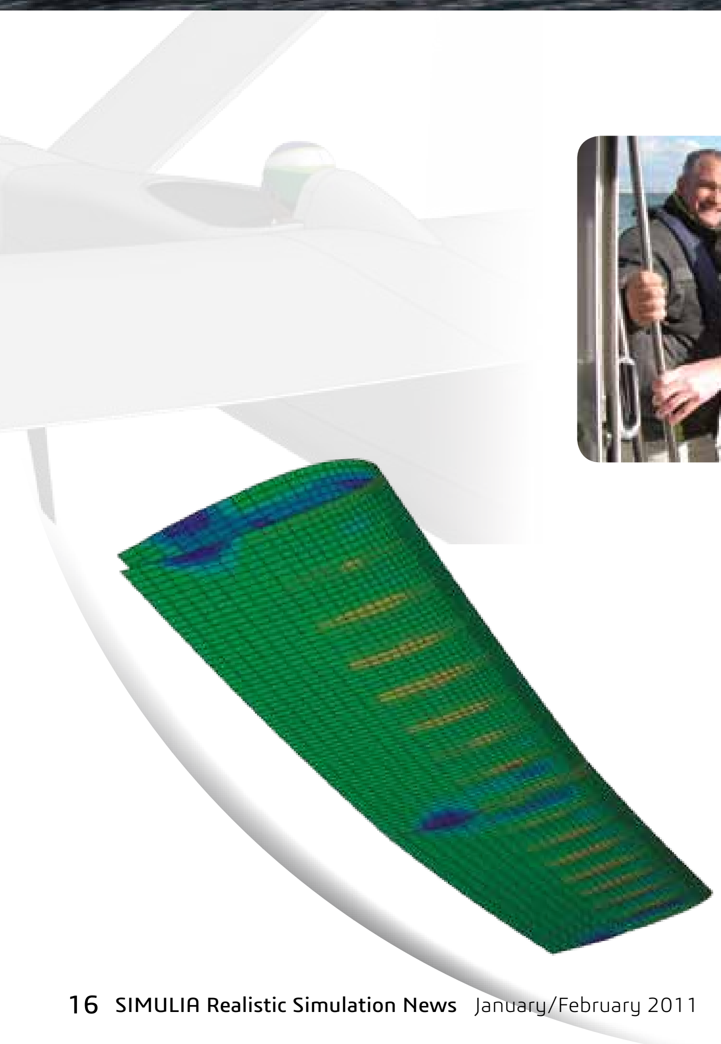
Catching the Wind with CAE

The two wing-sails and keels are rigidly connected through the hull center section. The pilot retracts a fairing which covers this section, allowing the wing-sails and keels to rotate through 90 degrees as the boat tacks.

Figure 1

Abaqus enabled us to quickly and efficiently visualize the effects of taking different approaches.

Tim Clarke
Founder and Engineering Lead at Verney Yachts



Verney Yachts uses Abaqus FEA to develop a sailboat without physical prototypes in pursuit of the world sailing speed record

Going fast—really fast—has always captured the imagination of engineers and inventors. In the sailing world, the speed record was most recently set in September of 2009 by the hydrofoil-design trimaran, *l'Hydroptère**. Prior record-holders included kite- and wind-surfers, and a proa and catamaran (*Crossbow I & II*). When the official 500-meter record was first documented by the World Sailing Speed Record Council in 1972, the speed was 26.30 knots (48.7 km/hr). The latest mark has almost doubled that pace at 51.36 knots (95.11 km/hr).

Tim Clarke, engineering team leader at Prospect Flow Solutions, Aberdeen, Scotland, was bitten by the speed-sailing bug when he first read about the *l'Hydroptère* team's record-setting preparations. Fascinated by both sailboats and aircraft as a child, Clarke spotted what he considered drawbacks with their approach and thought he could do better. Working evenings and weekends, he founded Verney Yachts in January 2009 and chipped away at a concept that breaks a host of sailboat design conventions.

Clarke's idea was to create a single-hull and equip it with two wing-sails—structures that, as their name implies, are a cross between a wing and a sail. The wing-sails in his design are rigid, not soft, manufactured from composite materials, and able to switch both position and function as the boat tacks, becoming either a wing if horizontal to the water or a sail if vertical (Figure 1).

With this new-concept boat, the *v-44 Albatross*, on the drawing board, the Verney team set their speed sights on 65 knots (120 km/hr) or greater—20 percent faster than the current record—without knowing whether the craft was feasible to build and without the opportunity to even construct a prototype.

To help translate the conceptual design into a physical reality, the team turned to Abaqus FEA from SIMULIA, the Dassault Systèmes brand for realistic simulation. The software enables them to test the boat's performance virtually, using a 3D-computer model to analyze the structural strength of components, their response to wind loads, and the craft's fluid and aerodynamic characteristics. The software also allows them to isolate, evaluate, and optimize structures critical to performance, such as the innovative wing-sails.

How a wing-sail works

Wing-sails are not new. The BMW *Oracle*, a trimaran sailboat, crushed its America's Cup competitor in February 2010 using a wing-sail. The *Greenbird*, a wing-sail equipped land-yacht, clocked 202.9 km/hr (126.4 mph) in March 2009, setting the wind-powered land speed record.

