THE YACHT report

The leading magazine for the design, construction, management, ownership & operation of luxury yachts

Issue 105

June 2009

Bracing Stuff

BEAMS AND PLIES

Class societies mandate a given skin thickness for composite yachts, which makes the basic structure heavier than is demanded by strength requirements analysis. This in turn drives builders of performance superyachts even harder than ever to seek to achieve lightness with strength elsewhere in the design. Here Design Engineer Katia Merle of SP, the marine division of Gurit (UK), explains their recent and on-going collaboration with Southern Wind Shipyard on two designs: one a proven successful seller and the other a new model in build in South Africa.

Southern Wind has become a strong player in the superyachts scene. Their award-winning 100ft (nine boats are sailing so far) and the new 110ft yachts currently under construction at the yard in Cape Town are competing against the most renowned superyachts currently on the market. Elegance, seaworthiness, quality of build and passion for design secured Southern Wind's reputation.

At SP, the marine business of Gurit, we provided structural materials and engineering consultancy for the 100ft and 110ft, adding structural efficiency to the winning design. The optimum compromise is often the one that integrates every aspect of the design, and we have worked in collaboration with the yard to integrate the structural requirements into their overall design spiral.

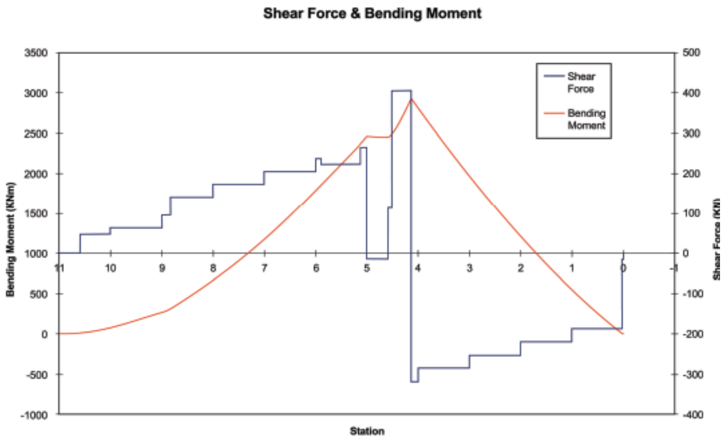
Hull and deck – a careful material selection

The hull and deck, supported by the internal structure, are analysed as a matrix of panels under sea pressures defined by classification society guidelines (see top image).

- Hull outer skin: Classification societies specify a minimum hull outer skin fibre weight to ensure the laminate is sufficiently robust. This criterion drives the hull laminate outer skin specification, which means additional plies have to be added to increase the thickness in excess of the minimum number of plies strictly required by a strength analysis.
- Hull inner skin: as the hull panels tend to flex under the sea pressure, the inner skin is loaded in compression in way of the bulkheads. This loading drives the hull inner skin laminate specification, with either fibre failure or skin wrinkling as the critical failure mode.

Considering a strip of sandwich panel as a beam, the bending stiffness (EI), and each ply's distance to the neutral axis (yNA), determine how much strain (ε) is experienced by each ply under a given bending moment (M). $\varepsilon = \frac{M \cdot y_{NA}}{EI_{NA}}$

Because of the thickness added to the outer skin to make it tough enough, the use of carbon fibre on the outer skin adds significantly to the cost without enough weight saving to justify it. However, using carbon fibre on the inner skin has a smaller impact on the cost (because the inner skin is thinner), but allows a much greater weight saving and, with fewer layers, potential production savings.



Taking advantage of the benefits of each fibre type, using carbon fibre where it is most effective, means the 100ft and 110ft yachts both feature hybrid glass/kevlar outer hull skin, and a carbon hull inner one.

Longitudinal stiffness

The sloop rig subjects the structure to very high longitudinal bending loads. These are generated by forestay and backstay tension, reacted by the mast compression (see above graph and image). The structure carries longitudinal rigging loads as a beam under a bending moment.

If the 110ft hull and deck laminates were just strong enough to react to this loading, the deflection created by the longitudinal bending would reach unacceptable levels. A lack of stiffness would lead to a reduction in forestay tension and a shortened waterline length when the boat deflects, which would dramatically reduce the upwind sailing performance. The inherent stiffness of the hull has to be taken into account: the elongated lines of Southern Wind designs and the requirement for high sailing performance are leading to a longitudinal stiffness-driven design.

