Efficient and sustainable naval design: Exploring the impact of vessel lengthening on propulsion and stability

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Abstract

Enhancing sustainability in ship design requires innovative solutions that improve environmental impact and operational efficiency. This study evaluates the impacts on propulsion and stability from lengthening an offshore field support vessel (FSV) by five meters at the midsection. The primary goal of this modification is to increase deck cargo capacity and reduce the Energy Efficiency Design Index EEDI. However, this hull modification introduces technical challenges related to the vessel's stability and operational performance, particularly in maneuvers requiring precise positioning. The comparison between the Prototypevessel and its lengthened version using the same propulsion system assessed parameters such as intact stability, brake power, performance under dynamic positioning systems, and potential resonance under dynamic anchoring conditions. Results highlight an increase of 138 tons in deck cargo capacity, working with the same draft of 4.25 meters and a significant 19.67% improvement in the EEDI, positioning the lengthened vessel as a sustainable and competitive alternative. On the other hand, a 2.23% increase in brake power (BkW) required at 14 knots was observed, along with a slight 0.36% reduction in propeller efficiency due to alterations in hydrodynamic flow.

Key words: Sustainability, Naval Innovation, Offshore Engineering, Maritime Design Efficiency, Field Support Vessel, Energy Efficiency Design Index, Deck cargo capacity, Dynamic positioning, Naval Design, propulsion, stability.

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Introduction

Background

Field Support Vessels (FSVs) are essential for offshore operations, providing logistical support to gas platforms at sea. They are known for their exceptional maneuverability, enabled by advanced propulsion systems and dynamic positioning (DP) technology, allowing them to maintain position even under challenging conditions such as wind, currents, and waves.

This study aims to compare the performance of the Prototype vessel with the lengthened version, keeping the same propulsion system, to assess its stability and dynamic positioning capabilities. Additionally, the study aims to determine whether the modification enhances operational efficiency while ensuring compliance with safety standards and maintaining effectiveness in offshore support operations.

Methodology

First, it is important to review the main characteristics of the Prototype vessel at its current configuration and the operational route defined for the vessel to navigate from Guayaquil to the Talara gas platforms, considering the critical conditions associated with “El Niño” meteorological events.

According to Guerrero *et al*. (2025), the structural assessment of the vessel focused on evaluating the permissible lengthening based on the sectional modulus of the original vessel. Using the calculations provided by the Poseidon software, the midship section modulus is 0.90 m³. The proposed five-meter lengthening is 0.771 m³, which remains within acceptable limits as per DNV rules. Fig. 1 shows the 3D model of the original vessel compared with the lengthened vessel, with the section to be added.

Table 1. General characteristics of the Prototype vessel.

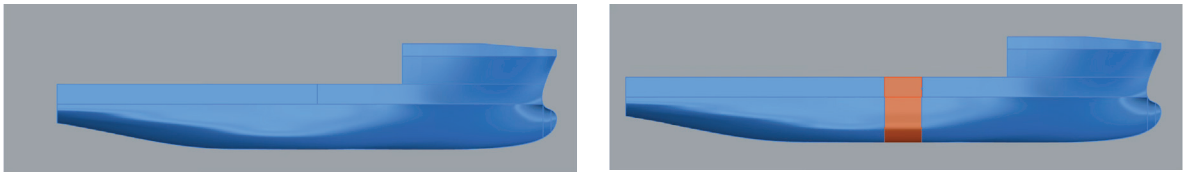
Description	Symbol	Original ship
Overall Length	L_{OA} *[m]*	66.80
Length Between Perpendiculars	L_{BP} *[m]*	63.00
Beam	*B [m]*	16.00
Molded Depth	*D [m]*	6.00
Draft	*T [m]*	4.25
Speed	*V [knots]*	14.00
Deadweight	*DWT [tons]*	900
Gross Tonnage	*GT [-]*	1800
Main Engines	-	2
Engine Power (per unit)	*PENGINE [kW]*	1935
Total Engine Power	*PTOTAL ENGINE [kW]*	3870
Engine RPM	*RPM*	1000
Propeller Diameter	*DPROPELLER [m]*	2.80
Energy Efficiency Design Index	*EEDI [-]*	255.38

Table 2. Prototype vessel operational route.

