Manipulation of wake asymmetries of a blunt body – wake equilibrium and drag reduction

Y. Haffner, J. Borée, A. Spohn

Institut Pprime – UPR 3346 CNRS, ISAE-ENSMA, Université de Poitiers – France

T. Castelain

Université de Lyon – LMFA UMR CNRS 5509, Ecole Centrale de Lyon, Université Lyon 1 – France

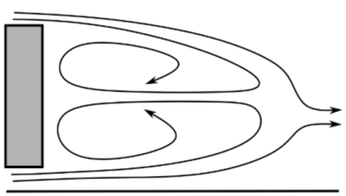
ANR project Activ_ROAD (ANR15CE220002)

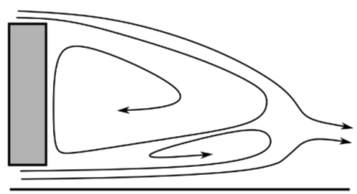
Motivations

Introduction

Asymmetries in the wake of simple blunt bodies

- Symmetry-breaking mode leading to large-scale wake asymmetries

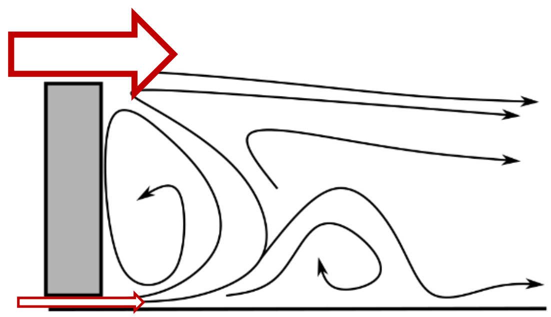




Bi-modal or static asymmetry

📖 Grandemange JFM 2014

- Asymmetries due to imbalance between momentum flux



Weak underbody flow

- Change of asymmetry or wake type only caused by minor geometric or flow conditions changes

Aspect ratio

Yaw — 📖 Bonnavion JFM 2018

Pitch — 📖 Gentile JFM 2017

Perturbing bodies — 📖 Barros JFM 2017

Underbody flow changes

📖 Castelain IJWEA 2018

Ground clearance

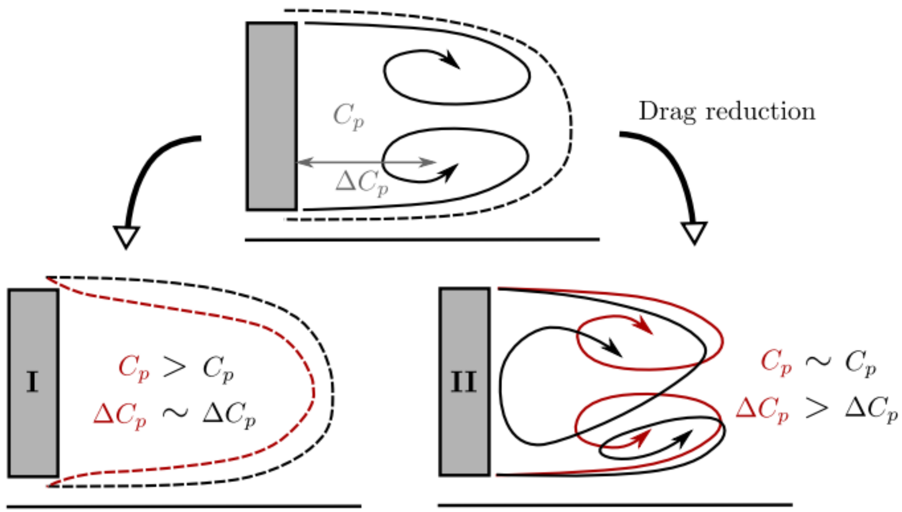
📖 Grandemange PoF 2014

What do we want ?

Introduction

Drag reduction of blunt bodies ?

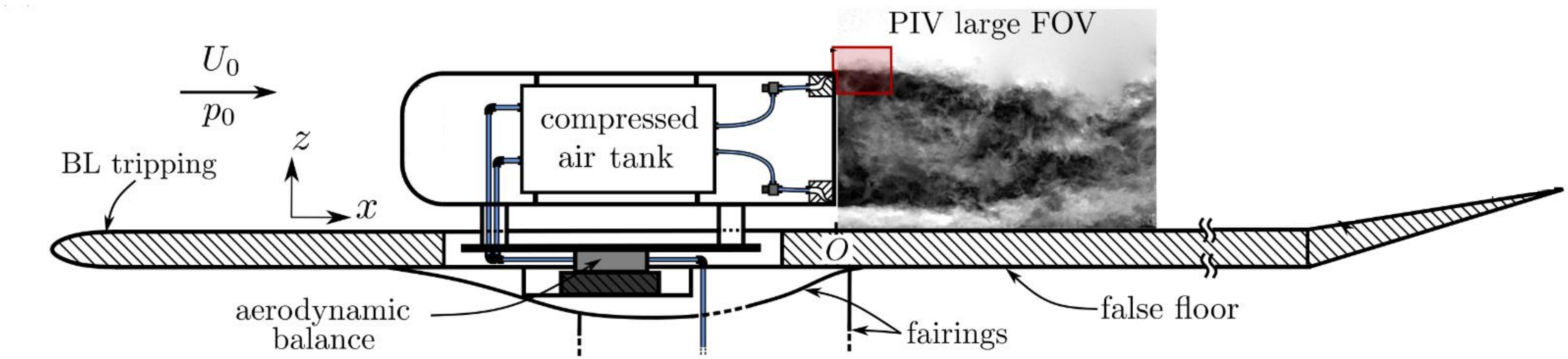
- Wakes asymmetries, change of topology and sensitivity of primary practical importance
- What is the best control strategy in each situation ? On which drag generating mechanism should we play ?
- Can we draw an efficient, robust and general control strategy to reduce drag in various conditions ?



