Development of the Volvo Ocean 65
Britton Ward, Farr Yacht Design Ltd., Annapolis, MD, USA
Chris Cochran, Farr Yacht Design Ltd., Annapolis, MD, USA

ABSTRACT
For the 2014-15 Volvo Ocean Race, the organizing authority made a dramatic shift in direction for the next two editions of the race opting to move to a smaller, less expensive yacht built to exceptionally strict one design standards. This paper outlines some of the motivations for this shift and details some of the critical features of the new Volvo Ocean 65 design and how they compare to solutions on the previous Volvo Open 70 yachts. Discussion of the logistical complexities involved in building the fleet of boats in the required time is also discussed. A review of the structural design is included to illustrate the efforts to improve construction efficiency, reduce cost and dramatically improve robustness of the yacht structures while minimizing the weight additions that result. Finally we review some of the extensive quality control procedures and manufacturing technology that has been employed in an effort to achieve a fleet of one design yachts that are as identical as possible.

NOTATION
VO65 Volvo Ocean 65
VO70 Volvo Open 70
FYD Farr Yacht Design
VOR Volvo Ocean Race
ISO International Standards Organization Scantling Rule [12215-5]
GL Germanischer Lloyd Guidelines for the Structural Design of Racing Yachts ≥ 24 m
RANS Reynolds Averaged Navier-Stokes

INTRODUCTION
Although perhaps the most competitive Volvo Ocean Race in history, the 2012 event suffered from a lack of entries and a series of significant damage and breakage events that saw a number of boats fail to complete different legs. In response to this and the continued global economic challenges the Volvo Ocean Race management elected to
move to a smaller, less expensive yacht built to closely controlled one design standards. This design will be used for the next two editions of the race. By adopting a one design model, significant cost reductions are achieved for hardware costs. When combined with savings from reduced crew sizes and dramatically reduced maintenance, repair and spares costs it should be possible for a very competitive campaign to be realized for under €15 million.

BACKGROUND

In the lead up to the decision on the future of the race, the Volvo Ocean Race management team spent a considerable amount of time considering options for the future that would retain the race’s profile as the preeminent around the world yacht race while increasing the number of competitive teams entered. In order to achieve this goal, the cost of mounting a competitive campaign needed to be reduced substantially. Several broad preliminary concepts were considered including; modifications to the existing Volvo Open 70 rule or freezing the design, development of new class rules, as well as various one design options including multihull, fixed keel water ballasted boats or significantly smaller canting keel boats.

Ultimately, the cost of an entire Volvo Ocean Race campaign is influenced by many factors with the hardware only representing approximately one third of that total. Personnel costs for sailors and the support teams are a significant cost center and one that is not well addressed by the existing development rule framework. A one design solution has the potential to create savings in campaign cost can be realized on a number of different levels:

- Shift to a smaller boat with a somewhat lower level of construction technology to reduce build hours
- Adoption of a complete one design package including, hull, appendages, sails and spars with controls to prevent team specific “optimization” programs.
- Economies of scale in building a large number of identical boats and sourcing common hardware etc.
- Centralized maintenance and support facilities which significantly reduce personnel costs
- A shared pool of spares and replacement parts

The fact that Volvo Ocean Race sourced funding to construct the tools as well as fuel the actual manufacturing of the boats is also of key importance as it significantly improves the chances of getting more boats on the start line. Historically the deadline of when you have to start designing and building a boat has stopped many late entries. Racing second hand boats in an open development class has also never been an attractive option.

There is a balance to be achieved between reducing boat and campaign costs, while continuing to attract the best sailors, and maintaining the high level of public interest the race has received to date. After much discussion amongst various stakeholders it became clear that the Volvo Ocean 65 needed to remain a true “King of the Ocean” retaining as many performance features as possible within the budget targets. While smaller or simpler boats can reduce costs dramatically, it was felt that this boat needed to be exciting to sail, and be capable of achieving record speeds.