N°	Point of Interest	Wave Height [m]	Period [s]	Sea State
1	Departure from Guayaquil port	0.50	6.71	2
2	Gulf of Guayaquil	2.00	8.87	4
3	Coast off Zorritos	2.50	9.20	4
4	Coast off Mancora	3.00	9.53	5
5	Talara Platforms Lot Z-2B	4.00	10.85	5

Source: Own elaboration

Fig. 1. 3D model of the prototype vessel and the lengthened vessel.



Intact Stability

In the intact stability study, an analysis is carried out to determine the KG limit of both vessels, with the objective of calculating the VCG of the deck cargo at different drafts. Subsequently, using the Maxsurf Stability program, the tank configuration of both vessels is defined and presented in Fig. 2, considering the weights corresponding to the hull, superstructure, machinery, insulation, and cargo. With all this information entered in the program, the analysis is performed for a specific condition and for stability at large angles. It is important to note that, in this analysis, the same tank loading condition has been considered for all cases to determine the increase in the carrying capacity of the vessels and evaluate their performance. As a result, hydrostatic data and GZ curves are obtained for the prototype and the modified version, which are evaluated according to the first-generation intact stability criteria established by the IMO.

Propulsion System

To evaluate the propulsion system of both models, the Maxsurf Resistance software was used to obtain the brake power BkW curves as a function of speed, using the Slender Body method, which is suitable for modeling the bare hull resistance of both hulls. Power losses due to the propeller configuration were considered by applying the propeller efficiency to calculate the brake power.

Resonance at dynamic anchorage

The behavior of vessels in dynamic positioning near the Talara platforms was evaluated, considering their offshore operational load case. The analysis included the wave period of the points of interest, to avoid potential resonance problems. The formulas used are the oscillation period of the vessel and the C coefficient, which are based on the main dimensions of the ship and the IMO Code on Intact Stability *(International Maritime Organization IMO, 2008*).

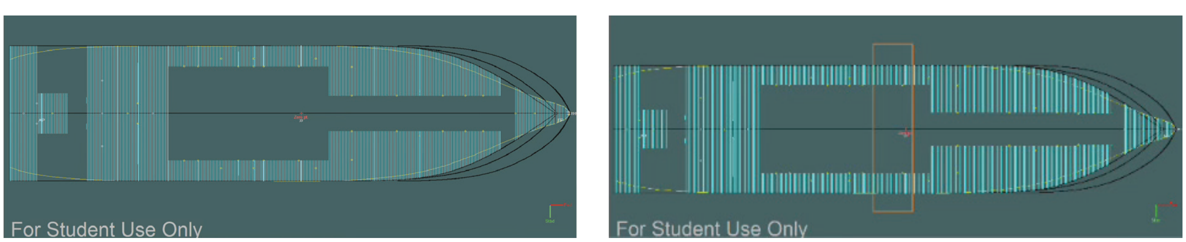
$$T_S = \frac{2CB}{\sqrt{GM_t}} \tag{1}$$

$$C = 0.373 + 0.023\frac{B}{D} - 0.043\frac{L}{100} \tag{2}$$

$$T_{TRANS} = F\,L_{WL}\,T \tag{3}$$

$$P = \frac{T_{TRANS}}{\eta_{MEDIA}} \tag{4}$$

Fig. 2. Tanks of the prototype vessel and the lengthened vessel.



$$V_{PSI} = \frac{188}{L_{BP}} F^{\frac{1}{2}} \quad (5)$$

$$T_{AZIMU} = K_T \, \gamma \, n_{ENGINE}^2 \, D_{AZIMU}^4 \quad (6)$$

$$T_{EFF} = T_{AZIMU} \cos\theta \quad (7)$$

Merit Criteria

The load coefficients of both vessels will be calculated according to SNAME *(Lewis, 1988)*, to evaluate their efficiency in terms of load capacity using equation (8), as a function of waterplane area and volume of the vessel.

