Lawrence Livermore National Laboratory

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

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National Full-Scale Aerodynamics Complex (NFAC) Ames Research Center

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Overview

Timeline

On going

- FY10 large-scale wind tunnel test at NASA Ames research center, NFAC facility, 90% complete

Barriers

Target

- By 2013 - Reduce aerodynamic drag of class 8 tractor-trailers by approximately 25% leading to a 10-15% increase in fuel efficiency at 65 mph

Budget

- Total project funding prior to FY09, $3.1M
- Funding received in FY09, $400K
- Funding for FY10, $700K

Partners

- Navistar, Inc.
- Michelin
- Freight Wing Inc.
- Kentucky Trailer
- Frito-Lay

Objectives

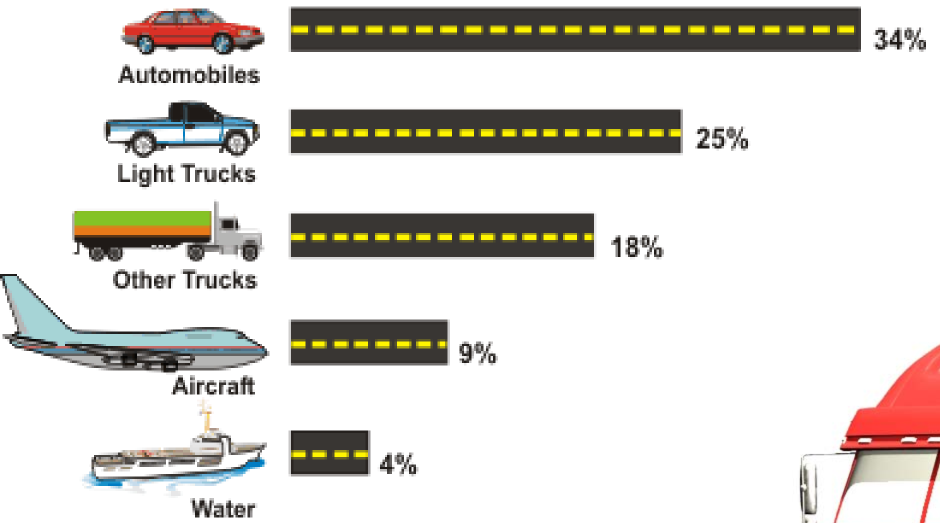
- ***In support of DOE's mission,*** provide guidance to industry to improve the fuel economy of class 8 tractor-trailers through the use of aerodynamic drag reduction
- ***On behalf of DOE*** to expand and coordinate industry participation to achieve significant on-the-road fuel economy improvement
- ***Demonstrate*** new drag-reduction techniques and concepts through use of virtual modeling and testing
- ***Full-scale wind tunnel validation of selected devices with industry collaboration and feedback***
- ***Joined with industry in getting devices on the road***

Milestones

- Full-scale wind tunnel test of selected drag reduction devices in collaboration with Navistar at NASA Ames research center, NFAC facility
- Testing schedule overview

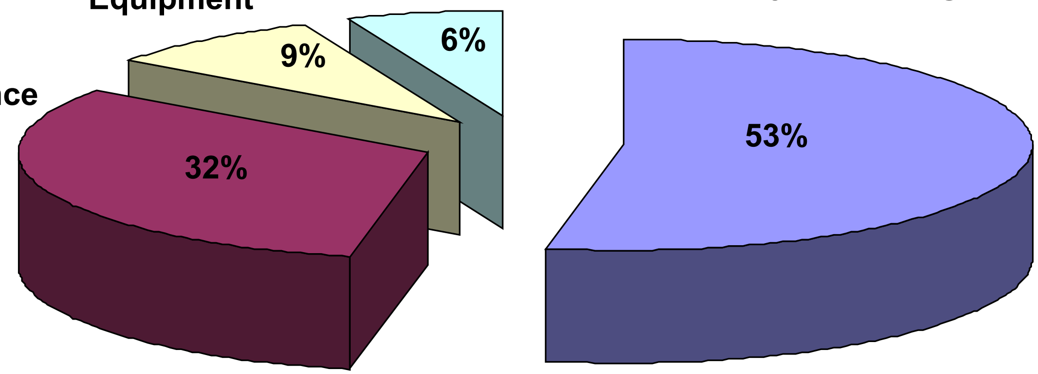
Project kick-off	March 4, 2009
Test Planning Meeting	October 5, 2009
Test Readiness Review (pre-install)	November 16, 2009
Test Article Installed in Tunnel	December 1, 2009
Begin Air-On Testing	January 26, 2010
Testing Complete	March 16, 2010
Test Article Removal	March 24, 2010
Test Equipment Removal Complete	February 11, 2010
Post test activities complete	April 30, 2010

