



Towards **E**ffective Flow Control
and **M**itigation of Shock Effects
In **A**eronautical Applications



**Workshops/Training schools: Turbulence Modelling for Unsteady Aerodynamic Flows
with SBLI (SC4)**

Unsteady CFD simulations for Active Flow Control

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➤ Introduction

➤ Numerical methods

- *NSMB solver, Chimera grid*

➤ Results

- *Steady blowing*
- *Pulsed blowing*
- *2D/3D Blowing-suction (ZNMF)*
- *Next Civil Generation Tilt-Rotor aircraft*

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Introduction



- Experimental research of the synthetic jet generator designs based on actuation of diaphragm with piezoelectric actuator

R. Rimasauskiene et al. 2014

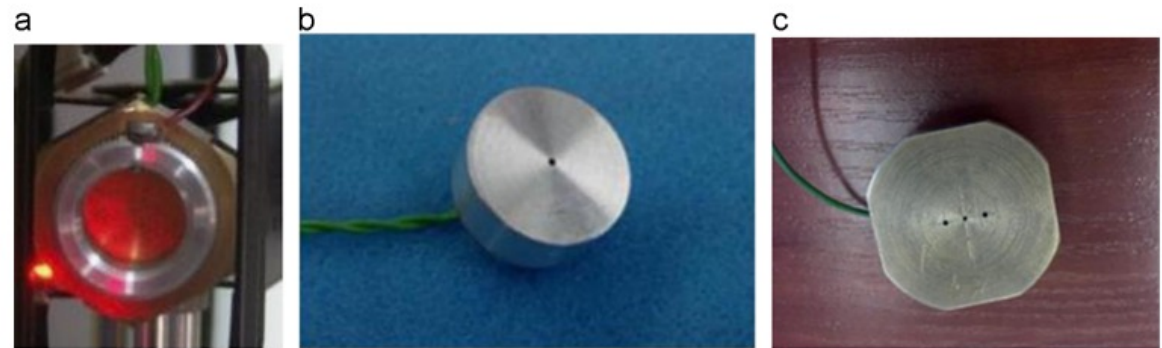
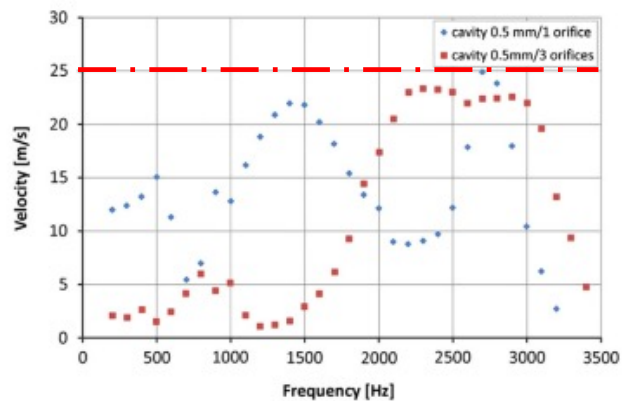


Fig. 5. Experimental equipment: (a) piezoelectric diaphragm fixed in the chamber of the synthetic jet generator; (b) synthetic jet generator with 1 orifice; (c) synthetic jet generator with 3 orifices.



Introduction



Design and Optimization of Piezoceramic Zero-Net Mass-Flux Actuators Matias A. Oyarzun¹ and Louis Cattafesta²

Lumped element modeling

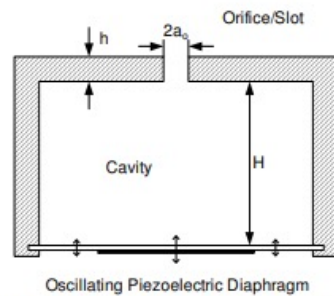
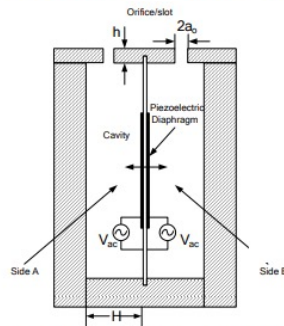


Figure 1: Schematic and equivalent circuit representation of typical ZNMF actuator.¹¹



5
Figure 3: Schematic of dual-cavity actuator and equivalent circuit representation.

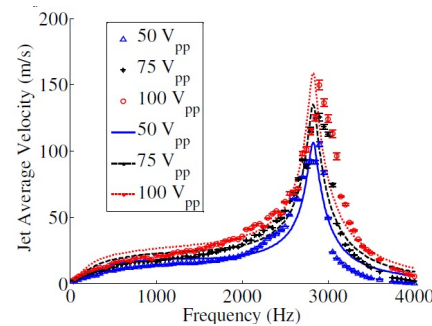


Figure 22: Exploded view of dual-cavity actuator

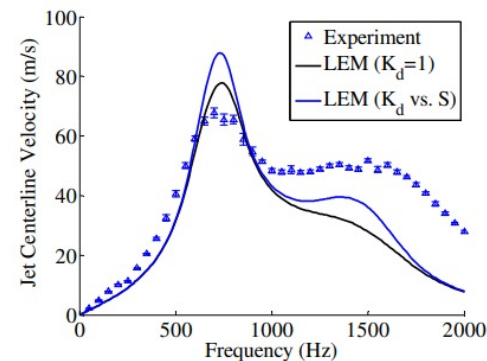


Figure 23: Dual mounted actuator characterization comparison ($100 V_{pp}$).



Introduction



■ Piezo actuators used in Active Flow Control

Synthetic jets by piezoelectric actuators

- orifice shape: slots with dimensions **0.67mm*30mm**;
- blowing angle: **45°** with respect to local wall tangent;
- Peak velocity: **80 m/s**;
- Frequency bandwidth: **200 Hz**.

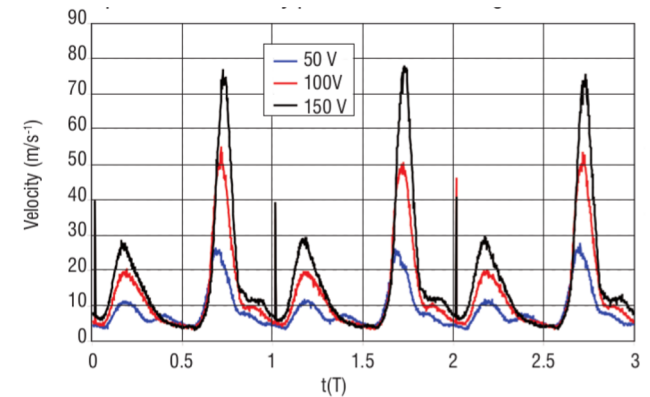


Figure 22 - Hot-wire velocity signal for three voltages at $f=200$ Hz

Fluidic actuator characterization

- Supersonic jet up 300m/s

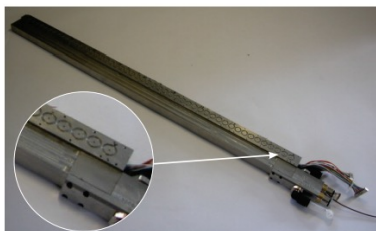


Figure 12 - Pulsed jet actuator (global view, left: detailed view of the orifices)

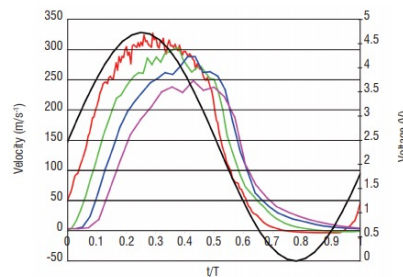


Figure 15 - Excitation voltage signal (in black) and hot-wire velocity signals for various frequencies at a supply pressure of 2.7 bars (red: 100 Hz, green: 300 Hz, blue: 500 Hz, purple: 700 Hz)

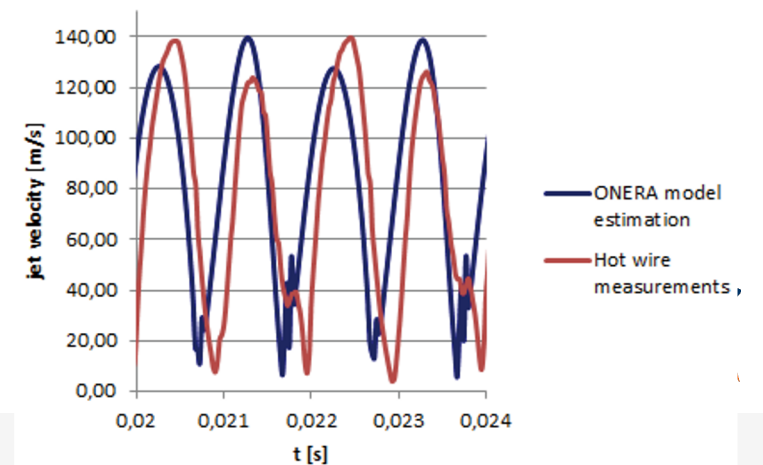
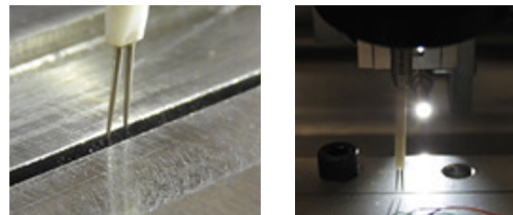
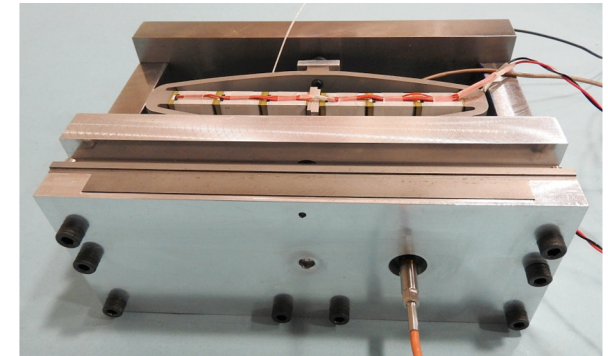


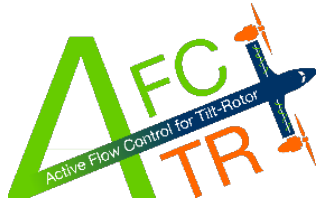
Introduction



ASPIC synthetic jet actuator

Slot dimensions: **1x150** mm²
Peak exit velocity during suction: 135m.s⁻¹
Peak exit velocity during blowing: **150m.s⁻¹**
Optimal actuation frequency bandwidth:
between **200 and 300Hz**
Actuator volume: **164x94x57**mm³





Active Flow Control 4 TiltRotor aircraft



Unsteady CFD simulations for Active Flow Control

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➤ *Pulsed blowing*

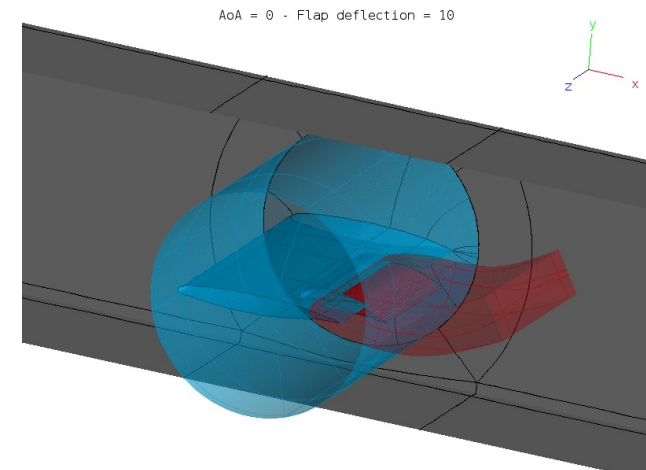
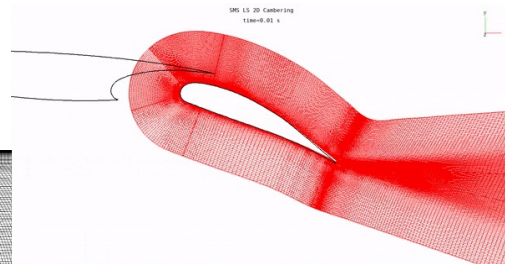
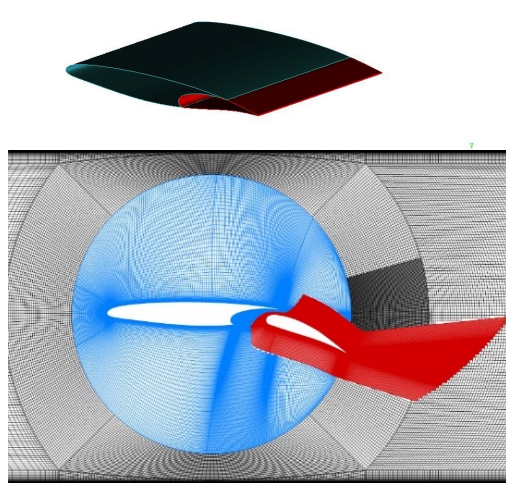
➤ *2D/3D Blowing-suction (ZNMF)*

➤ *Next Civil Generation Tilt-Rotor aircraft*

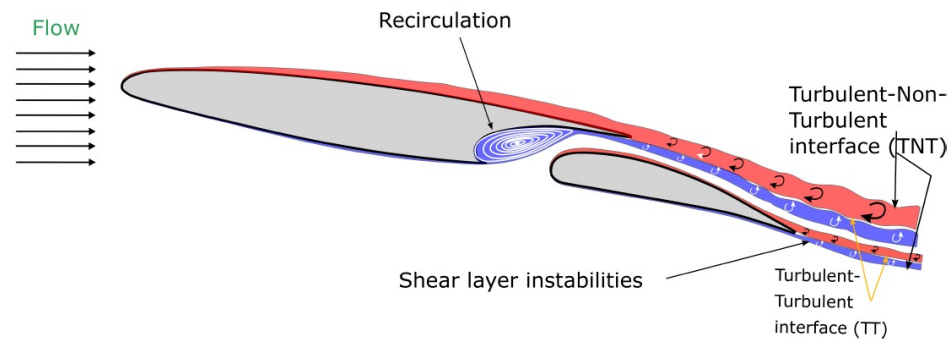
Numerical methods



➤ NSMB solver: Navier Stokes Multi-Block code



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



➤ Turbulence models: URANS (SA)

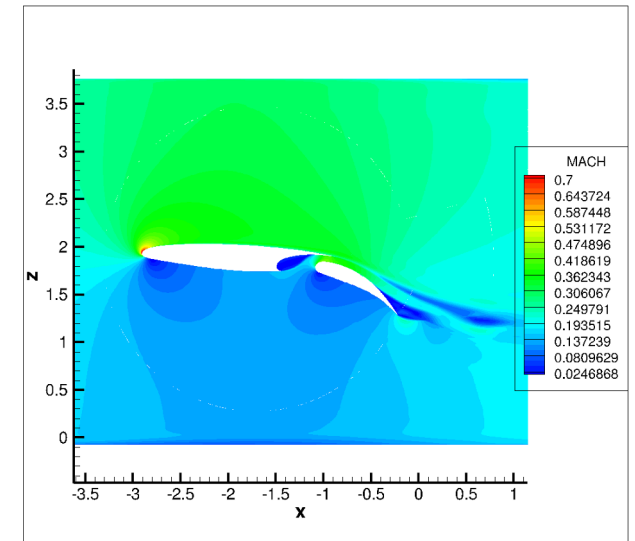
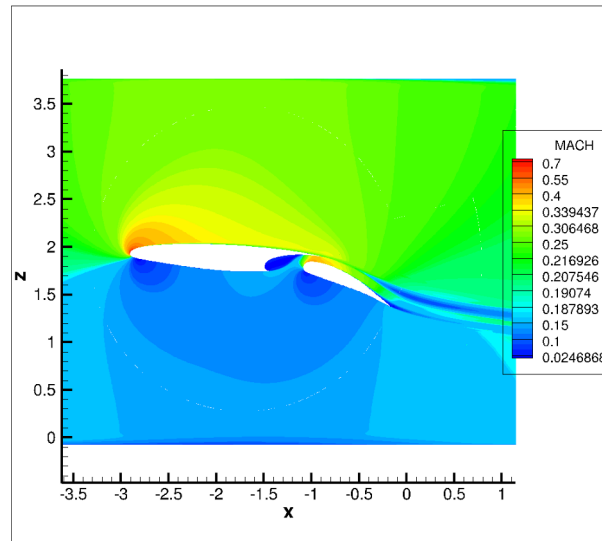
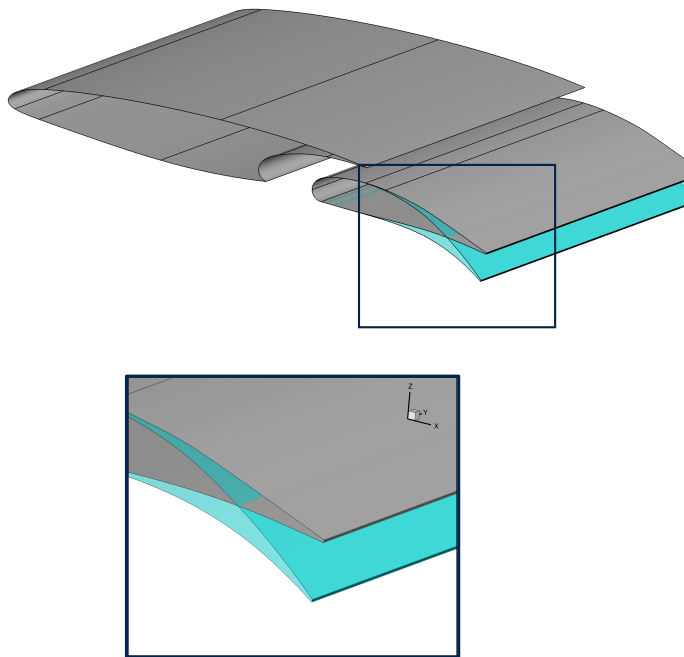
Unsteady CFD simulations for Active Flow Control

