Optimization of a Frigate's Operability Through Machine Learning

Pablo Romero Tello
Naval Technology Area. Applied physics and Naval technology department
Escuela Técnica Superior de Ingeniería Naval y Oceánica
Universidad Politécnica de Cartagena (UPCT)
E-mail: pablo.romero@upct.es

José Enrique Gutiérrez Romero
Naval Technology Area. Applied physics and Naval technology department
Escuela Técnica Superior de Ingeniería Naval y Oceánica
Universidad Politécnica de Cartagena (UPCT)
E-mail: jose.gutierrez@upct.es

Borja Serván Camas
Centre Internacional de Metodes Numerics en Enginyeria (CIMNE)
E-mail: bservan@cimne.upc.edu

Samuel Ruiz Capel
Department of Built Environment
Oslo Metropolitan University (OsloMet)
E-mail: samuelru@oslomet.no

CONTENTS

I. INTRODUCTION

- In this work a pre-trained **Artificial Neural Networks (SPRAI)** will be used to assess seakeeping scenarios of a Frigate.
- **Operativity** in military ships is crucial to mission deploy. It is expected to sail anywhere in the world, at any time of the year and in any sea state.
- Ship operativity can be defined as probability of a task can be made with effectiveness and safety .
- Equipment should be operative in safety during ship navigation.

- Ship shapes and mass distribution are essential to accomplish the seakeeping key performance indicators in ship missions.

II. OBJECTIVES

- **Optimization** using massive exploration of different ship geometries to improve operativity of a frigate.
- **SPRAI** (developed by the authors) tool will be used to carry out massive analysis.
- **Operativity** will be assessed for different operational zones, with different operational profiles of a frigate. We will use **Operational Effectiveness (OE).**
- To accomplish with the frigate operativity different **Key Performance Indicators w**ill be assessed: MSI, maximum pitch and roll movements, vertical and horizontal RMS acceleration, deck wetness, propeller emergence, and slamming.

II. SPRAI

What is SPRAI and what is it used for?

- SPRAI is a seakeeping prediction tool based on artificial intelligence.
- SPRAI has been developed to predict the seakeeping parameters of conventional monohull ships navigating under displacement conditions (no planning).

About SPRAI

- SPRAI is based on Artificial Neural Networks (ANNs). These ANNs have been trained for years using a dataset of some 20,000 ships. The training data was generated using a seakeeping code based on the Boundary element method (BEM) in the frequency domain. SPRAI is based on the work of Romero-Tello et al (2023) and Romero-Tello et al (2024).

References:

- *Romero-Tello, P., Gutierrez-Romero, J. E., and Serván-Camas, B. Prediction of seakeeping in the early stage of conventional monohull vessels design using artificial neural networks. Journal of Ocean Engineering and Science, Volume 8, Issue 4, August 2023, Pages 344-366.*
- *Romero-Tello, P. Diseño de Buques Adaptado al Comportamiento en la Mar Mediante Inteligencia Artificial . Tesis doctoral. Universidad Politécnica de Cartagena (2024).*

IV. METHODOLOGY

Frigate → RAOs (SPRAI) → Assessing KPIs → Operational Effectiveness

Wave Spectrum Operational Areas → RAOs (SPRAI)

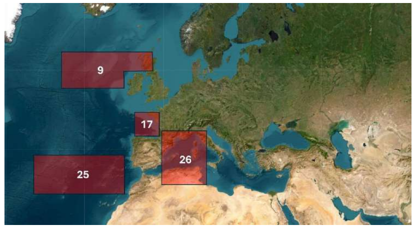
- We developed AI to massively evaluate thousand of ships candidates to maximize the operativity.
- Only ships' form coefficients are needed to explore the seakeeping performance.

