VALIDATION OF A FAST NON-EMPIRIC ROTOR NOISE PREDICTION MODEL FOR INSTALLED PROPULSORS

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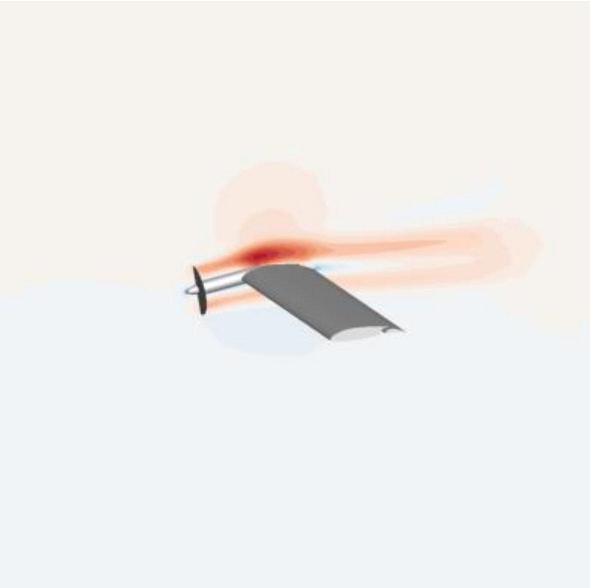
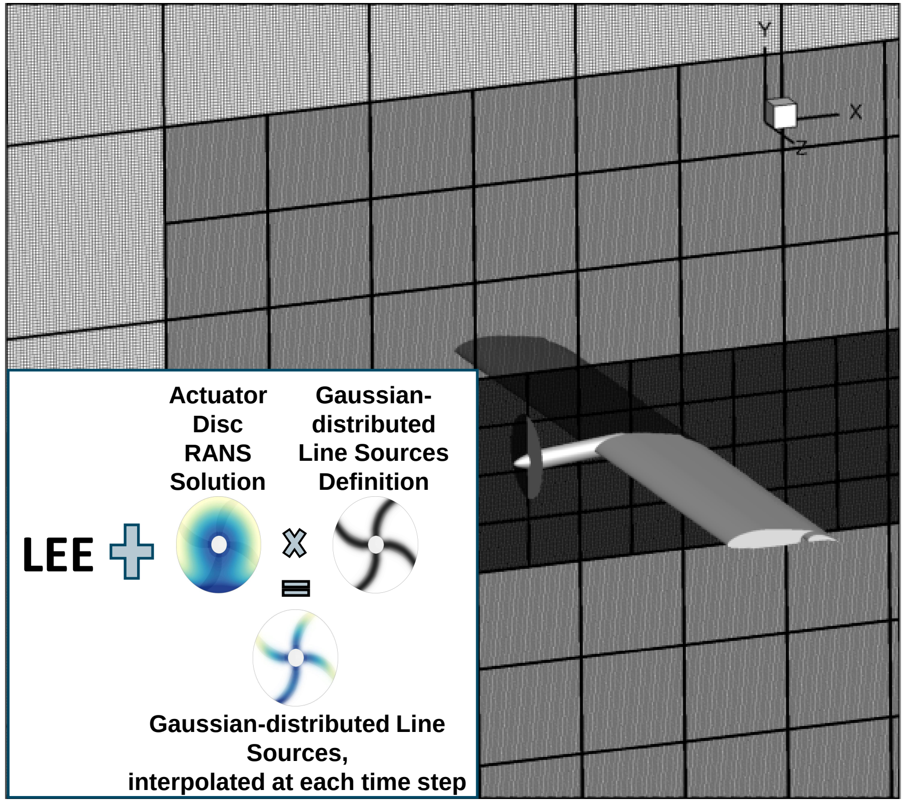
Advances in Rotor and Propeller Noise: Prediction, Mitigation, and Future Challenges, 21.10.2025

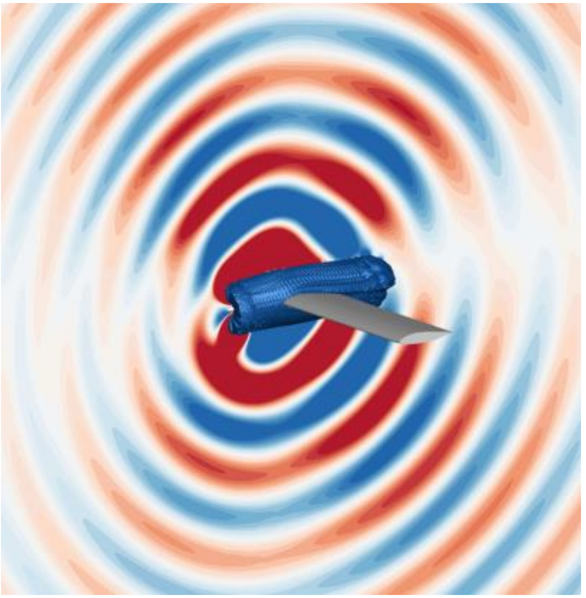
Methodology,
Non-Empirical CFD-CAA Rotor Tonal Noise Prediction

3D AD RANS





3D CAA



<u>Computational Fluid Dynamics (CFD)</u>:
3D Actuator Disc (AD) steady RANS,
DLR's TAU solver

<u>Computational AeroAcoustics (CAA)</u>:
3D Linearized Euler Equations (LEE) with Gaussian-distributed propeller loads replacing rotor blades geometry,
DLR's PIANO-IBM solver
(hierarchical Cartesian meshes)

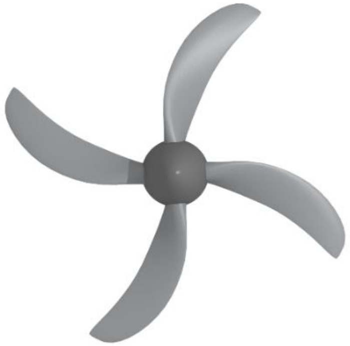
Methodology: Rotor Loading Source

Gaussian Regularized Sources

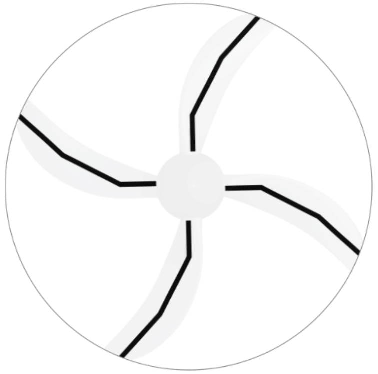
$$\boldsymbol{S}' = \boldsymbol{S} \cdot K(\mathrm{r},\phi,\mathrm{x}) - \overline{\boldsymbol{S} \cdot K(\mathrm{r},\phi,\mathrm{x})}$$

$K(\mathrm{r},\phi,\mathrm{x})$ Gaussian Regularization Kernel

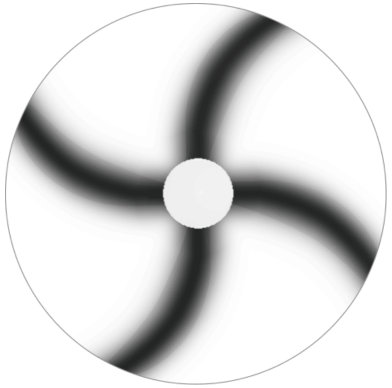
$\boldsymbol{S} = (w, w, w)$ Source Vector



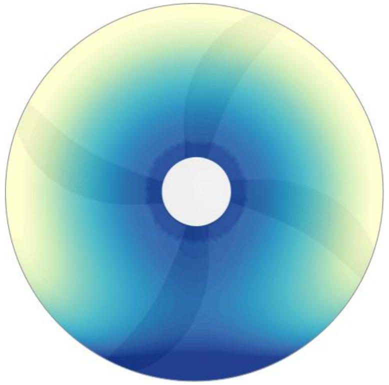
Original rotor blades to be modeled



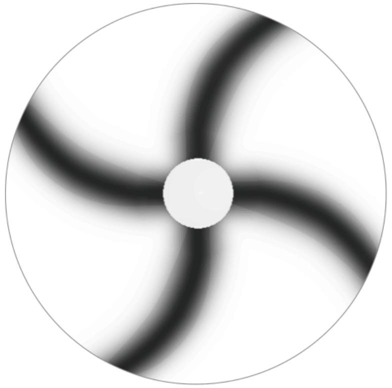
Line sources of constant strength $w = 1/N_{Blade}$, defined from the original rotor blades



