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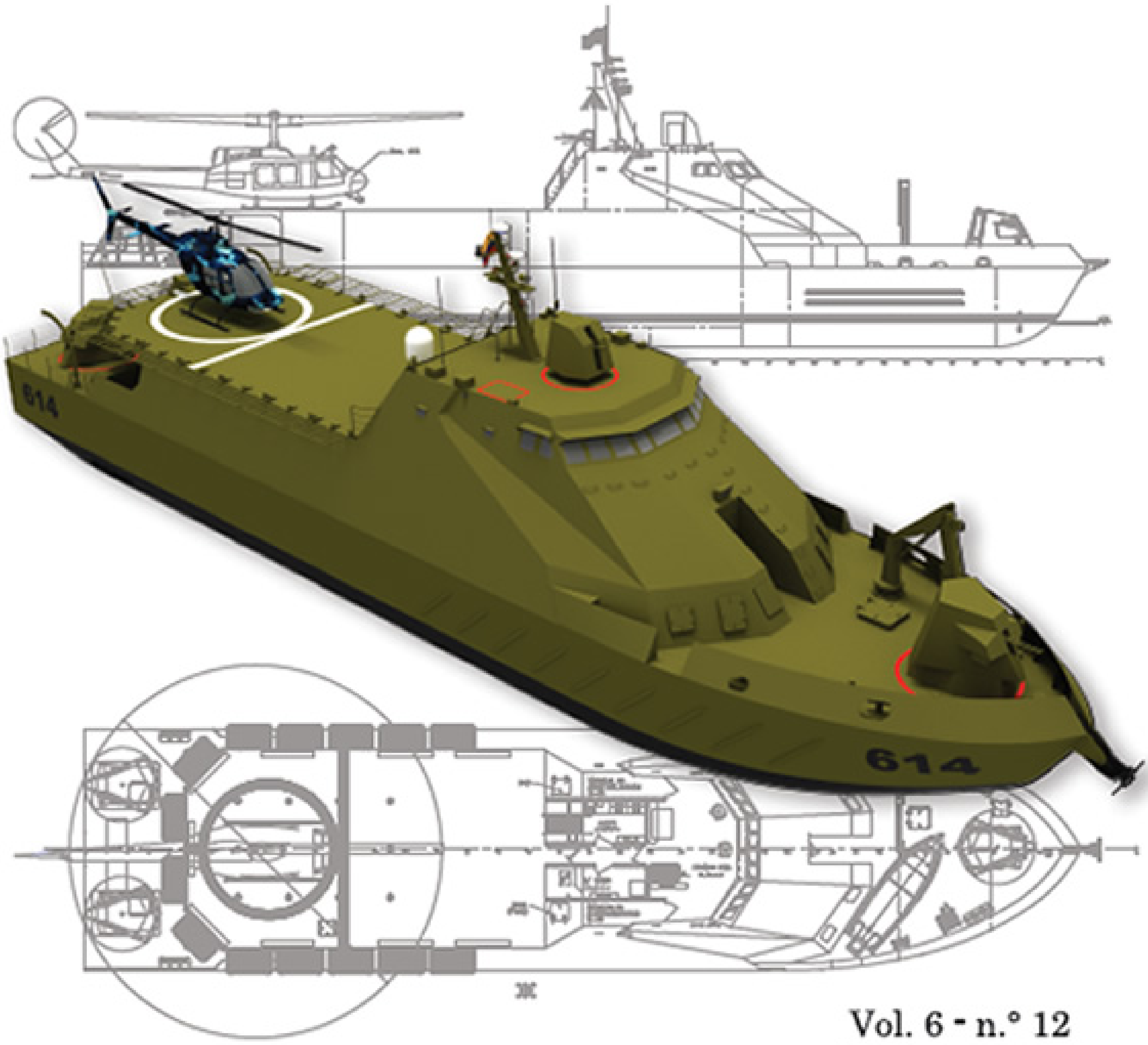

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Editorial Note

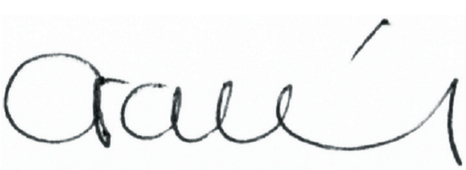
Cartagena de Indias, 21 January 2013

2012 will remain in COTECMAR's memory for being the year in which it received important recognition as *"Innovative Organization"*, evidencing the internalization of Innovation as fundamental part of our daily activity. We are proud of this achievement that deserved us four different awards: (1) 2012 PORTAFOLIO AWARD, (2) NATIONAL AWARD TO SCIENTIFIC MERIT, (3) SIMÓN BOLÍVAR AWARD FOR ENTREPRENEURIAL MERIT y (4) AWARD FOR INNOVATION IN BOLÍVAR. This would not have been possible without the commitment and sense of belonging from each of our collaborators, who frameworked within a culture for innovation permitted materializing the results of the activities on science, technology and innovation onto the service of the naval, maritime, and riverine industry.

The ***Ship Science and Technology*** Journal has been part of the achievement of these goals and, hence, continues within its process of consolidation by getting closer to its readers and authors through its new web page: www.shipjournal.co developed in the Open Journal System (OJS), which is a system of administration and publication of journals and periodic documents in the Internet.

This edition has participation from COTECMAR with research results on several of our fields of actionlike accessibility, seakeeping, and computational models. The international contribution was made by Panamawith the topic of neural networksand by Spain with the reduction of warship motion.

In our next volume, we expect to continue delivering timely and quality information.



Captain OSCAR DARÍO TASCÓN MUÑOZ
Editor of the Ship Science and Technology Journal

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Nota Editorial

Cartagena de Indias, 21 de Enero de 2013.

El 2012 quedará en el recuerdo de Cotecmar por ser el año en el que se recibieron importantes reconocimientos como *"Organización Innovadora"*, evidenciando la interiorización de la Innovación como parte fundamental de nuestra actividad diaria. Estamos orgullosos de esta hazaña donde fuimos merecedores de cuatro 4 diferentes premios: (1) PREMIO PORTAFOLIO 2012, (2) PREMIO NACIONAL AL MÉRITO CIENTÍFICO, (3) PREMIO AL MÉRITO EMPRESARIAL SIMÓN BOLÍVAR y (4) PREMIO A LA INNOVACIÓN EN BOLÍVAR. Esto no hubiese sido posible sin el compromiso y sentido de pertenencia de cada uno de nuestros colaboradores, que enmarcados dentro de una cultura de la innovación permitieron la materialización de los resultados de las actividades de ciencia, tecnología e innovación al servicio de la industria naval, marítima y fluvial.

La Revista ***Ciencia y Tecnología de Buques*** ha hecho parte de la consecución de estas metas y por ello continúa en su proceso de consolidación al realizar un importante avance en su acercamiento a los lectores y autores, con su nueva página web www.shipjournal.co desarrollada en OJS (*Open Journal System*), el cual es un sistema de administración y publicación de revistas y documentos periódicos en Internet.

Esta edición cuenta con la participación de Cotecmar con artículos resultado de investigaciones en varios de nuestros campos de acción tales como accesibilidad, comportamiento en el mar y modelos computacionales. La cuota internacional es aportada por Panamá con la temática de redes neuronales y España con la reducción de movimientos en buques de guerra.

Esperamos en el próximo volumen continuar entregándoles información oportuna y de calidad.

Capitán de Navío OSCAR DARÍO TASCÓN MUÑOZ
Editor Revista Ciencia y Tecnología de Buques

Accessibility applied to ships, case study Riverine Ambulatory Care Center (RACC)

Accesibilidad aplicada a embarcaciones, caso de estudio
Centro de Atención Ambulatoria Fluvial (CAAF)

Diana Lorena González [1]
Priscilla Areiza Frieri [2]

Abstract

Accessibility as a design concept is generally applied in land constructions; however, the medical character of the case study requires it to be considered in the design process as of its conceptual stage. The riverine ambulatory care center (RACC) is a mobile health unit to carry out medical missions in populations located on the riverbanks; given the RACC dimensions, these have limited medical services to primary care and health brigades. Physical barriers[1] are the causes for an environment being inaccessible; to eliminate them, from the RACC, an analysis and redesign was performed of the conceptual proposal, based on standards for accessibility, medical spaces, and ships. Two basic moments were taken for intervention, access and interior circulation, yielding as a result the design of an integrated system of products that eliminate the physical barriers from the environment, permitting boarding and offering medical services under equal, comfortable, and safe conditions. Accessibility as modifier of the environment to improve the quality of life of users should not only be applied in medical ships, this study opens an opportunity for industry to optimize the physical environment of other types of ships by applying this concept.

Key words: Accessibility, hospital ship, universal design, support products, reduced mobility, Riverine ambulatory care center (RACC)

Resumen

La accesibilidad como concepto de diseño se aplica generalmente en las construcciones en tierra, sin embargo, el carácter médico del caso de estudio requiere que sea considerado en el proceso de diseño desde su etapa conceptual. El Centro de Atención Ambulatoria Fluvial (CAAF) es una unidad sanitaria móvil para realizar misiones médicas en poblaciones ubicadas en la ribera de los ríos, por las dimensiones del CAAF han limitado los servicios médicos a atención primaria y brigadas de salud. Las barreras físicas[1] son las causantes de que un entorno no sea accesible, para eliminarlas del CAAF, se realizó un análisis y rediseño de la propuesta conceptual, apoyado en la normativa para accesibilidad, espacios médicos y embarcaciones. Se tomaron dos momentos básicos a intervenir, el acceso y la circulación interior, dando como resultado el diseño de un sistema integrado de productos que eliminan las barreras físicas del entorno, permitiendo un abordaje y prestación de los servicios médicos en condiciones iguales, confortables y seguras. La accesibilidad como modificador del entorno para mejorar la calidad de vida de los usuarios no debe ser aplicado solamente en embarcaciones médicas, con este estudio se abre una oportunidad para la industria de optimizar el entorno físico de otros tipos de embarcaciones, por medio de la aplicación de este concepto.

Palabras claves: Accesibilidad, buque hospital, diseño universal, productos de apoyo, movilidad reducida, Centro de Atención Ambulatoria Fluvial (CAAF).

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[1] Physical obstacles of the constructed environment that keep certain population groups from reaching, accessing, or moving throughout the particular building, place or zone. (University Institute of European Studies, Universidad Autónoma de Barcelona. Spanish Ministry of Labor and Social Issues, 2002).

[1] Obstáculos físicos del entorno construido que impiden que determinados grupos de población puedan llegar, acceder o moverse por un edificio, lugar o zona en particular. (Instituto Universitario de Estudios Europeos, Universidad Autónoma de Barcelona. Ministerio de Trabajo y Asuntos Sociales de España, 2002)

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Introduction

In recent years, COTECMAR has been requested by diverse entities to design medical ships, which has led to the emergence of the riverine ambulatory care center, which is in the conceptual design phase using as a base for its development the hull of the mothership-type River Patrol Support Ship (PAF-P).

However, its physical environment does not afford the suitable conditions to enter, circulate, and exit by using support products[1] like wheel chairs; difficulties like circulating the ramps between the pier and the ship or doors with inadequate dimensions are evident, generating a large amount of physical barriers that would hinder access of users to medical services, which goes completely against the RACC's final objective of offering the populations on the riverbanks an essential and indispensable theme to generate an inclusive environment that improves the quality of life, autonomy, and safety of users on board.

The problem of accessibility in ships has not been previously studied in the national industry, making it necessary to approach it as of constructions on land, specifically hospitals in which it has been studied in depth, emphasizing on individuals with reduced mobility; however, ships have by their very nature some characteristics that affect the arrangement of the physical space that must be considered to perform an accurate analysis, the structural requirements affecting the interior space, constant movement caused by navigation, and the high safety standards required, among others. From these aspects, the case study was analyzed, which defined two scenarios as a starting point: access and interior circulation.

The case study analysis concludes in eliminating the physical barriers; in the first instance, the proposal for access is the location of several products on the forecastle among which is highlighted a support product specially designed for the ingress of patients on wheelchairs or stretchers; regarding circulation, the general disposition was optimized according to the relationship of the medical services, to facilitate movement of patients, inputs and hospital wastes.

The following presents the analysis process and the design results in the RACC, which can be taken as reference for other studies.

Accessibility, definition, and strategies

Accessibility is a concept that has achieved particular importance during recent years in the architectural field; supported by different entities and initiatives that promote equality independent of each individual's physical, sensory, or emotional conditions, the concept has several definitions according to the point of view assigned to it, this specific case emphasizes the relationship between subjects and their surroundings:

"Accessibility is the set of characteristics that must be present in an ***environment, product, or service*** *to make it usable under* ***conditions of comfort, safety, and equality*** *by all people and, particularly, by those who have some disability[2]." (Ministry of Labor and Social Issues. Alonso, Fernando , 2003)*

Accessibility becomes perceptible with the appearance of barriers [3] that cause its absence and – consequently – discrimination, social exclusion, and reduction of comfort; various **types of barriers may be mentioned: intrinsic, environmental, and interactive** (*Smith, 1987*) associated to the subject, the context, and their interaction, respectively, the last is the most visible given that it is manifested everyday from architecture, urbanism, transportation, and telecomunications (*Amengual, 1996*); it is notable that it is not merely about a single context, which is why the vision of accessibility must be systemic to provide

[1] Instruments or special devices that permit carrying out diverse activities that without such aid would be left without possibility, that is, they are facilitating elements that help individuals to get as close as possible to normality, starting from their deficient capacity, transforming the environment to favor the integration of individuals with diverse deficits.

[2] People with disability include those with long-term physical, mental, intellectual, or sensory deficiencies that, upon interacting with diverse barriers, can impede their full and effective participation in society, in equal conditions with the rest." (*United Nations, 2007*)

[3] Barriers like expression of obstacles that causes the functional differences among people to become inequalities. (*Alonso, 2007*)

comprehensive solutions in all situations that so require it.

As an emerging tendency corresponding to the need to approach the theme from a comprehensive vantage point we have the **rehabilitation technologies** (*University Institute of European Studies, Universidad Autónoma de Barcelona, 2002*) defined as:

"Any technology from which products, instruments, equipment, or technical systems may be derived accessible by disabled individuals and/or the elderly – whether these are produced specially for them or with a general character – to avoid, compensate, mitigate, or neutralize the deficiency, disability, or handicap and improve personal autonomy and quality of life." (Swedish Handicap Institute, 1994).

For the practical application of these technologies – until now under development, two strategies are identified applied to the design of environments, products, or services:

- **Universal design:** *"Understand as Universal design the design of products and environments suitable to being used by the greatest number of people without need for adaptations or for a specialized design" (North Carolina State University, 1995)*
- **Design of technical aids or support products:** *"When reduced ability or capacity to handle that product reaches a given level, it will be necessary to follow a more specific strategy, which consists of designing special products or systems for people with a considerable loss of ability" (University Institute of European Studies, Universidad Autónoma de Barcelona, 2002)*

Thus, we may speak of the onset of degrees of accessibility because it is evident that the universal design is the ideal solution, but its application is not viable in all cases; applying one or another strategy depends on diverse factors like:

- Decrease or loss of certain ability to relate to the environment, the greater loss requires the solution to be more specific and it will be applied whenever no other reasonable mean is available to solve the problem.
- Environmental demands, given that on occasion the structural, environmental, or dimensional conditions of the space do not permit the design of a universal solution.

These degrees evidence how equal the environment, service, or product turn out (Alonso, 2007) to comfortably and safely relate regardless of the individual's condition, the degrees can be the result of the combination of both strategies applied in a specific situation.

There is an additional aspect to the problem of accessibility and it is most pertinent in its application on ships: limits, it is essential to consider every effort and means employed in the development of accessible solutions in relation to its results, consequences, and benefits (*Alonso, 2007*) within a specific context; limits determine the pertinence of investing economic, human, and time resources, given that in every project resources are limited and their best use must be sought. Design of accessible solutions from the environment results in many cases economically costly and its benefit is not notable against such an investment; however, the mere fact of considering the equality of conditions as a universal[4], ethical, legal, and socially non-negotiable principle is sufficient for its pertinence to be assessed and for it to be considered a priority within a list of requirements of a project or design from its start and not as a final repair that results in a poorly efficient adaptation.

By contextualizing the aforementioned to the Colombian case, the 2005 census found a 6.3% prevalence of individuals with some limitation, that is, that considering the total population for Colombia during that same year (42,090,502), it is calculated that there were 2,651,701 people in the country with at least one limitation; of these 76% perceive architectural barriers in their immediate environment (*Colombia Líder, Fundation Saldarriaga Concha, 2010*), which makes accessibility a national problem to which

[4] "Promote, protect, and ensure full enjoyment of human rights and fundamental freedoms under conditions of equality for persons with disabilities, and promote respect for their inherent dignity" (*United Nations, 2007*)

COTECMAR as a Science and Technology Corporation joins in the research, development, and innovation in favor of equality and social inclusion.

Application in ships

Basically, we can define four purposes for which ships are designed: as **business units** to transport diverse products immersed in market dynamics, support of the nation's defense and sovereignty for which warfare units are constructed, **passenger ships** aimed at tourism, and – lastly – auxiliary service ships **that** complement the aforementioned.

To evaluate the conditions limiting the application of accessibility within the shipping context, it is important to understand the most relevant characteristics of the spatial arrangement in ship design, among which we find:

- Reduced spaces, in addition to structural requirements being high, requiring habitability to be adapted to these.
- The arrangement of various decks requires vertical mobility, for their disposition it is important to consider the adequate angle de stairs and ladders according to the type of service provided – especially in evacuation routes.
- The ship's watertightness condition does not permit its doors to be located directly on the deck, but to keep a vertical distance (coaming or sill) that prevents water from entering, generating a physical barrier.
- Constant movement during navigation, caused by sea or river conditions (drift and pitch due to waves, wind, tides, currents, among others)
- The fact that it is an independent structure temporarily isolated from land, it demands some high safety standards given that it cannot receive immediate attention during emergencies.
- Requirement of a platform on land for boarding and disembarking of people. Boarding conditions can vary according to the site.
- Higher risk of accidents when containing large fuel tanks in engine rooms placed relatively close to habitable zones.

Another of the characteristics of ships affecting the interior design is the on-board population; two types of ships can be differentiated in terms of accessibility, those limited to a trained crew and those that permit access to individuals with reduced mobility.

Given the complexity of keeping the ship navigating safely, the International Maritime Organization (IMO) requires that all crew be trained in firefighting, first aid, survival, and social responsibility to be allowed to navigate, which is why individuals with physical limitations are denied access to merchant, fishing, auxiliary, or war ships in which the design of completely accessible spaces is not viable and the investment is not justifiable against the purpose of the ship; their population is limited to the trained crew, with some exceptions for short periods like boarding of researchers, family members or shipbuilders, as it is common in the case of the merchant marine; boarding of individuals with reduced mobility would increase the investment that is not justified against the ship's purpose.

Regarding passenger ships, specifically cruise ships, yachts, catamarans, and sailboats, boarding is permitted to any person independent of his/her physical condition; however, not all are designed for accessibility, this will depend on the client's specific needs, given that often their finality is not of public access. Cruise ships are – until now – the most advanced ships in this issue, given that they are governed by regulations that obligate them to provide accessible environments, which is why they are generally equipped with elevators, wide corridors, and trained crews to care for special passengers in case of emergency.

These are the two positions the naval industry has regarding accessibility from the point of view of reduced mobility, applications can be found from other perspectives according to the ship's final objective, like optimization of evacuation means, access to confined spaces, and other improvements that reduce the physical barriers increasing on-board safety and comfort.

This generates in the ships' physical environment special conditions that differ from a structure on land and which should be considered in the design process and – more so – in a ship with the characteristics of the case study where it is vital to provide conditions of equality.

Case study, Riverine Ambulatory Care Center (RACC)

The riverine ambulatory care center (RACC) is a mobile health unit designed by the R&D+i Direction (DIDESI) to conduct medical missions in populations located on the riverbanks and that do not have medical services available or with very low level of care. External healthcare advisors helped to design the RACC on the hull of the mothership-type (PAF-P) ship, which is a product designed and constructed by COTECMAR for the Colombian National Navy.

As a hospital ship, it is essential for it to permit embarking and optimal circulation of any individual under conditions of equality, safety, and comfort. Considering accessibility to the physical environment as fundamental part of the design process, an analysis and re-design of the RACC's conceptual proposal was carried out, particularly emphasizing on persons requiring support products for mobility; however, the lack of specific guidelines is notable for hospital ships, which generates an investigation opportunity to offer an innovative solution for an issue that has not been addressed at the national level.

