Topic: An aeroacoustic investigation of turbulent interference of a propeller on a UAM vehicle

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Overview

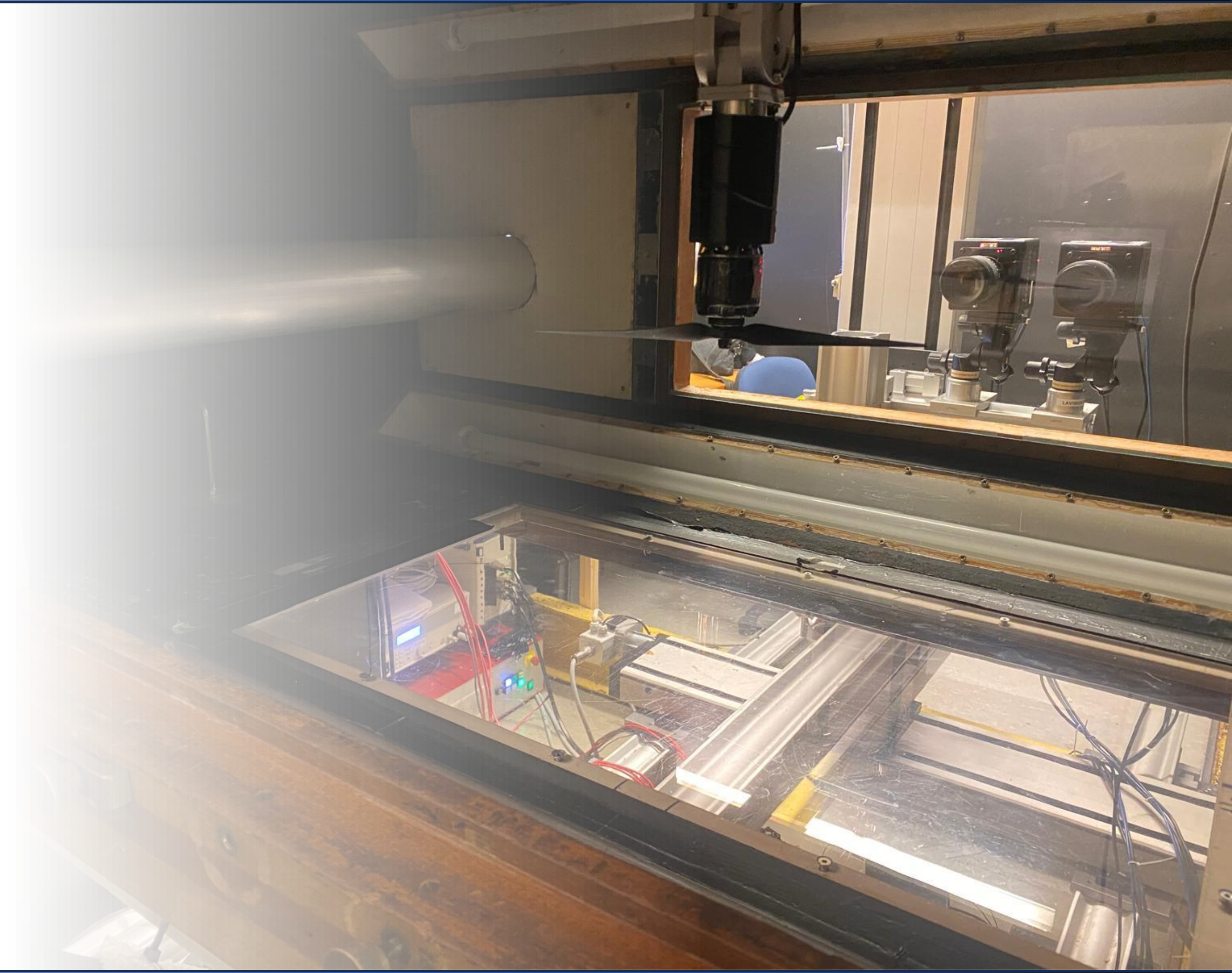
Background

Test overview and methodology

Results and discussion

Conclusions

Future work

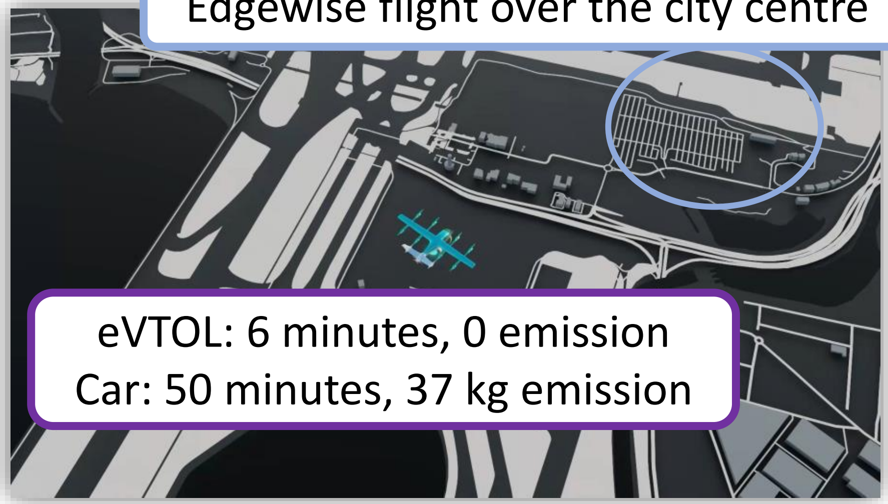


Background – UAM vehicles

Urban air mobility (UAM)

- **Green aviation** contributes to carbon neutrality and promotes technological advance
- The UAM market is estimated to be worth **$28 Billion by 2032** [1]
- Electric vertical take-off and landing (**eVTOL**) provides flexibility in urban area

Vertical Aerospace VX4



Edgewise flight over the city centre

eVTOL: 6 minutes, 0 emission
Car: 50 minutes, 37 kg emission

Aeroacoustic challenges of UAM vehicles

- Critical barrier to **community acceptance**[2]
- Complex flow field makes **cost-effective prediction** difficult
- Limited experimental data to **validate** low-order models
- Limited studies carried out on turbulence interaction

[1] F. Research, Global urban air mobility market worth $28.5 billion by 2032 (Nov 2024).
[2] D.P. Thipphavong et al., Urban Air Mobility Airspace Integration Concepts and Considerations, AIAA 2018-3676

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Background of tandem-rotor noise

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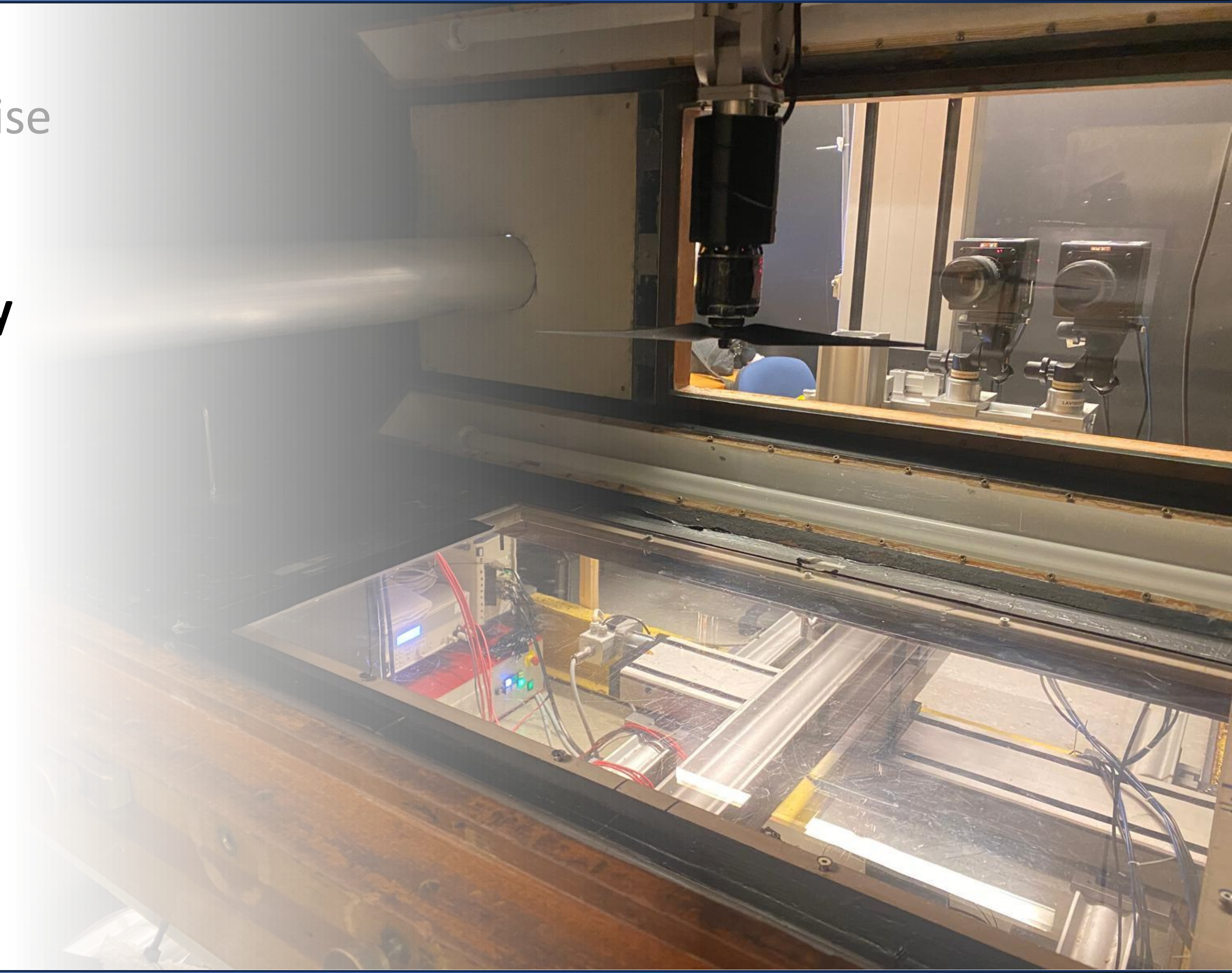


