EESC • USP
São Carlos School of Engineering
University of São Paulo

SPRING SCHOOL
AEROACOUSTICS

An overview of research conducted at the EESC-USP Fan Rig

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Overview

- SILENCE Research Project: a joint venture between Brazilian universities, Embraer, and government funding agency.

- Two topics investigated at the Department of Aeronautical Engineering at the São Carlos School of Engineering: airframe noise and fan noise.

- Fan noise is investigated with three approaches
  - Semi empirical/semi analytical
  - Computational (PowerFlow)
  - Experimental (**EESC-USP Fan Rig**)

Outline of this talk

- Objectives
- Description of the rig
- Spectral analysis
- Modal analysis and beamforming
- Semi empirical model
- Future work

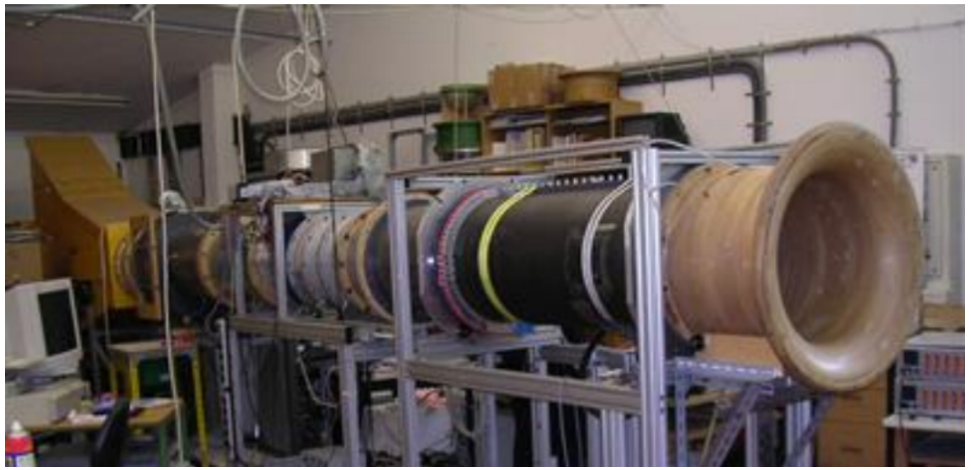
Objectives

- EESC-USP Fan Rig **purpose**:
  - Investigate the noise generating mechanisms of fan
  - Provide experimental data for other studies (including liner technology development at UFSC)

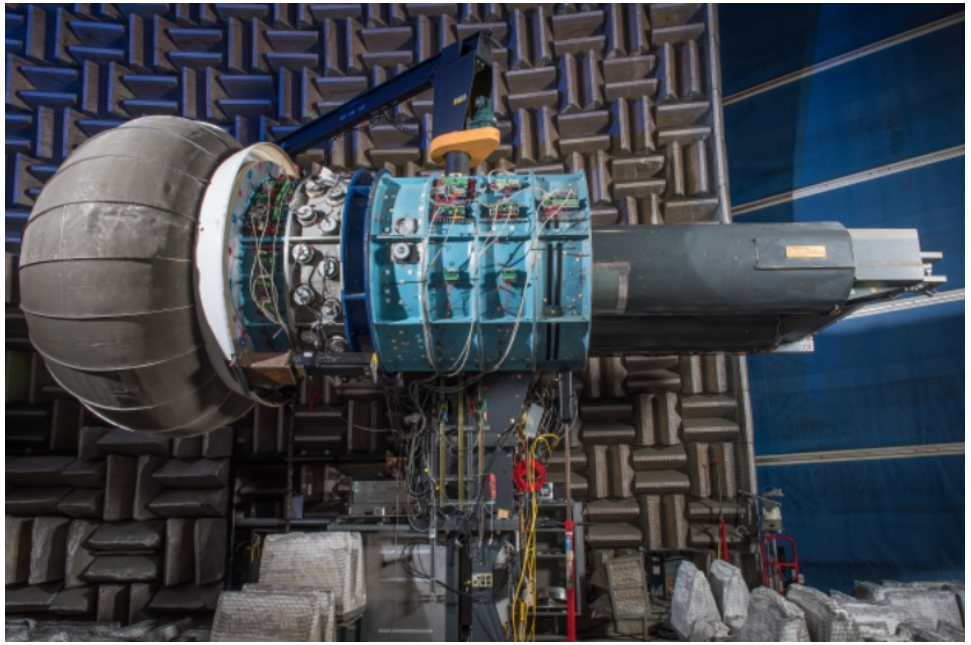
- Results are based on baseline measurements of a parametric campaign using three main parameters
  - Rotational speed (fan speed)
  - Throttling at the outlet (fan loading)
  - Rotor-stator spacing

Objectives

- Two basic options for rig design



DLR



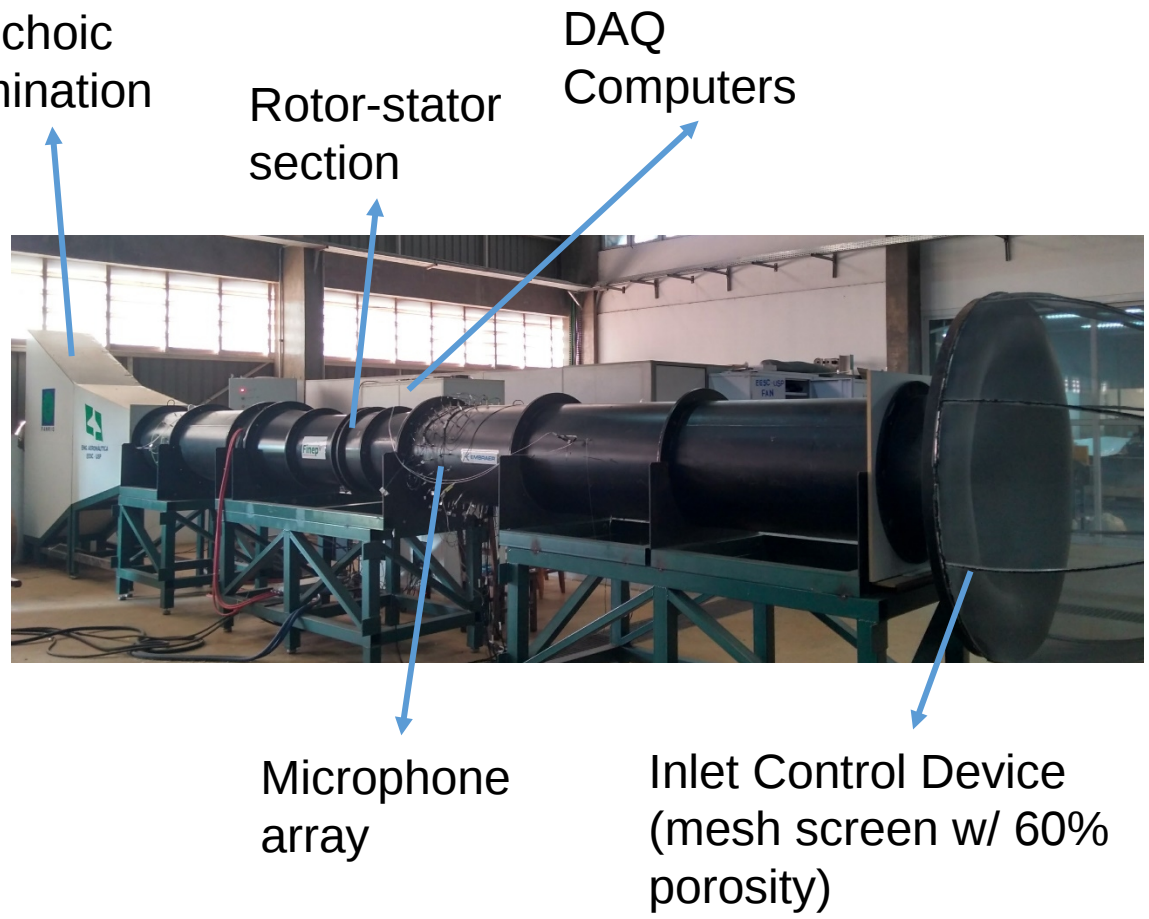
NASA

The EESC-USP Fan Rig

- EESC-USP Fan Rig: long-duct, low-speed fan aeroacoustics wind tunnel

- Rotor-stator geometry from ANCF, scaled down to 0.5 m diameter (16 blades and 14 vanes)

- Measurements systems:
  - Acoustic Measurements
  - Flow Measurements



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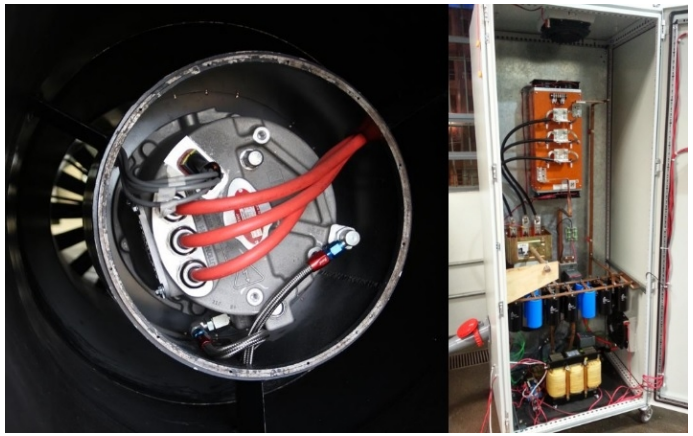
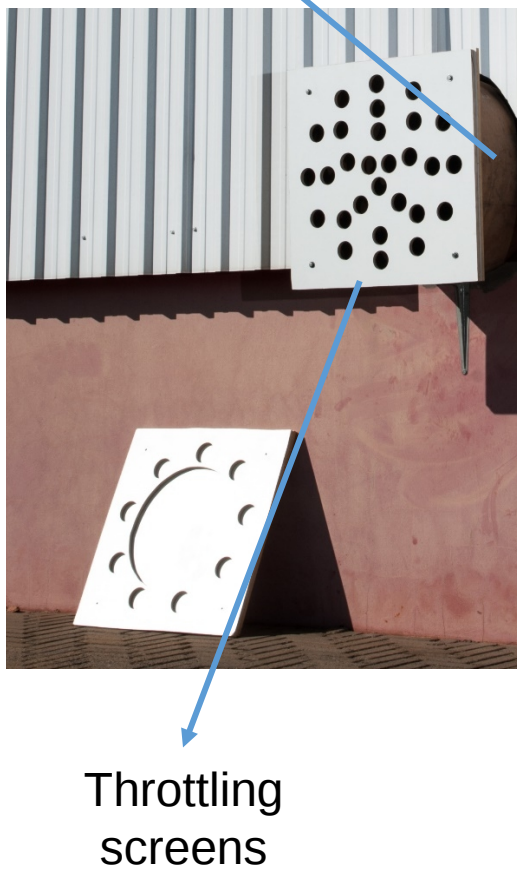


