SNAMES

Society of Naval Architects and Marine Engineers Singapore

Capturing innovative opportunities

37th Annual Journal 2017/2018

Hilli Episeyo, the world's first converted Floating Liquefaction Vessel delivered by Keppel Offshore & Marine

Society of Naval Architects and Marine Engineers Singapore

37th Annual Journal 2018

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President's Message

On behalf of the Council Members, a warm greeting to our members and readers.

This 37th Annual Journal is also our first electronic journal. I would like to thank the Chairman of our Publication Committee, Ivan Stoytchev for his time and effort to put the pieces together. Our thanks also to the contributing writers. Without your support, we would not be possible to publish this annual journal.

2017/2018 marked a remarkable session for SNAMES while we continue to function without a full-time secretariat, these would not be possible without the dedicated council members and strong support from our members.

Together with institutional partners from CORE, Joint Branch of RINA and IMarEST (Singapore) and our industry partners MAN Diesel and Turbo and WIN GD, we had hosted or co-hosting 12 technical talks/events.

The 32nd annual Chua Chor Teck Memorial was held on 29h January 2018 in Singapore Polytechnic Convention Centre with close to 400 attendees. Many of them are young members from the polys and SIT. This year our speaker was our own Fellow Member, Mr David S. S. Chin, Executive Director of Singapore Maritime Foundation (SMF) and his topic was "A Different Apprenticeship Journey - Reinvention Amidst Changing Circumstances & Opportunities". David shared his journey from apprentice in Keppel Shipyard to Director at Trade Development Board and Executive Director of SMF. He also shared his experience and insights on how Singapore reinvented herself and developed the world-class shipbuilding capabilities and how we took active steps at the World Trade to promote and increase international trade. He also shared the strategies of making Singapore an international maritime centre, and the works of SMF in attracting and groom young maritime talents for us to stay ahead of the competition.

Some other Major events we had include
1. 44th Annual Dinner at Regent Hotel on 17th Nov 2017. The event was graced by Ms Mary Liew, President of National Trades Union Congress (NTUC) and General Secretary of Singapore Maritime officers Union (SMOU).
2. SNAMES Members' Night 2017 at NUSS Suntec City Guild House on 23rd Jun 2017.
3. SNAMES Man Diesel & Turbo Industry Night at Mandarin Oriental on 29th Sep 2017.
4. SNAMES Win GD Technical Night at Singapore Polytechnic Auditorium on 30th Oct 2017.
5. SNAMES Golf Tournament 2018 at Raffles Country Club on 23rd Feb 2018

We are also actively contributing to the advancement of Singapore capabilities with our members representing in the following working committees:
1. Spring Singapore Technical Committee for Bunkering - Kenneth Kee
2. Spring Singapore Working Group for Mass Flow Metering for Bunkering – Kenneth Kee
3. Singapore Standard Organization Technical Committee Meeting for LNG Bunkering – Dr Guilio Gennaro / Foo Nan Cho
4. Offshore Technology Conference (OTC) Asia 2018 Technical Committee - Dr Arun Dev/Foo Nan Cho
5. Singapore Shipping Association (SSA) Specialist Diploma in Maritime Superintendency course working committee - Ivan Stoytchev /Dr Arun Dev

We hope to continue the closed ties that we had established over years with local organizations like ASMI, CORE, IES, Joint Branch (IMarEST & RINA), NP, SIT, SMOU, SMA, SNI, SSA etc. and continue to deepen our relationships with our international partners such as HKIMT, IMarEST, SNAME, SSNAME etc.

As I stepped down after 3 years as President, would like to thank our seniors who have been supporting and advising us from the back. Looking forward to an even stronger support from our members to the new leadership in building our technical expertise and knowledge in Naval Architecture and Marine Engineering and continue to make SNAMES the place for like-minded professionals to share and contribute in building our capabilities in maritime & offshore.

Foo Nan Cho
President 2017/2018

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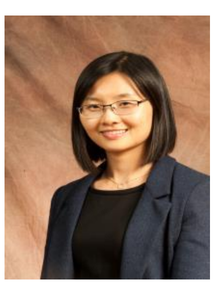

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1978/1979	Mr. Chua Chor Teck	Mr. Alan Bragassam
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1984/1985	Mr. Ronald M Pereira	Mr. Tay Kim Hock
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2015/2016	Mr. Foo Nan Cho	Mr. Prem Shankar
2016/2017	Mr. Foo Nan Cho	Mr. Prem Shankar
2017/2018	Mr. Foo Nan Cho	Mr. Prem Shankar

44th Annual Dinner 2017

Held on 17th November 2017 at The Regent, Singapore

Guest Of Honour
Ms Mary Liew
President of National Trades Union Congress (NTUC)
And General Secretary at Singapore Maritime Officers' Union (SMOU)

"A Different Apprenticeship Journey – Reinvention Amidst Changing Circumstances & Opportunities"

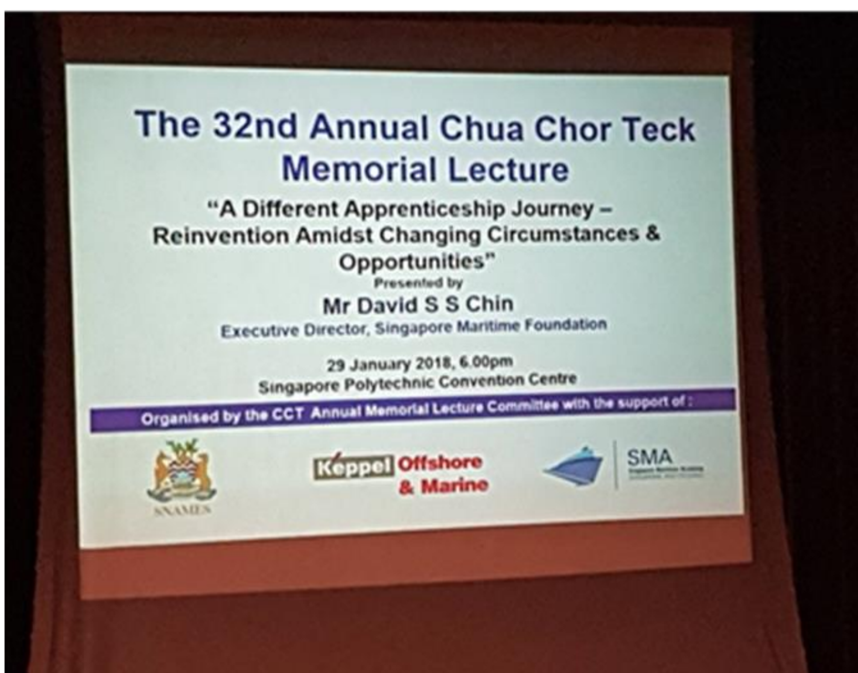
Presented by

Mr. David S S Chin

Executive Director, Singapore Maritime Foundation

29 Jan 2018

Singapore Polytechnic Convention Centre



Annual Golf Tournament 2018

Held on the 23rd of Feb 2018 at Raffles Country Club

Technical Talks

“Why is Technology Important for Society and how should we Educate and Train of Future Engineers”

Presented by
Mr. Peter Noble
16th May 2017
Singapore Polytechnic

Winterthur Gas & Diesel
“The Future of Merchant Vessel Propulsion”

30th Oct 2017
Singapore Polytechnic

“The Environmental and Efficiency Challenge-How to Select the Most Efficient Propulsion Concept Considering EEDI Limits”
by **Dr. Rudi Holtbecker**

“Digital Engine Diagnostic System (EDS) and Virtual Training Possibilities for WinGD Engines”
By **Mr. Gregory Sudwoi**

“Servicing Through New Channels to Reduce Cost”
By **Mr. Andrew Stump**

Technical Papers

Sudheesh Ramadasan, Sudhir Prajapati
Cybermarine Technologies Pte. Ltd, Singapore

Dr. Arun Dev
Marine Technology, Newcastle University in Singapore

Flooding Tanks: A Solution to High Frequency Resonance of Offshore Support Vessels

ABSTRACT

This paper is an attempt to understand the problem of High Frequency Resonance Response experienced by many of the present day offshore support vessels (OSVs) and to propose a solution towards the same. A simple roll stabilization arrangement using flooding tanks is being discussed as an optimum solution. The system works on the principle of the reduced vessel stiffness and shall be used to vary the natural frequency of roll depending on the dominant frequency of the operating sea states. The typical case of a 90m MSV is discussed where the system was installed successfully.

INTRODUCTION

Over the last few decades, the motion response of offshore support vessels has gained considerable importance due to its effects on machinery performance, human comfort and vessel's operability. Of the six degrees of freedom of rigid body motions of a vessel, the roll motion is of utmost importance due to its relatively large amplitudes and higher probability of resonance with waves. The design philosophy of offshore support vessels has changed dramatically during the last decade towards maximizing the cargo deck space and onboard accommodation. This led to a higher breadth to depth (B/D) ratios of these vessels than their conventional counterparts of similar displacements.

High B/D ratios resulted in large initial transverse metacentric heights (GM) and eventually high natural frequencies of roll motions. A ship with a relatively large GM can have a roll time period as low as 8 seconds (Barrass and Derrett, 2006) and such a vessel said to be stiff due to its quick and violent roll motions. Such high natural frequencies of roll motions make these vessels susceptible to resonance even in relatively calmer sea states where wave energy is concentrated at high frequencies. This phenomenon is called High Frequency Resonance Response and such resonance motions result in surprisingly high roll amplitudes, which not only affect the vessel's operability but also cause serious concerns regarding the vessel's transverse stability.

ROLL STABILISATION

Froude, in 1861 has found that the steepness / slope of the wave excites the roll motion. He concluded that as short waves appear to be steeper than long waves, there is no advantage in trying to reduce the natural roll period of the vessel and it is advisable to increase the roll period as high as possible to avoid resonance with the wave excitation periods (Perez, 2005). The Resonance Amplitude Operator (RAO) of roll can be as high as 10 or more for unsterilized synchronous rolling (Lewis, 1998). Large roll angles can make working on the ship difficult and can lead to motion sickness. The resulting accelerations make it difficult for the ship's personnel to operate the ship and must be resisted by machinery foundations and cargo lashings. Figure1 shows the very rapid decrease in motion sickness incidence (MSI) with increase in period above the usual synchronous roll period of ships.

The best way of reducing roll motion is by increasing roll damping. Gyroscopes, moving weight stabilizers, sails, antirolling tanks, fin stabilizing systems and bilge keels are the main concepts being used for roll stabilization. Fin stabilizing systems provides roll damping by lift forces due to the flow of fluid over fins while bilge keels produce eddies around them for dampening effect. Antiroll tanks have evolved from simple passive free surface tanks to more sophisticated U -tanks and free-flooding tanks with active control.

PASSIVE TANK STABILISERS

These stabilizers are called passive as they are not actuated. In 1874 Froude installed water chambers in the upper part of a ship for the purpose of achieving stabilization against roll (Gawad *et al*, 2001). The tuning of these tanks was done by variation of the depth of the water in the tank. Sellars and Martin (1992) classify the passive tanks into three basic types; free surface, U tube, and free flooding tanks. Controlled passive roll stabilizer is an advanced concept to improve the performance of a passive system by adding a sophisticated control system (Lewis, 1998).

Youssef *et al*. (2002) states that the tank stabilizers work on the principle of roll damping. The shifting weight of the fluid exerts a roll moment which by suitable design can damp the wave excited roll motion. When the stabilizer coupling / tuning factor; the ratio of the natural frequency of the stabilizer to the roll natural frequency is near unity, the movement of the tank liquid will be 90 deg out of phase with the roll of the ship at resonance and will counteract roll excitation (Sellars and Martin, 1992). The stabilizer affects roll amplitude only and the roll period remains unaffected. In practice, tuning factor is kept at slightly larger than unity to account for the difference in damping between the ship and the stabilizer (Lewis, 1998). Gawad et al. (2001) reports that a well-tuned, well designed tank can be very effective in reducing roll motions even up to 57%.

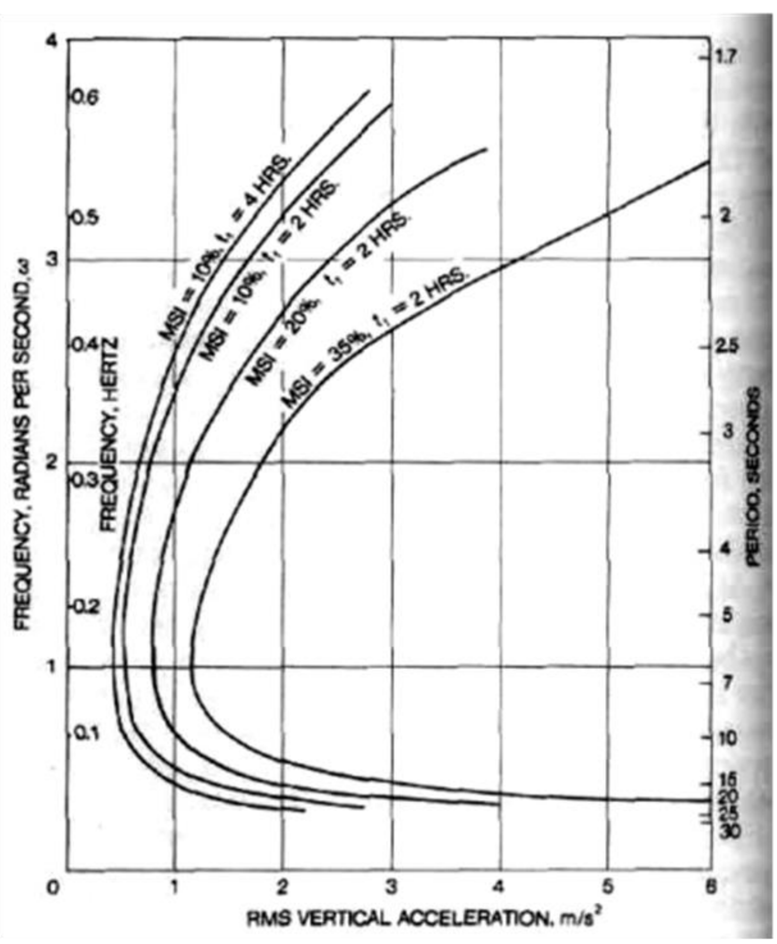


Figure 1 Motion Sickness Index (MSI) and roll period

Figure 2 shows the effect of the stabilizer tuning on stabilization. It can be observed that stabilizer with a natural frequency much higher than the ship's roll resonance frequency is effective only at high frequencies and a similar statement applies to one with a much lower natural frequency also. These stabilizers cannot eliminate roll motions completely as the stabilization is based on ship motions. It can be observed that when the resonance is suppressed, two additional minor peaks are generated (Hsueh and Lee, 1997).

Webster *et al*. (1988) identifies the primary factors affecting the performance of any antirolling tank are the tank free surface correction to GM, tank natural period and tank damping. Typically, a GM reduction of 10 to 30 percent along with a mass ratio of about 3.5% is employed to obtain significant roll motion reduction. Passive stabilizers are the most effective system of roll reduction at zero speed and hence are attractive for vessels with stationary operations like OSVs.

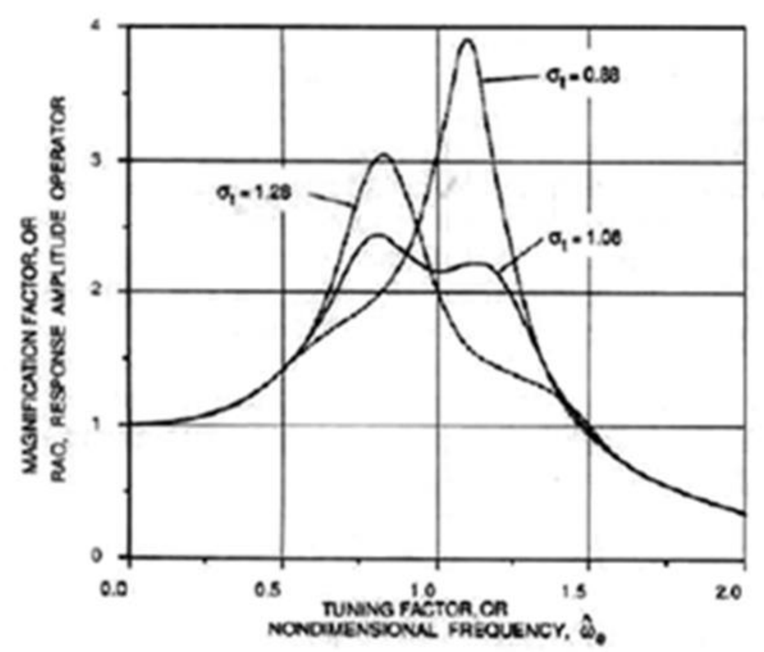


Figure 2 Effect of variations of stabilizer tuning on roll stabilization

FLOODING TANKS

The earliest free flooding tanks were basically Frahm or U Tube type tanks in which free-flooding was used to eliminate the tank's water crossover duct (Webster *et al*, 1988). In this configuration, the two wing tanks are not connected to one another except sometimes by an air duct at the top. Water flows in and out of each tank through openings in the hull to the sea.

Moaleji and Greig, (2007) discusses about the free flooding tanks retrofitted to six USN cruisers of the Pensacola and Northampton classes in 1931 – 1932. The tanks had no air cross connections and were successfully reducing the roll motion by 30–40% and increasing the roll period by 20%. Table 1 shows the improvements on roll motion achieved by Northampton.

Moaleji and Greig, (2007) mentions also about a more advanced version of free flooding tanks was tested at Stevens Institute of Technology which had a pipe cross connection at the tops of the tanks for the supply of low pressure air to control the water in the tanks and thereby the damping of the motion of the vessel. Results showed that this system could reduce roll by about 60%. The Slo-Rol system developed by Dr. G. Bergman of SeaTek International Inc. uses a similar principle but relies on compressed air for control of the water levels. In 1988, two configurations of free-flooding tanks; modified Slo-Rol and tuned free-flooding tanks were analyzed and model tested by Webster *et al*. (1988) for retrofitting to the aircraft carrier, USS Midway. The analysis demonstrated that a significant reduction in roll could be achieved.

Table 1 Roll motion improvements with use of tanks on the Northampton

	Measured Response for Ship Operating with	
	Tanks Closed Off	Tanks Operating
oll period, sec	11.8	14.15
oll amplitude, deg	25-30	15-20

The effectiveness of the free flooding tanks reduces as the ship speed increases, because at higher speeds water cannot get into the flooding port. The main advantage of free flooding tanks is the absence of a water crossover duct which does not necessitate major modifications during installation in an existing ship. However there can be a considerable impact on corrosion, fouling and maintenance. Large flooding ports required on the side of the ship can cause a significant momentum drag when the ship is underway.

FLOODING TANK THEORY

Figure 3 shows schematically a simple free-flooding tank installation. Webster *et al.* (1988) propose the following equation for the natural time period of a free flooding tank.

$$T = 2\pi\sqrt{\frac{\gamma d}{g}}$$

where d is the vertical distance between the flooding port and the internal free-surface of the tank, and γ is a nondimensional constant which takes into account the relative internal geometry of the tank.

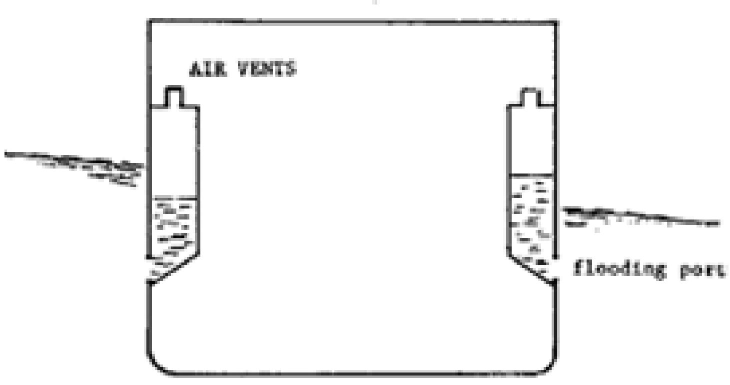


Figure 3 Simple free-flooding tank

It can be proved mathematically that γ is dependent on the relative size of the flooding port over the tanks internal free surface and the tanks natural period can be set by appropriately sizing the tank's inlet ducts relative to the tank internal free surface.

The dynamic operating range of the stabilizer is limited by the tank saturation. Tank saturation occurs when the water rises to the top of the tank or when the water level falls to the level of the flooding ports so that no more water can enter and exit the tanks respectively.

ROLL STABILISATION ARRANGEMENT FOR MSV

A novel concept was successfully tried on a 90m Diving Support Special Purpose Ship which was experiencing severe high frequency roll resonance motions. The system consisted of adequate numbers of port-starboard pairs of two types of flooding tanks, namely free flooding tanks and controlled flooding tanks. Free flooding tanks are permanently opened to sea by means of shell openings while the controlled flooding tanks can be opened to sea as desired by means of shell mounted pneumatically actuated and remotely operated valves. Figure 4 and Figure 5 display the controlled flooding and free flooding tanks respectively installed onboard the subject MSV.

The flooding tanks work based on the principle of reduction in vessel's GM and stiffness. The openings were sized based on a tuning factor greater that unity so that the natural frequencies of the fluid motion is higher than the natural frequency of roll leading to a subsequent increase in vessel's roll period. Free flooding tanks are used to increase permanently the vessel's natural time period of roll and thereby reduce the vessel stiffness. Controlled flooding tanks are used to vary the vessel's natural time period of roll as desired in accordance with the prevailing sea states to avoid resonance.

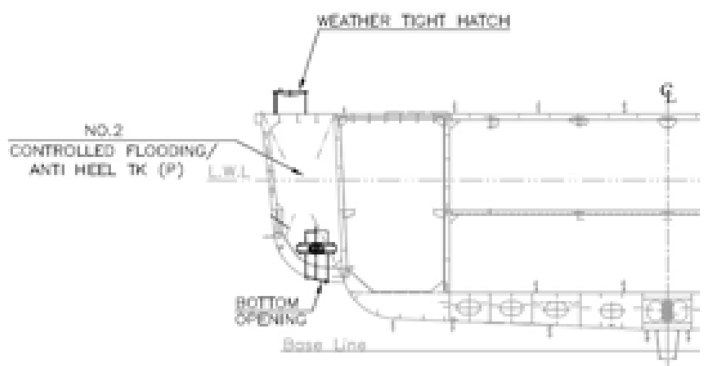


Figure 4 Controlled flooding tank of MSV

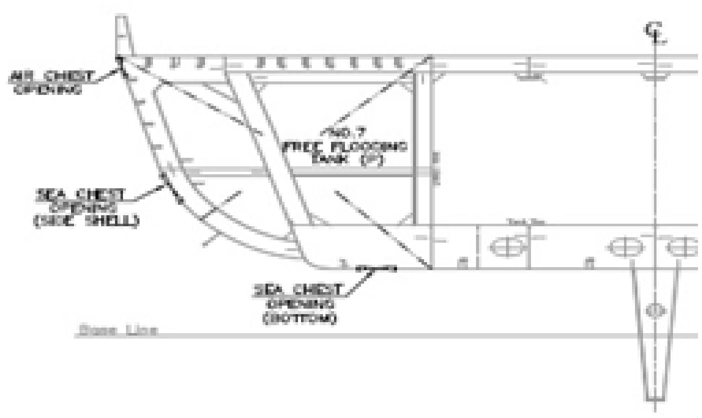


Figure 5 Free flooding tank of MSV

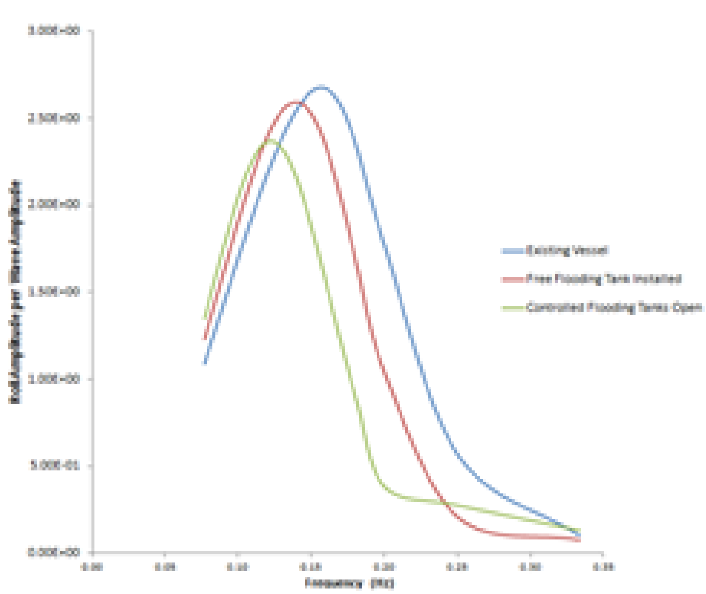


Figure 6 Roll RAO of MSV

RESULTS AND DISCUSSIONS

Figure 6 represents the effect of the roll stabilization arrangement on the roll RAO of the subject vessel. It can be observed that the roll frequency and amplitude reduces with the installation of the system. This reduction is natural frequency is due to the reduction in GM and the reduction in amplitude is due to the increased fluid damping in the tanks. This confirms well with the feedback from the vessel that the stiffness of the vessel has reduced considerably and original roll period of about 6 seconds has increased at least by 2 seconds post installation of the arrangement.

