A complementary study of simulations and experiments to characterize the mean structure of the recirculatory flow at the rear of a 3D blunt body at different attitudes

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Mean structure of the recirculating flow at the rear of a 3D blunt body at different attitudes

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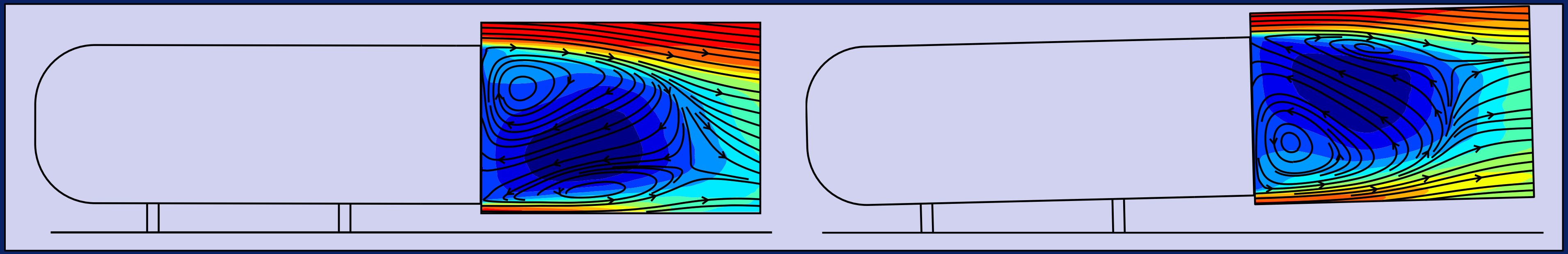

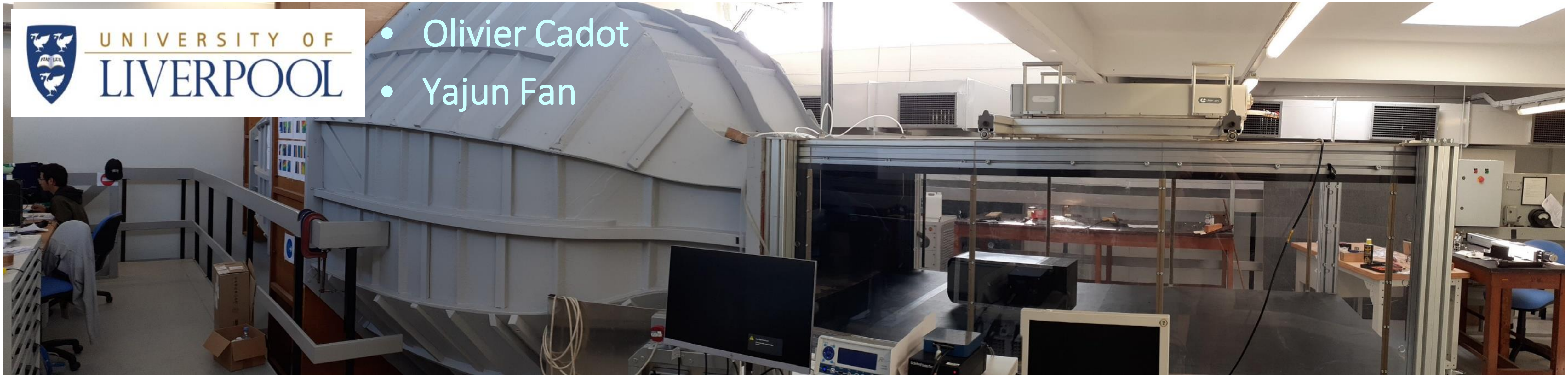
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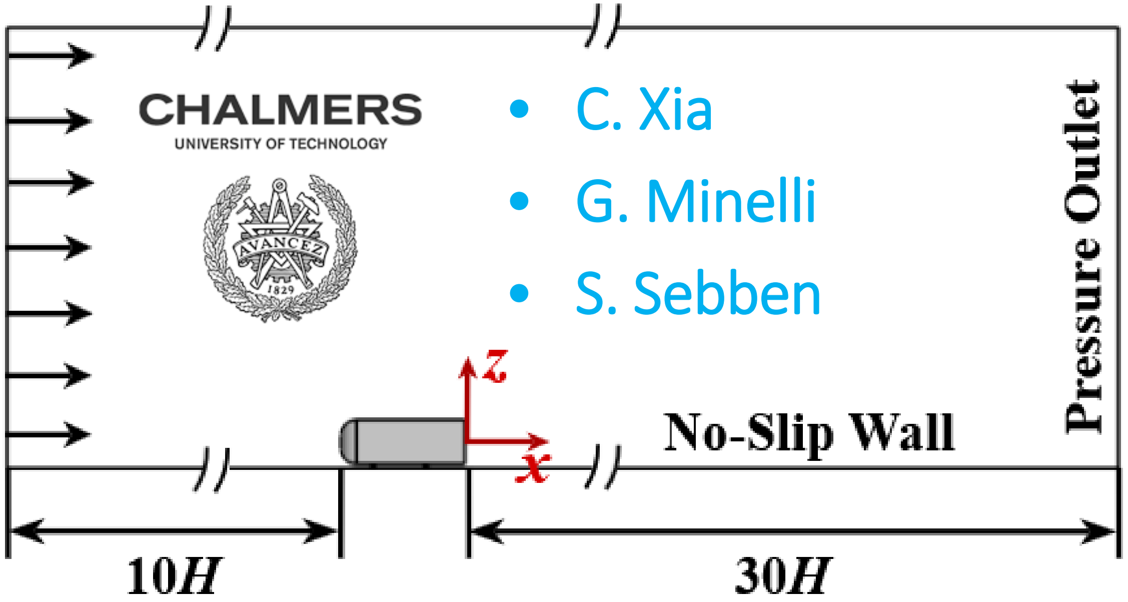
• Olivier Cadot
• Yajun Fan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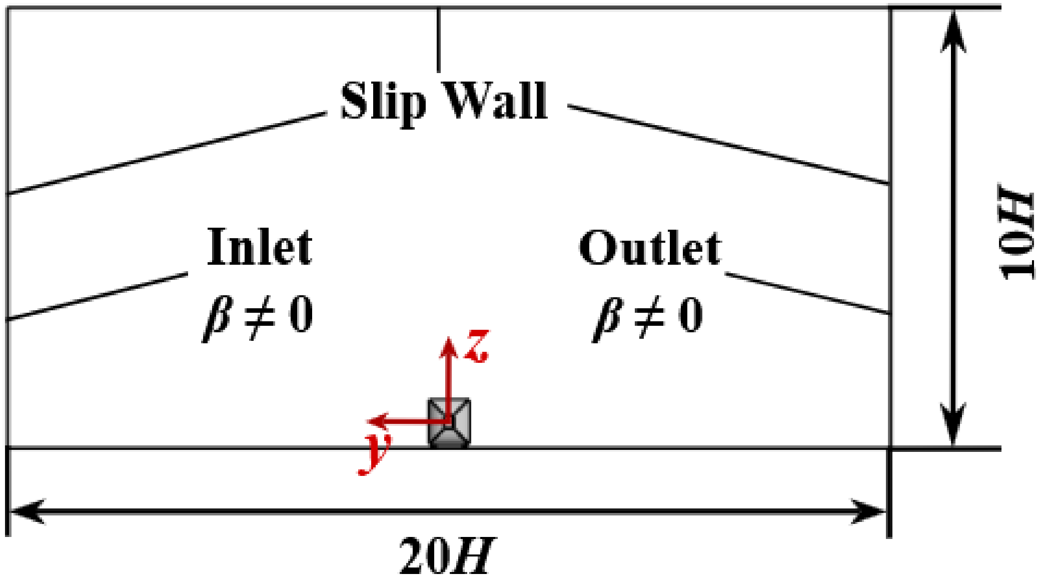
• C. Xia
• G. Minelli
• S. Sebben
Pressure Outlet
No-Slip Wall
z
x
10H
30H


Slip Wall
Inlet
$\beta \neq 0$
Outlet
$\beta \neq 0$
z
y
10H
20H

Summary

1. Introduction about steady asymmetry and recirculating flow structure of blunt trailing edge bluff-bodies
2. LES and Experiment at different body attitudes
3. Conclusion and perspectives

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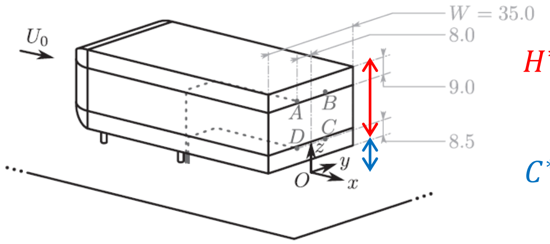
1. Introduction

