

Springer Series on Naval Architecture, Marine Engineering,  
Shipbuilding and Shipping 17

Luis Carral · Adán Vega · Jorge Carreño ·  
José de Lara · María Isabel Lamas ·  
Juan José Cartelle · Javier Tarrío ·  
Rodrigo Carballo · Patrick Townsed *Editors*

# Proceedings of the IV Iberoamerican Congress of Naval Engineering and 27th Pan-American Congress of Naval Engineering, Maritime Transportation and Port Engineering (COPINAVAL)

 Springer

# **Springer Series on Naval Architecture, Marine Engineering, Shipbuilding and Shipping**

Volume 17

## **Series Editor**

Nikolas I. Xiros, University of New Orleans, New Orleans, LA, USA

The Naval Architecture, Marine Engineering, Shipbuilding and Shipping (NAMESS) series publishes state-of-art research and applications in the fields of design, construction, maintenance and operation of marine vessels and structures. The series publishes monographs, edited books, as well as selected PhD theses and conference proceedings focusing on all theoretical and technical aspects of naval architecture (including naval hydrodynamics, ship design, shipbuilding, shipyards, traditional and non-motorized vessels), marine engineering (including ship propulsion, electric power shipboard, ancillary machinery, marine engines and gas turbines, control systems, unmanned surface and underwater marine vehicles) and shipping (including transport logistics, route-planning as well as legislative and economical aspects).

The books of the series are submitted for indexing to Web of Science.

All books published in the series are submitted for consideration in Web of Science.

Luis Carral · Adán Vega · Jorge Carreño ·  
José de Lara · María Isabel Lamas ·  
Juan José Cartelle · Javier Tarrío ·  
Rodrigo Carballo · Patrick Townsed  
Editors

Proceedings of the IV  
Iberoamerican Congress  
of Naval Engineering  
and 27th Pan-American  
Congress of Naval  
Engineering, Maritime  
Transportation and Port  
Engineering (COPINAVAL)

 Springer

*Editors*

Luis Carral  
Universidade da Coruña  
A Coruña, Spain

Adán Vega  
Autoridad Marítima de Panamá  
Panama, Panama

Jorge Carreño  
Ghenova  
Cartagena, Colombia

José de Lara  
Universidad Politécnica de Madrid  
Madrid, Spain

María Isabel Lamas  
Universidade da Coruña  
A Coruña, Spain

Juan José Cartelle  
Universidade da Coruña  
A Coruña, Spain

Javier Tarrío  
Universidade da Coruña  
A Coruña, Spain

Rodrigo Carballo  
Universidad de Santiago de Compostela  
Lugo, Spain

Patrick Townsed  
Universidad ESPOL de Guayaquil  
Guayaquil, Ecuador

ISSN 2194-8445

ISSN 2194-8453 (electronic)

Springer Series on Naval Architecture, Marine Engineering, Shipbuilding and Shipping

ISBN 978-3-031-49798-8

ISBN 978-3-031-49799-5 (eBook)

<https://doi.org/10.1007/978-3-031-49799-5>

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Switzerland AG 2024

This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG  
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Paper in this product is recyclable.

# Contents

<b>Proposed Improvement in Vessel Design Requirements to Facilitate On-Board Additive Manufacturing</b> .....	1
Ignacio Requena Rodríguez	
<b>An Introduction to Retro Bulb Concept</b> .....	7
Sergio A. Benavides Kroff	
<b>Adaptability of the Ship Design Process According with the Evolution of Technological Tools to Facilitate the Integration Processes Between Ship Design and Shipbuilding Activities</b> .....	19
Carlos Andrés Delgado-Agudelo	
<b>Study of Cross-Sectional Geometry of Floating Breakwater for the Gulf of Mexico</b> .....	27
Gabriela Albíztegui, Mariano Hernández, Mariana Silva, Aldo Cruces, José Hernández, and Karen Almeida	
<b>Scale Ship Design for Marine Training Centers</b> .....	37
Zayira G. Alvárez and Carlos R. Plazaola Lorio	
<b>Fire Protection Installations on Ships. A Review of the State of the Art</b> .....	45
J. A. Fraguera-Formoso, A. López-Arranz, J. C. Álvarez-Feal, and L. Carral-Couce	
<b>Ship Hull Modeling. Current Practical Perspective</b> .....	57
Raquel Cecilia Núñez Barranco González Elipe	
<b>Modelling the Hydrodynamic Response in Scale Ships Subjected to External Perturbations</b> .....	63
Miguel J. Moreno	

<b>Ultimate Longitudinal Strength of a Suezmax Tanker Ship Under Sagging Condition Using FEA and the IACS Method</b> .....	71
José P. Quispe, Segen F. Estefen, Marcelo Igor Lourenço, John H. Chujutalli, and Tetyana Gurova	
<b>High Fidelity Hydroelastic Model Applied to a Vessel Using MMR</b> .....	81
Antonio José Lorente-López, Julio García-Espinosa, Borja Serván-Camas, José Enrique Gutiérrez-Romero, and Pablo Romero-Tello	
<b>Experimental Evaluation of Stern Appendages on the Forward Resistance of a Displacement Hull</b> .....	87
José Ahumada, Luis Cárdenas, David Fuentes, Richard Luco, and Marcos Salas	
<b>Computational Analysis of a HDPE Fishing Vessel with a Novel Design</b> .....	93
R. M. Panduro, J. L. Mantari, J. Ramirez, J. Huerta, J. Laura, and W. Velásquez	
<b>Structural and Hydrodynamic Evaluation of a Fishing Vessel Made of HDPE</b> .....	99
J. Ramírez, J. Huerta, J. L. Mantari, A. Terán, J. Laura, and W. Velásquez	
<b>Methodological Design of a Longline Fishing Vessel</b> .....	105
J. L. Mantari, J. Ramírez, J. Huerta, I. Chino, A. Terán, L. Chambizea, J. Laura, and W. Velásquez	
<b>Trends in Highly Efficient HVAC Systems on Vessels</b> .....	113
Manuel Roldán and Carlos Lao	
<b>Effect of the Bow Shapes on the Sinkage of Ships</b> .....	119
Luis Perez-Rojas Luis and Adrián Portillo Juan	
<b>Time–Temperature Superposition Principle: A Tool for Predicting Long-Term Behaviour</b> .....	131
Daniel A. Souto-Silvar, A. Álvarez-García, Francisco J. Rodríguez-Dopico, and M. González-Taboada	
<b>Technological Implementations in the Naval Construction Area at the University of Cádiz: Ensuring the Future of the Naval Industry</b> .....	137
Daniel J. Coronil-Huertas, Santiago Pavón-Quintana, Ruth García-Llave, José J. Alonso-del-Rosario, and Juan M. Vidal-Pérez	
<b>Using the Naval Submarine Code (NSubC) as Means for Submarine Assurance During Design Construction and Operation</b> .....	143
Ch. von Oldershausen	

**The Joint Research Center: A Model for Industry-Academy Collaboration** ..... 153  
 Pablo Fariñas Alvariño, Rafael Morgade Abeal,  
 Tiago M. Fernández Caramés, and Ana Isabel Ares Pernas

**Evaluation of the Effect of Boundaries Condition and Welding Sequence on the Out-of-Plane Deformation of Welded Structure by Thermal Elastic–Plastic Analysis** ..... 159  
 Hector Ruiz, Eric Caballero, and Juan Blandon

**Cuban Fishing Shipbuilding. Capacity Utilization. Challenges and Perspectives Until 2030** ..... 167  
 Amado F. Galiano Ortiz, Natasha Águila Valdés,  
 and Carlos M.Álvarez Candelario

**V/E “Capitán Miranda”, More Than a Major Repair, the Defense of a National Symbol** ..... 173  
 R. Ramallo and E. Philippi

**Cavitation Typology in the Marine Environment in Copper-Based Alloys: Particular Case of Copper, Brass, NAB (*Nickel Aluminium Bronze*) and MAB (*Manganese Aluminium Bronze*)** ..... 181  
 L. Merino Galván, M. V. Biezma-Moraleda, and P. Linhardt

**Supplier Development Case COTECMAR: Lessons Learned for the Shipbuilding Sector** ..... 189  
 Victoria Cristina Berrío Payares, Jose Abel Carrasco Mora,  
 and Lina Maria Diaz Sarmiento

