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Peformance Analysis the Impact of Solar Panel Placement on the Deck House Fishing Vessel (20 GT) on Fishing Operation

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Abstract— **High stability is imperative, safeguarding against the unpredictable nature of the marine environment and promoting a secure working platform for crew members to do fishing operation. The aim of this study is to analyze the effect of laying solar panels on the deckhouse of small fishing vessels 20 GT. The additional load above which causes weight gain and will affect the ship's center of gravity is became the first effect of Fishing vessel stability. The second effect is on how the fishing vessel performs when there is a solar panel on the vessel. The data were collected by measuring the stability according to A.N Kyrylo's method with standard checks according to the IMO (International Marine Organization). Code on Intact stability calculated the ship motion by using the STRIP method and using the JONSWAP method to measuring the wave characteristics with the help of Maxsurf software. The results of this research show that the installment of solar panels above the deckhouse does not really affect the stability, where the results were meets the IMO standard criteria. The successful fishing operation of the vessels studied will only have a good performance at 1.5 meters, according to the seakeeping analysis.**

Keywords— Fishing Vessel, Solar Panel, Stability, Ship Motion

I. INTRODUCTION

Fishing vessels are versatile floating platforms capable of facilitating a myriad of activities[1]. Firstly, they function as efficient transportation vehicles, shuttling fishermen to and from designated fishing zones with ease and reliability. Additionally, these vessels serve as essential carriers for fishermen, housing their equipment, gear, and the resulting catch. Furthermore, they double as operational platforms during the intricate processes of fishing, providing stability and functionality amid the waves[2]. In the realm of marine resource utilization, fishermen rely on a diverse array of fishing vessels, each distinguished by variations in size and the materials employed in their construction[3]. From compact vessels designed for local coastal fishing to larger industrial trawlers equipped for deep-sea expeditions, the range is extensive. Moreover, the condition of these vessels spans a broad spectrum, from traditional craft steeped in heritage to modern marvels incorporating cutting-edge technology. This technological evolution is an ongoing endeavor, as fishing vessels continually integrate the latest advancements to enhance efficiency, sustainability, and safety in alignment with the ever-progressing landscape of marine innovation[4].

In accordance with Fyson [5], fishing vessels are specifically constructed ships tailored to the intricate demands of fishing endeavors. These vessels are meticulously designed with dimensions, deck layouts, cargo capacities, accommodations, engines, and a plethora of equipment, all meticulously adapted to suit the operational blueprint. A paramount consideration in this design process is ensuring robust stability, a critical factor essential for safe and efficient operations at sea[6].

Nomura and Yamazaki [7] underscore several fundamental technical prerequisites for fishing vessels engaged in fishing activities. Firstly, these vessels must boast a robust hull structure, capable of withstanding the rigors of maritime conditions encountered during fishing expeditions. Moreover, they must be optimized to enhance the efficacy of fishing operations, ensuring maximum productivity and yield. High stability is imperative, safeguarding against the unpredictable nature of the marine environment and promoting a secure working platform for crew members. Additionally, provision must be made for adequate facilities dedicated to the storage of the harvested fish catch, preserving its quality until it reaches shore for further processing and distribution. These criteria collectively define the essential attributes required for fishing vessels to fulfill their role effectively within the maritime industry[8].

Furthermore, it is imperative to take into account various factors, among which the vessel's maneuverability in response to encountered waves is of utmost significance. This pertains to the vessel's motion, which denotes its reaction to external forces exerted upon it[9]. The motion induced by external forces, including the unpredictable undulations of sea waves, significantly influences both the safety and comfort of the crew aboard the fishing vessel[10]. A vessel's ability to navigate and respond effectively to wave action directly impacts its operational efficiency and the well-being of its occupants.

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In challenging sea conditions, such as rough seas or adverse weather, the vessel's maneuverability becomes critical in ensuring the safety of the crew and the integrity of the fishing operations. Therefore, meticulous attention must be paid to designing vessels with optimal maneuvering capabilities, allowing them to navigate through varying sea states with agility and stability, thereby safeguarding the crew and enhancing overall operational performance[11].

