SEAKEEPING IN THE NAVIGATION – EXAMPLE IN TRIMARAN SHIPS

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Received 26 February 2012; accepted 11 May 2012

Abstract: Seakeeping ability is a measure of how well-suited a floating structure is to conditions when underway. A ship, boat, vessel or any other floating structure which has good seakeeping ability is said to be very seaworthy and is able to operate effectively even in high sea states. This paper presents an investigation of the seakeeping behaviour of a fast ferry multihull, which is a typical trimaran for operations in the mediterranean sea. Numerical results and the measurements at the trimaran agree quite well in frequency and time domain. The movements in trimaran ships are less than the movements of a conventional boat (monohull) equivalent. Assuming linearity, the trimaran's raos (Response Amplitude Operator) depend only on the trimaran's geometry, speed and heading. Although seakeeping theory has been extensively applied for monohulls, such studies have not been accomplished for trimarans. This paper provides important information regarding the seakeeping of trimaran ships and how to be used in numerous scenarios.

Keywords: naval engineering, seakeeping, trimaran ships.

1. Introduction

In the famous picture below (Fig. 1) we can see how a small fishing boat is able to survive to big waves, but it is far from being a comfortable condition for the fishermen aboard. These two different ideas, survival and comfort, are critical ideas to have in mind for any floating structure, and of course for any seastead that pretend to colonize the ocean.

Seakeeping directly impacts the design of a ship. Ship motions are considered when determining the principal dimensions of the ship and in developing the general arrangements of the ship's internal spaces. For example, in most vessels the far forward parts of the ship experience the worst ship motions and are commonly unacceptable for berthing passengers or crew. In exceptional cases where ship motions pose a threat to crew, structure or machinery, or when ship motions interfere with the ability of the ship to accomplish its mission, then the design must be modified so that ship motions are reduced.

To illustrate it better in the whole engineering design methodology we present the ship design spiral. The spiral (Evans, 1959; Laverghetta, 1998) describes the process as a sequence of specific design disciplines, both of synthesis (e.g. hull geometry, arrangement) and analysis (e.g. stability, seakeeping) in order to achieve a balanced design that meets the requirements.

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Fig. 1.
The Great Wave of Kanagawa

The spiral depicts important characteristics of the design like the iterativeness and the progressive elaboration of the design. However, the spiral represents the process in a macroscopic level. Some of those disciplines incorporate hundreds of activities. The seakeeping is a good example of that, as we will see later on.

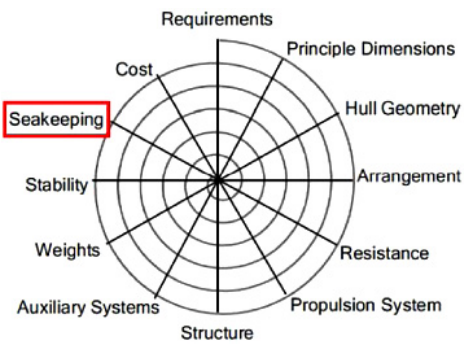

Fig. 2.
Generic Ship Design Spiral

In regards to seakeeping, comparison of different designs or assessment of a single design against specified criteria is dependent on accurate information for three concepts that will be described in next sections. Evaluation of seakeeping performance depends heavily on the environment that the vessels are being subjected to and the criteria which are being used to compare the designs. This is one of the reasons why comparing seakeeping performance is much more complicated than comparing calm water resistance or power requirements to achieve a specific speed. That implies that seakeeping analysis is a much more difficult problem compared with that of calm water resistance, and until fairly recently it has taken a very poor second place in preliminary hydrodynamic design for the majority of vessels (Perez and Lamas, 2011).

This is particularly true in the merchant fleet, the vessel's seakeeping performance being addressed relatively late in the design spiral (Fig. 2) by means of expensive model tests. In fact, a vessel's seakeeping characteristics depend on so many interrelating factors that it is virtually impossible to say what will happen if a specific change is made to the hull form without doing reasonably detailed analysis. This is because the answer depends not only on the hull form but also on the sea environment and the criteria against which the vessel is being assessed (the three main concepts that will be developed). Thankfully, designers now have several seakeeping tools to choose from, which are ideal for preliminary design. With these tools, a large number of design candidates may be easily and quickly compared and the best selected. Seakeeping computer programs are sophisticated enough and computers now powerful enough for a potential design to be analyzed in a matter of minutes; such an assessment could not be achieved in a towing tank.

