FLOW CONTROL STRATEGIES FOR DRAG REDUCTION OF A MID-SCALE TRAILER MODEL

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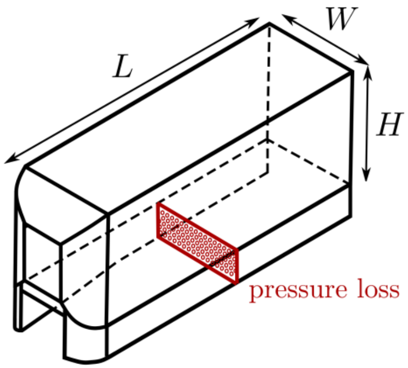
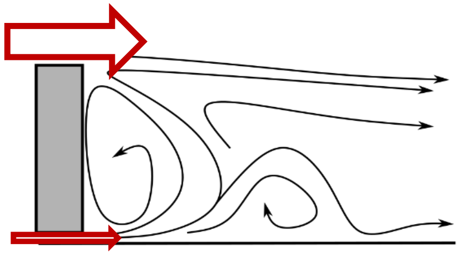
CONTENTS

Heavy truck's model

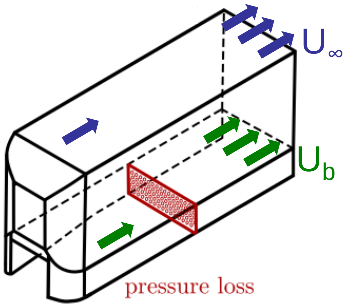


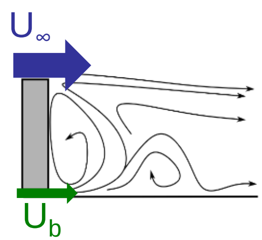


- Introduction:
  - Wake topologies related to the underbody momentum
  - Choice of one class for control
- Medium/high frequency forcing (***St_{act}= 5-15***)
  - Effects on mean field, deflection angle, pressure field
  - Changes within the turbulence
- Forcing strategy (***Local forcing***)
  - Influence on pressure recovery and drag reduction
  - How to improve the control efficiency?
- Conclusions & perspectives

Wake topologies

- G* =cte then driving parameter → ratio $\lambda = U_b / U_\infty$

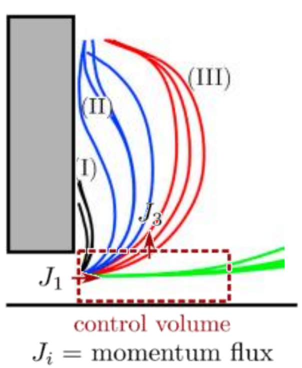


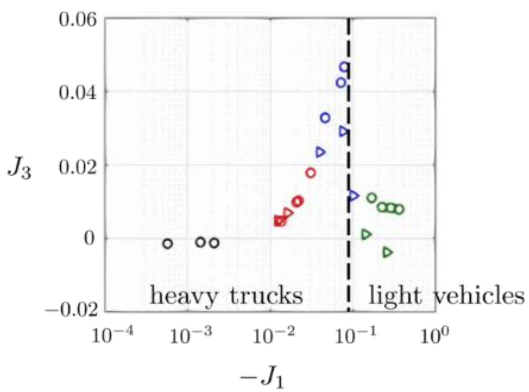


- four wake topologies

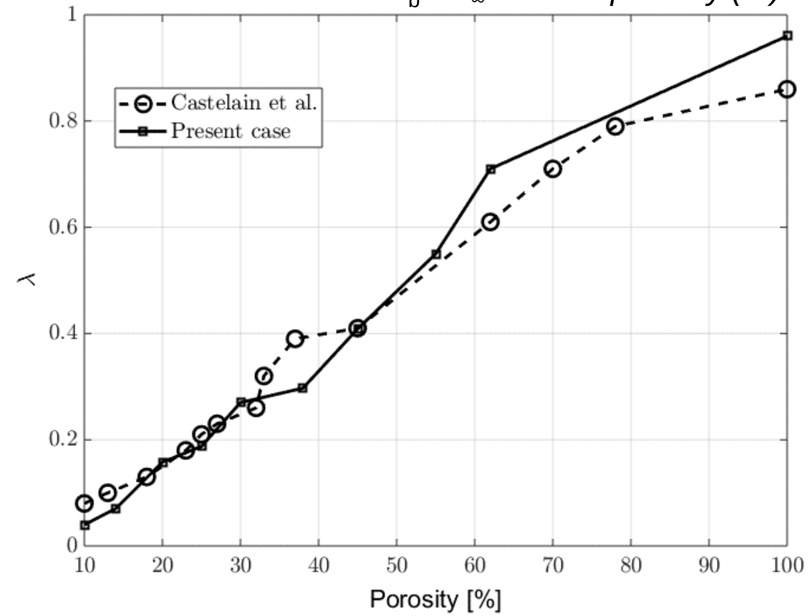
Parameters for the topology classification into classes :