Fishing vessels, fishing gear, and fishermen collectively constitute three pivotal elements that influence the prosperity of any fishing operation. Engaging in fishing activities, particularly at sea, entails inherent risks. Shockingly, the global average rate of fatal accidents, resulting in deaths among crew members of fishing vessels, stands at approximately 80 per 100.000 individuals [12]. This alarming statistic has drawn heightened scrutiny and concern from esteemed international bodies such as the International Maritime Organization (IMO), the Food and Agriculture Organization (FAO), and the International Labour Organization (ILO). These organizations, cognizant of the pressing need to enhance safety measures and labor conditions within the fishing industry, have dedicated concerted efforts to address these pressing issues[13]. Weight distribution on a vessel affects its center of gravity and, consequently, its stability and seakeeping. Modifications such as adding solar panels on the deck house can alter the weight distribution and raise the center of gravity, potentially impacting roll stability and pitch behavior. Studies on similar deck modifications suggest that careful placement and weight management are crucial to maintaining optimal seakeeping performance [14].

Through collaborative endeavors involving tripartite stakeholders—comprising governmental bodies, vessel owners, and fishermen—these global entities have instituted conventions aimed at promoting decent work practices throughout the fishing sector. Recognizing the imperative to safeguard the well-being of individuals engaged in fishing operations, these conventions serve as pivotal frameworks for implementing comprehensive safety standards and fostering equitable labor conditions across the industry. By fostering dialogue, cooperation, and regulatory enforcement, these initiatives strive to mitigate risks, reduce accidents, and enhance the overall welfare of fishing communities worldwide[15]. Environmental factors such as wave height, frequency, and direction also play a critical role in seakeeping. Smaller vessels like the 20 GT fishing vessels are particularly susceptible to adverse weather conditions. Ensuring that the vessel can handle expected sea states while maintaining operational efficiency is vital. Advances in weather prediction and real-time monitoring have improved the ability to manage and mitigate these environmental impacts [16].

The functions of fishing vessels, as outlined by Nomura and Yamazaki, emphasize the importance of ensuring that the placement of solar panels does not compromise the safety of fishing operations. Building upon prior research, the current study seeks to delve deeper into this topic by investigating the potential effects of installing solar panels on fishing vessels on the overall safety of fishing operations[17]. By examining the specific functions and operational requirements of fishing vessels, we aim to evaluate how the incorporation of solar panels may impact various aspects of safety, including maneuverability, stability, visibility, and crew accessibility. Through empirical analysis and simulation studies, we endeavor to assess the potential risks and benefits associated with integrating solar panel technology into fishing vessel design[18].

Seakeeping performance is typically assessed using criteria such as motion sickness incidence (MSI), operability index, and crew comfort levels. Key parameters include heave, pitch, roll, and vertical and lateral accelerations. These parameters are influenced by the vessel's hull design, weight distribution, and the sea state [19]. The hull design significantly impacts seakeeping. Fishing vessels often have to balance between stability for safe operations and hull form that allows for efficient movement through water. Research indicates that vessels with finer hull forms experience lower resistance and better seakeeping characteristics in moderate sea states but might be less stable in rougher conditions [20].

Technological advancements in computational fluid dynamics (CFD) and model testing have enhanced the understanding of seakeeping. CFD allows for detailed simulations of how modifications like solar panel installations affect vessel behavior in different sea states. Model testing in wave tanks complements these simulations, providing empirical data to validate theoretical models [21]. Case studies of fishing vessels with deck modifications provide practical insights. For example, a study on a modified fishing vessel with additional superstructures found that careful design adjustments could mitigate negative impacts on seakeeping. This involved optimizing the weight distribution and using materials that minimize additional weight [22].

This research aims to represent a pivotal milestone in understanding the feasibility and real-world implications of integrating solar energy solutions within the maritime sector. Moreover, it places paramount emphasis on safeguarding the welfare and security of fishermen and crew members operating within this challenging environment. By meticulously unraveling the potential ramifications of integrating solar panels onto fishing vessels, our goal is to offer invaluable insights that transcend mere theoretical discourse. These insights are poised to serve as a compass guiding future design strategies and regulatory initiatives within the dynamic landscape of the fishing industry.

Through a holistic examination of the safety implications associated with solar panel placement, we aim to empower stakeholders with the knowledge necessary to navigate the delicate balance between innovation and safety in maritime operations. This research thus stands as a testament to our collective commitment to fostering sustainable, safe, and resilient practices within the realm of maritime transportation and fisheries management.