With appropriate analysis, it is possible to optimize a hull form for specific routes (and the sea conditions that the vessel is likely to encounter on these routes) and the characteristics which are important to the successful completion of the vessel's mission. For instance:

- A cargo vessel might be optimized to reduce added resistance.
- A passenger vessel may be optimized for passenger comfort.
- A naval vessel could be optimized to minimize motion on the helicopter deck.

Each part of the problem, sea environment, vessel response and criteria, is of equal importance; however, perhaps the third is the least well understood and requires careful consideration.

This technical paper clarify the seakeeping calculation in Trimaran ships. In the past, seakeeping tank test were not affordable in most of the projects. There were not softwares prepared expecifically for calculating multihulls seakeeping, so it produces that there are not technical papers showing a trimaran seakeeping calculation.

2. Problem/Concepts to Understand Seakeeping

The overall performance of ships, vessels and any other offshore structure floating in the ocean depends on the seakeeping performance in specified ocean areas where the vessel is designed to operate. The seakeeping performance procedure is based upon the probability of exceeding specified vessel motions in a sea environment particular to the vessel's mission (the same three ideas explained in previous section, but with other wording). Given the operational area of the vessel, the percentage of time the vessel operates in a particular sea state can be determined from an oceanographic database through application of the Response Amplitude Operator (RAO). The predicted responses in motions are compared to the motion limiting criteria to obtain the operability indices. However, the operability indices are strongly affected by the chosen limiting criteria.

Therefore, it is required to describe three principal concepts in order to understand the seakeeping performance. Or in another words, seakeeping analysis is essentially a three part problem, as it is further described.

2.1. First Problem/Concept: Sea Environment

Estimation of the likely sea environmental conditions to be encountered by the vessel: the ocean conditions under which the vessel is operating. This can be described as sea state, wind speed, geographic region or some combination thereof. The oceanographic databases and wave spectra defines the sea environment.

2.2. Second Problem/Concept: Vessel´s Response in Motions

Prediction of the response characteristics of the vessel (Perez and Lamas, 2011): the response of the vessel in form of motions to the environmental conditions. The responses are a function of:

- The design sea state/environment conditions described above that gives the wave spectrum.
- The vessel characteristics: hull form and weight distribution, that give the transfer function called RAO, that is used to evaluated the motion of a vessel in the six degrees of freedom.

As commented, nowadays, computers have facilitated this problem. In the past, seakeeping tank test were not affordable in most of the projects.

2.3. Third Problem/Concept: Vessel´s Mission and Limiting Criteria

To define the Vessel´s Mission: what the vessel is intended to accomplish together with the specification of the criteria used to assess the vessel's seakeeping behaviour. This also defines the way in which the performance of different vessels is compared. The role of the vessel while at sea that is given by the motion limiting criteria, or seakeeping performance criteria: the established limits for the ship's responses. These are based on the ship motions and the accelerations experienced, and include comfort criteria such as noise, vibration and sea sickness, performance based values such as involuntary speed reduction, and observable phenomena such as bow immersion. Clearly, a drillship and a ferry have different missions and operate in different environments. The performance criteria will be different as well. Both may be considered seaworthy, although for different reasons based on different criteria. In the case of a ferry or any other passenger vessel, and of course of a structure for ocean colonization, the criteria are the habitability limits.

3. Vessel Motion

Vessel motions are defined by the six degrees of freedom that a ship, boat or any other craft can experience (Couser, 2000; Helasharju et al., 1995).

Translation:
- Heave is the linear vertical (up/down) motion.
- Sway is the linear lateral (side-to-side) motion.
- Surge is the linear longitudinal (front/back) motion.

Rotation motions: there are three special axes in any ship, called vertical, lateral and longitudinal axes. The movements around them are known as roll, pitch and yaw.

- Roll: is when the vessel rotates about the longitudinal (front/back) axis.
- Pitch: is when the vessel rotates about the transverse (side-to-side) axis.
- Yaw: is when the vessel rotates about the vertical (up-down) axis.

For general ship geometry, this leads to a system of six non-linear equations of motion. For the relatively common case of a floating structure with port-starboard symmetry, the system of six non-linear equations is reduced to two systems of three linear equations. With this assumption, the motion on the longitudinal plane (surge, heave and pitch) and the motions on the transverse plane (sway, roll and yaw) are decoupled.

