

MATERIALS AND STRUCTURES
FOR HIGH SPEED MOTOR YACHTS

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**The International HISWA Symposium
on Yacht Design and Yacht Construction**

INTRODUCTION

All those who are involved in high speed motor yachts are fully aware that weight reflects on performance. There is therefore a driving design parameter - minimum weight. This presents the structural engineer with the difficult task of balancing this requirement against two other important parameters of through life structural integrity and build costs.

Regardless of whether minimum weight is sought for performance gain, weight should never be wasted and all structures should be properly engineered. One of the great British engineers of the nineteenth century was undoubtedly Isambard Kingdom Brunel. During the development of the Great Western, Brunel wrote in 1854, "No materials shall be employed on any part except at the place and in the direction and in the proportion in which it is required and can be usefully applied for the strength of the ship.....". He obviously recognised the need for structural efficiency and perhaps the economic gain in not having any part of the structure over engineered.

In the last half of the twentieth century, the development of the high speed vessels has moved ahead considerably with the introduction of the planing hull and dynamically supported vessels - hovercraft, surface effect ships, hydrofoils etc.

This development has created the need to re-think structures, which together with the introduction of new materials, has led to a quiet revolution in how vessels are engineered and structured.

Progress however, has not been across all fronts of the marine industry - an industry which has always been traditional and perhaps for the small vessel industry, has lacked in the investment in design and the application of engineering principles. Again quoting Brunel, who in 1855 wrote, "We should get on much quicker if we had no

previous habits or prejudices on the subject".

The development of high speed ferries and military vessels has encouraged fresh thinking in how materials are used and how structures can be efficiently engineered. Many lessons have been learnt and this knowledge provides a sound base for the ongoing development of all types of high speed vessels, including motor yachts.

STRUCTURAL DESIGN METHODOLOGY

The modern motor yacht is a complex piece of engineering, packaged in a way which pleases the owner. The packaging is perhaps more important than the engineering as it is the first point of contact with the eye. The vessel must look good, but of course, it must perform.

Tradition has it that a yacht is designed by a Naval Architect, who has been trained to cover all aspects of design. The fact is however, a modern yacht is far too complex for any one professional person to undertake all the required activities and the Naval Architect has both a professional input with respect to hydrodynamics and lay-out, and a more important role as a Chief Designer and Project Manager. In this capacity, he will control all the professional activities, including possibly aerodynamics. A good design will be one which has been able to integrate all the skills, such that an acceptable compromise has been made to provide an optimum design.

With regards to the structure, it has become an accepted practice to use Classification Rules to provide the scantlings. Such Rules have become so widely used that, until recently, it was rare to find a fast motor yacht designed by first principles. Generally, the Rules approach provides an acceptable overall structure and there are Rules to be found for most types of materials - steel, aluminium alloy and fibre reinforced polymers. However, there are shortcomings in this Rule approach.

- (a) Rules are based on experience. This is a practical approach, but experience takes time to accumulate and therefore Rules will always be some distance behind modern technology.
- (b) Rules are empirical. This inevitably leads to conservatism and therefore optimised structures with respect to weight cannot be achieved.
- (c) Rules do not cover detail. As all designers, builders and owners know, trouble generally starts with poor detail.

Add to these factors that scantlings will vary between different Classification Rules and that all Classification Societies appear not to accept direct liability for use of their Rules, it is clear that if optimum performance is to be achieved, the structural design must be done by first principles and it must be done by those adequately trained in structural engineering and materials.

All Classification Societies will assess a design on a first principles approach, that is one which obtains the scantlings by direct calculation using either the loads stated in Classification Rules or those derived from accepted data. The larger and the more performance sensitive the vessel, then the more important it is to undertake the structural design by such a first principle approach.

As equally as important is the need to undertake the structural design in close collaboration with the vessel's designer responsible for the styling and lay-out. This avoids the traditional approach of the structural engineer, if appointed, of being asked to fill in the space left by the Naval Architect and the stylist.

Integrated design will avoid duplication of structure, ensure that adequate load paths are provided, assist in the correct selection of materials and above all, integration will lead to lighter weight.

In fact it is this integration of the structure with the other engineering and architectural requirements which is the foundation of the structural design methodology and when coupled with a first principle design approach, it is the route to optimum efficiency.

STRUCTURAL DESIGN

Load determination

For vessels less than 35 metres in length, the structure will be dominated by local loadings, particularly wave induced slamming.

