Investigation of the effects of wheels on the wake dynamics behind a simplified square-back vehicle [Powerpoint]

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G. Pavia, M. A. Passmore

INVESTIGATION OF THE EFFECTS OF WHEELS ON THE WAKE DYNAMICS BEHIND A SIMPLIFIED SQUARE-BACK VEHICLE

Background

- The turbulent wake behind square-back bodies shows a strong bimodal behaviour, whose characteristic time $T_l \approx 10^3\ W/U_\infty$ is about 2 or 3 orders of magnitude larger than the natural time for vortex shedding. (*Grandemange et al., 2013b*)

- An upwash or downwash dominated, lateral symmetry preserving state can be seen during the switch between bi-stable states. (*Pavia et al., 2018*).

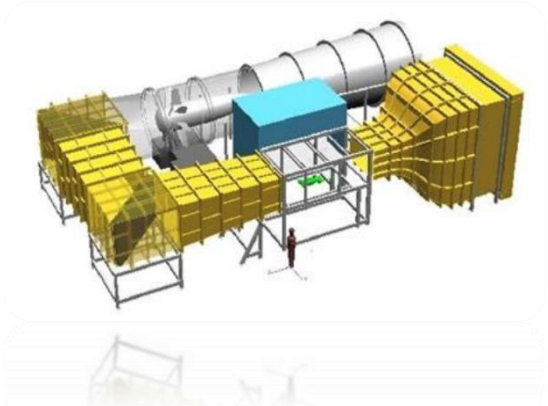
- The tendency of the wake to develop a bi-stable behaviour is seen to decrease as the distance between the top and bottom shear layers is reduced. (*Perry et al., 2016b*)

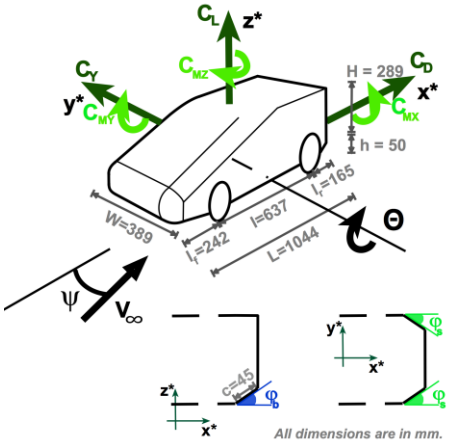
- The bi-stable mode has been shown to be responsible of large fluctuations in the side force at 0° yaw even in the case of more realistic geometries (*Grandemange et al., 2015; Pavia et al., 2017*).

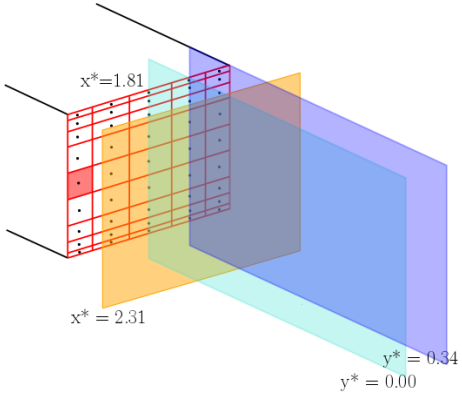
- In presence of short rear overhangs, the long-time wake unsteadiness is greatly reduced (*Pavia et al., 2017*).

Experimental Methodology

An experimental campaign was carried out in the Loughborough University Large Wind Tunnel using the Windsor body with stationary wheels. This work is a continuation of that presented in *Pavia et al., 2017*.







Small tapers (with a chamfer angle φ equal to $12°$) were applied to either the bottom or the side trailing edges of the model.

All tests were performed at a tunnel free stream velocity of $40\ \mathrm{m/s}$, resulting in a Reynolds number Re_H of $7.7 \cdot 10^5$.

Pressure tappings and PIV acquisitions were performed.

The sensitivity of the flow field to variations of the model pitch angle was also assessed.

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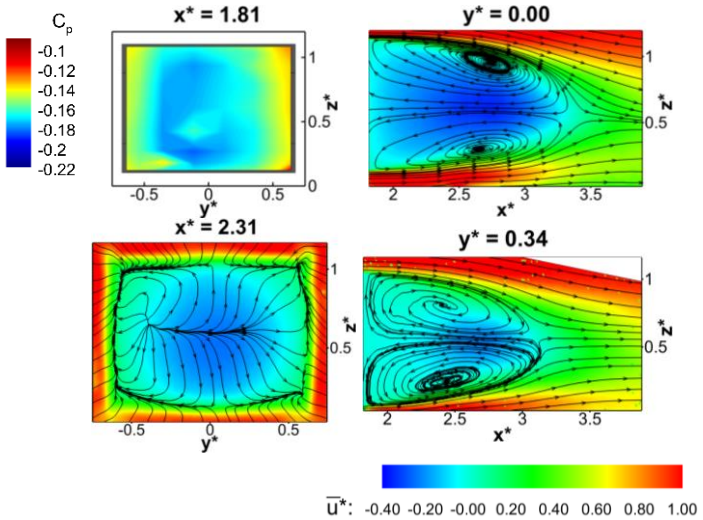
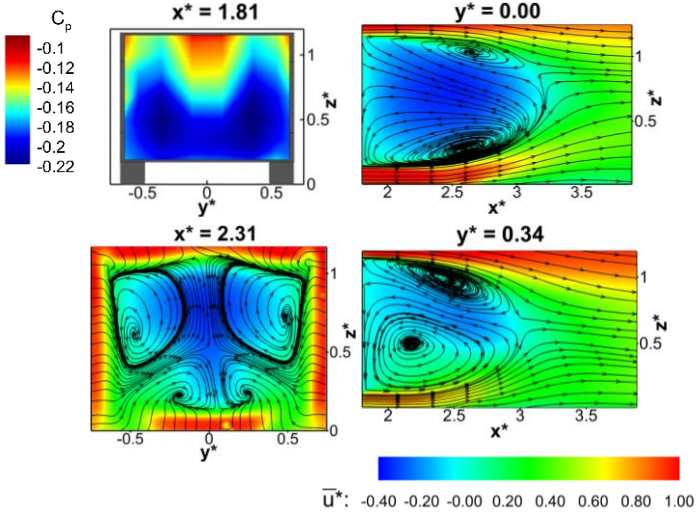
Time averaged results

No wheels *(Perry et al., 2016b; Pavia et al., 2018)*



Stationary wheels *(Pavia et al., 2017)*



The symmetry of the wake in the vertical direction is lost as wheels are added to the model.

