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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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Editorial Note

Cartagena de Indias, July 5th, 2024.

I would like to welcome you, after a semester full of research achievements and challenges, to this second edition of 2024 of our Journal Ship Science and Technology.

This year has been marked by important milestones in our history, such as the development of the final stages of the construction of the first Colombian Ocean Patrol Vessel (POC), a unit designed entirely by our Design and Engineering team and which constitutes an opportunity for COTECMAR to act independently as an integrator of all the ship's systems. In addition, we developed the advanced stages of the design of the first ship of the Colombian Frigate (Strategic Surface Platform Project) among other strategic challenges that will contribute to continue positioning us as a reference shipyard at national and regional level.

For this edition, we compiled articles of professional interest on different topics, such as: Navigating towards sustainable vessels: state of the industry and its relationship to SDGs, User-centered design for the marine industry. Case: Recommendations for future casemates, Fluid-Structural Interaction Study of the Structural Arrangement of a Riverine Low-Draft Combat Boat for Coastal Transit Conditions, Feasibility of Composite Material Construction without the Use of Molds and Design of a Self-Righting Pilot Boat of 9m Length.

Finally, it is worth remembering that we are working on the consolidation of agendas and programming of academic and scientific activities for our IX International Ship Design and Naval Engineering Congress - CIDIN, which will be held between March 12 and 14, 2025 at the COLOMBIAMAR Fair, and which will be developed within the framework of the Twenty-Fifth Anniversary of our Corporation; we will be telling you about its progress and from now on, you are all invited.

We are waiting for you.

At COTECMAR, "We're Moving Forward".

Cordially,

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

Nota Editorial

Cartagena de Indias, 5 de julio de 2024.

Quiero darles la bienvenida, luego de un semestre lleno de logros y retos en materia de investigación, a esta segunda edición de 2024 de nuestra revista Ciencia y Tecnología de Buques.

Este año se ha visto marcado por hitos importantes en nuestra historia, como el desarrollo de las etapas finales de la construcción de la primera Patrullera Oceánica Colombiana (POC), unidad diseñada en su totalidad por nuestro equipo de Diseño e Ingeniería y que se constituye en una oportunidad para COTECMAR de actuar de manera independiente como integrador de la totalidad de sistemas del buque. Además, desarrollamos las etapas avanzadas del diseño del primer buque de la Fragata Colombiana (Proyecto Plataforma Estratégica de Superficie) entre otros desafíos estratégicos que contribuirán a seguir posicionándonos como un astillero referente a nivel nacional y regional.

Para esta edición, compilamos artículos de interés profesional sobre diferentes temáticas, como son: Navegando hacia embarcaciones sostenibles: estado de la industria y, su relación con los ODS, Diseño centrado en el usuario para el sector naval Caso: Recomendaciones para futuras casamatas, Estudio de Interacción Fluido-Estructural por Condiciones de Transito Costero en el Arreglo Estructural de un Bote de Combate Fluvial de Bajo Calado, Factibilidad de Construcción en Materiales Compuestos sin la Utilización de Moldes y finalmente el Diseño de una lancha piloto autoadrizable de 9m de eslora.

Finalmente vale la pena recordar, que estamos trabajando en la consolidación de agendas y programación de las actividades académicas y científicas para nuestro IX Congreso Internacional de Diseño e Ingeniería Naval CIDIN, el cual será llevado a cabo entre el 12 y 14 de marzo de 2025 en la Feria COLOMBIAMAR, y que será desarrollado en el marco del Vigésimo Quinto Aniversario de nuestra Corporación; les estaremos contando de sus avances y desde ya, están todos cordialmente invitados.

Los esperamos.

En COTECMAR, “Seguimos Avante”.

Cordialmente,

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

Navigating towards sustainable vessels: state of the industry and its relationship to SDGs

Navegando hacia embarcaciones sostenibles:
estado de la industria y su relación con los ODS

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Jymmy Saravia Arenas [2]

Abstract

It is a fact that the maritime industry is betting on sustainability and decarbonization in its value chain. This implies designing and building sustainable vessels, which requires focusing not only on technical aspects of functionality and quality, but also on solutions that reduce the environmental impacts of the product throughout its life cycle while generating a positive social impact. This paper answers the question: What are the sustainable technology solutions - products and services - that, aligned with the SDG agenda, are being adopted by global shipyards today? The study follows a mixed methodology with a quantitative descriptive approach and qualitative approach using the content analysis technique by reviewing the sustainability reports available for public consultation of global shipbuilding companies as of 2021. (1) the average number of SDGs to which the industry claims to contribute is provided: 3, 7, 8, 9, 12, 13, 14 y 17. The industry is contributing through innovation projects focused on the design and construction of intelligent, efficient and sustainable vessels, including platforms for the offshore wind power market, zero-emission hydrogen-powered ships, technologies to reduce waste, technologies for automation and energy efficiency, and solutions for social benefit in communities, among others. This study has practical implications for emerging markets wishing to venture into sustainability issues as it provides a global perspective, trends and portfolio of solutions being adopted in the industry.

Key words: Shipyards, Shipbuilding, Sustainable vessels, Sustainable Development Goals -SDGs, Sustainability.

Resumen

Es un hecho que la industria marítima le está apostando a la sostenibilidad y la descarbonización en su cadena de valor. Eso implica, diseñar y construir embarcaciones sostenibles lo cual requiere enfocarse no solo en aspectos técnicos de funcionalidad y calidad, sino también en soluciones mediante las cuales se reducen los impactos ambientales del producto a lo largo de su ciclo de vida generando paralelamente un impacto social positivo. Este documento responde a la pregunta ¿Cuáles son las soluciones tecnológicas -productos y servicios- sostenibles que, alineadas con la agenda de los ODS, están adoptando hoy los astilleros globales?. El estudio sigue una metodología mixta con un enfoque cuantitativo de tipo descriptivo y el enfoque cualitativo utilizando la técnica de análisis de contenido revisando los informes de sostenibilidad disponibles para consulta pública de empresas globales de construcción naval a fecha de 2021. (1) se facilita el promedio de ODS en los que la industria declara que aporta así: 3, 7, 8, 9, 12, 13, 14 y 17. Se observa como la industria está contribuyendo a través de proyectos de innovación enfocados en el diseño y construcción de embarcaciones inteligentes, eficientes y sostenibles, incursionando desde plataformas para el mercado de la eólica marina, buques propulsados por hidrógeno cero emisiones, tecnologías para la disminución de los residuos, tecnologías para la automatización y la eficiencia energética, soluciones de beneficio social en las comunidades, entre otros. Este estudio tiene implicaciones prácticas en mercados emergentes que deseen incursionar en los temas de sostenibilidad pues proporciona una perspectiva global, tendencias y portafolio de soluciones que se están adoptando en la industria.

Palabras claves: Astilleros, Construcción naval, Embarcaciones sostenibles, Objetivos de Desarrollo Sostenible -ODS, Sostenibilidad.

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Introduction

The maritime sector faces more pressure to improve its sustainability and transparency practices, which requires its management to evolve in a more holistic and interrelated manner towards the dimensions of sustainability (integrating Environmental, Social and Governance risks). The players in this sector can be divided into main groups: maritime transport owners, design companies, shipyards, equipment suppliers and others *(Strandhagen et al., 2020)*. The shipbuilding industry is a largely globalized sector *(Para-González et al, 2020)*, its activities comprise the construction, repair and maintenance of vessels and naval apparatus. This industry is a typical example with a complex global supply *(Cerezo-Narvaez et al., 2021)* and chain structure in which components are supplied by manufacturers from different countries and then semi-finished and finished products are returned to customers around the world.

One of the challenges in sustainability, involves analyzing value chain processes with holistic life cycle thinking *(Könnölä et al., 2020)*, in particular, ship design where operational profitability is prioritized over improved environmental performance *(Strandhagen et al., 2020)*. An evolution towards the eco-design philosophy *(Könnölä et al., 2020)* has been proposed, which is materialized through technological innovations that reduce environmental impacts as well as responsible acquisition of materials and proper waste management.

Therefore, it is important to address the vision of sustainability in solutions -products and services- generating investments towards projects with innovative sustainable technologies and towards the use of cleaner fuels; in parallel, in operations reducing negative environmental impacts, without neglecting the associated social and governance risks. Today, Sustainable Development Goals (SDGs) are the most complete reference to address all of the above in the corporate strategy of organizations, given their comprehensive focus on the planet, people, prosperity, stability and partnerships. This paper aims at answering the following research questions: What are the technology solutions - sustainable products and services - that, aligned with the SDG agenda, are being adopted by global shipyards today? Which SDGs are being prioritized?

Research development

Research on sustainability for this industry according to the literature review can be grouped into four themes: oriented to promoting a green supply chain and green transportation; corporate social responsibility practices; incorporation of technologies and industry 4.0 and promotion of blue economy (See Fig. 1).

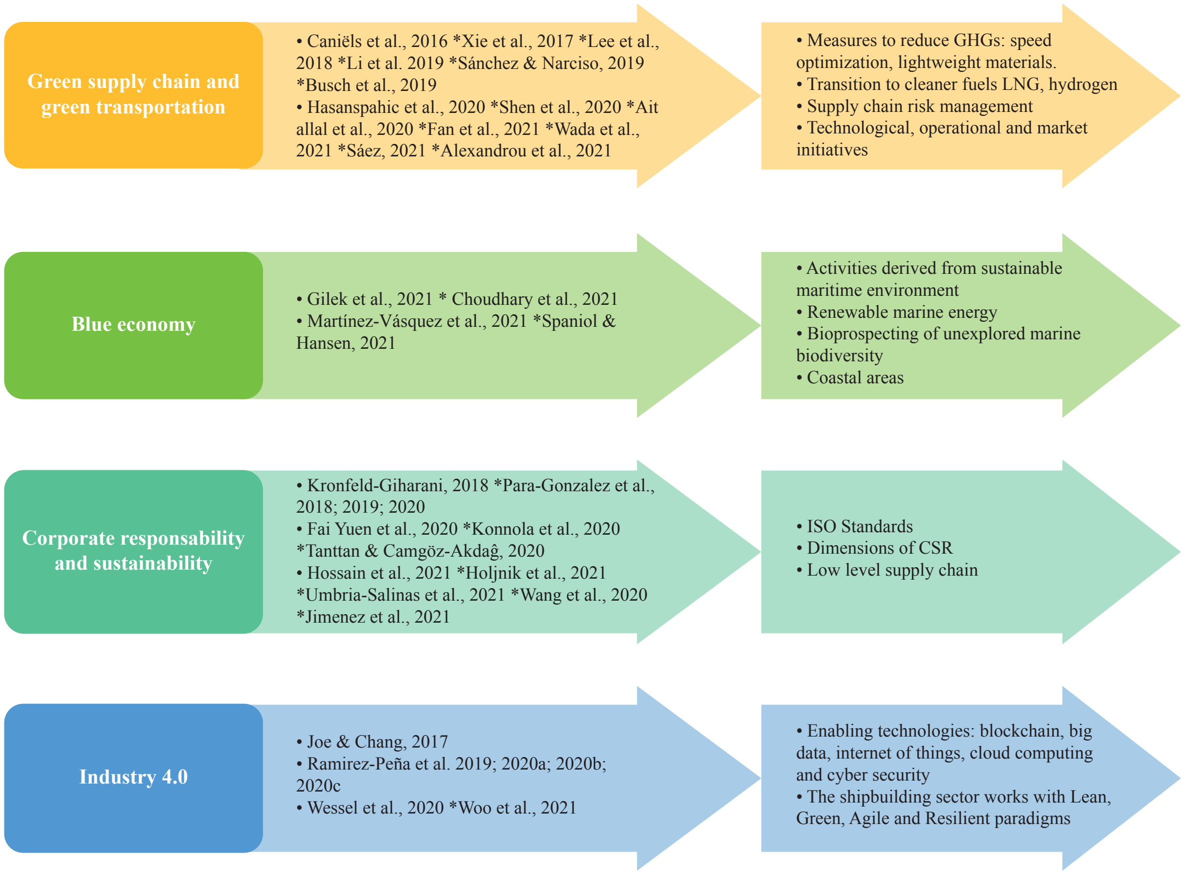
Sustainable vessels

Climate change is one of the most important global risks according to the latest World Economic Forum -WEF report, some of the current measures implemented by maritime transport to address this risk include reducing ship speed, transitioning to liquefied natural gas (LNG) fuel and/or biofuels and promoting the Energy Efficiency Design Index (EEDI) regulation.

But the most important and urgent measure is the introduction of zero-emission ships to achieve these goals *(Wada et al., 2021)*. The Getting to Zero Coalition initiative materializes and accelerates the decarbonization of maritime transport with the development and deployment of commercially viable zero-emission deep-water vessels by 2030, including the development of new marine fuels, derived from abundant untapped renewable resources (https://www.globalmaritimeforum.org/getting-to-zero-coalition).

Technological measures to reduce emissions in maritime transport *(Wada et al., 2021)* include changes in ship construction and the application of new technologies in shipping, such as: changes and innovations in hull design, power and propulsion systems, use of alternative fuels and energy sources, use of exhaust gas reduction and cleaning technologies, catalytic reduction systems (SCR) and scrubbers.

Fig. 1. Sustainability issues in the literature review for industry.



Today we see a deployment of collaborative projects in the global maritime industry, initiatives such as green corridors -zero emission maritime trade routes between ports- along with a transition strategy, are key elements in addressing sustainability challenges. Therefore, a continuous innovation process in the organizations that are part of the naval defense is fundamental, otherwise they can quickly become obsolete and compromise their ability to carry out their fundamental mission: to protect their country *(Cerezo-Narváez et al., 2021)*. A proactive stance towards environmental challenges by shipyards is critical and engaging in green innovations can generate business opportunities (Saether et al., 2021) which implies a long-term strategic focus on sustainability.

The research by Jokinen et al. (2022). conducted an image analysis of "The World's Most Sustainable Ships" in the future, identifying issues such as (1) life cycle thinking, which involves the entire supply chain being committed to the circular economy; (2) collaboration, economic realities and radical innovations -including Industry 4.0 technologies- which involves building a culture of trust in the value chain and establishing appropriate channels for radical ideas and problem solving with different stakeholders.

In ship maintenance and repair, efficient operational measures must also be implemented to reduce waste generated and GHGs emitted *(Ait allal et al., 2020)*. Solid and liquid wastes should be minimized through efficient management of the use of abrasive materials, solvents and other cleaning products. This waste must go through a recycling process by separation of oily water. A log should be kept to track the discharge of various ship maintenance and repair waste. Install a treatment plant for the treatment of surface water and rainwater that is dredged with the different waste existing in the dock.

The recycling of vessels is another of the issues identified in sustainability that must be addressed, being consistent with the life cycle thinking which must also be contemplated from the design *(Ocampo & Pereira, 2019)*; it consists of the dismantling of the structure and components of the vessel, there steel and other materials are recovered in good condition, the treatment of hazardous materials and safety conditions is carried out which generates certain economic, social and environmental impacts on the sites where they are carried out, hence the importance of doing this in certified shipyards *(Jokinen et al., 2022)*.

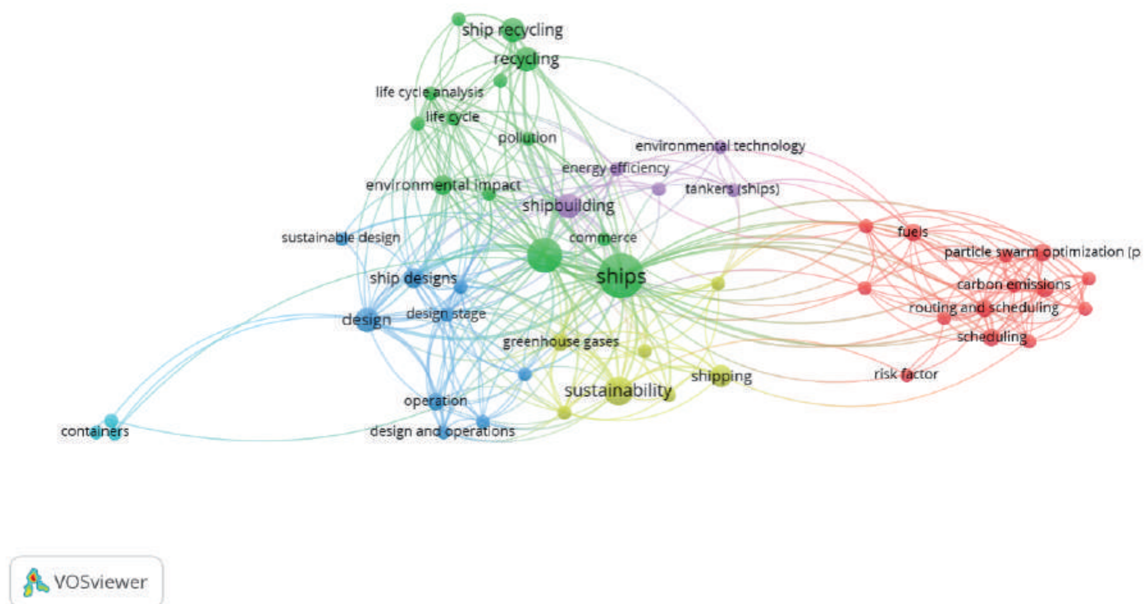
Industry and SDGs

Table 1. Role of the maritime industry in achieving SDGs.

SDG	SDG	Description
1	Poverty reduction	Ensure that maritime transport is safe, clean and creates prosperity and sustainable growth in a green and blue economy.
2	Zero hunger	Ensure efficient and cost-effective supply chains for global food distribution; safeguard an important source of nutrition, address illegal fishing.
3	Good health and well-being	Contribute to the reduction of maritime transport-related pollution in oceans, ports and coastal regions.
4	Quality education	Safety, security and environmental protection at sea depend on the education and training of seafarers.
5	Gender equality	Support gender equality and empower women in the maritime sector through a comprehensive and targeted program.
6	Clean water and sanitation	Minimize dumping and disposal of waste at sea, which is a key component of the overall waste management cycle.
7	Clean and affordable energy	Promote funding, research and development of clean energy technologies for the maritime sector.
8	Decent work and economic growth	Shipping is an important source of labor, especially in developing countries. Issues related to the health and welfare of seafarers.
9	Industry, innovation and infrastructure	More efficient shipping, working in partnership with the port sector, will be an important driver toward global stability and sustainable development.
10	Reduced inequalities	Improve capacity in countries that lack the know-how and resources to operate a safe maritime transport and efficient industry.
11	Sustainable cities and communities	They depend on a secure supply chain, helping improve maritime security and protect the global logistics infrastructure.
12	Responsible consumption and production	Reduce the generation of waste, both operational waste from ships and discharges at sea.
13	Climate action	Emissions control and solutions to minimize the contribution of maritime transport to air pollution and its impact on climate change.
14	Life below water	Responsible for global measures to improve international maritime transport safety and security, and prevent pollution from ships.
15	Life on land	Responsible for port security and is part of global efforts to stop illegal wildlife trafficking.
16	Peace, justice and strong institutions	Promotes effective institutions to ensure the safe, secure, and environmentally protective flow of maritime trade.
17	Partnerships for the goals	Partnership agreements with leading global and environmental organizations for the development of joint projects.

Source: Wang et al., 2020, p.14.

Fig. 2. Concurrence of keywords in literature review.



Methodology

The literature was reviewed in a high impact database which showed the growing trend and orientation of research associated with sustainability in the industry and sustainable vessels (see Fig. 2). This study also followed a mixed methodology, with a descriptive quantitative approach and using the content analysis technique, reviewing the sustainability management reports of 25 global shipbuilding companies (2020-2021) which are a powerful tool to explain whether SDGs are really important for the private sector and how companies effectively contribute to them *(Costa et al., 2022)*. Illustrative case studies were used to showcase leading practices of the organizations; only publicly available data are explicitly discussed in the document. We reviewed which SDGs are declared as prioritized by the organizations.

Results

For this research, 25 companies from 17 countries were selected, including holding companies (groups of companies), which allows for a global approximation. Companies today have a microsite on their website focused on sustainability referred to as: sustainability, corporate social responsibility, commitment, management and sustainable development, SDG or ESG. They have a non-financial management report referred to as: sustainability report, annual report, integrated report, CSR report, annual report or ESG report. They report on Sustainable Development Goals in their reports. All SDGs were prioritized by companies in the industry. In some cases, alignment with corporate strategy, prioritization and concrete indicators can be observed. In some cases, although their relationship with SDGs is not explicitly stated, a relationship can be established in the material issues of sustainability or corporate responsibility. The number of prioritized SDGs varies, with an average of 8. The minimum is 4 and the maximum is 17.

As can be seen in Fig. 3, SDGs being prioritized are those corresponding to the planet, *i.e.*, seeking to reduce environmental impacts (7, 12, 13, 14) through innovation (9) without neglecting the fact that this industry is intensive in skilled labor and contributes to the economic growth of the countries in which it operates (8).

Fig. 3. Prioritization of SDGs by global shipyards.

Table 2. Sustainable technology solutions from global shipyards.

Companies	SDG	Solutions
[1,2]	7, 13	Platforms for the offshore wind market (fixed and floating structures, installations), vessels for offshore wind farms and offshore aquaculture.
[2]	7, 13	Zeus -Zero Emission Ultimate Ship- the first prototype ship powered by hydrogen -fuel cells-. Zero Coaster intends to develop a new class of zero-emission bulk carrier for coastal shipping.
[2]	6, 14	State-of-the-art ballast water treatment and systems based on plankton pre-filtration and subsequent sterilization with ultraviolet rays.
[2, 3, 4, 11]	7, 13	Use of alternative fuels (Liquefied Natural Gas, Ammonia, Methanol, Liquid Hydrogen) Microbial Fuel Cells (MFCs) Change, the first hydrogen fuel cell-powered passenger ship with engine in the US. Lithium batteries First application of NRS® (Nitrogen Refrigerant System) in two LNG-FSUs. Wind assisted propulsion systems.
[2,4]	7, 12, 13 14	Safe and environmentally friendly LIMPIDH2O® technology: internationally patented technology for recirculation dredging provides the best way to achieve outstanding levels of environmental protection in special interventions and marine, lake or river works. Technology at ports when docked: the dockside electrification system that allows electricity to be supplied to the ship directly from shore, so that the ship's engines can be shut down while docked.
[2]	7, 13	FUCELL project operation of a power generation plant for marine applications, consisting of a hydrogen production plant, compression plant, storage and distribution to feed a fuel cell system combined with a super capacitor system. Fuel cell and hydrogen technology transferred to future vessels.
[2, 3, 4]	7, 13	Software tool to support decision making and monitor energy performance. SmartShip Solutions, Air Lubrication System (ALS): An energy saving device to reduce friction and drag when working on a hull by sending air to the bottom surface, applied to a methane tanker. SG system (shaft generator): power generation system by using the rotating shaft power of the ship's propulsion motor shaft in operation as a clean source of energy.
[2]	14	PIAQUO - mitigate problems related to underwater noise and reduce its impact on the marine environment ecosystem by optimizing propellers and developing a real-time self-assessment model;
[2]	12	The technological solutions adopted for the treatment of solid waste shall be implemented by converters, which allow for the drying and sterilization of waste and the consequent reduction of volume and weight and the subsequent automatic vacuum storage, increasing retention on board. The modern converters adopted allow a volume reduction of 70% and a weight reduction of 30%. Graywater and wastewater are collected in appropriate physical and chemical treatment units that macerate suspended solids and reduce Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) contents through aerobic processes. The process also includes disinfection by UV systems.

[2]	12	Voluntary certifications such as Green Passport provide, upon delivery of the vessel, the inventory of materials to be monitored during the life cycle of the vessel and is used to ensure that the vessel is scrapped in a safe and environmentally friendly manner.
[3]	12, 14	Technologies to deal with marine debris. During the COP26 'Go With The Flow' project, which encouraged engineers to participate in a challenge to design and build a prototype river cleaning vessel.
[3, 4]		Expand the types of vessels that feature new clean technologies, such as ALS, DS4 platforms and high manganese steel applied tanks.

The technological solutions - products and services - offered and declared in their sustainability reports by shipbuilding companies based on research, development and innovation to address sustainability challenges, mainly in environmental matters, were reviewed.

Conclusions

The shipbuilding industry is navigating towards sustainability, starting with innovation through the design and construction of smart, efficient and sustainable vessels; as well as innovative technological solutions and practices to address sustainability needs and challenges in its operations and during the use of the vessel by customers. In this regard, great challenges are evident from the design of products -vessels, equipment and naval by-products-, which requires research, development and innovation that can be carried out in alliances with universities, leading research centers and by accessing external resources, given the large investments required.

There is also an explicit commitment to the global sustainability agenda, as technological development is aimed at reducing polluting emissions and fuel efficiency, increasing energy efficiency, complying with international regulations that are increasing every day and providing quality and efficiency in the products and services offered. In short, the aim is to evolve towards vessels that are hyper-connected, energy self-sufficient, lighter with green or hybrid propulsion systems and capable of recycling up to 90% of the waste generated.

As can be seen, the shipbuilding industry is working on its portfolio of eco-friendly products and services, on the decarbonization of transportation and on making its shipyards more socially and environmentally responsible.

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User-centered design for the marine industry Case: Recommendations for future casemates

Diseño centrado en el usuario para el sector naval
Caso: Recomendaciones para futuras casamatas

DOI: https://doi.org/10.25043/19098642.251

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Abstract

User-Centered Design (UCD) is an approach to the design of objects and spaces that focuses on satisfying the needs and expectations of users in all phases of design, considering both the physical and tangible characteristics as well as the intangible ones, referring to their behaviors, reactions, thoughts and interpretations. The objective is to create an efficient user experience for the people who are part of the designed service, and that will be translated into benefits derived from interaction, confidence in the use of the service, user satisfaction, reduced execution times, increased productivity, feedback and continuous improvement of the service. In this context, this case study presents the process of research, analysis and ergonomic and user experience recommendations, from the UCD for the design of casemates designed in Cotecmar for river vessels, in order to demonstrate the importance of design methodologies in systems and combat elements in ships. The objective is to allow that the scenarios where human beings interact with their workspaces have optimal conditions, enable the comfort of users, and offer the conditions to achieve maximum productivity and efficiency on board.

Key words: User-centered design - Casemate - Ergonomics.

Resumen

Al considerar el diseño de objetos/espacios, debe contarse con una filosofía que considere las características, físicas y tangibles del usuario, así como aquellas, inherentes a su carácter intangible humano, como psicológicos, culturales y simbólicos. Por medio de un enfoque que tenga como eje central, la priorización del ser humano, en cada fase del diseño es posible acercarse ampliamente a suplir las necesidades y expectativas de las personas, y a través de la interacción, cumplir las expectativas de funcionamiento del servicio durante la actividad. A esta filosofía, se le denomina Diseño centrado en el Usuario, y su sentido primordial es el de incorporar una experiencia de uso eficiente para las personas, que, al integrarlo, perciban beneficios que permitan el incremento de la productividad, la confianza en el uso del servicio, la satisfacción al usuario, la reducción en tiempos de ejecución, y el soporte y mantenimiento del "servicio diseñado". Este documento presenta el proceso de investigación, análisis y recomendaciones antropométricas y ergonómicas desde el diseño centrado en el usuario, para las futuras casamatas con el propósito de crear la inquietud respecto a las principales áreas que abarca el tema la ergonomía y el diseño centrado en el usuario, sin entrar al detalle en ellas, de modo que en los futuros sistemas o elementos de combate en los buques que se construyan, como también cuando sea necesario definir procedimientos, planes y grados de alistamientos, se tenga presente cómo esta disciplina puede contribuir a crear experiencias de usuario confortables y espacios con condiciones óptimas para obtener la máxima productividad de los tripulantes, logrando así la mayor eficiencia a bordo.

Palabras claves: Diseño centrado en el usuario – Casamata - Ergonomía.

