in Figure 5. The class rules for such yachts do not limit the structure's properties and allow great design freedom.
The rules for monohulls cannot be applied here.

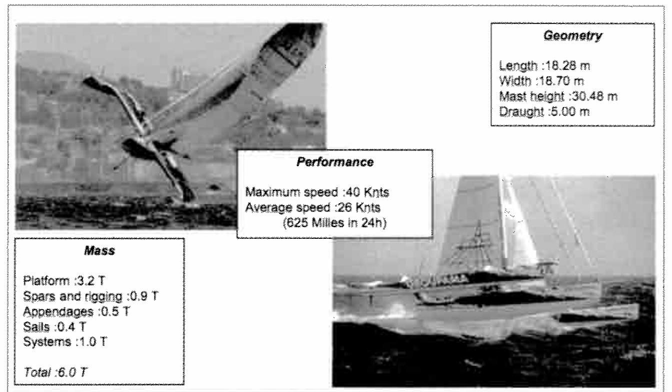

Fig.5: Overview of 60' ORMA Class boats

Loading cases

A set of loading cases has to be defined in order to represent all the dimensioning sailing conditions. First of all, a model of the whole rigging, including the mast and the shrouds, is produced to deduce the tension that will be used later to load the boat's platform. This model is implemented with the finite-element method and takes into account many sailing conditions, including wind speed and orientation, the type of sails hoisted (main sail height, forward sail among genoa, jib, staysail and gennaker). This analysis is used to programme a specific software called Autospar-Simspar (developed jointly by HDS and CRAIN), taking into account large displacements and the behaviour of uniaxial tensile cables.

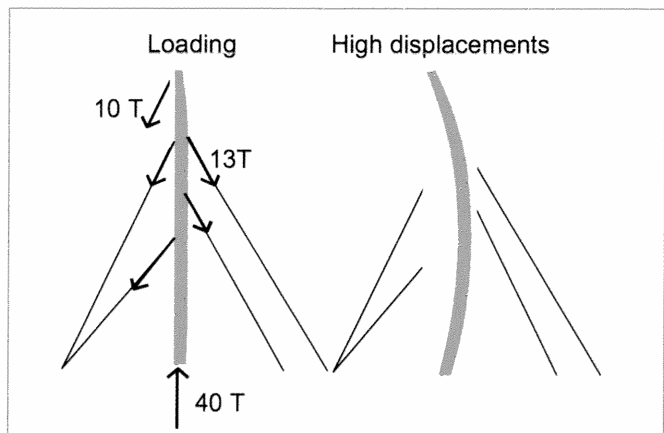

Fig.6: Hull loading generated by the rigging and the mast

It also provides the compression bending and torsion stresses on the mast and helps to choose the stiffness and stacking properties required to meet strength, deformation and buckling criteria. A typical rigging load set for a 60-foot ORMA multihull is shown in Figure 6. The loads from the rigging are about 150 kN at the forestay and 400 kN at the mast foot. These values seem very high considering the boat weight (approximately 6 tons).

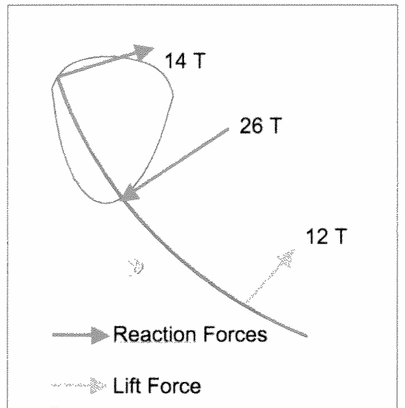

Fig.7: Side hull loading generated by the hydrofoil (60' ORMA Class)

A second type of loading is generated by the appendages (rudders, hydrofoils, daggerboard) that apply hydrodynamic lift forces ensuring the static equilibrium of the boat at constant speed. The appendages are usually linked to the platform by means of two thrust blocks or bushings which transfer the lifts to the multihull platform (Figure 7).

