Project Gemini - Design Development and Engineering of The World's Largest Sailing Catamaran

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SUMMARY

The 45m project Gemini, currently under construction in the USA, will be the world's largest sailing catamaran when launched. Catamaran yachts of this size are uncommon with monohulls dominating the market. The structural design and engineering of this large aluminium catamaran has pushed the boundaries of current classification society rules. The designers have worked closely with the vessel's classification society during the development of a new set of rules for the structural design of vessels of this type and size. An overview of the project background and decisions that led to a catamaran being selected are discussed together with a technical comparison of the proposed design with an existing monohull of comparable length. The naval architecture of this large catamaran is also discussed together with the structural analysis, design and production engineering challenges.

1. INTRODUCTION & BACKGROUND

Project Gemini began in 2000 when the vessel's owner decided to enter the yacht market. Having considered a motor yacht the owner initially chartered a range of vessel types and sizes between 2001 and 2003. After experiencing a cruising catamaran in the BVI during 2001 he instructed his Captain to investigate the market for pre-owned, larger vessel's. Despite an extensive search of the market no suitable vessel was located. At this point the owner re-considered his time-frame and set about creating a custom build – Project Gemini was born.

Early in 2004 the search for a suitable designer began and initial plans for a 100ft, all carbon design were drawn up. After initial project meetings onboard a 130ft catamaran under construction Gemini grew by another 15ft. In the summer of 2004 Van Peteghem - Lauriot Prévost (VPLP) were selected as the project's naval architects and design work began in earnest. Following further general arrangement development the vessel grew further to 145ft.

BMT Nigel Gee Ltd were initially contracted to undertake full structural design and analysis by direct calculation. Following signing of a build contract with Derecktor Shipyards in the USA, BMT Nigel Gee Ltd undertook further proof of concept engineering studies for items of complex outfit, weight engineering and full detailed design of structure, outfit and pipework for CNC production.

Figure 1: Project Gemini Rendering

2. LARGE SAILING CATAMARANS – HISTORICAL PERSPECTIVE

Historically sailing catamarans have been with us for thousands of years originating in Polynesia, the Pacific and Africa. The word catamaran originates from the Tamil word 'kattu' meaning "to tie" and 'maram' meaning "wood'. Tying two tree trunks together to make a floating platform that would serve as a home, carry livestock & family, etc., has been with us for a long time.

In recent history the development of the modern sailing (cruising) catamaran has seen steady growth. Whilst less popular than monohulls the cruising catamaran has become a keen favourite of the booming charter market where less experienced sailors can enjoy the benefits offered by catamarans; extra space, stability and comfort aboard. Brands like Lagoon, Moorings and other's have been quick to capitalise on this and have developed a range of smaller production cruising catamarans to meet the market needs. These typically tend to be up to 20m in length. The owner of Gemini was introduced to catamarans via a Lagoon 570 which he chartered with his family for diving holidays.

Development of larger custom designs for cruising has seen fewer new builds. Previous to the development of Gemini VPLP have designed the world's largest cruising catamaran, the 42m 'Douce France' (see figure 2-1) launched in 1998. The development of this design stemmed from design development of cruising catamarans mainly in the 23 – 30m segment and racing multihulls. However prior to the design and build of Douce France the custom cruising catamaran market was very limited for boats much beyond 25m. The launching of Douce France was a significant step.

Figure 2-1: Douce France

3. CATAMARAN VS MONOHULL

A number of leading production boat builders offer catamarans up to around 18m. Custom cruising designs above this size are less common and above 30m only a handful of examples exist.

In order to explore the headline benefits (and drawbacks) of the catamaran type an outline technical comparison is presented between Gemini and an existing (built) 45m monohull. Figure 3-1 presents an illustrative profile of the two vessels and Table 3-1 a comparison of the principal particulars.

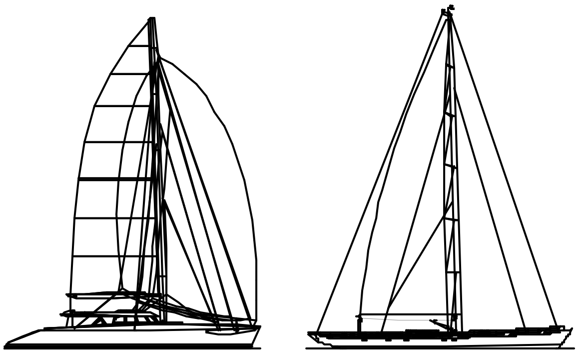

Figure 3-1: Catamaran & Monohull Profiles

It should be noted that the two vessels have not been developed from the same set of requirements and are only used for illustrative purposes on the basis that they are of comparable length and both of the same genre.