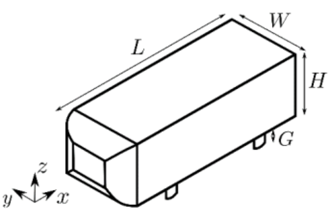
Wake bluffness Wake symmetry

Model and wind-tunnel setup

Experimental setup

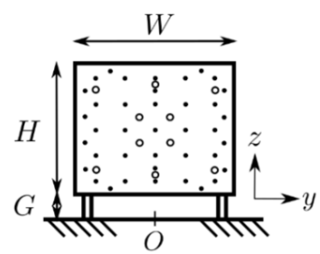


Parameters



U_0 = 25 m/s
H = 0.3 m
Re_H = 5.10^5
Blocage : 2.5 %
G = 0.05 m

Base pressure measurements



2 % precision on C_p

Aerodynamic balance

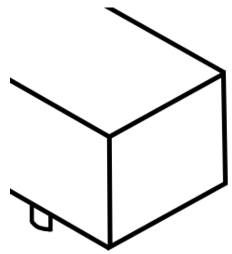
1% precision on drag coeff. C_x

Bifurcation scenario

Manipulation of unforced flow

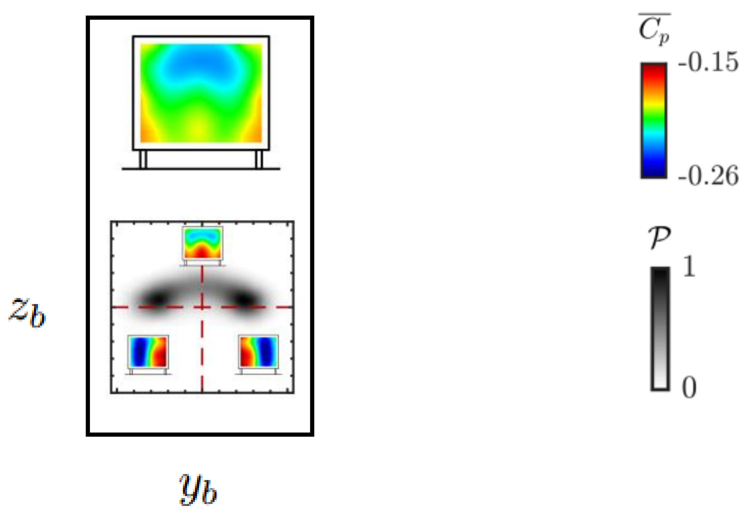
Base pressure barycentre

$$y_b = \frac{\sum_{i=1}^{N} y_i C_p(y_i, z_i, t)}{\sum_{i=1}^{N} C_p(y_i, z_i, t)} \qquad z_b = \frac{\sum_{i=1}^{N} z_i C_p(y_i, z_i, t)}{\sum_{i=1}^{N} C_p(y_i, z_i, t)}$$



Base pressure distribution

Barycentre location pdf

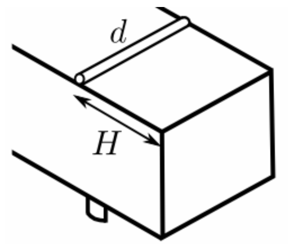


Bifurcation scenario

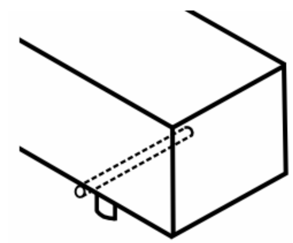
Manipulation of unforced flow

Passive perturbations

Top



Bottom



Base pressure distribution

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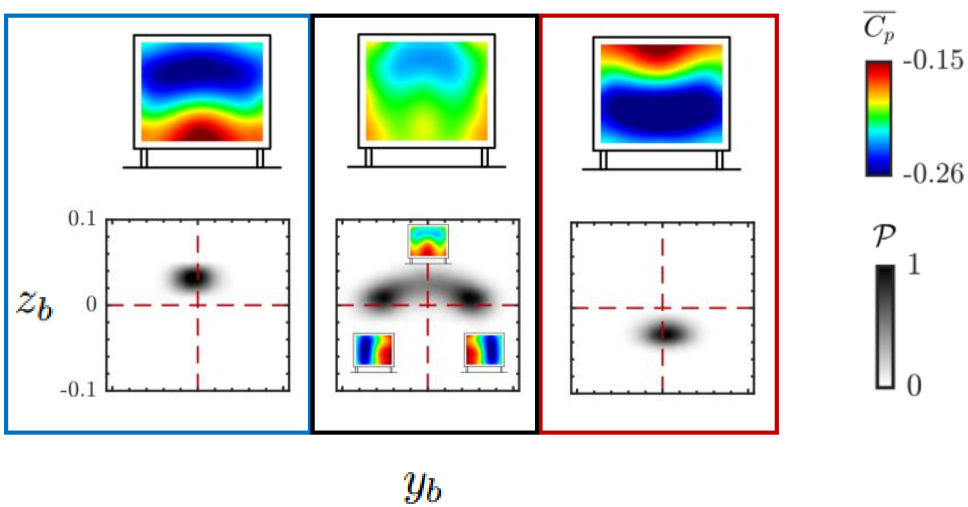

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Base pressure distribution

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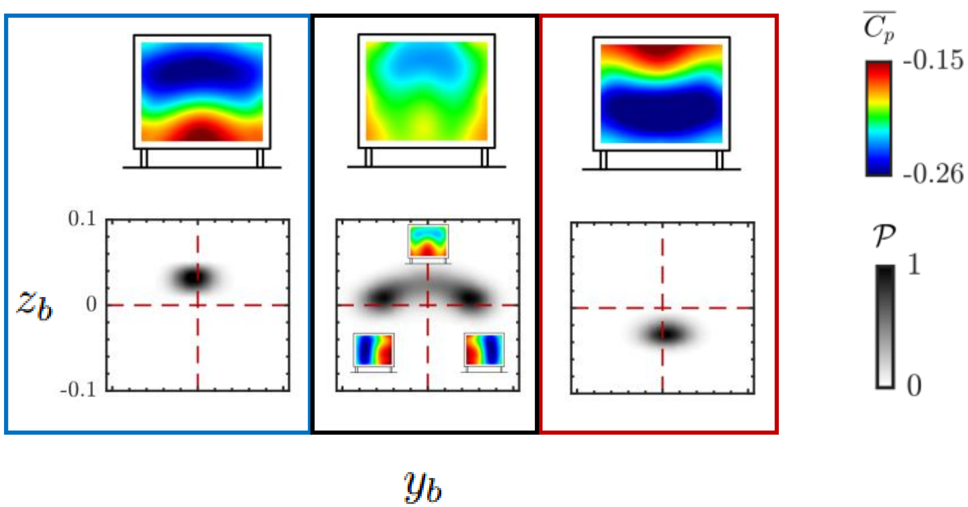
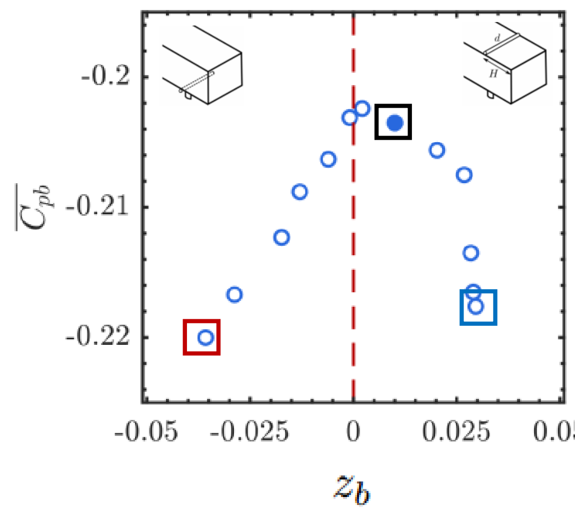
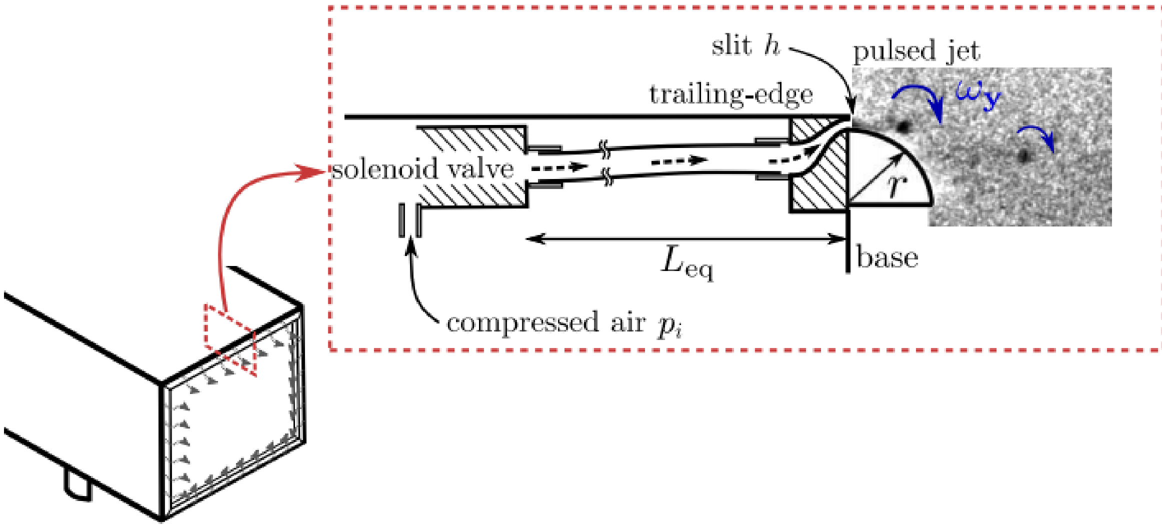




