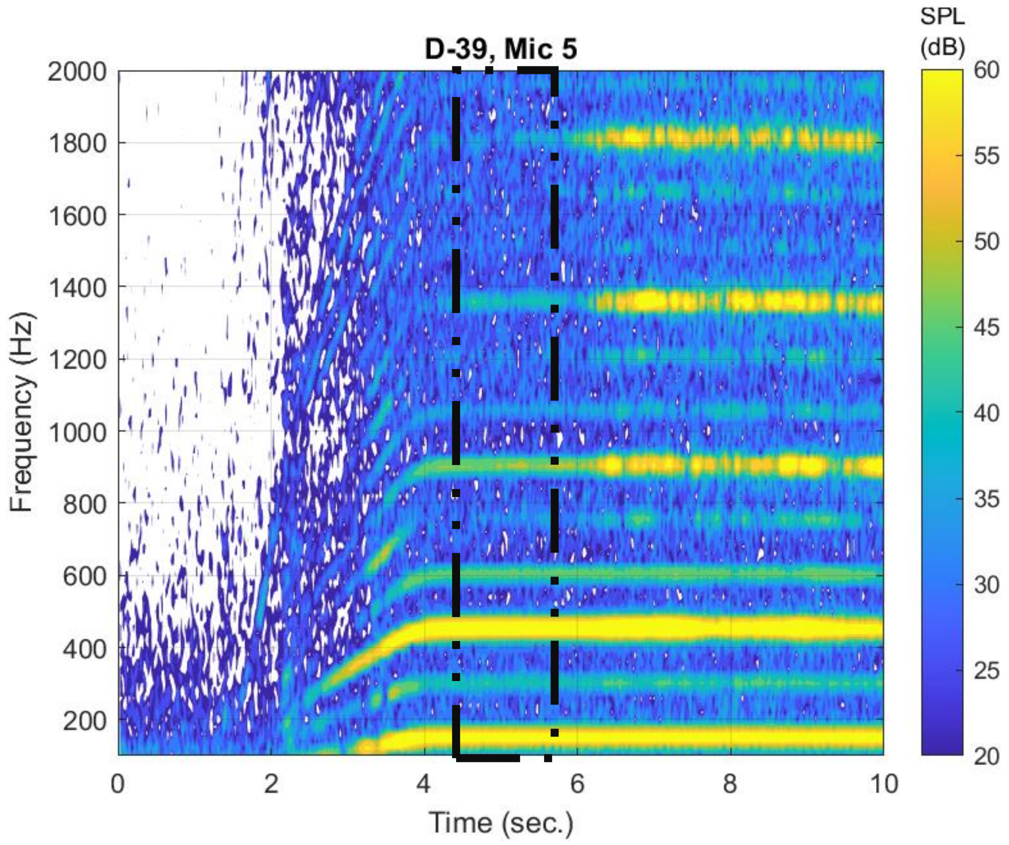
Three duct positions

- Duct downstream (DS)
- Duct centered
- Duct upstream (US)