Parameter	Catamaran GEMINI	Monohull NG380
Overall Length [m]	44.2	45.5
Waterline Length [m]	41.3	36.8
Max Beam [m]	16.6	8.9
Draught [m]	3.0	5.0
Sail Area 100% FT [sq.m]	878.0	990.0
Displacement [tonnes]	250.0	193.0
Wetted Surface Area	369.2	265.1
$L/\nabla^{1/3}$*	8.3	6.4
$SA/\eth^{2/3}$	22.1	29.6
SA/WSA	2.4	3.7
Useable Deck Areas		
Exterior [sq.m]	229.9	227.8
Interior [sq.m]	203.6	79.6

* Catamaran is based on demihull displacement

Table 3-1: Catamaran Vs Monohull

As is characteristic of the form the length displacement ratio of the catamaran is far superior to that of the monohull which will offer superior resistance characteristics at Froude numbers associated with off-wind sailing in higher wind speeds. Whilst the monohull carries some 52 tonnes of ballast (the catamaran carries none) the displacement of the catamaran is still some 30% heavier.

The wetted surface area of the catamaran is also some 40% higher than for the monohull. As a point of interest a close examination of the weight estimates for both vessels highlights that the structural weight for the catamaran was 85% higher than for the monohull.

The monohull carries 13% more sail area and has a significantly higher sail area displacement ratio. The catamaran also suffers from a significantly higher wetted area and consequently a lower sail area wetted area ratio.

A comparison of performance predictions are presented in Figure 3-2. Plots of predicted speeds for both 10 and 20 knots TWS are presented. Based on the parametric observations above it is unsurprising to observe that the predicted performance of the catamaran is lower than that of the monohull in the lower wind speeds and the reverse case is true in the higher wind speeds, mainly for reaching conditions.

From a practical perspective it is evident that the catamaran has significant advantages over the monohull. Table 3-1 illustrates that the useable interior floor area is some 250% higher for the catamaran leading to a significant increase in interior living space. The heel angles under sail will also be significantly lower for the catamaran which is favourable to some owners.

Whilst the useable external deck areas are shown as being comparable the deck area on the catamaran is far more flexible from an owner's perspective featuring wide beamed open areas concentrated around the yachts mid-body.

Additionally the catamaran has a significantly lower draught than that of the monohull which is a key consideration for accessing some cruising areas and ports. Whilst engineering a monohull of comparable draught is possible with either a lifting keel or shoal draught solution this is at the expense of increased complexity, either structurally or mechanically, or loss in performance.

Comparisons have also been made between the build prices of the catamaran and the monohull. The contract price for the catamaran was found to be approximately 35% more expensive than the monohull which is reflected by a near similar difference in displacement.

As would be expected the mohohull offers better windward performance and lower cost. However the catamaran provides higher off wind performance, higher interior volume and lower draught.