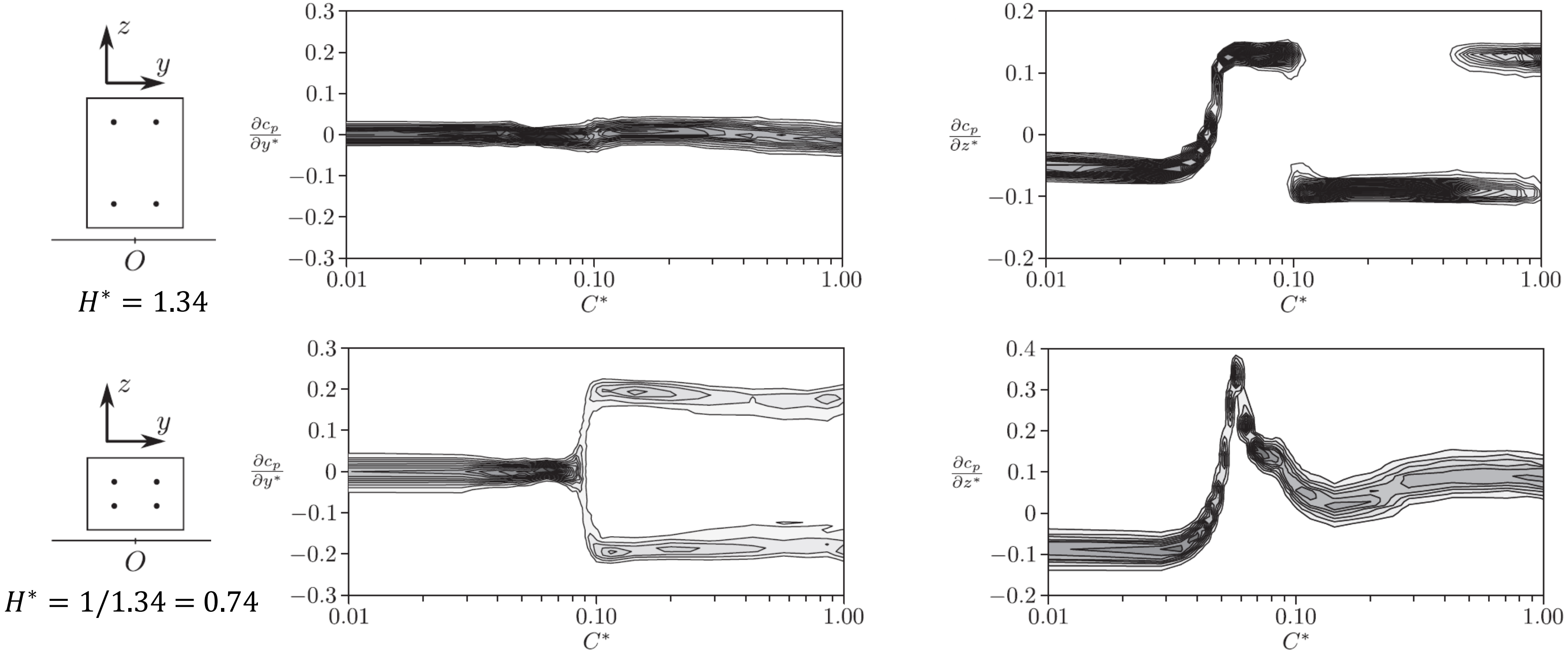


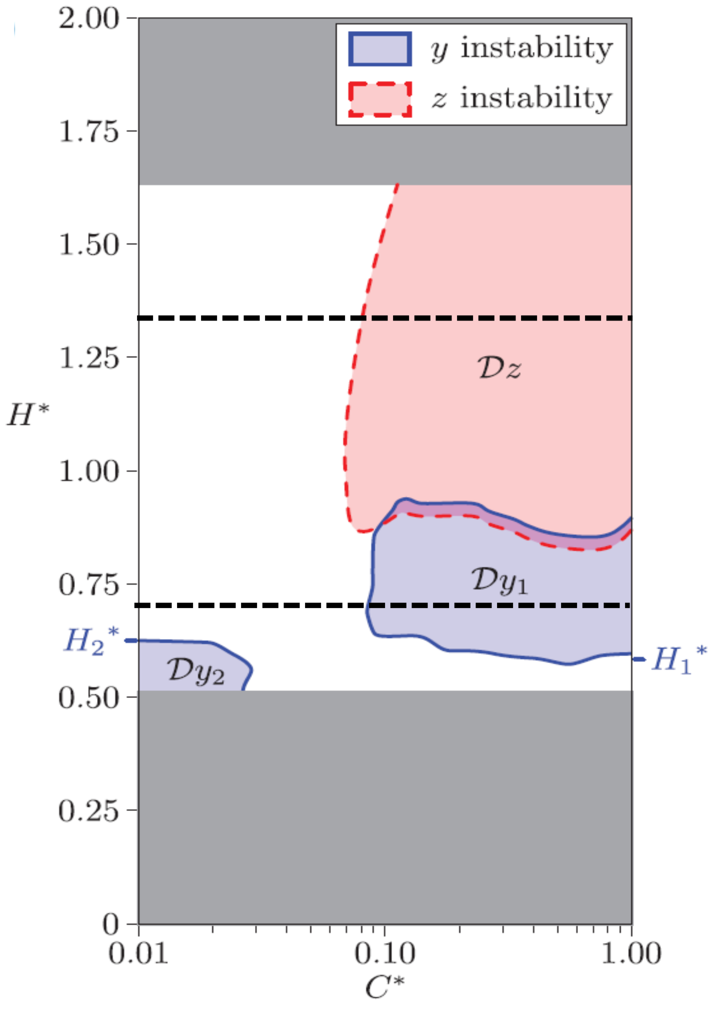
$H^* = \frac{H}{W}$

$C^* = \frac{C}{W}$

Grandemange, Gohlke & Cadot (PoF 2013)

$Re = 4.5 \times 10^4$





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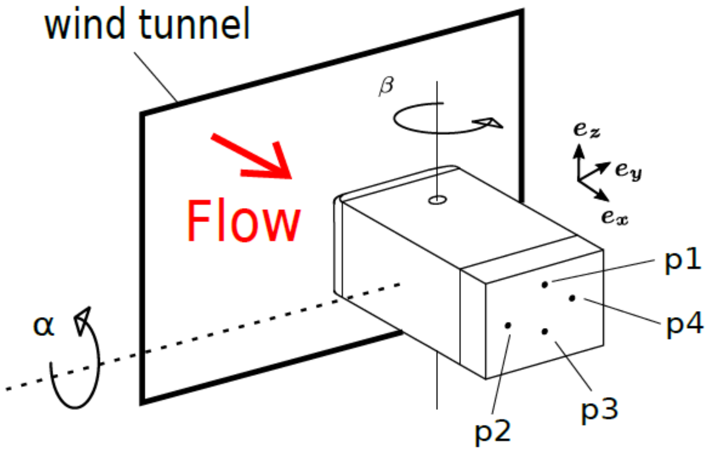
Permanent asymmetry when $\frac{2}{3} \leq \frac{H}{W} \leq \frac{3}{2}$

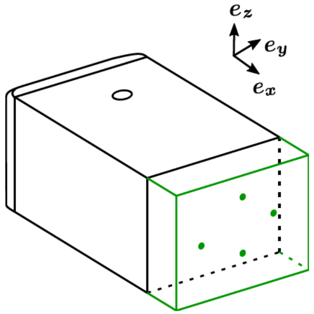


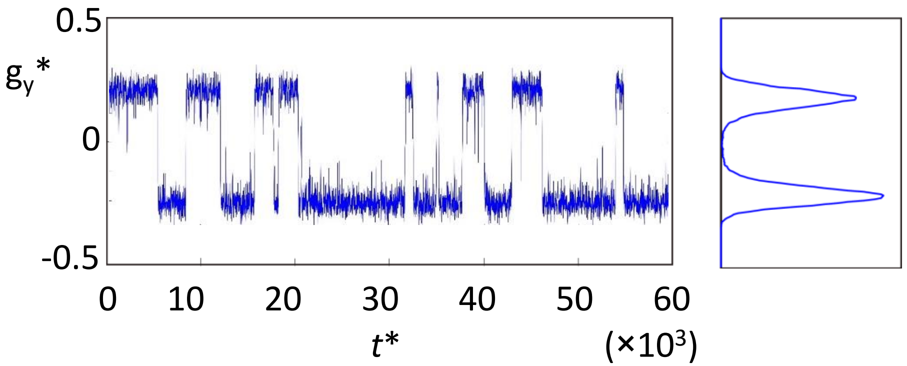
$$g_y^* = \frac{c_{p4} - c_{p2}}{\Delta_y^*}$$

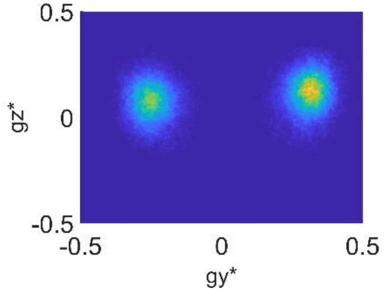
$$g_z^* = \frac{c_{p1} - c_{p3}}{\Delta_z^*}$$

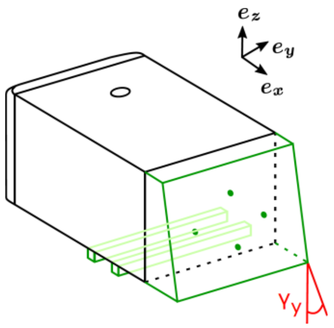
$$Re = 2 \times 10^5$$

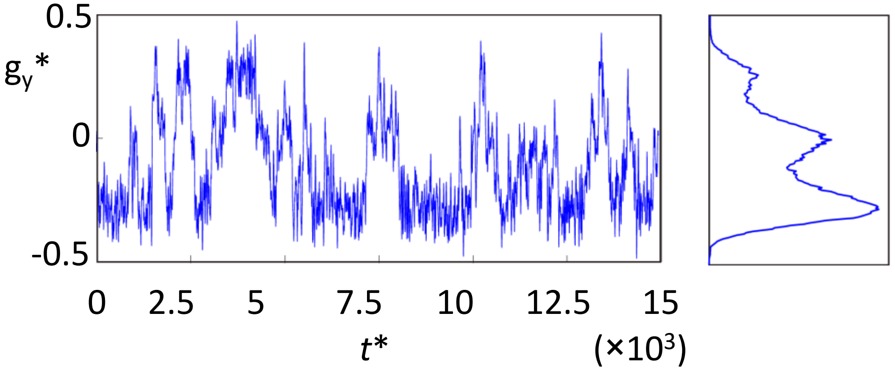
Legeai & Cadot (ExiF 2020)

