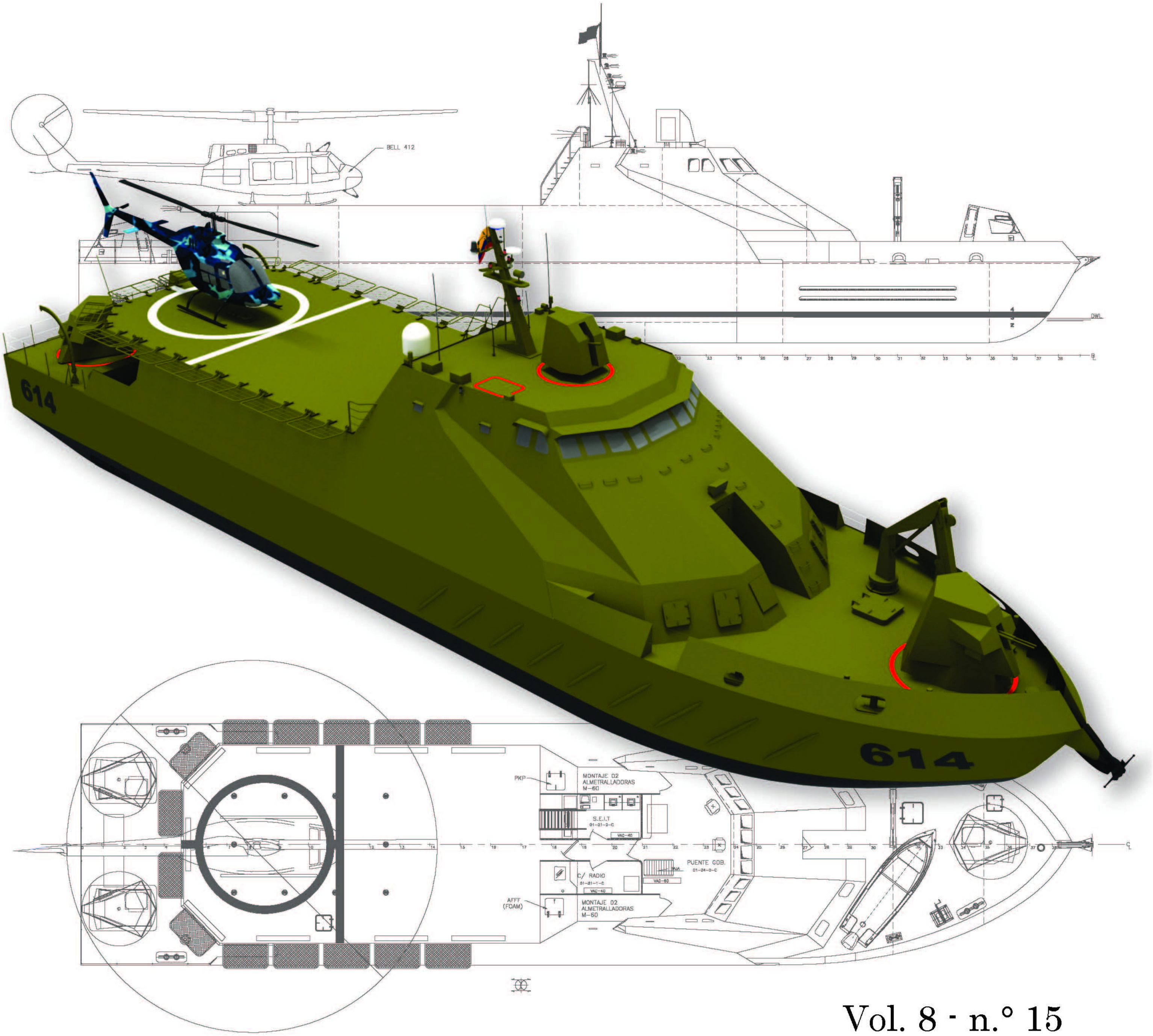
ISSN 1909-8642

SHIP
SCIENCE & TECHNOLOGY
CIENCIA & TECNOLOGÍA DE BUQUES

COTECMAR
COLOMBIA



Vol. 8 - n.° 15
(1 - 96) July 2014

Cotecmar
Vol. 8 - No. 15 - July 2014
ISSN 1909-8642
Ship Science & Technology

SHIP
SCIENCE & TECHNOLOGY
CIENCIA & TECNOLOGÍA DE BUQUES

Volume 8, Number 15 July 2014 ISSN 1909-8642

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

A publication of

Corporación de Ciencia y Tecnología para el Desarrollo de la Industria Naval, Marítima y Fluvial - Cotecmar
Electronic version: www.shipjournal.co

COTECMAR
COLOMBIA

Editorial Coordinator
Karen Domínguez Martínez. M.Sc.
Jimmy Saravia Arenas. M.Sc.

Layout and design
Mauricio Sarmiento Barreto

Printed by
C&D Publicidad & Marketing. Bogotá, D.C.

SHIP
SCIENCE & TECHNOLOGY
CIENCIA & TECNOLOGÍA DE BUQUES

Volume 8, Number 15 July 2014 ISSN 1909-8642

SHIP
SCIENCE & TECHNOLOGY
CIENCIA & TECNOLOGÍA DE BUQUES

Editorial Note

Cartagena de Indias, July 22nd, 2014.

After serving for 14 years in the naval, maritime and river industries, Cotecmar continues to consolidate itself as the leading organization in Colombia's shipbuilding industry and is currently spearheading the Latin American market by innovating with attractive products for the region. Throughout this year, the Company built and delivered to the Brazilian Navy the first series of MKII River Patrol Boats designed by Cotecmar, which strengthened this business relationship with a view to a joint development for the design of an Amazon Patrol Ship by the navies of Brazil, Peru and Colombia with the mission of protecting the natural resources and security across the Amazon basin.

On the other hand, during the first half of this year, the Corporation's organizational structure saw significant changes. As a result, today present there is a Science, Technology and Innovation Management that is responsible for leading the processes of innovation management and for positioning the Company's technological research and development as a source of generating competitive advantages. Rear Admiral Jorge Enrique Carreño Moreno, the Company's President, reinforces the concept that Cotecmar is a science and technology corporation by understanding that the organization is devoted to conducting applied research and technological development, whereby all management results are incorporated and validated in the naval industry with the specific aim of improving the Company's productive processes and generating new products.

The above is in addition to the fact that one of the Corporation's purposes is the divulgement and social appropriation of science and technology; hence, Cotecmar reiterates its conviction and commitment to share and transfer knowledge through the Ship Science and Technology (*Ciencia y Tecnología de Buques*) Journal, one of the most important specialized scientific media on engineering, naval architecture and other fields related to the shipbuilding, river transit, logistics and port industries.

In this issue of the Journal we present some research related to overall engineering systems for vessels, fuzzy control in navigation systems for autonomous vehicles, stability analysis, noise reduction, vessel power efficiency, ROV design and the development of antifouling paints based on organic marine extracts from the Colombian Caribbean region.

Once more, we encourage you to keep sharing and referencing our contributions to the naval scientific community and to allow for us to continue consolidating our Ship Science and Technology Journal within the national and international contexts.

Commander JOSÉ MANUEL GÓMEZ TORRES
Editor of the Ship Science and Technology Journal

SHIP
SCIENCE & TECHNOLOGY
CIENCIA & TECNOLOGÍA DE BUQUES

Nota Editorial

Cartagena de Indias, 22 de julio de 2014.

Tras cumplir sus 14 años de servicio en la industria naval, marítima y fluvial, Cotecmar sigue consolidándose como la organización líder en la industria naval colombiana y se abre caminos en el mercado latinoamericano con la innovación de productos atractivos para la región. Durante el presente año se han construido y entregado a la Marina de Brasil la primera serie de las Lanchas Patrulleras de Rio MKII diseñadas por Cotecmar y se afianzaron las relaciones con miras al desarrollo conjunto del diseño de un buque Patrullero Amazónico entre las marinas de Brasil, Perú y Colombia, cuya misión será la protección de los recursos naturales y la seguridad en la cuenca Amazónica.

Por otro lado, durante el primer semestre del año se presentaron cambios significativos en la estructura organizacional de la Corporación. Fruto de ello, hoy se dispone de una Gerencia de Ciencia, Tecnología e Innovación encargada de liderar los procesos de gestión de la innovación y el posicionamiento de la investigación y el desarrollo tecnológico como fuente de generación de ventajas competitivas. El Señor Contralmirante Jorge Enrique Carreño Moreno, Presidente de Cotecmar, refuerza el concepto de Cotecmar como corporación de ciencia y tecnología, entendiendo que es una organización encargada de hacer investigación aplicada y desarrollo tecnológico donde los resultados de su gestión son incorporados y validados en la industria naval, especificamente para el mejoramiento de sus procesos productivos y generación de nuevos productos.

Lo anterior, sumado a que uno de los propositos corporativos es la divulgación y apropiación social de la ciencia y la tecnología, se sigue con la convicción y compromiso de compartir y transferir conocimiento a través de la Revista Ciencia y Tecnología de Buques, uno de los principales medios especializados de divulgación científica sobre ingeniería, arquitectura naval y otros temas afines a la industria astillera, fluvial, logistica y portuaria.

En esta edición les presentamos investigaciones relacionadas con sistemas de ingeniería total de embarcaciones, control difuso para sistemas de navegación de vehiculos autonomos, análisis de estabilidad, reducción de ruido y eficiencia energética en buques, diseño ROV y el desarrollo de pinturas antiincrustantes a base de extractos orgánicos marinos del caribe colombiano.

Nuevamente los exhortamos a continuar compartiendo y referenciando nuestra contribución a la comunidad científica naval y nos permitan seguir consolidando a la Revista Ciencia y Tecnología de Buques dentro del contexto nacional e internacional.

Capitán de Fragata JOSÉ MANUEL GÓMEZ TORRES
Editor Revista Ciencia y Tecnología de Buques

VORGES – A Procedural Model for Total Ship System Engineering Developed by MTG MARINETECHNIK

VORGES – Un modelo procedimental para el sistema de ingeniería total de embarcaciones desarrollado por MTG MARINETECHNIK

André Neumann [1]

Abstract

Naval vessels are highly complex and sophisticated systems. The core issue concerning the planning of a future naval vessel is to identify operational needs, respective requirements and corresponding technical solutions, which are affordable in line with the budget. Due to the complexity of a naval vessel, it is impossible to answer this question by assigning a specific amount of money to a specific requirement. To address this issue, MTG developed the procedural model for total ship system engineering – called VORGES (VOrgehensmodell GEsamtentwurf Schiff) – that starts in the very early planning phase, enabling the procuring authority to generate a reference design that balances functional and technical requirements with the available budget. VORGES is an iterative and flexible process of continuous evolution that additionally involves the customer and end-user. With respect to user requirements, VORGES includes the generation of several conceptual and preliminary designs at different detail levels. The resulting design alternatives will be evaluated and compared against each other for critical factors like life cycle costs, project risks, military performance or requirements fulfilment. This will enable the procuring authority to make a comprehensive decision for the optimum design at the highest efficiency level of budget expenditure, hence, resulting in the formulation of the technical requirements for procurement.

Key words: Model, Total ship system engineering, planning.

Resumen

Las embarcaciones navales son sistemas altamente complejos y sofisticados. El asunto central en cuanto a la planeación de una futura embarcación naval es identificar las necesidades operacionales, los requerimientos respectivos y las correspondientes soluciones técnicas, que sean asequibles en línea con el presupuesto. Debido a la complejidad de una embarcación naval, es imposible responder esta inquietud mediante la asignación de una cantidad específica de fondos a un requerimiento específico. Para abordar este asunto, MTG desarrolló el modelo procedimental para el sistema total de ingeniería de la embarcación – denominado VORGES (*VOrgehensmodell GEsamtentwurf Schiff*) – que inicia en la fase temprana de planeación, permitiéndole a la autoridad de adquisiciones a generar un diseño de referencia que equilibre los requerimientos funcionales y técnicos con el presupuesto disponible. VORGES es un proceso iterativo y flexible de evolución continua que adicionalmente involucra al cliente y al usuario final. Con respeto a los requerimientos del usuario final, VORGES incluye la generación de varios diseños preliminares y conceptuales en diferentes niveles de detalle. Las resultantes alternativas de diseño se evaluarán y compararán entre sí para identificar factores críticos como costos de ciclo de vida, riesgos del proyecto, rendimiento militar o cumplimiento con los requerimientos. Esto le permitirá a la autoridad de adquisiciones tomar una decisión integral para el óptimo diseño al más alto nivel de eficacia de gasto de presupuesto, entonces, resultando en la formulación de los requerimientos técnicos para adquisición.

Palabras claves: Modelo, Sistema de ingeniería total, Planeación.

Date Received: December 13th, 2012 - *Fecha de recepción: 13 de Diciembre de 2012*
Date Accepted: February 7th, 2013 - *Fecha de aceptación: 7 de Febrero de 2013*

[1] MTG Marinetechnik GmbH, Germany. e-mail: Andre.Neumann@mtg-marinetechnik.de

Introduction

Changing geopolitical and economic conditions entails a major impact on the planning process of naval vessels. Planning and construction of Navy ships was in the past mainly dominated by a few nations, for both national demand and for export. The steady growth and increasing self-awareness of emerging countries lead to nationalization of both the planning and construction processes. While this trend is reinforced by the increasing demand of naval vessels, it also implements the request to increase expertise in the local market, as well as to consider national tactical and operational characteristics in the planning of future Navy ships to a maximum extent.

In most cases, the available defence budget for a certain typically top-prioritized and high-budgeted project is not sufficient enough to find the one and only design meeting all naval requirements. Therefore, it is of utmost importance to spend the allocated budget as efficiently as possible. In the late 80s, VORGES was developed as a methodology, tool, and procedure to specify a reference design for naval warships that balances the budget and naval requirements, enabling the procuring authority to formulate the technical specifications for the tender and building processes. It has since become the standard procedure to support the planning process of the German Navy for all types of surface vessels. As a result of the VORGES procedure, the procuring authority will be able to determine the required budget, as well as to procure the optimum naval vessel for their fleet. It is a one-stop service, finding affordable solutions by:

- Consolidating user requirements into feasible requirements,
- Creating meaningful sets of requirements,
- Developing a variety of possible ship designs,
- Estimating procurement and life-cycle costs,
- Calculating effectiveness measurements by simulation,
- Assessing the results in relation to the requirements.

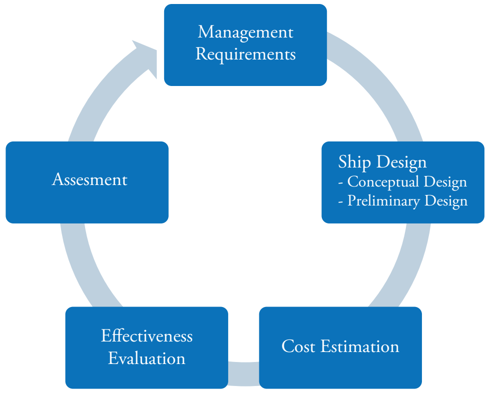
Additionally, VORGES is being used to answer "what-if" questions with respect to the influence of the budget. It means, in detail, that VORGES can investigate different technical solutions and their budgetary influence without the requirement to generate a complete design. This investigation must, thereby, be done on the basis of a base design. Especially during the Multirole Combat Ship Class 180 (MKS180) process, this procedure was of high value to answer questions related to different configurations or policies (e.g., different speed profiles, different manning concepts) in a very short time.

The VORGES methodology can be briefly described as an iterative process of standardized phases requiring expert knowledge, up-to-date databases, state-of-the-art CAE/CAD tools, and broad cooperation within the network, as well as active participation of the end-user.

As a basic framework, the planning process can be separated into two major steps. During the first step, the elaboration of several conceptual designs during a very short period, on the basis of generating a broad choice of different vessel designs, provides sufficient information for an initial selection process of one or more promising designs that meet the initial functional and budget requirements. After the selection, one or more preliminary designs will be created in high detail, enabling the procuring authority to determine the required technical specifications. Both steps are subdivided into further phases that can be described as a circular and iterative sequence of activities. By iterating this sequence, a promising design can be found by using the results of iterations to improve the accuracy of user requirements and use the modified requirements as an input for the next iteration.

A profound, in-depth description of this complex methodology is difficult within the framework of this paper. Therefore, the following paper will focus on the overall procedure, providing a thorough introduction of the VORGES process, the steps involved, and tools required.

Fig. 1. Circle of VORGES activities



Design Process

To close the identified gap of military performance and/or capability with respect to the operation of naval vessels, the procuring authority basically has three possibilities:

- Design and procure a new vessel (that also includes the modification of existing designs),
- Procure an existing design,
- Modify/upgrade/downgrade an existing vessel.

Either process requires thorough analysis as to what extent the gap can be bridged within the available budget or how the gap can be closed at the optimum cost-benefit ratio if there is no existing budget restriction. For this purpose and independent of the acquisition strategy, generation of a design is essential to allow the procuring authority to make a substantiated decision.

Conceptual Design

The conceptual design phase of the VORGES process is subdivided into eight phases. These phases are usually not processed sequentially. Dependent on the required design, it is also possible to elaborate several phases in parallel and to repeat already finished phases if the results of other preceding phases dictate. Fig. 2 provides an overview of the sequence and the dependences of the overall process.

Phase 1: Analysis of user requirements

The VORGES process starts with the analysis of the customer requirements. Usually, at an early stage of procurement planning, the procuring authority already has a set of specific formal requirements. These requirements often focus on procurement costs, engineering standards, documentary standards, and operational requirements for the total system. Experience shows that most customers also have a significant number of non-specified expectations for their future naval vessel. Therefore, an extensive dialog between the design authority and the procuring authority is essential to prepare the initial set of requirements.

The analysis process focusses on the clarification of the technical feasibility, as well as on the definition of the weighting of the different requirements, given that usually different weightings exist. On the basis of the set of requirements, the so-called hierarchy for benchmarking and prioritization can be defined by using the “Expert-Choice” tool, which was designed for complex decision making. With this hierarchy, the conceptual designs can be evaluated; this will be done at a later stage.

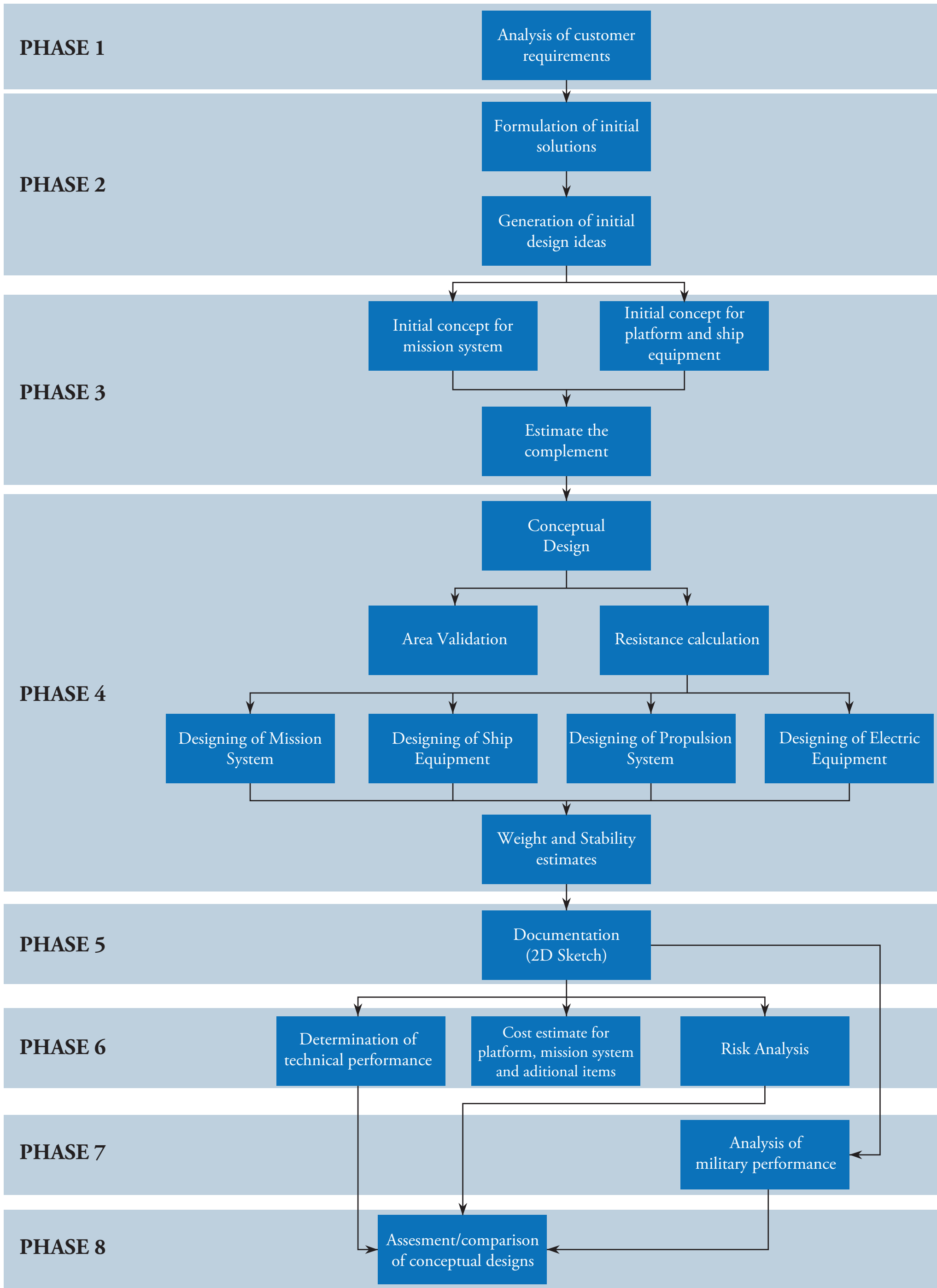
Simply using this stage as a pure analysis part is misleading. Over the course of the planning process, several circumstances or parameters like budget adjustments, change of the political preferences, and insights gained from other designs will influence the overall process. The more mature and detailed a vessel design becomes, the deeper the inherent technical and operational complexities can be evaluated. This regularly leads to the discovery of conflicts or contradictions among requirements.

Sometimes, this also requires updating and changing initial requirements that entail a sustained influence on the following planning process.

Therefore, VORGES handles these circumstances through a continuous requirements management process that takes care of:

- The analysis of the customer requirements,
- Supporting and consulting the customer/ change and quality management,
- Dealing with / prioritizing conflicting

Fig. 2. Flowchart of conceptual design process



requirements,

- Processing results from iterative conceptual designs into the requirements for future designs,
- Reducing complexity by structuring the requirements,
- Consolidating requirements into usable sets for vessel designs.

On the basis of the initial meaningful set of requirements, the initial planning process can be continued.

Phase 2: Formulation of initial solutions and design ideas

This phase is – based on the requirements defined – a first step to find initial ideas and solutions that meets a maximum of requirements. At this stage, ideas that document the various focal points that must be considered when implementing the requirements into technical solutions will be coordinated and documented. Due to limited budgets, it is usually not possible to implement all requirements into one technical solution. However, in most cases, it will also be very interesting for the procuring authority to gain an indication of the level of budget overrun. The initial solution gained describes a logical, meaningful and self-contained part of the defined customer requirements. This initial solution can be pictured as a filter through which the requirements are poured. Some requirements pass through completely, some partly, and others are withheld. The requirements found by using this methodology are called "Basic Requirements". These basic requirements will now be implemented into technical solutions that form the basis for the various possible design ideas, which include first details on the implementation of the individual requirements. It outlines, for example, the required number and types of ships and describes first technical solutions. On this basis, the technical design process can be started.

Phase 3: Development, generation, and adaption of building blocks and operational concepts

The technical implementation of different design ideas, as mentioned, is mainly done by finding the combination of building blocks meeting the basic requirements. Having different or competing building blocks will lead to further solutions and broaden the set of alterations and solutions, hence, significantly increasing the overall processing complexity.

As a general rule, a building block is built up from objects, which provide technical, functional, and cost data. The technical data are derived from components containing information like weight, volume, dimension, and electrical data. So-called "Payloads" will generally provide information with respect to costs and additional requirements for operation. Functional objects hold standardized functions as attributes for surface ships, *e.g.*, air defence. The basis to use the MTG planning software is the definition of the basic characteristics of the mission system, as well as of the platform that is being specified in detail in building blocks. To generate a high amount of conceptual designs in a short period of time, it is essential to have all building blocks available, up-to-date, and adjusted to the project. This implies the dependency to have a close cooperation with the naval industry and to actively participate in the network of naval design organizations.

The overall aim of this phase is to:

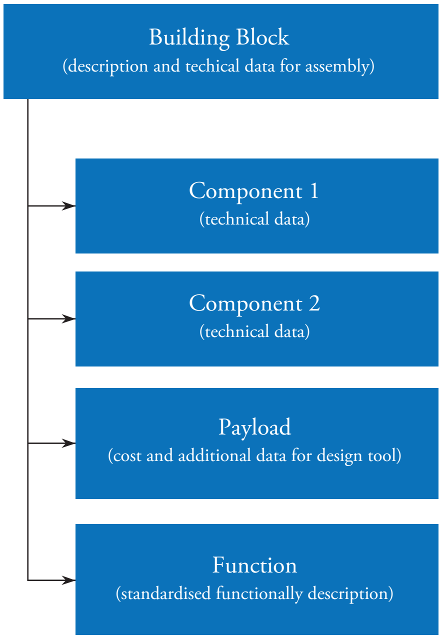
- Designate building blocks for the mission system,
- Designate building blocks for the platform and the ship equipment
- Find an estimate for the complement.

Based on the required capabilities (*e.g.*, ASW, ASuW, etc.) a list of basic technical requirements is generated. Based on this list of required technical functions, the responding building blocks can be designated to generate the initial concept for the mission system.

During this stage, the designer is responsible for picking the optimized set of building blocks from an overall catalogue of building blocks. In case of conflicting solutions, it might also be possible to think about having several competing designs reflecting different combinations of building blocks that meet the basic requirements. The selection and combination of the preferred building blocks have to be done in close cooperation with the experts responsible for the platform design, ship equipment design, and electrical design to get an overall concerted system. The result of the building blocks selection will be documented in the mission system sketch containing a basic diagram of the arrangement of the mission components.

Building blocks for the ship equipment can be designated on the basis of a combination of the information of the layout of the mission system and preconfigured standard platform concepts. Information being recognized and designated

Fig. 3. Definition of building blocks



during this step is:

- Type and class of vessel, ship equipment and technology,
- Hull form characteristics,
- Mobility, endurance, complement, required reserves.

The third step during this phase is the designation of the required manning for the overall system. Inputs will be taken from figures for preconfigured concepts for the different warfare areas, as well as from information with respect to:

- Approximate displacement
- Endurance
- Max speed
- Approximate length of the vessel
- Degree of automation (fixed factors)
- Maintenance concept
- Modular mission systems
- Planned detachments
- Watch cycles and routines
- CIC configuration

Based on the aforementioned inputs, the initial manning concept for planning can be formulated, but needs to be constantly adjusted during the on-going design process with more precise information available.

Phase 4: Conceptual design

With the first concepts of the corresponding mission system formulated, platform layout, designated building blocks for ship equipment, and resulting complement the conceptual design phase can be started to generate numerous variants of naval vessel designs incorporating the results of phase 3 in a short time frame.

The design process will be supported by the following software tools developed by MTG:

- Ship Design Programme (SVEP)
- Object Oriented Data Base System.

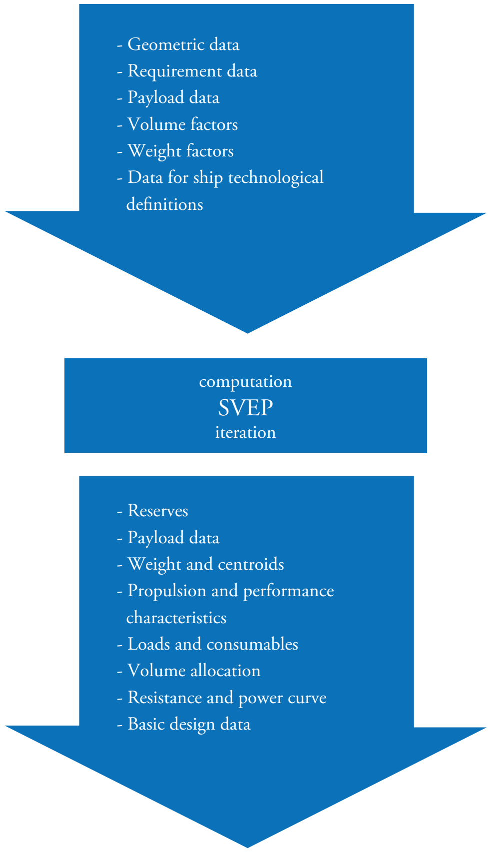
Furthermore, major commercial design tools like CAD-Systems for 2D/3D designs, hull design and hydrostatic software, CFD programmes for power prediction, as well as office tools for calculation and documentation are also being used, especially at a later stage during the Preliminary Design Phase.

The objective of the calculation and iteration in the conceptual phase is to create balanced ship designs with reference to parent hull forms, modelled on volume and mass calculations. The program uses a design algorithm with specific determinants for naval vessels, naval auxiliaries, and commercial vessels resting upon statistical analyses of consisting vessels. Fig. 4 displays a schematic diagram of the inputs and outputs of the SVEP computation.

A large part of the required input data is provided by the Database System as objects, which are called "Building Blocks" as described previously herein.

On the basis of the elaborated requirements, the ship designer starts looking for the corresponding building blocks by screening the linked functions. Afterwards, the main platform objectives like number of ships in class, ship type, endurance, speed, etc., will be set. The preparation of a rough drawing is necessary to estimate the main dimensions and to arrange the components that have a strong effect on them. Some information from the first sketch is also important for estimating the B/T-ratio (beam/draught) and the coefficient of fineness.

Fig. 4. Schematic diagram of SVEP computation



The rough drawing is not only for pre-estimating input data, but it is also used to evaluate the result of the Ship Design Program.

SVEP gets the technical data and the payload data from the database system. As a result of computation, SVEP generates, to name but a few, essential information like:

- Main dimensions,
- Displacement,
- Form coefficients,
- Volume allocation,
- Stability values,
- Propulsive power curve,
- Weights and centres of gravity,
- Machinery installations,
- Electrical installations,
- Weapons installations,
- Communication and sensors,
- Hull and superstructure,
- Technical equipment.

Simultaneously to the drawing preparation, the results will be validated. Important is the review of weight and centre of gravity by means of a more detailed weight estimation. The weight results of SVEP are rechecked here on the basis of built naval vessels or by using different well-established calculation methods to estimate the weight of each component. For a first stability analysis an adapted hull form from a hull library is used. In this stage of the design it is sufficient to prepare a rough lines plan, which is scaled in order to obtain the hull-coefficients and main dimension. Similar methods are used to validate the propulsive power and electrical power.

Phase 5: Documentation of conceptual design

After running the computation, the next step is the preparation of a drawing, composed of a side view, a top view, and an above water side view.

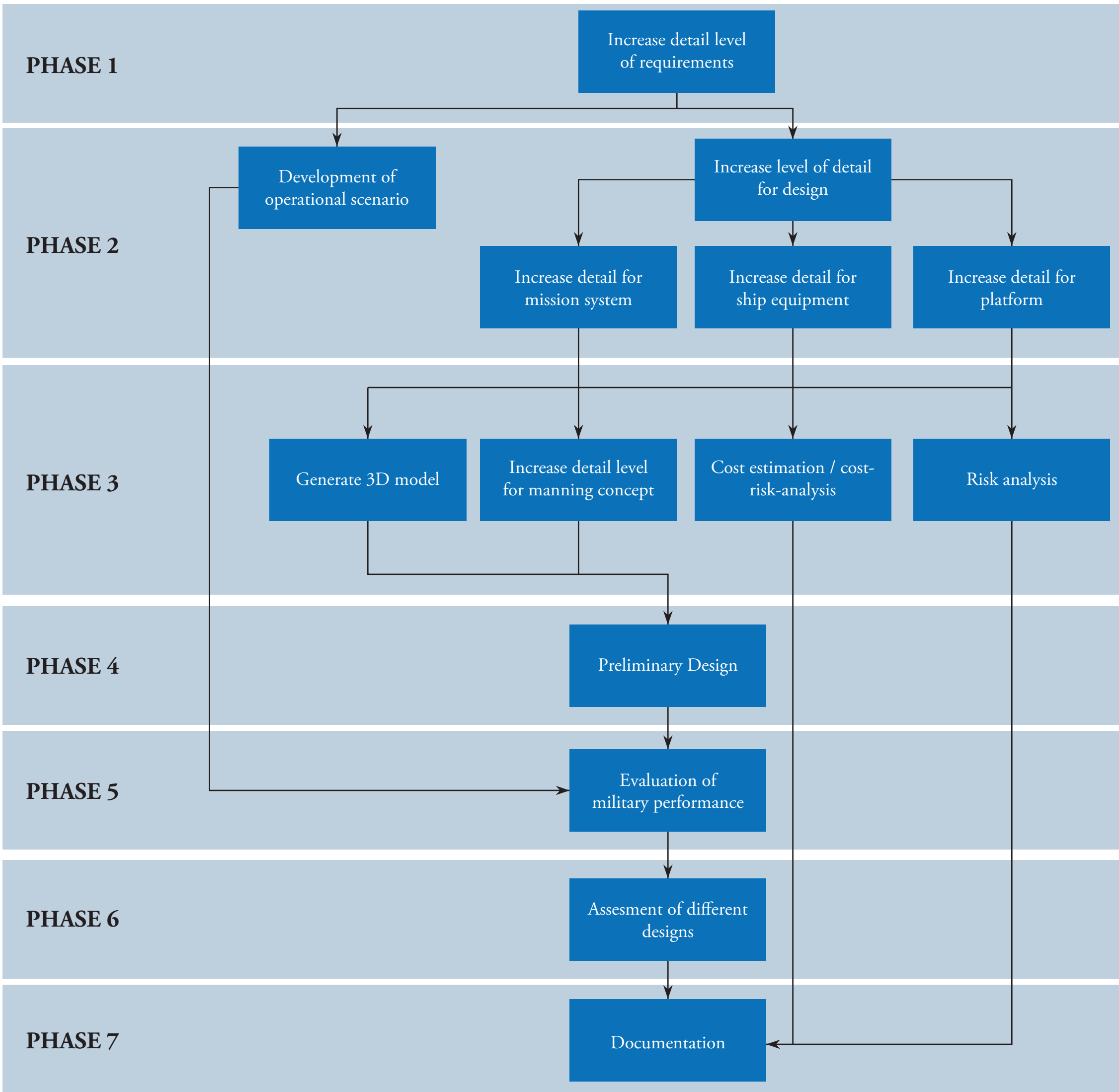
In reference to the results, the main dimensions and values like frame spacing, number of sections, position of bulkheads, and outline of hull and superstructure will be determined. This is followed by arranging the main components that have a strong effect on the design, *e.g.*, essentially horizontal and vertical main passage ways, stairwells, propulsion plant, exhaust pipes, switch boards, and -if required- helicopter facilities, cargo holds, RAS equipment, stern ramps and recesses for RHIBs. The main components of the required combat system, *e.g.*, weapons, sensors, and communication systems will also be arranged.

