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An Introduction to STR Hull Concept

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Sergio AB Kroff*

1 Naval Architect, Chile

***Corresponding Author:** Sergio AB Kroff, 1 Naval Architect, Chile.

Abstract

The idea for the Submerge Trimaran hull concept (STR) presented on this paper it's originated from the Nautilus System (NTLS) stabilizers for motions and currents, which is based on a 2 sides linear approximation using Keulegan-Carpenter number (KC) to obtain the roll motion damping coefficients from the roll decay test of high block coefficient vessels with bilge keels and from which it´s possible to understand that, the damping that's rules the roll motion of high block coefficient vessels with appendages is more significant at lower oscillations amplitudes (roll decay test latest cycles), it´s mean at lower KC numbers (KC <) were the steady state flow regime is predominant and the GM_T has a linear variation in the stability curve, which however didn't occur for larger oscillation amplitudes (roll decay test initial cycles) were highest KC numbers (KC >) are relevant (drag forces) meaning that, the action of appendages such as bilge keels is less effective in reducing roll amplitudes as results of the turbulence derived from the back and forth oscillating flow, being the main source for the energy dissipation the vessel hull form capability to generate waves. Therefore, the Submerge Trimaran hull (STR) is a NTLS variation to be applied in conventional vessels with advance velocity to obtain a reduction to the roll amplitudes by increasing the potential damping while restricting the transversal oscillation flow by doing a hull modification from a perspective that considers as a base a hull immerse in a steady state flow regime (lower KC numbers) that´s has the effect of varying the natural roll period, extending the GM_T (STR) linear variation in the transverse stability envelope for a broader range of sea state, as more external excitation energy it´s require to obtain the same conventional hull roll amplitude, as part of the main motivation for the STR hull concept development idea, which is to achieve an overall improvement to a vessel sea keeping performance to cross ocean routes efficiently with energy savings and decabornization.

Keywords: Nautilus System (NTLS); Submerge Trimaran Hull (STR); Roll Motion Control

Introduction

The Nautilus System concept (NTLS) as presented on the Introduction paper, is a roll motion and directional stabilizer which began to be developed early in 2020 ref.[13] is mainly conceive for floating systems for offshore applications with not intent to sail like FPSO´s by increasing the hull resistance to oscillate by contributing with an amount of additional mass from a light structure device attached to the hull base (bilge) with positive buoyancy that could act as well like a directional stabilizer (additional mass modulator stabilizer) being this considerations also understood by comparing the NTLS hull system with the mechanical vibration principle of a dual mass spring system dynamic absorber used in tall buildings to absorb the vibrations of a large mass structure (hull) by adding on top a smallest mass that vibrates with the building (NTLS) (fig.1), being the effect of the energy transference back and forth process (additional fluid inertia that oppose to the oscillation motion) the reduction of the main structure (hull) vibration, which in analogy are the angles of list (roll amplitude) it´s mean, more external excitation energy it´s required to achieve the same roll amplitude as would be obtained with a bare hull (GM_T) which has the effect to extend the envelope of the stability curve in which GM_TNTLS vary linearly for a broader range of sea estate.

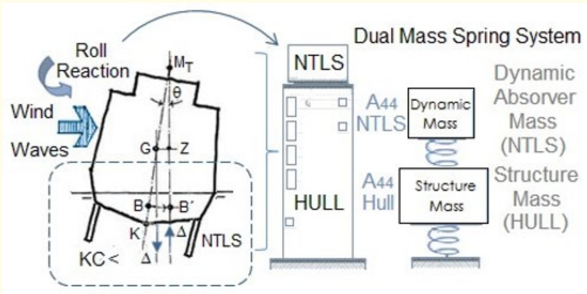

Figure 1: NTLS System dynamical system absorber comparison.

Therefore, in order to obtain an additional solution for the dynamic absorber analogy that can be applied in conventional vessels that require a velocity of service to obtain a reduction to the roll amplitudes, it will require a methodology based on achieve a potential damping increment.

Submerge Trimaran Hull (STR)

A vessel standing in waves is a dynamic system which under a linear assumption (uncoupled motions) roll can be described in analogy with one dimensional harmonic oscillator (1) where the additional mass (A_{44}) is associated with the acceleration (2) as the product of a linear contribution to the total mass of the vessel from the hull interaction with the fluid and the potential damping (B_{44}) associated with the velocity (3) is a term related with the hull form capability to generate waves as a mechanism of energy dissipation (Note: Inertia has no effect on the energy dissipation process). The periodicity of roll is determined by a vessel hull form, the maximum breadth and the weight distribution and the relationship among statics (restoring moment) and inertia (hull fluid interaction) determines the oscillation natural period (10) it´s mean, the roll period in which any external force can induce an unrestrained oscillation motion (resonance). Hence, the roll becomes a matter of concern when the waves frequencies coincides with the vessel natural oscillation frequency, that for instance this phenomena could occur when waves are fairly regular or when following waves in head seas induce a water plane variation that generate a vessel transversal instability (parametric roll) and also could occur when small change in direction or speed leads to a synchronous oscillation motion or when the excitation from rough and uneven sea make the vessel to react to the waves at intervals that coincide with his own periodicity (natural period), especially at certain sea state conditions in which the vessel may be submitted to transversal cyclic wave loads close to the natural frequency and the roll motion amplitude may became surprisingly high (say more than 30 degrees peak-to-peak) making the vessel reach heeling angles far from the restoring moment capability to maintain the vessel stability.