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Introduction

Science and Technology Corporation for the Development of the Naval, Maritime and River Industry - Cotecmar (as its acronym in Spanish), through continuous research, seeks to generate innovation and improvement in each of its products and services for the welfare of its customers and users, contributing from the design to make this possible. Among the corporation's products with opportunities for improvement is the casemate, an armored structure that protects the marines during combat, from where they can defend themselves and shoot when attacked; this is a very important element in the naval industry due to its function.

This project emerged as a manifestation of the need to improve the working conditions of marines and ship gunners, who must remain between six to eight (6-8) hours inside the casemates.

In addition, it was identified that, over time, the previously constructed casemates have been modified by some crews, adjusting them to the needs of vessels, and therefore there is no standardized product. Through the analysis of the user experience in the casemates, a series of recommendations are generated to incorporate in the future designs of the Corporation, providing welfare to the marines and satisfying both direct and indirect users, providing the basis for the design and construction of the casemate as a standardized product for the defense of the ships designed in Cotecmar.

Background

The naval industry has been gradually consolidating through the efforts of many people, who have contributed to the possibility of Cotecmar standing out in the Latin American panorama, through the prioritization of knowledge, since it has the design and engineering capacity to generate solutions tailored to the needs of the sector *(Tascón, 2019)* in the country and the region, consolidated within the 20 most innovative organizations at the national level *(Cotecmar, 2022)*. Throughout two decades, its infrastructure, both its Mamonal and Bocagrande plants, together with its repair and maintenance processes and activities are internationally recognized for their operational capacity, the quality of the materials used and the work performed, for which the corporation is backed by certifications: ISO 450001:2018 (occupational health and safety), ISO 9001:2005 (quality management system), ISO/IEC 17025:2017 (metrology laboratory), Protection of Vessels and Port Facilities-PBIP issued by the Colombian Maritime Authority, Dian acknowledgment as an Authorized Economic Operator and ISO 14001 (environmental management system).

Like other national defense institutions in more developed countries, it is expected that in the projects developed by the Corporation and the Colombian Navy (Armada de la República de Colombia - ARC), studies that integrate the human being are considered and applied which, among others, establish ergonomic and anthropometric guidelines and recommendations in all fields of the projects, in the systems to be developed and in the subsequent interactions, such as the size and distribution of spaces, distances, reaches and anthropometric clearances, accesses and circulations, control consoles, types of indicators, lighting codes, interfaces, chromatic perception, alarms, quantity, hierarchy and types of information, psychology of form (or Gestalt), physical environment and its characteristics (noise, temperature, lighting and ventilation), etc. Thus, systems are expected to fulfill their promise of use, facilitate their proper operation and, in addition, should not be adapted to the needs of users, due to previous usability experiences with the equipment already finished, in order to reduce the costs and implementation times that these modifications entail.

The role of human factors is oriented to ensure that all user interaction with systems contributes to the performance of activities, so that errors are minimized, productivity is increased and comfort and safety are improved *(Wickens, Gordon, & Liu, 1997)*. Thus, the framework for the performance of various activities during short or extended periods of operation is set out; including feeding, sleep cycle, on-call segments and enlistment ranks, job rotation (if permitted by operational requirements), climate control, time study, etc.

The study and analysis of the particular human behavior (in this case, the crews) and of the actions that are developed and during the periods of operation of the ships allows us to focus our design methodology in order to find solutions closer to solving the needs from the design. Cotecmar has been working for years on developments with a high level of detail that allows us to carry out early verifications of the usability of spaces, equipment and elements of the ships built in the shipyard. As an example, we have the Extended Reality Laboratory, which uses immersive extended reality environments (virtual reality, augmented reality and mixed reality) to test the interaction and operation of designs proposed by the design and engineering management.

User-centered design

Human-centered design is a problem-solving approach commonly used in product and service design and management frameworks, that develops solutions to problems by involving the human perspective in all steps of the problem-solving process.

User-centered design, hereinafter referred to as UCD, is a multidisciplinary approach to product development based on human needs, which seeks to better understand the target user and their activities, allowing for designing, assessing and improving design proposals, throughout the entire design process and with the purpose of creating more useful and usable products. *(Norman, 1988) (Vredenburg, Isensee, & Righi, 2002).*

In fact, UCD practices have been formalized by international standards *(ISO, 2006)*, which define it as an approach to developing interactive systems, making systems usable and useful, focusing on users, their needs and requirements, by applying human factors, ergonomics, knowledge and usability techniques, improving effectiveness and efficiency, human well-being, safety and health, user satisfaction, accessibility, sustainability and counteracting possible adverse effects of their use on human health, safety and performance. (ISO, 2006) Likewise, UCD methods enable the design of more desirable products, based on User Experience (UX); to bring to the market value-added products *(Norman, 1988)* that satisfy the needs, goals and feelings of the users from the design.

The needs are established based on the ship's missions, the number of passengers and crew members on the vessels and the design requirements are formulated once the research indicates the activities and processes that will be needed throughout the design and development process. Ergonomics as an unavoidable tool in the UCD process, allows us to make a thorough analysis of how people interact with the system and its elements to perform any type of activities, even if they involve some type of automation.

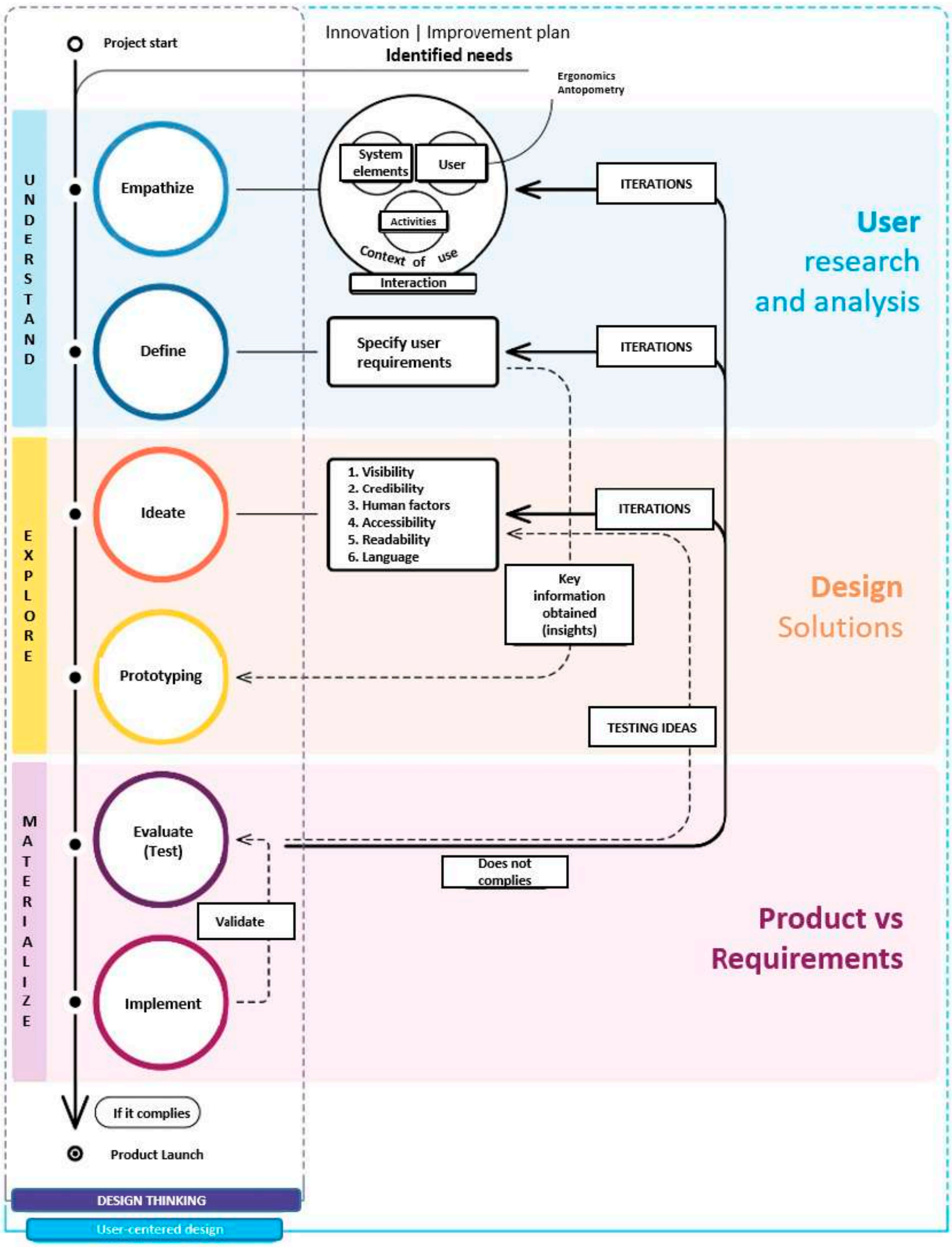
Ship design is a cyclical and iterative process that is managed holistically, where a people-centered approach positively contributes to the crew experience on board vessels. For this approach to be successfully integrated into ship design, it is necessary to understand the contexts of use, analyze the activities, visualize their roles, and then identify the needs to be solved through its implementation, followed by rigorous testing and assessment to determine whether the product is efficient from an onboard experience perspective (see Fig. 1).

Ergonomics

According to the definition of ergonomics or human factors (Human Factors and Ergonomics - HFE) adopted by the IEA (International Ergonomics Association) (IEA, s.f.) in 2000, it is the scientific discipline concerned with understanding the interactions between humans and other elements of a system, and the profession that applies theory, principles, data and methods to design and optimize human well-being and overall system performance. (IEA, s.f.)
HFE domains were also defined in 2000 by the IEA to include (IEA, s.f.):

Physical ergonomics. It deals with human anatomical, anthropometric, physiological and

Fig. 1. General outline of User-Centered Design. Proprietary figure.



Proprietary figure.

biomechanical characteristics in relation to physical activity. (Analyzes work postures, material handling, repetitive movements, work-related musculoskeletal disorders, workplace design, physical safety and health).

Cognitive ergonomics. It deals with mental processes, such as perception, memory, reasoning and motor response, as they affect interactions between humans and other elements of a system. (Study mental workload, decision making, skilled performance, human-computer interaction, human reliability, job stress and training, as these may be related to human system design).

Organizational ergonomics is concerned with the optimization of socio-technical systems (referring to systems where interaction takes place between people and machines, including those relationships between technology and users, as well as their psychological and cultural consequences on the individual and society), including their organizational structures, policies and processes. (Investigates topics such as communication, crew resource management, work design, work time design, teamwork, participatory design, community ergonomics, cooperative work, new work paradigms, virtual organizations, telework and quality management).

The HFE principles

HFE principles are rooted in socio-technical values. HFE participatory design principles and methodologies are applied in the design of tasks, jobs, products and environments. The principles of HFE are underpinned by the following core values (IEA, s.f.) *(AIE; OIT, 2019)*:

- Visualize human beings as assets.
- Technology as a tool to help human beings.
- Promotion of quality of life.
- Respect for individual differences.
- Responsibility of all stakeholders.

Iteration

Iterations can be defined initially as activity repetition processes in the thought processes of the designer or design teams throughout the design and development stages, iterations are aimed at building concepts and processes for materializing or representing designs.

The materialization or construction of products, as part of one of the approaches of the iteration processes, can be given in graphic language through sketches, or through three-dimensional artifacts. In the case study concerning the recommendations for the design of the casemates, three-dimensional models were made in Rhinoceros based on the survey of already built vessels, which allowed for the development of useful knowledge for the research during the user experience interview phase.

Anthropometry

Anthropometry is a fundamental discipline in the work environment, its relationship with ergonomics and safety, with the purpose of creating utensils, tools, equipment, considering its distribution and arrangement in space, through its geometric characteristics and its interaction with human dimensions, prioritizing the development of activities in a safe manner, and not involving the detriment of the physical conditions of people.

In this last section, it seeks to organize and design services by proposing the necessary spaces to develop specific activities in such a way that they can be carried out by the user, performing all the required movements, both close and extreme, without being exposed to possible risks derived from poor distribution, lack of space or excessive distance with respect to body dimensions. (Ministerio de trabajo e Inmigración Español)

The knowledge of static dimensions is basic for the design of products and makes it possible to establish the necessary distances between the body and its surroundings (dimensions of furniture, tools, etc.). The structural dimensions of the different body segments are taken on individuals in static, standardized postures, either standing or sitting.

The dynamic or functional dimensions are those taken from the working positions resulting from the movement associated with certain activities, i.e., it takes into account the study of the joints providing knowledge of the function and their possible movements, taking into account the biomechanics and making it possible to assess the capacity of joint dynamics. (Ministerio de trabajo e Inmigración Español)

Interaction

Action exercised reciprocally between two or more objects, agents, forces, functions, persons, etc. This concept is applied in countless scientific and humanistic areas, giving it a different connotation according to the context; however, it always maintains its original definition: it involves different objects, which influence and modify each other, taking into account the situation and the surrounding circumstances. The Interaction Design, defines the structure and behavior of interactive systems (IxDA, s.f.) and the interaction designers are in charge of creating meaningful relationships between these actors in order to achieve a goal through actions.

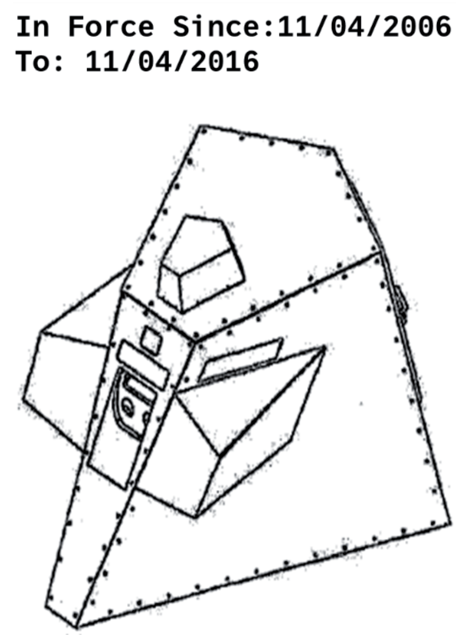
Casemates

The Casemate design has the first industrial design registration granted to Cotecmar, conferred with the power to protect its formal characteristics and internal configuration, effective from 11/04/2006 to 11/04/2016 (See Fig. 2).

It was designed and built with the purpose of offering possibilities for the transit and patrolling of Colombian rivers in areas of conflict with illegal armed forces. This design has been incorporated into vessels built by Cotecmar and has been installed in the defense system of existing Navy units. Currently, Cotecmar has developed casemates articulated by a hoop system, which allows it to rotate by means of a manual back up system, and pedals to steer it. It houses two 0.50 machine guns, six to eight boxes of ammunition, a chair and an armored steel structure that protects the gunner and the armament. These casemates fulfill defense functions, thanks to which they can repel attacks and defend ships with great firepower. It has five (05) windows to view the exterior, one of them on the armament shield. The front windows have the purpose of visualizing the target area for firing, the central window operates as the "sight" field of the armament, while the side windows provide a wider view of the surroundings, enabling the visualization for the positioning and turning of the casemate and the location of possible aggressors.

The casemate has a pair of niches located on the sides that are integrated into its shape, which allow for internal spaces to store ammunition. It has an air extractor on the upper surface and all its faces are angled (including niche faces), to repel and deflect impacts received. It has a welded and bolted steel structure, and two access areas: an exterior inclined door and a lower hatch that connects to the interior of the vessel.

Fig. 2. Representation of Casemate registered as an industrial design



Beyond the design and construction plans during these years, as of the date hereof, there is no written document that supports the design of casemates, as well as studies or destructive tests that indicate their state of vulnerability. At Cotecmar, the design of the casemate has been modified since 2002 and since then 3 versions have been generated. The most recent was designed in 2008 and no significant formal changes have been made between them. The materials used in this design are: steel and armored glass.

The design of casemates developed by Cotecmar has been installed in the ARC units, referred to Patrulleras de Apoyo Fluvial (River Support Patrol Boats), in their two versions, Heavy (PAF-P) and Light (PAF-L) of 40.3 m and 30 m in length, respectively. It should be noted that the design of these vessels is also proprietary to the Corporation.

Fig. 3. Heavy river support patrol boat - PAFP (left) and light river support patrol boat - PAFL (right).

Proprietary figure.

Objectives

Understand the current design of the casemates of some river vessels designed and built by the Corporation (taking into account that they have also been installed in existing ARC units) in order to analyze the user experience (crew and gunners) and identify the necessary aspects for their efficient operation.

- Check the physical conditions of the casemate.
- Map the interactions and activities where the casemate is a key element of the system.
- Identify opportunities for improvement in the design and construction of the casemates.
- Know the experience of casemate users.
- Propose a series of recommendations for the design of the next generation of casemates.

Methodology

Context

The user experience investigation originates from a Warranty Claim / Novelty Report received from the Naval Material Headquarters (JEMAN), requesting Cotecmar to make the necessary corrections and improvements to the casemate to allow for "easy removal and installation of the ammunition box". It is also mentioned that another vessel has a design that does allow this change of ammunition normally (referring to ARC Guillermo Londoño).

As a result of this request, the design team began a process to identify the possible fronts that would allow the analysis to be addressed, based on some questions such as: Why do ammunition spaces need to be different or larger than the existing ones? What do we need to validate before making any design proposal? How do users interact inside the casemates? What are the conditions of comfort and well-being of users when using the casemates? The research was based on these questions.

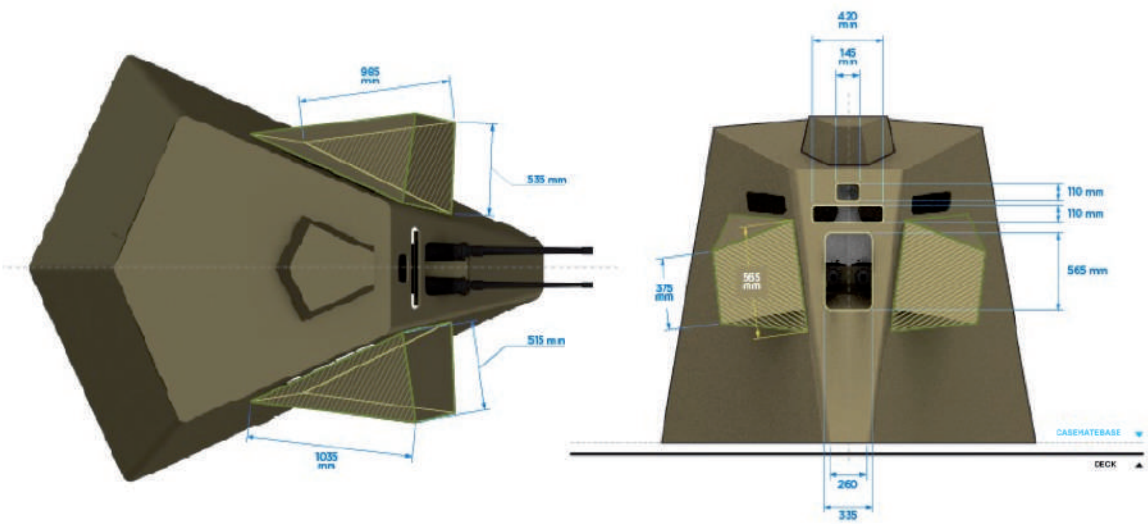
The purpose of establishing an analysis of these characteristics is to visualize the casemate as a product with spatial characteristics where a group of users (gunners) performs a series of activities interacting with the mechanisms of the casemate, where the efficiency in the fulfillment of its tasks as a defense and attack component of a ship is fundamental, and which must allow these tasks to be carried out without affecting the comfort of the user inside the casemate.

Survey

To learn how the crew interacts with the product, a dimensional survey was made of two casemates manufactured by the Corporation, installed on two Heavy River Support Patrol Vessels (PAFP): unit ARC SSCIM SENEN ALBERTO ARAUJO (Generation I) and unit ARC JUAN RICARDO OYOLA VERA (Generation III). In the survey it was possible to observe a relevant condition for the research, since there are some differences between these, present due to modifications in the design, such as:

- Modifications made by the vessel's crew. Including some for the purpose of improving

Fig. 4. Casemate and its dimensions.



Proprietary figure.

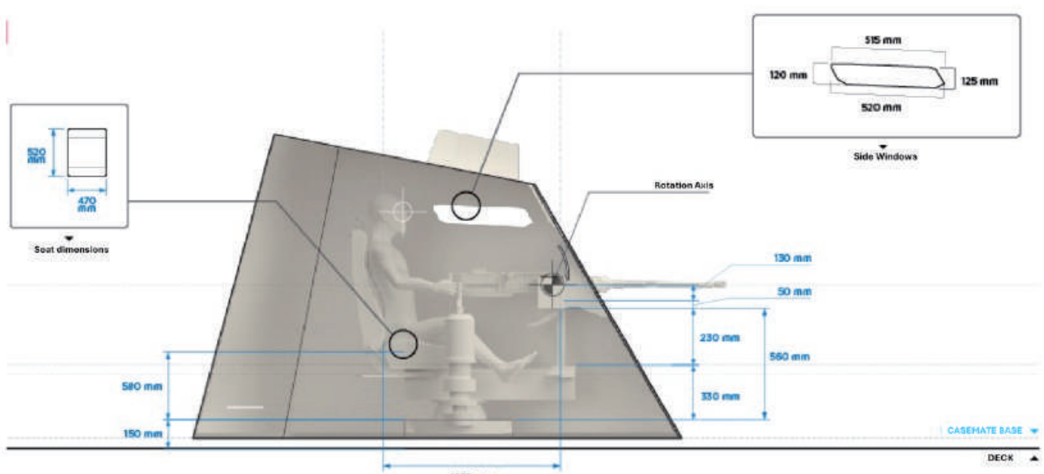
comfort in the operation of the casemates.
- Wear and tear of the casemate over time.
- Damage as a result of combat.

With the survey of the two casemates, a three-dimensional model was subsequently generated for validation and verification exercises. The following figures are the virtual representation of the casemate and the compilation of the dimensional log made.

The lengths of the main body and side niches (sizes, angles and shapes) were recorded in order to gather and understand the intentions of the users in carrying out each design intervention, and to contrast these versions with the original design and identify their differences (see Fig. 5).

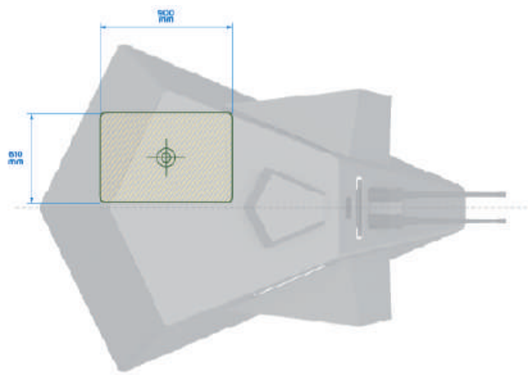
In addition to the survey of the main shapes and the outer body of the casemate, the dynamic dimensions and the operating ranges of the gunner to perform each activity were also recorded. In the three-dimensional model, the positions of each element (equipment, shafts or components of the casemate, etc. with their respective height and

Fig. 5. Casemate and its interior dimensions.



Proprietary figure.

Fig. 6. Casemate and its inner hatch.



Proprietary figure.

size) were spatially located and anthropometric checks were carried out with the crews and the research team (see Fig. 6).

Each of the access roads were identified and surveyed. Entry and evacuation exercises were also simulated using the access elements of the casemate (door, ladders, steps, handrails, grips and hatch) to analyze the sequence of the action.

With the information gathered from this anthropometric and ergonomic analysis, we began to visualize the interactions that the gunner must perform. As a research team, we reproduced the movements and postures that users must adopt to operate the casemate. This led to the identification of those weak points in the design that would later become opportunities for improvement. This provided the basis for the construction of interviews, in order to know the experience of use of the casemate by gunners in detail, and thus, to build the user journey map (Nielsen Norman Group, s.f.)[1] with the activities during the interaction, highlighting the key points or pain points (Group, s.f.)[2] that determine the perception of a user experience.

The first visit was to the heavy river support patrol boat ARC SSCIM SENEN ALBERTO ARAUJO (see Fig. 7), where casemates were observed with side niches much larger than the original design, reduced spaces for ammunition storage and advanced deterioration in its parts: doors, gunner's station (chair), windows and extractors. Being a vessel with three casemates on the same deck and at the same level, the synchronization of the turning radii is essential to avoid accidents. This task is vital for the operation and, even so, it was observed that the pedals for the user to turn the casemate were in poor condition and the rotation of the casemate had to be done manually.

Fig. 7. Casemate of the A.R.C. unit. SENEN ARAUJO.

[1] User journey map: It is a visualization of the process a user goes through to achieve a goal. It consists of the user's actions arranged in a timeline, into which the thoughts and emotions experienced by the user throughout various phases of the process are incorporated to create a narrative of the process and is compiled into an overall visualization of the moments of the activity. These yield the information that allows for the identification of Opportunities (along with additional context, metrics found and identification of those responsible for making the changes) that will lead to optimizing the user experience.

[2] Pain points: Defined as the problems that users may encounter in carrying out an activity. These are divided into three categories: At the interaction level (in particular with an interface or direct attention), journey level (in which the user wants to achieve a goal) and at the relationship level (in which the interaction affects the relationship with a company, organization or brand). Pain points are diverse (they can be broad or specific, direct or relatively insignificant, obvious or hidden) and identifying them is a first step in creating solutions that address real user needs.

The second visit was to the heavy river support patrol boat ARC JUAN RICARDO OYOLA VERA (see Fig. 8), which patrols the rivers of the Colombian Pacific coast. The casemates of this vessel have side niches corresponding to those of the original design. The casemate located on the centerline and on the bow has a special feature as it is elevated on a platform that places it at a higher height than the others that are located directly on the deck. This elevation requires the design to incorporate additional elements such as ladders, steps and grips to facilitate user access to the casemate.

Fig. 8. Forward casemate of A.R.C. unit. JUAN OYOLA.

User interviews

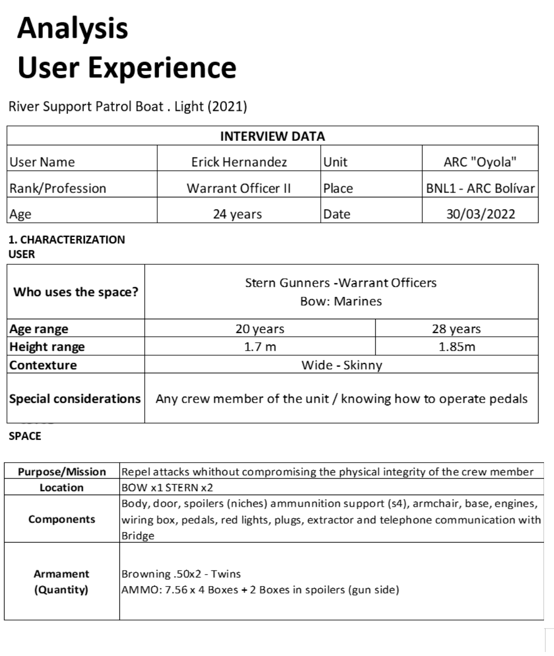
This method consists of formulating open questions or topics (semi-structured), which allow for a guided conversation on a given topic. In the case study, to know in depth the perceptions, opinions, desires and emotions of the users of the casemates. The interviews were conducted through informal dialogue, so that the interviewee felt comfortable and could express him/herself without feeling judged, allowing his/her opinions to be as true as possible to the experiences actually lived. *(Trujillo, 2016; Schindlholzer, 2008)* This tool allowed the research team to inquire qualitatively about the users' point of view. Likewise, it could be used in the information consolidation stage, after the usability evaluations, to deepen the users' perceptions of the interaction with the casemates. Additionally, it was complemented with the observation of contexts of use and the analysis of activities. The purpose of the interviews is to gather general information on the interactions and activities surrounding the use of the casemate and its systems, in order to learn about the users' experience and identify the strengths and weaknesses that may exist (see Fig. 9).