II. METHOD

2.1 Method of data collecting

The focus point of this study is a Multipurpose Fishing Vessel with a gross tonnage (GT) of 20. To gather pertinent data, we employ a data collection technique that relies on secondary sources, specifically accessing information from the Ministry of Marine Affairs and Fisheries (KKP). The primary dimensions and consumable data are extracted from this source and are cataloged in Table 1 for reference.

This approach allows us to utilize existing datasets provided by authoritative bodies, ensuring the reliability and accuracy of the information used in our analysis[1]. By leveraging this secondary data, we can effectively evaluate the various aspects of the Multipurpose Fishing Vessel, including its structural dimensions and consumable resources, facilitating a comprehensive examination of its characteristics and capabilities[2].

Table 1 serves as a valuable resource, presenting essential parameters that will underpin our subsequent analyses and investigations. Through meticulous scrutiny and interpretation of these data points, we aim to gain deeper insights into the operational dynamics and performance potential of the Multipurpose Fishing Vessel within the context of our research objectives.

TABLE 1.
SHIP PARTICULAR

No	Dimension	Unit	Size
1	Loa	M	17
2	B	M	3.6
3	H	M	1.9
4	T	M	1.3
5	Fb	M	0.6
6	Cb	-	0.55
7	B/T	-	2.76
8	Fb/B	-	0.16
9	Crew	Person	7
10	Speed	Knot	9

TABLE 2.
CONSUMABLE NEEDS OF FISHING VESSELS 20 GT

No	Item	Quantity	Unit Weight (Kg)	Total Weight (Kg)
1	Fresh Water	2	750	1500
2	Fuel Oil	2	1275	2250
3	Provisions	10	1.5	105
4	Crew	7	75	525
5	Fish & Ice	2	2500	5000

Utilizing the main dimensions and consumable size data provided previously, the next phase of our investigation entails transforming this information into a comprehensive line plan drawing. This intricate blueprint serves as the foundational framework for conducting an in-depth analysis of the vessel's stability and maneuverability[23]. In essence, the line plan drawing will meticulously capture the structural nuances of the ship, incorporating critical dimensions such as length, beam, draft, and freeboard, along with the strategic placement of consumable elements such as fuel tanks, water reservoirs, and storage compartments[24].

Once the line plan drawing is meticulously crafted, our focus will shift towards a rigorous assessment of the vessel's stability and maneuverability. Through advanced computational modeling techniques and hydrodynamic analysis, we will delve into the intricacies of the ship's behavior in various environmental conditions and operational scenarios[25]. This multifaceted analysis will provide invaluable insights into the vessel's performance characteristics, enabling us to gauge its resilience to external forces, its propensity for stable operation, and its agility in navigating through challenging waters. By scrutinizing factors such as metacentric height, turning radius, and rudder response, we aim to unveil the underlying dynamics shaping the vessel's operational prowess[26]. Ultimately, the culmination of these efforts will not only yield a comprehensive understanding of the ship's capabilities but also pave the way for informed design refinements and operational optimizations aimed at enhancing safety, efficiency, and overall performance at sea[27].

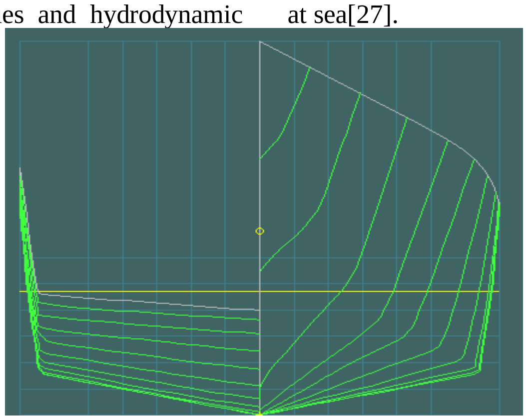

Figure 1. Fishing Vessel Lines Plan 20 GT

2.2 Stability Calculation

The processing of ship data is carried out using Maxsurf software. The analysis of data in ship stability calculations employs the formula from A.N. Krylov.

$$F_B = g\Delta = \rho g \nabla \quad (1)$$

The initial metacentric height equals the difference between the metacentric radii and the distance between the centre of buoyancy (B) and gravity G. $GM_0 = BM_0 - GB$ (2)

The transverse metacentre radius at each inclination is also called the metacentre difference.

$$r_\varphi = B_\varphi M_\varphi = \frac{dI_{WL}}{d\nabla} \quad (3)$$

The transverse metacentric radius for the upright position is:

$$r_0 = BM_0 = \frac{I_{WL}}{\nabla} \quad (4)$$

Where: Iwl = moment of inertia of the waterplane.