The effect of the roll stabilization arrangement on the response of the vessel to a 2m sea state having a peak period of around 6 seconds is demonstrated in Figure 7. As revealed from the figure, the reduction in the response spectral area is found to be quite significant and the reduction in significant response is around 50%.The arrangement also helps to vary the roll period of the vessel depending on the frequency content of the sea state by means of the controlled flooding valves. The vessel has not reported the problem of high frequency resonance post the installation of the arrangement. Additionally the system is used also as anti-heel arrangement in the event of damage to reduce the list of the vessel. The vessel is presently working on an international charter in Gulf of Mexico.

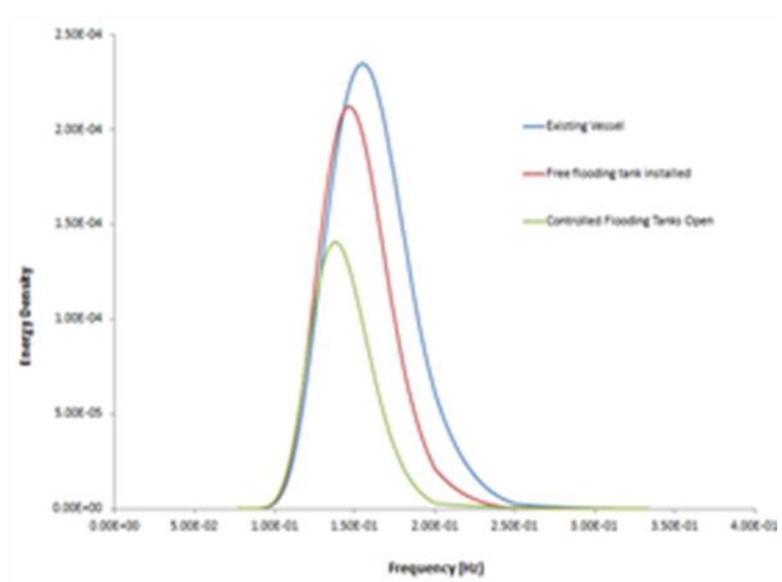


Figure 7 Roll Response Spectrum of MSV

CONCLUSION

The mentioned roll stabilization arrangement shall be tried as an optimal solution to the problem of stiffness and high frequency resonance response experienced by many of the present day OSVs. The system helps the Captain of the vessel to vary the roll natural frequency of the vessel depending on the dominant frequency of the sea seastate and avoid synchronous rolling. As the flooding tanks in the proposed arrangement do not require crossover ducts, only minor modifications to the vessels are required during installation. The momentum drag and speed loss due to the flooding ports shall be minimized by keeping the valves closed during voyage. This along with the abundance of wing tanks for the installation of the arrangement makes it an economic solution to the exiting OSVs.

ACKNOWLEDGEMENTS

The support provided by M/s. Cybermarine Technologies Pte. Ltd. in facilitating the studies and the leadership displayed by its Director, Mr. Bhasker Rao, in implementing the technology are sincerely acknowledged. A special thanks to first author's colleague, Mr. Rupesh Palav, for his DTP skills and his former colleague, Mr. Imran Siddiqui, for his revolutionary insights to the problem of High Frequency Resonance Response.

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**Marine Technology, Newcastle University in Singapore*

Effect of Hull Form and its Associated Parameters on the Resistance of a Catamaran

ABSTRACT

The total resistance of four different types of catamaran hull forms, which include the flat bottom, single chine, multi chine and the round bilge hull forms are presented and discussed in this paper. With the aid of Maxsurf software, the four catamaran hull forms were designed with the same principal dimensions, wetted surface area and the block coefficient. Maxsurf was then used to calculate the total resistance results of the four hull forms that lay in congruence to the displacement and semi-displacement speed range of Froude number (Fn) between 0.2 to 0.7. Also, three variations of the catamaran hull spacing parameter are also presented in this research to study the effect of an increasing separation to length ratio, S/L, on its total resistance. Discussions are made to evaluate for every result that was presented in this paper.

INTRODUCTION

Catamaran has become a popular choice among many passenger ferries, trawlers, and frigates as compared to the monohull. For example, the catamaran provides many benefits such as having a larger deck area and an excellent transverse stability due to its wider breadth. Moreover, the catamaran is also capable of providing a good rolling motion response in heavy seas.

The concept of a catamaran consists of two demi-hulls separated between a distance. Seemingly, the catamaran will experience a high frictional resistance due to having double the value of the wetted surface area as compared to a monohull. However, the large wetted surface area of a catamaran is not a major concern as it can usually be reduced by implementing a slender hull design. In fact, the frictional resistance component, which is typically dominant at low speeds, contribute a minor role in the total resistance of a catamaran, since the multihull vessel is mainly designed to operate at high speed. Hence, a significant contribution leading to an increase in the total resistance of a catamaran originated from the residuary resistance component, mainly the wave making resistance. The types of hull forms that are considered in the catamaran design stage and the varying separation distances set between the two demi-hulls can either provide a favourable or an adverse wave interaction effect, which, can have a various impact on the resistance results.

From the perspective of a naval architect, the importance of accurately understanding the effects on the types of catamaran hull forms and its hull spacing parameter can help to reduce the wave making resistance effectively. As a result, lowers the total resistance, enabling the ship owner to save on its fuel consumption and cost.

<u>Background and summary of conclusions from past research</u>

Previous studies have shown that the wave making resistance of a catamaran can be improved by varying the separation to length ratio parameter, S/L, as illustrated in Fig. 1. A higher S/L ratio of up to 0.4 can provide a favourable wave interference effect between the Froude number of 0.35 to 0.42 (Insel and Molland, 1992; Tasaki et al., 1963). However, studies on the use of a staggered hull catamaran have also shown to provide a better hydrodynamic behaviour on the wave resistance (Sahoo et al., 2006; Soeding et al., 1997).

Cirellio et al. (2013) and Zaraphoniti et al. (2001) have previously conducted the study of an asymmetrical catamaran hull shape between the Flat Side Inside (FSI) and the Flat Side Outside (FSO) hull configurations. Results showed that the FSO hull tends to generate a stronger wave interaction effects as compared to the FSI hull. Moreover, Utama et al. (2012) and Setyawan et al. (2010) have presented a study in comparing between the symmetrical and asymmetrical hull of a catamaran, and it was reported that the latter obtained a reduced number of in-phase wave systems generated between the two demi-hulls.

On the other hand, Iqbal and Trimulyono (2014) have shown how the resistance of a catamaran can be improved by optimizing the C_B.

Besides, studies on the resistance concerning the hard chine and the round bilge monohull form have also been presented. It can be learnt that the round bilge hull form exhibits a lower resistance between displacement to semi-displacement speed whereas the hard chine hull form is capable of providing favourable resistance results at planing speed. However, since the experiment was conducted based on a monohull form, hence, it does not take into account of the viscous and wave interaction factors attributed to the multihull forms (Armstrong and Clarke, 2009; Blount, 1995; Razenback and Bowles, 2010).

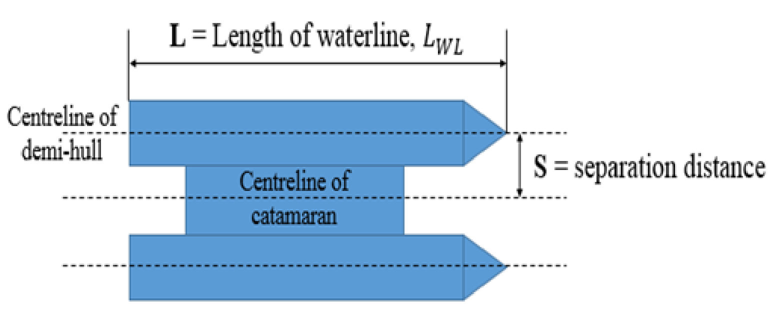

Fig. 1. Catamaran configuration indicating the S/L ratio

Aims and objectives

The aims and objectives of this research is to
• Provide a comparison study on the total resistance of the four different types of symmetrical catamaran hull forms which include the flat bottom, single chine, multi chine and round bilge hull forms.

• Analyse the resistance of the four hull forms at displacement speed range (Fn < 0.4) and semi-displacement speed range (Fn > 0.4).

• Investigate the effect of an increasing S/L ratio on the resistance of the four catamaran hull forms and provide an example of a free surface wave pattern analysis.

METHODOLOGY

Four types of catamaran hull forms were designe d using the Maxsurf Modeler software. These hull f orms, as shown from Fig. 2, include from a flat bot tom, single chine, multi (double) chine and round bilge hull forms.

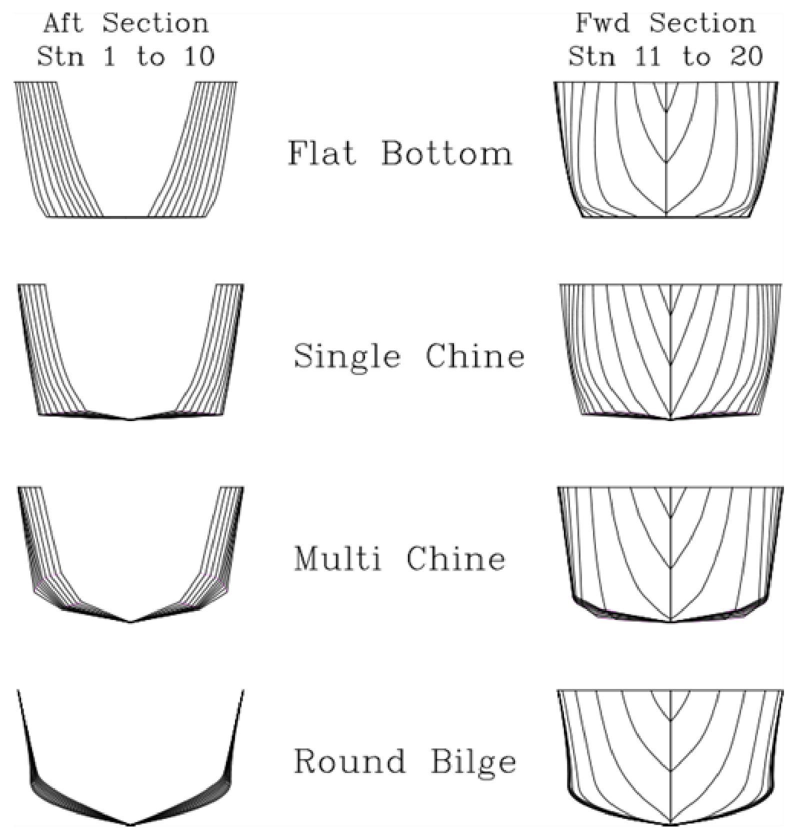

Fig. 2. Four types of catamaran hull forms designed using Maxsurf software.

Catamaran dimensions

As shown from Table 1, the principal dimensions which include the displacement (Δ), the length of waterline (L_{WL}), breadth (B), draft (T), depth (D) and the block coefficient, C_B, were kept constant among the four catamaran hull form designs. Hence, the following parameters such as the length to breadth ratio (L_{WL}/B), breadth to draft ratio (B/T) and the slenderness ratio ($L_{WL}/\nabla^{\frac{1}{3}}$) were also maintained to provide a more justified comparison study on the resistance results (Molland et al., 2011, Tupper, 2004). Moreover, the wetted surface area (WSA) and the displaced volume (∇) of the four catamaran hull forms were intentionally designed to produce a practically similar value with a difference in accuracy of less than 0.002% and 0.0001% respectively. Keeping the wetted surface area as constant will ensure that the four different types of catamaran hull forms will be able to provide a similar viscous resistance on each of its demi-hull. Thus, allowing an explicit comparison study on the wave interference effect of the multihulls among the four hull forms. The only parameters that were varied to produce the four catamaran hull form designs are the prismatic coefficient, C_P , and the ½ angle of entrance.

Table 1 Principal dimensions of the four catamaran hull forms obtained by Maxsurf.

Parameters	Flat Bottom	Single Chine	Multi Chine	Round Bilge
$\Delta\ (t)$	340.2	340.2	340.2	340.2
$L_{WL}\ (m)$	35.054	35.054	35.054	35.054
B of each demi-hull at WL (m)	9.174	9.174	9.174	9.174
T (m)	1.5	1.5	1.5	1.5
D (m)	3	3	3	3
WSA (m^2)	397.973	397.035	397.136	397.762
$\nabla\ (m^3)$	331.900	331.947	331.922	331.938
C_B	0.688	0.688	0.688	0.688
L_{WL}/B	3.821	3.821	3.821	3.821
B/T	6.116	6.116	6.116	6.116
$L_{WL}/\nabla^{\frac{1}{3}}$	5.063	5.063	5.063	5.063
C_P, Prismatic coefficient	0.748	0.756	0.816	0.830
½ angle of entrance $(degree)$	36.1	29	36.2	34.3

As shown from Table 2, three sets of catamaran hull spacing have been varied in this experiment for each of the four hull forms to provide a study on the effect of an increasing S/L ratio in the catamaran resistance. The separation distance, S, measured between the centre line of demi-hull to the centre line of the catamaran was varied at an interval of 7.5m, 11m, and 14.5m.

Table 2 S/L ratio variation.

	S = 7.5m	S = 11m	S = 14.5m
S/L	0.214	0.314	0.414

<u>Design process considerations</u>

The designs of the four hull forms were generated by Maxsurf based on varying the control points which are divided between the number of columns and rows, as shown from Fig. 3 and Fig. 4. The surface of the demi-hull shape is defined by the position of the control points. The location of each control point was varied by having to input the numerical values to its longitudinal, height and offset position to obtain the required four hull form designs. The four hull forms were created based on twenty stations, three buttock lines, and five waterlines.

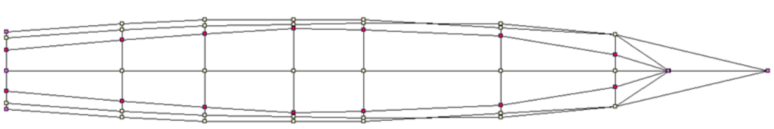

Fig. 3 Plan view of multi chine demi-hull representing columns of control points.

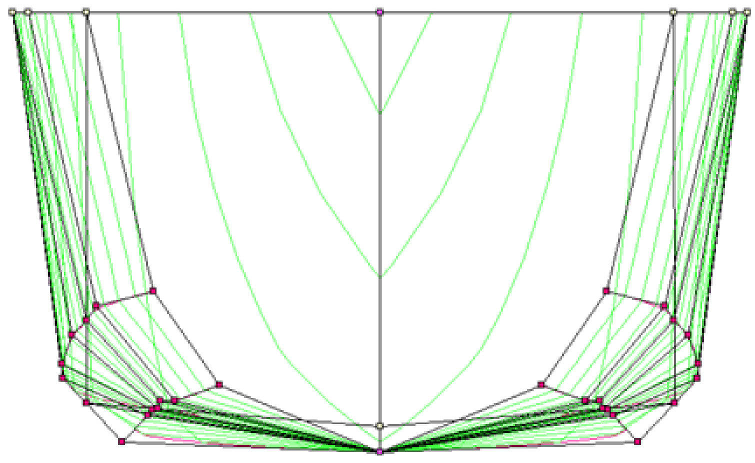

Fig. 4 Body plan view of multi chine demi-hull representing rows of control points.

The flat bottom hull was generated to obtain a flat keel from the forward section to the stern by adjusting the height of its bottom control points to the baseline, and it obtained with the lowest C_P, where most of its displacement is moved near the amidships, resulting in a narrow after body section.

As for the single chine and multi chine hull forms, additional rows of control points were added in the body plan view. The process of compacting and grouping two rows of control points in each column allowed an individual chine to be formed along the length of the catamaran hull, as shown from Fig. 5 and Fig. 6. The single chine hull form was designed with a shallow deadrise angle and as a result, it obtained the lowest ½ angle of entrance among the four catamaran hull forms. Whereas the multi chine hull form was able to design with a slightly deeper deadrise angle, and it obtained the highest ½ angle of entrance.

Fig. 5 Before compacting and grouping two control points.

Fig. 6 After compacting and grouping two control points to form a single chine.

Lastly, the round bilge hull form has been developed based on achieving a smooth curvature at the bilge of the hull along its length, and it obtained with the largest C_P, where most of its displacement located at the hull ends.

Sectional area curve

As shown from Fig. 7, the design of the four catamaran hull forms has been generated with a difference in the slope entrance of its sectional area curve. The design of the single chine hull form was obtained with a gradual slope at the bow of the sectional area curve, whereas the design of the round bilge, multi chine, and the flat bottom hull forms produced a slightly steeper slope entrance.

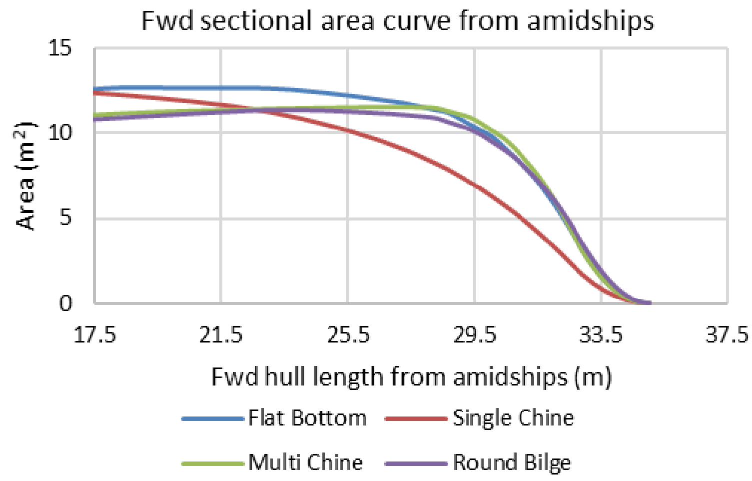

Fig. 7 Fwd sectional area curve from amidships.

Method of resistance calculation for catamaran

The resistance of the four hull forms was calculated based on the slender body method with the aid of the Maxsurf Resistance software by using the technique proposed by Insel and Molland (1992), which takes into account of the hull interaction effects attributed by the multihulls. The slender body method uses the first principle approach from the potential flow calculation. This method is suitable for application of slender hulls with a typical range of slenderness ratio between 5.0 to 6.0, which complement well with the design of the four catamaran hull forms.

The following formula in equation (1) proposed by Insel and Molland (1992) describes the method of calculating the total resistance of a catamaran. The total resistance coefficient of a catamaran, C_T , can be obtained through calculating the frictional resistance coefficient, C_F and the wave resistance coefficient, C_W, for two isolated demi-hulls. Besides, two interference factors are required to be taken into account in calculating the total resistance coefficient of a catamaran; these are the viscous interference factor, β and the wave interference factor, τ. The viscous interference factor, β, is obtained by the combination of changes in the pressure field, ϕ, measured around the demi-hull and the velocity augmentation, σ, measured between the two demi-hulls. Lastly, the wave interference factor, τ, is obtained from the wave interaction systems generated for each demi-hull.

$$C_T = (1 + \phi k)\sigma C_F + \tau C_W \quad (1)$$

where C_T = total resistance coefficient of a catamaran; C_F = frictional resistance coefficient based on ITTC 1957 correlation line; C_W = wave resistance coefficient for an isolated demi-hull; $(1+k)$= form factor for an isolated demi-hull; ϕ = changes in the pressure field around the demi-hull; σ = velocity augmentation between two demi-hulls and τ = wave interference factor.

The σ and ϕ can be combined to form a viscous interference factor, β, to suit the practical purpose of the experiment as shown from equation (2).

$$C_T = (1 + \beta k)C_F + \tau C_W \quad (2)$$

Slender body analysis geometry

The mesh series implemented by Maxsurf is symmetrical about the centre line of an individual demi-hull as shown from Fig. 8. The size of the mesh used in this experiment for the four types of catamaran hull forms was increased from default 81 contours to 201 contours. The primary objective of using a higher number of mesh contours is to provide a greater accuracy on the resistance prediction of the catamaran.

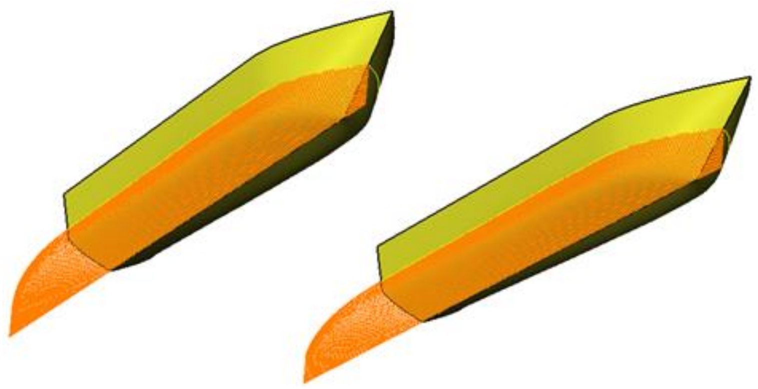

Fig. 8. Round bilge hull with a mesh size of 201 number of contours, symmetrical about the demi-hull.

RESULTS AND DISCUSSIONS

Frictional resistance of the catamaran demi-hull

As shown from Fig. 9, the demi-hull of the four different types of catamaran hull form have obtained the same frictional resistance results, between the range of Froude number,
Fn = 0.2 to 0.7. This objective has been achieved by having to design the four various hull forms with a practically similar wetted surface area. The impression is to allow a justified comparison study among the four different types of catamaran hull forms on its wave interference effect, which is a significant contribution to its resistance.

It can also be noted from Fig. 9 that a substantial increase in the frictional resistance of the four catamaran hull forms dominates at low Fn. As the speed increases further, the total resistance coefficient, C_F, of the four catamaran hull forms began to decrease correspondingly.

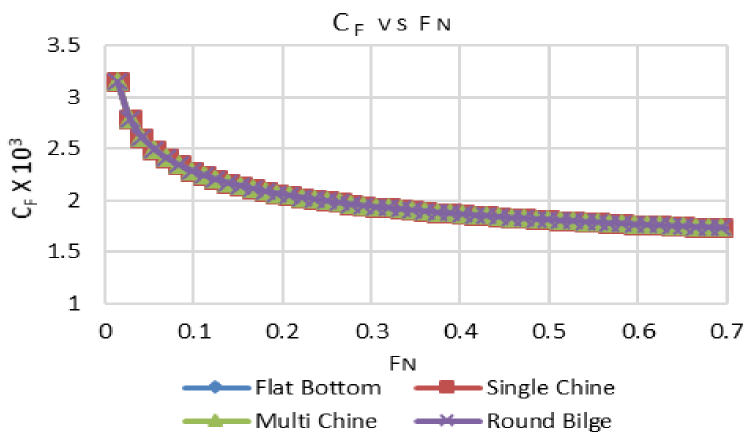

Fig. 9. Catamaran demi-hull frictional resistance

Effect of hull forms on the catamaran resistance at three various S/L ratios

It can be observed from Figs. 10 - 12 that at the region of displacement speed (0.2 < Fn < 0.43), generally all the four hull forms experienced an irregular wave interference effect with large number of pronounced humps and troughs, indicating a strong influence of the transverse waves. Within the displacement speed range, the wave interference effect of the four catamaran hull forms is mainly dependent on the Fn. The Fn at which a favourable wave interference effect can be obtained within the displacement speed range varies with the types of hull forms. Hence, to produce an efficient catamaran design that is required to operate within the displacement speed range, the choice of its service speed for the various types of catamaran hull forms must be prudently selected in the region whereby an adverse wave interference effect can be avoided, resulting in a lower resistance.

