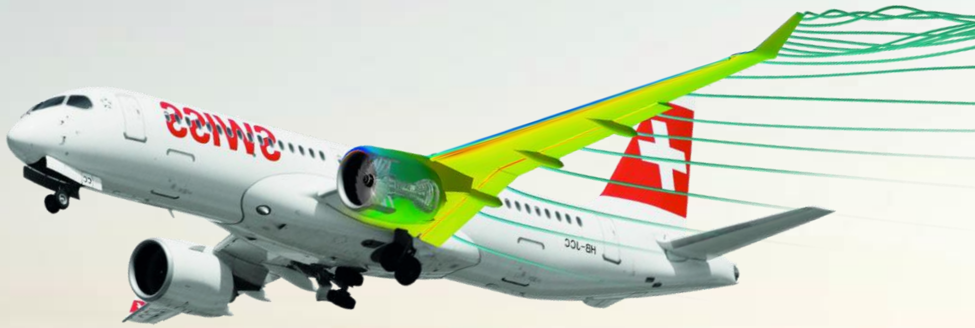
MODEL-SI
MODELING AND SIMULATION

ZHAW - Zurich University of Applied Sciences
EASA – European Union Aviation Safety Agency

EASA MODELSI Project Stakeholder workshop #2



10th July 2024, Winterthur (CH), Cologne (DE)

EASA
European Union Aviation Safety Agency

zh aw School of Engineering
ZAV Centre for Aviation

Aerodynamic analysis - results

Mid-Fidelity Simulations: DUST

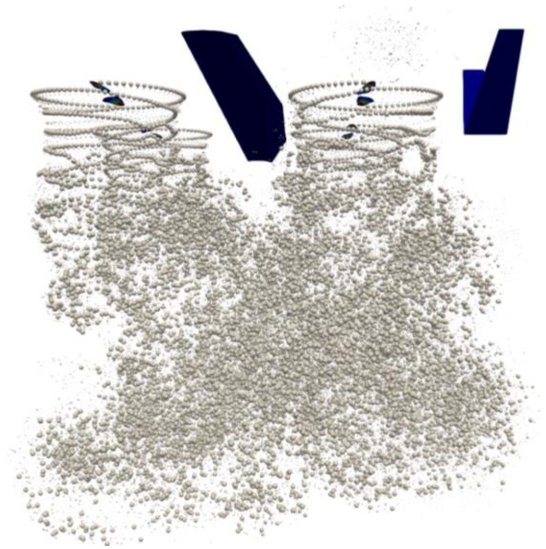
Hovering

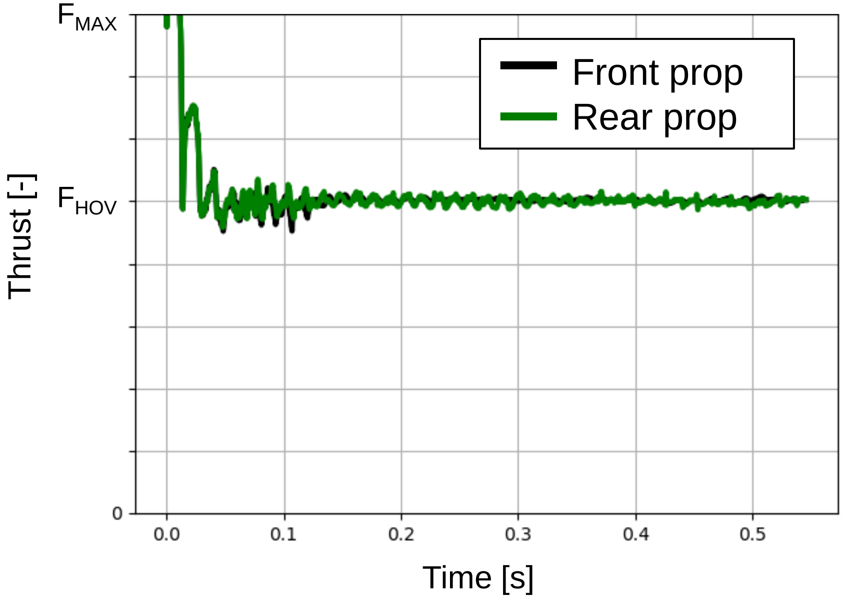
$AOA = AOS = 0°$

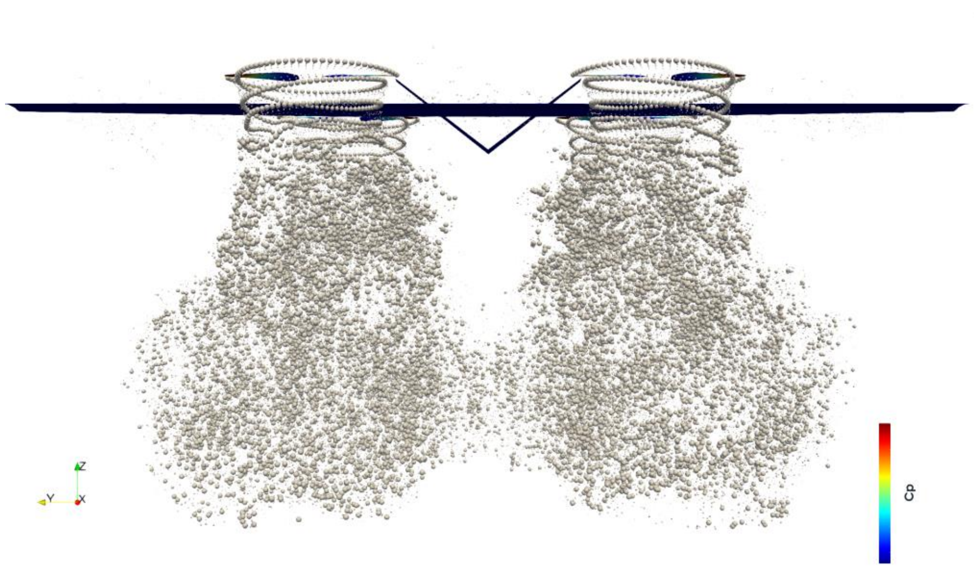
$U_\infty = 0\ m/s$

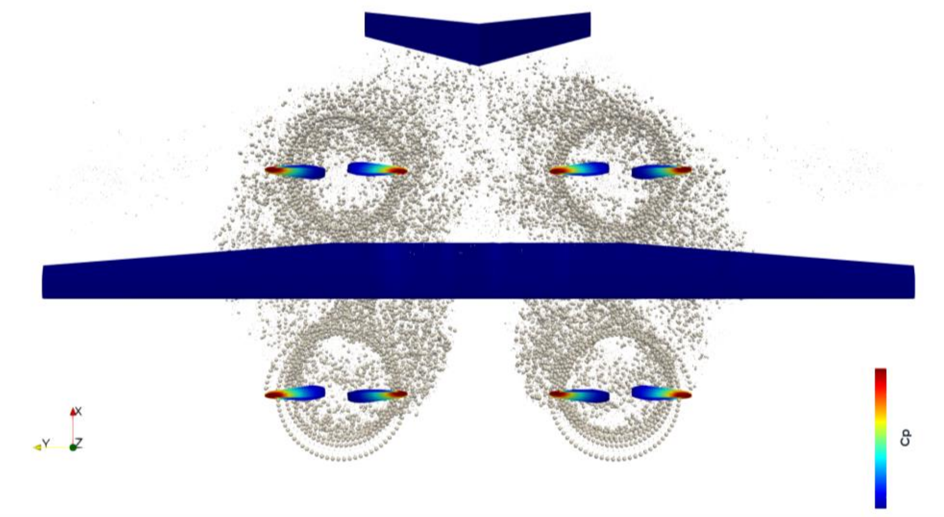
$N_{LP} = active\ const$

$N_{PP} = 0\ rpm$









Mid-Fidelity Simulations: DUST

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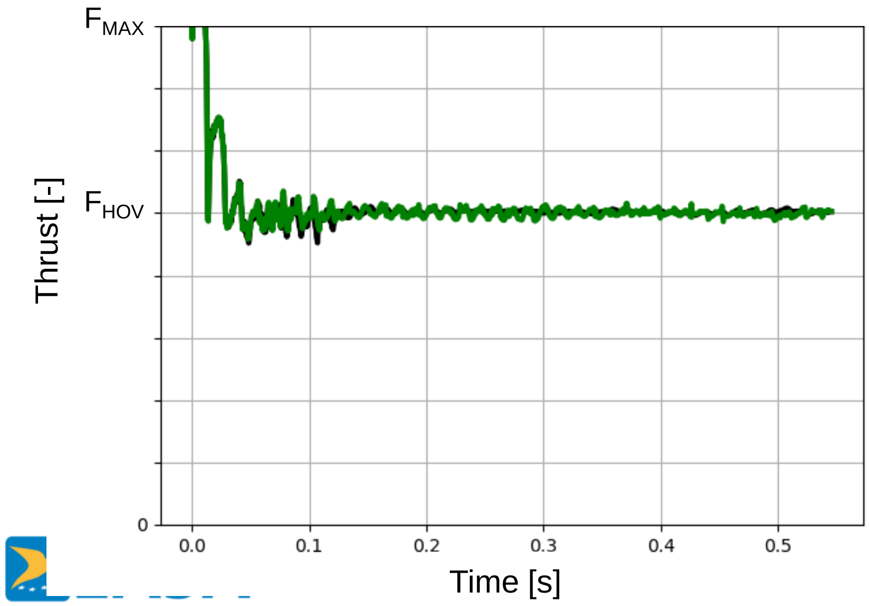
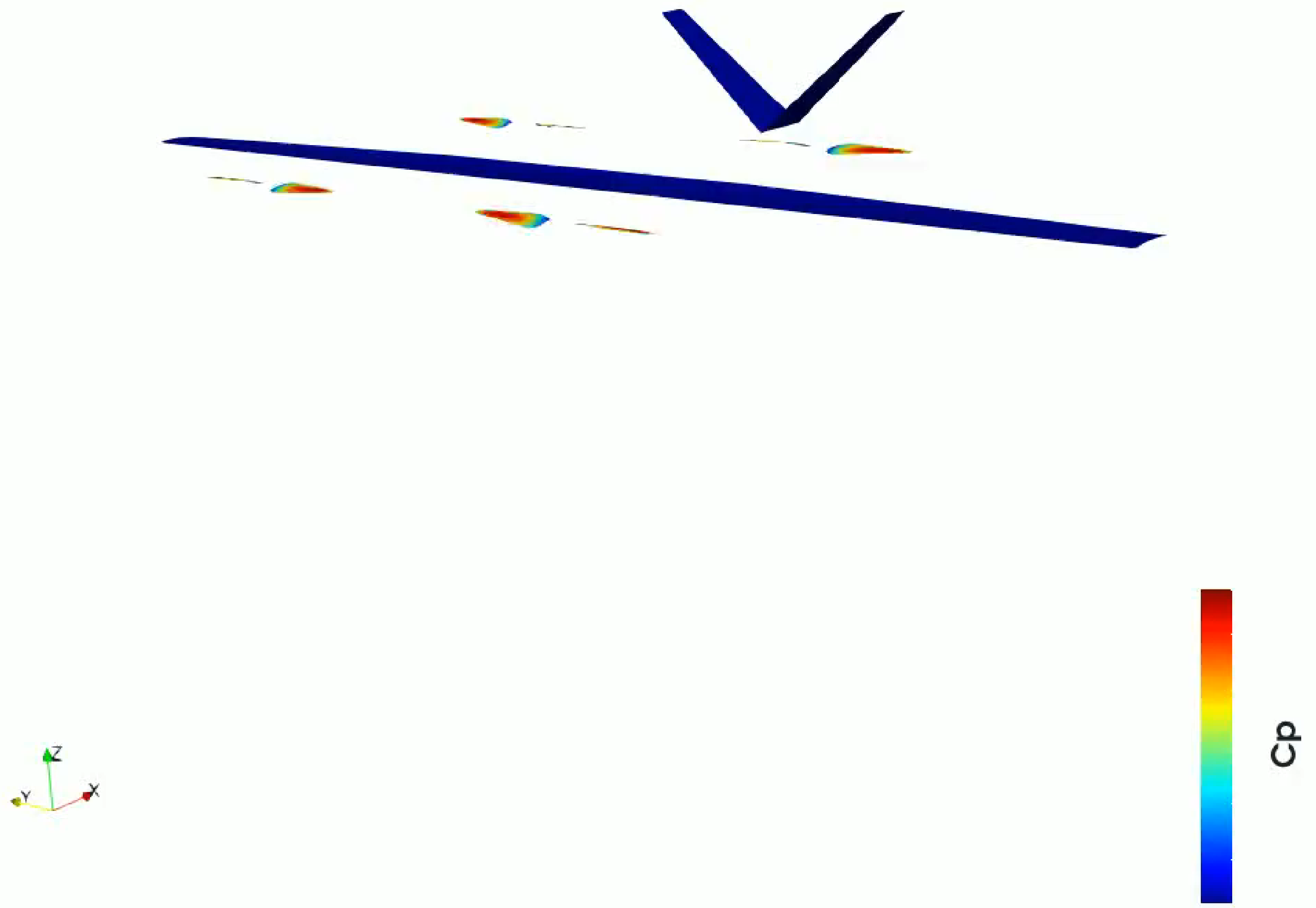




