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Ship Science & Technology is a specialized journal in topics related to naval architecture, ship design, hydrodynamics, dynamics of ships, structures and materials, vibrations and noise, technology of ship construction, ocean and marine engineering, standards and regulations, oceanography, maritime and river transport, and port infrastructure. 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 on paper and online.

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COTECMAR
COLOMBIA

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Editorial Note

Cartagena de Indias, January 10, 2021

In this new edition of our **Ship Science and Technology Journal**, we want to confirm our invitation to join us in the VII International Congress of Naval Design and Engineering CIDIN 2021, the main academic-scientific space for technology transfer for the strengthening of the naval, maritime and riverine industries through the participation of actors from the scientific, productive and technological sectors that are part of the innovation system of the shipyard sector and which is scheduled to take place on September 1 and 2, as a virtual space to share knowledge among our scientific community.

The International Ship Design and Naval Engineering Congress, is a space created to promote industrial development and usually takes place within the framework of the COLOMBIAMAR biannual Fair, however, in compliance with the restrictions imposed and the recommendations due to the virus SARS-CoV-2, this time it will be developed in digital format. The thematic axes for this Congress will be: Ship design and production, Shipyard 4.0 and the Competitiveness of the shipyard industry.

For this new edition of the Journal, we present very interesting topics related to the analysis applied to COTECMAR of integrated logistics support (ILS) in the shipbuilding industry, the analysis of the use of offshore platforms such as SWATH in the Colombian Pacific Ocean, the design of a marine propeller for scale racing boats, the conceptual design of a coastal patrol boat (CPV) with helicopter operations capacity and finally, the application of Cubic B-Splines Curves for Hull Meshing.

In these times of challenges, changes, and restrictions, we want to reiterate to all our readers the best professional and personal wishes. We look forward to your participation in our VII CIDIN 2021.

There we "see each other"!

Cordially,

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

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Nota Editorial

Cartagena de Indias, 10 de enero de 2021

En esta nueva edición de nuestra revista **Ciencia y Tecnología de Buques**, queremos confirmar nuestra invitación a acompañarnos en el *VII Congreso Internacional de Diseño e Ingeniería Naval CIDIN 2021*, principal espacio académico-científico de transferencia tecnológica para el fortalecimiento de la industria naval, marítima y fluvial mediante la participación de actores de los entornos científico, productivo y tecnológico que integran el sistema sectorial de innovación del sector astillero y el cual se encuentra programado para realizarse los próximos 1 y 2 de septiembre, como un espacio virtual para compartir conocimiento entre nuestra comunidad científica.

El Congreso Internacional de Diseño e Ingeniería Naval - CIDIN, es un espacio creado para promover el desarrollo y fortalecimiento industrial y el cual suele desarrollarse en el marco de la Feria bianual COLOMBIAMAR, sin embargo, en cumplimiento de las restricciones impuestas y de las recomendaciones debido al virus SARS-CoV-2, en esta oportunidad se desarrollará en formato digital. Los ejes temáticos para este CIDIN serán: Diseño y producción de buques, Astillero 4.0 y la Competitividad de la industria astillera.

Para esta nueva edición de la revista, presentamos temas muy interesantes relativos al análisis aplicado a COTECMAR del soporte logístico integrado (ILS) en la industria astillera, al análisis del uso de plataformas costa afuera tipo SWATH en el mar pacífico colombiano, al diseño de una hélice marina para embarcaciones de carrera a escala, al diseño conceptual de una patrullera de costa (CPV) con capacidad de operaciones con helicóptero y finalmente, a la aplicación de las Curvas B-Splines Cúbicas para el Mallado de Cascos.

Sea esta nuevamente la ocasión propicia en estos tiempos de retos, cambios y restricciones para reiterar a todos nuestros lectores, los mejores deseos profesionales y personales. Esperamos contar con su participación en nuestro VII CIDIN 2021.

¡Ahí nos "vemos"!

Cordialmente,

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

Analysis of integrated logistics support (ILS) in the shipbuilding industry. Advantages and improvement opportunities for the naval industry. COTECMAR case study

Análisis del soporte logístico integrado (ILS) en la industria astillera. Ventajas y oportunidades de mejora para la industria naval. Estudio caso COTECMAR

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Abstract

Integrated Logistics Support (ILS) applied in the world-class shipbuilding industry has set significant trends in the processes and life cycles of the products and/or systems developed. COTECMAR as a Countrywide pioneer company in this sector, with specific strengths in naval prototypes, has been developing actions together with the National Navy to integrate concepts related to ILS, in its processes. Therefore, a detailed analysis of how these processes are facing the requirements of such support, has become necessary, starting from the initial basis of the possible advantages and opportunities for improvement that this could bring to the corporation and the sector. This is based on the theoretical and conceptual foundations in the ILS framework and how these are developed in the company under analysis.

Key words: Integrated Logistic Support, Life Cycle, shipbuilding industry.

Resumen

El Soporte Logístico Integrado (ILS) aplicado en la industria astillera de clase mundial ha marcado tendencias significativas en los procesos de esta y en los ciclos de vida de los productos y/o sistemas desarrollados. COTECMAR como empresa pionera del país en este sector con fortalezas especificas en prototipos navales viene desarrollando acciones junto con la Armada Nacional para integrar en sus procesos conceptos relacionados con ILS, por lo que se ha hecho necesario realiza un análisis detallado de cómo están mencionados procesos frente a los requerimientos de dicho soporte, partiendo de la base inicial de las posibles ventajas y oportunidades de mejora que esto le podría traer a la corporación y al sector, lo anterior partiendo de los fundamentos teóricos y conceptuales en el marco del ILS y como estos se desarrollan en la empresa objeto del análisis.

Palabras claves: Apoyo Logístico Integrado, Ciclo de vida, industria naval.

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Introduction

Over the years, industries have increased the number of factors involved in improving their activities and/or processes, and their relationships with clients and/or suppliers.

As a result of the increase in client requirements and expectations, manufacturing practices are improved and product quality is enhanced. In the case of after-sales services, the industry has gradually advanced with strategies such as scheduled maintenance, preventive maintenance, or warranty support, among other aspects. To meet each of these strategies, the conditions of each company must be studied to comply with what is offered to the client.

In the industry of complex systems, such as aircraft, ships and/or submarines, which have a useful life of over thirty years, after-sales service plans are a rigorous task, which is enabled by strengthening the processes in the industry, considering the company's stakeholders (internal client and external client), resulting in a process that generates benefits for both the company and the customer.

The main objective of the analysis was to establish the advantages and opportunities for improvement for the naval industry and specifically for the company under study, COTECMAR. To achieve it, theoretical foundations were approached from a conceptual point of view, describing the ILS from the perspective of different authors, which simplified a global vision of this program. For this purpose, some authors were identified with the largest number of publications on this subject, specifically in the naval industry. Based on the theoretical analysis and the study of the logistic performance of the countries, some improvement opportunities were established for the Latin American naval industry and specifically for COTECMAR.

Theoretical discussion

ILS is defined as the set of management and technical processes, through which hardware or software considerations are integrated from early stages throughout the life cycle, enabling the planning, acquisition, implementation, evaluation and care of logistical elements, in search of cost and time effectiveness *(NATO, 2011)*.

In 1981, the Defense Acquisition Improvement Program (Department of Defense, 1986) was born, with it the ILS policy focused on a joint development of logistics activities, leaving aside the independent management of activities.

Based on the ILS concept, for a better understanding of the logistics elements that comprise it and the relationship they have in the life cycle of a system, it is necessary to address it in greater depth. However, not all the references agree on the handling of these elements (number of elements, denominations, activities, among others).

The following is a comparison of the elements used by different authors.

The elements presented in Table 1, are described below, according to the International Guide for the Use of S-Series Integrated Logistics Support Specifications *(ASD and AIA SX00I, 2016)*.

Computer Resources: This element is responsible for the planning and provision of hardware, software and labor resources necessary for computer systems.

Design Influence: Is responsible for the integration of the systemic engineering design features with the other functional elements of the ILS.

Facilities and Infrastructure: This element is responsible for the management of assets and/or fixed facilities required for the integration, support, and operation of the product.

Maintenance: This element identifies, plans, records and implements the requirements for maintenance.

Manpower & Personnel: It oversees identifying, planning, and assigning personnel with the necessary skills and aptitudes to provide support.

Table 1. Elements of ILS in the literature based on some references.

	Autor				
Element	**S-Series (i)**	**UK Mod (ii)**	**DoD (iii)**	**DAU (iv)**	**NATO (v)**
Computer Resources	X			X	
Design Influence	X			X	X
Facilities & Infrastructure	X	X	X	X	X
Maintenance	X	X	X	X	X
Manpower & Personnel	X	X	X	X	X
PHS&T	X	X	X	X	X
Supply Support	X	X	X	X	X
Technical Data	X	X	X	X	X
Training	X	X	X	X	X
Product Support Management	X			X	
Sustaining Engineering	X			X	

Note: X Indicates that the author develops this element.

Source: Authors.

Packing, Handling, Storage and Transportation (PHS&T): addresses personnel, support equipment, raw materials, spare parts, and induction tasks developed within the PHS&T framework.

Supply Support: its objective is to manage the processes and techniques necessary to determine supply requirements, catalogs, warehousing, spare parts management, and suppliers.

Support Equipment: its objective is to guarantee the necessary equipment to provide support during the operation.

Technical Data: aims at identifying, planning, validating, recording, and implementing actions for the development, acquisition, and maintenance of information.

Training: aims to identify, plan and record training support, to implement training strategies to operate, maintain and support the product during its life cycle, ensuring optimal performance and product utilization.

Product Support Management: consists of the elaboration of the support concept, the ILS plan and provides obsolescence reporting.

Sustaining Engineering: compares the product with its base configuration and identifies opportunities for improvement, analyzes the causes of deficiencies and evaluates the impact of corrections, proposing a range of corrective actions during operation.

The ILS Specification Council created a family of standards to establish and integrate the portfolio of specifications related to logistics elements for military and civil applications. These standards are born from the effort of different working groups integrated by personnel from the AeroSpace and Defense Industries Association of Europe (ASD) and some Ministries of Defense, which promoted the agreement on the specifications between the European and American industries *(ASD and AIA Overview, 2016)*. This portfolio is integrated by six standards which are listed below:

S1000D, developed for the specification of technical publications and querying of common databases *(ASD and AIA S1000D, 2016)*. Since its second version its scope was extended to land and maritime applications, as well as opening up to military and civilian systems.

S2000M presents a standard for the management of materials management processes. Topics such as procurement, spare parts lists and material sourcing are covered here. *(ASD and AIA S2000M 2017).*

S3000L, standard developed with a scope in all the processes and requirements necessary for a correct elaboration of the Logistics Support Analysis (LSA). It is one of the standards that covers more topics, including LORA, LCC and CM. *(ASD and AIA, S3000L, 2014).*

S4000P provides analytical methodologies for the identification and management of preventive maintenance task requirements (PMTR). In addition, it addresses an analysis of maintenance during the operation phase. *(ASD and AIA S4000P, 2017).*

S5000F, presents the basis for performing operational and maintenance performance analysis resulting in improved maintenance concept, support concept, detailed LCC life cycle cost information and more complex contract support management. *(ASD and AIA S5000F, 2016).*

S6000T, provides the basis for training needs analysis. *(ASD and AIA S6000T, 2016).*

The development of these six standards is based on the twelve elements mentioned in Table 1, most of which are related in a transversal manner in all the standards, which allows identifying the interaction between the documents.

In order to comply with the ILS, the development of each of the activities and tasks that make up each logistic element is required (Table 2), facilitating the understanding of the gradual development that must take place, given that there is a sequence or order established for these, which becomes a continuous feedback of the process.

In the case of the activities of each element, the inputs are presented to facilitate their realization and then the outputs that each of these should provide, thanks to this information a sequence can be organized by precedence rather than by a defined stage in the life cycle (Fig. 1).

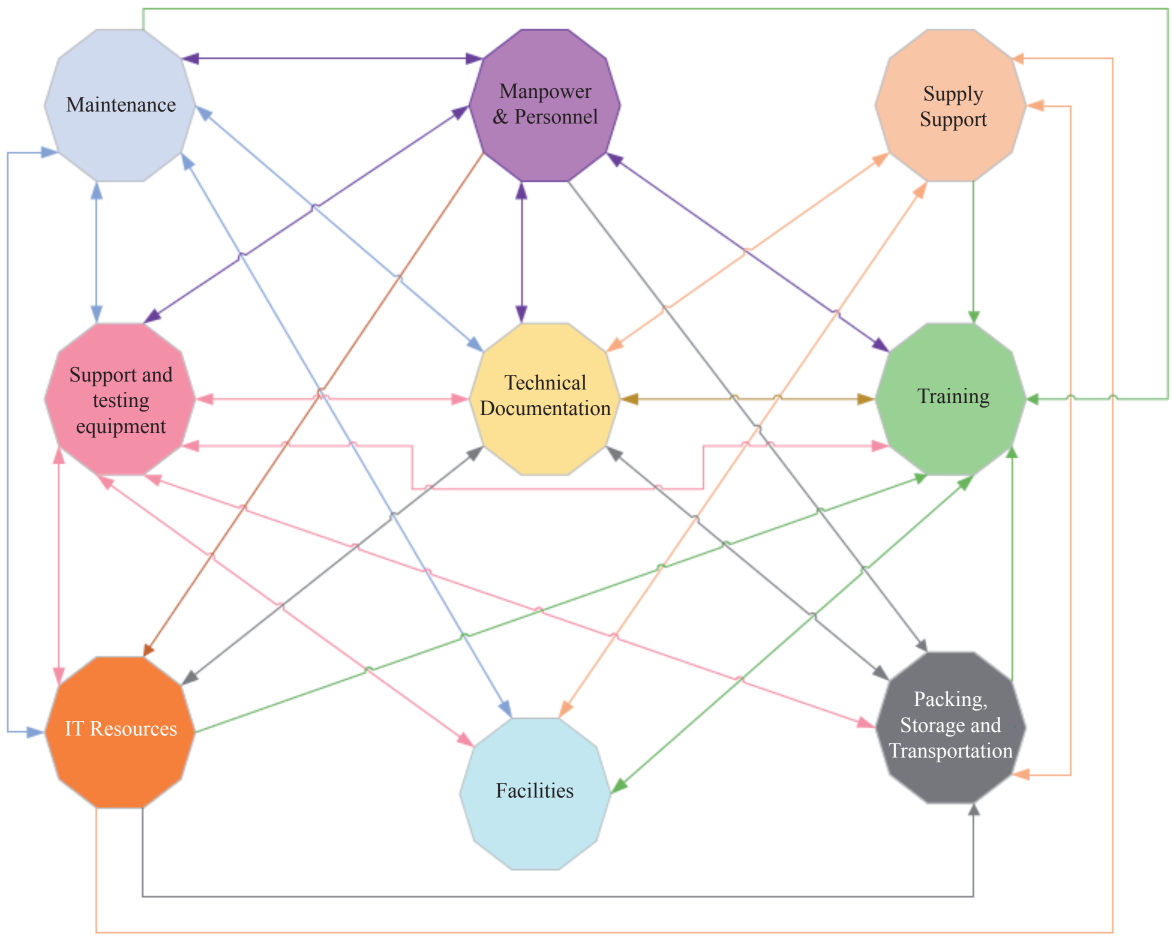
Continuing with the analysis of references, the Ministry of Defense of the United Kingdom through its Logistics Chain Support Manual

Table 2. ILS elements and activities.

ILS Element	Activities
Computer Resources	Computer Resources Analysis
	Provide Computer Resourses
Design Influence	Reliability, Availability, Maintainability Analysis
	LSA
	LCC
Facilities and Infraestructure	F&I Analysis
	Facilities and Infraestructure
Maintenance	Maintenance Concept
	Level of Repair Analysis
	Maintenance Tasks
	Supportability Safety Analysis
	Improve Preventive Maintenance
	Schedule Maintenance
	Diagnostics. Prognostics and Health Management Analysis
	Software Maintenance Analysis
Manpower & Personnel Analysis	Manpower & Personnel Analysis
Packaging, Handling, Storage & Transport	PHS&T Requirements
Product Support Management	Manage Contract
	Product Support Requirement
	ILS Plan
	Obsolescence Management
Supply Support Management	Provisioning Data
	Material Supply
Support Equipment	Support Equipment Requirements
	Support Equipment
Sustaining Engineering	Engineering Technical Analysis
	Develop & provide Engineering disposition & recommend design changes
Technical Data	Technical Data Package
	Technical Publications
Training	Training Need Analysis
	Training Plan
	Training Development
	Training

Source: Information obtained from ASD and AIA, SX00I (2016).

Fig. 1. Sequence diagram of ILS activities.



Source: Authors.

(Ministry of Defense, 2014) presents guidelines for the understanding of responsibilities in the framework of ILS development.

As can be seen in Table 1, this author does not handle the same elements as the S-Series or DAU family. One of the elements not found in other documents is *"Disposal and Termination"*, which refers to the efficient deactivation of the product, including its spare parts and materials. The author emphasizes the importance of knowing the deactivation process of the product once its useful life cycle is over, this should be done from early stages of the design and should consider the reduction of the environmental impact to be caused.

On the other hand, as Table 1 shows, the DoD does not handle all the elements, as is the case with the Ministry of Defense of the United Kingdom. The DoD also develops other interesting elements, among which is the *"Funding"* element, which highlights the importance of relating the needs of the support elements with the budget and funding procedures. This activity, in conjunction with other equipment programs, allows a more accurate forecast for the determination of costs during the entire life cycle. *(Department of Defense, 1986).*

Another reference is the DEFENSE ADQUISITION UNIVERSITY (DAU), which describes with a broad level of detail, which is not only maintained in the definition of the elements (Table 1) but transcends and involves other disciplines that favor the correct support of the product.

On the other hand, the NORTH ATLANTIC TREATY ORGANIZATION (NATO), better known in Latin America as OTAN *"North Atlantic Treaty Organization"*, handles the Life Cycle Cost (LCC) element in a particular way, and presents it independently, that is, it does not classify it as an ILS element. Although the other authors analyzed in this document also involve this program, NATO highlights the importance and necessity of LCC analysis because it must be present from the beginning of the design to ensure lower cost decision making. On the other hand, it relies heavily on logistic support analysis (LSA) to obtain inputs that simulate the logistic process, cost effectiveness models and trade-off studies that favor a better life cycle cost analysis.

Analysis of the Latin American context

As its name indicates, Integrated Logistics Support is developed within the framework of logistics activities and, as already discussed in this document, it is composed of elements that enable the development of an organization's logistics activities. However, when comparing the performance of logistics activities of countries, the "Logistics Performance Index" (LPI) is used, an indicator determined by the World Bank, which interactively compares countries or regions to identify and qualitatively recognize their logistics performance. This indicator is composed of six criteria *(worldbank.org, 2018)*, which are customs, infrastructure, ease of shipment agreements, quality of logistics services, product tracking and tracing, and times. In the case of Latin America as shown in Table 3, the first 9 countries in the ranking of this indicator can be observed, which mostly exceed the average of the 160 countries analyzed by the World Bank.

Now, how does the logistics performance index relate to Integrated Logistics Support? As can be identified, the ILS elements are focused on a company's own activities, it presents an internal strengthening of most of its processes, however, elements such as *"Supply Support"* and *"PHS&T"* are closely related, based on the specific analysis carried out in this document.

Table 3. LPI Ranking of Latin American Countries.