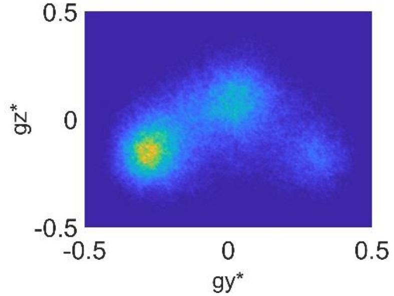


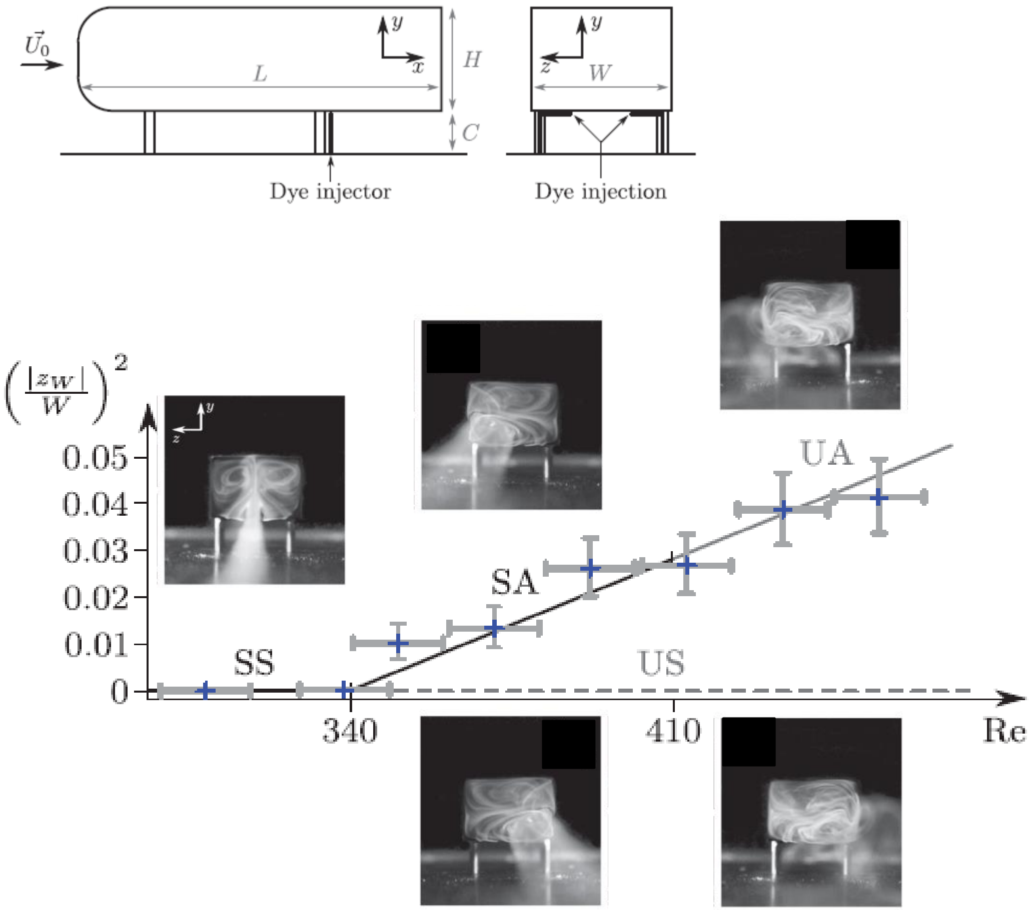




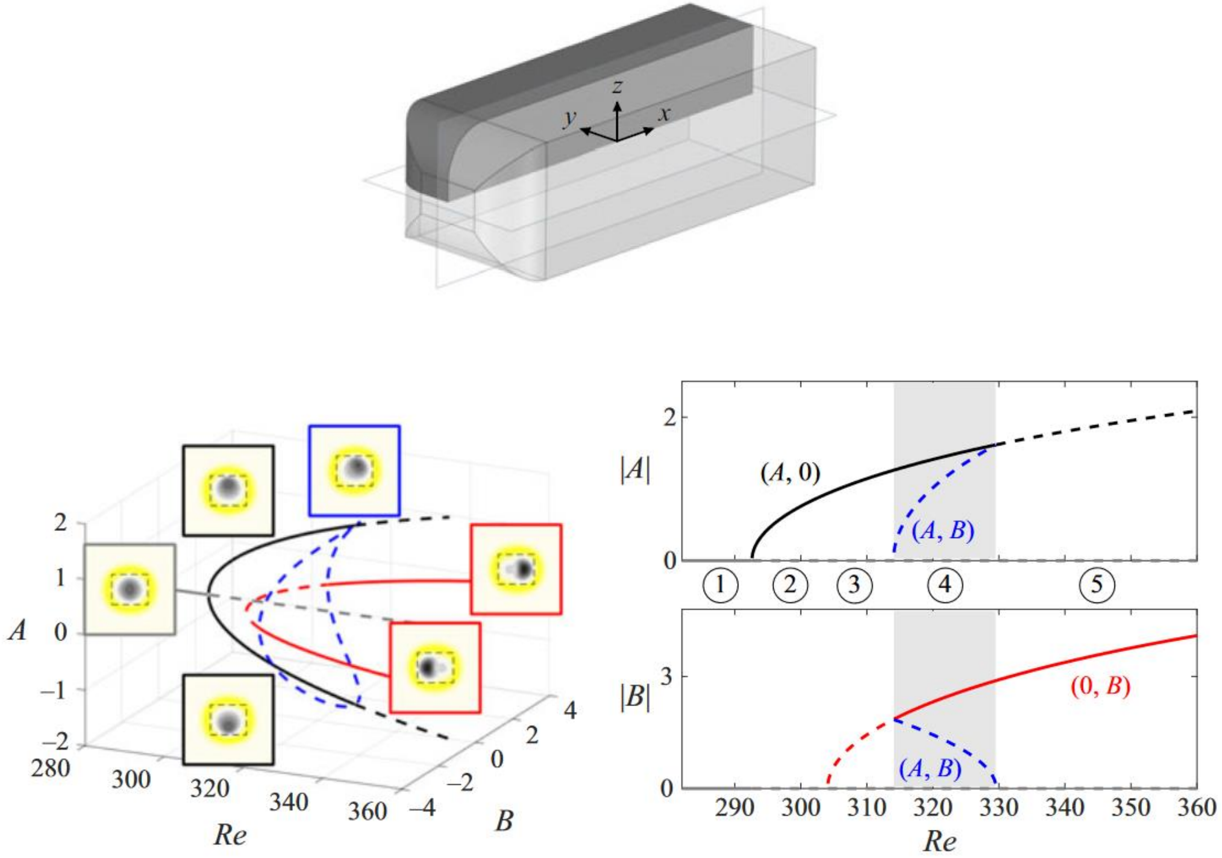








Grandemange, Gohlke & Cadot
(Phys. Rev. E 2012)



Zampogna & Boujo (J. Fluid Mech 2023)

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Two equilibrium states with a wake deviation towards the major axis direction of the base

Krajnovic & Davidson (JFE 2003)

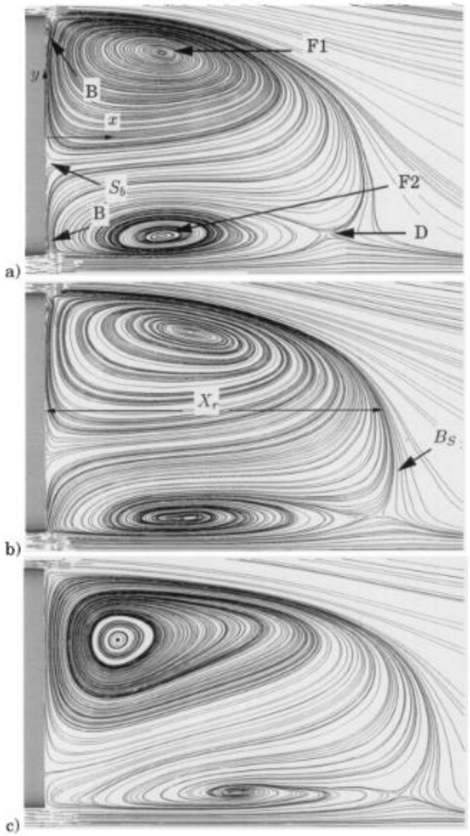


Fig. 9 Time-averaged streamlines projected onto symmetry plane $z=0$ of the bus. (*a*) Fine grid, (*b*) medium grid, (*c*) coarse grid.

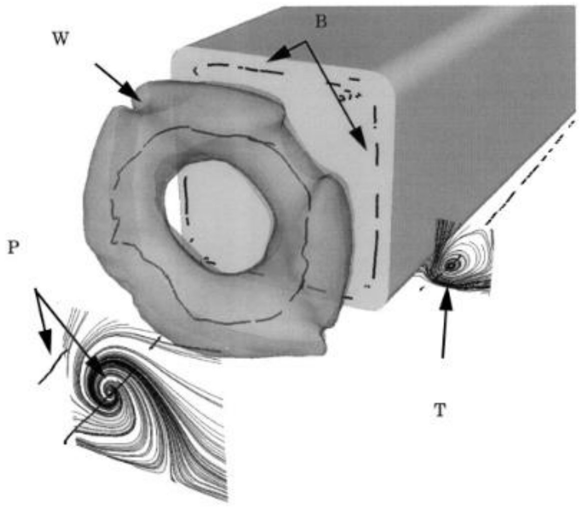
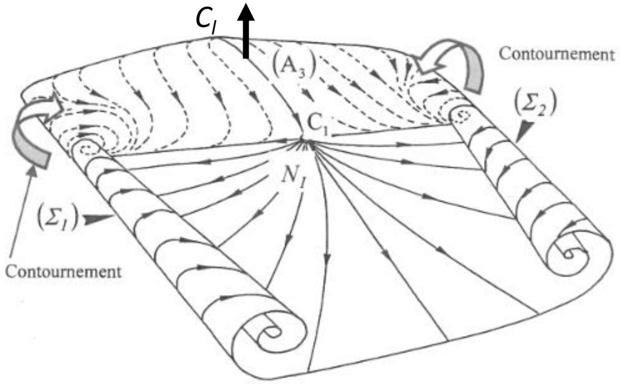
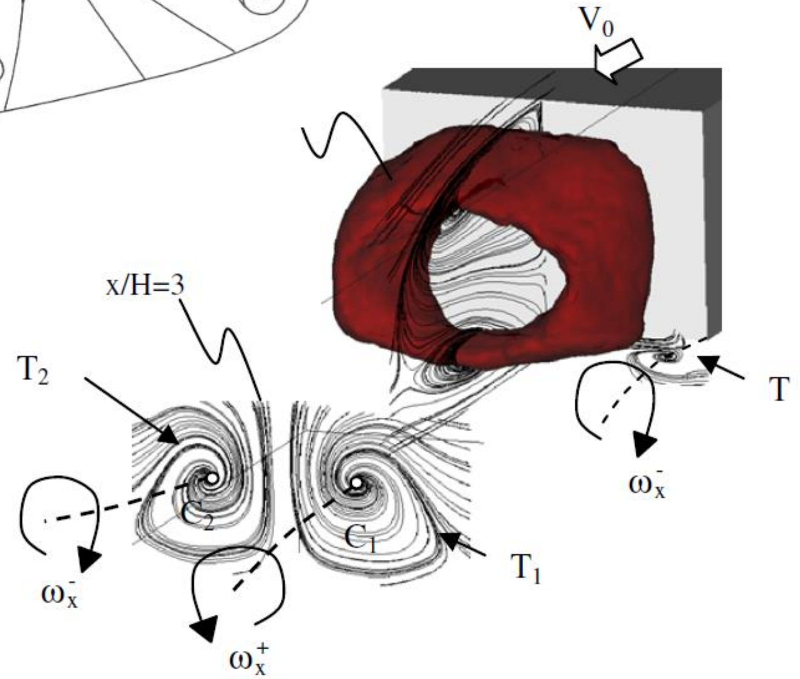


Fig. 10 The isosurface of time-averaged pressure $p=-0.20$. The black curves represent the vortex cores of the thin edge vortices *B*, the ring vortex *W*, and the longitudinal vortices behind the separation bubble *P*. Vortices on the right side ($z<0$), *P* and *T*, are visualized using streamlines in planes $x=1.4H$ and $x=-0.48H$, respectively (note that the mirror image vortices on the left side, i.e., $z>0$, are not shown in this figure). View of the rear face of the body.