The technical part of the Conceptual Design results in the 2D sketch accompanied by the following information:

- Main dimensions,
- Propulsion concept,
- Electric concept,
- Payload components (including mission concept).

Increased accuracy of technical solutions can be achieved by developing Preliminary Designs at a later stage in the process.

Fig. 5. Flowchart of conceptual design process



Phase 6: Determination of technical performance, costs, and risks

It is important to start the determination of the technical performance and the first cost estimation at this early stage to decide whether to proceed or to iterate in order to generate further designs.

Determination of the technical performance is done by a simple comparison of elaborated data with requirements set in the initial stage of the design process.

Based on the design regulations (design to budget, design to requirements), it is also essential to start the cost estimation at this stage to get a qualified statement of the most probable costs. A constant cost evaluation during the project is essential to:

- Define the budget funds,
- Validate different alternatives,
- Evaluate tenders and select economically reasonable solutions,
- Identify cost savings or potential for economy,
- Reduce risk.

The cost estimation process is subdivided into seven steps:

- Set up project,
- Define work breakdown structure (WBS),

- Choose estimation model,
- Generate cost estimate,
- Review and validate estimate,
- Perform cost risk analysis,
- Document estimate.

The cost estimation project is initiated by collecting technical, programmatic, and cost data. Additionally, it is required to adjust the accounting data for inflation, learning, and quantity. Furthermore, the acquisition strategy (competition, consortium) has to be gathered. Typical sources of data are: cost proposals of vendors, historical databases, governmental agencies (the customer), experts, and open source (Internet, Naval reference books). In addition, necessary assumptions (*e.g.*, inflation, wages, overheads) are identified in this step.

The next step is the definition of the WBS elements that will be derived from the conceptual design and as previously specified. A WBS, thereby, is a decomposition of the ship into smaller components or rather functional technical groups like hull structure, propulsion plant, electric plant, etc.

The selection of the estimation model depends on the current phase of the project. For cost estimating purposes, every future naval vessel is divided into platform and payloads. Two models are used in VORGES; one for the very early conceptual design phase (SCEM – Ship Cost Estimation Method) and one for the preliminary design phase (GELIMAKO – GEräteLIste MArineKOsten (Cost register of naval equipment)). Both models are the property of MTG Marinetechnik as no COTS software is available for this kind of estimation task. Both SCEM and GELIMAKO apply a combination of the previously mentioned methods. The main SCEM method is a parametric top-down estimation with Cost Estimating Relationships (CERs). The data points collected over the course of time are connected via polynomial or cubic spline interpolation. Parametric estimation is used for platform cost elements like hull, propulsion, and electric plant. Accordingly, independent variables like hull volume, installed propulsion, number, and kind of propellers or power of electric plant are used. It is not easy to generate CERs for payloads, so expert opinions and analogies are used. Engineering costs for design and construction, management, proofs, test and trials along with others are estimated via empirically found formulas. Typical parameters in these formulas are number of building yards involved, number of ships, installation costs of payloads etc. The SCEM is usually used for rough estimates and "what if"-questions.

After the input of all necessary data, the model generates the cost estimate at the push of a button. This always goes along with a review and validation of the estimate. Reviewing means to cross-check the overall estimate with historical projects to see if the results are plausible. Implausible results lead to a revision of all input data and to one or more re-runs of the estimation.

After the cost estimation, a cost risk analysis (CRA) is performed to consider and evaluate the uncertainties in the model and the input data. As a result of the CRA, confidence will be achieved as to what extent the budget will be met; over- or under-run will be determined. This essential information for the Project Management is rendered by a comprehensive approach to analyse available or new technical details and solutions, as well as other factors related to political and economic issues.

Aside from aforementioned, as a standard procedure in the German procurement process, an economic feasibility study has to be made, looking for an economically reasonable solution by investigating costs, available technology, and risks involved.

Finally, the estimate is documented and presented. The documentation compiles the assumptions made, the estimation methods used, and the main results such as cost per WBS group and total system costs.

Phase 7: Determination of military performance

As soon as the technical evaluation and cost estimation is finished, various conceptual designs will be evaluated for their military performance by using a Maritime Scenario Simulation Tool (MaSST). The MaSST software is a highly customisable simulation framework for tactical scenarios. It is based on a COTS professional simulation environment, which was originally designed for tactical land scenarios. For VORGES, the MaSST software environment was significantly enhanced with several proprietary add-ons for tactical maritime scenarios. The base software, combined with the add-ons for maritime operations, results in a simulation environment with blue-water and superior brown-water scenario capability.

The add-ons include, among others:

- Radar sensor simulation module,
- IR sensor simulation module,
- Gunfire simulation module,
- Missile simulation module,
- Surface ship kinematics module,
- Vessel generator module.

To collect and analyse the data generated by MaSST simulations, various data logging modules have been developed and integrated into the simulation environment.

By original design, MaSST is not a ready-made or turnkey tool, but instead a modular system, continuously growing and enhanced for new specific tasks. If required, MaSST can simulate all tactical maritime environments of a particular vessel design. In principle, all kinds of maritime operations can be created and represented, ranging from harbour protection scenarios - which do not require a large ops theatre but a very high level of detail instead- to complex sea/land or air/sea/subsurface multi-threat scenarios, including large-scale sea surveillance scenarios in which the operations theatre can easily measure thousands of square nautical miles. However, future development of MaSST will be focussed on the creation of a range of predefined simulated tactical scenarios, *e.g.*, for sea surveillance.

Today, the tool is already used to:

- Create and evaluate operational concepts,
- Determine key parameters for future naval procurement programmes,
- Compare different concepts for maritime operations,
- Determine the military capabilities of naval vessel designs.

Testing a naval vessel design in a simulated tactical environment during the early stage of planning and procurement yields several advantages, *e.g.*, design changes are possible at relatively low costs (compared to changes during later stages of the procurement process). Results from MaSST for a range of predefined and/or customised simulated tactical scenarios may also be included into the requirements for the vessel, enabling the procuring authority to specify design requirements grouped along different scenarios. Thus, complexity is reduced at an early stage of the procurement process. The results from the MaSST simulations can be fed back into the ship design process. This empowers the procurement project manager to balance operational restrictions and cost restrictions more efficiently.

Phase 8: Assessment of conceptual designs

Because multiple vessel designs for selection by the procuring authority have been created, the requirement for an unbiased and objective assessment methodology arises. In order to have an equitable and consistent framework to compare different designs with regards to the requirements, an evaluation hierarchy has been established within VORGES by applying the Analytic Hierarchy Process (AHP) using the COTS "Expert Choice" software tool.

The basic idea of AHP is pairwise comparison, which means that both sub-criteria and alternatives to be evaluated are compared pairwise and rated by means of a pre-defined scale. In principle, all possible pair combinations are considered and rated individually. This may result in a relatively high amount of pairwise comparisons; for 3 criteria to be compared, 3 pairwise comparisons need to be made, but for 25 criteria we arrive at 300 pairwise comparisons. Accomplishing pairwise comparisons results in a matrix that is transformed into a weighting/benchmark for the constituent criteria/alternatives. Pairwise comparisons are executed by using the so-called AHP scale.

This scale consists of values between the extremes, defined as follows:

1 equally relevant

3 slightly more relevant

5 considerably more relevant
7 way more relevant
9 utterly dominant
2, 4, 6, 8 intermediate values

In each pairwise comparison, one of the designs is assigned the appropriate value from the above scale to express its significance/weighting/suitability in relation to the other candidate in that pair.

As a result, the AHP methodology produces a ranked order of the different conceptual and, at a later stage, preliminary designs based on the procuring authority's requirements, which have been weighted.

The assessment phase concludes with an evaluation of the degree of requirements fulfilment in the different conceptual designs. It will be evaluated if there is at least one design meeting basic requirements. This will lead to the decision whether to continue the process and to start the preliminary design or to restart the conceptual design phase.

Preliminary Design

From the catalogue of different conceptual designs, the procuring authority and/or the end-user has to select one or more promising solutions that will be further investigated. During the preliminary design phase, the results from the conceptual phase will be verified and further detailed enabling the design team to extrapolate the requirements catalogue for the on-going procurement process.

The preliminary design phase is subdivided into seven phases almost analogue to the conceptual design process. Fig. 7 illustrates the different phases and interdependencies of the different preliminary design stages.

Phase 1: Increased detail level of requirements
With the knowledge gained in the conceptual phase, the initial requirements can be re-evaluated and reviewed with respect to their feasibility and meaningfulness. During Phase 1, the previously designated meaningful set of requirements will be further specified, detailed, and extended by additional technical and functional details. As a result of intense cooperation between the end-user and the designer, a specified decision matrix of rated functional but also essential technical requirements will be generated, substantially influencing the following design process and, hence, allowing final assessment of the different designs.

Phase 2: Development of operational scenario/ increased level of detail for design (platform, sensor and effector suite, ship equipment)
The basic operational scenario and environment have already been designated in the initial phase of the planning process. In order to start the evaluation of the military performance of the preliminary design, a detailed operational concept has to be developed. This step mostly requires the input of the procuring authority/end user and contains information related to the potential threat, mission environment, and logistic requirements.

Based on the functional requirements specified in Phase 1, a more detailed selection for the platform, the mission systems, and the ship equipment can be made. Details for the platform contain the generation of a 3D hull model, 2D outfitting and super structure, strength calculation, basic weight estimation, and determination of stability. Technical solutions and arrangement of the components will be further specified for the mission system, as well as for the propulsion, electric, and ship operations system. In some cases, a selection decision can be made; in other cases, resulting alternating or competing technical solutions will lead to new preliminary designs.

Phase 3: Generation of 3D model/manning concept/cost estimation/cost risk analysis risk analysis for payloads/ship equipment
In this phase, several steps will take place simultaneously. Generation of 3D models, along with further specifications of the manning concept will directly lead to the conceptual design, whereas the cost estimation and the risk analysis might have an effect on the design, but will mainly be required at later stages.

A special tool developed by MTG is used for the cost estimation at this step, different from the conceptual design phase, as more details that influence the cost estimation exist. The GELIMAKO tool is a bottom-up calculatory approach that uses engineering build-up, which is possible with detailed knowledge of the project and the design. GELIMAKO also incorporates different currencies, individual inflation rates per cost element, and price adjustment clauses.

Phase 4: Generation of preliminary design
The preliminary design eventually generated at this stage contains a 3D model, a detailed interior arrangement plan, a detailed equipment list, and a thorough cost estimation also specifying the expected life cycle costs.

Phase 5: Evaluation of military performance/ effectiveness
Based on the operational environment, as defined in Phase 2, the different designs will be analysed for their military performance in a predefined operational scenario by using the MaSST simulation tool. Thereafter, detailed information can be given to the effectiveness of the sensor set, the effector set, and the platform itself.

In addition to the military performance, other characteristics will need to be analysed. Those characteristics include analysis of the signature (magnetic, acoustic etc.), analysis of vulnerability, hydrodynamic characteristics, mission capabilities and sustainability, as well as the overall performance of the sensor effector functional chain.

For this phase, MTG uses its own self-developed software tools, which is owed to the fact that almost no commercially available and only some proprietary software exist for this task.

Phase 6: Assessment of different designs/ solutions
As in the assessment process of the conceptual design phase, the preliminary designs will be evaluated utilizing the decision matrix generated in Phase 2 in combination with the results of the AHP procedure with the "Expert Choice" tool. As a result, the procurement authority will obtain a list of the degree of requirements fulfilment and a cost benefit ratio comparison of the different designs. With these tools, the procuring authority is put in a position to either make a final selection or to continue the investigation/design process.

Phase 7: Documentation
Once the final selection has been made, the technical and functional characteristics can be derived from the preliminary design. From these documents, the Statement of Requirements containing technical specifications for invitations to tender can be prepared in a very short time, which enables the procuring authority to specify the ship and evaluate the technical and commercial proposals received from the naval industry.

MKS180 (Multirole Combat Ship Class 180)

Using a standardized and flexible multi-stage design process like VORGES will allow rapidly generating statements concerning the technical and operational feasibility. Additionally, it will be possible to investigate solutions and concepts based on different formal and informal requirements. The MKS180 project is a very good example to show the advantages of VORGES in a real-time scenario to find a complex design, balancing user requirements with the budget available.

History

MKS180 is one of many German Navy design projects for which MTG Marinetechnik has been responsible. It is a project to define a frigate design meeting current and forthcoming naval requirements and political preferences. Throughout the process, the basic requirements have been changed several times resulting in over 20 different designs and over 60 design alterations at different detail levels.

Within the first two years a total of 18 conceptual designs have been generated to consolidate the basic requirements. At the end of that phase, the procuring authority in cooperation with the Navy has made an intermediate selection, allowing intensifying the process and starting the preliminary design phase. The following period was mainly used to generate the preliminary

Table 1. MKS180 process

Period	Version	Type of design	Focus / Framework
Year 1	CD1	Conceptual	Initial start, design to budget
	CD2		Investigation of different variants of mission system on K310 platform
	CD5		
	CD6		
	CD7		
	CD8		
	CD3		Investigation of different hull forms of mission system analogue to K310
	CD4		
	CD9		
	CD10		
	CD11		Design with focus on modular mission system and organic assets
Year 2	CD15		Design according to military building standards
	CD1		Design according to civilian building standards plus military add-ons
	CD17		Conceptual designs based on updated requeriments catalogue
	CD18		
	CD12		Design to budget (civil platform plus basic mission systems)
	CD13		Design to budget (civil platform plus advance mission systems)
	CD14		Design to budget (military platform plus advance mission systems)
Year 3	PD1	Preliminary	Design to budget
	PD2		Design to requeriments
	PD3		Design to budget
Year 4	PD4		-
	PD5		-

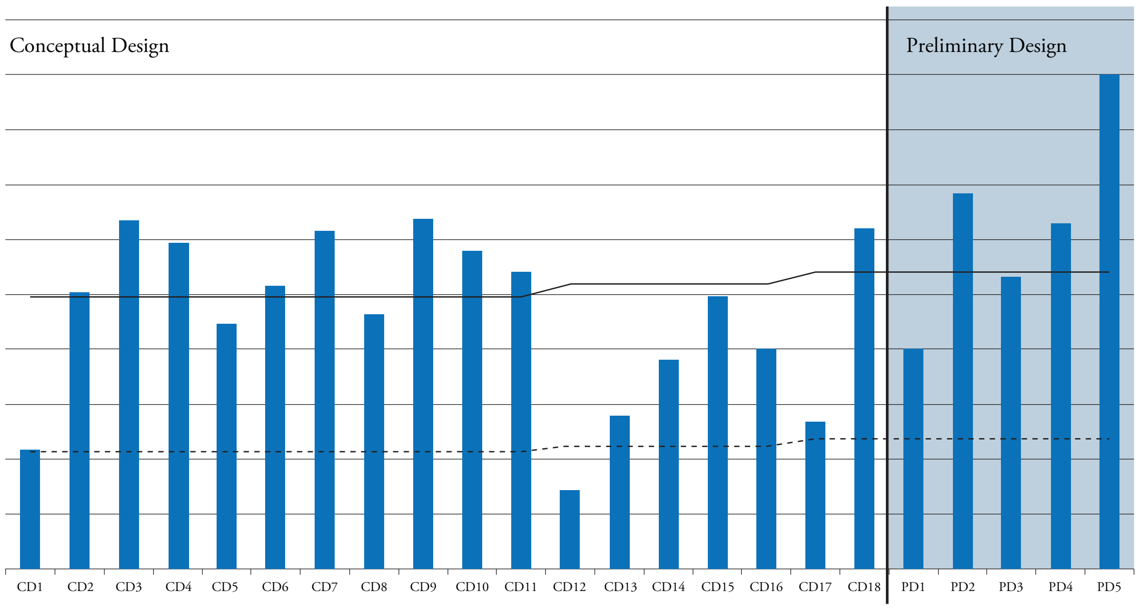
designs and carry out many other studies related to the project.

Results / Designs

The starting point for the project was the K130 design. Initially designated K131, MTG began to create several preliminary studies analysing the influence of using either civilian or military or a combination of both building standards on the overall complex system of a naval vessel to get a first feeling of the influence on prices and military performance.

Based on the initial very basic requirements, MTG started generating first designs and several preliminary studies. The resulting conceptual designs were primarily made to elaborate different designs on one side for different hullforms and different variants of the mission system on the other side. Independent of those designs, MTG made a design to investigate the influence of a high-end modular system on capabilities and price. After the selection of the hullform and the mission system, five designs were done on a design to budget or design to requirement and design according to civilian plus military add-ons or military building standard basis. During this phase a grand total of 18 conceptual designs have been finished and many different aspects have been investigated enabling the procuring authority and respective project management to consolidate the basic requirements and to adapt existing designs to changing military but also to civilian rules and regulations.

Fig. 6. Price trend during MKS180 process, including lower and upper budget restrictions



Until now, MTG has made a total of five preliminary designs based on the results of the conceptual design phase and the results of the preceding design. It was the VORGES methodology that allowed this complex investigation under the different frameworks that were either driven by changing naval requirements or by changing focuses of investigation.

During the overall process, the budget and the requirements had to be adapted as it was the procurement authorities/Navies' decision to proceed with a military design and a sophisticated modular mission system. The drawbacks of using a civilian design standard with military add-ons were not acceptable to the Navy.

This decision could fundamentally be made based on information gained during the conceptual and preliminary design phase.

Fig. 7 is a good example to show the influence of the different designs for the overall project. During the process, the Navy gained so much information and changed/extended the requirements that the displacement increased during the project to almost four times, compared to the beginning.

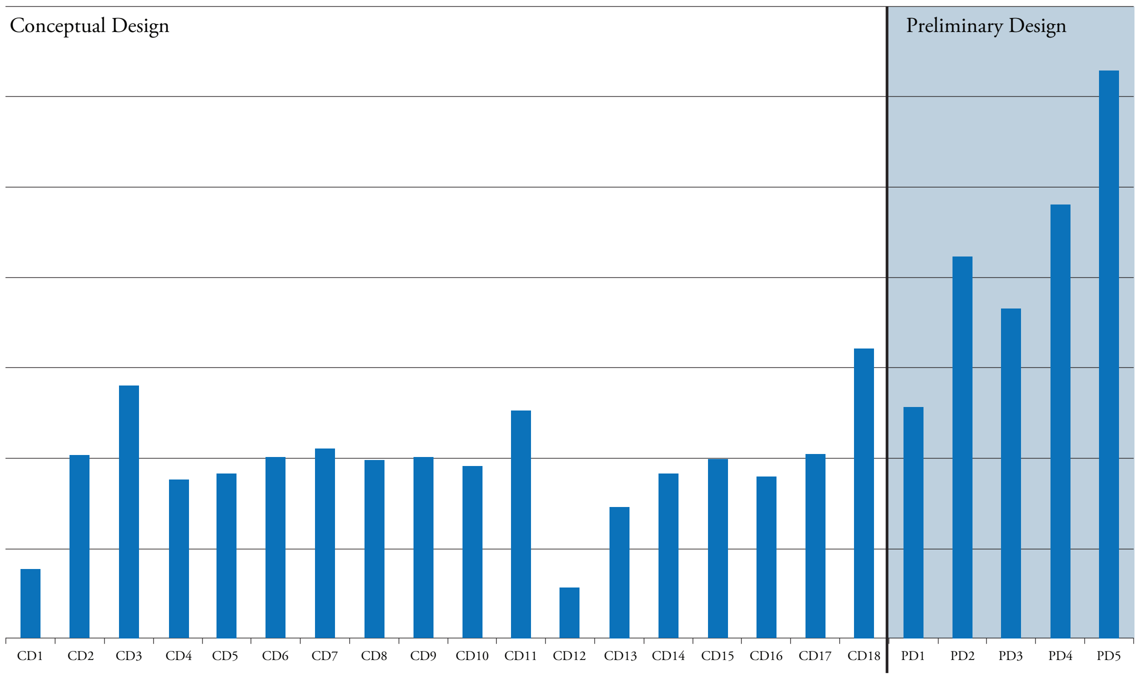
As mentioned earlier, based on the requirement to proceed with a military design standard, the budget had to be adapted several times throughout the project. Figure 6 gives a good overview of the tendency and price development of the several designs.

With PD5 finished recently, the procurement authority along with the Navy is now able to determine the final value for the defence budget and about to formulate the technical requirements that will be given to the industry to start the initial tender process.

Conclusions

During most naval procurement projects, the allocated budget is not sufficient to meet all requirements. For this matter, it is essential to have a methodology to generate numerous designs in a very short time balancing the different requirements. This enables the procuring authority to select from a set of different designs the one that meets the requirements at the highest level. VORGES, the procedural model for total ship system engineering, has been developed by MTG Marinetechnik as an iterative process for the conceptual and preliminary

Fig. 7. Development of displacement during the MKS180 process



design of surface naval vessels in the early planning phases. During the iterative design process, the requirements and costs are constantly evaluated allowing the early adjustment of either the budget or the requirements. Additionally, all designs will be evaluated for their military performance and assessed for their requirements fulfilment, thus, greatly reducing the complexity of the decision for the procuring authority. The ability and high flexibility to generate several different designs will enable the procuring authority to decide whether to continue the planning process or to start the formulation of the technical requirements that will then be forwarded to the naval industry. The flexibility and agility of the VORGES model will enable the design agency to rapidly adapt to any changes of functional requirements or rules and regulations that usually and almost invariably occur during the overall planning process.

The latest frigate design project, MKS180, is a good example to show the capabilities of the VORGES methodology. During the process, several designs have been generated in a very short period of time to look at all facets of probable solutions, designs, and design combinations. As one result of the learning process, the Navy along with the procurement authority repeatedly updated the budget, as well as the functional requirements several times and has finally been in a position to proceed with a design meeting military requirements to a maximum extent, which emerged as the latest PD5 design. *Hamburg, January 2013*

Author's biography

ANDRÉ NEUMANN joined the Systems Engineering Team at MTG Marinetechnik GmbH in 2012. He served for 15 years as a naval aviation officer in the German Navy, followed by 4 years in the maritime industry as a Project- and Key Account Manager. He holds an advanced degree in business administration and economics.

Bibliography

www.mtg-marinetechnik.de

Identification and Adaptive Fuzzy Control for Navigation Systems of Autonomous Vehicles

Identificación y control difuso adaptativo para sistemas de navegación de vehículos autónomos

Juan Contreras [1]
Manuel Ariza [2]
Luís Velásquez [3]
Alcides Ramos [4]
Vladimir Díaz [5]
Julián Arbeláez [6]

Abstract

This article presents a simple method to generate the automatic course control of surface naval vehicles by using fuzzy logic to adjust the parameters of the PID controller. The fuzzy systems constructed to automatically adapt the parameters of the PID controller are Mamdani type and use functions of triangular relevance for the antecedent and the consequent. An application to a real model is presented, exposing the identification process to obtain the mathematical model from experimental data, the temporal analysis from the mathematical model, obtain the parameters from the PI controller, and the results on course changes between 125° and 305°. Thereafter, and bearing in mind the range of Kp and Ti parameters in which the system is stable, a structure of a self-tunable fuzzy PI controller was presented and implemented with notable improvement in the response system.

Key words: identification, root locus, PID control, fuzzy PI control, self-tuning

Resumen

Este artículo presenta un método sencillo para la generación del control automático del rumbo de vehículos navales de superficie empleando la lógica difusa para ajustar los parámetros del controlador PID. El sistema difuso construido para adaptar automáticamente los parámetros del controlador PID es del tipo Mamdani y emplea funciones de pertenencia triangulares para el antecedente y el consecuente. Se presenta una aplicación a un modelo real, exponiendo el proceso de identificación para la obtención del modelo matemático a partir de datos experimentales, el análisis temporal del modelo matemático, la obtención de los parámetros del controlador PI, y los resultados ante cambios de rumbo entre 125° y 305°. Posteriormente, y teniendo en cuenta el rango de los parámetros Kp y Ti en que el sistema es estable, se presentó e implementó una estructura de un controlador PI difuso autosintonizable con una mejora notable en la respuesta del sistema.

Palabras claves: identificación, lugar de las raíces, control PID, control PI difuso, autosintonización

Date Received: December 13th, 2012 - *Fecha de recepción: 13 de Diciembre de 2012*
Date Accepted: February 19th, 2013 - *Fecha de aceptación: 19 de Febrero de 2013*

[1] Faculty of Naval Engineering - Escuela Naval Almirante Padilla, Cartagena de Indias, Colombia. e-mail: epcontrerasj@ieee.org
[2] Faculty of Naval Engineering - Escuela Naval Almirante Padilla, Cartagena de Indias, Colombia. e-mail: amatgwill@hotmail.com
[3] Faculty of Naval Engineering - Escuela Naval Almirante Padilla, Cartagena de Indias, Colombia. e-mail: jdesem@gmail.com
[4] Faculty of Naval Engineering - Escuela Naval Almirante Padilla, Cartagena de Indias, Colombia. e-mail: alcidesramos@yahoo.es
[5] COTECMAR. Research, Development, and Innovation Department. Cartagena, Colombia. e-mail: vdiaz@cotecmar.com
[6] Faculty of Naval Engineering - Escuela Naval Almirante Padilla, Cartagena de Indias, Colombia. e-mail: yeha8040@hotmail.com

Introduction

An autopilot is one of the most important devices on board a ship; it is connected to its governor system and makes course corrections based on information from the compass, GPS, and digital compass, among other sensors. An autopilot with adaptable parameters and optimization techniques incorporated can contribute to maintaining or following a desired course in such an efficient manner that it can reduce the route by up to 5%, thus, also reducing fuel consumption (Witkowska and Smierzchalski, 2008; Krishna et al., 2011).

The Proportional-Integral-Derivative (PID) control technique has been widely used in autopilots because of its simplicity and ease of implementation. However, the performance of PID controllers has not shown good results in the changing environmental conditions that can be encountered by the ship in its navigation route *(Nguyen et al., 2003; Loo and Mastorakis, 2007)*.

To design the course controller, it is necessary to have a mathematical model that describes, as closely as possible, the ship's dynamics. The motion of the ship at sea is described by a set of six complicated differential equations related to its six degrees of freedom *(Tzeng and Chen, 1999; Fossen, 2002)*. However, it is a common practice to consider only the horizontal plane, which is why the degrees of freedom are reduced to three and, thereby, the mathematical model is simplified *(Krishna et al., 2011)*. One of the most used models for the preliminary design of the course controller is the Nomoto model *(Velazco et al., 2008; Chang et al., 2010; Krishna et al., 2011)* due to its simplicity.

Fuzzy logic has turned out to be a very effective technique to overcome inconveniences presented by PID control, permitting the generation of fuzzy controllers with great adaptation capacity. In some cases, it is used as automatic adjustment mechanism (self-tuning) of PID controller parameters (*Velagic et al., 2003; Nguyen et al., 2003; Loo et al., 2007; Contreras, 2011; Contreras et al., 2011*).

This article is organized as follows. Section 2 presents a brief description of the scale model (surface vehicle) used during the identification and control tests; Section 3 describes the identification process used to obtain the mathematical model of the surface vehicle; Section 4 analyzes the temporal behavior of the mathematical model obtained and proceeds to calculate the parameters of the PID controller; Section 5 gives the structure of the self-tunable fuzzy PI controller and the results obtained, followed by the conclusions.

Description of the scale model

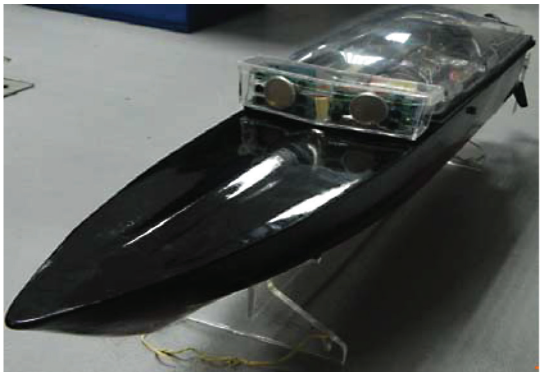
The surface vehicle used belongs to the Almirante Padilla Naval School, located in Cartagena, Colombia, and has a wooden hull, with a length of 0.78 m and a 0.22-m breadth. The dimensions of the model are presented in Table I and Fig. 1.

Table 1. Characteristics of the surface model

Item	Description
Length	0.78m
Breadth	0.22m
Depth	0.15
Weight	9.2 Kg
Propelling source	DC motor
Autonomy	1.2 h
Maximum velocity	1.3 m/s

Fig. 1. Surface vehicle used

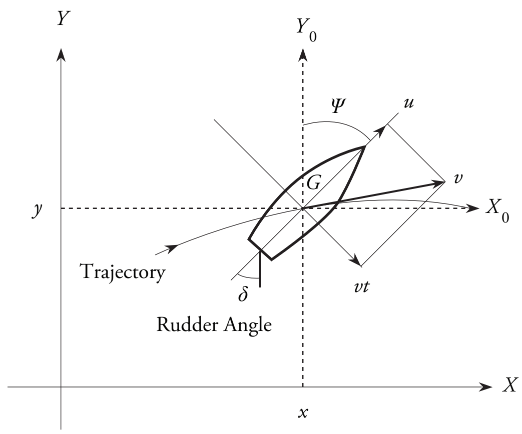
b) Version with vision and sonar system



The surface vehicle contains, among others, the following elements on board: electronic compass, GPS; accelerometers, propulsion motors, servomotors and rudder system, sonar, video camera, and RF communication module.

Identification of the Dynamics of the Surface Model

Fig. 2. Variables defining the ship's course



A simple model describing the dynamic behavior of a ship can be expressed through Nomoto's third-order model *(Tzeng and Chen, 1999; Du and Guo, 2004):*

$$\dddot{\psi}(t) + \left(\frac{1}{T_1} + \frac{1}{T_2}\right)\ddot{\psi}(t) + \frac{1}{T_1 T_2} H_N\left(\dot{\psi}(t)\right) = \frac{K}{T_1 T_2}\left(T_3\, \delta(t) + \delta(t)\right) \quad (1)$$

where *Ψ(t)* is the course angle and *δ(t)* is the rudder angle. If we assume initial conditions null, the Nomoto equation can be represented in the Laplace domain through the following transference function:

$$\frac{\psi(s)}{\delta(s)} = \frac{K(T_3 s + 1)}{s(T_1 2 + 1)(T_2 s + 1)} \quad (2)$$

The prior equation could be obtained through identification techniques using experimental data and selecting one of the structures of models included in the IDET identification tool by MATLAB (arx, armax, oe, etc.) that best approaches the dynamics represented by the experimental data.

To identify the course a maneuver similar to the zig-zag curve was used, varying the rudder angle between 20° and -20° (Fig. 3), which causes course changes of the physical model to port and starboard. The platform maintains approximately constant velocity during the whole maneuver. Several tests were conducted in the Bay of Cartagena de Indias, in El Laguito sector, seeking to obtain a mathematical model with enough precision to proceed to design the course control system.

We sought to obtain a low-order model, but due to the delay presented by the model's response it was not possible to reach a second-order model that permitted an analogy of the coefficients with the structure of the model by Nomoto. The best model was obtained with the AutoRegressive Moving Average eXogen (ARMAX) structure, whose discrete time representation is shown by the following:

$$\frac{\psi(s)}{\delta(s)} = \frac{0.02347}{z^4 - 1.29 z^3 + 0.2897 z^2} \quad (3)$$

In continuous time:

$$\frac{\psi(s)}{\delta(s)} = \frac{0.009098 s^4 - 1.213 s^3 + 60.65 s^2 - 1348 s + 11230}{s^4 - 85.02 s^3 + 2553 s^2 + 20390 s - 137.6} \quad (4)$$

The mean quadratic error achieved was 1.2446e+003. Fig. 4 shows the comparison between the real course real and the output of the ARMAX model.

Fig. 3. Data taken from the surface model identification experiment

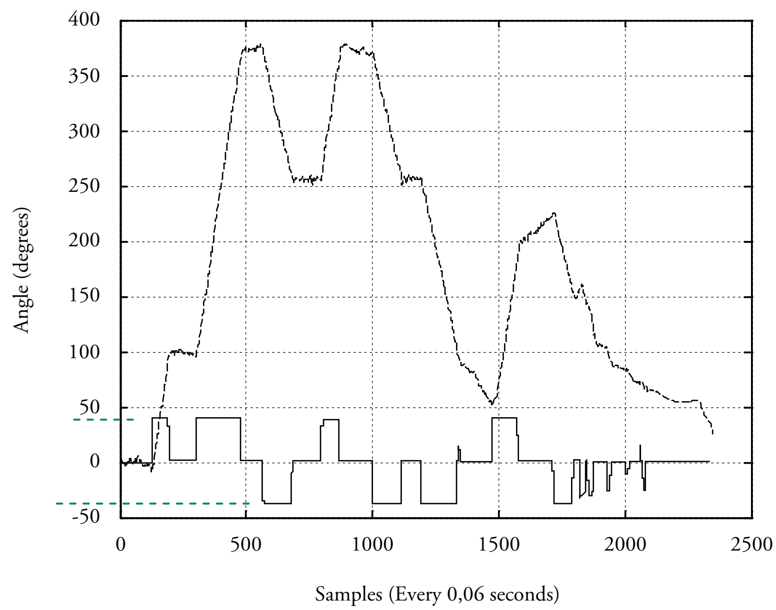
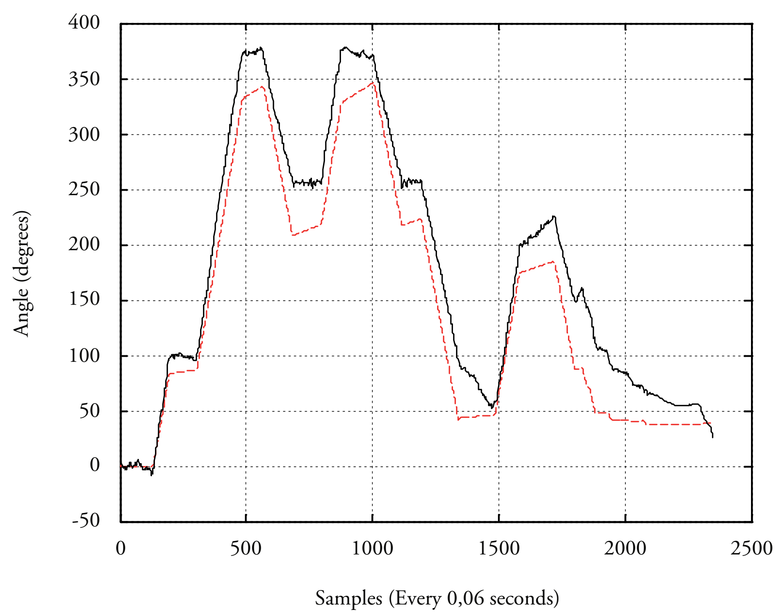


Fig. 4. Comparison between the vehicle's real response and the response of the ARMAX mathematical model on rudder angle variation



The mathematical model obtained is of fourth order, with a pole close to the origin (s1=0.0067), but on the positive side of the complex S plane, which indicates a tendency to instability. It presents a pole on the real negative axis (s2 = -18.3478) and two complex poles conjugated with real negative part (s3 = -33.3394 + j0.7993; s4 = -33.3394 - j0.7993), which give an indication that the system can have damped oscillations in its response (as long as it is taken out of the instability zone).

Design of the Pid Controller

After obtaining the mathematical model, we proceeded to design a PID controller to regulate the course of the surface vehicle. The first step was to obtain the system's Root locus (vehicle) to know its temporal behavior (Fig. 5).