DESIGN BRIEF

The design brief for the Volvo Ocean 65 involves a significant number of challenges. It calls for a boat with a similar performance pedigree to the Volvo Open 70 that it will replace, while requiring significantly enhanced structural margins for improved reliability, as well as reduced construction time, operating costs, and maintenance requirements. It also calls for lowering the entry barrier for less experienced and female teams. This is a one design class that is competing at the pinnacle of the sport, so it needs to be built to an unprecedented level of construction accuracy and adhere to strict quality control requirements throughout the build process in order to be viewed as a successful one design by its users. All of this needs to be achieved in an extremely short timetable in order to have at least 8 boats ready for the start of the next Volvo Ocean Race in late 2014.

DESIGN CONCEPT

Hull Form

After a number of conceptual iterations we have developed a concept that we feel successfully meets the competing demands presented by the design brief. The resulting design is 20.4m length overall with a beam of 5.6m. The requirements for improved robustness, reliability and construction efficiency have necessitated an increase in the weight of the yacht structure which is undesirable from a performance perspective but necessary in this case. In an attempt to maintain stability and low displacement we have increased the draft from 4.5m in a VO70 to 4.7m and have reduced the onboard system complexities substantially, saving weight and cost. At 5.6m the beam remains similar to the VO70’s maintaining high hull form stability appropriate for high speed off-shore sailing. This results in a relatively higher beam to length ratio compared to the VO70’s, producing a hull sectional shape that is well suited to a full length hull chine. The chine has the added advantage of creating very planar topsides that are much easier to form core into, avoiding parasitic weight additions and avenues for added weight of fairing that may differ between boats. Free of the VO70 box rule limitations that have driven most modern classes to plumb stems we have opted for a relatively longer forward overhang coupled
with a fine entry and reverse stem. When coupled with the reverse sheer line the result is a striking silhouette that gives the boat a modern, forward looking appearance. The reverse stem and forward overhang will also give the boat some extra effective length and improved sea-keeping characteristics when sailing in waves.

**Deck Arrangement**

The deck concept of the VO65 attempts to deliver on several important goals; increase safety, decrease physically demanding tasks, reduce costs, and simplify construction, all while providing the basic user interface that the sailors need to do their jobs.

![Figure 1 - VO65 Deck Arrangement](image)

Crew safety remains a core value of Volvo Ocean Race and the new design endeavors to make significant improvements in crew protection compared to the VO70’s. Dangerous water flow over the bow has been addressed by having a relatively high sheer line forward (similar freeboards to a VO70 despite being a smaller boat), a hard sheer corner, and with cabin geometry. High speed longitudinal water entrance into the cockpit will be mitigated by having a relatively taller cabin extend athwartships to the sail stack. The cabin itself is tall enough and broad enough in its shoulders to provide something to stand behind for most of the cockpit positions.

Whereas the VO70’s all incorporated a sliding companionway hatch due to weight and requirements for spinnaker dousing this left the crews very exposed to green-water. With the directive to improve crew protection a cabin house has been incorporated. This features a sharply chiseled water shedding forward outboard corner that combines with the boat’s unique stem shape to give the boat an iconic look that should be able to remain relevant for two VOR race cycles and beyond.

The running rigging and deck systems are above deck in order to improve waterproofing and reduce installation and maintenance costs. Major line groupings, where possible, are covered to prevent crew feet from rolling on lines, and improve sail movement on deck.

All headsails are sheeted either to a single set of leap frogging padeyes or spinnaker sheeting areas on the rail aft, which reduces the total deck hardware parts compared to a VO70 layout where overlapping headsails had to be catered to.

Three winch grinding pedestals have been retained for hoisting and furling maneuvers where they will be filled even in reduced crew scenarios. On more common maneuvers, a female team with higher crew numbers will be able to have more crew members grinding than on a male only boat. The winch drive-train has been set up longitudinally to provide clear and unobstructed access to the twin companionways which will make moving sails onto or below deck much more straightforward. The aft most grinding pedestal has been placed behind the main traveler for high speed reaching and running weight optimization. Mechanical advantage has been added wherever possible in purchase systems and winch gearing in order to reduce reliance on pure physical strength.

