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CHALLENGES ASSOCIATED WITH DESIGN AND BUILD OF COMPOSITE SAILING SUPER YACHTS

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Abstract.
The composite sailing yacht market is developing at a fast pace. Large ocean-going cruising yachts are capable of record breaking performances thanks to the continuing development in technology, materials and design, yet they are also required to have a luxurious fit-out. Composite materials can offer significant advantages when performance is part of the design brief.

Designing and manufacturing composite super yachts is challenging and rewarding. With increasing size of yachts, new parameters must be accounted for at both the design and manufacturing stages. Scaling up proven solutions for 100 foot boats is not necessarily valid, but experience gained over the years can be used to identify potential challenges and design new optimum solutions.

Increasing the size and performance of super yachts has a disproportionate effect on the load structural components must withstand. This in itself leads to fundamental questions; can one easily predict the loads associated with the increase in boat size? What type of laminate and material should one consider when designing various parts of the structure? How can deck structures withstand higher compressive load (from fore & aft bending) and still accommodate cut outs and aesthetic requirements from the architect and interior designers? What are the implications on the manufacturing process? Examples of such subjects will be addressed in this paper.

The paper will also highlight key issues related to timescale, project management and the decision making process as these will also have an impact on the final appearance and performance of luxurious, high performance super yachts.

1. INTRODUCTION

“Super yacht” is a term generally used to describe large sailing and power yachts of a size of 30m (100ft) and over. Large yachts have been built for many years. The famous J Class boats from the beginning of the 20th century are an historic example of what would now be called a cruiser/racer or racer/cruiser.

The number of super yachts built has increased over the last 30 years. There has been a steady growth in boats over 30m, but in the last 5 years orders for boats (motor and sail) over 50m has more than doubled. Although the majority of orders is for motor boats, in the same period the number of sailing yacht orders greater than 50m has doubled. Such large yachts are generally built using steel, aluminium and/or composite materials.

Large composite sailing yachts, such as the light displacement 32m composite ketch, Wallygator 2 launched in 1994, the 75m sloop Mirabella V launch in November 2003, the 45m light displacement all carbon fibre sloop “Visione” delivered in 2003, the high performance carbon fibre Wally 50m yacht scheduled to be delivered in 2010 or the high performance 60m Panamax Ketch project under construction at Baltic yachts clearly indicate the trend for larger yachts to be built using composite materials.

However, current orders [1] show that whereas 60% of the sailing yacht between 30m and 40m are built in composite, the proportion of composite sailing yachts drops down to 4% above 50m. 15 years ago it would have been uncommon to build a composite yacht over 30m long, but now this is the norm. So what are the reasons for and against building bigger boats in composite?

One of the limitations to the construction of large composite yachts is the finite number of specialist yards that are capable of such construction. The facilities required for such a build may not be too onerous (note the relative ease that one-off racing boats are built in initially empty sheds with little infrastructure). However the yard does need to have a knowledgeable technical office to handle the design information. Such specialist yards do exist and designing and building composite super yachts has proved to be not only challenging but also rewarding.

This paper through specific examples will focus in discussing how weight can be saved by the use of composite material and optimised design. It will mention some of the design and processing challenges associated with boat size increases and will highlight the importance of project management.

2. COMPOSITE CONSTRUCTION

There are few single-purpose boats; many big cruisers will take part in racing events at some point. Even without racing, busy owners want their boats to be able to make rapid transit to favoured cruising areas. Not

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surprisingly comfort, a high quality interior and also high performance are all often part of the design brief.

The principal reason that composite construction is chosen is to reduce the structural weight. Consequently it is usual that composite super yachts are high performance designs by definition.

2.1. STRUCTURAL WEIGHT

According to the naval architect, E Dubois [2], a 40m sailing craft made of Aluminium will have a structural weight of around 45 tonnes whereas the composite structure will be around 18 to 25 tonnes. Figure 1, which has been derived for high performance sailing yachts manufactured using various composite build processes, confirms the data provided by E. Dubois for cruising yachts. It also illustrates that further weight reduction can be achieved when adopting construction technology as for high performance composite racing yachts.

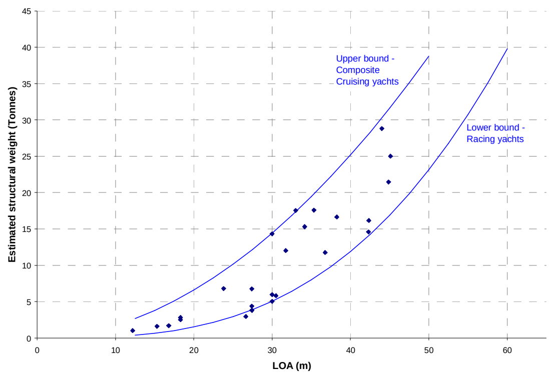

Figure 1: Composite structural weight versus LOA

2.2. PERFORMANCE

The length and displacement determine the general character of the boat including its potential performance. In Figure 2, the length to displacement trends for both cruiser and cruiser/racer high performance composite yachts are presented. Known values for composite boats are compared with existing published data from the literature and general trend for aluminium sloops.