Therefore, in order to obtain a solution for the dynamic absorber analogy that can be applied on conventional vessels to obtain a reduction of the roll amplitudes, let's apply the following heuristic stages by considering as first stage an observer located on a referential fix at the hull base which has 3 double bottom compartments oscillating with roll motion hence, the observer will perceive that, there is an oscillating fluid mass moving from port to starboard and backwards through the hull base (fig.2(a)) (e.g. oscillating flow on a submerge pipe on the sea floor, positioned transversally to a trend of waves on shallow waters ref.[4]) then, if the oscillating flow is considered like a "Free Surface Effect" (FSE) to be suppressed a procedure to restrict the flow would be as it's done by compartmentalizing a vessel double bottom with longitudinal bulkheads, then to understand how to apply this procedure, let´s consider that from the dual mass spring system comparison (fig.1) the smallest mass rather than being allocated at the building top it´s allocated underneath (hull base) were the exiting forces response act greatly releasing energy then, the next heuristic stage it's done having as a base the NTLS concept development principia of projecting a virtual draft, in this case mirroring the double bottom longitudinal bulkheads into the hull base (fig.2(b)) like vertical keels distributed transversally across the breadth, that's for this example generate 3 separating areas immerse in a steady state flow medium which under a lower KC number regime assumption, oscillate follow the GM_T linear variation (7) ("calm sea") ref.[1] being the concept of adding distributed vertical keels (longitudinal bulkheads) across the hull breadth denominated NTLS FSE, which in summary as above explained is developed from the perspective of considering the oscillation flow associated with roll motion like a "Free Surface Effect" (FSE) to be contain.

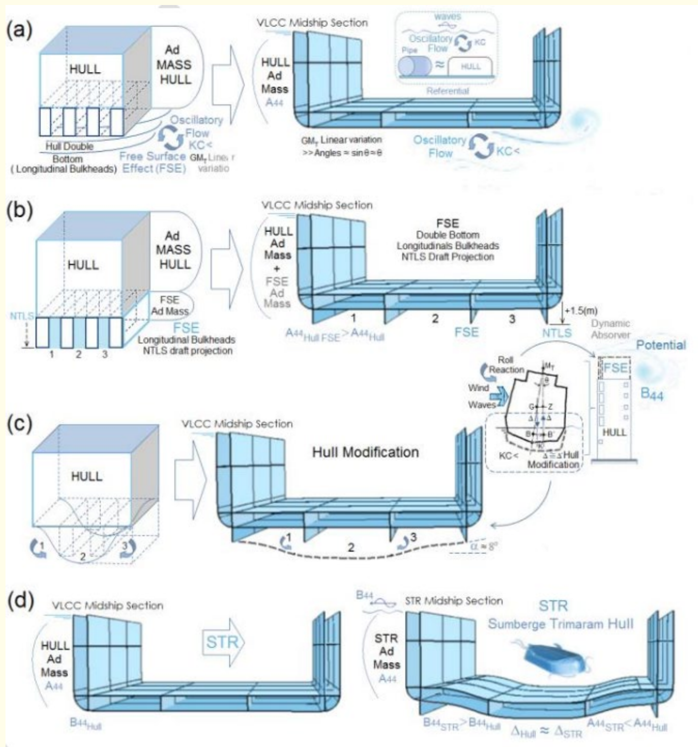

Figure 2: NTLS Free Surface Effect (FSE) concept heuristic stages.

Thus then, considering the previous stages (a) and (b) the following heurist step is based on the question ¿How it would be possible to make a hull geometric modification with a minimal interference to the restoration moment parameters to obtain a potential damping increment? Then, let's start with the VLCC from ref.[1] from which the hull modification will be made by doing a gradually geometrical variation maintaining the displacement (for comparison purpose) by transferring volume from the side mirroring compartments (1 and 3) to the central compartment (fig.2(c)) like an airplane with compact wings spam projected in angle from the tip (bilge radius) to the fuselage (center compartments) in similarity with a low angle V hull (≈8°) having as a base a convex hull bottom forming a "Trilobites" like shape that, when it´s consider together with the projected double bottom hull side mirroring bulkheads, form a Submerge Trimaran Hull (STR) as displayed on figure 2(d), that in this case it´s achieve with 1.5 (m) draft extension and a variation of 2% on the displacement and KB approx. of (–)0.2 (m) from the original VLCC hull as displayed on figure 3.

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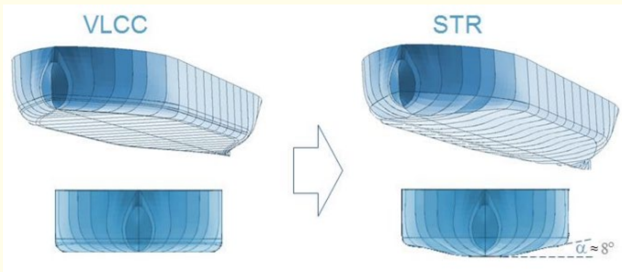

Figure 3: VLCC and STR hull concept form comparison.

Additionally, the process described to obtain the STR hull concept from a conventional hull modification, also can be understood by doing a comparison with the effect to slowing a pendulum harmonic oscillation with greater air resistance (vortex shedding = potential damping) by varying the pendulum mass shape (implicit modification) that, in this case is obtained by doing a volume transference, mirroring the double bottom longitudinal bulkheads into the hull base to reshape the pendulum mass (channel "U" to convex hull form "V") in order to increase the energy dissipation effect and thus then reduce the angle of swing, which is the angle of list from which the roll motion amplitudes is generated it´s mean, more external excitation energy it´s require to achieve the same angle of list as before the hull modification.

