Aerodynamics and Aeroacoustics of Coaxial Co-rotating Propellers (Config. A3)

Public Workshop: Novel Tools for Novel Aircraft

Bristol, 06 February 2025

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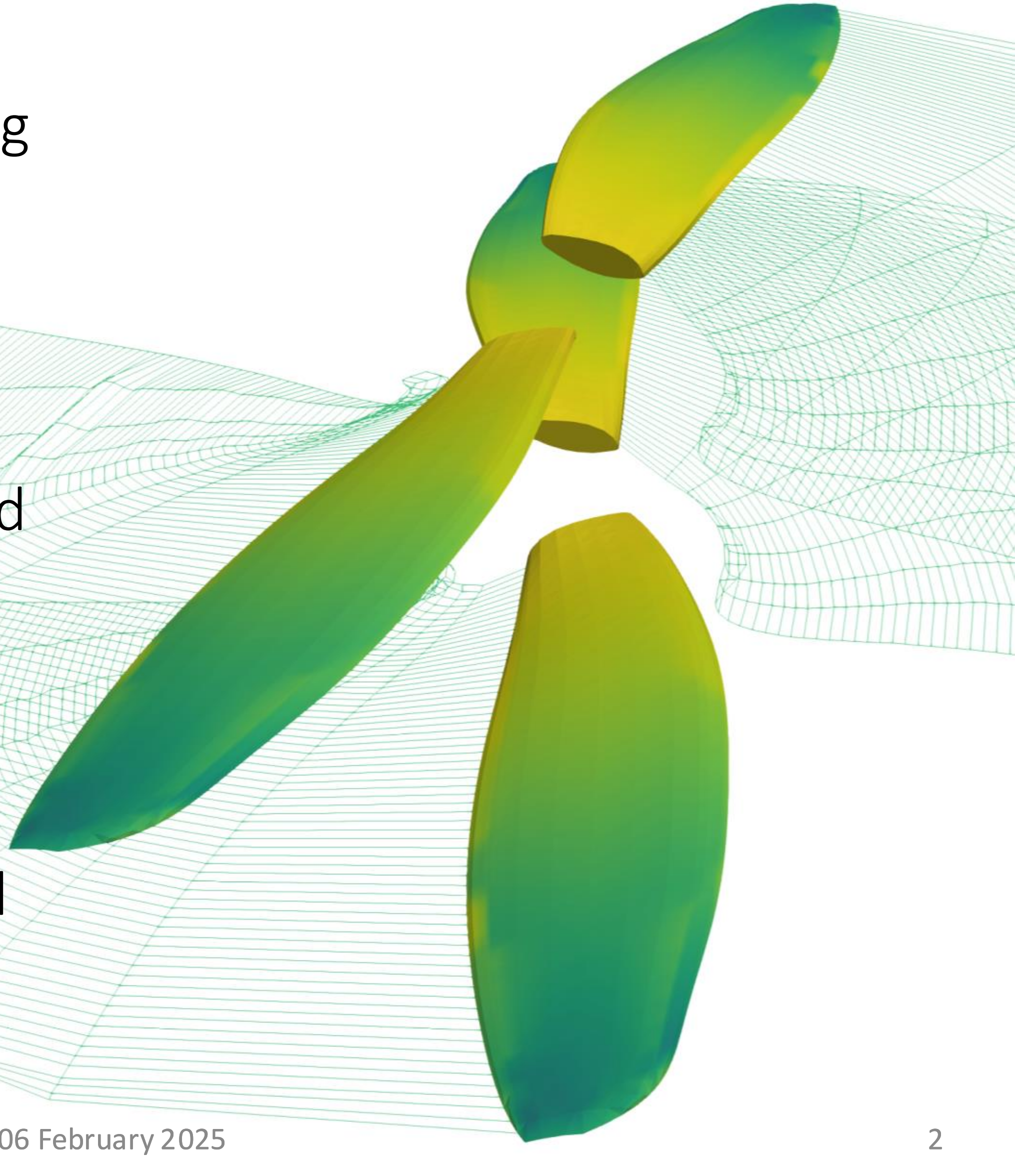
eVTOL mUlti-fideliTy hybrid desIgn and Optimization for low Noise and high aerodynamic performance - Grant Agreement 101138209

Objectives

1. Explore experimentally the trade-off space between performance and noise footprint of coaxial co-rotating propellers, within a test domain defined by the degrees of freedom of the problem (Φ, z).

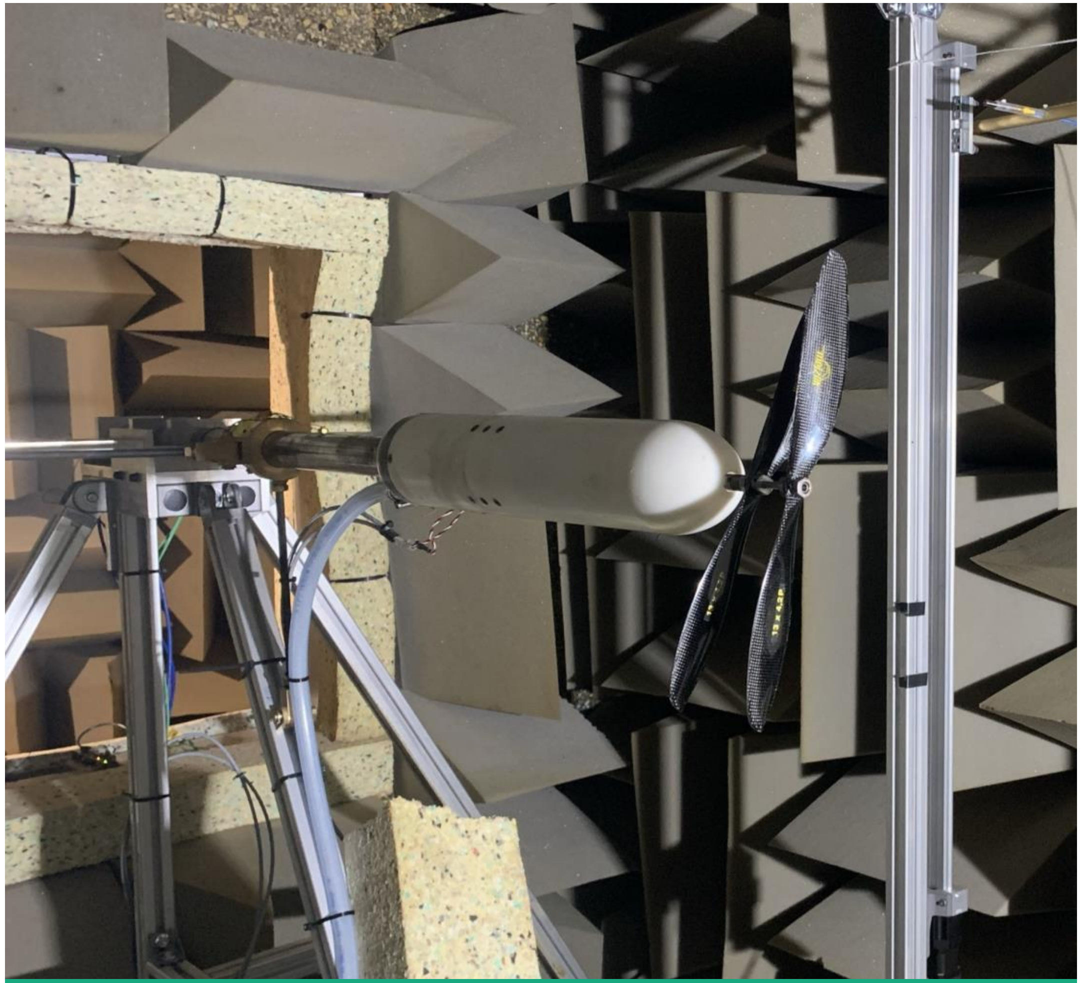
2. Retrieve the relationships between propulsive efficiency and noise generation found in literature and investigate new ones.