Table 3 Time-averaged pressure drag, lift, and rear pressure coefficients and dominating frequency (St_p) of the C_p signal (note that $\overline{C_p}$ means the integrated C_p over the rear surface)

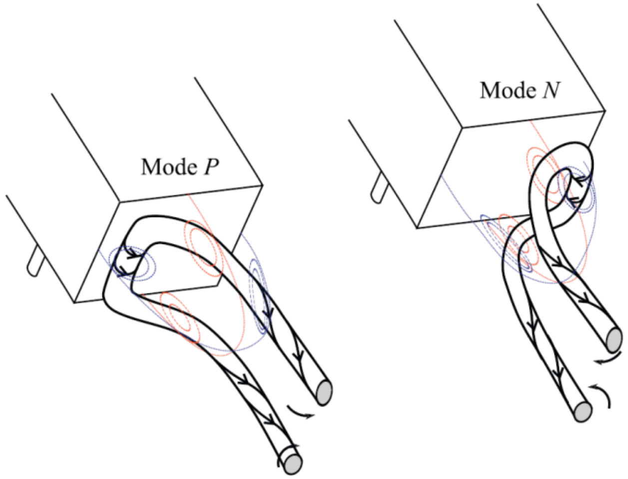
Case	$\langle C_D \rangle_t$	$\langle C_L \rangle_t$	$\langle \overline{C_p} \rangle_t$	St_p
Coarse	0.206	−0.066	−0.216	0.073
Medium	0.318	−0.066	−0.224	0.055
Fine	0.33	−0.071	−0.229	0.059



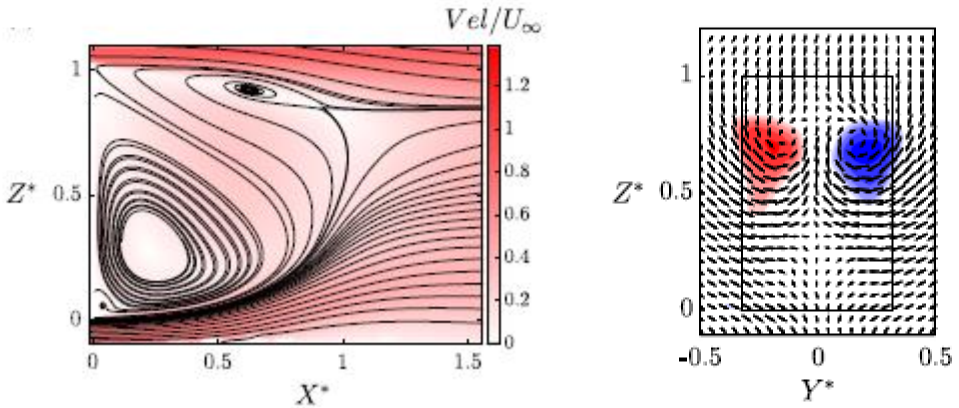


Rouméas. Gilliéron & Kourta (C&F 2008)

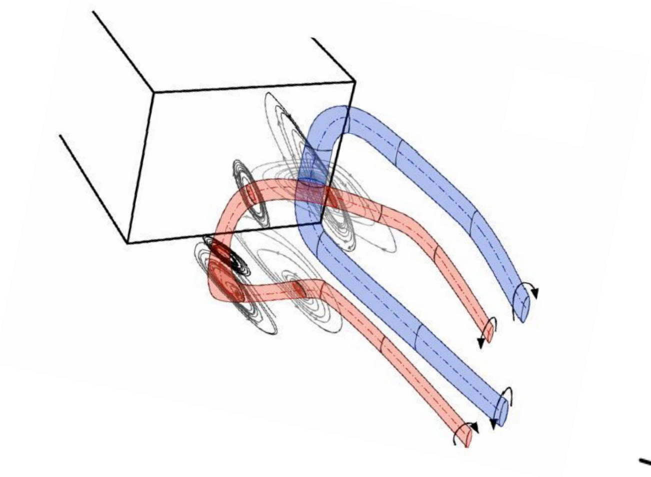
Evrard, Cadot, Herbert, Ricot, Vigneron, & Délery (JFS 2016)



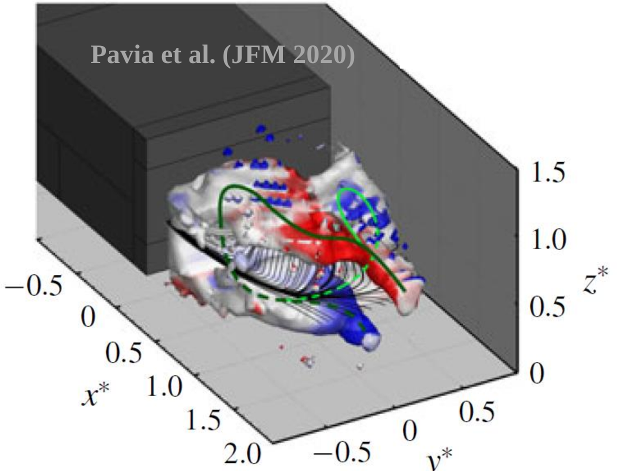
McArthur, Burton, Thompson & Sheridan (JFS 2016)



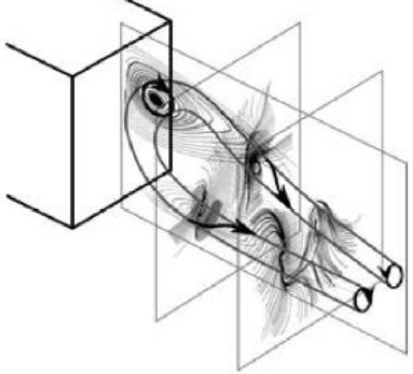
Perry, Pavia & Passmore (ExiF 2016)



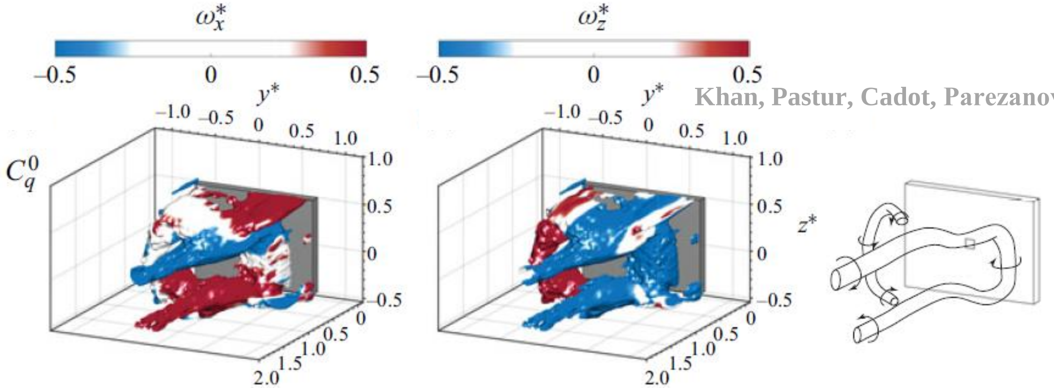
Pavia et al. (JFM 2020)

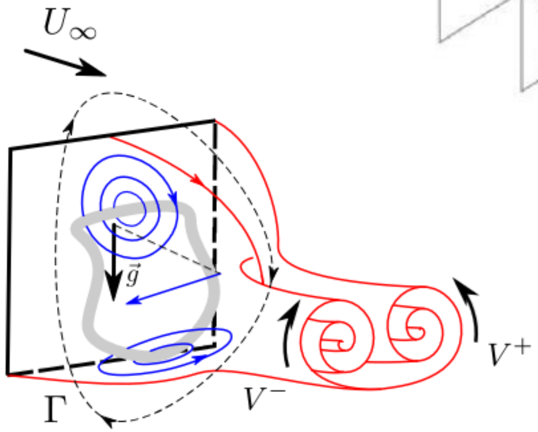


Schmidt, Nayeri & Paschereit (ExiF 2018)



Khan, Pastur, Cadot, Parezanović (JFM 2024)





Our proposition …

2. A complementary study of experiment and LES

Fan, Parezanovic & Cadot (JFM 2022)

Fan, Xia, Minelli, Sebben & Cadot (Submitted to JFM 2025)