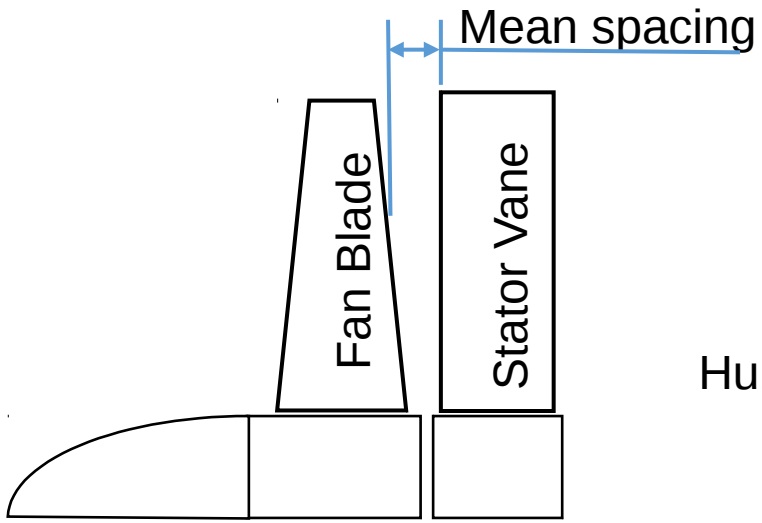
The EESC-USP Fan Rig

- Powered by a 100 hp electrical motor, up to 5000 rpm
- RPM is controlled via motor software (limited by vibration, which is acceptable up to 4500 rpm)
  - Velocities tested: 4500, 4250, 4000, 3750 and 3500 rpm
- Throttling is set using exchangeable screens at the outlet (they limit mass flow within the duct)
  - Tested configurations: Open throttle, 24.3%, 37.7%, 52.2%, 63.0%, 74.7% area restriction



The EESC-USP Fan Rig

- Rotor-stator spacing is set by bringing the fan upstream
  - Three configurations: 0.43 s/c, 0.95 s/c, 1.5 s/c (mean distance between blades TE and vanes LE, divided by blade chord)



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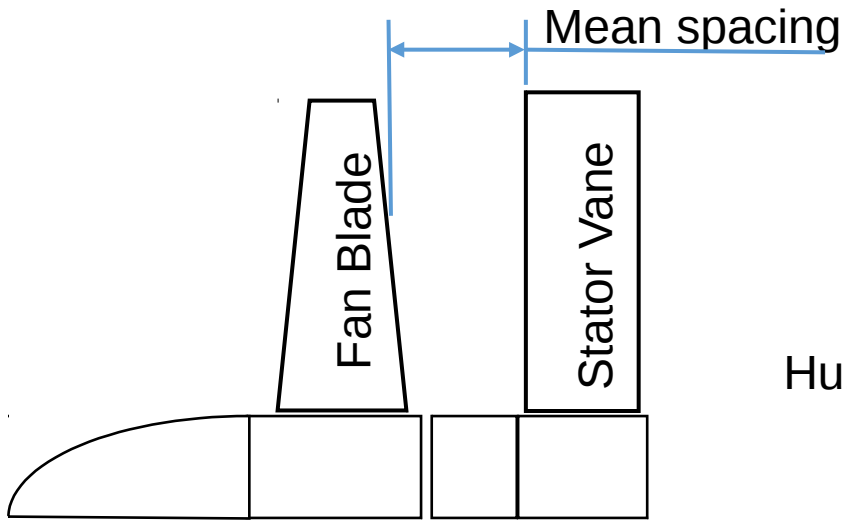
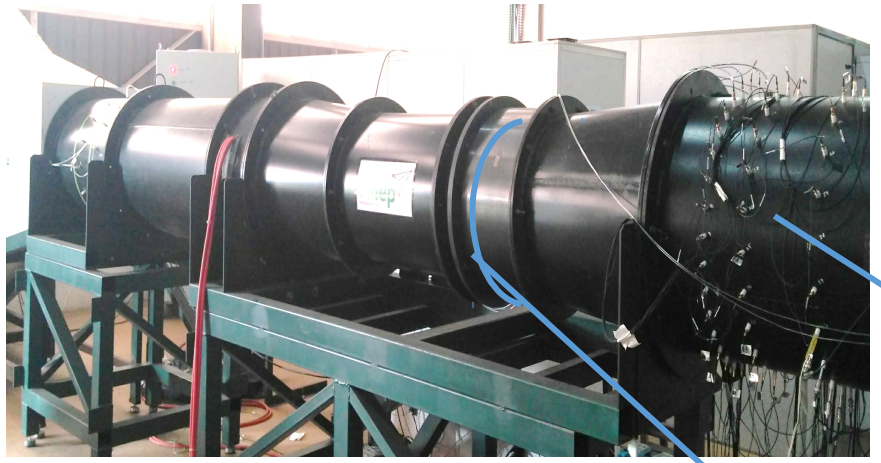
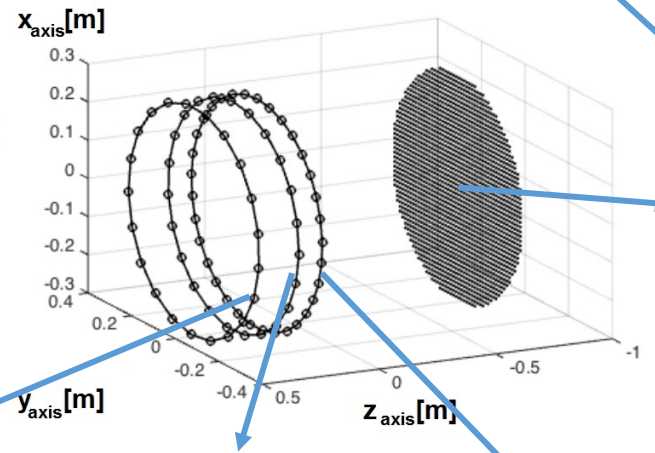


Acoustic Measurements

- 77 Microphones arranged in an antenna (GRAS 40PH-S2 and B&K Type)
- Acquisition using a NI PXI 1042Q and five NI4496 module boards with simultaneous acquisition
  - 39 seconds duration
  - 51.2 kHz sampling frequency





Microphone Array

Fan Plane

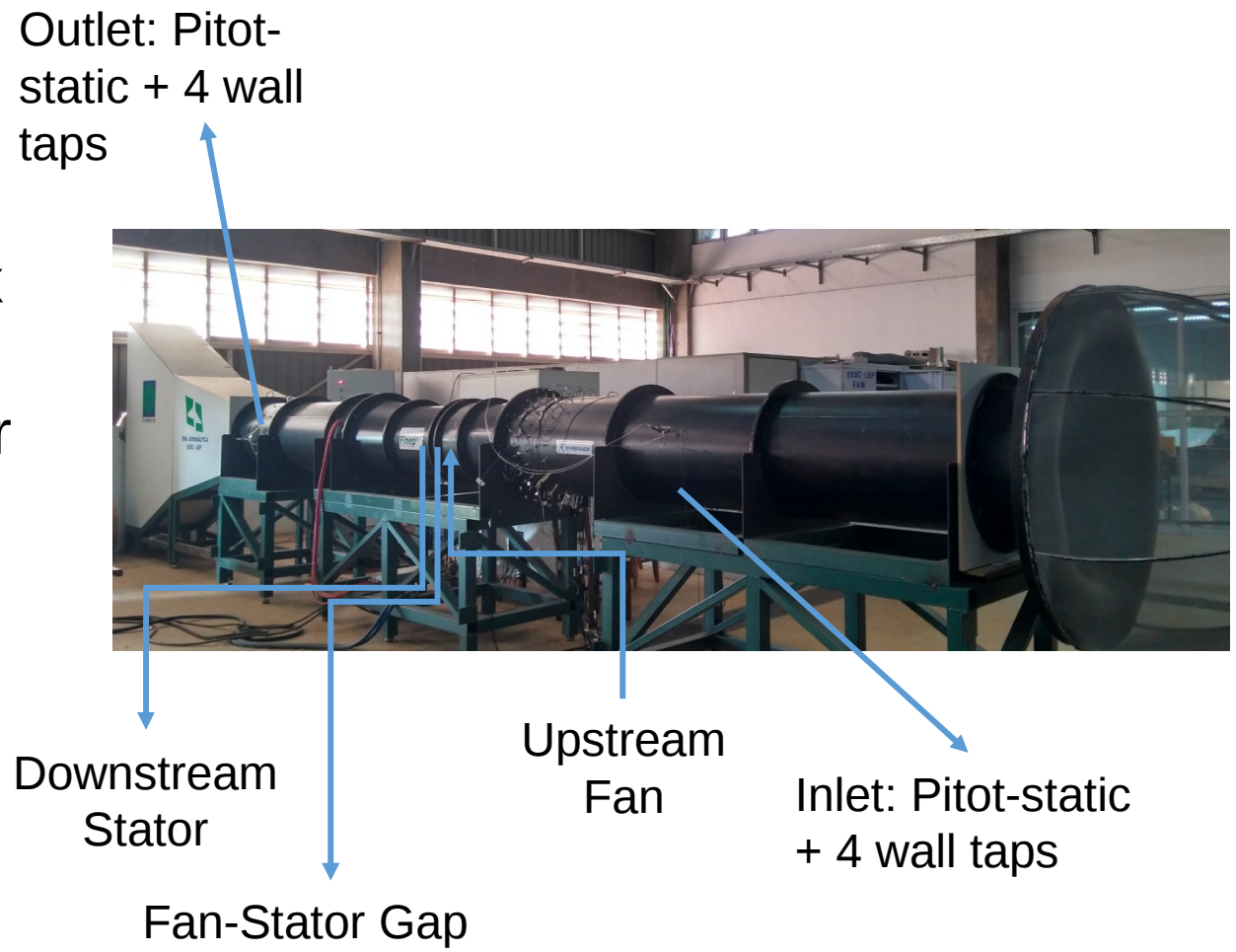
21 mics

23 mics

33 mics

Flow Measurements

- Pitot-static tube: Inlet, Outlet
- Static pressure taps: 4x Inlet, 4x Outlet, 1x upstream fan,1x fan-stator gap, 1x downstream stator
- Portable meteorological station to measure ambient pressure, temperature and humidity)

