About OMICS Group

OMICS Group International is an amalgamation of Open Access publications and worldwide international science conferences and events. Established in the year 2007 with the sole aim of making the information on Sciences and technology 'Open Access', OMICS Group publishes 400 online open access scholarly journals in all aspects of Science, Engineering, Management and Technology journals. OMICS Group has been instrumental in taking the knowledge on Science & technology to the doorsteps of ordinary men and women. Research Scholars, Students, Libraries, Educational Institutions, Research centers and the industry are main stakeholders that benefitted greatly from this knowledge dissemination. OMICS Group also organizes 300 International conferences annually across the globe, where knowledge transfer takes place through debates, round table discussions, poster presentations, workshops, symposia and exhibitions.

About OMICS Group Conferences

OMICS Group International is a pioneer and leading science event organizer, which publishes around 400 open access journals and conducts over 300 Medical, Clinical, Engineering, Life Sciences, Pharma scientific conferences all over the globe annually with the support of more than 1000 scientific associations and 30,000 editorial board members and 3.5 million followers to its credit.

OMICS Group has organized 500 conferences, workshops and national symposiums across the major cities including San Francisco, Las Vegas, San Antonio, Omaha, Orlando, Raleigh, Santa Clara, Chicago, Philadelphia, Baltimore, United Kingdom, Valencia, Dubai, Beijing, Hyderabad, Bengaluru and Mumbai.

Escola Tècnica Superior d'Enginyeries Industrial i Aeronàutica de Terrassa
UNIVERSITAT POLITÈCNICA DE CATALUNYA

Numerical Study on Active Flow Control using Synthetic Jet Actuators over a NACA 4421 Airfoil

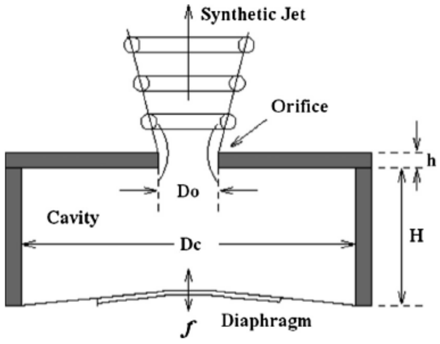
AUTHOR
Xavier Guerrero Pich

Summary

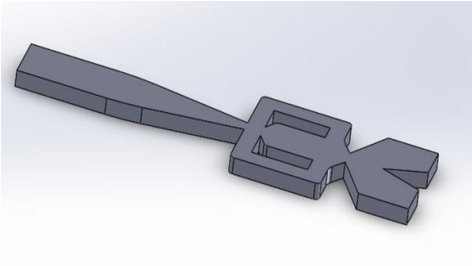
- Active Flow Control
  - Definition
  - Applications
- The Zero-Net-Mass-Flux
- Setting simulations
- Results
- Conclusion

Active flow control (AFC)

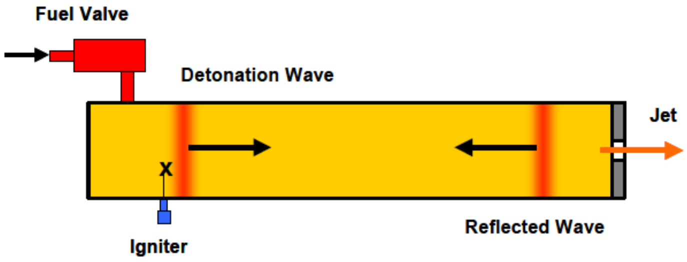
- Fluid dynamics technology which is used to improve the performance of aerodynamic surfaces under varying conditions.
  - **Active:** Implies that the technology is applied only when needed, to avoid the drawdown of the natural performance.



Zero-Net-Mass-Flux



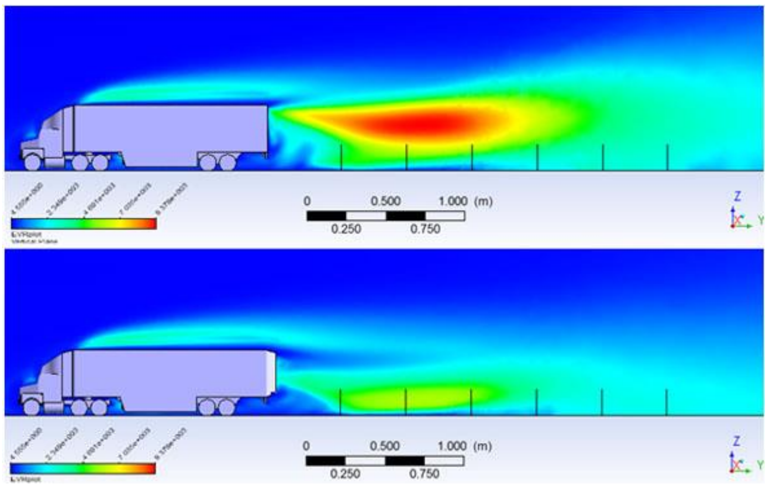
Fluidic oscillator



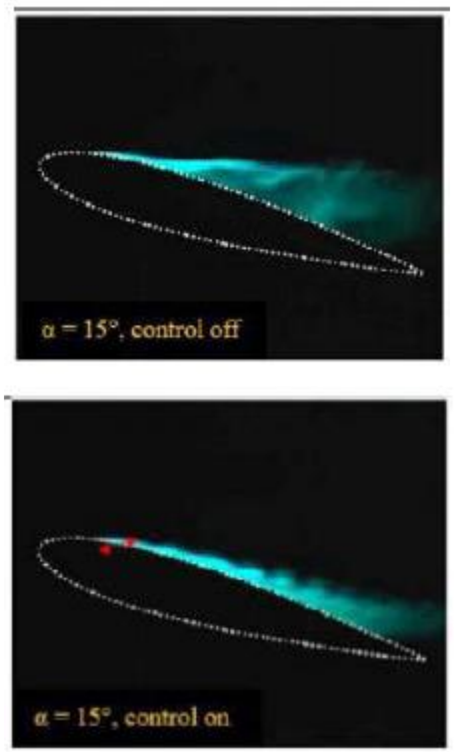
Combustion driven jet actuator

Active flow control (AFC)

- Wide application in different fields of research
  - Aerospace sector
  - Automobile industry



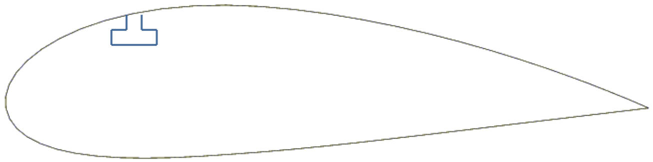
Vorticity in the back of the truck when using AFC



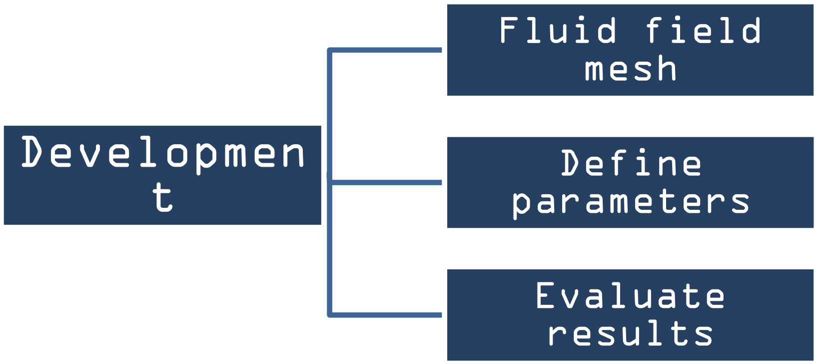
Tomoscopy flow visualization of the boundary layer without AFC (top) and using AFC (bottom)

The Zero-Net-Mass-Flux

- **Aim:** Study how a Zero-Net-Mass-Flux (ZNMF) can improve the performance of a NACA 4421 airfoil