The Root locus shows that the system has a pole that at low system gain is located near the origin but on the positive side of the S plane, which generates unstable behavior. This pole can be displaced to the left side of the S plane if the system's closed loop gain is greater than 0.0153. If the closed loop gain increases above 90, the system will again fall in instability. For the closed loop gain of 90, the system will have a critically stable behavior, which permits applying the Ziegler – Nichols method to design the PID controller.

Fig. 6 shows the application of a gain variable to the system to determine the critical gain, Kcr, which would bring the system to the critically stable state.

Fig. 5. Root locus of the surface vehicle model

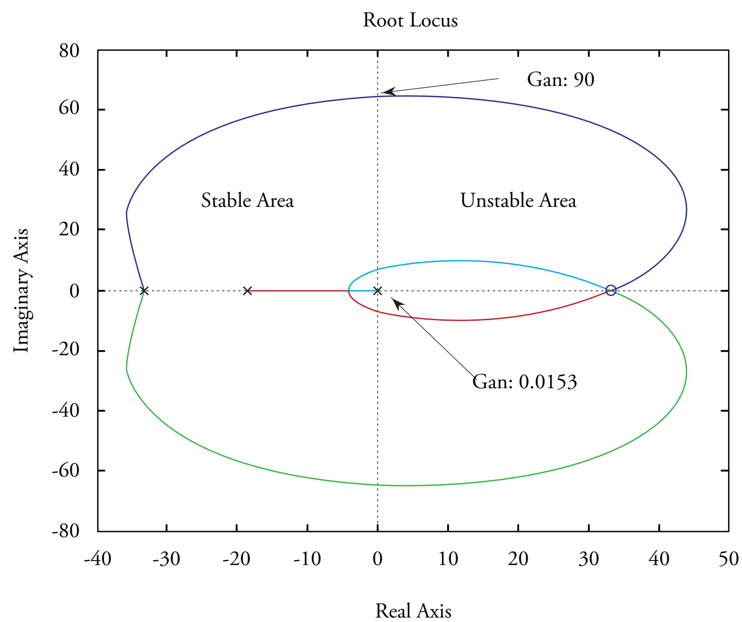
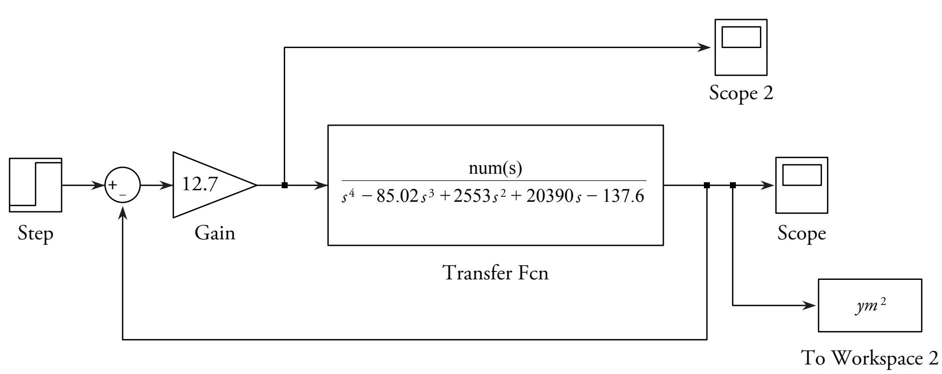


Fig. 6. Scheme to determine the critical gain, Kcr



The value of Kcr is 12.7. The critical period is obtained from Fig. 7.
The critical period, Pcr, is 0.93 seconds. With the value of the critical gain, Kcr, value of 12.7, we proceeded to seek the controller parameters in Table 2.

Fig. 7. Critical period, Pcr, obtained

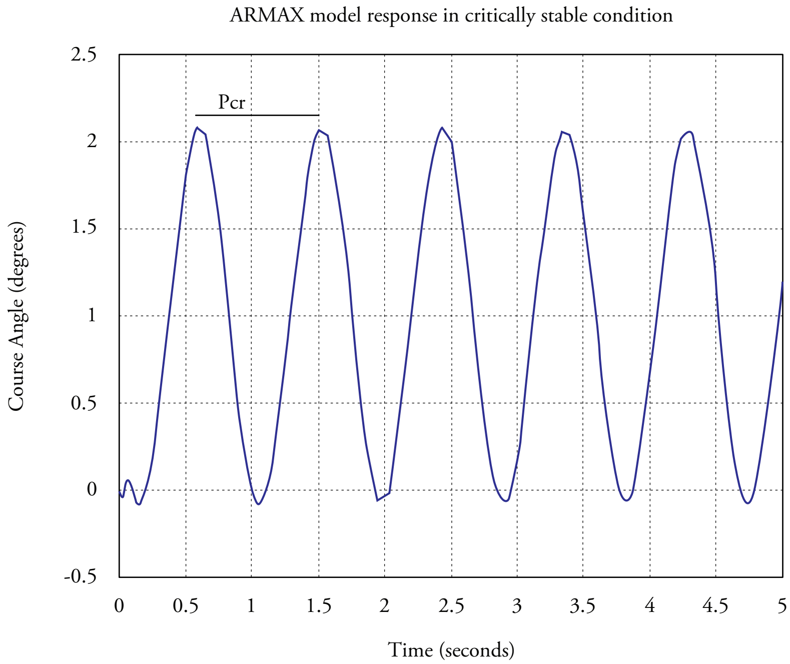


Table 2. Ziegler – Nichols' second method

Type of Controller	Kp	Ti	Td
P	0.5 *Krc*	∞	0
PI	0.5 *Krc*	1/1.2 *Pcr*	0
PID	0.6 *Krc*	0.5 *Pcr*	0.125 *Pcr*

That is, to obtain the PI controller, the parameters will be:

Kp = 0.5*Kcr = 0.5*12.7 = 6.35 (5)

Ti = Pcr/1.2 = 0.93/ 1.2 = 0.775 (6)

It should be noted that the SIMULINK PID equation differs from the conventional equation, thus:

Conventional equation of the PID:

u(t) = Kp[1 + 1/Ti + Td]*e(t) (7)

SIMULINK PID equation:

u(t) = [P + I + D]* e(t) (8)

That is, Kp = P; I = Kp/Ti; D = Kp*Td. Hence, for the SIMULINK simulation use P = 6.35 and I = 6.35/0.775 = 8.19

The system response with PID controller upon a 20-degree reference signal is shown in Fig. 8.

An error is reached in stationary state equal to zero; however, the over impulse is high. The results obtained in the tests on the prototype resulted with a higher over impulse due to delay in controller data transmission from the PC.

The proportional gain was adjusted to diminish over impulse and a better response was obtained with P = 3 (Fig. 9).

The results of the vehicle's real response to reference signal changes (desired course) from 300° to 125°, regulated with the PI controller, are shown in Fig. 10.

The real system response, shown in Fig. 10, presents oscillations, especially when the course

Fig. 8. Response of the controlled model (P = 6.35 and I = 8.19) on course change request from 0° to 20°

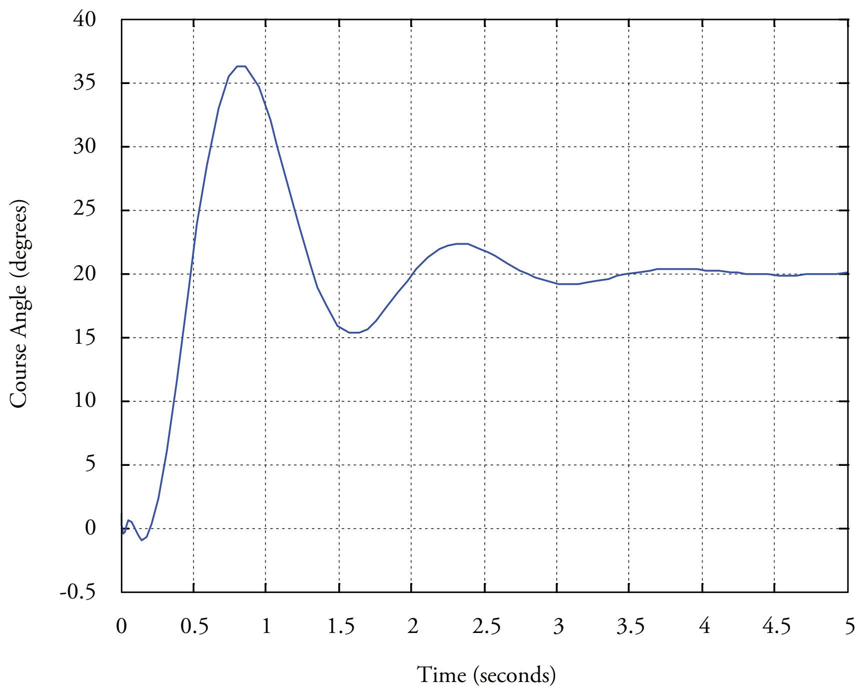
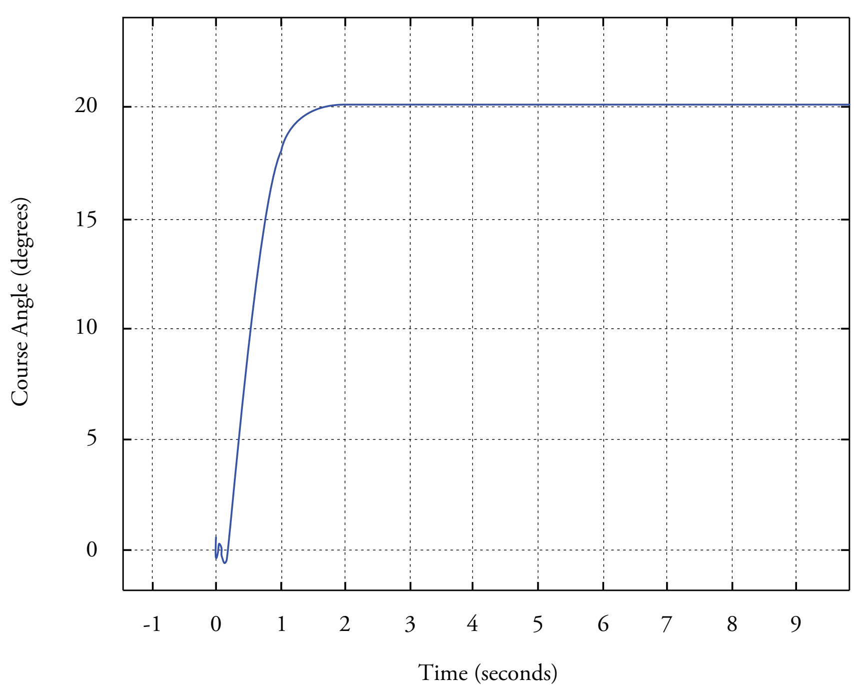
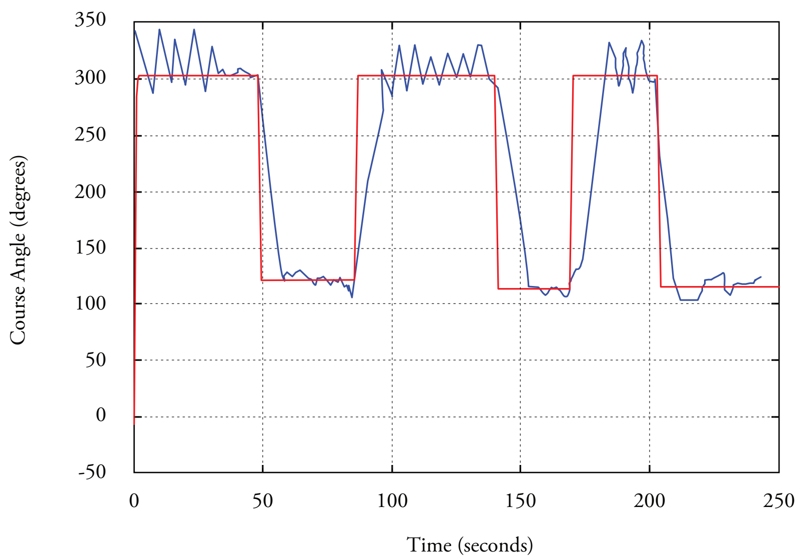


Fig. 9. Response of the controlled model (P = 3 and I = 8.19) upon change of course request from 0° to 20°



must be maintained. Hence, proceeding to include an adaptive fuzzy system that adjusts the gain from the PI controller according to the error size so that at high error values the controller action was higher than at low values, where the course must be maintained.

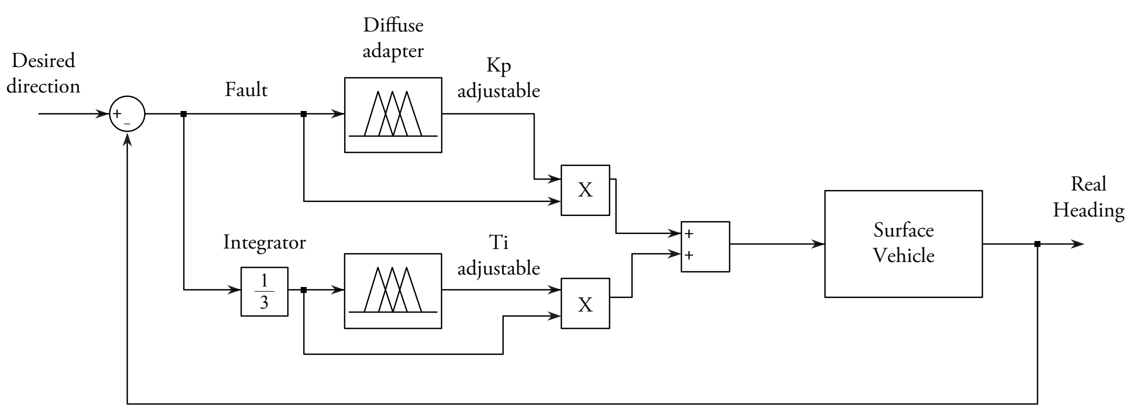
Fig. 10. Real response of the controlled vehicle (P = 3 and I = 8.19) upon course change request from 125° to 305°



Self-Tunable Fuzzy PI Controller

Fig. 11 shows the structure of the self-tunable fuzzy PI controller:

Fig. 11. Scheme of the PI controller with fuzzy adaptation



The range of the output universe of the proportional fuzzy adaptor was defined between 0.1 and 6 for the Kp generated not to bring the system to the instability zone. The range of the output universe of the integral fuzzy adaptor was defined between 1 and 100 for the Ki generated not to cause high oscillations.

The range of the error input variable was estimated between -180° and 80°. For both fuzzy adaptation systems, five fuzzy triangular sets were considered for the error input variable, symmetrically distributed so that the minimum values (-180°) and maximum values (180°) coincided with the modal value of the sets of two of the extremes. Likewise, three triangular sets were considered for the output variables. For each case, five fuzzy rules were considered (Table 3).

Fig. 12 shows the surface of the adaptive fuzzy system for the controller's proportional gain.

Table 3. Fuzzy rule base

Error \Gain	Low	Medium	High
Negative High			X
Negative Medium		X	
Zero	X		
Positive Medium		X	
Positive High			X

It can be noted from Fig. 12 that Kp takes values according to the error value, that is, depending on how off course the vehicle is.

Results

Results of the vehicle's real response upon reference signal changes (desired course) from 305° to 125°, regulated with self-tunable fuzzy PI controller, are shown in Fig. 13. Note a response without over impulses or significant oscillations, although with a slightly higher setting time than with the PI controller, given that Kp and Ti values diminish as the desired response (course) is reached.

Fig. 12. Fuzzy adapter surface of the PI's proportional gain

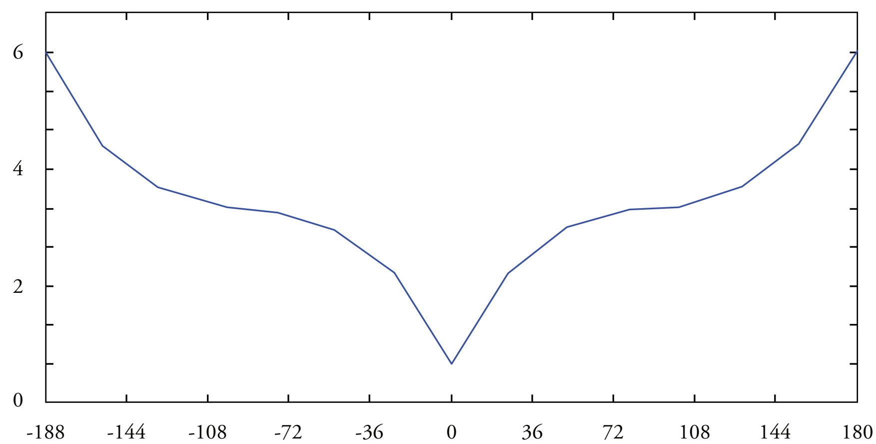
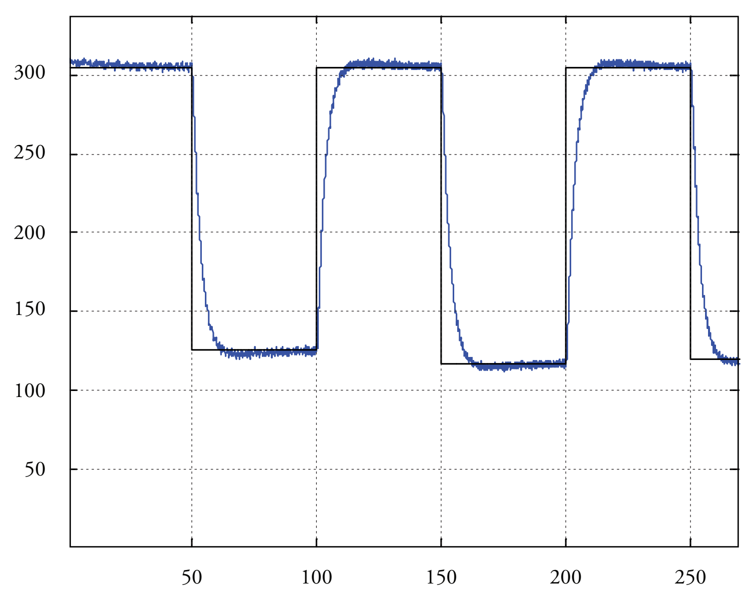


Fig. 13. Vehicle's real response self-tunable fuzzy PI controller upon course change request from 305° to 125°



Conclusions

This work presented the identification process of a surface vehicle scale model; analysis of the temporal response from the information delivered by the root locus of the mathematical model obtained; and, with the temporal analysis proceeded to obtain the parameters of a PI controller to regulate the vehicle's change of course, employing Ziegler Nichols second method. The data obtained from the application of the PI controller in a real operation of the vehicle permitted seeing that the vehicle followed the change of course ordered, but presented high oscillations in the permanent response (maintaining the course).

A simple structure was presented of a self-tunable fuzzy PI controller in which it is only necessary to indicate the range in which the Kp and Ti parameters can vary. Thus, if the error diminishes, then the gain (Kp and Ti) also diminishes, considerably reducing the oscillations in stable or permanent state.

References

CHANG W-J., CHANG C-H, KU C-C. "Fuzzy controller design for Takagi-Sugeno fuzzy models with multiplicative noises via relaxed non-quadratic stability analysis". Journal of Systems and Control Engineering, Vol. 224, No. 8, pp. 918-931. December 2010.

CONTRERAS, J. "Generating fuzzy controllers for ship steering". Annual Meeting of the North American Fuzzy Information Processing Society (NAFIPS), March 2011.

CONTRERAS, J., DURÁN, F. CELI, A. "Generating Fuzzy autopilot for ship maneuvering". Ship Science & Technology - Vol. 5, No. 9, pp.: 107-114. July 2011.

DU, J., GUO, CH. "Nonlinear Adaptive Ship Course Tracking Control Based on Back-stepping and Nussbaum Gain". Proceeding of the 2004 American Control Conference Boston, Massachusetts, pp. 3845-3850, July, 2004.

FOSSEN, T. I. "Marine Control Systems. Guidance, Navigation, and Control of Ships, Rigs and Underwater Vehicles". Marine Cybernetics. Trondheim, Norway. 2002.

KRISHNA, M., RAO, S., RAJU, R., "Theoretical and experimental investigation of gain scheduling and adaptive autopilots for a model boat". International Journal of Engineering Science and Technology. Vol. 3, No. 2, pp. 902–911, 2011.

LOO, C. K., MASTORAKIS, N.E. "Particle Swarm Optimization of Fuzzy Model Reference Learning Controller for Tanker Ship Steering". Proceedings of the 11th WSEAS International Conference on Systems, Agios Nikolaos, Crete Island, Greece, July 23-25, 2007.

NGUYEN L.A., Le M.D., NGUYEN S.H., NGUYEN V.T., NGHIEM T.H. "A New and Effective Fuzzy PID Autopilot For Ships". SICE Annual Conference. Fukui, Japan. 2003.

TZENG, CH-Y., CHEN, J.F. "Fundamental Properties of Linear Ship Steering Dynamic Models", Journal of Marine Science and Technology, Vol. 7, No. 2, pp. 79-88. 1999.

VELAGIC, J., VUKIC, Z., OMERDIC, E. "Adaptive fuzzy ship autopilot for track-keeping". Control Engineering Practice, vol. 11, pp. 433–443. 2003.

VELASCO, F.J., REVESTIDO, E., LÓPEZ, E., Moyano, E., Haro Casado, M. "Autopilot and Track-Keeping Simulation of an Autonomous In-scale Fast-ferry Model". 12th WSEAS International Conference on Systems, Heraklion, Greece, July 22-24, 2008.

WITKOWSKA, A., SMIERZCHALSKI, R., "Nonlinear Back-stepping Ship Course Controller", R&RATA, vol, 1, No. 2, pp. 147-155. Jun. 2008.

Analysis of Dynamic Stability of Planing Craft on the Vertical Plane

Análisis de estabilidad dinámica de embarcaciones de planeo en el plano vertical

Roberto Algarín [1]
Oscar Tascón [2]

Abstract

A dynamic model for the motion of planing craft on the vertical plane was developed; the motions of surge, heave, and pitch are coupled. Critical conditions that produce the inception of instability are evaluated. The Wagner model (1932) for 2D impact is extended for section with knuckles. Planing hulls were analyzed through the application of slender body theory. The results are compared with Tveitnes (2001), Peterson (1997), Savitsky (1964), Troesch (1992) and Celano (1998).

Key words: Slamming, Porpoising, planing boats, dynamic stability.

Resumen

Se desarrolla un modelo dinámico del movimiento de embarcaciones de planeo en el plano vertical acoplando los movimientos de avance y levantamiento, cabeceo. Se determinan las condiciones críticas que dan origen de la inestabilidad. El modelo de Wagner (1932) para el impacto 2D es extendido para secciones con codillos. Mediante la aplicación de la teoría de cuerpos esbeltos se analizan las embarcaciones de planeo. Los resultados obtenidos son comparados con Tveitnes (2001), Peterson (1997), Savitsky (1964), Troesch (1992), Celano (1998).

Palabras claves: impacto en el agua, botes de planeo, estabilidad dinámica.

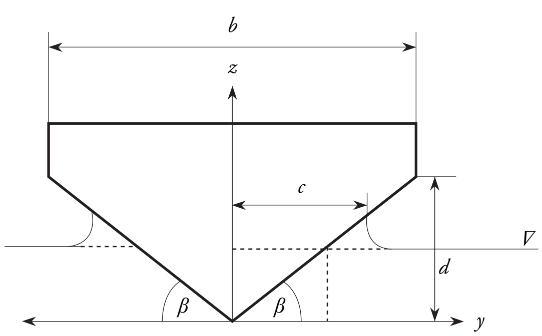
Date Received: January 22th, 2013 - *Fecha de recepción: 22 de Enero de 2013*
Date Accepted: March 6th, 2013 - *Fecha de aceptación: 6 de Marzo de 2013*

[1] COTECMAR. Research, Development, and Innovation Department. Cartagena, Colombia. e-mail: algarinr@cotecmar.com.co
[2] COTECMAR. Research, Development, and Innovation Department. Cartagena, Colombia. e-mail: otascon@cotecmar.com.co

Introduction

Wagner (1932) developed an analytic model to predict pressure distribution in the impact with symmetry entry. Fig. 1 shows a wedge section with symmetry entry, where b is the beam of the section, d is the keel-knuckle distance, β is the dead rise angle, y and z are the horizontal and vertical axis, respectively.

Fig. 1. Wedge section impact with symmetry entry



For this kind of section, pressure distribution is evaluated as:

$$\frac{P}{\rho} = \dot{w}\sqrt{c^2 - y^2} + \frac{\dot{w}cc}{\sqrt{c^2 - y^2}} - \frac{w^2}{2}\frac{y^2}{c^2 - y^2} \quad (1)$$

Where ρ is the fluid density, P is the pressure, c is the wetted half-beam, w is the vertical velocity, $\dot{c}$ is the time variation of the half-beam, which is evaluated as:

$$\dot{c} = \frac{\pi}{2}\frac{w}{tan\beta} \quad (2)$$

2D Impact

The Wagner model (1932) does not work after the flow separation from the knuckle, for this case the boundary condition P=0 on y=b/2 is applied, thus:

$$\frac{P}{\rho} = \dot{w}\sqrt{c^2 - \left(\frac{b}{2}\right)^2} + \frac{wc\dot{c}}{\sqrt{c^2 - \left(\frac{b}{2}\right)^2}} - \frac{w^2}{2}\frac{\left(\frac{b}{2}\right)^2}{c^2 - \left(\frac{b}{2}\right)^2} = 0 \quad (3)$$

When the section is moved with constant velocity $\dot{w} = 0$, replacing

$$\dot{c} = \frac{w^2}{2}\frac{\left(\frac{b}{2}\right)^2}{c\sqrt{c^2 - \left(\frac{b}{2}\right)^2}} \quad (4)$$

The variables are separated and integrated, the virtual half-beam wetted after the flow separation is:

$$c = \sqrt{\left(\frac{b}{2}\right)^2 + \left[\frac{3}{2}\left[w\left(\frac{b}{2}\right)^2 (t - t_0)\right]\right]^{2/3}} \quad (5)$$

Where c is the half-beam in the instant, t, and t_0 is the time when the flow is on the knuckle.

2D Dynamic Impact

The total force in the section is:

$$f_z = f_{HD} + f_{Hs} + f_v \quad (6)$$

Where f_{HD} is the hydrodynamic force, f_{HS} is the hydrostatic force and f_v is the sectional drag force. By integrating equation 1 the hydrodynamic force in the section is obtained:

$$f_{HD} = \rho\dot{w}\int_{-y1}^{y1}\sqrt{c^2 - y^2}\,dy + \rho\dot{w}\int_{-y1}^{y1}\frac{c\dot{c}}{\sqrt{c^2 - y^2}}\,dy - \rho\frac{w^2}{2}\int_{-y1}^{y1}\frac{y^2}{c^2 - y^2}\,dy \quad (7)$$

$$f_{HD} = -\dot{w}m_a + f_{HD} \quad (8)$$

Where

$$m_a = \rho\int_{-y1}^{y1}\sqrt{c^2 - y^2}\,dy \quad (9)$$

$$f'_{HD} = \rho\dot{w}\int_{-y1}^{y1}\frac{c\dot{c}}{\sqrt{c^2 - y^2}}\,dy - \rho\frac{w^2}{2}\int_{-y1}^{y1}\frac{y^2}{c^2 - y^2}\,dy \quad (10)$$

Fig. 2. Forces in the section

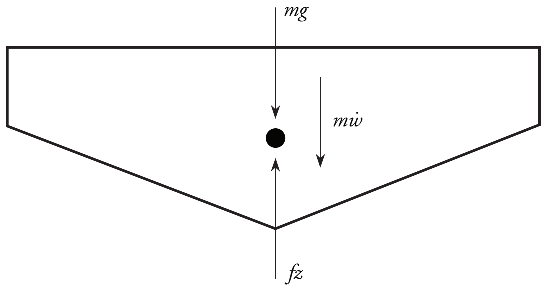


Fig. 2 shows the forced in the section. The equilibrium of forces in the section is:

$$\sum f_z = \dot{w}m_a + f'_{HD} + f_{HS} + f_v - mg = -m\dot{w} \quad (11)$$

Replacing

$$f'_z = f'_{HD} + f_{HS} + f_v \quad (12)$$

The hydrostatic force is calculated as:

$$f_{HS} = \rho g A_0 \quad (13)$$

Where g is the gravity constant and A_0 is the immersed area, the drag force is calculated as:

$$f_v = \frac{1}{2}\rho C_d (2y_1) w^2 \quad (14)$$

Where C_d is the sectional drag coefficient, which takes values of:

$$C_d = \begin{Bmatrix} w \geq 0, C_d = 0.5 \\ w < 0, C_d = -1.0 \end{Bmatrix} \quad (15)$$

The acceleration in the section is:

$$\dot{w} = \frac{mg - f'_z}{m + m_a} \quad (16)$$

2D Impact Results

The sectional force coefficient is defined as:

$$C_f = \frac{f_z}{\frac{1}{2}\rho b w^2} \quad (17)$$

Figs. 3, 4, and 5 show the results of force coefficient variation with immersion for different wedge sections; the results are compared with Tveitnes (2001) with a good agreement, the peak of force is over predicted.

Fig. 3. C_F vs. z/d, β=10°

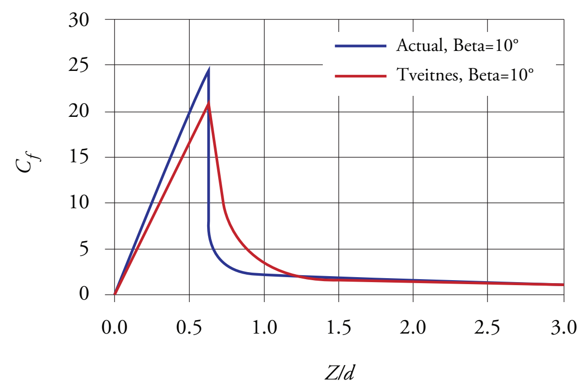


Fig. 4. C_F vs. z/d, β=20°

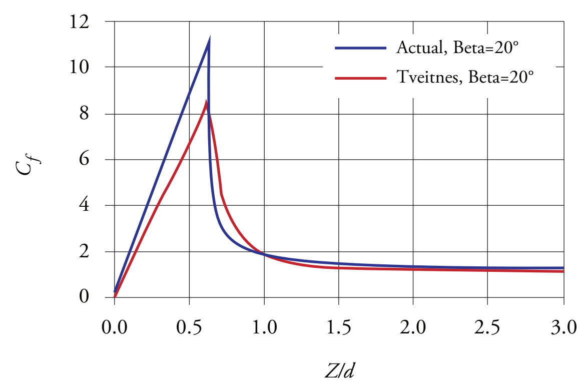
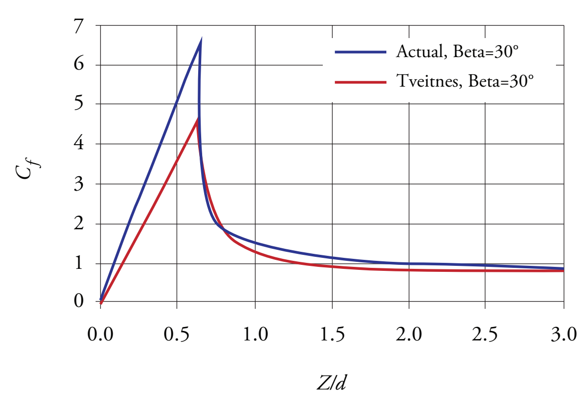


Fig. 5. C_F vs. z/d, β=30°



Figs. 6, 7, 8, 9, 10, and 11 show the results of acceleration with free drop; the section has the following properties: b = 2 ft, β = 20°, width = 8 ft. The initial height was varied by 2, 4, and 6 ft, while the mass of the wedge took values of 269 and 641lb. The results obtained are compared with Peterson (1997) with good agreement.

