DOE's Effort to Reduce Truck Aerodynamic Drag through Joint Experiments and Computations

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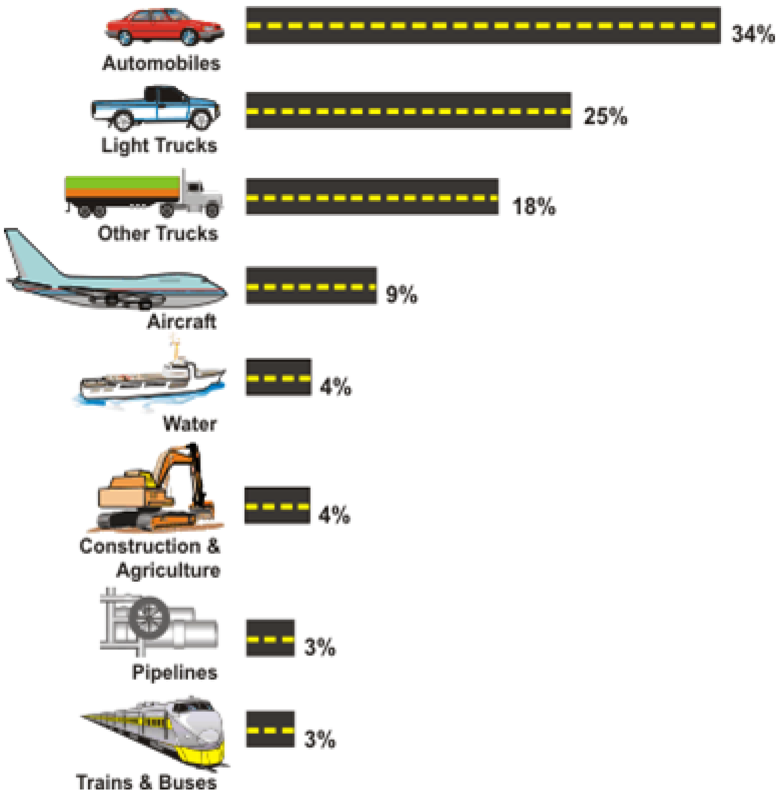
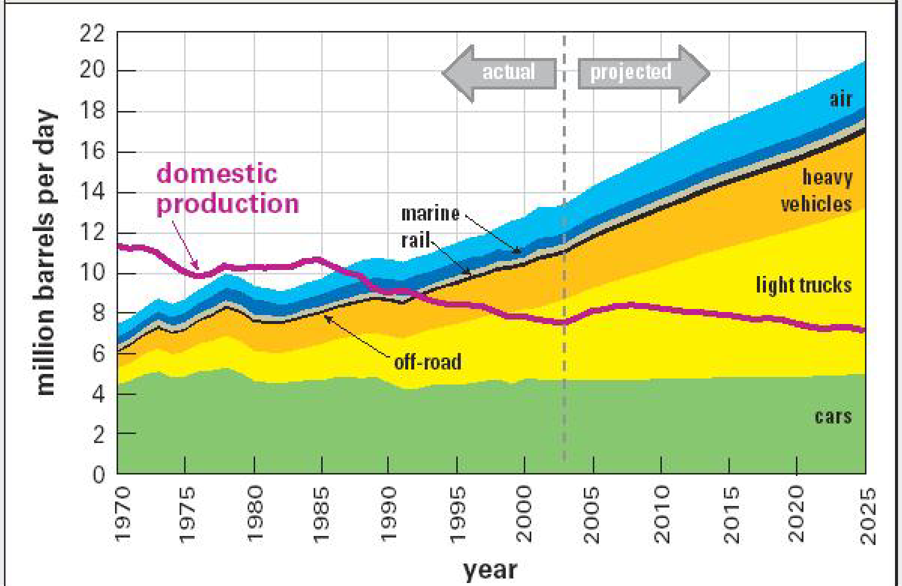
FreedomCAR and Vehicle Technologies Program

Class 8 tractor-trailers are responsible for 11 – 12% of the total US consumption of petroleum

1% increase in fuel economy = 245 million gallons diesel fuel/year saved

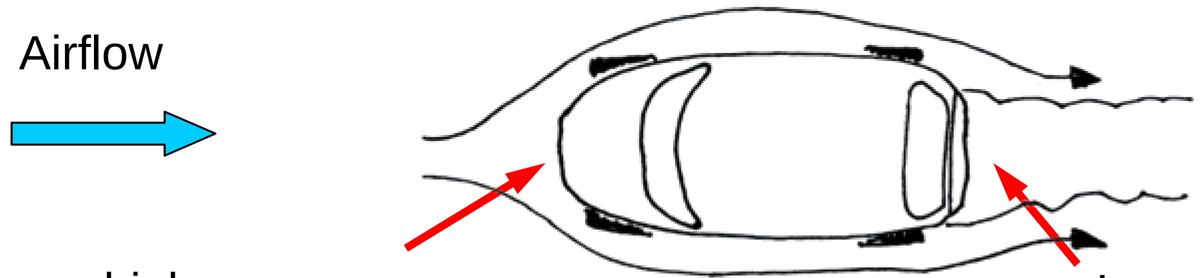




Source: *Transportation Energy Data Book: Edition 23*, DOE/ORNL-6970, October 2003; and *EIA Annual Energy Outlook 2004*, January 2004.