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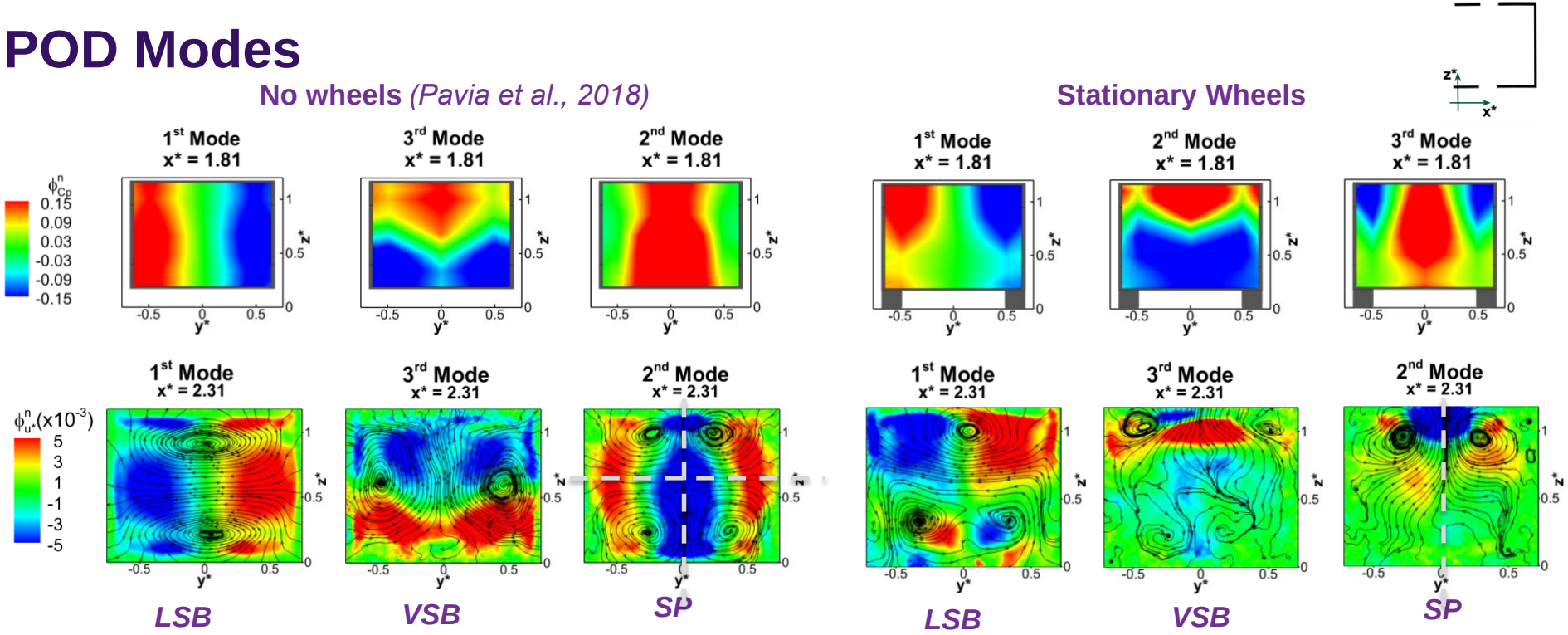
POD Modes

No wheels *(Pavia et al., 2018)*

Stationary Wheels



A flapping motion can be seen behind the rear wheels in the LSB mode.

A plane of symmetry is lost in the SP mode.

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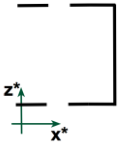
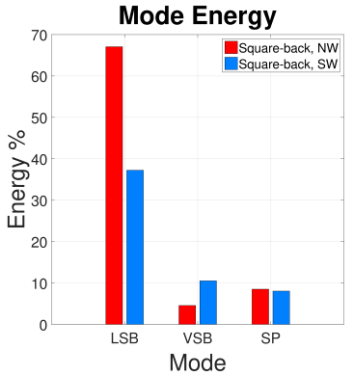
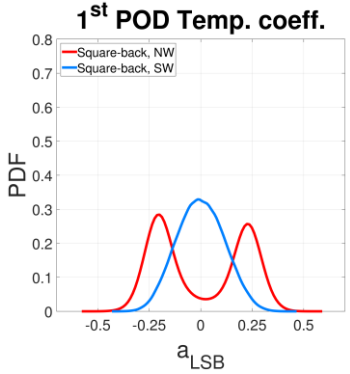
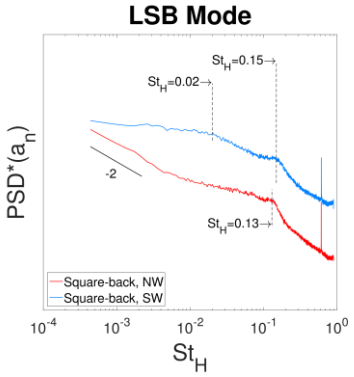
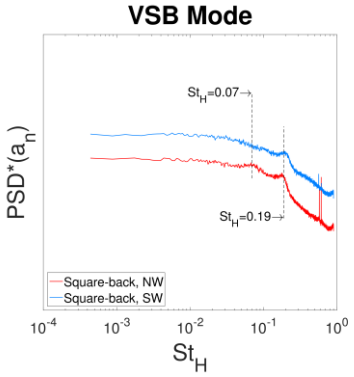
POD Modes (pressure data)

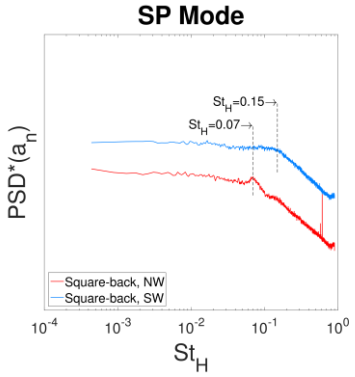












Evidence of the stabilisation of the wake in the lateral direction is provided by the weakening of the lateral symmetry breaking mode.

Changes are also seen in the short-time wake dynamics.

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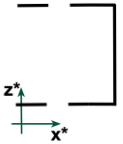
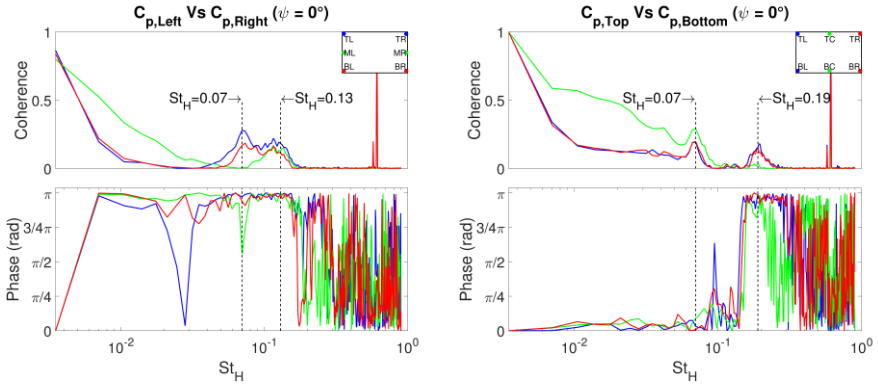
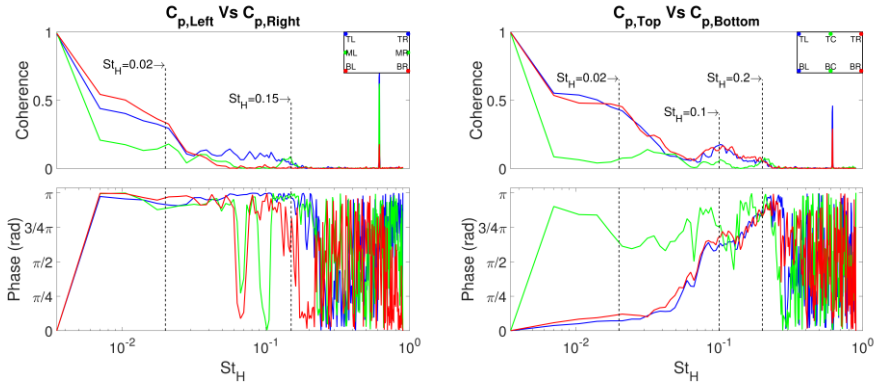
Coherence Analysis (pressure data)



No wheels *(Pavia et al., 2018)*



Stationary wheels



In the wheel case, the bi-stable mode is replaced by a low frequency lateral flapping motion with $St_H \approx 0.02$.

A vertical flapping motion with $St_H = 0.10$ becomes also visible.

