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

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April 2006

Work sponsored by
U.S. Department of Energy
Energy Efficiency and Renewable Energy
FreedomCAR and Vehicle Technologies Program

*Work performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract W-7405-ENG-48.

DOE Consortium for Aerodynamic Drag of Heavy Vehicles

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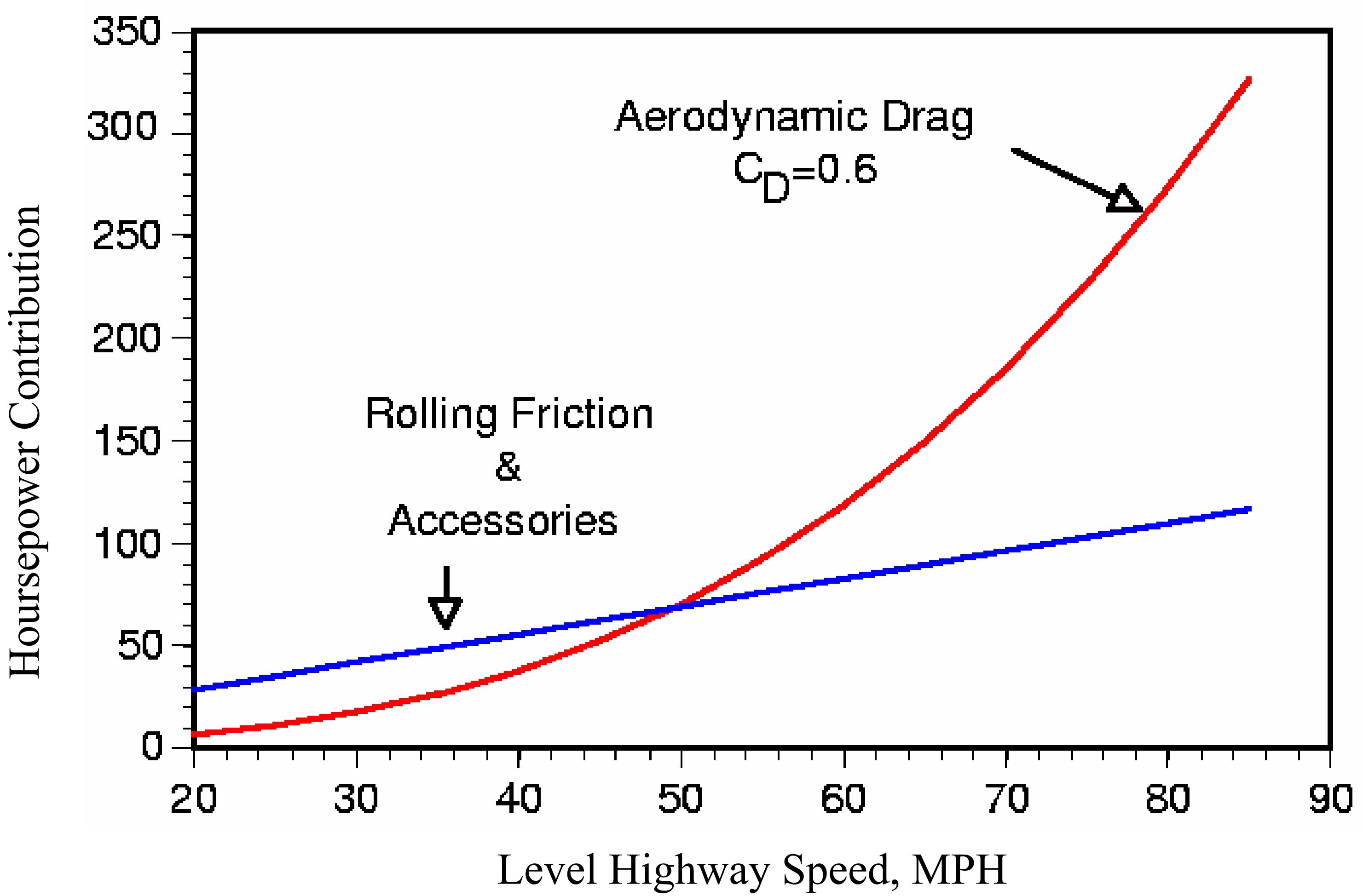
Class 8 tractor-trailers are responsible for 11 – 12% of the total US consumption of petroleum