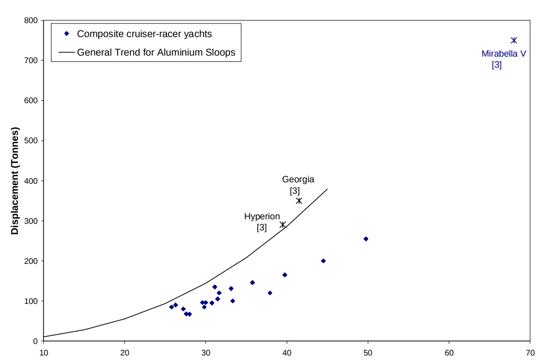

Figure 2: Comparison of length versus displacement for various type of design

Figure 2 highlights the fact that a reduction in displacement and so to some extent a gain in performance can be achieved by using composite.

To realise the full benefits of composite construction, the effects have to be run fully around the design loop. Simply converting to composite may initially save 25% of the structure weight. Passing this saving on to the rig and keel design can lead to a reduction in displacement. The now smaller displacement boat will have a reduced hull surface area, which gives a further saving. The structure for the resultant design can then be optimised further and be as much as 35% lighter. The resultant boat may now have a faster shape but less internal volume.

When looking at composite high performance sailing super yachts it is important to realise that the overall weight of the structure is only around a quarter of the overall weight of the boat. Optimised design should not stop at the structure; it should include a fully integrated design/build team as will be mentioned in more detail in section 5. This is essential as items such as systems and interior may contribute more than a third of the total weight [4].

2.3. COMPOSITE MATERIAL

Composite material is a general term which can be used to define a wide range of products. Fibre reinforced composite materials are widely used in the marine industry. They have gained their reputation as being a non corroding material, resistant to fatigue and leading to low maintenance structure. Composite construction can bring other benefits such as facilitating the imaginative shapes required for styling and in-built insulation, hence the trend for composite superstructures and masts on motor superyachts.

Fibre reinforced composite itself can describe conventional glass reinforced polyester material as well as advanced epoxy sandwich and single skin construction. As indicated in G. Harvey and A. Shimell [5] conventional glass reinforced polyester structural design will be around 5 to 20% heavier than aluminium alloy whereas an advanced glass/aramid epoxy design could be around 20% lighter and a carbon epoxy design could be around 45% lighter. The greatest weight saving typically comes with carbon-skinned Nomex honeycomb-cored sandwich.

The weight reduction is not only achieved by using a lighter material but also by optimising the design and using the right material with the right strength and stiffness properties for the right application. The strength and stiffness to weight ratio of various materials is best illustrated in Figure 3 [6]. The specific properties are the results of dividing the mechanical property of a material by its density. The range is provided by fibre orientation mix.

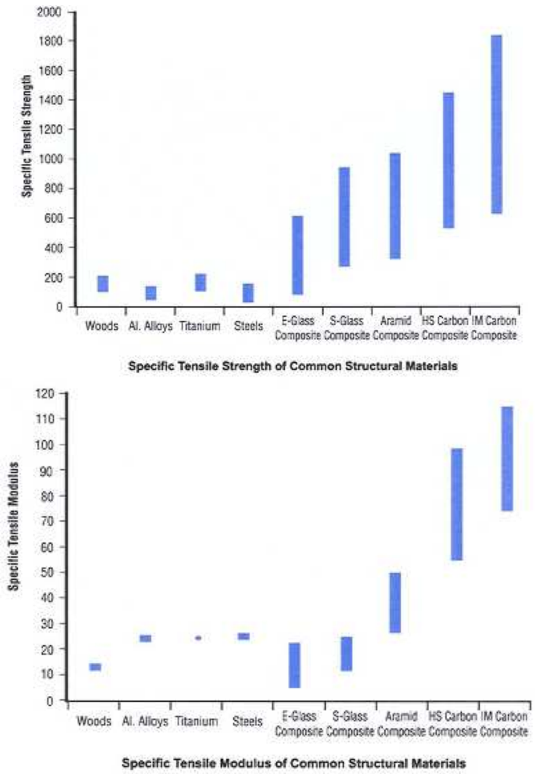

Figure 3: Comparison of specific tensile strength and modulus

Higher specific strength and stiffness can be achieved by the use of carbon reinforcement. However this does not come without a cost penalty. According to E. Dubois [2] for a 40m boat the cost of the aluminium structure will be around 20% of the overall cost of the vessel whereas an epoxy based composite structure with foam core would be around 30%. It is generally accepted that composite construction will increase build cost and design/build time. So, what is essential when considering using high performance material is to tailor the design to best use these materials. This is illustrated in Figure 4 where a comparative study between unidirectional glass and carbon epoxy laminate is provided. It demonstrates that using epoxy carbon laminate for stiffness driven design will only lead to a small cost penalty but more importantly will provide a large weight reduction. In this table no account is taken for the cost saving from reduced lamination time having fewer plies.

