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

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

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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

# Unsteady CFD simulations for Active Flow Control

## ➤ Introduction

## ➤ Numerical methods

- *NSMB solver, Chimera grid*
- *Modeling of ZNMF devices*

## ➤ Results

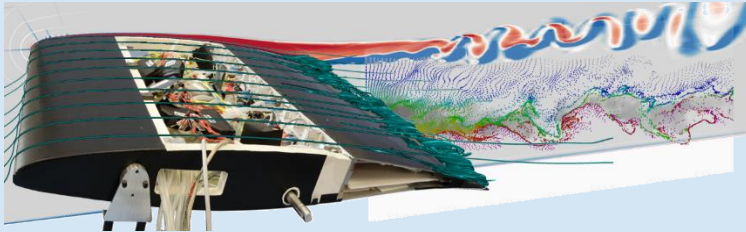
- *Validation*
- *AFC with ZNMF in 2D*
- *AFC with ZNMF in 3D*

## ➤ Conclusion and Perspectives



# Smart Morphing & Sensing

for aeronautical configurations



# Active Flow Control 4

## TiltRotor aircraft

CFS Engineering



Computational Fluids & Structures Engineering



Leonardo Helicopters



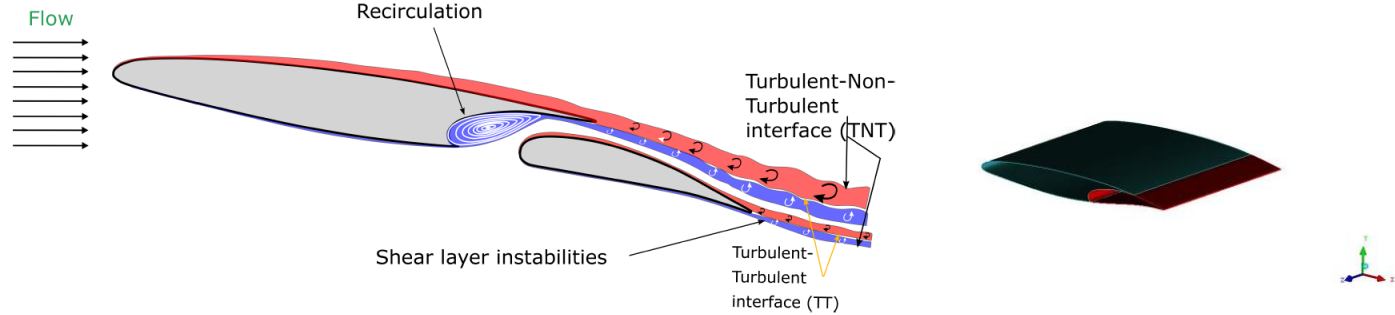
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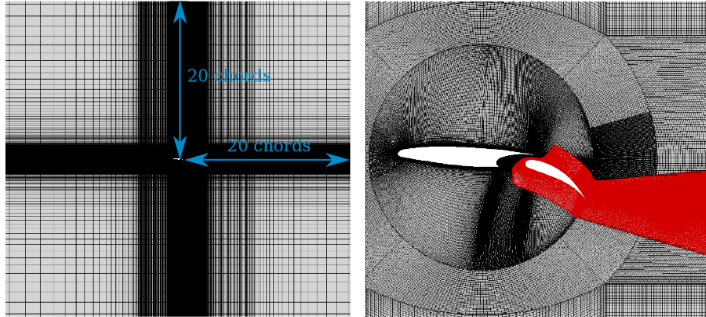
# Numerical methods

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

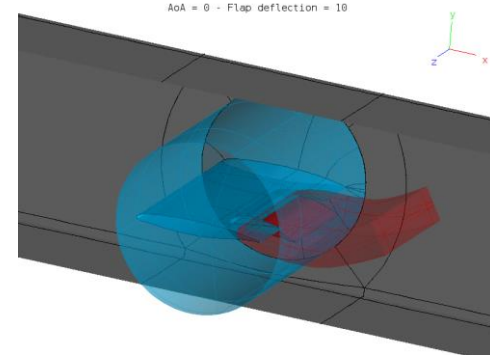
$U_\infty$	68 m/s
$Ma$	0.2
$\alpha$	$0^\circ - 8^\circ$
$\delta$	$10^\circ - 40^\circ$



