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DEVELOPMENT OF THE STRUCTURAL REQUIREMENTS IN THE VOLVO OPEN 70 RULE VERSION 2

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1 INTRODUCTION

The Volvo Open 60 Rule was used as the class rule for yachts eligible to enter the 2001/02 Volvo Ocean Race. This rule was developed from the Whitbread 60 Class Rule, used in 1993/94 and 1997/98 Whitbread Round the World Races and over a span of 12 years these rules produced yachts that survived record-breaking ocean racing.

During 2003 the Volvo Ocean 70 Rule was developed for a new class of 70-foot yachts eligible for the current 2005/06 Volvo Ocean Race. These boats were intended to be faster than their predecessors and differed by permitting canting keels, which had been proven in ocean races by the IMOCA Open60 monohulls, but for safety reasons the development of the rule drew on the experience embodied in the Volvo Open 60 Rule.

This paper deals with the development of the new rule rather than the performance of the boats built to it. The Volvo Ocean 70 Rule was reviewed following the conclusion of the 2005/06 Volvo Ocean Race and a number of changes were introduced into Version 2 of the Rule to address significant structural problems that occurred in some of the yachts.

2 BACKGROUND TO STRUCTURAL REQUIREMENTS

2.1 Volvo Open 60 basic rule principles

The Volvo Open 60 Rule (V.O.60) contained three main requirements to regulate the structures: permitted materials, minimum panel weights and compliance with the American Bureau of Shipping “Guide for Building and Classing Offshore Racing Yachts”.

These requirements were complementary since hull shells could be designed to the minimum panel weights in the permitted materials such that they would also comply with the requirements of the ABS Guide, which further provided the requirements for the internal members of the structure, e.g. frames, and for the keel fin and its attachments.

2.2 Changes for the Volvo Ocean 70 Rule

It was decided early in the development of the new V.O. 70 Rule to permit the use of carbon fibres and honeycomb cores in the hull construction, which, together with the anticipated performance increase, necessitated a review of the minimum panel weights.

Meanwhile, during the life of the Whitbread 60 and V.O.60 rules there had been changes to the associated regulations. The Council of European Communities Recreational Craft Directive 94/25/EC, commonly known as the RCD, came into force for vessels up to 24 metres in length and the ABS effectively withdrew the use of their Guide for yachts of less than 24 metres in length.

Other Classification Societies had also withdrawn their scantling rules for yachts in anticipation of the new harmonised ISO/CEN Standard 12215-5 “Small craft — Hull construction/scantlings — Part 5: Design pressures, design stresses, scantling determination” but unfortunately this had an extremely long gestation and was only in draft form at the time the new Volvo Ocean 70 Rule was being written and was untested for use in racing yacht design.

Some new requirements entered the 1994 Version of the ABS Guide and Notice #1 provided further changes before the ABS withdrew it’s publication. The existing V.O.60 Rule managed to continue to apply these requirements, using the Wolfson Unit MTIA as an independent organisation to check conformity of designs with the published requirements. It was, however, unclear whether there was a legitimate basis for making reference to the ABS Guide in a new rule. Attention was therefore directed towards the RCD even though racing yachts could be excluded from its scope.

2.3 Rationale for structural requirements

Det Norske Veritas (DNV) were consulted during the V.O.70 Rule development and although they did not become fully involved they provided an interesting rationale by distinguishing between the three aspects of the rules:

Fitness for purpose requirements, to ensure that important matters are addressed regarding structural integrity, e.g. structural arrangements and load cases.

Equal racing requirements, to ensure that matters are addressed on a common basis with appropriate measurements etc. so hull weights were similar.

Safety requirements, to ensure the safety for the people onboard, not necessarily the structural integrity of the yacht.

2.4 IMOCA Class Rules

The International Monohull Open Classes Association (IMOCA) was responsible for the Open 60 ISAF International Class, which had developed independently of the V.O.60 class and used the canting keel arrangement that was to be adopted in the new V.O.70 class.

Rule C-5 stated "The boat shall be constructed in such a way as to be able to stand, without irreparable damage, the forces of nature, which it is intended to have to face in the course of races classified by the ORC in category0….."

This was non-prescriptive and left the designers with the responsibility of producing adequate structural arrangements but was considered to be too open to be adopted in the new V.O.70 Rule.