How can we help to reduce consumption: Aero shaping and slowing down are a huge benefit

Most drag is from pressure difference



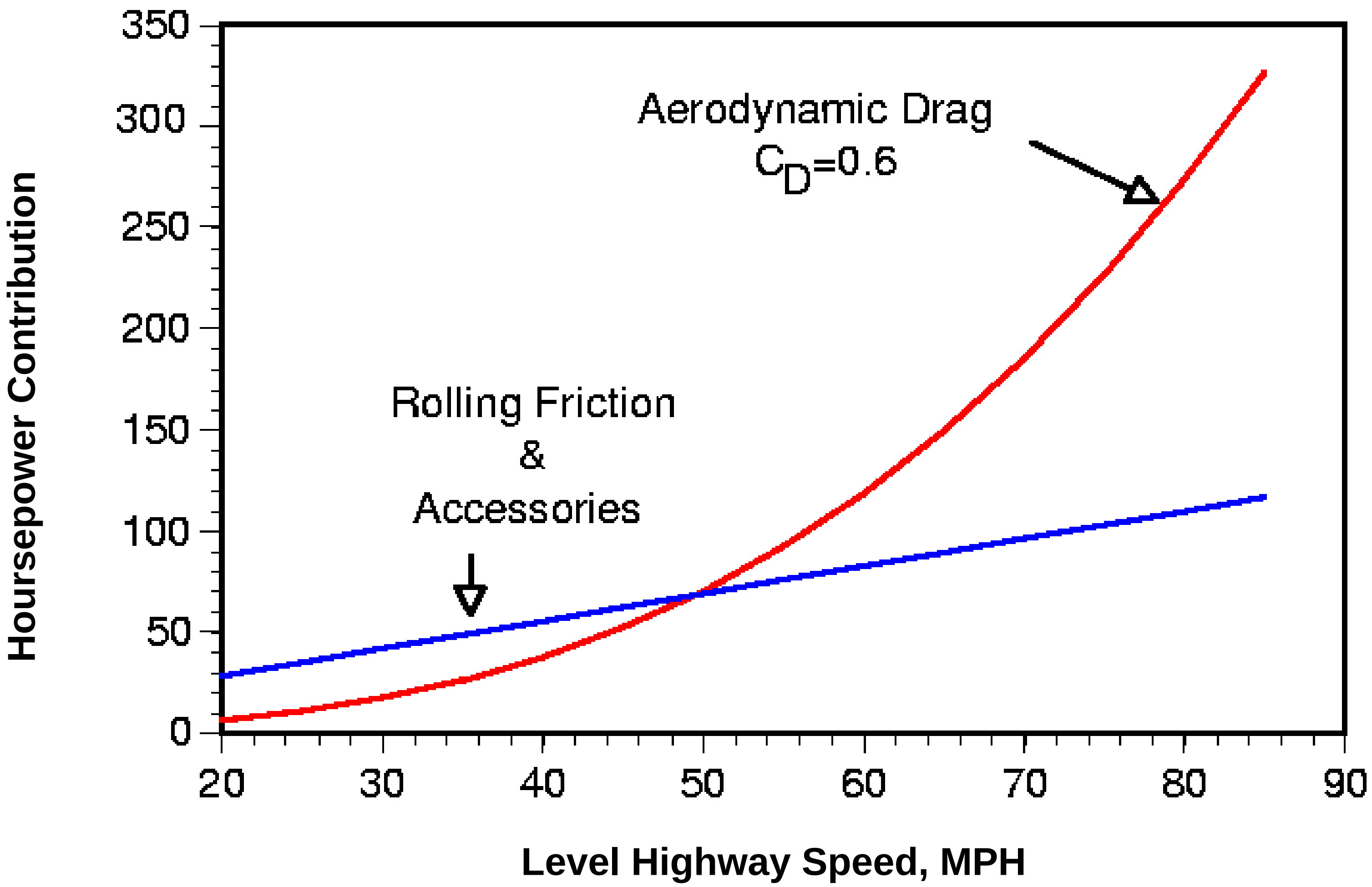
$$D = C_D \times S \times (1/2)\rho U^2$$

factor of 3 !