While a conventional aircraft wing needs a tail to provide stability, a wing-sail can achieve stability in other ways: In the BMW *Oracle*, it comes from a motorized trailing flap on a two-part structure (outside the rules for the speed-sailing record); and with the *Greenbird*, it's provided by leading-edge counterweights, as well as from the addition of a tail. But the *v-44 Albatross*' stability comes from the wing-sail itself.

On the *v-44 Albatross*, each of the 13-meter-long wing-sails is comprised of two sections: an inner plank (the half of the wing closest to the hull) and an outer plank (Figure 2). Named for the "flying plank," or "flying wing," technology (like the stealth bomber), the airfoil shape is designed to be inherently stable. Stability also comes from the use of counterweights, one for each plank (much like on the *Greenbird*), but not from a tail. "If we were to use a tail for stability, we would need one for each of the four planks," says Clarke. "That would add too much weight."

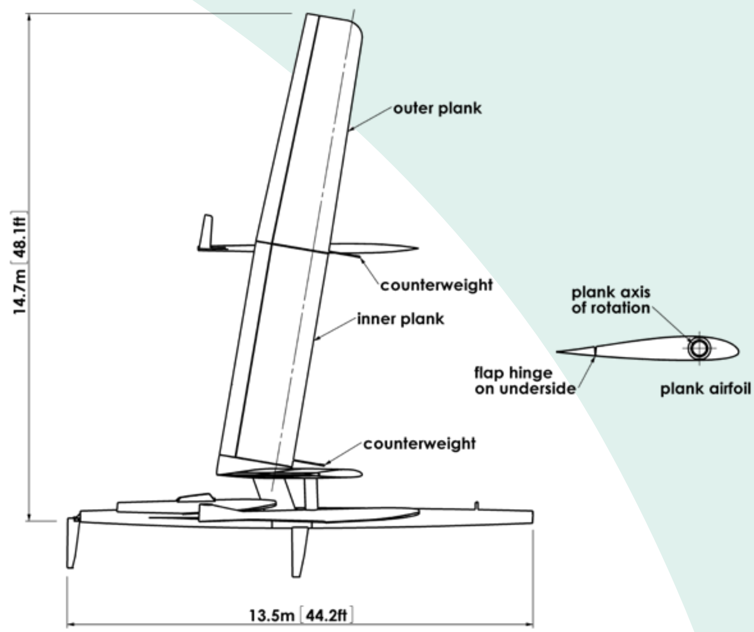


Figure 2. A diagrammatic view of the v-44 Albatross illustrating the structure of the wing-sails.

More specifically, each of the *v-44 Albatross*' planks are aerodynamically- and mass-balanced about their axes of rotation, and each are designed to weathercock, or find their own position in the airflow like a weathervane. The design of each plank is intended to mimic the behavior of a tubular spar centered at the axis of rotation, which has no tendency to rotate under bending loads. If the wing-sail did rotate as it experienced bending loads, it would upset the boat's aerodynamic balance. For this reason, a different structural approach needed to be taken when compared to a typical aircraft wing or wing sail. Because the wing-sail design is unproven in the field, the role of FEA for virtual design analysis is critical to the success of the project.

Modeling the wing-sail

When moving from conceptual to preliminary design, Clarke and his team needed to consider many wing-sail design variables. "Abaqus enabled us to quickly and efficiently visualize the effects of taking different approaches," says Clarke. Early in the design cycle, the team created some of the key models within Abaqus first and used the extensive functionality within the software's interaction module to simplify those models (emphasizing major members and minimizing components). The team also used SolidWorks Premium for additional 3D modeling and product data management.

Because the wing-sail's structure and function are so complex, the engineering team split the analysis into three stages: the spar, the ribs and secondary structures, and the skin. At each stage, as they built up the structure and added complexity, they wanted to ensure that the wing-sail was acting like a tubular spar with no orientation preference.

For the load case, they chose the worst-case scenario: the wing-sail operating in the horizontal plane and the boat at high speed with minimum keel penetration in the water. This situation generates lift across the entire wing-sail as well as the greatest bending loads. To run the simulations, they used a 64-bit Windows workstation with 32 GB RAM.

Customer Spotlight

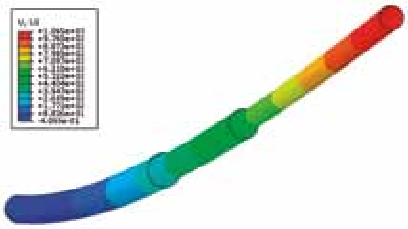


Figure 3. Analysis results of deflection for the carbon-fiber composite main spar.

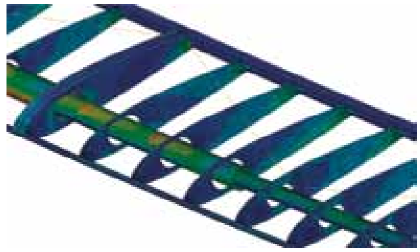


Figure 4. Traction loads applied directly to the main spar of the v-44 Albatross wing-sail.

