Fuel economy testing with aerodynamic add-ons for trailers

Working Group on Motor Vehicles
Brussels, 1st February 2012

ir. Gandert Van Raemdonck
Platform for Aerodynamic Road Transport
Rising energy prices
30% of operational cost is fuel cost

Source: ACEA
Improve delivered power
better engines and alternative energy sources
Improve required power
more efficient vehicle
Fuel consumption of trucks

Large aerodynamic improvement via roof deflector

Source: Presentation by Daimler
Defining problem areas
numerical simulations of a tractor semi-trailer
Circuit and operational tests

Underside: Ephicas SideWing
Research underside trailer
Numerical analysis & wind tunnel experiments

Wind tunnel experiments:
$\Delta C_\alpha = -14\% \text{ to } -17\%$
Applied Test protocol
Circuit testing

• Based on SAE Type II test protocol
• RDW Test facility in Lelystad, The Netherlands
• Two identical vehicle combinations
• Constant vehicle velocity (highway speed)
• Fuel savings measured through CANbus
Overview circuit tests SideWing

<table>
<thead>
<tr>
<th>configuration</th>
<th>testing method</th>
<th>abs. savings [l/100km]</th>
<th>CO2 reduction* [kg/100km]</th>
<th>Difference* [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SideWing</td>
<td>operational circuit</td>
<td>1.5</td>
<td>3.9</td>
<td>5.0</td>
</tr>
</tbody>
</table>

* tests executed during several test days in March 2010 and May 2010
Independent test
MIRA/STAS (Published in commercial Motor (UK) – 2010
TNO – Truck van de Toekomst (to be published in 2012)

<table>
<thead>
<tr>
<th>vehicle speed [km/h]</th>
<th>Streamline Trailer [l/100km]</th>
<th>Standard Trailer [l/100km]</th>
<th>abs. savings [l/100km]</th>
<th>pct. savings [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>64 km/h</td>
<td>25.56</td>
<td>27.11</td>
<td>0.56</td>
<td>2.05%</td>
</tr>
<tr>
<td>80 km/h</td>
<td>30.11</td>
<td>31.78</td>
<td>1.67</td>
<td>5.24%</td>
</tr>
<tr>
<td>89 km/h</td>
<td>32.00</td>
<td>34.67</td>
<td>2.67</td>
<td>7.69%</td>
</tr>
<tr>
<td>overall</td>
<td>29.56</td>
<td>31.19</td>
<td>1.63</td>
<td>5.23%</td>
</tr>
</tbody>
</table>
Double steering axles
‘Loss’ of savings

Wheel openings for double steering axles cost fuel
→ covering the wheels results in a fuel saving of 0.32 l/100km
→ extra width of 5 cm at both sides for aerodynamic wheel covering

<table>
<thead>
<tr>
<th>test</th>
<th>consumption [l/100km]</th>
<th>abs. ‘savings’ [l/100km]</th>
<th>pct. ‘savings’ [%]</th>
<th>wind velocity [m/s]</th>
<th>wind direction [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 Uncovered wheels</td>
<td>24.47</td>
<td>-0.32</td>
<td>-1.32%</td>
<td>3 – 4</td>
<td>SSW / WSW</td>
</tr>
</tbody>
</table>
Comparison with standard skirts

Standard trailer

Standard skirt: 0,5l/100km

SideWing: 1,5l/100km
Circuit and operational tests with drag reduction technologies for trailers

Rear-end: Guiding vanes, SDR, Active Flow Control
Guiding vanes
Numerical analysis & wind tunnel experiments

Simplified truck model

Numerical analysis: $\Delta C_D = -21\%$

Wind tunnel experiments:
$\Delta C_D = -20\%$
Circuit test guiding vanes
Height/width: 15–20cm; length: 50cm

Fuel savings of 0.5 litre per 100 km* for top vane only is measured → more research is required

* Results obtained at specific wind conditions on August 19th, 2011
System Drag Reduction

Height: 7cm

wind speed: 1 to 3 m/s
wind direction: South to West/South-West

<table>
<thead>
<tr>
<th>test configuration</th>
<th>fuel rate TV [l/100km]</th>
<th>fuel rate CV [l/100km]</th>
<th>abs. savings* [l/100km]</th>
<th>pct. savings [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>baseline</td>
<td>26.06</td>
<td>26.20</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>SDR</td>
<td>23.58</td>
<td>23.96</td>
<td>0.24</td>
<td>1.00%</td>
</tr>
</tbody>
</table>
Active flow control
Continuous blowing (simplified truck model)

Numerical analysis: $\Delta C_D = -20\%$
Active flow control
Boundary layer suction and pulsed blowing
Length: 15cm

Circuit tests are conducted with a full-scale prototype together with Ephicas, Tel Aviv University, and AFC technologies.