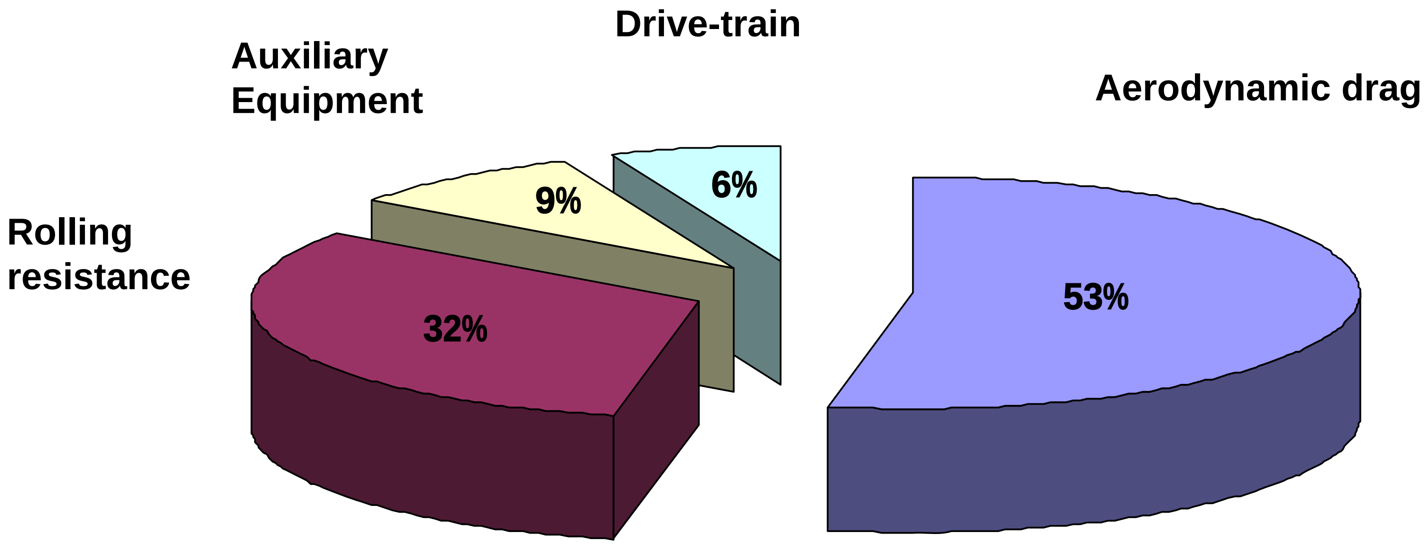
$$\frac{\Delta FuelConsumption}{FuelConsumption} = \eta \times \left(\frac{\Delta C_D}{C_D} + \frac{\Delta S}{S} + \frac{3\Delta U}{U} \right)$$

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

Overcoming aero drag represents over 50% of energy expenditure at highway speeds



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



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

The goal is to reduce aerodynamic drag and improve fuel economy

Objectives

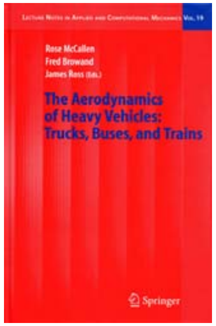
- ***In support of DOE's mission***, provide guidance to industry in the reduction of aerodynamic drag
- ***To shorten and improve design process***, establish a database of experimental, computational, and conceptual design information
- ***Demonstrate*** new drag-reduction techniques
- ***Get devices on the road***

The goal is to reduce aerodynamic drag and improve fuel economy, …

Accomplishments

- ***Drag reduction concepts developed/tested***
- ***Insight and guidelines*** for drag reduction provided to industry through computations and experiments
- ***Joined with industry*** in getting devices on the road and providing design concepts through virtual modeling and testing
- ***International recognition* achieved** through open documentation, database, and conferences

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



Annual review meetings

One to two per year meetings with other R&D organizations and industry

Workshops

Phoenix, AZ; Livermore, CA; Detroit, MI

Conference papers, panel participants at SAE and TMC meetings

2003 Monterey Conference

Organized an international conference titled, ***The Aerodynamics of Heavy Vehicles: Trucks, Busses, and Trains***, Asilomar Conference Center in Monterey, California on December 2-5, 2003. Attendees included top scientists and engineers in the field of aerodynamics from universities, government laboratories, and industry. The conference was sponsored by the United Engineering Foundation (UEF) with DOE as a major contributor. LLNL also provided support for a speaker and Freightliner, International, and Volvo heavy vehicle manufactures supported 3 separate evening socials. Team members presented several papers at the conference describing the goals and objectives of the DOE Project highlighting recent activities and results was constructed and displayed in the conference reception hall.

2007 Tahoe Conference

Organized an international conference titled, ***The Aerodynamics of Heavy Vehicles II: Trucks, Buses, and Trains***, Granlibakken Conference Center in Tahoe City, California on August 26-31, 2007. Attended by over 80 people from academia, fleet companies, aerodynamic testing centers, automobile, tractor, trailer, engine, and tire manufacturing companies, CFD software companies, high-speed train manufacturing companies, and national laboratories. The objective of this conference was to provide a forum for discussing the development and application of advanced computational and experimental methods for the aerodynamic design of trucks, buses, and trains. In addition, the conference gave the opportunity for fleet operators and tractor and trailer manufacturers to share an industry perspective on the shortcomings of current drag reduction devices and to make suggestions for operationally-minded improvements for these devices. **A follow-on conference to take place in two to three years in Europe is currently in the planning stages.**

Approach: design & optimize devices/concepts with industry collaboration and feedback

New devices and integration concepts
- Science based

Virtual testing environment
- Full-scale conditions
- Realistic truck geometry
- Moving ground plane
- Crosswind effects