A guest friendly zone has been maintained in the aft cockpit area for corporate sailing as well as Pro/Am type racing.

**Rig and Sailplan**

The sailplan is intended to incorporate the best concepts that have been developed for VO70’s and Open 60’s while simplifying the rig concept as much as possible. Unlike the VO70’s, the mast is deck stepped to simplify the interface between the mast and deck and to improve the stepping and unstepping of the rigs both on and off the water. Deck stepping the mast also has the benefit of shortening the mast tubes to assist with shipping and logistics.

Unlike the VO70’s, the chainplate base spans the entire width of the boat. Beyond simplifying boat construction, the increased chainplate width lightens the rigging components and enables a 3 spreader layout. The wide chainplate base eliminates the overlapping headsails used on the VO70’s. This is consistent with the reduction and simplification of the sail inventory that eliminates one of the headsails hanked onto the forestay and the specialized small staysail (which was counted as a storm jib for the VO70’s). Three sails flying from the sprit are retained, allowing for both masthead and fractional code 0’s, as well as an all-purpose furling A3/A5 for broad reaching and running.

Because the mast is deck stepped, a moderate spreader rake of 12 degrees is used to ensure that the mast is safe and stable, and to ensure that the teams cannot vary the mast
rake while racing. The backstay system consists of a backstay with a deflector and an independent check stay system. This provides sufficient mast control and the forestay tension required for each individual sail combination. A single backstay system with three deflectors was considered but the check stay system was felt to provide a more robust and reliable system.

**Interior Arrangement**

The interior layout of the VO65 reflects what has become common place on a variety of offshore boats ranging from shorthanded IMOCA 60s to fully-crewed VO70’s. The boat features tanks and machinery spaces located between the primary longitudinal structure of the boat. This reduces system installation and servicing time and results in a clean interior with clear unobstructed bays on either side of the boat.

The galley is located on the centerline behind the mast bulkhead, above the centralized machinery space to allow usage from either side. Forward of the mast bulkhead, there is a centerline head. There are 7 berths on either side of the boat with storage areas beneath the bunks secured by the outboard longitudinals. Compared to the boats used for the 2011/12 edition, the VO65 will have significantly less freely stackable gear. The majority of the gear below deck will be considered "sealed" and required to be kept in place during the leg. The pivoting navigation and media stations are located just aft of the companionway bulkhead which provides for easy communication with crew on deck, while limiting motions that are exaggerated at either end of the boat.

**Appendages**

The design features an appendage package which is very similar to a Volvo Open 70 in most respects. The keel fin is of forged steel with a composite trailing edge fairing designed to comply with Volvo Open 70 factors of safety for maximum bending stress limitations. In addition, the fin exceeds all of the new GL Guidelines for keels including torsional rigidity and fatigue life requirements. The canting keel system utilizes two opposing rams and is very similar to those systems used successfully in the VO70’s. As with the VO70’s the system has been designed to operate successfully with only one ram to insure redundancy of the system.

Some of our original conceptual options considered a single rotating and retracting center line daggerboard with the thought that this would ease the burden on the crews of the dual asymmetric daggerboard layout. After much discussion and consideration of requirements for spares etc. a dual daggerboard option was selected. In order to minimize the needs for spares the daggerboards are fully reversible. Unlike many of the VO70’s, the daggerboards are supported at the hull and deck which adds length and therefore weight to the boards. Although intermediate support structures could reduce the span requirements it was felt these added an undesirable level of construction complexity. The daggerboard incline angle has been set to allow the boards to be lifted by halyards from the mast avoiding the complexity and maintenance requirements of retractable lifting struts. There are performance improvements associated with more vertical or even negative incline angles on the daggerboards [daggerboard tip closer to centerline than the root], however, the performance loss is small and the maintenance requirements outweigh these options.

