Reducing Aerodynamic Drag and Fuel Consumption

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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)


**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.
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Most of the drag (90%, or more) results from pressure differences.

Net pressure force

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

- Drag coefficient, dependent upon shape
- Cross-sectional area
- Dynamic pressure
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Relationship between changes in drag and changes in fuel consumption

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

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

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

- \( \eta \approx 0.5-0.7 \) for a car or truck at highway speeds

- Make changes in shape to improve aerodynamics

- Reduce highway speeds—very effective!

- Make the car/truck cross-section smaller
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.
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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.
Wind tunnel tests

Two van-shaped vehicles, drag ratio versus spacing
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 \(\approx 6-7\%\).
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)
Two class-8 trucks close-following

3.2 liters/100 km
1.36 gal/100 mi
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
Early 1990’s

No aero shield
Huge radiator
Many corners
Protruding lamps, tanks, pipes, etc.
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, \( \text{Re} = 5 \times 10^6 \)

\[ \Delta C_D \approx 0.05 \]

Wedge:

Wind tunnel model, \( \text{Re} = 3 \times 10^5 \)

\[ \Delta C_D \approx 0.01 \]

Trailer base

Base flaps:

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

$\Delta C_D \approx 0.08$

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Gap

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

$\Delta C_D \approx 0.01 - 0.03$

The summary of improvements
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.
Hastening the adoption of improvements
Incentives for adoption of add-ons by trucking companies

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

For base-flaps & skirts

CC = $1800

Incentive \approx 2.5 \times ($ 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

CC = $4800

Incentive \approx 1.5 \times ($ 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