Relative properties of reinforcement types.

The figures are based on **approximate** reinforcement and resin prices.

	Fibre	E-Glass	Carbon
	Fabric Style	500g/m^2 Unidirectional Fibre, UT-E500	300g/m^2 Unidirectional Fibre, UT-C300
Total Cost		5.67	16.12 £/m2
For equal...		Number of plies required to match 1 x UT-E500	
Compressive Strength		1.00	0.70
Compressive Stiffness		1.00	0.39
		Cost of other materials to match 1 x UT-E500	
Cost basic		1.00	2.84
Cost equivalent strength		1.00	1.98
Cost equivalent stiffness		1.00	1.10
		Weight of other materials to match 1 x UT-E500	
Weight basic		1.00	0.65
Weight equivalent strength		1.00	0.45
Weight equivalent stiffness		1.00	0.25

Figure 4: Relative properties of unidirectional glass versus carbon epoxy laminate

2.4. SINGLE SKIN OR SANDWICH CONSTRUCTION

Further optimisation of the use of composite materials can come with the use of sandwich construction for specific application. Sandwich construction consists of two stiff fibre reinforced laminated skins separated by a core material such as foam or Nomex honeycomb. It is used as a preferred construction method for most structural shell panels of high performance yachts as it provides and efficient way to support distribute out of plane loads such as water pressure. There is an added benefit that sandwich structures have inherently good thermal insulation.

However, forward hull shell structures due to their intrinsic curvature are not as stiffness driven as the flat panels found in way of the hull top side, deck or internal structure. Core shear failure is often the main design criterion for sandwich hull bottom in the slamming area. As the length of the boat increases so does the design slamming pressure. For sailing super yachts replacing the high density core required to withstand the design slamming pressure by single skin laminate with adequate stiffening can be a better solution.

This illustrates that carrying out detailed design optimisation contributes in defining which type of construction will best contribute to achieving the design requirements.

3. FORE/AFT STRUCTURAL REQUIREMENT

One of the main global loadings to consider when designing larger sailing yachts is the longitudinal bending moment induced by rigging loads, which is much greater than that due to buoyancy distribution. Global longitudinal bending induced by rigging is caused by the tensile loads in the forestay and backstay pulling upwards on the bow and the stern, whilst the mast compression opposes with a downward action. The maximum bending moment induced by the rigging load occurs at the position of the main mast. The deck is subjected to compressive load, the hull bottom to tensile load and the hull topside to shear force (see Figure 5).

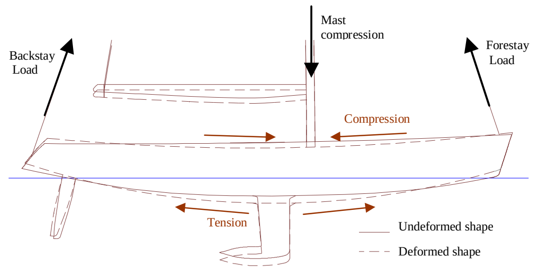

Figure 5: Hull bending

Longitudinal wave bending moment is derived following classification society requirements, or by first principles calculation. The critical moment is obtained under the sagging condition (as this adds to the rig induced bending moment), where the ends of the boat are supported by the sea and the midship section is not. As the length of the boat increases the effect of the wave bending moment on the overall bending moment can have a significant contribution and must be accounted for.

From a designer's point of view it is essential to ensure that sailing yachts are adequately rigid fore and aft to prevent excessive hull bending when subjected to such loading. This is required to minimise forestay sag, the loss of sailing length and to minimise the distortion of the designed hull lines. Generally, aside from local strength considerations due to stress concentrations, the design is stiffness rather than strength driven. As will be explained in the section 3.3, deck buckling stability can be a critical issue.

3.1. HULL GIRDER ANALYSIS

Hull girder strength and stiffness analysis for sailing yachts less than 20m to 24m is often regarded as simple and straight forward. This, however, cannot be considered as such, as the length of the boat increases. In this section, we will concentrate in describing the implication of an increase in length on the rigging bending moment.

Larger boats tend to have taller rigs and higher righting moment, and so higher rigging loads. Although there are many load application points and loads cases, the major contributor in this bending moment is that of the bow cantilever due to forestay load. Figure 6 indicates that the maximum working forestay load increases exponentially with boat length. This graph is based on existing composite high performance cruiser and/or racer yachts.

