Self-adaptive torsional and bending flaps for drag reduction in the squareback Ahmed body wake

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- 6 permanent members
- 2 postdocs
- 4 PhD students
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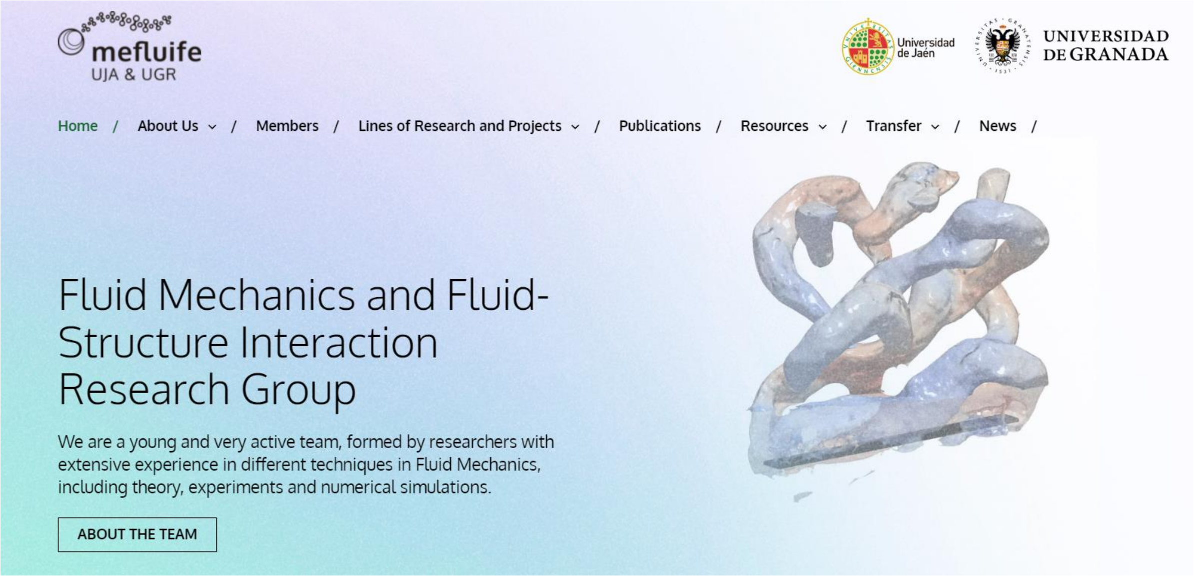
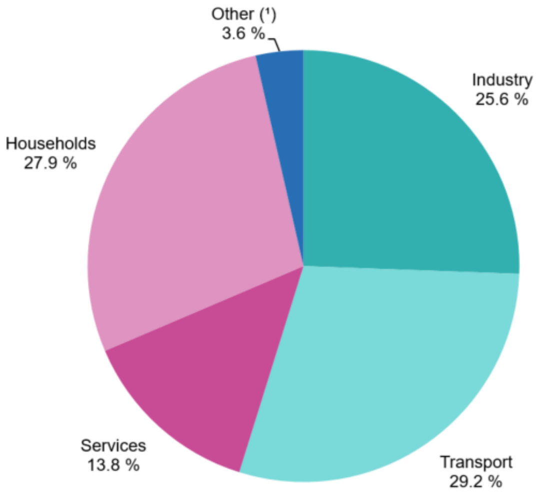


- Main research lines:
  - Multiphase flows: bubble dynamics
  - Bluff body wakes & FSI
  - Biomedical flows: CSF Flow

Motivation

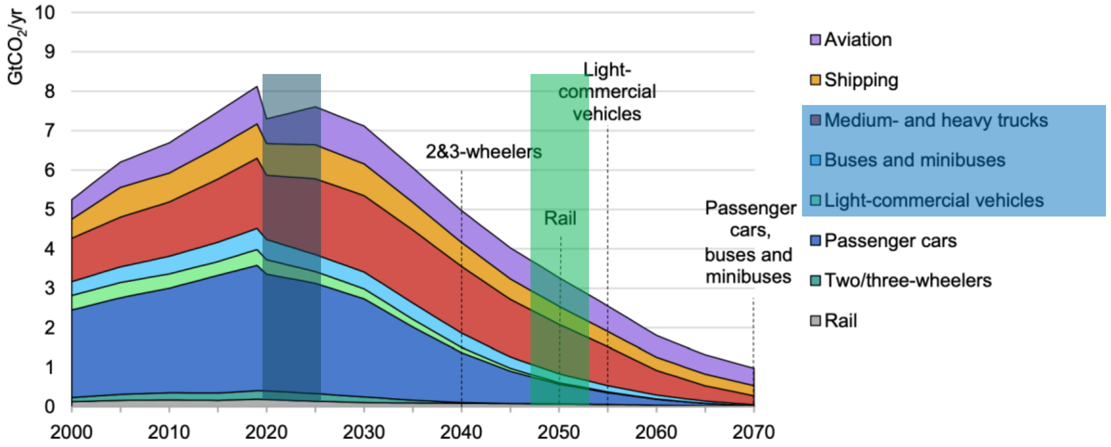
- Energy consumption in transport industry

Final energy consumption by sector, EU, 2021
(% of total, based on terajoules)



(¹) International aviation and maritime bunkers are excluded from category Transport.
Source: Eurostat (online data code: nrg_bal_c)

Figure 3.16 Global CO_2 emissions in transport by mode in the Sustainable Development Scenario, 2000-70



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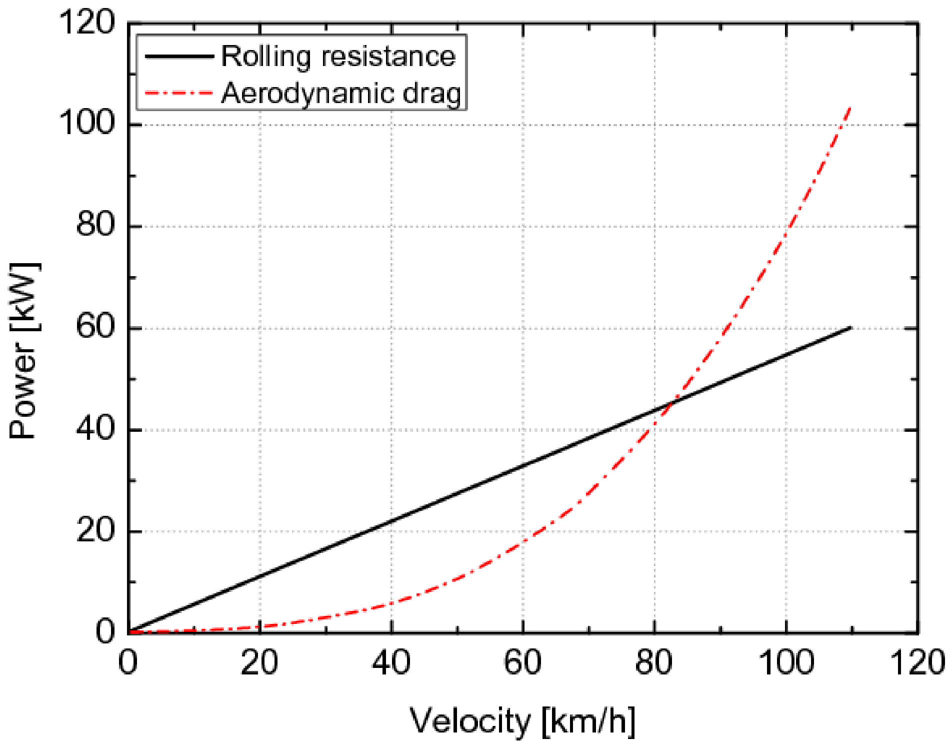
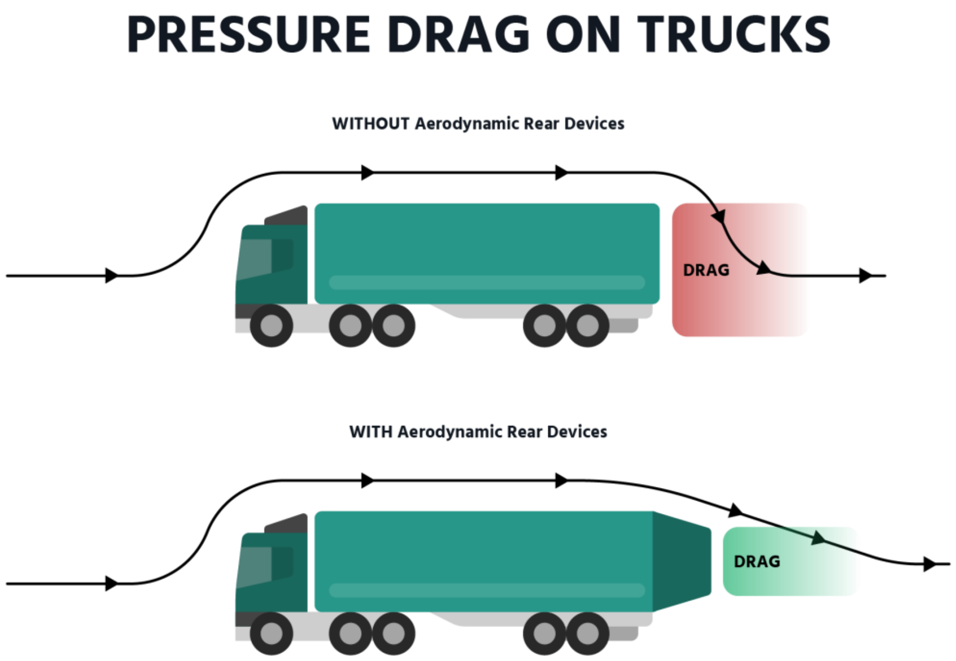
Introduction

- Reduce aerodynamic drag in heavy vehicles (lower emissions)
- Load capacity, practical requirements
- New regulations, great potential technological impact

Directive Europe 96/53/EC modified in EU 2015/719 and updated with the new legislation 2018/0130



