NWTF
NATIONAL WIND TUNNEL FACILITY

# Experimental sensitivity analysis of the aerodynamics of a simplified ground vehicle to the body clearance, yaw and pitch

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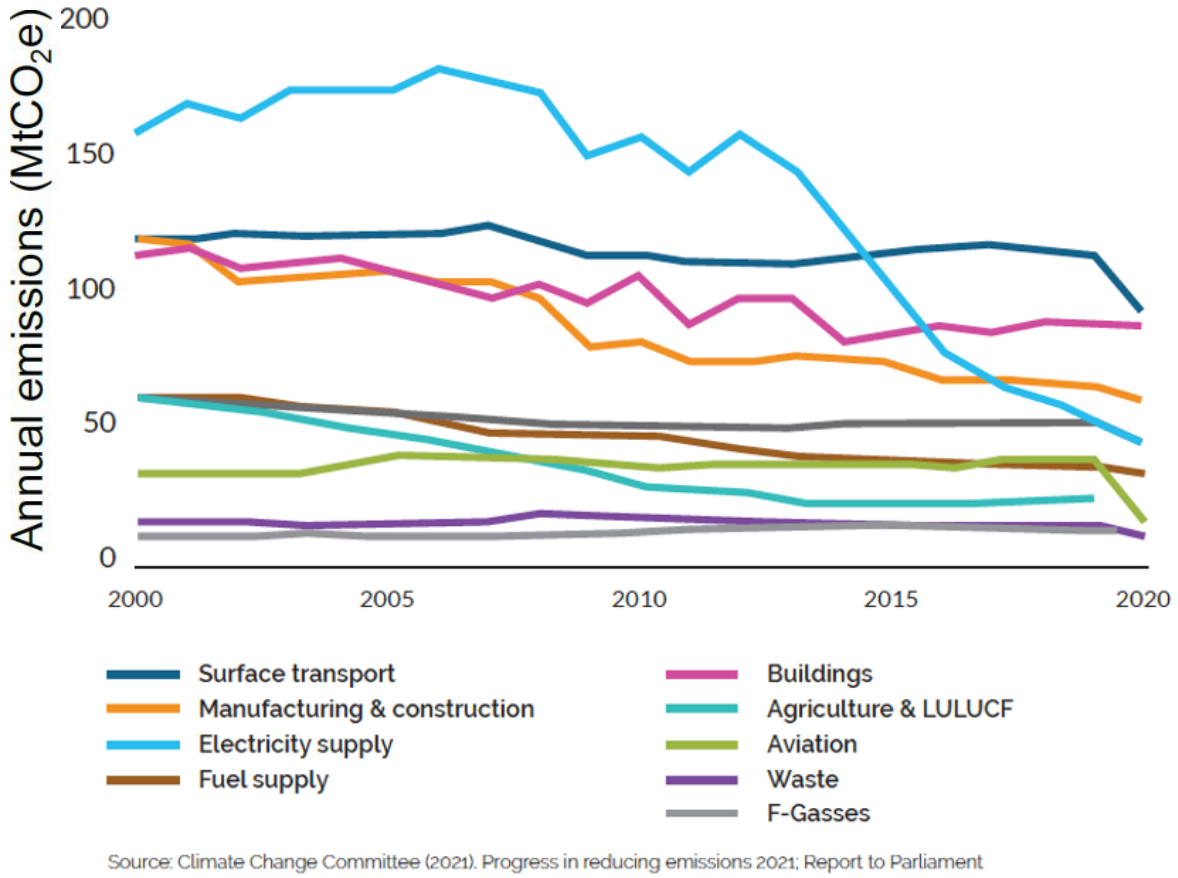
# Outline

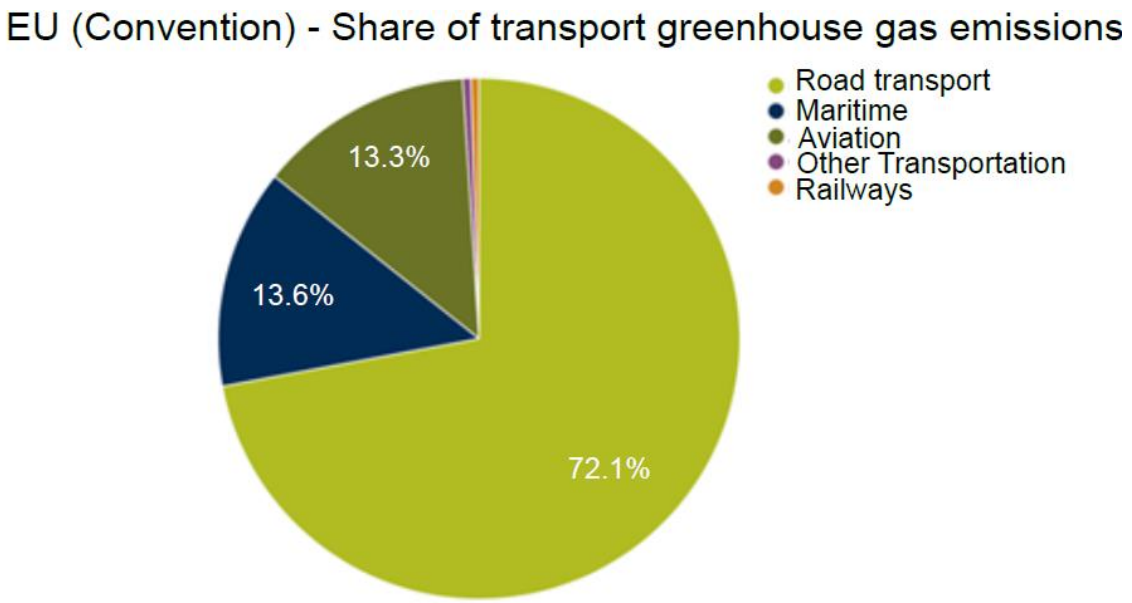
- Introduction
- Experimental set-up
  - Parametric study in yaw, pitch and clearance.
- Results
  - Wake orientation sensitivity to the attitude
  - Sensitivity of the aerodynamic coefficients to the attitude
- Conclusion

# Introduction

- The industrial context



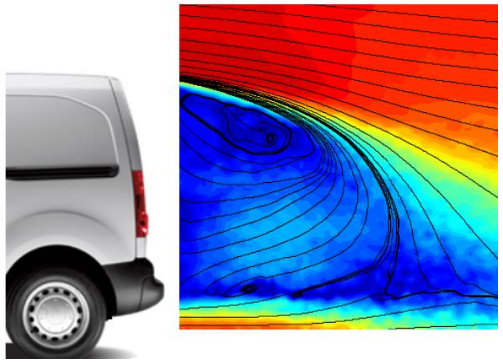

Source: Climate Change Committee (2021). Progress in reducing emissions 2021; Report to Parliament

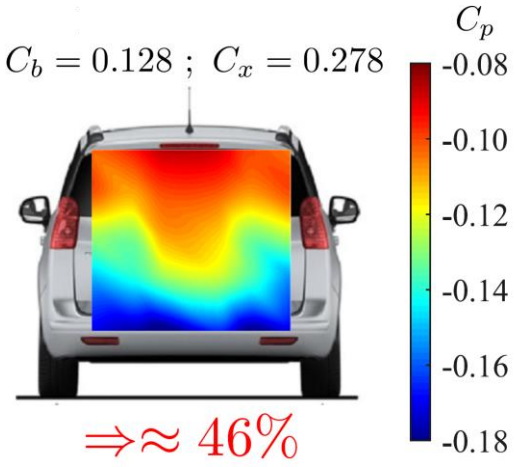



# Introduction

- The industrial context

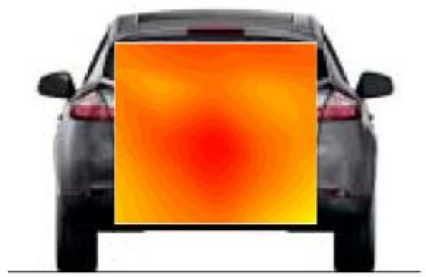
Source: Renault



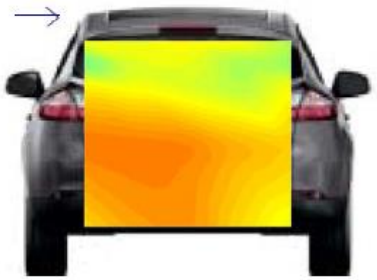




$\Rightarrow \approx 46\%$

Drag due to the wake



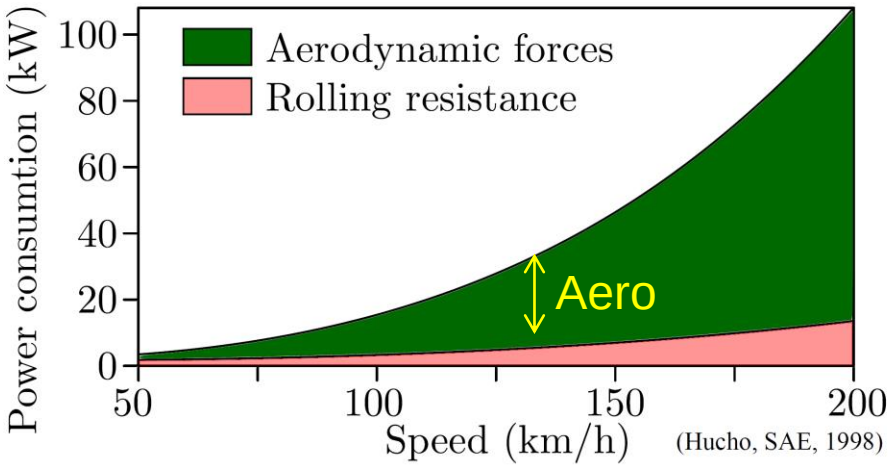
$C_b = 0.139$



$C_b = 0.176$

Bonnavion *et al.* 2017, 2019 JWEIA.

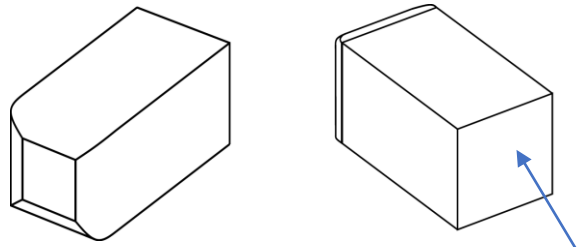
Crosswind 15 km/h



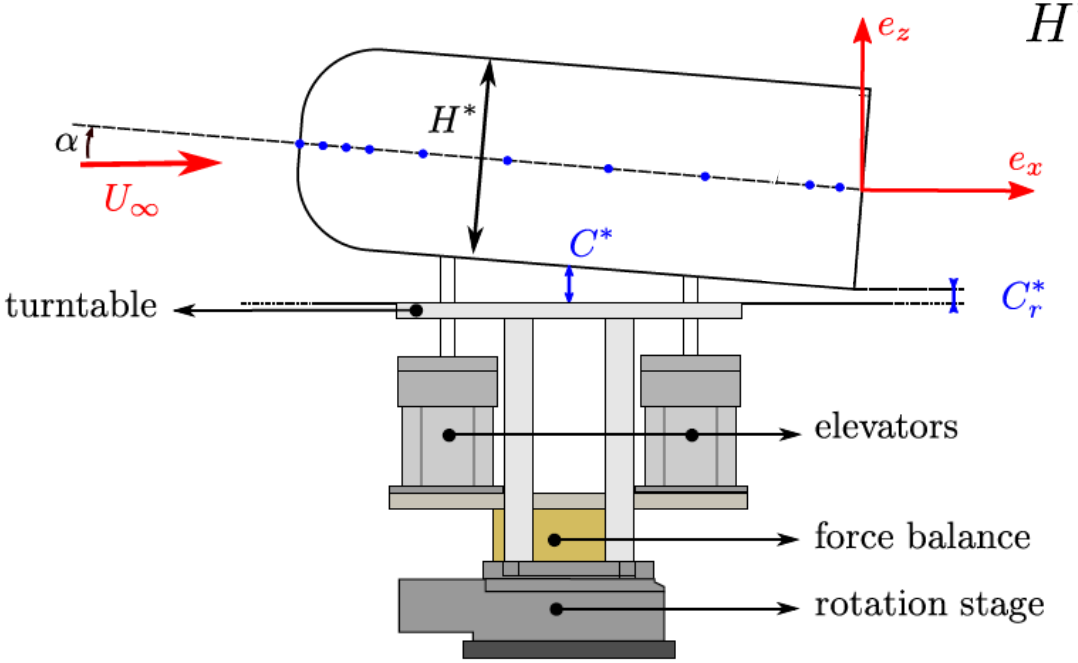

Urquhart PhD 2021 « Vehicle wakes in side wind »

