Lloyd's Register *Technical Papers*

The development of Trimaran Rules

by Dr F. Cheng, Mrs C. Mayoss and Mr T. Blanchard

Lloyd's Register

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Summary

The trimaran design has generated intense interest in recent years and the subject has been investigated around the world with a combination of design studies, numerical simulation, model testing and the construction of the large ocean-going technology demonstrator, RV Triton. It is becoming a viable option for both military and commercial applications.

With funding from the Ministry of Defence (MoD) and technical support by QinetiQ (QQ), Lloyd's Register (LR) is developing Rules for Classification of Trimaran Ships (Trimaran Rules). The Trimaran Rules include development of design loads applicable to the unique hull form of a trimaran, as well as a direct calculation procedure for analysis of new trimaran designs.

This paper describes briefly the structure and content of the Trimaran Rules, the rule development process involved and highlights some of the assumptions made. The emphasis of the paper is placed on the development of primary loads which are the main dimensional loads and the data utilised for calibrations.

Nomenclature

a_h	Heave acceleration (g)
a_z	Vertical acceleration due to roll and heave (g)
B_{mh}	Greatest moulded breadth of the main hull (m)
B_{wl}	Total moulded breadth of hulls at design waterline (m)
C_{bmh}	Block coefficient of the main hull
D_f	Longitudinal distribution factor
D	Depth of main hull (m)
F_f	Hogging or sagging correction factor based on the amount of bow flare, stern flare, length and effective buoyancy of the after portion end of the ship above the waterline.
F_{fh}	Hogging correction factor
F_{fs}	Sagging correction factor
f_{serv}	Service group factor depending on sea area of operations
g	Acceleration due to gravity and is to be taken as 9.81 (m s^{-2})
L_f	Factors varying with length
L_{sh}	Length of side hulls (m)
LT_f	Longitudinal torsional moment distribution factor
L	Rule length (m)
M_h	Horizontal wave bending moment (kNm)
M_{lt}	Longitudinal torsional moment (kNm)
M_{sph}	Splitting moment in hog (kNm)
M_{sps}	Splitting moment in sag (kNm)
M_{swh}	Still water bending moment in hog (kNm)
M_{sws}	Still water bending moment in sag (kNm)
M_{tt}	Transverse torsional moment (kNm)
M_{wh}	Vertical wave bending moment in hog (kNm)
M_{ws}	Vertical wave bending moment in sag (kNm)
M_o	Wave bending moment (kNm)
M_w	Vertical wave bending moment (kNm)
$\O_{max}$	Maximum roll angle (degrees) in beam sea conditions
	Water density (tonnes m^{-3})
V_{cd}	Volume of the cross-deck structure (m^3) on one side of the ship. The inside and outside boundaries of the cross-deck structure are to be taken as the vertical lines extending upward from points O and I, see Figure 6.
V_{mhs}	Volume of the main hull (m^3), which extends the length of the side hull. The outside boundary of the main hull is to be taken as a vertical line extending upwards from point O, see Figure 6
V_{sh}	Volume of one side hull (m^3). The inside boundary of the side hull is to be taken as a vertical line extending upward from the point O, see Figure 6.
W_{sh}	Total weight of one side hull including lightship weight and deadweight (tonnes).
x	longitudinal distance (m) from aft perpendicular, positive forward.
y	Transverse distance (m), from the centreline to the centre of gravity of the item being considered. y is positive to port and negative to starboard.
y_o	Distance between the centreline of the main hull and point O, as depicted in Figure 6.
y_{sh}	Distance between the centreline of the main hull and the centreline of the side hull, see Figure 6.
z	Vertical distance, in metres, from the baseline to the position or centre of gravity of the item under consideration. z is positive above the baseline.

1 Introduction

1.1 General

Lloyd's Register has already published extensive sets of rules to cover a multitude of ship types depending on their application, size, materials of construction and regulatory framework.

1.2 Existing Rules and Regulations

1.2.1 Rules and Regulations for the Classification of Ships (Ship Rules)

These rules cater for major commercial ships such as tankers, bulk carriers and container ships regulated under the framework of Safety of Life at Sea (SOLAS). These ships are generally large steel mono-hulls of robust construction and are typically ocean-going [1].

1.2.2 Rules and Regulations for the Classification of Special Service Craft (SSC Rules)

These rules cater for small to medium size craft with an emphasis on high speed and highly optimized construction, generally regulated under the framework of IMO International Code for High Speed Craft. These craft can be mono-hulls or catamarans of highly optimised construction with steel, aluminium or composite materials. Special Service Craft are generally operated in a restricted sea environment [3].

1.2.3 Rules and Regulations for the Classification of Naval Ships (Naval Ship Rules)

These rules cater for naval ships of all different sizes with varying operational environment. These ships are essentially steel mono-hulls and are regulated by the navies concerned. A distinct naval element is added in the form of military features to the hull structural requirements, machinery, electrical and control systems [2].

2 Rule structure

2.1 General

In general, classification rules cover a multitude of requirements for the design, construction and maintenance of ships. The elements described in 2.1 (a) to 2.1 (f) are typically included.

A trimaran design may fit within the framework of any of the three existing Rules listed in 1.2. Obviously a set of trimaran rules that encompass the following elements for each possible vessel type would be very extensive and voluminous indeed. A new approach for rule construction is therefore necessary.

2.1.1 Regulations

The regulations detail the relationships between various parties, builders, owners, class, flag and regulatory authorities. They also detail requirement for new construction surveys and periodic surveys that are required for the maintenance of class.

2.1.2 Materials

Rules for Materials provide detail requirements for material testing, certification and approvals.

2.1.3 Hull Structures

Hull structure rules provide requirements for the design of hull structures and they cover:

- Specification of loadings;
- Capability of structures to withstand the specified loadings; and
- Acceptance Criteria.

The load specification, capability assessment and acceptance criteria can either be expressed implicitly, as in the case of Ship Rules, or explicitly, as in the case of the SSC Rules, or a combination of both as in the case of Naval Ship Rules. They are usually referred to as prescriptive requirements.

Additionally, direct calculation procedures may also be provided and required to enable further checks to be carried out, for cases where prescriptive rules are considered to be inappropriate, or for cases where more advanced analysis is deemed to be more suitable, on an equivalent basis.

2.1.4 Machinery, Electrical and Control Engineering Systems

Machinery, Electrical and Control Engineering Rules detail the requirements for the safe installation, testing and operation of these systems.