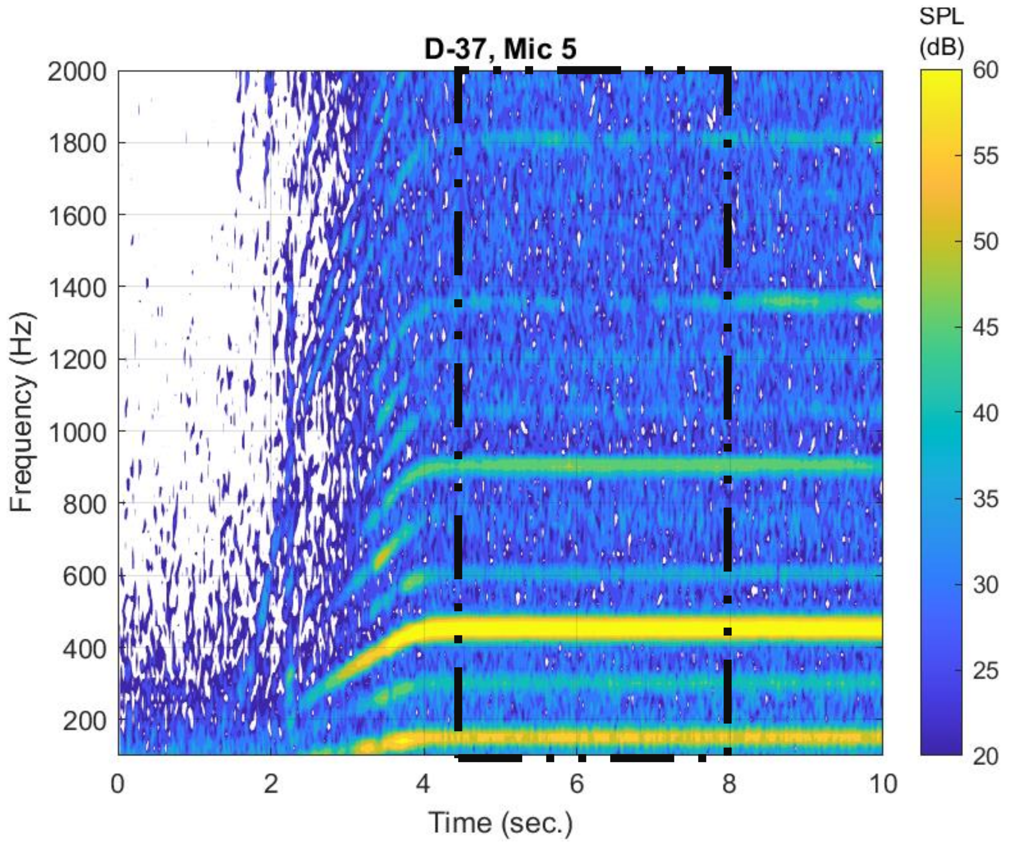


Recirculation in Static Tests – Isolated Propeller

Without Meshscreen Treatment
~1.5 seconds before onset of recirculation

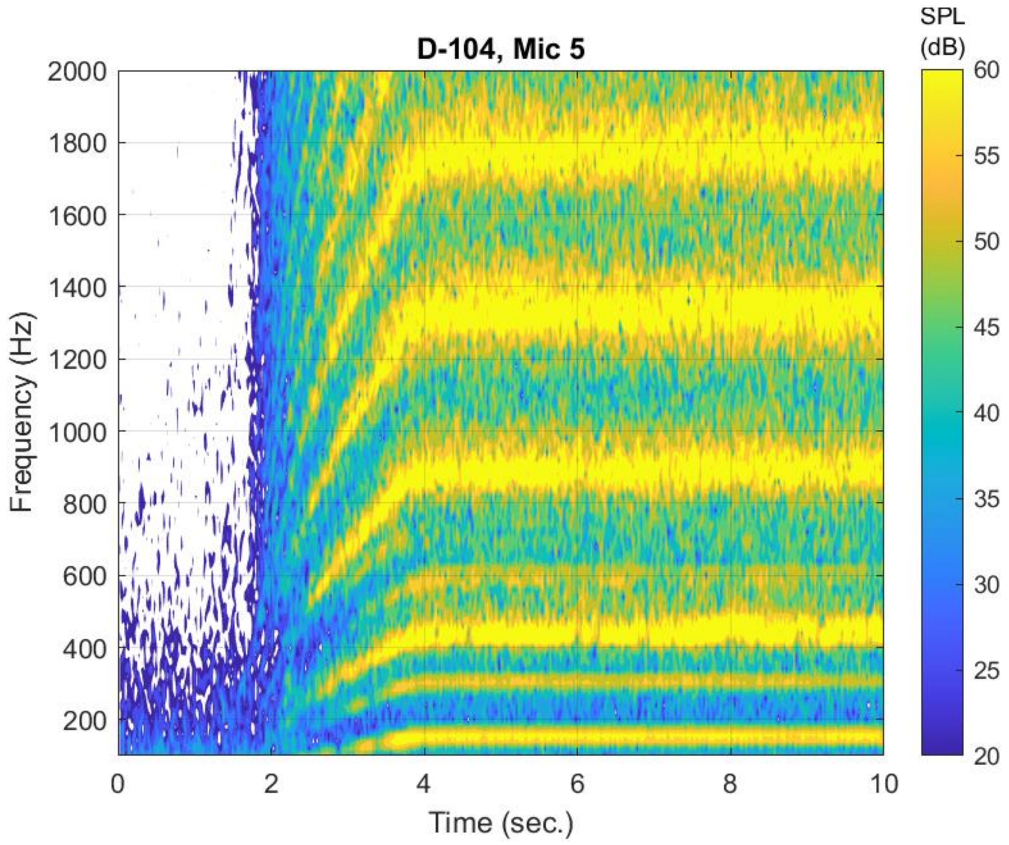


With Meshscreen Treatment
~3.5 seconds before onset of recirculation



Recirculation in Static Tests – Hardwall Duct

Without Meshscreen Treatment
Onset of recirculation not apparent



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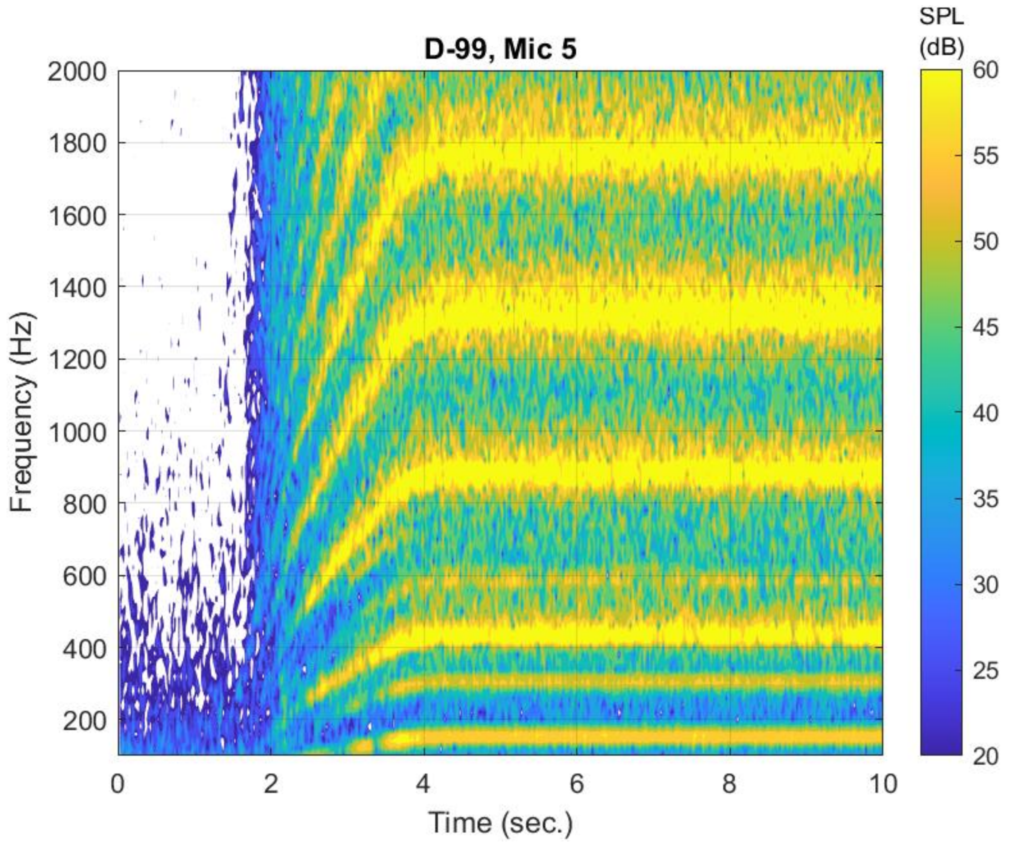
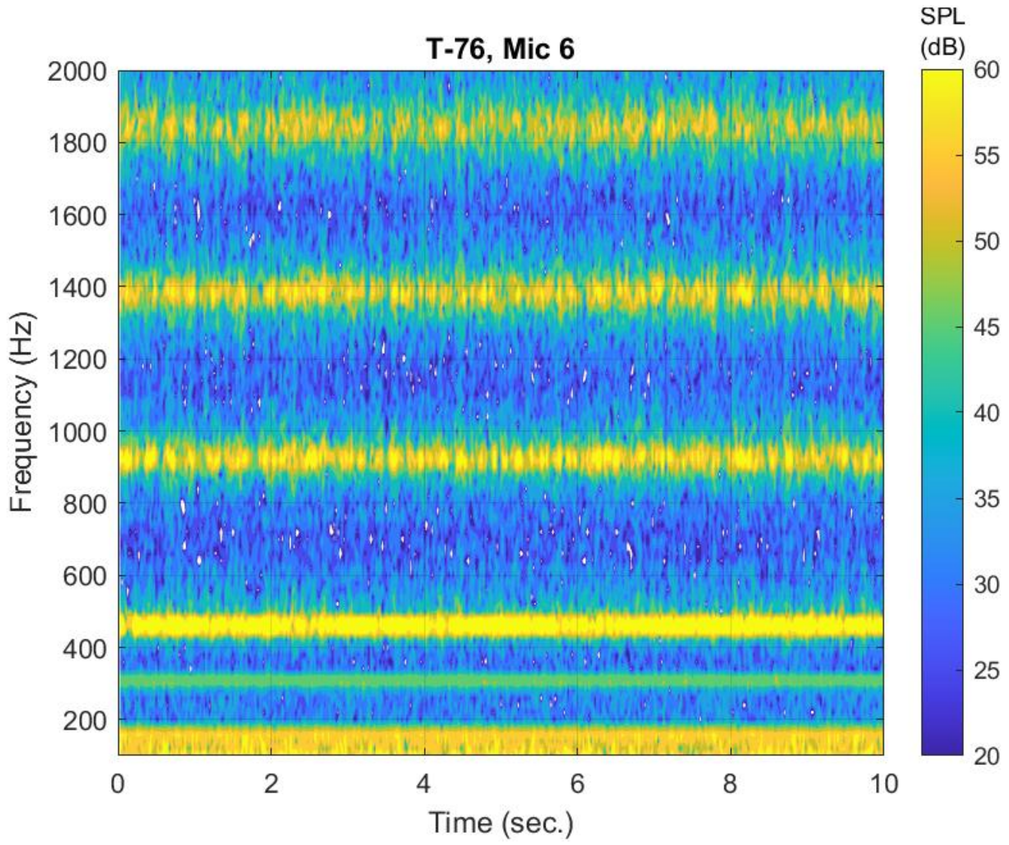
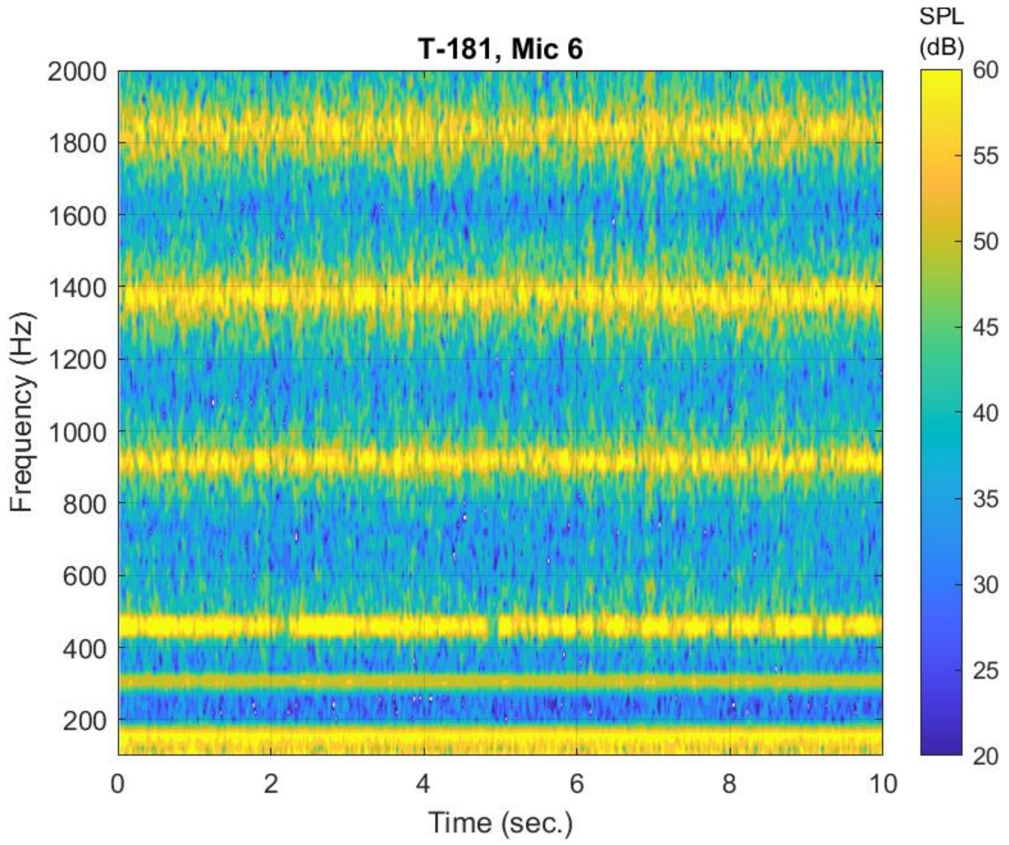


