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Unsteady CFD simulations of a synthetic jet for flow control around a high-lift wing-flap system

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56th 3AF International Conference on Applied Aerodynamics

28 – 30 March 2022, Toulouse - France



Unsteady CFD simulations for Active Flow Control

- Introduction
- Numerical methods
 - *NSMB solver, Chimera grid*
 - *Modeling of ZNMF devices*
- Results
 - *Validation*
 - *AFC with ZNMF in 2D*
 - *AFC with ZNMF in 3D*
- Conclusion and Perspectives

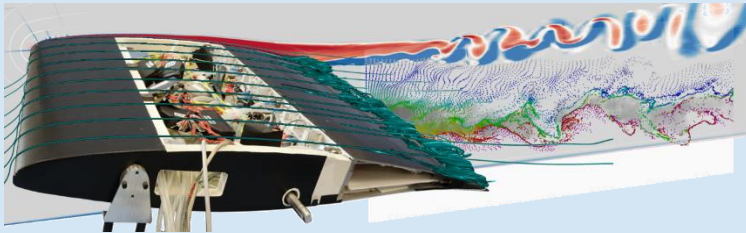
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Smart Morphing & Sensing

for aeronautical configurations



Active Flow Control 4

TiltRotor aircraft

CFS Engineering



Computational Fluids & Structures Engineering



Leonardo Helicopters



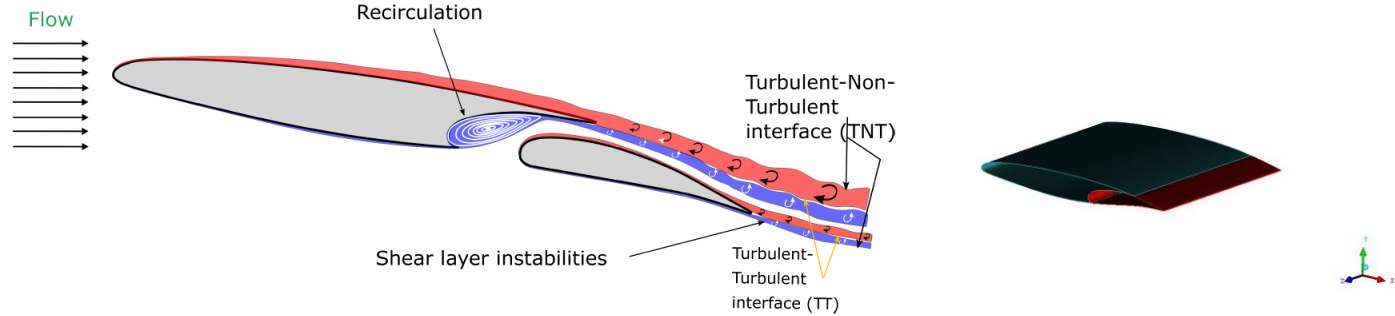
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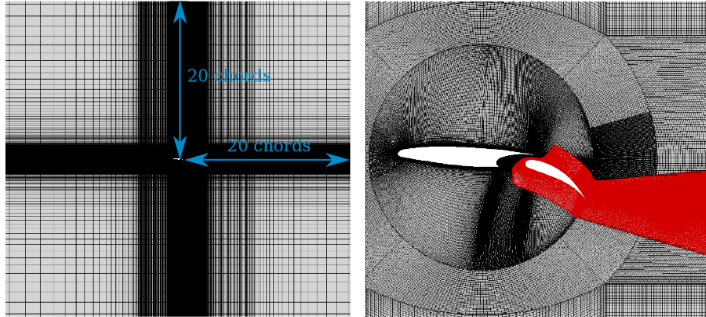
Numerical methods

➤ *NSMB solver: Navier Stokes Multi-Block code [Hoarau et al. 2016]*

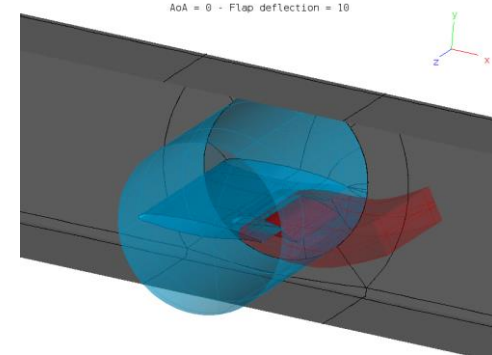
U_∞	68 m/s
Ma	0.2
α	$0^\circ - 8^\circ$
δ	$10^\circ - 40^\circ$