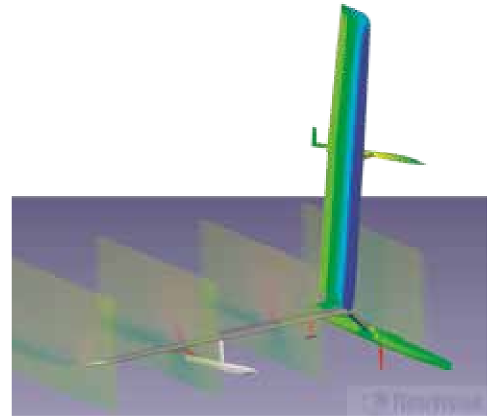


Figure 5. CFD analysis shows the predicted velocity vectors and pressure distribution at 40 knots boat speed.

How the conceptual wing-sail performed

The Verney team first analyzed the wing-sail's composite main spar (consisting of three tubular, nested sections connected by bearings), which runs like a spine inside the entire length of the structure's leading edge. After applying surface-traction loads, results indicated that maximum deflection at the tip was only about one meter, or 7.7 percent of the total 13-meter spar length (Figure 3). The maximum stress resulted in a reserve factor (a measure of strength) of 1.5 for compression and 2.9 for tension.

For the next analysis, the engineering group added the secondary structure, a series of carbon-fiber-covered foam ribs (each in the shape of the wing's cross-section), as well as the wing's leading- and trailing-edge, composite spars (Figure 4). These structures form the shape of each wing plank and allow aerodynamic loads to feed into the main spar. (This secondary structure is partially de-coupled from the main spar in a way that ensures it does not increase the stiffness of the overall structure.) Simulations illustrated that deflections perpendicular to the direction of the applied load are small, ranging from 0.5 to 1.4 percent.

Clarke and his team examined the full assembly in the third analysis, adding the Mylar/foam skin to the wing, as well as structural foam to the trailing edge and wire bracing between the ribs. The foam edges were represented using solid elements, the wire bracing using rigid beams, and the Mylar/foam with a single layer of thick conventional shell elements for the composite layup. Tension was applied to the skins by 'freezing' them within a thermal step. The simulation showed deflections perpendicular to the applied load ranging from 0.4 to 1.7 percent. Using this full-assembly model, the team calculated the skin deflection as well as absolute maximum stress within the secondary structure.

The three analyses validated the wing-sail concept, at the same time pointing out several design issues: the mass as modeled was heavier than in the conceptual design (progress with the boat layout and control system has since increased the wing-sail mass budget by 20 percent and increased the main spar diameter by 12 percent); the reserve factor for the main spar compression came in at 1.5, lower than the targeted 2.0 (future optimizations will lead to better composite layups and a reduction in stresses); and the overall deflection was under 10 percent (and can be compensated by adjusting the unloaded position of the two wing-sails on the hull, separating them by more than 90 degrees).

The Verney team is now engaged in extensive computational fluid dynamics (CFD) analyses of the aero- and hydro-dynamics of the boat using FlowVision HPC from Capvidia (a SIMULIA partner). For the above-surface aerodynamics, each fluid structure interaction (FSI) analysis couples Abaqus with the CFD software and involves capturing the movement of six independently rotating surfaces (four wing-sail planks and two outriggers) at different speeds across the boat's speed range (Figure 5). "This process helps us tune the control system and virtually test sail the boat before it is constructed," says Steve Howell, CFD lead. Analyses of the free-surface hydrodynamics will also be carried out and will examine design and performance of features such as the speed-critical keel.

When the design is finalized, the *v-44 Albatross* will be constructed without the benefit of prototypes or wind tunnel/tow-tank testing. Projects taking a similar, computational-only approach include Richard Noble's record-setting Bloodhound supersonic car, Richard Branson's Virgin Formula One Team, and the America's Cup winner BMW Oracle. "The cost of building physical prototypes is prohibitive for a project like ours," says Scott Tuddenham, project lead. "There's no margin of error. We have one chance to get it right."

With an eye on the speed-sailing record

To help the Verney team achieve its goal, Dassault Systèmes (DS) has chosen the *v-44 Albatross* project for its Passion for Innovation program. In keeping with the program's mission—to help individuals and organizations bring their innovative ideas to life—both DS organizations, SIMULIA and SolidWorks, are providing software, services, and support to assist in bringing the Verney team's dream to life.

The projected date for the speed-sailing record attempt is early 2013. The chosen site is the upcoming Summer Olympic's sailing venue in Portland Harbour in the UK. The Verney team hopes their boat will cover the official 500-meter distance in a scant 16 seconds or less. When it does, the *v-44 Albatross* will literally fly above the water, with only the keel breaking the surface.

Bringing a simulation-only design to life takes tremendous trust in the power of the engineering technology behind the design. "I used to think of FEA as a tool that produced a good prototype," says Clarke. "But now we're using the software to go straight from design to a finished product. It's a phenomenal age for engineering."

**The speed record now stands at 55.65 kts, set by a kite-board designed by Rob Douglas (USA).*

For More Information
www.verneyyachts.com