2.1.5 Military Features

These requirements are important for naval ships and are essential features of the Naval Ship Rules.

2.1.6 Fire Protection and Stability

These aspects are generally covered by International Conventions and Regulations and are pre-requisites for classification.

2.2 Overlay Rule structure

From the discussion in Section 2.1 above, it is obvious that it would be impossible to develop a trimaran rule set to cater for ships that are covered by any of the three main rules listed in 2.1. The Trimaran Rules are therefore developed as an overlay set of requirements to Lloyd's Register's Rules and Regulations described above and they will focus on essential elements that are unique to trimaran hull forms.

The relationship between the Trimaran Rules and the Ship Rules, SSC Rules and Naval Ship Rules is illustrated in Table 1. As it may be observed, the development of the Trimaran Rules is centred upon the hull structure aspects with particular emphasis in loads and capability assessment. Other aspects such as rules and regulations for materials are already covered by existing rules.

Table 1 Relationship between Rule sets

Rule element	Naval ship Rules	Ship Rules	SSC Rules
2.1.1	Common	Common	Common
2.1.2	Common	Common	Common
2.1.3	Trimaran Rules	Trimaran Rules	Trimaran Rules
2.1.4	Common	Common	Common
2.1.5	Common	Not applicable	Not applicable
2.1.6	Common	Common	Common

Many sources of data, as illustrated in Figure 1, are being used in developing environmental loads and in scantling determination. These include a full ship finite element analysis, local detailed finite element models, segmented model tests, MoD research vessel Triton sea trials data, hydro-elastic analysis and computational methods. This data, combined with Lloyd's Register's experience in rule development, will contribute to a rationally based set of Trimaran Rules.

For conventional ships, parametric formulae which are based on extensive service experience and theoretical experience, coupled with model test results, are available to provide a basis for Rule formulation. For trimaran vessels, there is very little service experience and design is mainly based on direct calculations verified by model experiments. Whatever the approach adopted, there is a need to provide guidance as to the range of validity of the various formulae and direct calculation methods, and they should be based on a unified philosophy and lead to a consistent level of safety.

In the development of the Trimaran Rules, major effort has been put in the development of empirical formulae to provide initial design solutions, an advanced calculation procedure is then provided by which a detailed analysis may be performed. These include procedures for developing loads, suitable modelling and loading techniques for structural analyses and appropriate acceptance criteria.

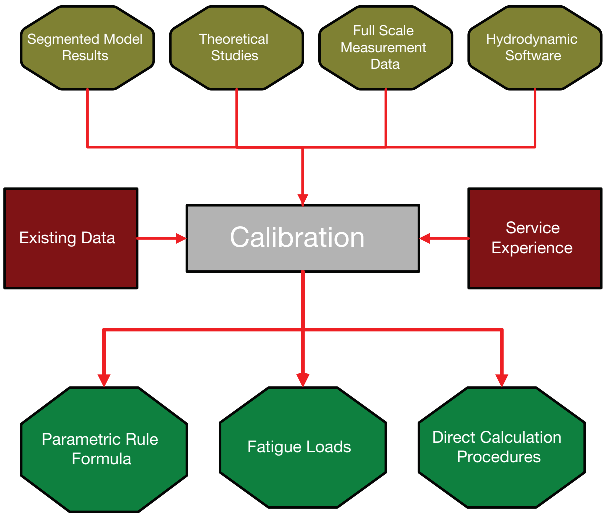


Figure 1: Data sources for load calibrations

3 Philosophy for Rule formulation and direct calculations

3.1 Rule development process

The design procedure, in the broad sense, involves the entire process from the initial concept to the final approved design ready for fabrication/manufacture. An important part of this process is the design control, or structural analysis, to ensure reliability against structural failure.

The design control consists of a number of steps:

- evaluation of environmental conditions,
- analysis of loads,
- analysis of response,
- evaluation of strength, and
- control of safety.

The rule development process will have to take all these elements into account. The analysis methods used may be based on theory, experiments or full scale measurements. An additional essential step in this development process is the calibration of the result against service experience as illustrated in Figure 2.

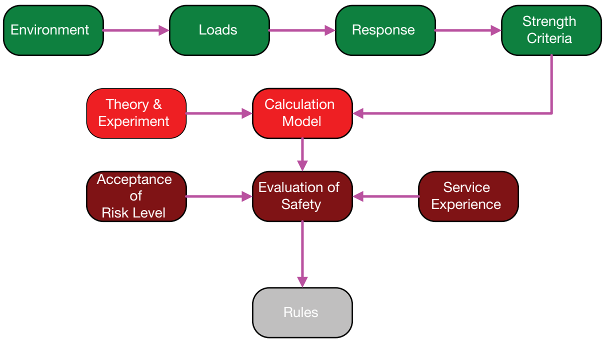


Figure 2: Rule Development Process

Conventional monohull ship structural design has, as its basis, about a hundred years of combined data and experience. This background allows the structural design of the hull to be pursued by relatively wellproven design methods. Within limits, one hull form is similar to previous hull forms, and the design is relatively forgiving to under or overestimation of the loads. Any radical departure from the normal hull forms would severely de-value the usefulness of accumulated expertise, as knowledge of the loads is essential for design of the hull structure.

The key element in the development of design procedures for trimaran vessels is the prediction of the loads acting on the hull structure. For trimarans, an initial emphasis must be placed on theory and experimental data in the absence of experimental data. Consequently, a level of conservatism must be applied in order to maintain an acceptable risk level.

3.2 Demand and capability approach

Trimaran ships can experience a combination of all the loads, described in Section 3, acting on the hull and their prediction is extremely complex. It is considered necessary to adopt a modern approach to the development of these Rules as illustrated in Figure 3.

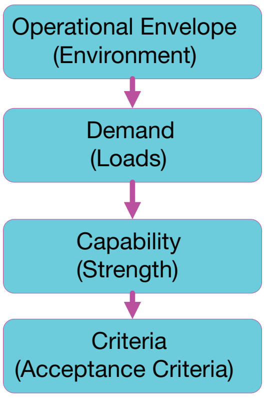


Figure 3: A modern rule format

This decoupling of load, strength and acceptance criteria opens the possibility to base new design approval on direct calculations using a similar approach, as illustrated in Figure 4.