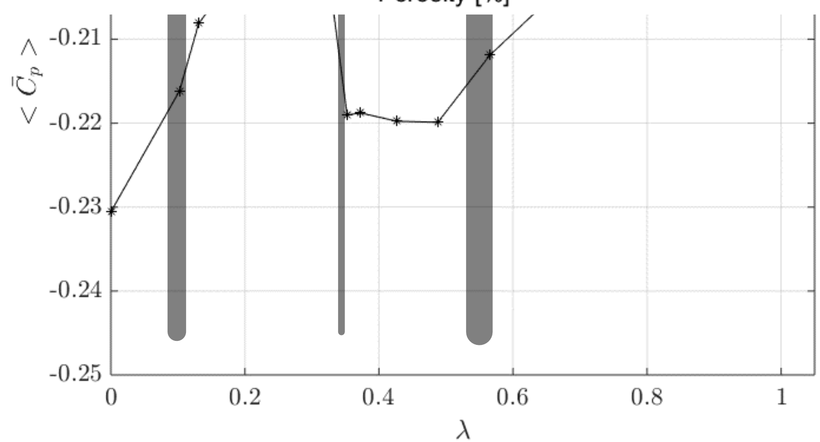
Momentum flux, Cp, gradients of pressure …





Evolution of ratio $\lambda = U_b / U_\infty$ with the porosity (%)





Castelain et al. JWEIA 2018

Wake topologies: selection of one case of study

- ❑ One specific wake topologies
- ❑ **Present case (Re_H 4.10^5) :**
  - ○ **class 3 with λ ~ 0.4**
  - ○ λ representative of real truck cases
  - ○ unfavourable base pressure and drag

<u>Control investigations</u>

❑ *Previous at LMFA*

(*PhD work of Chaligné* and *Szmigiel*)

- ○ control of flows : class 1 and 2

❑ flow modifications in present case :

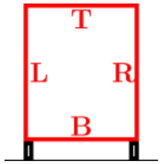
- ○ open-loop global forcing
- ○ forcing parameters:

P_{rel} = 1,9 bar → C_μ = DC N (sj/S) $(V_{jmax}/U_\infty)^2$ = 3.10^{-2}

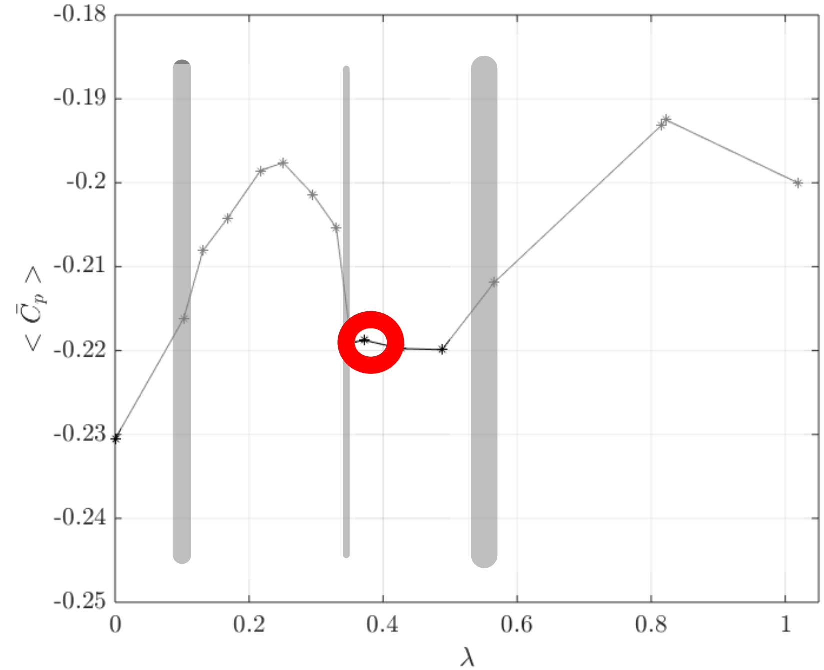
DC = 50 %

f_{act} = 350 Hz → St_{act}= fH/U_∞ = 5

- ○ **30%** of pressure recovery
- ○ **10%** of drag reduction



Spatially-averaged mean base pressure



Medium and high frequency forcing : mean velocity

***General features** of* class 3 flows without control:
- ❑ mean curved jet separated from the ground:
  - fluid caught up near the base
  - secondary vortex
- ❑ back-flow due to underbody flow :
  - flux convected towards the upper shear layer
  - impinge and limit the growth of SL