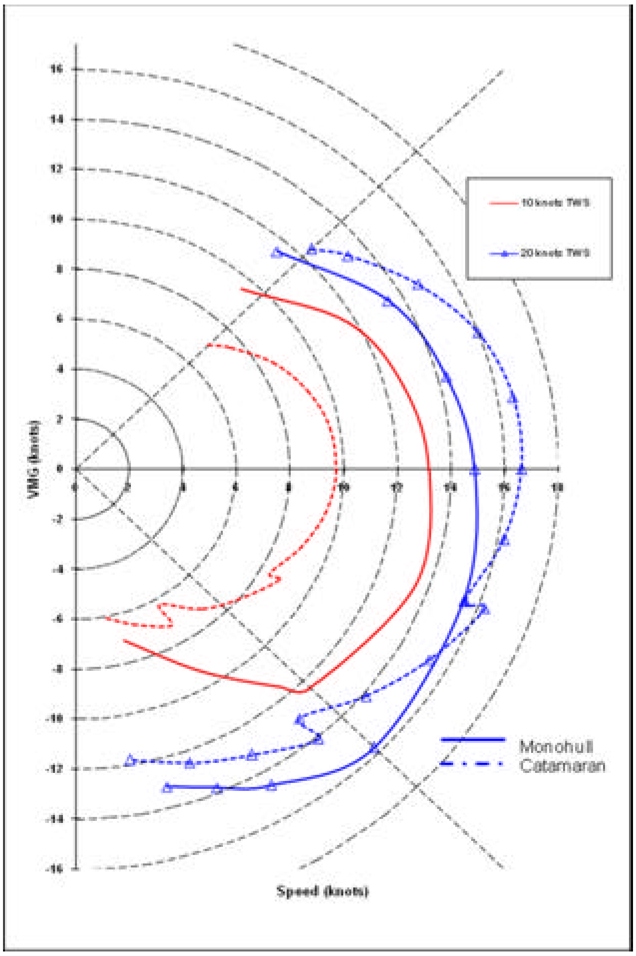

Figure 3-2: Catamaran & Monohull Polars

4. HULLFORM DEVELOPMENT

Because comfort was a priority aboard Gemini, the living areas and accommodation were the first features to be defined. The hull form was then designed around the interior and the volume requirements of the living area. The engine rooms were placed at midship for better weight distribution and this established the centre of gravity which was a crucial feature in guiding the hull form design.

A maximum draft of 3m was set by the client in order to assure entry into shallow waters and especially diving sites. A fixed fin keel was selected in preference to swinging dagger boards as the dagger boards would consume more interior space and also represented an added complication in terms of mechanics and risk in the event of grounding. The fin keel has the added benefit of lending itself easily as tankage and to dry dock the vessel.

The accommodation areas extend relatively far forward which meant that excessive volume was required in the forward sections of the hulls. The result is that Gemini has a rather deep keel line forward of the fin in order to keep a small angle of entry and ensure a modicum of performance.

In general the hull form, while paying attention to performance was mainly defined by the live-a-board nature of the yacht.

5. SAIL PLAN DEVELOPMENT

Much of VPLP's R&D in sail plan development has emerged out of work on aerodynamics in racing multihulls. Over the past 25 years from the first 50' foiler 'Gerard Lambert' built in 1983 to the most recent yachts like the 105' Groupama 3, VPLP have refined the technology together with experts like Mik Kermarec who devised specialist Velocity Prediction Programmes (VPP's) for these yachts. VPLP have used these VPP's extensively to derive the optimum sail plan for Gemini and whilst racing multihulls have different demands to cruising yachts like Gemini the final product is rooted in the same theory and technology.

The size of the sail area was constrained by the fact that the yacht has to be handled by a limited crew. Additionally larger sails would immediately increase the rig loads and make the sails less manageable. Furthermore a larger rig would impact on the structural weight and it was desired to keep the boat as light as possible so a compromise was set between sail area, performance and handling ability.

In general an overall ratio of sail area : displacement of 3 m^2/t was the goal for Gemini. Douce France had utilised a ratio of 3.9 m^2/t but was configured as a schooner so carried relatively more sail area. The final figure achieved for Gemini was 3.4 m^2/t. To put into perspective the relative performance differences between a racing and cruising multihull it should be considered that the ratio achieved on "Maxi Banque Populaire V", a 132ft (40m) trimaran currently under construction, is 32 m^2/t – almost 10 times as much power : weight.

Another parameter considered is the amount of heeling moment in relation to the maximum available righting moment. It should be appreciated that a cruising multi such as Gemini will heel very little (maybe up to 3° to 4°) whilst a racing multihull will 'fly' a hull. The racing multihull therefore is sailing much closer to the angle of maximum righting moment compared with the cruising design. Consequently the racing multihull requires constant attention to sail trim to avoid capsize in gusts whereas the cruising multihull will not.

Gemini has a maximum (100%) Righting Moment of 1500 tm and will sail with a maximum heeling moment equivalent to 49% of the max RM. Maxi Banque Populaire V has a righting moment of 260tm and when

flying a hull will sail with a maximum heeling moment equivalent to 100% of the maximum RM.
Gemini features a fully battened mainsail supporting a 10% roach together with twin furling foresails; a Solent jib of 125% LP and a staysail of 115% LP, a code zero style gennaker and asymmetrical spinnaker.

