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Ship Science & Technology is a specialized journal in topics related to naval architecture, and naval, marine and ocean engineering. Every six months, the journal publishes scientific papers that constitute an original contribution in the development of the mentioned areas, resulting from research projects of the Science and Technology Corporation for the Naval, Maritime and Riverine Industries, and other institutions and researchers. It is distributed nationally and internationally by exchange or subscription.

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Editorial Note

Cartagena de Indias, January 13th 2016

After fifteen years of Cotecmar's operations, different challenges have been assumed that made us to reinvent and ask ourselves about how we proceed regarding the particularities of a business where we have become into a reference for the region and in middle of an organizational culture that integrates military and civil manners in order to finally generate an own corporate identity based on innovation culture.

Today, it is a pride being recognized as an innovating company by all, that has every single employee, supported by the senior management office of the corporation, committed to give different improvements to products and process, hence the obtained accomplishments are pointed as reached goals by every person who belong to this great national challenge which addresses science, technological development and innovation leadership in naval, maritime and riverine Colombian industry.

It is an honor for me to introduce this issue, which represents the closing of fifteen years of scientific path of the corporation where by means of the Science Ship and Technology Journal, we have been able to produce and maintain an instrument of interaction and knowledge transfer between academy and industry that has allowed us to deserve the recognition proving our commitment to social science publishing, technology and innovation as a Cotecmar trademark to the country and the world.

The 18th issue of Ship Science and Technology Journal, continues the report of the best articles presented within the frame of The Fourth International Ship Design and Engineering Congress (CIDIN 2015), relating to: Propulsive Qualities of a catamaran vessels, vibration analysis for propellers, bimodal transportation model, electric propulsion system for PSVs, combat systems technologies and conversion from single hull to a double hull vessel.

We thank to our speakers and assistances who participated in The International Ship Design and Engineering Congress, to authors and readers for their interest, dedication and contributions that let us show their work to transfer and produce new knowledge in the scientific community of naval design, architecture and engineering.

Captain (R) CARLOS EDUARDO GIL DE LOS RÍOS
Ship Science and Technology Journal Editor

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Nota Editorial

Cartagena de Indias, 13 de Enero de 2016.

Después de quince años de operación de Cotecmar, se han asumido retos que nos han obligado a reinventarnos y preguntarnos la forma como operamos en las particularidades de un negocio donde hemos logrado convertirnos en referente para toda la Región y en medio de una cultura organizacional que integra costumbres militares y civiles, para generar finalmente una identidad Corporativa propia basada en la cultura de la innovación.

Hoy, es un orgullo para todos ser reconocidos como una organización innovadora en la cual todos los empleados, apoyados por la Alta Dirección de la Corporación, aportan al mejoramiento de productos y procesos, por tanto los logros conseguidos son metas alcanzadas por todas y cada una de las personas que somos parte de esta gran apuesta nacional encargada de liderar la ciencia, el desarrollo tecnológico y la innovación en la industria naval, marítima y fluvial de Colombia.

Es grato para mí presentar esta edición, que representa el cierre de 15 años de trayectoria científica de la Corporación donde a través de la Revista Ciencia y Tecnología de Buques hemos podido generar y mantener un instrumento de interrelación y transferencia de conocimiento entre la academia y la industria que nos ha hecho merecedores de reconocimientos que certifican ante el país y el mundo nuestro compromiso social de divulgación y apropiación de la ciencia, la tecnología y la innovación como marca Cotecmar.

La edición 18 de la revista ciencia y tecnología de buques, continua con la entrega final de los mejores trabajos presentados en el marco del cuarto Congreso Internacional de Diseño e Ingeniería Naval – CIDIN 2015, encontraremos en ella artículos relacionados con: Cualidades propulsivas de Catamarán, Análisis de vibraciones de hélices, modelo bimodal de transporte, sistemas de propulsión eléctricos en PSVs, tecnologías en sistemas de combate y gestión de procesos de conversión de una embarcación tipo monocasco a doblecasco.

Agradecemos a los conferencistas y ponentes participantes del Congreso Internacional de Diseño e Ingeniería Naval, a los autores y lectores por su interés, compromiso y aporte que nos permite colocar a su disposición trabajos de calidad para transferir y generar nuevo conocimiento en la comunidad científica del diseño, la arquitectura e ingeniería naval.

Capitán de Navío (RA) CARLOS EDUARDO GIL DE LOS RÍOS
Editor revista Ciencia y Tecnología de Buques

Propulsive Qualities of Catamaran Vessels

Cualidades propulsivas de buques catamaranes

José María Riola [1]

Abstract

During the last decade the civil and military applications of catamaran vessels have developed rapidly. Their particular area of proliferation is the short sea shipping where their power, economy, habitability and behavior have provided them a market niche. The rapid market growth ha caused catamarans to experience design modifications regarding size, speed, cargo diversity (passengers, vehicles, containers).

The purpose of this article is to show the work developed by the El Pardo Hydrodynamic Experiences Channel (CEHIPAR) regarding the propulsive qualities of catamaran vessels. This work is the result of the need expressed by the Ministry of Defense for provision of technical assistance and scientific research for an I+D program that established more adequate program parameters for a catamaran-type vessel from the propulsive point of view, in relation to its size and shape, so that it has the adequate information and trustworthiness when suggesting a vessel of this type as an alternative to other platforms, always within the scope of application of patrol-type or quick-attack-type vessels.
Key words: Catamaran, sea-keeping, propulsive qualities, CEHIPAR, advance resistance tests, hydrodynamics.

Resumen

Durante la última década el empleo de buques catamarán, en aplicaciones civiles y militares, se ha desarrollado rápidamente. Su particular área de actuación ha sido el denominado “short sea shipping” donde sus características de potencia, economía, habitabilidad y comportamiento en la mar le han conferido un nicho de mercado. El rápido crecimiento del mercado, ha hecho que los catamaranes hayan experimentado modificaciones de diseño en cuanto a tamaño, velocidad, diversidad de carga (pasajeros, vehículos, contenedores).

El objeto del presente artículo es dar a conocer el trabajo desarrollado por el Canal de Experiencias Hidrodinámicas de El Pardo (CEHIPAR) en materia de cualidades propulsivas de buques catamaranes. Este trabajo surge de la necesidad manifiesta del Ministerio de Defensa para la prestación de asistencia técnica, e investigación científica, para realizar un programa de I+D que establezca los parámetros de proyecto más adecuados para un buque tipo catamarán desde el punto de vista propulsivo, en función de su tamaño y formas, de modo que se disponga de información propia y con la adecuada fiabilidad, a la hora de plantear un buque de este tipo, como alternativa a otras plataformas, siempre dentro del ámbito de aplicación a buques tipo patrulleras o buques de ataque rápidos.
Palabras claves: Catamarán, comportamiento en la mar, cualidades propulsivas, CEHIPAR, resistencia al avance, hidrodinámica.

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Introduction

William Dampier, captain of an English vessel, occasional buccaneer and corsair, while at the same time an excellent writer, botanist and scientific observer, was the first British national to explore and map the coasts of New Holland (nowadays Australia) and New Guinea, circumnavigating the world up to two times.

Way back in 1697, travelling through the south-western coast of India searching for business opportunities he found a sort of vessel, built with little more than bound logs which he described as :"…at the Coast of Malabar there are vessels they call catamarans. They consist of a log, or two, sometimes a type of light would, that carry only one man, whose legs and bottom are always in the water...".

Nowadays one may see the "Kattumarams" in the coasts of Southern India where normally, the boat's logs are untied after each trip, drying them out until they can be used again.

The catamaran was used by the "paravas", a fishermen community of the southern coast of Tamil Nadu, as well as by the ancient Tamil Chola dynasty in the V century B.C. to transport its troops and conquer the regions of Southeastern Asia, such as Burma, Indonesia and Malaysia.

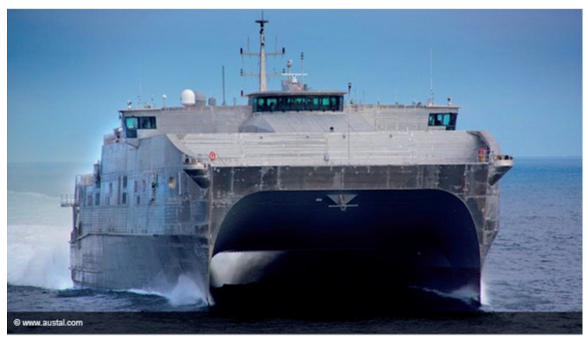
Fig. 1. Polynesian Catamaran.

It seems that even in prehistoric times, as evidenced by remains found dating back 3 or 4 millennia, that Austronesian navigators used double hull canoes to colonize Polynesia and settle in the most extensive group of islands in the planet.

The first documented catamaran in modern Europe, designed in 1662 as a member of the William Petty Royal Society was conceived so it could travel faster in shallow waters [7], with less wind and crew than other vessels of the time. Skepticism made it commercially unsuccessful, remaining an unused idea in the West for another 200 years.

During early 2002, the American Navy began building the new generation of vessels to conquer the possible asymmetric "anti-access" threats, such as mines, silent diesel submarines and rapid surface vessels; those known as Littoral Combat Ship LCS.

Fig. 2. Logisitics Support JHSV Vessel.



Currently, companies such as Austal and Lockheed Navy, leading the military application vessel design and fabrication sector, mainly for the U.S. Navy, have completely revolutionized these types of vessels, replacing the traditional structure with a revolutionary structure based in multihull solutions, with the purpose of achieving speeds that exceed 45 knots, larger flight decks for helicopters, as well as a considerable increase of internal spaces.

The main priority of the research project that supports this work is the study of the influence of hull separation [15] in catamarans to their advance resistance and therefore the power needed on board. For this purpose, each of the resistance components, as well as the interaction between the hulls, will be analyzed.

Research Procedure

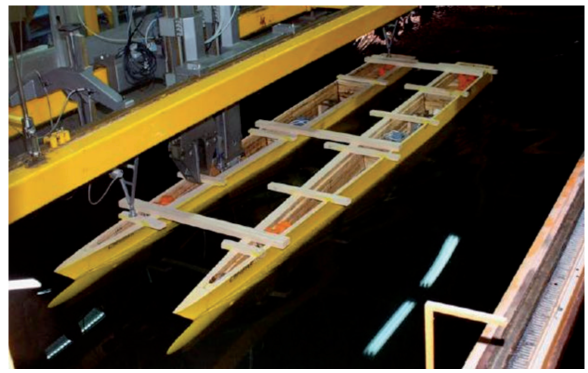
Collection and classification of information available from CEHIPAR

CEHIPAR, an Autonomous State Entity, internationally renowned in the area of hydrodynamics, that carries out projects, experiments and research for shipyards, shipping agencies, engineering offices, manufacturers and individuals, has been in charge in this case of compiling and classifying all the necessary information regarding bottom data and towing tests.

Among the highlighted suited, the importance and influence of hull separation for the resistance component is highlighted [8], as well as a numerical analysis of the individual and combined hulls, necessary activities to know the precision with which these mathematical calculations allow us to discern in each case the advantages of the shapes [5] chosen for a catamaran.

A set of bottoms (2328, 2625, 2688 and 2827) that made part of the catamaran stock of CEHIPAR were used, to which, additionally to the existing sea bearing behavior tests, towing tests restricting their freedom of movement to six degrees have been additionally performed.

Fig. 3. Scale model of a catamarán bottom.



Below are the main characteristics of said models, specifying the corresponding.

Table 1. Main bottom characteristics.

BOTTOM 2328			
Description	**Monohull**	**Catamaran I**	**Catamaran II**
Lpp (m)		24,00	
Lfl (m)		23,91	
B (m)	2,78	9,02	6,99
Centerline sep. (m)	0,00	3,46	1,90
Scale		1 : 7,500	

BOTTOM 2625			
Description	**Monohull**	**Catamaran I**	**Catamaran II**
Lpp (m)		69,72	
Lfl (m)		69,85	
B (m)	4,50	18,52	14,66
Centerline sep. (m)	0,00	14,02	10,16
Scale		1 : 16,000	

BOTTOM 2688			
Description	**Monohull**	**Catamaran I**	**Catamaran II**
Lpp (m)		42,64	
Lfl (m)		43,89	
B (m)	2,60	12,40	9,85
Centerline sep. (m)	0,00	9,80	7,25
Scale		1 : 10,000	

BOTTOM 2827			
Description	**Monohull**	**Catamaran I**	**Catamaran II**
Lpp (m)		60,00	
Lfl (m)		61,73	
B (m)	4,50	16,00	13,50
Centerline sep. (m)	0,00	11,50	9,00
Scale		1 : 10,320	

The numerical hydrodynamic studies where done using calculations of viscous fluids for the corresponding project speed and a comparative analysis of the shapes studied was done using procedures developed by CEHIPAR. The main parameters that depend of the bottom's geometry used to characterize it are found in the following table:

Table 2. Parameters of bottom geometry.

λ	Model scale
S_{CD}	Wet bottom surface without accessories [m^2]
S_{AP}	Wet bottom surface with accessories [m^2]
L_{PP}	Length between perpendiculars [m]
L_{WL}	Length during buoyancy [m]
L_{DES}	Displacement length (maximum submerged length) [m]
A_T	Transversal area exposed to the wind [m]

Values measured during resistance tests (*M*: model subindex, *S*; vessel subindex):

Table 3. Measured resistance values.

V_M	Model velocity [m/s]
R_{TMCD}	Total bottom model resistance without accessories [Kg]
R_{TMAP}	Total bottom model resistance with accessories [Kg]
Δ_{RTMAP}	RTMAP – RTMCD [Kg]

Non-dimensional coefficients (*M*: model subindex, *S*; vessel subindex):

Table 4. non-dimensional coefficients.

C_{AA}	Wind drag coefficient $\left[\frac{A_T}{S} * 10^{-3}\right]$
C_F	Friction coefficient according to ITTC'57 $\left[\frac{0,075}{(log_{10} R_e - 2)^2}\right]$
C_{TMCD}	Total Friction Coefficient of the bottom model without annexes
C_{TMAP}	Total Friction Coefficient of the bottom model with annexes
C_{RMCD}	Total Residual Friction Coefficient of the bottom model without annexes
C_{RMAP}	Total Residual Friction Coefficient of the bottom model with annexes
C_{TSCD}	Total Friction Coefficient of the bottom without annexes
C_{TSAP}	Total Friction Coefficient of the bottom with annexes
C_{RSCD}	Total Residual Friction Coefficient of the bottom without annexes
C_{RSAP}	Total Residual Friction Coefficient of the bottom with annexes
Δ_{CF}	Roughness Friction Coefficient $\left[\left(105 * \left(\frac{K_S}{L_{DES}}\right)^{1/3} - 0,64\right) * 10^{-3}\right]$
K_{CD}	Bottom shape factor without annexes
K_{AP}	Bottom shape factor with annexes
R_e	Reynolds Number $\left[\frac{V * L}{v}\right]$
F_r	Froude Number $\left[\frac{V}{\sqrt{g * L}}\right]$

Constants:

Table 5. Constants.

υ	Cinematic viscosity [m^2/s]
ρ	Mass density[$Kg*s^2/m^4$]
g	Gravitational constant [m/s^2]
K_S	Median height of bottom roughness. Standard Value $150*10^{-6}$ [m]

The experimental procedure was performed using the LAMBDA software developed by CEHIPAR; this software allows determining the total model friction coefficient (C_{TMCD}), as well as the residual friction coefficient, (C_{RMCD}), both for bottoms without annexes based on the following equations:

$$C_{TMCD} = \frac{R_{TMCD}}{\frac{1}{2}\rho\, S_{MCD} V_M^2} = (1 + k_{CD}) * C_{FM} + C_{RMCD} \quad (1)$$

$$C_{RMCD} = \frac{R_{RMCD}}{\frac{1}{2}\rho\, S_{MCD} V_M^2} \quad (2)$$

where the shape factor k_{CD} is determined by analyzing the results for Froude's number between 0.12 and 0.2, whether using the Prohaska method or the minimum method proposed by Hughes, all of them verified with the statistics of similar ships tested at CEHIPAR.

Known that the residual coefficient without annexes (C_{RMCD}) is the same for the model and the ship and there is no scaling effect for the shape factor k_{CD}, the total friction coefficient of the bottom without annexes is determined using the following expressions:

$$C_{TSCD} = \frac{R_{TSCD}}{\frac{1}{2}\rho\, S_{SCD} V_S^2} = (1 + k_{CD}) * C_{FS} + C_{RMCD} + \Delta C_F + C_{AA} \quad (3)$$

where the friction value without annexes of a real ship is:

$$R_{TSCD} = C_{TSCD} * \frac{1}{2}\rho\, S_{SCD} V_S^2 \quad (4)$$

and the effective power:

$$P_E = \frac{R_{TSCD} * V_S}{75} \quad (5)$$

When the bottom test is done with the annexes and there is no corresponding pull test of the bottom without annexes, the extrapolation of the test with annexes is done analogously to that indicated for the bottom without annexes, unless it expressly indicates otherwise:

$$\Delta R_{TMAP} = R_{TMAP} - R_{TMCD} \quad (6)$$

$$\Delta C_{TMAP} = \frac{\Delta R_{TMCD}}{\frac{1}{2}\rho\, S_{MAP} V_M^2} \quad (7)$$

The value of the increment of the friction coefficient for the real ship is determined using the expression:

$$\Delta C_{TSAP} = \Delta C_{TMAP} * \frac{C_{FS}}{C_{FM}} \quad (8)$$

$$C_{TSAP} = ((1 + k_{CD}) * C_{FS} + C_{RMCD}) * \frac{S_{CD}}{S_{AP}} + \Delta C_{TSAP} + \Delta C_F + C_{AA} \quad (9)$$

finally obtaining the total friction value for the ship with annexes:

$$R_{TSCD} = C_{TSAP} * \frac{1}{2}\rho\, S_{AP} V_S^2 \quad (10)$$

After analyzing and classifying the available information, we began with the market study for these types of vessels, as well as the speed ratio studies, capacity and route distance studies so that they are advantageous regarding monohull vessels, developing a series of steps to generate information for the design object of this report:

1. Definition of the shape parameter ranges for new existing catamarans
2. Developing a design that falls within the mean of the ranges obtained in the previous numeral.
3. Create a list with the bottom parameters that may influence the hydrodynamic characteristics.
4. Develop a systematic series from the design created in 2 that covers the ranges in 1.
5. Calculate the hydrodynamic characteristics of the systematic series using CFD.
6. Choose the best design.
7. Carry out the experimental trials with the bottom obtained in point 2 and the one chosen in point 6.

Table 6. CRS Study Range of values.

$- 0,06 < LCB / Lpp < 0$
$0,04 < LCB - LCF < 0,14$
$7,53 < L / \nabla^{1/3} < 11,29$
$0,729 < B_{MDH} / T < 1,457$
$3,21 < Lpp / Bs < 4.25$
$0,2 < Kyy < 0,3$
WITH AND WITHOUT FINS

Database

Table 7 shows the basic characteristics for military application catamarans extracted from a conscientious study and generated for this report.

Development of the Project

Initially there are two types of bottoms for each of the hulls that comprise a catamaran; symmetrical and asymmetrical shapes. In both cases, the influence of hull separation on resistance is important. Since there is a possibility of performing a numerical analysis of each hull and of the hulls together, it is necessary to precisely know what these mathematical calculations allow us to determine for each hull and the advantages of the shapes chosen for a catamaran (6).

Study of numerical hydrodynamics through viscous fluid calculation

CFD (12) software are tools based on the use of computers to simulate behavior of systems related to fluid flow, heat transfer and other physical processes. They work by solving the equations that determine the flow of fluids in the region of interest under conditions pre-established for the boundaries of said region. The set of equations that describe these types of physical processes are the Navier-Stokes equations; as it is known, these equations do not have a general analytical solution but can be simplified and numerically solved. They way in which these processes are performed depends on the CFD code used. The most common one, and the one on which CFX is based, is the one known as finite volume technique.

Using this technique, the region of interest is divided into smaller subregions, called control volumes, and the equations are simplified and solved for each control volume interactively. This way, there is an approximation to the value of each variable described in the physical process, at certain points within the defined domain. From these values, the full behavior of the fluid in the entire set can be deduced. On the other hand, the CFD codes can assume certain simplifications of the equations and thus classify them in different ways.

The calculations were made using the CFX 14.5 software developed by ANSYS, since it was a non-linear viscous program. Bottom number 2827 was split, and its main geometrical characteristics are shown in Table 8.

Table 7. Catamaran for military application.

Ship	Country	Desp. [Tm]	Length	Width	Depth	Maximum Speed [Kn]	Operating Speed	Propulsion	Mission
BORA (Commander)	Russia	1.050	64,00	17,20	3,80	55,0	[kn]	- 2 gas turbines (36.000 HP) - 2 diesel engines (20.000 HP)	Coastal defense operations
HSV (Logistic Support)	USA	1.695	95,47	26,16	3,70	45,0	17,0	- 4 diesel engines (39.130 HP)	Transportation of troops and supplies
JHSV (Logistic Support)	USA	2.362	103,00	28,50	3,80	43,0	37,5	- 4 diesel engines (49.456 HP)	Transportation of troops and supplies
FSF (Commander)	USA	1.600	79,90	21,90	3,50	50,0	35,0	- 2 gas turbines - 2 Diesel engines (68.478 HP total)	Coastal defense operations
TYPE 022 (Missile launcher)	China	224	42,60	12,20	2,50	36,0	40,0	- 2 Diesel engines (13.730 HP)	Missile defense and attack
SKJOLD (Commander)	Norway	274	47,50	13,50	1,00	60,0	-	- 2 Gas turbines (16.535 HP)	Coastal defense operations
STERENN DU (Mine hunter)	France	25	17,00	7,50	-	-	40,0	-	Mine detection
SKRUNDA (Patrol)	Latonia	125	25,70	13,50	2,70	20,0	-	- 2 Diesel engines (2.170 HP)	Coastal defense operations
SEA SHADOW (Furtive Ship)	USA	563	50,00	21,00	4,60	15,0	12,0	- 2 Diesel engines (2.038 HP)	Invisible al radar
USNS (Ocean Surveillance)	USA	5.368	85,78	29,16	7,90	12,0	9,0	- 2 Diesel engines (5.000 HP)	Surveillance and support operations
EDA-R (Deboarding vessel)	France	80	30,00	12,00	2,50	30,0	-	- 4 Diesel engines (3.800 HP)	Deboarding operations
ASR (Submarine Rescue)	USA	4.267	77,00	26,00	5,80	15,0	20,0	- 4 Diesel engines	Submarine rescue operations
INS (Hydrographical Ship)	India	500	49,80	16,00	2,20	18,0	-	- 2 Diesel engines (2.736 HP)	Nautical mapping
TSV (Logistic Support)	USA	1905	96,00	27,00	3,70	50,0	12,0	- 4 MTU 20V8000 M71L	Transportation of troops and supplies
AOS (Ocean Surveillance)	Japan	2850	67,00	29,90	7,50	11,0	37,0	- 4 Diesel engines	Surveillance operations
AGSC (Patrol)	Australia	325	36,6	12,8	2,65	11,0	-	- 2 Diesel engines	Coastal surveillance operations

Table 8. Main characteristics of bottom 2827.

LPP	60 m
Molded breadth	16 m
Molded draft	2.35 m
Seat breadth	0 m
Molded depth	7.46 m
Displacement	634.3 Tm
Model scale	10.32
Block Coefficient	0.274

Fig. 4 shows details of the transversal of the sections and contours, as well as the area and buoyancy curves for the selected bottom.

The calculations were done for a monohull configuration and two types of catamaran, with a hull separation of 9 and 11.5 m respectively. In all cases, calculations were done with a naked bottom at scale model, in 4 different speed regimes (between 14 and 30 knots approximately) and under meshing of very similar domain total.

Movement of the bottom has been restricted to its six degrees of freedom. For the case of the monohull (14), there is no point in freeing the ship, while in the case of the catamarans, computational time would have been excessive due to the large number of elements that comprise the mesh, given that the symmetry condition cannot be applied as a consequence of hull interference. The results obtained are show in Fig. 5.

Taking into account the results shown in Figure 5, we may deduce that the CFD calculations are valid for definition and optimization of monohull bottoms since, as observed, the differences with the test values are minimum and acceptable. However, the same cannot be said for the case of catamarans, were the CFD results do not have the required level of precision, always obtaining more optimistic results than those of the tests. Also, it may be observed that there are barely any differences between the points obtained for both hull separations studied, which suggests that using CFD it the most adequate option to optimize the distance between them. The decrease in quality of the CFD results for catamarans could be due to the incorrect simulation of hull interaction, suggesting the using a finer mesh for the separation area could be necessary and maybe a different turbulence model.

Comparative analysis of shapes

Using another application developed by CEHIPAR we may evaluate the area and buoyancy curves of a bottom. In the case herein exposed, being a catamaran, the shapes adopted for each of the hulls was analyzed, without evaluating the suitability of the symmetrical over the asymmetrical hull, as well as the separation.

This application, using the C_{ca} parameter indicates the existing directly proportional relation between the area curve and advance resistance (4), so that, the latter will be less as the C_{ca} index decreases. At the same time, it allows, based on an area curve, to obtain the optimized area curve keeping the

Fig. 4. Transversal section of section and contours. Area and buoyancy curves.

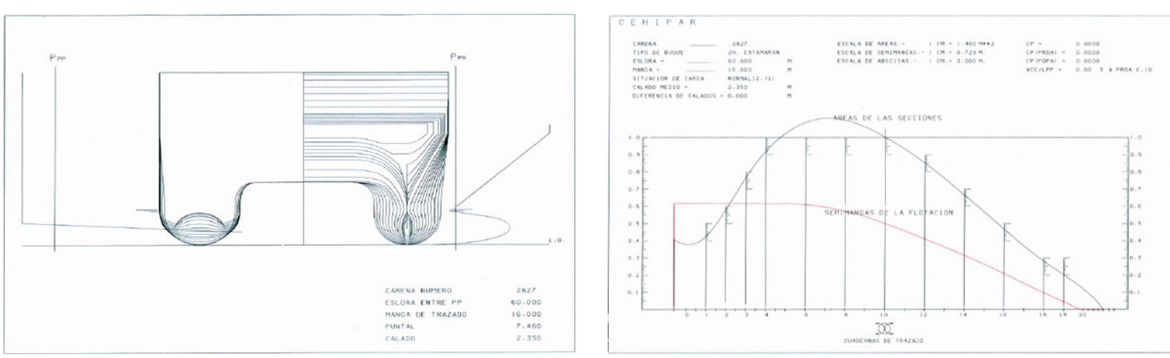


Fig. 5. Comparison of advance friction results. Tests vs. CDF.