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- **Results**
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Results



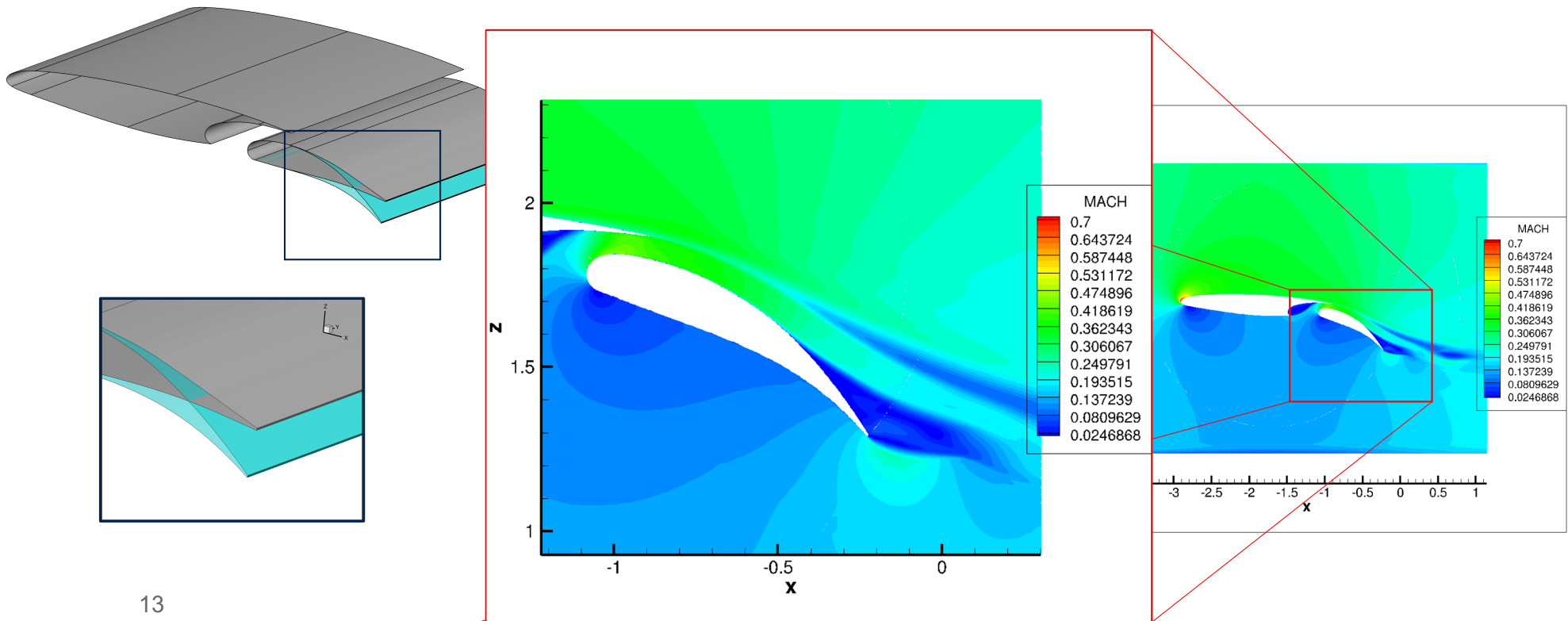
➤ Baseline and morphing with cambering (10cm)



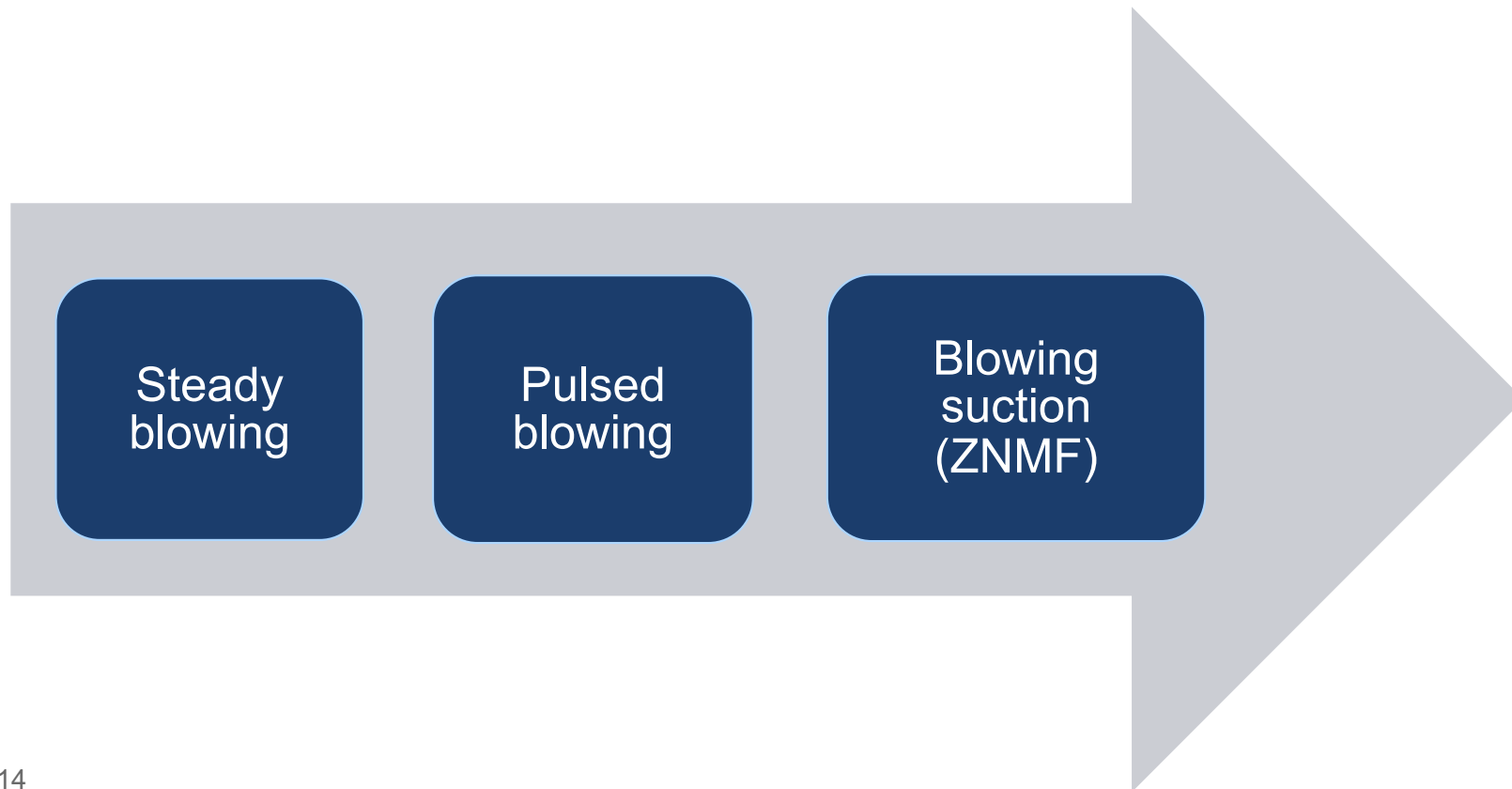
Results



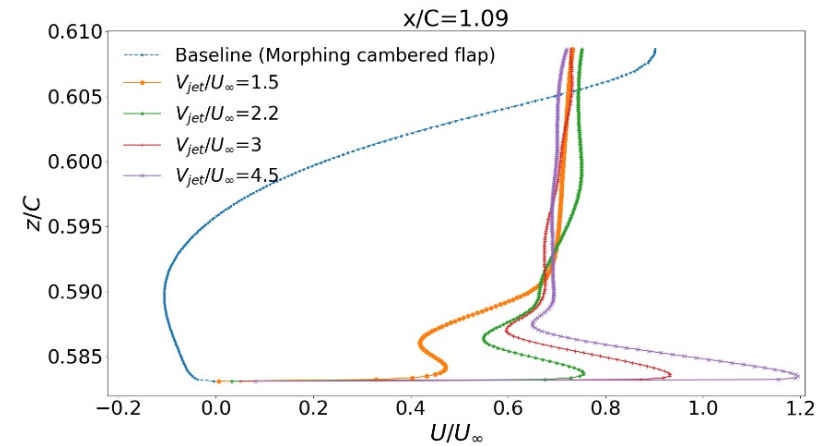
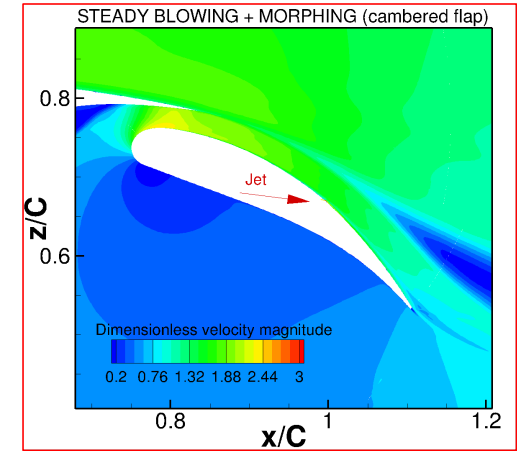
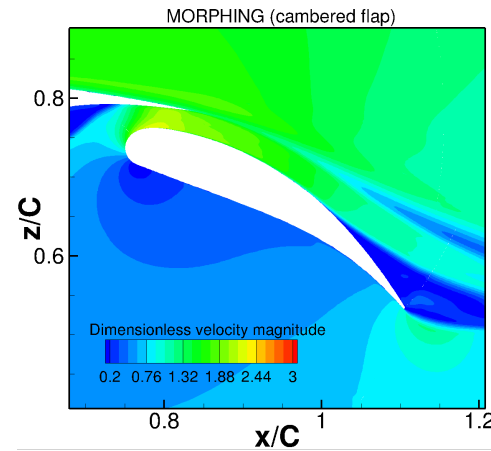
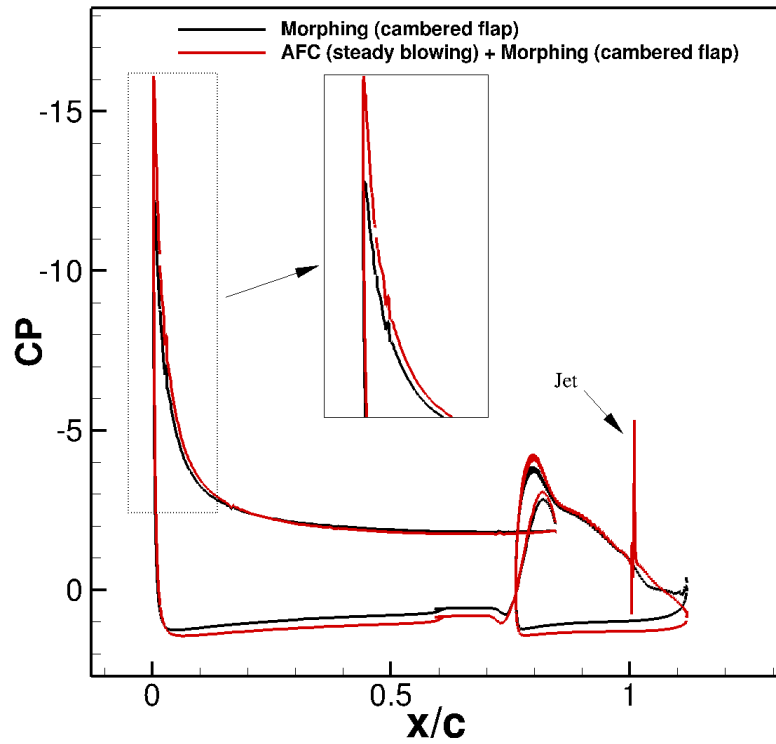
➤ Baseline and morphing with cambering (10cm)



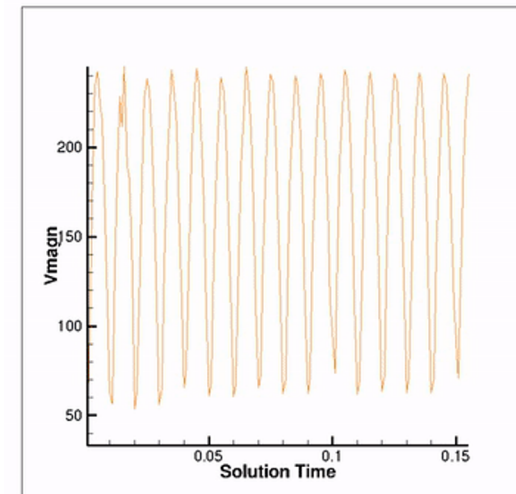
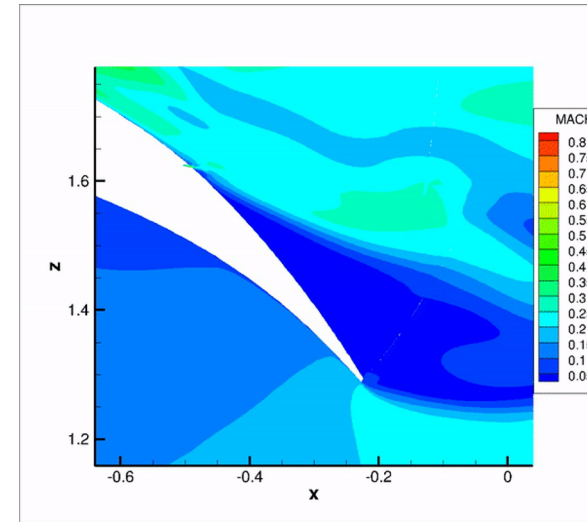
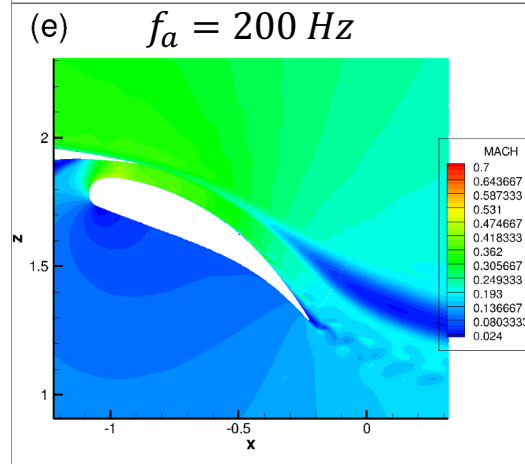
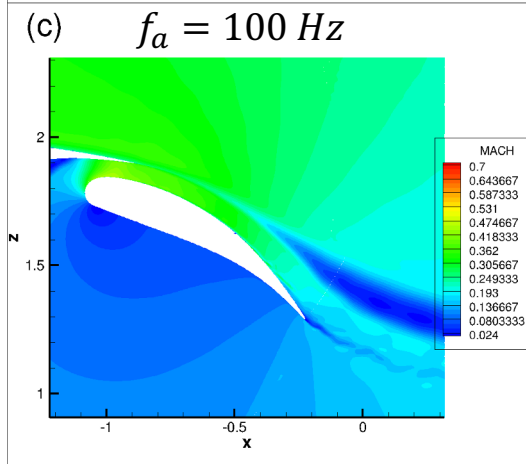
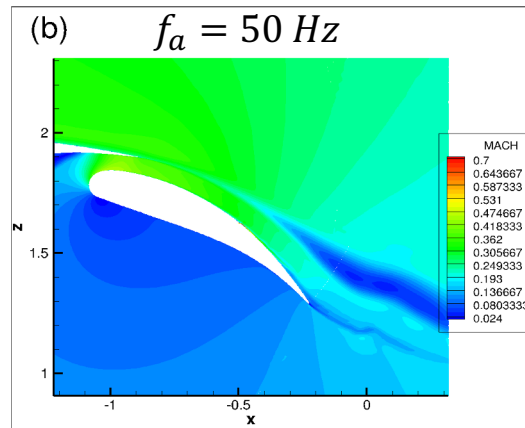
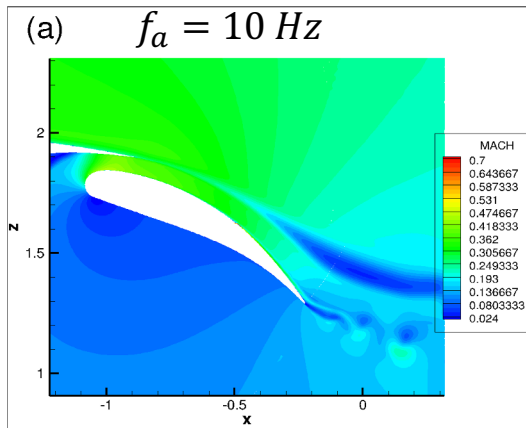
Active Flow Control



