
Chalmers, Gothenburg, 13-14 Sept 2009
ALES for Drag Reduction of Truck-Trailers

Mohammad El-Alti, Per Kjellgren and Lars Davidson
mohammad.el-alti@chalmers.se

ALES 2009, Göteborg, Sweden
Acknowledgments

Ph.D. Student  Mohammad El-Alti
Supervisor:    Lars Davidson
Co-supervisor: Per Kjellgren
VOLVO 3P:     Linus Hjelm
SKAB:         Bengt Karlsson
Aerodynamic drag > Rolling resistance
Introduction

Aerodynamic drag = Pressure + Skin friction

\[ F_D = \frac{1}{2} \rho A U^2 C_D \]

Streamlined body:

- Stagnation point
- Narrow wake

\[ F_{sf} \gg F_{\text{pressure}} \]

Bluff body:

- Large wake

\[ F_{\text{pressure}} \gg F_{sf} \]
**Idea: Passive Flow Control**

**Step 1:**
- Small angle
- $\Delta C_D \approx 5\%$

**Step 2:**
- Large angle
- $\Delta C_D < 0$

Rear end of a Bluff body
Idea: Passive + Active Flow Control

Step 3: Large angle

\[ \Delta C_D \approx 25-30\% \]

Add energy

\[ \Delta C_D \approx 25-30\% \leftarrow 15\% \text{ Fuel save} \]

Actuator

\[ u(t) = A \sin(2\pi F t) \]
Background

How much can we save in Sweden?

Average Heavy truck

<table>
<thead>
<tr>
<th># heavy trucks</th>
<th>80 000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel consumption :</td>
<td>28 liters /100 km</td>
</tr>
<tr>
<td>Annual driving distance:</td>
<td>50 000 km</td>
</tr>
</tbody>
</table>

Fuel save

1% → 12 million €
15% → 180 million €

Source: SCB
First step: Truck-trailer model

Vertical spanwise slice, \( dz = 0.2, 0.4, 0.8 \) and \( 1.0 \) m
Numerical method (1/5)

- Parameters to investigate/optimize
  - Flap length, FL
  - Flap angle, FA
  - Slot location / width
  - Slot angle, SA
  - Slot strength, $C_\mu$
  - Slot frequency, $F^+$

- Two codes investigated for LES
  - STAR-CD v4
    - 1 sim. sec ~ 1 week
  - FlowPhys v2
    - 1 sim. sec ~ 1 day
  - Re = 200 000, modified viscosity.

Our choice
Numerical method (2/5)

- Actuation modeling
  - Transient velocity-inlet
  - Constant spatial profile

\[
J_{rms} = \int \rho u_{rms}^2 \, dh = \rho u_{rms}^2 \Delta h
\]

\[
C_{\mu \, rms} = \frac{u_{rms}^2 \Delta h}{\text{chord} \frac{1}{2} u_\infty^2}
\]

\[
F^+ = \frac{F \cdot X_{TE}}{U_\infty}
\]

\[
u(t) = \sqrt{2}u_{rms} \sin(2\pi Ft)
\]
Numerical method (3/5)

**AFC Parameter** | **Value**
---|---
$FL$ | $0.75 \text{ m}$
$FA$ | $30 \text{ deg}$
$SA$ | $15 \text{ deg}$
$C_{\mu}$ | $1.0\%$
$F^+$ | $0.3$
Numerical method (4/5)

#cells: 1.5-3.3 million
Numerical method (5/5)

Wake region

Flap region

<table>
<thead>
<tr>
<th></th>
<th>$y^+$</th>
<th>$\Delta x^+$</th>
<th>$\Delta z^+$ LR</th>
<th>$\Delta z^+$ HR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max</td>
<td>2</td>
<td>30</td>
<td>150</td>
<td>75</td>
</tr>
<tr>
<td>Mean</td>
<td>1</td>
<td>20</td>
<td>100</td>
<td>50</td>
</tr>
</tbody>
</table>
Results

Drag history and frequency spectra

\[ C_D = 0.76 \quad C_D = 0.57 \quad \Delta C_D = 25\% \]

Mohammad El-Alti 8 June 2009
Results

Drag history of different spanwise domain sizes

$dz=0.8\, m, \quad \Delta C_D=30\%$

$dz=1.0\, m, \quad \Delta C_D=25\%$
Results

Instantaneous pressure

AFC OFF

AFC ON

Low pressure
Results

Instantaneous pressure, zoom around wake region

AFC OFF

Low pressure

AFC ON

Mohammad El-Alti 8 june 2009
Results

Instantaneous u-velocity, zoom around wake region

Attached flow

AFC OFF

Separation

AFC ON
Results

Instantaneous streamlines, zoom around wake region

Attached flow

AFC OFF

Separation

Forced vortices

AFC ON
Results

Instantaneous streamlines, zoom around flap region

AFC OFF  Separation  Forced vortices  AFC ON
Results

Movie: u-velocity, zoom around wake region

AFC OFF

AFC ON
Results

Movie: pressure, zoom around wake region

AFC OFF

AFC ON
Results

Time-averaged pressure, zoom around wake region
Results

Time-averaged pressure, zoom around wake region

AFC OFF

Low pressure

AFC ON

High pressure
Results

Time-averaged u-velocity, zoom around wake region

Attached flow

AFC OFF

Separation

AFC ON
Results

Time-averaged streamlines, zoom around wake region

- Large wake
- Attached flow
- Separation
- Narrow wake

AFC OFF
AFC ON

Mohammad El-Alti
8 June 2009
Results

Time-averaged streamlines, zoom around flap region

AFC OFF

AFC ON
Results

Time-averaged vorticity, zoom around flap region

AFC OFF

AFC ON

Mohammad El-Alti 8 june 2009
Results

RMS of pressure, zoom around wake region

AFC OFF

AFC ON
Results

Surface pressure distribution

Mohammad El-Alti 8 june 2009
Second step: Built and test of actuator

Simple synthetic-jet actuator

Max velocity – max $C_\mu$?
Slotwidth, speaker, cavity volume?
Third step: Build the prototype model

Simple synthetic-jet actuator
Forth step: Full scale test of the prototype model

Hällered proving ground

November 2009
Conclusions

• Drag reduction of 25-30%
  • Flow reattachment
  • Narrower wake size
  • Less intensive wake
  • Increased base pressure
• AFC works well for bluff bodies
Future work

• Optimization using RSM
• Parallellizing FlowPhys and/or using DES with STAR-CD
  • Fully 3D bluff body with AFC
  • Fully detailed truck-trailer with AFC
• More analysis on the drag reduction mechanism
• Study more applications of AFC
Thank you!

Questions