$$C_C = \frac{A_{WL}}{Vol^{2/3}} \quad (8)$$

Finally, EEDI values, as defined by the IMO – Marpol – Annex VI (IMO, 2022) Equation (9), was determined to analyze this merit criterion in terms of energy and environmental efficiency.

$$EEDI = \frac{\left(f_j \Sigma_{i=1}^{nME} P_{MEi} CF_{MEi} SFC_{MEi}\right) + \left(P_{AE} CF_{AE} SFC_{AE}\right)}{f_i f_c f_l Capacity f_w V_{ref} f_m} \quad (9)$$

Results

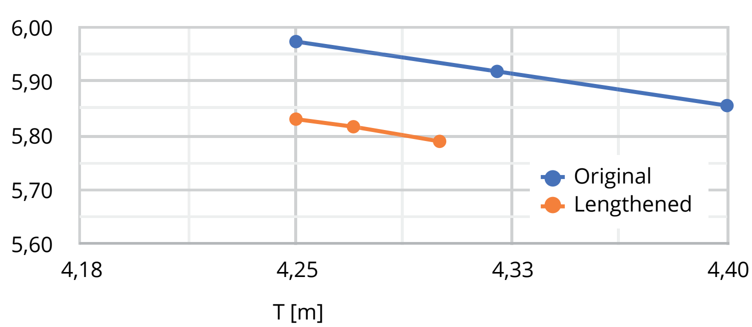
From the analysis performed to determine the vessel's KG limit at different drafts, the following results were obtained.
Similarly, as a function of the vessel's DWT, we found the load capacity of both the prototype and the lengthened vessel, as shown below.

With this, the position of the center of gravity of the deck cargo is calculated to know the maximum value of this parameter without compromising the stability of the vessel.

Table 3. KG limit – vessels.

Prototype			Lengthened		
Draft [m]	KG Limit [m]	DWT [tons]	Draft [m]	KG Limit [m]	DWT [tons]
4.25	5.973	900	4.25	5.830	1120
4.32	5.918	965	4.27	5.816	1142
4.40	5.855	1039	4.30	5.789	1172

Fig. 3. Vessels KG limit curves versus draft, based on Maxsurf Stability results.



Similarly, as a function of the vessel's DWT, we found the load capacity of both the prototype and the lengthened vessel, as shown below.

With this, the position of the center of gravity of the deck cargo is calculated to know the maximum value of this parameter without compromising the stability of the vessel.

Table 4. Weight detail – lightship.

Description	Symbol	Prototype	Lengthened	Difference %	Ratio
Hull	*WH [tons]*	956	1030	7.80	1.08
Superstructure	*WS [tons]*	97	97	0.00	1.00
Equipment	*WE [tons]*	272	294	7.94	1.08
Machinery	*WM [tons]*	293	296	0.96	1.01
Insulation	*WI [tons]*	243	258	6.12	1.06
Fixed ballast	*WFB [tons]*	132	138	4.49	1.04

Table 5. Weight detail – DWT.

Description	Units	Prototype	Lengthened	Difference %	Ratio
Fuel Oil	*[ton]*	334	417	24.92	1.25
Water Ballast	*[ton]*	180	185	2.58	1.03
Fresh Water	*[ton]*	225	219	2.67	0.97
Sewage water	*[ton]*	1	1	0.00	1.00
Cargo	*[ton]*	160	298	86.25	1.86
DWT	*[ton]*	900	1120	24.47	1.24

Fig. 4. Vessels KG cargo above main deck curves versus DWT, based on Maxsurf Stability results.