The potential for rudder failure is always a significant concern and some of our original concepts considered the use of an IMOCA 60 style kick-up rudder system to provide additional reliability to the rudder system. After discussion with many sailors the kick-up system was abandoned due to cost and complexity and a more conventional rudder installation considered. The rudder blade and stock laminates are designed to meet the most onerous of FYD design criteria, ISO and GL in order to be as robust as possible. Each boat will carry a spare rudder that is identical to the two primary rudders. In event of a rudder failure this can be installed back into the bearings while underway or installed in a transom hung cassette in the event of rudder bearing damage.

**ENGINEERING AND CONSTRUCTION**

Various engineering concepts have been considered, with significant input from the four builders supplying the various major boat components, sailors, and shore crew from the most recent Volvo Ocean Race.

Sandwich structures are used throughout, thus minimizing the amount of the internal structure required to stiffen the shell. The structural layout promotes easy movement of sails and other gear internally throughout the yacht. High strength carbon fiber is used almost exclusively for shell laminates and reinforcements, and a combination of foam and aramid honeycomb are used as sandwich core materials. Specific materials and lamination processes were discussed with each of the major component builders, allowing them to utilize their experience from building similar boats. Each structural component is therefore optimized to suit the global engineering requirements, while using the specific component builder’s preferred materials and construction methods.

**Scantling Rules**

For the VO65 multiple scantling rules were used as a guide for defining the structural requirements. The American Bureau of Shipping’s Guide to Offshore Racing Yachts (1994) [ABS, 1994], once considered a standard, is no longer enforced, however, its nuances are well understood and the rule continues to serve as a benchmark for certain types of yachts. The International Standard Organization’s classification rule (12215-5) [ISO, 2008] has since replaced ABS as the yachting standard and this rule largely

---

**Abs and ISO Standards**

ABS as the yachting standard and this rule largely
governed the laminate specifications in previous VO70 designs.

In addition, Germanischer Lloyd has recently published its own scantling rule for offshore racing yachts larger than 24m [Germanischer Lloyd, 2012], and a customized version of that rule has been developed for the VO65 and the design has been certified to be in compliance with this rule.

In some instances, such as (i) grounding loads, (ii) requirements on water tight hatches, (iii) keel bending stress limitations, (iv) canting keel system capabilities and (v) stability limits the Volvo Open 70 Rule provides significantly more stringent requirements than any of the scantling rules outlined above.

In addition to first principles engineering methods, each of these rules have been used in some form across the project. As a general policy, the most conservative of the available scantling rules, the VO70 rule or our internal FYD requirements, has been used in establishing design guidelines.

A Finite Element Analysis of the global bending behavior of the yacht when subjected to typical rigging and hydrodynamic loads, as well as a detailed review of the keel structure under a variety of load cases, was completed. The results were used to refine the laminate specifications and identify areas that may be subject to buckling events to refine the engineering of the yacht structure. Additional load cases were utilized to simulate and confirm compliance with the complex combined loading scenarios specified in the GL rule.

In order to ensure a robust and reliable structural solution, multiple layers of structural review have been established in addition to the FEA studies. The design drawings have been reviewed by independent engineering resources at Green Marine, Gurit UK, and Pure Design & Engineering in New Zealand, while Germanischer Lloyd has performed a complete review for structural compliance.

![VO65 Structural Arrangement](image)

![Third Generation VO70 Structural Arrangement](image)

Figure 2 - VO65 vs VO70 Structural Arrangements
Comparison of Structural Arrangements

The Volvo Open 70’s structural design was heavily driven by the need to achieve minimum displacement and maximum keel weight all while meeting the requirements of the ISO and VO70 structural rules. The result of this was structural arrangements that were heavily biased toward monocoque style structures with large hull panel spans, featuring hull shells with 45mm cores, extensive use of Kevlar honeycombs and heavily optimized laminate sequences that increased lamination time significantly.