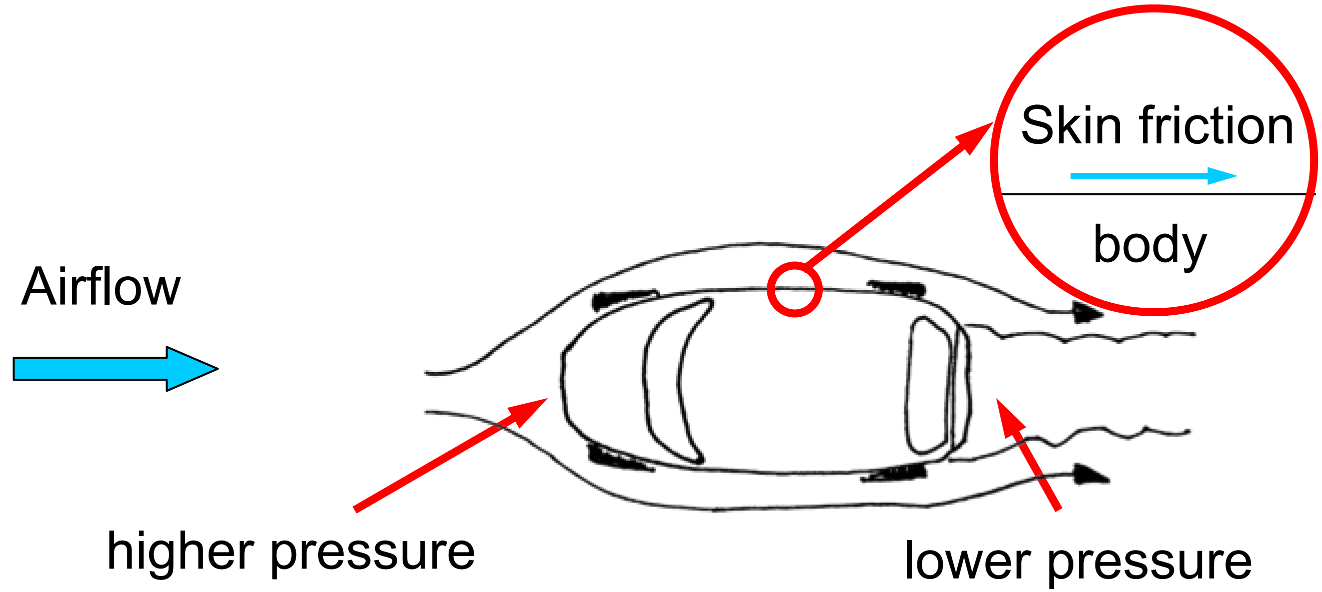
2002 Statistics

- 2.2 million registered trucks
- 138.6 billion miles/year driving, 3-4% increase/yr
- 5.2 mpg
- 26 billion gallons of diesel fuel/year consumed, 4-5% increase/yr
- 2.1 to 2.4 million barrels crude oil per day
- 19.7 million barrels crude oil per day total US consumption

Overcoming aero drag represents 65% of energy expenditure at highway speeds



Most of the drag 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

Reducing highway speeds is very effective

Relationship between changes in drag and changes in fuel consumption

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

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

make changes in shape
to improve aerodynamics

make the car/truck
cross-section smaller

reduce highway
speeds— factor of 3 !