Country	Year	LPI Rank	LPI Score
Chile	2018	34	3.32
Brazil	2018	56	2.99
Colombia	2018	58	2.94
Argentina	2018	61	2.89
Ecuador	2018	62	2.88
Paraguay	2018	74	2.78
Peru	2018	83	2.69
Uruguay	2018	85	2.69
Venezuela, RB	2018	142	2.23

Source: THE WORLD BANK (2018).

When reference was made to the *Supply Support* element, its objectives were identified, among which it must ensure the management of its suppliers. This activity involves an interaction between the company and an external agent, as well as with the supplier. In carrying out this activity, conditions such as delivery times, mode of delivery and associated costs will have to be analyzed, both for national and international suppliers.

In the *PHS&T* element, the company concentrates on the tasks required for proper packaging, handling, storage and transportation. Therefore, the access routes of the products to be serviced, the mode of transportation of the materials from the supplier to the company, and the transportation of the product from the company to the customer must be analyzed.

In both cases, if the LPI criteria have a low score, it could be inferred that product delivery is more difficult and costly in the country analyzed. Therefore strengthening the internal processes of the companies is necessary, accompanied by policies that promote better logistical conditions in each country.

The LPI ranking shows that European countries and the United States (Table 4) are within the first 20 positions, comprising 12.5% of the countries with the best logistics practices, where the companies that have participated in the development of the S-Series family standards are located.

Relationship between companies participating in the development of S-Series standards and the 2018 LPI ranking Table 4.

If Latin American companies were to implement ILS using standards such as the ones presented, they would improve their logistics processes, enhancing the competitiveness of the sector in a globalized scenario.

As a sample of this phenomenon, as a result of the growth of the naval and maritime production sector in Colombia, Decree 590 of 2018 is issued, which defines the entry of inputs and raw materials with zero tariffs (Presidency of the republic of Colombia, 2018), as a measure for streamlining the import processes of raw materials, which would influence the logistics performance indicator of the LPI, for this particular sector.

The Case of COTECMAR

COTECMAR is an innovative organization that works within the field of scientific and technological research, supporting the development of the Colombian maritime industry. Its experience in the advanced design and construction of customized naval platforms, as well as the repair and maintenance of vessels with high quality standards, technical expertise, and responsiveness in a timely manner, make it a regional benchmark.

Its influence in Latin America is identified through its export offer to countries such as Guatemala, Honduras, Costa Rica, Panama, Peru, Bolivia and Paraguay.

During 2017, the shipyard sector in Colombia generated 6,000 direct jobs and 4,363 indirect ones, thanks to its influence on fourteen other manufacturing branches such as metal mechanics, plastics, glass and chemicals, among others. *(Ministry of Commerce, Industry and Tourism, 2017).*

On the other hand, according to (Toro et al., 2015) there is a retribution in the operational profits of the investments made in science, technology, and innovation activities (ACTI). Even more importantly, this reference concludes that the benefits obtained for the company are greater to the extent that there is participation of all the companies in the sector.

Table 4. Relationship between companies participating in the development of S-Series standards and the 2018 LPI ranking.

LPI Rank	Country	Companies/Organizations that have collaborated for the development of the S-Series standards
1	Germany	Airbus Bundeswehr
		ESG Electronic System and Logistics GmbH
		HEME GmbH
		EADS Military Systems Airbus Helicopters KCIG
2	Sweden	Saab AB
3	Belgium	NATO
4	Austria	FACC AG
		Austrian Aeronautics Industries Group
		FBC
9	UK	UK Mod
		Augusta Westland LSC Group Ltd
		BAE
		Rolls Royce BAE Systems
14	United States	O'Neil Boeing
		Andromeda Systems ISS
		LOGSA NAVSEA/DoD
16	France	Airbus
		Dassault Aviation Eurocopter MBDA
		Airbus Helicopter
17	Spain	Airbus Defense and Space EADS Home
19	Italy	SELEX EX
		Isselnord Finmeccanica

Source: Authors. Information taken from (worldbank.org, 2018).

A study conducted *(Arango et al., 2011)* proposed that the modernization of logistics processes carried out by COTECMAR would mainly benefit from a productive system based on reverse logistics. Given the complexity of a vessel, achieving a reverse logistics system implies having great knowledge of the life cycles of the different components and materials that integrate the systems; this type of analysis is carried out in early stages described in the ILS references.

Based on the above, it can be deduced that the research and development activities carried out by COTECMAR together with the National Navy at the integrated logistics support (ILS) level will have a positive impact on the competitiveness of the sector and on the development of the national naval and maritime industry.

Conclusions

The implementation of ILS at the corporate level is an opportunity to define the customer's logistic requirements, allowing to know their needs and meet them in a timely manner, in the case of the naval and maritime industry, during the operation of the vessel.

The implementation of the ILS in COTECMAR would be reflected in the support to the vessel to make it reliable and maintainable during its operation impacting the national and international market (Latin America), thus increasing the technological level in research and development, logistic support processes and interaction with stakeholders such as customers and suppliers at national and international level.

On the other hand, it is important to highlight that the investment involved in the implementation of ILS would have a return that would be reflected in maintenance contracts and support to the life cycle of the vessels, as well as in the improvement of the products and services offered to its clients in the national and international naval and maritime industry.

References

ASD and AIA, Overview (2016). The S- Series ILS specifications. Brussels.

ASD and AIA, S1000D (2016). International specification for technical publications. 4th ed. [ebook] Brussels. Available at: http://s1000d.org/Pages/Home.aspx [Accessed Oct. 2018].

ASD and AIA, S2000M (2017). International specification for material management. 6th ed. [ebook] Brussels. Available at: http://www.s2000m.org/ [Accessed Oct. 2018].

ASD and AIA, S3000L (2014). International procedure specification for Logistics Support Analysis LSA. 1st ed. [ebook] Brussels. Available at: http:// www.s3000l.org/ [Accessed Oct. 2018].

ASD and AIA, S4000P (2017). International specification for developing and continuously improving preventive maintenance. 2nd ed. [ebook] Brussels. Available at: http://www.s4000p.org/ [Accessed Oct. 2018].

6. ASD and AIA, S5000F (2016). International specification for in-service data feedback. 1st ed. [ebook] Brussels. Available at: https://www.s5000f.org/ [Accessed Oct. 2018].

ASD and AIA, S6000T (2016). International procedure specification for training/TNA. [ebook] Brussels. Available at: http://www.s6000t.org/ [Accessed Oct. 2018].

ASD and AIA, SX00I (2016). International guide for the use of the S-Series Integrated Logistic Support (ILS) specifications. [ebook] Brussels. Available at: https://www.sx000i.org/ [Accessed Oct. 2018].

Data.bancomundial.org. (2018). World Bank Open Data | Data. [Online] Available at: https://datos.bancomundial.org [Accessed Oct. 2018].

Department of Defense Integrated logistics Support Guide. Defense Systems Management College. 1986.

Ministry of Commerce, Industry and Trade (2017). Proastilleros, MinComercio's program to boost this industry. Bogotá. Available at: http://www.mincit.gov.co/publicaciones/38122/proastilleros_el_programa_de_mincomercio_para_impulsar_esa_industria

Ministry of Defense. JSP 886 THE DEFENCE LOGISTIC SUPPORT CHAIN MANUAL. 2014.

ORGANIZACIÓN DEL TRATADO ATLÁNTICO NORTE. NATO International. ALP-10: NATO Guidance on Integrated Logistics Support for Multinational Armament Programmes. 2011.

Presidency of the Republic of Colombia (2018). Goods and raw materials to manufacture ships will be able to enter the country with zero tariffs. Bogotá. Available at: http://es.presidencia.gov.co/noticia/180404- Bienes-y-materias-primas-para-fabricar- barcos-podran-entresar-al-pais-con-ero- arancel.

Worldbank.org (2018). Home | Logistics Performance Index. [Online] Available at: https://lpi.worldbank.org/ [Accessed 19 Oct. 2018].

Analysis for use coastguard Offshore Platforms or SWATH Patrol Vessels in the Colombian Pacific Ocean

Análisis del uso de Plataformas Costa Afuera o Patrulleros SWATH de Guardacostas en el Mar Pacífico colombiano

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Abstract

The average cocaine seizure rate of coast guard operations in the Colombian Pacific can be improved. To enhance this indicator, detection and interdiction must be improved. Therefore, the option of using an offshore platform with better detection means, and several Rapid Reasponse Units (RRUs) stationed offshore, is being analyzed. As a result, offshore platforms are neither feasible nor viable due to the depth of the sea floor (> 2 km), but SWATH platforms can be used. The parametric design of two SWATHs is performed and an operational evaluation is made of the different current units and SWATHs. The operational evaluation of the different current units and the proposed SWATHs is carried out and contrasted with their acquisition and life cycle cost, showing that the SWATHs have a better efficiency/cost ratio. Therefore, they can be considered as an alternative to improve the efficiency of cocaine seizures and other coast guard operations.

Key words: Coast Guard, Colombia, Offshore platform, SWATH, OMOE.

Resumen

En las operaciones de guardacostas en el Pacífico colombiano, se tiene un promedio de incautación de la cocaína producida que puede ser mejorado. Para mejorar este indicador, se deben mejorar la detección e interdicción. Por ende, se analiza la opción de utilizar una plataforma costa afuera con mejores medios de detección, y varias Unidades de Reacción Rápida (RRU) destacadas. Como resultado las plataformas costa afuera no son viables ni factibles por la gran profundidad del mar (> 2 km), pero se pueden utilizar plataformas SWATH. Se realiza el diseño paramétrico de dos SWATH y se hace una evaluación operacional a las diferentes unidades actuales y las SWATH propuestas, a la vez que se contrasta con su costo adquisición y de ciclo de vida evidenciando que los SWATH tienen una mejor relación eficiencia/costo. Por ende, se pueden considerar como una alternativa para mejorar la eficiencia de incautaciones de cocaína y demás operaciones de guardacostas.

Palabras claves: Guardacostas, Colombia, Plataforma costa afuera, SWATH, OMOE.

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Introduction

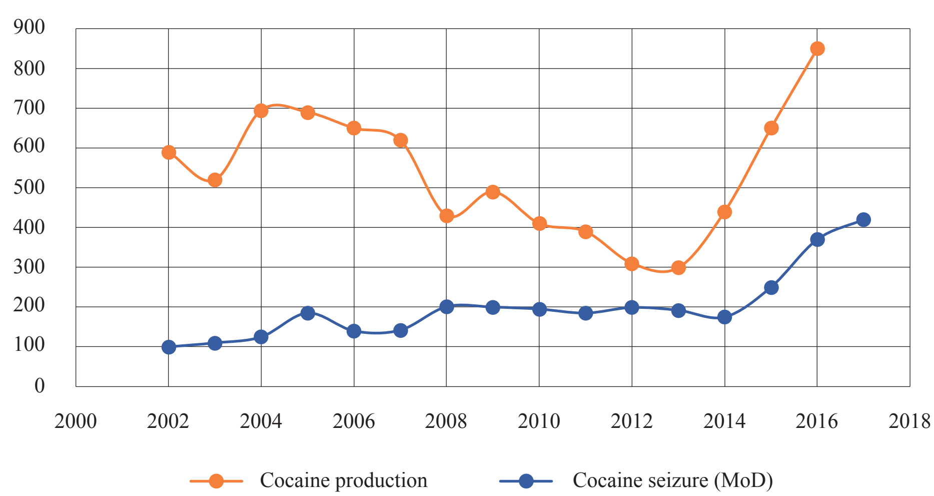
The Colombian Pacific comprises a maritime jurisdictional area of 359,948 km^2 and a coastline of 1589 km, which corresponds to 36% of the Colombian maritime territory. *(Comision Colombiana del Oceano, s.f.)*. Due to the particular conditions of the area, there are a large number of events related to drug trafficking in the country.

According to statistics from the Anti-Drug Directorate and contrasted with other sources, total drug seizures are in the order of 40% of the total produced. *(Revista Dinero, 2017)*, , so there is great potential to improve the operational method in the Colombian Pacific with means that have better interdiction detection capabilities.

The impact of drug seizures for the Colombian Navy (ARC), in the maritime phase is enhanced by the "RED NAVAL" strategy through operations carried out by units of the Pacific Naval Force. However, due to limitations in autonomy, fuel capacity, time spent at sea and support capabilities of the floating platform, some areas are left uncovered and are used by drug dealers to launch semi-submersibles or "GO FAST" type boats. They also saturate the available resources by sending several boats loaded with narcotics, where there is usually only one RRU to carry out the interdiction and legalization of seizures.

The effectiveness of the larger units used as platforms is not the most adequate for coast guard operations such as maritime interdiction, since their design is optimized for other types of naval operations. For example, in the case of the Coastal Patrol Vessel (CPV), it does not have the capacity to receive helicopters, or to launch and capture an aerial drone (Unmanned Aerial Vehicle- UAV). In addition, it requires pairing with a RRU to perform interdiction, but it does not have the capacity to carry a large RRU on board and must alongside or tug generating a great material wear to them. The Amphibious Landing Craft (BDA), despite having the capacity to carry an Apostle boat, does not have the capacity to make offshore movements due to its design as a landing craft, and in the case of the Offshore Patrol Vessel OPV) and the ARC Valle del Cauca, they are vessels with helicopter capability, easy offshore operation but high operation and maintenance costs. According to the above, it is necessary to evaluate the effectiveness of the strategy currently used in the Colombian Pacific in an integral manner, comparing the efficiency of each unit with its cost. For this purpose, operational factors for the development of coast guard operations were determined with a committee of experts and by means of an Overall

Fig. 1. Comparison of cocaine hydrochloride seizures vs. potential cocaine production.



Source: Own elaboration, based on (DICOD, 2018).

Measure of Effectiveness OMOE) methodology, the different existing platforms and a new proposal were analyzed.

Operational and Environmental Analysis

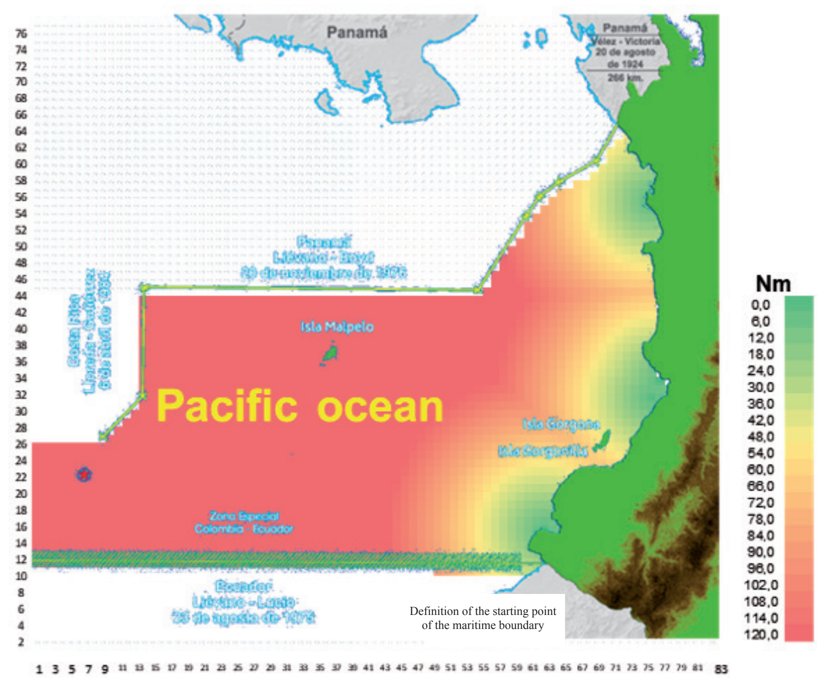
Initially, an application is developed in Visual Basic for VBA Applications language to show the distances from each point of the jurisdiction to the nearest coast guard station. The result is shown in Fig. 2.

An algorithm is then run to calculate the probability of intercepting a go-fast boat that is detected at each point in the jurisdiction, considering variables such as the course and contact speed, distance and bearing from the nearest base, speed difference between the go-fast and the RRU , and the range of the RRU given by the size of its fuel tank. The probability of interdiction is defined as the inverse of the percentage of the fuel tank required to perform the interdiction, if feasible. The resulting probability of interdiction result for ground-based stations is shown in Fig. 3, denoting a very low overall probability of interdiction.

Fig. 4 shows the morphology of the probabilities of interdiction, by locating a platform or floating unit in an optimized position, having an oval shape with a greater probability of interdiction to the east, since the traces or routes of the units to be intercepted are directed towards the west. Likewise, greater dispersion is generated as it moves away from the platform, since with a minimum course variation it can move away from the platform much more, thus the RRU must spend a greater percentage of fuel from its tank to intercept it.

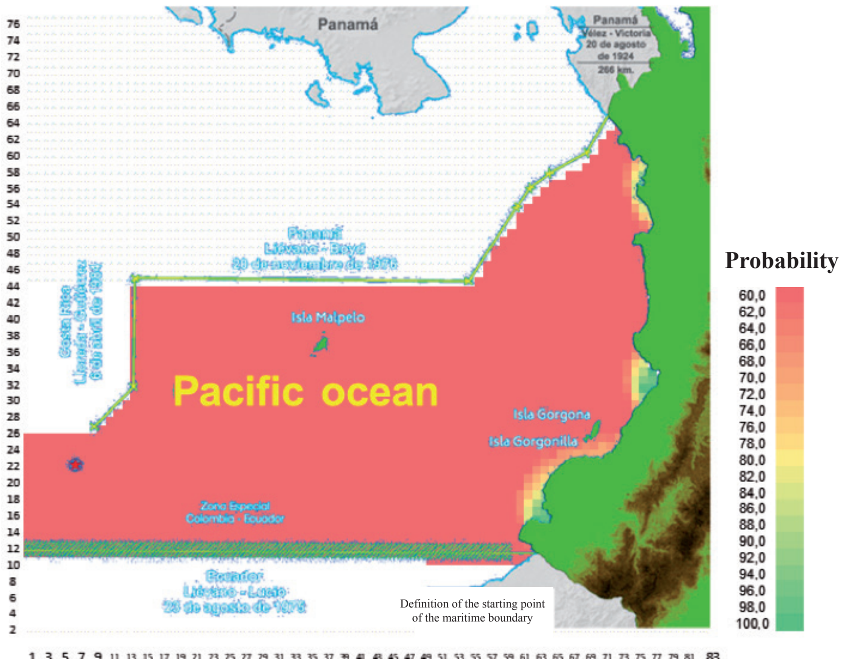
Analyzing the operational area of the Pacific Ocean, and its prevailing depths, the area where Jack Up type platforms could be installed (up to 20 meters deep), do not exceed 10 nautical miles (Nm) and in some cases, it is less than half a mile as shown in Figure 5. The next area where platforms with expensive anchoring systems could eventually be installed would be up to 200 meters deep. In the

Fig. 2. Distance to the nearest coastguard base (Figure 2: Distance to the closest coastguard base.



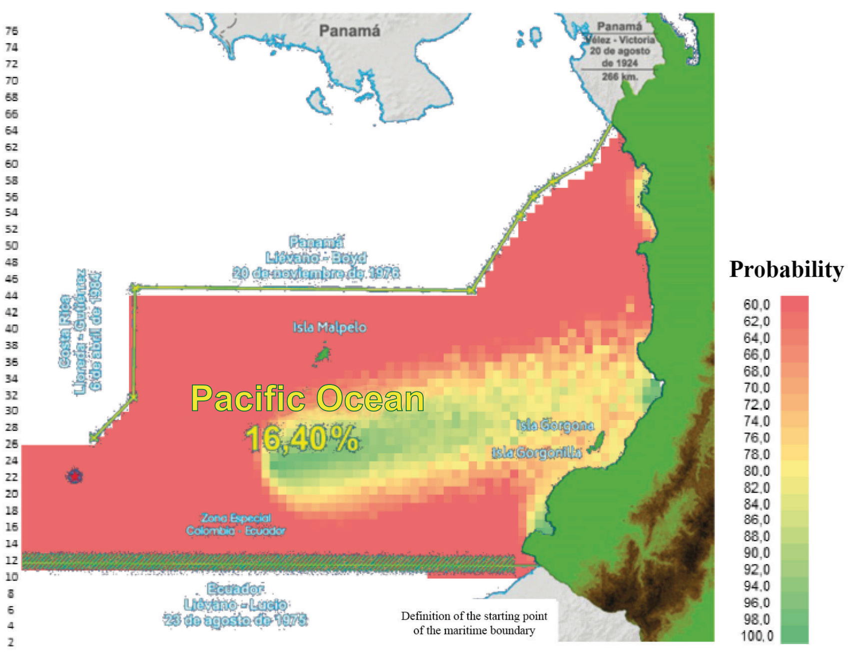
Source: Own elaboration.