User Experience Design (UXD) is the process of analyzing user needs in order to incorporate the results into the design, either an interface, spatial layout, usability or the way a person relates to a product. Therefore, when the analysis interviews were conducted, two gunners with different years of experience were selected. Aptitude questions were asked to find out if the gunner has the knowledge, physical and mental conditions necessary to operate the casemate, behavioral questions to develop a behavioral profile, situational questions to understand their behavior in certain situations, and opinion questions to find out what suggestions they considered to include in the design, what they expected from, and from their interaction with, the casemates and their general evaluation of the casemates.

Observation of contexts of use

The observation of contexts of use stems from the ethnographic research method, which focuses on describing a culture and its practices through understanding the social group from an immersive point of view; for such purpose, the research team used different tools, with observation and interview being the instruments that allowed for getting closer to users. Thus, observation in research allows us to identify and learn about the experiences of use of the crew (especially gunners), identifying the physical context of the immediate environment, giving relevance to the interaction relationships from the user's perspective. *(Spradley, 1980; Bonilla & Castro, 2005).*

Fig. 9. Form of interviews made with gunners - users of casemates (first sheet). Proprietary figure.



Analysis
User Experience

River Support Patrol Boat . Light (2021)

INTERVIEW DATA			
User Name	Erick Hernandez	Unit	ARC "Oyola"
Rank/Profession	Warrant Officer II	Place	BNL1 - ARC Bolívar
Age	24 years	Date	30/03/2022

1. CHARACTERIZATION USER

Who uses the space?	Stern Gunners -Warrant Officers Bow: Marines	
Age range	20 years	28 years
Height range	1.7 m	1.85m
Contexture	Wide - Skinny	
Special considerations	Any crew member of the unit / knowing how to operate pedals	

SPACE

Purpose/Mission	Repel attacks whithout compromising the physical integrity of the crew member
Location	BOW x1 STERN x2
Components	Body, door, spoilers (niches) ammunnition support (s4), armchair, base, engines, wiring box, pedals, red lights, plugs, extractor and telephone communication with Bridge
Armament (Quantity)	Browning .50x2 - Twins AMMO: 7.56 x 4 Boxes + 2 Boxes in spoilers (gun side)

Analysis
User Experience

River Support Patrol Boat . Light (2021)

INTERVIEW DATA			
User Name	Jorge Vásquez	Unit	ARC "Senen"
Rank/Profession	Professional Marine	Place	BNL1 - ARC Bolívar
Age	38 years	Date	30/03/2022

1. CHARACTERIZATION USER

Who uses the space?	Marines ALL THE CREW	
Age range	22 years	38 years
Height range	1.7 m	1.85m
Contexture	Wide - Skinny	
Special considerations	Must have prior instruction on the use and operation of the casemate	

SPACE

Purpose/Mission	Repel attacks won the unit Have early warning before being attacked It is the Harpoon remote combat system (newer than Scorpion)
Location	Top deck x3 units BOW: Harpoon Remote Combat System (Newer than Scorpion)
Components	Body, door, spoilers (niches) ammunnition support (s4), armchair, base, engines, wiring box, pedals, red lights, plugs, extractor and telephone communication with Bridge They share the characteristics of the ARC Oyola casemates
Armament (Quantity)	STARBOARD - PORT: Brawning 0.50 x 2 - Twins AMMO. 12.7 mm x 4 boxes - 2 boxes in spoilers (guns side). Supports on shaft for ammunition

Observation of contexts of use is an effective method for inquiring into natural situations of use about what gunners do. It allows us to reveal characteristics of the interaction with the products during the development of activities; evidencing the flows, errors, inefficiencies and challenges to complete the tasks.

However, this method does not make it possible to interpret what the users think and perceive; therefore, we combined the results with the interviews to forge a comprehensive view of the casemate use situation. *(Goodwin).*

We conducted observation of contexts of use with two gunners to visualize how different anthropometric percentiles interact with the casemate, and assess the ability of the casemate to adapt to users with different characteristics, how anthropometry affects the efficiency in the operation of the casemate, and what is the scope that each gunner has in interaction with the casemate,

Fig. 10. Vertical visibility range - 170 cm user height. Own figure.

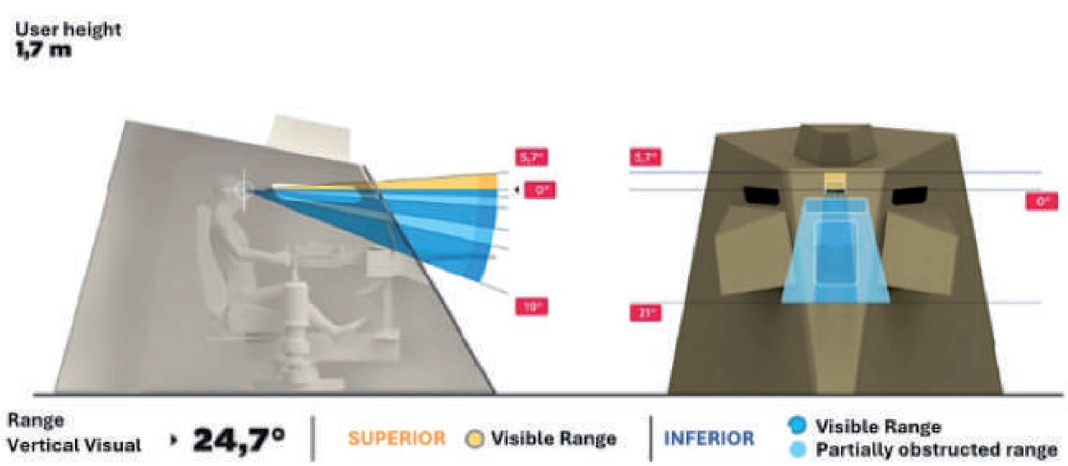


Fig. 11. Vertical visibility range - 180 cm user height. Own figure.

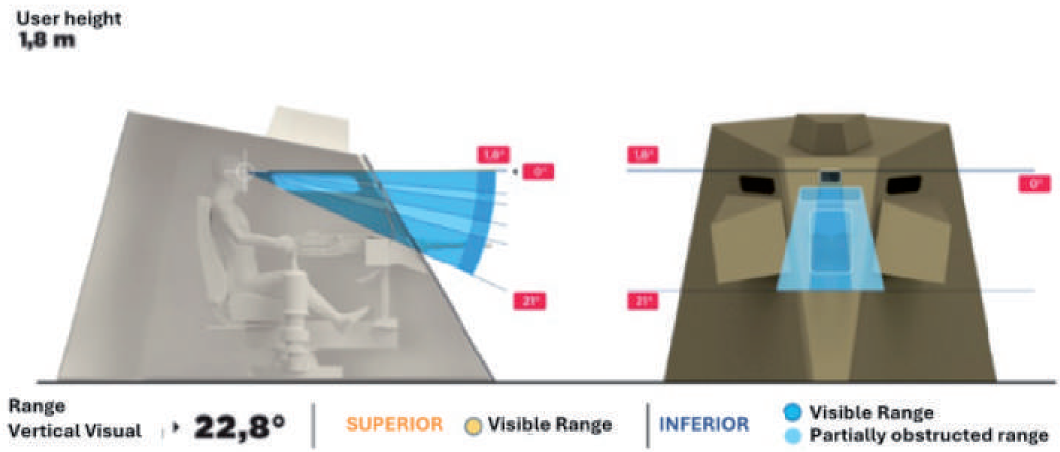
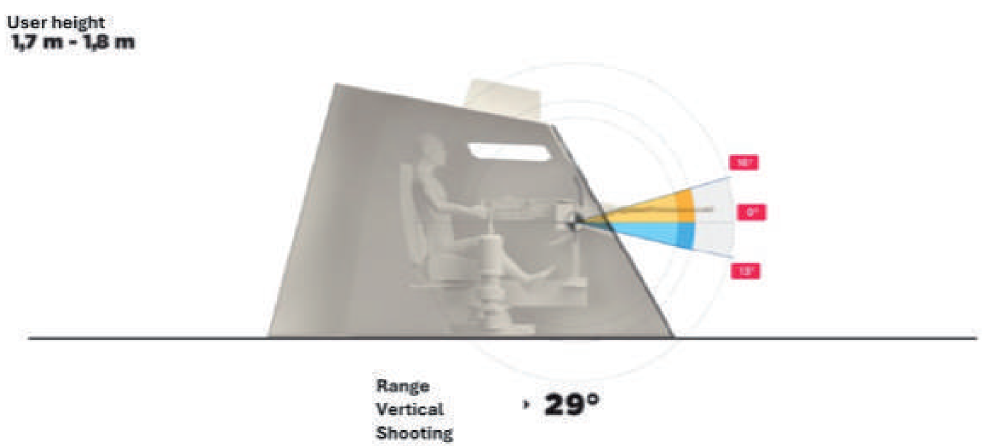


Fig. 12. Vertical firing range. Proprietary figure



we understood the origin of the differences and how these can affect the gunner in the prolonged use of the casemate (see Figs 10, 11, 12 and 13).

User profile

By means of the user profile, it was possible to select and describe the characteristics of two users (gunners), identifying the profile of the people for whom the design is intended, so that, in the future, checks can be made and the needs of use of those who interact with them can be met.

Likewise, the profiles identified reflect particular attributes that correspond to the personal experiences of each of the users, including context, rank, skills, knowledge, activities, demographic information, experience of use and general experience in interacting with the casemate and their perception of its design. *(Rubin & Chisnell, 2008).*

Usage evaluations

It is a method that collects user information during the development of tasks with one or more

Fig. 13. Swivel range and horizontal firing. Own figure

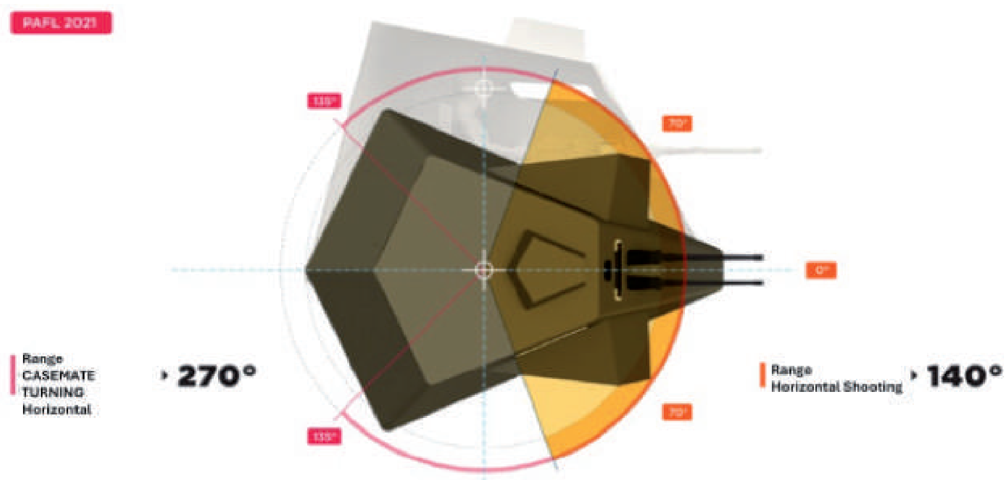


Fig. 14. Profile 1, Warrant Officer II. Proprietary figure.

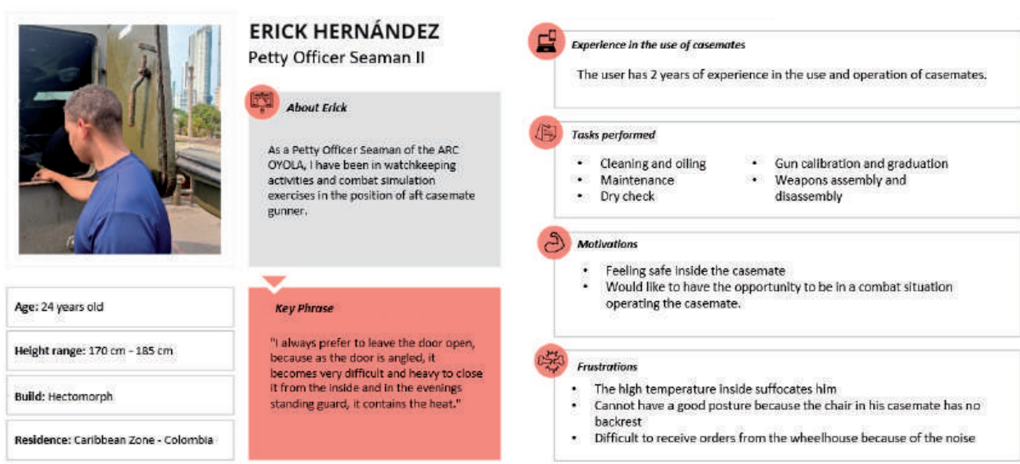
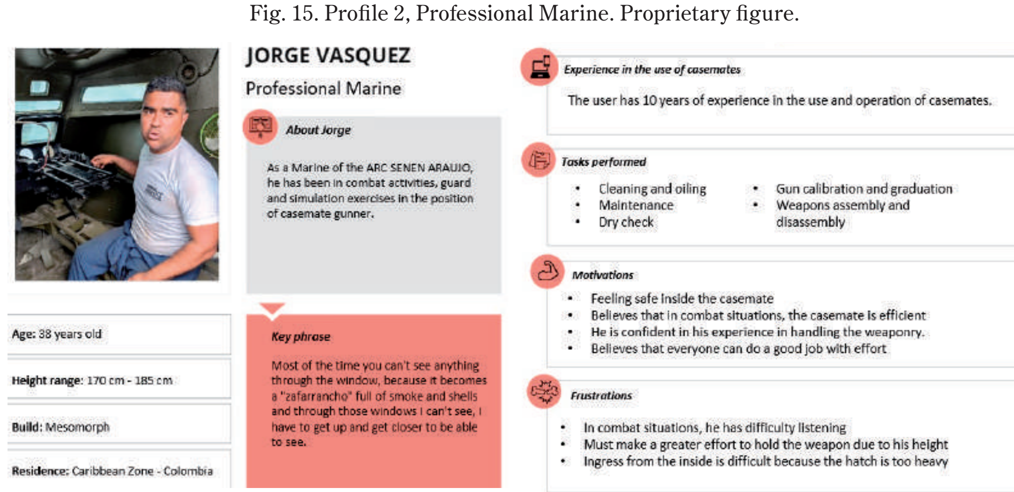


Fig. 15. Profile 2, Professional Marine. Proprietary figure.



prototypes. During this research, information was collected from the observations of context of use and from interviews made, making it possible to observe deficiencies or opportunities for improvement in the performance and provision of a service. *(Rubin & Chisnell, 2008).*

This type of evaluation was carried out using a protocol with clear objectives, the results of which were used to assess and compare different options for carrying out any of the activities with the casemate. It made it possible to highlight the deficiencies that the casemate may still have in terms of use and functionality, making it possible to identify points to improve interaction and, by extension, to increase the comfort and efficiency of the casemate's capabilities. *(Goodwin).*

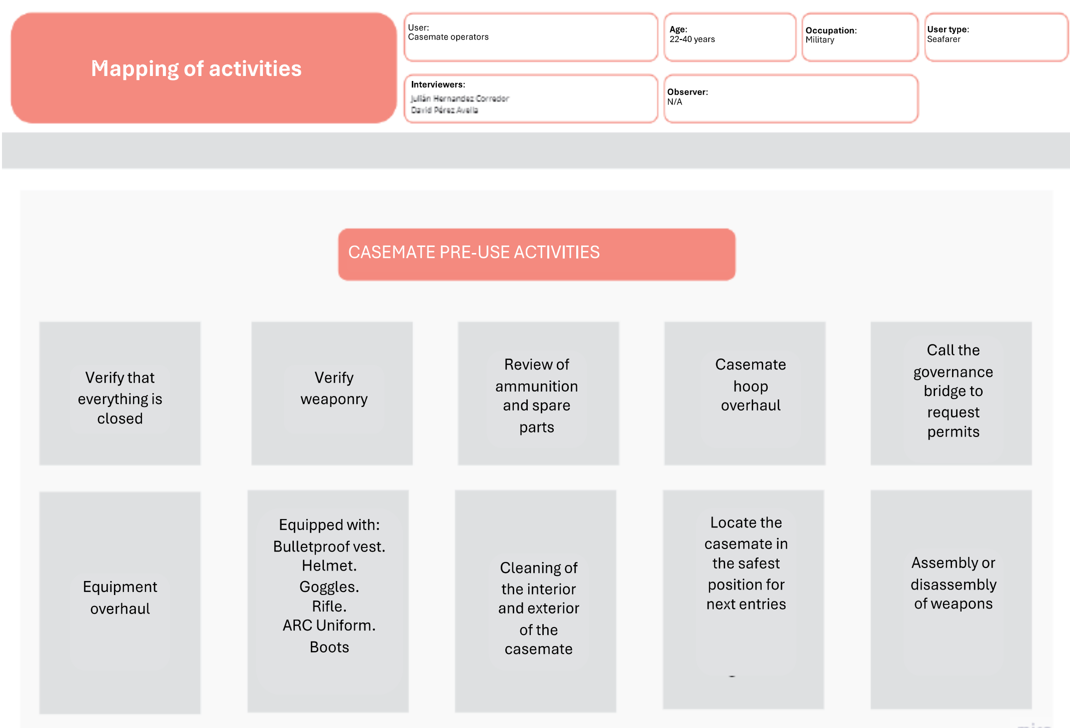
Through the analysis of the information gathered in the interviews, a visualization of activities was generated, which was divided into three general phases corresponding to the user journey map:

1. Activities prior to the use of the casemate.
2. Activities during the use of the casemate - This included an annexed phase aimed at analyzing the activities during the use of the casemate's armament.
3. Activities after the use of the casemate.

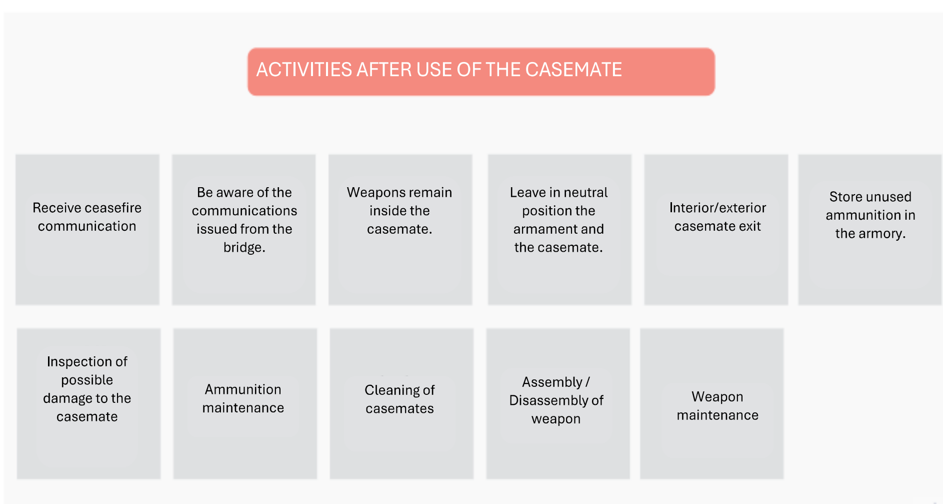
With this breakdown of activities, it was possible to identify the user's route along the basic activities (with their corresponding tasks) for the use of the casemate, differentiating them into necessary, useful or optional.

Comments, recommendations and responses to user interviews identified activities in need of design action for improvement (see Fig. 16).

Fig. 16. Mapping of activities carried out during the interaction with the casemate. Proprietary figure.




ACTIVITIES DURING THE USE OF THE CASEMATE
Entry to casemate from the outside
Access from the inner hatch
Adjustment of chair position according to measureme nts
Location of reserve ammunition for machine gun ammunition
Direct communication with governance bridge
Use of communication headset
Telephone use
Verify weapon components
Support heavy hatches and place in transit areas of the vessel.
Request for authorization for the use of weaponry
*Prohibited - Open fire if there is civilian population present
Authorization to fire only from the bridge
Press turn pedals with both feet
Turn the casemate in firing direction.
Vertical rotation of the weapon, in firing direction manually.
Maneuver weapon
View target
Open fire
Cease fire
Wait for indoor smoke to dissipate
Relocate firing target
Ammunition reloading and unloading
Communication with governance bridge for feedback on shots fired
End of fire
miro


ACTIVITIES AFTER USE OF THE CASEMATE
Receive ceasefire communication
Be aware of the communications issued from the bridge.
Weapons remain inside the casemate.
Leave in neutral position the armament and the casemate.
Interior/exterior casemate exit
Store unused ammunition in the armory.
Inspection of possible damage to the casemate
Ammunition maintenance
Cleaning of casemates
Assembly / Disassembly of weapon
Weapon maintenance
miro

User journey map

User journey maps make visible the steps users follow to achieve a goal through their actions. To expose an overall view of the experience, user journey maps should be based on actual testimonials and evidence supported by information gathered through research, rather than being an idealized or assumption-based representation of how users are expected to interact with a designed product. (Nielsen Norman Group, s.f.)

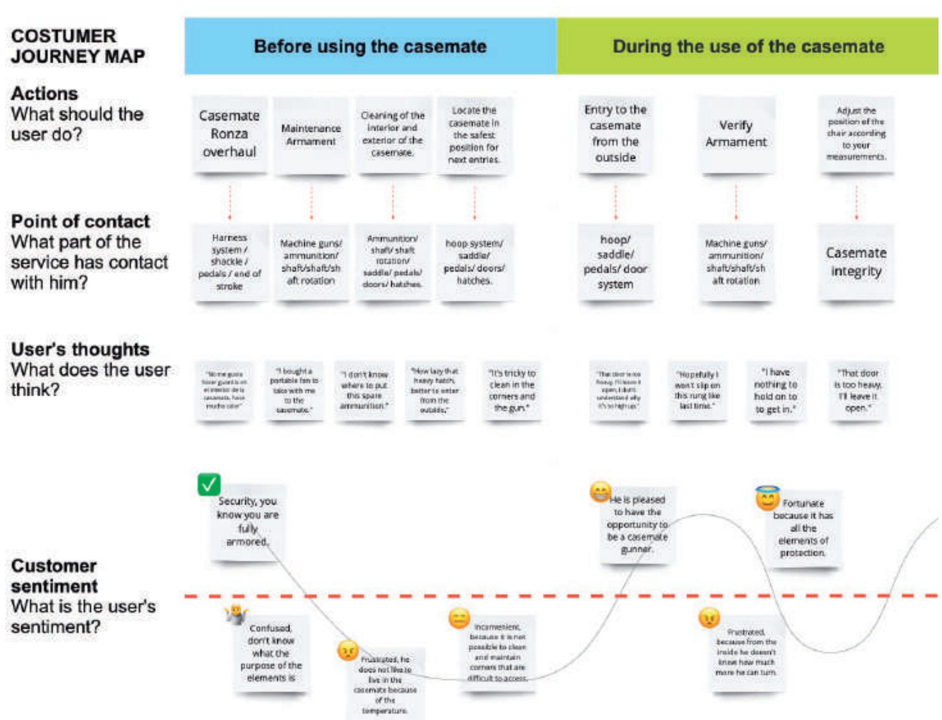
The user journey map is a tool that can be used to holistically understand the user experience, a process that records the phases (or moments) of activity development that coincide with those mentioned in point 4.6 (Usage evaluations). These phases were crossed with the variables of the analysis that corresponded to different topics that allow for understanding how the activity is carried out through the moments of each of the phases (See Fig. 17), categorized as follows:

- Actions: activities that users must perform to meet their objective.
- Contact points: points where the user interacts with the physical elements during the action.
- User's thoughts: phrases or comments made by the user while performing the activities or based on previous experience.
- User's feelings: Those emotions that are caused by the performance of actions, such as pleasure, joy, pain or frustration depending on what the interaction generates when carrying it out.

The map itself is a tool that helps visualize and share the research findings in a graphically organized manner and compiles the information gathered and the research findings. From this, a visual narrative is prepared to communicate "the user's journey" (as its name suggests) and all relevant moments, critical successes, pain points and any key (insight) that allows us to develop a design proposal that largely or fully satisfies the promise of use offered by a product.

With the information gathered in the User Journey Map, we analyze the points that are seen as critical, the pain points related to the interaction and determine how the users feel during each of the

Fig. 17. User journey map. Proprietary figure.



phases of the activity. Based on this information, design opportunities are proposed (see Fig. 18) that could help improve the complete user experience, making changes to alleviate pain points, improve functionality, accessibility and perception of the design so that, as a whole, they can increase the value of a relevant product in the historical record of design at Cotecmar.

Thus, a section is included that compiles the design opportunities, visualizing them in Fig. 18.

Design opportunities

Each identified problem becomes a design opportunity. Through the research, it is possible to identify the problems that may arise in the interaction and operation of the product, the weak points of the product, the user's needs, and the "gaps" in the current design of the casemates. From the comments received in the interviews, the investigation revealed some findings such as the following, corresponding to the dialogue with the crew of the patrol boat ARC "SENEN ARAUJO":

Fragments of interview made with user of ARC "SENEN ARAUJO

Question	User comments	Finding
1. How is the operation inside the casemate?	*"The motors [to perform casemate turning] don't always work."*	- Users must operate the motors manually to perform rotation.
5. How do you perceive the casemate seat?	*"The [seat] location and posture CANNOT be adjusted"*	- Change the seat for one that allows adjustment of the gunner's position and posture.
10. Physical conditions inside the casemate: How does it feel to operate the casemate?	*"High temperatures indoors"*	- Fans used to mitigate this condition.
12. What could be improved? What do you think can be incorporated into the design? How would these changes help?	*- Location of armament at chest level.* *- Pedals with lower base to rest the foot and heel.* *- Ventilation.* *- Change of ammunition (cartridge belt and ammunition boxes only).* *- Ammunition feed differs between left and right.*	- Modify the height of the gun location. - Modify the seat for the user. - Incorporate better ventilation system. - Optimize the ammunition change activity. - Unify the casemate's armament and ammunition. - Consider the possibility of including a firing guide to complement the sight and tracer projectiles.

Fig. 17. User journey map. Proprietary figure.

