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

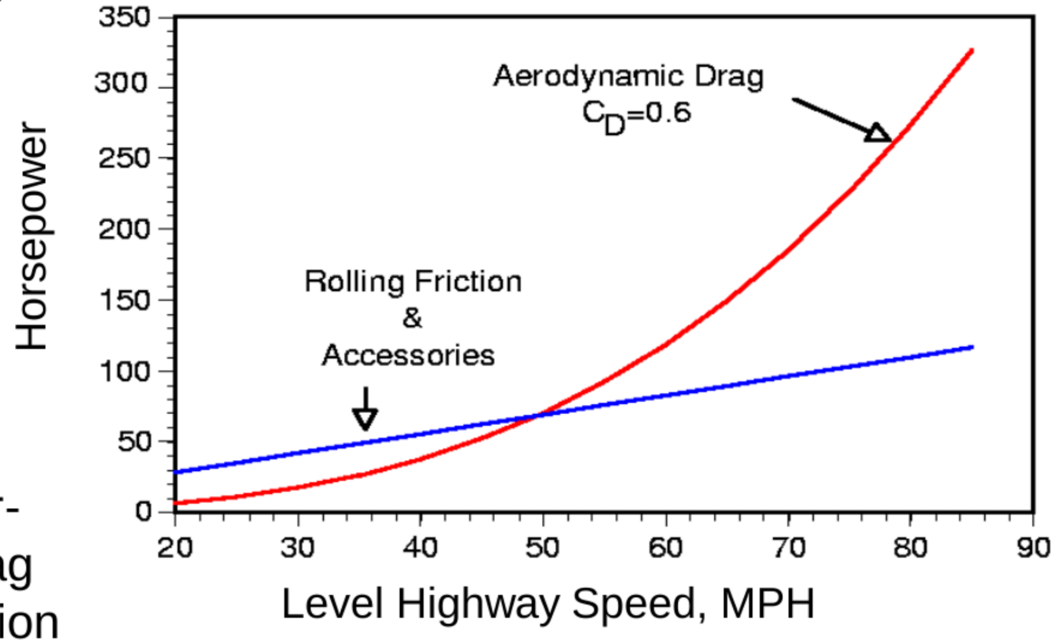
~ 2.47 million barrels/day **

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

* from DOT, FHA, Highway Statistics, 2002, and US DOT *Transportation Energy Data Book Edition 24*.