Analisys

The RACC has laboratory, pharmacy, general medical consultation, gynecology, dentistry, X-ray, minor surgery, operating room, and hospitalization services focused on observation and transfer; these services were defined based on the *"Manual of Activities, Interventions, and Procedures of the Compulsory Health Plan in the Healthcare Social Safety General System MAPIPOS" (Ministry of Health, 1994)*.
With these services in mind, the decks were divided into zones, thus: main deck to provide medical and complementary services (waste storage, health services, reception, among others), deck 2 (below the main) for crew quarters, and deck 01 (above the main) for navigation tasks and the heliport.

Population

Regarding the population, the term reduced mobility[5] was taken to define those users who because of some temporary or permanent disability require the use of support products (wheelchairs, canes, prosthesis) to move. These can be classified into ambulatories and non- ambulatories: ambulatories are those who in spite of their reduced capacity to move can walk without the need for a wheelchair, like the elderly, pregnant women, and persons with prosthetic limbs; non-ambulatories, in contrast, do require the use of wheelchairs as in cases of tetraplegia or paraplegia – this category can include the use of stretchers. The analysis also considered persons without mobility deficiencies like operations or medical personnel.

Scenarios

Considering that medical services are only provided with the ship moored or anchored, these conditions were taken as a starting point to establish the two moments that account for mobility activities: **access**, which contemplates the relationship with exterior processes of embarking or disembarking from water or land and **interior circulation**, which is the most adequate distribution according to the relationship between services and the dimension of compartments, doors, and corridors.

From these moments, it was established how the special conditions of ships limit the application of accessibility specifically in the case study, as shown by the following:

- ***Access:*** The RACC is a river ship that depends on the infrastructure of the Colombian hydrographic basins to moor; often these do not have a harbor or pier as access support, that is, the possibility exists that the floatation line is at land level; considering that the ship must

[5] The term disability is not taken as reference because it includes other deficiencies that remain beyond the project's reach

reach the highest possible number of populations, the distance between the line of flotation and the main main deck was taken as the maximum distance to allow boarding the ship, consolidating the most evident physical barrier.

In case river conditions do not permit the ship to reach the riverbank, an auxiliary boat is available to transport people to and from the ship to receive the required medical care.

Fig. 1. Boarding from land

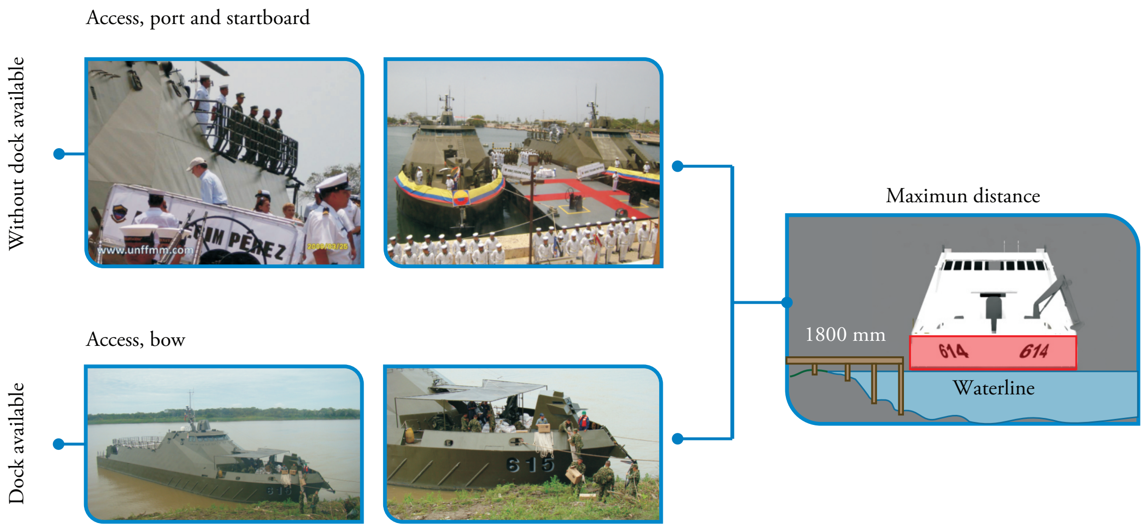
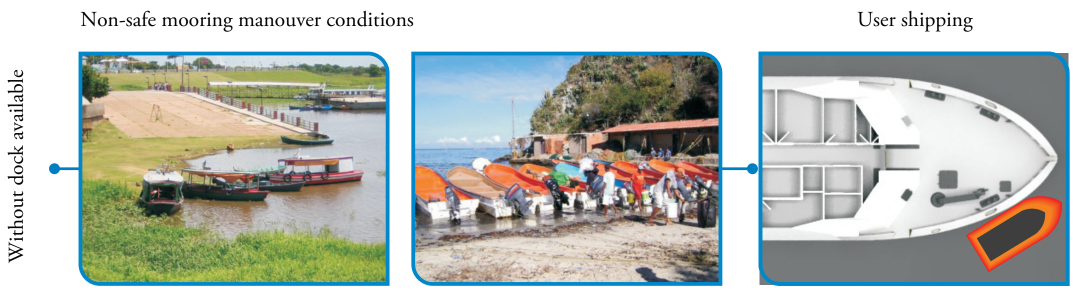


Fig. 2. Boarding from water

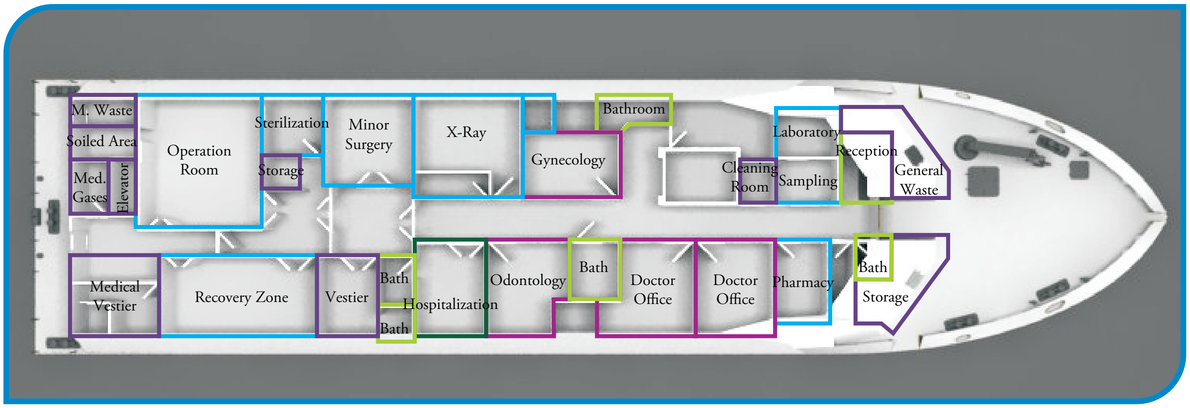


Circulation

The factor most affecting circulation within the ship is the reduced space, considering that it is a medical-type ship it is vital to provide adequate areas for each medical service and mobility among these that permits transit of wheelchairs and stretchers.

An additional factor that must be considered when analyzing accessibility is the means of evacuation; in case of emergency, the lives of patients and crew will depend on efficient evacuation routes.

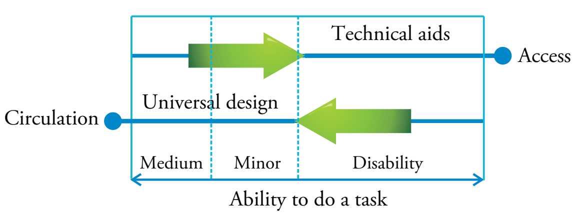
Fig. 3. Distribution of medical services, main deck



Methodology

The analysis and design process is part of the development of rehabilitation technologies (see item Accessibility, definition, and strategies), which is why it is pertinent to consider their strategies in applying accessibility criteria.

Fig. 4. Accessibility strategies



Source: (Ministry of Labor and Social Issues. Alonso, Fernando, 2003)

Different strategies were applied to both scenarios, access, design of technical aids and to circulation, universal design; apparently simpler and more functional would be to install a ramp, but demands of the context do not permit such with an adequate inclination for wheelchairs. The decision to undertake different strategies was made considering:

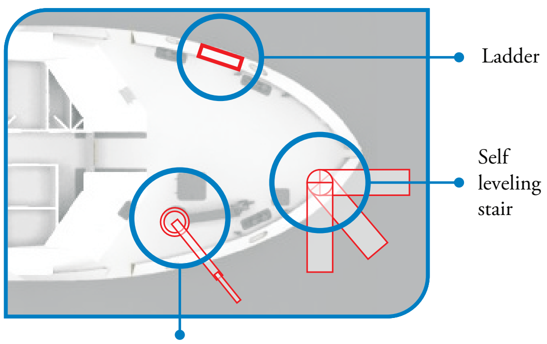
- Conditions for access from land are variable and depend on the place of birthing, although these could probably be optimal for an embarking system, they can turn out deficient for another, which is why it is important for the systems to be adaptable to the context.
- On the contrary, the interior is the context with the least physical barriers, which does not change due to external conditions; the problem here is to accomplish within a reduced space a correct relationship among the medical services according to their complementation, integration, or independence, which is why a universal solution is more viable; additionally, when taken as a means of reference in the design of the physical space it also permits passage of individuals without reduced mobility.
- It is difficult to estimate what physical limitations will be presented by users, which is why wheelchairs and stretchers were taken as main support products, given that they are essential for medical service care.

Results

Stemming from the analysis and by applying the aforementioned strategies, a system is proposed comprising various products to eliminate the embarking physical barriers during the boarding and circulation process.

Regarding access, the most important requirement is the system's adaptability to the context, leading to the proposal of three products located on the forecastle and that permit safe and comfortable boarding for all users: An 8-step self-leveling ladder that adapts to the height required for the place of arrival, a ladder for boarding from the water with the necessary height to board from an auxiliary boat and a support product designed specifically to board in a wheelchair and stretcher, which uses a crane as a lifting means, located thus:

Fig. 5. Disposition of access products, forecastle



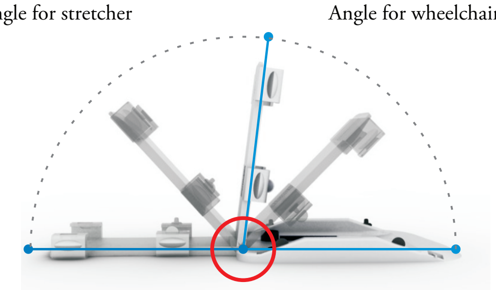
The location of the products is strategically designed to permit boarding via bow and starboard when boarding from land and via portside from the auxiliary boat.

The support product the crane uses as lifting system is a design by the DIDESI, developed within the framework of an internship in the equipment and habilitation Division, it was planned for **efficiency** by permitting boarding from water or land in wheelchair or stretcher, in addition to folding to reduce the space occupied when stored. It is **versatile** in that it allows the use of different wheelchairs and stretchers on the same platform.

The device secures the wheelchair or stretcher by means of two arms located on the upper part and secures patients with fastening belts that keep them stable, guaranteeing a safe lifting process. Finally, anthropometric and ergonomic criteria were considered (*Universidad de Antioquia, 1995*) for **comfortable** use of the product.

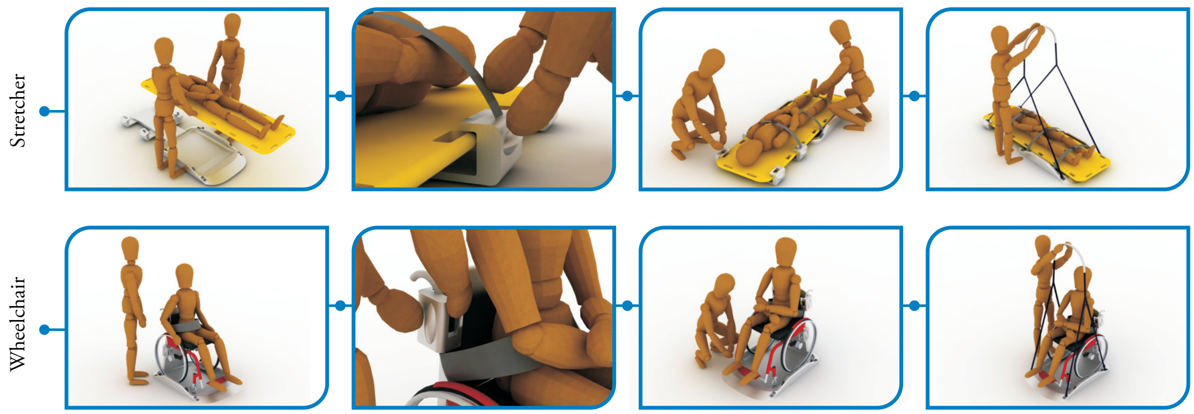
Fig. 6. Access support product for wheelchairs and stretchers

Fig. 7. Access support product, use angles



Source: Alatrista, 2008

Fig. 8. Use sequence of access support product



Source: Alatrista, 2008

For **circulation**, the first step was to establish the relationship among the medical services, this analysis was based on the study "Architectural Medical Program to Design Safe Hospitals" (*Alatrista, 2008*), which determines that among the services the following spatial links may be established (see Fig. 9 in pag. 18):

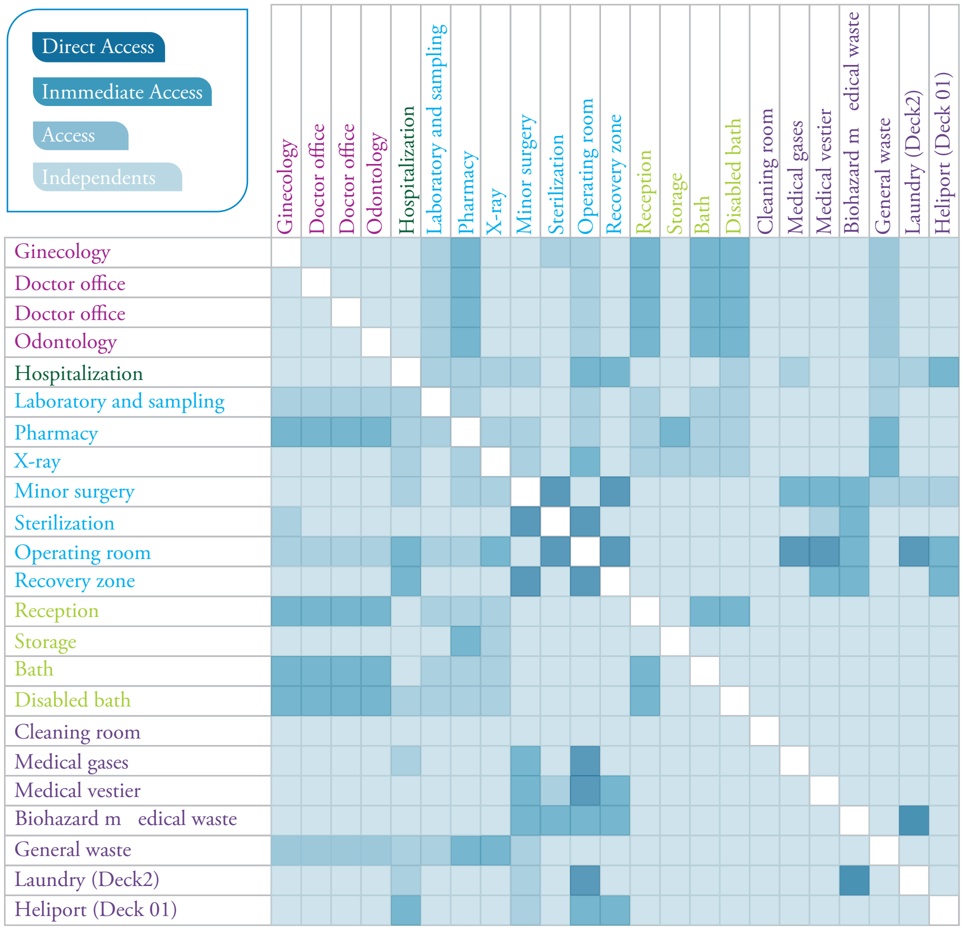
- ***Direct access:*** Units requiring to be located side by side to ensure rapid circulation, given the related tasks they perform.
- ***Immediate access:*** Units with complementary activities and which require having a rapid link for which they must have easy access and communication without necessarily being contiguous.
- ***Access:*** Units that perform related tasks, but do not require being near to each other or keep amongst them a relationship of easy communication.
- ***Independents (without relationship):*** Those without common tasks or activities

Adequate design of circulation ensures efficient movement of patients, personnel, visitors, as well as of materials and supplies, avoiding cross circulation (*Alatrista, 2008*). Additionally, it is worth considering some requirements of the medical structures like: protection of traffic in the surgery and emergency areas; crossing clean and dirty zones must be avoided, keeping hazardous wastes away from sterile zones; vertical circulation from and to the heliport, and the minimum area to provide a service.

From the aforementioned, the general arrangement was determined considering the flow of activities among compartments; for dimensioning, the regulatory reference was taken (I*CONTEC, 2005*) (*Instituto Mexicano del Seguro Social, 2000*), which suggests: minimum spaces for 90°, 180°, and 360° turns with wheelchairs and the minimum width of corridors and doors for passage of stretchers or wheelchairs, among others.

Services were also dimensioned; these are standardized by the Colombian Ministry of Social Protection (*Ministry of Health, 1996*) for land structures; however, the condition of reduced spaces within the ship does not permit the final areas to reach those required, which is why their size was reduced to the ergonomically and anthropometrically minimum necessary to develop activities in each compartment according to the service provided, considering that furnishings permit the ingress, turn, and exit of a wheelchair or a stretcher in spaces that so require it, as shown in Figs. 10 and 11 (see pag. 18).

Fig. 9. Relationships among medical services



Source: Alatrista, 2008

Fig. 10. Wheelchair circulation

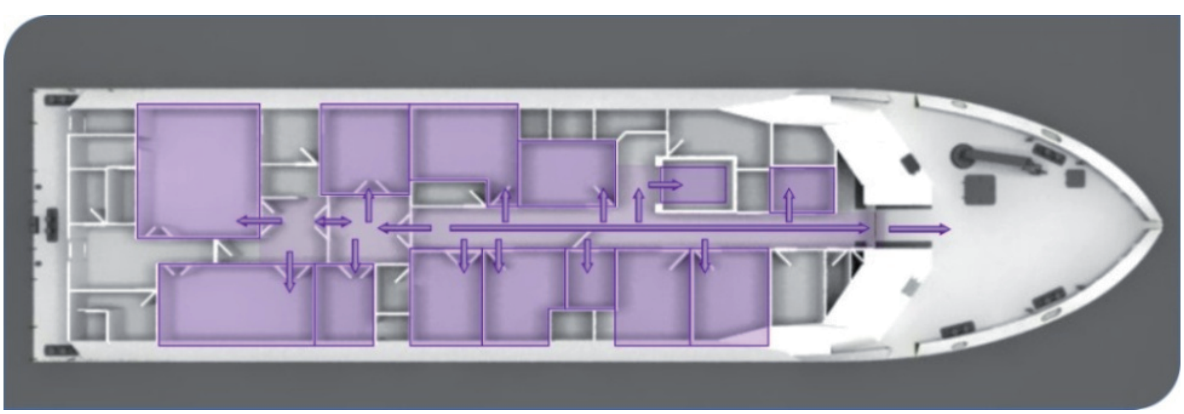
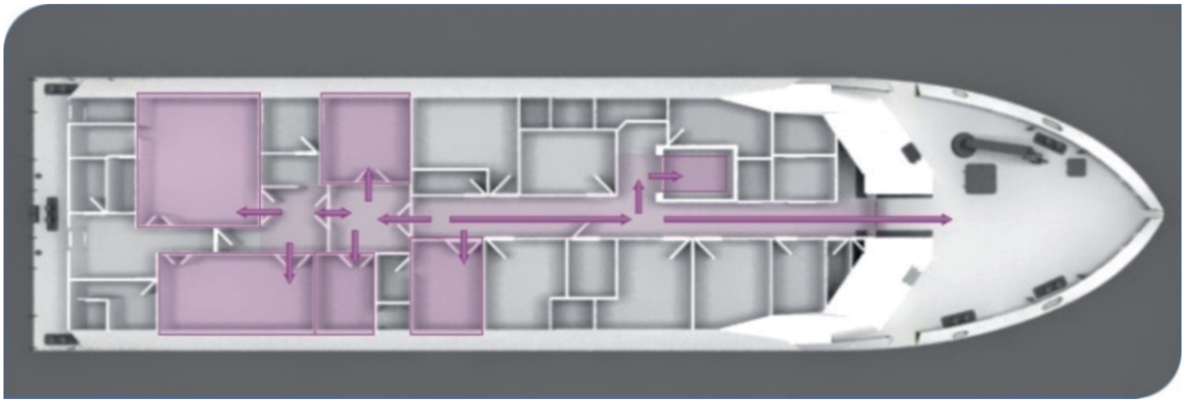
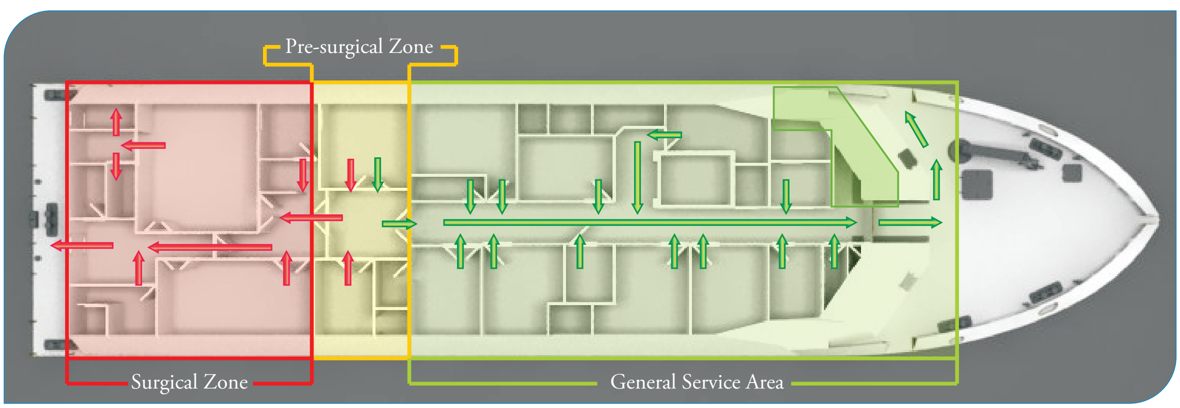


Fig. 11. Stretcher circulation



Adequate circulation of wastes is vital to provide a safe and aseptic environment, which is why two storage spaces are suggested while providing medical services: one for non-hazardous general wastes (green) and one for hazardous hospital wastes (red) resulting from surgical interventions.