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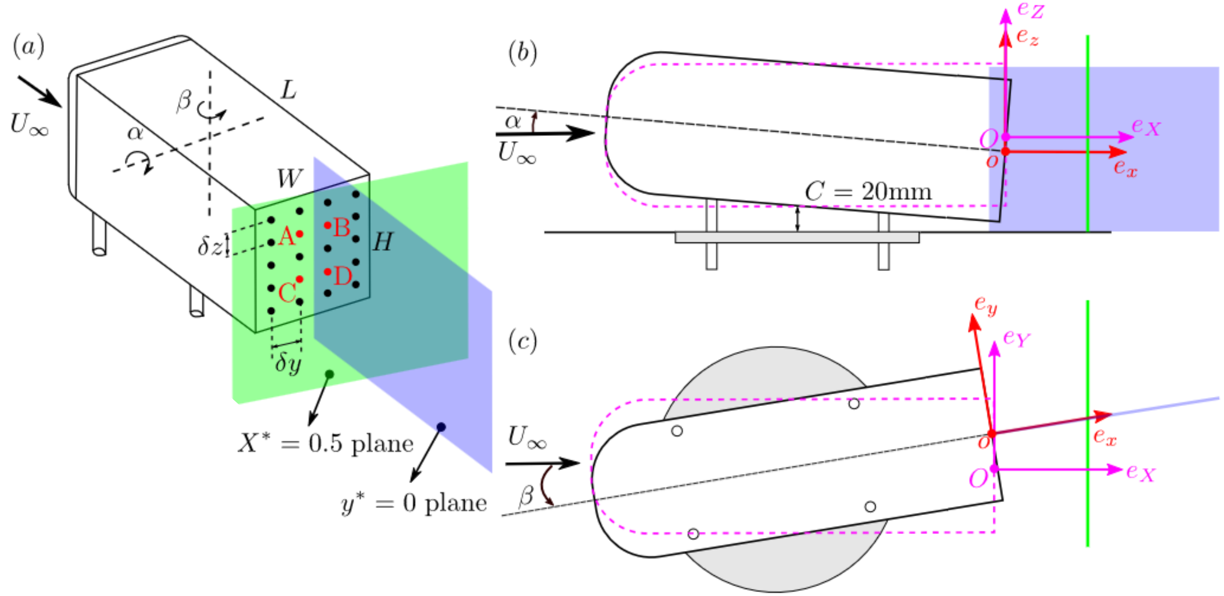
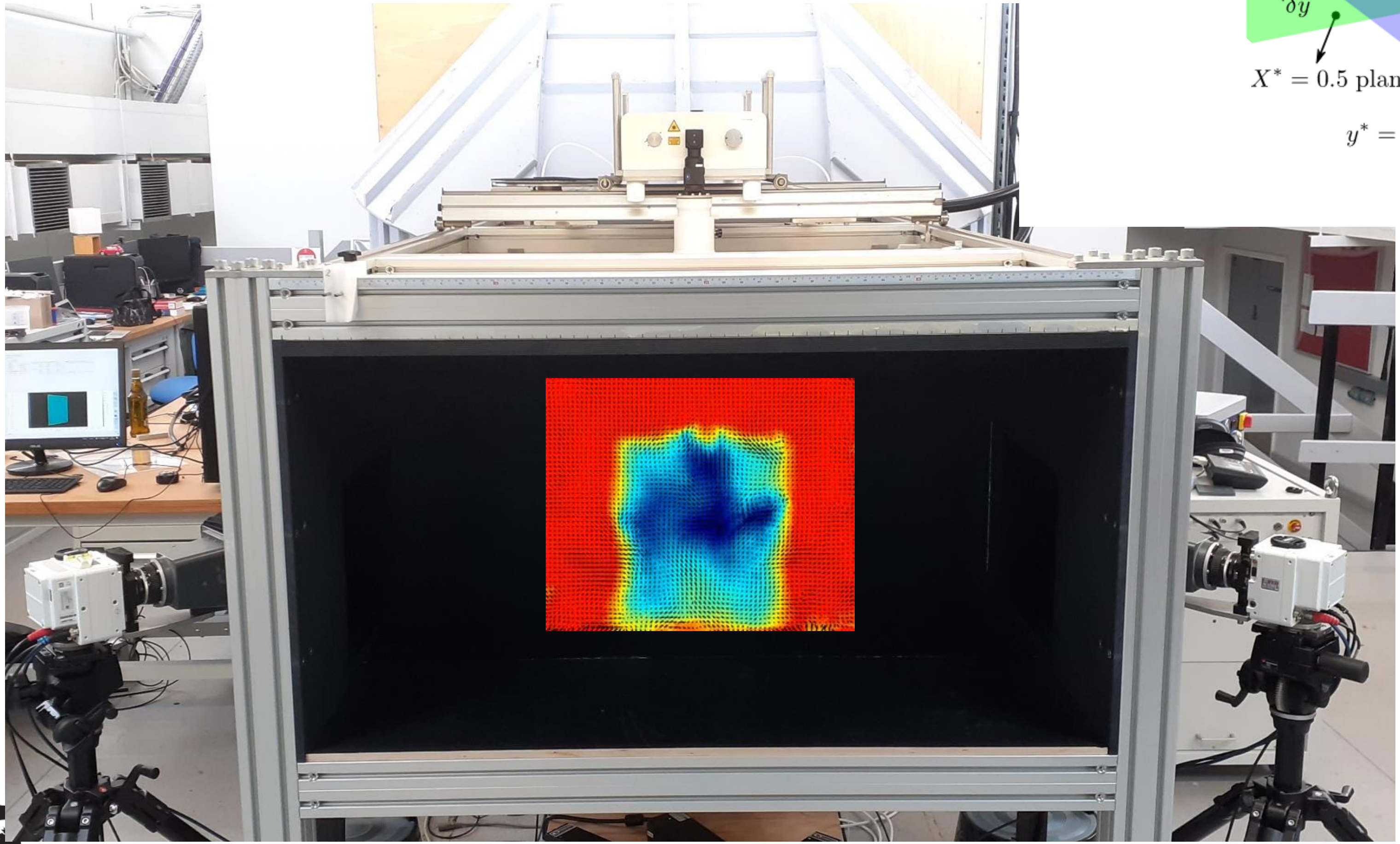
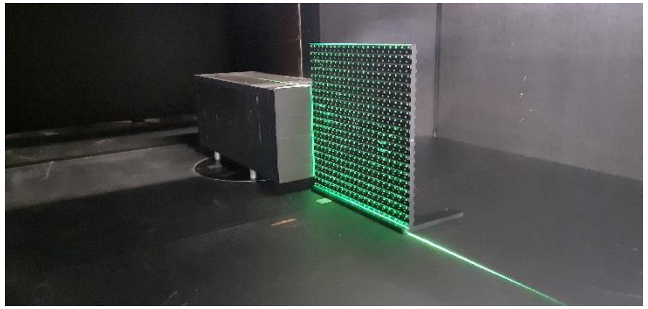
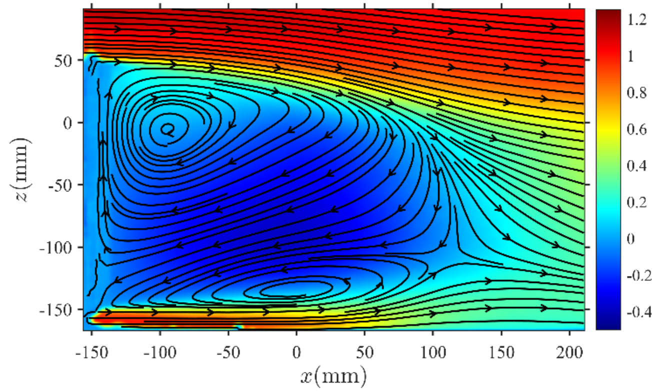

(a)
U_∞
L
W
H
α
β
δz
δy
A
B
C
D
$X^* = 0.5$ plane
$y^* = 0$ plane
(b)
α
U_∞
$C = 20$mm
e_Z
e_z
e_X
e_x
O
o
(c)
U_∞
β
e_y
e_Y
e_x
e_X
o
O






z(mm)
x(mm)
50
0
-50
-100
-150
-150
-100
-50
0
50
100
150
200
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4

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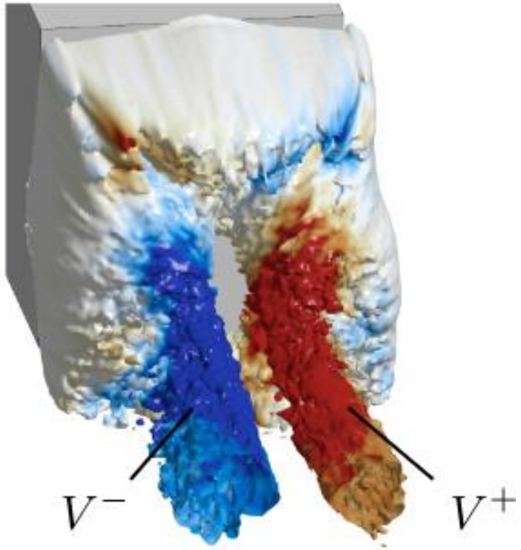
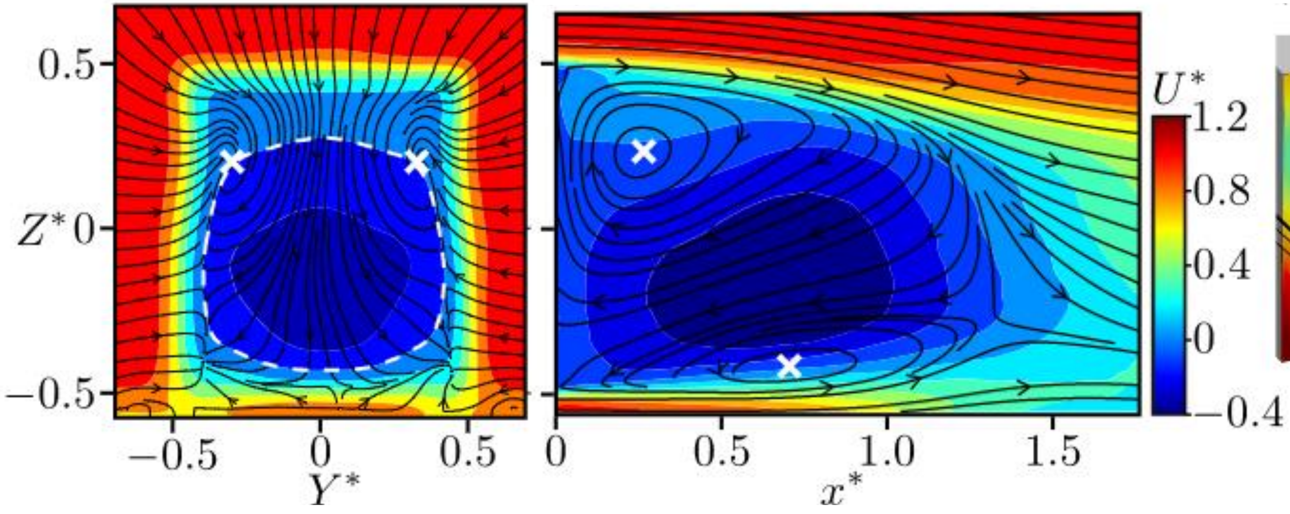
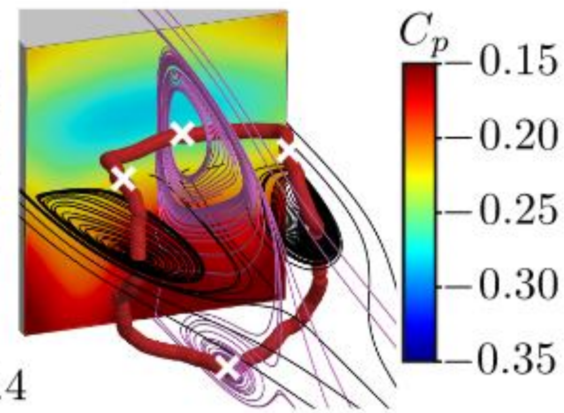
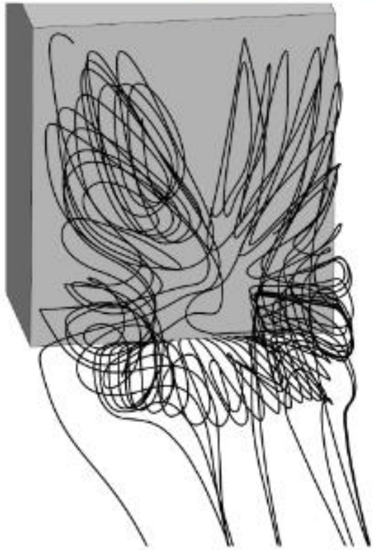
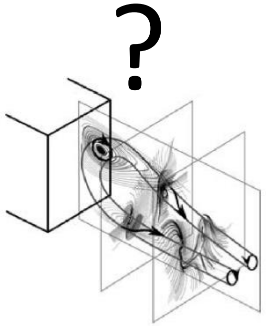
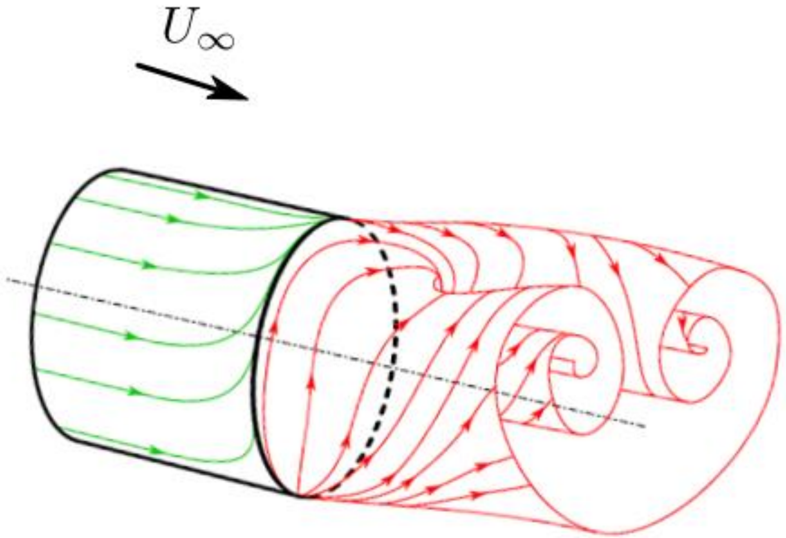