**Characterization of Mechanical Properties of Adhesives for Application in the Naval Sector Through Digital Image Correlation** ..... 195  
 Francisco J. Rodríguez-Dopico, A. Álvarez-García,  
 Daniel A. Souto-Silvar, and M. González Taboada

**Accelerated Aging Technique for Predicting Long-Term Behavior** ..... 201  
 M. Cabaleiro-Figueroa, I. Díaz-Gonzalez, Víctor M. Jiménez-Acosta,  
 Daniel A. Souto-Silvar, and Francisco J. Rodríguez-Dopico

**Subsea Infrastructures: Underwater Environment Analysis for the Submerged Cluster Approach** ..... 207  
 F. Javier Rodrigo, Rubén Denche, Luis F. Montero, and Rafael Calderón

**Analysis of HDPE Configurations Reinforced with Fiberglass as Hull Material for Artisanal Fishing Vessels** ..... 213  
 I. Chino, J. Ramírez, D. Bonifacio, J. L. Mantari, J. Huerta, N. Ramos,  
 S. Charca, and A. Molina

**Review: Offshore Wind Farms, Their Maritime Installation** ..... 221  
 Jorge Freiria, Romina Suárez, and Mariana Corengia



<b>Icebreaker Launching Analysis Using Full Scale Measurements and CFD Simulations</b> .....	227
José Ahumada, Miguel Mansilla, Alan Neumann, and Marcos Salas	
<b>Bibliometric Analysis of Environmental Impact in Shipbuilding with Wood, Steel, Fiberglass and Plastic</b> .....	233
Isabel Chino De La Cruz, Joel Huerta Mamani, Laureano José Luis Mantari, David Amaya Fuertes, Jorge Ramírez Rosas, and José Ramos Saravia	
<b>Femtosecond Laser Cleaning: A Green Technology for the Removal of Antifouling Paint on Marine GFRP Composites</b> .....	241
Alicia Moreno, Pablo Pardiñas, Javier Lamas, Alberto Ramil, and Ana J. López	
<b>Optimization in the Design of the PROARR Artificial Reef Module Through the Interaction Between the Hydrodynamic Models of Circulation in the Estuary and that of Food Delivery in the Vicinity of the Module</b> .....	247
María Isabel Lamas Galdo, Rodrigo Carballo Sánchez, Iván López Moreira, David Mateo Fouz Varela, Juan José Cartelle Barros, Lucía Santiago Caamaño, and Luis Carral Couce	
<b>Considerations on Alkalinity in the Use of Bivalve Shells for the Production of Artificial Reefs for the Galician Estuaries</b> .....	253
José Luis Mier Buenhombre, Carolina Camba Fabal, Fernando Barbadillo Jove, Carlos Álvarez Feal, María Isabel Lamas Galdo, and Luis Carral Couce	
<b>Design, Manufacture, Transportation and Installation of “Green Artificial Reefs” in the Galician Estuaries: An Opportunity for a Circular Economy and Sustainable Development</b> .....	261
L. Carral, M. J. Rodríguez-Guerreiro, I. Lamas Galdo, L. Santiago Caamaño, C. Camba Fabal, J. Tarrío Saavedra, A. Díaz-Díaz, L. Castro Santos, C. Álvarez Feal, A. Munín Doce, J. Cartelle Barros, and R. Carballo Sánchez	
<b>Design of a Fluvial Vessel to Response to Natural Disasters for the Ibero-American Pacific</b> .....	273
José María Riola, Miguel Andrés Garnica, and Farah Vergara	
<b>The Course of the South Eastern Pacific, Development and Opportunities</b> .....	279
Humberto Ramírez	

**Development of Positioning Models for Surface Buoys to Locate ROVs** ..... 287  
 Juan Vidal, Pablo Otero, Daniel Coronil, Santiago Pavón, Miguel-Angel Luque-Nieto, and Jose Juan Alonso

**Technological Alternatives for Sustainable River Mobility in Colombia** ..... 293  
 John E. Candelo Becerra, Leonardo Bohórquez Maldonado, Miguel Andrés Garnica López, and Edwin Giovanni Paipa Sanabria

**Efficiency Study of the Santarém Waterway Terminal Using the DEA and Stochastic Frontier Methods** ..... 303  
 Anna Júlia Sousa de Pina, Kadu Naoki Ishikawa, Gustavo do Nascimento Tocantins, Lucélia Marques Lima da Rocha, André Vinícius da Costa Aarújo, and Marcus Pinto da Costa Rocha

**Influence of the Climate Change on the Port Facilities and It’s Resilience** ..... 309  
 Francisco Corratgé García

**Nuclear Techniques in Floating Artifacts in Peru, Latin America, and the World** ..... 315  
 J. L. Mantari, M. Montoya, M. Saldarriaga, J. Huerta, J. L. Castro, A. Zúñiga, and J. Ramos

**CFD Model and Mathematical Approach of Photovoltaic Panels in Offshore Environments** ..... 323  
 María Isabel Lamas Galdo, Tomás Guillén Díaz, Pablo Rubial Yáñez, Laura Castro Santos, Almudena Filgueira Vizoso, Gabriela A. Oanta, and Asunción López Arranz

**Hydrodynamic Model of a Hydrokinetic Converter and Improvement in the Surrounding Ecosystem Through the Installation of Artificial Reefs** ..... 329  
 María Isabel Lamas Galdo, Luis Carral Couce, Juan José Cartelle Barros, Rodrigo Carballo Sánchez, Iván López Moreira, and David Mateo Fouz Varela

**Financing of Wave Energy Farms in Times of Crisis** ..... 335  
 L. Castro-Santos, P. Rubial-Yáñez, I. Lamas-Galdo, D. Cordal Iglesias, F. Puime-Guillén, T. I. Guillen-Diaz, Helena S. de Oliveira, A. Alcayde, and A. Filgueira-Vizoso

**Potential of Offshore Photovoltaic Solar Technology in the North of Chile** ..... 341  
 T. I. Guillen-Diaz, P. Rubial-Yáñez, M. I. Lamas-Galdo, D. Cordal Iglesias, F. Puime-Guillén, A. Filgueira-Vizoso, and L. Castro-Santos

**Wave Energy Resource Characterization and Site Selection for Its Exploitation in the Ría de Pontevedra** ..... 347  
 B. Álvarez, D. M. Fouz, I. López, and R. Carballo

**Energy Provided by the Sea and Its Possible Introduction in the Energy Matriz of Cuba, Bahia Study Cases and Its Cost** ..... 353  
 Roberto Luis González Suárez and María Josefina Morejón Fernández

**The Ship Model Basin, a Key Point in Hydrodynamics** ..... 359  
 Luis Perez-Rojas, Francisco Perez-Arribas, and Adrian Portillo-Juan

**Data Analytics Case Studies in Maritime Technology** ..... 375  
 Salvador Naya, Javier Tarrío–Saavedra, and Luis Carral

**Review: Maritime Green Hydrogen** ..... 381  
 Romina Suárez, Jorge Freiria, and Mariana Corengia

**Contributions from the Colombian Navy and Cotecmar in the Framework of the Energy Transition in the River Sector** ..... 387  
 Edwin Giovanni Paipa Sanabria, Miguel Andrés Garnica López, Yamileth Aguirre Restrepo, Linda Sofia Atencio Ortiz, and Edgar Eduardo Quiñones Bolaños

**Preliminary Study of the SHCC Sandwich Structure Application for Offshore Wind Turbine Towers** ..... 395  
 John H. Chujutalli and Segen F. Estefen

**Life Cycle Assessment for an Eco-Friendly Electric Boat for Navigation in the Atrato River, Colombia** ..... 409  
 Victor Borja Marrugo, Yamileth Aguirre Restrepo, Edwin Giovanni Paipa Sanabria, and Edgar Eduardo Quiñones Bolaños

**River Electromobility and Its Contribution to Sustainable Development Goals** ..... 417  
 Yamileth Aguirre Restrepo, Miguel Andrés Garnica López, Edwin Giovanni Paipa Sanabria, Julian Andres Zapata, and Edgar Eduardo Quiñones Bolaños

**Operation and Maintenance of Floating Offshore Wind Farms. Classification Society Vision** ..... 423  
 Javier González Arias, Jaime Pancorbo, and Jonathan Boutrot