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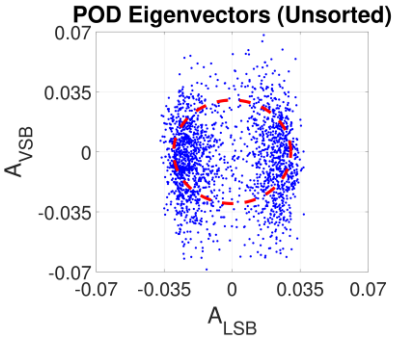
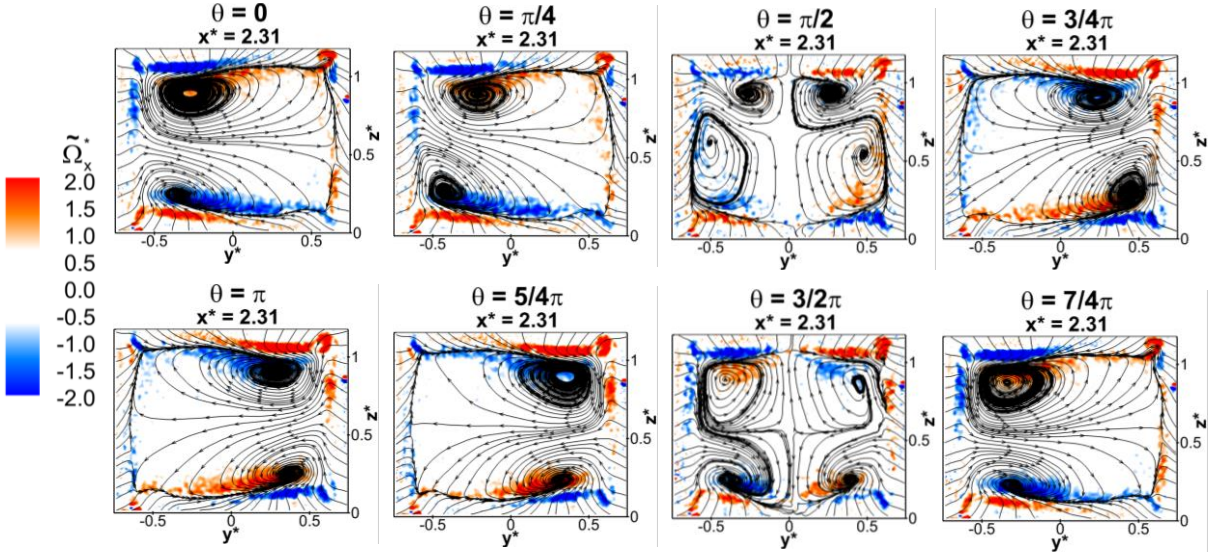
POD Filtered Phase Averaged Velocity Field



No wheels *(Pavia et al., 2018)*



The wake randomly switches between two lateral symmetry breaking states.

During the switch, two different lateral symmetry preserving states can be seen, each characterised by the predominance of either the lower recirculation or the upper recirculation.

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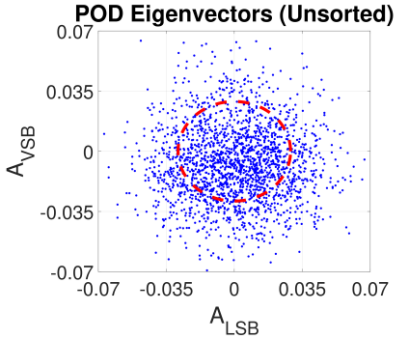
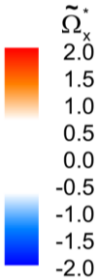
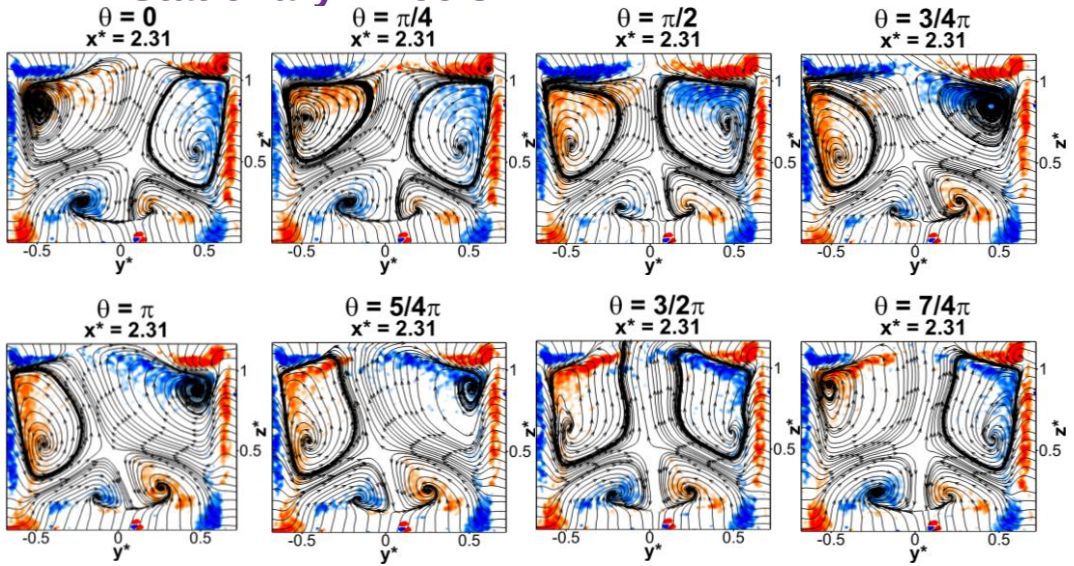
POD Filtered Phase Averaged Velocity Field





Stationary wheels



The wake locks in a four-vortex configuration. Only a swinging motion of the reverse flow is seen.

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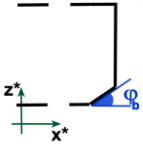
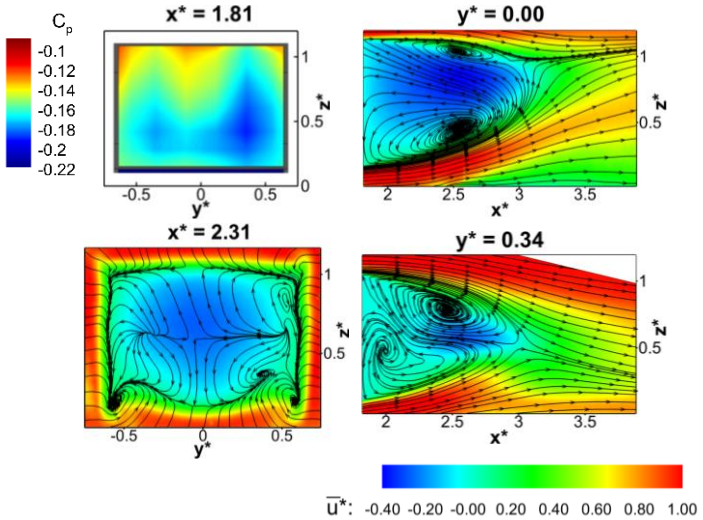
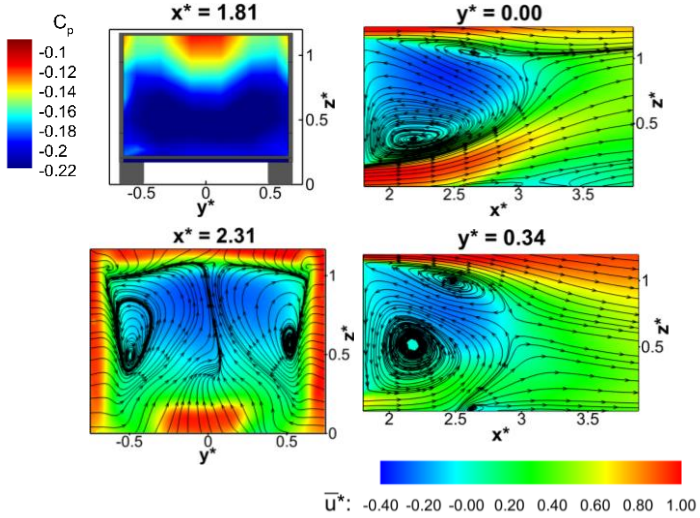
Time averaged results



No wheels *(Perry et al., 2016b)*



Stationary wheels *(Pavia et al., 2017)*



The addition of the wheels leads to a growth of the bottom recirculation seen in the plane at $y^* = 0.34$.