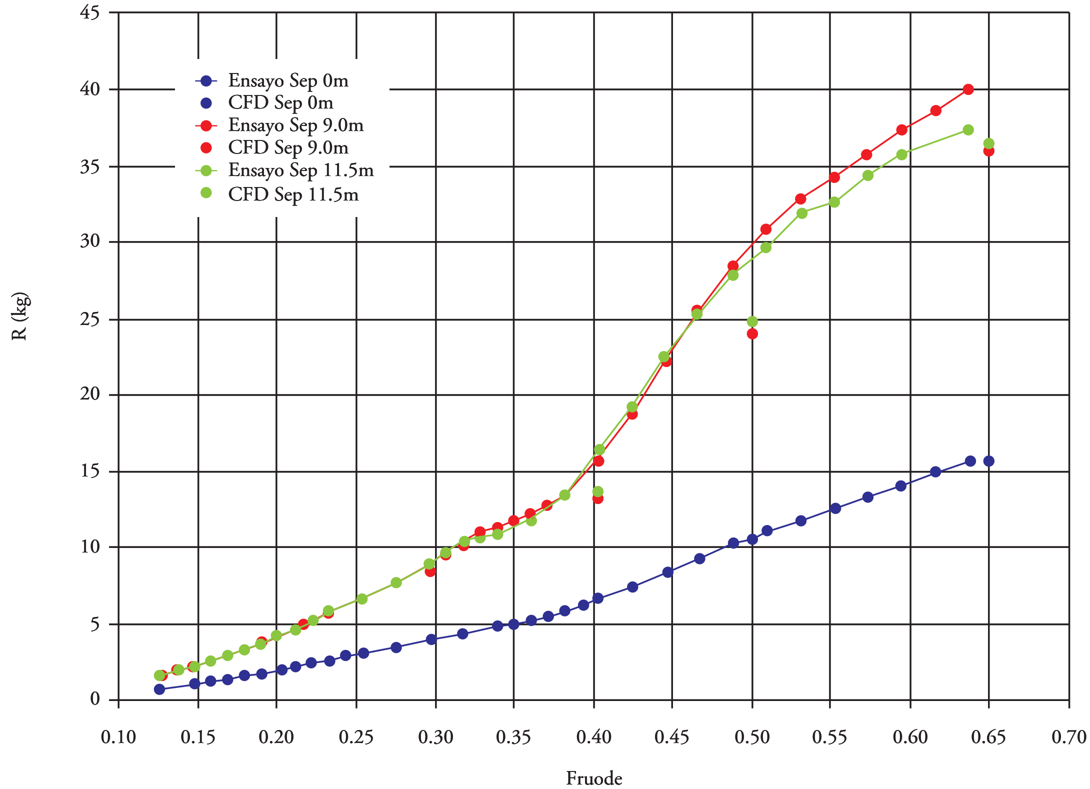


Fig. 6. Distribution of pressure and speed over bottom. Hull separation 9 m.

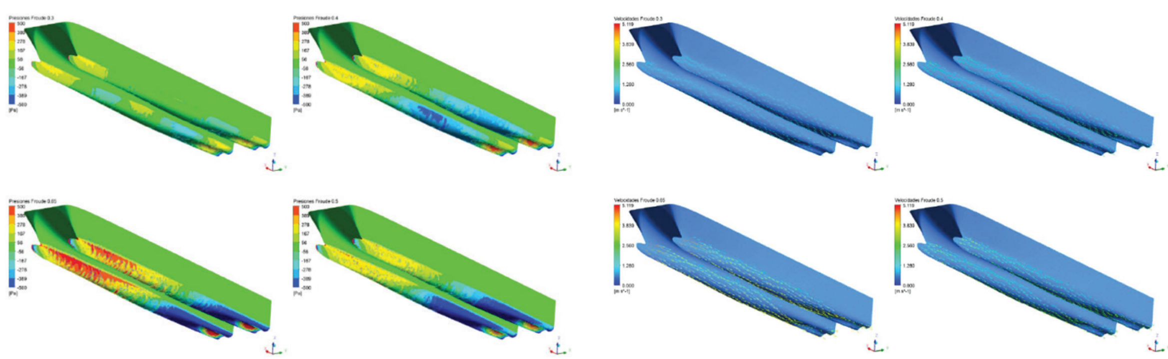
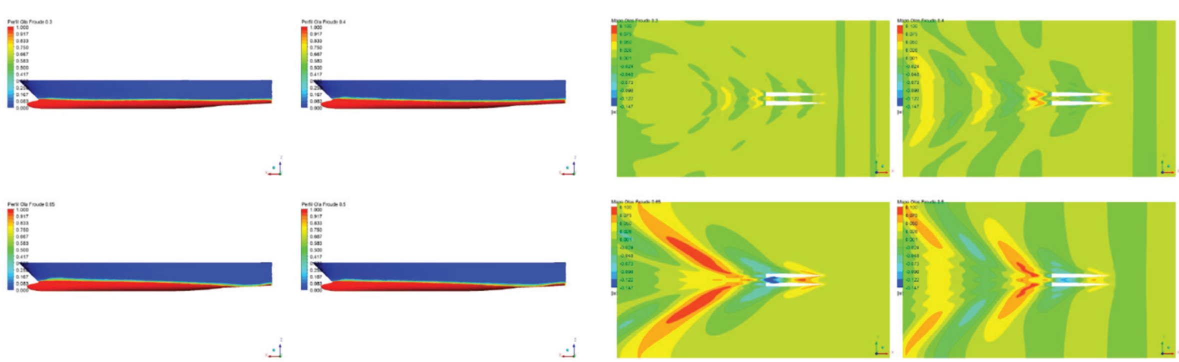


Fig. 7. Distribution of pressure and speed over bottom. Hull separation 9 m.



displacement of the original bottom. Analogously, once the bottom's buoyancy is studied, and the C_{cf} index is obtained, the application may assess the convenience of introducing modifications to it by adequate sleeve distribution. The lesser the C_{cf} index the less resistance to advance of the bottom.

It should be noted that when a modification of a bottom is made in order to obtain the optimized area curve, considerable reductions of viscous resistance could be obtained. In the case of obtaining attractive power efficiencies, these values should be taken carefully, because although the power variation of the C_{ca} and C_{cf} coefficients is linear, since this application is still in its development phase, there are no guarantees of the linearity up to its origin. Following are some of the most significant results of the tested bottoms.

- **BOTTOM 2328** – in this case, a modification of the shoulder of the original area curve resulted in almost a 10% decrease of the viscous resistance of the speed of 21 knots. On the other hand, for the same speed, a modification of the floatation curve allowed to reduce resistance by making waves, over 15%, a significant value due to the large specific weight it has over total resistance.

- **BOTTOM 2625** – in this case the first modification of the area curve allowed a reduction of more than 40% of the viscous resistance at a speed of 21 knots; this data generated reservation, making new modifications to the area curve only to the stern area to the master section, the modifications of buoyance barely reduced resistance through wave formation.

- **BOTTOM 2668** – it was decided not to introduce shape modifications that were not strictly necessary since they could be associated to changes of the elements of general disposition like the machine room. Due to this, in many cases, simple changes to the area curve of the front area suppose an optimal modification to reduce the total resistance by the same percentage.

- **BOTTOM 2827** – in the same way as bottom 2625, a first modification of the area curve with the subsequent reduction of close to 50% of viscous resistance at a speed of 21 knots, with certain reservations, making new modifications of the area curve only in the front area up to the master section.

Relative influence of resistance components

For the bottom shape project with optimized resistance behavior and therefore fuel consumption, it is necessary to have the most precise vision of how the resistance influences each of the components, treated separately, as well as together. For catamaran-type ships a detailed knowledge of hull interaction is needed, a study that is not necessary for monohull ships and, with great differences with respect to trimaran ships (3) since for those, 90% of the displacement volume is at the central hull.

Generally, a ships resistance is decomposed in viscous and residual resistant. Viscous resistance is pressure and friction, while residual is mainly resistance from waves that the ship generates while displacing water at a certain speed and by other components such as wave breakers, roughness, viscous-wave interaction, etc. Catamaran-type ships produce a particular phenomenon which is hull interference (1) between the hulls that compose that bottom and creates interference resistance.

Based on the experimental results of the bottoms tested in this investigation, we try to analyze the three components of resistance: viscous, residual and interference. To achieve this three towing tests have been conducted for each catamaran bottom, having firstly tested each of the hulls individually. This test must be performed with the dynamometer with six components since the individual hull does not have its own stability and it is therefore tested in the captive model, that is, the allowed monohull model has not been allowed to take dynamic seats.

The towing tests for catamaran bottoms have been done in the usual way, allowing the model to take the dynamic trim for each speed. The extrapolation of the results obtained from the towing tests has been done according to ITTC'78 indications.

Study of viscous resistance. Determination of the shape factor

As mentioned, viscous resistance is composed of pressure and friction resistance. The viscous resistance coefficient is expressed as:

$$C_V = (1 + k) * C_F \tag{11}$$

where C_F is the friction resistance coefficient calculated by the expression given by ITTC'57 for basic model-ship correlation line:

$$C_F = \frac{0{,}075}{(log_{10} R_e - 2)^2} \tag{12}$$

and R_n is the non-dimensional Reynolds number, dependent on speed V, length of displacement or maximum submerged length L_{DESP}, and cinematic water viscosity:

$$R_e = \frac{V * L_{DESP}}{v} \tag{13}$$

The k coefficient in the expression of the C_V viscous resistance coefficient, assumes the difference of shape between a flat plate and the ship, having different procedures to determine it, but, independent of the method used, its value should be practically the same. The k shape factor is calculated using the Proshaka method, in the way indicated by the ITTC, for individual hull, as well as for catamaran-type bottoms. As commented in this study, calculation of all the towing tests has been done using LAMBDA software developed by CEHIPAR.

- **BOTTOM 2328** – results of comparing the total resistant coefficients for the catamaran and monohull with the shape factor calculated using the Prohaska method, as well as using the same shape factor for the catamaran as the one obtained for the monohull, showed that if the shape factor determined in each test were to be used, the catamaran with hull separation of 3.462m would offer less resistance than the one with a theoretical infinite separation between hulls. On the contrary, if the test results are extrapolated using the shape factor of the monohull, the results agree more than expected.

- **BOTTOM 2625** – in this case it was observed that when extrapolating the tow test with the shape factor calculated for the catamaran, there could be estimated as valid as those obtained through testing of the monohull, even though considerations of resistance due to wave forming show the opposite. On the contrary, if the test using the monohull shape factor are extrapolated, the results agree more than expected.

- **BOTTOM 2688** – in the case of this bottom, no matter the hull separation, it may be proven that using the shape factor of a monohull to extrapolate the catamaran results is justifiable. The power obtained using the monohull shape factor will be between 2 and 3% more conservative than if using its own in each test.

- **BOTTOM 2827** – finally, this bottom showed that the results of total resistance coefficient for the catamaran and the monohull with the shape factor calculated using Prohaska's method, as well as using the catamaran with the same shape factor obtained for the monohull. The values obtained for the total resistance coefficient in extrapolation for the towing test ship, both for its own shape factors as for the monohull's, do not present any abnormality and the value generally decreases as separation between hulls increases. The power obtained using the monohull shape factor will be approximately between 1 and 2% more conservative than when using its own in each test. In view of the results obtained, it should be accepted as a reasonable practice to adopt the same shape factor for a catamaran as the one obtained from testing a monohull, since the results are slightly more conservative.

Study of resistance due to wave formation

In the same way as in the case of viscous resistance study, to calculate resistance due to wave formation (5) the four bottom models were tested, in the monohull and catamaran situations with two different hull separations (13). Also the extrapolated results of a real ship have been analyzed using the shape coefficients obtained using the Prohaska method for each test, as well as the one from the single hull.

- **BOTTOM 2328** – In this case the wave formation coefficient, C_w, corresponding to a larger separation between hulls, is less than that of a single hull. A priori, it would have to be interpreted as the wave trains generated by the catamaran are cancelled, at lease in part of the two hulls. However, using the catamaran for the same shape factor as the monohull, generally coefficient C_w is less than for the monohull than for the two catamaran models tested. The fact that the C_w values decrease as hull separation increases, shows that there is an interference resistance that decreases when separation increases, the limit value being that of the single hull, equivalent to an infinite separation between them.

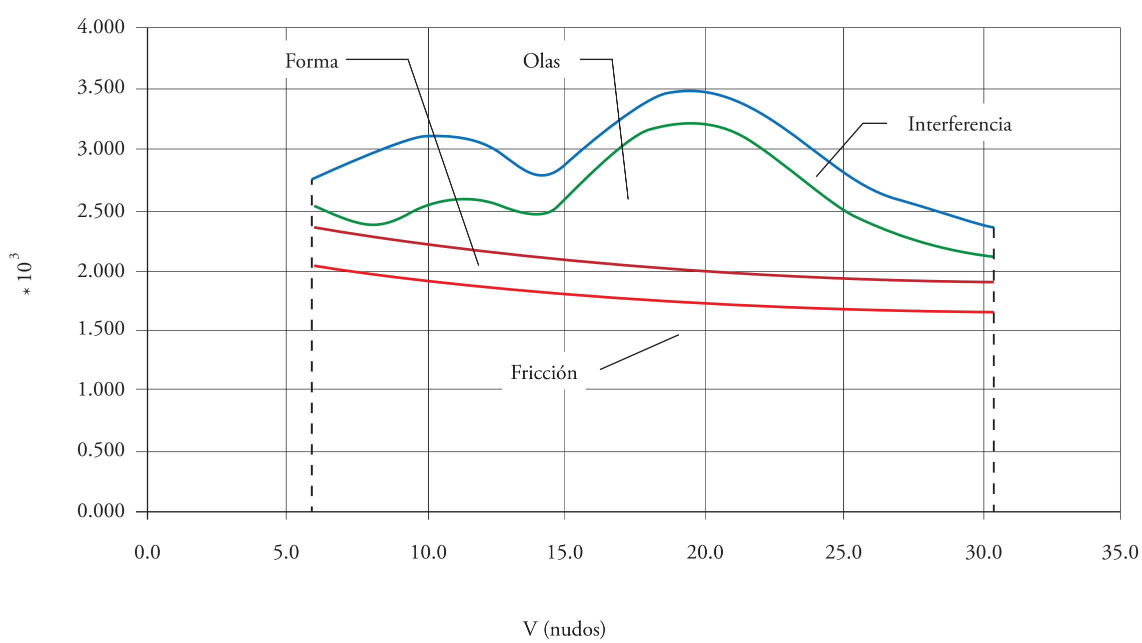
- **BOTTOMS 2625, 2688 y 2827** – for these bottoms, the wave formation coefficient, C_w, for low speeds are less for the catamaran bottom than for the monohull, whatever their separation. Since it was not proven that interference between both wave trains in both hulls can be partially cancelled, it is best to opt for a more conservative extrapolation using in for all cases the monohull shape factor. In the studied cases, the maximum wave formation coefficient, C_w, corresponds to a Froude number of 0.5.

Study of resistance of interference between hulls

The variations of the residual resistance coefficient, δC_w, as a function of Froude's number, F_n, were studied for each of the bottoms and separation between hulls, observing that for the smallest tested catamaran, interference resistance can be cancelled for very high values of F_n when in a planning zone where the resistance value due to wave formation is practically independent of the shapes, as well as observing a considerable influence in it of the separation between hulls.

To the contrary and for the rest of the bottoms, it is observed that for an F_n value of 0.4, interference resistance is practically independent from hull separation. In conclusion, this figure shows the different components of towing resistance, observing the relative importance of each of them so that when a project is developed the order of

Fig. 8. Carena 2827. Coeficiente de las componentes de la resistencia.



magnitude expected from shape optimization can be clear.

Results analysis and procedure validation

Application of catamaran-type platforms from the propulsive point of view.

Using software MJ-3A (2), developed during another project of the Spanish Ministry of Defense, to predict towing power without annexes of four patrol ships, of the same length and displacement as each of the four catamarans tested during this study, isolating each of the hulls, as well as with the same separations, comparing the results obtained for all of them. The patrol ship has a very similar propulsive behavior and much better than the catamaran when the catamaran's behavior is very similar when varying separation between hulls but also in relation to the individual hulls.

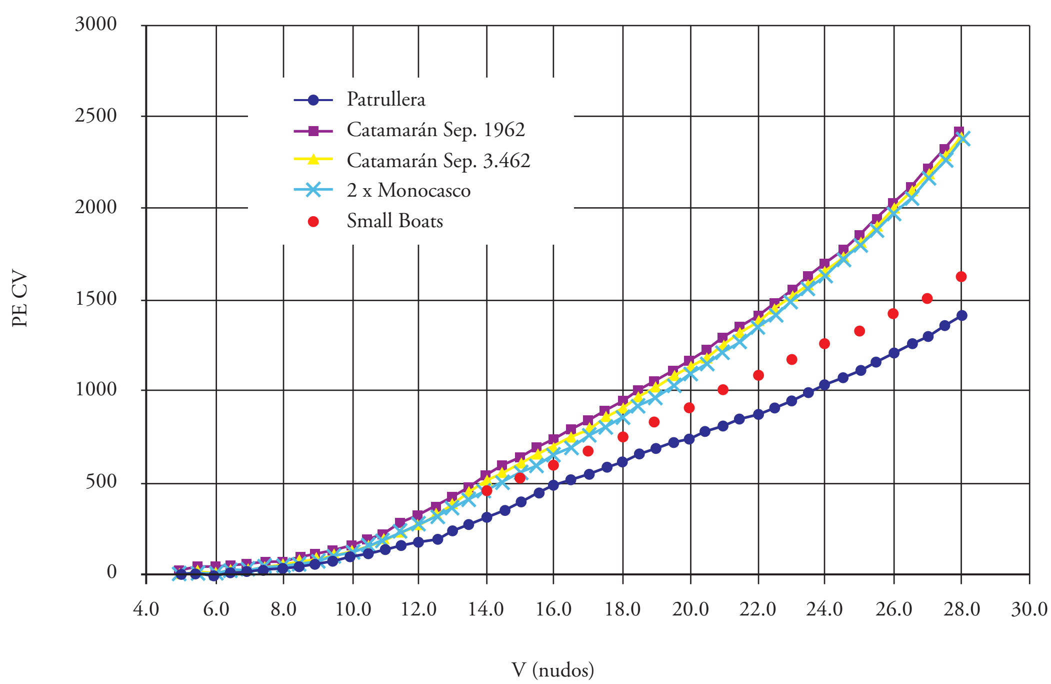
The possibility of improving resistance of shapes in this catamaran bottom does not justify the difference with the conventional patrol boat bottom. It is true that due to the small size of the boat, the prediction procedure of MJ-31 could not be especially adequate and the results could be very optimistic.

To prove this point, a power-speed (9) prediction was done for the conventional bottom using the SMALL BOATS program to obtain quick prediction for small high-speed boats than even though it is not un trustworthy as other methods, it does provide enough guidance for certain types of ships, such as yachts.

This new prediction for a conventional ship equivalent to tested catamaran 2328 turns out to be more pessimistic than the initial one and appears to confirm that this ship would have a better propulsive behavior with conventional bottom than with a catamaran bottom. From the comparison between the catamaran bottom and the conventional bottom for bottom 2668 we may conclude that the propulsive qualities of the catamaran bottom are better than those estimated for the monohull bottom of the same length and displacement even If the propulsive differences are between 5% and 15%.

Considering all this, we consider that the catamaran bottom is sufficiently optimized, with a margin for improvement in viscous resistance as well as wave formation resistance since the conventional shape bottoms are considered analogous to the patrol

Fig. 9. Bottom 2328. Effective towing power.



boats used as ships to perform the high-speed prediction, as a consequence of the comparison between the two types of platforms that in this case would be considered trustworthy.

From the comparison between the catamaran and the conventional bottoms for bottom 2827 we conclude that its propulsive qualities are worse than those estimated for the monohull bottom of the same length and displacement up to speeds of 15 knots, with a reduction of effective power between 1 and 30%. For speeds exceeding 15 knots there is an inversion of behaviors of catamaran bottoms, even though the propulsive improvement is minimal with barely 2% difference.

For the case of the catamaran, as well as for the conventional bottom, there could be an improvement to towing resistance projecting sufficiently optimized shapes.

Lastly, there is a comparison between the results obtained with bottom 2625, the longest tested catamaran. For this case, the conventional bottom shows less resistance than the catamaran bottom at all tested speeds. There could be a strong improvement to towing resistance modifying the shapes to obtain an optimized curve area.

From the propulsive point of view, and considering the results obtained from the different tests, the possibility to adopt catamaran-type shapes for the range of 40 to 70 m lengths should be studied. We should not forget other factors when selecting the type of ship, such as the positive aspects of the catamaran vessel regarding ampleness of decks with the versatility that it confers the ship, as well as the negative aspects such as the need for a more sophisticated control system to achieve better sea behavior (10).

Estimation of advance resistance for catamaran-type ships

With the data obtained in this investigation is is not possible to create a generalized prediction procedure for all catamarans, but only to provide some indications that may give an approximate idea of the resistance values for a catamaran within the value range of the ships studied herein. The election of a catamaran geometry needs to first optimize each of the monohulls, symmetrical or asymmetrical, depending on the ship's mission and the speed range. In the case of symmetrical monohulls, the project can use the same optimization criteria as for single hull ships.

The shapes of the monohull are valued using systematic variation of the different parameters that govern them and testing the corresponding models. Calculation of the initial shape factor, *k*, allows knowing friction resistance. As far as the wave component the Froude number is calculated, F_n, for which resistance is maximum and the approximate Cw (11) values for different F_n as a function of the Lpp / $\Delta^{1/3}$ parameter. With a similar precision the values of total resistance may be known, using for that the R/ Δ correlation formulas for all bottoms in the data base as a function of Lpp/ $\Delta^{1/3}$ .The value of R2 is larger than 0.85 for Fn between 0.5 and 0.6.

Conclusions

This article has tried to summarize the work done throughout an investigation financed by Spanish Ministry of Defense through the General Planning, Technology and Innovation subdirectorate, highlighting the interest in furthering the hydrodynamic knowledge on multihull ships, as is the case of catamarans. With the data obtained, indications and recommendations that could give an approximate idea of the resistance values for a catamaran where intended to be given, within the range of values of the ships studied herein.

This work intends to make an emphasis that at the time of designing the geometry of a catamaran there should be an optimization of each of the monohull that conform it, were the shapes have to be assessed using systematic variation of the different parameters that govern them, and testing of the corresponding values. This way, optimization of area curve, as well as buoyancy of the bottom maintaining the original displacements, have notable reduction associated to advance resistance.

Finally pointing out that incorporation of multihull ships to the naval industry has gone across borders, and that these types of constructions are becoming a current building trend for different navies as opposed to monohull structures, always based on the needs and typologies for which these units are used.

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A Bimodal Transportation Model for Steam Coal Exportation Based on Magdalena River as Main Waterway

Un Modelo Bimodal de Transporte para Exportación de Carbón Térmico basado en el Río Magdalena como Eje Principal

Henry Murcia [1]

Abstract

The aim of this work is to offer a new alternative to allow the release of the Colombian coal transportation system that nowadays is under a saturation state. For this reason it is proposed, the option of making the exportation of the surplus production granted by the thermic coal mining activity focused on the Cesar department, through a bimodal transportation system that will highlight on the Magdalena River as the most important way for the logistic development of the country. As main key and support tool, the Discrete Event Simulation (DES) methodology was used for conducting experiments based on information which has given the characterization of the proposed system. Hence, the establishment of the conceptual model that determinated and limit the system, a simulation in the software Rockwell Arena was implemented which results were tested and analyzed to study the performance of itself.

Key words: Discrete Event Simulation, thermic coal, Magdalena River, logistic development.

Resumen

Este trabajo tiene como objetivo, proponer una nueva alternativa que permita aliviar el sistema de transporte de carga colombiano de carbón que actualmente se encuentra en estado de saturación. Para esto se plantea la opción de realizar la exportación de los excedentes de producción, generados por la actividad minera de carbón térmico originaria del departamento de Cesar, a través de un sistema bimodal de transporte que hará énfasis en el Río Magdalena como arteria principal y eje potencial del desarrollo logístico del país. Como herramienta clave y de soporte, se utilizó la metodología de Simulación de Eventos Discretos (SED) con la finalidad de dirigir experimentos fundamentados en informaciones que caracterizan la propuesta presentada. Así luego de establecerse el modelo conceptual que determinó y delimitó el sistema propuesto, se implementó una simulación en el software Rockwell Arena, cuyos resultados fueron probados y analizados luego de haberse estudiado el desempeño del mismo.

Palabras claves: Simulación de Eventos Discretos, carbón térmico, Río Magdalena, desarrollo logístico.

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Introduction

Nowadays, the rhythm of the world's economy has experienced a high speed and accelerated growth with the industrialization for those who are known for having emerging markets. It is possible to highlight countries as China and India as the main leaders of a list twenty nations who are part of these markets.

In the same way that the economy of these emerging markets growth, the world coal demand has also been sensing a considerable increase because of the economic boom that the world is presenting since the last decades.

Instead of others energy sources as oil, gas or renewables, coal is a reliable and low price energy source that presents proven and guaranteed reserves for more than 150 years.

On the other hand, thinking about logistics approaches, coal has two important characteristics: Easy production with low technological component and a relatively cheaper transport.

Institutions as World Coal Association assert that the coal is the energy source responsible by 41% percent of the planet's electric power generation.[1]

According to this perspective, it is important that Colombia takes advantage of this natural resource, in function of the quality of its coal with low-ash and sulfur contents and high thermic value.

In Latin America, Colombia represents the country with highest coal reserves with 16.992Mt, which have allocated the country since 2010 in the top ten of coal exporters as fifth in the world.

By knowing this reality, Colombia must follow the model that countries, different of named from third world, have traced for the exploitation and development of its natural resources at the same time that improves its competitive advantages with the production growth and the implementation of technology.

In fact, it establishes one of the most important recommendations that the World Bank has proposed for these countries, maintaining that a country rich in natural resources that implements efficiently the appropriate technologies must grow in a similar way as those countries that based its growth on the industrial sector.

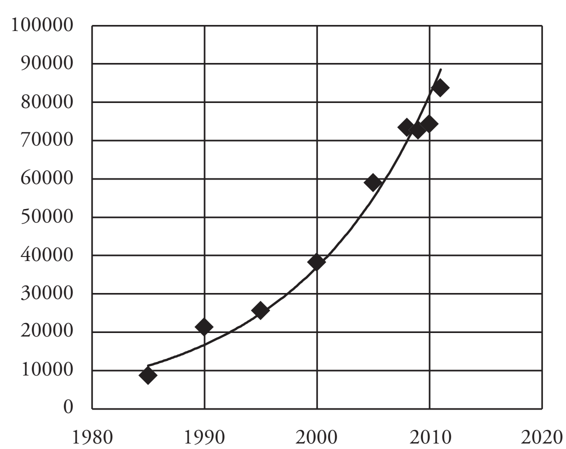
In this way, the main motivation for the development of this work is the proposition of a system in which the natural resources of Colombia notably the coal, could be transported by an economic and sustainable alternative having the Magdalena River as the main waterway for the coal flow until the Colombia's Caribe exportation ports.

Colombian Coal Market Overview

Production

Since 1985 until 2010, Colombian coal production has experimented an exponentially growth that is attributed to the beginning of coal extraction operations in the main pits of the north zone of the country by early 1980. See Fig. 1.[2]

Fig. 1. Coal Production in Colombia. (Data in thousands of tons).



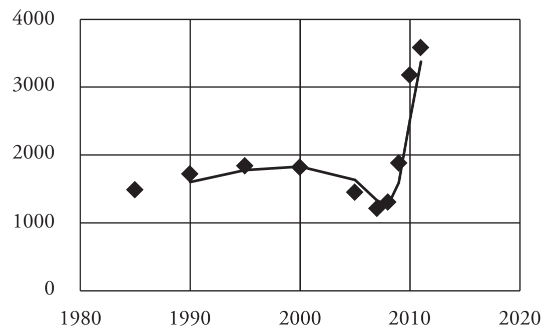
The coking coal (metallurgical coal), used on the steel and iron Industry, has not presented an important input in the total production for the

[1] Source: http://www.worldcoal.org/coal-energy-access/

[2] Figure based on data obtained from International Energy Agency "IEA STATISTICS, COAL INFORMATION 2012"

same period (1980 and 2011 finals). Fig. 2[3], shows the behavior that this kind of coal has featured over the total Colombian coal production.

Fig. 2. Coking Coal Production. (Data in thousands of tones).



According to the Fig. 2, it is possible to observe that coking coal production presented a decrease between the years 2000 and 2008, followed by an important recovery.