Collaborative Efforts

Industry
- Manufacturers
- Fleets

Scientists
- National Labs
- NASA
- Universities

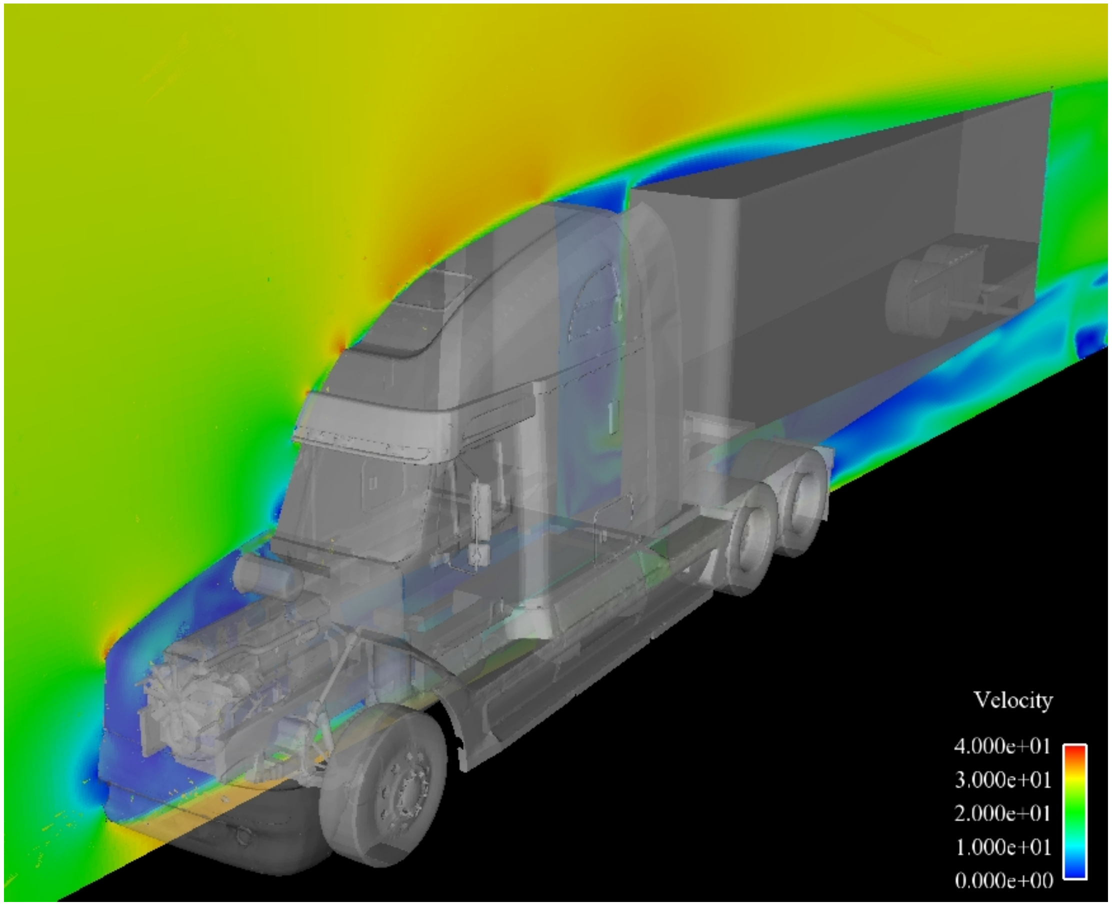
Full-scale wind tunnel validation
- NASA Ames 80x120
- NRC, Canada
- Freightliner

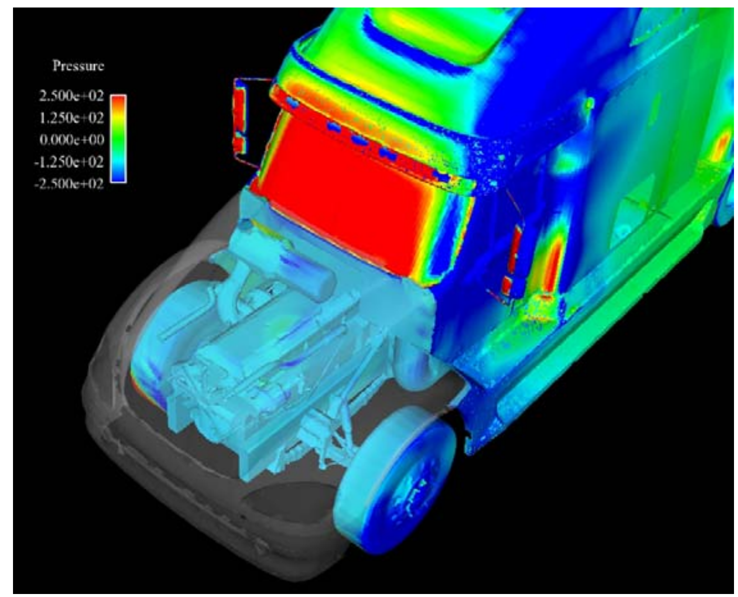
Track & road demonstration
- Manufacturers
- Fleets
- Scientists

Getting drag reducing add-on devices on the road

- **Full-scale wind tunnel validation of selected devices with industry collaboration and feedback (International, Michelin, …)**
- **Track and road test selected devices**
- **Identify candidate devices with commercialization potential**
- **Work through any operational issues with a third party device manufacturer**

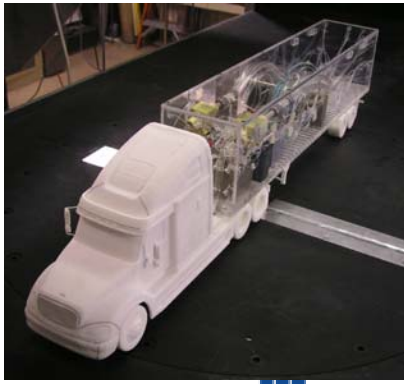
Computational fluid dynamics simulations are used to evaluate heavy vehicle aerodynamics with add-on devices



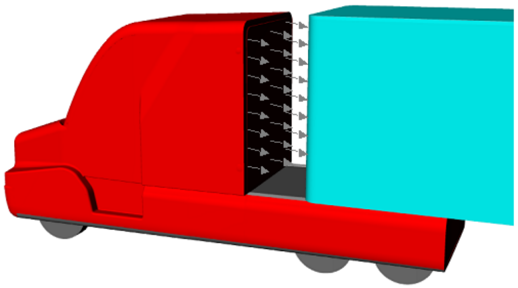


Research efforts are focused on simulation driven designs and experimental validation