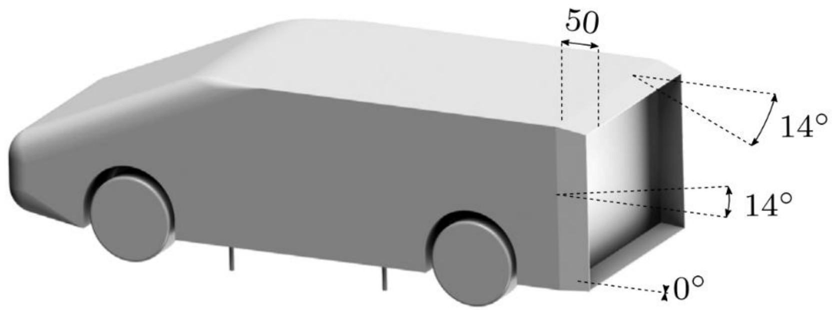
ICCT (International Council on Clean Transportation)

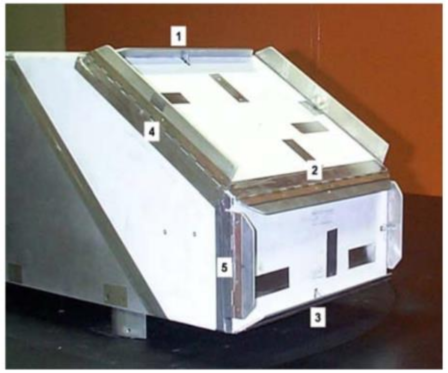


Introduction

- Vehicle models, drag reduction devices and physical mechanisms

Urquhart et al. (IJHFF 2020)





Beaudoin & Aider (EiF 2008)

Barros et al. (JFM 2016)

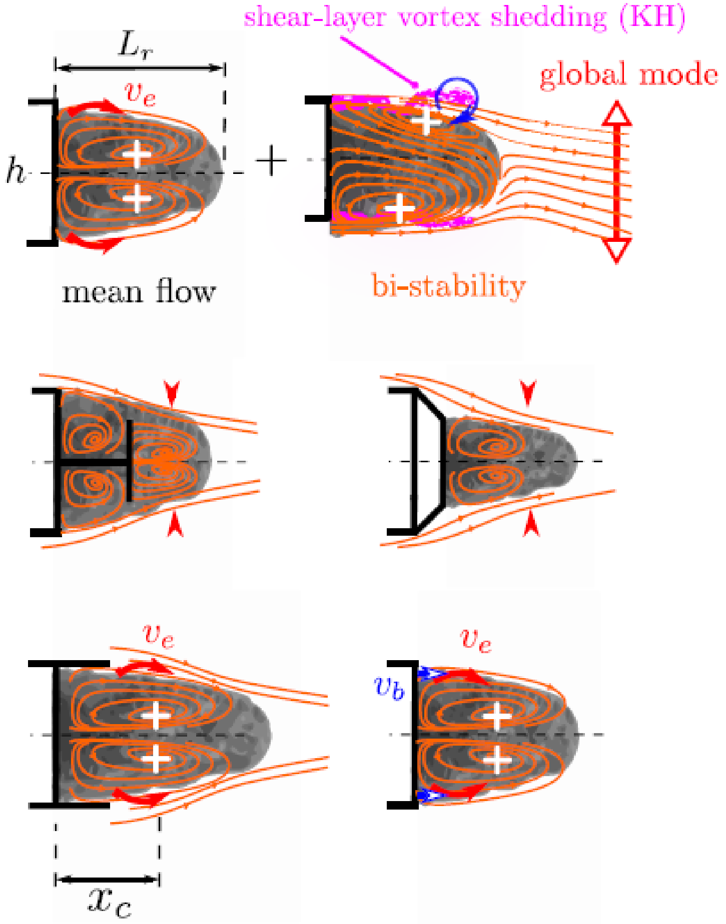
Reduced entrainment

Bubble elongation

Aerodynamic wake shaping

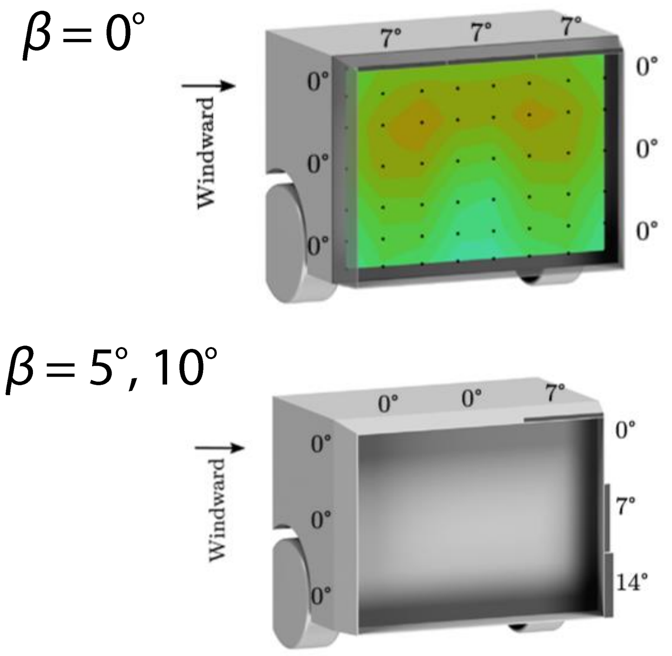
Reduced wake bluffness

Plumujeau et al. (EJMB 2023)

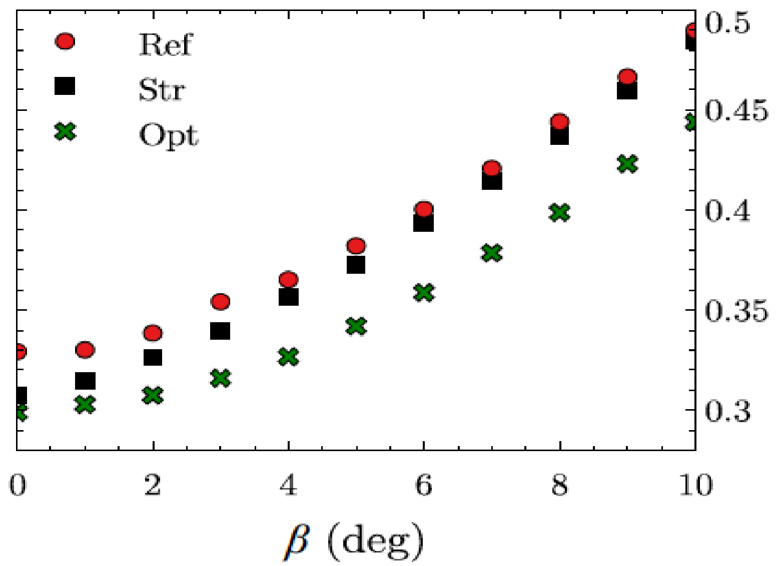


Introduction

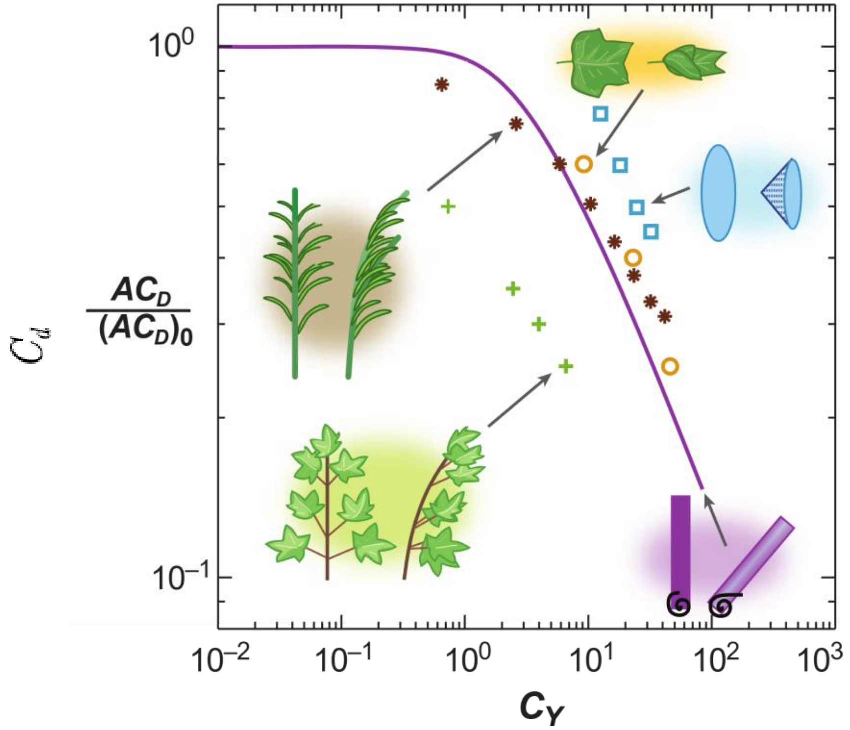
- Rigid passive devices
  - Limited efficiency in changing flow conditions
  - Crosswinds, different turbulent levels and gusts are common in real applications
  - Can we use bio-inspired self-adaptive devices?



