The Princess Yachts R35.

The DIGITALIZATION of VESSEL DESIGN

From racing yachts to commercial vessels

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In the America's Cup, every second matters. Engineering teams invest millions into sharpening the performance of their vessels to achieve success, using advanced simulation and optimization techniques to maximize efficiency. In the wider maritime sector, speed isn't always the primary goal. However, efficiency gains remain a vital part of reducing fuel costs, whether for leisure yacht owners or offshore wind crew transfer operators.

As ship design complexity increases to meet the demand for more sustainable, connected, cost-effective, and high-tech vessels, maintaining a competitive edge can be overwhelming. As in the America's Cup, success belongs to the disruptors, those who innovate better and faster than their competitors. These are the businesses that don't shy away from this rising complexity, but instead find new ways to harness it and turn it into a competitive advantage.

Since 2017, BAR Technologies (author Simon Schofield's company) has been harnessing and adapting the cutting-edge tools, control software, design expertise, and simulation techniques honed in the America's Cup and applying them to commercial marine arenas, including shipping, defense, leisure yachts, and offshore wind. The company specializes in multi-disciplinary, high-end computationally intensive projects. It relies on high-fidelity simulations and advanced optimization techniques to integrate a range of engineering skills and solve complex problems.

A key innovation has been FOSS, which stands for Foil Optimized Stability System. FOSS is a system of hydrofoils that can be fitted to a vessel to increase hull efficiency, reducing fuel consumption and CO_2 emissions while improving seakeeping. Our purpose here is to take an in-depth look at how FOSS was delivered for Princess Yachts' R35 sports vessel, and on offshore wind crew transfer vessels.

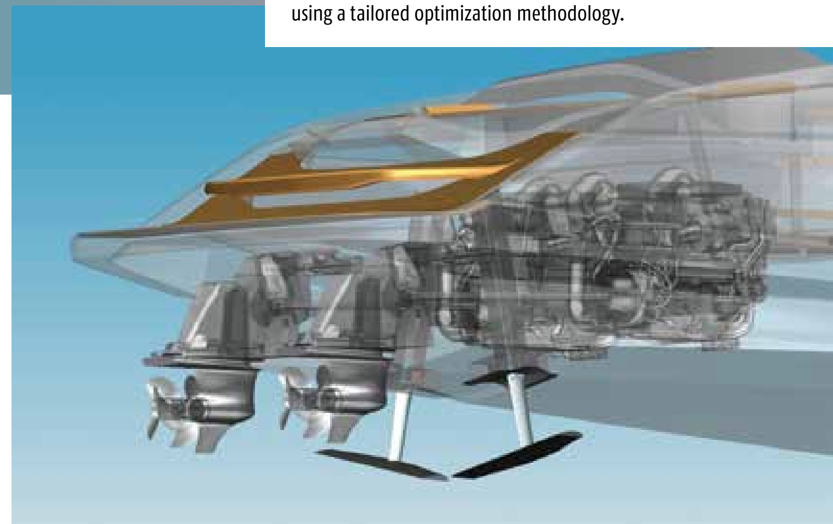
Development of FOSS

One of the first major projects BAR Technologies undertook stemmed from collaboration with Princess Yachts, who challenged the company to help develop a new breed of leisure powerboat. The boat builder required a powerboat with a reduced environmental impact and greater efficiency, especially at cruise speed—but without impacting the top speed. That needed to be combined with improved seakeeping, accessible performance and, crucially, a high level of passenger comfort.