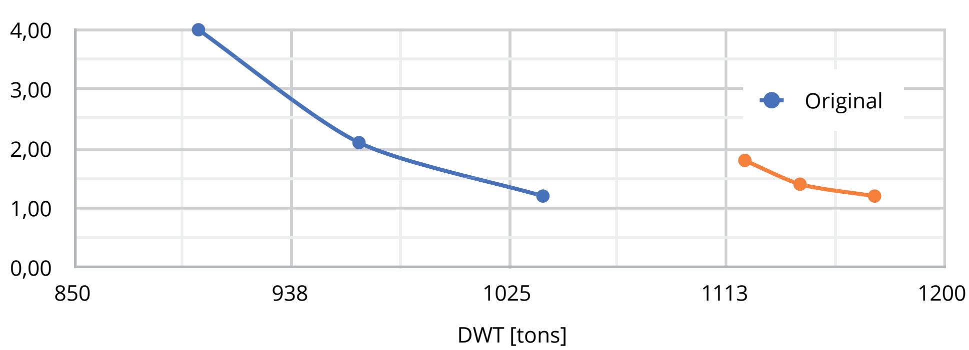


Table 6. Cargo KG above main deck – vessels.

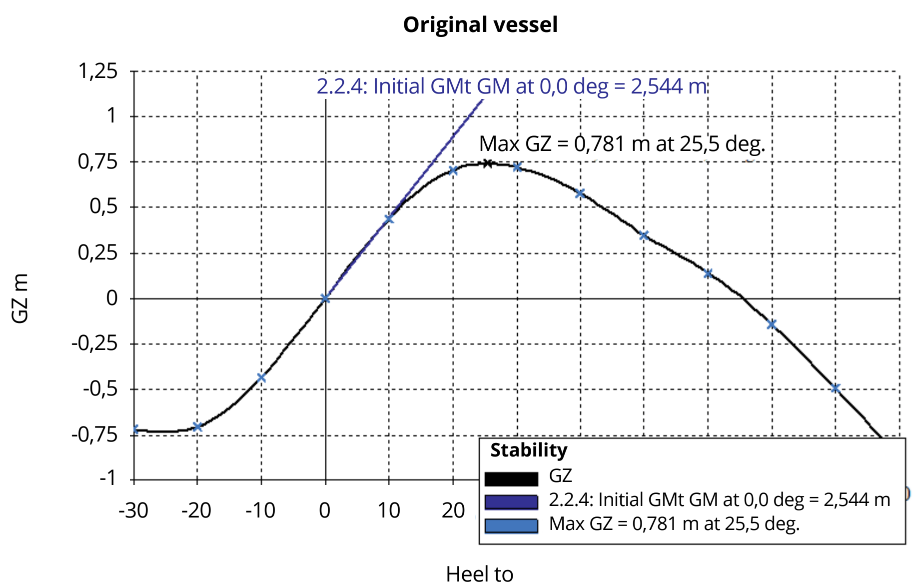
Prototype			Lengthened		
DWT [tons]	Cargo [tons]	Cargo KG above main deck [m]	DWT [tons]	Cargo [tons]	Cargo KG above main deck [m]
900	160	4.00	1120	298	1.80
965	225	2.10	1142	328	1.40
1039	299	1.20	1172	348	1.20

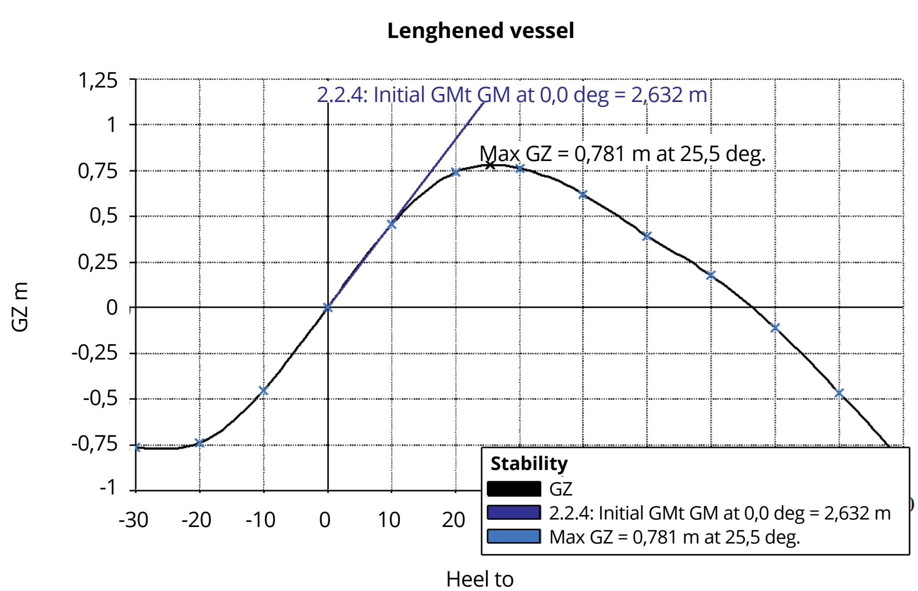
Table 7. Hydrostatic results of the vessels.