2D computational domain



3D computational domain



➤ *Turbulence models: URANS (SA) and DDES-SA*

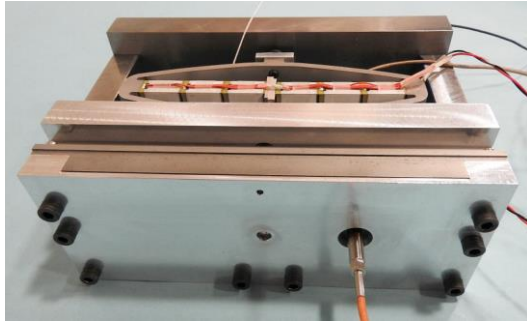
Numerical methods

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

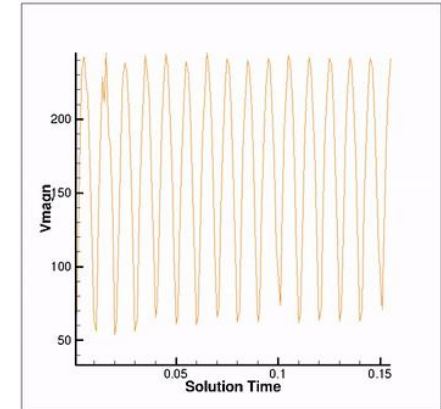
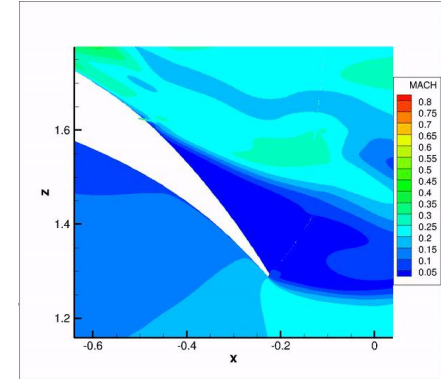
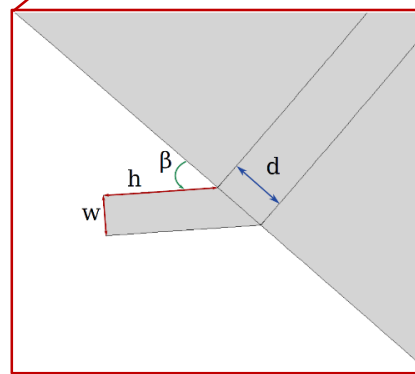
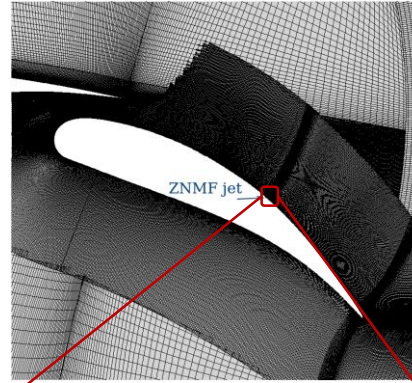
ASPIC synthetic jet actuator

ONERA

THE FRENCH AEROSPACE LAB



modelling
➔



Slot dimensions: $1 \times 150 \text{ mm}^2$

Peak exit velocity during suction: 135 m.s^{-1}

Peak exit velocity during blowing: 150 m.s^{-1}

Optimal actuation frequency bandwidth:
between 200 and 300Hz

Actuator volume: $164 \times 94 \times 57 \text{ mm}^3$

Numerical methods

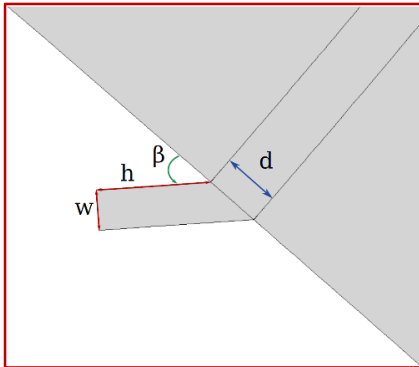
➤ Modelling of ZNMF devices

ASPIC mass flux

$$q_0^{ref} = V_0 \times d = 150 \times 10^{-3} = 0.15 \text{ m}^2/\text{s}$$

ZNMF devices' mass flux

$$q = V_0 \times w = V_0 \times d \times \sin \beta$$



Configuration	Diameter (mm)	Height (mm)	Inclined angle (degree)	Dimensionless velocity V_{jet}/U_∞	Mass flow ($\text{m}^2 \text{s}^{-1}$)	Dimensionless frequency F^+
1	1	2	15	8.363	0.150	7.844
2	1	2	30	4.326		
3	1	2	45	3.057		
4	3	6	15	2.768		
5	3	6	30	1.442		
6	3	6	45	1.024		
7	5	10	15	1.658		
8	5	10	30	0.865		
9	5	10	45	0.606		

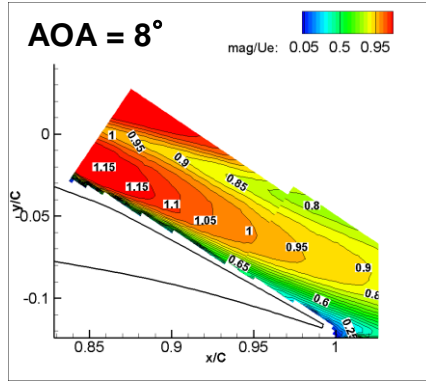
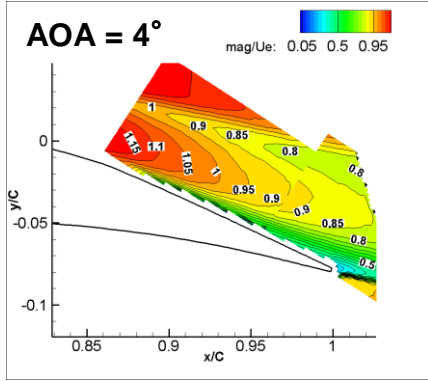
Velocity is adjusted to get the same mass flux for all cases

