Charting a Confident Course

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PHOTO: CHRIS CAMERON/CAMPER2011-12/VOLVO OCEAN RACE S.L.U.

Engineers at Emirates Team New Zealand rely on CFD from ANSYS to optimize sail performance for the seven-month Volvo Ocean Race.

The Volvo Ocean Race is one of the most grueling sports events in the world. In this event, held every three years, professional teams of 11 sailors guide their yachts over more than 39,000 miles of uncertain ocean conditions — a challenging route that spans the globe and includes some of the world's most treacherous seas, including those around Cape Horn.

From October through July, Volvo Ocean Race crews sail up to 20 days at a time, as they complete nine separate legs of the competition. Crew members face a daunting regimen of freeze-dried meals, waves up to 10 meters, and temperature swings from –5 C to 40 C.

While the race brings daily challenges for athletes, this demanding event also poses special problems for yacht designers. Race rules restrict each yacht to only eight sails for any given leg, compared to the 13 sails an America's Cup Class yacht typically carries for a two-hour race. Crew members manipulate the eight sails in navigating the transocean route, where wind conditions can range from becalmed to force 10 gales, originating from any point on the compass.

This combination of few sails and uncertain conditions means that Volvo Ocean Race competitors are often forced to sail at challenging headings and wind speeds without ideal sails for such conditions. The yacht's hull and appendages must be designed to compensate. Consequently, early in the boat design process, yacht designers must obtain a good understanding of the effects of different sail inventories and their capabilities.

SAIL PERFORMANCE: A CRITICAL EDGE

For the 2011–12 Volvo Ocean Race, Emirates Team New Zealand — a world leader in yacht racing — designed a boat backed by advanced technologies from ANSYS, with financial sponsorship provided by Spanish footwear manufacturer Camper. Team New Zealand has used ANSYS software for the past 14 years, achieving considerable success in applications of both aerodynamic and hydrodynamic design.

To understand the contribution of sail designs throughout the 39,000-mile Volvo campaign — and to feed this data back into the overall yacht design process — Emirates Team New Zealand engineers subjected these designs to an intensive combination of wind-tunnel testing and computational fluid dynamics (CFD) simulations using ANSYS CFX software.

With only a four-month design window for the entire yacht, the team placed a premium on using engineering simulation software from ANSYS to obtain fast and reliable CFD results. To establish a physical basis for CFD simulations, Emirates Team New Zealand engineers began their sail studies in a unique twisted-flow wind tunnel at the University of Auckland. Over the course of three days, they carried out 216 tests, fully covering the team's initial sail inventory across the range of wind speeds and angles expected during the race.

The team mounted small cameras on the model yacht, looking up at the sails. Using a specialized tool called VSPARS that calculates sail shape and position in real time, the designers were able to output full details about each sail stripe and rig deflection to an on-deck display. The digital images were used to generate accurate sail shapes to seed subsequent CFD analyses. They focused on getting a large collection of data for a wide range of sails, so engineers could quickly get a velocity prediction program (VPP) up and running — and understand the implications for the yacht's overall design.

RAPID RESULTS FUELED BY HPC

Next, block-structured grids were generated using ANSYS ICEM CFD Hexa. This approach produced a high-resolution boundary layer mesh around the mast and sails, while retaining manageable grid sizes, on the order of 8 million to 10 million cells. Since grid generation can be time consuming, this process was automated to increase productivity. By using Perl scripting running ICEM CFD and CFX-Pre in batch mode, the entire process took approximately 10 minutes for a 9 million-cell grid.

Emirates Team New Zealand engineers then relied on high-performance computing resources to each day evaluate dozens of sail combinations under a multitude of wind conditions. The team's Dell cluster is the largest private-sector computational cluster in New Zealand. It is optimized for CFX simulations with a smart queuing system that has increased Emirates Team New Zealand's design efficiency considerably.

As the hull and appendage design proceeded, the sail design process continued as well. Emirates Team New Zealand engineers used CFD studies to continuously refine the aerodynamic elements of the sails, to best suit the overall hull package being developed for both on- and under-water elements. This was a repeated, closed-loop process to ensure that the yacht's hull and appendages matched with the sail inventory.

ANSYS technology allowed Emirates Team New Zealand designers to analyze more than 2,000 different sail shapes and trims.

PHOTO: CHRIS CAMERON/CAMPER2011-12/VOLVO OCEAN RACE S.L.U.

Physical tests in a twisted-flow wind tunnel produced images that seeded subsequent CFD simulations of sail performance.

Since the eight sails on board the Camper yacht have to perform as promised under any wind conditions, robust design is critical. While physical tests in the twisted-flow wind tunnel were excellent at comparing the sails' overall performance, it could be difficult for engineers to determine why one sail performed better than another — and what design modifications could bring even further gains. CFD simulations, on the other hand, demonstrated exactly how and where performance gains could be made. Simulations were precise and repeatable, allowing for rapid parametric analyses. Subtle changes in trim and sail shape significantly improved the overall VPP results and ensured that the sails would work in tandem with other yacht components to deliver the highest possible performance for the entire boat.

TOOL FOR PREDICTABLE PERFORMANCE

The range of shapes and sizes associated with sail design is very broad. Designs for upwind sailing are very different from the ones used in downwind conditions.

