FLOW CONTROL STRATEGIES FOR DRAG REDUCTION OF A MID-SCALE TRAILER MODEL

Patricia Sujar-Garrido; Marc Michard and Thomas Castelain
Laboratoire de mécanique des fluides et d’acoustique, Lyon
CONTROL STRATEGY ON A SIMPLIFIED TRAILER

CONTENTS

Heavy truck’s model

- Introduction:
  - Wake topologies related to the underbody momentum
  - Choice of one class for control

- Medium/high frequency forcing ($St_{act} = 5-15$)
  - Effects on mean field, deflection angle, pressure field
  - Changes within the turbulence

- Forcing strategy (Local forcing)
  - Influence on pressure recovery and drag reduction
  - How to improve the control efficiency?

- Conclusions & perspectives
Wake topologies

- **G* = cte then driving parameter → ratio \( \lambda = \frac{U_b}{U_\infty} \)**

- **four wake topologies**

Parameters for the topology classification into classes:

- Momentum flux, \( C_p \), gradients of pressure ...

![Diagram of wake topologies](image)

**Evolution of ratio \( \lambda = \frac{U_b}{U_\infty} \) with the porosity (%)**

- \( \lambda = \frac{U_b}{U_\infty} \)
- **Porosity [%]**
- Castelain et al. JWEIA 2018
Wake topologies: selection of one case of study

- One specific wake topologies
- **Present case** (Re_H 4.10^5):
  - class 3 with \( \lambda \sim 0.4 \)
  - \( \lambda \) representative of real truck cases
  - unfavourable base pressure and drag

**Control investigations**

- **Previous at LMFA**
  - (PhD work of Chaligné and Szmigiel)
    - control of flows: class 1 and 2

- Flow modifications in present case:
  - open-loop global forcing
  - forcing parameters:
    
    \[
    P_{rel} = 1.9 \text{ bar} \quad \Rightarrow \quad C_\mu = DC N \left( \frac{sj}{S} \right) \left( \frac{V_{jmax}}{U_\infty} \right)^2 = 3.10^{-2} \\
    DC = 50 \% \\
    f_{act} = 350 \text{ Hz} \quad \Rightarrow \quad St_{act} = \frac{f_H}{U_\infty} = 5
    \]
  - 30\% of pressure recovery
  - 10\% of drag reduction

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**Spatially-averaged mean base pressure**
Medium and high frequency forcing: mean velocity

**General features of** class 3 flows without control:
- mean curved jet separated from the ground:
  - fluid caught up near the base
  - secondary vortex
- back-flow due to underbody flow:
  - flux convected towards the upper shear layer
  - impinge and limit the growth of SL

**With control**
- mean deflection of the potential flow on three sides of SL
- higher intensity on left and right side SL
- no significant effect of actuation in the curved jet

**First conclusions**
- No flow class changes under actuation
- Vertical assymmetry is only slightly modified (re-inforced)
- Similar conclusions for a higher frequency forcing ($f_{act} = 1050$ Hz, $St_{act} = 15$)
- Deflection of the potential flow is the main effect of actuation?
**Medium and high frequency forcing: deflection of the potential flow**

**with control**

- deflection at \( x^* \sim 0 \): \( \alpha_{\text{horizontal}} \geq \alpha_{\text{vertical}} \)
- global deflection of the wake
- analysis of streamlines (\( x^* = 0 \) and 0.08):
  - high flow deviation around flap location
  - max. deflection angle \( \sim \) flap angle
- similar results for \( St_{act} = 15 \)

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Mean pressure 2D field

- 2D-2C PIV measurements
- 2D N-S averaged equations (incompressible)
- stochastic integration scheme

*Oxlade JFM 2015*

- reference pressure: Bernoulli equation along a streamline within the potential flow without control:
  - agreement with mean base pressure measurements
  - base pressure vertically stratified
  - large area with negative pressure trapped by the curved jet

*Mean pressure map in the vertical mid-plane & in the base*
without control:
- base pressure vertically stratified
- large area with negative pressure

with control:
- global pressure recovery in the near wake linked with the global shift of wall pressure
- local large negative pressure peak over the base edge and the flap
- faster pressure recovery of the potential flow in $x$ direction

To be highlighted from this pressure analysis:
- good agreement with pressure measurements
- large pressure peak due to combination of passive and active actuation
- important base pressure recovery ($\gamma_p \sim 30\%$)
Medium and high frequency forcing: effects on the curved jet

**without control**
- mass flux convected from the underbody flow towards the upper part of the base

**with control**
- increase of control intensity ($P_{rel} \rightarrow C_{\mu}$):
  - impingement of the curved jet moves upstream from upper shear layer towards flap
  - negative vertical velocity above the flap

*Vertical mean velocity within the back-flow*

- Side shear layers are free from disturbances.
- Upper shear layer is linked to the curve jet
- Interaction curved jet/upper shear layer play a role in the development of turbulence?
Medium and high frequency forcing: turbulence in the shear layer

**without control**

- turbulent stresses higher in the upper SL
- low turbulent activity curved jet ($|U| \sim 0.3 U_{\text{inf}}$)

**with control**

- upper SL: turbulence level fewly increased
- side SL: reduction of turbulent stresses ($x^* \sim 0.1$)

Similar conclusions for higher frequency actuation

### Summary

- turbulent activity remains low
- Triggering instabilities by the impinging jet?
- Effect of forcing on turbulence level related with pressure recovery?

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Vukasinovic et al. JFM 2010

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Global efficiency

- Ratio between power recovery by drag reduction and power consumption for air compression
  - Acoustic feature (Michard et al. GDR 2017 Orléans)
  - Mass flow nearly proportional to:
    - $P_{rel}$ (valve inlet pressure at a fixed frequency)
    - DC (duty cycle)
    - $N$ (number of actuators)
- Present investigation focuses on reducing number of actuators with fixed values of $f_{act}$ and DC
- Local forcing? → limited number of actuator rows

$\gamma_p \sim 30\%$

Forcing strategy: energetic considerations

- Top + Left + Right
- Top
- Bottom
Forcing strategy: energetic considerations

Evolution of pressure recovery and drag reduction for different control strategies (& increase control intensity)

\[ \gamma_P = \frac{C_{Pb}}{C_{Pb0}} \]

\[ \gamma_D = \frac{C_x}{C_{x0}} \]

Results matching with previous analysis of the forcing effect on the individual shear layers

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Analysis of class III wake topology → Importance of the curved jet
Global forcing flow results:
• Wake dimensions reduction
• No vertical symmetrisation (natural asymmetric flow) since injection momentum is not modifying the underbody flux
• Angle deflection more important in the side shear layers
• Low level of turbulence compared with a class IV case
• Low effect of actuation on the turbulence level

Control strategy:
• TLR more performant for base pressure recovery and drag reduction
• Similar results for class IV case but caused by similar mechanism?

Perspectives
Better understanding of:
• unsteadiness
• relation between control parameters and pressure distribution around the flap (and deflection angle of the flow near the flap)
• performance of the control strategies for other classes (e.g. topology in class I)
THANKS

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