**The EU’s Sustainable Blue Economy: The Role of Artificial Reefs in Achieving the Climate Neutrality Goal** ..... 429  
 Gabriela A. Oanta, Asunción López Arranz, Juan José Cartelle Barros, Xose Luis Otero, Guillermo Díaz Agras, and Luis Carral Couce

<b>A Comparative Study of Possible Development Scenarios of Floating Wind Power in Brazil, Colombia and Spain</b> .....	439
Raúl Rodríguez Arias, Jorge Enrique Carreño Moreno, Frederico Cupello, A. Pereira, Clara Villela Fernandes, and Laura Castro-Santos	
<b>Analysis of the Feasibility, in Relation to Their Loading and Unloading Operations, of Providing Bulk Carriers with WASP</b> .....	445
Correa Ruiz Francisco José and Madariaga Domínguez Ernesto	
<b>Decarbonization Actions in the Cruise Sector. EUROMED Area</b> .....	451
José Ignacio Parra Santiago, David Díaz Gutiérrez, and Rodrigo Pérez Fernández	
<b>Safety Management on Warships: The Naval Ship Code</b> .....	457
Ruth García-Llave, Daniel J. Coronil Huertas, and Santiago Pavón Quintana	
<b>Cybersecurity in the Maritime Sector: A Point of Analysis in Risk Management</b> .....	465
Ferney Martínez, Luis Enrique Sánchez, Antonio Santos-Olmo, David G. Rosado, and Eduardo Fernández-Medina	
<b>Strengthening of Strategic Capabilities in the Integration of Electronic Systems, Through the Execution of R + D + i Projects</b> .....	471
Stefany Marrugo and Carlos Gil	
<b>Automated Surface Threat Evaluation on Naval Vessels with Limited Capabilities</b> .....	479
Camilo Barreto-Reyes and Mario Linares-Vásquez	
<b>Smart Cities and Their Impact on the Colombian Navy</b> .....	485
Jairo E. Martínez, Aldo F. Lovo, Victoria E. Ospina, and Andrea Ceballos	
<b>Implementation of an Onboard Decision Support System for Real-Time Stability Assessment of Fishing Vessels</b> .....	491
Richmond Selase Anku, Lucía Santiago Caamaño, Marcos Míguez González, and Vicente Díaz Casás	
<b>Simulation Model of a HVAC System for a Digital Twin</b> .....	499
Mehmet Anil Gürlek, Sara Ferreño González, and Alicia Munín Doce	
<b>Empirical Evaluation of Ultra Wideband for Shipyard 5.0</b> .....	507
Ángel Niebla-Montero, Paula Fraga-Lamas, José Varela-Barbeito, and Tiago M. Fernández-Caramés	
<b>Virtual Manufacturing: 3D Simulation of Shipbuilding Processes Based on a Game Engine</b> .....	513
Javier Pernas-Álvarez, Nerea Casal-Verdes, and Diego Crespo-Pereira	

**Malware Ahead! (Fighting Cyberthreats on Board Ships) ..... 519**  
 Enrique Cubeiro Cabello

**On the Development of a Digital Twin for Fire-Incident Onboard  
 Guidance ..... 525**  
 Muhammad Fuad Shofly, Marcos Míguez González,  
 Martín Landeira Freire, Silvia Gordillo Van Gils,  
 and Lucía Santiago Caamaño

**Process Digital Twin in Naval Manufacturing 5.0: A Case Study ..... 533**  
 Adolfo Lamas Rodríguez, Belén Sañudo Costoya, Elena Denisa Vlad,  
 Adrián Cora Sierra, and Lorenzo Ortiz Aneiros

**Methodology Development for Designing NDT Cells for Offshore  
 Nodes Using Virtual Commissioning Tools and Ergonomic Analysis .... 539**  
 Adolfo Lamas Rodríguez, Elena Denisa Vlad, Belén Sañudo Costoya,  
 and Óscar Manuel Castro Martínez

**Optimization of the Robotic Process for Welding and Spot-Welding  
 of Brackets in the Manufacturing of Bulkheads Using an Innovative  
 Robotic Gripping and Welding Tool ..... 545**  
 Adolfo Lamas Rodríguez, Santiago José Tutor Roca,  
 Javier Nicolás Montero Manso, Armando José Yáñez Casal,  
 and Alberto Ramil Rego

**Real-Time Musculoskeletal Risk Assessment Methodology Using  
 Virtual Reality and Motion Capture System for the Ultrasonic  
 Inspection Process of Components for Offshore Wind Farms  
 Foundations ..... 553**  
 Adolfo Lamas Rodríguez, Santiago José Tutor Roca,  
 Óscar Manuel Castro Martínez, and Lorenzo Ortiz Aneiros

**Digital Twin of an Offshore Nodes Manufacturing Line Through  
 Discrete Event Simulation ..... 559**  
 Belén Sañudo-Costoya and Adolfo Lamas-Rodríguez

**Digital Twin Model Development for Condition-Base Maintenance  
 Assessment in Robotic Manufacturing Processes Within a Shipyard .... 565**  
 Javier Nicolás Montero Manso, Alberto Ramil Rego,  
 Armando José Yáñez Casal, Adolfo Lamas Rodríguez,  
 and Santiago José Tutor Roca

**Digital Twin Proposal for Automated Processes in Shipbuilding:  
 An Implementation Strategy ..... 571**  
 Celia Carral Amenedo

**High-Fidelity Model-Based Simulation of a Medium Weight Shock Machine** ..... 577  
Álvaro López Varela, Vicente Meijido López,  
Constantino Bello Corbeira, Juan Dopico Mayobre,  
Pablo Fariñas Alvariño, Javier Cuadrado Aranda,  
and Daniel Dopico Dopico

**The Metaverse and Nautical** ..... 583  
Jorge De Santos Ruiz and Fernando Garrido De La Fuente

**The Industrial Campus of Ferrol: A Specialized Campus Stimulating the Knowledge Transfer** ..... 589  
Ana Ares-Pernas and María Jesús Movilla Fernández

**Study of the Influence of Different Tip Mass on a Piezoelectric Vibration Energy Harvester to Be Installed in a Machinery Foundation** ..... 595  
V. M. Contreras, J. M. Ahumada, and T. A. Moreno

**Impact of Simulators on Training Military Personnel in Maritime and Fluvial Operations: A Case Study of the Naval Academy of Cadets “Almirante Padilla” (ENAP)** ..... 617  
Aldo F. Lovo, Jairo E. Martínez, Andrés Orejarena-Rondón,  
Steven F. Montenegro, and Brandon S. Hernandez

# Proposed Improvement in Vessel Design Requirements to Facilitate On-Board Additive Manufacturing



Ignacio Requena Rodríguez

**Abstract** Advances in additive manufacturing mean parts can be made from a wide range of materials, including metal alloys commonly used in the naval industry. The development of Industry 4.0 also enables the evolution of predictive logistics and the interconnection of digital files provided by system and component suppliers. Furthermore, incorporating additive manufacturing capabilities on board a vessel can provide benefits in terms of operational flexibility and space savings for parts storage. However, this capability is conditioned by the sensitivity of 3D printing systems to vessel motion. The need to carry out additive manufacturing in a wide range of sea conditions makes it advisable to incorporate a reserve space at the vessel's point of maximum stability, along with damping and movement compensation systems, including both horizontal (galleries) and vertical (elevators) access passages for efficient distribution of manufactured parts and components and their transfer to outer decks for easier transportation to other vessels.

**Keywords** On-board additive manufacturing · Vessel design · Shipbuilding · 3D printing · Predictive logistics · Industry 4.0 · Ship stability

## 1 Introduction

Techniques and specifications in the design and construction of vessels have been evolving with the development of new knowledge, technologies and needs.

Additive manufacturing is now a relevant part of Industry 4.0, combining advances in digitalisation with new 3D printing technologies that allow the production of complex parts with materials commonly found in the naval field, including metal alloys [1, 2].

---

I. Requena Rodríguez (✉)  
Advantaria, Madrid, Spain  
e-mail: [idi@advantaria.com](mailto:idi@advantaria.com)

Incorporating this capability on board a vessel can provide significant logistical advantages by reducing storage space and increasing operational flexibility through the on-site manufacture of spare parts or bespoke tools [3].