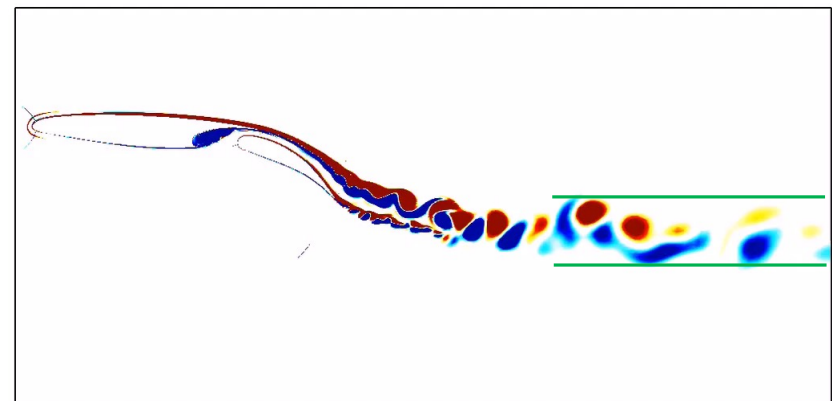
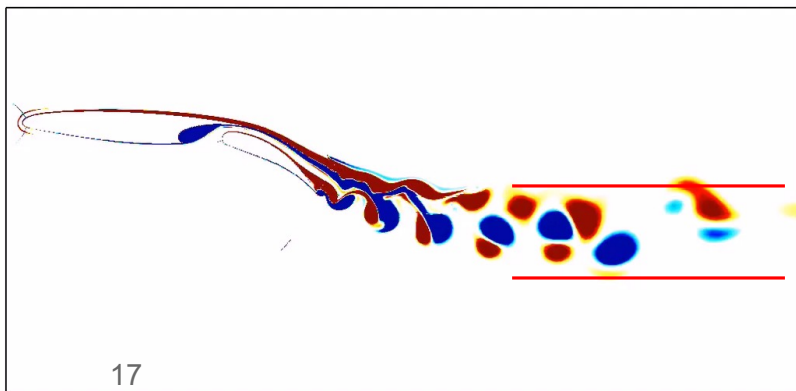
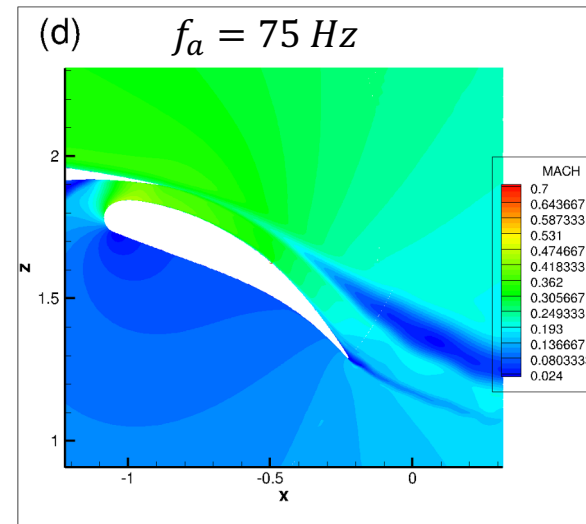
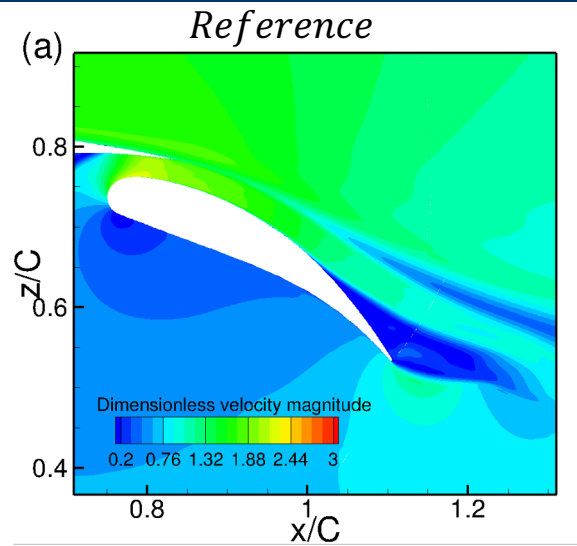
Active Flow Control (Steady blowing)



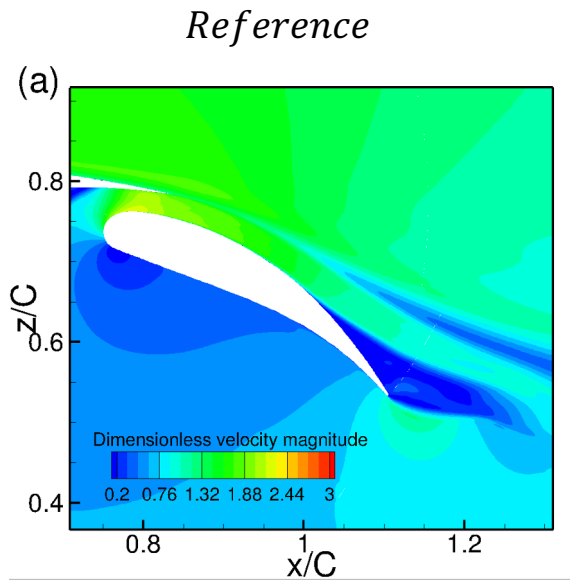
Active Flow Control (multiple-pulse blowing)



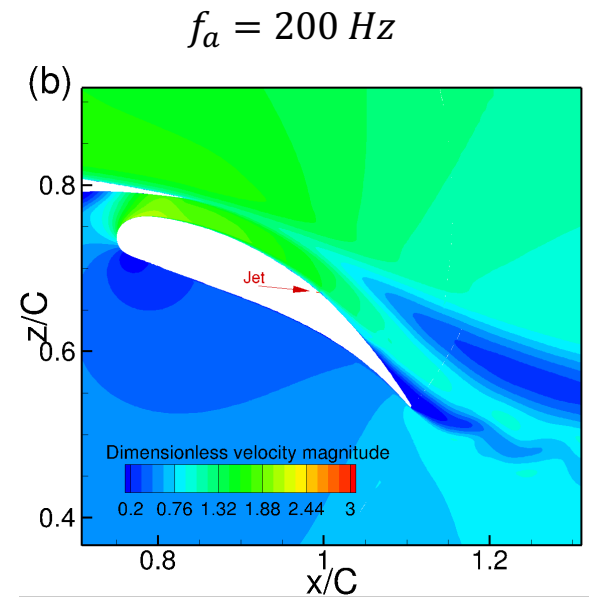
Active Flow Control (blowing-suction ZNMF)



Active Flow Control (blowing-suction ZNMF)



Morphing with only cambering



AFC blowing – suction + morphing (cambering)

Optimisation of the ZNMF jet in 2D simulation of a high-lift system

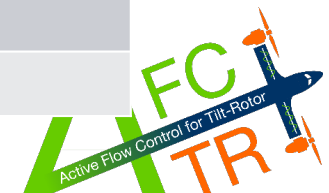
- Fixed jet dimensions 45°, 5mm

Velocity [m/s]	Frequency [Hz]				
	20	50	100	150	200
70	●	●	●	●	●
100	●	●	●	●	●
150	●	●	●	●	●
200	●	●	●	●	●

- Fixed jet dimensions 45°, 1mm

Location (%c)	
50	●
55	●
65	●
70	●

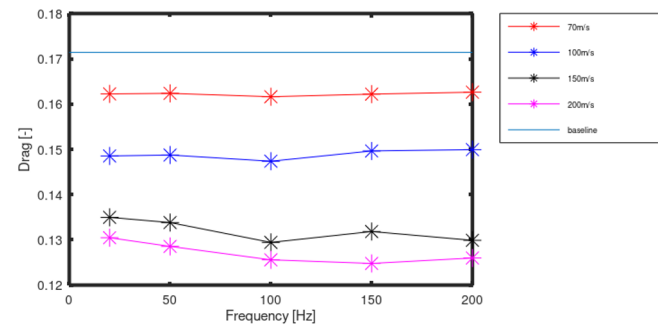
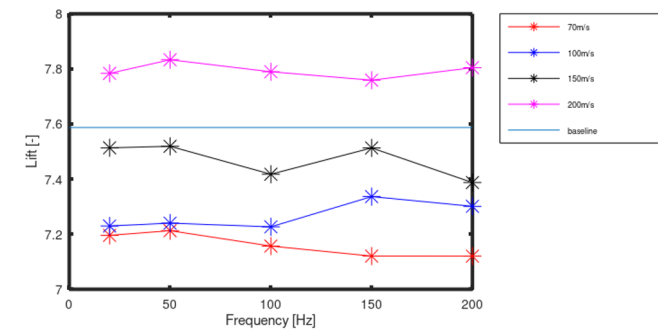
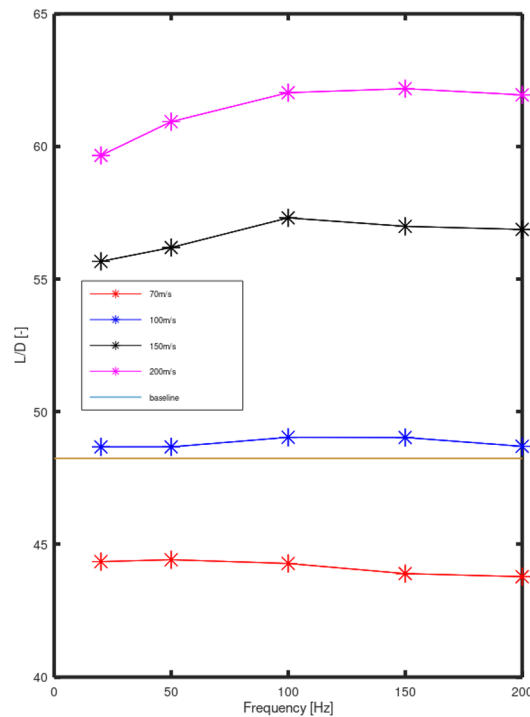
frequency (Hz)	
150	●
200	●
250	●
300	●



Optimisation of the ZNMF jet in 2D simulation of a high-lift system

- Fixed jet dimensions 45°, 5mm

Cases	C_l	C_d	Lift-to-Drag
70m/s			
20Hz	-5.2%	-5.7%	-7.6 %
50Hz	-4.9%	-5.6%	-7.4 %
100Hz	-5.7%	-6.03%	-7.74 %
150Hz	-6.19%	-5.7%	-8.5%
200Hz	6.187%	-5.45%	-8.9%
100m/s			
20Hz	-4.75%	-13.7%	1.4%
50 Hz	-4.61%	-13.65%	1.41%
100Hz	-4.79%	-14.32%	2.16%
150Hz	-3.4%	-13%	2.15%
200Hz	-3.8%	-12.83%	1.46%
150m/s			
20Hz	-1%	-21.53%	15.9%
50Hz	-0.93%	-22.2%	17.1%
100Hz	-2.27%	-24.7%	19.39%
150Hz	-1.01%	-23.35%	18.73%
200Hz	-2.67%	-24.48%	18.49 %
200m/s			
20Hz	2.55%	-24.15%	24.95%
50Hz	3.2%	-25.26%	26.95%
100Hz	2.63%	-26.9%	29.2%
150Hz	2.23%	-27.45%	29.54%
200Hz	2.85%	-26.7%	29.05%



Optimisation of the ZNMF jet in 2D simulation of a high-lift system

Different locations

- Fixed jet dimensions 45°, 1mm

Jet velocity=200m/s

frequency (Hz)	C_l	C_d	Lift-to-Drag
150	-0.61%	-21.02%	15.69 %
200	-1.21 %	-21.68%	15.9 %
250	-0,87%	-21.57%	16 .19 %
300	-0.64%	-21.46%	16.23%

Separation point →

Location (%c)	C_l	C_d	Lift-to-Drag
50	-1.96%	-15.63%	6.83 %
55	-1.33 %	-18.31%	11.04 %
65	-0,46%	-19.22%	13.2 %
70	-0.02%	-23.17%	19.56%

Optimisation of the ZNMF jet in 2D simulation of a high-lift system

Shape optimisation

NEW CASES : _____

| 1 | 60 | 1.0 | 15 | 0.2584000164180948 | $V=Q/D=***176,7244375/**0,2584000164180948= 683,918 \text{ m/s}$