2. 12° bottom trailing edge taper

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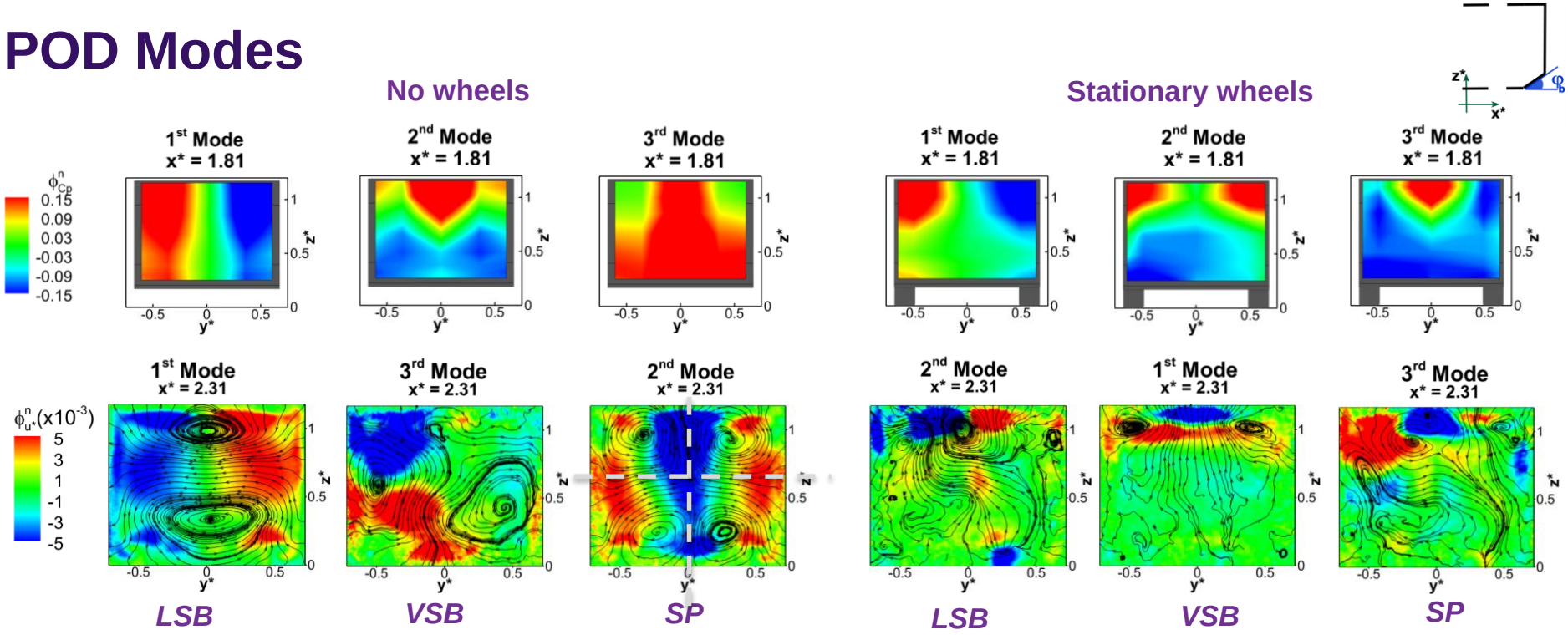
POD Modes



In the wheel case, coherent motions of the wake are seen only in the region close to the top trailing edge.

2. 12° bottom trailing edge taper

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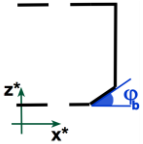
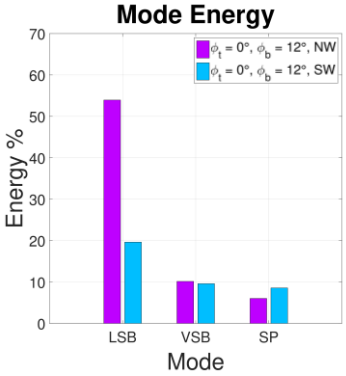
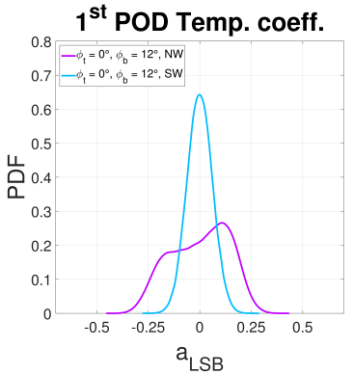
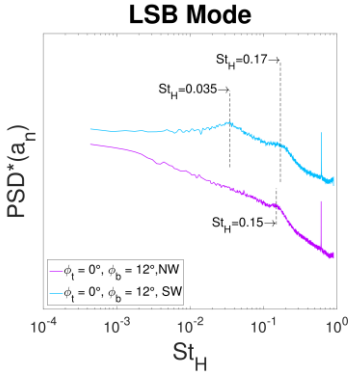
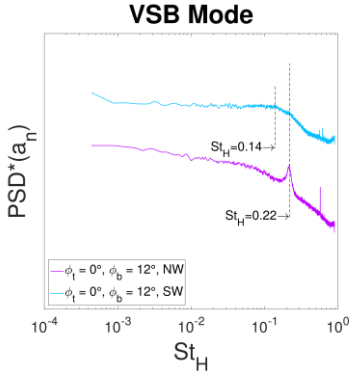
POD Modes (pressure data)

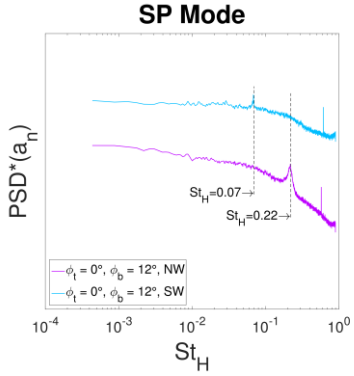












Following the addition of the wheels, the bi-stable mode is replaced by a low frequency lateral flapping motion with $St_H = 0.035$.

