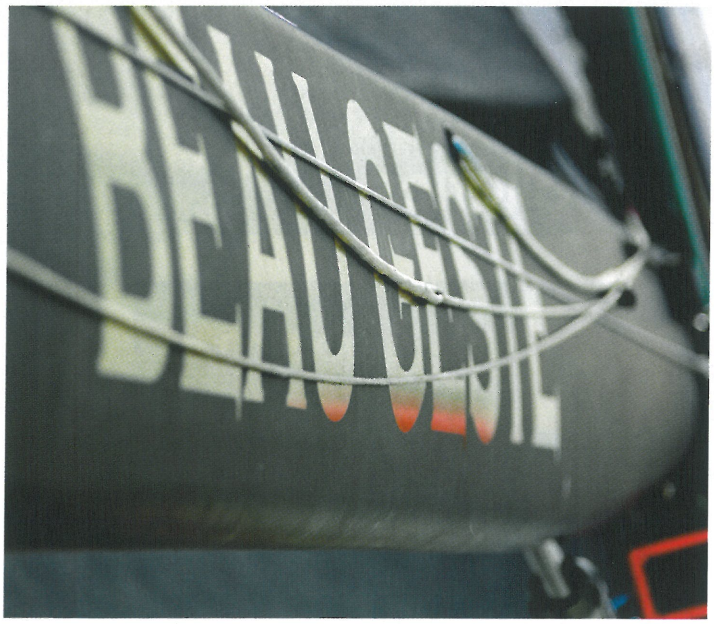
The 80ft racing yacht *Beau Geste* represents a complex process of finite element analysis.

When will it break?

Finite element analysis (FEA) is used widely in aerospace, automobile, heavy industrial and boatbuilding. It's a wordy way of asking: When will it break?



When the 80ft *Beau Geste* was launched in Auckland last year, she represented excellent use of FEA, Finite Element Analysis, by New Zealand structural engineers at Pure Design and Engineering.

FEA is software-based science used to determine the perfect point between building a structure strong enough to do its job while meeting all its other, often conflicting criteria. In a yacht that means being built light and fast.

Basically, it's about creating computer models of the project, in this case a racing yacht, and subjecting it to particular scenarios – such as crashing off a four-metre wave at 20 knots, sailing upwind at maximum righting moment in 40 knots or hitting a reef, as happened to *Team Vestas Wind*.

For each scenario, the FEA model estimates what stress levels will be induced in particular parts of the boat – eg, the bow, stern sections, rudder, rig or hydraulic rams for the canting keel.

This information allows the engineers to design the boat's structure so that, in theory, it won't break in acceptable scenarios but it won't be so over-built that the yacht will