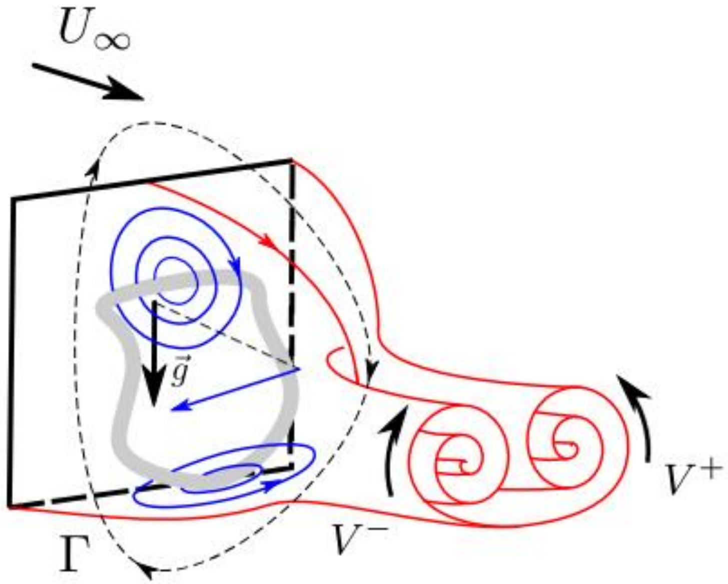








Délery, John Wiley and Sons (2013)



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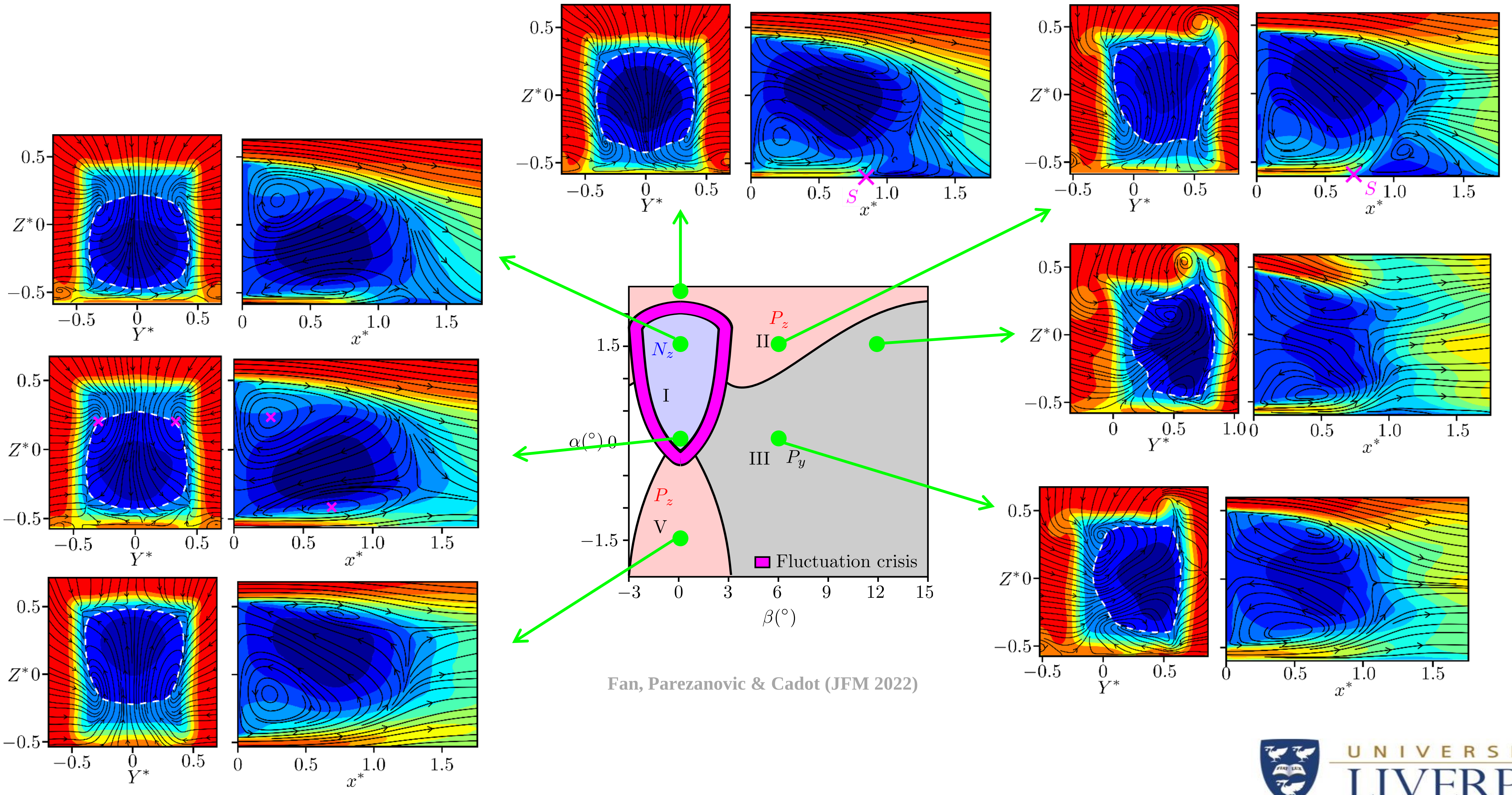
The asymmetric structure can increase or reduce the lift on the body through the vertical pressure gradient $\vec{g}$.

Change of body attitude



Fan, Parezanovic & Cadot (JFM 2022)

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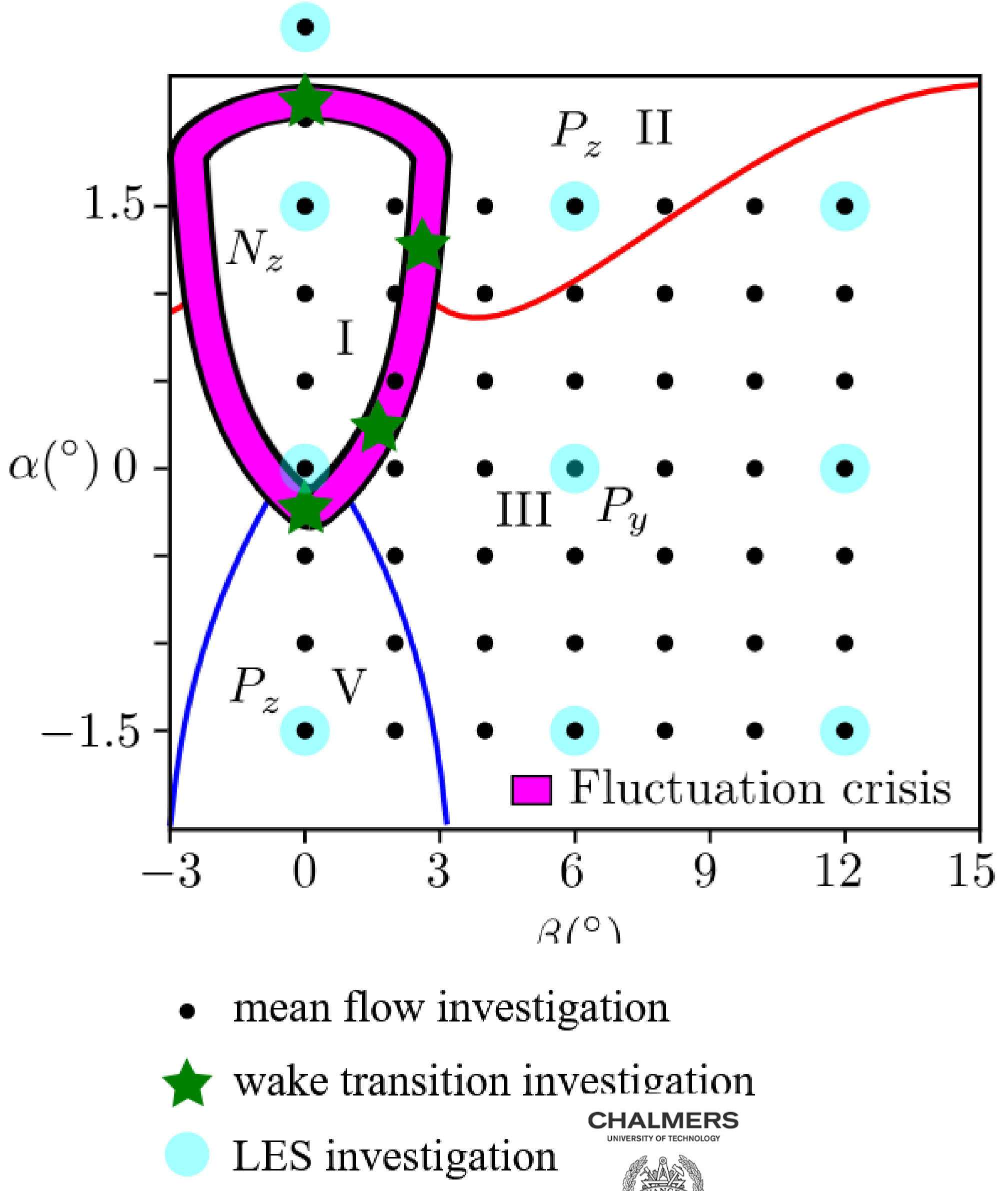

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Attitude (β, α)	C_i/C_i^{WT}	C_x	C_x^{LES}	C_b	C_b^{LES}	C_y	C_y^{LES}	C_z	C_z^{LES}
$(0°, -1.5°)$	0.895	0.321	0.318	0.222	0.225	0.005	0.000	-0.287	-0.420
$(0°, 0°)$	0.901	0.301	0.306	0.206	0.217	0.002	0.001	-0.095	-0.176
$(0°, 1.5°)$	0.896	0.320	0.322	0.218	0.229	0.001	0.000	0.052	0.019
$(0°, 2.6°)$	0.891	0.340	0.330	0.226	0.228	-0.015	-0.002	0.185	0.244
$(6°, -1.5°)$	0.868	0.348	0.341	0.257	0.262	-0.461	-0.507	-0.274	-0.389
$(6°, 0°)$	0.872	0.348	0.341	0.257	0.272	-0.475	-0.508	-0.088	-0.179
$(6°, 1.5°)$	0.868	0.341	0.325	0.248	0.252	-0.459	-0.495	0.078	0.034
$(12°, -1.5°)$	0.843	0.372	0.363	0.323	0.343	-0.962	-1.059	-0.216	-0.380
$(12°, 0°)$	0.848	0.373	0.350	0.321	0.335	-0.973	-1.066	0.014	-0.088
$(12°, 1.5°)$	0.843	0.381	0.350	0.318	0.328	-0.982	-1.083	0.249	0.221

TABLE 2. Force component and base suction coefficients obtained for the experiment with the correction factor C_i/C_i^{WT} (see Eq.2.6) and the LES at different body attitudes.