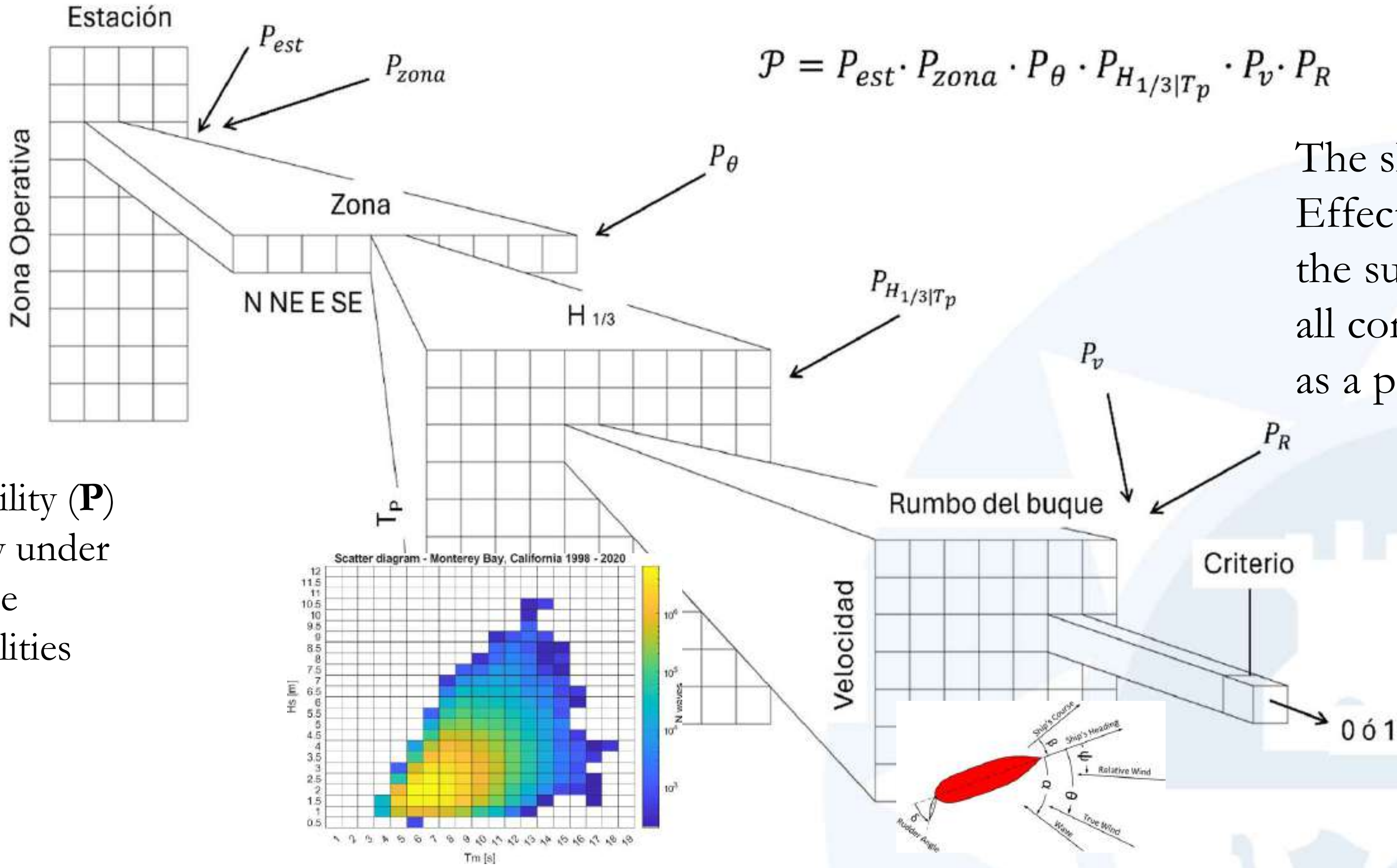
IV. METHODOLOGY. Key Performance indicators

Hull and Helicopter operations criteria		
Criterion Response	**Location**	**Criterion Levels**
		Helicopter Recovery
Vertical Velocity, RMS	Helicopter Platform	2.0 m/s
		Criteria for the hull (monohull)
Deck Wetness	Worst Station in bow region	30 occurrences / hour
Bottom Slamming	Worst Station in bow region	20 occurrences / hour
Propeller Emergence	¼ Propeller Diameter	90 occurrences / hour
		Default Criteria for the personnel
Pitch, RMS		1.5 deg
Roll, RMS		4 deg
Vertical Acceleration, RMS	Bridge	0.2 g
Lateral Acceleration, RMS	Bridge	0.1 g
Relative Wind, Mean Value	Flight Deck	35 kn
		Recommended Criteria for the personnel
Motion Sickness Incidence MSI	Task Location	20% of crew @ 4 hours
Motion Induced Interruption MII	Task Location	1 / min
Lateral Acceleration, RMS	Bridge	0.1 g
Relative Wind, Mean Value	Task Location if on Weather Deck	35 kn

$$
\begin{cases}
S_{ii}(\omega) = |RAO_{ii}|^2 \cdot S_{\xi\xi}(\omega) \\[2ex]
MSI\ (\%) = 100 \times \Phi \left\{ \dfrac{\log\left|\dfrac{\ddot{\eta}_{33}}{g}\right| - \mu_{MSI}}{0.4} \right\} \\[2ex]
a\,v_{\ RMS} = \sqrt{m_{4_{33}}} \\[1ex]
a\,h_{\ RMS} = \sqrt{m_{4_{22}}} \\[1ex]
mov_{máx} = \sqrt{2\ln(N)}\ \sqrt{m_0}
\end{cases}
$$

IV. METHODOLOGY. Operational Effectiveness





$$\mathcal{P} = P_{est} \cdot P_{zona} \cdot P_\theta \cdot P_{H_{1/3|T_p}} \cdot P_v \cdot P_R$$

The ship's Operating Effectiveness will be the sum of all **Pi** for all conditions analyzed, as a percentage.

It measures the probability (**P**) of the ship's operability under certain conditions as the product of the probabilities of occurrence of each conditional parameter.

IV. METHODOLOGY. Operational Effectiveness

$$OE = \sum_i P_i = \underbrace{\mathrm{P_{est}} \cdot \mathrm{P_{area}} \cdot \mathrm{P}_{\theta} \cdot \mathrm{P}_{\mathrm{H}_{\frac{1}{3}} | \mathrm{T_p}}}_{\text{Sea States}} \cdot \underbrace{\mathrm{P_R} \cdot \mathrm{P_v}}_{\text{Ship}} \cdot \mathrm{K}$$

The total probability will be multiplied by (K), which will be 0 or 1 depending on whether the KPI is accomplished.

The number of evaluations for a single vessel can become inordinate, if all possible combinations are considered.

$$N_{eval} = t \cdot p \cdot \prod_i (n_i \cdot m_i)$$

where t is the number of KPIs, p is the number of points to evaluate in the vessel, and n and m are the size of the matrix considered for each probability parameter **i**.