Figs. 10 - 12 also displayed that the single chine hull form experienced the least resistance among the four hull forms (0.2 < Fn < 0.7) whereas the multi chine hull form exhibited the highest resistance within the displacement speed range (0.2 < Fn < 0.35). Since the single chine hull form was designed with the lowest ½ angle of entrance = 29° and a gradual slope entrance of its sectional area curve, hence, it exhibits a reduced pressure around its bow stagnation point. As a result, it generates a lower wave height at the bow, leading to a lower wave making resistance. Furthermore, this can signify that the single chine hull form experienced a more favourable wave system as compared to the multi chine hull form, which was designed with a highest ½ angle of entrance = 32°. Hence, it can be implied that the wave making resistance of the four catamaran hull forms within the displacement speed range are dominated by the shape of its waterline entrance. In obtaining a lower resistance within the displacement speed range, the catamaran hull form should be designed with a low waterline angle of entrance and a sharper bow by reducing the slope entrance of the sectional area curve.

With reference from Figs. 10 - 12, as the Fn increases beyond 0.43, towards the semi-displacement speed range, the length of the four catamaran hull forms experienced an equal length to the transverse wave. As a result, all the four hull forms exhibited a steady increase in the total resistance. The resistance of the four catamaran hull forms is increased further until it reached to a hump, between the Fn of 0.48 to 0.5. At this range of Fn, the waves generated by the four hull forms are considered long; hence, it responds to a longer component of the free surface pressure distribution (Larsson et al., 2010). As a result, the wave making resistance of the four hull forms within the semi-displacement speed range is now dependent on its sectional area curve. Hence, the flat bottom hull form, which was designed with the lowest C_p of 0.748 and a narrow after body section, experienced the highest resistance among all the four hull forms at all three S/L ratios. Indicating a stronger wave interference effects that contributed to an unfavourable wave system generated between the two demi-hulls. The design of a higher C_p obtained by the multi chine and the round bilge hull forms exhibited a lower resistance than the flat bottom hull form. Hence, to avoid a high resistance within the semi-displacement speed range, the catamaran hull form should be designed with a higher C_p and a smaller mid-body area by distributing most of its displacement at the hull ends. Since a higher C_p is capable of providing an additional buoyancy on the hulls ends at high Fn, which improves the bow and stern wave systems towards achieving a favourable wave interaction system and a lower wave making resistance.

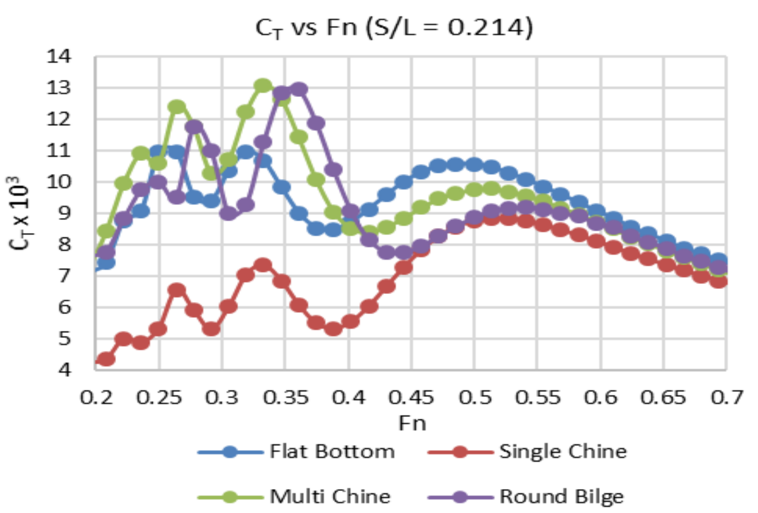

Fig. 10 Catamaran total resistance at S/L = 0.214.

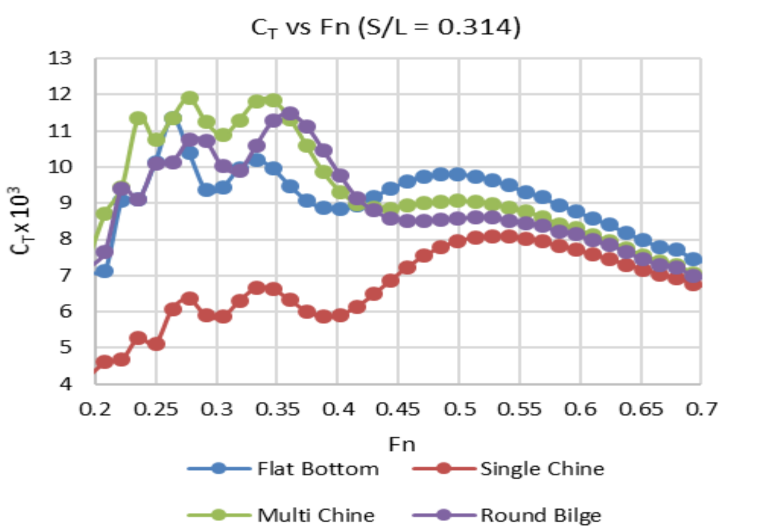

Fig. 11 Catamaran total resistance at S/L = 0.314.

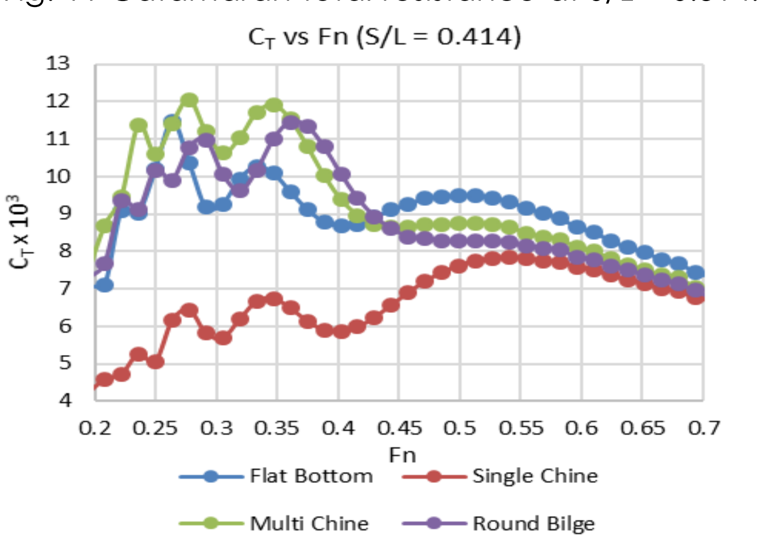

Fig. 12 Catamaran total resistance at S/L = 0.414.

Effect of an increasing S/L ratio on the catamaran resistance

Based on Figs. 13 - 16, it can be observed that the effect of an increasing S/L ratio within the displacement speed range (Fn < 0.43) in providing a beneficial resistance on the four catamaran hull forms is limited to a small range of Froude number. Rather, the S/L ratio is largely dependent on the Froude number. It can be noted from Figs. 13 - 15 that as the S/L ratio increases from 0.214 to 0.414, the flat bottom, single chine and the multi chine hull forms experienced a decrease towards a lower resistance at the limited speed range between the Fn of 0.3 to 0.35. Similarly, with reference to Fig. 16, the round bilge hull form experienced a reduction in its total resistance at the limited speed range between the Fn of 0.32 to 0.36. Hence, for a catamaran that is designed to operate between the displacement speed range, having a large hull spacing to obtain a lower resistance may not be an ideal solution towards an effective design. Instead, selecting a favourable speed to operate within the displacement speed range is a much better approach.

However, at the semi-displacement speed range (Fn > 0.43), the benefit of an increasing S/L ratio in achieving a lower catamaran resistance displayed a more pronounced effect. It can be noted from Figs. 13 - 15 that with an increasing of the S/L ratio from 0.214 to 0.414, the resistance of the flat bottom, single chine and the multi chine hull forms began to decrease correspondingly beyond the Fn of 0.43. Similarly, the round bilge hull form experienced a consistent decrease in its resistance at the semi-displacement speed range beyond the Fn of 0.48, as shown from Fig. 16. Hence, for a catamaran design that is required to operate between the semi-displacement speed range, increasing its hull spacing will be an ideal solution to provide a beneficial reduction in its resistance.

In general, the results of the four hull forms have shown that the benefit effect of increasing the catamaran hull spacing in achieving a lower resistance can be obtained at two different sets of the speed range. Consisting of the displacement speed range (0.32 < Fn < 0.36) and at the semi-displacement speed range (Fn > 0.48). It can be understood that between these two sets of Froude number range, improvements towards a favourable wave interference effect can be observed between the two demi-hulls along with an increasing S/L ratio.

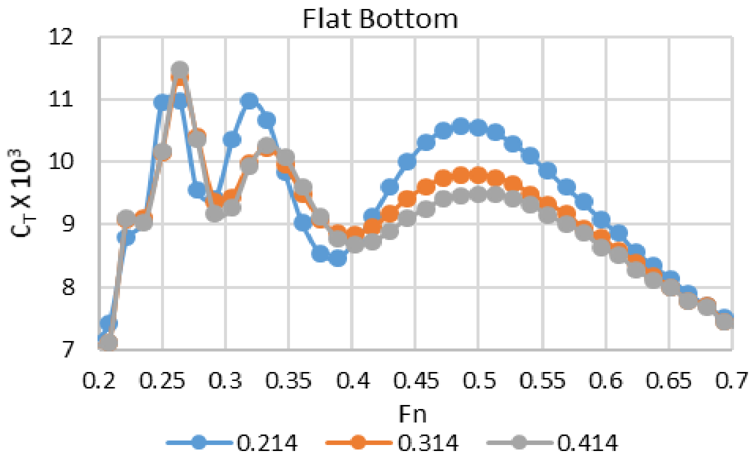

Fig. 13 Flat bottom hull at various S/L ratios.

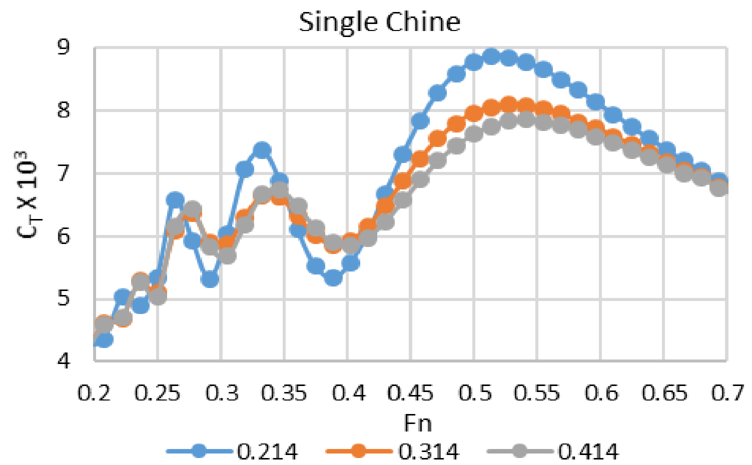

Fig. 14 Flat bottom hull at various S/L ratios.

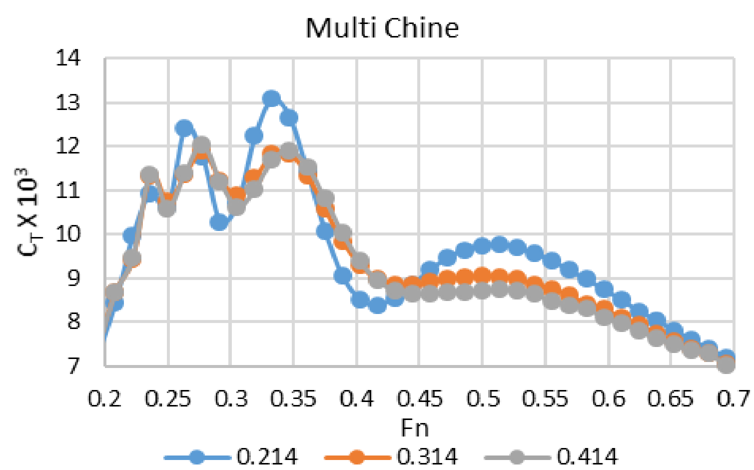

Fig. 15 Multi chine hull at various S/L ratios.

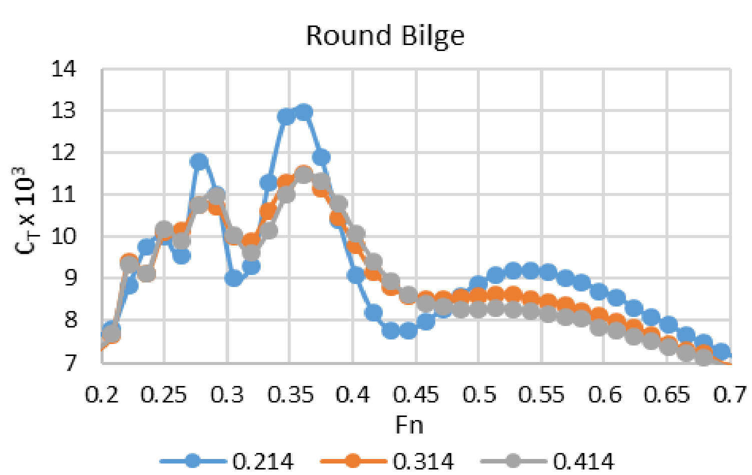

Fig. 16 Round bilge hull at various S/L ratios.

Free surface wave pattern analysis

Alternatively, the effect of increasing the catamaran S/L ratio on the wave interference between the two demi-hulls can be illustrated by observing the contours plots of the wave pattern as shown from Fig. 17 and Fig. 18. It can be seen from Fig. 17 that at the semi-displacement speed of Fn = 0.527, a significant number of prominent concentrated red, blue and purple contours indicating greater wave height generated by the multi chine hull can be observed at S/L = 0.214, signifying a complex wave pattern. As the S/L ratio increases further to 0.414, the large concentrated red, blue and purple contours began to spread out and weakened, indicating a lower wave energy being produced by the hulls resulting in a reduced wave making resistance, as shown from Fig.18.

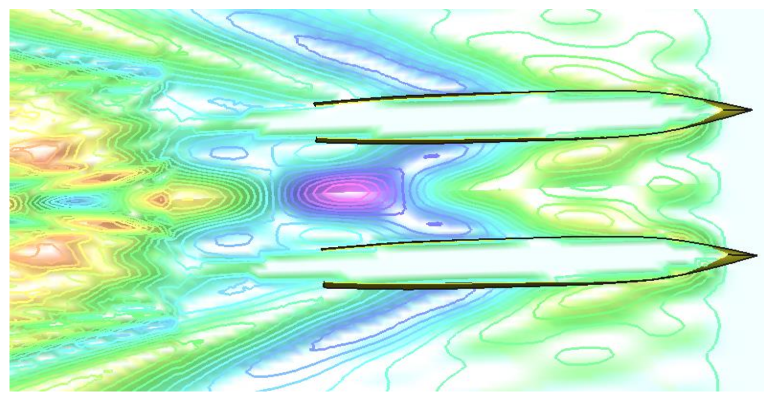

Fig. 17 Wave pattern of multi chine hull at Fn = 0.527, S/L = 0.214.

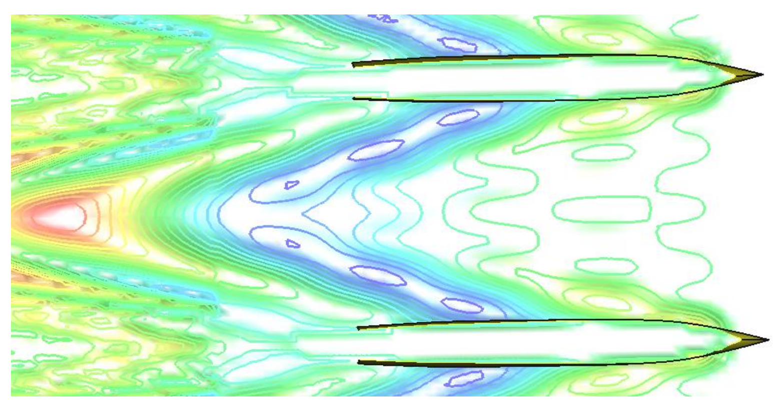

Fig. 18 Wave pattern of multi chine hull at Fn = 0.527, S/L = 0.414.

CONCLUDING REMARKS

In this paper, the hydroelastic problem for a circular VLFS subjected to wave is analyzed in an exact manner for both plate and fluid parts. The implementations if the method presented herein is not so complicated for engineers to obtain accurate solutions for their hydroelastic analysis. Most importantly, the theory used here is based on the more refined Mindlin plate theory, instead of the commonly used classical thin plate theory. With this advanced feature, we can obtain exact stress resultants that satisfy free-edge boundary conditions.

In summary, four different types of catamaran hull forms were designed with constant principal dimensions, wetted surface area and , to provide an explicit comparison study on the resistance. The four hull forms include the flat bottom, single chine, multi chine and the round bilge. Three variations of catamaran S/L ratio which consists of 0.214, 0.314 and 0.414 were also introduced to the four hull forms to investigate the effect of an increasing hull spacing on its resistance. Hence, the following conclusions can be drawn:

- At the displacement speed range of low Fn, the design of a large ½ angle of entrance and a steep slope of the sectional area curve at the bow contributed to a higher resistance. Whereas at the semi-displacement speed range of high Fn, the design of a low prismatic coefficient, lead to a large increase in the resistance.

- Among the four catamaran hull forms that were designed in this research, the single chine catamaran hull form produced the least resistance throughout the range of displacement and semi-displacement speeds between the Fn of 0.2 to 0.7, at all three S/L ratios of 0.214, 0.314 and 0.414. The optimum design parameter of the ½ angle of entrance = 29° and = 0.756 obtained by the single chine hull form have contributed to a more favourable wave interference effect.

- The lowest design of 0.748 and a narrow after body section obtained by the flat bottom hull form resulted in a large increase in the resistance at semi-displacement speed range.

- The effect of an increasing S/L ratio at the displacement speed range in providing a beneficial catamaran resistance is mainly erratic. The S/L ratio is largely dependent on the Fn value.

- The effect of an increasing S/L ratio at the semi-displacement speed range in providing a beneficial catamaran resistance is consistent and gradual.

- The increment of the S/L ratio from 0.214 to 0.414 displayed a beneficial reduction in the resistance of the four hull forms at the displacement speed between the limited range of Fn = 0.3 to 0.36, and the semi-displacement speed range beyond the Fn > 0.48.

<u>Recommendations</u>

The following possible approaches can be conveyed in expanding the knowledge of this subject in demonstrating the future direction of this research.

Designing a low ½ angle of waterline entrance for a particular catamaran hull form could provide a beneficial wave system in terms of reducing the elevated pressure at the bow wave. However, selecting its optimum , for a given specific operating speed is crucial as well in achieving a lower wave making resistance. Hence, to obtain an optimum , for a particular type of catamaran hull form and its operating speed, the Lackenby method can be proposed by varying its mid-sectional area.

Obtaining an optimum S/L ratio that fits for all types of catamaran hull forms may not be possible. The wave interaction effects which is due to the asymmetric pressure field and its velocity augmentation between the two demi-hulls may cause the catamaran viscous form factor to vary with different types of hull forms. Moreover, the interaction between the waves of the two demi-hulls can result in a complicated divergent wave system which varies with different types of hull forms. Hence, it is required to develop an iteration process in experimenting an appropriate hull spacing for a particular catamaran hull form during the design stage, which will aid in changing the wave making of the two demi-hulls to obtain a favourable wave interference effect.

As for the single chine and multi chine hull forms, improvements towards in obtaining a more beneficial resistance and propulsive efficiency can be achieved by varying the height of its chine placement. Optimizing the height of the chine may result in improvements on the wave interference system and its wake flow.

ACKNOWLEDGEMENTS

The first authors would like to their appreciation to Newcastle University (Singapore) in the support of this research work.

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Retrofitting a High Efficiency CLT® Propeller on a 175K m³ LNG Tanker: Comparative Service Performance Before and After.

ABSTRACT

The retrofitting of a SISTEMAR CLT® propeller on a 175K m³ LNG tanker, two years after its delivery, is presented and discussed in the present paper.

The retrofitting was performed with the aim of improving the ship propulsive performance obtained with the original conventional propeller and of solving cavitation issues of the original conventional propeller.

The design of the CLT® propeller was developed, for the same ship operating condition (draft, ship speed, propeller light running margin…), on the basis of the original towing tank tests and by new Open Water and cavitation tests carried out for two alternative CLT® propeller designs.

Comparisons of ship performance are presented using data of several trial reports obtained from the service monitoring system of the ship with original conventional propeller and with the CLT® Propeller.

The comparisons show large efficiency improvements, both in full load and ballast drafts, due to the installation of the CLT® propeller.
The gains measured at full scale are very close to those predicted from the model tests.

The CLT® Propeller was design to be totally interchangeable with the original propeller, as a result the retrofitting did not require any modification either to the shaft line or the vessel and it was not necessary to carry out either new shaft alignment calculations or torsional vibration calculations.

INTRODUCTION

The objective of this paper is to present the entire process and final results of the retrofitting of a Contracted and Loaded Tip (CLT) propeller designed by SISTEMAR for a single shaft LNG 175000 cbm tanker equipped with a diesel-electric propulsion system and originally propelled by a conventional five bladed propeller.

The reason of the retrofitting was to solve some cavitation problems which appeared during the first year of operation with the original conventional propeller and, in parallel, to improve the ship propulsive efficiency.

The optimization process for the design of the CLT propeller has been based on a reduced program of propeller model tests in open water condition because the detailed hull forms of the ship were not disclosed by the shipyard to the shipowner. In any case the program consisted in the evaluation of two series of new conventional and CLT designs, all compared with the original conventional propeller. The hull-propeller interaction propulsive coefficients (wake, thrust deduction and rotative relative coefficients) as well as the effective power (EHP) were obtained from the original self-propulsion tests; based on this and on the new Open Water tests the performance predictions were obtained for each design; the pressure pulses fluctuations on the hull were also tested in cavitation condition. All tests were carried out in INTA-CEHIPAR facilities in El Pardo, Madrid.

The final CLT design was selected; the full scale propeller was built and retrofitted in the next dry docking scheduled for the ship after four years of operation.

Comparative data of propulsion performance in service operation with the original conventional propeller and with CLT propeller will be presented in the following. These data have been obtained through the performance monitoring system installed on board that is continuously recording main propulsive parameters.

MAIN CHARACTERISTICS OF THE VESSEL, ORIGINAL CONVENTIONAL PROPELLER AND CLT® PROPELLER

Main characteristics of the vessel are given in Table 1, while main characteristics of the original conventional propeller and the definitive CLT propeller are given in Table 2.

LPP = 288,0 m
LWL = 285,0 m
B = 45,8 m
TF = 11,5 m
TA = 11,5 m
VOL = 114570 m3
MCR = 29700 kW
N = 84,9 rpm

Table 1. Main characteristics of the vessel

	CONV	CLT
D (m)	8,700	8,675
Z	5	5
P/D 0,7R	0,905	0,938
Ae/Ao	0,709	0,690
Skew (º)	24,50	23,23

Table 2. Original conventional and CLT propellers main characteristics

A picture of full scale CLT propeller during its installation is given in Figure 1.

Figure 1. CLT propeller

ANALYSIS AND MODEL TESTS CARRIED OUT BEFORE THE RETROFITTING

Description of model test program carried out

The model test program consisted in the evaluation of two series of new conventional and CLT designs performed by SISTEMAR, that have been compared with the original conventional propeller. All tests were carried out in INTA-CEHIPAR facilities in El Pardo, Madrid.

The exercise has been performed in two steps:

PHASE 1: Two new propellers have been designed, one of conventional type (CONV-B) and another of CLT type (CLT-C). The original propeller (CONV-A) model has been also built and tested for comparison (see Figure 2).

Figure 2. Model of original conventional propeller

PHASE 2: after model tests results analysis a second version of both types of propellers (CONV2 and CLT2) have been designed and tested. CLT2 model is shown in Figure 3.

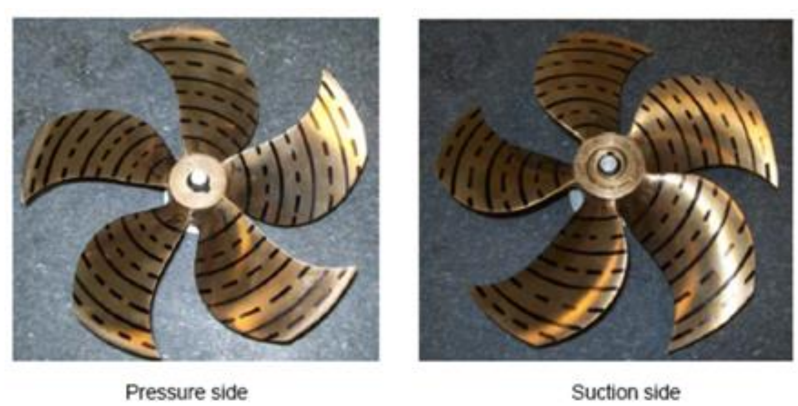

Figure 3. Model of CLT propeller

All designs have 5 blades and the same hub dimensions.