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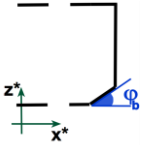
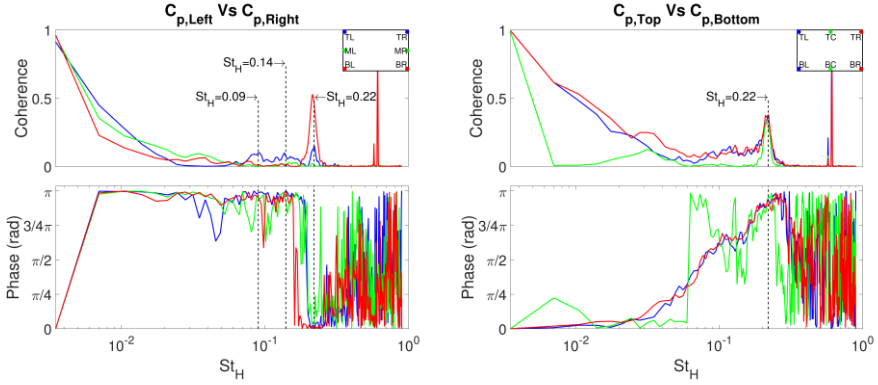
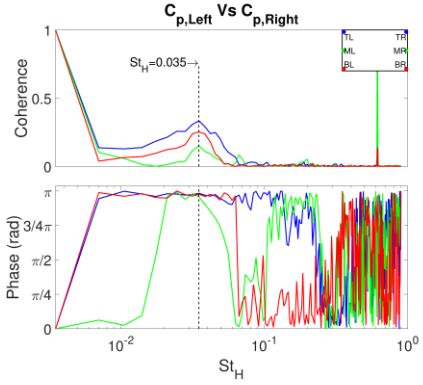
Coherence Analysis (pressure data)

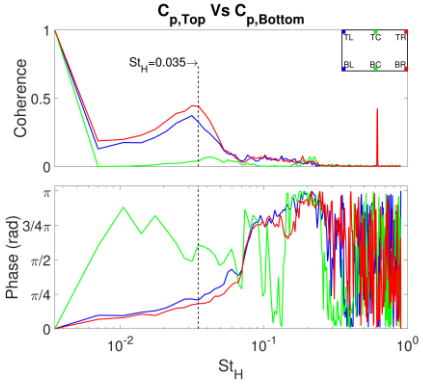


No wheels



Stationary wheels





The vertical flapping motion, seen in the no-wheel case at $St_H = 0.22$, is also suppressed.

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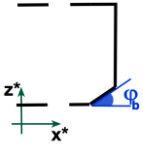
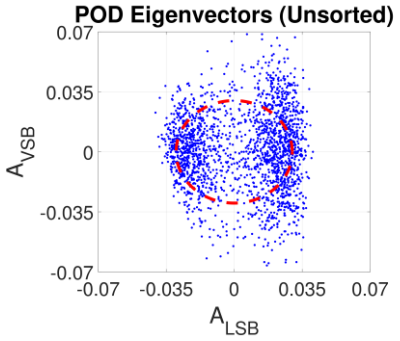
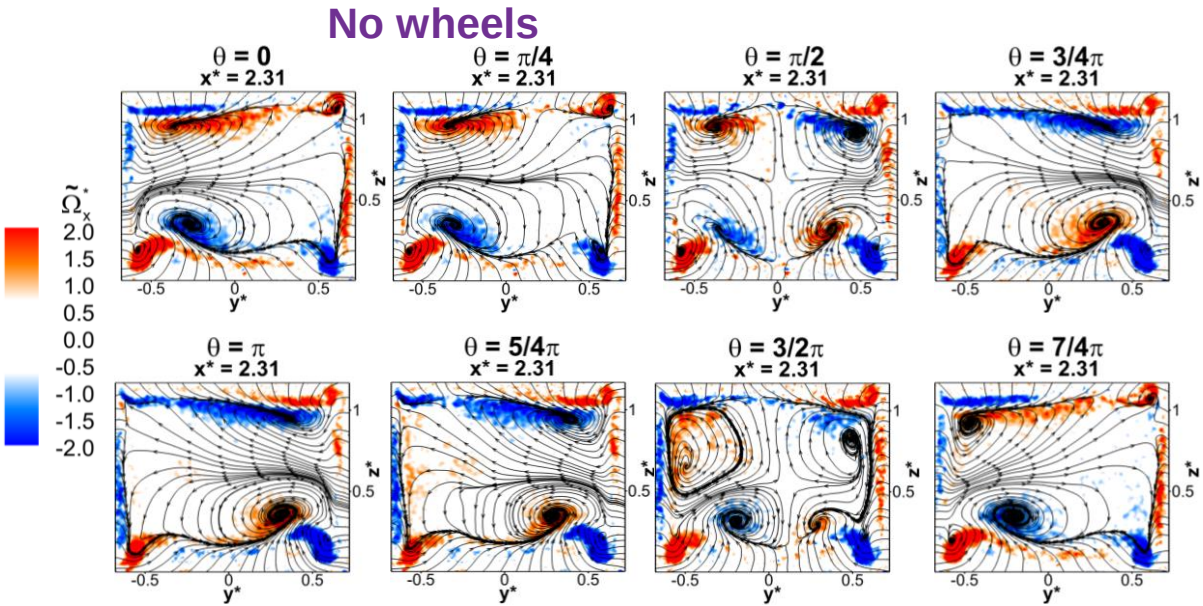
POD Filtered Phase Averaged Velocity Field







In the no-wheel case, the addition of the bottom taper has a limited impact on the bi-stable mode.

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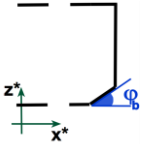
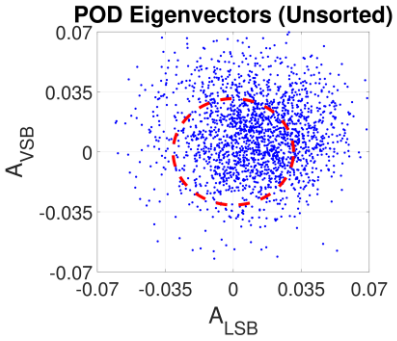
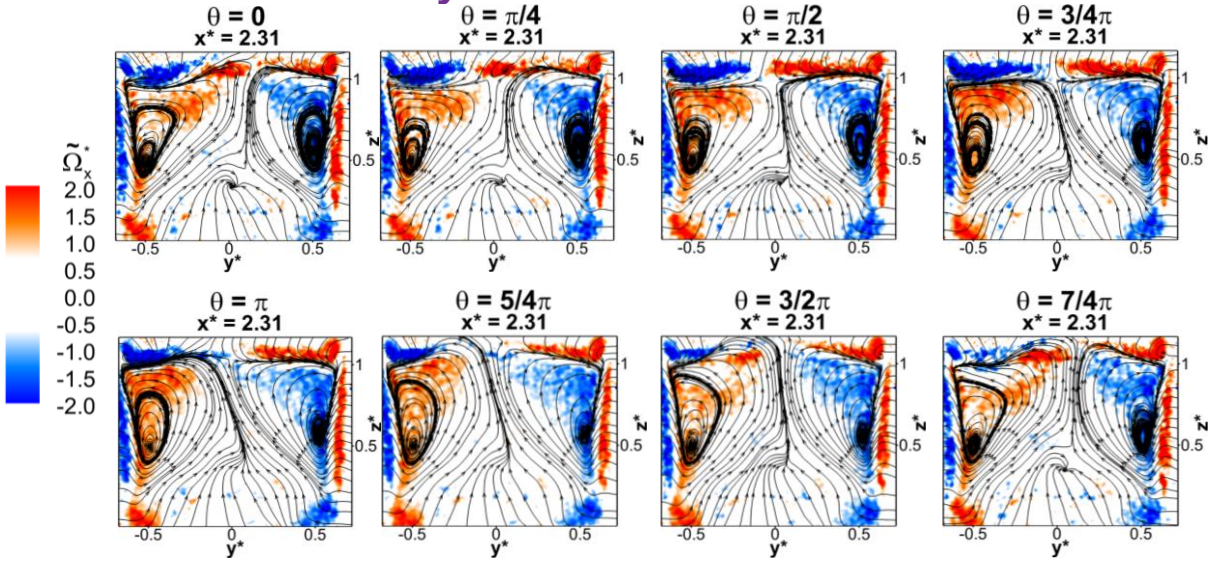
POD Filtered Phase Averaged Velocity Field





Stationary wheels



When the action of the taper is combined with that of the wheels, the wake locks in an upwash dominated state.

