SHIP
SCIENCE & TECHNOLOGY
CIENCIA & TECNOLOGÍA DE BUQUES

COTECMAR
COLOMBIA

OPV93
Offshore Patrol Vessel Class

ISSN 1909-8642 (Impreso)
ISSN 2619-645X (Online)

Vol. 12 - n.° 24
(1 - 68) January 2019

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SCIENCE & TECHNOLOGY
CIENCIA & TECNOLOGÍA DE BUQUES

Volume 12, Number 24 - January 2019 ISSN 1909-8642 (Impreso) - ISSN 2619-645X (Online)

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

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

SHIP

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Editorial Note

Cartagena de Indias, January 25^{th,} 2019.

In this edition, the Ship Science and Technology Journal opens a new issue with the scientific articles presented by researchers on the knowledge areas of naval design and architecture, maritime and oceanic engineering.

This issue has publications on safety standards in ship design, welding processes, validation of budget for shipbuilding, design of a tugboat, and the role played by the draughtsman of architecture and engineering in the naval, maritime and fluvial industry.

The effort of the *Corporation of Science and Technology for the Development of the Naval, Maritime and Riverine Industries - COTECMAR* to increase the visibility of research and work related to the sector's issues, has allowed the journal to be added to a new repository called *PERIODICA: Index of Latin American Journals in Sciences*, that publishes the articles in serial publications in the countries and territories of Latin America and the Caribbean. We thank the editors and peer reviewers who have collaborated in this work of scientific dissemination.

This year, at the gates of the VI International Ship Design and Naval Engineering Congress, and the XXVI Pan-American Congress of Naval Engineering, Maritime Transport and Port Engineering - COPINAVAL, it is expected to continue generating knowledge on the subject of innovation in the naval industry, disseminating research on new trends in ship design, dual-use technologies and development of the shipyard sector.

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

Nota Editorial

Cartagena de Indias, 25 de enero de 2019.

Esta edición de nuestra revista Ciencia y Tecnología de Buques abre un nuevo número con los artículos científicos presentados por investigadores en torno a las áreas de conocimiento de diseño, arquitectura e ingeniería naval, marítima y oceánica.

Para este número, la revista cuenta con publicaciones referentes a reglamentación de seguridad en el diseño de buques, procesos de soldadura, validación de presupuestos para la construcción de buques, diseño de un remolcador y el papel que juega el delineante de arquitectura e ingeniería en la industria naval, marítima y fluvial.

El esfuerzo constante de la *Corporación de Ciencia y Tecnología para el Desarrollo de la Industria Naval, Marítima y Fluvial – COTECMAR* por incrementar la visibilidad de las investigaciones y trabajos relacionados con los temas del sector, ha llevado a la indexación de la revista en un nuevo repositorio llamado *PERIODICA: Índice de Revistas Latinoamericanas en Ciencias*, el cual difunde los artículos contenidos en publicaciones seriadas editadas en países y territorios de América Latina y el Caribe. Agradecemos a los editores y pares evaluadores que han colaborado en esta labor de divulgación científica.

Por su parte, este año a puertas del VI Congreso Internacional de Diseño e Ingeniería Naval, y el XXVI Congreso Panamericano de Ingeniería Naval, Transporte Marítimo e Ingeniería Portuaria – COPINAVAL, se espera continuar generando conocimientos en torno a la temática de innovación en la industria naval, divulgando investigaciones sobre las nuevas tendencias en diseño de buques, tecnologías de uso dual y desarrollo del sector astillero.

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

Regulatory safety considerations about ship design

Consideraciones reglamentarias de seguridad sobre el diseño de barcos

DOI: https://doi.org/10.25043/19098642.175

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Abstract

In this article, some of the criteria established by the International Maritime Organization (IMO) will be described through technical documents related to the design of ships such as the Goal Based Standards (GBS) and the Risk-Based Ship Design (RBD). Later on, an approval model will be proposed for the design of new ships, taking into account the recommendations of the International Maritime Organization (IMO) while articulating the work of maritime administrations, the naval industry and classification societies.

Key words: Goal Based Regulations, Risk-Based Ship Design, Goal-Based Ship Construction, Ship Design Approval Process, SOLAS Convention, Safety Regulations.

Resumen

En el presente artículo serán descritos algunos de los criterios establecidos por la Organización Marítima Internacional (OMI) mediante documentos técnicos relacionados con el diseño de buques como son los Goal Based Standards (GBS) y el Risk-Based Ship Design (RBD). Posteriormente se propondrá un modelo de aprobación para diseños de nuevos buques que considera las recomendaciones de la Organización Marítima Internacional (OMI) mientras articula el trabajo de administraciones marítimas, industria naval y las casas clasificadoras.

Palabras claves: Reglamentos basados en objetivos, diseño de buques basado en riesgos, construcción de buques basada en objetivos, proceso de aprobación de diseño de buques, convenio SOLAS, reglamentos de seguridad.

Date Received: April 4th 2018 - *Fecha de recepción: Abril 4 de 2018*
Date Accepted: August 28th 2018 - *Fecha de aceptación: Agosto 28 de 2018*

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Introduction

Mariners and seafarers have always been exposed to deadly risks. It is not only because of the unpredictability of climate conditions or the enormous forces acting on the structure of ships, or the small error margins in the maneuvers of pilots and captains. Vessels and seafarers will always be exposed to risk *(IMO, 2012)* but there is definitely something that we can do about it.

Over time the maritime transportation industry has learned a lot. The bad experiences and even the catastrophes have left something good: "Valuable experience". The experiences, collected over many years, takes several forms today, and has been converted into current regulations and industry standards. It is even possible to say that the documents have been created to avoid the same events that caused them to exist in the first place.

The International Convention for the Safety of Life at Sea (SOLAS), is the document developed by the International Maritime Organization (IMO) to stablish universal rules for maritime safety. The SOLAS Convention was issued as a response to major maritime disasters and consists of a compendium of safety related regulations *(IMO, 2014)*.

This paper will deal with the needs of a Maritime Administration to establish an "Approval Process for New Ship Designs". This paper considers the analysis of relevant criteria related to Design for Safety (DFS), Risk Based Design (RBD) and Goal-Based Standards (GBS). Based on the information above, a methodology will be proposed to evaluate the new designs of ships.

Maritime Safety and the New Approach

The Solas Convention

The International Convention of Safety of Life at Sea (SOLAS), was adopted in November of 1974 and entered into force on May 1980. Due to the technical character of the information included, and the fast technological development of the industry, the document has been updated and amended on numerous occasions. The objective of SOLAS is in setting the standards regarding the construction, equipment and operation of ships. It can be considered to be the most important international treaty about shipping safety. *(IMO, 2014)*

In the ´90s the members of the Maritime Safety Committee realized that "prescriptive-based" regulations were not fit for purpose, and the IMO decided that the classical approach was not useful in solving the new needs of the industry. The response to this problem consisted in incorporating a "goal-based philosophy" into the technical regulations. *(IMO, 2015)*

The New Approach "Goal Based Regulations"

During recent years the International Maritime Organization has been working to change the method used to develop the maritime safety norms.The explanation for the change of thinking is that day by day more authors consider that the old prescriptive approach is based typically on the past experiences and prevents the advancement of the industry in the adoption of best practices *(Hoppe, 2010)*.

Fig. 1. Difference between approaches

It has been found that the "goal-based regulations" are effectives ways to incentivize innovation in the industry as the new model does not specify the means of achieving compliance. This fundamental fact contributes to enhancing creativity and the development of new technical solutions (Hoppe, 2010). As the opposite of the prescriptive model, the new approach of setting goals permits the introduction of new alternatives to achieve conformity.

"Goal-based standards" will be the suppport of classifications for the development of definitive prescriptive norms. This perspective also intends to be the foundation for the future international standards for shipping safety *(Hoppe, 2010)*.

The document titled "International Goal-Based Ship Construction Standards for Bulk Carriers and Oil Tankers" issued by the IMO Maritime Safety Committee gives a basic example that demonstrates the difference between a "goal-based" and "prescriptive" approach *(IMO, 2015)*:

- Goal-based: "People shall be prevented from falling over the edge of a cliff."
- Prescription: "You must install a 1-meter high rail at the edge of the cliff."

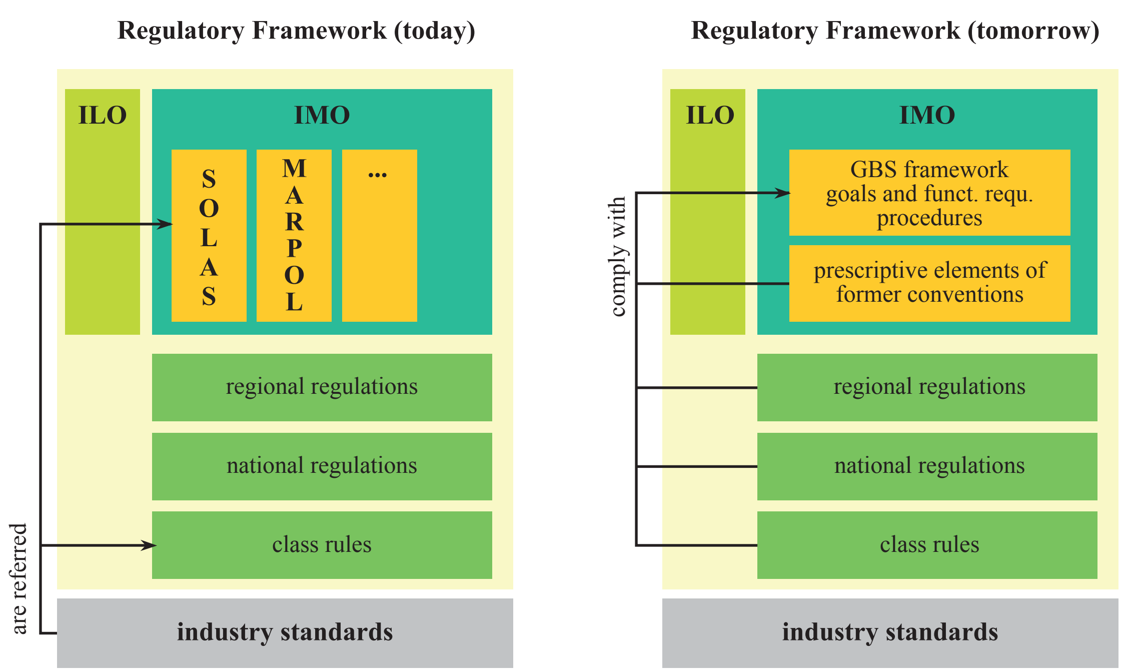
The Prescriptive approach, during the design stages will independently consider issues related to fire protection, marine engineering, naval architecture and other disciplines. Based on the experiences, the designer will propose the enhancing of the mentioned components in isolation from each other *(IMO, 2015)*. This will be materialized in improvements to the fire protection system, propulsion systems, adjustments and so on.

On the other hand the Goal Based approach will take into account a specific goal for instance "the ship should be designed for improved survivability so that, in the event of an accident, persons can stay safely on board " *(IMO, 2015)*. This basic change creates an holistic view that integrates all safety-related issues. The designer takes into account the experience in addition to risk-based methodologies.

Risk-Based Ship Design

Risk-Based Ship Design (RBD) is an innovative methodology that involves the use of advanced computing tools that allow the integration of probabilistic and risk-based approaches. It is important to note that in the traditional approach prescriptive regulations were developed utilizing empirical knowledge. This critical aspect is the

Fig. 2. Long Term Vision of IMO GBS



reason why this philosophy produces limited design possibilities. *(IMO, 2009)*.

The renowned industry expert, Mr. Vince Jenkins from Lloyds Register, explains in the article "Risk-based design" some of the challenges in the adoption of the new approach *(Jenkins, 2012)*:

- To adjust the goals to the right levels.
- Obtain the approval from the regulators.
- The increase of cost and effort during the design and subsequent stages.
- The culture in the organizations must be transformed. From passive compliance in prescriptive rules to active management to achieve the goals.

Goal-Based Ship Construction

Concepts:

The "Goal-based ship construction standards" is the way how IMO intends to play a larger role in determining the minimum requirements for shipbuilding. Traditionally this issue used to be only under the responsibility of classification societies and shipyards.

Basic principles and methodology:

The basic principles of GBS were defined in the IMO document "Goal-based Ship Construction Standards for Bulk Carriers and Oil Tankers" *(IMO, 2013)* as follows:

- Vessels in compliance with the environmental and security standards required during all their lifecycle.
- Ships designed according the norms and requirements applied by classification societies, recognized organizations, Administrations and IMO.
- Ship design and technology in clear compliance with demonstrable and verifiable, patterns and criteria.
- Ship design specific enough to avoid wrong interpretations.

In May 2010, IMO's Maritime Safety Committee (MSC) adopted a set of Resolutions related to Goal-Based Ship Construction Standards (GBS) (Toshiro, 2016). The International Association of Classification Societies (IACS) collaborated with the IMO Maritime Safety Committee (MSC) to create a five-tier system as follows:

- Tier I – Goals: High-level objectives to be met.
- Tier II – Functional requirements: Criteria to be satisfied. Goal-based Ship Construction Standards for Bulk Carriers and Oil Tankers.
- Tier III – Verification of conformity: Procedures for verifying that the rules and regulations for ship design and construction.
- Tier IV – Rules and regulations for ship design and construction. Detailed requirements.
- Tier V – Industry practices and standards: Standards, codes of practice and safety and quality systems for shipbuilding, ship operation, maintenance, training, manning, etc…

Fig. 3. Relations Between RBD and GBS

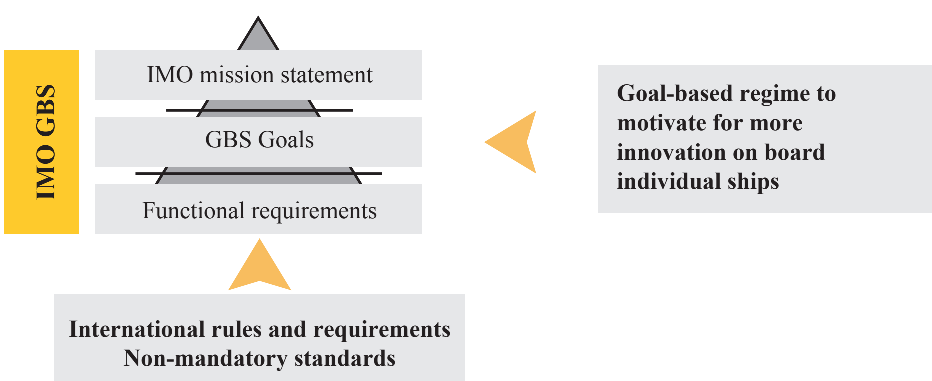
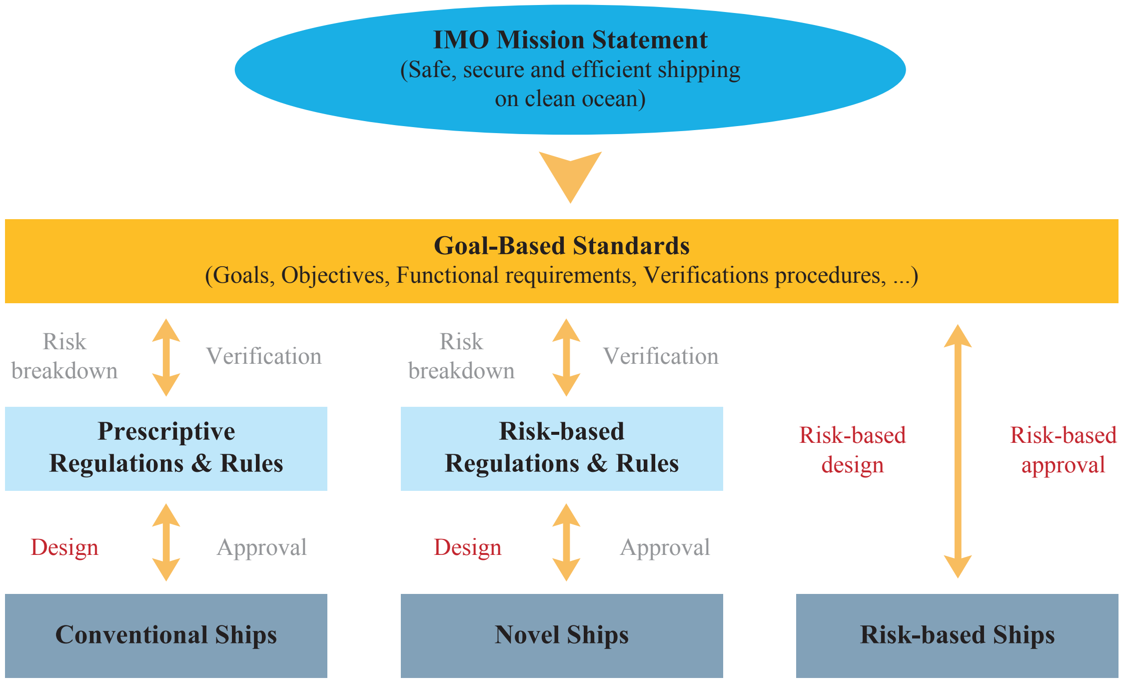
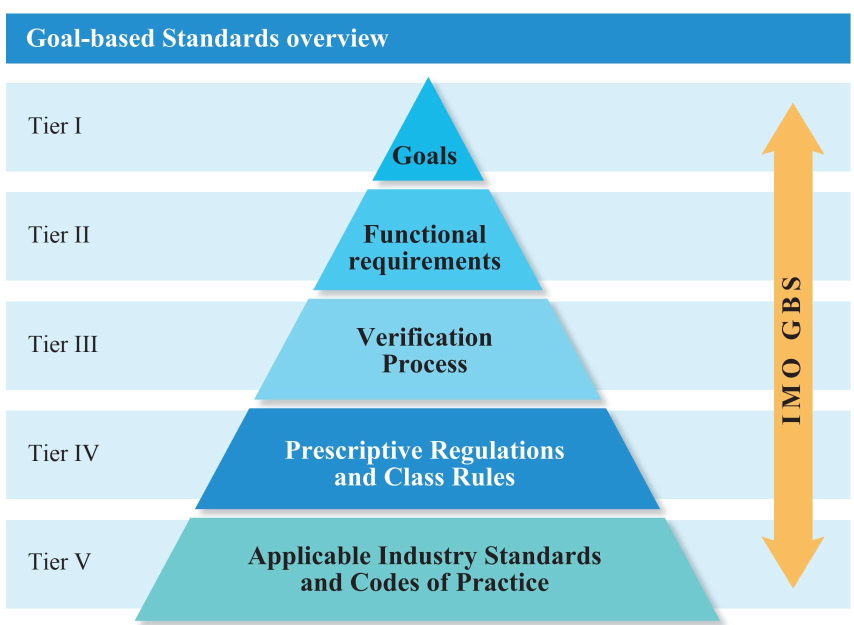


Fig. 4. Approaches to Fulfilling GBS



The new framework demands extra effort to generate innovative alternatives that achieve the goals without the existence of prescriptive requirements. It is an open door for engineers to innovate and to create solutions motivated by a raise in safety and sustainability standards. From that perspective, the goal-based standards framework can be considered as a license for innovation. *(Kent, 2011)*

Fig. 5. GBS Five-Tier System



Proposal of "Ship Design Approval Process"

Delimitation of the Process

Cosidering the available information comprised by documents, guidelines and industry standards the following proposal is developed towards stablishing a procedure for New Ship Building design. This kind of process should be established by the national maritime administrations while considering inputs from stakeholders.

