
Emirates Team New Zealand used CFD to predict the effect of design alternatives on yacht performance.

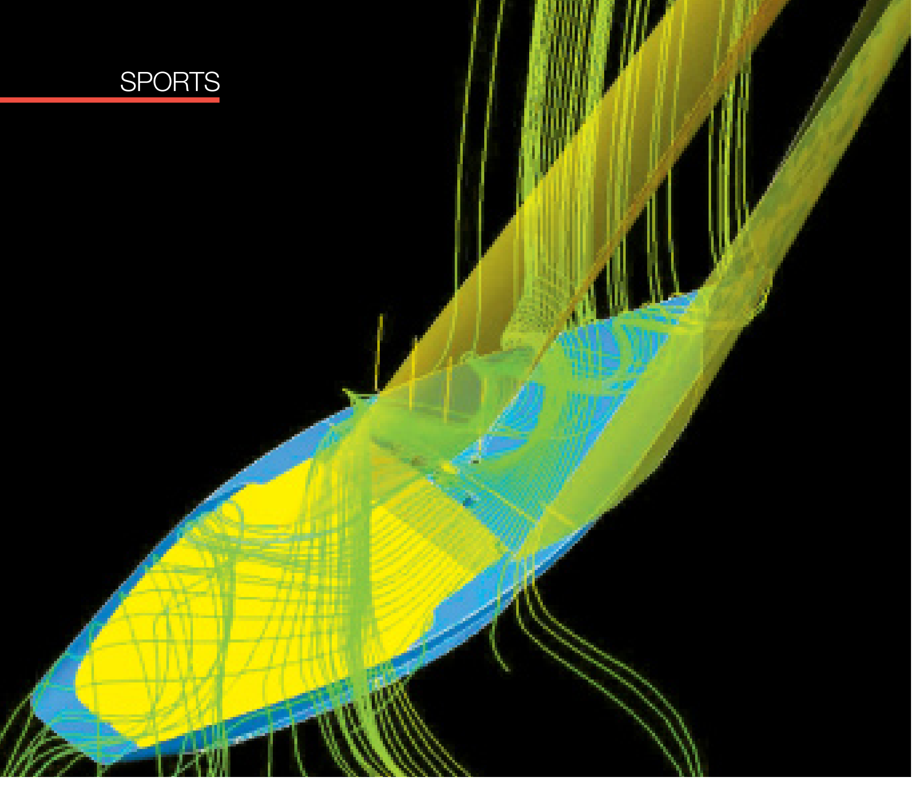
The Simulation Race for America's Cup

Yacht designers used engineering simulation in a variety of applications to edge out the competition.

The America's Cup is the most famous sailing regatta in the world and also the oldest active trophy in international sport. The trophy, originally known as the Royal Yacht Squadron Cup, was first awarded in 1851 when the New York Yacht Club schooner *America* defeated 15 Royal Yacht Squadron challengers in a race around the Isle of Wight in England. In honor of *America*'s victory in the first competition, and the subsequent dominance of American boats for over a century, the trophy officially became known as the America's Cup.

Despite its name, it is truly an international competition. In 2003, the Swiss challenger Alinghi defeated Team New Zealand to win sailing's grand prize; Alinghi successfully defended this summer at the 32nd America's Cup in Valencia, Spain. The boat sizes and designs have varied through the years, ranging from the 130-foot J-class yachts of the 1930s to a 60-foot catamaran in 1988. Since 1992 though, the teams have sailed an International America's Cup Class (IACC) sloop, a monohull boat that has an average length of about 75 feet. To determine which team would challenge Alinghi for the trophy in 2007, an ambitious schedule of regattas was held, commencing in 2004 and culminating with the Louis Vuitton Cup this past spring. The America's Cup match series was held in late June and early July, with Alinghi the winner in the closest Cup in recent history.

The racing syndicates that compete for the cup are composed of the best sailors, designers, sailmakers, nautical engineers and boat builders in the world. The top teams expend more than 150,000 labor hours to optimize the designs of their boats. All of the leading teams employ computer simulation to determine the power generated by the sails, the drag produced by the boat's hull and the air resistance of the deck. Four of the top teams, including BMW ORACLE Racing from the United States, South Africa's Team Shosholoza, Emirates Team New Zealand (ETNZ) and defending champion Alinghi from Switzerland, use computational fluid dynamics (CFD) software from ANSYS, Inc. to predict the effect of design alternatives on yacht performance down to the smallest details.