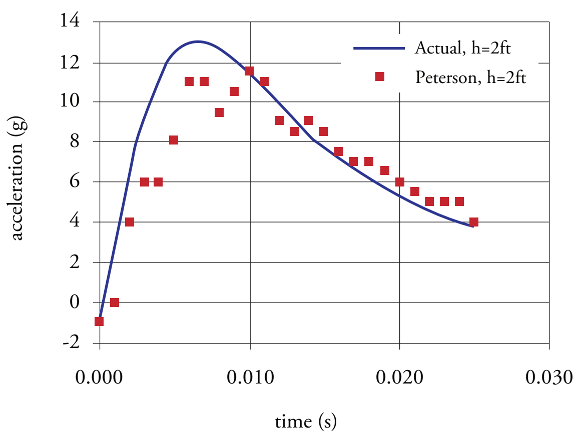


Fig. 6. Acceleration vs. time, h = 2 ft, m = 269 lb

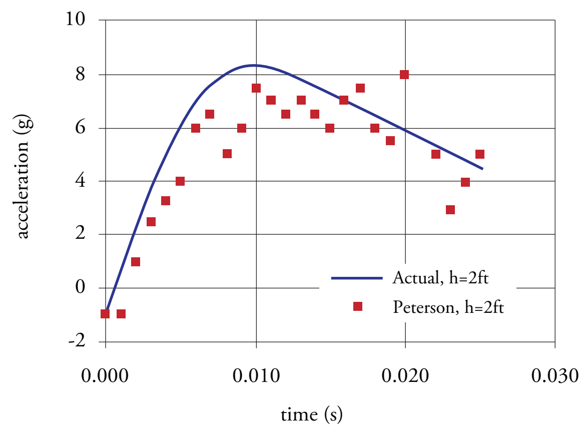


Fig. 9. Acceleration vs. time, h = 2 ft, m = 641 lb

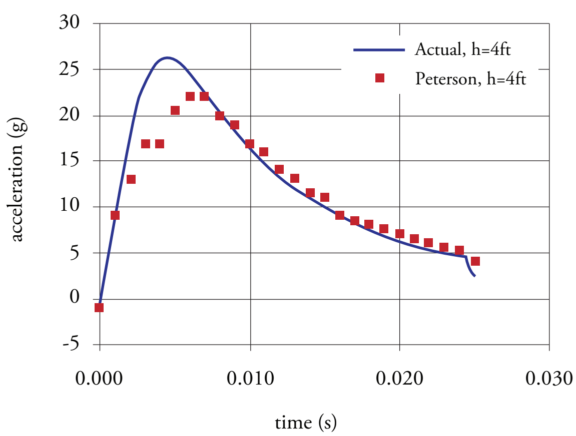


Fig. 7. Acceleration vs time, h = 4ft, m = 269lb

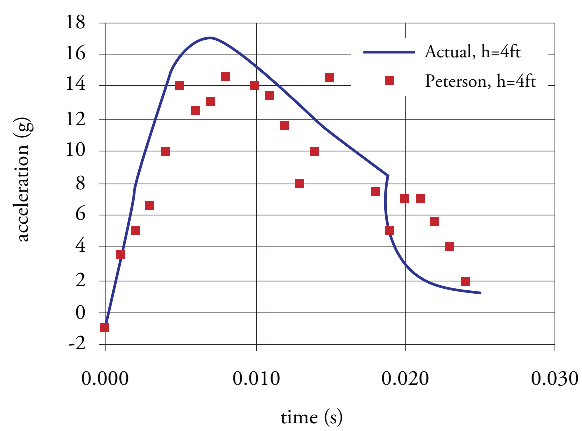


Fig. 10. Acceleration vs time, h =4 ft, m = 641 lb

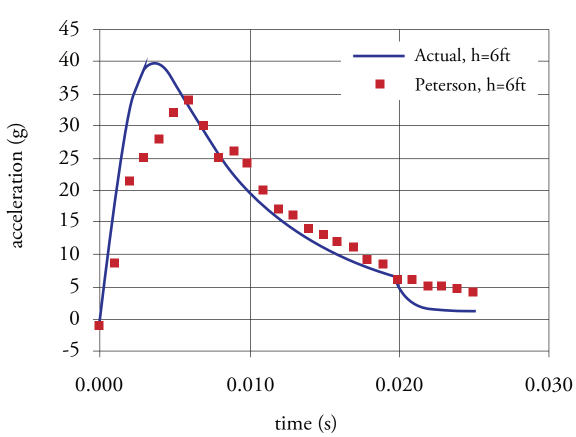


Fig. 8. Acceleration vs time, h = 6ft, m = 269lb

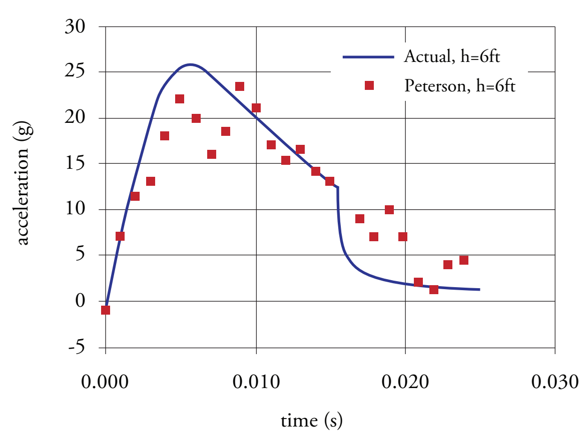


Fig. 11. Acceleration vs. time, h = 6 ft, m = 641 lb

Dynamic Model of Motion on the Vertical Plane of Planing Boats

Fig. 12 shows a planing boat on calm water, D is the draft in the transom, L_{cdg} and V_{cdg} are the horizontal and vertical position of the gravity center, θ is the trim angle, z_{cdg} is the height of the center of gravity with respect to the water line, x and z are fixed coordinates in the boat.

$$D = L_{cdg}\sin\theta + V_{cdg}\cos\theta - z_{cdg} \quad (18)$$

$$T_0 = D - (x\sin\theta + Z_1\cos\theta) \quad (19)$$

Replacing

$$T_0 = -(X - L_{cdg})\sin\theta + (V_{cdg} - Z_1)\cos\theta - z_{cdg} \quad (20)$$

If $\cos\theta \approx 1$

$$T_0 = -(x - L_{cdg})\sin\theta + (V_{cdg} - z_1) - z_{cdg} \quad (21)$$

The velocity impact of each section is evaluated as:

$$w = \frac{DT_0}{Dt} = \frac{dT_0}{dt} - U\frac{dT_0}{dx} \quad (22)$$

$$w = -(x - L_{cdg})\cos\theta\,(\dot{\theta}) - \dot{z}_{cdg} + U\left(\sin\theta + \frac{dz_1}{dx}\right) \quad (23)$$

By simplification

$$w = -(x - L_{cdg})(\dot{\theta}) - \dot{z}_{cdg} + U\left(\sin\theta + \frac{dz_1}{dx}\right) \quad (24)$$

Where $\dot{\theta}$ is the pitch velocity, $\dot{z}_{cdg}$ is the vertical velocity in the cg. The acceleration impact of each section is evaluated as:

$$\dot{w} = \frac{Dw}{Dt} = \frac{dw}{dt} - U\frac{dw}{dx} \quad (25)$$

$$\dot{w} = -(x - L_{cdg})(\ddot{\theta}) - \ddot{z}_{cdg} + 2U\cos\theta\,(\dot{\theta}) + \dot{U}\left(\sin\theta + \frac{dz_1}{dx}\right) - U^2\frac{d^2z_1}{dx^2} \quad (26)$$

By simplification

$$\dot{w} = -(x - L_{cdg})\ddot{\theta} - \ddot{z}_{cdg} + 2U\dot{\theta} + \dot{U}\left(\sin\theta + \frac{dz_1}{dx}\right) - U^2\frac{d^2z_1}{dx^2} \quad (27)$$

Calculation of Forces in the hull

Fig. 13 (pag. 30) shows the forces in the hull, where T is the thrust, F_N is the normal hydrodynamic force, M_{HD} is the hydrodynamic moment, mg is the weight, F_v is the viscous drag, δ is the angle of the propulsion shaft, d_v is the perpendicular distance between F_v and cg, d_T is the perpendicular distance between T and cg.

The normal force to the keel is evaluated as:

$$F_N = \int_0^l C_{tr}(x) f dx \quad (28)$$

Where l is the length of the boat and $c_{tr}(x)$ is the suction pressure coefficient of the transom, which is calculated as:

Fig. 12. Geometry properties in planing hull in calm water

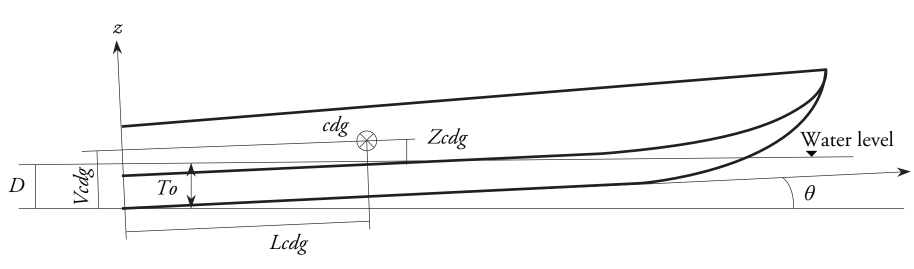
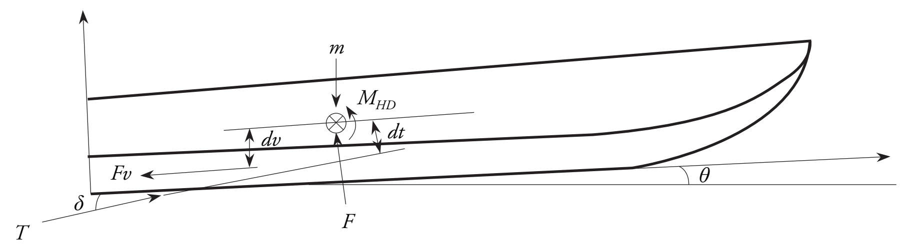


Fig. 13. Forces in the planing hull



$$c_{tr}(x) = \tanh\left(\frac{2.5}{0.34B\,C_v}\,x\right) \tag{29}$$

Replacing the normal force is:

$$F_N = \int_0^l \dot{w} c_{tr}(x) m_a\, dx + \int_0^l c_{tr}(x) f'_z dx \tag{30}$$

The solution of the first integral is:

$$\int_0^l \dot{w} c_{tr}(x) m_a\, dx = \int_0^l \left[-(x - L_{cdg})\,\ddot{\theta} - \ddot{z}_{cdg} + 2U\dot{\theta} + \dot{U}\left(\sin\theta + \frac{dz_1}{dx}\right) - U^2\,\frac{d^2 z_1}{dx^2} \right] c_{tr}(x) m_a\, dx \tag{31}$$

$$\int_0^l \dot{w} c_{tr}(x) m_a\, dx = (M_1 \sin\theta)\,\dot{U} - M_1 \ddot{z}_{cdg} + 2M_1 U\dot{\theta} - M_2\ddot{\theta} - \int_0^l U^2\,\frac{d^2 z_1}{dx^2}\, m_a\, dx \tag{32}$$

Where

$$M_1 = \int_0^l c_{tr}(x) m_a\, dx \tag{33}$$

$$M_2 = \int_0^l (x - L_{cdg})\, c_{tr}(x) m_a\, dx \tag{34}$$

By substitution

$$F_N = (M_1 \sin\theta)\,\dot{U} - M_1 \ddot{z}_{cdg} + 2M_1 U\dot{\theta} - M_2\ddot{\theta} + F'_N \tag{35}$$

Where

$$F'_N = \int_0^l -U^2\,\frac{d^2 z_1}{dx^2}\, m_a\, dx + \int_0^l f' dx \tag{36}$$

The hydrodynamic moment is calculated as:

$$M_{HD} = \int_0^l (x - L_{cdg})\, c_{tr}(x)\, f dx \tag{37}$$

$$M_{HD} = \int_0^l \dot{w}\,(x - L_{cdg})\, c_{tr}(x)\, m_a\, dx + \int_0^l (x - L_{cdg})\, c_{tr}(x)\, f'_z dx \tag{38}$$

$$\int_0^l \dot{w}\,(x - L_{cdg})\, c_{tr}(x)\, m_a\, dx = (M_2 \sin\theta)\,\dot{U} - M_2 \ddot{z}_{cdg} + 2M_2 U\dot{\theta} - M_3\ddot{\theta} - \int_0^l U^2 (x - L_{cdg})\,\frac{d^2 z_1}{dx^2}\, c_{tr}(x)\, m_a\, dx \tag{39}$$

Where M_3 is:

$$M_3 = \int_0^l (x - L_{cdg})^2\, c_{tr}(x)\, m_a\, dx \tag{40}$$

By substitution

$$M_{HD} = (M_2 \sin\theta)\,\dot{U} - M_2 \ddot{z}_{cdg} + 2M_2 U\dot{\theta} - M_3\ddot{\theta} + M'_{HD} \tag{41}$$

Where

$$M'_{HD} = -\int_0^l U^2 (x - L_{cdg})\,\frac{d^2 z_1}{dx^2}\, c_{tr}(x)\, m_a\, dx + \int_0^l (x - L_{cdg})\, c_{tr}(x)\, f'_z dx \tag{42}$$

The viscous drag force is calculated as:

$$f_v = \frac{1}{2}\rho C_a A U^2 \tag{43}$$

C_f is the friction coefficient, A is the wetted area of the hull. The equilibrium of forces in X is:

$$\sum F_x = T\sin(\theta+\delta) - F_N \sin\theta - F_v \cos\theta = M\ddot{x}_{cdg} \tag{44}$$

By replacing

$$\begin{aligned} &T\cos(\theta+\delta) - (F_N' + 2M_1U\dot{\theta})\sin\theta - F_v\sin\theta \\ &= (M + M_2\sin^2\theta)\dot{U} \\ &- (M_1\sin\theta)\ddot{z}_{cdg} - (M_2\sin\theta)\ddot{\theta} \end{aligned} \tag{45}$$

The equilibrium of forces in Z is:

$$\sum F_z = F_N\cos\theta - F_v\sin\theta + T\sin(\theta+\delta) - Mg = M\ddot{z}_{cdg} \tag{46}$$

By replacing

$$\begin{aligned} &(F_N' + 2M_1U\dot{\theta})\cos\theta - F_v\sin\theta + T\sin(\theta+\delta) \\ &-Mg \\ &= -(M_2\sin\theta\cos\theta)\dot{U} \\ &+ (M + M_1\cos\theta)\ddot{z}_{cdg} \\ &+ (M_2\cos\theta)\ddot{\theta} \end{aligned} \tag{47}$$

The equilibrium of momentum in y is:

$$\sum M_y = M_{HD} - d_vF_v + d_tT = l_{yy}\ddot{\theta} \tag{48}$$

By replacing

$$\begin{aligned} &M'_{HD} - d_vF_v + d_tT \\ &= -(M_2\sin\theta)\dot{U} + M_2\ddot{z}_{cdg} \\ &+ (l_{yy} + M_3)\ddot{\theta} \end{aligned} \tag{49}$$

The equations of motion are coupled obtaining the following expression:

$$\begin{bmatrix} M + M_2\sin^2\theta & M - M_1\sin\theta & M_2\sin\theta \\ -M_1\sin\theta\cos\theta & M + M_1\cos\theta & M_2\cos\theta \\ -M_2\sin\theta & M_2 & l_{yy} + M_3 \end{bmatrix} \begin{bmatrix} \ddot{x}_{cdg} \\ \ddot{z}_{cdg} \\ \ddot{\theta} \end{bmatrix} = \begin{bmatrix} T\cos(\theta+\delta) - (F_N' + 2M_1U\dot{\theta})\sin\theta - F_v\sin\theta \\ (F_N' + 2M_1U\dot{\theta})\cos\theta - F_v\sin\theta + T\sin(\theta+\delta) - Mg \\ = M'_{HD} - d_vaF_v + d_tT \end{bmatrix} \tag{50}$$

When the velocity of the boat is constant:

$$\begin{bmatrix} M + M_1\cos\theta & M_2\cos\theta \\ M_2 & l_{yy} + M_3 \end{bmatrix} \begin{bmatrix} \ddot{z}_{cdg} \\ \ddot{\theta} \end{bmatrix} = \begin{bmatrix} (F_N' + 2M_1U\dot{\theta})\cos\theta - F_v\sin\theta + T\sin(\theta+\delta) - Mg \\ = M'_{HD} - d_vaF_v + d_tT \end{bmatrix} \tag{51}$$

Results of the Application on Planing Boats

For analysis, the following parameters are defined:

$$c_v = \frac{U}{\sqrt{gB}} \tag{52}$$

$$c_\Delta = \frac{M}{\rho B^3} \tag{53}$$

$$c_L = \frac{F_z}{\frac{1}{2}\rho U^2 B^2} \tag{54}$$

$$\lambda = \frac{L_k + L_c}{2B} \tag{55}$$

Where c_v, c_Δ, c_L are the coefficients of velocity, load, and lift; λ is the mean wetted length, M is the displacement, B is the beam of the boat, L_k and L_c are the wetted length of the keel and the wetted length of the chine. Figs. 14, 15, 16, and 17 show the results of forces on steady condition for a constant forward velocity, the boat has the following properties: $V_{cdg}/B = 0.65$, $L_{cdg}/B = 1.47$ $\theta = 4°$ and $\lambda = 3$. η_3 and η_4 are the vertical elevation and rotation of the cg from the equilibrium position. The results are compared with Troesch (1992) and Savitsky (1964).

Fig. 14. F_z vs. η_3/B

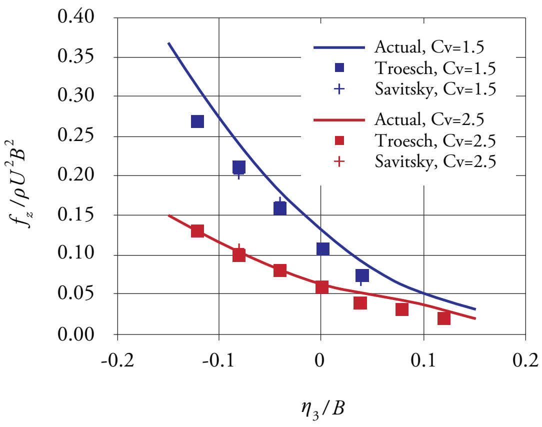


Fig. 17. M_y vs. η_5/B

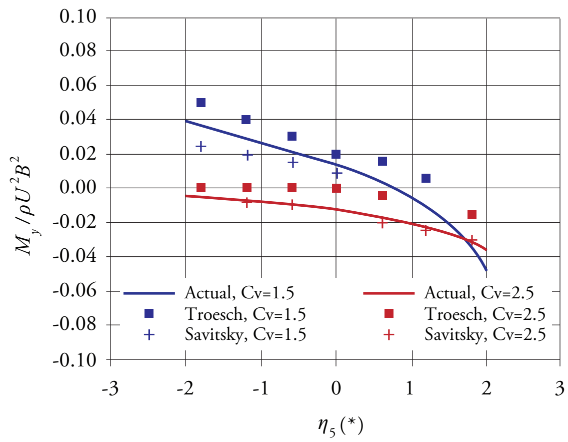


Fig. 15. M_y vs. η_3/B

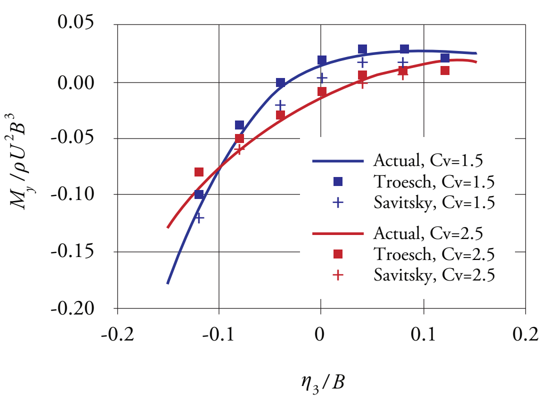


Fig. 18. $\theta_{critical}$ vs. CL, β = 10°

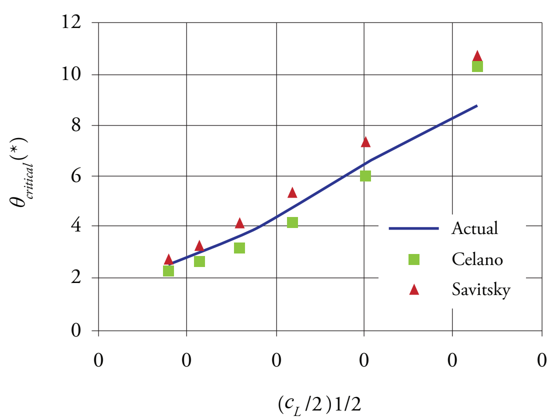


Fig. 16. F_z vs. η_5/B

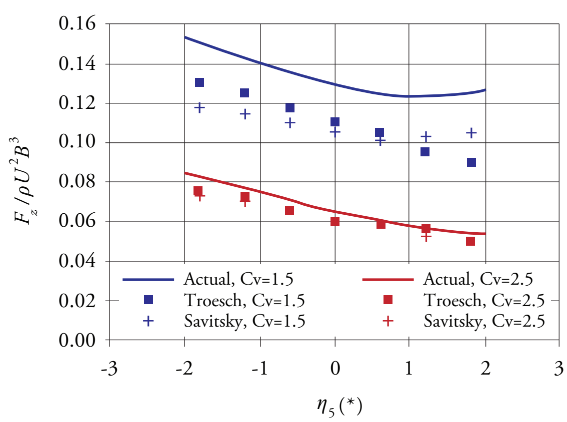
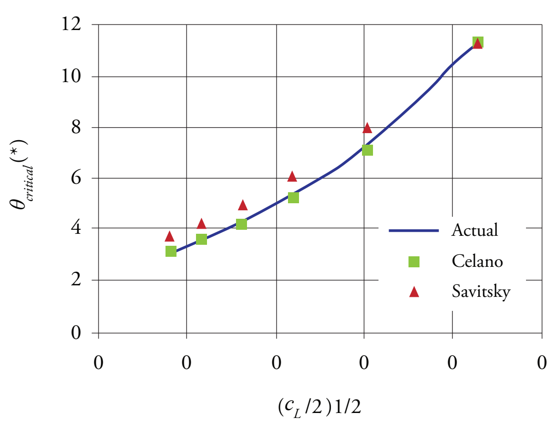


Fig. 19. $\theta_{critical}$ vs. CL, β = 20°



Figs. 18 and 19 show the critical condition that produces the inception of instability in the vertical plane for boats with β = 10° and β = 20°; the results are compared with Celano (1998) and Savitsky (1964). The criteria for the instability is the pitch amplitude oscillation, η_{50} > 1°. The boat has the following conditions: C_Δ = 0.394, *kyy/B* = 1.25 V_{cdg}/B = 0.4 and *l/B* = 5, where *kyy* is the gyration radius. The value of Lcdg was changed to find the critical condition for each configuration.

Conclusions

The Wagner model (1932) was extended for section with knuckle; force and pressure distribution were evaluated after the flow separation from the knuckle. The 2D dynamic impact was simulated; the results were compared with Peterson (1997) obtaining good agreement. The 2D impact was applied to a planing boat by the slender body theory and a dynamic model for planing hull in calm water was developed. The lift force and trim moment were calculated for ships in steady condition; the results obtained were compared with Savitsky (1964) and Troesch (1992). Critical conditions that cause the inception of porpoising were determined; the results are compared with Savitsky (1964) and Celano (1998) with good agreement.

References

ALGARÍN R. AND TASCÓN O. Hydrodynamic Modeling of Planing Boats with Asymmetry and Steady Condition, [on-line]. Avilable at: http://www.din.unina.it/HSMV%20 2011%20Proceedings/html/Papers/31.pdf. HSMV 2011, Naples, 2011.

ALGARIN R., BULA A.AND TASCÓN O. CFD modeling of 2D Asymmetric entry impact along with horizontal velocity, Ship Science & Technology. n° 9, Vol 5, 2011, p. 99-106.

CELANO, T. The prediction of Porpoising Inception for Modern Planing Craft. SNAME transaction,Vol. 106, 1998, pp. 269-292.

DEYZEN A. A nonlinear mathematical model of motions of a planing monohull in head sea, [on-line]. Avilable at: http://www.hiper08.unina.it/cd%20hiper%2008/HTML/Papers/16%20 -%20van%20Deyzen.pdf. 2008.

PETERSON R., WYMAN D. AND FRANK, C. Drop Tests to Support Water-Impact and Planing Boat Dynamics Theory, Technical report CSS/TR-97/25, 1997

SAVITSKY, D. Hydrodynamic design of planning hulls, Marine Technology, n°1, Vol 1, 1964, p71-96.

TROESCH A. On the hydrodynamics of Vertically oscillating Planning Hull, Journal of Ship Research, Vol 36, 1992, p317-331.

TVEITNES, T. Application of Added Mass theory in planing [Ph.D. Thesis]. Glasgow: University of Glasgow. Department of Naval Architecture and ocean engineering, 2001, 339p.

WAGNER, H. Über stoss – und Gleitvorgänge an der Oberfläshe von Flüssigkeiten. eitschrift für Angewandte Mathematik und Mechanik. August, No. 4, Vol. 12, 1932, p. 193-215.

ZARNICK E. A Nonlinear Mathematical Model of Motion of a planing boat in Regular Waves, Technical report DTNRDC-78/032, 1978.

Reduction of Underwater-Radiated Noise from Ships: New Shipbuilding Challenge. The Vessels "Ramón Margalef" and "Ángeles Alvariño" as Technological References of How to Build Silent Vessels

Reducción del ruido radiado al agua por los buques: nuevo reto de la construcción naval civil. Los buques "Ramón Margalef" y "Ángeles Alvariño" referentes tecnológicos de cómo construir buques silenciosos

Publio Beltrán Palomo [1]

Abstract

Abatement of noise radiated by all kinds of vessels, and specially Underwater-Radiated Noise, because of its impact on marine life, has become the most outstanding novelty and the most difficult challenge the shipbuilding industry has ever faced. Hence, the industry seeks to offer new solutions to comply with the new guidelines and requirements that have been recently introduced and promoted by the EU, marine institutions, and the scientific community. This new topic, already studied and solved by the navies because of their strategic requirements, is now in the limelight and all the different aspects are being studied and discussed among the different players mentioned. In this new trend, the appearance of some class notations with "different limits", assertions such as that the "propeller" is the major noise source, and the absence of consensus among the biological community about what should be the limits (for not affecting marine fauna), it is difficult to define the technological steps that should be followed. Until a consistent agreement is reached, the shipbuilding industry and the naval engineers will be "fighting against a ghost". Within this "confusing scenario", this paper is a clear example of how the Spanish shipbuilding industry is moving ahead to reduce the impact of new ships. The dynamic and acoustic design, developed by the authors, of the fishing research vessels "Ramón Margalef" and "Ángeles Alvariño" for the Oceanographic Spanish Institute and the experimental results obtained, in full compliance with ICES N°209 Underwater-Radiated Noise requirements, makes them reference vessels for the construction of "Silent Vessels".

Key words: Underwater-Radiated Noise, Noise and Vibration on ships, Silent Ships

Resumen

La drástica reducción del ruido exterior generado por todo tipo de buques, y en particular el Ruido Radiado al Agua y su impacto en la fauna marina y los ecosistemas, se ha convertido en el mayor reto tecnológico actual de la construcción naval civil. Se busca con ello responder, de forma inmediata, a los nuevos y exigentes requerimientos y directivas de inmediata aparición que se han establecido dentro de las políticas de protección del medioambiente de la Unión Europea, instituciones marítimas y comunidad científica. Este nuevo aspecto, ya abordado por razones estratégicas por las flotas militares, se ha convertido, por sus implicaciones técnicas, económicas y medioambientales, en el epicentro de un intenso debate con participación de todos los actores mencionados. La aparición de nuevas notaciones de clase con "diferentes límites", la existencia de ciertos asertos o afirmaciones, poco soportadas experimentalmente (por la ausencia de datos) como que la "hélice es la fuente principal" del ruido radiado al agua, y la ausencia de consenso entre la comunidad biológica acerca de los "límites umbrales" de la fauna marina, dificultan, a juicio del autor, la correcta definición de la estrategia tecnológica a seguir. Mientras no se logre un "acuerdo" entre la comunidad científica y el sector marítimo sobre estos aspectos, podremos estar "combatiendo a un fantasma". Dentro de este "escenario confuso", el presente artículo es un ejemplo de cómo la construcción naval civil española está avanzando para reducir el impacto de los nuevos buques. El diseño dinámico/acústico de los buques oceanográficos "Ramón Margalef" y "Ángeles Alvariño", del Instituto Español de Oceanografía, desarrollado por el autor, y los resultados experimentales obtenidos en cumplimiento con los estrictos Requerimientos ICES N°209 de Ruido Radiado al Agua, los convierte en "referentes tecnológicos" de cómo construir "buques silenciosos".

Palabras claves:

Date Received: September 28th, 2012 - *Fecha de recepción: 28 de Septiembre de 2012*
Date Accepted: February 7th, 2013 - *Fecha de aceptación: 7 de Febrero de 2013*

[1] TSI-Técnicas y Servicios de Ingeniería. Naval Architect & Marine Engineer- TSI´s Director. Madrid, España. e-mail: publiobp@tsisl.es

Introduction

As previously mentioned and within the framework of the Green Policy of the EC and maritime institutions like IMO and ILO, all the targets defined focus on combating and reducing the current "environmental impact" of all types of vessels that make up the current European Fleet. To fulfil this main target, special EC R&D projects have been promoted and launched to reduce emissions, as well as the Noise & Vibration (N&V) environmental impact of the vessels.

A common conclusion reached from these projects [9] is that the N&V-Full Signature (N&V-FS) of the vessel is required to assess properly its environmental impact. This indicator is made up by the N&V on board, Noise Radiated to Harbour (NRH), and the Underwater Radiated Noise (URN), being the URN and NRH the most outstanding novelty and, in the case of URN, the newest and greatest challenge to be faced.

In fact, very few data from "civilian vessels" regarding this aspect is available apart from some interesting results of URN measurements in the literature [1, 12, 13, 14]. These publications are very interesting because several URN signatures of various commercial vessels (mainly cruise ships), are presented. These URN levels come with detailed descriptions of the measurement conditions and of the ships' characteristics, which allows data analysis. This lack of URN data is because no URN requirements are available in the vessel contract specification. The only exceptions are the fishing research vessels (FRV) because of their performance requirements (they must not disturb fish species during observations).

This unwanted trend, related to the absence of URN experimental data within the current fleet, has been totally confirmed by the analysis carried out by the SILENV project [3]. In the SILENV-N&V database, generated from a total of 151 vessels, only five (3.1% of the total sample) have included specific URN requirements in their contract specifications. To enrich this poor scenario, dedicated on-site measurement activities were carried out to obtain the URN signature of 10 additional vessels (of different types) and, therefore, more available experimental data was collected.

Other important points to consider are the current measurement procedures. As a first attempt to standardize these, ANSI-ASA launched its standard "Quantities and Procedures for Description and Measurements of Underwater Sound from Ships" [2]. This URN measurement standard is thought to perform measurements of the underwater sound pressure in the far field and deep waters (to avoid reflections). The procedure selected has no inherent limitation with regard to the vessel's size. Usually, the results are: the noise pressure levels in third-octave in decibels referenced to 1 μPa at 1 m from both hull sides. Band levels are associated with the mid-frequency of the third-octave band. For many purposes, it is convenient to use the power spectral density per unit bandwidth (spectrum level).

An important parameter is the transmission loss (TL) used to calculate the radiated noise at 1 m from the ship. The "real" transmission loss depends on many parameters (sound frequency, salinity, sea state, sea bottom, water depth, local sound velocity, etc.,) and obtaining a real and precise value would be quite difficult. That is why, in measurement standards, simplified methods are used to assess transmission loss (TL). Usually, the formula TL = 20 Log DCPA (DCPA: Distance of Closest Point of Approach) is applied for all the frequency bands (ANSI-ASA standard), which produce considerable uncertainties to the results of the measurement, especially for low frequency. Finally, ANSI-ASA does not define targeted limits.

Recently (in January 2010), DNV published a new standard to measure underwater noise emitted by ships [10]. This "SILENT" standard specifies targeted limits and associated measurement procedures for shallow waters. The method used to define these limits is not known. The different targeted limits specified in this new standard are different, depending on the type of vessel considered. According to this Class Notation, the Society, based on an operational speed profile for typical hydro-acoustic operations submitted to it, will decide the "speed at which the vessel shall be tested". It is important to keep in mind that based on the practical expertise of the authors, this parameter becomes essential for suitable dynamic-acoustic design of silent vessels, and it should be defined and agreed at the beginning of the project. Likewise, in this Class Notation the TL is calculated according to the following formula: TL = 18. Log DCPA – 5dB.

Finally, since the 1990s, the URN target limits defined by the ICES (International Council Exploitation of Seas) °Regulation N° 209 [11] became a widespread standard used within the FRV family, especially in the modern ones. This standard specifies limits for 1/3 octave spectrum levels, at a speed of 11 knots, as seen in Fig. 1.

Within the current regulation framework, several operational experiences have been compiled. The first ones are related with the URN on-site measurement data processing and data presentation. Fig. 2 reports the usual format for the presentation of the URN Spectra: Pressure (ref 1 μPa) @ 1 m- 1/3 Octave Band (1 Hz) against Frequency (Hz).

Fig. 1. ICES Regulation N° 209. URN target limits at 11 knots

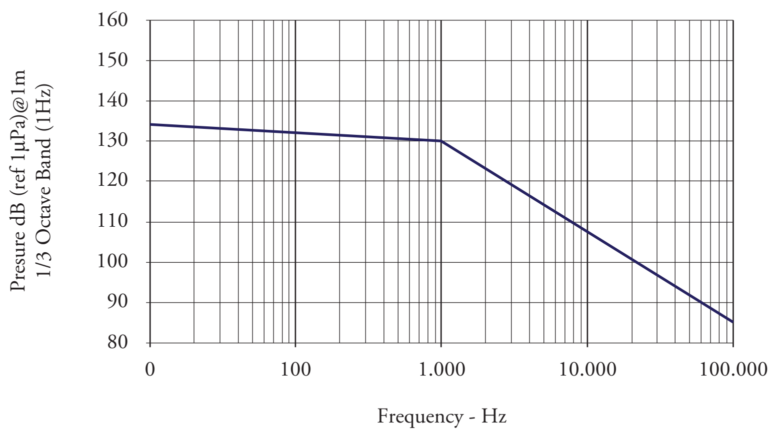
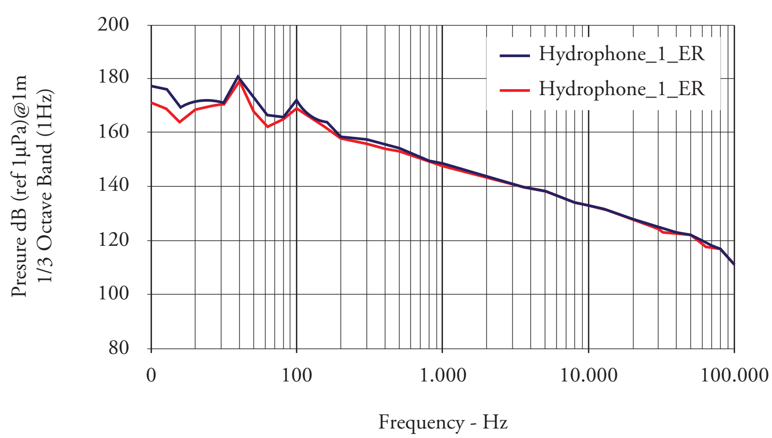


Fig. 2. Typical URN 1/3 Octave Band Spectra for Merchant Vessel at 28,5 knots



Finally, an intense debate to identify the main URN sources affecting the URN signatures of vessels has been opened. Traditionally, the propeller is considered the principal root cause of the URN signature of the vessels, with no experimental support. These kinds of assertions are made based on "old figures" and outdated information, where the propeller, of course, appeared as one of the main root causes of vibration on board. Based on the author´s point of view, with 36 years of experience as N&V consultant in the marine sector, with these "assertions" the shipbuilding industry is confused and cannot manage to understand what needs to be done to move ahead on improving the current situation.

To shed light on this matter, within the framework of the SILENV project on-site measurement activities were conducted to obtain the URN signature with sufficient frequency accuracy to identify the main URN sources (machinery and propeller) in the spectrum (Fig. 3).

These experimental results have identified the machinery and the propeller (Fig. 4), in this order, as the main contributors to the URN signature in a significant sample of vessels of the current European Fleet. This approximation is sound enough with the experiences documented at Glacier Bay, mainly related to passenger vessels [1, 12, 13, 14]. Currently, and based on these experimental data, the message to the shipbuilding industry is clear: abatement of the URN signature of "new vessels" will require preventive control of the sources and actions focused on reducing vibration energy transmission from main mechanical sources, like main machinery, to the hull. The intensity of the excitation induced by the propeller must be controlled, as well as its cavitation.

Fig. 3. Narrow band analysis for accurate identification of URN contributors

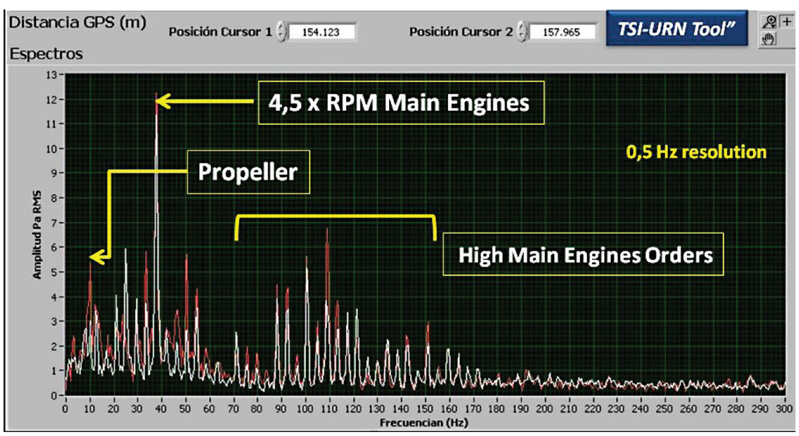
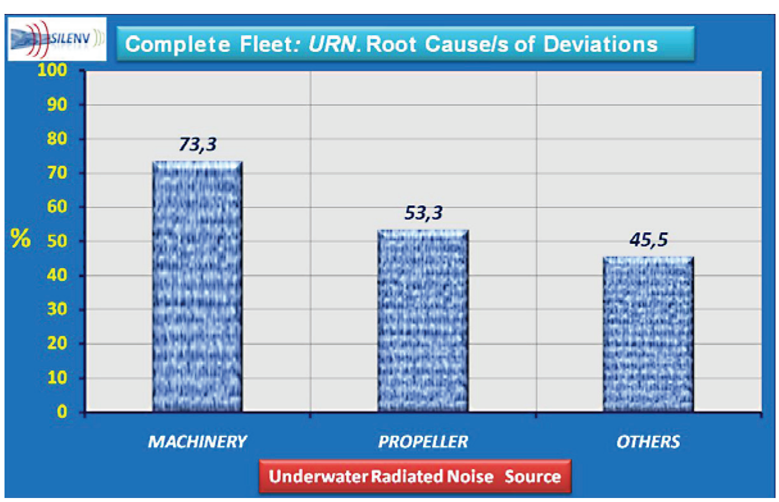


Fig. 4. Statistical Assessment. URN Root cause/s identification



Therefore, as a summary we can conclude that, first of all, it is unquestionable that the current debate amongst the scientific and technical marine communities as far as the impact of the underwater footprint of commercial vessels on marine life is concerned, is in the limelight. On the other extreme, we can find the current fleet for which, with very few exceptions (FRVs), there are no specific URN requirements included in their contract specifications. Consequently, availability of URN data is limited and, hence, impossible to accurately assess the real impact of each family of vessels on the oceans and on marine life. To move ahead in filling this URN data void, special mention should be made of the experimental database generated within the framework of the BESST and SILENV projects.