- The nature of the process; The process starts when the person submitting the design sends the preliminary sketch to the Maritime Administration officials and ends when the design is ready to initiate the construction process.

IMO Recommendations

The MSC.1/Circ.1455 "Guidelines for the Approval of Alternatives and Equivalents as Provided for in Various IMO Instruments " provides useful ideas to structure an approval process *(IMO, 2013)*:

1. The new designs should have different levels of approval.
2. A structured "approval process" is necessary to confirm that the design complies with the minimum statutory requirements for their intended operation. The process should be predictable and reliable.
3. Designers and administrations should develop a cooperative work to evaluate the safety and environmental protection aspects of the proposals.
4. In the alternative designs, the substitution of design measures with operational or procedural measures to reduce risk it is typically not permitted. The designs measures take priority over procedural measures.

The Evaluation Process

The MSC.1/Circ.1455 "Guidelines for the Approval of Alternatives and Equivalents as Provided for in Various IMO Instruments " defines the phases that should be accomplished during the process *(IMO, 2013)*:

1. Development of a preliminary design.
2. Approval of preliminary design.
3. Development of final design.
4. Final design testing and analyzes.
5. Approval

- Four levels of evaluation:

1. The process starts with the reception in the maritime authority of the preliminary design. A designated group of experts evaluates the conceptual idea and returns it to the designer with observations.
2. In the second phase, the classification society verifies the design and compliance with the established technical rules in the relevant

Fig. 6. Basic scheme of the process

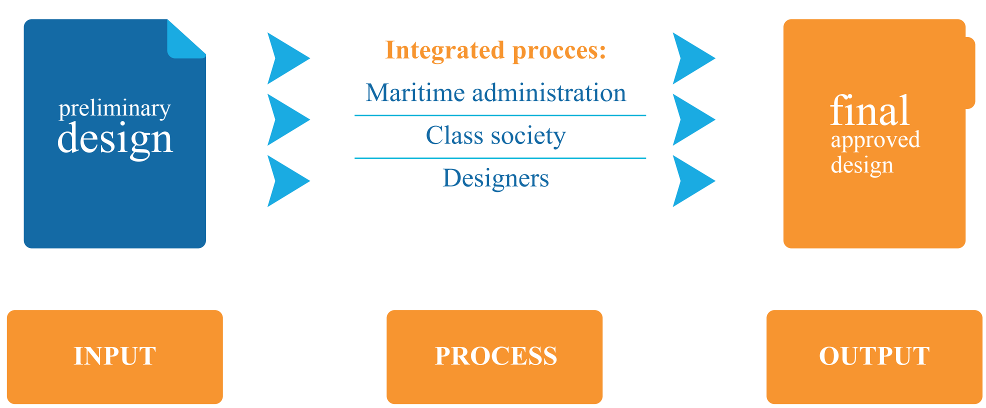
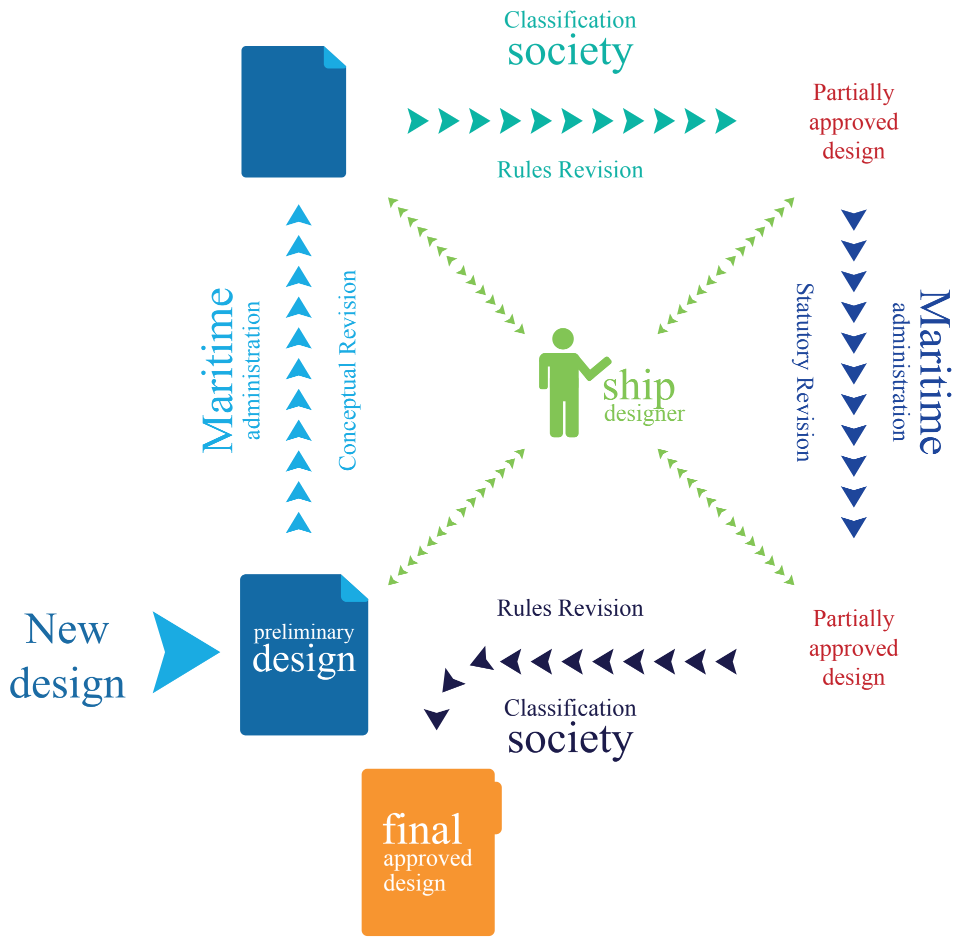


Fig. 7. Proposal of "Ship Design Approval Process"



scopes (stability, fire protection, life-saving appliances etc...)

3. The document is evaluated again by the experts of the maritime authority. In this stage, the main idea is to verify that the design is in agreement with the minimum regulations requirements for the intended operation.
4. In the fourth stage, the classification society evaluates the final design and verifies the construction plan.

It is important to highlight that throughout all the stages of the process the designer is receiving feedback and recommendations from the maritime authority designated group and classification society experts.

Fig. 7 illustrates the stages that a "Vessel Designs Approval Process" should have to assure compliance with the international instruments. The critical aspect of the system is the pooled work of Designers, Classification Societies, and Maritime Administrations.

Conclusions

After analyzing the material of several authors regarding the concepts of Goal-Based Standards (GBS), design for safety (DFS) and Risk Based Design (RBD) is possible to reach the following conclusions:

- The tendency in the International Maritime Organization (IMO) is to stablish a “Goal Based” regime. However, the “Prescriptive” approach will still be valid for particular technical issues. In other words, “Prescriptive” and “Goal Based” methods must be used as complementary parts in order to develop the future framework.

- According to the recommendations from International Maritime Organization (IMO) and maritime experts it is necessary to stablish a "New Ship Design Approval Process" with several levels. This paper proposes a "New Ship Design Approval Process" of four stages. The proposed frame is in compliance with IMO regulations and includes a clarification of the role of Maritime Authority and Classification Societies. Both institutions should carefully follow the work of the designer and provide the necessary feedback.

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Construction of productivity windows for fillet welds using the FCAW process for thin ship panel manufacturing

Construcción de ventanas de productividad de soldaduras en filete con proceso FCAW para la fabricación de paneles delgados de embarcaciones

DOI: https://doi.org/10.25043/19098642.176

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Abstract

The FCAW process used filler metal E71T-11 of Ø0.035" to apply fillet welds with a size of ~4mm on T-joints made of ASTM A36 steel, in a horizontal position, using 42 appropriate combinations of wire feed speeds -WFS- (between 50 and 540 ipm), voltages (13-33V) and welding speeds (4.2-24.5 ipm). The test welds applied with each combination were inspected visually and by macro-attack to establish their compliance with the acceptance criteria for naval panels provided by the American Bureau of Shipping - ABS. With these results, Voltage vs. WFS, Voltage vs. Amperage and Heat Input vs. WFS graphs were constructed, and productivity windows were drawn over them including the combinations of welding parameters capable of producing welds of acceptable quality. The productivity windows obtained with this method, called ARCWISE, allow proper welding parameters to be selected during the design of WPSs avoiding iterative processes of trial and error.

Key words: Panel, FCAW, Productivity Windows, ARC length, Welding procedure (WPS), ABS.

Resumen

Se utilizó el proceso FCAW con electrodo E71T-11 de Ø0.035" para aplicar soldaduras en filete de tamaño ~4mm sobre juntas en T de acero ASTM A36 en posición horizontal usando 42 combinaciones apropiadas de velocidades de alimentación de alambre –WFS– (entre 50-540 ipm), voltajes (13-33V) y velocidades de soldeo (4.2-24.5 ipm). Las soldaduras de prueba aplicadas con cada combinación se inspeccionaron visualmente y por macro-ataque para establecer su cumplimiento con los criterios de aceptación para paneles navales de la American Bureau of Shipping, ABS. Con los resultados se construyeron gráficos de Voltaje Vs WFS, Voltaje Vs Amperaje y Entrada de Energía Vs. WFS sobre los que se dibujaron ventanas de productividad con las combinaciones de parámetros capaces de producir soldaduras de calidad aceptable. Las ventanas de productividad construidas mediante este método, denominado ARCWISE, permiten seleccionar parámetros de soldeo durante el diseño de WPSs evitando procesos iterativos de ensayo y error.

Palabras claves: Panel, FCAW, Ventanas de Productividad, longitud de arco, procedimiento de soldadura (WPS), ABS.

Date Received: October 17th 2018 - *Fecha de recepción: Octubre 17 de 2018*
Date Accepted: December 20th 2018 - *Fecha de aceptación: Diciembre 20 de 2018*

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Introduction and justification

An efficient design of steel or aluminum naval vessels aims, among other factors, to satisfy the criterion of reducing the weight of these structures by leveraging the advantages offered by the panels from the point of view of rigidity, moment of inertia and construction facilities. A structural panel can be described as a relatively thin plate with a network of stiffeners that increase their moment of inertia, rigidity and ability to withstand loads reducing the use of building materials (Blodgett, 1966). A panel can be flat (decks, tanks) or with a complex geometry (hulls, superstructures, bottoms or inner-and-outer bottoms) and the stiffeners can be profiles of different cross sections such as angles, "Ts", "Is" or bulbs, which offers to the naval architects a wide variety of design alternatives for the construction of the various components of boats such as hulls, decks, bulkheads, bottoms, fuel, water and ballast storage tanks, etc. An initial phase of the construction of ships by means of the blocks assembly production method is the manufacture of panels consisting of, first, in making flat or curved plates using welded butt joints and, lastly, the assembly of the stiffeners in the plates with T-joints and joined using fillet welds *(Boekholt, 2011)*.

One of the most common constructive problems with structures made with thin-plate steel or aluminum panels is associated with the angular distortion of the fillet welds used for the stiffeners-plates connections (assembly of bulkheads, hulls and decks) which often results in local buckling and out-of-plane distortion which produces deflections and concavities in these structures *(C.L. Tsai, 1999)*. The angular distortion inherent to the fillet welds produces an angular change as shown in Fig. 1 *(Masubuchi, 1980)* that can result, depending on the panel, in angular deflection or buckling of the panels as illustrated in the Fig. 2 *(AWS, 1993)*.

There are several technical approaches to mitigate, or even solve, distortion problems that range from prevention at the design stage or during manufacturing, to the adoption of appropriate techniques to remove the distortion once it is present *(C.L. Tsai, 1999)*, (*Masubuchi, 1980), (ANSI/AWS D 3.5:93R, 1993)* and *(AISI/AWS D 3.7, 2004)*. Panel distortion control strategies can be grouped into: (1) design-related variables: use of design practices that facilitate the production of distortion-free panels, such as plates with the appropriate thickness, reduction of spacing between stiffeners, beveled T-joints, optimized assembly sequences, etc.; and (2) process-related variables: better control of certain welding variables that eliminate the conditions that promote distortion, such as the reduction of weld sizes and lengths, use of high welding speeds, the use of welding processes with low heat inputs, back-step techniques, proper welding sequences, controlled preheating, restriction fixturing, etc. *(C.L. Tsai, 1999)*.

Fig. 1. Angular change due to angular distortion of the fillet weld (Masubuchi, 1980)

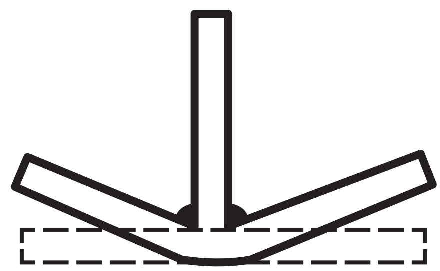
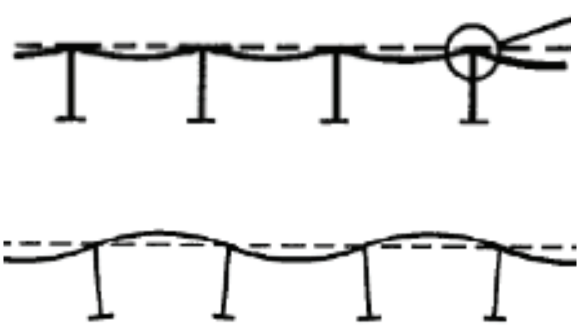


Fig. 2. Angular and buckling deflections due to the rigid welding of a panel-type structure (ANSI/AWS D 3.5:93R, 1993)

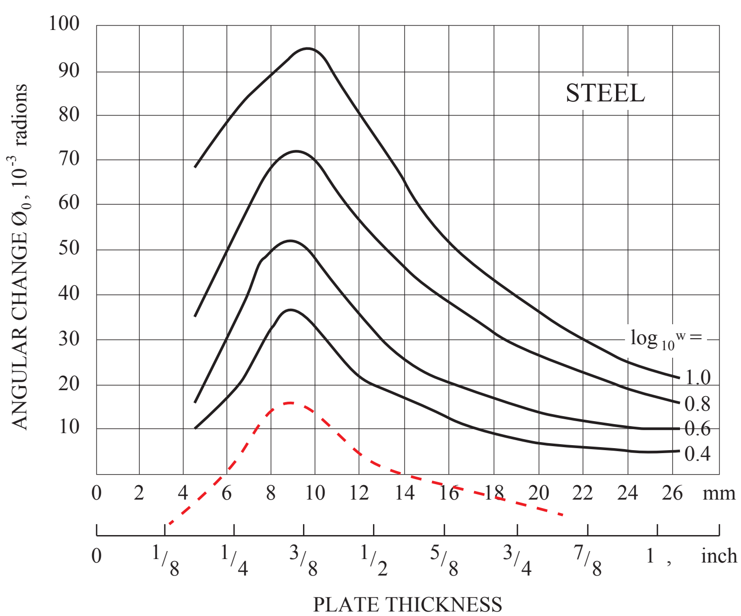


There are multiple research projects related with the distortion of panel-type structures in the naval industry and many prestigious researchers such as Masubuchi, Nakamura, Taniguchi, among others, have carried out research aimed at determining the magnitude of the angular change in T-joints with fillet welds as function of variables such as the material (aluminums or steels in general), the thickness of the plate and the electrode weight required for the unit length joint, which is a function of the size of the fillets. For low plate thicknesses of 9.5 mm (3/8") and thinner, a trend for the angular change to increase with the increase of the fillet weld size is noted (Fig. 3) and, consequently, with the heat input during the welding. This behavior is consistent with the recommendations available for the distortion control offered by different sources *(C.L. Tsai, 1999)*, *(Masubuchi, 1980) (ANSI/AWS D 3.5:93R, 1993)* and *(Miller, 2006)* with respect to keeping the fillet size at the smallest possible values allowed by the production process.

However, there are certain limitations in the adoption of this measure that appears to be so simple: (1) first, there is a trend to over-weld, which may be the result from three different sources: the design engineer, when trying to be more conservative, can specify fillets larger than those required, then the welder tries to make welds with sizes larger than those specified in the drawings to avoid possible rejections, and finally a bad assembly of weldments with root openings higher than 1.6 mm requires the application of a larger fillet weld to meet the effective throat resulting in over-welding; (2) second, in general, there is no information about welding parameters suitable for making specific sizes of fillet welds (in particular the smallest with 3 to 4 mm that are equivalent to an effective throat of 2 and 3 mm) and each welder uses a trial and error process in order to define their own parameters and try to accomplish your task. The importance of applying welds with an appropriate and consistent size is essential for implementing a distortion control plan because the application of welds larger than those needed will naturally result in more distortion and higher costs *(Miller, 2006)*.

