Journée CaSciModOT
OSUC Orléans
17 décembre 2014

CALCUL D'ÉCOULEMENTS TURBULENTS AUTOUR DE VÉHICULE TERRESTRE OU AÉRIEN

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Objectives

✓ **Using numerical simulations**

⇒
- Efficient numerical software
- Numerical scheme
- Mathematical models
- Relevant physical mechanism computations

✓ **Industrial applications:**

- Development of statistical computations
- But for unsteady turbulent flows
- Efficient URANS model : Semi-deterministic model

Turbulent models

✓ **URANS** ⇨ **existing models**

- Turbulent viscosity concept
- k-ε, k-ω sst
- Viscosity coefficient C_μ: constant

✓**Improved model :**

- Semi–deterministic model
- Viscosity coefficient C_μ : space and time flow dependent

Flow equations

- Decomposition

$$\Rightarrow \quad \phi(x_k,t)=\tilde{\phi}(x_k,t)+\phi_r(x_k,t)$$

Coherent Incoherent

- Equations for coherent part

$$\Rightarrow \quad \frac{\partial W}{\partial t}+\frac{\partial F_1}{\partial x_1}+\frac{\partial F_2}{\partial x_2}+\frac{\partial F_3}{\partial x_3}=0$$

- Shear stress tensor:

$$\sigma_{ij}=\left(\hat{P}+\frac{2}{3}\mu\left(\sum_{k=1}^{3}\frac{\partial \tilde{U}_k}{\partial x_k}\right)\right)\delta_{ij}-2\mu S_{ij}+\hat{\rho}\,\widetilde{u_i u_j}$$

Unknown

Closure procedure

✓ Closure model

$$\rho \widetilde{u_i u_j} = -2\mu_t S_{ij} + \frac{2}{3}\left(\rho \tilde{k} + \mu_t \left(\sum_{k=1}^{3} \frac{\partial \tilde{U}_k}{\partial x_k}\right)\right)\delta_{ij} + T_{ij}$$

✓ Turbulent viscosity

$$\mu_t = C_\mu \frac{\rho \tilde{k}^2}{\tilde{\varepsilon}}$$

$$C_\mu = \frac{2}{3(A_1 + \eta + \gamma_1 \xi)}$$

$$\Omega = \left(2\Omega_{ij}\Omega_{ij}\right)^{\frac{1}{2}}$$

$$S = \left(2S_{ij}S_{ij}\right)^{\frac{1}{2}} \qquad \eta = \frac{\tilde{k}S}{\tilde{\varepsilon}} \qquad \xi = \frac{\tilde{k}\Omega}{\tilde{\varepsilon}}$$

$A_1=1.25$ $\gamma_1=0.9$

Non-linear part

$$T_{ij} = -\frac{\rho \tilde{k}^3}{\tilde{\varepsilon}^2} \underline{f(\eta,\xi)}$$

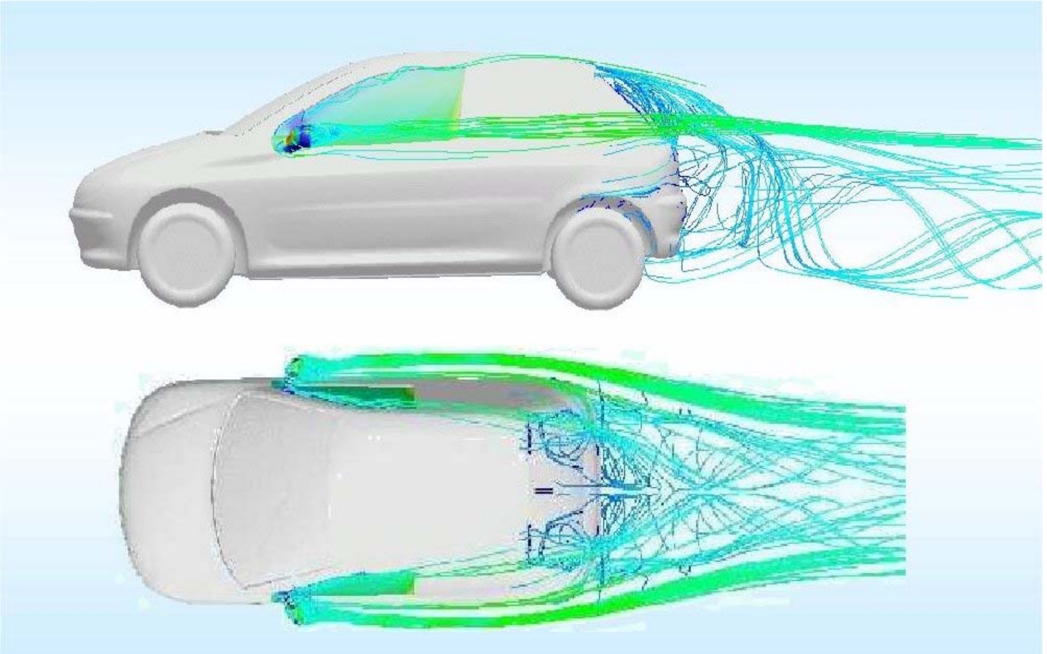
$$\times \Big[(C_{\tau 2} + 2C_{\tau 1} + C_{\tau 3})\left(S_{ik} S_{jk} - \frac{1}{3}\delta_{ij} S_{lk} S_{lk} \right)$$

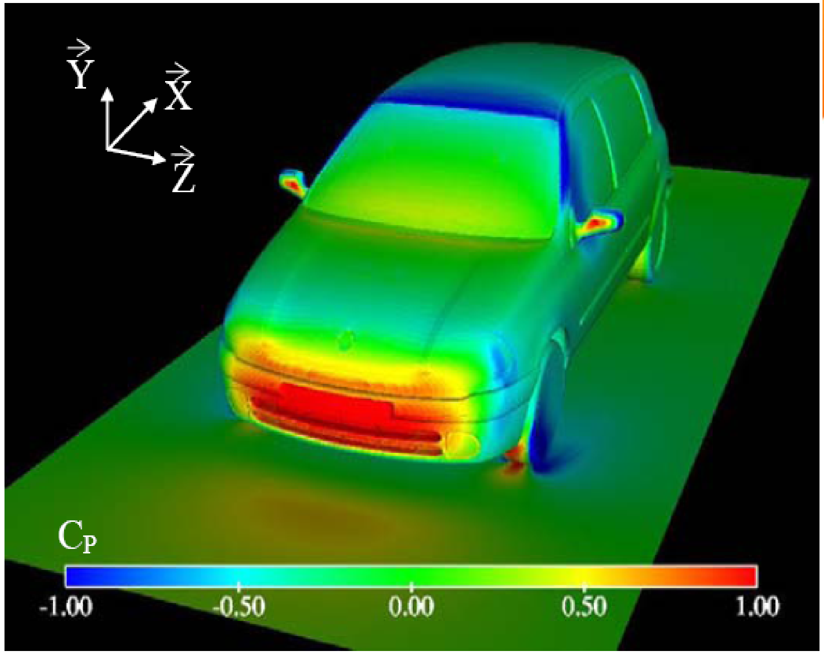
$$+ (C_{\tau 2} - C_{\tau 3})\left((S_{ik}\Omega_{jk} + S_{jk}\Omega_{ik}) - \frac{2}{3}\delta_{ij} S_{lk}\Omega_{lk} \right)$$