Description	Prototype	Lengthened
Draft Amidships [m]	4.25	4.25
Displacement [ton]	2893.00	3235.00
WL Length [m]	66.79	71.81
Wetted Area [m^2]	1176.70	1290.43
Waterpl. Area [m^2]	899.16	981.58
Prismatic coeff. (Cp)	0.65	0.66
Block coeff. (Cb)	0.60	0.63
Max Sect. area coeff. (Cm)	0.95	0.95
Waterpl. area coeff. (Cwp)	0.84	0.84
LCB from zero pt. (+ve fwd) [m]	-2.18	-2.71
LCF from zero pt. (+ve fwd) [m]	-5.43	-5.60
KB [m]	2.44	2.41
KG [m]	5.87	5.73
BMt [m]	5.92	5.89
BML [m]	91.17	104.50
GMt [m]	2.49	2.57
GML [m]	87.74	101.18
KMt [m]	8.36	8.30
KML [m]	93.62	106.92
MTc [ton.m]	41.05	48.97
RM at 1deg GMt.Disp.sin (1) [ton.m]	125.85	145.05
Trim angle (+ve by stern) [°]	-0.11	0.19

Similarly, the resulting plots for the righting arm curve GZ presented in Fig. 5, showed compliance with the properties of the righting arm curve mentioned in the 2008 International Code of Intact Stability, which details that the minimum area under the GZ curve up to an angle of 30 degrees must be at least 0.055 meters - radians, having values of 0.27 meters - radians and 0.275 meters - radians. It is also established that the area under the GZ curve up to an angle of 40° should not be less than 0.09 meter-radians, a parameter that, in our results, is equal to 0.389 meter-radians and 0.392 meter-radians for the original and the lengthened vessel, respectively. Finally, the area under the GZ curve between 30° and 40° should not be less than 0.03 meters - radians; for our vessels, it is 0.119 and 0.117 meters - radians.

Fig. 5. GZ curve for prototype (top) and lengthened vessel (bottom).





It is important to note that from this point forward, all results are expressed for the draft T = 4.25 [m].

Similarly, the resonance evaluation at dynamic anchorage for the original and the lengthened vessel is displayed in Tables 9 and 10, corresponding to the operational checkpoints outlined in Table 10. The results of the performance of the dynamic positioning system are shown on Tables 11 and 12. Finally, the results obtained for both the EEDI and merit criteria, are presented on Tables 13 and 14.

Fig. 6. Vessels brake power curves versus speed, using the Slender Body method based on Maxsurf Resistance results.