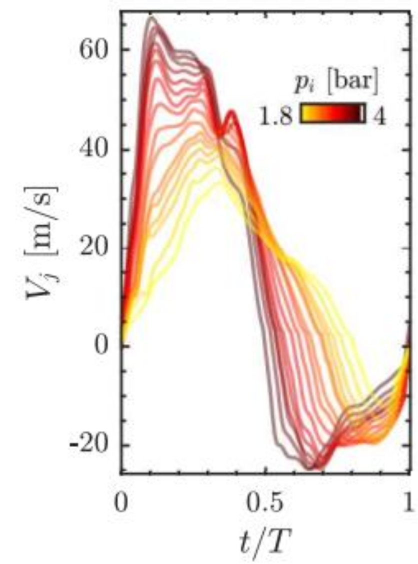
Different wake equilibrium related to different drag states

Forcing apparatus

Forcing flow asymmetries



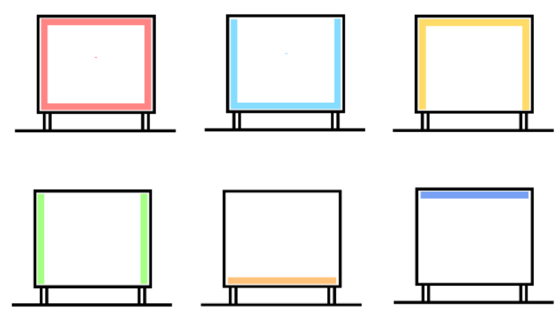
Phase-averaged exit velocity



Pulsed jets parameters

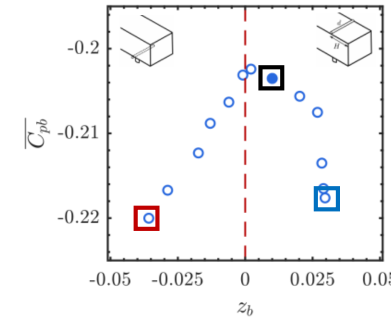
Slit thickness	$h = 1\,\mathrm{mm}$
Curved surface radius	$r = 9h$
Pulsing frequency	$St_\theta = f\theta/U_0 = 0.1$ $St_H = fH/U_0 = 12.5$
Pulsing amplitude	$C_\mu = d_c \dfrac{S_j V_{j_{\max}}^2}{S U_0^2}$

