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# Optimization of the Synthetic Jet to improve aerodynamic efficiency of the Next Generation Civil Tilt Rotor Aircraft

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# Optimization of the Synthetic Jet to improve aerodynamic efficiency of the Next Generation Civil Tilt Rotor Aircraft

*Hung TRUONG, A. Marouf, J.B. Vos, A. Gehri, and Y. Hoarau*

ICUBE laboratory, University of Strasbourg, France

CFS Engineering, EPFL Innovation Park, Lausanne, Switzerland

# Optimization of the ZNMF to improve performance of the NGCTR

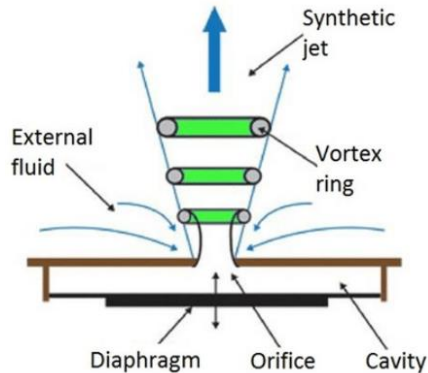
- Introduction
- Numerical methods
  - *NSMB solver and Meshing*
  - *Modeling of ZNMF devices*
- Results
  - *Critical Flow Conditions*
  - *Configuration 1 with horizontal nacelle*
  - *Configuration 2 with tilted nacelle*
  - *Configuration 3 with deflected aileron*
- Conclusions and Perspectives

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# Introduction

The overall objective of the AFC4TR project is to investigate the use of Active Flow Control using so called pulsed air blowing devices with Zero Net Mass Flux (ZNMF) to control the vortical flow for the Next Generation Civil Tilt Rotor (NGCTR) aircraft configuration.



## Active Flow Control 4 Tilt Rotor aircraft



CFS Engineering

Computational Fluids & Structures Engineering



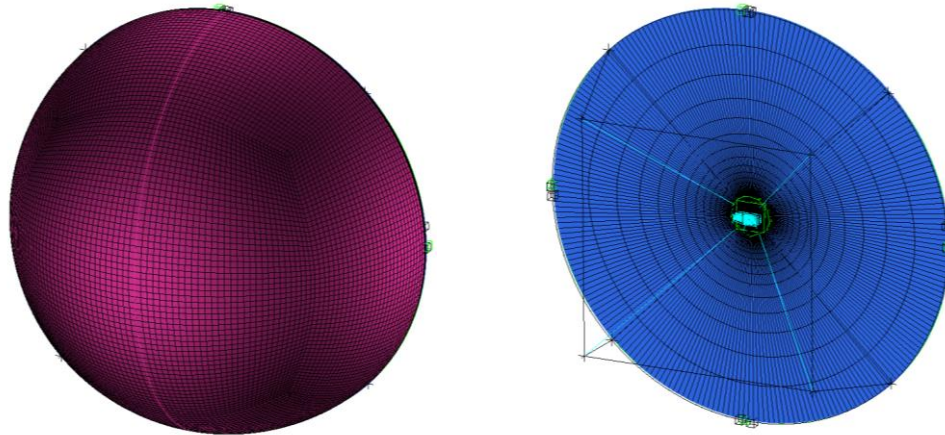
Leonardo Helicopters

# Optimization of the ZNMF to improve performance of the NGCTR

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# Numerical methods

- NSMB solver: Navier Stokes Multi-Block code (compressible NS equations using Finite Volume method) [Hoarau et al. 2016]
- Structured grids are designed following the gridding guidelines of AIAA CFD HighLift/Drag Prediction Workshops
- Farfield boundary  $> 100 \times C_{ref}$
- Turbulence model  $k - \omega - SST$
- Patched grid and chimera grid techniques are used



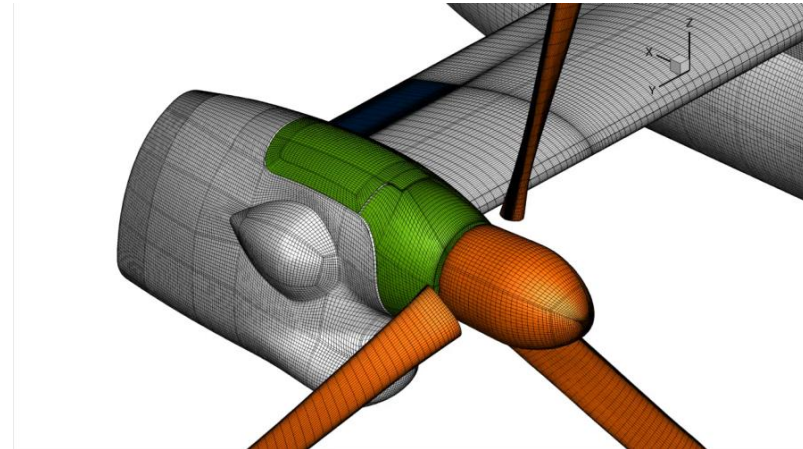
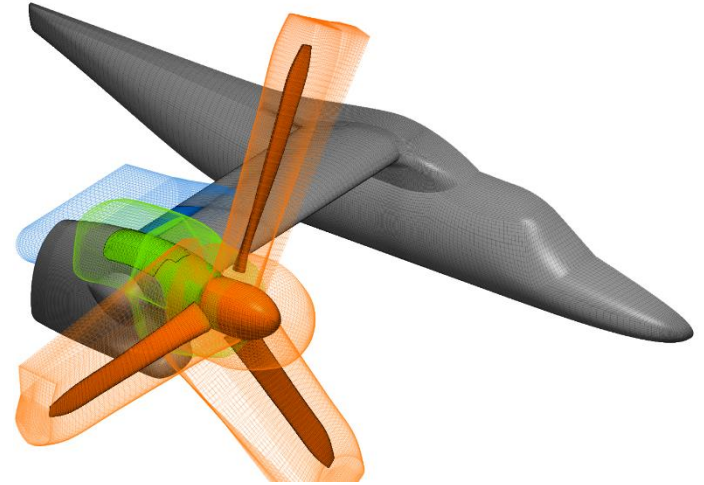
# Numerical methods

7 grid components that are merged together (within ICEMCFD or externally with Python scripts)

- Base (fuselage, wing, nacelle) - 10'200'000 cells
- Aileron - 620'000 cells
- Engine cover - 370'000 cells
- Engine - 450'000 cells
- Hub - 340'000 cells
- Blades - 770'000 cells/blade