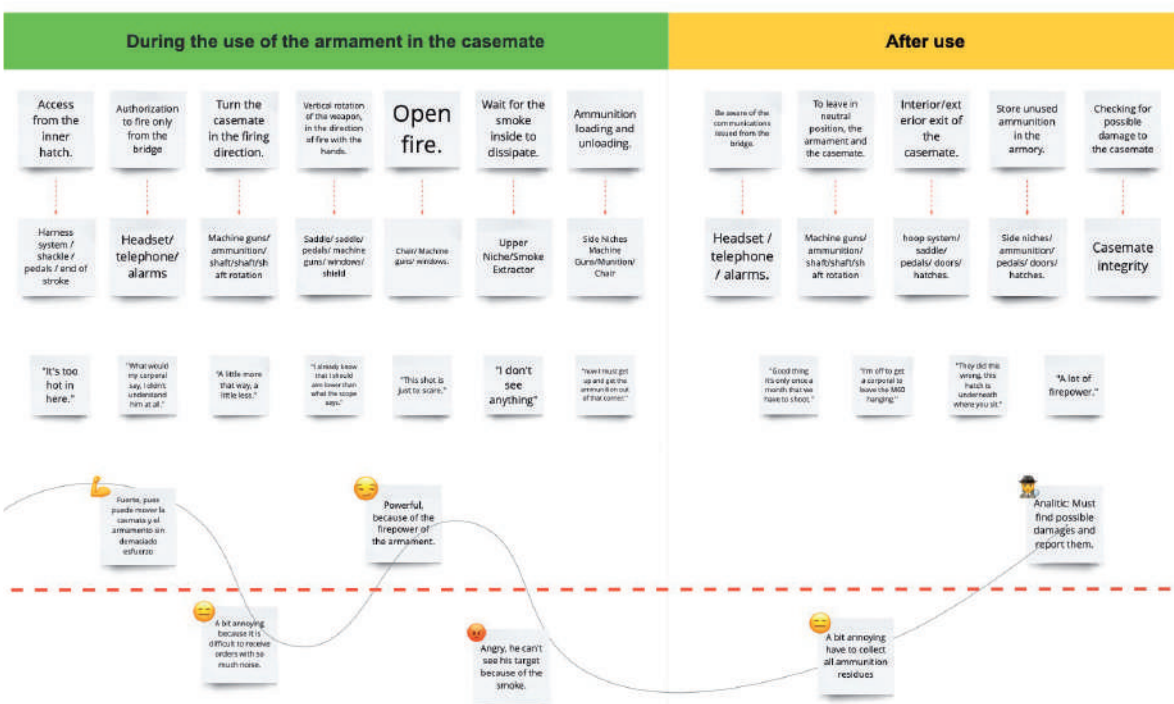
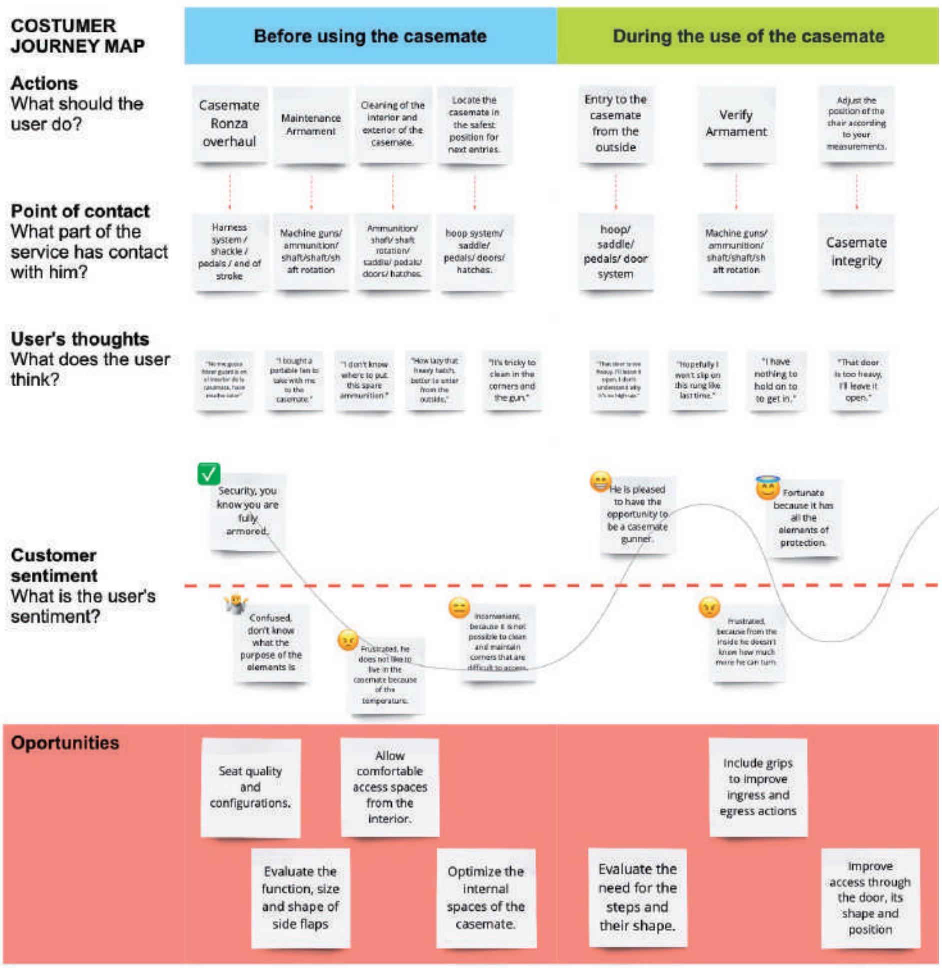


Fig. 18. User journey map including design opportunities. Proprietary figure.



Based on the findings of the information gathered, a list of the areas where design opportunities can be carried out was prepared. These design opportunities were separated into the following categories, according to the types of activities:

1. Visibility.
2. Access.
3. Operation.
4. Comfort.

In each of the categories, the design opportunities were segmented with the following labels that identify the pain points to analyze in order to establish the type of design intervention to optimize the design for the future:

- Problems: Those challenges faced by users in carrying out their activity.
- Needs: Those required by users to perform their activity and which are not being supplied at the time of analysis.
- Gaps: Those aspects absent in the interaction that, if present, could improve the development of the activity.

Visibility

1. Group the front windows into a single window of larger area to increase visibility on the shooting target.
2. Reduce side niche sizes to allow for enlargement of side windows.
3. Adjust the height of the side and front windows to provide comfortable visibility for shorter users within the 5th percentile of the Colombian population.

Fig. 18. User journey map including design opportunities. Proprietary figure.

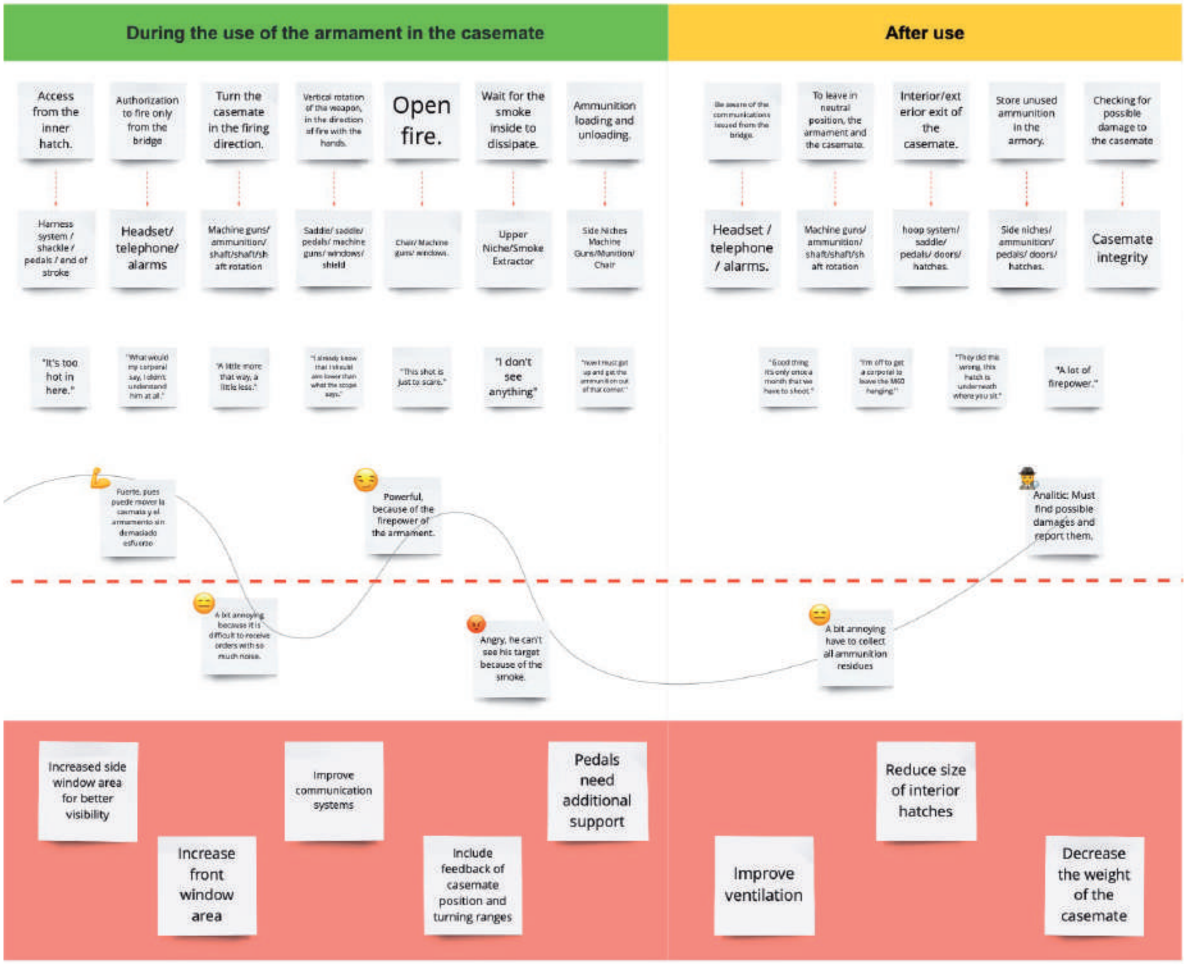
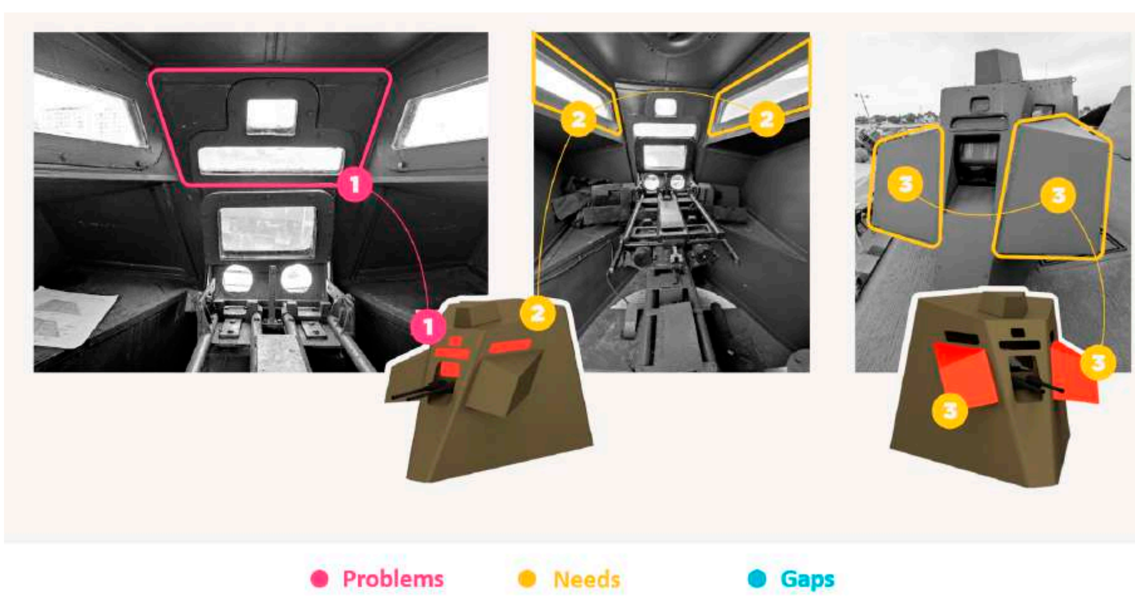


Fig. 19. Design opportunities: Visibility. Proprietary figure.



Access

1. Reduce the height from the deck to the door in order to allow shorter vertical access to the casemate.
2. Redesign the door to have a basic orthogonal (rectangular) geometry.
3. Include grips to facilitate access to the casemate, both from outside and inside the vessel.
4. Replace the square bar steps with treaded steps.
5. Review the position, orientation, shape and design of hatches (including their mechanisms) for access from the interior in order to optimize entry to the casemate.
6. Allow the reservation of a free area to facilitate access from inside the vessel to the casemate.
7. Restrict the opening swing of the door to the outside to ninety degrees (90°) in order to allow a quick and more comfortable closing.

Operation

1. Place the armament in a neutral position at the user's chest (pectoral) level.
2. The position of the gunner's seat must be adjustable longitudinally (Y-axis) and vertically (Z-axis) inside the casemate.
3. It must include a feedback system that provides visualization of the range of rotation and, in turn, indicates the radial "end of stroke" of the casemate.
4. Side niches:
   - Redesign the shape of the side niches in accordance with the general geometrical characteristics of the casemate. Increase the angles of inclined surfaces to increase the capacity to redirect the impacts received.
   - Volumetrically modify the niches to accommodate ammunition boxes mounted on the armament and allow quick and convenient access to them.
5. Include a hands-free communication system with acoustic protection.
6. Relocate the ammunition boxes located behind the user's seat to a position where they are directly accessible when operating the casemate.

****Weight:*** As an additional consideration, it is proposed that the redesign of the casemate should allow for a reduction in its overall weight in order to allow for greater efficiency in the turning radius to achieve the objectives more effectively.

Fig. 20. Design opportunities: Access. Proprietary figure.

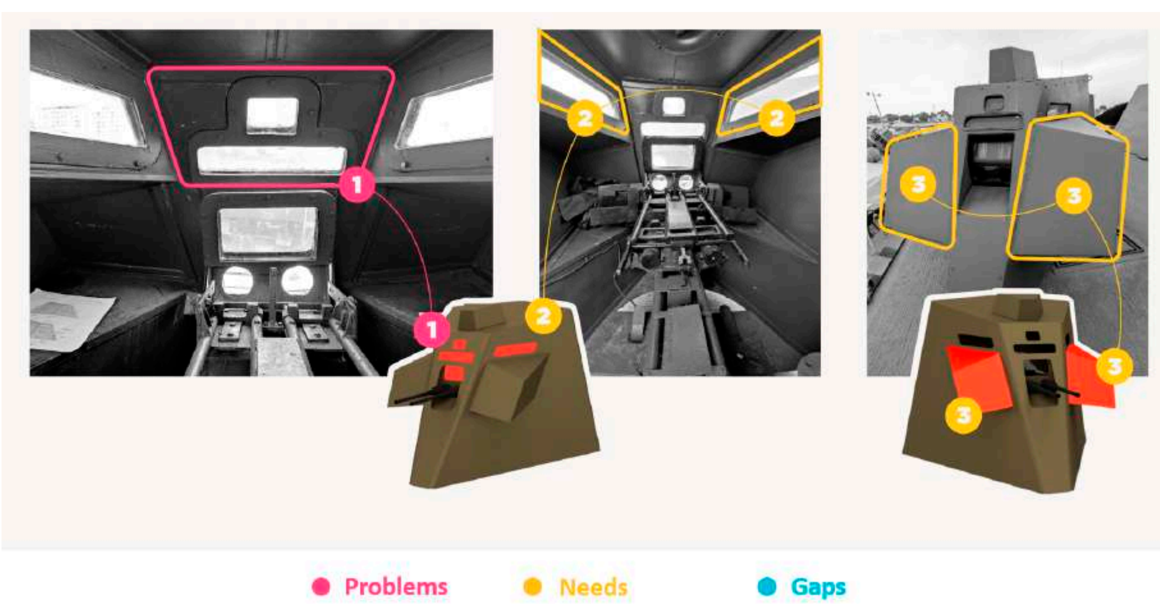
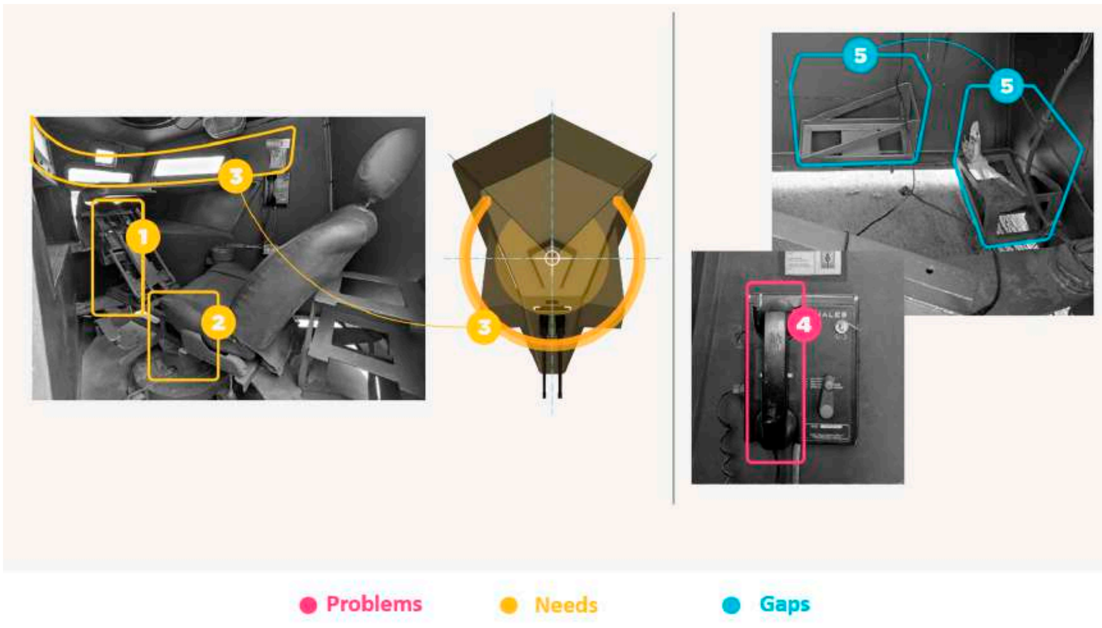


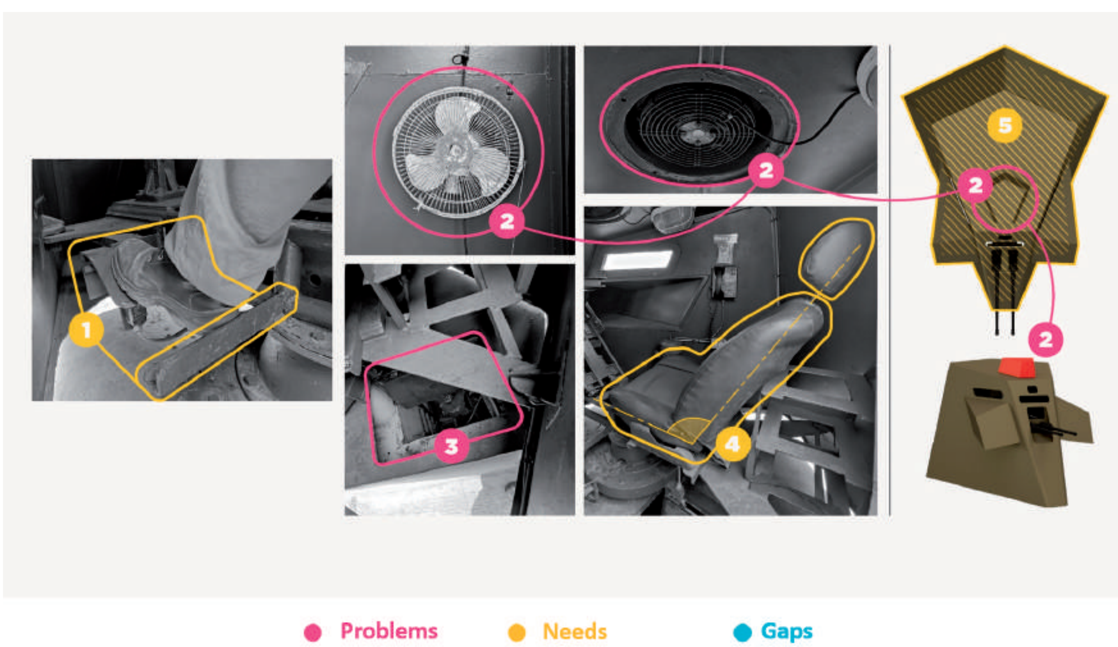
Fig. 21. Design opportunities: Operation. Proprietary figure.



Comfort

1. Redesign the base of the drive pedals to allow full foot and heel support.
2. Improve ventilation (and its operation system) inside the casemate: Increase and relocate ventilation equipment and grilles in areas of the casemate that increase and allow a continuous air flow and that do not compromise user integrity.
3. The user seat should be reclining and adjustable to different angles.

Fig. 21. Design opportunities: Confort. Proprietary figure.



4. Redesign formally and dimensionally, the internal hatch, including its fastening and drive systems.
5. Expand the interior space of the casemates while maintaining their geometric characteristics of defense, in order to allow comfortable movements for users within the 95th percentile of the Colombian population.

Conclusions

From the research it was possible to identify the points of intervention where improvements could be incorporated in the casemates in the future, in order to project a permanent, iterative and continuous spiral of design to increase the value of the product.

Having identified these points, the design process increases its ability to meet user needs, to approach the promise of a product in terms of its use and to achieve highly assertive design solutions that facilitate and make it possible to reach a product that is not restricted only to usability, but that meets the facets of user experience that Peter Morville proposes: valuable, usable, useful, desirable, accessible, credible, findable; these facets show that the experience revolves around people with different spheres and that interaction is not limited to efficiency and functionality, but that other fields of the human being have an impact: individual, social, cultural, contextual and specific to the product.

Through the incorporation of UCD processes and methodologies, which have been widely disseminated in other contexts and industries *(digital development, for example)*, the vision of building solutions from design has expanded, through a framework of joint creation with the user, which converge in a finished product, but not in an unalterable proposal; this means that it can continue to be tested, updated, adapted and improved over time according to changes in the technological scope, in the environment, and in people *(and therefore, in societies and culture)*. Therefore, it represents a multidisciplinary research area with an interdisciplinary work orientation (Hassan Montero & Martín Fernández, s.f.), a guideline fully implemented within the Corporation's Design Management.

Although the design of interfaces, furniture and spaces are the most widely developed areas of human-related design in the naval, maritime and river spheres (addressed by anthropometry and ergonomics), UCD and research on the user experience make it possible to increase those fundamental aspects of functionality and also to learn about approaches that emphasize interaction factors, traditionally neglected, such as the user's emotions and thoughts, as important attributes within this behavior.

Thus, investigating the user experience turns out to be the main input to deploy a "general map" that offers a broader and more inclusive perspective, which allows access to a deployment of resources necessary to know all the variables around an interaction: valuable information to materialize highly satisfactory solutions from efficiency to the welfare of the people involved, strongly impacting the perception and interaction between system, objects and human being, and therefore, being more in line with reality.

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Fluid-Structural Interaction Study of the Structural Arrangement of a Riverine Low-Draft Combat Boat for Coastal Transit Conditions

Estudio de Interacción Fluido-Estructural por Condiciones de Transito Costero en el Arreglo Estructural de un Bote de Combate Fluvial de Bajo Calado

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Abstract

The Riverine low draft combat boats are aluminium-built crafts designed to operate exclusively in low-depth riverine environments. Given the Colombian geography, these operations might be extended to estuaries or coastal transit conditions. Consequently, there is a need of studying the structural integrity of the hull in the case of coastal transit. A fluid-structural interaction study was performed in which the hydrodynamic hull pressures are associated as an input in a static structural finite element analysis. The obtained hull pressures were compared with the values suggested by the classification rules.

Key words: Hydrodynamic pressure, direct analysis, aluminum hulls, Fluid- Structural Interaction.

Resumen

Los botes de combate fluvial de bajo calado son embarcaciones fluviales con un arreglo estructural en aluminio exclusivamente diseñado para operar en ríos de baja profundidad. No obstante, debido a la geografía nacional, estas operaciones pudieran extenderse a condiciones de estuario o tránsitos costeros. De esta manera, surge la necesidad de evaluar la resistencia estructural del casco en condiciones de tránsito costero. Para tal fin, se realizó un estudio de interacción fluido estructural en la que se enlaza las presiones hidrodinámicas en el casco como entrada para un análisis por elementos finitos. Las presiones en el casco fueron contrastadas con los valores obtenidos con el uso reglas de las Sociedades de Clasificación.

Palabras claves: Presión Hidrodinámica, análisis directo, cascos en aluminio, Interacción Fluido – Estructura.

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Introduction

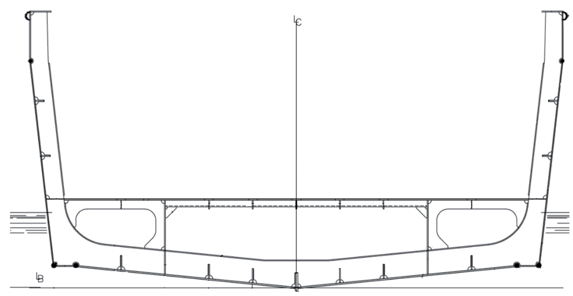
The riverine low draft combat boat designed with naval- grade aluminium and 10 m^2 polymeric ballistic protection panels on deck, can develop riverine patrolling and reconnaissance operations in low-depth waters. the technical feature of this boat includes a 24 knots maximum speed, an operative range of 300 km, and the capability to provide tactical fire support [1].

The structural arrangement of this boat was designed to maintain a low weight while the security of the crew, the structural integrity of the hull and the boat performance remain preserved at riverine conditions. To ensure the structural integrity of the hull, the scantling was performed according to recommendations and requirements of the classification societies ABS in "Rules for Building and Classing, High- Speed Craft; Hull Construction and Equipment" [2] and ISO 12215 "Small craft – Hull construction and scantlings – Part 5: Design pressures for monohulls, design stresses, scantlings determination" [3]. Given the structural arrangement obtained, its structural integrity was evaluated and improved by direct analysis in a global model according to "Class Guideline- Finite Element Analysis" by DNV-GL [4].

The hull scantling refers to the assessment of selected plates and stiffeners' geometrical dimensions in accordance with their mechanical properties and section modulus. The strength of the hull to environmental and duty external loads depends largely on the structural arrangement and its capability to withstand bending and shear stresses [5]. First, the hull girder strength was assessed according to cross-section inertial properties followed by local calculation of plates thickness and cross-section of primary and secondary stiffeners. In this way, the plates of the structure and the respective primary and secondary structural reinforcements are to be designed in such a way their mechanical strength is high enough to prevent crack initiation due to wave pressures on the hull [6].

The bottom structure of the vessel consists of a keel, a AW 5083 H321 bottom plate, six AW 6082 –T6 longitudinal stiffeners, and two side girders. The side hull structure consists of AW 6082-T6 flat-bar longitudinal stiffeners which purpose is to provide the required stiffness to the plates of the side. These side plates are to be vertically supported AW 5083 H321 frames [see Fig. 1]. Four of these frames are watertight bulkheads [7].

Fig. 1. Typical frame.



The deck is composed of a AW 5083 H321 plate and seven flat-bar longitudinal stiffeners. This deck is transversally supported by profiles deck beams and bulkheads and longitudinally supported by two side girders.

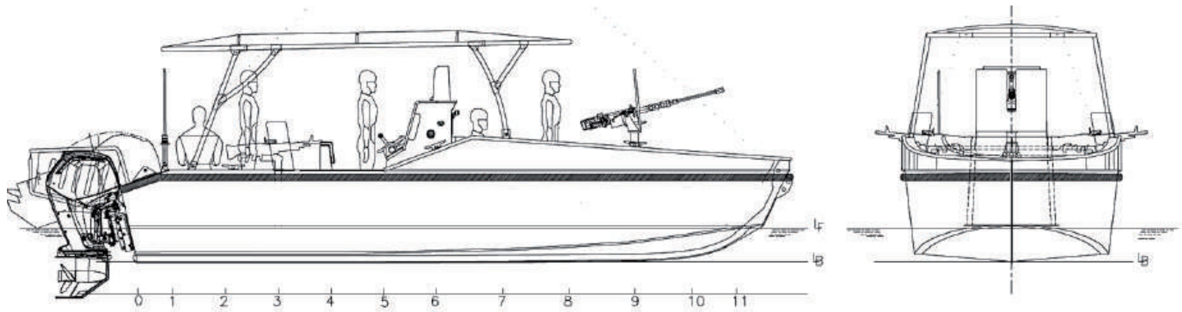
The principal particulars of this combat boat are summarized in the next table [see table 1] [see Fig. 2].

Table 1. Riverine combat boat principal characteristics.

Principal particulars	Values
Length over all	8.68 m
Length at waterline	7.05 m
Beam	2.42 m
Amidship depth	1.03 m
Draught	0.34 m
Installed power	134 kW
Full load displacement	3650 kg

Although the vessel was designed to operate in a riverine environment, it might occur the cases where the vessel is assigned to operate in estuaries or develop an occasional coastal transit between river mouths.