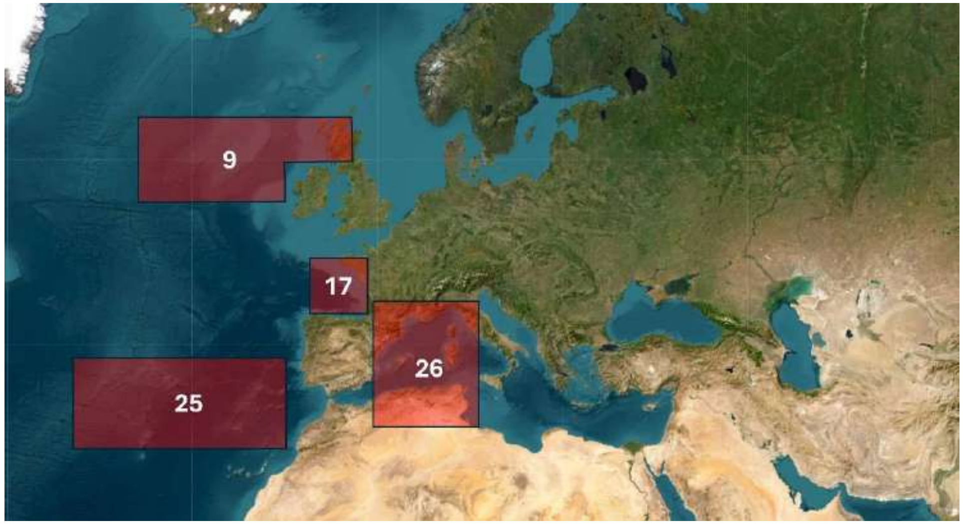
- **SPRAI enables the operability optimization by massive evaluation of ship's main form factors.**
- **This analysis can be carried out during the earlier ship design stages.**

V. APPLICATION CASE

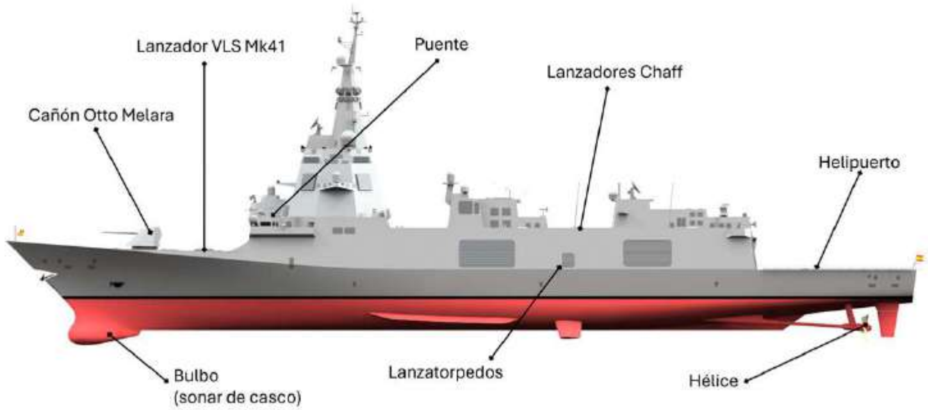
DTMB 5415 was a model conceived as a preliminary design for the U.S. Navy combat ships in the 1980s. The hull geometry includes a sonar dome and transom stern. It has twin propeller.

Characteristics	Unit	Value
Length overall, L_{OA}	m	153,300
Length between perpendicular, L_{pp}	m	142,200
Maximum beam, B_{OA}	m	20,540
Flotation beam, L_{FL}	m	19,100
Depth, D	m	12,470
Draught, T	m	6,160
Submerged volume, ∇	m^3	8424,4
Displacement, Δ	t	8636,0
KM	m	9,493
KG	m	7,555
GM	m	1,938
LCG	m	70,137
C_b	-	0,505
C_f	-	0,717
C_p	-	0,616
C_m	-	0,815
Roll radius of gyration, R_{xx}	m	$0{,}4 \cdot B$
Pitch radius of gyration, R_{yy}	m	$0{,}25 \cdot L_{pp}$
Yaw radius of gyration, R_{zz}	m	$0{,}25 \cdot L_{pp}$

V. APPLICATION CASE



Points of analysis



Probability of Ship Course - Fn

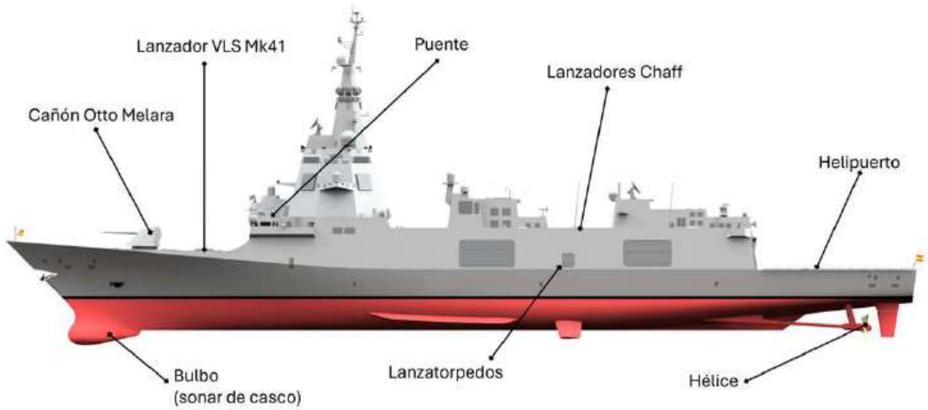
		0º	30º	60º	90º	120º	150º	180º
Fn	**0,05**	0,02	0,02	0,02	0,02	0,02	0,02	0,02
	0,10	0,07	0,07	0,07	0,07	0,07	0,07	0,07
	0,15	0,30	0,30	0,30	0,30	0,30	0,30	0,30
	0,20	0,50	0,50	0,50	0,50	0,50	0,50	0,50
	0,25	0,10	0,10	0,10	0,10	0,10	0,10	0,10
	0,30	0,01	0,01	0,01	0,01	0,01	0,01	0,01