A third type of loading is generated by the contact with water and has three sources: loading from the swell, hydrostatic pressure on the floats, and wave impact on the cross beams. Combined with the pitch motion of the boat, the swell may force the boat to dig in a wave. The static equilibrium is then disrupted and the hydrostatic pressure, which was previously applied all along the float, is then transfered to the front area (Figure 8).

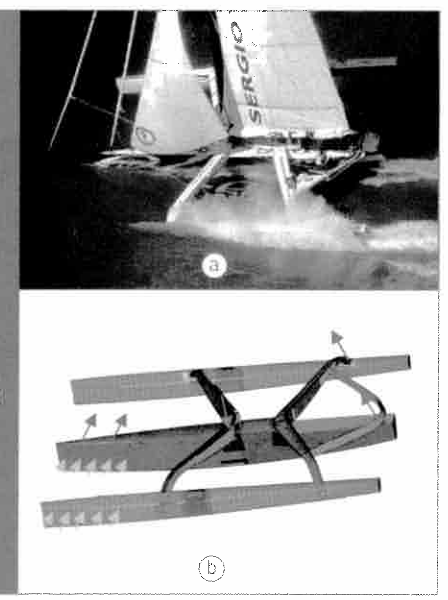

Fig.8: Digging side hull and the related loading case
(a) Digging of the float,
(b) Corresponding load modeled with FEM

This kind of behaviour suggests taking a "capsizing load" into account in the FEM through a hydrostatic pressure distributed along the front of the float to ensure the equilibrium of the structure, taking into account a dynamic factor to represent deceleration. In a more extreme situation (Figure 9), the front of the float structure must carry hydrostatic pressures up to 6×10^4 Pa. The wave impacts are not very well known but may seriously damage the cross beams of the boat. During the 2002 Route du Rhum race, many boats capsized and suffered damage in hellish weather conditions.

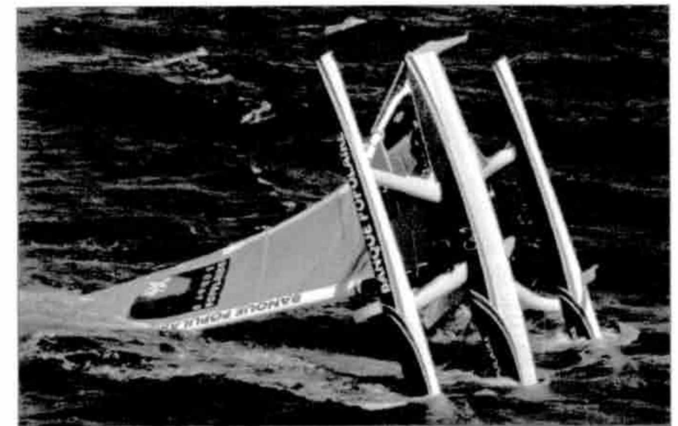
Fig.9: Hydrostatic load generated by a front capsize

The wave impacts were due to the swell crossing with a front part of the boat (the side of the floats or cross beams) at a speed around 20 m/s, which resulted in equivalent local pressures of 2×10^5 Pa, much higher than any other previous pressure. The impacted surface is represented by a circle around 0.4-0.7 metre in diameter. The parts concerned on the multihull must be able to withstand such pressures. The whole set of loading cases combines both general and local loads. This means that the structural design must be as light as possible, while being capable of withstanding the applied loads.
Structural design is based on the geometry of the boat and the above-mentioned set of loading cases, the first step of the HDS design loop consists in programming a finite-element model using a composite box type beam approach. This element makes it possible to calculate a displacement field and the corresponding stress in the laminated plies forming the platform sub-structures (central hull, cross beams and floats). This simple model provides a preliminary design that is used to optimize the structure in terms of overall geometry, hull cross-sections, floats, front & rear cross beams, and the stacking sequence of the laminates using carbon fibres with various stiffness modulus. Following this step, a full finite-element model is built using composite shell elements under small or large displacements hypotheses.