Fig. 2. Riverine low-draft combat boat.



In those cases, the hull could be subject to loads or pressures that overcome the structural arrangement resistance even though the assessment from rules and guidelines of the classification societies, which calculations are generally of semi-empirical nature and also are calibrated to secure the lifespan expected, allow a simplified approach of complex structural problems with a wide safety factor [8].

For the scantling of small crafts under riverine conditions, classification societies' rules dictate a design wave height of 0.5 m [2]. This wave height can be classified as a Beaufort sea state 2 scale but changes in wave frequency and direction will affect the level of pressure on the hull and hence, the stress levels along the structural arrangement [9].

Waves are an external agent with a considerable influence on the behavior of ships in a marine environment. The wave frequency is inversely proportional to the wavelength and celerity. The latter, given by the relation between wavelength and period, is a distinctive factor among surface waves and other types of wave motions [10]. The relative boat speed in relation to the waves is defined as the encounter frequency. The encounter frequency is a function of boat speed (Vs) and the encounter angle (β). This frequency is only zero when the velocity of the observer in the direction of wave propagation and the wave velocity are equal. On the other hand, when the wave speed is lower than the parallel component to the wave direction of the boat speed, the encounter frequency is negative and the boat overtakes the waves [11].

In the boat, each degree of freedom that has a restoring force has an associated natural frequency. These natural frequencies depend on the mass and stiffness properties of the system [10]. The interaction between the encounter frequency and the natural frequencies of the ship leads to a boat amplitude response. When the encounter and the natural frequencies present equal values might occur resonance phenomena. When the encounter frequency is very low, at head seas conditions, the dynamic effect associated with damping is virtually negligible and the boat motion amplitude is on the same order as the wave amplitudes. In the case of high wave frequencies, the boat responses are reduced because the short wavelength does not excite the hull motion [11].

Hence, the main aim of this work is to evaluate, by computational methods, the effects of hydrodynamic pressures on the hull's structural integrity at different headings and wave frequencies. The hydrodynamic behavior study was developed with the software Ansys Aqwa and the pressures were exported to the static structural model of Ansys Mechanical to evaluate the strength of the structural arrangement by the finite element method.

Methodology

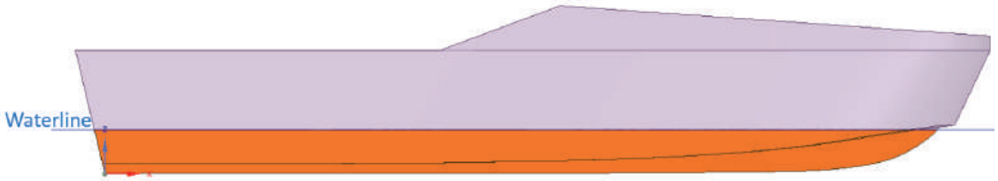
In the present methodology it was detailed the hydrodynamic diffraction computational model and the linked structural finite element development.

Hydrodynamic Diffraction model

Geometry

Shell modeling was carried out by using ANSYS

Fig. 3. Hull surface cut by the water surface.

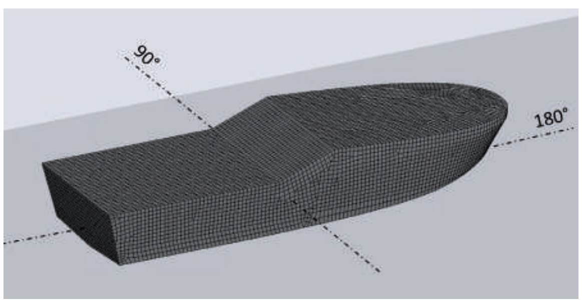


SpaceClaim 2022 software. Only external hull surfaces were included. These hull surfaces are divided by the waterline [see Fig. 3].

Meshing

The surfaces were meshed with 10029 elements and a defeaturing tolerance of 0.005 m. This element size allows a maximum frequency of 1.55 Hz for the analysis [see Fig. 4].

Fig. 4. Meshed model for the hydrodynamic analysis.



Hydrodynamic Response Analysis

The computations of the wave-induced motions were carried out by utilizing three- dimensional potential flow based in diffraction-radiation theory. The computations of the hydrodynamic pressures took into account all six degree of freedom rigid-body motions of the full. The environmental constants and mass properties are detailed in the next table [see table 2 & 3].

This analysis considers the operational profile at full load capacity. Wave headings (β) were evaluated with increments of 15°, the wave encounter frequencies (ω_e) covers a range from 0.015 Hz to 1.2 Hz with increments of 0.1 Hz [2]. For this study the wave pattern was simplified with a regular wave with 0.5 m amplitude as a first approach [2].

Table 2. Mass properties for the model.

Parameters	Values
Total mass	3650 kg
Longitudinal center of gravity	2.6 m
Transversal center of gravity	0.0 m
Vertical center of gravity	0.55 m
Radius of gyration –roll	0.82 m
Radius of gyration –pitch	1.76 m
Radius of gyration –yaw	1.84 m

Table 3. Environmental constants.

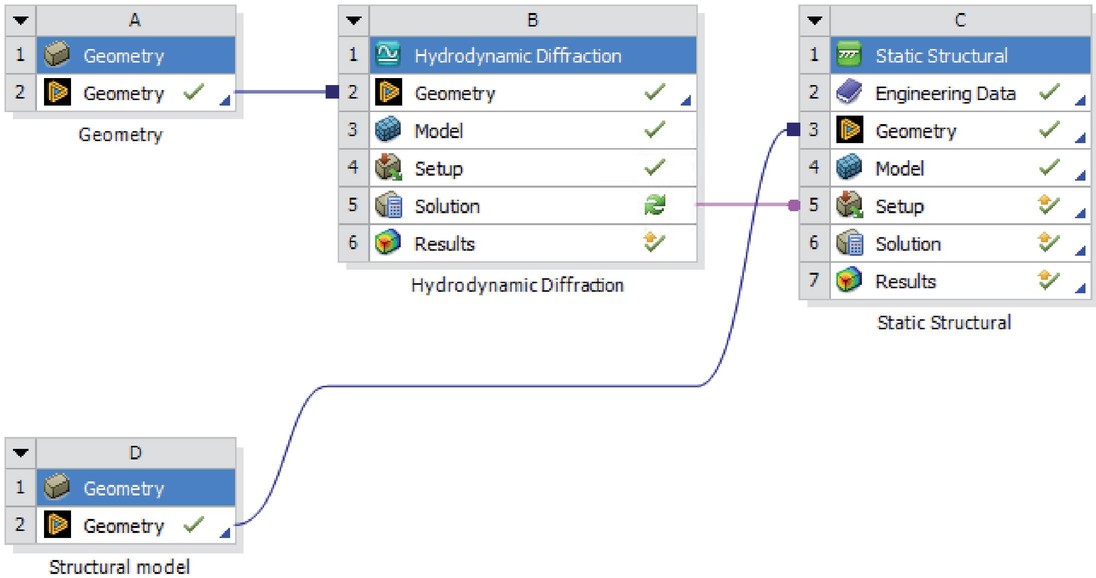
Characteristics	Values
Water Depth	4 m
Water density	1025 kg/m^2
Longitudinal water size	40 m
Transversal water size	25 m
Radius of gyration –yaw	1.84 m

The worst frequency-heading combination at which the hull's response amplitude is a maximum, was evaluated by direct analysis to obtain the effect on the structural arrangement according to the next block diagram [see Fig. 5].

Direct Analysis

Global modeling of the boat and the subsequent finite element method analysis are explained in detail in this section. The analysis is subjected to plain stress and linear-elastic mechanics simplifications.

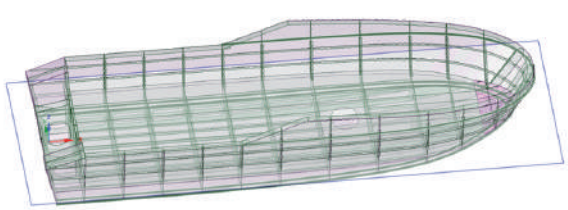
Fig. 5. Ansys Workbench block diagram.



Structural model Geometry

Shell modeling was carried out by using ANSYS SpaceClaim 2022 software [see Fig. 6]. Bonded contacts were used among structural elements given their welded connections.

Fig. 6. Global modelling using Ansys SpaceClaim.



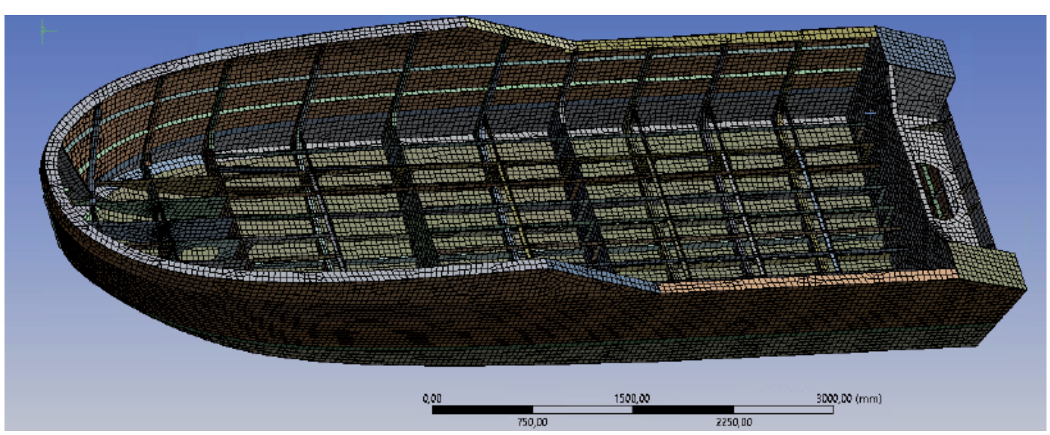
Meshing of the structural model

SHELL181 elements were used for meshing. This four-node element with six degrees of freedom at each node is suitable for analyzing thin to moderately thick shell structures [see Fig. 7]. After a convergence test, a 30 mm meshing element size was used. The shell geometry is represented by 4 Node Linear Quadrilateral elements; the degenerate 4 Node Linear Triangular option was only used as filler in mesh generation [4] [12].

Boundary Conditions

The boundary conditions for the global structural model should reflect simple supports that will

Fig. 7. Mesh of the structural model.



avoid built-in stresses so the reaction forces in the boundaries are to be minimized [4]. ANSYS Inertia relief option allows to exactly balance the force differences on the supports creating a state of static equilibrium. Two of these fixation points were applied at transom intersecting the main deck at portside and starboard, and the last one, in the bow centerline intersecting waterline.

Materials

5083- H321 aluminum alloy mechanical properties were assigned to plates whereas aluminum alloy 6082 T6 properties were set to stiffeners. The mechanical properties of both aluminum alloys are detailed in the next table [see table 4].

Table 4. Aluminum alloys mechanical properties defined for the model [10].

Properties	Al 5083-H321	Al 6082-T6
Density [g/cm^3]	2.66	2.7
Poisson's ratio	0.33	0.33
Young's Modulus [GPa]	70	70
Tensile yield strength [MPa]	220	260
Tensile yield strength (welded) [MPa]	145	125
Tensile ultimate strength [MPa]	305	310
Tensile ultimate strength (welded) [MPa]	290	190

Allowable Stress

This analysis is completed using the Maximum-Distortion- Energy Criterion in order to assess the structure against failure. This criterion takes both shear and normal stresses into account to develop a combined equivalent stress, σ_e A class allowable stress factor (*FP=0.85*) is added in such a way yield strength of the material is reduced [2]. The maximum allowable stress for plates is 123 MPa and 106 MPa for stiffeners specifically in heat-affected zones [see table 5].

Table 5. Allowable stresses on structural members.

Properties	Al 5083-H321	Al 6082-T6
Heat- affected zones	123 MPa	106 MPa
Non heat- affected zones	187 MPa	220 MPa

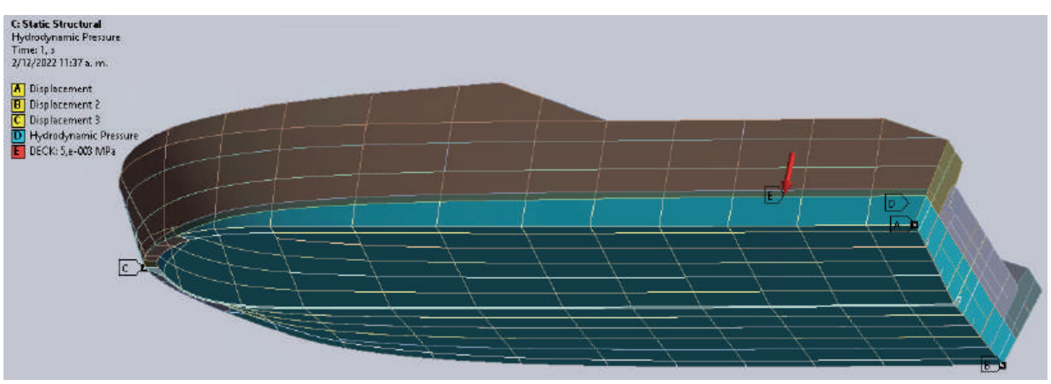
Load Conditions

Hydrodynamic pressure, imported from the Ansys Aqwa software, was applied on the hull below de waterline. Design pressure calculations from class requirements was assigned on the deck with a value of 5 kN/m2 [2] [3] [see Fig. 8].

Results and Discussion

In this section, the results of the hydrodynamic response analysis and the use of the obtained hull pressures results as an input of a structural analysis are detailed.

Fig. 8. Imported hydrodynamic pressures on the hull.



Hydrodynamic Response Analysis

Hydrostatic Results

From the hydrodynamic diffraction analysis, it was obtained the hydrostatic characterization of the boat. Some of these are summarized below [see table 6].

Table 6. Allowable stresses on structural members.

Characteristics	Values
Longitudinal center of gravity	2.6 m
Longitudinal center of Buoyancy	2.9 m
Actual volumetric displacement	3.78 m^3
Equivalent volumetric displacement	3.55 m^3
Cut water plane area	14.6 m^2

Hydrodynamic Pressures

Different wave frequencies and headings were tested in the proposed interval and it was found that the wave frequency of 0.44 Hz produces the highest pressure levels with a wave amplitude of 0.5 m [see Fig. 9].

Regarding the headings, the highest hull pressures were obtained with beam seas [see Fig. 10 & Fig. 11]. The lowest hull pressures were reported with head seas [see Fig. 12 & Fig. 13]. All with a wave height set in 0.5 m. The hydrodynamic pressure magnitude difference between both load cases is close to 7.5 times.

On the other hand, the obtained motions at different waves frequencies and headings showed that there are intervals in which the boat would present unsecure navigation and must be avoided.

Fig. 9. Hydrodynamic pressures as function of frequency.

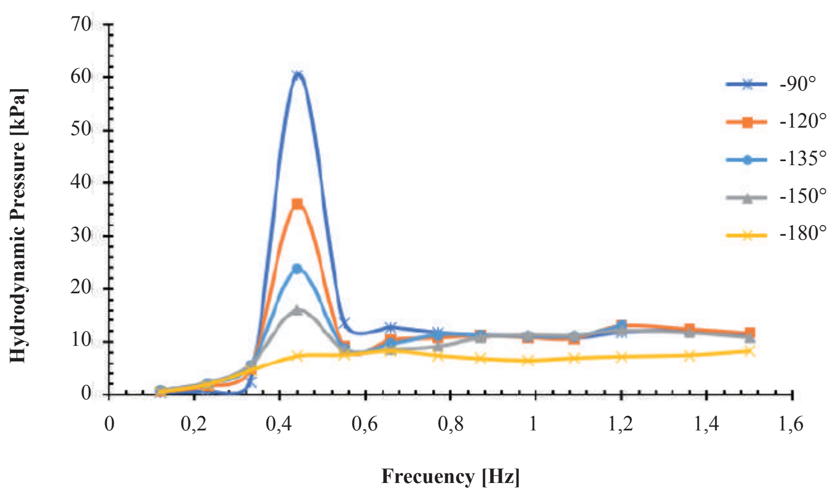


Fig. 10. Pressures and motions at 0.87 Hz and 180° heading – head seas condition.

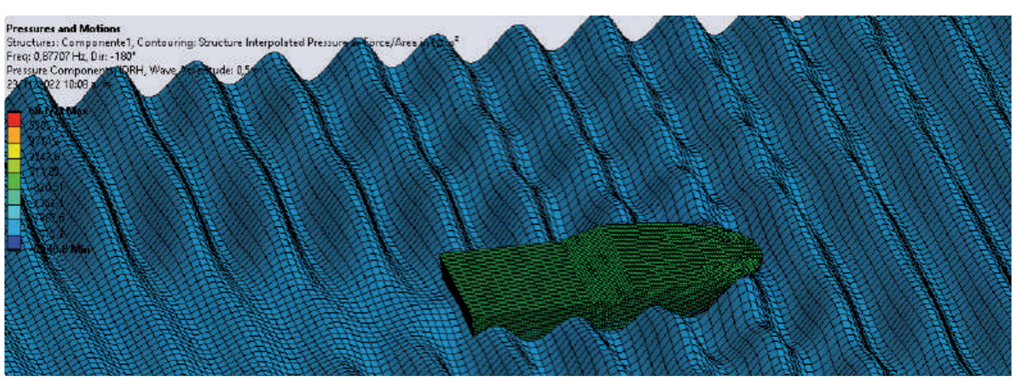


Fig. 11. Imported hydrodynamic pressures at 0.44 Hz and 180° heading – head seas condition.

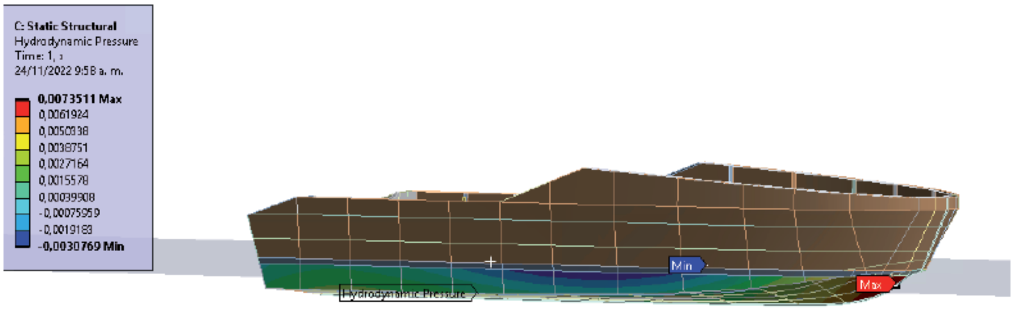


Fig. 12. Pressures and motions at 0.66 Hz and 90° heading– beam seas condition.

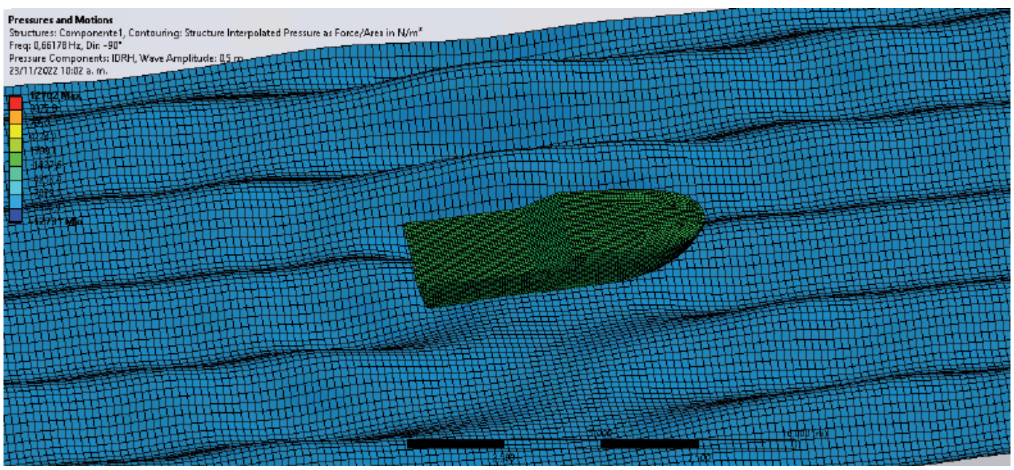
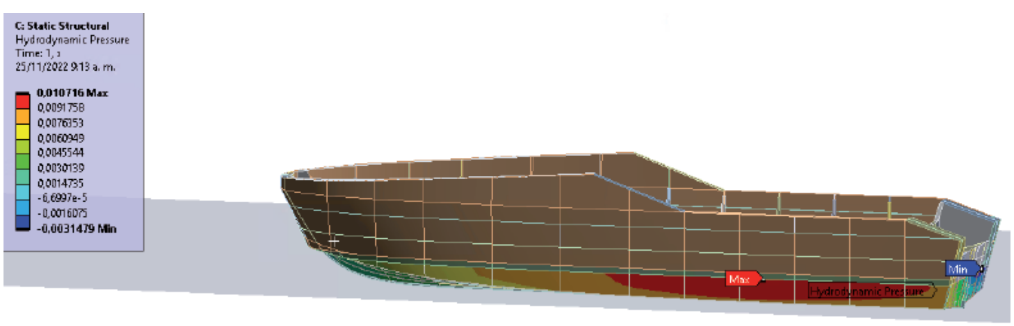
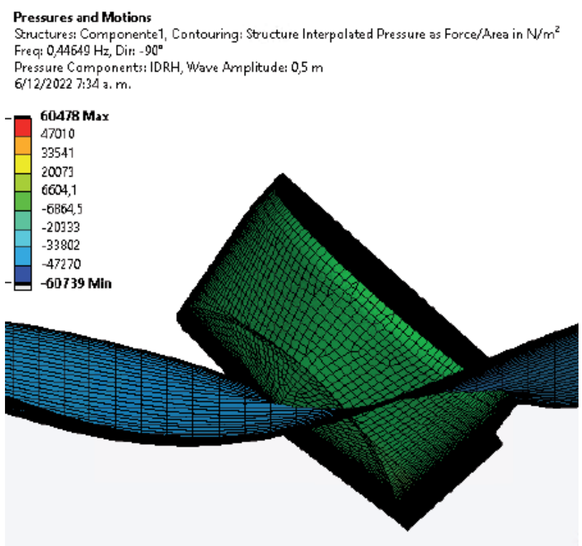


Fig. 13. Imported hydrodynamic pressures at 0.44 Hz and 90° heading – beam seas condition.



because the roll motion in a resonance frequency and due to the low draft of the hull and its flat bottom, the boat would avoid navigation with beam seas with a range of ±60° and a frequency interval from 0.44 to 0. 55 Hz [see Fig. 14]. Besides motion and load conditions there are additional conditions, such as crew comfort standards, that may generate additional affectations in the coastal transit navigation capabilities of the craft. These effects might be evaluated with further studies.

Fig. 14. Roll motion with beam seas (90°) at 0.44 Hz.



The calculation of hydrodynamic wave pressures according to classification rules such as ABS in [2] and LR in [14] at head sea conditions and also neglecting slamming pressure factors, present the both bottom pressures estimations as two times higher than obtained with the software [see table 7]. Additionally, because the time-dependent nature of loads and the hydro-elastic response of the structure under slamming conditions, the computational models used by the software are unable to estimate the resultant hydrodynamic pressure [15]. Considering the slamming pressure in Classification Society rules calculation would imply a local increase in the hull pressure close to 70 kPa [1].

Table 7. Hydrodynamic pressures on the bottom.

Method	Bottom Pressure	Difference [%]
Ansys AQWA	7.7 kPa	---
ABS "HSC"	16.7 kPa	116.8
LR "Special Service Craft"	10.3 kPa	33.76

In the case of incrementing the wave height from a typical sea state 2 with 0.5 m of wave height to a sea state 3 with 1.25 m of wave height, the hull presented an increase of 2.7 times in the hydrodynamic pressure from sea state 2 and 12.7 times higher from a sea state 1 at head seas conditions [see Fig. 15]. Analyzing the motions of the hull under sea state 3 conditions it was found that the boat would present an unsafe navigation in a wide range of headings and frequencies [see Fig. 16].

Fig. 15. Hydrodynamic pressure as a function of frequency and sea states.

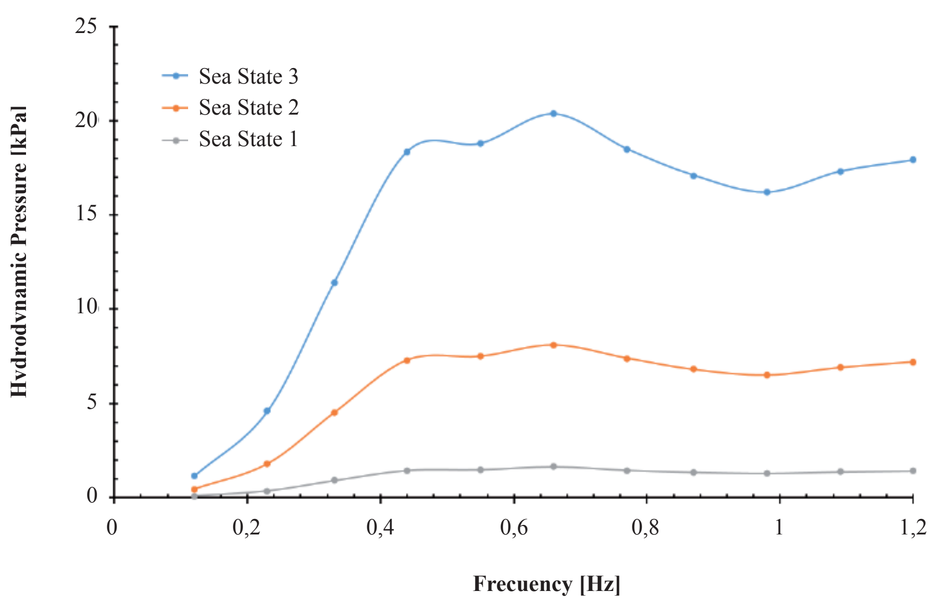
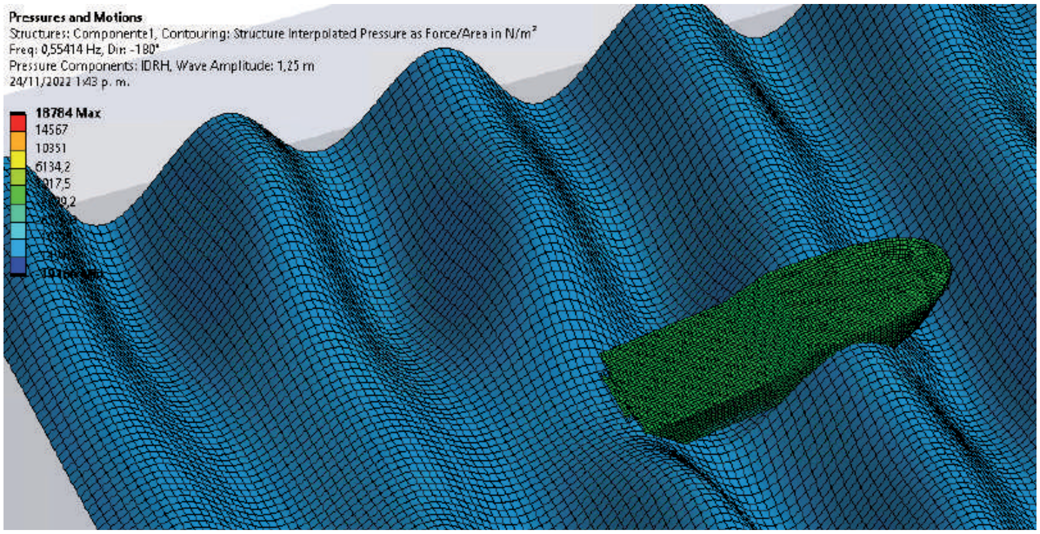


Fig. 16. Pressures and motions at 0.55 Hz and 180° heading with a wave amplitude of 1.25m.