The relationship between the two equations is:

$$r_\varphi = r_0 + \nabla \frac{dr_0}{d\nabla} \quad (5)$$

The static stability arm can be calculated using the following equation:

$$GZ = y_{B\varphi} \cos\varphi + (z_{B\varphi} - Z_B)\sin\varphi - GB\sin\varphi \quad (6)$$

Where : $y_{B\varphi}, z_{B\varphi}$ are the coordinates of the centre of buoyancy.

The equation $BN = y_{B\varphi} \cos\varphi + (z_{B\varphi} - Z_B)\sin\varphi$ is called the righting arm of form, and BC = BG sinφ is called the righting arm of weight. The formula can also calculate GZ:

$$GZ = y_{B\varphi} \cos\varphi + Z_{B\varphi} - KG\sin\varphi \quad (7)$$

The relationship between GZ and the inclined angle is assumed to be directly proportional for a slight inclination angle. Then the erection moment can be calculated by:

$$M_R = g\Delta\, GM_0 \varphi \quad (8)$$

The above formula is called the metacentre formula of stability. For all angles of inclination, the erection moment can be calculated by:

$$M_R = g\Delta\, GZ \quad (9)$$

The curve of the straightening arm must match the appropriate characteristics. An example of the GZ value at the slope angle $GZ20^0$, $GZ30^0$, $GZ40^0$, $GZ\ ^0m$ must match the slope angle m. The difference between the straightening arm and the angle of inclination is called the generalized metacentre height:

$$h_\varphi = \frac{d(GZ)}{d\varphi} = B_\varphi M - y_{B\varphi}\sin\varphi + Z_{B\varphi}\cos\varphi - KG\cos \quad (10)$$

Geometrically, this is equal to the distance between the metacentre M and the projection of G in the direction of the buoyant force, Z

$$E_R = \int_0^\varphi M_R\, d\varphi = g\Delta \int_0^\varphi GZ d\varphi \quad (11)$$

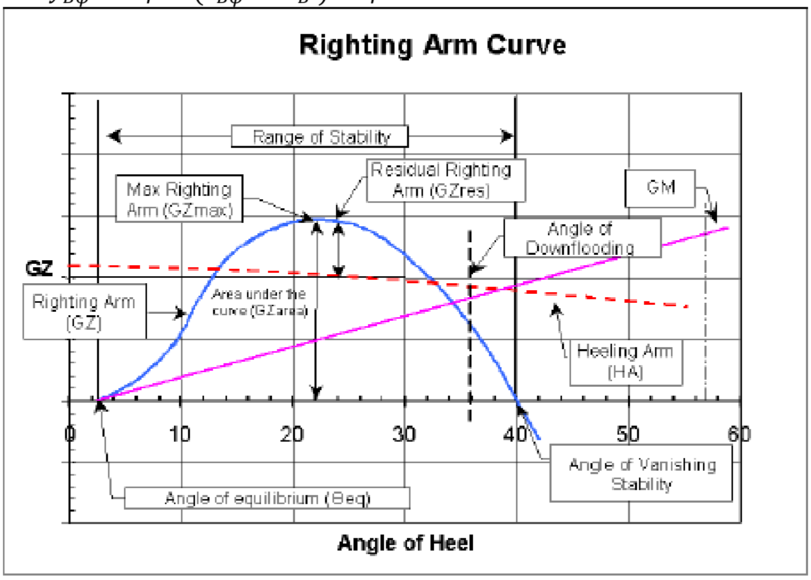

Figure 2. Stability Arm

The ship's stability arm is meticulously computed and assessed in accordance with the established stability standards set forth by the International Maritime Organization (IMO). Adhering to the guidelines outlined in the International Code on Intact Stability (IMO, 2008), specific criteria have been mandated for fishing vessels to ensure their safe operation in various maritime conditions.

These criteria serve as indispensable benchmarks for evaluating a vessel's stability characteristics, encompassing parameters such as metacentric height, angle of heel, and righting arm curve. Compliance with these rigorous standards is essential to mitigate risks and uphold the safety of crew members, safeguarding against the potential hazards posed by adverse weather conditions and dynamic sea states.