Fig. 3. Interdiction probability from the coastguard bases.



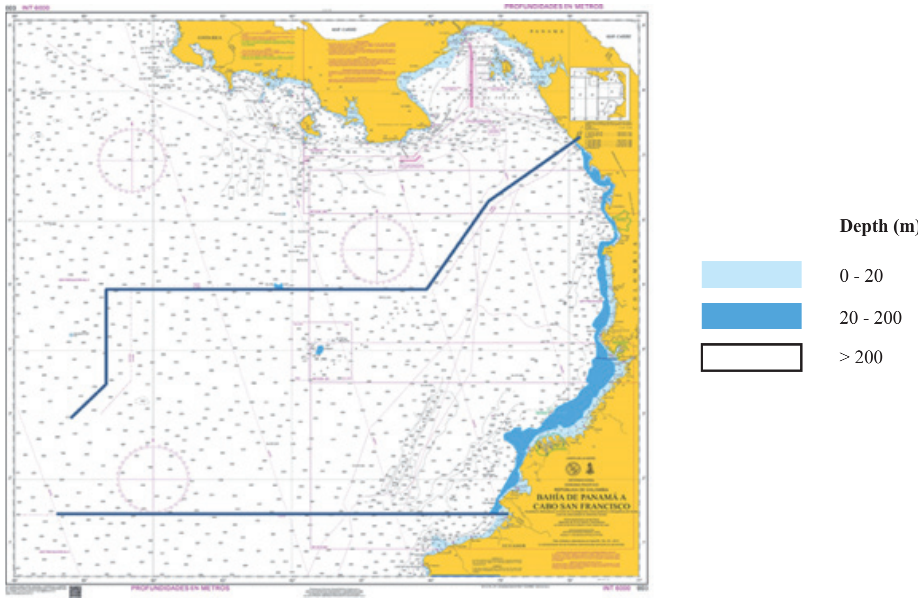
Source: Own elaboration.

Fig. 4. Probability of interdiction from the coastguard bases and one naval platform.



Source: Own elaboration.

Fig. 5. Ocean depths in Colombian pacific sea.



Source: (CIOH, 2011).

Pacific, the average is 19 Nm offshore, with some places at less than 2 Nm.

It is worth noting that the cost of moving the platform in this area of 20 to 200 meters is high, having to hire offshore service vessels (Offshore Service Vessel - OSV) with high capacity winches, thus losing the strategic advantage of the surprise of platforms or vessels that can move easily.

Therefore, the use of offshore platforms for coast guard in the Colombian Pacific is considered neither feasible nor viable. However, the use of Small Water Area Twin Hull (SWATH) type platforms will be analyzed due to their combination of characteristics as a platform having a wide cargo area capacity, in addition to an excellent behavior at sea, and having its own propulsion capacity. The following operational evaluation criteria will be established to compare current solutions or vessels with possible SWATH platforms.

Operational Evaluation Criteria - OMOE

Currently, there are several operational evaluation models for naval vessels, but there is not one for evaluating platforms specifically for coast guard operations. The different attributes or characteristics of a platform for coast guard operations deployment were consolidated and grouped into the four groups described in Table 1.

A proposal for the evaluation of each of the attributes was also made, which was validated and adjusted by the expert committee that accompanied this research.

In order to make a final assessment, a weighting must be given to each of the attributes listed above, considering those with greater relevance in fulfilling the different types of coast guard missions. For this purpose, a weighting exercise was done, according to the matrix methodology, confronting the elements one by one, and indicating their relative importance. The final result is shown in Table 2.

SWATH

SWATH platforms are considered to have high potential for the Pacific Coast Guard, due to features

Table 1. Evaluation criteria of the OMOE attributes.

Group	Capacity	Min value (0%)	Max Value (100%)	Unit
Mission	Fast boats	0	3	# RRU (Min Defender, Apostle)
	Helicopter	Nivel	Nivel	Helo Type (Light, Medium Light, Medium Heavy)
	UAV	0	4	# UAV
	Radar range (effective Go-Fast detection)	10	40	Nm - Nautic miles
	Defense	Nivel	Nivel	Ballistic protection defense levels and weapons number and caliber.
Permanence and support	Range	500	2000	Nm
	Autonomy	20	60	Days - hotel condition - max. accommodation capacity
	Autonomy boats	20	100	Fuel hours at max speed
	Workshop level F/B	0	3	workshop maintenance level
	Speed	8	30	Maximum [kn].
Flexibity	Additional accommodations	4	30	# People
	Additional TEU cargo - 15 ton /ea	0	4	# TEU
Welfare	Living space	4	12	m^2/person
	Seakeeping	0,5	0	MSI (Motion Sickness Index) - Hs = 2m

Source: Own elaboration.

Table 2. Atributes weighted per mission type.

Group	Capacity	BYR	Interdiction	Port security	Environmental protection
Mission	Fast boats	20%	17%	12%	15%
	Helicopter	9%	8%	6%	7%
	UAV	13%	11%	8%	10%
	Radar range	14%	12%	9%	10%
	Defense	3%	3%	2%	3%
Permanence and support	Range	2%	3%	2%	3%
	Autonomy	5%	6%	5%	8%
	Autonomy boats	7%	9%	6%	10%
	Workshop level F/B	4%	5%	3%	6%
	Speed	1%	1%	1%	1%
Flexibility	Additional accommodations	3%	3%	18%	10%
	Additional load	4%	4%	22%	13%
Welfare	Habitability	4%	5%	2%	1%
	Seakeeping	11%	13%	4%	4%
Total		100%	100%	100%	100%

Source: Own elaboration.

such as a large deck area and the ability to carry multiple RRUs, and a design that reduces wave motion by up to six times compared to a monohull of equal displacement. *(Collins, Clynch, & Rago,* *2005)*. This allows the RRUs to be safely maneuvered by crane in heavy seas, while offering personnel improved comfort during extended operations.

A parametric design of two SWATH type vessels was developed, based on the methodology proposed by *(Bondarenko, Boiko, & Seropyan, 2013) (Bondenko, Boiko, & Boikoyan, 2013)*, and considering the requirements established in Table 3, aiming to generate units with high performance for coast guard operations according to the OMOE criteria evaluations defined in section 3.2. The result of the design is shown in Table 4 with the main dimensions and characteristics, as well as some ambiance renders shown in Fig. 6 to Fig. 8.

Table 3. Design requirements for SWATH platforms.

Capacity	Unit	SWATH 1	SWATH 2
Maximum speed	kn	15	12
Range	Nm	1000	1000
Autonomy	days	60	40
Platform crew	# people	17	17
Boats - RRU	# units	3	2
Boats - crews	# crews	3	2
UAV - aircraft	# units	4	2
UAV - crews	# crews	3	2
Gasoline	gallons	8000	4800
Crane	ton@meters	20@15	20@15
Additional containers	TEU	2	2
Casemates	# units	4	3

Source: Own elaboration.

Table 4. Design result for SWATH platforms.

Capacity	Unit	SWATH 1	SWATH 2
Length	m	42.6	30.7
Beam	m	19.8	15
Molded Depth	m	7.5	6.6
Draft (max displ)	m	3.7	3.4
Maximum displacement	Ton	680	470
Drinking water capacity	m3	26.2	14.5
Diesel capacity	m3	75.5	38
Gasoline capacity	m3		
Crane	ton@meters	20@15	20@15
Accommodations	# people		
Diameter of submerged cylinders	m	2.75	2.7
Strut width	m	1.9	1.3
Price	M USD	21.2	14.4

Source: Own elaboration.

Fig. 6. Perspective views of SWATH 1 - port side out-haul.

Source: Own elaboration.

Fig. 7. Perspective views of SWATH 1 - port quarter.

Source: Own elaboration.

Fig. 8. Side view SWATH 1.

Source: Own elaboration.

Application of the OMOE

Subsequently, the OMOE model was applied to the most common current platforms and to the proposed SWATH alternatives, obtaining the results shown in Table 5.

Subsequently, the OMOE model was applied to the most common current platforms and to the proposed SWATH alternatives, obtaining the results shown in Table 5.

From this result it is evident that the platforms with the best performance for these missions are the SWATH and OPV type platforms. OPVs are the largest and most capable coast guard vessels, hence their high operational performance. SWATH platforms have a higher performance since only the effectiveness for coast guard operations is being evaluated and having more RRUs and UAVs gives them a better rating. In other words, SWATH platforms have been specially designed for coast guard operations, but they cannot perform other missions which the OPV can perform, such as Antarctic missions, coastal bombardment or sovereignty control.

A life cycle cost assessment exercise was also carried out for the vessels, seeking to carry out a comprehensive analysis of their effectiveness and cost, in order to have a better view of the decision making process at the time of acquiring a new platform. For this purpose, an operational profile of 60 outstanding days and 5 days of provisioning was considered, plus a minimum repositioning navigation, projected to 30 years. The results are shown in Fig. 9.

Finally, the OMOE operational efficiency is plotted for its acquisition cost (Fig. 10) to compare the different platforms in terms of their operational performance but also considering their cost.

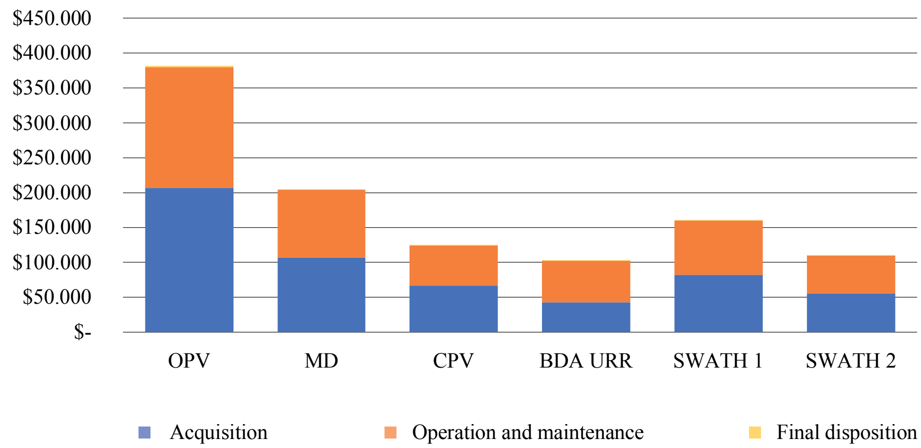
This figure shows that SWATH platforms have a better relationship between acquisition cost and performance for coast guard operations than other platforms. However, the economic feasibility analysis should not be done with the

Table 5. OMOE results by platform and mission.

Missions	Weighting	CPV	SWATH 1	OPV 80	PO 44	BDA RRU	SWATH 2
BYR	24%	12%	88%	75%	33%	40%	67%
Interdiction	51%	13%	88%	71%	35%	41%	68%
Port security	7%	10%	75%	66%	37%	48%	57%
Fishing and pollution protection	18%	13%	82%	66%	36%	45%	61%

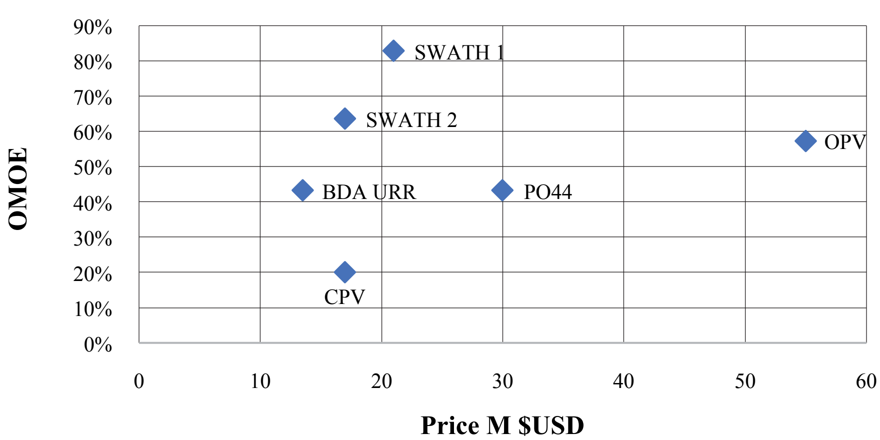
Source: Own elaboration.

Fig. 9. LCC Life Cycle Cost per Unit [M COP $].



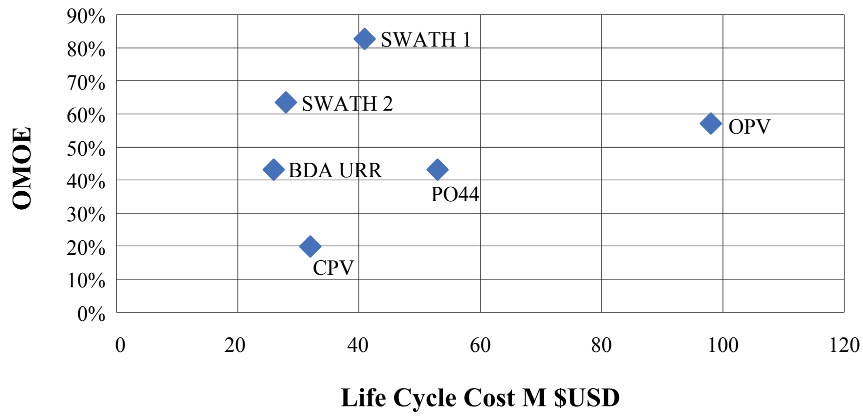
Source: Own elaboration.

Fig. 10. OMOE Pareto Chart - acquisition cost.



Source: Own elaboration.

Fig. 11. OMOE pareto chart - life cycle cost (LCA).



Source: Own elaboration.

acquisition cost alone but with its life cycle cost in order to make a better decision. Therefore, Fig. 11 shows the comparison of life cycle cost and operational performance.

Thus, it is clear that SWATH platforms prove a much higher ratio between their life cycle cost and operational performance for Coast Guard operations. This indicates that they are a feasible alternative to implement in the operational strategy in the Pacific, with a very important potential to increase the operational performance and therefore, the percentage of cocaine seizures with respect to what is produced, affecting the illegal groups that are financed by this illicit business more forcefully.

Although these results are derived from an initial parametric design, and therefore have a high uncertainty in their actual cost and characteristics, this is a starting point with considerable application potential due to its excellent results.

Conclusions

The maritime control strategy adopted by the Pacific Coast Guard has been continuously evolving and improving. However, there is still a wide road to improve on the 40% effectiveness indicator in terms of cocaine seized in interdiction operations.

Expanding the current strategy may be an effective alternative as has already been proven, but at a high economic cost due to the fact that the platforms used have not been specifically optimized for this type of operations.

The use of offshore platforms as traditionally used by the oil industry is not applicable for the Colombian Pacific, because it presents a submarine cliff leading to an average depth of 2000 to 3000 meters suddenly. The areas of less than 200 meters depth are less than 19Nm from the coast on average, which does not allow to deploy an effective offshore control and take advantage of the position as an operational advantage.

SWATH platforms are a technically feasible alternative, since their characteristics, such as their wide deck space, allow them to carry more RRU than a monohull of the same displacement, and their behavior at sea (seakeeping) is notably better, producing movements up to 6 times less than those of a monohull under the same wave conditions.

In the comprehensive performance and cost evaluation, the SWATH platform has a great potential by showing a similar performance to platforms that are twice as expensive in terms of acquisition and life cycle. These higher priced platforms, such as OPVs, have many other characteristics such as participation in international and Antarctic missions, AAW capabilities and others, but they are not suitable for the development of daily Coast Guard operations and therefore are not evaluated in this assessment.

Continue with the unit acquisition cycle, in parallel to a more detailed design phase, is recommended in order to improve the cost estimation and to be able to perform a more detailed analysis.

References

BONDARENKO, O., BOIKO, A., & SEROPYAN, I. (2013). Determination of the main characteristics of the small waterplane area twin hull ships at the initial stage of design. *Polish Maritime Research*, 11-22.

CIOH. (2011). *Visor de Cartas Naúticas*. Obtained from Centro de Investigaciones Oceanográficas e Hidrográficas: https://www.cioh.org.co/hidrografia/mapasCartas/carta003.php

COLLINS, C., CLYNCH, J., & RAGO, T. (2005). *Comparison of SWAth and Monohull Vessel Motion for regional Class Research Vessels*. Naval Postgraduate School. Monterey: Dudley Knox Library.

COMISIÓN COLOMBIANA DEL OCEANO. (s.f.). *Gestión del territorio marítimo costero*. Obtained from http://www.cco.gov.co/cco/areas/gestion-del-territorio-marino-costero.html

DICOD. (2018). *Resumen, estadísticas y resultados de la Campaña Naval Combinada "ORION I"*. Bogotá.

REVISTA DINERO. (2017). *Colombia pasó de productor a ser uno de los principales consumidores de droga*. Obtained from Revista Dinero: https://www.dinero.com/pais/articulo/cuanto-mueve-el-negocio-del-narcotrafico-en-colombia-2017/241953

Design of a marine propeller for scale racing boats in a speed and energy efficiency contest

Diseño de una hélice marina para embarcaciones de carrera a escala en concurso de velocidad y eficiencia energética

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Abstract

The process of optimized design, evaluation and manufacturing of high energy efficiency propellers for competition boats at scale is addressed in this research. This project uses the stages of hydrodynamic design, numerical testing and manufacturing of four prototypes as example. During the hydrodynamic design, three design methodologies were compared, namely: Blade Element Theory, lifting line theory and design based on DTMB propeller series. The objective function of the optimized design is based on obtaining the chord and pitch distribution that generates the greatest thrust, speed and efficiency. Similarly, the performance of each prototype was evaluated by CFD in a virtual channel registering thrust, torque and speed. Finally, the additive manufacturing process applied is presented. Prototyped propellers present efficiencies and maximum speeds approximately 15% higher than recommended commercial propellers for this type of boats. This study was developed by the Hydrometra group in the framework of the international competition Hydrocontest 2017.

Key words: Propeller, naval propulsion, energy efficiency, hydrodynamic design.

Resumen

En esta investigación se aborda el proceso de diseño óptimo, evaluación y fabricación de hélices de alta eficiencia energética para barcos de competición a escala. Este proyecto utiliza como ejemplo las etapas de diseño hidrodinámico, ensayos numéricos y la manufactura de cuatro prototipos. Durante el diseño hidrodinámico, se comparan tres metodologías de diseño, a saber: Teoría de los elementos de palas, teoría de línea de sustentación y diseño basado en la serie de hélices DTMB. La función objetivo del diseño optimizado se basa en la obtención de la distribución radial de cuerda y paso que genere el mayor empuje, velocidad y eficiencia. Del mismo modo, se evalúa el rendimiento de cada prototipo mediante CFD en un canal virtual registrando empuje, momento y velocidad. Finalmente, se presenta el proceso de fabricación aditiva aplicado. Las hélices prototipadas presentan eficiencias y velocidades máximas aproximadamente un 15% superiores a las hélices comerciales recomendadas para este tipo de embarcaciones. Este estudio fue desarrollado por el grupo Hydrometra en el marco del concurso internacional Hydrocontest 2017.