The potential damping effects generated from the STR hull concept that also can be understood from the previous harmonic oscillation pendulum system analogy (fig.4) also bring into play an additional effect which is the oscillation flow passing by through the STR hull (convex), which in comparison with the VLCC hull (channel) the STR hull form restrict the oscillation of the fluid mass flow, it´s mean more external excitation energy it´s required to achieve the same VLCC hull roll amplitude and therefore under the lineal approach considerations although, there is a reduction to the additional mass which lead to a natural roll period variation (10.a) also there is a variation to the roll amplitude product of the hull form factor, being this physical phenomenon also understood by comparing the oscillation fluid mass flow through both hull´s with a string vibrating in two modes and the relation with a pendulum harmonic oscillation system (fig. 4) as shown in figure 5, in which 1 node (L) string vibration is the oscillation flow through the VLCC hull and 2 node (L/4) string vibration is the oscillation flow through the STR hull, it´s mean A_{44}.STR ≅ 0.75 × A_{44}.Hull (Table 1).

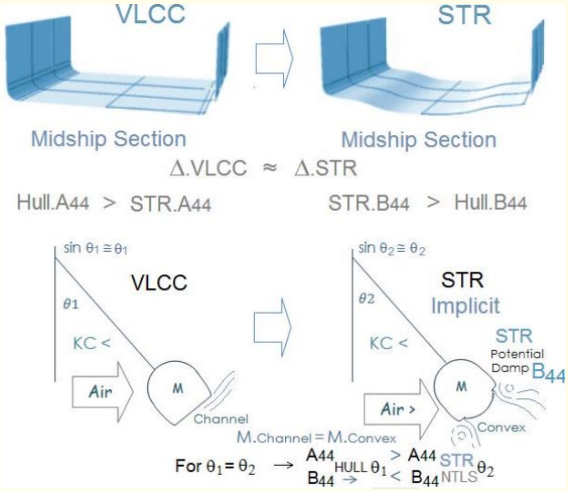

Figure 4: STR hull concept and harmonic oscillator pendulum system comparison.

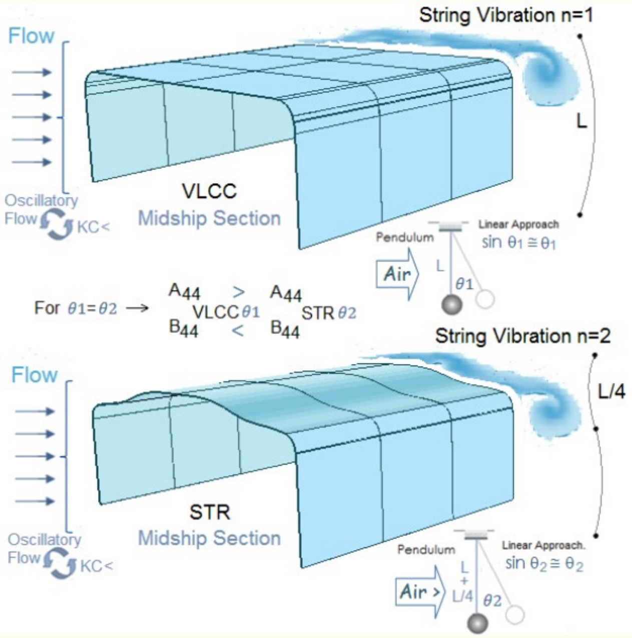

Figure 5: VLCC and STR hull concept oscillation fluid mass flow and string vibration comparison.

Submerge Trimaran Hull (STR) Roll Motion

Therefore, as a way to gain an understanding to the VLCC STR hull concept and the relation with the VLCC vessel transversal stability parameters values and their influence on the roll amplitudes (that for instance could be made by a symmetrical weight shifts to the ship's center of gravity or away from it without any appreciable variation in the gyration radius and whereas a very little variation can be made in the gyration radius without markedly varying the metacentric height), then let's consider having in mind consolidate naval architectural formulations for transversal stability ref.[7] from which, as long the geometrical hull modification don't affect significantly the KB the inclining arm GZ in the general expression of the restoring moment Mr = Δ GZ will not have any significant variation. being also that GZ = BM sin θ - GB sin θ (GZ = stability of form – stability of weight) is an expression modulated by the GB variation then, as long Δ.STR ≅ Δ.Hull (approximately at the same water plane area WL) BM it could be consider invariant as BM.STR = (Inertia.WL div ∇.STR) ≅ (Inertia.WL div ∇.Hull), therefore GZ.STR for small inclinations angle of list (sin θ ≅ θ) it´s assumed to be equal to GM_T.STRθ then Mr.STR = (Δ.STR×GM_T.STR) hence, consequently as the hull form vary with the draught increment, the bottom tanks compartment also experience a vertical variation and therefore the cargo area as well and by doing that, KG is expected to vary proportionally with KB at the same ratio as function of the expected structural re-arrangement, therefore also it could be assumed that GB.STR ≅ GB.Hull hence GZ.STR ≅ GZ.Hull which also is valid for GM = BM + (KB – KG) hence GM_T.STR ≅ GM_T.Hull (Table 1) it's mean, the STR restoring moment is Mr.STR ≅ Mr.Hull being the result of the hull form modification a potential damping increment B44.STR > B44.Hull (B44.STR ≅ 4 × B44.Hull) although A_{44}.Hull > A_{44}.STR (A_{44}.Hull ≅ 1.25 × A_{44}.STR) therefore, the STR hull modification increase the vessel resistance to oscillate by varying the hull form to obtain an increment to the potential damping which also restrict the oscillation fluid mass flow through the hull (fig.2(d)), leading to a roll amplitude variation as more external excitation energy it´s require to obtain the same original VLCC hull roll amplitude, it´s mean to achieve a similar quantity of fluid mass flowing through both hull´s in opposition to the oscillation motion (1.25 × A_{44}.STR) and therefore, obtaining a gain on the transversal stability response with a roll natural period modification (10.a).