Urquhart et al. (IJHFF 2020)



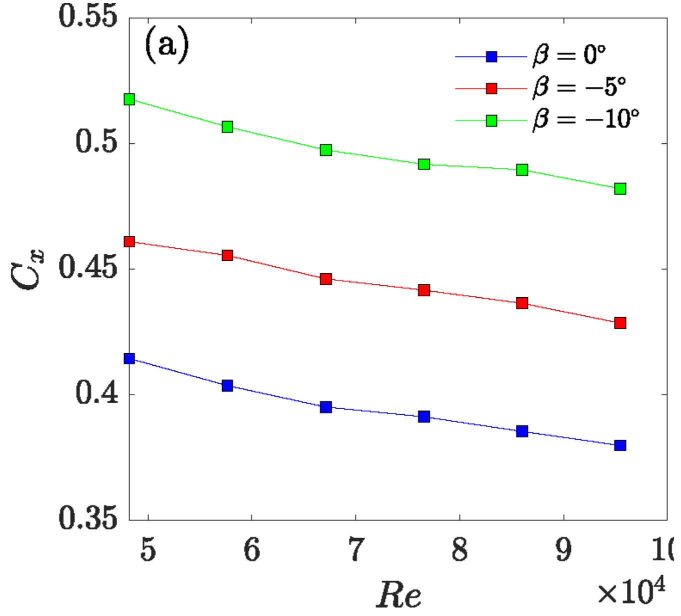
Lorite-Díez et al. (JWEIA 2020)

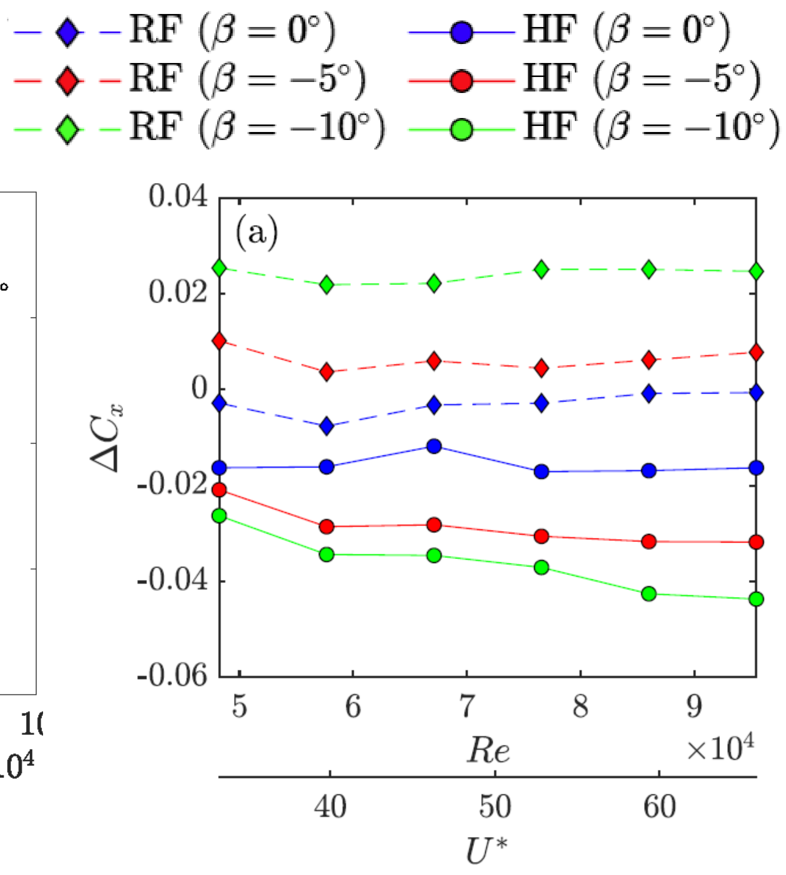


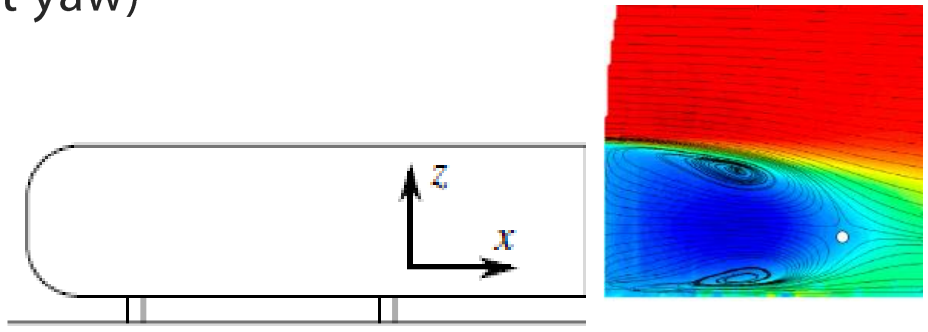
De Langre (ARFM 2008)

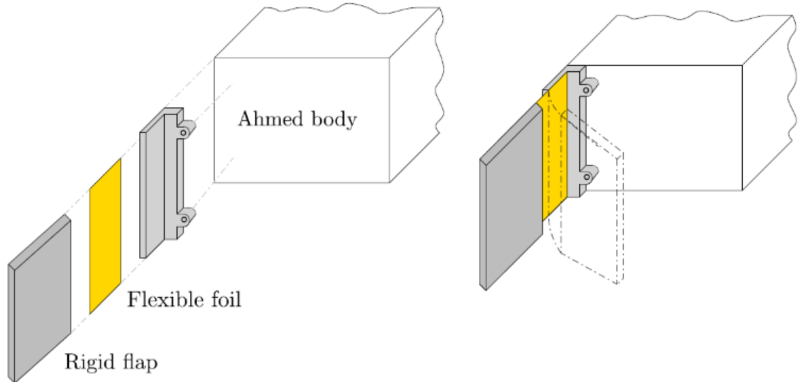
Previous Results

- 1 Degree-of-freedom hinged flaps
  - Rotary flaps are efficient to reduce the drag (especially at yaw)









Camacho-Sánchez *et al.* (PRF 2023)

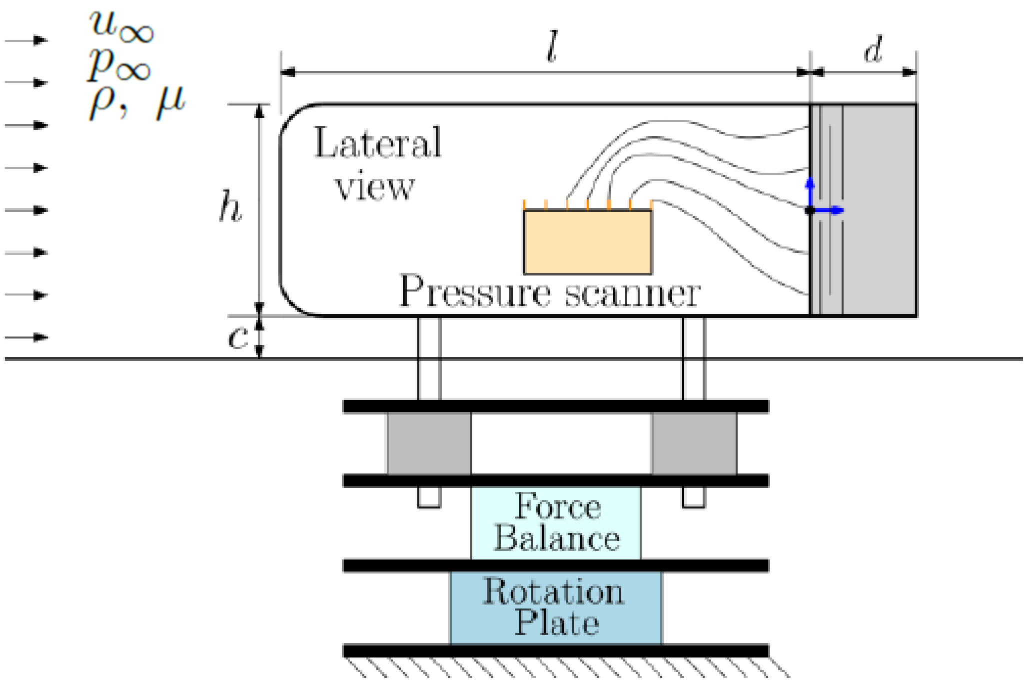
Experimental set-up

- Parametric ranges
  - Reynolds from 1.5e5 to 2.3e5
  - Flaps length (*d*) around 0.5*h*
  - Large mass ratios ~ 320
  - Reduced velocity U^* from 14 to 22
  - Different yaw orientations, β (-15:1:15)

$$Re = \frac{\rho u_\infty h}{\mu}$$

$$m^* = \rho_s/\rho$$

$$U^* = \frac{u_\infty}{f_n h}$$



Experimental set-up

- Measurements
  - 6 axis force balance
  - 64 channel miniature pressure scanner
  - Laser point distance sensors
  - High-speed imaging
  - StereoPIV measurements

Pressure

$$c_{p,i} = \frac{p_i - p_\infty}{\rho u_\infty^2/2}$$

$$c_B = -\frac{1}{n}\sum_{i=1}^{n} c_{p,i}$$

$$g_y = h\frac{\partial c_p}{\partial y} \simeq \frac{1}{2}h\left[\frac{c_{p,6} - c_{p,4}}{y_6 - y_4}\right]$$

$$g_z = h\frac{\partial c_p}{\partial z} \simeq \frac{1}{2}h\left[\frac{c_{p,8} - c_{p,2}}{z_8 - z_2}\right]$$

Forces

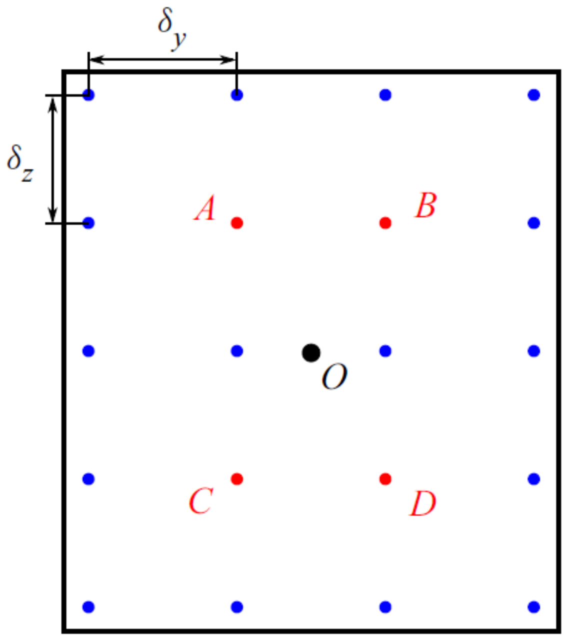
$$c_i = \frac{2f_i}{\rho u_\infty^2 hw}$$

