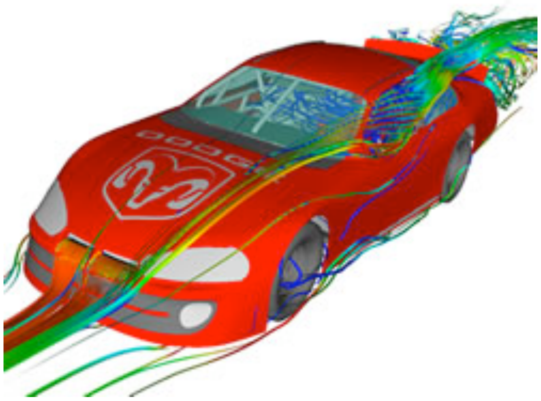
CFD visualization helps DaimlerChrysler accelerate return to NASCAR fast track

by Michelle Perkins



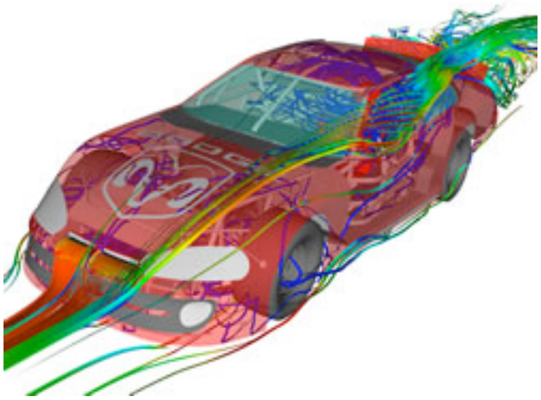
With 16 drivers competing in NASCAR's Nextel circuit -- including Ryan Newman, who notched eight wins and 11 pole positions last year -- it is easy to forget that only three years ago DaimlerChrysler's Dodge division was returning after a 25-year absence from stock car racing's most prestigious tour.

To gain a perspective on just how far Dodge has come, go back to 1999: DaimlerChrysler had fewer than 500 days to design and build a competitive car for the 43rd Daytona 500 in February 2001. The aerodynamics team accelerated its work with computational fluid dynamics (CFD), advanced visualization, and scale-model wind-tunnel development to augment traditional full-scale wind-tunnel and on-track testing. This combination of processes has since become the standard for DaimlerChrysler race programs and commercial cars.

Dodge's return began in late 1999 when the first 3/8-scale clay model of the Intrepid was produced and tested in the scale-model wind tunnel at the DaimlerChrysler Technical Center in Auburn Hills, Mich. After several additional scale-model tests, the first full-scale prototype was tested at the Lockheed-Martin wind tunnel in Marietta, Ga.

Once the development team was satisfied with the general body design, the full and 3/8-scale prototypes were digitized with laser scanners and reverse-engineered into CAD body surfaces for further development. One of these prototypes, R&D002, was used as the standard CAD reference for CFD. The actual car ran its first track test in May 2000, and was submitted to NASCAR for approval in August 2000.

Visualizing airflow streams



While full-size wind tunnel testing for aerodynamic development is commonplace among racing teams, only a few well-funded teams use scale-model testing and computational simulations. These tools are commonly used to design commercial cars, however, so it was natural for DaimlerChrysler to use them for the Dodge Intrepid racecar.

The first step for the team was to ensure the validity of CFD aerodynamics results by comparing them to those from wind-tunnel testing. The team's goal was to see a coefficient of drag within five percent, a coefficient of lift within 10 percent, and balance, or lift distribution, within five percent.

The Lattice-Boltzmann-based PowerFLOW solver from EXA Corp. was used for CFD testing. Simulations were run on Silicon Graphics Origin 2000 supercomputers. The development team used EnSight software from CEI to visualize the CFD results.