3. Retrieve the results obtained experimentally by employing a combined use of numerical tools to assess the advantages and limitations of a fully virtual design of such propulsive systems.



Experimental Methodology
Performance Campaign (1/2)

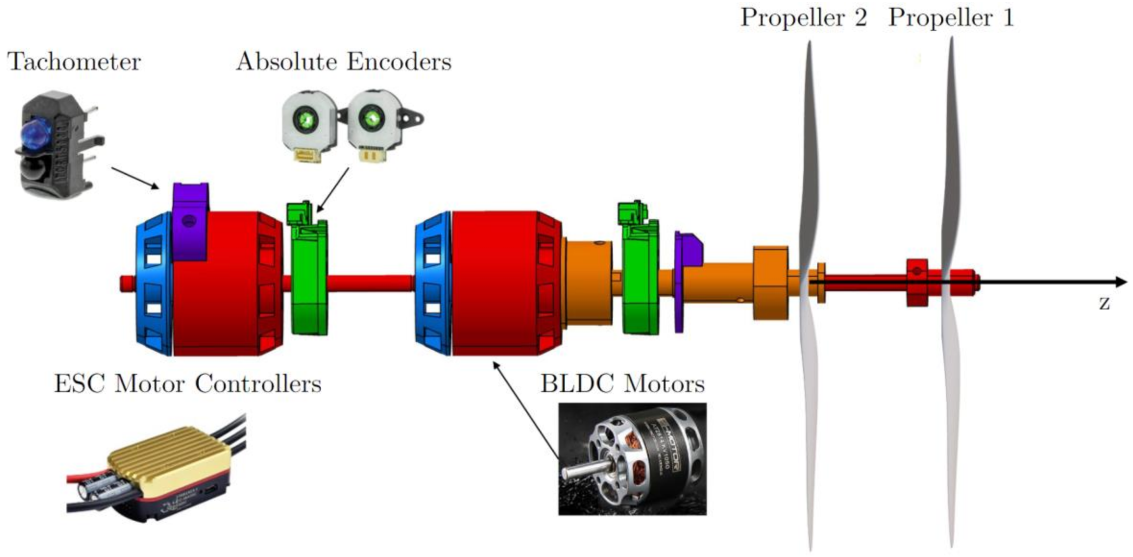
- Thrust and Torque measurements.
- Axial distance ranges from 21 mm to 42 mm with 7 mm increments.
- Phase offset ranges from -90° to +90° with 10° resolution, increased to 5° between -45° and +45°.
- Total of 116 tested cases, at a fixed velocity of 6000 RPM.
- Composite 2-bladed propellers, 33 cm diameter, commercial drones application.
- Performance(Φ, z) and efficiency(Φ, z).

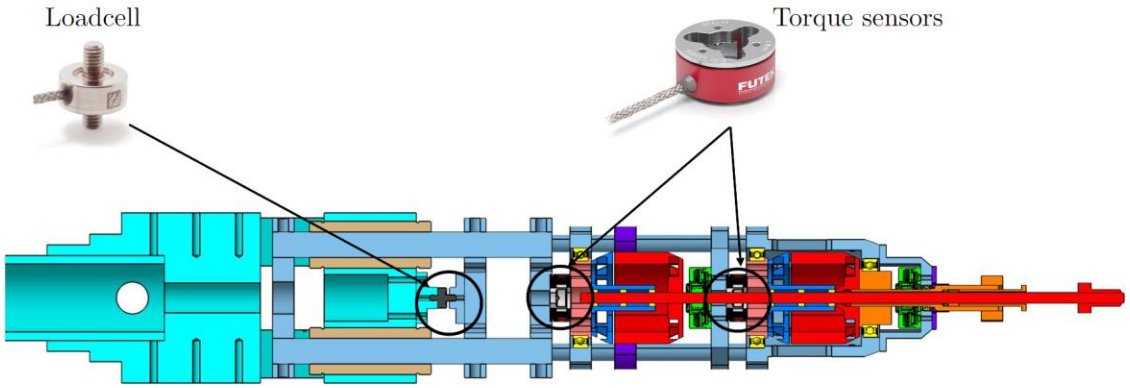


Experimental setup - ALCOVES

Experimental Methodology

Performance Campaign (2/2)





