DOE's Effort to Improve Heavy Vehicle Aerodynamics through Joint Experiments and Computations

DOE Annual Merit Review, Project ID # VSS006

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Kambiz Salari

Lawrence Livermore National Laboratory

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Overview

Timeline

Add-on aero device development will transition into an integrated approach to achieve even more significant drag reduction in FY13

- On-the-road testing of aero devices
- Improved design of selected aero devices
- Designed new tanker-trailer aerodynamic fairings

Barriers

- Reduce aerodynamic drag of class 8 tractor-trailers by approximately 25% leading to a 10-15% increase in fuel efficiency at 65 mph
- By 2015, demonstrate a 50 percent improvement in freight hauling efficiency (ton-miles per gallon).

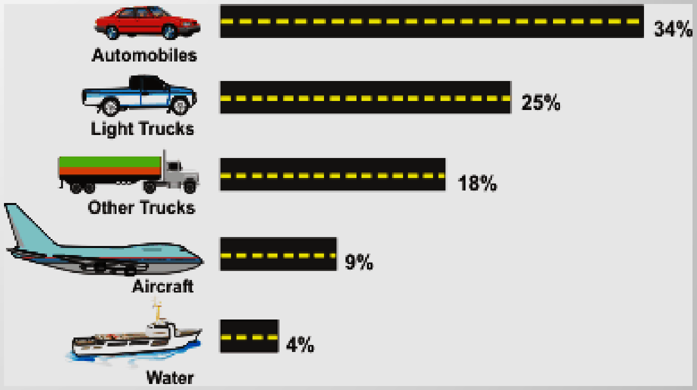
Budget

- Funding received in FY12, $650K
- Funding for FY13, $600K

Partners

- Navistar, Inc.
- Kentucky Trailer and Wabash National
- Freight Wing Inc. and ATDynamics
- Frito-Lay, Spirit, and Safeway
- Michelin
- Praxair

Class 8 tractor-trailers are responsible for 12-13% of the total US consumption of petroleum



Aerodynamic drag reduction contribution

12% reduction in fuel use = 3.2 billion gallons of diesel fuel saved per year and 28 million tons of CO2 emission
$13.0 billion saved/year ($4.05 per gallon diesel)

Aerodynamics and wide-base single tires contributions

17% reduction in fuel use = 4.6 billion gallons of diesel fuel saved per year and 40 million tons of CO2 emission
$18.6 billion saved/year ($4.05 per gallon diesel)

U.S. Department of Energy, Transportation Energy Data Book, Edition 29, July 2010

Objectives

- ***In support of DOE's mission,*** provide guidance to industry to improve the fuel economy of class 8 tractor-trailers and tankers through use of aerodynamic drag reduction
- ***Demonstrate*** new drag-reduction techniques and concepts
  - *Class 8 tractor-trailers and tankers*
- ***Joined with industry in getting devices on the road and to develop the next generation of highly aerodynamic class 8 tractor-trailers***
- ***On behalf of DOE*** to expand and coordinate industry participation to achieve significant on-the-road fuel economy improvement

Milestones

FY12

- Continue with the fuel economy track testing of selected aerodynamic devices at Transportation Research Center (TRC) facility in collaboration with Navistar
- Continue with collection of on-the-road performance data for the selected aero devices in collaboration with Frito-Lay and Spirit fleets
- Designed/Improved aerodynamic devices for tractor-trailers and tankers

FY13

- Improved design/performance of selected aero devices based on the knowledge gained from collected on the road device performance data
- **Investigating tractor-trailer integration in collaboration with our industry partners for significant drag reduction (geometry, flow, and thermal)**
- Conduct scaled experiments to validate the performance of aero devices for both tractor-trailers and tankers
- Continue with the development of aerodynamic fairings for tanker trailers
- Continue with collection of on the road performance data for the selected aero devices in collaboration with Frito-Lay and Spirit fleets

Science-based approach with computations and experiments to improve the aerodynamics of heavy vehicles

Design & validate devices/concepts for improved vehicle aerodynamics with industry collaboration and feedback

New/existing devices with integration concepts
- Science based

Virtual testing environment
- Full-scale conditions
- Realistic truck geometry

Full-scale wind tunnel validation
- NFAC/NASA Ames 80′x120′
- NRC, Canada
- Freightliner

Track & road demonstration
- Manufacturers and Fleets
- Scientists

Collaborative Efforts

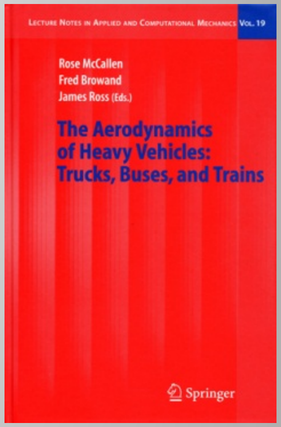
Industry
- Manufacturers
- Fleets

Scientists
- National Labs
- NASA
- Universities

Technical accomplishments

- ***Completed analysis and documentation of the full-scale wind tunnel test*** conducted at NASA Ames 80'x120' NFAC facility
- ***In collaboration with Navistar*** conducted fuel economy track tests at Transportation Research Center (TRC) facility
  - Twenty-four vehicle configurations were tested
- ***In support of the DOE's objective to bring candidate devices to the market,*** we are teaming with Navistar, Kentucky Trailer, Freight Wing device manufacturer, Michelin, and Frito-Lay's and Spirit's Fleets to perform track and on-the-road tests
  - Collecting on the road performance data for selected aerodynamic devices
- ***Improved the aerodynamics of a common tanker trailer*** to significantly increase the fuel economy
  - Designed and evaluated tanker fairings
- ***International recognition* achieved** through open documentation and conferences

Effectively disseminated information to industry as a leading R&D team



2003 ECI Conference, Monterey U.S.,

The Aerodynamics of Heavy Vehicles: Trucks, Busses, and Trains, December 2-5, 2003.