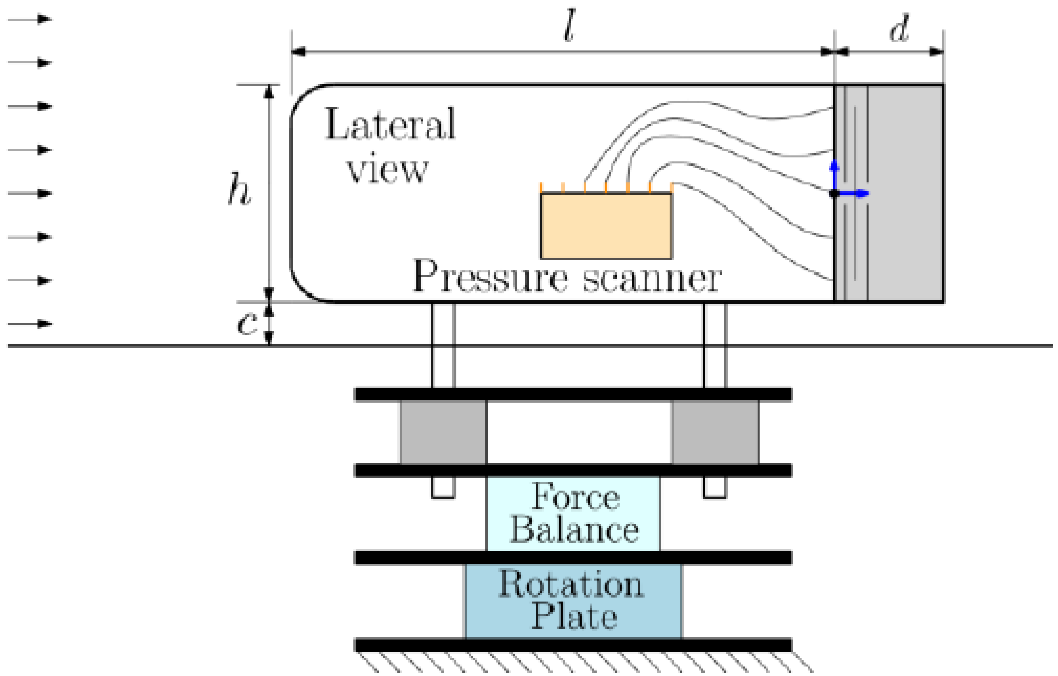
Nomenclature

$$A = \bar{a}$$

$$a' = a - A$$

$$\hat{a} = \sqrt{a'^2}$$

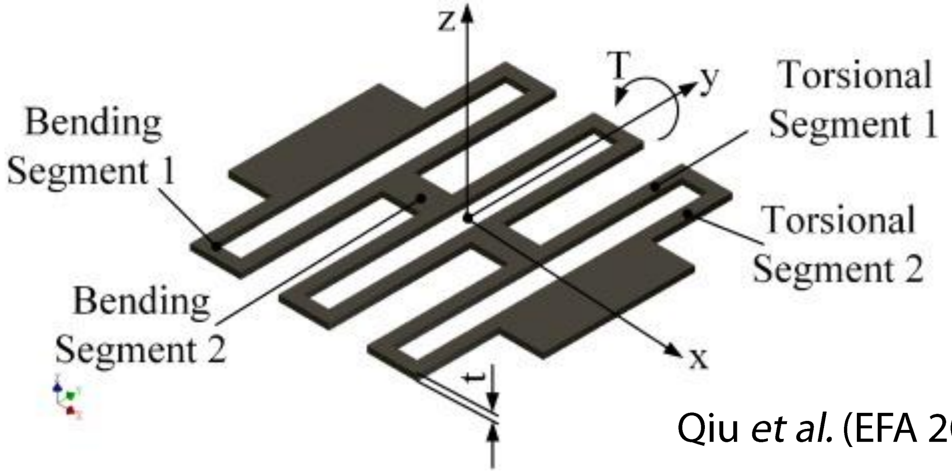




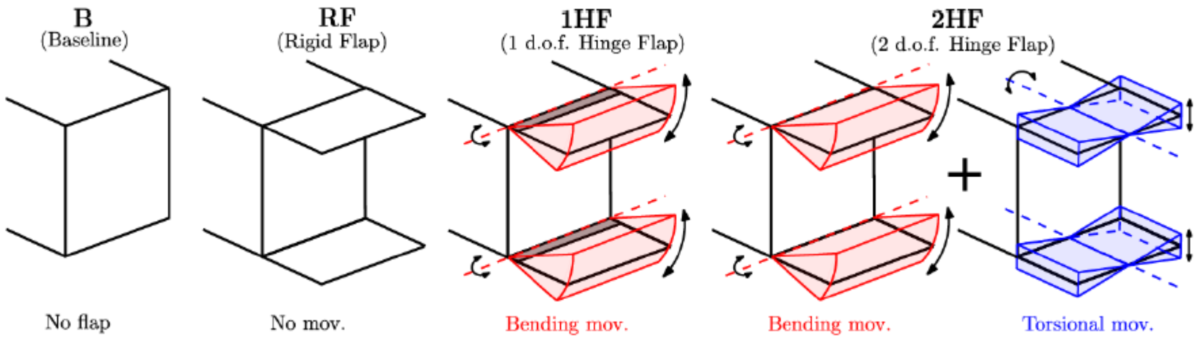
Results

- 2 Degree-of-freedom hinged flaps
  - Several configurations (RF, 1H, 2H)
  - Left-Right (LR), Top-Bottom (TB) dispositions

#	TOP	BOTTOM	LEFT/RIGHT
1	-	-	-
2	RF	RF	-
3	-	-	RF
4	RF	RF	RF
5	1H	1H	-
6	-	-	1H
7	2H	2H	-
8	-	-	2H



Qiu *et al.* (EFA 2016)

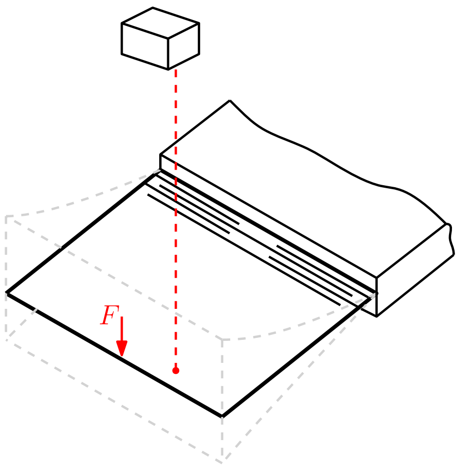


- **B** = Baseline case
- **RF** = Rigid flap
- **1H** = 1 DoF Hinge flap
- **2H** = 2 DoF Hinge flap

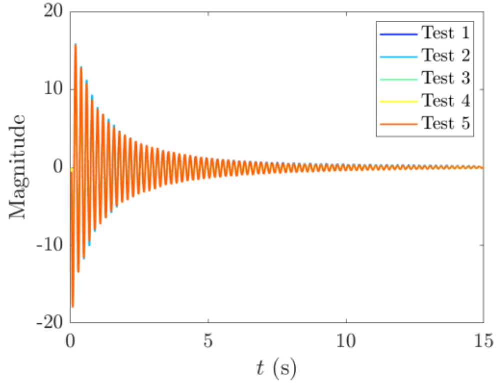
Results

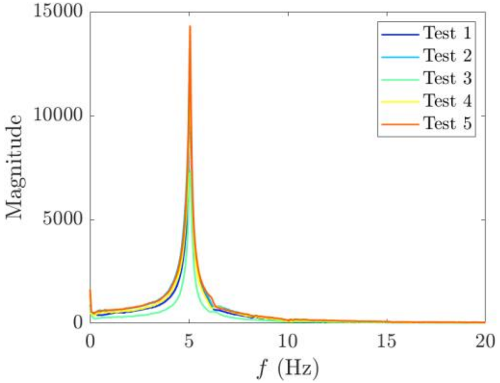
- 2 Degree-of-freedom hinged flaps
  - Several configurations
  - Mechanical characterization

Var.	1H	1H	2H	2H
$f_{n,b}$(Hz)	3.8	3.7	3.9	3.8
$f_{n,t}$ (Hz)	-	-	16.8	16.8
ξ_b	0.026	0.025	0.019	0.019
ξ_t	-	-	0.0100	0.009
m^*	320	320	320	320

