CFD Advances Racing Bike Performance

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Highly automated **computational fluid dynamics (CFD) workflows** enable the discovery of flow behaviors, **improving wheel aerodynamics.**

When it comes to bicycle racing, riders on road circuits choose bikes that are lightweight in design and aerodynamically optimized. From the frames to the wheels to the tires, the bike's design plays an integral role in helping the cyclist to compete successfully.

Not unlike the automotive and aerospace industries, manufacturers typically work to reduce the weight and aerodynamic drag of bikes in various ways. They may construct frames of lightweight material, such as carbon fiber composites, and tinker with the shape of the tubes that make up the frames. They may reshape the wheel rims or even reduce the number of spokes in the wheels to achieve greater aerodynamic efficiency. They may also tweak the tires' thickness and tread to reduce air resistance and rolling resistance on the road.

Wind tunnel testing and computational fluid dynamics (CFD) are commonly used to evaluate the drag force at the system level. However, to isolate and evaluate the drag impact of hundreds of design variables at the component level, wind tunnel testing is cost-prohibitive, and CFD analysis workflows historically have been too long to be practical.

Recently, technologists set out to explore and develop a highly automated, repeatable workflow methodology to radically accelerate the entire CFD process. Their results, presented at a recent American Institute of Aeronautics and Astronautics (AIAA) conference, enabled detailed flow dynamics simulations of multiple wheel configurations providing new insights into the role the tire, forks, brakes, tubes and rim play in bike performance. The study, validated by wind tunnel physical testing, brought to light new flow behaviors, spurring interest by a U.S. manufacturer of bicycle racing wheels to incorporate the CFD simulation methodology into its product development process.

Getting Into the Flow

Typically, flow dynamics has been performed through physical and wind tunnel testing, often focusing on the air flow around bicycle wheels. This new research, conducted by CFD technologists of Altair and CFD post-processor developer Intelligent Light, sought to automate and validate the predicted flow dynamics of a rotating wheel, taking into account the interactions with the fork, head tube, top tube, down tube, caliper and brake pads of bicycle component manufacturers.

The team applied various simulation tools including Altair's AcuSolve™, a finite-element based, general-purpose solver that handles complex fluid-structure interaction and multi-physics problems, plus Intelligent Light's FieldView 13 CFD post-processing and visualization package. Altair partners with Intelligent Light, offering a HyperWorks® OEM version of this software called AcuFieldView, available to all AcuSolve users.

Studying the aerodynamic flow around a rotating bike wheel and components, while in contact with the ground, presented a unique CFD challenge as multiple wheel and fork/frame combinations at 10 yaw angles were evaluated. The steady-state simulations generated approximately 3.6 GBs of AcuSolve data while the unsteady simulations resulted in nearly 1.2 TBs of data.

In the past, researchers would have been overwhelmed by this quantity of data and its complexity. The use of FieldView, however, provided the team with the tools needed to accelerate the analysis, mine the most valuable information and create compelling images and animations. In fact, two significant insights – an unexpected vertical force transition and previously unseen, highly resolved periodic flow structures – became apparent by employing FieldView's post-processing capabilities.

The automation and visualization capabilities contributed to a productive CFD workflow that was repeatedly put to the test as the study progressed. The ability to extend the routines to answer new questions and work with new datasets is an essential capability of any high-productivity workflow.

In particular, the team leveraged the FieldView FVX™ programming language to automate many post-processing tasks. Iterations that would have taken many weeks to accomplish in a traditional, serial workflow were completed in days.

For example, the CFD technologists ran the FieldView FVX routine 60 times to calculate the drag force for all wheel-and-fork combinations at two speeds. Some tasks – such as calculating circumferential variation, which entailed 3,600 calculations for each wheel-and-fork combination – simply would not have been possible without automation. By specifically developing automation methodologies that were geometry-independent and applicable to both steady and transient simulations with few or no changes, the team laid the groundwork for future extension of the research.