2D computational domain



3D computational domain



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

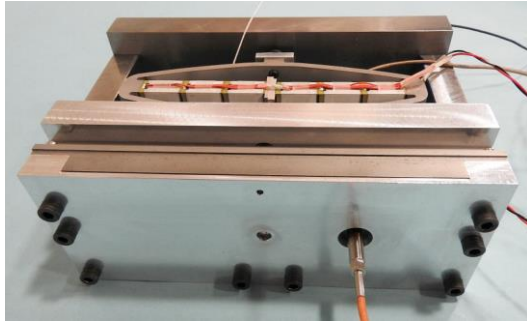
# Numerical methods

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

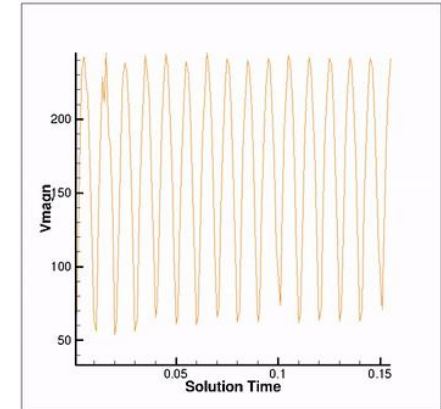
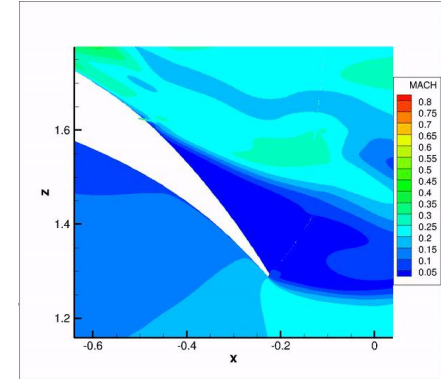
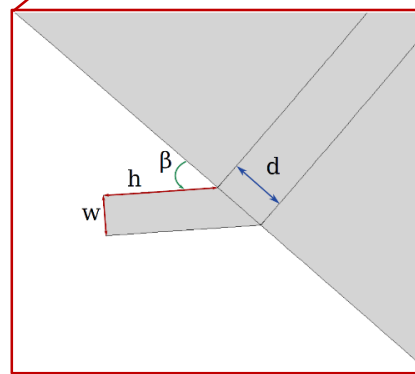
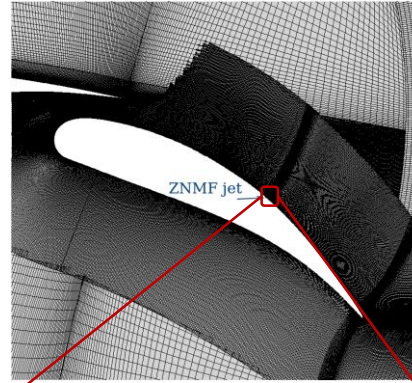
ASPIC synthetic jet actuator

ONERA

THE FRENCH AEROSPACE LAB



modelling  
➔



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

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

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

Optimal actuation frequency bandwidth:  
between 200 and 300Hz

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



# Numerical methods

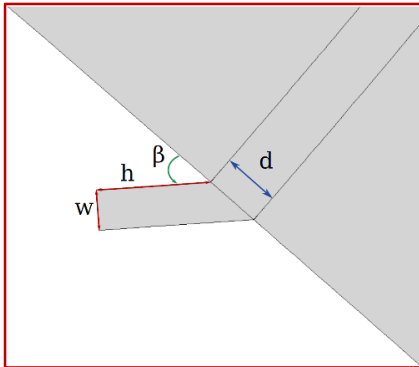
## ➤ Modelling of ZNMF devices

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 $V_{jet}/U_\infty$	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		

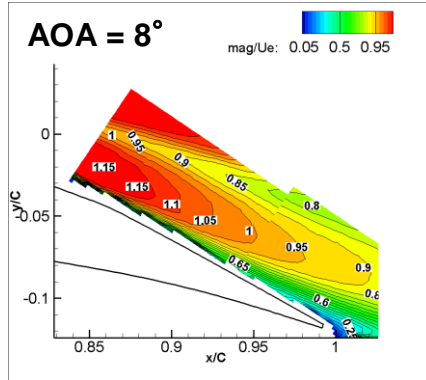
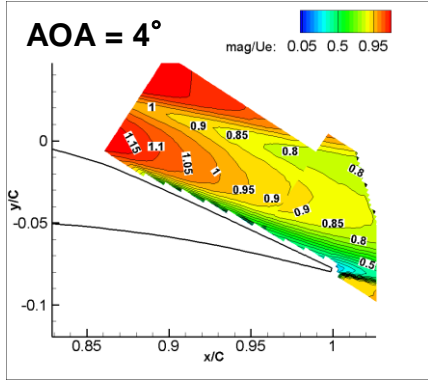
Velocity is adjusted to get the same mass flux for all cases

# Unsteady CFD simulations for Active Flow Control

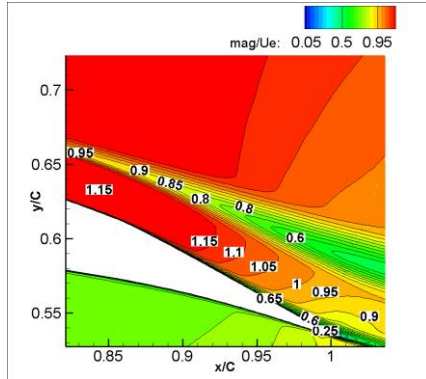
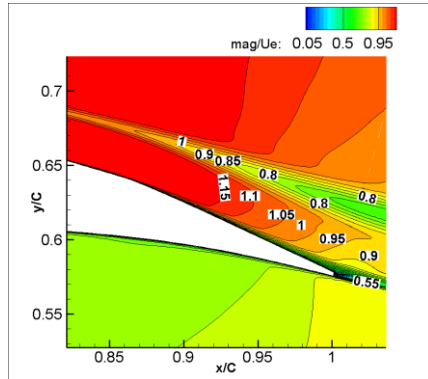
- Introduction
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# Validation with experimental data