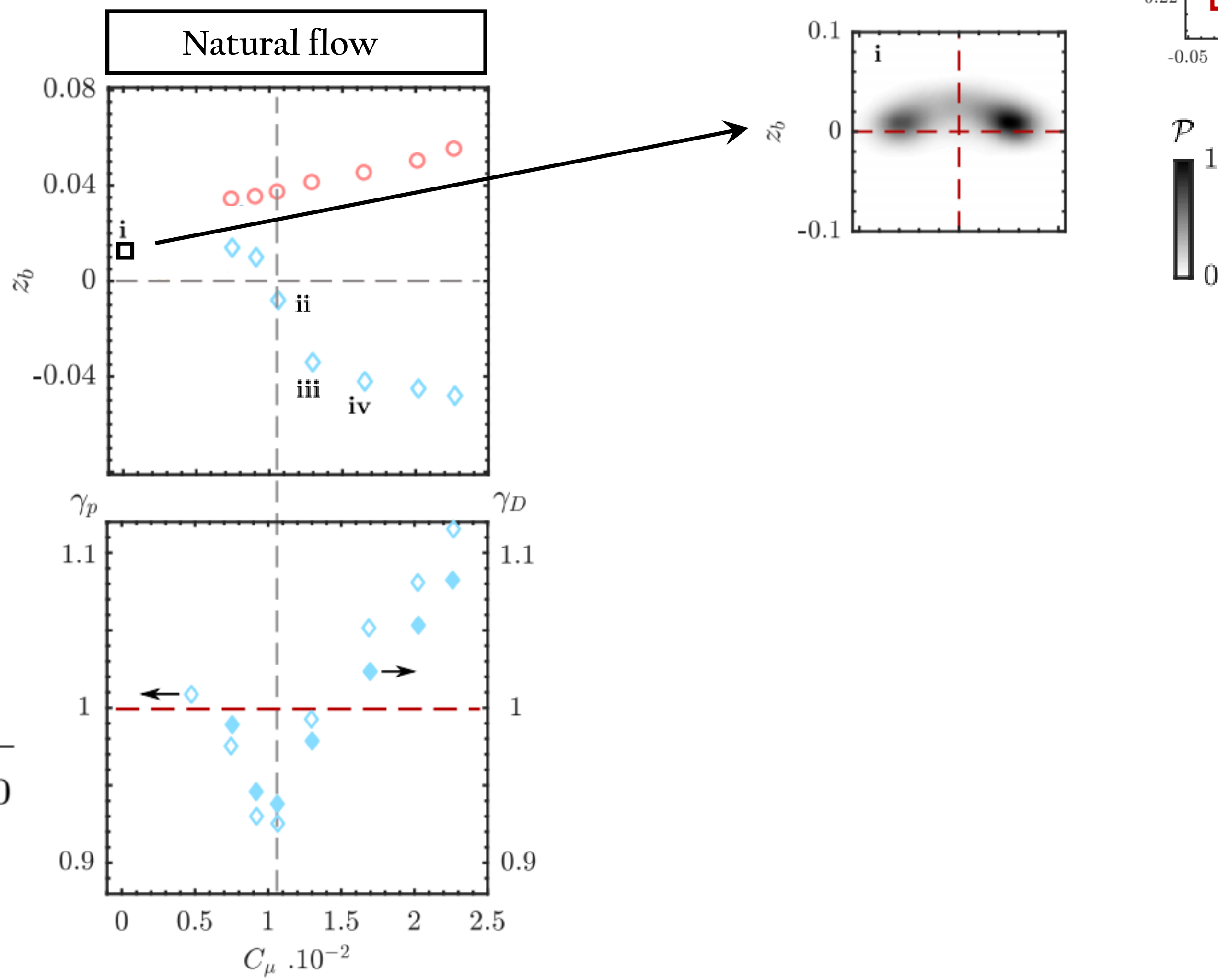
Forcing distribution



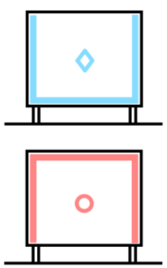
Wake symmetrization

Forcing flow asymmetries





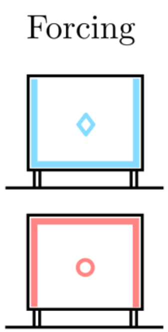
Forcing