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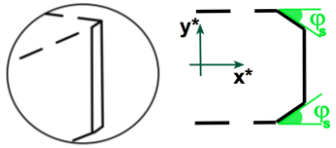
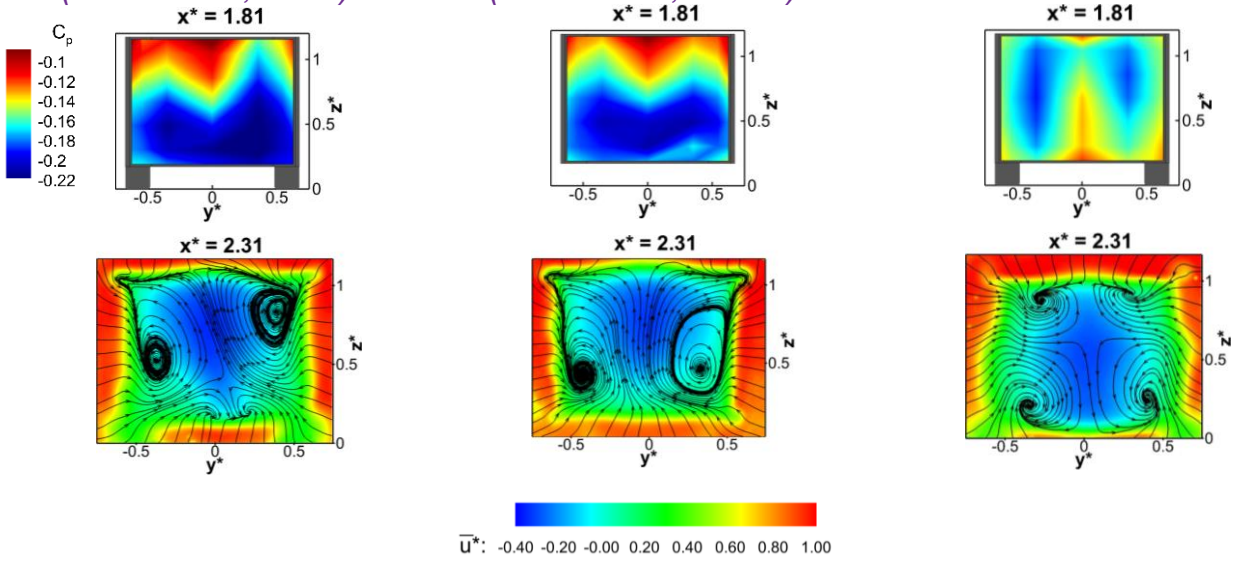
Time averaged results



$\phi_s = 12°, \Theta = 0.0°, SW$ *(Pavia et al., 2017)*

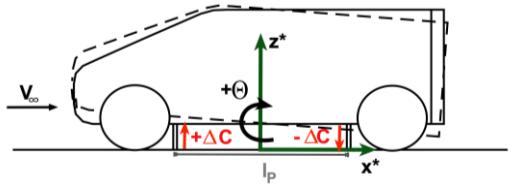
$\phi_s = 12°, \Theta = -2.0°, NW$ *(Pavia et al., 2018b)*

$\phi_s = 12°, \Theta = +2.0°, SW$



The symmetry in the vertical direction can be restored by pitching the model 'nose up'.

For $\Theta = +2.0°$, a 6.6% reduction in base drag over the same configuration tested at $\Theta = 0.0°$ is observed.



Strong similarities are seen in this case between the configuration with wheels, tested at 0° pitch, and the same model without wheels, tested a -2° pitch.

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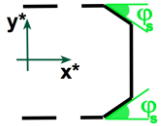
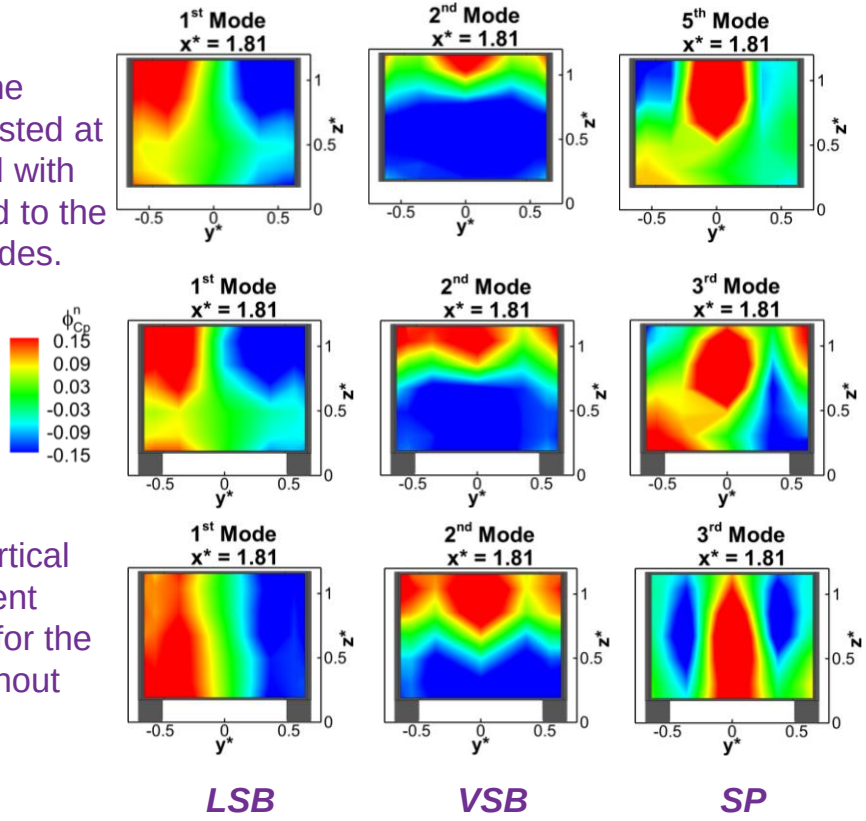
POD Modes



The similarities between the configuration without wheels, tested at -2° pitch, and the same model with wheels, tested a 0° pitch, extend to the shape of the POD spatial modes.



$\phi_s = 12°, \Theta = -2.0°, \mathbf{NW}$
(Pavia et al., 2018b)

$\phi_s = 12°, \Theta = 0.0°, \mathbf{SW}$

When the symmetry in the vertical direction is restored, coherent motions, similar to those seen for the simple square-back case without wheels, are observed.