1. The area under the GZ curve must not be less than:
   a. 0.055-meter radians up to 30°
   b. 0.09-meter radians up to 40°
   c. 0.03-meter radians between 30° - 40°.
2. More than 0.2 meters at 30°.
3. The metacentric height must not be less than 0.35 meters.

2.3 Weather Criterion

The stability of a ship can also be influenced by the weather conditions experienced while the ship is sailing. The heel angle that occurs on the ship can be affected by the wind conditions during sailing or in the area of the water. This criterion is regulated in the IMO 2008 Intact Stability Code Part A Ch.2.3 Severe Wind and Rolling Criterion (Weather Criterion).

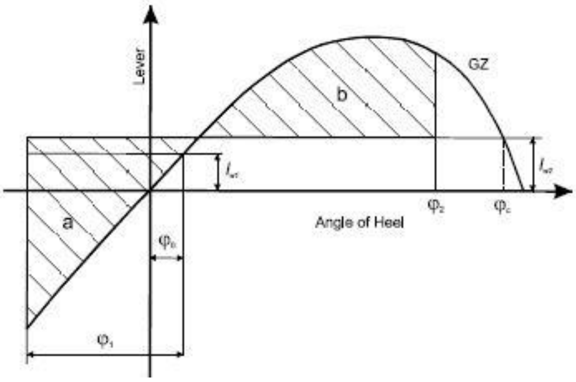

Figure 3. Severe Wind and Rolling

2.2 Seakeeping Calculation

The strip theory is a frequency-domain method in the sense that the problem has been formulated as a function of frequency. In this theory, the ship is divided into several transverse sections. Each section is treated in the calculation of hydrodynamic characteristics, where the coefficients of each section are integrated along the ship's hull to ensure the global coefficients of the ship's motion. The formula will be provided without derivation. For a broader scope of theoretical background, reference is made to Newman [28]. Two coordinate systems are used:

1. The ship-fixed system x, y, z, with axes pointing from the center of the ship forward, to the right, and downward. In this system, the center of gravity has a constant value.
2. The inertial system ξ, η, ζ. This system follows the forward motion of the ship at speed V and corresponds to the average time in the fixed-ship system.

Forces and moments acting on the ship are similarly combined into the six-component vector F.u, with F being a harmonic function of oscillation with encounter frequency We.

$$\vec{F} = R_e\left(\vec{F}e^{iw_e t}\right)\vec{u} = R_e\left(\vec{u}e^{iw_e t}\right) \quad (12)$$

The basic equation of motion is derived from F = M.u:

$$\left[-w^2{}_e(M+A) + iw_e N + S\right]\vec{u} = \vec{F_e} \quad (13)$$

Here M, N, A and S are real values of the 6 x 6 matrix. For a symmetrical mass distribution with respect to y = 0, the mass of the matrix M is :

$$M = \begin{bmatrix} m & 0 & 0 & 0 & mz_g & 0 \\ 0 & m & 0 & -mz_g & 0 & mx_g \\ 0 & 0 & m & 0 & -mx_g & 0 \\ 0 & -mz_g & 0 & \theta_{xx} & 0 & -\theta_{xz} \\ mz_g & 0 & -mx_g & 0 & \theta_{yy} & 0 \\ 0 & mx_g & 0 & -\theta_{xz} & 0 & -\theta_{zz} \end{bmatrix} \quad (14)$$

The mass moment of inertia θ is related to the origin of the ship-fixed system coordinates:

$$\theta_{xx} = \int (y^2 + z^2)\, dm;\ \theta_{xz} = \int xz\ dm \quad (15)$$

If we ignore the contribution of the dry tansom stren and other hydrodynamic forces due to the ship's forward speed, the restoring force matrix S is:

$$M = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \rho g A_w & 0 & -\rho g A_w x_w & 0 \\ 0 & 0 & 0 & gm\overline{GM} & 0 & 0 \\ 0 & 0 & -\rho g A_w x_w & 0 & gm\overline{GM_l} & 0 \\ 0 & 0 & 0 & 0 & 0 & \theta_{zz}w^2{}_g \end{bmatrix} \quad (16)$$

$$M = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \rho g A_w & 0 & -\rho g A_w x_w & 0 \\ 0 & 0 & 0 & gm\overline{GM} & 0 & 0 \\ 0 & 0 & -\rho g A_w x_w & 0 & gm\overline{GM_l} & 0 \\ 0 & 0 & 0 & 0 & 0 & \theta_{zz}w^2{}_g \end{bmatrix} \quad (17)$$