Nevertheless, the steam coal production represents to the country a high participation over the total production, instead of the coking coal, as shown in the Fig. 3[4].

[3] Figure based on data obtained from International Energy Agency "IEA STATISTICS, COAL INFORMATION 2012"
[4] Figure based on data obtained from International Energy Agency "IEA STATISTICS, COAL INFORMATION 2012"

Fig. 3. Steam Coal Production (Data in thousands of tones).

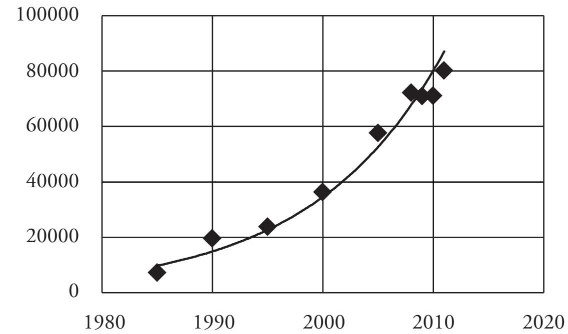


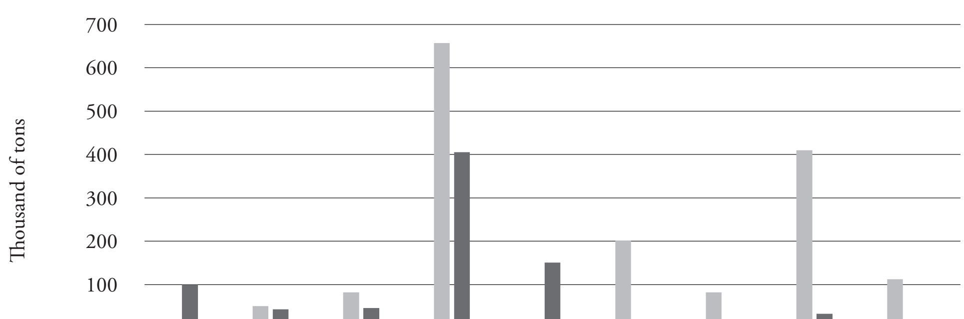
Fig. 3, shows the same period (starting in the 1980's and ending in 2011) more than 90% percent of coal production was characterized by the steam coal.

As a consequence of mineral extraction on the Colombian north zone, where are located the biggest coal reserves of the country and where important investments and development of technological level in the mining region are done.

Exportation

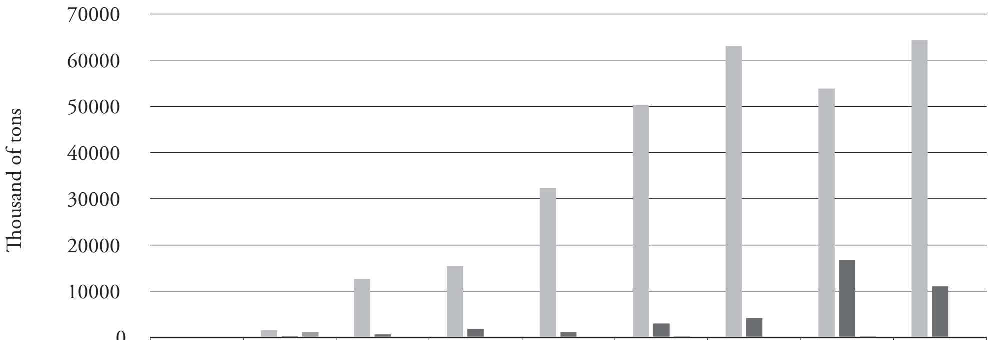
Founded on data from the document "Coal Information 2012" from the International Energy Agency, Fig. 4, Fig. 5 and Fig. 6 presents how have been the trends for Colombian coal exportations for the ending of 1978 until ending in 2011.

Fig. 4. Colombian Coking Coal Exportations.



	1978	1985	1990	1995	2000	2005	2009	2010	2011
OECD Countries	0	50	82	657	8	202	82	410	112
Non OECD Countries	100	43	46	405	151	0	0	33	0
Others	0	0	0	0	0	0	0	0	0

Fig. 5. Colombian Steam Coal Exportations. Data in thousands of tons.



	1978	1985	1990	1995	2000	2005	2009	2010	2011
OECD Countries	0	1585	12623	15392	32284	50231	63050	53818	64363
Non OECD Countries	50	310	702	1820	1159	3051	4172	16830	11050
Others	0	1176	52	0	122	327	0	279	0

Fig. 4 shows the biggest quantity of coking coal exported in the specified period of time belongs to the coals that were assigned to the countries that are part of the Organisation For Economic Cooperation and Development (OECD). Examples of these countries are the following: Belgium, Canada, France, Japan, Portugal, Spain, Austria, Korea, Italy, Israel, etc.

Moreover, Brazil who is one the country that does not belong to OECD, Brazil, was part of the final departure destinations for Colombian coal that contributed for the total amount of the exportations.

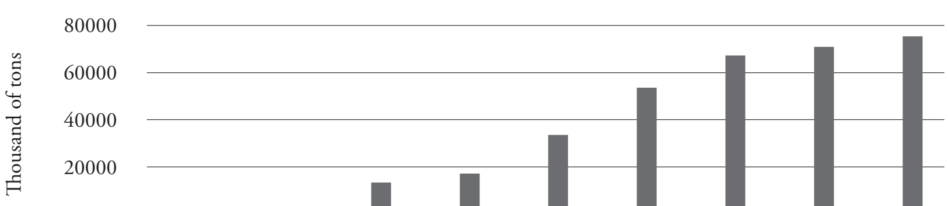
It is possible to appreciate in the Fig. 5 the steam coal consumption for the Colombian market belongs to the OECD countries, which concentrates almost the total volume of the production made in Colombia per year.

The exportation volume of steam coal was showed in the Fig. 6, fully exceeds the level of exportation for the coking coal produced in the Colombia hinterland in more than 94% percent over the total exported in the studied period.

The Cesar Department Case

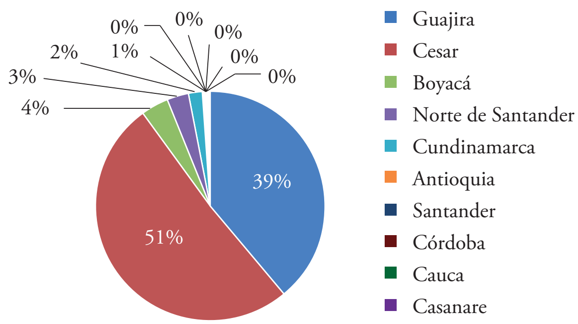
Currently, this department presents the biggest level of production for steam coal. In the year 2011, according to the Fig. 7, the Cesar Department had the biggest contribution in the national production. The 43,688 millions of tons produced in represented the 51% percent over the total production became this region as the main coal producer of Colombia.

Fig. 6. Comparison between Coking Coal Exportations and Steam Coal Exportation in Colombia. Data in thousands of tons.



	1978	1985	1990	1995	2000	2005	2009	2010	2011
Coking Coal	100	93	128	1062	159	202	82	443	112
Steam Coal	50	3073	13377	17212	33609	53609	67222	70927	75413

Fig. 7. Matrix of Colombian coal production by main producers centers (end of 2011).



Literature Review

According to the literature, it was possible to detect that exists a conventionalism around the concepts of simulation, system and model. It is because authors have accepted definitions that authors were enriched with new pragmatics and methodological contributions without changing the original root of these concepts.

Furthermore, it was observed that does not exist a unique and fixed procedure or methodology for conducting simulation projects. Nevertheless, there are several proposals of researches as Nylor (1966), Knepell (1993), Pegden (1995), Chwif (1999), Botter (2002), Law (2007), which are the results of experience in simulation area and at the same time became tools for helping people who wants to plan or execute these kind of works.

Consequently, the methodology to the development of simulation projects is an open topic that admits new contributions every day, looking for a realistic and intuitive modeling with a structured and methodical order to apply in real life of problems.

Related to works which apply simulation methodologies as; Mendes (1999), Bugaric e Petrovic (2000), Demirci (2003), Cassettari et al (2011), Cigiloni e Rossi (2011), Kondratowicz (1990), among others, it was observed that in every case the developed models have a significant detailing level because of the need of representing real problems in a reliable way with regard to find consistent answers.

As mentioned above, it is remarkable that each one of these, were made with the purpose of serve as a decision making tool when different scenarios where tested for answering transportation and logistics problems at the level of strategic planning for companies.

Close to the affinity of researches, the work of Cabrera (1995) presents an important help for the developing of this research, because of being a specific reference related to the sizing of a multimodal transport system in Colombia by using the Magdalena River, even though the author focuses his study on container applications.

The most important conclusion taken after the reviewing of literature is that the methodology will be used by this research project is the Discrete Event Simulation, because already exist similar works where this methodology were successfully applied for solving transportation and logistics problems related to waterways terminals, multimodal systems, sizing of port facilities for bulk cargo handling.

This technique (Discrete Event Simulation DEV) at the same time showed flexibility and robustness to allow the testing of different scenarios, policies and strategies for the optimal operation of systems.

Problem definition

The main goal for conducting this work is the creation of a model that allows simulating the transportation of steam coal produced in the main pits located in the north of Colombia, especially the Cesar department, using an intermodal system and thinking about the use of Magdalena River as the main Waterway with the purpose of sizing this system.

With the processing of the model are expected as the most important results the configuration of the fluvial fleet and the bimodal terminal, focused on the sizing of berths and coal storage required for attending the coal transport demand in twenty year planning horizon for a set of origins, departures and pre-defined transport modals.

The facilities for trucks coal loading in the producers centers will be not object of sizing and neither the road fleet required for transferring the coal to the intermodal terminal. It will be assumed that the road fleet will be contracted in a spot market and also that trucks are always available for operating in the system.

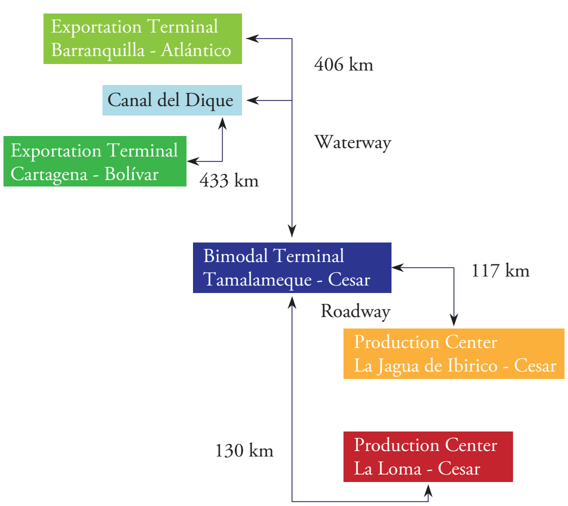
The model will be used by tracking the level of service, in such way that the system resources will have its capacities fixed for allowing to attend the exportation of coal demand per year during the defined period of time.

In that order of ideas, the main procedure for solving this sizing problem will concentrate efforts for identifying the minimum capacity and quantity of resources per year with the aim of guarantee the Colombian steam coal exportations.

System Characterization

The proposed system will have the following structure, see Fig. 8.

Fig. 8. System structure.

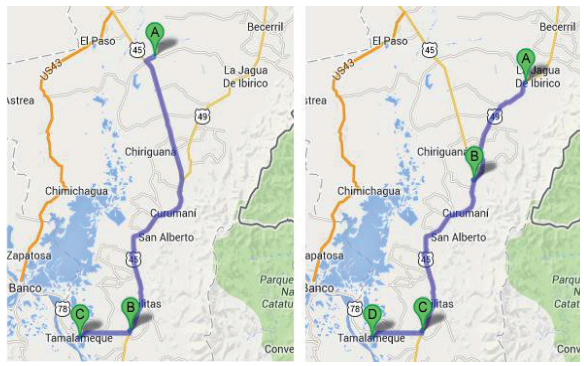


As shown in the figure 8, the proposed system will be composed by these elements:

- 2 Steam coal main producers centers
- 1 Intermodal terminal
- 2 Exportation terminals

For this system is desired to transport the surplus production of steam coal which has as main origins the municipalities of La Jagua de Ibirico and El Paso by mean of roadway until the municipality of Tamalameque. All these interest points are sited on Cesar department. According to the Fig. 9.

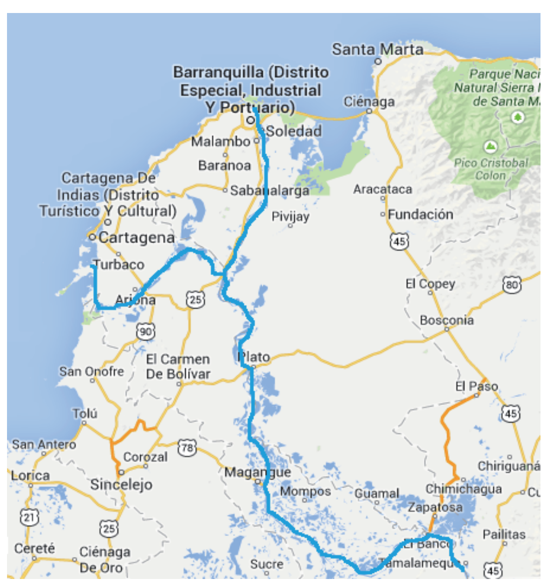
Fig. 9.



In the municipality of Tamalameque, the actual inland port will be used for the implantation of an intermodal (bimodal) terminal (interconnection between roadway and waterway).

The steam coal cargo will arrive to the mentioned terminal and there will be stored in a patio for being transferred to the river fleet that will be departure to the maritime ports of Cartagena and Barranquilla. see Fig. 10.

Fig. 10.



Considering the description above, the system can be characterized by the following subsystems:

a. Production Subsystem
The steam coal production will be focused on Cesar department. Here the main producers municipalities will be La Jagua de Ibirico and El Paso.

b. Roadway transport subsystem
This subsystem will be compound by the road element of the entire system, which is the only way for transferring the thermal coal produced until the bimodal terminal of Tamalameque, where the mineral will be stored.

c. Transhipment terminal subsystem
Here will be modeled the inland Tamalameque terminal, that will be the interface between the road modal and the waterway.

d. Waterway transport subsystem
The maritime ports of the north of Colombia (Cartagena and Barranquilla) will be linked with the intermodal terminal of Tamalameque by using this subsystem.

e. Exportation subsystem
The operations of exportations ports characterize the final subsystem of the proposed model.

Simulation Model and Results

By knowing the main problem and characterizing the system, a simulation model made in Arena 14, was developed for conducting experiments in order to size the proposed system.

It was necessary to define the main patron scenario. This scenario is:

"Transport of surplus production from thermal coal produced in the south region of Cesar department – Colombia, based on the expected demand forecast for a planning horizon of twenty years (2015 until 2035), through an intermodal system type: road, since the producers centers of La Loma (CES) and La Jagua de Ibirico (CES) until an intermodal terminal in Tamalameque (CES); waterway, since the intermodal terminal of Tamalameque, sailing the lower and middle zones of Magdalena River and the Canal del Dique with destination to exportations ports of Cartagena (BOL) and Barranquilla (ATL).

Using the main scenario as described above, a set of variables were determinated within its range of values with the purpose of testing the combinations of these looking for the best configuration that will size the proposed system.

These variables were:

- Coal loading positions in production center 1.
- Coal loading positions in production center 2.
- Coal unloading positions in the intermodal center.
- Coal barge loading positions for the intermodal center.
- Stock capacity for storing coal in the intermodal terminal.

The following assumptions were also considered:

- The five main points of the system have patios for storing the coal and works 24h per day.
- The convoys are composed by one Tugboat and a set of six barges using the configuration 2x3 (R-2B-2B-2B)
- There is not a flow of imported coal.
- There is not operations of barge fragmentations
- The river draught through the year has variability on its value between 6ft and 8ft.
- The system must allow the exportation of 400.000 tons at the end of the first year and must be capable of exporting 8 million tons by the end of the planning horizon.

With all these definitions were conducted the simulations[5] of the system for a time period of 20 years and 7 replications.

The obtained results were studied using a t distribution for a 5% level of significance in its confidence intervals.
Finally, after conducted 21 scenarios simulations were found the best configuration for the proposed

[5] All simulation parameters and values will be showed in the annexes.

system by determining the best values for sizing the intermodal terminal with:

- A total number of 19 river convoys at the end of the 20 years.
- 12 coal unloading positions for trucks.
- 2 coal loading positions for barges.
- 10.000ton storage capacity for stocking coal.

All these results were validated to use performance measures[6] for attending a level of service in order to avoid the presence of queues on every point in the system. Even more, these sizing results were evaluated by a sensibility analysis where was studied the performance of the system to study the effect of operations with barge fragmentations, the presence of a fixe draught and variation in coal demand.

Conclusions

This research focused on the proposition of a new alternative system for exporting the surplus production of thermal coal produced in the main pits of La Jagua de Ibirico and La Loma, both located on Cesar department of Colombia, with the aim to satisfy a 20 year forecast demand of the mineral for using a bimodal transportation option where the middle and low part of Magdalena river is showed to promote the development of the waterway thinking in the capabilities that the river can offer for exporting goods.

Based on the main geographic and interest points, it was used a discrete event simulation methodology for conducting experiments where was possible to find the best configuration for sizing the intermodal terminal that will link the road modal and the waterway required to export the thermal coal to the ports located in Cartagena and Barranquilla.

According to IEA statistics for the coal demand forecast, it was used a compound annual growth rate of 0,9% percent for attending the coal demand for the next 20 year. This rate represented approximately the exportation of coal with an annual growth of 400.000 tons, which required an optimal quantity or resources in the system to avoid congestion in order to attend a level of service for satisfying the expected amount of the mineral.

[6] These measures will be presented in the annexes.

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Hull girder: Forced vibration analysis by propeller excitations

Viga buque: Análisis de vibraciones forzadas por excitaciones de la hélice

Franklin Domínguez [1]

Abstract

The non-uniform wake around the propeller generates fluctuating forces on the propulsion shaft. This article presents a methodology used for the forced vibrations analysis of hull girder due to this propeller excitation. This approach is applied to a research boat considering the propeller working in the operating range using a finite element model including all ship structures, rudder, and propulsion lines with their respective supports. Added mass and damping in all submerged elements were also considered. Vibration levels acting in the vessel structure are compared with the limits proposed by ISO 6954 (2000).

Key words: lateral vibration, finite element model.

Resumen

La estela no uniforme alrededor de la hélice genera fuerzas fluctuantes en el eje de propulsión. Este artículo presenta una metodología usada para el análisis forzado de vibración de la viga buque debida a esta excitación de la hélice. Este procedimiento es aplicado a una lancha de investigación usando el método de elementos finitos incluyendo todas las estructuras de la nave, timón y líneas de propulsión con sus respectivos apoyos, considerando la hélice en el rango de operación. La masa añadida y amortiguamiento de todos los elementos sumergidos también se consideran en el análisis. Los niveles de vibración obtenidos en la estructura de la embarcación se comparan con los límites propuestos por ISO 6954 (2000).

Palabras claves: vibración lateral, modelo de elementos finitos, modos de vibración de viga buque.

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Introduction

Dynamic propeller forces need to be included to accurately verify that the hull girder supports all loads acting on it. These forces are a function of thrust, torque, and propeller frequency. Namely, it is a function of: i) rotational speed for fixed pitch propellers, and ii) pitch angle for controllable pitch propellers.

In the present work, Finite Element Method was used to estimate the deformation due to these forces acting over the hull girder. This method allows modeling hull girder considering all structural elements and the propeller dynamic forces. Numerical results expressed in RMS speed of vibration are compared to the limits proposed by the Classification Societies.

Finite Element Method Applied to the Hull Girder

There are several recommendations for the development of a Finite Element Model (FEM), especially by Classification Societies, in the present work; it was necessary to include mass and inertia of the structural elements of hull and superstructure, incorporating machinery foundations for hull girder vibration analysis.

Shell elements were used in the hull and in primary structures, and frame elements to model the secondary structures and pillars, see Figs. 1 and 2. The mass of the structure, equipment, tank liquid, and the added mass values of 40 and 20 [kg/m^2] on decks and sides respectively were distributed on

Fig. 1. Ship Finite Element Model.

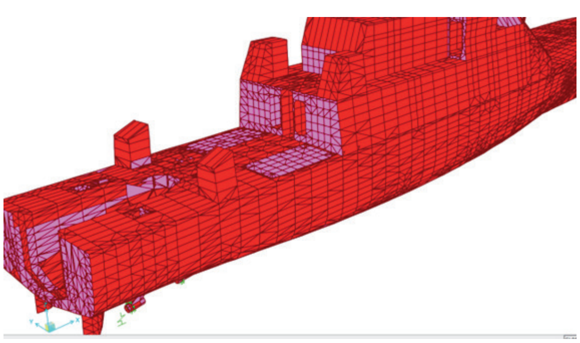
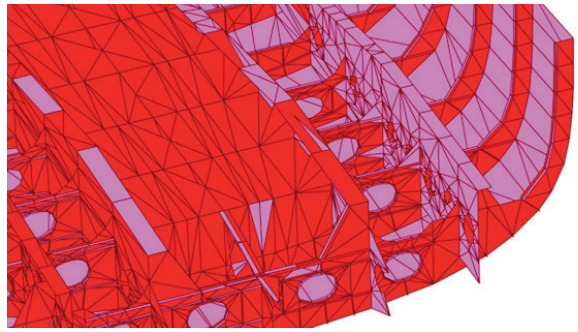


Fig. 2. FEM interior view: Engine room.

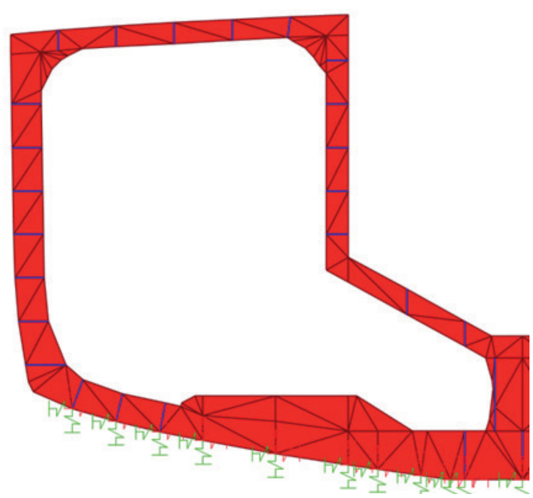


the corresponding nodes following Germanischer Lloyd (GL) recommendation.

Hydroelastic Hull Behavior

Restraints were placed to simulate the ship behavior into the water, using an equivalent spring system placed in the submerged surface of the hull to balance the ship weight. Spring stiffness was calculated using the volume of water displaced within specific sections, see Fig. 3. To verify that the restrictions are conveniently applied, each node deformation was verified using static weight of the vessel.

Fig. 3. Aft frame – Hull bottom restraints.



Hull added mass estimation

On elements that are submerged in water vibration moves a small fluid volume; its mass is called added mass. This mass is added to FEM model as a distributed mass over all submerged elements.

The added mass can be obtained from Seakeeping analysis for each speed and sea state [Lewis, FM 1929]. This mass is a function of the vessel encounter frequency,

$$\omega_e = \omega + (\omega^2/g)(U.\cos\mu) \quad (1)$$

Where ω_e = Encounter frequency (rad/s), ω = Wave frequency (rad/s), g= Gravity acceleration (m/s^2), U = Ship speed (m/s), and μ = Wave incidence angle (rad)

Added mass values for three different ship speeds with the same sea state 3 and following seas are shown in Table 1.

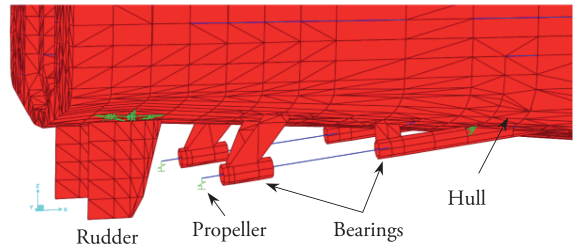
Table 1. Hull added mass.

Vel.	Sea State	ωe	Added mass	% of displacement
Knts		rad/s	ton	%
11	3	1.24	483	173%
18	3	1.5	436.9	157%
21	3	1.61	425.1	152%

Propulsion Line Behavior

The propulsion line transmits the thrust of the ship as well as the exciting forces from the propeller. It's lateral, axial, and torsional natural frequencies need to be considered to assess resonance. Figs. 4 and 5 show the FEM propulsion line included in this analysis.

Fig 5. Propulsion line in FEM.



Bearings location

Cutless bearings or roller bearings are included in our FEM model. Usually, bearing center is the support point, except for bearing close to the propeller, which is considered to 1/3 from the aft end of bearing.

The propulsion line natural frequencies depend on bearing position and stiffness. In the present study, 3 bearings were used, as shown in Fig. 6. Two aft supports are bronze – rubber cutless bearings. The propeller shaft had been modeled using beam elements. The propeller and flanges masses are included in their respective locations. The manufacturer provided the bearing stiffness value for accurate results.

Propeller added mass

The propeller accelerates its surrounding water and an added mass is generated, that was estimated using PRAMAD program [U OF MICHIGAN, 1980]. There are several formulas for estimating these masses M. Parsons (1980), Schwanecke (1963) or D. MacPherson (2007).

Fig. 4. Longitudinal cut at propulsion line.

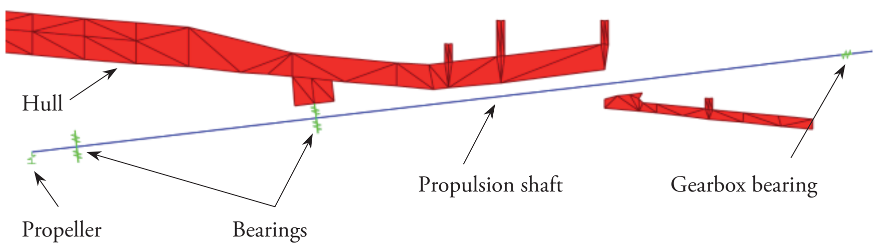


Fig. 6. Propulsion line drawing.

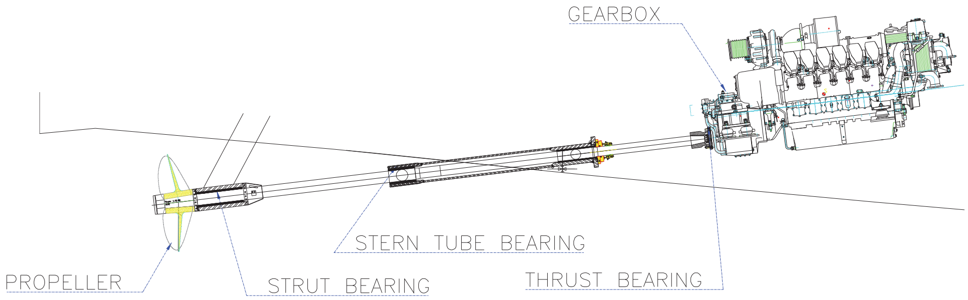
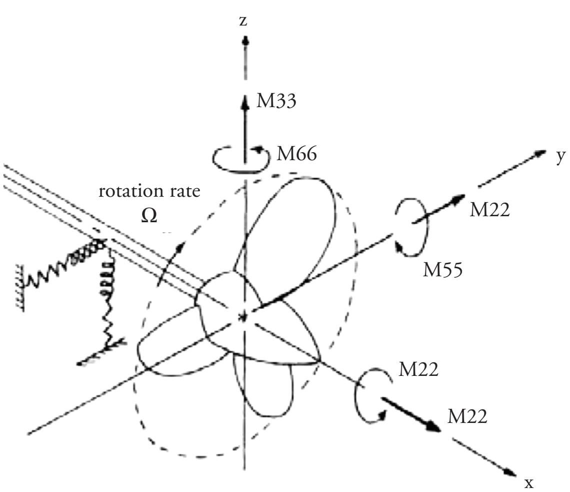


Table 2. Propeller added mass.