2007 ECI Conference, Tahoe, U.S.
The Aerodynamics of Heavy Vehicles II: Trucks, Buses, and Trains, August 26-31, 2007.

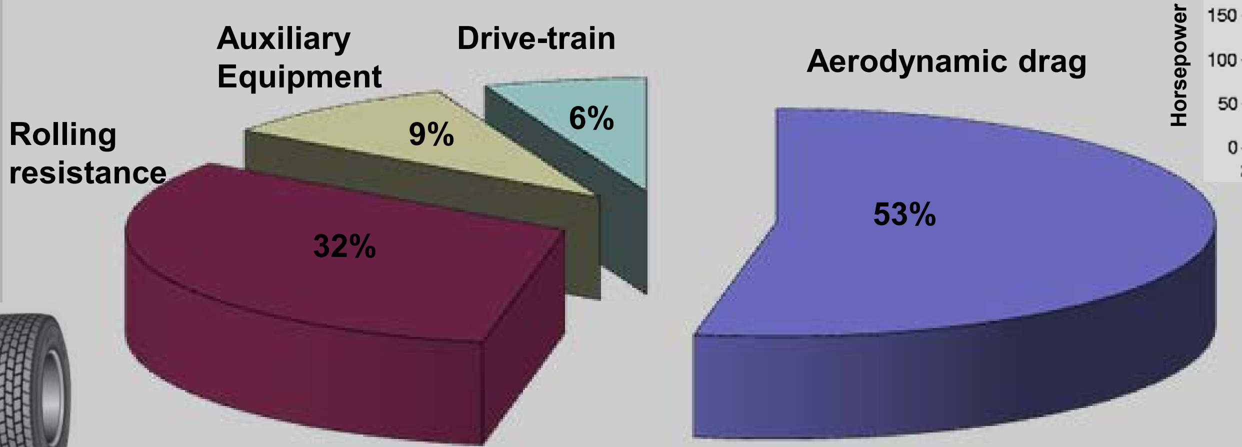
2010 ECI Conference, Potsdam, Germany,

The Aerodynamics of Heavy Vehicles III: Trucks, Buses, and Trains, September 12 – 17, 2010

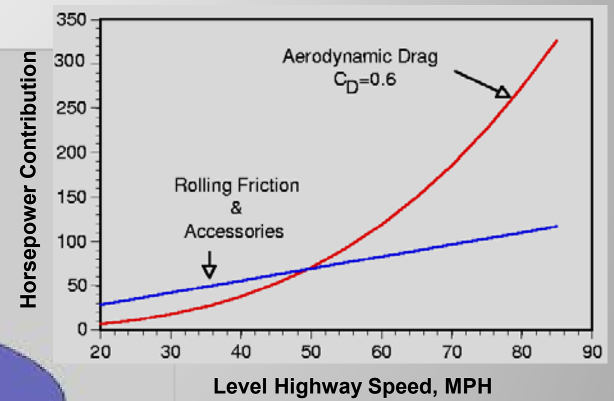
Conference papers, technical reports, workshops, panel participants at various meetings

ECI - Engineering Conferences International

Most of the usable energy goes into overcoming drag and rolling resistance at highway speeds



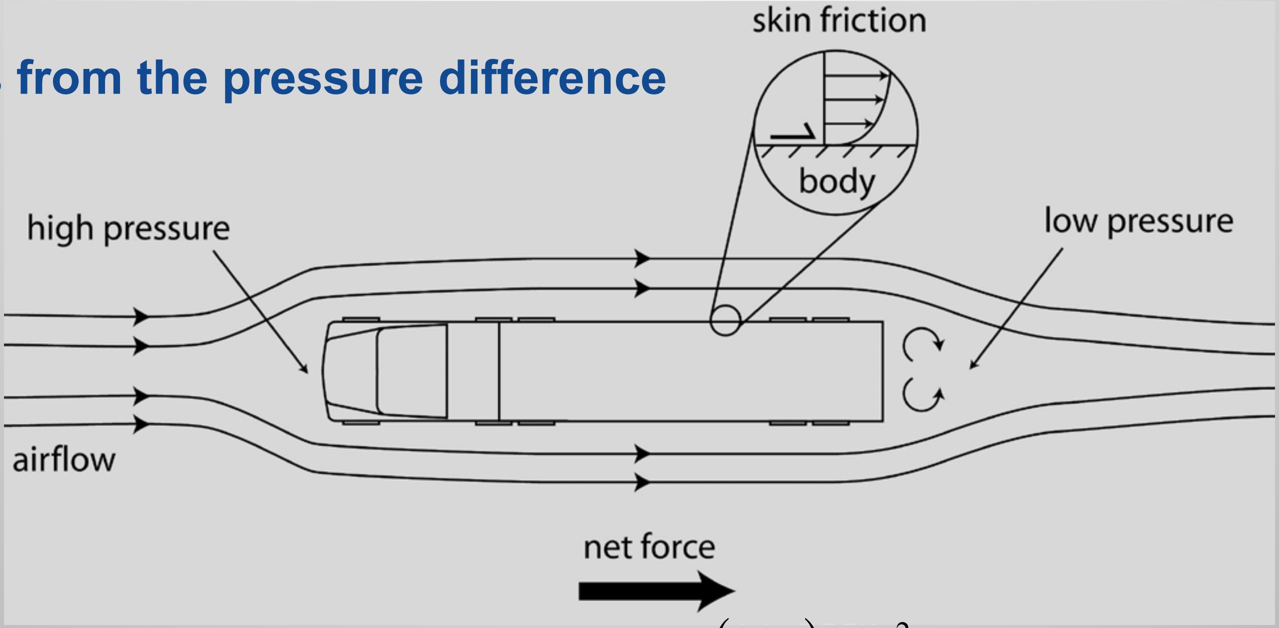
Wide-base single tires



Losses in nearly all of these categories can be reduced by employing presently available technology

