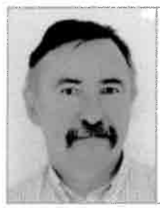
Structural design of racing yachts – State of the art

This paper gives a state of the art of racing yacht structural design, where carbon fibre/epoxy resin composites are widely used as monolithic or sandwich shapes. The paper discusses several case studies showing how monohulls and multihulls that meet class rules can lead to optimized strength-to-weight ratios. Some design principles for masts and appendages are also highlighted.



Hervé Devaux,
CEO
HDS Brest,

Pascal Casari,
Assistant professor
GeM - Université de Nantes,
Ecole Centrale de Nantes

The structural design of racing yachts offers a wide range of choices in terms of the architecture of the hull, appendages and rigging. However, a set of constraints related to high-performance composite manufacturing know-how and actual loading cases must be met. The challenge is to combine these factors so as to increase boat performance. This paper discusses a number of examples that focus on the structural design and the optimization of the most advanced sailing yachts.

Class rules for monohulls

Class rules for monohulls are governed by a series of parameters such as the maximum dimensions and the minimum weight of the boat. The materials are also defined to limit the range of thicknesses and stiffnesses. The minimum mass per surface unit is specified for safety reasons. An example of America's Cup Class yacht is presented below (Figure 1).

Fig.1: ACC CHN 95 and VOR 70' ABN AMRO one

Both classes impose a minimum weight and a maximum draught. As the righting moment is one of the main performance factors, the speed increases when the bulb weight is higher. At a constant total weight, the lighter the boat structure, the heavier the bulb. For example, the total weight of an America's Cup Class is 24 tonnes, including 21 tonnes for the bulb and less than 2 tonnes for the hull. The rest is shared between the mast, rigging and accessories. These boats are called "lead carriers". In this case, the designers try to minimize the structural mass by reducing the hull's mass per surface unit and the weight of local reinforcements.
The structure has to withstand different types of static and dynamic loads generated by the interaction of the hull and appendages with water or by tensions produced by the rigging. The design principles applied here use composite shell finite-element models for the entire hull structure. The minimum stacking sequence chosen for planking and deck are those imposed by class rules. Different loadings associated with suitable boundary conditions are applied. A number of reinforcements are added to ensure that strength, deformation and buckling criteria are met.

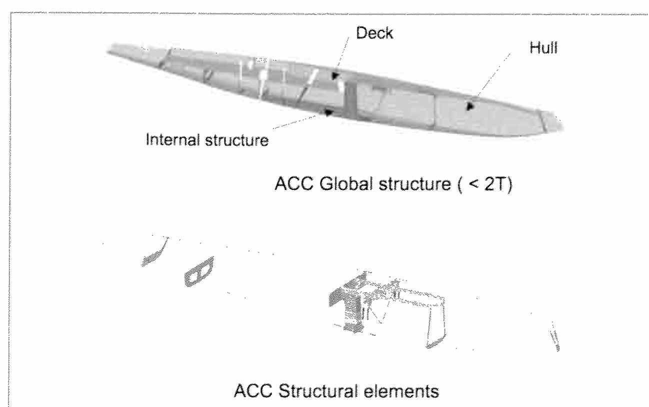


Fig.2: ACC structure's overview

Figure 2 shows a typical ACC class boat structure. The number of internal stiffening elements is reduced to a minimum.

Focus ...

HDS was created in Brest, France, in 1994. This team of less than 10 members specializes in the design and analysis of high-performance composite prototype structures, mostly for racing yachts. Their skills cover static, vibration and buckling analyses by means of numerical and analytical methods. The design and analysis software used include "home-made" FEA codes, Nastran, NISA, CosmosWorks, SolidWorks and Autocad. For example, co-operations were established with Bénéteau Yachts, Hexcel Composites, Ifremer, Jeanneau Yachts, Lorima, SouthernSpars, Marström, Formula Spars, Thales Group, ESA, DCNS, Peugeot PSA, IXSEA and many racing yacht skippers.