Unsteady CFD simulations for Active Flow Control

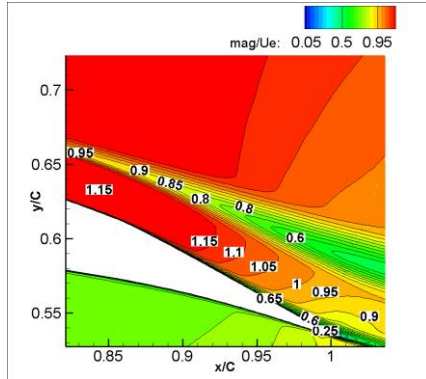
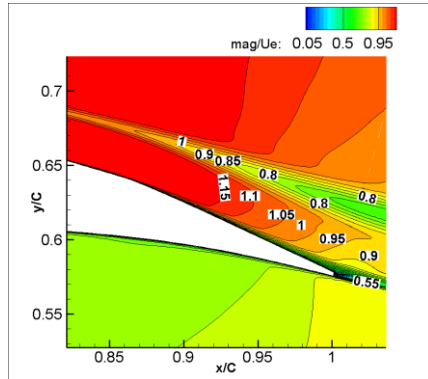
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Validation with experimental data

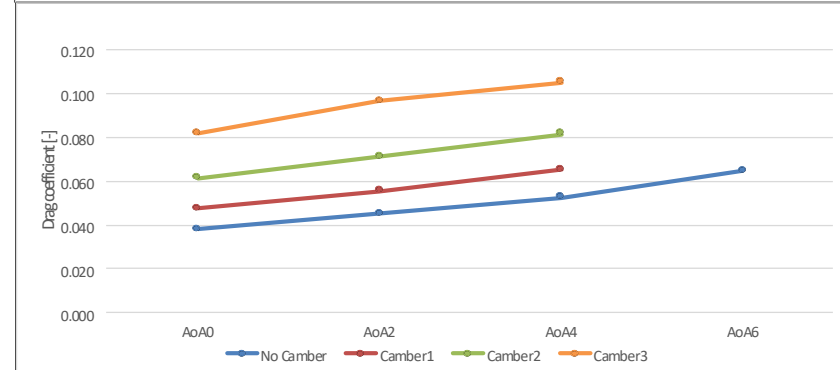
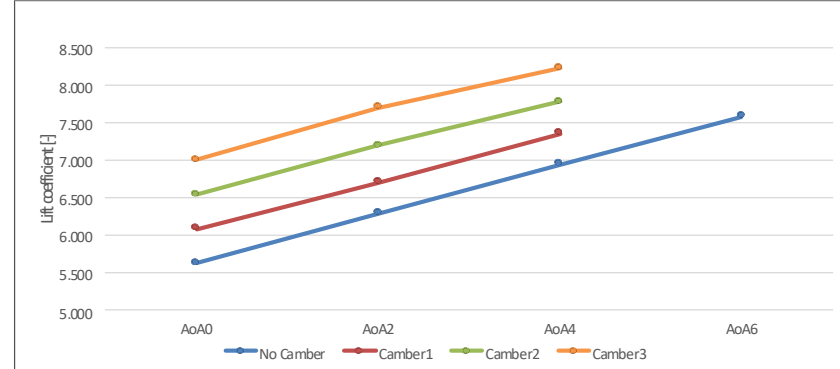
Experimental PIV



Numerical simulation

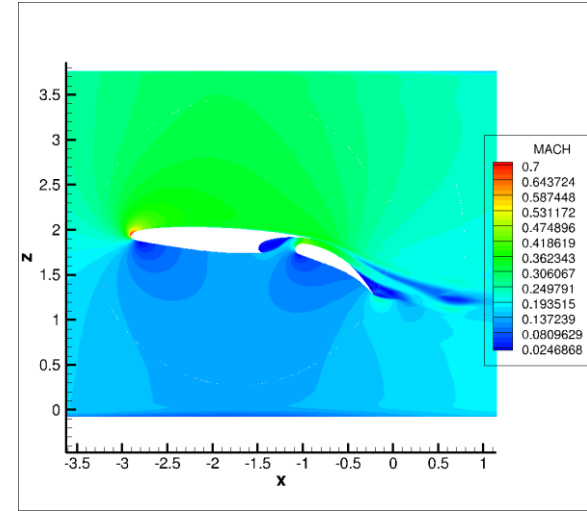
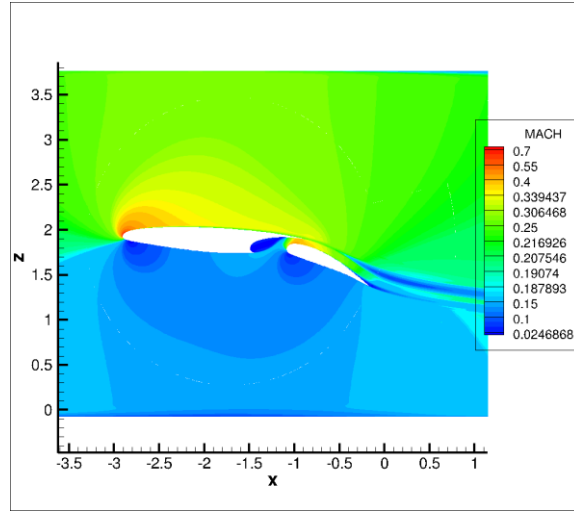
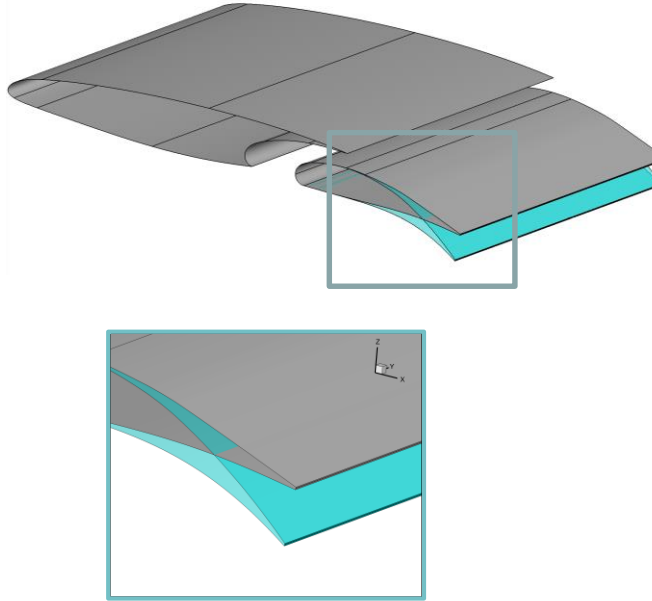