Improved fuel economy can be achieved through multiple avenues

Most drag is from the pressure difference



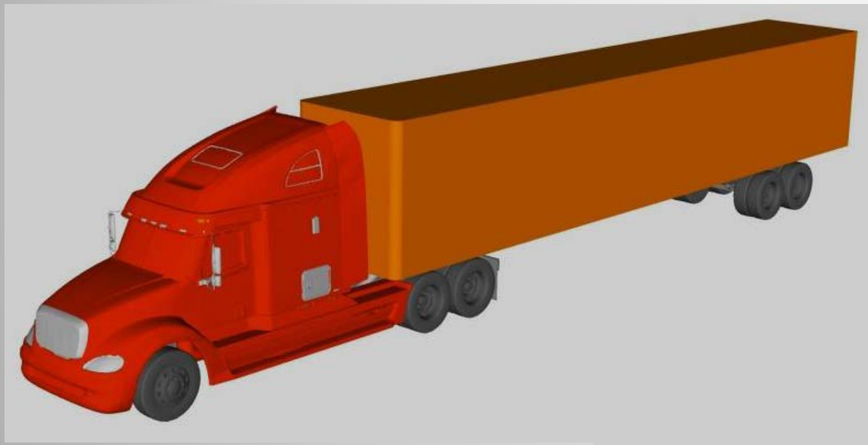
$$Drag = C_D \times S \times (1/2)\rho U^2$$

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

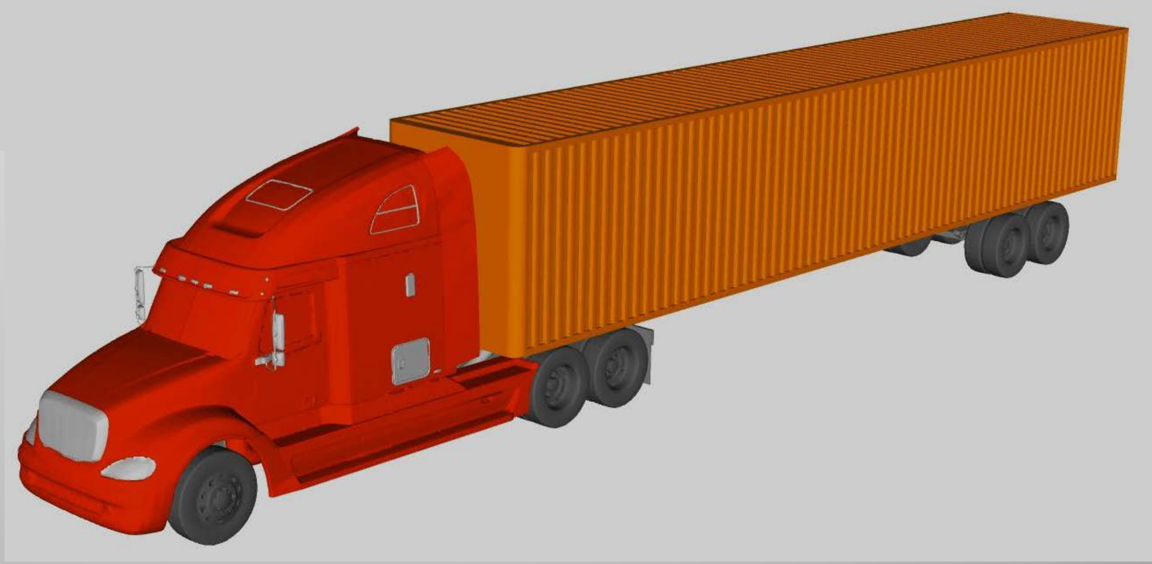
$\eta \approx$ 0.5-0.7 **shape** **cross-section** **speed**

A corrugated trailer results in a larger drag force

Trailer body 12%



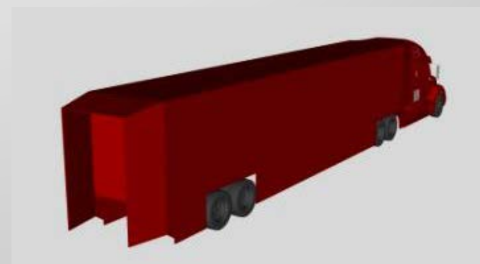
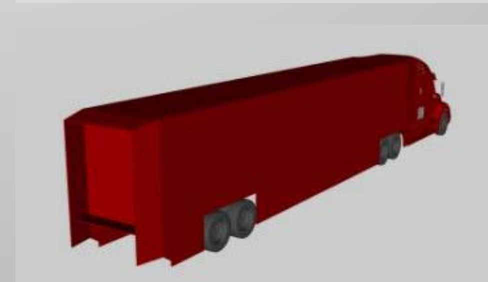
Trailer body 28%