$$+ (C_{\tau 2} - 2C_{\tau 1} + C_{\tau 3})\left(\Omega_{ik}\Omega_{jk} - \frac{1}{3}\delta_{ij}\Omega_{lk}\Omega_{lk} \right) \Big]$$

$$f(\eta,\xi) = \frac{1}{A_2 + \eta^3 + \gamma_2 \xi^3}$$

Drag reduction





✓ **European norms:**

- ➢ limitation of CO_2 emission
- ➢ Improvement of fuel consumption

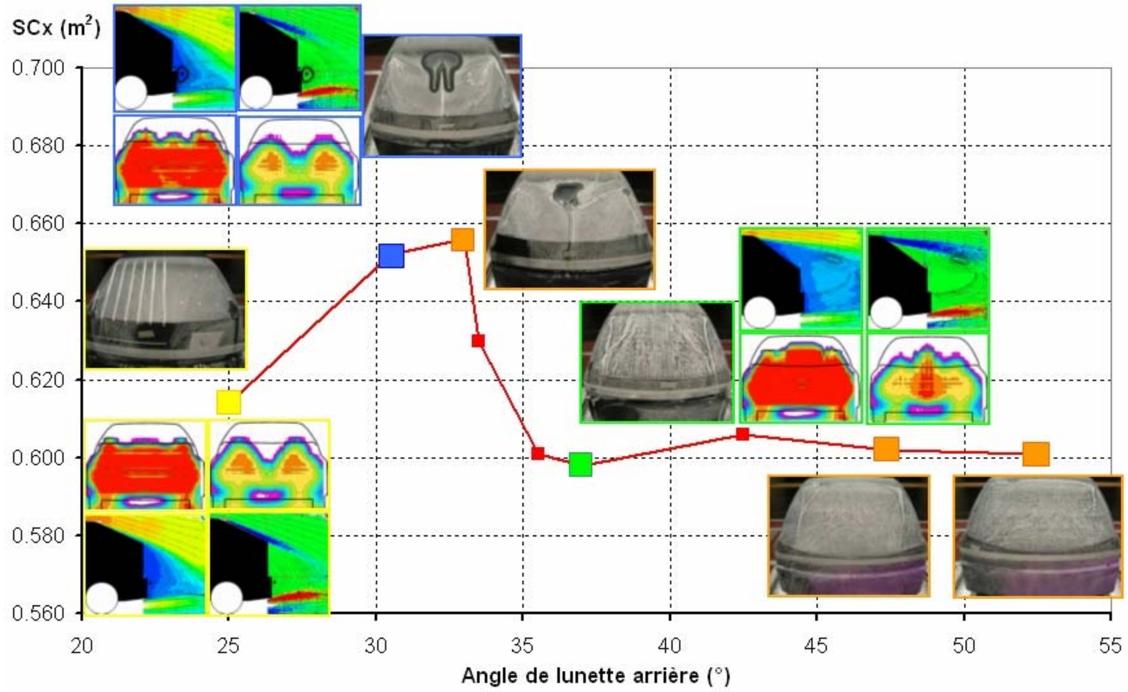
➡ **Drag reduction :**

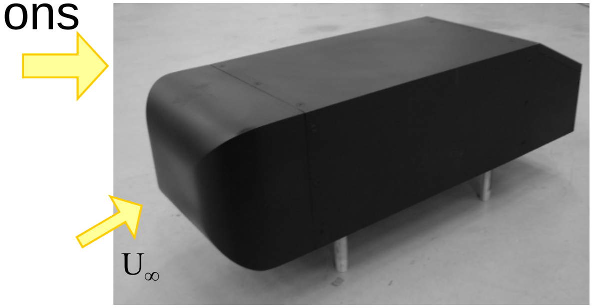
- ➢ Importance of pressure drag

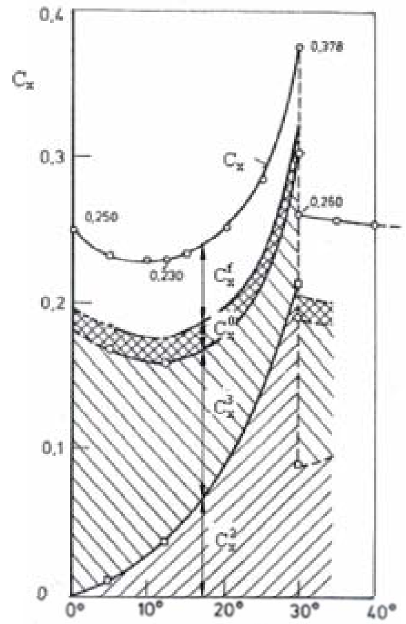
Aerodynamic drag

Simplifications

Rear window angle effects



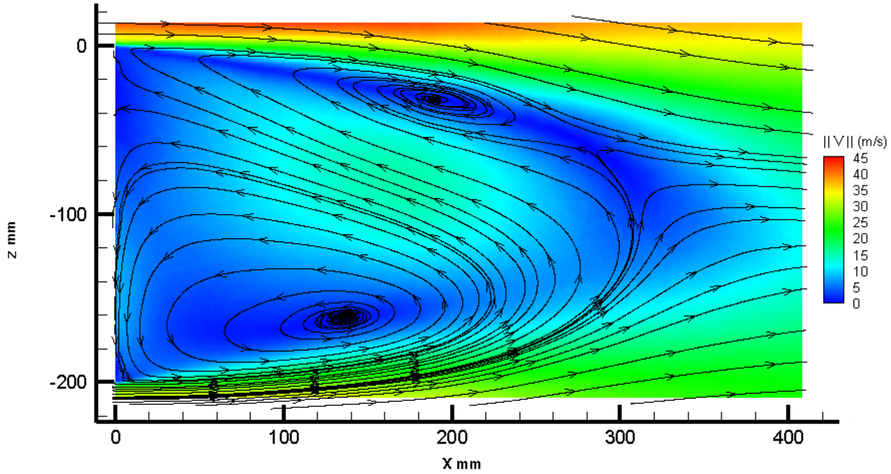


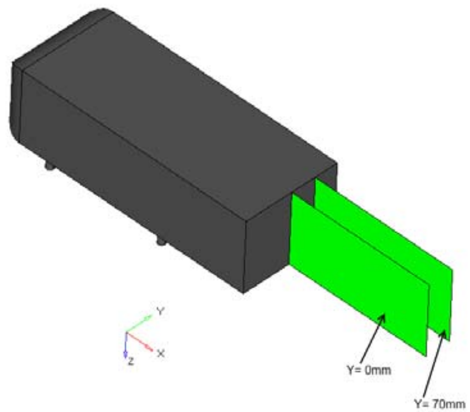


Ahmed body