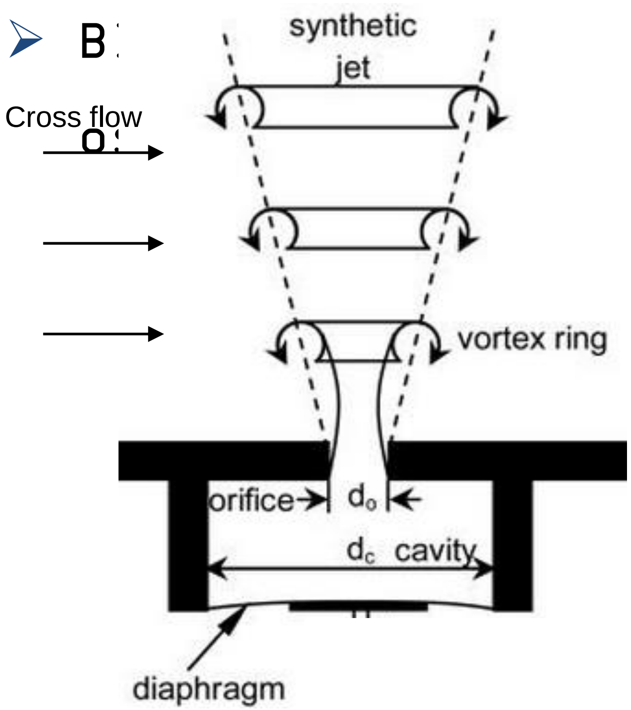


ZNMF set on a NACA 4421

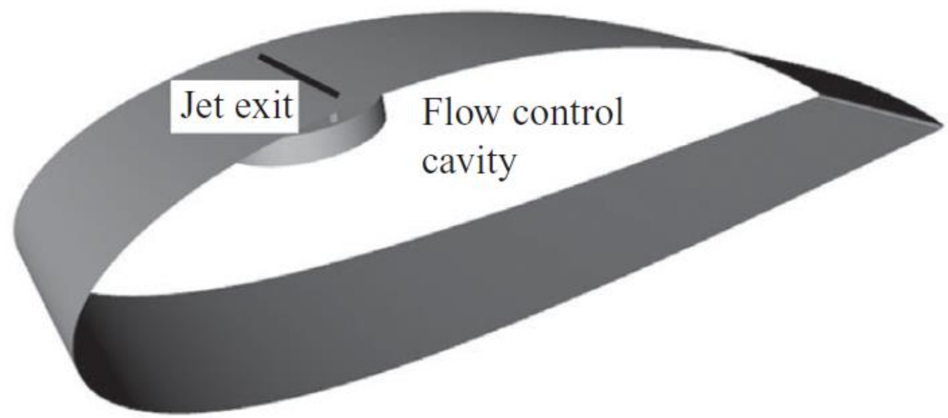


The Zero-Net-Mass-Flux

- No mass addition, only momentum to the embedding flow.
- B d suction stroke through an
  o ane.

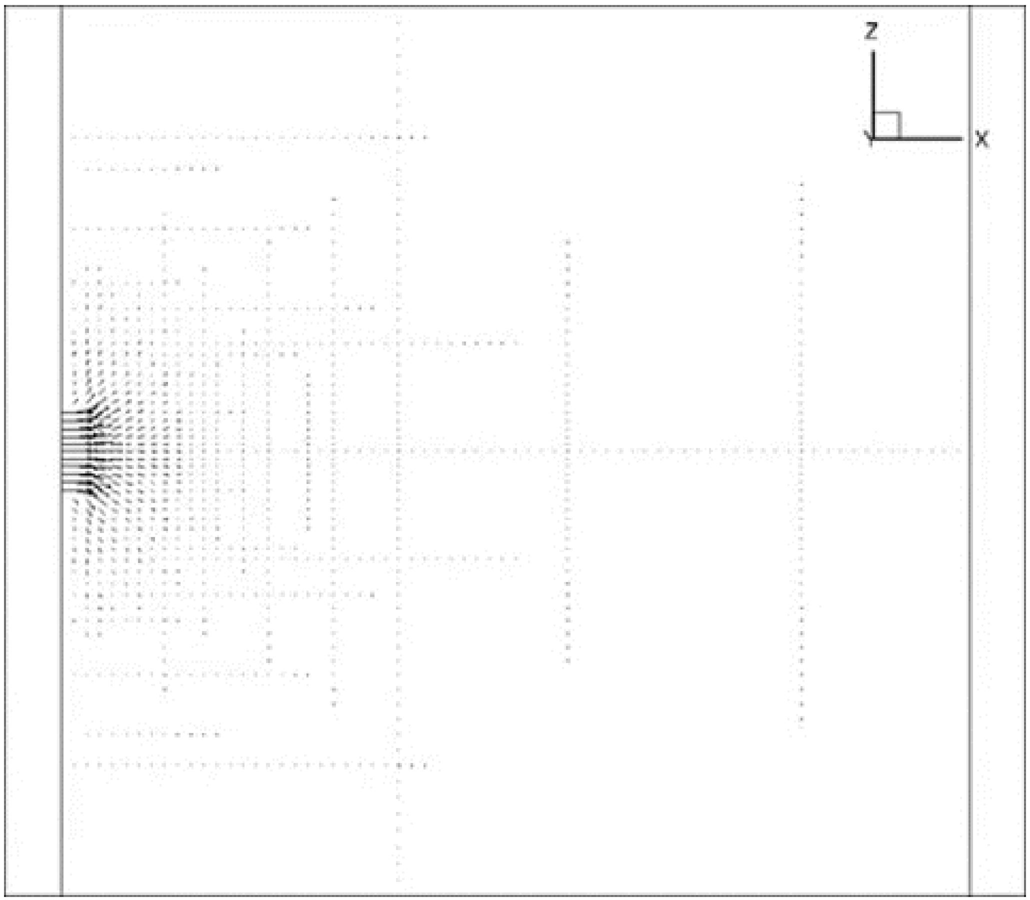


ZNMF scheme (Zhang, 2007)



Cavity set in the airfoil (Sahni, 2011)

The Zero-Net-Mass-Flux



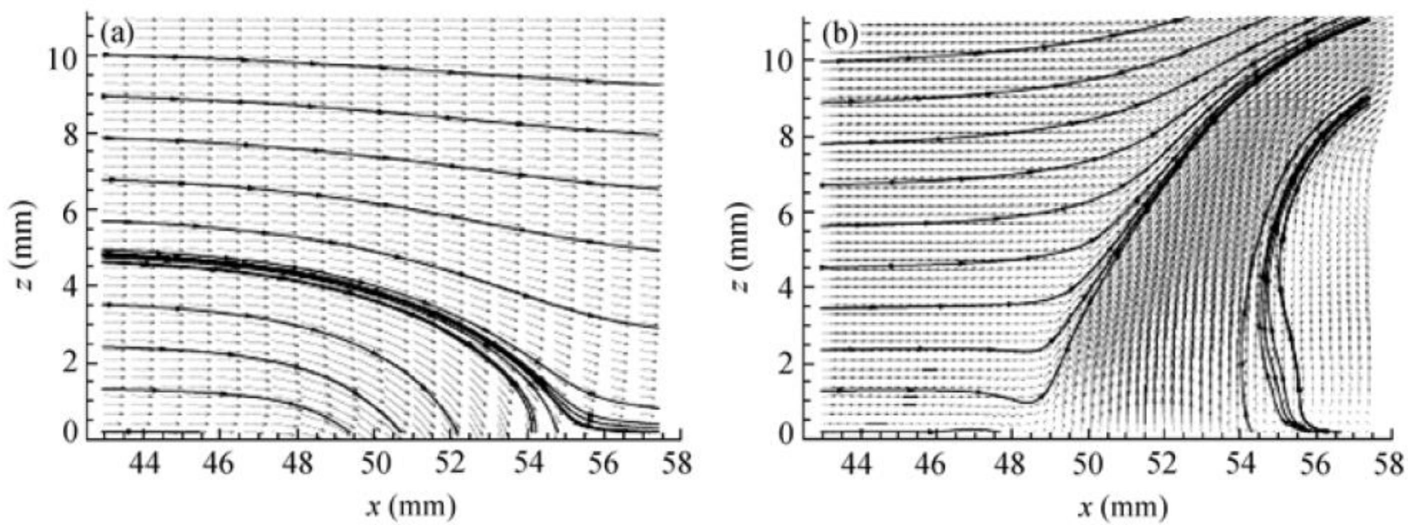
Synthetic jet behaviour
(quiescent flow)

State of the art

- Experimental studies to appreciate the jet behaviour *(Ugrina 2007)*

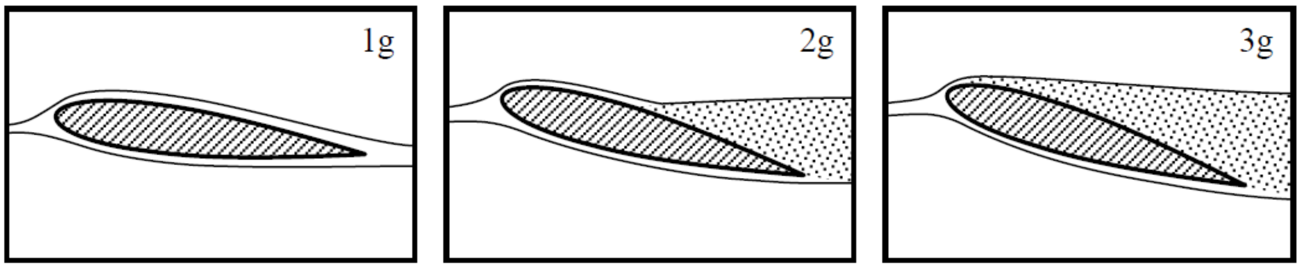
- Synthetic jet has to enter inside the boundary layer