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

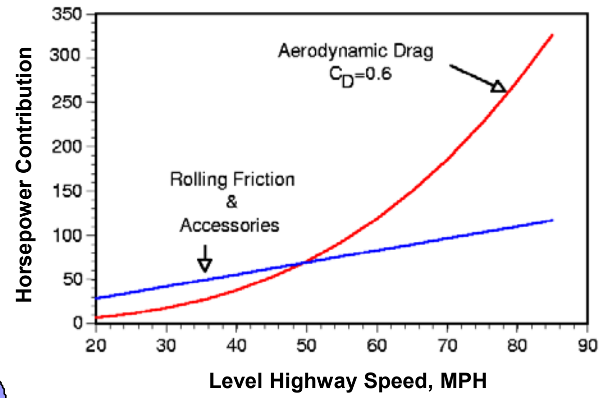


12% increase in fuel economy = 3.4 billion gallons of diesel fuel saved per year and 36 million tons of CO2 emission

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



Wide single tires



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

Science based approach to aerodynamic drag reduction for heavy vehicles

Design & test devices/concepts for aerodynamic drag reduction with industry collaboration and feedback

New/existing devices and 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

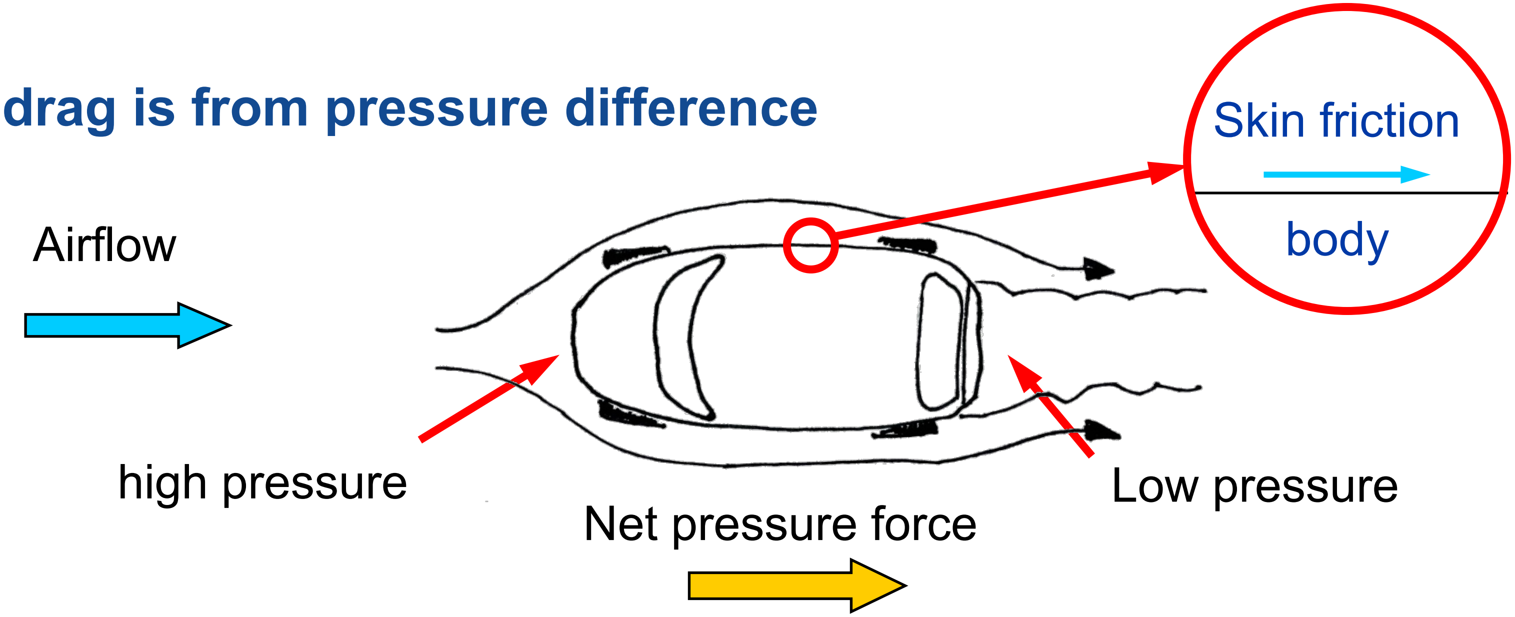
Collaborative Efforts

Industry - Manufacturers
- Fleets

Scientists - National Labs