Direction	Units	Value
M11	N.s2/m	332.6
M22	N.s2/m	48.9
M52	N.s2	37.2
M55	N.m.s2	40.0

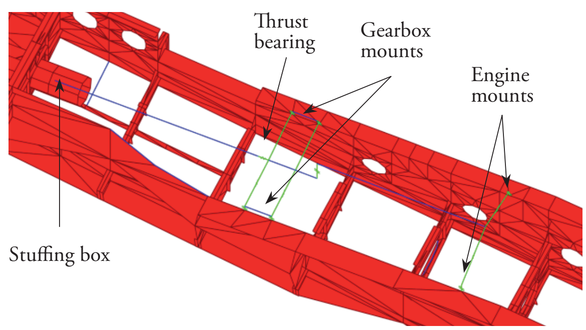
Fig. 7. Added mass nomenclature.



Thrust bearing and engine/gearbox flexible coupling Stiffness

In our model, thrust bearings are placed on the gearbox; and flexible mounts of gearbox & engine with the stiffness provided by manufacturer. Mounts properties were modeled for each direction (x , y , z). Fig. 8 shows the position of the elements used.

Fig. 8. Thrust bearing and engine/gearbox mounts.



Natural vibration analysis

Once the mentioned hull and propulsion line properties are modeled, vibration analysis can be performed for both, hull girder and propulsion line natural frequencies.

The FEM and the eigenvalue matrix method had been used to calculate the propulsion system vibrational modes. The finite element method divides a body in finite elements interconnected by nodes, which are equivalent to the original body; in the elastic zone the equations to find the nodes deformation can be expressed in matrix form as follows:

$$[M]\{Y\} + [K]\{\ddot{Y}\} = \{0\} \qquad (2)$$

where:

$[M]$ is the mass matrix of the system
$[K]$ is the stiffness matrix of the system
$\{Y\}$ is the displacement vector
$\{\ddot{Y}\}$ is the second derivative of displacement Y

Nowadays, computers allow this calculation accurately and for several degrees of freedom.

Tables 3 and 4 present the natural frequencies in the system working range.

Table 3. Hull girder natural frequencies.

Vertical direction			
Mode 1	**Mode 2**	**Mode 3**	**Mode 4**
Hz	Hz	Hz	Hz
3.59	7.46	15.16	28.3
Horizontal direction			
Mode 1	**Mode 2**	**Mode 3**	**Mode 4**
Hz	Hz	Hz	Hz
5.59	10.23	16.17	28.27

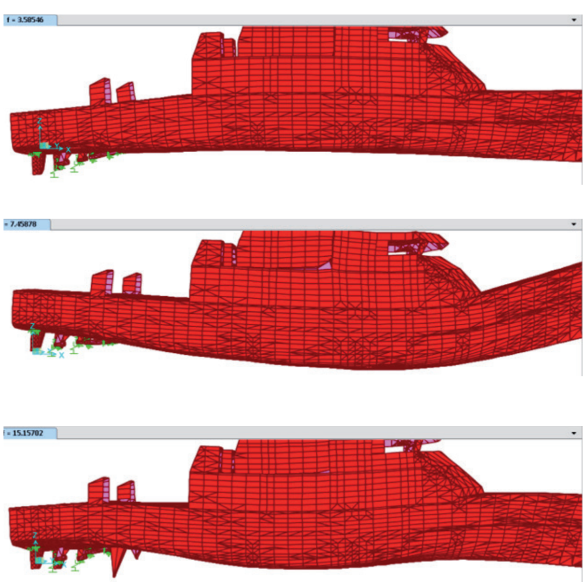
Table 4. Propulsion line natural frequencies.

Mode 1	**Mode 2**
Hz	Hz
23.49	29.73

Figs. 9 and 10 show the modal shape of natural frequencies.

It is recommended that the working range has to be from 650 RPM to 2000 RPM on engine, due to coincidence between hull girder natural frequencies

Fig. 9. Vertical direction mode shapes.



and engine and propeller excitation range as can be seen in Table 5.

Fig. 10. Horizontal direction mode shapes.

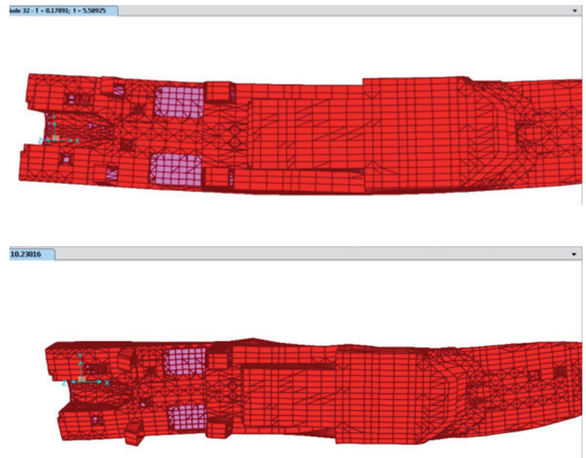


Table 5. Engine and propeller working ranges.

	Engine working range		
RPM	600	650	2000
Hz	10	10.83	33.3
	Propeller working range		
RPM	197	213.4	658
Hz	13.16	14.22	43.86

Figs. 11 and 12 show the natural frequencies mode shape found in the propulsion line. It should be noted that the first vibration mode is at the tunnel between Stern tube bearing and gearbox and the second mode at the propeller end. The first axial natural frequency is 37.77 Hz.

Fig. 11. First vibration mode 23.49 Hz.

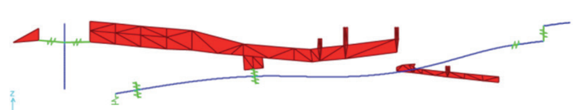
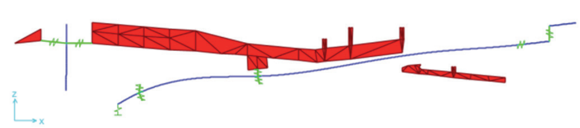


Fig. 12. Second vibration mode 29.73 Hz.



Propulsion line natural frequencies are within the working range and forced analysis should be considered to check the structures resistance and whether the proposed vibration levels standards are met.

Damping

Energy due to vibration on the ship can be dissipated as damping. Vibration analysis should consider three types of damping, namely: the propeller damping, the hysteresis damping and hull damping in water.

Propeller damping
Damping is generated when the propeller rotates in the water, the approximation of these values are shown in Schwanecke (1963) or M. Parsons (1980). The damping depends on the propeller rotation speed, therefore is determined for each operating condition, see Table 6. The damping is placed on the propeller node in the FEM. Structural deformations caused by the propeller excitation forces decreases due to the damping effect.

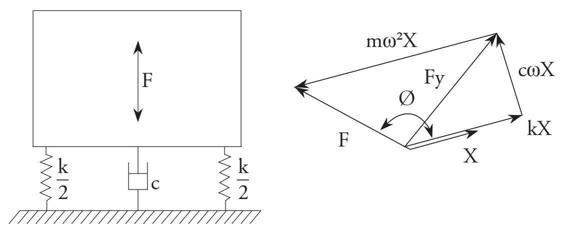
Structure damping
Hysteresis damping is caused by internal molecular friction on vessel structures, and its value is estimated using a coefficient 0.05 proportional to the stiffness.

Hull damping
Ship motion generates a damping (B33) which can be obtained from Seakeeping for each speed and sea state under study. These results are applied to the submerged hull.

Transmissibility

Flexible mounts reduce vibration effect produced by the engine on their foundations. In the case of study, the propulsion system has 2 front flexible rubber mounts for each engine and 2 flexible mounts for each gearbox.

Fig. 13. Perturbing force transmitted by the springs and damper. Thomson W., (1972).



Transmissibility is the relationship between the perturbing force and the transmitted force to the foundation and depends especially of the connection stiffness between the engine and the boat structure. For this study, flexible rubber mounts had been used.

There are several references that provide recommendations to know whether a particular mount is suitable to reduce engine forces transmission to structures. W. Thomson, (1972), shows a graph that has frequency (cpm) and the static deformation produced by the engine on the flexible mount or the connecting element as variables.

For the present study, the engine manufacturer provides several options for flexible mounts,

Table 6. Propeller damping for vibration analysis.

Damping (Schwanecke)					
Engine	RPM	1071	1356	1722	2000
Frec	HZ	23.49	29.73	37.77	43.86
C11	N.s/m	109071	138045	175354	203655
C22	N.s/m	11070	14011	17797	20670
C52	N.s	11119	14073	17876	20761
C55	N.m.s	12197	15436	19608	22773

tables 7 and 8 show the percentage of effectiveness of the system foundation.

According to transmissibility analysis results had been decided to use the 315 mount - 55SH due to the appropriate reduction of excitation forces transmitted by the engine and therefore these forces will not be considered in the analysis of vibration of the boat.

Table 7. Analysis of transmissibility for engine mount at 650 RPM.

Equiv. arrangement Flexible mounts	650 RPM Effectiveness dB	% Isolation
RD314 B-65Sh	-8.390	-590.2%
RD314 B-60Sh	-3.821	-141.0%
RD314 B-55Sh	-1.790	-51.0%
RD314 B-50Sh	0.165	3.7%
RD314 B-45Sh	1.821	34.3%
RD315 HD-65Sh	-1.009	-26.1%
RD315 HD-60Sh	2.819	47.8%
RD315 HD-55Sh	3.785	58.2%
RD315 HD-50Sh	5.221	69.9%
RD315 HD-45Sh	6.919	79.7%

Table 8. Analysis of transmissibility for engine mount at 2000 RPM.

Equiv. arrangement Flexible mounts	2000 RPM Effectiveness dB	% Isolation
RD314 B-65Sh	9.742	89.4%
RD314 B-60Sh	10.877	91.8%
RD314 B-55Sh	11.651	93.2%
RD314 B-50Sh	12.604	94.5%
RD314 B-45Sh	13.578	95.6%
RD315 HD-65Sh	12.006	93.7%
RD315 HD-60Sh	14.236	96.2%
RD315 HD-55Sh	14.919	96.8%
RD315 HD-50Sh	16.011	97.5%
RD315 HD-45Sh	17.403	98.2%

Forces and moments of propeller excitation

Propeller vibration forces are predominant in calculating propulsion line and boat structure vibration. These forces occur due to non-uniform water flow in the propeller creating periodic forces depending on the number of blades called propeller excitation forces. These forces are generated in the vertical, transverse and longitudinal directions.

Forces transmitted to the propulsion shaft (bearing forces)

For lateral vibration analysis (bending) should be considered vertical forces F_{33} and transverse F_{22} and their moments M_{33} and M_{22}, while for the axial analysis the longitudinal force F_{11} is considered, following same nomenclature shown in Fig. 7.

Exciting forces are decomposed into harmonic components using the Fourier analysis [Kumai, 1961]. Currently, Classification Societies recommend excitation values for each order based on the number of blades and thrust or torque on the propeller, as appropriate. For the study boat, the excitation values recommended by ABS (2006) had been used. The values of the forces applied to the study boat in 4 different working conditions are shown in Table 9.

Table 9. Propeller excitation forces for vibration analysis.

Frequency (HZ)	23.49	29.73	37.77	43.86
Order	1Z	1Z	1Z	1Z
Engine RPM	1071	1356	1722	2000
Total thrust	20503	35677	65830	91605
Total torque	4974	8476	15141	20936
Propeller excitation forces				
Axial F11 (N)	2358	4103	7571	10535
Vertical F33 (N)	246	428	790	1,099
Transv. F22 (N)	472	821	1514	2107
Moment M11 (N.m)	433	737	1317	1821
Moment M33 (N.m)	622	1059	1893	2617
Moment M22 (N.m)	1134	1932	3453	4773

Hull pressure forces (pressure fluctuation)

There are several causes that produce fluctuating pressures on the hull in the area of the propeller. These pressures fluctuate proportional to the propeller rotation speed, its number of blades (blade rate frequency), and cavitation.

Pressures can be obtained by experimentation, by numerical approximation (CFD) or by empirical formulas (*Holden, 1980*). For the current analysis, Holden formulas were used. These pressures vary according to working condition. Table 10 shows pressures values applied in an area of 1 m2 of each propeller, in all working conditions analyzed.

Table 10. Hull fluctuating pressures applied.

Frec. (HZ)	**15.2**	**23.5**	**28.3**	**29.7**	**37.8**	**43.9**
Order	**1Z**	**1Z**	**1Z**	**1Z**	**1Z**	**1Z**
Engine RPM	691	1071	1290	1356	1722	2000
Pressure PT (N/m²)	1108	3114	4962	5667	9847	14335

Working conditions to evaluate

For this study case, the reduction ratio is R = 3.04, and a 4 blades propeller was used. Therefore, the excitation will occur at a frequency:

$$f_{exc} = (RPM_{engine})(N_{blades})/R \tag{3}$$

Generally, the two first orders of the propeller excitation are considered: 1Z and 2Z, due to lower excitation magnitudes presented by higher orders.

Resonance conditions between the excitation frequency and propulsion line natural frequencies had been analyzed. Additionally maximum working condition (MCR) had been analyzed, which in this case is 2000 RPM.

The following table shows the resonances to consider

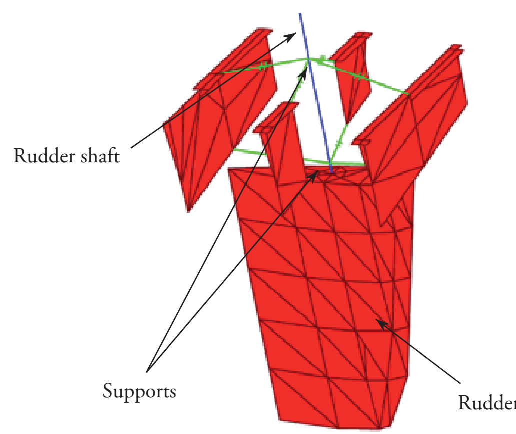
Table 11. Resonances table.

Natural Frec. (HZ)	**15.2**	**23.5**	**28.3**	**29.7**	**37.8**	**43.9**
Order	**1Z**	**1Z**	**1Z**	**1Z**	**1Z**	**1Z**
Engine RPM	691	1071	1290	1356	1722	2000

Rudder Line Behavior

Vibration analysis must consider the rudder behavior, to check if there is any resonance in the working range. Additionally it is important to know if the rudder holds up propeller fluctuating stress loads.

Fig. 14. Rudder finite element model



Rudder supports location

Rudder supports are usually cutless bearings. The FEM represents these supports in the corresponding directions. In the present study, rudder has two supports, upper one restricting rudder shaft axial movement and allowing only rotation and lower support. Due to the rudder shaft is modeled with frame element; constraints simulating the contact between the flanged shaft and the rudder shell had been included.

Rudder added mass

Rudder is also immersed in water and its added mass is considered in the FEM. Rudder is considered as a plate to find the rudder added mass. Mukundan (2002) method was used and its values are presented in Table 12. The rudder added mass was evenly distributed at nodes on rudder surface in their respective directions.

Table 12. Calculated rudder added mass.

Transversal added mass		
C	0.73	
psw	1025	Kg/m^3
B	0.824	m
L	1.44	m
B/L	0.572	
M* y	574.6	Kg
Longitudinal added mass		
C	0.21	
psw	1025	Kg/m^3
B	0.824	m
A	0.182	m
B/L	4.53	
M* x	20.89	Kg
Added inertia		
C	0.73	
psw	1025	Kg/m3
B	0.824	m
L	1.44	m
B/L	0.572	
MI*	12.2	Kg.m^2

Classification Societies Acceptance criteria

Classification Societies recommend limits for vibration velocity for crew, passengers, structures and machinery areas.

These limits are recommended to ensure people comfort in the accommodation areas and to prevent fatigue failure in local structures.

Living areas limits

Classification Societies recommend limits depending on craft type and accommodation or work sectors.

ISO 6954 (2000) proposed by Classification Societies such as ABS and Germanischer Lloyd had been taken as acceptance criteria for the evaluation of the study boat.

On Table 13, the classification refers to the area of application:

- A Class: is for passenger cabins,
- B Class for accommodation of crews and
- C Class for workspaces

Table 13. RMS vibration limits from ISO 6954 (2000) of 1-80 Hz.

RMS values of global vibration			
Classification	A	B	C
	mm/s	mm/s	mm/s
Values on which adverse comments are probable	4	6	8
Values below which adverse comments are not probable	2	3	4

There are voluntary limits known as comfort notations, which are limit values proposed by the Classification Societies to grant class notations, especially for passenger vessels.

Structure limits

There are vibration limits for not accommodating areas as tanks, mast, lazaretto structures, engine room, etc. These limits seek to avoid structural damage due to fatigue and the cracks occurrence due to vibration. Fig. 15, taken from ABS (2006), shows vibration peak limits for structures bellow which the risk to fatigue crack is expected to below. From Fig. 15 can be seen that for frequencies between 5 Hz and 10 Hz vibration peak limit recommended is 30 mm/s.

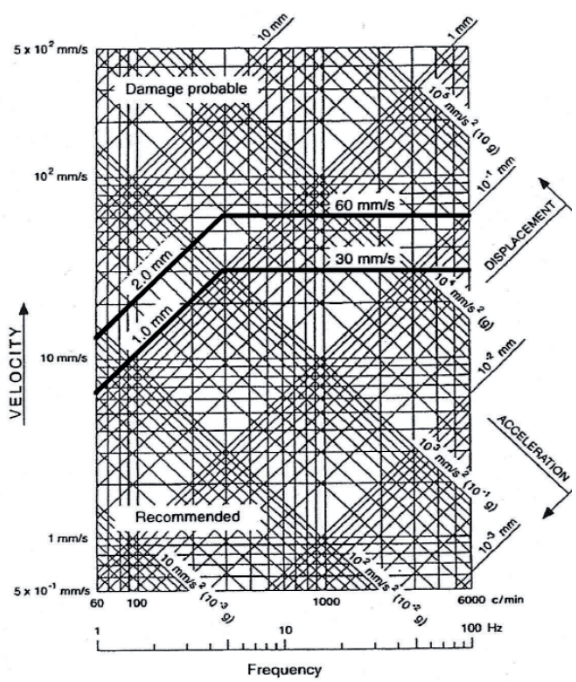
Hull structure and deck house forced analysis evaluation

Finite element method was used to perform a forced vibration analysis of the hull structure, using the following equation:

$$[M]\{\ddot{Y}\} + [C]\{\dot{Y}\} + [K]\{Y\} = \{F\} \quad (4)$$

where $[M]$ is the mass matrix of the system, $[K]$ is the stiffness matrix of the system, $[C]$ is the damping matrix system, $\{Y\}$: is the displacement vector, $\{\dot{Y}\}$the first derivative of displacement Y, $\{\ddot{Y}\}$ is is the second derivative of displacement Y, $\{F\}$: is the excitation force vector.

Fig. 15. Peak vibration limits for local structures.



Deformation was estimated at all nodes in the model, for each load condition. Figs. 16, 17, 18 and 19 graphically show deformation results.

Harmonic motion deformation as the case of vibration can be represented as follows, at any time t:

$$\delta = A * \sin(\omega_v . t) \quad (5)$$

where:

A = deformation amplitude (m)
ω_v= Vibration frequency (rad/s)
t = time (s)

Since the speed is the relationship between the deformation and the time, the vibration speed magnitude (V) can be obtained by the following equation:

$$V = A * \omega_v \quad (6)$$

Figs. 16, 17, 18 and 19 show as color-sectors the deformation that is proportional to vibration speed. There is greater deformation on aft bulkhead of upper deck house at 43.86 Hz condition.

Fig. 16. Deformation (mm) at 23.49 Hz condition.

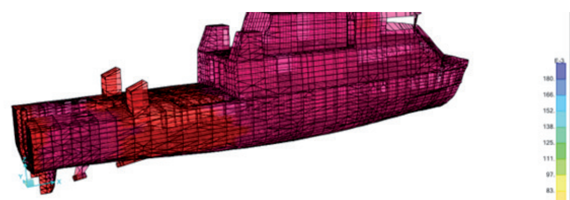


Fig. 17. Deformation (mm) at 29.73Hz condition.

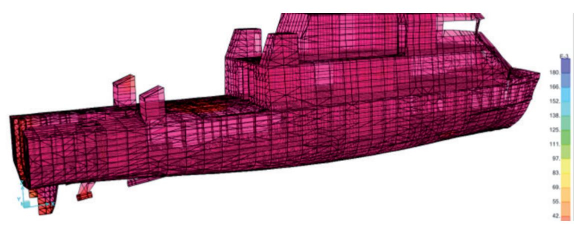


Fig. 18. Deformation (mm) at 37.77 Hz condition.

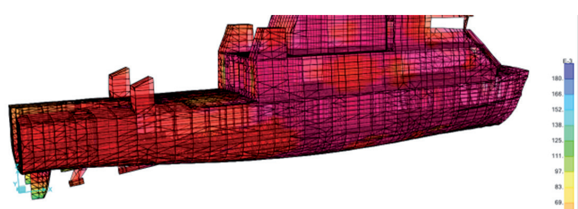


Fig. 19. Deformation (mm) at 43.86 Hz condition.

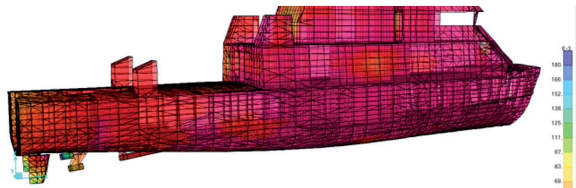
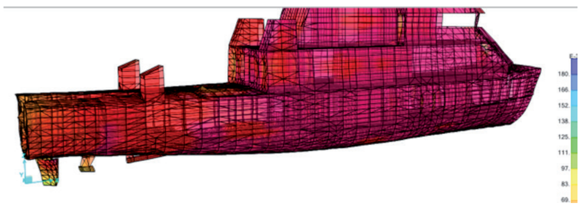


Fig. 20. Deformation (mm) at 43.86 Hz condition (reinforced bulkhead at upper deck)



Tables 14 and 15 show vibration speed values by sector for each condition, calculated from the deformation found with the FEM. Most vibration levels do not exceed the limits set by the rules, except the aft bulkhead on upper deck at 2000 RPM, where the limit is 6 mm/s.

Local Reinforcements to reduce higher vibration levels

The FEM allow us to carry out structural modifications to comply with the recommended limits.

In this case, it is requested to increase the section of the vertical reinforcements to the aft bulkhead on upper deck house.

Table 14. Vibration speed at accommodation.

	RMS vibration velocity (mm/s)					
Frec, (HZ) / Sector	**15.2**	**23.5**	**28.3**	**29.7**	**37.8**	**43.9**
			ACCOMODATION AREAS			
Inner main deck	0.44	0.32	0.25	0.33	0.84	0.52
Fore exterior main deck	0.16	0.15	0.09	0.24	0.99	0.51
Exterior deck 200	0.22	0.37	0.09	0.37	1.38	0.71
Interior deck 200	0.3	2.27	0.77	0.46	0.59	0.73
Upper side deckhouse	0.38	0.17	0.13	0.38	2.58	2.05
Lower side deckhouse	0.55	0.12	0.54	0.22	4.24	2.65
Aft bulkhead at deck 200	0.27	0.48	0.26	0.10	5.13	20.9

Table 15. Vibration speed at structure.

	RMS vibration velocity (mm/s)					
RPM	**691**	**1071**	**1290**	**1356**	**1722**	**2000**
Frec, (HZ) / Sector	**15.2**	**23.5**	**28.3**	**29.7**	**37.8**	**43.9**
			STRUCTURE			
Long. Beam over strut	0.25	0.25	0.65	0.42	0.80	4.99
Hull at stuffing box	0.65	0.94	1.82	1.44	2.60	2.70
Long. Beam over tunnel bearing	0.39	2.32	1.28	1.84	5.62	5.77
Pilot house roof	0.07	0.49	0.04	0.25	5.98	5.84
Transom/side intersect.	1.05	2.14	3.98	2.26	5.64	10.0
Aft bulkhead at deck 200	0.27	0.48	0.26	0.10	5.13	20.9

Fig. 20 shows the deformation in the same scale as the previous figures and shows the deformation decrease on aft bulkhead at upper deck, with respect to Fig. 19. This improvement can be seen in Table 16.

Table 16. Vibration speed after upper deck bulkhead reinforcement.

RMS vibration velocity (mm/s)			
RPM	**2000**		
Frec, (HZ) / Sector	**43.86**	**Limit**	**Direction**
ACCOMODATION AREAS			
Aft bulkhead at deck 200	4.42	6	X

Conclusions

- Acceptance criteria are effective, so the best way to avoid resonance problems is configuring the propulsion system to keep vibration below criteria.
- Natural frequencies of the propulsion line need to avoid the working range to prevent resonances.
- Natural frequencies of ship panels and structure need to avoid the working range of propeller excitation forces.
- Forced vibration analyses on hull girder including propeller excitation forces should be performed to identify sectors that do not meet standards.
- The results obtained in the design stage allow identifying possible failures, especially when there is resonance risk in the propulsion line.

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Appex

Boat main particulars		
Ship type	Investigation boat	
Overall length:	46 m	
Bea:	7 m	
Depth:	4m	
Draft:	1,9 m	
Engine data		
Strokes	4	
Cylinders Nº	12	
V angle	90	Grades
Bore	165	mm
Stroke	190	mm
Connecting rod l.	354	mm
Weight	6800	kg
Minimum rpm	500	
Maximum rpm	2000	
Max power x rpm	1680KW x 2000 RPM	
Torque @ 1680 kw	8.02	KN.m
Propeller data		
Type	Fixed pitch	
Blades Nº	4	
Diameter	1.397	m
Pitch	1.283	m
D.A.R	0.91	
Mass	363.7	kg
Polar inertia	41.18	$kg.m^2$
Gearbox data		
Ratio	3.04	

Evaluation of Medium Speed Diesel generator sets and energy storage technologies as alternatives for reducing fuel consumption and exhaust emissions in electric propulsion systems for PSVs

Evaluación de generadores diesel de media rotación y tecnologías de almacenamiento como alternativas para reducir consumo de combustible y la emisión de gases en sistemas de propulsión PSVs

Cristian A. Morales Vásquez [1]

Abstract

The use of electric propulsion systems in PSVs in Brazil has recently increased, leading to be the standard for most support vessels. In those ships, the common arrangement uses high-speed Diesel generator sets for power generation and induction motors driving propellers, reporting significant reductions in the fuel consumption and exhaust emissions compared with mechanically propelled PSVs. However, further abatements in these parameters could be achieved by implementing other technologies for power production. In this work, the use of medium-speed Diesel generator sets and energy storage technologies in electrically propelled PSVs is evaluated. For the above, the fuel consumption, exhaust emissions, mass, volume and acquisition costs of four arrangements are estimated and compared. Two of the arrangements are equipped with medium-speed Diesel generator sets, two with energy storage units and one with high-speed Diesel generator sets. Energy storage appears as interesting alternative for decreasing fuel consumption and emissions by optimal loading of Diesel engines. Medium speed generators also showed reductions in fuel consumption, but highest emissions. The arrangements with high-speed generators presented the lowest mass, volume and acquisition costs.

Key words: Electric Propulsion Systems, Energy Storage Technologies, Platform Supply Vessels, Diesel Generator Sets.