$\phi_s = 12°, \Theta = +2.0°, \mathbf{SW}$

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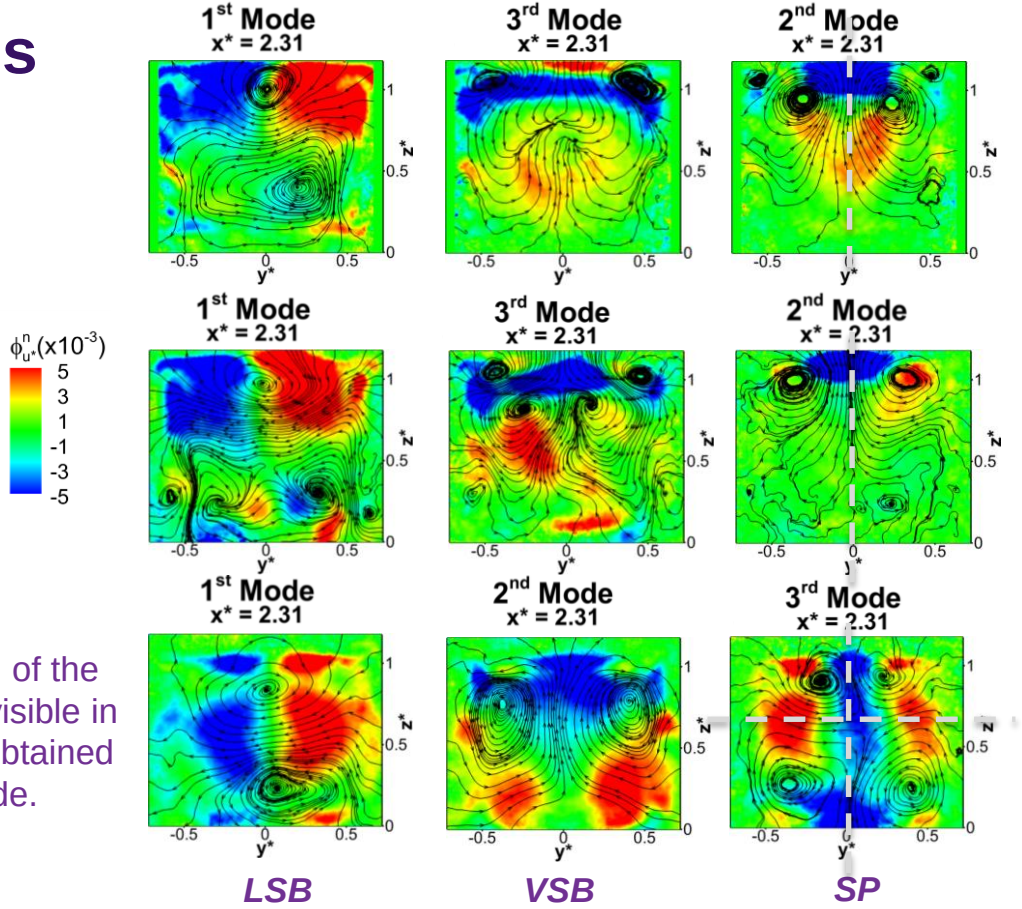
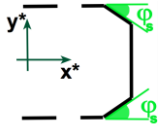
POD Modes





$\phi_s = 12°, \Theta = -2.0°, \mathrm{NW}$
(Pavia et al., 2018b)

$\phi_s = 12°, \Theta = 0.0°, \mathrm{SW}$

$\phi_s = 12°, \Theta = +2.0°, \mathrm{SW}$

The flapping motion of the wheels is no longer visible in the spatial function obtained for the LSB mode.

3. 12° side trailing edge tapers

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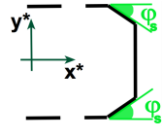
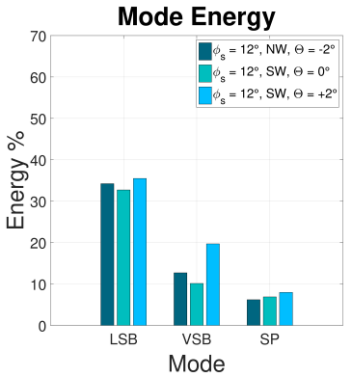
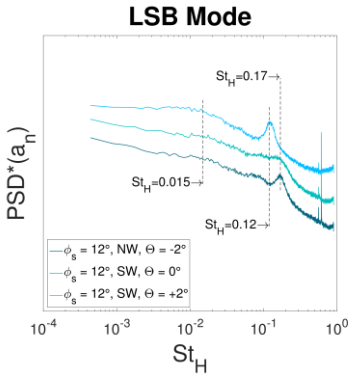
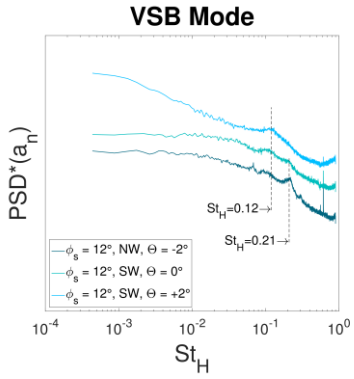
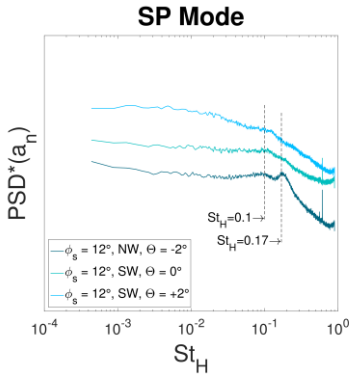
POD Modes (pressure data)

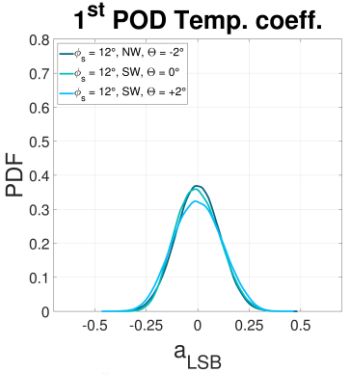


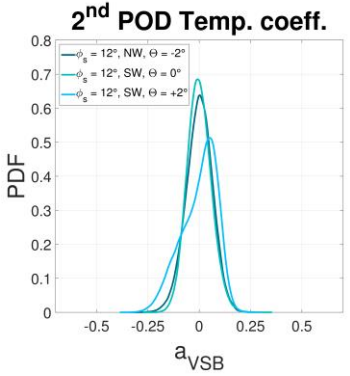












The restoration of the symmetry in the vertical direction is accompanied with an increase in the energy content of the vertical symmetry breaking mode.

A flapping motion with $St_H = 0.12$ is observed in these conditions in both vertical and horizontal directions.

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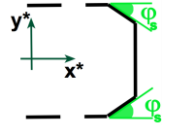
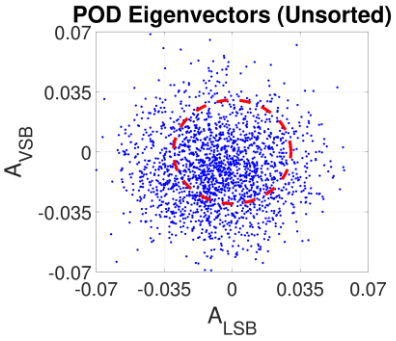
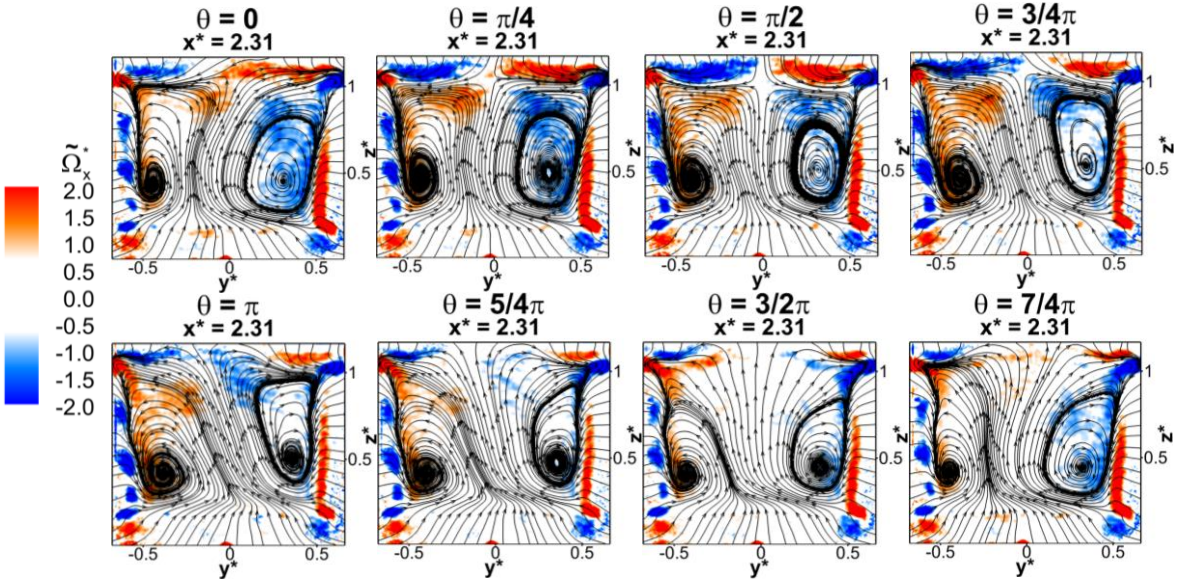
POD Filtered Phase Averaged Velocity Field



$\phi_s = 12°, \Theta = -2.0°, \mathrm{NW}$ *(Pavia et al., 2018b)*





The wake is locked in an upwash dominated state.