The JONSWAP (Joint North Sea Wave Project) spectrum constitutes an empirical relationship crucial for delineating the distribution of energy across different frequencies within the vast expanse of the ocean. Essentially, the JONSWAP spectrum serves as a refined iteration of the Pierson-Moskowitz spectrum, albeit with distinct characteristics. Unlike its predecessor, the JONSWAP spectrum never achieves full development, perpetually evolving due to the intricate interplay of nonlinear wave-wave interactions over extended durations.

Within the framework of the JONSWAP spectrum, waves persistently intensify over distance or time, as encapsulated by the α (alpha) equation. Additionally, the spectral peak assumes greater prominence, elucidated by the γ (gamma) equation. Hasselmann [29] underscored the significance of the latter formula in capturing more comprehensive nonlinear interactions, thereby enhancing our understanding of wave dynamics. At its core, the JONSWAP spectrum embodies a fundamental equation that underpins its formulation.

$$S(\omega) = \frac{\alpha g^2}{\omega^5}\ exp\left[-\beta\frac{\omega_p^4}{\omega^4}\right]\gamma^{\alpha} \quad (18)$$

Where :

$$a = \exp\left[-\frac{(\omega-\omega_p)^2}{2\omega_p^2\sigma^2}\right] \quad (19)$$

$$\sigma = \begin{cases} 0.07 & if\ \omega \le \omega_p \\ 0.09 & if\ \omega > \omega_p \end{cases} \quad (20)$$

$$\beta = \frac{5}{4} \quad (21)$$

Criteria for ship maneuvers using seakeeping [30]

TABLE 3.
SEAKEEPING CRITERIA

No.	Criteria	Value
1.	*Roll*	6 deg
2.	*Pitch*	3 deg
3.	*Lateral acceleration (at working deck AP & FP)*	0,1 g
4.	*Vertical acceleration (at working deck AP & FP)*	0,2 g

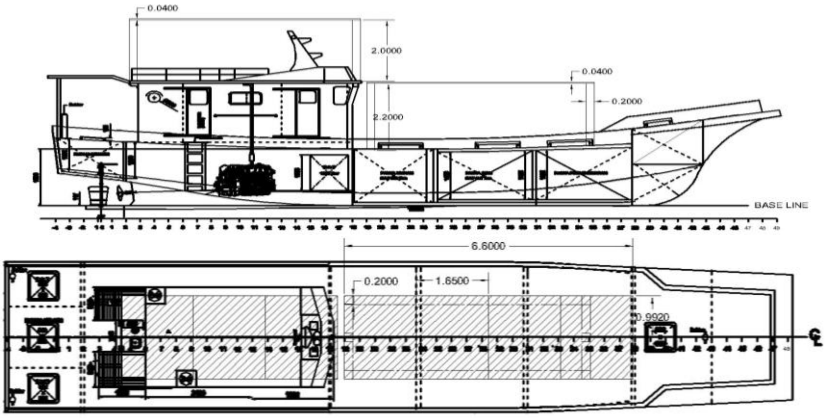

Figure 4. General Arrangement

III. RESULTS AND DISCUSSION

3.2 Stability Analysis

The vessel's load cases are structured in accordance with the guidelines and assumptions established by the International Maritime Organization (IMO) to address the specific needs and challenges encountered in the realm of fishing vessels. The vessel's operational states are organized to capture the full spectrum of potential scenarios it may encounter during its operations at sea. The vessel is operating at full capacity, with each compartment loaded to its maximum capacity of 100%. This loading condition allows for a thorough evaluation of the vessel's performance under demanding circumstances, providing insights into its stability, maneuverability, and overall operational efficiency when fully loaded with supplies and equipment.

The second scenario examines a situation where some consumables, such as fuel and freshwater, are at 50% capacity while other compartments remain empty. This scenario reflects a typical operational condition where the vessel may not be fully laden but still carries essential supplies necessary for its mission at sea. By analyzing this scenario, we can gain a nuanced understanding of the vessel's performance under partially loaded conditions, including its fuel efficiency and endurance.