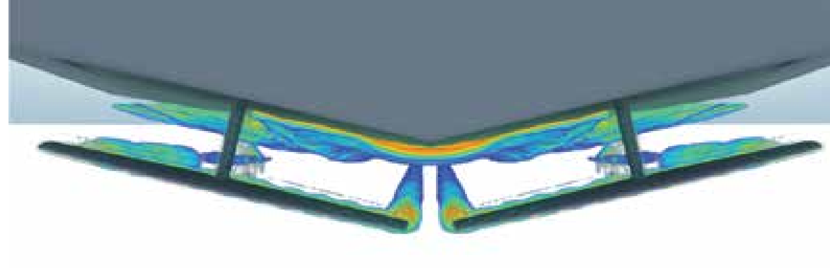
With a background in elite yacht racing, where fully foiling, flying boats are the norm, it seemed natural for BAR to look at hydrofoiling solutions. However, initial investigations indicated that although a leisure boat on foils would produce optimum efficiency, it would not be suitable for Princess's clients, who prioritize comfort to a far greater degree than the average professional yacht racing team. To meet the challenge, the company developed FOSS, an arrangement of hydrofoils that takes approximately 30% of the displacement of the vessel and combined this with a new hull form to improve both seakeeping and efficiency.

On the Princess Yachts R35, it was discovered that the optimal configuration was two fully retractable foils, controlled independently by a custom-made control system developed inhouse by BAR. This produces lift and increases the efficiency of the vessel, especially at cruising speeds. But the system also

The hull and foil combination on the R35 was developed using a tailored optimization methodology.



While the hydrofoils on an America's Cup yacht are used to lift the hull out of the water, the foils on the R35 are used to stabilize the boat in the water.



is used to dampen motion and improve the seakeeping of the vessel when underway. Similar to a high-performance car, FOSS provides additional control and grip when cornering, ensuring that the vessel is safe and controllable at all times for less experienced users. The adaptability of the system means that the vessel driver can select operational modes such as performance, sports, and comfort, which adjust the way the boat handles and how it reacts to throttle or steering inputs—and vitally, the wider sea state and the surroundings.

Above and below the waterline

The two companies partnered with Pininfarina, which worked on the styling above deck and produced the beautiful lines that characterize the R35. BAR undertook all the design below the waterline, including hull and foil simulation, optimization, and composite design, with the R35 being the boat builder's first fully carbon boat. BAR also developed the active control system that included the foils and the mechanical hardware around the foils, and carried out fault finding and testing for the embedded codes in the control systems. A prototype was built, supplied, and tested for approximately six months to support the development of the vessel, fine-tune the algorithms, and give the boat builder an early exposure to the way the vessel was going to feel before it stepped into full production.

BAR also partnered with Siemens Digital Industries Software (author Deborah Saban-Eppel's company) to draw on the software provider's 135-year experience in the marine industry. Xcelerator—Siemens' integrated portfolio of software, services, and application development platform—can be used as the technical software foundation for companies to become digital enterprises. Central to this digital ecosystem is closed-loop digital twin technology, which enables continuous product development, performance, operations, and lifecycle support.

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A digital twin of a vessel is a "single source of truth" repository of all of its mechanical, electrical, and software features. It ensures that the various design teams and suppliers always have access to the most up-to-date design data for improved collaboration and process execution, from initial design to detail and production design. It enables ship designers to better control the design spiral by bringing all their multi-discipline design processes into one single, centralized environment. This way, globally distributed teams can work with a common set of data, tools, and processes. This helps break down multi-domain silos, increase overall project efficiency, and improve business agility.

A significant step in the development of the R35 was to implement a high-fidelity digital twin to accurately predict the performance of the vessel, including speed, handling, and how the control algorithms for the foils could work best to counter motion to deliver the best user experience.

Digital toolset

A lynchpin of the design is NX, a widely used programming language for computer-assisted design (CAD) and geometry creation. The Princess R35 vessel was designed using parametric methods in NX. The hull optimization process was scripted and automated using NX Open and Python. A suite of languages, such as Simcenter Nastran, NX Drafting, and Fibersim, were instrumental in underpinning the composite design and developing the foil system. Additionally, the collaboration involved sharing large engineering assemblies, including fitting out the vessel. Teamcenter was used as the data management backbone, enabling data sharing in a controlled and reliable environment.

