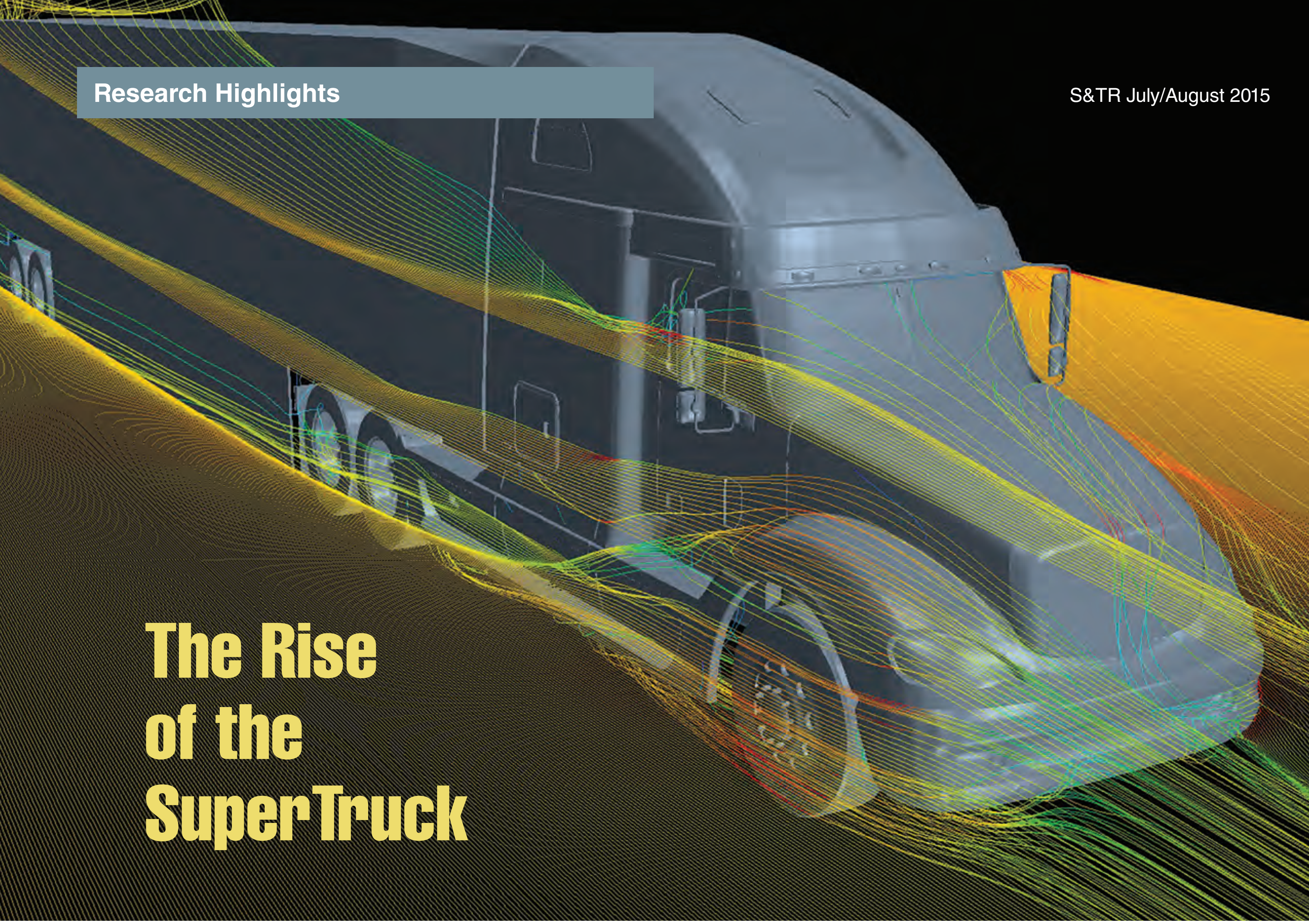


The Rise of the SuperTruck

TRACTOR–TRAILER semitrucks burn 36 billion gallons of fuel annually—11 to 12 percent of the U.S.'s total petroleum consumption. In addition, each truck expends more than 50 percent of its usable propulsion energy to overcome aerodynamic resistance at highway speeds. In 1997, the Department of Energy (DOE) established the Heavy Vehicle Aerodynamic Drag Consortium to examine ways to make heavy trucks more aerodynamic, reducing air resistance (or drag) to increase their fuel efficiency. The consortium included Livermore researchers, collaborators at academic institutions such as the University of Southern California and the California Institute of Technology, industry partners, and the NASA Ames Research Center (NASA Ames).