  - Too strong → Out of the boundary layer
  - Too weak → No effects on the boundary layer

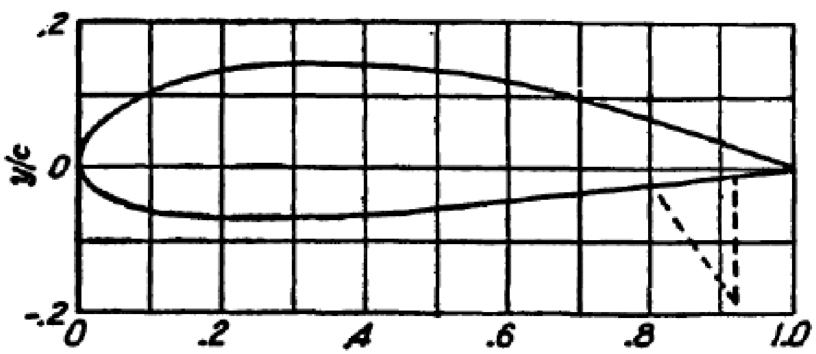


ZNMF jet streamlines (cross flow). (a)Suction stroke; (b) Blowing stroke (Ugrina, 2007)

Meshing the NACA 4421 Airfoil



Stall process in thick airfoils (Meseguer, 2004)



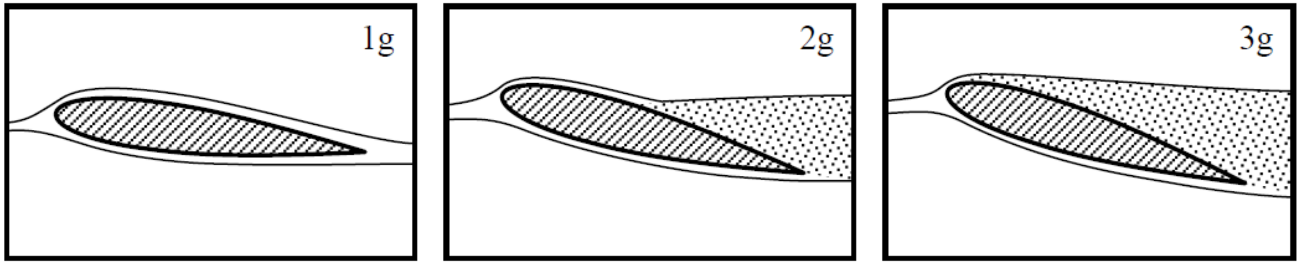
NACA 4421 Airfoil (Abbott, 1959)

Relative thickness: $\delta/c > 0.15$

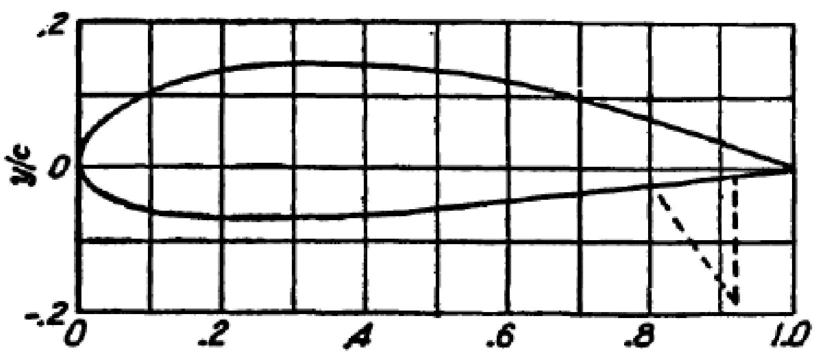
$$\frac{\delta}{c} = 0.21$$

Thick airfoil

Meshing the NACA 4421 Airfoil



Stall process in thick airfoils (Meseguer, 2004)



NACA 4421 Airfoil (Abbott, 1959)

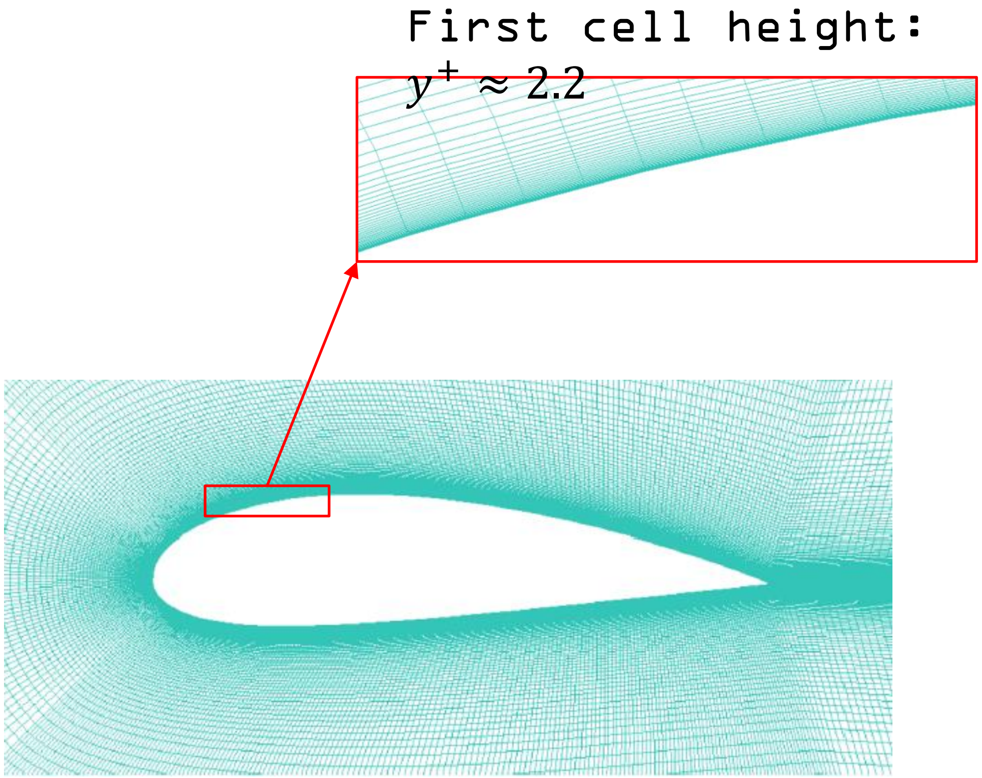
Relative thickness:

$$\frac{\delta}{c} = 0.21$$

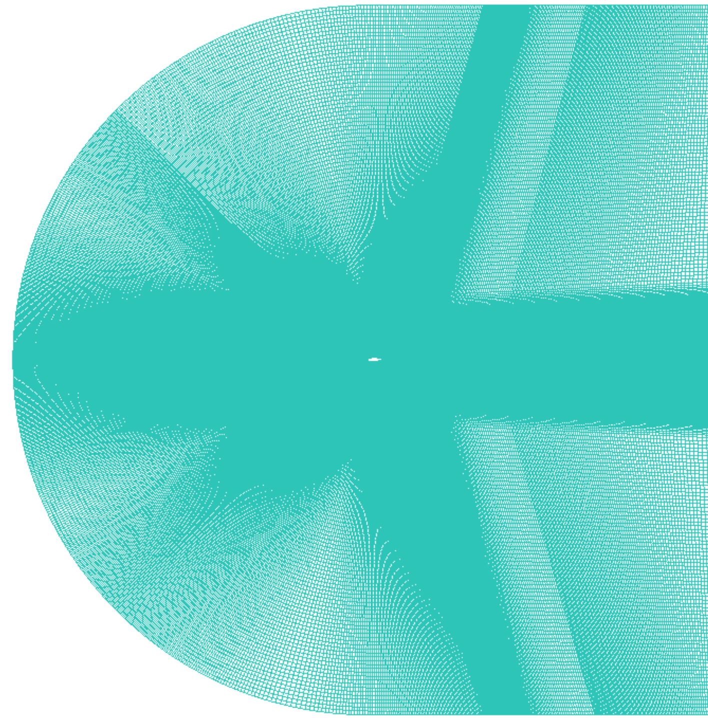
$\delta/c > 0.15$

Thick airfoil

Meshing the NACA 4421 Airfoil

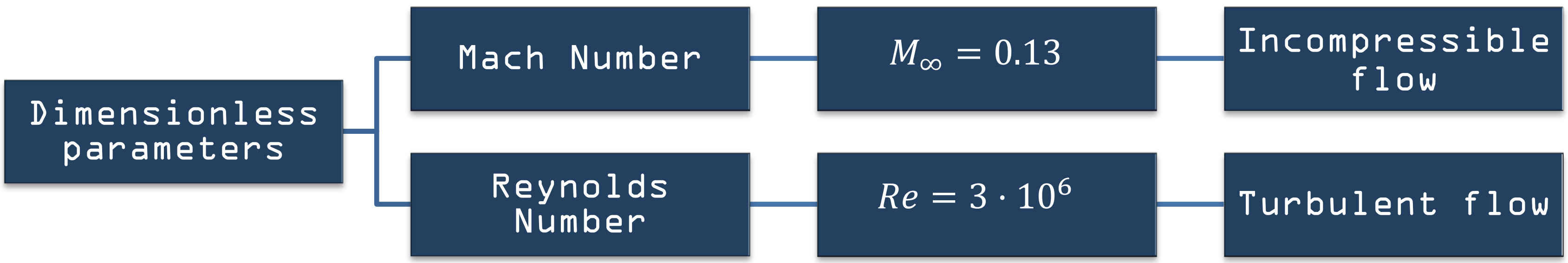


Mesh around the airfoil



Mesh in the fluid field

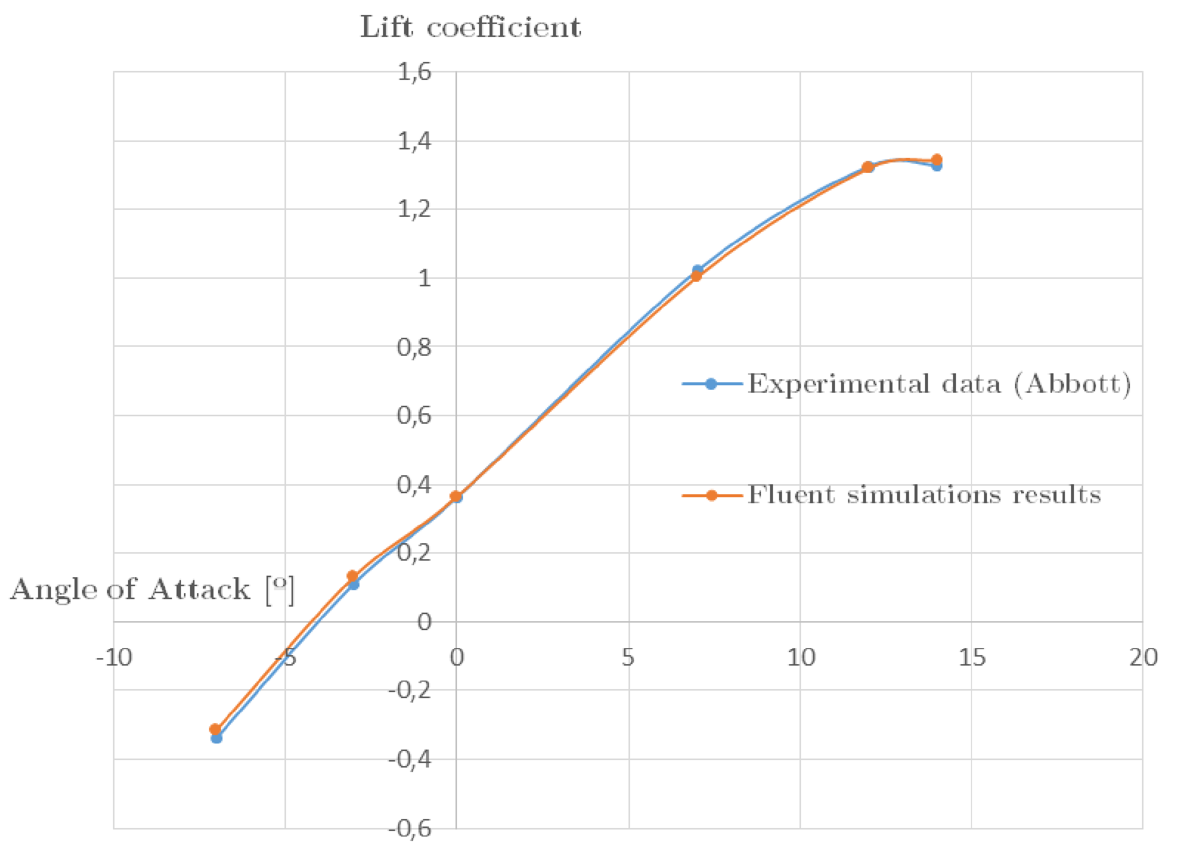
Setting simulations parameters



Characteristic parameters of the simulations

Solver used in the simulations

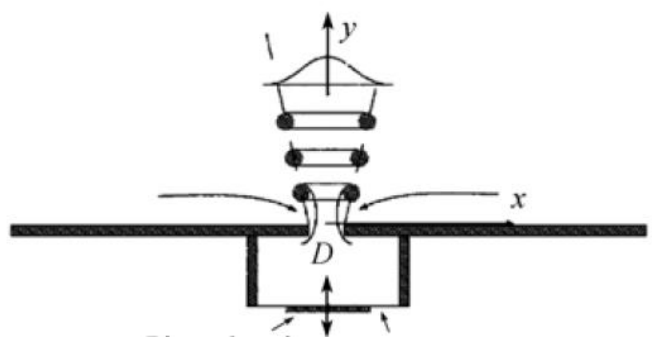
Evaluating mesh and parameters



$C_l - \alpha$ curve of NACA 4421 airfoil

Setting the ZNMF

- ZNMF can be simulated using boundary conditions
  - Sinusoidal function, without offset (no mass addition)
  - Velocity perpendicular to the surface, with a characteristic frequency

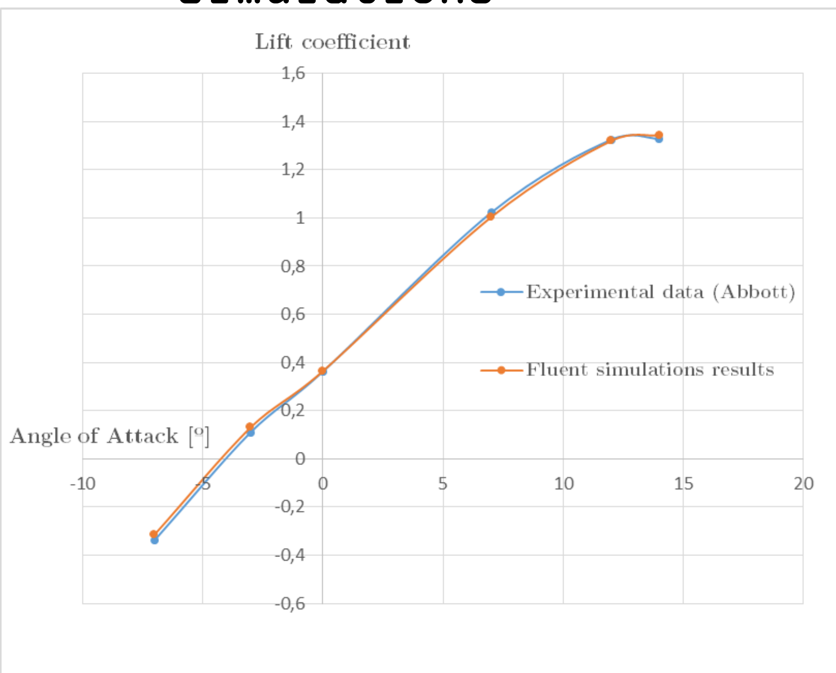


Sinusoidal function

- Amplitude (A) $[m/s]$ → Momentum coefficient c_μ
- Frequency (f) $[Hz]$ → Lift coefficient (transient)