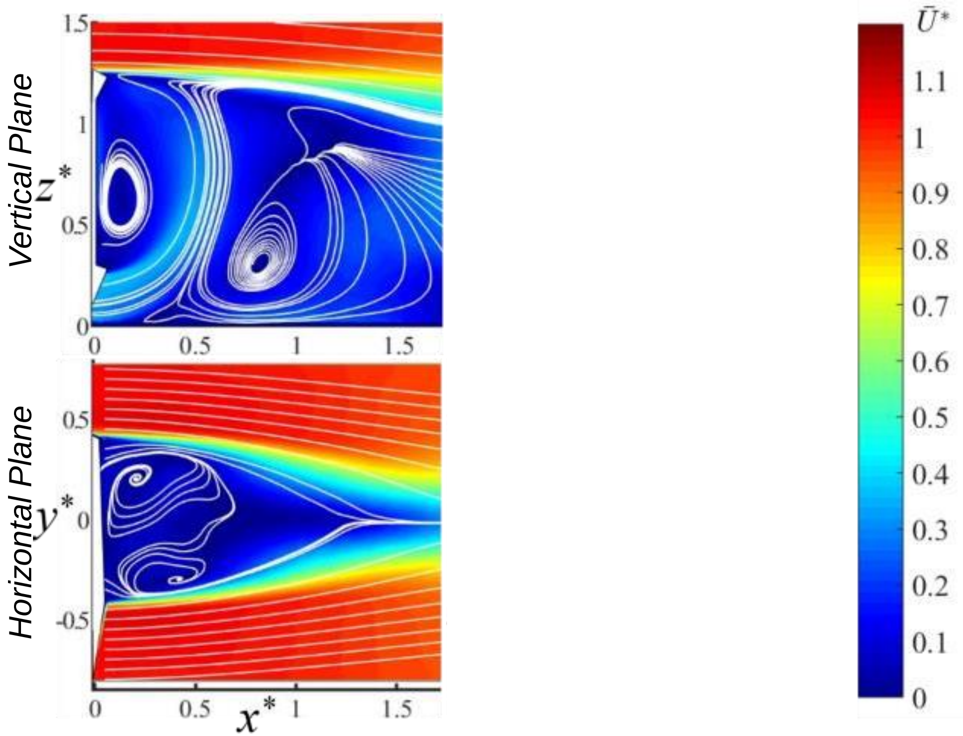
With control
- ❑ mean deflection of the potential flow on three sides of SL
- ❑ higher intensity on left and right side SL
- ❑ no significant effect of actuation in the curved jet

First conclusions

- **No flow class changes under actuation**
- **Vertical assymmetry is only slightly modified (re-inforced)**
- Similar conclusions for a higher frequency forcing (f_{act} = 1050 Hz, St_{act} = 15)
- **Deflection of the potential flow is the main effect of actuation?**

Mean velocity magnitude in both mid-planes

without control ***with control***

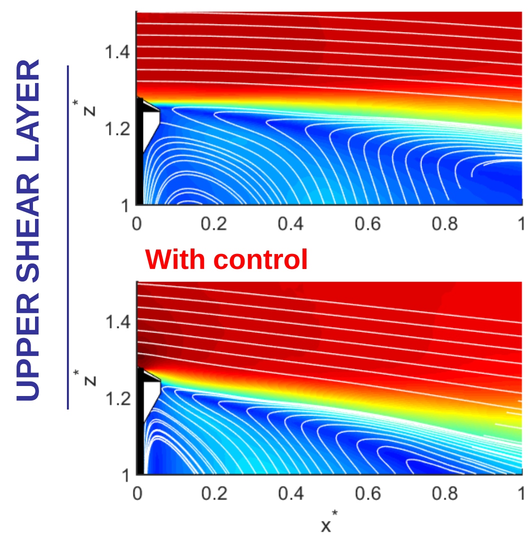


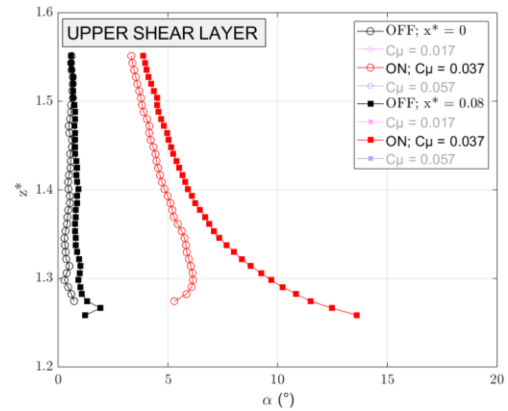
Medium and high frequency forcing : deflection of the potential flow