Research objective

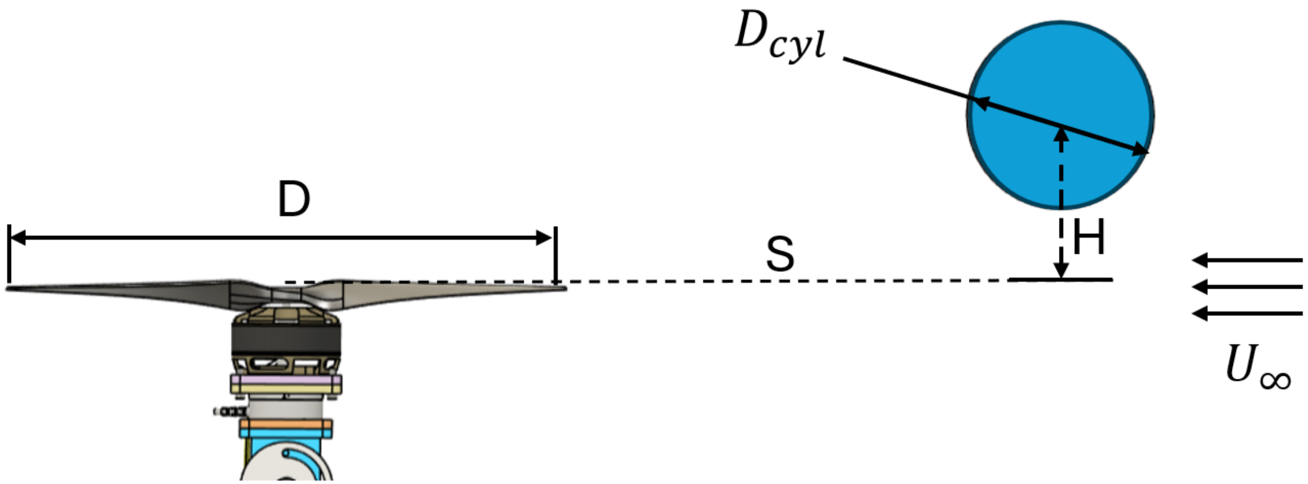
Experimental study of **turbulence interactions** in <u>edgewise </u>conditions

- *Aeroacoustic signatures from far-field microphones*
- *Nearfield flow measurement using phase-locked PIV*

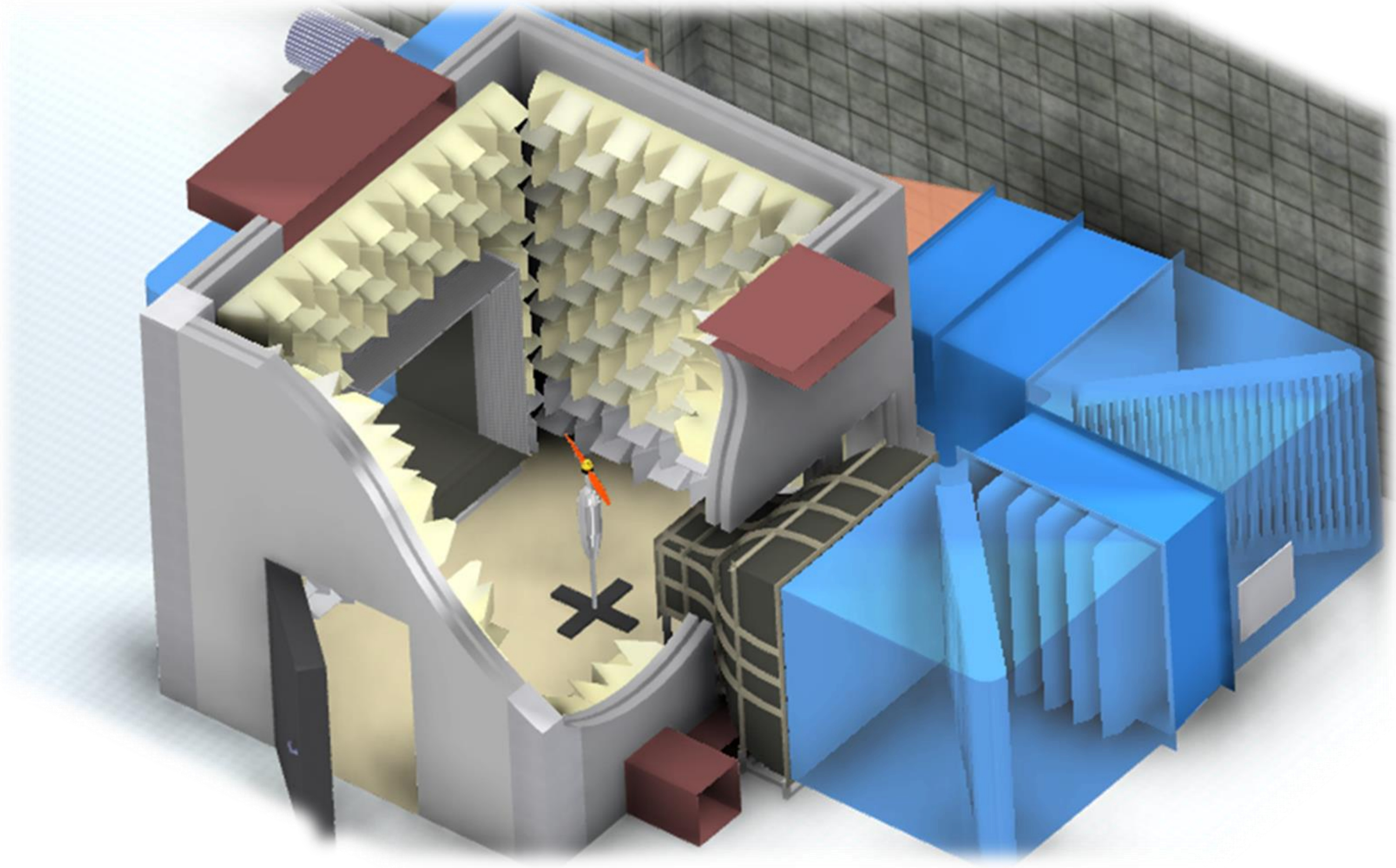
- *Gain a better understand **Haystacking** effects*

Methodology – Test Configuration

- **Free stream velocity:**
  - $U_\infty = 20\ ms^{-1}$
- **Propeller**:
  - D = 302mm (12")
- **Cylinder:**
  - H = 0, ±0.25D
  - S = 5D
  - D_{cyl}= 101.6 mm
  - $Freq_{cyl}$ = 40Hz



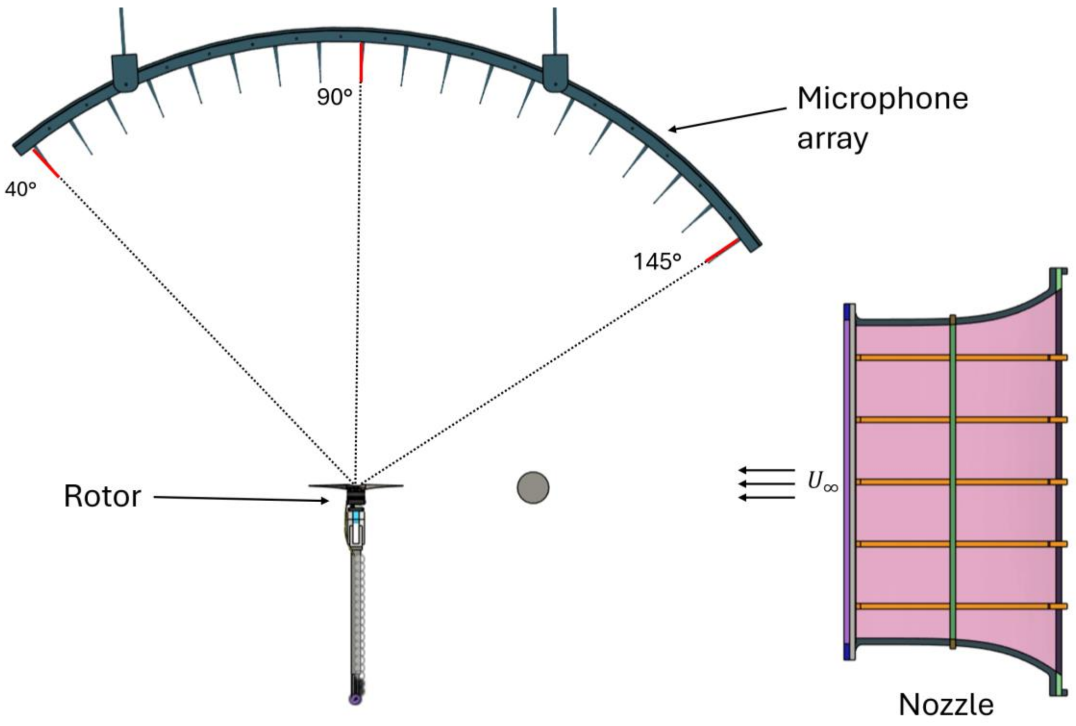
Methodology – Acoustic Test Facility



Pressure-Neutral Acoustic Wind Tunnel

- Open section, close-loop wind tunnel
- **1 m** (W) x **0.7 m** (H) Nozzle
- U_∞ range of **5 m/s** to **35 m/s**
- Turbulence intensity limited to approx. **0.2%**
- **Acoustically treated** section walls

Methodology – Acoustic Instrumentation



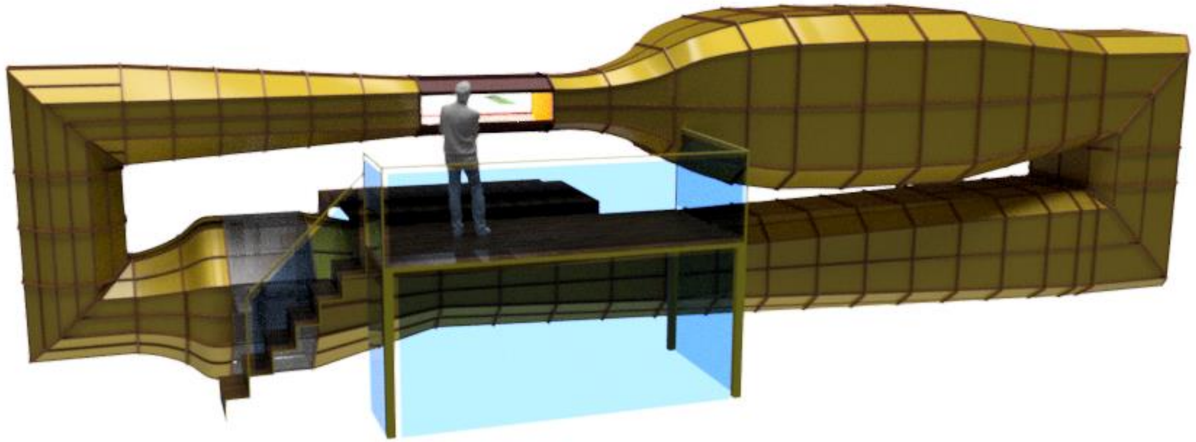
Top Array

- Coplanar with rotor
- 22 GRAS 40PL-10 microphones
- Observer range: $\theta = 40°$ to $145°$