Therefore, in order to quantify these effects in a simple mathematical modeling, from 1 degree of freedom uniform oscillating system and considering the assumption of uncoupled motions (linear), the canonical equation that's represents the roll for a vessel floating in calm waters with stable equilibrium without resistance to oscillate, it could be define as ref.[1]:

$$I_{Total}(\omega)\frac{d\,\theta^2}{dt^2} + B_{Damping}\frac{d\theta}{dt} + C_{Restoring}\theta = 0 \quad (1)$$

Were θ , $\frac{d\theta}{dt}$, $\frac{d\,\theta^2}{dt^2}$ are roll angle, velocity and acceleration associated with an external frequency of roll and ω is the oscillation responses in frequency being the total oscillation Inertia $I_{Total}(\omega)$ the sum of the free body vessel inertia I_{44} and $I_{44}(\omega) = A(\omega)_{44}$ the hydrodynamic inertia:

$$I_{Total}(\omega) = I_{44} + A(\omega)_{44} \quad (2)$$

Interaction fluid hull damping coefficient (wave making)

$$B_{Damping} = B_{44}(\omega) \quad (3)$$

Restoring moment coefficient (hydrostatic restoring)

$$C_{Restoring} = \rho\nabla g\, GM_T = K = C44 \quad (4)$$

Re-arrangement the roll motion equation (1):

$$(I_{44} + A(\omega)_{44})\frac{d\,\theta^2}{dt^2} + B_{44}(\omega)\frac{d\theta}{dt} + \rho\nabla g\, GM_T\theta = 0 \quad (5)$$

Therefore, considering a linear aprox. (sinθ ≅ θ) to the oscillation motion, GZ is assumed to be equal to GMθ then C_{44}:

$$C_{44}(\theta) = \Delta GZ \qquad (6)$$

$$GZ(\theta) = GM_T\theta \qquad (7)$$

Thus then, from ref.[1] the restoring moment coefficient C_{44} (θ) on ballast condition (70%) can be considered linear (sinθ ≈ θ) until 20º and 30o for full load condition (100%) hence:

$$I_{44}(\omega) \cong I_{44} = Constant \ (8)$$

Then, the natural roll frequency is:

$$Roll.\omega_{n_4} = \sqrt{\frac{\rho\nabla g\ GM_T}{I_{44}+A_{44}}} \qquad (9)\ \left(\sqrt{\frac{Static}{Inertia}} = Resonance\right)$$

Hence, the natural roll period is:

$$Roll.T_{n_4} = \frac{2\pi}{\sqrt{\frac{\rho\nabla g\ GM_T}{I_{44}+A_{44}}}} \qquad (10)$$

Therefore, the VLCC (conventional hull) and STR natural roll period comparison is:

$$Roll.T_{n_{4Hull}} = \frac{2\pi}{\sqrt{\frac{\rho\nabla g\ GM_{T.Hull}}{I_{44}+A_{44Hull}}}} \quad < \quad Roll.T_{n_{4STR}} = \frac{2\pi}{\sqrt{\frac{\rho\nabla g\ GM_{T.STR}}{I_{44}+A_{44STR}}}} \qquad (10.a)$$

The expression (10.a) (roll natural period) is valid for comparison matters since a new hull project that consider to be developed with the STR hull features, it would require further considerations with the vessel structural arrangement and loads conditions.

STR Hull Application Example

Therefore, in order to determine the STR hull natural roll period (T_N) variation effect, having as a base the VLCC from ref [1] (fig. 3) is applied a potential theory software ref [12] to obtain the RAO´s roll of both hull´s models, considering a VLCC hull displacement 151880.400(m3) (VLCC model 152227 (m3)) and STR model 155242 (m3) (2% variation) length 273 (m), length.pp 260 (m), breadth 44.500 (m), depth 22.840 (m) floating with a draught of 16,180 (m), STR model 17,680 (m) (variation (+) 1.50 (m)), Rxx 114.6 (m), GM_T VLCC 5.392 (m) and STR 5,032 (m) for a CG value of 12.62 (m) from the hull base and VLCC KB 8.5 (m) and STR KB 8.29 (m) (variation ≈ (–) 0.2 (m)). Hence, additionally in order to measure a CG variation influence on STR hull response, also it's made 2 CG variations, one STR G2 = 12.42 (m) following the STR KB variation of (-) 0.2 (m) and a STR G3 = 12.82 (m) considering (+) 0.2 (m) above CG, being the comparative RAO´s roll plot´s displayed in figure 6 and the results summarized on Table 1 as follow:

Furthermore, in order to gain a further understanding of the STR hull concept an evaluation on heave and pitch motions it´s made for the hull model STR in comparison with the VLCC hull considering a RYY1 approx. 65.75 (m), from which the heave and pitch RAO´s result are plot in the following graphs in figure 7(a) heave and figure 7(b) pitch:

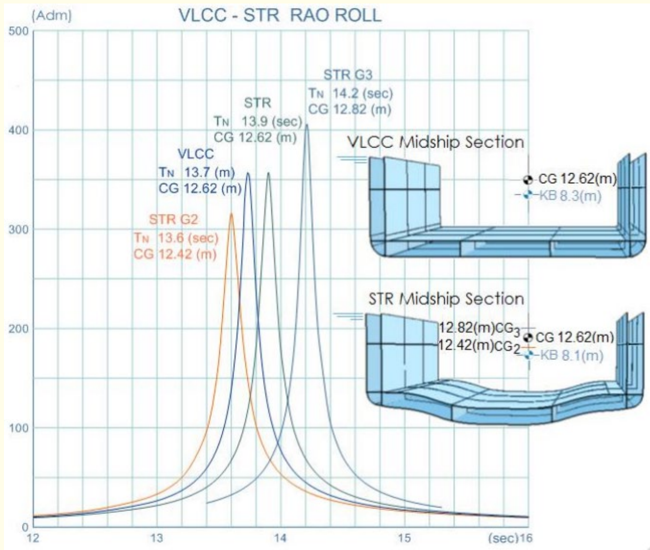

Figure 6: VLCC and STR hull´s RAO Roll.