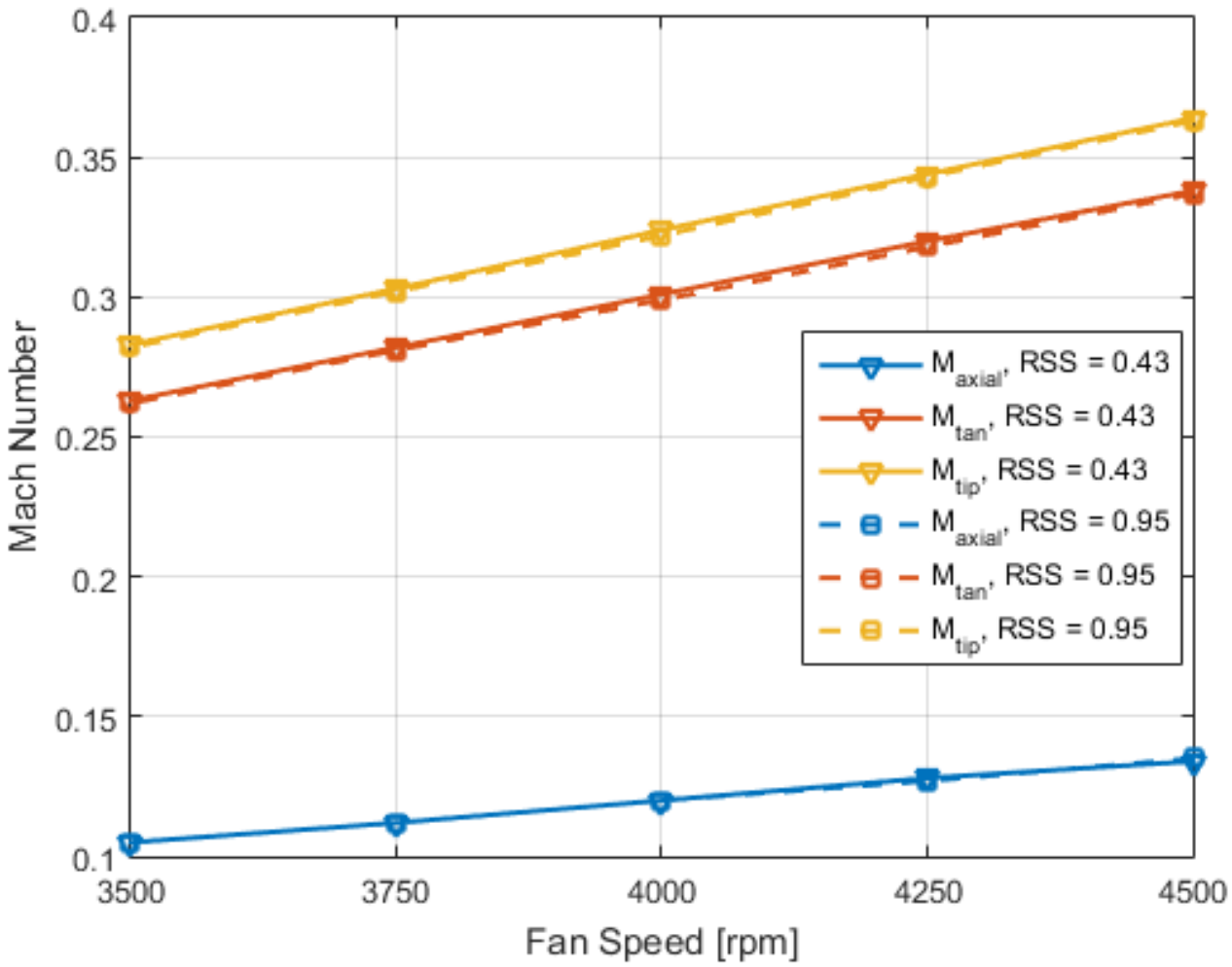


Spectral Analysis

- Data Post-Processing: Spectral Analysis & Modal Analysis
- Power spectral density estimation through Welch's method, Hanning window 2048 samples, 50% overlap between ensembles
- Modal decomposition uses beamforming
- With the beamforming integration, it is possible to obtain the sound power level for each mode

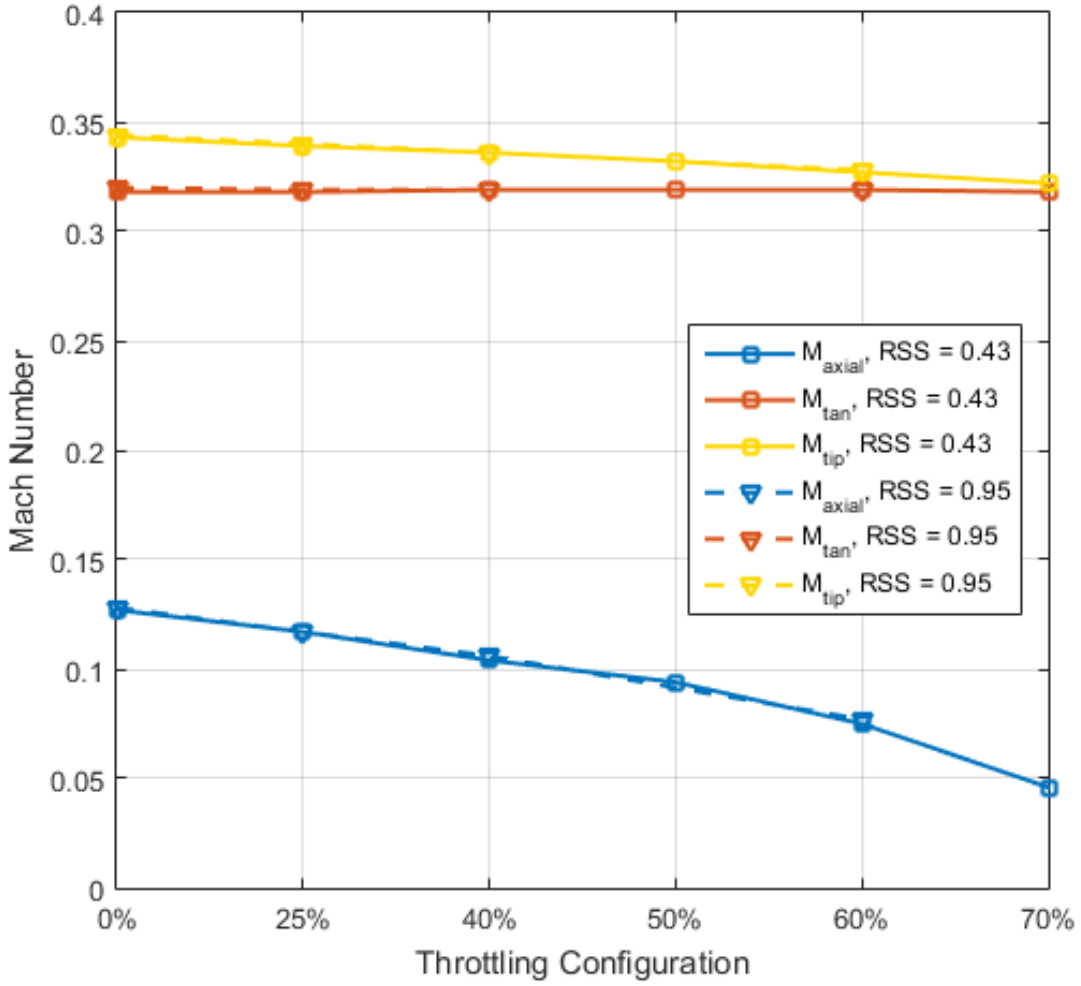
Results: Aerodynamics

- Higher M_{tan} → higher M_{axial}, but ratio is constant
- RSS does not change aerodynamics



