Analysis and control of the wake past the square-back Ahmed geometry

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Motivations

• Drag repartition over a vehicle:

  - Friction effects 10%
  - Side mirrors and others… 5%
  - Fore-body 5%
  - Air cooling 10%
  - After-body 30%
  - Wheels 15%
  - Under-body 25%

⇒ Study of the square-back model of Ahmed et al. (1984)

• Geometry massively used in the framework of flow control for drag reduction
Experimental set-up

- Eiffel wind tunnel
- Square-back Ahmed model
- \( \text{Re} = U_0H/\nu = 10^5 \)

Quantities normalized by \( H \) and \( U_0 \)

- 2D strain gauge balance: drag and lift
- Velocimetry: PIV and hot-wire measurements
- Pressure taps on the geometry
Mean flow: fluctuations of velocity

- Mean flow with a massive separation on the base

- Boundary layer detachments on the fore-body, reattachment on the sides around \( x = -3 \)

- Low base pressure responsible for 70% of the total drag as in Ahmed et al. (1984)

  ➔ Mixing layer activity associated with coherent wake motions
Global modes

- PIV at 3 kHz

- Two modes at $f^- = 35.4$ Hz and $f^+ = 48.4$ Hz:
  \[
  \text{St}_H = 0.13 \quad \text{i.e.} \quad \text{St}_W = 0.17 \\
  \text{St}_H = 0.17
  \]

⇒ Wake oscillations in the $y$ and $z$ directions
**Bi-stability: introduction**

- Low frequency evolutions in the velocity signal at $B$

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**Wake position in the $y$ direction?**

[Diagram showing velocity signals at $A$ and $B$ with frequency spectra]
**Bi-stability: evidence**

- Instantaneous velocity fields at 10 Hz ➔ Wake position in the y and z directions

Barycentrum of velocity loss:

\[ y_W = 0.043 \]
\[ z_W = 0.575 \]

- Two preferred wake positions

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Bi-stability: asymmetric flow

- Symmetric mean flow with two saddle points
- Superposition of two asymmetric flows with only one saddle point
Pressure signature of the bi-stability

- Base pressure distribution as an indicator of topology
- Asymmetry limited to the after-body
Experiments in laminar regime

1 cm/s < \( U_0 \) < 4 cm/s

200 < Re < 800

Study of the stable states depending on the Reynolds number
Stable laminar wakes

Steady Symmetric (SS)  
Re = 310

Steady Asymmetric (SA)  
Re = 360

Unsteady Asymmetric (UA)  
Re = 420

Reminiscent in turbulent regimes

Grandemange et al. (2012)
Conclusion on the natural flow

- **Oscillations** of the wake in the cross-flow directions:
  - Low energy in the structures around the separatrix
  - Limited effect on drag

- **Bi-stability** of the flow:
  - Off-centered wake position
  - Statistically symmetric flow
  - Lateral force \(\rightarrow\) Responsible for part of the drag

\(\rightarrow\) Wake control using local disturbances ?
Flow control using local disturbances

- Efficient to control the vortex shedding past cylinders
- High sensitivity in the mixing layers

Dalton et al. (2001)
Local disturbances in 3D wakes

- Global modes present in 3D wakes
- Sensitive to local disturbance

Axisymmetric geometries

Sensitivity of the stationary mode

Sensitivity of the oscillating mode

Theoretical study: Meliga et al. (2009)
Control using a vertical control cylinder

- Cylinder moved in the wake
- Construction of sensitivity maps
Vertical control cylinder: effects on the wake

- One asymmetric state selected by the disturbance

⇒ High sensitivity to residual asymmetries
Vertical disturbance: Sensitivity maps

- Selected asymmetric state dependent on $x_C$ and $y_C$
- Bi-stability reduced in the middle of the recirculation bubble
- Stable centered wake $\Leftrightarrow$ Increase in $C_{pb}$
Control using an horizontal control cylinder

- Displacement in the wake

\[ d = 0.05H \]

- 5% drag reduction
- 9% increase in the recirculation length

Natural flow

Optimal disturbed flow

\[ x_C = 0.45 - z_C = 0.24 \]
**Optimal horizontal control cylinder position**

**Natural flow**

**Optimal disturbed flow**

\[ x_C = 0.45 - z_C = 0.24 \]

- Bi-stability suppressed
- Reduction of the wake width
- Slight reduction of the fluctuating velocities

**Bi-stability sensitive to the top-bottom balance of the mixing layers**

- **Introduction**
- **Natural flow**
- **Disturbed flow**
  - Context
    - Vertical cylinder
  - Horizontal cylinder
- **Conclusion**
Conclusions & perspectives

- **Two global modes** associated with oscillations in the cross-flow directions  
  Kiya & Abe (1999): wake of rectangular and elliptic normal plates  
  ➔ Not responsible for large part of the drag

- **Bi-stability** of the natural flow:  
  - Two asymmetric states ➔ statistical symmetric mean flow  
  - Linked to a bifurcation in the laminar wake  
  - High sensitivity to the symmetry of the set-up  

- **Additional induced drag** associated with the forces in the cross-flow directions:  
  ➔ ≈ 5% of the total drag

Thanks to ESPCI for lending the low Reynolds water tunnel
Thank you for your attention

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