Methodology – PIV Test Facility

Low Turbulence Wind Tunnel

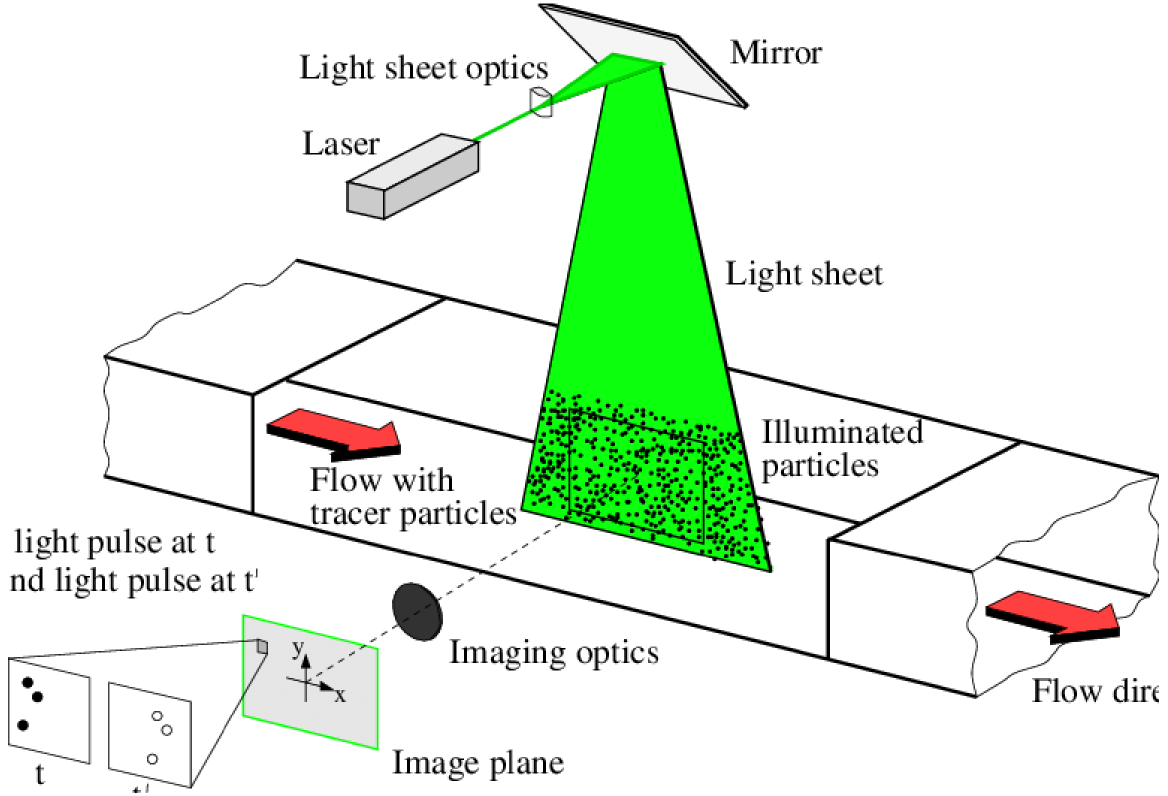
- Closed section, close-loop wind tunnel
- Octagonal shape with a **0.8 m** x **0.6 m** Working section
- U_∞ range up to **100 m/s**
- Turbulence intensity limited to approx. **0.05%**
- Fitted with a **LaVision tomographic PIV system**



Methodology – PIV Test Facilities

<u>Particle Image Velocimetry (PIV) Explained:</u>

- Flow field is seeded with tracer particles
- The imaging plane is illuminated using a high-power laser
- Cameras capture 2 frames of the imaging field in rapid succession
- Velocity field is resolved by calculating the displacement of tracer particles between the 2 frames

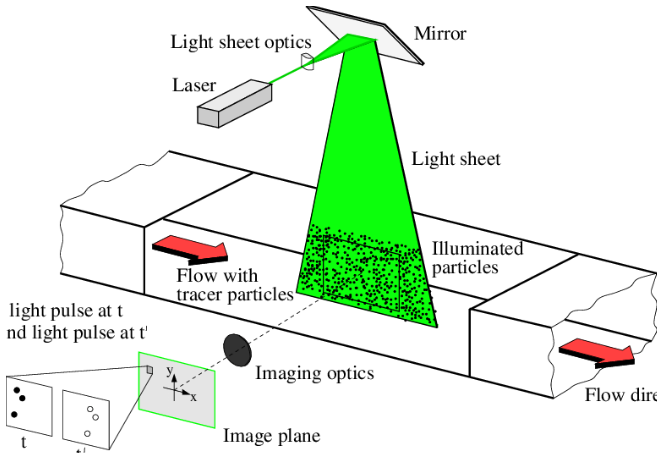


[3] - J. Kompenhans (2002). Application of Particle Image Velocimetry for the Investigation of High Speed Flow Fields.

Methodology – PIV Phase locking

<u>What is Phase locking:</u>

- The process of synchronizing the PIV data acquisition process with the blade azimuth position.
- In this case, the data acquisition process was triggered with an external signal generator



Propeller
RPM = 7,500 (125hz)

In Phase

Camera
2Khz

Laser
10Khz

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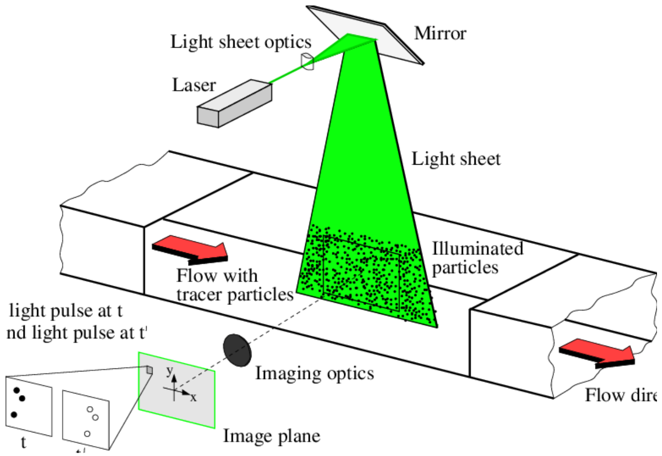
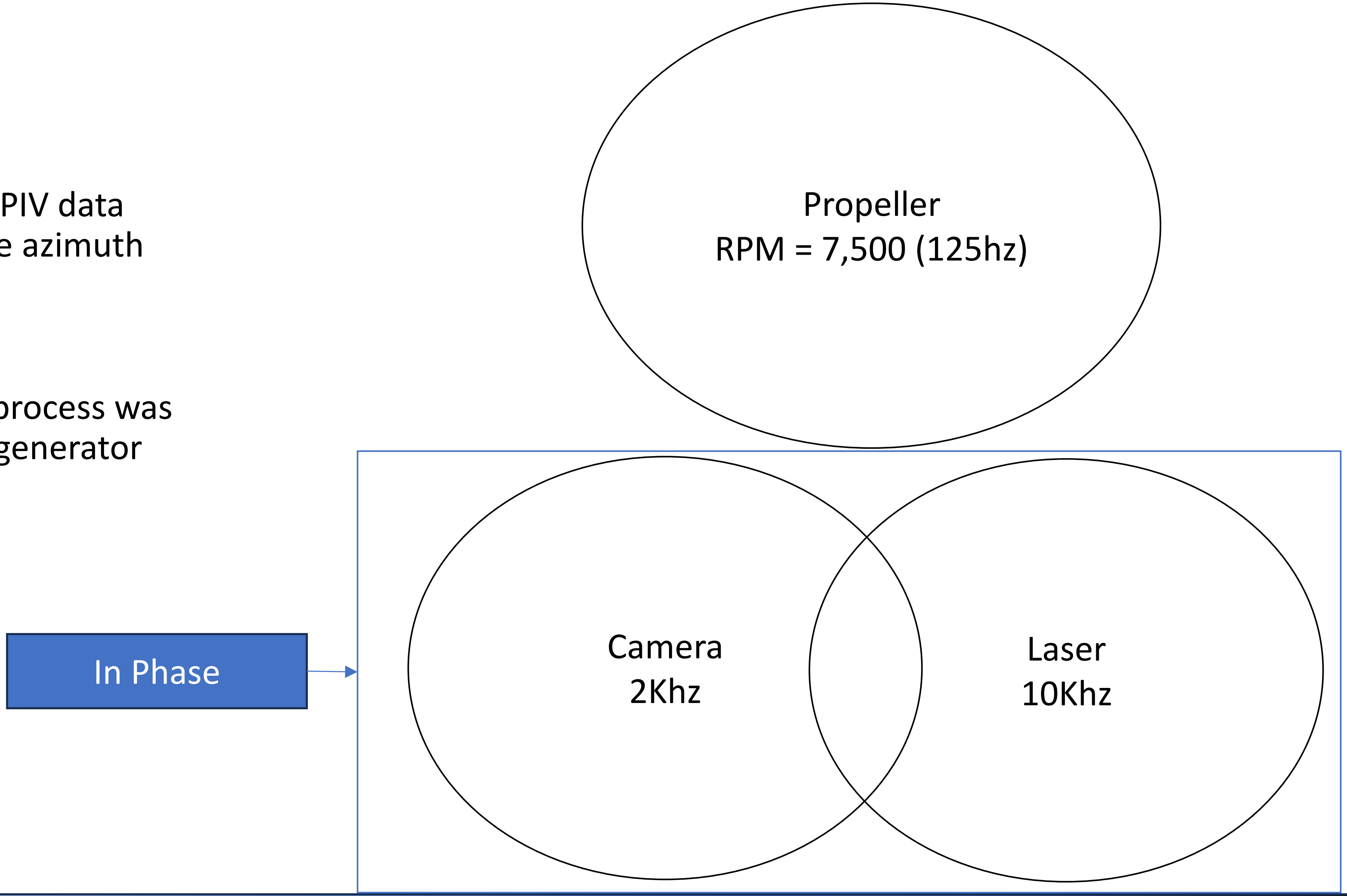
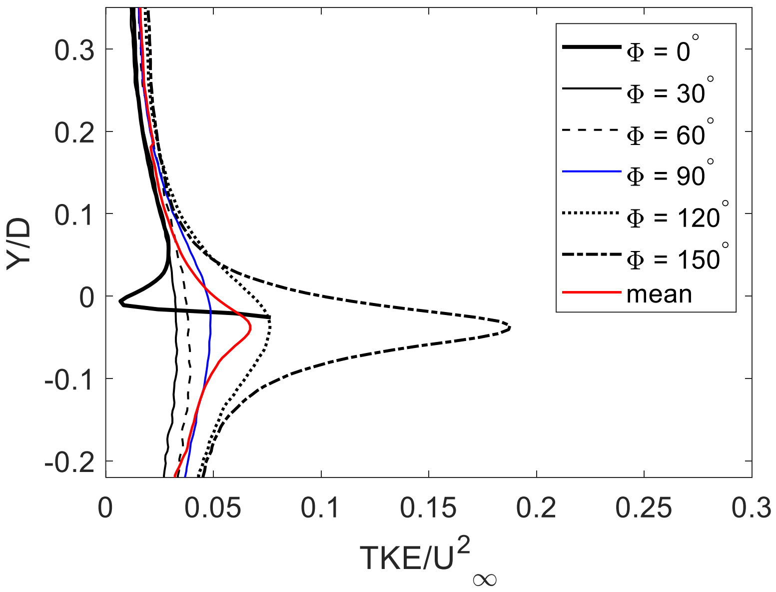
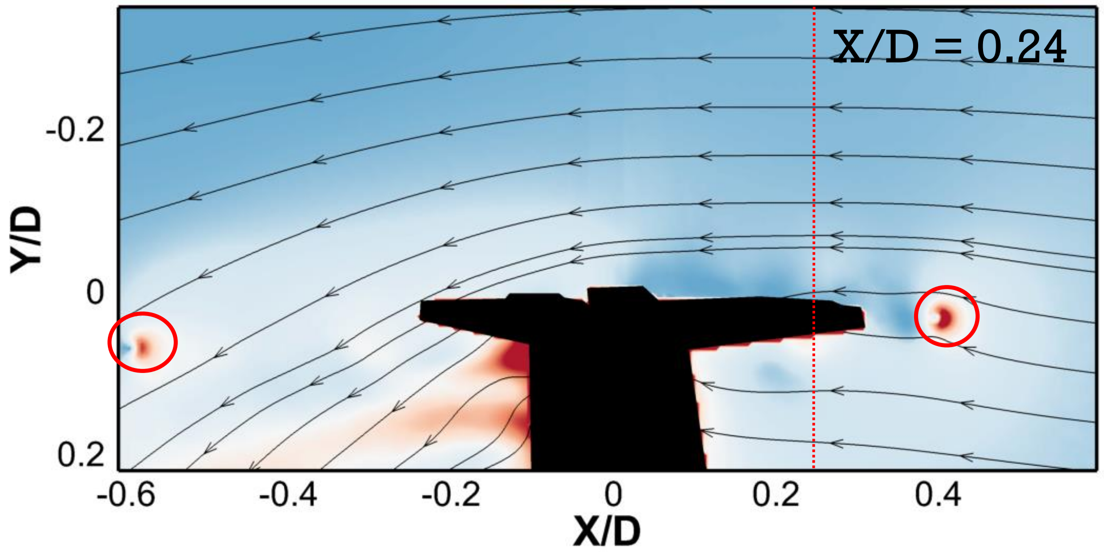