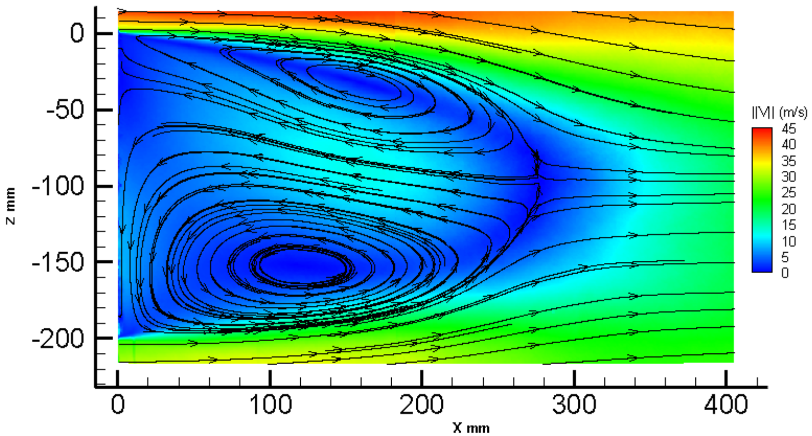
Velocity field

Median Plane

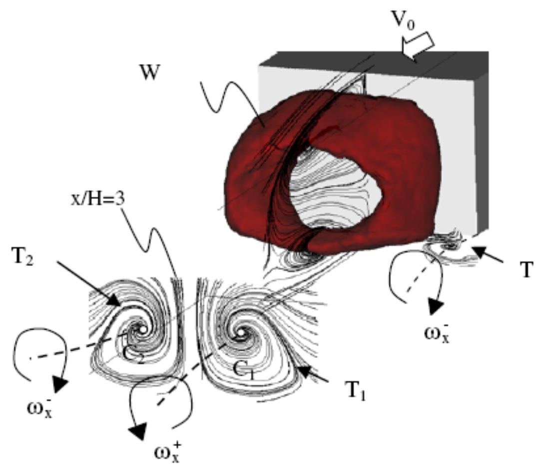




Plane Y = 70mm

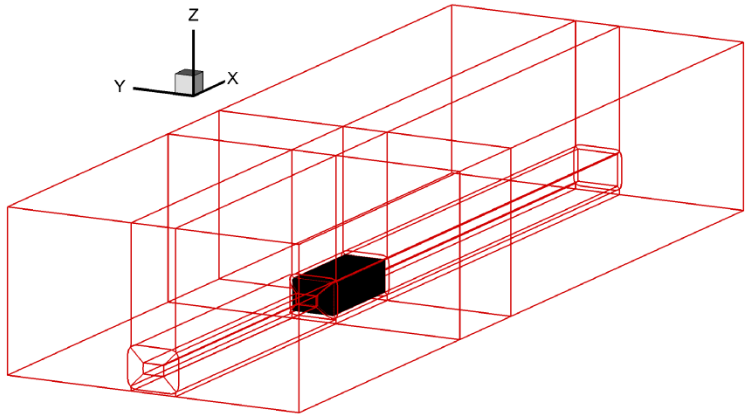


Thèse Arnaud LAHAYE



- Kelvin Helmholtz and vortex pairing (Strouhal greater than 1)
- Bénard – Von Karman vortex shedding in the far wake (St = 0.2)

Numerical Simulation: parameters



✓ **Boundary conditions:**

- Freestream velocity: 40 m/s
- Turbulent intensity: 1%
- Fixed ground plane

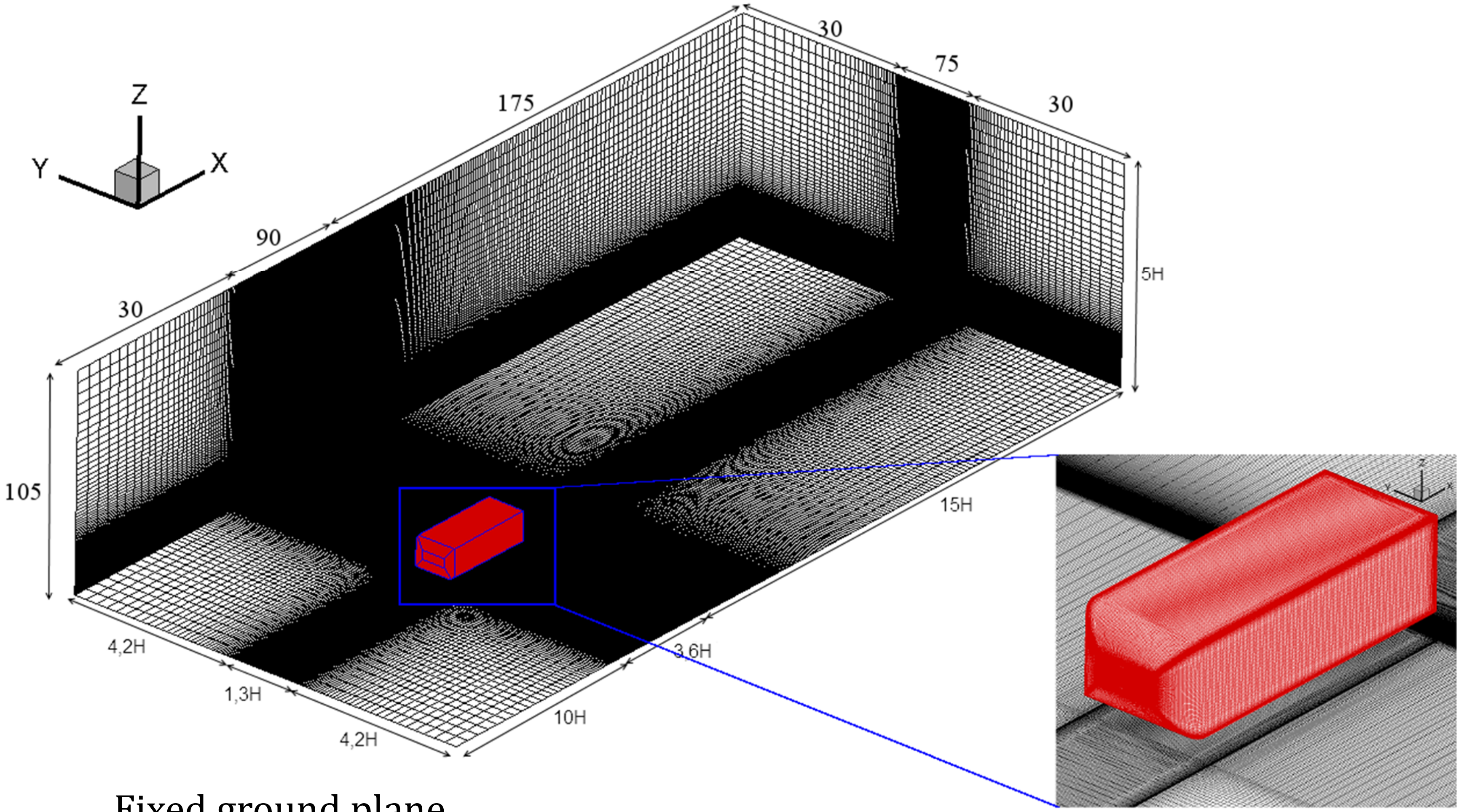
✓ **Numerical parameter:**

- U-RANS
- Space discretization: Jameson scheme
- Time discretization: Gear scheme
- CFL number : 5
- Time step: 10^{-4} s