All designs of conventional type have the same diameter than the original propeller (D= 8.700m) while CLT type propellers have a slightly reduced diameter (D= 8.675m).

For each propeller model in each program the following tests have been carried out:

- Open Water test and performance prediction
- Cavitation observation with modelized wake
- Pressure pulses measurements in cavitating conditions

Results of Open Water tests

Figure 4 shows the results of open water tests performed with the original conventional propeller and the two alternatives of CLT propeller studied. From these curves it is deduced an efficiency improvement for the CLT propeller over the original conventional propeller, even at model field; the improvement is higher at full scale after the scaling of the open water characteristic curves.

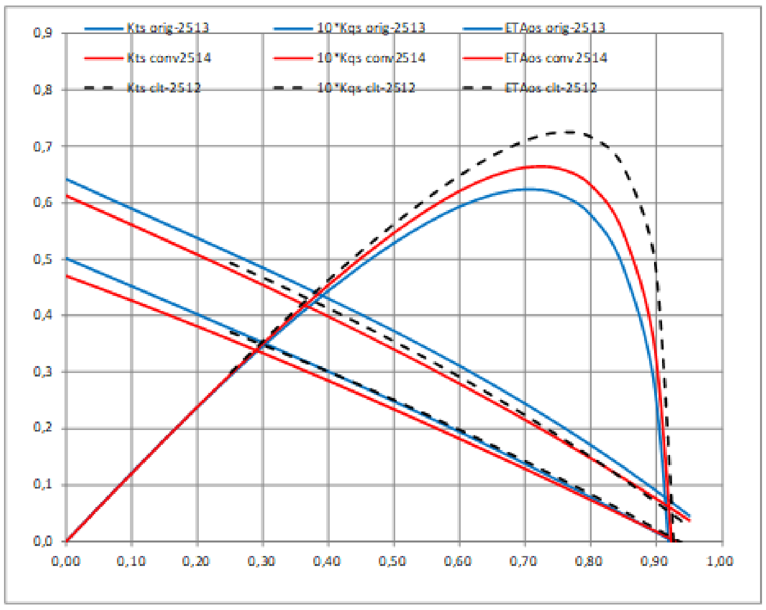

Figure 4. Open water test results

Performance Prediction Procedure

The method is based mainly in the procedures recommended by ITTC'78 to predict the performance of a ship based on model tests results (see ref. [1] and [2]). The following data must be used:

- Curve EHP-Vs, Effective Power of the hull predicted from resistance tests: EHP= Rt . Vs
- Propulsive coefficients: From self-propulsion tests.
  - ⇒ t (Thrust deduction coefficient),
  - ⇒ w_{ts} (wake coefficient computed at equal thrust for the ship scale), and
  - ⇒ ETAr (Relative rotative coefficient).
- Axial wake distribution in the propeller plane. From wake survey test.

These data are obtained from the original program of tests carried out with the designed hull form and the original conventional propeller.
The new propellers to be compared have been designed, propeller models have been built at a suitable scale and Open Water tests have been carried out. Curves of Kt and Kq versus J are scaled to ship size; and Kt/J2 curve is also computed.
Open Water scaled values to ship size have been deduced applying ITTC'78 method for conventional propellers and SISTEMAR method (refs.3,4) for CLT propellers.

Efficiency comparison:

With the original hull values (EHP, ETAr, t y wts) and for each speed the operating point of each propeller in this hull is determined, through the following parameter:

$$\frac{K_T}{J_{TS}^2} = \frac{EHP}{N_{ejes}^o \cdot \rho \cdot D^2 \cdot V_S^3 \cdot (1-t)(1-w_{TS})^2}$$

In the Open Water tests results of each propeller, with these values, corresponding values of Js and Kqs are read, and hence it is immediate to calculate:

$$rpm = 60 \cdot \frac{V_S \cdot (1-w_{TS})}{J_S \cdot D}$$

$$DHP(kW) = \frac{10K_{qs}}{10} \cdot \frac{2\pi\rho}{1000} \cdot \left(\frac{rpm}{60}\right)^3 \cdot \frac{D^5}{\eta_R}$$

Results of the full scale performance deduced with this procedure from model tests carried out with original conventional and definitive CLT propellers is summarized in Table 3.

	CONV-original	CLT
Full load prediction - 90%MCR –TRIALS		
V knots	20,40	20,98
RPM	83,8	86,1
Ballast prediction - 90%MCR –TRIALS		
V knots	20,42	21,01
RPM	82,9	85,0
V knots - Service prediction -SM=21%		
Full load	19,30	19,99
Ballast	19,31	19,98

Table 3. Original conventional and CLT propeller full scale performance deduced from model tests

Results of Cavitation tests

All cavitation tests have been carried out in CEHIPAR Cavitation Tunnel with the same procedure for wake simulation. Cavitation tests have been carried out in ballast draught which is the most unfavorable condition.

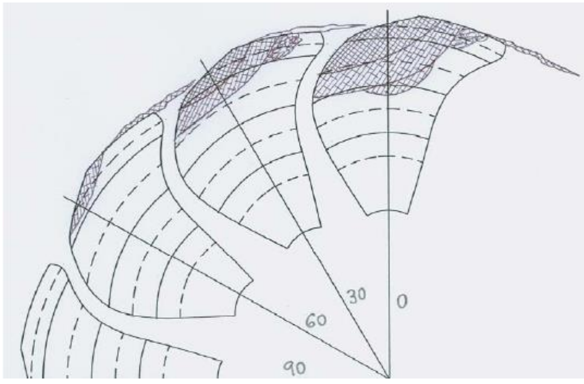

Figure 5. Cavitation observation test with original conventional propeller

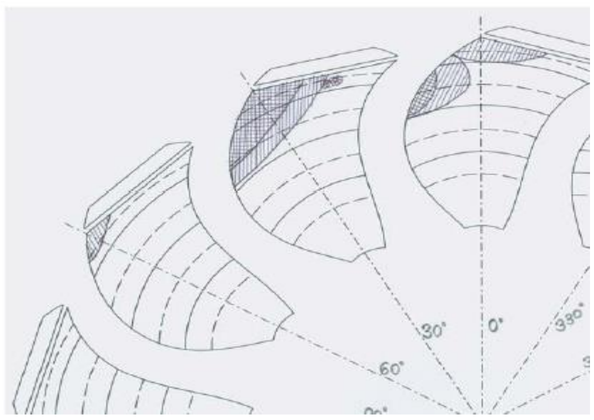

Figure 6. Cavitation observation test with CLT propeller

A cavitation sketch of the observation made during the test with the CLT propeller is shown in Figure 6. Fluctuating sheet cavitation with a small area of cloud cavitation, on the suction side, was observed between 20° and 40°, at 0,95R and ¾ of chord length. At model scale it was observed that the risk of erosion associated with this cloud cavitation was very low and it was decided to proceed with the full scale installation without further iteration in the design of the CLT propeller. As a matter of fact no cavitation erosion was detected on the CLT propeller in more than two years operations.

Results of Pressure Pulses measurements

Pressure pulses measured in ballast draft and extrapolated to full scale for the original conventional propeller are shown in Figure 7.

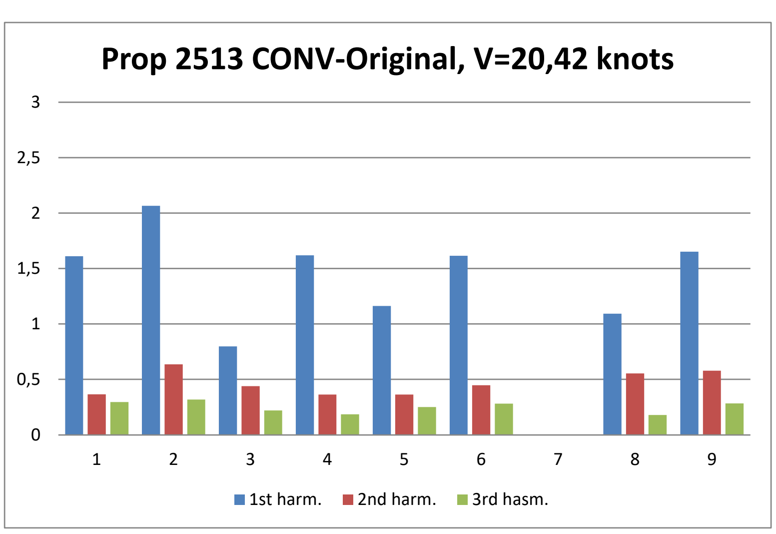

Figure 7. Full scale pressure pulses with original conventional propeller

Pressure pulses measured in ballast draft and extrapolated to full scale for the CLT propeller are shown in Figure 8.

Pressure pulses have been measured at the predicted speed for 90%MCR in each case; first harmonic is slightly higher in CLT case due to the higher speed of the test, but nevertheless it must be noticed that 2nd and 3rd order harmonics have been reduced in absolute value and with respect to the 1st harmonic, showing that the cavitation developed by the CLT Propeller is more stable.

The distribution of pressure pulses over the hull due to propeller action in both cases presents a level of intensity that is acceptable for this kind of vessels.

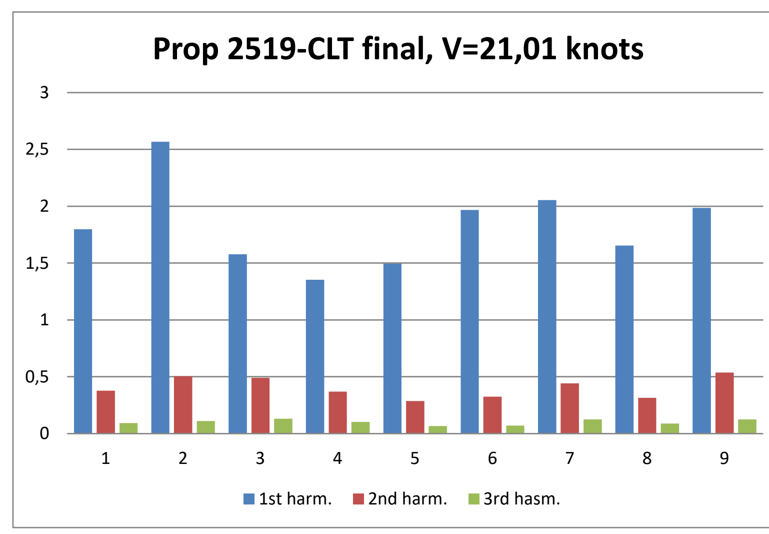

Figure 8. Full scale pressure pulses with CLT propeller

ANALYSIS OF FULL SCALE PERFORMANCE IN SERVICE, WITH ORIGINAL CONVENTIONAL PROPELLER AND WITH CLT® PROPELLER

Full Scale Performance Data

The ship is equipped with a Ship Performance Monitoring (SPM) system for continuous recording of engine and propulsion performance data, measuring torque, thrust and revolutions of the propeller rotating shaft. The shaft power sensor is able to measure shaft torque and thrust using strain gauge technique.

After retrofitting there were no possibility to perform standard sea trials due to operational needs of the ship. For that reason all comparisons have to be made based in data recorded by this Ship Performance Monitoring System.

SPM data	21B-1	21B-2	21B-3
Date	2015-07-13	2015-07-14	2015-07-16
Time	10:22	09:26	09:20
Load condition	ballast	ballast	ballast
Water depth, m	100	100	100
Wind estate	N-NE 10kn	W 11,4kn	SW 25kn
Sea estate	SE 1.5m	SE 2m	NW 5m
Record period, min	15	15	15
Vwind true, knots	10,3	10,8	26,2
Rel Dir wind, (º)	339	30	131
Beaufort	3,06	3,16	6,24
Tm, m	8,9	9,5	9,5
Trim, m	0,1	0,3	1
Ship course-GPS, (º)	162	160	57
Rudder angle, (º)	0,3	0	-0,4
Max. Hull Section Area, Am, m2	427,2	454,7	454,7
Ps-serv, kW	21128	20096	13576
Ns, rpm	76,9	75,3	64,7
Qs, kN.m	2625	2551	2003
Ts, kN	2230	2157	1711
Vs (LOG), kn	20,0	19,5	16,3
Vs (GPS), kn	20,2	19,4	16,9

Table 4. Example of data supplied by the SPM system reports

These daily reports corresponding to the first voyages of ship with conventional propeller after delivering and the first voyages of ship with CLT propeller after dry docking has been used to make the performance comparison of both propellers.

In order to compare performance results of both propellers and with predictions from model tests it is necessary to correct the full scale service data to homogeneous operation conditions. This comparison was done in ballast condition because much more data are available in this condition from the first voyages of the ship with both propellers.

Data Corrections

Two main corrections have to be applied to obtain homogeneous and comparable values of Power versus speed.

Correction due to water depth. In shallow waters where the blockage effect of the seabed can have some influence, the speed will be corrected applying the Schlichting method (ref. 5) to obtain the value of speed in deep water at the same power.

Correction due to weather conditions. Every daily report present some differences in draught and trim (usually small differences in displacement) but large differences in wind and sea states. To take all this into consideration it is more reliable to use DE JONG method (ref. 6), which consist in the use of a statistical formula to obtain the factor of correction to be applied to the measured power of each report period. DE JONG formula gives the percentage of correction that must be applied to the power of the ship to take into account the effects of wind and waves corresponding to this ship at a specific Beaufort Number (BN). The formula proposed by DE JONG is:

$$Cp(\%) = 5{,}75 - 0{,}793 \cdot \Delta^{1/3} + 12{,}3 \cdot BN + (0{,}0129 \cdot Lpp - 1{,}864 \cdot BN) \cdot \left(\frac{Lpp}{8}\right)^{1/2}$$

The value of *Cp* computed for the BN of each report period must be made relative to the value of *Cp* computed for the BN of reference considered. The formula includes correction for small differences in displacement and BN must be based in True Wind values. The relationship used to compute BN values is:

$$BN\ report\ period = \frac{TRUE\ WIND + 5}{5}$$

And the BN of reference has been BN=0 which allows comparing also with the predictions made for trials conditions from model tests.

$$Coef.PS = \frac{1 + \frac{Cp\ ref}{100}}{1 + \frac{Cp\ report\ period}{100}}$$

This “Coef. PS” must be applied to the measured power.

Final Comparison

Next figures 9 and 10 show the corrected data of reports obtained from the Ship Performance Monitoring system in several voyages in ballast condition.

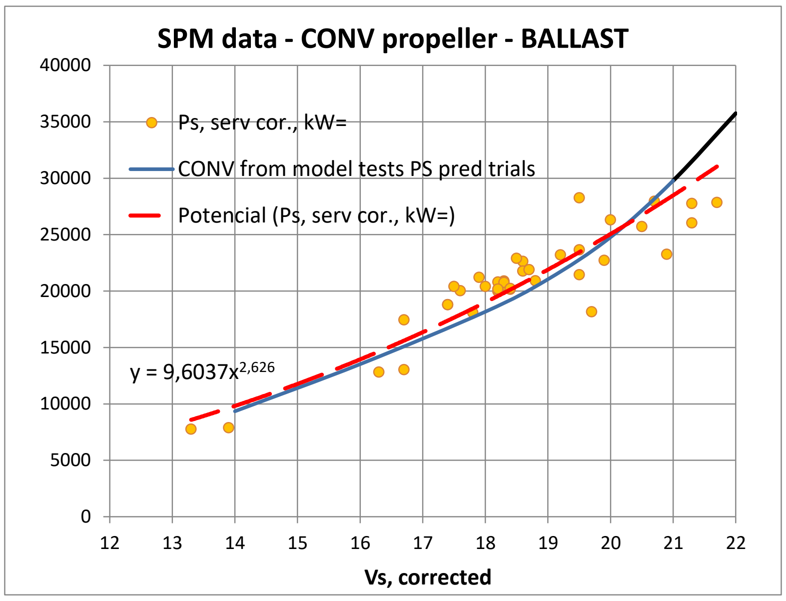

Figure 9. Full scale corrected data of CONVENTIONAL original propeller

The predictions obtained from model tests and the trend line obtained by regression in potential form of the data points have been included in both charts for ease of reference and better comparison.

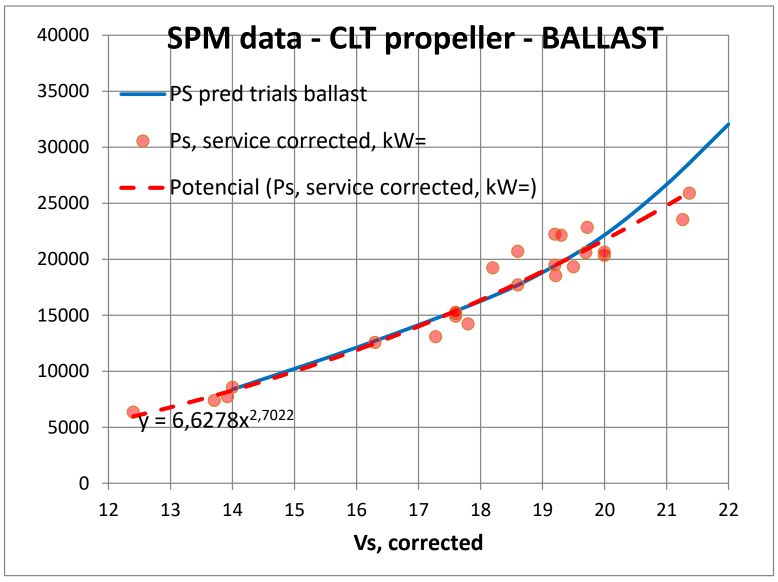

Figure 10. Full scale corrected data of CLT retrofitted propeller

VS knots	PS - CONV kW	PS - CLT kW	$\frac{PS-CLT}{PS-CONV}(\%)$
14	9821	8288	84,4%
16	13946	11889	85,2%
18	19001	16344	86,0%
19	21900	18915	86,4%
19,5	23446	20291	86,5%
20	25058	21728	86,7%

Table 5. Comparison of measured corrected data

Table 5 shows the comparison of measured corrected data obtained applying the regression formulae in each case.

A good agreement of model test prediction and SPM measurements for CLT in the operation range is shown in Figure 10.

The high gain deduced from Table 5 is not only due to the installation of CLT propeller. An improved painting scheme was applied during the drydocking and it was considered accounting for about 5% of the improvement.

CONCLUSIONS

In the retrofitting cases a reduced program of model tests is in general adequate and sufficient for the design of a new CLT propeller. And this has been confirmed in the project described in the present paper.

The design procedure has resulted in the design of a final CLT propeller capable of satisfying the design requirements.

The model scale predictions have satisfactorily and accurately matched the full scale observations and measurements.

The design and installed CLT propeller has improved the propulsive performance of the ship, at constant speed, by more than 8%, providing a comparable reduction in fuel consumption and emissions.

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Raising of the "Mediterraneo" Planning in Advance to Manage and Mitigate Risk

ABSTRACT

On 25 August 2016, in the port of Leghorn, Italy, the floating dock Mediterraneo sank at about 12 m depth along with the research vessel Urania, which had been docked for repairs. The design an the execution of the refloating took more then 6 months and was successfully completed with neither accidents nor near misses thanks to the careful evaluation of the uncertainties and the correct managing of the risks involved in the process.

INTRODUCTION

On 25 August 2016, the research vessel Urania was docked on the floating dock Mediterraneo, in the port of Leghorn, Italy.

While refloating operations were in progress, Urania abruptly tilted on her port side and fell from the block against the floor of the floating dock.

The crew of the vessel was on board attending the usual duties during an undocking operation when the incident occurred and a couple of them remained seriously injured.

The emergency teams promptly reached the scene of the incident and immediately realised that the only way of evacuating the personnel from the vessel, that in the meanwhile was listing on her portside and progressively flooding, was by means of launches going alongside.

However, at the time of the incident the water depth above the dock floor was of about 1 m only and it was not sufficient to allow the ingress of rescue launches, it was therefore decided to ballast the floating dock to increase its draft.

In the matter of a few minutes everybody was safely evacuated from the vessel. It was at this moment that a flow of water was noted entering the service corridors and the pump rooms of the dock.

The progressive flooding could not be stopped by using the bilge pumps of the dock and even the use of a portable submersible pump that had been promptly deployed on board in the meantime proved insufficient.

In the matter of a few hours the pump rooms of the dock were completely flooded and all the systems were out of service.

Figure 1. Research vessel Urania in the sank Mediterrano floating dock.

THE SCENARIO

The morning after, when a first assessment was carried out, the situation was as follows:

- Floating dock sitting on seabed, at a depth 12m
- Vessel lying on dock floor, which was at about 8 m below sea level, listed on portside
- Dock ballast compartments: flooded
- Dock pumps rooms: flooded
- Dock deballasting system: out of service
- Dock level monitoring: out of service

- Vessel hull: flooded, main deck about 1 m below the sea level
- Stability of the vessel: uncertain
- Vessel watertight compartments: open
- Vessel double bottoms: open
- Vessel pumping system: not available
- Extent of damage to vessel hull: unknown
- Extent of damage to dock floor and bottom: unknown
- Underwater visibility: from 50 cm to nil

According to the Italian law, as a result of the accident, the entire area was subject to criminal investigation and the accesses were restricted.

MAIN ACTORS

The investigation involved and a number close to three dozens of different stakeholders, among them:

- The shipowners,
- their H&M insurers and P&I Club
- the Port Authority,
- The owners of the dock and their insurers,
- the dock Managers and their insurers,
- the Coast Guard,
- all the persons which in the meantime had been put under criminal investigation, such as the Master of the vessel, the dock Manager, the divers who had verified the positioning of the vessel on the blocks, the shipyard etc.).

The project ad the the refloating operations had to be conducted in parallel with the criminal investigation and that it had to be approved by all the autoristies involved.

The Maint actors involved in the project were as follows:

- Principals, Port Authority of Leghorn and Azimut-Benetti, Leghorn
- Safety Management, Studio Sgrò, Viareggio
- Feasibility study, basic design, project management, refloating management, Stige Maritime,Genoa
- Finite element analysis, M&B, Stige Maritime, Genova
- Refloating calculations, Herbert Engineering, Singapore
- Workshop design of stabilizing structures, Teknoconsulting, Genoa
- Steel prefabrication, Gestione Bacini, Leghorn
- Laser and sonar scanning, Drafinsub Survey, Genoa
- Diving activities, Drafinsub, Genoa
- Logistics, Azimut-Benetti and Bettarini, Leghorn
- Temporary services, STIL and Martelli Impianti, Leghorn
- Antipollution assistance, Labromare, Leghorn

THE DESING OF THE REFLOATING

The design of the refloating operation had to be conducted in such a way to reduce the uncertainties and to manage the risks. However the design itself was subject to many constraints and uncertainties.

The poor visibility and the unknown stability condition of the vessel on the dock floor did not suggest detailed assessment by means of divers, so it was decided to carry out a combined sonar (below the water) and laser (above the water) scanning, to depict the scenario.

This campaign revealed that there was not enough space aside the vessel or the dock to have safe access for heavy lift vessels or crane barges, so the option of removing first the Urania by lifting her out of the dock was discarded and it was therefore decided to examine the possibility of raising again the floating dock, keeping the damaged vessel still on its floor.

This approach had also the advantage of minimizing the impact on the scene of the incident, thus allowing thorough investigation when the area would have been safely accessible to the appointed technicians.

The fortunate circumstance of a relatively small ship lying in a much bigger dock allowed to presume that some of the ballast compartments of the dock had not been damaged by the impact of the hull against the floor plates and a first feasibility study was run by using Hecsalv®

software. The study demonstrated that, assuming certain compartments were intact, their buoyancy would have sufficient to refloat the dock with the hull lying in it.

However there were uncertainties, in particular it was not possible to exclude any damage to the dock bottom, which might have suffered breaches when touching the seabed. In addition the watertightness of compartment boundaries was unknown, as some bulkheads might have been buckled due to the accident. Last but not the least, the status of intercepting valves of the ballast system was also unknown and it had to be assumed that all the ballast double bottoms were interconnected.

