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Case Study: Automotive

Toyota Motorsport wind tunnel helps automotive engineers design faster high-performance cars with sophisticated built-in PIV system

Tecplot software provides critical CFD visualization component in cutting-edge technology

The blink of an eye may mean nothing to most people, but in the high-pressure, high-stakes world of auto racing, it can be the difference between winning and losing. Glance at the results of almost any Formula One race and you'll see that the top three cars usually finish within a few tenths of a second of each other — barring major mechanical failure or driver error, of course. Getting the best performance possible out of these complex speed machines requires intense scrutiny and religious maintenance by experienced engineering teams who are relentlessly focused on finding ways to improve air flow, increase downforce, and reduce drag.

Motorsports engineers like Frank Michaux, a CFD/PIV researcher at Toyota Motorsport in Cologne, Germany, use a number of advanced analysis techniques to help them get peak performance out of all kinds of vehicles — from NASCAR, Sports Car, Formula One (F1) and other races to finely built model lines for highway use.

Michaux’s team maintains and operates two state-of-the-art automotive wind tunnels, each equipped with a built-in particle image velocimetry (PIV) system.

During the 2009 Formula One season, engineers wanted to study the wake behind the front wheels of a vehicle — a critical part of the flow that can affect the performance of the entire vehicle.

To be useful, the complex data derived from these state-of-the-art systems must be quickly and accurately interpreted and displayed. Toyota Motorsport sustains its winning edge by correlating its PIV results with computational fluid dynamics (CFD) simulations, both accurately measured and rendered by Tecplot software.

Inside the Wind Tunnels

Toyota Motorsport is a renowned center of excellence for automotive design and development. A service-focused company, it offers use of its wind tunnels to outside engineers and researchers as well as to those within the Toyota organization. Both wind tunnels are state-of-the-art facilities built less than ten years ago. One is equipped for full-scale testing, with a rolling road on which vehicles can reach simulated speeds of 70 meters per second. The second is used for model testing at a scale of approximately 60 percent.

Both feature permanent PIV systems, a rare and valuable research tool for design engineers.

PIV is an optical method of flow visualization that has been used for a couple of decades to obtain instantaneous velocity measurements and related properties in fluids. But it wasn't until very recently that PIV became a practical design tool for engineers, largely due to the increasing power and decreasing cost of both computers and digital cameras.

Development teams from many of the world’s largest and best-known auto makers travel to Cologne to take advantage of the advanced technology and expertise offered by the Toyota wind tunnel team.

"Many of today's motorsports cars are based on existing, commercially-available cars," said Frank Michaux. "If researchers can identify a way to reduce drag on a motorsports car, it's reasonable to assume that this information also may apply to future versions of a normal road car."

Optimization in auto racing is like everything else. It is a continuous process and, according to Michaux, most engineers sport a bit of a perfectionist streak. As a result, he says, they are never totally satisfied with what they've accomplished. This is a good thing, though, because each part or mechanical adjustment in a car—no matter how tiny—affects the flow, force or drag of the entire machine. Without that perfectionism, the small details could be easily overlooked. Since optimization is continuous and evolutionary, the speed with which engineers can compile and analyze data, and then apply it to a current project, becomes vital. A delay of even a few days can mean the difference between successful integration and failure.

"At Toyota Motorsport, we need to deliver data quickly. If you see that you are not capturing the flow correctly, then you need to adjust your CFD methodology until you get it right," Michaux continued. "The sooner and faster you can do that, the better."

During the 2009 Formula One season, engineers wanted to study the wake behind the front wheels of a vehicle — a critical part of the flow that can affect the performance of the entire vehicle.

At Toyota Motorsport in Cologne, Germany, engineers use wind tunnels with sophisticated built-in PIV systems to help design faster high-performance cars.

During a particle image velocimetry (PIV) test, Toyota Motorsport engineers position a camera at a 90-degree angle to the plane of the flow field. The wind tunnel is filled with fog, and the part that needs to be visualized is illuminated with a high-powered laser, creating a 2D plane.
Using Non-Intrusive Methods to Visualize and Quantify Air Flow

Before the advent of PIV, engineers would create simple vehicle models and then study the flow on the surface of the model. This was inefficient because they could only see the flow at the surface. They didn’t have the means to produce a 2D plane, for example, or accurately observe and record the critical wake of the wheels.