Other reasons for the current state are the novelty that this topic means for the civilian shipbuilding industry and, from the author's point of view, "the general confusion" in relation with the harmonization of the measurement procedures and about the limits. The ICES Regulation N° 209 limits appear, for some scientists, "still quite permissive" but excessive for the shipbuilders. So, the conflict remains unresolved. As will be detailed in the conclusions, harmonization, improved measurement procedures, and a "preliminary agreement" as far as the targeted limits are concerned between the scientific community and the marine sector is vital to define the technological strategy that should be followed to improve the current situation.

Based on the author´s expertise in building "silent ships", the FRV family, especially the most modern ones, becomes a point of reference and a clear example of the technological strategy that must be applied to minimise the impact of the vessels in the Oceans. They are a *"Technological reference"* because it will be possible to look at what types of dedicated solutions have been applied on them to reduce their URN signature. Of course, it must be kept in mind that other factors like cost/benefit ratios, fuel efficiency, and technical viability should be considered and properly weighted. Besides, they will also be a *"strategic reference"* because it will be possible to discover why the FRV family, contrary to the other ones, is fighting and moving ahead in the abatement of their underwater footprints. Certainly, it will enable increasing the level of sensitization of the rest of the fleet with regard to this new topic.

Case Studies: Frv "Ramón Margalef" & Frv "Ángeles Alvariño"

Introduction

At the end of August 2011, the FRV "Ramón Margalef" and, in the summer of 2012, the FRV "Ángeles Alvariño", which are almost twin ships, were delivered to the Spanish Oceanographic Institute (IEO, for the term in Spanish). As a result of the sea trials, the following main aspects could be highlighted: for the "Ramón Margalef" the maximum vibration level on board was *0.7 mm/s-rms*; noise on board at cabins was between *37 and 57 dB(A) and 87 dB(A)* at the engine room; noise levels radiated to harbour (NRH) in compliance with EC Directive 2006/87 (lower than 65 dB(A) at 25 m from both hull sides); and noise radiated to the water (URN) in compliance with ICES Regulation N° 209. For FRV "Ángeles Alvariño", the maximum vibration level on board was *0.7 mm/s-rms*; noise on board at cabins was between *50 and 55 dB(A)*; and noise radiated to the water (URN) practically in compliance with ICES Regulation N° 209. These experimental results, respecting the strictest N&V comfort and environmental requirements, placed the *"Ramón Margalef"* and *"Ángeles Alvariño"* among the *"most silent"* vessels of all the European Fleet and perhaps of the civilian fleet in the world. Thus, these vessels have become a clear milestone and indicator that the European and Spanish shipbuilding industry is capable of meeting the current needs focused on abating the N&V environmental impact of vessels.

These results are not a question of luck; they are based on solid pillars: the first one is the high level of sensitization shown by the owner (IEO), who defined a technical specification that included specific requirements to guarantee: comfort and good working conditions of the crew and scientists, reduction of the vessel's environmental impact, and, of course, the high efficiency of the scientific echo-sounders on board. Indeed, SIMRAD/KONSBERG, in another FRV in which the same methodology described below has been applied by the authors, confirmed that the "low background noise of the vessel" has enhanced the efficiency of the electronic equipment by more than 40%.

On the other hand, the excellent experimental results obtained enable validating and consolidating the *"Noise & Vibration Integrated Management"* methodology the author has been applying for over 36 years.

The aim of this paper was to present a brief description of the "N&V Integrated Management" methodology applied in the "Ramón Margalef" and "Ángeles Alvariño" FRVs. It is widely detailed in other authors' publications [3, to 8]. A summary of the experimental results obtained during the sea trials are also presented.

Description and main particulars of the vessels

Because of its size and capacity, the FRV *"Ramón Margalef"* is classified as a regional fishing research vessel. It has autonomy for 12 days and can provide accommodation for 11 researchers and technician staff, in addition to a crew of 12 members. The *"Ramón Margalef"* has diesel-electric propulsion made up of three gen-sets driven by GUASCOR F480TA-SG diesel engines with an output of 868 kW at 1,500 rpm, elastically mounted according to the criteria defined by the consultant (the author). This plant produces all the power required to drive the two INGETEAM-INDAR KN-800-5-b-"c" DC electric motors, as well as all the electric power for the ship´s on board services and machinery. The vessel has two shafts each driving a single fixed-pitch propeller. The main particulars and an overview of the vessel are reported in Fig. 5. The *"Ángeles Alvariño"* has the same characteristics as the *"Ramón Margalef"* except that it has only one shaft driving a single fixed-pitch propeller.

Fig. 5. Vessel's overview and main particulars

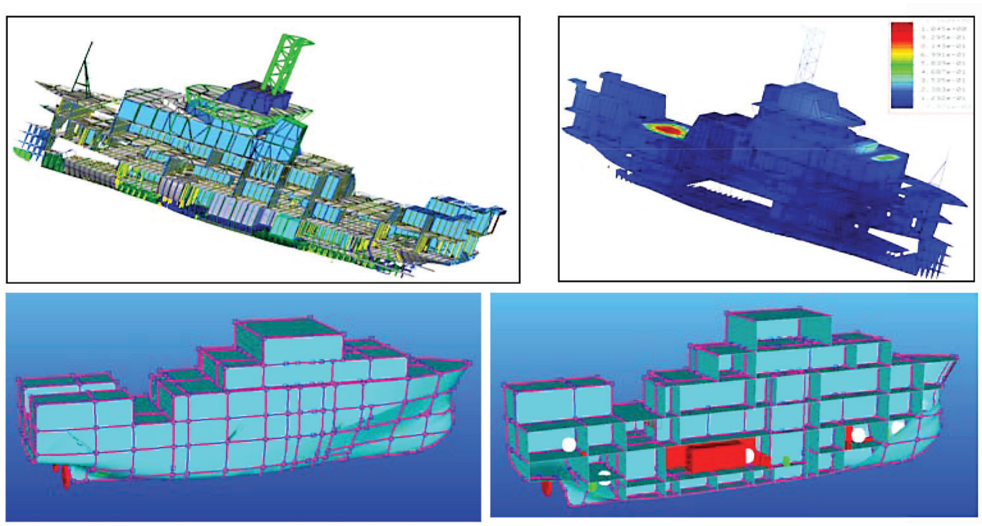
Length overall	46.70 m
Maximum breadth	10.5 m
Design draft	4.00 m
Depth to deck N° 3	7.10 m
Gross tonnage	988 t
Dead weight	230 T
Main propulsion	2 x 900 kW
Maximum speed	13 knots
Classification	BUREAU VERITAS

The "N&V Integrated Management" Methodology

Vessels are elastic systems under periodic forces from different sources. Consequently, they are vibration sensitive. The vibration levels obtained in the system (the vessel) depends, mainly, on three parameters: 1) intensity or magnitude of the excitation forces; 2) structure stiffness; 3) dynamic amplification at different frequencies due to resonance phenomena: local and global. Consequently, the possible actions that could be implemented if we want to keep vibration levels under certain limits are the following: A) minimise the system's excitation forces; B) avoid flexible structures from a dynamic point of view; C) avoid resonance phenomena (coincidence of structural frequencies and excitation frequencies). Similarly, and from an acoustic point of view, the vessel has built-in sonorous sources: main and auxiliary engines, propellers, hydraulic systems, HVAC, etc., airborne and structure-borne noise generators. The noise is transmitted or spread throughout the structure of the vessel (path) and reaches all the different locals and spaces (receptors) and it is also radiated to the water. Likewise, the possible actions that could be implemented to maintain noise levels under the predefined limits are the following: 1) minimise the sound power and vibration power at the noise sources; 2) reduce or diminish their transmission to the paths; 3) isolate the receivers.

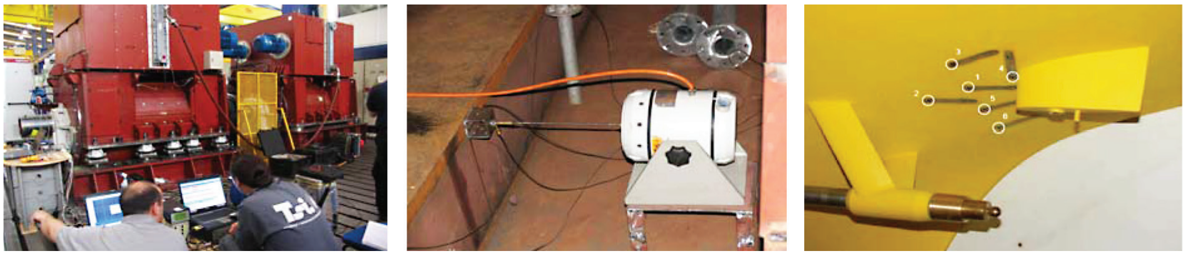
From an elastic-acoustic point of view, the hull becomes a wave radiator to the water due to the acceleration induced on it by the action of the main mechanical excitation sources and to the propeller. In this case, preventive actions and sources control shall be applied focused on reducing the vibrational energy transmitted to the hull by the main machinery and by the propeller. Thereby, dedicated factory acceptance tests (FAT) (for the main machinery) should be conducted, pressure pulses induced by the propeller and cavitation tests should be carried out to avoid this phenomenon. For the practical application of the previous "basic principles", inside the *"Noise and Vibration Integrated Management" (N&VCM)* and as a control mechanism, *"dynamic and acoustic specific requirements"* have been incorporated in the purchase specifications of the different supplies, as well as FAT procedures to control and verify their compliance before installing the most critical supplies on board. This *"first activity level"* has focused on the fact that the shipyard can develop a "control" of the main N&V and URN sources that are usually under the scope of suppliers. The intention with this "control mechanism" is to achieve and guarantee the so-called "contractual sensitivity" of the suppliers towards the dynamic and acoustic objectives of the project. If this easy task is not performed, the shipyard finds that, on many occasions, the solutions or countermeasures that should be implemented are more expensive. The vast expertise of the suppliers involved in similar projects has permitted, for the case of the *"Ramón Margalef"*, easy and efficient control.

The Shipyard assumed, from the beginning of the project, the fact that the "Dynamic and Acoustic Vessel Design" is mandatory. Thus, once the N&V main sources were under its control, a "second module or block of activities" that considered all the aspects that are competence of the shipyard like supplying a vessel structure with appropriate dynamic-acoustic design – with no resonances and with enough acoustic isolation to guarantee compliance with N&V contract requirements. Focused on achieving these N&V targets, a whole dedicated package of simulation tools and dynamic tests, such as N&V prediction calculations (Fig. 6) and radiated noise: outdoor and underwater, prediction calculations, were brought into play to achieve the optimal design.



To verify fulfilment of the "design criteria" defined by the consultant, related to the intensity of the excitations induced by the main machinery and by the propeller, as well as the theoretical results provided by the simulation tools applied, a whole package of model tests and on-site dynamic tests: FAT and Inertance Tests (Fig. 7) have been applied at different stages of the project.

Fig. 7. FAT, Inertance and Model tests developed for the "Ramón Margalef" design



After this entire analytical-experimental process, the vessel is ready to pass the most important test: the sea trials.

The sea trials: Results

All the sea trial measurements were performed at the Vigo Bay (Spain) according to protocols previously approved by the owner, the shipyard, and BUREAU VERITAS. Some of the results are summarised in the figures ahead.

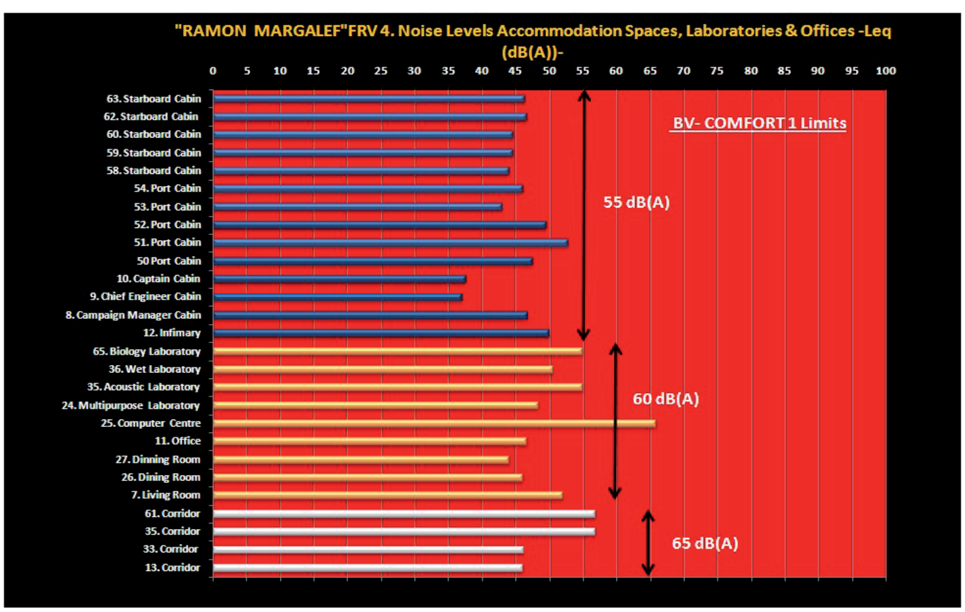
Noise on board

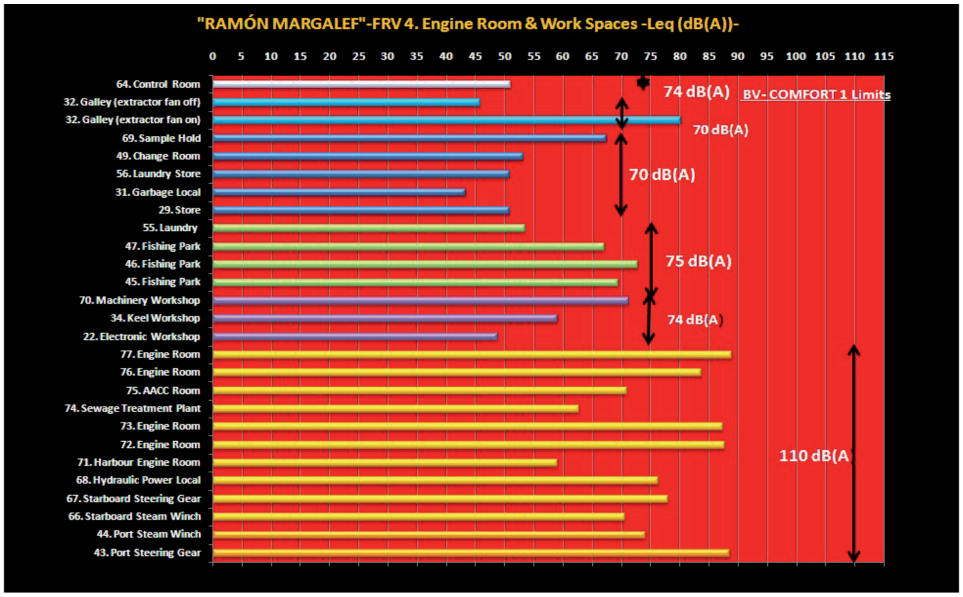
For the Accommodation / Laboratories-Public, and Engine Room/Work spaces, the noise results obtained have been reported through bar diagrams (Figs. 8 and 9).

The numerical results reveal that:

"Ramón de Margalef": For accommodation and laboratory/public spaces, the noise on board average values are *-9.6 and -10.1 dB(A)*, respectively, lower than the corresponding BV-COMF VIB 1 limits (55, 60, and 65 dB(A), respectively). A special mention must be made of noise levels achieved in the engine room and in the machinery spaces with an average value of *-32.6 dB(A)*, lower than the BV's limit (110

Fig. 8. "Ramon Margalef" noise on board: accommodation and engine room spaces





dB(A)) and than the new IMO amendment limits, in progress.

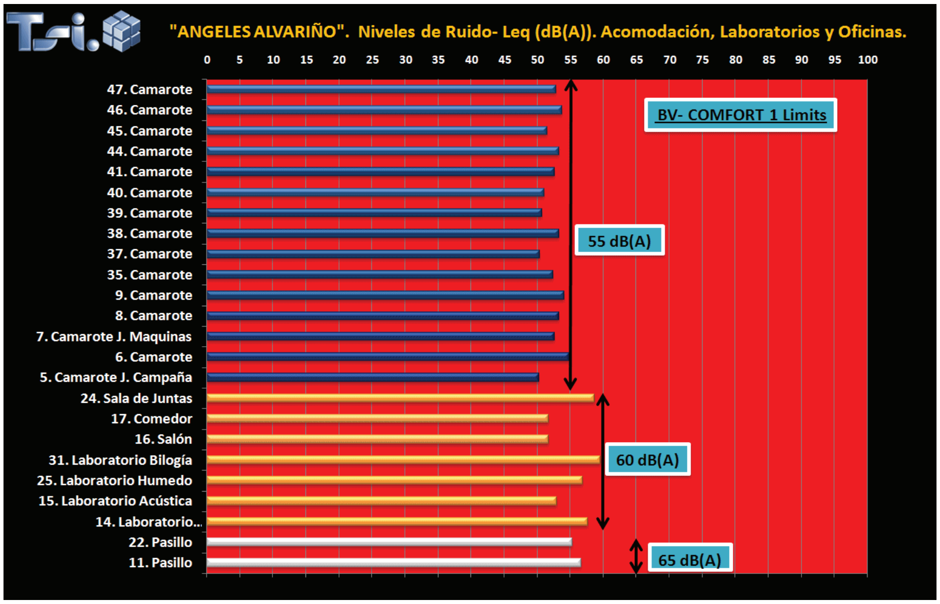
"Angeles Alvariño": For accommodation and laboratory/public spaces, average values of noise on board are *-2.7 and -6.2 dB(A)*, respectively, lower than the corresponding BV-COMF VIB 1 limits.

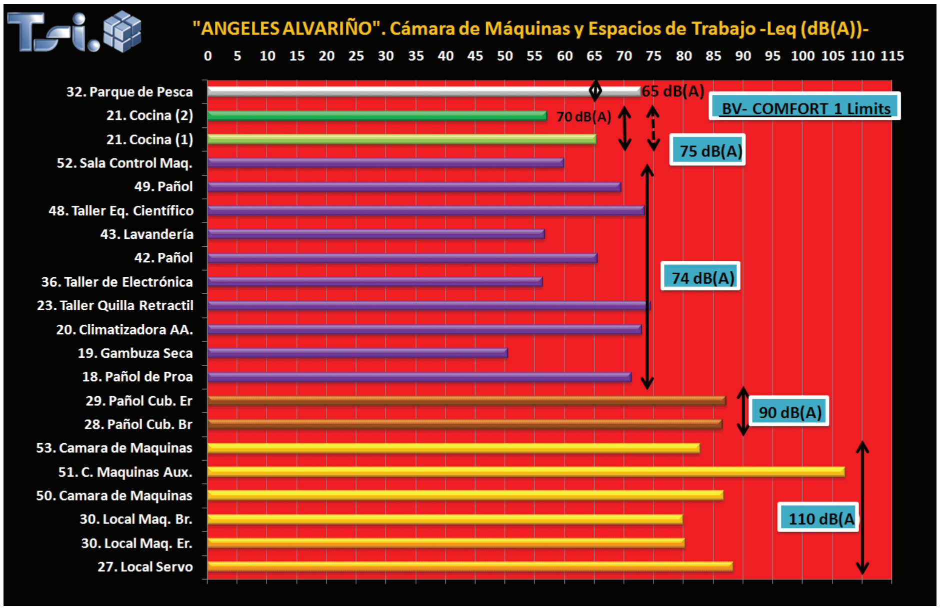
Vibration on board

For the accommodation/laboratories-public, and engine room/work spaces, the vibration results obtained are reported in the bar diagrams in Figs. 10 and 11.

"Ramón de Margalef": For a total of 36 locations at the accommodation and laboratory/public spaces, the average vibration on board achieves a significant value of *-2.7 mm/s-rms*, lower than the corresponding BV-COMF VIB 1 limit (3 mm/s-rms). A Special mention must be made again for

Fig. 9. "Ángeles Alvariño" noise on board: accommodation and engine room spaces

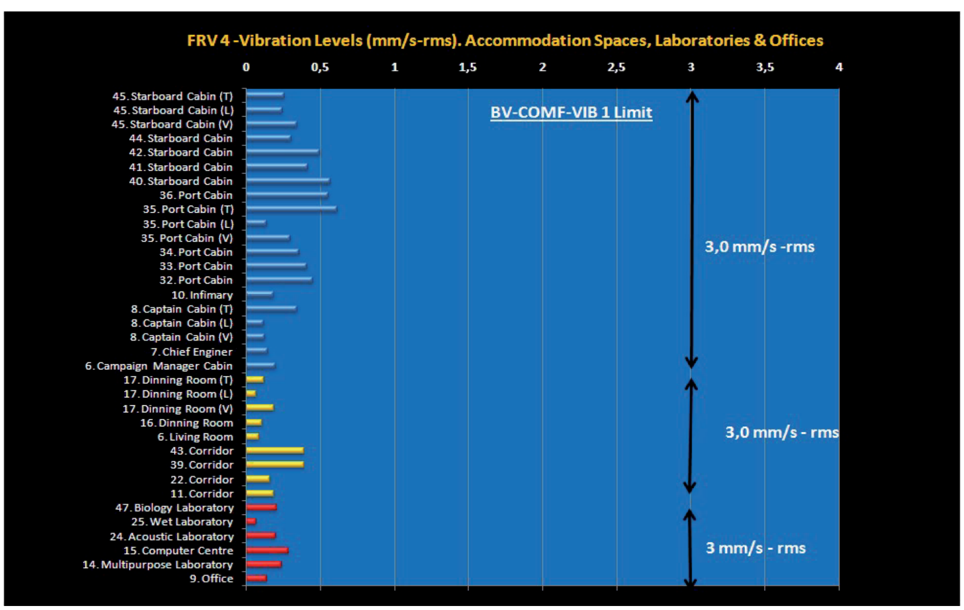


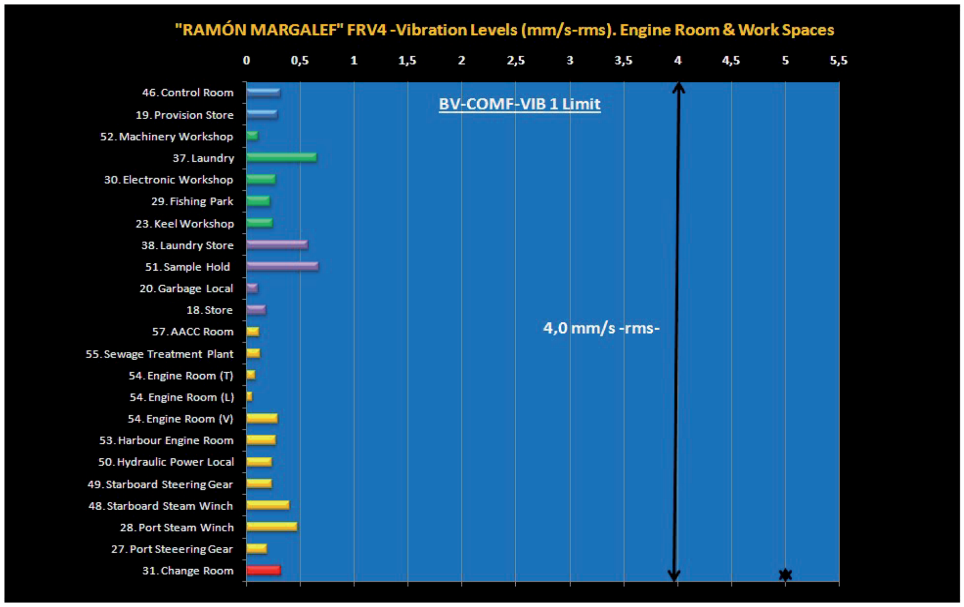


the vibration levels at 23 locations in the engine room and in the machinery spaces with an average deviation of *-3.7 mm/s-rms*, when compared with the corresponding BV-COMF VIB 1 (4 mm/s-rms).

"Ángeles Alvariño": As with the previous vessel, for a total of 36 locations at the accommodation and laboratory/public spaces the average vibration on board achieves a significant value of *-2.7 mm/s-rms*, lower than the corresponding BV-COMF VIB 1 limit (3 mm/s-rms), and in the engine room and machinery spaces with an average deviation of *-3,6 mm/s-rms*, when compared with the corresponding BV-COMF VIB 1 (4 mm/s-rms). All these values are a clear indicator of the low vibrational energy distribution achieved along the vessel's structure due to the preventive actions adopted.

Fig. 10. "Ramón Margalef" vibration on board: accommodation and engine room spaces





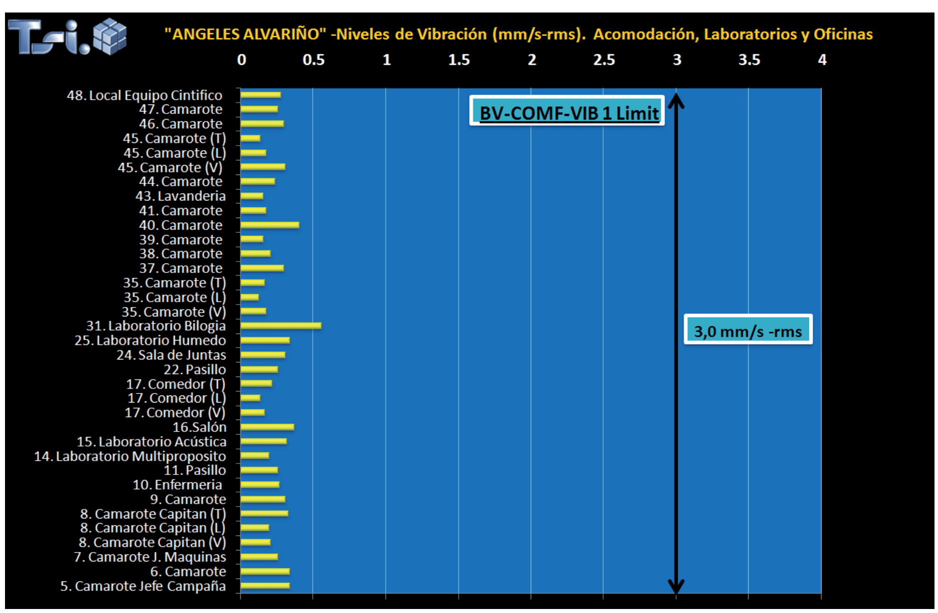
Noise Radiated to Harbour (NRH)

"Ramón Margalef": The corresponding results related to this topic are reported in Fig. 12 and were carried out within the framework of the on-site measurement activities of the SILENV project (which is why "Ángeles Alvariño" does not have the NRH signature). As noted, the outdoor noise levels at 20 m from the starboard hull-side along the whole length of the "Ramón Margalef" are below 65 dB (A), according to the preliminary SILENV limits adopted and the limits established by EC Directive 2006/87 and by ISO 2922/200 Acoustic [15].

Underwater-Radiated Noise (URN)

A sequence of the URN measurement tests and the results obtained in terms of URN pressure (ref 1μPa) @ 1m 1/3 Octave Band Spectra (1 Hz) at an

Fig. 11. "Ángeles Alvariño" vibration on board: accommodation and engine room spaces



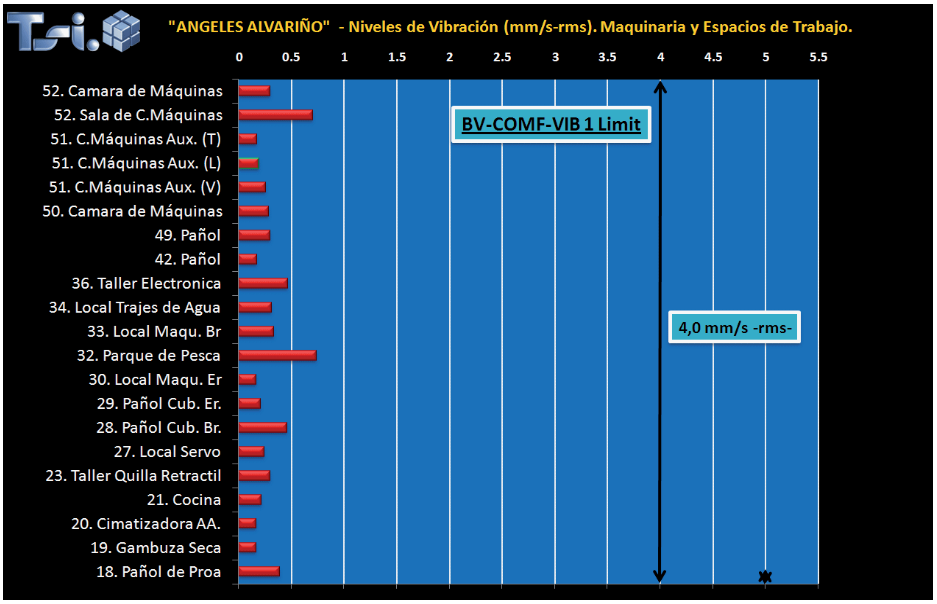
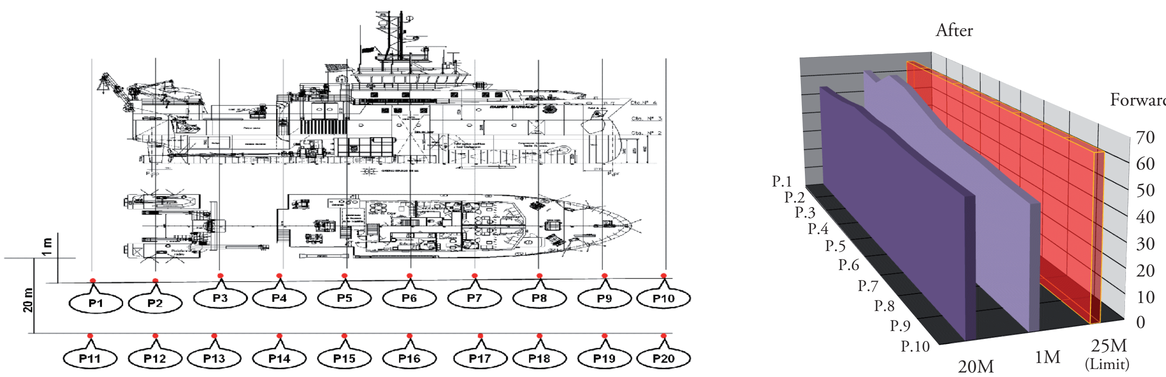


Fig. 12. "Ramón Margalef" starboard hull side outdoor noise levels



operational speed of 11 knots, for both hull sides, are reported in Figs. 13 and 15.

"Ramón Margalef": examination of Fig. 13 enables us to state that the FRV *"Ramón Margalef"* complies with the ICES Regulation N° 209 [11]. The narrow band analysis has permitted proving that the small deviations observed at low and high frequencies are not related to URN sources but to the disturbance that the measuring device suffered because of the sea state and because of some interference that came from a meteorological sound-buoy operating in the area.

Finally, as a complementary "external indicator" of the low underwater footprint of the FRV "Ramón Margalef", Fig. 14 shows the "high resolution" of the data obtained by IEO scientists (courtesy of SIMRAD/ KONSBERG) with the on-board echo-sounders, during the geological research carried out by the vessel in its first investigation about the sudden appearance of a new volcano in the coast of "El Hierro Island" (Canary Islands - Spain).

