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Firm Uses DOE's Fastest Supercomputer to Streamline Long-Haul Trucks

Sophisticated simulation on the world's fastest computer for science makes trucks more aerodynamic, saves fuel, helps environment.

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Image courtesy of BMI SmartTruck

Trailers equipped with BMI Corp. SmartTruck UnderTray components can achieve between 7 and 12 percent improvements in fuel mileage.

Those big rigs barreling down America's highways day and night are essential to the country's economy—they carry 75 percent of all U.S. freight and supply 80 percent of its communities with 100 percent of their consumables. But there is a price to pay. These long haul trucks average 6 miles per gallon or less, and annually dump some 423 million pounds of CO_2 into the environment.

BMI Corporation, an engineering services firm headquartered in Greenville, SC, has teamed up with Oak Ridge National Laboratory (ORNL), NASA, and several BMI corporate partners with large trucking fleets, to attack the problem. The BMI engineers are combining their aerospace and race car design expertise with the power of the Oak Ridge Leadership Computing Facility's (OLCF's) *Jaguar* supercomputer, supported by DOE's Office of Science, to create a new, long haul "SmartTruck" that will increase fuel efficiency and reduce carbon emissions.

According to BMI founder and CEO Mike Henderson, the new California Air Resource Board (CARB) regulations, combined with increasing fuel costs, are catalysts for substantial changes in truck design. CARB calls for a minimum 5 percent fuel mileage improvement for long haul trucks and trucking fleets. Companies like BMI partners Frito-Lay, PepsiCo, and Swift Transportation must meet these new standards in order to drive their fleets in that state. CARB puts a lot of pressure on truck owners, generating an urgency to comply. Companies are looking for a highly effective solution—in the shortest time possible.

Says Henderson, a 30-year veteran of the Boeing Company and the auto racing world: "There has not been much investigation into how to make trucks aerodynamic. But we've shown we can make big systems very aerodynamic—just look at planes. You can do the same with trucks if you do it right."

Cluster Couldn't Cut It

To meet these new requirements, BMI launched their SmartTruck program and initially worked on a modest high-performance computing (HPC) cluster to tackle the design of new, add-on parts for long haul Class 8 (18-wheeler) trucks. But the cluster did not have computational power to provide the progress needed in the required time frame.

"We initially ran our simulations on an HPC cluster with 96 processors," recalls Henderson. "We were unable to handle really complex models on the smaller cluster—the solutions lacked accuracy. We could explore possibilities, but not run the detailed simulations needed to verify that the designs were meeting our fuel efficiency goals."

"On smaller clusters we have to simplify the problem, and you try to do it artfully so as to not eliminate a feature that is important for the design," he adds. "But you run the risk of missing something important. For example, instead of modeling the entire air canister configuration with all its tubes and connections, we could only create a single blob that produced a wake that may or may not have been accurate. It's tough working on aerodynamically dirty vehicles like trucks. Sleek race cars are easier—with a truck you're never sure which feature is going to be the one that gets you."

Putting the *Jaguar* Pedal to the Metal

To meet their computing needs, BMI applied for and received a grant through the ORNL Industrial HPC Partnerships Program to run their simulations on *Jaguar*, a Cray XT5 computer running at a peak speed of 2.33 petaflops, or over two thousand trillion calculations per second. This has allowed BMI to address the California CARB requirements and, as Anastos says, "lets us to get our foot in the door of this fast-growing marketplace for add-on parts by developing unique packages that can be applied to current tractor/trailer systems."

BMI engineers are now using the most complex truck and trailer model that have ever been simulated for computational fluid dynamics (CFD) analysis. With the exception of the individual nuts and bolts, every feature of the truck is modeled. In many key locations, the CFD grids are accurate to one tenth of an inch. The team models half the tractor and trailer for simulation and analysis purposes, using up 107 million grid cells in the process. To study yaw—what happens when the vehicle swerves—they simply mirror the grid and double it, using 215 million grid cells to accurately model the entire vehicle.

BMI engineers are running their simulations with NASA's Fully Unstructured Navier Stokes (FUN3D) application. FUN3D is a suite of computational fluid dynamics codes for analysis, adjoint-based error estimation, mesh adaption, and design optimization of fluid dynamic simulations.

Says Henderson, "Solutions must be Navier Stokes—no short cuts need apply.