Regularisation of line sources of constant strength w with Gaussian Kernel $K(\mathrm{r},\phi,\mathrm{x})$



AD surface RANS solution



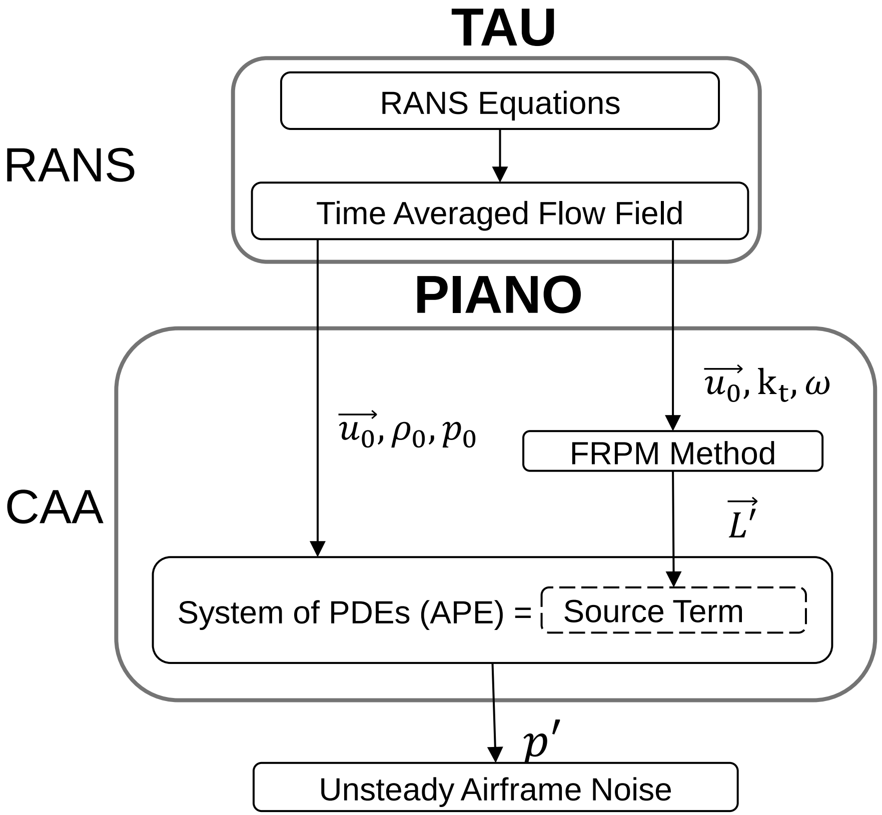
Regularised line sources of constant strength w

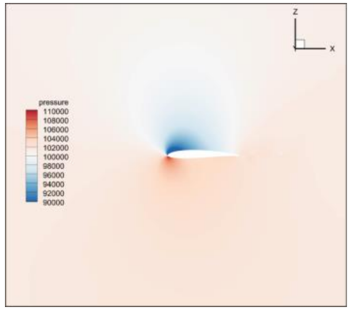
Resulting rotor line sources

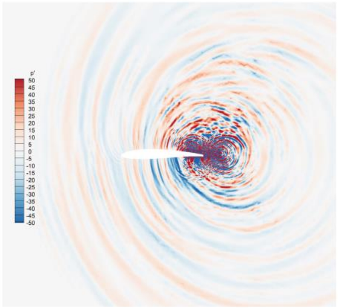
Methodology: Rotor Broadband Noise Prediction

2D automated tool-chain for rotor broadband noise prediction.
Inputs are airfoil profiles at different rotor blade spanwise locations.

Rotor Trailing Edge Noise Prediction







Correction and summation of different sections' contributions to broadband noise prediction at each mic:

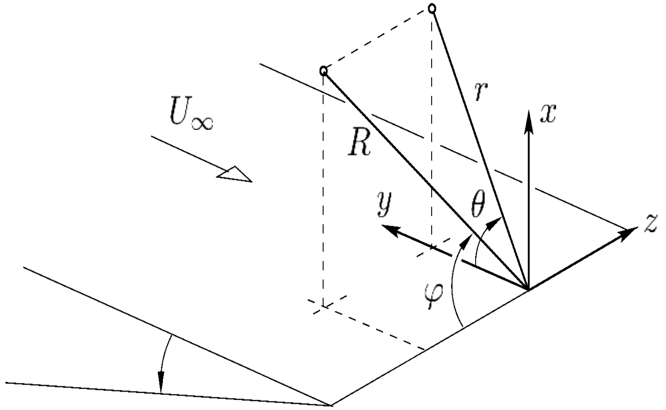
$$L_{p,Span} = 10\log_{10}\left(\frac{d_{Section}}{d_{Section,Ref.}}\right)$$

$$L_{p,Distance} = 10\log_{10}\left(\frac{r_{SectionCircleMics}}{r_{TrailingEdgeToFarfieldMic}}\right)$$

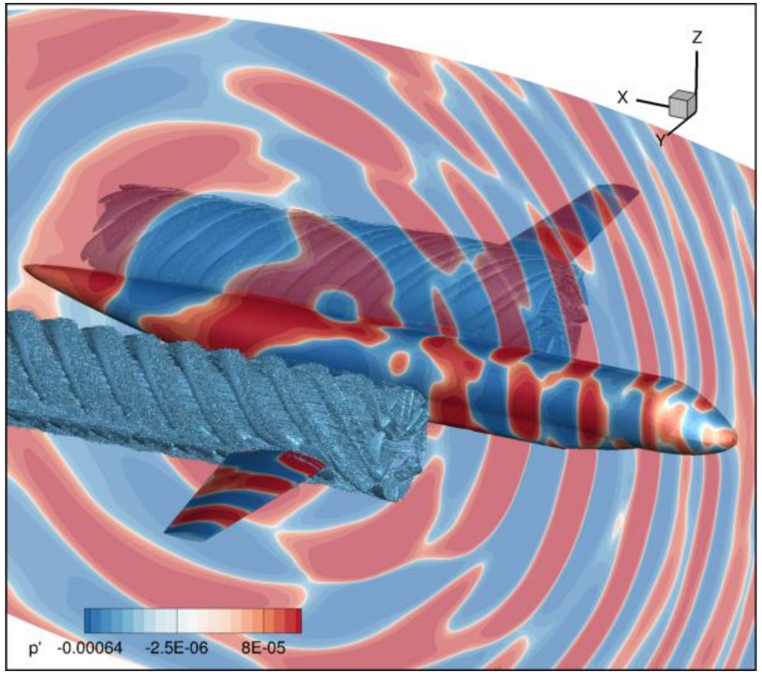
$$L_{p,2D-3D} = 10\log_{10}\left(\frac{1.4}{\pi}\frac{d_{Section}}{r_{SectionCircleMics}}Mach_{Section}\right)$$