2.5 Fundamental Rule Policy

It is worth noting here the Fundamental Rule Policy that is stated at the beginning of theV.O.70 Rule:

"The Volvo Open 70 Rule is intended to produce fast, single mast monohull keelboats of similar performance, suitable for long distance racing offshore at the highest level of the sport. The need for safety and self-sufficiency is paramount. The Rule is intended to foster gradual design development leading to easily driven, seaworthy yachts of high stability, requiring moderate crew numbers. Any development that is contrary to this policy may give rise to Rule change."

This also embodies the three rule aspects identified by DNV; safety; self-sufficiency, which is dependent upon fitness for purpose; and similar performance, which is partly achieved through equal racing requirements.

2.6 Safety and risk assessment

Failures continue to occur in racing yachts despite best attempts by regulators, designers and builders to ensure structural integrity so the risk of failure needs to be assessed to improve safety for the sailors. Table 1 was prepared during the development of the V.O.70 Rule and was used to identify the important safety requirements to be incorporated into the Rule.

Further details about the risk assessment can be found in reference 6 and a full study was conducted into the buoyancy subdivision requirements with regard to flooding and stability.

A major concern was the risk of failure of the fin or bulb leading to capsize of the yacht with no prospect of self-righting. Therefore it was considered important to include in the Rule load cases, material properties and factors of safety for the ballast keel to try and ensure that the keels were adequately strong and to ensure "similar performance".

2.7 Concepts for the V.O.70 Rule

Seahorse Rating Limited put together the V.O.70 Rule for the Volvo Ocean Race organisation and together they consulted with a number of designers and other organisations and held a series of meetings. One of the issues was the degree of openness allowed by the Rule and the scope for design. A balance had to be struck between rule prescriptions and designer's responsibilities and also between the dichotomy of intent expressed in the Fundamental Rule Policy for both similar performance and design development.

Perhaps surprisingly, the consensus view amongst designers consulted during the Rule development was a preference for some prescription within the Rule.

3 SAFETY RULES

The concept of safety was widely accepted but it is difficult to define in a rule so to avoid semantic problems reference was made to the Essential Safety Requirement given in the RCD. The hope was that the Directive had already been well drafted and would gain international recognition.

3.1 Essential safety requirement

The essential safety requirement 3.1, "Structure" given in the RCD states:

"The choice and combination of materials and its construction shall ensure that the craft is strong enough in all respects. Special attention shall be paid to the design category according to section 1, and the manufacturer's maximum recommended load in accordance with section 3.6."

This is similar to the IMOCA Open 60 Class Rule C-5, quoted earlier in this paper but has a more formal status – being part of the RCD. It is a non-prescriptive statement so required reinforcing for incorporation into the V.O.70 Rule.

3.2 Conformity assessment

The RCD is a complex document consisting of 15 Articles and 15 Annexes with cross referencing between them. Full conformity is required for production yachts built and sold within the EU and it was within the bounds of possibility that a V.O.70 yacht could achieve this.

Instead the V.O.70 Rule merely refers to Annex VII (EC Type-examination Module B), which applies to ocean sailing yachts between 12m and 24m in length and for full CE Marking would involve a Notified Body, some of which are Classification Societies, checking the technical documentation. An exception was written in the Rule to the requirement to use a Notified Body but for the 2005/6 race the Volvo Ocean 70 Rule Management Group (RMG) invoked the Rules requiring designers to make their technical documentation available and sought the assistance of the Wolfson Unit MTIA to check this – a task that the Wolfson Unit thought it had relinquished when it consulted on the change from the V.O.60 Rule to the V.O.70 Rule.

Annex VII of the RCD refers to relevant standards and to Article 5, which also relates to standards and this is perhaps the part of the conformity assessment with the least clarity, due to the transition between Classification Societies rules and guides that had been withdrawn and the new harmonised ISO standard that was in draft form. It was assumed that designers would select the standard they would work to and it would be their responsibility to conform to its requirements. In practice most designers continue to work informally to the requirements of the ABS Guide. It would seem difficult for the ABS to withdraw existing knowledge from prior application of their Guide even if its status is withdrawn.

4 STRUCTURAL DESIGN

The new V.O.70 Rule embodied the principles of the three main structural requirements in the V.O.60 Rule but with different applications. The permitted materials had changed, new panel weights were specified and the conformity assessment was less prescriptive.