The engine can be deflected from  $0^\circ$  to  $90^\circ$

Total mesh 25 millions cells





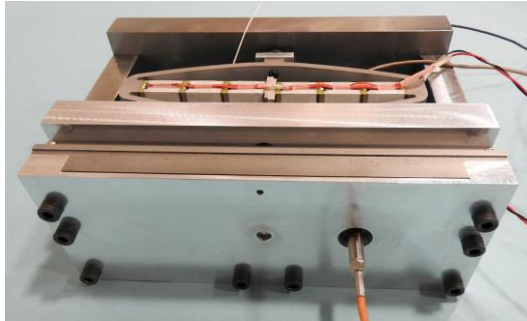
# Numerical methods

## Modelling of Zero-Net-Mass-Flux (ZNMF) devices

ASPIC synthetic jet actuator

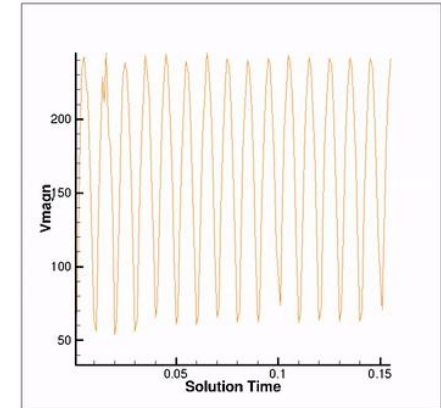
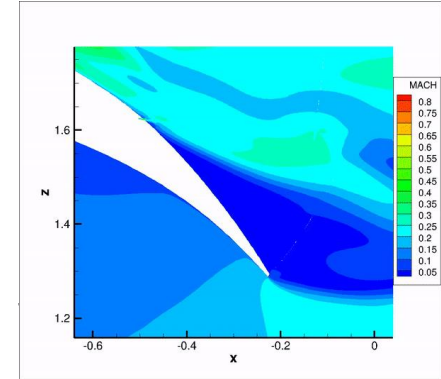
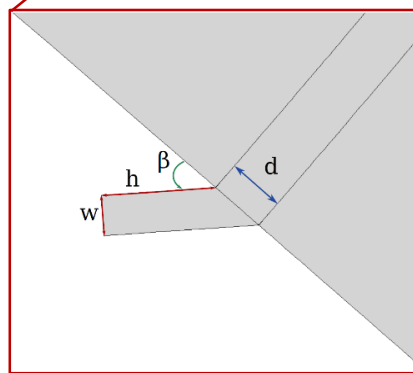
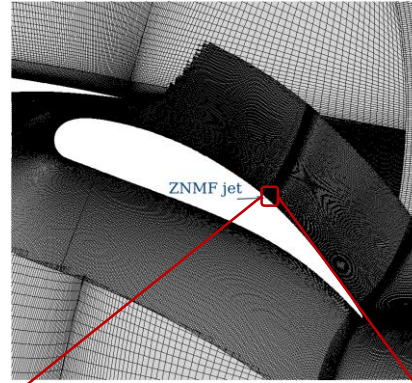
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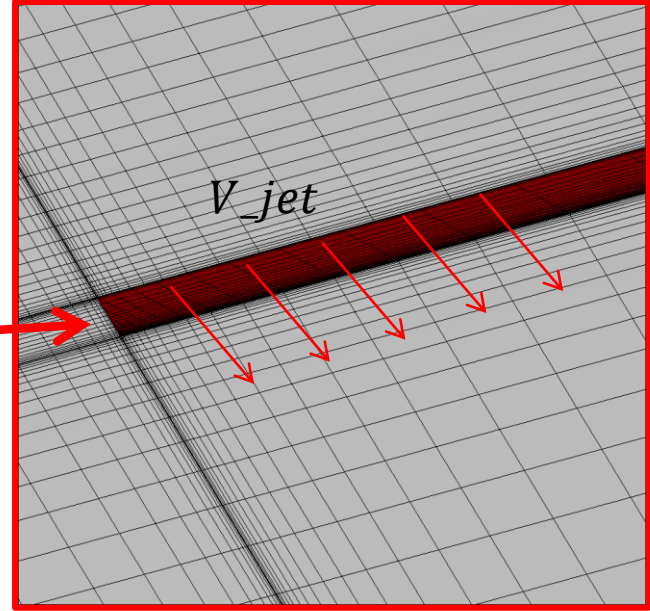
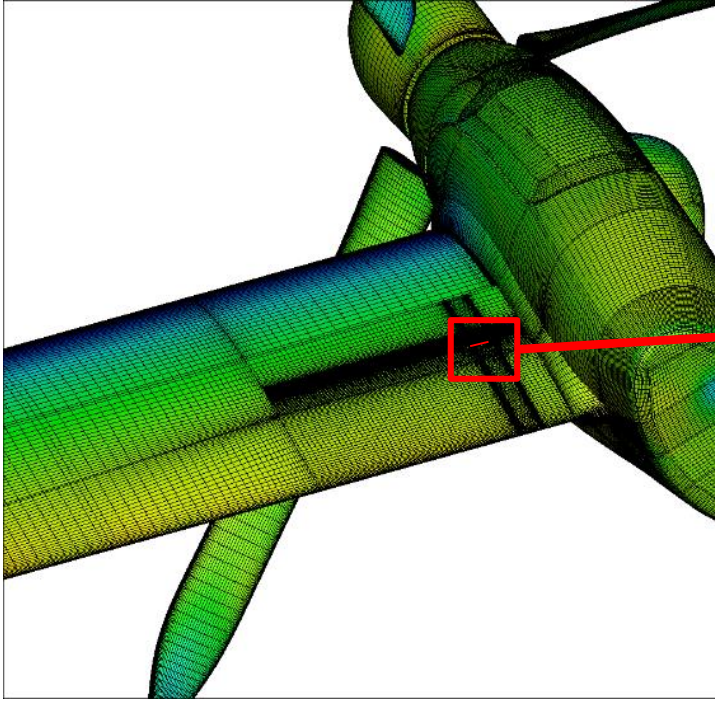
Slot dimensions:  $1 \times 150 \text{ mm}^2$   
Actuator volume:  $164 \times 94 \times 57 \text{ mm}^3$

modelling  
→



# Numerical methods

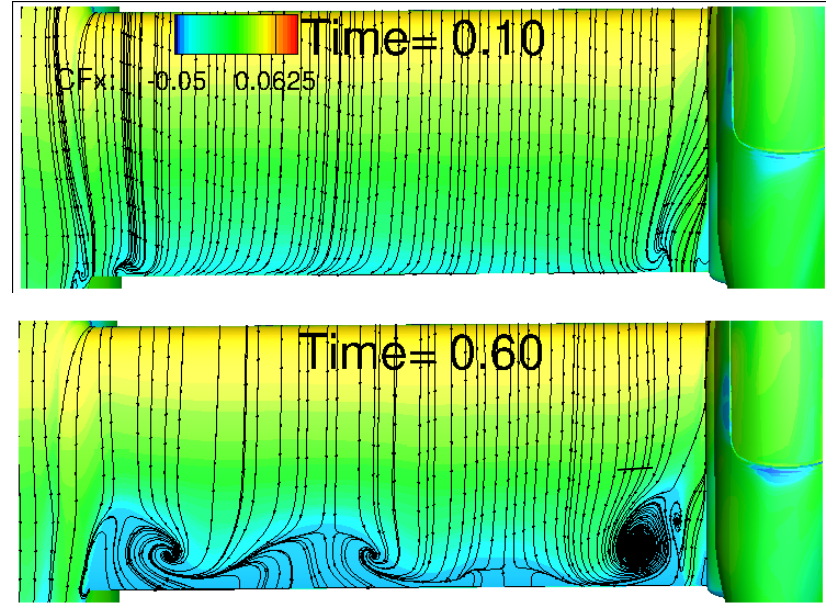
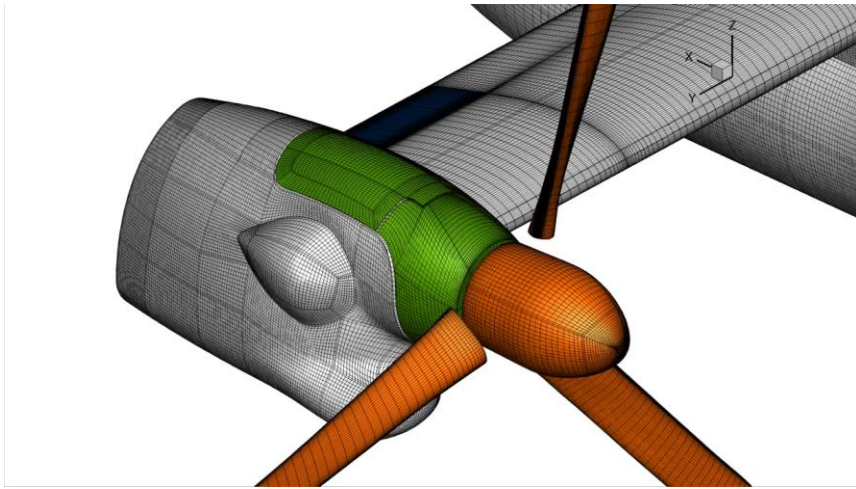
## Modelling of ZNMF devices



# Optimization of the ZNMF to improve performance of the NGCTR

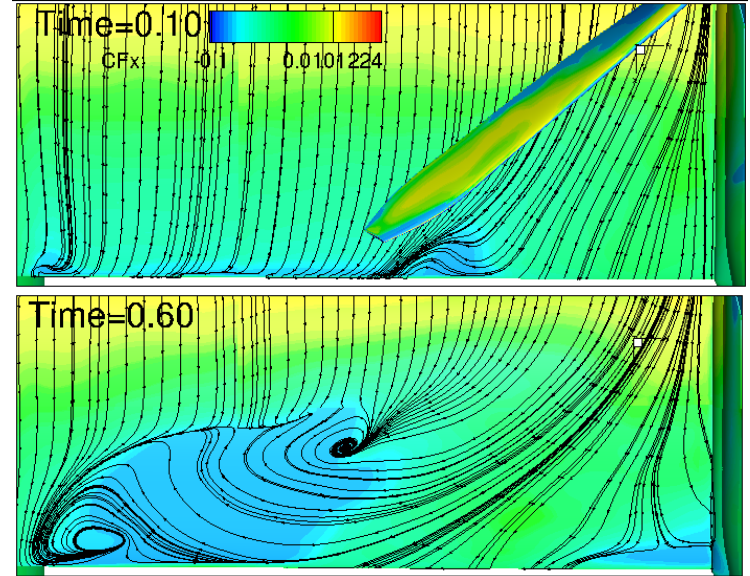
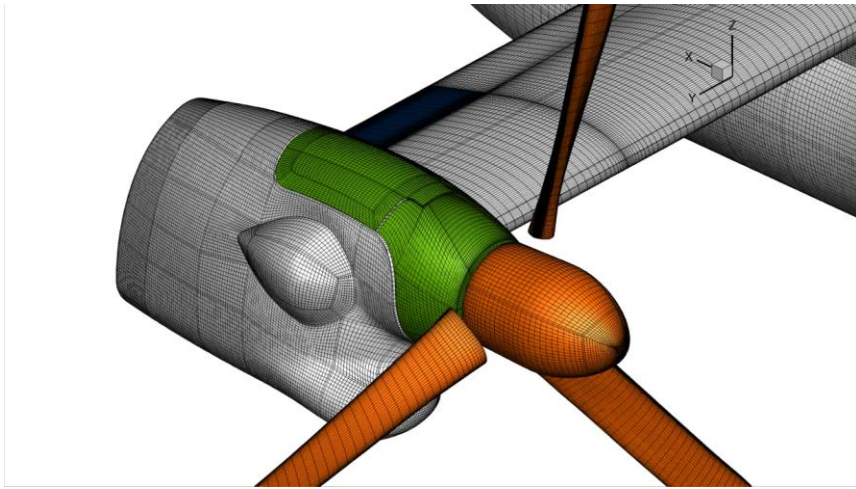
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# Critical Flow Conditions