- NASA
- Universities

Fuel consumption and aerodynamic drag

Most drag is from 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**

Aerodynamic drag breakdown on a typical truck

	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%

Full-scale wind tunnel test at NFAC facility

- More than a year of planning was required to get into the NFAC facility at NASA Ames Research Center
- Low tunnel blockage of about 1%
  - Tunnel wall effect is minimum
- Wind tunnel walls are acoustically treated
- Wind tunnel operating conditions
  - Nominal wind speed 60-80 mph
  - Full-scale Reynolds number ~5e6

NASA Ames, NFAC 80’×120’ wind tunnel

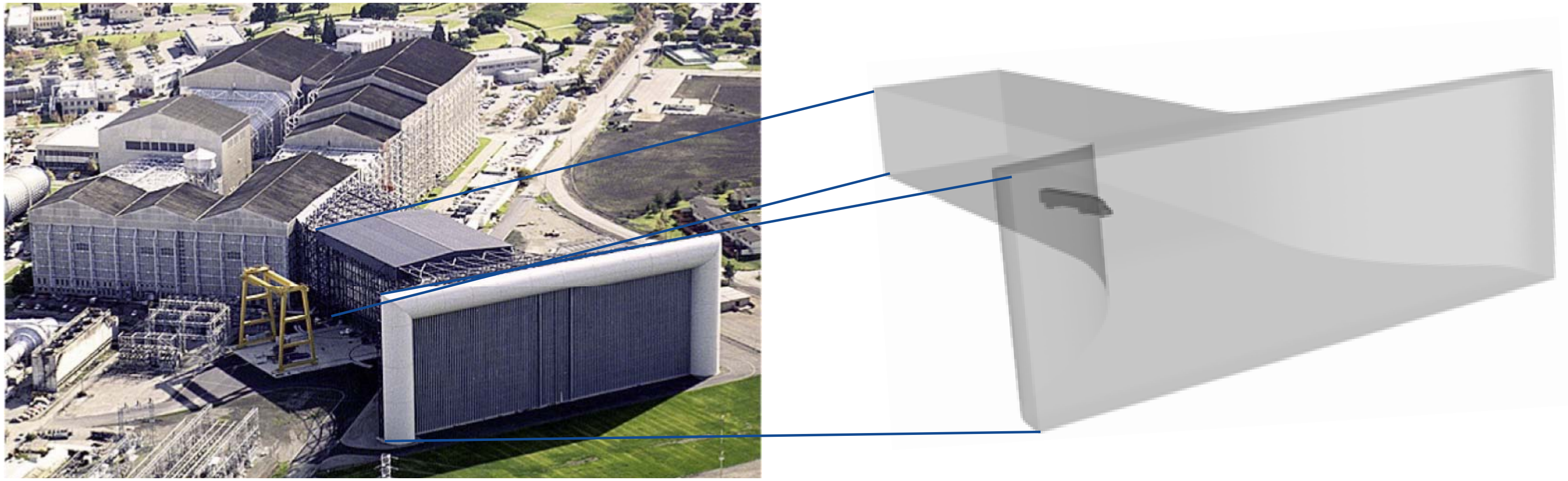
Full-scale wind tunnel test at NFAC facility, …