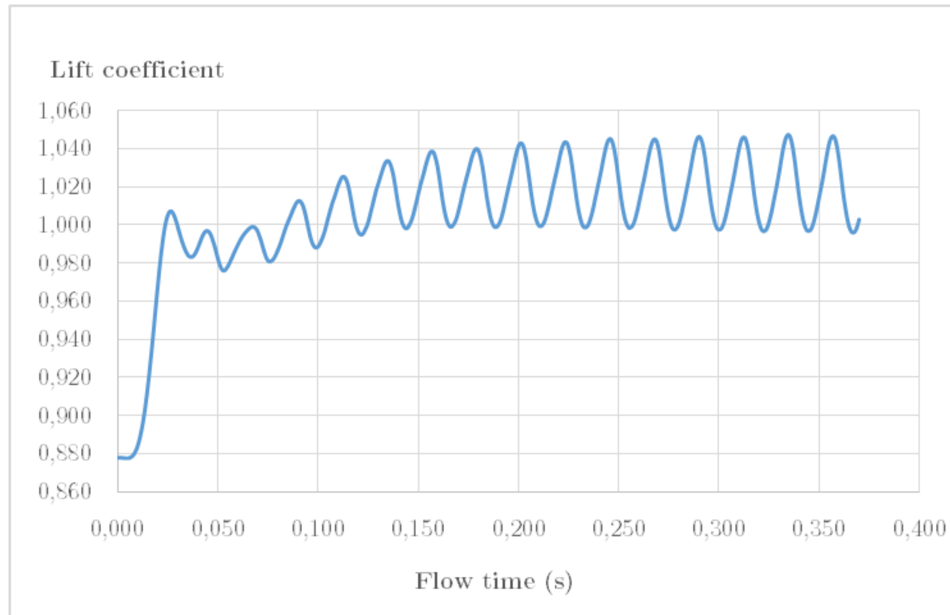
Setting the ZNMF

STATIC Simulations



$C_l - \alpha$ *curve of NACA 4421 airfoil*

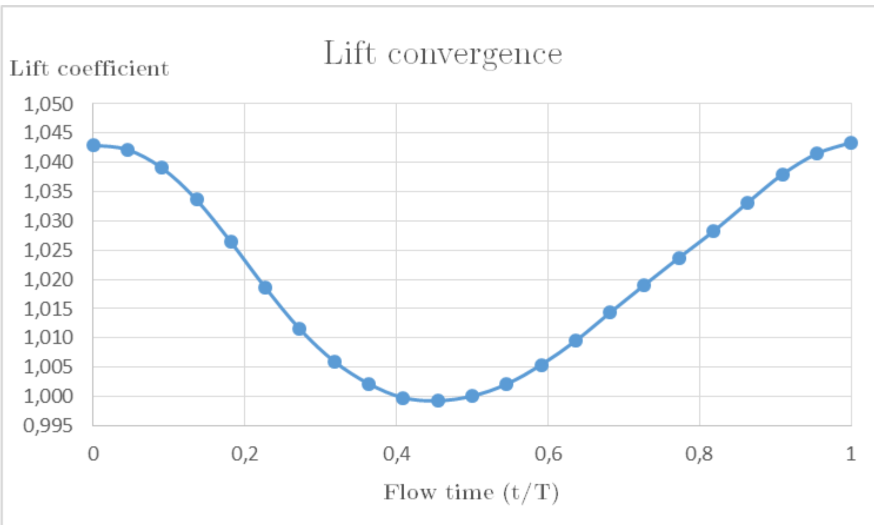
DYNAMIC Simulations



Lift coefficient value in dynamic simulations

Setting the ZNMF

Frequency (f) $[Hz]$



$$\boldsymbol{f \approx 45\ Hz}$$

Amplitude (A) $[m/s]$

Momentum coefficient

$$c_\mu = \frac{Momentum\ near\ orifice}{Momentum\ upstream}$$

$$c_\mu = \frac{h \cdot A^2 \cdot \rho_x}{c \cdot U_\infty^2 \cdot \rho_\infty}$$

$$\boldsymbol{A \approx 90\ m/s}$$

Setting the ZNMF

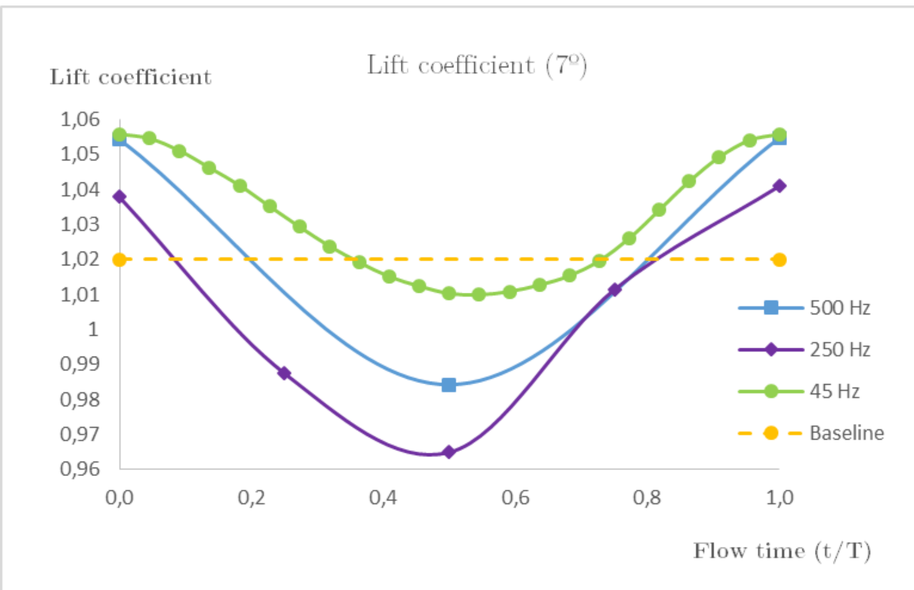
- Different frequencies have to be studied
  - Same order of magnitude *(Durrani, 2011)*
  - One order of magnitude larger *(Zhang, 2008)*

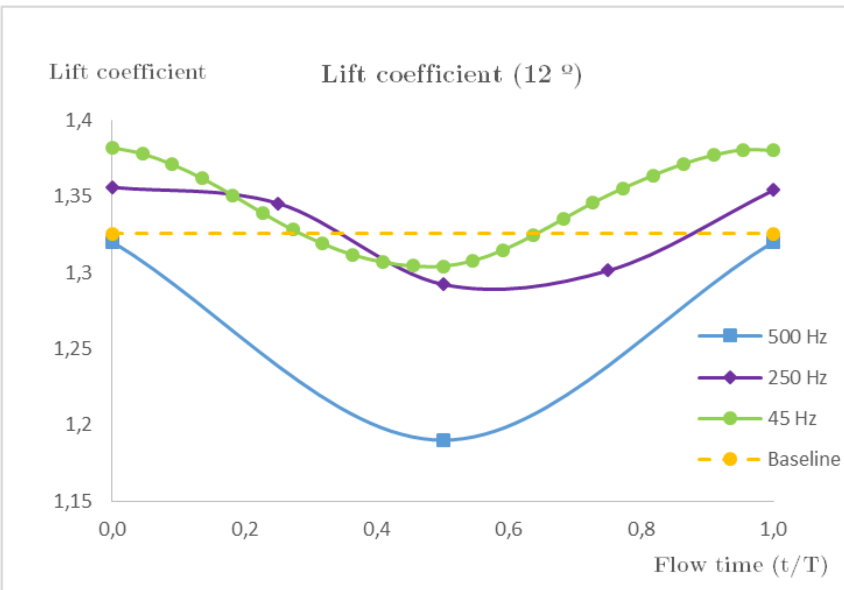
SCENARIOS (Frequencies & Angles of attack)									
Angle of attack	7º			12º			14º		
Frequency (Hz)	45	250	500	45	250	500	45	250	500

- Other parameters settled following experimental bibliography
  - Orifice length $(h = 2\,mm)$
  - Orifice position $\left(\frac{x}{c} = 0{,}17\right)$