There is insufficient data on slamming pressures and this is an area where more research is required. Early work by Allen and Jones ⁽¹⁾ together with Savitsky and Brown⁽²⁾ forms the basis of current empirical formulae used in Classification Rules, but there appears to be difference of opinion as to how such data is used. Shenoj and Harari ⁽³⁾ have compared the slam pressures for different vessel weights from different Classification Societies' Rules showing considerable variations in values. Hayman ⁽⁴⁾ has undertaken research into slam pressures of falling bodies using V-shaped hull models made in FRP sandwich and welded aluminium alloy, giving results which show that the shear force in a sandwich core can be underestimated using a uniform pressure approach.

Clearly, more work is required in this area and no doubt, further researches will address this lack of data.

Design work undertaken by the Author on fast vessels over the last twenty five years, indicates that slam pressures are perhaps over estimated, as so very few failures have occurred. One fact is clear, the pressure time is extremely short, which together with the trapped air between the hull and the impacting face providing a cushion, results in less load being felt by the structure.

Small fast vessels are therefore designed to satisfy localised loads, inertias, personel loads and environmental forces of green sea and wind.

Larger vessels need to take into account the overall effects of bending and torsion, coupled with localised loadings. The provision of adequate load paths, a point not always appreciated by many designers, being the key factor in permitting overall or global forces to be adequately reacted.

The difficult area in load determination for fast vessels is that of hard object impact. The sea contains significant amounts of debris and impacting even a small floating object at 50 knots, can cause extensive damage. Hayman ⁽⁴⁾ has been addressing this problem, looking at the behaviour of steel and aluminium alloy vessels impacting a 20 foot container, a 1 tonne pallet and a timber log. Accelerations up to 20 g have been estimated for small vessels impacting at 50 knots, reducing to about 6 g for larger vessels. The work has extended to FRP sandwich structure which has led to data for estimating accelerations at impact.

There is a need to review the design loads for fast vessels, particularly as it is now recognised that a first principle or direct calculation approach is the only efficient method for such vessels. It is anticipated that Classification Societies will be producing a set of requirements and guidelines for the use of both direct calculation and model tests.

However, using the data available today, albeit limited, provides a sufficiently accurate analysis and it can always be argued that it is better to have done calculations on limited data than not to have done any calculations at all.

Analysis

There is no doubt of the power of Finite Element Analysis (FEM) and with modern computing technology, together with user friendly software, this approach is becoming more widespread. It is also greatly abused. Too often vast models of vessels are created into which are put loading data so basic or inaccurate, that it only emphasises the classic remark "rubbish in, rubbish out".

FEM has its place and is useful in establishing load paths, bending moments and forces in simple models for larger vessels and for investigating stress and displacement levels for localised structure.

There is however, no substitute for good basic analysis using conventional structural theory and a good structural engineer will be able to create a structure sufficiently accurate to meet the anticipated loads without going near a computer.

Of particular value though is the progress being made in recent years in the development of computer programs to calculate motions and loads for fast vessels. Linear and non-linear programs are under development and this should considerably augment the analysis tools for fast vessels, leading to integrated analysis packages.

Structural format

The point has already been made about integrated design and the need for a structural engineering input at the conceptual stage of design. Retrospective engineering design and the "filling in the space" approach is a recipe for disaster.

Structural formats have to be worked out in conjunction with the other disciplines to ensure an efficient use of space and materials. Fast motor yachts are dominated by the aesthetics and clearly this will lead to compromises in structural format.

A good example is the main saloon area of a large modern fast motor yacht.

Space is the aesthetic requirement, but space will lead to an increase in structure due to greater free spans. Discreet use of supports, worked out in conjunction with the interior designers, will lead to an efficient use of structure and will avoid the potential problems caused by inadvertently putting in an interior partition which ends up carrying the load, resulting in cracked finishes.

But possibly the most important aspect of the structural format is the provision of adequate load paths and avoiding discontinuities in the structure. The larger the vessel, the more important this becomes as global forces tend to dominate.

MATERIALS

The choice of building material is often influenced by a number of factors which have nothing to do with engineering. Tradition is perhaps the most common factor and if an owner wants a steel yacht, then that is his prerogative. But structural weight is the criteria when designing high speed vessels and the choice of material, or materials as there will be many different types used in one vessel, should be made on an engineering and cost basis.

The cost factor is critical as despite the potential through life cost savings of having a lighter vessel, it is difficult to justify to many owners the possible higher capital cost due, perhaps, to more expensive materials.

Large motor yachts are usually individual builds and therefore very much a "one-off" contract. Tooling costs, incurred by using current production techniques of FRP, cannot therefore be generally tolerated. As a result, aluminium alloy has become the predominant building material for such vessels, with steel used for slower vessels.