With these limitations in mind (the difficulty in obtaining small fillets in the panels avoiding over-welding and not having a robust database of welding parameters that allow to the manufacturers to obtain fillets in a consistent manner) it is advisable to take advantage of an experimental strategy developed in 1996 by the Edison Welding Institute called "ARCWISE" *(Harwig, 2000)*. With this method an experimental series is carried out which consists of applying weld beads with an specific welding process under different parameters (amperage,

Fig. 3. Angular change of a weld in free fillet depending on the plate thickness and the weight of the electrode per unit of length (Masubuchi, 1980)



voltage, speed) in order to obtain a required weld (for example a fillet with a size of 5mm) under certain quality criteria (for example acceptance and rejection criteria given by a welding code for the defined fillet). The final result of the ARCWISE method is a set of graphs and productivity windows that serve as tools to select the different combinations of parameters for a welding process with which it is possible to obtain the desired weld by complying with pre-established quality criteria, without over-welding that increases distortion. With this systematic strategy is eliminated the frequently seen iterative approximation that consists of varying parameters such as voltage, amperage and speed, until the welding procedure values are found.

The objective of this paper is, therefore, to present the methodology and the results of the implementation of the ARCWISE strategy for the specific case of a small fillet weld (4 mm) that could be desirable to obtain consistently with the FCAW process for manufacturing thin panels of naval vessels with low thickness (approximately 5-6 mm). Following, each one of the steps of the ARCWISE methodology are explained in detail and the results of its application and the respective analysis of the results are included with the idea that it can be applied for different configurations found in the construction of naval building panels in order to reduce, in some degree, the impacts of angular distortion of the stiffeners of components such as decks, bulkheads and hulls. It should be clarified that the issue of distortions is a complex broad topic, and one whose solution requires multiple inter-related working fronts, one of which is shown in this paper. The present information may not be considered, in any case whatsoever, as being sufficient to avoid the distortion troubles.

Experimental methodology

The methodology followed in this work is based on the experimental strategy known as "ARCWISE", which is based on a volume (or mass) balance between the input of filler material delivered by a welding process (GMAW, FCAW, SAW) applied under specific parameters and the material that is actually deposited in the weldment. The volumetric flow of the process is equal to the volumetric flow of the applied weld. The effectiveness of the method is based on that in order to keep constant the welding area using different parameters, is required that the relationship between the wire feed speed (WFS) of a process and the welding travel speed (TS) must be constant, as is explained in the Test matrix with constant deposit area. In other words, if the WFS/TS relationship is kept constant, then the cross section area of the weld will remain the same. The steps or stages of the ARCWISE methodology are as follows:

- Definition of the “application” (type and size of the weld and acceptance and rejection criteria).
- Construction of a test matrix with constant deposit area.
- Application of test welds with a constant arc length.
- Weld profile measurements.
- Construction of the operative windows and productivity windows.

The ARCWISE methodology is explained in detail below, step by step, using a real and concrete example interesting for the manufacture of thin panels in the naval industry.

Application of the ARCWISE method, results and analysis

Defined Application

The application is defined as the set of design factors (base material, thicknesses, type of joint, type and size of weld, profile of the bead, position) and the respective acceptance and rejection criteria that are normally based on an applicable welding code.

For our example we took a T-joint of ASTM A36 steel plates with a thickness of 4.8 mm (3/16") joined by a fillet weld with a leg size 5/32" (~4mm) in horizontal position (2F) as illustrated in Figures 4 (A), (B) and (C).

The rules for the classification of naval vessels according to the American Bureau of Shipping (ABS) were used to define the acceptance and rejection criteria. The Rules for Materials and

Welds Part 2 of ABS *(ABS, 2016)*, establish in Chapter 4 "Welding and Fabrication", Section 1 "Hull Construction", paragraph 5.17 "Inspection of Welds" that the inspected welds must be evaluated according to the acceptance criteria given in the ABS Guide for the Nondestructive Inspection of Hull Welds *(ABS, 2018)* which, in its paragraph 1.3 "Visual Inspection of Welds" establishes that the acceptance criteria are indicated in the Section 10 "Acceptance Criteria For Hull Welds" paragraph 5 "Evaluation from Visual Inspection (VT), Magnetic Inspection (MT) and Liquid Penetrant Inspection (PT)." This ABS guide also establishes in section 1.1 that the surface appearance of the welds during the construction of hulls must meet the requirements of Recommendation No. 47 of the IACS (IACS, 2012). The criteria applicable to fillet welds according to the ABS and the AIACS are summarized in Table 1.

Table 1. Acceptance criteria for non-primary members for vessels

FEATURE OR DEFECT	MINIMUM VALUE	MAXIMUM VALUE
Porosity diameter	0 mm	< 1 mm
Undercut (all the length)	0 mm	≤ 0.5 mm
Undercut (Max. 90 mm)	0 mm	≤ 0.8 mm
Reinforcement	0	≤ 2 mm
Root penetration	≥ 0	
Cracks	0	0
Melting fouls	0	0
Overlap	0	0

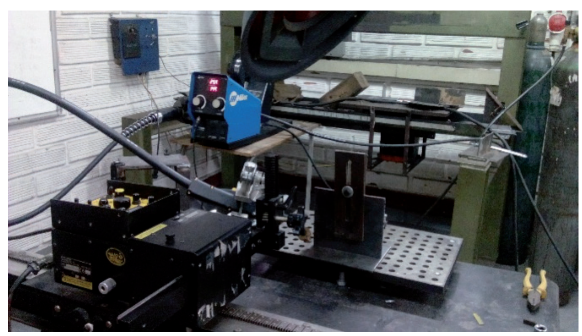
Plates of ASTM A36 steel with 3/16" (4.8 mm) assembled in T-Joints were used for the test coupons. FCAW process was used to apply the welds with a Ø0.035" (Ø0.9 mm) Lincoln self-shielded electrode NR-211-MP which meets the standard AWS A5.20 Class E71T-11, CDEN, contact tip to work distance of 13-14 mm, horizontal position (2F) and working angle of 45°. A constant voltage power source Miller Invision 456MP and a Miller feeder S-74D with the gun installed in a Bug-O welding automated system were used. The Figure 4 illustrates the equipment used for the application of welds in mechanized mode and the arrangement of coupons.

Test matrix with constant deposit area

In this stage of the ARCWISE methodology a matrix of welding tests is created that consists of defining the number of weld test and the welding parameters of each bead (wire feed speed –WFS–, voltage V, arc length –LA– and travel speed of welds –TS–) calculated in order to obtain always a constant deposit area –DA–, i.e. welds with the same cross section.

Fig. 4. Equipment used to apply test welds in horizontal position (2F)

(A) General equipment arrangement



(B) Bug-O machining equipment and coupon test

(C) Pistol and coupon arrangement in 2f

The basis for the construction of the matrix is therefore the area of the cross section of the weld defined in the application that, for our case, is a fillet with a 5/32 "(~ 4 mm) leg, whose area is calculated as $DA = b*h/2 = 4*4/2 = 8$ mm^2. This theoretical area should be increased by a reinforcement factor, r, with approximately 20% that represents the convexity of the fillet weld.

Constant deposit area tests are based, as already stated, on a volume or mass balance between the material delivered by the process (that is a function of the wire feed speed –*WFS*–, the cross section area of the filler metal –*AW*– and the deposition efficiency of the welding process –η_d– assumed to be equal to 0.8 for *FCAW*) and the material that is actually deposited on the weldment (which is function of *DA*, r and the welding speed –*TS*–). With this volume balance it is possible to find a dimensionless ratio between the wire feed speed *WFS* and welding speed *TS* that will always have a constant value for the same application, as shown below:

$$DA \times TS \times r = WFS \times A_W \times \eta_d \tag{1}$$

$$\therefore \quad \frac{WFS}{TS} = \frac{(DA \times r)}{(A_W \times \eta_d)}$$

That for our application will be:

$$\frac{WFS}{TS} = \frac{(\frac{4x4}{2} \times 1.2)}{(\frac{\pi x 0.89}{4} \times 0.8)} \approx 19.29$$

$$\frac{WFS}{TS} = 19.29$$

Maintaining this value of *WFS*/*TS* ≈ 19.3 the different values of *WFS* are found as a function of the application speeds of typical welds for the *FCAW* process in manual mode that can be in the range of 5 ipm (2.1 mm/s) and 30 ipm (12.7 mm/s). The *WFS* variation was established from 50 ipm up to about 500 ipm with increments of 30 ipm; then, the corresponding *TS* values were calculated to construct the matrix shown in Table 2.

Table 2. Matrix of application parameters of test welds with constant deposit area

Length of the arc (mm)	Wire feed speed (ipm)	Voltage (V)	Welding speed (ipm)
~ 1	80	13.0	4.2
	110	13.5	5.7
	140	15.0	7.3
	170	18.0	8.9
	200	19.0	10.4
	230	20.3	12.0
	260	20.3	13.5
	290	20.3	15.1
	320	20.8	16.7
	350	20.8	18.2
	380	20.8	19.8
	410	21.0	21.4
	440	21.0	22.9
3	50	14.3	2.6
	80	16.0	4.2
	110	18.0	5.7
	140	20.2	7.3
	170	22.0	8.9
	200	22.0	10.4
	230	22.0	12.0
	260	22.5	13.5
	290	23.0	15.1
	320	23.8	16.7
	350	23.1	18.2
	380	24.5	19.8
	410	25.3	21.4
	440	26.1	22.9
	470	26.6	24.5
	500	29.7	26.0
	530	30.0	27.6
	560	30.3	29.2
5	170	26.6	8.9
	200	27.0	10.4
	230	27.1	12.0
	260	27.5	13.5
	290	28.6	15.1
	320	29.5	16.7
	350	29.8	18.2

5	380	30.1	19.8
	410	31.8	21.4
	440	33.1	22.9
	470	33.1	24.5

Units of the English system were used as the welding equipment adjustments employ this system. The voltage and arc length values indicated in Table 2 are explained in the following paragraph. It is noted that the *WFS*/*TS* ratio of each test weld is ≈ 19.3.

Thus, the welding parameters were defined to experimentally apply 42 test fillet welds with constant deposit area according to the application defined in this study. To improve the validity of the results, other 42 replica welds were applied in the study. With these 42 welds most of the productive spectrum of the FCAW process is covered to obtain consistently this specific fillet weld (or application) with the class and diameter of the electrode used and in the 2F position.

Application of welding tests with constant arc length

The ARCWISE methodology requires that the welds be applied with a relatively constant arc length (*LA*). The LA is approximately proportional to the arc voltage so it gives an indication of its level. On this study were used three levels of arc length: (1) *LA* ≈ 5 mm that is presented in high arc voltages between 27 and 33V; (2) *LA* ≈ 3mm that is presented in voltages between 14 and 30V; and (3) *LA* approximately 1 mm (an arc that is almost flush with the weld puddle having a height close to 1mm) which is produced at the lowest voltages between 13 and 21V (See Table 2).

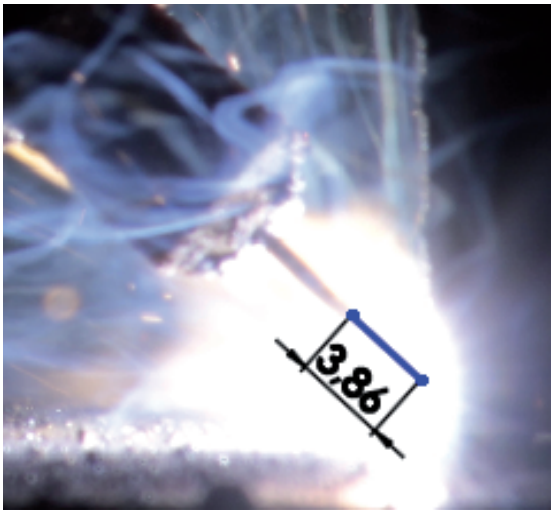
To establish the *LA*, pictures of the welding arc were taken for each *WFS* varying the voltage to get required *LA* (~ 1, 3 and 5 mm). A DSLR Canon Rebel T3i camera was used with an EF 75-300mm telephoto lens with UV filter and mounted on 50" tripod at an approximate distance of 1.6 m. To achieve a good contrast of the arc and the electrode tip, the pictures were taken at a speed of 1/500s, with diaphragm aperture of *f*22 in burst mode and with the lights of the laboratory switched off. Fig. 5 illustrates the layout of the Camera and the weld coupon. The voltages obtained for each *WFS* and *LA* are included in Table 2.

Fig. 5. Layout for the photographic record required for measuring the arc length

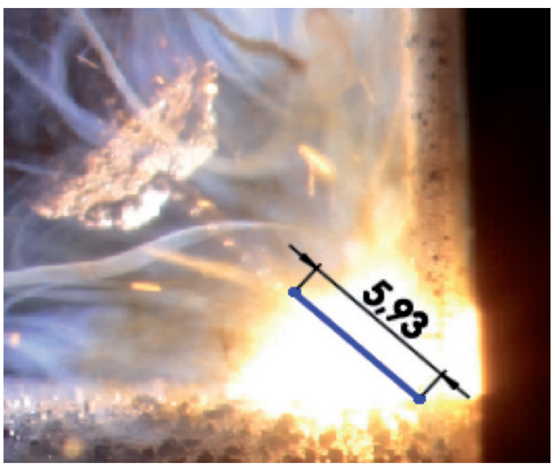
Fig. 6 shows arc pictures of three test welds processed in SOLIDWORKS with the pre-selected *LA* measurements calculated taking as reference the contact tube diameter and/or the electrode diameter.

Fig. 6. Photographs and measurement of the length of the arc. Program used: SOLID WORKS

a) Arc length of approximately 1 mm.



b) Arc length of approximately 3 mm.



c) Arc length of approximately 5 mm.

With the information indicated in Table 2, the test welds on ASTM A36 steel coupons were applied and replica coupons were also welded for each combination of parameters.

Dimensions, shape and profile of the weld measurements

At this stage of the ARCWISE methodology the welded coupons were visually inspected using typical welding gauges for measuring attributes such as the fillet size, undercutting, concavity, convexity, overlap, cracks, etc., that allowed to evaluated whether the criteria of acceptance established for the application was met. The results of the visual inspection for the test fillet welds and the evaluation are presented in Table 3.

From the results it can be calculated that the average area of the weld beads is 8.3 mm2 ± 1.3 mm^2, which is very close to the *D*A area of the fillet considered in the application. The differences can be due to the level of process efficiency η_d=0.8 which is a theoretical value and not a measured value. For future jobs it would be better to measure the process deposition efficiency for various *WFS*s in order to achieve a better match with the weld areas. The average size of the fillets also stayed at a value close to 3.7 mm regardless the change in arc power (*P*=*V***I*) caused by variations in the arc length and the *WFS*s.

Subsequently, each test coupon was cut into two cross sections, as illustrated in Fig. 7, in order to polish the welds using abrasive cloths with particle size #100 to #400 and attack them with the reagent NITAL 5 (95% ethyl alcohol + 5% HNO_3) to reveal their macro-structure and take macro-photographs in a stereoscopic microscope. The pictures of each section (two per coupon) were processed in SOLIDWORKS to estimate the dimensions of legs, undercuts, convexity, penetration, the presence of welding defects such as undercuts, lack of fusion, lack of penetration, etc., and evaluate whether they met the acceptance criteria for the application.

Fig. 7. Weld Coupon WFS= 470 ipm and LA = 3 mm in sections for the macro-attacks

Fig. 8 (A) presents the macro-photograph of the welding applied with *WFS*=320 ipm, *LA*=3 mm and 23.8 V (left fillet) and that of its replica (right fillet), respectively. Fig. 8 (B) shows the image processed in SOLIDWORKS with the fillet estimated dimensions.

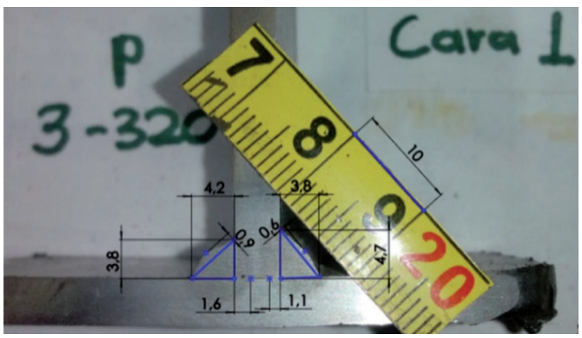
Table 3. Results of the visual inspection of the welds and evaluation against the criteria provided by the American Bureau of Shipping -ABS

WELD TEST DESIGNATION (LA-WFS-V)	WELD SIZE 1	WELD SIZE 2	UNDERCUT	CRACKS	"OVERLAP"	BEAD SHAPE	LACK OF FUSION	POROSITY	MEET ABS REQUIREMENTS?
1-80-13.0	0.0	0.0	0.0	N	Y	EC	Y	N	**NO**
1-110-13.5	4.1	2.9	0.0	N	Y	EC	Y	N	**NO**
1-140-15.0	3.5	1.9	0.0	N	Y	EC	N	N	**NO**
1-170-18.0	3.7	3.5	0.0	N	N	F	N	N	**YES**
1-200-19.0	3.5	3.5	0.0	N	N	F	N	N	**YES**
1-230-20.3	3.8	3.5	0.0	N	N	C	N	N	**YES**
1-260-20.3	3.6	4.3	0.0	N	N	C	N	0.6	**YES**
1-290-20.3	3.5	3.8	0.0	N	N	F	N	0.5	**YES**
1-320-20.8	3.5	4.0	0.0	N	N	F	N	N	**YES**
1-350-20.8	3.8	3.7	0.0	N	N	F	N	N	**YES**
1-380-20.8	3.7	3.8	0.0	N	N	C	N	N	**YES**
1-410-21.0	3.5	3.3	0.0	N	Y	C	N	N	**NO**
1-440-21.0	3.6	2.3	0.0	N	N	C	N	N	**NO**
3-50-14.3	COMPLETELY IRREGULAR BEAD								**NO**
3-80-16.0	2.3	4.0	IRREGULAR BEAD						**NO**
3-110-180.0	3.0	3.3	0.0	N	N	C	N	N	**NO**
3-140-20.2	3.6	4.5	0.0	N	N	F	N	PT	**YES**
3-170-22.0	3.7	4.3	0.0	N	N	F	N	N	**YES**
3-200-22.0	4.2	3.6	0.0	N	N	C	N	N	**YES**
3-230-22.0	3.6	3.7	0.0	N	N	F	N	0.5	**YES**
3-260-22.5	3.7	4.3	0.0	N	N	F	N	0.6	**YES**
3-290-23.0	4.1	3.7	0.0	N	N	F	N	0.7	**YES**
3-320-23.8	3.9	3.5	0.0	N	N	F	N	0.8	**YES**
3-350-23.1	4.2	3.7	0.0	N	N	F	N	1.3	**YES**
3-380-24.5	4.2	3.6	0.0	N	N	C	N	0.9	**YES**
3-410-25.3	4.1	4.3	0.0	N	N	C	N	N	**YES**
3-440-26.1	3.8	3.5	0.0	N	N	C	N	1.0	**YES**
3-470-26.6	4.1	3.9	0.0	N	N	C	N	0.8	**YES**
3-500-29.7	3.7	2.1	1.2	N	Y	C	N	0.9	**NO**
3-530-30.0	3.3	3.6	1.4	N	N	EC	N	PT	**NO**
3-560-30.3	IRREGULAR		1.4	N	Y	C	N	PT	**NO**
5-170-26.6	3.3	3.5	1.2	N	N	F	N	N	**NO**
5-200-27.0	3.8	3.9	1.1	N	N	F	N	0.6	**NO**
5-230-27.1	3.6	4.2	0.8	N	N	F	N	N	**YES**
5-260-27.5	3.8	3.9	0.8	N	N	C	N	0.9	**YES**
5-290-28.6	4.3	3.6	1.2	N	N	C	N	1.0	**NO**
5-320-29.5	3.8	3.7	1.0	N	Y	C	N	2.5	**NO**
5-350-29.8	4.1	4.4	1.6	N	N	C	N	N	**NO**
5-380-30.1	3.5	4.5	1.8	N	N	C	N	1.4	**NO**
5-410-31.8	3.8	3.9	0.0	N	N	C	N	N	**NO**
5-440-33.1	3.3	4.2	1.4	N	N	C	N	0.5	**NO**
5-470-33.1	IRREGULAR		2.0	N	Y	EC	N	N	**NO**