Results: Lift coefficient

- The ZNMF should decrease the amplitude of the oscillation



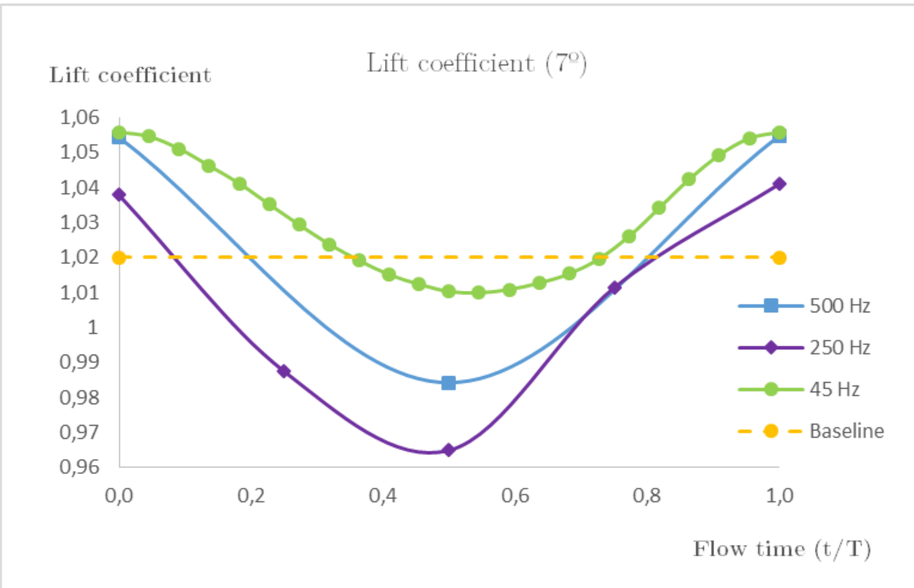


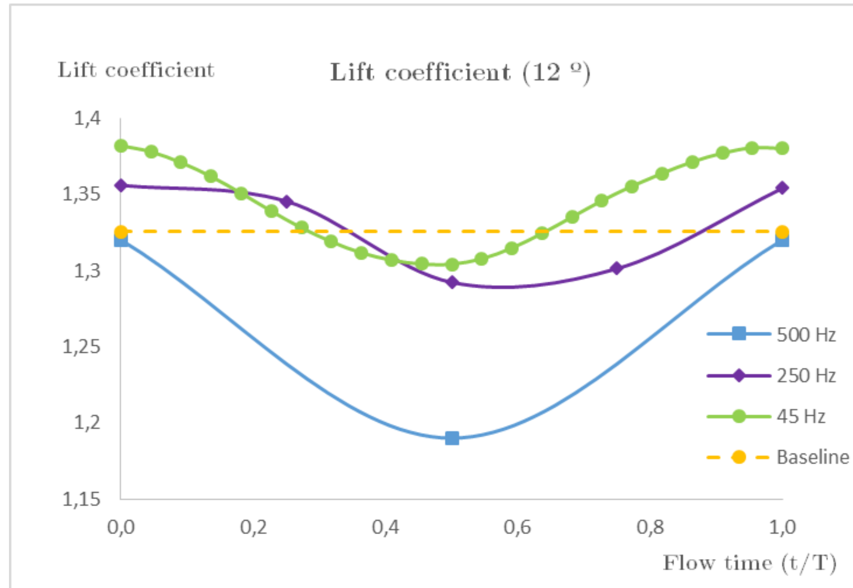
7º			
Frequency	45 Hz	250 Hz	500 Hz
Amplitude	0,046	0,076	0,071