Direct Analysis

Given the results of the hydrodynamic pressures on the hull as function of heading, frequency, and a wave amplitude of 0.5 m, critical direct analysis was carried out with a heading of 90° and a frequency of 0.44 Hz. At this load case, the highest pressures were found in the vicinity of the bottom – side connection. The side panels presented an equivalent maximum stress near to 84 MPa with a consequent 2.7 safety factor [see Fig. 17].

Frames and bulkheads showed stress values between 25 MPa to 45 MPa in the hull pressure influence zone. Nevertheless, there is a spot in the frame above deck in a bulkhead station where equivalent stresses close to 140 MPa are reported, but given the local effect of this spot, the structural integrity of the frame is deemed unaffected because of local plastic deformation in the profile [see Fig. 18].

On deck, the assemble with the side frames bring as consequence maximum equivalent stress values under 80 MPa located in temperature welding affected zones leading to a safety factor of 1.81 [see Fig. 19].

Regarding a heading of 120°, stress levels increases towards the bow reaching values up to 97 MPa [see Fig. 20]. At this load case the transversal stiffeners located at the stern showed a stress increase close to 31% in comparison to the load case at 90° [see Fig. 21].

Fig. 17. Stress distribution on the sides with beam seas.

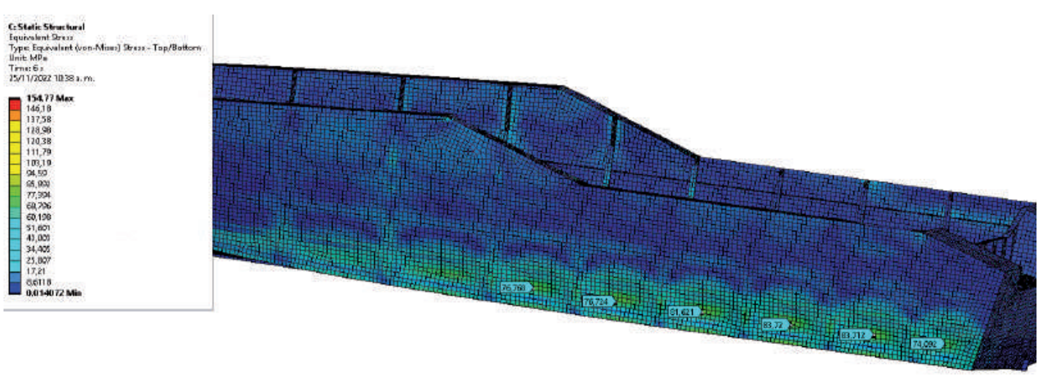


Fig. 18. Stress distribution in the frames with beam seas.

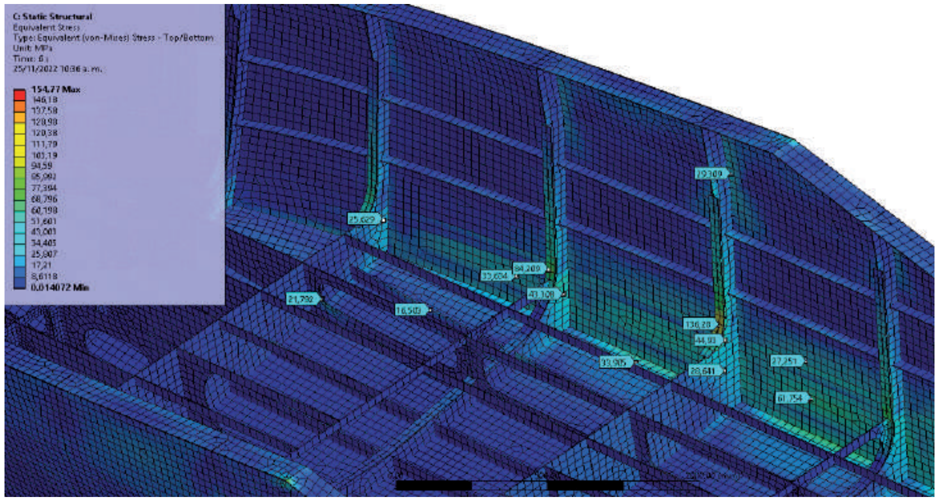


Fig. 19. Stress distribution over the deck.

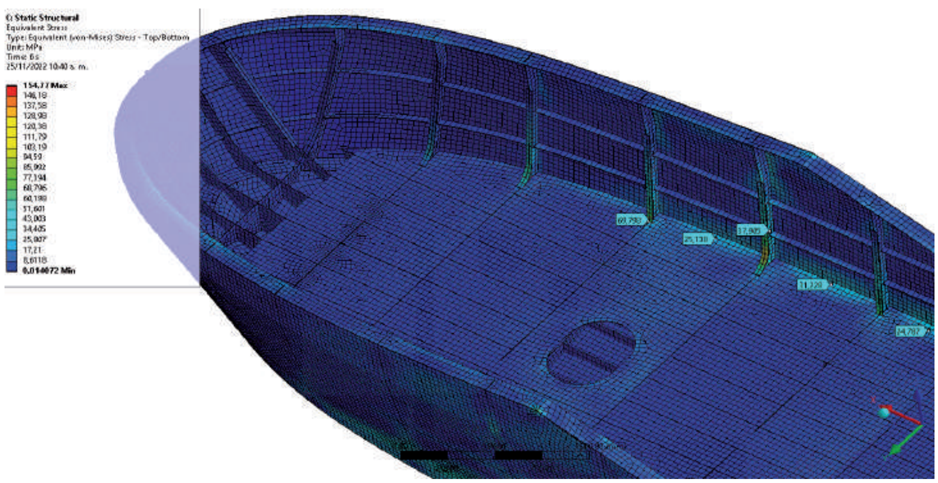


Fig. 20. Stress distribution above 20 MPa with a 120° heading..

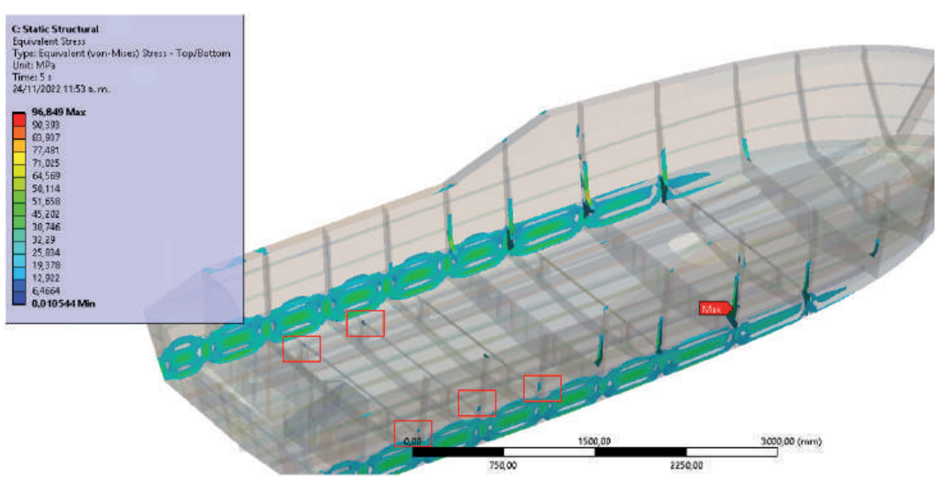


Fig. 21. Stress distribution in side's plates and internals.

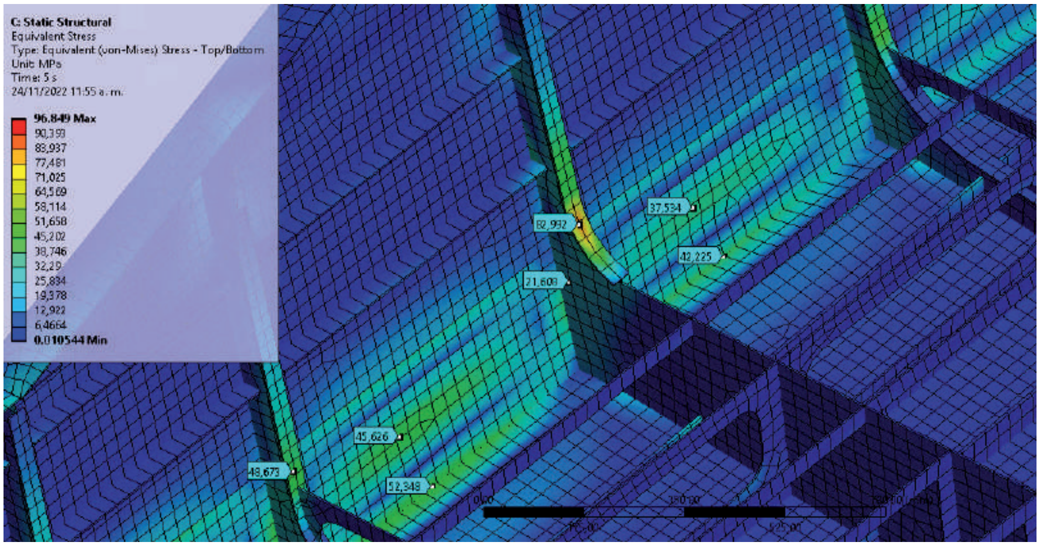


Fig. 22. Hydrodynamic pressure distribution on the bottom.

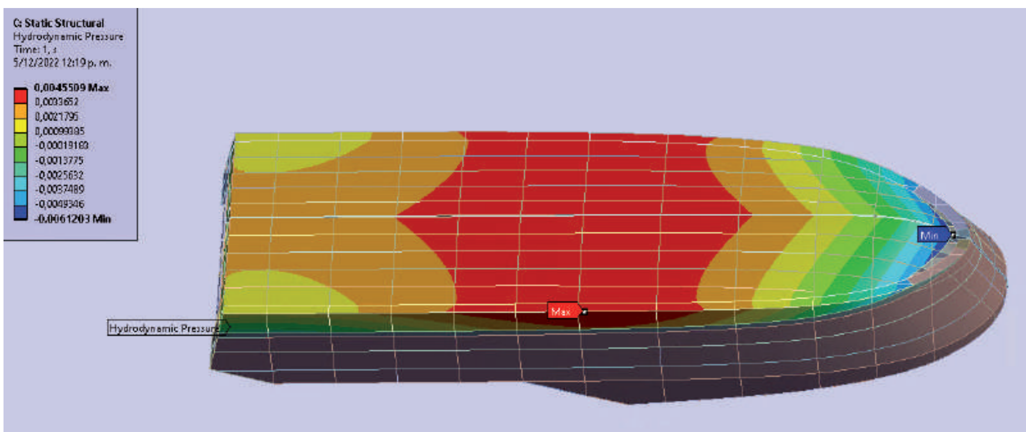
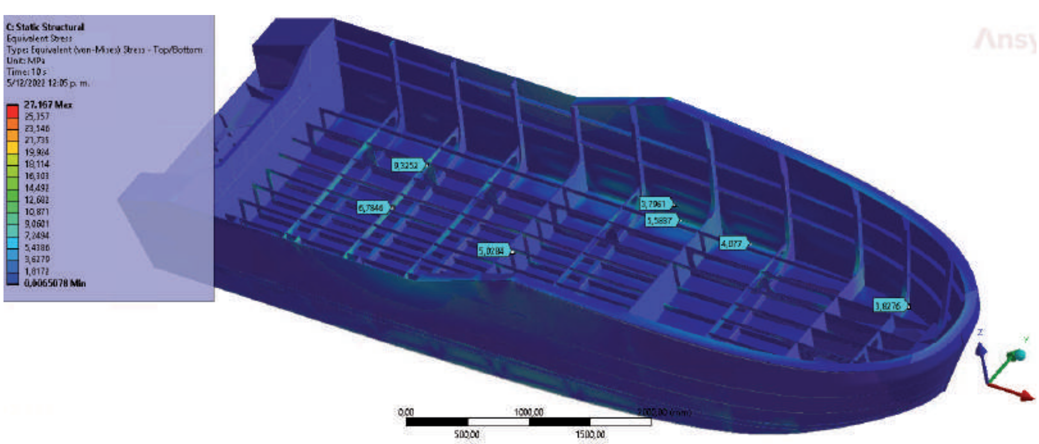


Fig. 23. Stress distribution in internals below deck.



At head seas conditions, the effect of hull's hydrodynamic pressures on the structural arrangement stress levels decreases in comparison with others load cases and this behavior is consistent with the pressure levels showed in Fig. 9. Higher stresses are reported in the bottom – side assembling [see Fig. 22 & Fig. 23].

With a different phase angle at the same heading and frequency, it was found a maximum hull pressure with a value of 7.7 kPa [see Fig. 24 & Fig. 25]. Nonetheless, given the reinforced structure at bow zone designed to withstand slamming pressures and beaching maneuvers, the stress levels in the affected zone showed in Fig. 26 are up to 5 MPa.

Structural details are characterized by high stiffness at their end connections and sharp corners. That ends might produce singularities; which means, there are points in the model where stress values tend towards non-real infinite values. If mesh convergence cannot be reached in certain high-stress points even with mesh refinement, these points are deemed to be singularities.

A high gradient stress zone was spotted at the portside gunwale, after mesh convergence was not reached; the reported high stress values are deemed as a singularity [16] [see Fig. 27].

At sea state 3, with a consequent wave amplitude of 1.25 m, a resonance frequency of 0.44 Hz, and a heading of 120°. Stress levels increase in such a way reach values up to 126 MPa in the chine and 115 MPa in the side plates. Given the allowable stresses stated in table 5, the lowest safety factor in plates

Fig. 24. Hydrodynamic pressures on the hull as a function of the wave phase angle.

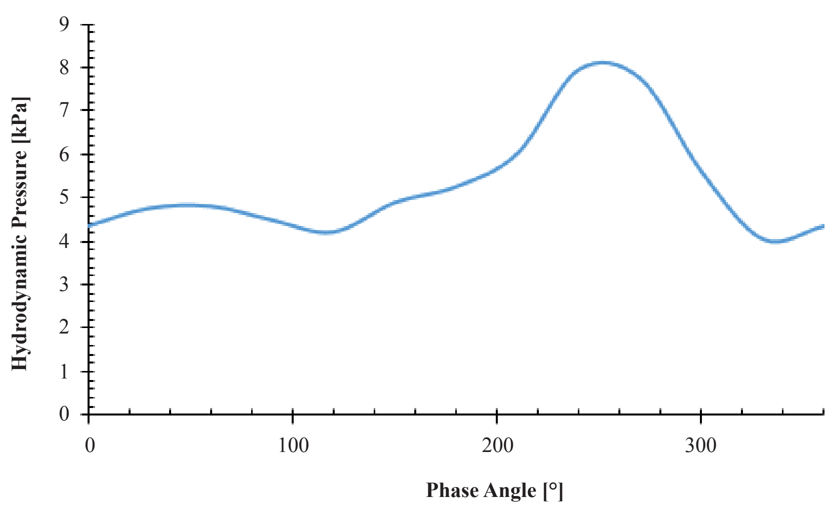


Fig. 25. Location of the maximum hydrodynamic pressure on the bottom with a 260° wave phase angle.

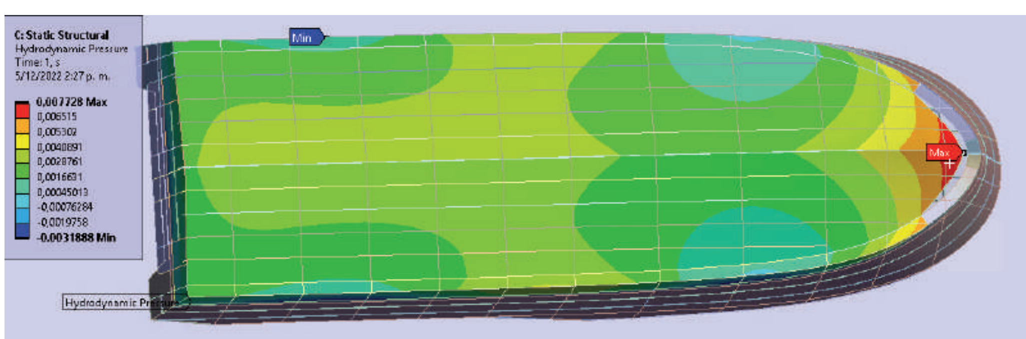


Fig. 26. Stress levels at aft section of the boat.

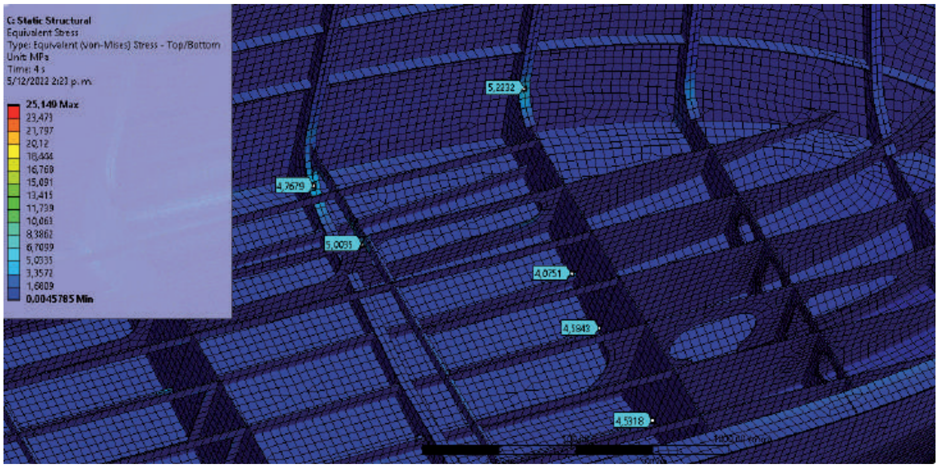


Fig. 27. Stress levels at aft section of the boat.

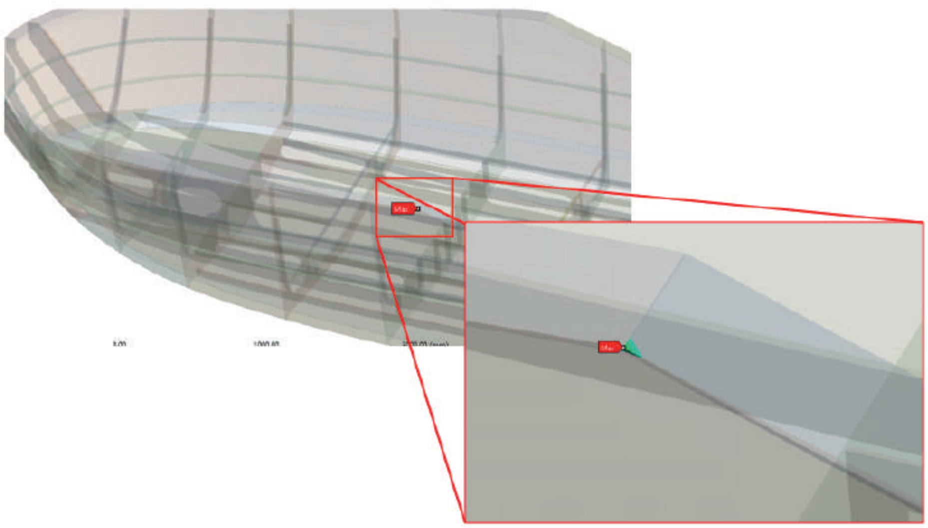
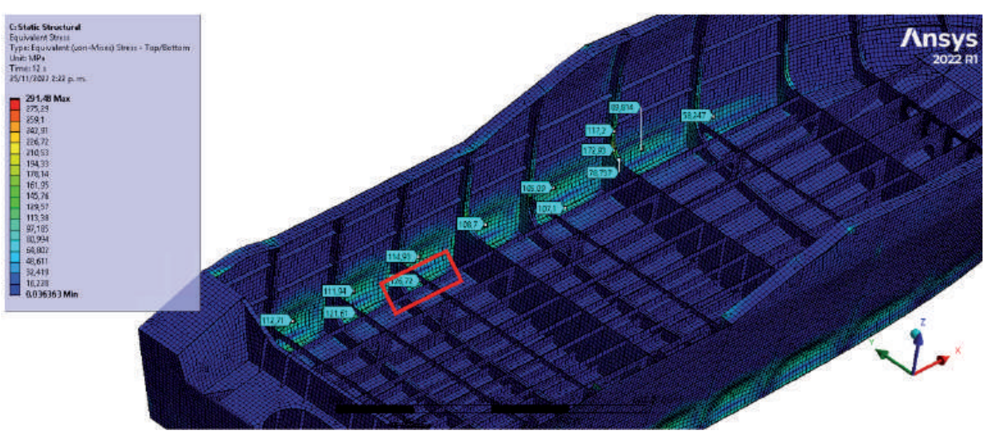


Fig. 28. Stress levels at sea state 3 and 120° heading conditions.



is 0.98 in the chine and 1.62 in the side plates. Regarding profiles, the lowest safety factor is about 1.27 in non-affected zones. Higher stresses than the allowed are situated in heat-affected zones in one of the side frame stiffener; however, given the focused nature of these, their localized plastic deformation will not compromise overall strength. Nevertheless, the insufficient safety factor of a chine plate zone, the pressures exceed the strength of the structural arrangement [see Fig. 28].

Conclusions

The structural arrangement strength for a riverine low-draft combat boat was analyzed by a hydrodynamic response analysis and direct analysis. It can be concluded that the structure of the hull can withstand sea state 2 conditions. Nevertheless, the low draft of the vessel and its flat bottom might imply unsecure navigation specially under beam waves ± 60° conditions within frequencies from 0.44 Hz.to 0.55 Hz, thus the design performance will be drastically reduced at estuaries and coastal transit conditions. Further considerations, such as crew comfort standards, might reduce even more the coastal transit capabilities of the boat.

According to the obtained hydrodynamic pressures on the hull by this computational model, Classification Societies Rules apply safety factors up to 2, this without having into account slamming pressures components. Given the time-dependent loads and the hydro-elastic structural response characteristic of slamming, the calculation of this phenomenon outpaced the computational model used by the software.

Sea state 3 present unsafe navigating conditions in a wide range of frequencies and headings because the boat motions. Additionally, at 120° of heading at resonance frequency of 0.44 Hz the structural arrangement strength of the side- bottom assembly is not enough to withstand the imported hydrodynamic pressures.

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Feasibility of Composite Material Construction without the Use of Molds

Factibilidad de Construcción en Materiales Compuestos sin la Utilización de Moldes

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Abstract

The evolution of materials applied to shipbuilding has meant, to a large extent, the possibility of optimized designs in shapes and weights, preponderant aspects in Naval Architecture. The present work shows in a generic way the application of Composite Materials in the construction of ships and naval artifacts and specifically the feasibility of applying a construction technique without moulds, supported by successfully developed examples.

Key words: Composites, structures, Shipbuilding, Design.

Resumen

La evolución de los materiales aplicados a la construcción naval ha significado, en gran medida, la posibilidad de diseños optimizados en formas y pesos, aspectos preponderantes en la Arquitectura Naval. El presente trabajo muestra de manera genérica la aplicación de Materiales Compuestos en la construcción de naves y artefactos navales y de manera específica la factibilidad de aplicar una técnica de construcción sin moldes, avalado por ejemplos desarrollados con éxito.

Palabras claves: Composites, estructuras, Construcción Naval, Diseño.

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Background

One of the main obstacles in deciding to use composite materials in the construction of a boat, in addition to technical considerations, is the cost involved in the process, which is usually associated with the prior construction of a matrix, a mold and finally the part required. Opting for variants in the construction systems has led to propose a method that avoids the cost involved in the manufacture of molds and which result is proven at least with an effective example. Before describing the method and showing a practical application, it is pertinent to define, in a very generic manner, some parameters involved in these processes.

What do we mean by composite materials?

We know as composite materials those that are made of two or more materials, which mechanical properties are inferior to those obtained as a whole.

Constituent Materials

We will consider as constituent materials at least the following:

- Resins, whether polyester, vinyl ester or epoxy, or their improved variants.
- Reinforcements, such as glass fibers, aromatic polyamide, carbon or hybrid fibers
- Fillers to modify resin properties
- Polyvinyl chloride cores, phenolic paper, balsa wood, cedar, etc.

Constituent Materials

We will consider at least two basic structures:

- Monolithic structures, consisting only of resins (and their fillers) and reinforcements
- Sandwich structures, to which we will add a core

Lamination Methods

Normally, the lamination method tends to be confused with the construction method, so it is necessary, at least, to point out the former, in order to clarify its applicability within the latter.

We know mainly three lamination methods:

Fig. 1. A and B Manual lamination of hull and superstructure, C Mold lamination and D Finished part (source: A and B): OMORA Project, School of Naval Engineering, Universidad Austral de Chile).

- Method of wet manual lamination, which consists of laminating the final part on an open mold. This is carried out by manual execution of the lamination using rollers, brushes or tools that allow the resin to be impregnated into the reinforcement.
- Vacuum lamination method, applied to different construction methods, allows uniform pressure on the laminate components. Today it is a widely used method that mainly consists of generating a vacuum bag containing the part to be laminated where a vacuum environment is applied that theoretically provides 1 Bar of pressure on the structure.
- Lamination by infusion. This type of lamination allows for a combination of vacuum lamination and zone-controlled lamination. It basically consists of generating a vacuum environment, similar to that described above, but not including the resin in the process, which is added by suction from the fittings arranged in certain areas of the part. The control prior to resin injection must be very meticulous and the resin must have a thixotropy that allows impregnation and advancement throughout the part in defined times.

Construction Methods

Construction methods can be approached depending on the number of parts to be developed and the level of finish to be obtained. Thus, we can define three systems, which associated with different lamination methods, will result in the finished part. It should be noted that the construction method will also depend, undoubtedly, on the costs to be assumed, hence, the final result of this work, intends to contribute with the practical introduction of a method, which we can call hybrid, favoring the final cost of the part.

- Construction by means of female mold: it consists of building a matrix, generally in wood, containing the shape of the part, for example the hull, to later generate a mold from

Fig. 2. General scheme of vacuum lamination.

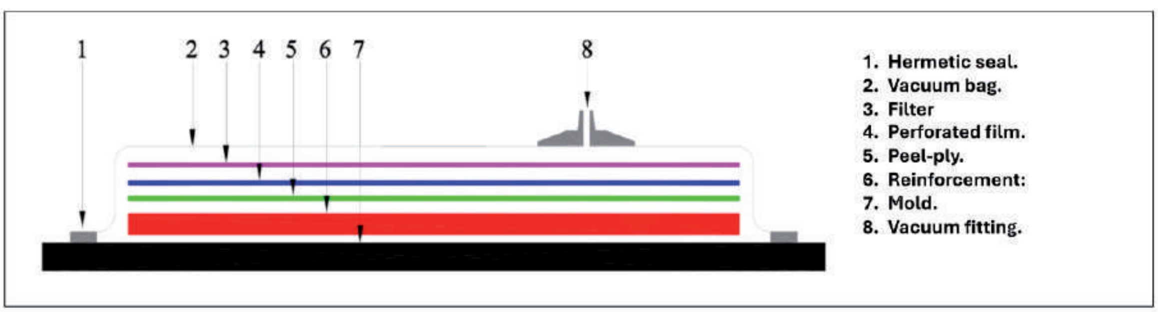
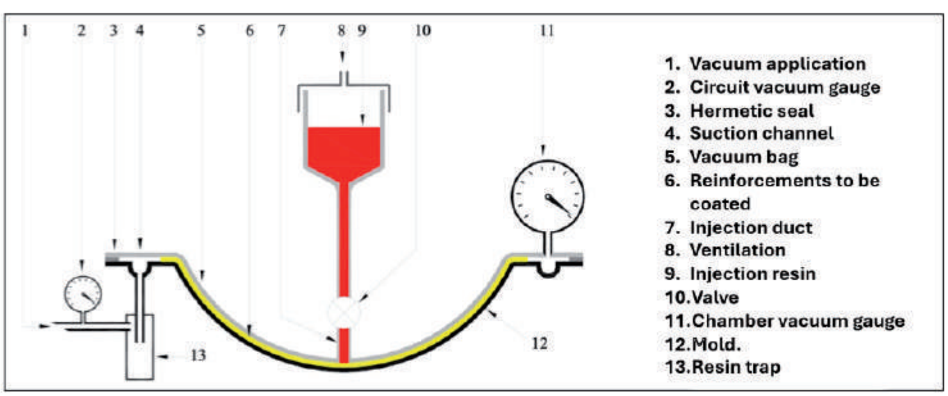


Fig. 3. General infusion lamination scheme.



that matrix, which will be used to laminate the final part. Here we can apply any of the lamination methods described above.