In general, a low length/canoe body draft ratio is representative of a naturally stiff boat, where minimum additional material will be needed over the strength requirement to achieve the target length/deflection ratio. Conversely, a high length/canoe body draft ratio is representative of a naturally more flexible boat, so extra stiffening material will be needed. $\delta = \iint \frac{M}{EI}\, dx dx$

Considering the boat as a beam under the bending moment (M) created by the rigging loads, the deflection (d) is inversely proportional to the bending stiffness (EI) of the hull at each section.

The combined effects of using higher modulus fibres (that is carbon), and positioning them as far away as possible from the neutral axis, is the most effective way to increase the EI at each section and bring the deflection down to an acceptable level. The optimum distribution of the stiffening tapes is one that brings the neutral axis of the boat close to the middle of the complete depth. Thus they are positioned where it is most effective to do so, that is at the shear line and at the centreline around the keel.

Hull and deck beams

The same principles of designing for strength and stiffness apply to hull and deck beams, which divide hull and deck shells into a matrix of panels. Hull and deck beams can account for up to 15% of the total composite weight and material cost for a yacht of this size. At a given load (wave pressure), the bending moment applied to hull and deck beam will increase proportionally with the square of the beam length, whereas the shear load is proportional to the beam length. Acceptable bending strength and stiffness are achieved by adding stiff material as far as possible from the neutral axis of the beams. The optimum is to add a capping of carbon unidirectionals along the edge of the beams.

The biaxial material in the shear webs (the sides of the beams) has to provide sufficient shear strength for a given load and depth of beam. At equivalent shear strength, carbon fibre laminates will be lighter than glass fibre, but carbon fibre webs are not otherwise adding to the bending efficiency of the beam. Thus the contribution of carbon shear webs to weight saving is small compared to using unidirectional carbon in the beam cappings. Following a constant research for appropriate compromise, the 110-footer uses all carbon beam cappings, whereas all beam webs are glass fibre.

Adjusting the core layout for the owner's cabin

The very open and spacious interior layout (see image) of Southern Wind's 100ft and 110ft yachts is a strong factor in their popularity with owners. However, the structural general arrangement presents hull panels of unsupported lengths of up to 4 metres – a challenge for the composite structure. With spans this large, some hull panels become stiffness-driven. Special considerations were needed to accommodate this feature on the Southern Wind 110ft, and avoid the addition of transverse beams across the owner's cabin.

Based on the principle previously described, the most effective way of increasing the EI of the panel was to increase the lever from the skins to the neutral axis. To achieve this, a thicker core has been used on the hull topsides in this cabin. The thicker core also provides a better acoustic and sound isolation, which is appreciated in this area of the boat.

When the FE analyst looks at the space required for systems…

One of the challenging aspects of superyachts is the amount of space for systems required on board, and more importantly from a structural design perspective, the number and the size of the penetrations required to run the systems through the structure. This offers new challenges for both composite structural designers and naval architects or interior designers.

Our experience gained by working in conjunction with Southern Wind's in-house design office made it clear that defining a penetration map as early as possible in the project is the key to its success.

In many cases, penetration reinforcement can be designed using straightforward engineering methods or experience of similar structures, but some of the penetrations needed for these boats were larger and more challenging to design. Therefore SP built a local Finite Element (FE) model of the area to verify that the proposed reinforcements would be strong enough. The penetration at the edge of the bulkhead, at the interface with the hull, creates a stress concentration in the hull, which could lead to a local core shear failure. Several options were investigated using the FE model to address this problem. In the end, we recommended the addition of a high-density core pad to support the hull locally under the penetration and provide a smoother transmission of the load from the bulkhead to the hull. With this level of analysis, problems that are intractable by conventional means can be solved with confidence, allowing greater space for the systems and the interior.