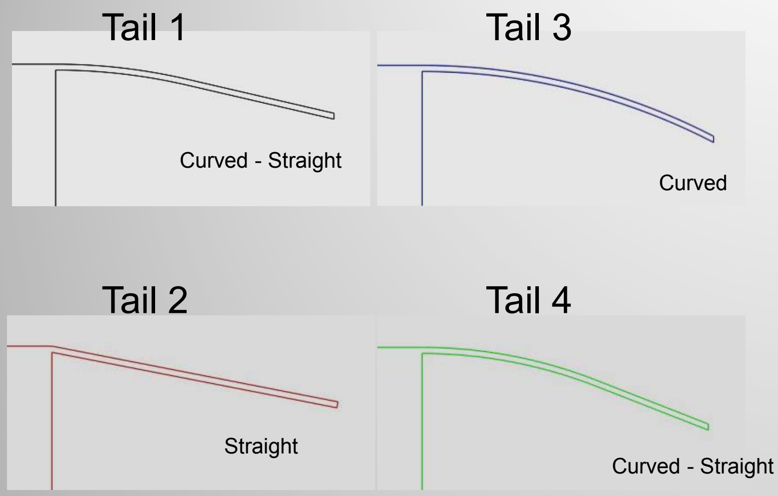
Baseline configuration

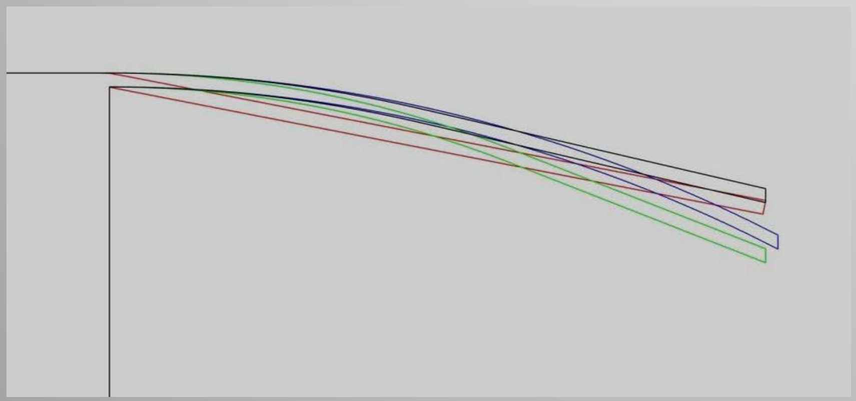
~16% increase in drag at highway speed
~8% decrease in fuel economy

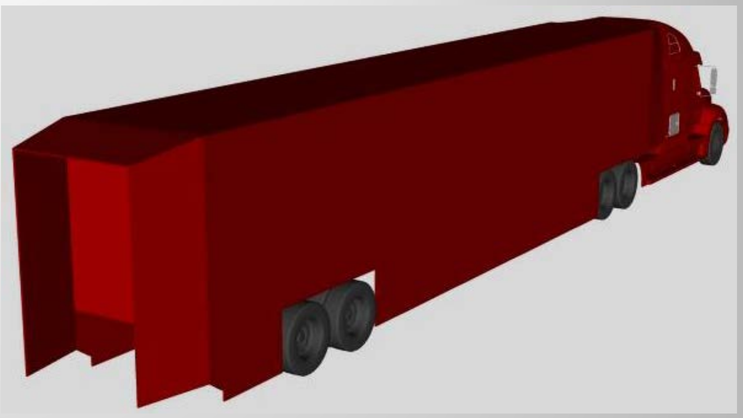
Add-on aerodynamic devices show significant potential to improve fuel economy

			ΔC_D (%)
Baseline			----
Gap Seal + Skirt + 48" tail (3-sided)			**-0.175 (-26.0 %)**
Gap Seal + Skirt + 32" tail (4-sided)			**-0.175 (-26.1 %)**

Curved tails show similar performance compared to straight tails





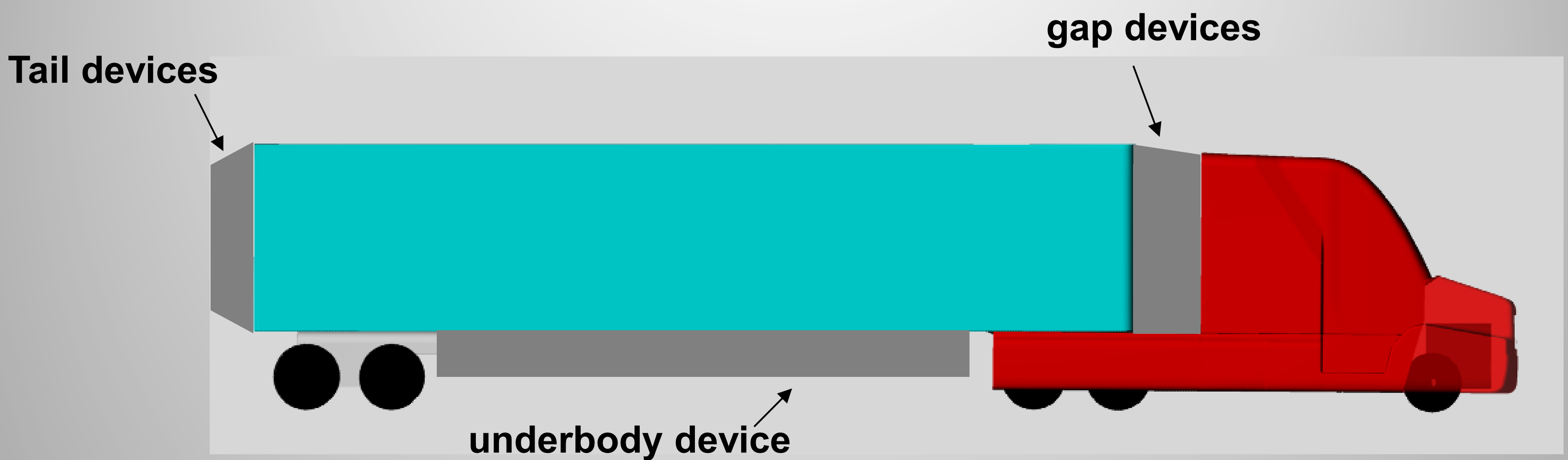


- Tail 1: 2.5 m curved radius into a straight section → 10° effective angle
  - **ΔC_D = -0.167 (-24.8%)**
- Tail 2: straight section → 11° angle
  - **ΔC_D = -0.175 (-26.0%)**
- Tail 3: curved tail with a radius of 2.66 m → 13.64° effective angle
  - **ΔC_D = -0.147 (-21.9%)**
- Tail 4: 2.0 m curved radius into a straight section → 15° effective yaw angle
  - **ΔC_D = -0.154 (-23.0%)**