Methodology – PIV Phase Locking



Turbulence Intensity (Ti) slice at Y/D = 0.24



Turbulence Intensity (Ti) plot of the baseline case with velocity streamlines (ϕ = 120°)

Why use phase locking?

- Results in a “frozen” flow field picture
- Phase-locked measurements enable the flow evolution to be observed.

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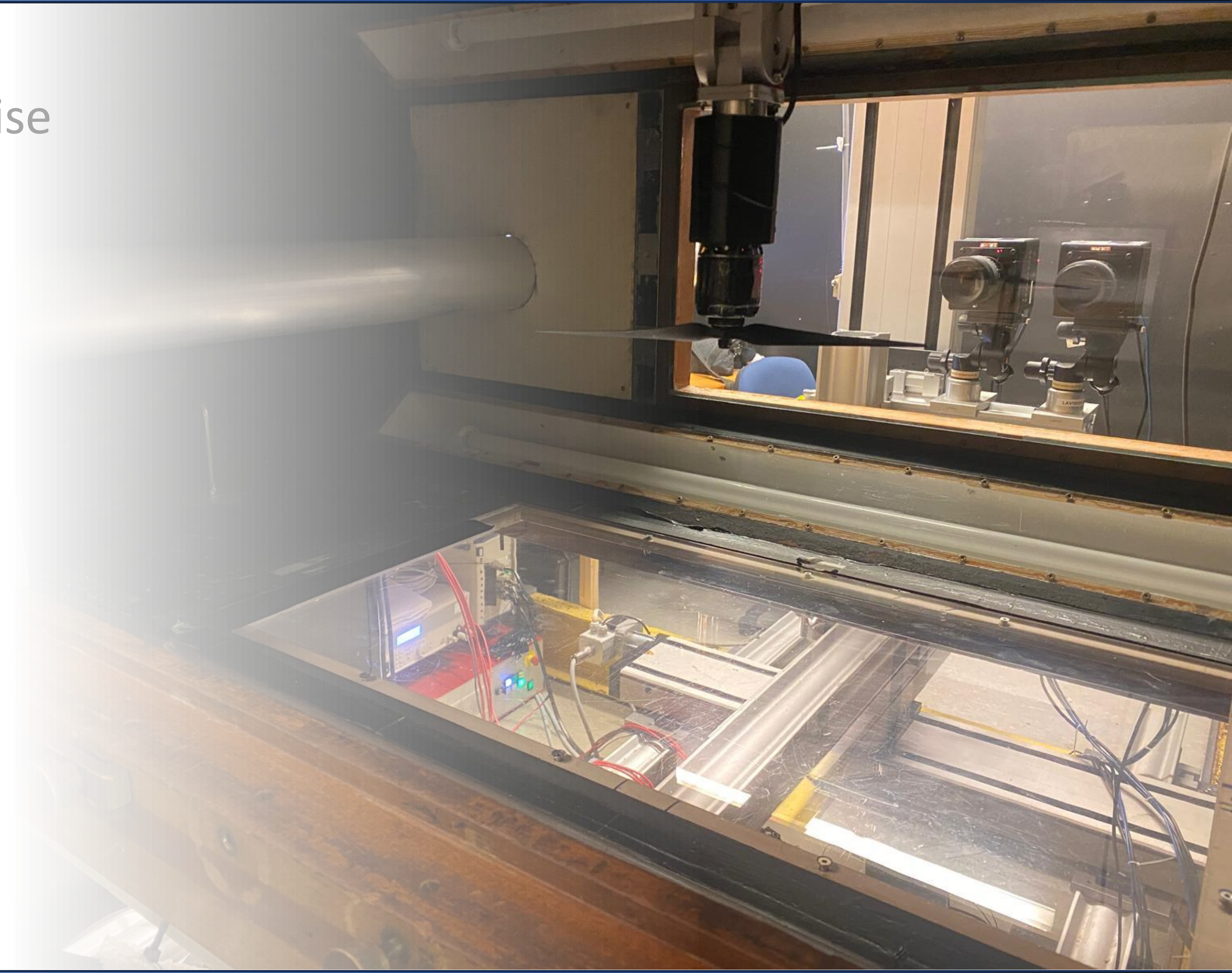
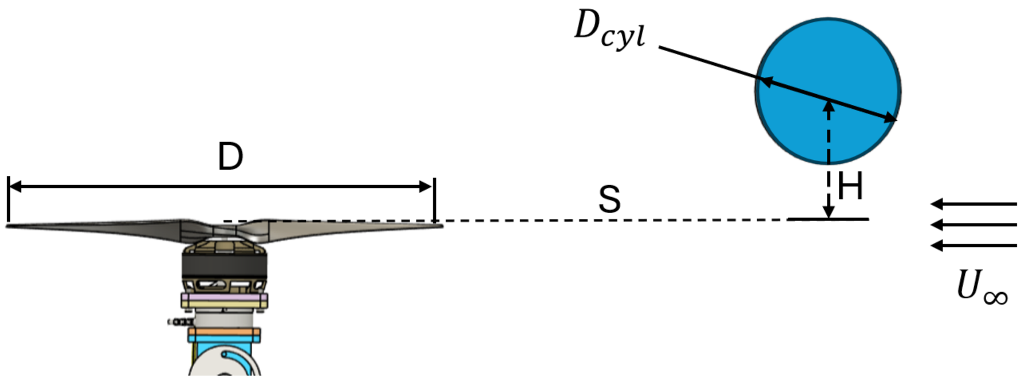


Results and Discussion



Test case:

- 7500 RPM: High Thrust condition – Edgewise flight
- 20 m/s inflow
- $\mu = 0.167$
- S = 5D

Presented results:

Directivity

- Overall sound pressure level (OASPL)