Palabras claves: Hélice, propulsión naval, eficiencia energética, diseño hidrodinámico.

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Introduction

Naval propulsion based on propellers has been an efficient and reliable propulsion method *(Carlton, 2010)*. The design of these propellers has evolved gradually in tandem with the development of theories whose objective is to model the hydrodynamic phenomena associated with the generation of lift and drag forces in a rotating solid on which a flow impinges. Throughout the study of hydrodynamics, these theories have increased their accuracy and complexity. Initially, the modification of the momentum in an incident flow to a rotating porous disk was considered, which extracts from or delivers to the momentum flow (Mejía, 2005). Later, the geometry of the rotor blades on which the flow impinges was considered, this is done by the two-dimensional evaluation of the forces exerted by the flow on an aerodynamic profile in relation to its chord and angle of incidence, afterwards, this information is computes in different radial sections of cross or elements of cross that, finally, reproduce the action of the cross as the summation of the actions of each element of cross *(Mejía, 2005) (Marten, 2013)*.

Then, the lift - line theory or lift line is developed, which identifies the circulation of the vortices around the solid as the generator of the lift phenomenon and by means of the integration on radial sections it allows to know the force that is exerted on the whole of the propeller, this theory is widely treated in *(Flood, 2008), (Chung, 2007), (Epps, 2016)* and *(Epps, 2013)*. This theory has been transferred to computer codes that facilitate the computation of the properties of propellers to achieve optimal designs. Among these codes are commercial versions and some versions of free use as OpenProp *(Epps, 2013)*, software used in this study.

Another classic approach in the design of propellers refers to series of propellers registered in the literature that can be considered as an initial basis for the design of a propeller. These series have dimensionless geometries based on the length of the chord; this allows adapting the design to geometric design requirements, conserving the properties of the propellers originally developed during the generation of the series of propellers *(Carlton, 2010)*. Some of these series are DTMB *(Brizzolara, 2008)* and Wageningen B series *(Oosterveld, 1975)*.

In addition, methods for evaluating the performance of propeller prototypes have recently emerged through Computational Fluid Dynamics (CFD), this approach allows, in general, to know in broad strokes the performance of the propellers and the alteration of the surrounding flow *(Brizzolara, 2008), (Trejo et al., 2017)* and *(Kulczyk., 2007)*. It is thus possible to estimate the forces on the propellers and the distribution of pressure on its surface, a phenomenon related to the presence of cavitation on the surface of the propeller. It should be noted that there are different studies that make comparisons between different approaches to design a propeller, as seen in *(Knutsen, 2016)* and *(Gur, 2008)*.

Materials and Methods

In the present work the geometrical design of propellers is proposed to generate two final propellers assigned to the two required operating conditions described as Heavyweight (HW) and Lightweight (LW) conditions. Therefore, the two required operating conditions, based on the different races of the contest, are described in the (Table 1).

The design of proposed propellers for these conditions is made by means of several design methods, such as design based on the DMTB series adapted to the operating conditions of the

Table 1. Required operating conditions for the contest.

Operating condition	Boat displacement [kg]	Motor power [kW]	Angular speed [RPM]	Boat required speed [m/s]	Nominal torque [Nm]
HW	220	1300	1700	4.0	5.5
LW	50	1300	2500	5.0	4.0

propellers to be designed, an optimized design by means of the blade element and momentum theory and another optimized design through the theory of lifting-line in the OpenProp software. This design approximations are shown below with the modifications made for the present design case.

DTMB Series: The DTMB series, developed in the David Taylor Model Basin, consists of a family of immersion propellers complete and absent of cavitation that have three or more blades, whose pitch varies along its radial axis. The geometry of these propellers is represented in a dimensionless way through standard tables whose base is the modified NACA 66 profile and curvature line a = 0.8 (Brizzolara, 2008). The DTMB series includes three-bladed propellers (DTMB 4119), four-bladed (DTMB 4381), and five-bladed propellers (DTMB 4382, 4383 and 4384). Examples of this series are presented in (Fig. 1).

As mentioned above, the design of the propeller has as a technical requirement: the generation of a three-blade propeller, therefore, the DTMB propeller is selected as the basis for the geometry of the propeller to be designed. (Table 2) shows the dimensionless standard table of the DTMB 4119.

Fig. 1. Examples of DTMB propeller series. (Brizzolara, 2008).

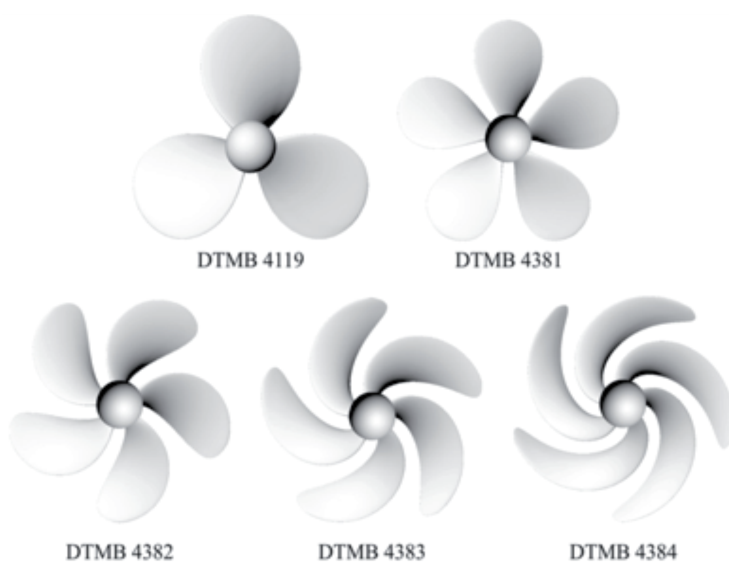


Table 2. Standard dimensionless parameters of the DTMB 4119 propeller. (Brizzolara, 2008).

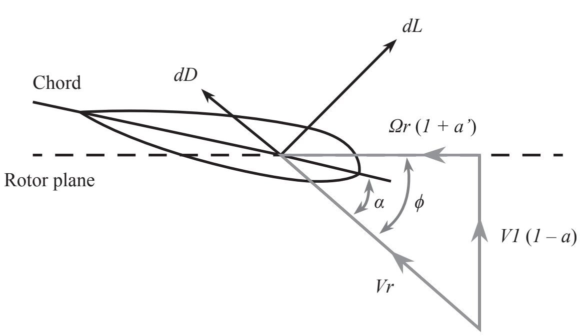
r/R	c/D	P/D	tmax/c	fmax/c
0,2000	0,3200	1,1050	0,2055	0,0143
0,3000	0,3635	1,1022	0,1553	0,0232
0,4000	0,4048	1,0983	0,1180	0,0230
0,5000	0,4392	1,0932	0,0902	0,0218
0,6000	0,4610	1,0879	0,0696	0,0207
0,7000	0,4622	1,0839	0,0542	0,0200
0,8000	0,4347	1,0811	0,0421	0,0197
0,9000	0,3613	1,0785	0,0332	0,0182
0,9500	0,2775	1,0770	0,0323	0,0163
0,9800	0,2045	1,0761	0,0321	0,0145
1,0000	0,0800	1,0750	0,0316	0,0118

Blade element and momentum theory (BEMT): This theory joins the relationship between the angle of incidence and the length of the chord with the force on the paddles and the torque on them.

This considers force differentials and moment differentials that are exerted on a radius differential in a blade, which is extrapolated between blade sections. These differentials are related to the drag and lift coefficients for each aerodynamic profile that shapes the blade element; In addition, these coefficients are related to the angle of incidence of the blade element that is defined by the relative speed of the blade determined by the speed of rotation and the speed of entry of the air flow, as shown in (Fig. 2).

$$dF = \frac{\rho}{2} cV_T^2 \left[C_D * Sin\varphi + C_L * Cos\varphi \right] N\, dr$$
$$dT = \frac{\rho}{2} cV_T^2 \left[C_L * Sin\varphi - C_D * Cos\varphi \right] rN\, dr \quad (1)$$

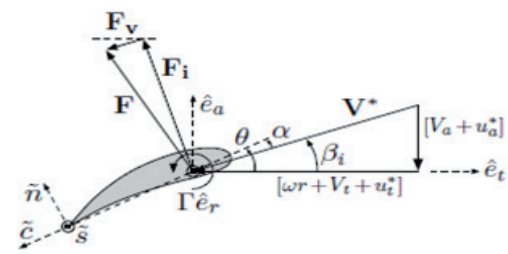
Fig. 2. Forces and velocities in a section of a blade (Mejía, 2005).



Lifting-line theory: This theory considers each vane as a line of support with vorticity at the exit aligned with the local velocity of the flow. In addition, each palette divides the palette into discrete radial sections, having properties of the two-dimensional aerodynamic profiles in each section *(Epps, 2013)*.

From there, the charges are computed by integration over the entire length of the blade of the charges in each two-dimensional radial section. As shown in (Fig. 3). The application of this theory is done through OpenProp software *(Epps, 2013)* developed at the Massachusetts Institute of Technology in MATLAB.

Fig. 3. Diagram of forces in a radial section of a blade (Epps, 2013)..



The input data required varies depending on the module used, but in general are: diameter, family of aerodynamic profiles, thrust or required thrust coefficient, speed of advance of the boat and angular velocity of the propeller at the design point, power on the axis, among others. The software covers a large part of the design stages, from a parametric study whose result is the optimum diameter for the propeller considering the motor and the required thrust. In addition, output variables for the optimized design modules are chord distribution, angle of incidence, aerodynamic profile, thrust coefficients, torque and efficiency. These data can then be processed in such a way that they are comparable to other prototypes or commercial propellers, as shown in the following sections.

Comparison by lifting-line theory: Through the OpenProp software, the comparison of the four propeller designs was made to determine which are the best designs and the features they offer in relation to the other designs. Since the four designs are dissimilar, the study was made based on four dimensionless numbers that allow a reliable comparison, according to the theory of dimensional analysis. These numbers are the coefficient of advance *J*, coefficient of thrust *Kt*, coefficient of torque *Kq* and hydrodynamic efficiency ηHydro, expressed respectively as follows:

$$J = \frac{V}{nD} \qquad Kt = \frac{T}{\rho n^2 D^4}$$
$$Kq = \frac{Q}{\rho n^2 D^5} \qquad \eta_{Hydro} = \frac{J}{2\pi}\frac{Kt}{Kq} \quad (2)$$

Where V is the forward speed of the boat or velocity of the incoming flow to the plane of rotation of the propeller, n is the angular velocity of the propeller in revolutions per second, D is the diameter of the propeller, ρ is the density of the fluid, T is the thrust force that is generated on the surface of the propeller and Q is the torque of the propeller.

Finally, the presence of cavitation on the suction side of the blades is evaluated for the selected propellers based on the cavitation inception criteria. The cavitation will occur when the minimum negative pressure coefficient, *Cp*, is equal to the cavitation number, σ *(Molland, 2007)*. Therefore, the cavitation will be present in the zones of the blade where,

$$\frac{-c_p}{\sigma} = 1 \tag{3}$$

Results

Obtained Geometries: Through the methodologies presented, four propellers are obtained. All geometries present a skew radial distribution based on the original distribution of the DTMB 4119 propeller because the effect of the skew on the performance of the propeller is out of the reach of this analysis.

For each design, the front view of the vanes and the distribution of the chord, curvature and thickness of the profile in different radial positions, respectively, are presented. In addition, for all designs, a nose or hub of 7 cm in diameter was taken as the reference, like those available in the market.

DTMB Series (DTMB): Based on the DTMB series, the geometry presented in (Fig. 6a) is obtained. From this, it can be highlighted that it provides the blades with the profiles with the largest chord for the radial sections of which it is composed.

Lifting-Line Speed (LLS): By defining optimization parameters according to a velocity propeller, smaller diameter and maximum angular velocity, 0.22 m and 2500 RPM respectively, a first design was obtained by optimization, based on the lift-line theory, called LLS propeller. This propeller, in relation to the other designs, is the one that has the smallest length of chord for each of its radial sections. This geometry is presented in (Fig. 6b).

Lifting-Line Heavyweight (LLH): For the second design by means of the OpenProp free software, optimization parameters were defined according to a thrust propeller or heavy load transport, larger diameter and lower maximum angular speed, 0.25 m and 1700 RPM respectively, a first design was obtained by optimization, based on the hydrodynamic theory of lifting-line, called heavyweight propeller.

Based on these two designs, it can be affirmed that the optimization reduces the chord in the cross sections and therefore the surface area of the propeller. This design is presented in (Fig. 6c).

Blade Element Momentum Theory (BEMT): The fourth one designed represents the optimization methodology through BEMT. In this, a minimum total surface area was considered to reduce to the maximum the presence of any type of cavitation on the surface of the pallets. The mentioned minimum area was determined by means of the formula suggested by Keller [18], which relates the ratio of minimum expanded area to avoid cavitation with the diameter of the propeller D, the static pressure at the centre of rotation of the propeller Po, the steam pressure of the water for the conditions in which the propeller Pv operates, the number of paddles Z, the maximum expected thrust T and a correction coefficient whose value corresponds to 0 for a very high speed propulsion, 0.1 for boats propelled by two propellers and 0.2 for propulsion by a single propeller. This formula is expressed as:

$$\left[\frac{A_E}{A_O}\right]_{min} = \frac{(1.3 + 0.3Z)\,T}{(P_O - P_V)\,D^2} \tag{4}$$

The optimization was then applied to a propeller of 0.22 m in diameter and the geometry shown in (Fig. 6d) was obtained. This propeller has the longest cord length in its radial sections compared to the three designs presented above.

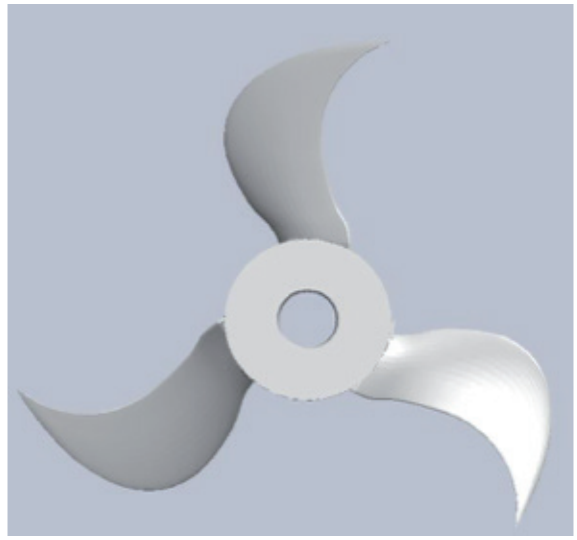
Finally, the four obtained propellers are summarized and characterized by their main geometrical properties in the (Table 3).

In order to select the two best propellers for the speed and heavy load vessels that will participate in the contest, comparative graphs were made for each coefficient considering the four proposed designs, these graphs are presented for *Kt*, *Kq* and ηHydro in the (Fig. 7). As a result of this comparison, the design Speed is selected as a propeller for speed and the Heavyweight design for heavy load, because it presents the efficiency and thrust coefficient of greater value in the range of coefficients of advance of interest. These geometries are processed by CAD software to be the basis of CFD simulations and to be manufactured for experimental tests.

Mentioned CAD-processed geometries are presented as a heavy load propeller and speed propeller in (Fig. 4) and (Fig. 5), respectively.

Fig. 4. Speed propeller.

Fig. 5. Heavyweight propeller.



In addition, it is possible to observe that the Speed propeller is the one with the highest hydrodynamic efficiency in the entire range of advance coefficients, which is why it is the adequate propeller for the energy efficiency category that is part of the contest.

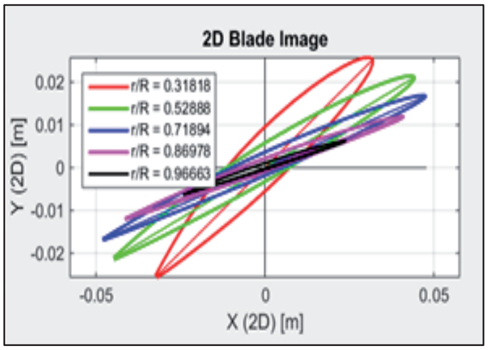
Propellers manufacturing: Based on the CAD geometries obtained, the propellers for the category of speed and the category of heavy load are manufactured by means of additive manufacturing in ABS M30. These propellers are shown in (Fig. 8) and (Fig. 9).

CFD lifting-line non-dimensionless results: The results obtained by means of the computational application of the lifting-line theory are integrated to the performance data of the motor (exclusive property of the manufacturer) and presented as the final charts of performance of the complete propulsion system for the two selected propellers (Fig. 10) and (Fig. 11).

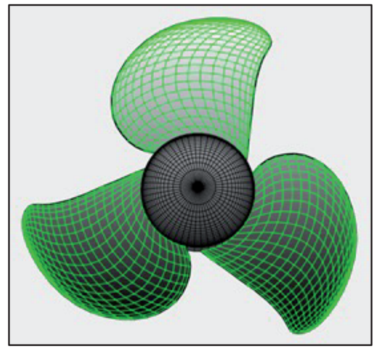
Table 3. Summary and characterization of the obtained propellers.
P/D: pitch/diameter, EAR: Expanded Area Ratio.