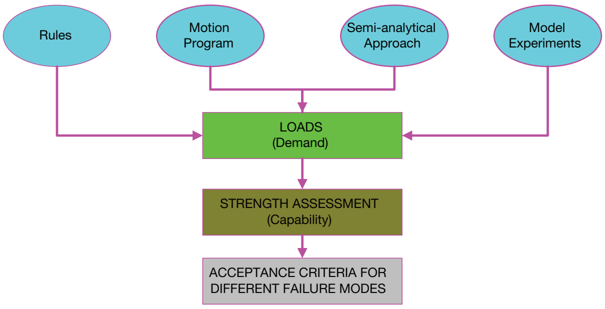


Figure 4: Load determination

From a class point of view, this is important as while the classification rules should be as simple as possible to use, the direct calculation approach should provide the same uniform technical standard for all kinds of hull configurations and sizes thus allowing for optimisation by more detailed analysis.

It is obvious that while the strength assessment techniques (finite element analysis, for example) can be applied directly to conventional designs, it is more difficult to establish design load formulations that are equally well adapted to different hull configurations, speed ranges and ship sizes. Therefore the main emphasis for rule development would be the determination of loads.

4 Classification of loads

4.1 General

The overall load on a trimaran, or indeed any ship, consists of four components: namely; primary, secondary, tertiary and internal loads as illustrated in Figure 5. The classification of loads as primary, which affect the hull as a whole; secondary, which affect large panels of the hull such as bulkheads; and tertiary or local, which have a local effect only, has been made for convenience in relation to structural considerations. It has developed to satisfy the needs of the structural engineers requiring a simplified approach to structural analysis problems. All loads, with the exception of thermal loads, originate from forces or pressures applied over small areas. Whether these loads are subsequently treated in a local or an integrated form is largely a matter of analytical convenience. However, such a classification has found to be useful in identifying the dominating forces for direct calculation purposes.

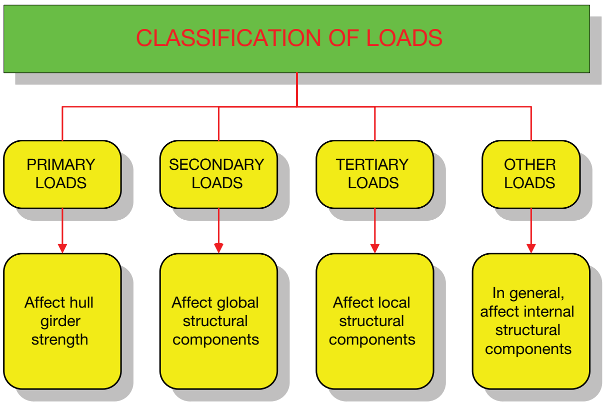


Figure 5: Classification of loads

4.2 Primary loads

The primary loads which must be considered for the design of trimaran are:

4.2.1 Wave Induced Bending Moment, and Still Water Bending Moment

For mono-hull ship, the longitudinal wave induced bending moments are the most important primary loads acting on the vessel and are most severe in head seas.

Likewise, the longitudinal wave induced bending moment acting on a trimaran will be of significance and is maximised in the head sea condition. This primary load will drive the design of the longitudinal hull girder. There are, however, additional primary loads influencing the design of the transverse structure.

4.2.2 Splitting Loads

A splitting moment occurs when the side hull is being pushed away or towards the centre hull by wave actions. Consideration of the splitting loads is of particular importance in determining the scantlings of the cross-deck structure.

Available model data and theoretical studies have provided some insight into the nature and magnitude of these loadings on catamarans and SWATH ships. Further model tests and Triton trials data have been more recently available for derivation of these loads for trimarans.

4.2.3 Torsional Loads

The torsional loads acting on the trimaran are of similar importance to the splitting loads, especially for the strength assessment of the cross-deck structure. The most severe heading for torsional loads is quartering (bow or stern) seas. Though the responses are similar, the torsional load may be considered to act about the transverse or longitudinal axis.

The transverse torsional load, together with the splitting loads, drives the scantling design of the cross deck structure.

The longitudinal torsional load acts on the longitudinal hull girder, particularly the centre hull. In most cases, this load will not be of great significance as the hull girder is a closed section. However, in cases where the centre hull is extremely slender, the side hulls are relatively small and/or the transverse distance between the side hulls and centre hull is large, this load may become significant.

4.2.4 Horizontal Bending Moment

As with the longitudinal torsional moment, the horizontal bending moment is not likely to be of great significance. However, in combination with other global loads, as prescribed in the Advanced Calculation Procedure, the horizontal bending moment may influence some local structure, such as the connection of the cross-deck structure to the main and side hulls.

4.2.5 Fatigue Loads

Because the majority of the loads imposed on trimaran ships are cyclic in nature, the possibility of failure by fatigue must never be forgotten. Indeed most structural failures that occur in service life of a ship result from fatigue. While there is a large body of knowledge on the fatigue performance of conventional designs, there is very little work done and little knowledge in relation to trimaran ships. The most important task in the question of fatigue performance of trimaran ships is the determination of the fatigue loading.

4.3 Secondary and tertiary loads

The secondary load and tertiary loads which must be considered for the design of large high speed craft are:

4.3.1 Loads in a Seaway due to External Water Pressures, including Slamming and Green Water Loads.

This category of loads is probably the most important from a local strength point of view, and in fact, is often the governing criteria for the design of the small to medium size vessels. In general, these loads can be sub-divided further into the following components:

- **Bottom slamming**
  Bottom slamming arises as the result of the pitching and heaving motion of the ship at speed where it usually undergoes a severe hydrodynamic impact on re-entry. The impact is typically rapid and intense to generate a high pressure impulse on the bottom plating. This event is often accompanied by a loud booming sound, particularly apparent for larger ships. The duration of this type of slamming force is in general less than 100 milliseconds. Bottom slamming has been the most common cause of hull structural damage. The magnitude and duration of the impact pressure depend on, or are sensitive to, the angle and relative shape of the hull and the water surface, and the encounter velocity and frequency.

- **Bow flare slamming**
  Bow flare slamming is the rapid immersion of the upper flared portion of the bow deeper into the water. This is a more gradual phenomenon than bottom slamming, usually without any sound unless the flare is very concave. This event lasts for less than a second, but nevertheless imparts a relatively sudden and intensive force to the forward part of the ship. The bow flare slamming is an important consideration for fine hull form ships. The main difference between bottom and bow flare slamming is that the forward bottom slamming is always associated with the emergence of the forebody, while bow flare slamming is not.