Resumen

El uso de sistemas de propulsión eléctricos en PSVs en Brasil se ha incrementado recientemente, tendiendo a ser la norma en la mayoría de los barcos de apoyo. En dichas embarcaciones, el arreglo más común utiliza generadores Diesel de alta rotación para generación de energía y motores de inducción accionando propulsores. Tal arreglo ha reportado reducciones significativas en el consumo de combustible y en las emisiones contaminantes, comparado con los PSVs con propulsión mecánica. Sin embargo, disminuciones adicionales en estos parámetros se podrían lograr implementando otras tecnologías para la producción de potencia. El uso de generadores Diesel de media rotación y de tecnologías de almacenamiento de energía en PSVs con propulsión eléctrica, es evaluado en este trabajo. Para lo anterior, el consumo de combustible, las emisiones contaminantes, la masa, el volumen y los costos de adquisición de cuatro arreglos son estimados y comparados. Dos de los arreglos están equipados con grupos generadores Diesel de media rotación, dos con unidades de almacenamiento de energía y uno con grupos generadores Diesel de alta rotación. Las unidades de almacenamiento de energía se presentan como una alternativa interesante para disminuir el consumo de combustible y las emisiones por medio de la carga optima de los motores Diesel. Los generadores Diesel de media rotación también mostraron decrementos en el consumo de combustible pero presentan las más altas emisiones de contaminantes. Los arreglos con generadores Diesel de alta rotación presentan la menor masa, volumen y costos de adquisición.

Palabras claves: Sistemas de Propulsión Eléctrica, Tecnologías para Almacenamiento de Energía, Barcos de Apoyo a Plataformas, Grupos Generadores Diesel.

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Introduction

In the marine industry, Diesel Electric propulsion systems are increasingly implemented, mainly, due to the fast development of power electronics, enhancement of processing capacity of microprocessors, improved efficiency and power density of the electrical machines. When compared with mechanically propelled arrangements, the system offers several advantages, which, from certain points of view, compensate the higher investment costs and transmission losses at the short or medium term. The lower fuel consumption due to the possibility to optimize the loading of diesel generator sets; the higher reliability due to generator set redundancy; and the flexibility in location of thruster devices, switchboards and generator sets.

Major users of electric propulsion systems are vessels in which the power demand from auxiliary/ hotel loads is as great as for the propulsion system (i.e. cruisers, passenger vessels) or vessels with changing operational conditions and equipped with electrical actuators (*i.e.* PSVs).

In Brazil, the number of electrically propelled PSVs is growing, leading to be the standard for most support vessels. Most of these vessels uses high speed Diesel generator sets for power production and induction motor driving propellers. The decrease in fuel consumption, compared with mechanically propelled PSVs, is about 700 Ton of Diesel fuel per year (*Adnanes, 2003*). Furthermore, exhaust emissions (CO_2, NO_x and SO_x) are also diminished.

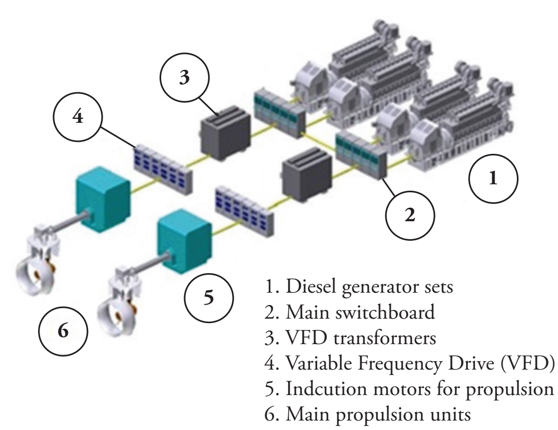
However, further reductions in the above parameters could be achieved by implementing other technologies for power production and energy storage. Medium speed Diesel generator sets and energy storage devices appear as appropriate alternatives for this purpose, as evaluated by Dedes, Turnock and Hudson (2010, 2012). Since medium speed Diesel engines present lower SFOC (Specific Fuel Oil Consumption) than the high speed ones, the operative costs are inferior. Energy storage could improve fuel consumption and exhaust emissions by maintaining the Diesel engines loaded at their optimum operational point (the loading in which the SFOC is the lowest).

In this work, the influence of arrangements with medium speed Diesel generator sets and energy storage devices in electrically propelled PSVs is evaluated, focusing in the fuel consumption and exhaust emissions, as well as the mass, the volume and acquisition costs. This purpose is achieved by a performance assessment of four electric propulsion arrangements applied to the basic hull form of a PSV: the first with high speed Diesel generator sets, the second with medium speed Diesel generator sets, whereas the third and the fourth are the same as the first and the second, respectively, with energy storage devices connected to the main switchboard.

Diesel-electric propulsion system for PSVs

The general arrangement of the Diesel-electric propulsion system for twin propeller vessels is depicted in Fig. 1.

Fig. 1. General Arrangement of the Diesel-Electric Propulsion System for Twin Propeller Vessels (MAN, 2012).



The prime movers drive the electric generator producing electrical energy. The electric power is distributed and transmitted to the propulsion motors which provide torque to the propulsion units. The electric motors are driven by Variable Frequency Drives (VFD) which are feed by transformers.

Energy storage devices could be added to the configuration for load compensation, for energy back up or for supplying energy to the loads when the power demand is low. Among different battery technologies, the ZEBRA batteries are reported as suitable for shipboard applications (*Dedes, Turnock and Hudson 2010, 2012; Manzoni, Metzger and Crugnola, 2008; Aspin and Hayman, 2009*).

Conventional Diesel electric propulsion for PSVs uses high speed Diesel generator sets because of its low initial costs and low mass. However, medium speed Diesel generator sets offers lower operational costs. In Table 1 the main differences between Diesel generator sets are presented.

Table 1. Main Parameters of High and Medium Speed Diesel Generator Set (Woud and Stapersma, 2002; Vasquez, 2014).

Parameter	High speed	Medium speed
SFOC (g/kWh)	200-220	170-210
Specific mass (kg/kW)	2,3-6	5-20
Specific volume (dm^3/kW)	2,8-8	4-28
Capital Cost (US$/kW)	236-315	289-433
Fuel burned	MGO	MDO, HFO
NOX Emissions (g/kWh)	7-13	10-18

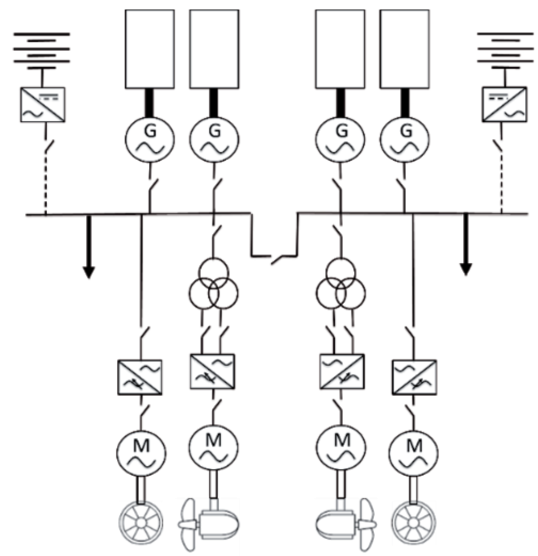
Methodology

Arrangements for evaluation

The four electric propulsion arrangements for analysis are illustrated in Fig. 2.

The Diesel generator sets are represented by the empty rectangles connected to the generators; the switchboards receive the power from the generator sets for distribution to the vessel loads. Each switchboard section supplies power to one of the main propulsion drives, to one of the dynamic positioning drives, as well as to the half of the auxiliary and hotel loads (represented by the arrows). Since the batteries bank are connected to the switchboard in two arrangements, their connection is represented by dashed lines.

Fig. 2. One Line Diagram of the Electric Propulsion Arrangements Under Evaluation.



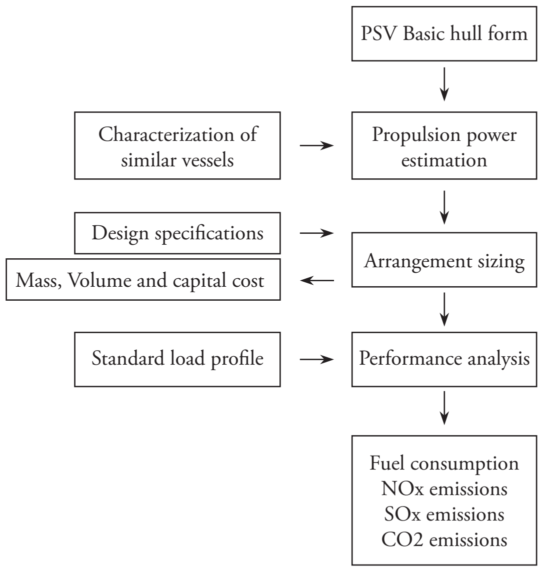
The arrangement 1 has high speed generator sets, the arrangement 2 has medium speed generators, the arrangement 3 and 4 are the same as the 1 and 2, respectively, but with the batteries bank connected to each section of the main switchboard.

Methodology

The methodology to analyze the electric propulsion arrangements is presented in Fig. 3.

The starting point is the basic hull form of a PSV, from which the resistance to advance is estimated. Afterwards, the propulsion power is obtained. Next, the four electric propulsion arrangements are sized. The main properties of the arrangements, namely mass, volume and acquisition costs are compared. Later, a performance analysis for each arrangement is made by simulating the power demand from the PSV for a typical service. The fuel consumption and exhaust emissions (NO_x, SO_x and CO_2) for every arrangement are estimated. Finally, a comparison between arrangements is made to determine the effect of the medium speed

Fig. 3. Proposed Methodology.



Diesel engines and the batteries bank in the fuel consumption and the exhaust emissions.

Propulsion power and arrangement sizing

The case study is the basic hull form of a conceptual design of a PSV for the pre-salt oil fields at Santos Basin (Weiss, et al., 2012). The project is conceived for a service speed of 15 knots, a total capacity of 4500DWT and is required to have Diesel Electric propulsion system with dynamic positioning system classified as class 2. The main parameters of the PSV are shown in Table 2.

Table 2. Main Parameters of the PSV Hull Form Under Study (COPPE/UFRJ, IPT & USP, 2012).

Parameter	Value
Beam	19m
Draft	6,6m
Length between perpendiculars	86,9m
Length of waterline	86,9m
Displacement	7932m^3

Propulsion power estimation

The main input for power estimation is the vessel resistance. Besides, characterization of similar vessels is conducted to have as much information to be used as a guide for the alternatives.

Resistance to advance

The resistance is obtained for all the speed range (from 1 to 15knots) and for two conditions: for laden voyage i.e. 100%∇ and partial load voyage *i.e.* 75%∇. The above is made using a spreadsheet based in the statistical methodology proposed by Holtrop and Mennen (1982) and Holtrop (1984). The results are increased by 15%, considering the resistance margin. The final resistances for the PSV are: **400kN** for laden voyage and **314kN** for partial load voyage, both at 15knots (*Vasquez, 2014*).

Characterization of similar vessels

The characterization was performed considering 32 electrically propelled PSVs which are operating in Brazil (see details in *Vasquez, 2014*). From the characterization, it was seen that the used prime mover is the High Speed Diesel Engine at 1800rpm; the rated voltage is 690V or 480V at 60Hz; the vessels have two Z-drive azimuth thrusters for main propulsion with FPP or CPP with or without nozzles. The nozzle or propeller diameters drops within 36% to 68% of the design draft. From the characterization an expression to estimate the mass for a conventional Diesel electric propulsion system for PSVs was obtained (*Vasquez, 2014*):

$$M_{DE} = 3 \times 10^{-6} P_v^2 + 0{,}0119\, P_v + 38{,}834 \qquad (1)$$

Where M_{DE} is the mass of the electric propulsion system in kg and P_p is the total propulsion power in kW.

Propulsion power estimation

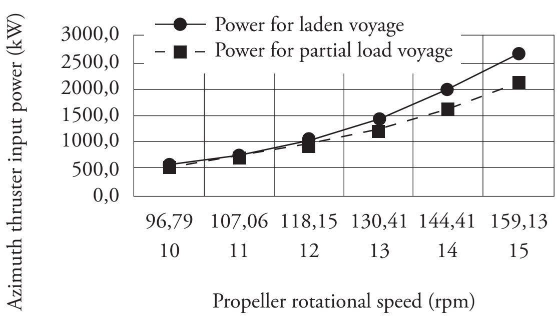
The propulsion power is estimated considering the following conditions (*Vasquez, 2014*):

- Propulsion units: Z-drive nozzled azimuth thrusters.
- Propeller and nozzle: Ka 4.70, FPP propeller and 19A nozzle. Propeller+nozzle diameter is limited to 65% of the design draft. Considering commercial nozzle diameter, propeller diameter must be lower than 3,46m.

The closest commercial diameter for propeller is 3,4m. Pitch to diameter ratio is fixed as 1,2.

The torque, thrust, propeller rotational speed and required input power are obtained using the systematic series for the selected propeller and nozzle (*Bose, 2008*) along with the propulsion coefficients proposed in Holtrop and Mennen (1982) and Holtrop (1984) for twin screw vessels. The maximum required power at the input of each propeller including 5% mechanical losses of the thruster (*Muller, 2008*) is **2663kW** at 1200rpm. Fig. 3 shows the required power vs. speed curve for each azimuth thruster for speeds from 10 to 15 knots at the two operational conditions. Finally, the power margin is settled as 10%, according to the recommendations in literature (*Brinati, 2011*). As a result, each electric motor for propulsion must deliver at least **2929kW**.

Fig. 4. Power vs. Speed Curve of the Main Azimuth Thrusters for Laden and Partial Load Voyage.



Arrangement sizing

Design specifications

The electric propulsion arrangements should comply with rules established by classification societies and the IMO about pollutant emissions and redundancy requisites.

Pollutant emissions

The MARPOL 73/78 annex VI limits the NOx emissions of Diesel engines operating at 1800rpm to a maximum of 7,8g/kWh, for the ones at 900rpm the limit is 9,2g/kWh. The SOx are limited by settling a maximum sulfur content for fuel of 3,5% (*IMO, 2004*).

Dynamic positioning system

The vessel is required to have a dynamic positioning system class 2 (*IMO, 1994*). According to the IMO, the electric propulsion arrangement must be split into two sections connected between them by bus tie breakers. Furthermore, the thrusters intended to operate as side thrusters for dynamic positioning must be doubled along with their associated equipment.

Voltage level

The voltage level for every arrangement is settled as 690V, 3phase, 60Hz according to the recommendations from IEEE (2002), section 4.4.

Arrangement sizing

Component Sizing

The induction motor for main propulsion must meet the following conditions:

- Rated output power ≥ 2929kW
- Rotational speed ≤ 1200rpm
- Rated voltage = 690V

A commercial motor is selected from a catalog. Its important features are shown in Table 3. It should be noted that there are two motors for main propulsion.

The induction motors for the two bow thrusters must provide maximum 830kW, each, for dynamic positioning under design conditions. In these conditions, the main propulsion units acts as stern thrusters providing maximum 156kW each, as shown in Fig. 5. The main parameters of the selected motors for the bow thrusters are presented in Table 3.

The characteristics of the VFDs and transformers for main propulsion system and the VFDs for the dynamic positioning system are detailed in

Fig. 5. Power Requirements for Dynamic Positioning (COPPE/UFRJ, IPT & USP, 2013).

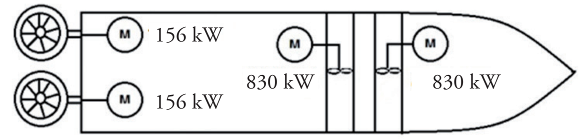


Table 3. It must be taken into account that each component is doubled.

Table 3. Important Parameters of the components for the propulsion arrangements (Vasquez, 2014).

Parameter	Value
Induction motor for main propulsion	
Rated power (kW)	2940
Rotational speed (rpm)	1192
Rated efficiency	96,9%
Rated power factor	0,86
Mass (for reference) (kg)	12118
Volume (for reference) (m3)	5,12
Estimated cost (US$)	328.410
VFD for main propulsion (Siemens, 2011)	
Rated output power (kW)	3600
Input power factor	0,96
Approximated mass (kg)	4260
Approximated volume (m3)	6,86
Rated efficiency	97,5%
Estimated cost (US$)	749.854
Transformer for VFD (Vasquez, 2014)	
Rated output power (kVA)	3251
Rated efficiency	98,5%
Approximated mass (kg)	6617
Approximated volume (m3)	2,68
Estimated cost (US$)	54.884
Induction motor for dynamic positioning	
Rated Power (kW)	880
Rotational speed (rpm)	1195
Rated efficiency	96,5%
Rated power factor	0,83
Mass (for reference) (kg)	6533
Volume (for reference) (m3)	2,57
Reference cost (US$)	226.965
VFD for Dyn. Pos. (Siemens, 2011)	
Rated output power (kW)	1000
Input power factor	0,96
Approximated mass (kg)	2800
Approximated volume (m3)	4,48
Rated efficiency	97,5%
Reference cost (US$)	206.714

Power request from auxiliary loads
The power request from auxiliary/hotel loads (pumps, navigation equipment, HVAC, compressors, etc.) was estimated from a detailed load balance presented in Arcoverde (2013).

*Total electrical deman*d
The total power demand from one section of the main switchboard is estimated considering the power flow shown in Fig. 6. The losses (efficiencies) are defined as η_x, power factors as $P.F._x$, active power as P_x and apparent power as S_x.

The total apparent power distributed by each switchboard section is composed by active and reactive components. In Table 4, the total power demands for each type of operation are shown.

The required current rating for each switchboard section is 3242A. The commercial unit with closest rating is 4000A, which has an estimated mass equal to 700kg, volume of 8,44m^3 and an efficiency of 99,5%.

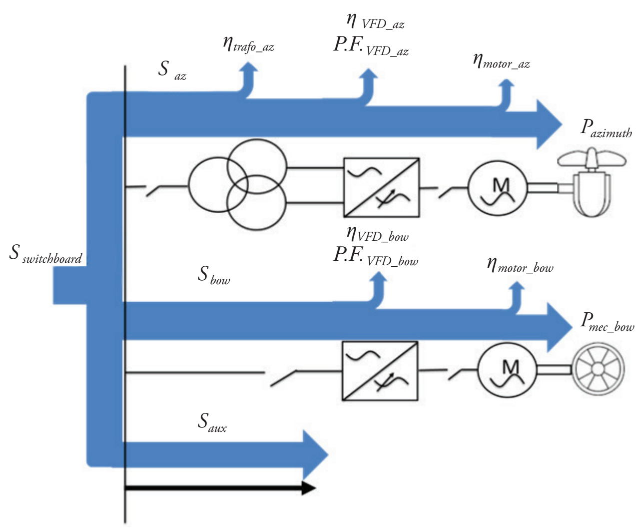
Diesel generator sets
The maximum power demand corresponds to laden voyage. Considering 4 Diesel generator sets, the minimum power rating for each generator set is 1850kW and 1948kVA, respectively.

For the high speed unit of the arrangement 1, the MTU 2045-XC6DT2 meets the conditions. For the medium speed unit of the arrangement 2, the MAN 9L21/31 is a good choice. Their main characteristics are shown in Table 5.

Table 4. Total Electrical Demands for the PSV (Vasquez, 2014).

	Prop. (kVA)	Auxiliary (kVA)	Total (kVA)
Laden voyage	6557@ pf=0,96	1232@ pf=0,85	7751@ pf=0,95
Partial load voyage	5277@ pf=0,96	1232@ pf=0,85	6457@ pf=0,95
Dynamic Pos.	2230@ pf=0,96	1484@ pf=0,85	3782@ pf=0,92
Port/ anch.		853@ pf=0,85	853@ pf=0,95

Fig. 6. Power Flow Diagram for Each Main Switchboard Section.



Sizing of batteries bank for arrangements 3 and 4

The batteries bank are added to arrangement 1 and 2, becoming the arrangement 3 and 4, respectively. The batteries bank is implemented with the objective of compensating the lack or excess of power in order to keep the Diesel engines working at their optimum operational point. Furthermore, they are also sized to supply the required power while the vessel is in port. The sizing process is considered the same for both arrangements.

Table 5. High Speed Diesel Genset Parameters (Vasquez, 2014).

Parameter	MTU 2045-XC6DT2	MAN 9L21/31
Rated Power (kWe)	2045	1915
Mass (kg)	16994	36500
NOx (g/kWh)	7,29	9
Volume (m^3)	45,4	37,1
SFOC at (50%MCR) (g/kWh)	209	193
SFOC at (75%MCR) (g/kWh)	200	189
SFOC at (100%MCR) (g/kWh)	202	192
Generator efficiency	96,75%	96,75%
Estimated cost (US$)	546.860	670.250

The storage capacity is determined as 14504kWh (*Vasquez, 2014*). The main parameters of the ZEBRA batteries are shown in Table 6, as well as their values for the required storage capacity.

The batteries bank requires a power converter with bidirectional power flow capability and AC/DC conversion. The main features of the converter are shown in Table 7.

Table 6. Values for the required batteries bank.

Parameter	Unitary Values	Total Values
Mass	115Wh/kg[1]	126122kg
Volume[2]	180kWh/m^3	80,6m^3
Cost	US$12,7/kg[3]	US$8,702x10^6

Table 7. Parameters of Power Converters for Batteries Bank (Vasquez, 2014).

Parameter	Value
Rated power (kW)	1400
Power factor (AC side)	1
Rated efficiency	97,5%
Approximated mass (kg)	1360
Approximated total volume (m^3)	1,85
Reference cost (US$)	290.274

1 Dedes, Turnock and Hudson (2012).
2 Manzoni, Metzger and Crugnola (2008).
3 Dedes, Turnock and Hudson (2012).

Mass, volume and capital cost comparison

The mass and volume for each arrangement are shown in Fig. 7. The first element corresponds to the mass prediction obtained with Equation 1.

Capital costs are also presented in Fig. 8; they do not include the cost of azimuth thrusters.

Fig. 7. Mass and Volume for the Arrangements.

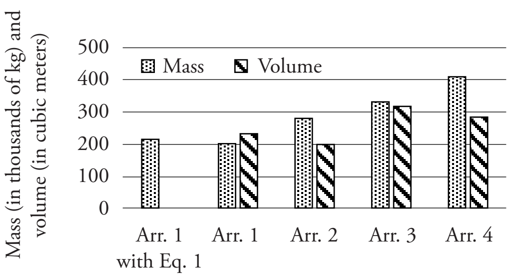
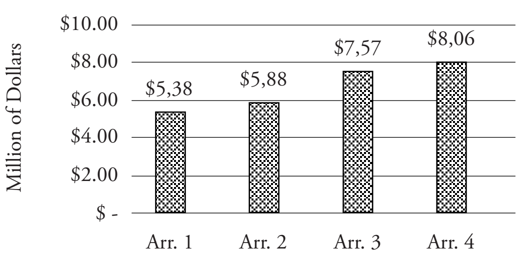


Fig. 8. Capital Costs for Each Arrangement.



From the figures, the following analysis can be performed:

- The mass obtained with Equation 1 is 11% greater than the estimated mass of the arrangement 1. The formula gives reasonable values which can be used for early stages of project design of this type of ship.
- The arrangements with medium speed Diesel engines presented higher mass than arrangements with the high speed ones. The difference can exceed the 200% (more than 200ton)
- The above implies that less payload can be transported by a PSV with Diesel electric arrangements with medium speed gensets than with high speed gensets. Moreover, the use of batteries bank can further reduce the amount of payload that can be transported.
- The acquisition costs of the arrangements are proportional to the mass.

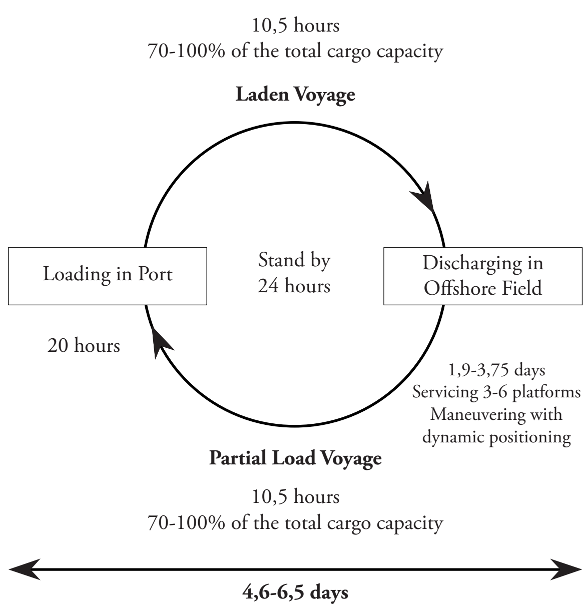
Performance analysis

The fuel consumption and exhaust emissions from each arrangement are estimated by evaluating the performance of the Diesel engines and batteries bank. The above is made by simulating the power demand from the electrical system of the PSV for a typical service.

Operational profile

The typical operational profile for a PSV is divided in: loading in port, laden voyage, dynamic positioning operation, partial load voyage and standby/anchored operation. The above is depicted in Fig. 9 showing also the average duration of each service.

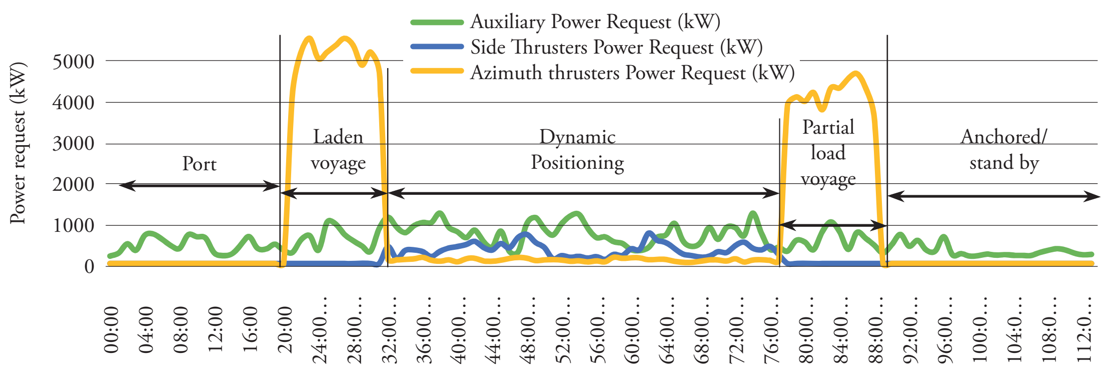
Fig. 9. Typical Operational Profile for a 4500DWT PSV Operating at Santos Basin.



Load profile

The load profile for an electrically propelled PSV with 4500DWT serving the Santos Basin is constructed using the time periods presented in Figure 8, the maximum load demands shown

Fig. 10. Reference Load Profile of the 4500DWT PSV with electric propulsion for Santos Basin.



in Table 4 and the operative conditions of a high deadweight PSV described in Murta and Suzano (2013) and Medeiros (2010).

The load profile for a complete service of the electrically propelled PSV for the Santos Basin is depicted in Fig. 10. The duration of each type of operation is indicated in the figure.

Fuel consumption

The fuel consumption is determined using the power flow in Fig. 11 as reference. The load profile is the input and the power that each Diesel engine must deliver is obtained computing the losses of each component. The mass of the fuel required to produce the demanded power in each sample is defined by:

$$fuel\ consumption = \int_{t_1}^{t_2} hSFOC_n Engpower_n\, dt \qquad (2)$$

Where h is the number of Diesel engines in operation, $SFOC_n$ is the engine specific fuel consumption correspondent to the delivered power; $Engpower_n$ is the power delivered by all Diesel engines in kW, $t_{1,2}$ are the time limits between samples and the sub index n is the number of the sample. The fuel consumption is given in grams.

The SFOC curves for the engines of arrangements 1-3 and 2-4 are shown in Figure 11. The SFOC curves vary as a function of engine loading. The lowest value is when the loading is between 70-90% of the MCR.