4.1 ISO/CEN Standard 12215-5

This standard was published in draft DIS form and a final draft FDIS was circulated to the Working Group in September 2005, after the current fleet of V.O.70 yachts had been designed, and was embodied in the new Wolfson Unit HullScant program. It is anticipated that the Standard will be published in 2007. The HullScant program was developed to aid the conformity assessment of the V.O.70 yachts and simplifies the input of material properties and layups and comparison with the ISO Standard requirements. A simple example of the associated graphical output is in Figure 1. The program was based on an earlier version, used within the Wolfson Unit for assessment of the V.O.60 yachts to the ABS Guide, and not commercially available because of Copyright and Intellectual Property Rights held by the ABS.

4.2 Application to V.O.70 yachts

The technical documentation and hull scantlings of the V.O.70 yachts were compared with the requirements of both the ABS Guide and the DIS ISO standard.

There are several points of note with regard to the application of the ISO Standard:

The introduction to the Standard states: “The working group considers this International Standard to have been developed applying present practice and sound engineering principles. The design pressures of this International Standard shall be used only with the equations of this International Standard.” This means that the pressures should not be taken as reliable values to be used in Finite Element Analysis.

There is no “Alternatives” clause in the Standard, such as found in Classification Society rules. Its requirements therefore have to be followed strictly according to the published text.

Part 5 of the ISO Standard does not include structural requirements for the ballast keel, reinforcing the need to have included these within the V.O.70 Rule, and Part 6 is still in draft.

Round bilges and hard chines can be considered as natural stiffeners for panels, enabling large panels to be sub-divided for structural calculations. This is somewhat different to the curvature correction within the ABS Guide and can lead to different panel sizes with the same strength limitations.

4.3 Design of the hull shell

The minimum panel weights specified in the V.O.70 Rule were derived following comparative calculations based on the requirements of the ABS Guide and a consultation process with designers, with responses based on their experience with other successful racing yacht designs.

The Rule panel weights oscillated during the consultation but ended up being within 7% of the values in the V.O.60 Rule, heavier in the bottom forward and generally lighter elsewhere. This took account of the higher strength of carbon fibre, the lighter displacement and greater length of the V.O 70 yachts and an expectation of higher loading due to the anticipated increase in performance, which may have been underestimated given reports from the sailors.

An intention in setting the minimum panel weights was to allow designers to opt for single skin in parts of the bottom without incurring a weight penalty, to avoid the possibility of core shear in areas notorious for damage due to slamming.

Aramid fibres, used in the construction of the V.O.60 yachts, have relatively poor compressive strength and were a ruling property in the scantling determination for these boats. By comparison, carbon fibres are significantly stronger in compression, so there were generally few problems in designing a sandwich hull shell to the minimum panel weights that complied with the conformity assessment standards.

Providing adequate core thickness to meet shear strength requirements remained the main design issue. It is recognised that, in practice, material choice and construction methods and standards are also very important in maintaining structural integrity.

4.4 Design of internals, including stiffeners

Both the ABS Guide and the ISO Standard deal with the requirements for internal structural components. The watertight sub-division requirements of the V.O.70 Rule placed bulkheads that also provided structural support for the hull shell. Core shear requirements then determined panel sizes and the placement of intermediate internals, although, as previously discussed, there were differences depending on the chosen standard.

It was, however, considered that a more formal requirement should be written into the Rule, in lieu of the requirement in the ABS Guide for stringers in the slamming area, so maximum panel dimensions were specified. This resulted in duplicity of requirements and it is not uncommon in such instances to find one of the requirements becomes effectively redundant.

5 STRUCTURAL REQUIREMENTS FOR BALLAST KEELS

The ABS Guide contained specific requirements for the design of ballast keels or fins and their attachments. These had been strictly applied to the V.O.60 yachts; according to the published text of the Guide and not the alternatives that some design offices had approved by the ABS. Despite their slender appearance V.O.60 fins had proved to be robust. Whilst the need to comply with the essential safety requirement should have ensured that the V.O.70 ballast keels would also be robust, the consensus view from designers and the rule makers was that some prescription should be provided. The absence of reference to the ABS Guide in the V.O.70 Rule meant that the structural requirements for ballast keels had to be incorporated into the Rule.

5.1 Load cases

The sailing and grounding load cases were based on those formerly published the ABS Guide. They used the yacht’s displacement including the bulb, as applied to the V.O.60 yachts, not excluding the bulb, as used by some design offices according to “alternatives” previously accepted by the ABS.