RUN | 4 | 60 | 3.0 | 15 | 0.7809431719217895 | $V=Q/D= 176,7244375/0,7809431719217895 = 226,296$

RUN | 7 | 60 | 5.0 | 15 | 1.30165528528316 | $V=Q/D= 176,7244375/1,30165528528316= 135,769$

RUN | 2 | 60 | 1.0 | 30 | 0.4997186801380233 | $V=Q/D=176,7244375/0,4997186801380233 = 353,64785$

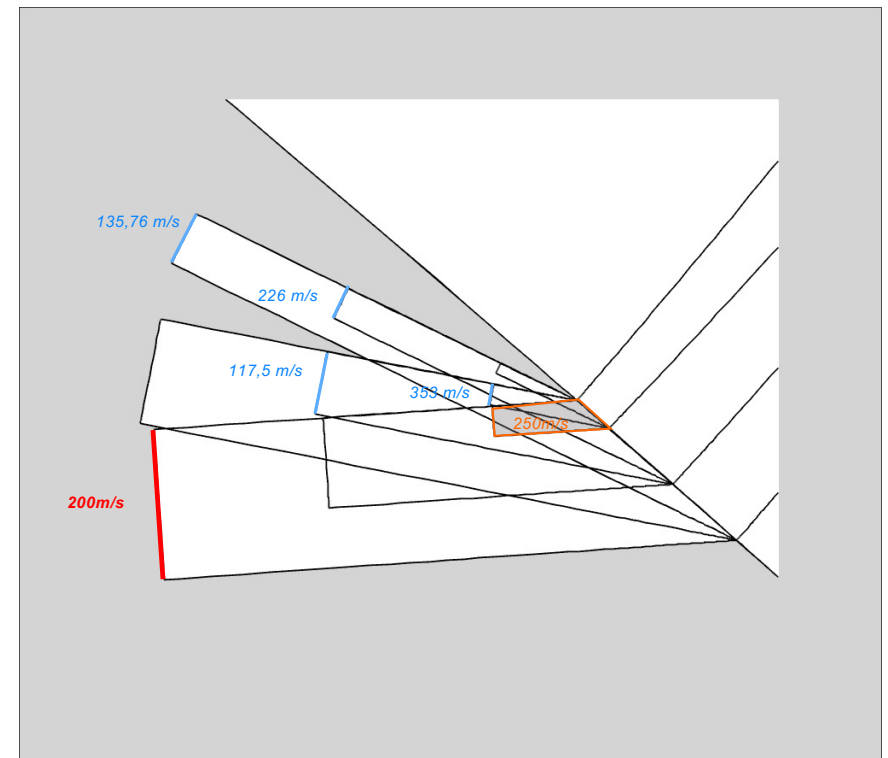
RUN | 5 | 60 | 3.0 | 30 | 1.504052613272536 | $V=Q/D= 176,7244375/1,504052613272536 = 117,49884$

| 8 | 60 | 5.0 | 30 | 2.506799708017016 | $V=Q/D= 176,7244375/2,506799708017016=70,498$

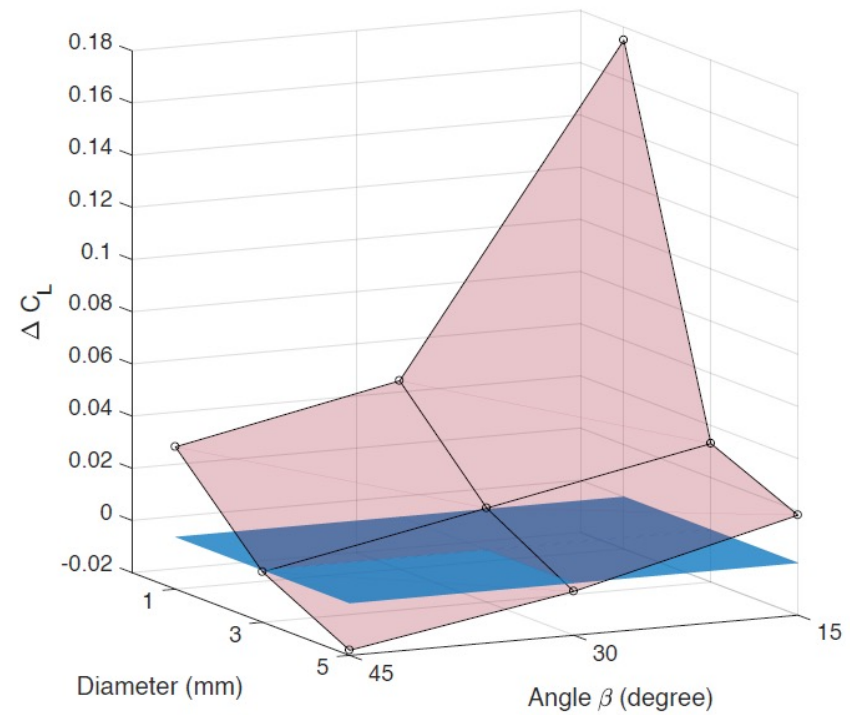
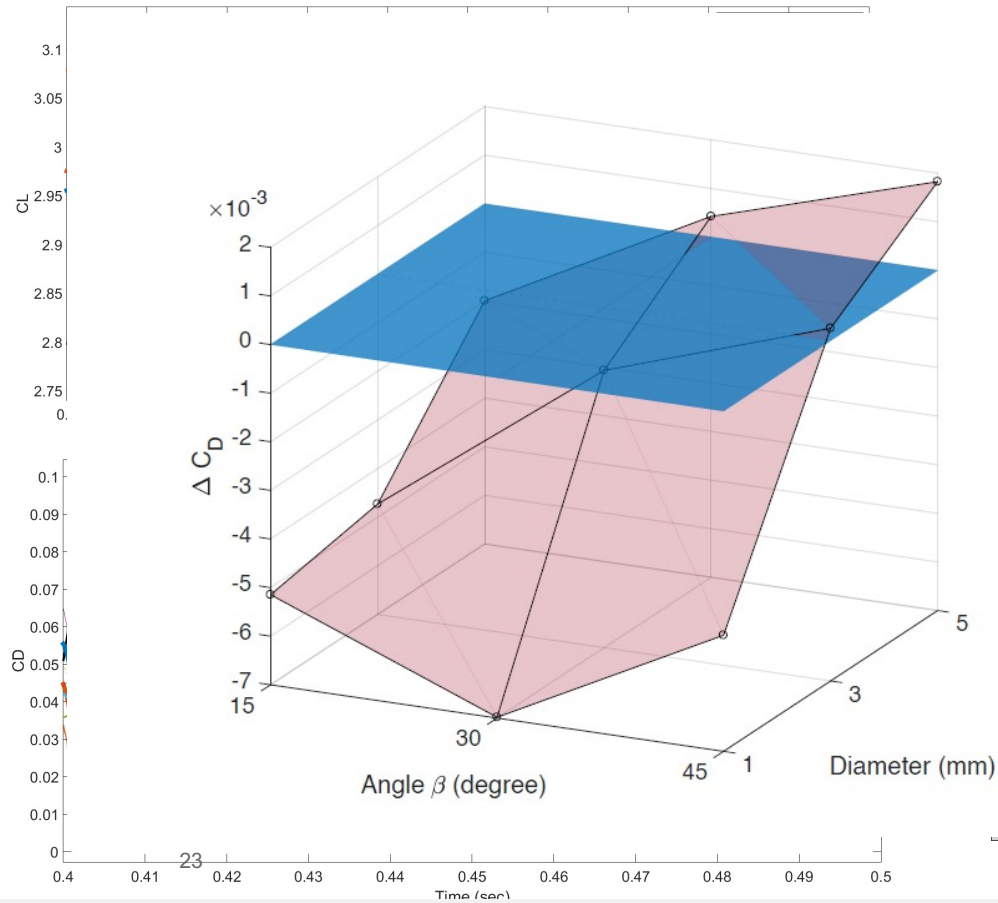
| 3 | 60 | 1.0 | 45 | 0.7068977552277825 | $Q=\underline{V \times D} = 250 \times 0,7068977552277825 = 176,724 \text{ m}^2/\text{s}$
(REFERENCE)

| 6 | 60 | 3.0 | 45 | 2.124637415255685 | $V=Q/D= 176,7244375 /2,124637415255685= 83,1786337899601$

| 9 | 60 | 5.0 | 45 | 3.541139370040709 | $V=Q/D= 176,7244375 /3,541139370040709= 49,9060$



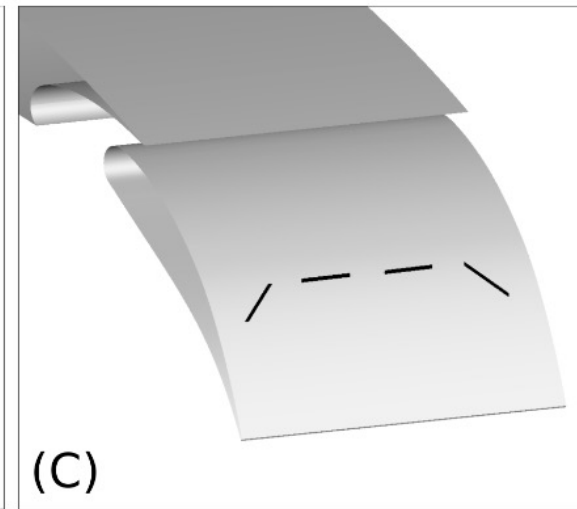
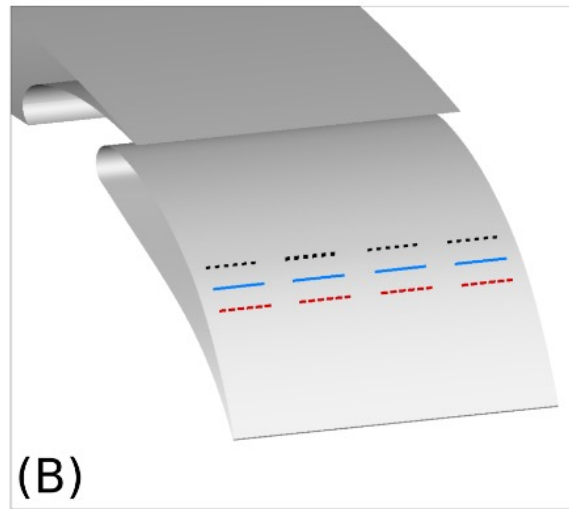
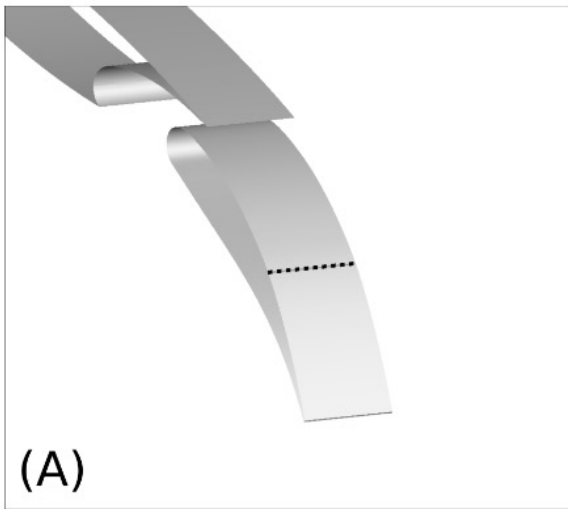
Optimisation of the ZNMF jet in 2D simulation of a high-lift system



3D configurations



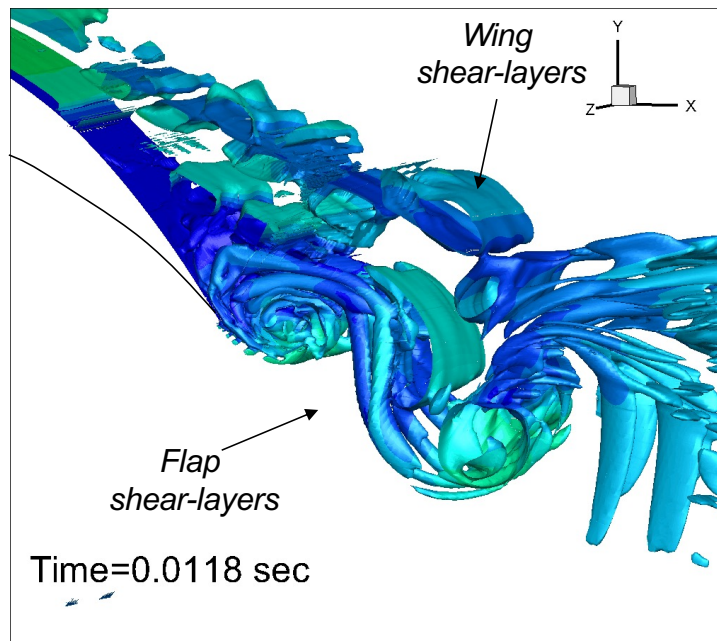
- 3D with a fixed span



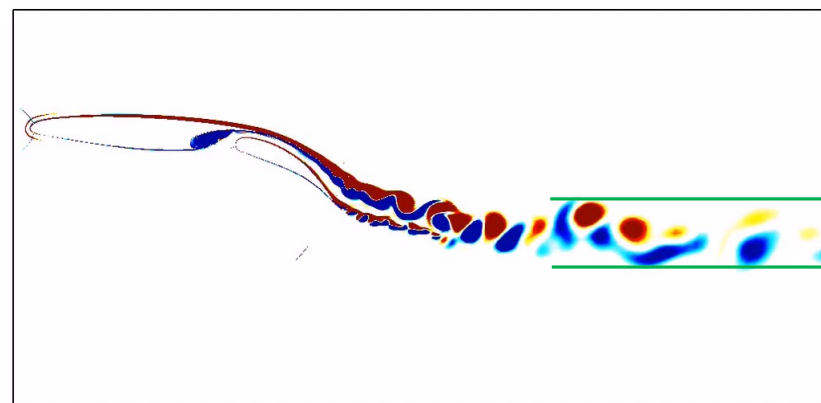
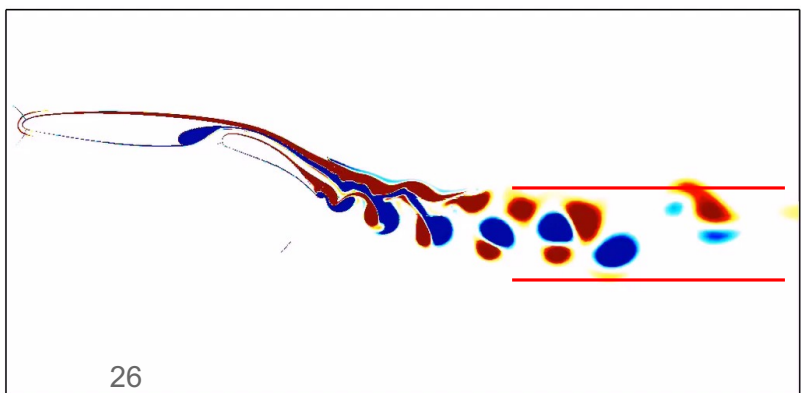
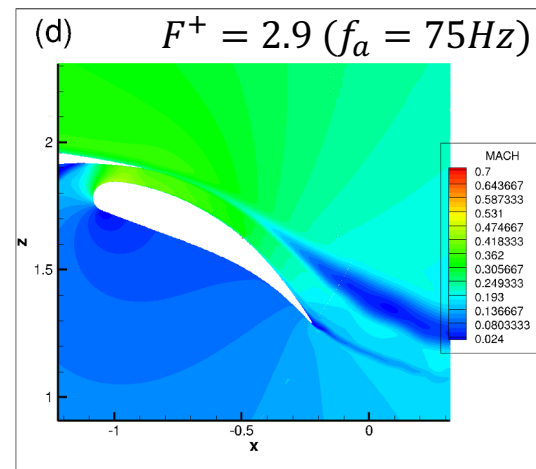
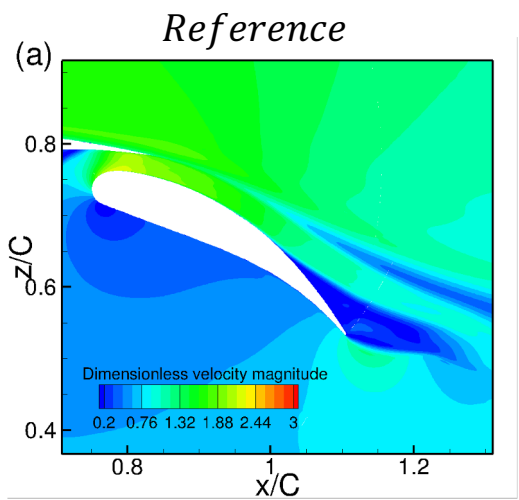
ZNMF (1mm x 150mm x 45deg)