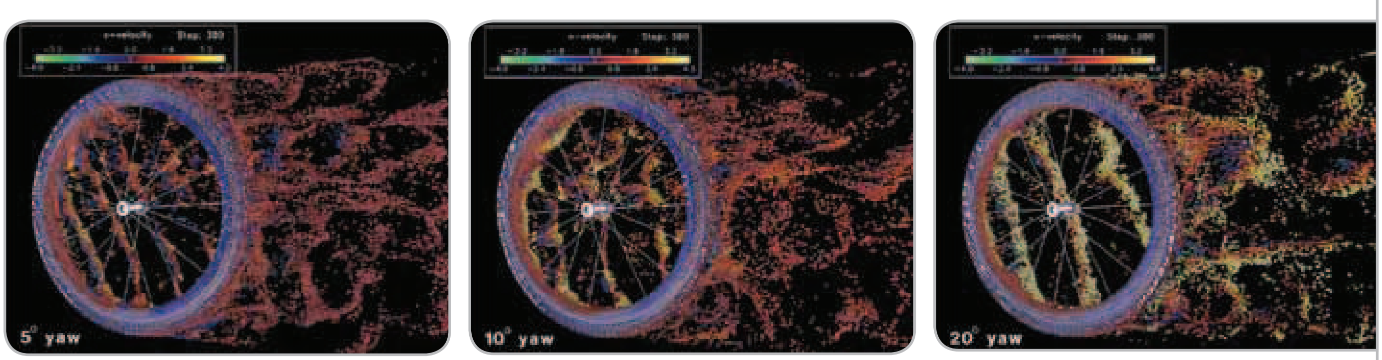
Automation Accelerates Productivity

Post-processing the large volume of data in the bicycle wheel study was significantly accelerated with FieldView running in parallel on eight processors. FieldView FVX routines allowed the automated workflow and custom visualization to be produced in batch mode without user intervention, enabling the team to post-process multiple cases and time steps concurrently while running AcuSolve to generate additional solution data. Further, the data management challenges of dealing with terabytes of data were addressed through the use of FieldView XDB files, which are a fraction of the size of original solution data files. These tools are available in AcuFieldView.

Performing post-processing while solutions are being generated greatly increases engineering capability and decreases overall time. Hardware and software investments are put to their best use for higher productivity. As a result, complex engineering and research studies can be performed within project time constraints while maximizing return on CFD investments in technology and people.

On the Road to Success

The CFD-based research returned key findings – that the drag force does depend on the wheel and is influenced by the choice of the front fork, and that the wheel rim and tire, not the hub and spokes, dominate the overall drag. These findings not only challenged conventional wisdom but also spurred Zipp Speed Weaponry, an Indianapolis, IN,



The combination of Altair's AcuSolve CFD solver and Intelligent Light's FieldView post-processing technology automated detailed flow dynamics simulations of multiple wheel configurations at different yaw angles, yielding new design insights to enhance racing bike performance.

Zipp Speed Weaponry, a manufacturer of advanced bicycle racing wheels, couples wind tunnel testing with the use of computational fluid dynamics software to assess design options.

manufacturer of advanced bicycle racing wheels and cycling components, to apply CFD technology in the design of its Firecrest line of racing wheels.

Josh Poertner, Zipp's technical director, explains that reading the AIAA papers was a huge game changer. "All the effects outlined in the study," he says, "are the ones that we could measure in the wind tunnel but generally couldn't explain – and definitely couldn't predict. The work beautifully explains much of the 'why.' It instantly made sense to us and re-characterized our approach to designing wheels. It made us realize that we could start to design for stability."

Balancing the competing requirements for speed and stability has always been challenging, but the study's findings opened up solutions for the Zipp team. The visualization let the team assess the problem in a new light.

Poertner says, "Actually seeing the center of pressure distributed across the wheel is so much more meaningful and intuitive in iterating design. We learned how to optimize the center of pressure to eliminate steering torque, which removes the 'push' and wind gust issues. We also pushed the vortex-shedding frequency higher, well above natural frequency, and the resulting amplitude reductions nearly eliminate a rider's perception of buffeting."

Zipp's Firecrest design cut drag on the front half of the wheel by a couple percent and reduced drag on the back half of the wheel by 50%. The result is a product that is not only stable but also fast – and the market's response to this innovative wheel has been just as swift.

Deeper Insight through Rapid Visualization

The primary objective of the research was to more realistically model the performance of a commercial bicycle wheel by including more of the components around the front wheel and by running transient instead of steady-state CFD simulations. The co-processing and concurrent post-processing methodologies developed for the study made the analysis of many wheel/fork/component combinations with AcuSolve and FieldView both possible and practical in a commercial setting.

More importantly, the research and partnership between Altair and Intelligent Light provided rare insight into the wheel's aerodynamic performance. In fact, through visualization, CFD technologists were able to "sit" on the edge of the wheel and ride through its rotations, capturing for the first time the unseen complex interactions happening with every turn of the wheel. More recently, the work has been extended to incorporate full bicycle systems, allowing for the isolation and exploration of components and their drag influence.

The Zipp 808 Firecrest Carbon Clincher Wheelset, evaluated with simulation tools, is used in triathlon races, offering an alternative to deep-dished tubular.

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