Fig. 12. Management of wastes, sectors, and circulation routes



All this analysis and redesign process yielded as a result the conceptual design of the main deck as an accessible environment for wheelchair and stretcher mobility, which promotes social inclusion.

The other decks were not detailed given that patients are restricted from entering therein. The design was complemented with a system of products through which all persons – regardless of their physical condition – could safely and comfortably embark.

Conclusions

- Accessibility is not a widely studied issue in the Colombian naval industry; however, when considering it within the medical context it becomes essential and consolidated as a first step in studying the topic at the national level, which should not only be applied to ships where ingress is permitted to persons with reduced mobility; in ships in general it can contribute to optimize access to reduced spaces and to the reduction of risks during emergency cases through the arrangement of evacuation routes.

- Consideration of accessibility within the design process facilitated the elimination of environmental barriers, permitting comfortable access and circulation of persons with reduced mobility is spite of the variable context, promoting equality and social inclusion; concepts that have addressed considerably in the naval industry.

- Habitability in ships must be adapted to more specific requirements than a structure on land; occasionally, regulations leave a series of gaps where decisions must be made based on ergonomic and anthropometric criteria, as in the case of the space for medical spaces, where by studying in detail the relationships, activities, and processes it was possible to provide a solution, which although not being the recommended solution for a structure on land, permits optimally providing a service, ensuring rapid and efficient movement and communication of materials, inputs, and personnel among the medical units, besides adding conditions of bio-safety while providing medical services.

- The problem of accessibility is complex given the multiplicity of situations and variables that must be considered when evaluating its pertinence; some of these are evidenced in the case study; however, no methodology or standard exists to guide its approach. It is necessary to study each case in particular from a systemic view. This study can be taken as a reference of the analysis process.

Recommendations

- Analysis of accessibility in this study is limited to the conceptual design phase; it is recommended that subsequent design phases consider other variables like furnishings, medical equipment, and signposting for accessibility to be comprehensive.

- The accessibility standard applied in ships is scant or null in case of hospitals, which halts the development of proposals of great social contribution like the RACC; it is necessary to promote the standardization of this theme, promoting the development of the naval industry in this field.

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Vertical plane response of a ship on irregular seas

Respuesta en el plano vertical de un buque en mar irregular

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Marcelo Cali [3]

Abstract

This work presents the study of the sea response on the vertical plane for a 40-m length overall coastal patrol vessel (CPV-40) of Colombia's National Navy. The condition studied is at full load and at patrol and maximum speeds. First, we analyzed the response for regular waves with incidence angles of 90º, 120º, 150º, and 180º, obtaining the response for heave and pitch motions through the SCORES program that uses the method called "girdle theory". From the response, it was verifiedthat the amplitudeof the response is proportional to the amplitudeof the incident wave. Thereafter, the calculation of the vertical acceleration was made for four ship positions: bow, stern, cabin, and bridge, with the greatest vertical accelerations on the bow. Finally,the study was conducted for irregular sea considering as measuring parameters the vertical acceleration on the bridge and the pitching angle for the patrol operation, from the NATO document, compliance was verified of the study parameters at RMS level. It was found that for this condition the vessel complies and, hence, the personnel will not be affected in the performance of their functions.

Key words: seakeeping, irregular sea, coastguard patrol, SCORES, RMS

Resumen

En este trabajo se presenta el estudio de la respuesta al mar en el plano vertical para una embarcación de 40 metros de eslora tipo Patrullera de zona de costera, CPV-40 (por sus siglas en ingles Costal Patrol Vessel), de la Armada Nacional de Colombia. La condición estudiada es a plena carga y a velocidades de patrullaje y máxima. Primeramente se analizó la respuesta para olas regulares con ángulos de incidencia de 90º, 120º, 150º y 180º obteniéndose la respuesta para los movimientos de levantamiento y cabeceo mediante el programa SCORES que utiliza el método llamado "teoría de fajas". A partir de la respuesta se verificó que la amplitud de la respuesta es proporcional a la amplitud de la ola incidente. Posteriormente se realizó el cálculo de la aceleración vertical para cuatro posiciones en el buque: proa, popa, camarote y puente de gobierno, presentándose las mayores aceleraciones verticales en la proa. Finalmente se realizó el estudio para mar irregular considerando como parámetros de medición la aceleración vertical en el puente y el ángulo de cabeceo para la operación de patrullaje, a partir del documento de la NATO, se verificó el cumplimiento a nivel de RMS de los parámetros de estudio. Encontrándose que para esta condición la embarcaron cumple y por lo tanto el personal no se verá afectado en el desempeño de sus funciones.

Palabras claves: comportamiento en el mar, mar irregular, patrullero de costa, SCORES, RMS

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Vessel Description

The coastal patrol vessel CPV-40 is a design carried out and constructed by German shipyard, FASSMER, for the Colombian National Navy and it is designed to comply coastguard functions in the Caribbean Sea and the Pacific Ocean of the Republic of Colombia. Mainly border control and marine safety operations are among the functions performed by the vessel; additionally,the ship is in capacity of performing search and rescue operations, environmental control, and humanitarian aid, among others. It has a 15-day autonomy and capacity to transport 24 crew members, along with a 2,000-nautical mile reach at 12 knots under 245-ton displacement conditions and zero seat.

The ship has the following operational profile for 180 days of annualwork:

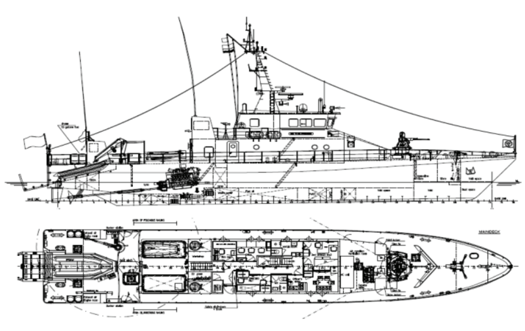
-Patrol speed from 7 to 9 knots: 55%
-Cruising speed from 12 to 15 knots: 35%
-Maximum speed from 19 to 21 knots: 10%

Main Dimensions

Length overall:	40.00 m
Beam:	7.40 m
Forestay:	3.80 m
Draft:	1.86 m
Full-load displacement:	245 Ton

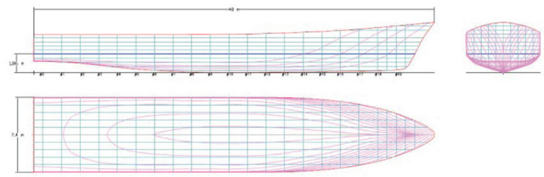
Figs. 1 and 2 show the lateral view of the general disposition, along with the CPV-40 shape lines, respectively.

Fig. 1. General disposition, lateral view



Source: Fassmet (2011)

Fig. 2. CPV-40 shape lines



Source: Fassmet (2011)

Response on regular waves

The following shows the study of the response on regular waves from the implementation of data files of the SCORES program, which permits finding the response to motions generated by irregular seasand regular waves. Values were obtained for frequency of encounter, heave and pitch amplitude, for two speed conditions (12 and 19 knots), and design draft of 1.86 m.

Heave

Figs. 3 and 4 show that the tendency in each of the extremes is: for small ratios of λ/L, the amplitudes tend to be null, except for incident waves at 90º; asthis ratio takes on values toward the far right, the response increases until reaching its maximum value.

The maximum amplitude at a speed of 12 knots is equal to the amplitudeof the incident wave. Upon increasing the speed to 19 knots, amplitudes are produced above the amplitude of the incident wave; this is noted from a wavelength 1.5 times the length overall. If the incidence angle of the wave train is 90°, increased response does not occur with increased speed.

For both speeds, the wave train incidence angle only affects for wavelengths below 1.5 times the length overall; for higher wavelength values, the heave response remains constant in the maximum value.

With higher speed, higher heave amplitude for incidence angles 120º, 150º, and 180º.

Fig. 3. Heave graphic Vs.Wavelength / Length, speed 12 Kn

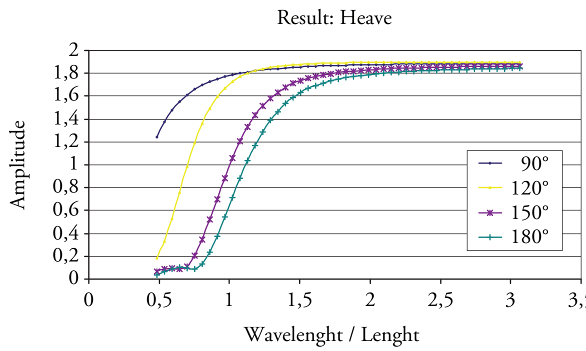


Fig. 5. Pitching graphic Vs.Wavelength / Length,speed 12 Kn

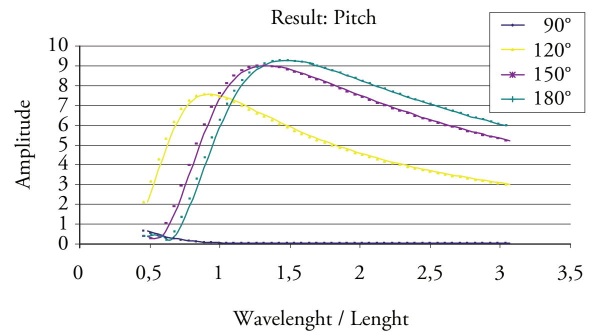


Fig. 4. Heave graphic Vs.Wavelength / Length, speed 19 Kn

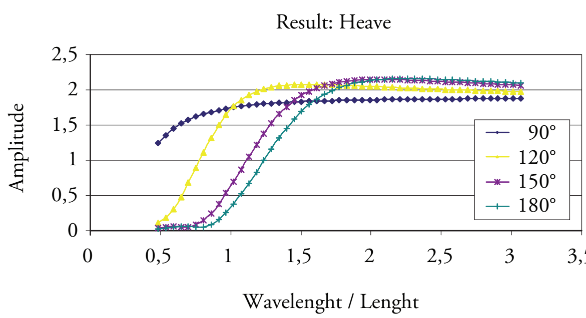
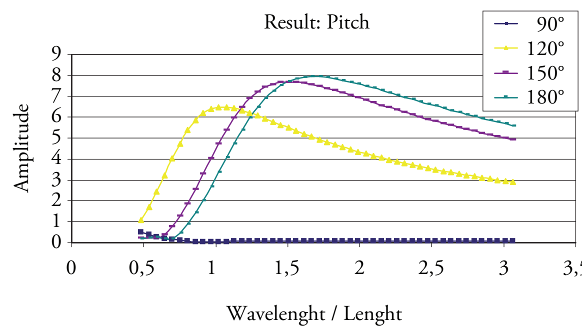


Fig. 5. Pitching graphic Vs.Wavelength / Length,speed 19 Kn



Pitching

Figs. 5 and 6 show that the tendency in each of the extremesis: at small wavelength/ship ratios the amplitude tends to be null; as the ratio takes on values toward the far right, the amplitude shows a negative slope.

When the incidence angle is 90° the amplitude is null, as expected, given that the wave trains on the side do not produce pitching but balance because the ship's length overall is aligned with the wave crest (front of the wave). The amplitude increases as the incidence angle increases. As the vessel's course is changed toward 90º, responses decrease.

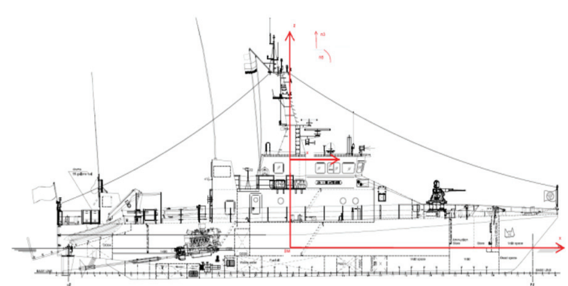
Within an intermediate range of λ/L, the maximum amplitude value occurs, presenting the resonance phenomenon. The highest resonance responses occur when the waves come from the bow, that is, at 180°.

Calculation of vertical acceleration

For vertical acceleration, four points on the ship were analyzed: bow, stern, bridge, and cabin.

x_1 = 3.0 m $\quad$ x_2 = 16.5 m

x_3 = -3.6 m $\quad$ x_4 = -18.0 m



Source: Fassmet (2011)

The motion equationfor the vertical plane is given by:

$$\omega(x,t) = \eta_3 - x \cdot \eta_5$$

$$\omega(x,t) = \zeta_3 e^{i(\omega t + \theta_3)} - x\zeta_5 e^{i(\omega t + \theta_5)}$$

$$\omega(x,t) = (\zeta_3 Cos\,\theta_3 + i\,\zeta_3 Sen\,\theta_5 - x\,\zeta_5 Cos\theta_5 - ix\,\zeta_5 Sen\,\theta_5)e^{i\omega t} \quad (1)$$

$$W = \sqrt{R_{eal}^{\;2} + I_{mg}^{\;2}}$$

$$|\ddot{\omega}|(x,t) = \omega_e^{\,2}\, W$$

From the data given by the SCORES program, values are takenfor phases and amplitudes in heave and pitch with which calculation is made of accelerations for each point and these are seen in Figs. 10 and 11.

Fig. 10. Graphic of Vertical acceleration Vs. Wavelength/ Length Speeds of 12 Kn

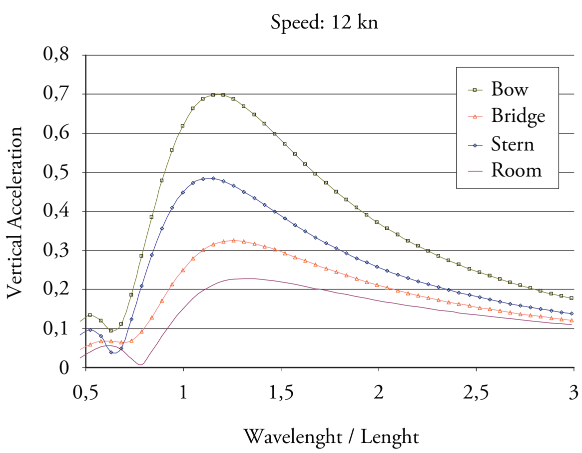
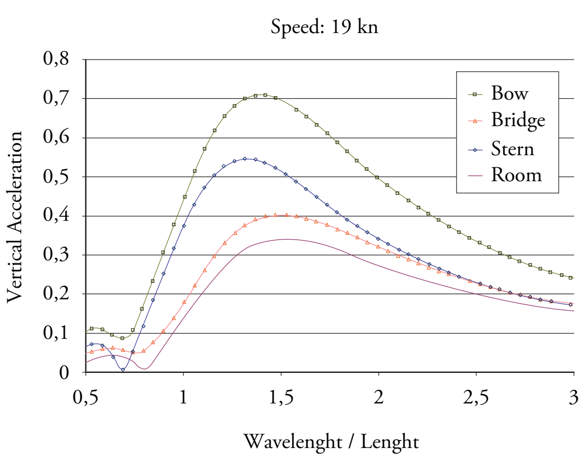


Fig. 11. Graphic of Vertical acceleration Vs. Wavelength/ Length Speeds of 19 Kn



From Figs. 10 and 11, it may be noted that the highest accelerations occur in the bow; these are given for wavelength/ship ratios between 1.2 and 1.5 when speedis 12 knots and between 1.4 and 1.5 for speedof 19 knots. The lowest accelerations occur in the cabin, which is a point to stern closet o the mid section.

Response in irregular sea

Continuing with the study, heave and pitch motions were considered in irregular seas, establishing as measuring parameters acceleration on the bridge and the pitching angle. NATO [1],in its publication *"Common Procedures for seakeeping in the ship design Process"*, established recommendations of parameter acceptance limits according to the mission for military ships. This study took as acceptance limits those recommended in said publication for personnel performance; these are detailed in the following table:

Table 1. Acceptance parameters according to NATO

Motion	Limit	Location
Motion sickness incidence (MSI)	20% of the crew @4h	Work place
Motion-induced interruption (MII)	1/min	Work place
Relative wind	35 knots	Work place if on exposed deck
Roll	4°	
Pitching	1.5°	Bridge
Vertical acceleration	0.2 g	Bridge
Lateral acceleration	0.1 g	Bridge
Relative wind	35 knots	Flight deck

This work was limited to analyzing vertical acceleration on the bridge and pitching angle measured in terms of RMS.

The condition of the ship for the analysis is at full load and at patrol speed of 12 knots, with 180° incident waves with respect to ship motion (sea by bow). Likewise, according to the operation zone, a sea state of 4 is established with the following characteristics:

- Significant wave height (Hs): 1.88 m
- Period (Tp): 7.6 s.
- Wind speedBft: 10 knots

From the results on regular waves, we calculated the spectrum of the parameter response from the following equation:

$$S^{+}_{\mathrm{Re}\,sp}(\omega_e) = S^{+}_{Olas}(\omega_e)\, RAO^{2} \qquad (2)$$

$RAOS^{2}$ of the parameters analyzed are presented in the following figures:

Fig. 12. RAOS² for vertical acceleration

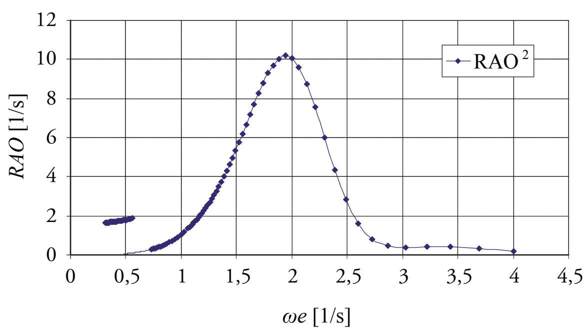
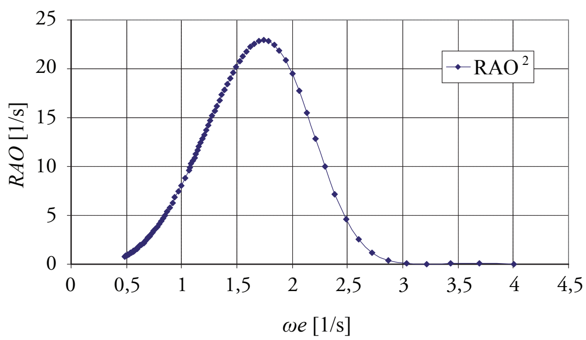


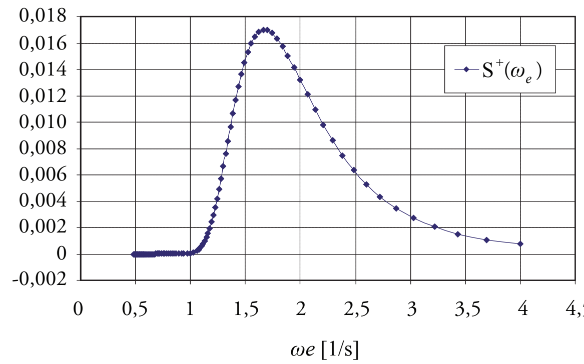
Fig. 13. RAOS² for pitching



The representation of the spectrum of the irregular sea for the state of this study was developed from the Pierson-Moskowitz formula, which is presented in Fig. 14.