Having a centralized, integrated environment is critical to maintaining continuity and interchangeability of data over a wide range of simulation tools. Otherwise, the data one department hands over to another could be in a format that adds ambiguity and decreases accuracy, resulting in unnecessary delays. Adopting a digital thread approach by leveraging a common set of data and processes across as many simulation departments as possible enables ship designers to better manage and mitigate risks and respond quickly to requirement changes.

Another key element enabled by adopting a digital twin and digital thread approach is boosting innovation through simulation. Deploying automated multi-domain design space exploration and optimization enables ship designers to understand, explore, optimize, and test virtually any aspect of ship performance, from individual components to sub-systems to the full ship system. This leads to increased confidence in the vessel performance from the earliest phases of design, and significantly reduces development time as a process that would previously have taken weeks can now be completed in a matter of days.

BAR Technologies develops hulls using digital twin and automated design processes, so most hull production is optimized digitally, not by humans, ensuring maximum performance. The optimization toolset selects components out of an existing library and crafts an optimization algorithm for a specific hull. Crucial to this process is the large-scale batch creation of geometries, which is where the scripting capability within NX comes into its own. This enables the assessment of huge numbers of geometries conforming to specific limitations such as displacement.

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The hydrofoils on the R35 are automatically adjusted to provide better seakeeping characteristics and lower fuel consumption.

This automated process calls on Simcenter STAR-CCM+ for the computational fluid dynamics (CFD) analysis of the geometries created. The resulting data is used to train neural networks using artificial intelligence techniques and eventually find the hull design that delivers the highest performance.

One of the limitations of the competition in the America's Cup led to a benefit that helped to shape BAR Technologies' design processes. Tank testing was banned under the competition rules. That meant that having complete confidence in the CFD results was key to success. Princess Yachts wanted further confirmation, so tank testing was used to corroborate the optimization achieved. The model independently verified the simulation results, which predicted a 30% increase in scoring against the optimization criteria. Although tank testing is still occasionally requested by customers, today it is no longer a design requirement.

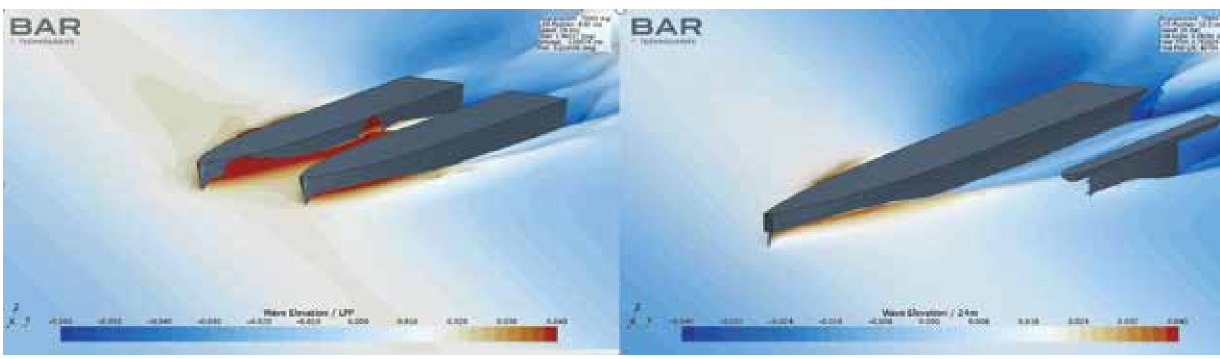
The race to net zero

Offshore wind is growing rapidly, requiring a new wave of crew transfer vessels (CTV) to enable the construction and servicing of wind farms globally. The industry is naturally keen to increase its green credentials. As scrutiny on the carbon emissions of the sector grows, key players such as original equipment manufacturers and operators also are naturally looking to decarbonize the maritime supply chain. In the long run, this will mean alternative fuels and electrification, depending on the operational profile of the vessel. However, to smooth this transition, it is vital to ensure that the underlying vessel platform is already efficient, reducing costs to the operator as the new technologies are rolled out. The most efficient hull remains the most efficient, regardless of the fuel used and this efficiency leads to earlier deployment for any given operational profile.