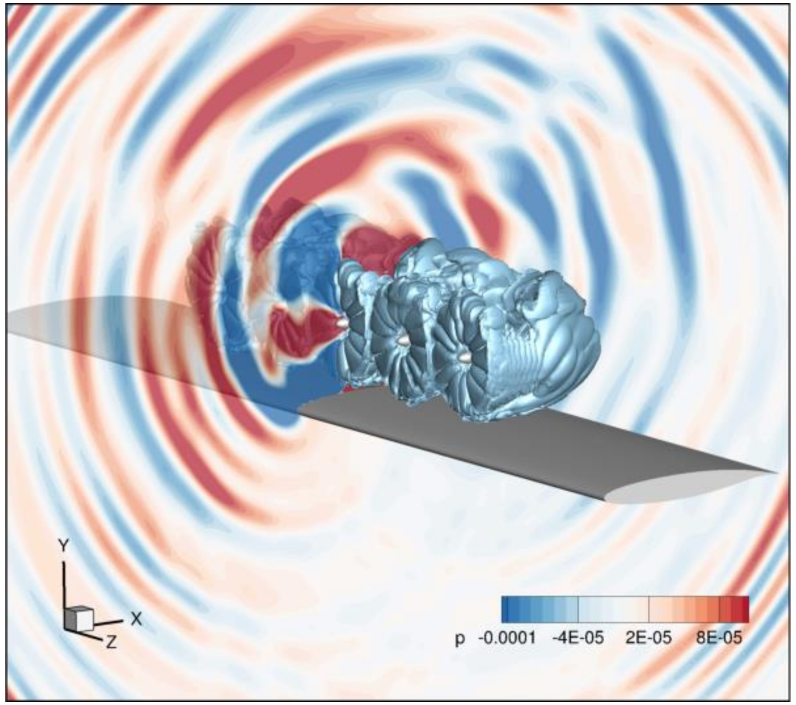
$$L_{p,Amplitude} = 10\log_{10}\left(\frac{\sin^2\phi}{(1 - Mach_{Section} * \cos\xi)^4}\right)$$

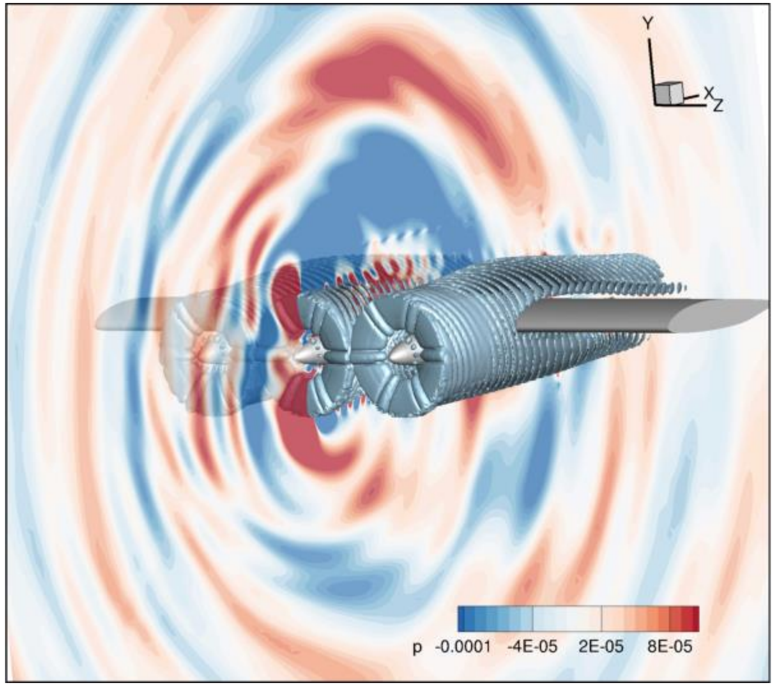
$$L_{p,Corrected} = L_{p,Span} + L_{p,Distance} + L_{p,2D-3D} + L_{p,Amplitude}$$



Model Application Examples

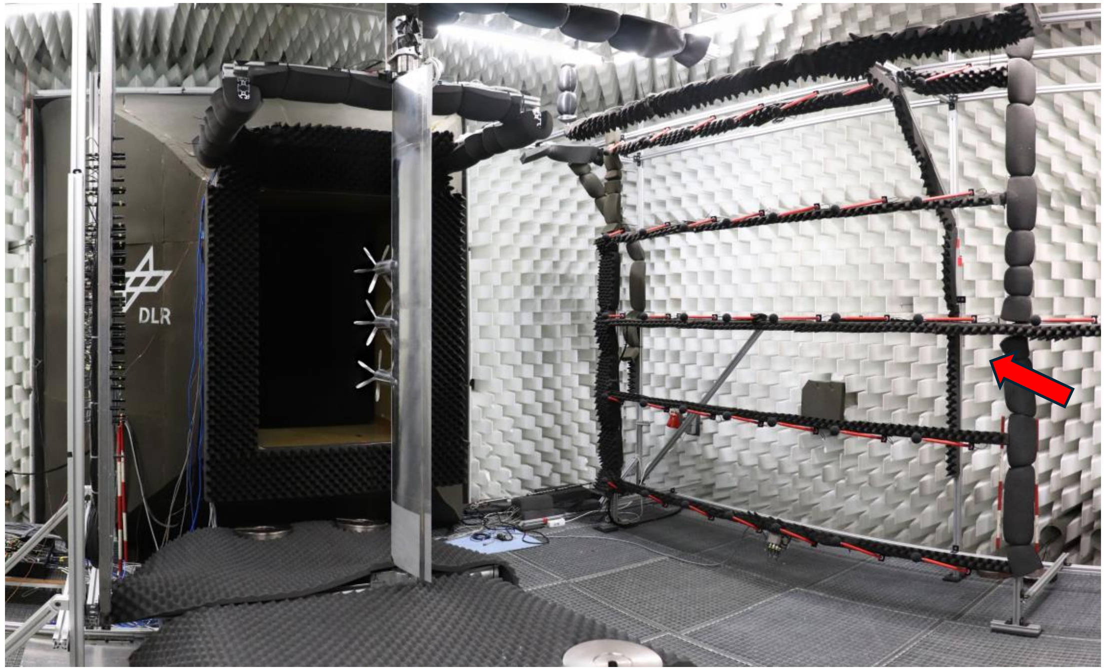




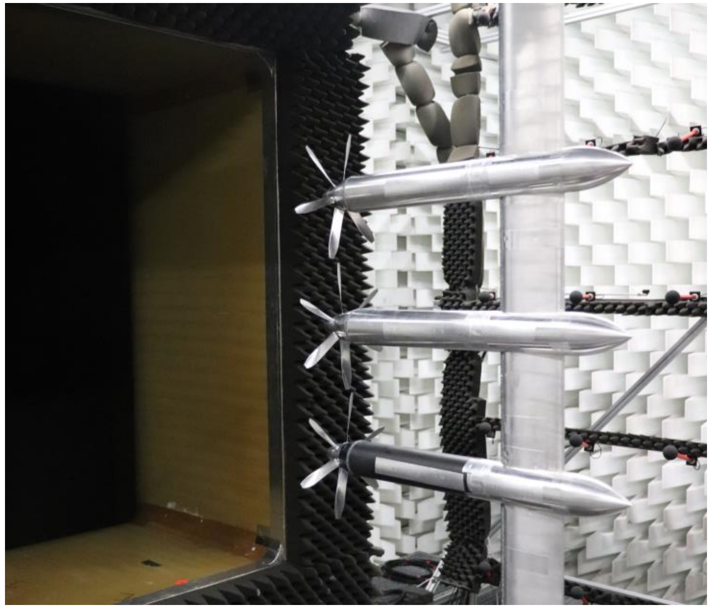


Validation Cases

Single Propeller	Three Propellers
Isolated	**Isolated**
Flap Retracted	**Flap Retracted**
Flap Deployed 15°	**Flap Deployed 15°**



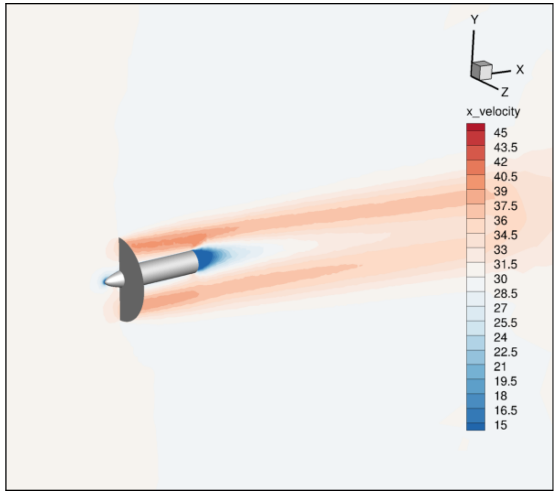
- 6 bladed TU Delft X-PROP model propeller, diameter D = 0.2032m
- Inflow velocity U_∞= 30m/s, Angle of attack = 0°
- Propellers RPM = 8858 [rev/min], Advance Ratio = 1
- RANS Computational Domain Size: Free-field setup of dimensions 50*D
- CAA Computational Domain Size: Dimensions 30*D