In comparison, the VO65 contains a more traditional structural arrangement. 35mm cores are still utilized in the forebody with aramid honeycomb in the topsides and aft bottom panels. Corecell M130 used in the forward bottom slamming region to provide improved tolerance in slamming events. Figure 2 shows a comparison of a third generation VO70 and the new VO65 and you will note the significant amount of additional structural elements in the new design. This clearly comes with a weight consequence but is a direct result of the importance of reliability and robustness.

Failures of the core in slamming zones have been a consistent source of concern for the VO70’s and significant effort was taken in the development of the internal structural arrangement and core selection process to improve the panel scantling to protect from these events.

To minimize build time the hull construction has been completed using the SPRINT® resin infusion system and makes extensive use of broad-goods to reduce lamination and curing times to allow the hulls to be produced in rapid succession.

The deck and interior structure are made from pre-impregnated carbon and foam/honeycomb cores.

Build Process & Logistics

The undertaking to design and build at least 8 boats before the start of the 2014 race presents a number of significant logistical hurdles. Capacity wise, it is unlikely that any yard would have the capacity to produce this many boats in the given time frame.

In light of this, a consortium of builders was assembled under the guidance of Green Marine to coordinate the build by distributing tooling and component construction across four yards. Broadly, the consortium is organized as follows [See Figure 3]:

- **Green Marine** [Hythe, United Kingdom] – Prime Contractor, completes installation of some internal structure, fit-out of systems, deck installation, appendage fitting and commissioning. Construction of rudders and additional internal structure components.
- **Multiplast** [Vannes, France] – Deck tooling, deck lamination, manufacture and installation of deck and winch support structures, manufacture of interior components. Manufacture of select internal structure components.
- **Persico Marine** [Nembro, Italy] – Hull tooling design and manufacture, Hull lamination, Daggerboards, Keel Ram support structure construction and installation. Installation of internal structure.
- **Decision SA** [Ecublens, Switzerland] – Manufacture of internal structure components.

Additional core components are sourced from the following suppliers.

- **Southern Spars** [Auckland, New Zealand] – is supplying the masts, booms and EC6+ rigging.
- **North Sails** – is the sole supplier of sails until the completion of the 2014-15 event.
- **Cariboni** – Keel Canting mechanisms and keel bearings
- **Harken** – Winch Systems
- **Irons Brothers** – Keel and Bulb

Quality Control

Anyone who has raced one design boats can testify that in some classes there can be significant differences in performance. This can be a result of different building techniques or degradation in tooling over time or any one of a myriad of other issues. One of the explicit requirements of this design is that it produces boats that are as identical as possible. Given the complexity of canting-
keel offshore racing yachts and the extensive amount of equipment aboard, this is a significant challenge, made even more-so given the fact that there is no time to build and test a prototype and feed that information back into the design cycle.

Achieving this objective begins with the design drawings which must be more detailed than typically required for one-off projects. The engineering of the boat reflects extensive thought about assembly sequences and techniques for locating and assembling parts in an accurate and repeatable way. The design and construction and quality control of tooling is central to achieving the desired outcome. The tooling for this project must be capable of creating 16 parts requiring significantly more robust tooling design and construction than is typically found in one-off projects.

The hull tooling was constructed in Italy by Persico Marine Industries from a milled male plug [see Figure 4]. The hull tool itself is built from infused carbon and the backing structure was analyzed in Finite Element tools through cure temperature cycles to insure that any deformation through temperature ramps is correctly dissipated and that the resulting hull shell is the correct shape [see Figure 5 and Figure 6]. Similarly, the canting keel support structure is built from infused carbon molds and is pre-milled by numerically controlled milling machines, along with the keel support bulkheads to insure precise, repeatable alignment and assembly of these critical parts. Critical structure, including all of the canting keel attachment system, select bulkheads and longitudinal structure are installed before the hull is released from the tooling. The hull tooling, hull shape and structural assembly are all confirmed by laser tracking and verification.