FIG 1: AN OVERVIEW OF THE BEAU GESTE FE MODEL

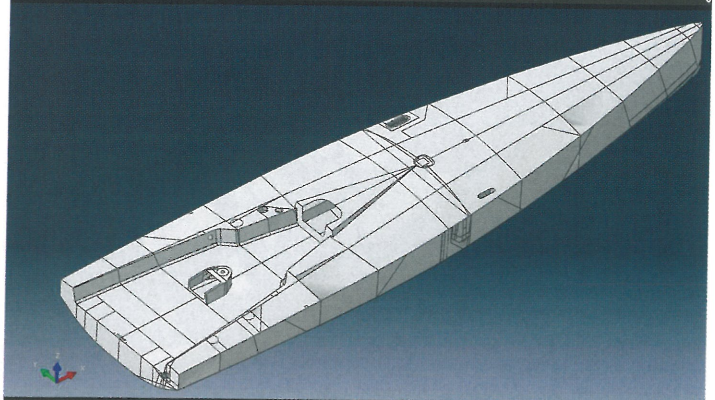
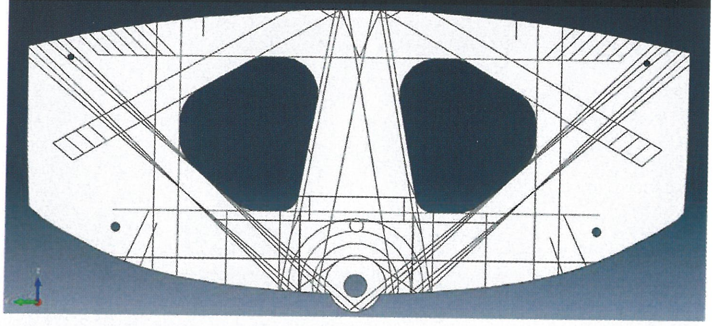
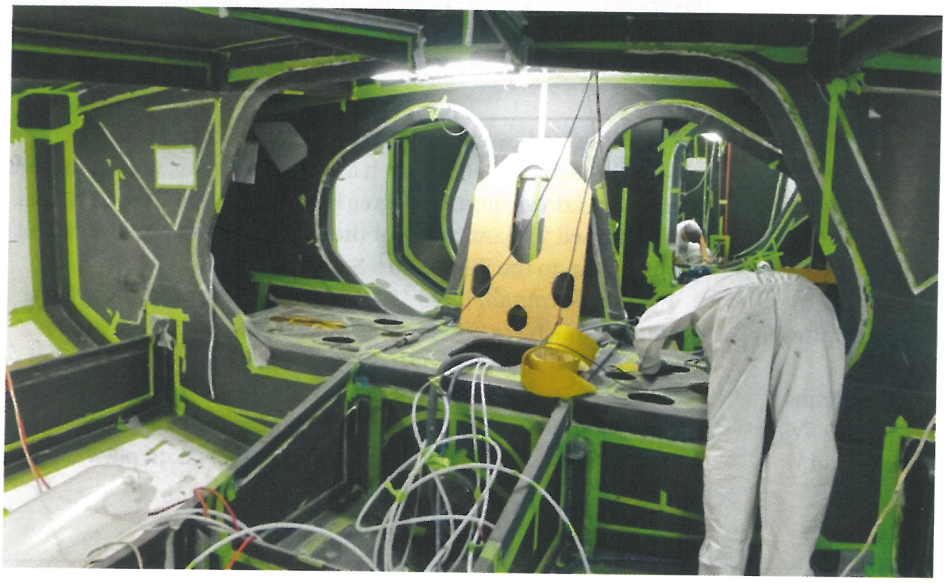


FIG 2: THE MAST BULKHEAD IN THE FE MODEL WITH LAMINATE PARTITIONS



BELOW: Figure 4: The forward and aft mast bulkheads installed either side of the keel shelf.



perform poorly. In other words, it will be as light as possible while achieving the strength it needs to cope with its expected load scenarios.

ENGINEERING *BEAU GESTE*

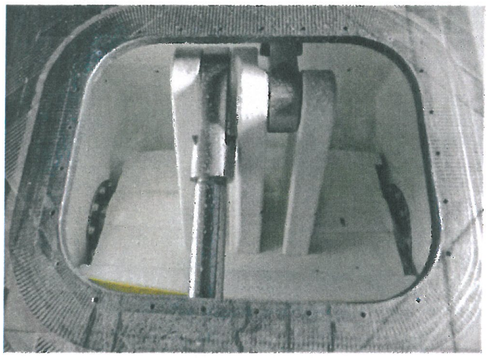
Botin Partners in Spain designed the hull, internal spaces and sailing systems of *Beau Geste* with the owner and sailors, then transferred the 3D hull, deck and internal geometry in computer files to Pure Design and Engineering in New Zealand to do the structural engineering.

Up to this stage *Beau Geste* existed only in computer files. Pure completed the structural engineering, assisted by FEA, then produced construction drawings for Cookson Boats to build the boat. She is an excellent example of how FEA can be used to optimise high performance light weight structure.