- **Simulations**
  - **Underbody – alternative concepts to side skirts**
    - **ΔC_D = 0.04 (6.5%) drag reduction**
  - **Gap flow treatment**
    - **Uniform bleeding flow from 0 to 20% of free stream velocity**
    - **ΔC_D = 0.07 (15%) for 10% free stream**
    - **ΔC_D = 0.15 (30%) for 20% free stream**
    - **Not accounting for power input**
- **Reduced-scale experiments on tractor base bleeding**
  - **Freightliner Columbia model in NASA wind tunnel**
  - **Generic model in USC water channel**
- **Full-scale experiments on tractor base bleeding**
  - **Freightliner tractor in Freightliner wind tunnel**
- **Planning stages for full-scale experiments at NASA Ames 80x120 wind tunnel**
  - **With industry collaboration (International, Michelin, …)**

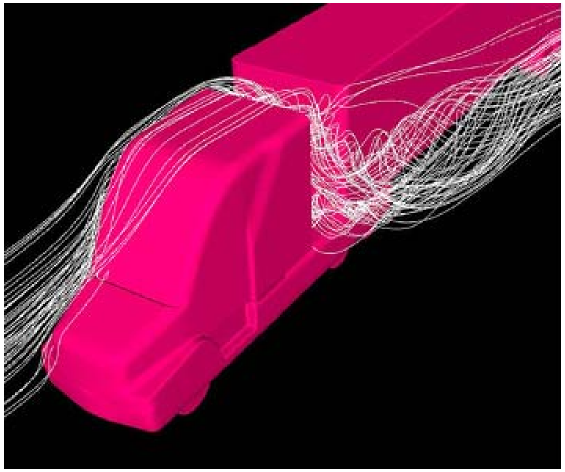


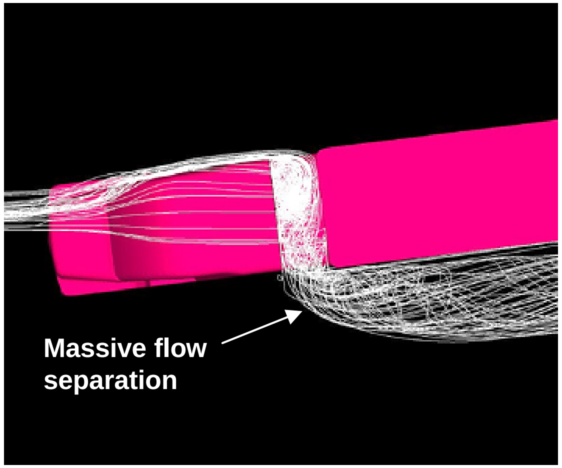
Tractor base bleed drag reduction concept