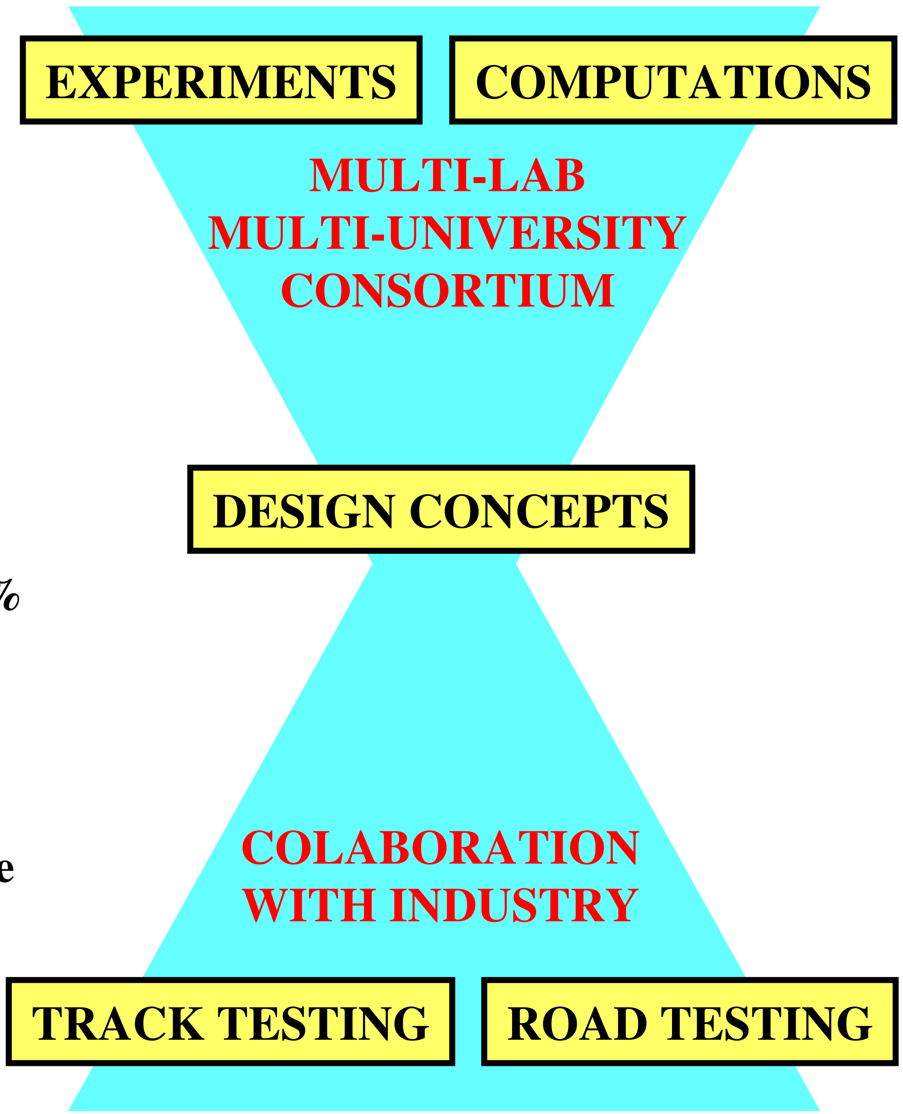
The goal is to reduce aerodynamic drag by 25% - 12% improved fuel economy or 4,200 million gal/year