Mid-Fidelity Simulations: DUST

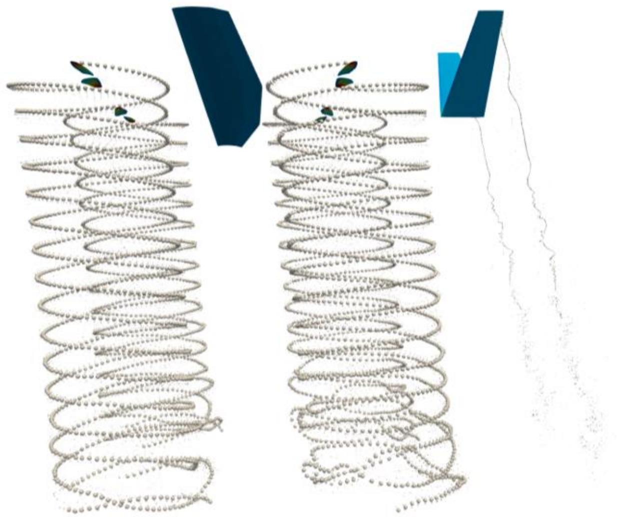
Hovering ascent

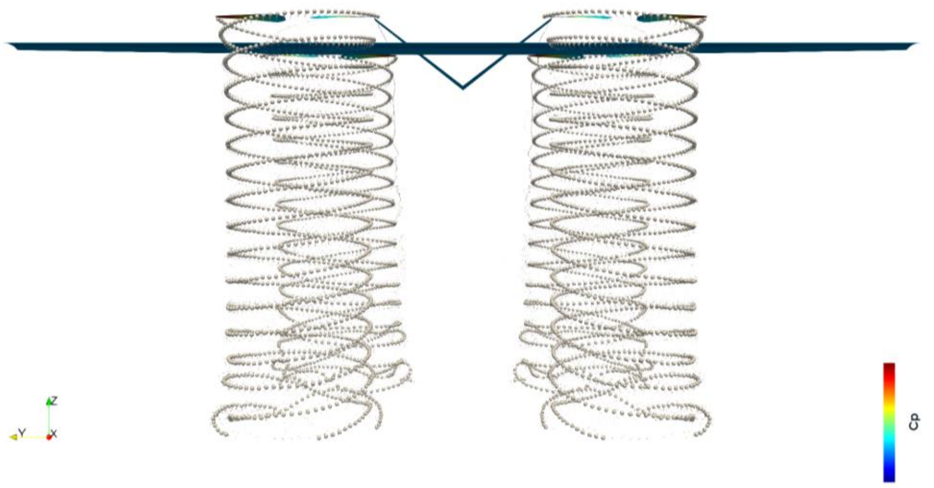
$AOA = -80° \; AOS = 0°$

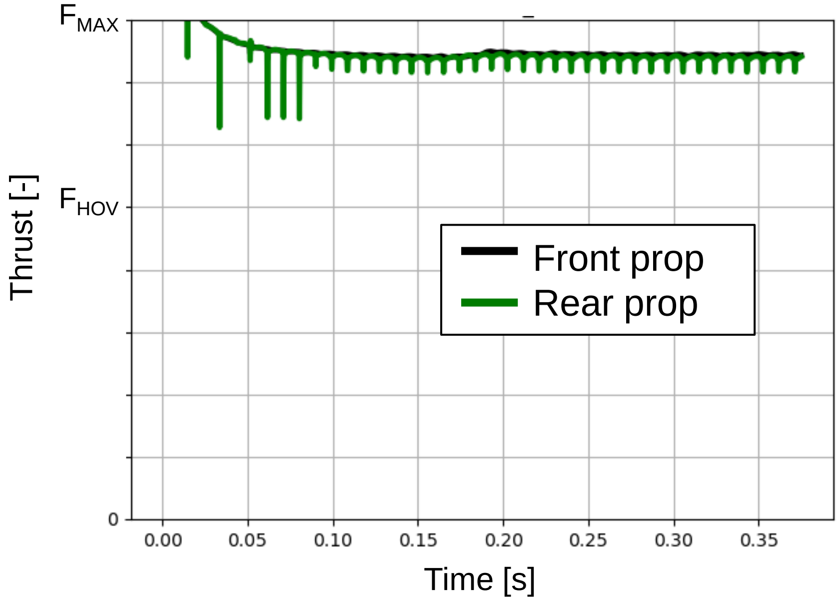
$U_\infty = 10\, m/s$

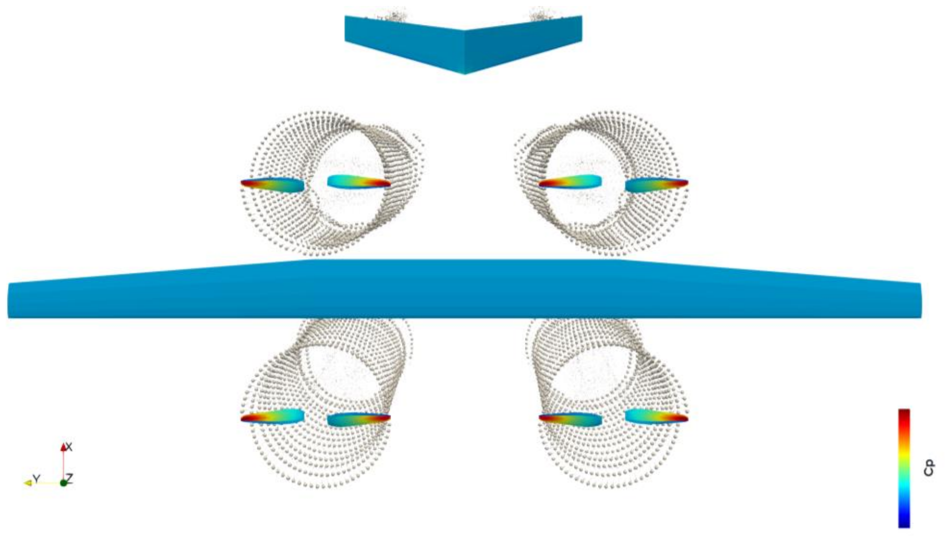
$N_{LP} = const.$

$N_{PP} = 0\, rpm$









Mid-Fidelity Simulations: DUST

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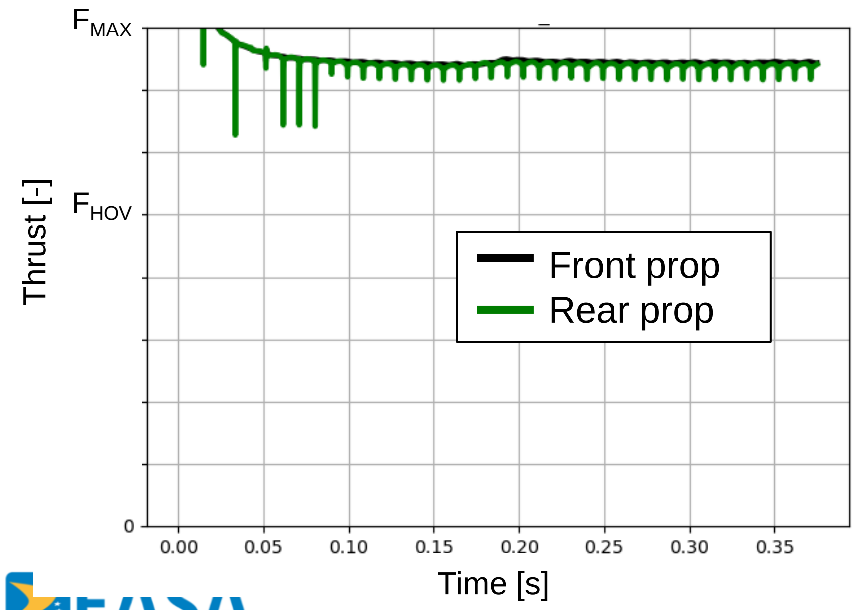