"Angeles Alvariño": examination of Fig. 15 allows us to state that this FRV almost complies with the ICES Regulation N° 209 [9]. The narrow band analysis and the comparison of these results with the ones corresponding to the "Ramón Margalef" has permitted proving and confirming that the small deviations observed are due to the existence of a single shaft driving a fixed-pitch propeller,

Fig. 13. "Ramón Margalef" URN measurements & URN 1/3 Octave Band Spectra @ 11 knots

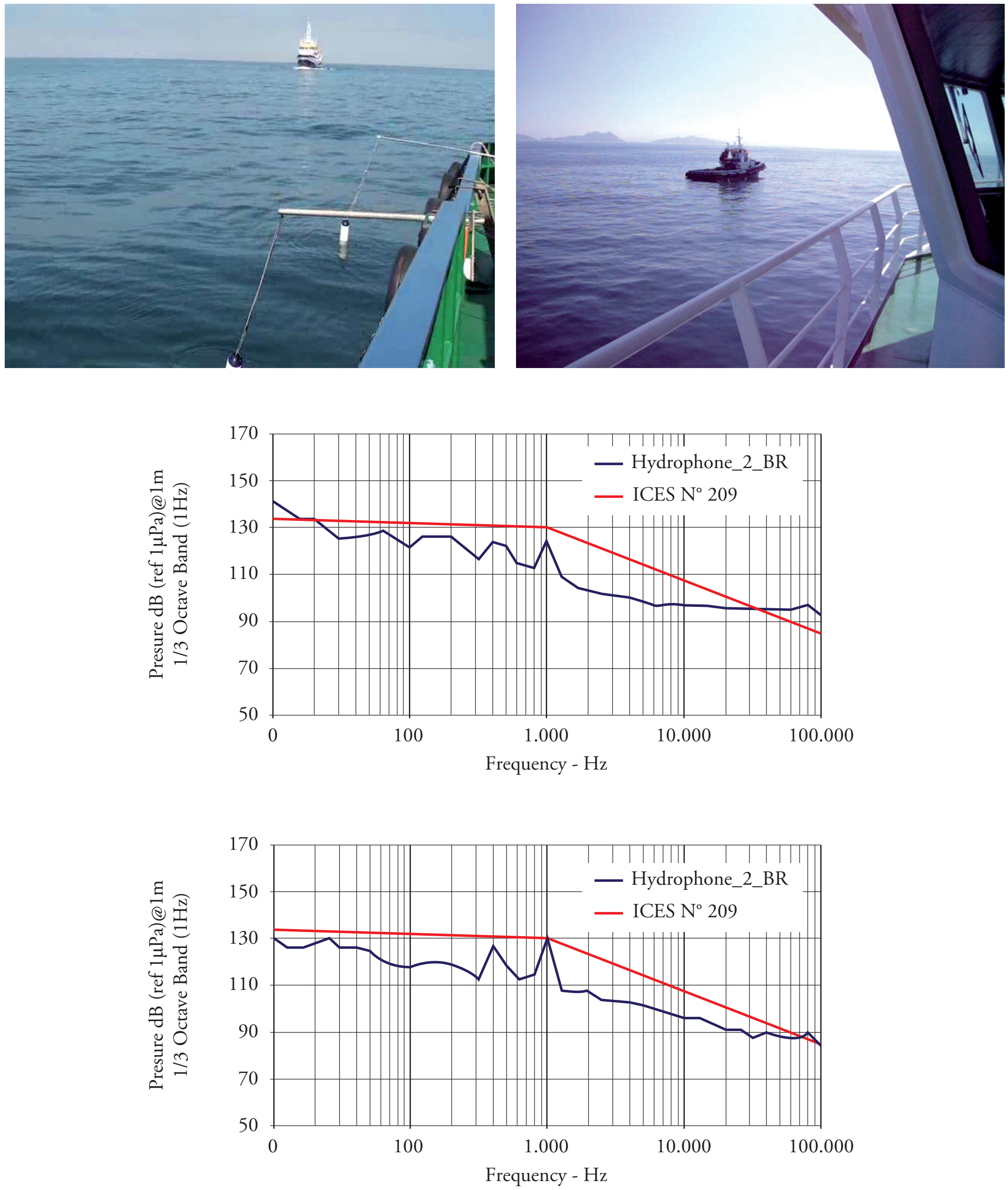


Fig. 14. "Ramón Margalef" geological data on appearance of new volcano (courtesy of SIMRAD)

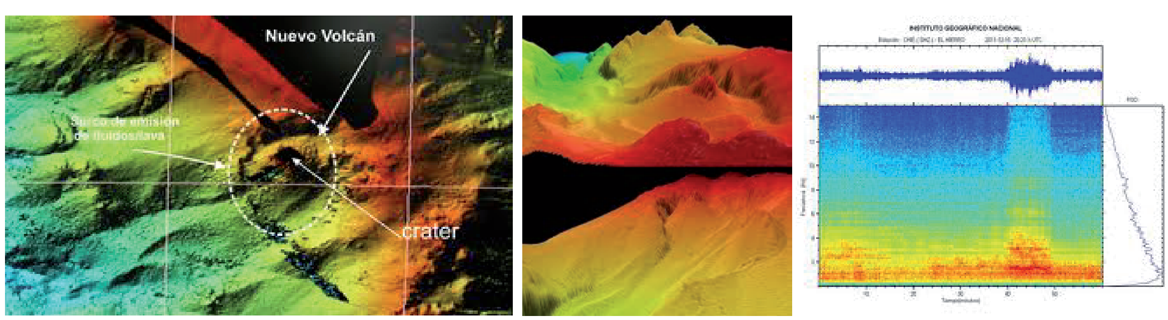
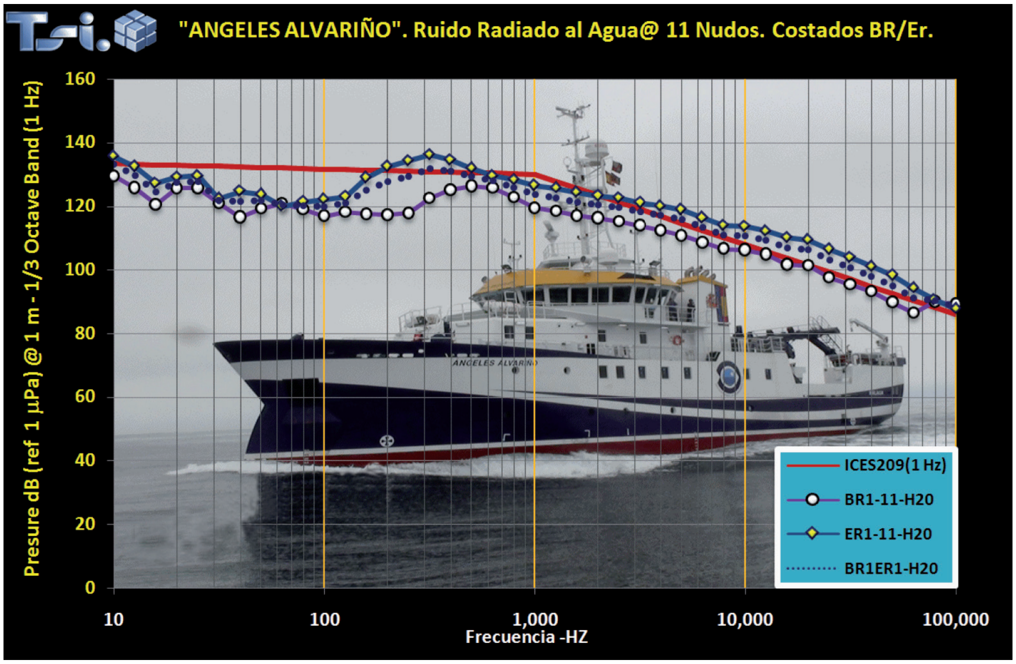


Fig. 15. "Ángeles Alvariño" URN measurements & URN 1/3 Octave Band Spectra @ 11 knots



which produces flow problems at the stern of the vessel because the inflow to the propeller is not as good as in the FRV *"Ramón Margalef"*.

Conclusions: "Lessons Learnt"

Some of the most interesting conclusions and lessons learnt, according to our judgement, are detailed as follows:

- The experimental results support the FRV "Ramon de Margalef" as a civilian technological reference within the field of "silent vessels", showing that the European and the Spanish shipbuilding industry is ready to meet the current and future environmental requirements within the framework of the new EC Green Policy.
- The practical cases of the FRV "Ramón Margalef" and "Angeles Alvariño" have shown the validity of the "N&V Integrated Management" methodology to be applied as a practical guide in designing and building "silent vessels". This methodology can also be applied for commercial vessels considering and properly weighting the cost/benefit ratio, fuel efficiency, and technical viability.
- Once these two essential pillars: shipbuilding capabilities and availability of successful "practical guides" have been consolidated, the *"battle against high noise levels in the Oceans"* requires, from the author´s point of view, establishing clear, well-founded, and coordinated policies based on the following points:
  - ***Technological:*** Harmonization of measurement procedures and improvements in measuring devices and in the acquisition and post-processing process, are essential. Precise identification of the *"enemies"* (URN sources), to properly confront them, will not be submitted to "unfounded assertions", but will be based on consistent experimental results.
  - ***Preliminary Limits Definition:*** The target is *"to reduce the underwater noise to protect marine fauna"*. Two key questions arise and need to be answered: *How much must we reduce the noise?* (Unfeasible for the current fleet); and *How much will it cost for a new vessel?* A first consensus between the scientific community and the shipbuilding industry is essential if some preliminary URN limits are to be defined.

Perhaps these preliminary limits are not as strict as many biologists would like, but they will obligate the shipbuilding industry to move ahead and assess the impact that achieving these limits has on the costs, thus, their technical-economic viability.

– ***Regulatory Framework:*** The complete lack of URN requirements in contract specifications has been confirmed as the main cause of URN data unavailability. The premise *"no one does anything if they are not forced to"* is well stated. This status needs to be changed and to do so, the following actions must be carried out: *Firstly*, there should be thorough dissemination of the EC policy within the marine sector (currently immersed in a "difficult crisis") focused on not "*forcing*" but "convincing" about the advantages of fighting against the URN impact. *Secondly*, the lack of URN data for most of the current fleet hindered suitable "URN management" and identification of vessels that should not enter protected areas. The URN signatures from a representative sample of vessels are, therefore, needed, independently of the compliance with whichever the URN limits are. The same criteria should be applied for the new constructions.

- Finally, retrofitting old vessels to reduce the current underwater noise levels is technically and economically unfeasible. Fleet renewal must be based on full compliance with "environmental requirements: emissions, fuel consumption reduction and N&V".

Acknowledgements

The Spanish Oceanographic Institute deserves a special mention for the initiative and the motivation of all the players: shipyards, suppliers, and consultants on achieving the objectives of the project. Some of the results presented were obtained within the framework of the BESST and SILENV project. Gratitude goes to all the partners that have participated. Finally, it is important to note that the building of the research vessel *"Ramón Margalef"* has benefitted from EU Regional Structural Funds under Grant FICTS-2011-03-01.

References

[1] ADVERSON, Vendittis 2000, Radiated noise characteristics of a modern cargo ship.

[2] ANSI/ASA S12.64-2009/Part 1: Quantities and Procedures for Description and Measurement of Underwater Sound from Ship – Part 1: General Requirements.

[3] BELTRÁN P., SALINAS R. *et al.*, SILENV Project D 2.2.1.

[4] BELTRÁN, P. 2001. Noise vibration on ship prediction: Basic engineering tool to fulfil the current requirements of comfort and quality. Naval Engineering Magazine.

[5] BELTRÁN, P. *et al.*, 2006. "Silent Fishing Vessels. A milestone for small and big Spanish shipyards. Lessons learnt". Naval Engineering Magzine.

[6] BELTRÁN, P. 2007. The Fishing Research Vessel "Miguel Oliver". Naval Engineering Magazine.

[7] BELTRÁN P. 2008. Oceanographic Ship "Miguel Oliver": The excellence on Noise and Vibration on board fulfilling ICES-Nª209. First Prize 47th Congress of Naval Engineering and Maritime Industry.

[8] BELTRÁN, P. & TESORERO, M.A. "Spanish Shipbuilding ready to meet the new and demanding Environmental Requirements: New Challenges and Business Opportunities". Ingeniería Naval 887. Silver Price 49th Congress of Naval Engineering and Maritime Industry.

[9]. BESST- Breakthrough in European Ships and Shipbuilding Technologies & SILENV- Ships oriented Innovative Solutions to Reduce Noise

& Vibration, project funded by the EC within the 7th FP.

[10] DNV-Silent Class Notation. Part 6, Chapter 21, January 2011.

[11] ICES Regulation N° 209.

[12] KIPPLE, NVSSCCD Report, Coral Princess Underwater Acoustic Levels (2004).

[13] KIPPLE, NVSSCCD Report, Volendam Underwater Acoustic Levels (2004).

[14] KIPPLE, Southeast Alaska Cruise Ship Underwater Acoustic Noise. Naval Surface Warfare Center- Detachment Bremerton Technical report NSW CCD-71-2002-574 (2002).

[15] ISO 2922/2000 Acoustics - Measurement of airborne sound emitted by vessels on inland waterways and harbours.

Energy Efficiency: an Opportunity for Research and Improvement

Eficiencia energética en buques: una oportunidad de investigación y superación

Luis Guerrero Gómez [1]
Montserrat Espín García [2]

Abstract

In this paper, Bureau Veritas explains the new international regulations on air pollution, its origin, and its position in the marine market to help and develop several technical solutions suitable to the world's fleet.

Key words: Energy efficiency, regulatory framework, energy efficiency design index, energy efficiency operational index, ship energy efficiency management plan.

Resumen

En este artículo, Bureau Veritas explica las nuevas reglamentaciones internacionales sobre contaminación del aire, así como sus orígenes y su posición en el mercado para ayudar y desarrollar diferentes soluciones técnicas aplicables a la flota mundial.

Palabras claves: Eficiencia energética, marco reglamentario, índice de eficiencia energética de diseño, índice de eficiencia operacional, plan de gestión de la eficiencia energética a bordo.

Date Received: - *Fecha de recepción:*
Date Accepted: - *Fecha de aceptación:*

[1] Bureau Veritas, Departamento Naval. Madrid, España. e-mail: Luis.guerrero@es.bureauveritas.com
[2] Bureau Veritas, Departamento Maquinaría, Electricidad y Seguridad. Madrid, España. e-mail: montserrat.espin@es.bureauveritas.com

Introduction

During the 20th century, environmental awareness increased in our personal mindset and professional activity. A way to reduce environmental pollution is to improve energy efficiency in every aspect of our lives: household energy consumption, industrial energy consumption, and transport energy consumption. Given that in the current society energy mainly comes from the combustion of products containing carbon (fuels, coal, gases) and because this combustion produces substantial air pollution due to greenhouse gases, the concept of carbon footprint was developed. It is defined as the total greenhouse gases produced by direct or indirect effects from an individual, organization, event, or product.

Therefore, in accordance with the information and data published by the International Energy Agency (IEA), during 2010, the total CO_2 emissions attributed to human origin were 30,276.1 million tons; this value is higher than the value of total emissions produced during 2009. Total CO_2 emissions increased by 4.6%. We must keep in mind that the total CO_2 emissions value in 2009 was lower than in 2008 due to the financial crisis endured by western economies. Under normal conditions, the natural trend is a steady increase of CO_2 emissions generation. Therefore, actions have to be taken to reduce CO_2 emissions. Among other important data, published by IEA, the percentages of CO_2 emissions by sectors must be accounted. Fig. 1. The percentage of CO_2 emissions from the generation of electricity and heat is 41.2% (compared to 40.8% of emissions during 2009 in this sector), this being the most air pollutant activity, and followed very closely by the transport percentage of CO_2 emissions during 2010 at 22.31% (20.8% during 2009), and then followed by the manufacturing industries and construction activities (20.4% of CO_2 emissions during 2010) and the other sectors with a percentage of CO_2 emissions of 16.69%.

Focusing on the transport activity (Fig. 2.), most CO_2 emissions are generated by road transport (16.8% of the total CO_2 emissions and 73.6% of the CO_2 emissions produced by the transport activity); meanwhile, only 2.13% of the total CO_2 emissions are due to maritime transport (9.5% of the CO_2 emissions generated by the total transport activity). As estimated, 90% of the overall tons involved in the commercial activity are carried by ships. It implies that marine transport is the most efficient means of transport from the environmental point of view.

Fig. 1. Percentage of CO_2 Emissions by Activities (2010)

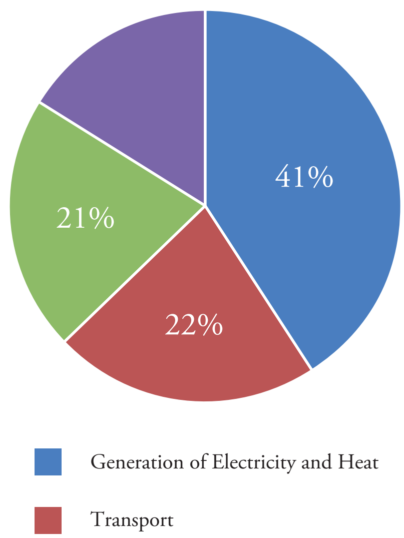
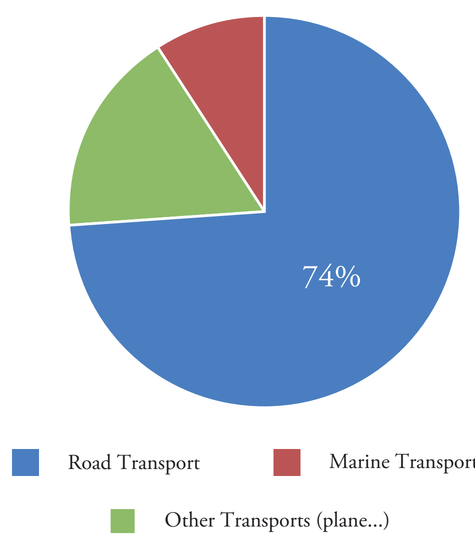


Fig. 2. Percentage of CO_2 Emissions (transport sector, 2010)



Regulatory Framework

Taking into consideration the previous data on air pollution due to CO_2 emissions, and with marine transport being a "green transport" compared to other types of transport, additional efforts to control and slow down CO_2 emissions must be requested.

Given that marine transport is a global commercial activity, international organizations have expressed high concern about air pollution. This has resulted in several international anti-pollution regulations; the latest regulations are focused on air pollution.
It has to be emphasized that all international regulations are enforced by the flag states. Therefore, if the flag states do not ratify the regulations and/or conventions, the vessels under that flag are not obligated to achieve the international regulations. In any case, the port authorities where the vessels are moored could request compliance with the international regulations. For this reason, the international regulations, in general, are easily applicable.

Thus, the International Maritime Organization (IMO) has adopted a relevant role, carrying out prompt actions thereof. So, considering that one of the main ways of reducing greenhouse gas emissions is to reduce carbon fuel consumption on board (it is mostly due to propulsion and electrical generation on board); the outcome is that more efficient use of energy reduces CO_2 emissions.

The IMO published the MEPC 203 (62) Resolution, adopted on 15 July 2011, "Amended to the Annex of the Protocol of 1997 to amend the International convention for the prevention of pollution from ships, 1973, as modified by the protocol of 1978 relating thereto" and this resolution has been finally attached to Chapter 4 Annex VI of MARPOL 73/78 Convention, named as "Regulations on Energy Efficiency for Ships".

From the regulatory framework point of view, the resolution adopts two sets of actions:

- Firstly, new ships are submitted to new requirements not applicable to existing ships.
- Secondly, new requirements are dedicated to existing ships that have to be modified to be updated to verify the new regulations, but not in all the extent as to comply with the regulations for new ships because such would bring unfeasible investments. In other cases, a time frame is established to adapt existing vessels or their equipment to the rules.

In our case, air pollution, the new regulation is applicable to vessels over 400 GT and involved in international voyages.

Within this regulation, and taking into account the implementation phase, existing ships are only forced to set out a "Ship Energy Efficiency Management Plan" and to implement it (MARPOL Annex VI, Chapter 4, regulation 22). For new ships, the MARPOL Annex VI, Chapter 4, rules 20 to 23 apply.

In this rules, MARPOL states the definition of an energy efficiency index. At this moment, this index is mostly applicable to vessels devoted to transport goods or people, whereas it is not yet applicable to "service vessels".

Likewise, MARPOL states that an energy efficiency design index should be calculated, so that it is defined at the design stage taking into account several factors. Additionally, the rules include that an energy efficiency index should be defined, which is the maximum energy efficiency index allowed for the type of ship.

Energy Efficiency Index Definition

Generally, the energy efficiency design index (EEDI) is defined as the ratio of the environmental impact of the ship and the benefit received by the community from shipping. The IMO, in MEPC Circ1/681, and in the revision MEPC 212(63) on 2 March 2012, provides some guidelines to calculate the EEDI:

$$EEDI = \frac{\text{Impact to enviroment}}{\text{Benefict to society (transport work)}} = \frac{\text{Power} \times \text{Fuel Consumption} \times CO_2 \text{ Emission Factor}}{\text{Capacity} \times \text{Ship Speed}} \quad (1)$$

And developing the formula:

(2)

being:

- C_F: non-dimensional CO_2 emission coefficient. MEi and AEi stand for main engines and auxiliary engines, respectively.
- V_{ref}: Ship speed.
- Capacity: the definition of capacity depending on the type of vessel (GT's, passengers).
- P: Power (kW).
- SFC: Certified specific fuel consumption (gr/kWh)
- f_j: is a correction factor to account for the specific design elements. It depends on the ice class and/or the propulsion redundancy
- f_w: non-dimensional coefficient, indicating the decrease of speed in representative sea conditions of wave height, wave frequency, and wind speed.
- $f_{eff(i)}$: factor of availability of innovative energy efficiency technology.
- f_i: factor of technical and/or regulatory constraint as per a table.

Feasible Actions to Increase Energy Efficiency

Once the EEDI has been defined, we have all the parameters to modify and to perform increased energy efficiency. Thus, we can work with the following parameters:

- Diesel engine power (both propulsion and auxiliary diesel engines); obviously, if the diesel power is reduced, the fuel consumption will be lower. Anyway, we have to take into account the specific fuel consumption curve, because the diesel engine can run in a low power condition and its consumption is very high and the maintenance is also higher if the diesel engine runs in this condition all the time. Therefore, the diesel engines should run at load regimes defined by the manufacturer, or at least very close to this point.
- Capacity: with a higher capacity, the energy efficiency will be lower.
- Speed: if vessel sails at higher speeds, the energy efficient coefficient will be lower, but everybody knows the relation between power and speed follows a cubic law; therefore, in any cases, the power needed to increase the speed a knot, is very high and it is opposed to increased energy efficiency.

Considering the above parameters, it is time to suggest the feasible measures to increase energy efficiency on board. These types of measures will modify the parameters to obtain a better energy efficiency coefficient; these measures can be grouped into three:

- Vessel Design Optimization: the measures regarding hydrodynamic design of the vessel, sizing of the vessel, etc... are included in this item. Therefore, the measures that can be enclosed are the following:
  - – Choice of vessel size: the unitary cost of the vessel is lower if the vessel is bigger.
  - – Hydrodynamic optimization of hull: if a good hydrodynamic hull is designed, the power needed to move the vessel to a predetermined speed is lower; hence, fuel consumption is also lower. Obviously, this measure is not applicable to existing vessels, because a large modification should be performed and the high cost of the transformation makes the project not

viable. On the other hand, this measure is highly recommended for new vessels, when the design can modify the hull to reduce power needs.

– Propeller Optimization; as described in the previous paragraph, hull or propeller optimization in an existing vessel can be an important factor in energy efficiency. As known, the larger the diameter of the propeller the better its efficiency, but the propeller's diameter is limited by the stern height. Additionally, there are several propeller designs whose efficiency is higher than traditionally designed propellers, like CLT design, CR propeller). In this respect, hydrodynamic designers have a vast field to investigate.

– Addition of special devices to steer the water flow; Naval Architects are developing several devices to steer the water flow to the propeller; therefore, the efficiency of the propeller is increasing. Thus, hydrodynamic designers can perform studies on stern shapes.

- Propulsion Optimization: This paragraph mentions the means and devices developed to modify and improve the propulsion system; therefore, the new ways to produce energy (green energies) and their applications in the marine market are also included. Research and development projects are under way such as the following:

  – Alternative energy; this way, several technologies, which are applicable on shore installations, can be used on board vessels. A number of initiatives have been studied and developed, as retrofit of conventional vessels to use liquid natural gas as fuel (not LNG vessels), including the passenger vessels. The IMO is involved in developing specific regulations to consider using these types of fuels on board and, nowadays, some vessels have been retrofitted to LNG fuel. The high efficiency of gas achieved 20% energy saving. Solar panels and wind energy are also applicable.

  – Improvements in machinery performance; if the maintenance schedules are verified and the efficiency of the machinery is increased by the designers, finally, energy saving is achieved.

  – Reducing energy consumption on board

- Optimizing the ship's operation: if the ship operation can be more efficient, fuel consumption can be lower. The following measures can be enclosed in this item:

  – voyage planning optimization;

  – Speed optimization; if the vessel can sail at a lower speed and has enough time to arrive to port, fuel consumption is reduced. This measure can be quite interesting for the owner, but sometimes it cannot be applicable (poor environmental conditions, delayed departures and/or arrivals to harbours). Additionally, this measure involves an exhaustive schedule of the vessel and the fleet.

  – Trim and ballast optimization; the objective of this measure is that vessel sails under optimal conditions, therefore, minimum resistance and good immersion of the propeller is provided. This measure involves hydrodynamic studies (hull and propeller).

  – Hull and propeller maintenance; if hull and propeller are clean, energy saving can achieve 6%. Nowadays, paint manufacturers are involved in new coatings whereby hull resistance can be optimized by new technology-coating systems.

  – Energy management; in this field, the owner can develop procedures and improve modifications on board to increase energy savings. Examples of these measures are: the resistive lights are changed by low consumption lightings or LED lighting technologies, reduction of the load of equipment or deactivating if they are not in use, high maintenance or replacing of the thermal insulation of holds in case of breaking.

Implementation of Ship Energy Efficiency Management Plans

Hitherto, we have been talking about the regulations applicable to the energy efficiency on board, and we have explained several measures to take into account to obtain energy savings. We mentioned that MARPOL requires the implementation of a ship energy efficiency management plan (SEEMP) and that it is applicable to all vessels (new and existing ships).

As explained by MARPOL, the purpose of the implementation of the ship energy efficiency management plan is to set out a procedure to be used by the company or the owner and that it will end up in energy saving and reduction of CO2 emissions.

For this purpose, IMO has developed guidelines to improve ship energy efficiency management plans (Fig. 3.)(See MEPC.1/Circ.683).

The following steps are to be followed in the plan:

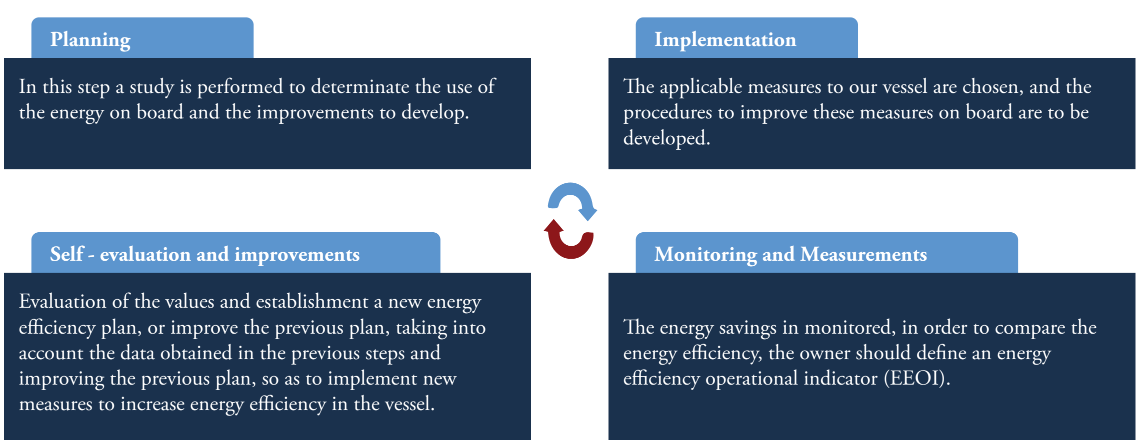
- Planning: In this step, a study is to be performed to list the energy use on board and the improvements expected from the application of the energy saving measures; this step studies the measures available and their influence on the vessels.
- Implementation: During this step, the actions applicable to our vessel are chosen, and the procedures to improve the results on board are to be developed.
- Monitoring and Measurements: obviously, when the actions are implemented on board, energy saving will be monitored and it is carried out when we measure fuel consumption and other parameters. In this step, in order to compare energy efficiency, the owner should define an energy efficiency operational indicator (EEOI). The IMO has published guidelines to help the owners in this step (MEPC.1/Circ.684).
- Self-assessment and improvements: after some time, the owner has to evaluate, update, and implement a new energy efficiency plan, or improve the previous plan, taking into account the data obtained in the previous steps and improving the previous plan to implement new measures to increase energy efficiency in the vessel.

SEEMP has to be developed by the owner or technical department, but the main problem found when the owner has started to develop the SEEMP has been the definition of a good energy efficiency operational index. Thus, Bureau Veritas has offered to owners the development of this Ship Energy Efficiency Management Plan, evaluating their needs and defining the EEOI applicable by taking into account the activity of their vessels.

Therefore, the procedure developed by Bureau Veritas has been the following:

- Firstly, during the planning step, Bureau Veritas has offered to owners the full measures available to obtain energy saving on board their

Fig. 3. Guidelines to improve ship energy efficiency management plans



vessels. From a technical point of view, Bureau Veritas assigns a value (from 1 to 5) to each measure, in accordance with the percentage of energy saving expected to be obtained if the measure is implemented on board the vessel. In this point, the owner, depending on the feasibility of the measure (where technical and economic reasons participate) assigns a value to each measure. The final idea is to obtain a value for each measure in function of energy saving and the feasibility to implement the measure on board; therefore, all measures are classified by a value. Throughout the process, communication between the owner and the Bureau Veritas experts is ongoing and due to this good communication between both parts, the planning steps are performed in a short time.

- When the measures are evaluated, the implementation step is easily settled because the only item pending is the implementation of a timeline for each measure by the owner.
- The monitoring step, as indicated, is the most problematic phase because an EEIO index should be defined for each vessel. As stated, this EEIO index is defined by IMO guidelines, but it is only applicable if the vessels transport goods from a port to another port. The problem is when the EEOI index defined by the IMO is used in "working vessels" (fishing vessels, auxiliary vessels, tugboats, fire fighting vessels, vessels to supply fuel to other vessels, ...). In this case, quite a few problems have emerged that have required bigger efforts.

The steps to follow to define new EEOI's applicable to the "working vessels" have been taken according to IMO guidelines. As defined by the IMO guidelines, the EEOI can be defined as:

$$EEOI = \frac{\sum_j FC_j x C_{F_j}}{cargo\ xD} \left[\frac{TnCO_2}{Tn\ x\ knot} \right] \qquad (3)$$

Therefore, IMO establishes the EEOI as a measure according to CO_2 emissions (Tn CO_2) for each unit of cargo (Tn) and distance to transport.

As mentioned, this formula cannot be easily applied to working vessels; therefore, Bureau Veritas, in agreement with the owners, has defined several indications to be applicable to the vessels and taking into consideration the parameters that are easily measured on board.

Conclusions

This procedure has been implemented to several types of vessels like: fishing vessels, tuna fishing vessels, auxiliary vessels, tugboats, fire fighting vessels, vessels used to deliver fuel to other vessels). The experience of carrying out this interaction between the shipyard and Bureau Veritas has given way to a more personal relationship between the Classification Society and the shipyard, a relationship Bureau Veritas seeks to always maintain with all its clients (not only the shipyards), as well as to technical enrichment by both parties.

Bibliography

http://www.bureauveritas.com/

ROV Design for Pluvial Applications

Diseño ROV para aplicaciones pluviales

Carlos Lozano [1]
Max Dutra [2]

Abstract

Brazil is a country where disaster levels increase each year due to changing climatic conditions, principally in the south east region. Disorganized occupation in urban areas, with inadequate structures increases the probability of these disasters. This work sought to study environments with high levels of floods and river overflow by using a robot, which could monitor the soil of possibly polluted rivers, as well as sediments and detritus. This work shows a proposal for a mechanical structure that will be used as a prototype for future developments. Two different alloys of materials and dimensions were tested for the same structure; the first one is "2024-T4" aluminum, and second one is "ASI 316" steel. The best results in terms of safety factor (SF) were obtained with the aluminum alloy with 4.64 SF. The structure shows mechanical characteristics that allow the usability for the proposed application; Solid Works was used for tests and designs.

Key words: ROVFLUV, Applied Robotics, Mechanical Design, Environmental Protection, Structure Analysis

Resumen

Brasil es un país donde los niveles de desastres aumentan cada año debido a las condiciones climáticas cambiantes, principalmente en la región sur oriental. La ocupación desorganizada en áreas urbanas, con estructuras inadecuadas aumenta la probabilidad de estos desastres. Este trabajo pretende estudiar los entornos con altos niveles de inundaciones y desbordamiento de ríos mediante el uso de un robot, que pueda monitorear los suelos de ríos posiblemente contaminados, así como sedimentos y detrito. Aquí se muestra una propuesta para una estructura mecánica que se utilizará como prototipo para desarrollos futuros. Se probaron dos diferentes materiales de aleaciones y diferentes dimensiones para la misma estructura; el primero fue aluminio "2024-T4", y el segundo fue acero "ASI 316". Los mejores resultados en términos de factor de seguridad (SF, por su sigla en inglés) se obtuvieron con la aleación de aluminio con 4.64 SF. La estructura muestra características mecánicas que permiten su utilización para la aplicación propuesta; Solid Works se utilizó para las pruebas y los diseños.

Palabras claves: ROVFLUV, Robótica aplicada, Diseño mecánico, Protección ambiental, Análisis estructural

Date Received: November 7th, 2012 - *Fecha de recepción: 7 de Noviembre de 2012*
Date Accepted: February 7th, 2013 - *Fecha de aceptación: 7 de Febrero de 2013*

[1] Mechanical Department - Federal University of Rio de Janeiro, Rio de Janeiro - Brazil. e-mail: krloslozano@ufrj.br
[2] Mechanical Department - Federal University of Rio de Janeiro, Rio de Janeiro - Brazil. e-mail: max@coppe.ufrj.br

Introduction

Floods represent a big problem in the Brazilian south and south-east regions. Due to unplanned occupation of river lands, the Brazilian populations must endure floods and mudslides [1, 2]. Furthermore, human, environmental, and material damage changes the region's vulnerability.

The level of soil on river beds is a variable that can be used to measure the degree of danger areas near rivers, given that this is dependent on the amount of water that the bed has in a specified interval of time.

The autonomous vehicle [3-7], object of this project, consists of a system that provides monitoring of river beds compare to [8, 9], through the detection of significant changes in ground levels, as done in [8, 10, 11]; also, with data transmission over wireless networks. Based on the technology of embedded systems, the autonomous vehicle will also get information related to physical and chemical conditions of the water (temperature, density, salinity, pH, and other variables) [12, 13]. The vehicle will also have the functionality of remote handling when the system detects any abnormalities or changes in the environment and the solution depends on human intervention [9]. Therefore, a communication interface is established based on wireless networks (IEEE 802.11), optical networks and/or sensor network (IEEE 802.15.4E) and mesh networks. This interface will provide greater flexibility to the autonomous vehicle, facilitating its configuration and operation in areas of difficult access [12, 14].

Future modifications will be included (the projection of a decision center, oriented environmental monitoring), which will add value to the project to process the information perceived by the autonomous vehicle and use of disaster prevention.

This work will be present a proposal for a mechanical structure that will be used as a prototype for future developments.

Materials and Methods

For the present application, Solid-Works software was used, along with analysis tools through finite elements. Two materials were tested: 2024-T4 (ASME) aluminum alloy and L316 alloy steel (AISI). Further, we used two structures of different dimensions to validate different behaviors.

Material Properties

The first material used was the aluminum alloy known as aeronautical construction material (2024-T4), whose composition includes: Al: 90.7%, Cr: 0.1%, Cu: 4.9%, Fe: 0.5%, Mg: 1.8%, Mn: 0.9%, Si: 0.5%, Ti: 0.15%, Zn: 0.25%. Aluminum alloys are well known in different applications for their properties for machinability and surface finish, with high strength and adequate workability. They are used in structural applications, like, aircraft fittings, fuse parts, hydraulic valve bodies, piston rectifier parts, worm gears, fastening devices; in this application aluminum was used because the environment where the robot will operate presents high pressure and corrosion conditions due to the depth and chemical components of the water.

The second material used was 316-L stainless steel; the characteristics for this material include good cold formability and high strain hardening capacity. Generally, it is not magnetic, but may have small amounts of ferrite; thereby, presenting mild magnetism. When cold-deformed, it becomes partially martensitic and lightly magnetic. It is very ductile. Machinability is considered bad except for steels and resulfurized CORFaC. Corrosion resistance: shows high resistance means in acetic acid, sulfuric 1% picric, nitric, oleic acid, formic acid, boric acid, benzoic acid and chromic at 20 °C. Good resistance means in concentrated acetic acid at 70 °C, citric acid, 10% oxalic acid, phosphoric acid at 100 °C, 5% sulfuric acid at 20 °C. Saline solutions: chlorides of magnesium, calcium, zinc, potassium permanganate, potassium sulfate at 20 °C, nitrate, cyanide and copper acetate. Applications in sea water: good resistance at 20 °C. Water: good resistance at any temperature.

Structure

For the structure, a tubular profile was used with two different diameters, which will from now on be known as minor-car (MC) and normal-car (NC). The MC has an external diameter of 0.03 m and internal wall of 0.005 m; the NC has an external diameter of 0.05 m and internal wall of 0.01 m.