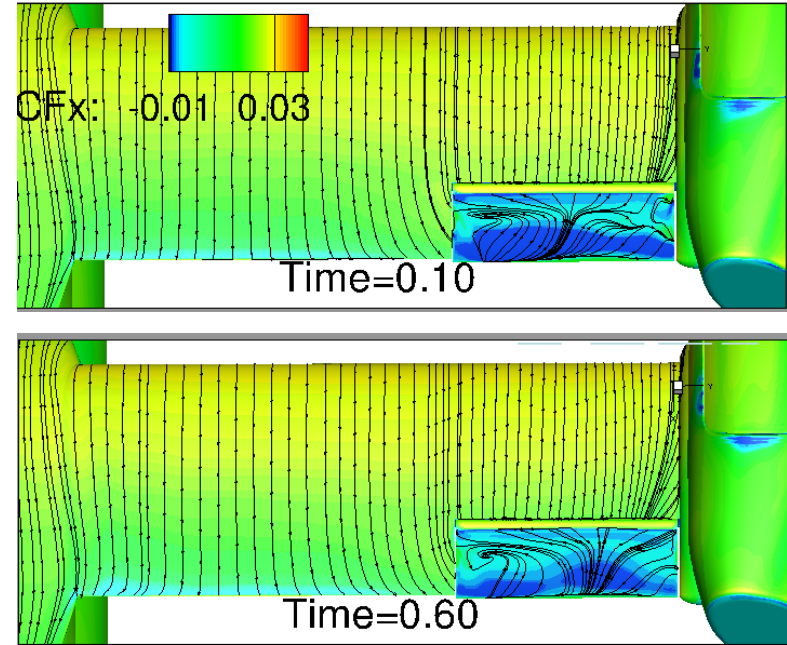
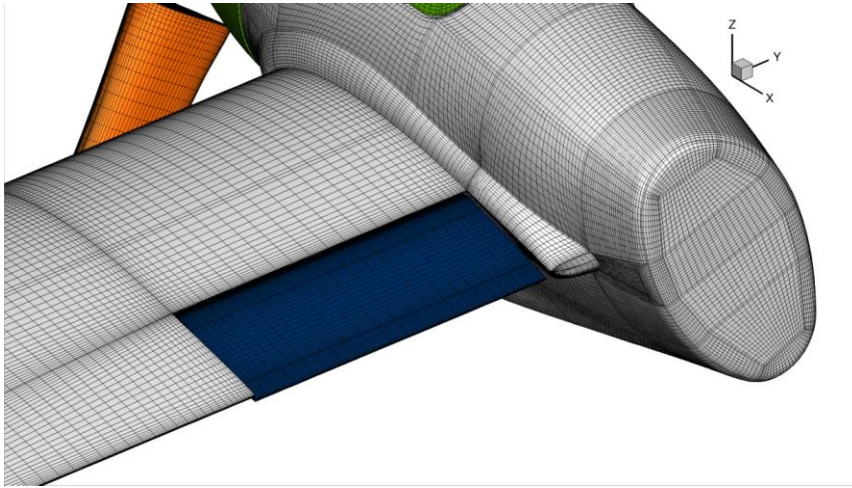
Skin friction  $CF_x$  component contours with streamlines of CF ( $CF_x$ ,  $CF_y$ ,  $CF_z$ ) with **horizontal nacelle**

# Critical Flow Conditions



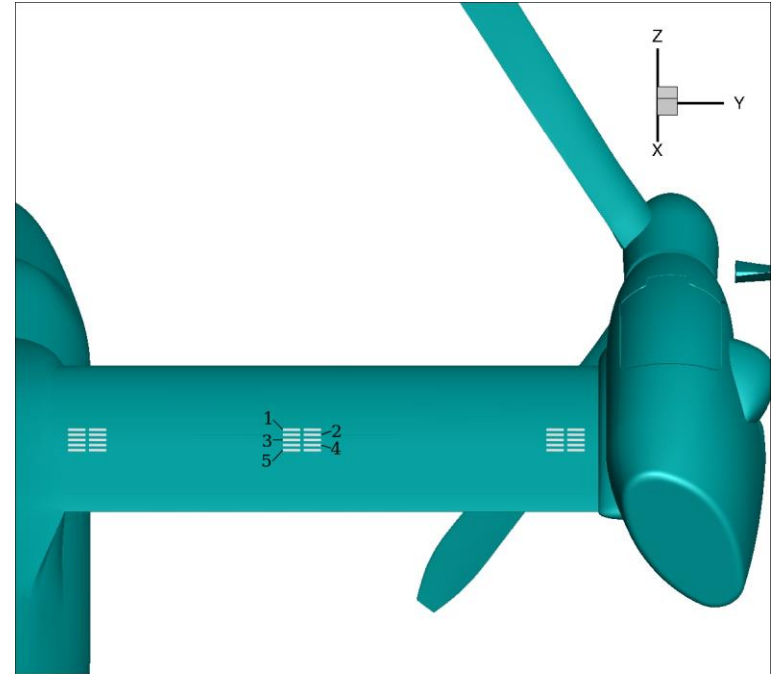
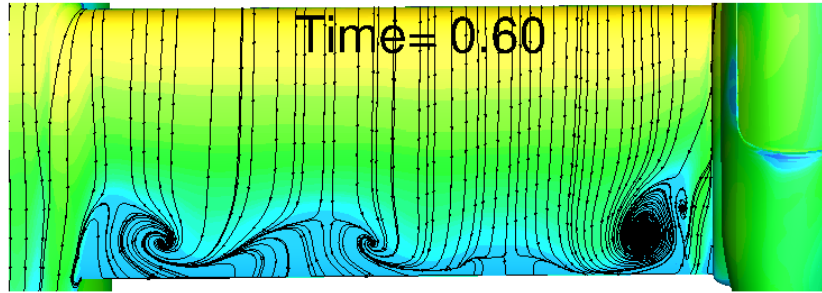
*Skin friction  $CF_x$  component contours with streamlines of CF ( $CF_x$ ,  $CF_y$ ,  $CF_z$ ) with **tilted nacelle***

# Critical Flow Conditions



*Skin friction  $CF_x$  component contours with streamlines of CF ( $CF_x$ ,  $CF_y$ ,  $CF_z$ ) with **deflected aileron***

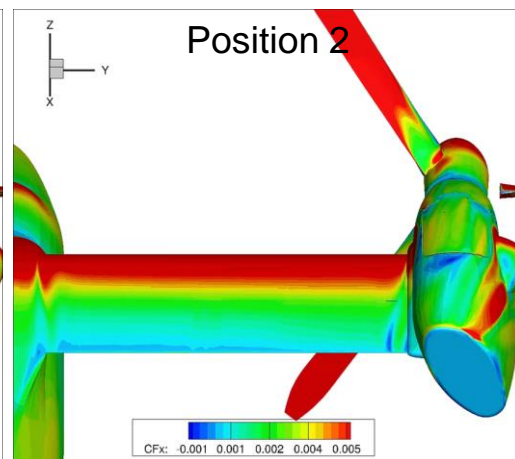
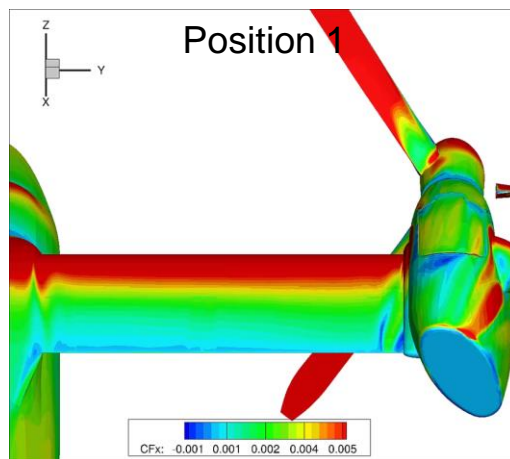
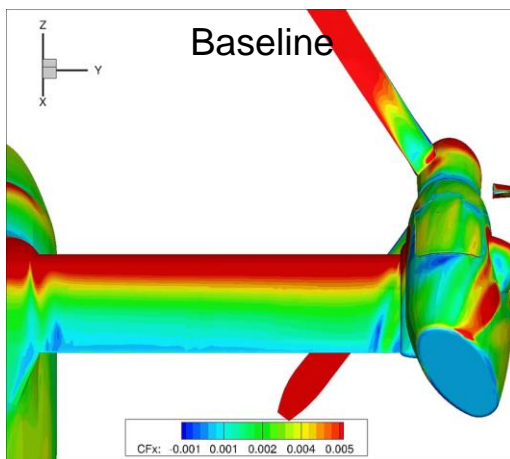
# Configuration 1 with horizontal nacelle



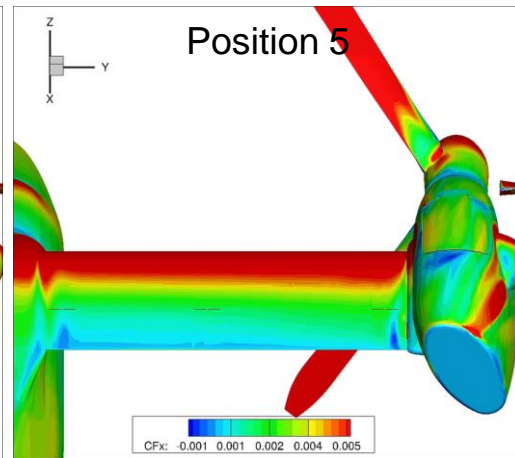
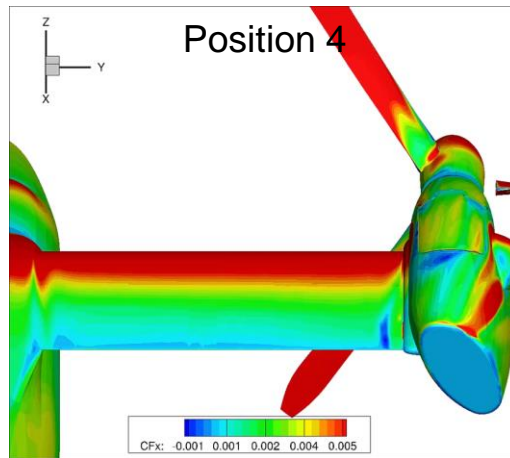
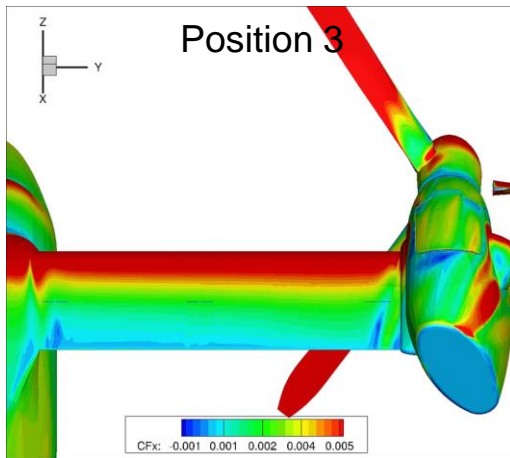
*6 ZNMFs are placed upstream of three zones of separation*