## 2 Current Challenges

The experimental installation of polymer 3D printers in US Navy vessels started in 2014 aboard the *USS Essex*, followed by the *USS Bataan* in 2016 [4]. More recently, these two Wasp-class landing helicopter dock amphibious assault ships have received permanent metal alloy additive manufacturing equipment, along with scanning and machining tools [1, 2, 4]. Similar systems have also been installed on other ships of the same class, as well as on nuclear-powered vessels such as the aircraft carriers *USS John C. Stennis* and *Eisenhower*, the submarine *USS Virginia* [4], and the French aircraft carrier *Charles de Gaulle* [3]. In this regard, numerous companies and organisations are actively developing processes associated with certification of printed parts. Similarly, the new Defence Industrial Strategy 2023, published by the Spanish Ministry of Defence [5], includes this additive manufacturing capability in the naval field, and different evaluation tests have been carried out by the Spanish Navy (Armada).

The on-board use of these systems presents distinct challenges related to the movement of the ship, power requirements for the machinery (which are already available in the aforementioned large vessels), humidity and salinity conditions, and the distribution of large parts from the additive manufacturing points to the required locations.

It is therefore necessary to implement controlled environments in order to regulate salinity and humidity; to incorporate access galleries and spaces in the design of certain vessel types in order to ensure the smooth transportation of manufactured parts both inside and outside the vessel; and to provide sufficient storage capacity for the required materials.

At the same time, the sensitivity of 3D printing systems to vessel motion can significantly impact the quality and strength of the manufactured parts. Solutions are thus required in order to, as far as possible, dampen such movements and rotations during the additive manufacturing process, increasing the range of sea conditions in which effectiveness is maintained.

## 3 Stability Inside the Vessel

The centre of gravity (which, in a vessel, coincides with the centre of mass [6]), is initially calculated in the design phase, in order to ensure its stability by analysing the metacentric height [7] in conjunction with the centre of buoyancy, and in order to allow the hull's longitudinal trim.



While there may be slight changes in its position due to load distribution during vessel operation, the centre of gravity remains the point of least movement and maximum stability on board, with the displacement amplitudes caused by rotation (roll, pitch and yaw) being referenced according to the distances to this centre of mass [8].

## 4 Location and Access to Additive Manufacturing Systems

As mentioned above, in addition to the location of the additive manufacturing process at the vessel's point of maximum stability, it is necessary to incorporate access passages that allow adequate transport of the parts produced.

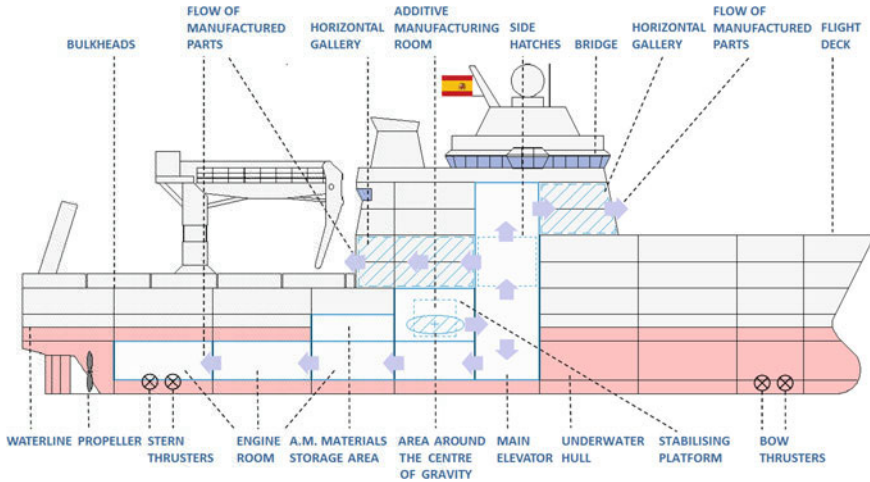
In this context, the centre of gravity's potential positions (depending on load distribution) constitute a volume located in the central part of the craft. This area often has limited access in many ships (such as corvettes, frigates, destroyers and civilian passenger vessels), making it impractical to transport large parts from this location to other areas within or outside the ship.

It should also be noted that the operational flexibility provided by on-board additive manufacturing is multiplied by the possibility of transporting the manufactured parts to other units of the same task group. As a result, it is foreseeable that the latest generation of vessels with this equipment will be able to play a joint role alongside previous generations (without such capability) in developing a mission. It is therefore considered advisable to ease transport to the outer decks and sides of the ship, in addition to facilitating access to those interior locations where temporary or permanent parts may be necessary (e.g., the engine room) (see Fig. 1) [9].

As shown in the diagram above, both horizontal (galleries) and vertical (elevators) access passages are incorporated for easier distribution of parts to the engine room, the aft deck, the flight deck (in this case located at the bow) and the side hatches for transfer to other ships, while also allowing the transport of materials in reverse direction to the storeroom and the additive manufacturing room. Compartmentalisation and security requirements must also be taken into account through the incorporation of bulkheads [10–12], which will depend on the civil or military nature of the vessel and its type of classification.

Longitudinal bulkheads can generally be used in the passageways, while transverse bulkheads can be employed in the vertical galleries, integrating watertight doors for personnel and larger doors for parts. These new access spaces can also replace other existing galleries in order to optimise interior distribution.

The feasibility of implementing such a design will vary depending on the type of vessel and on the typical use of the space around the centre of mass. Moreover, the larger the total volume of the hull, the less significant the relative impact of the location of these spaces in the central area in relation to overall ship design. Similarly, the system will be more effective in vessels with greater displacement, given their higher degree of stability.



**Fig. 1** Schematic diagram showing a possible design, by way of example, in an underwater intervention vessel, indicating the transport flow of the parts

At the same time, it is foreseeable that additive manufacturing equipment will need to be upgraded or replaced with newer systems or equipments with greater capabilities during the life cycle of a vessel. These access spaces can therefore allow the 3D printing machinery to be upgraded, or, if necessary, be replaced with other equipment that can benefit from installation in this area of greater stability of the ship, such as operating rooms, intensive care units, or certain scientific devices that are particularly sensitive to movement.

Similarly, the reserve space around the centre of mass enables the use of stabilisation platforms with pendular elements and shock absorbers, which can also be used for the medical or scientific applications mentioned above. It is also advisable to incorporate systems that allow a slight displacement of the stabiliser platforms along the longitudinal and vertical axes, in order to be able to relocate the systems in the event of a change in the centre of gravity due to the loads.

## 5 Conclusions

The ability to use additive manufacturing on board a vessel to produce robust, large parts in materials commonly used in the shipbuilding industry offers significant advantages in terms of utility, improving both logistics and operational flexibility, thus indicating the potential for this equipment to become standard.

The machinery used in 3D printing is extraordinarily sensitive to movement, and the quality and strength of the parts depends on achieving sufficient stability conditions during this process.

The reserve space around the vessel's point of greatest stability (centre of mass), combined with the incorporation of damping systems, can extend the range of sea conditions in which additive manufacturing is feasible.

The incorporation of interior access galleries (e.g., to the engine room), as well as access spaces to the outer decks and sides of the vessel, can allow the transport of large parts to where they may be needed, including to other vessels taking part in the mission.

In summary, these design proposals are aimed at facilitating the integration of additive manufacturing capabilities on board, which provide relevant logistical and operational advantages.