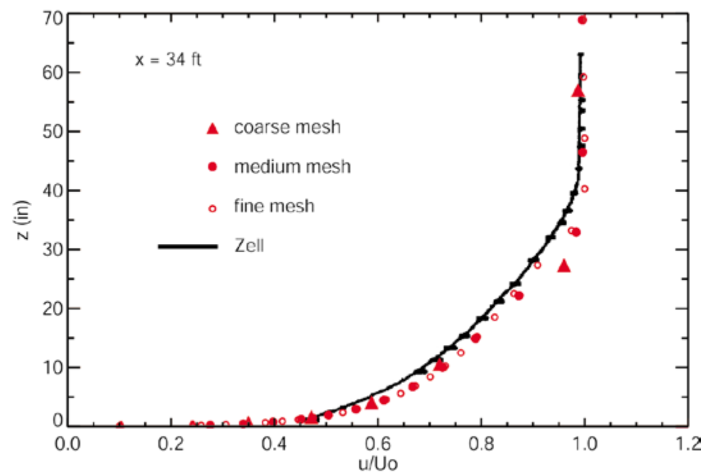
- Different combinations of tractors and trailers were tested
  - Two tractors – Prostar sleeper and day cab
  - Three trailers – 28' & 53' straight frame and 53' drop frame
- Performed 140 wind tunnel runs
- Twenty-three aerodynamic drag reduction devices/concepts were tested from LLNL, Navistar, Freight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

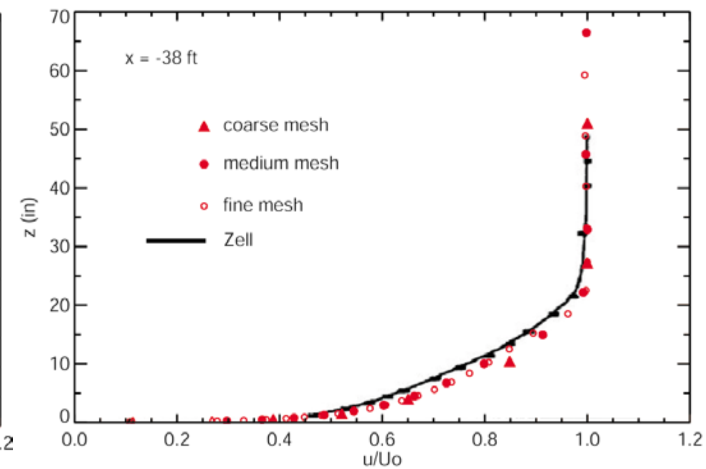
Challenges with underbody flow representation

- Mounting hardware
  - 6" off the ground
  - Air bearing platforms and shoes
- No moving ground plane
- Non-rotating tires
- Wind tunnel boundary layer
- About 6" deep acoustic layer that can modify the pressure field near ground surface
- Follow-up track tests would eliminate all the above underbody flow modifications and it will further improve our interpretation of the full-scale wind tunnel test results