- 3D DDES-SA



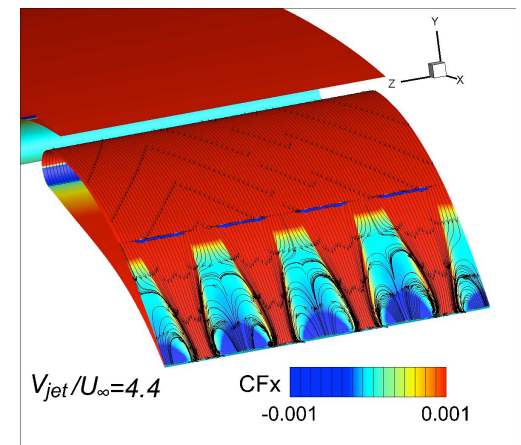
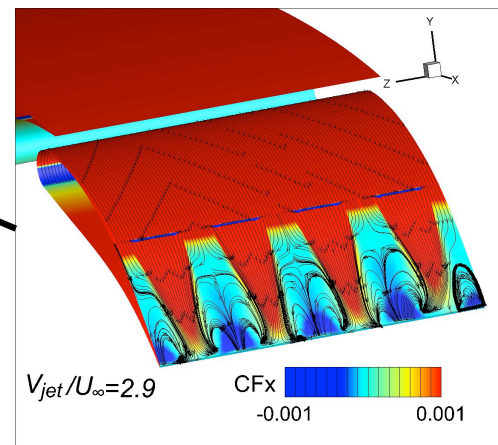
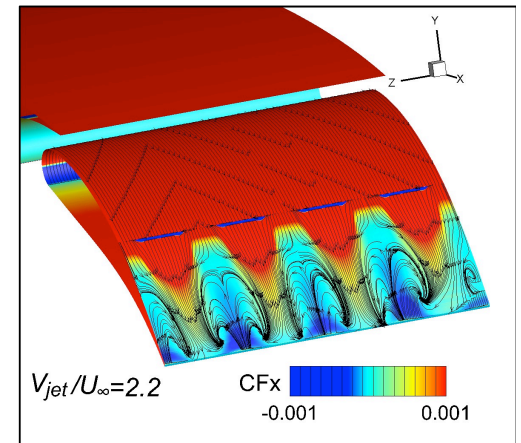
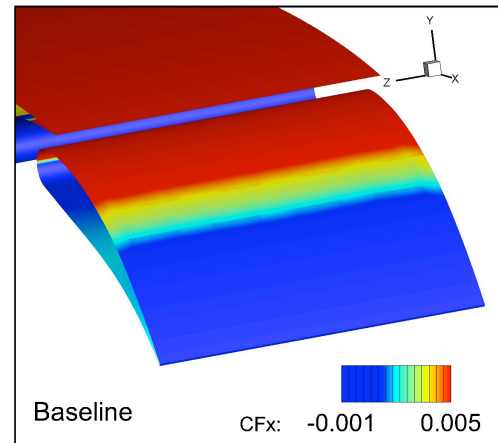
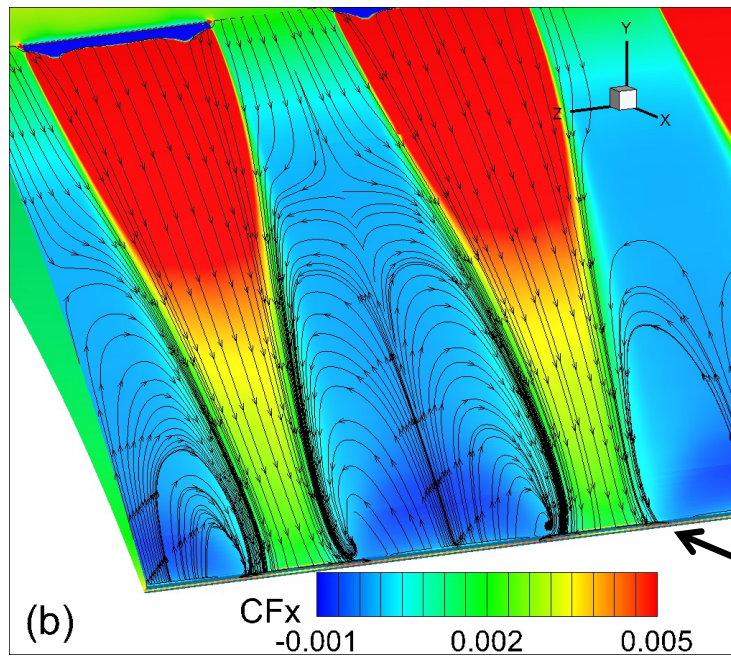
2D configuration



3D configurations



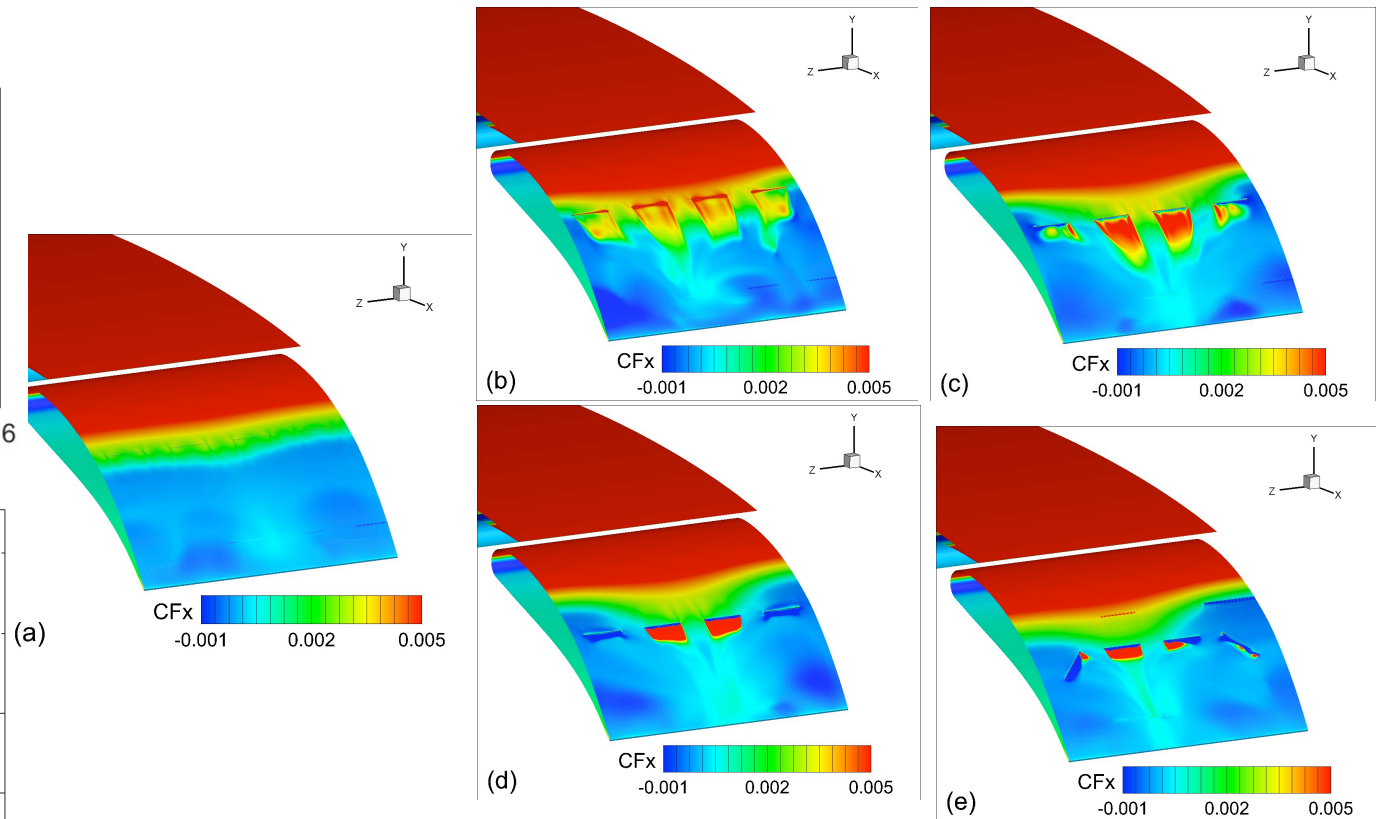
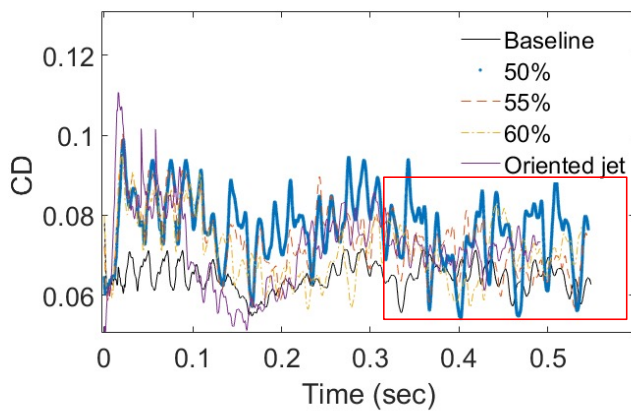
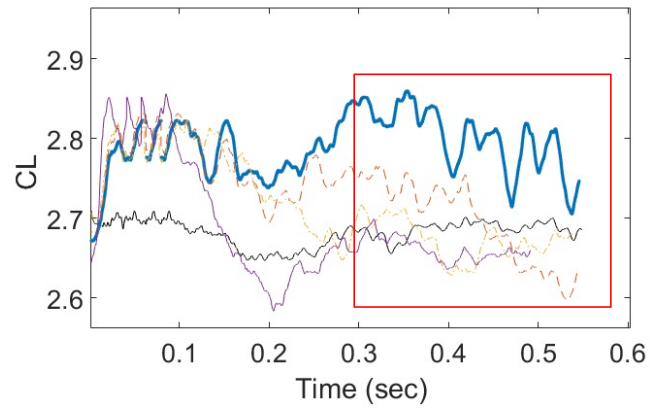
- RANS (SA)



3D configurations



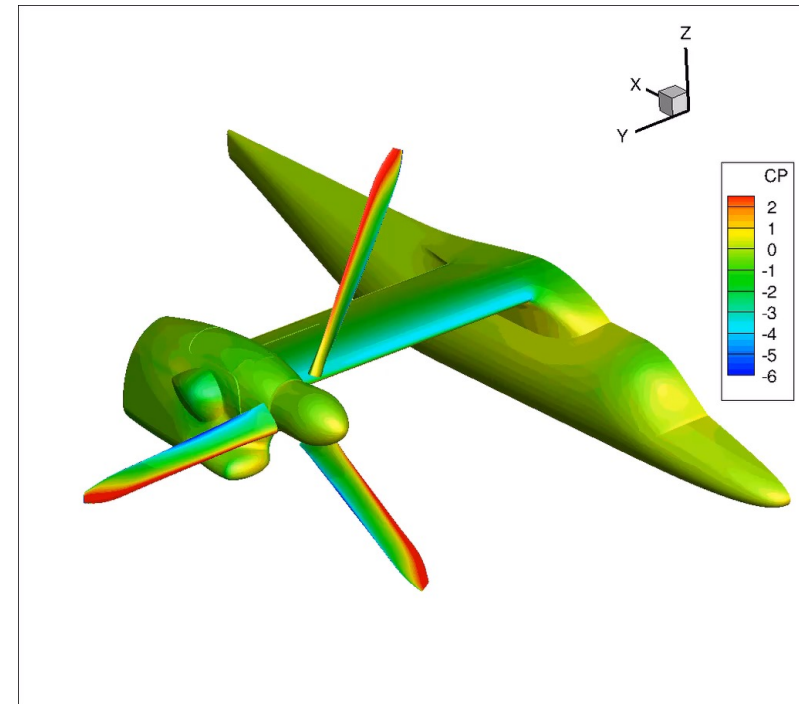
• URANS (SA)



Next Generation of Tilt-Rotor aircraft NCGTR



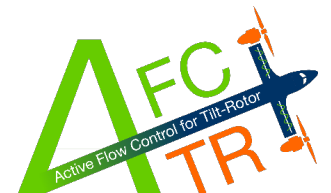
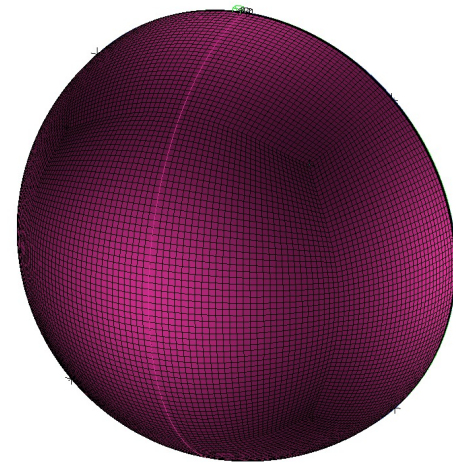
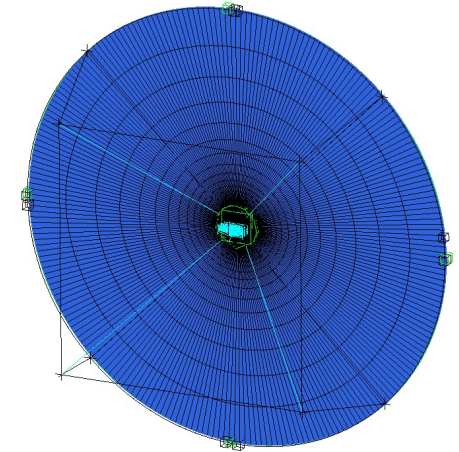
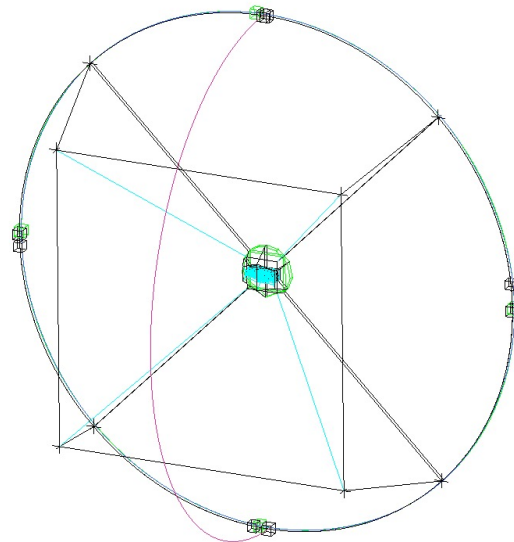
Leonardo Helicopters



Grid Generation NGCTR

Structured grids are designed following the gridding guidelines of AIAA CFD HighLift/ Drag Prediction Workshops

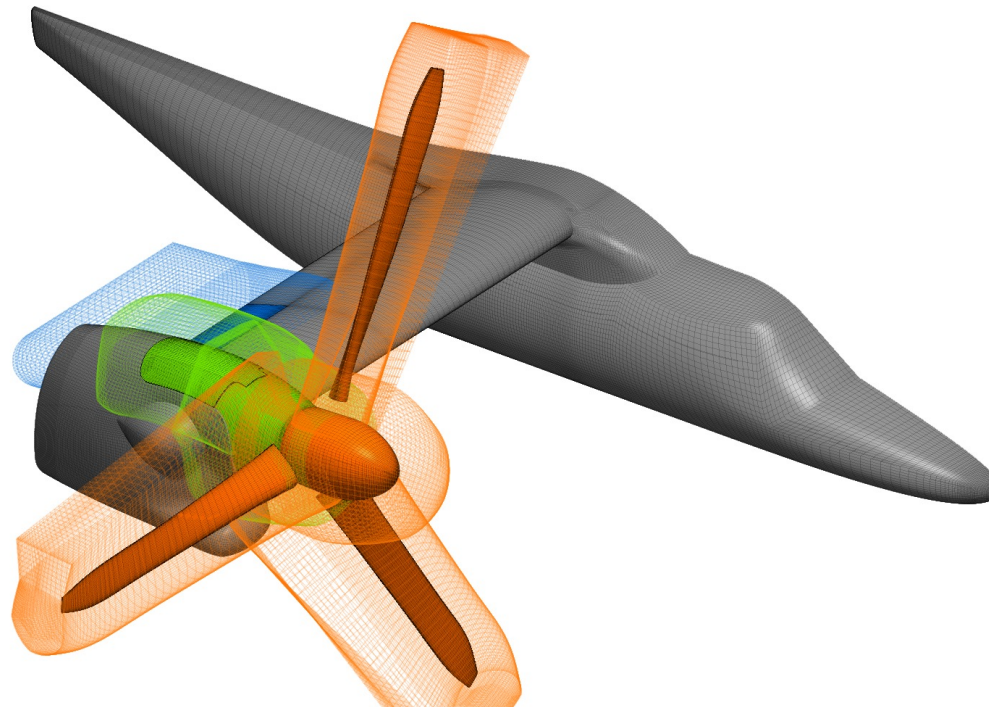
- Farfield boundary $> 100 \cdot C_{ref}$