THRUST COEFFICENT

$$C_T(\Phi, z) = \frac{T}{\rho\, n^2\, D^4}$$

POWER COEFFICENT

$$C_P(\Phi, z) = \frac{P}{\rho\, n^3\, D^5}$$

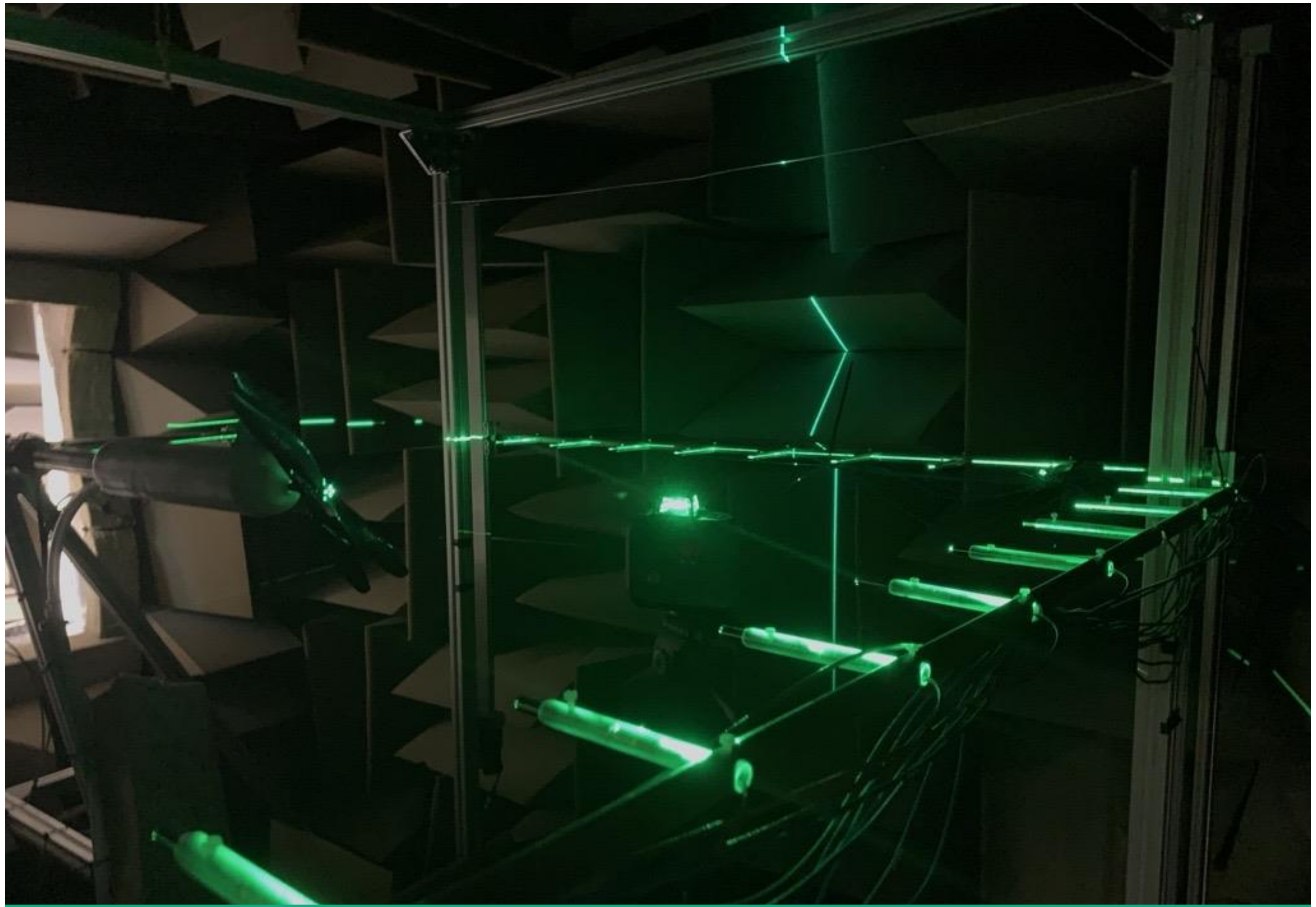
POWER LOADING

$$PL(\Phi, z) = \frac{T}{Q\, \omega}$$

with $n = \frac{RPM}{60}$ and $P = 2\pi n Q$

Experimental Methodology
Noise Campaign

- ALCOVES anechoic chamber of VKI
- 24 GRAS microphones antenna.
- Noise footprint in the 3D space around propellers
- Directivity of Noise
- Tonal Noise
- Overall Broadband Noise
- Total of 62 tested cases.


Microphone antenna alignment with shaft - ALCOVES

Numerical Methodology

Loads Simulation

Geometry & Motion

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FlightStream

↓

Aerodynamic Loads

↓

BATMAN $^{\pi}$

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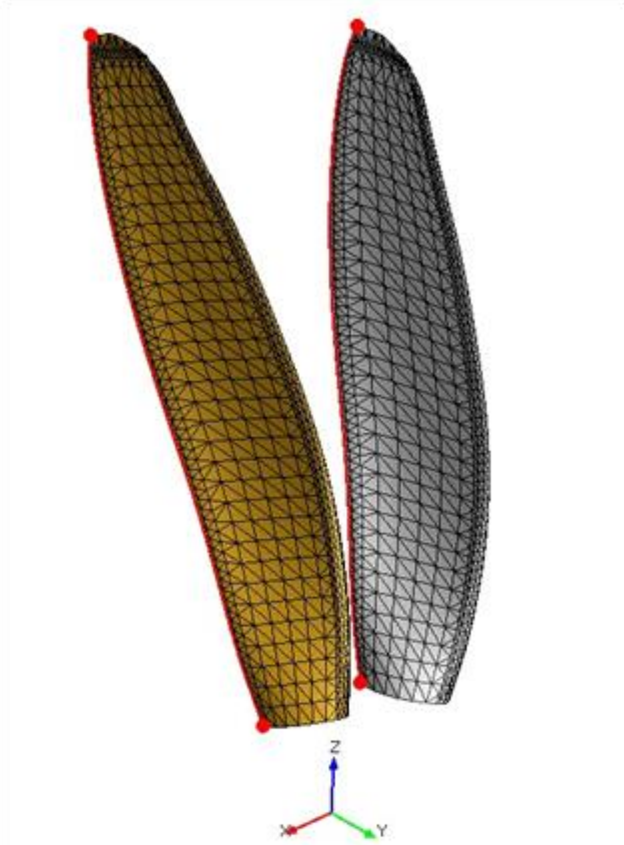
Tonal noise

FlightStream: commercial **surface vorticity solver**



Adopted Tessellation

- Number of propellers revolutions: 8
- Wake termination point: 1.5 D = 45 cm
- Time increment: 0.3 ms, corresponding to 10.77 °/iter
- Number of iterations: 268
- Number of faces: 2568
- Tessellation size: 2.1 mm on blade tip, leading and trailing edge patches; 4.2 mm on flatter patches

Numerical Methodology

Noise Simulation

Geometry & Motion

↓

FlightStream

↓

Aerodynamic Loads

↓

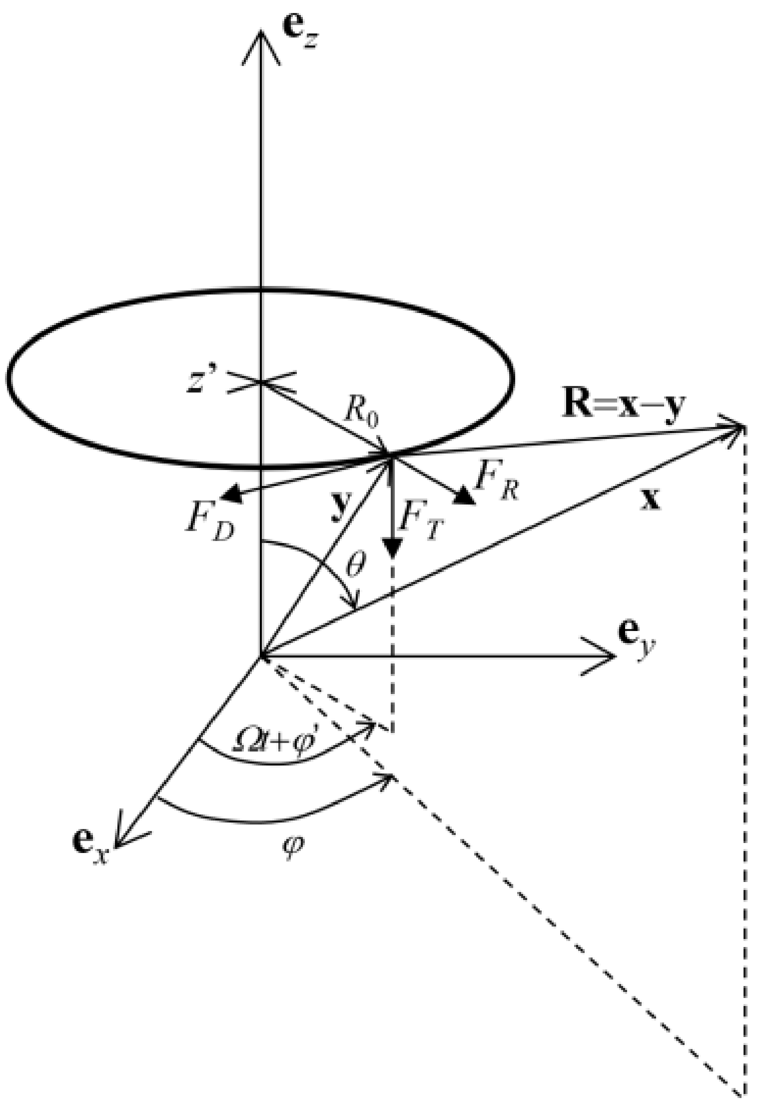
BATMAN $^{\pi}$

↓

Tonal noise

BATMAN $^{\pi}$ in house CAA platform

- FWH analogy
- Lighthill tensor associated with turbulence is neglected.
- Forces acting on the propellers are periodic.
- Far-field approximation.
- The source domain is considered acoustically compact.