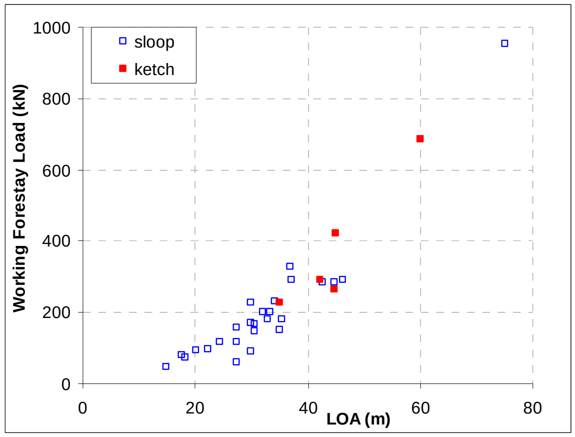

Figure 6: Working forestay load versus LOA

As the length of the boat increases so too does the distance between the mast and the forestay, J. This is illustrated in Figure 7. This increase is a function, as expected, of the type of rig. A ketch, naturally has a shorter lever for a given boat size.

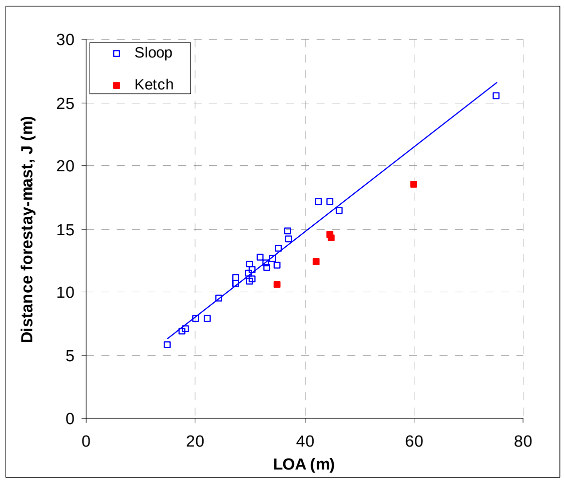

Figure 7: J versus LOA

Applied bending moment can be directly derived from forestay load and J. The evolution of the bending moment as a function of boat length is illustrated in Figure 8 for both ketch and sloop.

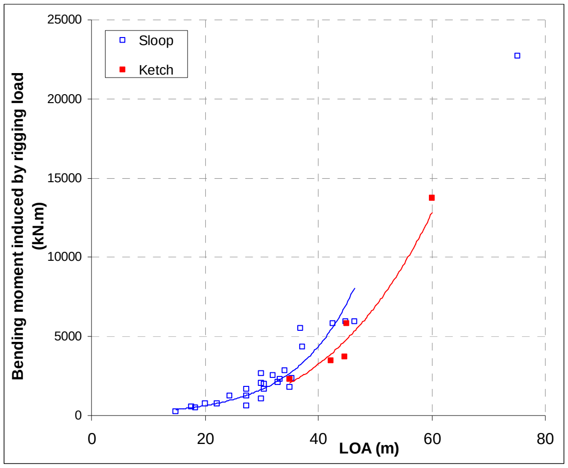

Figure 8: Bending moment versus LOA

Correspondingly the bending moment predicted in way of the main mast of a ketch is lower than the bending moment seen by a sloop of the same size. However, the overall longitudinal bending behaviour of a ketch will also be influenced by the presence of the second mast, resulting in two overlapping triangular bending moment distributions. Then the effects of hull wave/buoyancy induced bending moment may become relatively more significant. This more complex behaviour must not be neglected when analysing the structural stiffness of those yachts.

3.2. STIFFNESS REQUIREMENT

The maximum deflection, w, of a yacht can be derived using beam bending theory as shown in equation 1.

$$w = \iint \frac{M}{EI} dxdx \qquad \text{Equation 1}$$

As illustrated within equation 1, for given rig loadings and specified geometry, improving the stiffness of the hull girder relies on increasing the boat section EI values.

The hull form drives the amount of material needed to gain the required stiffness. A low length/canoe body depth ratio is representative of a naturally stiff boat, where minimum additional material will be required to achieve the target stiffness. On the other side, a high length/canoe body depth ratio is representative of a naturally soft boat, where the structural design is likely to be globally stiffness driven. As boats get bigger they tend to get sleeker, i.e. the length increases more than the depth.

The increase in length to depth ratio and the increase in applied bending moment indicate that in order to reach the required design stiffness, much higher values of section EI will need to be achieved as the boat length increases. This is illustrated in Figure 9.