Add-on aerodynamic devices on the road today

MICHELIN

Add-on aerodynamic devices contribute significantly to improved fuel economy



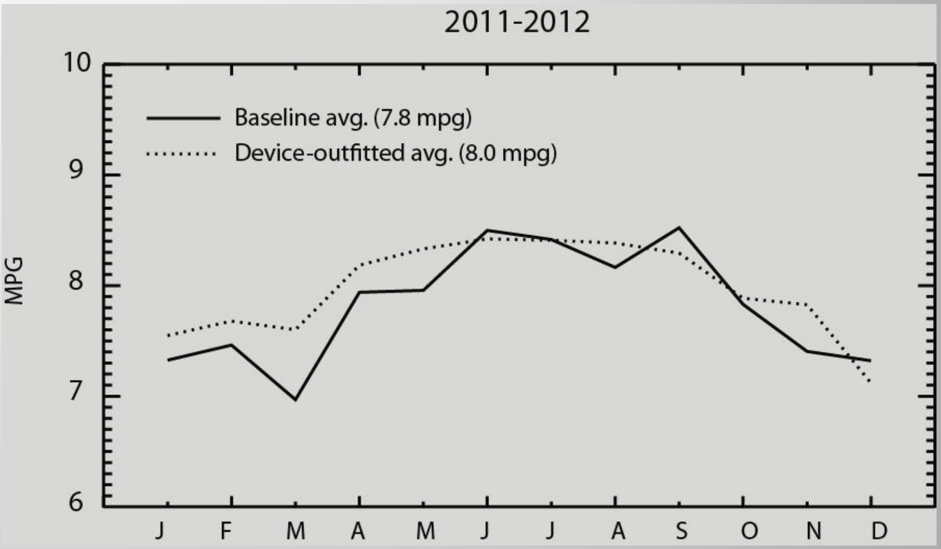
- Tail devices: 4-7% FEI (Fuel Economy Improvement)
- Underbody devices: 5-7% FEI
- Gap devices: 1-2% FEI
- Wide base single tires: 4-5% FEI

Add-on aerodynamic devices are being tested and adopted by fleet members of our team

- There are roughly 2 million tractor-trailers in the US that can be retrofitted with aerodynamic devices:
  - ***Trailer tail***
  - ***Trailer skirt***
  - *Tractor-trailer gap fairing*
  - *Tractor fairings*
- Since 2010 the rate of customers/fleets acceptance has significantly increased
- Based on an input from our collaborators Freight-Wing and ATDynamics by the end of 2013 we could see ~3-4% of the market deploying these devices

We are collecting large amounts of on-the-road fuel economy data in collaboration with the Frito-Lay and Spirit

- 2011-2012
- Frito collaborators: Bob Bartlett, Bob Raduchel, Joe Gold
- 32 trailers outfitted with add-on drag reduction devices and single wide-base tires
- 76 tractors
- 94 vehicle routes
- 9.1e5 miles of baseline vehicle fuel economy data > 60 mph
- 4.9e5 miles of fairing trailer fuel economy data > 60 mph
- Data sorting parameters (36):



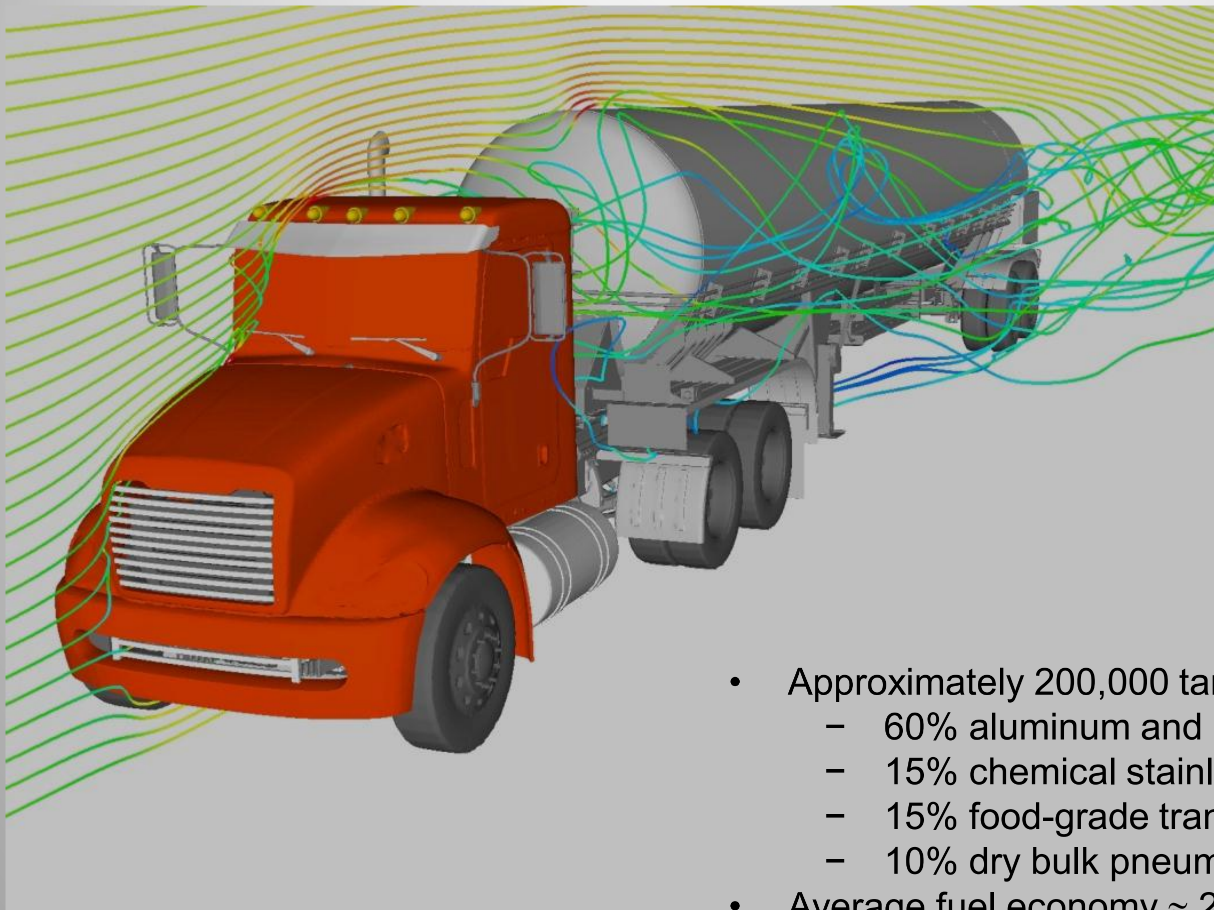
MinSessionDrivingTimeStamp	MaxTimeStamp	Fuel	Axles	Fairing Description
Months	MaxTime	MPG	GEAR	Trip Avg Miles
Days	MinTimeStamp	MPH	ENGINE	Trip Avg MPH
Years	MinTime	Faring	H.P.	
MinSessionTime	Trip	Trailer	EGR/DPF	
MinSessionTimeString	DriverName	Baseline	TRANSM	
Hour	Vehicle	Trailer	Trailer	
Min	Miles	Make	Type	
AMPM				