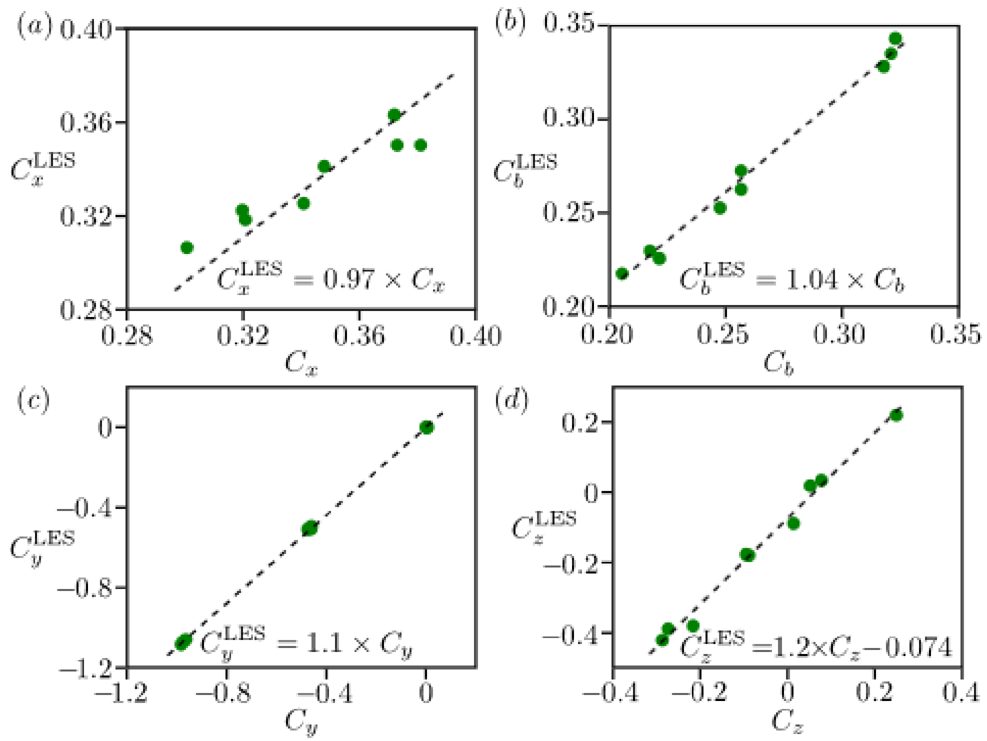
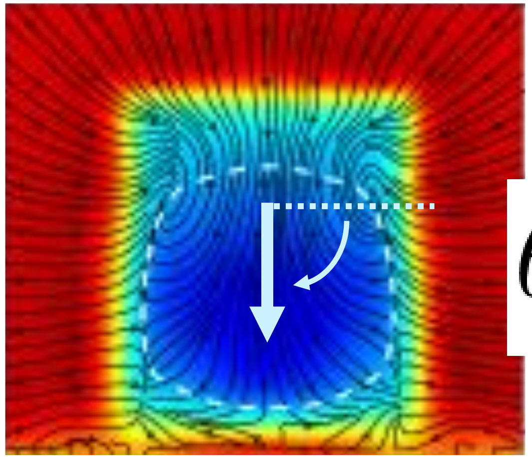


FIGURE 5. Comparison of the aerodynamic coefficients obtained from the experiment and the LES for: (a) drag; (b) base suction; (c) side force and (d) lift.

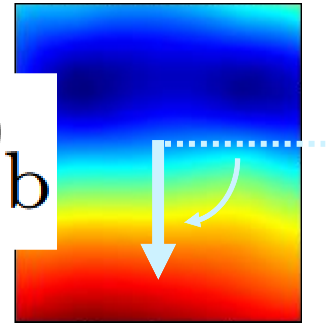
Wake orientation in attitude space

Reverse cross-flow angle



$$\theta_{\mathrm{R}} \approx \theta_{\mathrm{b}}$$

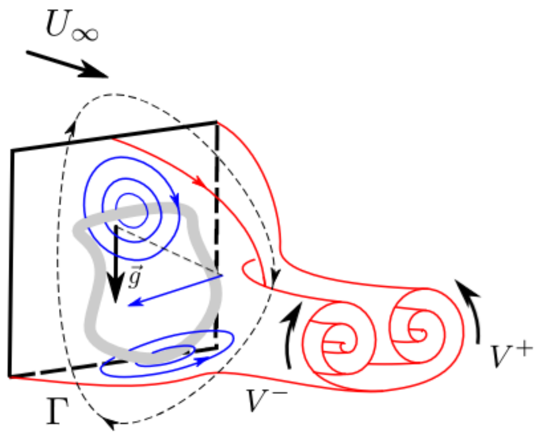
Base pressure gradient angle

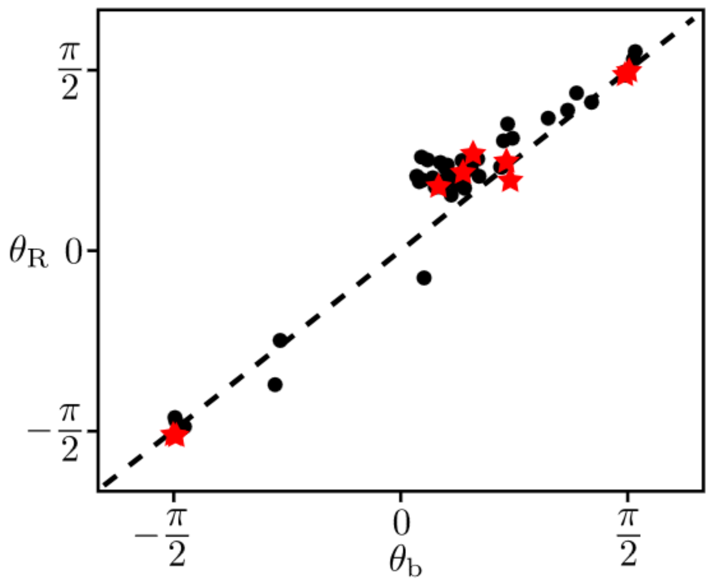


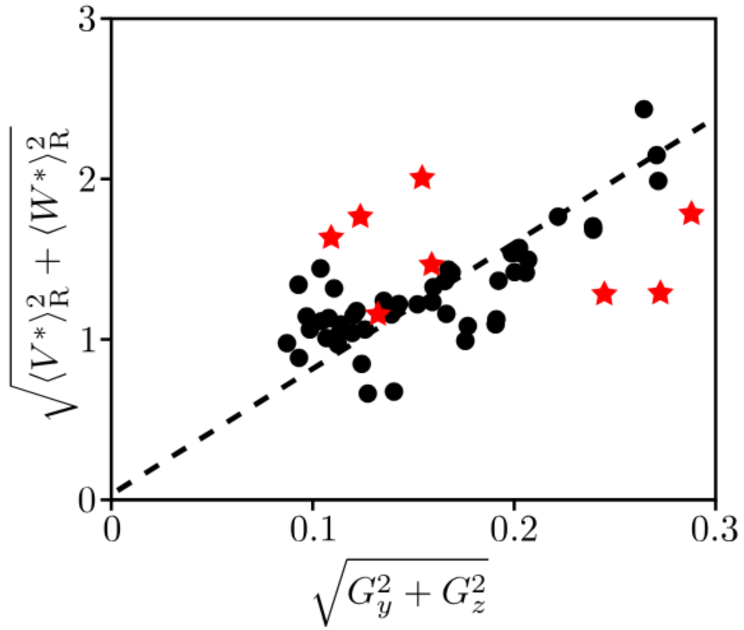
$$\langle W \rangle_{U<0} \quad \langle V \rangle_{U<0}$$

$$\theta_{\mathrm{R}} = \arctan \frac{\langle W^* \rangle_{\mathrm{R}}}{\langle V^* \rangle_{\mathrm{R}}}$$

$$\theta_{\mathrm{b}} = \arctan \frac{G_z}{G_y}$$







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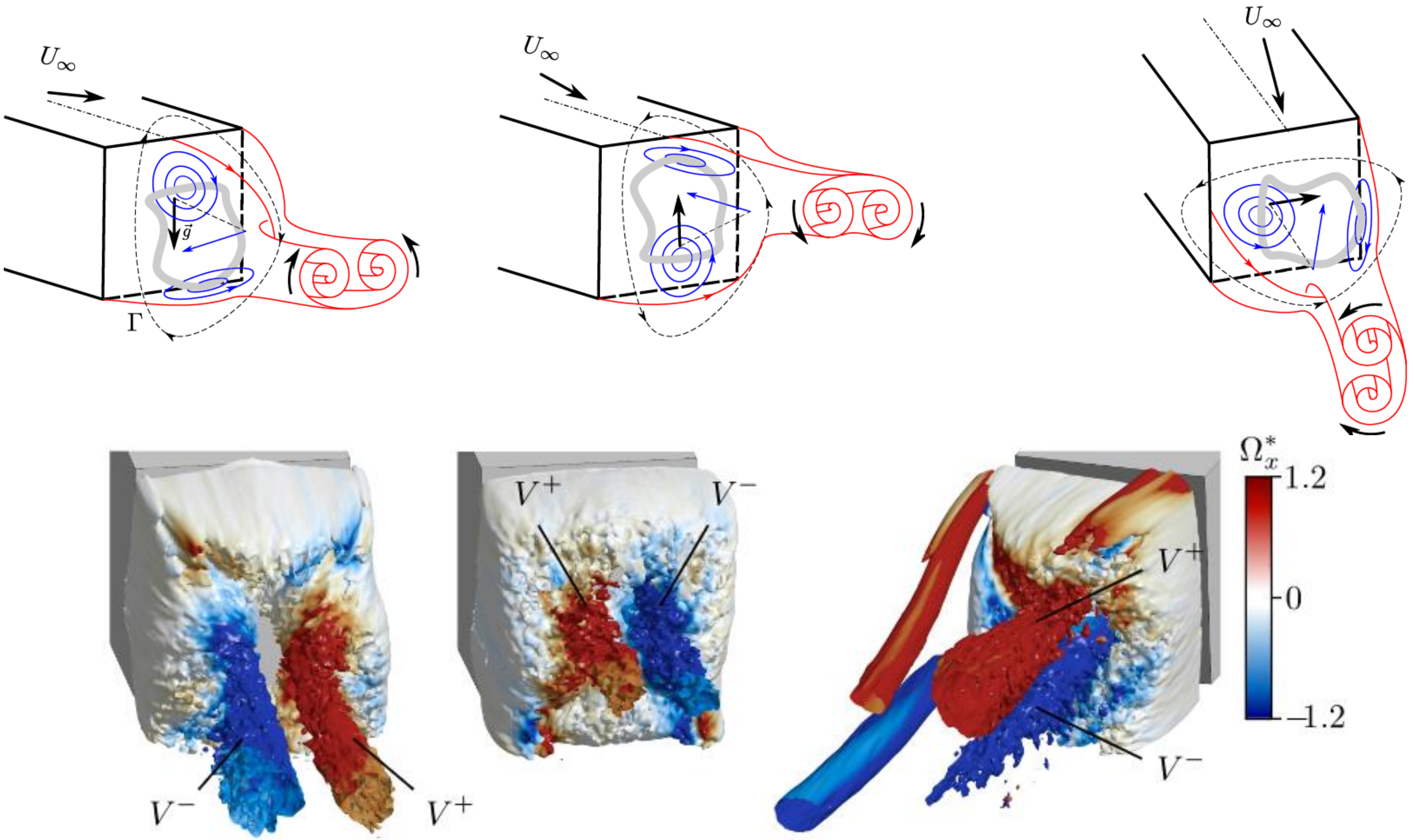