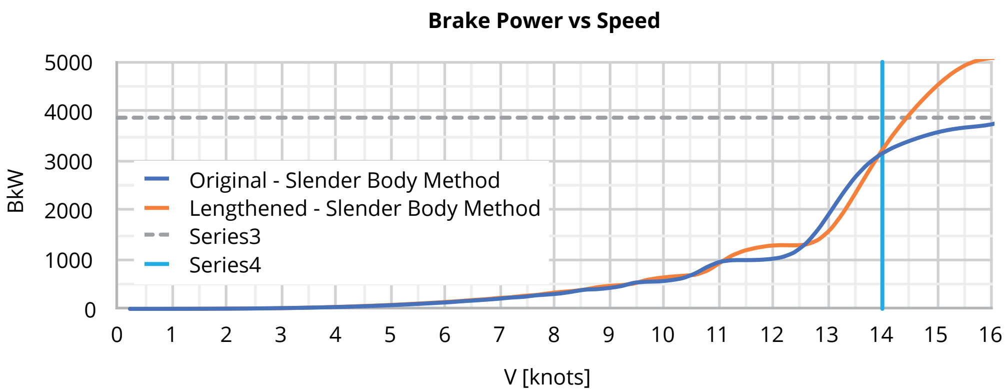


Table 8. Propeller performance for the vessels at 14 knots.

Symbol	Prototype	Lengthened	Difference %	Ratio
η [-]	53.16%	52.96%	0.36	1.00
BkW	3148.57	3218.70	2.23	1.02

Table 9. Periods of operational checkpoints and vessels.

Symbol	Prototype	Lengthened	Difference %	Ratio
T_{W1} [s]	6.71	6.71	0.00	1.00
T_{W2} [s]	8.87	8.87	0.00	1.00
T_{W3} [s]	9.20	9.20	0.00	1.00
T_{W4} [s]	9.53	9.53	0.00	1.00
T_{W5} [s]	10.85	10.85	0.00	1.00
T_S [s]	8.23	8.06	2.05	0.98

Table 10. Resonance evaluation of the vessels.

Operational Checkpoints	Symbol	Prototype TS = 8.23 s		Resonance	Lengthened TS = 8.06 s		Resonance
		7.81	8.64		7.65	8.46	
Departure from Guayaquil port	TW_1 [s]	6.71		No	6.71		No
Gulf of Guayaquil	TW_2 [s]	8.87		No	8.87		No
Coast off Zorritos	TW_3 [s]	9.20		No	9.20		No
Coast off Mancora	TW_4 [s]	9.53		No	9.53		No
Talara Platforms Lot Z - 2B	TW_5 [s]	10.85		No	10.85		No

Table 11. Transverse thruster performance of the vessels.

Symbol	Prototype	Lengthened	Difference %	Ratio
η_{MEDIA} [kg/hp]	11.00	11.00	0.00	1.00
F_{TRANS} [kN/m²]	0.13	0.13	0.00	1.00
T_{TRANS} [kN]	34.81	37.57	7.94	1.08
P [kW]	237.32	256.16	7.94	1.08
V_{PSI} [°/s]	1.08	1.00	7.35	0.93

Table 12. Retractable bow azimuthal performance.

Symbol	Prototype
KT [-]	0.24
n_{ENGINE} [rev/s]	4.17
D_{AZIMU} [m]	1.70
T_{AZIMU} [kN]	35.67
T_{EFF} [kN]	25.22

Table 13. Comparison of C_C values of the vessels.

Symbol	Prototype	Lengthened	Difference %	Ratio
AWL [m²]	899.84	980.52	8.97	1.09
Vol [m³]	2822.88	3156.18	11.81	1.12
C_C [-]	4.51	4.56	1.15	1.01

Table 14. Comparison of EEDI values of the vessels.

Description	Symbol	Prototype	Lengthened
Main Engine(s) Emissions	PME [kW]	1935.00	1935.00
	CFME [gCO2/ gFuel]	3.206	3.206
	SFCME [g/ kWh]	190.00	190.00
Auxiliary Engine(s) Emissions	PAE [kW]	193.50	193.50
	CFAE [gCO2/ gFuel]	3.206	3.206
	SFCAE [g/ kWh]	215.00	215.00
Deadweight	DWT [tons]	900	1120
Reference Speed	VREF [knots]	14.00	14.00
Factors	fj [-]	1.00	1.00
	fi [-]	1.00	1.00
	fc [-]	1.00	1.00
	fl [-]	1.08	1.08
	fw [-]	0.72	0.72
	fm [-]	1.00	1.00
Energy Efficiency Design Index	EEDI [-]	255.38	205.15

Table 15. MSI Comparison.