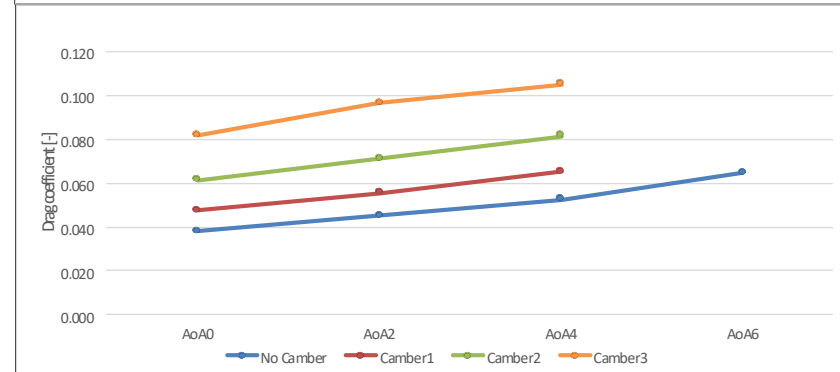
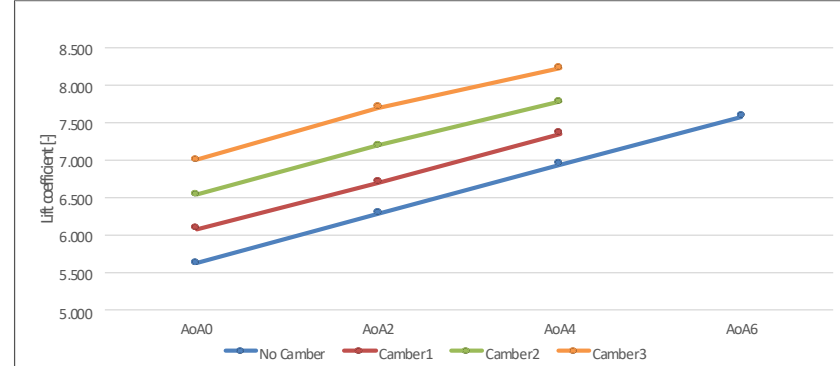
## Experimental PIV



## Numerical simulation

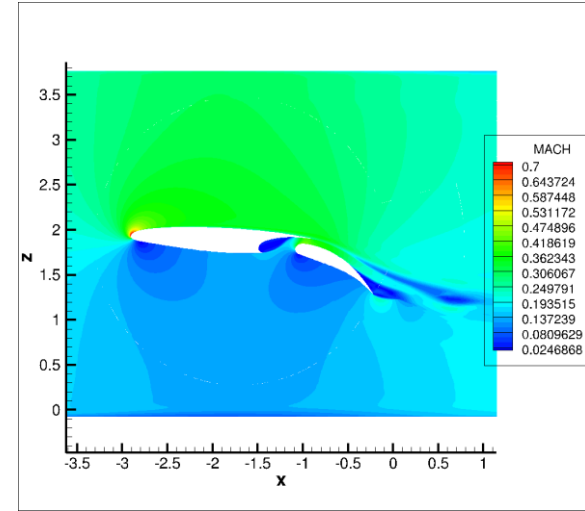
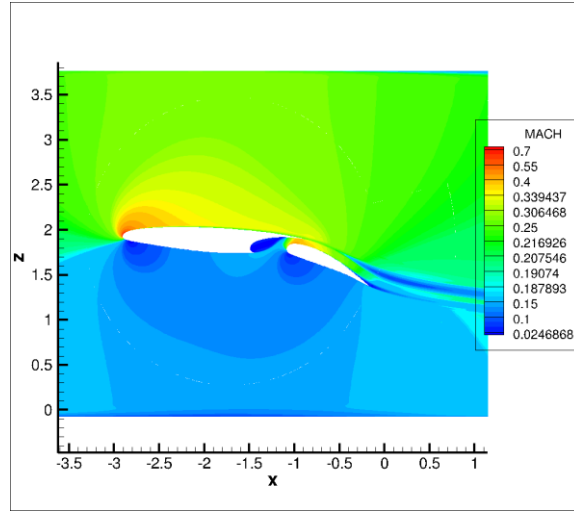
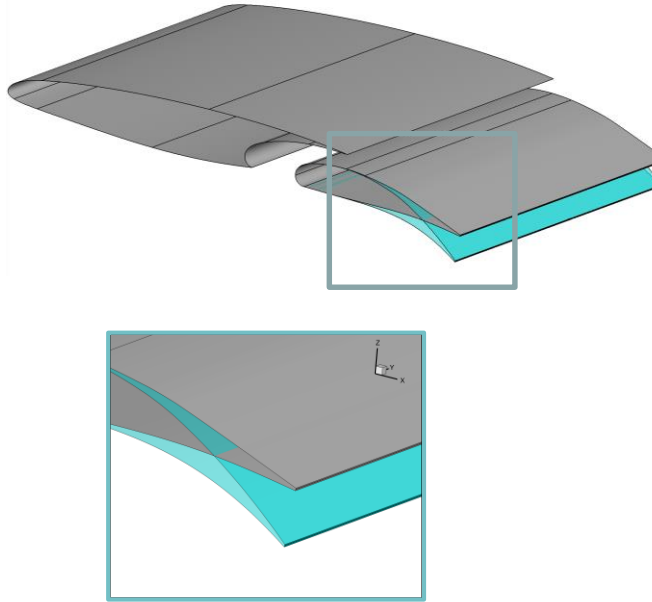