✓ **Turbulence modeling:**

- Turbulence model: k-ω with SST correction

Simulation parameters



Fixed ground plane

$y^+ \approx 40$

Physical time ≈ 1s

Number of cell:
5 400 000

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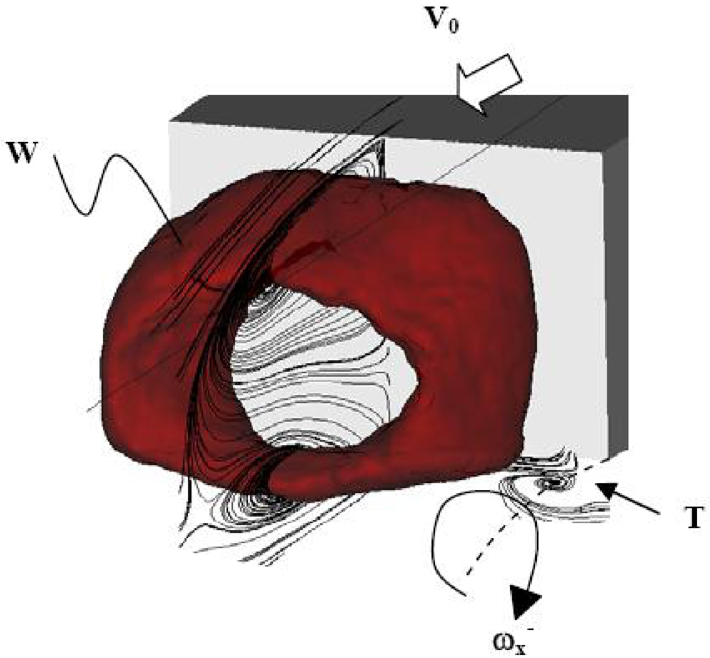
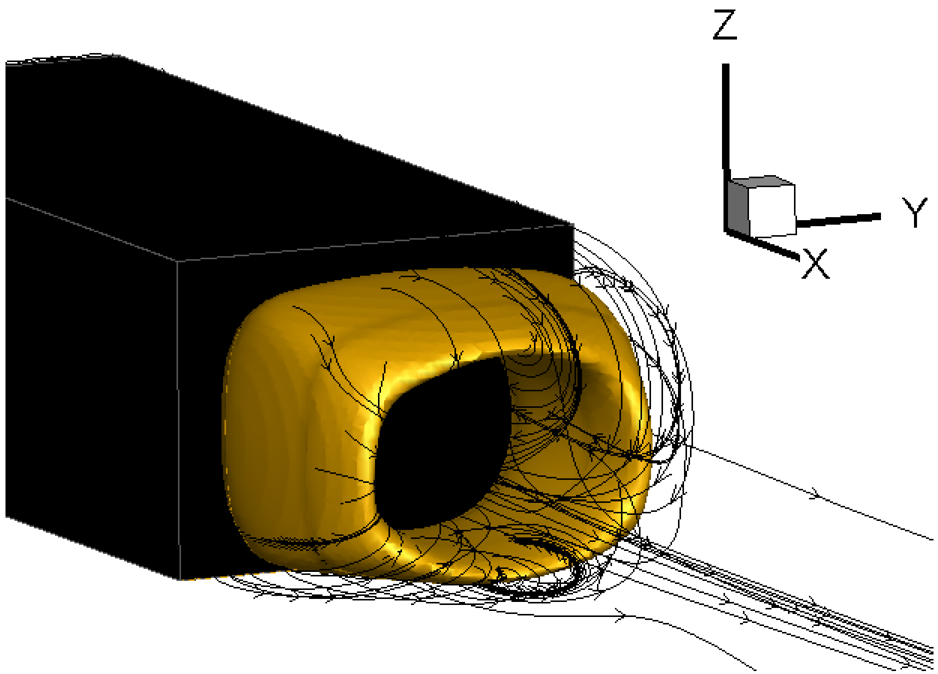
Mean flow

Topology of the near wake



Total pressure loss iso-surface of coefficient Cp_i=1.17 (*Roumeas, 2009*)



Total pressure loss iso-surface of coefficient Cp_i=1.11

- C_D = 0.296 (*Wassen,2010* => C_D= 0.279, *Verzicco, AIAA , 2002* => C_D= 0.291)
- The circular vortex ring that generates the pressure drag on the base of the model is reproduced by the simulation.

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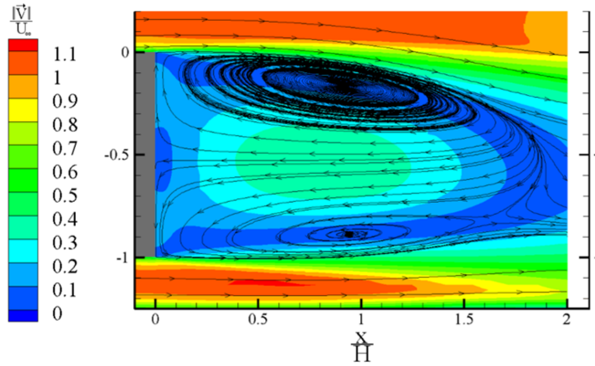
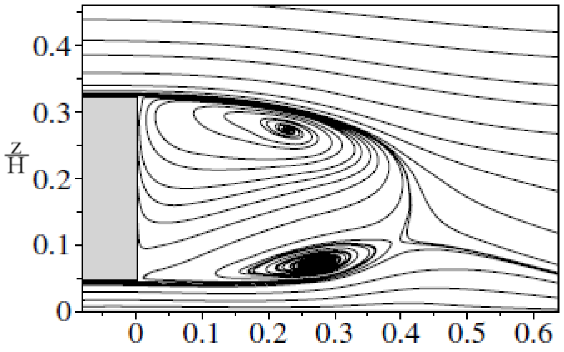
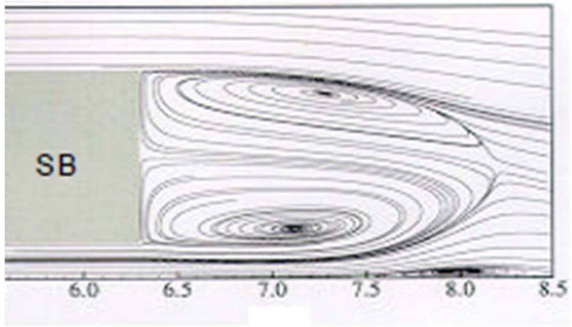
Mean flow