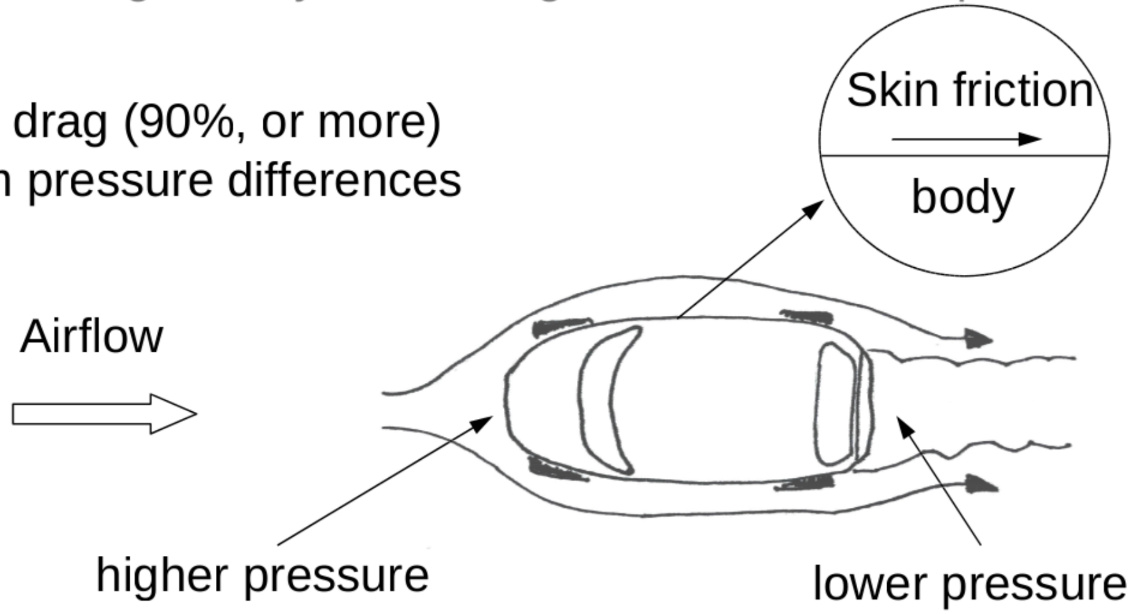
**$26.5/(365 \times .7 \times 42)$

Contributions to power consumption from drag and rolling resistance for a typical class-8 tractor trailer



Power required to over-come aerodynamic drag is the greater contribution at highway speeds

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



Net pressure force

$$D = C_D \times S \times (1/2)\rho U^2$$

drag coefficient, dependent upon shape

cross-sectional area

dynamic pressure

Relationship between changes in drag and changes in fuel consumption

$$Power = D \times U + RR \times U + AuxP$$

$$Fuel\ Consumption \equiv FC = (bsfc) \times Power$$

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

η: property of the driving cycle
$\eta \approx$ 0.5-0.7 for a car or truck at highway speeds

$\Delta C_D / C_D$: Make changes in shape to improve aerodynamics

$\Delta S / S$: make the car/truck cross-section smaller

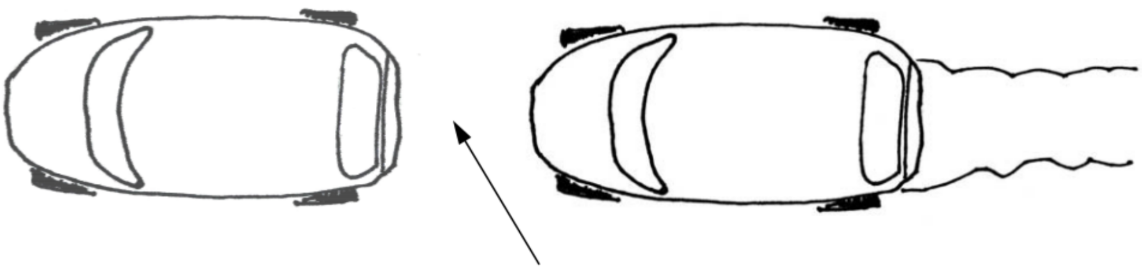
$3\Delta U / U$: reduce highway speeds—very effective!