Propeller	Z	Diameter [m]	Pitch [m]	P/D	Skew [deg]	Rake [m]	EAR
DTMB	3	0.22	0.18	0.79	-7.55	0	0.528
LLS	3	0.22	0.18	0.82	-7.55	0	0.225
LLH	3	0.25	0.27	1.09	-8.03	0	0.235
BEMT	3	0.23	0.15	0.65	-7.73	-0.04	0.496

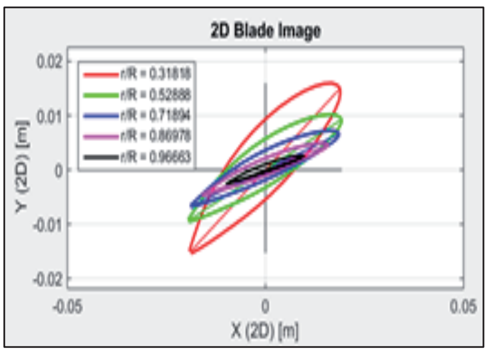
Fig. 6. (6) (Left) Radial sections of the geometry obtained by the specified methods.
(Right) Front view of the geometry obtained by the specified methods.
a) DTMB; b) LLS; c) LLH; d) BEMT



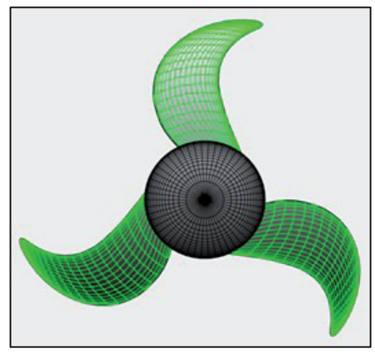
a)



a)



b)



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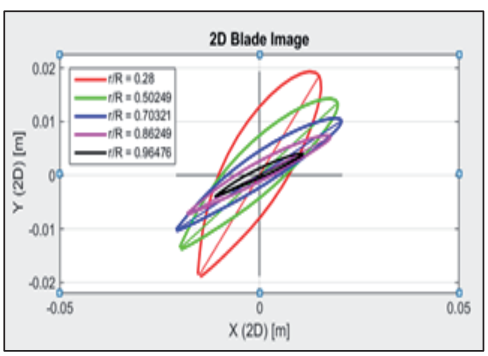
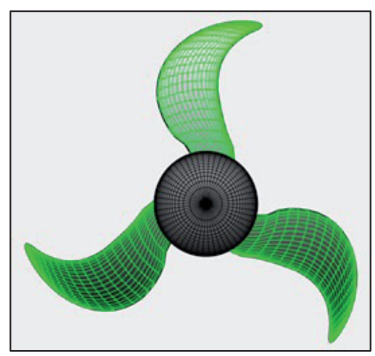
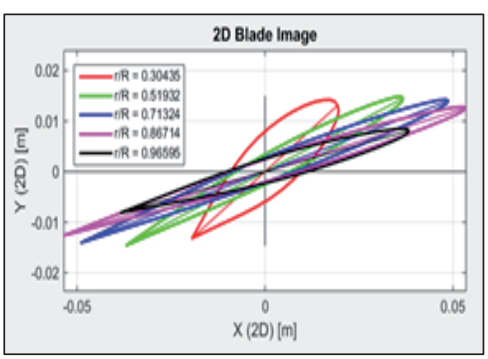


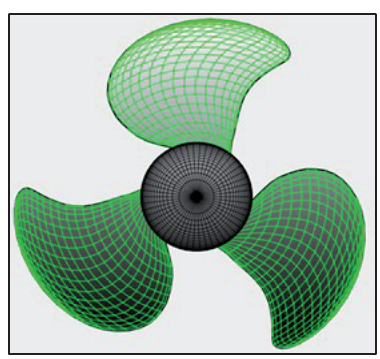
c)



c)

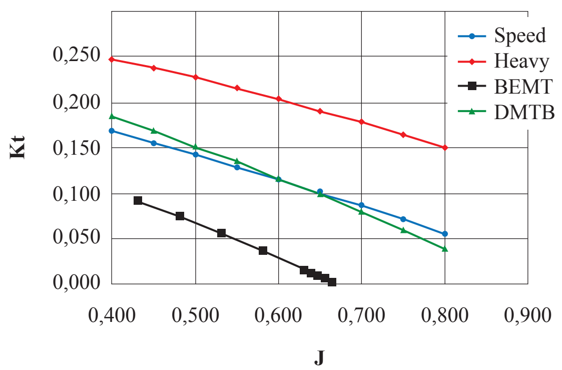


d)

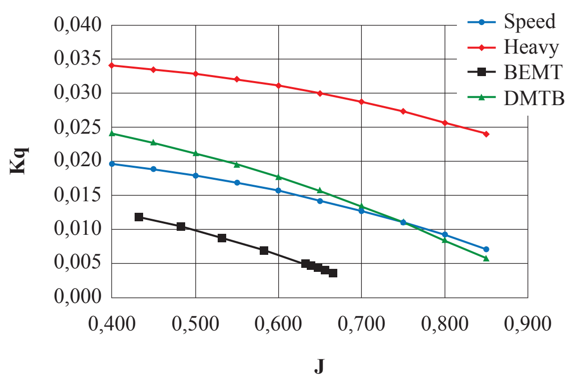


d)

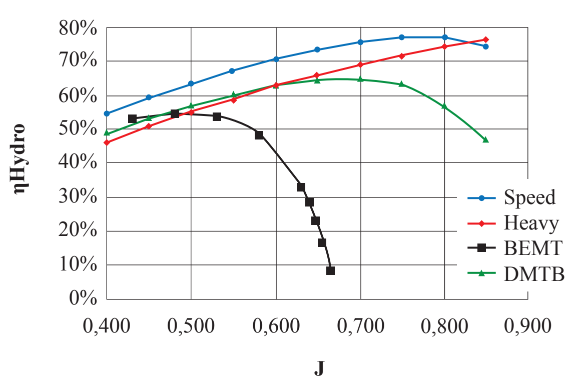
Fig. 7. Performance charts for the designed propellers. (Blue: Speed propeller, Red: Heavyweight propeller, Black: BEMT propeller and Green: DTMB propeller).



a) Thrust coefficient vs. advance coefficient.



b) Torque coefficient vs. advance coefficient.



b) Hydrodynamic coefficient vs. advance coefficient.

Fig. 8. Speed propeller prototyped by means of additive manufacturing in ABS M30.

Fig. 9. Heavyweight propeller prototyped by means of additive manufacturing in ABS M30.

CFD lifting-line non-dimensionless results: The results obtained by means of the computational application of the lifting-line theory are integrated to the performance data of the motor (exclusive property of the manufacturer) and presented as the final charts of performance of the complete propulsion system for the two selected propellers (Fig. 10) and (Fig. 11).

Finally, the possible cavitation is evaluated for the LLH and LLS propellers, the distribution of the relation described in the (Equation 3) is plotted on the suction side of their blades in order to identify the points where the relation is equal to 1 for sea water under standard conditions. The (Fig. 12) shows the lack of cavitation inception in the suction side of their blades, the most critical side due to the low pressure required to generate the propulsion of the ship.

Fig. 10. Thrust generated by the propulsion system as function of the advance speed for the two operating conditions.

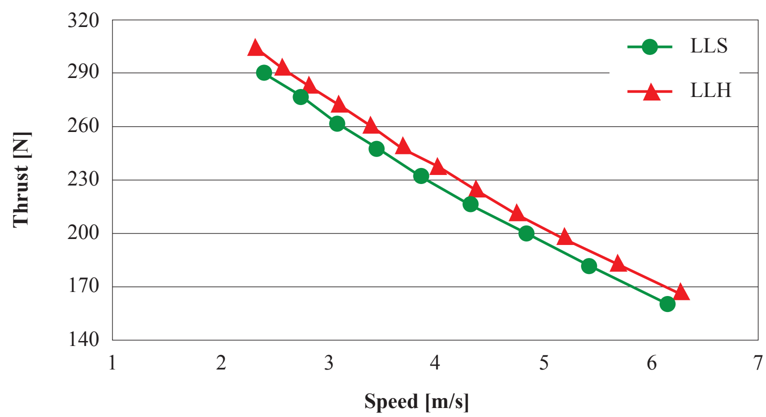


Fig. 11. Hydrodynamic efficiency of the propulsion system as function of the advance speed for the two operating conditions.

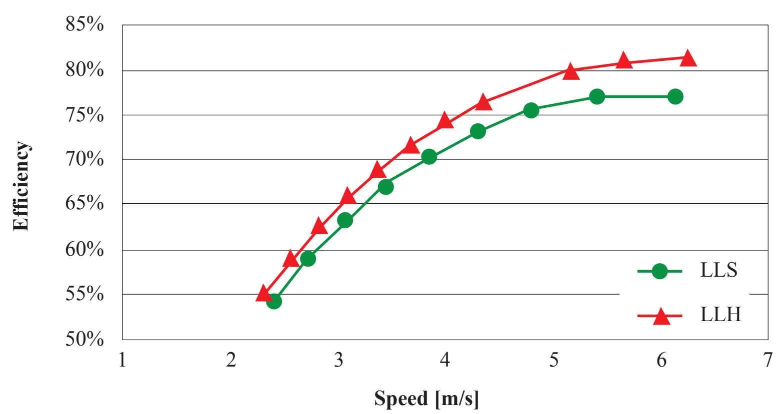
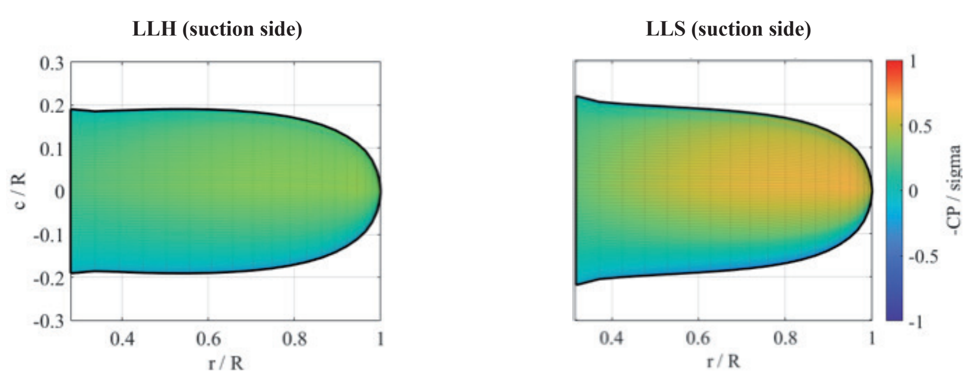


Fig. 12. Field of the cavitation relation -Cp/σ on the suction sides of the LLH and LLS propellers.



Discussion and Conclusions

From the results obtained by means of the lifting-line theory, it is possible to affirm that the propeller prototypes with the best performance are the propellers optimized by the lifting-line theory. This is because their hydrodynamic efficiencies are around 10% higher than the coefficients of the other two designed prototypes. In addition, it is concluded that the lifting-line theory and the optimization methods based on this, allow obtaining propellers with greater hydrodynamic efficiency, that is, it manages to more efficiently convert the input power into useful lift force avoiding high losses due to slippage and drag.

By means of the comparison of the results obtained by experimentation and by CFD simulation, it can be concluded that, due to the complexity of the geometry, since this is defined in a parametric way by guidelines, the mesh needs to be deformed excessively, which can imply that it does not capture the viscous phenomena that occur on the surface of the propeller and the pressure differences that act on it, responsible for the lift and drag forces. In addition, the results of cavitation by means of CFD are not conclusive since they underestimate the generated thrust, which is directly related to the pressure difference between the high and low-pressure faces of the propeller, criteria used to identify areas where cavitation may occur.

As future work several development points are recognized that can benefit the design of propellers, these points are: to realize a dynamic experimental assembly, to include the effects that provoke on the propeller the hull or the hulls of the boat, implementation of a mechanical system that allows the variation of the passage of the blades while they are in operation, and simplifying the method of obtaining the geometries to achieve meshes of higher quality.

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References

[1] A. MOLLAND and S. TURNOCK, Marine rudders and control surfaces. Oxford: Elsevier/ Butterworth-Heinemann, 2007.

[2] B.P. EPPS and R.W. KIMBALL, OpenProp v3: Open-source software for the design and analysis of marine propellers and horizontal-axis turbines. URL: http://engineering.dartmouth.edu/epps/openprop, 2013

[3] B.P. EPPS, "On the rotor lifting-line wake model", Journal of Ship Production and Design, vol. 32, 3:1-15, 2016.

[4] B.P. EPPS, R.W. KIMBALL, "Unified Rotor Lifting-line Theory", Journal of Ship Research, vol. 57, 4:1-21, 2013.

[5] C. JENG-HORNG, S. YU-SHAN, “Basic design of a series propeller with vibration consideration by genetic algorithm”, J. Mar. Sci. Technol. 12: 119-129, 2007.

[6] CHUNG, "An enhanced propeller design program based on propeller vortex lattice lifting-line theory" Master Thesis, Massachusetts Institute of Technology, 2007.

[7] D. CABEZÓN *et al.*, "Comparison of turbulence models for the computational fluid dynamics simulation of wind turbine wake in the atmospheric boundary layer", Wind Energy., vol. 14, 7: 909-921, 2011.

[8] D. MARTEN, J. WENDLER, “QBlade Guidelines v0.6”, QBlade, TU Berlin, 2013.

[9] E. KNUTSEN SKÅLAND, "The Influence of the Choice of Propeller Design Tool on Propeller Performance", Master Thesis, Norwegian University of Science and Technology, 2016.

[10] J. CARLTON, Marine propellers and propulsion, Third Edition., Butterworth-Heinemann Ltd, 2010.

[11] J. KULCZYK, Ł. SKRABURSKI, M. ZAWIŚLAK, "Analysis of screw propeller 4119 using the Fluent system", Archives of Civil and Mechanical Engineering, vol. 7, 4:129-137, 2007.

[12] J.M. MEJÍA *et al.*, "Propuesta Metodológica para el Diseño de las Aspas de Turbinas de Viento de Eje Horizontal", Energética, 33:37-45, 2005.

[13] K. M. FLOOD, "Propeller performance Analysis Using Lifting-line Theory", Master Thesis, Massachusetts Institute of Technology, 2008.

[14] M.M.C. OOSTERVELD, P. VAN OOSSANEN, "Further Computer-Analysed Data of the Wageningen B-screw series", International Shipbuilding Progress, vol. 22, 251:3-14, 1975.

[15] O. GUR, A. ROSEM, "Comparison between blade-element models of propellers" The Aero. Journal, vol. 112 1138: 689-704, 2008.

[16] S. BRIZZOLARA, D. VILLA y S. GAGGERO, "A systematic comparison between RANS and Panel Methods for Propeller Analysis", Proceedings of 8th International Conference on Hydrodynamics, 2008.

[17] TREJO I. *et al.*, "Analysis of a ship propeller using CFD codes", MARINE 2017, Barcelona, Spain, 2017.

Conceptual design of coastal patrol vessel (CPV) with flight deck for the reception and deployment of helicopter

Diseño conceptual de buque patrullero de costa (CPV) con cubierta de vuelo para la recepción y despliegue de helicóptero

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Abstract

This paper presents the development of the conceptual design of a coastal Patrol vessel with the capacity to receive and deploy a helicopter, in order to increase the efficiency of coastguard operations developed by the Colombian National Navy. As a starting point, the design of the coastal patrol vessel built by Cotecmar and named CPV46 was taken, on which modifications were implemented in its main dimensions and distribution of spaces, which allowed to include a flight deck to receive a BELL 412 EP helicopter, complying with the regulations for this type of operations.
This design was developed based on the design spiral method, where each turn of the spiral includes estimates and performance calculations influenced by each other and corresponding to the different stages of the design. For this work, the conceptual design was divided into eight booklets containing the state of the art, mission profile, capacity sizing, naval architecture, propeller selection, generator selection, stability study and cost estimation, concluding in the feasibility of the design based on its cost at a conceptual level.

Key words: Conceptual design, efficiency, design spiral, iterative, mission profile

Resumen

En este trabajo se presenta el desarrollo del diseño conceptual de un buque Patrullero de costa con capacidad para recibir y desplegar un helicóptero, con el fin de incrementar la eficiencia en las operaciones de guardacostas desarrolladas por la Armada Nacional de Colombia. Como punto de inicio se tomó el diseño del buque patrullero de costa construido por Cotecmar y denominado CPV46, sobre el cual se implementaron modificaciones en sus dimensiones principales y distribución de espacios, lo que permitió incluir una cubierta de vuelo para recibir un helicóptero BELL 412 EP, cumpliendo la reglamentación para este tipo de operaciones.
Este diseño se desarrolló en base al método de la espiral de diseño, donde cada vuelta del espiral incluye estimaciones y cálculos de desempeño influenciadas entre sí y que corresponde a las diferentes etapas del diseño. Para este trabajo se dividió el diseño conceptual en ocho cuadernillos que contienen el estado del arte, perfil de misión, dimensionamiento de capacidades, arquitectura naval, selección del propulsor, selección del generador, estudio estabilidad y estimación de costo, concluyendo en la viabilidad del diseño en base a su costo a un nivel conceptual.

Palabras claves: Diseño conceptual, eficiencia, espiral del diseño, iterativo, perfil de misión.

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Introduction

The Colombian Navy currently has four CPV coast patrol vessels and four Point Class vessels for coastguard operations, although those Point Class vessels have reached the end of their useful life and are in the process of being discharged. The Colombian Navy has found it necessary to have oceanic patrol vessels (OPVs) and even missile frigates for patrol operations in coastal areas, on sizing capacities for this type of operations and increasing their costs.

"Coastal patrol vessel" project (CPV) with flight deck for the reception and deployment of helicopters, mitigating the oversizing of units used by the Colombian Navy in coastguard operations, such as OPV or missile frigates, increasing the efficiency of these coastguard operations.

Methodology

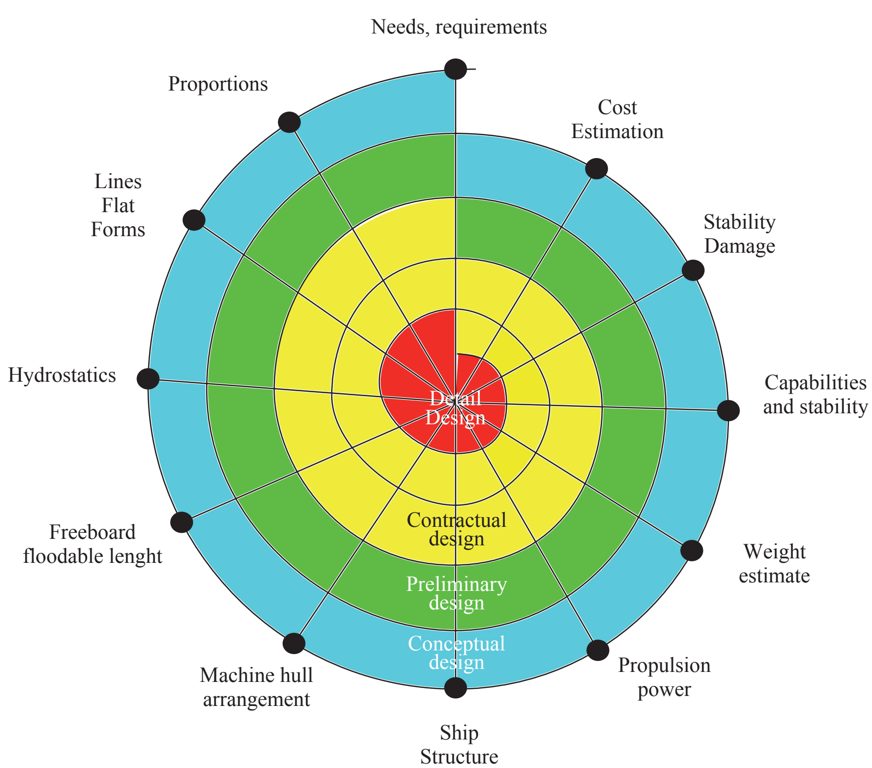
The type of descriptive research and the methodology of the design spiral has been highlighted, resulting in a cyclical and iterative method, in which each of the project phases is related to each other, establishing a relationship in each phase of the project. phases, this results in that the concepts and the results in each phase must be verified several times until they adapt to the considerations that keep the phases to each other. In this work a first spin of the spiral is done, which defines a conceptual level of the vessel.

Design Restrictions

This design was adjusted in compliance with the design standards of the Lloyd's Register Classification Society, in addition to complying with the regulations that regulate nationally and internationally the transit and safety of ships, such as the IMO or MARPOL norms, and the local regulations of the maritime authority DIMAR.

The main restriction of this design falls on the ship's beam, which is wide enough to meet the Lloyd's Register standards for flight decks according to the helicopter it will receive.

Fig. 1. Design spiral, recovered from (Jimenez & Pino, 2016).



The rotary wing aircraft with which the Colombian Navy has, consist mainly of Bell 412 EP helicopter, so this design was adjusted so that the flight deck can receive this type of aircraft without problems.

Mission Profile

The coastal patrol vessel should serve as a platform to develop operations of "maritime interdiction, patrolling and surveillance of maritime spaces, and provide support in border control operations to detect, intercept, stop, board, visit and inspect vessels, supply of rapid reaction units, as well as the deployment, taking and supply of boats for visitation and interdiction, "in addition to providing assistance to vessels and people in shipwreck or state of emergency, as required by international conventions *(Defensa.com, 2014)*.

Main Capabilities of the Design

In this paper, the capacities with which coastal patrol vessel designed and built in Cotecmar (CPV-46) are currently being considered and adjusted, adding the capacities required to receive and deploy a helicopter.

The scope of this conceptual design results in 2000 miles at 12 knots of speed, with a food and water autonomy of 17 days for 23 people.

