First to the Finish Line

In a sport where winning is often decided by split seconds, the BMW Sauber F1 Team uses fluid dynamics solutions from ANSYS to lower lap times through improved vehicle aerodynamics.

By John Krouse, Senior Editor and Industry Analyst, ANSYS Advantage

Formula 1 (F1) race cars are strange-looking beasts, resembling *Star Wars* fighting machines more than motor vehicles. The numerous odd-shaped appendages, exposed tires and open cockpit all contribute to considerable air resistance. Indeed, the aerodynamic drag of these cars is worse than that of a brick.

The reason for such low aerodynamics is that F1 rules mandate these configurations — along with standardized tires and restrictions on engine development — to limit car speeds, thereby making for a slower, safer and more exciting race in which vehicles are more evenly matched. Nevertheless, within these evolving restrictions, aerodynamics is a key performance driver for teams wanting to improve car lap times by the fractions of a second needed to win races, according to Willem Toet, head of aerodynamics for the BMW Sauber F1 Team.

Given these demands, developing optimal racecar aerodynamics is a huge engineering challenge involving a wide range of conflicting requirements. In straightaways, highest speeds at full throttle are gained with aerodynamic "slippery" vehicles, in which components exposed to the air stream are integrated. These include the chassis, underbody, engine cover with air inlets, vehicle nose, side pods with cooling inlets, wheels, brakes, suspension and exhaust system.

During cornering, braking, accelerating and high-speed maneuvering in the pack, the key is road-holding ability from downward forces produced by airfoil surfaces on the vehicle. At speeds above 170 km/h (106 mph), this force against the track typically equals total vehicle weight so that the car could drive upside down across the ceiling — at least in theory.

These high downward forces inevitably increase air resistance and lower the vehicle's top speed, however. The aerodynamicist must balance these trade-offs so that the time gained on the bends is not lost on the straightaways. Every part of the bodywork must be designed to provide maximum downward force with a minimum of drag. Moreover, downward force at the front and rear of the vehicle must be carefully apportioned depending on characteristics of individual racetracks. Also, aerodynamic parts such as fins, diffusers, wings and barge boards must provide optimal downward force without interfering with air inlets or engine cooling. The aerodynamic design from the front of the car to the rear depends on the shape and placement of all these components, and the vehicle reacts extremely sensitively to the slightest design alterations.

Compounding these technical complexities, teams have only nine months to develop a new car. Chassis, engine, transmission and, above all, aerodynamic concept must be right at the very first attempt. There is no time for multiple prototype cycles, and, when the first tests are held in January, it is generally too late for wholesale changes. Furthermore, during the racing season the idea of "standing still" with the same design is an alien concept. "At practically every one of the 18 races, teams make some kind of improvement so that their cars at the end of the season have very little in common with the original designs," said Toet. "With a race scheduled every two weeks, the clock is ticking to make performance-enhancing modifications on their cars before competitors do."

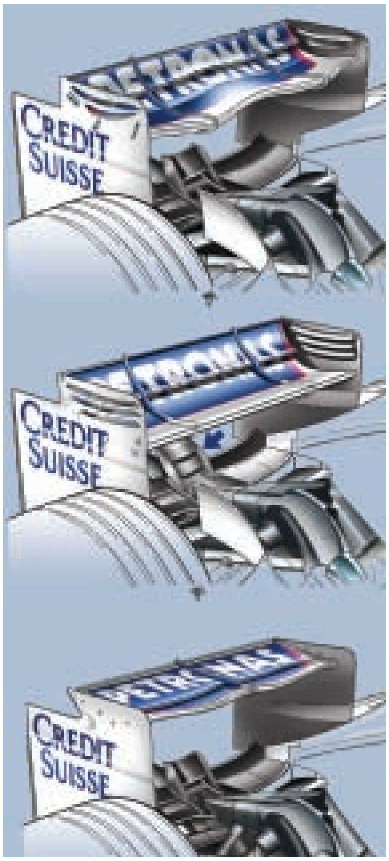
Simulation is a Must-Have Tool

In contending with the above technical challenges and demanding timetables, today's racing aerodynamicists simply cannot rely on intuition or trial-and-error methods. Rather, engineering simulation has become a standard part of vehicle development for most teams.