## References

1. Maritime-executive.com: First 3D printer installed on U.S. Navy Ship for evaluation underway. <https://maritime-executive.com/article/first-3d-printer-installed-on-u-s-navy-ship-for-evaluation-underway>, 2022/07/11
2. Naval Sea Systems Command, U.S. Navy: Metal 3D printer installed on USS Baatan (2022). <https://www.navsea.navy.mil/Media/News/Article/3209856/metal-3d-printer-installed-on-uss-bataan/>, 2022/11/04
3. Le Journal de l'Aviation. Rafale takes off from the Charles de Gaulle with a 3D printed part. <https://www.journal-aviation.com/en/news/43971-rafale-takes-off-from-the-charles-de-gaulle-with-a-3d-printed-part>, 2020/03/11
4. Banks, N., Ferreira, D.J., Mccauley, J.A., Trinh, J.T., Zust, K.S.: Navy Additive Manufacturing Afloat Capability Analysis, 11–60. Naval Post Graduate School, Monterey, CA (2020)
5. Spanish Ministry of Defence: Estrategia Industrial de Defensa, 71 (2023)
6. Feynman, R.: The Feynman Lectures on Physics, “Mainly Mechanics, Radiation, and Heat, Vol. I, Ch. 19. California Institute of Technology (1963)
7. Babicz, J.: Wärtsilä Encyclopedia of Ship Technology, 2nd ed., 382 (2015)
8. Papanikolaou, A.D.: Methodology for the evaluation of large amplitude ship motions in waves and of dynamic stability. In: Third International Workshop on Theoretical Advances in Ship Stability and Practical Impact, 168. Athens (1997)
9. Requena, I.: Vessel hull to facilitate on-board additive manufacturing of components, Patent Application P202130858 (2021)
10. Lamb, T. (ed.): The Society of Naval Architects and Marine Engineers, “Ship Design and Construction”, Vol. I. ISBN: 0-939773-40-6 (2003)
11. Bureau Veritas: Rules for the Classification of Naval Ships (2020)
12. DNV: Rules for Classification—Ships (2022)

# An Introduction to Retro Bulb Concept



Sergio A. Benavides Kroff

**Abstract** The idea for the Retro Bulb concept presented on this paper it's originated from a linear approximation to obtain the roll motion damping coefficients from the decay test of high block coefficient vessels with bilge keels using Keulegan-Carpenter number (KC). Hence, from this analysis it is possible to understand that, the damping that's rules the roll motion of high block coefficient vessels with appendages its more effective at lower oscillations amplitudes (roll decay test latest cycles), its mean at lower KC numbers ( $KC <$ ) were the laminar flow regime is predominant and the  $GM_T$  has a linear variation in the stability curve, which however didn't occur for larger oscillation amplitudes (roll decay test initial cycles) were highest KC numbers ( $KC >$ ) are relevant and therefore the appendages effectiveness such as bilge keels are neglected as results of the turbulence derived from the back and forth oscillating flow, being the main source for the energy dissipation the hull geometry. Therefore, taking into account this factors, from the Submerge Trimaran (STR) hull concept which proposes a modification to the submerge hull geometry by considering the flow produced by the roll motion (oscillatory flux measure by KC numbers) like a free surface effect to be contained by making a draft variation at the same displacement, in order to generate a potential damping increment (energy dissipation) to reduce the angle of list (roll motion amplitudes) and from which the Retro Bulb concept arise by doing a geometrical projection from a conventional vessel bulbous bow to the STR hull extended draft to obtain an additional mass increment into the system to reduce the angle of list (roll motion amplitudes) within the stability curve in which  $GM_T$  varies linearly for a broad range of sea estate which allow navigate ocean routes more efficiently with energy savings and decarbonization.

**Keywords** Retro bulb (RTB) · Keulegan-Carpenter number (KC) · Roll motion control

---

S. A. B. Kroff (✉)  
Av. Lo Ovalle 1321, San Miguel, Santiago 7142677, RM, Chile  
e-mail: [sergio.kroff@gmail.com](mailto:sergio.kroff@gmail.com)

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2024  
L. Carral et al. (eds.), *Proceedings of the IV Iberoamerican Congress of Naval Engineering and 27th Pan-American Congress of Naval Engineering, Maritime Transportation and Port Engineering (COPINAVAL)*, Springer Series on Naval Architecture, Marine Engineering, Shipbuilding and Shipping 17, [https://doi.org/10.1007/978-3-031-49799-5\\_5](https://doi.org/10.1007/978-3-031-49799-5_5)

## 1 Introduction

The NTLS system concept (NTLS) as presented on the Introduction paper, it's a roll motion stabilizer mainly conceive for floating systems for offshore applications with not intent to sail like FPSO's, that act by increasing the hull resistance to oscillate by projecting a virtual draft from a light structure device with positive buoyancy acting like an additional mass modulator stabilizer, which also can be understood in comparison with the mechanical vibration principle of a dual mass spring system dynamic absorber used in tall buildings to absorb the vibrations of a large mass structure (hull), by adding on top a smallest mass that vibrates with the building (NTLS), being the effect of the energy transference back and forth process (additional fluid inertia that oppose to the oscillation motion) the reduction of the main structure (hull) vibration and therefore expanding a floating system margin of safely operation scenarios by reducing the angles of list (roll periodicity variation) contained within the envelope of the stability curve in which  $GM_T$ NTLS vary linearly for a broad range of sea estate as more external input energy its required to achieve the same angle of list (roll amplitude) that would be obtained with a bare hull. Therefore, taking into account this factors, from the Submerge Trimaran Hull concept (STR) which proposes a modification to the submerge hull geometry, by considering the flow produced by the roll motion (oscillatory flux measure by KC numbers) like a free surface effect to be contained by making a draft variation at the same displacement, in order to generate a potential damping increment (energy dissipation) the Retro Bulb (RTB) concept arise by doing a geometrical projection from a conventional vessel bulbous bow to the STR hull extended draft to obtain an additional mass increment to reduce the angle of list (roll motion amplitudes) within the stability curve in which  $GM_T$  varies linearly for a broad range of sea states which allow navigate ocean routes more efficiently with energy savings and decarbonization..

## 2 Retro Bulb and STR Hull Roll Motion

As previously explained, the NTLS additional mass effect with the STR hull it's substituting by a potential damping increment, hence from the STR hull development stages an additional variation that's could be obtained from the NTLS principia to insert an additional mass increment into the STR hull system, is by doing a modification from the VLCC [1], bulbous bow projected into the STR hull extended draft like an NTLS device at the bow from which its obtained an additional mass contribution into the STR hull system by adding a vertical projection at the bow to obtain an additional mass gain. Hence, from a STR hull obtained from a VLCC [1] (length 273 (m), length.pp 260 (m), breath 44.500 (m), depth 22.840, full load draught 16,180 (m) STR 17.68(m)), presented at the STR hull concept introduction paper, the bulbous bow modification is madr by extending the bulbous bow curvature (plane xz) with a vertical projected back ward interpolation to the STR hull draft, which form a

convex vertical keel underneath the bow area named NTLS Retro Bulb (RTB) being this modification applied for the STR model with a vertical projection length of 2.5(m), inner length of 55 (m) and 19(m) width (Fig. 1).

Hence for comparison purposes the RTB modification is applied for both models STR and VLCC hull's with a vertical projection length of 2.5 (m) STR (Fig. 2a) and 4 (m) VLCC (Fig. 2b), with an inner length both of 55 (m) and a max. width of 19 (m) as its displayed on the following Fig. 2: Therefore, as a way to gain an understanding to the Retro Bulb concept let's start with VLCC STR hull modification and the relation with the VLCC vessel transversal stability parameters values and their influence on the roll amplitudes, and by considering that this modification didn't cause a transversal stability variation, that for instance could be made by a symmetrical weight shifts to the ship's center of gravity or away from it without any appreciable variation in the gyration radius and whereas a very little variation can be made in the gyration radius without markedly varying the metacentric height, then let's consider the following assumptions having in mind the naval architectural formulations for transversal stability [4], hence as long the geometrical hull modification don't affect significantly the KB the Inclining arm GZ in the general expression of the restoring moment  $M_r = \Delta GZ$  will not induce any significant variation and also as  $GZ = BM \sin \theta - GB \sin \theta$  ( $GZ =$  stability of form—stability of weight) expression modulated by the GB variation, as long  $\Delta_{STR} \cong \Delta_{Hull}$ , BM it could be consider invariant as  $BM_{STR} = (Inertia.WL \div \nabla_{STR}) \cong (Inertia.WL \div \nabla_{Hull})$ , therefore  $GZ_{STR}$  for small inclinations angle of list ( $\sin \theta \cong \theta$ ) its assumed to be equal to  $GM_T \cdot STR \cdot \theta$  then  $M_r \cdot STR = \Delta \cdot STR \cdot GM_T \cdot STR$ . Hence, as the hull geometry vary with the draught increment, the bottom tanks compartment also will increase vertically and consequently the cargo area and by doing that, KG is expected to vary proportionally with KB at the same ratio as function of the expected structural re-arrangement, therefore also it could be assumed that  $GB \cdot STR \cong GB \cdot Hull$  hence  $GZ \cdot STR \cong GZ \cdot Hull$  which also is valid for  $GM_T = BM + (KB - KG)$  hence  $GM_T \cdot STR \cong GM_T \cdot Hull$ , it's mean the STR restoring moment is  $M_r \cdot STR \cong M_r \cdot Hull$  being the hydrodynamic roll potential damping increase by the hull draft shape variation  $B_{44} \cdot STR > B_{44} \cdot Hull$  although  $A_{44} \cdot Hull > A_{44} \cdot STR$ , which however, with the Retro Bulb modification (RTB) there is an additional mass contribution to the system