Mach=0,15 ($U_\infty = 51,5$ m/s)



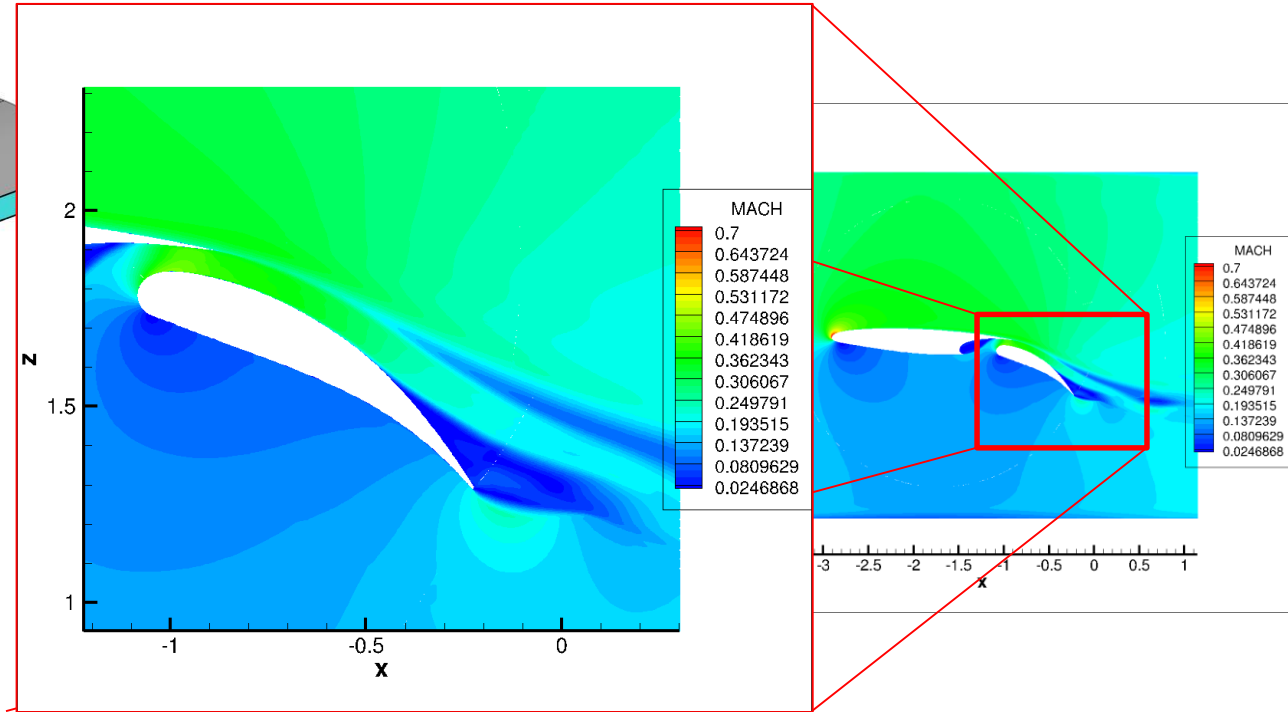
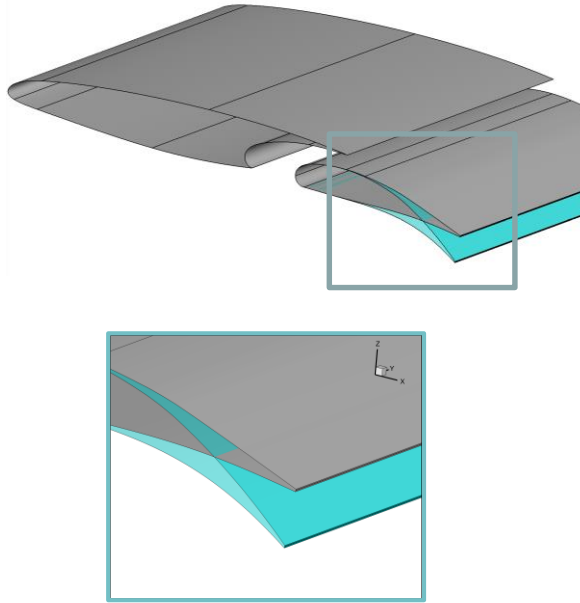
Active Flow Control with ZNMF in 2D

