The megayacht *Happy Days* at sea. Photo by Neil Rabinowitz.

Designing for **Strength, Speed and Luxury**

Simulation software from ANSYS helps a yacht designer deliver the optimal combination of luxury and performance.

By Chad Caron, Naval Architect, Delta Marine Industries Inc., Washington, U.S.A.

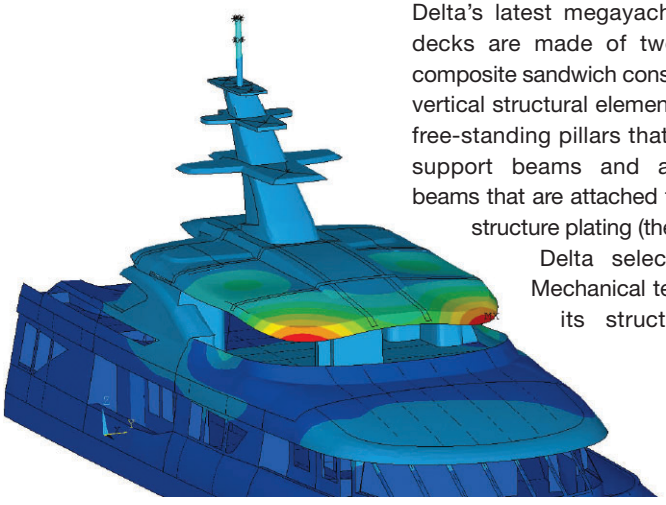
Purchasers of 100-foot plus megayachts have come to expect the ability to customize the interior design to a level that matches their wildest dreams. Award-winning yacht builder Delta Marine has become one of the world's leading builders of megayachts — in part through expertise in designing carbon fiber structures that enable virtually any interior configuration while providing high levels of strength, durability and performance. However, giving interior designers the freedom to place walls or partitions wherever they wish creates structural design challenges by increasing the complexity of the load paths.

Graphite composites provide the ideal material for megayacht design because they are stiffer and stronger than metals per unit of weight, making it possible to build a lighter and stronger boat. Composites enable more flexible designs because their physical properties can be tailored to a very high degree. In the past, interior design was constrained by structural considerations; more recently, advancements in composites have provided designers with far more flexibility. For example, the location of pillars today can be more readily accommodated by structural engineers to suit the interior designers' vision.

Traditional design methods, such as handbook formulas and rules of thumb, are not adequate to achieve an optimized structural assessment for these new types of interiors. This means that analysis typically needs to be performed on a global basis, which in turn requires very powerful software and hardware.

The horizontal structural elements in a megayacht are the decks. In Delta's latest megayacht, the three decks are made of two-inch thick composite sandwich construction. The vertical structural elements consist of free-standing pillars that are used to support beams and also vertical beams that are attached to the superstructure plating (the mullions).

Delta selected ANSYS Mechanical technology as its structural design



Bimini top and mast first vibration mode for the *Happy Days*, the largest composite yacht built in the Americas, showing total displacement sum

software seven years ago because the yacht maker believed that the software's composite analysis capabilities were well ahead of competitors. At the time ANSYS Mechanical was the only finite element software Delta could find with a composite shell element. As composites simulation technology has progressed, according to Delta, the ANSYS Mechanical package has maintained an advantage in composite design capabilities.

The Delta Marine team models the major shapes of the yacht in Rhinoceros®. The Rhinoceros model is exported to a neutral file format and imported into ANSYS Mechanical software to provide the geometry for the model. The naval architect uses composite shell elements to model the laminate stack layer-by-layer and uses solid elements for foundation parts that are cast in resin and in scantlings (frame and structural support dimensions) that have core that is structurally significant.

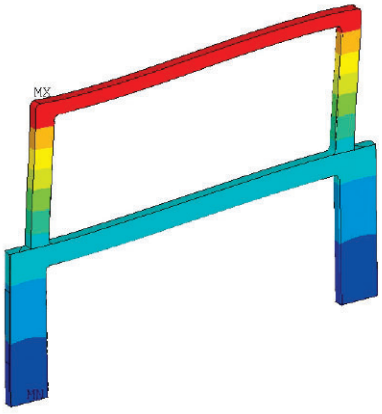
The prediction of vessel vibration frequencies is dependent on the total weight distribution for the yacht. The interior design has the potential effect of increasing overall weight through the substantial use of hardwood and stone, especially common in today's yachts. Delta has developed parametric approaches to estimate interior weights using targets on a per-square-foot basis for various materials. The outfit weight along with the other structural and mechanical weight components coupled with the hydrodynamic added mass of the water directly affect the vibration frequencies and mode shapes the yacht will exhibit. Accurately predicting these frequencies and mode shapes is critical to successful design.

Delta designed its new mega-yacht in two stages: first for strength and then to resist vibration. Today's yacht buyers are interested in a luxurious interior and a high cruising speed, but it is critical to optimize the structural elements to deliver the required strength while avoiding any extra weight that would reduce the speed of the boat. The designer uses ANSYS Mechanical technology to evaluate global and local stresses on a layer-by-layer basis. Most other finite element analysis packages merely average the loads over the stack.

ANSYS Mechanical tells the engineers exactly where the load is going, down to the individual composite layer. This simplifies the design of the mullions, beams and pillars. The ability to distribute the loads among the different layers also helps to tune the laminate stack. Delta uses ANSYS reports to detail and defend structural decisions that the regulatory body rule books cannot cover adequately.

Even after a structure has been designed to support the design loads, the yacht may still vibrate. The Delta designer performs modal analysis to investigate its primary modes of vibration using the same ANSYS Mechanical model. The technology determines the natural frequencies of the mass matrix. The analysis results in a recent project showed that the first mode of vibration was a racking mode, which meant that the superstructure of the boat vibrated horizontally, with the decks decoupling from each other like a deck of cards sliding back and forth.

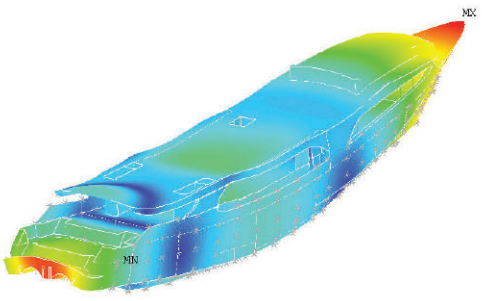
The engineers addressed the concern by adding a racking frame, a structure that spans two decks and resists horizontal motion. Delta



Delta's latest project has a racking frame, shown here, resisting a roll acceleration. This is a relative plot of displacement for a given frequency.

modeled the racking frame using 0/90 and +45/-45 biaxial laminate and unidirectional carbon fiber. The analysis results identified the stresses on the structure and helped determine which layer buildup should be used on each particular part of the frame. Delta was also concerned about the longitudinal second mode of vibration identified in the modal analysis. This mode generated a high bending moment near the middle of the ship, which was addressed by strengthening the hull and decks to make them stiffer in the area that experiences the highest bending moment.

ANSYS Mechanical simulation makes it possible to determine exactly how loads distribute through this complex structure, so that engineers can tailor the properties of structural elements to provide strength and stiffness exactly where it is needed. These capabilities free the designers to put walls and partitions wherever they want and keep the weight to a minimum level. As a result, the new boat delivers the optimal combination of luxury and performance. ■



Mr. Terrible's hull first mode of vibration

Mr. Terrible cruising Alaska. This 154-foot semi-displacement design is built for high-performance, reaching maximum speeds of 24-knots. Photo by Neil Rabinowitz.