# Experimental Set-up

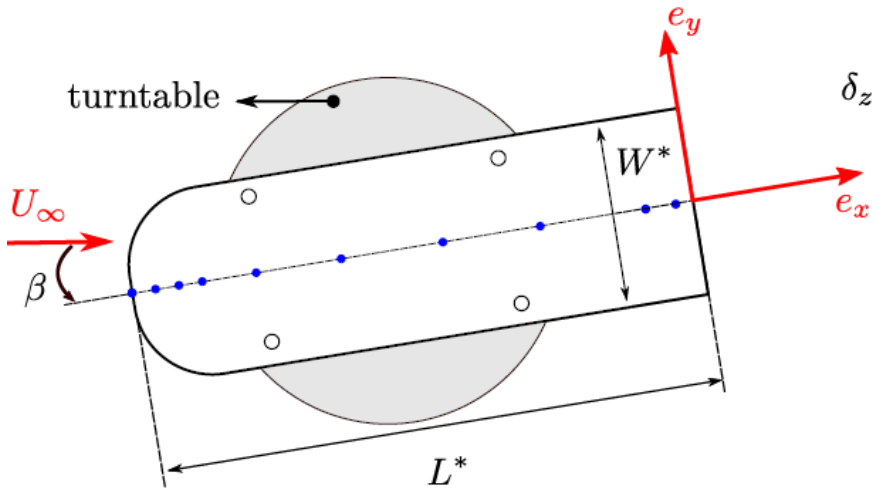
- Flat backed Ahmed body
- Fine adjustment in pitch $\alpha$, yaw $\beta$ and clearance $C$
- Force balance and local pressure measurements

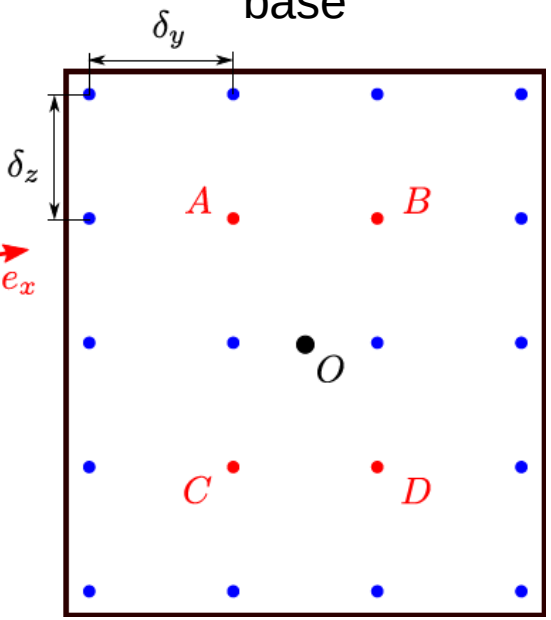


base

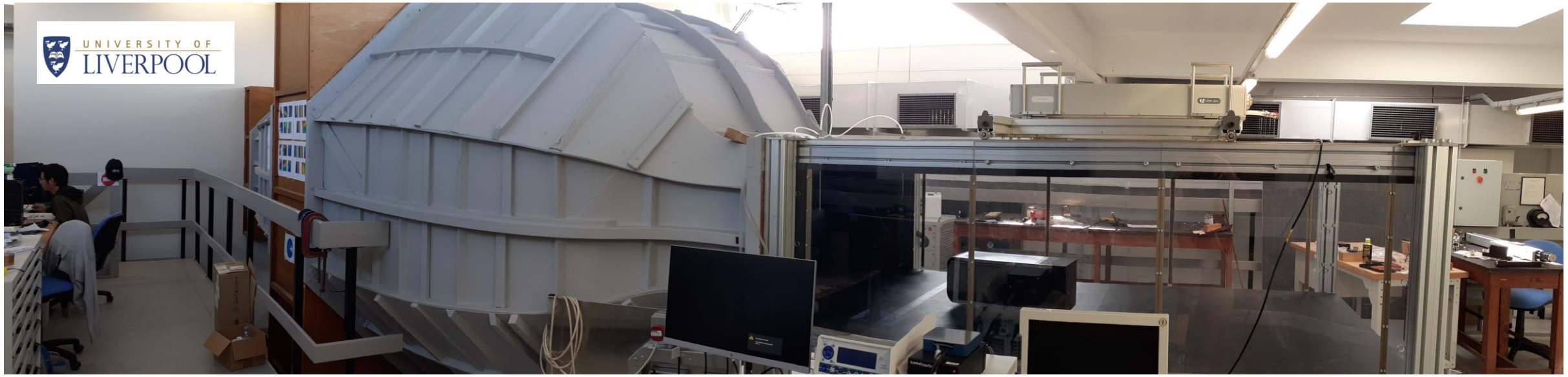



$H^* = 1,\ W^* = 0.9$




$\mathrm{Re} \approx 210000$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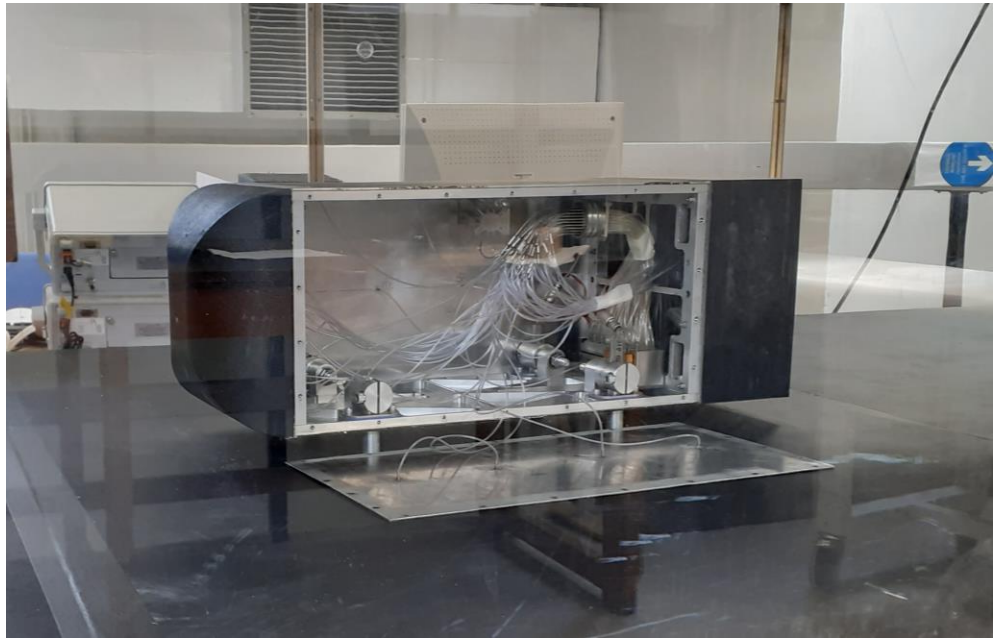
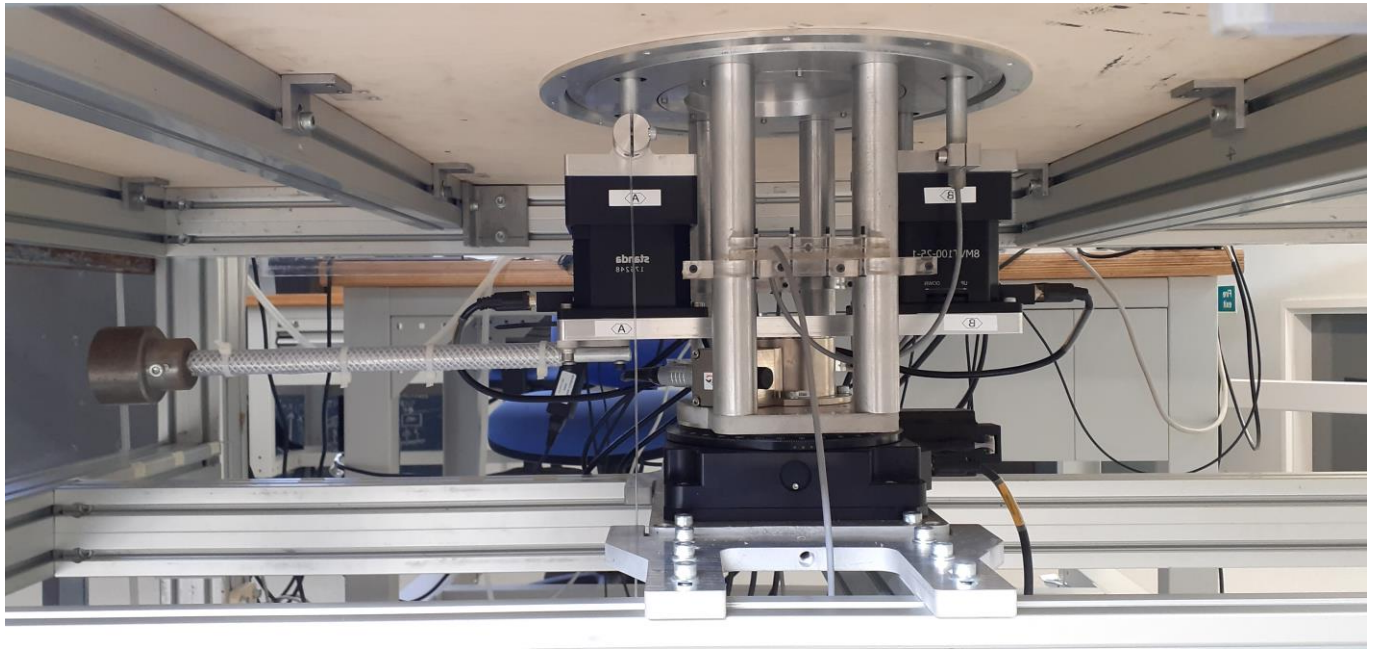




# Parametric studies

- Parameters space : $(\beta, C, \alpha_o = 0^o)$
  - $-15.5^o < \beta < +2^o$ by steps of $\delta\beta = 0.5^o$ and $0.01 < C < 0.17$ by steps of $\delta C = 2.5\ 10^{-3}$.
  - 2400 configurations (7 hours)

- Parameters space : $(\beta, C_o = 0.1, \alpha)$
  - $-15.5^o < \beta < +2^o$ by steps of $\delta\beta = 0.5^o$ and $-2.3^o < \alpha < +2.3^o$ by steps of $\delta\alpha = 0.1^o$.
  - 1692 configurations (5 hours)

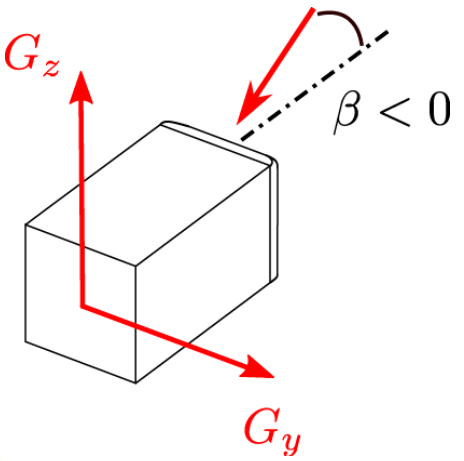
- For each configuration : 10 s duration acquisition at 1Khz of the 6 aerodynamic components of the force balance and the 64 pressure taps.

- Strain gages drift (force balance) : 200 s is required for the drift amplitude to exceed the measurements noise.

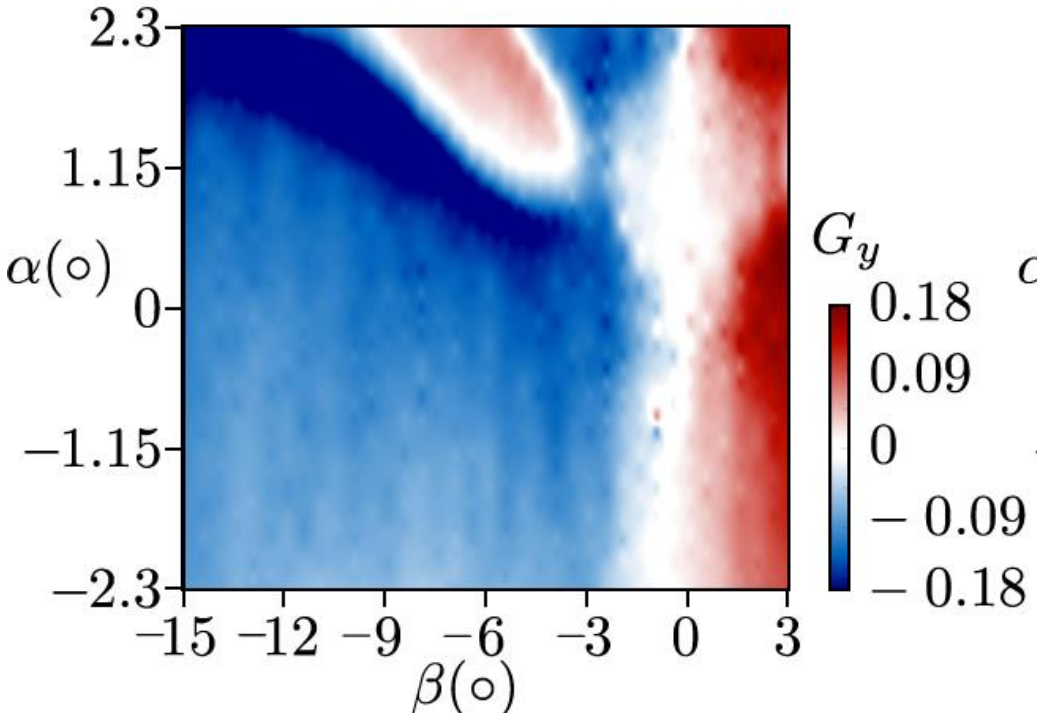
- Parametric study procedure :
  - Flow set at a dynamic pressure of $q = 150$ Pa ($U_\infty = 15.8$ m/s, Re=200 000).
  - Configurations explored following a minimised path.
  - Every 200 s, the model moves to a reference position (chosen for its weak unsteadyness: $\beta_{ref} = -5^o, C_{ref} = 0.1, \alpha_{ref} = 0^o$) and then the mean measurements obtained from a 20 s acquisition are substracted to all the following measurements.
- Post processing
  - The parametric procedure is reproduced in exactly the same manner with no wind to substract the non-aerodynamics loading such as gravity loads and cables deformation connected between the (moving) body and the fixed acquisition station.