➤ Baseline and morphing with cambering (10cm)

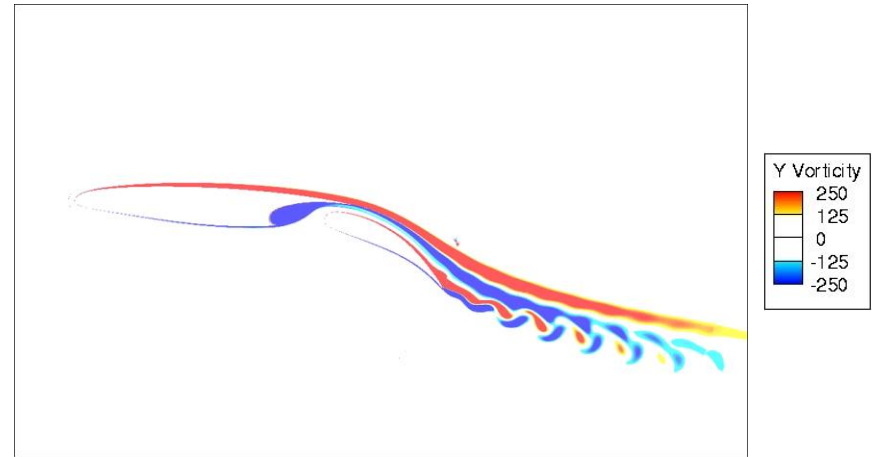
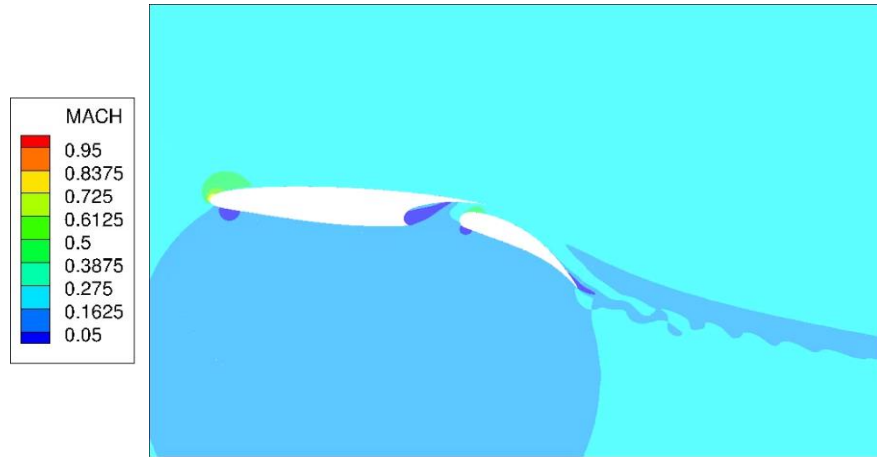


Active Flow Control with ZNMF in 2D

➤ Baseline and morphing with cambering (10cm)