0.51	Description	Prototype	Lengthened	Difference %	Ratio
a [m/s²]	Head Wave: Bridge	1.40	1.30	7.14	0.93
	Beam Wave: Load Area	0.50	0.51	2.00	1.02

Discussion

Fig. 3, along with Table 3, identifies the optimal draft for positioning the highest center of gravity of the deck cargo without compromising the intact stability of either the Prototype vessel or the lengthened vessel. This characteristic is of interest to the shipowner, as it involves a support vessel for offshore gas platforms where the deck cargo can be of significant magnitude. In addition, in terms of weight distribution, an increase of 24.44% in DWT is obtained with the five-meter lengthening, which translates into an increase of 138 tons in deck cargo capacity, in addition to a 25% increase in fuel capacity, as well as a variation of only 3% in terms of freshwater and wastewater capacity. The results considered the fact that the draft to be used for the remainder analysis was 4.25 m, as it allows for a greater cargo height while ensuring good propulsion system performance, enabling efficient operation at a speed of 14 knots.

Based on the hydrostatic results in Table 7, the comparison of stability parameters between the Prototype and the lengthened vessel highlights key differences. The lengthened FSV presents a slightly higher metacentric height, from a GMt equal to 2.49 meters to 2.57 meters, indicating an enhancement in stability in intact conditions, in addition to a significant improvement in longitudinal stability, as evidenced by an increase of about 14% in longitudinal metacentric height and 15% in longitudinal center of buoyancy.

Analyzing the behavior of both vessels, it is observed in Figure 6 that the lengthened vessel requires slightly more power as speed increases, especially below 12 knots. This behavior suggests that at lower speeds, the lengthening of the vessel generates higher drag, which increases the power demand of the installed engines to reach and maintain these speeds, compared to the Prototype. Even though the lengthened vessel reaches 14 knots, Table 8 showcases that the brake power increases by 2.23%, which could imply a higher load on the engines and a lower efficiency in terms of speed. Additionally, the efficiency of the propeller configuration shows a minimal decrease of 0.36% between the Prototype and the lengthened vessel. This behavior could be attributed to the fact that the lengthening of the hull alters the flow conditions in the area close to the propeller, disturbing the uniform flow and causing energy losses *(Lewis, 1988)*.

Table 11 shows that vessel length has a slight impact on transverse propulsion, increasing the thrust TTRANS and the required power P by 7.94%, while reducing the rotational speed VPSI by 7.35%, all while maintaining the recommended pressure F for FSV vessels. Table 12 confirms that azimuthal propulsion performance is unaffected, supported by a recommended thrust coefficient KT to meet standards *(Carlton, 2007)*. Table 13 shows a slight increase of 1.15% in the CC load coefficient of the lengthened vessel compared to the Prototype vessel, suggesting that the lengthening of the vessel contributes to a marginal improvement in its efficiency in terms of cargo capacity.

Finally, Table 14 shows a significant improvement in the energy efficiency of the vessel, reflected in the reduction of the EEDI in the lengthened version, with a decrease of 19.67%. This change indicates that, although the lengthened vessel displays a slight improvement in load factor, it has achieved a much more substantial improvement in energy efficiency. Similarly, the resulting plots for the righting arm curve GZ presented in Fig. 5, showed compliance with the properties of the righting arm curve mentioned in the 2008 International Code of Intact Stability, which details that the minimum area under the GZ curve up to an angle of 30 degrees must be at least 0.055 meters - radians, having values of 0.27 meters - radians and 0.275 meters - radians. It is also established that the area under the GZ curve up to an angle of 40° should not be less than 0.09 meter-radians, a parameter that, in our results, is equal to 0.389 meter-radians and 0.392 meter-radians for the original and the lengthened vessel, respectively. Finally, the area under the GZ curve between 30° and 40° should not be less than 0.03 meters - radians; for our vessels, it is 0.119 and 0.117 meters - radians.