- 4 navigation zones (9, 17, 25, and 26)
- 121 points (scatter plot Hs –Tp)
- 6 velocity considered
- 7 ship courses
- 4 seasons
- 8 points of analysis

$2{,}6 \times 10^6$ assesments /ship

V. APPLICATION CASE. Ship candidates

Parameter	Range
Length between perpendicular, L_{pp}	[120,7; 163,3] m
Flotation Beam, B_{FL}	[16,235; 21,965] m
Draught, T	[5,228; 7,073] m
Flotation coefficient, C_f	[0,701; 0,948]
Midship coefficient, C_m	[0,693; 0,937]



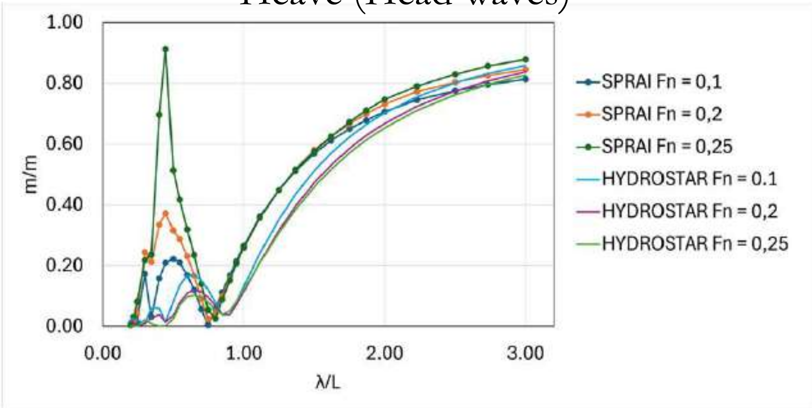
Optimization constraints:

- Displacement is constant.
- Six parametric variations for each parameter.
- Block coefficient should be within the range of ±15 % of the original ship

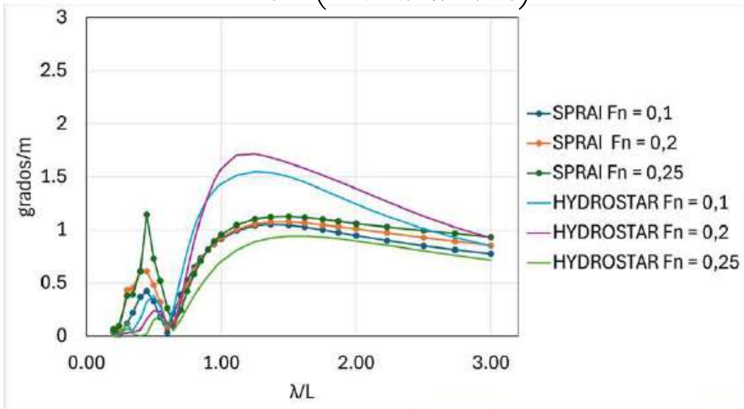
5.148 Ship candidates

IV. APPLICATION CASE. Initial verifications

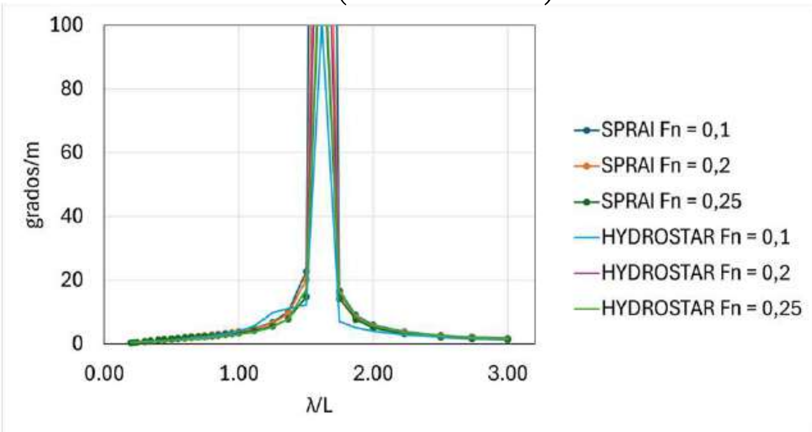
Heave (Head waves)