Mean velocity field in the vertical longitudinal plane



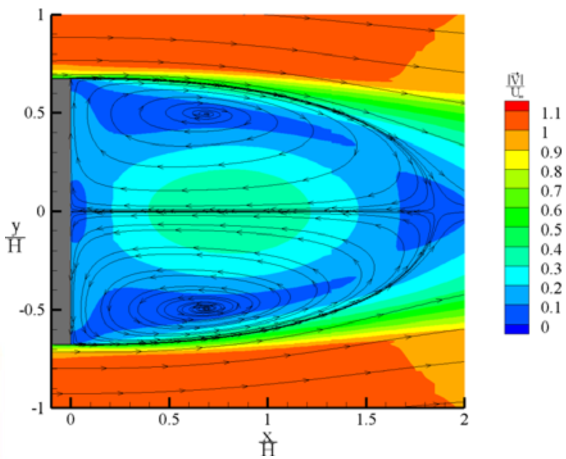


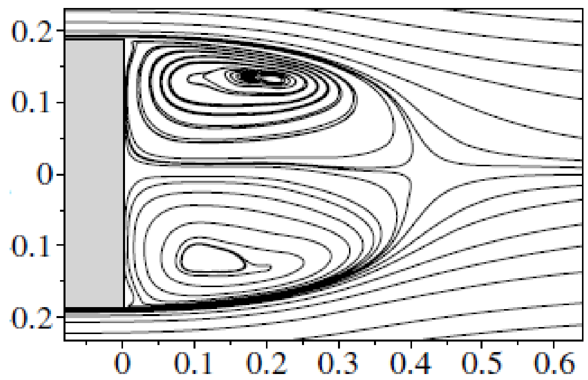
Wassen et al , 2010



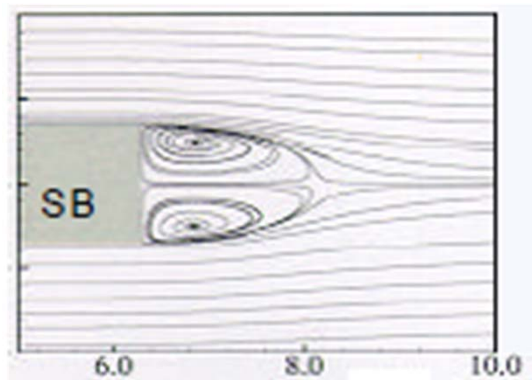
Khalighi et al, 2001

Mean velocity field in the horizontal longitudinal plane



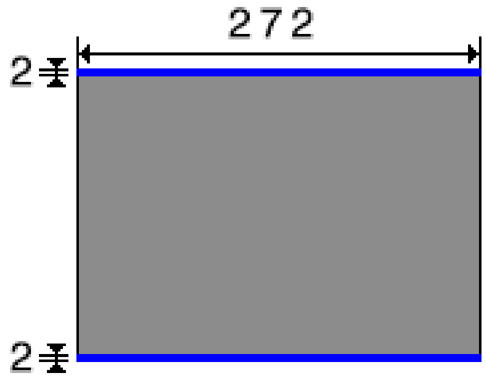


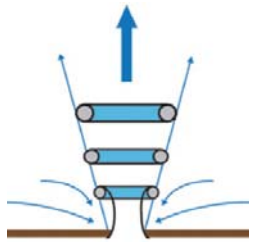
Wassen et al , 2010



Khalighi et al, 2001

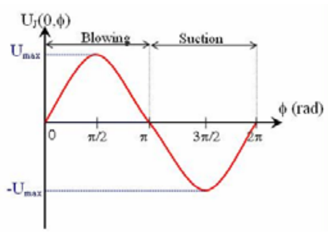
Control setup





- The synthetic jet is modeled with a boundary condition imposing a periodic injection along the slots.

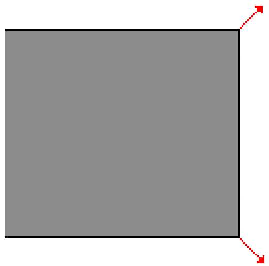
- Three orientations have been tested.



- The momentum coefficient ($c_{\mu} = \dfrac{2 \cdot h \cdot u_{Act}^2}{H \cdot U_{\infty}^2}$) varies between 0.005 and 0.02.

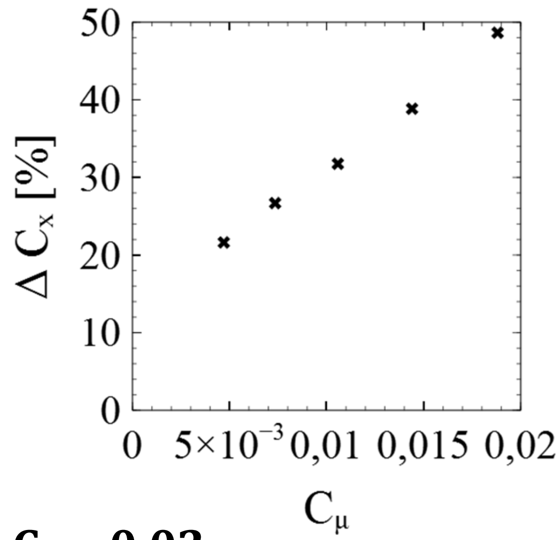
- The reduced frequency of the synthetic jet ($St_{Act} = \dfrac{f_{act} \cdot H}{U_{\infty}}$) varies between 0.1 and 0.8.