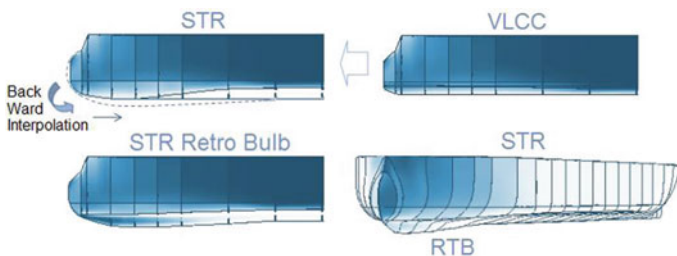
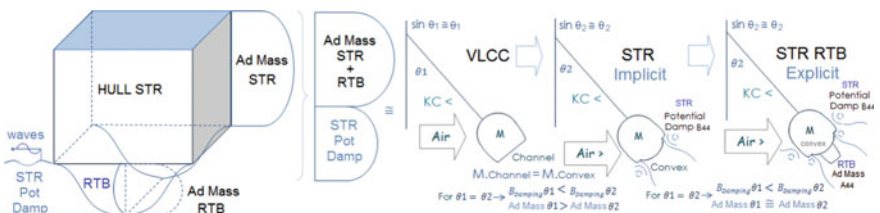
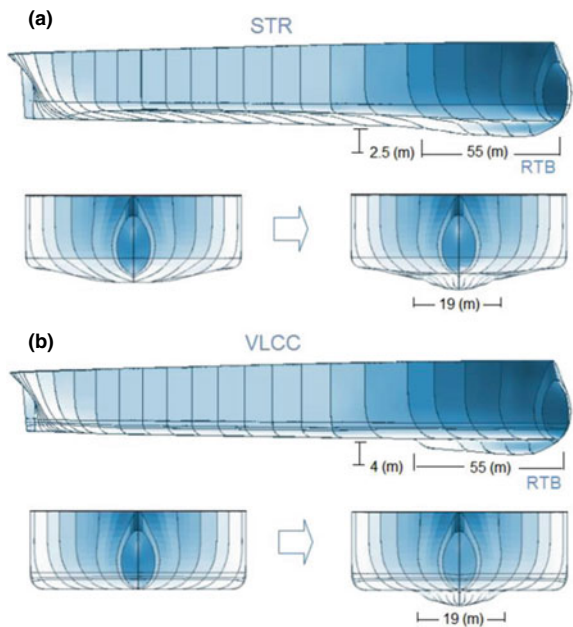


Fig. 1 STR hull modify with retro bulb

A44.STR.RTB > A44.Hull, and the same assumption it could be made, if it's considered a similar VLCC modification (RTB) A44.Hull.RTB > A44.Hull, therefore the STR hull modification with RTB could be consider in similarity with an implicit dynamical absorber that increase the vessel resistance to oscillate by varying the hull geometry by increasing the vessel energy dissipation plus an additional mass contribution from the Retro Bulb to induce an angle of list reduction as more external energy input its require to obtain the same original VLCC hull roll amplitude and therefore obtaining a gain on the transversal stability response within the stability curve in which  $GM_T$ .STR RTB varies linearly for a broad range of sea estate and consequently shifting the vessel roll natural period (e.g. pendulum with additional air resistance by varying the mass shape from a channel hull to a convex hull shape that generates additional vortex shedding or in this case potential damping plus an additional mass contribution from the Retro Bulb like an NTLS device, Fig. 3).

**Fig. 2** STR hull (a) and VLCC hull (b) retro bulb modification



**Fig. 3** STR Hull with RTB concept harmonic oscillator pendulum system comparison

Therefore, in order to quantify these effects in a simple mathematical modeling, from 1 degree of freedom uniform oscillating system under the linear assumption of uncoupled motions, the canonical equation that's represents the roll for a vessel floating in calm waters with stable equilibrium without resistance to the oscillation could be define as [1]:

$$I_{Total}(\omega) \frac{d\theta^2}{dt^2} + B_{Damping} \frac{d\theta}{dt} + C_{Restoring} \theta = 0 \quad (1)$$

Were  $\theta$ ,  $\frac{d\theta}{dt}$ ,  $\frac{d\theta^2}{dt^2}$  are roll angle, velocity, and acceleration associated with an external frequency of roll excitation were  $\omega$ : is the oscillation responses in frequency and the index 44 indicate the transversal hull reaction (4) due to roll (4), being the total oscillation Inertia  $I_{Total}(\omega)$  the sum of the free body vessel inertia  $I_{44}$  and  $I_{44}(\omega) = A(\omega)_{44}$  hydrodynamic Inertia (additional mass)

$$I_{Total}(\omega) = I_{44} + A(\omega)_{44} \quad (2)$$

Interaction fluid hull damping coefficient (wave making)

$$B_{Damping} = B_{44}(\omega) \quad (3)$$

Restoring moment coefficient (hydrostatic restoring)

$$C_{Restoring} = \rho \nabla g GM_T = K = C_{44} \quad (4)$$

Re-arrangement the roll motion equation:

$$(I_{44} + A(\omega)_{44}) \frac{d\theta^2}{dt^2} + B_{44}(\omega) \frac{d\theta}{dt} + \rho \nabla g GM_{T\theta} = 0 \quad (5)$$

For a linear oscillation motion GZ is assumed to be equal to  $GM_T \theta$  ( $\sin\theta \cong \theta$ ) C44

$$C(\theta) = \Delta GZ \quad (6)$$

$$GZ(\theta) = GM_T \theta \quad (7)$$

From [1, 2] the restoring moment coefficient on ballast condition (70%) could be considered linear until 20° and 30° for full load condition (100%), hence:

$$I_{44}(\omega) \cong I_{44} = Constant \quad (8)$$

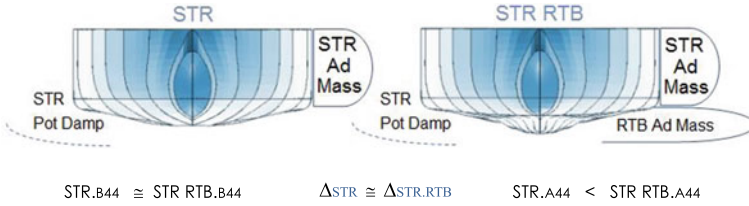
Were the natural roll frequency:



$$Roll.\omega_{n_4} = \sqrt{\frac{\rho \nabla g GM_T}{I_{44} + A_{44}}} \left( \sqrt{\frac{Static}{Inertia}} = Resonance \right) \quad (9)$$

Hence, the natural roll period:

$$Roll.T_{n_4} = \frac{2\pi}{\sqrt{\frac{\rho \nabla g GM_T}{I_{44} + A_{44}}}} \quad (10)$$



$$STR \quad Roll.T_{n_{4STR\_RB}} = \frac{2\pi}{\sqrt{\frac{\rho \nabla g GM_{STRRTB}}{I_{44} + A_{44STR} + A_{44RTB}}}} > Roll.T_{n_{4STR}} = \frac{2\pi}{\sqrt{\frac{\rho \nabla g GM_{STR}}{I_{44} + A_{44STR}}}} \quad (11a)$$

$$VLCC \quad Roll.T_{n_{4Hull\_RB}} = \frac{2\pi}{\sqrt{\frac{\rho \nabla g GM_{HullRTB}}{I_{44} + A_{44Hull} + A_{44RTB}}}} > Roll.T_{n_{4Hull}} = \frac{2\pi}{\sqrt{\frac{\rho \nabla g GM_{Hull}}{I_{44} + A_{44Hull}}}} \quad (11b)$$

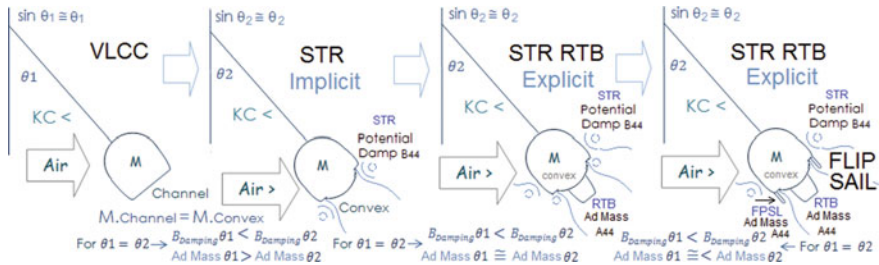
Therefore, the expression (11a) and (11b) represent the roll natural period variation for both STR and VLCC modify with the NTLs Retro Bulb (RTB) concept (Note: for edition simplification purpose  $GM_T$  it's considered to be GM).