- **Cross-deck slamming**
  This type of slamming arises as a result of the heaving and pitching motion of the ship causing the impact of waves on the flat underside centre body and leading edge of the cross-deck structure. This phenomena is exacerbated by the ‘funnelling effect’ between the side and main hull. Such forces can result in large accelerations and related structural loads acting on the ship which must be accounted for in the determination of the local strength of the cross deck structure.

- **Green sea loading**
  The green sea loading of the wet deck forward is another source of transient loading that excites vibratory response and is caused primarily by the relative ship motion to the water’s surface. In many cases, this load may simply be the static head of water scooped up by the bow as it submerges downward until it runs off. The duration of this load is therefore relatively long. However, there may be a dynamic component, especially if the ship is moving forward at high speed into head sea, particularly common for fine form ships. In some instances, the whipping stress generated can constitute a sizable percentage of the sagging bending moment.

4.3.2 Load due to the Impact of Solid Objects and Robustness Considerations

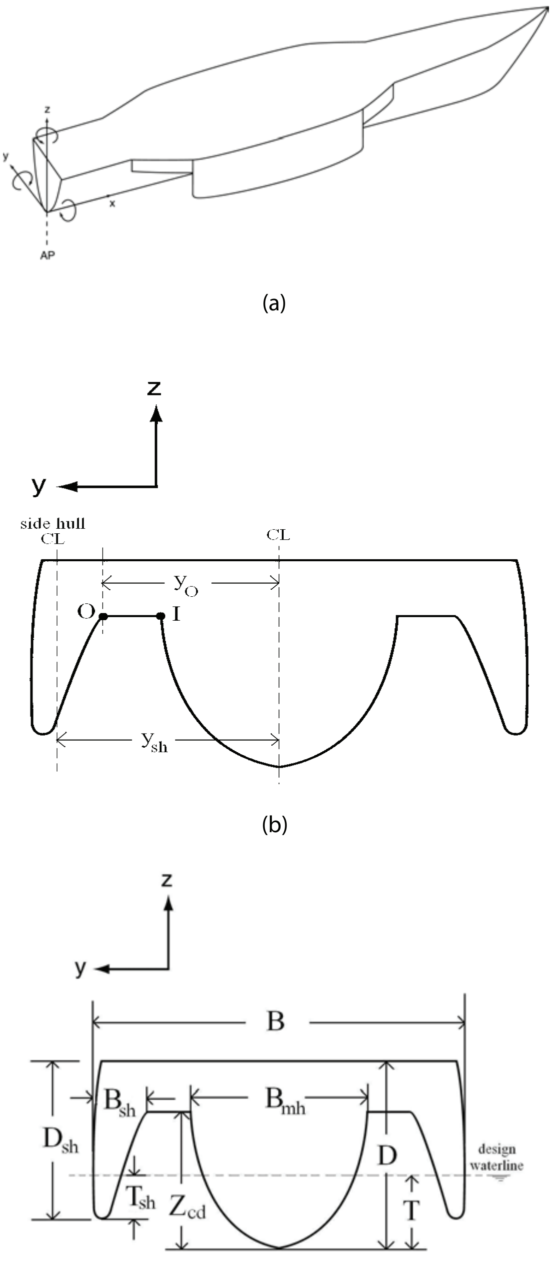
These types of loads are very difficult to quantify. Traditionally, they have been taken care of by specifying minimum scantlings based upon service experience. It has been argued by many that existing robustness requirements do not allow the full use of advanced materials and technology. However, until more service experience is gathered for trimarans, these type of requirements are considered necessary.

4.4 Other loads

Other types of secondary loads include thermal loads, loads arising as a result of cargo (weight and distribution) and vessel motions, and due to sloshing of liquids. These loads are important and are required to be taken into account in design. However these types of loading are common to all types of vessels and are therefore not uniquely specified in the Trimaran Rules.

5 Rule formulation for primary loads

Major efforts have been devoted to the derivation of primary load components as these loads are the principal dimensional loads for structural synthesis. Empirical formulae are provided for the loads based on a database of existing designs with calibration carried out using the direct analysis results provided by QinetiQ. The data sets used for direct analysis are those from numerical simulations, model test data and Triton sea trial measurements. Sign conventions and definitions used are shown in Figure 6.



(a)

(b)

(c)

Figure 6: Sign conventions and definitions

5.1 Vertical bending moment [CAM5]

The vertical bending moment formulae implemented in the Trimaran Rules have similar form to that of a mono-hull ship. The premise is that the trimaran behaves similarly to a mono-hull. All available trimaran data against which the moment values are validated suggest that the magnitude is reasonable. A comparison of the maximum Rule values calculated for the designs in the database versus the QinetiQ parametric analysis results is provided in Figure 7.

The rule formulae are given as:

$$M_w = F_f D_f M_o$$

$$M_{wh} = F_{fh} D_f M_o \quad \text{(Hog)}$$

$$M_{ws} = F_{fs} D_f M_o \quad \text{(Sag)}$$

$$M_o = 0{,}1 L_f f_{serv} L^2 B_{wl} (C_{bmh} + 0{,}7)$$

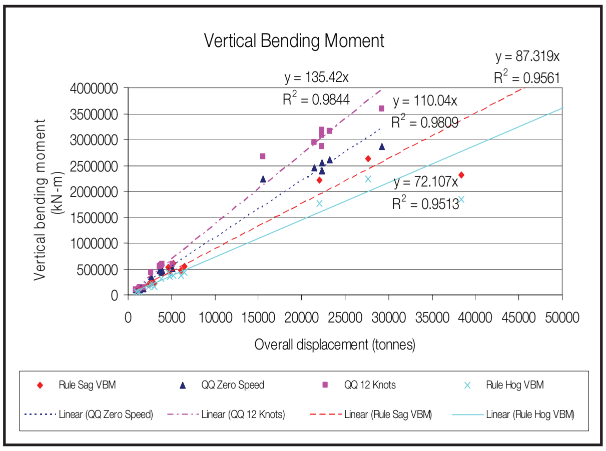


Figure 7: Vertical bending moment comparisons

The distribution factors for vertical wave bending moments vary according to the side hull position. This distribution factor is given by:

Df = 0 at aft end of L

$$= 1 \text{ from } \left(0{,}35 - \frac{x}{4L}\right) L \text{ to } \left(0{,}6 - \frac{x}{4L}\right) L$$

= 0 at forward end of L

It is assumed that the side hull position has a greater influence on the longitudinal distribution of the vertical bending moment than the relative displacement of the side hull. The distribution factors were tested against results from QinetiQ's parametric assessment as depicted in Figure 8. This plot is provided to represent only the fore and aft distribution of the moment, the magnitudes of the moment have been normalised.