N	NO
Y	YES
F	Flat bead contorn
C	Convex bead contorn
EC	Excesive convexity
PT	Piping porosity
(green)	Meet Requirements
(orange)	No meet requirements
LA	Arc Length
WFS	Wire Feed Speed
V	Voltage

Fig. 8. Macro-Photography of welding applied with WFS= 320 ipm and LA = 3 mm

(A) Macro-photography of the weld and replica



(B) Photo processed in SOLIDWORKS

Fig. 9 includes a chart with a collection of representative macro-photographs covering a wide range of the spectrum of test welds from this study between *WFS*=110 ipm to 470 ipm, for the three arc lengths. Framed with a solid green color border are shown the welds that have been evaluated as "acceptable" according to the acceptance criteria of the ABS-Guide for Nondestructive Inspection of Hull Welds, both for visual inspection and macro-examination. It is noted that with the lowest power levels, *i.e.* at low voltages and amperages (or *WFS*), and low welding speeds, the welds exhibit overlaps, excessive convexity, lack of fusion between the weld metal and base metal, low dilution and lack of penetration in the root of the join. At low *WFS*s and higher voltages the electric arc was extremely unstable and the welds obtained were very non-uniform and discontinuous, so these welds do not were examined by macro-attack. The deepest undercuts are seen at the higher voltages (high arc lengths), being higher when amperage (*WFS*) and the welding speed become greater; this is because the electric arc is wider and directly impacts the base metal. It can be seen that the penetration and dilution of the welds increases with the increase of the arc power ($P=V*I$), *i.e.* at higher voltages (*LA*) and amperages (*WFS*), since it is well known that the increase in power and the welding speed increases the melting efficiency of the process *(Kou, 2002)*. At the highest wire feed speeds and low voltages ($LA \approx 1$ mm), a phenomenon called "stubbing" occurred which consists in that the tip of the solid electrode strikes against the base metal without an adequate metal transfer, which produces discontinuous and bad quality welds.

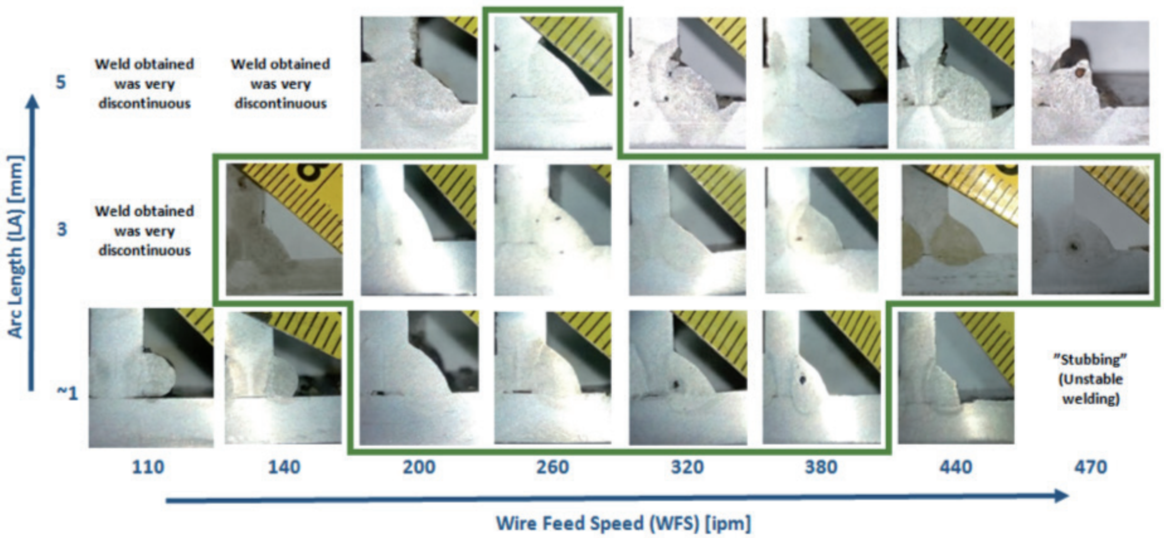
The results of visual inspection and macro-attack examination serve to define productivity windows or sets of welding parameters in order to obtain fillet welds that met both application and pre-defined acceptance criteria.

It is important to see that most of the welds applied with the average arc length ($LA \approx 3$ mm) were acceptable in quality, same as those of lower arc voltages, except for the lower amperage levels below 100A. At very high voltages the acceptance rate was substantially reduced.

Construction of graphs and productivity windows

In the final stage of the ARCWISE method the productivity or operative windows are built that can be graphs of Voltage vs. *WFS* or Voltage vs. Current which include the points of the combination of parameters used for each weld, the welding speed lines and the union of the points of those welds evaluated as acceptable in order to draw on the charts the regions of fulfillment of the quality criteria. This window contains the set of welding parameters that enable to obtain the desired weld or application satisfactorily. Figs. 10 and 11 includes the graphs of Voltage vs. *WFS* and Voltage vs. Amperage, respectively, for the application defined for this work, in addition to the respective productivity windows (shaded) constructed after evaluating the results of the visual inspection and macro-examination.

Fig. 9. Photo-ultrasounds with the shape of the welding cords according to the welding parameters



The shaded area of both graphs would be the productivity window and represents the set of combinations of welding parameters that would make it possible to obtain during the production welds according to the design (fillets with leg ~4 mm in 2F position), using the *FCAW* process with an electrode class E71T-11, Ø0.035 " (Ø0.9 mm), which meet the pre-established acceptance criteria.

Welds outside this window would not meet the required quality level, either with respect to their dimensions or contain of defects.

Fig. 10. Voltage vs. WFS graph and productivity window for the application of this study

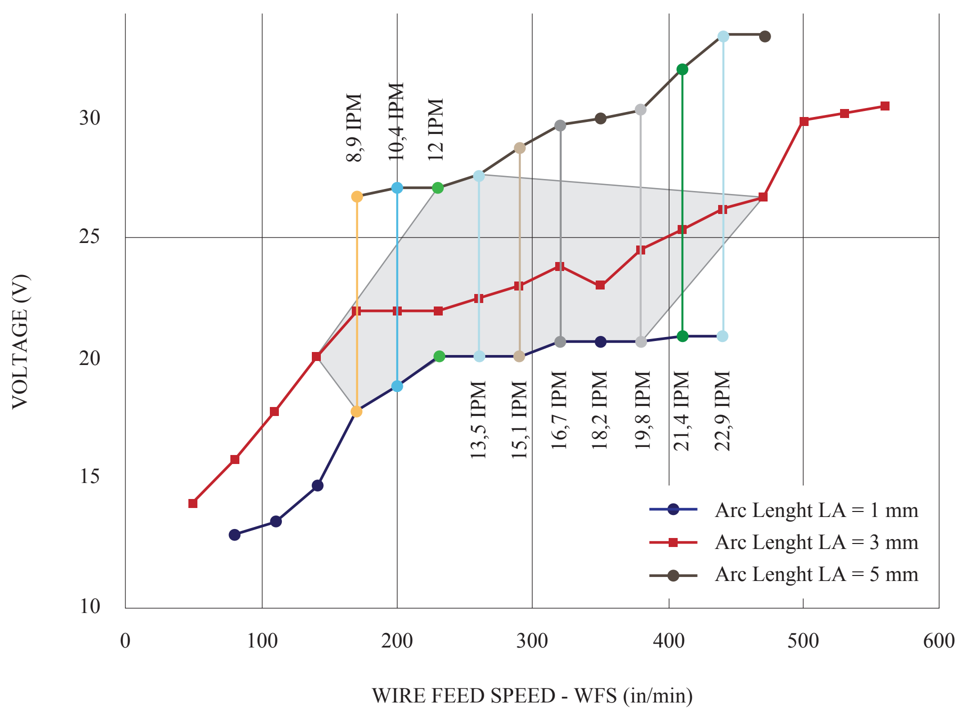
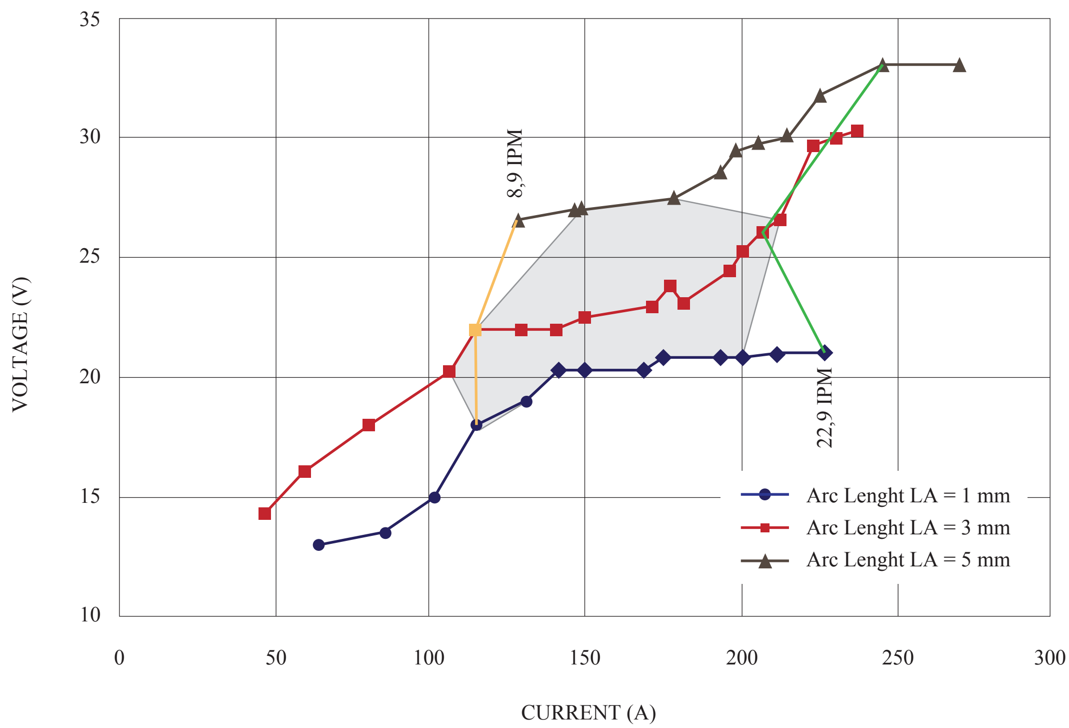


Fig. 11. Voltage vs. Current graph and productivity window for the application of this study



The graphs and productivity windows built within the scope of this study with the FCAW process are limited by zones where the levels of welding parameters (*WFS*, amperage and voltage) are too low to achieve penetration, root fusion and appropriate sizes and shapes of the fillet welds, and by zones with very high levels of welding parameters (Voltage and *WFS*) that produce unacceptable undercuts.

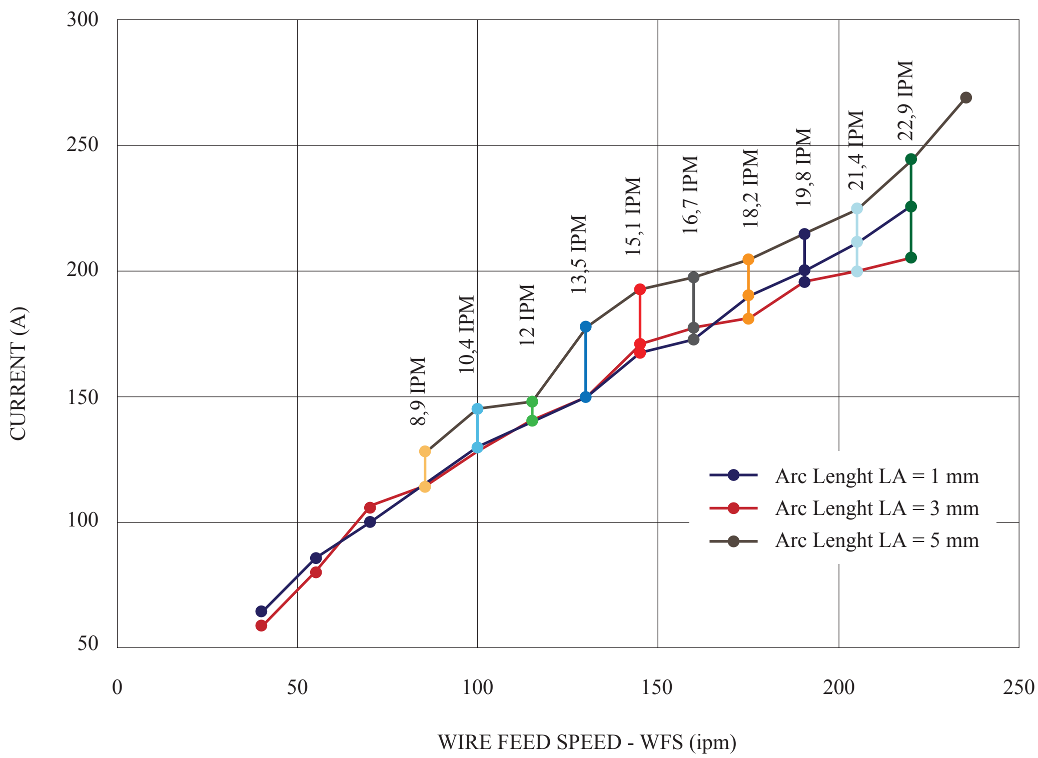
Through the construction of this kind of graphs the selection of welding parameters for a specific application is facilitated as they allow suitable voltages and amperages or WFSs to be found without having to use the iterative trial and error strategy that is more complicated to use and, very often, results in delays and frustration, and also can be avoided the use of parameters from books that do not take into account the specific weld required. The big number of welding parameters that allow to obtain a fillet weld with a leg size ~4 mm is highlighted, which, from the perspective of the angular distortions of panels illustrated in Fig. 3, would have a weight of electrode consumed per unit of length W = 0.785 g/cm calculated through Equation 2:

$$W = \left(\frac{S_W{}^2}{2}\right) * \frac{\rho}{\eta_d} \qquad (2)$$

Where Sw is the leg size of the fillet weld (0.4 cm), ρ is the steel density (7.85 g/cm^3) and ηd is the process efficiency (0.8). With this value for W we are able to use Fig. 3 and plot the dotted red curve which is for a fillet close to 5 mm and see that the angular distortion for a plate with T=6 mm can be around 10 radians (about 0.6°) or less.

As a complement to the Voltage vs. *WFS* and Voltage vs. Current graphs, it is also very useful in semi-automatic processes, such as the *FCAW* or *GMAW*, to have the relationship between the current and the *WFS*, which is also constructed collaterally with the ARCWISE strategy without other tests. Fig. 12 shows the relation of Current vs. *WFS* that allows the conversion of the arc current (which is normally a parameter of interest in welding) into wire feed speed which is the parameter that is adjusted in the *GMAW/FCAW* welding equipment.

