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Challenge:

- Competitive sailing requires robust part design in order to withstand the higher loads placed on the boat and its components during aggressive racing. At the same time, the designs must be as lightweight as possible to remain within race-class weight requirements. Advanced engineering company iXent was called on by the owner of racing sailboat Alegre 3 to contribute to strengthening and lightweighting a key component design.

Solution:

- iXent used Tosca Structure, Isight and Abaqus to develop a design for a winch gear that would undergo extreme stress during operation.

Benefits:

- The company was able to deliver a highly optimized part design that had not previously been explored. SIMULIA's products enabled them to quickly consider alternative designs and arrive at the best solution.

The graceful swoop of a racing sailboat through ocean waters is a compelling sight. There's the slice of streamlined bow through the waves, the dramatic shift of massive sails, the side-to-side rush of the crew as the boom swings and the boat comes about—and the flurry of "coffee grinder" teams frantically winding the winches to drive the rope lines that fine-tune the whole performance.

The manpower that makes those winches work is impressive: Two sailors, facing each other, grab and turn a pair of handles together at breakneck speed. The rotational force they generate is transferred through a gear to a large winch controlling a variety of running-rigging lines. These lines—halyards, downhauls, sheets, etc.—are either tightened or released by a whole series of deck-top winches that change the position of the sails and boom. A recreational sailboat employs lighter, one-handed winches, but it's a different story on a racing boat, where up to six two-person teams must supply the manual energy that drives all the vessel's key working components.

"The more aggressively you sail these racing boats the higher the loads on the winch-gear structure get," says Thomas Hahn, founding partner of iXent, a German technology consulting and engineering services company that specializes in applied lightweight engineering of composite materials. He should know: Hahn and co-founder Christoph Erbelding helped design components for the U.S.'s Oracle Team USA sailboats that won two America's Cup championships.

Why two aeronautical engineers designed a yacht winch

Although now known for their sailboat expertise, Hahn and Erbelding originally trained as aeronautical engineers—and then went on to spend years in the automotive industry. It was their Munich location (close to Audi, BMW and Mercedes), and iXent's extensive (and still ongoing) advanced automotive composites work, that led to their being chosen to join the Oracle Team USA "technical competence" team in 2004 by BMW, a sponsor of the America's Cup. iXent's profile in high-tech yacht racing evolved rapidly from there as Oracle Team USA went on to win both the 2010 and 2013 Cups; they are currently working with the 2017 team.

Of course the yachting world is a vast one, with hundreds of races held around the globe in a wide variety of classes based on length, hull type, rigging, etc. A key race for owner-drivers of the larger boats (the Maxis, above 72 feet long), the Rolex Maxi Worlds, has been held at the Costa Smeralda Yacht Club in Porto Cervo, Italy, every September for 35 years. A "Mini-Maxi" competition for "smaller" maxi boats was added in 2010. Regardless of length, the Maxis are all known for pushing the boundaries of design and technological innovation.

The owner of one Mini-Maxi, the Alegre 3 (24 meters), became a client of iXent when a colleague they'd worked with on the 2010 Oracle team, winch specialist Jon Williams of Stay In Phase Ltd., recommended iXent's capabilities. The Alegre team was looking to fine-tune design and weight to help overcome the second-place finishes they'd had to settle for in the previous two years at Porto Cervo.

Every area on the boat was open to review, leading to some significant developments. The ramp deck was made into a continuous surface from cockpit floor to foredeck, creating an unbroken load path that increased the stiffness. The keel fin was bolted to a keel tower internally to further maximize stiffness and produce the biggest possible righting moment.

To accommodate the increased loads on the rigging due to all that added stiffness, Williams asked iXent to reimagine the winch design—making it more robust while taking out as much weight as possible. The primary winches needed to be placed in the optimal location for the trimmers, on pods which incorporated the winch gears into vertical shafts for maximum rigidity.

Simulation leads to tougher, lighter designs

iXent focused on the support plate that holds everything in place inside each winch shaft. Many other gear-support designs Hahn had seen were just flat, circular plates highly susceptible to bending and twisting under excess stress. "The plate has to be really, really strong," he says. "I've seen this in reality: a weak support starts bending and wiggling around.