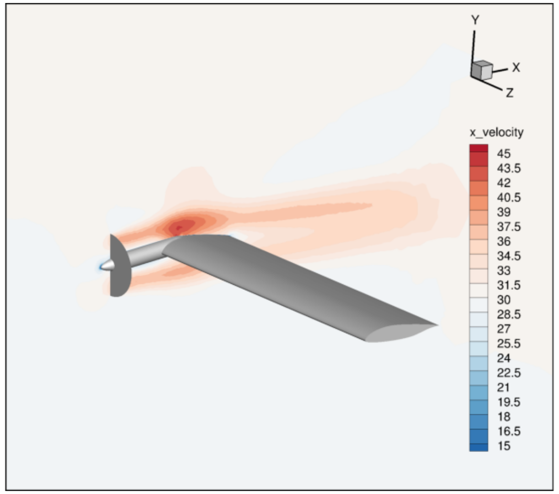


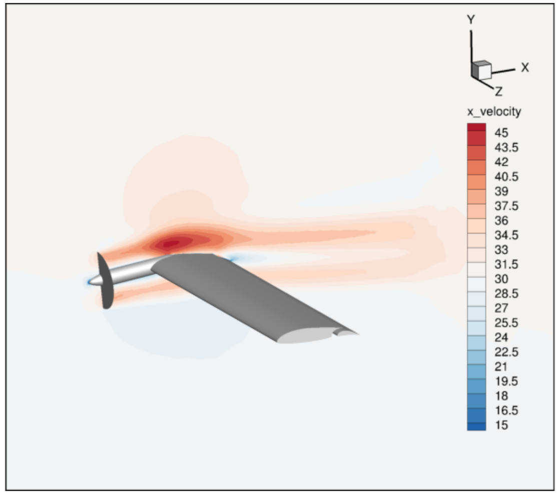
Model Validation, RANS Vel. Contour Plots