with control

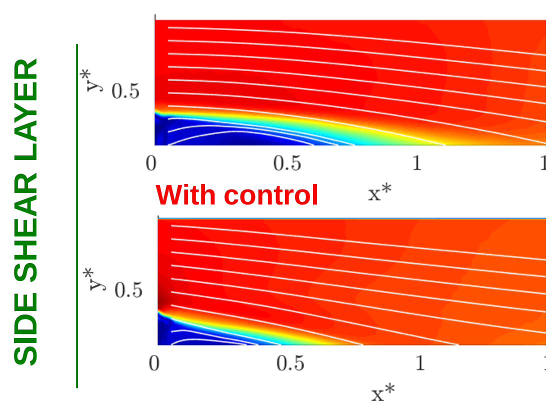
- ❑ deflection at ($x^* \sim 0$) : α horizontal >: α vertical
- ❑ global deflection of the wake
- ❑ analysis of streamlines (x^* = 0 and 0.08) :
  - ○ high flow deviation around flap location
  - ○ max. deflection angle ~ flap angle
- ❑ similar results for St_{act} = 15

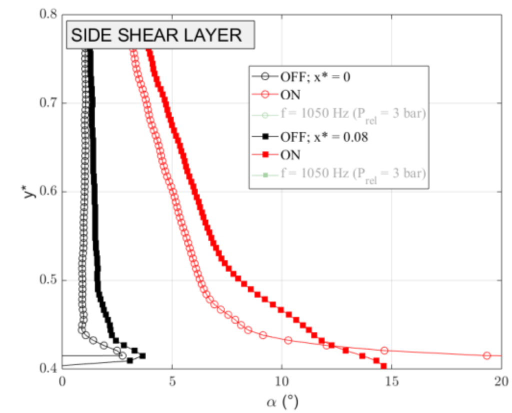
Without control

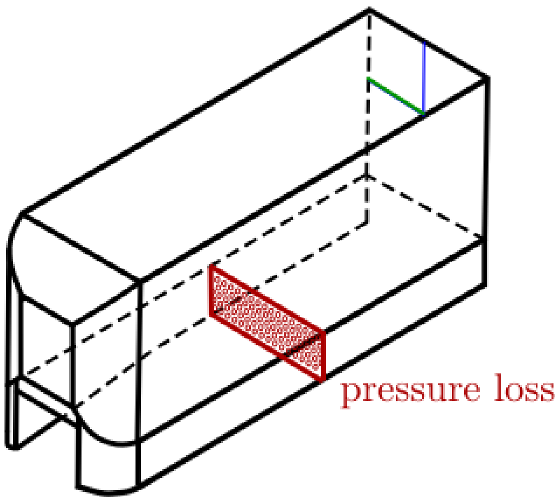




Without control







Medium and high frequency forcing : mean pressure

Mean pressure 2D field

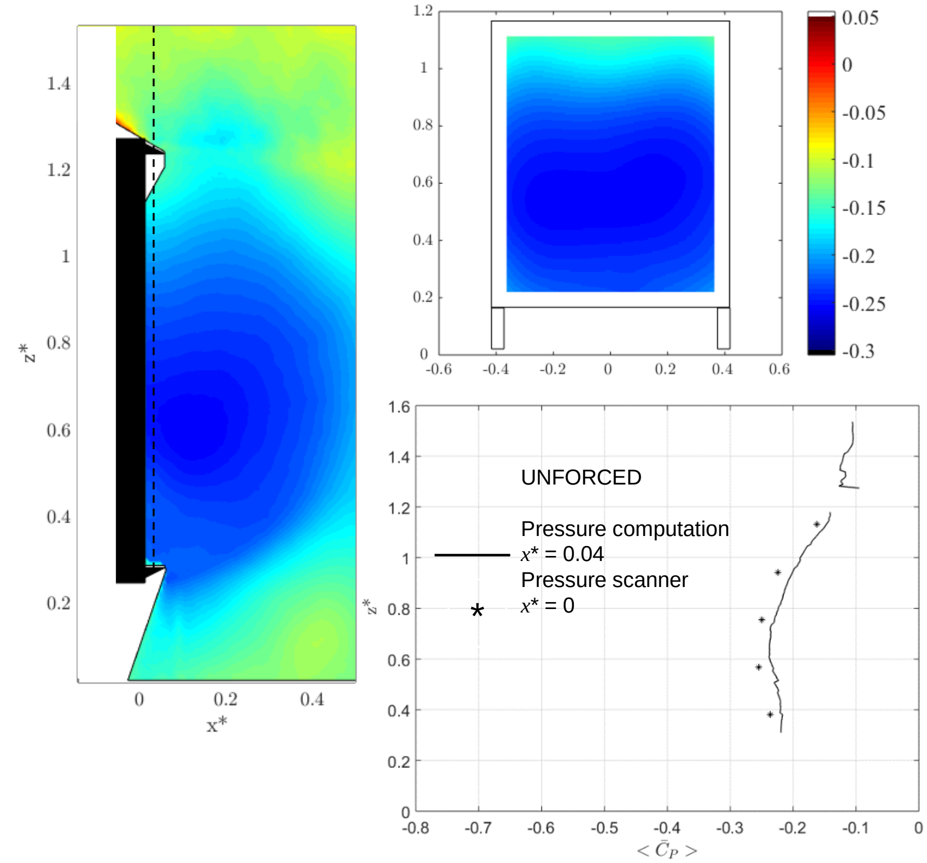
- 2D-2C PIV measurements
- 2D N-S averaged equations (incompressible)
- stochastic integration scheme

  Oxlade JFM 2015
- reference pressure: Bernoulli equation along a streamline within the potential flow