To compensate for these shortcomings, engineers employed several ad hoc techniques, like putting a smoke probe in the wind tunnel in order to better “see” the air flow. But in an industry where seconds count, these methods didn’t accomplish what engineers really wanted: to fully capture accurate flow data for the area of interest, and to do so very quickly.

“By looking at the smoke, we could visualize the flow, but we were unable to quantify it. You could only make assumptions about speeds based on the visual aspects of the flow,” said Michaux. “The whole problem in this industry is how to visualize air flow without introducing something new into that flow that could potentially compromise the results. With the PIV method, you can really attach numbers to air flow.”

PIV allows for the visualization of the flow field almost exactly as it appears in the wind tunnel, without influencing the very flow field that engineers are seeking to measure. Toyota’s PIV system involves filling the tunnel with a fog or mist with essentially the same density as air. When the air flows through the tunnel, the small particles that make up the fog simply float, making this PIV method as non-intrusive as current technology will allow.

For a PIV test, engineers position a camera at a 90-degree angle to the plane of the flow field they want to study. The tunnel is then filled with the fog, and all tunnel lights are turned off. Next, engineers illuminate the part that needs to be visualized with a high-powered laser, creating a 2D plane. Simultaneously, a series of two-set photos are taken at extremely rapid intervals—generally 10 to 20 microseconds. Equipped with this sort of ultra-slow-motion digital imaging, engineers can easily measure the rate and direction of the flow.

Integrating PIV with Tecplot for Complete Visualization and Understanding

During the 2009 Formula One season, engineers wanted to study the wake behind the front wheels of a vehicle. This is a critical part of the flow; if it isn’t perfectly calibrated, the performance of the entire vehicle could be severely compromised. Upon being presented with the problem, the Toyota Motorsport team realized they needed to look at options for adding or modifying various front-end parts, for example, adding an under-nose turning vane or modifying the front wing to create or influence an outwash. The goal is to push the flow out from under the nose of the car, forcing the wake of the car as far “outboard” as possible.

After gathering the raw data from the PIV measurements of the “separation point” on the front tires, engineers post-processed the data using Tecplot software, which allowed them to see and measure the exact position of separation. Each of Toyota’s PIV measurements consist of 300 datasets, with each dataset containing two images taken 10–20 microseconds apart. The end result of the PIV process is a complete 2D field of vectors. Engineers subsequently plotted the velocity magnitude, or vorticity, with vectors based on the average of all 300 datasets. The corresponding CFD result was then also imported into Tecplot software. Engineers compared the PIV and CFD data sets to determine whether their CFD methods were within tolerances. Whenever necessary, the engineers tweaked the CFD process to get it closer to the wind tunnel results.

In the case of the separation point on the front tires, initial tests showed that the separation point was late and too far back from the tires. The engineers altered the CFD methodology based on these observations, imported the new results into their Tecplot software, and compared it with the PIV results to evaluate their progress. The process was repeated until they arrived at a design that placed the separation point at an optimal position on the tires. This method of CFD / PIV analysis helps engineers derive simulations of real world conditions that are as accurate as possible in a surprisingly short timeframe.

“The choice of Tecplot software for our automotive testing was fairly obvious,” observed Michaux. “Almost everyone in the automotive research industry uses it, making it easy to share information with other researchers or engineers. And if you need to use PIV software from a different provider, the output can still be read in Tecplot software. It’s simple to switch back and forth without completely changing your post-processing chain.”

With speed and accuracy the name of the game, Toyota Motorsport, along with Tecplot software, can provide a number of diverse automotive clients the data gathering, interpretation and visualization they need to lap the competition.

“We have the ability to accommodate a wide range of CFD and PIV requirements, and have a team of knowledgeable engineers available to assist with acquiring and visualizing the results,” said Michaux. “Tecplot software plays a significant role in helping us achieve that level of automotive science and service.”

After comparing the PIV results with the CFD results, the CFD methodology is optimized and is then used to run further CFD simulations.