The grounding load cases are notional and are assessed using a quasi-static analysis, which will not represent actual dynamic behaviour in real instances. Nevertheless they provide a useful method for ensuring that the ballast keel is designed to cope with impact loads and the high accelerations associated with the performance of canting keel yachts in ocean racing conditions. V.O.60 yachts have been reported to survive grounding on rocks, so their experience was embodied in the Rule, and one of the V.O.70 yachts was reported to have grounded during the Cape Town port race.

5.2 Design stresses and factors of safety

It is the keel scantlings that are important when comparing strength and these are determined from the combination loads, stresses and factors of safety.

There was a general opinion that the factor of safety needed to be higher for a canting keel than for a fixed fin, because the canting keel generally operates at higher angles. Sailors’ reports of high vertical accelerations due to the speed of the V.O.70 yachts sailing over waves also confirm the need to consider higher fin loadings.

The V.O.60 Rule and the ABS Guide included maximum strength values for design purposes. Higher strength steels could be used in the construction but the increased strength added to factor of safety and could not be used to reduce the keel scantlings. This strength was included in the V.O.70 Rule. Care was taken to ensure that the overall design of the ballast keel would be relatively stronger than the V.O.60 keel, taking account of the different bulb weights and leaving designers with the choice of construction and materials.

6 STRUCTURAL PROBLEMS REPORTED DURING THE 2005/06 VOLVO OCEAN RACE.

A number of problems were reported in the media and on the Volvo Ocean Race website. Many of these were subject to further examination but confidential reports were not available for this paper. The media reports mainly concerned problems that led to obvious issues that affected the race, such as the retirement of yachts from legs of the race, sudden speed loss or, sadly, *Movistar's* abandonment. Some less obvious problems remained largely unreported, although word spread within the race community.

The obvious structural problems for the hull and canting keel were:

i) Loss of keel fairings, the so called bomb doors, which led to pressurisation of the keel compartment when the yachts were sailing at speed.

ii) Hydraulic ram rod end failures, which led to loss of control of the keel cant angle.

iii) Damage and failures within the structure associated with the canting keel, which could progressively worsen.

iv) Failure of a deck structure, which restricted the sail loads that could be applied. This was an isolated incident attributed to construction problems

Notable absences from this list were:

a) Failures of the canting fin, so there were no incidents of catastrophic loss of stability.

b) Breaches of the hull shell, so there were no major incidents of flooding.

Nevertheless, the reported problems gave rise at the time to concerns about the integrity of the yachts and good seamanship was displayed in the incidents to ensure the safety of the crew by their self-sufficiency.

The hydrodynamic pressurisation of the keel compartment, caused by high speed water entering when the fairings were lost, exceeded the normal hydrostatic pressures and probably exceeded the hydrodynamic pressures for the bottom shell of the hull, such as those given in the ABS Guide, reference 3, and the ISO Standard 12215-5, reference 4. The effective remedy was to slow the boat but if the fairing loss remained undetected the keel compartment could be breached leading to flooding of the central hull compartment. The watertight bulkheads and sub-divisions were designed to keep the yacht afloat in such an incident but the crew's concerns were expressed in the regular reports on the website.

The ram rod end failures were potentially serious since an uncontrolled keel and bulb, the so called "free-Willy" problem, leaves the hull and rig free to roll and could potentially break-up the internal structure. There was the safeguard of having two rams for redundancy but when one failed there were concerns because the other was either similarly loaded or twice as loaded so likely to also fail.

In the event the crews managed to contain the ram failure problems, which began in leg 1 on *Ericsson Racing Team*, and it was not damage to the rams but rather their associated structure that led to *Movistar's* abandonment during leg 7.

It was clear from the Volvo Ocean Race reports following leg 2 that the rod end failure on *Pirates of the Caribbean* involved fatigue and by then crew reports were widespread about the high dynamic loading compared to other racing yachts, although experience from the IMOCA Open 60 yachts had been taken into account when drafting the Volvo Open 70 rule and ram failure had not been raised as a particular problem.

Dynamic loading remains a difficult issue to address within the Volvo Open 70 rule since even scantling rules such as the former ABS Guide and the recent ISO Standard only use quasi-static loads and pressures in their scantling calculations. Section 8 of this paper describes tank tests in waves that illustrate the complex nature of the dynamic loading on a canting keel.

There were also some mast structural problems that arose during the race but these were outside the scope of the structural requirements of the rule and this paper.