Objectives

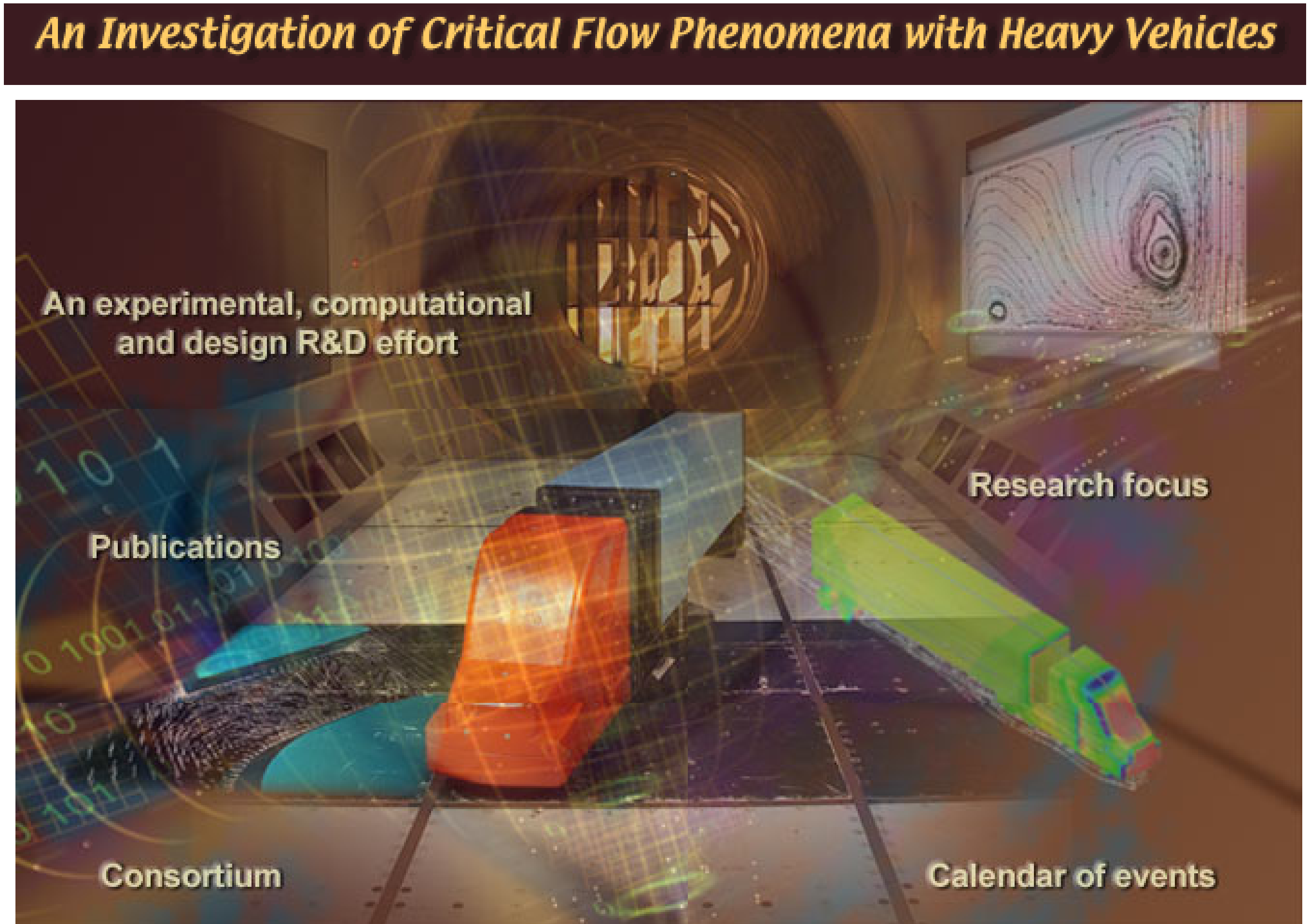
- In support of DOE's mission, provide guidance to industry in the reduction of aerodynamic drag
- To shorten and improve design process, establish a database of experimental, computational, and conceptual design information
- Demonstrate new drag-reduction techniques
- Get devices on the road

Accomplishments

- Concepts developed/tested that exceeded 25% drag reduction goal
- 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 and database



Well attended, documented yearly meetings with industry and website have been very beneficial



http://en-env.llnl.gov/aerodrag/

Effectively disseminate information to industry and have international recognition as the world 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

Magazine articles
Several in Design News

International UEF Conference, December 2002, Monterey, CA

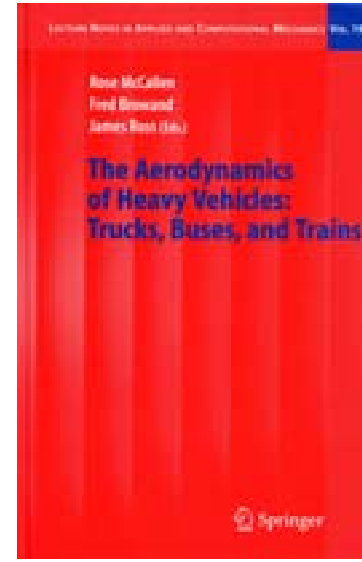
Papers, panel participants at SAE, AIAA, TMC meetings

Papers at Jul 2004 AIAA meeting, Portland Oregon

1. *DOE's Effort to Reduce Truck Aerodynamic Drag – Joint Experiments and Computations Lead to Smart Design*
2. *Evaluation of Commercial CFD Code Capabilities for Prediciton of Heavy Vehicle Drag Coefficients,* ANL
3. *A Study of Reynolds Number Effects and Drag-Reduction Concepts on Generic Tractor-Trailer,* NASA
4. *An Experimental Study of Drag Reduction Devices for a Trailer Underbody and Base*, LLNL
5. *Computational Prediction of Aerodynamic Forces for a Simplified Integrated Tractor-Trailer Geometry*, LLNL
6. *Characterization of the Flow Structure in the Gap Between Two Bluff-Bodies*, USC
7. *Unsteady Turbulent Flow Simulations of the Base of a Generic Tractor/Trailer*, Auburn and SNL
8. *2-D, Bluff Body Drag Estimation using a Green's Function/Gram-Charlier Series Approach*, SNL