4. Factors Affecting Vessel Responses

A number of factors affect the vessel responses:

1. Size: A larger vessel will generally have lower motions than a smaller one. This is because the relative size of the waves is lower.
2. Dimensions.
3. Form.
4. Weight distribution characteristics.
5. Displacement: A heavier ship will generally have lower motions than a lighter one. Given that the wave energy is the same for each vessel and provides the exciting force, the one with the greater mass will have the lower accelerations.
6. Stability: A stable ship will tend to follow the wave profile closer than a less stable one. This means that a more stable ship will generally have higher accelerations but lower amplitudes of motion.
7. Freeboard: The greater a vessel's freeboard the less likely it is to immerse the deck. Deck immersion is often a seakeeping criterion, as it affects mission capability in a number of ships.

4.1. How to Predict Vessel Motion and Response

There are a number of ways of estimating the behaviour of the ship or floating structure when it is subjected to waves:

1. Prior experience in similar designs.
2. Calculation and numerical simulation. Calculations can be performed:
   a) Analytically for simple shapes like rectangular barges.
   b) But need to be calculated by computer for any realistic shaped ship.
3. Model tested: found through physical model testing in a tank test.
4. Measured on board the own vessel.

The results of some of these calculations or model tests are the transfer functions called *Response Amplitude Operators* (RAO). For a floating structure they will need to be calculated for all six motions and for all relative wave headings.

The use of numerical simulation with computing models for predicting a vessel's response is very useful, since it provides a cheap means of assessing a large number of design alternatives early in the design spiral. Once the design has converged to one or two alternatives, these can then be tank tested if a higher degree of certainty is required.

5. Computing Vessel Motion

Computing the response of a vessel advancing in waves is a non-linear phenomenon which involves the vessel dynamics and hydrodynamic forces. Although a non linear analysis has been presented by different authors, for many applications the order of the nonlinearities is small enough that a linear theory provides accurate results. Experimental theoretical results have shown that linear theory gives accurate results over a wide range of scenarios. As a consequence, the linear theory of ship motion is the most widely used. The computing numerical methods for predicting vessel RAOs can be broken down into two main groups: time domain and frequency domain.

5.1. Frequency Domain: Strip Theory

Frequency domain methods are simpler and less computationally intensive. Most of these methods use strip theory. Basically the vessel's motions are treated as forced, damped, low amplitude sinusoidal motions. Strip theory has many simplifying assumptions, yet is fast and able to produce good results for a wide variety of seakeeping problems. The two main limitations are that vessels must be sufficiently slender (high length to beam ratio) and that the Froude number must not be too high.
Strip theory involves dividing the vessel into a number of transverse sections. Then the hydrodynamic properties of these sections are computed, assuming 2D in viscid flow, with no interference from upstream sections. From these values, the coefficients in the equations of motion may be found and this, in turn, yields the vessel's response to the waves.

5.2. Time Domain

Time domain methods model the wave passing the hull. At small incremental steps in time, the instantaneous net force on the hull is computed by integrating the water pressure and frictional forces on each part of the hull. Using Newton's Second Law, the acceleration on the hull is computed, this is then integrated over the time step to compute the new vessel velocity and position. Although this procedure sounds relatively straightforward, these methods are still under development in universities and other research establishments and are not routinely used by commercial naval architects. The main problems occur in being able to accurately predict the hydrodynamic forces acting on the hull and the fast computers (even by today's standards) required to run the programs.

5.3. Difference Between Frequency and Time Domain Methods

The main difference between frequency and time domain methods is that for frequency domain methods, the response for a particular frequency is calculated in one step, whereas time domain methods require many thousands of time steps before a regular periodic response is achieved. Hence time domain methods require several orders of magnitude more computing resource than frequency domain methods.

Strip theory is an excellent tool for preliminary design or where the scale of the project or operation of the vessel does not warrant in depth seakeeping analysis. This is due to its speed and cost effectiveness. Simple seakeeping analysis using inexpensive strip theory methods should become part of the day-to-day design work of all naval architects. Where seakeeping performance is critical, large scale model tests, more sophisticated numerical modelling and correlation with full scale trials data should be used.

Numerical prediction tools for seakeeping have not yet reached the stage where they can reliably predict absolute motions data with the accuracy of large scale model tests. However, they are very useful for comparative analysis, particularly in initial design where seakeeping performance would perhaps otherwise be virtually ignored due to constraints of time and budget. For developments to be made to numerical and model testing techniques, correlation with the results of full scale trials is essential.