# Configuration 1 with horizontal nacelle

*Simulations show skin friction  $CF_x$*

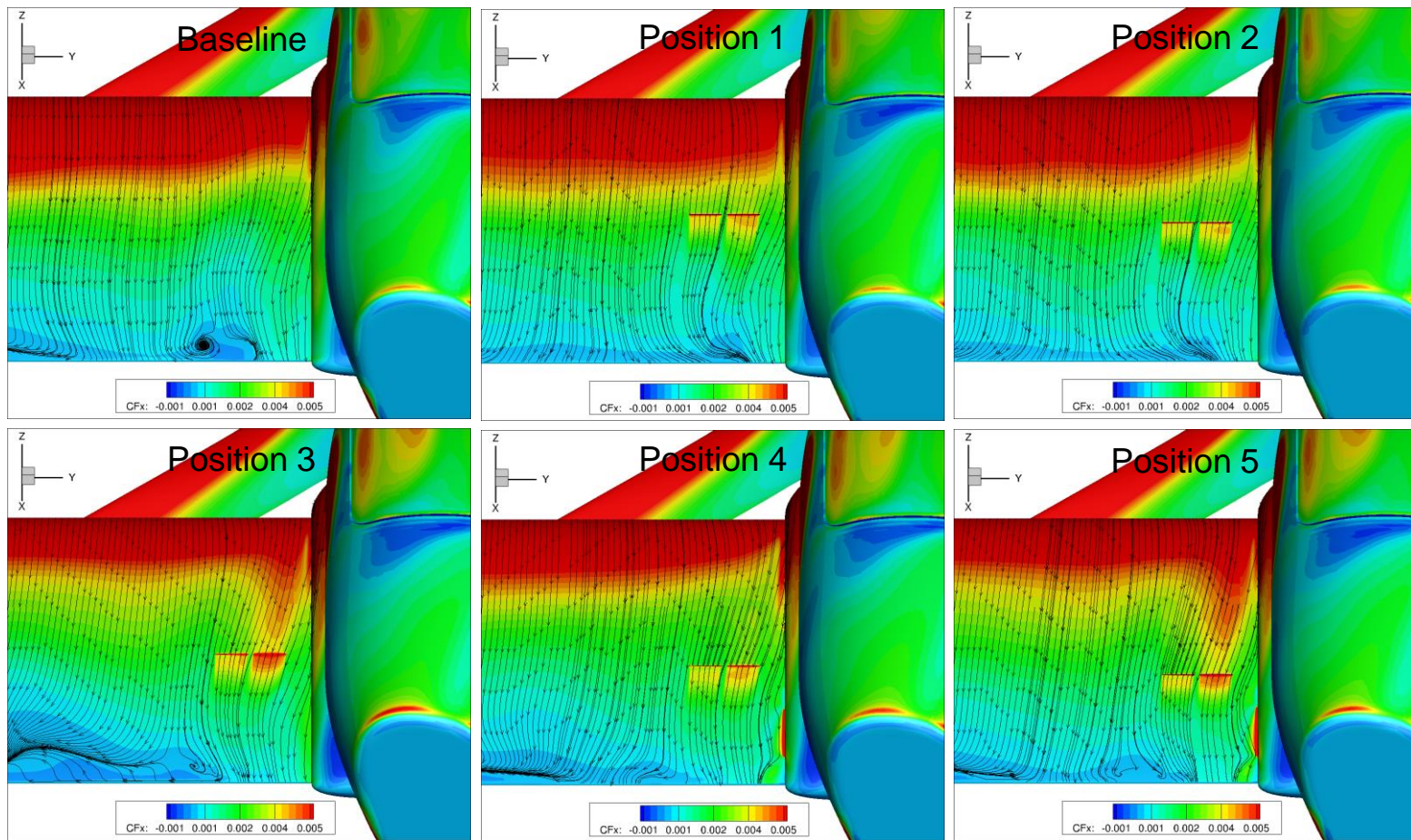


*ZNMF parameters*  
 $v = 300 \text{ m/s}$   
 $f = 65 \text{ Hz}$





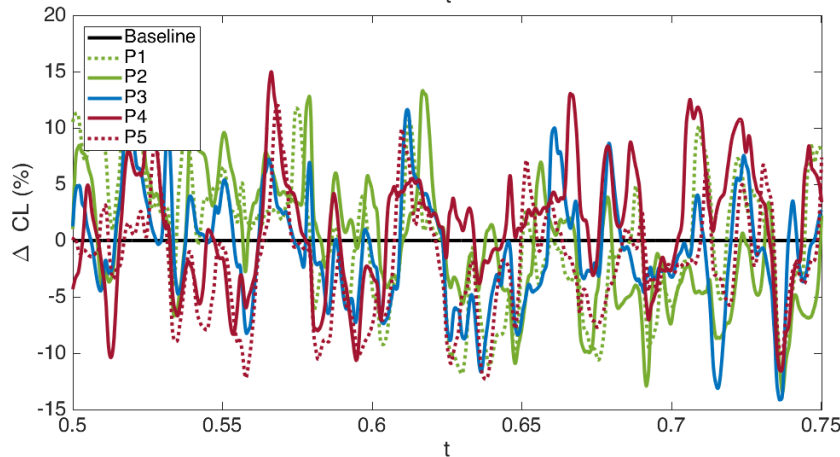
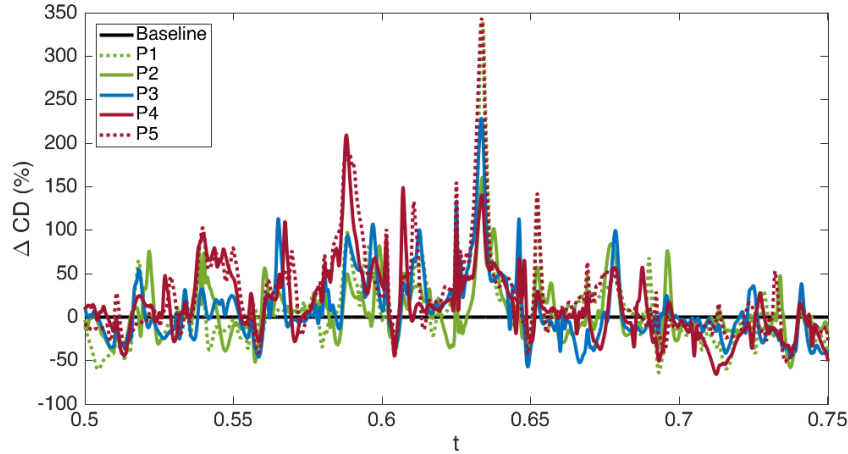
# Configuration 1 with horizontal nacelle



*Simulations show  
skin friction  $CF_x$*

*ZNMF parameters  
 $v = 300 \text{ m/s}$   
 $f = 65 \text{ Hz}$*

# Configuration 1 with horizontal nacelle



Forces integrated on the wing  
for the 5<sup>th</sup> and 6<sup>th</sup> rotations of the propeller

$$\bar{C}_L, \bar{C}_D = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \bar{C}(t) dt$$

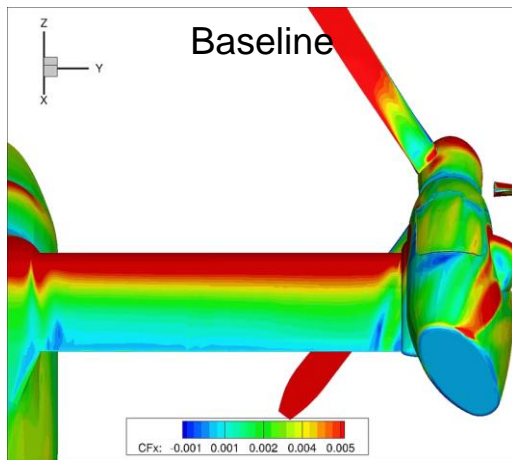
ZNMF position	ΔCD	ΔCL	ΔCL/CD
1	-1.11%	0.05%	1.18%
2	-1.15%	-0.23%	0.93%
3	0.18%	-0.86%	-1.03%
4	5.90%	1.24%	-4.40%
5	14.66%	-2.24%	-14.74%