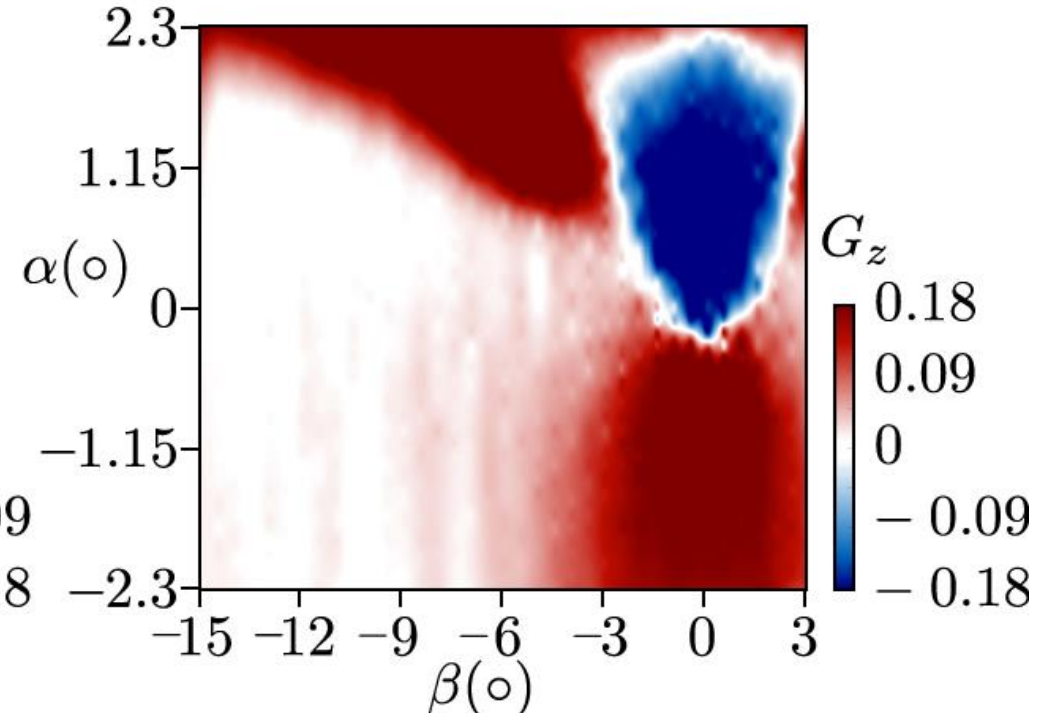
# Wake orientation sensitivity to the attitude