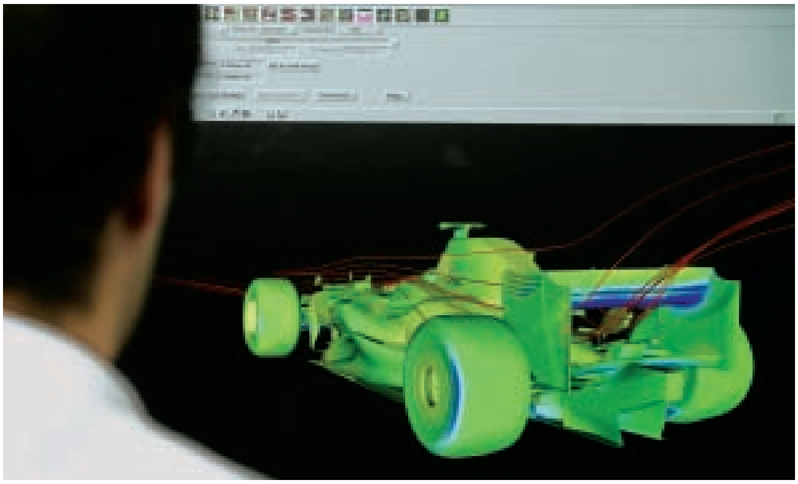
Finite element analysis became universally used in the racing industry as early as the 1980s, while simulations of air flow appeared in the early to mid-1990s. In recent years, computational fluid dynamics (CFD) simulation has experienced a real boom period in racecar design because of the ability to quickly and cost-effectively study aerodynamic efficiency and investigate the impact of design modification and alternative what-if changes on vehicle performance.

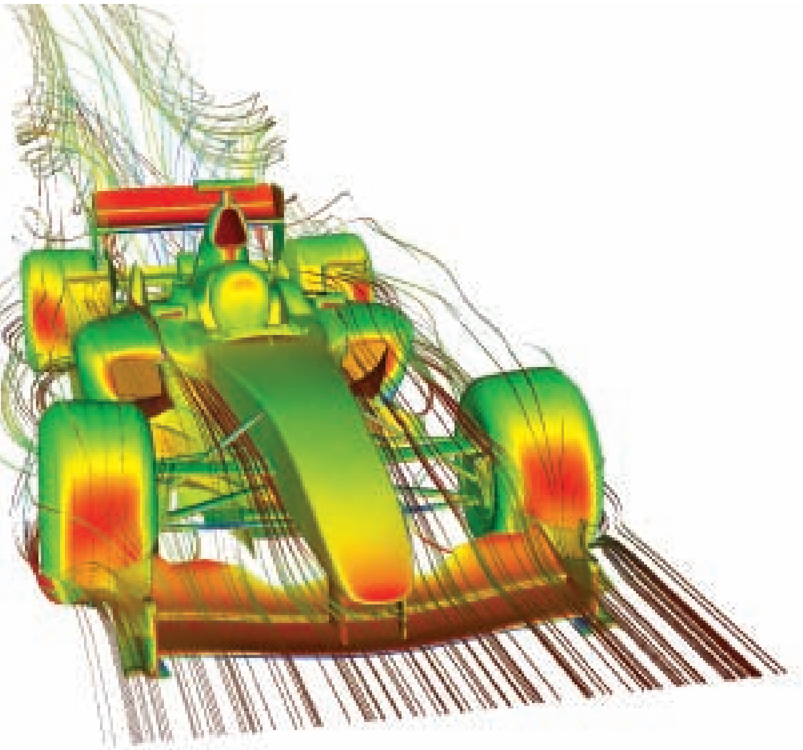
Fluid flow simulations are used extensively in these applications and range from the stationary analysis of individual components (wing profiles, for example) up to investigations of the entire vehicle as well as non-stationary simulations, such as interactions within the vehicle when overtaking another car. Also covered are fluid flow considerations that are outside the field of aerodynamics, such as sloshing inside a fuel tank.

Demonstrating a commitment to expanding its use of CFD, the BMW Sauber F1 Team recently upgraded its high-performance supercomputer cluster specifically developed for efficiently processing these simulations. Made by DALCO AG of Switzerland, the cluster has a peak computing speed in excess of 50 teraflops (one trillion calculations per second) with a compute section based on Intel® Xeon® 5160 dual-core and E5472 quad-core processors. With this processing power and the efficiency of fluid dynamics solutions from ANSYS, BMW Sauber F1 Team's engineers can process full-vehicle simulations in a matter of a few hours, instead of the weeks otherwise required on conventional machines.