Production vessels can amortise tooling costs, therefore FRP dominates the smaller yacht market. FRP will produce the lightest structure when properly engineered

and with its good environmental performance, provides a vessel structure with excellent through life performance qualities.

There is though, growing concern about the fire performance characteristics of FRP, particularly with the levels of smoke omitted by polyester and epoxy resin systems. Passenger carrying high speed ferries is an area where this concern is naturally at its highest. The International Maritime Organisation (IMO) has addressed this problem of "fire restrictive materials" in the Draft Code of Safety for High Speed Craft by introducing tests on materials to determine the levels of heat, smoke and toxic gases in a given fire scenario. The tests are severe and in general will rule out most unprotected polyester and epoxy resin systems, leaving only the phenolic resin systems capable of meeting the requirements.

It is probable that over the coming years, legislation will reach the motor yachts leading to restrictive use of some current FRP materials.

It should also perhaps be noted that aluminium alloy will become structurally unstable at 200°C plus and should therefore be adequately insulated in fire hazard areas.

Aluminium alloy is an acceptable choice for primary structure but has the disadvantage of reduced permissible stress in the welded zone. This has led to the development of purpose designed extruded shapes to reduce the amount of welding and to strategically place the weld zone such that it is in the area of least stress. High speed ferries use extensive amounts of such extrusions, which also leads to a weight reduction over a conventionally fabricated aluminium alloy structure.

Of increasing interest is the use of bonding aluminium alloy, which when combined with a limited use of mechanical fasteners, gives the designer the ability to work the material to its full strength.

Underwater plasma cutting of aluminium alloy has decreased the problems of distortion of plates and sections leading to reduced costs of finishing and painting.

High strength steels, as used in offshore structures, will perhaps receive more attention as commercial freight vessels increase in speed. Steel has the particular advantage of being capable of withstanding most fire requirements, it gives an extremely robust structure and has a high stiffness. This latter property of stiffness is important because large fast vessels built down to minimum weight will be governed by overall structural stability.

There is therefore a good candidate list of materials for primary structure whose properties, advantages and disadvantages are reported elsewhere ⁽⁵⁾, but no doubt a choice of build material will continue to be influenced by non-engineering factors. If weight is taken seriously though, development will in time perhaps lead to :

- (a) use of higher strength steels
- (b) more bonded and mechanically fastened aluminium alloy structures
- (c) "No tool" production techniques for FRP structures using fire compatible resin systems.

With respect to secondary structures there has been a minor revolution in materials for fast motor yachts where "synthetic" materials have at long last been accepted by designers and owners as a means for serious weight reduction. Simulated marble or indeed, marble "veneers" are good examples. But possibly of more importance, has been the use of sandwich construction to replace the extensive use of plywood for bulkheads, furniture and fittings. Several companies now supply the industry with lightweight boards finished in everything from wood veneers to plastics, and of course, marble. Weight savings of about 75% are claimed for many of these applications.

High speed ferries are beginning to venture into the use of high performance FRP materials for machinery components, particularly drive shafts. Significant weight savings can be achieved as a result of lighter materials and reduced bearings, due to greatly improved whirling characteristics. There is no doubt that future development will include high performance "composites" being supplied to other machinery areas - waterjets, gearboxes and even possibly engines.

Materials with respect to cost

This is an area which perhaps does not receive the attention that is necessary to quantify overall costs, possibly hindered by the selection of the build materials based on "non-engineering" judgement.

Cost is always in the structural engineer's remit, and in high speed ferry design, it is a driving design parameter and it is becoming more of a driving parameter in motor yacht design.

It is perhaps though unfortunate that capital cost and through life cost cannot always be considered simultaneously. A lighter structure and therefore a lighter vessel will use less fuel or have a greater range for similar fuel quantities or have a higher performance. Weight therefore will influence through life cost in one way or another.

The environmental performance of a material will also influence through life cost - FRP being an excellent example where reduced or even zero painting costs arise. Motor yacht design needs to address the cost aspects carefully and fast motor yachts can benefit considerably by a careful choice of structure and materials with respect to through life costs.

CONCLUDING REMARKS

The importance of minimum weight for high speed vessels is now recognised and

this paper has attempted to provide a basic philosophy in which minimum weight can be effectively achieved - a philosophy which is not necessarily limited to high speed motor yachts.

Future progress can only be made with an even closer collaboration between all professional disciplines, legislative authorities and Classification Societies, all of which will contribute to the further research that is necessary to ensure the safe operation of vessels.

Hopefully, innovation will be allowed to flourish and designers will be encouraged to explore new grounds free of prescriptive rules in an environment which permits design to progress against accepted procedures.

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