Mach=0,15 (  $U_\infty = 51,5$  m/s)



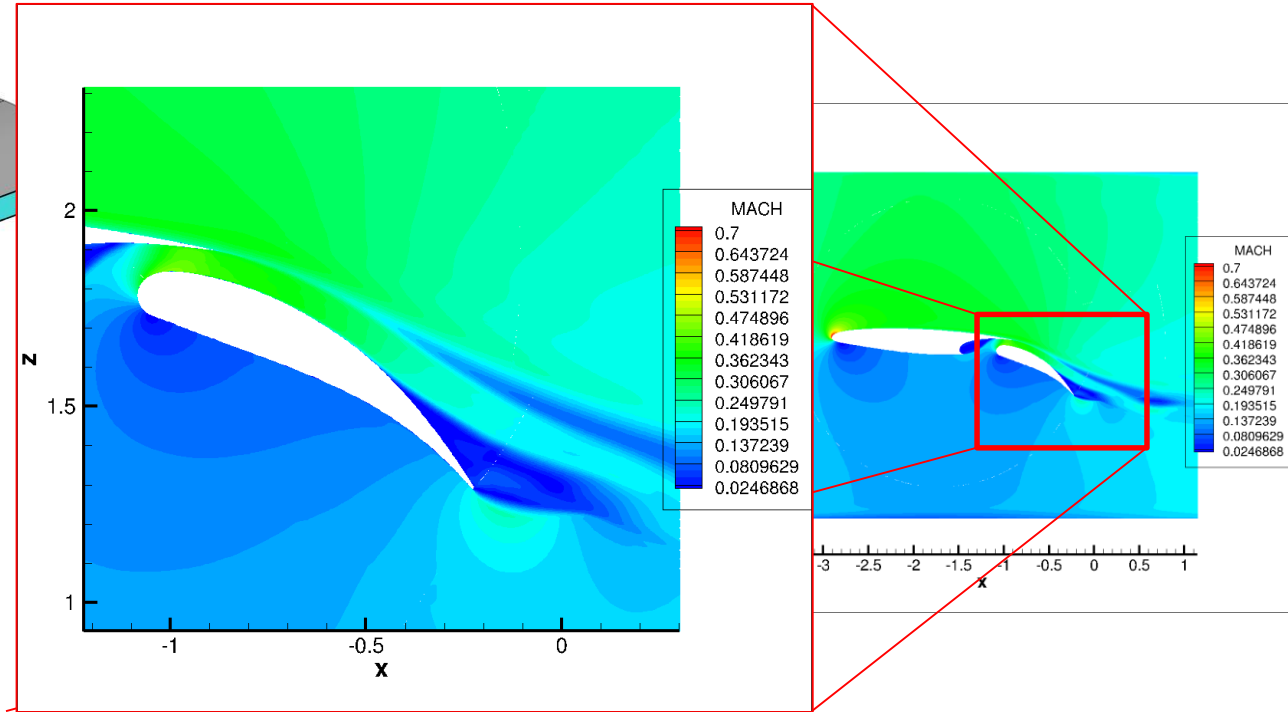
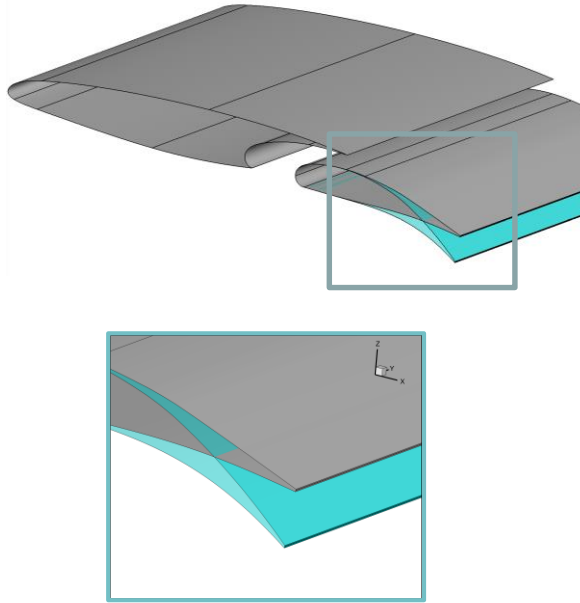
# Active Flow Control with ZNMF in 2D