Isolated | **Flap Retracted** | **Flap Deployed**

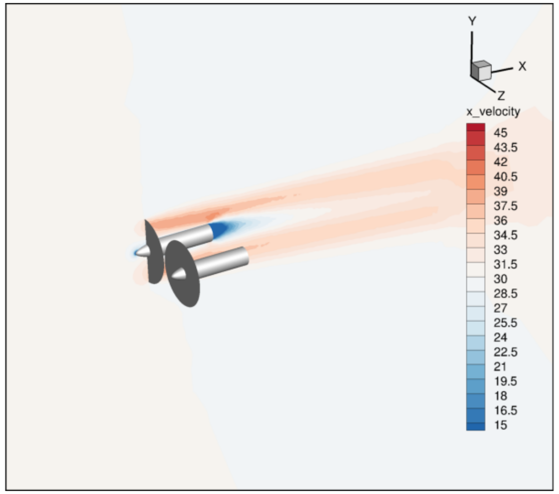
Single Propeller

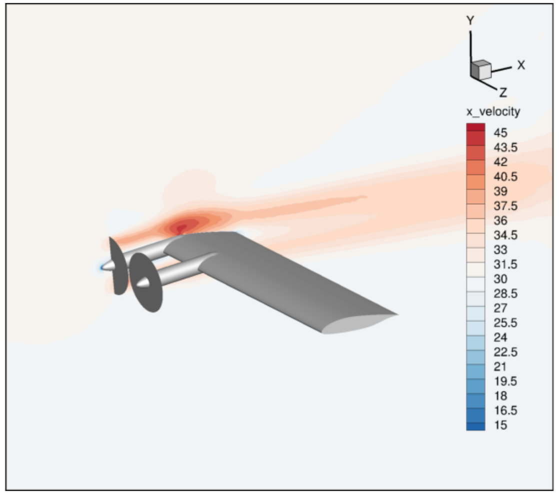


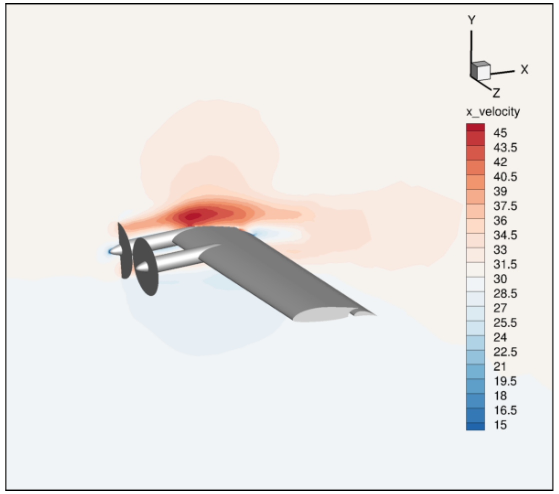




Three Propellers





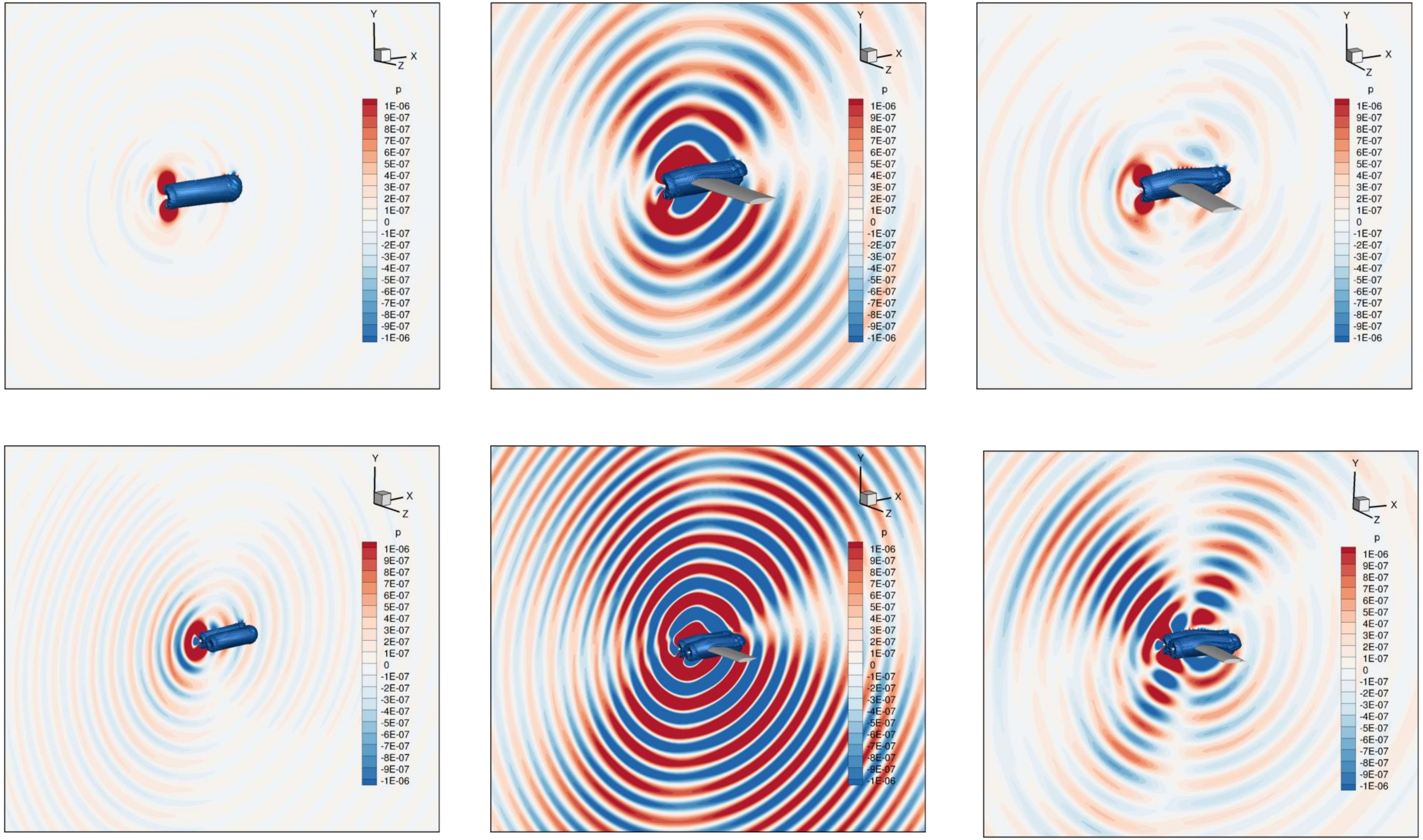


Model Validation, CAA p fluct. Contour Plots

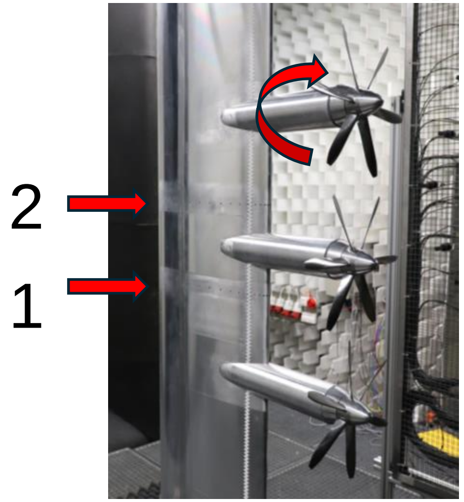
Isolated | **Flap Retracted** | **Flap Deployed**

Single Propeller

Three Propellers



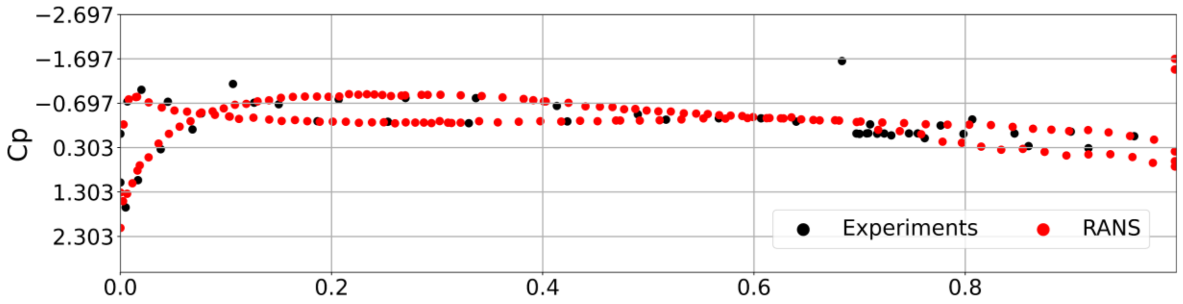
Model Validation, Pressure Coefficient, Single Propeller

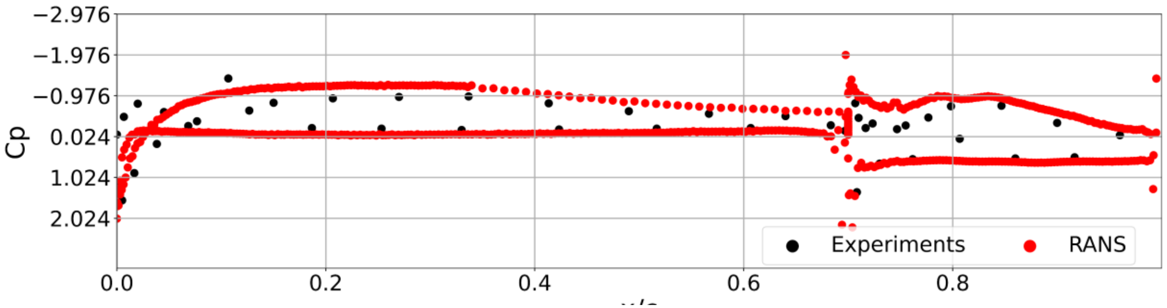


Flap Retracted

Flap Deployed

1





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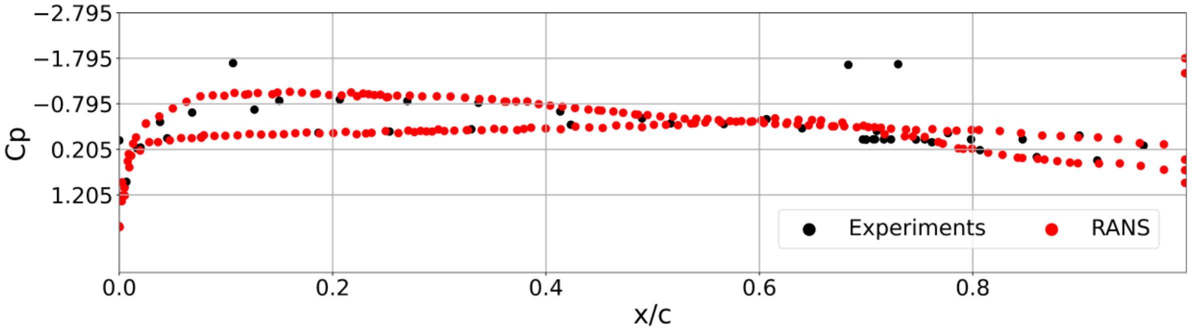
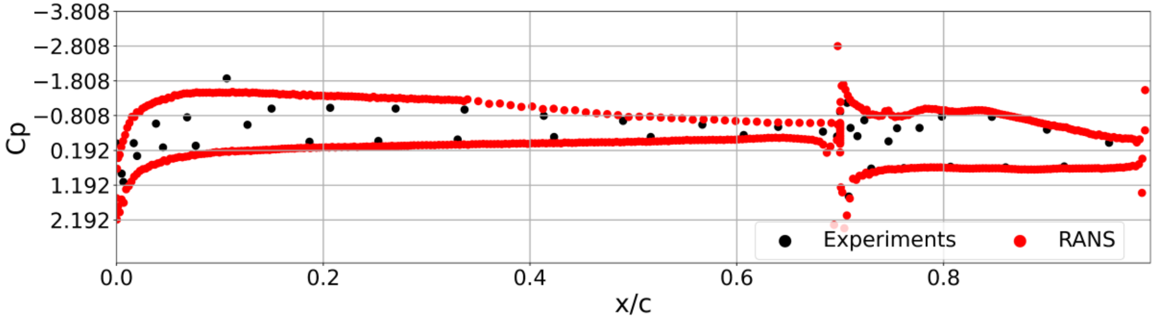
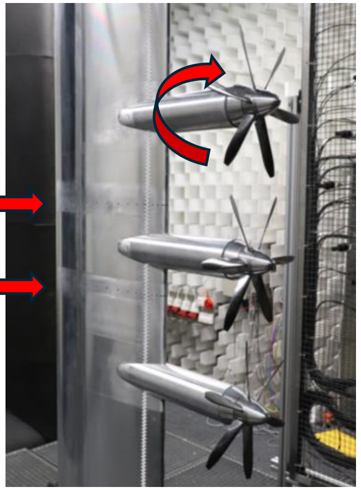