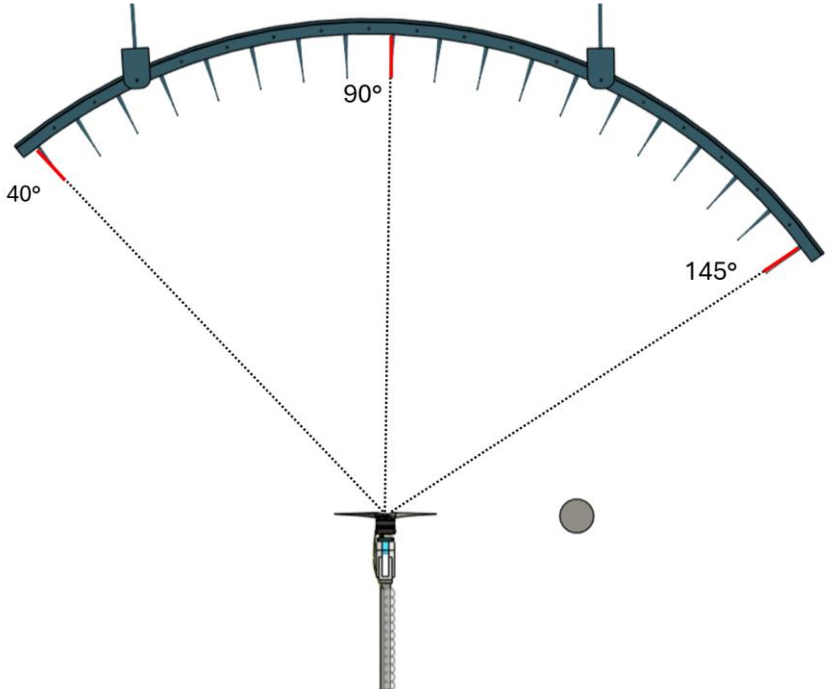
Noise spectra

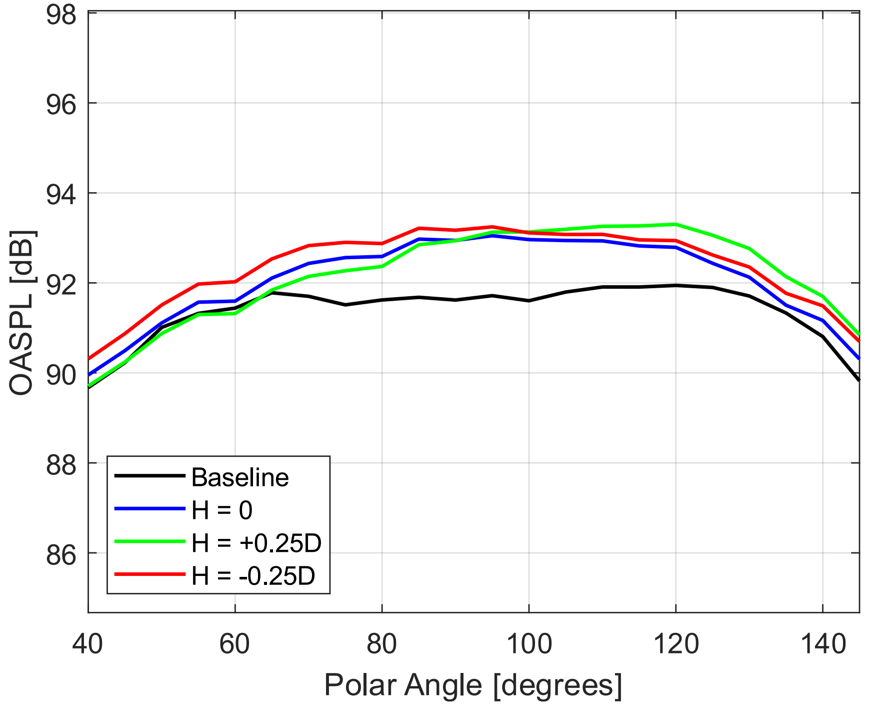
- Sound pressure levels (SPL) at 3 different cylinder heights

PIV Profiles

- Velocity profiles for H = 0

7500 RPM and 20 m/s inflow ($\mu = 0.167$)

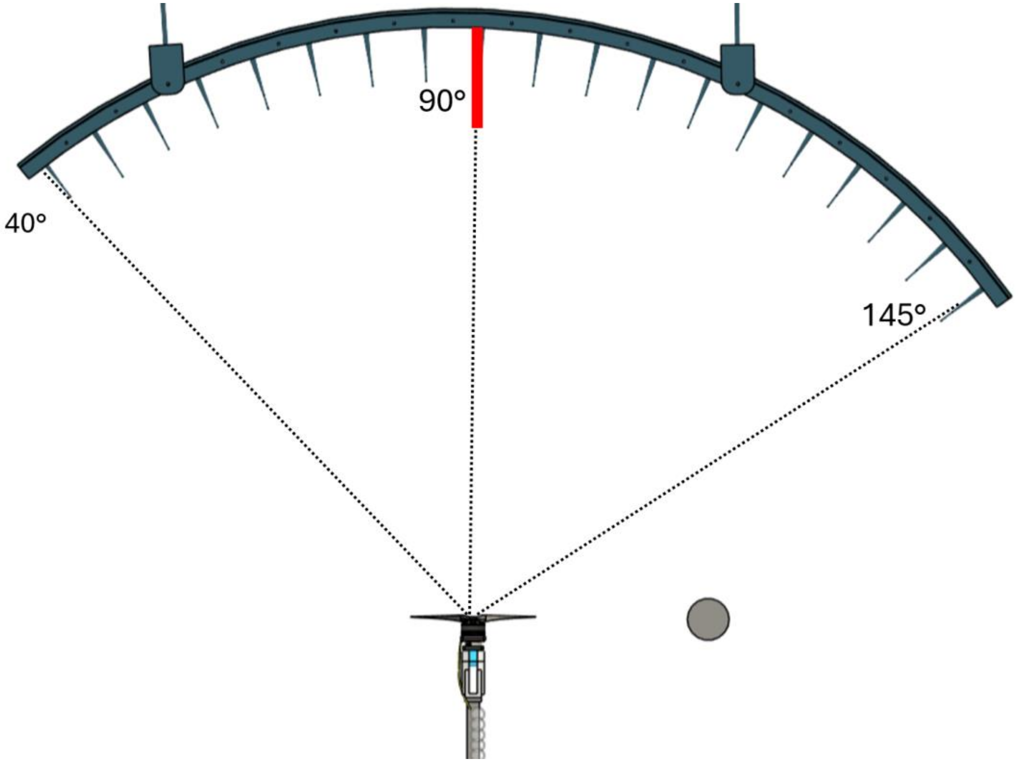




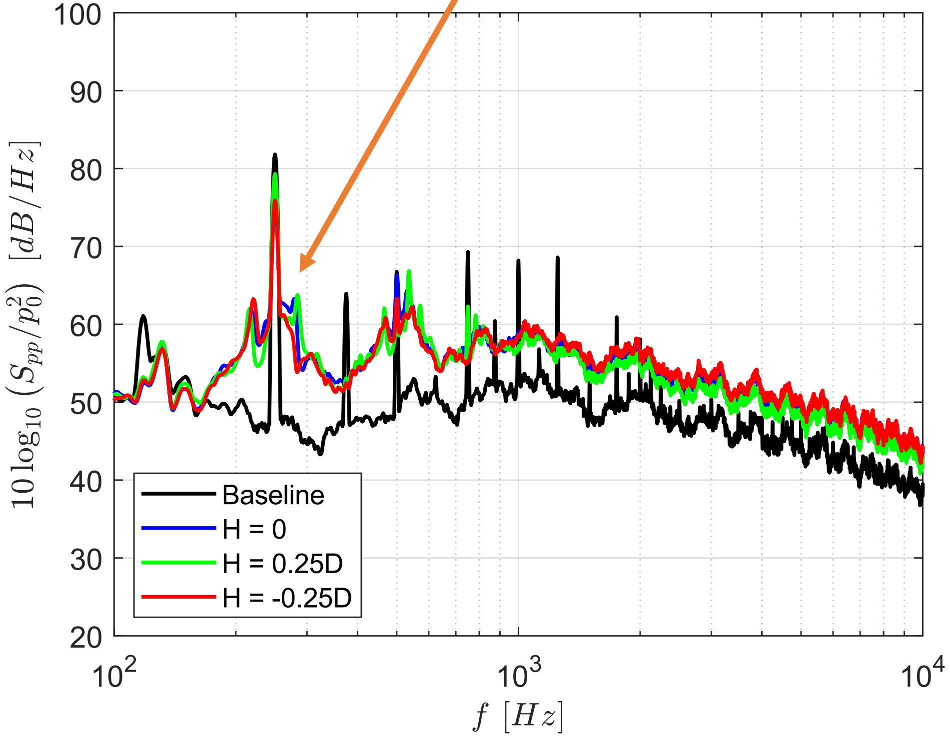
- Overall OASPL increase with all 3 cases
- H = 0 and H = -0.25D have similar sensitivities due to interactions with the motor body