Papers at Nov 2005 SAE meeting, Chicago, Il

1. *DOE's Effort to Reduce Truck Aerodynamic Drag through Joint Experiments and Computations,* McCallen, et al.
2. *Development of Guidelines for the Use of Commercial CFD in Tractor-Trailer Aerodynamic Design,* Pointer, Sofu, ANL
3. *Computational Fluid Dynamics Simulations of Heavy Vehicle Aerodynamic Drag Reduction Devices,* Ortega, LLNL
4. *Detailed Experimental Results of Drag-Reduction Concepts on a Generic Tractor-Trailer,* Storms, et al, NASA Ames
5. *Wind Tunnel Test of Cab Extender Incidence on Heavy Truck Aerodynamics,* Radovich, USC
6. *A comparison of Spray Dispersion Calculations in a Heavy Vehicle using Unsteady RANS and LES,* Paschkewitz, LLNL
7. *Entrainment and Ejection from Rolling Tires – Understanding Tire Splash,* Eastwood, Salari, LLNL, Browand, et al, USC
8. *Computational Simulation of Tractor-Trailer Gap Flow with Drag-Reducing Aerodynamic Devices,* Castellucci, Salari, LLNL
9. *Improved Pneumatic Aerodynamics for Drag Reduction, Fuel Economy, Safety and Stability Increases for Heavy Vehicles,* Englar, GTRI



Fleets are profit driven and safety and driver comfort must be considered

Several trailers for every tractor

- Devices on trailer must be more economical

Maintenance, initial cost

- Devices add to cost & maintenance
- Related brake wear & performance issues

Safety

- Brake cooling
- Visibility – passing cars, brake lights, etc.
- Stopping distance

Driver preferences

- Style & chrome
- Access to underbody
- Turning radius (side extenders restrict)
- Devices are a nuisance, can be noisy, etc.

The trucking industry is multifaceted

Separate tractor & trailer manufacturers

Fleet owners/operators

- Customer that drives manufactured design

Docks and access

- Rear loading and at given height
- Road dips, bumps, sharp turns

Regulations

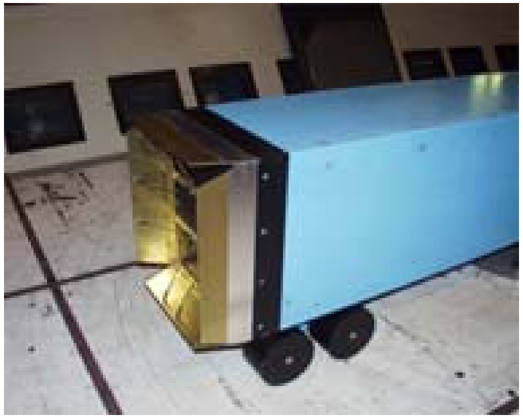
- Boattail can extend up to 5-ft from base of trailer – as of 4/02
- Control on trailer length NOT overall length

Conventional or Bullnose

Cabover Engine

Goal - *Reduce heavy vehicle drag by 25%*

Approach



Identify major contributors to drag

- **Experiments**
- **Simulations**

Design drag reducing add-on devices

- **Utilize knowledge from experiments and simulations**

Evaluate add-on devices using

- **Wind tunnel experiments**
- **Simulation**
- **Track tests**
- **Road tests**

Get drag reducing add-on devices on the road

- **Assist with operational and design concerns**


NEAR-TERM BENEFIT
baseflaps
NORCAN ALUMINIUM
TRANSTEX COMPOSITE
aerovolution
Top Cab Extender
Taper
Incidence Angle Adjusters
Tractor/trailer model in 12' PWT
25% DRAG REDUCTION
U.S. XPRESS ENTERPRISES, INC.
FREIGHTLINER
PACCAR Inc
VOLVO
Mack
MICHELIN
A better way forward
INDUSTRY INVOLVEMENT
GOOD SCIENCE