6. Seakeeping in Multihull Vessels. A Trimaran Study

We have seen that seakeeping analysis is a fundamental part of the design process of a ship. Due to its complexity, seakeeping analysis is usually completed in a late stage of the spiral design process. Although this approach can be successfully used for monohull vessels, it is not optimal in designing more innovated hull forms, due to the high degree of uncertainty of the seakeeping performance of the vessels. The recent interest in multihull vessels poses a problem to the naval architecture world as little is known about such hull forms and a limited number of design tools are available to analyze them. Trimaran hull forms are shown in Fig. 3.

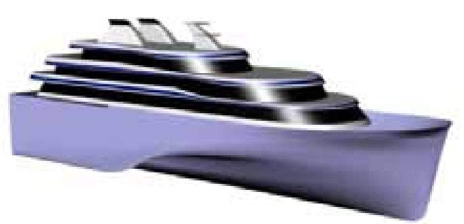

Fig. 3.
Trimaran Hull Forms

Although strip theory has been extensively validated for monohulls, such validation has not been completed for trimarans. If proven accurate and reliable, strip theory could provide important information regarding the seakeeping of trimaran ships and be used in numerous scenarios (Ackers et al., 1997; Begovic et al., 2010).

When calculating motions at remote locations, the trimaran ship is assumed to rotate about the centre of gravity. Hence the distance of the remote location from the centre of gravity is of interest. We have calculated this distance internally and all positions are measured in the coordinate system described before.

Table 1
Main Dimensions of Ship Used in the Study

Length between perpendiculars	50 (m)
Displacement	850 (tons)
Passengers	250
Fuel capacity	15000 (l)
Water capacity	2500 (l)
Maximum Speed	42 (knots)
Autonomy	500 (miles)

We have created a trimaran ship for this paper, which main dimensions/characteristics have been shown in the Table 1. Visualization of the ship forms used in the study has been shown in Fig. 4.

The main advantage of the trimaran ship studied, with respect to the seakeeping, is to have a flotation area smaller than the monohull ships equivalent and a *moment of inertia longitudinal* and *longitudinal metacentric height* small (Migali et al., 2001; Mizine and Amromin, 1999; Pattison and Zhang, 1994).

Having an area of reduced buoyancy is a necessary condition but not sufficient to ensure a good seakeeping. Due to the two lateral hulls it is possible to reduce the vertical oscillation, and to increase the righting arm of pitch at high speeds.

A trimaran, as the rest of the vessel, has six degrees of freedom, three linear and three angular. These are: surge, sway, heave (linear motions in x, y, z axes, respectively) and roll, pitch, yaw (angular motions about the x, y, z axes, respectively). For convenience, the degrees of freedom are often given the

subscripts 1 to 6; thus heave motion would have a subscript 3 and pitch 5.
In each relative position of the trimaran ship as a rigid solid with respect to the sea, it receives the pressures and impacts that joined with local effects to the forces of acceleration and speed that affect on each point as the same rigid moving parts. It means the masses suffering from aboard the action of the sea and affects to turn on the structure, which also receives the action of the sea.

Roll response is estimated assuming that the trimaran ship behaves as a simple, damped, spring/mass system, and that the added inertia and damping are constant with frequency.
In this technical paper, the spectrum used has been ITTC. The ITTC always has a peak enhancement factor of 1.0. It is often useful to define idealised wave spectra which broadly represent the characteristics of real wave energy spectra. The Bretschneider or ITTC two parameter spectrums are defined below (Eqs. (1-3)):

$$S_{ITTC}(\omega) = \frac{A}{\omega^5} \cdot exp\left(\frac{-B}{\omega^4}\right) \quad (1)$$

Where:

$$A = 172.75 \cdot \frac{\bar{H}_{char}^2}{\bar{T}^4} \quad (2)$$

and

$$B = \frac{691}{\bar{T}^4} \quad (3)$$

The two parameters are the characteristic wave height, $\bar{H}_{char}$, and the average period $\bar{T}$. The information about wave characteristics in the Mediterranean Sea has been checked in the reference (Athanassoulis et al., 2004). By calculation the various spectral moments it may be shown that (Eqs. (4-8)):