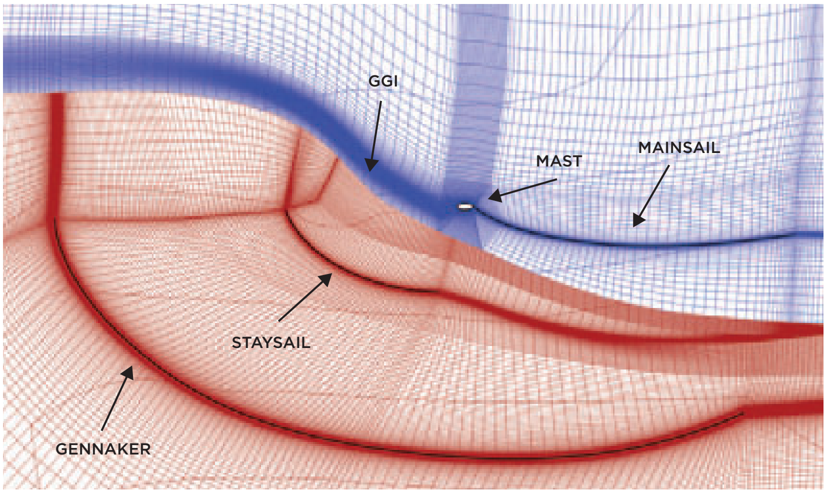
Sails must be smaller under conditions of very high wind velocity. Whatever the size and shape of the sails, the key to predicting sail performance is accurately simulating turbulence and behavior of the boundary layer close to the sail surface. This requires well-validated turbulence-modeling capabilities.

Emirates Team New Zealand's sail designers find the k-ω shear stress transport (SST) turbulence model invaluable in conducting daily aerodynamic studies. Key to efficient analysis of sails is achieving good performance across a range of flows, from low to high shear, without requiring changes to mesh topology. Automatic wall functions in the CFD software are also important, as they allow homogeneous turbulence modeling across different resolution meshes for the various sail components. The implementation of Menter's SST model within CFX provides design accuracy, robustness and speed — and the technology remains in a class of its own for yacht sail analysis.

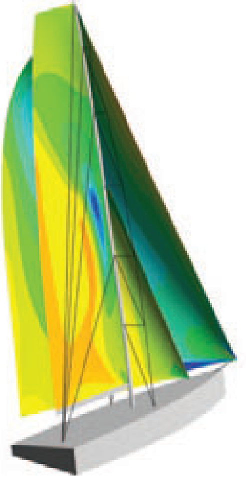
Another important facet of sail design is analyzing deformation in the sail. In upwind situations, in which the sails are relatively flat and stiff, aerodynamic pressures can be obtained from a panel method. But for large spinnakers used in downwind conditions, accurately mapping deformation of the sail and subsequent change in aerodynamic performance is critical. To accomplish this, the design team coupled the ANSYS software's aerodynamics capabilities with the sail manufacturer's in-house structural analysis code.

The smooth workflow from geometry to ANSYS ICEM CFD meshing software to the CFD solver allowed the designers to rapidly perform a large number of simulations. The results provided information on sail performance under varying aerodynamic conditions, which was fed back into the structural design of the sails. Throughout preparation for the Volvo Ocean Race, designers performed coupled fluid–structure interaction assessments, an iterative loop in which CFD analysis provided a new sail shape, which was then subjected to structural analysis.

The team's short design cycle and tight budget placed a premium on fast turnaround, from initial concept through final analysis. In meeting these demands, the generalized grid interface capability in CFX proved invaluable, allowing high-quality ANSYS ICEM CFD hex meshes to be built around different sail components — and often re-used when designers were making minor trim changes. In all, ANSYS technology allowed Emirates Team New Zealand designers to analyze more than 2,000 different sail shapes and trims in developing sails for the 2011–12 Volvo Ocean Race.



Block-structured grids of the sails generated based on images from wind-tunnel tests. To retain high-quality cells and a simple blocking topology, Emirates Team New Zealand engineers made use of generalized grid interfaces (GGIs).



The CFD simulations included sails, boom, mast and approximate hull geometry. CFD results allowed the team to model rigging windage by sampling velocities at discrete locations along each rigging element — and then pinning these elements to the CFD geometry.

CONFIDENT COURSE

As Camper Skipper Chris Nicholson eases through the doldrums in search of wind during the challenging months of the Volvo Ocean Race, ANSYS simulation software is probably the last thing on his mind. As the Camper yacht blasts through 10-meter waves deep in the Southern Ocean, the sail trimmers are unlikely to be thinking about the supercomputer sitting in a carefully climate-controlled server room in Auckland, relentlessly churning through sail design iterations. Nevertheless, ANSYS software helped to set a confident course toward victory in the Volvo Ocean Race.

A successful Volvo campaign lies in the confluence of a myriad of fields, from engineering design and analysis to sailing skill and sound meteorology. Using ANSYS fluid dynamics has removed a lot of the guesswork from Emirates Team New Zealand's sail design process, allowing team members to be much more precise in their engineering and performance analyses. That has led to a very robust sail design and a high level of integrity for sails when subjected to uncertain conditions once the yacht is under way.

CFD analysis alone can't guarantee a win in the demanding Volvo Ocean Race, but ANSYS technology helps to drive reliable sail performance — and an overall yacht design that maximizes the potential of those all-important sails.