Characteristics and main dimensions

The dimensions were determined, taking as a starting point the hull of the CPV-46, designed and built by Cotecmar, in this way the dimensions were adapted so that it could receive a BELL 412 EP helicopter, in Fig. 2 the main dimensions of the BELL 412, of which we take the diameter of rotor of 14.02 meters and the separation between skids of 3.24 meters for the dimensions of the flight deck.

Lines of Form

Through the MaxSurf Modeler computational tool, a computational model of the CPV hull with flight deck is developed, obtaining the next forms:

Fig. 2. Planos Bell 412 EP (Textron Company, 2006).

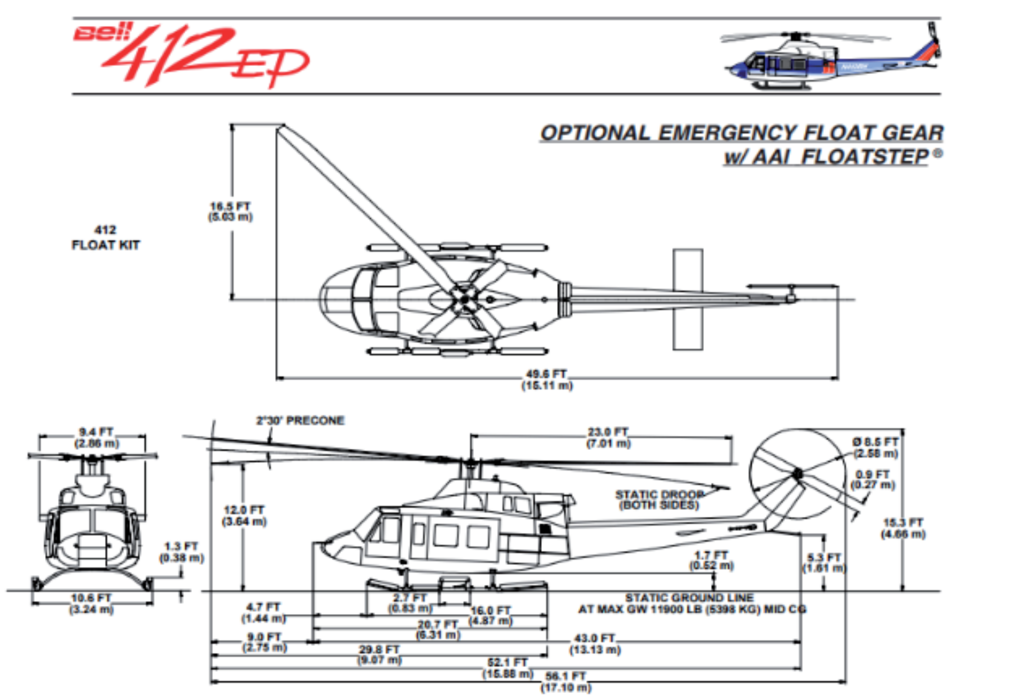


Fig. 3. Lines of forms.

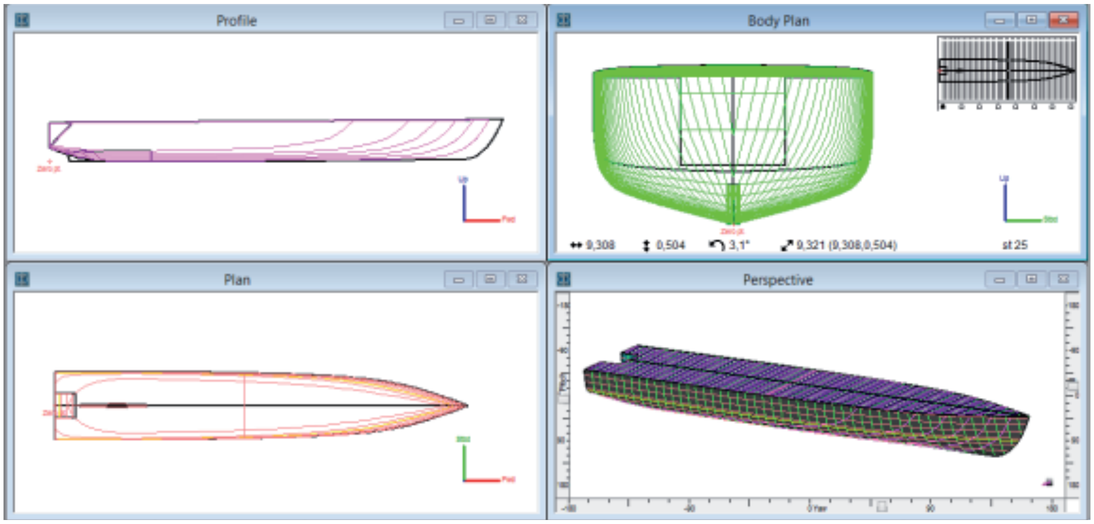


Table 1. Dimensions and general characteristics of this design.

Lenght	49	[Meters]
Breadth	8	[Meters]
Depth	4,56	[Meters]
Draught	2,1	[Meters]
Displacement	414,7	[Ton]
Cruise speed	12	[Knot]
Maximum speed	19	[Knot]

Power Estimation

By means of the computer tool MaxSurf Resistance, the resistance to advance of the computational model of the hull between 6 and 19 knots is estimated, obtaining the results shown in Table 2.

From the result presented in the previous table, the 15% resistance of appendices that we assume has this design is added resulting in a resistance of 216, 66 KN for 19 Knots of speed.

The effective power (PE) is the result from multiplication the resistance estimated in KN by the speed in m/s, from here the brake power (PB) required by the propulsion engines is estimated, resulting from a margin of 90% aging and a propulsive efficiency assumed in 60% of the effective power (PE), as shown in Table 3.

Dimensioning of Tanks

Knowing the fuel and lubricant consumption of the propulsion engines and generators, the tank capacity is estimated considering the reach of 2000 nautical miles at 12 Kn and the autonomy of 17 days for 23

Table 2. Resistance to advance.

Vel (Knt)	Froude No. (LWL)	Holtrop Resist (KN)
6	0,143	7
7	0,167	9,4
8	0,19	12,4
9	0,214	16,3
10	0,238	21,3
11	0,262	27,4
12	0,286	36,3
13	0,309	48,3
14	0,333	57,5
15	0,357	65,1
16	0,381	76,9
17	0,405	101
18	0,428	144,6
19	0,452	188,4

Table 3. Power estimation.

Vel (Knt)	PE with service margin (KW)	PB (KW) ηp=0,6	PB total (KW) MCR=90%
6	28,550	47,584	52,871
7	44,729	74,548	82,831
8	67,433	112,388	124,875
9	99,722	166,203	184,669
10	144,790	241,317	268,130
11	204,881	341,469	379,410
12	296,106	493,509	548,344
13	426,824	711,374	790,416
14	547,211	912,018	1013,353
15	663,791	1106,318	1229,242
16	836,383	1393,971	1548,857
17	1167,157	1945,261	2161,401
18	1769,292	2948,821	3276,467
19	2433,287	4055,478	4506,087

people, this taking into account the fact that Water and fuel pumps do not suck a remaining 10% of the tanks and the tanks are not filled to more than 95% to prevent them from overflowing. Estimate the minimum tank capacity resulting in the next table.

Table 4. Minimum capacity of tanks of this design.

Fluid	Volume (m^3)
Water	13,8
Fuel	33,78
Lubricant Oil	1,79

From the previous information, the tanks are dimensioned with the MaxSurf Stability computational tool, resulting in the next distribution of tanks:

Table 5. Tank capacity of this design.

Fluid	Volume (m^3)	Weight (Ton)
Water	14,856	14,856
Fuel	34,138	28,678
Lubricant Oil	2,029	1,867
Hydraulic oil	0,538	0,495
URR gasoline	7,14	5,354
Gasoline Helicopter	7,14	5,354
Grey waters	3,043	2,778
Sewage water	3,043	2,778

Study of Weights and Definition of The Gravity Center Of The Vessel In Lightship

This design used the cubic number (NC) method, which maintains a ratio of length x breadth x depth between two vessels, keeping a real reference to develop the estimate of a design. Knowing the dimensions and loads of the CPV-46, the study of weight in the condition of displacement light ship or also known as thread weight was developed, estimating the load distribution and center of gravity of this design (CPV-49), with a margin of error of 3% in this displacement condition, resulting in what is presented in Table 6.

Study of Dead Weight

The dead weight represents the load carried by the vessel and the contents of their tanks, whether water, oil, fuel, ballast, crew, food, etc. For this design, the helicopter that will be located on the flight deck and the contents of the water, ballast and fuel tanks are considered deadweight.

Below is the distribution of the deadweight quantities for this design, fulfilling the

Table 6. Light ship distribution of this design.

SWBS	Description	Weight (ton)
100	Hull and structur	135,06
	Superstructur	16,09
	Flight deck	5,00
200	Propultion	40,17
300	Electric plant	20,97
400	Control and command	4,87
500	Auxiliary systems	32,46
	Helicopter sistems	1,00
600	Acomodations	62,03
700	Armament	11,12
	Lead	2,56
	Total	331,32
	Margin 3%	9,94
	Light ship	341,26

minimum total tank capacities estimated previously and according to the distribution of Maxsurf Stability tanks and the number of crew established for this design.

Table 7. Deadweight distribution of this design.

Features	Weight (Ton)
Helicopter	5,4
Crew	1,8
Food	3
Load	2,988
Content tanks	60,212
Total	73,4

Study of Transversal Stability

For this design the stability study was developed for three (03) loading conditions, maximum displacement, half load and light ship, by means of the MaxSurf Stability computational tool, these load conditions were simulated, obtaining positive results in the required criteria. by the IMO stipulated in chapter three of resolution A 749 "Intact stability without damage code ", which apply to vessels over 24 meters in length.

Scantling

This design was developed following the rule of Lloyd's Register, "Rules and Regulations for classification of Naval Ship" of 2018, where it is established as an initial step to determine the type of vessel that is being designed according to the standard, as a result this category was categorized. design as a NS3 type, this category covers ships with less than 1500 tons displacement and with frontline roles that can operate individually or in a group of operations, corresponding to ships for mine sweeping, landing on beaches, coastal defense or fast patrol boat.

The construction materials were selected for this design, taking as reference the materials used in the CPV-46.

Table 8. Building materials (STX, 2014).

Location	Material
Hull	Steel ASTM AH32
Super-structure	Aluminum A 5083

For the NS3 category certain guidelines are preserved for the development of the estimation and calculation of the scantling, such as the minimum plate thicknesses and the moments of inertia of the structural reinforcements, resulting in the following master frame.

Fig. 4. Main frame scantling.

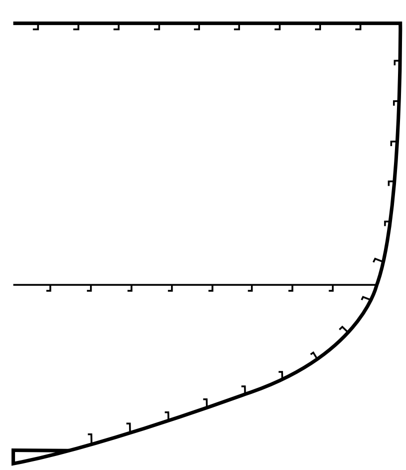


Table 9. Dimensions structural elements of the master frame.

Structural elements	Dimensions
Deep plate	thickness 9,525 mm
Bilge plate	thickness 9,525 mm
Side plate	thickness 6,35 mm
Deck 2 plate	thickness 6,35 mm
Principal deck plate	thickness 6,35 mm
Reinforce keel core	thickness 9,525 mm
Reinforce keel wing	thickness 9,525 mm
Longitudinal reinforce deep	Angle 80x40x8
Longitudinal reinforce bilge	Angle 80x40x8
Longitudinal reinforce sides	Angle 50x50x8
Longitudinal reinforce deck 2	Angle 50x50x8
Longitudinal reinforce principal deck	Angle 50x50x8

The module of section of the master frame was estimated and compared with the minimum of module section that according to the International Association Classification Society (IACS) *(Ávila, 2018)* for the dimensions of this design, resulting in the following.

Table 10.

Master frame section module	Minimum of module section according to IACS
0,2858 m^3	0,1161 m^3

We estimate the maximum bending moment that the master frame supports according to its section modulus and the creep stress of the construction material ($M_{max} = Z^*\sigma_0$), resulting in M_{max} = 90027 KN^*m.

According to *(Avila, 2018)* the maximum bending moment that the master frame can support, must be greater than the bending moment calculated according to the IACS, which adds a bending moment in calm waters (M_{sw}) and a bending moment in waves (M_{Wv}).

The bending moment in calm waters includes the concept of the ship beam, where the total of the structure of the ship is taken as a beam, this ship beam according to the global and local loads to which it is subjected generates certain shear stresses and moments bending, in the maximum bending moment produced in the ship beam is taken as the bending moment in calm waters, which can be found by means of the MaxSurf Stability computational tool, resulting in an $M_{sw(-)}$) = 11424,76 KN^*m in shear.

The moment in waves (M_{Wv}) is separated into two types of moments, moment in waves by grief or moment in waves by sheer, estimating the two directions in which the ship can be flexed longitudinally. The moments in waves are calculated from the next formulas and then added to the moment in calm waters to determine the maximum moment according to IACS *(Ávila, 2018)*.

Grief:

$$M_{wv(+)} = 0{,}19 * M * C * L_{WL}^2 * B * C_B$$

$$M_{wv(+)} = 12023{,}95 \ \ KN * m$$

$$M_{IACS} = M_{sw} + M_{wv(+)} = 599{,}19 \ KN * m \tag{1}$$

$$M_{IACS} = 599{,}19 \ KN * m$$

Sheer:

$$M_{wv(-)} = 0{,}11 * M * C * L_{WL}^2 * B * C_B$$

$$M_{wv(-)} = 6961{,}234 \ \ KN * m \tag{2}$$

$$M_{IACS} = 18385{,}994 \ KN * m$$

According to the previous results, we can conclude that the master frame complies with the capabilities to withstand the ship's loads at sea.

Vertical Speeds on the Flight Deck

According to the Lloyd's Register standard, the maximum permissible vertical speeds for a flight deck in a design according to the state of the sea at the Douglas scale are in the next table:

Table 11. Vertical Velocity (Lloyd's Register, 2018).

Sea state	Vertical velocity (m/s)
6	3,72
5	3,35
4	2,97
3	2,60
2	2,23

With the Maxsurf Motion computational tool (Bentley Engineering), the sea behavior of the computational model of this design was simulated, according to the Douglas scale, these simulations were developed for a sea 4 and a sea 5 for the Caribbean Sea region, with a modal period and a height of the wave as presented in the next table:

Table 12. Sea conditions in MaxSurf Motion computer simulation.

State of the sea (Caribbean)	Wave height (m)	Modal period (s)
4	1,7	6,515
5	2,6	9,062

According to the results of this simulation of the computational model, it is observed that the Lloyd's Register standard is satisfactorily fulfilled, as presented in the next table.

Table 13. Summary result vertical speeds on the flight deck.

State of the sea	Maximum admissible values	Minimum value / maximum obtained
Sea 4	2,97	0,126 / 0,494
Sea 5	3,35	0,222 / 0,785

Conclusions

During the development of this design, the proposed objectives were achieved through the phases mentioned in the research methodology.

It was determined that the minimum length to include in the design of the CPV-46 a flight deck, is 49 meters according to the "Rules and Regulations for the classification of Naval Ship" standard of the Lloyd's Register Classification Society, in addition to reduce the maximum speed from 20 Knots to 19 Knots, because it would require that each propeller engine had more than 1300 KW of power to be able to achieve that single knot of difference, increasing much more the maximum displacement and the need for tank capacity made out of fuel.

During the development of this design, it was observed that for a breadth of 7.5 meters (initial breadth with which this design was estimated) favorable results were not obtained in their transverse stability, for which an 8 meter breadth was determined to counteract this situation, offering favorable results in the study of stability.

References

ALBERTO GRANADA LÓPEZ, P. H. (2017). *Informe de la estimación de la distorsión en el valor de las importaciones colombianas*. Dreccion de Impuestos y Aduanas Nacional.

ÁVILA, B. (2018). Notas de clase de "Estructura del Buque", curso Ingeniería Naval. Cartagena: Escuela Naval Almirante Padilla.

BENTLEY ENGINEERING. (s.f.). Maxsurf 20 V8i.

BLANCO, J. M. Proceso de Construcción de un Buque. En J. M. Blanco, *LA CONSTRUCCION NAVAL* (págs. 63-64).

BRAKHAGE, M. (10 de Mayo de 2011). *Zarpa hacia Colombia, la nueva patrullera de costa ARC 11 de Noviembre*. Recuperado el 01 de Junio de 2018, de Webinfomil.com: http://

www.webinfomil.com/2011/05/zarpa-hacia-colombia-la-nueva.html

Buque Patrullero. (28 de Julio de 2008). Recuperado el 01 de Junio de 2018, de Wikipedia: https://es.wikipedia.org/wiki/Buque_patrullero

CATERPILLAR. (s.f.). 3516C *HD MARINE PROPULSION*. Recuperado el 20 de OCTUBRE de 2018, de CATERPILLAR : http://www.teknoxgroup.com/fileadmin/user_upload/3516C_-_HD.pdf

CATERPILLAR. (s.f.). CAT C4.4 *Diesel Engine*. Recuperado el 21 de Octubre de 2018, de Gecolsa: https://gecolsa.com/uploads/product/equipment/brochure/C4.4_-_72.4-111.3bhp.pdf

CATERPILLAR. (s.f.). *Propulsores marinos*. Recuperado el 10 de otubre de 2018, de finanzauto: http://www.finanzauto.es/es/productos/soluciones-energeticas-y-de-propulsion/marino/propulsores

CENTRO INTERNACIONAL MARITIMO DE ANALISIS CONTRA EL NARCOTRÁFICO. (2016). Análisis eventos presentados contra el narcotrafico en la region I trimestre.

DANE. (s.f.). *Departamento Administrativo Nacional de Estadísticas*. Recuperado el 28 de Octubre de 2018, de DANE: http://www.dane.gov.co/index.php/52-espanol/noticias/noticias/4026-indice-de-precios-al-consumidor-ipc-ano-2016-y-diciembre-2016

Defensa.com. (4 de Noviembre de 2014). *Botado en Colombia el ARC "Punta Espada"*. Recuperado el 10 de Junio de 2018, de Defensa.com: https://www.defensa.com/colombia/botado-colombia-arc-punta-espada

EL UNIVERSAL. (27 de Julio de 2016). *Así será la Armada Nacional en 2030*. Recuperado el 30 de Marzo de 2018, de El Universal: http://www.eluniversal.com.co/colombia/asi-sera-la-armada-nacional-en-2030-231543

EL UNIVERSAL. (31 de Octubre de 2014). *Bautizan primer buque patrullero de costa construido en Colombia*. Recuperado el 30 de Marzo de 2018, de El Universal Cartagena: http://www.eluniversal.com.co/cartagena/bautizan-primer-buque-patrullero-de-costa-construido-en-colombia-175580

FUENTES, D. (2018). Estimación de potencia. *Notas de clase, Resistencia al Avance, docente CC Fuentes David*. Cartagena.