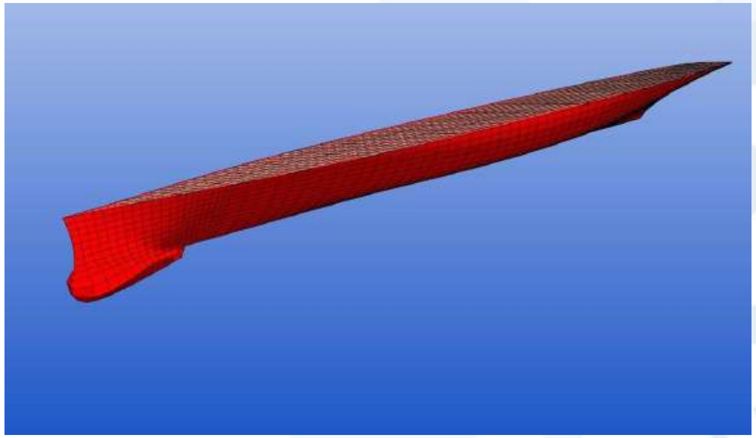


Pitch (Head waves)



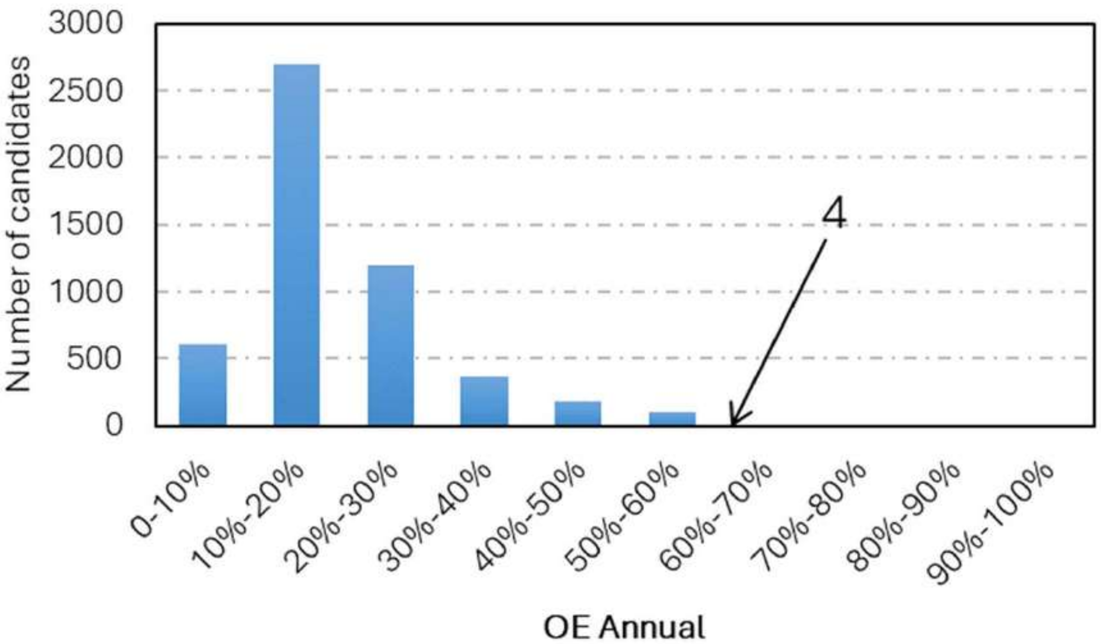
Roll (Beam waves)

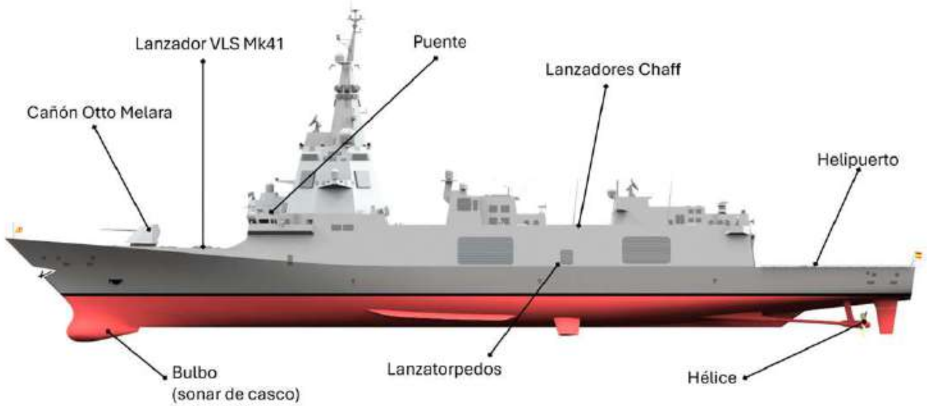




- SPRAI versus Hydrostar BV
- Initial verifications
- Three Froude numbers

V. APPLICATION CASE. Results





- Only four ships has annual Operational Effectiveness higher than 60%
- Original ship has an OE of 15%
- Small changes (less than 15%) in ship's form coefficients increases the OE up to 45%.
- North Atlantic navigation reduces OE significantly

IV. APPLICATION CASE. Results

South Atlantic

	Est 1	Est 2	Est 3	Est 4
0-10%	4594	4189	2949	3808
10%-20%	340	512	853	713
20%-30%	143	209	534	257
30%-40%	59	122	311	176
40%-50%	10	92	181	115
50%-60%	1	22	105	66
60%-70%	1	2	102	12
70%-80%	0	0	71	1
80%-90%	0	0	42	0
90%-100%	0	0	0	0