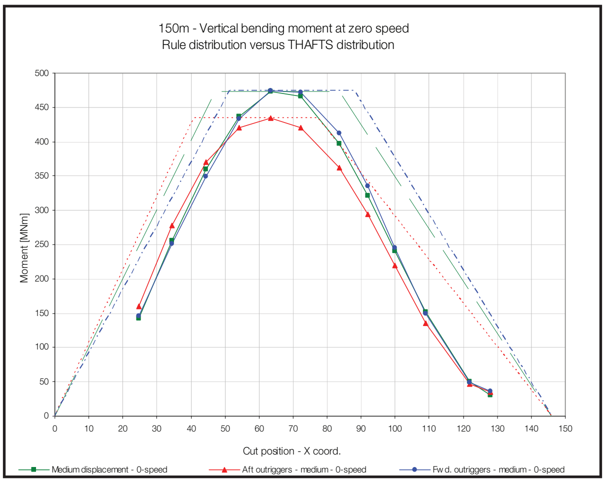


Figure 8: Vertical bending moment distribution factors

5.2 Horizontal bending moment

The horizontal bending moment was derived on the same basis as the vertical bending moment except that the pressure distribution is integrated over the depth rather than the breadth of the ship. The factor, Lf, used for this equation was then derived using QinetiQ's parametric results and comparing this to the calculated Rule values, see Figure 9. A comparison of the horizontal bending moment versus overall displacement is given as Figure 10. The magnitude of the horizontal bending moment is given as follows:

$$M_{\mathrm{h}} = D_{\mathrm{f}}\, L_{\mathrm{f}}\, f_{\mathrm{serv}} L^2 D (C_{\mathrm{bmh}} + 0{,}7)$$

$$Lf = -\left[70 \left(\frac{L}{100} \right)^2 + 5L \right] \mathrm{x}10^3$$

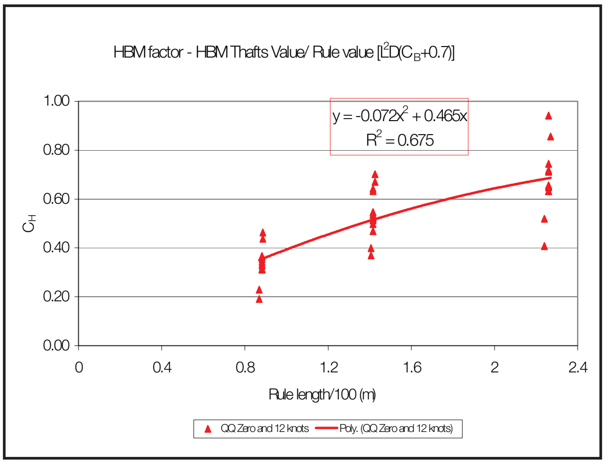


Figure 9: Determination of factor, Lf

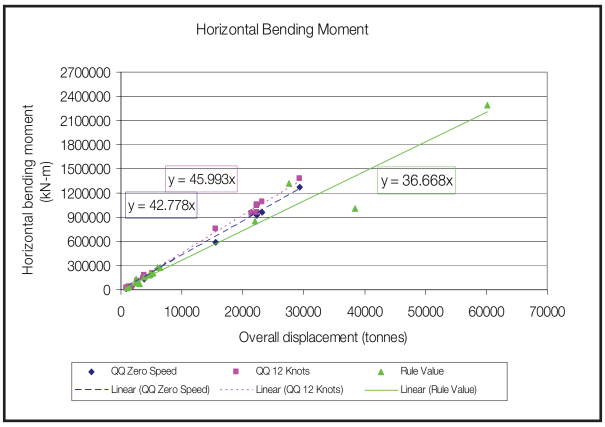


Figure 10: Horizontal bending moment comparison

The distribution factor is taken to be the same as for the vertical bending moment as the premise of the calculation is the same.

5.3 Longitudinal torsional moment

The longitudinal torsional moment is derived using a conservative equivalent static wave to that occurring in a quartering sea. This mass is multiplied by the heave acceleration. Potential pitch and roll acceleration components are assumed to cancel within the scope of this simplified calculation. A distribution factor was then derived using the parametric data from QinetiQ, see Figure 11.

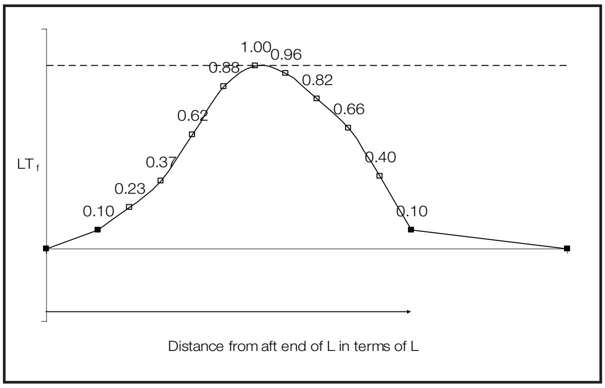


Figure 11: Distribution Factor LTf

Comparison of results is shown in Figure 12. It should be noted that this comparison is made versus side hull displacement, resulting in a significant spread in the plot. This spread may not exist if a volumetric comparison is plotted.

$$M_{\mathrm{lt}} = 7{,}5 L T_{\mathrm{f}}\, f_{\mathrm{serv}} \rho \left(V_{\mathrm{sh}} + V_{\mathrm{cd}} + \frac{V_{\mathrm{mhs}}}{2} \right) y_{\mathrm{sh}} a_{\mathrm{h}}$$

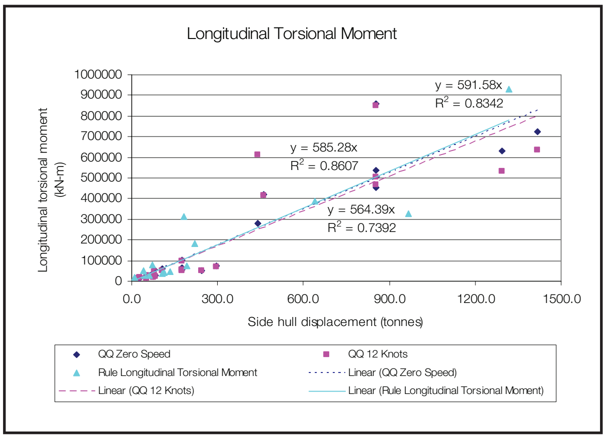


Figure 12: Longitudinal torsional moment comparison

5.4 Splitting moment

The splitting moment is also derived from first principles in a similar manner to those currently used for a twin hulled ship. In the case of the trimaran, there is a hog and sag splitting moment. The hogging moment assumes the side hulls are completely out of the water, while the sagging assumes complete submersion of the side hulls.