Results and Discussion – Far-field Noise Spectra

7500 RPM and 20 m/s inflow ($\mu = 0.167$)



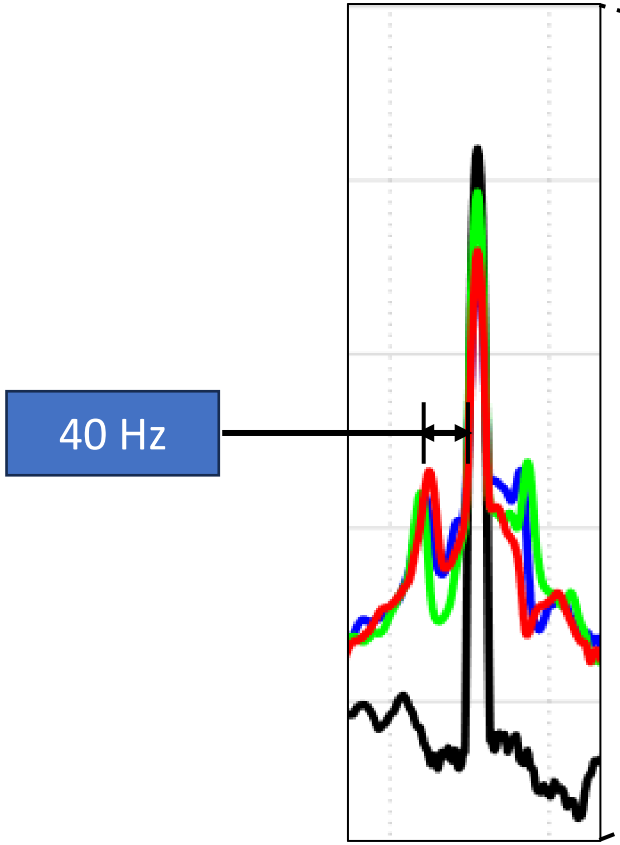
Evidence of Haystacking

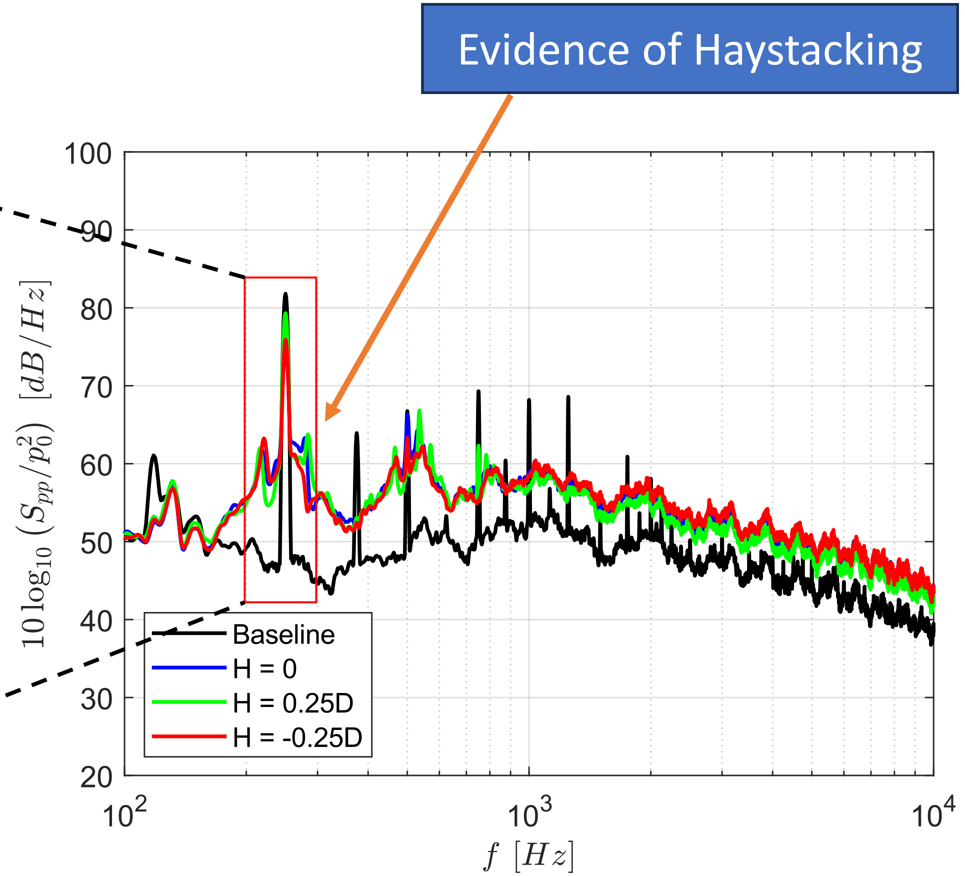


- Overall SPL increase in all 3 cases
- Haystacking observed in the BPF

Results and Discussion – Haystacking

7500 RPM and 20 m/s inflow ($\mu = 0.167$)

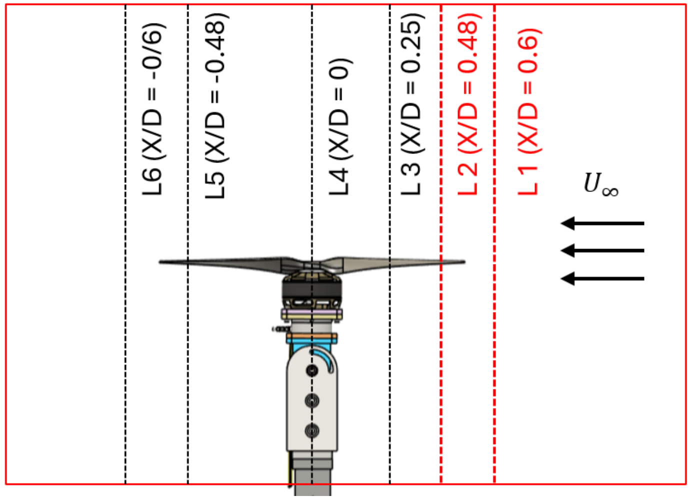


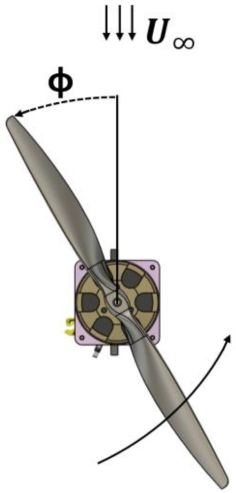


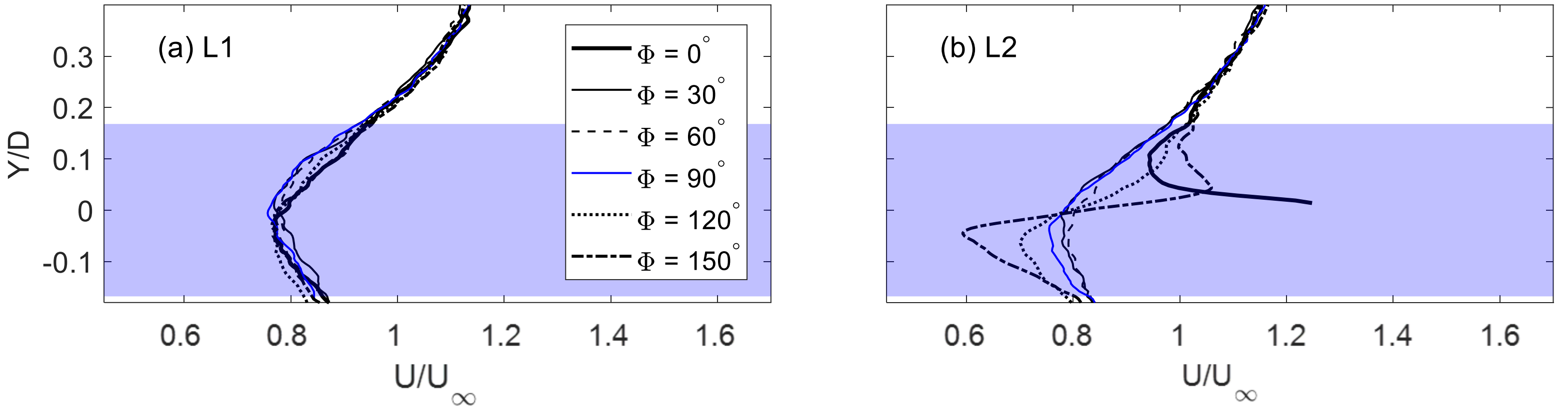
- Overall SPL increase in all 3 cases
- Haystacking observed in the BPF

Results and Discussion – Far-field Noise Spectra

7500 RPM, 20 m/s inflow ($\mu = 0.167$) and H= 0







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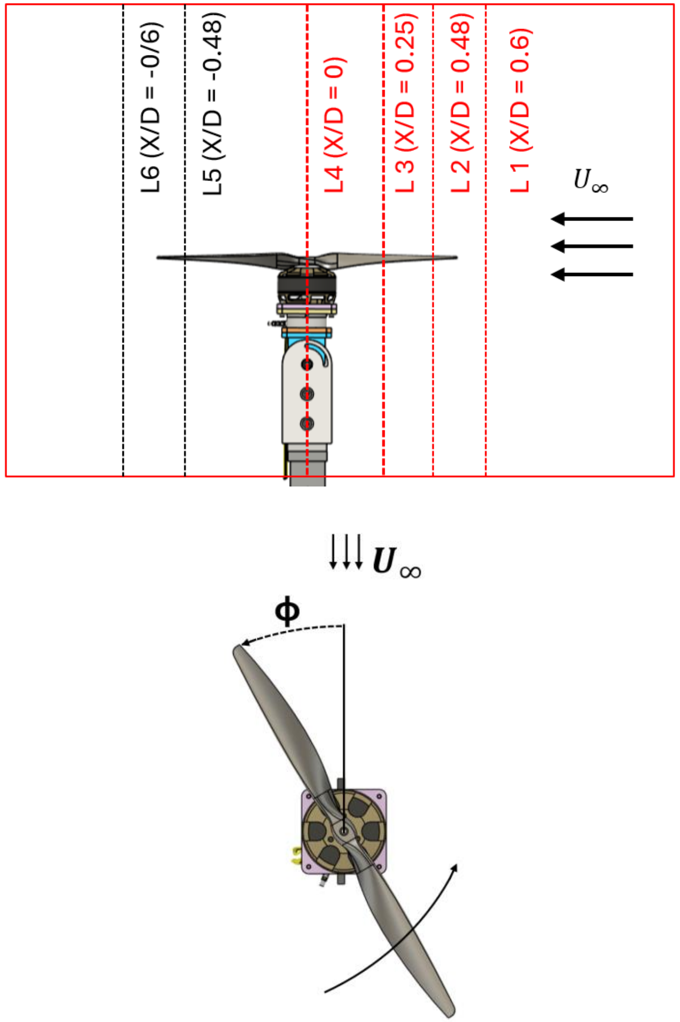