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

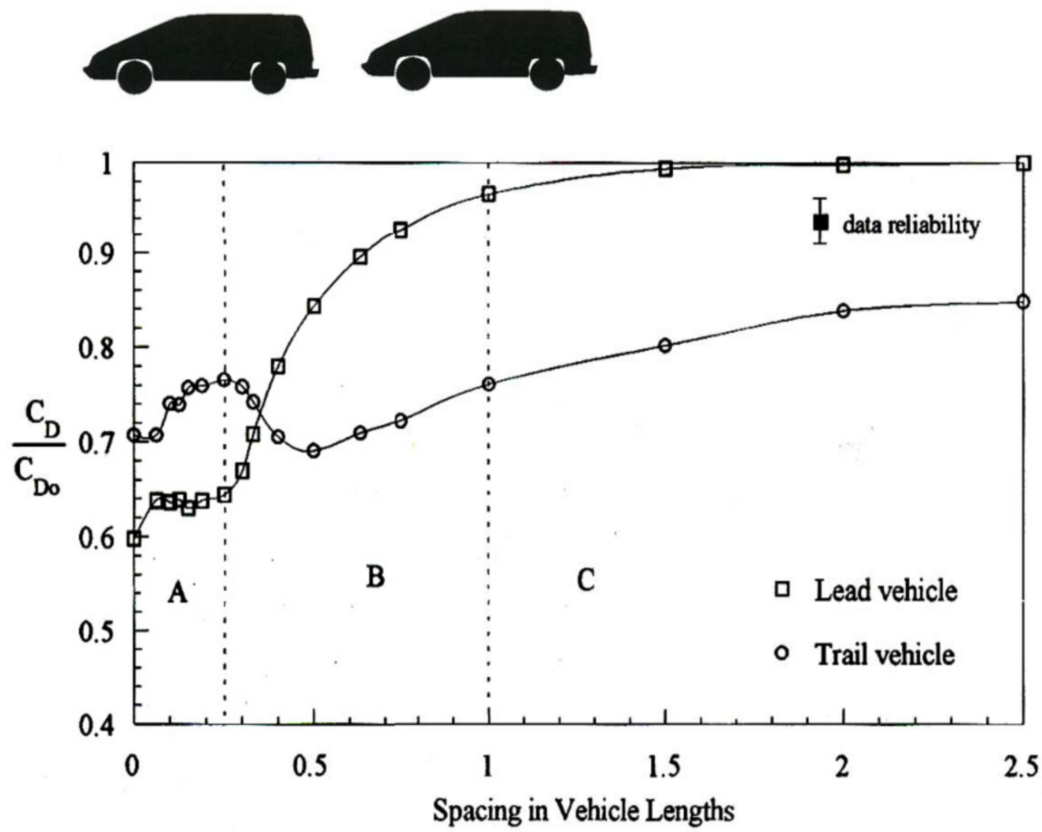


Pressure is higher in the “cavity” than would be experienced by a vehicle in isolation.

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

Wind tunnel tests

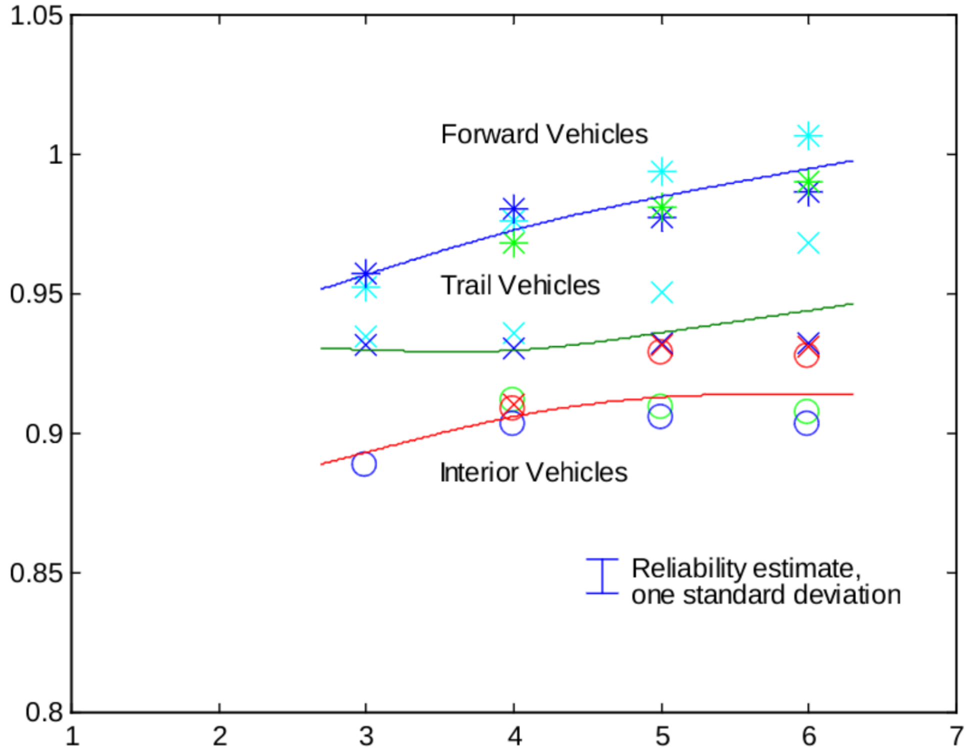
Two van-shaped vehicles, drag ratio versus spacing



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 ≈ 6-7%.