6. STRUCTURAL DESIGN

Minimum structural weight was a key design factor in order to maintain good sailing performance. Both aluminium and composite construction was considered during the early design phase. Lightweight aluminium construction was selected due to shipyard limitations imposed by the vessel's length and beam for advanced composite construction. To minimise the weight of the aluminium structure high strength Sealium alloy was selected. This 5383 alloy has higher strength properties than the more widely used 5083 series, combined with improved fatigue and corrosion resistance.

BMT were initially tasked with the production of the class level structural design. In the autumn of 2004 a survey of the major classification societies was undertaken covering ABS, DnV, BV and GL. The main considerations were that the class society of choice had a clear approach and experienced methodology from the outset, in order to avoid unpredicted analysis having to be undertaken at a later design stage. Additionally, given Gemini's unusual proportions, a good level of communication was paramount to progressing the project with quick turn around of all technical queries and plans by class.

It was concluded that all of the major class societies could accommodate the design of Gemini but that BV had the most experience with this yacht type having previously classed Douce France. This vessel was classed in 1999 and since that time had been subject to detailed inspection during annual surveys to examine the performance of the local and global structure in service. Additionally BV had just completed a long period of research and development in order to finalise a set of new rules for large yachts including specifically large catamarans (which subsequently became BV Yacht Rules). Further more BV had previously worked with VPLP during 2003 in the development of a number of load case scenarios appropriate for the design of large catamaran structures.

Local stress analysis was based on rule calculation for normal local load cases such as sea pressure, slamming as well as high impact loads for the forward section of the wetdeck.

Three global hull load scenarios were considered, combined in each case with the global forces induced by sailing rig loads .

1. Forward Wave - head sea load case.
2. Diagonal Wave – quartering sea load case inducing torsion into the cross deck structure and main transverse bulkheads.
3. Rushing Wave - this load case is also based on a forward, quartering sea condition, but considers the effect of a severe lateral wave impact onto the forward part of one hull.

The above global load cases were dominated by sailing rig loads with the torsional loads from load case 2 proving to be the most difficult to meet. Sailing rig loads for catamarans vary significantly from monohulls with the former having very low sailing heel angles and widely spaced shrouds, typically resulting in lower rig loads for catamaran designs. The rig loads were provided by leading sailing rig designers HDS and were 225t for mast compression (approximately equal to the yacht's displacement) and 70t for the maximum shroud load.

Finite element analysis (FEA) was used to analyse both stress and deflection from both global loads and the high localised loads at the mast base and rig attachments. Stress plots for the Rig Load & +ve Torsion under load case 2 are shown in Figure 6-1.

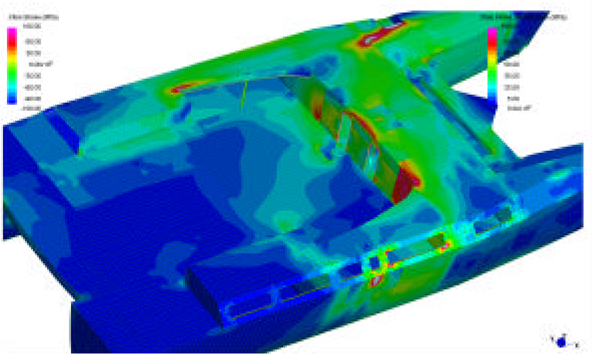

Figure 6-1: Stress plots for the Rig Load & +ve Torsion

The yachts interior arrangement features an owner's cabin in the forward end of the cross-deck to provide panoramic views. The large access door apertures through the mast bulkhead to access this area posed one of the most significant challenges for the structural design of the yacht. Figure 6-2 shows the FEA stress plot for this area under Rig Load & +ve Torsion, load case 2.

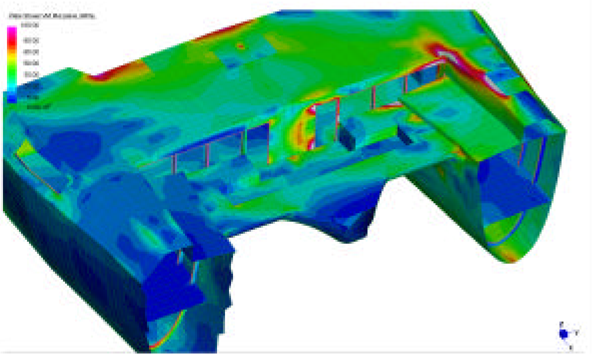

Figure 6-2: Main Mast Bulkhead Apertures

FEA was also used to minimise scantlings and weight of structure in way of other key areas of structure. These included.