Mid-Fidelity Simulations: DUST

Hovering descent

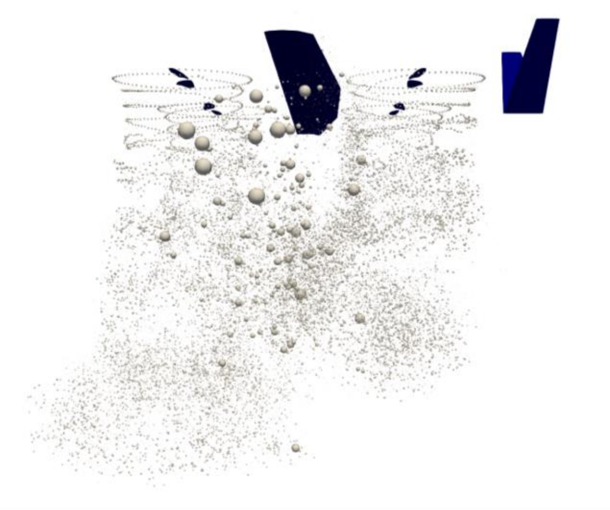
$AOA = 90°$

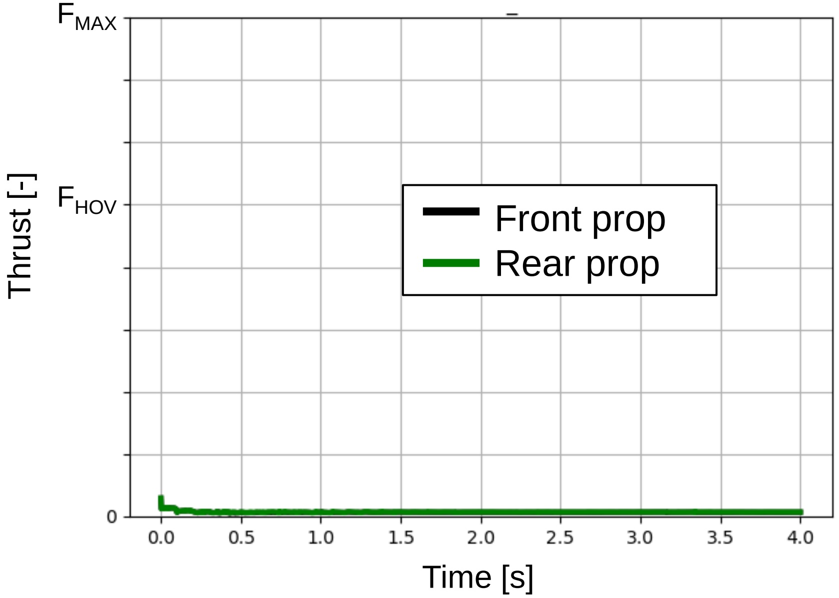
$AOS = 0°$

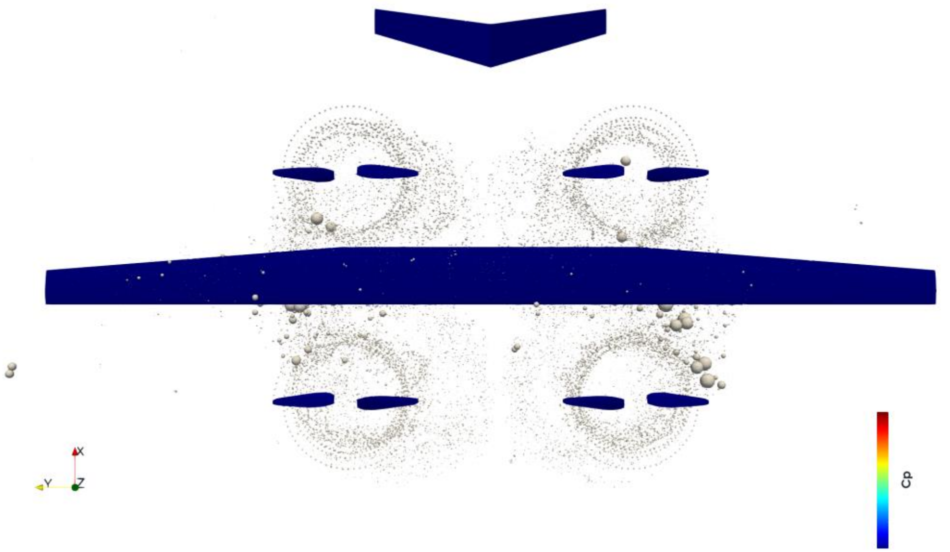
$U_\infty = 10\, m/s$

$N_{LP} = active$

$N_{PP} = 0\, rpm$







Mid-Fidelity Simulations: DUST

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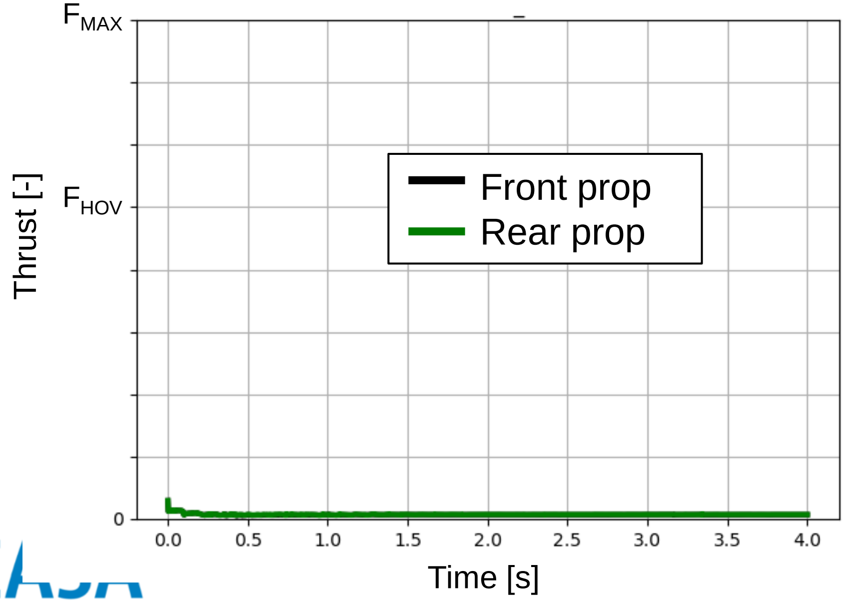
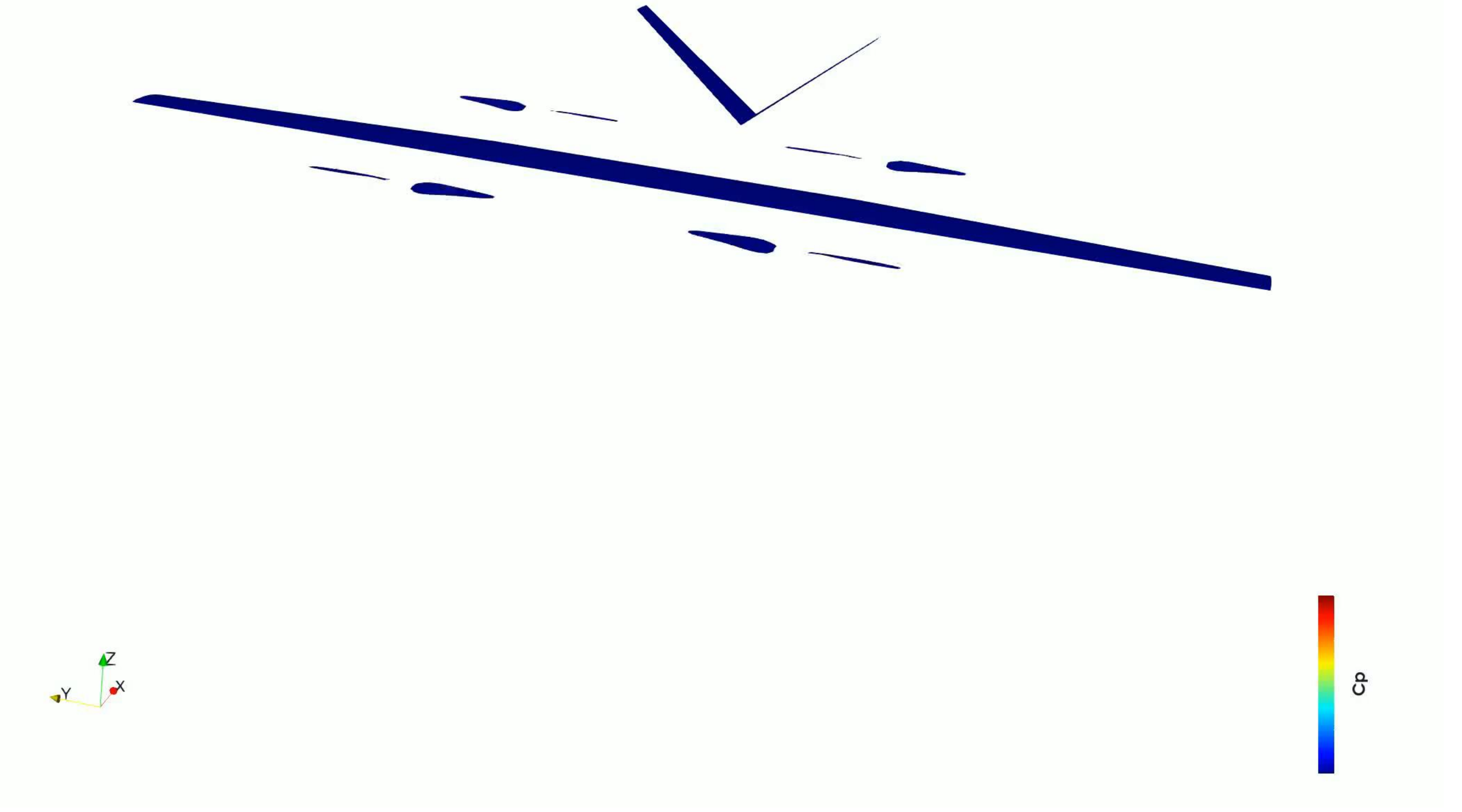