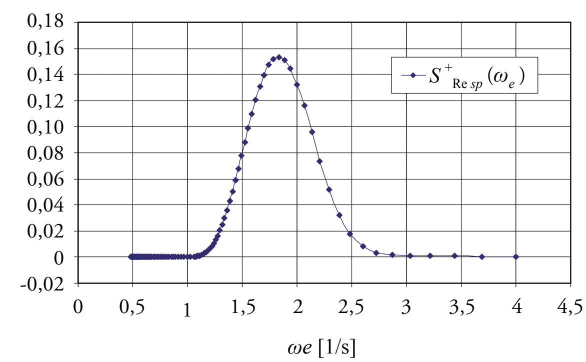
$$S^{+}(\omega) = \frac{8.1x\,10^{-3}}{\omega^{5}} g^{2} e^{-0.74\,(g/V\omega)^{4}},\ S.I \qquad (3)$$

Fig. 14. Wave spectrum



The response spectra were obtained from equation (2); these are presented in the following:

Fig. 15. Spectra of the response for vertical acceleration



Variance and RMS of the response are obtained from the following equation:

$$\sigma_{\mathrm{Re}\,sp}^{\;2} = \int_{-\infty}^{\infty} d\omega_e\, S_{\mathrm{Re}\,sp}^{\;+}(\omega_e) = RMS^{2} \qquad (4)$$

The results for the responses and the recommended limit values in terms of RMS are presented by the following table:

Table 2. Recommended limit values in term of

Motion	CPV	Limit	Location
Pitching	0.54°	1.5°	
Vertical acceleration	0.03 g	0.2 g	Bridge

From the previous table, it can be noted that for the condition at full load, navigating at a speed of 12 knots and at sea state of 4, crew performance will not be affected.

Compliance of the recommendations also implies analysis of other events of occurrence, like: immersion of the stern, slamming, and others. These can be obtained from the moments of the response spectrum from the following equation:

$$m_n = \int_0^{\infty} d\omega \ \omega^n \ S^+(\omega_e) \quad (5)$$

Moments Mo, M2, and M4 were obtained and are represented in the following tables:

Table 3. Moments M_o, M_2, and M_4 for vertical aceleration

Moments	Units	Vertical acceleration bridge
M_o	[m2/s^4]	0.11
M_2	[m2/s^5]	0.141
M_4	[m2/s^7]	0.184

Table 4. Moments M_o, M_2, and M_4 for pitching

Moments	Units	Pitching
M_o	[Degrees^2]	0.29
M_2	[Degrees2/s]	0.33
M_4	[m2/s^3]	0.39

Conclusions

From the present study, the following may be concluded:

- The response amplitude is proportional to the amplitude of the incident wave.
- Of the factors studied in this work, ship speed, incidence angle of the wave trains, wavelength and amplitude, the most significant in heave amplitude is wavelength, and for the pitching amplitude it is ship speed.
- The incidence angle of the wave trains is not significant for heave; only its interaction with speed and wavelength.
- The values of maximum acceleration appear in the bow and the minimum values in the cabin, which is the nearest point to the mid section.
- In the condition at full load, navigating at a speed of 12 knots, and sea state of 4 crew performance will not be affected.

References

[1] NATO, North Atlantic Treaty Organization, December, Military agency for standardization 2000.

[2]LEWIS E. Principles of Naval Architecture. Volume III. Motions in waves and Controllability. ISBN 0-939773-02-3. November, 1989.

Computational models for anti-air and anti-submarine warfare simulation

Modelos computacionales para simulación de guerra antiaérea y antisubmarina

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José Gómez Torres [3]

Abstract

This paper describes the generation and simulation process of computational models oriented to the analysis of the operational situations (OPSIT) of anti-air warfare (AAW) and antisubmarine warfare (ASW), with the purpose of evaluating the effectiveness of different combinations of threats, weapons, and sensors of the Colombian Navy. A detailed description of the OPSITs modeling process is presented by using the selected discrete events simulation tool. The experiments design process and the statistical analysis of the results is also described, using a statistical analysis tool. All this to provide the Colombian Navy with a tool it can use to evaluate the systems that could be part of future units.

Key words: Simulation, discrete events, modeling, antisubmarine warfare, anti-air warfare, experiment design

Resumen

El documento describe el proceso de generación y simulación de modelos computacionales orientados hacia el análisis de unas situaciones operacionales de guerra antiaérea (AAW) y Antisubmarina (ASW), con el fin de evaluar la efectividad de diferentes combinaciones de amenazas, armas y sensores de la Marina Colombiana. Se presenta una descripción detallada del proceso de modelación de las situaciones operacionales en la herramienta de simulación de eventos discretos seleccionada, así como también se describe el proceso de diseño de los experimentos y el tratamiento estadístico de los resultados, empleando una herramienta de análisis estadístico. Lo anterior tendiente a proporcionar a la Armada Colombiana, una herramienta para la evaluación de los sistemas que podrían componer las futuras unidades.

Palabras claves: simulación, eventos discretos, modelación, guerra antisubmarina, guerra antiaérea, diseño de experimentos.

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Introduction

Simulation tools allow modeling phenomena or events of different complexity and are used as support tools in the decision making process because they base their predictions on mathematical methods that yield results that are very close to the real ones. In fact, simulation can be defined as the act of imitating a real system, representing certain characteristics or its behavior.

This document seeks to describe the process of generating and simulating computational models of antisubmarine (ASW) and anti-aircraft warfare (AAW) by using discrete event simulation. The aim of the development of such models is to use them as tools for conceptual exploration of future units to evaluate the effectiveness of different weapons system configurations considered at this stage. That means that these models will be other tools to optimize processes of conceptual design of units afloat.

The methodology used to develop the models begins with the selection of operational situations to simulate, then it is necessary to identify the different threats, weapons, and sensors and their possible combinations within the selected scenario; this is introduced to the selected simulation tool and results obtained will undergo statistical processing to successfully analyze them.

Conceptual Framework

Some key concepts related to this topic are presented to provide tools to improve understanding of the paper.

Discrete Event Simulation

Discrete event simulation is a computer technique for dynamic systems modeling. In this type of simulation, events are generated and managed over time using an event queue ordered by the simulation time in which events must occur, thus, the simulator can read the queue and trigger new events.

Operational situation (OPSIT)

Operational situations are the scenarios used as base for evaluating different configurations of weapons, sensors, and threats for both ASW and AAW.

OPSIT Selection and Description

To select OPSITs that will be simulated, it was necessary to gather a group of experts in ASW, which comprised ASW officers and petty officers from ARC Almirante Padilla type frigates of the Colombian Navy and for a submarine warfare expert from the Colombian submarine fleet. For AAW, it was possible to obtain technical advice from an officer from DARET and an officer who is studying in the Naval Postgraduate School (NPS).

For ASW the publication MXP-1 (D) (Navy) (Air) of the U.S. Navy (Multi-National Submarine and Anti-Submarine Exercise Manual) was taken as reference from which two operational scenarios were selected among several proposed. For ASW, the OPSITs selected are:

1. Port leaving with submarine opposition. (Similar to Casex C-7)
2. Coordinated submarine search in an area.

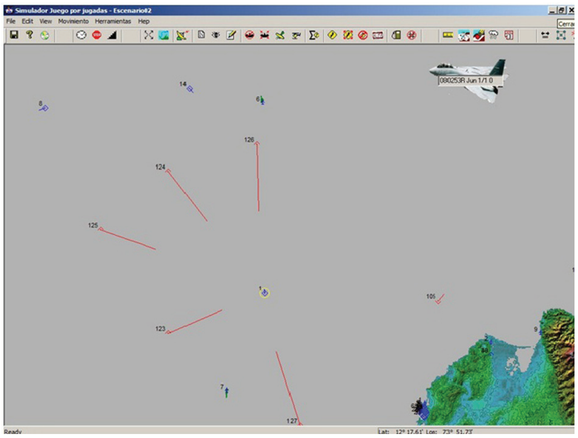
The configuration of each OPSIT depends on the specific need to be evaluated. For cases presented in this document, the units involved in the first OPSIT are: two ships (with Helicopters), one tanker (main body), and one submarine.

In the second OPSIT had: one ship (with helicopter) and one submarine.

The first OPSIT mission is the main body protection and neutralization of the threat, while for the second OPSIT, the only objective is to neutralize the threat.

Fig. 1 provides an overview of the AAW OPSIT, showing enemy aircraft in red and the unit attacked is in the center in blue. In this case, the unit's fundamental mission is to defend itself against the attacks.

Fig. 1. Panorama of the AAW OPSIT



For AAW, the OPSIT was basically modeled as missile air defense, where a ship is the target of a coordinated enemy aircraft attack, using air-surface missiles (ASM).

Mission Evaluation

In order to have metrics to evaluate each mission, some requirements have been designed to determine its success, based on the calculation of measures of performance (MOP) and a measure of effectiveness (MOE) for each OPSIT.

The measure of effectiveness is defined by the weighted sum of the measures of performance established; that is:

$$MOE = W_1 \cdot MOP_1 + W_2 \cdot MOP_2 + \cdots W_n \cdot MOP_n \quad (1)$$

Where W_1, W_2, W_n are factors representing the importance of each MOP. For ASW, these values were determined from surveys made in that regard to two of the commanders of Almirante Padilla type frigates of the Colombian navy.

In the ASW OPSIT, the MOPs are:

- MOP_1 = Tanker survival probability
- MOP_2 = Survival probability of the ships
- MOP_3 = Threat neutralizing probability

And the MOE of this OPSIT is:

$$MOE = 0{,}25 \cdot MOP_1 + 0{,}25 \cdot MOP_2 + 0{,}5 \cdot MOP_3 \quad (2)$$

For the second ASW OPSIT, the MOPs are:

- MOP_1 = Survival probability of ships
- MOP_2 = Threat neutralizing probability
- MOP_3 = Time to detect the submarine

And the MOE of this OPSIT is:

$$MOE = 0{,}25 \cdot MOP_1 + 0{,}34 \cdot MOP_2 + 0{,}41 \cdot MOP_3 \quad (3)$$

Finally, for the AAW OPSIT, the MOP is equal to the MOE; due to this, only one MOP will be evaluated:

- MOP1 = Survival probability of ships

And the MOE is:

$$MOE = MOP_1 \quad (4)$$

Threat Characterization

The AAW OPSIT takes into account three possible threats. Bear in mind that for this particular case, ASM missiles and not the planes are assumed as direct threats, given the assumption that a plane is not going to approach within the range of the ship guns.

Data presented in Table 1 are some of the features of the threats selected.

Table 1. AAW OPSIT threats characteristics

Threat	Characteristics	Values
MISSILE 1	Speed	0.88 Match
	Range	62 MN
	RCS	0.2 m
	Shooting distance	60 MN
	Final phase height	18 ft

MISSILE 2	Speed	2.5 Match
	Range	27 MN
	RCS	0.1 m
	Shooting distance	25 MN
	Final phase height	15 ft
MISSILE 3	Speed	0.93 Match
	Range	36 MN
	RCS	0.2 m
	Shooting distance	35 MN
	Final phase height	9 ft

Both ASW OPSITs take into account two possible threats. The general characteristics of the two submarines, which are relevant to the appropriate development of the models, are presented in Table 2.

It is worth stating that the selection of the threat and its operating characteristics are subject to change, depending on the needs of the situation.

Table 2. ASW OPSITs threats characteristics

	Submarine 1	Submarine 2
Sonar:	STN Atlas DBQS40 sonar suite: detection sonar	Integrated Lira system, incorporating the hydrophones horseshoe and flank arrays;
Torpedo:	12 [maximum speed 35 kt; range 28 km at 24 kt; 12 km at 35 kt]	18 [Speed: 30-50 kt, Range: 27 n miles/13.5 n miles]
Missile:	Optional.	10 VLS cells.
Counter-measures:	Defense system Tau torpedoes	N/A.-
Speed:	12 kt (surface) 20 kt (submerged)	10 kt (surface) 19 kt (submerged)
Range:	8,000 Mn at 8 kt (surface); 420 Mn at 8 kt (submerged)	6,000 Mn at 7 kt (surface); 650 n miles at 3 kt (submerged)
Operational depth:	700 m	300 m

Technological Options

For the ASW OPSITs, the technological weapons and sensors options taken into account are presented in Table 3.

Table 3. ASW Technological Options

	Technological Options	Variable
Hull sonar	Option 1	Frequency: (4.5 kHz) Power: 96 kW
	Option 2	Frequency: (7. 5 kHz) Power: 36 kW
VDS	Option 1	Frequency: (12 kHz)
	Option 2	Frequency: (5 kHz) Power: 96 kW(peak)
TAS	Option 1	Frequency: (< =1 kHz)
	Option 2	Frequency: (< =1 kHz)
Ship torpedo	Option 1	Speed: 28 kt Range: 13.5 Km
	Option 2	Speed: 29 kt Range: 23 Km
	Option 3	Speed: 45 kt Range: 11.11 Km
ASW Helo.	Option 1 (8 sonobuoys 1Torpedo)	Autonomy: 1.4 Hours Torpedo: Option 2
	Option 2 (VDS 1Torpedo)	Autonomy: 2 Hours Torpedo Option 1

For the AAW OPSIT, configurations of the ship weapons and sensors that will be evaluated in the simulation are shown in Table 4 and technological options taken into account appear in Table 5.

Table 4. Ship configuration options

	Radar	ESM	SAM	CANNON	CWIS	ECM	CHAFF
Config. 1	Opt. 1	Opt. 1	Opt. 2	Opt. 1 and 2	NO	Opt. 1	Opt. 1
Config. 2	Opt. 2	Opt. 2	Opt. 1	Opt. 1 and 2	NO	NO	Opt. 2

Table 5. AAW technological options

		Options	Characterístics	Values
SENSORS	**Radar**	Option 1	Maximum Theoretical Range	10.79 MN
			Antimissile probability	80%
		Option 2	Maximum Theoretical Range	10.79 MN
			Antimissile probability	80%
	ESM	Option 1	Sensitivity	-75 dBm
			Minimum Frequency	1 GHz
			Maximum Frequency	18 GHz
		Option 2	Sensitivity	-65 dBm
			Minimum Frequency	0.5 GHz
			Maximum Frequency	40 GHz
WEAPONS	**SAM**	Option 1	Range	8.09 MN
			Speed	2.5 Match
			Impact probability	30%
			Minimum distance	0.4 MN
		Option 2	Range	8.09 MN
			Speed	2.5 Match
			Impact probability	30%
			Minimum distance	0.4 MN
	CANNONS	Option 1	Caliber	127 mm
			Shots per minute	40
			Effective range	16.19 MN
			Minimum distance	0.3 MN

WEAPONS	CANNONS	Option 2	Caliber	40 mm
			Shots per minute	300
			Effective range	3.2 MN
			Minimum distance	0.3 MN
		Option 3	Caliber	76 mm
			Shots per minute	120
			Effective range	16.19 MN
			Minimum distance	0.3 MN
		Option 4	Caliber	20 mm
			Shots per minute	450
			Effective range	1.07 MN
			Minimum distance	0.2 MN
	ECM	Option 1	Reaction time	1 sec
			Simultaneous threats	Yes
	CHAFF	Option 1	Cloud time	40 sec
			Fake target size	10,000 m2
			IR Signature	yes
		Option 2	Cloud time	40 sec
			Fake target size	10,000 m2
			IR Signature	yes

Simulation Models

To make the OPSITs models in the simulation tool it was necessary to develop a logic diagram to have greater clarity on the logical relationships among the different processes occurring in each. Fig. 2 presents one example.

The general scheme for the development of simulation models is presented in Fig. 3.

Endogenous variables that constitute the inputs or the simulation model are on the left side of Fig. 3; the state variables, which condition the simulation process, are on the central part, and – finally – the exogenous variables as result of the process are in the right side of the figure.

Then, the modeling process begins in the simulator. An example of the blocks created in the simulator is presented in Fig. 4 (see pag. 36).

For the AAW OPSIT, the model starts with the creation of a couple of objects, which will be necessary for assigned properties, these properties are read from an Excel spreadsheet that has all the values needed for the model to function. Once read, these properties are stored in the object in form of attributes.