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

Wake symmetrization

Forcing flow asymmetries



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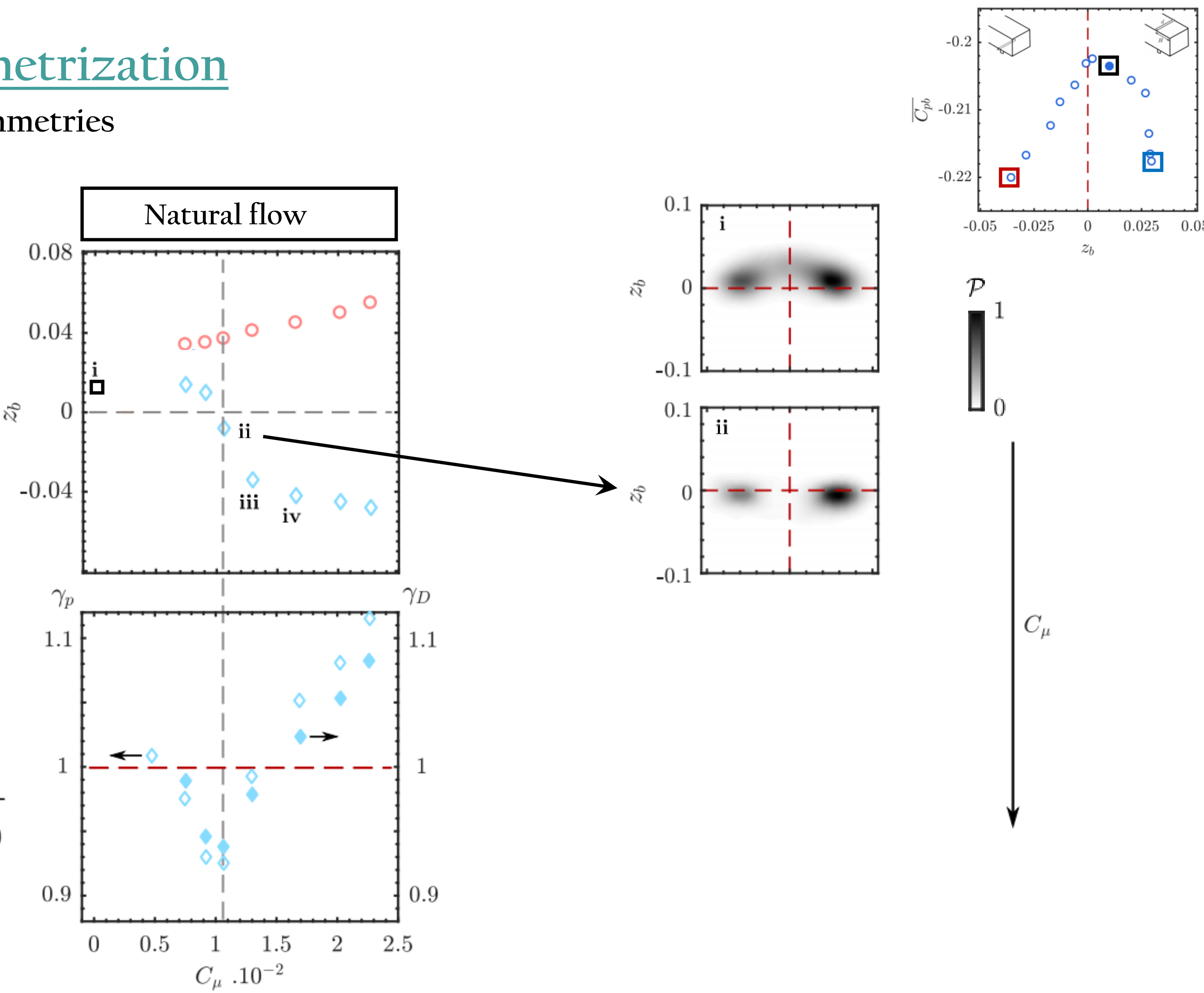
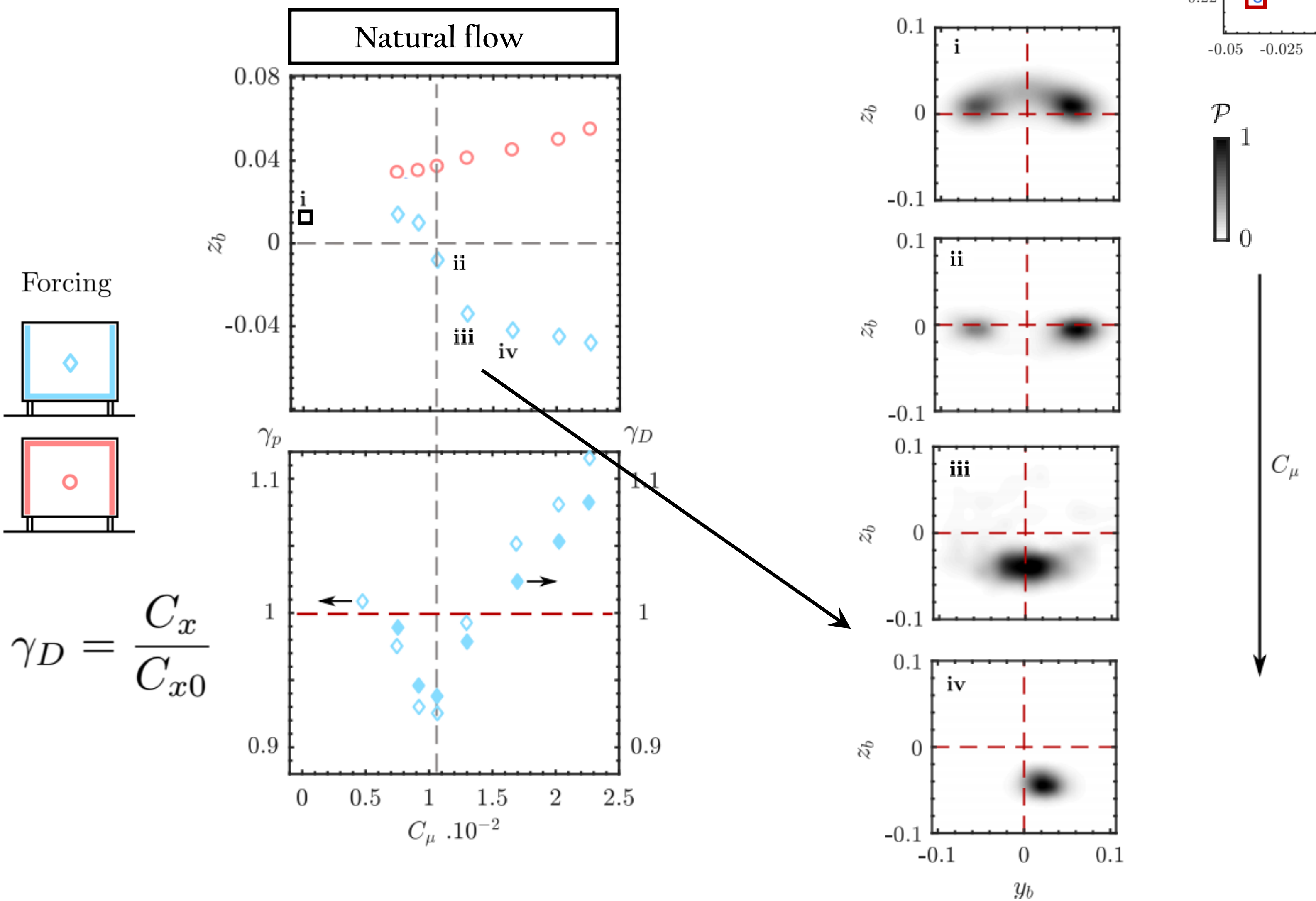