Vessel model	***GM_T (m)***	***KB (m)***	***Adm. A44 ·10^7***	***T_N (sec)***
VLCC	5.392	8.347	67.18	13.7
STR	5.034	8.152	49.19	13.9
STR G2 cg (–) 0.2 (m)	5.234	8.152	49.19	13.6
STR G3 cg (+) 0.2 (m)	4.834	8.152	49.19	14.2

Table 1

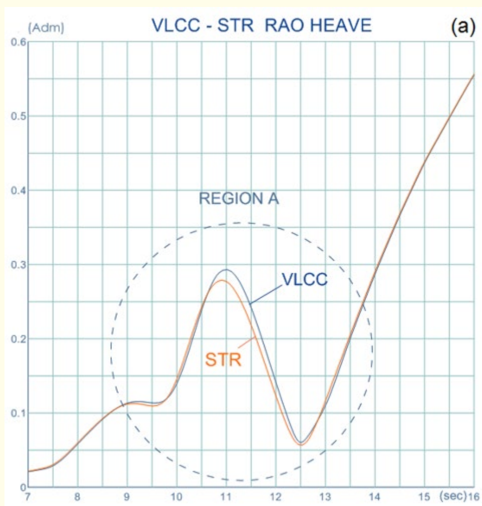

Figure 7(a): STR and VLCC RAO heave.

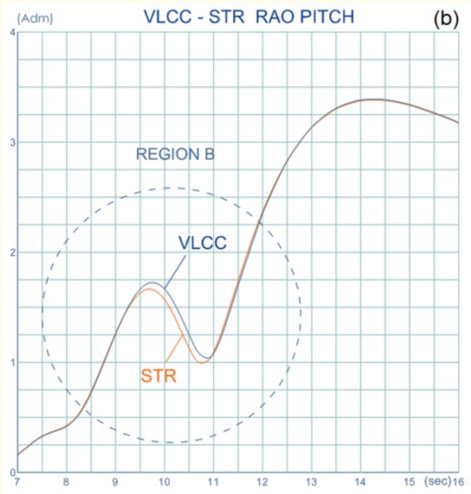

Figure 7(b): STR and VLCC RAO pitch.

Summary and Results Discussion

The Submerge Trimaran (STR) hull concept presented through these pages is an extension of the Nautilus System stabilizer concept (NTLS) which its conceive focusing in floating system for offshore application with no intention to sail by increasing the floating system additional mass and consequently reducing the roll amplitudes and therefore in order to pursuit an application for conventional vessels that's require a velocity of service, the STR hull concept ref [14] it´s conceived based on the NTLS concept principia ref [13] to obtain a hull modification by inserting a virtual draft to increase a vessel wave making capability (potential damping) to obtain a reduction to the roll motion amplitudes with the pursuit to enhance in overall a vessel sea keeping capability to cross ocean routes efficiently with energy savings and decarbonization.

Hence, the STR hull concept presented on this publication is obtained from a VLCC hull ref [1] by doing a hull form modification from which it´s obtained a displacement variation of 2% and KB ≈ (–)0.2 (m) for a hull full load draught condition, evaluated through a potential theory software ref [12] with the aim to obtain an understanding of the STR hull concept state of the art in comparison with the VLCC hull motion response for a 90o beam seas in which also was consider a 2 CG variations following the STR hull KB.STR variation, together with a motion response comparison for heading seas (180o) heave and pitch.

Therefore, from the roll RAO motion response for beam seas (figure 6) it's possible to determinate that, the roll natural period variation among the VLCC hull (13.7 (sec)) and the STR hull model (13.9 (sec)) is 0.2 (sec) in which also a CG (12.62 (m)) variation with KB (-0.2 (m)) it's tested for the model STR G2 CG = 12.42 (m) and CG (+0.2 (m)) for the model STR G3 CG = 12.82 (m) resulting for the hull´s models STR G2 a roll natural period value of 13.6 (sec) ((-)0.1(sec) shift) and for STR G3 a roll natural period value of 14.2 (sec) (0.5 (sec) shift) product of the additional mass and GM_T value variation (10.a) as displayed on Table 1.