Hydrodynamic results from a parallel study

According to Guerrero *et al*. (2025), Table 15 shows that the lengthened vessel reduces heave accelerations by 8% compared to the original design; both configurations exceed the ISO 2631 comfort threshold of 1 m/s² in the bridge area within 30 minutes of exposure, particularly under beam wave conditions. Roll accelerations remain almost unchanged, with a slight increase in the lengthened vessel, but both configurations remain within acceptable limits for up to 2 hours of exposure. In terms of comfort, overall improvement is limited: the cargo area, located at the stern, reaches the discomfort threshold after 2 hours, while the midship and other regions remain tolerable for up to 8 hours. This indicates that although the lengthened design offers some improvements, it does not fully meet the comfort criteria established for such vessels.

Options to improve energy efficiency

An alternative option would be to implement a diesel-electric hybrid system, which could reduce CO_2 emissions by up to 20% *(Wärtsilä, 2024)*. However, this system is expensive and requires considerable space for generators/shaft motors and batteries, which would reduce the ship's carrying capacity. Additionally, the installation and maintenance of the hybrid system would involve significant investments. Therefore, although the hybrid system offers a greater reduction in emissions, the lengthening of the vessel remains the best option, as it increases the cargo capacity without compromising the available space, positioning it as a viable and sustainable option in today's market (Berzosa, 2024). Not only does this approach address the need to reduce emissions, but it also optimizes the overall performance of the vessel, enhancing its competitiveness in terms of operating costs and cargo capacity.

Emerging technologies

These innovations, whether in the design of the vessel or in improvements to its propulsion system, aim to achieve significant reductions in greenhouse gas emissions and enhanced energy efficiency, aligning with international standards such as the EEDI of the International Maritime Organization (IMO). By meeting these regulatory requirements, the modified design enhances its operational sustainability and reinforces the international competitiveness of the vessel, positioning it as a viable and efficient alternative in the maritime industry.

Conclusions

Lengthening this vessel by five meters, as required by ownership, has proven to be an effective solution to increase its capacity and improve EEDI and operational stability. This modification increases the deck cargo capacity by 138 tons while improving stability by means of a 14% increase in longitudinal metacentric height and a 13% rise in longitudinal center of buoyancy. These improvements enable better trim control and allow higher deck loads without compromising safety. Additionally, compliance with first-generation intact stability criteria set by the IMO ensures operational safety under normal operating conditions.

From a sustainability perspective, the lengthened design achieves a remarkable 19.67% improvement in EEDI, positioning it as a more environmentally friendly option. Although the increased resistance at lower speeds requires more power, especially from 14 knots onward, the transverse and azimuthal propulsion systems operate optimally and without resonance issues near offshore platforms. This design not only enhances the vessel's capacity and efficiency but also meets the current demands for sustainability in the maritime industry, offering a more competitive and internationally compliant solution.

Recommendations

Before proceeding with any vessel lengthening process, a thorough analysis is essential to prevent potential failures and avoid unnecessary costs in construction and operation. Despite the improvements in the lengthened vessel, a comprehensive structural analysis of the lengthened section is recommended. In case of resonance problems at dynamic anchorage, the vessel's design should be re-evaluated, and roll-damping devices should be considered if necessary. Additionally, the behavior of the lengthened vessel under various sea states should be assessed.

Limitations and Future Research

Although this analysis provides a detailed insight into the effects of hull lengthening, it is important to acknowledge that the simulations are based on computational models, without experimental validation, and other operating conditions must be taken into consideration to apply them directly to the project. To enhance and validate the results obtained, it is recommended that physical model tests be conducted. Furthermore, exploring hybrid propulsion systems (diesel – liquefied natural gas), or even the combination of a lengthening with a hybrid system, could be a promising area for future research, given the growing focus on reducing carbon footprints, particularly in relation to EEDI.

Contributions

- Juan Jurado: Methodology, writing, tables, figures, validation of results, recommendations.
- Ignacio Chinchin: Introduction, abstract, writing, discussion, conclusions.
- Franklin Domínguez: Work structure, supervision, final edition.

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