Insignificant gain since the flow detachment is not as strong as expected

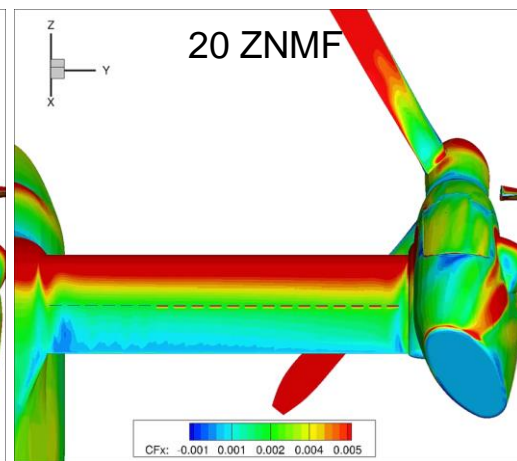
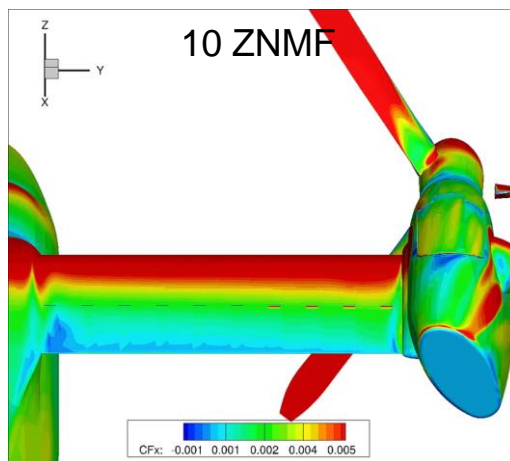
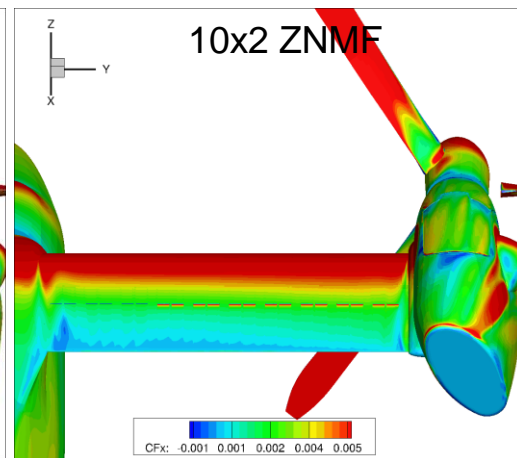
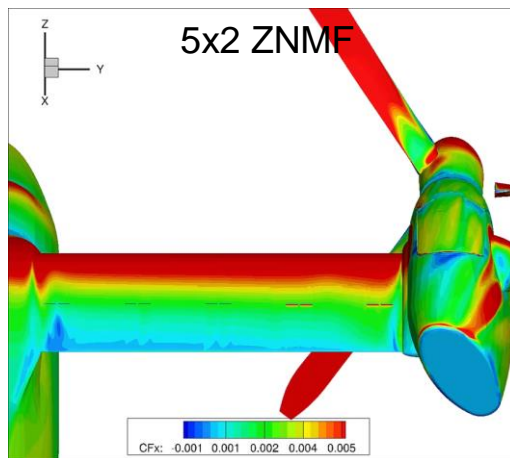
=> the ZNMF position remains to be optimized

# Configuration 1 with horizontal nacelle

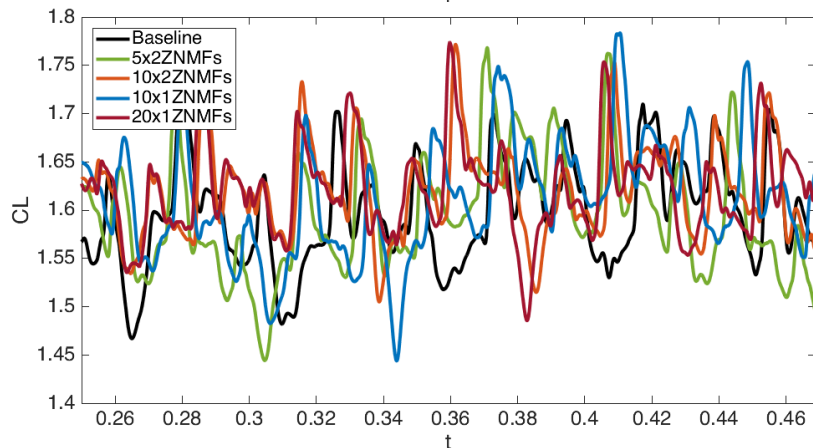
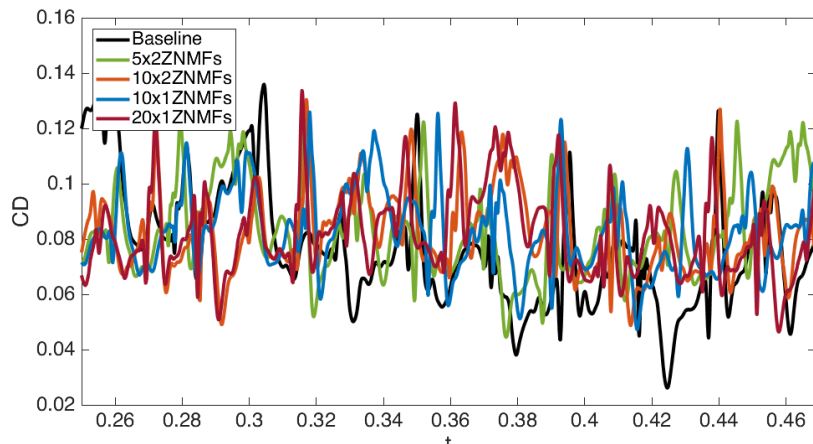
Simulations show skin friction  $CF_x$



ZNMF parameters  
 $v = 300 \text{ m/s}$   
 $f = 65 \text{ Hz}$



# Configuration 1 with horizontal nacelle



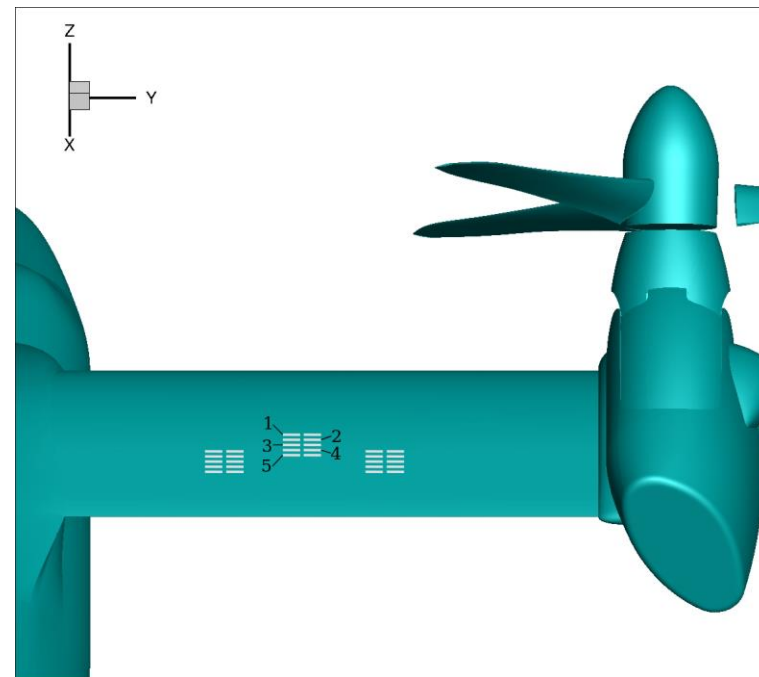
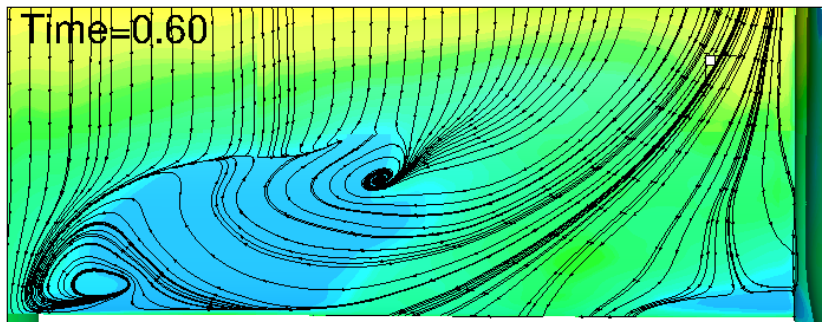
Forces integrated on the wing  
for the 4<sup>th</sup> and 5<sup>th</sup> rotations of the propeller

$$\bar{C}_L, \bar{C}_D = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \bar{C}(t) dt$$

ZNMF position	$\Delta CD$	$\Delta CL$	$\Delta CL/CD$
Baseline	0.078401	1.5899	20.27916
5x2	0.081561	1.601834 +0.75%	19.63971 -3.15%
10x2	0.0824	1.620681 +1.94%	19.66842 -3.01%
10x1	0.083497	1.603649 +0.86%	19.20601 -5.29%
20x1	0.082924	1.621328 +1.98%	19.55205 -3.59%

Lift enhancement accompanied with drag increase  
=> lift-to-drag ratio decreases