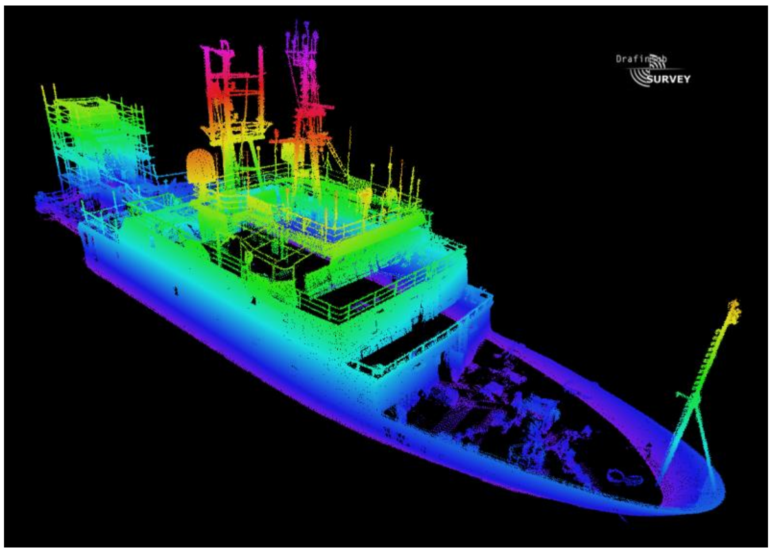

Figure 2. 3D Point Cloud of Research Vessel Urania

Many simulations were run, allowing to individuate the solution which appeared to be the best compromise between the presence of undamaged compartment, the relatively easiness of access by divers to intercepting valve and the expected result.

A preliminary refloating plan was therefore drafted leaving two major issues yet to be addressed:

- How to remove water from given compartments in a controlled and reliable manner
- How to stabilize the hull of the vessel in order to avoid any unexpected movement during the raising of the dock.

The solution to the first issue came from quarry technology and it was planned to hire a number of powerful draining pumps. These pumps have the advantage of providing a high capacity, although at a relatively low delivery head, and are designed to run also in muddy water, as it could be the case. These pumps were available on the market and it was easy to procure them in the number and size required by the refloating plan.

By fitting a pump in each of the compartment to be emptied, comparing its nominal capacity with the volume to be emptied, it was possible to estimate the duration of each refloating stage, in order to check residual grounding reaction, hydrostatic stability, trim, longitudinal stresses during the entire refloating process.

In order rationally to design a reliable stabilizing system, the laser and sonar scanning carried out in the first stages was of paramount importance.
Without having a single operator approaching the vessel, it was possible to determine its exact position in the dock, its inclination, as the laser scanning of the superstructures of the Urania created a cloud of points that, superimposed to the 3D model of the vessel, allowed the creation of a complete model of both the vessel and of the dock.

The sonar scanning, although quite imprecise due to the background noise generated by the reflections of the sonar waves against the floor and the sides of the dock, allowed to individuate some sections which were free from obstructions or interfering objects, such as debris fallen from the vessel during the incident and the keel blocks and pillars of the original docking plan.

The removal of these interfering obstacles was not possible both because it was not allowed by the constraints of the ongoing incident investigation and because it was not known which contribution they were giving to the stability of the hull, if stuck underneath it.

However, a few sections were individuated which were free from obstacles and also in way of reinforced frames of both the vessel and of the dock. The stabilizing devices therefore had to be located in these sections.

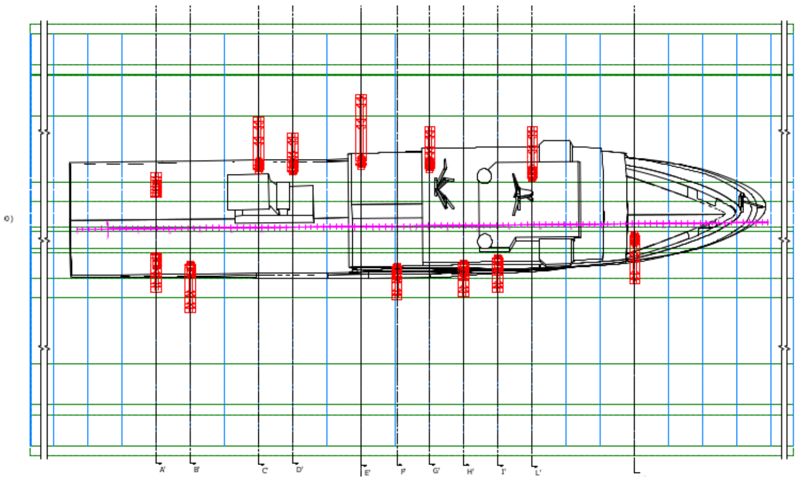

Figure 3. Scheme of additional supports

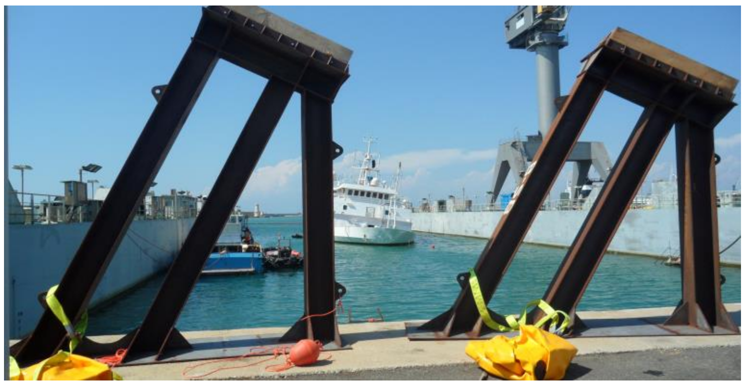

Figure 4. Two additional supports

A dynamic simulation was run and it demonstrated that, although after the incident and in the immediate aftermath the Urania had always listed portside, the weight distribution and the pattern of contact areas between the hull and the dock floor was inducing the vessel to regain her upright position, thus to rotate to starboard. The stabilizing system was therefore to be designed considering blocks on starboard side, pushing against the hull, and rods on portside, pulling it.

In order to estimate the design loads on each stabilizing device, both dynamic simulation by using Runge-Kutta algorithm and by-dimensional analysis were performed and they indicated that, considering also some safety margins, the maximum pulling force on the portside rods was to be estimated in about 30 t and the maximum pressure load on the starboard side blocks was in the region of about 100 t.

Finite Element Analysis was carried out on each stabilizing device and prefabricating instructions were transferred to manufacturers.

The entire project desing process requested about six months to be completed.

THE PREPARATION

Specialist construction divers were mobilised while the stabilizing devices and the pipes that had been designed to lower the draining pumps in the double bottoms were manufactured.

Figure 5. The hyperbaric chamber deployed on site for all the duration of the prepration and of the refloating.

The divers planned to work in daily shifts only, two teams at the same time in two different location. This implied the intervention of almost thirty persons, including in the figure certified construction divers, team supervisors, a superintendent, safety, logistic and technical personnel. A trawler, two assisting tenders, containerised workshop, hyperbaric chamber and emergency launch and recovery system (LARS) were moved to the site.

The stabilizing devices were lowered in the dock basin, placed by divers in their exact position in almost nil visibility and welded to the dock floor.
Temporary openings were executed on the dock floor both to insert the pumping pipes and to get access to the valves, which were to be closed to reduce the free surface in ballast compartments during the raising. Without this precaution, during the refloating there might have been an unacceptable loss of hydrostatic stability.

Openings were cut on the vessel's hull to allow the water to flow out during the raising, both to reduce weight and to avoid excessive and uncontrolled dynamic stresses on stabilizing structures.

Sitxeen draining pumps were lowered in the designated double bottoms, having an aggregate pumping capacity of about 5,700 m3/h.

Figure 6. Lowering of pumping pipe into dock

Figure 7. Lowering of pump into pumping pipe

Remote level controls were fitted in each compartment and in the hull of the vessel, to monitor the progress on emptying operations such as to perform on-site and on-time verification during the refloating process.

Eight weeks after the beginning of the diving activity on site, everything was ready for the refloating operations.

THE REFLOATING

On 14th August 2016 the draining pumps were started and a first lightening of the dock was carried out, to bring it to the residual grounding reaction that had been calculated as the starting condition for the refloating.

The morning after the pumps were started and stopped in sequence, keeping all the movements, list, trim and calculated stresses under careful monitoring.

It took about nine hours for the dock floor to raise above the water again, with the listed hull of the Urania firmly in the same position she had assumed after the incident.

Figure 8. Research vessel Urania after the completion of the refloating of Mediterraneo

The dock was declared floating and stable the day after, when it was confirmed that no further water ingress was in progress, that there was no undesired passage of water from a ballast compartment to another and that it was not necessary to keep running any draining pump.

FACTS AND FIGURES

Lightship of Urania, abt 1,000 t
Lightship of the floating dock, abt. 9,000 t
Aggregate weight of stabilizing structures, 24 t
Aggregete capacity of pumping system, 5,720 m3/h
Aggregated diving time, abt. 1,000 manhours
Project and design, abt. 6 months
Prefabrication of stabilizing structures, abt. 2 months
Preparation time, 52 days
Refloating time, 9 hours
Incidents or near-misses, Nil

CONCLUSIONS

The Refloating of Mediterraneo proved to be a success, not only in the desing and in the execution of the refloating itself, but in particular in the assessment of the uncertainties and in the management of the associated risks, also my making use of the available technology.

A documentary movie covering the refloating of Mediterraneo is available on youtube:

“Raising of the Mediterraneo”
https://www.youtube.com/watch?v=K2duyKjVJuI&t=79s

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Need for an Integrated Sustainable Shipping Index

ABSTRACT

According to the United Nations, the three pillars of sustainability are social, environmental, and economic and these are inextricably linked. Currently, there are reporting and accounting standards for sustainability which can be used by the shipping industry and these include the Triple Bottom Line (TBL) framework for sustainability accountability, Global Reporting Initiative (GRI) Sustainability Reporting Standards, and the Sustainability Accounting Standards Board (SASB) Marine Transportation Sustainability Accounting Standard. There is also a rating system for environmental performance of ships known as the Clean Shipping Index (CSI). However, there is no index globally which covers all three critical areas of sustainability in shipping. This article looks at the TBL, GRI, SASB and CSI and then argues why it would be useful for the shipping industry to have an Integrated Sustainable Shipping Index (ISSI).

1. INTRODUCTION

According to the United Nations, the three pillars of sustainability are social, environmental, and economic and these are inextricably linked (UN, 2012).

There has been a greater emphasis on environmental sustainability in shipping by the IMO in the recent years through the various International Conventions. These are the Prevention of Pollution from Ships (MARPOL) Annex VI to reduce emissions of greenhouse gases (GHG) from ships, the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM) Convention to prevent the spread of invasive harmful aquatic organisms carried by ships' ballast water, and the Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships.

Social sustainability in shipping has also progressed with the IMO's and the ILO's efforts in improving the training, safety and employment standards of the seafarers through the Standards of Training, Certification and Watchkeeping for Seafarers (STCW) Convention and the Maritime Labour Convention (MLC) respectively.

Economic sustainability in shipping has however experienced drastic changes due to the shipping cycles in both dry and wet cargoes. The swings in the shipping economy have caused disruptions to the industry resulting in insolvent companies, seafarers without jobs, new-builds abandon at shipyards, ships at the anchorages without charters, and banks left with non-performing loans.

As such, the International Chamber of Shipping reasoned that the stakeholders of the shipping industry should give equal priority to each of the three pillars of sustainable development because unless the industry is economically viable it will also not be able to deliver the improvements in environmental and social sustainability (ICS, 2013).

John Elkington also argued that "the social and economic dimensions of the agenda - which had already been flagged in the Brundtland Report (Brundtland et al., 1987) - have to be addressed in a more integrated way if real environmental progress was to be made" (Elkington, 2004).

The need for companies to look at all three dimensions of sustainability performance in an integrated manner has resulted in different business reporting models which can guide the organisations to understand, demonstrate, communicate, report and improve such performance (Medel-González et al., 2013).

The reporting and accounting standards for sustainability which can be used by the shipping industry include the Triple Bottom Line (TBL) framework for sustainability accountability, Global

Reporting Initiative (GRI) Sustainability Reporting Standards, and the Sustainability Accounting Standards Board (SASB) Marine Transportation Sustainability Accounting Standard. There is also a rating system for the environmental performance of ships known as the Clean Shipping Index.

This article looks at TBL, GRI, SASB and CSI and then argues why it would be useful for the shipping industry to have an Integrated Sustainable Shipping Index. The article is organised into five main sections: Introduction; Overview and Comparison of TBL, GRI and SASB; Clean Shipping Index; An Integrated Sustainable Shipping Index, and Concluding Remarks and Recommendations.

2. OVERVIEW AND COMPARISON OF TBL, GRI and SASB

2.1 TBL framework for sustainability accountability

The term Triple Bottom Line (TBL) was coined in 1994 by Elkington (1997). He argued that organisations should be preparing three different bottom lines instead of just one bottom line, which is the traditional measure of profit or loss in the profit and loss account statement. The other two bottom lines are the "people account" – a measure in the form of how socially responsible an organisation has been throughout its operations, and the "planet account" – a measure of how environmentally responsible it has been (Hindle, 2009).

However, the 3Ps (Profit, People, and Planet) do not have a standard unit of measure. Profits are measured in dollars, but what should social capital and environmental health be measured in? Hence, finding a conventional unit of measurement is a challenge. Furthermore, there is no universal standard method for calculating the TBL (Slaper and Hall, 2011).

In his report to the Norwegian Shipping Association on the "Corporate Social Responsibility and the Shipping Industry", Vilsted (2004) considered that the triple bottom line was a supplement and not a replacement for the financial results as an indicator of the company's performance, and that good financial results were not only the first bottom line, but also the most important one.

In their research project on Corporate Social Responsibility (CSR) in the Baltic Sea Maritime Sector, Kunnaala et al. (2013) had asked the shipping companies they surveyed as to what CSR measures their company were involved in. The CSR measures selected by the participants included Safety, Social, Environmental and Economic. Although there was no direct link in the report that these shipping companies might be using the TBL framework for sustainability accountability, it could be inferred that the TBL concept was being practised by these companies as Safety measures could also be grouped under Social measures.

2.2 GRI Sustainability Reporting Standards

The Global Reporting Initiative (GRI) was founded in Boston, the United States of America in 1997. It is an independent international organisation that is now based in Amsterdam, the Netherlands. It promotes the use of sustainability reporting as a way for organisations to become more sustainable and contribute to sustainable development (GRI, 2017a). The GRI Sustainability Reporting Standards (GRI Standards) which were released in October 2016 have superseded the G4 Guidelines and will be required for all reports or other materials published on or after 1 July 2018 while the G4 Guidelines remain available until then (GRI, 2017b).

GRI has also actively participated in the international multi-stakeholder ISO 26000 development process from the beginning, and supports this first ever non-certifiable ISO standard on (Corporate) Social Responsibility. ISO 26000 was published in November 2010 and provides guidance on how businesses and organisations can operate in a socially responsible way. Both ISO 26000 and the GRI Guidelines cover the most common economic, environmental and social issues and impacts. However, while ISO 26000 is intended to give guidance on the actions and expectations for organisations to address each of these topics, the GRI Guidelines provide guidance on what to report for each of these issues specifically (ISO, 2010).

There is also a link between TBL and GRI. John Elkington had been involved since the early days of GRI and was also a former member of the GRI Board of Directors. He was responsible - alongside General Motors - for switching GRI from an environmental focus to a triple bottom line focus (GRI, 2012).

According to Singhal and Dev (2016), integrating non-financial reporting, such as sustainability and CSR reporting is a relatively recent trend which has expanded over the last twenty years.

This geographic expansion could be seen when in August 2016, the Maritime and Port Authority of Singapore (MPA) announced an initiative to help publicly-listed shipping companies with the cost of their sustainability reports. Companies which took up MPA's offer would have to publish their sustainability reports before 31 December 2017 and would have to meet international reporting standards such as the GRI. Earlier in June 2016, the Singapore Exchange (SGX) made sustainability reports mandatory for all listed companies on a 'comply or explain' basis from the financial year 2017. Hence, the MPA scheme was expected to support maritime companies in their sustainability efforts. According to Andrew Tan, the Chief Executive of MPA, "the triple bottom line - people, planet and profits - will enhance (the maritime companies) shareholder value" (Eco-Business, 2016, SGX, 2016).

An exploratory study of the ten largest container shipping companies done by Olsen (2015) based on the GRI Guidelines had found that sustainability reporting among the container shipping corporations varies widely in both quality and level of disclosure, from companies issuing several hundred pages lengthy sustainability reports to companies with only a single webpage with information on sustainability. The best aspect reported was the category; Economic, Environmental and Social Aspects, with social elements being the weakest part.

2.3 SASB Sustainability Accounting Standards

The Sustainability Accounting Standards Board (SASB) was established in 2011 and is based in San Francisco, the United States of America. It is an independent standards-setting organisation for sustainability accounting standards. The standards are designed to improve the effectiveness and comparability of corporate disclosure on material environmental, social, and governance (ESG) factors in the United States Securities and Exchange Commission (SEC) filings. The SASB currently has a provisional standard for the marine transportation industry that was published in September 2014. There is also a separate provisional standard for the cruise lines that was published in December 2014 (SASB, 2017).

In the exploratory study of the cruise industry sustainability, Szymanowicz (2016) had found that large cruise ship firms are more likely than small cruise ship firms, to report the outcomes of their sustainability activities through official reports following the GRI's disclosure framework. He had also cited the critical environmental and social concerns raised by the cruise lines research brief by SASB.

Using the SASB's provisional standard for cruise lines as a guide, Jones et al. (2016) also had a similar finding in their exploratory review as Szymanowicz. Only the top two cruise ship operators published extensive sustainability reports which covered some environmental, social and economic issues while the other leading cruise corporations published more limited information on sustainability. They even suggested that the leading cruise companies' current commitments to sustainability are "primarily couched within existing business models centred on continuing growth and consumption and that these commitments represent a weak approach to sustainability".

2.4 Comparison of TBL, GRI and SASB standards

Table below provides a summary comparison of TBL, GRI and SASB standards:

Item	TBL	GRI	SASB
1. Year started	1994	1997	2011
2. Number of standards/topics	The three sustainability pillars of Social (People), Environmental (Planet), and Economic (Profit). No detailed topics under each and no universal standard method for calculating them.	G4 has 36 GRI Sustainability Reporting Standards consisting of 3 universal standards and 33 topic specific standards are grouped under economic, environmental and social.	Marine Transportation standard has 4 topics, of which 3 can be grouped under environmental and social. Business ethics could be considered the only economic topic. Cruise Lines standard has 5 topics which can be grouped only under environmental and social. No economic topic.
3. Relation to other international standards	Not applicable	ISO 26000:2010 Guidance on social responsibility	Not applicable
4. Industry specific standard	No	No	Yes. More than 80 industries in 10 sectors including marine transportation and cruise lines.
5. Specific Unit of Measure for reporting requirements	No	Yes. Examples are injury rate (social), GHG emissions in metric tons of CO_2 equivalent (environmental), and percentage of procurement spent on local suppliers (economic).	Yes. Examples are air emissions for NOx, SOx and particulate matter in metric tons (environmental), lost time injury rate (social), and regulatory fines associated with bribery (economic).
6. Usage in the shipping industry	Not believed to be widely used but this is also because there are no detailed topics under TBL. It is more of a conceptual framework.	Believed to be the most widely used sustainability framework among the three based on the literature review carried out for this article.	Not much information available on its usage in the shipping industry from the literature review carried out.

3. CLEAN SHIPPING INDEX (CSI)

CSI was set up in Gothenburg, Sweden in 2007 by Ulf Duus and Jan Ahlbom (Green4Sea, 2014). It is a non-profit organisation and is coordinated by a secretariat and overseen by an independent board. To guarantee that all technical data is fairly scored and up-to-date, the methodology for determining the index is reviewed by a professional committee of experts and researchers (CSI, 2017a).

It is an online tool where transport purchasers can compare the environmental performance of different ships. All the shipping companies that are affiliated to the index publish information about their ships. On the other side, transport purchasers can see how the different ships perform in relation to each other (Green4Sea, 2014). A network of cargo owners from Sweden, Germany and the Netherlands has agreed to use CSI in their procurement process. Several ports are also using CSI for lowering their port dues for clean ships. From 2018 onwards, the Swedish Maritime Administration intends to give a significant tax reduction for well-performing vessels according to the CSI (CSI, 2017b).

The environmental parameters used by CSI are CO2 emissions, nitrogen oxides (NOx) emissions, sulphur oxides (SOx) emissions, particulate matter (PM) emissions, use of chemicals, and water and waste management. For the scoring of CO2, the vessel efficiency is compared to a reference vessel of the same type and size, calculated mainly using data published by the International Maritime Organisation (IMO). For NOx, the level of emissions defined by Tier I, II and III levels set by the IMO serve as the reference for scoring. The basis for scoring in SOx and PM is how much sulphur is present in the fuel, or whether the exhaust gases are treated. In the chemicals section, scoring depends on the chemical used in antifouling paint, the type of stern tube oil, hydraulic fluids and gear oils used, the type of boiling cooling water treatment system installed, the chemicals present in cleaning agents used and the type of refrigerants applied. The waste water section covers the treatment of sewage and grey water, management of solid waste, sludge oil handling and bilge water treatment. The shipping company will submit the data for the above environmental parameters, which will then be audited by a CSI accredited classification company (CSI, 2017b).

The environmental standards of the GRI are wider in scope than CSI as they cover eight main groups which are material, energy, water, biodiversity, emissions, effluents and waste, environmental compliance, and supplier environmental assessment (GRI, 2017b). However the environmental parameters of the CSI would already be adequate for shipping as they are more industry specific and hence relevant. Besides, CSI is an index which allows for more straightforward comparison.

The shortcoming for CSI is that it looks only at environmental sustainability and not economic and social sustainability as well. It leads to the next section on why there is a need for an integrated sustainability index.

4. AN INTEGRATED SUSTAINABLE SHIPPING INDEX (ISSI)

Medel-González et al. (2013) claimed that sustainability problems cannot be analysed or understood if an integral perspective is not considered. As mentioned earlier, CSI only looks at the environmental aspect and does not cover the economic as well as social aspects of sustainaibility.

The economic aspect of sustainainablity cannot be neglected and is always essential. An organisation that is loss-making would not be able to sustain operations in the long run. However, economic sustainability is not just revenues, operating costs, and profits but should also look at the wages paid to the employees ashore and on board, the tax contributions to governments, the investments made to community projects, as well as the positive and negative indirect economic impacts of the organisation. An example of positive indirect economic impact is the adoption of information technology tools such as ship performance monitoring system which could help to increase ship energy efficiency, thereby reducing fuel costs as well as emissions.

The authors would like to propose that organisations should also carry out detailed risk planning when considering investments such as the ordering of newbuilds at shipyards. The over-ordering and speculative building of new ships during the boom years in a shipping cycle has never been sustainable and have also exacerbated the over-supply of vessels during the bust years. Such a situation can be found not only in dry bulk shipping but container ships, tankers and the offshore sector as well and this cycle is repeated. Although the shipping cycle cannot be prevented as it is subjected to geopolitics as well as economic ups and downs, however, its volatility can be mitigated if organisations are financially disciplined and “not to jump on the bandwagon” and place speculative orders during good economic times and when capital is readily available.

The social aspect of sustainainablity cannot be left out of the equation as well. It would cover topics such as occupational health and safety, training and education, wages, contractual terms, as well as non-discrimination and equal opportunity. According to Kunnaala *et al*. (2013), "shipping companies engage in CSR to gain competitive advantage and to increase maritime safety. The social aspects of CSR take into account the well-being and skills of the employees, corporation and other stakeholders of the company."{Kunnaala, 2013, Corporate Social Responsibility and Shipping: Views of Baltic Sea Shipping Companies on the Benefits of Responsibility}{Kunnaala, 2013, Corporate Social Responsibility and Shipping: Views of Baltic Sea Shipping Companies on the Benefits of Responsibility}

Although GRI considers all the three key areas of sustainability, it is not as easy as CSI, which is an index, to compare the sustainability performance of different shipping companies. According to Medel-González et al. (2013), "an index offers decision makers condensed information for performance monitoring, benchmarking comparisons and decision making. [It is] an aggregation of statistics and or indicators, which often summarised a lot of related information, using an organized method of weighting, scale and normalisation, adding multiple variables into a summary".

An integrated sustainable shipping index (ISSI) would be useful to ship owners to assess and monitor on how well they are doing in overall sustainability compared to their industry peers and where are the areas for improvement. Such an assessment could be verified by a third party auditor, similar to CSI.