The results of our full-scale wind tunnel test conducted at the NFAC facility have been documented

"Aerodynamic drag reduction of class 8 heavy vehicles: a full-scale wind tunnel study," LLNL technical report, LLNL-TR-628153

- Different combinations of tractors and trailers were tested
  - Two tractors – Prostar sleeper and day cab
  - Three trailers – 28' & 53' straight frame and 53' drop frame
- Performed 140 wind tunnel runs
- Twenty-three aerodynamic drag reduction devices/concepts were tested from LLNL, Navistar, Freight Wing, ATDynamics, Aerofficient, Laydon, Windyne, and AeroIndustries

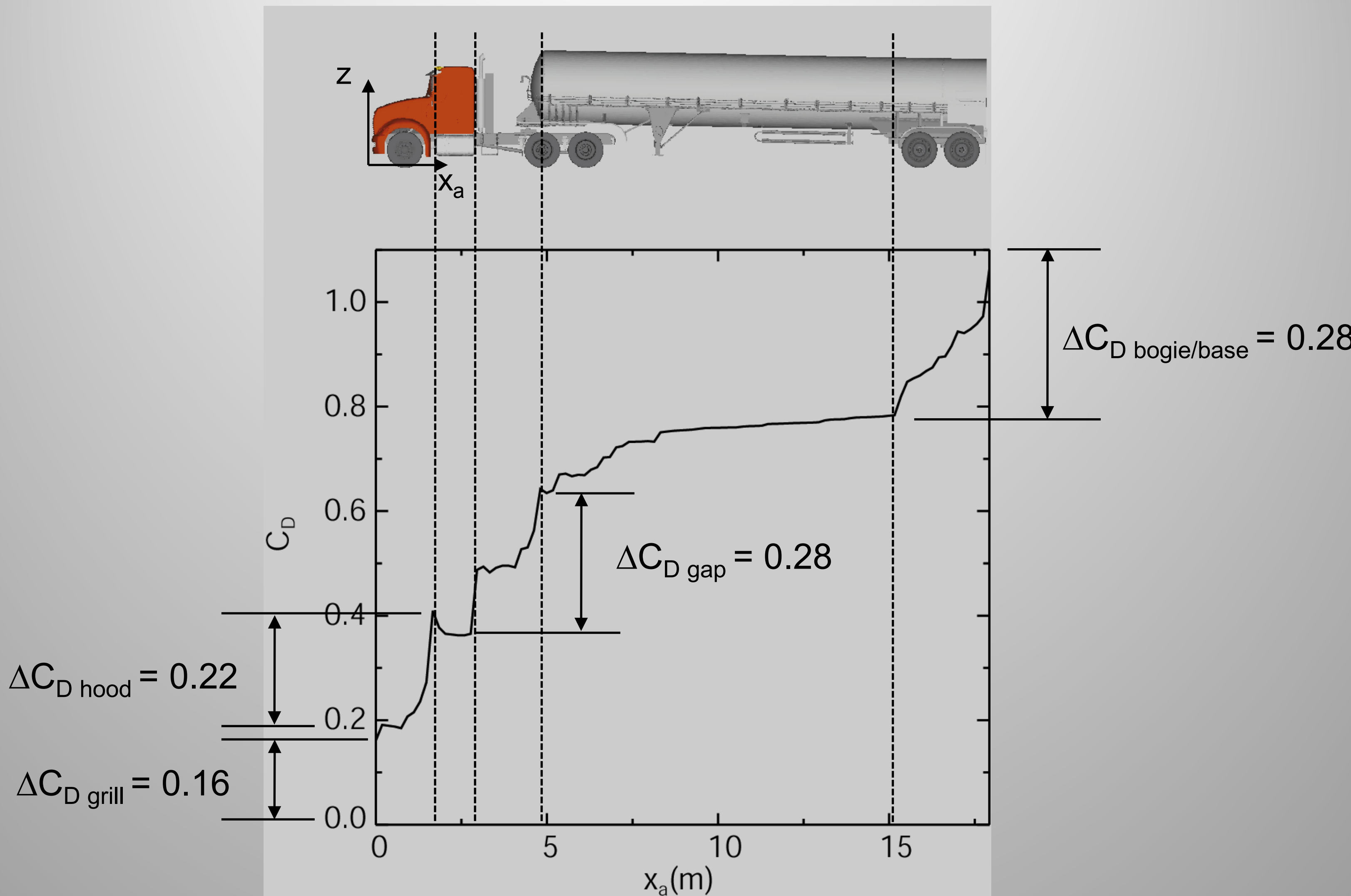
Improving tanker trailer aerodynamics for better fuel economy