# Configuration 2 with tilted nacelle

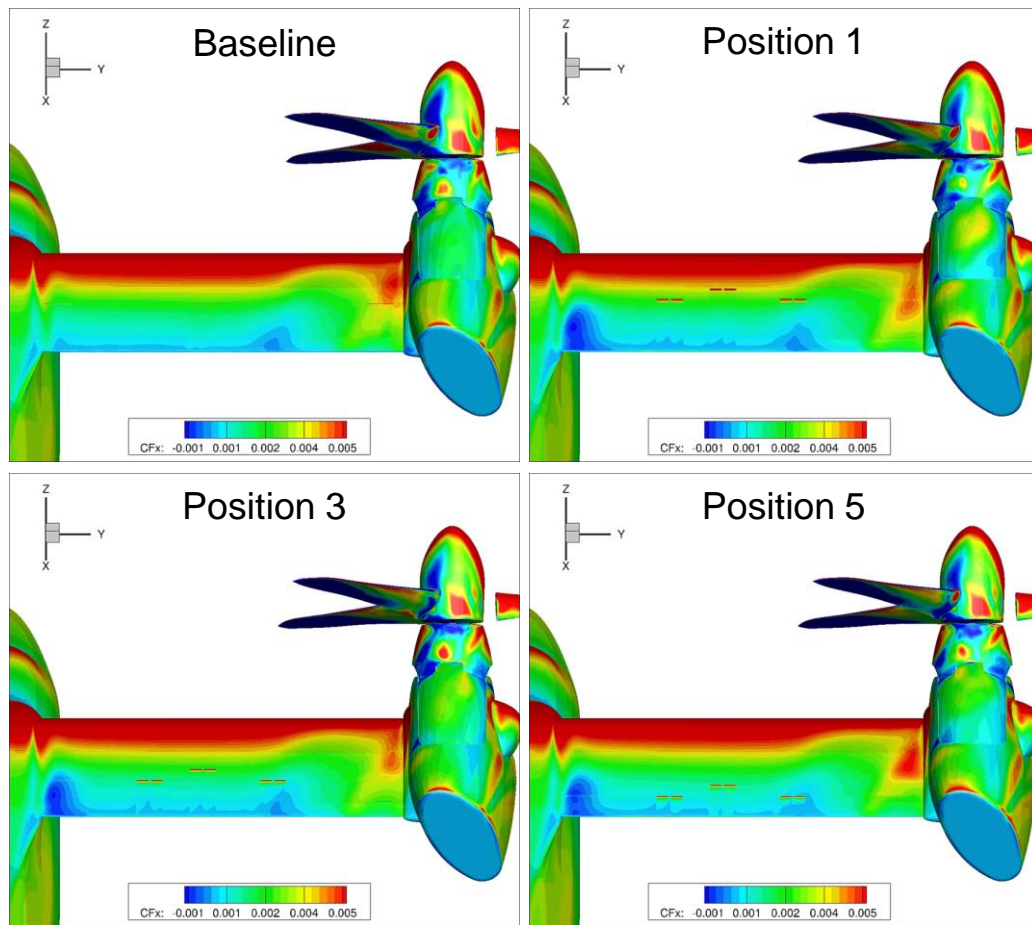


*6 ZNMFs are placed upstream of the separation zones in the middle of the wing*

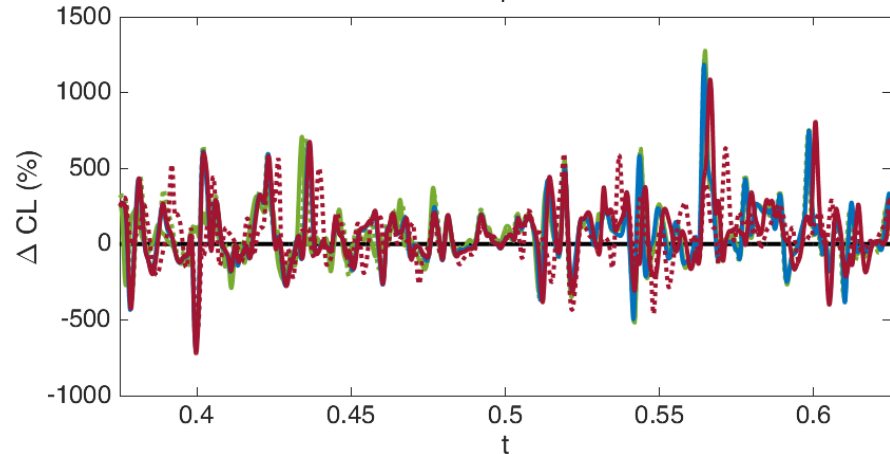
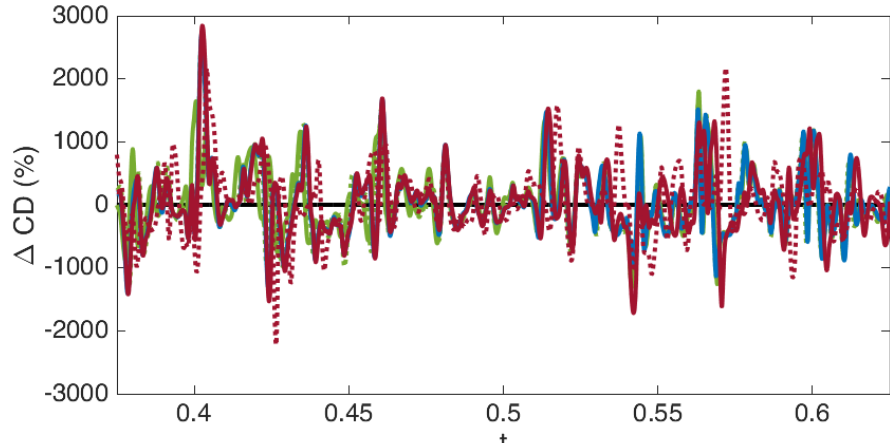
# Configuration 2 with tilted nacelle

*Simulations show  
skin friction  $CF_x$*

*ZNMF parameters  
 $v = 300 \text{ m/s}$   
 $f = 65 \text{ Hz}$*



# Configuration 2 with tilted nacelle



Forces integrated on the wing  
for the 4<sup>th</sup> and 5<sup>th</sup> rotations of the propeller

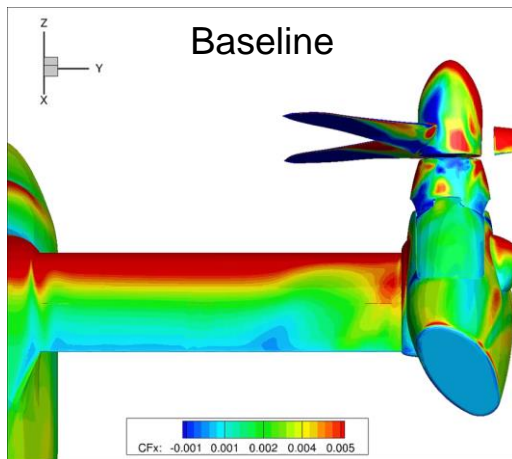
$$\bar{C}_L, \bar{C}_D = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \bar{C}(t) dt$$

ZNMF position	$\Delta CD$	$\Delta CL$	$\Delta CL/CD$
1	12.29%	14.32%	1.82%
2	22.14%	12.86%	-7.59%
3	16.75%	12.34%	-3.78%
4	21.80%	12.66%	-7.51%
5	23.19%	11.87%	-9.19%

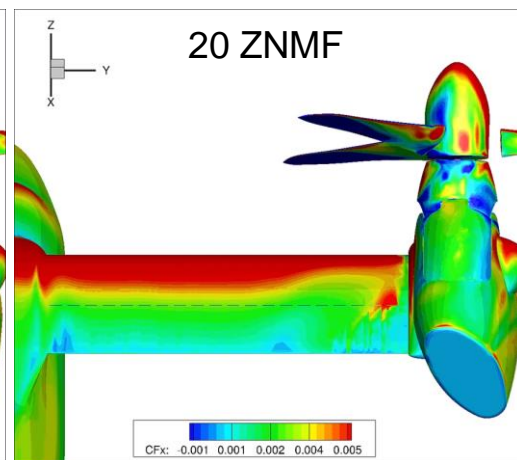
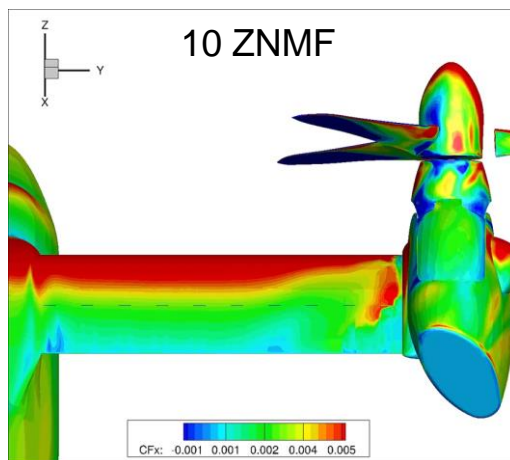
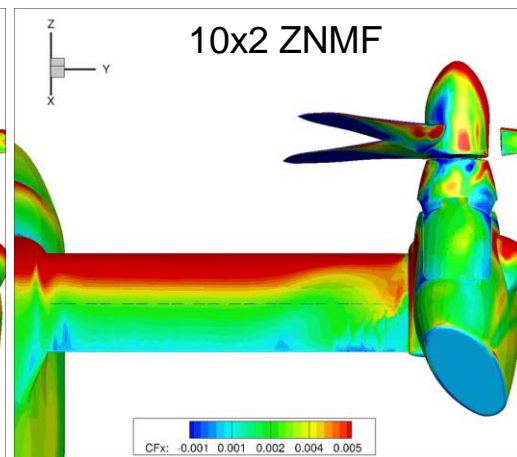
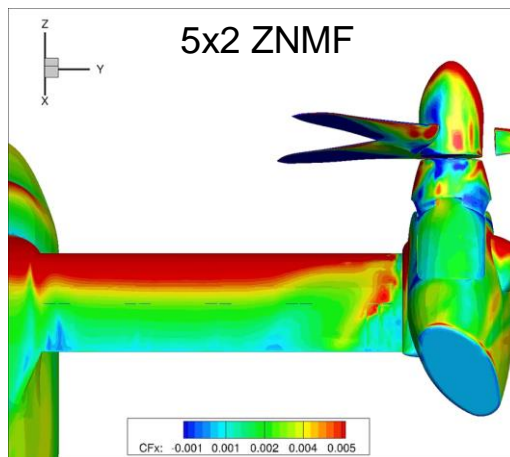
Lift enhancement accompanied with drag increase  
=> lift-to-drag ratio decreases