GARCIA. (6 de Enero de 2013). *Nuevos Helicópteros Bell 412 Para la Armada Nacional*. Recuperado el 10 de Junio de 2018, de Webinfomil: http://www.webinfomil.com/2013/01/nuevos-helicopteros-bell-412-para-la.html

GARCIA. (10 de Mayo de 2011). *Zarpa hacia Colombia, la nueva patrullera de costa ARC 11 de Noviembre*. Recuperado el 01 de Junio de 2018, de Webinfomil.com: http://www.webinfomil.com/2011/05/zarpa-hacia-colombia-la-nueva.html

HOLGUIN CUELLAR, M. A. (2013). Labores cumplidas durante el período comprendido entre junio de 2012 y junio de 2013 y el estado de los negocios adscritos a este ministerio. Conforme al Artículo 208 de la Constitución Nacional. En M. A. Cuellar, *Memorias al Congreso 2012-2013* (pág. 30). Cancilleria, ministro de relaciones exteriores.

JIMENEZ, N., & PINO, J. (2016). *Recuperado de Diseño Conceptual Buque Tipo CPV para el Pacífico*. Cartagena: Escuela Naval de Cadetes Almirante Padilla.

LabSI INVEMAR. (2009). *Colombia 50% Mar*. Recuperado el 10 de Junio de 2018, de Invemar: http://www.invemar.org.co/50-mar

LLOYD´S REGISTER. (2018). Parte 3 "Main Hull Structure". En Lloyd´s Register, *Rules and Regulations for the classification of Naval Ship* (págs. 75-209). Lloyd's Register.

LLOYD'S REGISTER. (2016). Geometric Properties of Rolled Sections. En Lloyd's Register, *Rules and Regulations for the classification of Inland Waterways Ships* (págs. 65-66). Lloyd's Register.

LLOYD'S REGISTER. (2018). Part 1 Regulations, Volumen 1 Ship Structures. En L. Register, *Rules and Regulations for the classification of naval ship* (pág. 11). Lloyd's Register.

LLOYD'S REGISTER. (2018). Parte 5 "Environmental Conditions". En Lloyd's Register, *Rules and Regulations for the classification of Naval Ship* (págs. 301- 374). Lloyd's Register.

LLOYD'S REGISTER. (2018). Parte 6 "Hull Construction in Stell". En Lloyd's Register, *Rules and Regulations for the classification of Naval Ship* (págs. 378-539). Lloyd's Register.

LLOYD'S REGISTER. (2018). plating general. En Lloyds Register, *Rules anf regulations for the classification of naval ship* (pág. 387). Lloyd's Register.

LLOYD'S REGISTER. (2018). Rules and Regulations fot the classification of naval ship. En L. Register, *Military Load Specification Volumen 1, Part 4, Chapter 2, Section 5* (pág. 253). Lloyd's Register.

LLOYD'S REGISTER., C. C. (2018). *Rules and Regulations for the Classification of Naval Ships*. Lloyd´s Register.

REVISTA DINERO. (1 de Marzo de 2018). *Costo de Vida*. Recuperado el 28 de Octubre de 2018, de Revista Dinero: https://www.dinero.com/economia/articulo/inflacion-total-de-2017-en-colombia-ipc/253916

STX, O. &. (30 de 10 de 2014). Planos Costal Patrol Vessel. *Planos CPV - 46*. Corea del Sur.

TEXTRON COMPANY. (2006). *Bell 412 EP, product specifications*. Textron Company.

WEBINFOMIL. (31 de Marzo de 2015). *ARC Punta Ardita y ARC Punta Soldado fortalecen la seguridad marítima de Colombia*. Recuperado el 10 de Junio de 2016, de Webinfomil.com: http://www.webinfomil.com/2015/03/arc-punta-ardita-y-arc-punta-soldado.html

WEBINFOMIL. (3 de Noviembre de 2014). *ARC Punta Espada, primer buque patrullero costa CPV-46 construido en Colombia*. Recuperado el 10 de Junio de 2018, de Webinfomil.com: http://www.webinfomil.com/2014/11/arc-punta-espada-cpv-46-armada-colombia-cotecmar.html

WEBINFOMIL. (5 de Octubre de 2018). *Armada de Colombia retiró del servicio al buque patrullero ARC "Cabo Corrientes"*. Recuperado el 13 de Octubre de 2018, de Webinfomil.com: http://www.webinfomil.com/2018/10/armada-de-colombia-retiro-del-servicio.html

Application of Cubic B-Spline Curves for Hull Meshing

Aplicación de Curvas B-Splines Cúbicas para el Mallado de Cascos

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Abstract

This paper describes the development of a regular hull meshing code using cubic B-Spline curves. The discretization procedure begins by the definition of B-Spline curves over stations, bow and stern contours of the hull plan lines. Thus, new knots are created applying an equal spaced subdivision procedure on defined B-spline curves. Then, over these equal transversal space knots, longitudinal B-spline curves are defined and subdivided into equally spaced knots, too. Subsequently, new transversal knots are created using the longitudinal equally spaced knots. Finally, the hull mesh is composed by quadrilateral panels formed by these new transversal and longitudinal knots. This procedure is applied in the submerged Wigley hulls Series 60 Cb=0.60. Their mesh volumes are calculated using the divergence theorem, for mesh quality evaluation.

Key words: Cubic B-Spline Curves, Hull Mesh, Quadrilateral Mesh Panel, Divergence Theorem.

Resumen

El presente artículo describe un código computacional, desarrollado para la elaboración de mallas regulares de cascos utilizando cuvas B-Splines cúbicas. El procedimiento de mallado comienza con la definición de curvas B-Spline, en el sentido transversal del casco, sobre las estaciones y los contornos de la proa y popa de un plano de líneas de forma. Por medio de estas curvas B-Spline es posible la creación de nuevos puntos igualmente espaciados en las regiones donde fueron definidas. Posteriormente, con estos puntos son trazadas curvas B-Spline cúbicas en el sentido longitudinal del casco, las cuales son utilizadas para obtener puntos igualmente espaciados, que permiten la creación de nuevas estaciones. Finalmente, los puntos transversales y longitudinales son utilizados para formar los paneles cuadrilaterales de la malla del casco. Este procedimiento es aplicado en los cascos sumergidos del modelo de casco Wigley y Serie 60 Cb=0.60. Los volumenes de estas mallas son calculados usando el teorema de la divergencia para servir como parametro de control de la calidad de la malla.

Palabras claves: Curvas B-Spline Cúbicas, Malla del Casco, Malla de Paneles Cuadrilaterales, Teorema de la Divergencia.

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Introduction

Traditionally, hull lines are designed manually using flexible wood beams known as splines, which can be fixed with lead weights or ducks for drafting a specific curve. The defined spline curve can be controlled locally or globally by moving ducks, which is useful for fairing. This process is necessary to obtain the hull and begin calculations such as hydrostatics, hydrodynamics, stability, structures and ship construction and production. This drafting process has been historically represented by mathematical models. One of the first efforts in this area was the work of Frederik Chapman, who in 1776 used parabolas to represent waterlines and other hull surface curves *(Ventura, 1996)*. In 1915, David Taylor also used mathematical equations for parabolas, hyperbolas and fifth order polynomials to represent the hull shapes of his systematic series. Between 1915 to 1970 several researchers used polynomials and other analytical geometric functions to represent hulls. Nevertheless, parabolas and conventional polynomial equations are difficult when fairing and locally modifying curves.

Mathematical models more similar to the wood spline drafting procedure began to appear. In 1957, Paul de Casteljau developed a spline described by parametric curves defined by control points, to be introduced in the Citroën automotive industry. In a parallel research, Paul Bezier developed an equivalent mathematical representation known as Bezier curve, while he had been working for Renault during 1962. A limitation of these curves was the impossibility to be modified locally for nearby control points, and its dependence on the number of control points with curve degree *(Rogers, 1977)*.

One of the most important contributions to a closer mathematical spline representation, without the issues of the Bezier curves, occurred in 1940, when Schoenberg developed a spline function based on a parametric mathematical representation of third degree polynomial to fit statistical data named as B-Spline or Basis Spline *(Cabral, et al., 1990)*. The properties, characteristics and piecewise adaptation of this function were studied and developed in 1972 by Carl de Boor *(De Boor, 2001)*. Further, B-Splines were introduced into Computer Aided Design (CAD) software by J. Ferguson for Boeing Co in 1963.

With increasing computer processing capacity in the 60's, the application of CAD in ship design also grew. Nowadays it is possible to perform hydrostatic, stability, structural and hydrodynamic analysis with it. Using a group of knots known as a mesh to represent the hull surface. This mesh can be composed of quadrilateral (regular) or triangular (irregular) knot arrangements.

This paper describes the mathematical formulation and methodology using in Salhua (2010) for a quadrilateral hull mesh generation code, using cubic B-Splines curves to represent submerged hulls. Finally, the Wigley model Series 60 Cb=0.60 hull are used for mesh generation evaluations.

Mathematical Formulation

B-spline definition

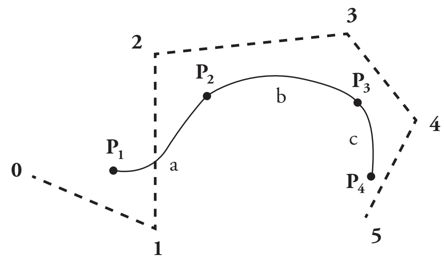
A B-Spline function is a mathematical representation of a piecewise polynomial curve through parametric equations. Each segment is joined following geometric (C0), slope (C1) and curvature (C2) continuity conditions. Moreover, a cubic B-Spline function has a polynomial order of 4 and has to follow two conditions *(Riesenfeld, 1973)*:

a) The cubic B-Spline needs to be a third degree polynomial on each segment.

b) The first and second derivatives are continuous on each segment.

A piecewise cubic B-spline curve can be composed by m segments where each one is defined by four control points. A complete B-Spline curve needs to have m+1 knots and m+3 control points. Each neighboring segment shares three control points, so each segment has a different one, *(Yamaguchi, 1978)*. As a example shown in Fig. 1, the curve has 4 knots, 3 segments and 6 control points.

Fig. 1. Cubic B-Spline with 3 segments.



Segments	Knots	Control Points
a	P_1 - P_2	**0,1,2,3**
b	P_2 - P_3	**1,2,3,4**
c	P_3 - P_4	**2,3,4,5**

The B-spline mathematical formulation of cubic B-spline knots depends on blending the functions and control points, see equation (1), *(Cabral, et al., 1990)* and *(De Boor, 2001)*.

$$\vec{P}_{i(t)} = E_{0(t)}\vec{V}_{i-1} + E_{1(t)}\vec{V}_i + E_{2(t)}\vec{V}_{i+1} + E_{3(t)}\vec{V}_{i+2} \quad (1)$$

Where:

i: knot identification number.
$\vec{P}_{i(t)}$: B-spline (x,y,z) knots vector.
$\vec{V}_{i-1}$, $\vec{V}_i$, $\vec{V}_{i+1}$, $\vec{V}_{i+2}$: Control points (X, Y, Z) vectors.
$E_{0(t)}$, $E_{1(t)}$, $E_{2(t)}$, $E_{3(t)}$: B-spline blending functions.

The blending functions are created to transform a polynomial equation into a piecewise and parametric curve B-Spline equation. These are imposed on each segment along curve and satisfy C^0, C^1, C^2 continuity conditions. Primarily, they allow for local control of the curve shapes. That is an improvement against simple polynomials, in which any change in any part modifies the entire curve. They are defined in 1D parameter t and vary from 0 to 1. Therefore t=0 corresponds to the initial knot segment and t=1 corresponds to the last one. The cubic B-Spline blending functions are shown in equations (2) to (5) *(Yamaguchi, 1978)*:

$$E_{0(t)} = \frac{t^3}{6} + \frac{t^2}{2} - \frac{t}{2} + \frac{1}{6} \quad (2)$$

$$E_{1(t)} = \frac{t^3}{2} - t^2 + \frac{2}{3} \quad (3)$$

$$E_{2(t)} = -\frac{t^3}{2} + \frac{t^2}{2} + \frac{t}{2} + \frac{1}{6} \quad (4)$$

$$E_{3(t)} = \frac{t^3}{6} \quad (5)$$

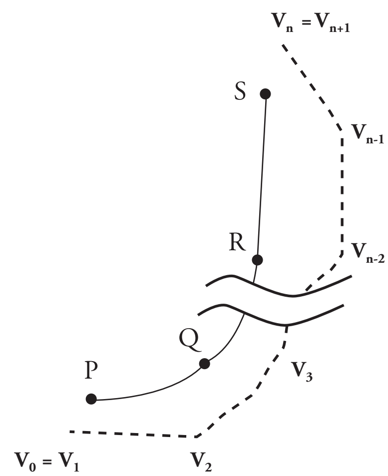
The number of control points exceeds the number of knots, Yamaguchi (1978) suggests the use of two additional boundary conditions equations to complete the system, see equations (6) and (7).

$$\vec{V}_0 = \vec{V}_1 \quad (6)$$

$$\vec{V}_n = \vec{V}_{n+1} \quad (7)$$

These conditions are applied as shown in Fig. 2.

Fig. 2. Open B-Spline curve.



Considering the parametric variable t of the blending B-Spline functions equal to zero to identify the initial knot and one for the final knot of each curve segment, *(Cabral, et al., 1990)*. The base functions are:

$$E_0(0) = \frac{1}{6} \quad (8)$$

$$E_1(0) = \frac{2}{3} \quad (9)$$

$$E_2(0) = \frac{1}{6} \quad (10)$$

$$E_3(0) = 0 \tag{11}$$

The last base function E3 (0) is equal to zero when t = 0, so the mathematical cubic B-Spline equation can be represented with only three base functions and control points, see equation (12).

$$\vec{P}_{i(t)} = E_0(0)\,\vec{V}_{i-1} + E_1(0)\,\vec{V}_i + E_2(0)\,\vec{V}_{i+1} \tag{12}$$

Equation (12) is applied through the four knots of Fig. 1 to obtain B-Spline control points by solving the linear system shown in (13) with the application of boundary conditions shown in equations (6) and (7).

$$\left[\vec{P}\right] = \left[E(0)\right].\left[\vec{V}\right] \tag{13}$$

Where:

$[\vec{P}]$: vector of curve knots.

$$\left[\vec{P}\right] = \begin{bmatrix} \vec{P}_1 \\ \vec{P}_2 \\ \vec{P}_3 \\ \vec{P}_4 \end{bmatrix}$$

$[\vec{V}]$: vector of control points.

$$\left[\vec{V}\right] = \begin{bmatrix} \vec{V}_1 = \vec{V}_1 \\ \vec{V}_2 \\ \vec{V}_3 \\ \vec{V}_4 = \vec{V}_5 \end{bmatrix}$$

[E(0)]: blending functions matrix when t=0.

$$\left[E(0)\right] = \begin{bmatrix} E_0(0)+E_1(0) & E_2(0) & 0 & 0 \\ E_0(0) & E_1(0) & E_2(0) & 0 \\ 0 & E_0(0) & E_1(0) & E_2(0) \\ 0 & 0 & E_0(0) & E_1(0)+E_2(0) \end{bmatrix}$$

Length calculation

A total length of the B-Spline curve is calculated by each segment curve and then added for a total, see equation (14).

$$S_{Total}(t,m) = \sum_{i=1}^{m} S_i(t) \tag{14}$$

Where:

$S_i(t)$: Length of segment i.
t: parameter of blending functions, in this case $t = 1$.

$$S_i(t) = \int_0^{t=1} \sqrt{\left(\frac{dx_i(t)}{dt}\right)^2 + \left(\frac{dy_i(t)}{dt}\right)^2 + \left(\frac{dz_i(t)}{dt}\right)^2}$$

m: Total number of segments of a B-Spline curve.
x_i, y_i, z_i: Coordinates of the B-spline curve.

$$\frac{dx_i}{dt} = \frac{dE_0}{dt}X_{i-1} + \frac{dE_1}{dt}X_i + \frac{dE_2}{dt}X_{i+1} + \frac{dE_3}{dt}X_{i+2}$$

$$\frac{dy_i}{dt} = \frac{dE_0}{dt}Y_{i-1} + \frac{dE_1}{dt}Y_i + \frac{dE_2}{dt}Y_{i+1} + \frac{dE_3}{dt}Y_{i+2}$$

$$\frac{dz_i}{dt} = \frac{dE_0}{dt}Z_{i-1} + \frac{dE_1}{dt}Z_i + \frac{dE_2}{dt}Z_{i+1} + \frac{dE_3}{dt}Z_{i+2}$$

The derivatives of the blending functions are shown as follows:

$$\frac{dE_0}{dt} = -\frac{t^2}{2} + t - \frac{1}{2} \tag{15}$$

$$\frac{dE_1}{dt} = \frac{3t^2}{2} - 2t \tag{16}$$

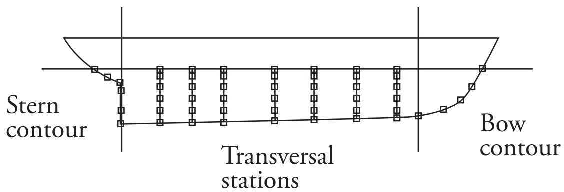
$$\frac{dE_2}{dt} = -\frac{3t^2}{2} + t + \frac{1}{2} \tag{17}$$

$$\frac{dE_3}{dt} = \frac{t^2}{2} \tag{18}$$

Methodology

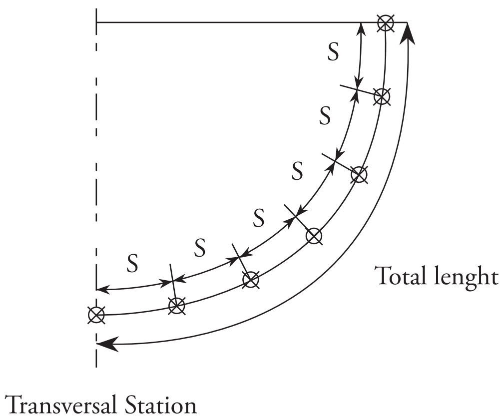
A hull lines plan is used to extract knots from three regions: Stern contour, Transversal stations and Bow contour, see Fig. 3.

Fig. 3. Hull lines of ship.



B-Splines curves are defined individually over each station, stern and bow contours. Further, their total lengths are calculated (S_{total}), as described in section 2.2.

Fig. 4. Station divided in equal length subdivision.



Over each B-Spline curve, the total length is equally subdivided by a desired subdivision N_{tran}, as follows:

$$s_{tran} = \frac{S_{total}}{N_{tran}} \tag{19}$$

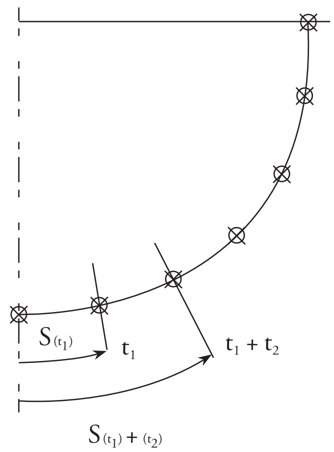
To obtain the segments and t parameters in each curve that correspond to the equally spaced length subdivision, see Fig. 5. A root-finding algorithm numerical method is applied for the following function:

$$f_s(t,i) = i * s_{tran} - S_{total}(t,i) \tag{20}$$

Where:

i: is the segment number of a curve.

Fig. 5. Station equally subdivision.



To solve the equation (20), the secant method is used *(Nakamura, 1991)*, see equation (21).

$$t_j = t_{j-1} - f_s(t_{j-1}, i)\frac{(t_{j-1} - t_{j-2})}{(f_s(t_{j-1}, i) - f_s(t_{j-2}, i))} \tag{21}$$

Where:

j: index subdivision of *t*.

Through this subdivision procedure, new knots are created to obtain equal subdivided B-Spline curves. In these equally spaced knots, longitudinal B-splines curves are defined and subdivided into equally spaced knots (NLong). Furthermore, over these new longitudinal knots, new transversal stations and stern and bow contours are created. This procedure is executed transversally and longitudinally to obtain a new hull discretization.