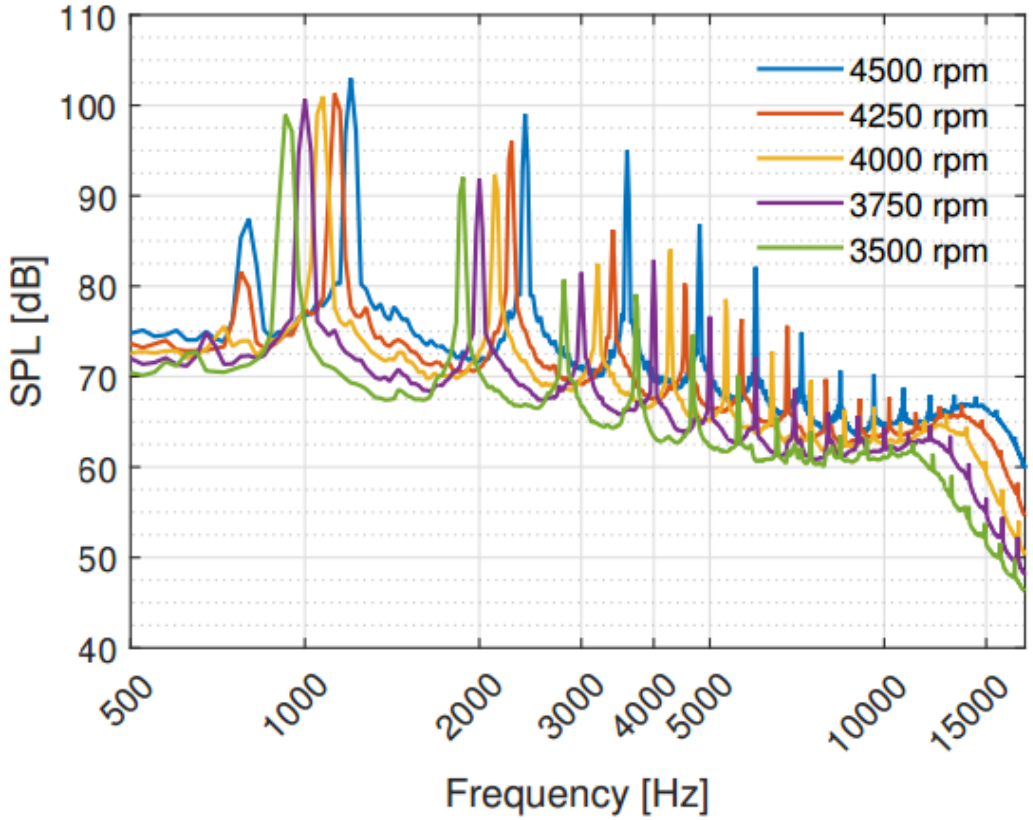
Results: Aerodynamics

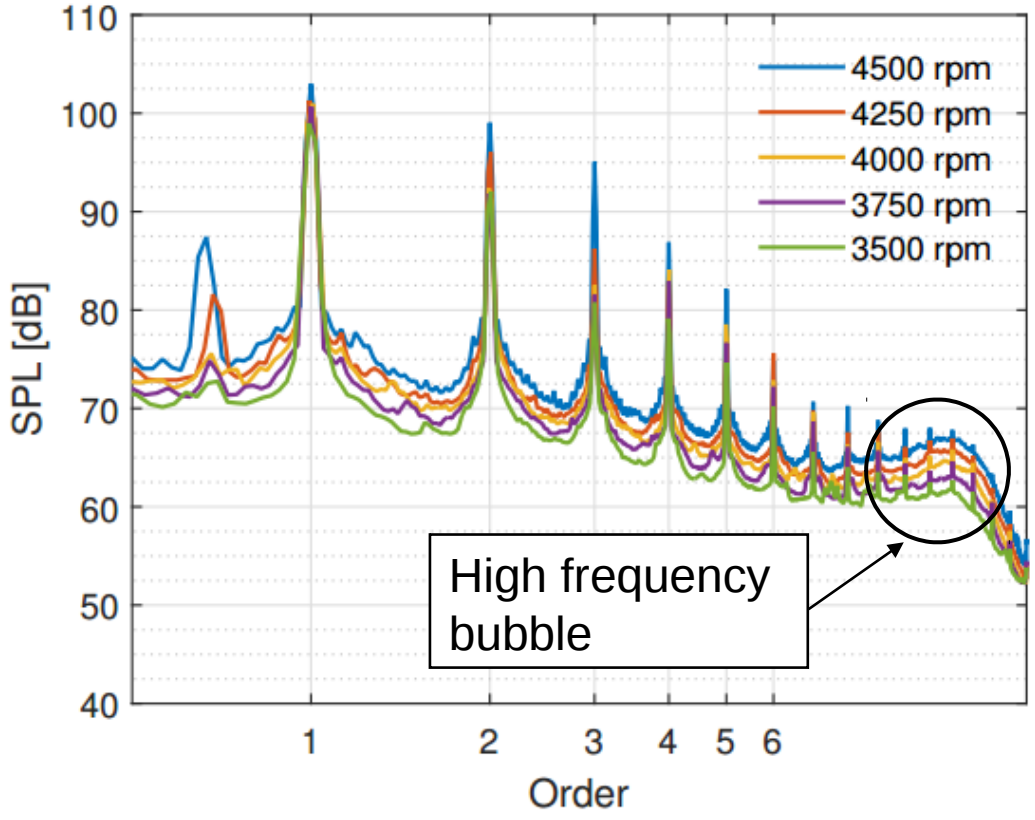
- Higher throttling → lower M_{axial} (constant RPM)
- RSS does not change aerodynamics



Results: Fan Speed

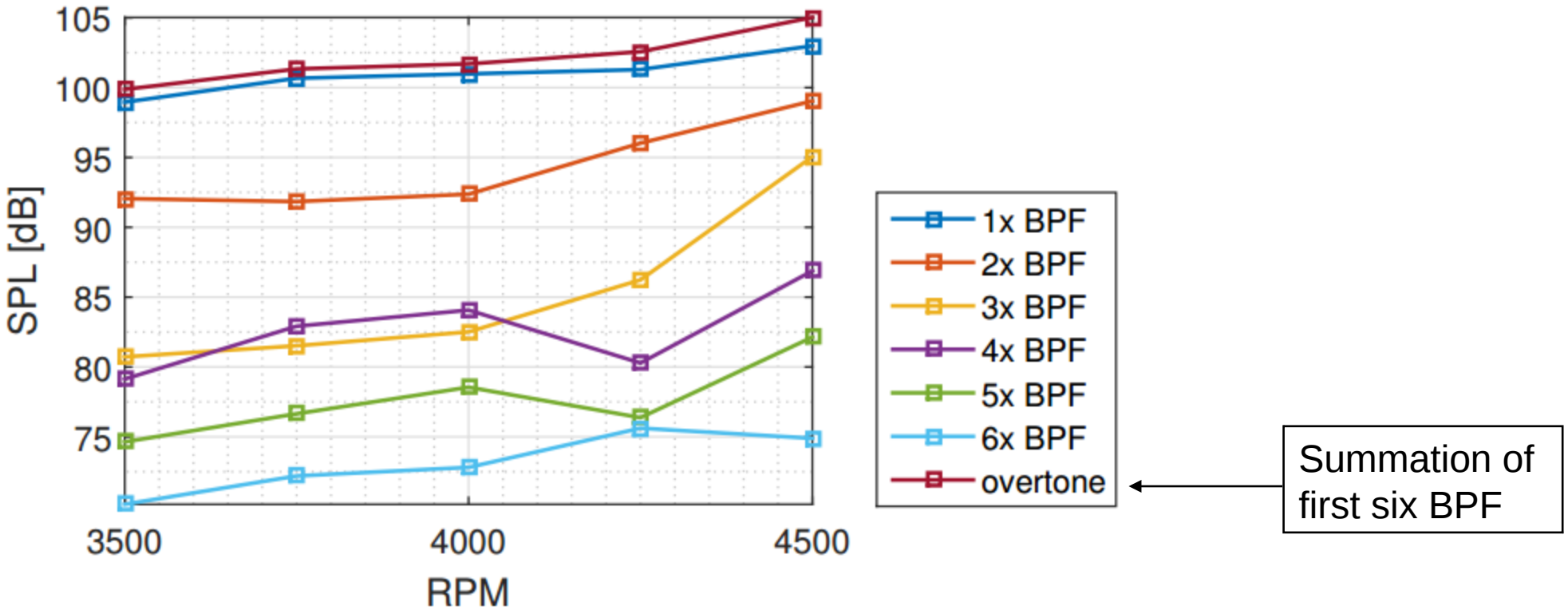
- Averaged spectra for all the mics signal. High frequency bubble centered at the 12th BPF





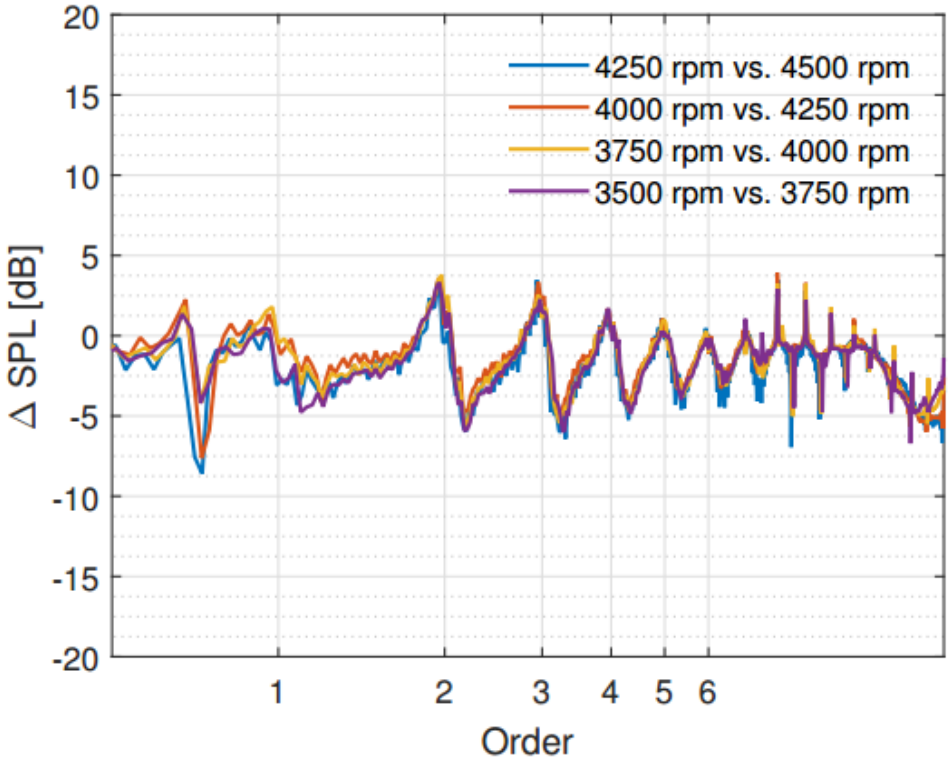
Results: Fan Speed

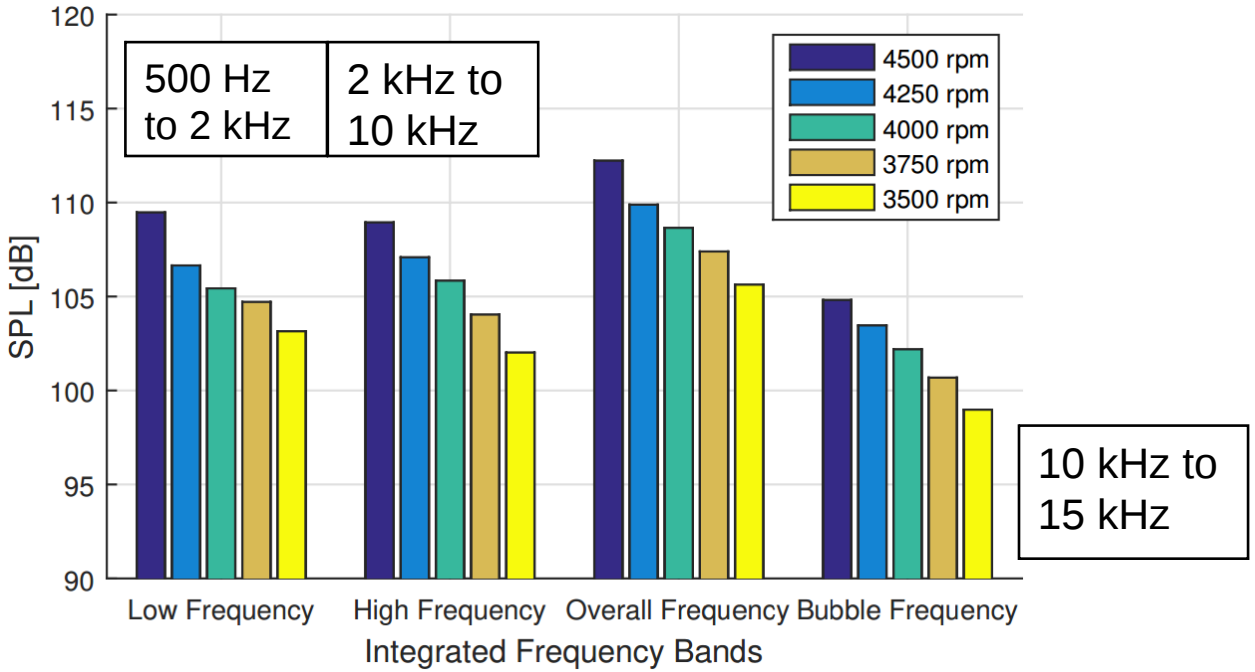
- Increase in fan speed → increase in tonal noise