The benefits of attaining a good index score for a ship owner could include:

- Improved reputation in its corporate social responsibility (CSR)
- Increased loyalty from internal stakeholders such as employees ashore and at sea (seafarers)
- Increased goodwill from external stakeholders such as charterers and shippers
- Better confidence of the other stakeholders such as financial institutions, creditors, and shareholders in the shipping company

5. CONCLUDING REMARKS AND RECOMMENDATIONS

The following can be concluded from the above findings on the reporting and accounting standards for sustainability which can be used by the shipping industry:

- Triple Bottom Line (TBL) is one of the earliest available sustainability accounting framework, but it is not believed to be widely used in the shipping industry because there are no detailed topics under TBL. The originator of TBL, Elkington can be attributed to switching the Global Reporting Initiative (GRI) from an environmental focus to a triple bottom line focus.
- Among the three sustainability reporting and accounting standards, GRI has the most comprehensive framework with three universal standards and thirty-three topic specific standards. It is also believed to be the most widely used in the shipping industry among the three. However, GRI sustainability reporting varies widely in both quality and level of disclosure, from companies issuing several hundred pages lengthy sustainability reports to companies with only a single webpage with information on sustainability.
- Among the three, Sustainability Accounting Standards Board (SASB) accounting standards are the most recent with industry specific standards for marine transportation and cruise lines. However, there is not much information available on its usage in the shipping industry from the literature review carried out, and there is only one economic related topic for its marine transportation standard and none for its cruise line standard.

Clean Shipping Index (CSI) is an environmental specific index used by shipping and allows for easier comparison between shipping companies using it. However, it does not look at the other two areas of sustainability, which are economic and social.

This article, therefore, explains the need for an Integrated Sustainable Shipping Index (ISSI), which allows for more natural comparison between shipping companies on their overall sustainability performance. It is recommended that further research is carried out on setting the framework for such an index. Such research could begin with the gathering of data from shipping companies. This data will then be analysed to identify the sustainability aspects and impacts. Indicators will be selected from the significant impacts, and the ISSI will be calculated based on the indicators which are determined by the weight of the indicator in each aspect.

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The Next Disruptive Technology that the Marine Industry Needs to be Prepared

Abstract

In the last two hundred years the ships have undergone changes driven by technological developments. Sails gave way to steam with the invention of steam engines. Steam was replaced by the force of combustion taking place inside the engine itself. With each change there were casualties. Sail making for ocean-going vessels were made redundant and with the advent of internal combustion engines, boiler making too. The next technological advance may see the end of internal combustion engine makers, in fact the end of all carbon based prime movers and happily the end of carbon emission by ocean-going vessels. Demand for clean energy to combat climate change has driven technological advances in renewables and nuclear energy. France is investing heavily in nuclear. The US 's agenda to keep people employed in the exploitation of fossil energy has so far succeeded in driving the best and brightest in nuclear energy to seek partnership with farsighted and deep pocketed organisations in China. India is not far behind.

As a result, before this mid-century, we can expect more disruption in the marine industry. Global demand for oil and gas will diminish and shipyards whose mainstay is building offshore oil and gas rigs will be among the first casualties of the shift from carbon based power plants. It is the responsibility of the leadership in such shipyards to ensure that the generation that comes after them is prepared for the tectonic shift. Likewise those who are charged with the education of young engineers and naval architects have a similar responsibility.

Executive summary

Climate change is real. The combustion of fossil fuels is a major cause. Mercantile tonnages use fossil fuels and are a major contributor the greenhouse gases that have resulted in global warming as well as to the pollution of the atmosphere with life threatening PM2.5 particulates.

IMO, currently exempt from obligations under COP 21, needs to address this problem decisively and urgently.

Renewables are unlikely to be a viable alternative to oil for marine propulsion.

Nuclear energy is safe, clean and will contribute much to keeping the planet habitable for all life-forms.

Shipbuilders must prepare itself for the next disruptive technology: nuclear power.

NS Savannah and era of boundary-breaking purs uits

NS Savannah built in the United States, by New Yo rk Shipbuilding Corporation entered service in 196 2. She had the distinction of being the first non-mi litary nuclear powered vessel to set sail. Not only was she a cargo ship, she was a lavishly furnished passenger ship with space for 60 passengers on to p of her 14,040 tons cargo capacity.

A 74 MW Babcock Wilcox PWR nuclear reactor powered two De Laval steam turbines driving her single screw, giving her a top speed of 24, cruising speed of 21 knots and a range of 300,000 nautical miles (equivalent to 14 times round the world!) between refuelling. No passenger cruiser or cargo ship today can match that range. No fuel tank was needed, nor a funnel nor time for refuelling. She was space efficient, green and clean.

NS Savannah is a testimony of what is possible in an era when the engineers and scientists were free to experiment and test boundaries without the constraints of political agenda and an overregulated administrative environment. It was an era that inspired sputniks and manned missions to space and the moon.

As President Kennedy famously said in 1962:

"*We choose to go to the moon. We choose to go to the moon in this decade and do the other things, not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one which we intend to win, and the others, too.*"

The long-term objective of NS Savannah override commercial considerations: The nuclear reactor cost $28,300,000 while the rest of the ship cost $18,600,000.

Safety was of course a major consideration when you design ships that were pushing the envelope. The discerning passengers were living, dining, drinking and sleeping within a stone's throw of a fissioning nuclear reactor. The archives showed her service were impeccable. There was no negative report of any incidents with her reactor in her lifetime.

"The 50-foot (15 m) long containment vessel houses the pressurized-water reactor, the primary coolant loop and the steam generator. The steel vessel has a wall thickness varying from 2.5 inches (6.4 cm) to 4 inches (10 cm), designed to accommodate the 186 psi (1,280 kPa) (gauge) pressure generated by a ruptured primary coolant pipe."[1]

NS Savannah was decommissioned in 1972 after ten years of faultless service (reactor wise).

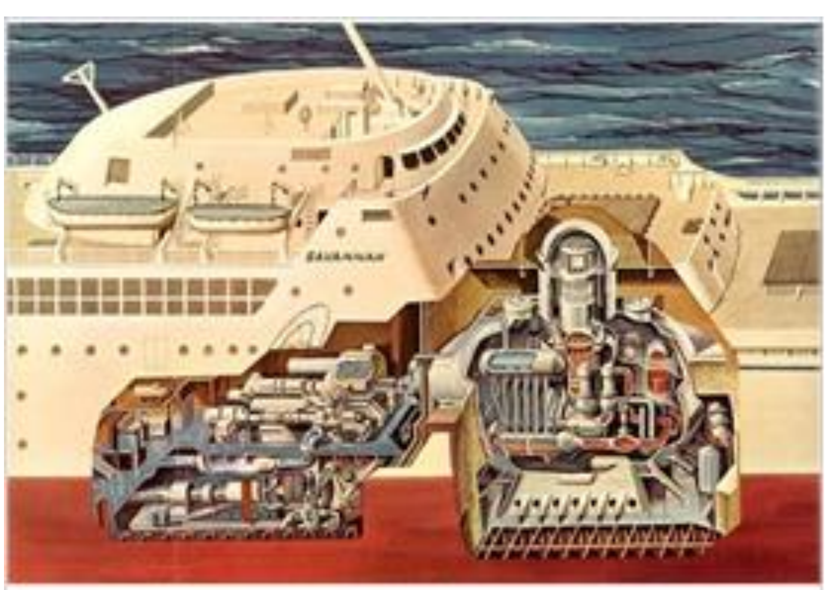

Fig. 1 The nuclear reactor of NS Savannah. Notice there is no funnel, as there is no CO2, NOx or SOx or indeed any gas emitted by it.

Her demise was not because her reactor was a risk. The world's ports were trending towards containerisation and she was not designed for carrying containers. The pace of life had changed. Loading and discharging cargos in port are boring times for passengers eager to move on. Ships had either to be designed to carry cargo or passengers, not both.

Nuclear powered merchant ships in spite of their costs and perceived risks had many advantages

prompting other nations to attempt to break the boundaries of conventional fuels. The Germans launched a passenger-cum-ore carrier in 1964 powered by a 38 MW reactor, named after the man who discovered nuclear fission, Otto Hahn. Built in Kiel by shipbuilder Howaldtswerke it had a capacity of 14,079 dwt. "In 1972, after four years of operation, her reactor was refuelled. She had covered 250,000 nautical miles (463,000 km) on 22 kilograms of uranium."[2]

The Japanese launched their first nuclear ship in 1970. Powered by a 36 MW, Mitsubishi PWR reactor, it was operated by the Japan Atomic Research Institute. It suffered a minor incident that lead to protests by fishermen who effectively sealed her fate.

In 1988, the Russians put into service their nuclear powered merchant ship named Sevmorput. On board was a KLT-40 135 MW reactor, the largest to date. Designed for crossing the icy conditions of the Artic transiting from the Pacific to the Atlantic Oceans it could transport 1238 TEUs or if not carrying containers it had room for 74 lighters (LASH). The vessel crosses continuous ice fields up to 1 meter thick at a speed of about two knots.

"Underway on nuclear power"

With those four words in Jan 17, 1955, from Commander Eugene Wilkinson of USS Nautilus (SSN 571) submarine operation took a quantum leap forward smashing previous records of endurance, range, and stealth and just as importantly boosting morale and living conditions for crew with unparalleled supply of clean water, and fresh air.

Up until then submarines had to surface to run their diesel engines to charge their batteries and to refuel. Nuclear powered submarines need not refuel for their entire lifespan of 25 or more years. The nuclear fission needs no oxygen unlike combustion in engines nor emits any kind of gas. The energy released per kilogram of fuel is several million times more that oil making the heat source very compact.

"The US Navy has accumulated over 6200 reactor-years of accident-free experience involving 526 nuclear reactor cores over the course of 240 million kilometres, without a single radiological incident, over a period of more than 50 years. It operated 82 nuclear-powered ships (11 aircraft carriers, 71 submarines – 18 SSBN/SSGN, 53 SSN) with 103 reactors as of March 2010. In 2013 it had 10 Nimitz-class carriers in service (CVN 68-77), each designed for 50-year service life with one mid-life refuelling and complex overhaul of their two A4W Westinghouse reactors."[3] Russia too has a large fleet of nuclear powered submarines although with a less impressive safety record.

Fig. 2 Built in Zaliv Shipyard, Kerch, Ukrain SSR nuclear powered ship Sevmorput has been in service since 1988

Today nuclear reactors as a heat source for conversion to mechanical power has fallen out of favour.

We shall explore if there are good reason to revisit nuclear. However, before that let us pause and review what has developed in the last two hundred years that has brought us to this point where ships are almost exclusively propelled by oil.

From muscles to fossil fuels

According to a report published in Nature in July 2017, the first humans arrived in Australia 65,000 years ago.[4] It was brute muscle and oars that took them there and it defined the beginning of the first sea worthy craft. Another 60,000 years passed before the next technological change, around the pre-historic period of Mesopotamia, took place. Rudimentary sails made their appearance.

Wind power remained the dominant prime mover for several more millenniums, until coaled fired boilers replaced wind in the mid-19th century. Coal was soon replaced by oil. With the invention of internal combustion engines, furnaces, boilers and steam drums soon became obsolete.

As a liquid fuel oil was more easily loaded into bunker tanks and fed into the engines. As each ton of oil had almost twice the energy of each ton of coal, it was no brainer to make the switch and increase the range of vessels. Nonstop crossing of oceans was no longer at the mercy of the wind or lack of it.

While current reserves of coal will outlast that of oil, the return to coal to propel ships is unlikely for environmental reasons. That is not to say oil is clean. It is not. Fuel oil produces 0.28 kg of carbon dioxide per kWh[5] of energy output (compared to 0.34 kg for coal.) Emma Maersk with a propulsion capacity of 81 MW would produce 544.3 tons of CO2 per 24-hour sailing

A 2015 study by the Directorate General for Internal Policies commissioned by the European Parliament ("Emission Reduction Targets for International Aviation and Shipping) concluded that shipping could account for 17% of the world CO2 emission in 2050 if left unregulated. "… the IMO, the UN body tasked with tackling the climate impacts of shipping, has so far failed to grasp the nettle on shipping's growing contribution to greenhouse gas (GHG) emissions, while the proposal for emissions cuts from industry – as represented by the International Chamber of Shipping - would fall short of what shipping needs to do to help meet the 2°C warming target limit by some 121%."[6]

The shipping industry has traded the clean power of wind for the dirty power of fossil fuel in the name of progress. 17% of the world's emission is a staggering percentage: more than the emission of the whole of the US (14.34%) and about twice that of the EU (9.62%).

Hereafter, we consider the reasons to be concerned with the use of fossil fuel for maritime transportation.

The collateral damage from burning fossil fuel

A ton of bunker fuel may cost $400 to a ship operator but the damage it does to all living creatures, including human beings is incalculably more. This is because the emissions, carbon dioxide, NOx and SOx stay within the biosphere, in the air and oceans creating havoc long after the fuel has expended its energy. The operator pays for the energy that the ton of fuel delivers but not for the collateral damage.

The damage arising from gases emitted by ships is not confined to their homeports but to all living things in the air, land and sea living along their trade routes. For that reason, greenhouse emission from a ship has the potential to do more damage than the emission from a plant generating electricity for its consumers.

The quantity of CO2 emitted in the busy shipping lanes of the world is very considerable considering the huge tonnages that passes through them annually. That CO2 is absorbed by the water vapour in the air to form carbonic acid, which eventually enters the ocean as acid rain with a pH of 5 to 5.5. As a result, the pH value of seawater has dropped from 8.2 to 8.1. Phytoplanktons are essential for life on the planet. They are responsible for producing 50% of the oxygen in our atmosphere. Together with zooplanktons, they form the first link of the oceanic food chain. The acidification of ocean destroys these microscopic creatures, which the larger more complex sea creatures depend for nourishment. It ultimately affects the availability of seafood that humans depend on as well.

More deadly for humans are particulate matters 2.5 microns or smaller (PM2.5). They are small enough to pass through the walls of the lungs into the blood stream, causing respiratory problems, cardio vascular diseases, lung cancer and premature deaths. The following sampling taken from WHO[7] shows more people die of air pollution than of AIDS and malaria combined.

Country	Total number of deaths	Deaths per 100,000 capita
China	1,032,833	76
India	62,1138	49
Singapore	1,094	21
Japan	3,0790	24
Russia	14,0851	98
Norway	636	13
US	38,043	12
UK	16,355	26

CO2 concentration in the atmosphere has increased from an acceptable level of 350 ppm to a million-year high of 410 ppm according to a report in April 2017 of the Scientific American[8]. The knock-on effect of this is that the warmer climate leads to the release of methane from the permafrost of Siberia, Canada and Alaska. Methane is a greenhouse gas about 30 times more potent than CO2. A positive feedback loop is created accelerating climate change.

The melting of permafrost may be accompanied by cataclysmic events. "Permafrost is a very good preserver of microbes and viruses, because it is cold, there is no oxygen, and it is dark," says evolutionary biologist Jean-Michel Claverie at Aix-Marseille University in France. "Pathogenic viruses that can infect humans or animals might be preserved in old permafrost layers, including some that have caused global epidemics in the past."[9] Carbon dioxide and methane trap heat in the atmosphere causing global temperature to rise resulting in the melting of the polar ice caps that in turn result in rising sea levels. The loss of the ice caps, a serious threat in itself to the Arctic and Antarctic wild life, also reduces the amount of solar heat, which the planet reflects back into space further aggravating the rate of global warming.

It is impossible to put a number to the cost of the damage done by rising levels or the cost of putting in place mitigating solutions. It is easily in the trillions of dollars in terms of inundation of cities, destruction of vegetation and farms, coastal erosion, loss of livelihoods. The construction costs of flood barriers (e.g. London's Thames Barrier, Venice's MOSE Flood Gate, and Netherland's Oosterscheldekering) are of the order of billions of dollars: not something, which many nations can afford.

IMO shies away from addressing greenhouse gas emission now

The cost of producing energy from oil, gas or coal is not fully accounted. Victims of wanton greenhouse gas emissions receive no compensation. The UN body that regulates shipping worldwide the IMO, International Maritime Organisation seems powerless to address the problem.

IMO Secretary-General Koji Sekimizu said, "The Paris Agreement represents remarkable progress and builds on the 1992 Rio Earth Summit, which itself was a significant step forward. The absence of any specific mention of shipping in the final text will in no way diminish the strong commitment of IMO as the regulator of the shipping industry to continue work to address GHG emissions from ships engaged in international trade."[10]

That was in 2015. A year on, the road map that would require shipping companies to start reducing greenhouse gas emissions was shelved " until 2023."[11]

Huffington Post's critical headline 15 Nov 2017 speaks for all: "The Shipping Industry Bullied Its Way Out Of Doing Anything To Fight Climate Change. Even as emissions from cargo vessels are surging, the industry is refusing to adhere to the Paris Agreement."[11]

From oil to renewables?

Oil and other fossil fuels are depletable resources. Although this is plainly so, many studies attempt to dispute this, asserting that new technologies will always be found to discover and extract oil. This is another "inconvenient truth," which oil companies will deny vehemently to ensure their stock prices do not weaken like candles in the sun. The fossil fuel production in many countries has already past the peak.[12] As oil reserves fall, the cost of extraction will rise as accessibility to deposits become more challenging.

In this section, we shall briefly survey a few technologies that have emerged to harness renewable energy to propel ships.

There is significant progress in harnessing energy with wind turbines. UK leads in this field. It expects to be producing at least 25 gigawatts by the end of the next decade,[13] about twice the total generating capacity in Singapore. The average cost from 2015-2016 was £97 (USD 128) per MWh[14] for marine wind farms(presumably at source before distribution cost.) The average retail price in UK is 15 p/KWh. Clearly wind energy is a viable renewable.

According to a report in Science Alert, "In January (2017), a new record was hit in India with a contract to supply solar power for (US) $64 per megawatt-hour (MWh), and by August (2017), that had dropped all the way to (US) $29.10 per megawatt-hour."[15] Even if we double this incredulously low cost, solar also appears to be a viable renewable.

However, solar and wind are not transportable energy. One cannot put them in tanks as fuel for ships. There are two possible but costly technologies to convert these energies into forms, which may be transportable and storable in ships: hydrogen and batteries. Both technologies are at the low end of the development curve. They face steep challenges for many years to come. The biggest battery to date has a capacity of 100 MWh, which is good for about 10 hours between recharge to propel a small ship.

Generating hydrogen as a fuel on board with wind or solar has practical limitations. Solar panels generate about 200 W/sq. m in good sunlight and none at night. A 300 m x 50 m vessel will have space to generate 1.5 MW on a good sunny day for a few hours when the sun is in the zenith and assuming half the deck is covered with solar panels, not sufficient for even a small cargo ship. With wind the power is even less. The offshore wind farm known as the London Array has a nameplate capacity of 630 MW. It occupies 100 sq.km and is expected to deliver 39% of its nameplate capacity on average. Its surface power density is therefore 2.45 W/sq. m.
Direct-on-board means of using wind to propel ships have been around for several hundred years. 600 years ago the Chines Admiral Zheng He led a fleet of 317 ships,[16] carrying 28,000 men, supplies and horses which sailed from China across the Indian Ocean all the way to East Africa. The entire fleet were powered by wind. "Soft sails" are still in use today for small crafts but are impractical for large ships.

In more recent years, "hard sail" technologies have emerged.

The UT Wind Challenger developed by the Japanese (a collaboration of NYK, MOL, K-Line, Oshima Shipbuilding, Tadano and Class NKK) is a "hard" sail with a surface area of 4000 m2. The sails are vertically mounted and retractable. In cross section, each sail takes the shape of an aerofoil. Wind flowing over the sails from the side creates a horizontal thrust, which propels the ship forward.

The Germans developed a propulsion system of harnessing wind energy using the Magnus effect as early as 1924.

The Magnus effect is simply the Bernoulli's Principle applied to a rotating cylinder. Air flowing at right angles to the axis of the rotating cylinder separates. On one side, the air is "pushed" forward and on the other, it is retarded. The difference in velocity creates a net force perpendicular to the flow and the axis of the rotor. This force propels the ship along its centreline. The magnitude of the force depends on the velocity of the wind, the vertical length and diameter of the rotor.

This technology was abandoned but has recently been revisited. The ECO Ship 1 with four Flettner rotors 27 meters tall and 4 meters in diameter was launched in August 2008 in Lindenau GmbH shipyards in Kiel, Germany.
Both solar and wind have limitations for ship propulsion.

Back to nuclear?

The energy source for ship propulsion has to be very "dense." That means the energy output per unit of the appropriate measurement (mass, volume or surface area) needs to be high. As discussed above, both wind and solar energy are not dense enough. Batteries needed to store their output compare poorly with oil. A one - MWh lithium-ion (cobalt) battery weighs 6700 kg and has a volume of 2.5 m3. The weight and volume of oil to produce the one MWh of energy is 88 kg and 0.8 m3 respectively.

The global fleet of nuclear vessels

According World Nuclear Association, there are more than 180 small nuclear reactors powering about 140 ships, chalking up more than 12,000 reactor years.[17] The fissile material is uranium oxide with enriched with uranium 235. A higher enrichment (above 20% compared to 3.5% for civil reactors) of the fuel is needed in case of submarines owing to space constraints and the prolonged core life of 20 to 50 years.

While the global fleet is largely owned by the US and Russia (and France to a smaller extent), China and India too have naval nuclear reactor capability. India built its own nuclear powered submarine Arihant (6000 dwt). Its 85MWe using 45% enriched uranium, was successfully fired up (went critical) in 2013. Brazil currently building its own fleet of submarines with French assistance have ambitions to develop indigenous capability.

Although the crew work, eat and sleep 24 x7 within meters of the live reactors, "(t)he cancer risk to the group of personnel occupationally exposed to radiation associated with naval nuclear propulsion plants is less than the risk these same personnel have from exposure to natural background radiation. This risk is small in comparison to both the risks accepted in normal industrial activities, and the risks regularly accepted in daily life outside of work."[18]

Small Modular Reactor (SMR)

A modern Gen 4 small modular reactor (SMR) is as compact as a standard twenty-foot container weigh about 20 tons and capable of producing 70 MW of thermal energy (heat) sufficient to produce 25 MW electricity. Four such SMRs has the capacity to generate 100 MW of electrical power, enough to keep the largest container ship or passenger liner sailing for several years without refuelling. Hyperion, one such manufacturer, announced the sale of their 25 nuclear reactors in Aug 2008.[19]

Nuclear reactors built in the 1960s last 50 or more years. There is no reason to believe the new reactors will not last as long. The economic life of the reactor is longer than the life of a ship. Therefore, instead of the practice of changing engine, the practice in future may well be building a new hull and using the existing reactor.

Safety

The fissile material uranium 235 is fabricated in small pellets. These pellets are loaded into small tubes made of zirconium alloy, which are ductile, highly corrosion resistant and permeable to neutrons. A number of tubes are bundled together and kept inside a steel pressure vessel with wall thickness of 80 mm or more.

The circulating water not only serves to transport the heat to the steam generator but also acts as a moderator. A runaway reaction cannot occur so long as the fuel rods remain immersed in the circulating water.

Unlike in a diesel or heavy fuel oil internal combustion engines there are no explosive combustible gas mixture. Fission reaction produces only solid by-products.

Controlling the fission process

The fission process is controlled by control rods, which by absorbing the free neutrons regulates the rate of fission. When the control rods are fully inserted the fission stops in less than 2 seconds. The control rod assembly is held vertically by electromagnet above the reactor. In an emergency or when there is a power failure (e.g. when the coolant system malfunctions) it drops by gravity. The fission stops. The heat generated falls to about 7% with a one or two second. The decay or residual heat will dissipate rapidly with the help of the passive cooling system.

Spent fuel

Spent fuel rods are kept in a pool where it remains for as long as necessary (for decades). Spent fuel are not totalled depleted of energy. They may be recycled in later generation breeder reactors. They are no longer considered nuclear waste but a potential energy resource.

Passive cooling

The three nuclear accidents, Three Mile Island, Chernobyl and Fukushima, were indeed unfortunately as they could have been prevented. They all suffered meltdowns from the decay heat when the cooling water system malfunctioned. The design of their cooling system depended on an external input, which failed. The decay heat caused the temperature of the fissile material to rise uncontrollably following the termination of the fission. Meltdown occurred.

Modern reactors incorporate a passive cooling system, which does not depend on any external input. It keeps cooling water in circulation even if there a total power failure occurred at the plant. The system uses gravity and convection to circulate cooling water, hence the term "passive."