Fig. 11. Power Flow Diagram for Estimating the Diesel Engines Delivered Power.

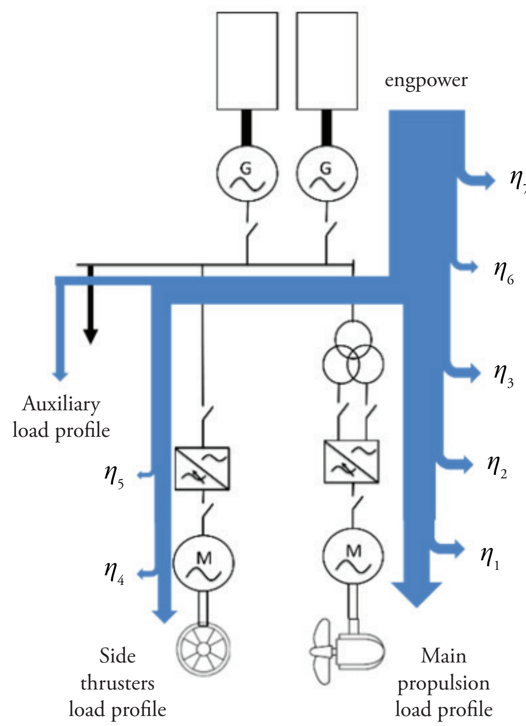
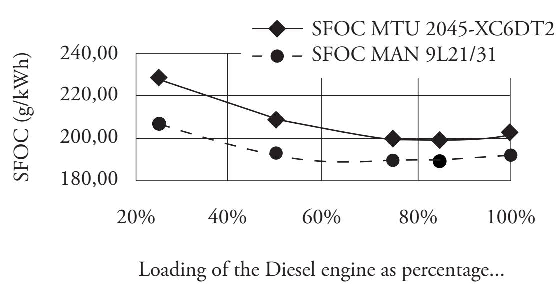


Fig. 12. SFOC for Diesel Engines of Arrangements 1 to 4.



The power delivered by the Diesel engines is determined assuming that each generator set delivers the same power. Furthermore it is considered that the energy compensation from batteries is mainly focused for dynamic positioning, stand by and port operations.

During dynamic positioning and stand by, the batteries are operating along with Diesel engines or without them. When both are in operation, the Diesel engines are maintained loaded at their optimal operating point (in which the SFOC is lowest) while the batteries compensates the lack or excess of power by delivering/taking energy. When the batteries are fully loaded, the Diesel engines are shut down and only batteries are supplying energy. For port operation, the PMS only allows the batteries to supply energy until their depletion.

During laden and partial load voyage the batteries are mainly taking energy; however, they keep the engines loaded at their optimal operating point.

Fig. 13 shows the loading and the delivered power from Diesel engines of arrangements 1 and 2. Fig. 14 depicts the power demand from arrangement 3; in this figure, the energy provided by the batteries is represented by the yellow areas while the energy taken is shown by the green areas. For the arrangement 4, a similar behavior as Fig. 14 is expected.

From the figures it can be noted that the loading of the Diesel engines for arrangements 1 and 2 is below 50% for more than 80% of the total service time. While in the arrangement 3, the Diesel engines are mostly loaded between 75% and 85%. In fact, for arrangements 1 and 2, the average loading of engines is 50% with a standard deviation of 28,8%. For arrangements 3 and 4 the average loading of engines is around 80,9% with a standard deviation of 1,7%.

Fig. 15 presents the estimated fuel consumption for a service with the operational profile presented in Fig. 9.

Fig. 13. Performance Analysis for Arrangements 1 and 2.

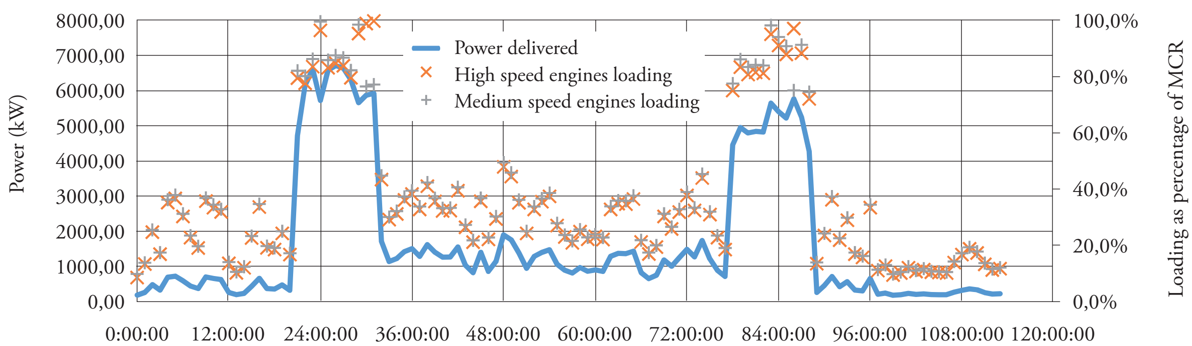


Fig. 14. Performance Analysis for Arrangement 3.

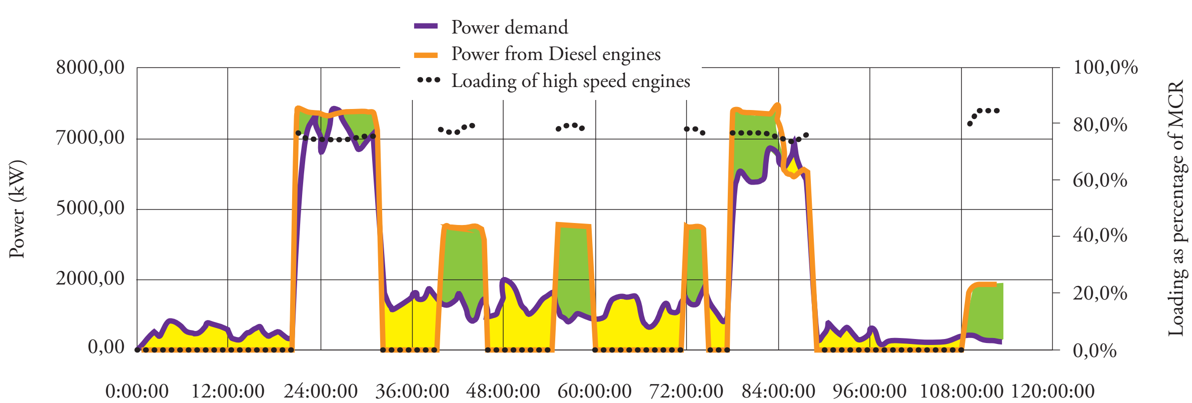
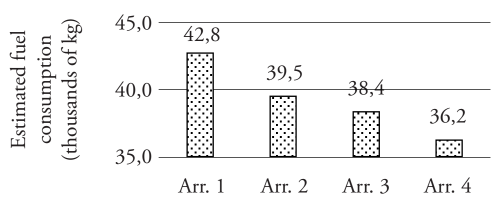
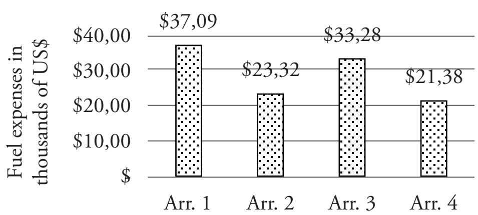


Fig. 15. Estimated Fuel Consumption of Each Arrangement for a Typical Service.



Since the high speed Diesel engines burn MGO and the medium speed ones are fueled with HFO, the fuel expenses per service are shown in Fig. 16. Fuel prices were taken from Petromedia (2014) at 18-08-2014 referenced at the port of Singapore.

Fig. 16. Estimated Fuel Expenses for Each Arrangement per Service.



Exhaust emissions

The exhaust emissions from Diesel engines considered for estimation are the Nitrous Oxides (NO_X), Sulphur Oxides (SO_X) and Carbon Dioxide (CO_2), which are the most studied emissions from ships in the literature (*Cisneros, 2012; Corbett and Koehler, 2003*). The exhaust gases can be obtained applying power based factors (in g/kWh) or fuel based factors (kg/tonne of fuel burned) (*Dedes, Hudson and Turnock, 2010*). In the case of the NO_X emissions, they are specific for each motor and are usually defined using power based factors (in g/kWh) depending on the energy delivered by the engine.

The mass of NO_X released to the environment can be approximated by:

$$NO_X = (ef_{NO_X}) \int_{t_1}^{t_2} h\, Engpow_n \, dt \qquad (3)$$

Where, ef_{NOx} is the NOx power emission factor given in g/kWh, NO_X is the total mass of NOx released in g.

The SO_X and CO_2 emissions are defined using fuel based factors, thus, they depend on the mass of fuel burned. Regarding the SO_X emissions, they also depend on the sulfur content in the fuel. The mass of SO_X and CO_2 released to the environment are defined as following:

$$SO_X = (ef_{SO_X}) \text{ } fuel\ consumption \qquad (4)$$

$$ef_{SO_X} = 20 \times \% \text{ } sulfur\ content \qquad (5)$$

$$CO_2 = (ef_{CO_2}) \text{ } fuel\ consumption \qquad (6)$$

Where, %sulfur content is the sulfur content of the fuel as a percentage of the total mass or volume, ef_{SOx} is the SOx fuel emission factor in kg per 1000kg of fuel burned, ef_{CO2} is the CO_2 fuel emission factor in kg per 1000kg of fuel burned. The SOx and CO_2 mass is given in kg.

The exhaust emissions are obtained for each arrangement assuming the following:

- The sulfur content of the MGO is settled as the maximum admissible: 1,5% (*IMO, 2004*).
- The sulfur content of the HFO is settled as the maximum permitted by the MARPOL 73/78 Annex VI, 3,5% (*IMO, 2004*).
- The CO_2 emission factor is 3190kg per each 1000kg of fuel burned, disregarding the engine type and the fuel type.

Taking into account the above equations and conditions, as well as the performance analysis and fuel consumption of section 5.3, the exhaust emissions from each arrangement for a typical service are shown in Fig. 17 and 18.

Fig. 17. Estimated NOx and SOx Emissions per Service.

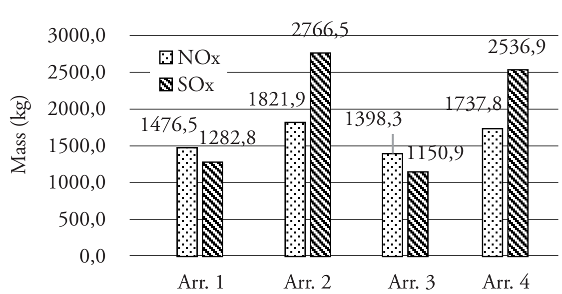
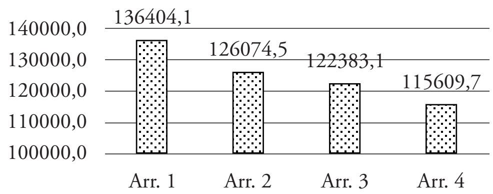


Fig. 18. Estimated CO_2 Emissions per Service.



Comparison of fuel consumption and exhaust emissions of each arrangement

From the previous results for the 4 arrangements, the following analyses can be made:

- Owing to the low SFOC, the fuel consumption of the medium speed generator unit is significantly lower than the fuel consumption of the high speed ones. The differences range between 5,5% (2200kg) to 8,3% (3300kg).
- The reduction in fuel consumption can lead to reduce the space dedicated for fuel storing, allowing to be used for payload transport. Nevertheless, for the present case, the additional payload transport would not be higher than 3300kg, which does not compensate the additional 78000kg of the medium speed generator sets.
- It was seen how the operational point of the Diesel engine, influences the fuel consumption. The arrangements where the Diesel engines were optimally loaded, presented lower fuel consumption than the other arrangements.
- The use of batteries bank along with high speed Diesel generator sets have shown better results in reduction of fuel consumption that the arrangements with medium speed units. The fuel reduction between arrangements 1-3 was approximately 4400kg, whereas for the arrangements 2-4 the reduction was 3300kg.
- Although the potential fuel reduction with the use of batteries in electric propulsion arrangements, their additional mass reduces significantly the payload that can be transported. For this case, the capacity of the PSV will drop by 129ton.
- The arrangements with medium speed units presented US$11.000 of less fuel expenses compared with the arrangements with high speed units. The difference between arrangement 4 and arrangement 1 is greater than US$15.000 per service. Assuming 6 services per month, the economies can reach up to US$1'080.000.
- The CO_2 and SOx emissions were seen proportional to the fuel burned. In the case of SOx emissions, they are also dependent on the fuel type.
- Regarding the NOx emissions, they are related to the energy delivered by the Diesel engines; the NOx values are neither influenced by the loading of the Diesel engines nor the reduction of the fuel consumption. Therefore, the difference of NOx emissions between arrangements was not higher than 30kg.
- Taking into account the effects of the batteries bank over the loading of the Diesel engines, they are a good alternative to reduce the fuel consumption of the vessels. As a consequence, the CO_2 and SOx released to the environment can also be reduced by its implementation.

Conclusions

The influence of medium speed Diesel generator sets and batteries bank over fuel consumption and exhaust emissions in electric propulsion systems in PSVs was evaluated.

The medium speed Diesel generator sets shown an important reduction in fuel consumption and fuel expenses of the electric propulsion arrangements when compared with high speed Diesel generator sets. Nonetheless, the additional mass and acquisition costs of the arrangements with this type of generating set unit could produce a negative effect over the lifecycle cost of the project. The NOx and SOx emissions increased with this type of Diesel engine.

The reduction in the fuel consumption by the use of energy storage system was demonstrated. In fact, it was seen that the batteries kept the Diesel engines loaded at their optimum operational point, burning less fuel per unit of energy when compared to the conventional electric propulsion arrangements. In this context, the batteries stand as an important alternative to reduce the impact of the exhaust emissions by decreasing the fuel burned and, consequently, the CO_2 and SOX emissions. Nevertheless, batteries present significant increments in mass, volume and capital costs.

The economic impact of the above technologies require a feasibility study in order to establish if the reduction in fuel consumption compensates the lower incomes due to lower payload.

Regarding the exhaust emissions, the approach used in the present work was fuel-based factors for the estimation of the SOx and CO_2 emissions; while for the NOx emissions the estimation was made using power based factors. Consequently, the NOx emissions were slightly affected by the reduction of the fuel consumption. With respect to the CO_2 and SOx emissions, they are strongly dependent on the amount of fuel burned, since the fuel-based factor is related to the fuel consumption.

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Moving-Object management method of combat system using main memory DBMS

Método de gestión de objeto en movimiento de un Sistema de combate usando la memoria principal DBMS

Jongsu Hwang [1]

Abstract

The naval combat management system conducts a comprehensive analysis of obtained information and integrates it with on-board sensors, weapons, and other equipment. Furthermore, it automatically performs all processes such as engagement plans, weapon assignments, and target detection using already pre-deployed database information. Thus, it is important to manage moving objects from many different kinds of sensors. In this paper, we will introduce the Moving-Object management method of combat systems using the In Moving Object DBMS. This is based on the main memory database technology provided by the high-speed transaction processing performance.

Key words: MO DBMS, Moving Object, Combat system, Track management.

Resumen

La gestión del sistema de combate naval conduce a un análisis compresivo de información obtenida y se integra con sensores a bordo, armas y otros equipos. Además, ejecuta automáticamente rosoa los procesos tales como planes de combate, asignaciones de armas y detección del objetivo usando información de bases de datos pre-desplegadas. Así, es importante gestionar los objetos en movimiento de diferentes tipos de sensores. En este artículo, presentaremos el Método de gestión de objeto en movimiento de un Sistema de combate usando la memoria principal DBMS. Esto es con base en la memoria principal de la tecnología de base de datos proveída por el desempeño de procesamiento de transacción de alta velocidad.

Palabras claves: MO DBMS, Objeto en movimiento, sistema de combate, gestión de rastreo.

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Introduction

The naval combat management system conducts a comprehensive analysis of obtained information and integrates it with on-board sensors, weapons, and other equipment. Furthermore, it automatically performs all processes such as engagement plans, weapon assignments, and target detection using already pre-deployed database information.

Most combat management systems are using the database to manage obtained sensors, weapons data and information needed to command. But due to the data management system performance limitations, combat management utilizes only stores management. And the data management system can't process real-time data. In addition, there is difficulty with the sharing and integration of data because the data management system stores non-real-time data through the file system. So, it has been required quickly access the database and reduce network overload between the database and the applications.

This paper will propose a method for the moving object database used by the target fusion of combat management systems. It uses the moving object database and provides high speed transaction processing performance and storage features of moving object location in real time. It also processes a feature of spatio-temporal query. The paper is organized as follows. Section 2 describes the track management features. Section 3 presents the main-memory database management system. Section 4 describes the moving objects database features. Section 5 introduces the Kairos moving object database. Section 6 details our application method. Section 7 concludes the paper with directions for future work.

Track Management

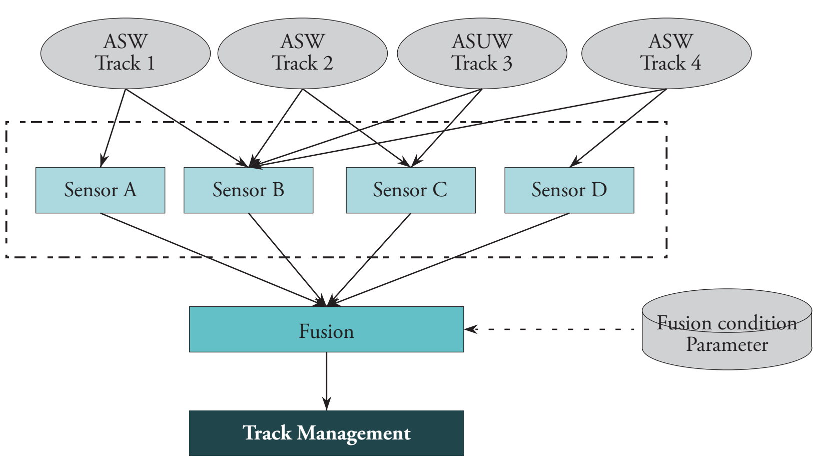
The track manager is an improved component within combat systems that receives and translates information from air, surface and subsurface sensors to create an integrated picture of the locations and paths of aircraft, ships and submarines in a battle space area.

The process of combining data has been called sensor correlation and fusion, or simply data fusion. [1]Data fusion is a multilevel, multifaceted process dealing with the registration, detection, association, correlation, and combination of data and information from multiple sources to achieve a refined state and identity estimation, and complete and timely assessments of the situation.

Sensors produce individual observations or measurements (source track) that must be placed in proper context first to create organized data sets, and then evaluated to infer higher-level meaning about the overall content for the information.

The process of fusion which partitions data into associated categories includes correlation and

Fig. 1. Track Fusion.



association stages. In a typical problem, the data from different sensors are partitioned to associate all measurements from common targets into individual target categories. Sensor measurements are compared with correlation metrics that use temporal, spectral or spatial properties to score each alternative assignment hypothesis. The sensor data is then associated with the corresponding data from other sensors and is assigned to categories.

[2]Track Management has been developed by open architecture. It will potentially be installed on many surface and air platforms. OA (Open Architecture) framework will assist the Navy with integrating a single, cost- effective track manager that can be easily maintained and upgraded to meet emerging customer requirements.

In this paper, we put emphasis on the OA framework track management using the COTS (commercial on-the-shelf) database.

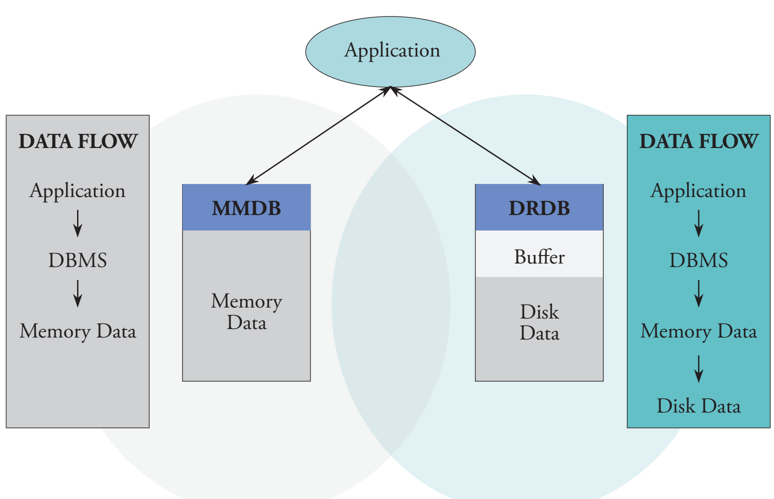
Main memory Database management system

[3]In a main memory database system (MMDB) data resides permanently in the physical memory; in a conventional database system (DRDB) it is disk resident. In a DRDB, disk data may be cached into memory for access; in a MMDB the memory resident data may have a backup copy on disk. So in both cases, a given object can have copies both in memory and on disk. The key difference is that with the MMDB, the primary copy lives permanently in the memory. This is because data can be accessed directly through the memory, MMDBs can provide fast response times and transaction throughputs, when compared to DRDBs This is especially important for real-time applications where transactions have to be completed by their specified deadlines.

A computer's main memory clearly has different properties from that of magnetic disks, and these differences have profound implications on the design and performance of the database system. Although these differences are well known, it is worthwhile reviewing them briefly.

A) The access time for the main memory is magnitudes less than for the disk storage access.
B) The main memory is normally volatile, while disk storage is not. However, it is possible (at some cost) to construct a nonvolatile main memory.
C) Disks have a high, fixed cost per access that does not depend on the amount of data that is retrieved during the process. For this reason, disks are block-oriented storage devices. The main memory is not block oriented.
D) The layout of data on a disk is much more critical than the layout of data in the main

Fig. 2. MMDB and DRDB.



memory, since sequential access to a disk is faster than random access. Sequential access is not as important in main memories.
E) The main memory is normally directly accessible by the processors, while disks are not. This may make data in main memory more vulnerable than disk resident data to software errors.

Table 1. Compare DRDB and MMDB.

	MMDM	DRDB
Data model	Relational	Relational
System Structure	Client/Server and inner DB	Client/Server
Server Structure	Multi-Thread	Multi-Thread / Multi-Process
CPU Use Rate	lower CPU use rate using simple search Algorithm	Higher CPU use rate using complicate search Algorithm
DISK I/O	Minimum disk I/O in order to Recovery	Normal disk I/O in order to Select, Insert, Update, Delete

These differences have effects on almost every aspect of database management, from concurrency control to application interfaces.

Moving Object Data management system

[4]The moving object databases stores all kinds of data related to a moving object, such as location, direction, and other temporal data. Therefore, this kind of database considers how real world phenomena represented in the database is positioned in a given spatial and temporal framework, and requires defining new data types and operations. The moving object database utilizes not only spatial database concepts, but also temporal database concepts.

The major motivation for studying spatial databases is for the support of geographic information systems. Early GIS made only limited use of the DBMS technology. However, commercial spatial databases offer spatial extensions now. Hence, it can be stored all the data of a digital map in the database. All diverse entities can be modeled by three fundamental abstractions which are point, line and region.

On the other hand, the goal of the temporal database research has been to integrate temporal concepts deeply into the DBMS data model and query language and to extend the system accordingly to achieve efficient execution.

In most of the applications, it is possible to visualize the world as a digital map, with altitude and other data. New indexing techniques are implemented on spatial and temporal data in order to efficiently query this kind of data. Thus, R-tree indexing and its derivatives are used in moving object databases. Moving object databases have fully been implemented. For this paper, we used a Kairos MO database.

The Kairos MO is a main memory database that provides high-speed transaction processing performance. In addition to high performance, the Kairos MO database provides a storage feature for moving object location in real time, and processing feature of spatio-temporal query.

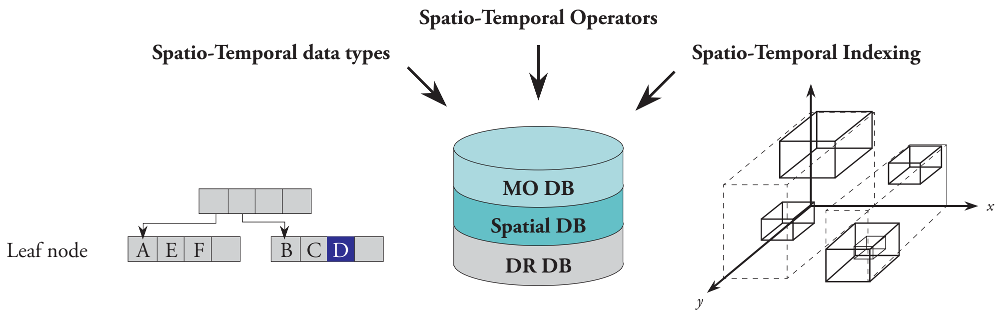
The Kairos MO database is based on the Kairos spatial database.

In order to express moving object, it provides spatio-temporal data type, spatio-temporal operators, an index for spatio-temporal data, and processing for uncertainty. Thus, it supports a function for the processing of moving objects which change their positions or shapes constantly over time. It also supports the Kairos Spatial object processing function.

Kairos moving object database system overview

[5]The usage of the Kairos moving object database in this paper, gives features regarding about data type, operator, and index.

Fig. 3. Kairos moving object database overview.



Spatio-Temporal Data Type

The Kairos MO database supports three type data types: temporal data type, spatial data type, and moving object type. The Moving object type comprises an MBase type for representing value which changes over time, and MGeometry for representing moving objects which change their positions or shapes over time.

Spatio-Temporal Operator

The Kairos MO database supports various spatial-temporal operators: moving object creation and updates, attribute information analysis and extraction, as well as the phase relationship between each spatio-temporal object.

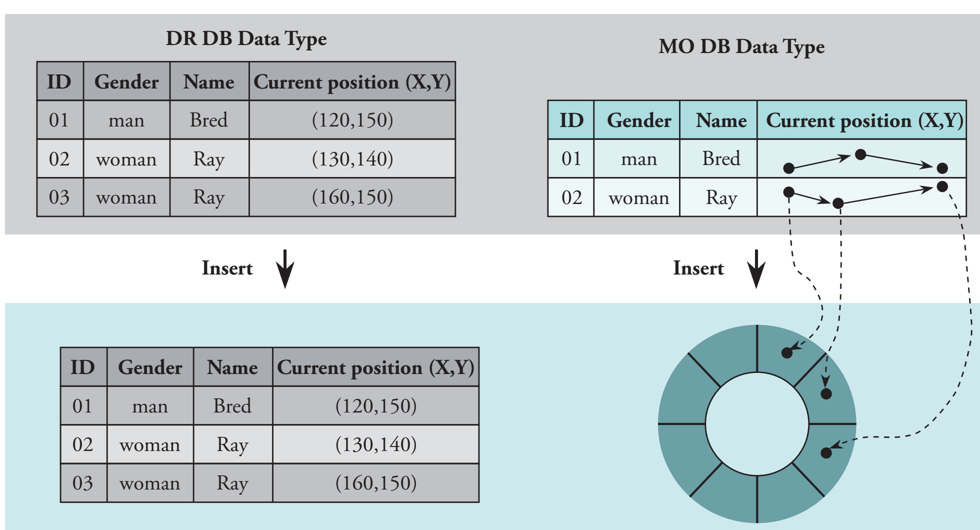
Table 1. Compare DRDB and MMDB.

Operator	Description
Spatio- Temporal Relation Operators	Analysis spatial phase relationship between moving spatial object-moving spatial object or moving spatial object-spatial object.
Set Operators	One moving spatial object or moving spatial objects.
Trajectory Relation Operators	Analysis phase relationship of trajectory of moving object.
Temporal Relation Operators	Analysis time phase relationship between temporal object – temporal object.