Flow on cases – no recirculation concerns

Isolated Propeller



Hardwall Duct



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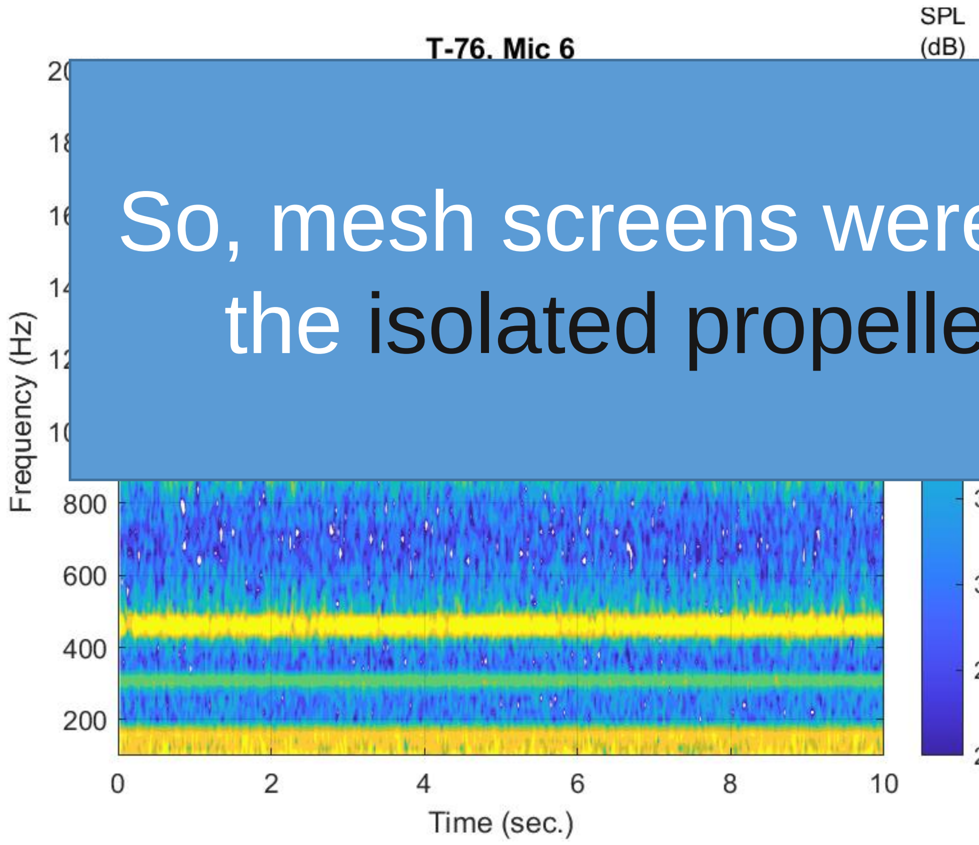

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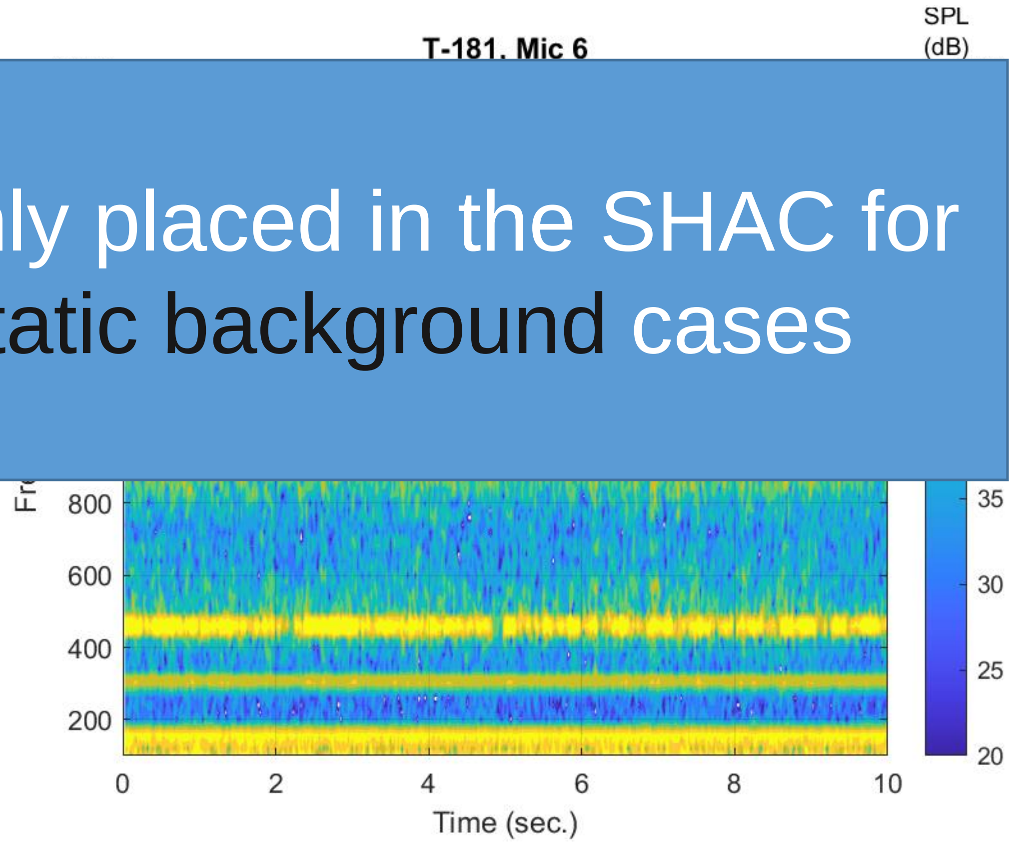
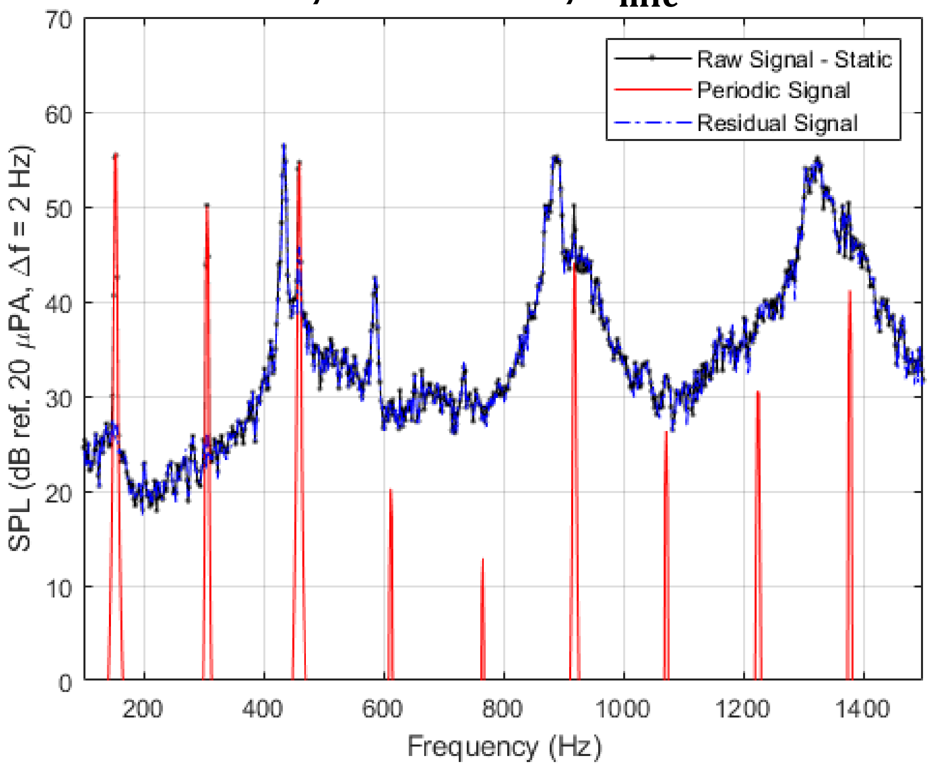


