Drag reduction of a Ahmed body using pulsed jets

*International Forum of Flow Control (IFFC – 2)*

**P. JOSEPH**  
*Institut AéroTechnique (IAT)*  
CNAM, France  
pierric.joseph@cnam.fr

**X. AMANDOLESE**  
*Aerodynamics Department*  
CNAM, France  
xavier.amandolese@cnam.fr

**J-L. AIDER**  
*PMMH Laboratory*  
UMR 7636 CNRS  
ESPCI ParisTech, France  
aider@pmmh.espci.fr

**Acknowledgements:**

This work was carried out in the framework of a ANR research programme (CARAVAJE) supported by ADEME.
Introduction

• CARAVAJE Project:
  – « Control of the external aerodynamics of automotive vehicles by pulsed jets »
  – Partnership between seven industrials and laboratories
  – Thematic ANR project financed by ADEME
Summary

• Experimental setup

• Experimental measurements

• Reference results

• Pulsed jets actuation

• Control results

• Conclusion
Experimental setup

- Reference Ahmed body model

- Standard dimensions with 25° slant angle.
Experimental setup

- S4 wind tunnel facility, at Institut AéroTechnique

5m x 3m cross section (turbulence ≈ 1% ; wind - speed up to 40 m/s).

Raised floor with airfoil shaped leading edge.

Drag reduction of a Ahmed body using pulsed jets - IFFC-2 - Pierrick JOSEPH
Experimental measurements

• Drag measurements

- 6 components unsteady aerodynamic balance.
- Precision < 0,5 %.
Experimental measurements

• Wall measurements:

– 127 pressures taps.
– Surface oil flow visualisation.
Experimental measurements

- Wake measurements:
  - 2.5D exploration device.
  - Various probes (hot wire, Kiel, 7 holes...).
Reference results

• Boundary layers measurements – incoming flow

![Graph showing boundary layer measurements](image)

- Boundary layer - 0.7 m after leading edge - 20 m/s

- \( y = 0.7 \text{ m}; U_e = 20 \text{ m/s} \)

- \( 1/8 \text{ th Power law} \)

- \( \delta = 25 \text{ mm} \)

- \( H = 1.25 \)

*Drag reduction of a Ahmed body using pulsed jets - IFFC-2 - Pierric JOSEPH*
Reference results

• Boundary layers measurements – incoming flow

Boundary layer - 0,1 m before slant edge - 20 m/s

\[ \delta = 24 \text{ mm} \]
\[ H = 1,21 \]

Drag reduction of a Ahmed body using pulsed jets - IFFC-2 - Pierric JOSEPH
Reference results

• Drag results

- Significant Reynolds effect.
- Consistent with reference results ([Ahmed 1984]: $C_x = 0.285$ for $Re \approx 4.2 \times 10^6$).
Reference results

- Wall pressure and visualisations measurements

  - Reynolds effect on the recirculation bubble and surface pressure distribution.

Drag reduction of a Ahmed body using pulsed jets - IFFC-2 - Pierric JOSEPH
Reference results

• Wake measurements

\[ \text{Re} = 1.4 \times 10^6 \]

144 mm behind model

Position of the measurements plan

- Kiel probe measurements.
- Flow structure consistent with classical Ahmed topology [Ahmed 1984].

\[ C_{\text{Pi}} = \frac{P_{\text{TA}} - P_{\text{TM}}}{\frac{1}{2} \rho V^2} \]

With \( P_{\text{TA}} \) the undisturbed flow total pressure and \( P_{\text{TM}} \) the wake total pressure.
Reference results

- Unsteady measurements in wake (Kiel and hot wire)

<table>
<thead>
<tr>
<th>Location</th>
<th>Frequency (Hz) – 20 m/s</th>
<th>Strouhal (Slant height based) – 20 m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>32 Hz</td>
<td>0,15</td>
</tr>
<tr>
<td></td>
<td>32 Hz</td>
<td>0,15</td>
</tr>
<tr>
<td></td>
<td>32 Hz</td>
<td>0,15</td>
</tr>
<tr>
<td></td>
<td>140 Hz</td>
<td>0,66</td>
</tr>
</tbody>
</table>
Reference results

- Unsteady measurements in wake (Kiel probe)
Reference results

- Unsteady measurements in wake (Kiel probe)
Pulsed jets actuation

• Control system description

– Open loop system with solenoid valve:
  • Frequency from 5 Hz to 300 Hz.
  • Speed up to 80 m/s – 90 m/s (depends on exhaust geometry).
Pulsed jets actuation

• Control system description

Component implantation inside Ahmed model.

Solenoid Valves
(Matrix Ltd document).

Jets exhaust (near slant edge).
Pulsed jets actuation

• Control system location

– 2 blowing locations: « roof end » and « slant top edge »
– 3 exhaust geometries.

Drag reduction of a Ahmed body using pulsed jets - IFFC-2 - Pierric JOSEPH
Control results

- Influence of the forcing parameters on drag

---

Drag reduction of a Ahmed body using pulsed jets - IFFC-2 - Pierrick JOSEPH
Control results

• Influence on the local pressure – slant surface

Drag results:
- Broken line – roof end
- Winglets – roof end
- Continuous line – slant top edge
- Broken line – slant top edge

Upper slant surface pressure:
- Broken line – roof end
- Winglets – roof end

Drag reduction of a Ahmed body using pulsed jets - IFFC-2 - Pierric JOSEPH
Control results

- Influence on the local pressure – vertical surface

Drag

Vertical surface pressure

Drag reduction of a Ahmed body using pulsed jets - IFFC-2 - Pierric JOSEPH
Conclusion

• Effective experimental setup.
• Significants drag reduction.

<table>
<thead>
<tr>
<th>Setup</th>
<th>Drag reduction (%)</th>
<th>Frequency (Hz)</th>
<th>St. (slant height based)</th>
<th>Jet Speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broken line – roof</td>
<td>7,8</td>
<td>140</td>
<td>0,66</td>
<td>77</td>
</tr>
<tr>
<td>Continious line – slant edge</td>
<td>7,5</td>
<td>75</td>
<td>0,35</td>
<td>22</td>
</tr>
<tr>
<td>Broken line – slant edge</td>
<td>6,3</td>
<td>260</td>
<td>1,22</td>
<td>41</td>
</tr>
<tr>
<td>Winglets – roof</td>
<td>6,9</td>
<td>240</td>
<td>1,13</td>
<td>75</td>
</tr>
</tbody>
</table>

• Begining of comprehension of Cx reduction mechanisms.
Perspectives

• Extensive parametric study: position, exhaust geometry, forcing parameters

• Highlight the fluid - mechanisms involved by unsteady pression and flow analysis

• Tests of MEMS actuators for better performance and efficiency.