$$m_0 = \frac{A}{4 \cdot B} \quad (4)$$

$$\bar{H}_{char} = 4 \cdot \sqrt{m_0} \quad (5)$$

$$T_Z = 0.92 \cdot \bar{T} \quad (6)$$

$$T_P = 0.0 \quad (7)$$

$$\varepsilon = 1.1 \text{ (broad band spectrum)} \quad (8)$$

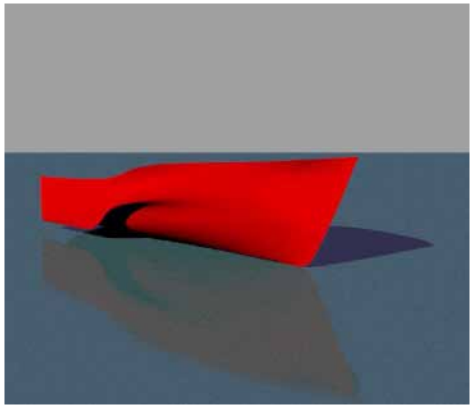

Fig. 4.
Visualization of the Ship Forms Used in the Study

Thus, the Bretschneider or ITTC two parameter spectrums are a broad band spectrum and contain all wave frequencies up to infinity. This is why the average period between peaks is zero since there will be infinitesimally small ripples with adjacent peaks. However, in practice the high frequency ripples are neglected and the spectrum will effectively be narrow banded in which case (Eq. (9); Eq. (10)).

$$H_{1/3} \approx 4 \cdot \sqrt{m_0} \quad (9)$$

Hence,

$$\bar{H}_{char} \approx H_{1/3} \quad (10)$$

The modal period may be found by differentiating the wave energy spectrum and finding the maximum (slope = 0) (Eq. (11)):

$$\omega_0 = \sqrt[4]{\frac{4 \cdot B}{5}} = \frac{4.849}{\bar{T}} \qquad (11)$$

Where (Eq. (12)):

$$T_0 = 1.296 \cdot \bar{T} = 1.41 \cdot \bar{T}_Z \qquad (12)$$

The added resistance calculated is due only to the motion of the trimaran ship in the waves. For this study, the method applied is the Salvesen method. The method developed by Salvesen is purported or claimed to be more accurate for a wider range of hull shapes than those developed by Gerritsma and Beukelman. Whilst Gerritsma and Beukelman have found their method to be satisfactory for fast cargo ship hull forms, the Salvesen method is valid for multihull vessels. The Salvesen method is based on calculating the second-order longitudinal wave force acting on trimaran ships (Sariöz and Narli, 2005; Saunders, 1957). Theoretically, this method may also be applied to oblique waves. Head seas approximation: here a simplifying assumption that the trimaran ship is operating in head seas is used, this speeds up the calculations to some degree. This method is exactly valid in head seas and can be applied with reasonable accuracy up to approximately 20° either side of head seas; i.e. 160° < μ < 200°.

Table 2
Trimaran Analysis Results in Function of Each Item

Items	m_0	RMS	Significant Amplitude
Modal period	9.997 (s)	--	--
Characteristic wave	4.000 (m)	--	--
Spectrum type	ITTC	--	--
Velocity	15.000 (knots)	--	--
Trimaran ship displacement	657.506 (m3)	--	--
Trimaran ship trim	0.000 (rad)	--	--
Wave force method	Head seas approx.	--	--
Added resistance method	Salvesen	--	--
Pitch gyradius	13.752 (m)	--	--
Roll gyradius	6.200 (m)	--	--
Wave spectrum	1.000 (m^2)	1.000 (m)	2.000 (m)
Encountered wave	1.000 (m^2)	1.000 (m)	2.000 (m)
Added resistance	214.827 (kN)	--	--
Heave motion	0.797 (m^2)	0.893 (m)	1.786 (m)
Roll motion	0.000 (rad^2)	0.000 (rad)	0.000 (rad)
Pitch motion	0.003 (rad^2)	0.051 (rad)	0.101 (rad)
Heave velocity	1.060 (m^2/s^2)	1.030 (m/s)	2.059 (m/s)
Roll velocity	0.000 $(rad/s)^2$	0.000 (rad/s)	0.000 (rad/s)
Pitch velocity	0.000 $(rad/s)^2$	0.070 (rad/s)	0.140 (rad/s)
Heave acceleration	1.911 (m^2/s^4)	1.382 (m/s^2)	2.765 (m/s^2)
Pitch acceleration	0.010 $(rad/s/s)^2$	0.100 rad/s/s	0.200 rad/s/s

Table 3

Trimaran Analysis Results in Function of Each Frequency (First Part)