Influence of momentum coefficient

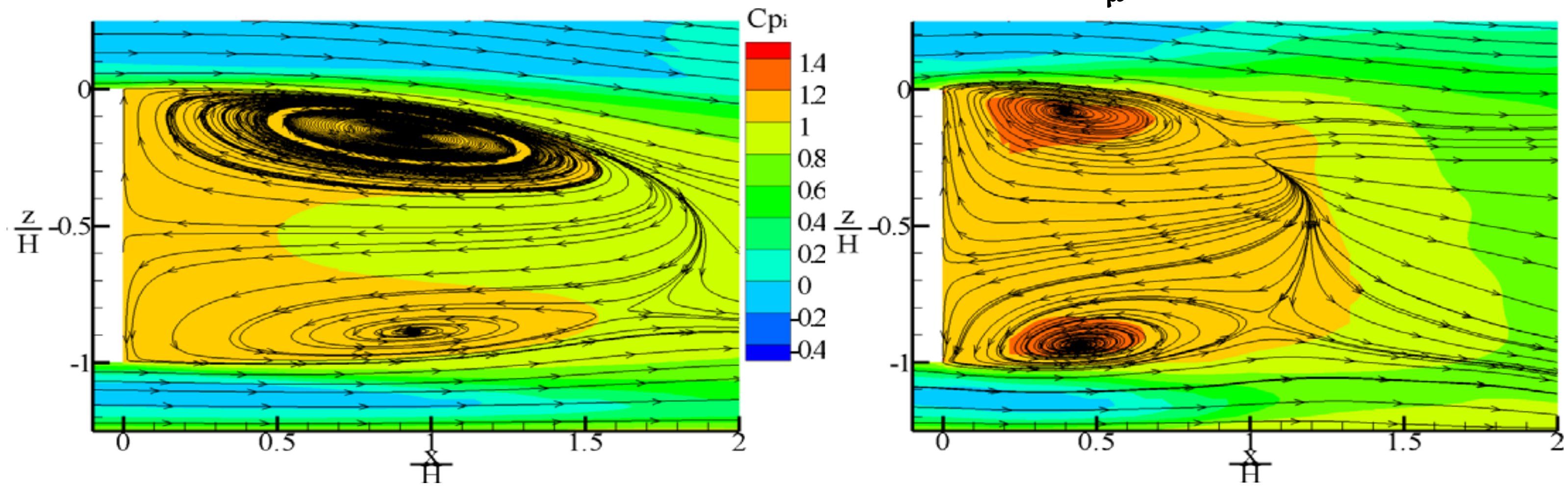


$St_{Act} = 0.17$

$C_\mu = 0.02 \equiv u_{Act} = 40\ m.s^{-1}$

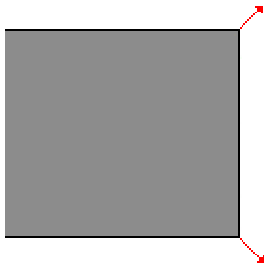


Un-controlled flow **$C_\mu = 0.02$**



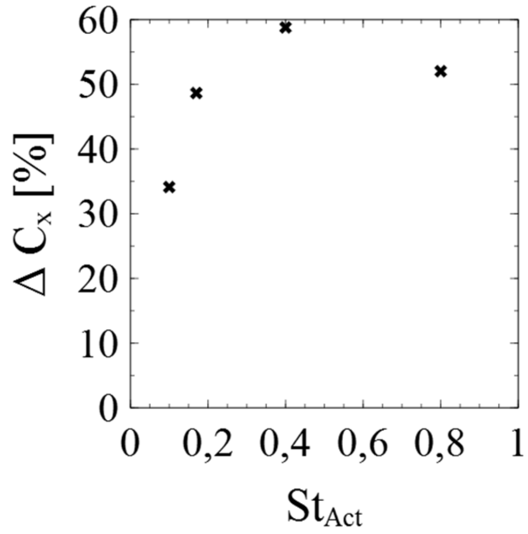
- $\Delta C_D = 48\ \%$
- The mean recirculation length decreases.
- The height of the wake increases.

Influence of the reduced frequency

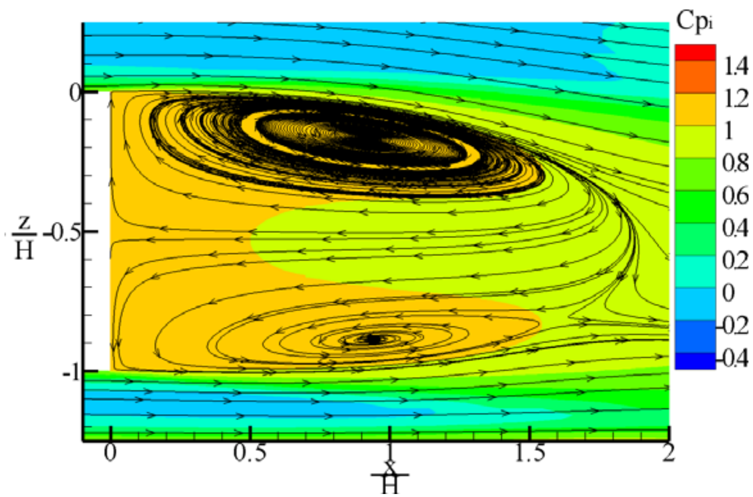


$\theta = +45°$

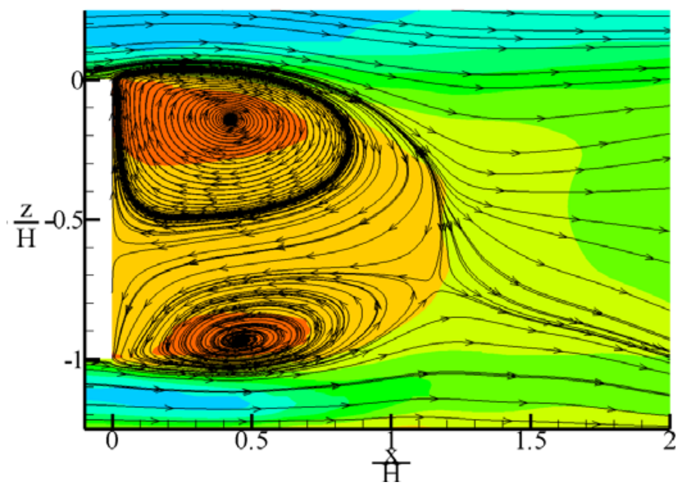
$C_\mu = 0.02 \equiv u_{Act} = 40\ m.s^{-1}$



Un-controlled flow

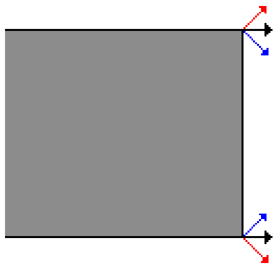


St_{Act} = 0.40

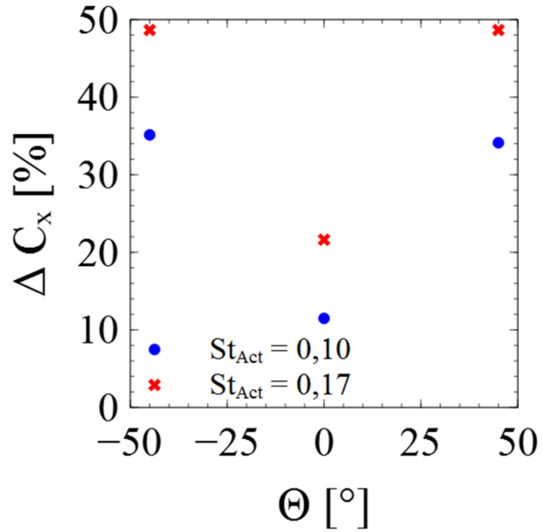


- ΔC_D = 60 %.