So, mesh screens were only placed in the SHAC for the isolated propeller, static background cases

Why have the background free stream flow on?

Hardwall Duct US

Static, 9198 RPM, $\theta_{mic} = 0°$



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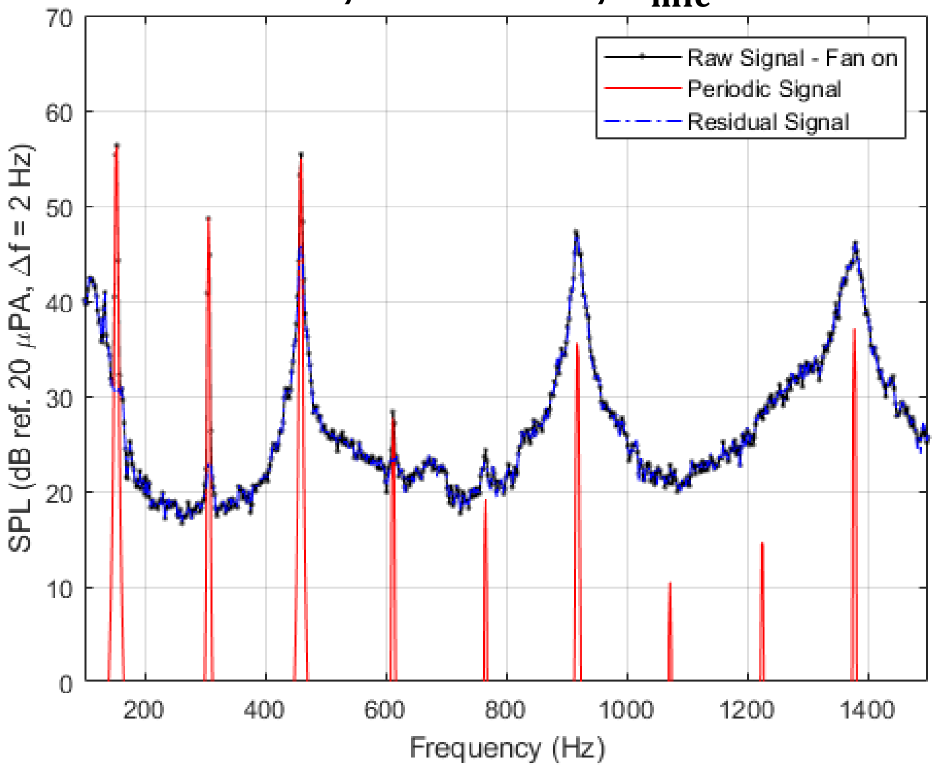

- With no background flow on (static), the spectrum shows additional tonal content below the low harmonic BPFs.
- This is consistent at multiple rotation rates and could be due to inlet separation.

- A background flow of approximately 5 m/s was turned on in the SHAC.
- This removed the additional low frequency tones, as well as “splitting/spreading” behavior.
- The freestream may be helping reattach the flow

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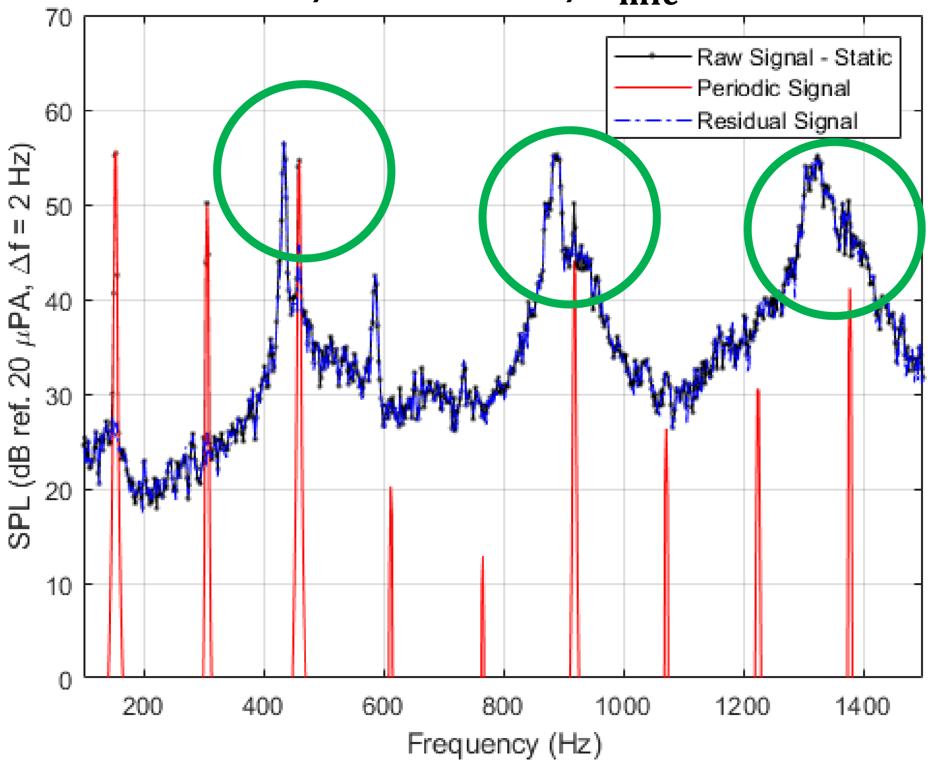

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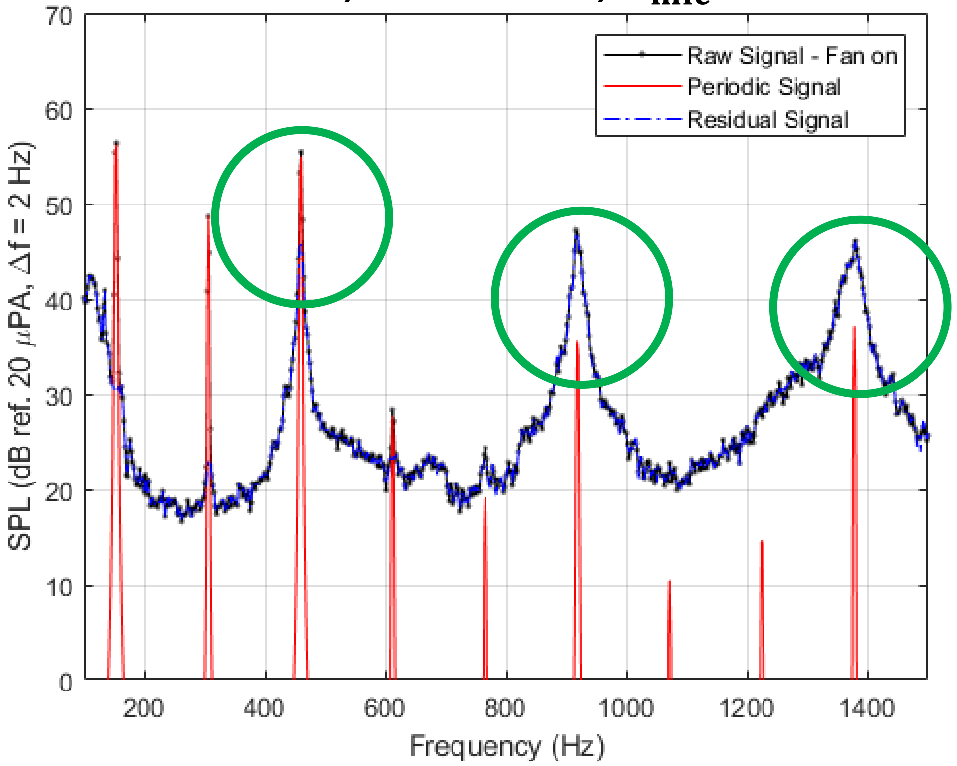