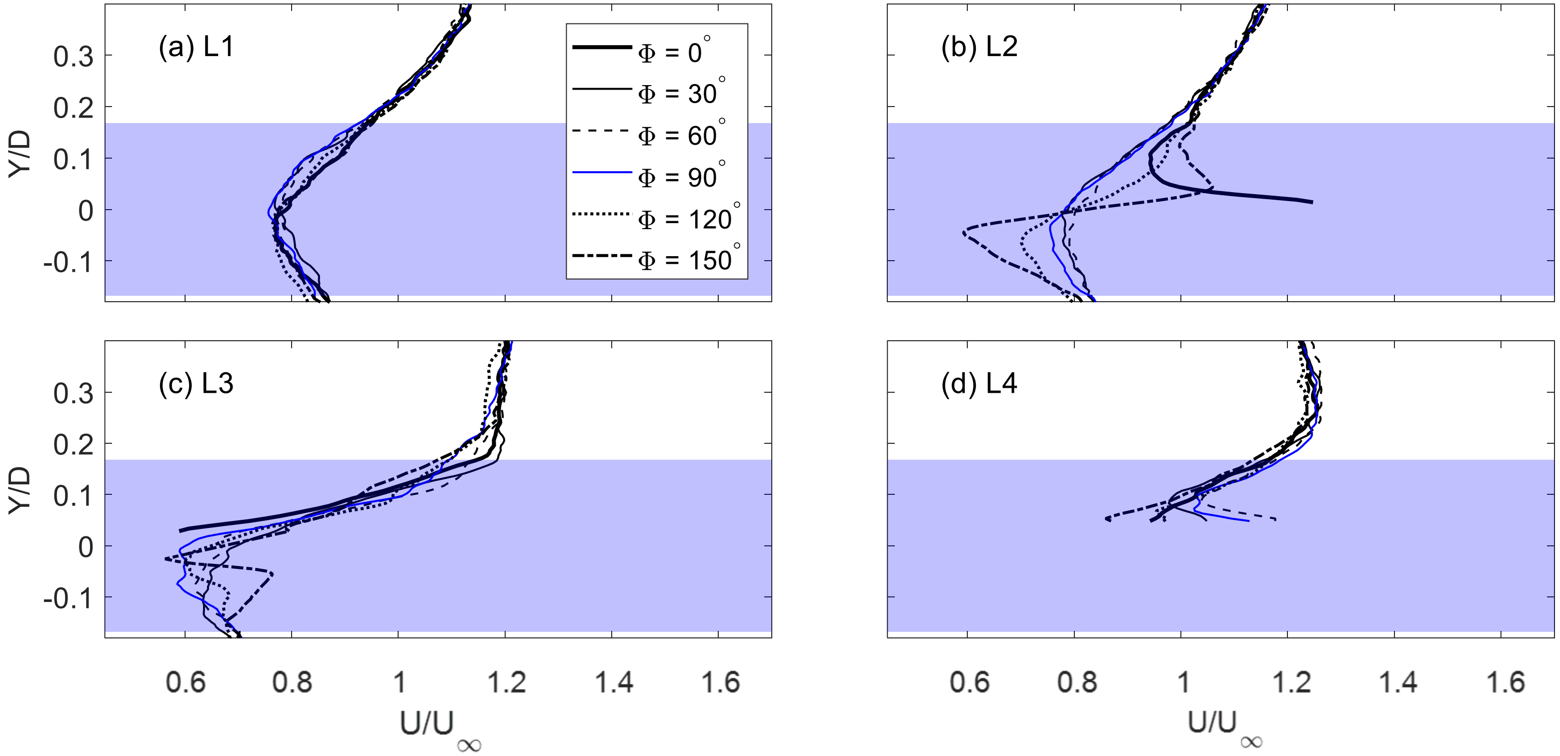

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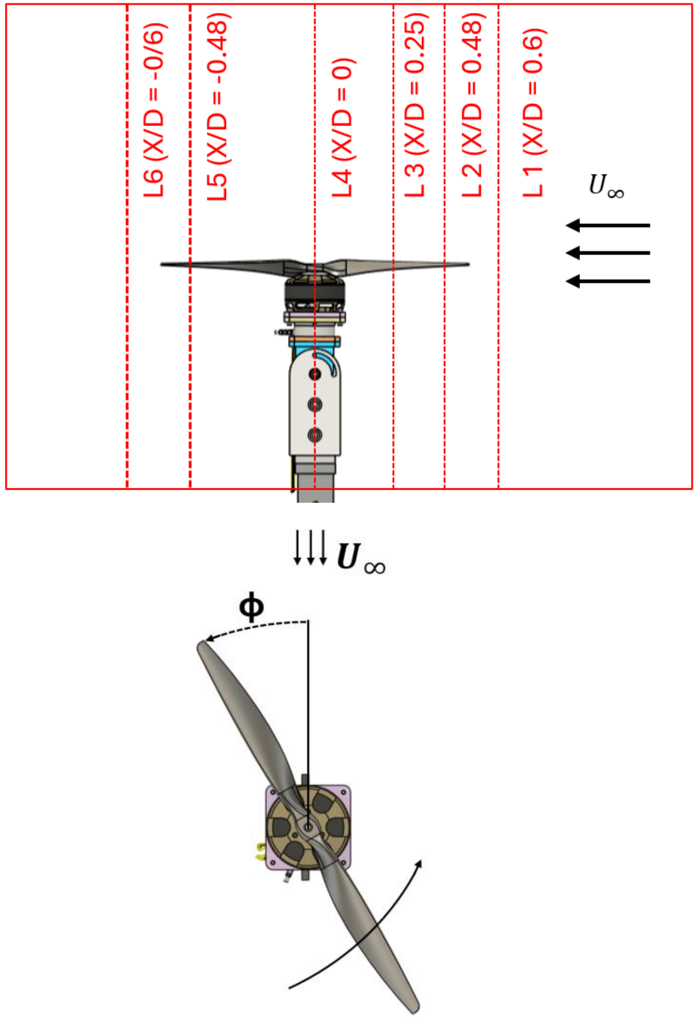

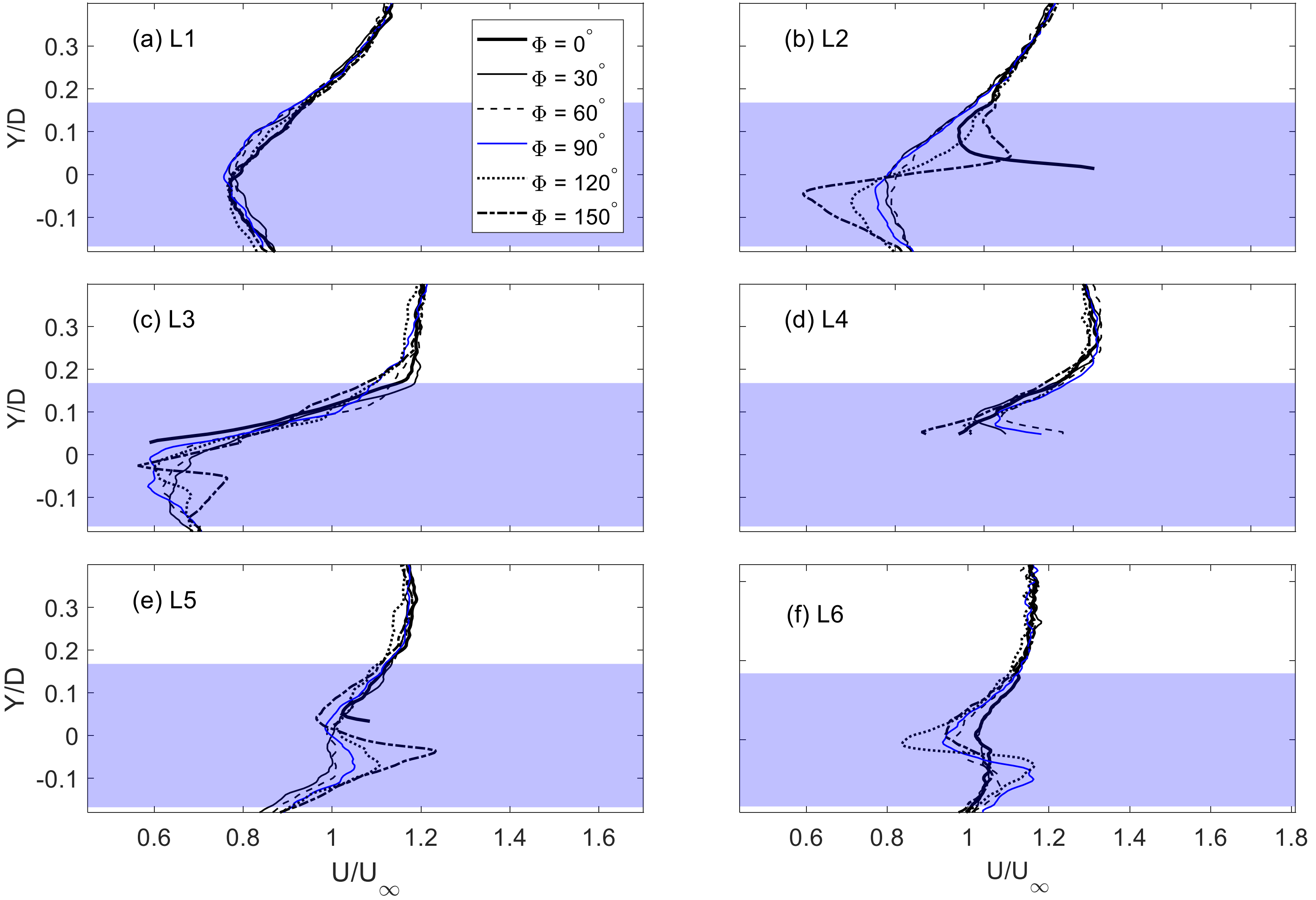

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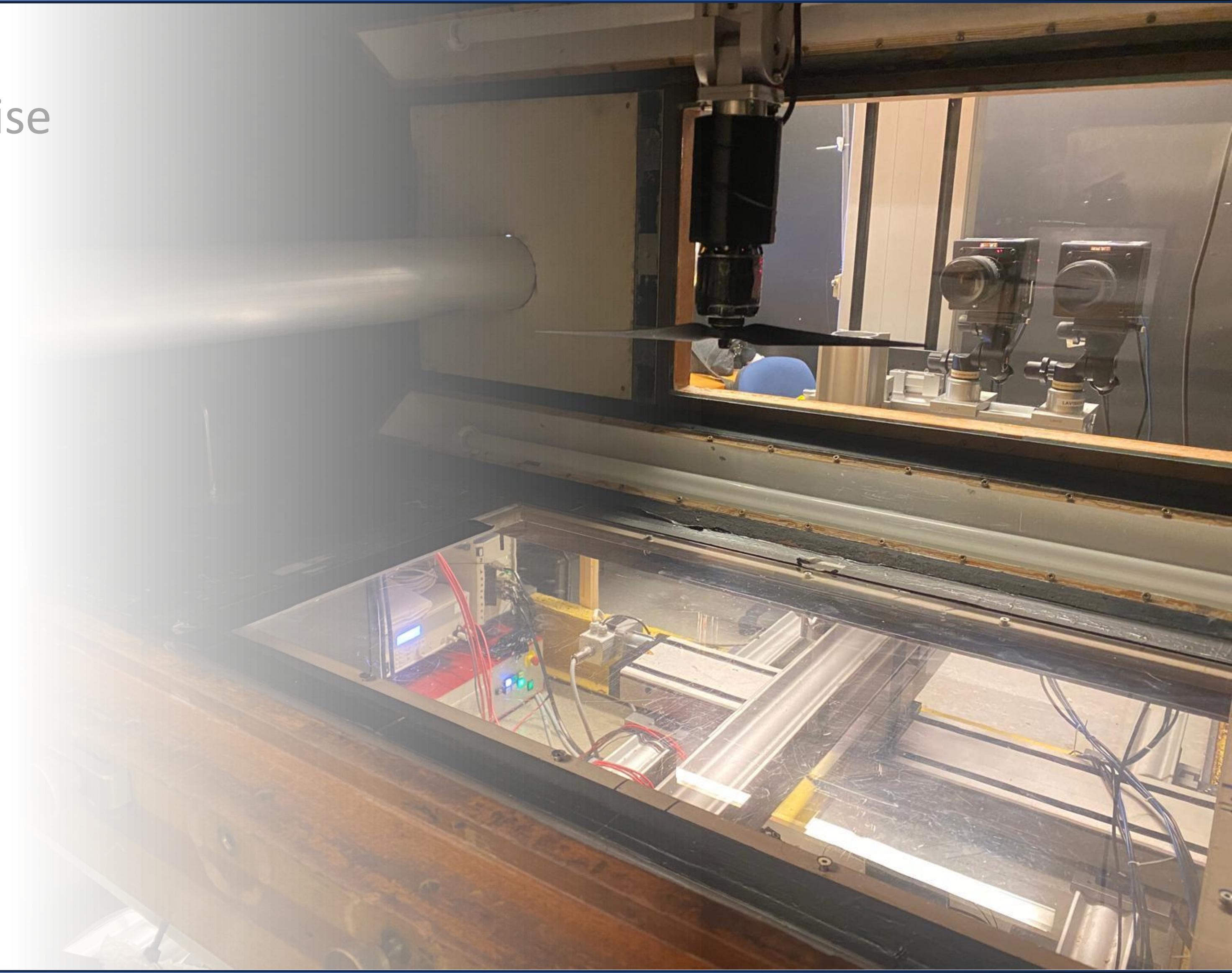


Conclusions

<u>Successfully carried out acoustic and phase-locked PIV experiments investigating turbulence interactions on a UAM rotor in Edgewise flight</u>

- Pinpoint the underlying drivers of haystacking
- Exceeded experimental capabilities
  - Successfully conducted phase locked PIV at 7,500 RPM
- Made available data for use in numerical models

Hyundai PAV

Future work

Extended test cases

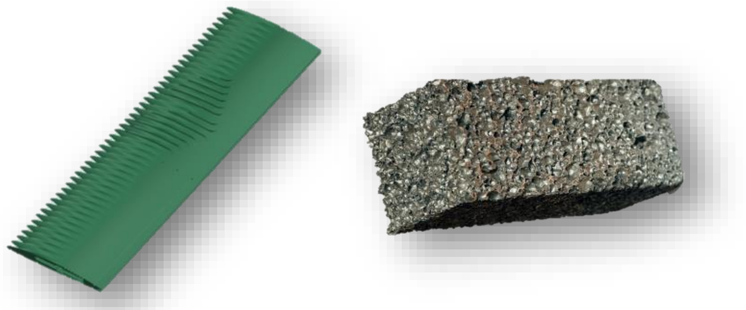
- Full PIV characterization of various cylinder configurations
- Phase-locked acoustic measurements

Numerical methods

- Creation of analytical models to predict changes in noise and performance of the propeller
- Validation of CFD methods

Noise mitigation methods

- Blade optimisation for noise mitigation (tip geometry, TE serration, etc.)