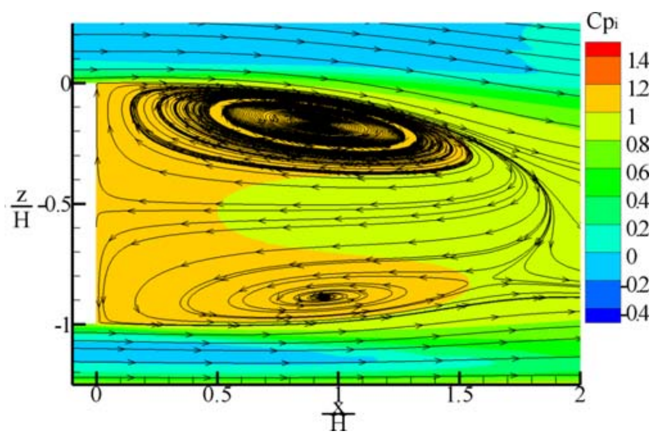
Influence of the orientation of the synthetic jet



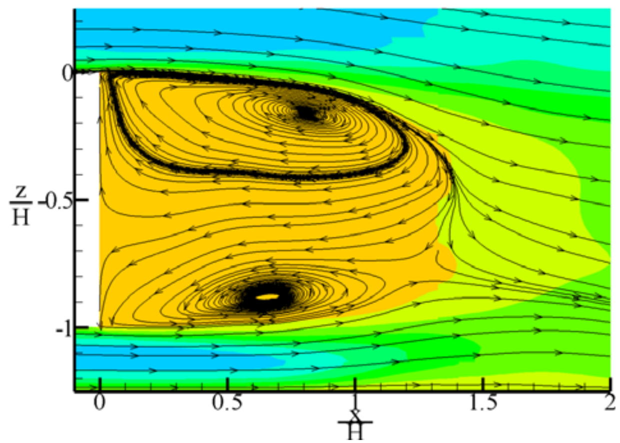
$C_\mu = 0.02 \equiv u_{Act} = 40\ m.s^{-1}$



Un-controlled flow



St_{Act} = 0.17 et θ=0°



- ΔC_D = 21 %

Transonic Buffeting on the aircraft

✓ **Shock wave/boundary layer interaction**

⇒ **Buffeting**

- Flow instabilities: self sustained oscillations
- Important effects on aerodynamic performances and aircraft manoeuvrability

- Vibration and material damages: structure fatigue
- Alteration passenger's comfort

✓ **Buffeting prediction:**

- Identification and characterization of buffeting mechanisms and prediction of predominant phenomena

Numerical simulations

✓ **Two numerical codes: Fluent & DynFluid**

- Transient implicit density-based solver
- Second-order space and time accuracy
- Dual time step

Computational conditions

- ✓ **Geometry: OAT15A profile**
- ✓ **Far-field conditions:**

$$\mathrm{Re/m} = 3.\times 10^{6} \quad M_{\infty} = 0.73$$

$$P_{\infty} = 77000\,Pa \quad T_{\infty} = 300K$$

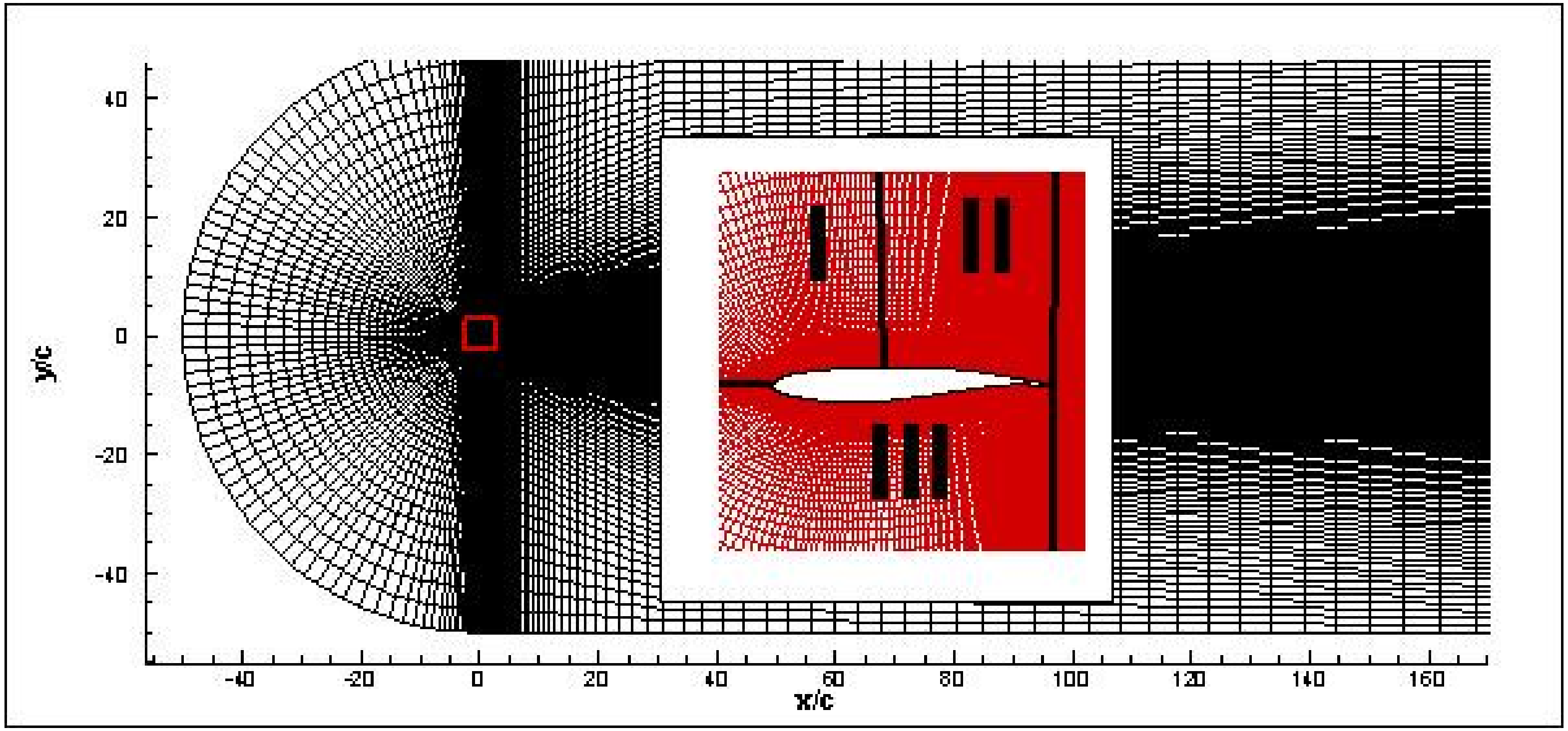
$$AoA = \alpha = 4^{\circ} \text{ or } 4.5^{\circ} \quad \mathrm{c} = 0.23\,\mathrm{m}$$

- Jacquin L, Molton P, Deck S, Maury B, Soulevant D (2005) AIAA paper 2005-4902
- Kourta A., Petit G., Courty J.C., Rosenblum J.P. (2005), International Journal for Numerical Methods in Fluids, vol. 49, pp. 171-182

Computational conditions

✓ **Meshes:**

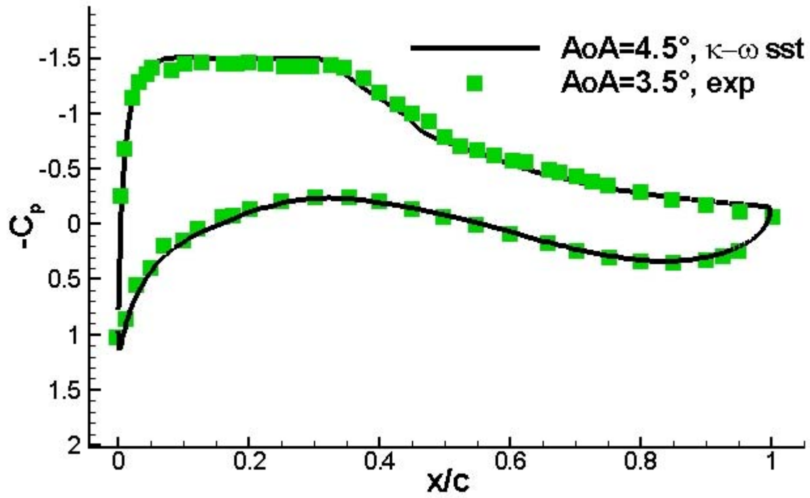
2D: 102.000 nodes
3D: 102.000x20 ΔZ= 5 mm