Livermore's work on creating more aerodynamic tractor–trailers is funded by DOE's Office of Energy Efficiency and Renewable Energy through the Vehicle Technology Office. At the start of the consortium, the scope of the project—then led by the Laboratory's Rose McCallen—focused primarily on altering the design of existing trucks. (See *S&TR*, May 2003, pp. 25–28.) "We needed to understand the key areas of resistance and drag on the vehicle to make technological improvements," says Kambiz Salari, who began leading the project with researcher Jason Ortega in 2007.

Nearly 20 years after the project began, the collaborative effort has resulted in the development of drag-reducing technologies that can be retrofitted to existing semitrucks. Such devices are already helping U.S. fleets realize fuel economy improvement (FEI). Building on this success, Livermore has shifted its research approach toward the design of a highly aerodynamic integrated tractor–trailer for DOE's SuperTruck initiative, which aims to develop tractor–trailers that are 50 percent more efficient than conventional models.

Identifying a Need

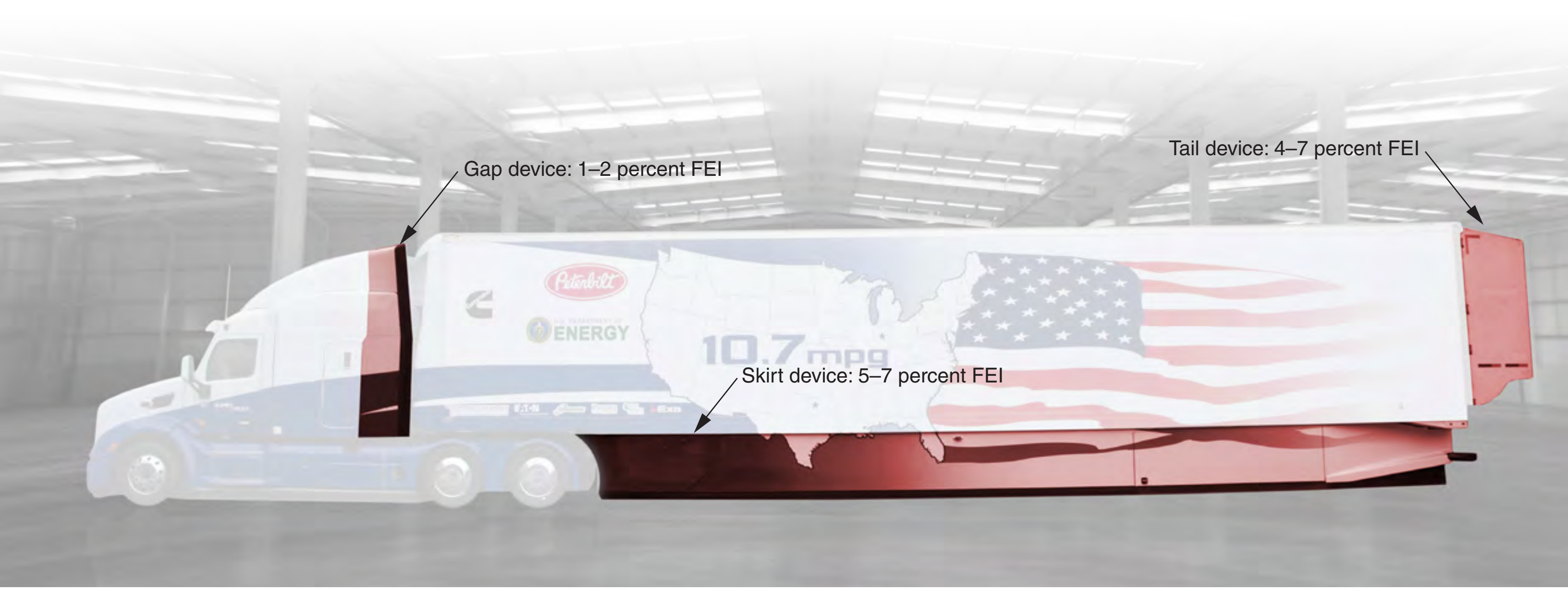
Through computational airflow simulations produced on the Laboratory's high-performance computing (HPC) systems and experiments conducted at NASA Ames' wind-tunnel facilities, Livermore researchers found that a semitruck's underbody, back end, and gap between the tractor and trailer produce the most drag. Subsequently, the team designed, simulated, and tested add-on devices that could make the vehicles more aerodynamic. Pairs of flat panels, called skirts, attach to either side of the trailer to shorten the gap between the trailer and the ground, reducing air currents along its sides and underside. A tail device fastens to the trailer's rear edges and extends at an angle to lessen the vehicle's wake. Finally, a gap panel fills the space between the tractor and trailer to prevent airflow inside the void. The Livermore team has garnered several patents and records of inventions for these devices, which are manufactured by industry partners based on Livermore design recommendations.