Cantabrian

	Est 1	Est 2	Est 3	Est 4
0-10%	4799	3870	2279	3965
10%-20%	296	806	1229	746
20%-30%	51	256	605	249
30%-40%	2	144	455	137
40%-50%	0	68	210	50
50%-60%	0	3	154	1
60%-70%	0	1	123	0
70%-80%	0	0	87	0
80%-90%	0	0	6	0
90%-100%	0	0	0	0

Eastern Mediterranean

	Est 1	Est 2	Est 3	Est 4
0-10%	0	0	0	0
10%-20%	203	44	0	0
20%-30%	703	464	0	257
30%-40%	1641	735	134	561
40%-50%	1364	1392	427	1231
50%-60%	769	1179	713	1255
60%-70%	274	836	1336	1114
70%-80%	142	308	1351	478
80%-90%	52	178	927	205
90%-100%	0	12	260	47

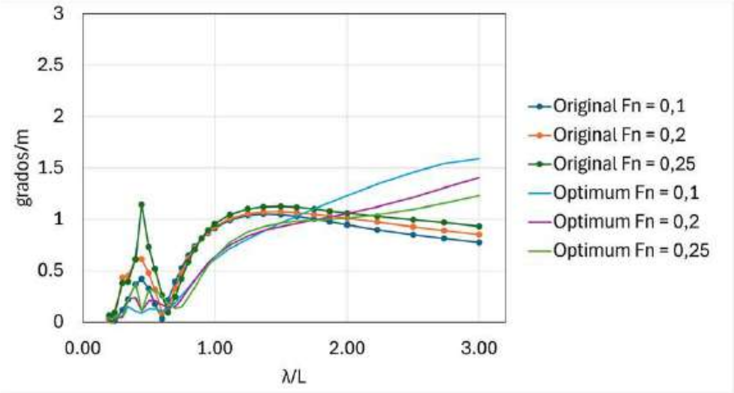
North Atlantic

	Est 1	Est 2	Est 3	Est 4
0-10%	5056	4352	2823	4637
10%-20%	92	527	1093	341
20%-30%	0	175	612	132
30%-40%	0	89	271	38
40%-50%	0	5	140	0
50%-60%	0	0	108	0
60%-70%	0	0	79	0
70%-80%	0	0	22	0
80%-90%	0	0	0	0
90%-100%	0	0	0	0

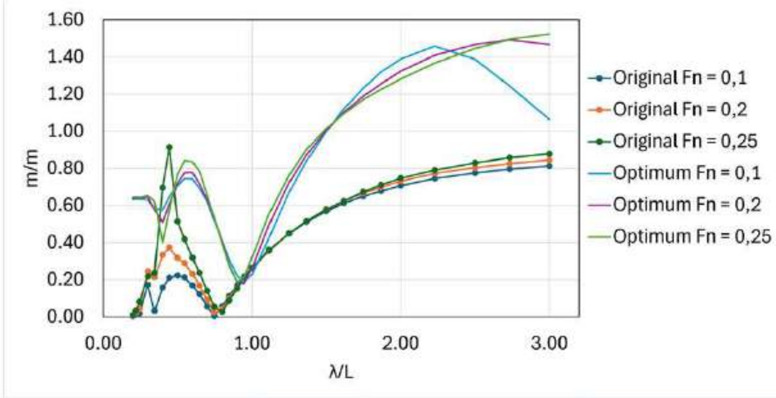
Number of ship candidates per range of operativity and operational zone

IV. APPLICATION CASE. Results

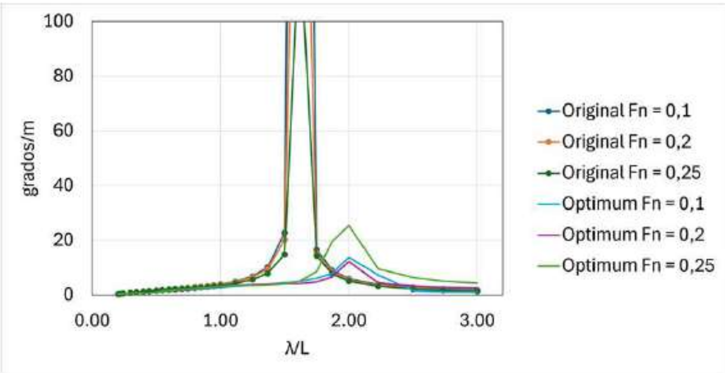
Heave (Head waves)



Pitch (Head waves)



Roll (Beam waves)



- Natural periods are increased
- Roll amplitudes at natural frequencies are reduced significantly.