The rule formulae for splitting moment at point I are given as follows (see Figure 6 for definitions):

$$M_{sph} = 25\, f_{serv} W_{sh} a_z \left(y_{sh} - \frac{B_{mh}}{2} \right) \text{ (Hog)}$$

$$M_{sps} = 15\, f_{serv} \frac{(\Delta - 2W_{sh})}{2}\, a_h \left(y_{sh} - \frac{B_{mh}}{2} \right) \text{ (Sag)}$$

The rule formulae for splitting moment at point O are given as follows (see Figure 6 for definitions):

$$M_{sph} = 25\, f_{serv} W_{sh} a_z (y_{sh} - y_O) \text{ (Hog)}$$

$$M_{sps} = 15\, f_{serv} \frac{(\Delta - 2W_{sh})}{2}\, a_h\, (y_{sh} - y_O) \text{ (Sag)}$$

The magnitudes of the splitting moments are compared to QinetiQ's parametric values, as well as to design values for Triton and the two frigate designs. The factors for the splitting moments were calibrated against the parametric values, see Figures 13 and 14. A factor of 2,5 was calculated for the hogging splitting which is coincidentally the same as the factor applied for the catamaran splitting moment. The sagging factor obtained is 1,5. The comparison of splitting loads to design values resulted in reasonable agreement.

Long term analysis of QinetiQ's model tests was also performed for splitting loads. Load gauges were fitted to four locations on the models; at the connection of the cross deck beams to the main hull, forward and aft. Although these models were not segmented models, but rigid models, they gave a good indication of the general magnitude of the computed values. The general magnitude of the long term splitting moment is in the order of that obtained using the Rules.

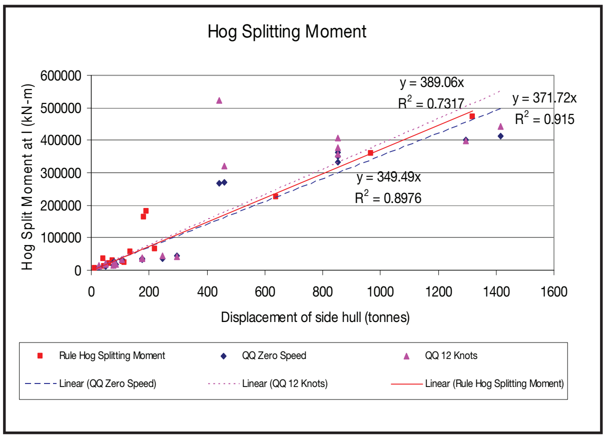


Figure 13: Hog splitting moment comparison

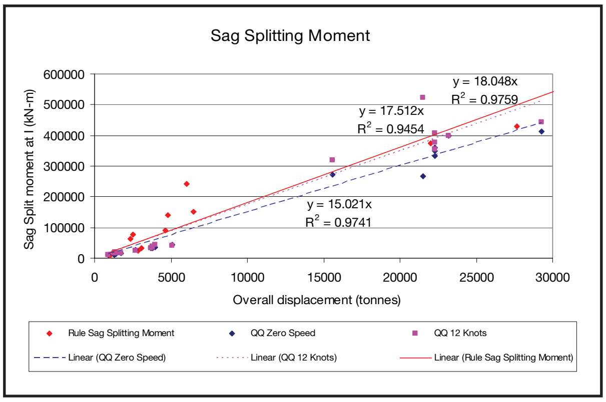


Figure 14: Sag splitting moment comparison

5.5 Transverse torsional moment

The transverse torsional moment is calculated in a similar manner to the longitudinal torsional moment except that the moment is calculated about the transverse axis of the ship. The mass is also multiplied by the heave acceleration. Factors are again calculated using QinetiQ's parametric results. Comparisons are provided in Figure 15.

$$M_{tt} = 3{,}75 f_{serv} \rho (V_{sh} + V_{cd}) L_{sh} a_b$$

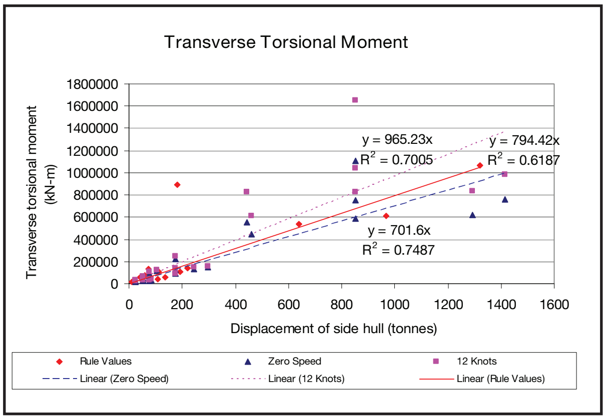


Figure 15: Transverse torsional moment comparison

6 Rule formulations for secondary and tertiary loads

Secondary and tertiary loads are considered local in nature and they were mainly derived from existing rule formulations from the Ship Rules, SSC Rules and the Naval Ship Rules. Thus far, they have been calibrated against the scantlings of RV Triton and two MoD frigate designs. Validation against other designs is ongoing and University College of London (UCL) is contracted by MoD to provide some of this validation.

Scantlings for RV Triton are calculated based on the empirical formulae and compared with those fitted. The comparisons for tertiary structures are shown in Figures 16 and 17. It can be observed the robustness criteria in the form of minimum requirements are, in some cases, governing. These comparisons do not include scantling requirements for impact loads. In all cases the as built scantlings are in compliance with the rule requirements.