Challenges with wind tunnel modeling

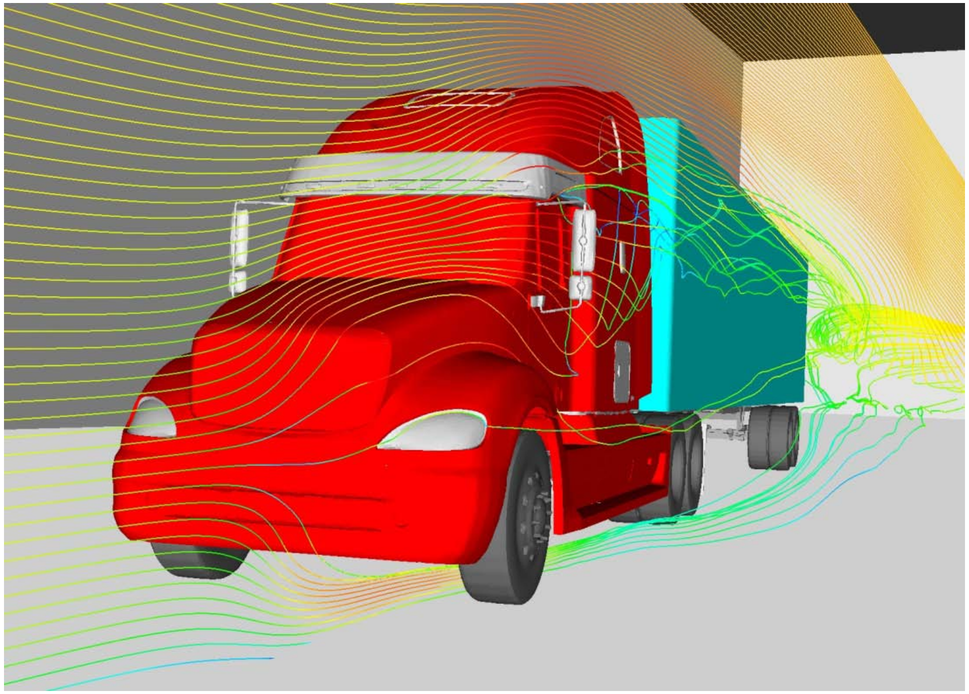




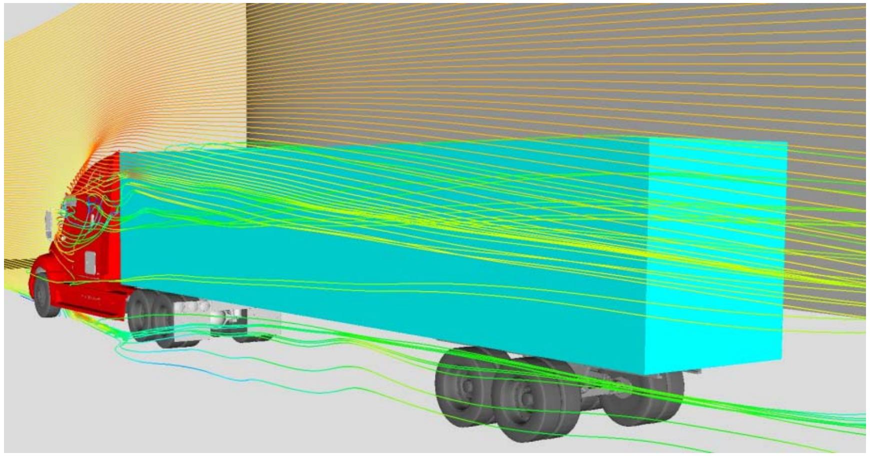


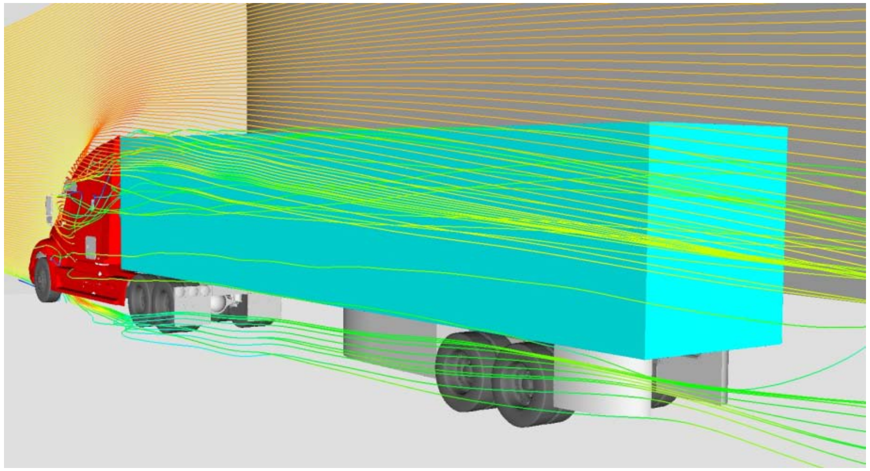
Zell, P.T., Performance and test section flow characteristics of the National Full-Scale Aerodynamic Complex 80- by 120-foot wind tunnel, NASA TM 103920, 1993.