Likewise, from the results obtained for the response amplitudes operators (RAO) in heave and pitch, there is a motion amplitude reduction in heave (fig.7(a)) for the wave period interval between 9.1 (sec) and 12.6 (sec) (Region A, from potential to transition from small potential damping to the motion in phase with the waves) and for pitch (fig. 7(b)) there is a motion amplitude reduction on the wave period interval between 9.1 (sec) and 10.9 (sec), (Region B, transition from small potential damping to the motion in phase with the wave) being this motion response variation, mainly product of the hull form and wave irradiation capability (energy dissipation) of the STR hull (STR.B44 ≈ 4 × VLCC.B44) as can be appreciated on the 2D flow images in figure 8(a), obtained by using Navier- Stokes solve approximation on both hull´s models and the hull FSE model, emulating a roll free decay test (fig. 8(b)) initial ½ cycle at lower KC number flow regime (small damping b2 ref[1]) in which can be appreciated that, the STR hull form has more effectiveness in comparison with the VLCC hull in restringing the passage of the incoming flow generated from hypothetically releasing the hull´s models at the same initial angle of list, it´s mean more external excitation energy it´s required to achieve the same VLCC oscillation amplitude as the amount of fluid moving by the VLCC is approximately 1.25 times the amount of fluid moving through the STR hull (fig.5) which mean, there is a variation to the oscillation periodicity (roll natural period) as its show on figure 6 (Table 1) although both hull´s models has approximately the same displacement (10.a) and when considering a comparison with the VLCC FSE hull model that has a GM_T value similar to the VLCC hull, this hull model has a strong oscillation damping effect, product of the fluid mass flow restriction through the FSE keels from which also it´s generated an additional mass increment which result in a considerable natural roll period variation, as can be appreciate on Table 2 in the following chapter.

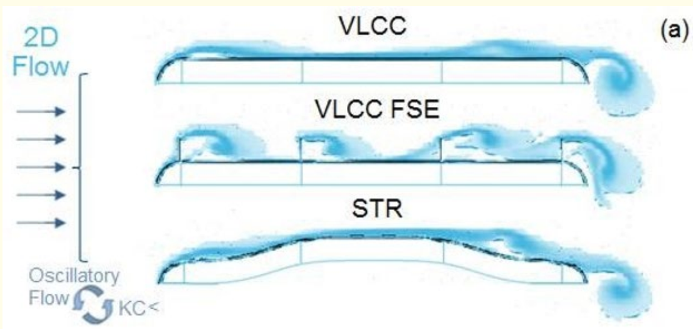

Figure 8(a): VLCC, VLCC FSE and STR bottom hull´s models 2D flow, emulating initial ½ oscillation cycle at lower KC.

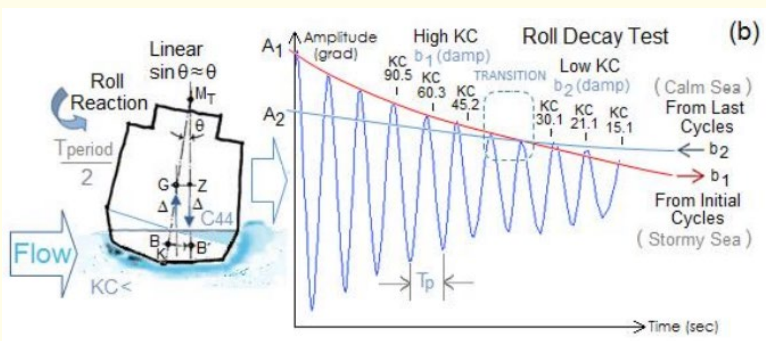

Figure 8(b): Roll free decay test and 2D flow effects, emulating initial ½ oscillation cycle comparison.

In summary, the STR hull when is compared with the VLCC hull (U shape) the additional mass (A_{44}) will decrease partially (A_{44}.STR ≅ 0.75 × A_{44}.Hull) in function of the side hull reduction (Table 1) although the potential damping (B44) will increase (B44.adm e-13 STR 4.5762 > 1.30064 B44.adm e- 13 VLCC) as product of the angular hull base projection of 8° (V shape) from the bilge to the extending draft at the convex hull base, that also has the effect of restrict the flow passage through the bottom as can be appreciated on figure 8(a), which means, although there is a reduction to the additional mass there is also a variation to the roll periodicity due to the hull form efficiency in restrict the transversal oscillation fluid mass flow than a conventional vessel, which eventually for instance could lead to suppress the parametric roll phenomena enhancing in overall a vessel sea keeping performance to achieve a velocity of service with energy efficiency (low carbon emissions) and therefore with the transverse stability parameters variation and the additional mass reduction the natural roll period value is modified (10.a) extending the GM_T (STR) linear variation in the transverse stability envelope for a broader range of sea state, as more external excitation energy it´s require to obtain the same VLCC hull roll amplitude, which in reference to figures 4 and 5, this physical phenomenon also can be understood by comparing the reduction of the additional mass and flow restriction effect by the STR hull form, with a pendulum harmonic oscillation system in which as the pendulum string length L is extended L/4 (A_{44}.Hull @ 1.25×A_{44}. STR) it takes more time to complete one oscillation, it´s mean, as the VLLC roll motion is the pendulum with string length L then, in order to achieve the same swing amplitude, it will require the addition of more external excitation energy to the pendulum with the extended string length, being the vortex's shedding effect generated by the pendulum mass reshape (convex) the mechanism under which the external excitation energy is dissipated, equivalent to the STR hull potential damping increment.

Therefore, the response variation among the VLCC and STR hull´s models is mainly based on the hull form factor and where the STR hull in general has been improved the VLCC hull response in heave and pitch with a gain on the transversal stability from a natural roll period variation of 0.2(sec) (Table 1) being both hull's models response for large wave periods (evanescent) becoming similar as product of the increasing relation among the potential damping and additional mass effects.

Further Initiatives

The Nautilus System (NTLS) concept (stabilizers for motions and currents) is based on the idea to use a passive and easily constructed device to reduce floating systems roll motion amplitudes and at the same time enhance the directional stabilization capability to align with the main environmental actions, expanding the safety operation margin scenarios within a broader range of sea states and in order to pursuit an application for conventional vessels that's require a velocity of service, the STR hull concept it´s conceived from a hull modification based on the NTLS concept principia (fig.2) to obtain a reduction to the roll amplitudes by increasing the potential damping while restricting the transversal oscillation flow process described in the pages of this publication and from which, in the same line of thought, new applications can be developed like the ones described as follow.