# Base pressure gradient orientation



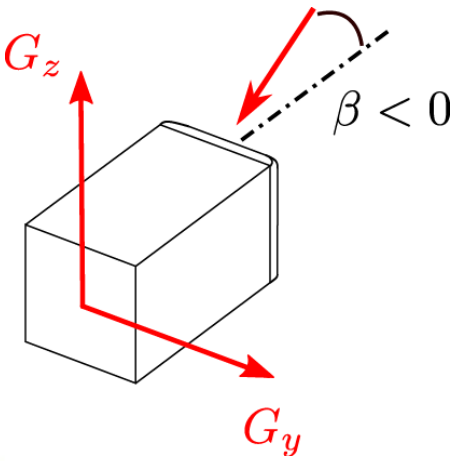

- Parameters space : $(\beta, C_o = 0.1, \alpha)$



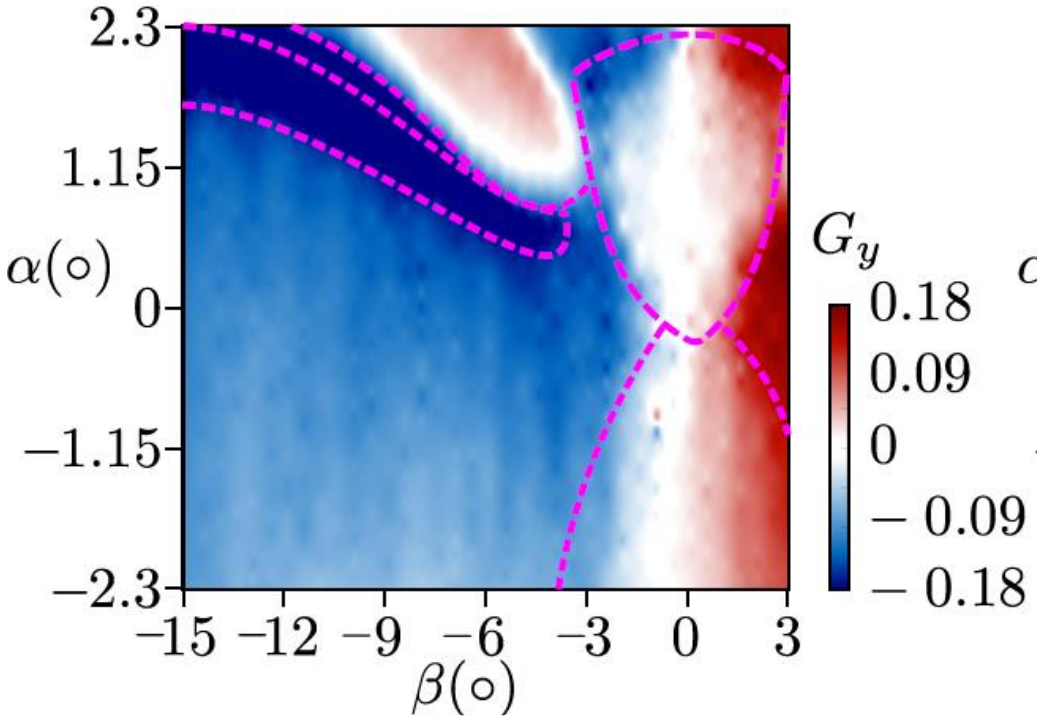



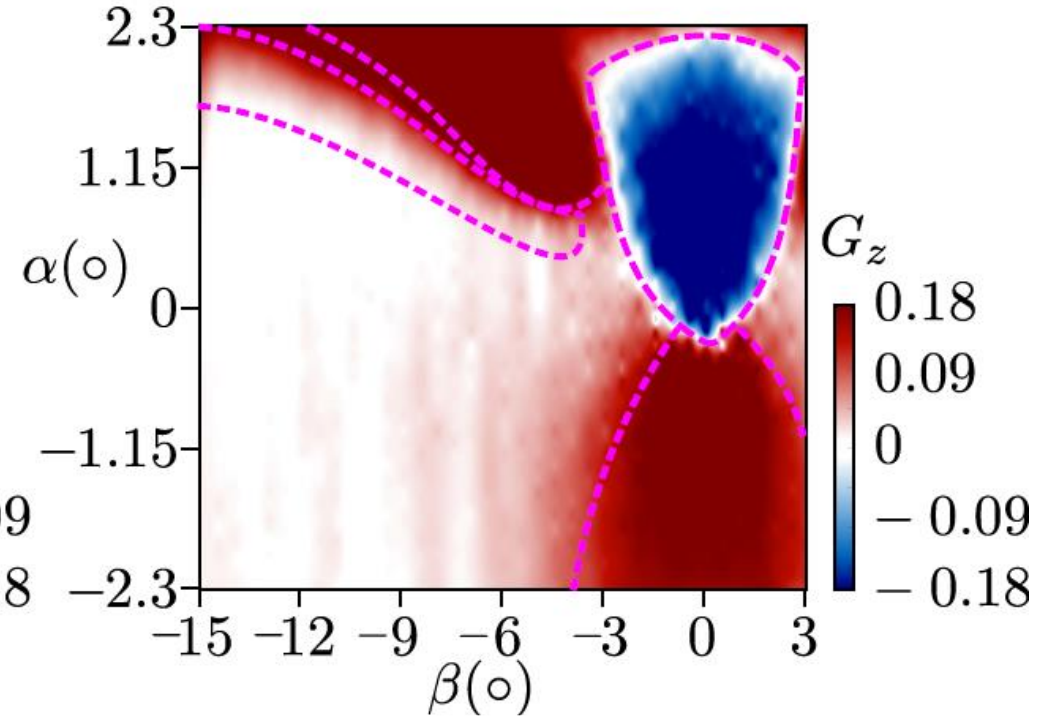

Clear changes of gradient orientations

# Base pressure gradient orientation

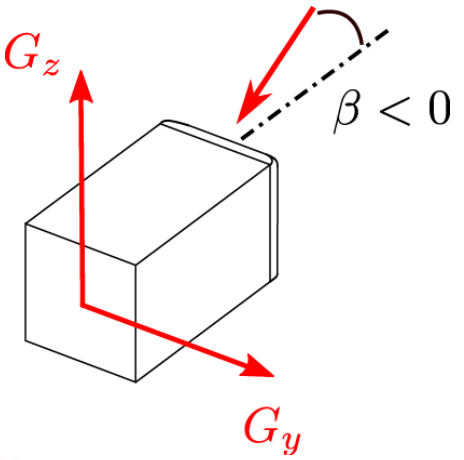



- Parameters space : $(\beta, C_o = 0.1, \alpha)$

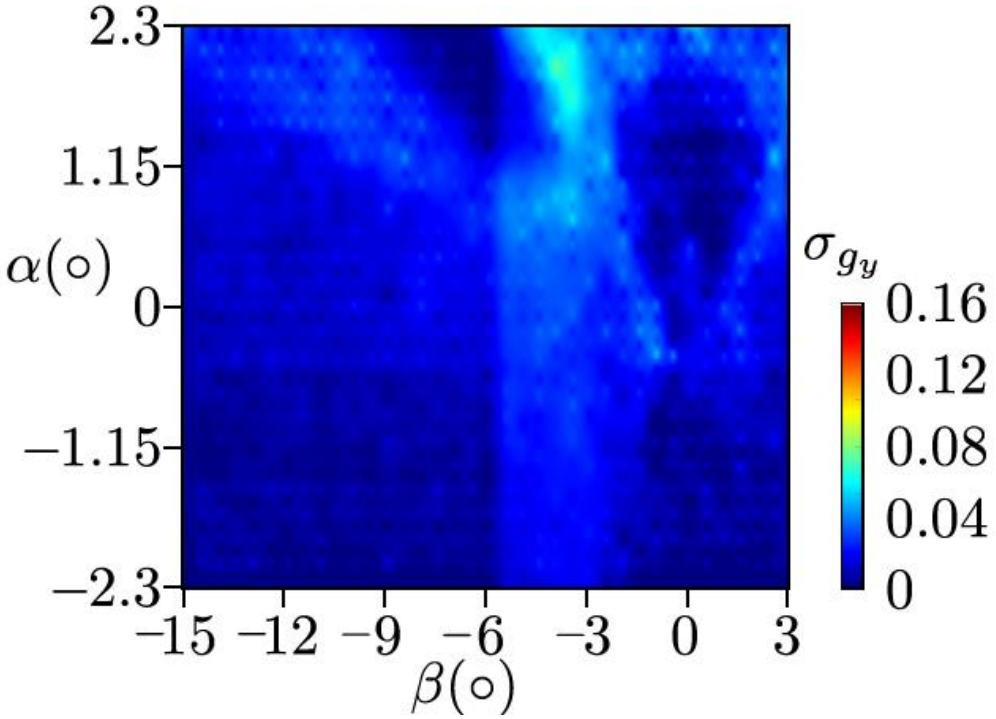


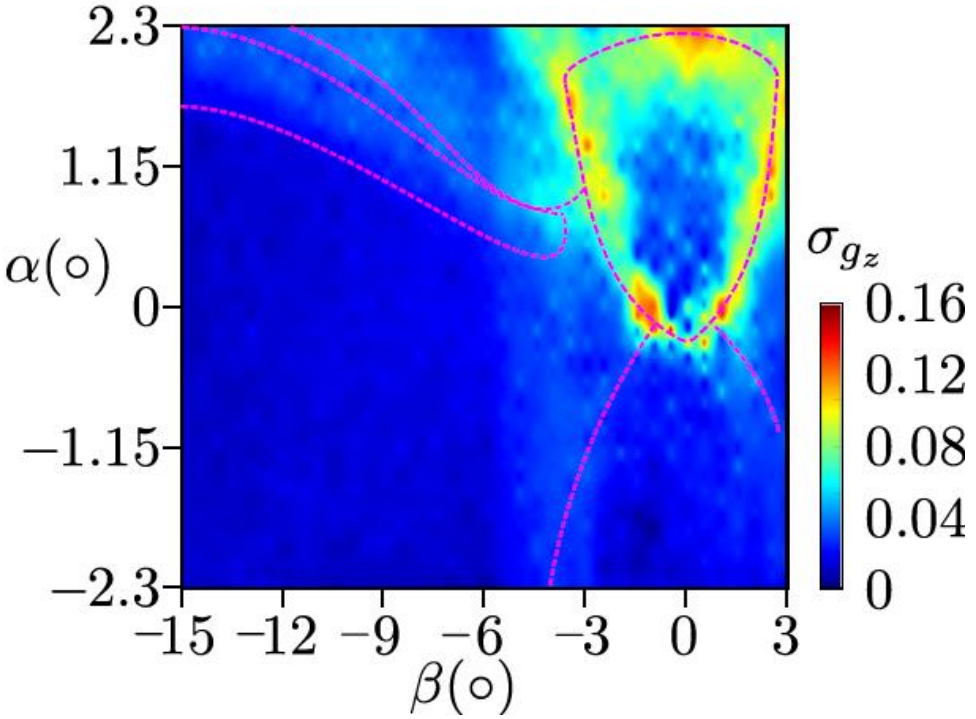



# Base pressure gradient fluctuation

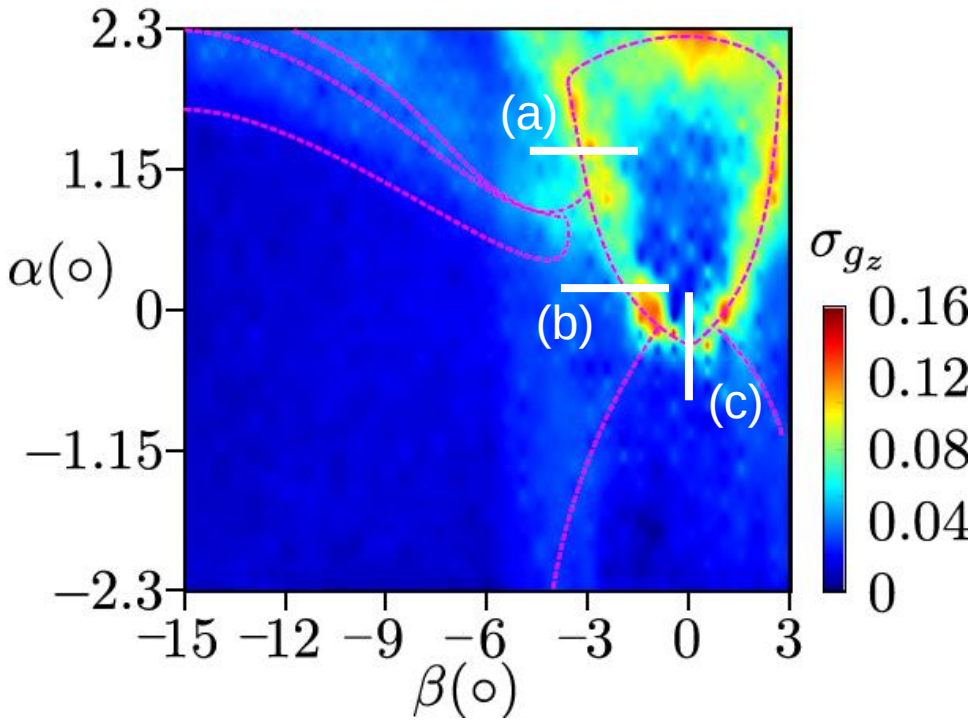


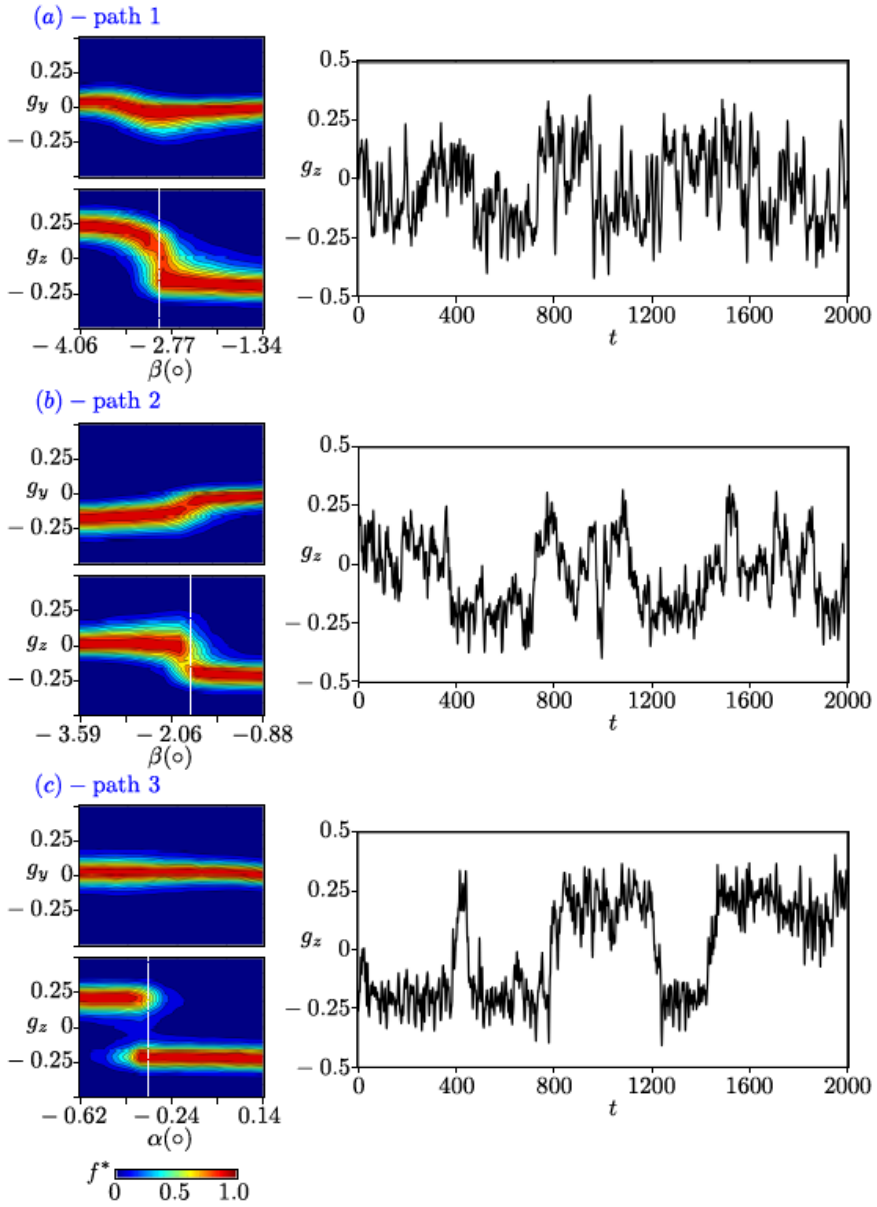

- Parameters space : $(\beta, C_o = 0.1, \alpha)$



# Unsteady transitions




**Grandemange, Gholke, Cadot** PRE (2012) “Reflectional symmetry breaking of the separated flow over three-dimensional bluff bodies”

# Transition in yaw

**Bonnavion et al.** JWEIA (2019)
“Asymmetry and global instability of real minivans' wake”

GROUPE RENAULT
STELLANTIS

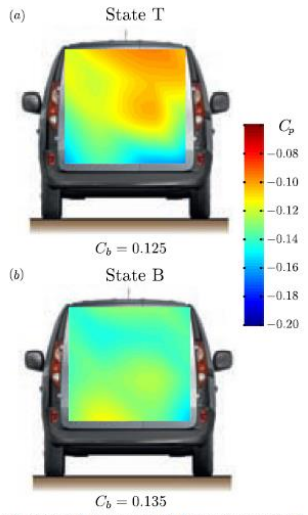



Fig. 22. Conditionally averaged base pressure distribution $C_p(y^*, z^*)$ for the Renault Kangoo ($\beta = +4.0°$): (a) State T – (b) State B.

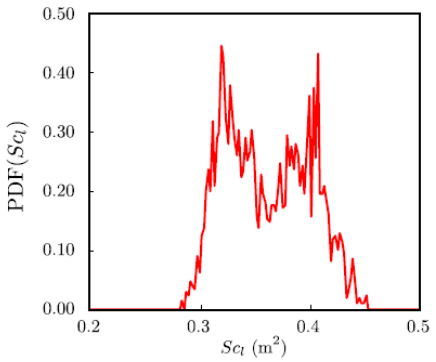
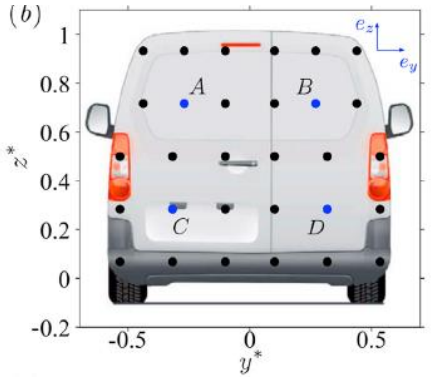



Fig. 18. Probability density function of $Sc_l$ for the Renault Kangoo ($\beta = 4.0°$).



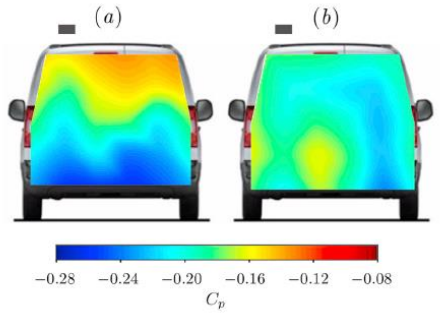
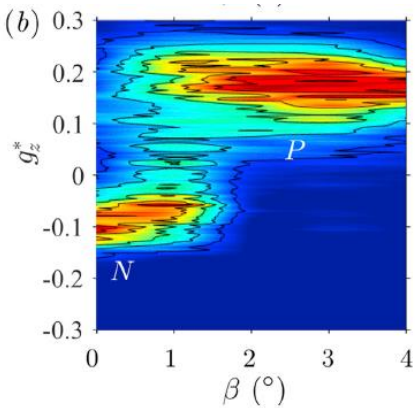
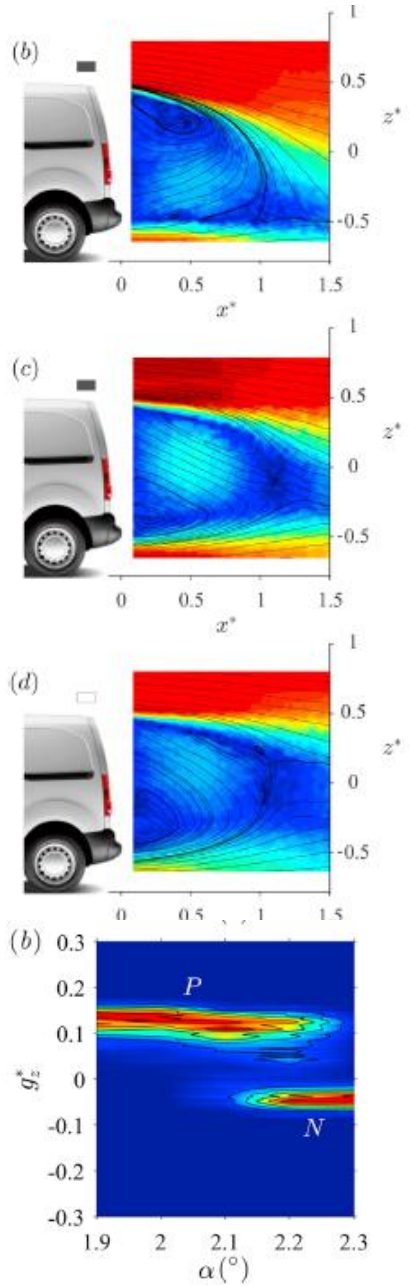
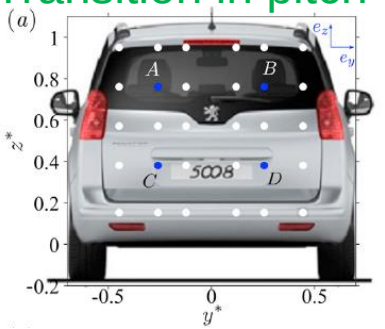



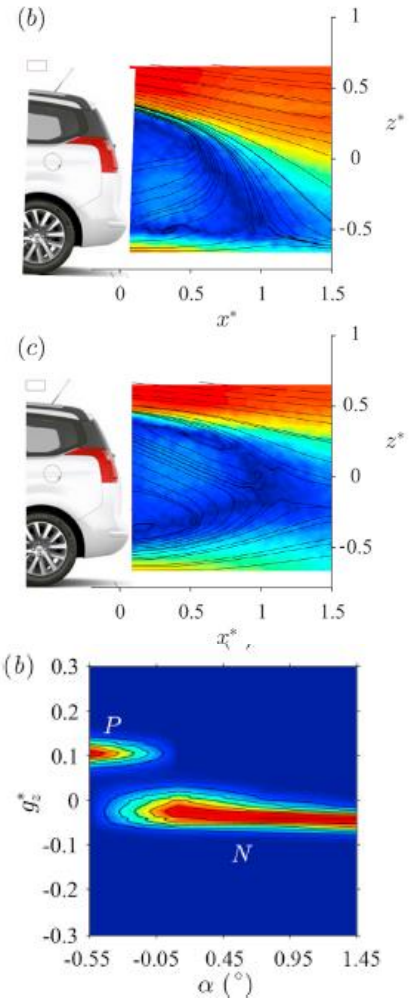

Fig. 10. Conditionally averaged mean base pressure distributions $C_p(y^*, z^*)$ (see text) for states P (a) and N (b) of the Partner in yaw at $\beta = 1°$ and with closed air-intake.