Grid Generation NGCTR

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

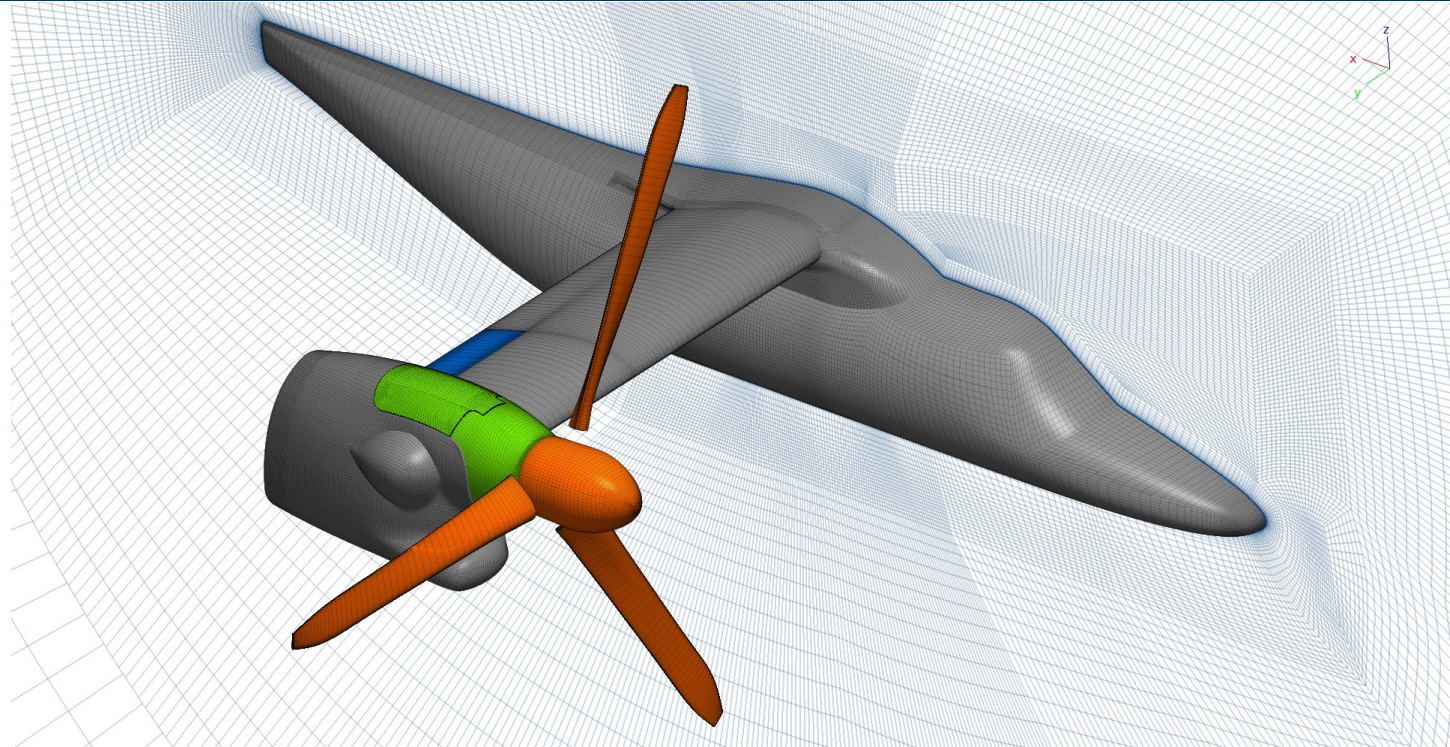
- Base (fuselage, wing, nacelle) - 10'200'000 cells
- Aileron - 620'000 cells
- Engine cover - 370'000 cells
- Engine - 450'000 cells
- Hub - 340'000 cells
- Blades - 770'000 cells/blade



Grid Generation NGCTR

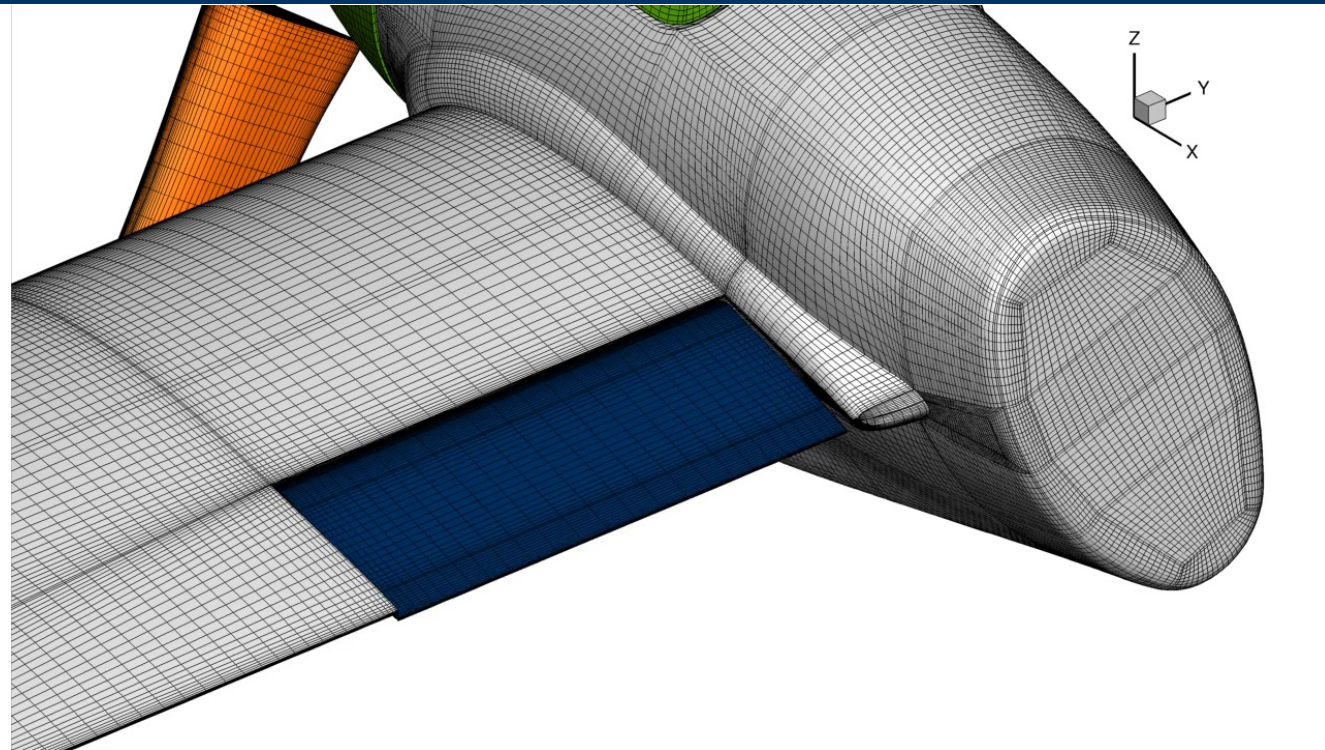
NGCTR baseline grid

- 900 structured blocks
- 14'300'00 cells
- 7 movable parts using Chimera overlapping technique



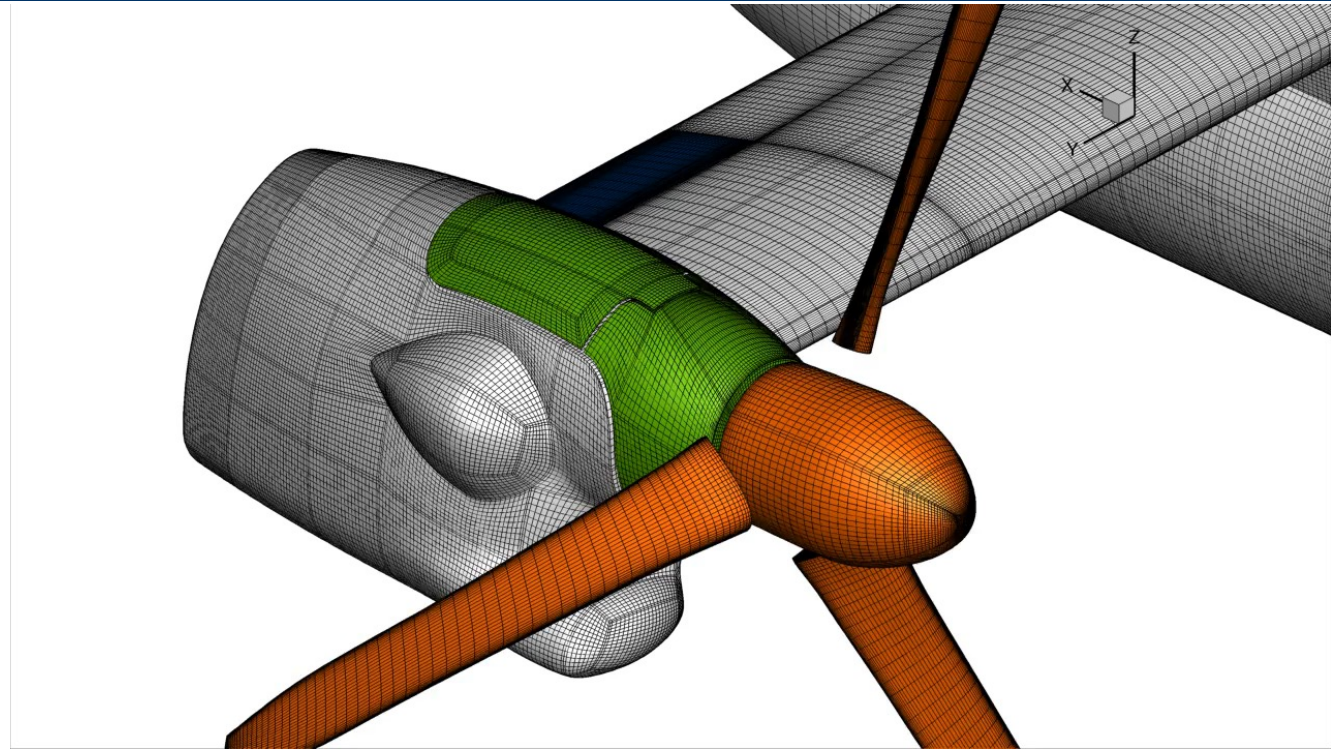
Grid Generation NGCTR

- Aileron deflection +/- 35°



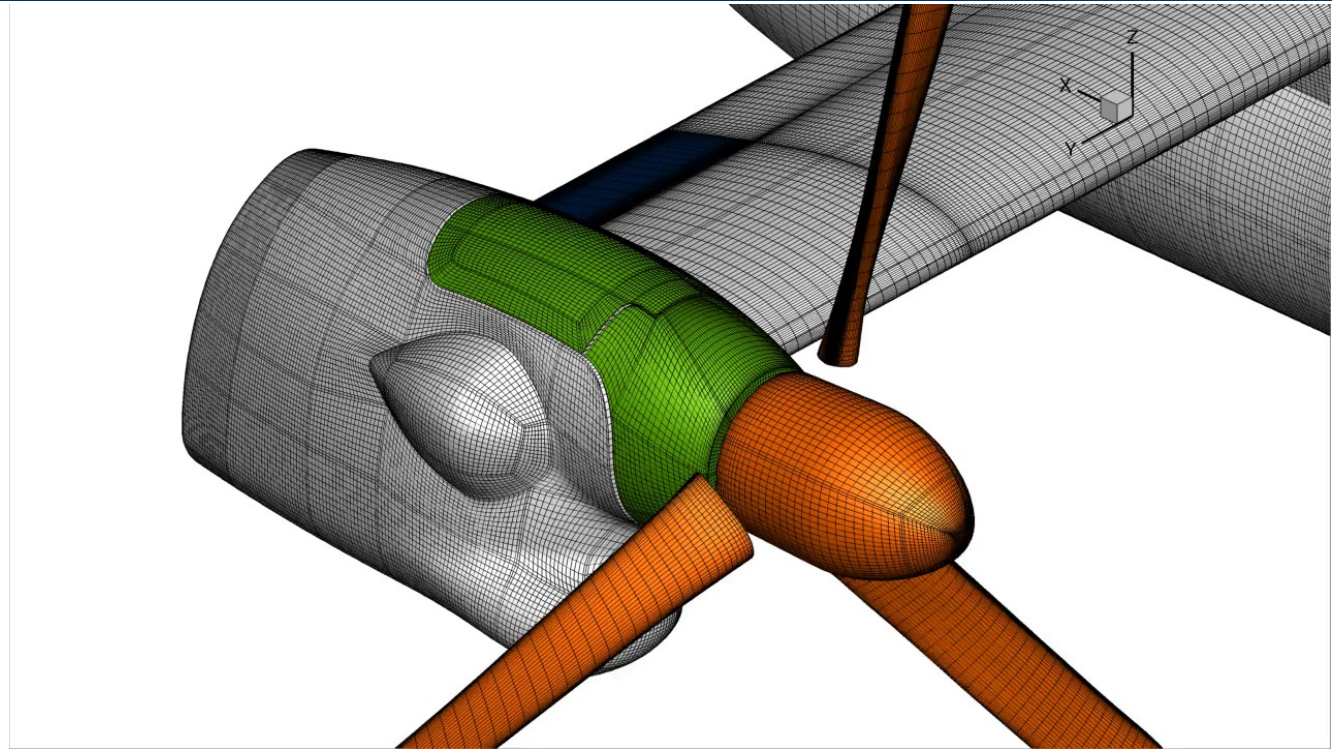
Grid Generation NGCTR

- Engine deflection from 0° to 90°



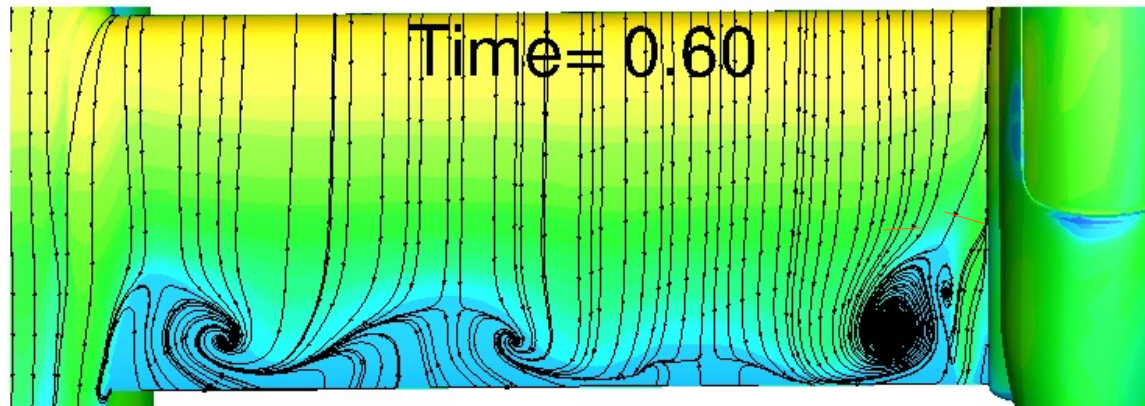
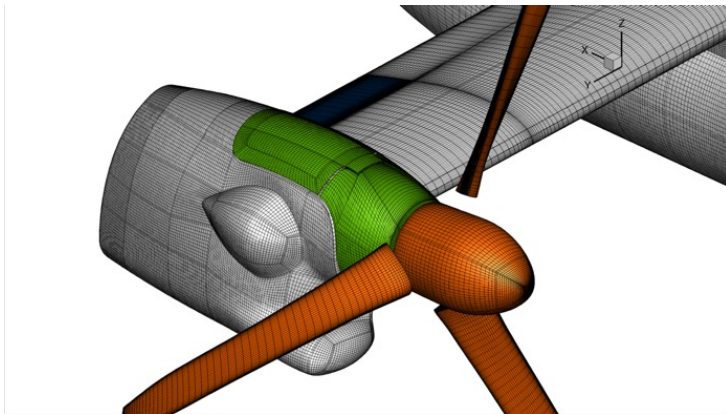
Grid Generation NGCTR