7 CHANGES TO THE STRUCTURAL REQUIREMENTS FOR VERSION 2 OF THE VOLVO OPEN 70 RULE.

Following the 2005/06 Volvo Ocean Race the Rule Management Group sought opinions on the development of Version 2 of the Rule. These were generally in favour of developing the requirements from the original rule rather than introducing new requirements.

A number of changes were, however, introduced partly to clarify the Rule:

i) Specific reference was made to ISO 12215-5 for conformity assessment

ii) The requirement for ring frames was removed, leaving intermediate internal structural arrangements between bulkheads up to designers but within the conformity assessment requirements.

i) Load cases for keel design were explicitly applied to the canting mechanism and associated structure

iii) The terms sailing and grounding were deleted from the load cases and the horizontal load in case 2 is to be considered in both fore and aft directions.

7.1 Discussion of the changes

It was suggested that reference to the Recreational Craft Directive was unjustified because the RCD states that craft solely intended for racing shall be excluded from its scope. It is perhaps a little strange that the Volvo Open 70 Rule opts into certain aspects of the RCD however the UK Marine and Coast Guard Agency (MCGA) published comments on the RCD indicating that it is the manufacturer's choice to seek exclusion.

Reference was made to the RCD because it provided definitions of safety requirements and specified requirements for conformity assessment so avoided the need for these to be redefined within the Volvo Open 70 Rule. There was not strong opposition to reference to the RCD and its removal would necessitate the addition of equivalent rules.

Reference to ISO 12215 was included although it is currently only issued as an FDIS and it is unclear whether it is yet accepted as a harmonised standard, however its status has risen since the original Volvo Open 70 Rule was written and it is referred to in the MCGA comments on the

RCD. It was also used in the previous conformity assessment of the existing boats so its inclusion clarifies the status quo.

8 TANK TESTS TO INVESTIGATE THE DYNAMIC LOADING ON A CANTING KEEL IN WAVES.

In order to investigate further the nature of the dynamic loading that caused fatigue problems in the hydraulic rams, tank tests were performed in waves on a model with a separate dynamometer attached to the keel. An existing model was available at short notice that had been used previously for University of Southampton School of Engineering Science student projects and represented a 6.5m LOA Mini Transat, not a Volvo Open 70, however this class pioneered the use of canting keels and the results can be scaled from the model to represent a 70ft yacht. The Mini Transat boat was of lighter displacement/length ratio than a Volvo Open 70 so there were options in the selection of a representative scale.

8.1 Model and scaling

The model was 2.17m LOA and is shown under test in Figure 2. It represented the length of a Volvo Open 70 yacht at 1:10 scale and the keel fin, bulb and attached dynamometer then had a scale mass of 7.3t compared to approximately 6t for the yacht. The displacement, however, corresponded to 35t at this scale compared to 14t for a Volvo Open 70 but for the tests in waves it was probably better to scale the length and keel mass than the overall displacement, which would have required the use of 1:7.5 scale.

8.2 Tests and results

Tests were conducted in irregular head seas at the GKN/WAL No. 3 towing tank on the Isle of Wight at scale speeds between 10 and 27 knots and significant wave heights between Hs=1-2m. The lateral force was measured together with the motions and vertical accelerations of the boat. Due to model limitations the keel was canted to the maximum angle of 30 degrees and most of the tests were run with the hull at zero angle of heel.

Results from a typical time history are shown in Figures 3 and 4 and reveal some interesting characteristics. The run corresponded to a scaled speed of 27 knots into 2m significant wave height and the pitch motion, shown in Figure 3, was relatively large with a range of 10 degrees and high accelerations were also measured. The keel lateral force, shown in Figure 4, showed positive peaks that corresponded to the troughs in the motion, where the boat was pitching down into the waves and slamming on occasion.

A positive keel lateral force was associated with loading from the downward gravitational direction acting normal to the canted keel and also corresponded to the righting moment produced by the keel and bulb. The peaks in the loading shown in Figure 4 correspond to slam loading on the keel. It can be seen that the mean keel lateral force is, however, negative and this corresponds to the hydrodynamic lift, which is necessary to react against the sail force but produces a destabilising moment.

8.2 Force components

The loading on the keel therefore consists of several components: gravitational, due to the cant angle; hydrostatic, due to the buoyancy; hydrodynamic, due to the varying lift force; and inertial, due to the pitch motions. In addition higher frequency components than those in the pitch motions can be seen in the keel lateral force record and these represent the dynamic response of the keel and dynamometer mounting arrangement and were of smaller magnitude than the general wave induced loads. The net result of these components is the record shown in Figure 4 and it can be seen that in this test the lateral force was generally less than the keel weight except following a slam at 65 seconds.