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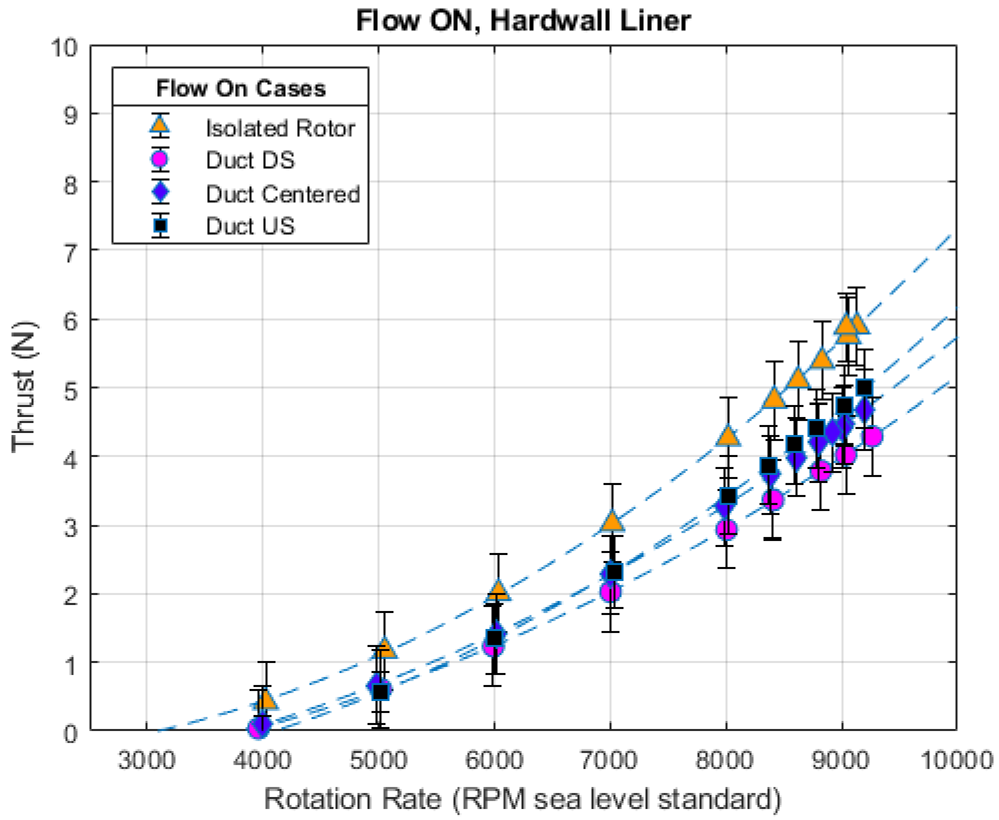
Performance Results

Flow off, 9000 RPM sea level standard

- The **isolated propeller** produces **1.7 lbs** of thrust
- The **ducted propellers** produce **~1.5 lbs** of thrust with the ducts center installed, with **~0.55 lbs** of that being generated by the ducts

Flow on, 9000 RPM sea level standard

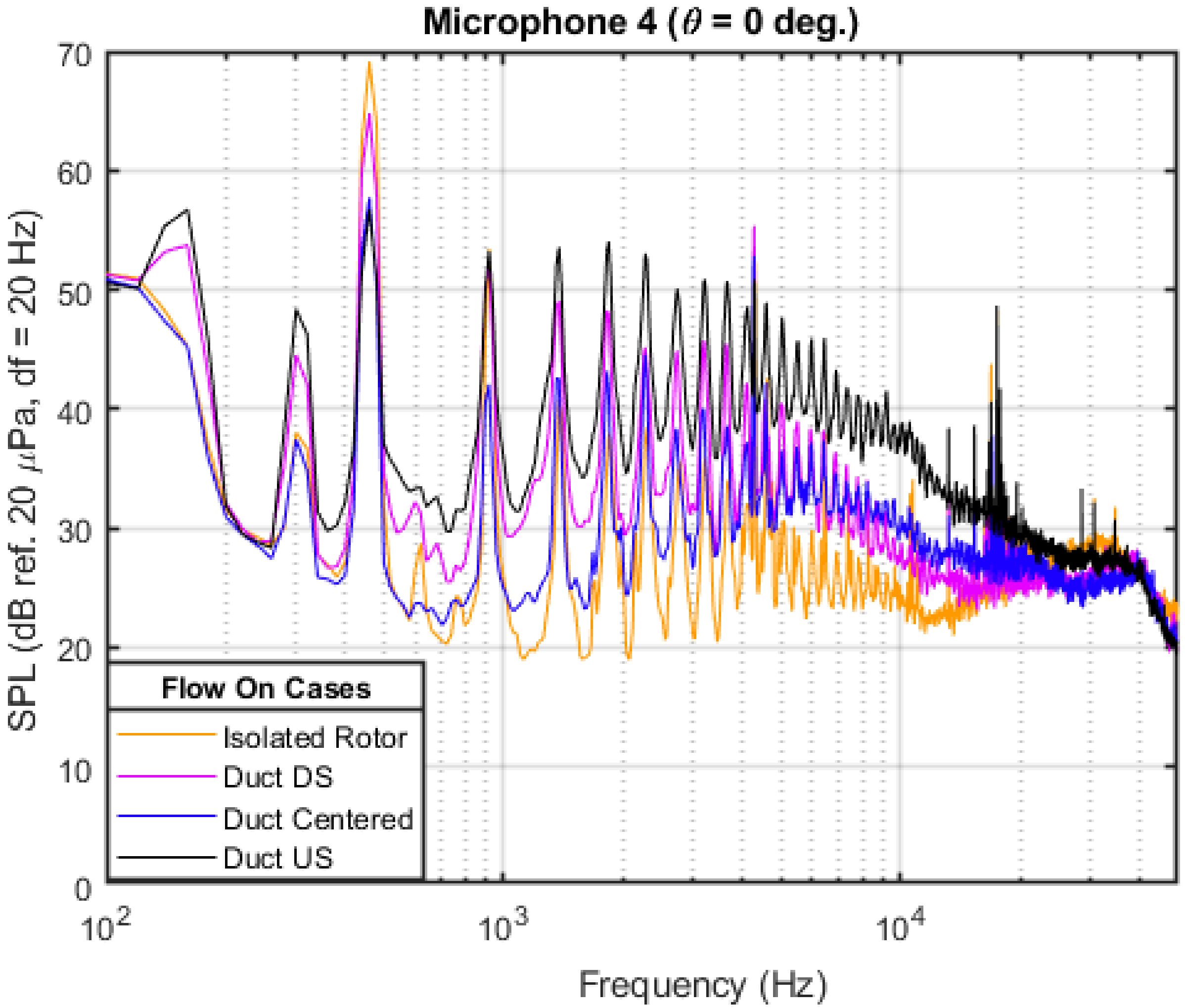
- The **isolated propellers** produces **1.3 lbs** of thrust
- The **ducted propellers** produce **~0.97 lbs** of thrust with the ducts center installed, with **~0.1 lbs** of that being generated by the ducts
- The **net thrust** and **torque** increase when moving the ducts **upstream** for the **flow ON** cases.