Spatio-Temporal Index

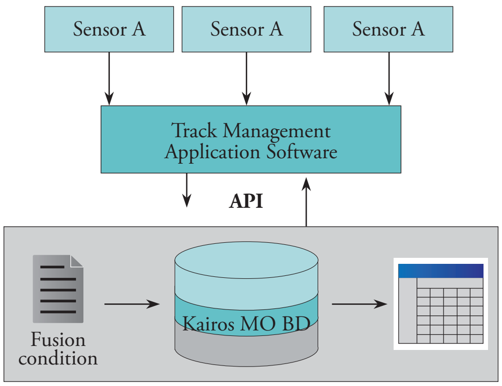
The Kairos MO database supports the spatio-temporal index of a 3D R* Tree structure. It uses minimum bounding rectangle information

Fig. 4. Moving object DB data type.



for high spatio-temporal query process performance.

Fig. 5. Database Track Management Sequence.

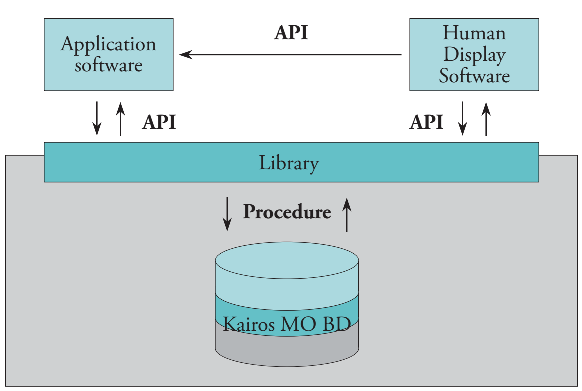


Database track management sequence is as below

A. Create table with a reference to parameter for the target fusion's available condition.
B. Database API (application program interface) calls using triggers when sensor track information is input.
C. Determine fusion availability according to the target's location using the moving object database function.
D. Insert results into the fusion table.
E. Return the fusion table value from the database.

It can store, update, create track using moving object database, by the process of using a track management sequence. It can also fuse using the moving object database function.

Fig. 6. Database Track Management API.



If you look at the API interface, application software and human display software are connected with the database track management by library. It is processed through about 100 API calls. The application software obtains a fast result and response using the database procedure.

Conclusion and future

In this work, the usage of the moving object databases, which have different capabilities than traditional databases, is defined for track management. This paper proposes a method that the moving object database be used with target fusion.

The use of a commercial on-the-shelf product guarantees reliability and usability. Furthermore, it has a cost- effective track manager that can be easily maintained and upgraded to meet emerging customer requirements.

In the future, databases can replace the track-management function of combat management systems. As a common module, it can also be applied to various combat management systems.

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Conversion from a Single-Hull to a Double-Hull Oil Barge, Keeping the Load Capacity

Conversión de una barcaza petrolera de monocasco a doble casco, conservando la capacidad de carga

Ramón Velasco Stoll [1]
John Schuler Frantzen [1]

Abstract

This document consists of a description of the project for converting a bunker oil barge from single-hull to double-hull, for this to meet the regulations of the maritime authority of Peru and the rules of the RINA Classification Society. It is exposed to the Owner, technical and economic options, in order to bring to him the best solution in time and budget. Also, is brought into discussion, the benefit to the owner that it would be of converting the outer hull. So as well, is presented, the challenges faced during the production process and the solutions adopted by the engineering team and shipyard production.

Key words: Conversion, single-hull, double-hull, bunker oil barge.

Resumen

Este documento consiste en una descripción de un proyecto para convertir una barcaza petrolera de monocasco a doble casco, para esto convergen las regulaciones de la autoridad marítima de Perú y las reglas de la sociedad clasificadora de RINA. Es expuesto al propietario, opciones técnicas y económicas, para otorgarle la mejor solución en tiempo y presupuesto. También, se trajo a discusión el beneficio para el propietario que sería convertir el caso exterior. Así mismo, se presentan los diferentes retos asumidos durante el proceso de producción y las soluciones adoptadas por el equipo de ingenieros y de producción de buque.

Palabras claves: Conversión, monocasco, doble caso, barcaza petrolera

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Introduction

The purpose of this document is to expose the activities developed during the work of converting a bunker oil barge capacity of 16,000 barrels, with RINA class, from single hull to double hull, to meet the regulations of the national maritime authority to transport of liquid fuels in Peru.

The work begins with the meeting between the shipyard and ship-owner, in order to determine the scope of the modernizing jobs. There were two critical points of the project, the first one, the effect of conversion of the barge with its capable of maintaining the load capacity , and the second one, meet the need of the owner, proposing to it, a short-term project delivery. Additionally, the Owner required having the latest date for entry of the barge to the dock and a date as close to their departure. It was vital propose to him, the shortest possible time for standstill of the barge in the yard, so they can continue to meet its trade commitments with their customers.

The Design Office of the shipyard Construcciones A. Maggiolo S.A. (CAMSA), in conjunction with staff of the yard, developed a constructive strategy so that they were able carry out the conversion of the barge attending to the needs of the ship-owner. Conversion single hull to double hull it was planned through the change in width and depth of the Barge. Will be fabricated Modules at both sides and new double bottom, which constitute the new side shell of the hull. Building blocks and erection sequence, allowed us to define a schedule of activities in conjunction with the ship-owner. Project milestones are set according to the schedule provided, which were subsequently considered in the contract signed between the shipyard and ship-owner.

At the beginning of the work, the shipyard planned the preparation of the pieces and parts, sub-assemblies and assemblies of the new modules. With these structures, the different panels and modules of the port and starboard sides and double bottom were made. All work was carried out by performing traceability and under quality assurance standards. The conceptual design and construction works were inspected by the classification society RINA (Italian Register of Ships) member of IACS (International Association of Classification Societies).

Brief history of Maggiolo Shipyard

Construcciones A. Maggiolo SA (CAMSA) was founded in 1942 by Don Augusto Maggiolo Cavenecia, At Chucuito City area in the port of Callao, department of Lima in Peru. In the beginning, small boats for artisanal fisheries were built. By the mid-50s with the development of industrial fisheries in Peru, the company expands its operations, and starts a period of shipbuilding industrial fishing of anchovy (purse seiners) intended for fish meal.

Fig. 1. View of Shipyard CAMSA - Chucuito in the port of Callao.

The Peru became the world's largest producer of fishmeal, in those years CAMSA had up to 40 vessels under construction at a time. In the late

50s, the shipyard delivered a series of patrol boats to the Peruvian Navy. During the 60s, they came to convert more than 300 industrial fishing vessels. During the 70, 80, and 90 shipyard focuses on maintenance the Peruvian industrial fishing fleet. In the late 90s, investments increased the capacity of Dry-docking, for vessels up to 55 meters in length and 1,000 tons of displacement.

In the early 2000, begin construction of fishing vessels including cooling systems in warehouses (RSW) with a length of up to 55 meters; at the same time, in order to correct the conditions of stability and freeboard Peruvian fishing boats, CAMSA begins to proceed with the modification of these vessels (extensions). In late 200, CAMSA acquires a new field of 55 hectares, which began operations in 2010. This new shipyard has the capacity to serve ships up to 105 meters in length and 2,500 tons of displacement.

Fig. 2. Vista Shipyard CAMSA- Barlovento Oquendo near the port of Callao.

Fig. 2. View of Ferry project Shuttle maneuver.

In 2011, CAMSA builds a Ferry to 82.4 meters with capacity for 850 passengers and 160 cars. In 2012, a Platform of Petroleum Exploration is constructed with 100 meters high and 1,800 tons.

Project Background

Through Regulating R. D. 018-2011 (DICAPI, et al., 2011) which requires all ships and barges greater deadweight 150DWT, transporting, storing or producing oil in bulk, and operating within the maritime domain of Peru and inland water, must have double hulls. This comes as additional reach the requirement of international MARPOL convention which entails taking double hull vessels or barges with greater deadweight 5000DWT.

Within the scope of the standard, Peru maritime authority has issued certificates for extension of time, setting as peremptory date until 31 December 2014 for vessels that have not yet reached 25 years of service. Whereupon it was established that as of that date, ships or barges that do not have double hull and double bottom as required by MARPOL and DICAPI not will be allowed to operate.

With this background, the ship-owner and shipyard started talks to propose the best alternative for carrying out the project of conversion to double hull and double bottom in the Barge ANTU, the same that has the following characteristics:

Table 1. Project Data Sheet (Compilation).

Owner / Ship Name:	PETROTANKERS S.A. / Barcaza "ANTU"
Length :	64.200m
Width:	10.584m
Depth:	4.400m
Deadweight:	2336 DWT (Aprox.)
Place of operation:	Bahía del Callao
Classification (RINA):	C • barge-oil product (pi>60 C); sheltered waters

Analysis of Alternative Solutions

To initiate the technical and economic evaluation of the project as well as develop basic engineering, and due to the barge did not have reliable information as to the physical condition of structures, complete inspection of the barge was necessary, Noting the level of detail required for this stage, we proceeded to inspect the barge at anchor in the port of Callao. During project appraisal, CAMSA present two work alternatives, which could be met by existing shipyard facilities, which were:

- External Modification
  To pursue this alternative would involve modifying the width and depth of the barge. It would require the development of detailed engineering for the construction of new compartments double bottom and double hull side.
- Internal Modification
  Which would involve the need for Dry-docking during the time required to modify the internal structures of the barge, without altering the dimensions of the width and depth, but reduced load capacity.

The advantages and disadvantages of the alternatives listed below:

According to this preliminary assessment, the ship-owner requested to carry out the proposed modification of the outer hull, since in this way the impact on future operations would not be affected by the loss of capacity of 27% compared to the original conditions. Maintaining the capacity at 100% allowed the customer clearly finance the project and also shows the additional benefits of starting work without having the barge aground in the shipyard.

Development of the Project

Once the contractual conditions is been defined, CAMSA requested to the ship-owner the Dry-docking of the barge in the shipyard for a period of 48 hours, in order to carry out a technical inspection and collect detailed information for the development of project plans which they were unable to be evaluated during the first inspection. This activity allowed to the engineering office team; determine existing distortions and misalignments in the original barge. Module planes are shown in the figures shown below:

Table 2. Validation of Alternatives Project (Compilation).

Description	External Modification	DRDB
Advantage	- Ease of module construction of the hull and double bottom - Longer commercial use, late entry into the shipyard for doing work. - Relatively short duration work and stay in shipyard - Availability of space in the yard (No use of docks) - Conservation capacity of the ship (DWT)	- Low steel consumption, utilization of internal structures. - The new structures will accommodate existing, being avoided problems of misalignment. - Lowest price project
Disadvantage	- Increased consumption of Steel - Increased cost of the Project - Possible misalignments relative to the old hull structures	- Loss of carrying capacity of the barge (DWT) - Greater downtime of the barge
Relative amount of steel to be processed in% (C)	165%	100%
Relative cost per Kg. steel processing (c)	1	1.5
Relative cost of the project[1]	165/150 = 1.1	150/150 = 1
Variation DWT	0%	-27%

[1] Value obtained from the ratio of the External Project Cost divided on the Internal Cost Project.

Fig. 4. Breakdown of module DFZ1ER.

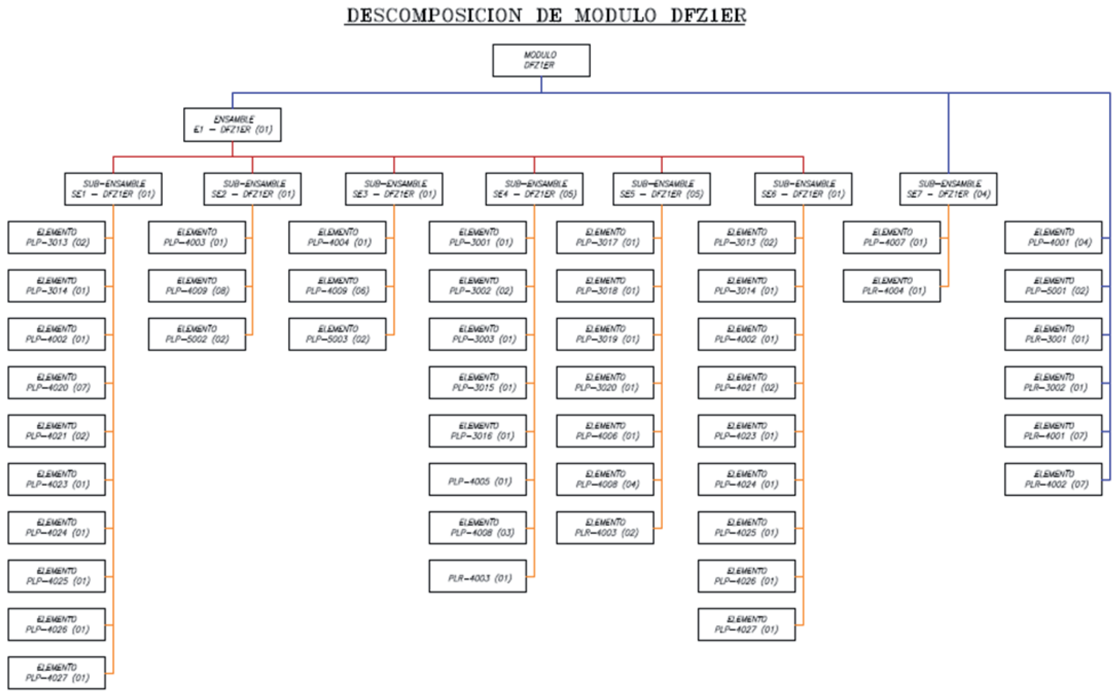


Fig. 5. Isometric View of DFZ1ER module.

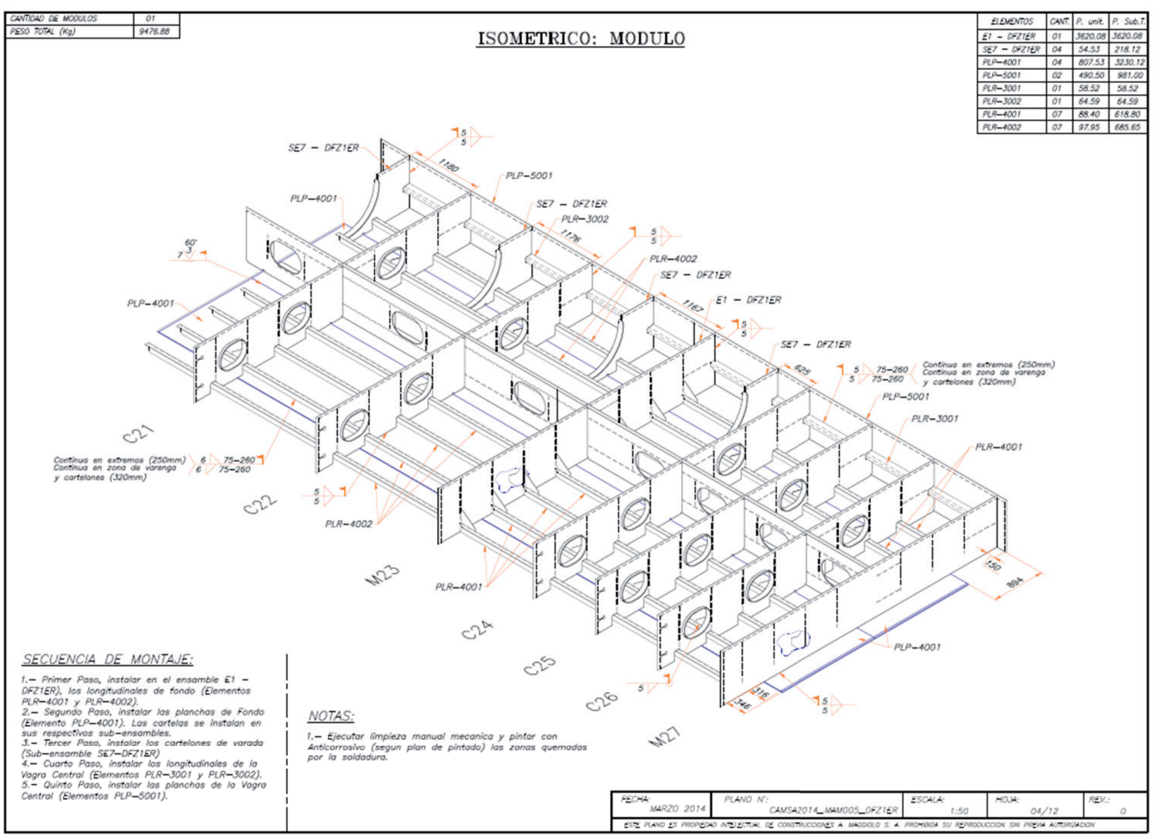
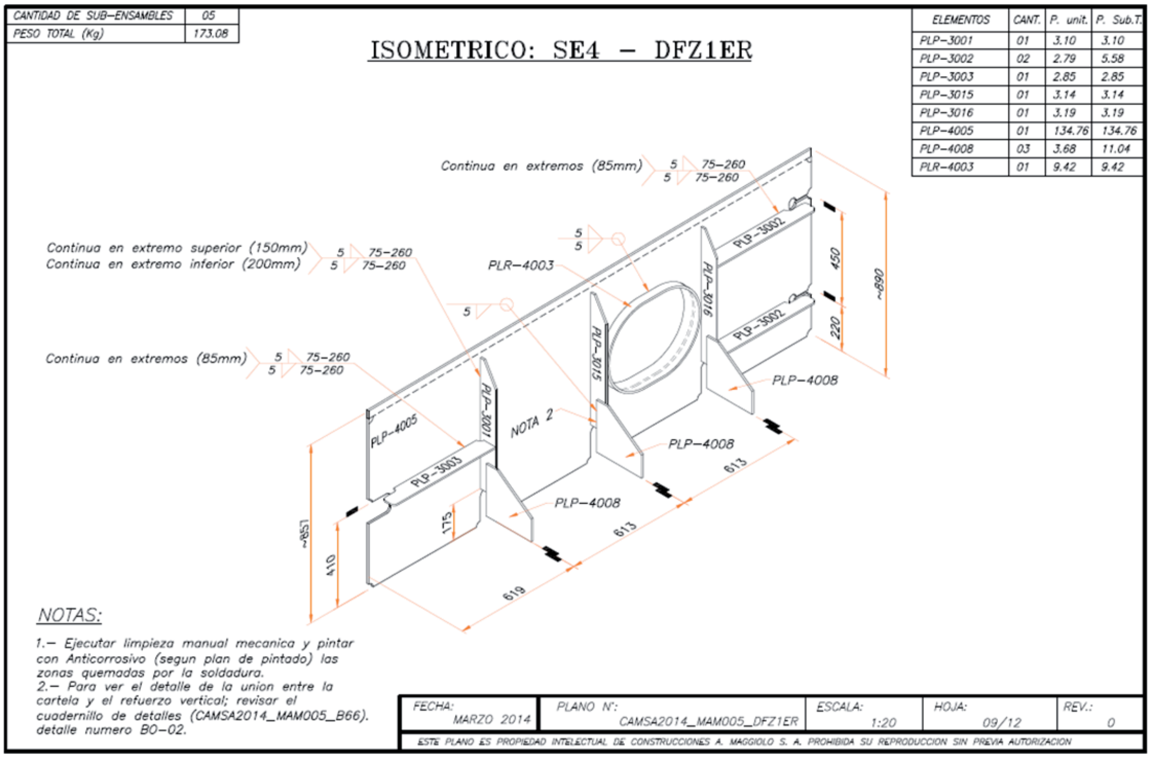


Fig. 6. Isometric View SE4 - DFZ1ER module.



The engineering office prepared the detailed engineering information for the area of production, a way that allows the cutting of 100% of the parts, subassembly and assembly of panels and modules side hull and double bottom. The deliverables were classified according to:

- Development of Detail Engineering.
- Fabrication of parts (Nesting[2]).
- Installing Modules and modification of the bow and stern.

Fig. 7. Steels Parts - Fabrication Phase.

Fig. 8. View of panels – Sub Assembly.

[2] Nesting: placing process in a steel plate as information necessary for cutting pieces executed automatically by a numerically controlled flame cutting machine, avoiding wastage.

Fig. 9. Panels of bottom and side hull.

Fig. 10. RINA inspection in the yard.

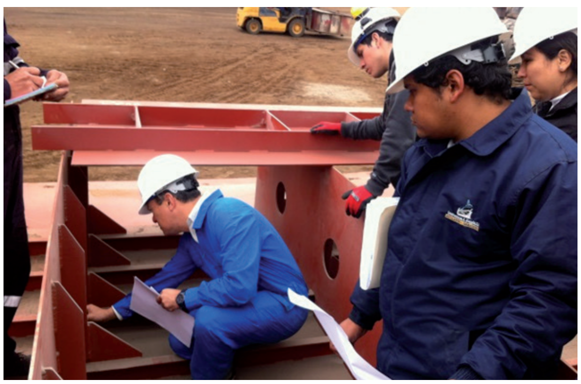


Fig. 11. View of Double Bottom.

Fig. 12. View of Side Hull.

Fig. 13. View of the bow.

Fig. 14. View of the stern.

Modular Manufacturing Challenges

During the initial inspections on the barge, it was found existing deformations in the bottom and on the sides of the barge, produced throughout their services. Reason why all modules have worked with machining allowances strategically placed to absorb these deformations without the need to reduce the regulatory distances double hull and double bottom. The machining allowances were trimmed with existing hull shape.

Another challenge, a little more complicated of coping, was the misalignment of existing structures, presumed to be due to the age of the barge and all repairs that he received throughout his life. Ultimately this misalignment was impossible to make new structures are aligned to existing structures. Neither was feasible to build structures misaligned since it would require a lot of work and the concept of modularity and standardization that were exposed advantage to adopt the outer hull conversion would be lost.

Misalignment sections structures were observed up to 40mm. To determine how these structures are affected by misalignments indicated, the following analysis was performed.

Calculation of hydrostatic pressure on the double bottom plate

For this calculation the following data were obtained:

- Height of liquid cargo tanks to the top of the vent pipe (h) = 7.75m
- Approximate density of load (d) = 1,000kg / m3
- Acceleration of gravity (g) = 9.81m / s2

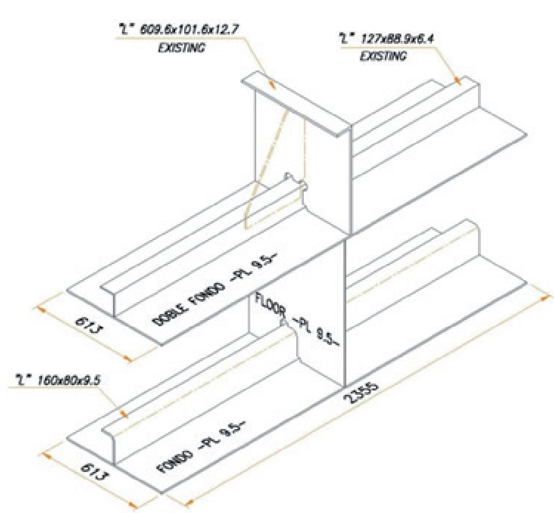
With these data it was found that the value of the hydrostatic pressure that occurs on the bottom plate is 76,000N / m2.

Determination of the typical analysis section.

Typical section, Is a representative section to help simplify the calculations, the same as shown below:

- The width of the typical section of 613mm (spacing between longitudinal)
- The length of the typical section of 2355mm (separation between bottom transverses)

Fig. 15. Typical Section.



Considerations for stress transfer

Another approach which simplifies the calculations without lead to significant errors knows how their stress between the structures of the barge is transmitted. In general, the forces are transmitted via the adjacent structures which have increased resistance to deformation; i.e. the stress that have greater moment of inertia.

Our analysis is simplified to apply the concepts of bottom floors; in this case, the deformation is directly proportional to the load applied divided by the moment of inertia.

$$Deformation = Cte \times \frac{load\ applied}{Moment\ of\ inertia\ (I)} \quad (1)$$

In this regard, if two bottom floors subjected to the same deformation, the load applied is distributed in proportion to the moments of inertia, as follows:

$$\frac{Load\ applied\ in\ Floor\ 1}{Moment\ of\ inertia\ in\ Floor\ 1\ (I_1)} = \frac{Load\ applied\ in\ Floor\ 2}{Moment\ of\ inertia\ in\ Floor\ 2\ (I_2)} \quad (2)$$

Thus, it showed the sequence of force transfer from the inner bottom plate to the reinforcing structures of the double bottom:

- The plate supports the hydrostatic pressure of the liquid.
- Longitudinal double bottom are attached to the plate using the welding between longitudinal reinforcements and inner bottom plate.
- The bottom floors (new and existing) holding the longitudinal absorbing stress in proportion to its moment of inertia.
  - Existing misaligned floors, are tied to the longitudinal through the welded joint between the web of longitudinal reinforcement and the web of the floor, absorbing 11.8% of stress (see "Moment of inertia of bottom floor"), which is not a problem.
  - The new floors are tied to the longitudinal through a prismatic cross-section, with

rectangular horizontal section of 9.5mm x 6.4mm, absorbing the 89.2% of stress (see "Moment of inertia of bottom floor"), which is a problem.

Moment of inertia of the bottom floor

By continuing, it shown the moment of inertia of the new and existing floors, including involved plates, with respect to a longitudinal axis (xx) passing through its neutral axis.

- $Ixx_{(existing\ floor)}$ = 1097x106mm4 (11.8%)
- $Ixx_{(new\ floor)}$ = 8140x106mm4 (89.2%)

Fig. 16. Section of calculation lxx in existing bottom girders.

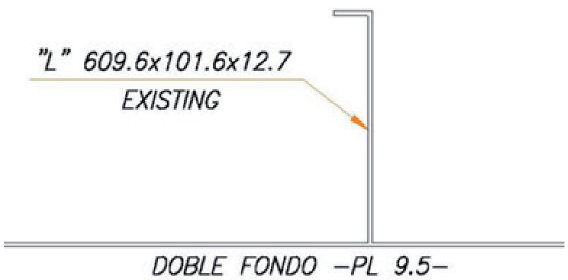
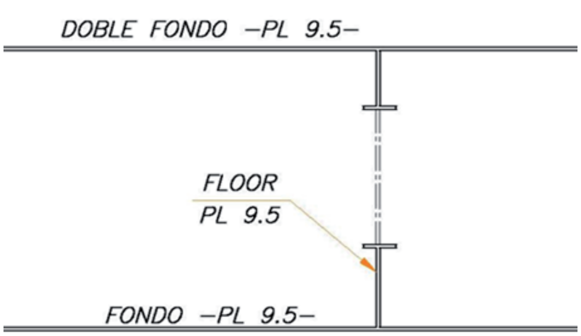


Fig. 17. Section of calculation lxx in new bottom floors.



Intersection stress in the new bottom floor and longitudinal of the double bottom

In Figs. 18, 19 and 20 it shown the critical area of study, it will serve to obtain technical and viable solution states. The calculation of stress at the point shown is applied by:

- The acting pressure on the inner bottom plate (P) = d * g * h = 76027Pa
- The acting force on the plate of typical section (Ft) = P * 0.613 * 2.355 = 109754N
- The longitudinal force transmitted to the bottom floor (F) = 0.892 * Ft = 97900N
- Transversal area for calculating normal stress = 9.5 * 6.4 = 60.8mm2
- Normal stress = 97900/60.8 = 1610.2N/mm2

In the demonstrated calculation it is observed that the stress concentration well exceeds the allowable value (235N / mm2), so it is necessary to increase the stress transmission area at least 14 times, to ensure that these results do not exceed the permissible values and maintain a safety factor equal to or greater than 2.

Fig. 18. Critical Zone of evaluation.