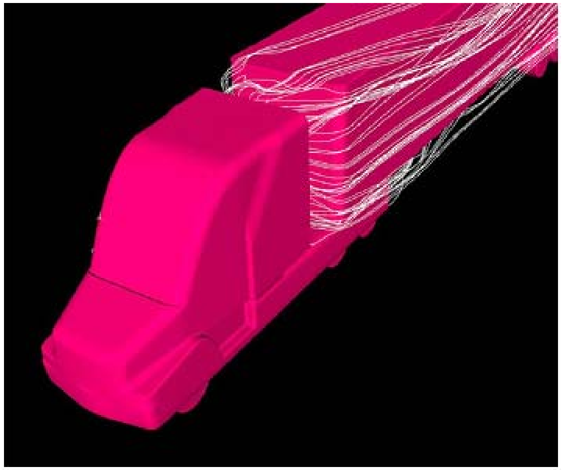
Gap bleeding flow

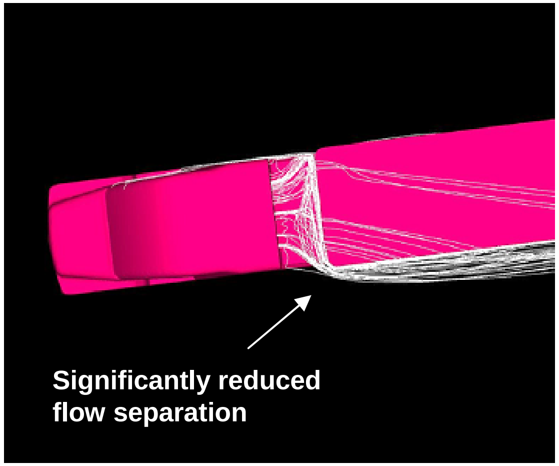
No bleeding, 6° yaw angle





With bleeding, 6° yaw angle



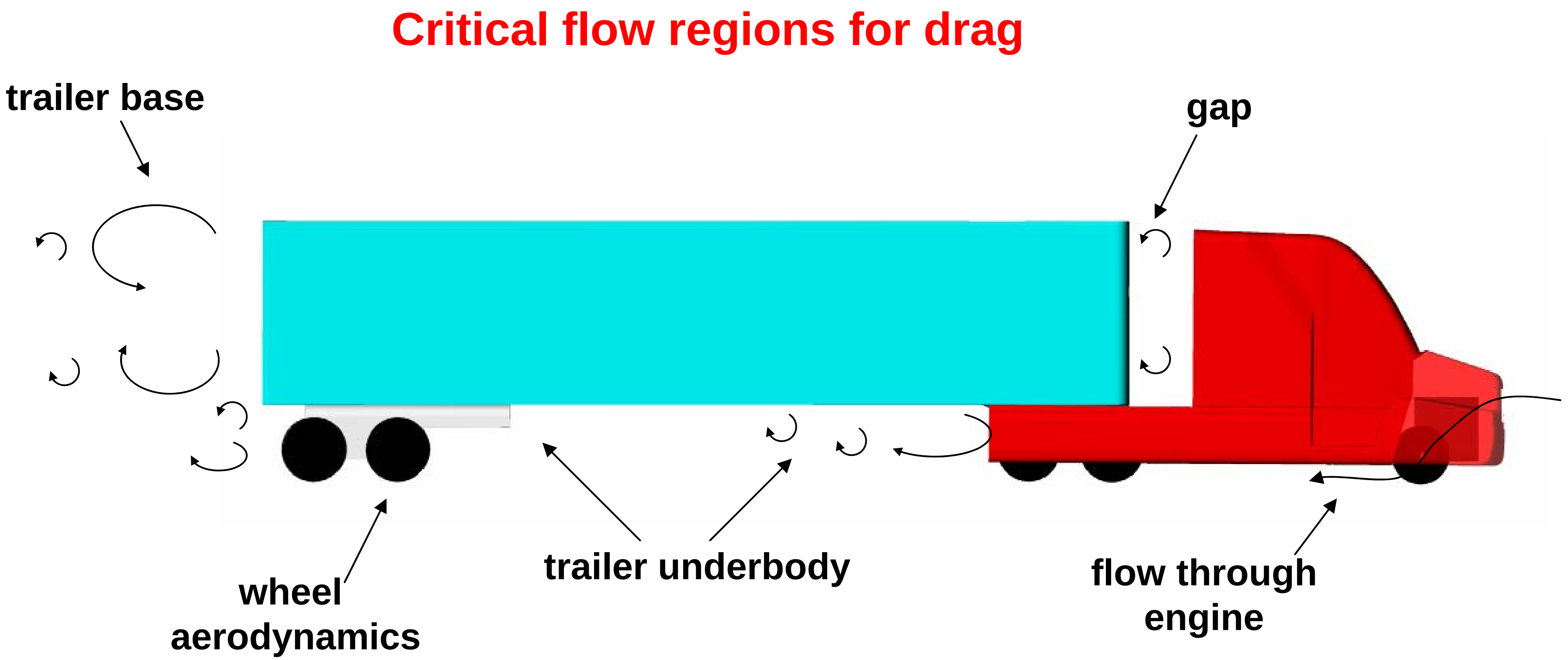


Heavy vehicle drag evaluation using CFD simulations

	C_d	C_d pres	of total	C_d vis	of total
Tractor	0.431	0.417	97%	0.014	3%
Trailer body	0.106	0.078	74%	0.028	26%
Trailer axle & wheel assembly	0.112	0.107	96%	0.005	4%
Vehicle	0.649	0.602	93%	0.047	7%

	C_d	of total
Tractor	0.431	66%
Trailer	0.208	34%
Vehicle	0.649	100%

Means of achieving drag reduction



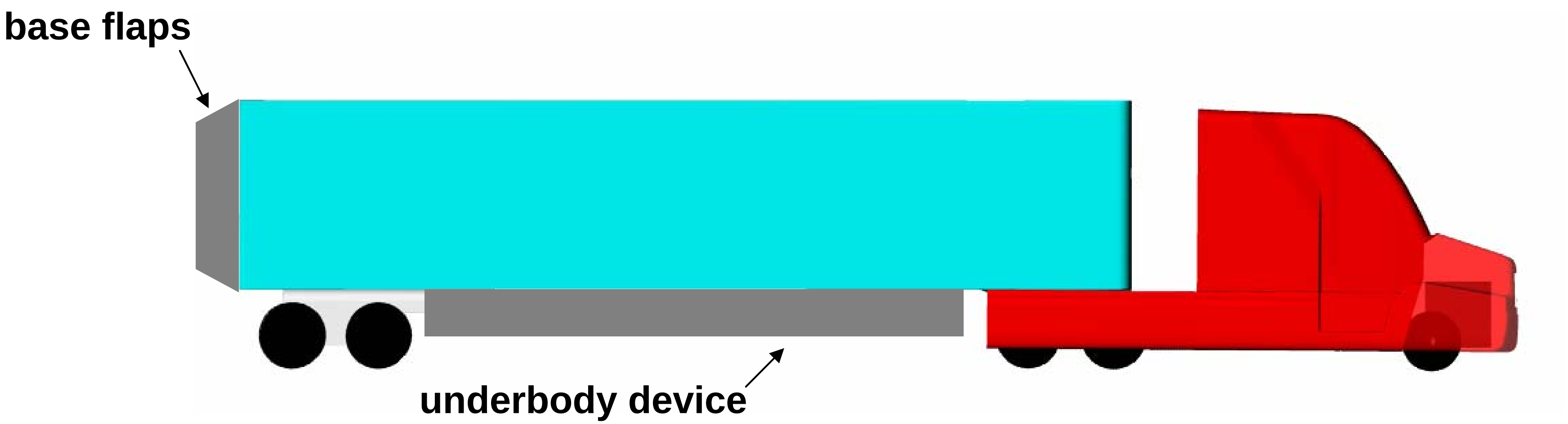
Achieve drag reduction by
- Geometry modification
- Flow conditioning