Results: Fan Speed

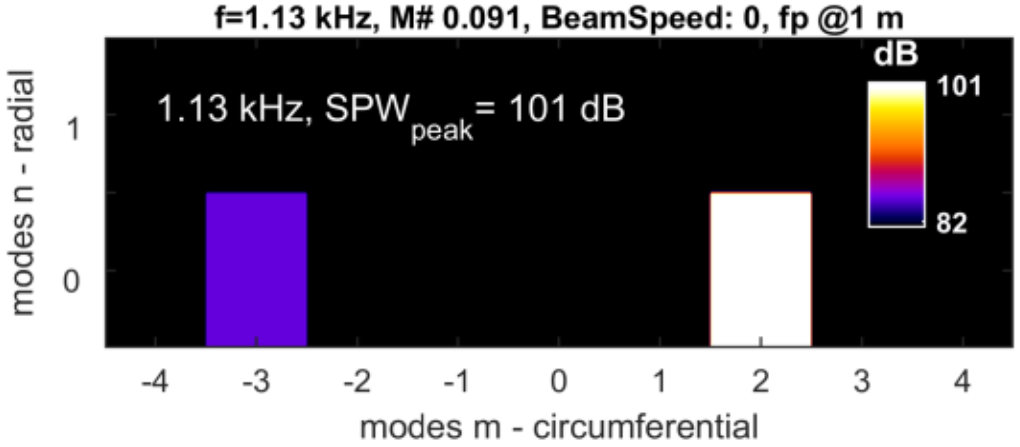
- Broadband variation for each 250 rpm increase seems to be close to constant (curves superposed)

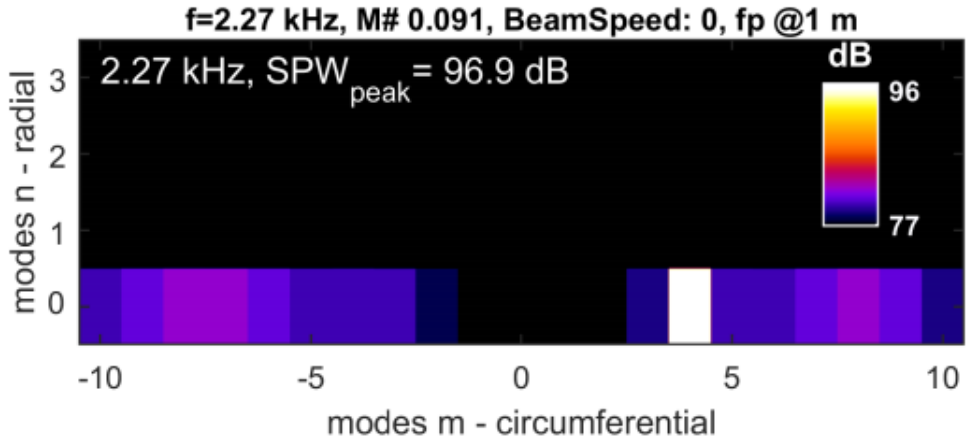


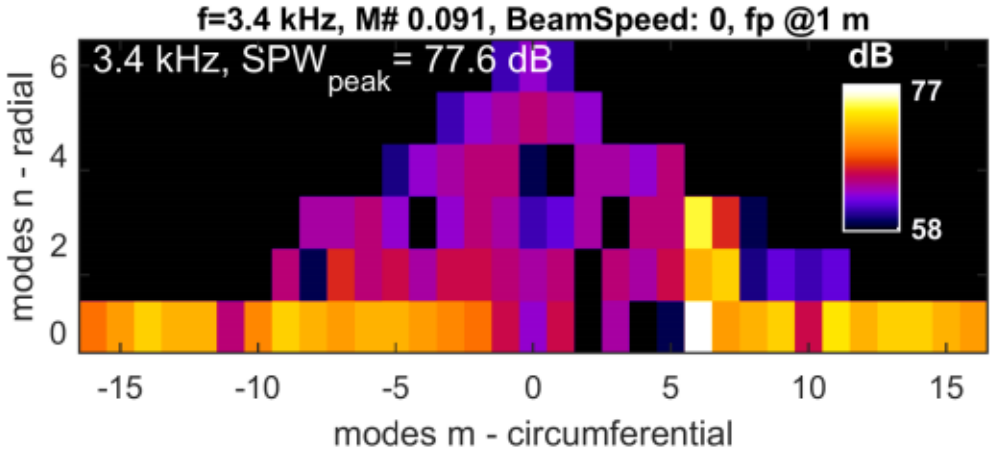


Results: Fan Speed

- Tyler-Sofrin modes (4250 rpm, RSS = 0.43, open throttle)