"It is very difficult to visualize the airflow streams under a ground vehicle, or under its hood, during a traditional - scale or full-size - wind-tunnel test," says Jean-Michel Esclafer de La Rode, product engineer at DaimlerChrysler. "Visualizations help us better understand the aerodynamics of ground effects on both our production and race vehicles."

DaimlerChrysler used EnSight to generate and animate large sets of streamlines around the car to depict airflow patterns. Surface visualizations and vector clips made patterns readily visible to the development team. Areas of high and low pressure depicted in the visualizations were used to determine cooling opening locations, separated wake regions, and other aerodynamic characteristics. Three-dimensional streamlines were shown underneath the car as a typical "horseshoe" vortex that trails a vehicle.

The DaimlerChrysler team found a close correlation between CFD and wind-tunnel results, providing the confidence needed to use computational testing for real-world simulations.

Race against time

DaimlerChrysler's first real-world simulations focused on single vehicles. New boundary conditions were added to the computational models to simulate spinning tires and the moving ground. This type of situation would be complex and expensive to re-create in a wind tunnel. EnSight's client/server option enabled DaimlerChrysler to visualize the very large files generated by the CFD solver.

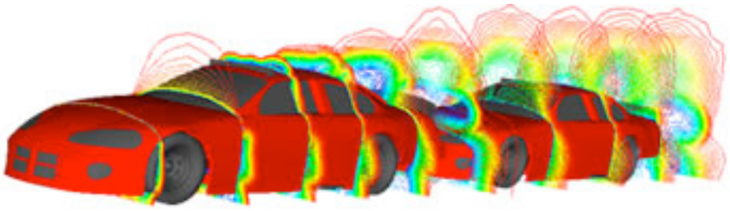
"In the racing industry, time is our enemy," says Esclafer de La Rode. "EnSight allowed us to distribute the large data files to different servers, which greatly improved computing speed."

According to John Brzustowicz, a product engineer at DaimlerChrysler, CFD results from the single vehicle tests showed that drag increased with rolling road boundary conditions.

"These results differed from many published reports for production-type vehicles, but once the development team noted that down force also increased significantly, the findings made sense," Brzustowicz says. "An experimental simulation of rolling road, performed several months later at the FKFS/IVK University of Stuttgart wind tunnel, further validated the CFD results."

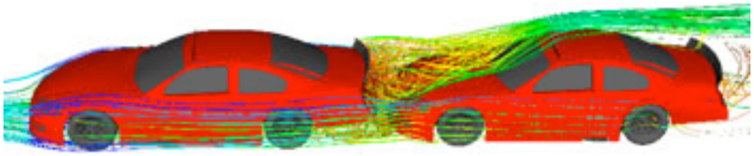
Simulated drafting

With single-car simulations completed and conforming to Daytona 500 aerodynamic requirements, the final step was performing drafting tests for the Dodge Intrepid in multi-car situations.



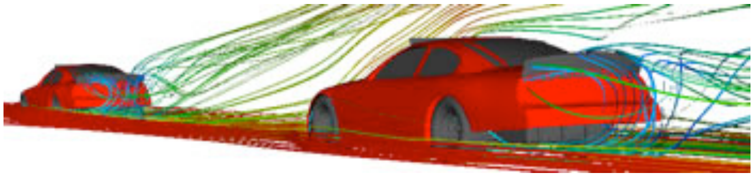
"During a NASCAR race, most cars remain packed together for the majority of the 200 laps," says Brzustowicz. "The development team's goal was to understand the role of aerodynamics in determining why some cars move to the front, while others fall back."

This time, the development team used Computational Dynamics' Star-CD software to conduct several multi-car simulations. Star-CD generated smaller model sizes and allowed for testing in steady-state mode, which provided faster solutions than in transient mode. The simulations ran on Silicon Graphics Origin 2000 supercomputers over 24 hours using eight CPUs.



"The data showed that for two cars with the same horsepower, the trailing vehicle might never reach the leader because it would create more drag than the car in front during the approach," says Esclafer de La Rode. "EnSight was used to display 3D streamlines depicting airflow upstream and downstream. The CFD results showed that most of the air from the lead car's wake actually lifted up and passed over, not around, the trailing car."