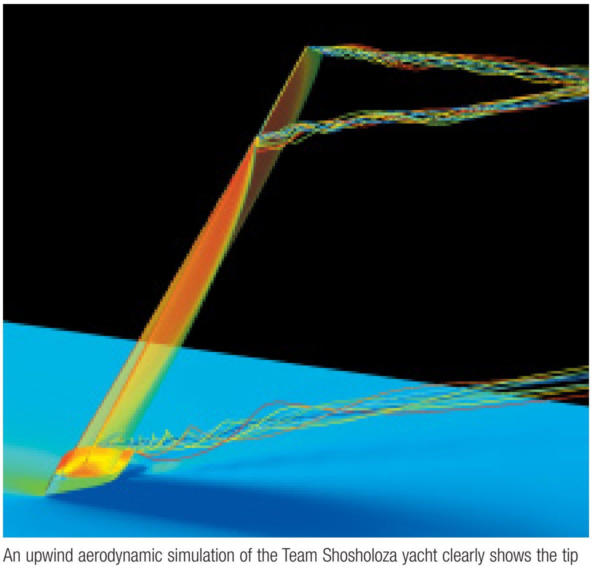
CFD simulates the wind flowing over the deck and cockpit of the Alinghi boat. Note the vortex that formed in the bow where the wind wraps around on the deck.

The two most critical aspects of yacht performance are the sail aerodynamics and the hydrodynamics of the hull and appendages. Picture this analogy: A racing yacht is like a plane floating on its side with one wing sticking up in the air and the other down into the water. The art of yacht design is to extract drive force because the two fluids (air and water) have different speeds and directions. The curvature of the sails generates lift in a manner similar to an airplane wing, while the keel of the boat generates lift in the opposite direction — like the opposite wing of the airplane — to prevent the boat from moving sideways. The keel can be proportionately much smaller than the sails because it operates in a fluid 800 times denser than air. As in aircraft design, improving performance of a racing yacht is basically a question of maximizing lift and minimizing drag. Small changes in geometry often make the difference between a competitive boat and an also-ran.

BMW ORACLE Racing: It's In the Details

In the 2003 competition, BMW ORACLE Racing used a public-domain CFD code to simulate the performance of their boat. However, they found that meshing and solution times were so long that they were forced to simplify their models to the extent that they could not distinguish between small design changes. For the 2007 race, the team used ANSYS CFX software. BMW ORACLE Racing ran models with 10 to 15 million cells on large computer clusters that can resolve the performance impact of the smallest design changes. The team's designers simulated the performance of large numbers of different sail shapes and trims to understand performance under a variety of conditions. They evaluated the aerodynamic effects of the deck, such as the shape of edges and corners and the position of the winches, and they also looked at the shape of underwater components, such as the ballast bulb.

"Our new simulation methods make it possible to model the most complex problems down to the finest details in a day or two," said Ian Burns, design team coordinator for BMW ORACLE Racing. "We now can determine the effect of the smallest changes, such as the shape of the deck or small hardware components on the mast. Some of these changes can have a significant impact on performance and are helping us make significant performance improvements. We have analyzed and improved nearly every detail of the boat with ANSYS CFX software."



An upwind aerodynamic simulation of the Team Shosholoza yacht clearly shows the tip vortices. Induced drag reduction is important for sails operating near their maximum lift.

Team Shosholoza: Big Things from Small Packages

Team Shosholoza, South Africa's first America's Cup entrant, was one of the smaller teams in this year's competition. Unlike some of the larger teams, Shosholoza has only one boat, so it can't rely on running two boats against each other to evaluate design changes. Therefore, CFD simulation is critical to the team, which has built a 42-node cluster that places it near the top in terms of computing capabilities among the smaller entrants. Shosholoza used computer-aided design (CAD) tools to develop a parametric model of the boat and then read the model into the ANSYS ICEM CFD Hexa meshing tool, which quickly generates a series of models by varying a key design variable over a defined range. Shosholoza then solved the models with ANSYS CFX software, and designers used the results for force and drag to predict the velocity.