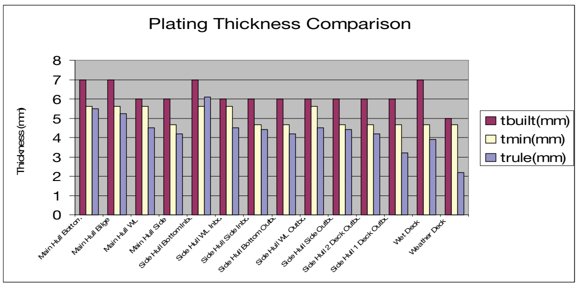


Figure 16: Comparison of rule and as built scantlings

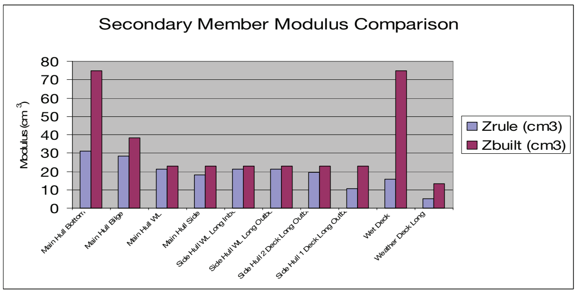


Figure 17: Comparison of rule and as built scantlings

7 Advance calculation procedure

After obtaining an initial design using the empirical formulae given in the Rules, the designer, builder or owner is to undertake a detailed analysis of the structure according to the Advanced Calculation Procedure. This procedure consists of Structural Strength Analysis and Verification section which is mandatory, as well as an optional Load Development Procedure. A flow diagram describing the overall analysis is provided as Figure 17.

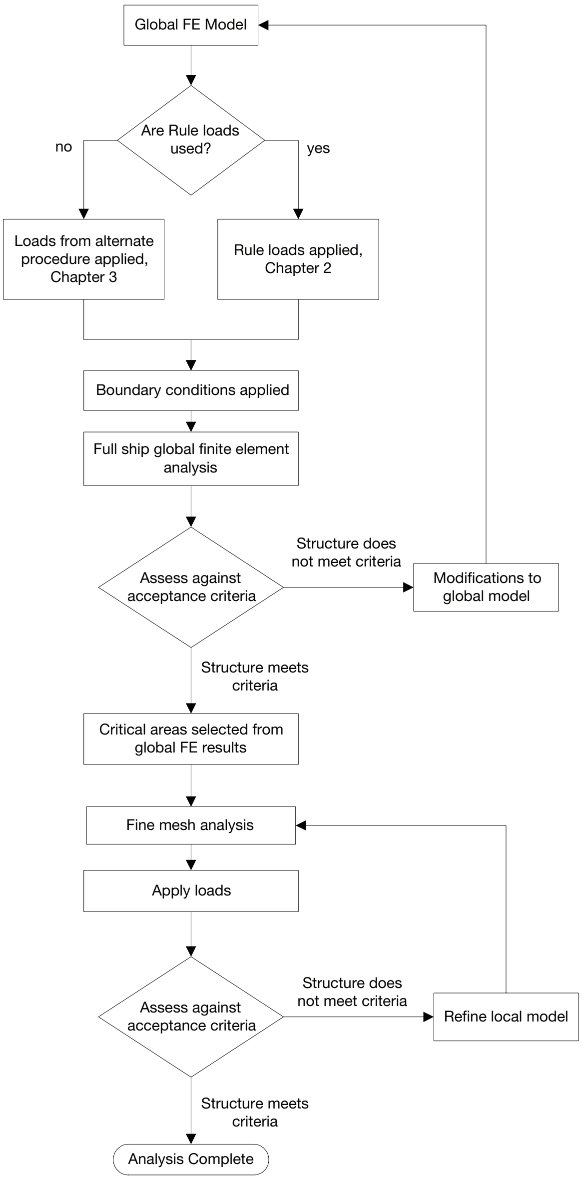
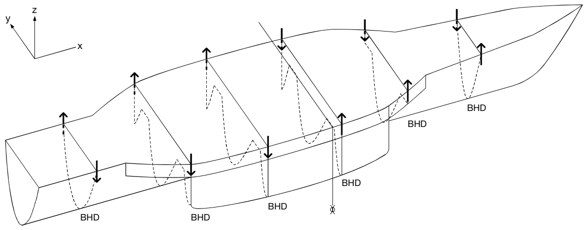


Figure 18: Advanced Calculation Procedure Flow Diagram

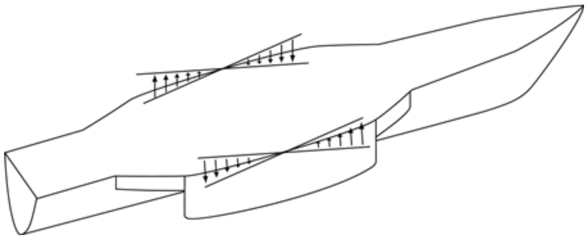
7.1 Structural strength analysis and verification

This portion of the Advanced Calculation Procedure describes how to undertake a finite element analysis of the trimaran structure. This includes guidance on modelling of global and local structure, as well as details on application of loads for each of the primary loads. Figure 19, for example, depicts the application of load for the longitudinal and transverse torsional moments.

Also included in this procedure are requirements for boundary conditions, as depicted in Figure 20, as well as details on load combinations to be evaluated and acceptance criteria against which to evaluate the structure.



(a) Longitudinal Torsional Moment



(b) Transverse Torsional Moment

Figure : Load Application for Torsional Moments

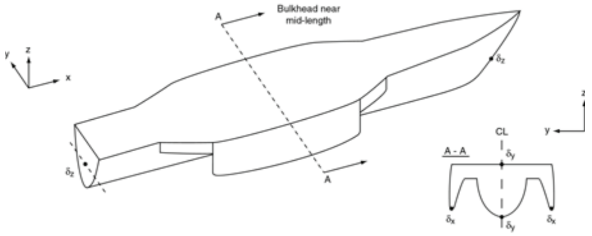


Figure 20: Boundary Conditions for Global Model

7.2 Load development procedure

This portion of the Advanced Calculation Procedure describes how to undertake the development of wave-induced loads acting on the structure by a ìfirst principlesî approach. The procedure provides more realistic loading scenarios, improving the user's confidence in the loads which are to be applied to the finite element model. It provides a method to derive the design loads using direct calculation techniques. These loads may be used as the design loads instead of the Rule loads in all aspects of structural assessment provided that the proposed loads are submitted and approved by LR. The procedure then describes how to apply these loads to the finite element model. An overview of the steps of the Load Development Procedure is given in Figure 21.