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>
> — Thomas Hahn, founding partner of iXent

If the support deflects, the whole drivetrain locks up and you can't move your mainsail."

So how to go about designing the optimum winch-gear support for the Alegre? While iXent applied its own extensive industry knowledge, and several proprietary techniques they'd rather not discuss, Hahn is happy to name some of the simulation tools his group depended on to guide much of their innovation: from the SIMULIA portfolio, Tosca Structure (for non-parametric topology optimization); Isight (for process automation and parametric optimization); and Abaqus (for finite element analysis). Their primary CAD tool was Dassault Systèmes' CATIA.

"We see the whole simulation package as a big help," says Hahn. "The simulation process chain we have here basically covers everything from conception up to detailing. Our customers know we are using cutting-edge technology. If you don't use it you will be left behind. These digital tools definitely support us in making our experience-based decisions."

That experience dictated that the plate be made from composite materials. "You always push for your designs to be as light as possible because these boats have to really fly nowadays and, in the case of Alegre, the class rule limits your maximum weight," says Hahn. "So with any component, if you can design something lighter with composites, you should do it. Even just leaving off a few grams, multiplied over several parts, can add up to a significant weight difference."

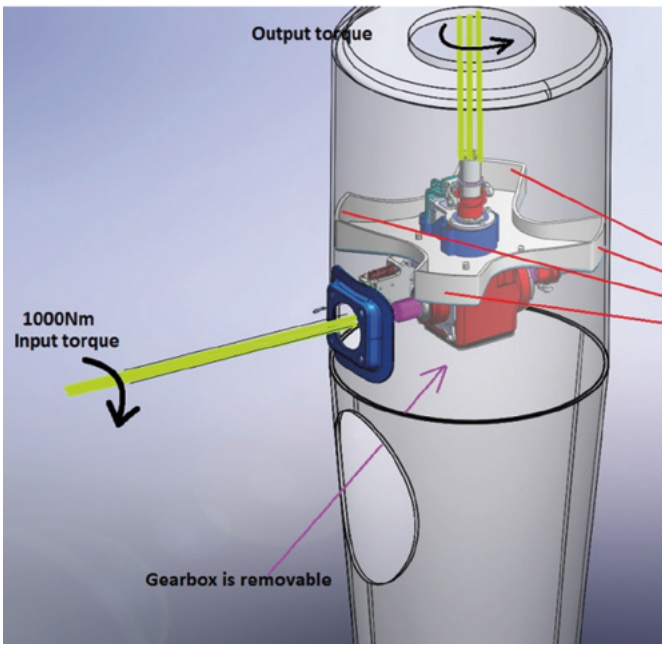
Tackling the durability challenge required additional assessment of just what sort of loads the winches would experience during a racing event. "Six crew members on three winches can produce up to 1200 newton meters when they're sheeting in a mainsheet sail—that's like generating a load greater than the weight of three mid-sized cars," says Hahn. "Another way of looking at it is that 1200 Nm is about three times the torque moment of modern three-liter diesel engines, which are known for their optimal torque production."

Tosca fuels imagination, innovation—and "the Batman"

With load estimates in hand, the team was ready to perform a non-parametric analysis of the problem using Tosca. "We like to think differently about every design problem we take on," says Hahn. "We say, 'Let's think innovatively about it'—and this is why we use Tosca. You define a structure which is essentially a black box at the beginning. You add in your anticipated load cases—top, bottom, up to as many as ten.

"Even as an experienced engineer, I can't fully imagine what the optimum structure is in terms of where I can save weight and where I have to add material in. But Tosca automatically runs through all the possibilities to give you a meshed, almost Rorschach-like pattern that identifies the most efficient structure."

Because the initial Tosca result bore a strong resemblance to the Bat Signal projected into the sky to call the Caped Crusader to the rescue, the team affectionately dubbed the new winch support design "The Batman."



Winch gear (red) and support (grey and white) inside shaft. Winch (not shown) is at top.

