Collaborators

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Work sponsored by
U.S. Department of Energy
Energy Efficiency and Renewable Energy
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
How can we help to reduce consumption: Aero shaping and slowing down are a huge benefit

Most drag is from pressure difference

Airflow

higher pressure

Net pressure force

lower pressure

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

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

\( \eta = 0.5 - 0.7 \)

shape cross-section speed

factor of 3!
Overcoming aero drag represents over 50% of energy expenditure at highway speeds.

![Graph showing the contribution of aerodynamic drag and rolling friction to horsepower at different highway speeds.](image-url)
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

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

Track & road demonstration
- Manufacturers
- Fleets
- Scientists

Collaborative Efforts
Industry
- Manufacturers
- Fleets

Scientists
- National Labs
- NASA
- Universities
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
    - $\Delta C_D = 0.04$ (6.5%) drag reduction
  - Gap flow treatment
    - Uniform bleeding flow from 0 to 20% of free stream velocity
    - $\Delta C_D = 0.07$ (15%) for 10% free stream
    - $\Delta C_D = 0.15$ (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

No bleeding, 6° yaw angle

Gap bleeding flow

Massive flow separation

With bleeding, 6° yaw angle

Significantly reduced flow separation
Heavy vehicle drag evaluation using CFD simulations

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Means of achieving drag reduction

Critical flow regions for drag

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

base flaps

underbody device
Means of achieving improved fuel economy

Gap devices tested: (at least 5)
- Base bleed
- Side extenders
- Roof extender
- Splitter plate
- Gap sealer
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


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
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