- Aft stbd topside shell tender bay door.
- Mainsheet track loads in the aft section of the flybridge deck.
- Anchoring arrangement foundations.
- Chainplates & other rigging connections.
- Twin "bomb bay" style doors for launch of the large tender through the aft wet deck structure.

7. DESIGN CHALLENGES

A number of features developed for Gemini require specific mention;

Due to the inherent nature of the catamaran the large L/b ratio of each hull means that stowage space for equipment and water toys becomes limited and a greater level of ingenuity is require to achieve a workable solution. As such early detailed investigations were carried out to ensure that the design intent could be achieved in the hull form as originally proposed.

The equipment in question included the stern passerelle, swim platform, dive access door, limo tender and rescue boat stowage.

7.1 TRANSOM GARAGES

The transom area was set aside for stowage of some significant items of outfit. The efficient design of these areas from an efficient engineering production perspective presented some interesting challenges.

The port side garage housed a dive compartment and the lower section of the transom shell had to accommodate a dive access door, stern passerelle and swim platform. All the apertures had to be watertight and be installed to a yacht finish with smooth operation. Also included in this confined space was the port stern thruster and steering gear.

The stbd side garage housed the rescue boat, a 4.0m general purpose RHIB with a side shell launching door and launching cranes, as well as the stbd stern thruster and steering gear.

In the early stage of the design, BMT completed a preliminary 3D study of this area and equipment so that the hull lines and internal geometry could be fixed allowing design work in other areas of the vessel to be continued with confidence. From this study technical specifications for the equipment were developed to the level of accuracy required. Examples of the early arrangement models are shown in figures 7.1 and 7.2.

Due to the complexity and integration with the hull shape, the structural requirements, the equipment design and the effective water tight integrity issues, contracts were placed with Freeman Marine Equipment Inc to provide the water tight doors and hatches and with C-Quip International Ltd to provide the platform, passerelle and rescue boat cranes. Together BMT, Freeman and C-Quip went through many loops of a complex design spiral to ensure that the integration of all the various components would interface properly in this very congested area.

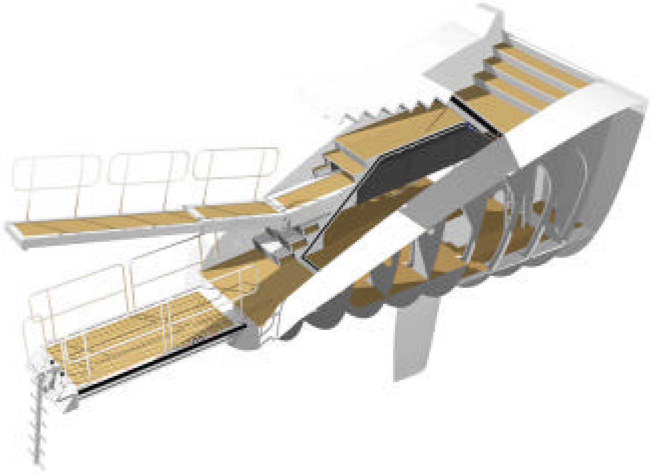

Figure 7.1: View showing Port side Swim Platform, Dive Access and Stern passerelle.

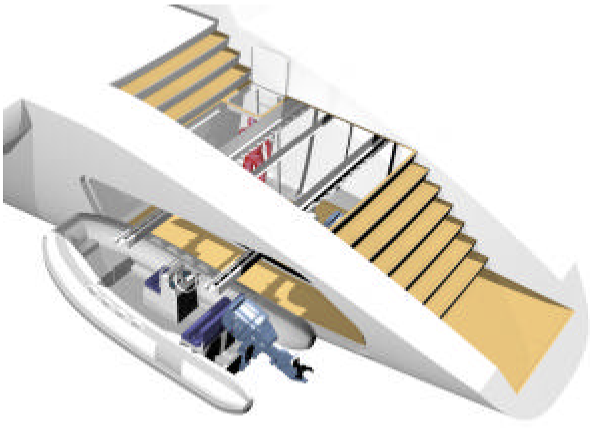

Figure 7.2: View showing stbd side crew tender launching & stowage

To maximise the size of the equipment the structure was designed around the equipment and in places, the housing of the equipment was re-designed by BMT so that the same piece of structure had a dual role that satisfied the operational requirements of the specific equipment, but also acted as a primary structural member of the hull structure. This enabled material duplication to be minimised saving important space, and weight.