The deck mold was constructed at Multiplast from a male plug. All hardware placement and positioning was confirmed on the plug prior to mold manufacture [see Figure 7]. The accurate and repeatable alignment of deck hardware fit-out is of critical importance and is insured by use of extensive templating and positive locating mechanisms.
Use of custom developed jigs is made throughout the assembly process to insure all components are located consistently in each boat. System runs and interior componentry were all verified using a full scale mock-up [see Figure 8] at Green Marine to verify penetration requirements and to pre-measure and fit all electrical, plumbing and hydraulic routes.

A detailed quality control plan is in place at all component manufacturers including non-destructive testing of all composite structures. Material testing of all composite materials was also completed to verify material properties in engineering.

An extensive system of documentation has been developed to inventory the tooling and all components produced such that every item’s production history can be tracked in entirety, including all non-destructive testing, material qualifications and which batches of materials were used in production of each material.

PERFORMANCE ENHANCING FEATURES

In addition to increasing the draft of the boat to 4.7m we have taken the opportunity to add a number of performance enhancing features that were prohibited in the Volvo Open 70. Given the one design nature of the new program these features can be added with only minor incremental cost.

The ability to vary the trim of high speed offshore boats such as the VO70’s, IMOCA60’s or the VO65 is critical to maximizing the boats performance, especially in high speed reaching and running conditions. In the VO70’s this was achieved by moving the sail stack and all stackable gear as far aft as possible and then filling a single aft centerline 1600L ballast tank. By reducing the sail inventory and limiting stackable gear in the VO65 we have reduced the available trimming moment. To address this, the VO65 now features two 800L aft wing tanks that add a significant amount of stability in addition to their trimming effect. The venturi fill scoops can be actuated from the deck in addition to an electric ballast pump system.

Reflecting on experience with our successful Open 60 designs and after discussion with many sailors, the boat also incorporates a forward centerline 1000L water ballast tank. This helps to create a bow down attitude when sailing in waves and increases the inertia of the boat improving the boat’s motion in waves. This should act to reduce the occurrence of major slamming events helping to meet the reliability objectives.

The IMOCA 60 fleet permits the use of outriggers to sheet sails outboard of the sheer, something that is prohibited in most classes. The use of the outrigger [See Figure 9] allows you to widen the sheeting angle of selected sails improving efficiency. It has the added benefit of extending the useable range of these sails and reducing wear. After some consideration it was felt that the addition of an outrigger system would be a significant benefit to the VO65 and the boat is fitted with a single outrigger that can be used in two locations.

The VO70 rule required the keel-pin axis to be parallel to the waterline. This results in a very low and sometimes negative lift loading on the keel fin resulting in a significant induced drag increase. From our very first IMOCA 60’s we felt there was value to adding some incline to the keel pin to insure it remained positively loaded in operation. In recent years many of the later generation IMOCA 60’s have pursued significantly larger keel-pin incline angles (up to 8 degrees in some cases) indicating this is fertile ground for exploration. For additional background of the phenomena at work with inclined keel-pin performance see “Tuning of Appendages for an IMOCA60 yacht” by Campbell, I. et al., 2012.

Unrestrained by the VO70 rule we have added incline to the keel-pin axis, raising the front end of the canting keel rotation axis [See Figure 11]. The inclined rotation axis has a number of positive effects on the performance of the...
boat. Firstly it creates a large vertical lift force on the keel fin which reduces the effective displacement of the boat, reducing wetted surface and reducing the drag of the entire yacht system. Secondly, even when canted and heeled, the keel creates a positive side force which reduces the leeway angle. This is a significant factor for high beam to draft hull forms such as this as they present a very asymmetric shape to the flow as they heel. As the boat operates at more negative leeway the amount of asymmetry reduces substantially providing an associated reduction in form and residuary resistance. Operating at negative leeway angles also has the advantage of effectively increasing the sail sheeting angles, further improving the aerodynamic efficiency of the yacht. All of these are positive performance factors but they are countered by the large heeling moment generated by the additional loading on the keel which must be overcome by depowering of the sails or an increase in the bulb weight. The trade-offs are quite complex and often very subtle and need to be assessed in context of the expected racing conditions and their impact on the dynamic trim of the boat at speed.