In the case of ships, the nuclear reactors are located below the water line. Through heat exchangers, the cooling water is in contact with an infinite heat sink external to the hull. The reactor would always be under a positive cooling water head. Excessive temperature escalation of the fissile material is not possible and meltdowns are not conceivable.

Conclusion

Climate change is real. IMO needs to face the issue of carbon emission from ships squarely, decisively and urgently. The use of oil as a fuel has led to the deaths of millions of people and caused untold misery for those afflicted with diseases caused by air pollution. Global warming and rising sea levels have resulted in loss of livelihood for farmers and fishermen the world over. These are innocent victims. Oil consumers as well as producers have a moral duty to address this problem.

Renewables are unlikely to provide a viable alternative to oil as an energy alternative for marine propulsion. The use of hydrogen and batteries for energy storage face immense challenges, unlikely to be resolved for several decades, if at all.

Nuclear power is safe. It has been used safely in mercantile operations since the launching of NS Savannah in the 1960s. There has never been a serious radiological event in the use of nuclear reactors for marine operation in military and civil applications.

Nuclear power is clean. It will be a major step to avoid a 2-degree tipping point that could spell disaster for the biosphere.

Shipyards have a key role to play not only to build nuclear powered ships but also to contribute to a cleaner planet. They have to prepare for the next disruptive technology. The road to a nuclear technology is a long one. Just as we did in the 1960s, when we started on a journey that has lead Singapore to become a world leader in offshore oilrigs, we need to offer opportunities for our young engineers to gain experience in establishments such as Reed College in Portland, Oregon.

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The Numerical Modeling Method Application For Cathodic Protection System Optimism Of Ship In Marine Environment

ABSTRACT

The corrosion of the ship/boat body and offshore structure by sea water and marine atmospheric is a long term challenge to marine and ship/boat industry. The modernized design on corrosion-resistance of ship/boat body and offshore structure is a boomingly technology for both shipbuilder and the ship owner/operator. The technique of numerical simulation is currently rising and it becomes to play more and more roles as being applied in corrosion-resistance design and assessment. This study focus on the issue of cathodic protection system optimism of ship in marine environment through numerical modeling. This paper presents a 3D software tool for the design and optimization of cathodic protection systems for submerged structures. It provides the corrosion engineer an intelligent tool for managing operational costs, significantly reducing expensive commissioning surveys and costly repairs, adding major value to the cathodic protection business. In this paper, the protection level of a hypothetical marine vessel using impressed current cathodic protection (ICCP) systems has been investigated. In addition, the underwater electric potential (UEP) of the vessel is calculated.

Keywords: Cathodic Protection; Numerical Simulation; ICCP; Ship Body; Marine Environment

INTRODUCTION

Cathodic Protection (CP) systems are widely applied to buried and offshore structures, as they compensate for the loss in physical protection due to the degradation of the applied coating over time by electrochemical method. Most often, these CP systems contain a series of impressed current and/or sacrificial anodes, normally placed at a remote distance from the structure. The entire configuration of the CP system and the structures illustrates particular characteristics that necessitate and justify the use of numerical simulations.

Firstly, the low accessibility of these structures make installation, maintenance and repair very expensive. Besides, the geometry of most steel structures that are subject to cathodic protection is too complex to allow analytical or even empirical estimations to determine the local protection level. Numerical modeling provides significant benefit by identifying insufficiently protected regions - possibly subject to corrosion, and overprotected regions - subject to excess gas evolution and hence coating disbonding. As a consequence, numerical modeling allows simplification and optimization of installation, maintenance and repair. Moreover, numerical models provide reference values for measurements on operational sites, enabling to trace and solve all possible anomaly.

Most of the publications dealing with the computation of the CP of both buried and submerged structures are based on the well known Boundary Element Method (BEM) [1]. Orazem et al. [2,3] use a 3D BEM approach to compute the protection level of large coating defects on pipelines. Results are presented for a pipe segment of limited length (10 feet), in presence of a parallel anode system. Riemer and Orazem [4] produced results for a larger pipeline (> 6 km) with coating defects of varying size and investigated the ability of coupons in the vicinity of the defects to measure off-potentials. Adey [5] applied a full 3D approach to calculate the potential field in the neighborhood of jacket joints under cathodic protection of sacrificial anodes. The present authors [6] used a 3D coupled multi-domain BEM approach to simulate the protection level of a buried pipe segment surrounded by a concrete vault.

Aoki et al. [7] applied the BEM to detect a coating defect on a ship hull. DeGiorgi [8] made a significant contribution to the modeling work of the CP of ships. Diaz and Adey [10] simulated the stray current corrosion of a vessel berthed to a steel dock protected by sacrificial anodes. The same authors presented a methodology based on boundary element techniques to determine the optimum anode configuration for shipboard ICCP systems.

The simulations presented in this paper are achieved using a commercial software package [11] with details as specified below.

MATHEMATICAL MODEL

The initial version of the software was based on the BEM which was for performance reasons soon replaced with the more advanced Fast Multipole Method [12]. Both methods have the advantage that only the boundaries of the 3D model need to be meshed. The disadvantage however is that due to the intrinsic properties of both BEM and FMM, the resulting system matrices remain quite populated, which severely limits the number of surface elements that can be used. Therefore, a complete new software code has been developed which is based on the well-known Finite Element Method (FEM) [13]. Using FEM, the complexity of the problems that can be solved (i.e. the total number of surface elements) has been increased with at least an order of magnitude (when compared to FMM). In order to apply the FEM a 3D volume mesh generator is required that produces the meshes needed for the computations [14]. In this software all meshes are generated in a fully automated way based on the CAD model. The non-linear system equations are solved using a Newton-Raphson iterative method [15], combined with an advanced iterative linear solver to solve the resulting system of equations at each iteration. It is concluded that when the Potential Model is solved using the FEM, the technical issue is rather a mesh generation problem, while a solver based on the BEM struggles more with matrix assembly and system inversion.

Physical model

Since the seawater is assumed to feature only charge transport with normal ohmic resistivity effects, the potential model holds, being described by the Laplace equation:

$$\overline{\nabla}(\overline{j_n}) = 0 \qquad \overline{j_n} = -\sigma\overline{\nabla}U \qquad (1)$$

The phenomena occurring in the diffusion layer and at the electrode interface are encompassed in the (non-linear) boundary conditions described further on.

For domains with a constant electrical conductivity σ, equation (1) simplifies to:

$$\overline{\nabla}(\overline{\nabla}U) = 0 \qquad (2)$$

Boundary conditions

For CP-simulations, the steel electrode polarisation is often encompassed in a single, measured electrode polarisation curve, relative to a mixed corrosion potential E_{corr}:

$$j_n = f(V - U - E_{corr}) = f(\eta - E_{corr})$$

with U the potential in the electrolyte adjacent to the electrode, V the metal potential and $\eta(j_n)$ the polarization overvoltage being a function of the local current density j_n.

DESCRIPTION OF THE PROBLEM

In this paper, the cathodic protection level of a hypothetical marine vessel (catamaran type) using 4 separate impressed current cathodic protection (ICCP) systems, each delivering 3 Amps, will be investigated (see Figure 1).

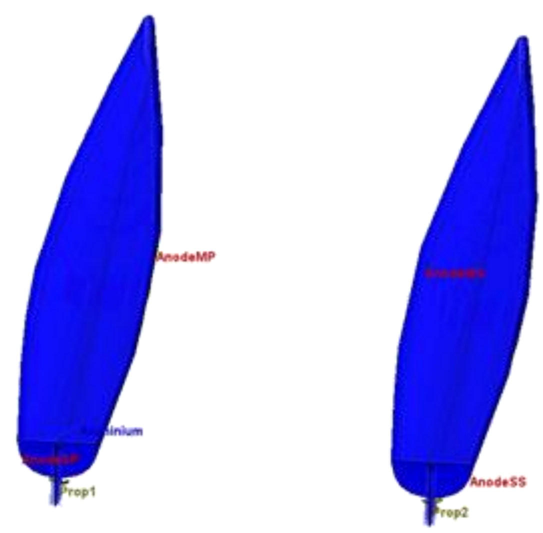

FIGURE 1 – layout of the catamaran with 4 ICCP systems: Anode MP, MS, SP, SS

(M = middle, S = stern; P = port, S = starboard)

The total length of the vessel is 120 m, with a width of 40 m (waterline). Two ICCP systems are located in the middle (inside) of the catamaran, one at the port side (MP), the other one at the starboard side (MS). The other two ICCP systems are located at both sterns (outside) and are denoted as anodes SP and SS.

The resistivity of the seawater is assumed to be 0.25 Ωm. The catamaran material used in the simulations is marine aluminum with polarization behavior as measured by Kim [16]. The corresponding corrosion potential is -880 mV versus the Ag/AgCl reference electrode. The coating of the catamaran is considered to be non-ideal. The coating defects are assumed to account for 1.0 percent of the total surface area. To that purpose, the polarization curve for the bare aluminum as obtained in [16] has been scaled with a factor 0.01 for the current density. The propellers are made from nickel, aluminum and bronze (NAB) and have a corrosion potential of -200 mV (versus Ag/AgCl). The polarization data are taken from the work by Hack [17]. It is assumed that the propeller and support are electrically continuous. The anodes are 7.5 cm in diameter and have a length of 1.5 m. The anode material is a typical metal oxide for which the data have been taken from a proprietary database. A detailed view of the propeller and support with nearby anode is presented in Figure 2.

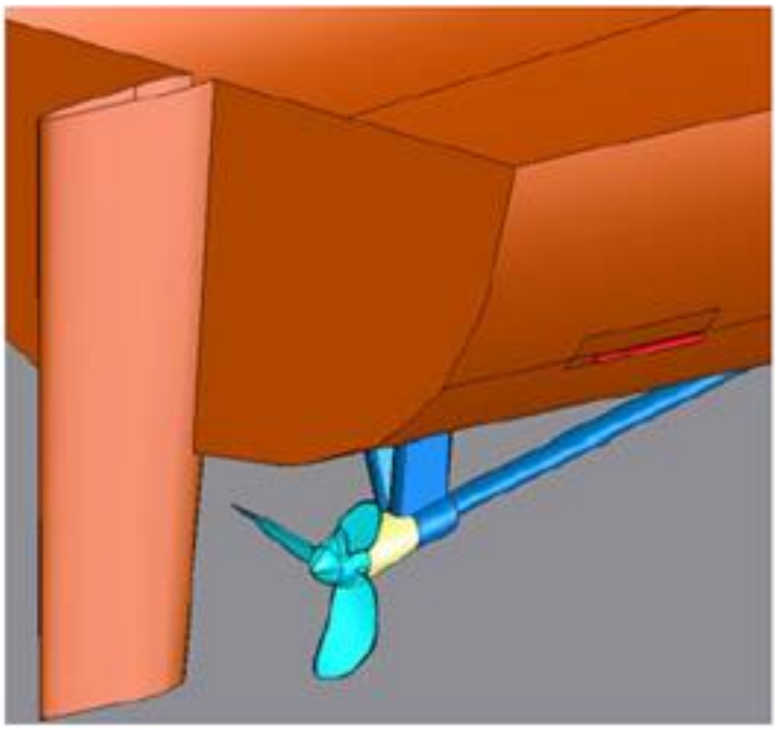

FIGURE 2 – Detailed view of the propeller and support with nearby anode (starboard site).

The software allows taking into account the complete electrical wiring of the ICCP systems (current generator and all cabling). To that purpose a number of electrical components are available as outlined in Table 1. The non-ideal behavior of both the current generator and voltage generator can be taken into account through the use of the additional resistors Rp and Rs, respectively. In this paper it is assumed that the current generator (rectifier with constant current output) is ideal, hence a very large value for the parallel resistor Rp is taken (1 MΩ).

TABLE 1 Overview of the components to create an electrical network

Components	Description	Parameters
Current generator	a Rp I b	I [A], R_p [Ω]
Voltage generator	a V Rs b	V [V], R_s [Ω]
Resistor	a R b	R [Ω]
Grounding	a	N.A.

COMPUTATIONAL SPECIFICATIONS

The total number of triangular surface elements used to solve the problem is about 200,000. The corresponding tetrahedral volume mesh consists out of nearly 2,500,000 elements. Details of the triangular surface mesh near one of the propellers and at waterline level is presented in Figure 3. The total calculation time on a 2.2 GHz laptop is less than 6 minutes for 9 iterations in the Newton-Rapson procedure, after which a sufficient convergence level was reached.

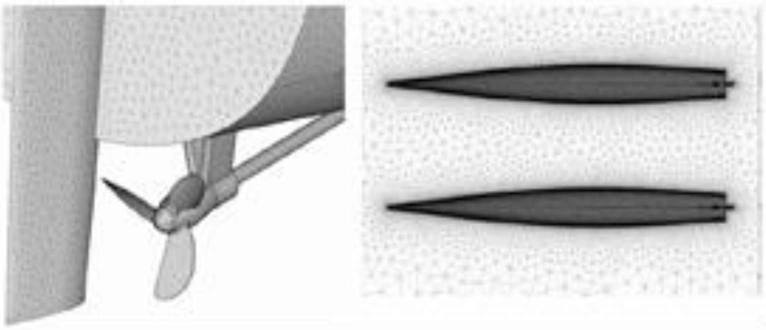

FIGURE 3 – Zoom of surface mesh near one of the propellers (left) and at waterline level (right)

RESULTS AND DISCUSSION

Simulation of cathodic protection levels In a first simulation the default situation is investigated. All four ICCP systems are active delivering a total protection current of 12 A

The calculated "off" potential distribution along the hull is presented in figure 4. The average "off" potential is -977 mV which means that taking into account the corrosion potential of -880 mV, an average polarization of the hull of -97 mV is obtained.

Figure 5 (left) shows the "off" potential along the hull near the stern anode at starboard side. From this picture it can be observed that there is a slight overprotection of the hull directly near the

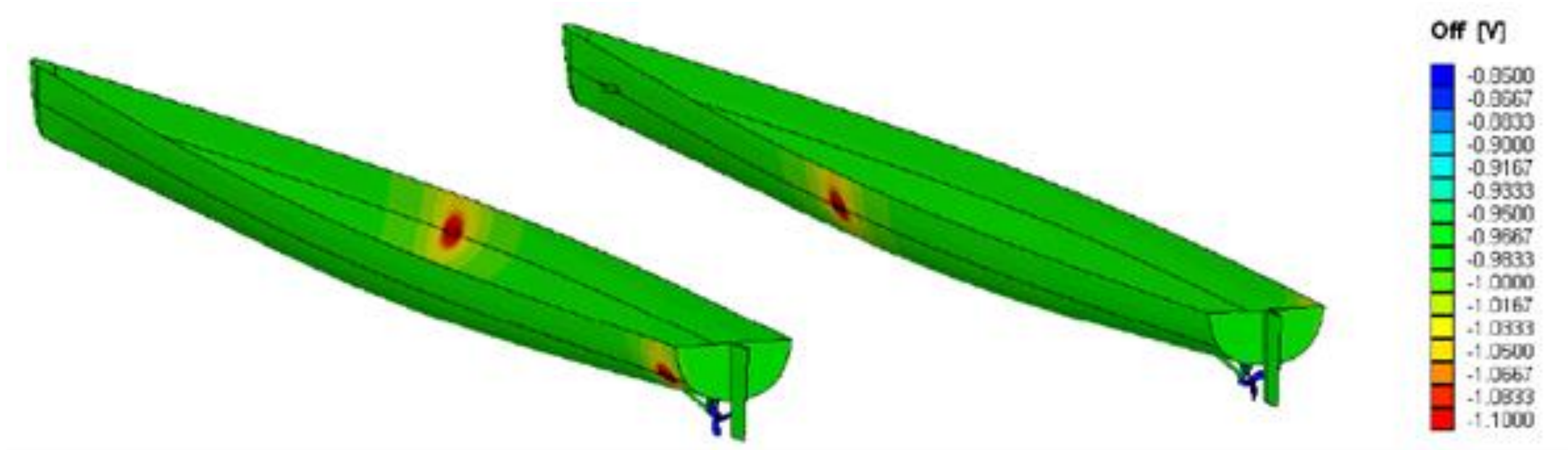

FIGURE 4 – "Off" potential distribution along hull - normal operation

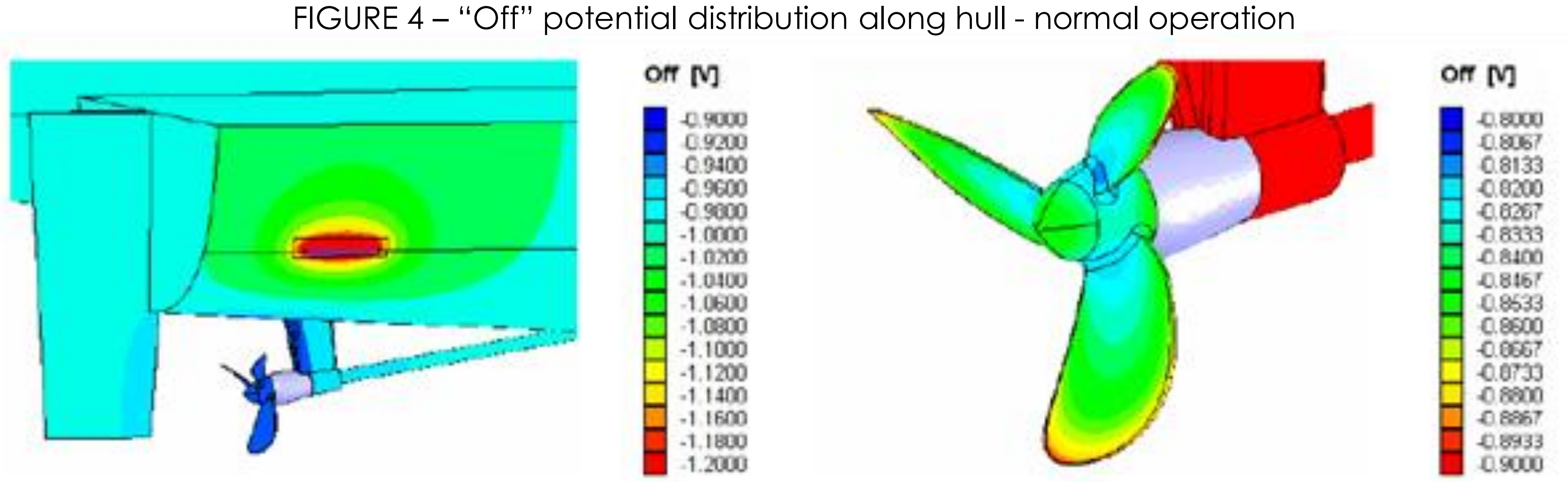

FIGURE 5 – "Off" potential distribution near anode (left) and propeller (right) - normal operation

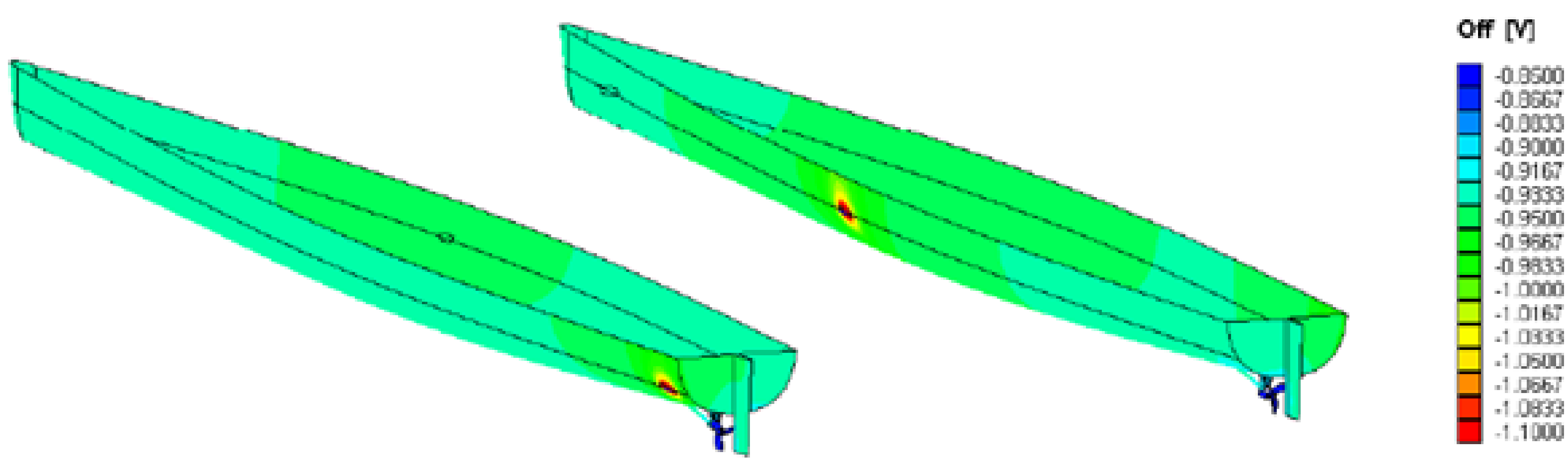

FIGURE 6 – "Off" potential distribution alonghull – mid anode at port side fails

anodes with "off" potentials more negative than -1200 mV. Similar conclusions can be drawn from Figure 5 (right) presenting the calculated protection levels at the bare propeller. The obtained "off" potential at the hull near the propeller drops to -930 mV which means a polarization of only -50 mV which is below the minimum required limit of -100 mV.

In a second simulation the effect of a failing mid anode at the port side has been investigated which reduced the overall protection current to 9 A. This can very easily be achieved by switching off the rectifier that connects that anode to the hull. The calculated "off" potential distribution along the hull is presented in figure 6. The average "off" potential is -937 mV which means that the average polarization level of the hull dropped to -57 mV. Similar conclusions can be drawn for a failing stern anode at the port side as can be seen from figure 7. In this case the average polarization level drops to -59 mV. Figure 8 gives a summary of the calculated cathodic protection levels for the different situations.