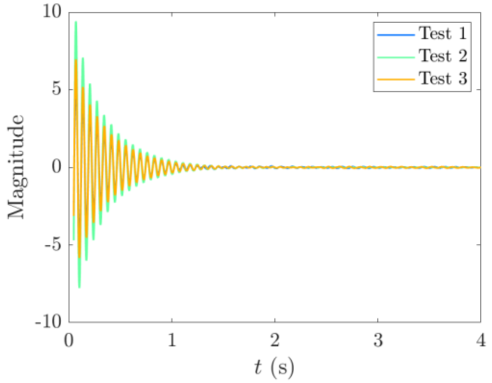


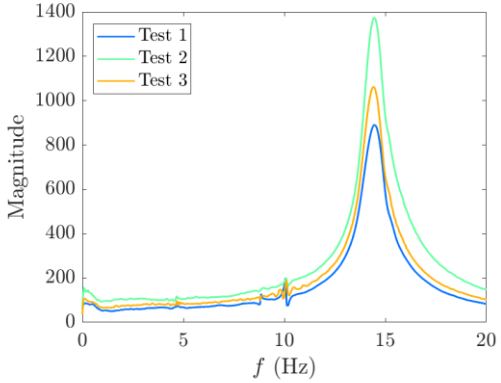
Bending





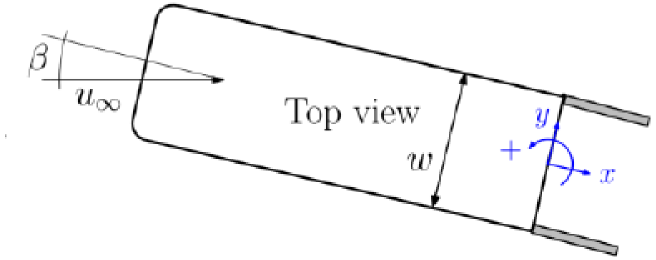
Torsional

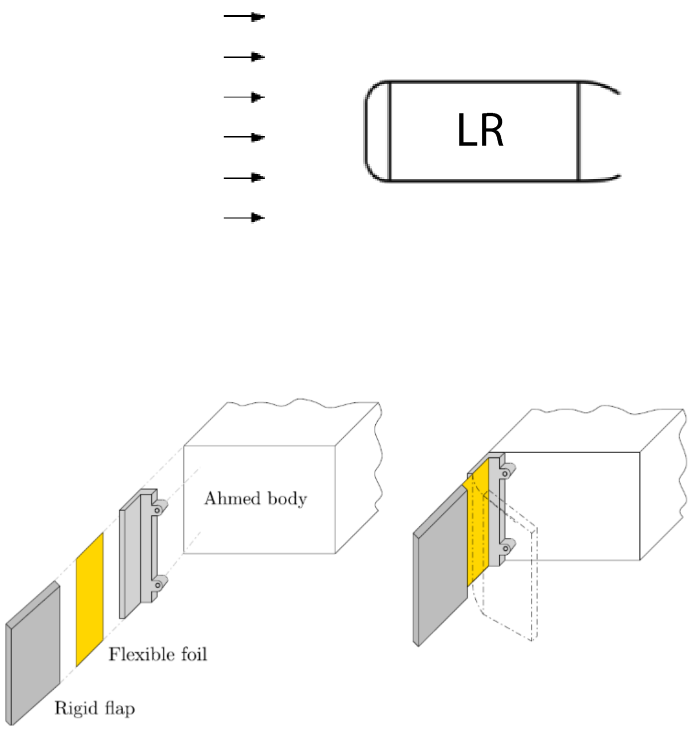


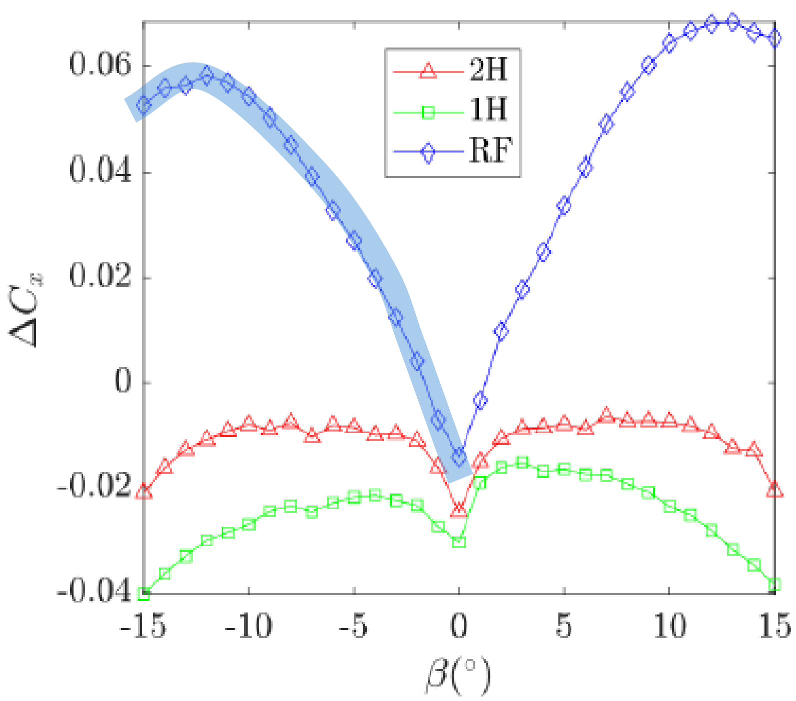


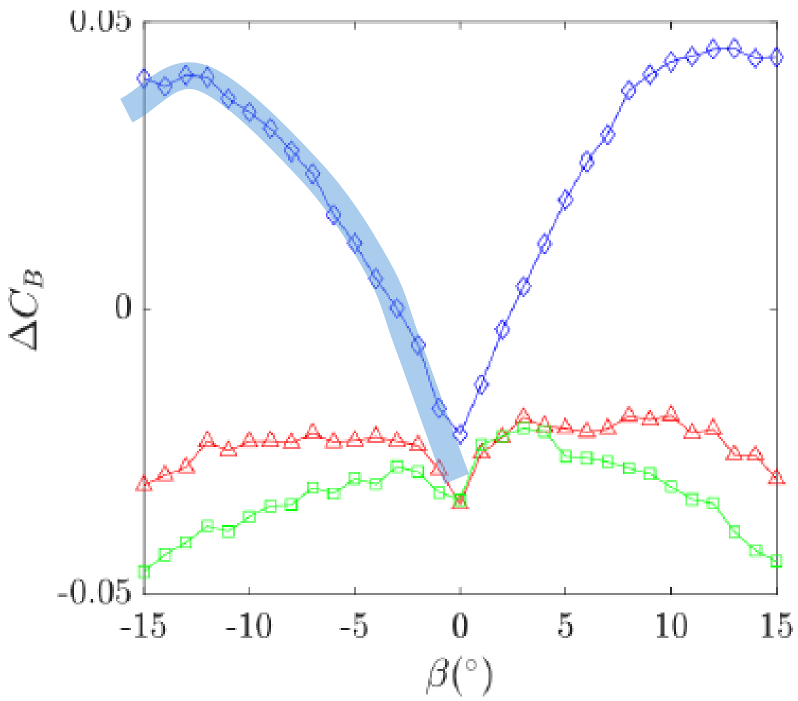
Results

- 2 Degree-of-freedom hinged flaps
  - $U^* = 18.4$ (bending), $Re = 1.87 \cdot 10^5$
  - Under LR configuration , RF only works at $\beta = 0^o$



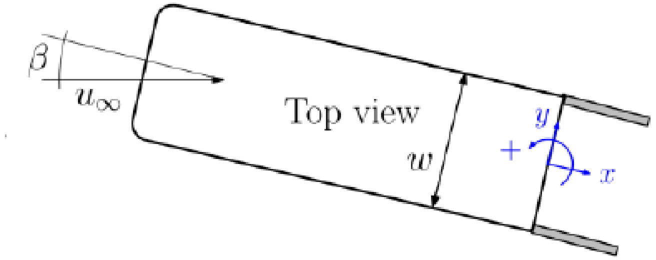


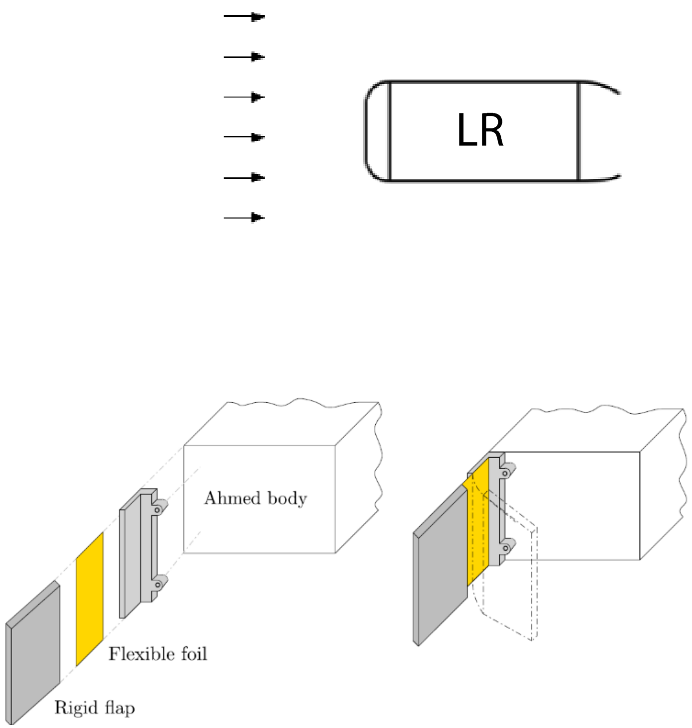


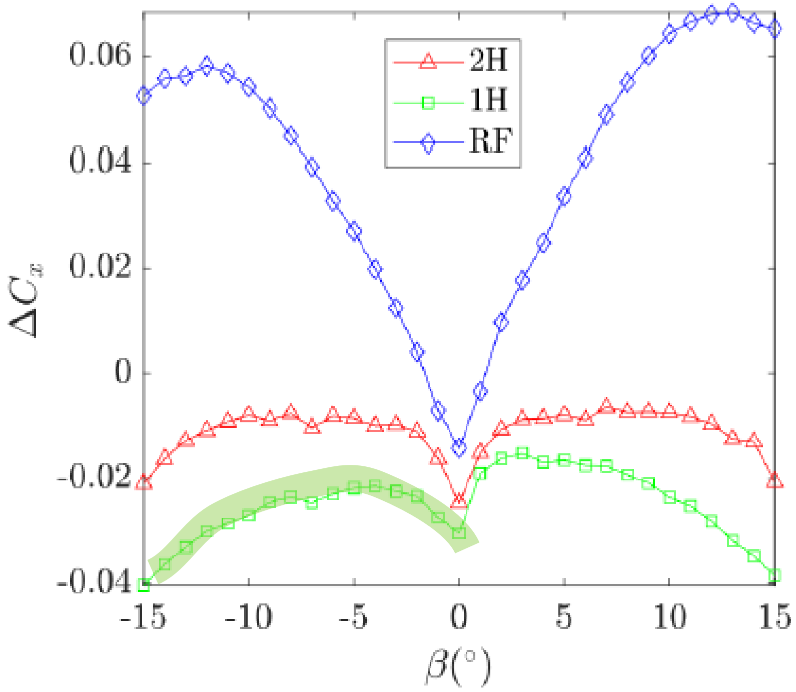


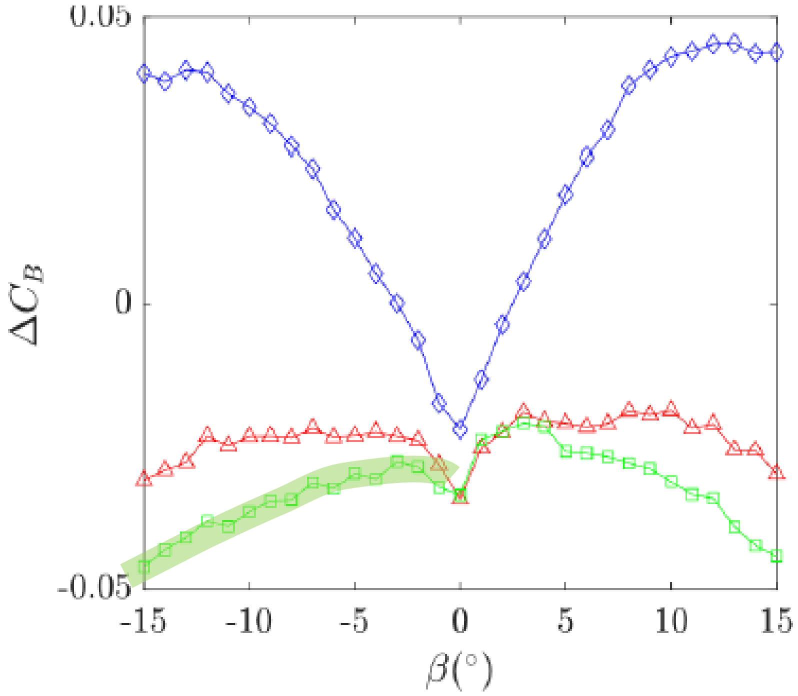
Results

- 2 Degree-of-freedom hinged flaps
  - $U^* = 18.4$ (bending), $Re = 1.87 \cdot 10^5$
  - Under LR configuration, 1HF is the best option