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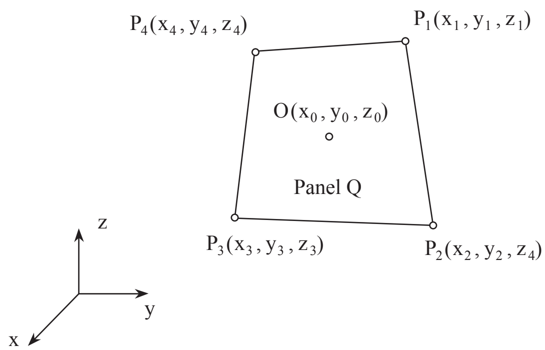
The generated mesh is used to define single planar quadrilateral panels, see Fig. 6 , over the entire hull surface.

Fig. 6. Panel configuration.



The hull volume is calculated through the transformation of volumetric into superficial integration. Through the divergence theorem, see equation (22), applied over all hull surface.

$$\int_{v} \nabla.\vec{r}dV = \oint_{s} \vec{r}.d\vec{S} \qquad (22)$$

Where:

Position vector $\vec{r} = x\vec{i} + y\vec{j} + z\vec{k}$
x, y, z :coordinates of each quadrilateral panels.

Considering the hull surface is composed by several planar panels, a formulation for volume calculation is shown in equation (23), *(Alvarez & Martins, 2007)*.

$$V = \frac{1}{3}\sum_{Q=1}^{N_T} \left(Xo_{(Q)}\, n_{x(Q)} + Yo_{(Q)}\, n_{y(Q)} + Zo_{(Q)}\, n_{z(Q)} \right) S_Q \qquad (23)$$

Where:

V: volume (m^3).
$Xo(_Q)$, $Yo(_Q)$, $Zo(_Q)$: centroid coordinates of panel Q.
$nx(_Q)$, $ny(_Q)$, $nz(_Q)$: normal vector components in the centroid of panel Q.
NT: total number of hull surface panels.

Results

In order to evaluate the effectiveness of the computer code implemented with the methodology described previously, the Wigley hull *(Journee, 2001)* Series 60 Cb = 0.6 hull *(Todd, 1953)* are used for mesh generation tests and their submerged volume is used for mesh quality evaluation.

Wigley Hull

This hull has round shapes and can be represented using a parabolic equation, see equation (24), shown in Journee (2001).

$$y = \frac{B}{2}\left[1-\left(\frac{2x}{L}\right)^2\right]\left[1-\left(\frac{z}{T}\right)^2\right] \qquad (24)$$

Where:

B: beam.
L: length.
T: draught.
x: longitudinal coordinate of a hull station.
z: vertical coordinate of a hull station.
y: transversal coordinate of a hull station.

The main dimensions of the hull used are:

Table 1. Dimensions of Wigley hull.

Parameter	Value	Unit
Lwl	z1.0	m
B	0.10	m
T	0.0625	m
Cb	0.444	
∇	0.00278	m^3

The submerged hull lines have fore and aft symmetry as follows:

Fig. 7. Submerged Wigley hull lines.

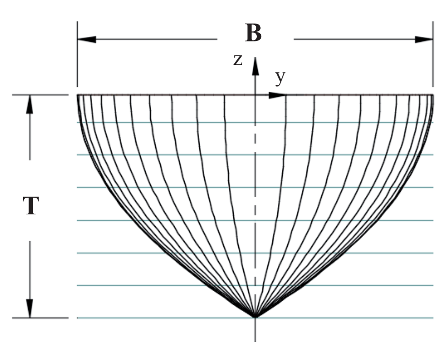
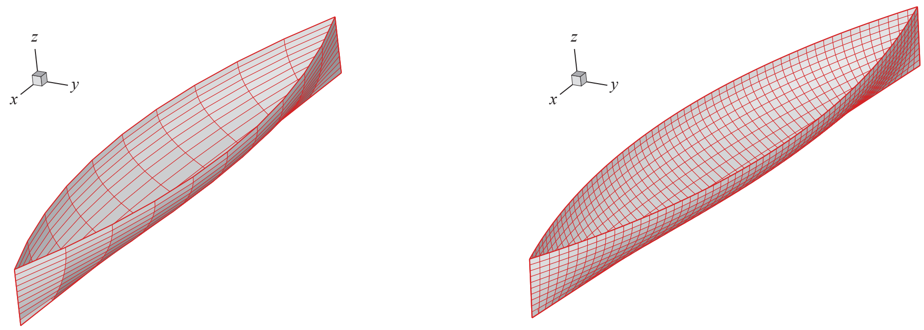


Fig. 8. Wigley Hull with two types of discretization.



Mesh 1
Total panels: 300

Mesh 2
Total panels: 800

Extracting discrete points of these hull stations as original knots, several meshes are generated only over one band of the hull, due to transversal symmetry. Two of these hull meshes are shown in Fig. 8.

Fig. 9 shows a comparison between the original and B-spline knot stations in longitudinal positions x=0.842m and x=0.526m. The cubic B-spline curves represent properly the behavior of these stations, despite the use few original knots. This is due to the C^2 continuity between the original and the B-Spline station.

A comparison of several calculated mesh volumes with theoretical value (Table 1), is shown in Table 2. From Table 2, it is possible to observe a good convergence with increasing mesh refinement.

Series 60 – Cb = 0.6

This hull represents a merchant-type ship, its development is described in Todd (1953). It has a flat bottom which is almost ship length and a straight side at the midship region, see submerged body in Fig. 10.

Fig. 9. Station comparisons between original and B-spline representations.

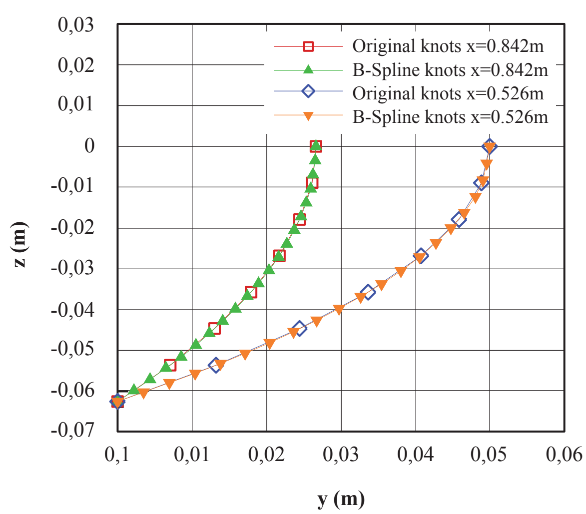


Table 2. Volume Comparison of Wigley hull meshes.

Mesh	Panels	Calculated Vol. (m³)	Volume error
1	300	2.766E-3	0.504%
2	800	2.772E-3	0.288%
3	1500	2.774E-3	0.216%
4	2400	2.774E-3	0.216%
5	3500	2.774E-3	0.216%

The main dimensions of the submerged body are described in Table 3.

Through the methodology described before, it is possible to create and refine hull meshes, see Fig. 11.

Considering the offset table, described in Todd (1953), as original knots to represent a B-Spline curve, a poor representation of midship section was observed, see Fig. 12. This is due to the discontinuity of the curvature (C2) between

Fig. 10. Series 60 Cb = 0.60 submerged hull lines.

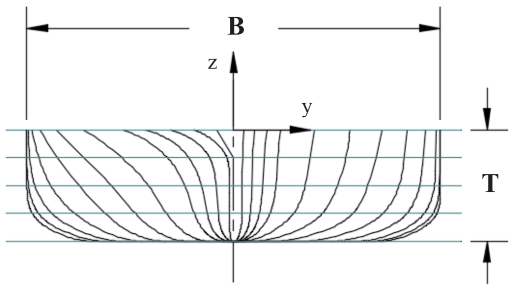
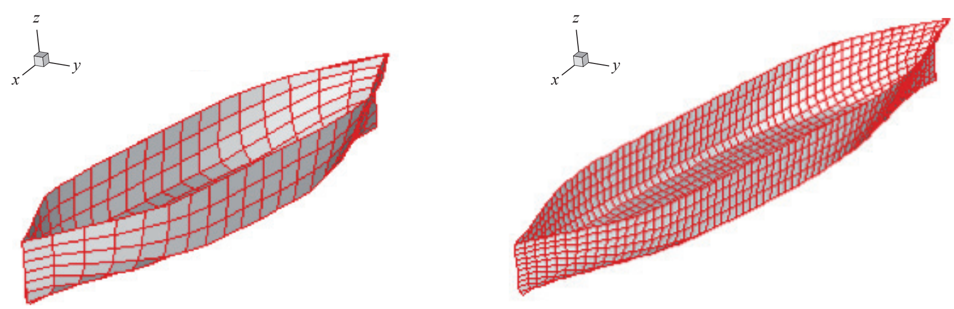


Table 3. Dimensions of Wigley hull.

Parameter	Value	Unit
Lwl	1	m
B	0.1428	m
T	0.05715	m
Cb	0.6	
∇	0.004096	m^3

Fig. 11. Series 60 Cb=0.6 Hull with two types of discretization.



Mesh 1
Total panels: 300

Mesh 2
Total panels: 800

straight parts (bottom and side) and the rounded bilge. For that reason, the cubic B-Spline curves used in this work do not represent properly the stations composed by straight and rounded parts.

To overcome the issue of C^2 continuity, flat bottom and bilge are defined by more original knots. This action increases the number of control points over these parts, adjusting the curvature transition of

Fig. 12. Midship station comparisons between original knots and spline representation.

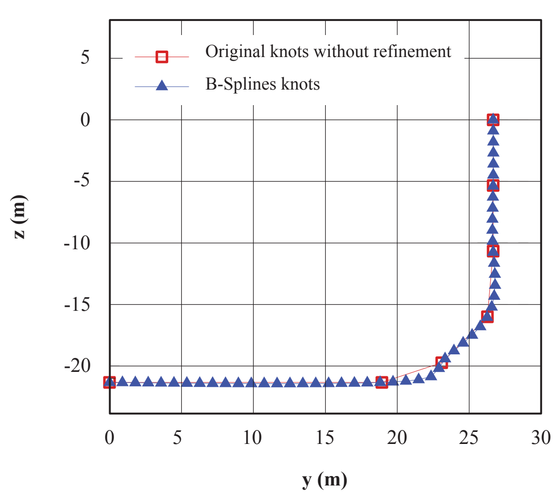
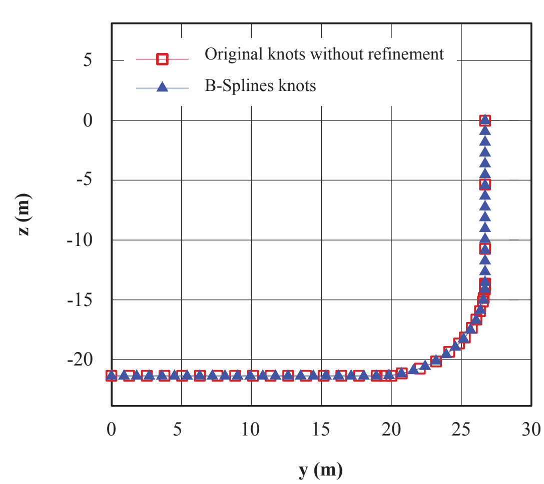


Fig. 13. Midship stations comparisons between original knots and refinement and spline representation.



the B-Spline curve segments more accurately, but the required number of original knots is high, as shown in Fig. 13.

Table 4 presents a comparison of several calculated mesh volumes with the expected one (Table 3).

Table 4. Comparison of volumes of Series 60 Cb =0.60 meshes.

Mesh	Panels	Calculated Vol. (m^3)	Volume error
1	300	4.024E-3	1.758%
2	800	4.035E-3	1.489%
3	1500	4.037E-3	1.440%
4	2400	4.038E-3	1.416%
5	3500	4.039E-3	1.392%

From Table 4, it is possible to see a convergence behavior increasing mesh refinement.

Conclusions

A numerical code for hull mesh discretization requires further development. This code uses cubic B-Spline curves for the representation of transversal stations, bow and stern contours of a curved hull plan lines. This procedure is the initial stage to create new equally spaced knot curves in transversal and longitudinal directions to conform the mesh.

The parameter for the hull mesh evaluation quality is the submerged volume. It is evaluated using the divergence theorem associated with the quadrilateral panels of a hull mesh.

Two hulls are used for code evaluation, Wigley and Series 60 – Cb =0.60.The Wigley hull has parabolic stations, in which the cubic B-Splines used adjust properly. Several mesh refinements have shown a good convergence even in a coarse mesh. This is due to the hull lines being rounded with C^2 continuity and cubic B-Spline.

In the case of the Series 60 – Cb = 0.60 hull, the flat bottom and side of the parallel body creates problems in the cubic B-Spline representation due to C2 discontinuity. To overcome this issue, more original knots need to be allocated in the straight regions to force the cubic B-Spline curves to adjust to these stations. This adjustment allows to work around this limitation. Nevertheless, the value of the volume converges with increasing refinement. That was expected because a higher refinement allows to represent the submerged body more accurately.

To solve discontinuity problems, the use of a B-Spline formulation with non-uniform blending functions and special treatment of control points in the connection between regions as flat bottom or straight side with round bilge, as described in Cabral *et al.* (1991).

References

[1] R. L. ALVAREZ and M. R. MARTINS, “Otimização das Formas de Cascos de Deslocamento em Relação a sua Resistência ao Avanço”, in *XX Pan-American Conference of Naval Engineering* (COPINAVAL), São Paulo, 2007.

[2] CABRAL J., WROBEL L. and BREBBIA C., A BEM formulation using B-splines: II- multiple knots and non-uniform blending functions, *Engineering Analysis with Boundary Elements*. 1991, vol 7, issue 1.

[3] CABRAL J., WROBEL L. and BREBBIA C., A BEM formulation using B-splines: I- uniform blending functions, *Engineering Analysis with Boundary Elements*. 1990, vol 7, issue 3.

[4] DE BOOR C., A Practical Guide to Splines, *Applied Mathematical Sciences*. 2001.

[5] J. J. JOURNEE, “Discrepancies in Hydrodynamic Coefficients of Wigley Hull Forms”, in *Proceedings of the 3rd International Conference on Marine Industry (MARIND)*, Varna, 2001.

[6] S. NAKAMURA, *Métodos Numéricos Aplicados com Software*. 1th ed. Naucalpan de Juarez, Mexico, Prentice Hall Inc, 1991.

[7] NOWACKI H., Five Decades of Computer-Aided Ship Design, *Computer-Aided Design*. 2010, vol 42, pp 956-969.

[8] R. F. RIESENFELD, "Applications of B-Spline Approximation to Geometric Problems of Computer Aided Design", Ph.D. dissertation, Dept. of Systems and Information Science, Syracuse University, NY, 1973.

[9] ROGERS D. F,. "B-Spline Curves and Surfaces for Ship Hull Definition", in *Symposium of Computer Aided Hull Surface Definition (SCAHD)*, Annapolis, MD, 1973.

[10] C. SALHUA, "Hydrodynamic Interference between Ships with Forward Speed in Waves", D.Sc. dissertation (in portuguese), Dept. of Naval and Ocean Engineering, Federal University of Rio de Janeiro, RJ, Brazil, 2010.

[11] TODD F.H., Some further experiments on single-screw mechant ships forms - serie 60, *SNAME Transaction*, 1953.

[12] USHATOV R., POWER H. and Rêgo SILVA J. J., Uniform bicubic B-splines applied to boundary element formulation for 3-D scalar problems, *Engineering Analysis with Boundary Elements*, 1994, vol 13, pp. 371-381.

[13] VENTURA M. F., "Ship Hull Representation by Non-Uniform Rational B-Spline Surface Patches", M.Sc. thesis, Dept. of Naval Architecture and Ocean Engineering, Glasgow, UK,1996.

[14] YAMAGUCHI, F. A., A New Curve Fitting Method Using a CRT Computer Display, *Comp. Graph and Image Processing*. 1978, pp 425-437.

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[1] R. J. Vidmar. (1994). *On the use of atmospheric plasmas as electromagnetic reflector*s [Online]. Available FTP: atmnext.usc.edu Directory: pub/etext/1994 File: atmosplasma.txt.

WWW

Basic form:
[1] J. K. Author. (year, month day). Title (edition) [Type of medium]. Available: http://www.(URL)

Example:
[1] J. Jones. (1991, May 10). Networks (2nd ed.) [Online]. Available: http://www.atm.com

E-Mail

Basic form:
[1] J. K. Author. (year, month day). Title (edition) [Type of medium]. Available e-mail: Message:

Example:
[1] S. H. Gold. (1995, Oct. 10). *Inter-Network Talk* [Online]. Available e-mail: COMSERVE@RPIECS Message: Get NETWORK TALK

E-Mail

Basic form:
[1] J. K. Author. (year, month day). Title (edition) [Type of medium]. Available Telnet: Directory: File:

Example:
[1] V. Meligna. (1993, June 11). *Periodic table of elements* [Online]. Available Telnet: Library.CMU.edu Directory: Libraries/Reference Works File: Periodic Table of Elements

Patents

Basic form:
[1] J. K. Author, "Title of patent," U.S. Patent x xxx xxx, Abbrev. Month, day, year.

Example:
[1] J. P. Wilkinson, "Nonlinear resonant circuit devices," U.S. Patent 3 624 125, July 16, 1990.

Standards

Basic form:
[1] Title of Standard, Standard number, date.

Example:
[1] IEEE Criteria for Class IE Electric Systems, IEEE Standard 308, 1969.

Theses (M.S.) and Dissertations (Ph.D.)

Basic form:
[1] J. K. Author, "Title of thesis," M.S. thesis, Abbrev. Dept., Abbrev. Univ., City of Univ., Abbrev. State, year.

Example:
[1] J. O. Williams, "Narrow-band analyzer," Ph.D. dissertation, Dept. Elect. Eng., Harvard Univ., Cambridge, MA, 1993.

Unpublished
These are the two most common types of unpublished references.

Basic form:
[1] J. K. Author, private communication, Abbrev. Month, year.
[2] J. K. Author, "Title of paper," unpublished.

Examples:
[1] A. Harrison, private communication, May 1995.
[2] B. Smith, "An approach to graphs of linear forms," unpublished.

Periodicals
NOTE: When referencing IEEE Transactions, the issue number should be deleted and month carried.

Basic form:
[1] J. K. Author, "Name of paper," *Abbrev. Title of Periodical*, vol. *x*, no. x, pp. *xxx-xxx*, Abbrev. Month, year.

Examples:
[1] R. E. Kalman, "New results in linear filtering and prediction theory," J. Basic Eng., ser. D, vol. 83, pp. 95-108, Mar. 1961.

References
NOTE: Use *et al*. when three or more names are given.

References in Text:
References need not be cited in the text. When they are, they appear on the line, in square brackets, inside the punctuation. Grammatically, they may be treated as if they were footnote numbers, e.g.,
as shown by Brown [4], [5]; as mentioned earlier [2], [4]–[7], [9]; Smith [4] and Brown and Jones [5]; Wood et al. [7]
or as nouns:
as demonstrated in [3]; according to [4] and [6]–[9].

References Within a Reference:
Check the reference list for ibid. or op. cit. These refer to a previous reference and should be eliminated from the reference section. In text, repeat the earlier reference number and renumber the reference section accordingly. If the ibid. gives a new page number, or other information, use the following forms:
[3, Th. 1]; [3, Lemma 2]; [3, pp. 5-10]; [3, eq. (2)]; [3, Fig. 1]; [3, Appendix I]; [3, Sec. 4.5]; [3, Ch. 2, pp. 5-10]; [3, Algorithm 5].

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