Mid-Fidelity Simulations: DUST

Transition

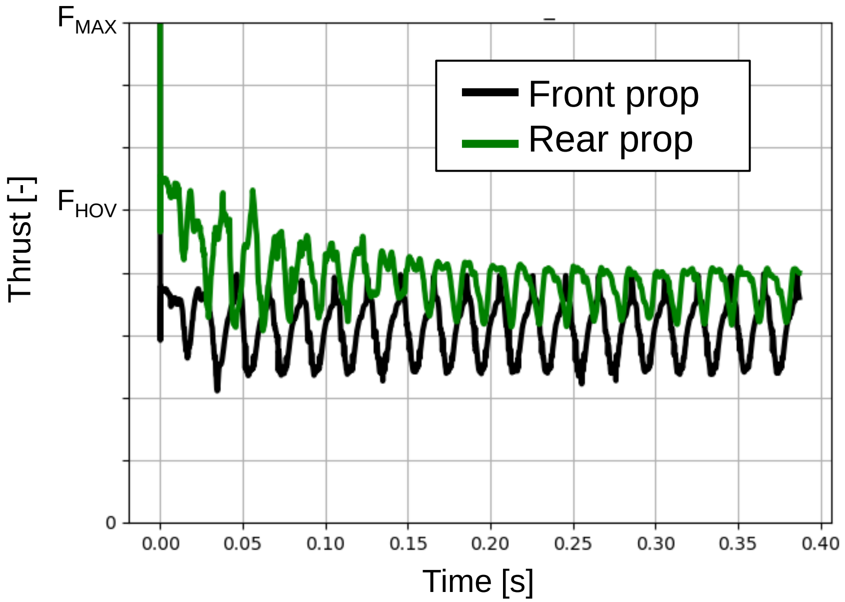
$AOA = -2°$

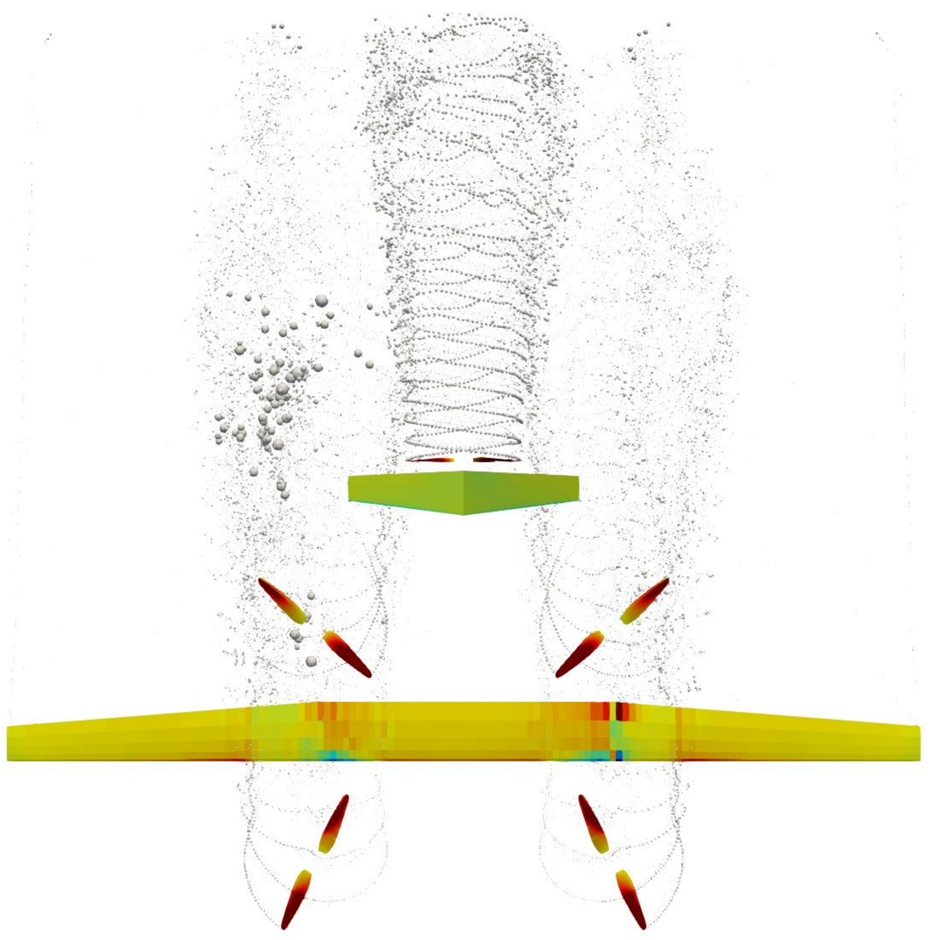
$AOS = 0°$

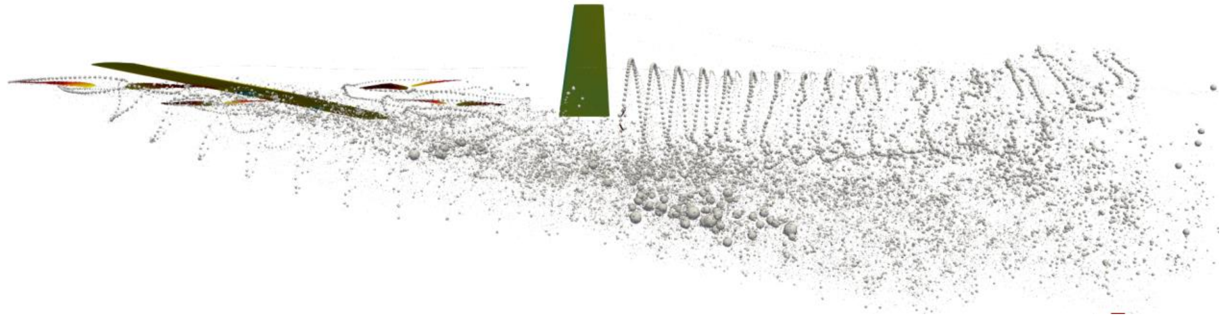
$U_\infty = 10\ m/s$

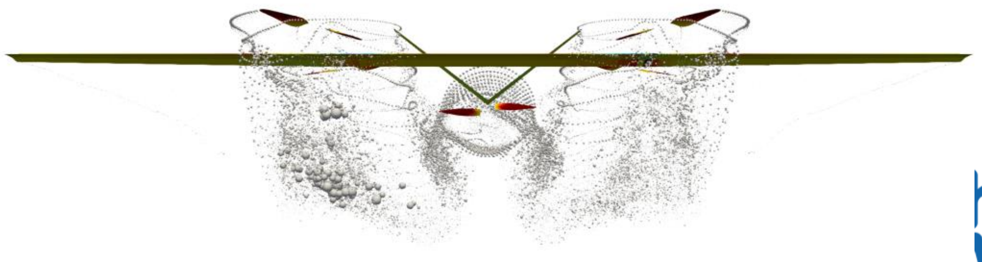
$N_{LP} = active$

$N_{PP} = active$









Mid-Fidelity Simulations: DUST

Transition

$AOA = -2° \; AOS = 0°$

$U_\infty = 10 \; m/s$

$N_{LP} = active$

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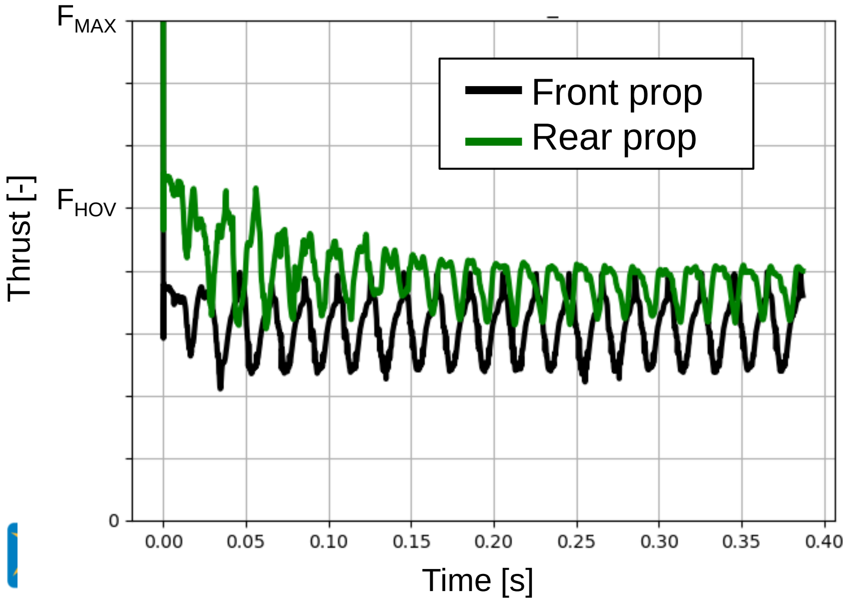

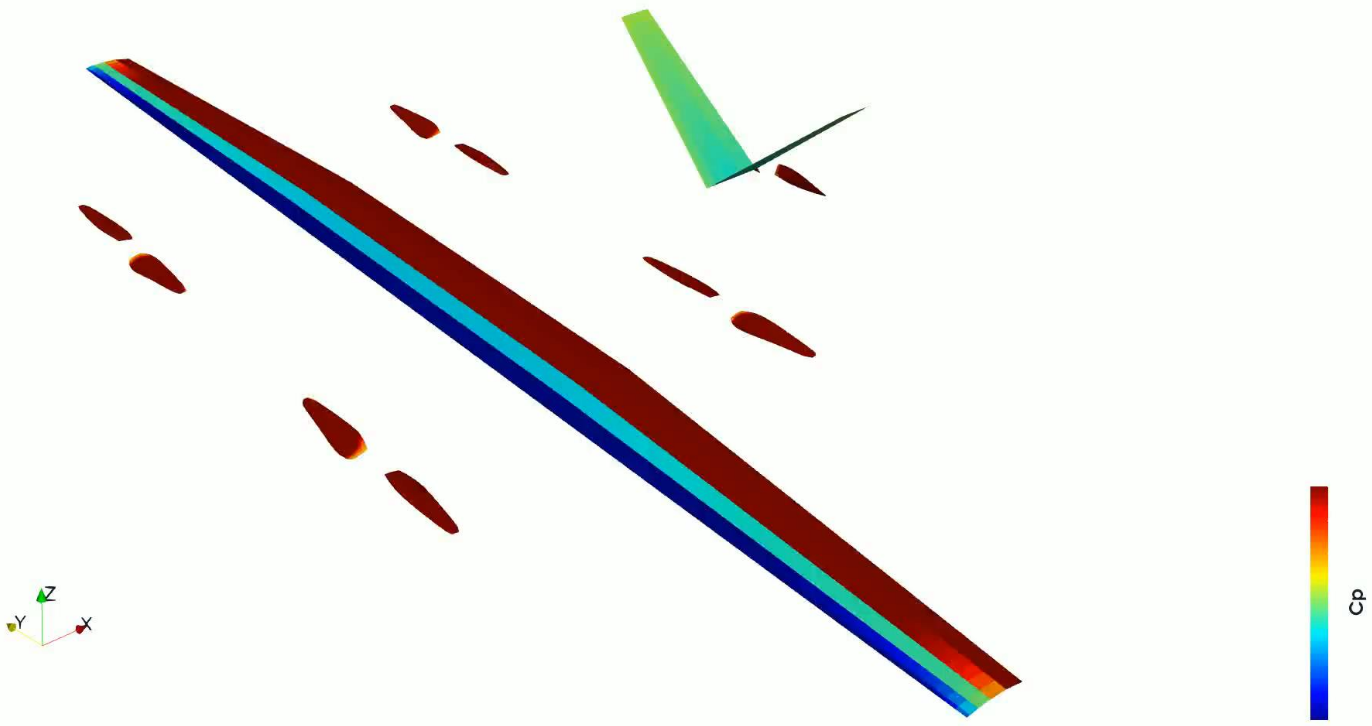

DUST Wing force distribution comparison

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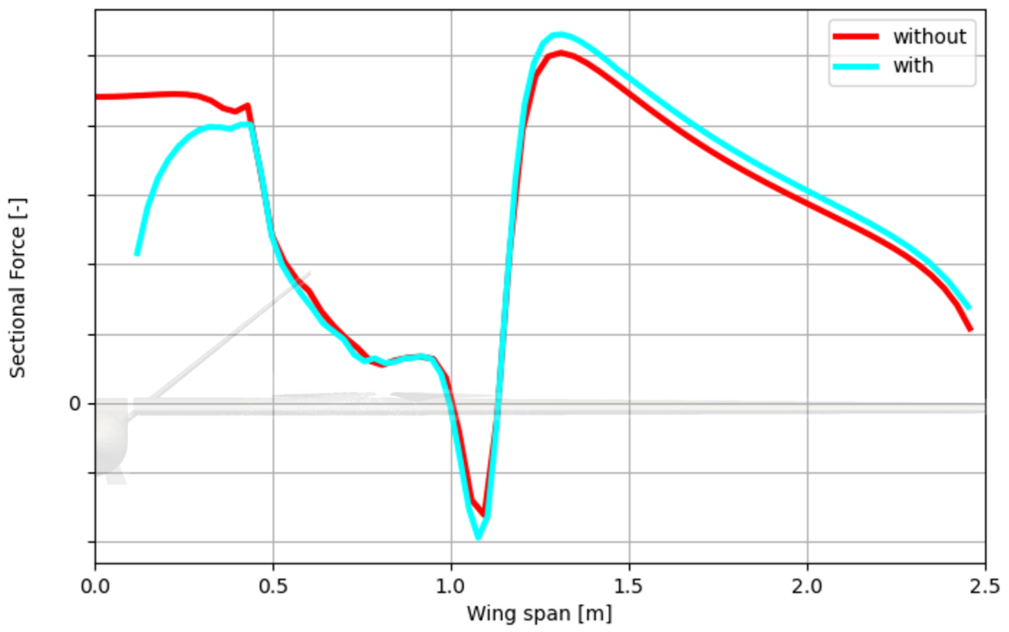
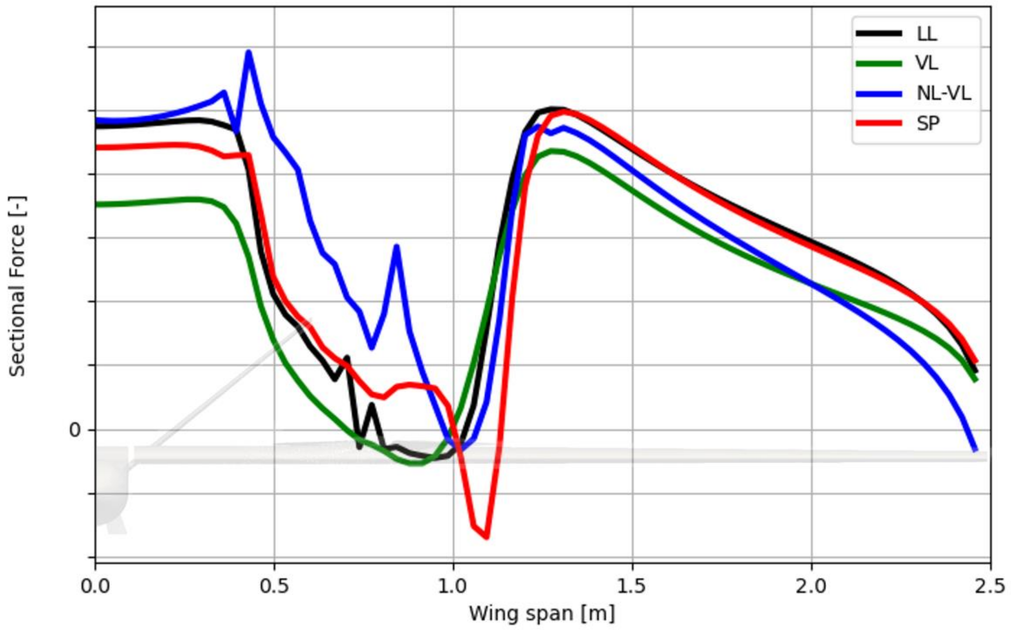
Comparison between a simulation with and without the fuselage



CASE	FRONT PROPELLER THRUST	REAR PROPELLER THRUST	WING LIFT FORCE
% DIFFERENCE WITH/WO FUSELAGE	+0.1	-0.2	-7.03

Comparison of the wing aerodynamic modeling:

- Lifting Line (LL)
- Vortex Lattice Method (VL)
- Non-Linear Vortex Lattice Method (NL-VL)
- Surface Panels (SP)



% DIFF BETWEEN METHODS	FRONT PROPELLER THRUST	REAR PROPELLER THRUST	WING LIFT FORCE
SP	-	-	-
NL-VL	+2.1	+0.3	+6.1
VL	-0.4	+3.0	-19.2
LL	+1.2	+7.0	+3.8

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Mid-Fidelity Simulations: DUST

Comparison of the wing aerodynamic modeling:

- Lifting Line (LL)
- Vortex Lattice Method (VL)
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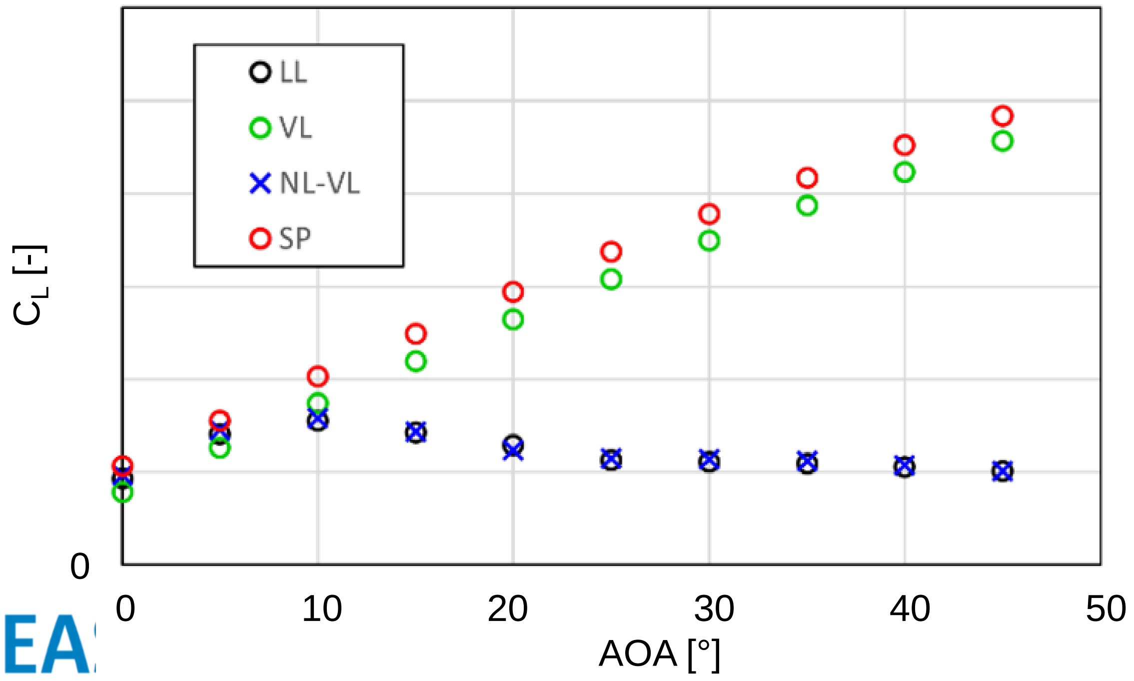
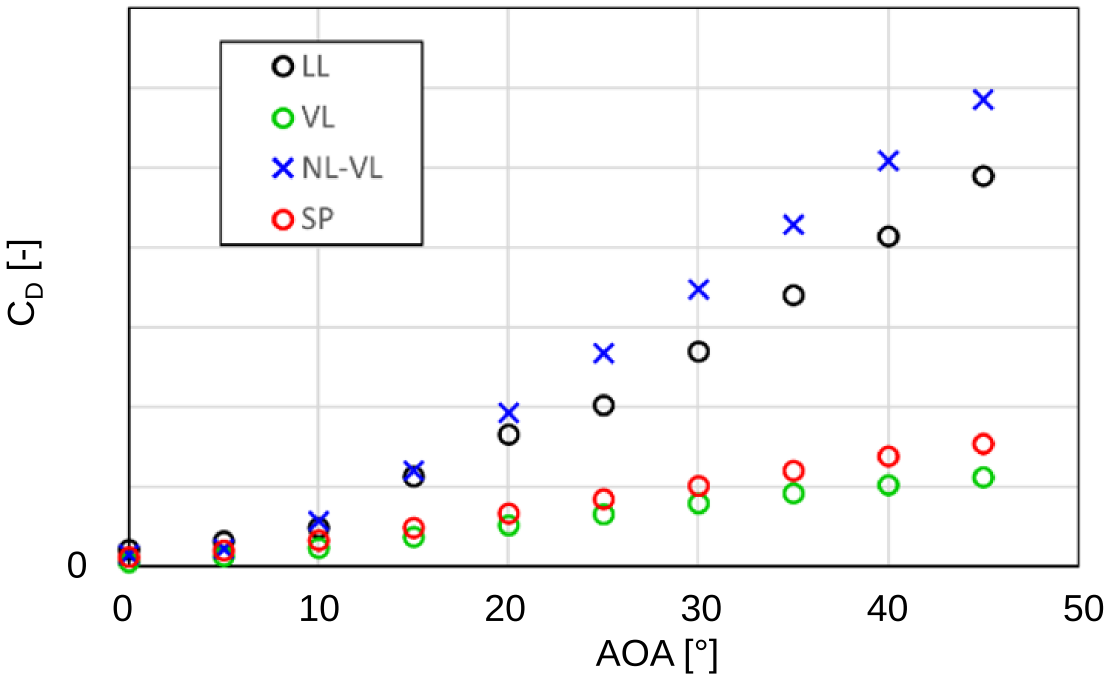


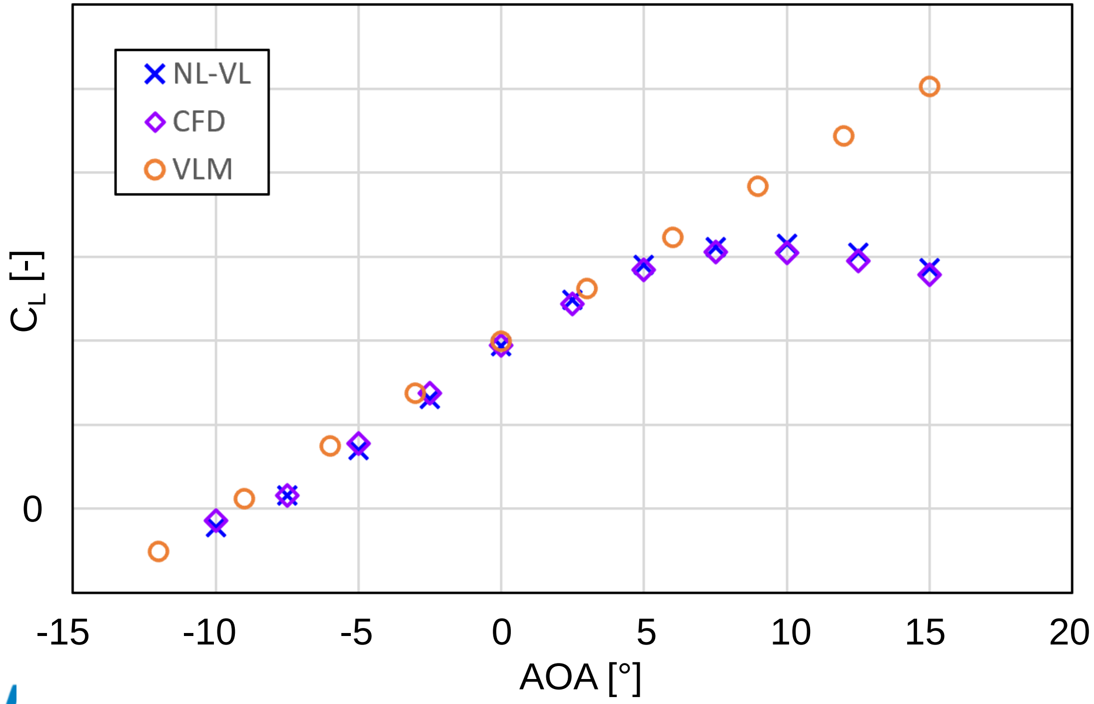


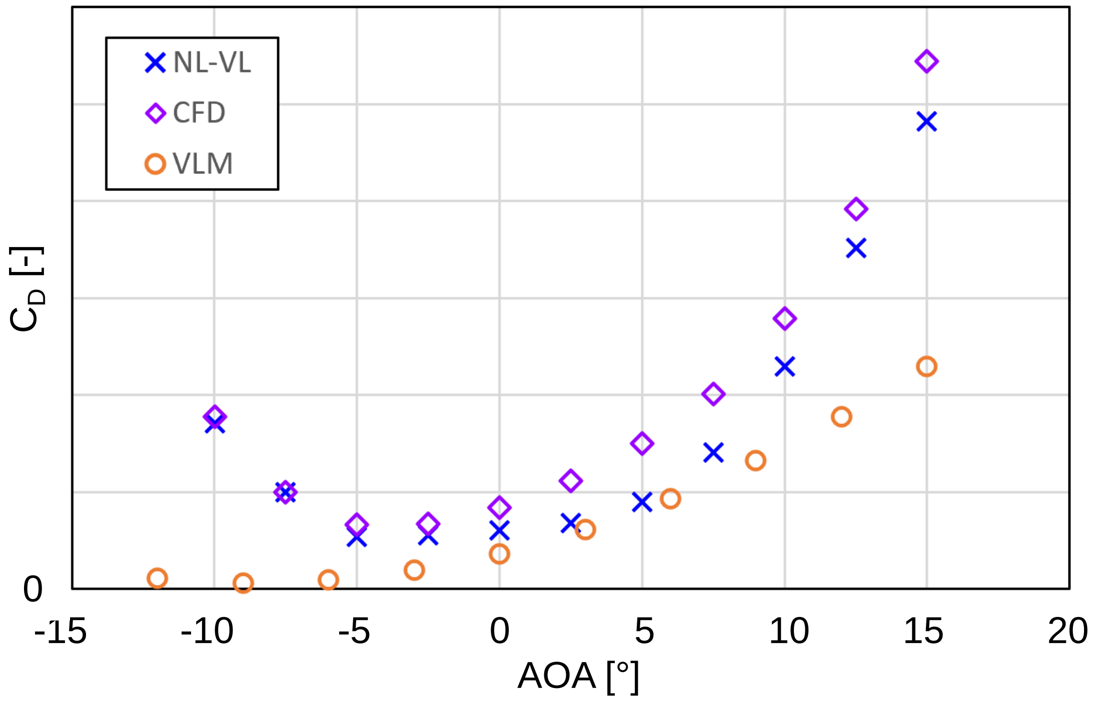
Wing aerodynamics comparison

MODEL-SI MODELING AND SIMULATION

Comparison between different models fidelity:

- Low-fidelity: Vortex Lattice Method (Tornado)
- Mid-fidelity: Vortex Particle Method (DUST)
- High-fidelity: CFD steady RANS