# Configuration 2 with tilted nacelle

Simulations show skin friction  $CF_x$

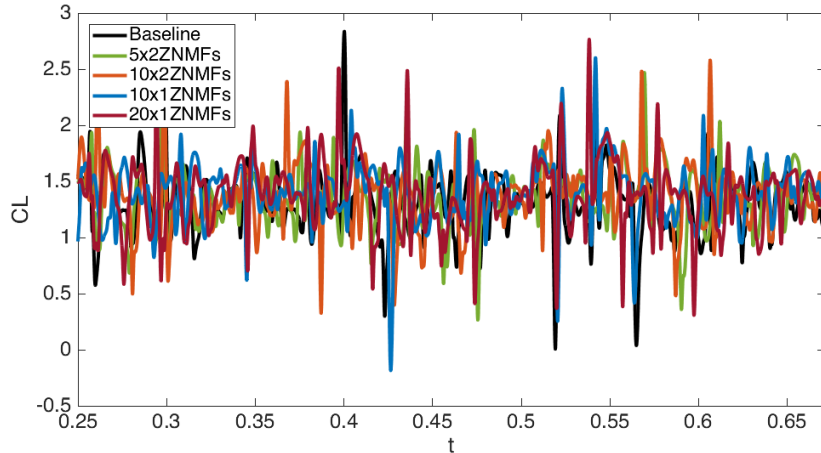
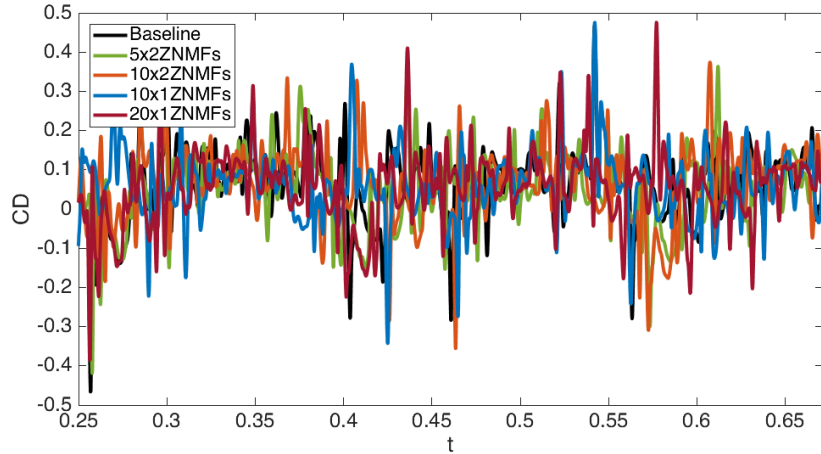


ZNMF parameters  
 $v = 300 \text{ m/s}$   
 $f = 65 \text{ Hz}$





# Configuration 2 with tilted nacelle



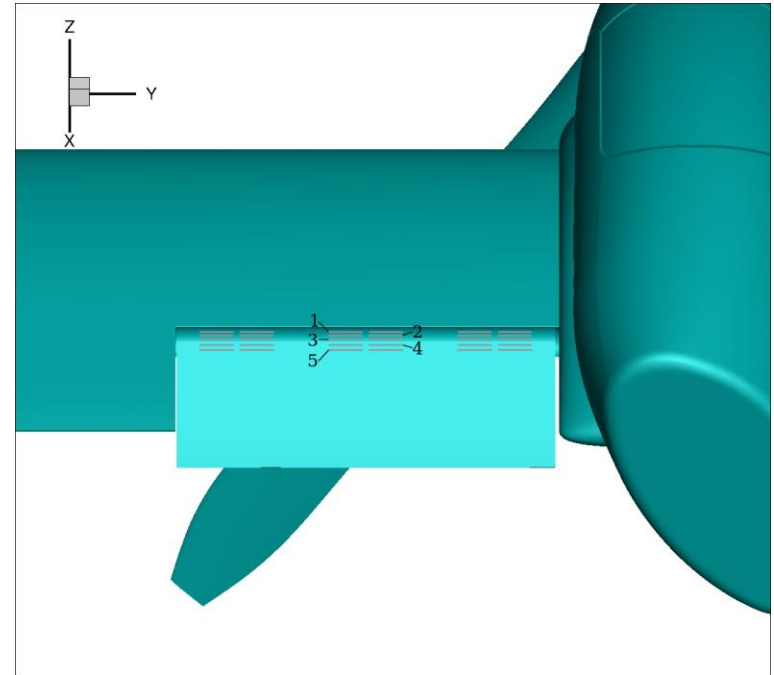
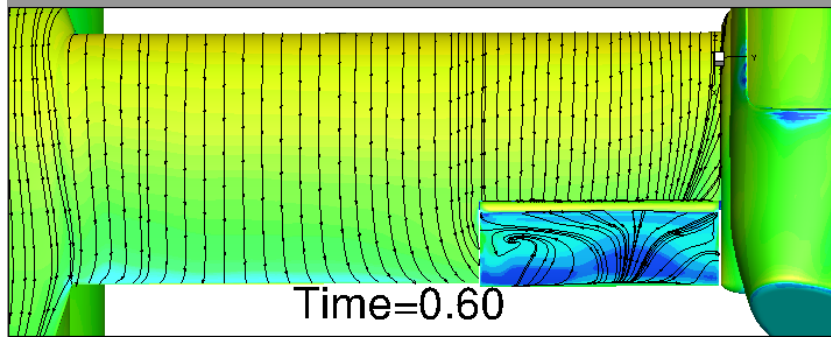
Forces integrated on the wing  
for the 4<sup>th</sup> and 5<sup>th</sup> rotations of the propeller

$$\bar{C}_L, \bar{C}_D = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \bar{C}(t) dt$$

ZNMF position	$\Delta CD$	$\Delta CL$	$\Delta CL/CD$
Baseline	0.062931	1.318551	20.95223
5x2	0.051597 -18.01%	1.360576 +3.19%	26.36939 +25.85%
10x2	0.060883 -3.26%	1.38261 +4.86%	22.70945 +8.39%
10x1	0.058348 -7.28%	1.401107 +6.26%	24.01302 +14.61%
20x1	0.053571 -14.87%	1.387395 +5.22%	25.89821 +23.61%

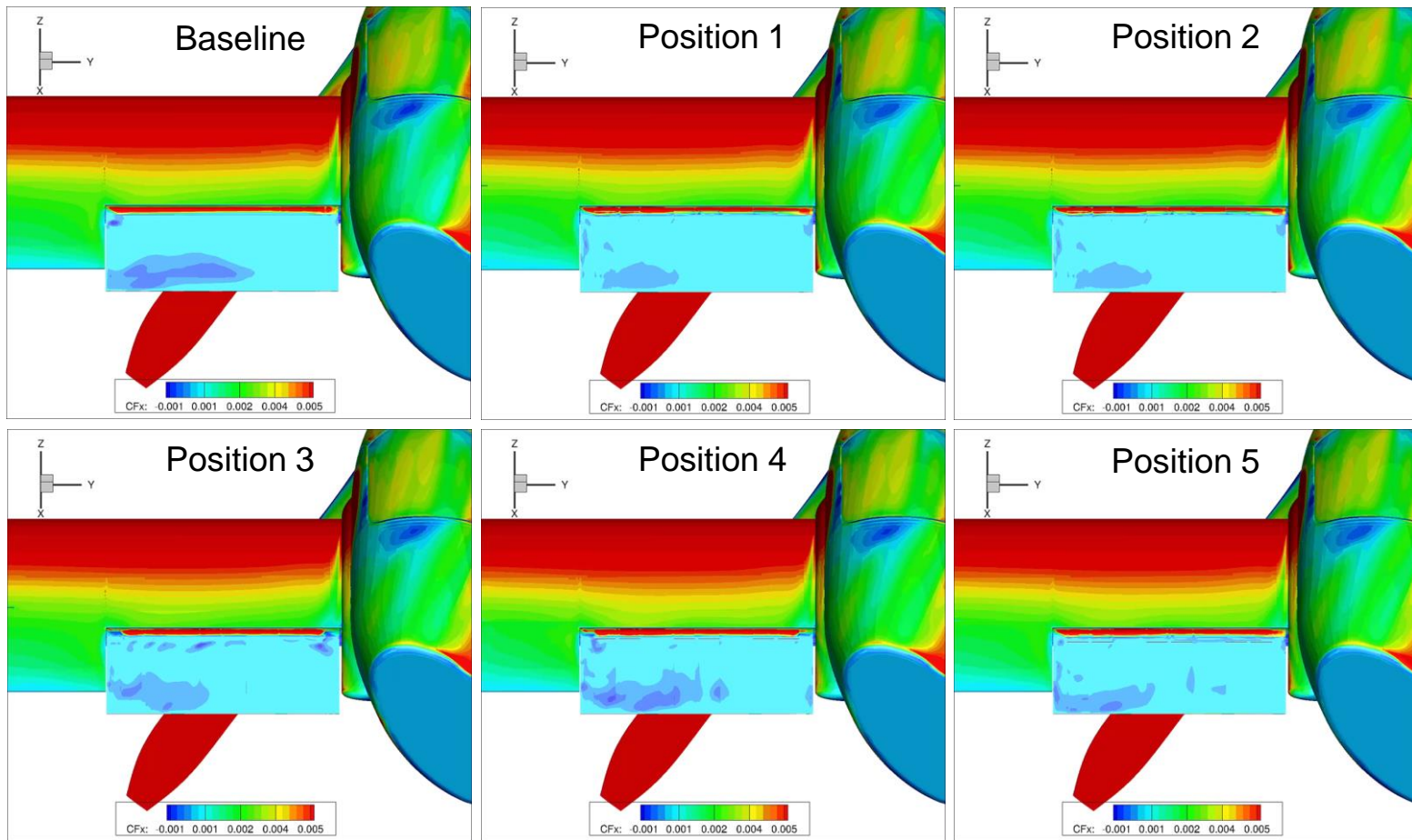
Lift enhancement accompanied with drag decrease  
=> lift-to-drag ratio increases