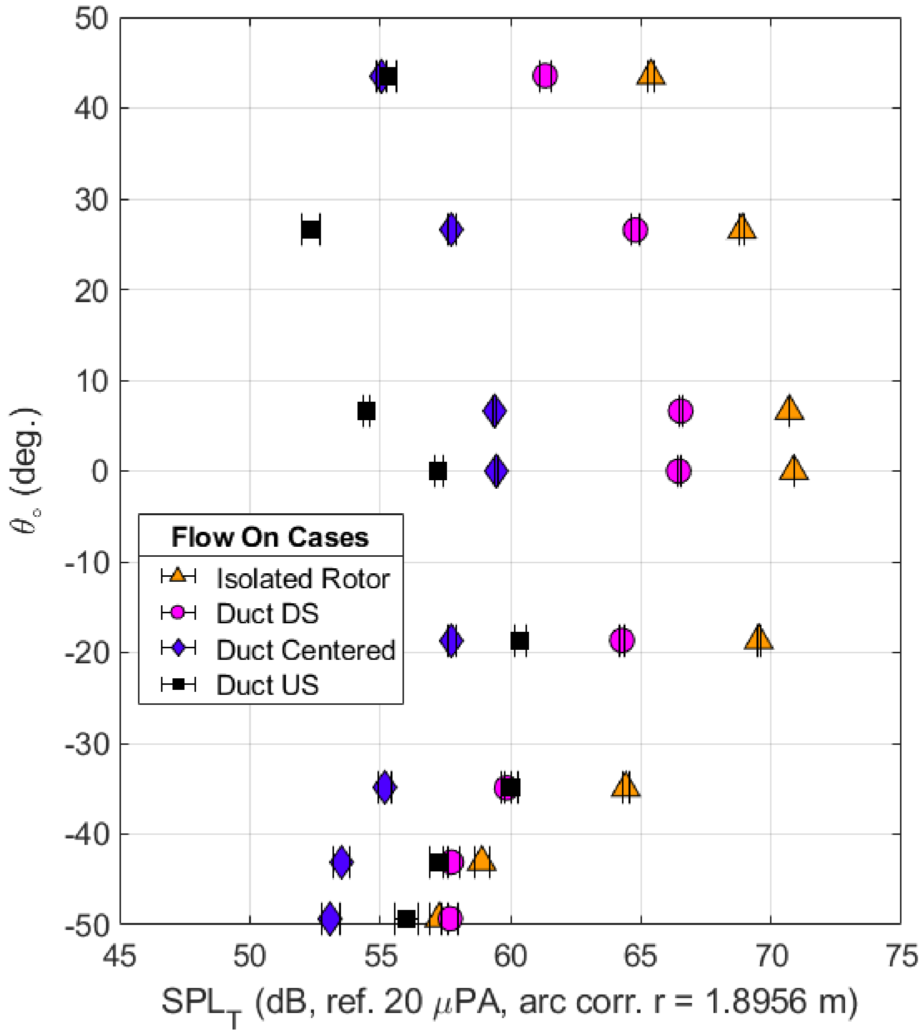
Note: duct is not aerodynamically designed and may not be the most optimized configuration.