The design process used FEA in two stages.

Firstly, the naval architect may use CFD (computational fluid dynamics, another form of FEA) to test the hull performance under different sailing conditions and identify its response – ie, how much drag does the hull produce and how fast will it go?

Once the hull shape is finalised, Pure's engineers develop the composite structures for these to ensure strength and stiffness; for example, a winch pedestal in the cockpit needs to be well anchored in place and its loads need to be distributed through the cockpit. The engineers use traditional techniques – hand calculations – and then check



ABOVE: Figure 3: The mast bulkhead under construction. LEFT: Figure 10: Keel and rams installed in the boat.

FIG 5: THE FORWARD AND AFT MAST BULKHEADS WITH THE KEEL AND RAM ARRANGEMENT ASSEMBLED IN ABAQUS. NOTE: KEEL SHELF REMOVED

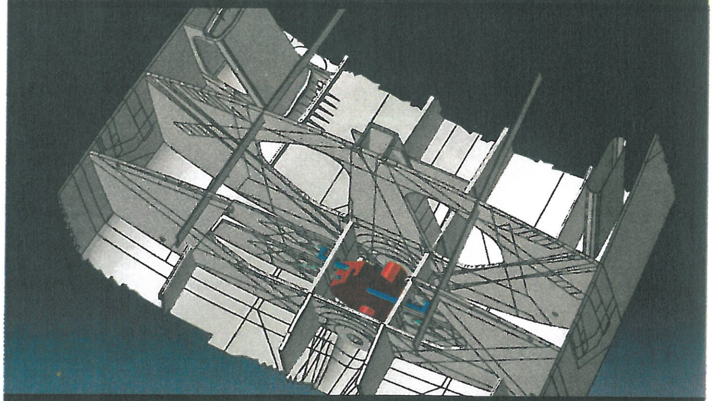
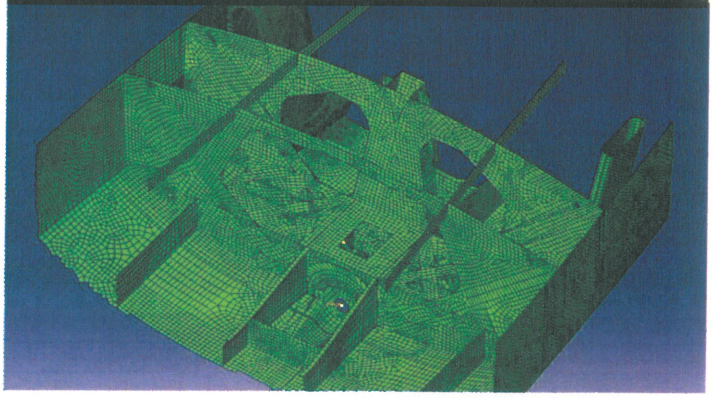


FIG 6: AN OVERVIEW OF THE MESH



the design to understand the structure's responses with FEA.

At this stage the FEA will highlight any areas that require additional laminate or attention. Boat structures are inherently complicated with many different load paths working simultaneously in different directions. The yacht's interior arrangement and sailing systems complicate this process further. FEA allows engineers to visualise these load paths and how they fit into the overall loads of the boat.

Before constructing the FE model, Pure developed preliminary laminates using traditional hand calculations to meet the DNV-GL Scantling Certification requirements to suit different load cases. These load cases cover the basic structural and safety requirements for situations such as bow slamming, grounding and severe knockdown; ie, a 90-degree heel. From these requirements, Pure designed the laminates for the hull, deck and bulkheads and applied them to the FEA model. See Figure 1.

Bulkheads contain up to 150 layers of carbon fibre. Every layer of carbon fibre has a different purpose and is included in the model. For example, the mast bulkhead, the most highly-loaded bulkhead in *Beau Geste*, contains 87 individual laminate regions to deal with the load from the deck-stepped mast, forward keel trunnion and the V1/D1 (vertical 1, diagonal 1) chain plates.