# Transition in pitch

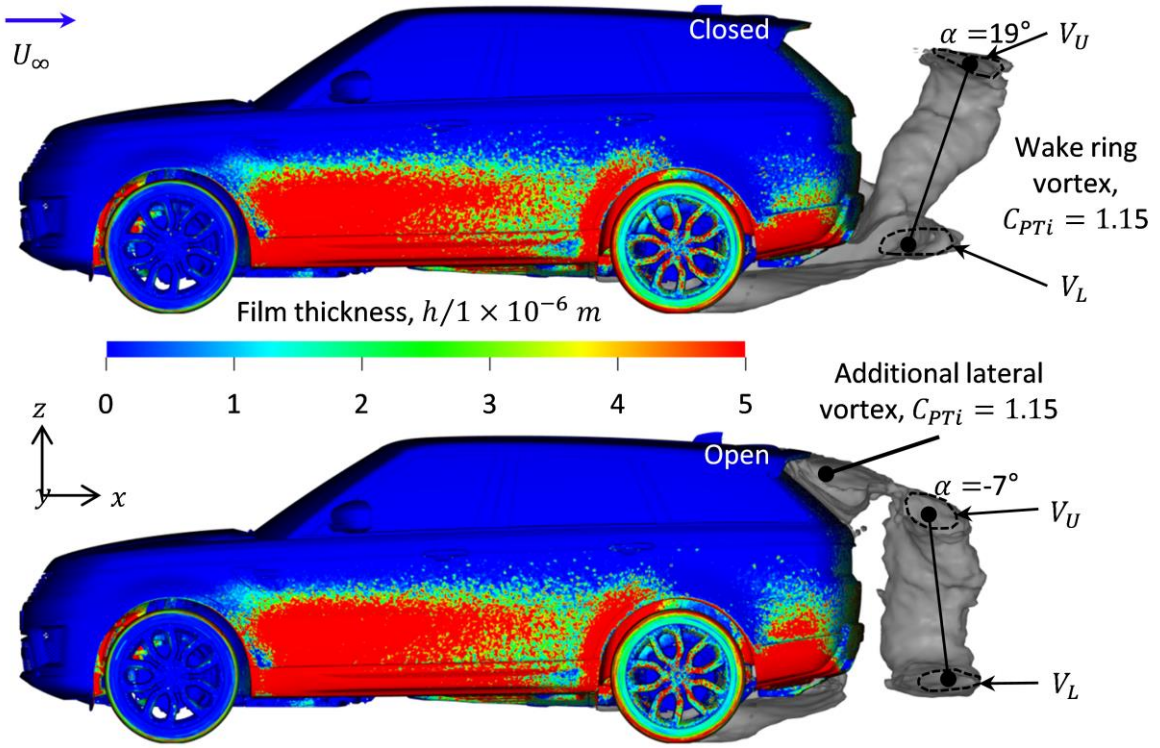


# SUV car


Slots closed

Slots open



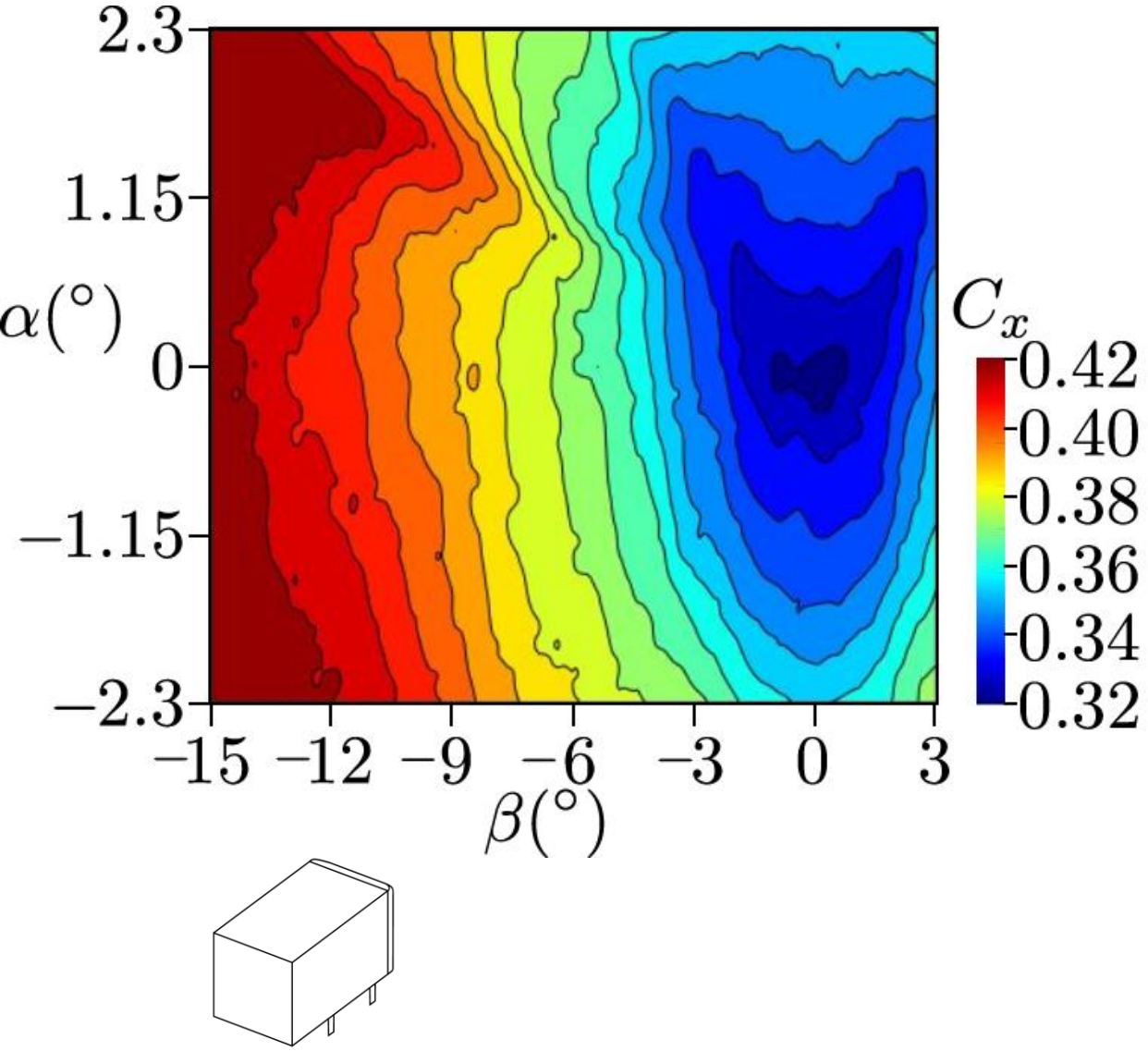

JAGUAR

LAND ROVER

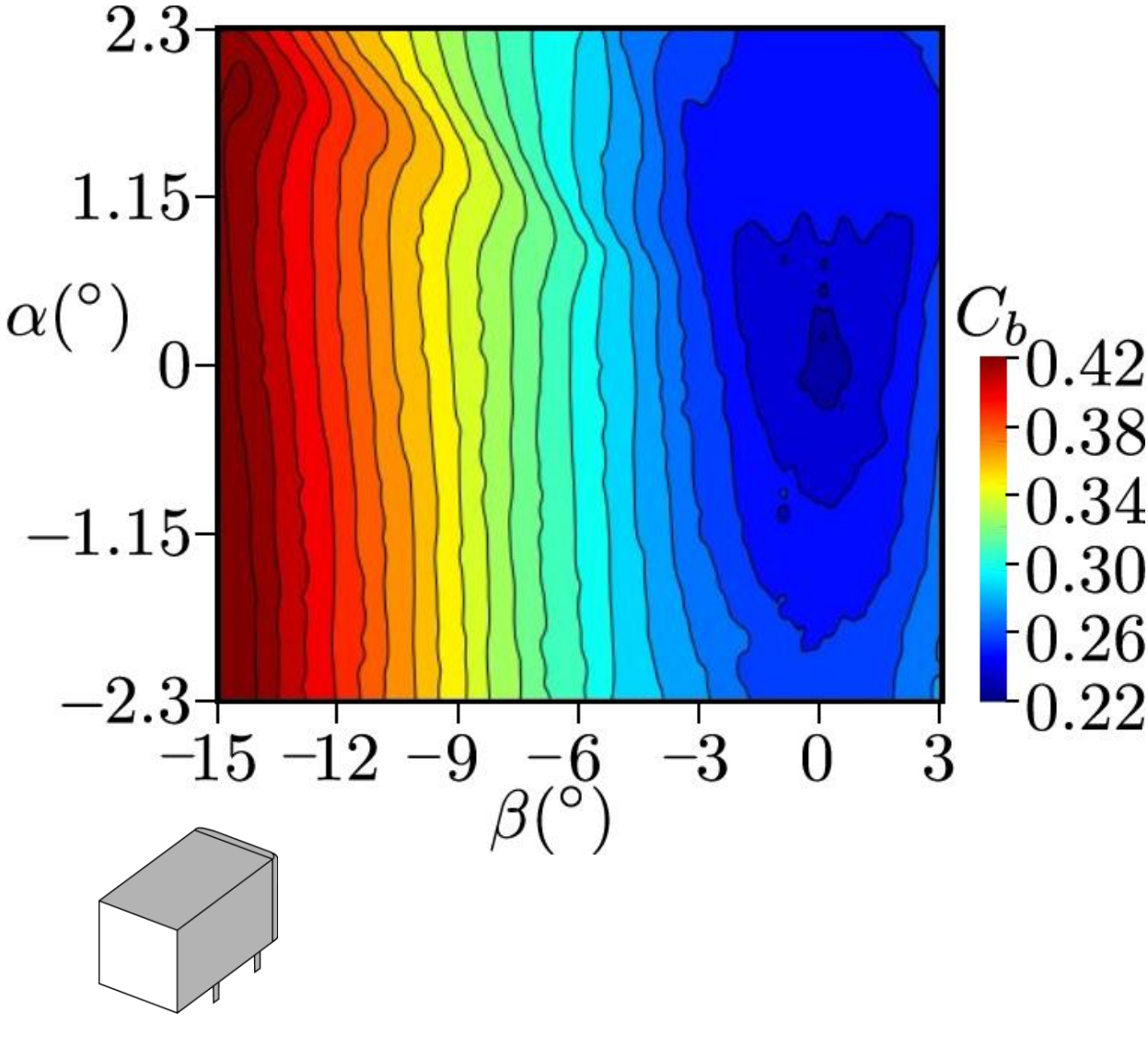
**Gaylard. A. P.** (2019)
Vehicle Surface Contamination, Unsteady Flow and Aerodynamic Drag (EngD Thesis), Warwick University, UK.