Fig. 2. Logical diagram for variable initialization of AAW OPSIT

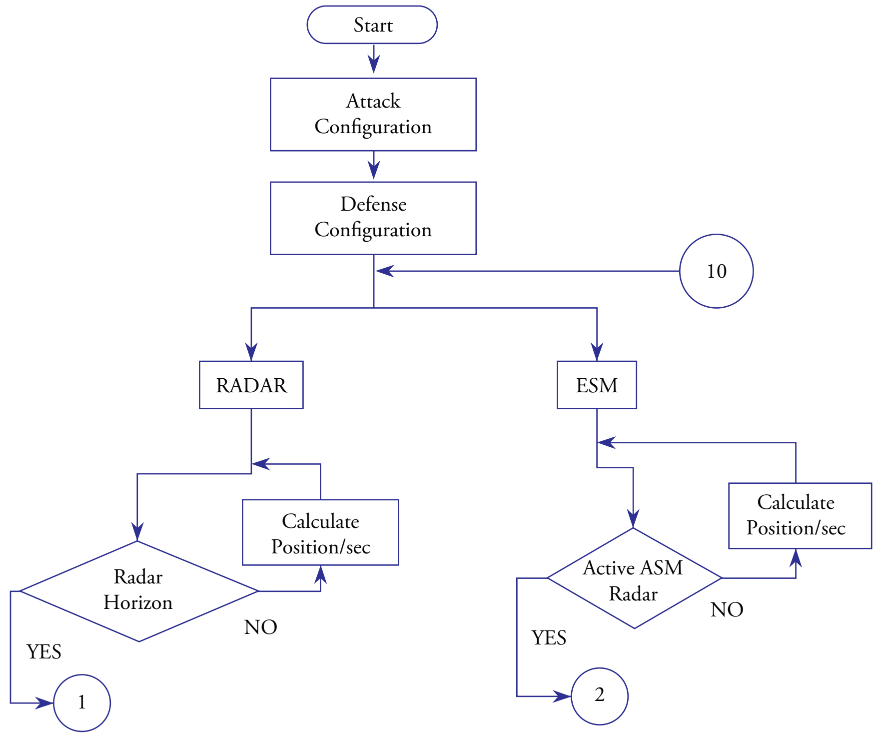


Fig. 3. General diagram of the simulation process

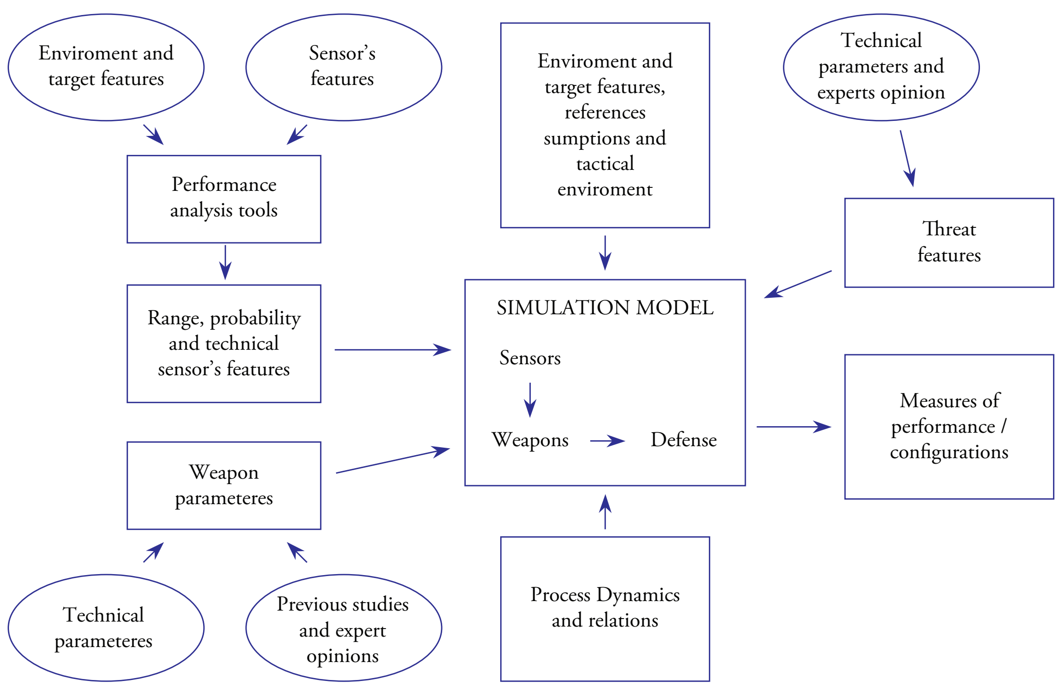
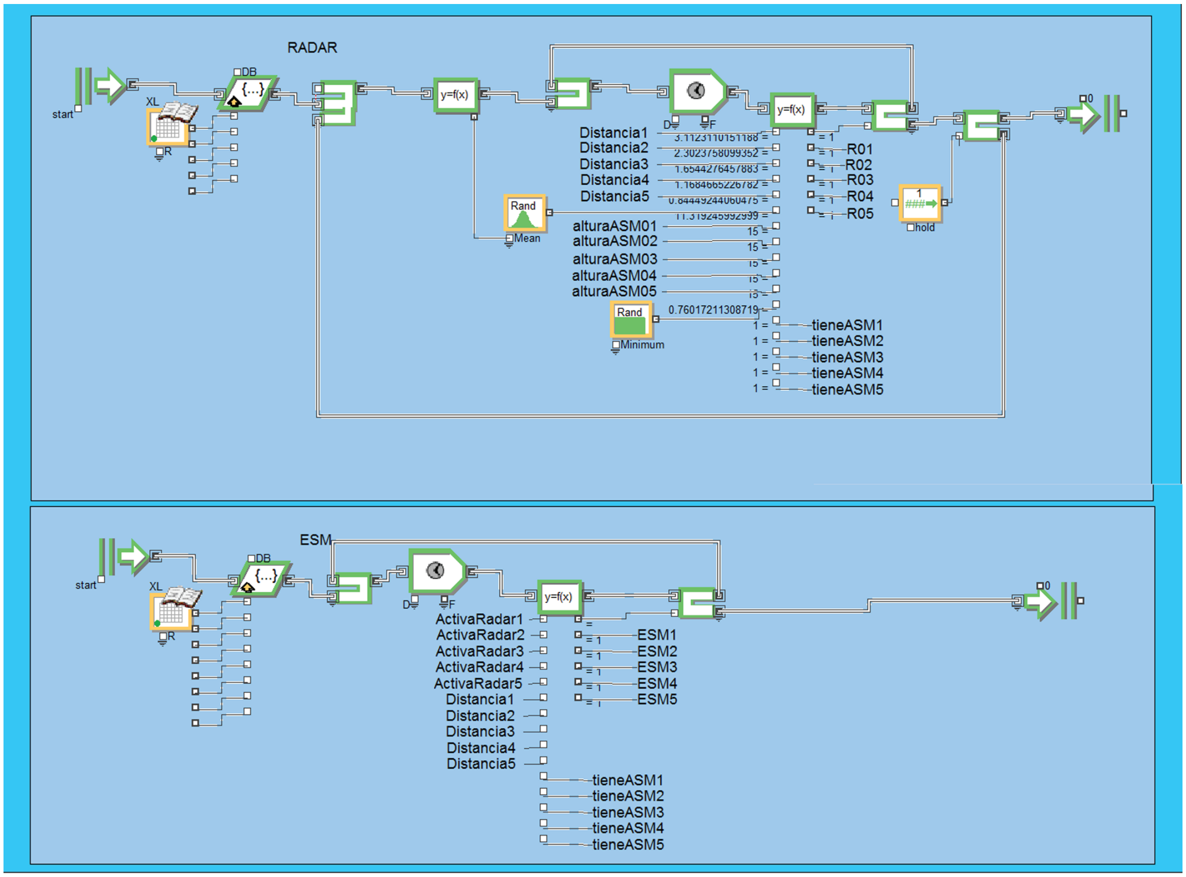


Fig. 4. AAW ship sensor model in the simulator



When each object has its attributes, it is necessary to calculate whether threats are within the detection range of each sensor. If threats are within range, the sensor determines the distance and sends the information to a queue of weapons that will assign the appropriate defense (defense of barriers concept); otherwise, the sensor will continue sweeping the area until achieving detection.

In general, the AAW model block presented in Fig. 4 was used to simulate the dynamic approach (simulation sampling) of enemy missiles fired. When these missiles are within range of the sensors, detection occurs. This detection activates a weapons assignment queue, which is another object or event in the simulation.

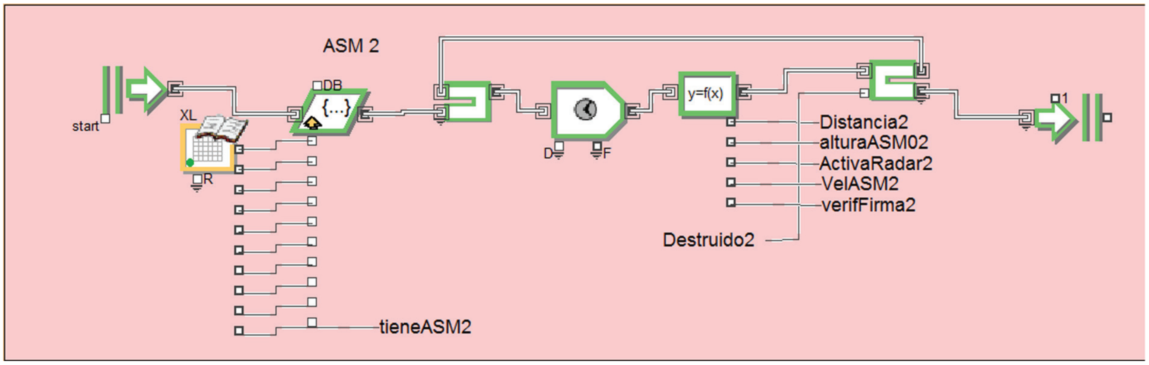
Likewise, all OPSIT threats were modeled in the simulator. The activation of each threat constitutes an event in the simulation. For the AAW OPSIT, the specific threats are ASM missiles; therefore, these were modeled in the simulator, as shown in Fig. 5.

For the case shown in Fig. 5, the simulation begins with the activation of each threat in the Excel spreadsheet. The model loads the properties of each missile, which are read from the Excel spreadsheet that has all the values needed to run the simulation. Once the properties have been read, they are stored in the object (an object for each threat) in the form of attributes.

Subsequently, the algorithm that allows:

- Calculate the path of the trajectory of the missile's towards the vessel.
- Activate the missile radar when is located at a specified distance from the ship.
- Activate the missile's Electronic Counter-Countermeasures systems (ECCM).
- Placing missiles in the final height, stipulated in the Excel document.

Fig. 5. Threats simulator model



Finally, the algorithm receives from the weapons queue the weapons assignment, the missile deactivation order, in case this was shot down by the weapon system.

Experimental Design and Results

To define the configurations of the experiments to be run in the discrete event simulator, it was necessary to perform an experimental design for which we used the JMP software, a tool for data statistical analysis.

Basically, the process consists of introducing the variable names that will result from the experiments, which in this case are the MOP raised on initial sections for each OPSIT and, factors that intervene in the experiments, which in this case are the different sensors and weapons selected for evaluation.

Once we have the necessary data, the experimental design is generated and a list of data is obtained for each experiment. Each experiment is run the necessary number of times to obtain acceptable statistical data.

For the first ASW OPSIT, the resulting design of experiments is 18, which means that it is possible to evaluate 18 possible scenarios. For each of them, Table 6 presents its measures of performance. In the second ASW OPSIT, the software showed that 30 experiments would be needed. The results of MOP for this scenario are presented in Table 7.

Finally, for the AAW OPSIT, six experiments were made, considering the two specific vessel configurations of sensors and weapons that were shown in Table 5, only varying the threat.

The results for this MOP scenario are shown in Table 8.

For these OPSITs, the reliability of the models simulated was evaluated in the statistical analysis software and the relative importance of each variable in each configuration was verified.

Table 6. ASW OPSIT1 Experiment Design Results

Experiment	MOP 2	MOP 1	MOP 3
1	27.60%	28.30%	0.00%
2	43.30%	44.40%	54.40%
3	30.85%	30.70%	28.60%
4	41.10%	40.20%	50.30%
5	27.45%	27.50%	0.70%
6	43.85%	44.50%	49.40%
7	34.50%	34.20%	26.40%
8	27.85%	28.70%	0.00%
9	33.95%	33.90%	30.00%
10	40.65%	41.30%	21.70%
11	31.25%	31.60%	24.90%
12	44.50%	43.90%	21.30%

13	49.50%	49.10%	49.10%
14	28.35%	29.50%	4.00%
15	50.00%	52.30%	45.50%
16	43.85%	43.40%	50.40%
17	36.30%	38.00%	0.00%
18	38.40%	37.50%	0.00%

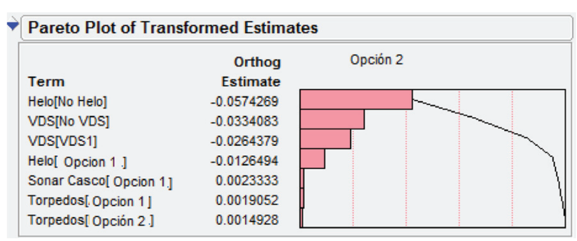
Table 7. ASW OPSIT2 Experiment Design Results

Experiment	MOP 1	MOP 2	MOP 3 (Min)
1	25.00%	12.40%	2453.253
2	84.48%	63.14%	912.747
3	32.10%	16.26%	2305.71
4	59.36%	42.38%	1525.92
5	83.10%	62.46%	973.896
6	49.74%	26.22%	2065.041
7	52.72%	31.72%	1912.449
8	50.64%	28.44%	2003.331
9	32.12%	15.36%	2367.981
10	50.64%	28.44%	2003.331
11	75.46%	54.44%	1205.028
12	70.12%	51.12%	1275.153
13	48.90%	32.96%	1808.103
14	52.96%	31.24%	1924.791
15	15.14%	3.24%	2703.459
16	75.96%	56.44%	1162.953
17	69.56%	50.28%	1306.008
18	55.42%	32.28%	1828.86
19	49.88%	37.84%	1739.661
20	49.88%	27.44%	2030.259
21	70.94%	54.38%	1170.246
22	73.32%	49.88%	1440.648
23	85.28%	65.20%	908.259
24	56.96%	32.88%	1809.225
25	50.86%	39.14%	1702.074
26	48.74%	24.70%	2107.677
27	51.92%	29.92%	1962.378
28	83.74%	59.62%	1075.437
29	75.58%	56.56%	1153.416
30	66.94%	50.92%	1271.226

The analysis of variance results provided by the software allows having a high level of confidence on the statistical model because correlation coefficients were obtained between 0.88 and 0.99, meaning that the models in the discrete event simulator produce consistent data.

Considering the results presented in the Pareto plots, similar to what is presented in Fig. 6 for both ASW OPSITs, it was possible to note that at least 45% of the variability of the model depends on the presence or absence of helicopters. Also, it was clear the relevance the VDS/TAS-type sensor has; in fact, at least 18% of the variability of the model depended on the lack of these sensors on the platform.

Fig 6. ASW OPSIT 1 Pareto Plot of MOP_2



The results obtained from the AAW simulation model, for characteristics raised in each experiment, show that configuration 1 has the best performance, given that it can attend all missiles simultaneously. This is a significant advantage, given that it reduces weapons reallocating dependence. Similarly, the weapons range of configuration 1 is higher than the weapons range of the other configuration, allowing saving time during the defense process.

Table 8. AAW OPSIT experimental design results

	Missile 1	Missile 2	Missile 3
Config. 1	17%	39%	60%
Config. 1	14%	32%	44%

Regarding threats, missile 2 showed that because of its high speed, the probability of survival of the platform to which it is confronted is greatly reduced and, in some cases, weapons systems are completely ineffective against this threat, given that the highest probability of survival obtained at the end of the simulations does not exceed 20% in any case.

Conclusions

With the tactical situations presented in the paper, it was possible to evaluate the relationships between weapons and sensors systems, which allow inferring that with a common configuration of weapons and sensors, it will be possible to evaluate tactical situations that ultimately lead to a study of doctrine or tactical procedures, using these same models.

The models structured have high flexibility to adapt to any type of analysis; these could be about threats or configuration of the platforms. Excel interfaces facilitate data input process and final statistics.

Also, it was possible to observe, through the experimentation process, that a strong relationship exists between the sensor and weapon selected, *i.e.*, it is not possible to obtain the expected results when the features of one of the two exceeds the other because it is not significant to have a sensor with a long range, if the weapon used cannot neutralize the threat detected.

Finally, it is important to note that the results obtained from the simulation of these models allow validating these methods; however, these are not convincing to make decisions on what is the best configuration because too much of the data or characterizations of the weapons, sensors, and threats provided to the model were speculative due to the absence of information available in the market. This implies that upon making the analysis of real equipment that could be installed in future ships; it is necessary for sensors and weapons manufacturers to provide the necessary information to perform an analysis that could help to conclude about the best configuration.

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Development of a neural network model to predict distortion during the metal forming process by line heating

Desarrollo de un modelo de red neuronal para la predicción de distorsión durante el proceso de formado metálico utilizando líneas de calentamiento

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Abstract

In order to achieve automation of the plate forming process by line heating, it is necessary to know in advance the deformation to be obtained under specific heating conditions. Currently, different methods exist to predict deformation, but these are limited to specific applications and most of them depend on the computational capacity so that only simple structures can be analyzed. In this paper, a neural network model that can accurately predict distortions produced during the plate forming process by line heating, for a wide range of initial conditions including large structures, is presented. Results were compared with data existing in the literature showing excellent performance. Excellent results were obtained for those cases out of the range of the training data.

Key words: network model, plate forming, distortion prediction, line heating, back propagation

Resumen

Con el fin de lograr la automatización del proceso de formado metálico por medio de líneas de calentamiento, es necesario conocer de antemano la deformación que se obtendrá bajo condiciones de calentamiento específicos. En la actualidad, hay diferentes métodos para predecir la deformación, pero, éstos se limitan a aplicaciones específicas, y la mayoría de ellos dependen de la capacidad computacional existente, de modo que sólo estructuras simples pueden ser analizadas. En este artículo, un modelo de red neuronal que puede predecir con precisión las distorsiones producidas durante el proceso de formado de placas curvas mediante líneas de calentamiento, para una amplia gama de condiciones iniciales, incluyendo estructuras de gran tamaño es presentado. Los resultados del modelo de red neuronal fueron compararon con datos existentes en la literatura y estos muestran una excelente precisión. Para aquellos casos que están fuera del rango de datos de entrenamiento de la red también se obtuvieron excelentes resultados.

Palabras claves: Modelo de red, formación de placa, predicción de la distorsión, line heating, retropropagación

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Introduction

The process of forming three-dimensional surfaces via line heating has been used for several decades in shipbuilding. The procedure is performed manually and it is considered one of the most difficult to understand techniques.

Thus, it becomes difficult for shipyards to maintain a sufficient number of technicians, who are able to do this work without many complications [1].

This leads us to conclude that it is necessary to automate the system in order to restore the small number of skilled workers. To achieve this goal, many investigation projects have been carried out. They can be divided into three main groups: those seeking to understand the situation [2, 3, and 4], those wishing to develop automatic machines that can bend a plate [5 and 6], and finally those seeking to understand the relationship between heating conditions and the deformation to be obtained [7 and 8]. The last group being the most difficult task found until now.

Predicting the distortion produced by heating a plate is confusing because it is influenced by many factors like the amount of heat, speed of the heat source, thickness of the plate and by secondary factors like the cooling method, the initial deformation of the plate, residual stresses, cooling method, etc., [9 and 10].

Given the complexity of the problem, it requires using mathematical tools that involve all these variables when analyzing the problem; being the finite element method (FEM), through a three-dimensional thermal-elastic-plastic analysis, the method offering the best performance [11]. On the other hand, FEM is limited to analyzing small plates without complex heating patterns. This is far from the reality of shipbuilding where large and complex geometries must be developed.

With the purpose of contributing to the solution of this problem, the authors propose a neural network model trained by using data obtained from FEM studies and validated experimentally. In this neural network, the prediction of deformation produced during the process of metal forming by line heating is achieved with considerable accuracy, for heat conditions and sizes of plates that have not been possible to achieve with traditional methods of prediction distortions.

Analysis of the distortion due to heating lines

The process of plate forming by line heating can be seen as a method of forming a flat plate into a three-dimensional object, with a desired shape, by using the angular shrinkage and distortion produced by plastic stress, induced by heating and subsequent cooling [1]. The deformation is largely dependent on the heat input, the speed of the heat source and the plate thickness.

According to [2], heat-induced deformation can be represented by four main components of inherent distortion, as shown in Fig. 1, and expressed by Equations 1 to 4 as follows;

$$\delta_y^i = \int \in_y^* dydz / h \tag{1}$$

$$\delta_x^i = \int \in_x^* dydz / h \tag{2}$$

$$\theta_y^i = \int \in_y^* \ (z - h/2)\ (h^3/12)\ dydz \tag{3}$$

$$\theta_x^i = \int \in_x^* \ (z - h/2)\ (h^3/12)\ dydz \tag{4}$$

Where δx is the longitudinal inherent shrinkage, δy is the transverse inherent shrinkage, θx is the longitudinal inherent bending, and θy is the transverse inherent bending. εx^* and εy^* are the components of the inherent strain. The *xy* plane is in the direction of the heating line, and the *zy* plane is transverse to the heating line, *h* is the plate thickness. These relationships can be used to predict deformation with remarkably good results, but it is demonstrated that the deformation given by Equations 1 to 4 are affected by other factors, so they are not as effective when the process is complex [4].

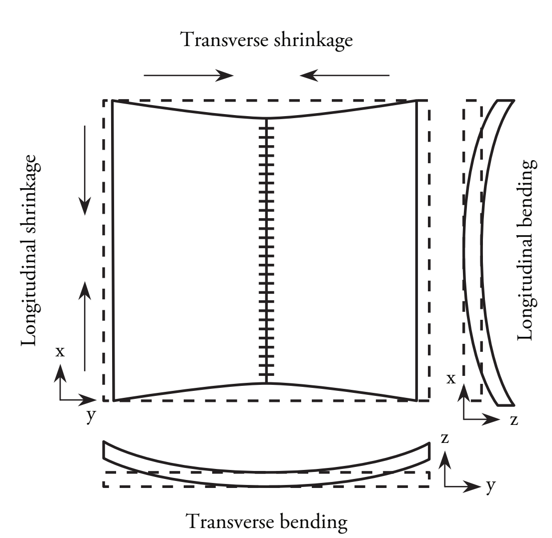
Extraction of data for the development of the neural network model

An outstanding characteristic of neural networks is their ability to generalize to future data. To achieve maximum development of this characteristic, the network needs to be trained by using as many details as possible so that it can find the characteristics that distinguish the behavior of the data.

To enhance the model of interest, we first specified the information that we would use as training for the network. To do this, we used results published in [3]. In that work, the relationships described in Equations 1 to 4, for thick plates, for a wide range of heating conditions are plotted. Figs. 2 to 5 show a summary of the data. As seen in the figures, the relationship between inherent deformation and applied heat can be described by mathematical relationships. However, for conditions of heating out of the range used in that study, there is no reference in the present literature.

To obtain the largest possible number of data from the figures, information points, from each graph, are extracted. Then, regression, to achieve smooth behavior of the data while understanding the deformation behavior, for a given applied heating requirement, is performed.