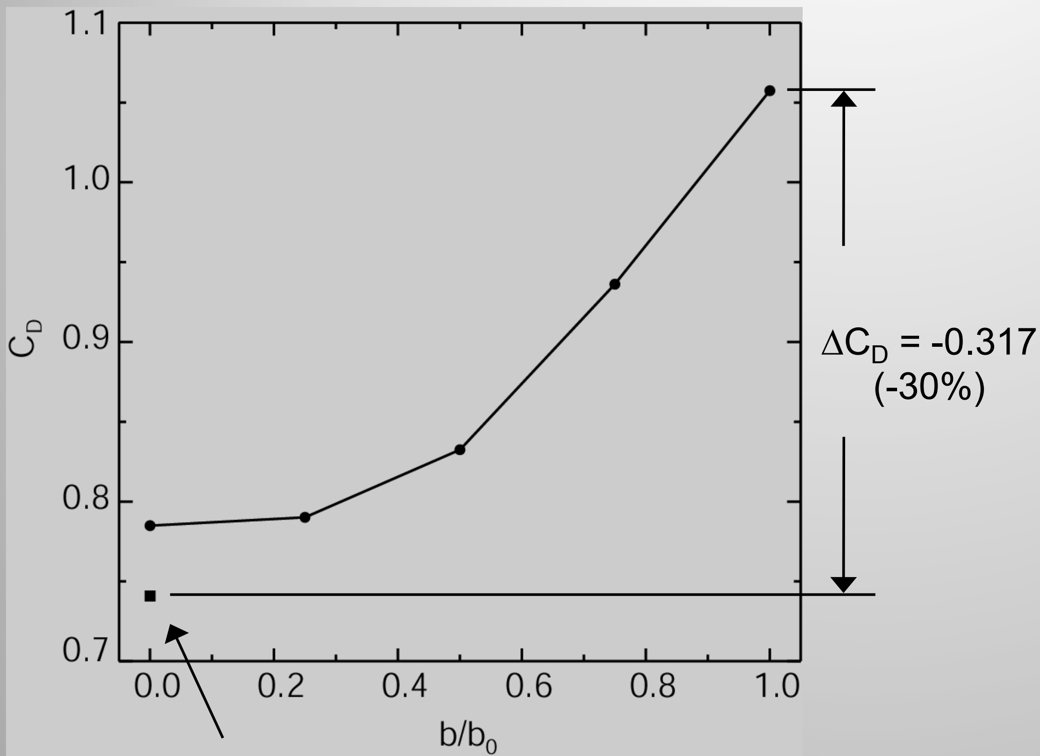
- Approximately 200,000 tanker trailers in the United States[1]
  - 60% aluminum and petroleum product service
  - 15% chemical stainless steel trailers
  - 15% food-grade transportation
  - 10% dry bulk pneumatic trailers
- Average fuel economy ≈ 2 km/L (5 mpg)[2]

1. National Tank Truck Association, www.tanktruck.org
2. US Department of Transportation, Transportation Energy Data Book, Edition 26, 2007

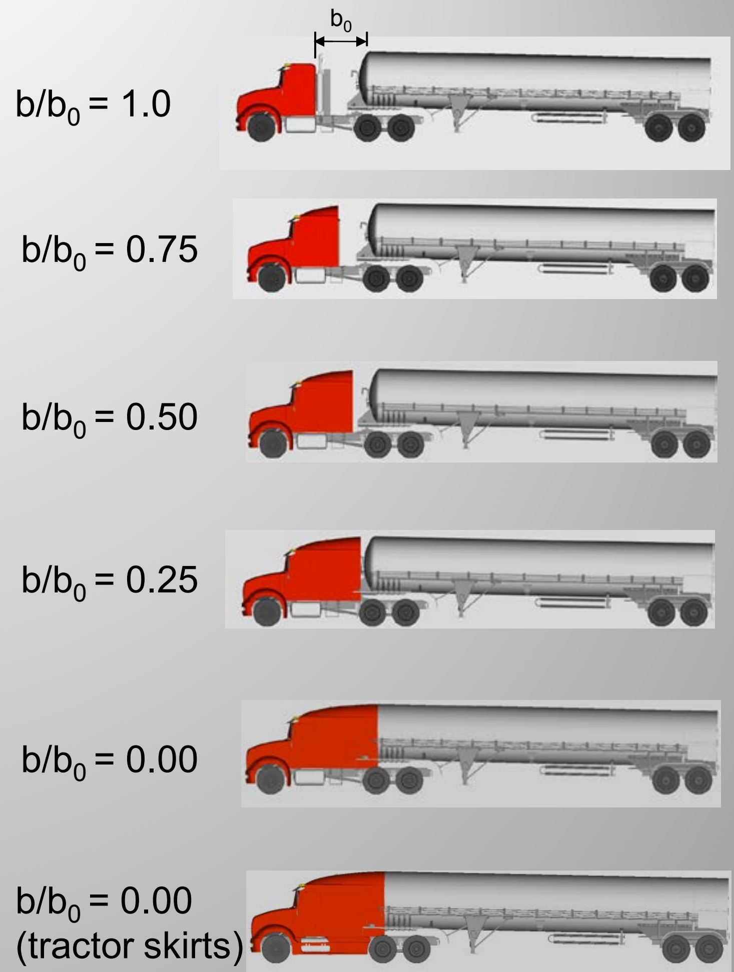
There are several major drag sources on a tanker trailer