The difficulty with this design philosophy relates to production; the equipment manufacturer wants to build the door to their standard design (as far as possible) whilst managing concerns over the actuation of a door that is a complex shape, and production issues associated with welding distortion that can occur when inputting heat close to the door gutter and seals. The solution was to have the equipment manufacturer build a portion of the vessel surrounding the doors – in this way the yard had a simple interface and the door manufacturer had close control over the amount of heat input from welding in the region of the door gutters and seals.

Consequently this structural unit was broken down further so that Freeman Marine could build a section incorporating the WT door and hatches. This sub-unit was carefully planned so that firstly it was not too large to be transported and secondly on arrival at the shipyard it would slot seamlessly into the lower sub-unit structure built by the shipyard.

BMT provided the same CNC code to both Freeman Marine and the shipyard, labelled according to which facility was to produce which unit. A similar arrangement was provided on the Stbd side regarding the crew tender side launching doors and launching cranes.

7.2 MAIN TENDER LAUNCHING SYSTEM

The vessels owner required a large RHIB tender for use on Gemini and their preference was to use an 11m Scorpion design. One of the key requirements from the early design brief was that this should be completely concealed. As the transom area had been taken by other equipment an alternative solution had to be found. After considering a number of concepts it was decided that the only feasible stowage location was in a garage housed within the main cross deck structure between the demi-hulls launched through bomb-bay style doors.