Acoustic Results: Hardwall Duct Flow On

Raw Spectra

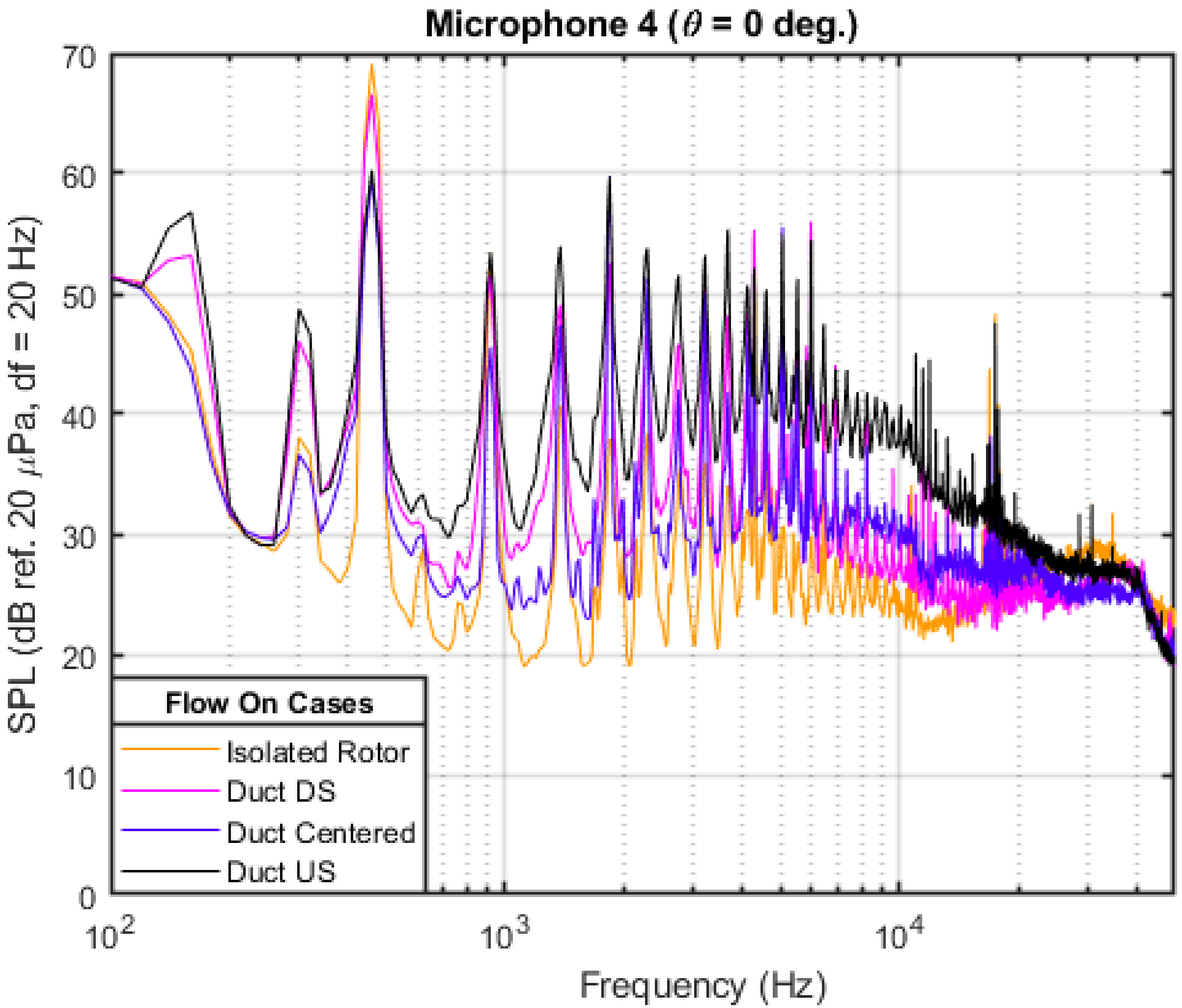


Extracted BPF Tone

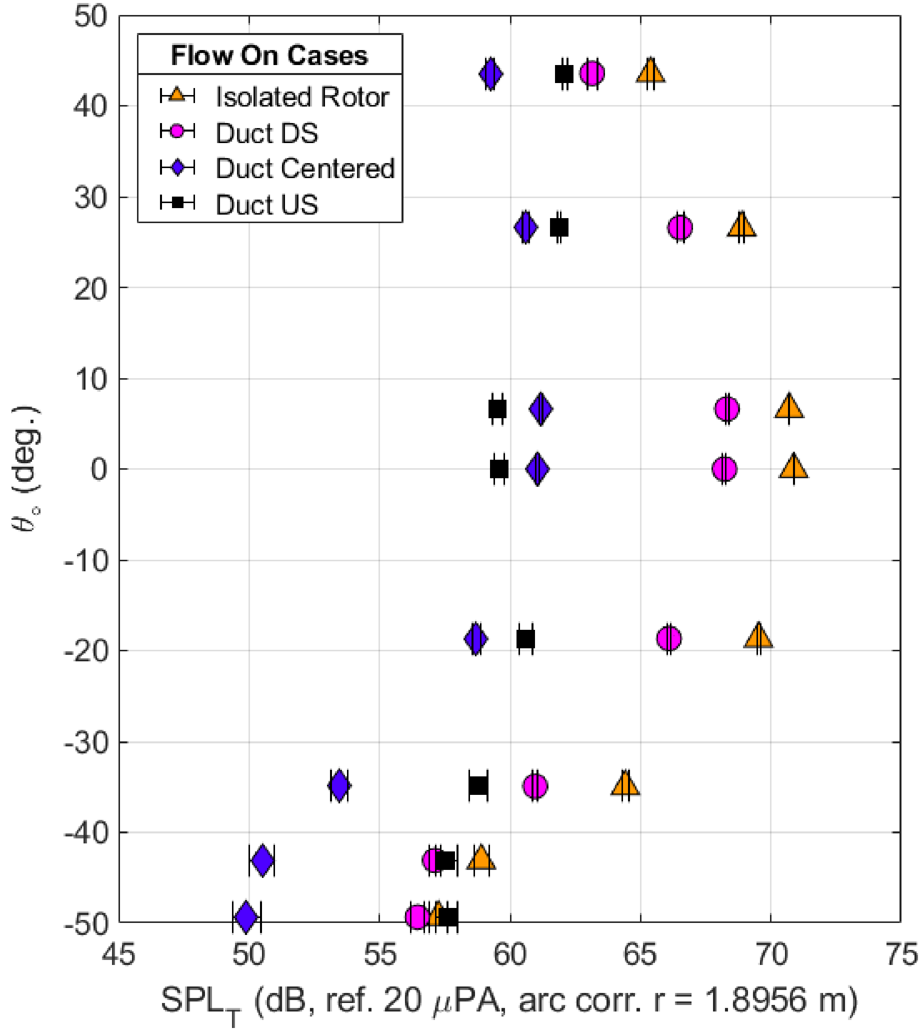


Acoustic Results: L02 Duct Flow On

Raw Spectra

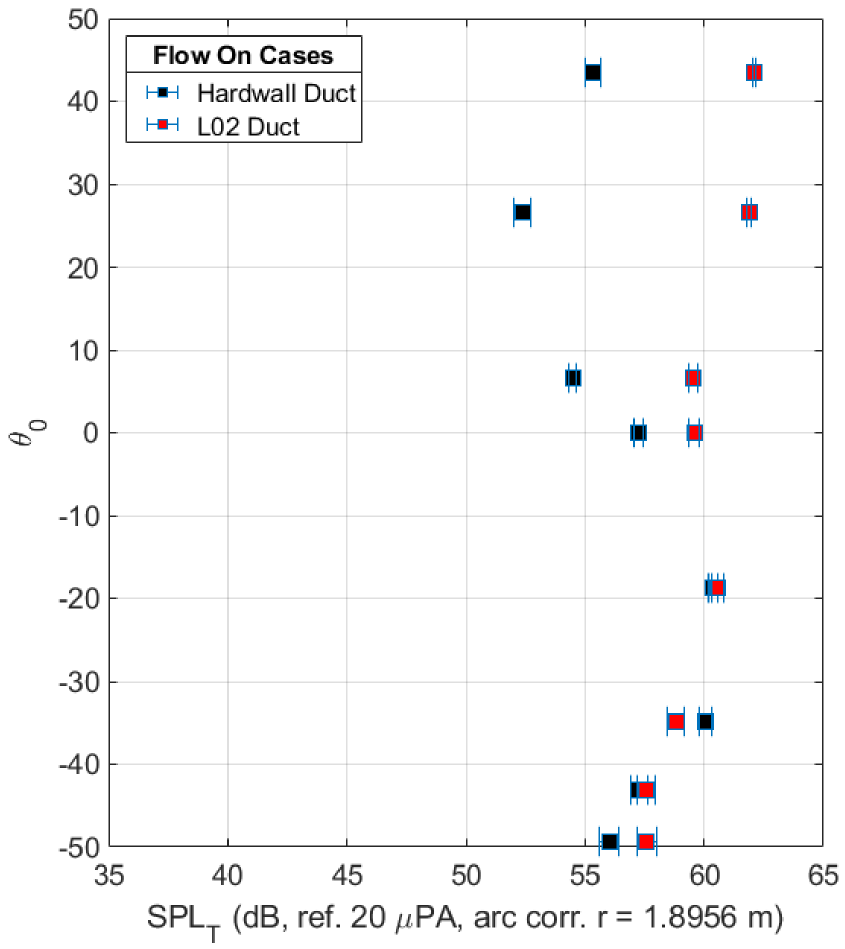


Extracted BPF Tone

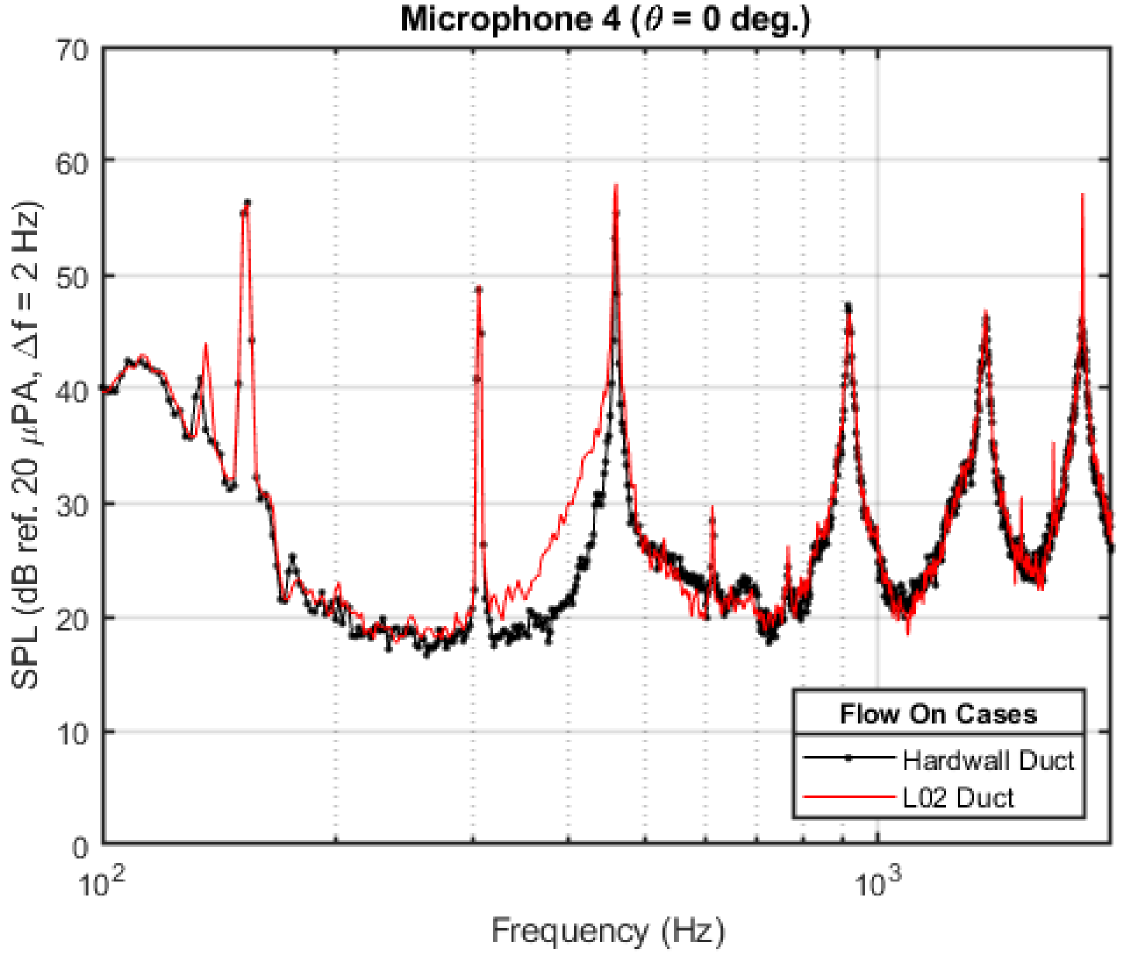


Initial Duct Comparisons – Duct US

Flow On – Extracted BPF Tone

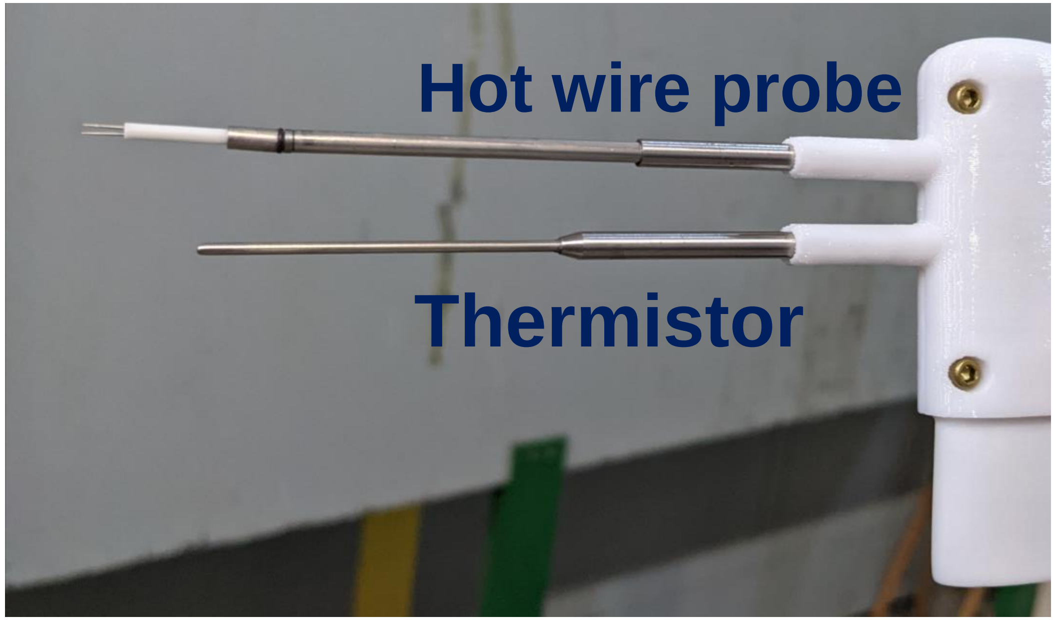


Flow On – Raw Spectra



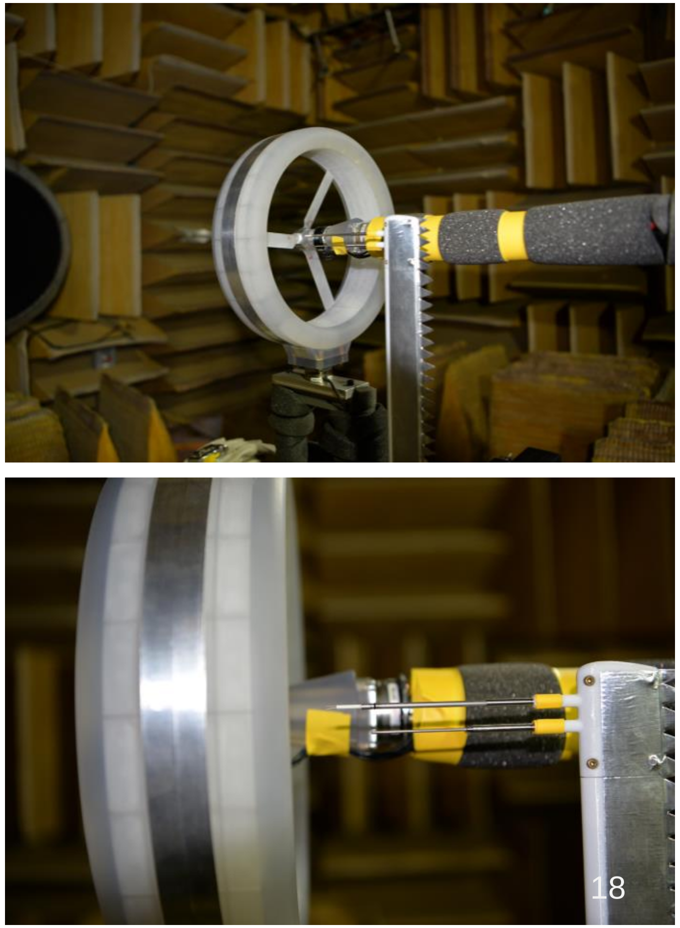
Additional Measurements: Hot Wire Probe

- Motivation
  - To diagnose flow separation near inlet lip
  - To get a better sense of hydrodynamics responsible for large increase in broadband noise
- Two surveys
  - Freestream hot wire survey
  - Wake survey
- Two probes
  - Mini CTA Anemometer 54T42 with 55P16 hot wire probe
  - 90P10 thermistor



Free Stream Survey

Wake Survey



Conclusions

- Experiment data were obtained for various ducted propeller configurations