Model Validation, Pressure Coefficient, Three Propellers

2

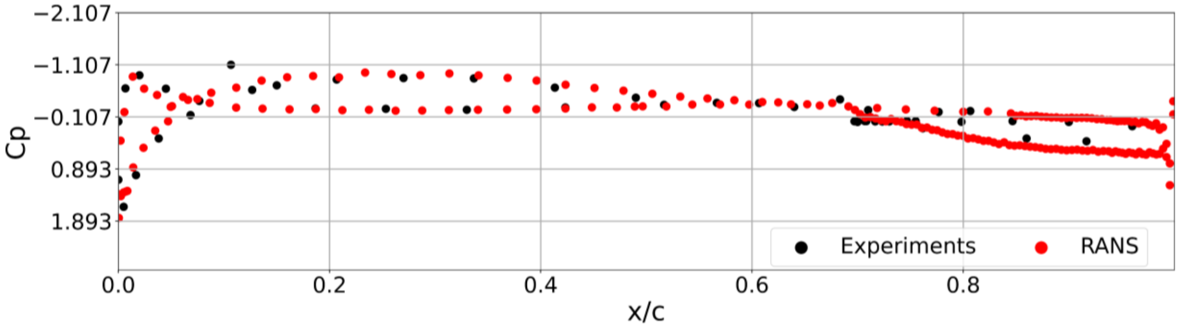
1

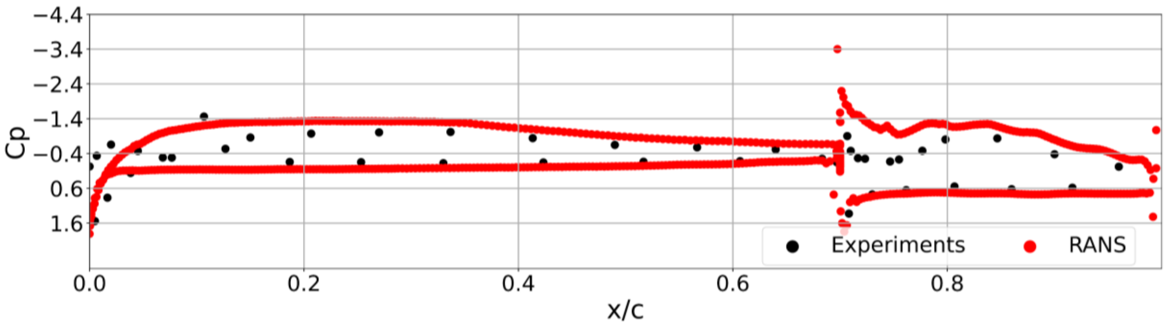


Flap Retracted

Flap Deployed

1





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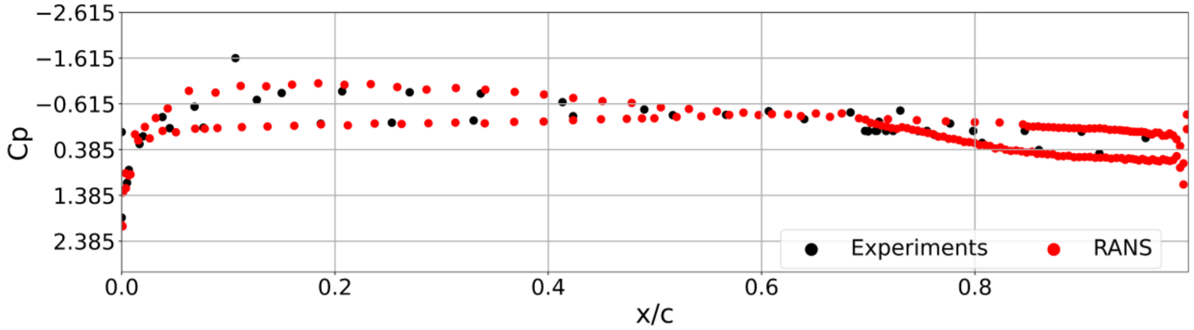
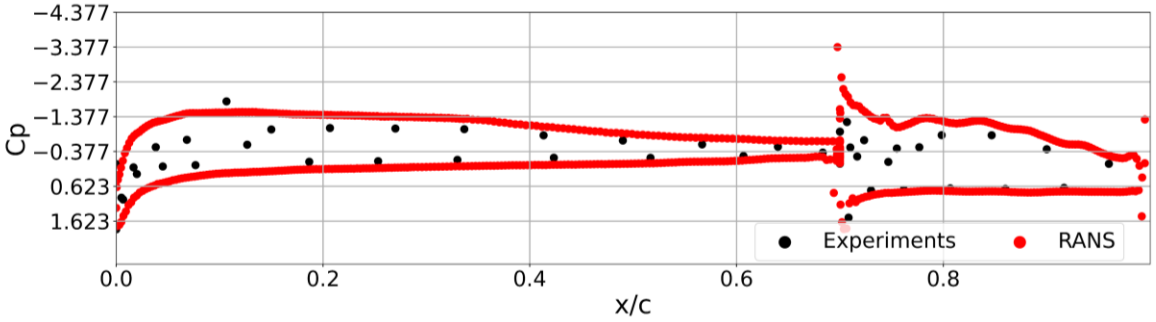
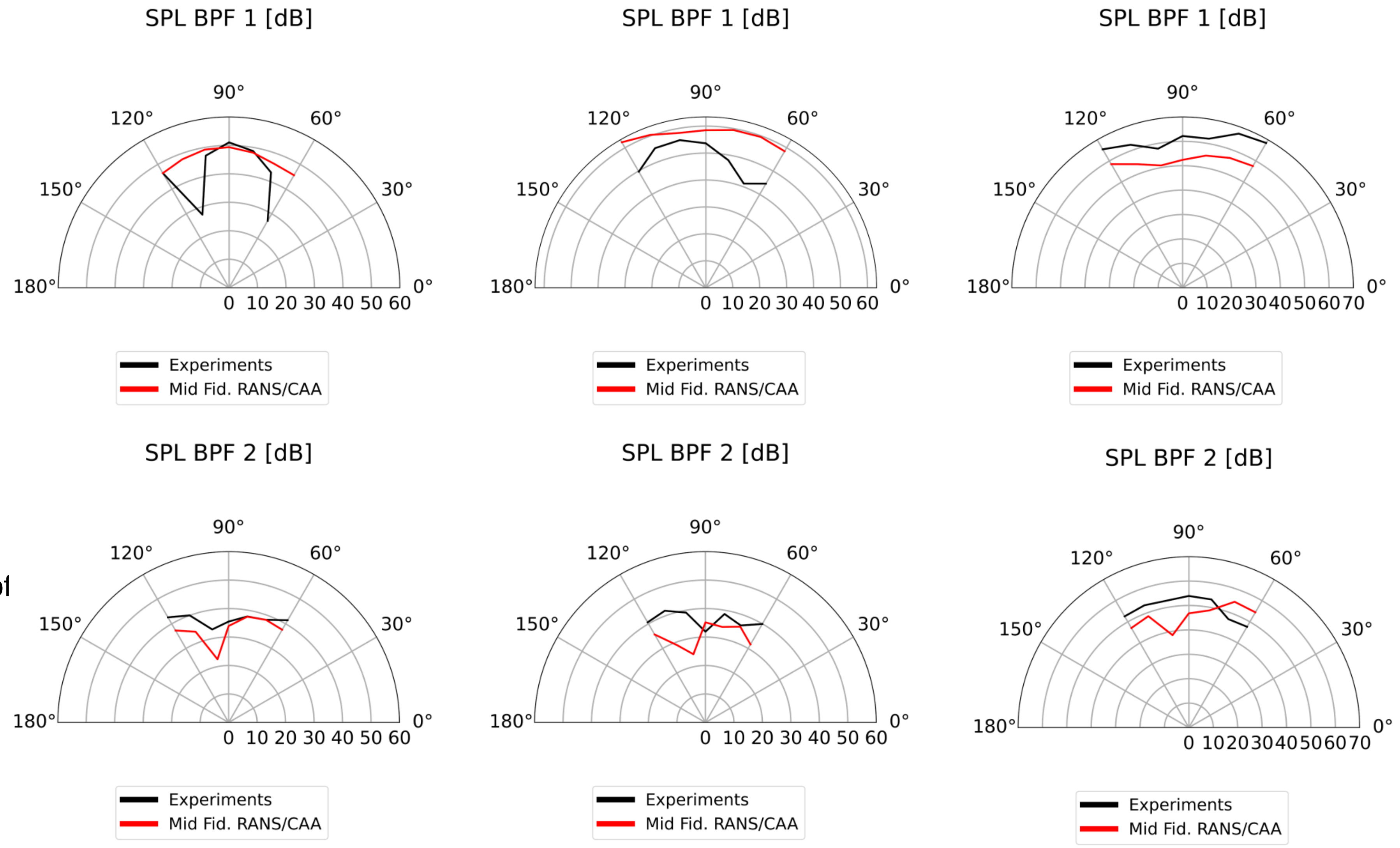




Model Validation, Directivity Plots, Single Propeller

- Simulations results for **isolated prop.** with experiments **in agreement for 1st and 2nd BPF**. Max SPL location and values captured
- Simulations results for **installed prop.** show **differences in 1st and 2nd BPF** with experiments, to be investigated (influence of wind tunnel jet shear layer?)