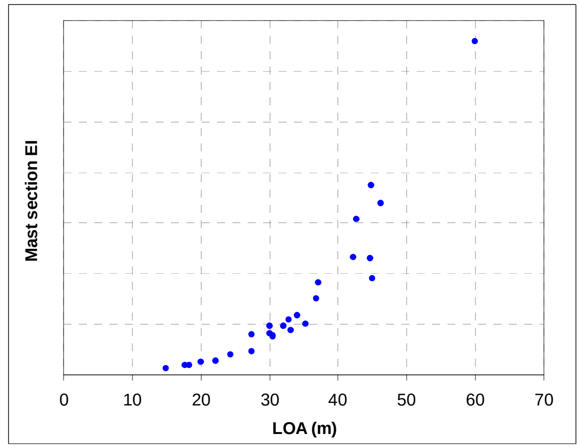

Figure 9: Trend of section EI at mast values versus LOA

The best way to increase the section EI values without drastically increasing the structural weight of the yacht relies in adding material as far away as possible from the hull girder neutral axis. This is an example where composites allow a much more optimised design. Material selection, orientation and location can be optimised to provide the required stiffness at an optimum weight. The hull and deck shells are stiffened to meet the desired stiffness requirement, by adding unidirectional fibres where it is most efficient to do so, i.e. along the hull bottom and along the side deck or along the hull top sides close to the gunwale. Using unidirectional carbon laminate, which has a modulus around three times higher than unidirectional glass fibre, is the usual solution. For design where weight and performance are key parameters, standard modulus high strength unidirectional carbon (HSC) tapes can be replaced by more expensive intermediate modulus (IMC) or high modulus (HMC) unidirectional carbon fibres. IMC and HMC fibres provide respectively, for the same fibre weight, a gain in modulus and hence stiffness of 20% and 50% when compared to HSC fibres.

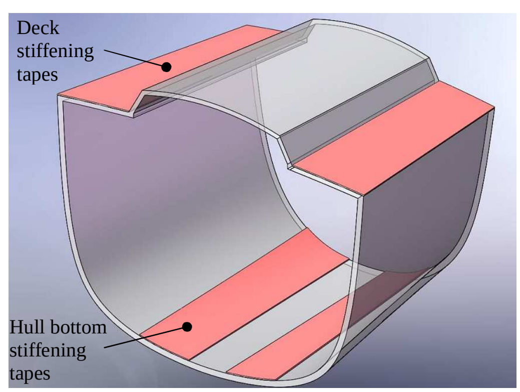

Figure 10: Hull girder stiffening tapes

3.3. DECK TAPE DESIGN

Stiffening tapes must be added in way of the deck and/or hull topsides to ensure hull girder rigidity. To be efficient these tapes must be continuous along the length of the boat. Discontinuities caused by cockpit, coachroof and hatch cut outs mean that the deck tapes are most commonly added in way of the side deck. Typically for an 18m yacht the deck tapes are spread over the full width of side deck as illustrated in Figure 11

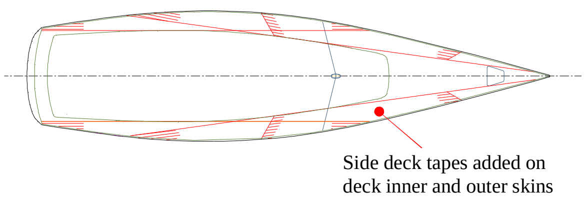

Figure 11: Typical example of stiffening deck tapes

The exact amount of carbon deck tapes required is a function of several factors including the boat length, deck basic sandwich laminate and effective deck width.

Typically, the deck of an 18m high performance composite cruiser/racer, manufactured using sandwich construction with a 25mm thick core, requires about two additional 300g/m^2 unidirectional IMC tapes on each skin of the sandwich laminate. A 20m sailing yacht with the same basic deck laminate would require about three additional layers per skin and a 25m boat about four additional layers per skin, and so forth.

The deck, as mentioned previously, is subjected to compressive load. Compression forces in the deck can be derived by adding the compression induced by the hull girder bending (see Figure 5) to the horizontal component of the rigging loads. Stability of the deck sandwich panel under such load must be considered and investigated.

Sandwich panels when subjected to compressive load can fail due to:

1. Local stress concentration;
2. Euler panel buckling;
3. Shear crimping buckling;
4. Skin wrinkling;
5. Skin dimpling.

The dominating failure modes for deck sandwich panels subjected to compressive load are Euler buckling and shear crimping. Shear crimping is a form of sandwich panel buckling in which the wave length of buckle is very short and is dominated by core shear modulus. Skin wrinkling, that occurs when one or both skins buckle as a plate on elastic foundation, can also happen under pure compressive load but it tends to occur after Euler buckling and shear crimping. Skin dimpling can occur with honeycomb and corrugated core. It is directly related to cell size and skin thickness. Commonly used Nomex and skin thickness tend not to make this mode normally a concern.

Figure 12 provides typical deck Euler and shear crimping buckling safety factors (SFs), as a function of boat length. This figure has been derived based on a typical case study. It provides an example of how the design solutions will be driven by the change in failure mechanism as the boat length increases. It is important to emphasise that there are many variables, and where exactly this transition from one design to another will occur for a specific design can vary from the presented example as this depend on boat structural general arrangement and material/process selection.