# Configuration 3 with deflected aileron



*6 ZNMFs are placed near the leading edge of the aileron*

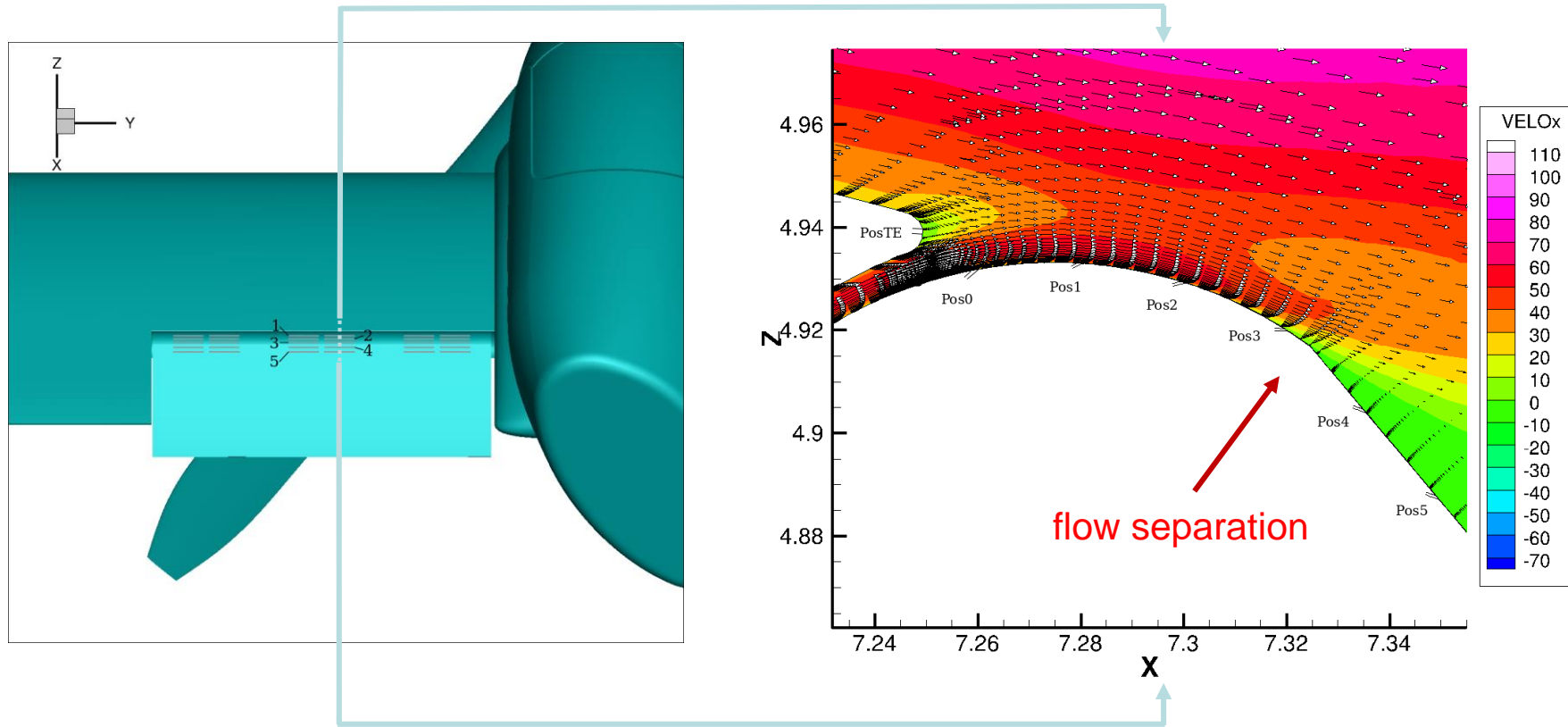
# Configuration 3 with deflected aileron



*Simulations show skin friction  $CF_x$*

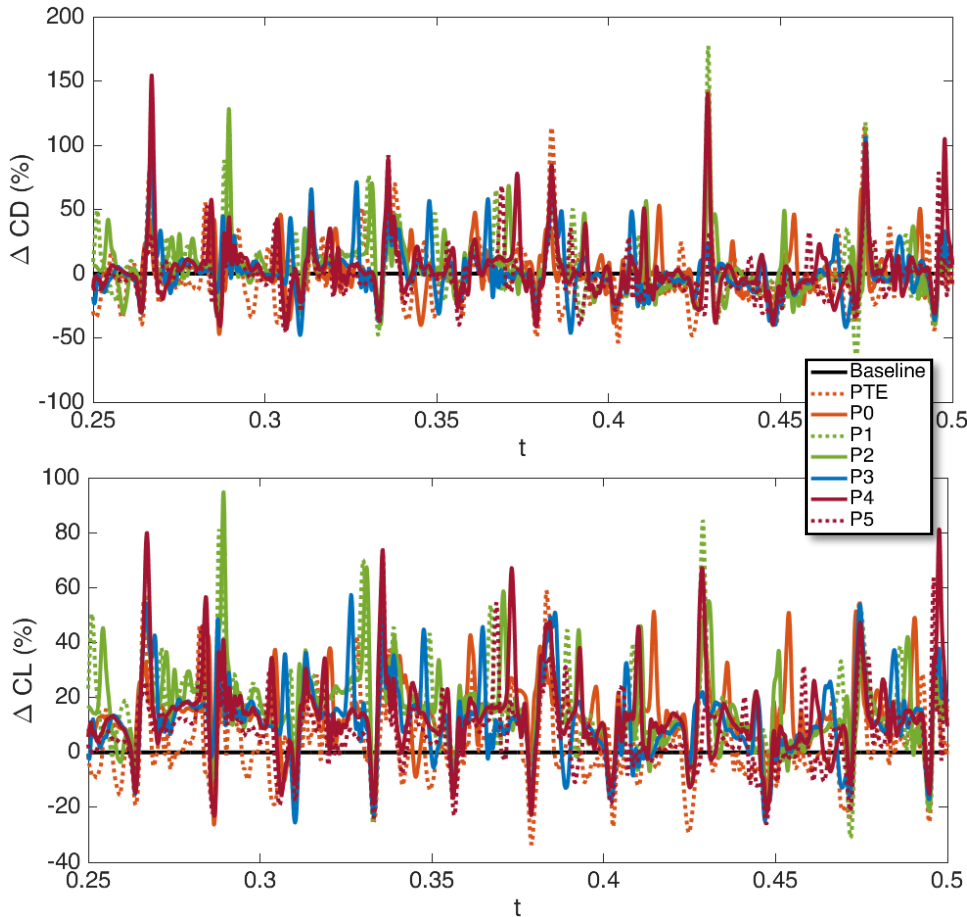
*ZNMF parameters  
 $v = 300 \text{ m/s}$   
 $f = 65 \text{ Hz}$*

# Configuration 3 with deflected aileron



*ZNMF positions on deflected aileron*

# Configuration 3 with deflected aileron



Forces integrated on the aileron  
for the 3<sup>rd</sup> and 4<sup>th</sup> rotations of the propeller

ZNMF position	$\Delta CD$	$\Delta CL$	$\Delta CL/CD$
TE	-4.27%	2.10%	6.65%
0	0.04%	13.10%	13.06%
1	1.33%	14.10%	12.60%
2	2.23%	14.52%	12.03%
3	-0.14%	10.64%	10.80%
4	1.77%	11.81%	9.86%
5	-3.36%	5.79%	9.47%

Lift enhancement while drag remaining unchanged  
=> lift-to-drag ratio is improved effectively

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- **Conclusions and Perspectives**

# Conclusions

- CFD simulations to optimise location of ZNMF for flow control of NCGTR (reference parameters of the ZNMF  $v = 300m/s$ ,  $f = 65Hz$ ,  $D/H = 1mm$ ,  $Angle = 45^\circ$ )
- ZNMF devices are able to reduce flow separations in critical flow regions, but their location needs to be selected with care
- Optimization of ZNMF position
  - Configuration 1: Insignificant gain since the flow detachment is not as strong as expected
  - Configuration 2: Improvement of lift (+14.32%) and increase of drag (12.3%) => higher lift-to-drag ratio (1.8%)
  - Configuration 3: Lift enhancement while drag remaining unchanged => L/D ratio of the aileron is improved effectively (12%)



<https://cleansky.virtualfair.be/>

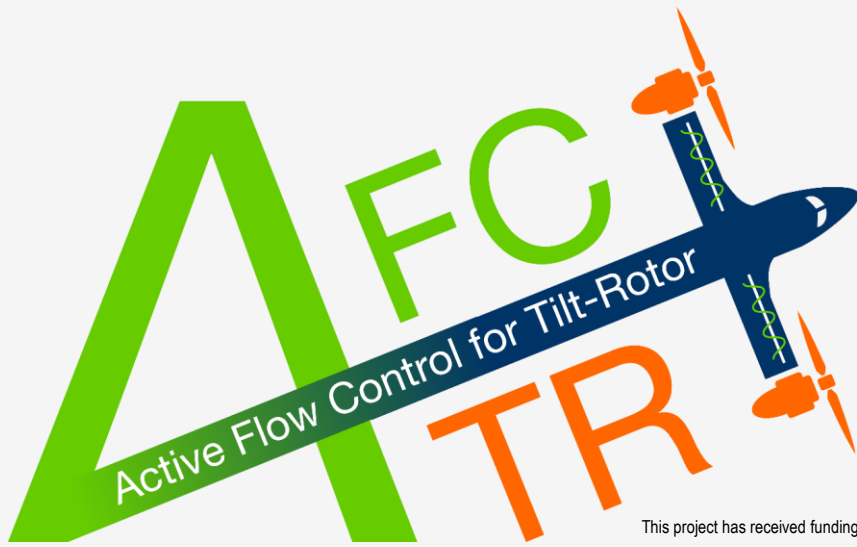


# Acknowledgement

This project has received funding from the European Union's H2020 - CleanSky2 research and innovation framework programme under grant agreement No 886718



Thank You !



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Computational Fluids & Structures Engineering



Université

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