Isolated | **Flap Retracted** | **Flap Deployed**



Model Validation, Directivity Plots, Three Propellers

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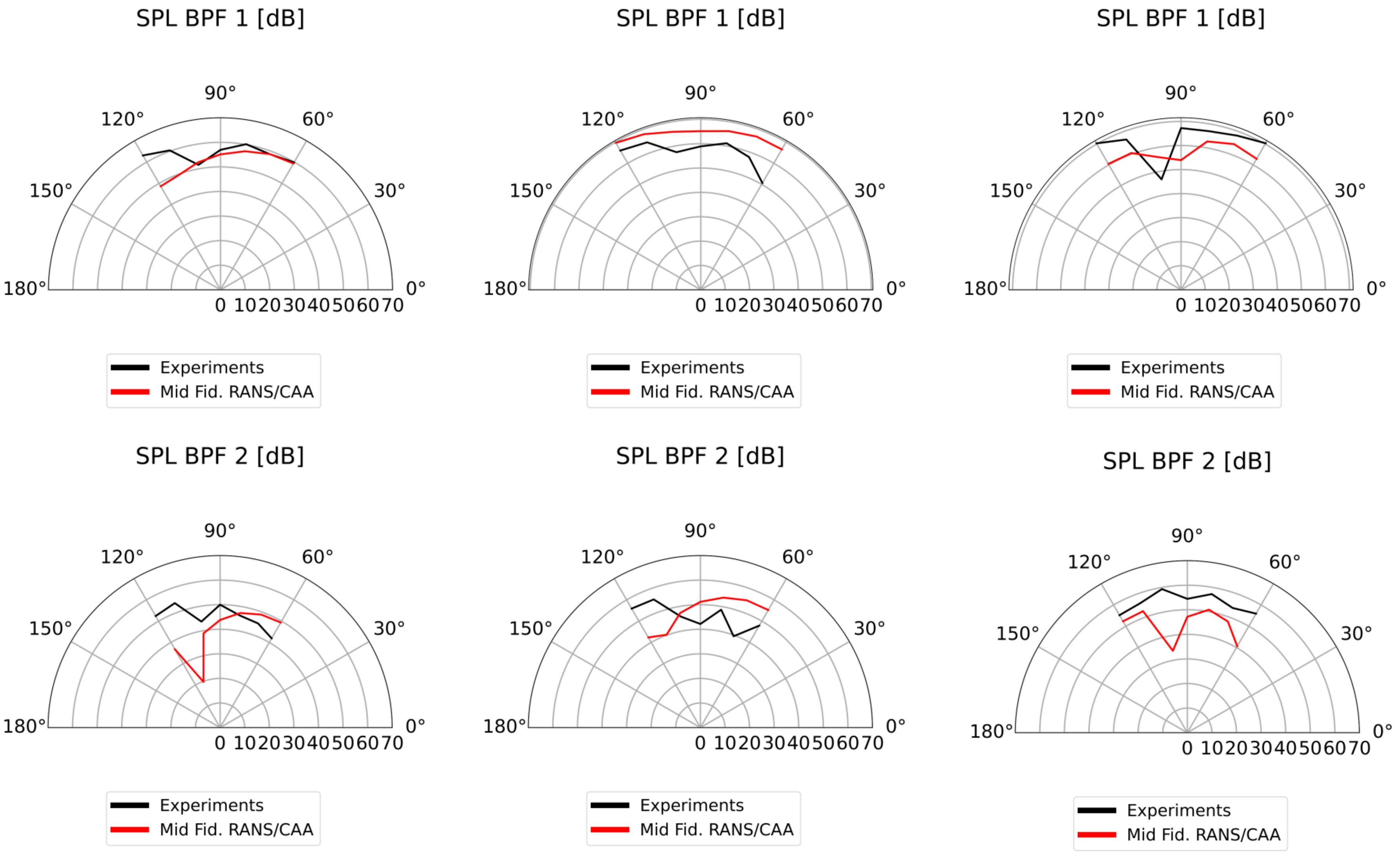
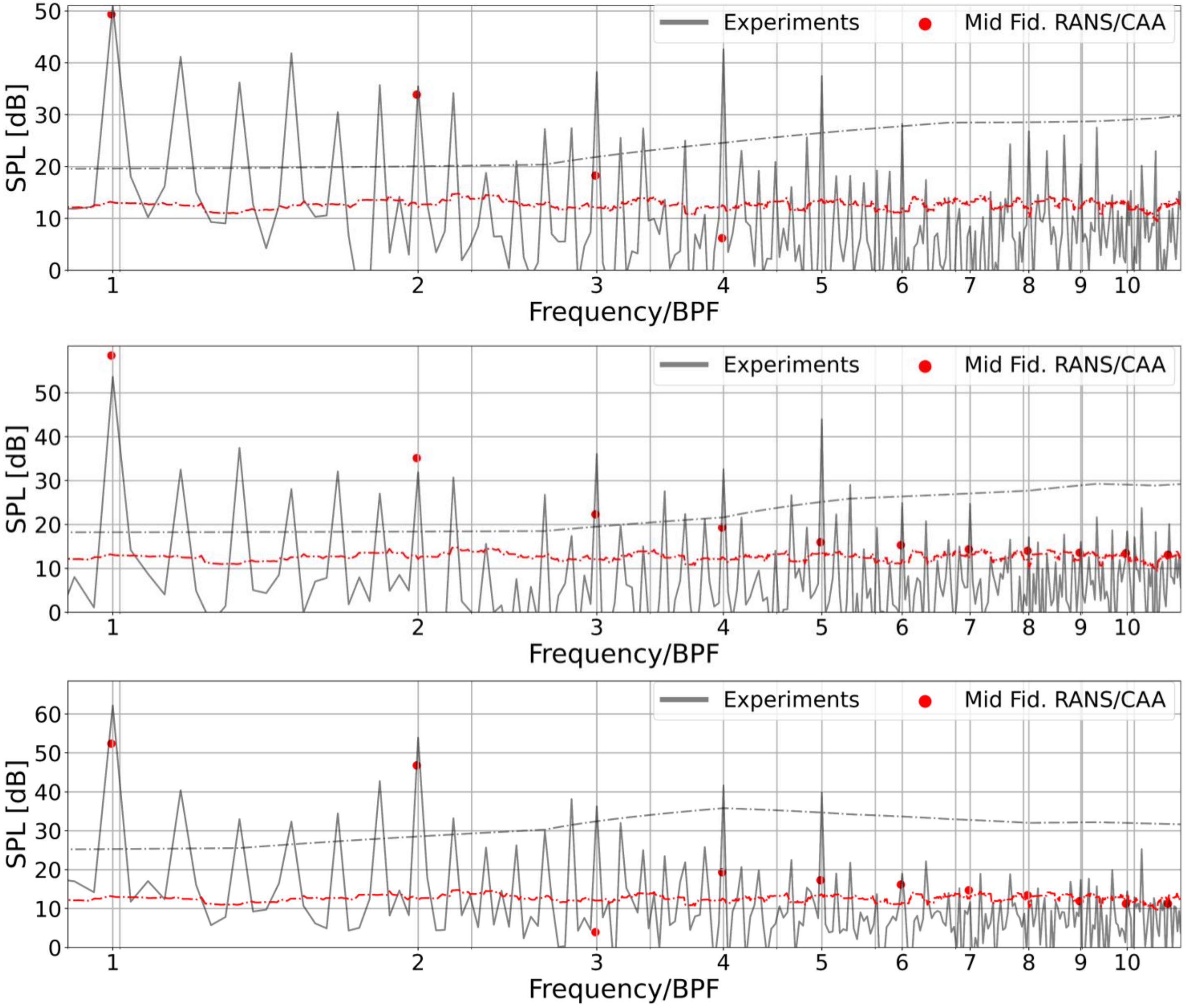
Isolated | Flap Retracted | Flap Deployed