The site at Crows Landing

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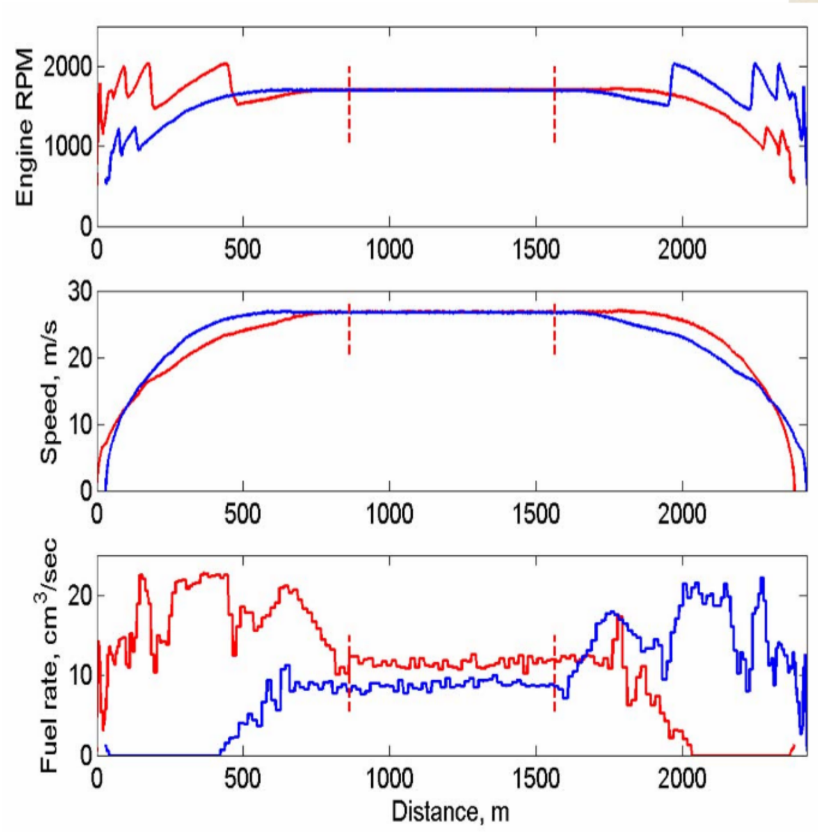