The dynamic component of the keel lateral force is shown in Figure 5 for various runs in different sea-states and at different speeds. The root mean square (rms) value for the force was normalised using the keel weight and the results show its variation with the rms acceleration measured above the keel. It is noted that significant values are approximately twice the rms values and the peak acceleration exceeded 1g in some runs. The acceleration was also recorded near the bow, at station 1 on the model, and was generally a factor of 1.7 greater than at the keel. It can be seen from Figure 5 that there is good correlation between the acceleration and keel force so onboard acceleration measurements, taken whilst racing, can be used to indicate keel loading.

8.2 Correlation

Pressure measurements in the canting keel hydraulic system on racing yachts had previously indicated that the 90 degree heel load was occasionally exceeded, see reference 7. The force measurements from the tank tests shown in Figure 4 were also consistent with this. In the Volvo Open 70 Rule the sailing load case, or load case 1 in version 2 is concerned with this condition and includes a minimum safety factor of 3. It is clear from the tests that this factor of safety is necessary, not only to ensure that overloads can be tolerated but also to ensure adequate fatigue life, which was not the case for some of the hydraulic rams on the Volvo Open 70 yachts in the 2005/06 Volvo Ocean Race.

9 CONCLUSIONS

Drafting a new rule for a faster class of ocean racing yachts is a difficult task and designing to it is also difficult because of the higher speeds and absence of any prior boats for experience. Record breaking performances were achieved by the new Volvo Open 70 yachts during the 2005/06 Volvo Ocean Race and a new Version 2 of the Rule was developed based on experience from the problems encountered during the race. Time will reveal whether the issues were correctly addressed.

10 ACKNOWLEDGEMENTS

The Volvo Ocean Race organisation and Seahorse Rating Ltd. led the development of the V.O.70 Rule and this paper represents just part of their development process. The author thanks both organisations for their invitation to be part of the process and their permission to publish this paper and colleagues at the Wolfson Unit MTIA for their work on the Rule and assistance with the tests.

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DEVELOPMENT OF THE STRUCTURAL REQUIREMENTS IN THE VOLVO OPEN 70 RULE VERSION 2

Figures

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Item	Requirement	Safety issues	Safety backup	Compliance
Hull plating	Minimum weight/m^2 Maximum span	Watertight integrity Global hull strength	Buoyancy subdivision	Core sample
Deck plating	Minimum weight/m^2	Watertight integrity	Buoyancy subdivision	Core sample
Bulkhead plating	Minimum weight/m^2	Maintain intact compartments	Life rafts	Core sample Flooding test
Fin	Minimum strength	Essential for stability	Habitability when Inverted	Calculation
Bulb	Minimum strength	Essential for stability	Habitability when inverted	Calculation
Dagger board	None	Related damage to hull	Fin and rudder	N/A
Rudder	Minimum weight Half the weight for 2	Need to reach port	Emergency rudder	Weigh rudder
Mast and rigging	Minimum weight	Need to reach port	Jury rig Engine	Weigh