Fig. 12. Graphic with the Current relationship VS WFS



Finally, in order to show that the databases that are possible to build applying the ARCWISE method can be very diverse, the productivity window drawn on the graph of the relation of the Heat Input vs. WFS is included as an example in Fig. 13. The heat input (HI) is calculated by Equation 3:

$$HI = \frac{(V * I)}{TS} \tag{3}$$

It shows that the heat input is kept almost constant for each arc length independently of the *WFS* employed. The HIs associated with arc lengths $LA \approx 1$ mm and $LA \approx 3$ mm have very similar levels and its averages are 13 kJ/in (330 kJ/mm) and 15 kJ/in (385 kJ/mm), respectively. With these average HI values the approximate fillet size *W* that could be obtained can be estimated by the following empirical relationship proposed by Miller *(Miller, 2001)*:

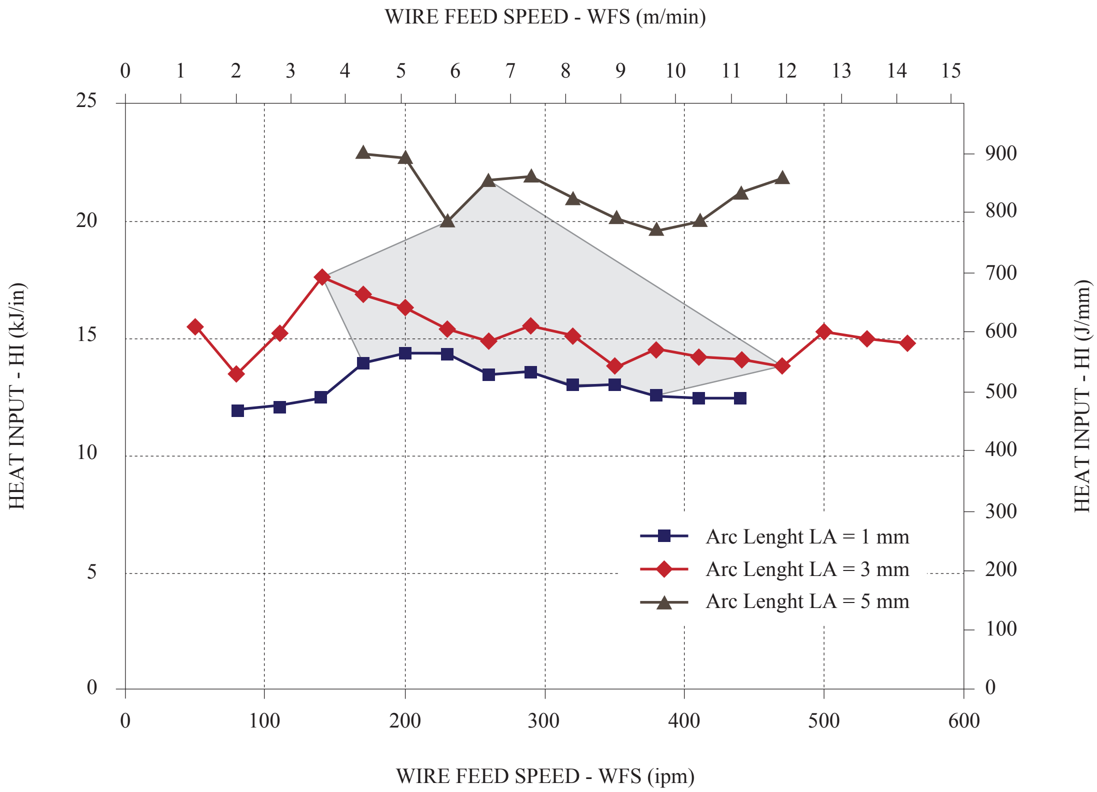
$$W = \sqrt{\frac{HI}{500}} \tag{4}$$

Where *W* represents the fillet leg size in inches and HI is the heat input in kJ/in. Therefore, with a HI between 13 and 15 kJ/in, there would be fillet sizes between 4.1 and 4.4 mm, which are the same order of magnitude of the application, but a little larger than those obtained in the study.

With the window shown in Fig. 13, it is possible select suitable welding parameters to make the weld defined in our application modifying, for example, the WFS in order to increase productivity when the deposition rate goes up, without this change implying, necessarily, a significant elevation of the heat input that results in greater distortions.

Other graphics of interest that can be built for production based on the experimental ARCWISE strategy could be: Heat input vs. Deposition rate, Area of molten metal vs. *WFS* or *TS*, Dilution % vs. *WFS*, Current or *TS*, among others. There are multiple possibilities.

Fig. 13. Graphic with the relationship of the power input vs. WFS and the productivity window for the application studied



Conclusions and future studies

It has been shown how use the ARCWISE method for the building of productivity windows which can be used as engineering tools to facilitate the selection of welding parameters during the design of a WPS in order to achieve a specific application which meets a particular design combined with a set of acceptance criteria. The graphs cover a wide spectrum of parameters for a welding process in relation to WFS, current, voltage and welding speed, required to obtain a specific weld or application, clearly differentiating the combinations of adequate parameters from those that are inadequate. The ARCWISE methodology can be very useful when it is necessary to build a database with welding parameters to obtain small weld sizes that reduce the level of distortions in thin panels such as those used in the manufacture of midsize and small ships. The construction of the windows does not require sophisticated tools, equipment or tests and can be achieved with a relatively low number of testing welds.

Proposal for future jobs

A job such as that presented in this paper can be the base for a panoramic project of a thin-panel construction company that covers the numerous applications of production resulting from combining different weld sizes, plate thicknesses, positions, welding processes (GMAW, FCAW, SAW, etc.) and electrode classifications and diameters. If is desired, the project could be focused on the application of small fillet welds (3 mm or even less) for the manufacture of thin panels with plates 4 or 5 mm thick for ship components such as shells, decks, bulkheads, among others.

Acknowledgment

The authors of this paper express their acknowledgments to the Universidad Nacional de Colombia, Medellín campus, and especially to the Welding Group and the Welding Laboratory of that campus for its support, financing and infrastructure, which enabled the development of this project.

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Application of the Montecarlo method for the validation of the budget of a suezmax type ship

Aplicación del método de Montecarlo para la validación del presupuesto de un buque tipo Suezmax

DOI: https://doi.org/10.25043/19098642.177

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Abstract

As the name suggests, the budget for the construction of a ship, in this case a Suezmax, means to specifically pre-suppose in economic terms, the activities and movements to carry out during the construction of said ship. The importance of this essential phase of the construction process lie one hand in budgeting a competitive price in the market, but without causing economic losses for the shipyard, in order to make a profit for the company. This study proposes the use of the Monte Carlo method to obtain a greater reliability in the valuation of the Suezmax vessel; in this case, the triangular method will be used, which starting point is based on results obtained from previous research and from which the most likely, most pessimistic and most optimistic ship budget is obtained in order to later perform a simulation.

For the realization of said simulation the ship is divided into different items, that will be assigned an optimistic and pessimist percentage based on a likely budget, according to the degree of trust of the shipyard in said concept. The final scope will be the calculation of the management reserve used to rectify any unforeseen item(s) in the construction of the ship.

Key words: Monte Carlo Method, Project Management, Budget, Shipbuilding, Suezmax.

Resumen

Tal y como dice su nombre, el presupuesto de un buque, en este caso un Suezmax, es justamente pre-suponer en materia económica, las actividades y movimientos a realizar durante la construcción de dicho buque. La importancia de esta fase esencial del proceso de construcción radica por un lado en presupuestar un precio competitivo en el mercado, pero sin que llegue a causar pérdidas económicas para el astillero, de manera que se busque un beneficio para la empresa. En este estudio se utilizará el método de Montecarlo para conseguir mayor fiabilidad en la tasación del buque Suezmax; en este caso, se empleará el método triangular cuyo punto de partida se basa en resultados obtenidos en investigaciones anteriores y del que se obtiene el presupuesto del buque más probable, el más pesimista y el más optimista para posteriormente realizar una simulación. Para la realización de dicha simulación se divide el buque en diferentes ítems, a los que se les asignará un porcentaje optimista y pesimista determinado en base a un presupuesto probable, según el grado de confianza del astillero en dicho concepto.
El alcance final será el cálculo de la reserva de gestión que se emplea para subsanar cualquier imprevisto en la construcción del buque.

Palabras claves: Método de Montecarlo, Gestión de Proyecto, Presupuesto, Construcción Naval, Suezmax.

Date Received: December 19th 2018 - *Fecha de recepción: Diciembre 19 de 2018*
Date Accepted: January 20th 2019 - *Fecha de aceptación: Enero 20 de 2019*

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Introduction

Suezmax are classified as shuttle tankers with special construction, and are used transport different kinds of liquid fuels with its dimensions optimized for crossing through the Suez Canal, therefore avoiding the route through South Africa, shortening the journey and saving time on the way. This type of vessel has a transport capacity of between 0.9 and 1.2 million barrels of crude oil, with its highest demand being on the west coast of Africa for shipments to the Caribbean, the East coast of the United States or the North of Europe and the Black Sea.

Therefore, one of the biggest risks involved in the construction of a vessel with these characteristics is to obtain a final cost, because its new construction price can oscillate between 52 million € and 94 million €. The fact that the end value fluctuates, because a reliable method has not been followed, can result in a project with losses for the shipyard, either because it does not have the ability to complete the project with the estimated budget or because the final value of the ship is not competitive.

To mitigate this problem, the most current project management studies, such as those carried out by the Project Management Institute PMI[1] or by the International Project Management Association (IPMA)[2], propose the use of the Monte Carlo method to estimate the project management margin. This method has been verified not only in the field of project management, but also in other knowledge areas of engineering[3], Therefore, this method is considered to be valid for the estimation of uncertainties.

Purpose

The scope of this article is to calculate the management reserve (which is a budget item for contingencies) for a Suezmax-type vessel using the Monte Carlo probability method as a tool to obtain a greater level of reliability in the appraisal of the real value of the ship.

Definition of the method

The Monte Carlo method is a non-deterministic or numerical statistic method based on the simulation of random variables, which allows both physics and mathematical problems to be solved[4].

For this particular case the triangular method is used[5], which is based on the results of budgets obtained through the breakdowns that were reflected in Table 1; it is necessary to define 3 stages to break down the concept of the ship's budget: the most likely, the most pessimistic and the most optimistic.

Methodology

Once the 3 cases have been obtained, the Monte Carlo method will be used through a simulation.
The calculation of the budget is based on the breakdown of the ship into different parts, using as a basis the nomenclature of the technical manuals employed in the US Navy[6], which differs from that of a civilian ship simply by eliminating item 700, which corresponds to weapon systems as a Suezmax ship, as a civilian ship, does not have this item. Although this budget breakdown is for military vessels, its application to merchant ships is completely valid, as it contemplates the full scope of the project, serving as a cost concepts structure.[7]

The percentages of the optimistic and pessimistic margins are shown in Table 2, which have been obtained from the PMBOK[8] Guide on the basics of project management.

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[8] A Guide of the Project Management Body of Knowledge (PMBOK Guide) Sixth Edition, 2018

Table 1. Breakdown of the concept

100	Hull structure
200	Propelling plant
300	Power Plant
400	Communications and control
500	Ancillary services
600	Equipment and enabling
800	Technical Services
900	Support for the ship during construction
---	Staff dedicated to the work

Table 2. Percentages of optimistic and pessimistic margins

	Optimistic	Pessimistic
Low confidence	175%	75%
Medium confidence	125%	90%
High confidence	110%	95%
Overlap	0	0

The simulation is based on a shipyard located in western Europe taking into account the capacity and degree of knowledge that a shipyard with these characteristics has to carry out the tasks of each part, being able to adjust the margins in each item, as shown in Table 3. These percentages refer to the increase or decrease with respect to the base budget or the most likely budget.

Based on the percentages that have been assigned through the PMBOK reference, and that have been reflected in the methodology, are shown in Table 4, which reflects either the base budget or most likely budget, as well as the budgets that are calculated by applying the coefficients set out in Table 3.

From where can be observed that the highest physical construction cost of the ship would be in the hull structure (approximately 25%), which requires greater clarity when organizing the project. On the other hand, support for the ship during construction covers different aspects and that present great uncertainty, such as launching, control of weights, logistical and management support, scaffolds and beds, tests, etc. which imply a high likely budget and therefore present a greater impact on the margins.

The use of Staff only for the work would cover approximately 50% of the percentage of the total budget due mainly to the number and cost of the labour that a project of this magnitude requires.

The reference values of Table 4 are obtained through a breakdown of each of the items cited, using the formulas[9] that express each concept and multiplying them by a unit price.

Using the percentages displayed in Table 3, the value of the likely budget is closer to the optimistic budget (about 11%) than to the pessimistic budget (34%) and it can be concluded that the weighting reflected in the method is conservative.

[9] Albariño-Castro, R. Azpiroz Azpiroz, J. Meizoso Fernandez, M. Basic merchant ship project. 1997. Page 135 -141.

Table 3. Percentages of margins broken down into concepts

	Pessimistic	Optimistic
100 - HULL STRUCTURE	110%	95%
200 - PROPELLING PLANT	110%	95%
300 - POWER PLANT	110%	95%
400 - COMMUNICATIONS AND CONTROL	175%	75%
500 - ANCILLARY SERVICES	125%	90%
600 - EQUIPMENT AND ENABLING	125%	90%
800 - TECHNICAL SERVICES	175%	75%
900 - SHIP SUPPORT DURING CONSTRUCTION	175%	75%
STAFF DEDICATED TO THE WORK	125%	90%

Table 4. Pessimistic, Probable, optimistic budget in each concept

	Pessimistic	Likely	Optimistic
100 - HULL STRUCTURE	€22,148,775	€20,135,250	€19,128,487
200 - PROPELLING PLANT	€5,528,828	€5,026,207	€4,774,897
300 - POWER PLANT	€1,460,873	€1,328,066	€1,261,663
400 - COMMUNICATIONS AND CONTROL	€262,500	€150,000	€112,500
500 - ANCILLARY SERVICES	€2,249,412	€1,799,529	€1,619,576
600 - EQUIPMENT AND ENABLING	€436,837	€349,469	€314,522
800 - TECHNICAL SERVICES	€2,358,738	€1,347,850	€1,010,888
900 - SHIP SUPPORT DURING CONSTRUCTION	€9,434,953	€5,391,402	€4,043,551
STAFF DEDICATED TO THE WORK	€48,255,000	€38,604,000	€34,743,600
TOTAL COST OF CONSTRUCTION OF THE SERIES	**€92,135,915**	**€74,131,774**	**€67,009,685**

Results

Once the triangular Monte Carlo method is programmed, a number of "dice throws" or iterations are selected to perform the calculations. In this case, 10,000 iterations have been chosen, an amount that does not produce a surcharge in the numerical calculation but that it is enough to obtain a relevant result. It has been verified that the method converges from 2,000 iterations onwards, although the calculation process of 10,000 iterations does not imply an appreciable overcost in the simulation, which is why it has been considered the most suitable for performing the calculations.

In Fig. 2, the triangular distribution of the Monte Carlo method is observed and therefore it can be deduced that the likely budget will be where there is a greater number of iterations (approximately 76 million €) corresponding to the upper point of the triangle, and the optimistic and pessimistic budgets (Table 4) correspond to the lower end points of the graph. The red line of the graph shows the cumulative percentage of the probability that the project has in having said cost, or a lower one.

Regarding the management reserve shown in Fig. 2 it is observed that the value is adequate for the project to be competitive in different offers, without

Fig. 1. Result of the analysis of the Monte Carlo triangular distribution

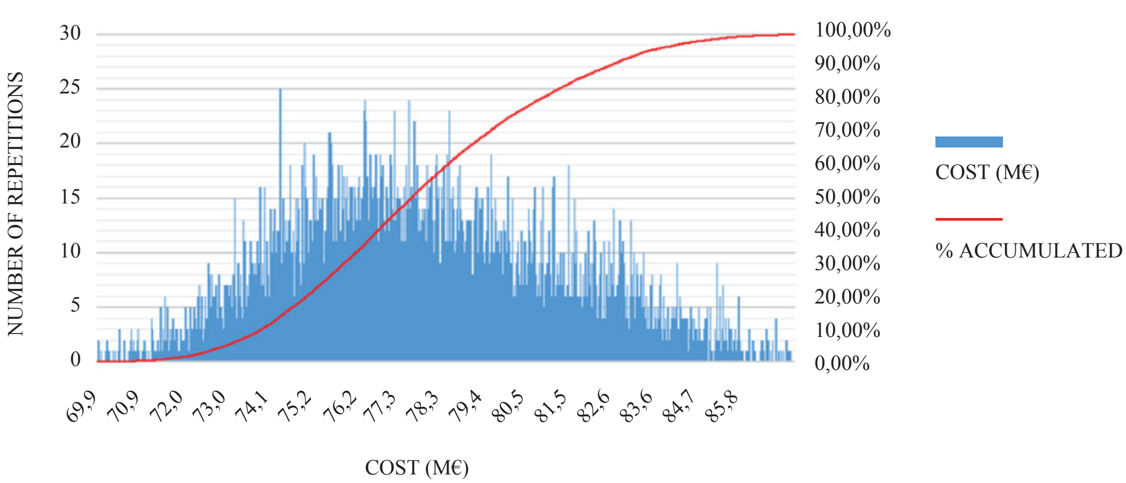
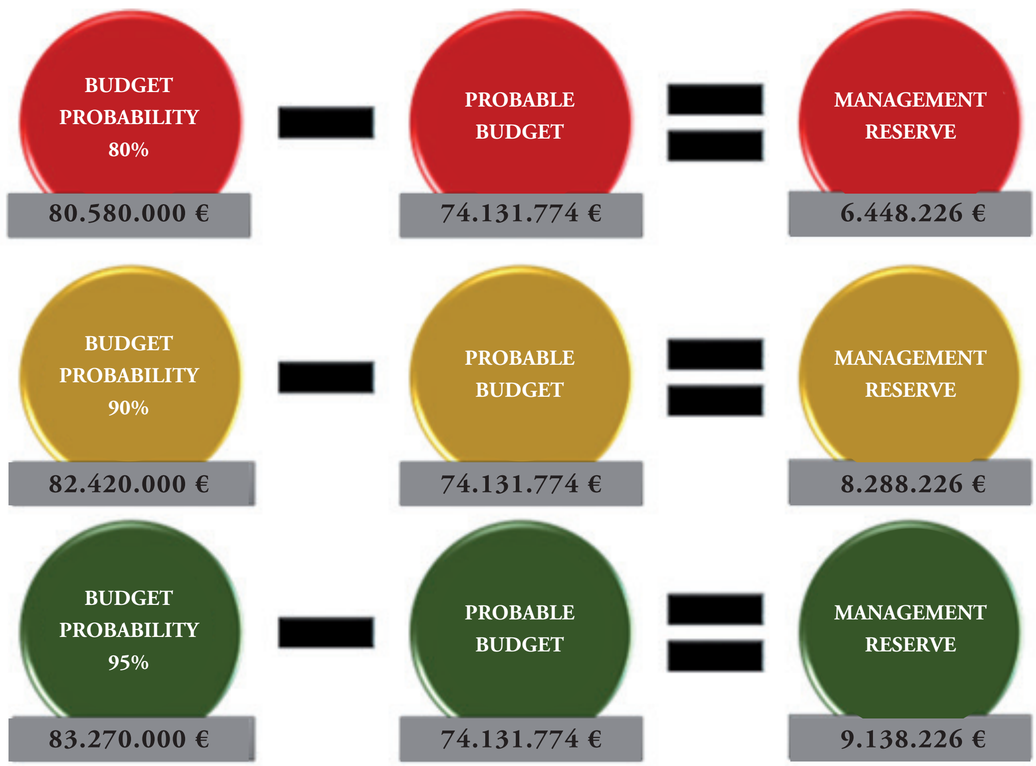


Table 5. Budgets based on the analysis of Monte Carlo

RESULTS	M €	PROBABILITY	DEVIATION
OPTIMISTIC BUDGET	67.01	< 0.10%	
PROBABLE BUDGET	74.13	12.2%	
PESSIMISTIC BUDGET	92.14	100%	
BUDGET PROBABILITY OF 80%	80.58	80%	8.7%
BUDGET PROBABILITY OF 90%	82.42	90%	11.2%
BUDGET PROBABILITY OF 95%	83.27	95%	12.3%
BUDGET PROBABILITY OF 100%	88.39	100%	19.2%

Fig. 2. Management Reserve Procurement scheme



the risk of possible losses for the company, with corresponding values between 8% and 10% of the ship's base budgets in the different probabilities.