Fig 1. Components of Inherent Deformation produced by line heating



In addition to the information mentioned above, the relation between heating condition and rate of the heating source for independent plate thicknesses, as shown in Fig. 6 [3], was incorporated, in the analysis. Based on the heating equation (Equation 5) [8], we can obtain the current and voltage, required to generate the heating conditions. Here, it is necessary to mention that the plate surface temperature is 800 °C, which is the recommended temperature to achieve plate forming by line heating.

$$Q = \frac{\eta VI}{sh^2}\left[\frac{\mathrm{J}}{\mathrm{mm}^3}\right] \tag{5}$$

Fig 2. Relationship between transversal shrinkage and heat input

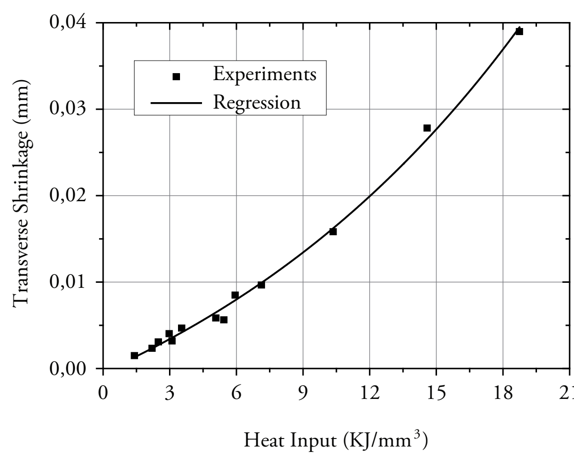


Fig 3. Relationship between longitudinal shrinkage and heat input

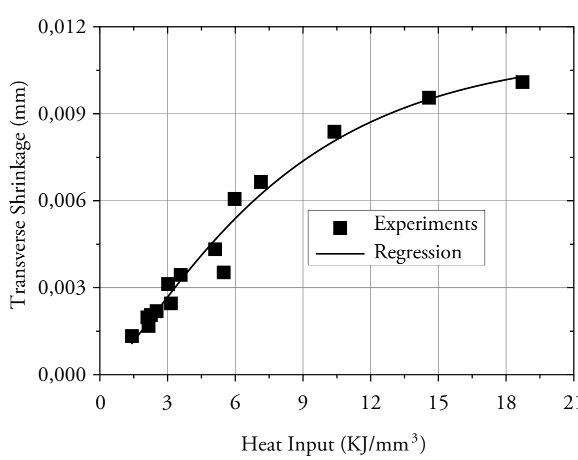


Fig 4. Relationship between transversal bending and heat input

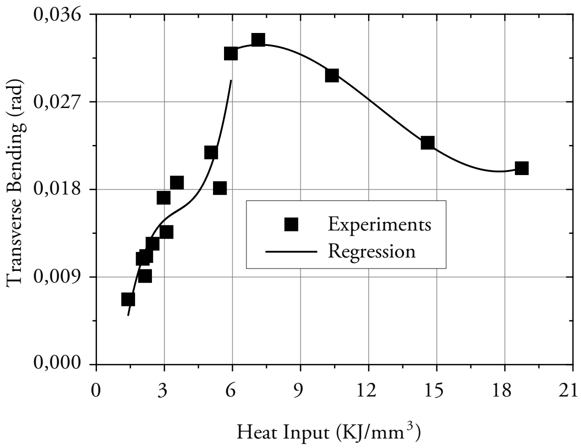


Fig 5. Relationship between longitudinal bending and heat input

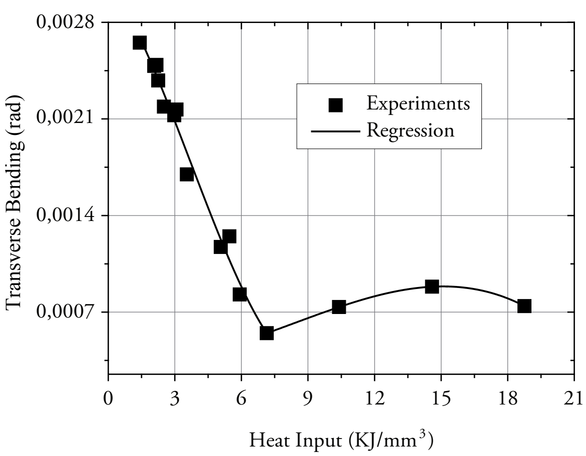
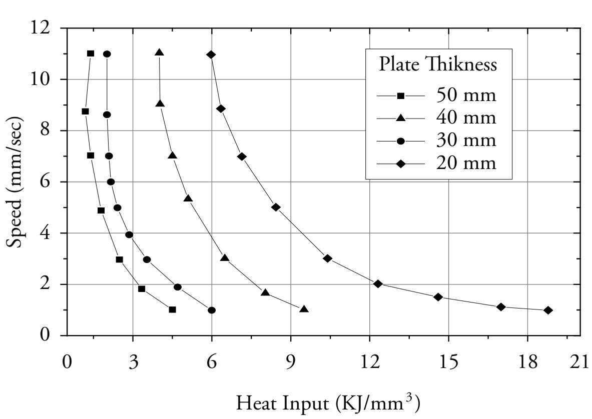


Fig 6. Relationship between speed of the heating source and heat input for different plate thickness



To support the network with the largest training data, we evaluated Equation 5 for different ranges of voltage, current, speed of the heating source, plate thickness and heat input as follows:

Voltage: V = 30 to 45 Volts
Current: I = 300 to 1200 Amps
Speed: s = 1 to 11 mm / sec
Plate thickness: h = 10 to 50 mm
Heat Input: Q = 1 to 20 KJ / mm

Table 1. Model of individual cases used as input of the network

Heating Condition	Case #1	Case #2	Case #3
Voltage [Volts]	40	40	40
Current [Amp]	1255.37	1012.96	919.74
Speed [mm/seg]	11.01	9.97	7.92
Thickness [mm]	50	50	50
Q/h^2	1.36	1.21	1.39
Deformation			
δy/h [mm]	0.00125	0.00106	0.00128
δx/h [mm]	0.00103	0.00088	0.00105
θy [rad]	0.00463	0.00267	0.00493
θ x[rad]	0.00270	0.00275	0.00269

After evaluating Equation 5 for each variable, more than 700 different points were achieved. The data was arranged in individual cases, where for each heating condition the four components of inherent deformation (described in Equations 1 to 4) were obtained, as shown as an example in Table 1. Note that "case" refers to the vector of values used as input of the neural network; more precisely, we refer to the heating condition used to prepare the network. The four components of deformation are called the vector “target”. These four components are the known response extracted from Figs. 1 to 5, also associated to the heating conditions.

Neural network model to predict the distortion due to heating lines

After gathering the information we want to emulate, we continue developing the neural network, to accurately replicate the information. To develop the network, we must first create architecture (layers, neurons, and training functions) that derives the characteristic patterns of the training data, thus, ensuring that the network has the best performance.

Network architecture

A multilayer network, from a host of others, was chosen because we wanted the network to get the best generalizations of the results. The training algorithm used is the back-propagation model [12], given its good performance in predicting nonlinear functions.

Number of layers

One of the common uses of neural network is to approximate functions or specific patterns. However, a single layer may not be sufficient to represent a function because the behavior may not be fully captured. In the case of the network to predict the distortion, to avoid any possible lack of accuracy, three layers were used.

Number of Neurons

The hidden neurons play a vital role in the operation of a neural network given that they work as feature detectors. Once the learning process begins, the hidden neurons gradually begin to recognize outstanding features presented by the training data.

It should be noted that using few neurons may cause poor fit, while the opposite may result in a tight network. These characteristics are undesirable because they reduce the generalization ability of the network, yielding incorrect results and increasing error in the results.

To determine the optimal number of neurons, it is necessary to establish a criterion in assessing where the smallest amount of hidden neurons permits the best performance closest to the known response.

The mean square error (MSE) is a standard that provides details of the error of the output response generated by the neural network with respect to the desired output response. The MSE is defined as:

$$MSE = \frac{1}{m} \sum_{i=1}^{m} (h_{ci} - h_i)^2 \qquad (6)$$

Where h_{ci} is the desired response from the network (targets), h_i is the neural network response (output), and m is the number of data analyzed. This rule becomes necessary because it evaluates the accuracy of the results, as the fixed weights, at each step of the iteration, during the learning process [13].

Fig. 7 shows that by increasing the number of neurons, MSE varies and, therefore, the neural network error.

Network Training Process

The standard back-propagation algorithm was used in developing the network for distortion prediction. This is an algorithm of descent gradient in which the network weights moves along the negative value of the gradient of the function of execution.

The training of neural networks can be more effective if certain processes are performed on the input and output data. The processes performed on the input data improve the way the network reads the input information. Before training the network, inputs and outputs are scaled to keep them within a range: from -1 to 1. Thus, the activation functions of the neurons are automatically sensitized, obtaining a better performance of the network.

Generalization of the neural network

One of the largest features that occur during the development of neural networks seeks to know how good the response of the network will be for inputs to which the network has not been trained. Some techniques exist in the literature commonly used to improve the generalization of a neural network, these are: early detection (cross-validation), removing the weights, and inclusion of noise to the data during training [14]. In this article, we used the cross-validation technique [15] to generalize the network because it resulted as the most appropriate after several trials. In the cross-validation used to determine the generalized network data correctly, we divided the training data into three subsets: a training subset, a validation subset, and a testing subset, which was the one selected for this network.

Results

Using as the selection criterion the cross-validation techniques, we selected the neural network from a number of possible networks. Then, by using the MSE, we computed the error of the entries that have not been seen by the neural network; thereby, the network selected is the one that presents the lowest validation error.

To evaluate the network that best fits the data, 20 different neural networks were developed. By varying the number of layers and neurons of each one, the best one was chosen after comparing the performance of each.

Table 2 shows the most significant networks obtained and how using MSE selection criterion, we selected the 12-8-4 network. Fig. 8 shows the results of the validation test of the 12-8-4 network. The figure displays the three subsets used for testing. One can see that beyond 469 days, both the test error and the validation error tend to increase, while the training error decreases as the ages pass. Each network has its characteristic curve, which served as a basis for selecting the network.

The 12-8-4 network has a total of three layers. The first layer has 12 neurons, the second eight and the third (the output layer) has four neurons. Furthermore, the cross-validation test also analyzed the network response to the training data. Figs. 9, 10, 11, and 12 show the network response; these figures show the correlation between the training data (from the literature) and the network response

Fig 7. Relationship between the number of neurons and the MSE

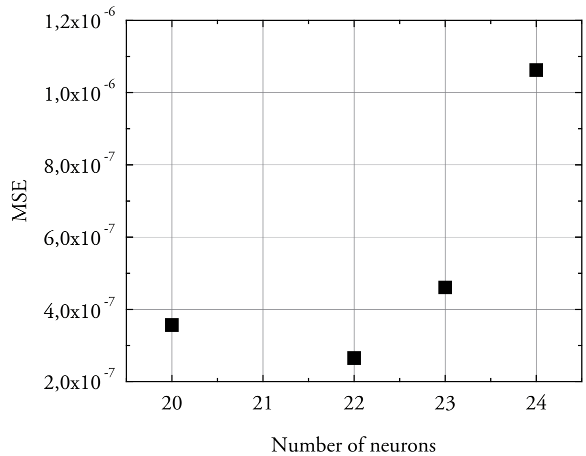
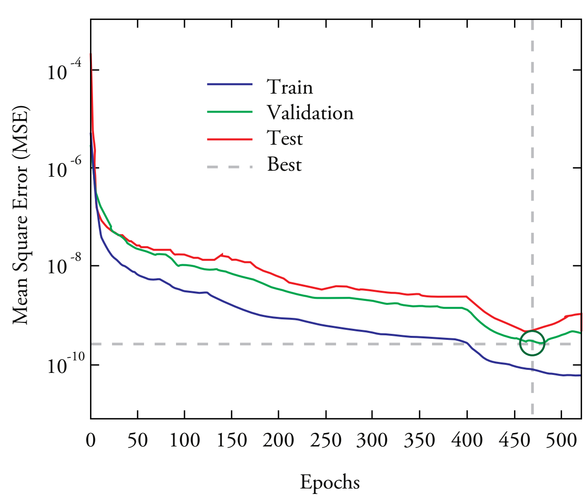


Table 2. Examples of networks presenting the best performances

Network	MSE Validation	Correlation
15-4	1.28E-8	0.9765
20-4	9.14E-9	0.9820
8-6-4	5.32E-10	0.9949
10-8-4	2.17E-9	0.9925
12-8-4	2.74E-10	0.9999
12-8-6-4	7.67E-10	0.9994

Fig 8. Validation test of 12-8-4 network



after the network training. It seems that the values calculated by the network are close to the training values, so we can say that the network has precisely calculated the deformation.

Fig 9. Comparison between the network response and the training data for Transverse Inherent Shrinkage

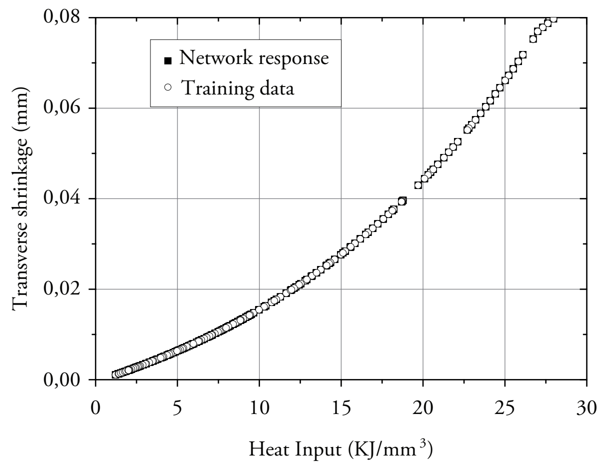
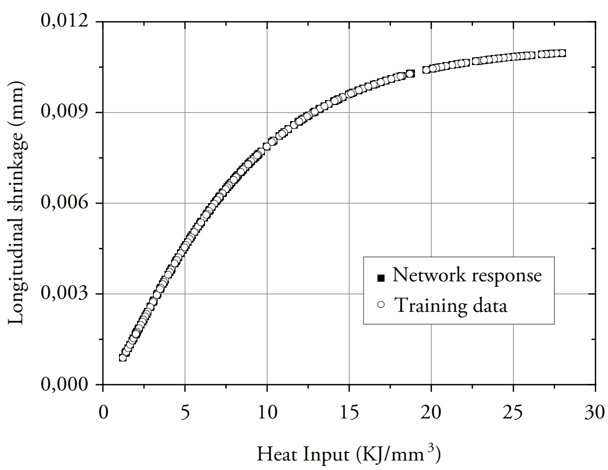


Fig 10. Comparison between the network response and the training data for Longitudinal Inherent Shrinkage



Validation of the results

After obtaining the deformation components by using the neural network, we should confirm the accuracy of the network for arbitrary data, those which the network has never learned (generalization). For that, the network was trained using additional cases obtained from the study presented in [8] (Table 3). The percentage of error between the inherent deformation of the study and the network response is shown in Table 4. By comparing results, we concluded that the error is negligible; given that these are cases for which the network had never been trained, the accuracy of the network could be considered as sufficiently good.

Fig 11. Comparison between the network response and the training data for Transverse Inherent Bending

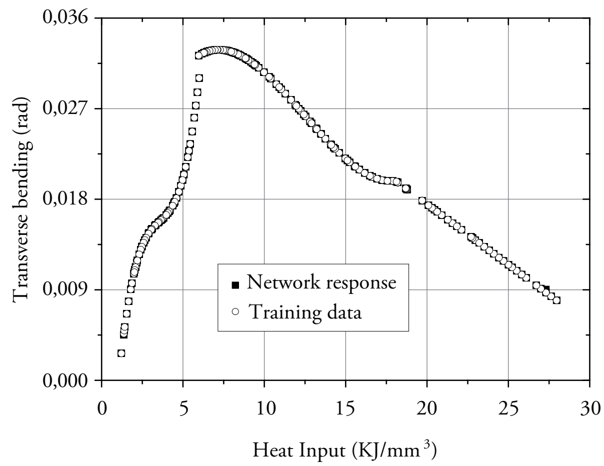
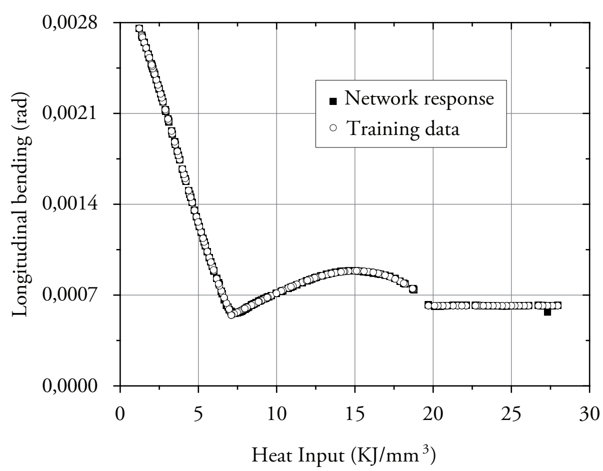


Fig 12. Comparison between the network response and the training data for Longitudinal Inherent Bending



Conclusions

In this paper, we propose using neural networks to predict distortions induced by heating during the line heating process. The following are the conclusions from this study:

- A tool that allows accurately predicting the distortion generated in a plate due to line heating was developed based on a neural network model.
- The results demonstrate that the network has good performance not only for the range of training data, but also for data that have not been learned before.
- Using three layers results in a good approximation of the deformation produced by heating.
- The neural network herein developed may also offer good response in case of other thermal processes given that the input used is independent of the process.
- Using neural networks is an effective alternative in predicting distortions induced by heating during plate forming by line heating.

Table 3. Heating condition and values of inherent Deformation used as references [8]

Heating Condition	**Case #1**	**Case #2**
Voltage	33	37
Current	800	500
Speed	2.50	1.50
Thickness	50	40
Heat Input	3.17	5.78
Inherent Deformation		
Transverse Shrinkage	0.0037	0.0076
Longitudinal Shrinkage	0.0028	0.0052
Transverse Bending	0.0152	0.0271
Longitudinal Bending	0.0020	0.0010

Table 4. Comparison between the network response and the results shows in [8].

Case #1	δy	δx	θy	θx
Data from [3]	0.0037	0.0028	0.0152	0.002
Network Response	0.0037	0.0028	0.0152	0.002
% Error	0.1039	0.0173	0.3535	0.0698

Case #2	δy	δx	θy	θx
Data from [3]	0.0076	0.0052	0.0271	0.001
Network Response	0.0076	0.0052	0.0269	0.001
% Error	0.0324	0.0462	0.7693	0.1533

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Smoothing warships movements based on wavelets

Reducción de los movimientos del buque de guerra basándose en wavelets

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J.M. Girón [2]
J.J. Díaz [3]

Abstract

In seakeeping terminology, the Quiescent Period is known as the period of calm in rough waters to allow the ship to perform operations such as landing aircrafts and unmanned aerial vehicles (UAVs), aswell as the entry of landing crafts in the basin. Quiescence refers to the interval of time where all ship motions are within acceptable limits to perform a desired activity. Among the key issues for Quiescent Period Prediction is to be able to measure waves from a suitable distance and predict ship motions in response to waves encountered; both aspects are crucial and must be taken into account. Many of the opearations performed at sea are carried under severe weather conditions, as a result of this situation there is a need to determine this called "window of opportunity" that allows carrying them out. The paper aims to explain from the point of view of Quiescent Period Prediction, the most promising wave measurement systems, which are currently based on radar, but the main question is that if we want predictions a few seconds ahead, it will be appropriate to measure waves at a distance of some hundreds of meters, describing the new mathematical model based on wavelets in determining the spread of the waves from their initial measurement until they reach the vessel.

Key words: Quiescent Period, Wavelet, Ship Motions, Seakeeping, Control, Hydrodinamics

Resumen

Dentro del ámbito del comportamiento en la mar, se denomina Periodo Quiescente a aquellos periodos de calma que se producen en un estado de mala mar que permiten al buque llevar a cabo operaciones como pueden ser el aterrizaje de plataformas aéreas, vehículos aéreos no tripulados (UAVs) o la entrada de lanchas en el dique. El término quiescente hace referencia al intervalo de tiempo durante el cual los movimientos del buque se encuentran dentro de los límites aceptables para llevar a cabo una actividad determinada. Las claves para llegar a predecir los Periodos Quiescentes están en ser capaz de llegar a medir las olas desde una distancia adecuada, y ser capaz de llegar a predecir los movimientos que dichas olas inducirán en el buque una vez le alcance; ambos aspectos son cruciales y deberán ser tenidos en cuenta. Muchas de las operaciones que se realizan en la mar se llevan a cabo bajo condiciones climatológicas adversas, y es en estos casos donde surge la necesidad de determinar una "ventana de oportunidad" que nos permita llevarlas a cabo. El artículo trata de explicar desde el punto de vista de la predicción de periodos quiescentes los sistemas de medida de oleaje más prometedores, actualmente basados en radar, pero la inquietud principal es que si queremos una predicción de varios segundos en adelanto es necesario medir las olas a una distancia de cientos de metros, para ello se describirá el nuevo desarrollo matemático basado en "wavelets" que se ha empleado para determinar la deformación que sufren las olas desde su medida inicial hasta que alcanzan la plataforma.

Palabras claves: Periodos Quiescentes, Wavelet, Movimientos del Buque, Comportamiento en la Mar, Control, Hidrodinámica

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Introduction

A study for Quiescent Period Prediction (QPP) seeks improved prediction of quiescent periods for wave-induced ship motions. The different reviews carried out on the research have identified several existing technologies for wave and ship motion measurement, *(Riola and Girón, 2010)*. However, concerning shipborne instrumentation for QPP purposes only a few recent solutions are available, for instance radar.