### 3 Retro Bulb Application Examples

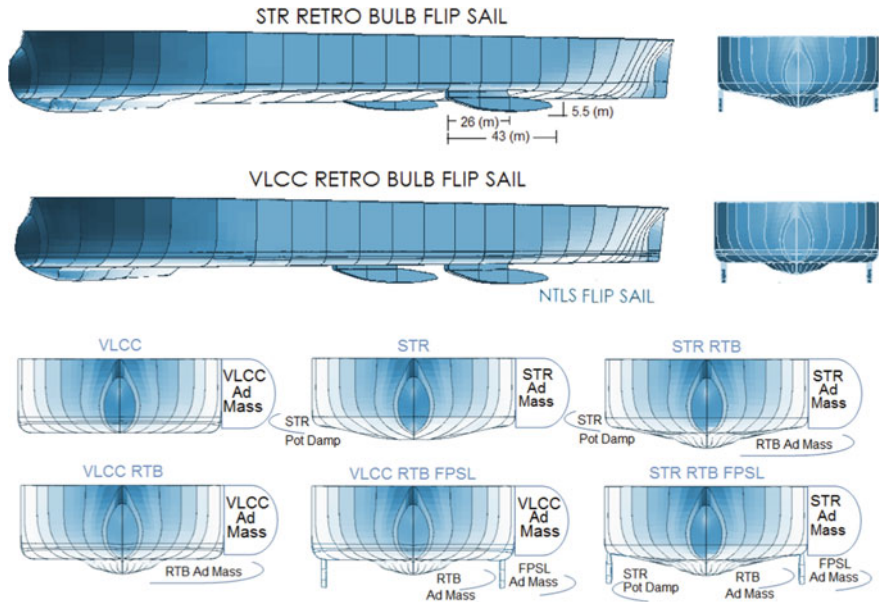
The Retro Bulb (RTB) concept natural roll period shift effect, can be appreciated from the RAO's roll plot obtained from the potential theory implemented on the program Scores [5], with the STR hull obtained from a VLCC modification [1–3] with a displacement 151,880.400 (m<sup>3</sup>) (VLCC model 152,227 (m<sup>3</sup>), STR model 155,242 (m<sup>3</sup>) 2% variation) length 273 (m), length.pp 260 (m), breath 44.500 (m), depth 22.840 floating with a draught of 16,180 (m), Rxx<sub>1</sub> 14.600 (m),  $GM_T$  5.392

(m), CG 12.62 (m) and KB 8,347 (m) STR KB 8.147 (m), from the hull base, in comparison with the STR Retro Bulb (RTB) as presented on Fig. 2 a and the VLCC also modify with Retro Bulb (Fig. 2b) and with an additional set of hull's models with the NTLS FLIP SAIL (FPSL) presented on the NTLS introduction paper (Fig. 5), from which the roll RAO's are plot in the graph on the flowing Fig. 6 , being the results summarized on Table 1 as follow:

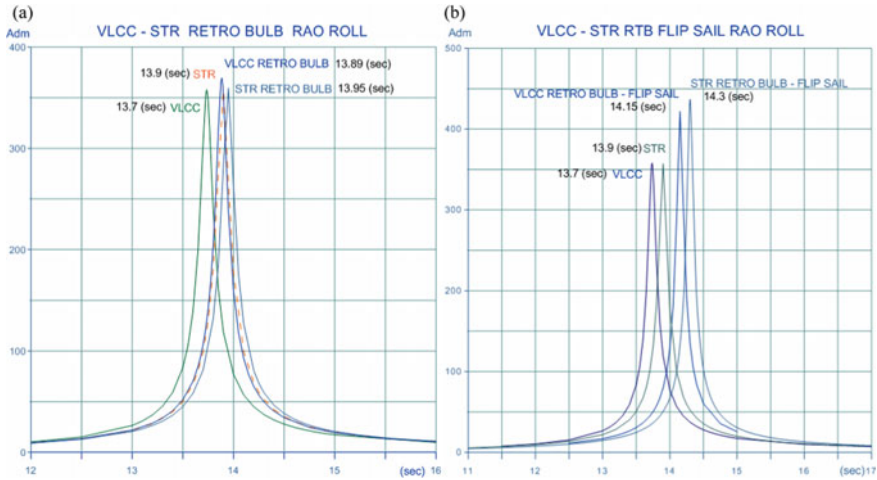
Therefore, from the roll motion RAO response for beam seas it's possible to determinate that, the roll natural period variation among the VLCC hull (13.7 (sec)) and the VLCC Retro Bulb (13.88(sec)) is 0.18 (sec) and the STR hull (13.9 (sec)) and the STR Retro Bulb (13.95 (sec)) is 0.05 (sec) which also is 0.25 (sec) shift from



**Fig. 4** VLCC, STR, STR RTB, STR RTB flip sail concepts harmonic oscillator pendulum system comparison



**Fig. 5** VLCC and STR hull's with retro bulb and NTLS flip sail



**Fig. 6 a** VLCC and STR hull’s RTB RAO roll; **b** VLCC and STR hull’s RTB Flip Sail RAO Roll

**Table 1 .**

Vessel model	GM <sub>T</sub> (m)	KB (m)	Adm. A44 × ·10 <sup>7</sup>	T <sub>p</sub> (sec)
VLCC	5.392	8.347	67.188	13.7
STR	5.034	8.152	49.19	13.9
VLCC RTB	5.256	8.29	66.548	13.88
STR RTB	4.998	8.133	49.42	13.95
VLCC RTB FPSL	5.211	8.26	80.571	14.15
STR RTB FPSL	4.956	8.11	67.166	14.3

the VLCC T<sub>p</sub>. Furthermore, the STR hull modify with the Retro Bulb and NTLs Flip Sail have a natural roll period of 14.3 (sec) which mean produce a shift of 0.6 (sec) from the VLCC bare hull T<sub>p</sub> and 0.4 (sec) shift, from the bare STR hull T<sub>p</sub>. Also, is important comment that the VLCC hull with the same modifications (RTB and FLPS) have a natural roll period of 14.15 (sec) meaning a shift of 0.45 (sec) from the bare VLCC hull that match the STR hull model (13.9 (sec)) as the hull model VLCC Retro Bulb with a roll natural period of 13.88 (sec) (Table 1). Likewise, the motions that are directly affected with the NTLs implementation are those that have a restoring response from the hull displacement volume (roll, heave and pitch), hence, in order to obtain a broad perspective of the Retro Bulb concept potential application, an evaluation on heave and pitch motion were made for the models STR and VLCC modify with Retro Bulb and Flip Sail considering a RYY<sub>1</sub> approx. 65.75 (m), from which the heave and pitch RAO’s result are plot in the flowing plots Fig. 7(a) heave and Fig. 7(b) pitch: <sub>1</sub>