Figure 12 has been derived based on the assumption that the sandwich deck is made using carbon epoxy pre-preg skin and 25mm P500 core commonly used on composite cruiser boats between 20m to 40m.

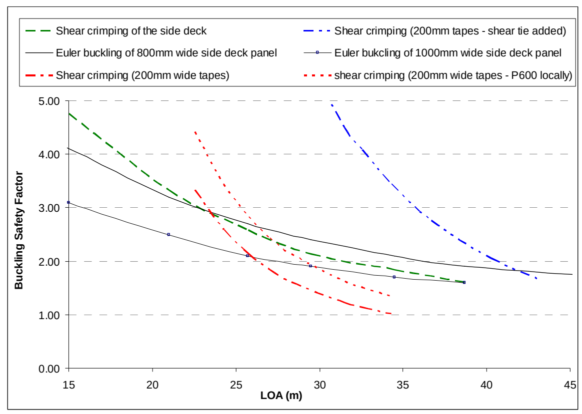

Figure 12: Buckling SF versus length

Euler buckling and shear crimping of the side deck have been calculated based on the assumption that the required stiffening tapes were added over the full width of the side deck. Euler buckling is the dominant buckling mode for the smaller boat range. For those boats, the larger the unsupported side deck panel the lower the Euler buckling safety factor will be. If a SF of around 2.5 on buckling is agreed as acceptable for our case study, then Figure 12 clearly illustrates, that for boats over around 22m to 25m with large unsupported side deck panel, adding tapes along the full width of the side deck sandwich structure is not a viable solution anymore. One possible solution relies on adding additional supporting structure (i.e., several stiff deck beams) and reducing the unsupported panel width. This option is often considered not only to lead to a heavy weight penalty but may clash with the interior requirements. One alternative is to concentrate the tapes (as a “UD plank”) on both skins along the edge of a panel support. This solution will be effective only for a limited range of boat lengths due to shear crimping likely to occur in way of the strip of tapes. Shear crimping stability can be improved by adding a higher density core locally in way of the tapes or by adding shear tie as illustrated in Figure 12. However none of these solutions can be considered as feasible above around 36m to 40m. For larger boats, additional support is required to prevent buckling.

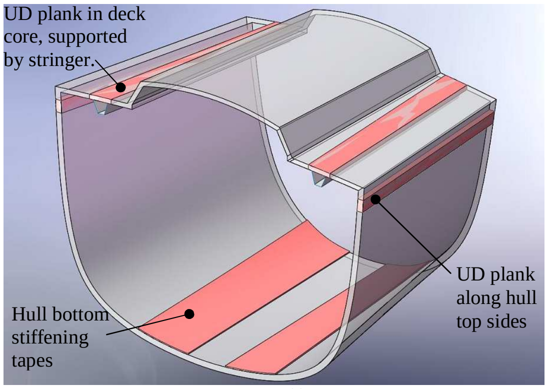

Figure 13: Hull girder stiffening tapes showing UD planks along the deck

Adding a longitudinal stiff deck beam in way of a strip of tapes or UD plank, as illustrated in Figure 13, can help preventing the panels and tapes from buckling, but this in itself may become prone to buckling and should be carefully designed. The hull to deck joint on the other hand provides intrinsic stability which helps prevent any tapes added next to it from buckling. However, the outboard edge of the deck may have stanchions, chainplates or other fittings that interfere. Consequently the tapes may be moved to the slightly less efficient position on the hull top sides.

This case study clearly demonstrates that as the length of the boat increases, alternative solutions to adding continuous tapes along the full width of the side deck or next to the edges of side deck panels must be considered. Ensuring the stability of the side deck panel and achieving the required deck stiffness value, i.e., EA value, for super yacht is a challenging design process. Finite element analysis is a valuable tool that can help optimising the deck structural design [7].

Figure 14 illustrates, based on existing composite boats, the evolution of the deck section EA values at the mast as a function of boat length. As explained before, deck design must evolve as the boat length increases. Clarification of how and when the changes in deck design concept are likely to occur as the boat length increases are outlined in Figure 14.

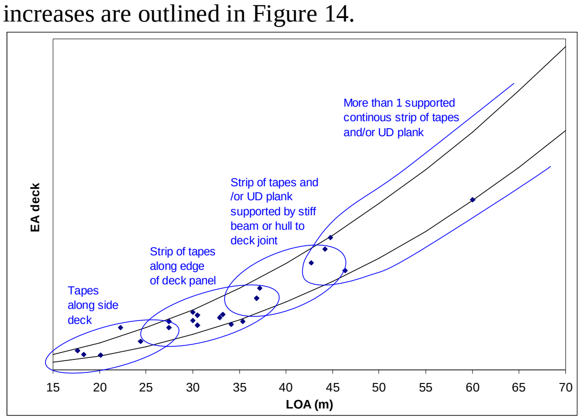

Figure 14: Stiffening tapes design versus boat length

So for a super yacht, it appears apparent that the main challenge for the structural engineer relies in adding one or more continuous strips of tapes or plank of carbon UD along the length of the boat side decks and hull topsides. These planks must be adjacent to adequate structural support to prevent buckling. The requirement for these tapes to be continuous also implies that they should remain away from any hatch cut outs or fittings. No matter where the engineer tries to put these UD planks there will be a conflict and so a compromise has to be found. The bigger the boat is, the bigger the influence on the overall design.