According to a 2014 Fleet Fuel Study conducted by the North American Council for Freight Efficiency, industry trends indicate that U.S. fleets are increasing their adoption rate of FEI products and technologies. The study included 11 fleets, each of which had adopted at least one drag-reduction device. If the entire U.S. fleet implemented these add-on technologies, fuel consumption could be reduced by 15 percent, which translates to 5.1 billion gallons of diesel fuel saved annually. Carbon dioxide emissions also would be reduced by approximately 52 million tons per year. Salari estimates total cost savings at nearly $21 million annually. If gas prices fluctuate around $3 per gallon, fuel savings for each vehicle would offset the cost of purchasing drag-reducing devices within six months to one year.

A Two-Step Process

Proposed aerodynamic concepts are first tested on HPC systems to evaluate each device's effectiveness under realistic road conditions. Simulations highlight the flow fields of a tractor–trailer using particle traces colored according to flow speed (shown on p. 18). If the simulation results indicate considerable fuel savings, Livermore builds a one-eighth-scale physical prototype of the device for testing at NASA Ames' 2- by 3-meter wind tunnel. "We make approximations in our simulations," says Ortega. "Wind-tunnel experiments and their resulting data help validate our device designs." Salari adds, "The wind-tunnel facility is our workhorse."

Inside the facility, researchers can reproduce air flow at highway speeds. Particle image velocimetry (PIV) is a technique that uses laser beams to measure the velocity and direction of airflow in a series of planes. Using PIV, researchers can measure the flow fields in the wind tunnel and determine flow patterns through time. If more testing is required, a full-scale wind-tunnel experiment is conducted at the NASA Ames National Full-Scale Aerodynamics Complex (NFAC), the world's largest wind tunnel. The 24-by-36.5-meter complex is ideal for testing a full-scale



Drag-reducing devices are designed to help tractor–trailers realize fuel economy improvement (FEI). The Department of Energy's SuperTruck demonstration vehicle is shown above with approximate FEI percentages provided by the gap, skirt, and tail devices. (Photograph of truck by Sarah Gerrity.)

tractor–trailer system, in which the trailer alone measures 16 meters. “Collaborating with NASA and applying their expertise and PIV technology to this effort has created a strong, fruitful synergy,” says Ortega. “We work with some of the best wind tunnel operators in the world.”

When a device proves promising in wind-tunnel experiments, the team then approaches manufacturers to build devices for track and road testing. These tests produce data on a device’s effectiveness and help manufacturers determine specifications for production.

More Sophisticated Models

In the early 2000s, Livermore computer scientists first modeled a generic transportation system—a simplistic design that lacked detail. As HPC advanced, algorithms became more sophisticated, decreasing simulation time and resulting in increasingly accurate tractor–trailer models. Livermore researchers now use a more precise generic conventional model (GCM) for simulations that features truck details such as a hood, door handles, engine, wheel wells, and mirrors. GCM is unbiased—it does not favor the geometry of one manufacturer’s truck over another—and as such provides data applicable to many manufacturers.

Zachary Vane, a Ph.D. candidate at Stanford University, recently joined Livermore’s research team and is helping further the Laboratory’s computational capabilities. He is investigating advanced simulations to streamline the next-generation integrated tractor–trailer physical-testing process. The computational approach uses fewer modeling assumptions to solve Reynolds-Average Navier Stokes equations, thus providing an improved

A tractor is suspended at the NASA Ames National Full-Scale Aerodynamics Complex (NFAC), the world’s largest wind tunnel. NFAC’s testing section can easily accommodate a complete tractor–trailer. NFAC has been used for full-scale performance testing of aerodynamic add-on devices. Full-scale testing of a new tractor–trailer design is planned for early 2016.