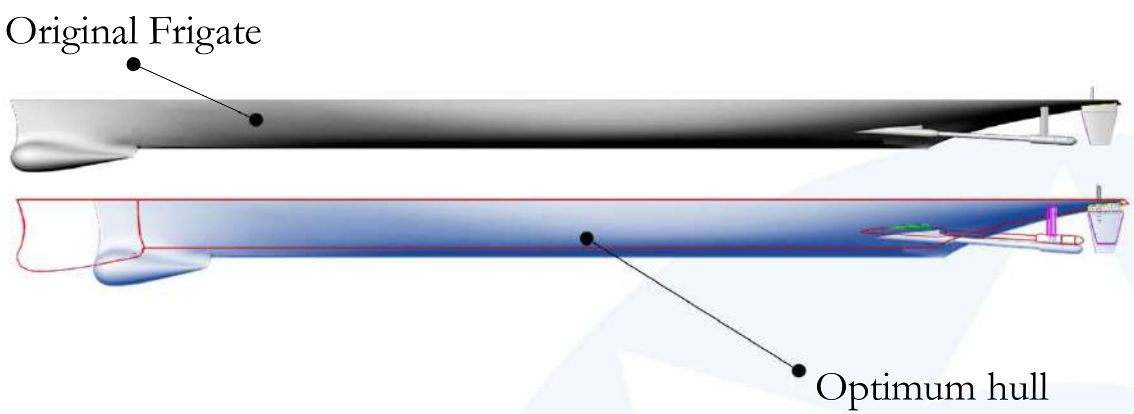
VI. CONCLUSIONS

Original Frigate

	Est 1	Est 2	Est 3	Est 4
North Atlantic	0%	2%	6%	1%
Eastern Mediterranean	36%	45%	67%	50%
Cantabrian	1%	3%	9%	3%
South Atlantic	1%	1%	5%	2%

Optimum Frigate

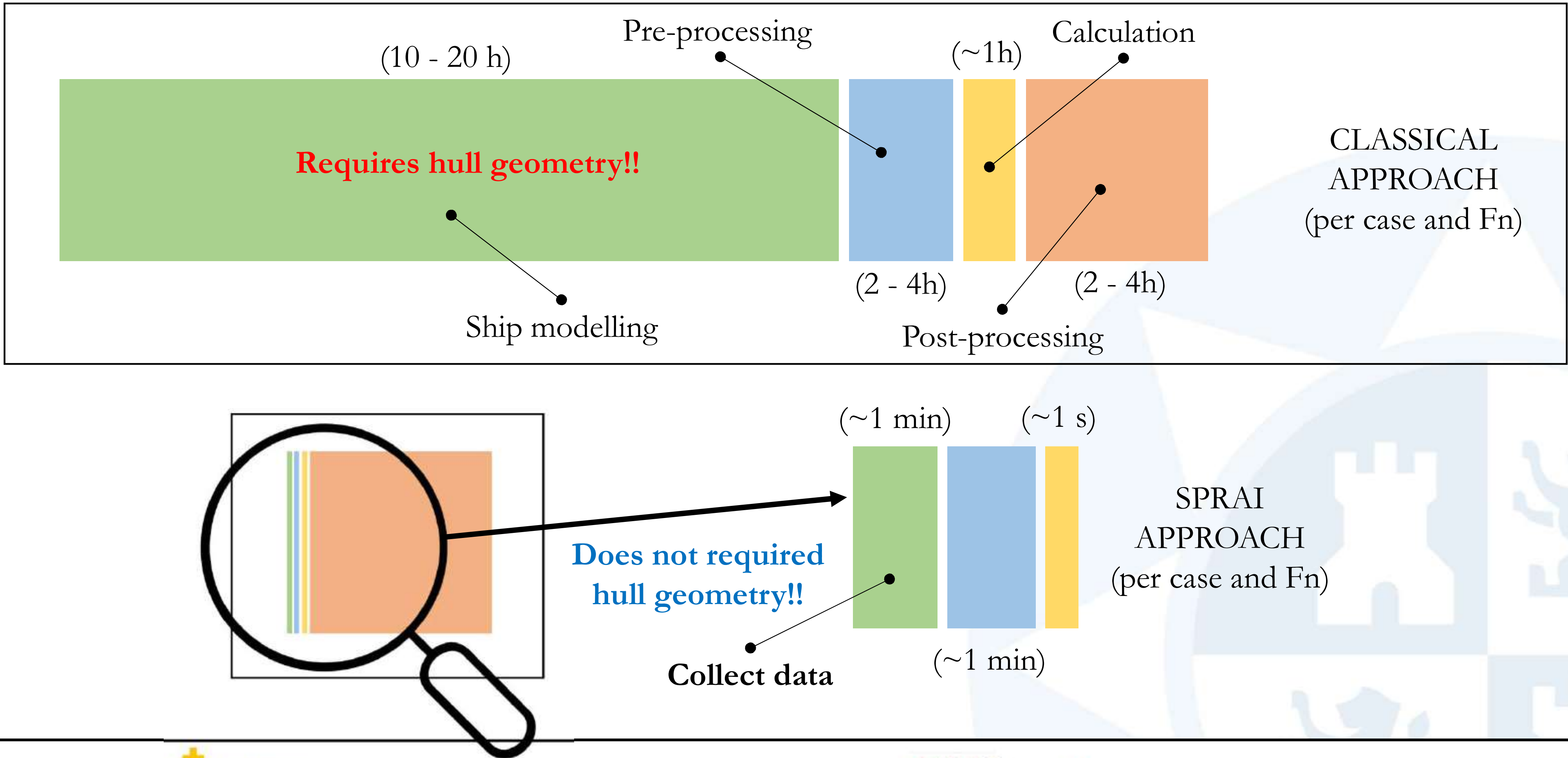
	Est 1	Est 2	Est 3	Est 4
North Atlantic	19%	44%	73%	37%
Eastern Mediterranean	78%	86%	95%	88%
Cantabrian	37%	60%	85%	58%
South Atlantic	62%	70%	85%	78%