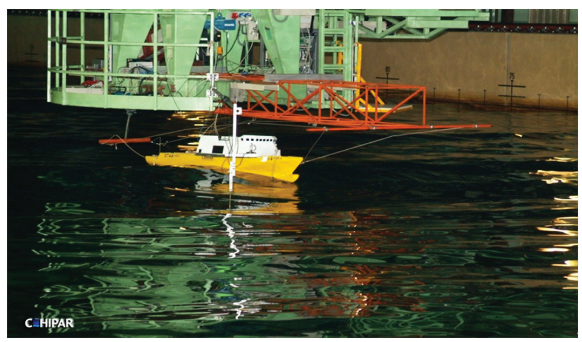
In the current climate of reduced manning and increasingly sophisticated sub-systems in warships, tools providing guidance and assistance to operators are invaluable. During critical tasks such as aircraft operations, especially in AUVs, it may only become apparent that response limits have been exceeded when it is too late to take any action.

The ability to predict vessel motion is critically important in a large number of sectors in the shipping industry (offshore sector, float over installations, remote operator vehicle handling, helicopter landing and take off,…) where the viability of certain types of operations depend on wave-induced motions and on the need for a short quiescent period in which it is possible to safely perform an operation.

This study developed the specification for a follow-up project, where a technical demonstrator for quiescent period prediction was produced, and was complemented by results of sea trial off(NOT CLEAR). It essentially concerns measurement and prediction of waves (as well as ship motions), both under controlled conditions in tank tests, and in open seas to test wave measurements extracted from X-Band radar. But the main objective is the characterization and prediction of the quiescent period, via multi-resolution analysis and wavelet decomposition, expected to determine the occurrence probability of the downstream quiescent periods (ship motions) as function of the upstream quiescent period (swell measurements), whilst also calculating the distance of the measurement zone.

The navy operational requirements focus on short-term prediction for helicopter or UAV ship landing and take off. The programme is based on the theoretical application of "wavelets" in determining the spread of waves, and combines this with radar image processing and navy operational requirements. The El Pardo Hydrodynamic Ship Model Basin (CEHIPAR, for the term in Spanish) also contributes to carrying out tests with the scale model ship at its facility, the Ship Dynamics Laboratory (SDL) that provides the latest technology for wave generation and devices to measure ship motions in the presence of waves and wind. This is expected to result in the following: precise knowledge on current methods and technology for wave measurement to predict real-time ship motions due to waves and elicit military operational requirements about QPP, *(Riola and Girón, 2010)*.

Fig 2. Scaled model at CEHIPAR

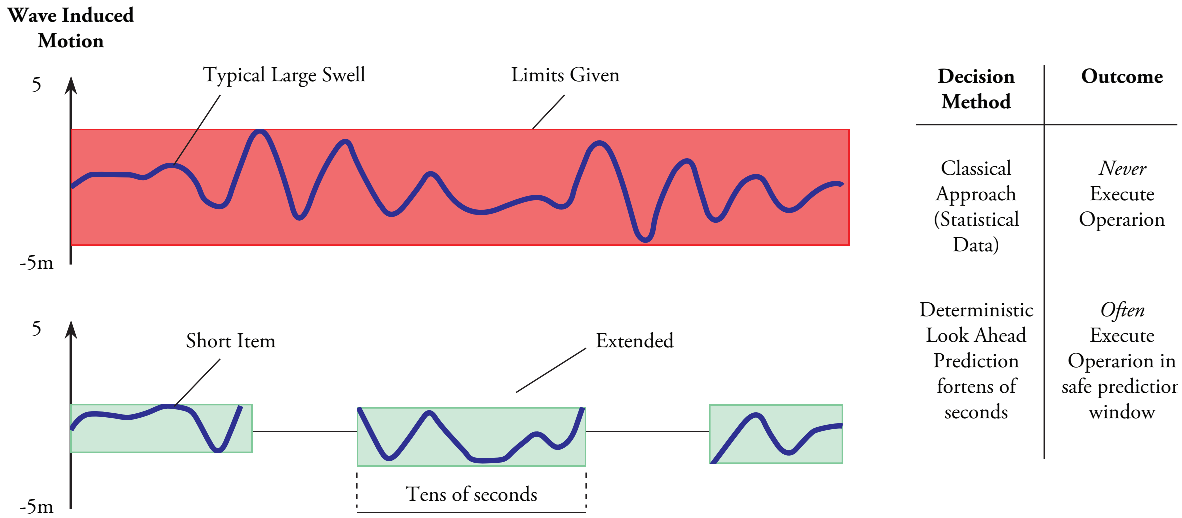


In order to obtain the experimental data for the research, a series of experiments were carried out with a scaled model in the Seakeeping Basin. It has an attached wave sensor that measures incident waves several meters before the bow seeking to emulate the effect of radar or any other measurement system capable of measuring waves at a given advance distance.

Wave Predicition

The reviews of QPP methodologies identified two types of approaches. The approach based on the ship's past history may offer short prediction horizon (some 6-10 seconds). The approach based on distant wave measurement may offer a much longer prediction horizon (up to 2 minutes), but it is recent and requires testing.

Fig 3. QPP methodologies



The best results of the deterministic view of sea-wave propagation, which allows making short-term predictions of the sea surface profile, are around 30 seconds, *(Morris et al., 1997)*, using simulations based upon typical sea models that have shown that, under realistic conditions, accuracy above 90% prediction. This paper implies that for a large swell sea, it is realistic to expect prediction of the actual shape of the sea surface up to 30 seconds into the future with surface level prediction errors as low as 10% of the mean significant wave height. Nowadays, it is possible to know the sea surface within a range of more than 3 nautical miles by using X-Band radar. If we can process these data in time and determine the deformation of the incident wave, vessel motions from this wave elevation can be predicted. It is essential to determine the most important parameters that must be deduced as input for the wave propagation model.

(Nieto-Borge et al., 2004) proposed a method to estimate sea surface elevation maps from marine radar image sequences. This method is the extension of an existing inverse modeling technique to derive wave spectra from marine radar images, which assumes linear wave theory with temporal stationarity and spatial homogeneity of the sea surface elevation observed. *(Dannenberg et al., 2009)* introduced the development of a system capable of determining vessel motions two minutes ahead under mild sea states.

Ship Motion Model

Ship motions are defined by the six degrees of freedom that a ship can experience, three translations and three rotations, although methods exist for both passive and active motion stabilization used in some designs (static hull features such as skews and bilge keels, or active mechanical devices such as counterweights, anti-roll tanks, and stabilizing fins) excessive ship motions may hinder the vessel's ability to complete its mission.

In order to study the dynamic behavior of ships navigating under severe conditions, it is imperative to develop their governing equations of motion taking into account the inherent nonlinearity of large-amplitude ship motion. The following set of equations determines the basis for modelling ship motion:

$$(m + a_{11})\ddot{x}_1 + b_{11}\dot{x}_1 = F_1 \tag{1}$$

$$\begin{aligned}(m + a_{22})\ddot{x}_2 + b_{22}\dot{x}_2 + a_{24}\ddot{x}_4 + b_{24}\dot{x}_4 \\ + a_{26}\ddot{x}_6 + b_{26}\dot{x}_6 + c_{26}x_6 = F_2\end{aligned} \tag{2}$$

$$\begin{aligned}(m + a_{33})\ddot{x}_3 + b_{33}\dot{x}_3 + c_{33}x_3 + a_{35}\ddot{x}_5 \\ + b_{35}\dot{x}_5 + c_{35}x_5 = F_3\end{aligned} \tag{3}$$

$$\begin{aligned}a_{42}\ddot{x}_2 + b_{42}\dot{x}_2 + (I_{44} + a_{44})\ddot{x}_4 + b_{44}\dot{x}_4 \\ + c_{44}x_4 + a_{46}\ddot{x}_6 + b_{46}\dot{x}_6 + c_{46}x_6 = F_4\end{aligned} \tag{4}$$

$$a_{53}\ddot{x}_3 + b_{53}\dot{x}_3 + c_{53}x_3(I_{55} + a_{55})\ddot{x}_5 + b_{55}\dot{x}_5 + c_{55}x_5 = F_5 \quad (5)$$

$$a_{62}\ddot{x}_2 + b_{62}\dot{x}_2 + c_{64}\ddot{x}_4 + b_{64}\dot{x}_4 + (I_{66} + a_{66})\ddot{x}_6 + b_{66}\dot{x}_6 + c_{66}x_6 = F_6 \quad (6)$$

Normaly, through its complexity some movements are ignored (surge and sway) and the yaw´s effect is counteracted by the rudder´s action, so in these cases the modeling ignores certain movements because of their small size compared to other movements.

The sea state is the general condition of the free surface on a large body of water with respect to wind waves and swells at a certain location and moment. A sea state is characterized by statistics, including wave height, period, and energy spectrum. The STANAG 4194 *"Standardized Wave and Wind Environments and Shipboard Reporting of Sea Conditions"* adopts the 'wind sea' definition of the Douglas Sea Scale, where the use of common sources of wave and wind data for NATO Operational Areas and their application to assess operability, interoperability, and habitability characteristics of participating nation ships and establish ship designs.

The requirements taken into account for this study are included in the STANAG 4154 *"Common Procedures for Seakeeping in the Ship Design Process"*. This document incorporates contemporary seakeeping assessment technologies and specifies requirements for designers during the ship design cycle. It establishes common procedures for seakeeping assessment, for use in the ship design process and for future developments in supporting operational forces at sea. The limits for vertical and short takeoff and vertical landing operations specified in the document are roll 2.5º, pitch 1.5º, vertical velocity 1.0 m/sec (all of them are given in terms of root mean square amplitude). These limits are defined to permit launching and recovery of aircraft within established operational envelopes. These limits were specified for an air capable ship comparison by Comstock, *(Bales and Gentile, 1982)* in terms of generic criteria, which may be used as default values for any design study.

Several papers have been published regarding the quantification of the necessary prediction time to be operationally practical. *(Colwell, 2004)* indicated that with 6-second duration, it is possible for a helicopter to land on a ship (note that enough time should be allowed to secure the helicopter on deck). *(Sherman, 2007)* indicated that the anticipation must be between 8 to 10 seconds in pitch, and 20 seconds into roll.

Methodology

Measurement of sea waves can be carried out near the bow, or from a distance. The study has identified the following technologies: for short-distance - vertical radar near the bow, ultrasonic devices; and for long-distance - radar and use of 3D fast Fourier transform.

Concerning state-of-the-art on wave measurement technology and devices, a large summary of the available theory about sea waves and their propagation is available, and the technological solutions for wave measurement are listed: buoys, vertical radar, pressure, and velocity sensors. But the most promising technologies are radar for distant waves, Light detection and ranging (LIDAR), stereo photogrammetry, and remote sensing.

Fig 4. X-Band radar installation for wave measurement

Classical prediction approaches use statistical data to assess whether a task can be carried out or not. Actually, at present most ship motions are estimated through human observation. However, this may result in the outcome that an operation is never executed, although QPs do exist which have not always been correctly predicted. Our methodology, called *"look forward"*, is a very attractive method from a control engineering point of view, it delivers real-time wave forecasting and ship motion predictions in the relatively short term. This method requires three different tasks: 1) measurement system - the incident wave must be measured providing information about wave data, at least the significant wave height, predominant wave direction and frequency; 2) wave propagation model - to compute wave deformation along its travel to the ship, for that it is necessary to predict its propagation and its resulting deformation until it reaches the ship; 3) model of the ship dynamics - to compute all ship motions in the sailing response to the wave encountered.

Research

In order to provide an experimental basis for the research, several experiments were carried out with a scale model in a seakeeping basin with a wavemaker. The model has an attached wave sensor that measures incident waves several meters in front of the bow to emulate the effect of radar or any other measurement system capable of measuring waves from a certain distance in advance. The seakeeping laboratory has a 150 x 30 x 5-m basin equipped with a principal carriage and sub-carriages whose objective is high-precision reproduction of all possible horizontal movements along the basin against regular and irregular waves.

The method assumes that a device is taking measurements of distant waves. During the development of the method, several experimental tasks were performed, based on towing tank with wavemaker and scaled ships. The wave measurement device was emulated using a water level sensor attached at some distance from the ship. The final status reached shows QPP satisfactory results.

Wavelet analysis is becoming a common tool for analyzing localized energy variations within a time series. By decomposing a time series into time-frequency space, one is able to determine both the dominant modes of variability and how those modes vary over time. The wavelet transform has been used for numerous studies. In this research, the Fourier Transform has not been used because, although this transform identifies all spectral components present in a signal, it does not provide any information regarding the temporal (time) localization of these components. Fourier Transform is used in stationary signals where the spectral components do not change over time, so it is not necessary to know any time information. However, non-stationary signals consist of time varying spectral components and some other ways to determine time localization of spectral components must be found.

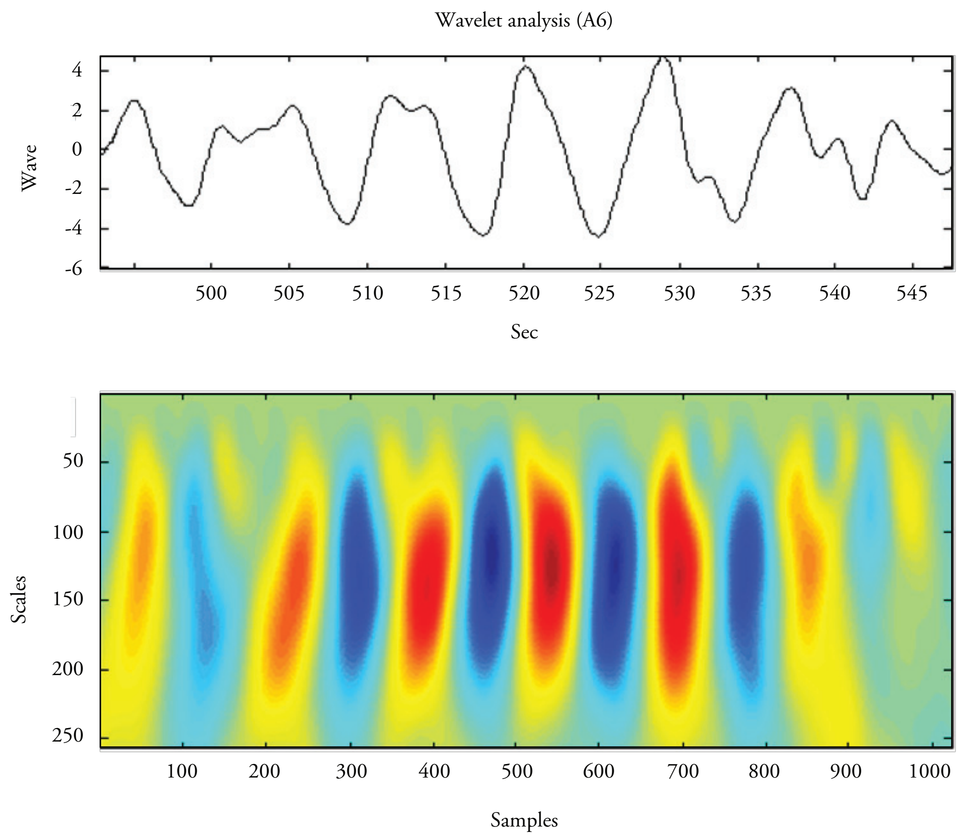
The following figure (see Fig. 5 in page 56) illustrates a wave analysis with Morlet´s wavelet and its scalogram. The fundamental idea is that the wave is changing, deforming itself over time and this information must be analysed, "photo after photo" of the deformation.

The implementation of this method requires two fundamental aspects, taking data collection and digital processing; thereby, two subsystems are necessary: the data collection subsystem and the processing unit. The data collection system allows measuring the incident wave from a distance and extracting a temporary record of the principal parameters like wave height to send them to the digital processing unit. The second subsystem can be represented in several ways (micro-controller, embedded computer, industrial computer...).

A series of experiments were performed at the SDL, where the pitch-heave-roll motions of a scaled military ship were recorded, by moving this scale vessel against irregular seas generated by the wavemaker. Data were obtained with irregular seas from SSN4 to SSN7, with Bretschneider and JONSWAP spectra. Concerning ship speed and heading, the experiments considered three speeds (18, 19, and 20 knots), and headings of 180º, 135º, 90º, 45º, and 0º. All the results were analyzed to get an idea of the occurrence of quiescent periods.

Waves were measured; our proposed QP prediction method takes data from distant waves, applies

Fig 5. Morlet´s wavelet scalogram

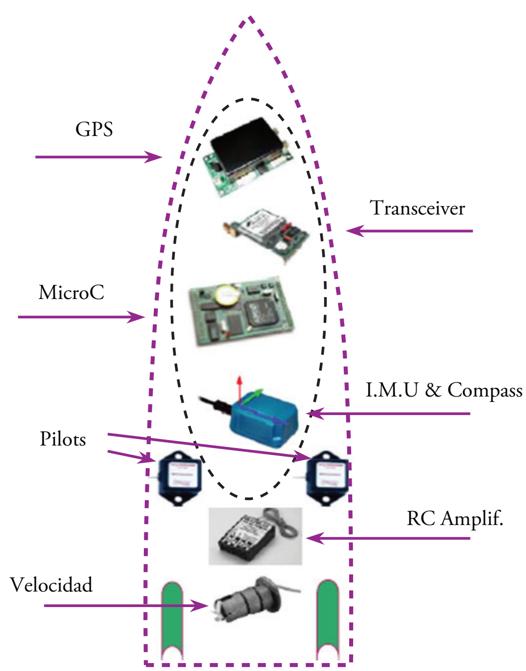


wavelets, and predicts the waves the ship will encounter. It is a method that looks forward, taking advantage of sensors like Radar or LIDAR. In our case, irregular waves were generated and their propagation was measured with several water height sensors fixed at regular distances along the basin. These experimental data constitute the basis for evaluating the performance of the QP prediction.

The main instrumentation implemented in the model at SDL was a micro-controller for the onboard system to carry out experimental tests, whose data are the baseline of the experiments and must be used to determine the kindness of the research. The model has also self-control in terms of direction and speed, to ensure greater reliability, instead of methods where the model is towed. Fig. 6 shows the onboard instrumentation.

The main data of interest obtained in SDL are listed as a set of variables: incident waves, pitch,

Fig 6. Sensors



roll, heave, and vertical accelerations in different positions, which provide different results because the ship's center of gravity could be on the bow or on the stern flight deck. By using these experimental data, it is possible to apply the STANAG 4154 limits and graphically represent what happens. In order to study this phenomenon, we took into account the concept of minimal warning time and minimal forecast time whose definitions are: minimal warning time is the minimum advance time with which the occurrence of a QP needs to be known for the prediction to be useful. The prediction is made for a specific operation of which a "critical part" and its duration are to be known. The minimal forecast time is the sum of the minimal warning time plus the duration of the critical part of the operation and needs to be shorter than the prediction window of the QP predictor.

The following figures were the result of these experimental tests; one test is presented ahead (SSN5 sea state, heading 180º and 19 knots). These

Fig 7a. Wave (H180, v19, SSN5)

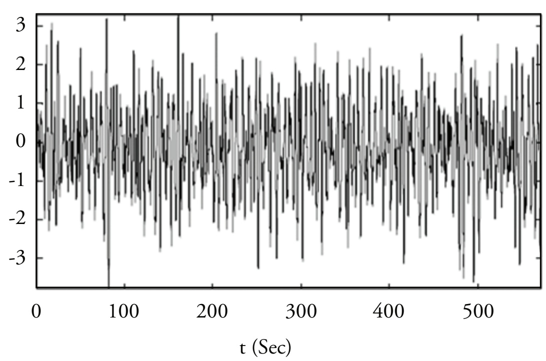
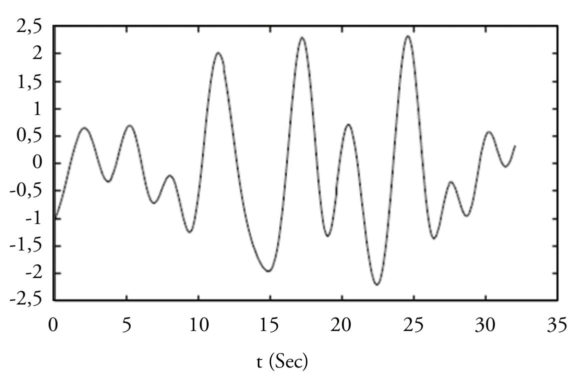


Fig 7b. Filtered Wave (H180, v19, SSN5)



figures show the original data and the pre-processed data. The first group includes the original data obtained. As a first signal cleaning task, low-pass filtering was applied to eliminate high-frequency noise. The low-pass filtering is different for each data record. The following figures represent the pre-processed data, which was filtered to clean the high-frequency noise of the signals. A recursive Chebyshev filter was used with a Matlab filtfilt instruction to avoid inducing mismatches.