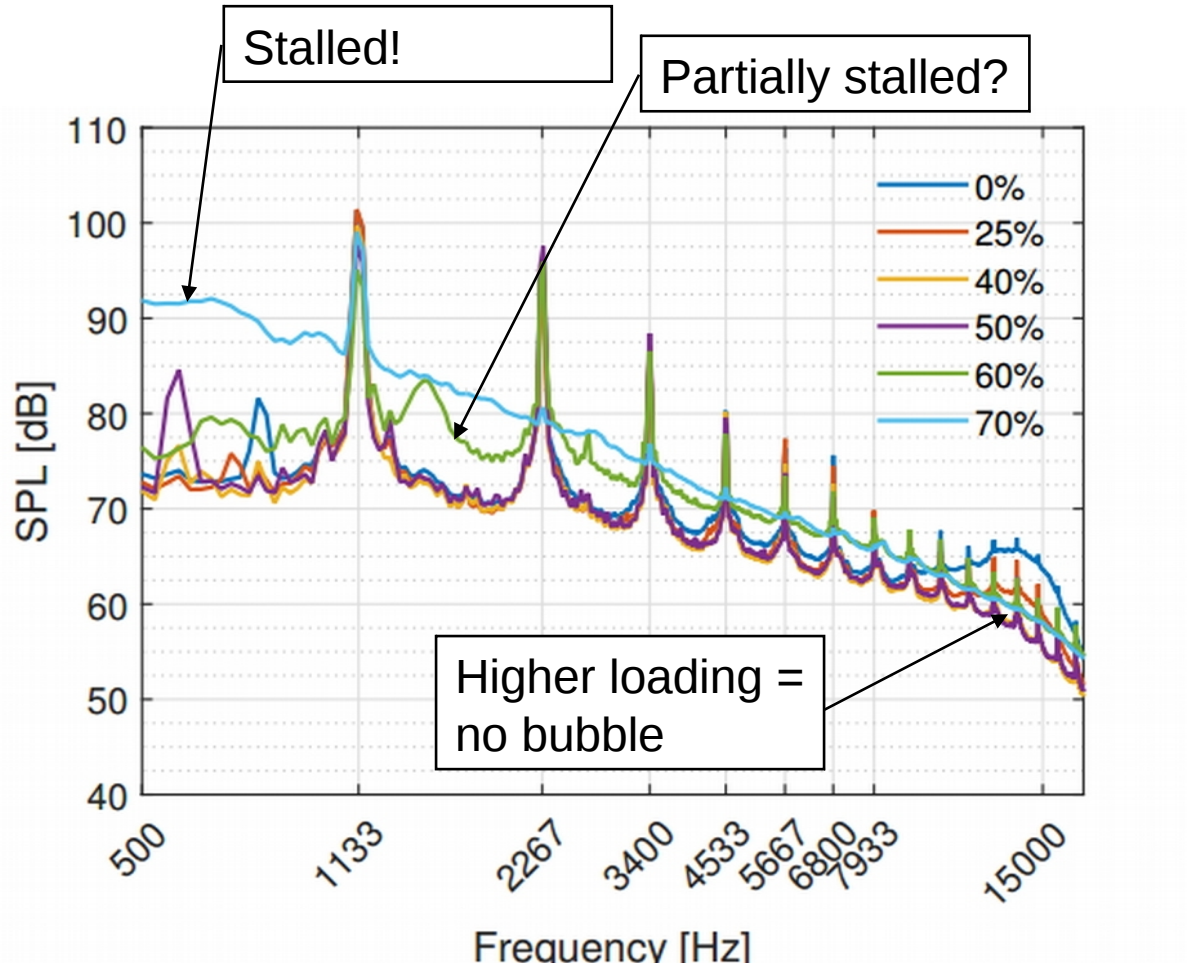






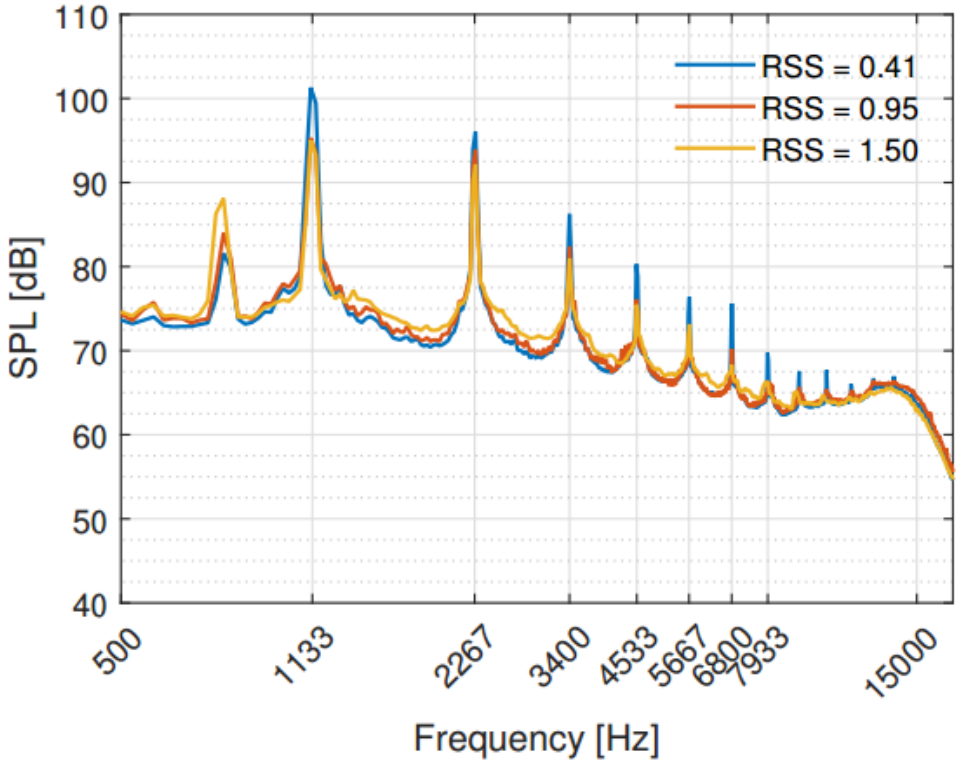
Results: Throttling

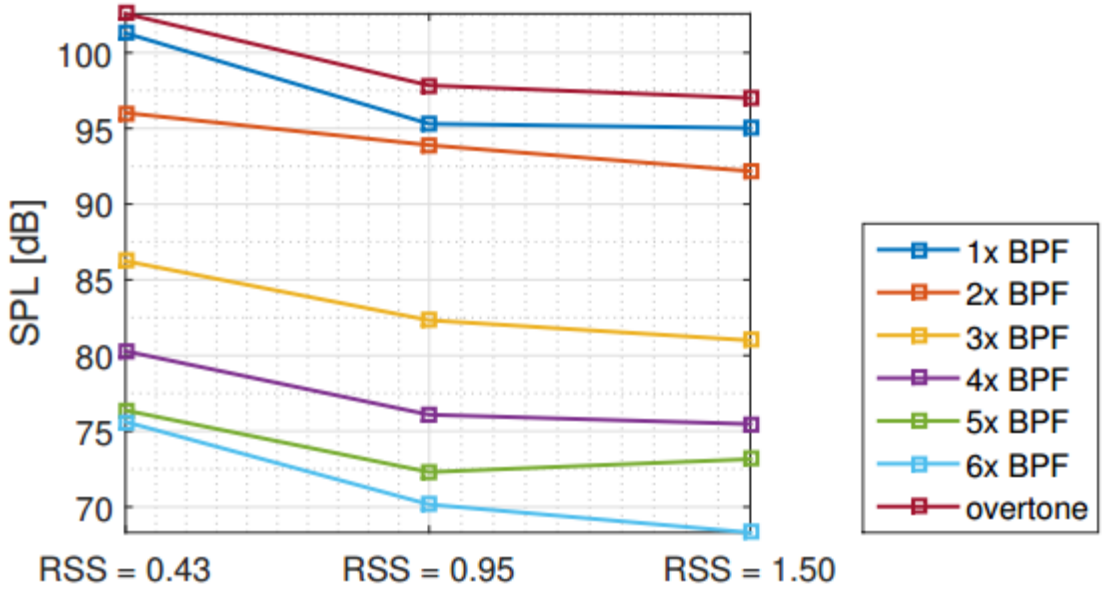
- Throttling changes fan loading
- Open throttle, AoA at the tip is around 1.3 deg and 17.5 deg at hub
- At 25%, 2.9 deg and 19.8 deg
- At 70%, 14.9 deg and 42.8 deg (it should really be stalled!)
- Bubble disappear with higher loading



Results: RSS

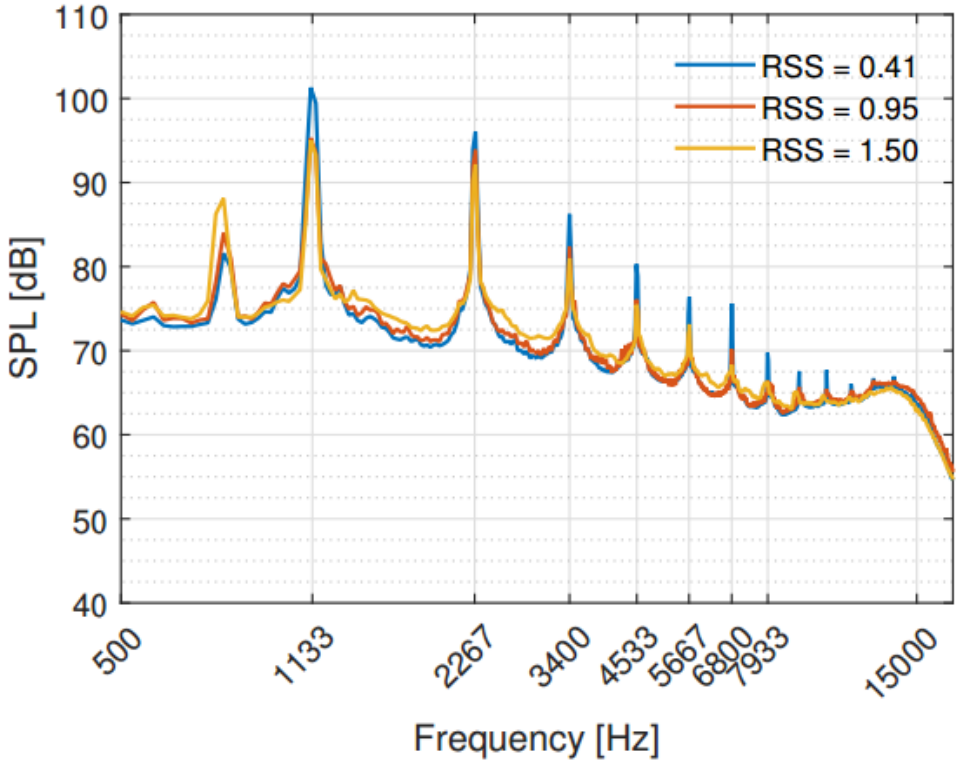
- Increase in RSS produces a decrease in tone levels
- Higher order tones are more attenuated (blade wake is smoothed out exponentially before impinging on stator vanes)

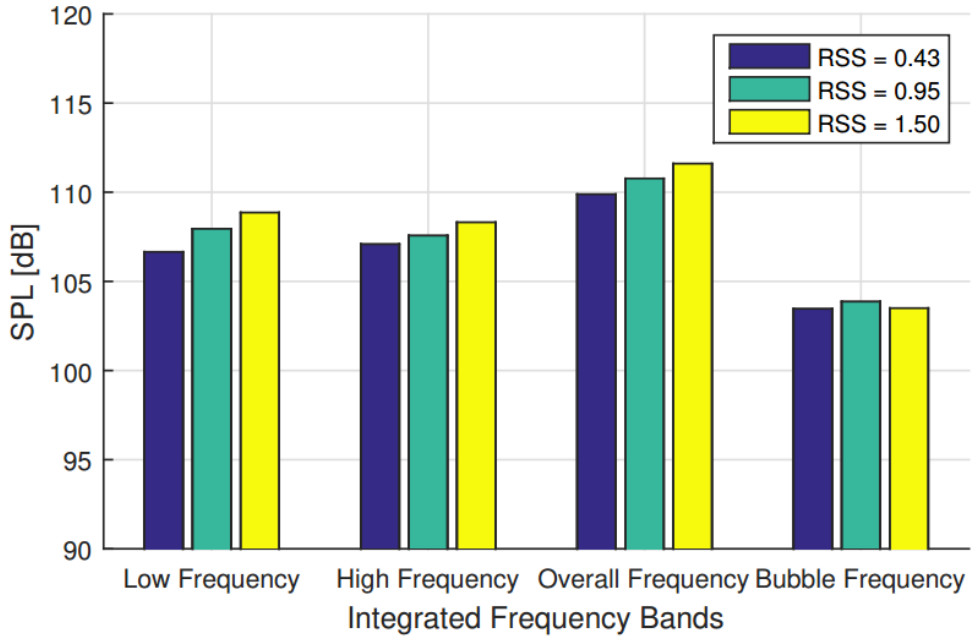




Results: RSS

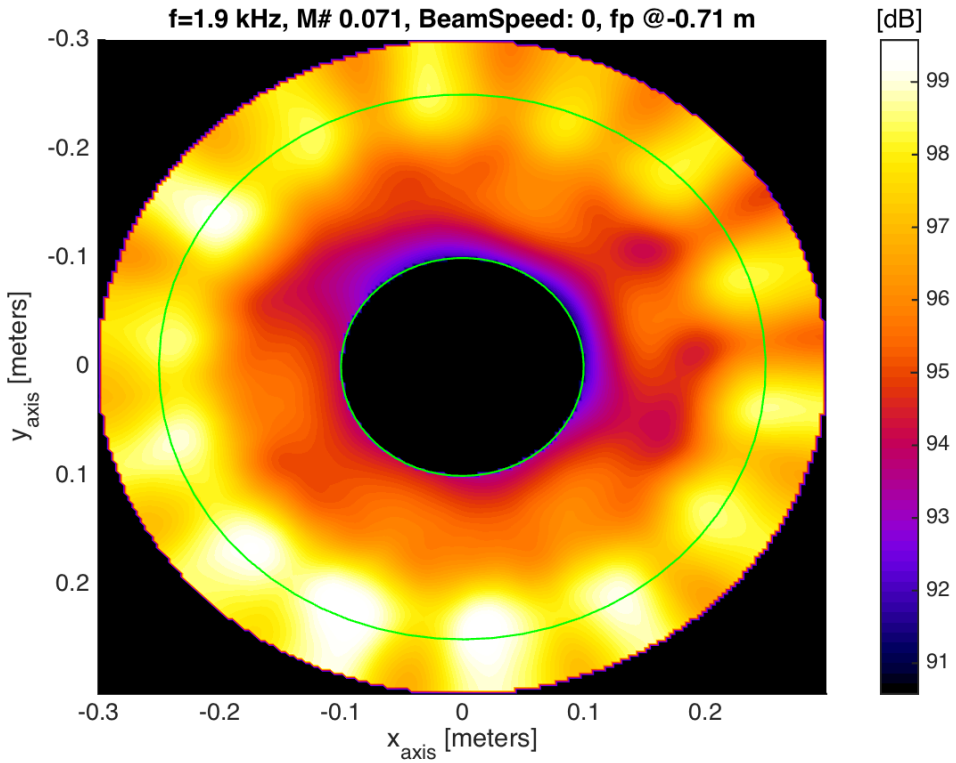
- Increase in RSS produces an increase in broadband (except for the “bubble”).