Aerodynamicists tune the configuration of the rear diffuser to provide different downward force strength depending on characteristics of individual tracks. Top to bottom shows designs used in the 2007 season for races at Montreal, Canada; Barcelona, Spain; and Monza, Italy.





Fluid Dynamics Complements Wind Tunnels

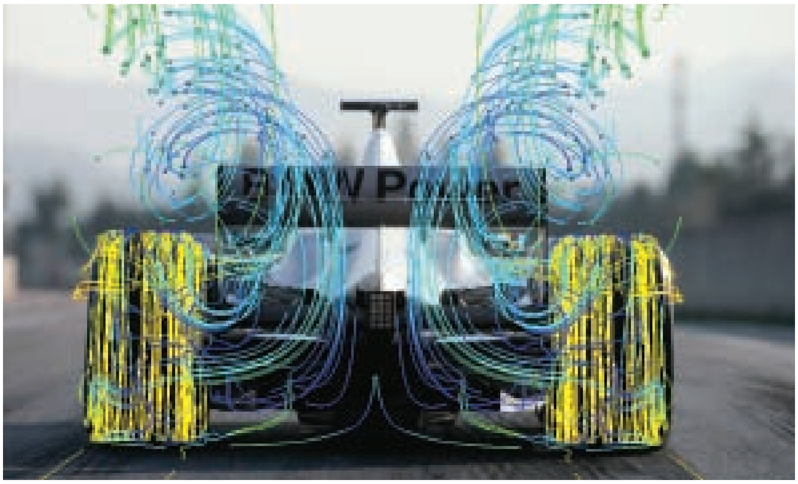
"The latest upgrade of our supercomputer was a decisive reinforcement of our CFD capacity. Unlike other teams, we didn't plan to build a second wind tunnel. Instead, we have used the key relationship commitment with our high-performance computing (HPC) partners, including ANSYS, to continue to develop and exploit the expanding potential for CFD that high-performance computing gives us," explained Mario Theissen, BMW Motorsport director.

He added that wind tunnel testing will continue as an important design element of their Formula 1 racing car design. The BMW Sauber F1 Team's wind tunnel generates wind speeds up to 300 km/h (188 mph) and features what is known as a "rolling road" that can simulate the interaction between the vehicle and the road surface. Using the wind tunnel, engineers can readily see the effect, on the actual vehicle, of minor adjustments made on the spot to part geometries and orientations.

"The big difference with CFD compared to wind tunnels is that you not only get results, but you also get an understanding of what goes on. Wind tunnel testing remains important with experimental work and CFD complementing each other," said Theissen. He noted that comparative wind tunnel measurements are also used for calibration and validation of the fluid flow calculations to increase the accuracy and reliability of simulation results. The range and detail of data collected, reproducibility of the results, and a better understanding of complex aerodynamic interactions are all strong arguments in favor of CFD simulations.

In an expanding range of studies, simulation is used to overcome limitations of wind tunnel testing. Because vehicles generally are stationary for wind tunnel tests, for example, evidence concerning air-flow characteristics can be rather vague in many regions. Also, wind tunnel tests are of little use in investigating heating and cooling effects because the engine is not running and brakes are not at operating temperature. In contrast, fluid dynamics simulations take all these factors into account, and calculations can be applied to all physical parameters, including those

Top view of the current model BMW Sauber F1.08 shows the aerodynamic complexity of a Formula 1 racecar.



involving variations in multiple interrelated parameters. In the final analysis, however, it is the testing on the racetrack itself that is the actual yardstick for evaluating the success of the aerodynamic methods in use and deciding to what extent they have been effective.

Coping with New Regulations

Beginning with the 2009 racing season, new regulations for the configuration of Formula 1 cars will drastically limit the use of aerodynamic surfaces. Many components, such as winglets to direct airflow, will become history. These constraints will certainly result in slower lap times, and performance of all the racing teams will likely become more closely matched.

"New regulatory changes do not mean that CFD simulations will become less important or that the work of aerodynamicists will diminish," Toet emphasized. "On the contrary, demands of the new motor sports rules are pushing aerodynamic designs further than ever and radically increasing the efforts of teams to maintain optimum performance." He noted that the front wing will be completely re-engineered, for example, to compensate for the lack of winglets, which are responsible for producing sufficient down force in critical situations. "Now more than ever, CFD continues to be a major factor influencing overall lap times and an indispensable tool in the development of Formula 1 racecars." ■

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