"What *Jaguar* and FUN3D allow us to do," he adds, "is to break the truck into literally hundreds of pieces. We examine the drag on each piece and determine how it interacts across the entire system. Working at that level of detail and resolving the flow on each component is something you can't do with a small cluster—even with the highly efficient FUN3D system, single solutions can take two-three days. With these run times, design and refinement are difficult and optimization techniques are not practical. But with *Jaguar*, we were able to reduce single run times to less than two hours. Large, fine-grain solutions were shown to be very accurate, and aerodynamic development was terrifically accelerated"

Henderson notes that the process they follow is an excellent learning experience, it's "what we call the UFD part of the process—understanding fluid dynamics," he says. "This detailed look at what's actually happening under varying conditions drives the design package. You can create solutions that are both practical and cost effective, while providing the desired aerodynamic results."

Add-on Parts for Added Fuel Savings

Among the components simulated on *Jaguar* is BMI's Trailer UnderTray System. It includes a variety of fuel-saving components, such as aerodynamic wheel fairings and a special sled that attaches to the axels to direct airflow under the suspension towards the rear of the vehicle. The rear diffuser, the biggest component of the UnderTray System, is installed in front of the trailer's rear bumper, and is a major factor in optimizing air flow and boosting fuel efficiency.

"Compared to an airplane or a high performance race car, air flowing over these trucks moves relatively slowly," says John Anastos, BMI project engineer. "As a result, effects produced by one component impact the operation of all the others. For example, most trucks have a rain gutter running along the top of the trailer just above the rear doors. Its job is to protect people on shipping docks from getting wet as they load and unload the trailer. It works, but it's a horrible aerodynamic eyesore and negatively impacts the efficiency of the rest of the truck's components.

"Using *Jaguar* and FUN3D has provided us with many 'aha moments' and this was one of them," he continues. "Our detailed CFD simulations allowed us to see exactly how the UnderTray and the rain gutter interact under varying conditions. With this information, we have aerodynamically redesigned the rain gutter to recapture the air, create a healthy airflow boundary layer, and direct the flow down into the wake where it improves operating efficiency, rather than hinders it."

The engineers validate their CFD models by physically testing trucks equipped with SmartTruck components at sites such as the shuttle landing facility at the Kennedy Space Center—an 18,000 foot long landing strip that is the straightest, flattest piece of cement in the world. Other circular tracks in Texas are also used to road test the designs. These tests have validated BMI's CDF simulations, yielding, according to Henderson, "remarkably similar" results. Performance predictions for fuel mileage improvements with a minimum package of add-on parts were 6 percent—test results showed gains of up to 6.8 percent. "That differential is actually quite consistent with the drag predictions we see in aircraft. I'm very happy with that correlation," Henderson says.

BMI is now working with NASA to improve FUN3D and capitalize on the code's newly developed optimization techniques, especially adjoint optimization. This approach uses two sets of equations to determine the sensitivities of all the design variables at once. The sensitivities are then passed on to the optimizer to determine the best configuration.

Designing the Truck of the Future

In subsequent work, BMI will improve the aerodynamics of both existing tractors and trailers. For example, BMI knows from its simulation work that it can exceed the 6 percent improvements it has already achieved. Notes Henderson: "Our detailed simulations indicate that advanced components, like our aerodynamically designed Trailer UnderTray, will result in fuel efficiencies of nearly 12 percent."

But the real payoff will come when BMI starts with a "clean sheet" design to create the truck of the future from the ground up.

"Our preliminary studies indicate that we can make huge aerodynamic improvements to this Super Truck and still get all the elements you need for comfort and efficiency inside the shell," Henderson concludes.

The sleek, aerodynamic counters of this advanced truck will provide a lower drag coefficient than that of a low drag car, with anticipated fuel efficiencies running as high as 50 percent. The potential payoff is huge. If all the country's 1.3 million long haul trucks operate with the same low drag as a well designed passenger car, the US could annually save 6.8 billion gallons of diesel fuel; reduce CO_2 by 75 million tons; and save $19 billion in fuel costs—super savings resulting from the inspired work of a savvy group of engineers and a supercomputer without equal.

Funding

Jaguar: DOE Office of Science, Office of Advanced Scientific Computing Research

Research: DOE Office of Science via ORNL's Industrial HPC Partnerships Program

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