Encount. frequency (rad/s)	Spec. density of wave (rad/s)	Charact. wave (m)	Heave RA	Heave Phase (rad)
0.26	0.22	1273.078	1.000	0.000
0.63	0.46	286.375	0.991	-0.001
1.01	0.66	140.307	0.978	-0.008
1.21	0.76	107.113	0.978	-0.045
1.41	0.85	85.676	0.973	-0.148
1.62	0.93	70.855	0.914	-0.357
1.82	1.01	60.082	0.735	-0.657
2.02	1.09	51.944	0.487	-0.942
2.23	1.16	45.608	0.286	-1.154
2.43	1.23	40.553	0.161	-1.349
2.63	1.30	36.436	0.093	-1.636
2.83	1.37	33.026	0.064	-2.069
3.04	1.43	30.161	0.057	-2.471
3.24	1.49	27.723	0.057	-2.707
3.44	1.55	25.627	0.055	-2.83
3.65	1.61	23.806	0.049	-2.902
3.85	1.67	22.212	0.040	-2.955
5.00	1.96	15.960	0.004	-0.868
6.16	2.23	12.355	0.013	-1.945
7.31	2.48	10.031	0.005	-2.881
8.47	2.71	8.416	0.003	-1.134

The mean square, $m_{0,}$ of the spectrum is the area under the spectrum and gives a measure of the total response of the trimaran ship. See Table 2 for the Trimaran analysis results in function of each item, and Table 3 and Table 4 in funtion of each frequency.

The RMS is the square root of the mean square, and for this study, the significant amplitude is twice the RMS value (the significant height, measured peak to trough, is twice the significant amplitude).

Table 4

Trimaran Analysis Results in Function of Each Frequency (Second Part)

Encoun. frequen. (rad/s)	Roll RA	Roll Phase (rad)	Pitch RA	Pitch Phase (rad)	Added resist. (kN/m^2)
0.26	0	1.511	1.033	-1.551	11.750
0.63	0	1.391	1.092	-1.647	52.181
1.01	0	1.095	1.094	-1.838	99.271
1.21	0	0.607	1.060	-1.991	123.79
1.41	0	-0.328	0.984	-2.202	146.553
1.62	0	-0.892	0.833	-2.486	160.158
1.82	0	-1.117	0.591	-2.808	153.573
2.02	0	-1.228	0.346	-3.041	132.487
2.23	0	-1.293	0.183	-3.106	113.300
2.43	0	-1.336	0.098	-3.031	99.967
2.63	0	-1.366	0.054	-2.894	90.289
2.83	0	-1.389	0.031	-2.800	82.916
3.04	0	-1.407	0.017	-2.869	77.810
3.24	0	-1.422	0.009	2.965	75.360
3.44	0	-1.434	0.008	2.197	75.288
3.65	0	-1.444	0.010	1.782	76.470
3.85	0	-1.452	0.011	1.591	77.721
5.00	0	-1.484	0.004	0.180	70.542
6.16	0	-1.502	0.002	-2.026	63.522
7.31	0	-1.514	0.001	1.936	52.267
8.47	0	-1.522	0.001	-0.054	43.705

Irregular ocean waves are typically described in terms of a wave spectrum. This describes a wave energy distribution as a function of wave frequency. The continuous frequency domain representation shows the power density variation of the waves with frequency and is known as the wave amplitude energy density spectrum, or more commonly referred to as the wave energy spectrum.

The Response Amplitude Operator (RAO), also referred to as a transfer function (this is similar to the response curve of an electronic filter), describes how the response of the trimaran ship varies with frequency. These are normally non-dimensionalised with wave height or wave slope. Trimaran heave and pitch RAOs are shown below (Fig. 5):