# Sensitivity of the aerodynamic coefficients to the attitude

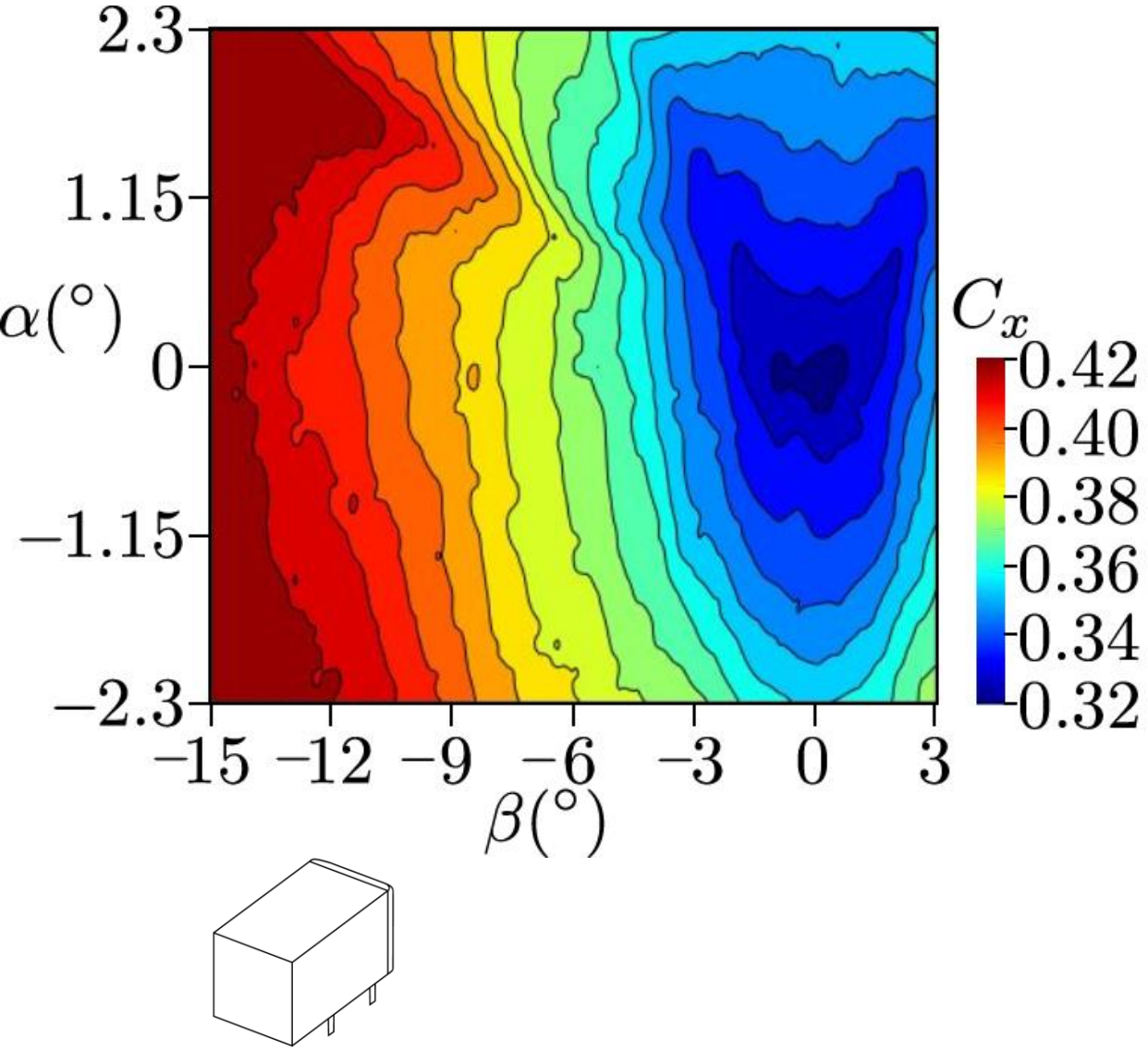
# Aerodynamic coefficients



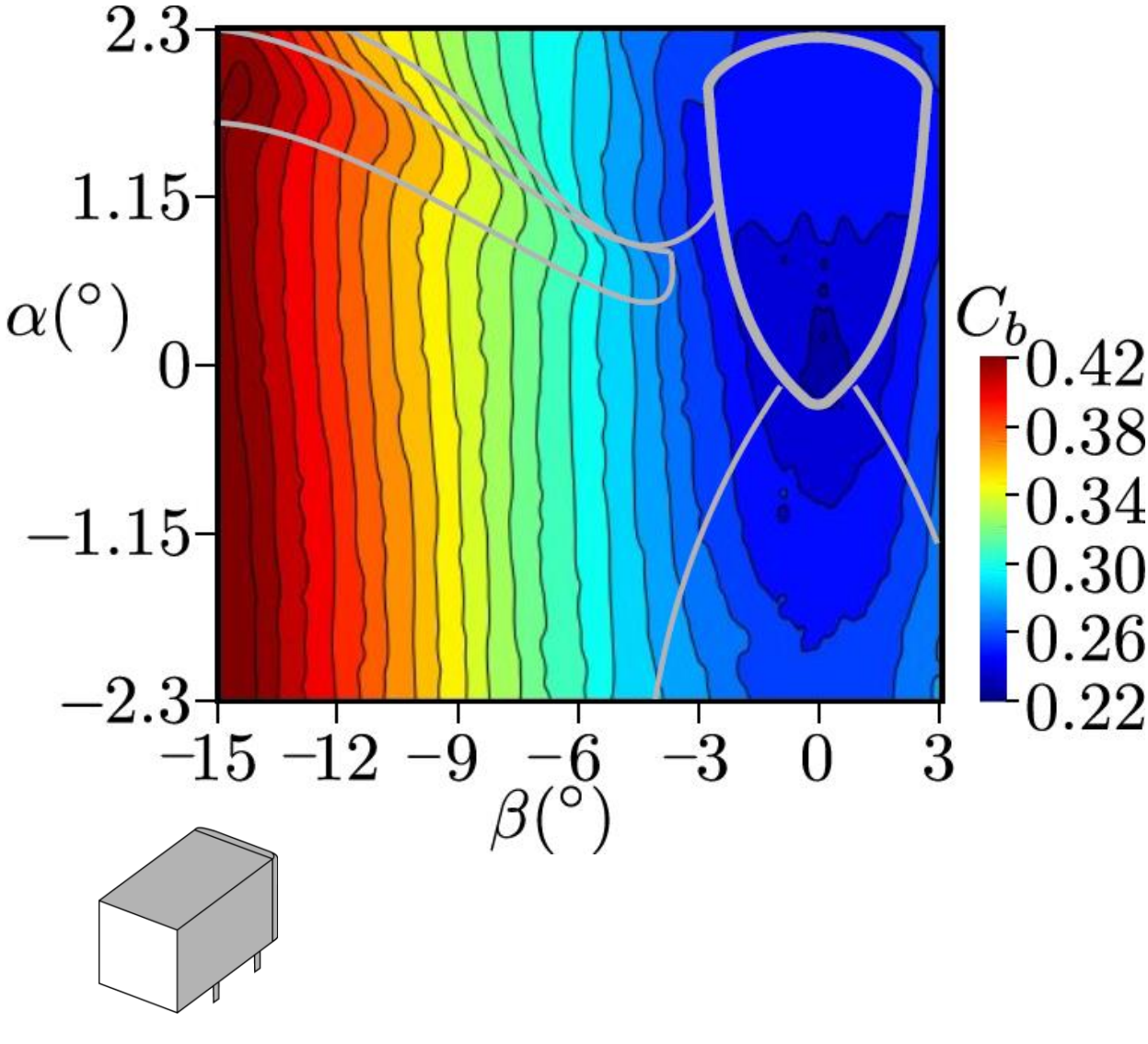


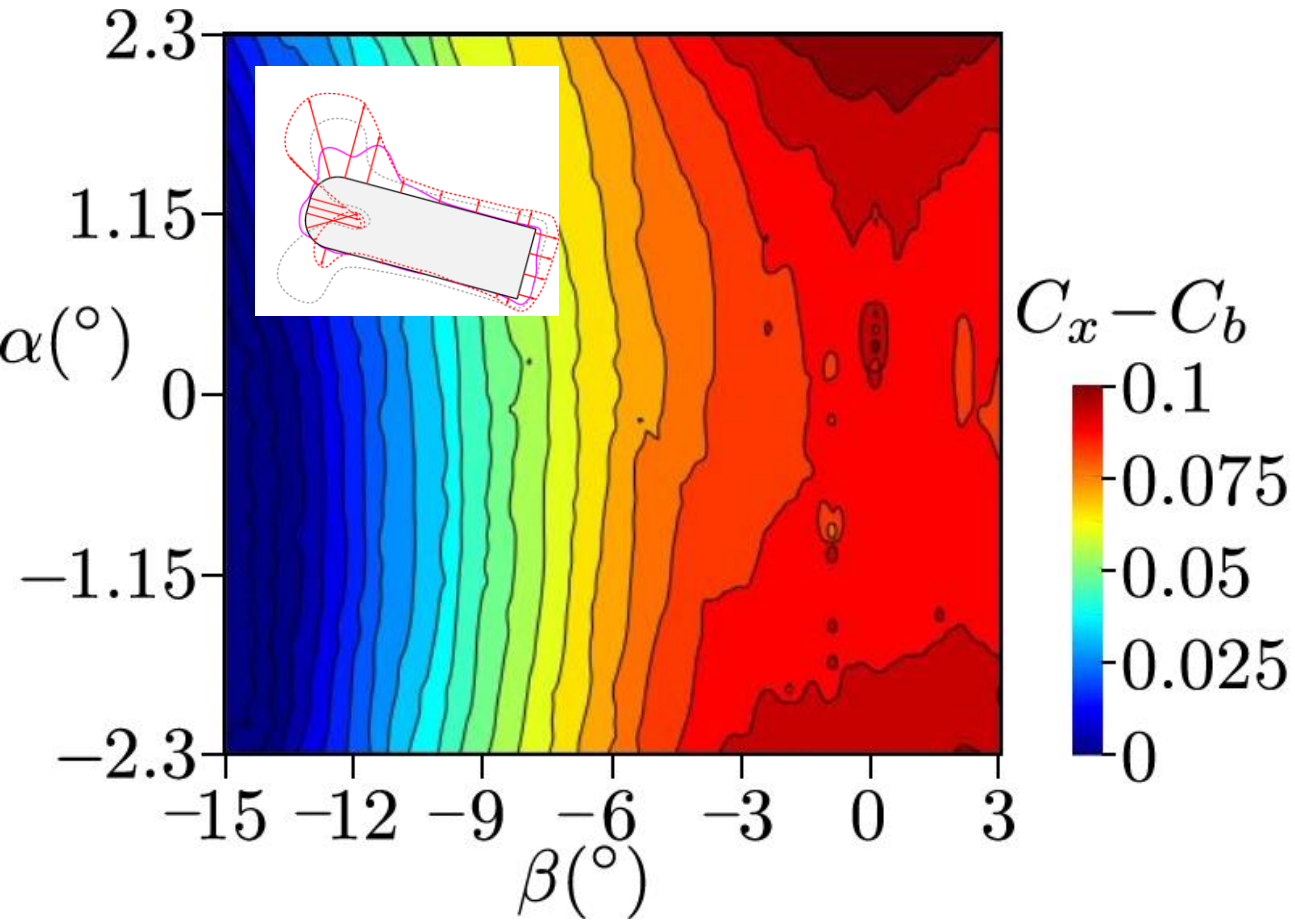
# Aerodynamic coefficients

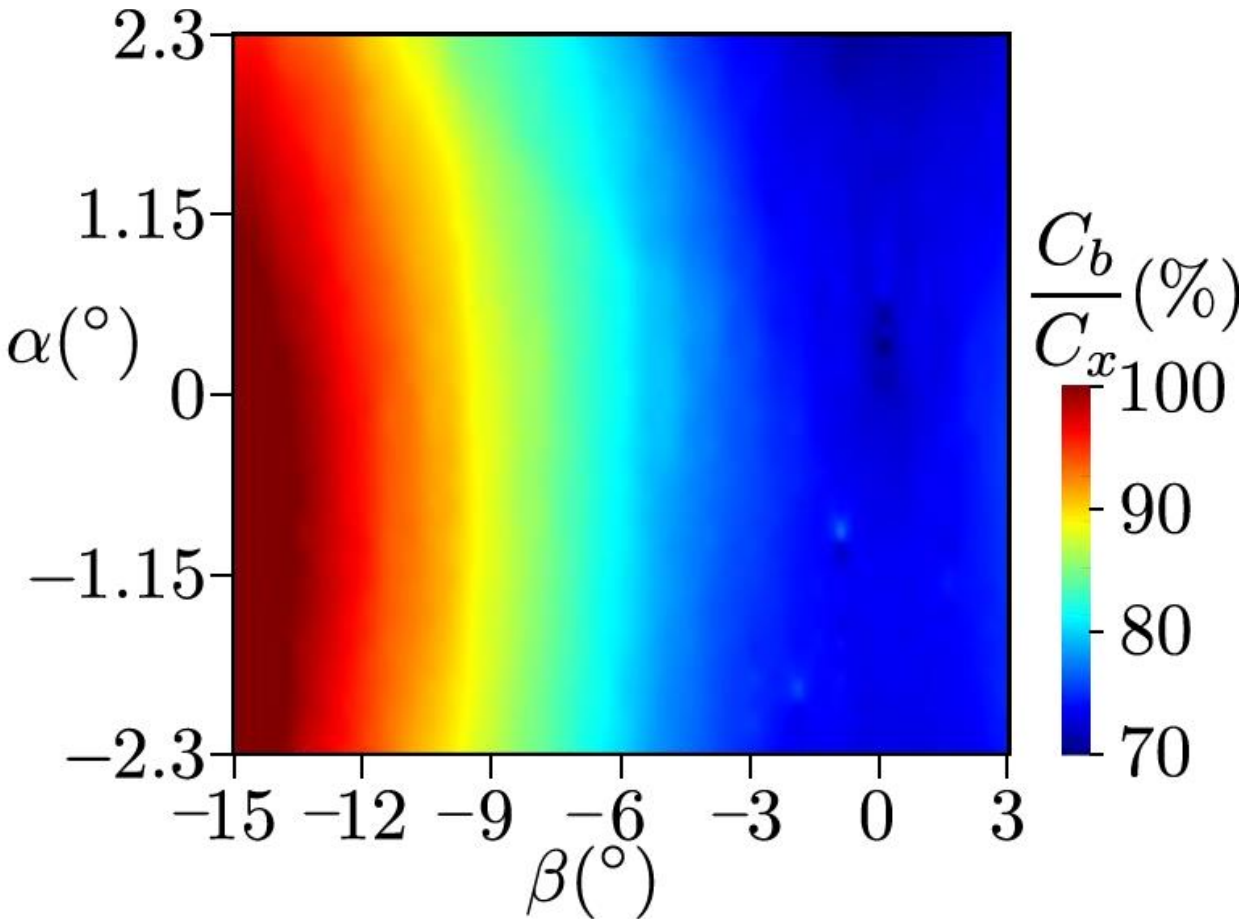


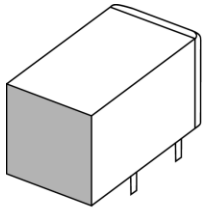


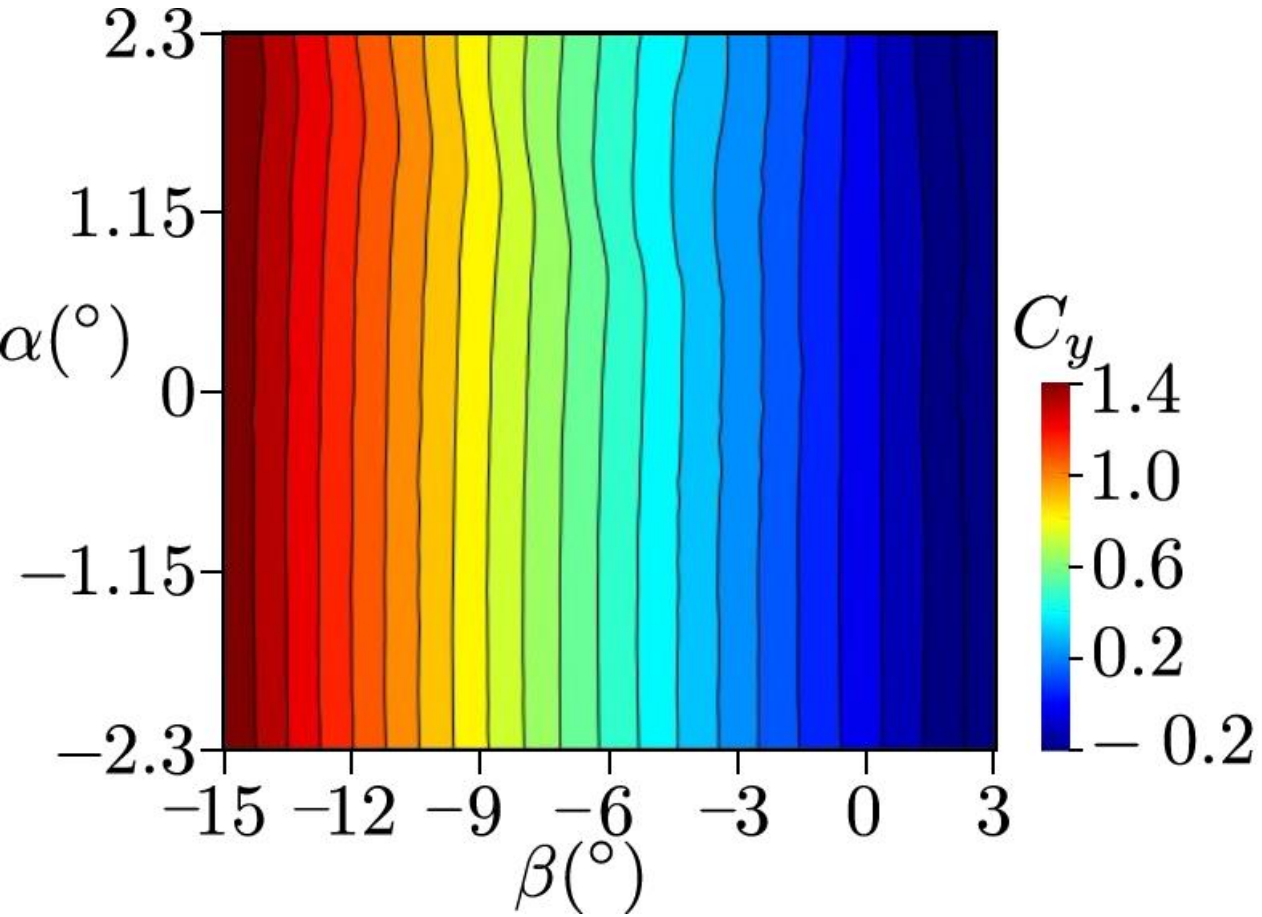
# Aerodynamic coefficients

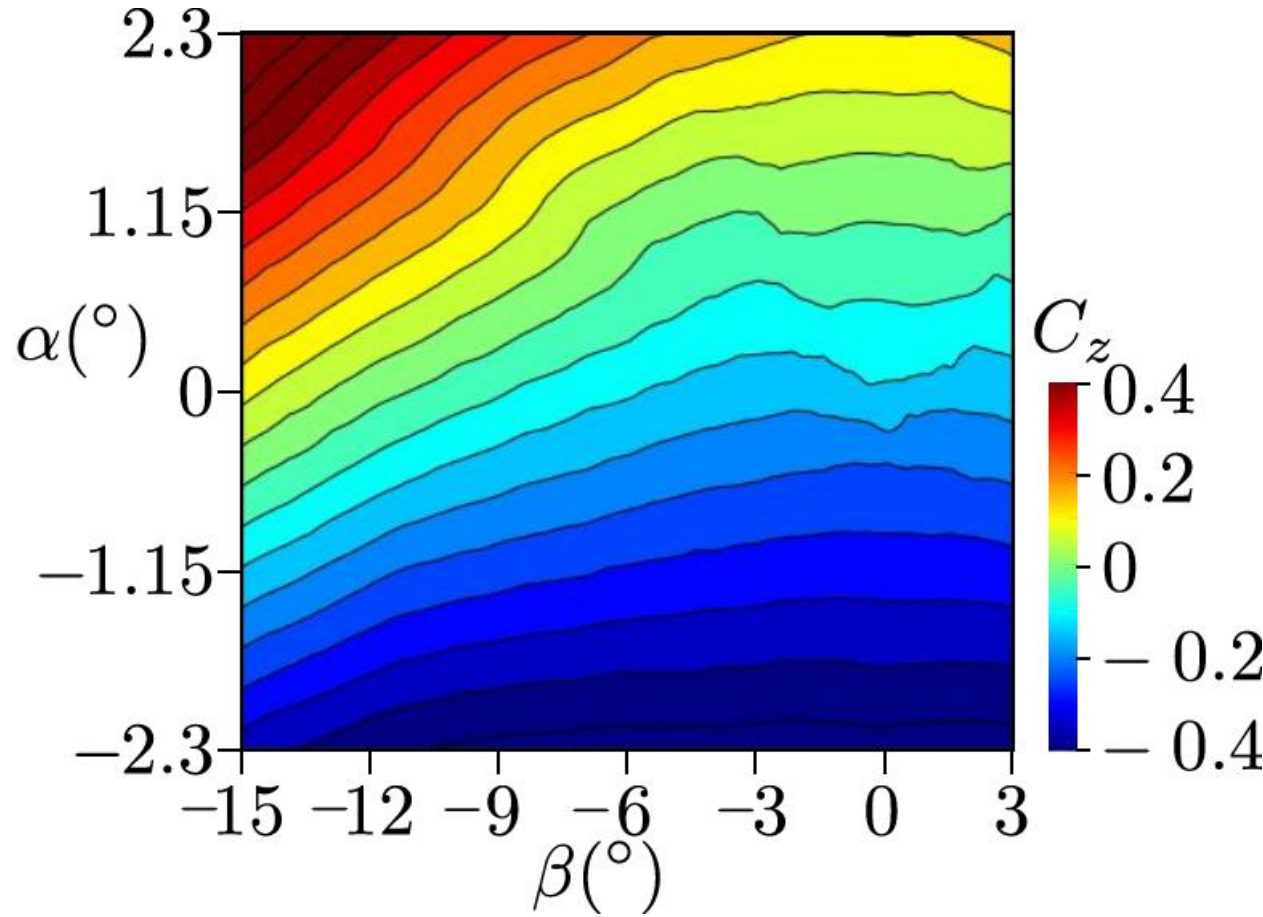


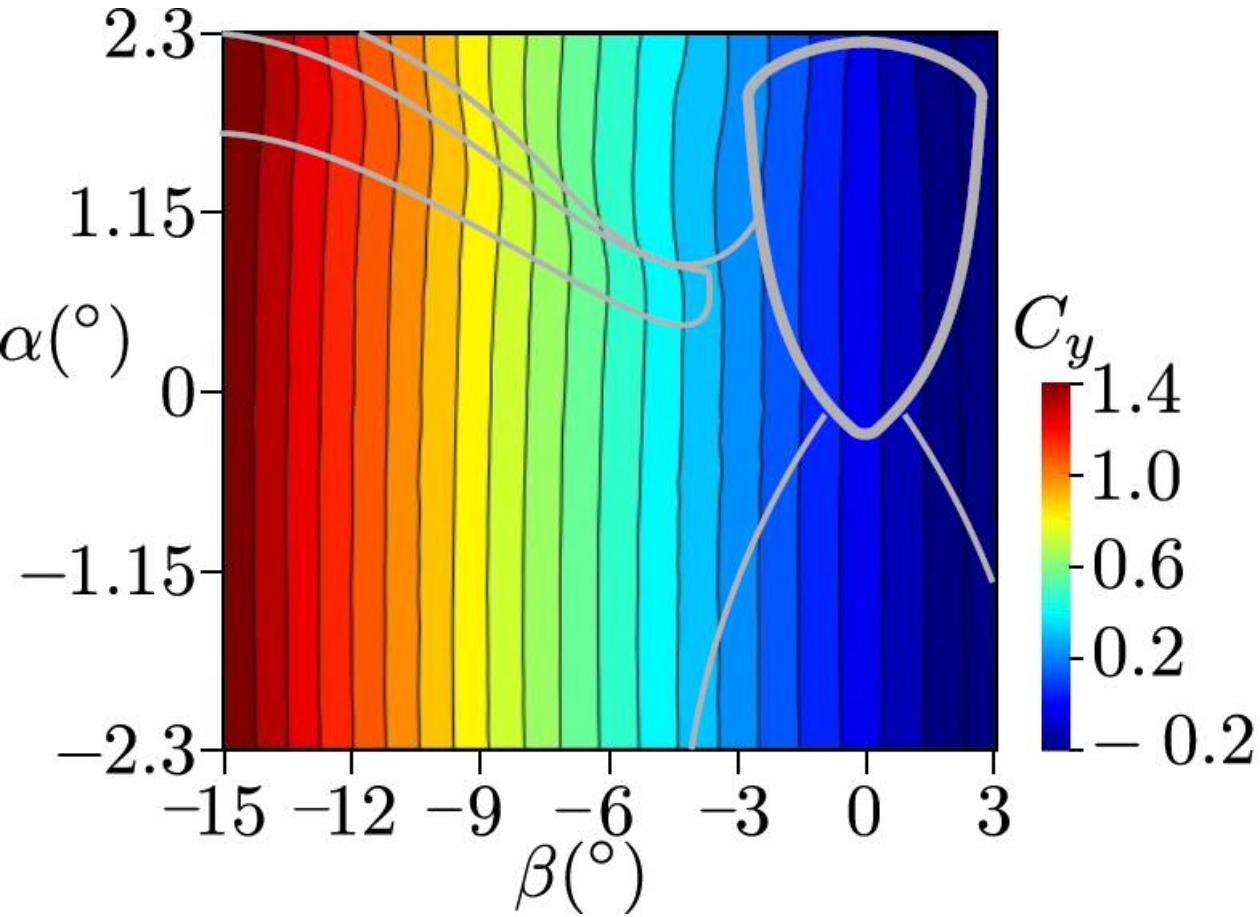



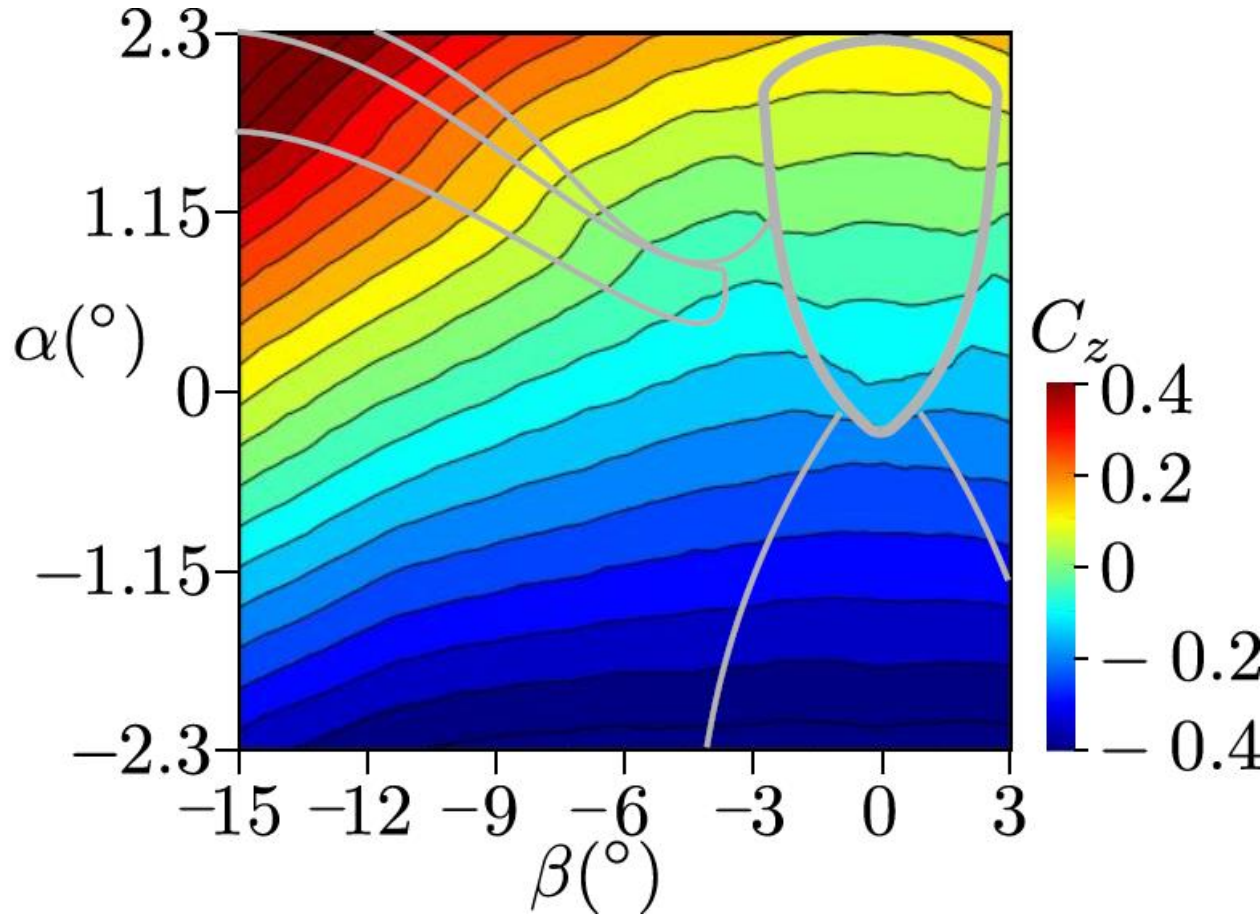