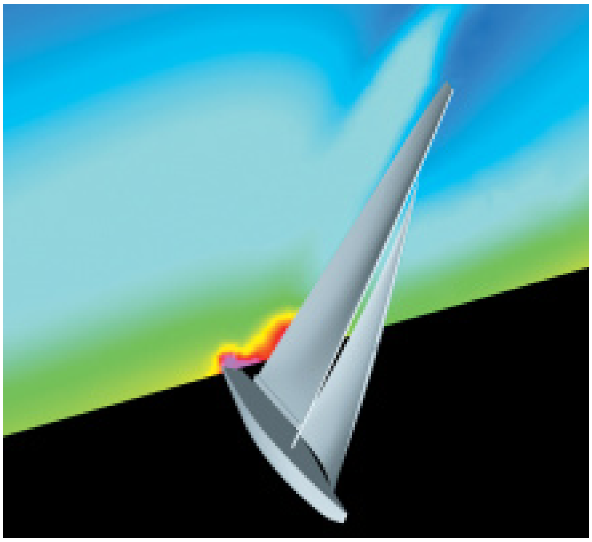
"To date, the area where we have made the greatest improvements is in the shape of the sails," said Christos Pashias, fluid dynamicist for Shosholoza. "We are trying to get as much power out of the sails as possible because the winds in Valencia are so light. We set up a parametric model to automatically generate sail models. This enabled us to have a quick turnaround and study more shapes. Being a new team, initially we made improvements of between 5 and 10 percent in driving force. A 1 percent improvement in driving force typically increases the speed of the boat by about 0.1 percent. We have tested boats with the new designs and discovered that they actually do provide the performance improvements that ANSYS CFX predicts. Since we made those initial big gains, we have made many other improvements that have provided smaller gains, typically in the area of 1 percent, which is what most teams are after. Testing already has shown that these predictions are accurate, so we trust them to make more improvements."

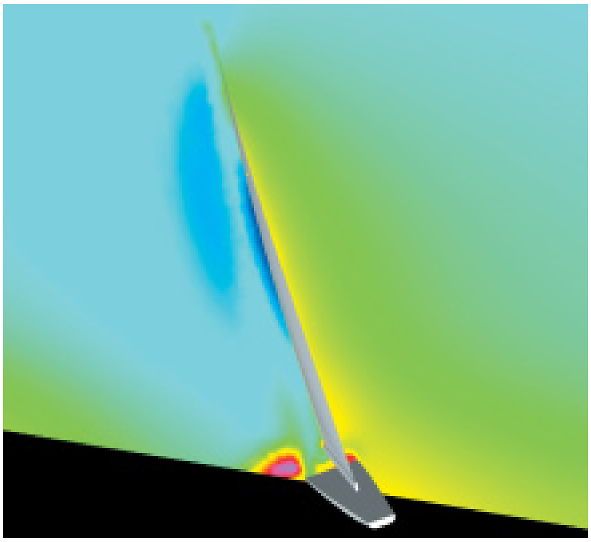
Shosholoza also used FLUENT CFD software to better understand the flow of water around the yacht. The ranking of candidate hull shapes by FLUENT software agreed well with experimental results.

Emirates Team New Zealand: Location, Location, Location

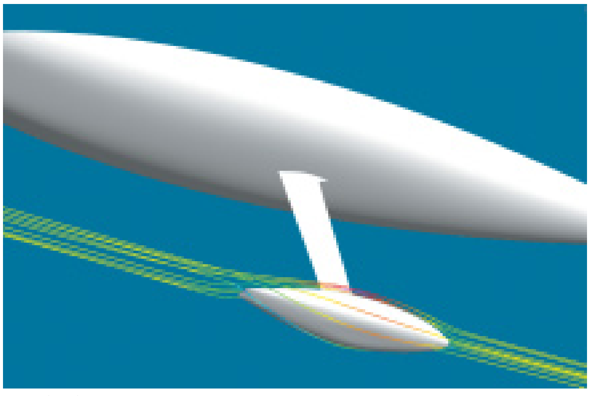
ETNZ has been focused on improving the ballast bulb at the bottom of the boat. At about 21 tons, this torpedo-shaped lead component makes up nearly 80 percent of the boat's mass and provides the craft with the stability to balance a very large sail area. Choosing a bulb shape with a lower center of gravity increases the boat's righting moment and enables the sail to provide a larger driving force. On the other hand, moving to a lower drag force wastes less of the available driving force and increases the speed of the yacht. In preparing for the 2003 race, the New Zealand designers were able to lower the center of gravity substantially without any increase in drag. With these major improvements under its belt, the team's goal for 2007 was to make more subtle and site-specific changes, such as optimizing the bulb design for the expected conditions off Valencia.