Leveraged industry funding for track and road testing

Base-flaps

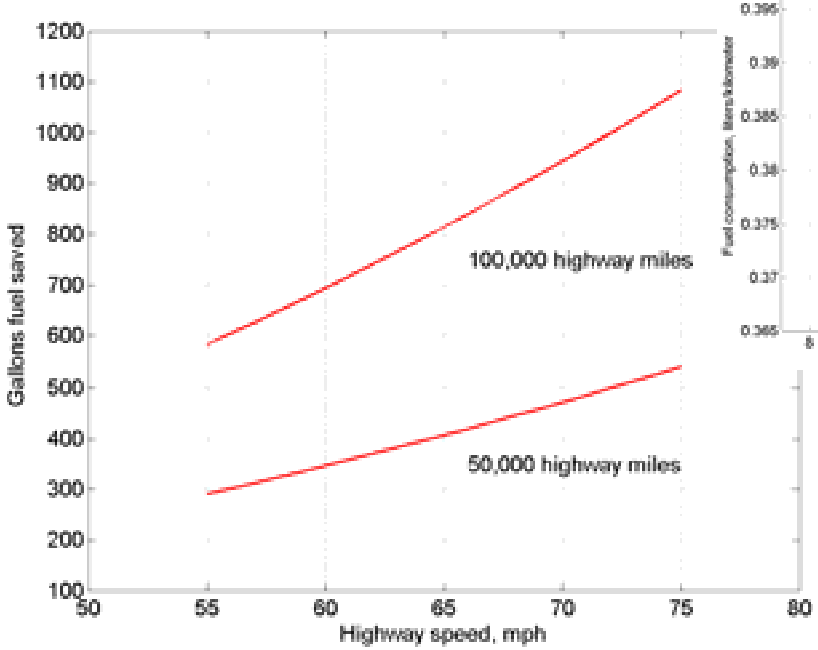
Track Test: NORCAN/Wabash/USC – 4.2% fuel savings

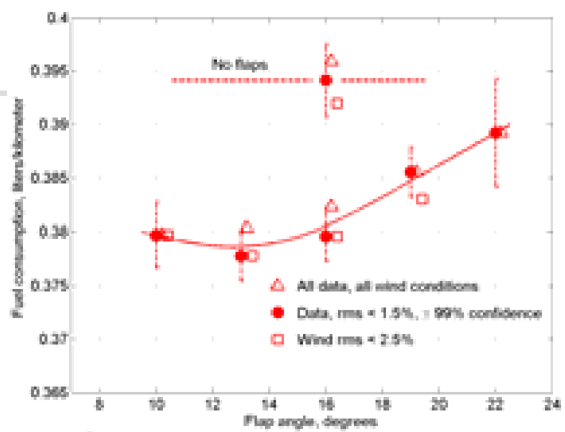
Road Test: NORCAN/DFS – 6% fuel savings

Clarkson University – 10% fuel savings

Pneumatic Device

Track Test: Volvo/Great Dane/GTRI





Add-on devices have big pay-off but have operational and maintenance issues

Increased Fuel Economy Possible

> 4% trailer base-flaps

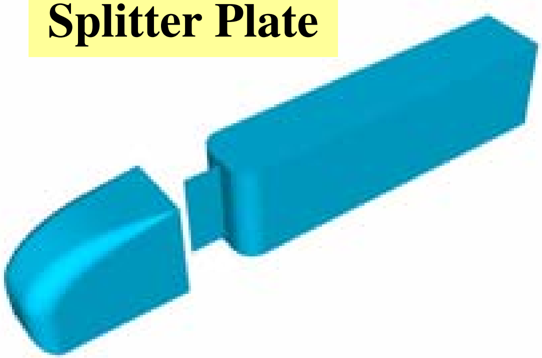
> 6% trailer skirts

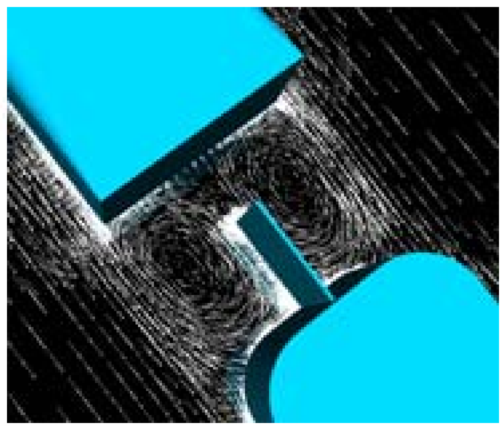
<u>> 2% gap splitter plate/side extenders</u>

> 12% Total – 130 midsize tanker ships !