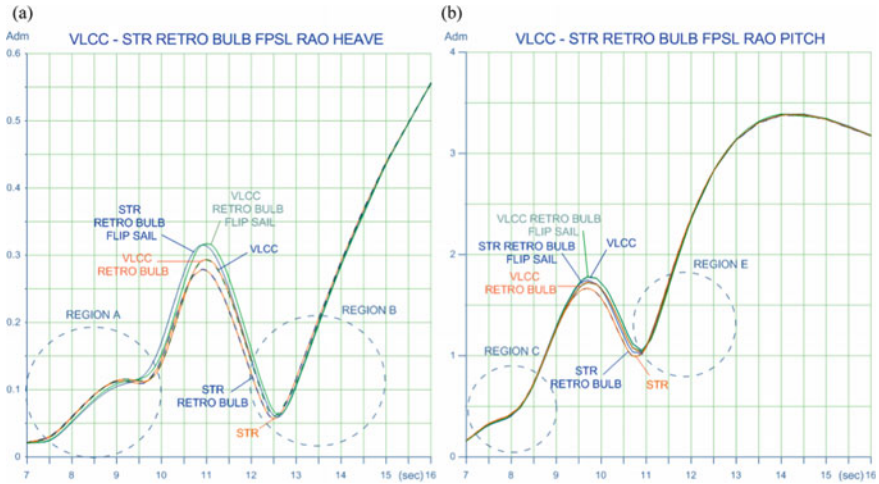
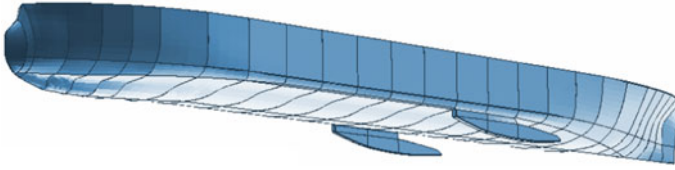


Fig. 7 VLCC and STR hull’s with RTB and NTLs Flip Sail RAO’s Heave (a) and Pitch (b) graphs

## 4 Summary

The origin of the Retro Bulb (RTB) concept presented through these pages is an extension of the Nautilus System stabilizer concept (NTLS) which began to be developed early in 2020 from a Calm Buoy concept developed on 2010 based on [1] which is a proposal for a roll motion control and directional stabilizers with a structure design conceived with neutral or positive buoyancy that could easily be attached to the hull with a minimal maintenance and with the hydrodynamics geometry properties required to generate an additional mass with the aim to enhance floating systems such as FPSO transversal stability and directional stabilization, being the starting point to pursue the RTB development to obtain a practical NTLS application with focus on conventional vessels to improve the sea keeping capability by doing a bulbous bow geometrical modification in order to contribute from an additional mass increment to reduce the angle of list (roll motion amplitudes) within the stability curve in which  $GM_T$  varies linearly for a broad range of sea estate. Hence, the Retro Bulb concept presented on this publication is obtained from a STR hull derived from a VLCC hull from [1–3] with a displacement volume variation of 2% for a full load draught (Fig. 8), being this modification applied for both models VLCC and STR hull’s with a vertical projection length of 2.5 (m) STR and 4 (m) VLCC, with an inner length both of 55 (m) and a max. width of 19 (m) as it shows on Figs. 2a and 2b, to be evaluated through the potential theory analysis using the program Scores [6] with the aim to obtain an understanding of the Retro Bulb effect considering a CG fix at 12.62 (m) from the VLCC hull base and with an additional set of hull’s models with FLIP SAIL (FPSL) state of the art presented on the NTLS introduction paper (Fig. 5) for a 90° beam seas and for heading seas (180°) heave and pitch motions.

1–3 6



**Fig. 8** STR retro bulb hull with NTLS flip sail concept

Therefore, from the roll motion RAO response analysis for beam seas it's possible to determinate that, the roll natural period variation (Fig. 6a) among the VLCC hull (13.7 (sec)) and the VLCC Retro Bulb (13.88(sec)) is 0.18 (sec) and among the STR hull (13.9 (sec)) and the STR Retro Bulb (13.95 (sec)) is 0.05 (sec) which also is 0.25 (sec) shift from the VLCC  $T_p$  (Table 1). Furthermore, the STR hull modify with the Retro Bulb and NTLS Flip Sail have a natural roll period of 14.3 (sec) (Fig. 6b) which mean a shift of 0.6 (sec) from the VLCC bare hull  $T_p$  and 0.4 (sec) shift from the bare STR hull  $T_p$  (Table 1). Also, is important to comment that the VLCC hull with the same modifications (RTB and FLPS) have a natural roll period of 14.15 (sec) meaning a shift of 0.45 (sec) from the bare VLCC hull that overcome the STR hull model (Table 1), as for instance the model VLCC Retro Bulb have a roll natural period of 13.88 (sec) that match the STR hull  $T_p$  (13.9 (sec)) as product mainly derived from the Retro Bulb vertical projection in a hull section (center line) with lower breath (bow) that increase the hull additional mass (Table 1) emulating the STR hull potential damping effect response, its mean a conventional vessel could be modify with a Retro Bulb to enhance the transversal stability, being the results of the combination VLCC RTB with the NTLS Flip Sail (additional mass modulator) (Table 1) a roll natural period of 14.15 (sec) which is 0.45 (sec) shift from the VLCC  $T_p$  (13.7 (sec)) and 0.6 (sec) shift from the STR RTB with the NTLS Flip Sail  $T_p$  (14.3 (sec)), (Table 1). Moreover, the VLCC models with Retro Bulb and Flip Sail have a significant roll motion shift response variation from the original VLCC hull as the STR hull with the same modifications, the results obtained for the response amplitudes operators (RAO) for heave and pitch motions (Fig. 7) the STR and STR RTB hull's models had the lowest amplitudes response on the interval of wave periods between 10.4 (sec) and 12.5 (sec) for heave (Fig. 7a) and the interval between 9.3 (sec) and 10.9 (sec) for pitch (Fig. 7b), mainly function of the wave irradiation capability of the STR hull and the STR hull with Retro Bulb, that have a closer roll natural period among them (13.9 (sec) to 13.95 (sec)) its mean, both generate more energy dissipation (potential damping) than the others models on these periods interval, being the response amplitude variation in heave (Fig. 7a) for the STR RTB Flip Sail with lowest amplitude response on the interval between 7 (sec) and 9.25 (sec) (Region A) and on the interval between 12.6 (sec) and 15.0 (sec) (Region B) in which also the hull model VLCC RTB Flip Sail had a lower amplitude response in similarity for the pitch response (Fig. 7b) (Region C) and on the interval between 11 (sec) and 12.5 (sec) (Region E), based on the oscillating flux equilibrium originated from the interaction among the RTB and the FPSL device that reduce the

heave and pitch response on those intervals in comparison with the VLCC and STR hull's. Additionally, although the VLCC models Retro Bulb and the Retro Bulb Flip Sail had a considerable natural roll period shift response than the bare VLCC hull, the response amplitude variation in heave and pitch (Fig. 7) for the hull's models with NTLS Flip Sail is greater, based on the oscillating flux originated from the interaction among the hull and the NTLS device, being the response variation among all those hull's models mainly product of the hull form factor, its mean the bare STR hull and the STR Retro Bulb hull in terms of the response magnitude, has been improve the VLCC hull in heave (int. 9.4 (sec) and 12.5 (sec)), pitch (int. 8.25 and 11.0 (sec)) with a gain on the transversal stability from a natural roll period shift of 0.2 (sec) and 0.5 (sec) each, being all hull's models response for large wave periods (evanescent) becoming similar, product of the increasing relation among the potential damping and additional mass effects.

## 5 Conclusion

Furthermore, the Nautilus System (NTLS) concept (stabilizers for motions and currents) is based on the idea to use a passive and easily constructed device to reduce floating system roll motion amplitude and at the same time enhance the directional stabilization capability to align with the main environmental actions, which among others factors minimize mooring and risers tension, expanding the safety operation margin scenarios within a broader range of sea states that will allow the development of innovative, reliable and economic solutions for ultra-deep-water regions and environmentally sensitive areas and with the potential to be applied on conventional vessels as additional research studies could determinate the best STR hull to obtain an optimal combination of roll, heave and pitch motions to achieve a service velocity and maneuver capability in function of the vessel application as the structural and hydrodynamic impact of the NTLS Retro Bulb (RTB) and NTLS FLIP SAIL (FPSL) concepts (e.g. the relation among and the NTLS FPSL dimension with the roll motion reduction and the vessel dynamics for different load conditions) to be implemented on new or converted hull (Fig. 8) to cross ocean routes efficiently with energy savings and decarbonization (e.g. longitudinal structural strength improvements, reduction in the parametric roll and LNG vessels sloshing probabilities occurrences) and therefore, by considering all these factors that are part of the NTLS System potential applications like the STR hull, Retro Bulb (RTB) and FLIP SAIL (FPSL), new fields of research and development it could open for classification societies, companies and academic institutions.