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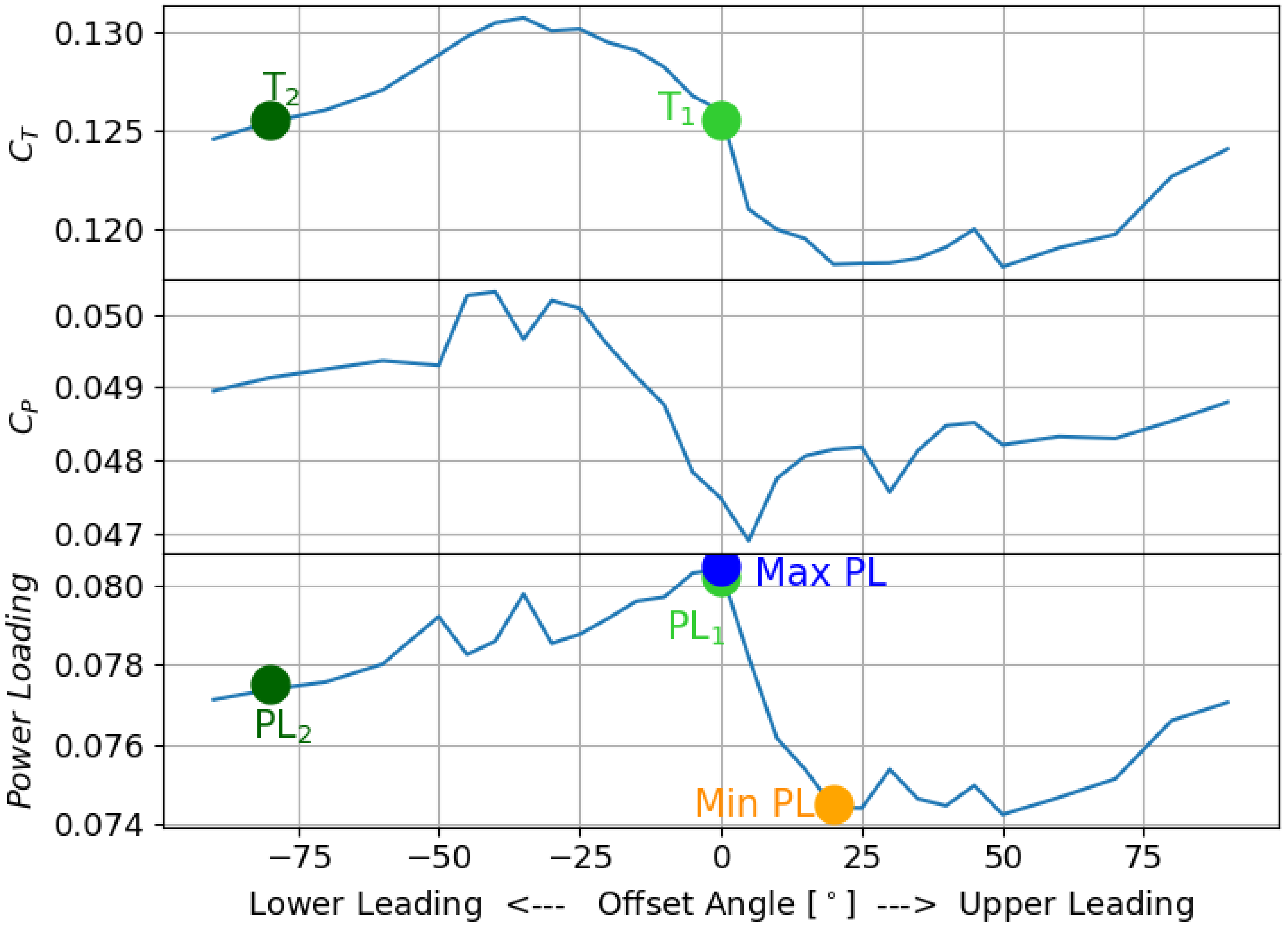
TONAL NOISE by ROTATING DIPOLE at first BPF