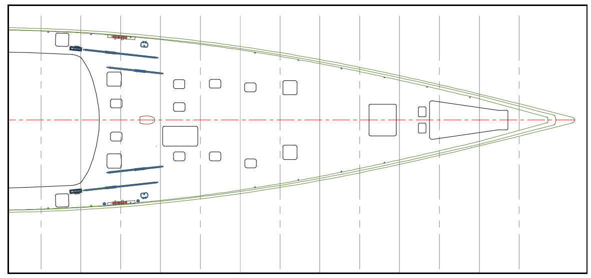
Figure 15: Typical super yacht foredeck general arrangement

Figure 15 is an example of the foredeck of a sailing super yacht showing the large number of deck cut outs, which is guided by the interior design. These cut outs add stress concentrations and clearly reduce the width of the effective side deck, in some instances to a narrow strip of material. This highlights the requirement for all parties in the design team to discuss at an early stage the design solutions and determine acceptable compromises that will lead to the best optimised design from both a structural and aesthetic/comfort point of view.

4. OTHER DESIGN CONSIDERATIONS

Increasing boat size and so the loading will have an impact not only on the main global loading but also on all structural design aspects of the boat such as shell design, mast and rigging supporting structures, keel design and processing. The aim of this section is not to discuss in detailed all the other design considerations but highlight some key challenges.

4.1. KEEL DESIGN

To make a big boat fast, you need a deep keel, but if your draught is too deep, then you can't get in to the harbour. Hence the prevalence of lifting keels on boats above about 35m LOA.

The classification society rules for grounding are based on displacement, to the point that it becomes harder and harder to design a composite keel structure. This will be tempered with the design philosophy of the keel structure and the “what if” scenario being considered. Opinions differ on the acceptable consequences of a severe grounding. Generally we would consider that the boat should be able to be driven onto a soft sandbank perhaps once a season without any concerns for the structure. In the event of a severe grounding, i.e. a “crash”, damage might be acceptable so long as watertight integrity is not lost.

It is not the overall loads that are the greatest challenge on bigger boats, but designing a mechanical system that can effectively dissipate load into enough composite. The Panamax Ketch for example has an ultimate design load of some 3000 Tonnes applied to the hull intersect, as a local point load.

All the considerations for detail design of keel structures for composite boats could become a topic for a paper in its own right.

4.2. PROCESSING

As mentioned in section 2, the highest weight saving is obtained by using high quality laminate. Yards often have a preferred manufacturing process such as infusion, wet-preg, wet laminate vacuum consolidated or pre-preg. Infusion on large yachts is feasible but requires skill and knowledge to ensure the process is adequately set up and to prevent dry spots. It is a risky process which can lead to complete loss of structural part if it is badly set up. Processes other than infusion require long open time systems to laminate large areas such as super yacht hull. Typical extra-slow hardeners give a full working day before each cure. The longest available open time comes from pre-preg, which gives weeks rather than hours of lamination time between cures.

The curing process of the laminate is another challenge in itself. Large structure means requirement for a large oven, even if only for an overnight 60°C post-cure of a wet-laminated system. The curing process must also be controlled in order to reduce exotherm or thermal distortion especially in way of thick laminate. Pre-preg lamination requires a more sophisticated oven typically up to 85ºC with control of the temperature and air flow around all parts of the component.

Problems with exotherm can be avoided with suitable cure schedule using dwell temperature to burn off some of the resin energy. Several cure stages may be needed for thicker laminate. FE analysis, test panels and trials are methods that can be used to verify the process/laminate. The required minimum cure temperature is defined by the resin system used. Recent material developments have led to lower temperature pre-pregs which can reduce the cost of tooling, oven and heat input.

As boat length increases, so does the overall core thickness of the sandwich laminate. The limited number of core thicknesses available on the market and the difficulty of forming thick sheets of foam to the required hull curvature can be overcome by using two or more sheets of foam core. Nomex honeycomb requires care to be taken in the process to prevent blow off of the skins. This is caused by the expansion of the entrapped air and moisture held in the hygroscopic Nomex paper and phenolic binding resin.

Trial samples and tests on manufacturing process are required to validate, optimise and improve processes for large scale structure. Non destructive testing is also often used on the finished product to control and validate the quality of the laminate.

Recent advances in materials mean also that fire retardant materials, with a similar level of protection to that given for aircraft interiors are now available for use in marine structural applications and interiors.