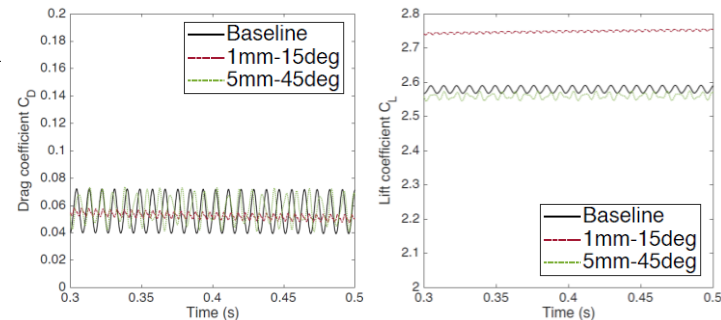
Active Flow Control with ZNMF in 2D



Active Flow Control by ZNMF in 2D

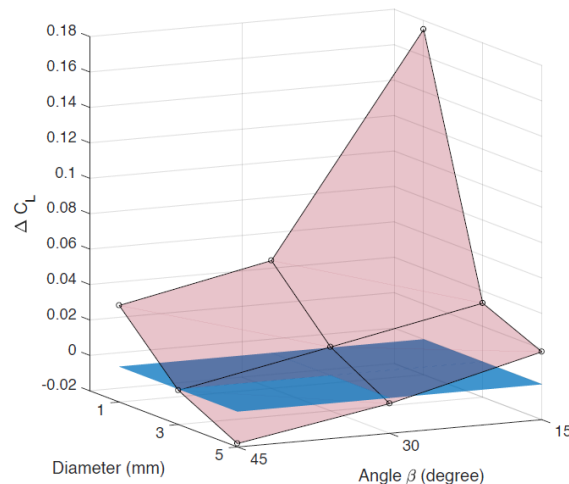
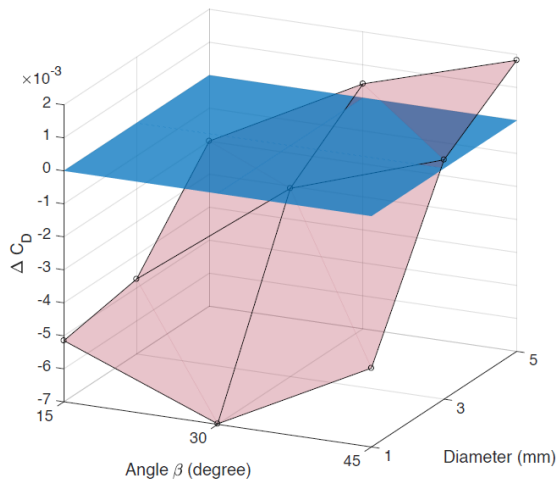
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9	5	10	45	0.606		

Time history of forces in the baseline, the best case and the worst case



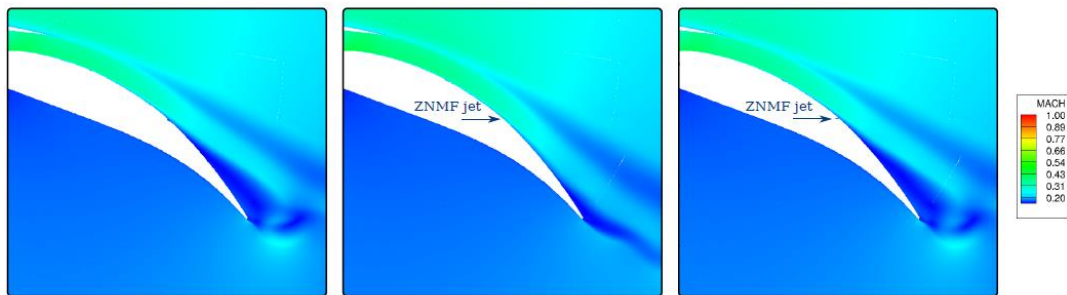
1mm-15deg \Rightarrow 6.78% increase in lift

5mm-45deg \Rightarrow 0.7% decrease in lift



The effect of the ZNMF characterized by the variation of the drag (left) and the lift (right)

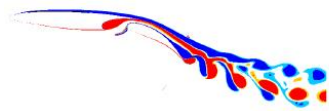
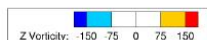
Active Flow Control by ZNMF in 2D



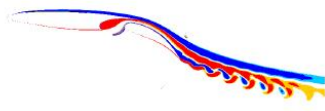
Base line

ZNMF (1mm, 15°)

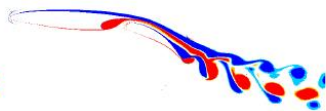
ZNMF (5mm, 45°)



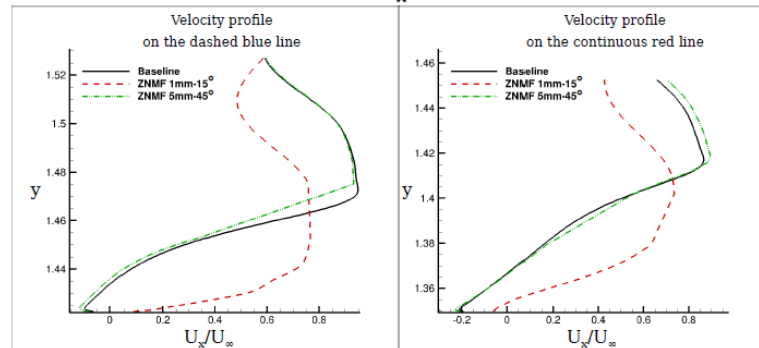
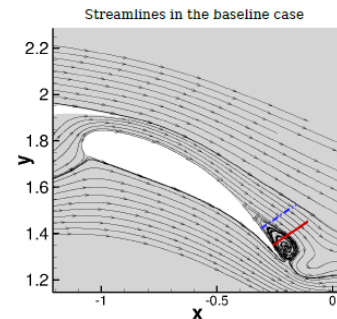
Base line



ZNMF (1mm, 15°)



ZNMF (5mm, 45°)

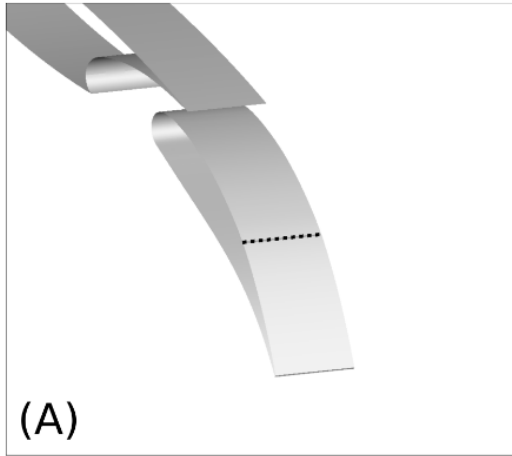


Control strategy for using ZNM:

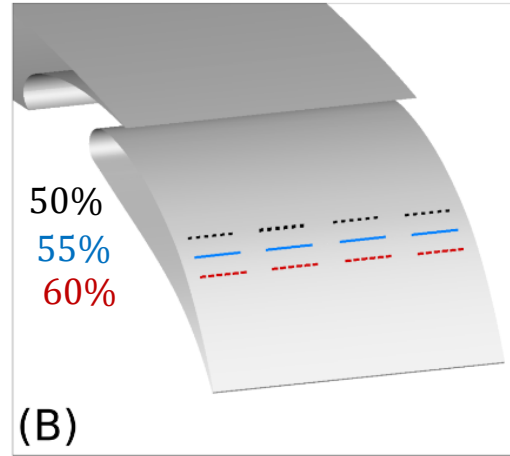
- small size with high velocity is better than large size with small velocity
- the orientation should be tangential to the wing surface

Active Flow Control by ZNMF in 3D

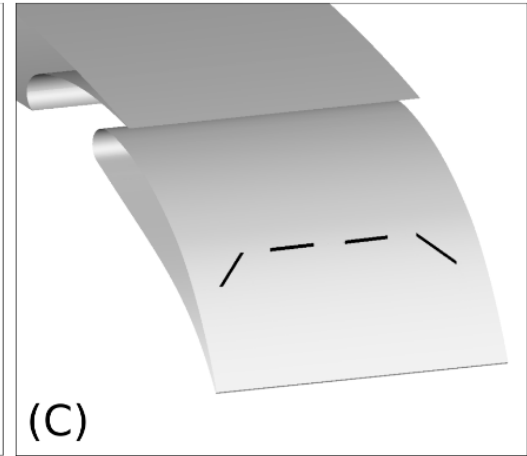
➤ Studied configuration



Small span



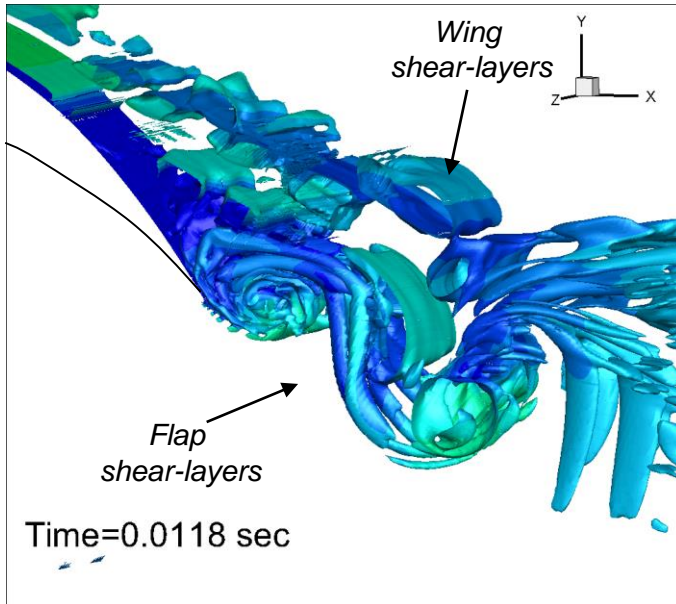
ZNMF location



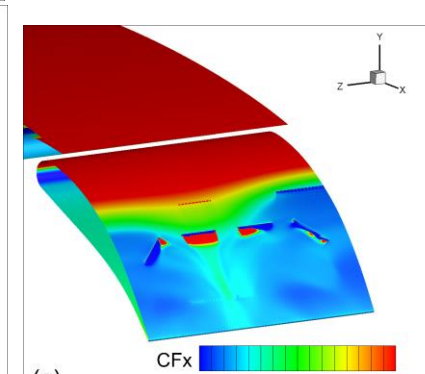
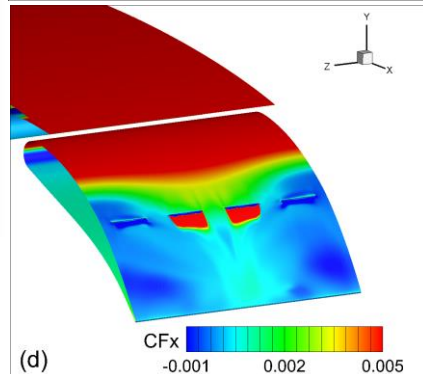
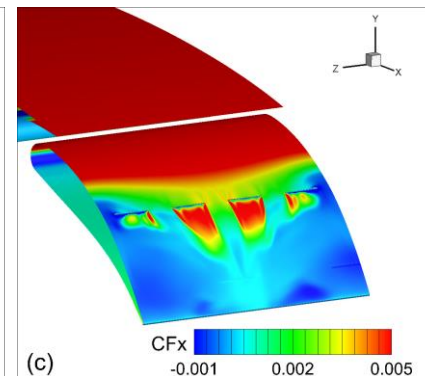
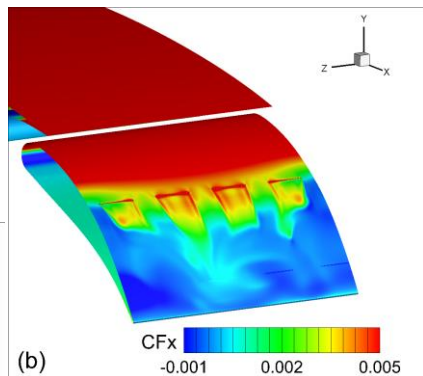
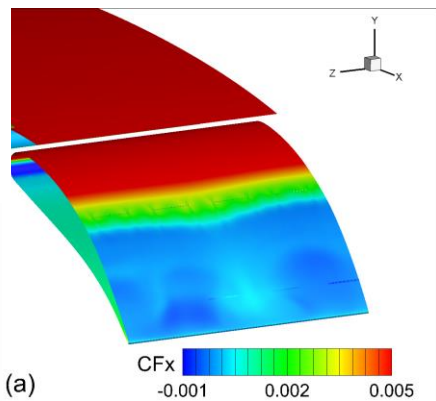
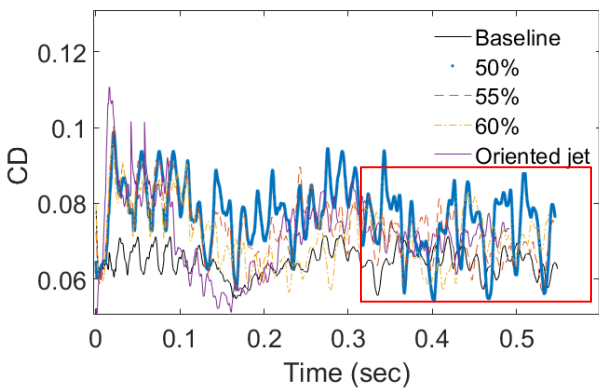
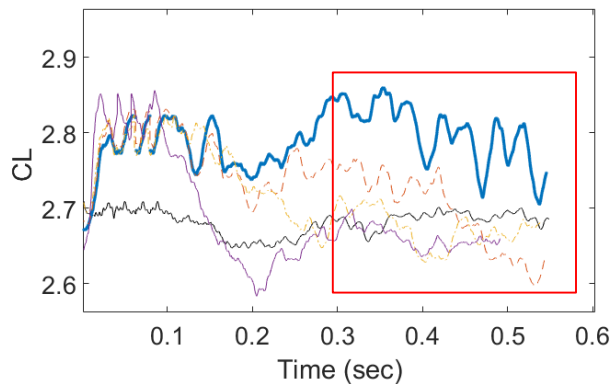
ZNMF orientation

Active Flow Control by ZNMF in 3D

- *Hybrid turbulence modelling DDES-SA with ZNMF*



Active Flow Control by ZNMF in 3D