without control :

- agreement with mean base pressure measurements
- base pressure vertically stratified
- large area with negative pressure trapped by the curved jet

Mean pressure map in the vertical mid-plane & in the base



Medium and high frequency forcing : mean pressure

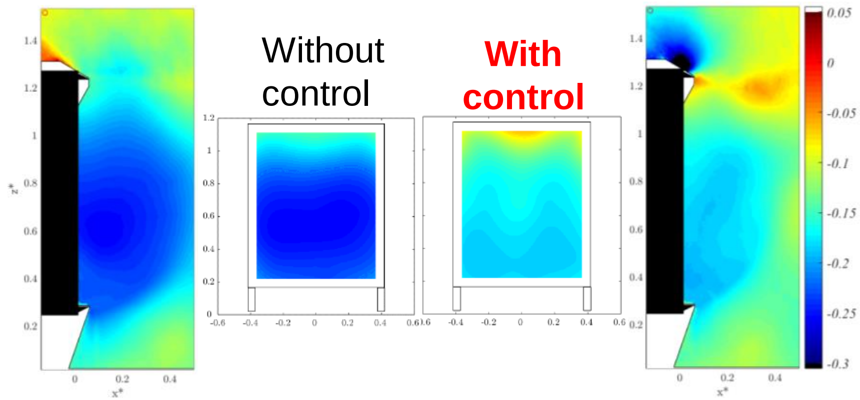
without control :
- base pressure vertically stratified
- large area with negative pressure

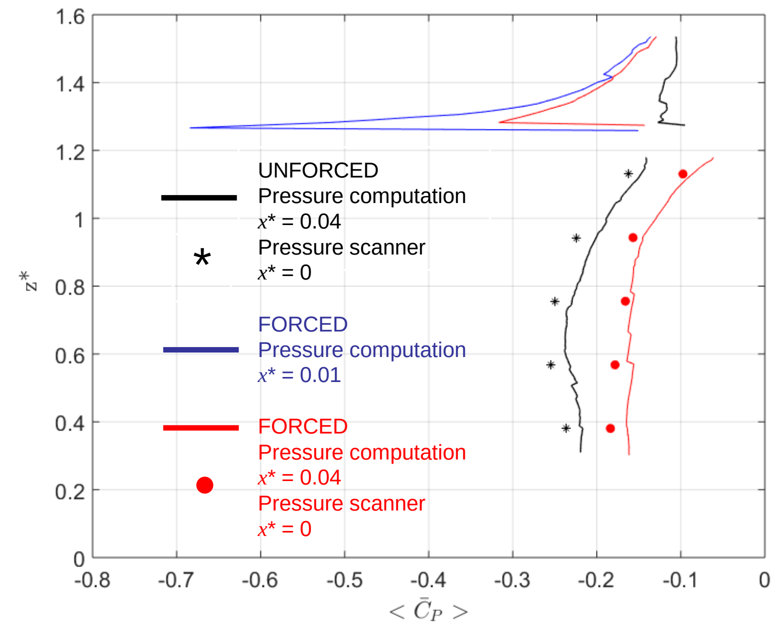
with control
- global pressure recovery in the near wake linked with the global shift of wall pressure
- local large negative pressure peak over the base edge and the flap
- faster pressure recovery of the potential flow in ***x*** direction