5. STRUCTURE VERSUS AESTHETIC AND COMFORT REQUIREMENT

As illustrated in the previous section, adding UD planks along super yacht decks is a necessity which has to be integrated with the whole design. Accommodating both structural and interior requirements is, as discussed in more details in this section an important part of super yacht design.

A composite super yacht, being generally lighter displacement, tends to have a smaller canoe body. If the interior volume is the same, then there is less space between the hull shell and interior to contain the systems and the structure. Planning of the use of this space requires greater effort than for an aluminium construction. Aluminium frames and floors tend to have lightening holes cut, which is a pre-made path for systems. However, “lightening holes” tends to be a contradiction in terms for composite engineers.

Our experience is that the hull and deck shell support can be easier to design for a 45m boat than a 30m boat, simply because the interior headroom requirement is the same, yet the hull depth has increased. As size increases much beyond this, there is a tendency to use the available volume for other interior space, such as storage or to fit another deck level, at which point the problem becomes acute again.

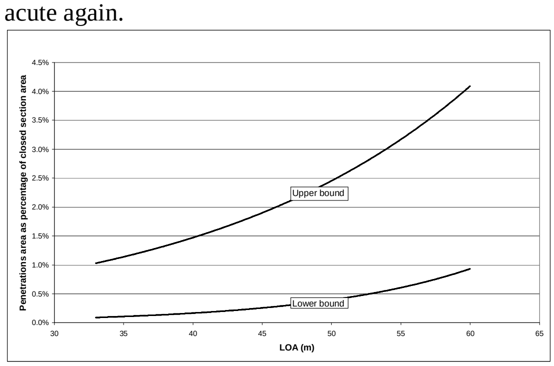

Figure 16: Penetration area versus LOA

Figure 16 shows the trend of the amount of space taken up by systems penetrations through the primary structure for a number of real boat examples. As would be expected, the scatter is massive, but the general trend is clear that as the boat size increases, greater attention is required for this.

Cut outs added within structural components such as structural bulkheads will create an area of local stress concentration. Ensuring from a structural point of view that systems penetrations are added in non critical area is essential. The idea that all penetrations are designed and agreed before construction, may be somewhat Utopian, but has to be a target for an efficient and lightweight overall design.

To make the best overall design in the required time scale, all parties in the design team need to work together effectively. Nevertheless, this can be quite a challenge as requirements are naturally contradictory and the interior, structure and systems fight for the available space. The increased use of modern 3D CAD software does facilitate this task. Sometimes this work is not helped by contractual arrangements (e.g. the systems designer working for the yard and the interior designer working directly for the owner). Since the systems and structures are required to be hidden behind the luxury interior it can be these two disciplines fighting for space against the interior designer. Fundamentally the interior designer and structural engineer see differently. Whereas the structural designer sees walls (i.e. the structure), the interior designer does not see the walls but only the space in between.

Composite engineers and interior designers need to get along in a project, but someone has to referee. On a smaller boat this is the Naval Architect, but big projects need strong and knowledgeable project managers.

This requirement is even more important when looking at composite super yachts. Not only must the manager control the decision making process but also ensure that any design philosophies such as a weight saving optimisation process is made a team exercise. As mentioned by R. Payne and N. Siohan [8], the key for a winning design is to establish a "philosophy" at an early stage in the project and to provide a good project management as well as a good team work between designers, structural engineers, classification society and builders.

6. CONCLUSION

There has been a general trend for boat size to increase and for composite construction to be used with increasing confidence.

Composite offers the industry the possibility to build attractive high performance super yachts. This paper has demonstrated, using examples based on sailing super yachts, how composite material with careful design and controlled processes can contribute in weight saving. Structural weight saving for both motor and sailing super yacht can lead to improved performance. As boat size increases so does the complexity of the design, and solutions do not necessarily scale up. Not only detailed design and controlled processing but also project management, team work and clearly defined project philosophy will contribute in overcoming the challenges associated with super yacht design and build and will lead to the success of such high profile projects.

7. REFERENCES

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8. AUTHORS BIOGRAPHY

Marion Meunier holds the current position of project design engineer at Gurit. She is responsible for managing and carrying composite structural design. She was awarded in 2001 a PhD on dynamic responses of composite structure carried out at the University of Southampton. She has been working for 7 years as a composite structural engineer. Within SP/Gurit, her previous experience includes design of 20m to 60m cruiser/racer sailing yachts, high performance motor boats and composite superstructure for motor super yachts.

Rod Fogg has been working at SP/Gurit for 20 years and holds the current position of principal engineer. He has a background in high performance designs such as America's Cup, Volvo Ocean Race and Open 60s. He has also been responsible for the composite structural engineering of a number of composite sailing super yacht “milestone” projects, including “Wallygator 2”, “Mari-Cha3” and “Visione”.