12º			
Frequency	45 Hz	250 Hz	500 Hz
Amplitude	0,078	0,104	0,130

Results: Lift coefficient

➢ The ZNMF should decrease the amplitude of the oscillation



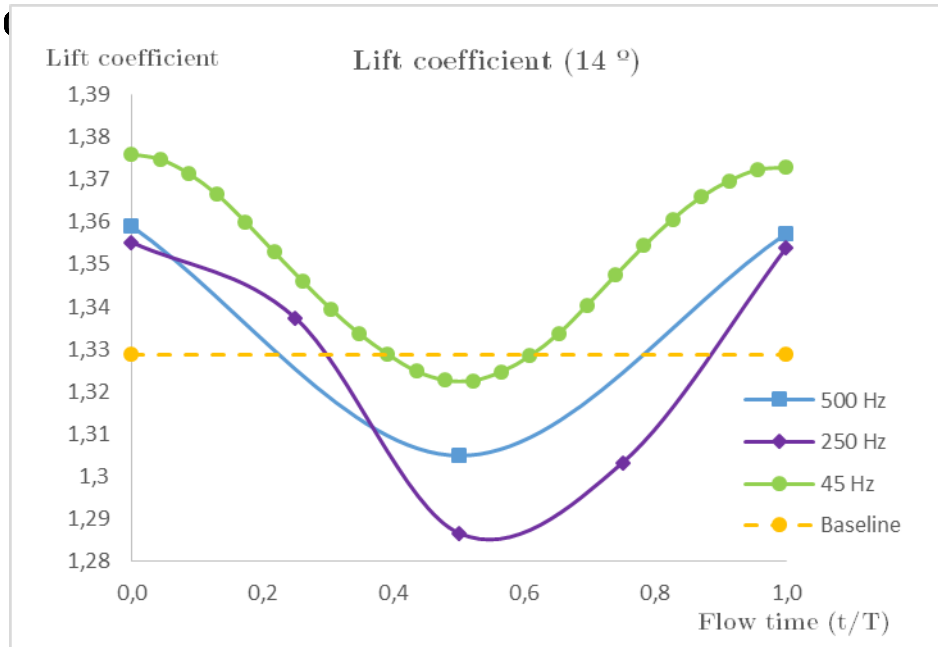


7º			
Frequency	45 Hz	250 Hz	500 Hz
Amplitude	0,046	0,076	0,071

12º			
Frequency	45 Hz	250 Hz	500 Hz
Amplitude	0,078	0,104	0,130

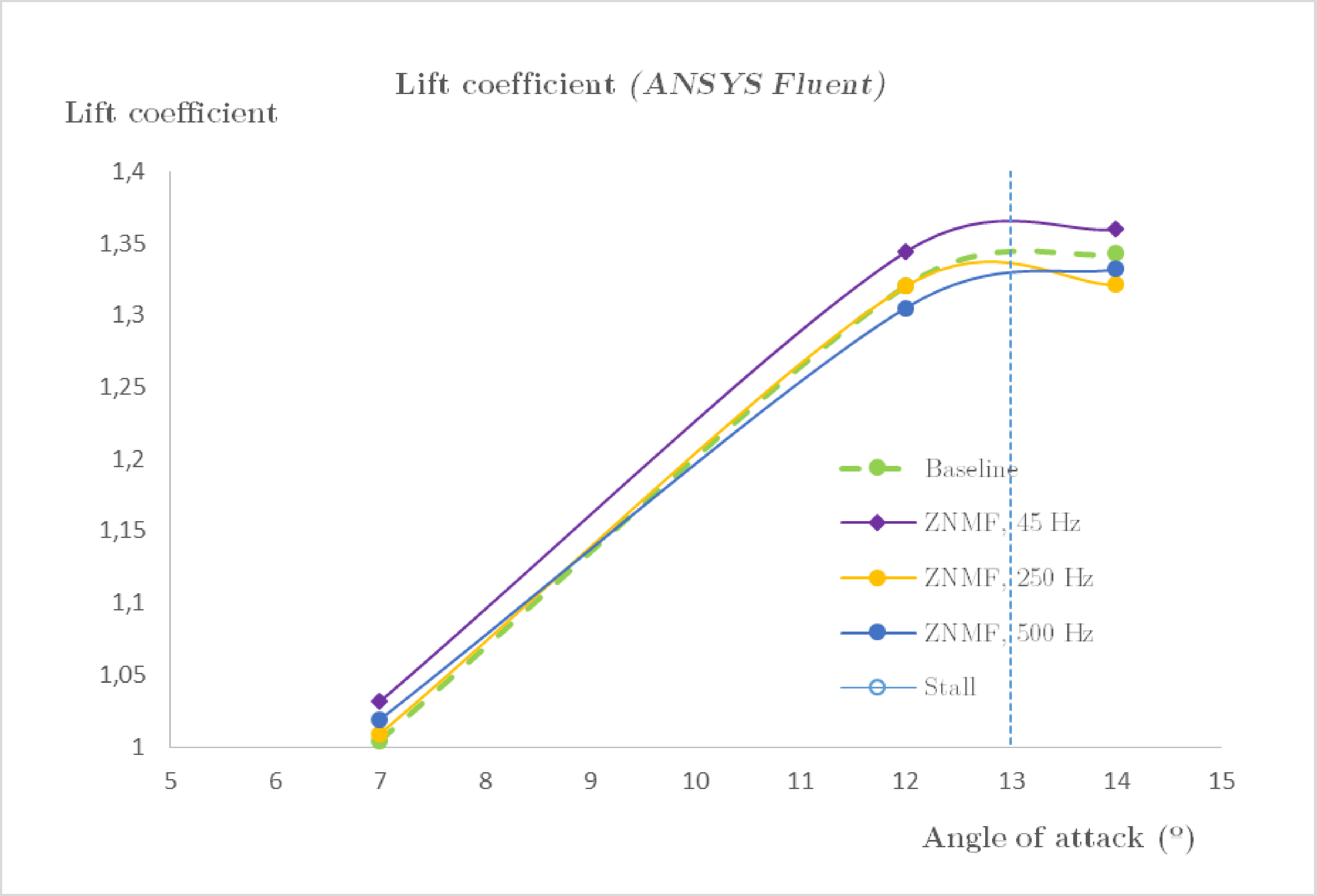
Results: Lift coefficient

- The ZNMF should decrease the amplitude of the oscillati

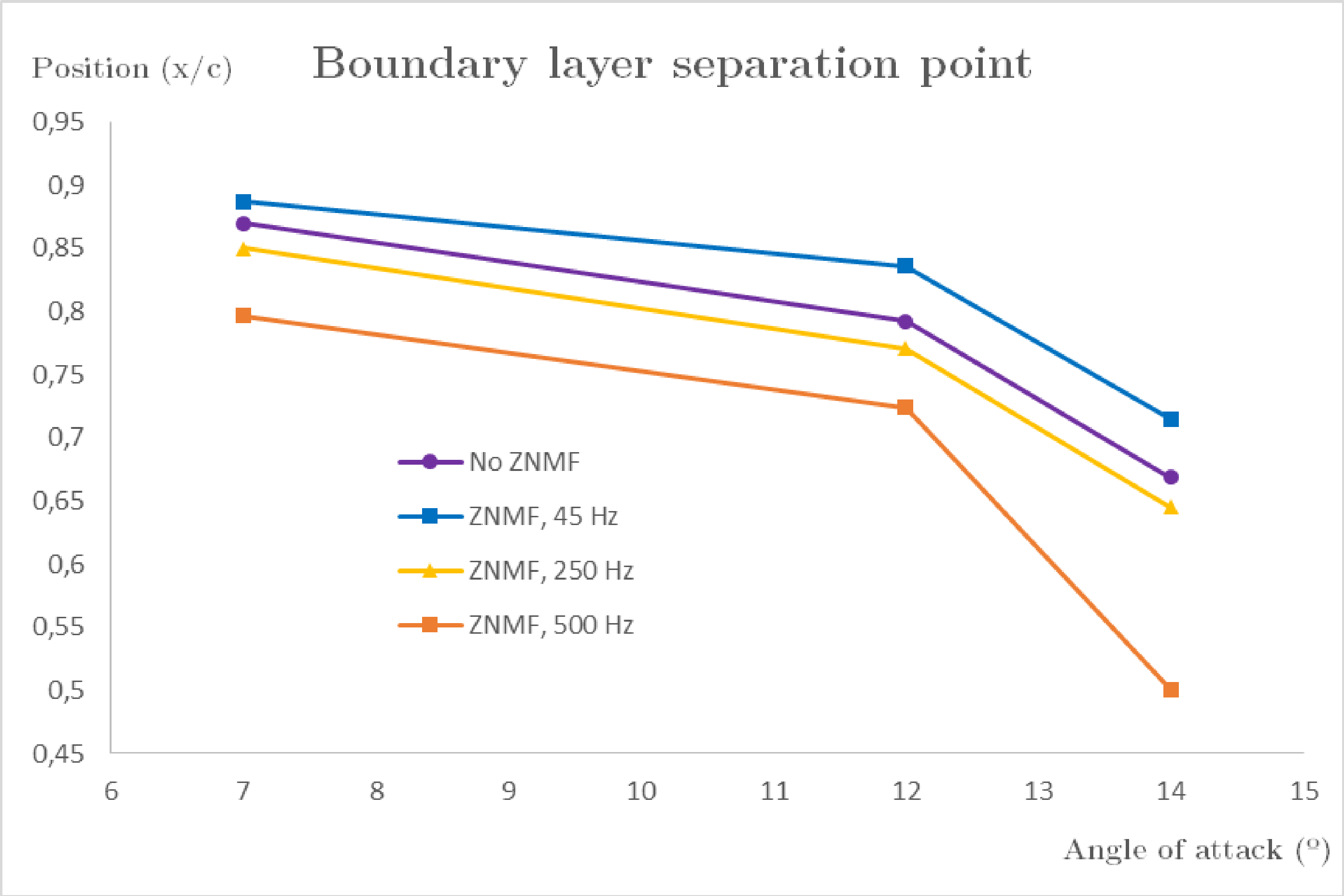


14º			
Frequency	45 Hz	250 Hz	500 Hz
Amplitude	0,078	0,104	0,130

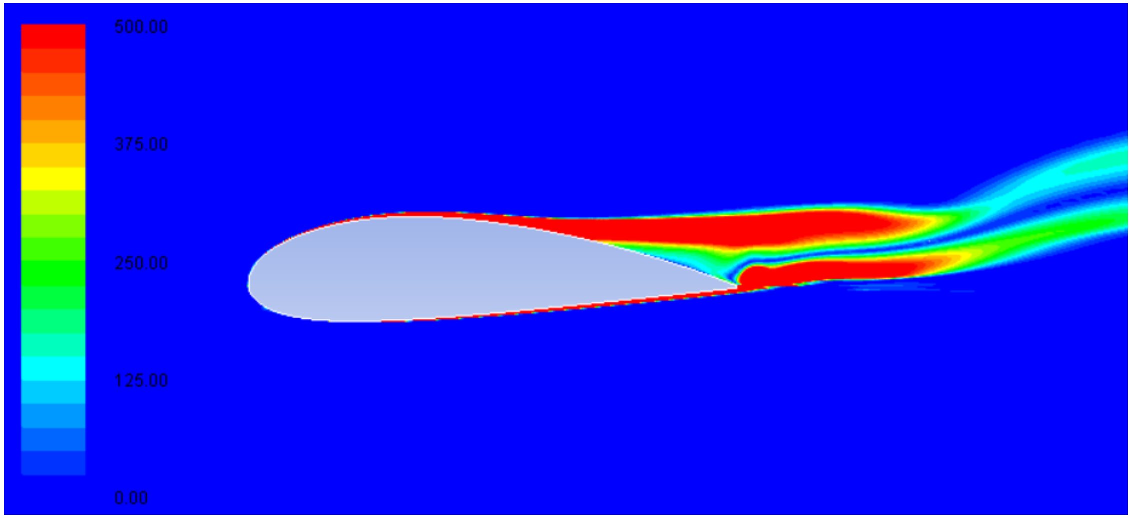
Results: Lift coefficient



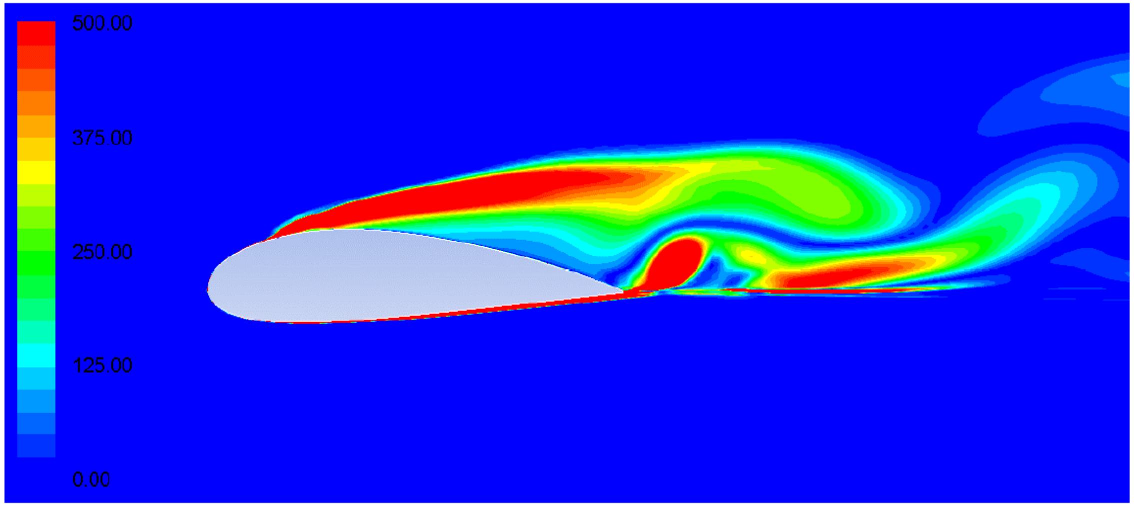
Results: Boundary layer separation



Results: Vorticity magnitude



Vorticity [1/s] of a NACA 4421 without ZNMF.
$\alpha = 12^{\circ}$ (ANSYS Fluent)



Vorticity [1/s] of a NACA 4421 using ZNMF.
$\alpha = 12^{\circ}$ (ANSYS Fluent)