For NC, the principal volumetric properties for both materials were obtained, shown on Table 1.

Also, for MC, the principal volumetric properties for both materials were obtained, shown on Table 2.

Table 1. NC in Aluminum and Steel alloy

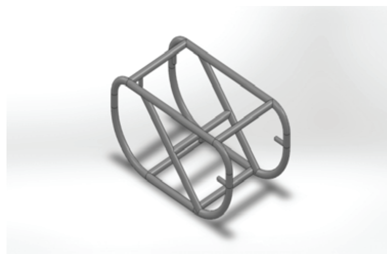
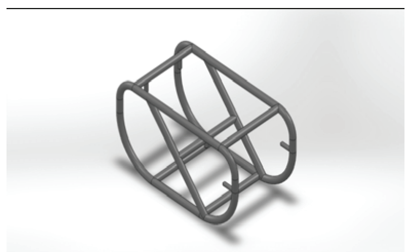
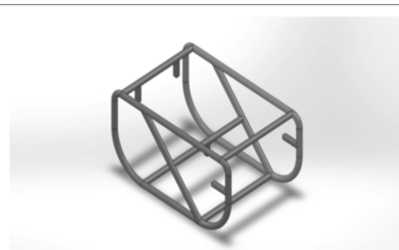
Material	Type of design	Focus / Framework
Aluminum 2024-T4		Mass: 38.1723 kg Volume: 0.0137311 m^3 Density: 2780 kg/ m^3 Weight: 374.089 N
Stainless Steel 316-L		Mass: 109.848 kg Volume: 0.0137311 m^3 Density: 8000 kg/ m^3 Weight: 1076.52 N

Table 2. MC in Aluminum and Steel alloy

Material	Type of design	Focus / Framework
Aluminum 2024-T4		Mass: 9.52268 kg Volum: 0.00342542 m^3 Density: 2780 kg/ m^3 Weight: 93.3223 N
Stainless Steel 316-L		Mass: 27.4034 kg Volume: 0.00342542 m^3 Density: 8000 kg/ m^3 Weight: 268.553 N

Forces Applied

Both of structures were tested with the same applied forces (78.5 N + 38.5 N); forces represent the maximum forces due to the four thrusters propulsion, and the second force is relative to the force that a generator will add to the structure. And pressures (2.354.400 N/m^2) come from the maximum application of the robot in the extreme river depth observed, which is 240 m. The structure was also fixed on two components representing the ground connection between the car and the soil of the water.

Results

This work tested four models (two for each material NC and MC); each model with the same conditions represents different behaviors, as expected. Results for aluminum in NC and MC are presented for both of the structures; furthermore, the results obtained for the steel alloy will be presented.
Both structures were tested and analyzed in two ways, tensile analysis (Tables 3 and 4) and safety factor analysis (Tables 5 and 6). They were obtained from Von Misses theorem; these results were calculated with Solid Works tools through finite element analysis.

Table 3. Tensile analysis in Aluminum alloy

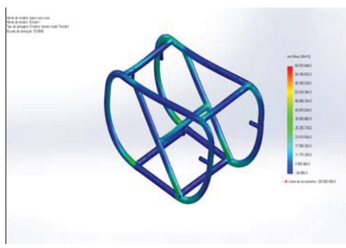
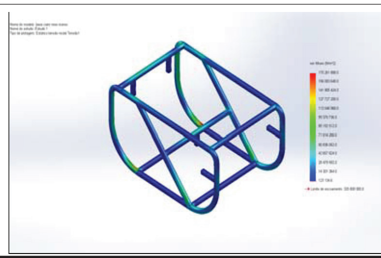
Material	Type of design	Focus / Framework
Aluminum 2024-T4 Normal Car		Min: 134906 Max: 6.99768 $*10^7$
Aluminum 2024-T4 Minor Car		Min: 123135 Max: 1.70262 $*10^8$

Table 4. Tensile analysis in Stainless Steel alloy

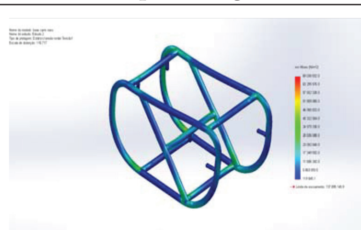
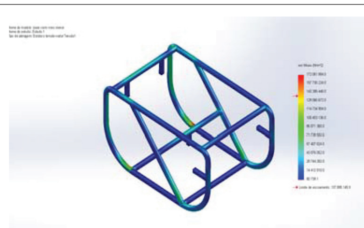
Material	Type of design	Focus / Framework
Stainless Steel 316-L Normal Car		Min: 119845 Max: 6.90388 $* 10^7$
Stainless Steel 316-L Minor Car		Min: 80739.1 Max: 1.72062 $* 10^8$

Table 5. Safety factor analysis in Aluminum alloy

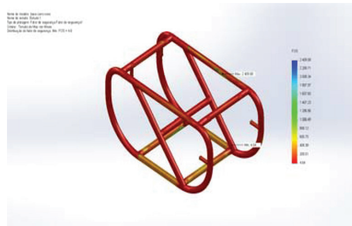
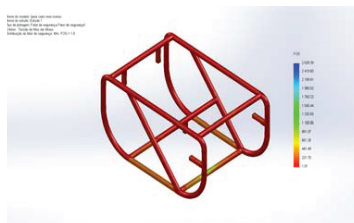
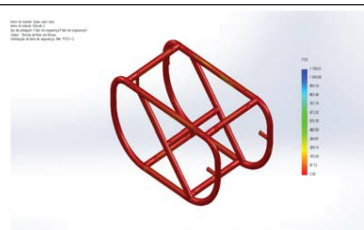
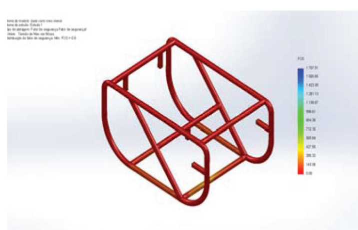
Material	Safety Factor Analysis	Min and Max values
Aluminum 2024-T4 Normal Car		Min: 4.64 Max: 2409.08
Aluminum 2024-T4 Minor Car		Min: 1.90 Max: 2639.39

Table 6. Safety factor analysis in Stainless Steel alloy

Material	Safety Factor Analysis	Min and Max values
Stainless Steel 316-L Normal Car		Min: 1.99 Max: 1150.61
Stainless Steel 316-L Minor Car		Min: 0.80 Max: 1707.91

Conclusion

The results were analyzed in terms of minimum tension (MT) and safety factor (SF); the best result was obtained with the aluminum alloy with 134.906 of MT and 4.64 in SF, which refer to the NC structure. This represents that the structure has mechanical characteristics that allow its use for the proposed application.

It was very important for this study to apply the Solid Works environment for design and test analysis; its properties facilitated the process and its changes, which will improve the structure for the final purpose.

Future works will improve in the structure of new equipment and components, so, the models will have to be re-validated for new configurations or changes that could arise.

Acknowledgements

We thank Capes, CNPq for doctoral scholarships and financial help for investigation.

References

1. MACHADO, M.S., MACHADO, S.W.S., COHEN, S.C., "A rota das chuvas em Petropolis: cenário de uma inundação", V Seminario Internacional de Defesa Civil – DEFENCIL, Ananis Eletrônicos. São Paulo, Novembro, 2009.

2. CONFEDERAÇÃO NACIONAL DE MUNICÍPIOS, "Desastres naturais no Brasil, Analise das portarias de Situação de Emergência e Estado de Calamidade Pública de 2003 a 2010". Estudo Técnico/ CNM – Maio de 2010", available in: http://portal.cnm.org.br/sites/9000/9070/Estudos/PlanejamentoUrbano/DesastresNaturaisnoBrasil-CNM.pdf, Access in: 03/04/2011.

3. KIM, J.,HAN, J., CHUNG, W.K., YUH, J., LEE, P. M., "Accurate and Practical Thruster Modeling for Underwater Vehicles", Proceedings of the 2005: IEEE International Conference on Robotics and Automation, pp. 175-180, 2005.

4. SAAB SEAEYE LTD. DATASHEET OF SEAEYE FALCON & FALCON DR. http://www.seaeye.com/falcon.html, access in: 30/03/2011.

5. GRIFFITHS, G., JAMIESON, J., MITCHELL, S., RUTHERFORD, K., "Energy storage for long endurance AUVs", In, Advances in Technology for Underwater Vehicles, Conference Proceedings, March 2004.

6. JALBERT, J., BAKER, J., DUCHESNEY, J., PIETRYKA, P., DALTON, W., BLIDBERG, D.R., CHAPPELL, S., NITZEL, R., HOLAPPA, K., "A Solar-Powered Autonomous Underwater Vehicle", in: Proceedings of OCEANS 2003, v. 2, pp. 1132-1140, 2003.

7. DEWIJS, B., "Auv/Rov Propulsion Thrusters", IEEE Conference and Exhibition OCEANS 2000 MTS., v. 1, pp. 173 – 176, Provience, RI, USA, September 2000.

8. NEWMAN, J.B., STAKES, D., "Tiburon: Development of a n ROV for Ocean Science Research", OCEANS '94, Oceans Engineering for Today's Technology and Tomorrow's Preservation, Proceedings, v.2, pp. II/483 – II/488, Septembro, 1994.

9. BINGHAM, D., DRAKE, T., HILL, A., LOTT, R., "The Application of Autonomous Underwater Vehicle (AUV) Technology in the Oil Industry – Vision and Experiences", in: XXII FIG International Congress, pp. 1-13, Washington –DC, USA, 2006.

10. MARCO, D.B., HALEY, A.J., "Current Developments in Underwater Vehicle Control and Navigation, The NPS ARIES AUV", IEEE Conference and Exhibition Oceans 2000 MTS, v.2, pp. 1011-1016, September 2000. USA.

11. CHOI, S.K., EASTERDAY, O.T., "An Underwater Vehicle Monitoring System and Its Sensors", Lecture Notes in Control and Information Sciences, Springer Link, v. 271, pp. 551-560, 2001.

12. AKYLDIZ, I.F., POMPILI, D., MELODIA, T., "Underwater acoustic sensor networks: research challenges", Elsevier, pp. 257-279. February 2005.

13. CHU, J.S. LIEBERMAN, A.,DOWNS, P. "Automatic camera control for AUVs: A Comparision of image Assessment Methods", Proceedings of the 1992 Symposium on Autonomous Underwater Vehicle Technology, pp. 191-201, Washington DC, USA,1992.

14. FLETCHER, B. "UUV Master Plan: A Vision for Navy UUV Development", IEEE Conference and Exhibition Oceans 2000 MTS, v.1, pp. 65-71, September 2000. USA.

Anti-fouling Paints Based on Extracts of Marine Organisms from the Colombian Caribbean

Pinturas antiincrustantes a base de extractos de organismos marinos del caribe colombiano

C. Puentes [1]
K. Carreño [2]
M. Santos-Acevedo [3]
J. Gómez-León [4]
M. García [5]
M. Pérez [6]
M. Stupak [7]
G. Blustein [8]

Abstract

Habitually, control of biological fouling includes application of paints containing toxic substances that end up contaminating marine ecosystem. Many organisms prevent settlement of other species synthesizing secondary metabolites that could be used in the elaboration of environmentally friendly anti-fouling paints. This work evaluated the behavior of anti-fouling paints based on extracts from marine invertebrates in the Colombian Caribbean: *Agelas tubulata, Myrmekioderma gyroderma, Oceanapia peltata, Aplysina lacunosa, Neopetrosia próxima, and Holothuria glaberrima*. The painted panels were submerged in the port of Mar del Plata (Argentina); after 90 days in the sea significant differences were registered in the total coverage between the painted panels and the controls ($p<0.05$). The results obtained represent important progress toward using natural compounds in controlling encrustations.

Key words: biofouling, sponges, sea cucumbers, anti-fouling paints.

Resumen

Habitualmente, el control de las incrustaciones biológicas incluye la aplicación de pinturas que contienen sustancias tóxicas que resultan contaminantes para el ecosistema marino. Muchos organismos previenen el asentamiento de otras especies sintetizando metabolitos secundarios que podrían utilizarse en la elaboración de pinturas antiincrustantes amigables con el medio ambiente. En este trabajo se evaluó el comportamiento de pinturas antifouling a base de extractos de invertebrados marinos del Caribe Colombiano: *Agelas tubulata, Myrmekioderma gyroderma, Oceanapia peltata, Aplysina lacunosa, Neopetrosia proxima y Holothuria glaberrima*. Los paneles pintados se sumergieron en el puerto de Mar del Plata (Argentina); luego de 90 días en el mar se registraron diferencias significativas en la cobertura total entre los paneles pintados y los controles ($p<0,05$). Los resultados obtenidos representan un avance importante hacia la utilización de compuestos naturales en el control de las incrustaciones.

Palabras claves: biofouling, esponjas, pepinos de mar, pinturas antifouling.

Date Received: March 31th, 2014 - *Fecha de recepción: 31 de Marzo de 2014*
Date Accepted: May 18th, 2014 - *Fecha de aceptación: 18 de Mayo de 2014*

[1] Tesista. Instituto de Investigaciones Marinas y Costeras (INVEMAR). Santa Marta - Colombia. e-mail: carlos.puentes@invemar.org.co
[2] Tesista. Instituto de Investigaciones Marinas y Costeras (INVEMAR). Santa Marta - Colombia. e-mail: katerine.carreno@invemar.org.co
[3] Investigador. Instituto de Investigaciones Marinas y Costeras (INVEMAR). Santa Marta - Colombia. e-mail: msantos@invemar.org.co
[4] Investigador. Instituto de Investigaciones Marinas y Costeras (INVEMAR). Santa Marta - Colombia. e-mail: jgomezleon@invemar.org.co
[5] Profesional CICPBA. Centro de Investigación y Desarrollo en Tecnología de Pinturas (CIDEPINT). La Plata - Argentina. e-mail: biofouling@cidepint.gov.ar
[6] Profesional CONICET. Centro de Investigación y Desarrollo en Tecnología de Pinturas (CIDEPINT). La Plata - Argentina; Universidad Nacional de La Plata. La Plata - Argentina. e-mail: biofouling@cidepint.gov.ar
[7] Profesional CONICET. Centro de Investigación y Desarrollo en Tecnología de Pinturas (CIDEPINT). La Plata - Argentina. e-mail: biofouling@cidepint.gov.ar
[8] Investigador CONICET. Centro de Investigación y Desarrollo en Tecnología de Pinturas (CIDEPINT). La Plata - Argentina; Profesor. Universidad Nacional de La Plata. La Plata - Argentina. e-mail: antifouling@cidepint.gov.ar

Introduction

Biofouling is known as the attachment and growth of micro and/or macroorganisms on any natural or artificial submerged substrate. The formation of biofouling is a process that implies a series of stages that lead to the consolidation of a community of encrusting organisms subject to changes in function of the prevailing conditions in the system. One of the most widely accepted approaches considers this process formed by distinct phases that include biochemical conditioning of the surface followed by settlement and growth of pioneer bacteria, unicellular organisms, and late-stage prokaryotes (microfouling) and, finally, development of macroscopic organisms (macrofouling) *(Wahl, 1989; Railkin, 2003; Chambers et al., 2006)*.

Marine biofouling seriously affects submerged structures (ships, platforms, buoys, culture farms, etc.) causing big economic losses of diverse nature. Particularly, attachment on hulls of vessels implies an increase between 40 and 50% in fuel consumption due to increased motion resistance (IMO- International Maritime Organization, 2002); in turn, settlement of organisms favors corrosion processes, generating high costs related to cleaning, removal, fairing, and repainting requiring millions of dollars yearly throughout the world. When the bottoms of vessels are not protected by antifouling systems they can accumulate up to 150 kg of biofouling per square meter in less than six months in the sea, which is why it is necessary to use effective methods for its control *(Callow and Callow, 2003)*.

Use of anti-fouling paints is the most efficient method to control biofouling. The action mechanism of these paints is based on the controlled release of or pigments that contain generating a highly toxic interface that avoids attachment of organisms *(Caprari and Lecot, 2001)*. Anti-fouling paints have very particular characteristics that, due to their mode of action, are totally differentiated from the other types known; the paint film modifies permanently its characteristics when it is submerged, with the fundamental objective being that of achieving adequate solubilization de toxic. The toxic loss has a critical minimum value that depends on the toxic used and on the paint formulation; below said value, the paint has no preventive action.

The initial solubilization of the biocide (initial leaching rate) is generally high, given that it results from excess toxics accumulated in the paint film. This value is important because the paint must start to act immediately after the immersion and the effectiveness will depend on the solubility of the toxic, on the characteristics of the vehicle, on the surface area of toxic particles, and on the conditions of temperature, salinity, and pH of the water. After several days of immersion, a constant leaching rate is reached.

During the last four decades, antifouling pigments have been used of excellent biocide power but highly contaminating and harmful to the biota. Among these, there are mercuric oxide (HgO), mercuric arsenate (AsO_4Hg_3), arsenic trioxide (As_2O_3), cuprous arsenite (AsO_3Cu_3), and organometallic substances; mainly tributyltin oxide (TBTO) and triphenyl tin oxide (TPTF). However, research conducted fundamentally in the northern hemisphere confirmed the impact of organoarsenic compounds added to paints on marine life; among these, deformation of shells and imposex phenomena in oyster populations *(Bettin et al., 1996; Pereira et al., 1999; Wu et al., 2010)*, immune responses, neuro-toxic and genetic affections in fishes *(IMO, 2002; Ferraro et al., 2004)* and bio-accumulation in mammals *(Yebra et al., 2004)*. As a consequence of these results, as of 1991, strict regulations were established for the use of this substance in many countries, later resulting in legislation that culminated in the total prohibition of the application of anti-fouling paints based on TBT since the start of 2003 and the prohibition of their manufacture as of 2008 *(Chambers et al., 2006)*. By virtue of these restrictions, possible replacements have been developed like Irgarol 1051®, Sea-Nine 211®, chlorothalonil, dichlofluanid, tolylfluanid, and zinc pyrithiona *(Voulvoulis et al., 1999; Konstantinou and Albanis, 2004; Bellas, 2005)*. However, these compounds have been found in relatively high concentrations in ports, marinas, and coastal zones *(Martínez et al., 2001;*

Voulvoulis et al., 2000; Voulvoulis et al., 2002; Reitsema, 2008).

Biofouling is known as the attachment and growth of micro and/or macroorganisms on any natural or artificial submerged substrate. The formation of biofouling is a process that implies a series of stages that lead to the consolidation of a community of encrusting organisms subject to changes in function of the prevailing conditions in the system. One of the most widely accepted approaches considers this process formed by distinct phases that include biochemical conditioning of the surface followed by settlement and growth of pioneer bacteria, unicellular organisms, and late-stage prokaryotes (microfouling) and, finally, development of macroscopic organisms (macrofouling) *(Wahl, 1989; Railkin, 2003; Chambers et al., 2006).*

Marine biofouling seriously affects submerged structures (ships, platforms, buoys, culture farms, etc.) causing big economic losses of diverse nature. Particularly, attachment on hulls of vessels implies an increase between 40 and 50% in fuel consumption due to increased motion resistance *(IMO- International Maritime Organization, 2002)*; in turn, settlement of organisms favors corrosion processes, generating high costs related to cleaning, removal, fairing, and repainting requiring millions of dollars yearly throughout the world. When the bottoms of vessels are not protected by antifouling systems they can accumulate up to 150 kg of biofouling per square meter in less than six months in the sea, which is why it is necessary to use effective methods for its control *(Callow and Callow, 2003).*

Use of anti-fouling paints is the most efficient method to control biofouling. The action mechanism of these paints is based on the controlled release of or pigments that contain generating a highly toxic interface that avoids attachment of organisms *(Caprari and Lecot, 2001).* Anti-fouling paints have very particular characteristics that, due to their mode of action, are totally differentiated from the other types known; the paint film modifies permanently its characteristics when it is submerged, with the fundamental objective being that of achieving adequate solubilization de toxic. The toxic loss has a critical minimum value that depends on the toxic used and on the paint formulation; below said value, the paint has no preventive action.

The initial solubilization of the biocide (initial leaching rate) is generally high, given that it results from excess toxics accumulated in the paint film. This value is important because the paint must start to act immediately after the immersion and the effectiveness will depend on the solubility of the toxic, on the characteristics of the vehicle, on the surface area of toxic particles, and on the conditions of temperature, salinity, and pH of the water. After several days of immersion, a constant leaching rate is reached.

During the last four decades, antifouling pigments have been used of excellent biocide power but highly contaminating and harmful to the biota. Among these, there are mercuric oxide (HgO), mercuric arsenate (AsO_4Hg_3), arsenic trioxide (As_2O_3), cuprous arsenite (AsO_3Cu_3), and organometallic substances; mainly tributyltin oxide (TBTO) and triphenyl tin oxide (TPTF). However, research conducted fundamentally in the northern hemisphere confirmed the impact of organoarsenic compounds added to paints on marine life; among these, deformation of shells and imposex phenomena in oyster populations *(Bettin et al., 1996; Pereira et al., 1999; Wu et al., 2010)*, immune responses, neuro-toxic and genetic affections in fishes *(IMO, 2002; Ferraro et al., 2004)* and bio-accumulation in mammals *(Yebra et al., 2004).* As a consequence of these results, as of 1991, strict regulations were established for the use of this substance in many countries, later resulting in legislation that culminated in the total prohibition of the application of anti-fouling paints based on TBT since the start of 2003 and the prohibition of their manufacture as of 2008 *(Chambers et al., 2006).* By virtue of these restrictions, possible replacements have been developed like Irgarol 1051®, Sea-Nine 211®, chlorothalonil, dichlofluanid, tolylfluanid, and zinc pyrithiona *(Voulvoulis et al., 1999; Konstantinou and Albanis, 2004; Bellas, 2005).* However, these compounds have been found in relatively high concentrations in ports, marinas, and coastal zones *(Martínez et* *al., 2001; Voulvoulis et al., 2000; Voulvoulis et al., 2002; Reitsema, 2008).*

Bearing in mind the aforementioned and due to the vast bioactive potential found in natural products obtained from marine organisms or which are synthesized by them, currently, studies are focused on optimizing methods that permit their incorporation onto anti-fouling paints.

The natural products are chemical entities synthesized by cells of plants, animals, and microorganisms that are not used in the primary metabolism, which has granted them the name of "secondary metabolites" *(Pawlik, 2011).* The functions of these metabolites are not as evident on the survival of the organisms as are the products of the primary metabolism; however, they play a fundamental ecological role in the development and survival of the species that synthesize those *(Harper et al, 2001).*

Currently, one of the most promising fields of search of natural products is that of marine organisms, given that they synthesize secondary metabolites that have proven to have great potential in the pharmaceutical, cosmetic, and agrochemical industries. Their potential has also been shown for development of molecular probes, enzyme technology, production of chemical precursors and nutritional supplements *(Pomponi, 1999).* Growing interest in substances produced by marine organisms is mainly because many of the compounds they produce are unique at structural level and have pharmacological properties *(Jha and Zi-rong, 2004).* This search for new natural products has resulted in the report of over 18,000 compounds isolated from 4,796 species from 24 different phyla, which is equivalent to 0.27% of the known species of marine organisms (*Blunt et al., 2008).*

Current research on the topic focuses on the search for environmentally friendly compounds. Emphasis has been made on identifying active principles existing in organisms that naturally do not present epibionts and which have not developed inhibition or repulsion mechanisms to protect their bodily surface *(Harder, 2009)* or rather in those that have developed chemical defenses against predators, which is why it is assumed that secondary metabolites are potential antifouling agents *(Davis and Wright, 1989; Clare et al., 1992, Pawlik, 1992; Abarzua and Jakubowski, 1995; Clare, 1996; da Gama et al., 2002; Rao et al., 2007).* The effect fouling provokes upon organisms is varied, numerous compounds act as anesthetics, others as repellents of the attachment or as inhibitors of the properties that determine the adhesion mechanisms without having biocide effects *(Omae, 2003).* However, although the antifouling action of these compounds has been widely proven, until now their incorporation onto paints has not been concrete.

This work evaluated the behavior of anti-fouling paints of soluble matrix based on extracts of marine invertebrates from the Colombian Caribbean, seeking to find environmentally friendly formulations with potential application on vessels and other submerged structures. For this, extracts were elaborated from *Agelas tubulata, Myrmekioderma gyroderma, Oceanapia peltata, Aplysina lacunose*, and *Neopetrosia proxima* sponges and from the *Holothuria glaberrima* sea cucumber.

Methodology

Study area

The study was developed near Santa Marta in the Colombian Caribbean and Mar del Plata in the Argentine Atlantic. The area for the collection of marine organisms includes different locations along the coastal zone of the Tourism, Cultural, and Historical District of Santa Marta, in the department of Magdalena to the north of the Colombian territory, between the bay of Neguange in the Tayrona Natural National Park and the beaches by the airport on the extreme south of the urban perimeter of the city of Santa Marta.

The study zone in Argentina is located in the port of Mar del Plata, province of Buenos Aires, situated to the south of Cabo Corrientes (38°08'S – 57°31'W). The sampling site used to carry out the experiences is the *Club de Motonáutica* located in the port.

Species evaluated

The species studied were *Agelas tubulata, Myrmekioderma gyroderma, Oceanapia peltata, Aplysina lacunosa, Neopetrosia proxima* sponges and the *Holothuria glaberrima* sea cucumber.

The sponges belong to the Phylum Porifera and are fundamentally marine organisms, whose principal characteristic is multicellularity (they do not form true tissue). Their structure is constituted by pores and channels through which water currents flow used to carry out most of their functions. These are eminently sessile, filtering, and mostly asymmetric organisms; except for some less complex species with radial symmetry *(Mille, 2008)*. Sea cucumbers, in turn, belong to the Phylum Echinodermata characterized for having a calcareous internal skeleton and complex organ systems.

Agelas tubulata

In the *Agelas* genus species are characterized for having styles with rows of spines with more or less regular spaces as the only type of spike present. *A. tubulata* (Fig. 1) forms clusters that can exceed 20 cm heights, with tubular shape, apertures 5-8 cm in diameter, yellow-orange coloring, with a smooth surface and of elastic and compressible consistency *(Lehnert and Soest, 1996)*. It is broadly distributed in the Caribbean, being reported in Belize, Cuba, Caiman Islands, Greater Antilles, and Venezuela *(Lehnert and Soest, 1996; Miloslavich et al., 2010)*.

Fig. 1. A. tubulata

Myrmekioderma gyroderma

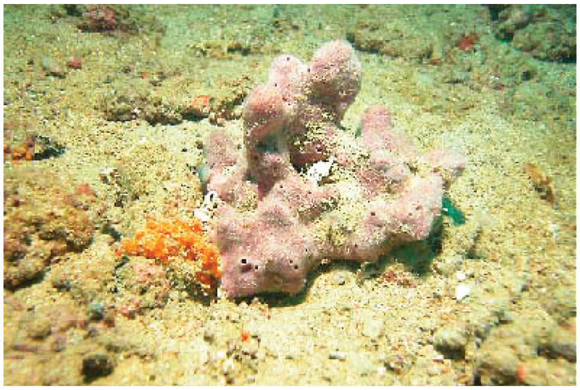
The *Myrmekioderm*a genus is characterized for generating encrusting or massive formations, presenting a hispid surface, with characteristic excavated meanders, sinuous or straight channels, and grooves. On occasion, it forms tuberculated polygonal plates *(Hooper, 2002)*. The *M. gyroderma* species (Fig. 2) may or may not present lobed or cushion shape, often reaching high thickness, with osculate 4-10 cm without determined position, with coloring from yellow to bright orange, of irregular surface and firm, elastic consistency and somewhat lumpy on touch *(Alcolado, 1984)*. It has broad distribution throughout the Caribbean, Greater Antilles, Colombia, Panama, Gulf of Mexico *(Alcolado, 1984; Miloslavich et al., 2010)*.

Fig. 2. M. gyroderma

Neopetrosia proxima

The *Neopetrosia* genus includes compact species with a finely hispid surface, which is smooth and velvety on touch; of hard, rock-like consistency; of irregular sizes and shapes *(Desqueyroux-Faúndez and Valentine, 2002a)*. The *N. proxima* species (Fig. 3) is presented as encrustations, as fingerlike erect lobes with thickened apices, or flattened to sub-spherical masses. It has punctate, microhispid surface, in general full of detritus. Its coloring is commonly brown with light or dark purple or violet tones; unexposed sides and cream interior. The consistency is firm, hard, somewhat difficult to break and cut, exuding sticky mucus upon touch *(Zea, 1987)*. It is distributed in Colombia (Urabá, Cartagena, and Santa Marta), Brazil, Puerto Rico, and the Virgin Islands *(Zea, 1987)*.

Fig. 3. N. proxima



Oceanapia peltata

The *Oceanapia* genus is constituted by species of massive, globular, or lamellar form, with long tubular processes or fistulas, open or close in its ends *(Desqueyroux-Faúndez and Valentine, 2002b)*. *Oceanapia peltata* is a massive globular species that is usually embedded in the sand; it has fistular cylindrical projections that protrude from the sand and have smooth ends or projections with pagoda form, with 2-4 cm width and 1 mm thickness, with cream or grayish color (Fig.4). The consistency of the body globule is slightly compressible and quite fibrous; also, the fistulas on touch are smooth, softer, and less fibrous *(Collin et al., 2005)*. The species is registered at 50-100 m depths in Colombia, Florida, Cuba, and Bocas del Toro (Panamá) *(Collin et al., 2005)*.

Fig. 4. Oceanapia peltata

Aplysina lacunosa

The *Aplysina* genus is characterized by the presence of fibers of a single class, without exogenous detritus and by the presence of a thick medullar component. The fibers form a regular reticulum with large polygonal meshes without specialized surface arrangement *(Bergquist and Cook, 2002)*. The *A. lacunosa* species (Fig. 5) forms solitary tubes or in groups of up to 50 cm in height and 4-10 cm of diameter. It has thick walls from 1.5 to 2.3 cm and above. It is a species of firm consistency, not very compressible and in very big specimens these are more flexible and soft *(Zea, 1987)*. It is distributed in Colombia (Urabá, Cartagena, Santa Marta, and Providencia), the Bahamas, Florida, Jamaica, Puerto Rico, the Dominican Republic, Curaçao and Bonaire *(Zea, 1987)*.

Fig. 5. A. lacunosa

Holothuria glaberrima

This echinoderm species, *Holothuria glaberrima* Selenka, 1867, is small, reaches a maximum length of approximately 15 cm; it has a cylindrical body with soft skin, numerous tube feet on the ventral surface also presenting small and inconspicuous dorsal papillae and long tentacles that are quite branched and dendritic (Fig. 6). They have gregarious habits and typically inhabit coastal areas of low tides, exposed to wave action *(Lewis, 1960; Hendler et al., 1995)*. Their distribution extends to the south of the Bahamas and in the western Caribbean to Trinidad and in Colombia coasts (Tierra Bomba, Cartagena; Punta de la Loma, Santa Marta) to Mexico *(Lewis, 1960; Caycedo, 1978; Hendler et al., 1995)*.

Fig. 6. Holothuria glaberrima

Processing of samples

The invertebrates studied were obtained through manual collection in natural substrates with autonomous diving equipment. Prior to the extraction process, the material is cleaned (removal of accompanying fauna and other elements); the tissue is cut into portions and deposited in jars and frozen at -15 °C. Thereafter, the samples are lyophilized between 36 and 48 hours at -45 °C and 0.120 mbar. The weight of the dry material obtained is recorded, followed by phase to obtain the extract.

Extraction of the metabolites present in the tissues of the organisms selected is carried out by using a methanol/dichloromethane mix (1:1) that permits the dissolution of a broad range of compounds according to the methodology used by Castellanos (2007). The dry tissue is subjected to extraction through maceration at room temperature (20 °C) during 24 hours by submerging it in the solvent mixture and maintaining continuous agitation at 120 rpm. After this time, gravity filtering is carried out by employing slightly compact degreased cotton as filter; the leftover tissue is again extracted under the same conditions until completing 72 hours of extraction, filtering every 24 hours. To obtain a mixture free of solvents, the solution resulting from each filtration is concentrated by using a rotavapor with a heating bath at 38 °C; under pressure of 600 mbar during one hour the dichloromethane is removed and at 100 mbar during three hours the methanol is removed. If necessary, the extract is lyophilized to bring the sample to complete dryness; lastly, the resulting material is decanted to a clean jar to register what will be denominated “total extract”. A portion of the total extract is destined for the fractionating process according to the scheme shown in Fig. 7.

The portion of the extract denominated organic phase was reserved to prepare anti-fouling paints.

Preparation of soluble matrix paints

In soluble matrix paints, the toxic and the vehicle are solubilized jointly, with diminished film thickness. For the formulation of the vehicle rosin resin is used, which is the principal film forming material. Rosin resin is of natural origin; it is extracted from conifers and it is soluble or erosional by water. It is of acidic nature and composed of 90% resin acids, mainly abietic and levopimaric acid *(Rascio et al., 1988)*. The free carboxyl groups (-COOH) allow it to react with alkaline sea water (pH 8) forming soluble resinates and facilitating the release of the toxic substance. However, the colophony generates an excessively soluble film, which is not very adherent and brittle, which is why it is plasticized by incorporating oils or varnishes; its solubility in sea water is affected by the drying time *(Rascio et al., 1977)*.

The paints were prepared at the CIDEPINT pilot plant (Argentina). For this, a porcelain ball mill was used constituted by a 1-l capacity cylindrical container (jar) that rotates according to a horizontal axis on cylindrical bearings powered by a motor (Fig. 8). The porcelain jar used has an adjustable lid and it is loaded with the paint components. The dispersion is achieved fundamentally through the cascade effect produced by the motion of the spheres. The pigment particles are subjected to impact and shear effort *(Giúdice, et al., 1980)*.

During a first stage, the ligand of the paint was elaborated by dissolving rosin resin and oleic acid (plasticizer) in a xylene/mineral turpentine mix in a high-speed disperser. The jar was loaded with the ligand and the pigments (zinc oxide and chalk) and these were dispersed for 24 hours. The

Fig. 7.