"It was important to understand where the airflow was coming from, and just as importantly, where it was heading downstream," adds Brzustowicz. "This allowed us to understand which surfaces could benefit most from further development activities. A surface encountering high flow values will benefit more from aerodynamic development, than an area in a low flow region. Which surfaces are important might not be obvious when vehicles are traveling in a pack."



Brzustowicz uses a race at Talledega a few years ago to illustrate this concept. During the race, a car with a mangled right front fender remained in the pack, as long as the vehicle was in the wake of a lead vehicle. On its own, the vehicle could not have kept pace with undamaged cars. This was a case of a surface becoming less important in the draft.

With a conventional aerodynamic development program, there might have been a sequential use of CFD, followed by scale-model and full-scale testing.

"In this case, we used tools such as CFD to improve our checks and balances system in our aerodynamics program," says Brzustowicz. "CFD results were validated and proven a useful tool, so that EnSight visualizations could be used during wind-tunnel testing or other standalone work, without questioning their accuracy."

CFD under the hood

Aerodynamics and body design aren't the only areas of a race car that benefit from CFD and visualization. These technologies are also important in maximizing engine performance.

The manufacturer provides each team with NASCAR approved parts, including engine blocks, cylinder heads, intake manifolds, water pumps and valve covers. It is each team's job to tweak these parts for the best performance - whether it is best gas mileage or top horsepower.

The specifications for NASCAR engines, which share some similarities to engines built during the 1960s, make airflow extremely important for performance. NASCAR engines don't have fuel injection, standard on most cars since the mid-1980s. Instead, they use a carburetor that limits air flow to the engine. It is one of the many limits placed on the performance potential of the engine.

"Engines are air pumps to which we add fuel to generate power," says Pat Baer, an engine performance engineer at DaimlerChrysler's Technology Center. "We want to minimize the flow resistance in everything from how the air enters the carburetor ducting all the way out the tail pipe. The plan is to have some control over the quality of the airflow, minimizing turbulence while enhancing the homogeneity of the fuel and air mixture and creating bulk motion within the cylinder to promote fast and consistent combustion."

The R5/P7 engine, Dodge's most recent NASCAR entry, went through several iterations before being submitted to NASCAR for approval. The engineers developing the engine work together to build the collection of systems that makes up the engine.

"Many aspects of the engine are developed in 'group think'," says Baer. "For example, we all worked together on the coolant flow through the engine with help from CFD models."

The greatest role Baer sees for CFD in engine building, however, is its impact on the learning curve.

"I've seen a young engineer who knows nothing about air flow go through a few design and CFD iterations and come up with a better part than I made," he says.

Visualization is also important for experienced technicians who develop engine components on a flow bench. Seeing a CFD visualization helps them understand the air flow of a current design and what needs to be done to make improvements.

"I'm convinced CFD modeling takes years off the personnel development cycle," says Baer.

Results show on the track

The validity of development and testing using CFD simulation and visualizations was established immediately by DaimlerChrysler's results in the 2001 Daytona 500. All 10 Dodge Intrepid vehicles qualified for the race, and three of them occupied the top positions. Dodge led more laps than any manufacturer, with the top finisher placing fifth.

Since 2001 and its return to NASCAR Winston Cup (now Nextel), DaimlerChrysler has continued to increase its reliance on the concurrent use of CFD, advanced visualization, and wind-tunnel and on-track testing for aerodynamics and engine flow.

"The increased use of CFD and advanced visualization software like EnSight has led us to direct design changes that provided us with racing advantages many times over the past few years," says Esclafer de La Rode.

While Dodge's success can perhaps most directly be attributed to its racing teams and drivers, the innovations and technology that goes into the vehicle design continues to play a major role in keeping DaimlerChrysler on the NASCAR fast track.

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