Wake symmetrization

Forcing flow asymmetries



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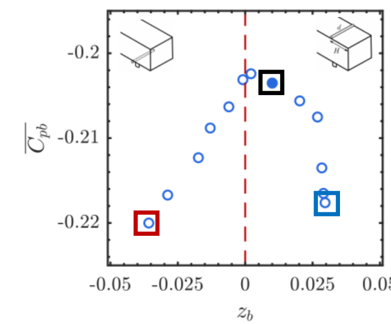
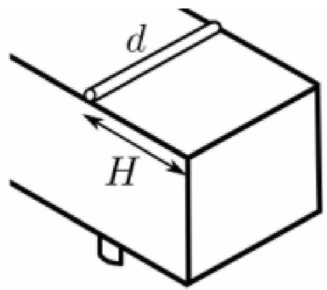


Drag optimality is achieved at perfect vertical symmetry under asymmetric forcing

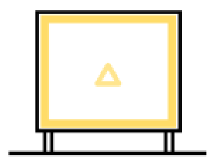
Two drag reduction mechanisms

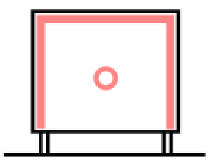
Forcing flow asymmetries

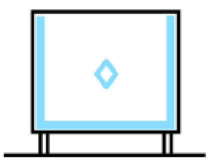
Top perturbed



Forcing







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

0.87

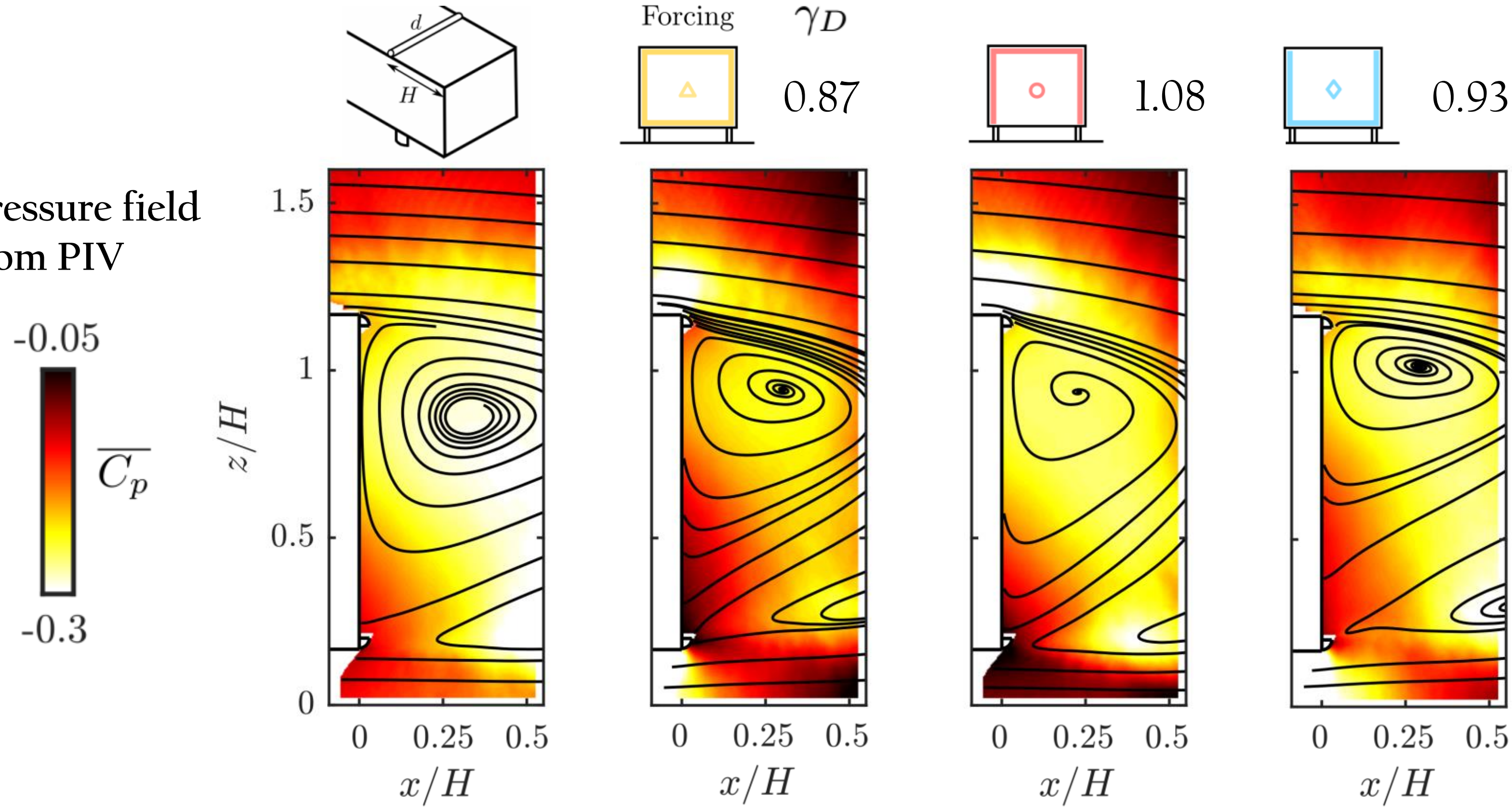
1.08

0.93

Two drag reduction mechanisms

Forcing flow asymmetries

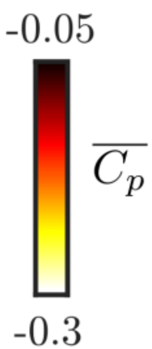
Pressure field from PIV

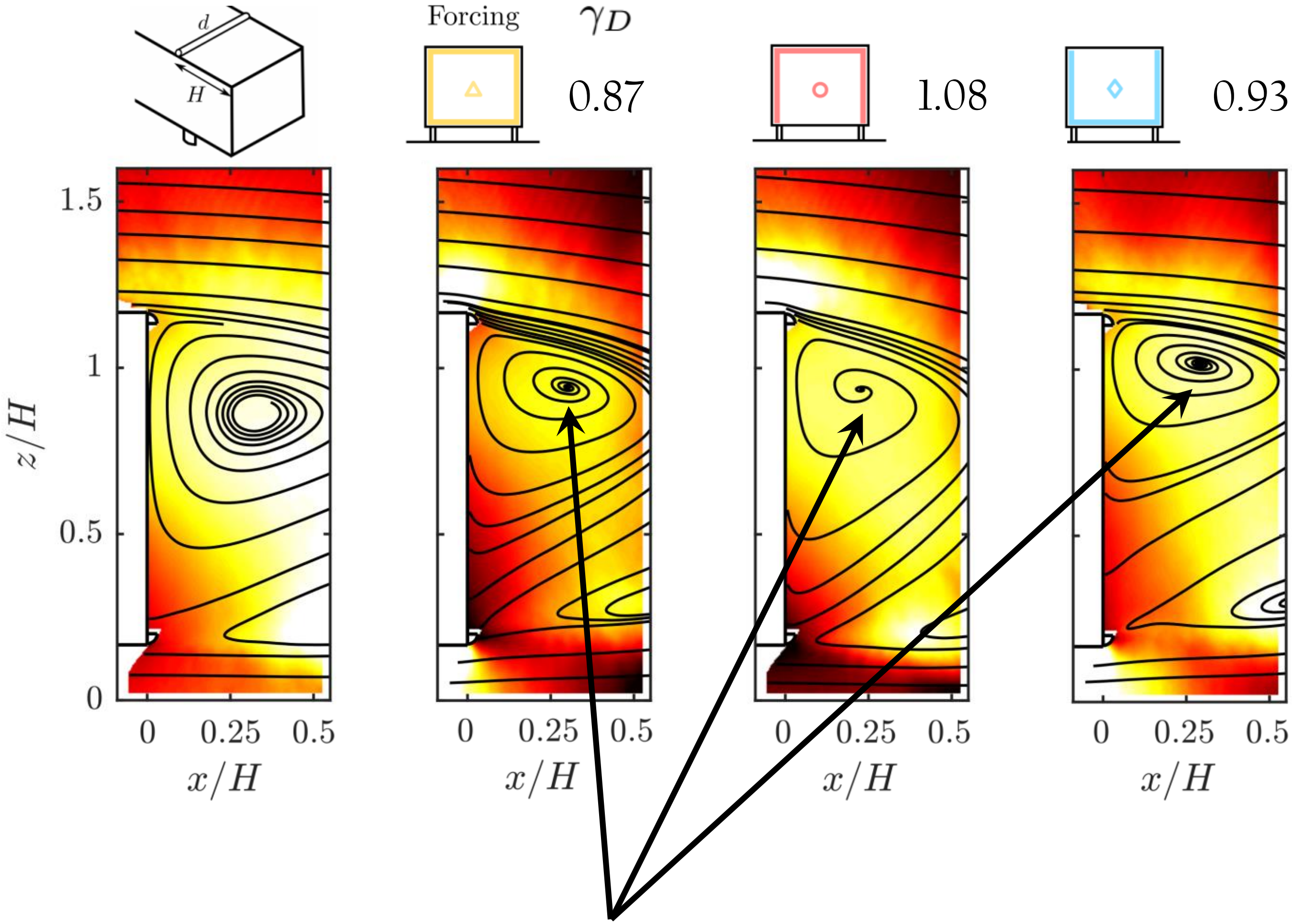


Two drag reduction mechanisms

Forcing flow asymmetries

Pressure field from PIV

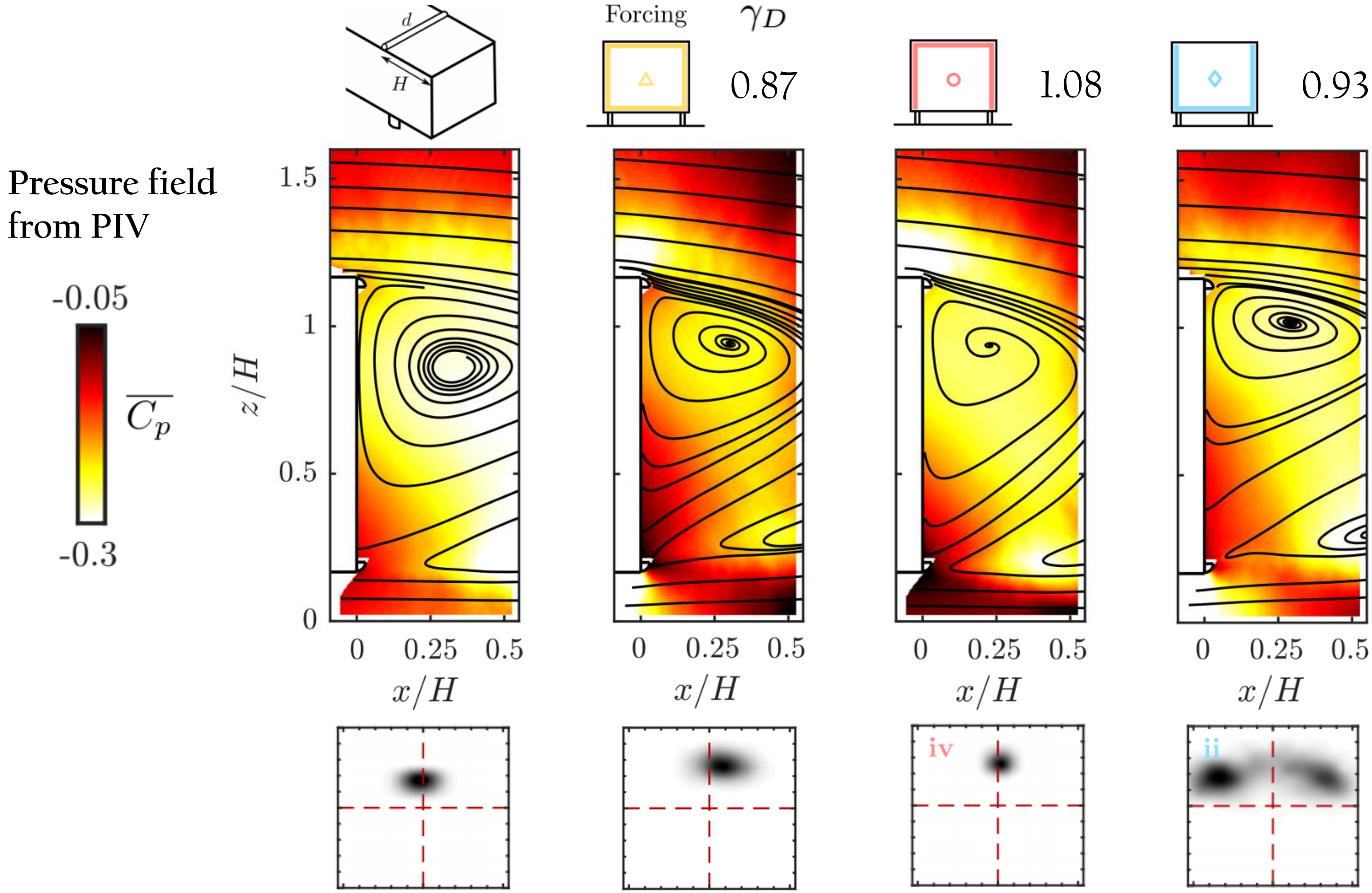




Global pressure recovery in the wake

Two drag reduction mechanisms

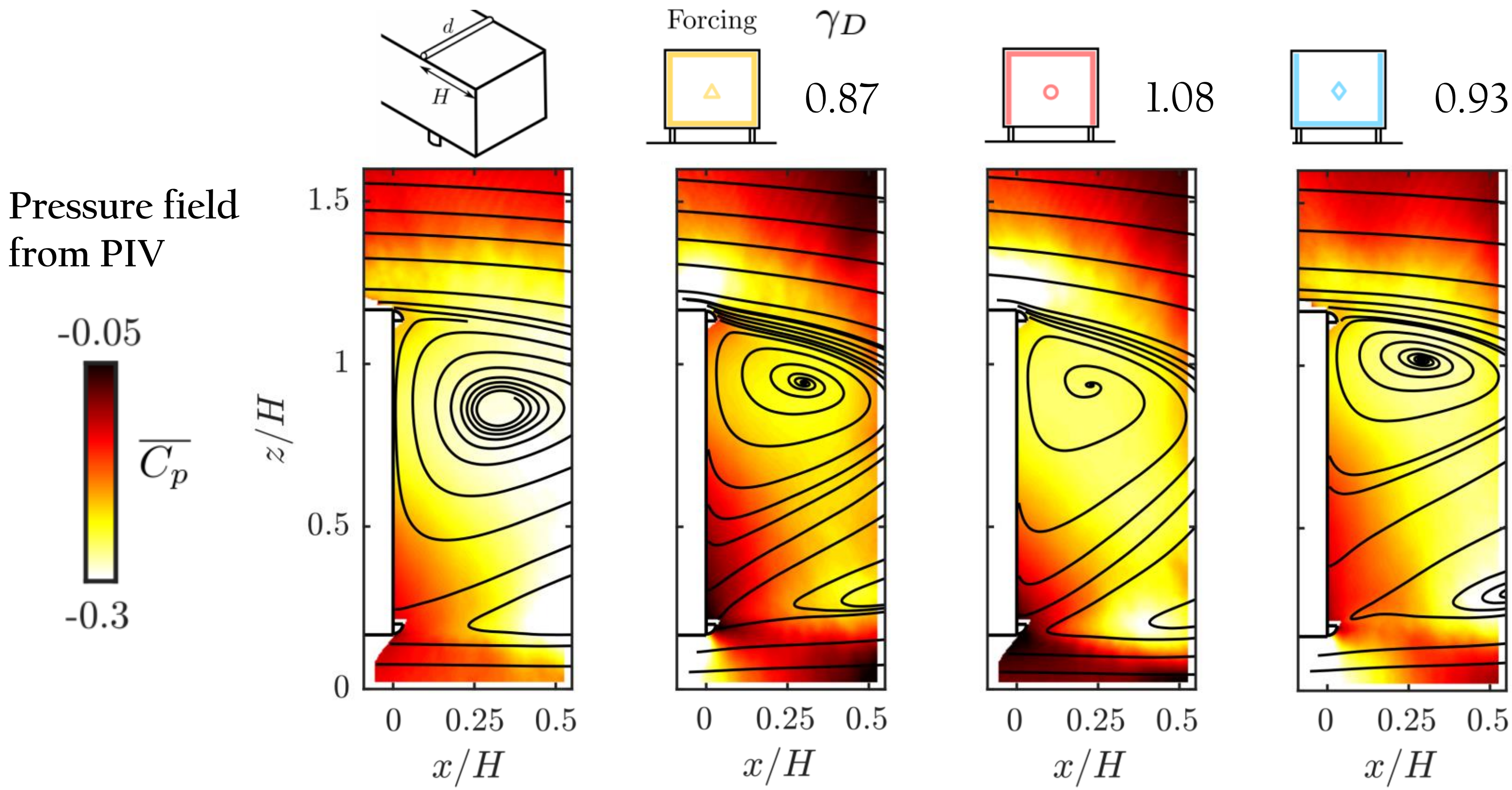
Forcing flow asymmetries



Massive reorganization of the inner recirculating region

Two drag reduction mechanisms

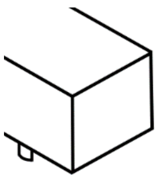
Forcing flow asymmetries

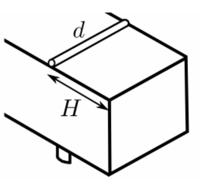