To be highlighted from this pressure analysis :

- good agreement with pressure measurements
- **large pressure peak due to combination of passive and active actuation**
- **important base pressure recovery (γ_p ~ 30%)**

Mean pressure map in the vertical mid-plane & in the base





Medium and high frequency forcing : effects on the curved jet

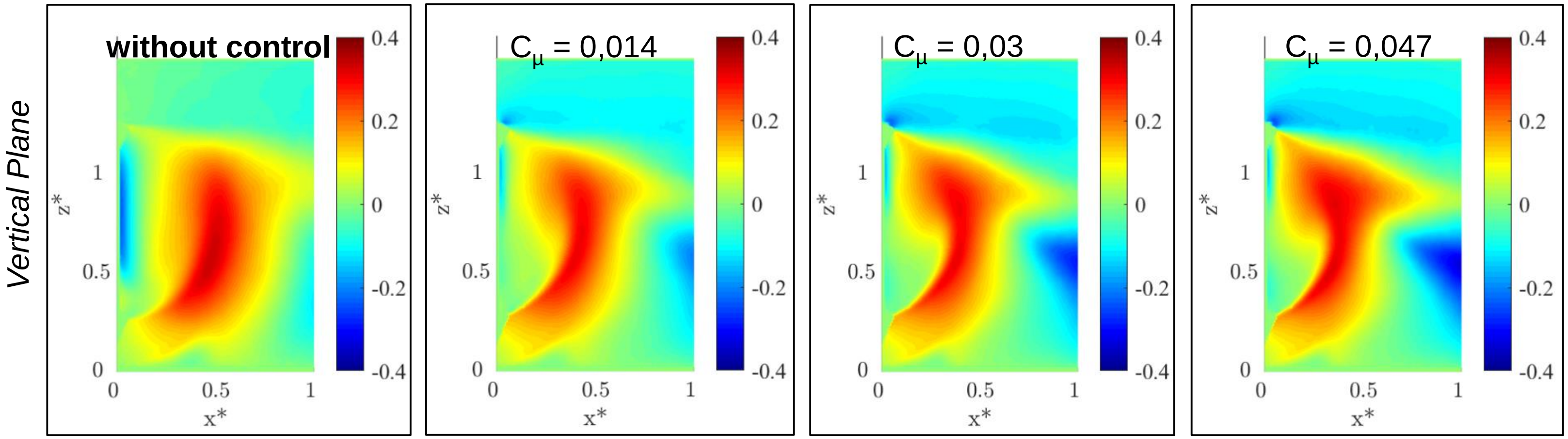
without control

- mass flux convected from the underbody flow towards the upper part of the base

with control

- increase of control intensity (P_{rel} → C_{μ}) :
  - impingement of the curved jet moves upstream from upper shear layer towards flap
  - negative vertical velocity above the flap

Vertical mean velocity within the back-flow



- **Side shear layers are free from disturbances.**
- **Upper shear layer is linked to the curve jet**
- **Interaction curved jet/upper shear layer play a role in the development of turbulence?**

Medium and high frequency forcing : turbulence in the shear layer

without control

- ❑ turbulent stresses higher in the upper SL
- ❑ low turbulent activity curved jet (|U| ~ 0.3 U_{inf})