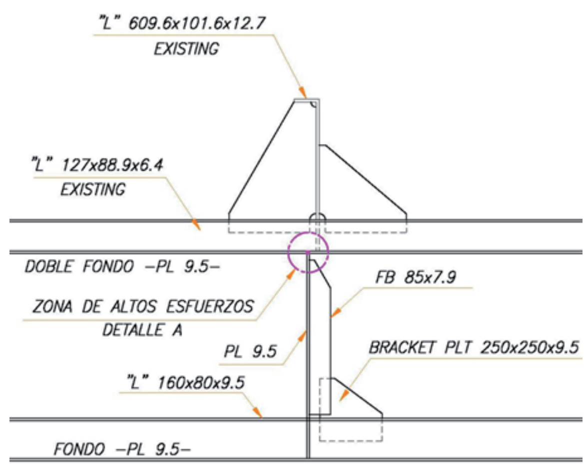


Fig. 19. Detail A.

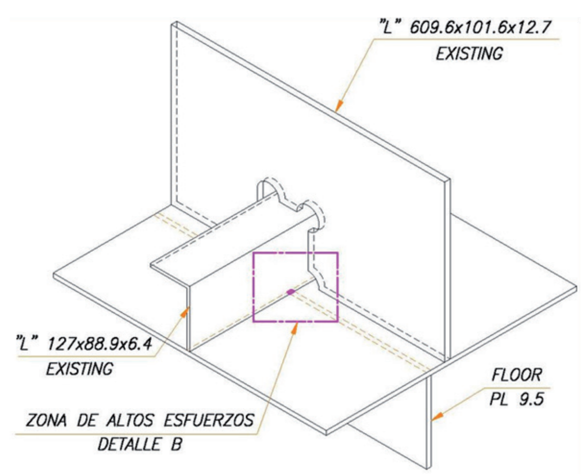
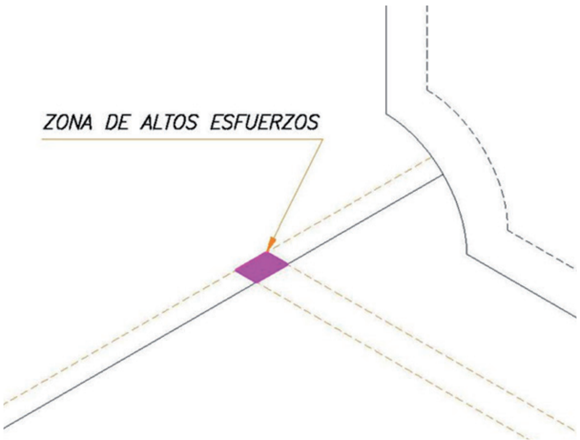


Fig. 20. Detail B.

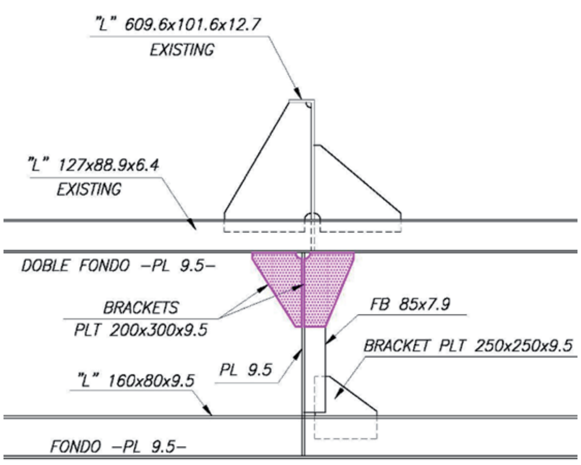


Distribution proposal of stress

Fig. 21 below shows the proposal to reduce the stress concentration generated in the misalignment of the structures.

This proposal increases the stress transmission area to 2361.6mm2, which helps reduce the normal stress from 1610.2 to 41.4N / mm2, which is considered safe (safety factor equal to 5.6)

Fig. 21. Proposal of reinforcement by two gussets 200x300x9.5.



Distribution proposal of stress

The project was developed as planned. Table 3 summarizes the project.

Conclusions

- The short time that the barge was in the yard without operating was meaningful and beneficial to the Owner.
- Performing the conversion of double hull barge using the external original hull, allows the barge keep 100% of its original charge capacity. With which, from the economic point of view, keep up future flows of freight operation, which facilitate the investment financing of the project.
- The solution proposed by the shipyard engineering office, allowed providing technical and economically viable solution to the problem of misalignment of structures. Since it would not be possible to remove the existing bottom girders because, according to what observed by RINA, these bottom girders serve to reduce the unsupported length of the longitudinal double bottom deck.
- The benefits of working over the outer hull, allowing using a modular construction strategy, achieving higher productivity and better working conditions within the shipyard.
- This project was the first work of conversion outer hull barge, performed successfully in Peru.

References

DICAPI, DG and Coastguards of Peru, Directorial Resolution 018-2011, Rules relating to the requirement of double hull vessels between 150 DWT. Less than 5000 DWT.

Table 3. Project Results (Compilation).

Project	Before	After
Length:	64.200m	64.200m
Width:	10.584m	12.123m
Depth:	4.400m	5.187m
Dead weight:	2336 DWT	2336 DWT
Class (RINA):	C • barge-oil product (pi>60 C); sheltered waters	
Project Start Date:	12 Mayo 2014	
Date of Dry-docking for inspection (48 hrs.)	22 Mayo 2014	
Dry-docking date for fabrication start	14 Julio 2014	
Time Length of block manufacture	15 Mayo al 30 Julio 2014	
End date of Project:	18 Noviembre 2014	
Project Duration time:	120 días de trabajos de construcción 25 días de pruebas a flote	

Fig. 22. View Barge "ANTU" in final stages of work.
Behind the fishing vessel "SIMON" after lengthening it.

A method for track fusing using data association in naval combat system

Un método para fusión de trayectoria usando asociación de datos en el sistema de combate naval

Eunmi Oh [1]

Abstract

In today battlefield multi-sensors installed on naval ship are acquiring too much information. Information is used through naval combat system to improve reaction capability to threat more quickly and precise. For acting to threat, we have to make a decision whether same ones what each target from multi sensor and execute track fusion according to result of judgment. So in this paper, we propose the track fusion method using track's varied information. We predicted and estimated the target state based on dynamic information using data association filter so made valid measurement area what is assumed that track exists. This algorithm can set up the criterion what is adaptive current status of track. Second we selected track among existing tracks in valid area by attributing weighting. The weight considers track's information like identification, category and so on. We would like to execute more precisely track fusion through this fusion algorithm.

Key words: Combat Management System, Track Fusion, Data Association, Tracking Filter.

Resumen

Actualmente los sensores múltiples del campo de batalla instalados en una embarcación naval están adquiriendo demasiada información. La información es usada a través del sistema de combate naval para mejorar la capacidad de reacción y para amenazar de manera rápida y precisa. Actuar para amenazar, se debe tomar una decisión sobre cuál de los objetivos del sensor múltiple y ejecutar la fusión de trayectoria acuerdo el resultado del criterio. En este artículo, proponemos el método de fusión de trayectoria usando información variada de rastreo. Pronosticamos y estimamos el estado del objetivo en información dinámica usando filtro de asociación de datos lo cual hizo válida la medida de área que es asumida como trayectoria existente. Este algoritmo puede establecer el criterio cuál estado actual de adaptación de trayectoria. En segundo lugar, se eligió la trayectoria entre las existentes en un área válida mediante la atribución de ponderación. La ponderación considera la información de la trayectoria tal como: identificación, categoría, entre otros. Se podría ejecutar la fusión de trayectoria de manera más precisa a través de un algoritmo de fusión.

Palabras claves: Gestión de sistemas de combate, fusión de trayectoria, asociación de datos, filtro de trayectoria.

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Introduction

Naval combat management (CMS) system receives information from multi-sensors and weapons, tactical data communication mounted on ships. It plays a role as brain of battle ship by monitoring battlefield, executing threat evaluation of detected tracks to help command decision of commander, acting to threat tracks. Therefore, in naval ship target detection from multi-sensors, detected target tracking, command decision and action for engagement is constantly repeated.

Today sensor capability is growing day by day, and consequently a lot of the high quality target information is obtained together. So we should start from the correct identification of the target in order to respond effectively to the threat. For this reason, the naval combat system has been required a technique for fusion tracks from each sensor are determined same target. This fusion technology is very important because the threat evaluation and engagement are executed on the basis of a fused target.

The condition for determining that the same target considers the various feature of track like identification (hostile, friend, neutral…), form (point track, bearing track…), category (air, surface, subsurface ...), position and maneuver information. In real battlefield situation, some attributes of target (identification, category, form, etc..) doesn't easily change but target state (position, maneuver) changes each time. Because prediction of track state is difficult so precise track fusion technology what is adaptive with maneuver is required.

In this paper, we propose a method for track fusing by estimate track state variable using a dynamic filter. First, validation gate of reference target is stochastically calculated using data association. (The same target from other sensors is assumed to exist in the validation gate) And then a measurement that is determined to be equal to the reference target among measurements are located in validation gate is selected. The validation gate is calculated by predicted state variable from dynamic filter and measurement of sensor.

In chapter II~IV, related theories and simulation result are suggested, in the last chapter a conclusion is showed.

Background

Track management is one of the main data processing algorithms of the CMS. This has the functions to process and fuse incoming data from multi sensors and communication systems. In today as mission type is changing solo to join, importance of the track processing is gradually being raised. Condition of the track fusion that has been operating in the combat system of the ship is as follows [1]:

1. Track attributes (Identification, category, type, etc.) match
2. Track position – distance between the candidate tracks have to below criteria.

But if the distance between the candidate tracks is configured as a constant, it can't reflect the battlefield situation. Therefore a lot of studies for track fusion are being carried out and research on data fusion is especially active.

Data fusion is to fuse acquired measurements from multi sensor and to trace trajectory of fused tracks using data association. This is method for obtaining a better tracking performance in the clutter environment. In data association method, track and measurement means like this:

- Measurement : acquired target information at the current time.
- Track: estimated measurement with traceability

And Data fusion that estimates track state variable (position, maneuver) exists in different forms.

1. Measurement fusion : measurements from multi sensor are fused in fusion center and then estimate track based on the fused measurement. (fusing → generating track)
2. Track to Track fusion : Local tracks are created by estimating track from each sensors. And

then when between local tracks are determined to same, track fusion is executed.(generating local track → fusing)

To do the measurement fusion must be assumed that the measurements come from same target. On the other hand in track to track fusion we determine whether the local tracks is same track of target, after that fuse. Most of sensor mounted ship transmits measurements with traceability. So CMS have only to confirm that each track of multi sensors is same target. Therefore requires modification of data fusion, in this paper we propose a method for track fusing by making a decision as same target using data association methods.

Track Management in CMS

Track management in CMS is to manage many type of track is composed source track, system track, tactical track. Source track is measurement from sensor. It is raw data. System track is a fusion of source tracks of each sensor. Tactical track is generated from fusion between system track and data link track The fusion is executed with the rules. The procedure of track management is in the following picture.

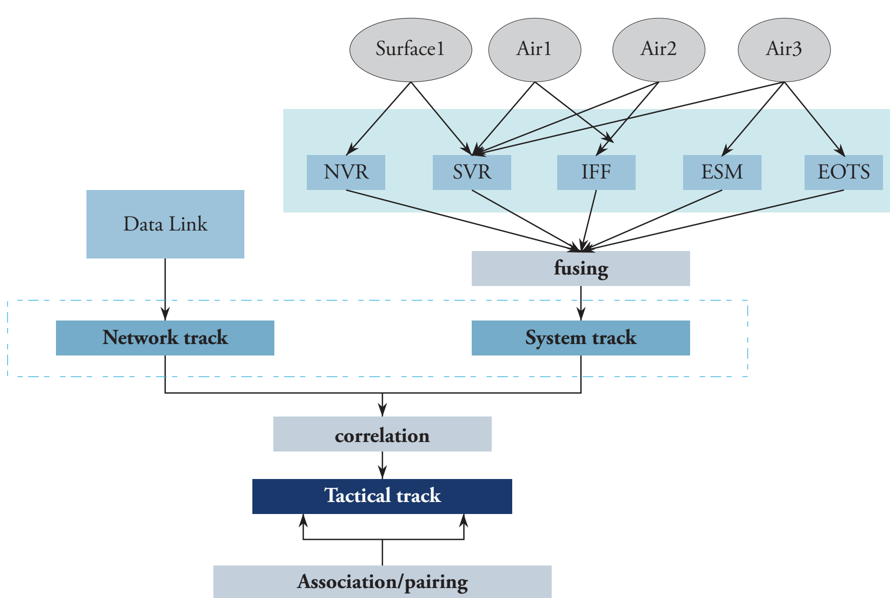
Tactical tracks that are created by the same procedure as above figure are represented on a chart of tactical display and used in tactical operation as top-level track. Tactical track information is automatically updated according to sensor update. But modification or deletion of some track information could occur by the operator. The fusion is very important function in the track management because tactical operates based on the fused track (tactical track).

Types of sensor(source) to acquire tracks are different from each other ship and track information is also different, too. Thus, the fusion is performed by using the common information. The types are as follows.

- Position (Latitude, Longitude, Altitude or X, Y, Z)
- Maneuver (Velocity, Course)
- Bearing
- Track Form (Point, Bearing)
- Track Identification (Hostile, Friend, Neutral, Pending, Unknown)
- Track Category (Air, Surface, Subsurface, Land)

Track fusion takes place using information such as above and the fusion conditions are as following.

Fig. 22. Procedure of track management.



1. The sensors (sources) of tracks have to be different from each other.
2. Forms of tracks have to be same.
3. Categories of tracks have to be same.
4. Identifications of tracks have to be allowed conflict,
5. The distance between tracks has to be less than criteria.

If candidates for fusion satisfy the all condition such as above, the fusion could be performed based on the unique value assigned to each sensor. The information of the sensor with the highest value becomes the representative information of the fused track.

On the other hand, when fused track is judged that is same track no longer, the defusion could take a place. The conditions of defusion are below and if fused track satisfy any of them, the defusion can be executed.

1. When conflict of the tracks (to form a fused relationship) identification is generated.
2. When the distance between the tracks (to form a fused relationship) increases.

As mentioned in the introduction, some attribute of track (type, form, identification, etc.) aren't easily changed but because the position or maneuver information changes every time track, distance between fused tracks may can't be the same each time for update.

So this paper would like to propose a new method about conditions relating to the distance in order to increase the accuracy of fusion.

The fusion

When the track is located within the validation area of other track.

The defusion

When the track moves out of the validation area of other track.

The validation area is set adaptively to the situation in the track using the method used by the data association and the concerned theory and methods will be suggested in the next chapter.

The validation area calculation

Data association method is to select a measurement what is determined as target from a number of measurements and to combine with trajectory of target in clutter environment. At this time the measurements have to be located within validation area.

The validation area is an area having a probability of presence of target and generated on the basis of estimated state variable by the tracking filter. Because the track fusion of CMS is to determine as same target, this paper would suggests the fusion method by applying concept of validation area.

For calculation of the validation area tracking filters are used and it is based on the Kalman Filter [2]. Kalman filter is an algorithm that uses a series of measurements observed over time, containing noise

Fig. 2. Track fusion.

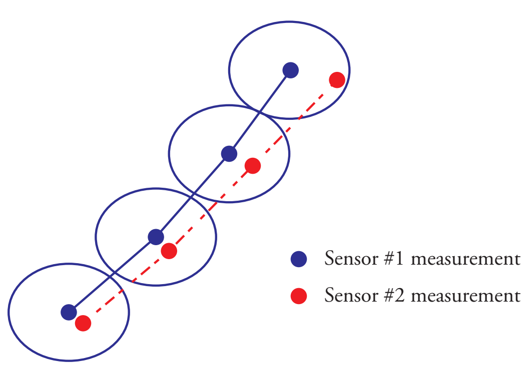
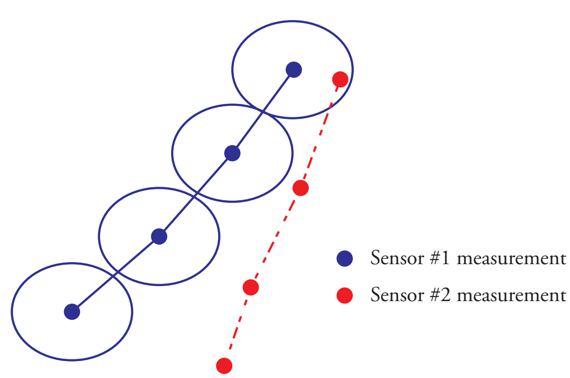


Fig. 3. Track defusion.

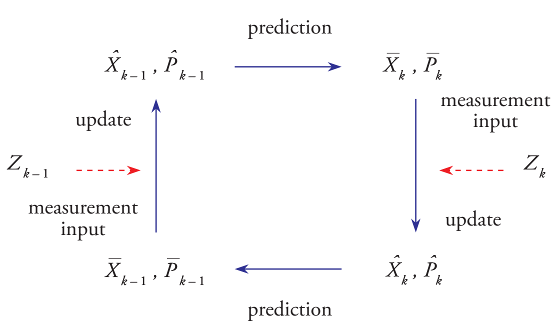


and other inaccuracies, and produces estimates of unknown variables that tend to be more precise than those based on a single measurement alone (Wikipedia). The Kalman filter has numerous applications in technology likes Radar, robotics, etc. Its algorithm is composed 2 steps.

- Prediction : predict the state variables at the present time (*k*) on the basis of updated state variables in the previous time (*k* – 1)
  - Outputs : $\bar{X}_k$, $\bar{P}_k$
- Update : estimate the state variables on the basis of predicted state variables and measurement at the present time (*k*)
  - Outputs : $\hat{X}_k$, $\hat{P}_k$

X_k is a state variable and includes position, velocity and acceleration and the like. Also P_k is a error covariance matrix at time k . The whole loop of the Kalman filter is shown in the following below figure.

Fig. 4. Procedure of Kalman filter.



Specific information for estimating the state and error covariance value is the same as Fig -, and then in this paper, we present a method to drive the validation area measured from the data association by applying the Kalman filter.

The validation area is formed with predicted position as a center at present time (*k*) and predicted position is calculated from updated state at previous time (*k* – 1). The validation area is an ellipsoid and could be presented like this.

Fig. 5. Kalman filter.

$$\bar{X}_k = \phi_k \hat{X}_{k-1}$$
$$\bar{P}_k = \phi_k \hat{P}_{k-1} \phi_k^T + Q_k$$
$$K_k = \bar{P}_k H_k^T (H_k \bar{P}_k H_k^T - R_k)^{-1}$$
$$\hat{X}_k = \bar{X}_k + K_k (z_k - H_k \bar{X}_k)$$
$$\hat{P}_k = (I - K_k H_k) \bar{P}_k$$

The validation area is formed with predicted position as a center at present time (*k*) and predicted position is calculated from updated state at previous time (*k* – 1). The validation area is an ellipsoid and could be presented like this.

$$G_\gamma(k) = \{v_k \mid {v_k}^T {S_k}^{-1} v_k \le \gamma\} \tag{1}$$

$v_k (v_k = z_k - \bar{z}_k)$ is a measurement residual as Gaussian distribution. Its mean is 0 and covariance is S_k.

$S_k (S_k = H_k \bar{P}_k H_k^T + R)$ is a residual covariance and $\sqrt{\gamma}$ is gate size of validation area. Also the volume of the validation area with the n-dimensional is derived as follows.

$$V_G = C_n |S_k|^{\frac{1}{2}} \gamma^{\frac{n}{2}} \tag{2}$$

n is the dimension of the measurement, the value becomes like

$$C_1 = 2, C_2 = \pi, C_3 = \frac{4}{3}\pi \tag{3}$$

in accordance with the *n*.

Distance between the predicted position ($\bar{z}_k$) and measured position (z_k) is determined by NDS (normalized distance squared) D what is calculated by using residual and residual covariance. NDS D is derived as follows at time *k*

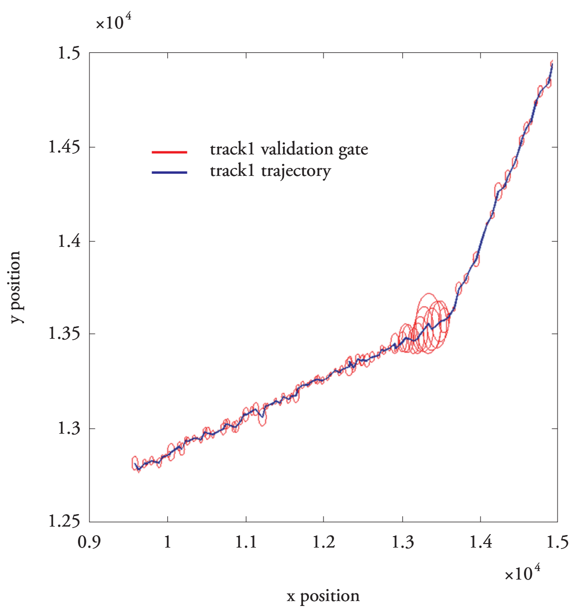
$$D_k = v_k{}^T S_k{}^{-1} v_k \tag{3}$$

NDS D has been reflected in the current status of the target because it is calculated by normalized value considering the error between predicted position and measured position. So when NDS D is less than criteria, the measurement can be assumed that came into the validation area.

As an example, the result of validation area was shown. Two-dimensional Model that is the basis for the fusion was set like this:

- The initial position: (+15000m, + 15000m)
- The initial velocity: (–70.71 m/s, –70.71 m/s) and then from 20 second will start up in the other direction.
- Sampling time: 1 sec
- Measurement error: $v_z \sim N(0,(15m)^2)$, $v_y \sim N(0,(15m)^2)$
- Filter for estimating: Kalman filter

Fig. 6. The validation area.



As a result, the validation area was expended because of increasing of difference between measured position and predicted position by unexpected turn at 20 second.

Like this because the validation area is gained by reflecting the estimated target's status in order to apply this method, target estimation(tracking) should be robust. Today various data association method being studied to improve performance of tracking and detailed information will be presented in the next chapter.

Data association

In clutter environment, data association [3~5] method is to predict and estimate of target state by finding a measurement of the target. This method using the target information can be divided into three.

1. Utilizing the signal strength of measurements
2. Utilizing the distance of measurements
3. Utilizing both the signal and the distance of measurements

But measurements what is considered to estimate have to be located within validation area. The details are shown in Table 1.

In addition studies being carried out for tracking maneuvering vehicles like IMM (Interacting Multiple Model) [6] algorithm or using the track information as weight to calculate probability. Therefore, such tracking filters will be applied effectively in combat systems of managing track information by multi-sensors.

Conclusion

The combat management system not just to manage the raw data for target from each sensor, it should fuse and manage through to determine as the same target. It is important function to assist mission execution. So in this paper, a new method for track fusing was proposed. The method is to apply the validation area of data association. In data association the validation area is an area having a probability of presence of target and generated on the basis of estimated state variable by the tracking filter. Many type of tracking filter was presented and a simulated result was included in the previous chapters. Making the validation area is adaptive because it is reflects the current situation of the

Table 1. Type of tracking filter.

Type	Name	Description
Signal base	SNF, PSNF	Considered as a target the measurement that have a greatest signal strength in the validation area
Distance base	NNF, PNNF	Considered as a target the closest measurement to the center of the validation area.
Signal and distance-base	IPDAF	Based on signal strength and distance from center of validation area of measurement, each measurement's probability that comes from real target is calculated and estimate is executed by considering the probability.
	MPDAF	Measurements are sorted to ascending order of distance from the center of validation area. And then apply this results are as weight to probability and a measurement what have highest probability is selected as a real target. (the probability that comes from real target consider both signal strength and distance)
	HPDAF	Measurements are sorted to descending order of signal strength. And then apply this results are as weight to probability and a measurement what have highest probability is selected as a real target. (the probability that comes from real target consider both signal strength and distance)

target. So this method using data association may be useful because the consideration target of the current battlefield status. But if prediction and estimation of track are failed, wrong validation area is made also. Therefore, robust tracking performance is required.

Also not robust tracking performance, but other factors should be considered further. First, one is time synchronization between the sensors because acquisition cycle is different. Second, operational time of the tracking filter should be considered for the track to be managed as a maximum at the same time.

In addition to these limitations, It is necessary to continuous research about the applicability of the tactical element and other information of track to improve the fusion accuracy.

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All articles must be sent to the editor of The *Ship Science and Technology* Journal accompanied by a letter from the authors requesting their publication. Every article must be written in *Microsoft Word* in single space and sent in magnetic form.
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All articles must contain the following elements that must appear in the same order as follows:

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It must be concise (no more than 25 words) with appropriate words so as to give readers an idea of the contents of the article. It must be sent in English and Spanish language.

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The author's name must be written as follows: last name, initial of first name . Affiliations of author must be specified in the following way and order:

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Abstract
A short essay of no more than one hundred fifty (150) words, specifying content of the work, scope, and results. It must be written in such a way so as to contain key ideas of the document. It must be sent in English and Spanish language.

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Introduction
The text must be explanatory, clear, simple, precise, and original in presenting ideas. Likewise, it must be organized in a logical sequence of parts or sections, with clear subtitles to guide readers. The first part of the document is the introduction. Its objective is to present the theme, objectives, and justification of why it was selected. It must contain sources consulted and methodology used, as well as a short explanation of the status of the research, if it were the case, and form in which the rest of article is structured.

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It is made up of the theoretical framework supporting the study, statement of the theme, status of its analysis, results obtained, and conclusions.

Equations, Tables, Charts ang Graphs
All of these elements must be numbered in order of appearance according to their type and must have their corresponding legends, along with the source of the data.

Equations must be numbered on the right hand side of the column containing it, in the same line and in parenthesis. The body of the text must refer to it as "(Equation x)". When the reference starts a sentence it must be made as follows: "Equation x". Equations must be written so that capital letters can be clearly differentiated from lower case letters. Avoid confusions between the letter "l" and the number one or between zero and the lower case letter "o". All sub-indexes, super-indexes, Greek letters, and other symbols must be clearly indicated. All expressions and mathematical analyses must explain all symbols (and unit in which they are measured) that have not been previously defined in the nomenclature. If the work is extremely mathematical by nature, it would be advisable to develop equations and formulas in appendixes instead of including them in the body of the text.

Figure/Fig. (lineal drawings, tables, pictures, figures, etc.) must be numbered according to the order of appearance and should include the number of the graph in parenthesis and a brief description. As with equations, in the body of the text, reference as "(Fig. X)", and when reference to a graph is the beginning of a sentence it must be made as follows: "Fig. x".

Charts, graphs, and illustrations must be sent in modifiable vector file format (*Microsoft Excel, Microsoft Power Period*, and/or *Microsoft Vision*).

Pictures must be sent in TIF or JPG format files, separate from the main document in a resolution higher than 1000 dpi.

Foot Notes
We recommend their use as required to identify additional information. They must be numbered in order of appearance along the text.

Acknowledgment
Acknowledgments may be made to persons or institutions considered to have made important contributions and not mentioned in any other part of the article.

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The bibliographic references must be included at the end of the article in alphabetical order and shall be identified along the document. To cite references, the Journal uses ISO 690 standards, which specify the mandatory elements to cite references (monographs, serials, chapters, articles, and patents), and ISO 690-2, related to the citation of electronic documents.

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They must be made in two ways: at the end of the text, in which case the last name of author followed by a comma and year of publication in the following manner:

"Methods exist today by which carbon fibers and prepregs can be recycled, and the resulting recyclate retains up to 90% of the fibers' mechanical properties" (*Davidson, 2006*).

The other way is:

Davidson (2006) manifests that "Methods exist today by which carbon fibers and prepregs can be recycled, and the resulting recyclate retains up to 90% of the fibers' mechanical properties".

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