"We developed a genetic algorithm that works by defining the geometry of the bulb with control points whose coordinates and weighting are considered to be genes," said Nick Holroyd, designer for ETNZ. "Then the population was seeded with a range of candidates, and mutations were introduced into each generation to adequately spread the population across the design space. Each candidate was simulated with ANSYS CFX software using the laminar-to-turbulent transition model to provide a drag value. This value is factored against the stability contribution of the shape to provide a fitness score for the design. We developed a family of new bulb shapes with a better





Simulations were conducted under a wide variety of conditions to determine performance. Velocity magnitude contours around the hull and sails of the BMW ORACLE Racing boat are shown (windward above and leeward below) with plane cuts that are perpendicular to the boat track.



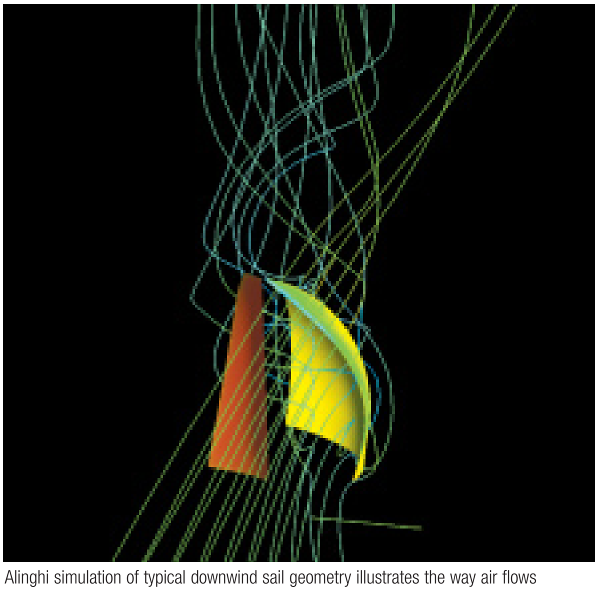
BMW ORACLE Racing has analyzed and improved nearly every detail of the boat, including the keel–ballast bulb juncture.

Team Shosholoza

drag/stability trade-off for the racing conditions expected at Valencia. This approach made it possible to evaluate the design space with much less time than would have been required manually."

Alinghi: Defending Its Honor

Winner and defending champion Alinghi used CFD to evaluate every portion of the boat, including the sails, the underwater portion of the hull and deck details. Alinghi designers spent more than a year evaluating CFD results compared to wind tunnel testing and scientific papers. "We gained confidence in the ANSYS CFX software and calibrated its results," said Jim Bungener, CFD engineer for Alinghi. "The main areas where we have made performance improvements have been in the winglets on the ballast bulbs and the downwind sails or spinnakers. We also have made smaller gains in areas such as winch placements and pillar shapes. These improvements have significantly increased the speed of the boat. When considered as a whole, the results that we have achieved with CFD aided us considerably in defending the America's Cup." Bungener also used ANSYS Structural software to identify the composite laminar structure that withstands the loads on the hull while minimizing weight.



Alinghi simulation of typical downwind sail geometry illustrates the way air flows over the sails. A large vortex is created behind the spinnaker, a billowing sail used when the wind is behind the boat.

Steady Wins the Race

Computer simulation has played a crucial role in the boat design process for many of the top racing syndicates. With all entrants now using CFD to optimize the performance of their boats, different design groups have arrived at generally the same conclusions and made substantial performance improvements. As a result, the boats are closer together in terms of performance, making tiny improvements that much more important. The teams now are all creating finer and finer meshes using larger clusters of computers so they can evaluate the effects of smaller design changes on yacht performance. The America's Cup is thus becoming a showcase, not only for the world's fastest yachts but also for its most powerful simulation tools. ■

This article was written through contributions from Alinghi, BMW ORACLE Racing, Emirates Team New Zealand and Team Shosholoza.