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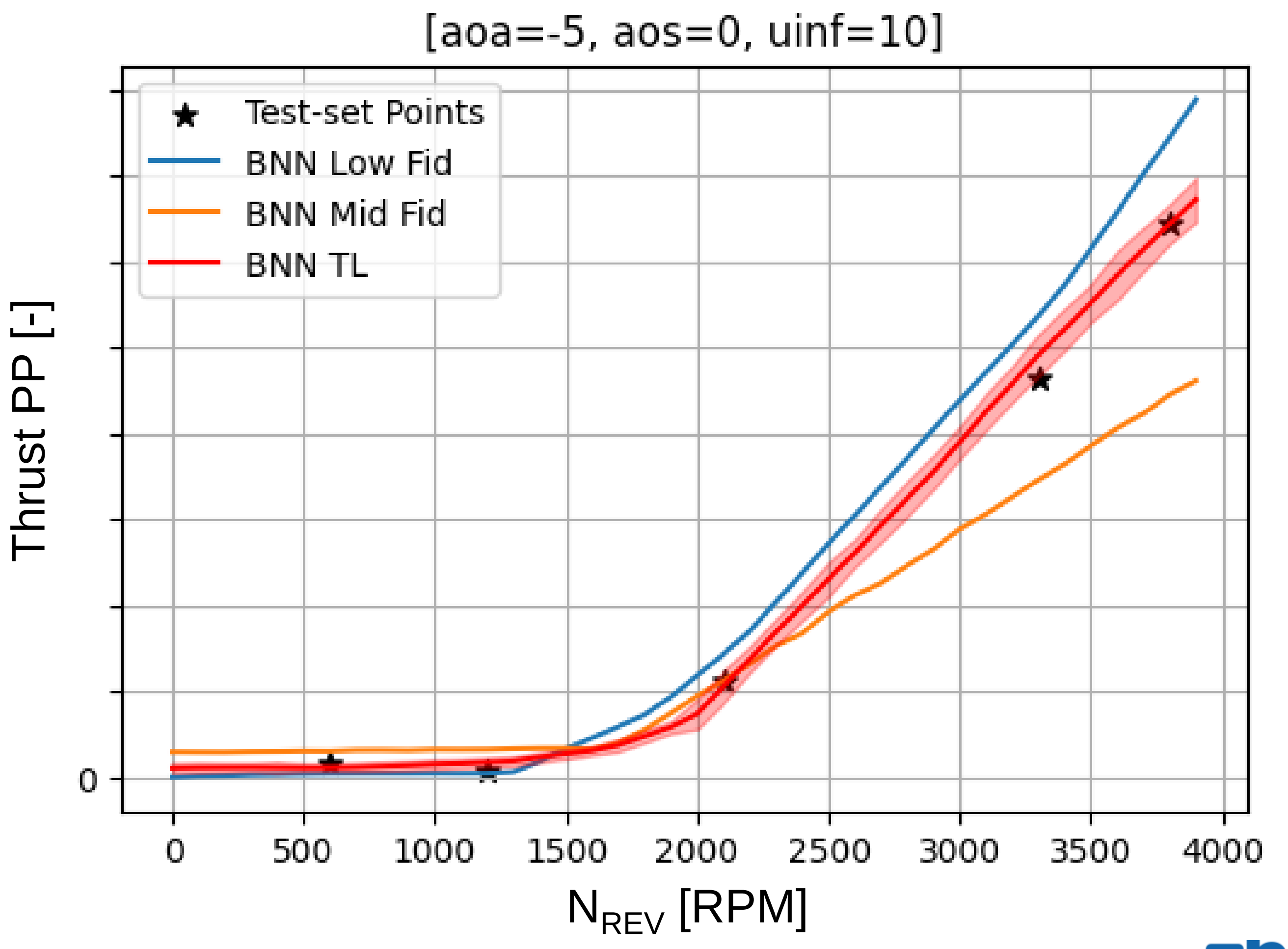
Multi-fidelity modeling - results

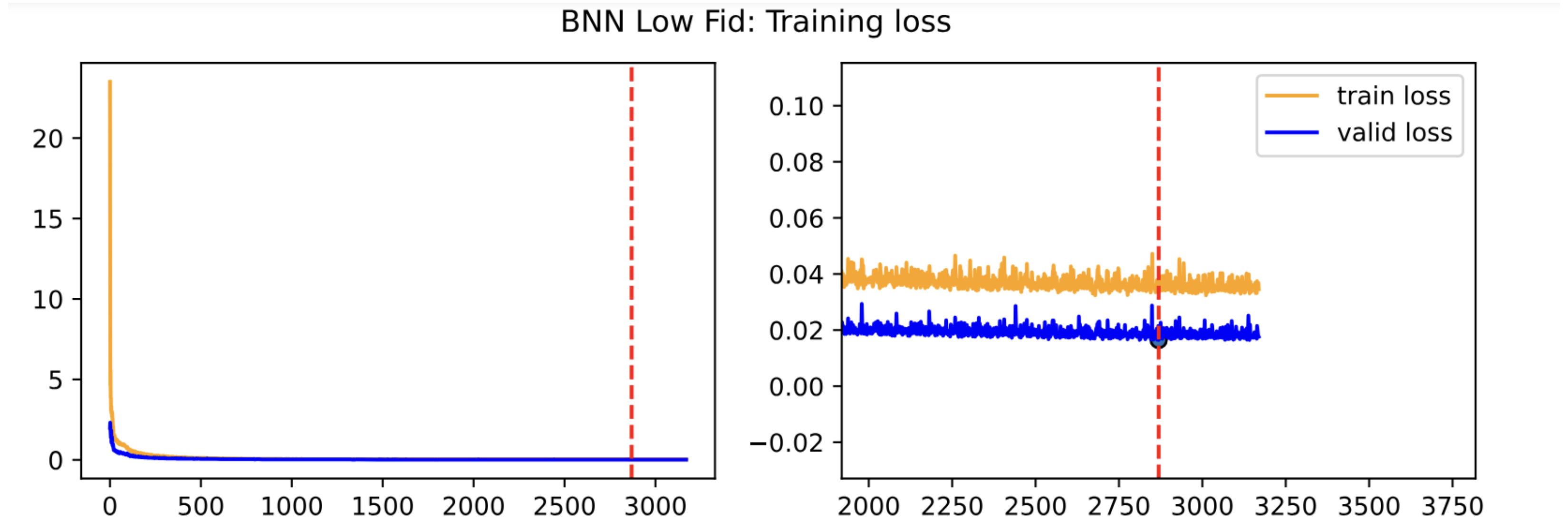
BNN results: Model Integration

BNN with TL achieves good accuracy and consistently outperforms single models trained on separate datasets. The uncertainty quantification provided valuable insights into the model's convergence capability (epistemic) and data coherence (aleatoric). The model was ultimately integrated into the system.

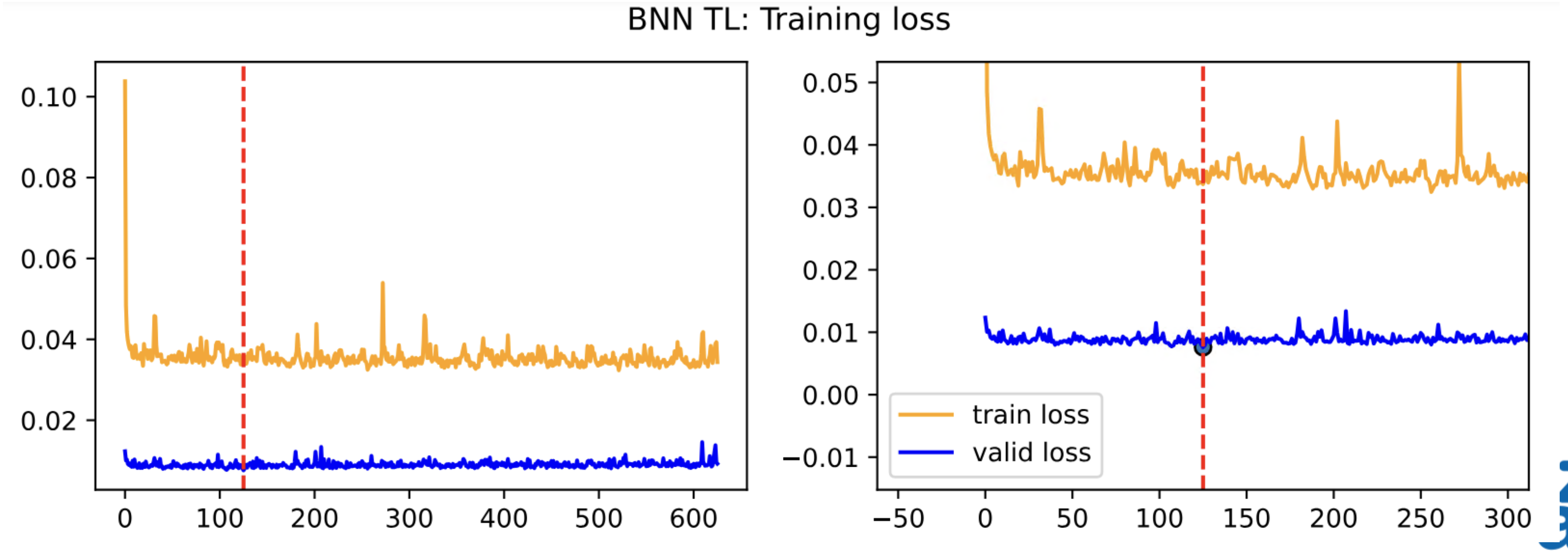


BNN results: Training

Pre Train Loss



Transfer Learning Loss



BNN results: Results

Model	Training Time	Prediction Time	Average Perc. Error	Average Perc. Confidence	N. Params
BNN LF	~41 min	~0.02 sec	8.5%	94.2%	174932
BNN MF	~35 min	~0.02 sec	6.4%	92.1%	19092
DF: BNN TL	~55 min	~0.02 sec	1.8%	97.3%	174932
DF: CoKriging	~4 min	~0.005 sec	5.9%	88.2%	-

Benchmarks on NVIDIA Quadro P2000 GPU

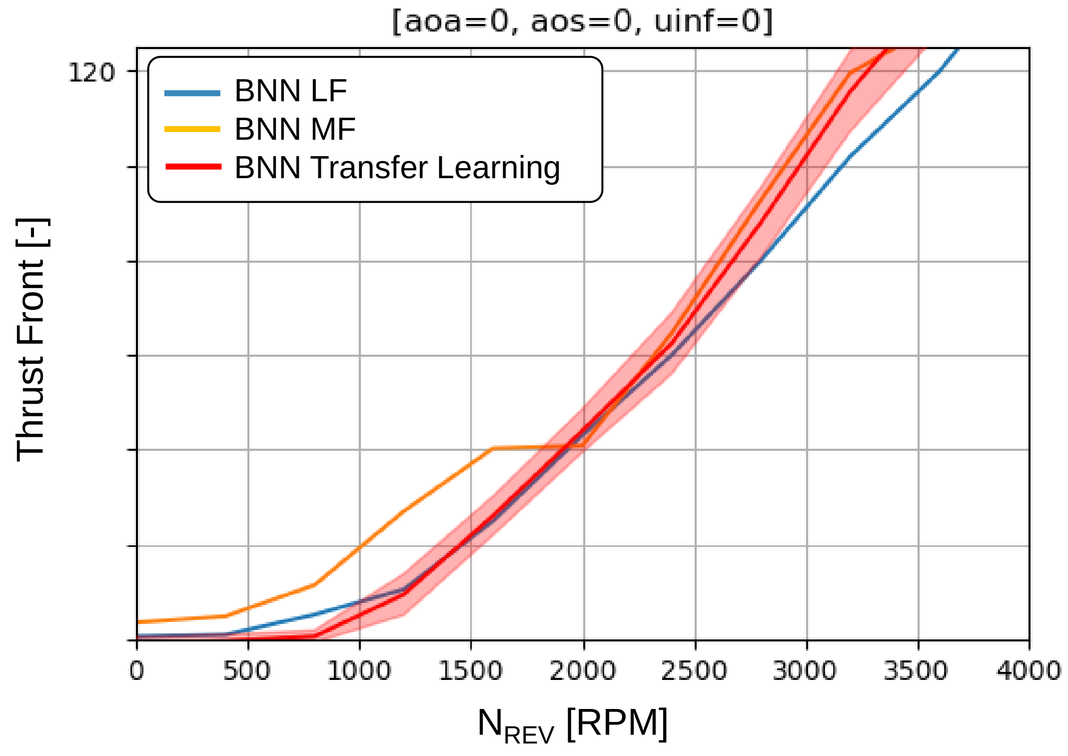
Final model hyperparameters:

- **Input dimension**: 8
- **Output dimension**: 10
- **Number of layers**: 5
- **Optimization Function**: LeakyReLU
- **Learning rate**: 0.0016
- **Learing rate during TL**: 0.0081