NTLS Retro Bulb (RTB) Concept

Hence, from the STR hull development stages an additional potential variation is a bulbous bow modification obtained from the STR hull draft projection into the VLCC bulbous bow from ref. [1], like an NTLS device from which it´s obtained an additional mass contribution into the STR hull fluid mass system to reduce the angle of list (roll motion amplitudes), being the modification made by extending the bulbous bow curvature (plane xz) with a vertical projected back ward interpolation to the STR hull draft, forming a convex vertical keel underneath the bow area named NTLS Retro Bulb (RTB) being this modification applied for the STR model with a vertical projection of 2.5(m), length of 55 (m) and width 19(m) in comparison with an harmonic oscillation pendulum system (e.g. fig.4) as it´s describe in figure 9.

NTLS Flip Sail (FPSL) Concept

Further NTLS applications with conventional vessel that's require a service velocity must have additional considerations especially with the physical phenomena related with the hull-fluid interaction, being the area of the hull on which an NTLS application could have least impact, is at the hull parallel body junction with the aft area in which the flux that's comes from the bow to the hull continuous section expand to the stern. Hence, having in mind the effects that comes with the implementation of additional devices into the submerged part of the vessel with the advance velocity resistance and the influence on the directional stability, an NTLS device conceive from the perspective of a slender body immerse into a flux theory, could be an advantage as a potential source of renovation for conventional vessels development consider a slight extra drag disturbances to the vessel design velocity and maneuverability, this stabilizer concept is inspired in nature derived from a dolphin flipper like shape denominated NTLS Flip Sail (FPSL) conceive to be applied for instance at the STR hull parallel body junction with the aft section (bilge radius) with lengths 43(m) and 26(m), depth 5.5

(m) being the effects derived from this device also understood by doing a comparison with an harmonic oscillation pendulum system (e.g.fig.4) as it´s describe in figure 10 as follow:

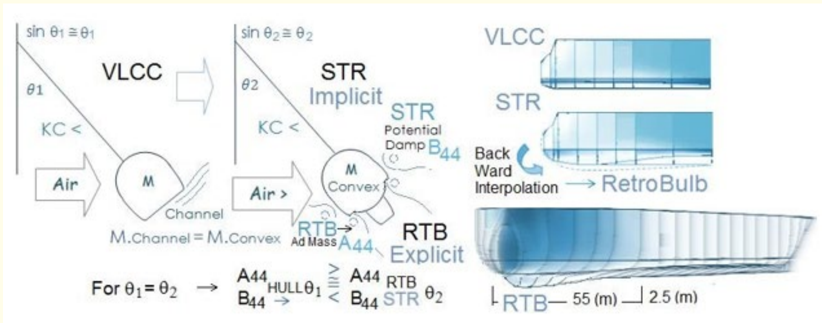

Figure 9: STR hull RTB concept and harmonic oscillator pendulum system comparison.

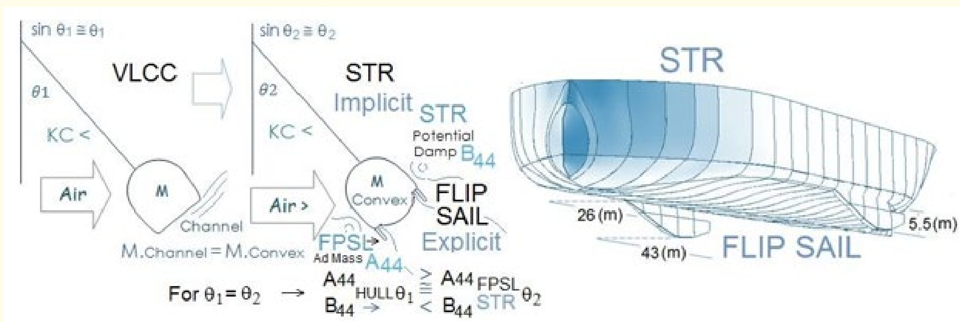

Figure 10: STR hull FPSL concept and harmonic oscillator pendulum system comparison.

NTLS Free Surface Effect (FSE) Concept

Likewise, from the NTLS concept of adding distributed vertical keels (longitudinal bulkheads) across the hull breadth denominated NTLS FSE, which in summary is developed from the perspective of considering the oscillation flow associated with roll motion like a "Free Surface Effect" to be contain (fig.2(b)) apply as example with the VLCC ref. [1] distributed through the breadth at the parallel hull body, composed by 4 vertical keels of 4 (m) depth, 2 (inner) from the center line with 104 (m) length, separated by 20 (m) and 2 (external) at the hull girder side with 91 (m) length, separated by 44 (m) in comparison with an harmonic oscillation pendulum system (e.g.fig.4) as it´s describe in figure 11 as follow:

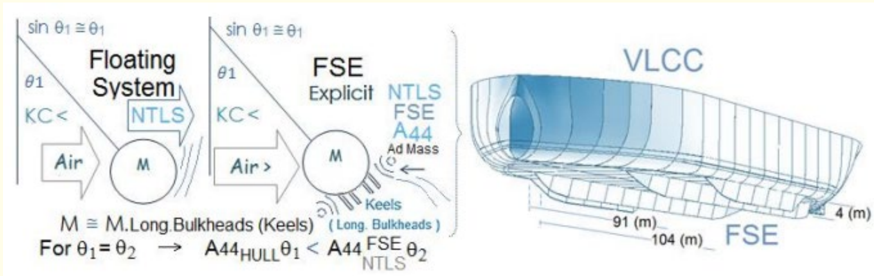

Figure 11: VLCC hull FSE concept and harmonic oscillator pendulum system comparison.