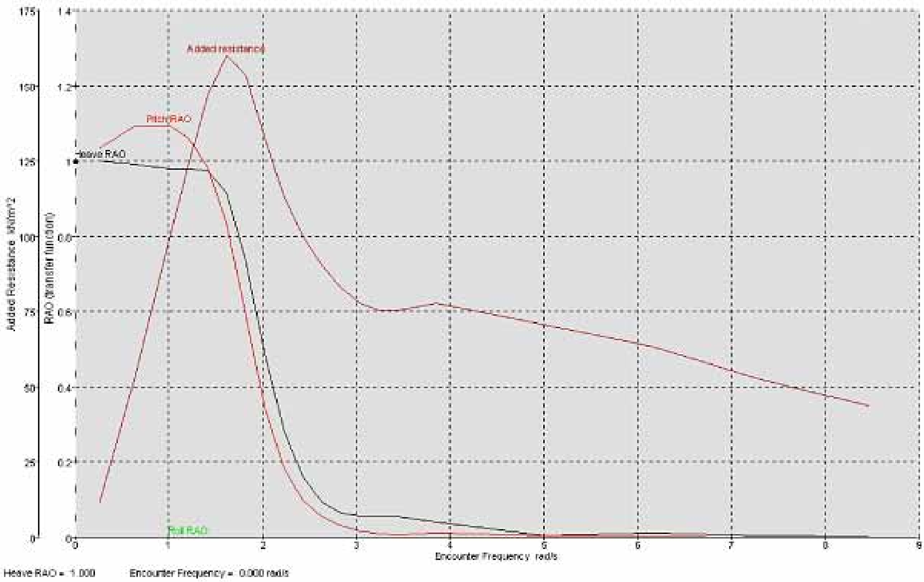

Fig. 5.
Seakeeping of the Trimaran Ship Studied in the Mediterranean Sea

The spectral representations of sea conditions are central to determining the response of the trimaran in the seaway.
This Fig. 5 may be seen that the RAOs tend to unity at low frequency, this is where the trimaran simply moves up and down with the wave and acts like a cork. At high frequency, the response tends to zero since the effect of many very short waves cancel out over the length of the trimaran. Typically the trimaran will also have a peak of greater than unity; this occurs close to the trimaran ships natural period. The peak is due to resonance. An RAO value of greater than unity indicates that the trimaran's response is greater than the wave amplitude (or slope).

7. Conclusions

As it was mention in the introduction, this technical paper clarify the seakeeping calculation in trimaran ships. In the past, seakeeping tank test were not affordable in most of the projects. There were not softwares prepared expecifically for calculating multihulls seakeeping, so it produces that there are not technical papers showing a trimaran seakeeping calculation. This paper has newly given a study of a trimaran seakeeping and also a study of the three principal concepts in order to understand the seakeeping performance: sea environment (estimation of the likely sea environmental conditions to be encountered by the vessel), vessel´s response in motions (prediction of the response characteristics of the vessel and, vessel´s mission and limiting criteria.
The assessment of seakeeping performance of a trimaran in a specified sea area is a common

computational procedure. This procedure requires the prediction of transfer functions for different speed and headings for each response. These transfer functions are then combined with an appropriate spectral formulation based on the sea area characteristics. The results can be presented in a polar format where for each speed and heading combinations the variation of motion characteristics with increasing sea state can be established. Provided that a set of reliable seakeeping criteria are available the habitability of a trimaran in different sea states can be estimated.

However, there are no universally agreed criteria for comparing the seakeeping performance of alternative designs. For a fast ferry trimaran, the criteria are dominated vertical and lateral accelerations. ISO 2631 provides *severe discomfort boundaries* as a function of frequency and exposure time. The results indicate that even slight variations in exposure time may result in significant differences in estimated habitability. Hence, the methods currently used for comparing the seakeeping capabilities of trimarans can be misleading.

The estimated habitability of a fast ferry trimaran in a specified sea area strongly depends on the selected limiting acceleration level. Therefore, particularly in comparative seakeeping analyses, the chosen set of criteria and its parameters must specifically be described in order to provide reliable seakeeping performance information.

Seakeeping analysis is a fundamental part of the design process of a trimaran. Due to its complexity, seakeeping analysis is usually completed in a late stage of the design process. Although this approach can be successfully used for monohull vessels, it is not optimal in designing more innovated hull forms, due to the high degree of uncertainty of the seakeeping performance of this kind of vessels. The recent interest in trimaran ships poses a problem to the naval architecture world as little is known about such hull forms and a limited number of design tools are available to analyze them. The movements in trimaran ships are less than the movements of a conventional vessel (monohull) equivalent. Assuming linearity, the trimaran's RAOs depend only on the trimaran's geometry, speed and heading. Although strip theory has been extensively validated for monohulls, such validation has not been completed for trimarans. If proven accurate and reliable, strip theory could provide important information regarding the seakeeping of trimaran ships and be used in numerous scenarios.

Although numerical predictions of wave-induced motions are extremely reliable, further verifications may be required with model tests. Empirical data is necessary to ascertain parameters used in the numerical model. Numerical modelling of first order wave motions is highly accurate, but drag coefficients and air-gap (interference between hulls) are best determined with model testing.

This encouraging result relates just to the motion behaviour of a typical multihull.

In future studies we plan to extend the scope investigating also the structural response as well as specific local phenomena related to wave grouping, wave steepness and wave breaking.

Acknowledgements

Author is heartily thankful to his family for encouragement, guidance and support from the initial to the final level of the technical paper. Lastly, regards and blessings are offered to all those who supported the completion of the technical paper in any respect.