- One-Off Construction: When it is required to build only one part, we normally use a construction system that avoids the construction of the mold, but requires a considerable number of man-hours in surface finishing. Its cost must be evaluated according to the degree of finish desired for the final part. Special care must be taken in the dimensioning of the base support parts, since they must be considered without the thickness

Fig. 4. Construction method using female mold. - A, B and C matrix construction; D Mold laminated in the matrix, E hull demolding and F finished part. (Source: Project NCH_008 NavTec Ltda - Cotecmar).

Fig. 5. ONE-OFF construction method - A- base matrix construction, B- inner skin lamination, C- core lamination, D and E- outer skin lamination and F- finished parts.

of the structure. Although the ONE - OFF method can be considered as a "moldless" method, unlike the final method proposed, it requires a supporting "structural base" that involves the construction of a matrix, and it is not feasible to add definitive structural parts in the initial hull lamination process, and these must be included once the hull is completely laminated, including its inner and outer skins.

- Strip Plank construction: The Strip Plank construction system is applied exclusively in sandwich structures, the core being laminated first, which will be fixed to the layer. Different materials can be used for the core, including balsa wood and PVC foam. The method requires a base matrix on which the core will be placed as a first action, then the outer skin will be laminated, the hull will be rotated and the inner skin will be laminated as well. Like the ONE-OFF system, it requires a high number of man-hours in finishing.

Proposed Construction without Mold

One of the construction alternatives using a variant of the methods described above offers the possibility of substantial cost savings, avoiding the construction of a mold and ensuring the quality of the finished part.

Base Proposal

The proposal is mainly based on using a layer built with the hull shapes, which dimensions must consider the discount of the complete thickness, to later laminate, independently from the layer, developed parts that will be mounted and assembled to constitute the final structure. Although the method is mainly applied to sandwich structures, it has been used for monolithic structures, using a system very similar to steel erection and construction. The substantial difference with the Strip Plank method is that the laminates are made, almost entirely, before being installed on the layer, by means of developed and flat-laminated parts.

Step by step description

The following figures detail a "step-by-step" application of the method, in this case, in the construction of an 8-meter RIB. Although the method allows for the addition of previously developed and laminated parts, areas that are more difficult, either because of their curvature or their position, should be assembled with parts laminated only in the inner (or outer) skin as appropriate.

Fig. 6. Construction method using female mold. - A, B and C matrix construction; D Mold laminated in the matrix, E hull demolding and F finished part. (Source: Project NCH_008 NavTec Ltda - Cotecmar).

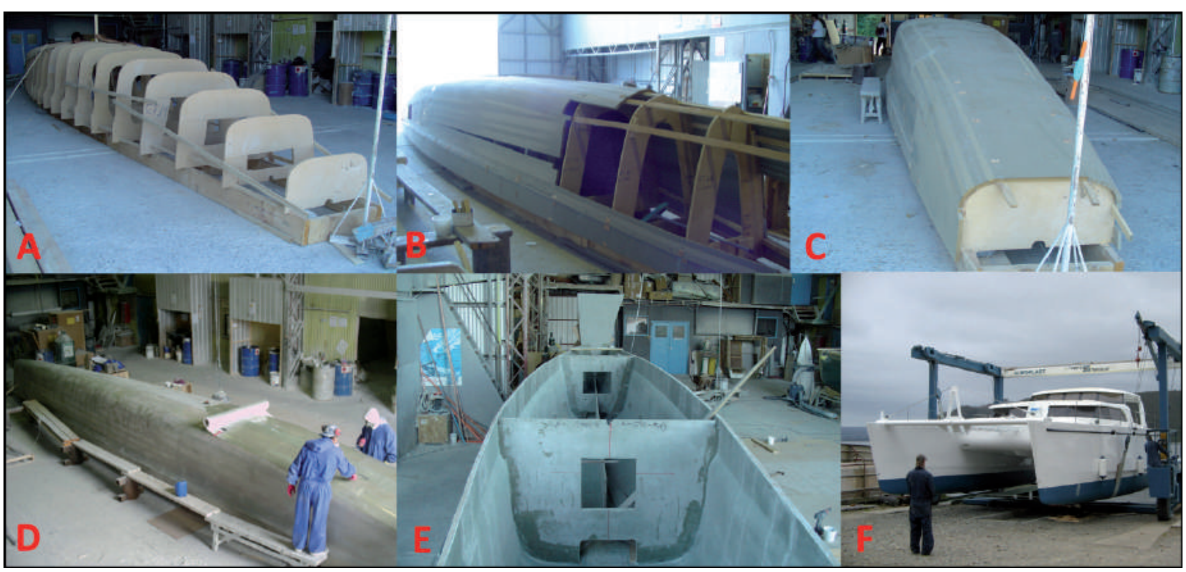
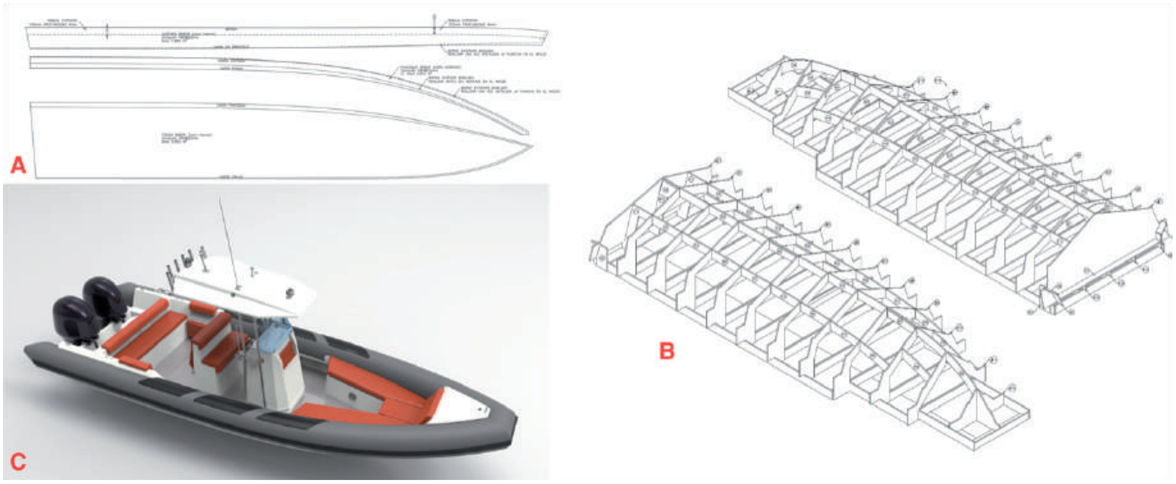
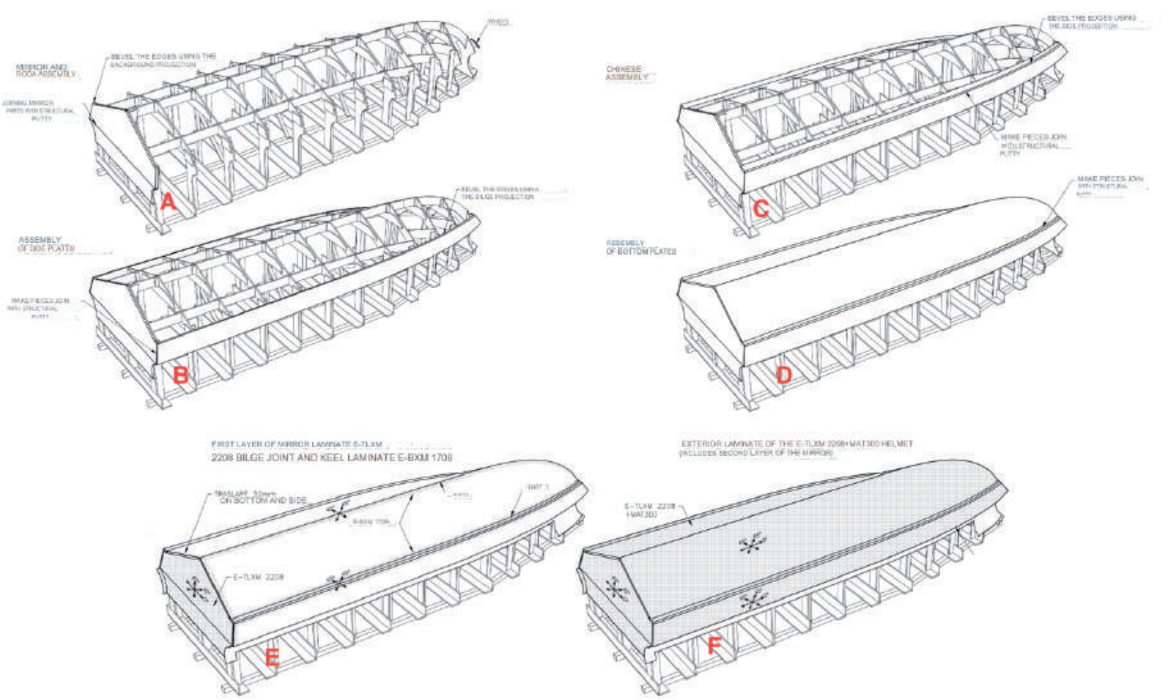


Fig. 7. A - development of hull parts and flat lamination, B - design and assembly sequence of layer and C - digital mock-up of the project (source: Project NT_522 - NavTec Ltda. / M&M Colombia).



Source: Project NT_522 - NavTec Ltda. / M&M Colombia.

Fig. 8. Hull assembly sequence.



Example of application

The application example is a support vessel for the salmon industry to transport personnel to and from the salmon farming centers in southern Chile.

The ship was designed to be built in composite materials and sandwich structure, propelled by water jet. The structural calculation was carried out using international standards, in this case, ISO 12-215 and Bureau Veritas, in addition to the calculation of specific zones using the finite element method.

Fig. 9. General longitudinal profile.

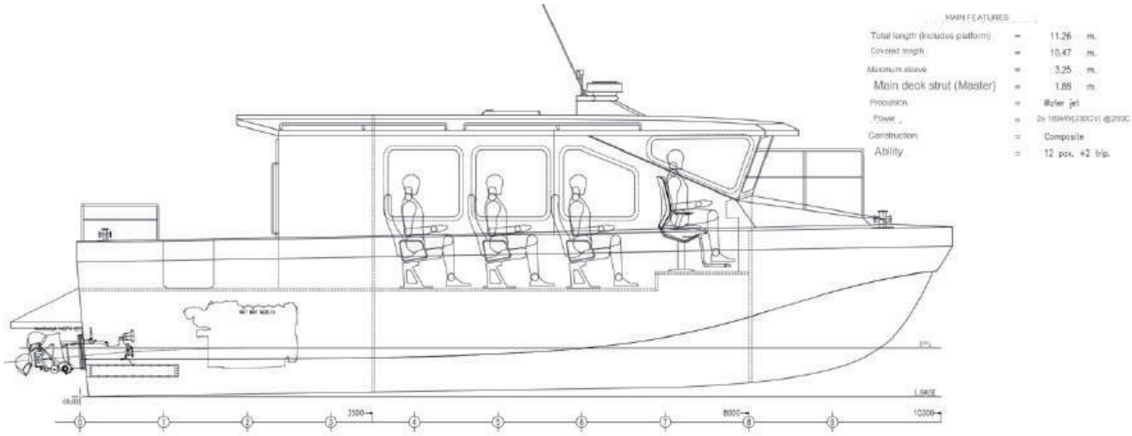


Fig. 10. Digital mock-up.

Fig. 11. Layer sections.

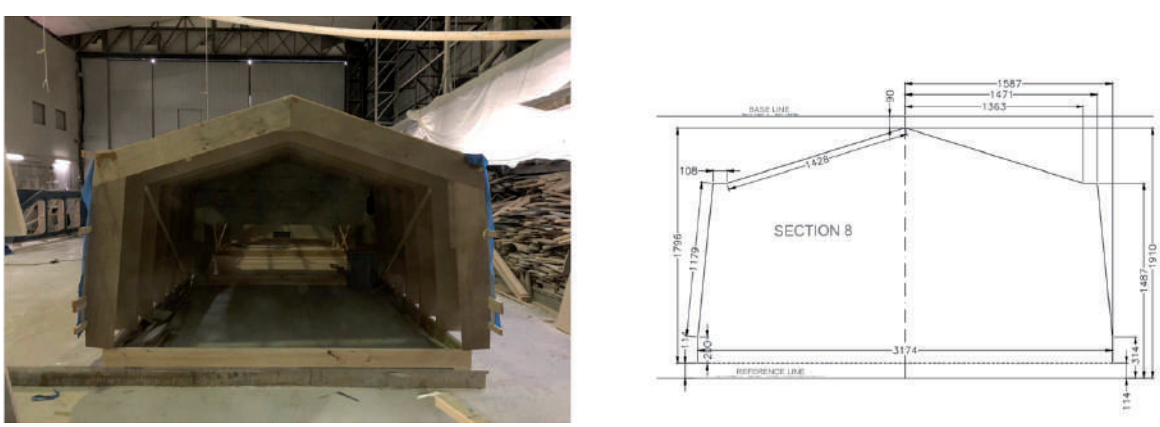


Fig. 12. Development of hull parts and laminate table.

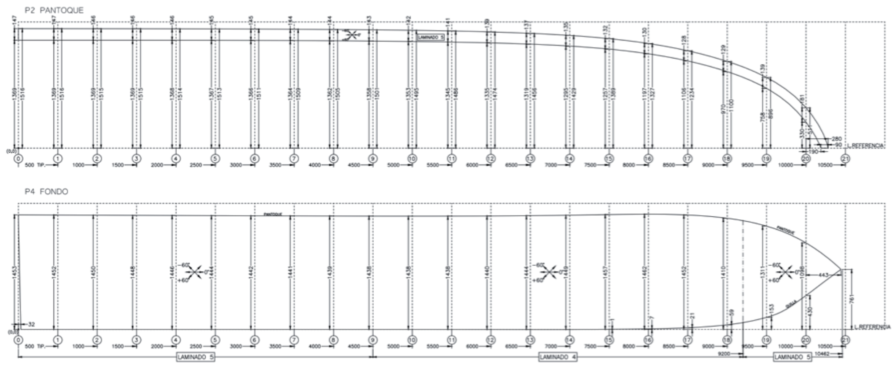
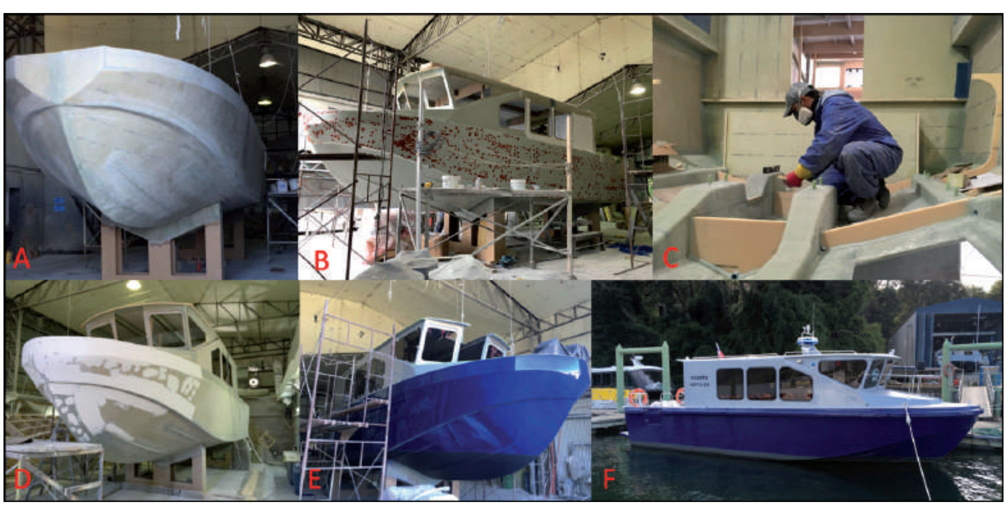


Fig. 13. Sequence of laminates: A - construction of base matrix, B and C - plat parts lamination, D - lamination of superstructure roof, E and F - lamination of hull.

Fig. 14. Finishing: A -hull turn, B -finishing and caulking, C -engine room structure lamination, D -surface finishing, E -hull painting, and F -finished vessel.



General Cost Considerations

Although the technical aspects are relevant, the economic aspect is even more so. Tables 1 and 2 show, in general terms, the materials used and a list of approximate production costs of the boat, with and without molds.

Table 1. General table of structural materials.

Fabric	Architecture	Qty. (m^2)
MAT 300	Mat	356.40
EBX 1700	45º,-45º double bias	71.41
TLX 2700	0º, 45º,-45º Warp Triaxial	182.58
TLX 3600	0º, 45º,-45º Warp Triaxial	78.98
H60 @20mm	pvc foam	42.48
H60 @25mm	pvc foam	23.13
H80 @30mm	pvc foam	79.55
H100 @30mm	pvc foam	16.51

Table 2. General cost estimate.

Item	US$
Structures	35000.-
Equipment / propulsion	108000.-
Miscellaneous and others	160000.-
Total cost	303000.-
Cost Mold for series	105000.-
Base matrix cost	15000.-

The cost of the mold usually amounts to 4 or 5 times the cost of the structure, varying according to the labor costs of each shipyard.

The cost differential associated with the application (or not) of the method can only be correlated in the case that in both situations only one vessel is built, which normally does not happen when they are serial vessels, in which case, the mold is prorated at least in the first 5 vessels.

As a Conclusion

The use of composite materials in the marine industry has been encouraged by the wide range of possibilities, not only in applications in high competition boats, but also in the military and civil industry. The costs associated with these materials, while often higher than traditional materials such as steel, aluminum and wood, have been reduced by implementing construction methods that allow savings in some part of the production chain. The method shown here demonstrates the above, avoiding the construction of a mold and/or fine-finish matrix base, which in terms of cost, can reach a value much higher than that of the hull construction.

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Design of a Self-Righting Pilot Boat of 9 m Length

Diseño de una lancha piloto autoadrizable de 9 m de eslora

DOI: https://doi.org/10.25043/19098642.254

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Abstract

Pilot service is the logistic activity provided to ships to facilitate the entry and exit in a specific port, which are knowledgeable about the area and the maneuvers to be performed. Currently the port of Cartagena de Indias is a strategic being in the Caribbean Sea, being located near the Panama Canal and in front of the crossroads of the main maritime routes of global trade. Where there is a high maritime traffic of merchant ships, which require a pilot service for entry and exit to the port, this service must be accompanied by a means to mobilize the pilot to the point of boarding the ship, serving as a logistical transport necessary to fulfill a role of comprehensive maritime security for the assistance of these ships that require the service to enter the port of Cartagena. Therefore, COTECMAR corporation has seen the need to have its own design for this type of vessel complying with all national and international regulations established, based on the classification society Bureau Veritas, and allowing self-righting in case of capsizing with the high speed of 27 knots for its approach to the authorized point to perform the maneuvers. This work presents numerical regressions, structural calculations, stability calculations, propulsion and generation design, general layout, seakeeping, and cost analysis.

Key words: Naval Engineering, Design, Pilotage, Self-righting, stability, seakeeping, regressions.

Resumen

El practicaje es la actividad logística que se brinda a los buques para facilitar el ingreso y salida en un puerto especifico, que son conocedores de la zona y las maniobras a realizar. Actualmente el puerto de Cartagena de Indias es estratégico en el mar Caribe, al estar ubicado cerca al canal de Panamá y frente al cruce de las principales rutas marítimas del comercio global. Donde hay un tráfico marítimo alto de buques mercantes, los cuales requieren un servicio de piloto práctico para la entrada y la salida al puerto, este servicio debe estar acompañado de un transporte para movilizar al piloto hacia el punto de embarque en el buque, sirviendo como transporte logístico necesario para cumplir un rol de seguridad integral marítima para la asistencia de estos buques que requieran el servicio para ingresar al puerto de Cartagena. Por eso, COTECMAR ha visto la necesidad de tener un diseño propio de este tipo de buques cumpliendo con todas las normativas nacionales e internacionales establecidas, basándose en la sociedad de clasificación Bureau Veritas y que permita autodrizarse por sí solo en caso de volcamiento con la alta velocidad que maneja de 27 nudos para su aproximación al punto autorizado para realizar las maniobras. Este trabajo presenta regresiones numéricas, cálculos estructurales, cálculos estabilidad, diseño de propulsión y generación, disposición general, comportamiento en la mar y análisis de costos.

Palabras claves: Ingeniería Naval, Diseño, Practico, Autoadrizable, estabilidad, Comportamiento en la mar, regresiones.

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Introduction

This work focuses on designing a vessel to transport pilots in the port of Cartagena de Indias [1]. It emphasizes the crucial role of transportation in enabling pilots to move efficiently from the dock [2] [3], where they board, to merchant ships (see Fig. 1). Such vessels play a vital role in maritime security by assisting ships entering the port [4]. Designing these vessels [5] involves analyzing variables to match the mission and required functions.

The study specifically examines the design of a self-righting pilot boat, 9 meters in length, capable of reaching speeds of 27 knots (85% MCR). Data from similar vessels were analyzed to determine the main dimensions through statistical regression. These dimensions informed the hull shapes, ensuring they meet all operational requirements for the vessel's mission.

Fig. 1. Practical pilot boarding.

Source: AMURA.

Once the hull shapes were generated, the hydrostatic characteristics were determined using the Maxsurf Modeller program [6]. Resistance values were calculated using Maxsurf Resistance to predict power requirements and select the optimal propulsion and generation systems, as well as a suitable steering system. A structural analysis was conducted to ensure the vessel could withstand anticipated loading conditions, and stability analysis included assessing the vessel's self-righting capability and behavior at sea. Additionally, an economic feasibility analysis of the project was carried out based on classification society guidelines [7] [8] and relevant international and national standards.

Parent vessel

The dimensions of the preliminary parent vessel design were based on the KRVE 58 (see Fig. 2), which shares characteristics similar to those proposed at the outset of the design process. The KRVE 58 is a proven aluminum crewtender designed for transporting crew, pilots, and personnel. It features a Deep-V hull with reinforced sides, an enclosed main deck, and an enclosed wheelhouse. This established crew concept has been in reliable service for years in the port of Rotterdam, which, like Cartagena, is among Europe's most significant ports. These vessels are utilized extensively for transporting pilots and personnel, averaging 4,000 operational hours per year per boat. The design of the KRVE 58 is specifically tailored for the demanding conditions of Rotterdam harbors and is noted for its robustness [9].

Fig. 2. KRVE 58, Preliminary Crewtender Characteristics.

v	32	kn
L_T	8,95	*m*
L_{FL}	7,8	*m*
B	3,1	*m*
T	0,7	*m*
Δ	9,5	*ton*
P	455	*kW*
C_{FL}	0,78	*N/A*

Source: KRVE & Habbeke, 2008.

Additionally, various pilot boats worldwide were selected from the Significant Small Ships journal (2020) [10], which share similar characteristics with the base vessel. Main dimensional characteristics were derived through regression analysis to establish the foundational values upon which the project is based. This approach ensured that the final parameters of the boat were verified to fall within established ranges.

Dimensions

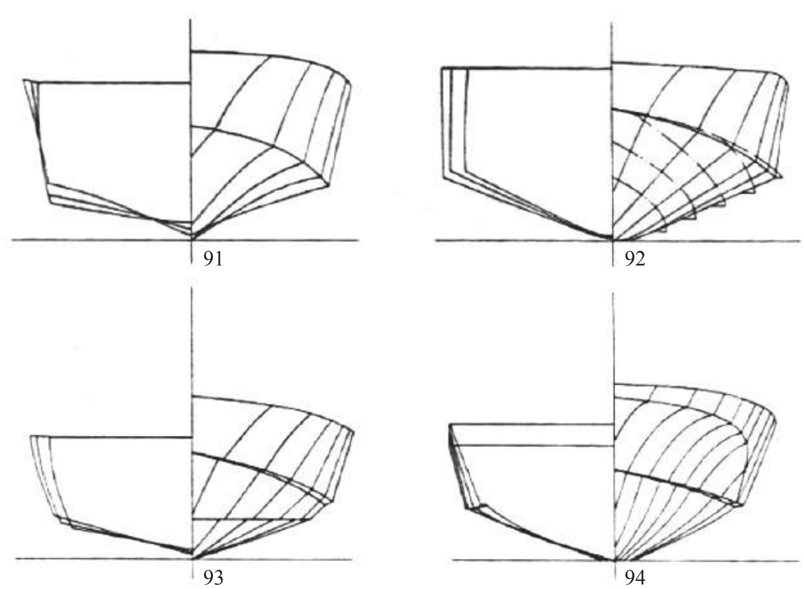
To achieve appropriate hull shapes [11], the design considered the operational specifications and requirements, focusing on facilitating planing [12]. Planing vessels utilize hulls that enable them to rise above the water's surface, generating dynamic lift and reducing resistance caused by wave formation. This effect requires a hull design with V-shaped frames, straight longitudinal lines, minimal bow inclination, and a transom stern that avoids excessive convex shapes to promote smooth water flow separation. This design increases stern volume, counteracting suction effects from water flow.

These characteristics are crucial for overcoming initial resistance caused by wave formation crests. As the vessel transitions into a planing state, frictional resistance becomes predominant, underscoring the importance of minimizing wetted surface area through structural features such as chines, anti-spray measures, and bottom strakes [13]. These elements collectively optimize flow separation and reduce frictional resistance during operation.

To determine the beam of the project, a scatter plot with smoothed lines was generated using the overall length (LT) and beam (B) values from the vessel database. This plot identifies the line that best fits the LT/B ratio. The R-squared (R^2) value indicates how well the data points fit this line, with higher values indicating a better fit. To ensure greater precision, the R^2 value was adjusted by excluding vessels that deviated significantly from the trend line, minimizing discrepancies in the index..

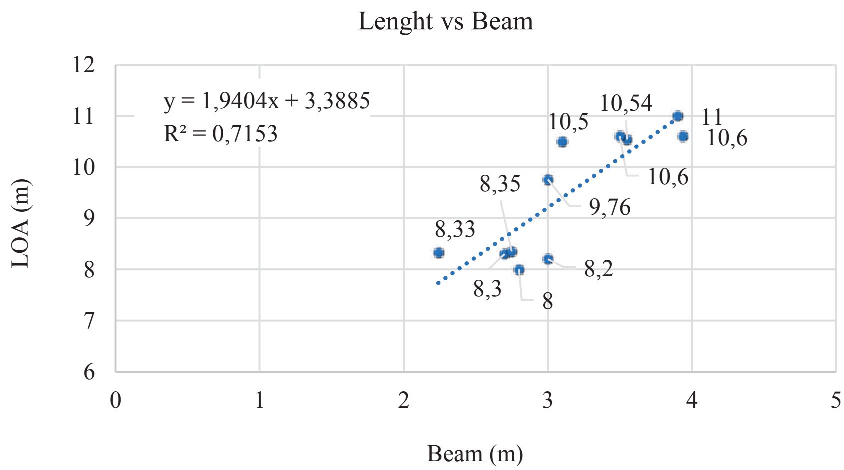
Following the same methodology and using a beam value of 2.89 meters, Equation (1) was employed to calculate the various dimensions.