Summary

Hence, in order to gain an overview on the potential applications of these NTLS modifications (RTB, FPSL and FSE) into the natural roll period value, it´s made an evaluation following the Item 4, STR hull application example procedures, for the hull´s models VLCC RTB, STR RTB, VLCC FPSL, STR FPSL, VLCC FSE and the hull´s models combination of both modifications VLCC RTB FPSL, STR RTB FPSL in comparison with the hull´s VLCC and STR (figure 12) being the results summarized on Table 2 (VLCC) and Table 3 (STR) from which, for a CG 12.62 (m) fixed from the hull base, the influence of the slightly KB variation into the GM_T and the additional mass value product of this modifications into the static and dynamic relation that determine the natural roll period value (TN) variation (10.a) is clear.

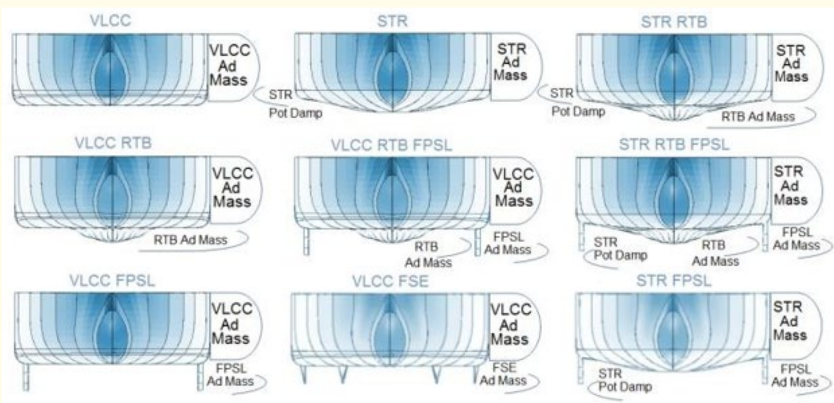

Figure 12: Hull´s models VLCC and STR with RTB, FPSL and FSE.

VLCC hull's models

Vessel model	GM_T (m)	*KB (m)*	*Adm. A44* $\cdot 10^7$	T_N (sec)
VLCC	5.392	8.347	67.18	13.7
VLCC RTB	5.256	8.291	67.54	13.88
VLCC FPSL	5.346	8.334	81.52	14.0
VLCC RTB FPSL	5.211	8.263	81.57	14.15
VLCC FSE	5.332	8.292	94.19	14.2

Table 2

STR hull's models

Vessel model	GM_T (m)	*KB (m)*	*Adm. A44* $\cdot 10^7$	T_N (sec)
STR	5.034	8.152	49.19	13.9
STR RTB	4.998	8.134	49.42	13.95
STR FPSL	5.302	8.131	66.94	14.25
STR RTB FPSL	4.956	8.112	67.16	14.3

Table 3

Conclusion

Therefore, based on the comparative motion response analysis presented on this publication, in order to consider the STR hull concept state of the art ref. [14] a potential contribution to the naval industry (e.g. longitudinal structural strength improvements, reduction in the parametric roll and LNG vessels sloshing probabilities occurrences) it will require extensive research studies on various aspects involved into the factors that are part of a vessel design, which has the objective to implement the STR hull (e.g. fig.13) to obtain an optimal combination of heave, roll and pitch to enhance in overall a conventional vessel sea keeping performance and maneuver capability in function of a velocity of service to cross ocean routes efficiently (e.g. improvements to the propeller hull interaction in open waters) with energy savings and decarbonization as the hydrodynamic impact of further initiatives such as the NTLS : Retro Bulb (RTB), FLIP SAIL (FPSL) and FSE concepts into a new or converted vessel and of which the NTLS FSE having in mind considerations with the addition of appendages into a hull and the influence into a vessel maneuverability and operational harbor draught constrain, it can bring into the naval building scenarios considerable transversal and directional stability improvements over conventional bilge keels for most of the conventional vessels and therefore by considering all these factors that are part of the STR hull concept and potential applications, new fields of research and development it could open for classification societies, companies and academic institutions.

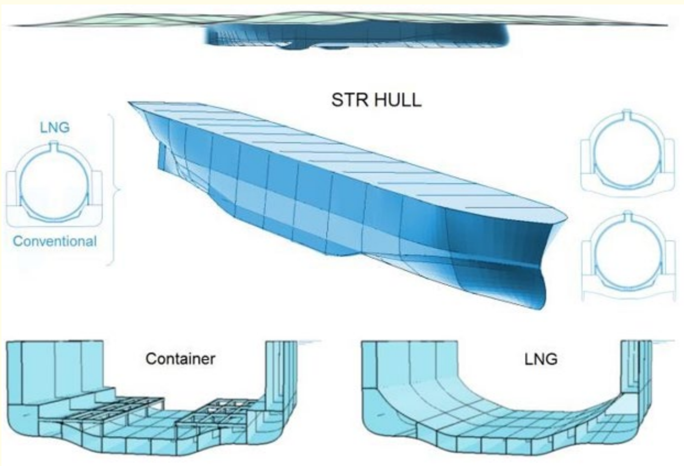

Figure 13: Serie 60 Submerge Trimaran hull (STR) and STR Container and LNG vessels midship sections state of the art.

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