References

Ackers, B.B.; Micheal, T.J.; Tredennik, O.W.; Landen, H.C.; Miller, E.R.; Sodowsky, J.P.; Hadler, J.B. 1997. An Investigation of the Resistance Characteristics of Powered Trimaran Side-Hull Configuration, *Society of Naval Architects & Marine Engineers (Transactions),* 105: 349-379.

Athanassoulis, G.A.; Stefanakos, CH.N.; Gerostathis, TH.P.; Gaillard, P.; Ravazzola, P.; Kontolios, CH.; Cavaleri, L.; Ber-Totti, L.; Sclavo, M.; Ramieri, E.; Dentone, L.; Noel, C.; Viala, C.; Lefevre, J.-M. 2004. *Wind and Wave Atlas of the Mediterranean Sea.* Western European Union, WEAO Research Cell. 386 p.

Begovic, E.; Migali, A.; Pensa, C. 2010. Experimental Study on the Resistance of Trimaran Hull Configuration. *International Conference on Ships and Shipping Research NAV 2000,* Venezia.

Couser, P. 2000. *Seakeeping analysis for preliminary design*. Ausmarine 2000, Fremantle WA, Baird Publications. 10 p.

Evans, J.H. 1959. Basic Design Concepts, *Naval Engineers Journal*, DOI: http://dx.doi.org/10.1111/j.1559-3584.1959.tb01836.x, 71(4): 671-678.

Helasharju, H.; Sundell, T.; Rintala, S.; Karppinen, T. 1995. Resistance and Seakeeping Characteristics of Fast and Large Multihull Vessels. In *Proceedings of the International Conference on Fast Sea Transportation FAST 1995, Lübeck-Travemünde,* Germany.

Laverghetta, T.A. 1998. *Dynamics of Naval Ship Design: A Systems Approach*. Dissertation (Naval Engineer, Ocean Systems Management). Massachussets Institute of Technology. 187 p.

Migali, A.; Miranda, S.; Pensa, C. 2001. Experimental study on the efficiency of Trimaran. Configuration for high-speed very large ships. In *Proceedings of the International Conference on Fast Sea Transportation FAST 2001,* Southampton, United Kingdom.

Mizine, I.; Amromin, E. 1999. Large High Speed Trimaran–Concept Optimization. In *Proceedings of the International Conference on Fast Sea Transportation FAST 1999,* Seattle, United States of America.

Pattison, D.R.; Zhang, J.W. 1994. *Trimaran Ships*. Transactions. The Royal Institution of Naval Architects. RINA. Vol. 137.

Perez, R.; Lamas, M. 2011. El comportamiento en la mar en estructuras flotantes. *Anales de mecánica y electricidad* 6: 24-29.

Sariöz, K.; Narli, E. 2005. Effect of criteria on seakeeping performance assessment, *Ocean Engineering*, DOI: http://dx.doi.org/10.1016/j.oceaneng.2004.12.006, 32(10): 1161-1173.

Saunders, H. 1957. *Hydrodynamics in Ship Design*. Volume 2, Society of Naval Architects and Marine Engineers – SNAME, New York, United States of America. 980 p.

POMORSTVENOST U PLOVIDBI – PRIMER TRIMARAN BRODOVA

Rodrigo Pérez Fernández

Sažetak: Pomorstvenost broda je mera prilagodljivosti strukture objekta na vodi uslovima plovidbe. Za svaki brod, čamac ili bilo koji drugi plovni objekat koji ima dobru pomorstvenost kaže se da je veoma sposoban za morsku plovidbu i efikasan čak i na velikim talasima. U ovom radu je predstavljeno istraživanje pomorstvenosti višetrupnog brzog broda, tačnije trimarana koji je karakterističan za plovidbu na Sredozemnom moru. Numerički rezultati i merenja na trimaranu su dobro usklađeni u frekvenciji i vremenskom domenu. Kretanja trimarana brodova su manja od kretanja odgovarajućih konvencionalnih (jednotrupnih) brodova. Pod pretpostavkom linearnosti, operator amplitude odziva (RAO) trimarana zavisi samo od njegove geometrije, brzine i kursa plovidbe. Iako je teorija pomorstvenosti u velikoj meri primenjena na jednotrupne brodove, takve studije nisu rađene za trimarane. Ovaj rad pruža značajne informacije koje se odnose na pomorstvenost trimaran brodova i mogućnost njihovog korišćenja u brojnim situacijama.

Ključne reči: brodomašinstvo, pomorstvenost, trimaran brodovi.