Table 1. Risk assessment for construction requirements

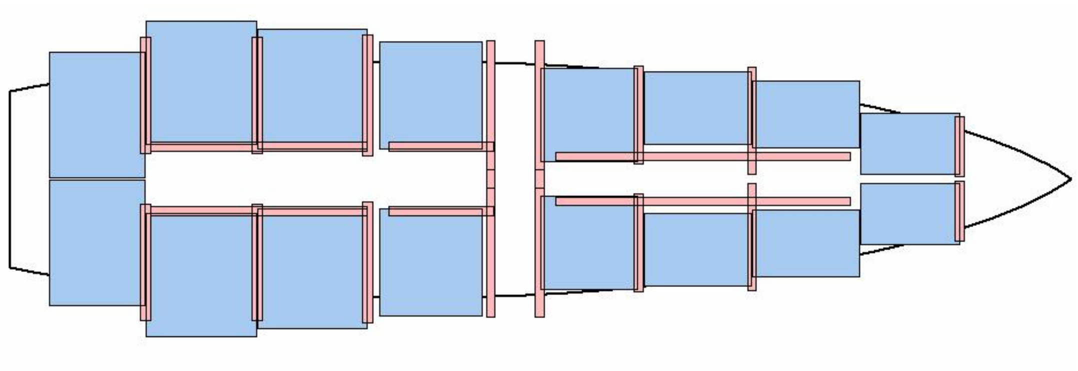

Figure 1. HullScant output showing panel layout

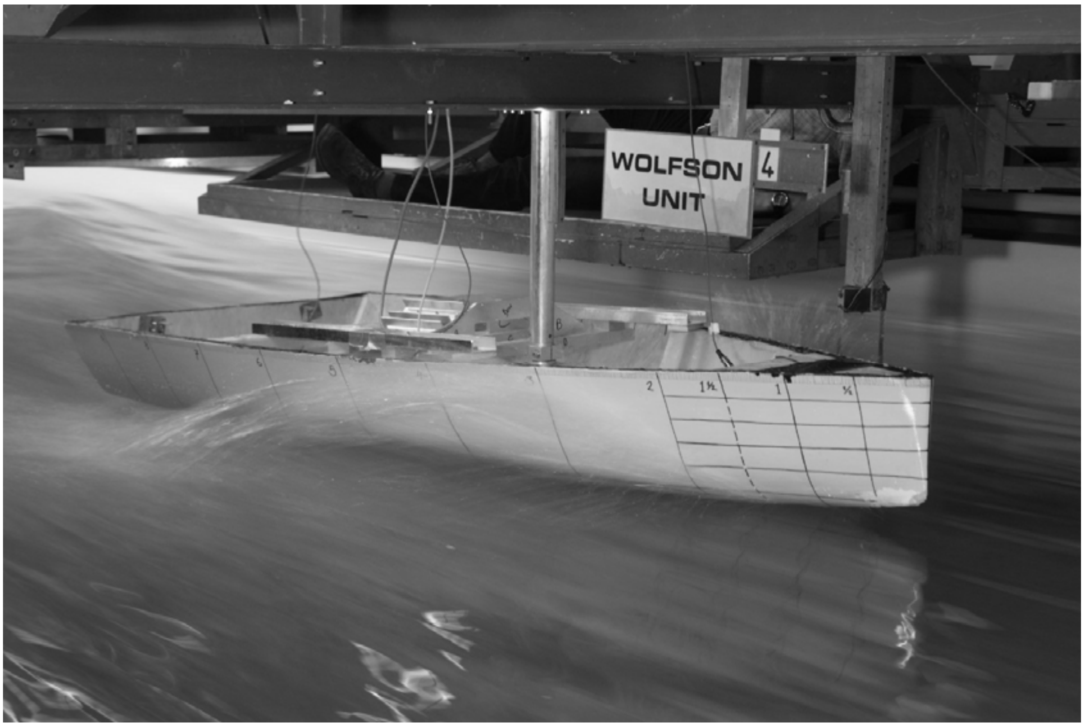

Figure 2. Model under tests in waves

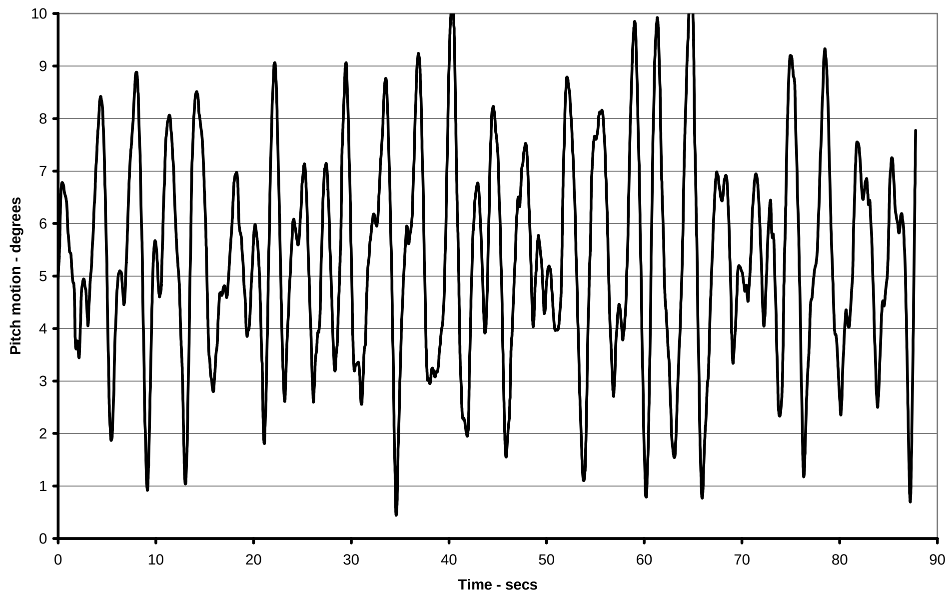