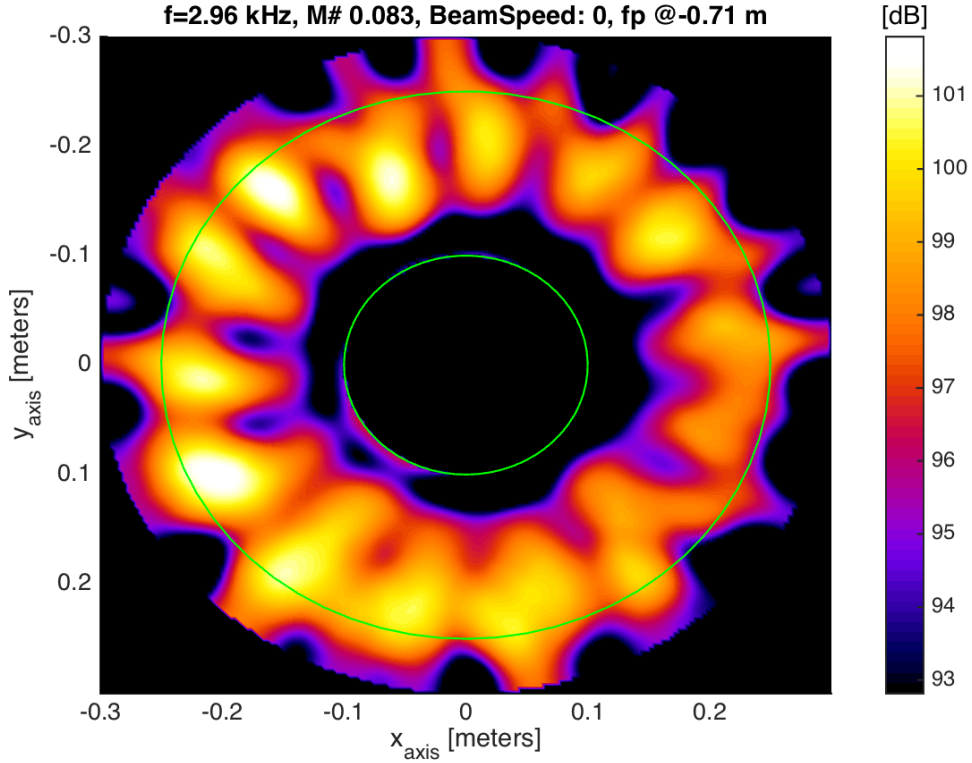


Results: Static beamforming

- Hard to focus on static sources due to strong rotating noise. A pattern of 14 sources is visible, the number of stator vanes



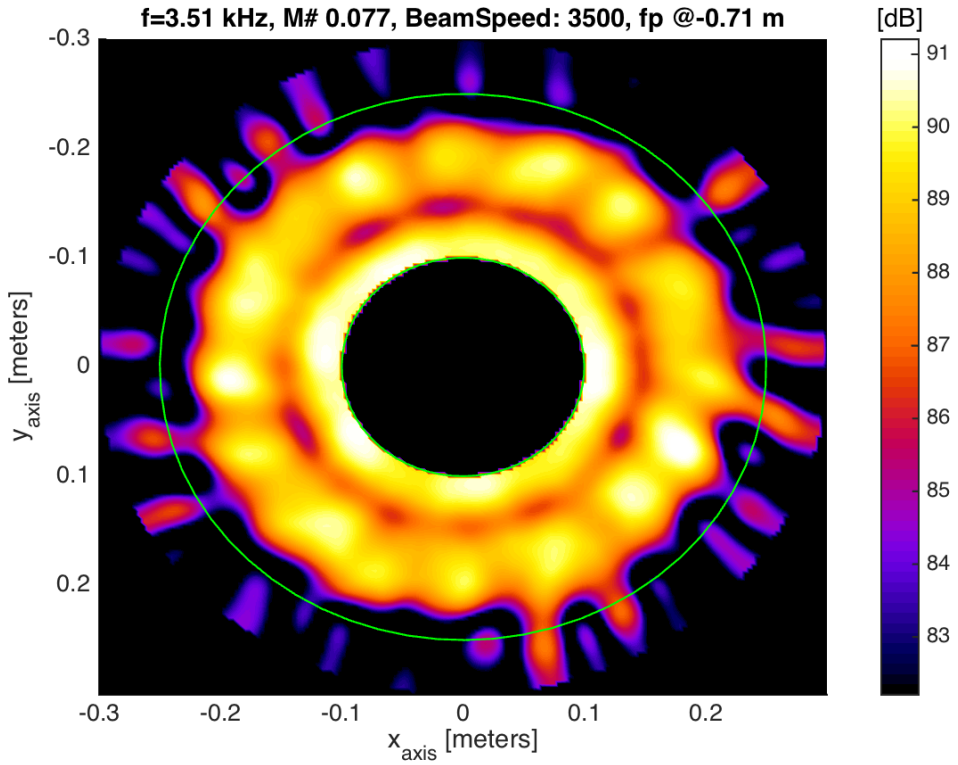
3200 RPM

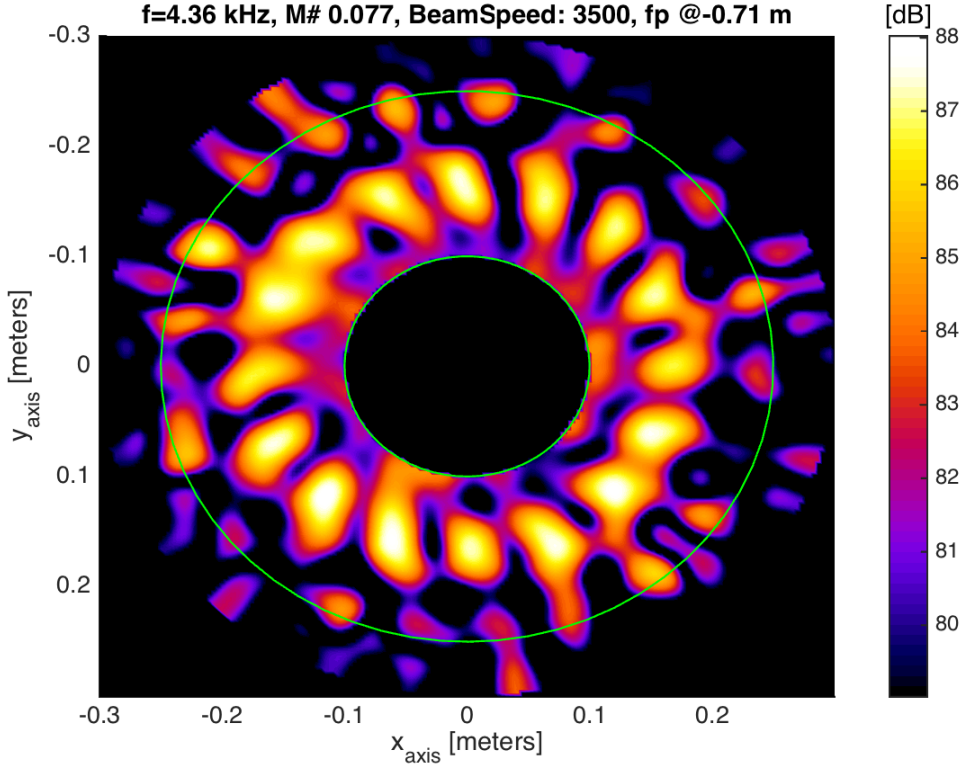


3500 RPM

Results: Rotating beamforming

- Rotating beam modal steering vectors and interpolated pressure signals to generate a virtual rotating array (Herold et al, 2015)