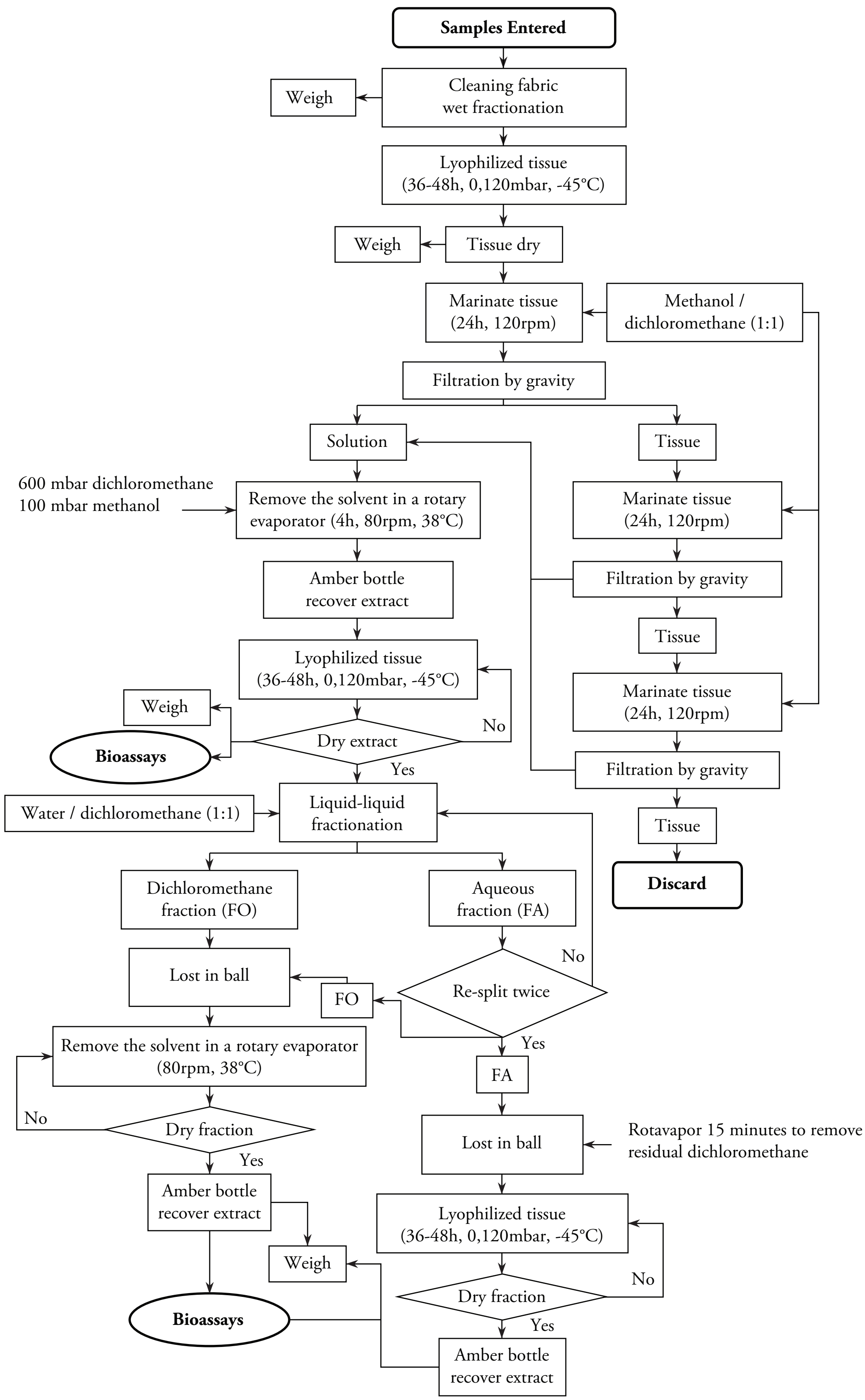

Samples Entered
Weigh
Cleaning fabric wet fractionation
Lyophilized tissue (36-48h, 0,120mbar, -45°C)
Weigh
Tissue dry
Marinate tissue (24h, 120rpm)
Methanol / dichloromethane (1:1)
Filtration by gravity
Solution
Tissue
600 mbar dichloromethane
100 mbar methanol
Remove the solvent in a rotary evaporator (4h, 80rpm, 38°C)
Marinate tissue (24h, 120rpm)
Amber bottle recover extract
Filtration by gravity
Tissue
Lyophilized tissue (36-48h, 0,120mbar, -45°C)
Marinate tissue (24h, 120rpm)
Weigh
Bioassays
Dry extract
No
Yes
Filtration by gravity
Water / dichloromethane (1:1)
Liquid-liquid fractionation
Tissue
Discard
Dichloromethane fraction (FO)
Aqueous fraction (FA)
No
Lost in ball
FO
Re-split twice
Yes
Remove the solvent in a rotary evaporator (80rpm, 38°C)
FA
No
Dry fraction
Yes
Lost in ball
Rotavapor 15 minutes to remove residual dichloromethane
Amber bottle recover extract
Lyophilized tissue (36-48h, 0,120mbar, -45°C)
Weigh
No
Dry fraction
Yes
Bioassays
Amber bottle recover extract

Fig. 8.

paint obtained was filtered and fractionated into seven portions; one of these was used as negative control (P1) and the remaining ones were added to the extracts (organic phase) dissolved in the same solvent mixture used for the paint (Tables 1 and 2).

Table 1. Composition of the paints

Components	% V/V
Zinc oxide	16.2
Chalk	10.8
Rosin resin	27.0
Oleic acid	6.0
Xylene/mineral turpentine (1:1)	40.0
Extracts (organic phase)	1.0

Table 2. Identification of the paints

Identification	Extracts (organic phase)
P 1	Control
P 2	*Agelas tubulata* (Demospongia, Agelasidae)
P 3	*Myrmekioderma gyroderma* (Demospongia,Heteroxydae)
P 4	*Holothuria glaberrima* (Echinodermata, Holothuriidae)
P 5	*Oceanapia peltata* (Demospongia, Phloeodictyidae)
P 6	*Aplysina lacunosa* (Demospongia, Aplysinidae)
P 7	*Neopetrosia* (Xestospongia) *proxima* (Demospongia, Petrosiidae)

The anti-fouling paints prepared were applied with a brush on 120 x 40 mm sanded acrylic panels previously degreased with toluene. Four coats of paint were applied with a 24-hour drying time between them until obtaining a final dry-film thickness of 75 ± 5 µm. The panels with each type of paint were placed on aluminum racks in series of six and were submerged in the port of Mar del Plata registering the behavior of each formulation after 45 and 90 days. The estimation of attachment of organisms on panels exposed with or without formulations in the sea in function of time was evaluated through a grid as a guide to observe the whole panel given its small size. The panels were removed and observed in the laboratory. Abundance was registered for each species from the macro and microfouling and percentages were estimated.

Results

The results from the first 45 days demonstrated that significant differences exist regarding the percentage of total coverage between the painted panels and the controls ($p<0.05$). The differences were basically due to settlement of the *Enteromorpha intestinalis* and *Ectocarpus* sp. algae, colonies of the *Bugula* sp. briozoo, and to the sandy tubes of the *Corophium* sp. amphipod. The paints presenting the best antifouling behavior were: P4, P5, P6, and P7. Paint P3, in turn, did not present antifouling effect because the attachment registered did not differ statistically from the controls. However, reduced percentages of attachment of organisms could be noted, especially of the *Polydora, Bugula, Ectocarpus, Enteromorpha*, and *Corophium* genera (Fig. 9).

Coincidentally, after 90 days of exposure to the sea significant differences were observed in total coverage between the painted panels and the controls ($p<0.05$) (Fig. 10). The species that determined those differences were the same that were registered during the first sampling to which *Hydroides elegans* was added.

All the paints studied showed antifouling activity, except for P3 (*Myrmekioderma gyroderma*) whose

Fig. 9.

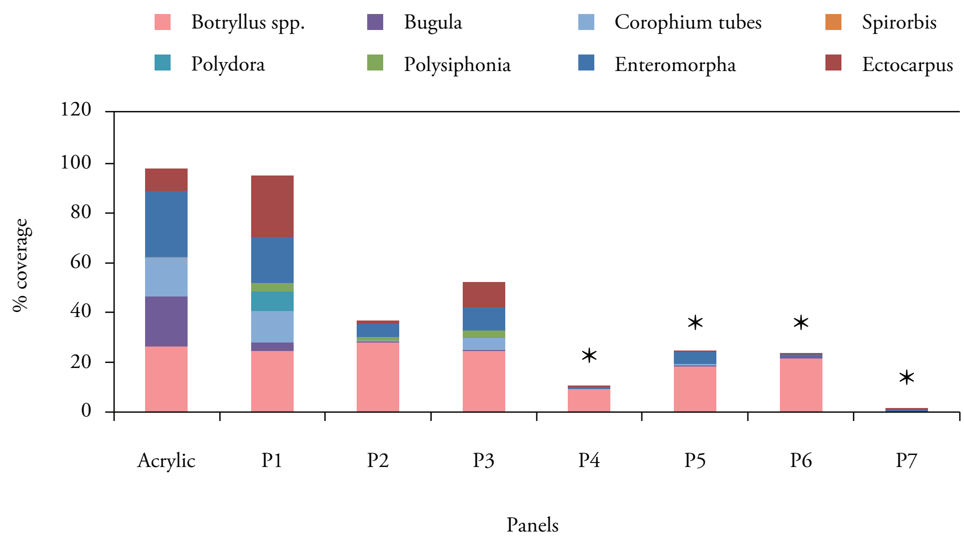
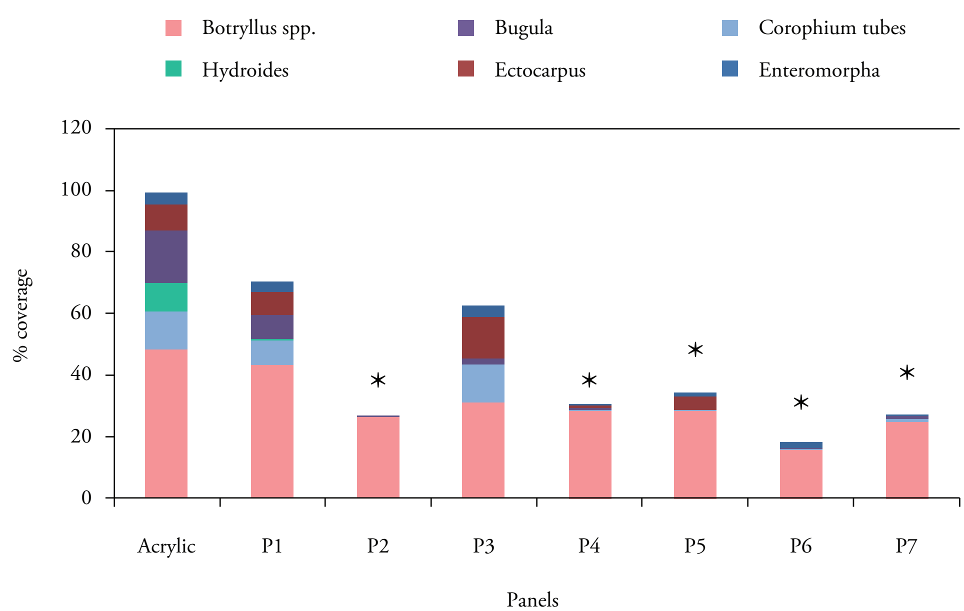


Fig. 10.



behavior was similar to the controls, as occurred during the first sampling. However, it must be highlighted that the paints containing organic fractions of extracts of *Agelas tubulata, Holothuria glaberrima* and *Neopetrosia proxima* presented the best behavior, significantly inhibiting attachment of species present in the fouling from Mar del Plata except for Botryllus sp. ($p<0.05$) (Table 3) (Fig. 11). It is worth mentioning that all the organic fractions tested completely inhibited attachment of Hydroides elegans, calcareous tube forming polychaete considered among the most aggressive species of local fouling.

Discussion

Porifera are among the most studied groups in function of the vast amount of secondary metabolites they produce and that they represent

Table 3. Antifouling activity of extracts on organisms from biofouling

Components	P_1	P_2	P_3	P_4	P_5	P_6	P_7
Enteromorpha	-	+	-	+	+	-	+
Ectocarpus	-	+	-	+	-	+	+
Bugula	-	+	+	+	+	+	+
Hydroides	-	+	+	+	+	+	+
Corophium tubes	-	+	-	+	+	+	+
Botryllus spp.	-	-	-	-	-	-	-

(+) Positive antifouling activity; (-) negative antifouling activity

an important source of new structures. In this sense, the biggest flow of information on the theme corresponds to this group (33% of the articles reported), followed by chordates (8%), and echinoderms (5%). The number of compounds isolated from these phyla is 6668 for sponges, 1047 for echinoderms, and 977 for chordates *(Blunt et al., 2008)*.

The most common biogenesis routes of secondary metabolites in sponges from the Demospongiae class (group to which the sponges studied in this group belong) are isoprenoids (50%), amino acids (25%), and acetogenins (22%) *(Harper et al., 2001)*. These metabolites present diverse biological activities like, for example, anti-predator and anti-epibiotic *(Becerro et al., 2003; Tsoukatou et al., 2007; Hellio et al., 2005; Clavico et al., 2006; Thakur and Anil, 2000; Harper et al., 2001; Faulkner, 2002; Blunt et al., 2004)*.

Also, studies carried out on isolating and identifying natural products extracted from echinoderms have focused fundamentally on sea cucumbers that have shown antifungal, antiviral, and antitumor activity *(De Marino et al., 1997; Bryan et al., 1996; Haug et al., 2002; Bryan et al., 1992; Villasin and Pomory, 2000; Hua et al., 2009)*; in some species like Holothuria leucospilota, it was proven that compounds extracted from their tissues avoided development of biofilms formed by diatoms *(Moshake et al., 1994; Gonsalves, 1997)*.

The huge potential of marine organisms as producers of secondary metabolites remains evident in this work, given that of six species evaluated five presented antifouling activity. More so, if we bear in mind that only the organic fraction of the extracts has been used, it could be assumed that bioactive metabolites could be present in the aqueous fraction and even synergic interactions among metabolites from both fractions that until now have not been contemplated. This point of view does not dismiss, then, that the *Myrmekioderma gyroderma* sponge, which in this focused work did not show antifouling activity, could be of use.

Due to the excellent results obtained in this series of experiences, it would be of interest to continue with these types of studies, conducting immersion tests with painted panels for more prolonged

Fig. 11.

periods to verify the effect of the extracts on other species present during distinct times of the year. Combinations of extracts should also be studied in the laboratory and at sea to detect synergic effects to maximize the antifouling activity.

It is also transcendental to conduct bio-guided tests to establish what molecule or molecules from the organic fraction of the extracts are responsible for this activity and, thus, offer a concrete alternative for their use, by obtaining the product through chemical synthesis or through organism or tissue cultures.

Conclusions

1. All the extracts included in anti-fouling paints of soluble matrix showed antifouling activity, except for those from Myrmekioderma gyroderma whose behavior was similar to the controls.
2. The best antifouling behavior was presented by paints containing the organic fractions of Agelas tubulata, Holothuria glaberrima, and Neopetrosia proxima extracts.
3. All the extracts tested completely inhibited attachment of Hydroides elegans, calcareous tube forming polychaete considered among the most aggressive species of local fouling.

Bibliography

ABARZUA, S. and S. JAKUBOWSKI. 1995. Biotechnological investigation for the prevention of biofouling: I. Biological and biochemical principles for the prevention of biofouling. Mar. Ecol. Prog. Ser. 123: 301-312 pp.

ALCOLADO, P.M. 1984. Nuevas especies de esponjas encontradas en Cuba. Poeyana. 271: 1–22 pp.

BECERRO, M.; THACKER, R.; TURON, X.; URIZ, M. AND PAUL, V. (2003). Biogeography of sponge chemical ecology: comparison of tropical and temperate defences. Oecologia, 135, 91-101.

BELLAS, J. 2005, Toxicity assessment of the antifouling compound zinc pyrithione using early developmental stages of the ascidian Ciona intestinalis. Biofouling. 21: 289-296 pp.

BERGQUIST, P.R. AND S.D.C. COOK. 2002. Family Aplysinidae, en: Hooper, J.N.A. y R.W.M. van Soest (eds.). Systema Porifera: a guide to the classification of sponges. Kluwer Academic/Plenum Publishers, New York. 1082–1085 pp.

BETTIN, C., J. OEHLMANN and E. STROBEN. 1996. TBT-induced imposex in marine neogastropods is mediated by an increasing androgen level. Helgoland Mar. Res. 50 (3): 299–317 pp.

BLUNT, J.; COPP, B.; MUNRO, M.; NORTHCOTE, P. and PRINSEP, M. (2004). Marine natural products. Nat. Prod. Rep. 21, 1- 49.

BLUNT, J.W., B.R. COPP, W.P. HU, M. MUNRO, P.T. NORTHCOTE and M.R Prinsep. 2008. Marine natural products. Natural Products Report. 25: 35-94 pp.

BRYAN, P.; MCCLINTOCK, J.;MARION, K.; WATTS, S. and HOPKINS, T. (1992). Feeding deterrence and chemical defense in echinoderm body wall tissues from the Northern gulf of Mexico. Amer. Zool,, 32, 100.

BRYAN, P.; RITTSCHOF, D. and MC CLINTOCK, J. (1996). Bioactivity of echinoderm ethanolic body-wall extracts: An assessment of marine bacterial attachment and macorinverebrate larval settlement. J. Exp. Mar. Biol. Ecol., 196, 79-96.

CALLOW, M.E. and J.A. CALLOW. 2003. Some New Insights into Marine Fouling. World Super Yacht. 1: 34-39 pp.

CAPRARI, J. y C. LECOT. 2001. El control de bivalvos invasores Limnoperna fortunei (Dunker, 1857) en la Central Hidroeléctrica Yacyretá mediante pinturas. Actas Seminario Internacional sobre Gestión Ambiental e Hidroelectricidad, Salto Grande. 24 p.

CASTELLANOS, L. 2007. Metabólitos mayoritarios de las esponjas excavadoras Cliona delitrix y Cliona tenuis, y su papel como aleloquimicos en la competencia por espacio con corales hermatípicos. Tesis de doctorado en Ciencias Química. Universidad Nacional de Colombia, Facultad de Ciencias, Posgrado en Química. 211 p.

CAYCEDO, I.E., 1978. Holothurioidea (Echinodermata) de aguas someras en la costa norte de Colombia. An. Inst. Inv. Mar. Punta Betín. 10: 149–198 pp.

CHAMBERS, L.D., K.R. STOKES, F.C. WALSH, y R.J. WOOD. 2006. Modern approaches to marine antifouling coatings. Surf. Coat. Tech. 201 (6), 3642–3652 pp.

CLARE, A. 1996. Marine natural product antifoulants: status and potential. Biofouling. 9: 211-229 pp.

CLARE, A.S., D. RITTSCHOF, D.J. GERHART y J. MAKI. 1992. Molecular approaches to nontoxic antifouling. Invert. Reprod. Dev. 22: 67-76 pp.

CLAVICO, E.; MURICY, G.; DA GAMA, B.; BATISTA, D.; VENTURA, C. and PEREIRA, R. (2006). Ecological roles of natural products from the marine sponge Geodia corticostylifera. Mar. Biol., 148, 479-488.

COLLIN, R., M.C. DIAZ, J.L. NORENBURG, R.M. ROCHA, J.A. SANCHEZ, A. SCHULZ, M.L. SCHWARTZ and A. VALDES. 2005. Photographic identification guide to some common marine invertebrates of Bocas Del Toro, Panama. Caribb. J. Sci. 41 (3): 638–707 pp.

da GAMA. A., R. PEREIRA, A. CARVALHO, R. COUTINHO y Y. YONESHIGUE-VALENTIN. 2002. The effect of seaweed secondary metabloites on biofouling. Biofouling. 18: 13-20 pp.

DAVIS, A. and A. WRIGHT. 1989. Interspecific differences in fouling of two congeneric ascidians (Eudistoma olivaceum and E. capsulatum). Is surface acidity an effective defense? Mar. Biol. 102: 491-497 pp.

DESQUEYROUX-FAÚNDEZ, R. y C. VALENTINE. 2002a. Family Petrosiidae, en: Hooper, J.N.A. y R.W.M. van Soest (eds.), Systema Porifera: a guide to the classification of sponges. Kluwer Academic/Plenum Publishers, New York. 906–917 pp.

DESQUEYROUX-FAÚNDEZ, R. y C. VALENTINE. 2002b. Family Phloeodictyidae, en: Hooper, J.N.A. y R.W.M. van Soest (eds.), Systema Porifera: a guide to the classification of sponges. Kluwer Academic/Plenum Publishers, New York. 893–905 pp.

DE MARINO,S.; IORIZZI, M.; ZOLLO, F.; MINALE, L.; AMSDLER, C.; BAKER, B.; MCCLINTOCK, J. (1997). Isolation, structure elucidation, and biological activity of the steroid oligoglycosides and polyhydroxysteroids from the Antarctic starfish Acodontaster conspicuous. J. Nat. Prod., 60, 959-966.

FAULKNER, D. (2002). Marine natural products. Nat. Prod. Rep., 19, 1-48.

FERRARO, M.V., A.S. FENOCCHIO, M.S. MANTOVANI, C. DE OLIVEIRA RIBEIRO y M.M. CESTARI. 2004. Mutagenic effects of tributyltin and inorganic lead (Pb II) on the fish H. malabaricus as evaluated using the comet assay and the piscine micronucleus and chromosome aberration tests. Genet. Mol. Biol. 27: 103–107 pp.

GIÚDICE, C., J. BENITEZ, V. RASCIO y M.

PRESTA. 1980. Study of variables which affect dispersion of antifouling paints in ball mills. Journal Oil Colour Chemistry Association. 63 (4): 153 p.

GONSALVES, C. (1997). Effect of holothurian and zoanthid extract on growth of some bacterial and diatom species.. J. Ind. Mar. Sci., 26, 376-379.

HARDER, T. 2009. Marine epibiosis: concepts, ecological consequences and host defence. En: Marine and industrial biofouling. Springer series on biofilms. 4 (II): 219-231 pp.

HARPER, M.K., T.S. BUGNI, B.R. COPP, R.D. JAMES, B.S. LINDSAY, A.D. RICHARDSON, P.C. SCHNABEL, D. TASDEMIR, R.M. VAN WAGONER, S.M.VERBITSKI y C.M. IRELAND. 2001. Introduction to the chemical ecology of marine natural products, en: McClintock, J.B. y B.J. Baker (eds.). Marine Chemical Ecology. CRC Marine Science Series. 3–69 pp.

HAUG, T.; KJUUL, A.; STYRVOLD, O.; SANDSDALEN, E.; OLSEN, M. and STENSVÅG, K. (2002). Antibacterial activity in Strongylocentrotus droebachiensis (Echinoidea), Cucumaria frondosa (Holothuroidea), and Asterias rubens (Asteroidea). J. Invert. Pathol. 81, 94-102.

HELLIO, C.; TSOUKATOU, M.; MARÉCHAL, J.; ALDRED, N.; BEAUPOIL, C.; CLARE, A.; VAGIAS, C. and ROUSSIS, V. (2005). Inhibitory effects of Mediterranean sponge extracts and metabolites on larval settlement of the barnacle Balanus amphitrite. Mar. Biotechnol., 7, 297-305.

HENDLER, G., J.E. MILLER, D.L. PAWSON and P.M. KIER. 1995. Sea stars sea urchins and allies: Echinoderms of Florida and the Caribbean. Smithsonian Institution, Washington. 392 p.

HOOPER, J.N.A., 2002. Family Desmoxyidae, en: Hooper, J.N.A. y R.W.M. van Soest (eds.), Systema Porifera: a guide to the classification of sponges. Kluwer Academic/Plenum Publishers, New York. 755–772 pp.

HOOPER, J.N.A. y R.W.M. VAN SOEST. 2002. Systema Porifera: a guide to the classification of sponges: Volume 1: Introductions and Demospongiae. Springer. 1810 p.

HUA HAN, YANG-HUA YI, LING LI, BAO-SHU LIU, MING-PING LA, HONG-WEI ZHANG (2009). Antifungal active triterpene glycosides from sea cucumber Holothuria scabra. Acta Pharmaceutica Sinica, 44 (6), 620-624.

IMO - International Maritime Organization, 2002. Antifouling Systems. Londres. 31 p.

JHA R.K. Y X. ZI-RONG. 2004, Biomedical compounds from marine organisms. Marin Drugs. 2: 123-146 pp.

KONSTANTINOU, I. and T. ALBANIS. 2004. Worldwide occurrence and effects of antifouling paint booster biocides in the aquatic environment. Environment International, 30: 235-248 pp.

LEHNERT, H. y R.W.M. VAN SOEST. 1996. North Jamaican deep fore-reef sponges. Beaufortia. 46 (4): 53–81 pp.

LEWIS, J.B., 1960. The fauna of rocky shores of Barbados, West Indies. Can. J. Zoolog. 38: 391–435 pp.

MARTÍNEZ, I., M. FERRER, A. HERNANDO, R. FERNÁNDEZ-ALBA, F. MARCE y D. BARCELÓ. 2001. Occurrence of antifouling biocides in the Spanish Mediterranean marine environment. Environ. Technol. 2: 543-553 pp.

MILLE, S.R. 2008. Invertebrados. Instituto Politécnico Nacional, México. 662 p.

MILOSLAVICH, P., J.M. DÍAZ, E. KLEIN, J.J. ALVARADO, C. DÍAZ, J. GOBIN, E.

ESCOBAR-BRIONES, J.J. CRUZ-MOTTA, E. WEIL, J. CORTÉS, A.C. BASTIDAS, R. ROBERTSON, F. ZAPATA, A. MARTÍN, J. CASTILLO, A. KAZANDJIAN y M. ORTIZ. 2010. Marine biodiversity in the Caribbean: Regional estimates and distribution patterns. PloS ONE. 5 (8): 1–25 pp.

MOSHAKE, S.; GARG, A.; ANIL, A. AND WAGH, A. (1994). Growth inhibition of periphytic diatoms of methanol extract of sponges and holothurians. Ind. J. Mar Sci., 23, 57-58.

OMAE, I. 2003. General aspects of tin-free antifouling paints. Chem. Rev. 103: 3431-3448 pp.

PAWLIK, J. 1992. Chemical ecology of the settlement of benthic marine invertebrates. Oceanogr. Mar. Biol. Annu. Rev. 30: 548-551 pp.

PAWLIK, J.R. 2011. The chemical ecology of sponges on Caribbean reefs: Natural products shape natural systems. BioScience. 61 (11): 888-898 pp.

PEREIRA, W., T. WADE, F. HOSTETTLER y F. PARCHASO. 1999. Accumulation of butyltins in sediments and lipid tissues of the Asian clam, Potamocorbula amurensis, near mare island naval shipyard, San Francisco Bay. Mar. Pollut. Bull., 38: 1005-1010 pp.

POMPONI, S.A. 1999. The bioprocess–technological potential of the sea. Journal of Biotechnology. 70: 5-13 pp.

RAILKIN, A.I., 2003. Marine Biofouling: Colonization Processes and Defenses, primera edición. CRC Press. 303 p.

RAO, D. J. WEBB, C. HOLSTROM, R. CASE, A. LOW, P. STEINBERG y S. KJELLEBERG. 2007. Low densities of epiphytic bacteria from the marine alga Ulva australis inhibit settlement of fouling organisms. Appl. Environ. Microbiol. 73: 7844-7852 pp.

RASCIO, V., W. BRUZZONI, R. BASTIDA y E. ROZADOS. 1977. Protección de superficies metálicas. Serie III - Manuales Científicos, Nº 1, LEMIT. 454 p.

RASCIO, V., C. GIÚDICE y B. DEL AMO. 1988. Research and development of soluble matrix antifouling paints for ships, offshore platforms, and power stations. A review. Corros. Rev. 8 (1-2): 87-153 pp.

REITSEMA, T. 2008. Antifouling Biocides in Perth Coastal Waters: A Snapshot at selected areas of vessel activity. Water science technical series. Report nº WST 1. 48 p.

THAKUR and ANIL, (2000). Antibacterial activity of the sponge Ircinia ramosa: Importance of its surface-associated bacteria. J. Chem. Ecol.., 26, 57-71.

TSOUKATOU, M.; MARÉCHAL, J.; HELLIO, C.; NOVAKOVIC, I.; TUFEGDZIC, S.; SLADIC, D.; GASIC, M.; CLARE, A.; VAGIAS, C. and ROUSSIS, V. (2007). Evaluation of the activity of the sponge metabolites avarol and avarone and their synthetic derivatives against fouling micro- and macroorganisms. Molecules, 12, 1022-1034.

VILLASIN, J. and POMORY, C. (2000). Antibacterial activity of extracts from the body wall of Parastichopus parvimensis (Echinodermata: Holothuroidea). Fish. Shellfish Immunol., 10, 465-467.

VOULVOULIS, N., M. SCRIMSHAW y J. LESTER. 1999. Appl. Organometall. Chem. 13: 135-143 pp.

VOULVOULIS, N., M. SCRIMSHAW y J. LESTER. 2000. Occurrence of four biocides utilised in antifouling paints, as alternatives to organotin compounds, in waters and sediments of a commercial estuary in the UK. Mar. Poll. Bull. 40: 938-946 pp.

VOULVOULIS, N., M. SCRIMSHAW y J. LESTER. 2002. Comparative environmental assessment of biocides used in antifouling paints. Chemosphere, 47: 789-795 pp.

VROLIJK, N., N. TARGETT, R. BAIER, R. y A. MEYER. 1990. Surface characterization of two gorgonian coral species: implications for a natural antifouling defense. Biofouling. 2: 39-54 pp.

WAHL, M. 1989. Marine epibiosis. I. Fouling and antifouling: some basic aspects. Mar. Ecol-Prog. Ser. 58 (1): 175–189 pp.

WU, J., P.J. MENG, M.Y. LIU, Y.W. CHIU y L.L. LIU. 2010. A high incidence of imposex in pomacea apple snails in Taiwan: A Decade after Triphenyltin Was Banned. Zool. Stud. 49 (1): 85–93 pp.

YEBRA, D.M., S. KIIL y K. DAM-JOHANSEN. 2004. Antifouling technology: past, present and future steps towards efficient and environmentally friendly antifouling coatings. Prog. Org. Coat. 50 (2): 75–104 pp.

ZEA, S. 1987. Esponjas del Caribe colombiano., Primera edición. Catalogo Científico, Bogotá. 286 p.

Editorial Guidelines for Authors

Thematic Interest

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.

Typology

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.

Format

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.

Author and Affiliations
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.
- City (Province/State/Department).
- Country.

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.

Bibliographic References

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.

Quotations

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".

List of References

Bibliographic references of original sources for cited material must be cited at the end of the article in alphabetical order and according to the following parameters:

In the event of more than one author, separate by commas and the last one by an "and". If there are more than three authors write the last name and initials of the first author and then the abbreviation "*et al.,*".

Books

Last name of author followed by a comma, initial(s) of name followed by a period, the year of publication of book in parenthesis followed by a comma, title of publication in italics and without quotation marks followed by a comma, city where published followed by a comma, and name of editorial without abbreviations such as Ltd., Inc. or the word "editorial".

Basic Form:
LAST NAME, N.I. *Title of book*. Subordinate responsibility (optional). Edition. Publication (place, publisher). Year. Extent. Series. Notes. Standard Number.

Example:
GOLDBERG, D.E. *Genetic Algorithms for Search, Optimization, and Machine Learning.* Edition 1. Reading, MA: Addison-Wesley. 412 p. 1989. ISBN 0201157675.

If a corporate author
Write complete name of entity and follow the other standards.

Basic form:
INSTITUTION NAME. *Title of publication*. Subordinate responsibility (optional). Edition. Publication (place, publisher). Year. Extent. Series. Notes. Standard Number.

Example:
AMERICAN SOCIETY FOR METALS. *Metals Handbook: Properties and Selection: Stainless Steels, Tool Materials and Special-Purpose Metals*. 9th edition. Asm Intl. December 1980. ISBN: 0871700093.

When book or any publication have as author an entity pertaining to the state, write name of country first.

Basic form:
COUNTRY, ENTITY PERTAINING TO THE STATE. *Title of publication*. Subordinate responsibility (optional). Edition. Publication (place, publisher). Year. Extent. Series. Notes. Standard Number.

Example:
UNITED STATED OF AMERICAN. EPA - U.S. Environmental Protection Agency. Profile of the Shipbuilding and Repair Industry. Washington D.C. 1997. P. 135.

Journal Article

Basic form:
Last name, N.I. Title of article, *Name of publication*. Edition. Year, issue designation, Pagination of the part.

Graduation Work

Basic form:
Primary responsibility. *Title of the invention*. Subordinate responsibility. Notes. Document identifier: Country or issuing office. *Kind of patent document*. Number. Date of publication of cited document.

Example:
CARL ZEISS JENA, VEB. *Anordnung zur lichtelektrischen Erfassung der Mitte eines Lichtfeldes. Et-finder*: W. FEIST, C. WAHNERT, E. FEISTAUER. Int. Cl.3 : GO2 B 27/14. Schweiz Patentschrift, 608 626. 1979-01-15.

Presentation at conferences or academic or scientific event

Basic form:
LAST NAME, N.I. Title of the presentation. In: Sponsor of the event. *Name of the event*. Country, City: Publisher, year. Pagination of the part.

Example:
VALENCIA, R., et al. Simulation of the thrust forces of a ROV En: COTECMAR. P*rimer Congreso Internacional de Diseño e Ingeniería Naval CIDIN 09*. Colombia, Cartagena: COTECMAR, 2009.

Internet

Basic form:
LAST NAME, N.I. *Title of work*, [on-line]. Available at: http://www.direccion_completa.com, recovered: day of month of year.

Example:
COLOMBIA. ARMADA NACIONAL. Cotecmar gana premio nacional científico, [web on-line]. Available at: http://www.armada.mil.co/?idcategoria=545965, recovered: 5 January of 2010.

Acceptance

Articles must be sent by e-mail to the editor of The *Ship Science and Technology* Journal to otascon@cotecmar.com or in CD to the journal's street mailing address (Cotecmar Mamonal Km 9 Cartagena Colombia), accompanied by the "Declaration of Originality of Written Work "included in this journal.

The author shall receive acknowledgement of receipt by e-mail. All articles will be submitted to Peer Review. Comments and evaluations made by the journal shall be kept confidential. Receipt of articles by The Ship Science and Technology Journal does not necessarily constitute acceptance for publishing. If an article is not accepted it shall be returned to the respective author. The Journal only publishes one article per author in the same number of the magazine.

Opinions and declarations stated by authors in articles are of their exclusive responsibility and not of the journal. Acceptance of articles grants The Ship Science and Technology Journal the right to print and reproduce these; nevertheless, any reasonable petition by an author to obtain permission to reproduce his/her contributions shall be considered.

Further information can be obtained by:
Sending an e-mail to sst.journal@cotecmar.com
Contacting Oscar Dario Tascon (Editor)
The Ship Science and Technology (Ciencia y Tecnología de Buques) office located at: Cotecmar Mamonal Km. 9, Cartagena Colombia.
Phone Number: 57 - 5 - 6685377.

SHIP
SCIENCE & TECHNOLOGY
CIENCIA & TECNOLOGÍA DE BUQUES

Statement of Originality of Written Work

Title of work submitted

____

____

____

I hereby certify that the work submitted for publication in The *Ship Science and Technology* journal of Science and Technology for the Development of Naval, Maritime, and Riverine Industry Corporation, COTECMAR, was written by me, given that its content is the product of my direct intellectual contribution. All data and references to material already published are duly identified with their respective credits and are included in the bibliographic notes and quotations highlighted as such.

I, therefore, declare that all materials submitted for publication are completely free of copyrights; consequently, I accept responsibility for any lawsuit or claim related with Intellectual Property Rights thereof.

In the event that the article is chosen for publication by The *Ship Science and Technology* journal, I hereby state that I totally transfer reproduction rights of such to Science and Technology for the Development of Naval, Maritime, and Riverine Industry Corporation, COTECMAR. In retribution for the present transfer I agree to receive two issues of the journal number where my article is published.

In witness thereof, I sign this statement on the ______ day of the month of _______________ of year ______________, in the city of _______________ .

Name and signature: ________________________________

Identification document: ________________________________

Km. 9 Vía Mamonal - Cartagena, Colombia
www.shipjournal.co

Vol. 8 - n.° 15
July 2014

COTECMAR

www.shipjournal.co