Figure 3. Pitch motion in waves

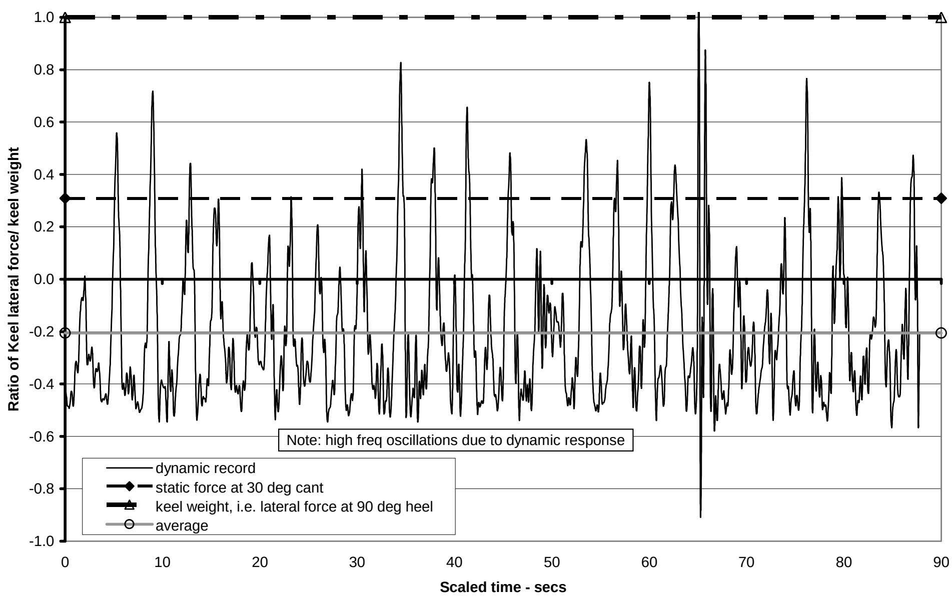

Figure 4. Corresponding keel lateral force record in irregular waves

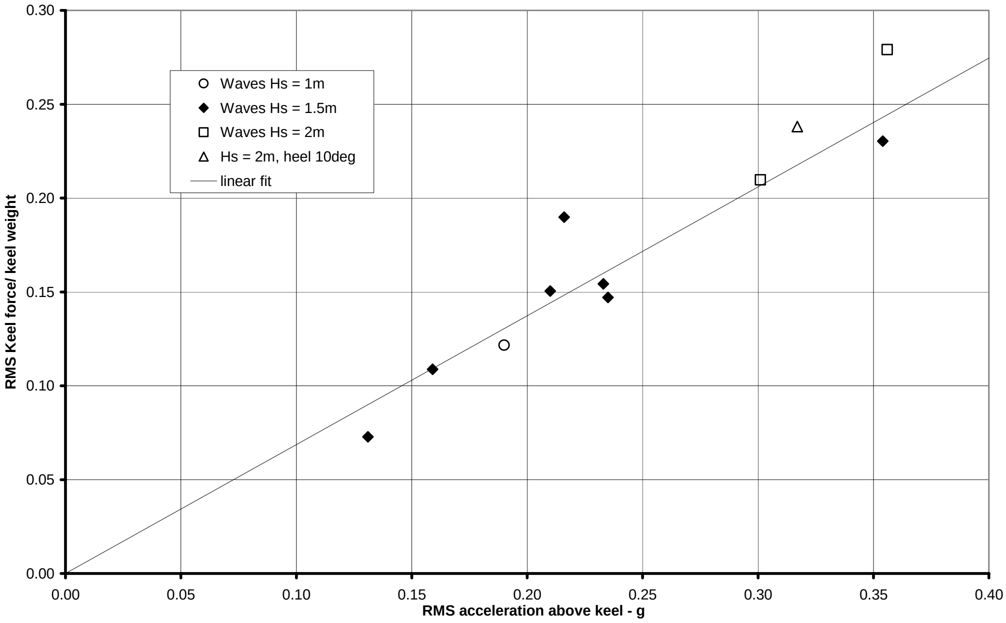

Figure 5. Variation of dynamic keel force component with acceleration for various speeds and wave periods