More informations: www.hds-design.com

GeM is a civil engineering and mechanics research laboratory established in Nantes, France, that involves almost 100 members, including PhD students. One of the laboratory's teams works on the design, testing and structural health monitoring of high-performance composite materials and structures. Recent research results related to modelling and characterization of process-induced internal stress states in composite laminates, durability assessments and strain field characterization using Bragg grating sensors led to publications in scientific journals. The team focuses on the modelling of long-fibre thermoplastic or thermoset composites.

More informations: www.ec-nantes.fr/gem

The figure shows the forestay bulkhead, the deck reinforcement around the sail bunker, the mast foot and the chainplates for lateral rigging, the keel box structure, the mainsail sheet railtrack, and the backstay bulkhead. Particular emphasis was placed on the design of the mast foot structure (Figure 3).

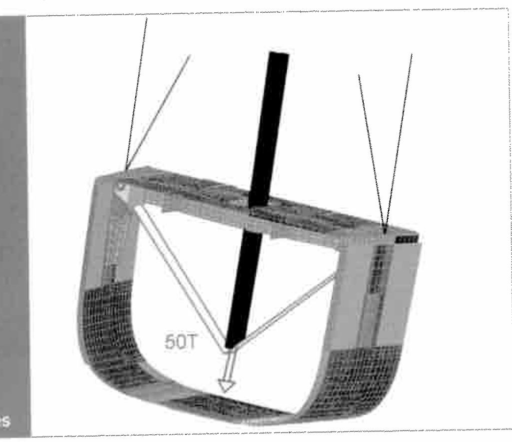


Fig.3: Mast foot design with side rigging and chainplates

The mast goes through the deck and ends on the platform as a V-shape stripe. The shrouds are mounted on lateral chainplates. The so-called V-strap structure applies a compression force of about 500 kN onto the mast-foot and transfers it to the chain-plates clamped to both the hull and the deck. A closed loading loop was established: compared to a traditional design, the hull and deck of the boat are unloaded and mostly carry loads induced by the forestay, the mainsail sheet and the backstay tensions. The V-strap is loaded in tension only. It is made of carbon prepreg, which ensures high stiffness, and weighs around 20 kg.

Another innovation was introduced in the structural design of the link between the hull and the keel spar (Figure 4).
The keel is made of steel for stiffness and the bulb end is composed of 20 tonnes of lead. Inside the hull, a keel box made of carbon-epoxy laminate ensures load transmission between the bottom of the hull and the deck. The keel spar is bolted to the end of this box. For this type of boat, the total weight of the internal structure, including the local reinforcements, does not exceed 20% of the weight of the whole hull-deck structure.

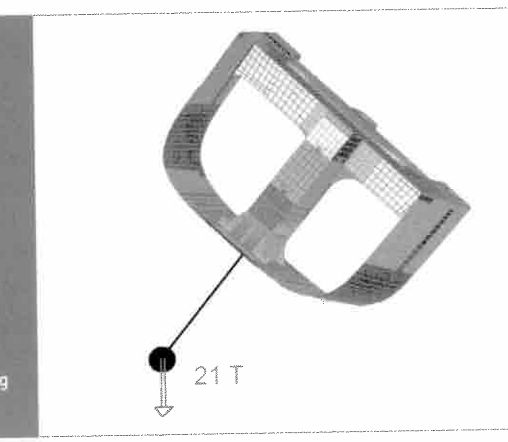


Fig.4: Load-carrying keel box for the bulb

Ocean-racing multihulls

These yachts, generally over 15 metres long, are designed for crossing the oceans or sailing around the world. They have two or three hulls and benefit from a high righting moment provided by their great width. They do not need any additional weight like a keel or a bulb. As a comparison, at the same 18-metre length, an ocean racing multihull is 50% lighter than an IMOCA racing monohull and its righting moment is double; this means that such a yacht can withstand sailing forces that are twice as high.
As the speed of multihulls increases with a higher righting moment and lower weight, the designer's goal is to ensure the strength of the structure while using as little material as possible. A design protocol was established for 60-feet ORMA class multihulls, that often race across the Atlantic. The main characteristics of these multihulls are summarized