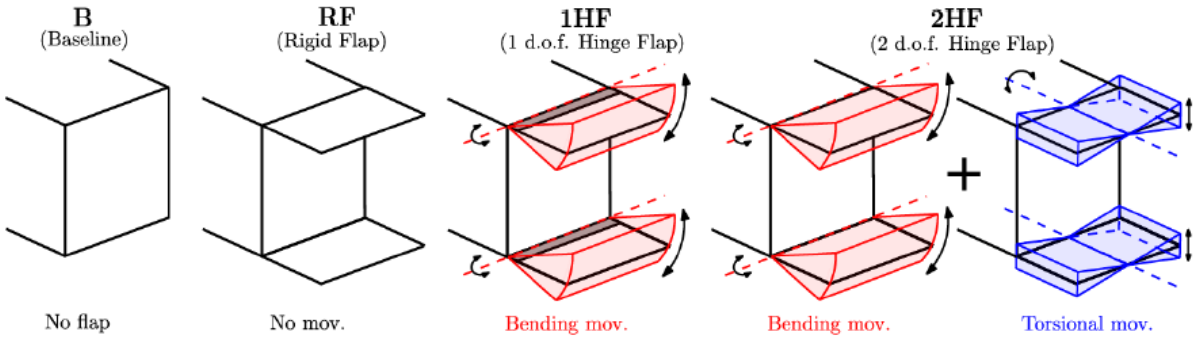


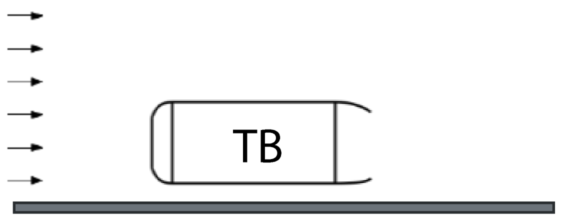


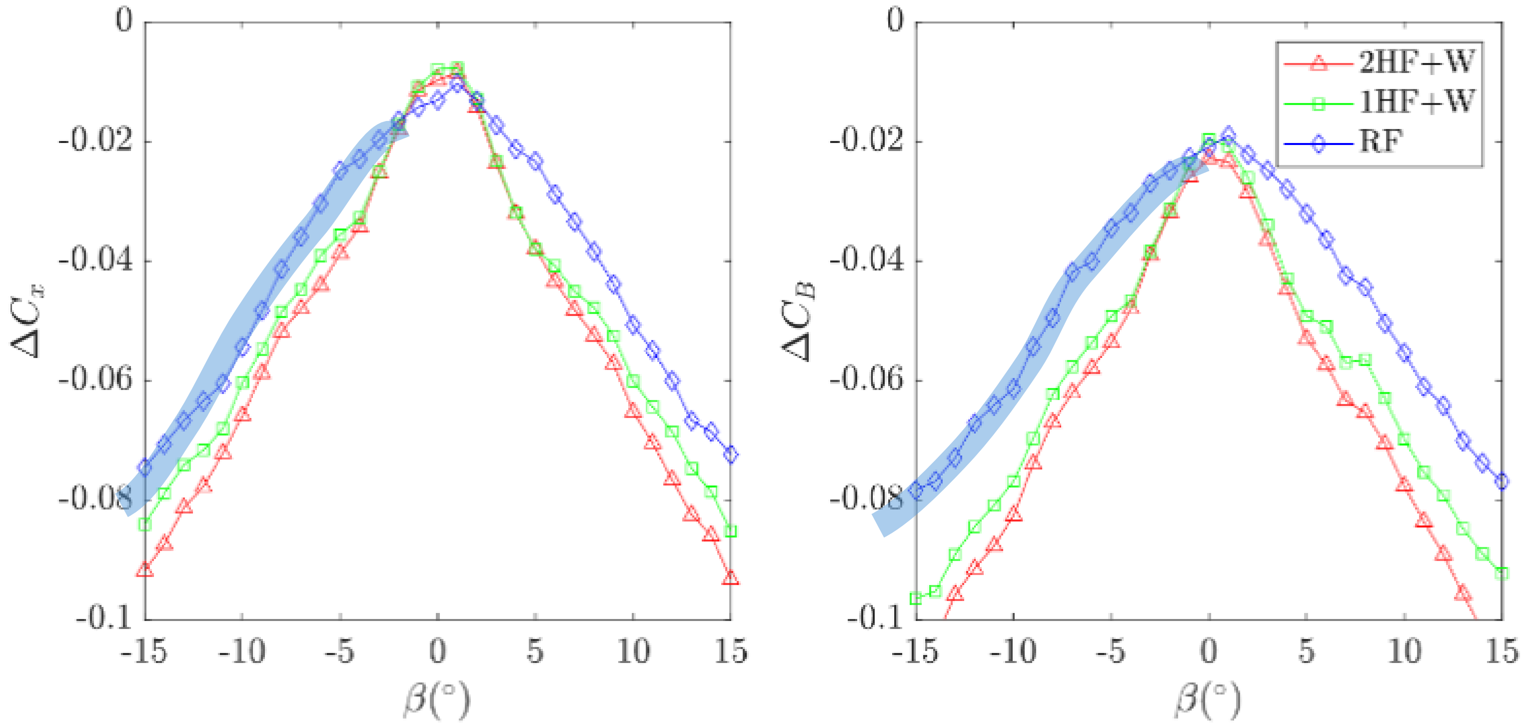


Results

- 2 Degree-of-freedom hinged flaps
  - $U^* = 18.4$ (bending), $Re = 1.87 \cdot 10^5$
  - Under TB configuration, RF is effective

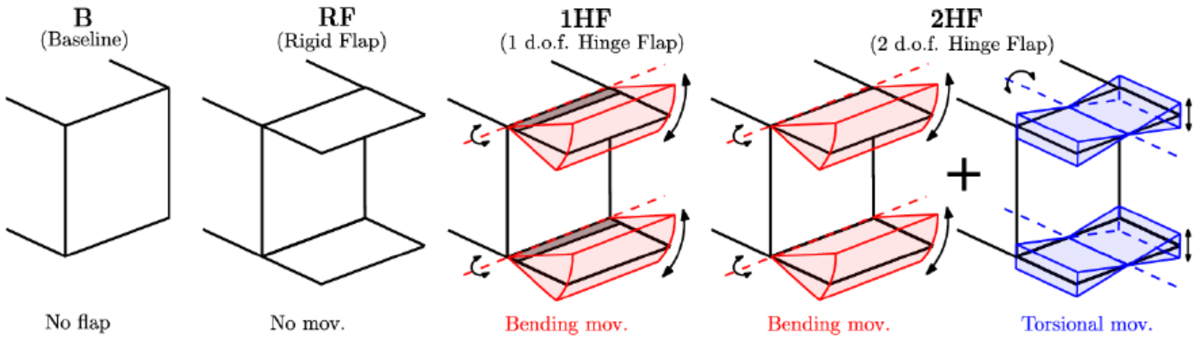


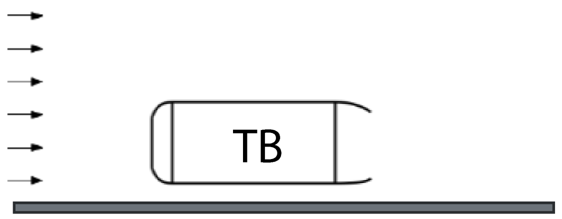


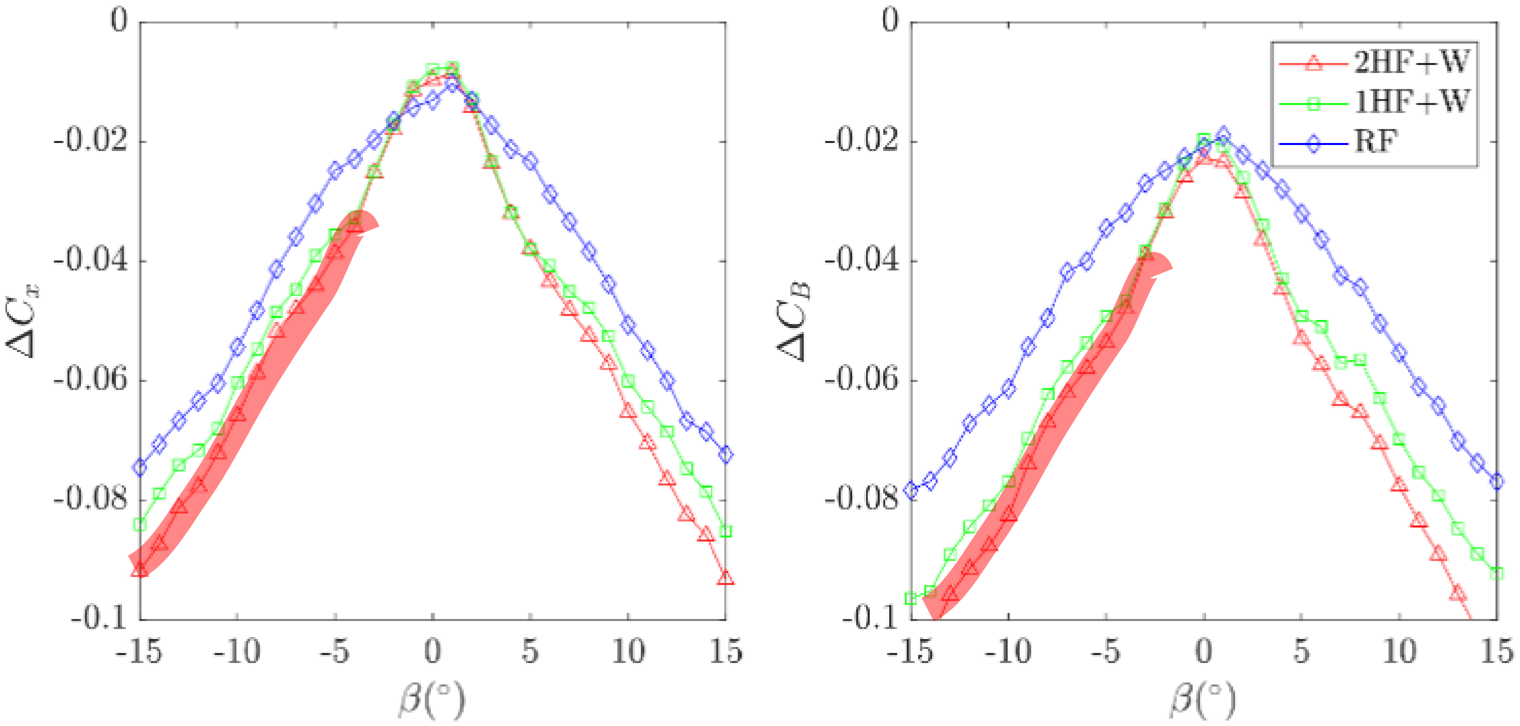


Results

- 2 Degree-of-freedom hinged flaps
  - $U^* = 18.4$ (bending), $Re = 1.87 \cdot 10^5$
  - Under TB, 2HF improves with yaw