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6. Conclusion and perspectives

- A 3D structure of the recirculating flow is proposed :
  - The recirculating flow is subjected to a steady instability leading to an asymmetry towards the major axis of the base
  - This asymmetry is associated with a circulation provoking the closure of the separated surface into two longitudinal vortices
- The LES will be applied to a moving ground (real boundary condition for ground vehicles)

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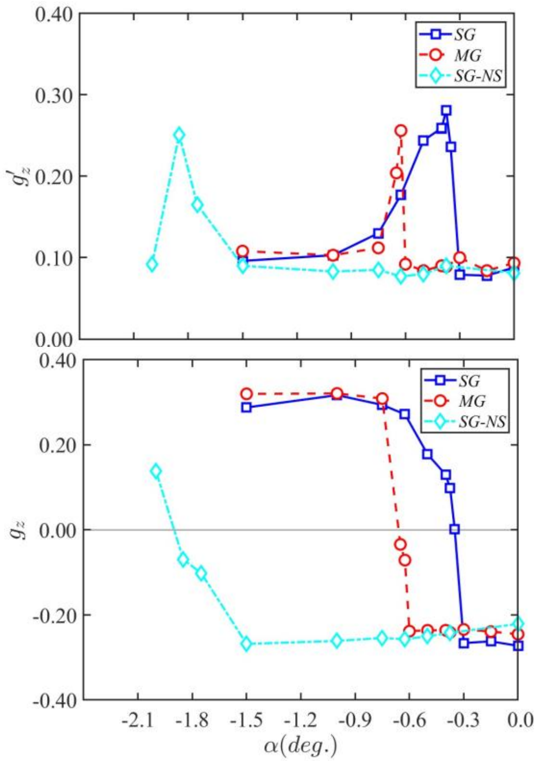
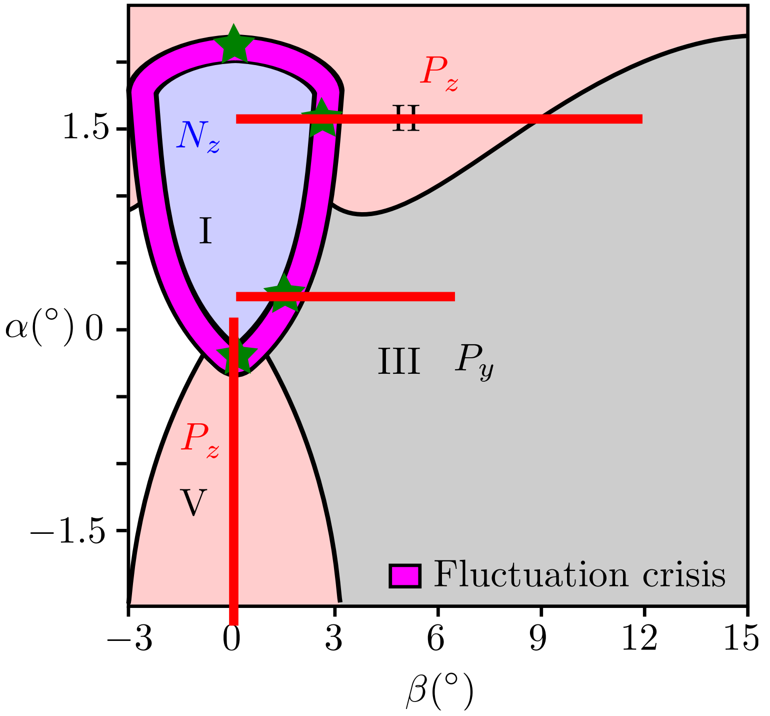
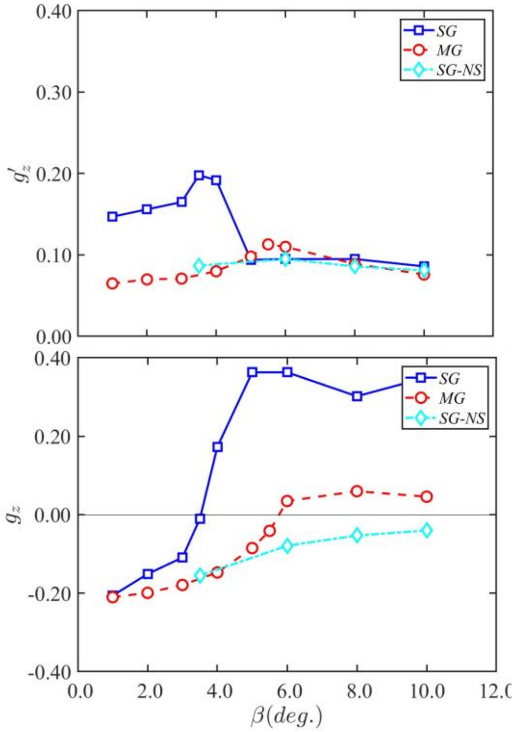
Thank you for your attention

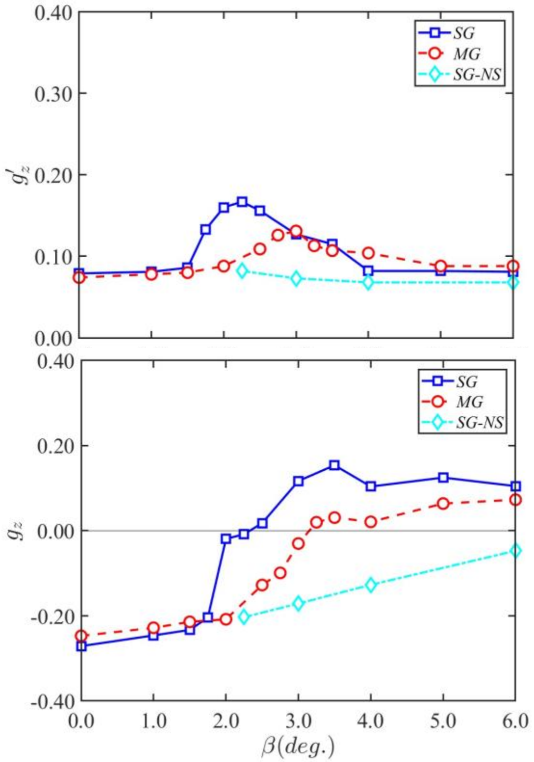
Role of static ground and suppports

Static Ground (SG)
Moving Ground (MG)
Static Ground No supports (SG-NS)



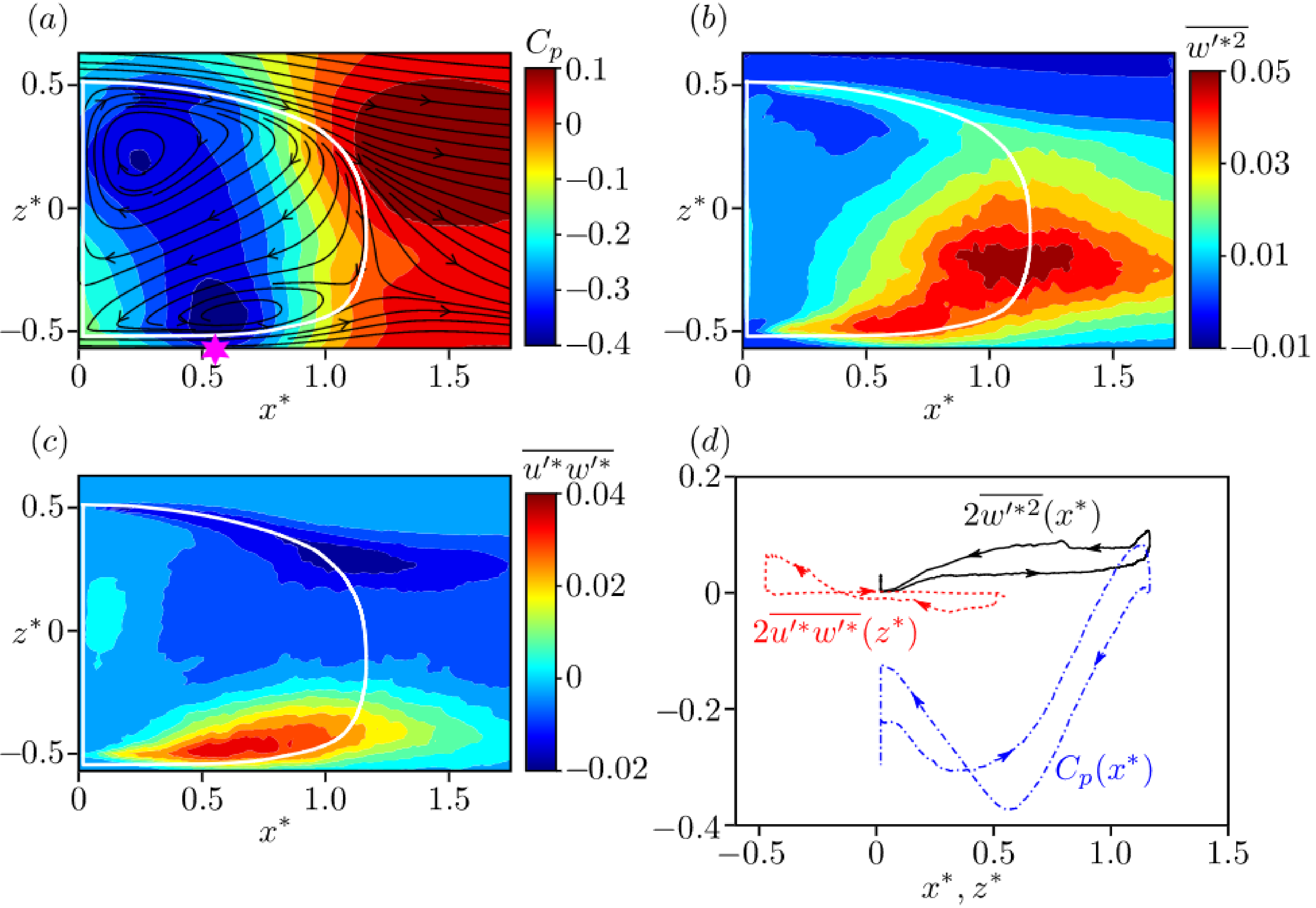






Separatrix equilibrium

$$-\oint_{\mathscr{C}} C_p dx^* - \oint_{\mathscr{C}} 2\overline{w'^{*2}} dx^* - \oint_{\mathscr{C}} 2\overline{u'^* w'^*} dz^* = 0,$$



Ground separation

- Boundary layer (static floor)
- Adverse pressure gradient