Conclusions

In the table of results on budgets based on the Monte Carlo analysis (Table 5) the probability that budgets could have (optimistic, likely and pessimistic) are obtained directly through the breakdown of the different items (Table 4).

With the Monte Carlo method it is possible to know the probability of achieving a budget of 80% and 95% of certainity, depending on whether the company takes a conservative (95%) or risky (80%) strategy; the value of 100% probability would not be a determining value because it usually corresponds to a random iteration corresponding to said amount of money.

With respect to the results obtained in the management reserve, a margin of 6.5 million € has been achieved which corresponds to an 8.7%

deviation from the budget. This would be the decision of 80% probability, being the riskiest of the three. If one wants to be more conservative the same would be done with 90% or 95%, in which it would obtain a management reserve of 9 million € and 14 million € respectively that is equivalent to 11.2% and 12.3% of budget deviation.

All the results obtained by applying the methodology set out in this investigation are aimed at providing more information to the shipyard's management, thus facilitating senior management decision-making.

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Conceptual design of a 20 TBP port tugboat for the "Bahía Málaga" ARC Naval Base

Diseño conceptual de una embarcación tipo remolcador de puerto de 20 TBP para la Base Naval ARC "Bahía Málaga"

DOI: https://doi.org/10.25043/19098642.178

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Abstract

This work is part of the development of a conceptual proposal for a 20-ton bollard pull harbor tug, for the support of vessels no greater than 7,500 tons of displacement with safety standards for port maneuvers within the jurisdictional areas of the Colombian maritime authority (DIMAR) for the Colombian Navy. The design of this vessel was focused in providing the best opportunities to take into account, because the Colombian Navy fleet will have new vessels with greater displacement by the year 2030, this growth will be require the acquisition of new tugs. The execution of this design was based on the regulation of the "American Bureau of Shipping", abbreviated ABS, complying with all the specifications and parameters of a harbor tug. The Colombian Navy units of this type are currently boats whose useful life is over 5 years, which entails unsafe maneuvering, risking human lives and the units themselves. Currently, the Navy requires new towing services to comply with its institutional mission. This project seeks to develop a conceptual design for future projects to undertake the construction of this vessel. In this way, we will be fulfill the development objectives of the Strategic Surface Force the Faro 2030 Plan.

Key words: Bollard pull, autonomy, advance Resistance, Van Oortmerssen.

Resumen

El presente trabajo se enmarca en el desarrollo de una propuesta conceptual para un remolcador de puerto de 20ton de bollard pull, propuesto para realizar sus operaciones en bahía, para el apoyo de embarcaciones no mayores a 7500 toneladas de desplazamiento manteniendo las normas de seguridad para maniobras dentro de las áreas jurisdiccionales de la autoridad marítima (DIMAR). El diseño de esta embarcación fue enfocado con el fin suplir las necesidades futuras teniendo presente que la flota naval colombiana para el año 2030 tendrá un gran número de buques, este crecimiento obliga a la adquisición de nuevos remolcadores. La realización de este diseño se basa en el reglamento de la casa clasificadora "American Bureau of Shipping", abreviado ABS, cumpliendo con todas las especificaciones características y parámetros de un remolcador de puerto. Las unidades colombianas de este tipo actualmente son embarcaciones que su tiempo de vida útil puede haber pasado más 5 años, lo que conlleva a tener maniobras inseguras, arriesgando vidas humanas y las propias unidades. Actualmente la Armada Nacional requiere nuevas embarcaciones de remolcadores apropiados para cumplir con la misión institucional buscando también el aporte a la protección del medio ambiente. Este proyecto busca iniciar con un diseño conceptual con el fin de que proyectos futuros lleguen a la construcción de esta embarcación, de esta manera se cumpliría uno de los objetivos para el desarrollo de la Fuerza Estratégica de Superficie plan Faro 2030.

Palabras claves: Tracción punto fijo, resistencia al avance, Van Oortmerssen.

Date Received: November 18th 2018 - *Fecha de recepción: Noviembre 18 de 2018*
Date Accepted: January 6th 2019 - *Fecha de aceptación: Enero 6 de 2019*

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Introduction

This project seeks to carry out the conceptual design of a port towing unit to provide assistance to the sailing, mooring, and movement maneuvers of vessels in waters restricted by the channel. The main objective is to study the design of a bay tug with a capacity of 20TBP (Ton Bollard Pull), in order to acquire it for the Pacific Naval Base (BN2), considering that at the moment, the Pacific Naval Force does not have a tug type unit.

Work Objectives

General objective

Carry out the conceptual design of a tugboat with a capacity of 20TBP (Ton Bollard Pull) for the Bahía Málaga Naval Base, in order to assist the maneuvers of the surface units.

Specific objectives

1. Prepare the mission profile study, based on the requirements of the National Navy and define its main dimensions.
2. Conduct research on port tugs with a 20 TBP capacity.
3. Design the shape lines as the basis for preliminary stability, maneuverability and intact stability calculations in order to determine the buoyancy of the tugboat.
4. Estimate the ship's forward resistance and determine the power required in the propulsion system.

Methodology

The work methodology will be through the use of the design spiral, which is cyclic and iterative, and seeks to establish and develop the concepts proposed in each phase of the project considering that these concepts have a direct relationship between them, therefore all considerations must be taken into account to define a concept, constantly reviewing the concepts in order to achieve a result that adapts to the characteristics experienced by the design spiral. Applying it in all the phases of the project, requires the development to be carried out point by point and relating to each one to reach its center or detailed design phase.

From the data, the tasks are developed sequentially and when the first round of the design spiral is completed, it can be said that the vessel has been defined at its preliminary design level. Every time the spiral goes through its completion of a new cycle, the corresponding task is deepened in its definition.

Within the design spiral (Fig. 1), the conceptual design of a 20TBP tug for the Malaga Bay Naval Base will be developed, comprising 8 booklets where each one will contribute to the final objective of delivering the "Ship Project" design listed in the following table:

Table 1. List of booklets for "Ship Project" design

Booklet	Specifications
1	Concept exploration
2	Mission Profile study
3	Dimensioning
4	Naval architecture calculations
5	Systems Dimensioning
6	Electrical Balance
7	Capacities and stability
8	Cost

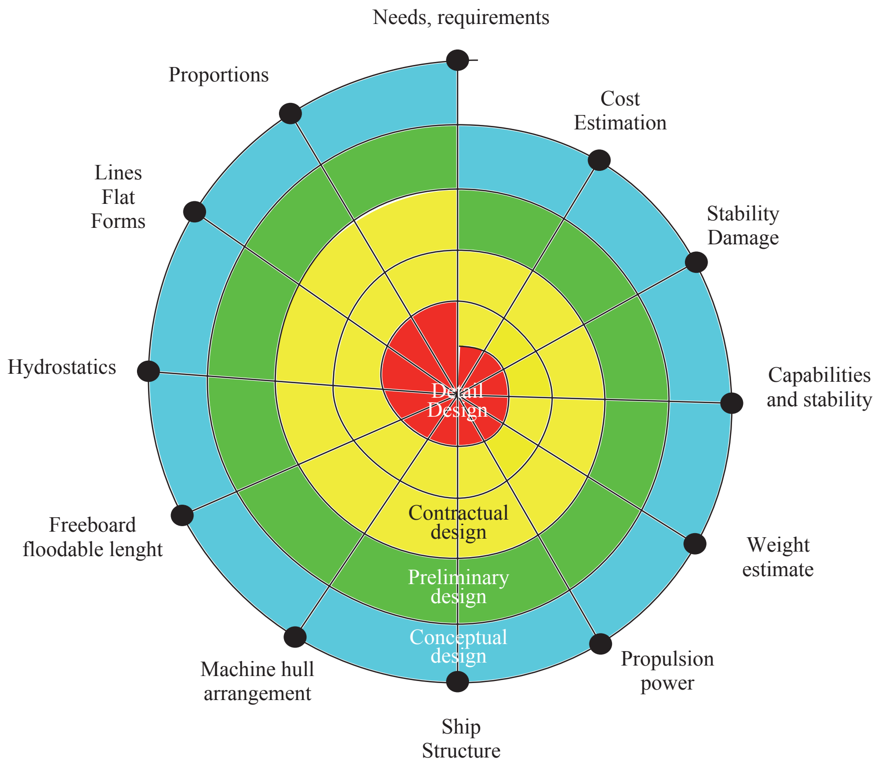
Mission profile

Its main function will be to tow and support the maneuvers of vessels that arrive, depart, change dock, transit through the channel, maneuvers restricted to vessels that require the assistance of the tugboat. This vessel has a bullard pull of 20 ton for a maximum operating capacity of 7500 tons deadweight.

The mode of operation will be dedicated to towing and assisting maneuvers since they will be its main functions for which the port towing vessel will be designed.

It will have an annual operation of 2304 hours with the following operation profile:

Fig. 1. Design Spiral, by (Gonzalez, 2011)



Speed from 0 to 6 knots	30%.
Cruise speed from 6 to 10 knots	60%.
Maximum speed of 11 knots	10%

In order to determine the main dimensions of the design, it was necessary to compile a database of existing vessels through different means of information from which information was obtained from ten (10) vessels shown in the following data table:

Table 2. Dimensions and general characteristics

General dimensions and Characteristics		
Length	17	[Meters]
Beam	7	[Meters]
Height	3,4	[Meters]
Depth	2,3	[Meters]
Displacement	162	[Ton]
Speed	11	[Kn]
Autonomy	15	[Days]
Crew	4	[Persons]

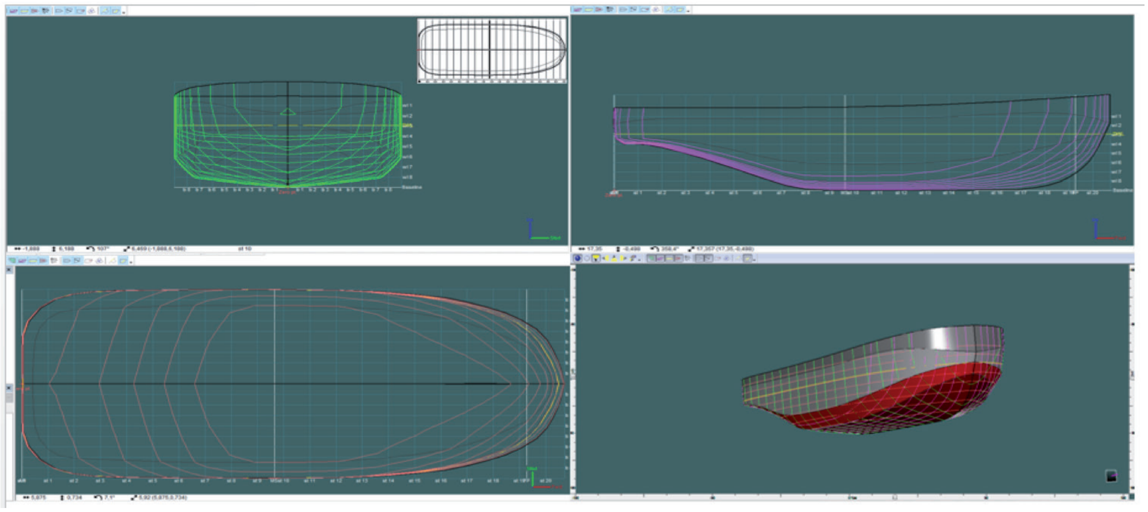
Shape lines

The definition of the ship shapes is of great importance in the design. From these shapes it the storage and handling needs of the cargo are verified. The speed is also checked through different procedures in the test channels or through the maxsurf software.

The shapes of the tug project are conditioned by the activity carried out by the vessel. Although it is qualified as a cargo ship by the Classification Society Guidelines, it is a ship that provides a service, so the cargo will not be decisive in the choice of its forms, but due to its design and function, the ship resistance must be reduced as much as possible.

According to the specification, the project vessel is a conventional type tug that will perform assistance and support functions, which is decisive in the choice of design.

Fig. 2. Hull shapes



Advance resistance

Different methods of analysis are available to determine the ship resistance of a vessel.

a. **Experimental methods:** These are the processes traditionally used in model trials. This procedure is often expensive and slow, so it is often used in the final stages of the project to validate the expectations of the project.
b. **Statistical methods:** These methods are based on regression analysis on model tests and measurements of real ships.
c. **Finally, numerical methods.** This is the method we have used for resistance analysis and power prediction.

These processes are performed through computer simulation tools. One of the main advantages of using these tools is that it allows you to evaluate the possible modifications in the shapes at any time.

The Van Oortmerssen method was determined for this project, since it has much more correlation for this type of tugs, being an algorithm designed to predict the advance resistance focused on small cargo vessels, fishing vessels and tugs, *(Arbuniéz & Caja, 2015, p. 34).*

The analysis shows that for a speed of 11 Kn there is a total resistance of 117.1 KN and an estimated power of 1124.373 KW which are the starting point for power prediction.

Powering

Based on the data obtained, referring to the advance resistance and calculation of the optimum propeller for the vessel being designed, the vessel in the project will have two axle lines with one power in each engine:

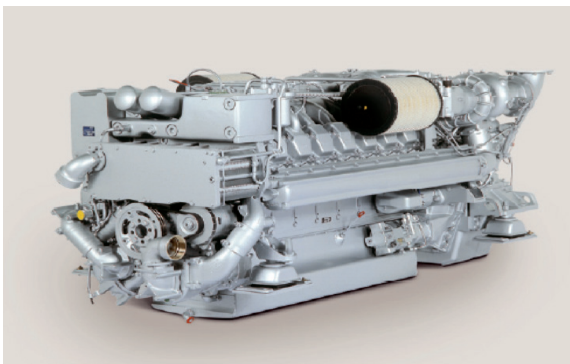
BHP: 592 KW

Table 3. Engine Comparison

Name	CAT	MTU 12V 2000 M61	MAN D2862
Power	850 HP	805HP	749 HP
Rated speed	1800 RPM	1800 RPM	1800 RPM
Cylinders number	12V	12V	12V
Specific fuel consumption	**205,3** $\frac{g}{KWh}$	**215** $\frac{g}{KWh}$	**213** $\frac{g}{KWh}$
Consumption g/h	41,0	34.1	38
Dimensions mm	1931 x 1300 x 1204	1890 x 1400 x 1290	2130 x 1153 x 1230

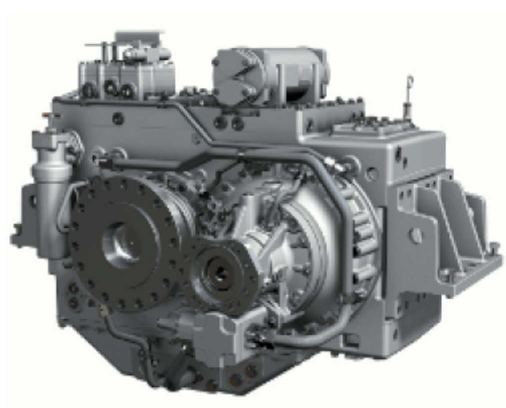
The selected engine is a Diesel MTU 12V-M61, which compared to the other engines observed in the table has a fuel consumption g/h which equals a better performance, and the dimensions show that it is smaller than the other two engines shown in the data table. The engine is from the German company MTU with a power of 1184 Kw equivalent to 1610 HP.

Fig. 3. Marine engine MTU 12V2000M61



According to the chosen engine manual, by recommendation it is compatible with the ZF 5000 NR2H gearbox with a 2.963 ratio, which does not require a special manufacturing order.

Fig. 4. Transmission ZF 5000 NR2H



The design of this vessel requires that the propulsion system has a 4-blade propeller. To avoid torsional vibrations and synchronisms induced by axial thrust of the blades, kort type nozzles are implemented for each propeller, which decreases the vibration induced in the hull by the propeller, since it provides a greater regularity of the flow inside, reducing the fluctuations generated by the propulsion engine. It also provides protection to the flow of water affected by the propeller and therefore decreases pressure variations on the hull around the propeller. These nozzles are designed to increase the traction force of the tug at low speeds.

Table 4. Propeller characteristics

Helix	
Diameter (inches)	67,29
Pitch (inches)	48,44
Z	4
P/d	0,7

Command and Surveillance

The tug must have the following navigation and communications equipment GMDSS A1 (Global Maritime Distress and Safety System) is a SOLAS and IMO convention, an international agreement on safety procedures, types of equipment and communications protocol to enhance maritime safety, divided into 4 maritime zones. The ship design will use zone a1 which is between 20 - 30 MN from the coast.

- TR-20
- An MF/HF transmitter-receiver with double PR-300 feeder equipped with DSC-6A equipment for MF selective call control.
- Two VHF transmitter-receiver devices with DSC equipment and extensions to cabins, dining room.
- One Tron TR-20 portable radiophone
- One Navtex NX-500 receiver
- One 406 MHz EPIRB radio beacon
- One 9 GHz radar transponder
- One high-resolution radar
- GPS receiver with LCD plotter
- Gyroscopic with interface for autopilot, repeaters and navigation equipment
- Master logbook with backup compass and alidades to mount on the compass
- Graphic and digital Echo sounder with LCD screen
- One anemometer with sensors on indicators

- For indoor communications, command telegraph equipment shall be mounted on a transmitter and two receivers, a maneuvering loudspeaker system with 2 repeaters on the main deck and the bridge.