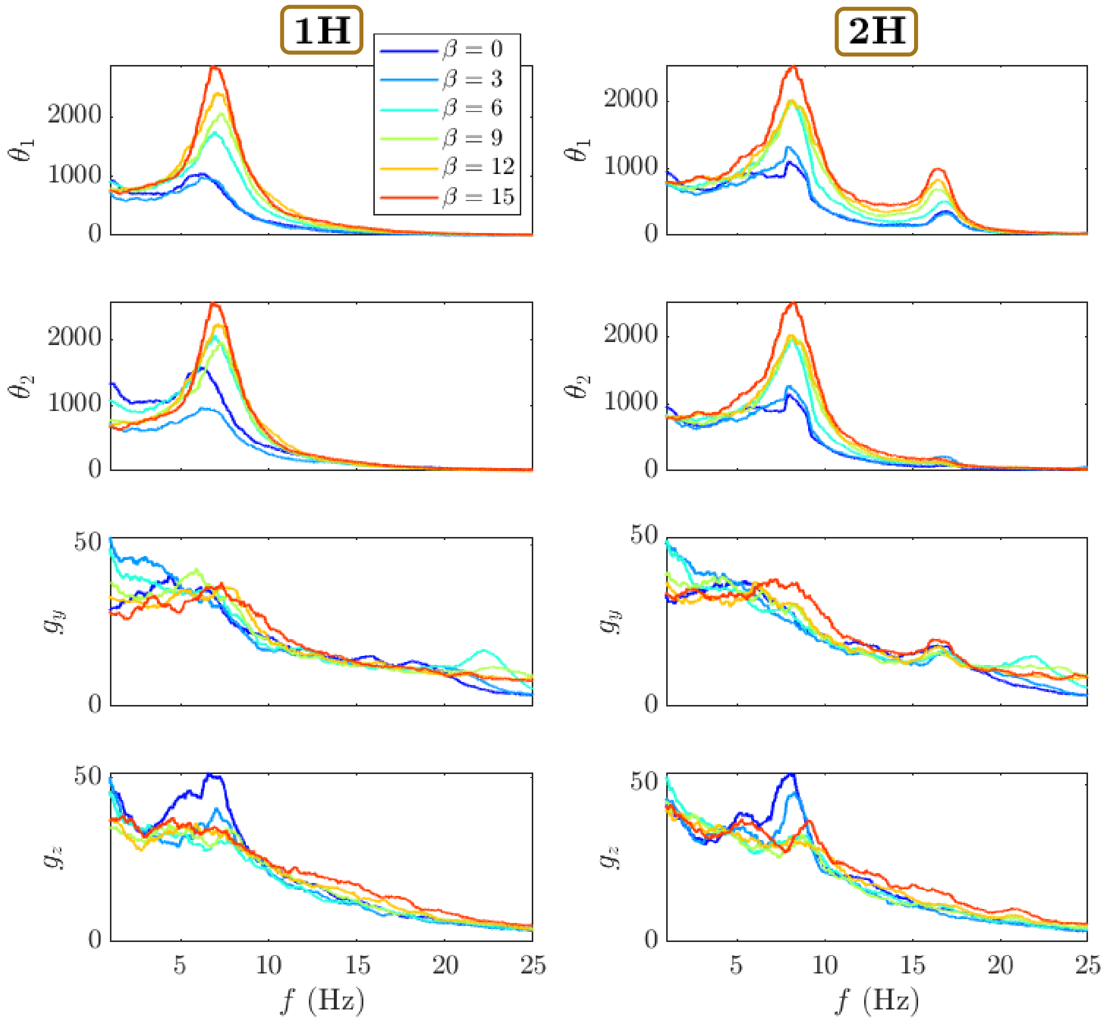


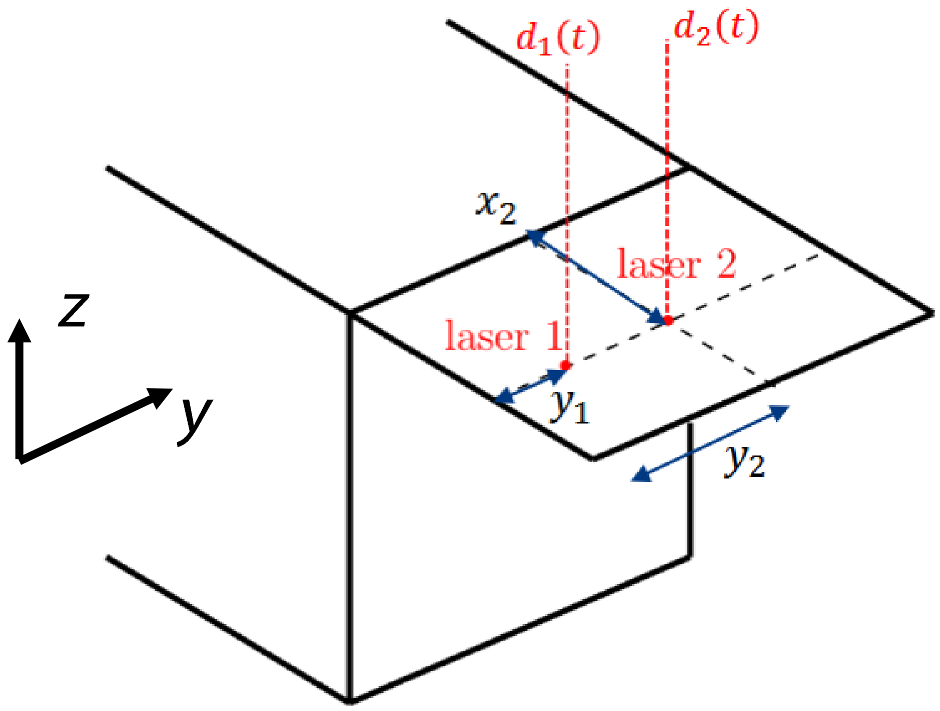




Results

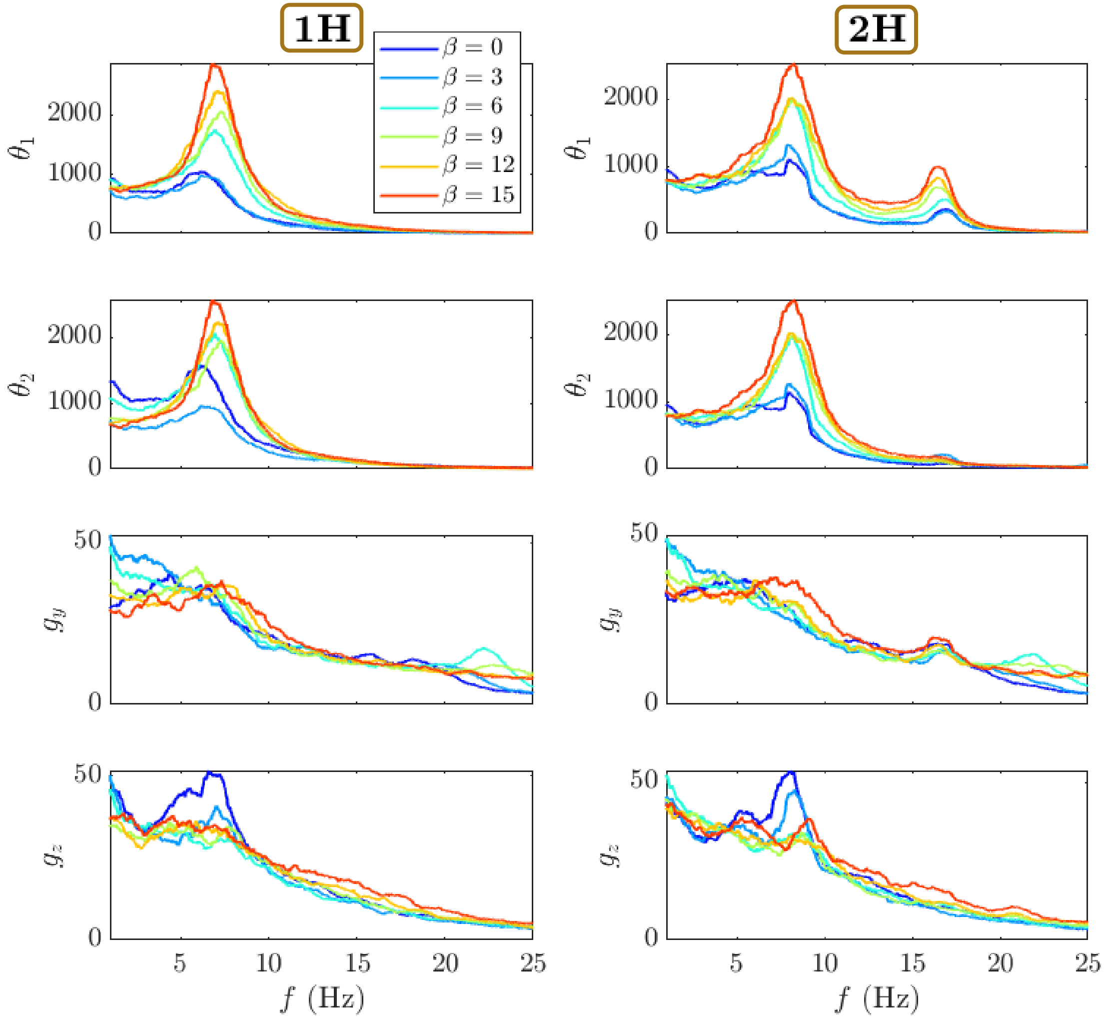
- 2 Degree-of-freedom hinged flaps
  - 2HF starts to modify the wake at $\beta > |5^o|$