BAR partnered with Chartwell Marine to develop a CTV fit for current and future operations. Chartwell Marine has extensive experience in the sector and are used to designing around the key challenges faced by offshore wind operators, such as significant sea states. Comfort, seakeeping, and fuel reduction are key considerations. But increasingly, CO_2 emission reduction has become a major focus for wind farm owners and operators putting out tenders, so this was paramount in the design focus. However, while innovating as far as possible, operational familiarity for crew and personnel was crucial, especially as offshore wind technicians are first and foremost industrial personnel, not seafarers. Maximizing deck carrying capacity also was a primary consideration to enable the vessel to carry loads in the way operators require. Finally, the design had to be cost-sensitive to be commercially viable.

Meeting these challenges led to the development of differently sized vessels, each meeting a specific set of requirements. One of these is the BAR Tech 30, an alternative to the 24-m, 24-crew, standard CTV. Unlike traditional catamaran CTVs, the BAR Tech 30 has a main hull designed for optimum efficiency

A visual of the BAR Tech 30 produced with NX Render. The vessel's hydrofoils are controlled by algorithms to minimize the roll and pitch of the vessel and increase comfort for the personnel onboard.



Comparing design performance: a classic catamaran (left) vs. the BAR Tech 30. These images show how visualizing the simulation results gives context and confidence to engineers and stakeholders.

coupled with a small waterplane area outrigger, and incorporates FOSS technology. The hydrofoils are controlled by algorithms to minimize the roll and pitch of the vessel and increase comfort for the personnel onboard.

In terms of efficiency savings, the vessel can deliver a 30% reduction in fuel consumption or CO_2 emission at 25 knots, and 22% at 30 knots. The vessel also delivers a significant reduction in vertical acceleration, which is the primary cause of seasickness and discomfort. Depending on the size and the encounter angle of the waves, this can be up to 70%. This means the vessel can operate in significant wave heights of over 2 m, as opposed to traditional catamarans, which normally operate in significant wave heights up to 1.5 m.

Seakeeping and maneuvering simulations were performed using Simcenter STAR-CCM+. The foils were modeled using an overset mesh (also known as Chimera or the overlapping grids) approach and controlled using an algorithm derived from the control system used on the vessel. By leveraging the expression-based reports and parameter capabilities within Simcenter STAR-CCM+ during the simulation, the foils position was adjusted to emulate how they would react in real life. The seakeeping simulations were performed both in three degree of freedom and six degree of freedom. The six degree of freedom simulation also included a PID controller to control engine power and steering.

Resistance evaluations were performed with the foils active to optimize the foils positioning for both low- and high-speed maneuvering. BAR was also able to use Simcenter STAR-CCM+ to accurately simulate and compare the low-speed maneuvering capabilities of the vessel to ensure performance in all criteria versus the benchmark. Finally, push-on simulations were carried out to calculate the forces involved, and to reverse-engineer the thrust requirements and the engine horsepower needed for an optimal push-on onto the turbine foundation.

Cornerstone

The future of maritime design is simulation driven. The digital twin, which has become an essential part of that future, is the cornerstone of simulation-driven ship design. From exploring basic CAD concepts to performing a detailed hull optimization, or carrying out automated CFD-based performance analyses to running 6 degree of freedom seakeeping and maneuvering simulations, the digital twin offers insights into design choices and enables ship designers to get the design right the first time.

New advances in simulation and digital twin technology will keep unlocking new avenues of computerized design optimization, which is crucial to drive efficiency to new heights across the maritime sphere, from leisure to energy, and support progress toward looming net zero goals. To reach the potential of the digital design revolution, however, it will be vital to ensure the standardization of data and coding best practice across organizations and wider collaboration between supply chain stakeholders. **MT**

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