Model Validation, Narrow Band Plots, Single Propeller, Mic. 90°



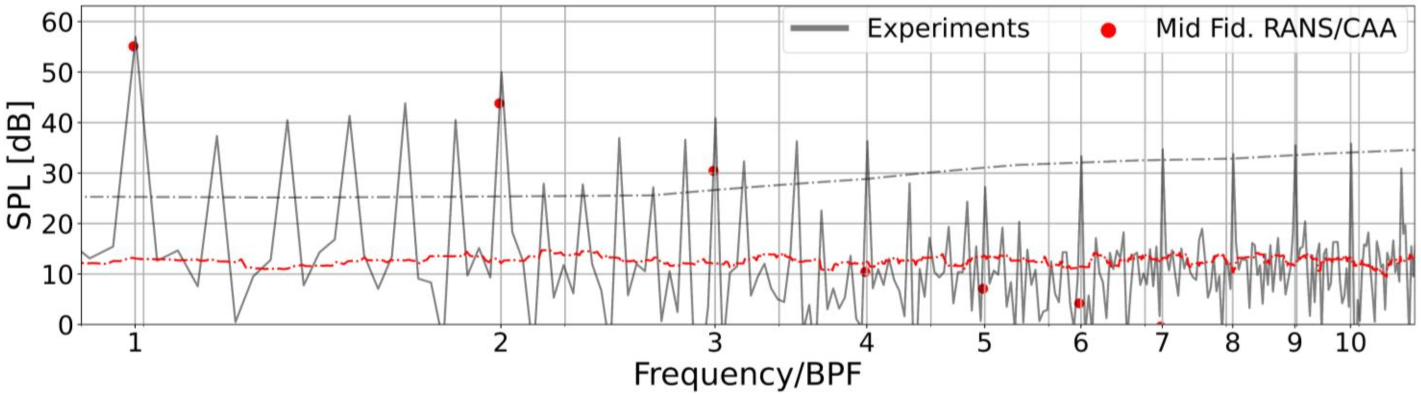
Isolated

Flap Retracted

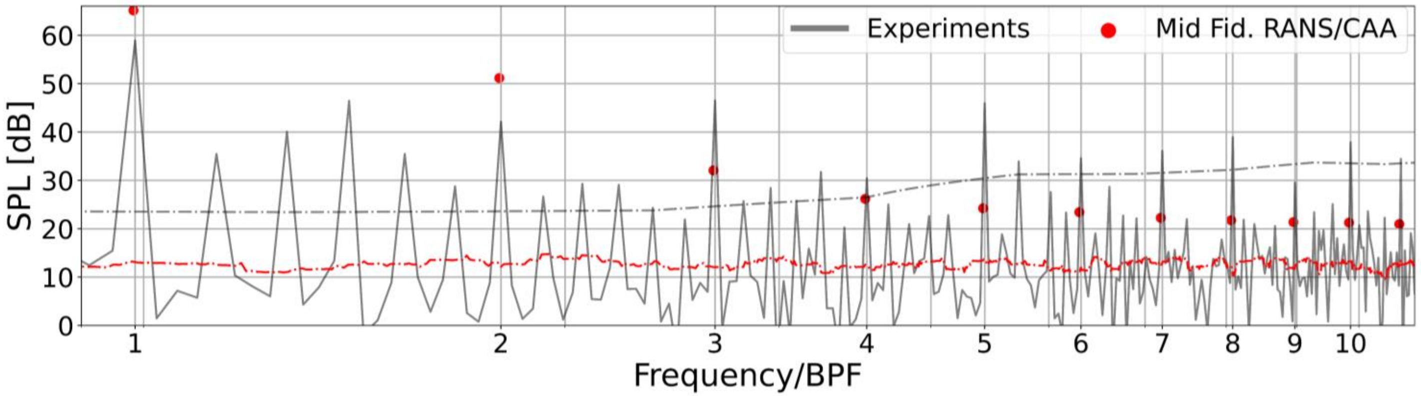
Flap Deployed

- Simulations results for **isolated prop.** with experiments **in agreement for 1st and 2nd BPF**.
  - 1st and 2nd BPF captured
  - Propeller's blade trailing edge broadband noise levels very low as expected
    - Relevant SPL expected to be shifted to higher frequencies due to Strouhal number similarity for small scale propellers
- Simulations results for **installed prop.** show **differences in 1st and 2nd BPF** with experiments, to be investigated.
  - Broadband noise experimental levels probably related to rotor tip vortices interaction with wing

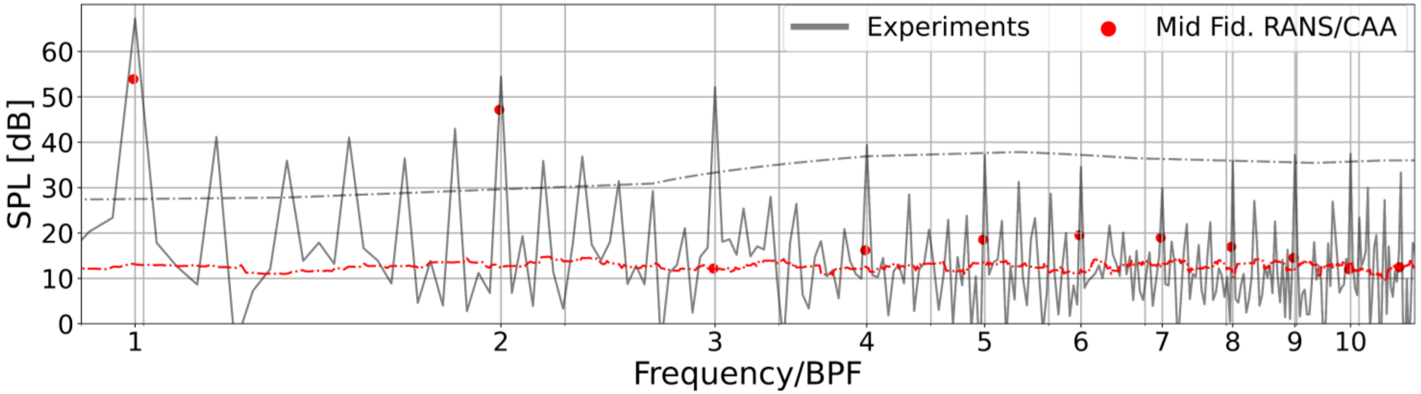
Model Validation, Narrow Band Plots, Three Propellers, Mic. 90°



Isolated



Flap Retracted



Flap Deployed

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  - Broadband noise experimental levels probably related to rotor tip vortices interaction with wing

Computational Cost of the Model

Computational Step	Computational Cost [CoreHours]
2D RANS for AD table creation	128 Cores * 15 blade sections * 1.5 Hours = 2880 CoreHours
3D AD RANS to generate background meanflow and AD solution for CAA	640 Cores * 1 Hour = 640 CoreHours
3D CAA tonal noise prediction	1536 Cores * 5 Hour = 7680 CoreHours
2D CFD-CAA trailing edge broadband noise prediction	128 Cores * 15 blade sections * 5.5 Hours = 10560 CoreHours
TOTAL	21760 CoreHours

Conclusions

- Experiments show strong unexpected tones, probably related to the electric motors

- **Isolated propeller** tonal results in **agreement with experiments**
- **Installed propeller** tonal results show **differences with experiments**
  - A possible reason could be the influence of wind tunnel jet shear layer on wave propagation

- **Propeller trailing edge broadband noise** predictions in **agreement with expectations** for small scale propellers
  - Relevant SPL expected to be shifted to higher frequencies due to Strouhal number similarity for small scale propellers
  - Nevertheless, propeller trailing edge noise prediction approach efficient (**~ 10000 CoreHours** needed)
    - Can tackle realistic propeller sizes, for which this additional acoustic component might be relevant

Acknowledgments

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