- Engine deflection foreseen in the project from 0° to 30°



Brief summary of the separated flow around NCGTR aircraft

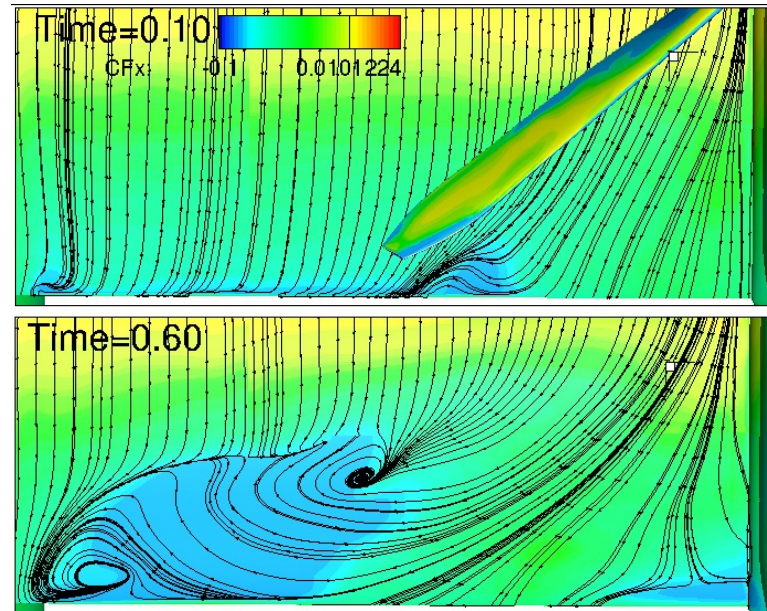
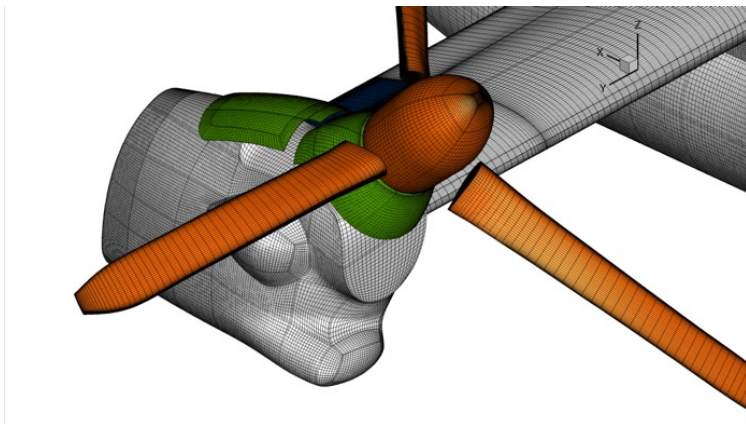
- NCGTR configuration - $K-\omega$ - SST



Skin friction C_{fx} component contours with streamlines of CF (C_{fx} , C_{fy} , C_{fz}), angle of attack high, nacelle 0° , closed gap and no fence

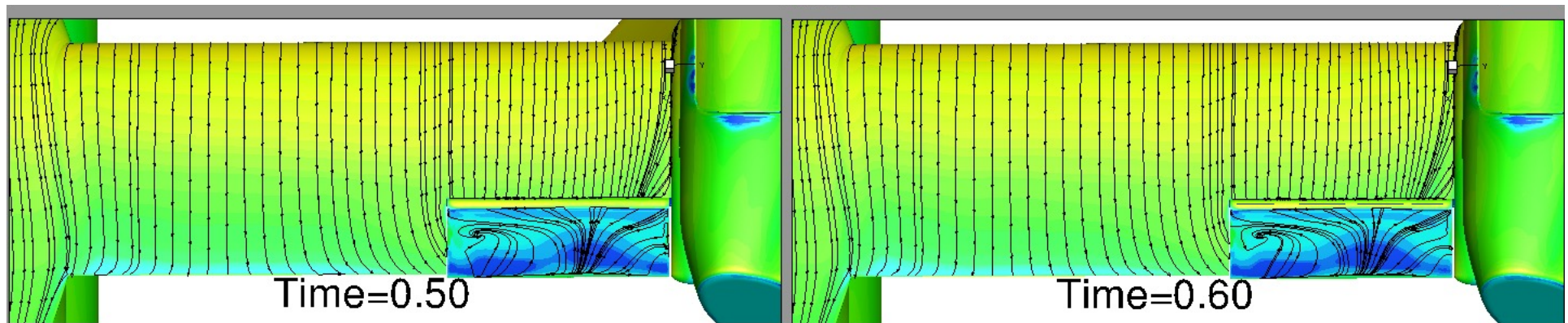
Brief summary of the separated flow around NCGTR aircraft

- NCGTR configuration



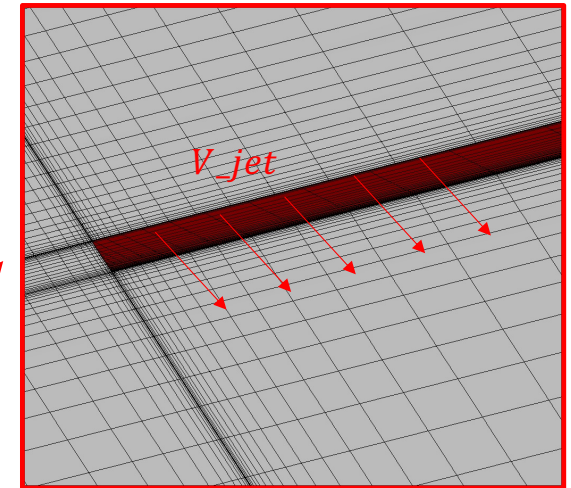
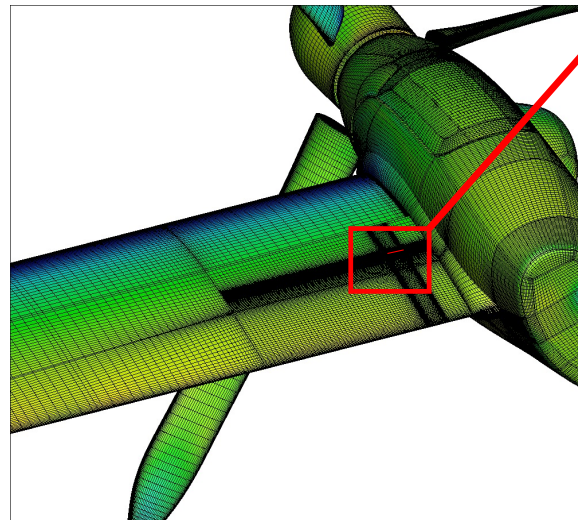
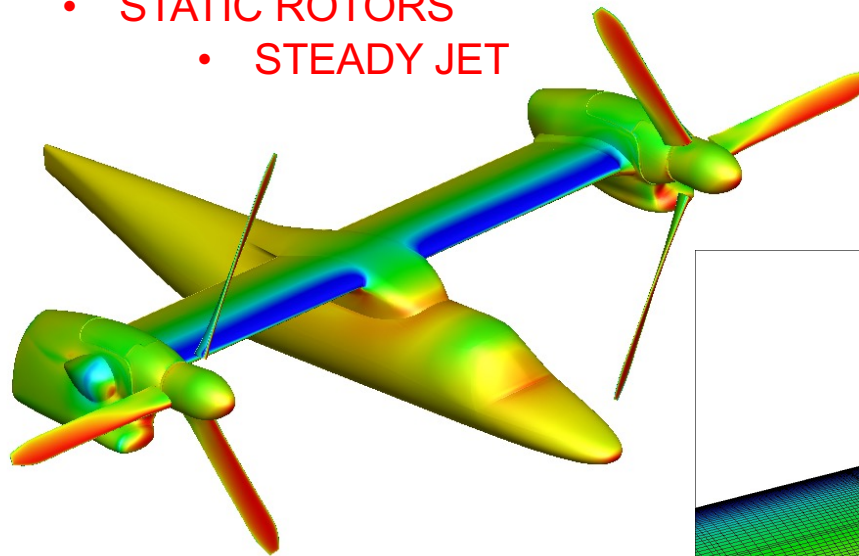
Skin friction C_{Fx} component contours with streamlines of CF (C_{Fx} , C_{Fy} , C_{Fz}), angle of attack high, **nacelle**, closed gap and no fence

Brief summary of the separated flow around NCGTR aircraft



*Skin friction C_{fx} component contours with streamlines of CF (C_{fx} , C_{fy} , C_{fz}), angle of attack high, **aileron deflection deflected**, rotation of blades and no fence*

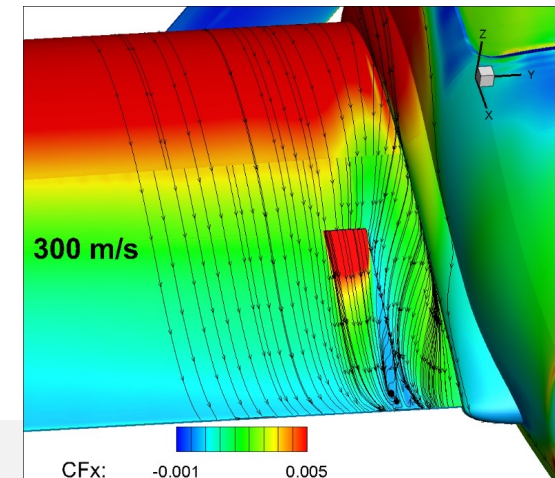
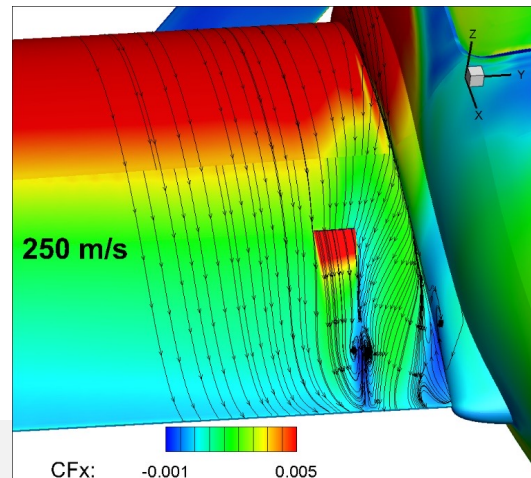
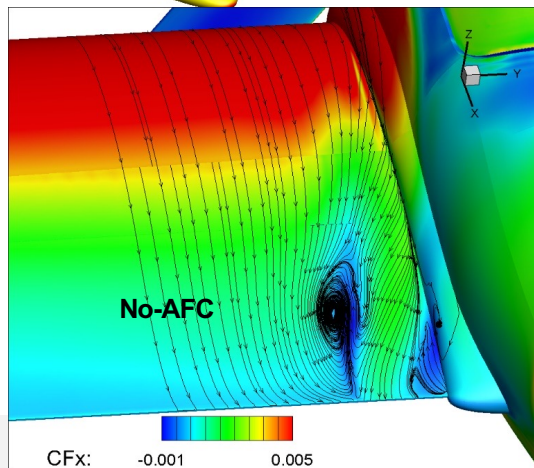
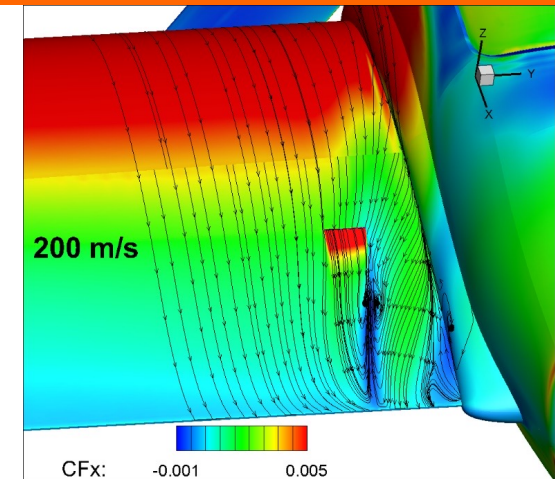
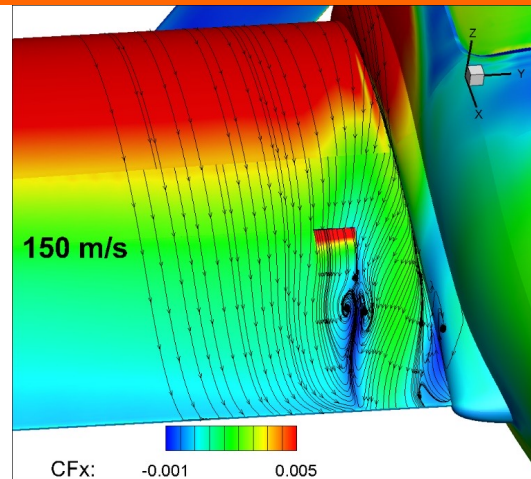
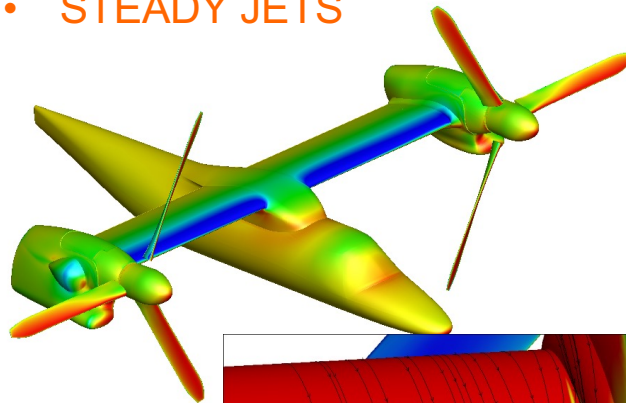
- STEADY STATE
 - STATIC ROTORS
 - STEADY JET



NCGTR

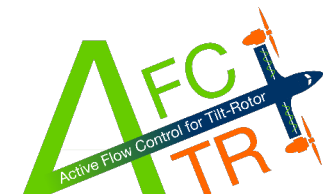
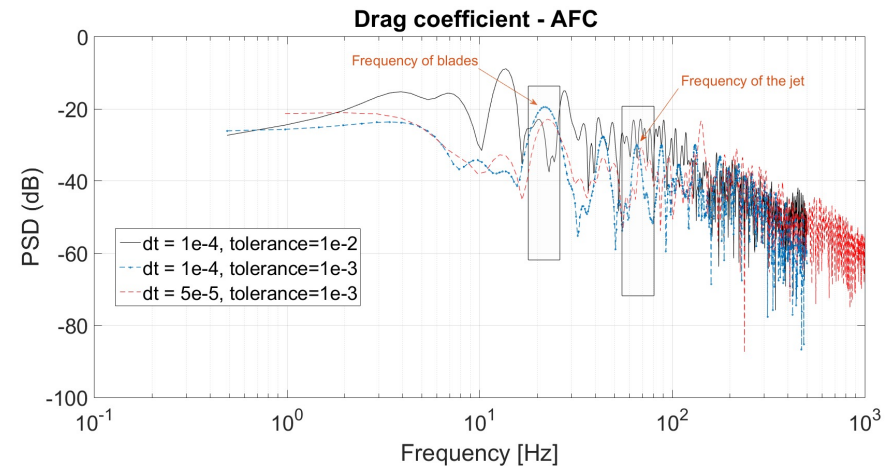
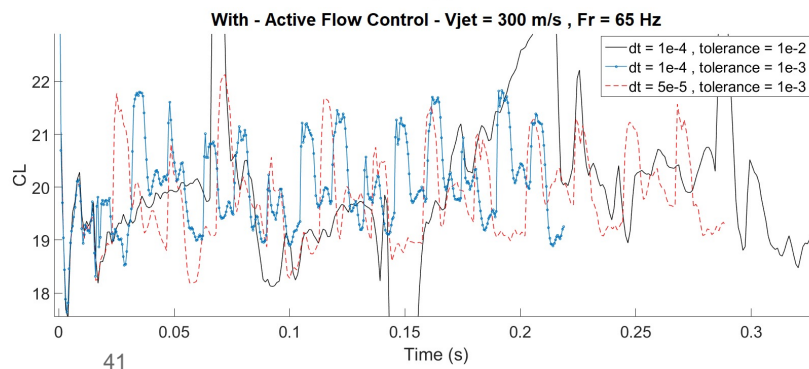
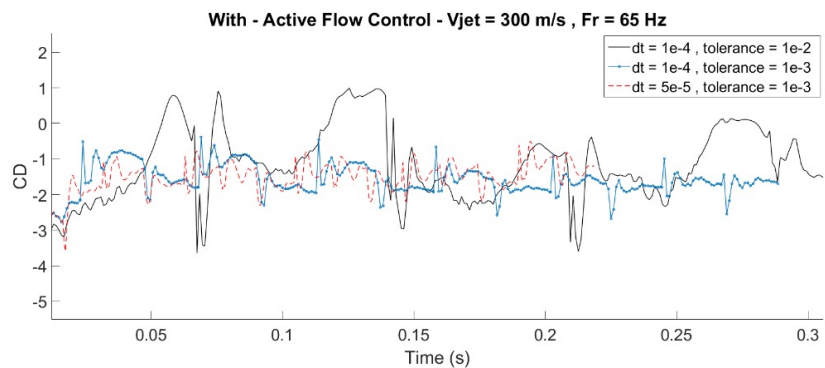