With all laminate for the structural components applied, the model is assembled and floated. See Figures 2 and 3.

Beau Geste generates power from the hull, rig and keel. She has a canting keel supported by two bulkheads and driven side to side by a primary and secondary hydraulic ram arrangement. The FE model contains a representation of all these components.

The keel fin for *Beau Geste* was approximated using a wire to connect all the necessary parts of the keel and bulb. The points in the keel represent the tip of the bulb, centre of mass of the bulb, centre of mass of the keel, forward and aft trunnions and ram attachment points. The wire representation of the keel was then assigned a rectangular section shape approximating the actual keel section. The same process was repeated to represent the hydraulic rams. All three parts – the hull, keel and rams – were assembled to give the complete model. See Figures 4 and 5.

MAKING IT WORK

Applying loads to a boat is complicated. Take the scenario of a boat sailing upwind. In calculating the loads on the boat, engineers consider buoyancy, drag, gravity, heel angle, rig loads, sheeting positions, appendage loads, cant angles, sail stacking and crew positions. All these need to be accounted for in some form.

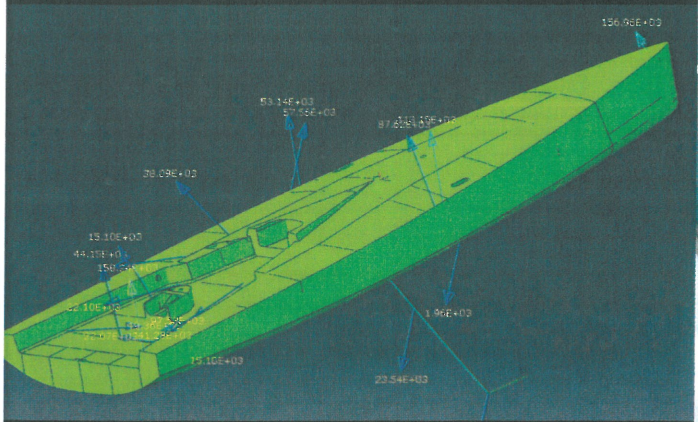


FIG 7: LOADS APPLIED TO THE MODEL TO SIMULATE UPWIND SAILING

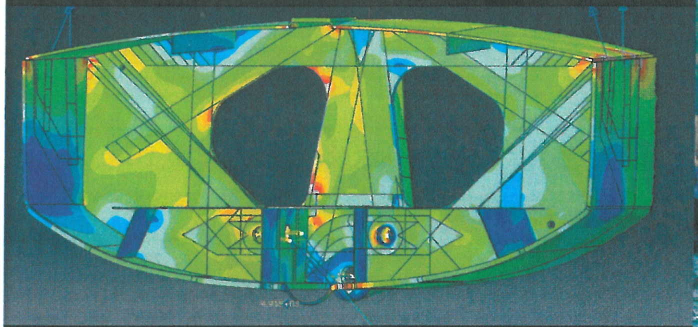


FIG 8: STRAIN RESULTS OF THE MAST BULKHEAD AND SURROUNDING STRUCTURE

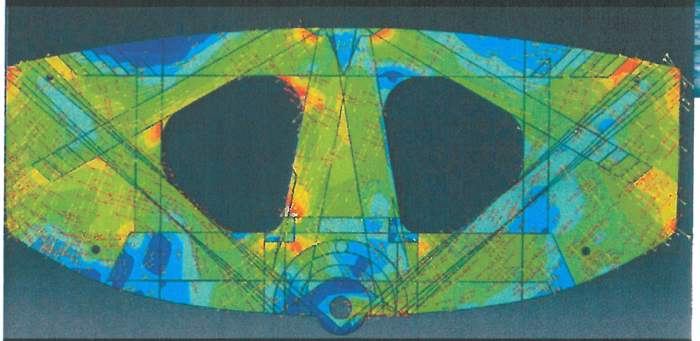


FIG 9: STRAIN VECTORS OF THE MAST BULKHEAD

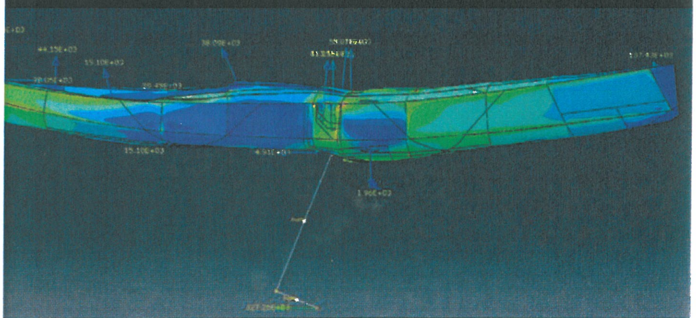


FIG 10: BEAU GESTE UNDER GROUNDING CONDITIONS (DISPLACEMENT MAGNIFIED X20)

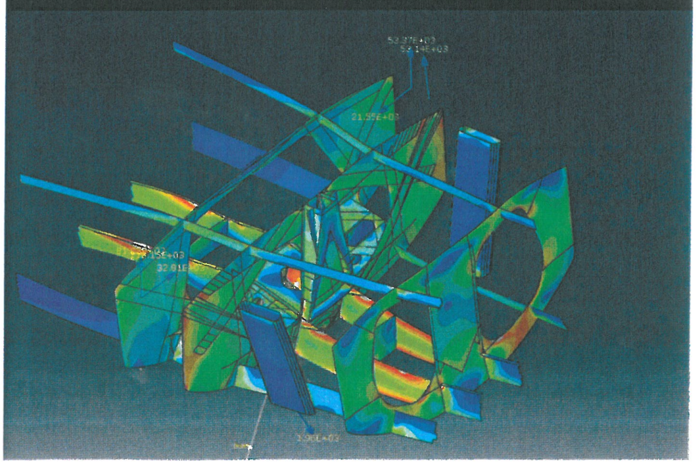


FIG 11: INTERNAL STRUCTURE UNDER THE GROUNDING LOAD CASE