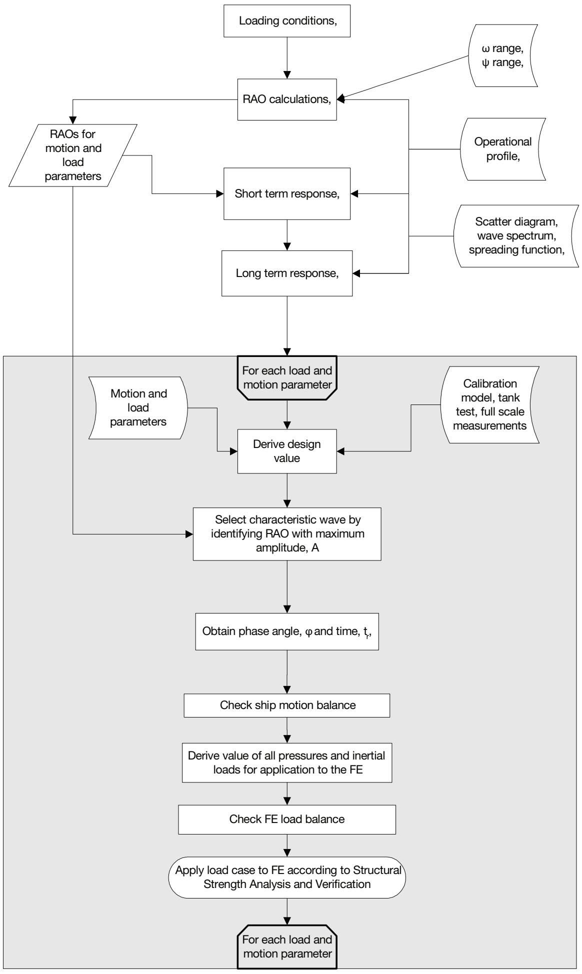


Figure 21: Load Development Procedure

8 Load combinations and acceptance criteria

Parametric formulae for primary, secondary and tertiary loads are provided for the initial derivation of scantlings. It is then required that a three dimensional finite element analyses be carried to examine the adequacy of the global strength in accordance to the acceptance criteria given in the Rules.

The loads applied to the finite element model may either be derived according to the Advanced Calculation Procedure or the Rule values may be used. If the Rule values are used for the primary loads, then the load combinations described in 7.1 are to be evaluated. If the loads are obtained from direct calculation, pressures, which inherently include a combination of primary responses, will have been derived.

8.1 Load combinations

There are four sea conditions for which the primary responses are maximised. These are as follows:

8.1.1 Head Seas

The head sea conditions correspond to the maximum hogging and sagging bending moments. The main areas that require examination are the mid-ship structure, deck and keel longitudinal stresses and maximum shear at the side hull termination.

For the hogging condition, the following load combinations are to be applied to the model:

$$M_{swh} + M_{wh} + 0{,}3M_{sph} + 0{,}2M_{tt}$$

For the sagging condition, the following load combinations are to be applied to the model:

$$M_{sws} + M_{ws} + 0{,}3M_{sps} + 0{,}2M_{tt}$$

8.1.1 Bow Quartering Seas

The bow quartering sea conditions correspond to the maximum longitudinal torsional moment and the maximum horizontal bending moment. Main areas that require examination include the torsional strength of the main hull, warping of the cross deck, as well as the connections of the side hulls to the main hull through the cross deck structure.

For the examination of the longitudinal torsional strength, the following load combination is to be applied to the model:

$$-0{,}3M_{h} + 0{,}3M_{sph} + M_{lt} + 0{,}3M_{tt} \pm M_{sw}$$

where M_{sw} is the still water bending moment (M_{swh} or M_{sws}) that gives the highest stress for the combination.

For the examination of the horizontal bending strength, the following load combination is to be applied to the model:

$$M_{h} + 0{,}4M_{sph} -0{,}3M_{tt} \pm M_{sw}$$

where M_{sw} is the still water bending moment (M_{swh} or M_{sws}) that gives the highest stress for the combination.

8.1.3 Beam Seas

The main areas that require examination are the bending and shear strength of cross deck structures, and connections of side hulls to the main hull.

For the splitting hog condition, the following load combination is to be applied to the model:

$$M_{swh} + 0{,}1M_{wh} + M_{sph} + 0{,}2M_{lt}$$

For the splitting sag condition, the following load combination is to be applied to the model:

$$M_{sws} + 0{,}1M_{ws} + M_{sps} + 0{,}2M_{lt}$$

For the maximum roll condition, the following load combination is to be applied to the model:

$$M_{sws} + M_{ws} + \theta_{max}$$

is determined from simplified formulae given in the Rules or from direct computations.

8.1.4 Stern Quartering Seas

The main areas that require examination are the torsional strength of the hull, warping of the cross deck and the connections of the side hulls to main hull through the cross deck structures.

For the examination of the transverse torsional strength, the following load combination is to be applied to the model:

$$M_{swh} + 0{,}2M_{wh} - 0{,}2M_{h} + 0{,}5M_{sph} + M_{tt}$$

8.2 Acceptance criteria

The results from the finite element analysis are to be assessed against acceptance criteria on yield, buckling and deflection as given in the Rules. Similar acceptance criteria are used to assess the structure using the empirical formulae, thus maintaining a consistent safety margin.

9 Conclusions

The trimaran design has now become a viable option for both military and commercial applications. With funding from the MoD and support by QinetiQ and more recently University College London, Lloyd's Register is developing Rules for Classification of these vessels. The Trimaran Rules development involves principally the development of design loads applicable to the unique hull form of a trimaran, as well as a direct calculation procedure for analysis of new trimaran designs.

The development of the these rules has been a very complex task as there is relatively little data and service experience available for calibration in comparison with conventional mono-hull ships. Efforts have been put in the area of load development, in particular, the development of primary loads. It is recognised that it is not sufficient just to provide prescriptive design formulae, but it is also important to provide the necessary framework to achieve a safe and economic design through direct analysis. The Trimaran Rules adopt a modern demand and capability approach which enables direct analyses to be performed for both load computation and strength analysis. The overall philosophy of the Rules is to ensure that a consistent level of safety is achieved whatever route the design is generated, through a consistent set of acceptance criteria.

It is anticipated the Trimaran Rules will be published formally in 2005.

10 Acknowledgements

The authors wish to express their sincere thanks to the Ministry of Defence for their financial support and to QinetiQ for their technical support during the development of the Trimaran Rules. Colleagues in Lloyd's Register who contributed to these Rules are gratefully acknowledged.

Views expressed in this paper are solely those of the authors and they do not represent necessarily the views of Lloyd's Register and any supporting organisations.

11 References

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