Auxiliary Systems

The tugboat will need the basics for its operation and therefore the following auxiliary equipment must be installed:

- Two starting air compressors from 14 m3/h to 30 bar.
- One emergency starting air compressor from 9 m^3/h to 30 bar
- Pressurized air dryer filters
- One petrol purifier with a capacity of 1500 l/h
- One electric centrifugal pump of 40 m^3/h at 3 bar for fresh cooling water service, as backup for the main engine.
- Two centrifugal electric pumps of 70 m^3/h at 3 bar, for the salt water pump of the main engine.
- One electric centrifugal pump of 15 m^3/h at 3 bar, for transferring fresh water within the ship.
- Two centrifugal electric pumps of 25 m^3/h at 4 bar and 40 m^3/ha 1,5 bar, for flushing, firefighting, ballast and bilge pumping.
- One electric helical pump of 5 m^3/h at 1,5 bar, for oily waters.
- One self-suction electric pump with a 15 m^3/h screw at 2 bar, for fuel transfer.
- One 2.5 m^3/h at 5 bar self-suction screw electric pump for the main engine fuel reserve service.
- One 35 m^3/h at 10 bar self-suction screw electric pump for the main engine reserve oil lubrication service.
- One electric centrifugal pump of 1 m^3/h at 2 bar, for waste water discharge.
- One electric centrifugal pump of 20 m^3/h at 2,5 bar, for salt water cooling of the air conditioning equipment.
- One salt water hydrophore, consisting of a pump of 2 m^3/h at 3 bar, with a 50 l capacity tank.
- One fresh water hydrophore composed of a pump of 4 m^3/h at 3 bar, with a 50 l. capacity tank.
- One bilge separator with a 1 m3/h capacity.
- One biological waste water treatment plant, which receives by gravity and treats waste water for 4 people on board.
- Two axial and reversible fans with a flow of 25000 m3/h each, for the ventilation of the machine room.
- One centrifugal fan with a capacity of 2000 m^3/h for the engine service room.

Outfit and Furnishings

The ship shall have enough space to accommodate a crew of 4 persons consisting of:

- Under the main deck two double cabins equipped with bunk beds, wardrobe and desk, bathroom with shower, toilet and washbasin, washing machine and dryer for crew, living room for 4 people, stainless steel kitchen, food pantry room, with a freezer inside, a longitudinal corridor from stern to bow will connect the engine room with a hatch entrance and exit, then with cabins on each side, along the corridor there will be communication with the bridge on the main deck that will have a hatch to exit the bridge, interior doors will be galvanized steel with PVC or stainless steel, acoustic insulation and thermal insulation for high noise reduction and fire resistant.

Structural Design

The structural study of a ship can be carried out by considering it as a beam ship in which the shear and flexural stress to which the ship is subjected in a specific condition are studied, for the calculation of these stresses the most drastic conditions must be taken into account.

The **American Bureau of Shipping** (ABS), part 3, guide for building and classing will be used for the analysis.

For this project, which is defined as a Conceptual Design, a breakdown will be made of the main structural elements of the vessel "20 TBP Port Tug for the National Navy", the frames, web frames, longitudinal and transverse bulkheads. Vessels of this type have mainly, a transverse structure with special reinforcements in the keel area, the propellers and especially in the bulwark, an area that can be especially subject to blows during operations.

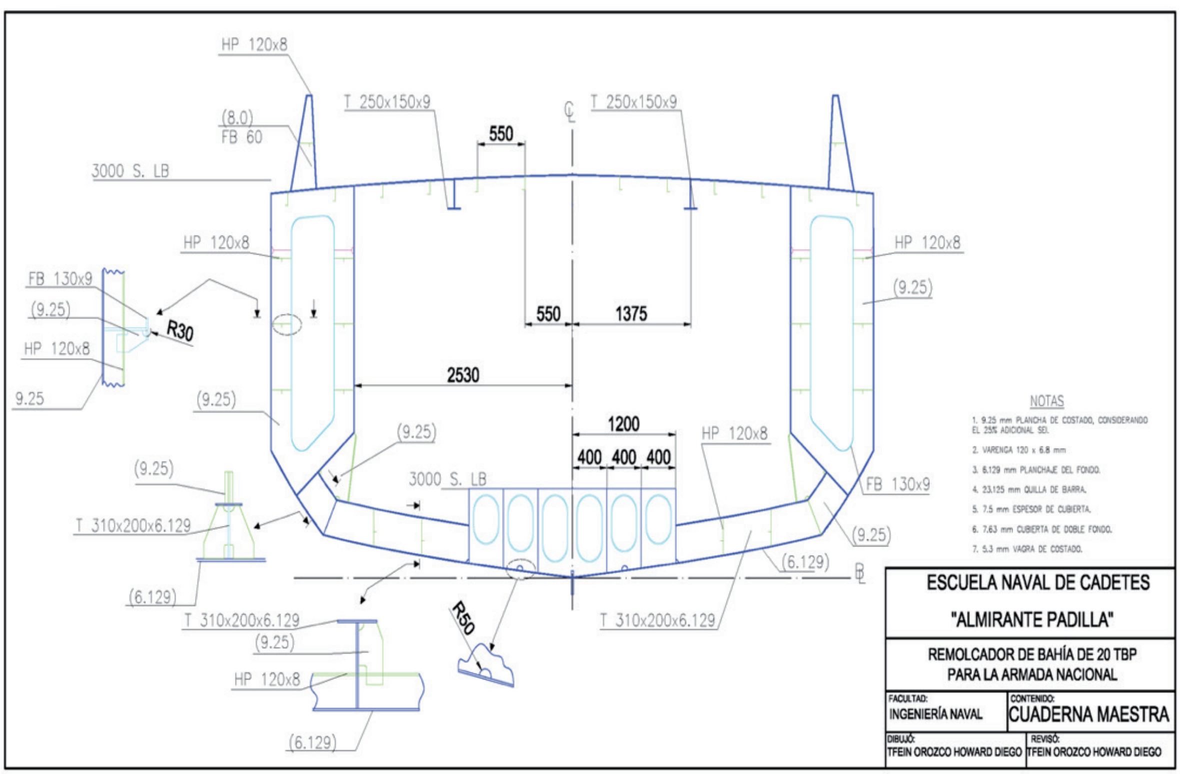
Table 5. Selected reinforcements

Thicknesses	
Depth, double depth, central rail	6,25 mm
Bar keel	12,82 mm
Rod	11,25 mm
Codaste	22 mm
Side Girder	5,3 mm
floor	6,8 mm
Double bottom roof	7,13 mm
Bottom plating	6,129 mm
Bottom beams (stern)	14 mm
Watertight bulkheads	7,04 mm
Machine room bulkheads	6 mm
Collision bulkhead	6,6 mm
Side plate	9,25 mm
Cover thickness	7,5 mm

Estimate of electricity generation system

In order to carry out the electrical balance, the loading conditions in port, navigation, maneuvering and emergency have been studied. From this study, the power in KW required for the power plant was obtained. This consists of two main Caterpillar generators, model C4.4 of the following technical characteristics: 100kW, 125 kVA, 220VAC, 320Amp, power factor 0.8, 1800 RPM and an emergency Caterpillar generator C4.4 Model ACERT 4.4 three phase, 36kW, 120V 240V, 60 HZ, 1800 rpm. The main generators will be located in the machine room on both sides, connected to the main board. The emergency

Fig. 5. Master binding



engine generator will be located in a separate compartment for that system only.

The diesel engine of the emergency generator will be started by means of an electric engine and battery, connected by means of a low voltage contactor to the emergency bars in the panel.

Cost Estimate

The cost estimate for this tugboat design was made in a general way, in order to obtain a conceptual estimate of the costs for construction. The calculation of estimated costs is calculated without considering the "other" expenses that may result, where only the hull, structure, material, costs of shipyard, equipment, machinery and facilities were estimated.

For the estimation calculations the approximation established by *(Carreyette, 1977, p 245)* is used, in which you can estimate the price of a ship, considering the following characteristics for a tugboat:

Table 6. Characteristics of the 20 PBS tugboat

Main Characteristics		
Flotation Length (Lw)	16,32	m
Beam (B)	7	m
Prop (D)	3,4	m
Draft (T)	2,3	m
Displacement (A)	162	Tn
Threaded Weight	122	Tn
Dead Weight	40	Tn
Block Coefficient (Cb)	0,586	
Crew	4	Persons
Propeller Power	1543	Php

Finally, an estimation of the shipyard costs is made, which includes services, materials, tools, equipment, machinery, among other elements. Also, the estimation of the general expenses is made, which are included and are characterized by carrying a % of expense similar to 30% of total cost in man hours. It is also estimated that the construction profit is 5%.

Table 7. Estimation of the total cost of the vessel

Estimated total cost of vessel construction	
Total cost of steel and profiles	$ 507´960.000
Total cost of welding	$ 76´194.000
Total cost for man hours	$ 82´170.000
Total cost of machinery, equipment and systems	$ 1.141´000.000
Total cost of shipyards and other	$ 180´000.000
Total general cost	$ 24´651.000
Estimated total cost	$ 2.011´975.000

In principle, the estimated cost of building the port tugboat would be $2,011'975,000 Colombian pesos.

Conclusions

In this investigation, the proposed objectives were met.

A conceptual design was achieved, fulfilling each of the proposed objectives, concerning port tugboat for the National Navy, having the necessary capabilities to support the vessels of the entire naval fleet. It is of great importance that the design of a vessel of this type can be developed into its construction, considering the institutional plan of the National Navy of compliance, plan 2030.

The design and context of this project is achieved with the help of computer tools, being able to design the hull shapes in the Maxsurf software, maintaining the main characteristics, determining a reliable analysis. It was also possible to analyze and evaluate the type of propulsion, propellers and generators to be selected.

For the propulsion system, the installation of two 1610hp MTU propellers, two lines of axles with 4 blades propeller, a diameter of 67.29in, were considered, thus meeting the power requirement to overcome the advance resistance of these vessels.

The design focused on the calculation of the advance resistance, and weight capacities, all analyzed and determined with the computational tools.

Finally, an approximate cost estimate was determined, considering the conceptual analysis up to its construction and launching, analyzing each possible cost, dividing the construction by construction groups and taking an organization with reference in the design and construction methodology. The total cost estimate for this tugboat was $2.011´975.000 projected for construction in 2020.

To carry out the development of this project requires great knowledge in computational tools focused on design and engineering analysis, focused on the naval issue. In addition, it must have a permanent company of teachers, naval engineers and the shipyard's own engineers, in this case, Cotecmar.

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The draughtsman of architecture and engineering in the naval, maritime and fluvial industry of Cartagena

El delineante de arquitectura e ingeniería en la industria naval, marítima y fluvial de Cartagena, Colombia

DOI: https://doi.org/10.25043/19098642.179

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Abstract

Careers and industry tend to go hand in hand with the references that are formed throughout their history, but there are careers hidden from them, without demeriting their importance in their process and growth. The Architectural and Engineering Draughtsmen are professional technologists who are active in the Naval Industry and little is referred to them as an associated profession. However, for all those who are immersed in this industry, the work they perform and their recognition in supporting the achievement of projects in the different design and construction stages is very clear. What is really worth highlighting in them, is the growth and evolution they have taken in this industry.

The times when the draughtsman transcribed ideas into drawings and plans is on the verge of extinction. Today, trained personnel is required and available to develop virtual models giving characteristics associated with the properties of each element and its integration into the total function of the project. These technologists have the experience and specific knowledge in the industry, and become the right hand of designers, engineers and builders, to develop designs from their basic stage to the closure of projects, with the confidence that they can receive alarms and ideas that make possible the completion of each job. For this reason, they take the name of designers or modelers according to the particular case of the company for which they work.

Key words: Naval Industry, Draughtsmen, Draftsman, Modellers, Drawing

Resumen

Las profesiones y la industria tienden a ir de la mano en relación a las referencias que se van formando a lo largo de sus historias, sin embargo existen profesiones que se quedan ocultas ante estas, sin demeritar su importancia en el proceso y crecimiento de las mismas. Los Delineantes de Arquitectura e Ingeniería son tecnólogos profesionales activos en la Industria Naval y poco se referencian como profesiones asociadas a esta, sin embargo para todos los que están inmersos en esta industria la labor que ellos ejecutan y su reconocimiento en el apoyo a la consecución de los proyectos en las diferentes etapas del diseño y la construcción es muy clara, lo que realmente vale la pena destacar en estos, es el crecimiento y evolución que han tomado en esta industria.

Los tiempos en que el delineante transcribía ideas en dibujos y planos está en vía de extinción, hoy se cuenta y se requiere personal capacitado para desarrollar maquetas virtuales otorgando características asociadas a la propiedades de cada elemento y su integración en el total de la función del proyecto, estos tecnólogos que ahora cuentan con la experiencia y el conocimiento específico en la industria, se convierten en brazos derechos de los diseñadores, ingenieros y constructores, para elaborar los diseños desde su etapa básica hasta el cierre de los proyectos, con la confianza en que de ellos se puedan recibir alarmas e ideas que vayan haciendo posible la culminación de cada trabajo, es por esta razón que toman el nombre de proyectistas o modelistas según el caso particular de la empresa para la cual laboren.

Palabras claves: Industria Naval, Delineante, Dibujantes, Modelistas, Dibujo

Date Received: February 15th 2018 - *Fecha de recepción: Febrero 15 de 2018*
Date Accepted: July 13th 2018 - *Fecha de aceptación: Julio 13 de 2018*

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Introduction

Throughout history, the branches of engineering have stood out for their specific application of knowledge, providing solutions to human needs, becoming recognized for the specialization of the study and application of technologies, leaving aside the diversity of skills that are immersed in the implementation of each project. However, multidisciplinarity is a great contribution within management, although specific and inevitable, not necessarily visible to the external community.

Within Engineering, the Navy is responsible along with Naval Architecture for the design, construction and maintenance of marine and river vessels, as well as their systems. In the industry outside this sector, the tendency is only to relate this area of knowledge with the construction of the ship itself and the design aspects that make it viable. However, there are other important aspects that make up the construction of a ship; this is how Architecture and other Engineering specialties take importance in the contribution to the development of these projects is given way. These are some examples:

1. **Architecture and Interior Design:** it is perhaps the least recognized but the one that actually confronts the external community in terms of comfort and aesthetics; today we can speak of areas related to Architecture but with a specific character such as Naval Interior Design, this being the branch responsible for the distribution and design of living spaces and accommodation in work spaces, ensuring better performance of the tasks determined in the operation of ships, vessels or naval artifacts, considering their function, ergonomics and comfort as main design characteristics.

   In accordance, the Naval Design offices have trained personnel for this function such as: Architects, Industrial Designers, Architectural and Engineering Draughtsmen. (1) or Technical Draughtsmen, who meet the specific needs of their area in each project.

2. **Engineering: Electrical, Electronic, Electromechanical, Mechanical and Mechatronic** among others, are in charge of the design, management, construction and commissioning of the ship's functional and operational systems.

   Their work teams include Engineers related to specific branches, Architectural and Engineering Draughtsmen or Technical Draughtsmen.

Historical framework

Design offices

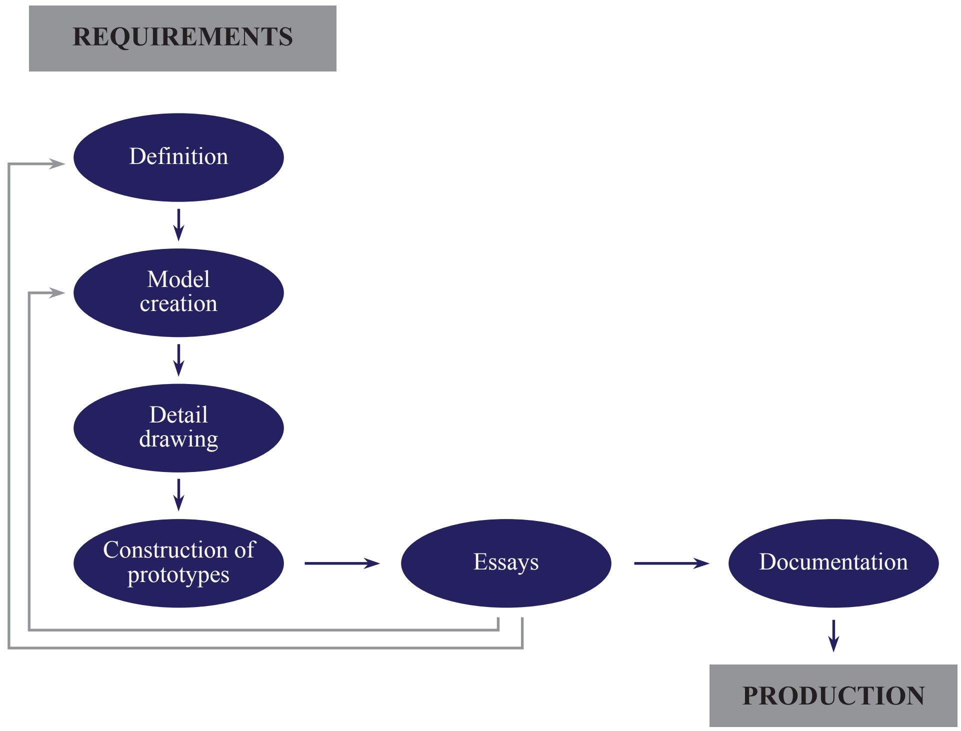
The offices dedicated to design have remained throughout history as the main project managers in the industry, however technological advances have changed their appearance according to the needs dictated by the execution of their tasks, previously the designs were presented in paper form (blueprints) and physical models made in offices equipped with drawing tables and tools for manual use such as pencils, technical pens, square rulers, parallels and compasses among others, see Fig. 1. in response to what was then considered to be the design process consisting of the steps described in the document "Computer Aided Design of the Universidad de Valencia". (2) which can be seen in Fig. 2.

Thanks to the emergence of CAD systems which went commercial since the 1960s with the first

Fig. 1. Former Design Offices

Source: Taken from https://www.picgrum.com/media/1200980706114963202_174351312, access date: November 20, 2017.