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Conclusion

- The Active Flow Control using ZNMF with blowing-suction and morphing with a cambering flap: a lift increase with a refrain of the drag increase are achieved;
- Strategy for using ZNMF: small size with high velocity is better than large size with small velocity;
- The orientation of ZNMF devices should be tangential to the wing surface;
- 3D hybrid modeling was performed: interaction of shear-layers, reattachment of the BL, wake thinning;
- The position of the jet is an essential factor;

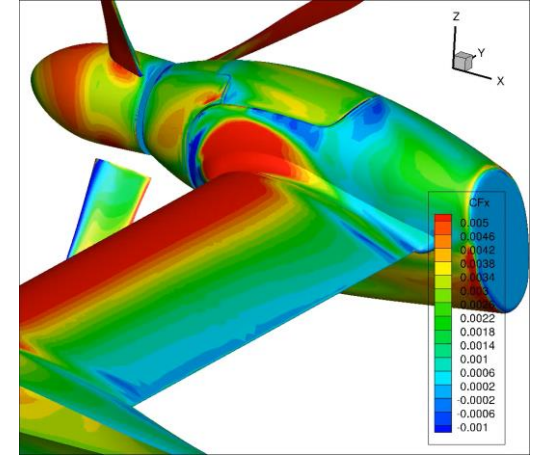
Perspectives

- Examine the flow control around a Tilt-Rotor Aircraft using ZNMF

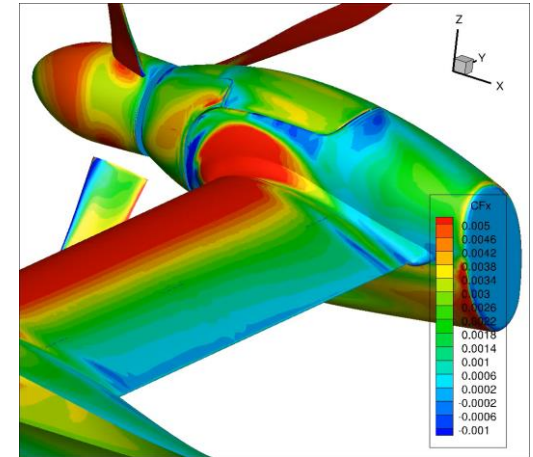


<https://cleansky.virtualfair.be/>

No AFC



ZNMF





Thank You !