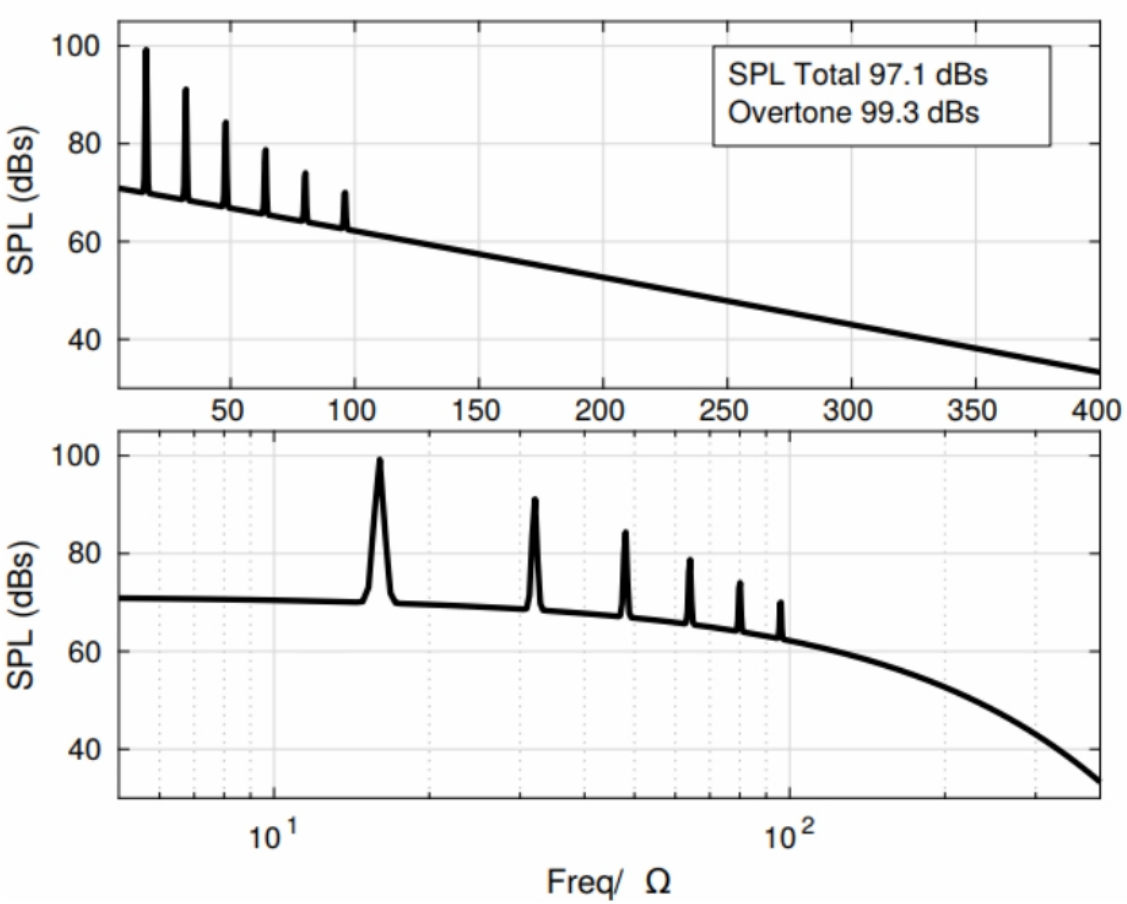
Results: Semi empirical model

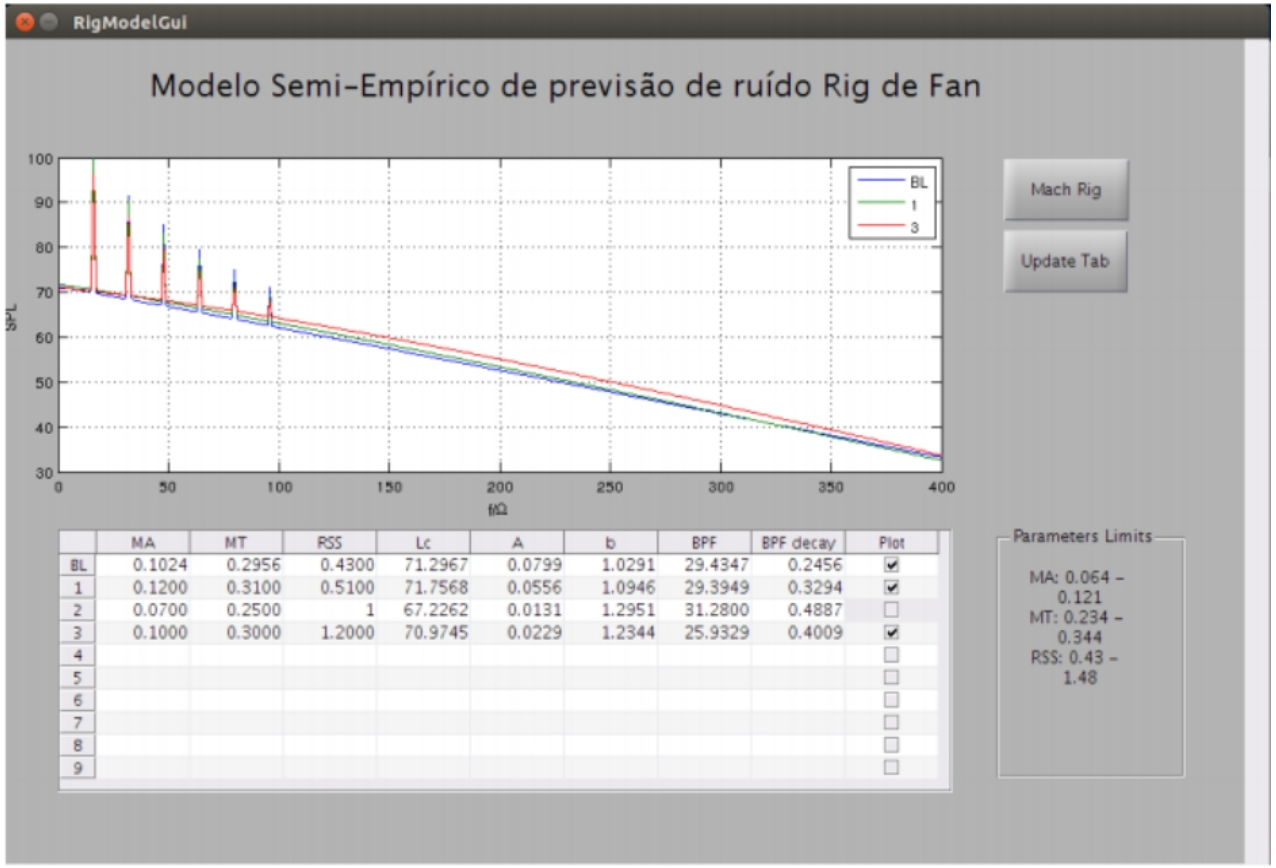
- Broadband noise was modeled by pink noise and tonal with exponential behavior, resulting in 5 parameters: broadband noise level, decay, form factor and tonal noise level and decay

- Surface Kriging regression was used to adjust the parameters

- Three different cross validation techniques are applied to the model: Monte Carlo, leave one out and repeated k-folds

Results: Semi empirical model





	MA	MT	RSS	Lc	A	b	BPF	BPF decay	Plot
BL	0.1024	0.2956	0.4300	71.2967	0.0799	1.0291	29.4347	0.2456	☑
1	0.1200	0.3100	0.5100	71.7568	0.0556	1.0946	29.3949	0.3294	☑
2	0.0700	0.2500	1	67.2262	0.0131	1.2951	31.2800	0.4887	☐
3	0.1000	0.3000	1.2000	70.9745	0.0229	1.2344	25.9329	0.4009	☑
4									☐
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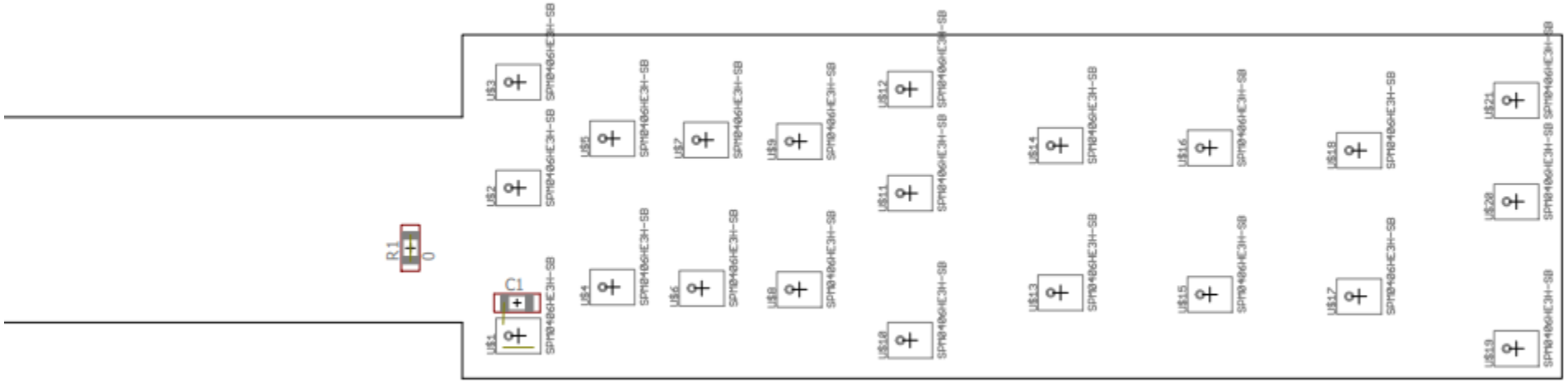
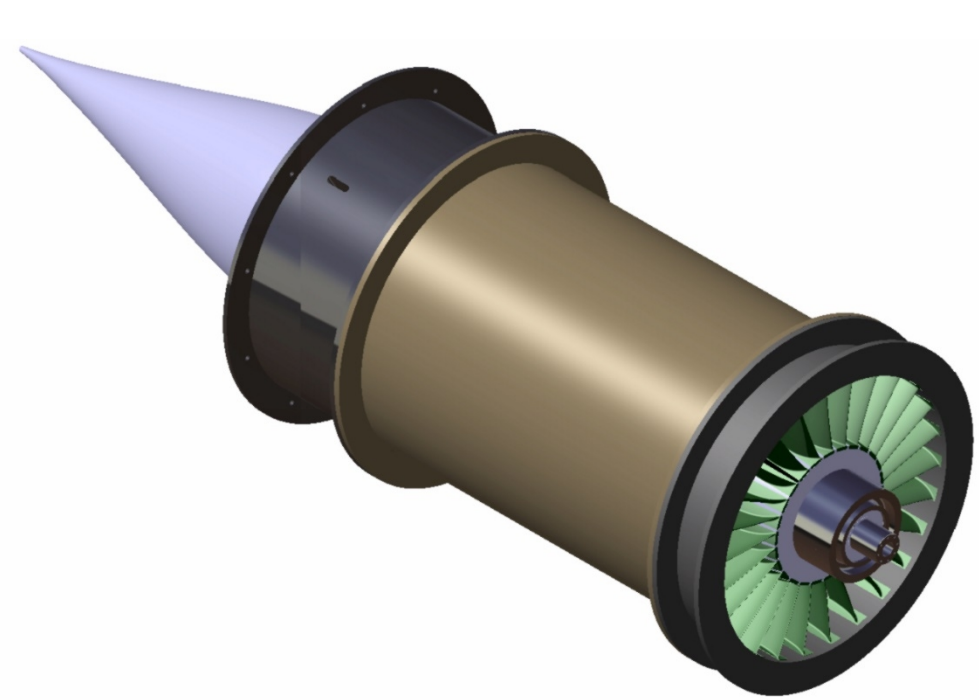
Current work

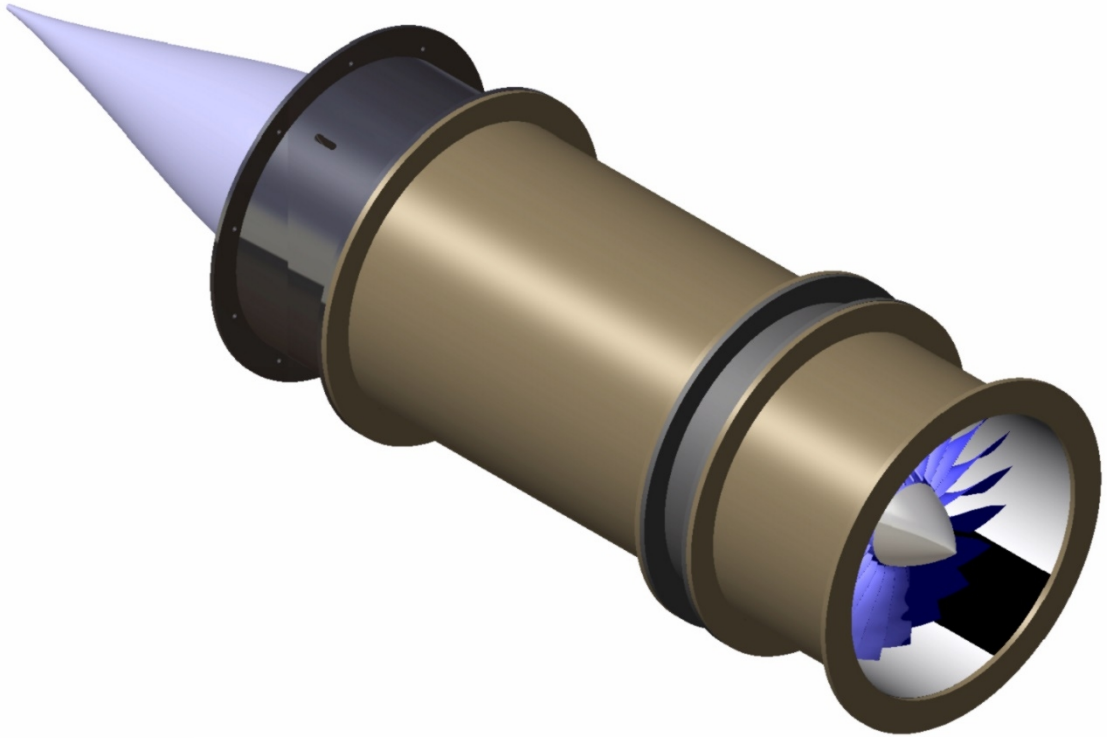
- Tests with an instrumented vane



Current work

- Installation of the SDT fan





Questions?
Thank you!