Fig 7c. Pitch (H180, v19, SSN5)

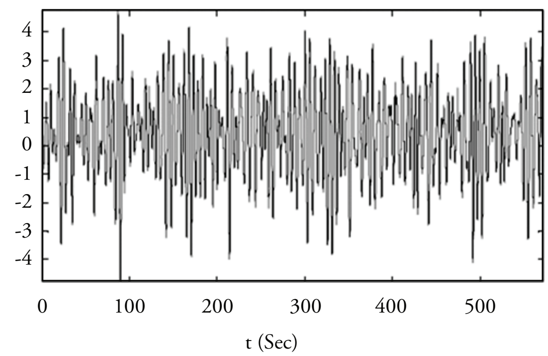


Fig 7d. Filtered Pitch (H180, v19, SSN5)

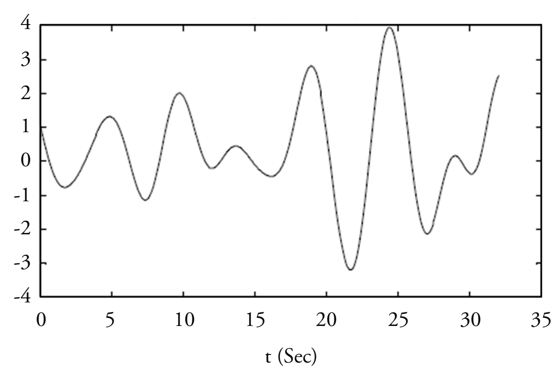


Fig 7e. Roll (H180, v19, SSN5)

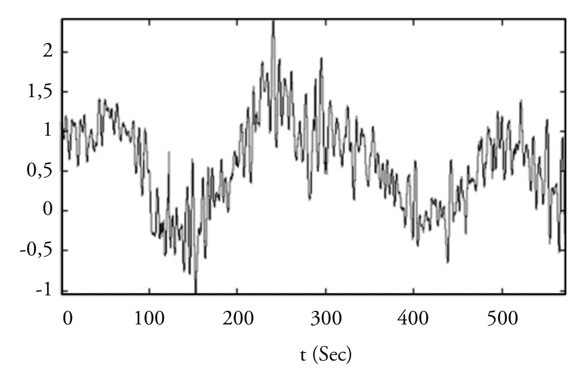


Fig 7f. Filtered Roll (H180, v19, SSN5)

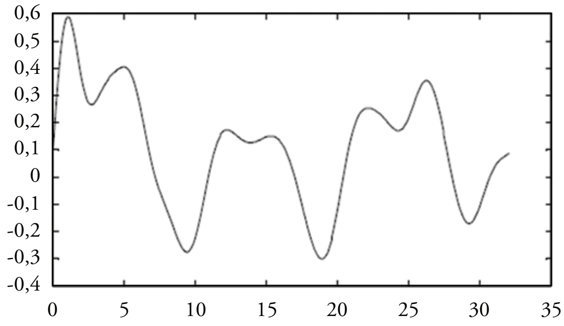


Fig 7g. Acdg (H180, v19, SSN5)

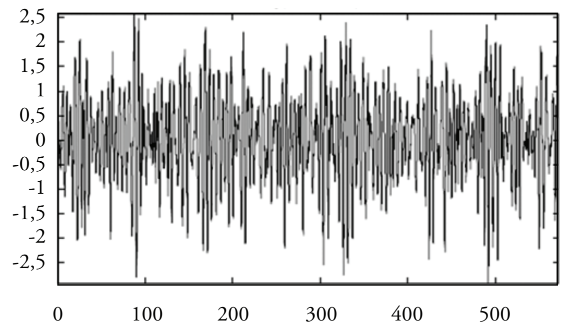
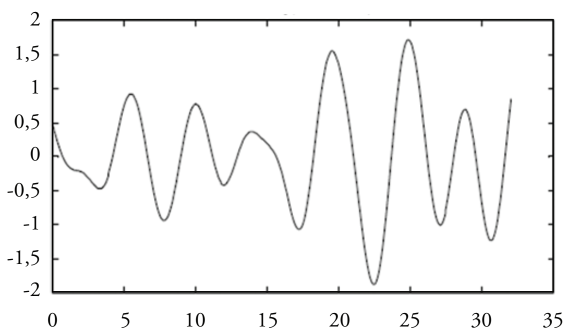


Fig 7h. Filtered Acdg (H180, v19, SSN5)



Wavelets

Extensive literature is available to explain the wavelets. If we have a signal to analyze, for example a sinusoidal signal, we select one baby wavelet, which in this case is a Gaussian wavelet, and modify this wavelet (changing two parameters: duration and time shift) until the baby wavelet matches, as closely as possible, the segment of the signal under analysis. Once this wavelet is obtained, we subtract the wavelet form the signal and try to find another baby wavelet to match the remaining signal, and so on along the specified number of iterations. The final result of the process is to have the signal decomposed into a sum of baby wavelets.

The initial mathematical position was proposed by *Joseph Fourier (1807)*, who indicated: *"An arbitrary function, continuous or with discontinuities, defined in a finite interval by an arbitrarily capricious graph can always be expressed as a sum of sinusoids"*. Several publications support this stance, such as *(Vetterli and Kovacevic, 2009)*, *(Lee and Kwon paper, 2003)*.

Fig 8a. Morlet wavelet (mostly sinusoidal)

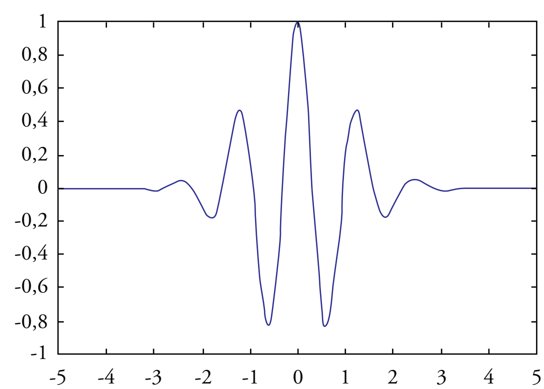
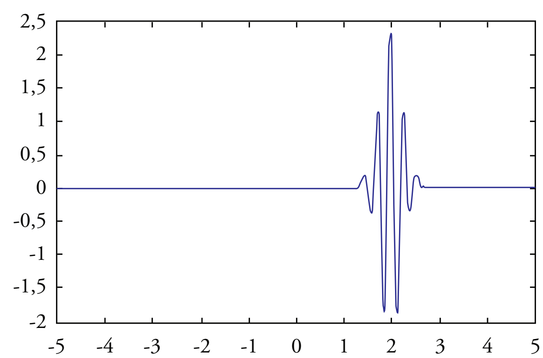


Fig 8b. Baby wavelet



$$f(t) = a_0 + \sum_{k=1}^{\infty} a_k \cos k\,\omega_0\, t + b_k \text{ sen } k\,\omega_0 \qquad (7)$$

$$F(\omega) = \int f(t) e^{-j\omega t} dt \tag{8}$$

$$f(t) = \frac{1}{2\pi} \int F(\omega) e^{j\omega t} d\omega \tag{9}$$

$$e^{j\omega t} = \cos(\omega t) + j \sin(\omega t) \tag{10}$$

A wavelet, ψ, is a zero-average function, which is dilated with a scale parameter (s) and translated by another (u), like a windowed Fourier transform, a wavelet transform can measure the time-frequency variations of spectral components, but it has a different time-frequency resolution.

$$\int_{-\infty}^{\infty} \varphi(t) dt = 0 \tag{11}$$

$$\varphi(t)_{u,s} = \frac{1}{\sqrt{s}} \varphi(t - u / s) \tag{12}$$

The wavelet transform can also detect and characterize transients with a zooming procedure across scales; this zooming capability not only locates isolated singular events, but can also characterize more complex multifractal signals having non-isolated singularities.

The proposal measured waves, analyzed and decomposed them into wavelets. Then the wavelets were propagated according to their own group velocity till reaching the ship. And, finally, from the propagated wavelets the wave that will reach the ship is synthesized (recovered). In summary, three steps take place: analysis, propagation, and recovery. Fig. 9 (see page 60) shows the analysis performed on a wave group under SS5 sea condition; the first is the decomposition of the measured wave into wavelets; thesecond is the subsequent analysis after the propagation, 30 seconds after the initial one, proving how the wave group spreads itself until reaching the vessel.

Conclusions

Currently, the overall decision making process is more efficient and inclusive and has speeded up; it is for this reason that the prediction of QPs is of utmost importance. The warship scenario in which we move is increasingly complex and demanding. The accelerated rythym of the growth of scientific and technological development is of great benefit but also presents a big challenge for any country. One of the reasons is the increased use of UAVs, which need to automatically land on ships. Likewise, the progressive introduction of automated tasks in sea operations demands better prediction of QPs. These appreciations are confirmed by recent NATO Science and Technolgy Organization (STO) workshops. Therefore, it is advisable to continue and extend the research on QPP. In general, computers, software tools, and electronic technology have reached a very powerful status, but this should be well exploited. On the other hand, from the experiences during the study with commercial solutions for distant wave measurements, it seems that more should be done for QPP, given that QPP is not only a matter of distant measurement, it also involves a suitable methodology for QP prediction.

While, traditionally, ship motion limits have been described in terms of maximum pitch and roll, these metrics do not fully capture the nature of ship motion and may contribute to unnecessarily restrictive boundaries. We must reinforce the idea that Dynamic Deck Motion Limits (DDMLs), based on real-time measurements of motions can be combined with QPP technology to determine a period of acceptable motions to land helicopters or UAVs. In summary, two main challenges exist for future research: distant wave measurement and QPP methods.

Because the starting instant of the "operational window of opportunity" has to be known sufficiently in advance, it is necessary to include the minimal warning time and the duration of the critical operation itself. As result of the experiments, a final figure was made for each. It shows four records: one record for roll, one for pitch, one for heave, and the fourth is the combination of the other three records and represents when there is a QP according to STANAG 4156. Fig. 10 (see page 61) shows a "1" level meaning when we achieve the objectives and a "0" when these are not acheived.

Fig 9a. SSN5 packet (begin), wavelet analysis

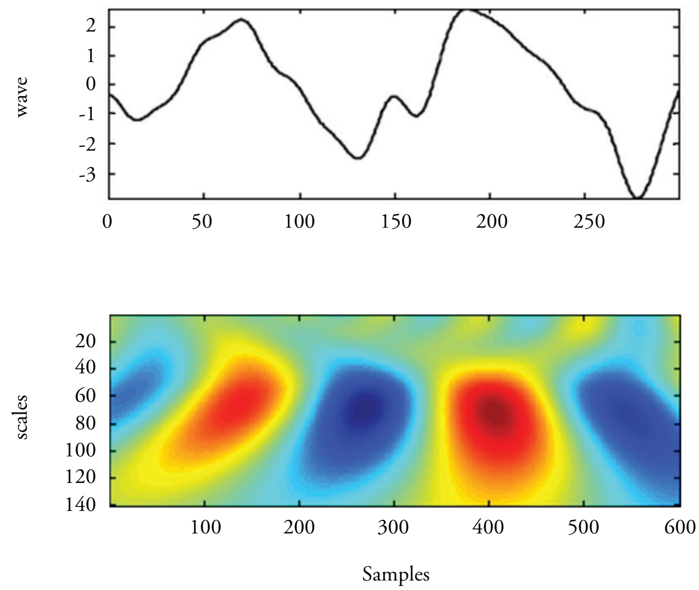
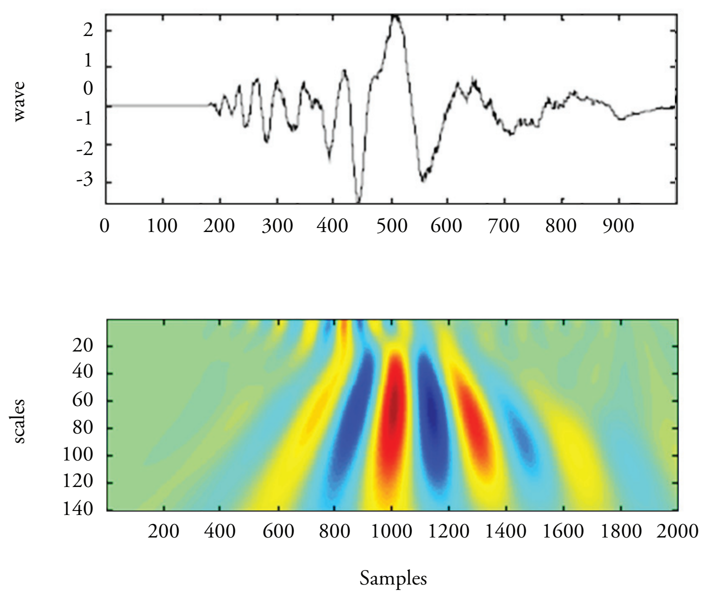


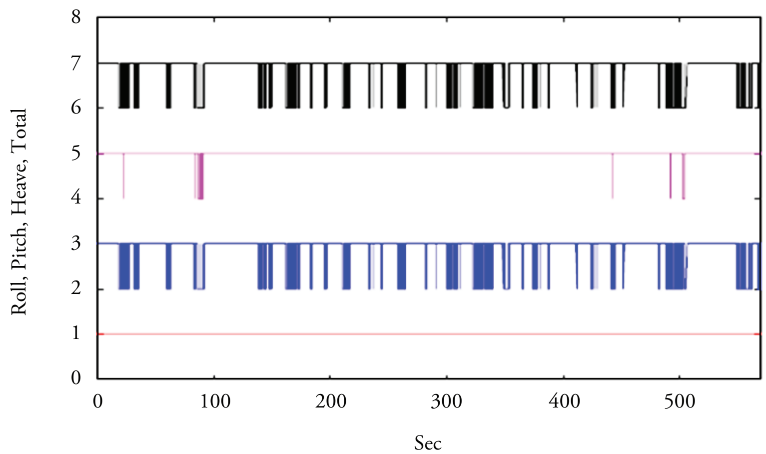
Fig 9b. SSN5 packet (after 30s), wavelet analysis



The combination of three ones yields another one and its translation is a QP. Then we must analyze when these QPs have enough advance time to become an operational window of opportunity.

As a result of research, we can state that as the intensity level of the sea increases, the number of quiescent periods is consistently lower. Also, we can safely assume that the great majority of QPs, with the procedure already described, have been identified, with the propagation method based on wavelets also being a resounding success. We must stress that the best conditions studied were an SSN4 sea state and 0° heading in which case we are talking about a constant QP, and obviously under the most adverse conditions with SSN7 many QPs

Fig 10. SSN5 Results, 180°, 19 knots



were determined with enough quality to allow for different onboard operations, as it is also shown by STANAG.

For that reason, we focused our research to ensure that relevant knowledge and technology are available and that they are subjected to analysis by using the best possible methods to be taken into account in warship operation activities like: ramp clearance during landing operations; helicopter landing/take-off or pickup/delivery operations during VERTREP or sling operations; launch/recovery of manned crafts - operation of deployment and retrieval of small crafts with hoisting gear; launch/recovery of unmanned vehicles (UAV, USV or UUV); launch and recovery of remote operated vehicles (ROV) or rigid inflatable boats (RIB); cable tensioning during abeam replenishment at sea; launch/recovery of towed sonar; general handling, traverse or maintenance and repair activities; firing operations; etc.

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Information of the Volume 6

Información del Volúmen 6

Author Index

Editorial Guidelines for Authors

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The *Ship Science and Technology* Journal accepts for publication original engineering contributions in English language on ship design, hydrodynamics, dynamics of ships, structures and materials, vibrations and noise, technology of ship construction, marine engineering, standards and regulations, ocean engineering and port infrastructure, as well as results of scientific and technological research. Every article shall be subject to consideration by the Editorial Council of The *Ship Science and Technology* Journal deciding on the pertinence of its publication.

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The *Ship Science and Technology* Journal accepts to publish articles classified within the following typology (COLCIENCIAS 2006):

- *Scientific and technological research articles*. Documents presenting detailed original results of finished research projects. Generally, the structure used contains four important parts: introduction, methodology, results, and conclusions.
- *Reflection Articles*. Documents presenting results of finished research as of an analytical, interpretative, or critical perspective of the author on a specific theme, resorting to original sources.
- *Revision Articles*. Documents resulting from finished research in the field of science or technology in which published or unpublished results are analyzed, systemized, and integrated to present advances and development trends. These are characterized by presenting an attentive bibliographic revision of at least 50 references.

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All articles must be sent to the editor of The *Ship Science and Technology* Journal accompanied by a letter from the authors requesting their publication. Every article must be written in *Microsoft Word* in single space and sent in magnetic form.
Articles must not exceed 10,000 words (9 pages).
File must contain all text and any tabulation and mathematical equations.
All mathematical equations must be written in *Microsoft Word Equation Editor*. This file must contain graphs and figures; additionally, they must be sent in a modifiable format file (soft copy). Also, abbreviations and acronyms have to be defined the first time they appear in the text.

Content

All articles must contain the following elements that must appear in the same order as follows:

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

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

- Business or institution (including department or division to which he/she belongs).
- Street mailing address.
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Abstract
A short essay of no more than one hundred fifty (150) words, specifying content of the work, scope, and results. It must be written in such a way so as to contain key ideas of the document. It must be sent in English and Spanish language.

Key Words
Identify words and/or phrases (at least three) that recover relevant ideas in an index. They must be sent in English and Spanish language.

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

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

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

Equations must be numbered on the right hand side of the column containing it, in the same line and in parenthesis. The body of the text must refer to it as "(Equation x)". When the reference starts a sentence it must be made as follows: "Equation x". Equations must be written so that capital letters can be clearly differentiated from lower case letters. Avoid confusions between the letter "l" and the number one or between zero and the lower case letter "o". All sub-indexes, super-indexes, Greek letters, and other symbols must be clearly indicated.

All expressions and mathematical analyses must explain all symbols (and unit in which they are measured) that have not been previously defined in the nomenclature. If the work is extremely mathematical by nature, it would be advisable to develop equations and formulas in appendixes instead of including them in the body of the text.

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

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

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

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

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

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

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

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

The other way is:

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

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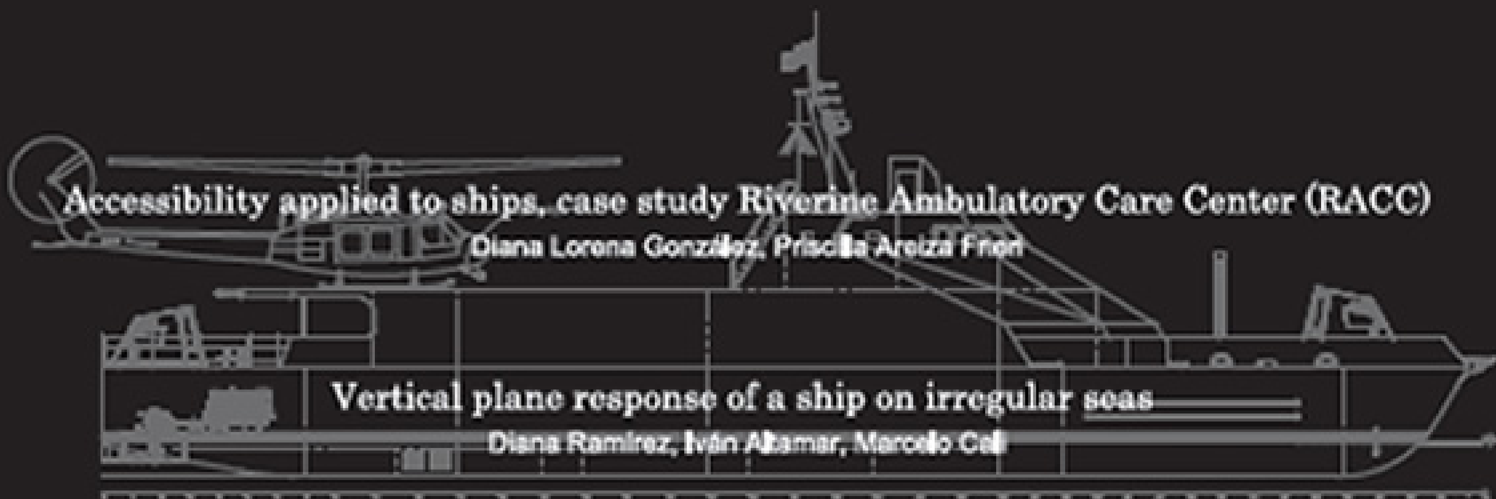

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