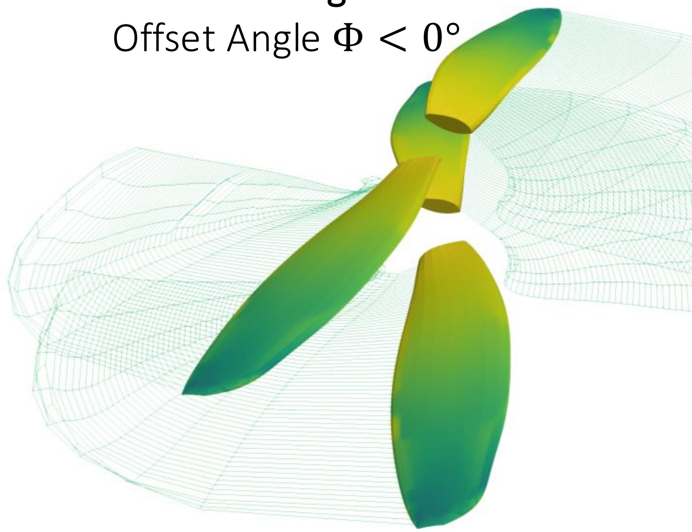
Results

Performance Measurements

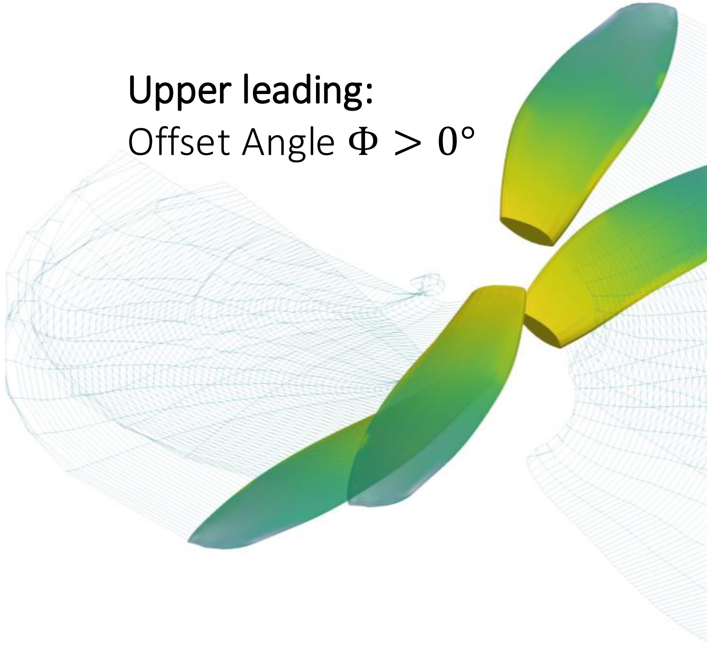
Example case: z = 35 mm



Lower leading:
Offset Angle $\Phi < 0°$



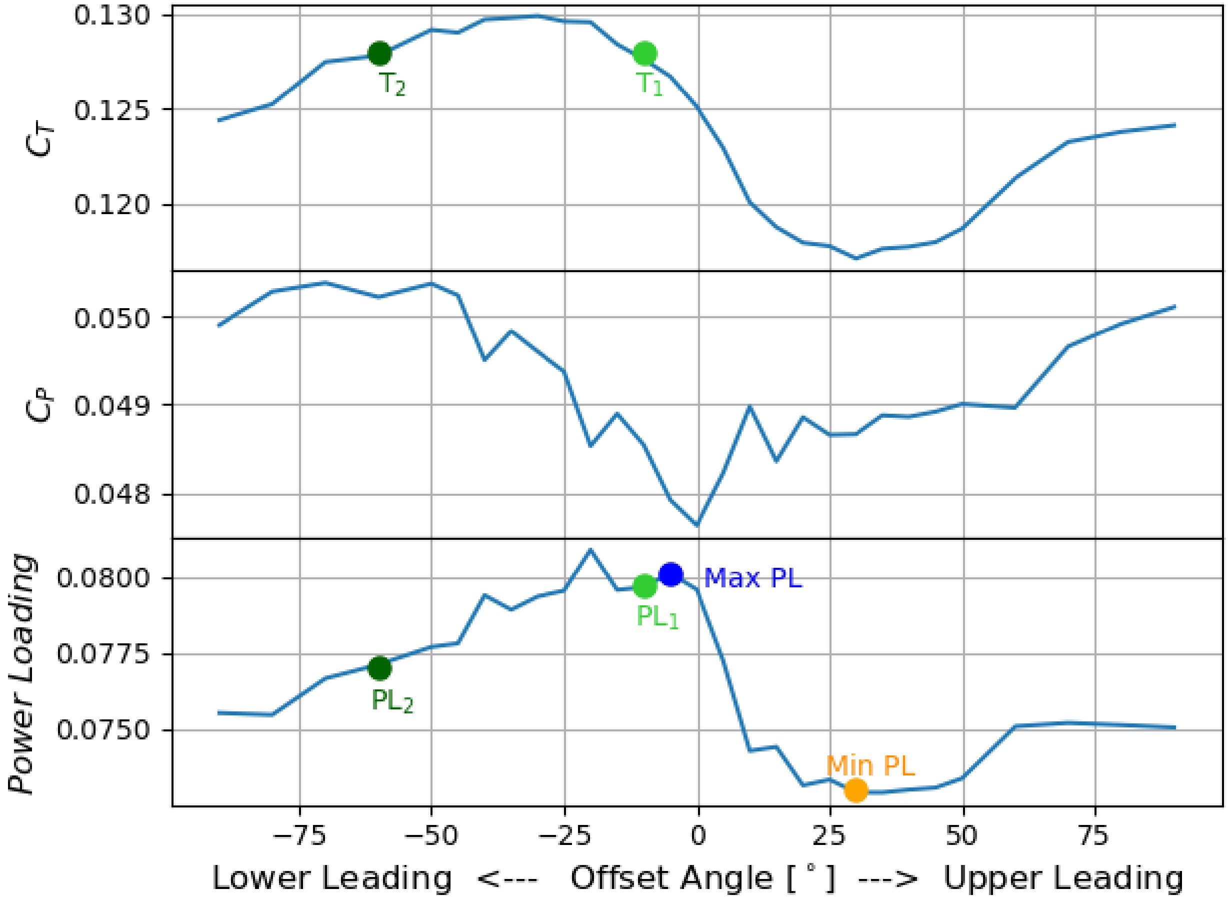
Upper leading:
Offset Angle $\Phi > 0°$



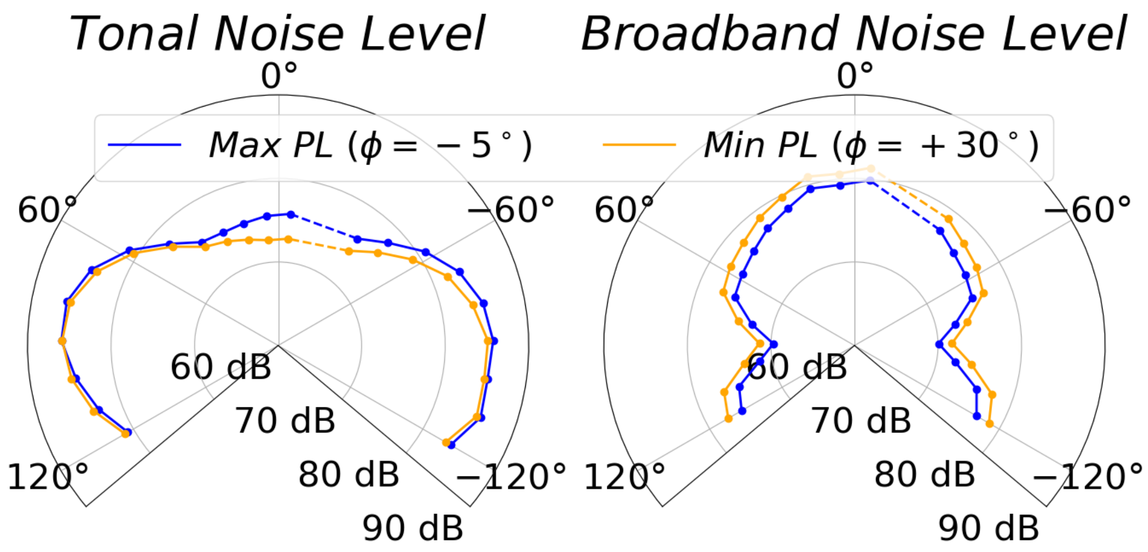
Results

Aeroacoustics Results (1/3)

Example case: z = 28 mm



MAX-MIN POWER LOADING ANALYSIS:



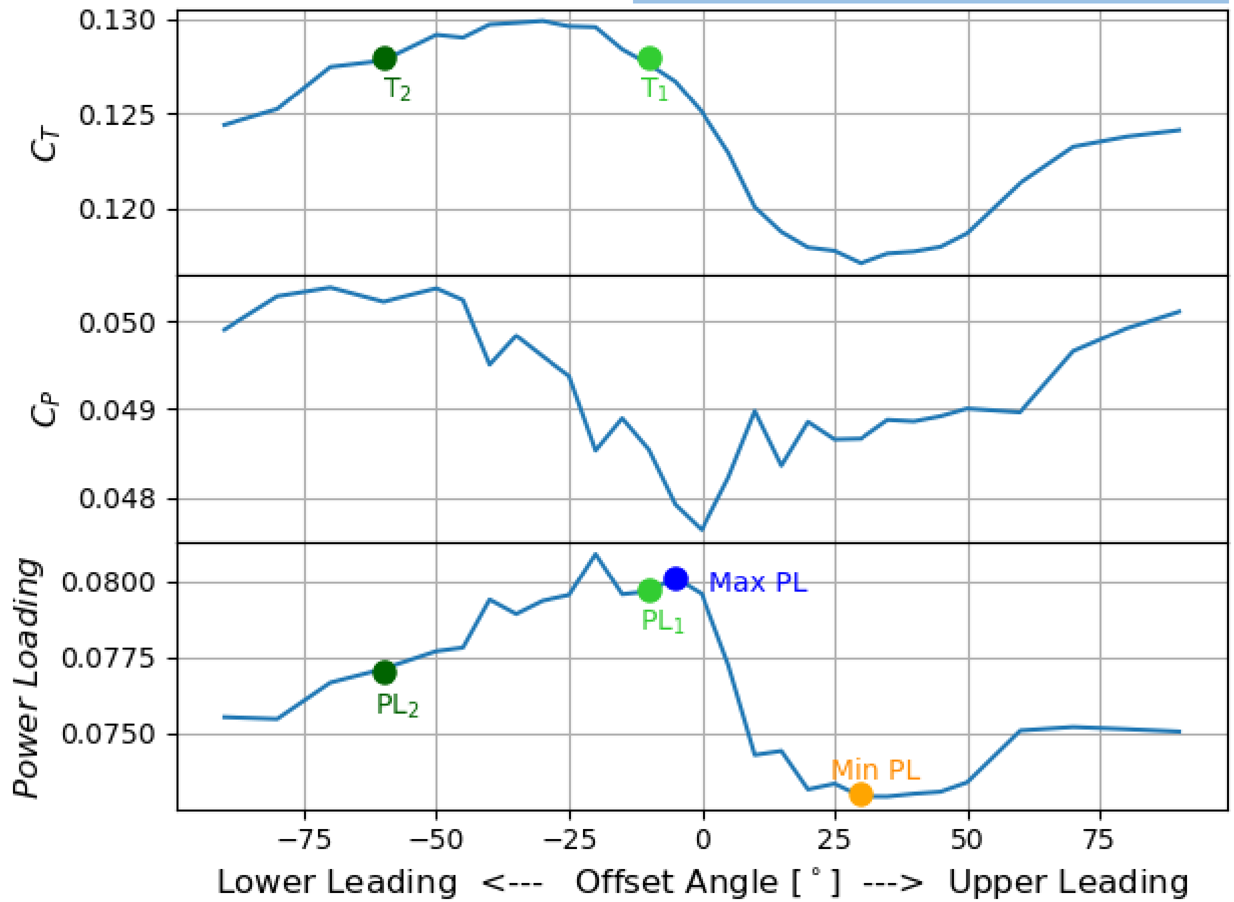
- Higher Efficiency → Lower OABBN
- Tonal noise unaffected