Simulation of underwater electrical potential (UEP)

The software can also be used to calculate the underwater electrical potential (UEP) of the catamaran. The calculation of the electrical field in the seawater around the vessel is straightforward as it can be obtained directly from the gradient of the potential obtained in the nodal points of the FEM volume mesh. Figure 9 shows the calculated x-component of the electrical field on a cutting plane 2 m below the

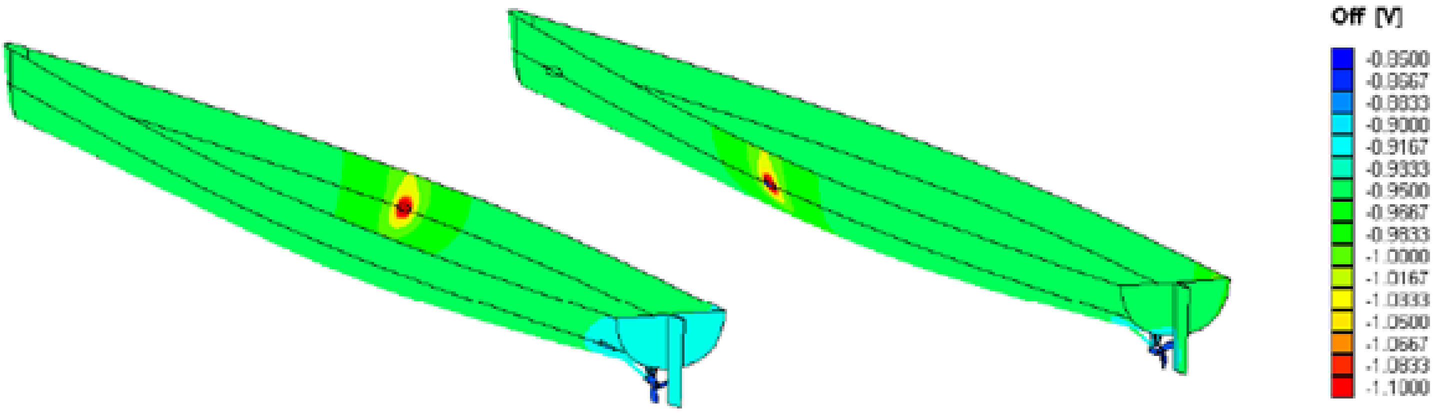

FIGURE 7 – "Off" potential distribution along hull – stern anode at port side fails

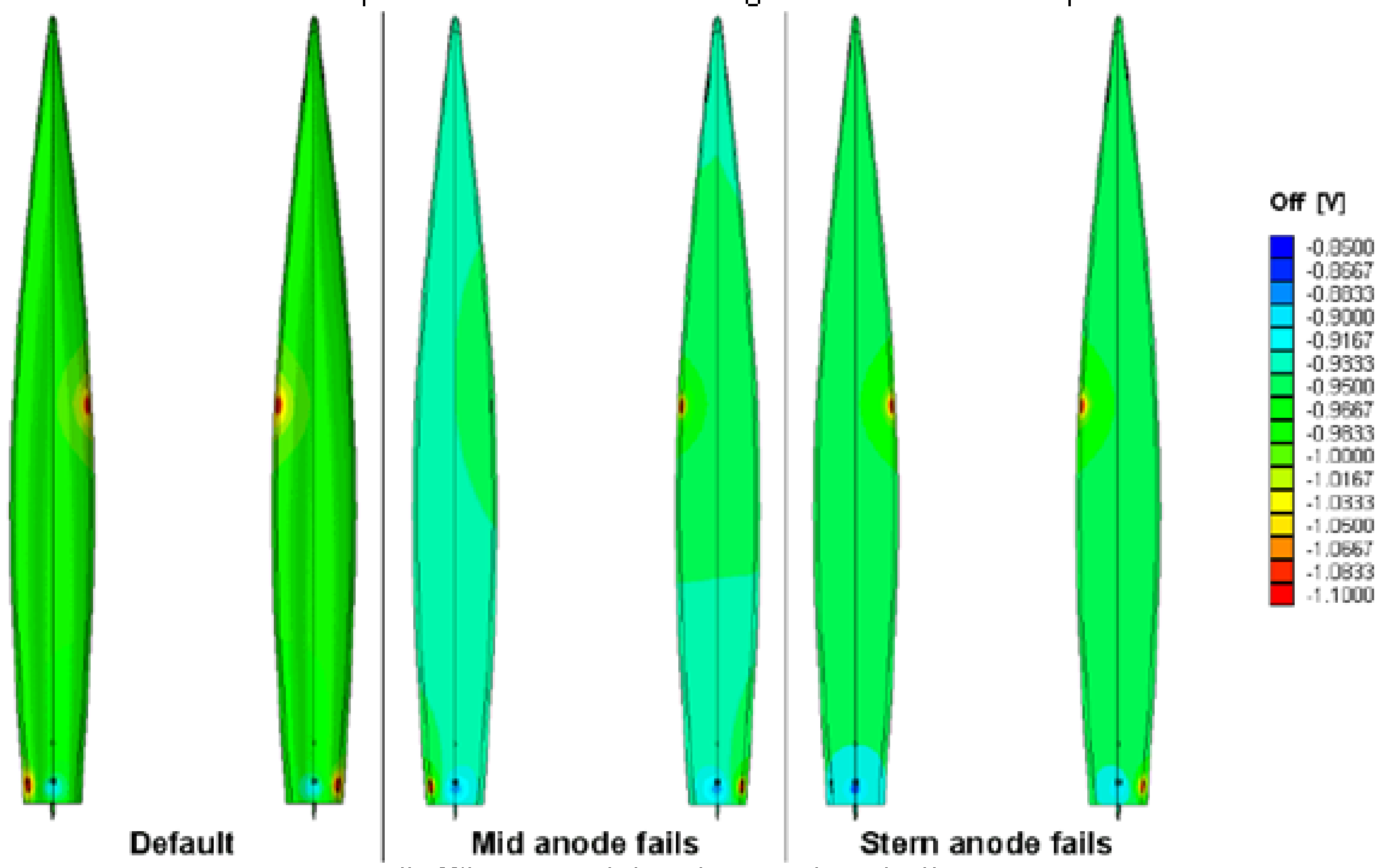

FIGURE 8 – "Off" potential distribution along hull – comparison

keel. Figure 10 gives an overview of the three components of the electrical field at the center of the catamaran and at the keel at port side, both 2 m below the keel.

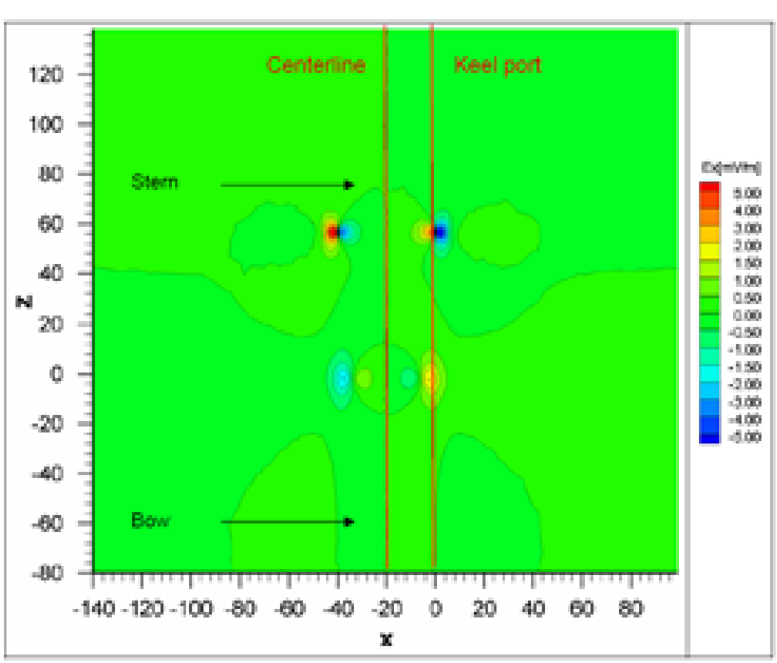

FIGURE 9 – Underwater Electrical Potential UEP (Ex in mV/m) 2 m below keel

CONCLUSIONS

In this paper a 3D software tool for the design and optimization of cathodic protection systems for submerged and buried structures has been presented. The software is entirely CAD integrated, offering a user-friendly interface for the CP design.

Using this software, the protection level of a hypothetical marine vessel using impressed current cathodic protection (ICCP) systems has been investigated in normal operation and under anode breakdown both at mid ship and stern.
The software has also been used to calculate the underwater electric potential (UEP) of the catamaran.

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LNG as Marine Transportation Fuel - Outlook, Drivers and Challenges

ABSTRACT

Most of the Analysts report that LNG as a fuel will capture substantial market share in the transportation sector by 2035. The key drivers for LNG to be a major player as fuel in the transformation sectors are Environmental advantages, Economic benefits and established improved Technology. LNG as marine fuel has unfolded great deal of business opportunity in the shipping industries. LNG bunkering is one such new avenues in marine sectors. IMO - IGF Code Rules is the new regulation applicable for the receiving ship, using LNG as fuel.
The key challenge in this development will certainly be safety, though LNG has maintained for many years an exemplary safety track records. Other associated challenges are not considered be showstoppers. it is essential that all stakeholders from regulators to ship owners to suppliers work together in order to provide a solid and commonly agreed framework that would enable LNG to take its centre role in the global energy supply-demand dynamics.

INTRODUCTION

The global rise in production of Natural gas specially in North America, Australia and middle east regions has led to heightened interest in the utilisation of natural gas and LNG as a transportation fuel. More importantly, the enforcement from the regulatory authority like International Maritime Organization (IMO) and International Convention for the Prevention of Pollution from Ships (MARPOL) on emission guideline to control climate change issue, has deepen the need for utilisation of LNG as prime fuel in the marine transportation. The mandate from IMO and/or MARPOL limits the presence of sulphur content in marine fuel as depicted Fig-1 below.

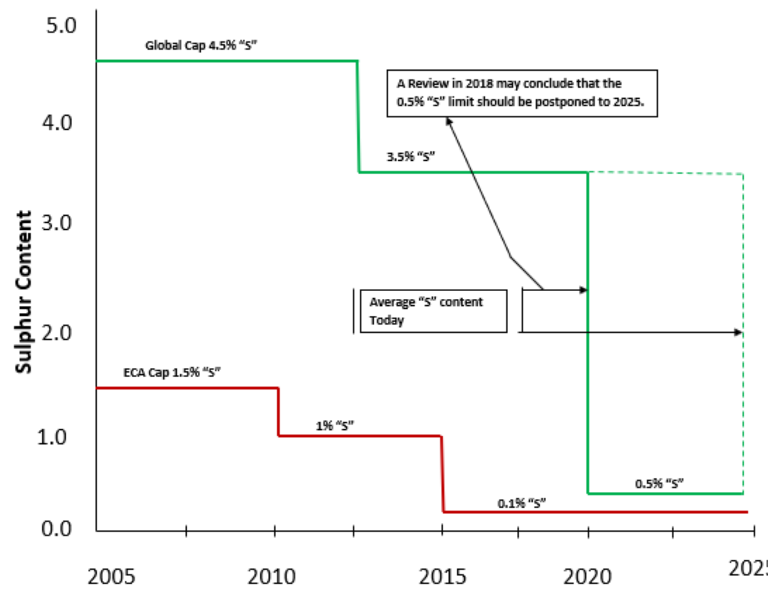

Fig-1: MARPOL Annex VI timeline for adoption of sulphur content in marine fuels in Emission Control Areas(ECAs) and Global perspective (Reference - 1).

The information sited in the Fig-1 above is self-explanatory. There are four (4) ECAs in effect who came under the mandate in different time lines. They are (1) Baltic Sea since May 2006, (2) North Sea since November 2007, (3) North America (US and Canada) since August 2011, and (4) U.S. Caribbean since January 2013. The effectiveness of the mandate i.e the adoption or implementation of Annex VI sulphur reductions in marine fuel initiatives have been largely limited to the ECAs. No alternative route such as application of scrubber in the engine exhaust line or adoption of ultra-low sulphur fuel like refined MDO/MGO etc seems economically viable at the current scenario when LNG is cheaper and abundant.

The above two cardinal aspects have evolved myriad of business opportunities in marine and offshore industries to introduce the utilisation of LNG, necessitating the development of various facilities and infrastructures. Some of the salient avenues of LNG usage are:

1. FLNG fuel handling system (LNG storage and distribution facility) within the Ship, Tug, supply vessel,
2. Cost effective duel fuel engine and Gas engine, including possibility of converting Diesel Engine to Gas Engine.
3. LNG Bunkering Facilities in port, LNG Terminal and in high sea location.
4. Development of Exclusive bunkering ship for ship to ship bunkering facility in high sea location.
5. Conversion of used and idle PSVs to LNG Bunkering Vessel Ship as opportunity grows.

As a result of several factors, LNG is being touted as a viable alternative for ship owners and operators to meet the Annex VI low sulfur fuel requirements both for global trade and in ECAs. It is worth highlighting in this context that LNG is not absolutely Sulphur free. The specification of LNG in numerous LNG Sale and Purchase Agreements translates to about 0.004% on a mass – mass basis, which is well below the 0.1% S required in ECAs from 2015. It is also worth mentioning that IMO recognizes the need for regulations of non-LNG ships that use LNG as fuel and engage in international trade. This has caused the development of International Code of Safety for Ships Using Gases or Other Low Flashpoint Fuels (IGF Code) to tighten the guidelines on Safety for Natural Gas Fuelled Engine Installations in Ships.

MARKET OUTLOOK

Most of the Analysts report that LNG as a fuel will capture substantial market share in the transportation sector by 2035. The significant potential is seen in the road transport, where annual demand is expected to reach 96 MMTPA, **while demand in the marine sector could grow to the tune of 75 to 80 MMTPA.** The rail sector could also add by another 6 MMTPA to a global demand. The Market estimates (Reference-2) an exponential growth in the number of LNG fuelled ships, with currently (as of March 2017) 104 LNG fuelled ships in operation worldwide and 119 confirmed LNG fuelled newbuilds (excluding LNG carriers and inland waterway vessels). The number of ships in operation has more than doubled in the last 4 years and until 2018 it is expected a further growth of at least 30%. A growing number of the new ships are 'LNG ready' or have dual fuel engines, meaning that they can switch to LNG when the market for this is favourable.

There is also a positive developments in cross-industry initiatives, such as the strategic MOU between Shell, Qatar gas and Maersk Group [Reference -3] as well as the SEA/LNG [Reference -4] coalition of which DNV GL is a member. DNV GL is contributing in many areas to lower the barriers for adopting LNG as fuel. One such initiatives is launching of an intelligence portal (LNGi), the market's only LNG bunkering map with worldwide information and continuously updated information and which provides detailed and visual insight to existing and planned LNG bunker opportunities around the world.

Additionally, our research includes an assessment of the impact of LNG fuel variability on engine performance (as part of the work to prepare for an LNG fuel standard) and developing standards for safe and cost-efficient LNG transfer at bunkering stations, to support globally consistent regulations.

The scope for displacement of bunker fuel oil by LNG is potentially huge. However, LNG as a bunker fuel currently faces a number of challenges; notably the investment required in ships propulsion and fuel handling systems and in bunkering facilities, plus development of new international safety regulations, and LNG availability

The ferries and offshore service vessel will dominate the LNG bunkering market during the forecast period. Ship-to-ship LNG bunkering market is expected to witness a CAGR of 56.0% by 2023 owing to its quick transfer operation. Europe with a market share of 85.0% is currently dominating the LNG bunkering market due to the presence of a majority of LNG bunkering stations in the region. Norway, with the largest number of bunkering operations dominates the LNG bunkering market in the European region.

Asia-Pacific region backed by high marine trade is expected to grow at the fastest rate during the forecast period. The LNG bunkering market in North America is expected to be benefited owing to the decline in natural gas price in the region. Qatar, in Middle East and Africa region is expected to make a good business in the LNG bunkering market owing to the abundance of LNG in the region. By 2020, DNV GL estimates that about 400 to 600 LNG bunker vessels will be operational globally. Given the progress thus far, industry giants believe that it will definitely be one of the most significant alternative fuels going forward. Well, let's wait and watch.

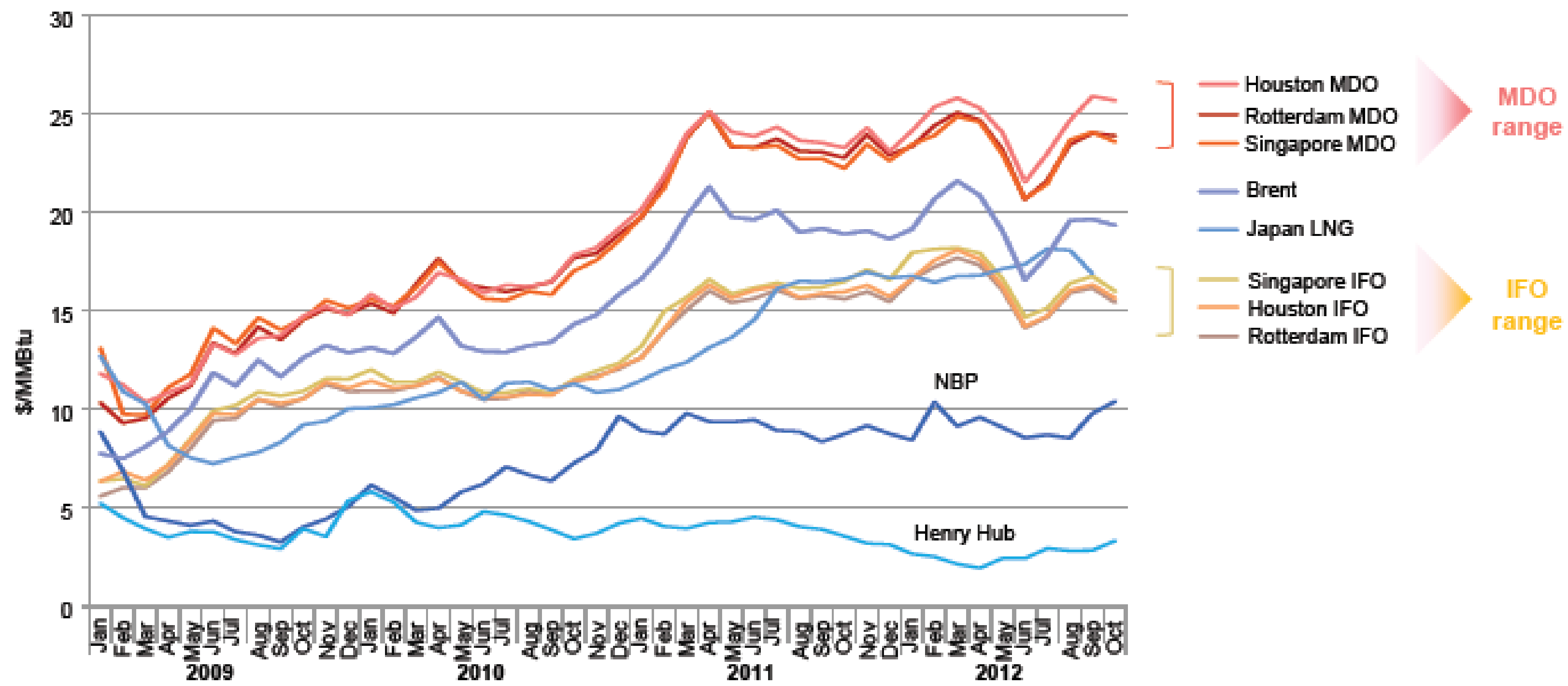

Fig-2: Fuel Cost Comparison (Economic Driver): - Conventional Marine Fuel vs Natural Gas/LNG (Reference -1).

DRIVERS

The key drivers for LNG to be a major player as fuel in the transportation sectors are:

1. The use of LNG as fuel allows ships to conform MARPOL Annex VI requirements for both worldwide trades and operation in ECAs as its sulfur content is negligibly low that is well below the regulation. Moreover, LNG reduces NOx emissions to a great extent permitting the MARPOL Annex VI requirement without the need for post treatment. (Marine Dominated **Environmental Driver**)

2. It is observed that in most of the countries, natural gas and LNG are lower priced than high sulphur marine fuel oils or diesel oil on a heating value basis. In some markets, natural gas and LNG are lower priced than high sulphur marine fuel oils on a heating value basis. The depicted Fig-3 implicate that LNG price at japan is even lower than the MDO price in all key locations. More importantly the sulphur content in prevailing MDO fuel may not meet IMO regulation from 2020.

This scenario is expected to last longer based on the worldwide producible gas reserves and continuous development in cost effective drilling/extraction technology and liquefaction Technology. (**Economic Driver)**

3. All three sectors – Road, Rail and Marine are well placed having cost effective technology needed LNG dispensing facilities and engine type conversion. The usage of LNG in these three sectors are in existence for many years in USA, Europe, China and other Asian countries. (**Technological Driver**)

4. Incentives and Tax concession/exemptions will promote the use of LNG, Wetemans said. In Europe, for example, the Connecting Europe Facility Fund has provided incentives to build the early infrastructure for LNG use. (**Government/Regional Driver**)

In view of the above, there have been recent focus among the high-profile oil and gas players to promote the use of LNG for dispensing as fuel in long haul trucks/train and as a bunker fuel in the marine sector. The scope for displacement of conventional diesel oil or bunker fuel oil by LNG is potentially huge.

CHALLENGES

The challenges in using LNG as a bunker fuel are numerus, notably

- The investment required in ships propulsion, fuel handling systems and in bunkering facilities.
- Development of new international safety regulations and operational Guidelines.
- Uninterrupted availability of LNG at the port or at offshore bunker place.

However, with the challenges being perceived and faced, the question is what extent can LNG as a bunker fuel be developed by the end of decade? The presentation will cover the advantages of LNG as a bunker fuel, challenges faced for widespread implementation, and the pace and potential for LNG to displace established fuels.

The bunkering facilities are normally having three base cases. Their configurations are as follows:

- Tank to ship, } Onshore/Terminal Application
- Truck to ship,

- Ship to ship – Offshore Application

The mission critical regulatory compliance for the operation of the LNG bunkering system are guided by the following documentation

IMO - IGC Code Rules for the bunker boat,

IMO - IGF Code Rules for the receiving ship, the ship using LNG as fuel
SIGTTO and OCIMF Guidelines for LNG transfer and Port Operation

Onshore regulations EU, NFPA, FERC

Besides the above codes, a new ISO document is on development aim to addressing: Guidelines for systems and installations for supply of LNG as fuel to ships. The aim shall be to provide guidance on how to:

- Meet safety requirements.

- Establish operational and control procedures to ensure safe, practical and aligned operations in different ports.
- Identify requirements to components to ensure safety equipment compliance.
- The focus shall be on the safety aspects of the bunkering operations

- To define the interface between the ship and the fuel supply facilities, to ensure that a LNG fuelled ship can refuel safely in ports with LNG fuel supply facilities

The prudent concern in this development will certainly be safety. All these new developments necessitate all stakeholders of LNG eco-system are sufficiently educated and overwhelmingly trained. LNG has maintained for many years an exemplary safety track record that has to be maintained in order to protect the whole LNG industry. As always, the stakes are higher than the sole business potential for bunker LNG itself. In order to be able to develop a sustainable market there are many challenges to overcome but none has been identified as a showstopper. However, as described herein, it is essential and urgent need that all stakeholders from regulators to ship owners to suppliers work together synchronically in order to provide a solid and commonly agreed framework that allow LNG to take its share of this new demand to the interest of all involved parties.

CONCLUSION

Everyone's mantra these days is GO GREEN and rightly so, considering the massive toll that pollution has taken on the planet, Governments, corporations and citizens alike are doing their best welcoming clean energies, technologies and products. There are lot challenges ahead but none of them identified to be a showstopper. Stricter environmental regulations are changing the way the maritime industry views conventional fuels. Many organisations are looking at gradually abandoning the use of polluting heavy fuel oils, in favour of cleaner, more sustainable fuels like liquefied natural gas (LNG). Active initiatives and greater push from Government, corporation and Financier are needed to make the LNG infrastructure ready and conducive to the ship owners and all marine transporters. Then, LNG is definitely "The Marine Fuel" in future, as cleaner and cheaper alternatives always receive more attention to meet stricter environmental regulations and greater profit margin.

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Author's Background

Tushar has earned more than 35 years' experience in offshore/onshore Oil, Gas and LNG industries. His main focus has been on Engineering, EPCIC Project Management, Business Development, O&M Support, Risk Management and training of professionals. Tushar has worked with many Internationally reputed companies likes Shell, Bechtel, Foster Wheeler and Sembcorp and successfully completed many complex and mega projects.

He has published and presented several Industry Focus papers in OTC and GasTech Conferences and other journals. He is a Senior Member of the American Institute of Chemical Engineers, member of OTC conference committee and

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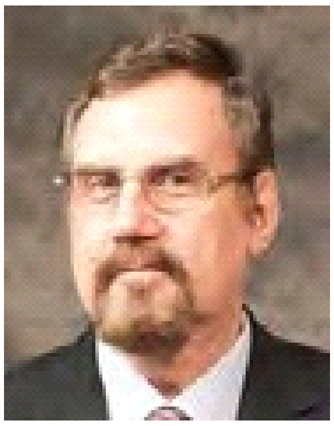

Editor's Note

For year 2018, we have chosen the theme "Capturing Innovative Opportunities" for SNAMES 37th Annual Journal. The climate change, preservation of our environment and global condition of maritime industry switching to the demand of digitalization and respectively for new design of vessels as autonomous, hybrid and eco vessels. Furthermore, the stricter environmental regulations for using newer, safer and cleaner energy is the next technological advance and challenge in maritime industry, so we are facing the new chapter of shipbuilding.

We hope that trough the various technical papers, covering leading-edge innovations and breakthroughs in the maritime industry, readers across the industry -professionals, technologists and business leaders will be inspired and encouraged to think and act beyond their current boundaries.

In a process of preparing the Annual Journal we were very pleased to receive the papers which are written by accomplished professionals and academics.

1. **LNG as Marine Transportation Fuel - Outlook, Drivers and Challenges** by Tushar Poddar

2. **Need for an Integrated Sustainable Shipping Index** by Raymond Chia and Dr. Arun Kr. Dev

3. **Retrofitting a high efficiency CLT® propeller on a 175K m^3 LNG tanker: Comparative service performance before and after** by Juan González-Adalid, Mariano Pérez Sobrino and Giulio Gennaro

On behalf of the SNAMES Council, I would like to thank you and appreciate the companies and partners who have unreservedly supported the Journal and SNAMES over the years via advertisement placements, event sponsorships and participation in SNAMES-organized events. We look forward to our partners continual strong support and our members in our activities.

I would like to thank you to all SNAMES Council Members who work hard and closely to make every activity and event successful.

I wish you and your organization fair wind and following seas in the year ahead.

Sincerely

Ivan Stoytchev
Chairman
Publication Committee

SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS SINGAPORE

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