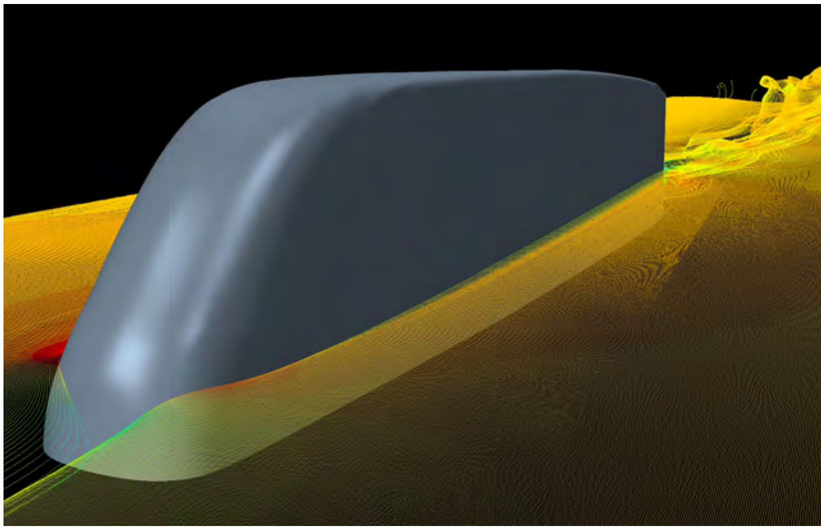
predictive capability over current computational tools. In addition, because this approach only models small-scale motions near the vehicle, it reduces high computational costs associated with other methods. This cost reduction allows the new approach to be applied to complex geometries such as an integrated tractor–trailer system. "When it comes to tractor–trailers, too many potential designs exist to physically test each one in the wind tunnel," explains Vane. "Computer simulations, however, may allow us to narrow 100 possible experiments down to the 5 most promising designs." With more advanced HPC systems and improved models, the team can provide higher fidelity airflow data to industry partners and more accurately recommend drag-reduction technologies to device manufacturers.

The Long Haul

Within the past two years, the Laboratory's research has evolved from producing add-on devices to completely redesigning the tractor–trailer rig. "We can't change much more on existing vehicles," explains Ortega. "By installing the skirt, tail, and gap devices on semitrucks, drivers will see great fuel economy improvement. However, to significantly optimize vehicles, we need to take a different approach." Toward this end, Livermore is developing aerodynamic specifications to benefit DOE's SuperTruck initiative, a collaborative effort to create a next-generation highly aerodynamic integrated tractor–trailer geometry, reduce tractor–trailer weight, and improve heavy-duty engines.

Livemore's first-generation highly aerodynamic integrated truck model, the Generic Speedform One (GSF1), was created using a one-eighth reduced-scale clay model in NASA Ames' wind tunnel last year. "We're thinking outside the box with the GSF1 design," says Ortega. "Being creative makes it fun." Initial testing for the new model involved 132 wind-tunnel experiments.

The integrated tractor–trailer structure is configured lower to the ground with a teardrop shape, enclosed wheel wells, trailer skirting, rounded trailer edges and tractor nose, and an optimized tail geometry. Though the truck still requires a gap between the tractor and trailer to allow it to turn, the gap's size will be modified to prevent drag. The proposed GSF1 model reduces the aerodynamic drag compared to existing road vehicles by more than 65 percent. "Imagine the fuel-efficiency savings from retrofitted trucks, doubled," explains Salari. The Livermore team plans to further refine and enhance the GSF1 shape through scaled-model wind-tunnel testing and computational optimization of surface geometry. A full-scale wind-tunnel test of an aerodynamic tractor–trailer is planned for 2016 at NFAC.



A simulation of the Generic Speedform One (GSF1) model shows flow patterns around the vehicle with particle traces colored by velocity magnitude. An integrated tractor–trailer geometry such as the GSF1 is the next step toward improving fuel efficiency for heavy vehicles.

Salari's work in aerodynamics research recently earned him the Distinguished Acheivement Award from DOE's Vehicle Technology Office. Going forward, Salari and Ortega, along with their colleagues and collaborators, continue to look for more opportunities to improve fuel economy. As an example, Salari has proposed eliminating trailers' corrugated sides, a feature that undermines fuel efficiency by 10 percent. Livermore will also continue research on tanker–trailer aerodynamic improvement, a market ripe with fuel-saving possibilities.

Research opportunities and the relevance of this work motivate the team. "Our research really is applicable to everyday life," says Ortega. "It's been extremely rewarding to see the technologies we helped develop materialize on the road."

—Lanie L. Rivera

Key Words: aerodynamic truck, Department of Energy (DOE) SuperTruck initiative, drag-reducing device, fuel economy improvement (FEI), Generic Speedform One (GSF1), Heavy Vehicle Aerodynamic Drag Consortium, NASA Ames National Full-Scale Aerodynamics Complex, particle image velocimetry (PIV), semitruck, tractor–trailer.

For further information contact Kambiz Salari (925) 424-4635 (salari1@llnl.gov).