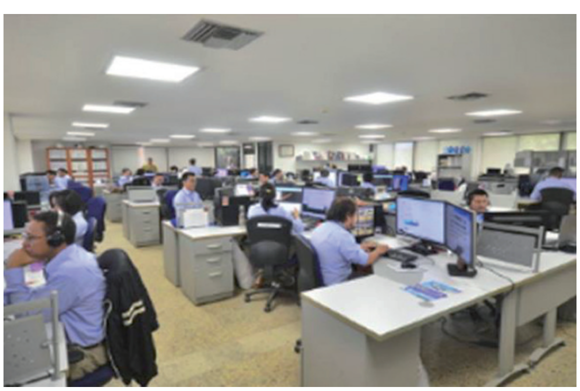
Fig. 2. Design Process



computer-aided drawing program, Sketchpad (3) The offices began to change their design processes due to the incursion of Computer Aided Design software. See Fig. 3.

In a broad sense, we can understand Computer Aided Design (CAD) as the "application of computing to the design process" *(Salmon, 1987)*. Pointing out the definition, we will understand by CAD System, a computer system that automates the design process of some type of entity, to discard as CAD systems the applications that affect only a specific aspect of the design process. The computer tool can be used in most of the tasks of the process, being the drawing where it has been most copiously used. (2)

Fig. 3. Current Design Offices



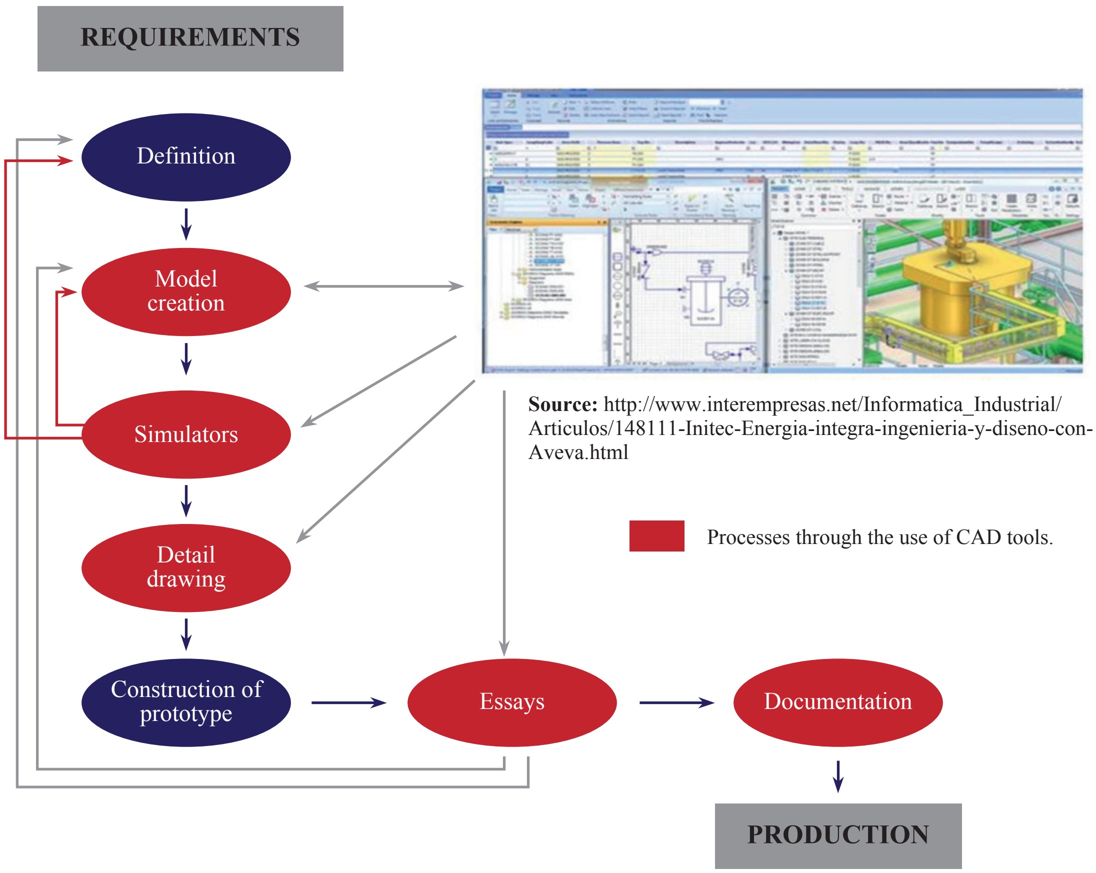
Source: Taken from Retrieved from http://www.cotecmar.com/services/design-engineering, access date: 20 November 2017

This incursion of computer science in design offices gave way to the modification of the design process, reason why become are steps under the use of the CAD tools, as it can be visualized in the Fig. 4 based on the document "Design Assisted by Computer of the University of Valencia". (2)

Impact of the architectural and engineering draughtsman on the naval design offices in the city of Cartagena de Indias

The measurement of this impact is the result of the research development of the teaching project "Measurement of the impact of the Architecture and Engineering Draughtsman in the Local

Fig. 4. Design Process with CAD Tools



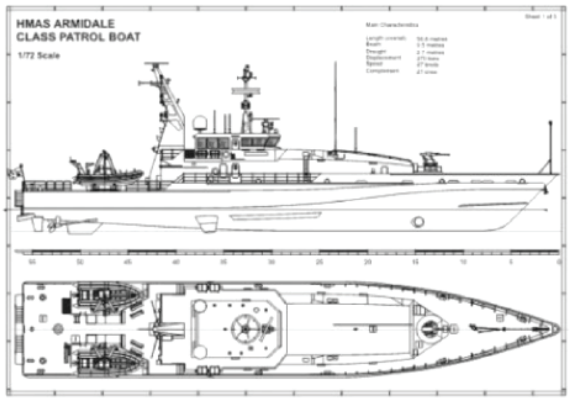
Industry". (4) with a view to strengthening the academic program in question, which was used to take samples such as surveys, working groups with the productive sector and interviews with academic staff, representatives of the local industry and program graduates.

According to the different professions that intervene in the execution of projects in the naval industry it is possible to speak of multidisciplinarity in terms of applied knowledge, although knowledge becomes specific to the interior of the design and construction spaces, considering that the main branch (Naval) adapts to the requirements of the specific object (ships and naval devices); it is possible to evidence that there is an auxiliary profession that can adapt to each of these needs within the specifics of each engineering component of the different branches, as in the case of the technical draughtsmen or the draftsmen for Architecture and Engineering. These professionals (technologists) are responsible for materializing the designs through electronic models and plans that accompany the design and construction process of ships, which strengthens their participation, allowing them to become true professionals of the naval industry, through the specific experience of multidisciplinary technologists.

Commonly called Draughtsmen today take the name of Designers, able to elevate an idea to a digital reality and land it in the construction stage, going through the design processes from the conceptual or preliminary idea to the evaluation and closing of the project, it is not uncommon to see how they intervene in the different aspects of all stages, highlighting the following activities as part of their functions:

- **Elaborating basic plans for the first stages of the design:** At this stage the Draughtsmen develop plans mostly in two dimensions (2D) using CAD tools, under the instructions derived from the designer, these plans are mainly schematics or general arrangements, see Fig. 5 that determine the operation and equipment of the specific design.

Fig. 5. General layout plan of the Offshore Patrol Vessels (OPV). The HMAS Hammersley by Sea Patrol



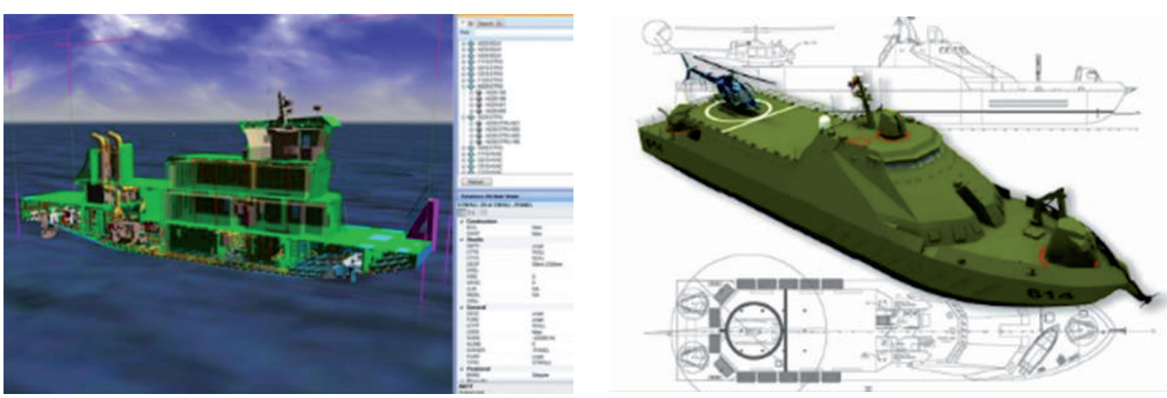
- **Modeling the virtual model to define the design:** It is here where the implementation of new technologies and skills takes place, the draughtsman becomes a designer or modeler who creates the virtual model of the project, giving each element its own characteristics to determine its real function within the final product, in such a way that this model becomes a prototype of what will finally be built, thus foreseeing inconveniences in the construction process. see Fig. 6.

- **Elaborating the detailed plans to transfer them to the construction area:** After the creation of the model, the draughtsmen to use the electronic model, elaborating plans of the different systems or parts and all the necessary information for their elaboration (construction plans) and later assembly (installation plans), guaranteeing in this way, the total construction of the project.

- **Field verification of construction under the As Built process:** at this stage draughtsmen review what is built under the instructions given in the plans or with the collection of data in relation to changes to the design during construction for the re-engineering process.

- **Finally, supporting the evaluation and closure stage:** with all the data taken from the previous the re-engineering process begins by updating the model and plans related to the change. Even though these changes improved the product and it is necessary to have an updated database for future constructions, if they were relevant only for the current construction, the model is not updated, but the plans are updated so that at the end of the project it has accurate information. In general, at this stage the draughtsman supports the design team in everything concerning plans or models to ensure that the project database has all the information that was given at all stages of design and construction of the product.

Fig. 6. Works carried out by Architect and Engineer Draughtsmen of the Colombian Naval Industry



Source Taken from http://www.cotecmar.com/servicios/diseno-e-ingenieria
http://www.cotecmar.com/servicios/ciencia-y-tecnologia. Date accessed: 22 November 2017.

Table 1. Competencies of the Draughtsmen of Architects and Engineers related to the naval Industry

COMPETENCIES ACQUIRED IN THE ACADEMY	SKILLS ACQUIRED IN THE LOCAL SHIPBUILDING INDUSTRY
Interpretation and elaboration of the naval drafting.	Interpretation of basic engineering design, materials handling and design standards.
Terminology, symbology and naval nomenclature.	Knowledge of the design and production process. Management of basic concepts of the different areas that intervene in the naval industry, (SWBS).
Management of basic naval architecture concepts such as: orientation and recognition of structural elements, regulations (classifying houses). etc.	
Digitization of general layout plans and construction details.	Elaboration of naval plans in all stages of design and production.
Drafting by Triangulation.	Modeling, generation and use of electronic models in specialized software.
2D and 3D scanning in AutoCad.	Modeling, generation and use of electronic models in specialized software.

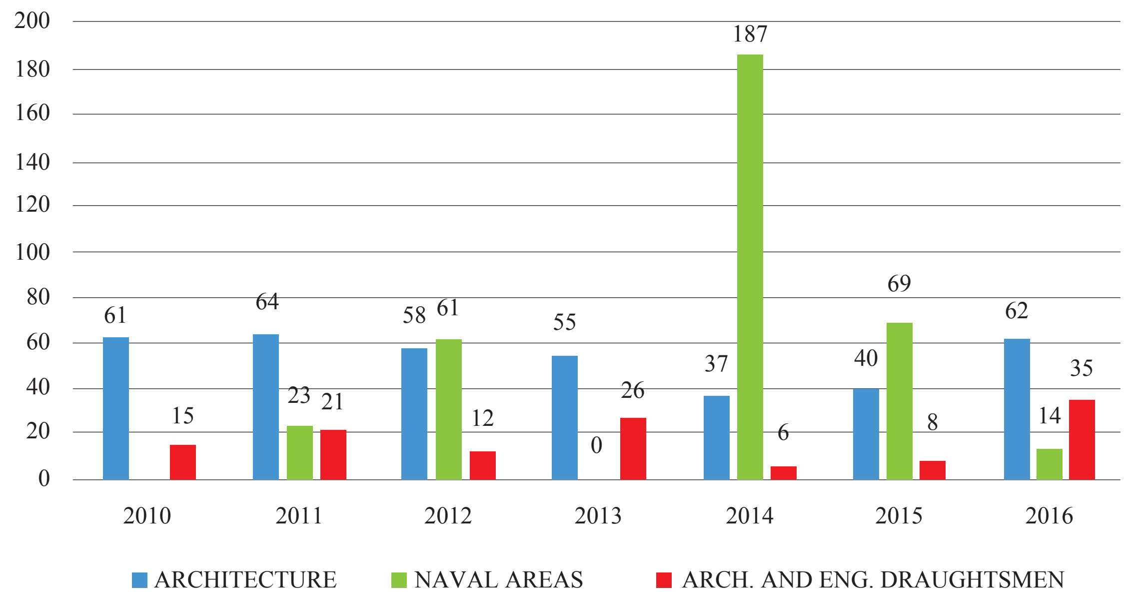
It is clear that in all these activities these professionals carry out their work hand in hand under the instruction and review of engineers and professionals from different branches, however it is good to highlight that their work is important. These technologists achieve ta specific experience, accumulate a number of skills additional to the academic training process, but strictly necessary in the development of the Naval Industry.

It should be noted that the Naval Academy in the country before 2011 applied only to military personnel in the Escuela Naval de Cadetes Almirante Padilla ENAP naval school, an institution that received the power to issue degrees related to Naval Engineering by the Ministry of National Education and the Colombian Association of Universities ASCUN in 1968 and which received recognition as a university in 1977. (5) Since then, it has been training professionals in the area, including the Master`s in Naval Engineering that has Qualified Registration since July 2010. The academy for civilian personnel takes its first steps at the professional level with the Technological University of Bolivar which obtained its Qualified Registration for the undergraduate degree in Naval Engineering in August 2016. (6) and for the Master`s in Naval and Oceanic Engineering in February 2011 (7)Therefore, a large part of the professions involved in this industry have taken acquired knowledge through work experience within it.

The Institución Colegio Mayor de Bolívar was empowered to provide technical training as Draughtsmen Experts on March 22, 1947, however these technicians did not have skills in the naval area, later the contents of the program were expanded to include engineering areas and obtaining their first promotion as Technologists in Architecture and Engineering Draughtsmen in 1980. (8) with competences in the naval area acquired through the Naval Drawing subject, which, as of 2013, takes the name of Engineering Drawing IV. (9). Its microcurriculum is related to the Interpretation and elaboration of Naval Drawing and the development of basic contents of naval architecture. With it the graduates of the program enter the industry with the basic knowledge to guide themselves and appropriate the specific knowledge with greater agility, adapting to the environment and allowing them to increase their skills to a specific level, achieving positions as draftsmen, designers or modelers.

Considering these academic programs as trainers for the fulfillment of the functions in the naval industry, we will look at the data of the Labor Observatory in Colombia to evidence the reception and approach to the coverage of the labor

Fig. 7. Statistical data taken from the Labor Observatory in Colombia



demand in the city, assuming that engineering is multidisciplinary, we observe only the trend in Naval careers, Architecture and Draughtsmen. Here is the data taken between 2010 and 2016 highlighting that this is an increasing trend.

It is clear that each program has different needs and expectations towards the population and its demand, however, it is good to analyze that, despite being an auxiliary career the Tecnologist in Architecture and Engineering Draughtsmen are maintained despite the crisis suffered by the construction branch in the city. Much of this is due to the support provided by these auxiliaries in the local industry such as the case of the Navy, who gain strength daily and that according to the data reported by graduates of the program, COTECMAR is the leading company in this industry in the city, it is also in employing the largest number of graduates in its plant, reaching to have about 20 or more draftsmen within its employees and contractors.

The Draughtsman seen as a Projector or Modelist

This professional has decisive functions in the Naval Industry since he is in charge of transferring the basic design generally elaborated in a schematic way to the digital or virtual reality, through the process of detail engineering in modeling the virtual model. The model must be a prototype with the parametrically exact components and their specific properties in order to be able to determine in advance all the possible inconveniences of the construction process and to provide a solution to them before beginning construction of the project, in such a way that, at the moment of executing the model in the production engineering, they are confident of the delivered product (construction plans). This is how the design and construction offices of this industry carry out their projects and therefore, have trained personnel for this work.

At the moment in the Naval Industry of Colombia, exactly in Cartagena, these functions are carried out mainly by Tecnologists in Architecture and Engineering Draughtsman of the Colegio Mayor de Bolívar under the direction of the Engineers or Architects of each area, executing the competencies received during their academic formation but mainly the experience and specific training received in the industry. These professionals who fulfill the functions described previously within the stages of the design and construction, are qualified not only with the use of software of naval

Fig. 8. Virtual Model Vs. Ship Under Construction

design and modeling but also, they understand of subjects like management and processes of design and production, materials handling and design standards, symbology and interpretation of schemes, among others, Although these subjects are learned in the exercise of the function every day, it becomes more necessary to include them in the academic offer, clarifying that this would imply elevating the category of education passing perhaps from technologists to professionalization, taking into account the credits and scopes established by the National Ministry of Education.

Conclusions

Today the Architectural and Engineering Draughtsman is a widely required professional in the Naval Industry, given the impact of his functions in the design and construction of ships and naval artefacts. The skills of the Draughtsmen have evolved with the technological advances in the area, and we no longer speak only of traditional blueprints and models, as we live the digital era. Therefore, the functions of the Draughtsman are now subject to the development of virtual models and the exploitation of these models. Thanks to the rapprochement of academia with the industry, it has been possible to determine that although it is necessary to maintain and reinforce the basic knowledge of the Draughtsman, it is also necessary to increase the skills related to the exercise of functions as Modelers or Designers and to grant them the character of graduate, closing, in this way, the existing gap between the profiles and the current demand of the Naval Industry in the city. It should be noted that this profile is required by other branches of local industry such as petrochemistry and all those related to the design and construction of industrial plants, making it a need to offer programs that meet the local, national and international industry requirements.

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www.shipjournal.co

Vol. 12 - n.° 24

January 2019

COTECMAR

www.shipjournal.co