Base flaps

Splitter Plate





Skirts

Addressing Issues

With our understanding of the key flow mechanisms, we are <u>developing less obtrusive and optimized innovative design concepts</u> using computational fluid dynamics and experiment

To get devices on road, consequences of aero improvements or use of devices need to be addressed

Operational and Maintenance Issues – previous slide

Tractor Aero - Underhood

Contouring hood reduces grill, reducing coolant flow

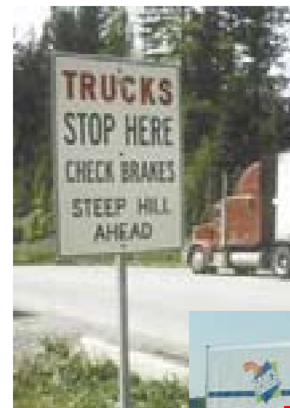
EPA 2007 regulation – more cooling needed

Devices effect Brakes

Reducing resistance

- Increases braking distance
- More braking down hills - overheating

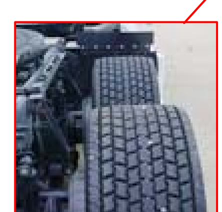
Devices restrict critical air cooling

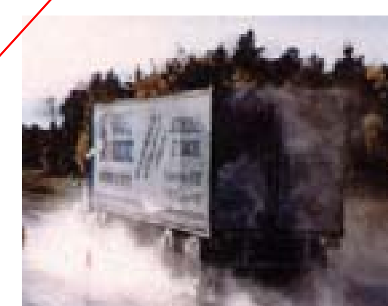


Device and Wheel Aero with Splash & Spray

Wheel aero - super singles vs duals, wheel guards/flaps, etc

Visibility: Base treatment/skirts appear to enhance upwash





Approach - Leveraging Efforts

- Overlaps with device optimization
- Industry/university support
- Seeking joint funding – DOT/EPA/industry

<u>Teaming/collaborations</u> with industry and communications with ATA/TMC, TMA have been beneficial

Vehicle Aero

Computations - PACCAR CRADA

Full-scale wind tunnel testing – NRC Canada collaboration

Full-scale/truncated wind tunnel design – Freightliner/NASA

Road tests - seeking collaborations with Dana/ORNL

Devices

Track/road tests – NORCAN/WABASH/USC, NORCAN/DFS

Wind tunnel/track/road tests - Volvo/Great Dane/GTRI

Wind tunnel tests/design concepts – Solus, NORCAN

Computations – Aerovolution, NORCAN

Tractor Aero – Underhood

Computations - CAT CRADA, new Cummins CRADA

Experiments/Computations – NRC full-scale wind tunnel experiments

Safety – Braking distance/cooling, visibility

Experiments - Michelin funding for splash and spray

Computations - seeking joint DOT support for brake performance issues

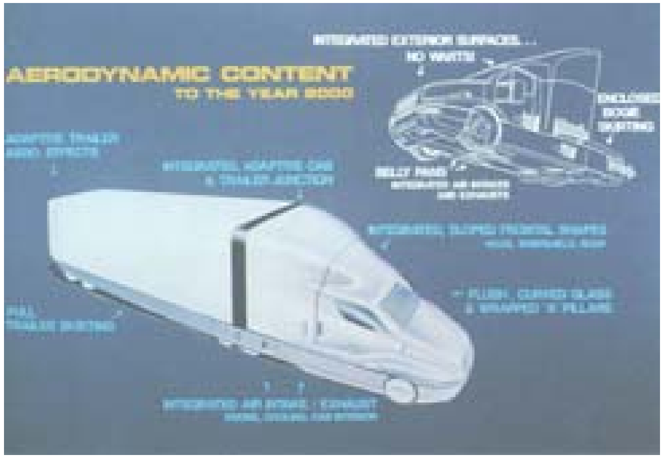
Accomplishments and Future Direction

Accomplishments

- <u>Concepts developed/tested</u> that exceeded 25% drag reduction goal
- <u>Insight and guidelines</u> for drag reduction provided to industry through computations and experiments
- <u>Joined with industry</u> in getting devices on the road and providing design concepts through virtual modeling and testing
- <u>International recognition</u> achieved through open documentation and database