Means of achieving drag reduction

Base devices tested: (at least 12 concepts)

Offset boattail plates
Angled base flaps with matching seams of each flap
Angled base flaps with gaps between each flap seam
Angled base flaps forming an octagon shape (since corners were taped)
Offset boattail plates used in combination with fillets
Curved offset boattail plates
Base bleed
Trailer base with a radius of curvature
Horizontal plate located at trailer base and extending into wake
Winglets to produce counter-rotating vortice in wake
Acoustic perturbation concept
Coanda blowing

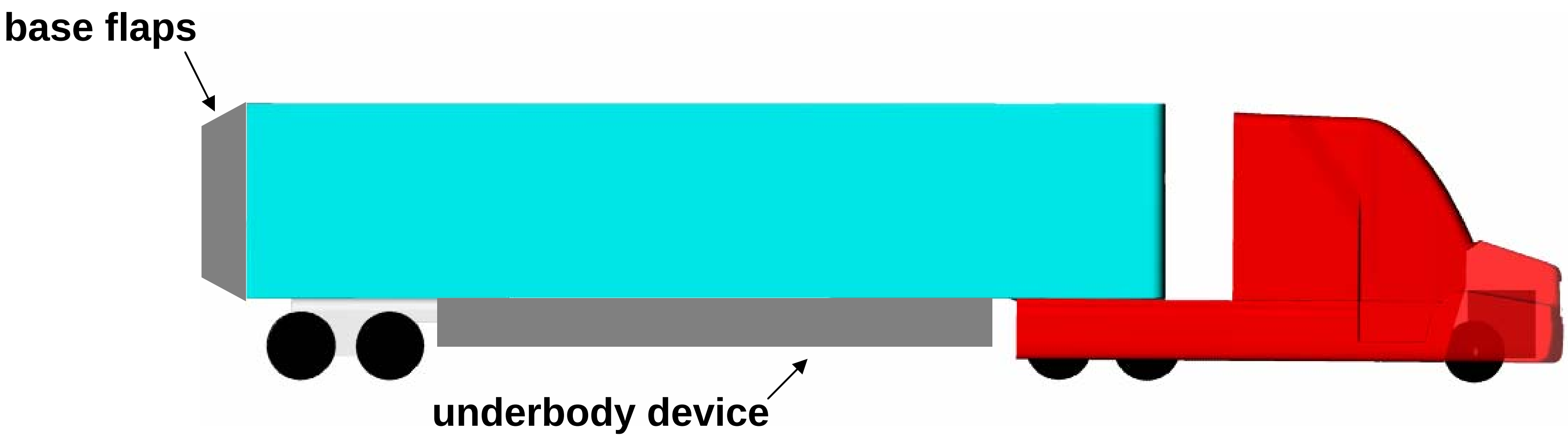
Means of achieving drag reduction

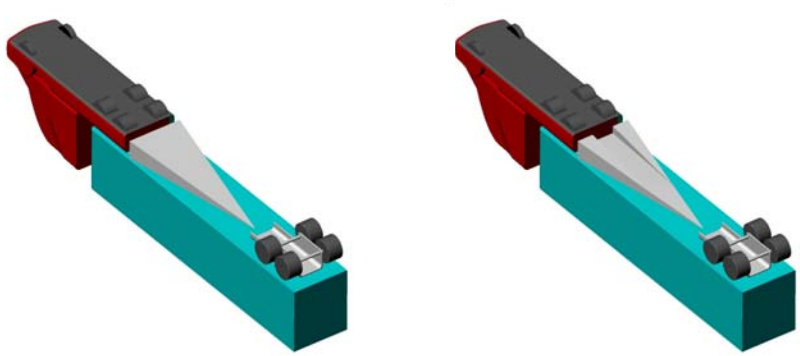


Underbody devices tested: (at least 6)

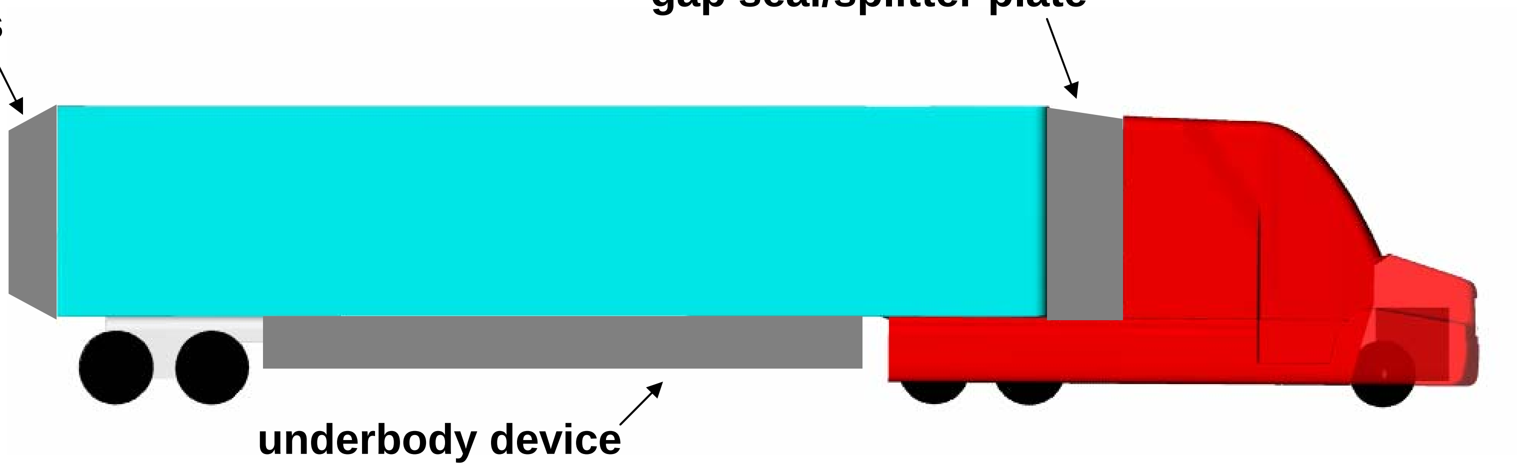
Straight skirts (long and short)
Wedge skirts (long and short)
Wedge skirts with centerline skirt
Underbody fairings
Belly box
Skirts that surround the entire trailer underbody