## ➤ Baseline and morphing with cambering (10cm)

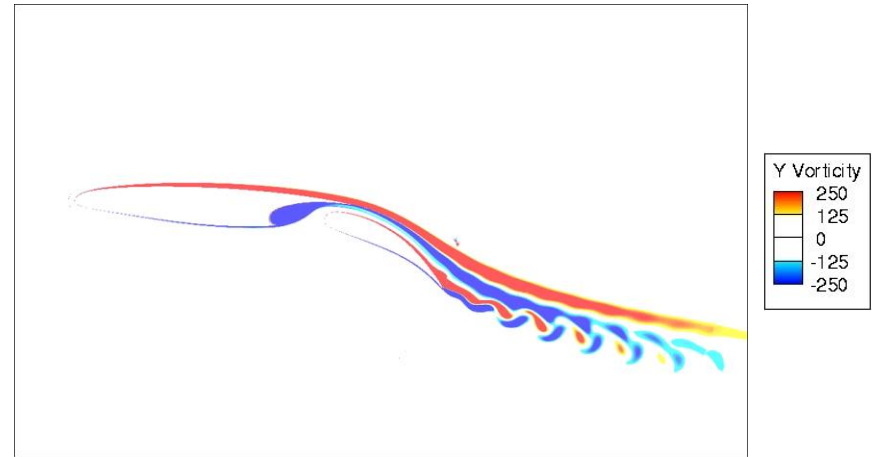
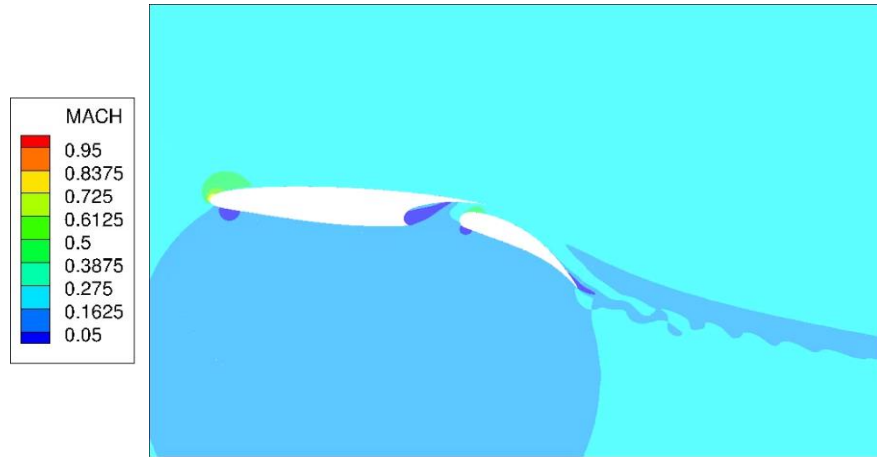