Conclusions

- The ZNMF improves NACA 4421 performance, best results at 45 Hz
  - Lift coefficient oscillation amplitude supressed
  - Boundary layer separation point moved upstream
  - Separated region diminished
- The actuator has to be precisely calibrated
- Future work needed to get study the effect of each parameter
  - Change C_μ value
  - Change orifice parameters (length, position)
  - Compare ZNMF performance with other AFC devices

Applying AFC in automobiles

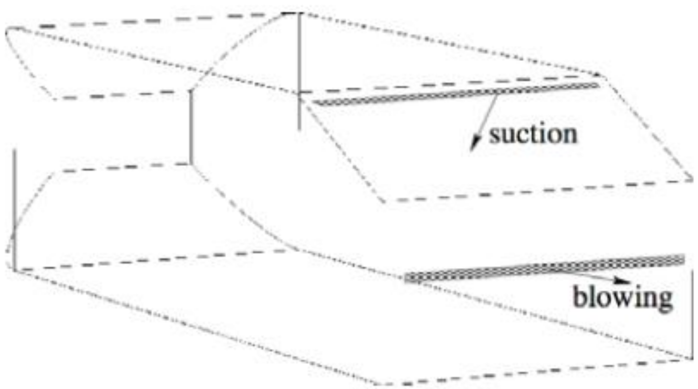
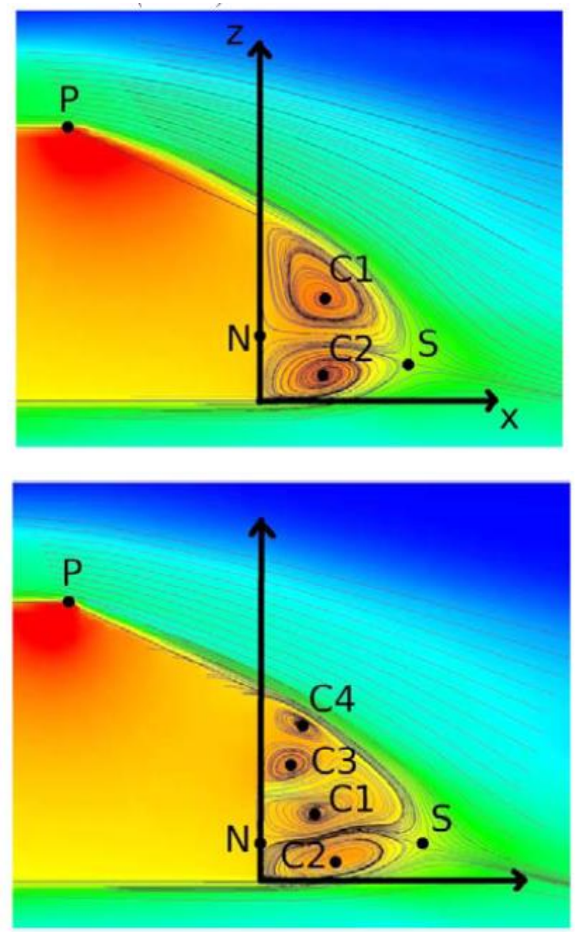


Fig. 7. Transversal control jet lines.



Streamlines in the back of the car without AFC (top) or using it (bottom)

Escola Tècnica Superior d'Enginyeries Industrial i Aeronàutica de Terrassa
UNIVERSITAT POLITÈCNICA DE CATALUNYA

Numerical Study on Active Flow Control using Synthetic Jet Actuators over a NACA 4421 Airfoil

AUTHOR
Xavier Guerrero Pich

Sustainability study

High lift device → Fuel savings → CO_2 emissions decreased

- ZNMF actuator saves up to 3% of a common commercial aircraft fuel consumption *(Agarwal, 2012)*

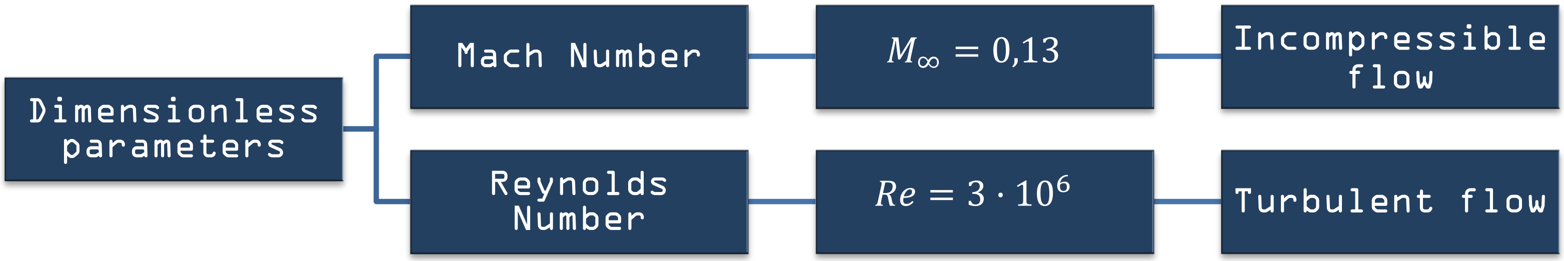
Hourly flight

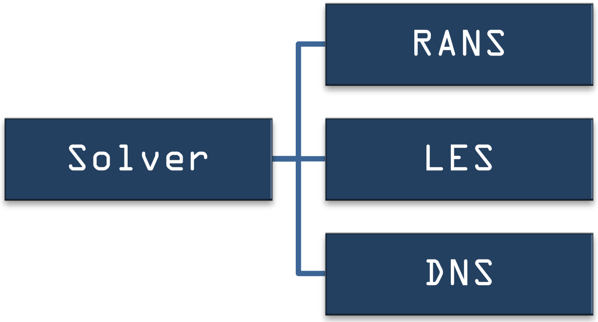
A320 consumption
$2500\ kg_{kerosene}/h$

A320 emissions
$3{,}23\ kg_{CO_2}/kg_{kerosene}$

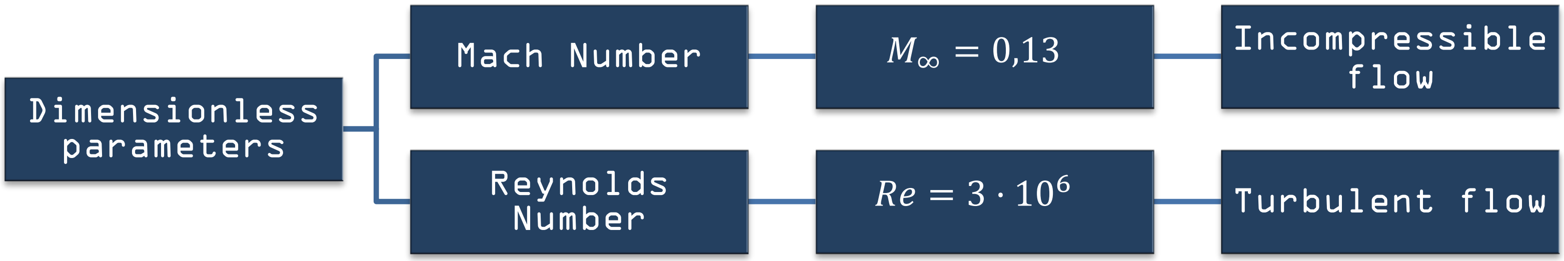
CO_2 emissions saved
$240\ kg\ CO_2$

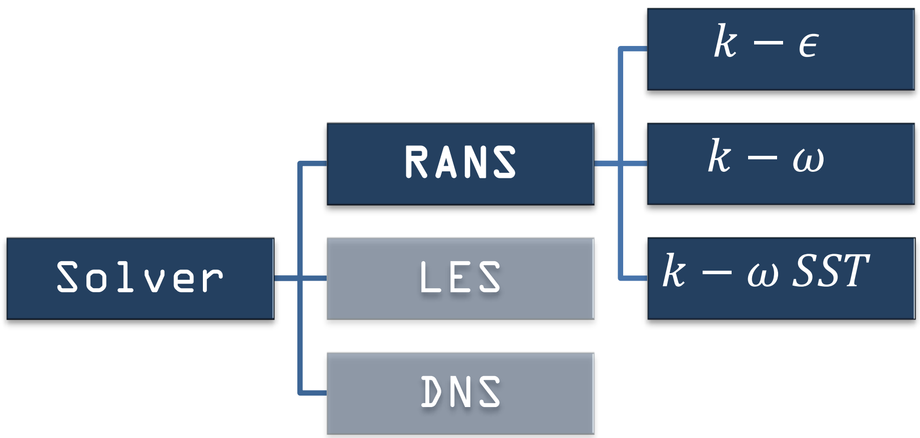
Setting simulations parameters





Setting simulations parameters





Setting simulations parameters