Means of achieving drag reduction





Means of achieving improved fuel economy



Gap devices tested: (at least 5)

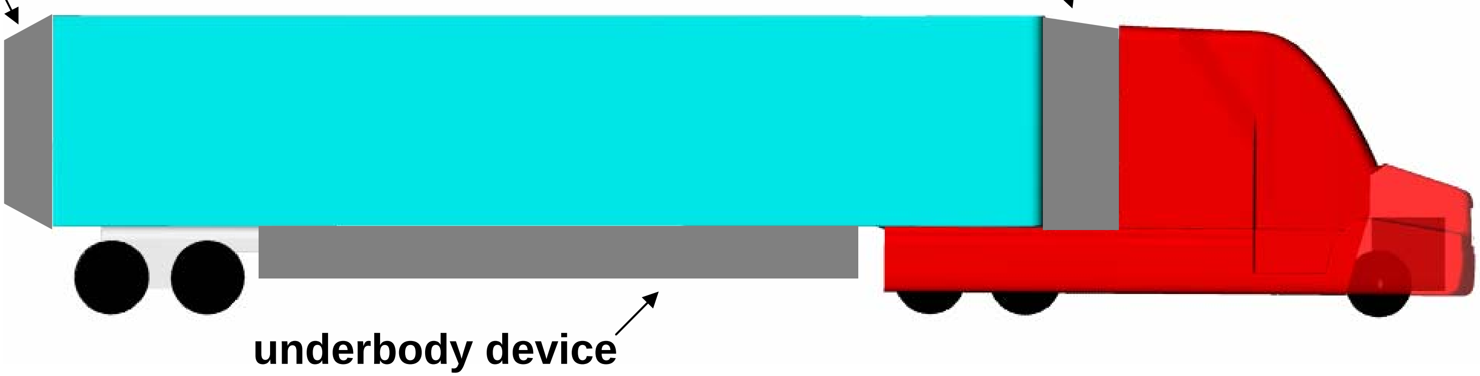
Base bleed
Side extenders
Roof extender
Splitter plate
Gap sealer

Patents and Record of Inventions

Patents and ROIs (8)

1. **Provisional patent:** Drag reduction of a heavy vehicle by means of a trailer underbody fairing
2. **Patent application**: Wide area base bleed/injection apparatus for reducing aerodynamic drag of bluff body vehicles
3. **Patent:** Apparatus and Method for Reducing Drag of a Bluff Body in Ground Effect Using Counter-Rotating Vortex Pairs
4. **Patent:** Boattail Plates with Non-Rectangular Geometries for Reducing Aerodynamic Base Drag of a Bluff Body in Ground Effect
5. **Patent:** Aerodynamic Drag Reduction Apparatus for Gap-Divided Bluff Bodies such as Tractor-Trailers
6. **Patent:** Aerodynamic drag reduction apparatus for wheeled vehicles in ground effect
7. **ROI:** Aerodynamic drag and stability control of a heavy vehicle through the use of articulating base flaps
8. **ROI:** Drag reduction of a bluff body in ground effect through the use of wedge shaped boattail plates

Performance of add-on devices



- **Base flaps: 4-10% FEI**
- **Underbody devices: 5-6% FEI**
- **Gap devices: 1-2% FEI**

Significant performance data exists for the trailer base-flaps

Base-flaps

- **Track Test: Transtex/Wabash/USC – 4.2% fuel savings**
- **Road Test: Transtex/DFS – 6% fuel savings**
  Clarkson University – 10% fuel savings

Transtex/Wabash/USC

Transtex/DFS, Canada

Clarkson University

Future Plans: Simulation guided design and optimization of devices/concepts with industry teaming

- **CFD Simulations**
  - **Underbody devices**
  - **Tractor base bleeding flow**
  - **Device optimization**
  - **Vehicle integration**
- **Full-scale experiments**
  - **Teaming with industry**
  - **Wind tunnel testing, e.g.,**
    - **NASA Ames 80x120**
- **Track and Road testing**
  - **Teaming with fleets, e.g.,**
    - **US Xpress**
    - **Robert Transportation, Canada**
    - **WAL-MART**
- **Getting devices on the road**
  - **Team with industry and a 3rd party manufacturer**
  - **Resolve any operational issues of selected add-on devices**

Great Dane's Aero2 design

Other fuel economy and safety issues related to aero

Rolling resistance – parasitic energy loss

Splash & spray – safety

Collaborative effort with USC/Michelin/LLNL