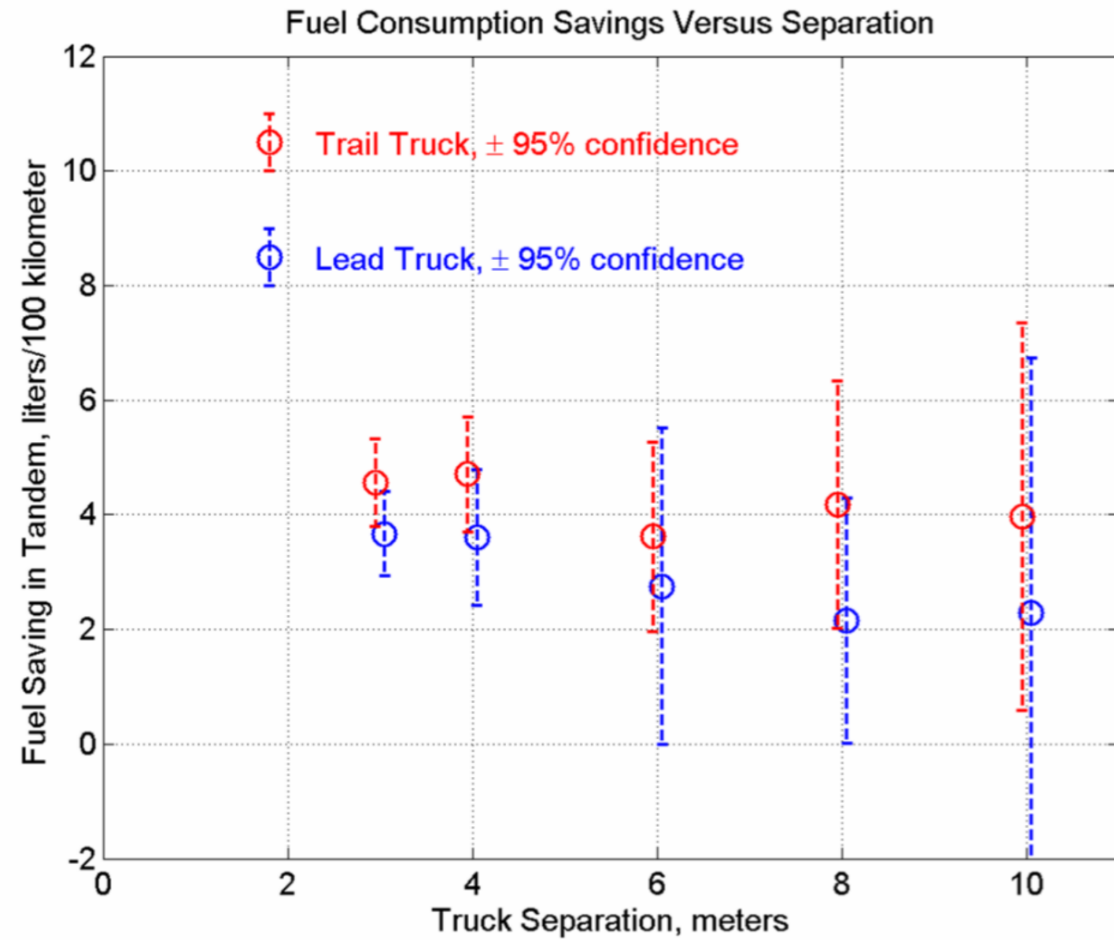
Single truck: southbound (red)
northbound (blue)

Two century-class Freightliner trucks under computer control at 4-meter spacing.

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**

The DOE Energy Efficiency and Renewable Energy, Office of FreedomCAR & Vehicle Technologies, supports a collaborative effort of 9 organizations: LLNL, SNL, ANL,NASA Ames, USC, Caltech, UTC, Auburn, GTRI