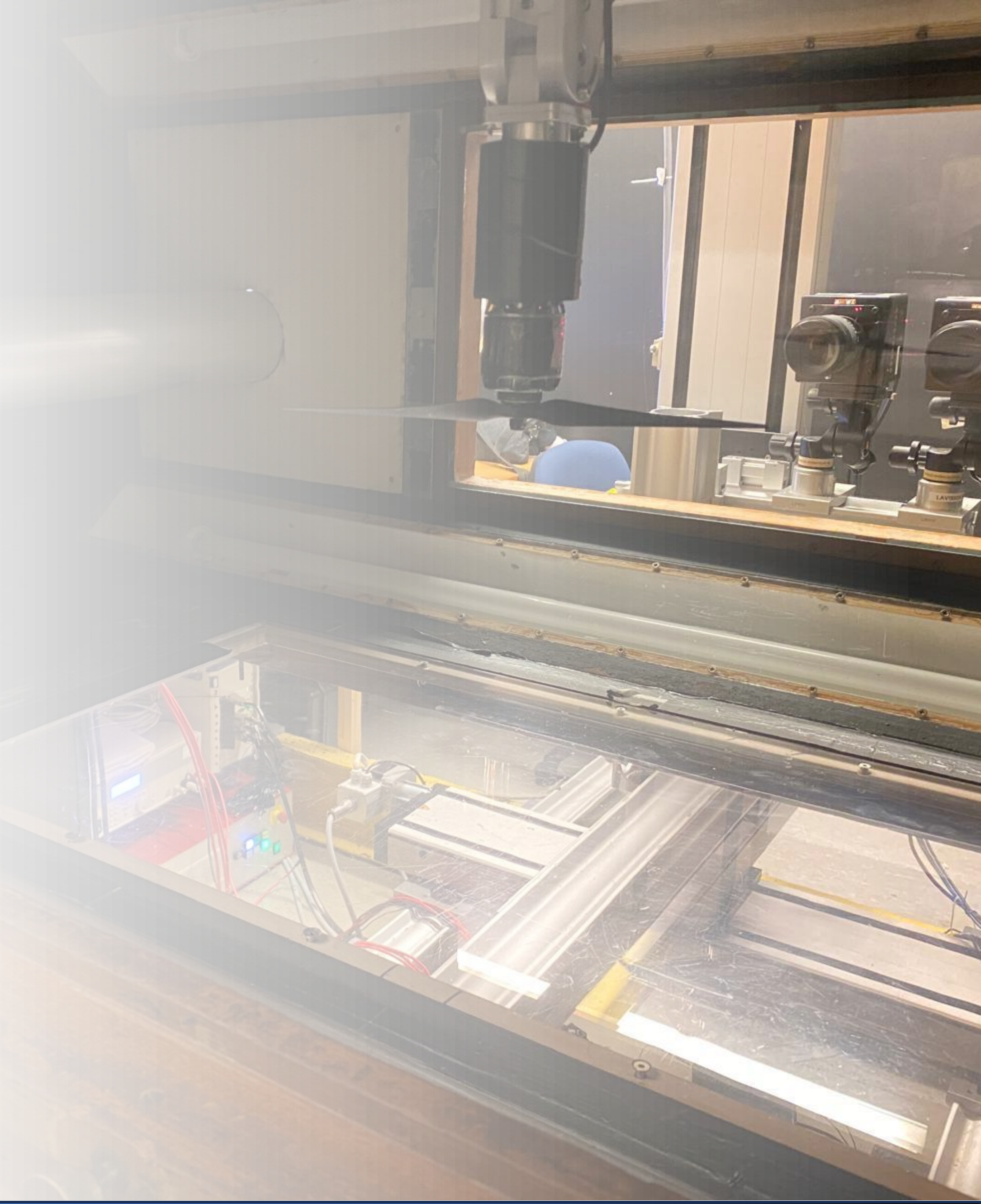
Examples of noise mitigation methods

BERP, the most famous blade tip optimisation case

Thank you

Acknowledgements:

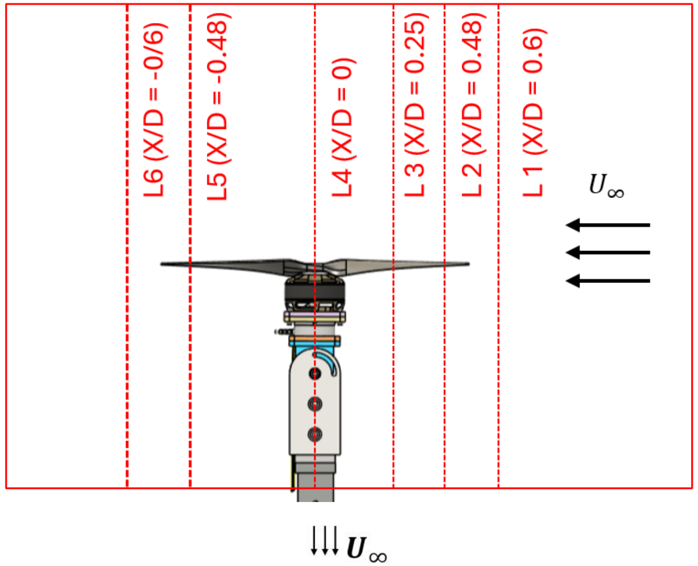
- RP4 Supervisor: Mahdi Azarpeyvand
- University of Bristol team: Xiao Liu, Lab technicians & Workshop team.

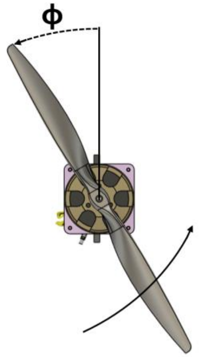


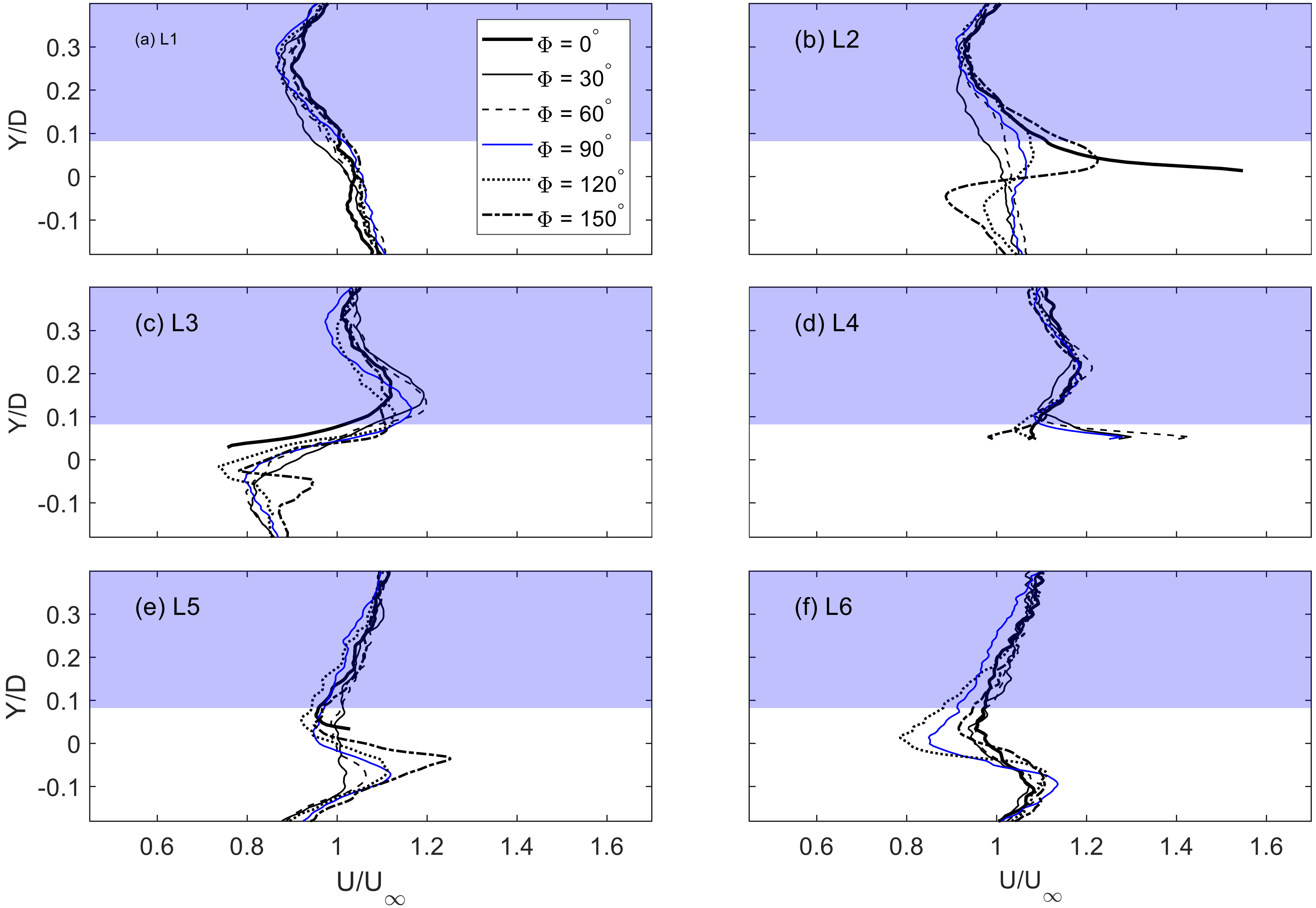
APPENDIX

Results and Discussion – Far-field Noise Spectra

7500 RPM, 20 m/s inflow ($\mu = 0.167$) and H=0.25D







Results and Discussion – Far-field Noise Spectra

7500 RPM, 20 m/s inflow ($\mu = 0.167$) and H= -0.25D