Confirmed what suggested in recent literature

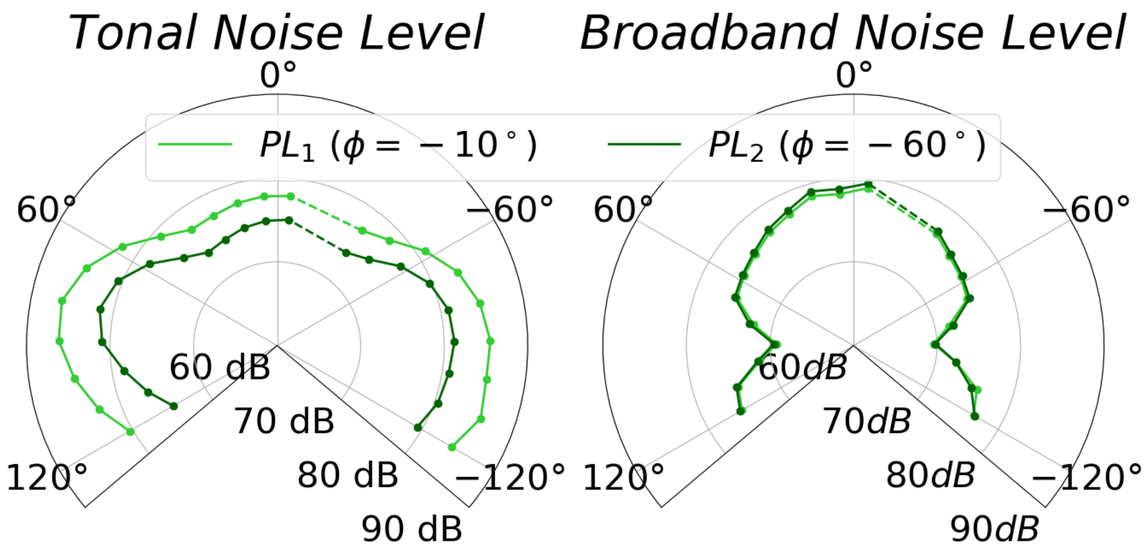
Results

Aeroacoustics Results (2/3)

Example case: z = 28 mm



FIXED THRUST ANALYSIS:



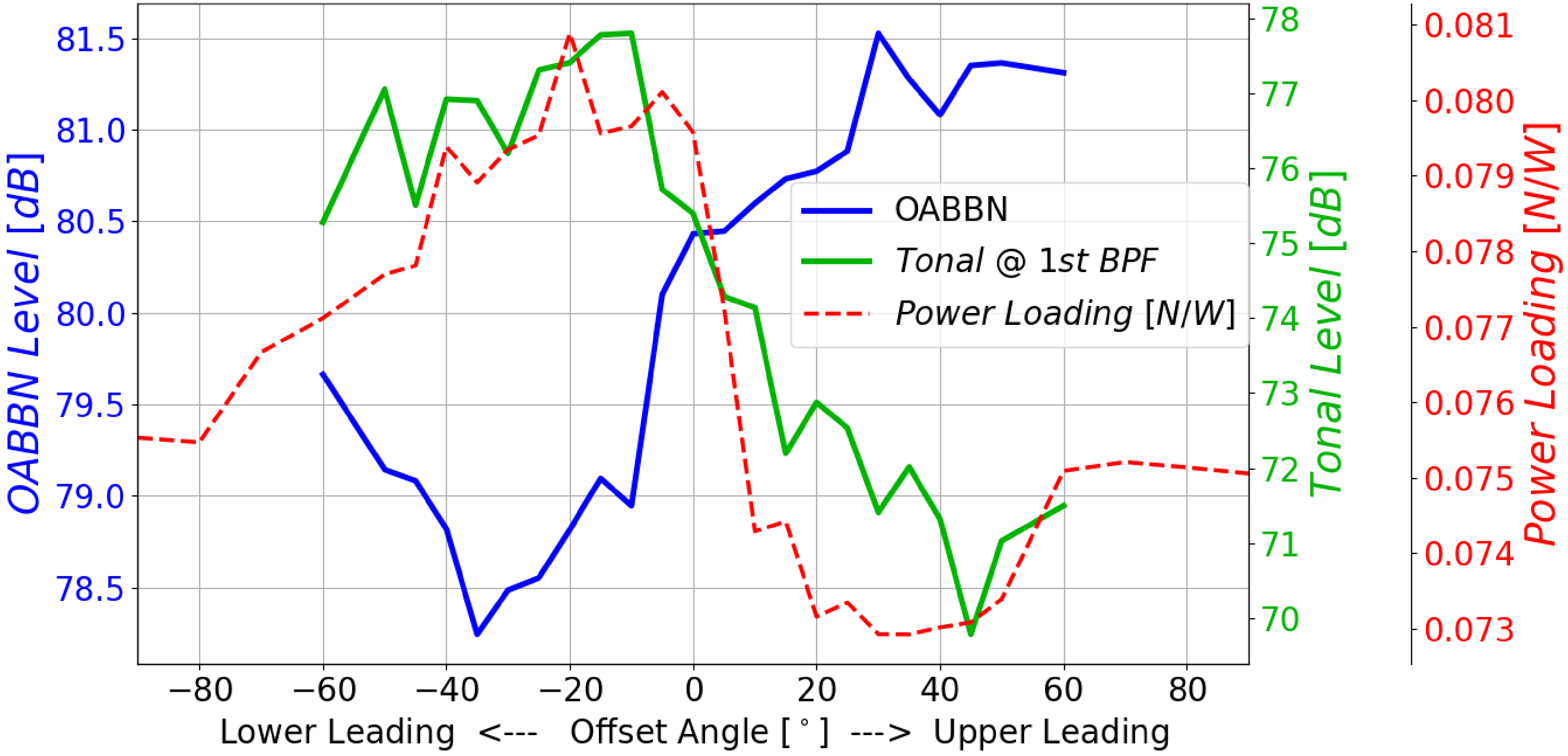
- OABBN unaffected
- Higher Efficiency → Higher Tonal Noise

Relationship still under investigation

Results

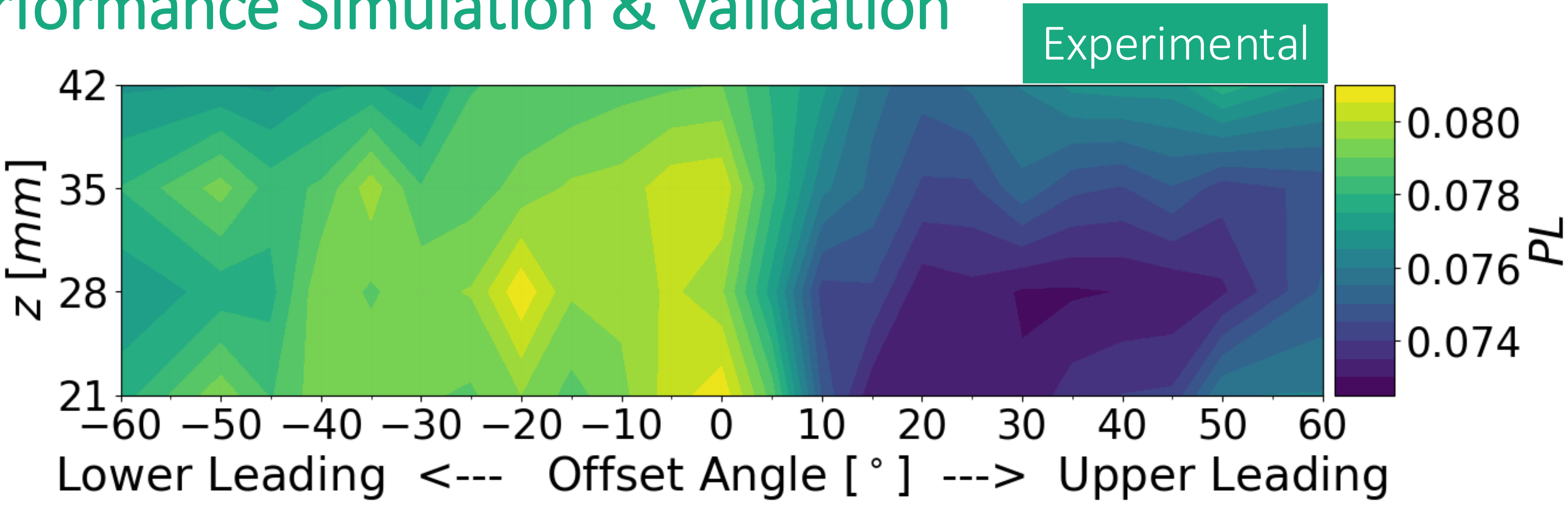
Aeroacoustics Results (3/3)