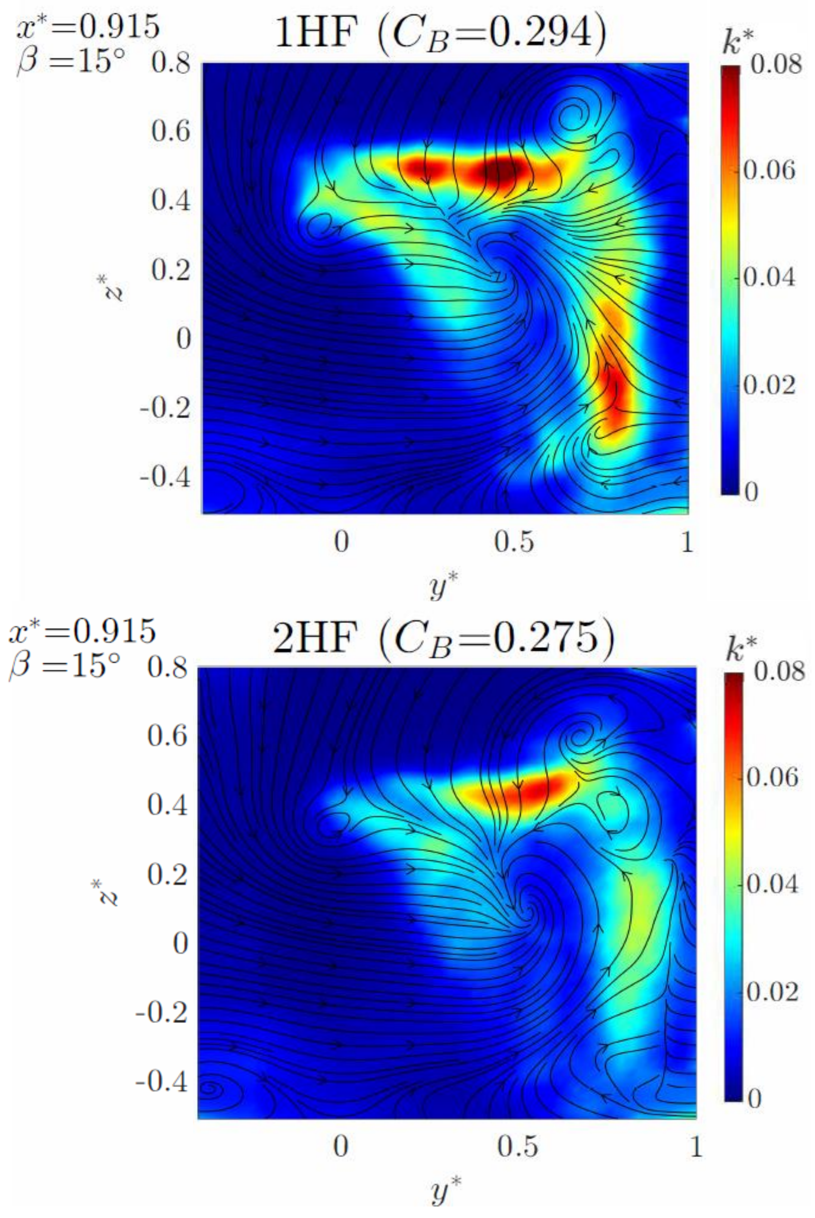




Results

- 2 Degree-of-freedom hinged flaps
  - 2HF starts to modify the wake at $\beta > |5°|$

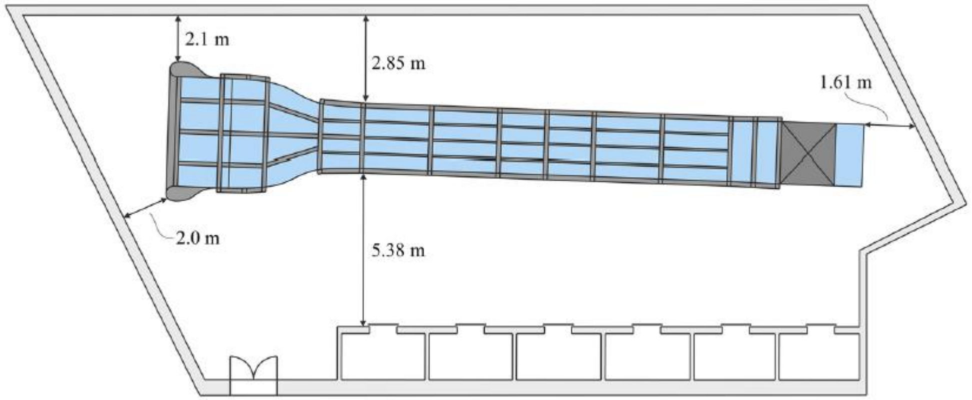


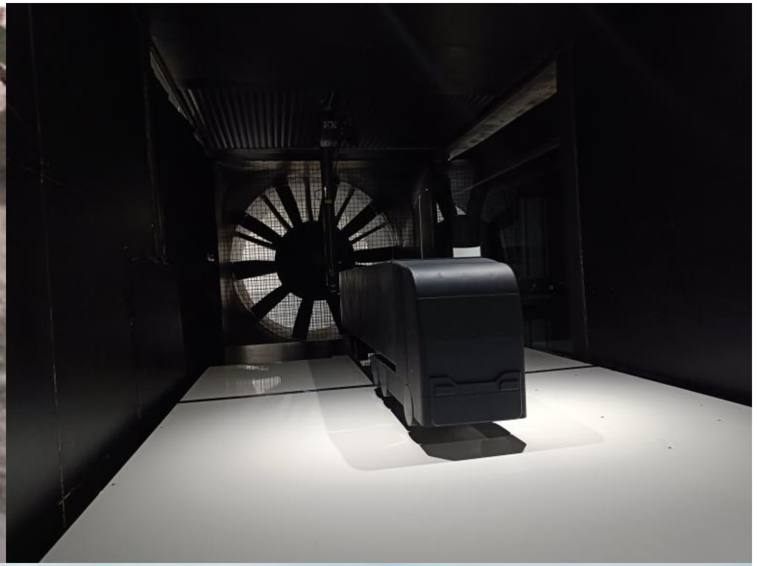


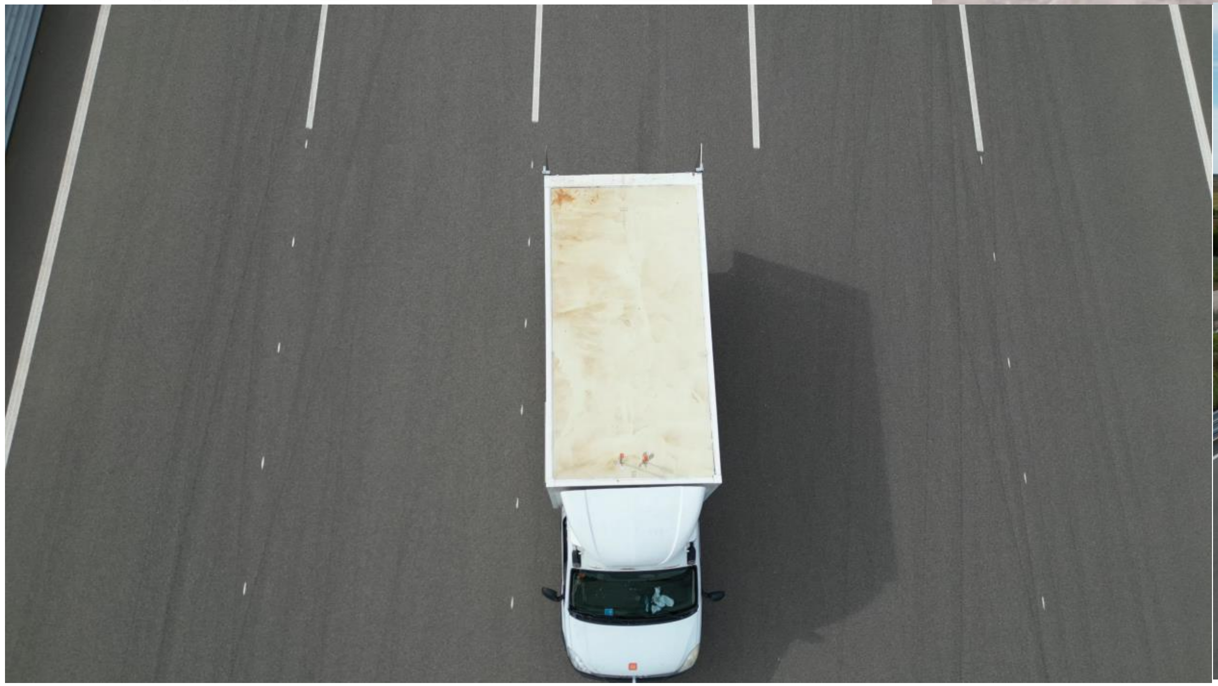
Conclusions

- 3D Self-adaptive flaps with different DoF are able to reduce C_D under different flow conditions
- For reducing drag under yaw, TB configurations are better than LR
- The increase of degrees of freedom improves the performance under yaw
- The DoF of the flaps show different FSI mechanisms with the 3D wake
- Flexible flaps could help in the design of real and effective drag reduction devices

Ongoing works







Thank you for your attention

Questions?

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