*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

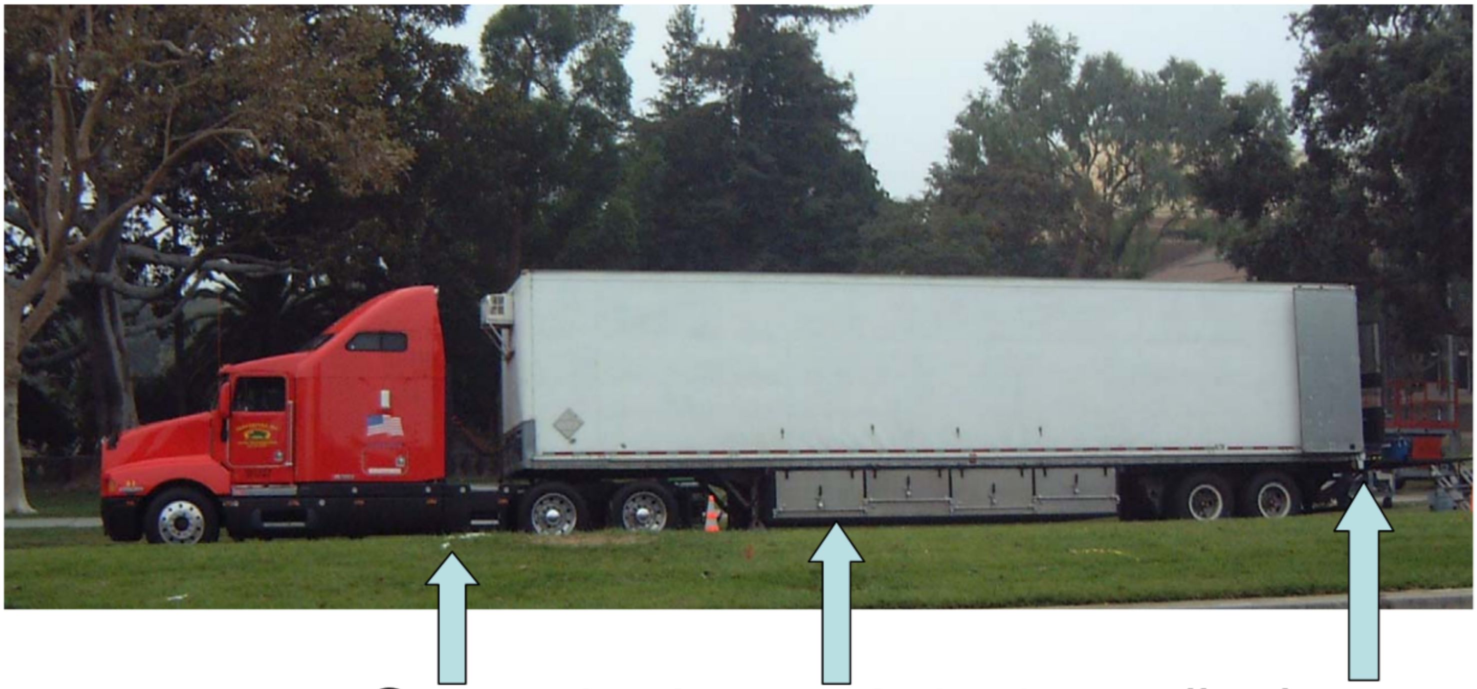
Built-in aero shield

Small radiator

Rounded corners

Recessed lamps, tanks, etc.

Areas of possible improvement



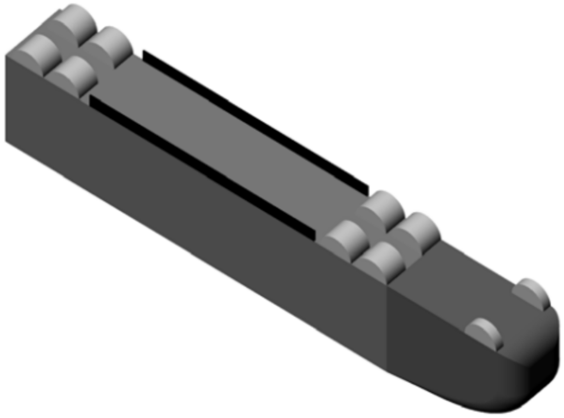
Gap
- cab extenders
- splitter plate

Wheels & underbody
- skirts
- underbody wedge

Trailer base
- boat-tail plates
- flaps

Wheels & underbody

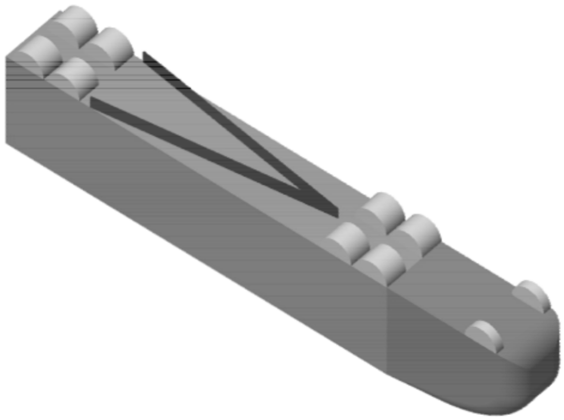
Skirts:



Wind tunnel model, full scale conditions, Re = 5×10^{6}

$\Delta C_D \approx 0.05$

Wedge:



Wind tunnel model, Re = 3×10^{5}

$\Delta C_D \approx 0.01$

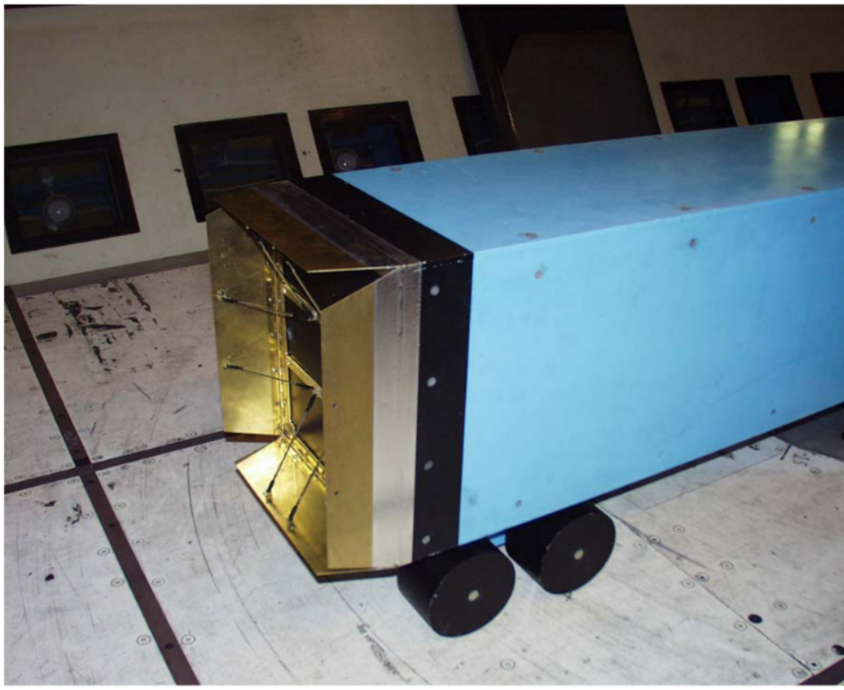
DOE's Effort to Reduce Truck Aerodynamic Drag through Joint Experiments and Computations Leading to Intelligent Design, R. McCallen et al., *Proc. of the 2005 SAE Commercial Vehicle Engineering Conference*, Chicago, Illinois, Nov. 1-3, 2005

Trailer base

Base flaps:

Wind tunnel model, full scale conditions, Re = 5×10^6

$\Delta C_D \approx 0.08$



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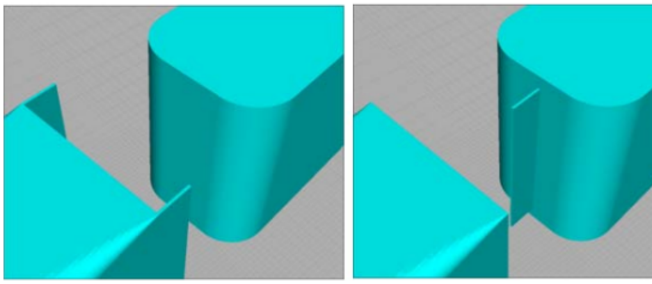
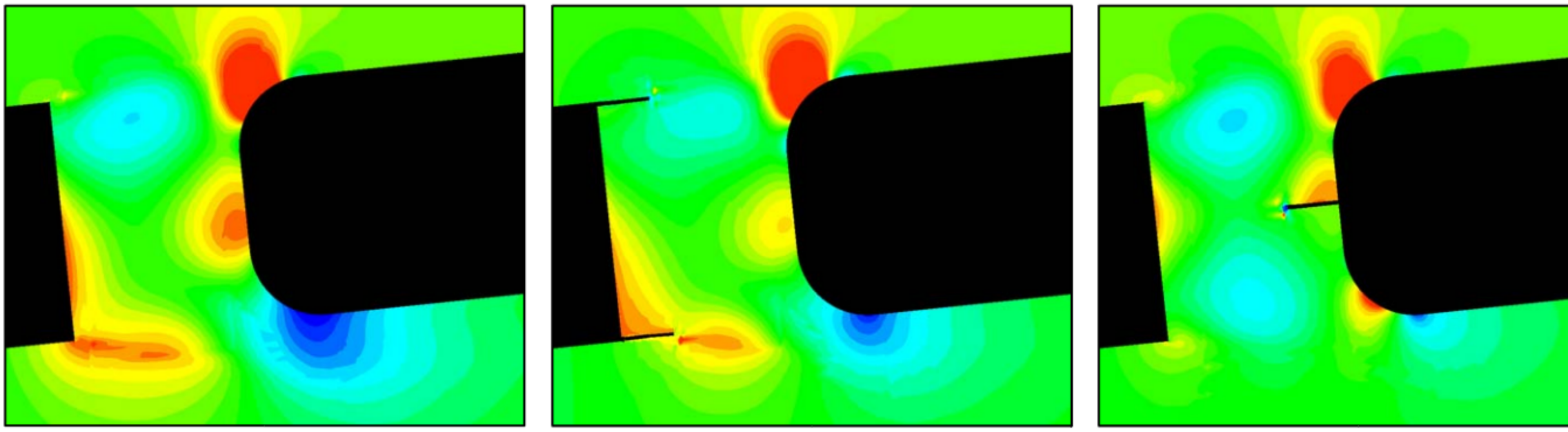
Gap



Cab extenders or trailer splitter plate

RANS computation Re = 3×10^5

$\Delta C_D \approx 0.01 - 0.03$



Computational Simulation of Tractor-Trailer Gap Flow with Drag-Reducing Aerodynamic Devices, P. Castellucci & K. Salari, *Proc. Of the 2005 SAE Commercial Vehicle Engineering Conference*, Chicago, Illinois, Nov. 1-3, 20

The summary of improvements

Add–ons:

Base flaps, skirts, gap control, $\Delta C_D \approx 0.13\text{-}0.15$

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

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

For base-flaps & skirts

CC = $1800

Incentive $\approx$ *2.5* $\times$ *($ per gal diesel)*

At $3.00 /gal, the saving would be 7.5 $\times$ *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 $\times$ *cost of add on, or $21,600*

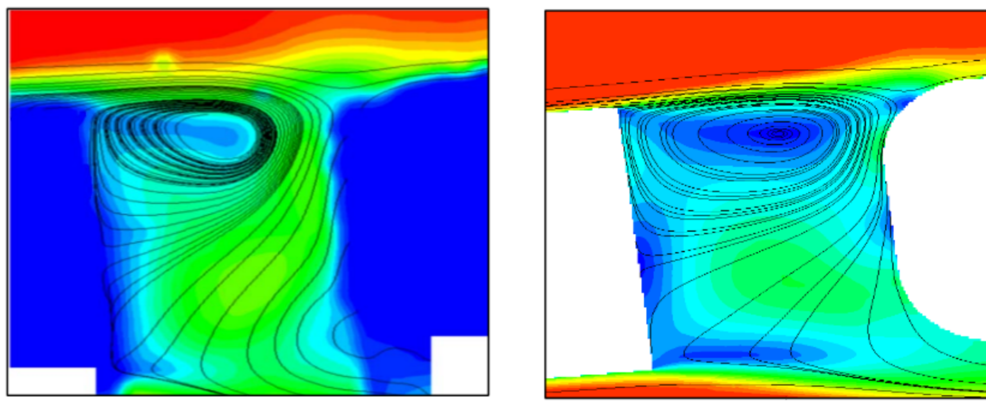
Reducing Aerodynamic Drag and Fuel Consumption

Encourage research in CFD

National Labs have the computing capabilities

Universities have expertise in new code development

University support particularly needed



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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