Given the complexities of these trade-offs and the implications on helm load and balance that result from the changing of load sharing between hull, keel, daggerboard and rudder we felt it was important to complete a more detailed study of these effects to avoid any pitfalls.

In fixed keel designs, different appendage concepts can be evaluated at a given speed by examining results from a yaw sweep at fixed heel and interrogating the side force/drag polar at the sailing side force. Unfortunately, this technique is insufficient to analyze the impact of adding keel-pin axis incline angle as we need to allow the boat to find the best speed incorporating the balance of the side force, heeling moment and vertical force effects. This requires the use of a VPP methodology where we balance aerodynamic forces and moments against hydrodynamic force and moment response surfaces that are a function of speed, heel, yaw, daggerboard depth and rudder angle.

To populate these hydrodynamic surfaces we utilized NUMECA’s Fine/Marine RANS flow solver [See Figure 12] and FYD’s High Performance Computing cluster to simulate the hydrodynamics at select operating conditions. The data was then incorporated into hydrodynamic response surfaces using a “radial basis function” technique.

Balancing this hydrodynamic data set with wind tunnel derived aerodynamics models, allowed us to refine our understanding of the interplay of these trade-offs and to select a more optimal keel axis incline angle. Additional studies leveraged this data to refine our daggerboard positioning and section size.
As expected, the impact of keel-pin axis-incline angle has a very powerful impact on the performance of the boat, with the vertical force generated by the keel substantially reducing the overall drag of the yacht system, especially at high speed. However, the impact of the hydrodynamic heeling moment from the keel is apparent and results in depowering at lower wind speeds. The performance advantage is most pronounced when sailing in fully powered conditions and degrades rapidly as you approach the limits of a sail sets depowering capacity. This work indicates that in certain conditions the impact of the keel pin incline is enough to negate the fact that the VO65 is smaller, heavier for its size and has a lower righting moment than the VO70. In certain conditions it should be capable of approaching similar speeds to a VO70.

While this work supported a keel-pin incline angle of 5 degrees as close to optimal for a typical Volvo Ocean Race course, the optimal value is very dependent on the expected sailing conditions. For instance, the Vendee Globe race has significantly less upwind sailing compared to the Volvo and this is reflected in a large proportion of higher speed reaching and running which will tend to target larger keel pin incline angles. For races with more upwind sailing with lower speeds and higher heel angles a lower incline angle will be more optimal as the keel induced heeling moment is of more importance.

**PERFORMANCE COMPARISON**

Initial performance predictions for the VO65 show it to perform about 2.5 – 3% slower than a VO70 with the VO65 being slightly biased toward downwind sailing. This is born out in weather routing simulations over the last race course. Table 1 shows the relative averaged elapsed times of the VO65 and VO70 sailing on the 2011-12 Volvo Ocean Race course. These simulations reflect the results of 30 optimized weather routes run in each of 8 calendar years of high resolution data to build a suitable statistical representation.