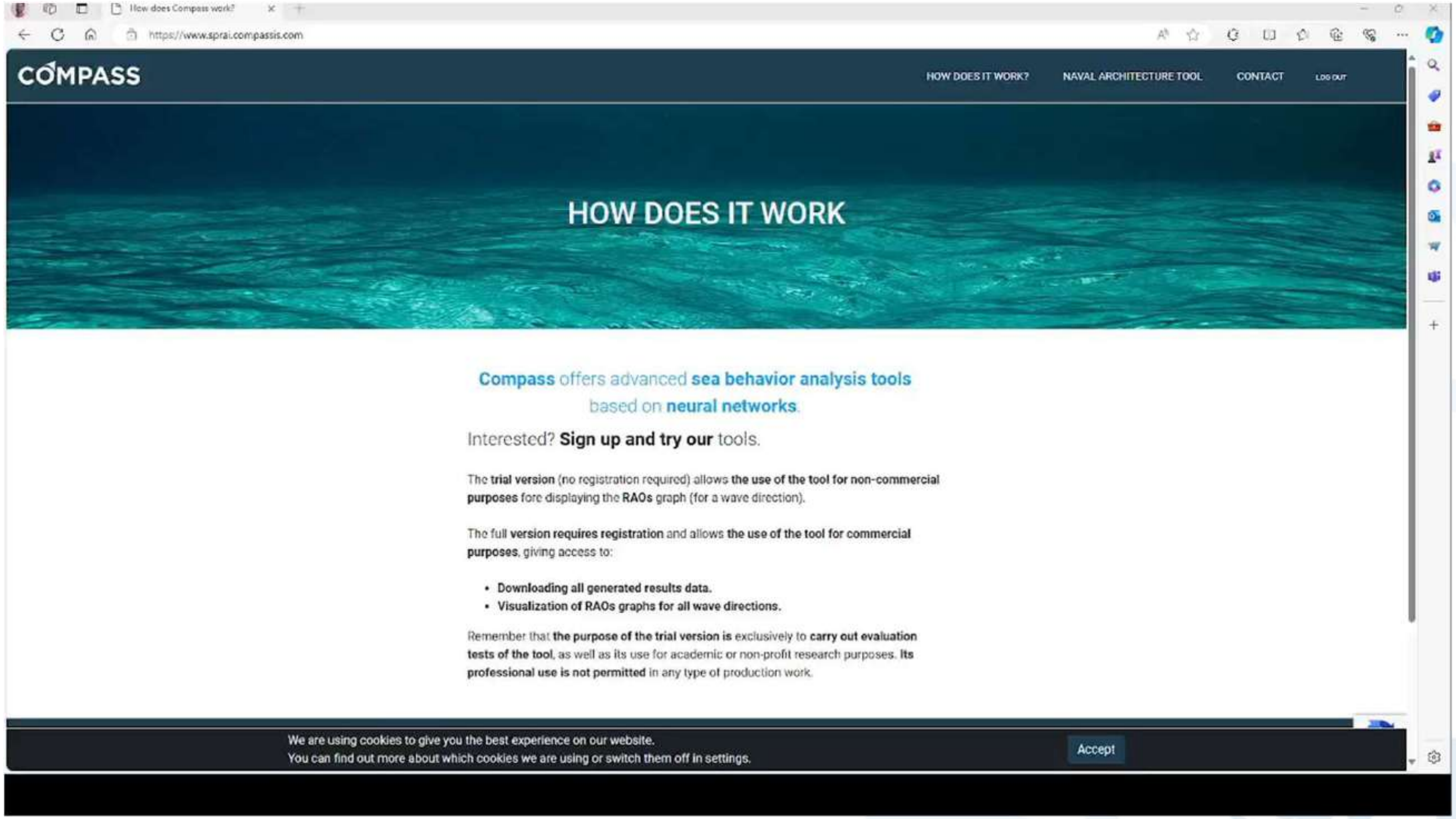
	Optimum	Original
L_{pp}	120,70	142,20
B	21,97	20,54
T	5,60	6,16
C_b	0,568	0,505
C_f	0,849	0,717
C_m	0,693	0,815
OE	0,659	0,146

- High number of calculations (up to $2{,}1 \times 10^8$) to achieve best operational profile
- Most ships candidates have low OE
- Improving OE in all seasons and operational zones.
- This analysis is not allowable with traditional techniques.
- Computation times less than 48h.

V. DISCUSSION



VI. SPRAI WEB


How does Compass work?
https://www.sprai.compassis.com
COMPASS
HOW DOES IT WORK?
NAVAL ARCHITECTURE TOOL
CONTACT
LOG OUT
HOW DOES IT WORK
Compass offers advanced sea behavior analysis tools based on neural networks.
Interested? Sign up and try our tools.
The trial version (no registration required) allows the use of the tool for non-commercial purposes fore displaying the RAOs graph (for a wave direction).
The full version requires registration and allows the use of the tool for commercial purposes, giving access to:
• Downloading all generated results data.
• Visualization of RAOs graphs for all wave directions.
Remember that the purpose of the trial version is exclusively to carry out evaluation tests of the tool, as well as its use for academic or non-profit research purposes. Its professional use is not permitted in any type of production work.
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THANKS FOR YOUR ATTENTION

jose.gutierrez@upct.es

Questions?