→ Solution was not performing as expected.
→ More research is required, no short-term solution.
Circuit and operational tests with a rigid, a foldable and an inflatable tail

**Rear-end: Boat Tail**
Initial boat tail design
Wind tunnel experiments (simplified truck model)

Wind tunnel experiments complete tail on simplified truck:
\[ \Delta C_D = -40\% \]
Stepped tail design
Wind tunnel experiments (simplified truck model)

Wind tunnel experiments
stepped tail on simplified truck:
$\Delta C_D = -10\%$
Research different boat tail concepts
Numerical analysis & wind tunnel experiments

Numerical analysis: $\Delta C_D = -12\%$

Wind tunnel experiments: $\Delta C_D = -14\%$
Full-scale road test with rigid tail of varying length

full scale test of one year... ... savings up to 2 l/100km

<table>
<thead>
<tr>
<th>tail length</th>
<th>fuel savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 m</td>
<td>0.8 l/100km</td>
</tr>
<tr>
<td>1.5 m</td>
<td>1.7 l/100km</td>
</tr>
<tr>
<td>2.0 m</td>
<td>2.0 l/100km</td>
</tr>
<tr>
<td>2.0 m *</td>
<td>1.5 l/100km</td>
</tr>
</tbody>
</table>

* test results with extra-long bumper
Improved design: foldable tail
No issues with loading/unloading cargo
Circuit test with collapsible tail
Length: 1.3m; no extra width

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<th>fuel rate CV [l/100km]</th>
<th>abs. savings* [l/100km]</th>
<th>pct. savings [%]</th>
<th>wind velocity [m/s]</th>
<th>wind direction [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>baseline</td>
<td>25.72</td>
<td>25.22</td>
<td>–</td>
<td>–</td>
<td>3 – 5</td>
<td>SW / WSW</td>
</tr>
<tr>
<td>open-cavity</td>
<td>25.53</td>
<td>26.15</td>
<td>1.12</td>
<td>4.29%</td>
<td>5 – 6</td>
<td>WSW / W</td>
</tr>
</tbody>
</table>

* measured at specific weather conditions of test days, March 11th and 12th, 2011
Exemption granted to Ephicas for test on public roads in Netherlands

Safety test* road users... resulted in test on public roads

Temporary exception is granted by RDW after safety test.

Average savings of 1.65 l/100k m at constant speed of 85 km/h on public road

* Safety test executed in close cooperation with RDW (Dutch Regulating Authorities) on March 11th, 2011
Difference in fuel savings
Both tests are executed with different tractors

Circuit test with older tractor: average savings of 1.12 l/100 km

Operational test with new tractor: average savings of 1.65 l/100 km
# Circuit test with an inflatable tail

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<th>abs. savings [l/100km]</th>
<th>pct. savings [%]</th>
<th>wind velocity [m/s]</th>
<th>wind direction [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>baseline</td>
<td>27.58</td>
<td>24.58</td>
<td>–</td>
<td>–</td>
<td>4 – 5</td>
<td>WNW → WSW</td>
</tr>
<tr>
<td>inflatable tail</td>
<td>26.58</td>
<td>24.55</td>
<td>0.97</td>
<td>3.95%</td>
<td>4 – 5</td>
<td>W / WSW</td>
</tr>
</tbody>
</table>

* measured at specific weather conditions of test day (May 27th, 2011)
SideWings + foldable tail
Combining two add-ons (for existing trailers)

Wind tunnel experiments:
ΔC_D = -24%

Circuit test:
fuel savings 2.36 l/100 km
Aerodynamic add-ons
and their economical advantages

- High fuel cost and CO$_2$ savings
- No loss of cargo volume
- Fits on existing fleet
- Relatively low investment cost
- No decapitalisation (value conservation of existing fleet)
- No huge adjustment cost for existing trailer production facilities
- No restriction intermodal transport (fits on trains/boats)
- Unnecessary to modify existing infrastructure (parking/docking places, bridges, etc.)
Putting results into perspective

- Simplified truck model
  - Standard tail: -40%
  - Stepped tail: -10%
  - Continuous blowing: -20%
  - Vanes: -21%

- Detailed truck model
  - Standard tail: -14%
  - Sidewing+tail: -24%
  - Not measured on detailed model

- Full-scale road test
  - Foldable tail: -5%
  - Sidewing+tail: -8%
  - Suction/blowing: -??%
  - Vanes: -??%

Succesfull full-scale validation

More research needed
Hoerner’s relation

Only a rear-end solution drastically reduces drag coefficient of a truck

Source: Hoerner, Fluid Dynamic Drag, 1965
Best performing solutions

- **underside – SideWing**: validated fuel fuel savings (1.5l/100km) and successfull operational implementation
- **Rear-end – Foldable tail**: validated fuel saving (1.1–1.6l/100km) and successfull operational implementation, when folded fit on trains/boats
- **Combination** of SideWings and a foldable tail: validated fuel saving on circuit (2.36l/100km)

Concept study  On the road today?
Regulations (1)

Requisted dimensional modifications/exemptions for steering axle trailers

• Extra width of 5cm for wheel covering

• small series of trailers

wheel covers of 5cm thick
Regulations (2)

- Extra **unloaded length** of **1,5m** for aerodynamic rear-end solutions (as already in adopted in the USA), no extra width is required for the tail
- Modifying regulation 96/53/EC (weight and dimensions) and 97/27/EC (under ride protection)
Safety

• EU has to define the safety requirements for aerodynamic rear-end devices
• Industry will develop and design solutions accordingly
Successful implementation on a larger scale requires

- Expanding **testing trajectories** for trailers with add-ons
- **Incentives** to accelerate the implementation of aero add-ons
  - Performance labelling
  - Tax advantages (maut/CO₂)
  - Area/region restrictions
  - Support for initial investments
Thanks for the attention

The industry is challenged to develop the most efficient, save and practical solution.

Information:
Gandert Van Raemdonck
gandert.vanraemdonck@part20.eu
+31 (0)15 711 27 37