<table>
<thead>
<tr>
<th>Leg</th>
<th>VO65 [hours]</th>
<th>VO70 [hours]</th>
<th>delta [hours]</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>457.8</td>
<td>446.8</td>
<td>11.0</td>
<td>2.5%</td>
</tr>
<tr>
<td>2</td>
<td>319.6</td>
<td>310.4</td>
<td>9.2</td>
<td>3.0%</td>
</tr>
<tr>
<td>3</td>
<td>294.9</td>
<td>286.3</td>
<td>8.6</td>
<td>3.0%</td>
</tr>
<tr>
<td>4</td>
<td>438.1</td>
<td>424.6</td>
<td>13.5</td>
<td>3.2%</td>
</tr>
<tr>
<td>5</td>
<td>390.8</td>
<td>381.2</td>
<td>9.6</td>
<td>2.5%</td>
</tr>
<tr>
<td>6</td>
<td>332.3</td>
<td>324.5</td>
<td>7.7</td>
<td>2.4%</td>
</tr>
<tr>
<td>7</td>
<td>228.6</td>
<td>223.6</td>
<td>4.9</td>
<td>2.2%</td>
</tr>
<tr>
<td>8</td>
<td>143.9</td>
<td>140.4</td>
<td>3.5</td>
<td>2.5%</td>
</tr>
<tr>
<td>9</td>
<td>44.3</td>
<td>43.2</td>
<td>1.1</td>
<td>2.6%</td>
</tr>
<tr>
<td>Total</td>
<td>2650.3</td>
<td>2581.1</td>
<td>69.2</td>
<td>2.7%</td>
</tr>
</tbody>
</table>

Table 2 shows a similar comparison to a 2011-generation IMOCA 60 and shows the VO65 to be 11–14% faster over the same Volvo course. This result is partially attributable to the larger focus on upwind sailing in the Volvo Ocean race as compared to the more downwind biased Vendee Globe courses.

<table>
<thead>
<tr>
<th>Leg</th>
<th>VO65 [hours]</th>
<th>IMOCA 60 [hours]</th>
<th>delta [hours]</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>457.8</td>
<td>532.4</td>
<td>-74.6</td>
<td>-14.0%</td>
</tr>
<tr>
<td>2</td>
<td>319.6</td>
<td>364.9</td>
<td>-45.3</td>
<td>-12.4%</td>
</tr>
<tr>
<td>3</td>
<td>294.9</td>
<td>344.1</td>
<td>-49.2</td>
<td>-14.3%</td>
</tr>
<tr>
<td>4</td>
<td>438.1</td>
<td>498.8</td>
<td>-60.7</td>
<td>-12.2%</td>
</tr>
<tr>
<td>5</td>
<td>390.8</td>
<td>443.4</td>
<td>-52.5</td>
<td>-11.9%</td>
</tr>
<tr>
<td>6</td>
<td>332.3</td>
<td>388.2</td>
<td>-55.9</td>
<td>-14.4%</td>
</tr>
<tr>
<td>7</td>
<td>228.6</td>
<td>269.1</td>
<td>-40.5</td>
<td>-15.1%</td>
</tr>
<tr>
<td>8</td>
<td>143.9</td>
<td>167.5</td>
<td>-23.6</td>
<td>-14.1%</td>
</tr>
<tr>
<td>9</td>
<td>44.3</td>
<td>51.0</td>
<td>-6.7</td>
<td>-13.1%</td>
</tr>
<tr>
<td>Total</td>
<td>2650.3</td>
<td>3059.5</td>
<td>-409.1</td>
<td>-13.4%</td>
</tr>
</tbody>
</table>

**CONCLUSIONS**

By themselves the significant and often conflicting goals within the design brief of this type represent a challenge for a design group. This is made all the more daunting when the logistical challenges of coordinating between multiple build sites and an extremely compressed design and build
Despite these challenges we are confident that we have produced a design that is a worthy successor to the VO70. Although a smaller and heavier boat than the VO70 we have incorporated performance enhancing features without significant budgetary cost to keep performance at the highest possible levels. Safety has always been a hallmark of the Volvo Ocean Race and the VO65 has been developed from the outset to meet or exceed previous VO70 requirements in addition to providing far more crew protection than was possible in the VO70 development rule framework. Finally, the structure has been engineered to significantly higher standards than previous designs in every effort to improve robustness and see the entire fleet complete each leg of the course.

At present construction is in full swing at all the yards and production is on schedule for the first boat to be launched in June of 2013.

REFERENCES