Design of full-scale wind tunnel test relied on computational results



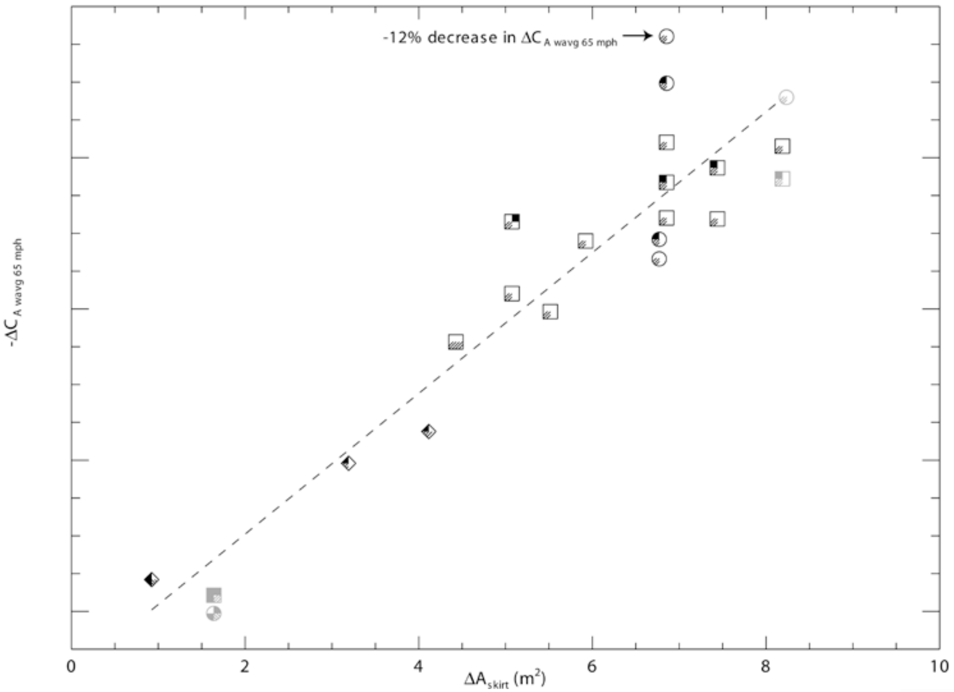
Velocity streamlines about a class 8 heavy vehicle at 6.1 degrees yaw angle in the 80'×120' wind tunnel.



