Reducing Aerodynamic Drag and Fuel Consumption

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Reducing Aerodynamic Drag and Fuel Consumption

Year 2002 statistics for combination trucks (tractor-trailers)
on nation’s highways *

2.2 million trucks registered
138.6 billion miles on nation’s highways, 3-4% increase/yr
26.5 billion gallons diesel fuel consumed, 4-5% increase/yr

5.2 mpg, or 19.1 gallons/100 miles

~ 2.47 million barrels/day **

~ 12-13% of total US petroleum usage (19.7×10^6 bbls/day)

* from DOT, FHA, Highway Statistics, 2002, and

** 26.5/(365×.7×42)
Contributions to power consumption from drag and rolling resistance for a typical class-8 tractor trailer

Power required to overcome aerodynamic drag is the greater contribution at highway speeds.
Most of the drag (90%, or more) results from pressure differences.

\[ D = C_D \times S \times \left( \frac{1}{2} \right) \rho U^2 \]

- **Drag coefficient**, dependent upon shape.
- **Cross-sectional area**.
- **Dynamic pressure**.

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Relationship between changes in drag and changes in fuel consumption

\[ \text{Power} = D \times U + RR \times U + \text{AuxP} \]

\[ \text{Fuel Consumption} = FC = (bsfc) \times \text{Power} \]

\[ \Delta \frac{FC}{FC} = \Delta \frac{P}{P} = \eta \times \left( \frac{\Delta C_D}{C_D} + \frac{\Delta S}{S} + \frac{3 \Delta U}{U} \right) \]

Make changes in shape to improve aerodynamics

property of the driving cycle \( \eta \approx 0.5-0.7 \) for a car or truck at highway speeds

reduce highway speeds—very effective!

make the car/truck cross-section smaller
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Improved fuel economy from close-following
At large spacing, close-following results in drag saving (fuel saving) for the trail vehicle...

...because the trail vehicle experiences a diminished dynamic pressure in the wake. The two vehicles collectively have less drag than the two in isolation. This can be regarded as a decrease in drag coefficient. It is well understood.
At sufficiently close spacing—less than one vehicle length in the case of a car, or one vehicle height in the case of a truck—the interaction is stronger.

Pressure is higher in the “cavity” than would be experienced by a vehicle in isolation.

The drag of each vehicle is less than the corresponding drag in isolation. Both vehicles save fuel in the “strong interaction” regime.
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Wind tunnel tests

Two van-shaped vehicles, drag ratio versus spacing
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Measuring fuel consumption directly using instantaneous outputs from engine map. Three Buick LeSabres under computer control, traveling in HOV lanes I-15, San Diego. PATH Program, UC Berkeley, California DOT
Results from test.

Average fuel consumption saving for three-vehicles at 0.8 car length spacing is $\approx 6-7\%$. 

![Graph showing fuel consumption savings for Forward, Trail, and Interior Vehicles at different car lengths with a reliability estimate and one standard deviation.](image)
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The site at Crows Landing
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Two century-class Freightliner trucks under computer control at 4-meter spacing.

Single truck: southbound (red) northbound (blue)
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Two class-8 trucks close-following

3.2 liters/100 km
1.36 gal/100 mi

Fuel Consumption Savings Versus Separation

- Trail Truck, ± 95% confidence
- Lead Truck, ± 95% confidence

Fuel Saving in Tandem, liters/100 kilometer vs. Truck Separation, meters
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Improved fuel economy from other shape changes

The DOE effort to reduce truck aerodynamic drag*


*see, for example, The Aerodynamics of Heavy Vehicles: Trucks, Buses, and Trains, eds., R.McCallen, F.Browand, J.Ross, Lecture Notes in Applied and Computational Mechanics, Springer-Verlag, 2004
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Early 1990’s

- No aero shield
- Huge radiator
- Many corners
- Protruding lamps, tanks, pipes, etc.
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Model year 2000

Built-in aero shield
Small radiator
Rounded corners
Recessed lamps, tanks, etc.
Areas of possible improvement

- Gap
  - cab extenders
  - splitter plate
- Wheels & underbody
  - skirts
  - underbody wedge
- Trailer base
  - boat-tail plates
  - flaps

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Wheels & underbody

Skirts:
Wind tunnel model, full scale conditions, $Re = 5 \times 10^6$

$\Delta C_D \approx 0.05$

Wedge:
Wind tunnel model, $Re = 3 \times 10^5$

$\Delta C_D \approx 0.01$

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Trailer base

Base flaps:

Wind tunnel model, full scale conditions, $Re = 5 \times 10^6$

$\Delta C_D \approx 0.08$

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Gap

Cab extenders or trailer splitter plate
RANS computation $Re = 3 \times 10^5$

$\Delta C_D \approx 0.01 - 0.03$
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The summary of improvements
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Add-ons:
Base flaps, skirts, gap control, $\Delta C_D \approx 0.13-0.15$

For $C_D \approx 0.6$, $\Delta C_D / C_D \approx 0.22$, implies $\Delta FC / FC \approx 11\%$

Close-following:
Field tests demonstrate $\Delta FC \approx 1.36$ gal/100 mi
$\Delta FC / FC \approx 7\%$

Add-ons plus close following may not be additive gains!
Probably a portion is, $\Delta FC / FC \approx 15\%$

If fully implemented, would result in reduction in current usage of 0.37 Mbbls/d = 135 Mbbls/yr, and a reduction of 60 Mtonnes CO$_2$ released.
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Hastening the adoption of improvements
**Incentives for adoption of add-ons by trucking companies**

\[
\text{Incentive} = \frac{\text{Cost of fuel saved (250,000 mi)}}{\text{Capital Cost of add-on}}
\]

For base-flaps & skirts

\[
\text{CC} = \$1800
\]

\[
\text{Incentive} \approx 2.5 \times (\$ \text{ per gal diesel})
\]

At $3.00 /gal, the saving would be

\[
7.5 \times \text{cost of add on, or } \$13,500
\]

For base flaps, skirts & close-follow

\[
\text{CC} = \$4800
\]

\[
\text{Incentive} \approx 1.5 \times (\$ \text{ per gal diesel})
\]

At $3.00 /gal, the saving would be

\[
4.5 \times \text{cost of add on, or } \$21,600
\]
Encourage research in CFD

National Labs have the computing capabilities

Universities have expertise in new code development

University support particularly needed

Encourage field test experiments

Trucking companies are besieged with ideas for fuel saving add-ons

Type II SAE sanctioned tests take place, but usually results are not made public

Close-following geometries have not been explored systematically

Need field tests under controlled conditions (such as Crows Landing) to isolate the most promising technology