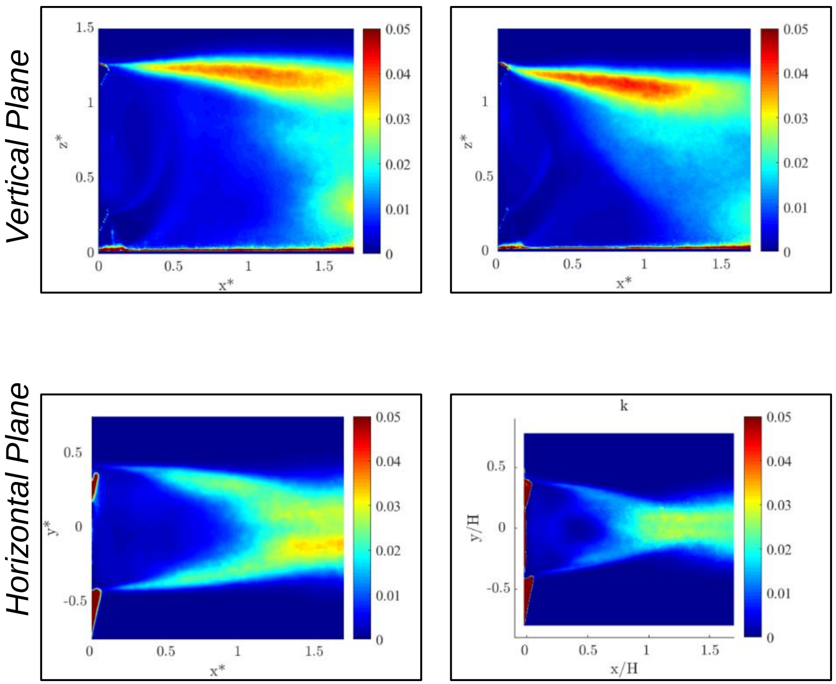
with control

- ❑ upper SL: turbulence level fewly increased
- ❑ side SL : reduction of turbulent stresses (x^* ~ 0.1)

Similar conclusions for higher frequency actuation

Turbulent kinetic energy

without control | ***with control***



Summary

- ➢ turbulent activity remains low
- ➢ Triggering instabilities by the impinging jet ?
- ➢ **Effect of forcing on turbulence level related with pressure recovery?**

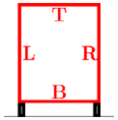
Vukasinovic et al. JFM 2010

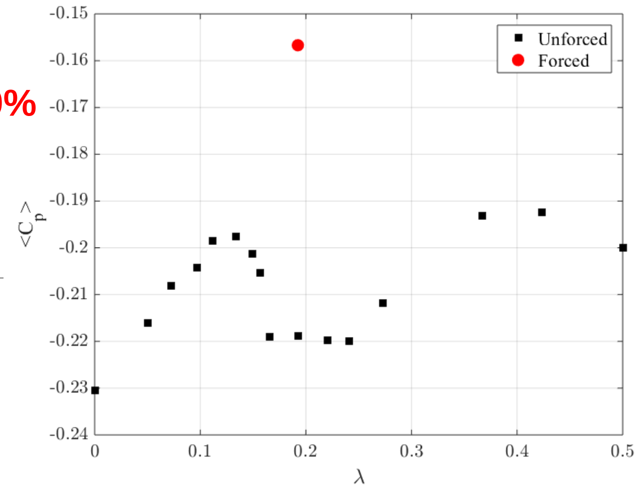
Forcing strategy : energetic considerations

Global efficiency

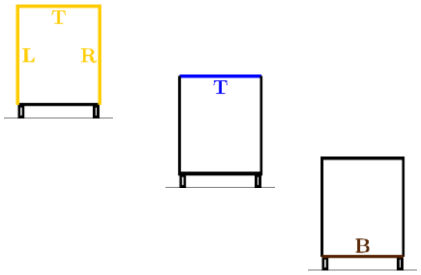
- ❑ Ratio between power recovery by drag reduction and power consumption for air compression
- ▪ Acoustic feature (📖 *Michard et al. GDR 2017 Orléans)*
- ▪ Mass flow nearly proportional to:
  - P_{rel} (valve inlet pressure at a fixed frequency)
  - DC (duty cycle)
  - N (number of actuators)
- ❑ Present investigation focuses on reducing number of actuators with fixed values of f_{act} and DC
- ❑ *Local forcing ?* → limited number of actuator rows