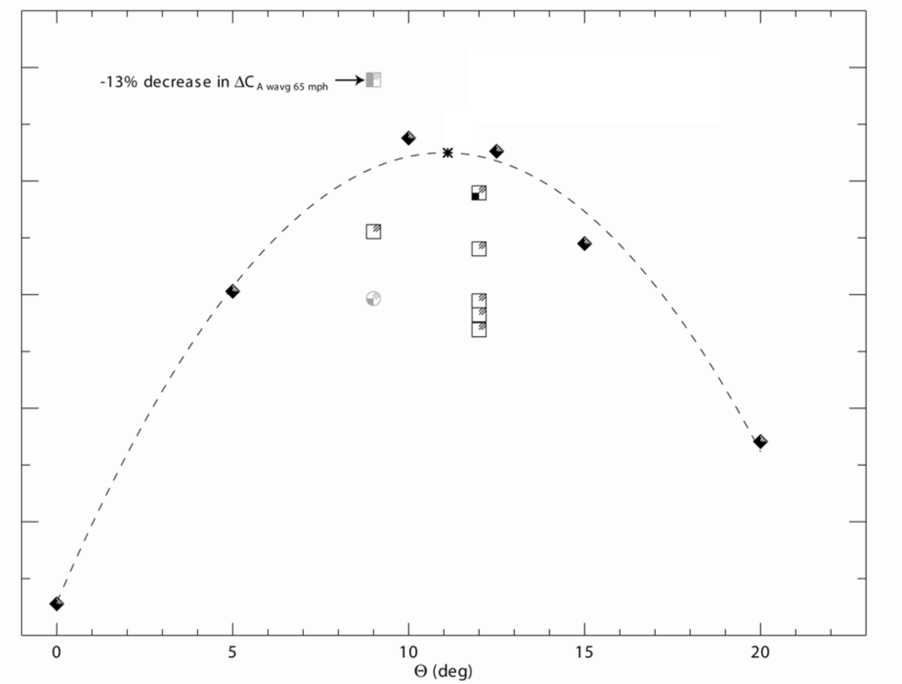


Performance of drag reduction devices

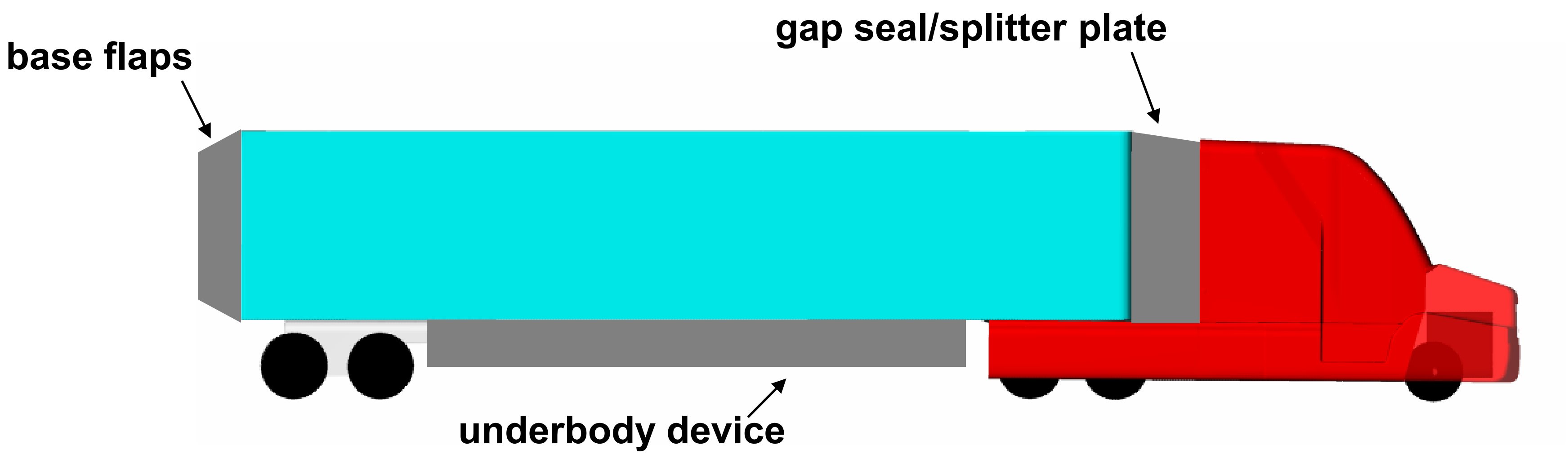
Underbody devices



Trailer base devices



Performance of aerodynamic devices



- Base flaps: 5-10% FEI (Fuel Economy Improvement)
- Underbody devices: 5-8% FEI
- Gap devices: 1-2% FEI
- Super wide single tires: 4-5% FEI

Technical accomplishments

- ***In collaboration with Navistar*** conducted a full-scale wind tunnel validation test of candidate devices at NASA Ames research center, NFAC facility
  - ***Twenty-three aerodynamic drag reduction devices/concepts were tested*** from LLNL, Navistar, Freight Wing, ATDynamics, Aerofficient, Laydon, Windyne, and AeroIndustries
- ***In support of the DOE's objective to bring candidate devices to the market within 2.5 years,*** we are teaming with Navistar, Kentucky Trailer, Freight Wing device manufacturer, Michelin, and Frito-Lay's Fleet to perform track and on the road tests
- ***Aerodynamics of a common tanker trailer*** has been investigated in collaboration with Praxair for significant gains in fuel economy
- ***Insight and guidelines*** for drag reduction provided to industry through computations and experiments
- ***International recognition* achieved** through open documentation and conferences

Future plans

- Apply the top candidate devices from the full-scale wind tunnel test toward track and on the road tests (DOE objective)
  - Improve design/performance of selected drag reduction devices based on the knowledge gained in the full-scale wind tunnel test
  - Validate the performance of the redesigned aero devices
- Continue to work with Praxair to design aerodynamic drag reduction devices to improve the fuel economy of a typical tanker trailer
- Apply aerodynamic-based surface optimization to add-on devices
- Continue to evaluate and design new and existing drag reduction devices/concepts using LLNL's virtual testing environment
- Explore the benefits of tractor-trailer integration for drag reduction (geometry, flow, and thermal)
- On behalf of DOE, continue to coordinate industry participation and achieve industry-accepted drag reduction devices

Summary

- Conducted full-scale experiments in collaboration with Navistar and Michelin in the world's largest acoustically-treated wind tunnel to obtain performance data
  - Two tractors and three trailers were used
  - High quality data was obtained due to negligible wind tunnel blockage effects (~1%)
  - Obtained acoustic signatures of selected drag reduction devices
- All performance data will be available to public and will serve as the foundation to bring candidate devices to the market within 2.5 years