- STEADY STATE
 - STATIC ROTORS
 - STEADY JETS



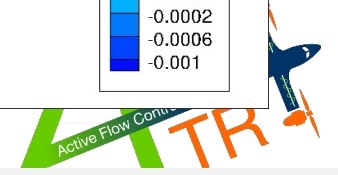
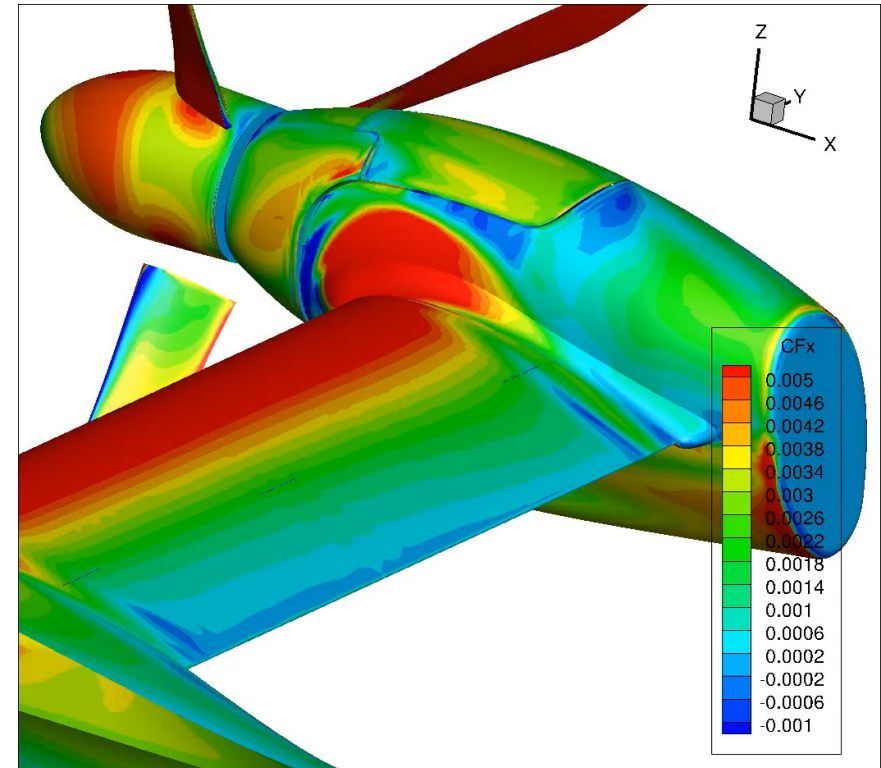
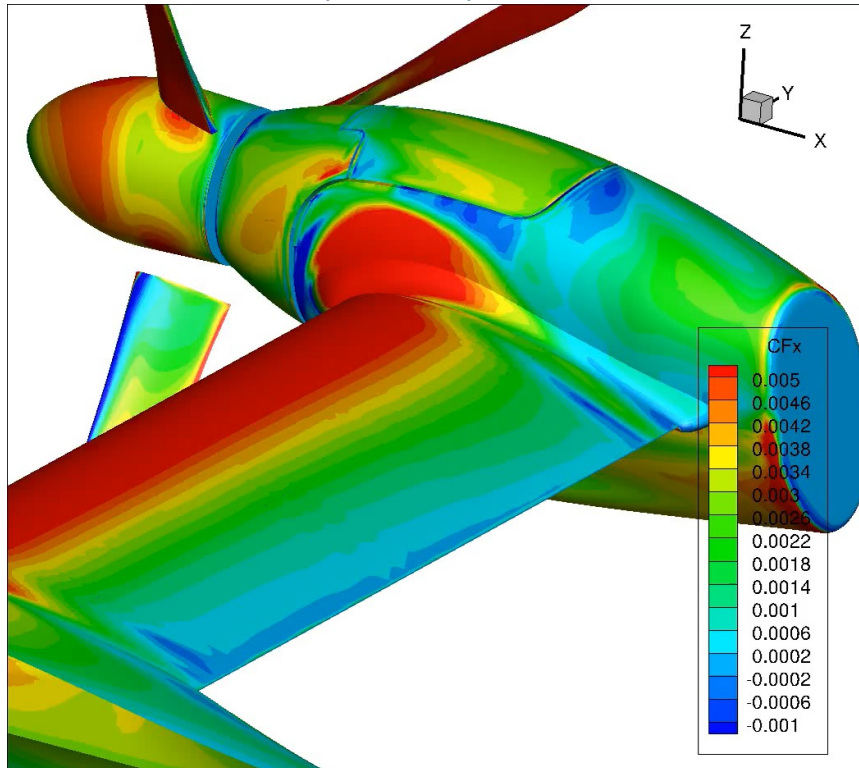
Validation of unsteady simulations

Time step & tolerance effects



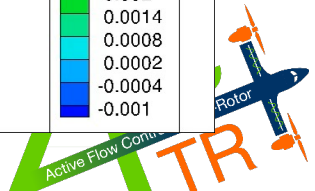
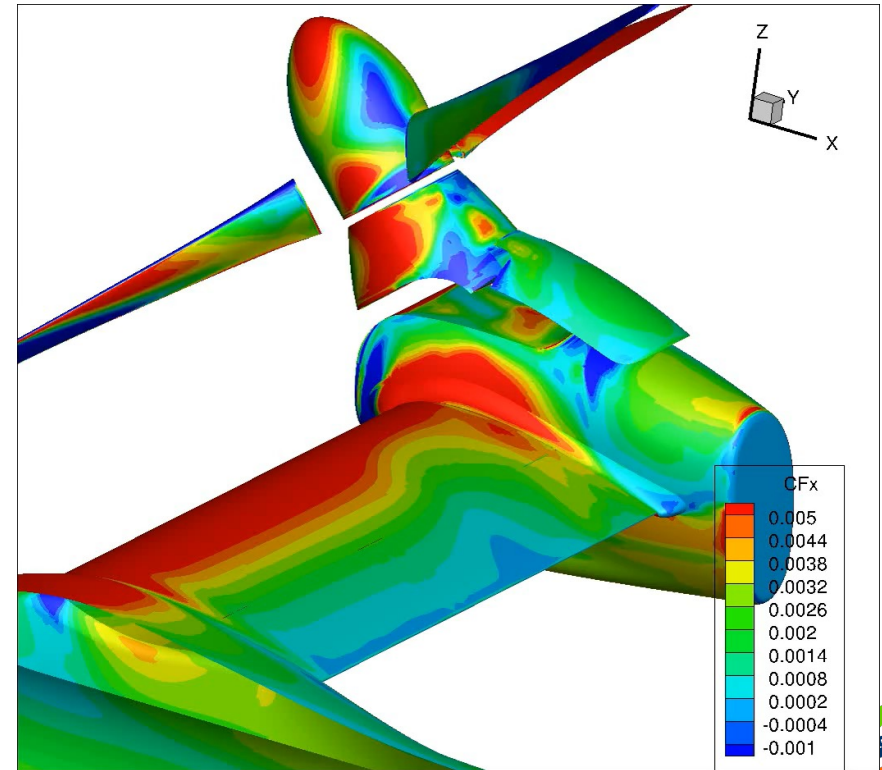
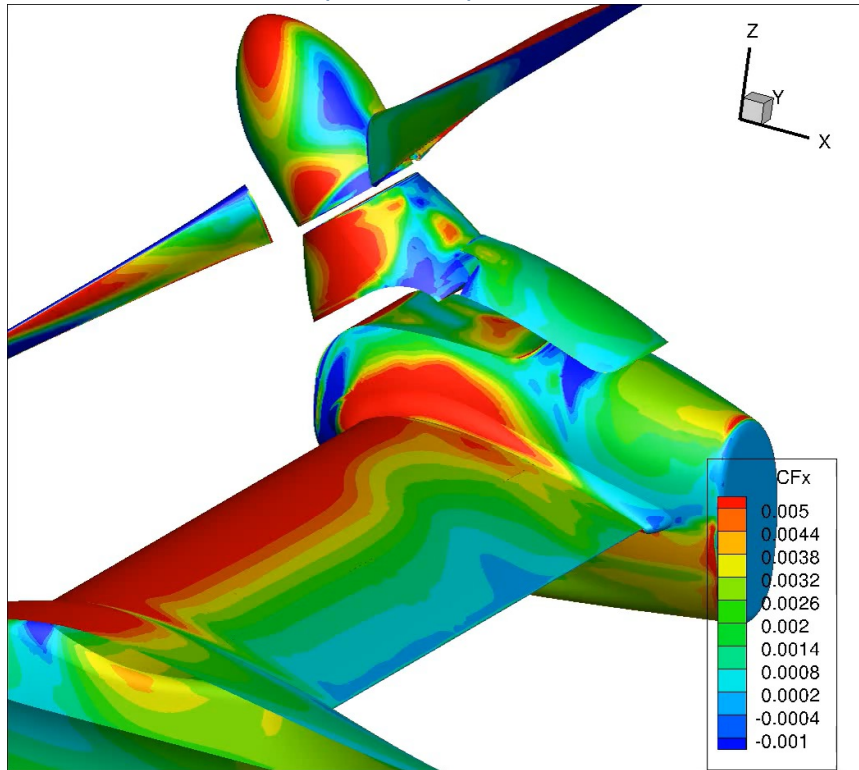
CASE 1

- UNSTEADY STATE (6ZNMF)



Case 2

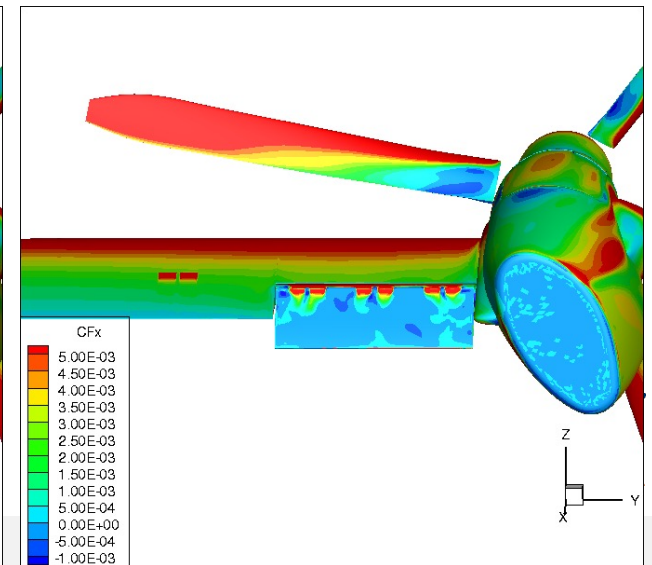
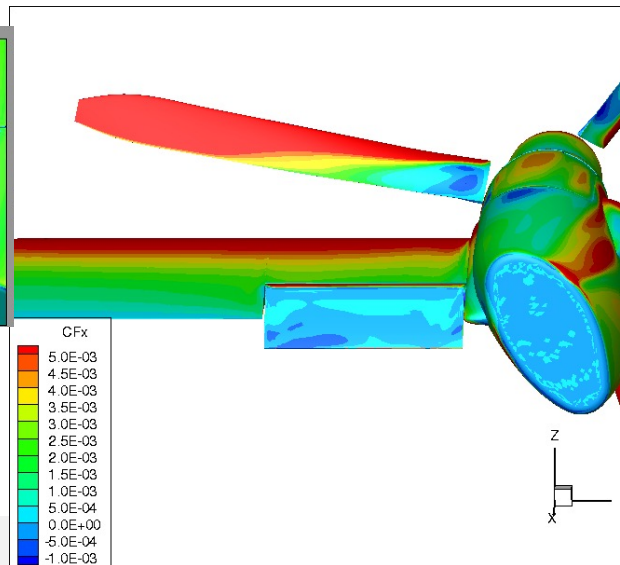
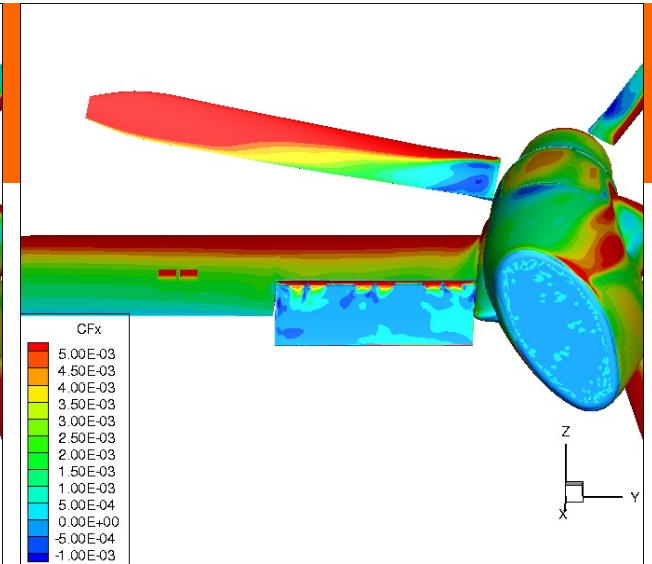
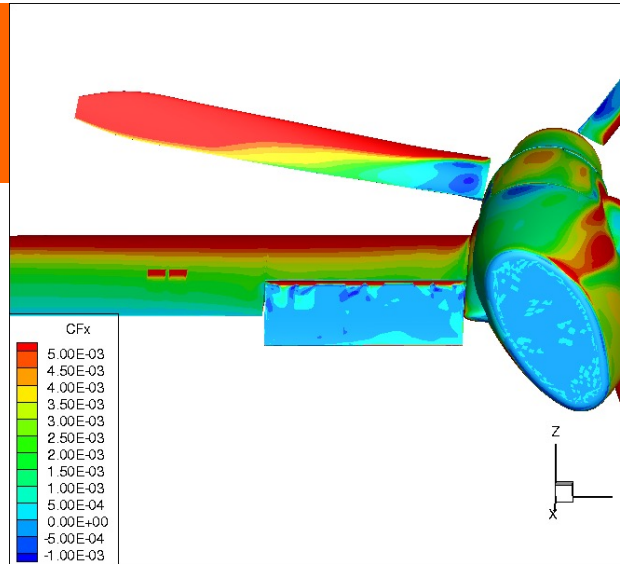
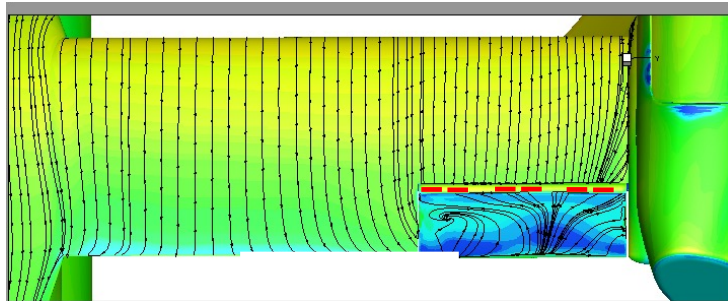
- UNSTEADY STATE (6ZNMF)



- CASE 3

- UNSTEADY STATE (6ZNMF)

- 6 ZNMF integrated in the Aileron for different positions regarding the separation line



Acknowledgements

The AFC4TR project has received funding from the European Union's H2020 - CleanSky2 research and innovation framework programme under grant agreement No 886718





Thank You !