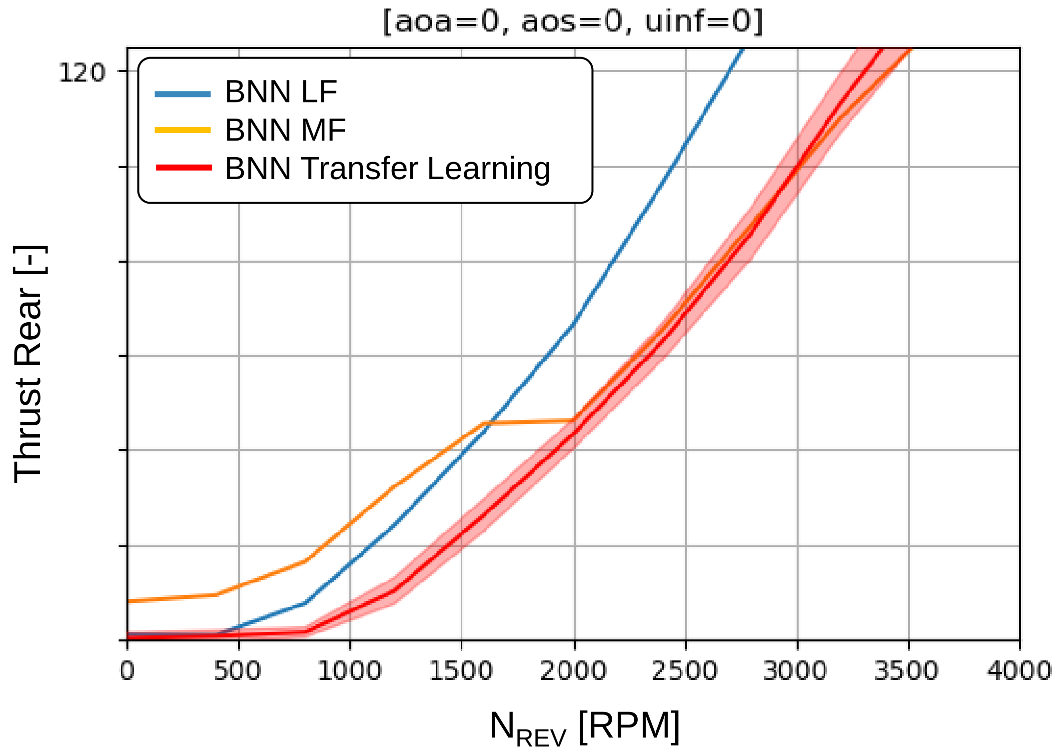
BNN results: Results

$$AOA = AOS = 0° \; U_\infty = 0 \; m/s \; N_{LP} = active \; N_{PP} = 0 \; rpm$$

Front propeller



Rear propeller



Flight mechanics analysis - results

Flight Tests

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The eVTOL is equipped with standard sensors and additionally:

- accelerometrs
- strain gauges

Key notes:

- Several flights were accomplished in the entire flight envelope in both Helicopter and Airplane mode
- Structural modes were identified
- Flight test data is compared with simulation data

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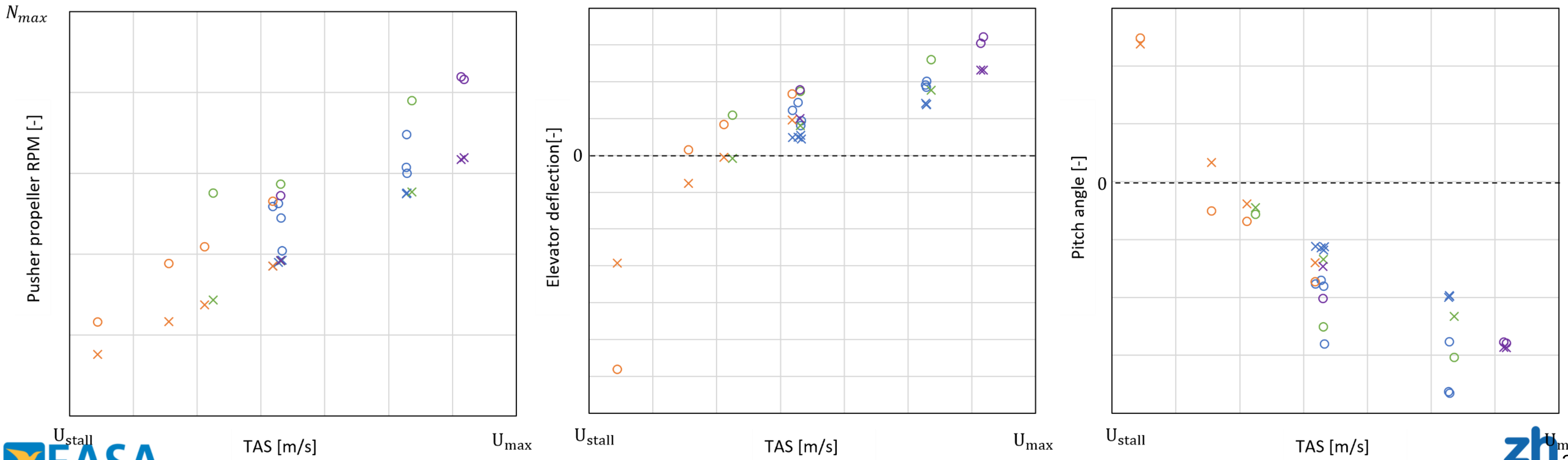
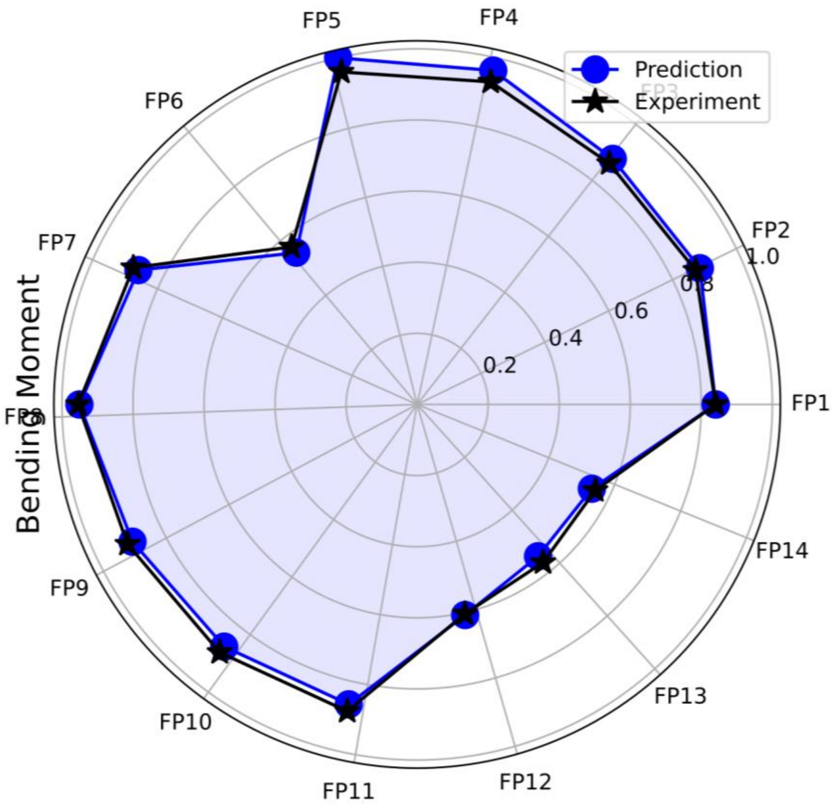
Flight Mechanics comparison

Trimmed conditions comparison in AP mode between:

- **O** LF Flight Mechanics model
- **✖** Flight test data



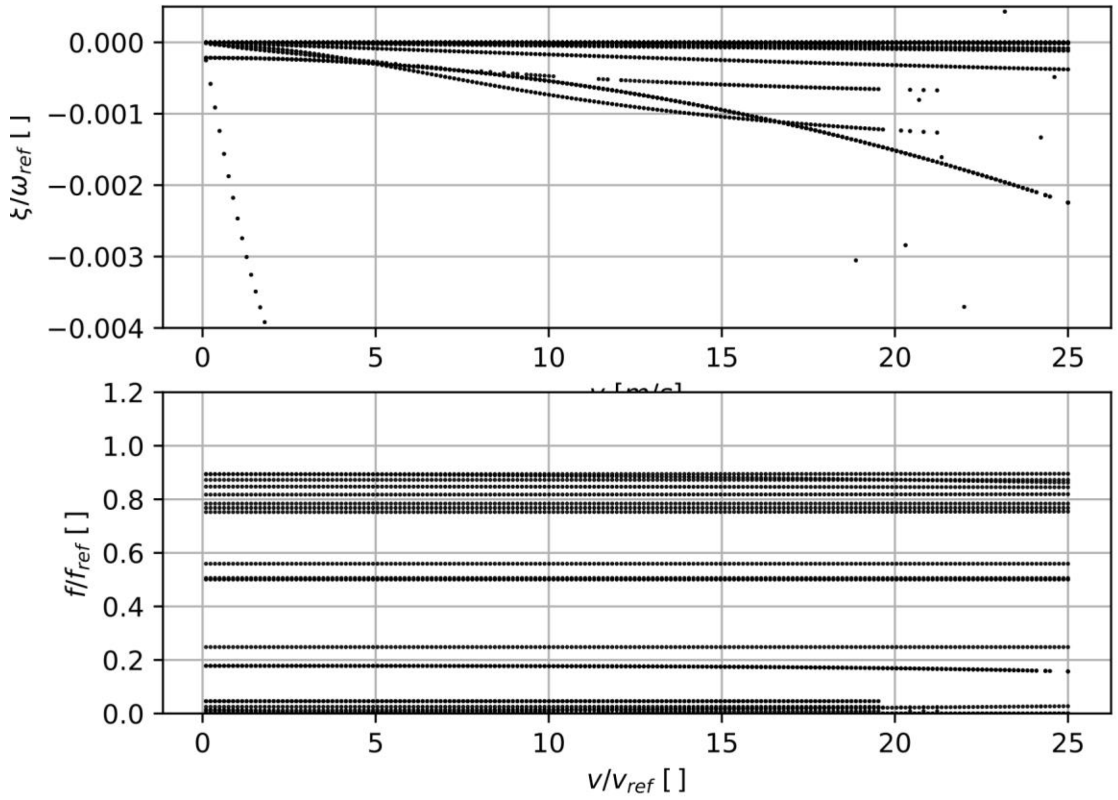
Aeroelastic results: Bending moment

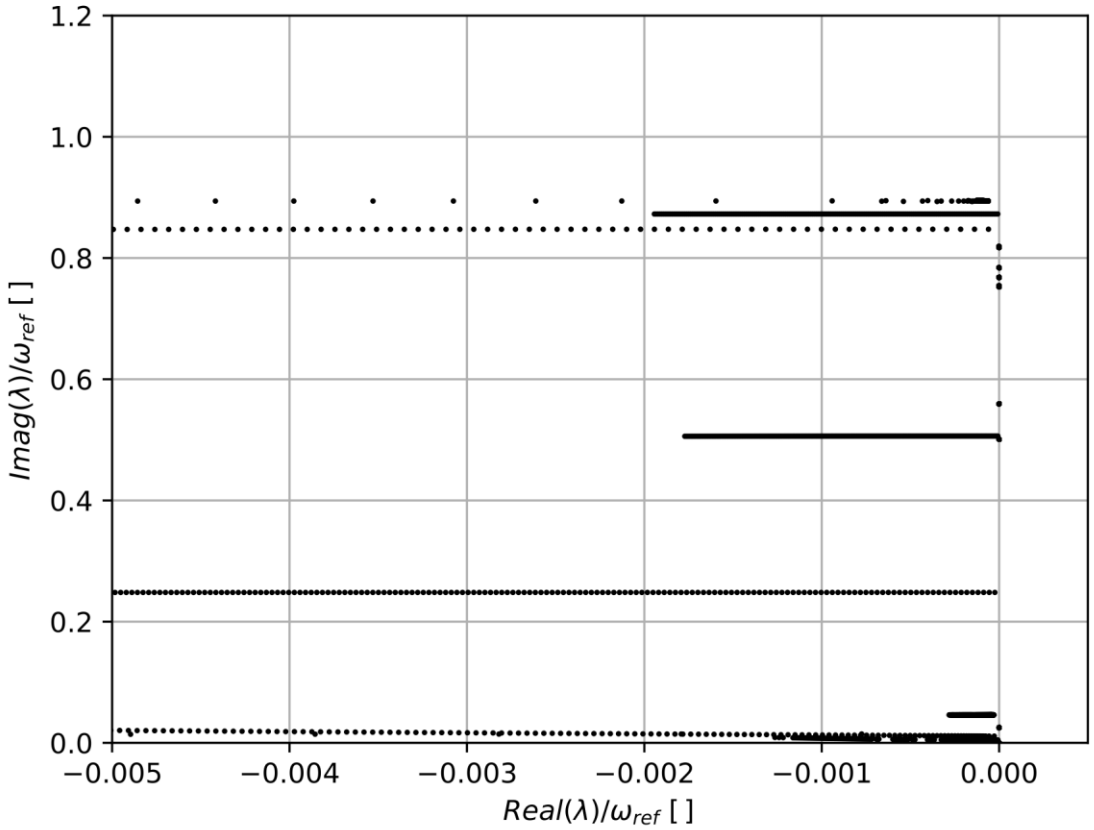


- FP1, FP2, Level Turn 150 m
- FP3, FP4, FP5, Level Turn 95 m
- FP6, Hover,
- FP7, FP8, Level Turn 95 m
- FP9, Level Turn 185 m
- FP10, Level Turn 160 m
- FP11, Level Turn 95 m
- FP12, FP13, FP14, Hover

Linear stability analysis

Aeroelastic results: Linear stability analysis (airplane mode)





Conventional V-g plot and root locus, in this case, no unstable mode is detected.

Aeroelastic results: Linear stability analysis (helicopter mode)

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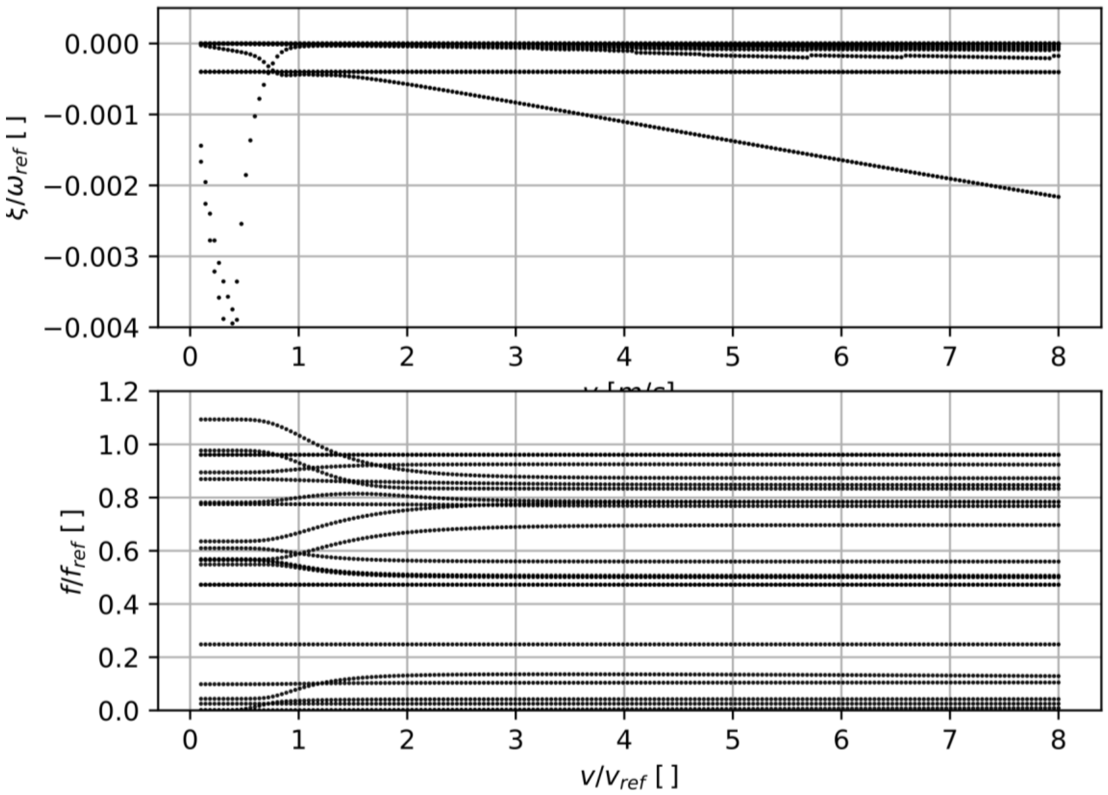

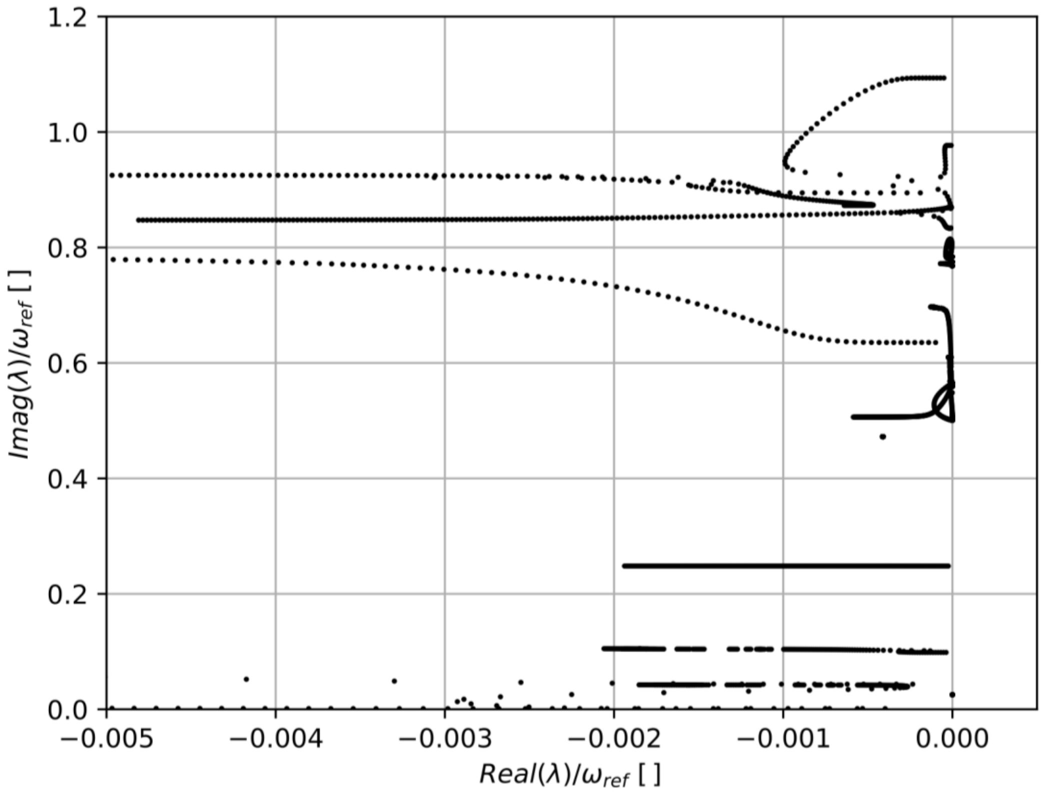

Conventional V-g plot and root locus, in this case, no unstable mode is detected. Note that in helicopter mode, the eigenvalues analysis is only possible if multi blade transformation provides a time constant system of equations. Conversely, an approach like Floquet is necessary.

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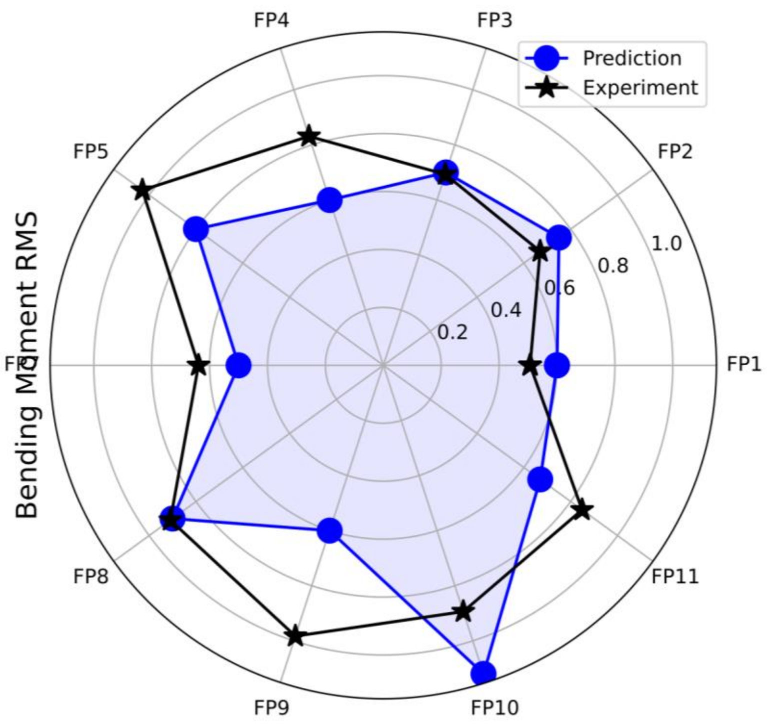
Aeroelastic results: Bending moment RMS



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Aeroelastic results: Acceleration (eVTOL CG) RMS

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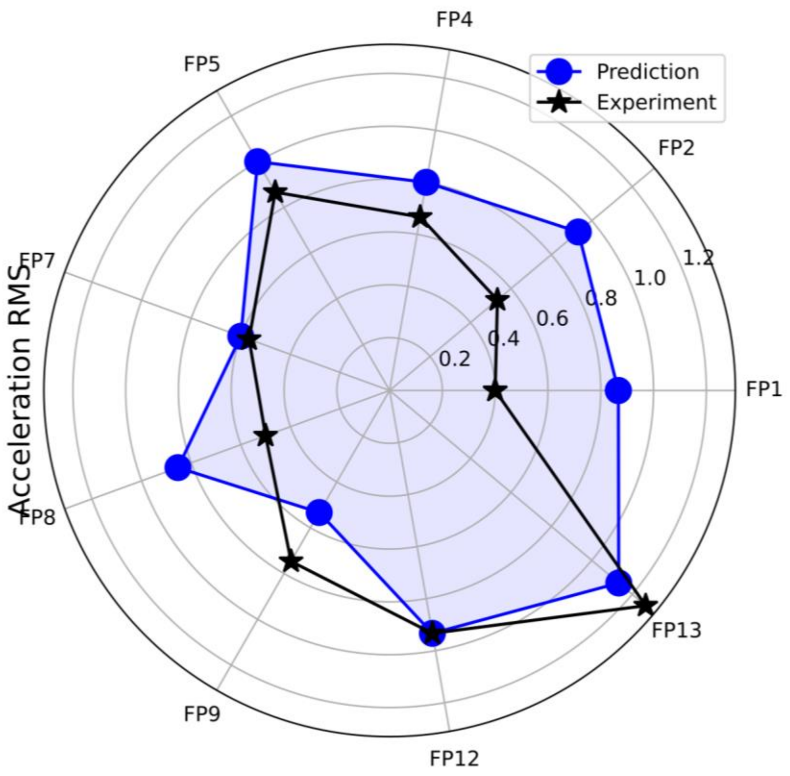

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Thank you!
Questions?

School of Engineering
ZAV Centre for Aviation