# Active Flow Control with ZNMF in 2D

## ➤ Baseline and morphing with cambering (10cm)



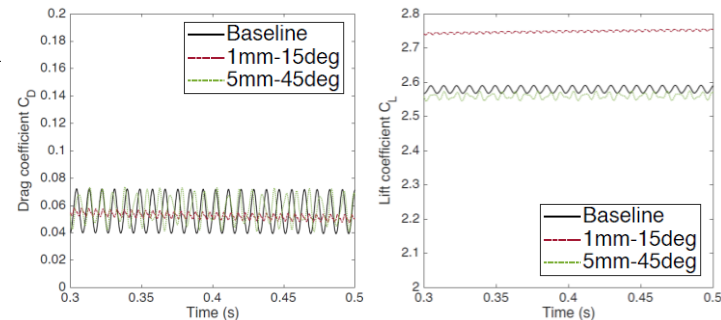
# Active Flow Control with ZNMF in 2D



# Active Flow Control by ZNMF in 2D

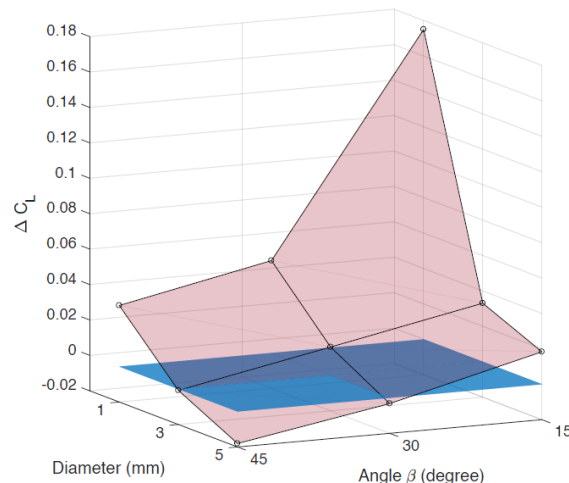
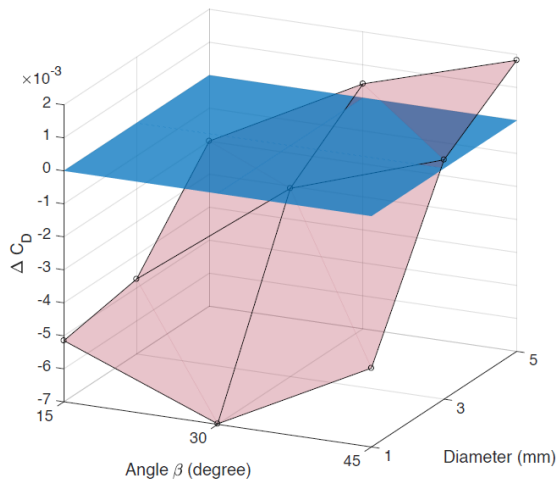
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8	5	10	30	0.865		
9	5	10	45	0.606		

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



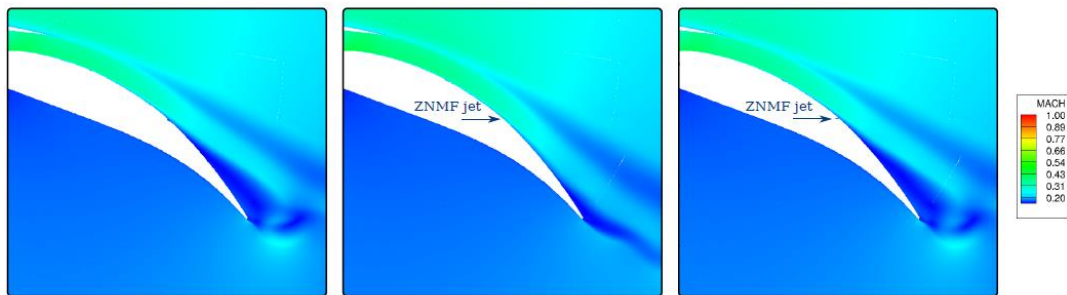
**1mm-15deg  $\Rightarrow$  6.78% increase in lift**

**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)

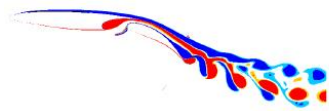
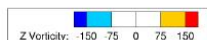
# Active Flow Control by ZNMF in 2D



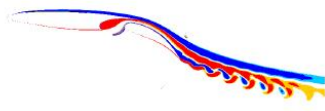
Base line

ZNMF (1mm, 15°)

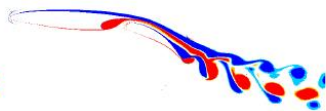
ZNMF (5mm, 45°)



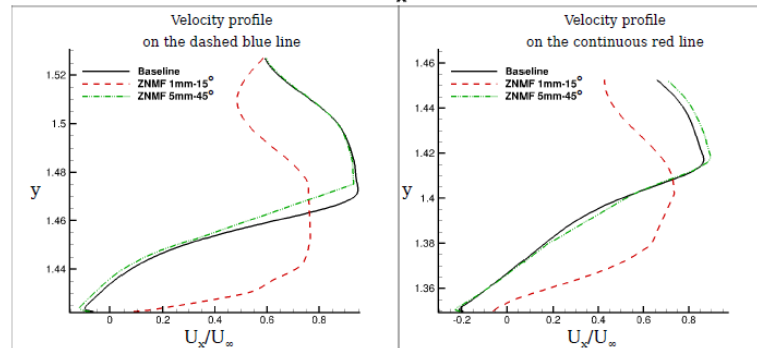
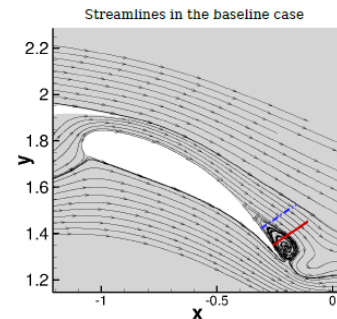
Base line



ZNMF (1mm, 15°)



ZNMF (5mm, 45°)