γ_p ~ 30%



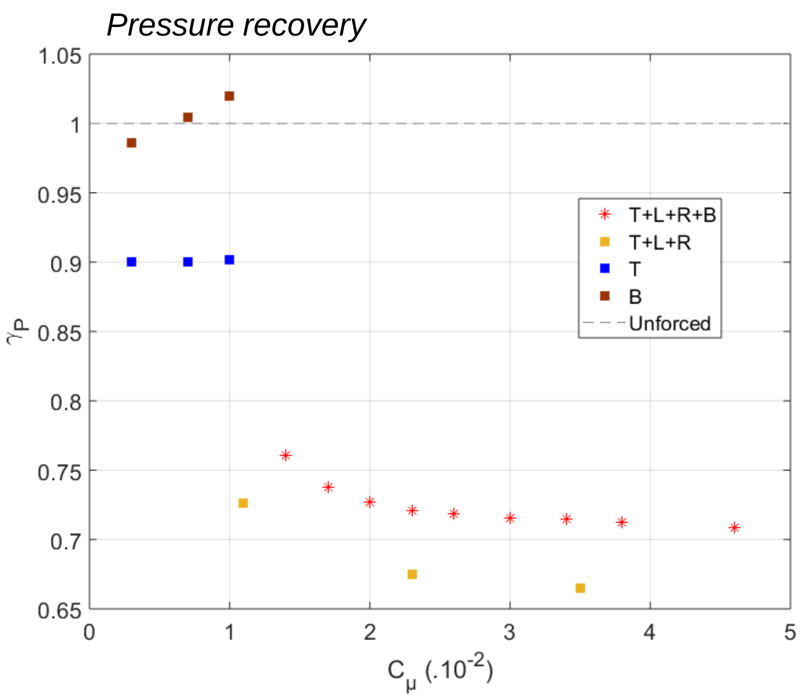


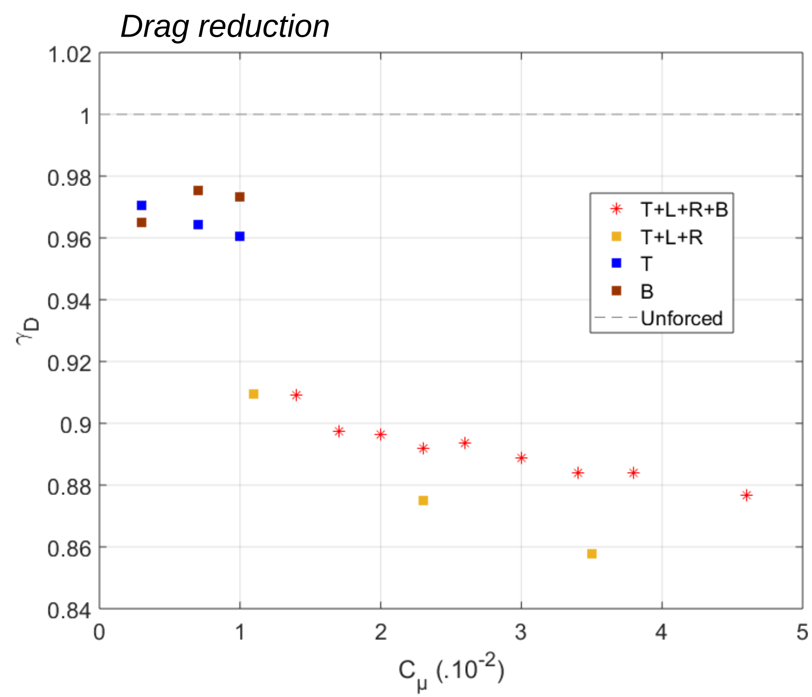
- ❑ Top + Left + Right
- ❑ Top
- ❑ Bottom

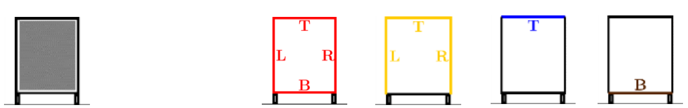


Forcing strategy : energetic considerations

Evolution of pressure recovery and drag reduction for different control strategies (& increase control intensity)

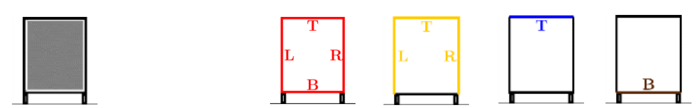






$$\gamma_P = \overline{C_{Pb}} / \overline{C_{Pb0}}$$

28%	33%	10%	0%



$$\gamma_D = C_x / C_{x0}$$

12%	12%	3 %	2 %

Results matching with previous analysis of the forcing effect on the individual shear layers

CONCLUSIONS and PERSPECTIVES

- Analysis of class III wake topology → Importance of the curved jet
- Global forcing flow results:
  - Wake dimensions reduction
  - No vertical symmetrisation (natural asymmetric flow) since injection momentum is not modifying the underbody flux
  - Angle deflection more important in the side shear layers
  - Low level of turbulence compared with a class IV case
  - Low effect of actuation on the turbulence level

- Control strategy :
  - TLR more performant for base pressure recovery and drag reduction
  - Similar results for class IV case but caused by similar mechanism ?

Perspectives

Better understanding of:

- unsteadiness
- relation between control parameters and pressure distribution around the flap (and deflection angle of the flow near the flap)
- performance of the control strategies for other classes (e.g. topology in class I)

THANKS

GDR Contrôle des décollements– IMFT, Toulouse – 8-9th November 2018