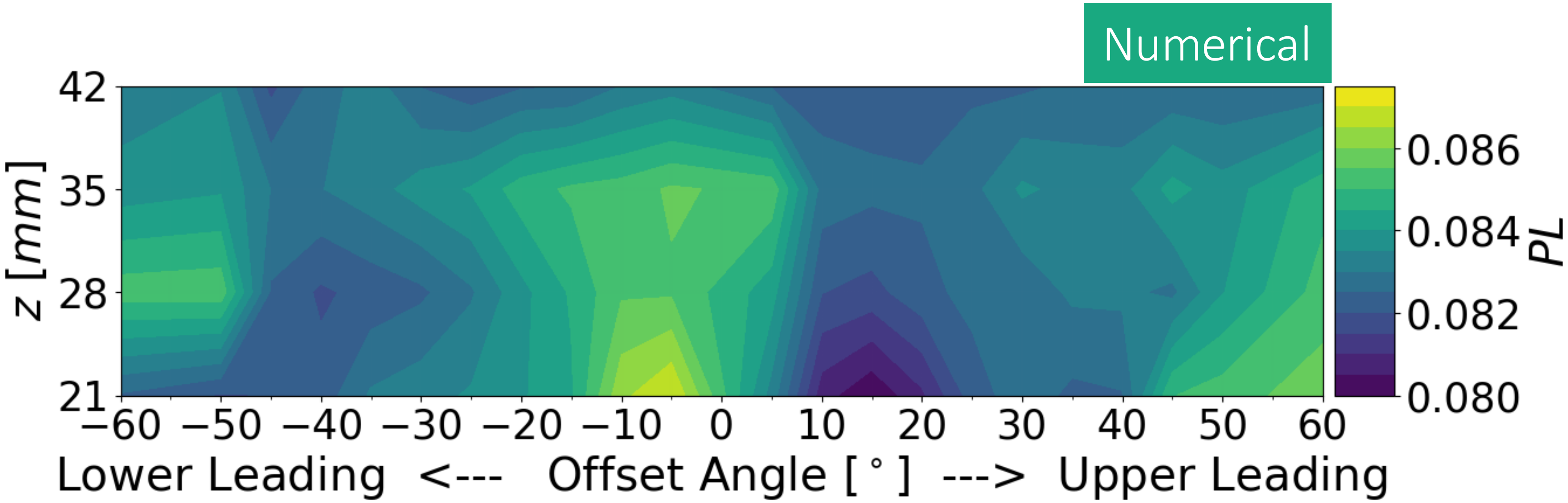
z = 28 mm case



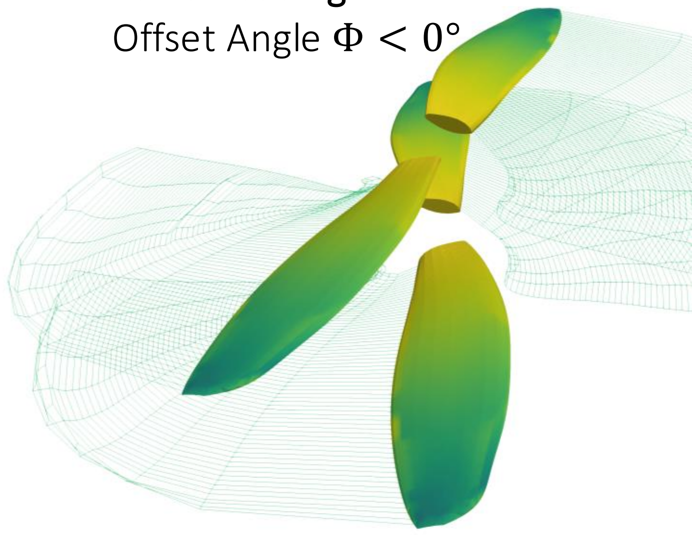
Results

Performance Simulation & Validation

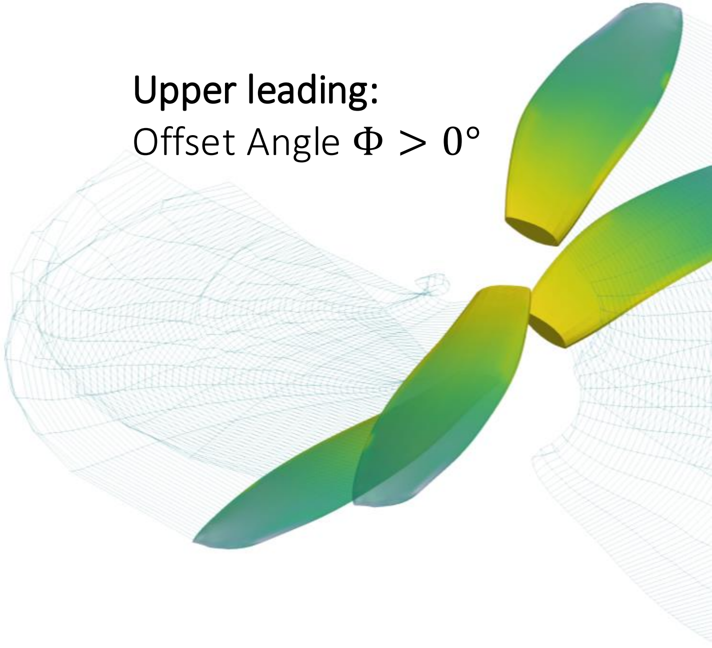




Lower leading:
Offset Angle $\Phi < 0°$



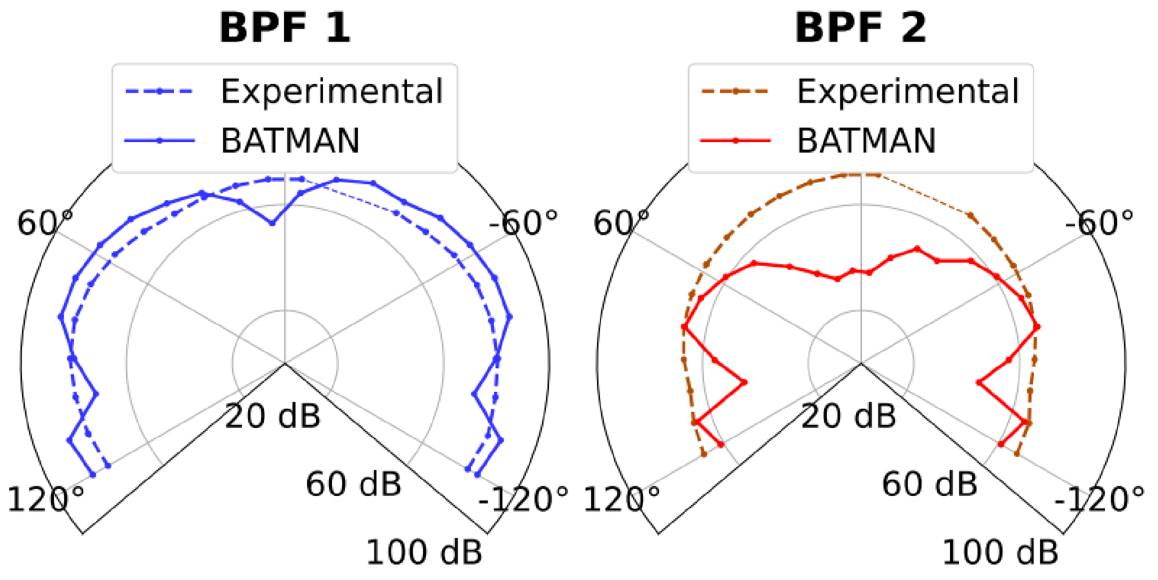
Upper leading:
Offset Angle $\Phi > 0°$



Results

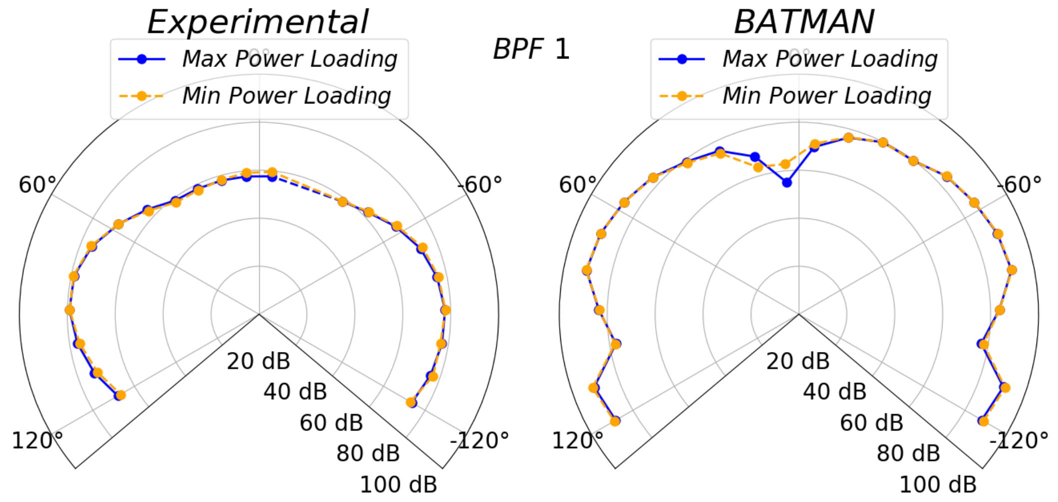
Noise Simulation & Validation

FlightStream + BATMAN$^{\pi}$ as predictor for the 1st BPF

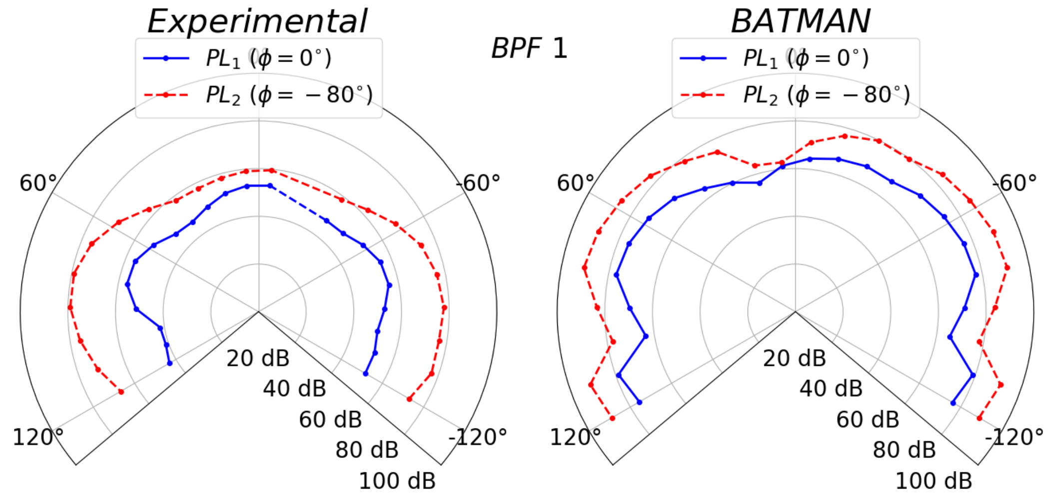


Recirculation from the 2nd BPF - Single Propeller case

MAX-MIN POWER LOADING ANALYSIS:



FIXED THRUST ANALYSIS:



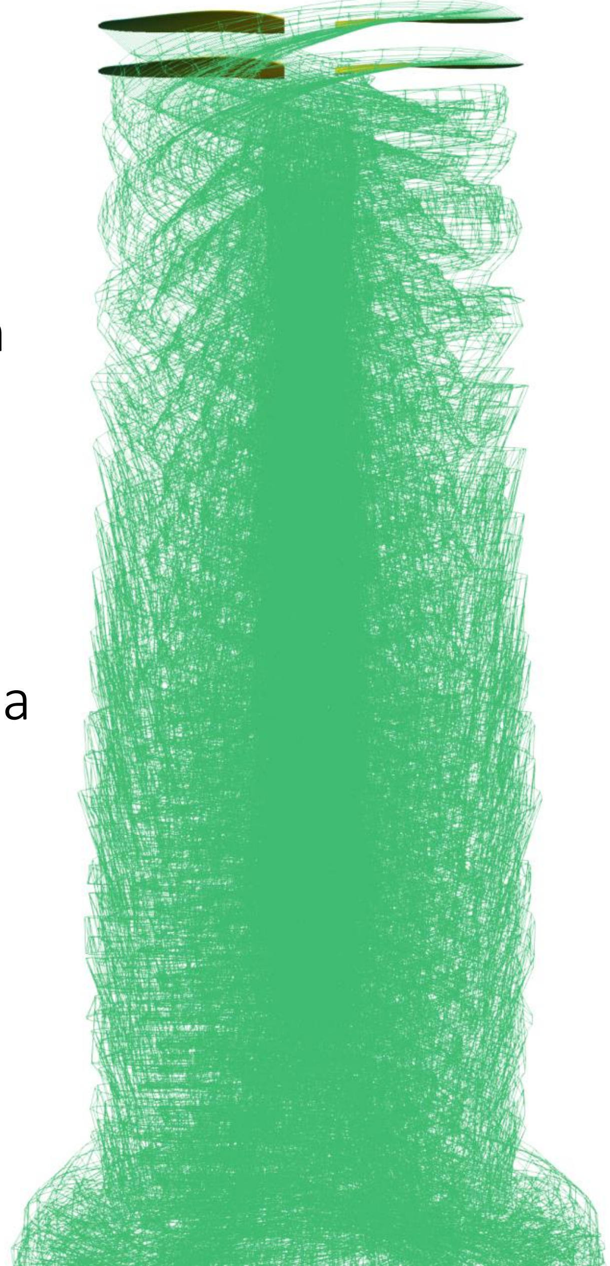
Conclusions

1. Creation of a wide Experimental Dataset of performance and noise for coaxial co-rotating propellers, as a function of (Φ, z).

2. Relationships between propulsive efficiency and noise have been retrieved and depicted, confirming the ones suggested in recent literature, and bringing further insights.

3. The aeroacoustics relationships highlighted experimentally have been predicted by a combined use numerical tools, approaching a fast and fully virtual design.

4. The numerical predictions have been validated for the first BPF.



Thanks for your kind attention!

Questions are welcome

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