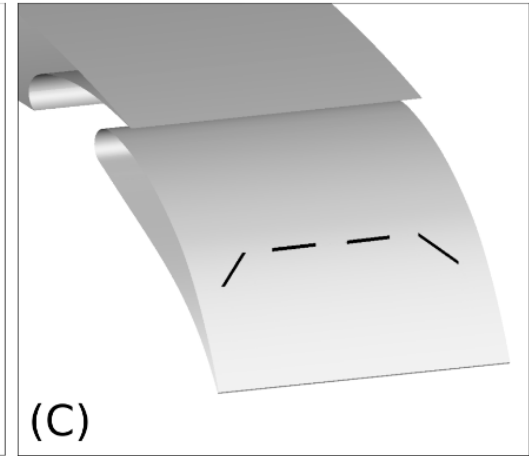
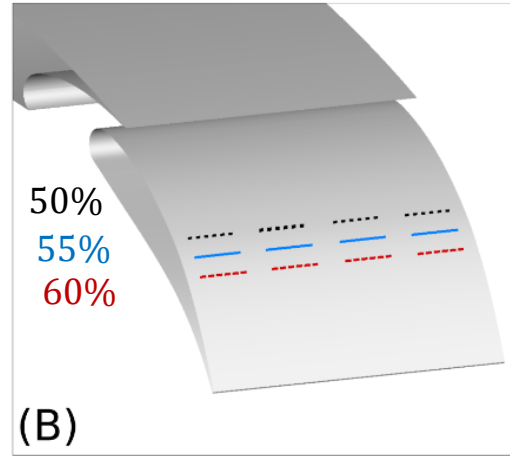
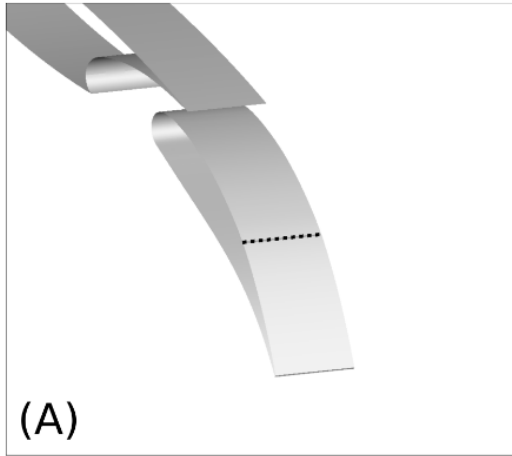
Control strategy for using ZNM:

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



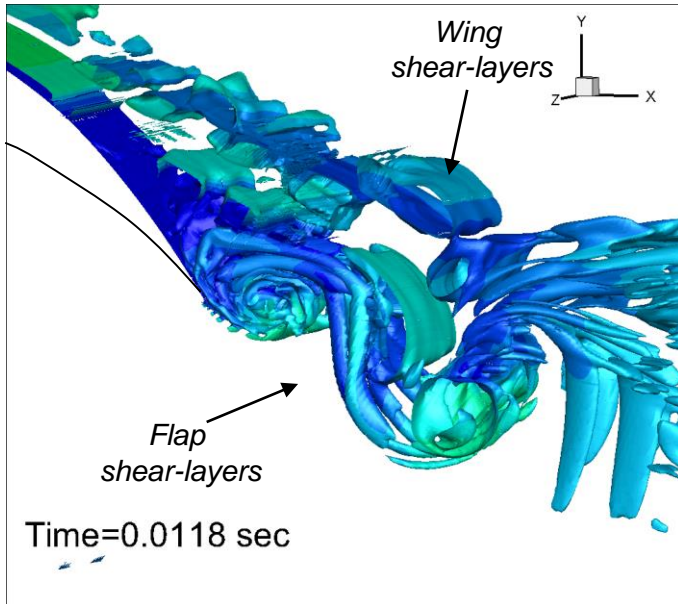
# Active Flow Control by ZNMF in 3D

## ➤ Studied configuration

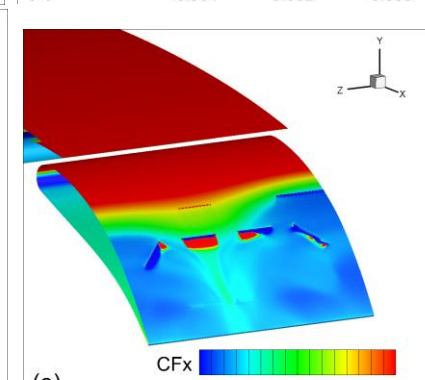
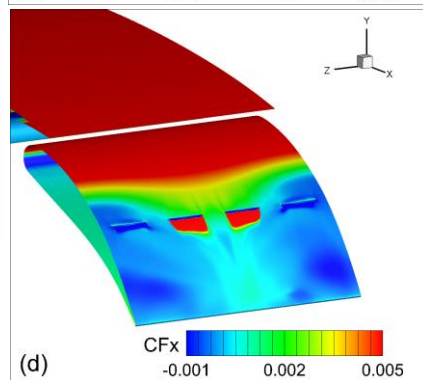
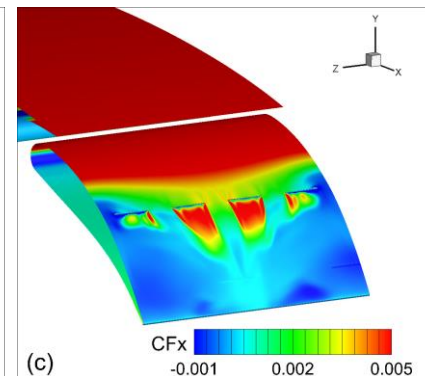
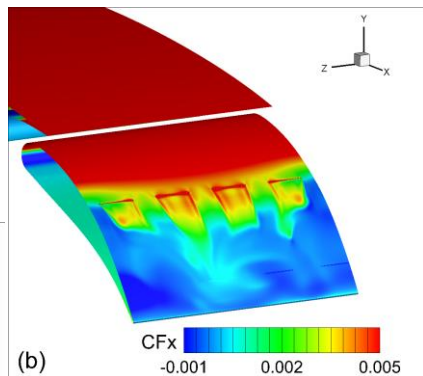
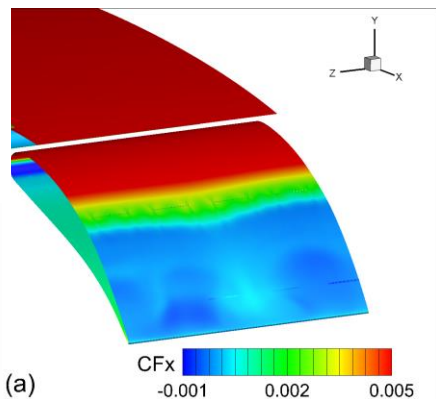
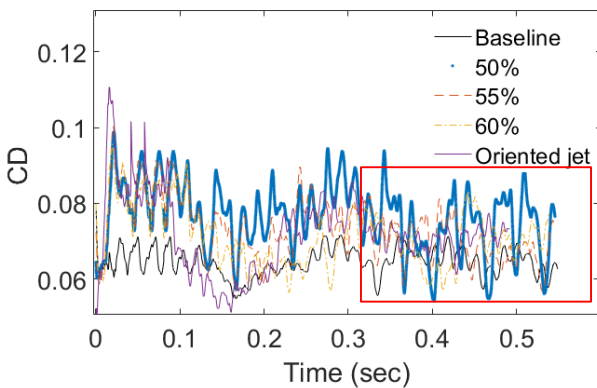
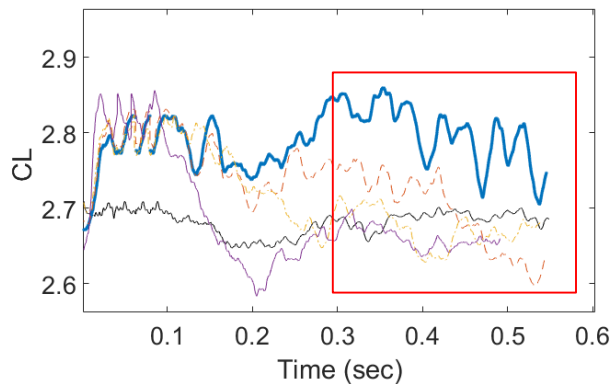


# Active Flow Control by ZNMF in 3D

- *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;

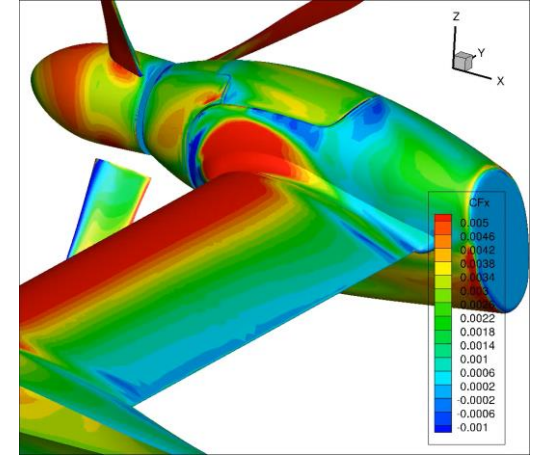
# Perspectives

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

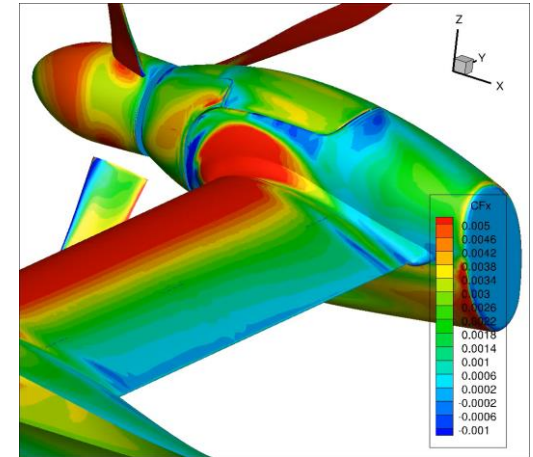


<https://cleansky.virtualfair.be/>

No AFC



ZNMF





Thank You !