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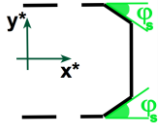
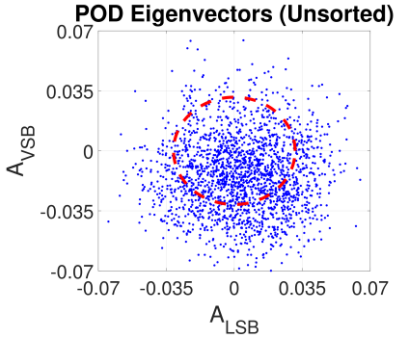
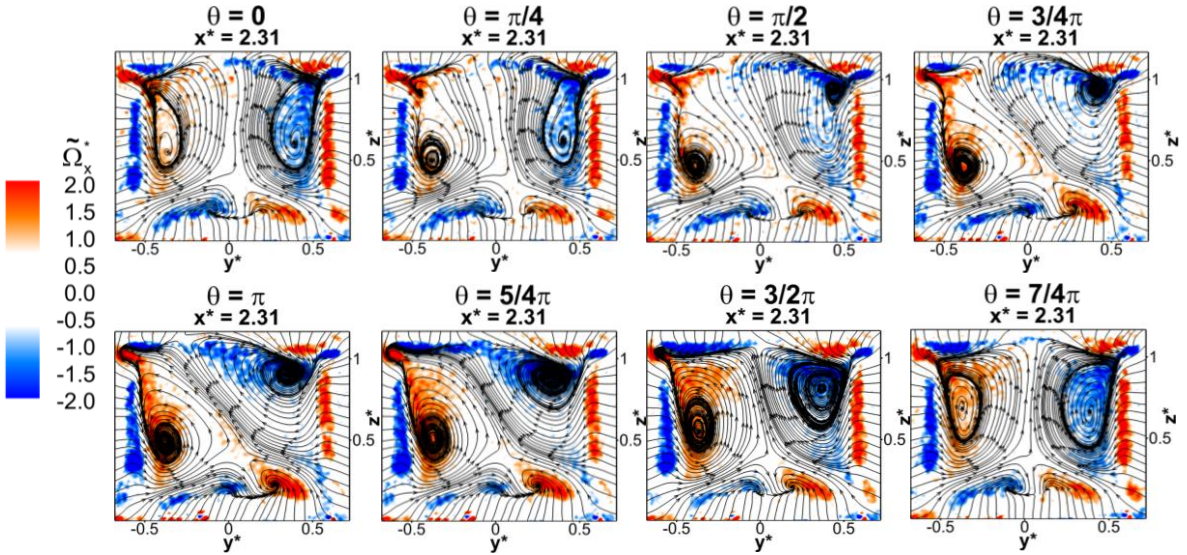
POD Filtered Phase Averaged Velocity Field



$\phi_s = 12°, \Theta = 0.0°, SW$





Similarly to that seen for the square-back case with wheels,
only a swinging motion of the flow reversal is observed in these conditions.

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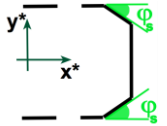
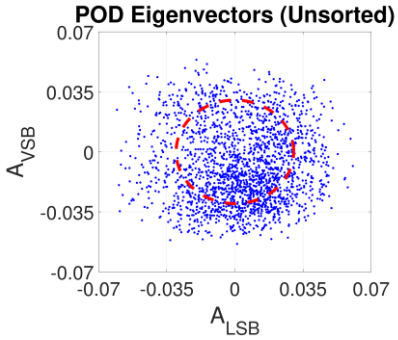
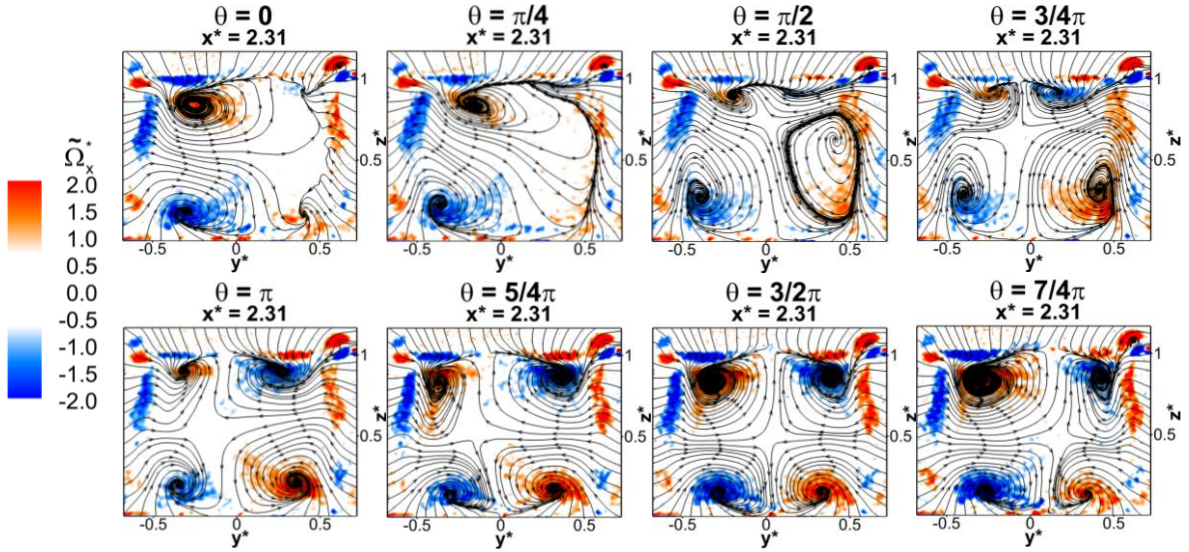
POD Filtered Phase Averaged Velocity Field



$\phi_s = 12°, \Theta = +2.0°, SW$





The wake is seen to switch between two lateral symmetry breaking states, a downwash dominated state and a symmetry preserving state.

Conclusions

The effects produced by the addition of (stationary) wheels on the unsteady wake developing downstream of a simplified square-back geometry have been investigated by means of pressure tappings and PIV acquisitions:

- The addition of the wheels is shown to affect the wake dynamics both locally, with the appearance of a flapping motion just behind the rear wheels, and on a more global scale.

- For the simple square-back case, the long-time lateral symmetry breaking mode is replaced by a low frequency lateral motion with $St_H \approx 0.02$. A vertical flapping motion, with $St_H = 0.10$, becomes also visible.

- The frequency of the lateral motion is seen to increase up to $St_H \approx 0.035$ when a short taper is added to the bottom trailing edge. In the same conditions, the vertical flapping motion observed in the no-wheel case is no longer visible.

- When tapers are applied to the side trailing edges and the model pitch angle is increased up to $\Theta = +2°$, the recovery of the symmetry in the vertical direction has been reported to yield a $\approx 6.6\%$ base drag reduction over the same configuration tested at $\Theta = 0°$. This, however, has not be found to be linked with the stabilisation of the wake.

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Thank you!

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