Central hull design

This section is loaded in bending with rigging tensions and in torsion with the cross beam deformations caused by the asynchronous motions of the floats. In addition, equilibrium is completed by the stresses generated by the mast foot, the dagger-board and the rudder, and by the distributed or local pressures.
A typical central hull structure is shown in Figure 10, including the main loads.
A structural function is assigned to each area of the cross section: the regular side planking is made of ±45 plies of HR or IM carbon fibre prepregs over a honeycomb core (48 or 64 kg/m³). These plies (thickness 0.6 mm per skin) carry shear stresses caused by bending and torsion, as well as hydrostatic and impact pressures. The bulkheads or ribs limit the panel size to help withstand local pressure. Each "corner" of the cross section is fitted with a high-modulus UD carbon prepreg bar in order to bear lateral and longitudinal bending and to provide satisfactory bending stiffness.

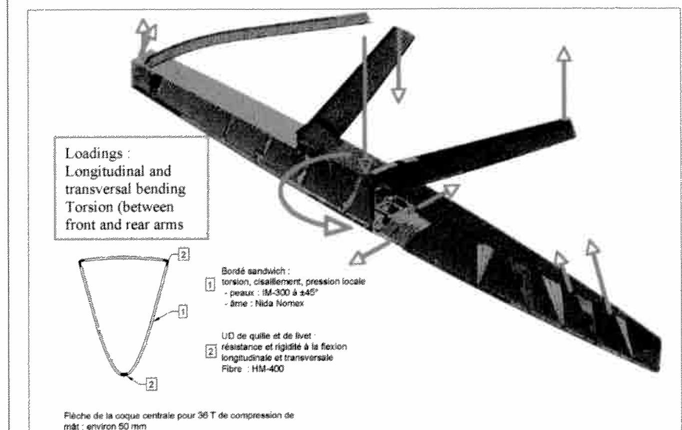

Fig.10: Structural details of the central hull

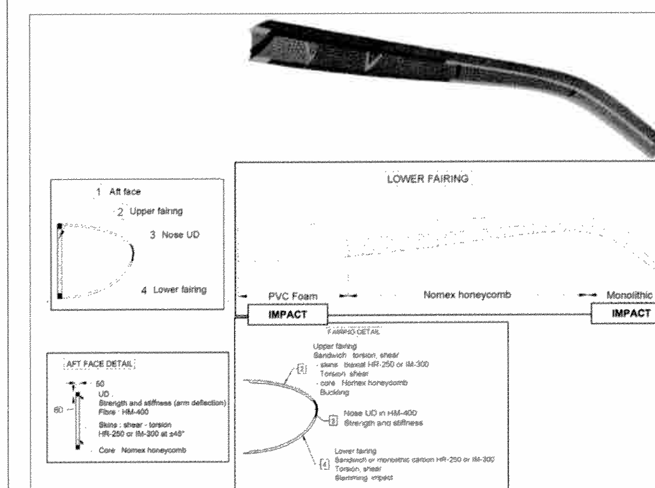

Fig.11: Typical design criteria for a racing multihull

Cross beam design

The cross beams link the floats to the central hull (Figure 11). They are subjected to bending and shear loads resulting from both the lift of the leeward float and the tension of the windward shroud. They bear torsion from the twist of the whole platform and are subjected to high local impact pressures.
The cross-section is made of two parts:
- A stem wall that behaves like an I-beam with a core made of ±45 plies and a honeycomb core as a spacer, and with flanges formed by unidirectional carbon plies in order to bear bending and transverse shear stress,
- A sandwich front fairing with a honeycomb or a foam core and ±45 carbon skins. Carbon UD plies are added at the front of this part. The fairing is subjected to longitudinal bending and shear stress. The whole cross-beams can also carry the torsion