Drag changes explained by the coupling between wake bluffness
AND symmetry of the recirculating region

Flow control efficiency

Forcing flow asymmetries





Configuration – Forcing	C_μ	γ_D	η
Natural – F_{TBLR}	0.014	0.93	38.2
Natural – F_{TBLR}	0.021	0.89	31.1
Natural – F_{BLR}	0.011	0.94	44.8
Top perturbed – F_{TBLR}	0.012	0.93	51.9
Top perturbed – F_{TBLR}	0.018	0.87	51.9
Top perturbed – F_{BLR}	0.009	0.96	40.6
Top perturbed – F_{BLR}	0.012	0.93	38.2
Top perturbed – F_{B}	0.003	0.95	137.7
Top perturbed – F_{B}	0.005	0.93	103.7

Control efficiency

$$\eta = \frac{\Delta P_D}{P_S}$$

Power expenses in control

Power saving by drag reduction

Control strategies mainly based on symmetrisation of energetic interest

Conclusions and outlooks

Conclusions

- Two distinct drag reduction mechanisms : wake bluffness and wake symmetry
- Coupling of both to achieve drag reduction in various asymmetric configurations : interest in adaptive control for changing real flow conditions
- Generalization to other asymmetries (cylinder perturbations similar to pitch, yaw or ground clearance variation in selecting the wake asymmetry)

Thank you for your attention.

Any questions ?