The drag coefficient decreases as the tractor-tanker gap becomes smaller

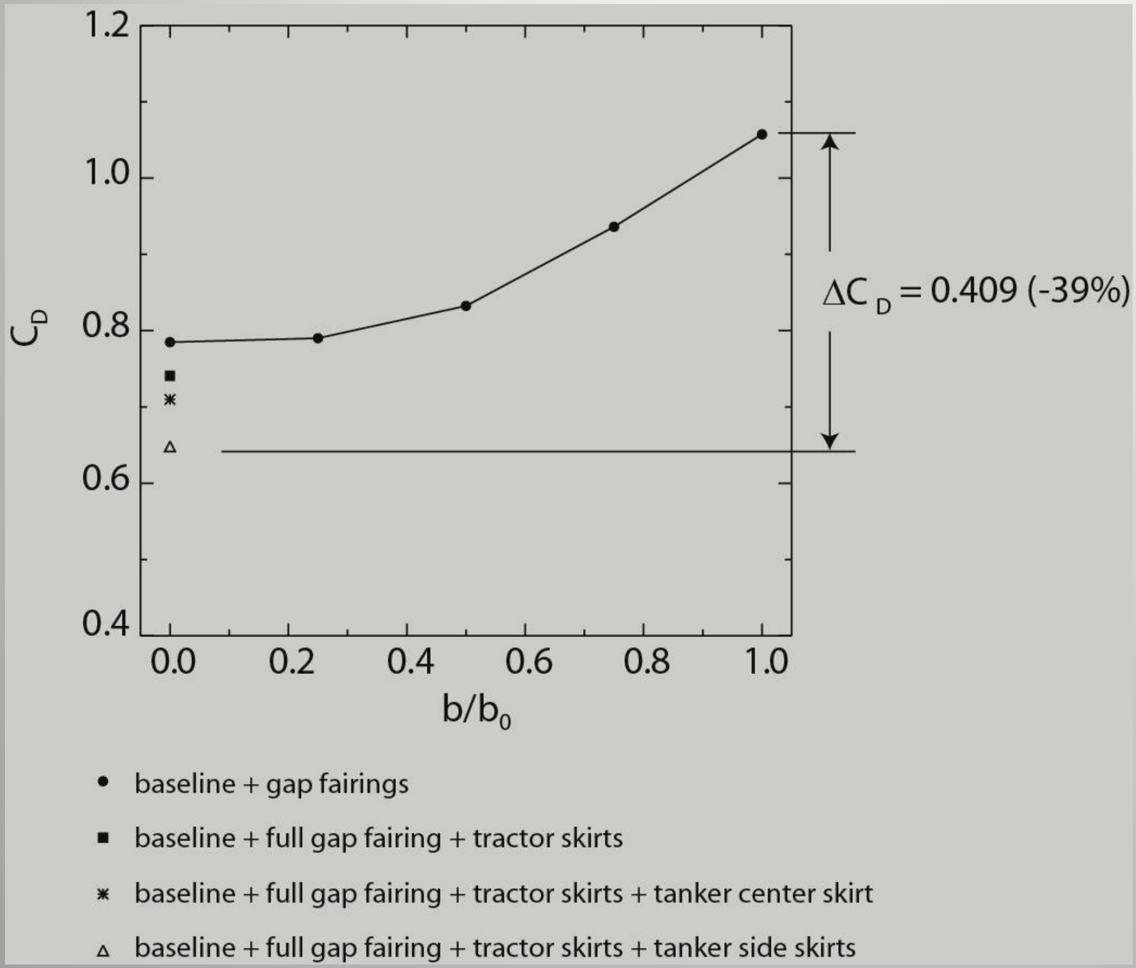


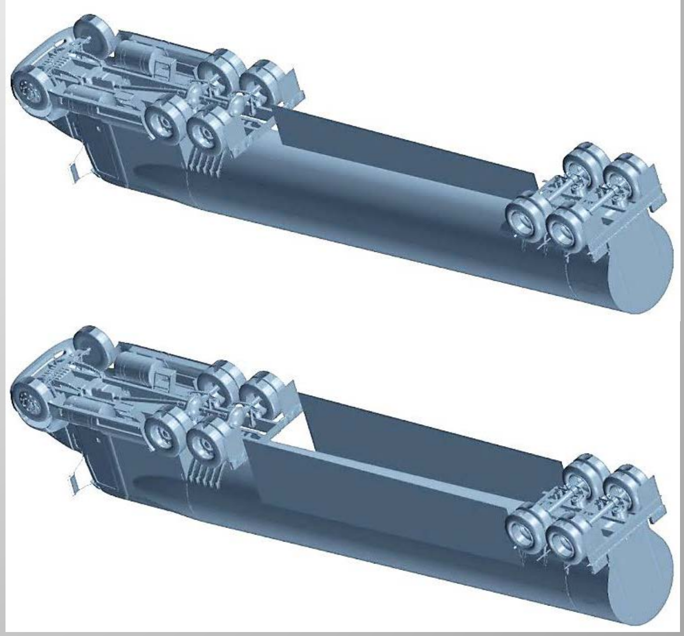
tractor skirts



- Tractor skirts (wheel-to-wheel) provide an additional ΔC_D = -0.044 over the complete gap fairing alone

The drag coefficient can be further reduced by treating the tanker underbody





Future plans

- **Tractor-trailer integration is the next step toward significant fuel economy improvement (> 50% aerodynamic drag reduction compared to heavy vehicles on the road today)**
- Continue with the track and on-the-road performance evaluation of integrated aerodynamic treatments
- Conduct scaled experiments to validate the performance of integrated aerodynamic treatments of tractor-trailers and tankers
- Continue to work with tanker fleets to improve fuel economy
- On behalf of DOE, continue to coordinate industry participation to design the next generation of highly aerodynamic heavy vehicles

Summary

- Completed the full-scale wind tunnel test analysis and documentation in collaboration with Navistar, Michelin, and a number of device manufacturers
    - Two tractors, three trailers, and twenty-three devices were tested
- Performed track tests of selected aerodynamics devices in collaboration with Navistar, Freight Wing, and Michelin
- Continue collecting and analyzing on the road device performance data with our team: Navistar, Kentucky Trailer, Freight Wing, Michelin, Frito-Lay, and Spirit
- Evaluated the aerodynamic performance of curved tail devices
- Achieved major reduction in aerodynamic drag for tanker trailers through geometry modifications