# Aerodynamic coefficients



# Aerodynamic coefficients

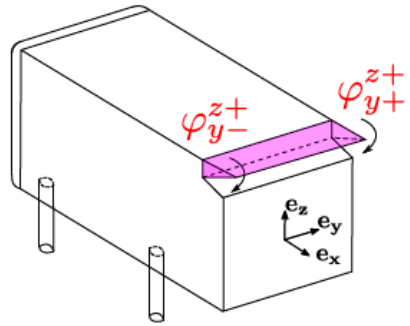


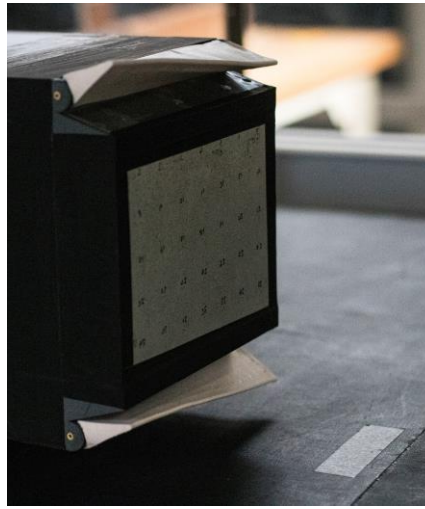



# Conclusion

- Parametric studies show the high sensitivity of the wake orientation to the attitude of a simplified ground vehicle (i.e. various flow condition : mass loading, crosswind)
- This sensititivity is due to the presence of the steady wake instability, reminiscent of a low Reynolds number bifurcation. It induces lift, side force and drag variation.