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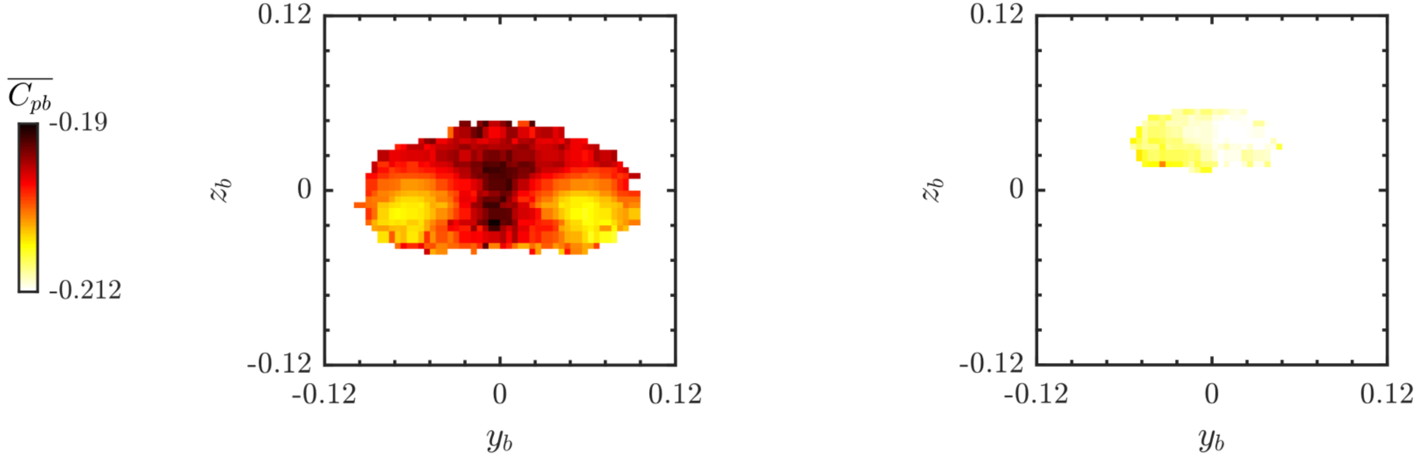
Base drag evolution

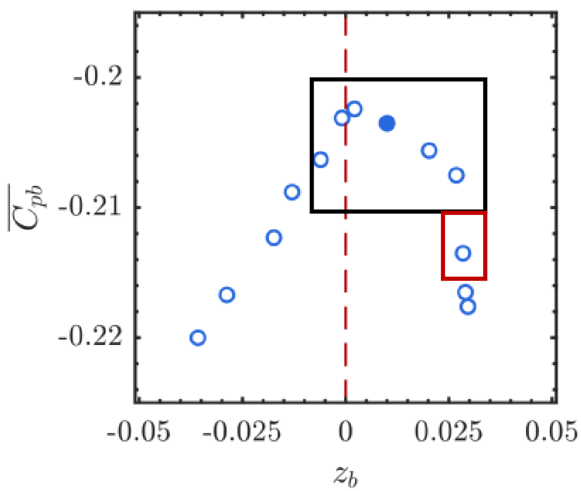
Manipulation of unforced flow

Conditionally averaged base drag



Mean base drag

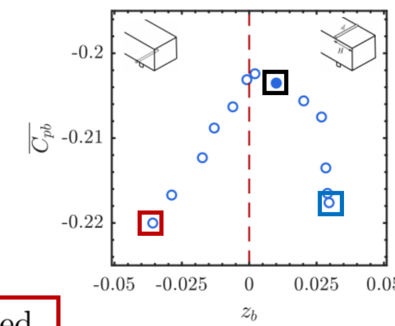
Only unsteady symmetry-breaking configurations



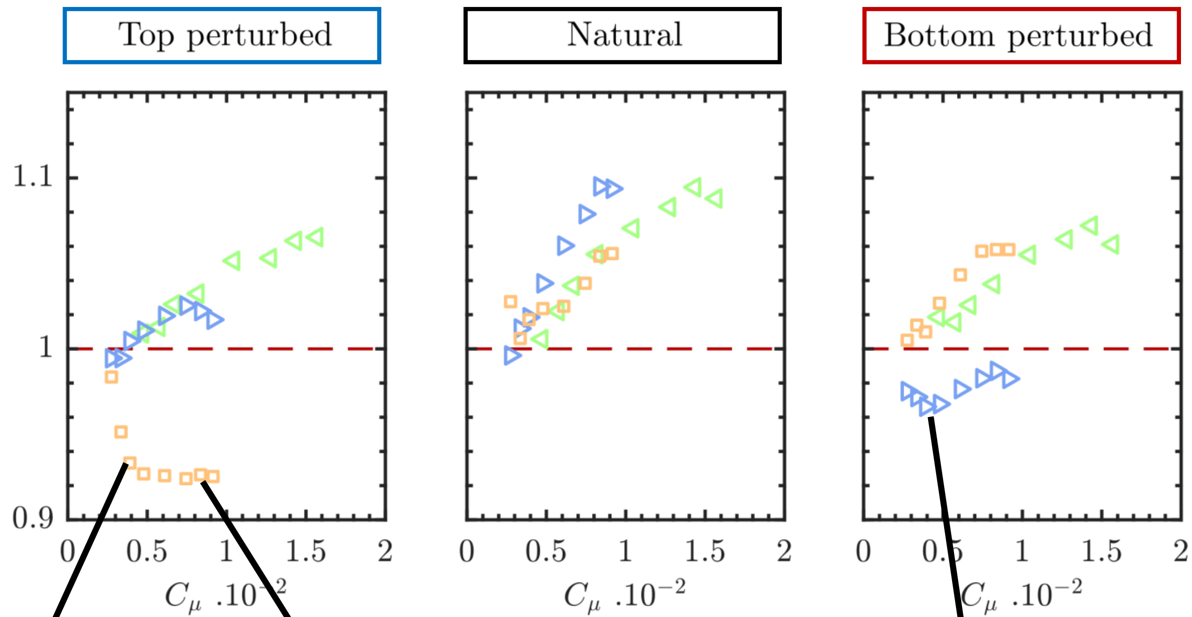
First static symmetry-breaking configuration

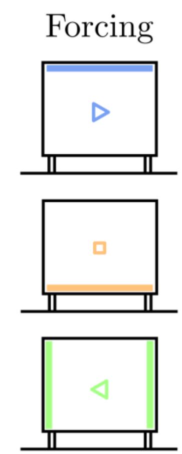
Global drag changes

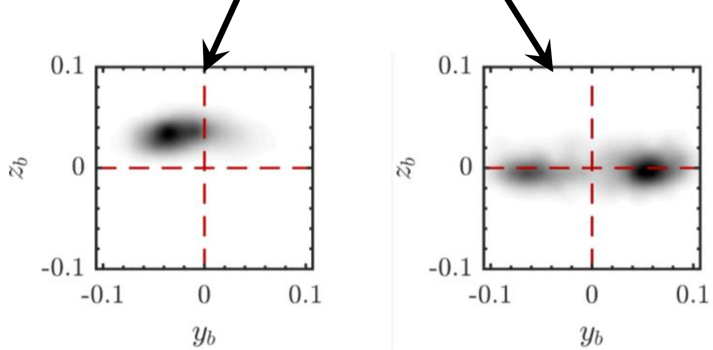
Forcing flow asymmetries

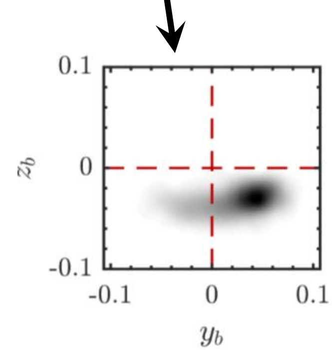


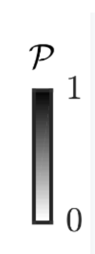
$$\gamma_D = \frac{C_x}{C_{x0}}$$











Global drag changes

Forcing flow asymmetries