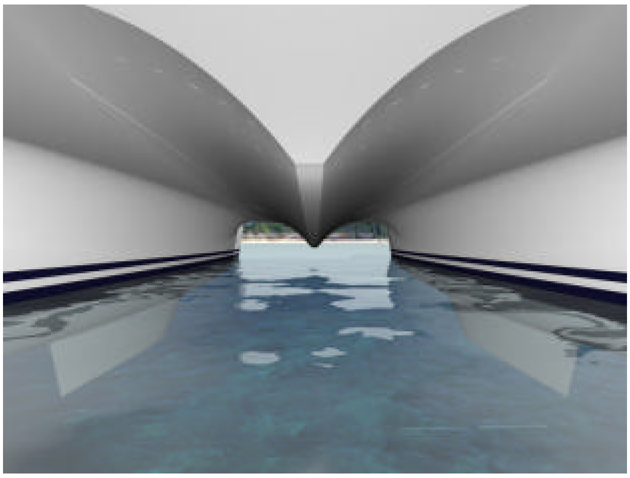

Figure 7.2.1 – Cross Deck Door Closed

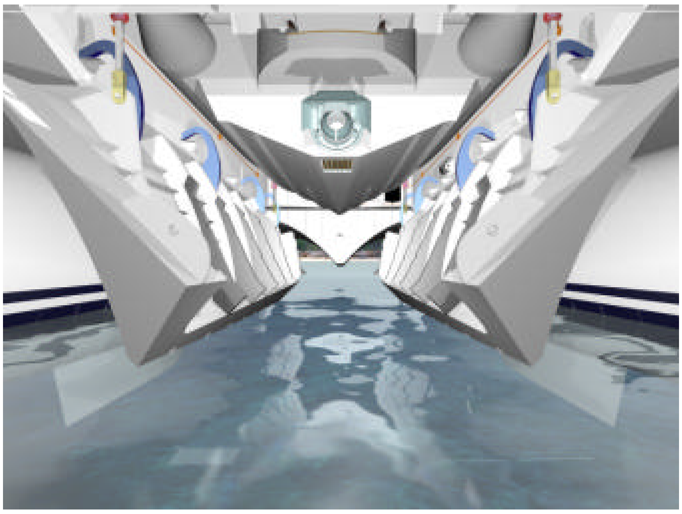

Figure 7.2.1 Cross Deck Door Open

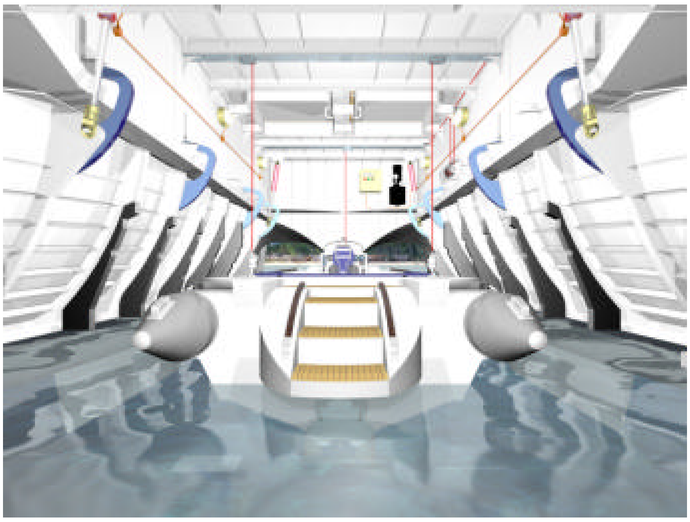

Figure 7.2.1, 7.2.2 and 7.2.33: Showing the stages of deployment of cross deck tender.

The above figures show the doors as developed through the early outfit concept design studys undertaken by BMT. Through close co-operation with Freeman Marine a rotary shaft hinge system has been incorporated to reduce the space requirements of the hinge and simplify the associated systems.

Once again due to the complexity of the structure, production issues and small fit-up tolerances Freeman marine undertook the production of the bomb-bay doors. Due to the complex geometry and the associated sealing problems BMT provided CNC code for additional sections of hull structure so that Freeman Marine could build the sections of the hull structure adjacent to the doors, pre-install their doors, restrain the unit to simulate the hull, then test / set-up the installation prior to shipping. This allowed the team to control the proximity of heat input to the door seals through welding during final installation and ensures the systems work prior to leaving their facility.

8. PRODUCTION ENGINEERING

BMT Nigel Gee Ltd were contracted by Derecktor Shipyards to undertake the detailed and production engineering design of project Gemini. This project totalled some 18000 hours of design and engineering to produce the final production design and CNC cutting files. BMT utilised ARL ShipConstructor software in the development of the structure and pipe work systems.

The yacht was broken down into 14 structural units, each unit break being carefully considered for production aspects. A careful balance needed to be established between the central units which required positioning in the yard building facility, the larger units being made available for pre-outfitting and impacts caused by the flow of information on long lead items between vendors, the shipyard and the production design team at BMT. Of these 14 units the transoms and the anchor units were broken down further due to the construction process discussed in section 7.

Part of BMT Nigel Gee's contract was to provide weight guarantees for the structural weight of the vessel as well as undertake weight monitoring on the vessel for information provided by others. Where possible on the completion of each structural unit, weighed weights were returned from the yard and compared with both the early engineering estimates which formed the basis of the guarantee, and the detailed 3d structural production model from which the CNC cut parts were developed. These figures have shown that currently the vessel is 6% below the contracted structural weight estimate.

9. CONCLUSIONS

The historical development of large sailing catamarans leading to the development of Gemini has been discussed.

A comparison between Gemini and a similarly sized mohohull has illustrated that the catamaran offers improvements in off wind performance, significantly increased interior volume and lower draught but at an estimated cost difference of approximately 35% for a vessel of this size.

The production design and engineering challenges have been discussed and it has been illustrated that maintaining the complete design and engineering within one small team, from early concept right through to detailed production engineering has ensured the success of the project, particularly in relation to meeting the vessels structural weight budgets.

The choice of hullform for this type of design is not based on exhaustive performance analysis comparisons. Practical considerations and personal preferences normally dictate the selected vessel type. It has been discussed that large custom cruising catamarans to date have not been constructed in large numbers and currently monohulls dominate the market. It is hoped that the successful delivery of Gemini will partly serve to re-address this balance and it is hoped that more vessels of this type will follow.

VPLP and BMT Nigel Gee are currently collaborating on even biger vessels, the 70m design 'Sadia' for example, as illustrated in figure 9-1. This yacht features yet further design challenges in terms of accommodating a seemingly endless list of special features, more commonly associated with higher volume motor yachts; a submarine in the stbd transom, diving room, accommodation for 22 crews and 12 guests, sauna & Turkish bath, gym, cinema, advanced AV system with a DJ & VJ booth, twin spas and multiple large tenders.

Figure 9-1: 70m 'Sadia'

10. AUTHORS' BIOGRAPHIES

Jago Lawless holds the position of Engineering Manager at BMT Nigel Gee Ltd. He is the production design project manager for project Gemini and a range of other vessels currently under construction to designs by BMT Nigel Gee Ltd.

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