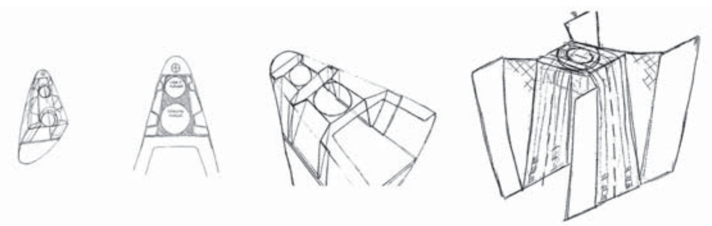
Further work has been carried out since to investigate the effect of the turn of bilge and the aspect ratio of the hull panel. Systems penetrations are one challenge that has risen with the abundance of larger composite superyachts in the last few years, creating the need for a better understanding of the implications for the composite structures. SP is currently working on the subject, aiming to provide clear guidelines at an early stage of each project.

Detail design, from the drawing board to the boat

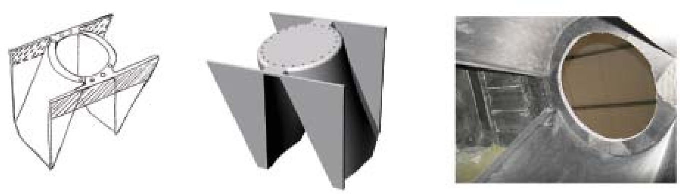
From deck fittings to the engine beds or the bow thruster, we worked extensively with the builder on detail design. Concepts have been discussed with their in-house design office, to integrate the requirements of the production and the high levels of reliability expected of these yachts. Even after more than 20 years of engineering high-performance composite boats, conceptual work means a lot of sketching and a little preliminary number-crunching.

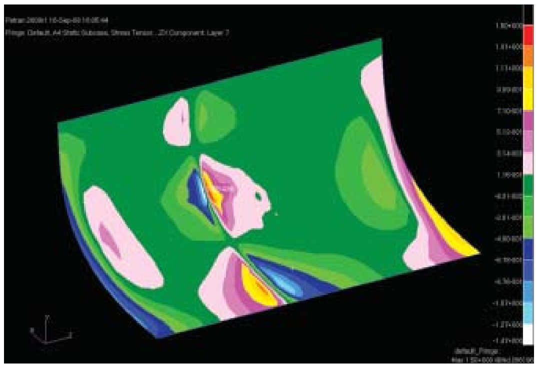
And it always starts with a design brief. In this case, a mixture of yard in-house design office for the original requirements, shop floor workers for the building sequence and the practicality of the design, and ourselves for the integrity of the structure.

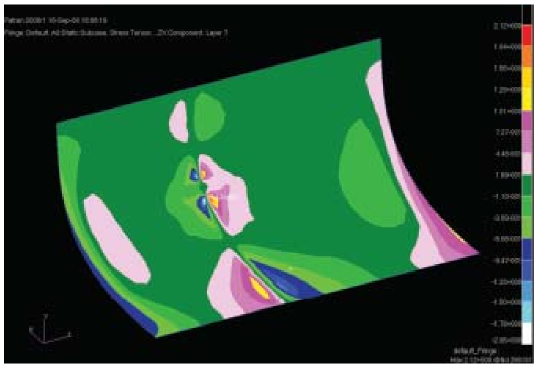
The 110-footer features Bamar Forestay and Code zero furling fittings, which have the novel feature of simply being bolted through the deck.

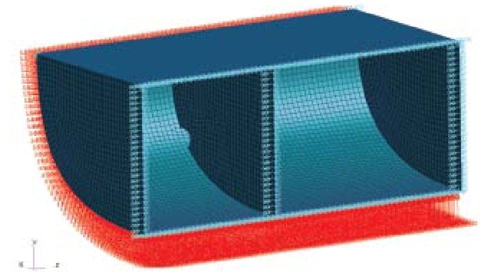


There is no bulkhead or existing structure underneath the deck to take the load.









There is a need for a practical solution as the deck will only be dropped on the hull at the last minute.

• The aim is to create a one-piece moulding, which will eliminate bending to avoid unnecessarily heavy laminate (bottom images).

From the drawing board to the yacht, a strong communication line was established between us and the yard to develop concepts for details design, then make them work from every perspective.

Conclusion

Designing today's high-performance cruising yachts demands co-operation between the boat yard, design office and structural engineers right from the outset. With a combination of intelligent fibre selection, innovative conceptual design and production-oriented engineering, Southern Wind and SP's engineers have worked together to produce two very striking and successful yachts.

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