- Future work
  - Process hot wire data
  - Process acoustic and performance data and identify trends in BPF

- Things to Consider
  - When the duct is installed, the system produces less thrust at the same RPM than when the propeller is isolated. Therefore, a better comparison may be made at a low isolated rotor RPM case
  - When comparing the tonal content of duct cases, it may be best match mechanical rotation rate, as opposed to the corrected sea level standard rotation rate, because the liner is tuned to a certain frequency

Acknowledgments

Funding

Revolutionary Vertical Lift Technology (RVLT) Project

ONERA

Special Thanks

Frank Simon

LSAWT Crew: John Swartzbaugh, Stan Mason, Jeff Collins, Bryan Lamb, Mick Hodgins

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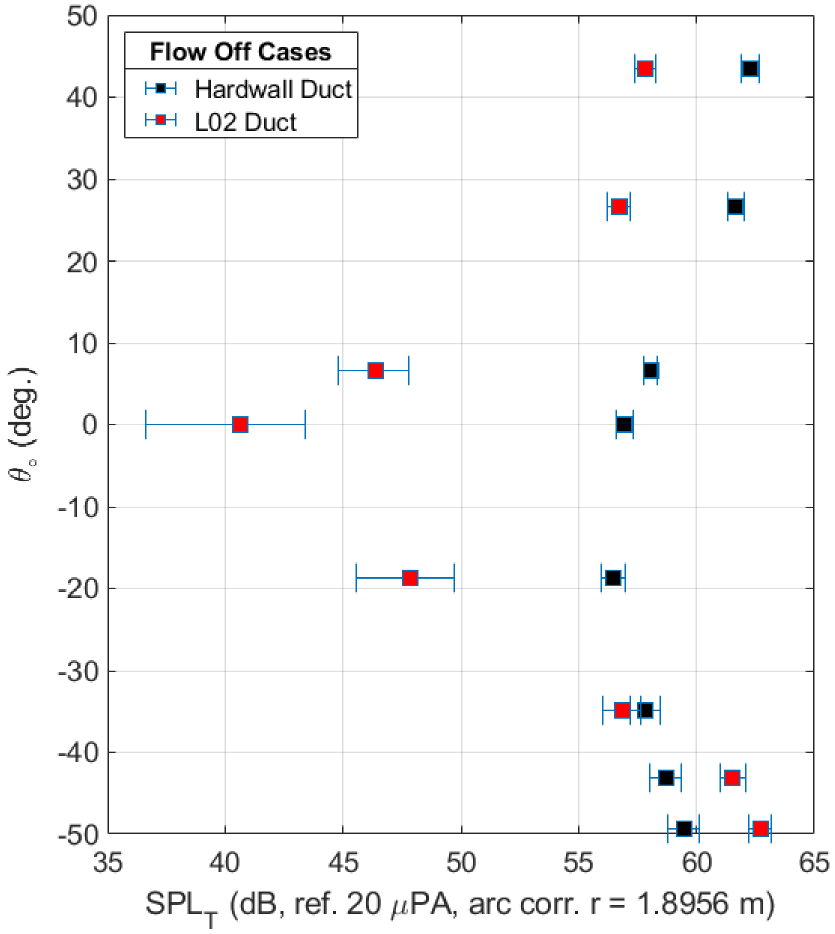
Thank you, any questions?

Extra Slides

Initial Duct Comparisons – Duct US

Flow Off – Extracted BPF Tone



Flow Off – Raw Spectra