- PIV investigation to understand wake orientation with attitude
- Upcoming work : drag reduction in variable attitudes with adaptive spoilers, to test different control strategies.

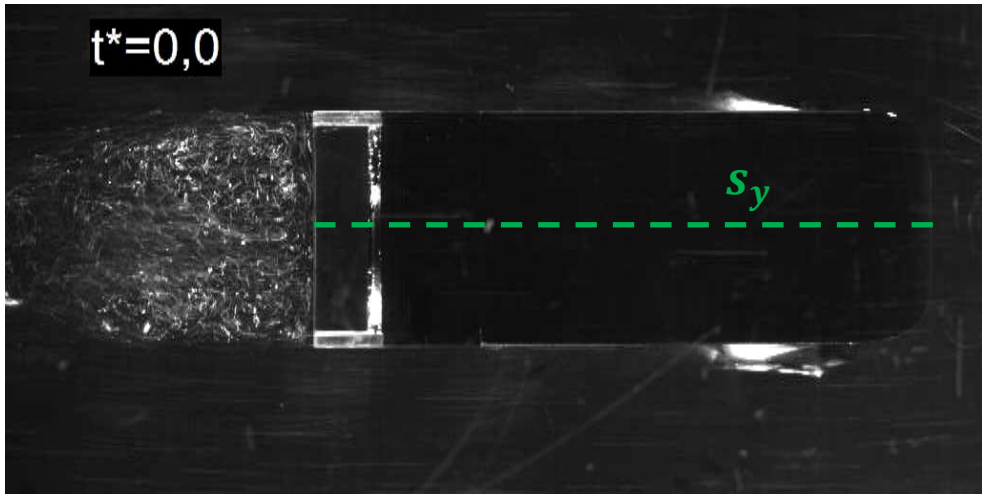
Thank you

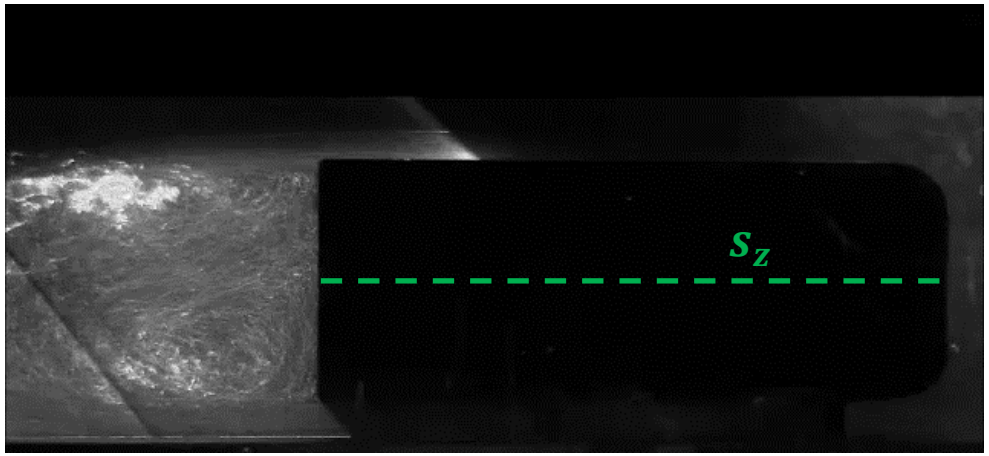


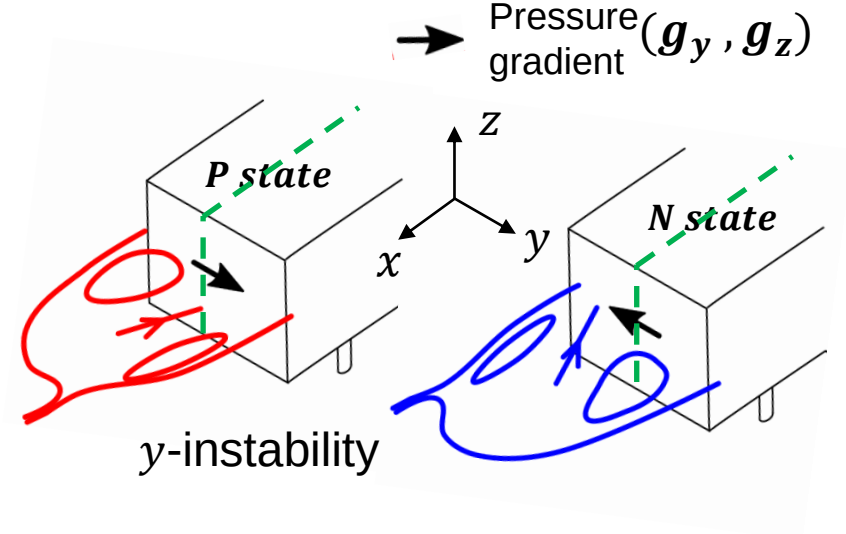
# Symmetry breaking

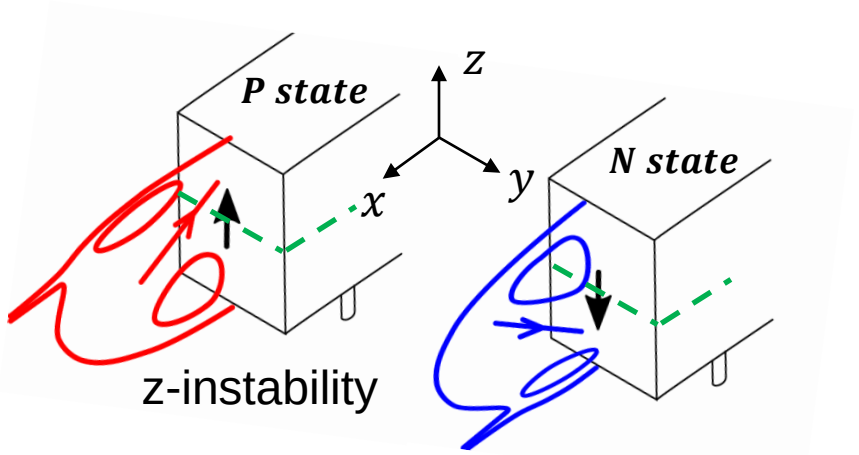
- Simplified geometry



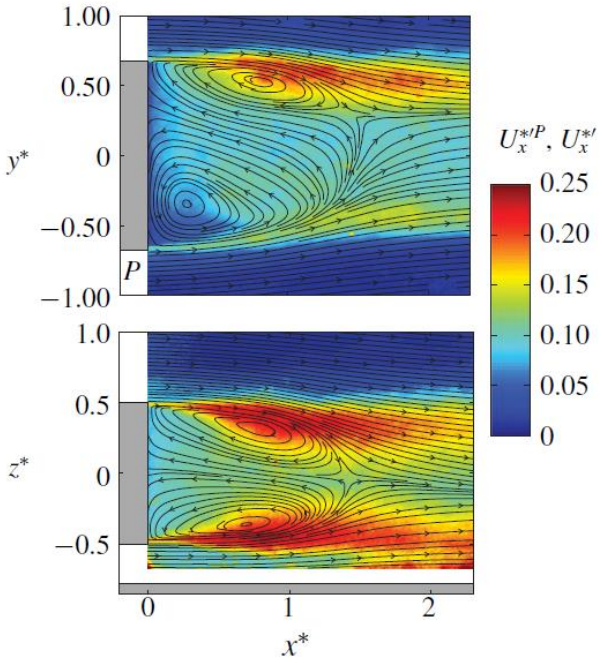




ENSTA Re=250 000




Grandemange *et al.* 2013 PoF




Re=100 000