Future

- <u>Virtual testing</u> capability to reduce design and testing process for less obtrusive/optimized devices
- <u>Underhood/underbody</u> investigations to improve aero & enhance thermal control
- <u>Economic & duty-cycle</u> with PSAT – Mechanistic data: Large drag contribution, variable with yaw, speed, geometry, environment, etc.
- <u>Vision</u> – integrated vehicle design



Courtesy of International Trucks

The DOE Consortium will Design the Next Generation Integrated Vehicle

- **Design from scratch**
- **Science-based approach with validation**
- **Full-scale demonstration with industry**

NEAR-TERM BENEFIT

ROCKY MOUNTAIN INSTITUTE

FREIGHTLINER

PACCAR Inc

VOLVO

Mack

MICHELIN

U.S. XPRESS ENTERPRISES, INC.

Double Vehicle Efficiency

INDUSTRY INVOLVEMENT

GOOD SCIENCE

In Memory

Dr. Sid Diamond was our DOE Program Manager, supporter, and dear friend. This Consortium effort would not exist without Sid's vision, dedication, perseverance, and passion. His enthusiasm for this project, with his wonderful gusto for life, was contagious and pushed our effort forward. He will be dearly missed.

Program Review – DOE Consortium for Heavy Vehicle Aerodynamic Drag Reduction

Relevance to DOE Objectives

- Class 8 trucks account for 11-12% of total US petroleum consumption
- 65% of energy expenditure is in overcoming aerodynamic drag at highway speeds
- 12% increase in fuel economy is possible and could save up to 130 midsize tanker ships per year

Approach

- Good Science: Computations in conjunction with experiments for insight into flow phenomena
- Near-Term Deliverables: Design concepts and demonstration (wind tunnel, track, road testing)
- Information Exchange: collaboration with industry, dissemination of information (website, conferences, workshops)

Accomplishments

- DOE Consortium: MYPP with industry, leveraged ASCI funds, complimentary, LDRD/Tech Base, University, NASA funds
  - We understand flow mechanisms/restrictions, how to design, and model/test/evaluate
- Supporting DOE objective while addressing industries' most pressing issues
  - <u>Computational modeling</u>: choice of turbulence models/wall functions, grid/geometry refinement, commercial tools, validated methodology and tools for industry guidance and use
  - <u>Experiments</u>: advanced diagnostics at relevant highway speeds in pressure wind tunnel, realistic geometry with and without devices, validation database, experimental scaling - Determined if and when okay to test scaled models at reduced speeds, and road/track tests
  - <u>Design</u>: boattails, baseflaps, blowing, splitter plate, wedges/skirts – 8 Records of Invention and 3 Patents
- Increased fuel economy : >4% base treatment, >6% skirts/wedges, ~2% gap device, savings 4,200 millions of gal/yr
- Other transportation issues that benefit, e.g., reduce drag of empty coal cars by 20%, savings 1-2 millions of gal/yr
- Addressing consequences with aerodynamics and use of devices - Underhood, brakes, visibility, etc

Technology Transfer/Collaborations

- Multi-Lab (LLNL, ANL, SNL, NASA, GTRI), multi-university (USC, Caltech, UTC, Auburn) effort with NRC-Canada
- Industry
  - Vehicle Aero - PACCAR CRADA, design of Freightliner wind tunnel
  - Devices – track tests/WT experiments/computations with NORCAN/WABASH, Volvo/Great Dane, Solus, Aerovolution
  - Underhood - CAT CRADA complete, new Cummins CRADA, NRC-Canada full-scale wind tunnel testing
  - Safety - Michelin splash/spray funding, sought DOT support
  - Fleets – US Xpress, Dana, DFS, Payne

Future Directions – Integrated vehicle design

- Getting devices on road
  - Develop less obtrusive/optimized device concepts and transfer technology to industry
  - Demonstration wind tunnel, track, road tests - leverage work with Dana/ORNL, NRC-Canada, TMA
- Underhood - improved aerodynamics with enhanced thermal control
- Economic/duty cycle evaluation with PSAT
  - Provide mechanistic data, review road/track test plans, provide needed assistance in calibration/evaluation to Dana/ORNL