Fig. 3. Hull shapes of high-speed craft.



Source: Gonzalez, 1991.

Fig. 4. Length vs Beam.



$$B = \frac{L_T - 3.3885}{1.9404} = 2.89m \quad (1)$$

To determine the draft, the same method was applied using regressions of beam (B) against draft (T), as shown in Fig. 5. Additionally, to validate this result, a second regression was conducted using overall length (LT) and beam (B), yielding a draft value of 0.66 meters.

To estimate the block coefficient, an arithmetic mean was calculated using all values from Equation (1).

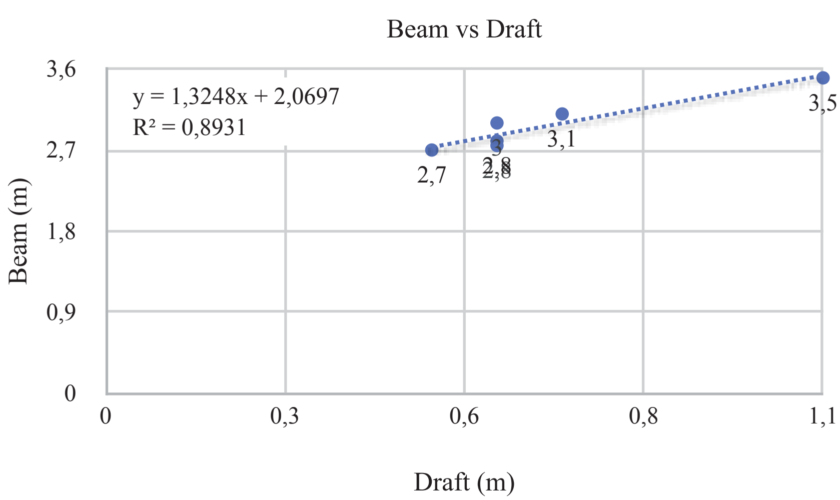
$$X = \frac{\sum_{i=1}^{N} C_{Bi}}{N} = 0.5075 \approx 0.51 \quad (2)$$

Once the displacement of the vessel was obtained.

$$\Delta = Lwl \cdot B \cdot T \cdot \rho \cdot C_B$$
$$= 7.8 \cdot 2.89 \cdot 0.66 \cdot 1.025 \cdot 0.51 = 7.725\ ton \quad (3)$$

The calculation was performed to determine the deadweight and lightship (LS). The lightship refers to the total weight of the vessel once construction is complete and it is ready to sail, excluding cargo, passengers, stores, consumables, and crew; but including fluids in equipment and piping. The remaining weight constitutes the deadweight, which is the difference between the displacement at a specific load line or draft and the displacement of the vessel in lightship condition [14].

Fig. 5. Beam vs Draft.



Within the deadweight, Marine Diesel Oil (MDO) fuel weight and volume are estimated using equations (2) and (3), along with lubricant weight from equation (4), and crew weight. This collective sum yields the deadweight in equation (5), which subsequently determines the displacement at a specific draft in equation (6).

$$\text{Fuel weight } (P_{DO}) = \frac{\text{Hours of use} \cdot C_e \cdot BHP \cdot MCR \cdot 1{,}1}{1000} = 0{,}55 \text{ ton} \quad (4)$$

$$\text{Fuel volumen } (V_{DO}) = \frac{P_{DO}}{\rho_{DO}} = 0{,}62\ m^3 \quad (5)$$

$$\textit{Lubricant weight}(P_{LO}) = 0.04 \cdot P_{DO} = 22{,}1\,Kg \quad (6)$$

$$LS = P_{Consumption} + P_{pas.trip} = 1{,}18\,ton \quad (7)$$

$$PR = \Delta - PM = 7{,}725 - 1{,}18 = 6{,}54\,ton \quad (8)$$

To calculate the fuel weight, we use data from the parent vessel where the main engine power is *BHP* = 455 *kW* and specific fuel consumption: *Ce* = 175.63 *g/kW-h*, with an autonomy of 200 nautical miles operating at 85% of Maximum Continuous Rating (MCR), as specified in the project parameters, plus a 15% margin.

The calculation for fresh water for the cooling system of onboard equipment is initially set at 100 liters. For provisions, a daily consumption rate of 5 kg per person is chosen. Given that the vessel will not operate more than one day away from port, a total weight of 80 kg per person is estimated for the 6 crew members, resulting in a total crew weight of 480 kg.

Forms

The shape generation defined the geometric model, adhering to form coefficients and shapes derived from the sizing process. The Maxsurf Modeller program was utilized to adjust the shapes for a planing boat. A parametric transformation was employed to achieve the specified and defined dimensions, based on selecting a hull that meets the required criteria. This process involved modifying and adapting the outcome of the parametric transformation. The resulting dimensions are presented in Table 1.

Table 1. Hydrostatic parameters obtained by Maxsurf Modeller.

Parameters	Pilotboat	Units
Δ	6,295	Ton
V	6,142	m^3
T	0,66	M
LT	9	M
LWL	8,234	M
B	2,89	M
BWL	2,238	M
CP	0,741	
CB	0,505	
Cwl	0,802	
CM	0,682	
LCB	3,222	m (from forward)
LCF	3,458	m (from aft)

The area curve depicts the distribution of frame areas along the length, thereby determining the displacement throughout the vessel's length. Additionally, it facilitates the identification of the hull's center of gravity, which is pivotal for the vessel's stability and performance.

Fig. 6 illustrates the boat's area curve, showcasing a characteristic shape typical of fast vessels known for their favorable seakeeping qualities [15]. This includes a mirrored stern and a forward body that occupies more than half of the vessel's length, with minimal aft body presence.

Fig. 6. Area curve of pilot boat. By Maxsurf Modeller, 2022.

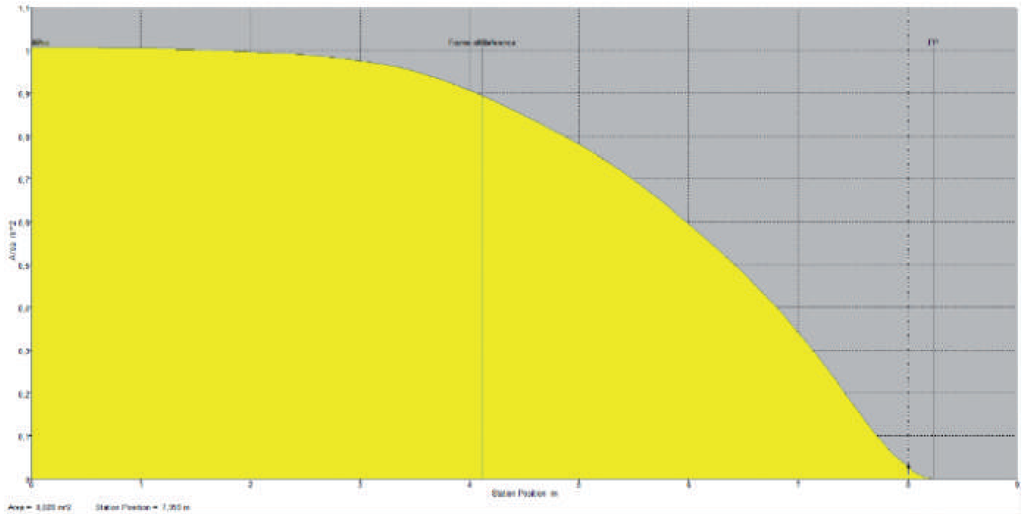
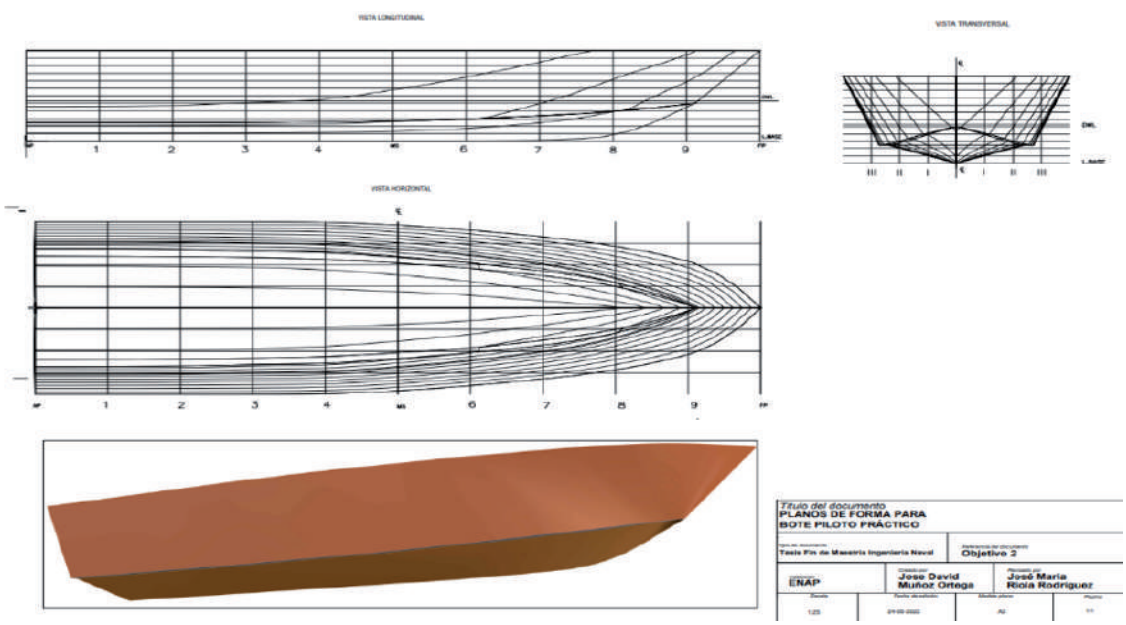


Fig. 7. Plane of forms.



Design of propulsion system

Using the Maxsurf Resistance program, resistance prediction was conducted employing two methods: the Compton method, suitable for displacement or semi-displacement vessels like motorboats or pleasure craft, and the Savitsky method, commonly used for planning boats operating in planing conditions [16]. These predictions covered speeds ranging from 0 to 27 knots.

The results were obtained for the bare hull, excluding appendages or equipment weights, and assumed free-water navigation conditions. Fig. 8 illustrates the resistance as a function of speed. Through this analysis, the hump speed, approximately 10 kn, was determined.

Using equation (9), the brake power (BHP) can be calculated, incorporating a mechanical efficiency ranging from 0.94 to 0.96, with an average of 0.95.

Fig. 8. Resistance vs speed.

Fig. 9. Power vs speed.

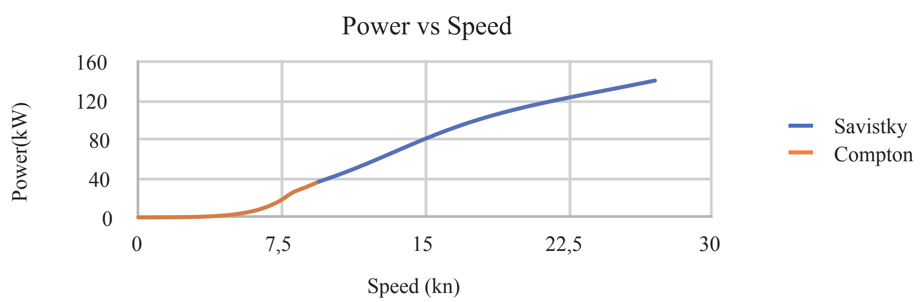


Table 2. Results obtained by Maxsurf Resistance.

RT	11 kN
EHP	140,42 kW

The propulsive efficiency, derived from waterjet specifications, is set at 0.9.

$$BHP = \frac{140,42}{0,9 \cdot 0,95} = 164,23\ kW \tag{9}$$

As previously mentioned, the vessel is designed to achieve a maximum speed of 27 knots at 85% of its Maximum Continuous Rating (MCR), with an additional 15% service margin. Therefore, the power is defined as follows:

$$BHP_T = \frac{164,23 \cdot 1,15}{0,85} = 222,2\ kW \tag{10}$$

As the analysis was made with the bare hull, the engine power is 111.1 kW for each shaft line, it is estimated that the power to be developed for each shaft line will increase to approximately 200 kW.

Choice of propulsion system

The chosen steering system for the practical boat will be a waterjet [17], which will be coupled with an electric motor. This choice is advantageous for improved maneuverability, high-speed navigation, and reduced noise and vibrations. With an effective power requirement of 140.42 kW, and considering the boat will have two thrusters, each waterjet must deliver a minimum of 120.21 kW of power.

Upon analysis, both the HJ241 and HJ212/213 models meet the minimum power requirement of 260 kW, as indicated in Figure 10. The HJ241 model is selected due to its lower operational revolutions per minute (rpm), ensuring compatibility with the electric motor coupling.

When selecting an electric motor for marine propulsion, it is essential to consider that electric motors typically operate at lower rpm ranges compared to waterjets. Among the available types, 2-pole motors offer the widest range of rpm capabilities, making them the most suitable for integration with the chosen waterjet system.

Fig. 10. HamiltonJet Catalog Series 80 to 900 kW.

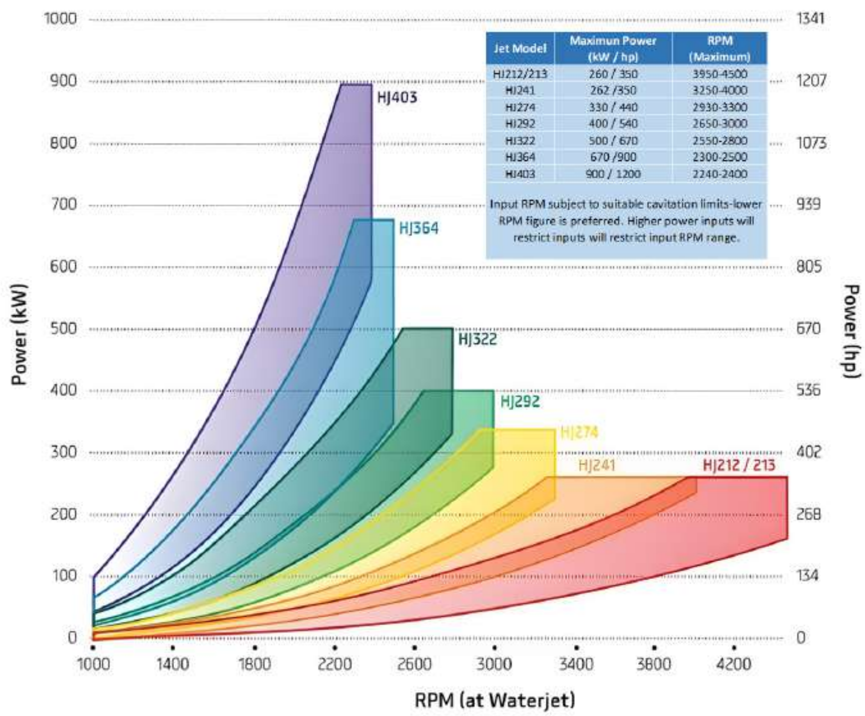
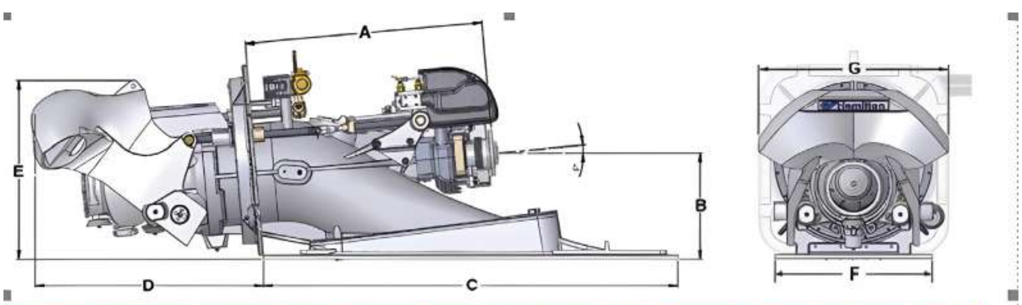


Fig. 11. HamiltonJet Catalog Series 80 to 900 kW.



Jet Model	A (mm)	B (mm)	C (mm)	D (mm)	E (mm)	F (mm)	G (mm)	Intake Block (kg / lbs)	Dry Weight (kg / lbs)	Entrained Water (kg / lbs)
HJ212	450.3[a]	252	762	609	440	386	450	7 / 15.4	75 / 165	17 / 37
HJ213	413	249	762	609	420	386	450	7 / 15.4	84 / 185	17 / 37
HJ241	424	284	829	705	491	451	502	10 / 22	104 / 229	26 / 57
HJ274	570	302	1100	710	548	470	608	22 / 48.5	152 / 335	35 / 77
HJ292	681	330	1180	750	550	495	608	26.4 / 58	187 / 412	45 / 99
HJ322	866	371	1380	835	637	550	680	37 / 82	260 / 573	62 / 137
HJ364	937	420	1634	901	709	621	747	62 / 137	408 / 899	79 / 174
HJ403	1053	474	1723	1080	752	690	904	72 / 159	641 / 1407	110 / 243

Source: Hamilton, 2022.

Fig. 12. W22 IE3 Premium efficiency engine.

Source: NEMA, 2022

Power generation and distribution

For the selection of the generator set, the initial electrical balance must take into account the estimated electrical power demand (kW) required by various auxiliary systems. This preliminary assessment is crucial and will be based on information provided by the project manager, data from similar vessels, and research from the "Universidad Politécnica de Madrid."

To proceed, a table should be created listing the planned consumers and analyzing the varying load demand scenarios corresponding to each operation mode established for the vessel. This table will help outline the comprehensive electrical requirements necessary for effective generator set selection and integration into the vessel's electrical system.

The apparent power calculation is essential for selecting the appropriate generator set for each consumer onboard. The preliminary electrical balance will provide estimated values for active power (kW), apparent power (kVA), and reactive power (kVAR) under various electrical load conditions.

In this calculation, an additional margin of 20% has been factored in to account for losses and equipment not initially considered. This ensures that the generator set chosen can reliably meet the vessel's electrical demands, including unexpected loads and operational contingencies.

System	Consumer	#	Unit power (kW)	Total output	Power demanded (kW)	FP
Propulsion System	Starting Equipment	2	0,8	0,93	0,86	0,8
	Drive Motor	2	200	0,97	206,19	0,93
Steering System	Servomotor	2	10	0,98	10,20	0,92
Fuel System	Racking Pump	2	0,2	0,98	0,20	0,92
	Feed Pump	2	0,15	0,98	0,15	0,92
	Circulation Pump	2	0,15	0,98	0,15	0,92
Cooling System	Cooling Pump	1	8	0,98	8,16	0,92
Ventilation System	MR fan	2	0,2	0,98	0,20	0,92
	MR exhaust fan	2	0,15	0,98	0,15	0,92
Ballast System	Ballast Pump	1	0,29	0,98	0,30	0,93

Bilge and bilge system	Bilge Pump	3	0,72	0,98	0,73	0,93
	MR Bilge Pump	1	1,44	0,98	1,47	0,93
	Emergency Bilge Pump	1	0,72	0,98	0,73	0,93
Fresh Water System	FW pump	1	0,04	0,98	0,04	0,93
Grey and Black Water System	Black Water Pump	1	0,09	0,98	0,09	0,93
Fire Fighting System	Fire Fighting alarms	1	0,1	0,93	0,11	0,8
	Fire Fighting Systems	2	0,7	0,93	0,75	0,8
Lighting System	Navigation Lights	1	0,02	0,93	0,02	0,8
	Internal Lighting	1	0,73	0,98	0,74	0,8
	External Lighting	1	0,915	0,98	0,93	0,8
	Emergency Lighting	1	0,33	0,98	0,34	0,8
Enabling System	Hvac	1	0,31	0,98	0,32	0,8
Navigation and Communication System	Navigation Equipment	1	0,8	0,93	0,86	0,8
	Internal com.	1	0,4	0,93	0,43	0,8
	Outer com.	1	0,4	0,93	0,43	0,8
Mooring System	Winch	1	0,23	0,98	0,23	0,93

Table 3. The preliminary electrical balance.

	Navigation	Maneuvering to the Vessel	Maneuvering berthing and departure
Apparent (kVA)	460,78	396,79	323,49
Active (kW)	428,02	368,96	300,58
Reactive (kVAr)	170,65	145,98	119,56

For selecting the power plant, adherence to level 3 or TIER III emission standards is crucial due to regulations governing SOx and NOx emissions under the MARPOL Convention. Caterpillar has been chosen for its accessibility and reputation for providing top solutions in power generation. Specifically, the CAT C9.3 ACERT [19] model has been selected as it meets these stringent emission requirements and is well-established in studies for fast boats and vessels of similar class.

This decision ensures compliance with environmental regulations while also meeting the performance demands expected for the vessel.

Table 4. Calculated operating speeds for CAT 250 kW engine.

	Power (kW)	Navigation	Boarding and landing	Berthing and departure
Configuration	250	87%	75%	61%

Fig. 13. CAT 9.3 ACERT TM" Marine Generator Engine.

Source: CAT.

The operational regimes for the engine configuration 2x250 have been analyzed as shown in Table 4.

Structural design

Aluminum alloy AA5083 H321, chosen for the boat, is highly favored in marine applications for its excellent resistance to intergranular corrosion in seawater.

Table 5. Mechanical properties of alloy 5083 H321.

Yield stress	228 Mpa
Tensile stress	317 Mpa
Young's modulus	70,3 Gpa
Density	2,66 g/cm^3
Poisson's coefficient	0,3

According to Bureau Veritas [20], the heeling length is defined as the horizontal distance measured at the waterline of the heeling draft or summer float, extending from the bow to the stern perpendicular. This length must align with the length between perpendiculars, ideally falling between 96% to 97% of the waterline length for the specified draft.

For the pilot boat, where the waterline length is equivalent to the length between perpendiculars, measured at 8.234 meters, the scantling dimensions will be defined accordingly:

Table 6. Scantling dimensions.

Scantling length (Le)	7,9 m
Scantling beam (Be)	2,238 m
Scantling draft (Te)	0,66 m
Scantling depth (He)	1,5 m

It is necessary to calculate the bending moments and shear forces to which the vessel will be subjected.

Table 7. Bending moments and shear stresses..

		Sheer	**Damage**
Still water	Bending moment (kNm)	0	10,39
	Shear stress (kN)	0	5,05
Induced by waves	Bending moment (kNm)	-10,39	8,31
	Shear stress (kN)	-31,16	27
Load induced	Bending moment (kNm)	-133,45	133,45
	Shear stress (kN)	-51,86	51,86

The calculation of pressures used to verify the scantling of the vessel's plates and structural stresses aims to determine maximum parameters that adhere to the project's requirements. Bureau Veritas [20] specifies the following criteria for hull pressures:

- Hydrostatic pressures *(Ph)*: Generated by sea pressure in both swell and calm waters.
- Hydrodynamic pressures *(Pw)*: Resulting from ship movement, including functional side impacts for plate and secondary element calculations, bottom impacts for hull bottom structural elements, and pressures from pounding, crucial for planning hull structural elements.
- Internal local pressures *(Pi)*: Induced by internal loads within the vessel.

With the results obtained previously on the resistance that the ship's structure must have with respect to hydrostatic and hydrodynamic pressures, the scantling of the structure is defined.

Bureau Veritas [20] conducts calculations to determine the minimum thickness required for each structural component based on local loads. The scantling of plates, primary, and secondary reinforcements is defined in accordance with the NR600 R04 E standard:

- Bottom structure.
- Side structure.
- Deck structure.
- Transverse and longitudinal bulkhead structure.

Costs

One of the critical aspects for completing the project successfully is its feasibility, particularly in evaluating the acquisition costs for constructing and operating the vessel [21]. These costs must align with market conditions and facilities. It's essential to seek technical design solutions that do not increase costs yet still attract shipowners. The project's feasibility also depends on aligning construction costs at the shipyard [22], which benefits from the difference between construction costs and the agreed-upon client price. Thus, generating economic benefits for the shipowner is crucial for ensuring profitability.

To estimate the cost of materials and equipment, three procedures will be considered:

- Experimental formulations
- Data obtained from equipment and system manufacturers.
- Data obtained from projects of similar vessels.

Fig. 14 illustrates the percentage breakdown of costs associated with the project, providing an approximate analysis for materials and equipment expenses.

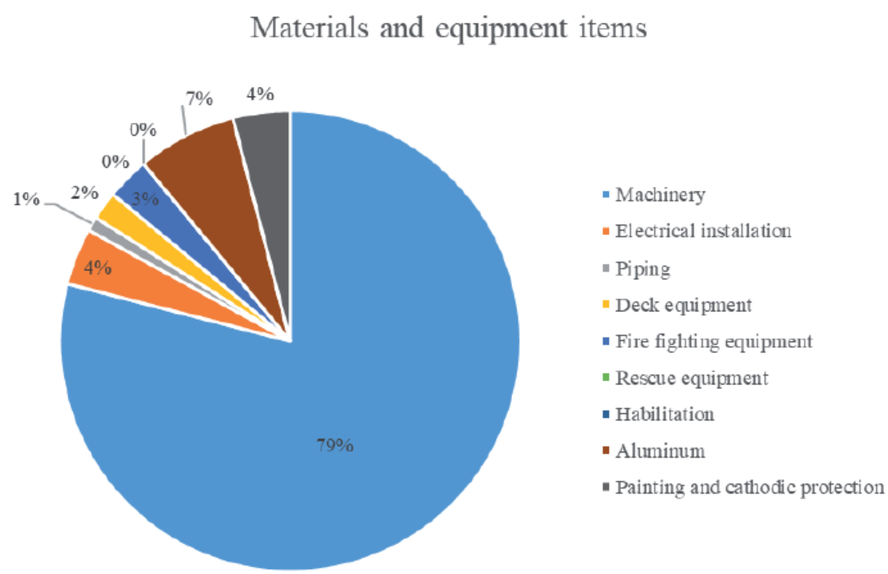
Table 9. Costs.

Equipment	Costs (€)
Materials and equipment	400.000 €
Labor	200.000 €
Overheads	100.000 €
Total cost	700.000 €

Table 8. Bending moments and shear stresses.

		Bottom	Side	Main Deck	Engine room deck	Watertight Bulkheads	Superstructure
Hydrostatic		11,46	5,88	5,88	-	-	-
Hydrodynamic		132,27	38,5	-	-	-	38,5
Internal	Displacement	-	-	-	24,1	5,52	-
	Planing	-	-	-	23,82	5,06	-

Fig. 14. Materials and equipment items.



Conclusions

- A boat has been designed for practical piloting to establish a domestic design for potential construction within the country, aiming to reduce reliance on imported vessels. The design includes its form, general layout, and structural analysis at the conceptual stage. Naval architecture calculations are now necessary to analyze stability in planing and semi-displacement conditions, as well as to assess self-righting parameters and sea behavior characteristics specific to its V-shaped hull.

Fig. 15. Pilot boat.

Source: DAMEN [23].

- For optimal hydrodynamics, the bow shapes are designed to enhance sea-keeping qualities, while the stern provides sufficient lift for navigation. Once the vessel transitions into planing, resistance primarily arises from friction. Therefore, incorporating a hard knuckle facilitates flow separation, significantly reducing wetted surface area and enhancing stability. Additionally, the hull bottom features strakes to separate flow, minimizing frictional resistance, reducing spray for a more comfortable sailing experience, and enhancing speed by decreasing pressure and viscosity components of forward resistance.

- When analyzing the operational regimes of the generator plant configuration, it is apparent that the maneuvering time for docking and launching is close to the lower allowable limit. However, this maneuvering time is considered insignificant. The use of two generators allows for better weight and load distribution to meet the boat's requirements, facilitating the configuration and layout in the engine room.

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