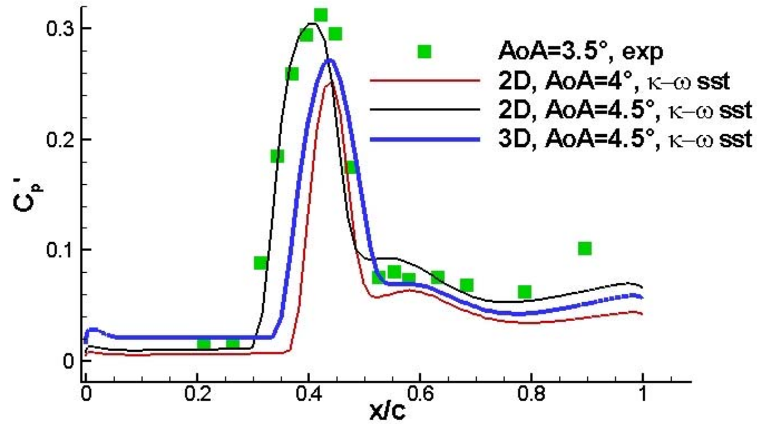
ANR SPICEX

Computational results

✓ **Pressure distribution:**

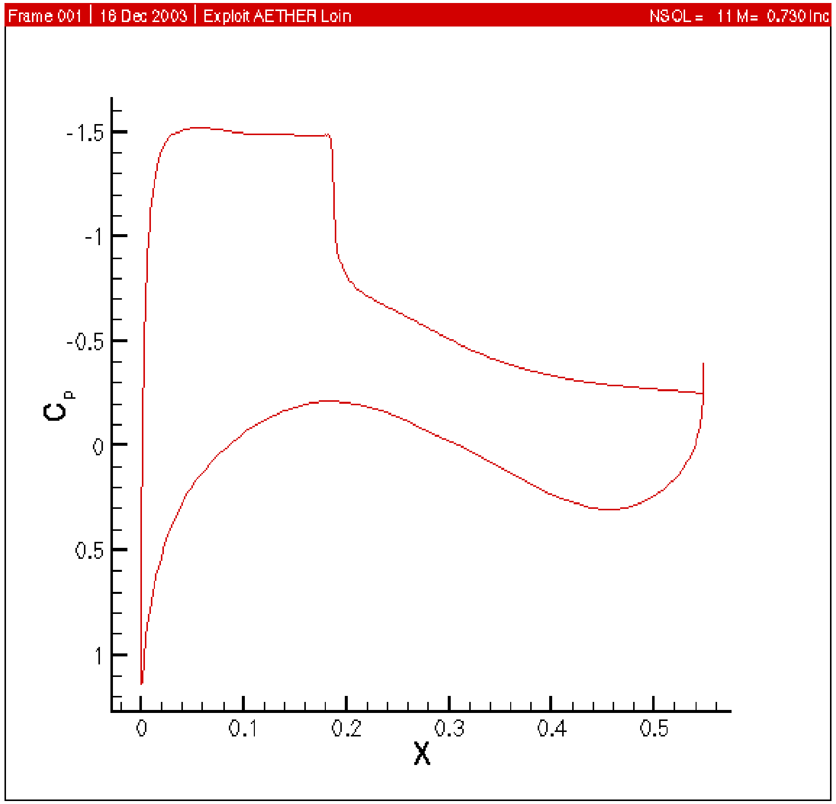


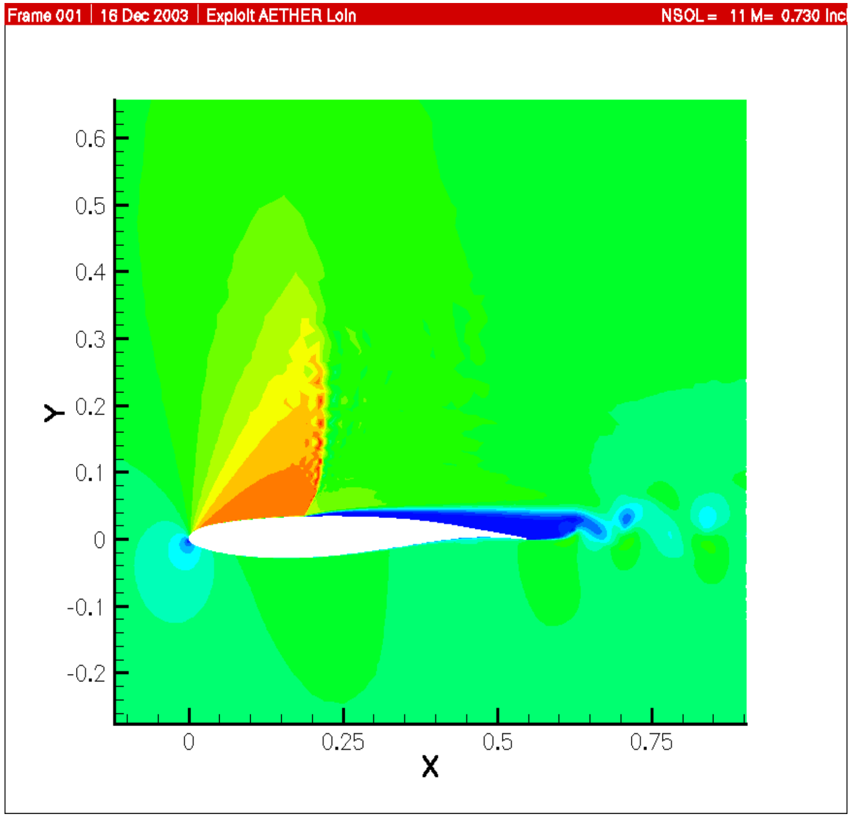
Pressure coefficient



RMS pressure

Transonic buffeting on OAT51A





Shock oscillation frequency : St=0.072

Wake frequency: St = 2.75

Transonic buffeting on OAT51A

Case	St	$\overline{C_L}$
Experiment (α=3.91°)	0.078	0.91
ONERA computation (α=4°)	0.074	0.97
Kourta et al. **(**α=4°)	0.072	0.965
This study (α=4°)	0.072	0.924

Strouhal number and lift coefficient

Conclusions

- Computation of subsonic 3D bluff body wake
- Computation of transonic buffeting and shock wave boundary layer interaction on OAT15A

- Semi-deterministic model able to predict Both low and high velocity flow and capture unsteadiness

- Future work:
  - Computations with large mesh cells
  - Coupling with LES