For *Beau Geste* there was a load case for the boat sailing upwind, with maximum righting moment – this was the boat heeled to 25 degrees with the maximum 40 degrees cant on the keel.The weight of the hull, keel fin and bulb were supported by a hydrostatic pressure applied to the hull surface. Rig loads were applied to counter balance the righting moment generated by the keel and balanced by the dagger foil and drag on the hull. See Figure 7.

Once the meshed model is balanced and checked, the engineers could review the results. For the mast bulkhead, for example, they could see how every layer of carbon fibre contributes strength and stiffness under the influence of the rig and appendage loads. See Figures 6, 8 and 9.

The engineers also looked at the extreme case of grounding, by applying a point load at the tip of the bulb. This approximates the deceleration on the hull when the bulb suddenly stops.

Team Vestas Wind unintentionally gave structural engineers the world over a perfect example of what happens when a canting keel racer slams over a reef at more than 20 knots.

An FE analysis allowed Pure's engineers to simulate *Beau Geste* grounding and its effect on critical structural components such as the mast bulkhead. An iterative approach was taken to ensure that *Beau Geste* met the DNV-GL Scantlings. Laminate was added and the analysis re-run, and checked until an optimal solution was developed. See Figures 10 and 11.

THE REALISATION OF A MODEL

Once the engineers at Pure were satisfied with the laminates they adjusted their 2D drawings to match the laminates in the FEA model. The drawings specify the build procedure, extents of the laminates and tapering that are difficult to capture in the FE model. The drawings were then certified by DNV-GL, in Hamburg, Germany before being issued to the builder, Cookson Boats for construction.