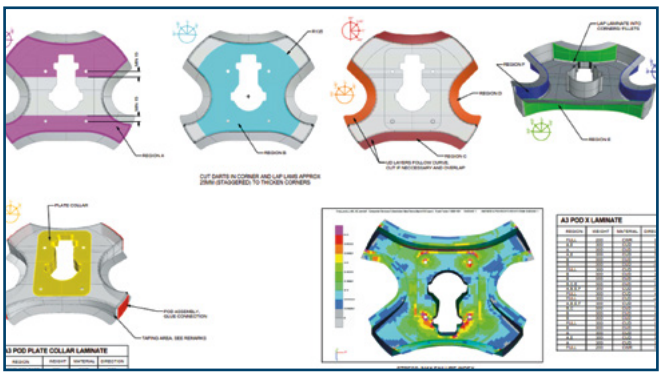
An initial design space for a winch gear support plate optimization exercise. Designs that stay with such a flat, circular shape can be susceptible to warping under the high stresses of competitive sailing.

Next the team rebuilt their Tosca geometry in CATIA, refining it further into a 3D CAD representation. They then used the pre-processor ANSA (from Beta CAE) to extract an executable file into Abaqus, setting up a system of torques and moments that represented the envelope of loads the part would see during operation.

Isight and Abaqus optimize composites design

Finally the team employed Isight to automatically drive a series of Abaqus FEA analyses toward an optimized composite laminate design that had the least possible weight but satisfied all the required boundary conditions. "You can't do this degree of optimization by hand," says Hahn. "You might have intuition, but it's really amazing how these tools squeeze out the last bit of weight savings from your laminates."

(Left) iXent's first Tosca iteration of the sailboat gear support and (Right) the final output.



(Top) Final drawings for the Batman winch-gear support plate design. Note phalanges along outer edges (upper right image) that provide additional stiffness. (Bottom) A finished Batman composites component.

Interestingly enough, Tosca can also contribute to a determination of composite orientation later on in the production process, Hahn notes. "Tosca basically creates a truss/bridge type of structure that uses the least amount of material to minimize bending. Of course, composites work in much the same way: Their fiber orientation is strongest along the length of the fiber, in either compression or tension. So why not use Tosca to design a composite laminate, because the principles are the same."

The final Batman design achieved a weight savings of around 17% compared to a typical such component in a racing yacht. And—coincidentally or not—the Alegre, with its newly optimized winch gear supports, won the Mini-Max competition in 2014.

Winning takes a team

Hahn is a busy man, and was pleasantly surprised to hear of the win some months after it happened. "I don't think you win by being strong in just one field," says Hahn. "You win by having the best total 'package'—very good sailors, very good shore support and, of course, good design. In this case our client really likes the final Batman solution, which is both light and strong. If you go at every part on your boat with those goals surely you would end up with the optimum design package."

That winning attitude helps iXent bring their Tosca expertise to bear on a variety of weight reduction challenges faced by their automotive and manufacturing-automation clients as well. "While the Batman example is a nice demonstration of what is possible, we also use Tosca for much bigger structures, like topologies on larger parts of cars as well as boats," says Hahn. "You can use Tosca for almost any structure when you are not clear what the most efficient shape looks like; Tosca sparks your imagination and gets you out of your design rut."

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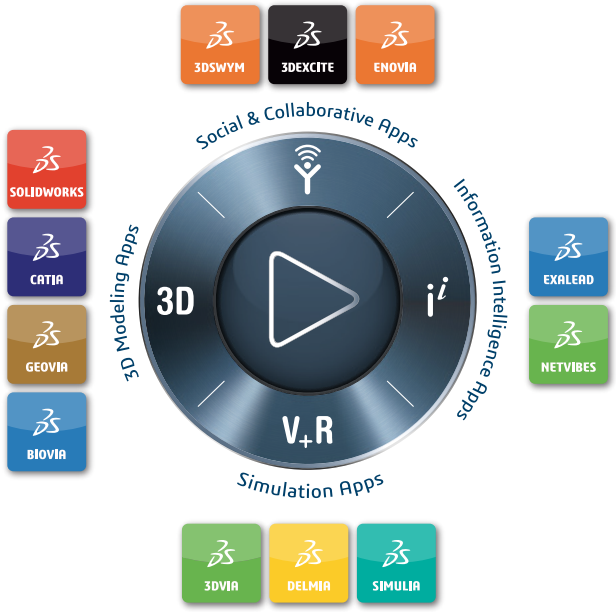

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