We consider whether the vessel has solar panels on board, as they affect its weight distribution, stability, and energy efficiency. Our thorough analysis ensures that our evaluation accurately reflects the vessel's configuration and operational capabilities. This enables us to identify areas for potential improvement and optimization. This systematic approach to structuring load cases comprehensively evaluates the vessel's performance under a range of realistic operating conditions. By gaining a deeper understanding of its capabilities and limitations, we can make informed decisions to enhance its safety, efficiency, and effectiveness in fulfilling its role within the maritime industry.

TABLE 4.
LOADCASE CONDITION OF FISHING VESSEL

Item Name	Loadcase 1 tonne	Vert. Arm 1 m	Loadcase 2 tonne	Vert. Arm 2 m	Loadcase 3 tonne	Vert. Arm 3 m	Loadcase 4 tonne	Vert. Arm 4 m
'LWT								
Lightship	13.240	1.320	13.240	1.320	13.240	1.320	13.240	1.320
Solar Panel 1	0.000	0.000	0.264	4.000	0.264	4.000	0.000	0.000
Solar Panel 2	0.000	0.000	0.264	4.000	0.264	4.000	0.000	0.000
Total LWT	13.240	1.320	13.768	1.423	13.768	1.423	13.240	1.320
'DWT								
Food	0.105	1.600	0.105	1.600	0.105	1.600	0.105	1.600
Crew	0.525	2.900	0.525	2.900	0.525	2.900	0.525	2.900
CF 1	0.000	0.000	0.000	0.000	2.500	0.929	2.500	0.929
CF 2	0.000	0.000	0.000	0.000	2.500	0.929	2.500	0.929
FOT (S)	0.406	0.800	0.406	0.800	0.812	1.100	0.812	1.100
FWT (P)	0.792	1.347	0.792	1.347	1.585	1.612	1.585	1.612
FWT (S)	0.792	1.347	0.792	1.347	1.585	1.612	1.585	1.612
FOT (P)	0.406	0.800	0.406	0.800	0.812	1.100	0.812	1.100
Total DWT	3.027	1.478	3.027	1.478	10.424	1.269	10.424	1.269
Total Loadcase	16.267	1.349	16.795	1.433	24.192	1.357	23.664	1.298
FS correction		0.032		0.031		0.000		0.000
VCG fluid		1.382		1.464		1.357		1.298

Loadcase 1 analyzes the operational dynamics of the fishing vessel while navigating with an empty cargo hold and no solar panel installations. In Loadcase 2, the vessel remains unladen but utilizes solar panels to generate essential energy onboard. The vessel's potential for sustainable energy utilization is highlighted by this configuration, demonstrating the versatility of solar power in maritime applications.

Loadcase 3 shows a further step into the realm of practicality by exploring how the vessel performs when fully loaded with cargo, while benefiting from the integration of solar panels. This approach prioritizes the vessel's operational readiness in real-world conditions, highlighting the crucial relationship between cargo capacity and renewable energy solutions.

In contrast, Loadcase 4 evaluates the vessel's performance when fully loaded without utilizing solar panels. This scenario demonstrates the vessel's exceptional performance in traditional operating conditions, setting a high standard for measuring the benefits of solar energy integration.We meticulously evaluate the weight of each component to determine the longitudinal and transverse positions of the vessel's center of gravity. Specifically, the center of gravity shifts from 1.382 meters in Loadcase 1 to 1.464 meters in Loadcase 2, then down to 1.357 meters in Loadcase 3, and further to 1.289 meters in Loadcase 4. The calculations clearly demonstrate that the center of gravity shifts in a predictable manner across all four Loadcases, with the introduction of solar panels having a significant impact on the vessel's weight distribution and stability profile. This trend highlights the importance of carefully considering the placement of solar panels in order to maintain optimal stability and safety.

The stability arm (GZ) values for inclinations ranging from 0° to 90° were calculated using the A.N. Krylov method through Maxsurf software. This analysis demonstrates the vessel's stability characteristics under varying degrees of inclination, which is crucial for ensuring safe operation in dynamic maritime environments. The graph of these stability arm values, shown in the diagram below, provides a visual narrative of the vessel's stability performance, facilitating a deeper understanding of its behaviour and resilience under different operating conditions. This analysis aims to optimize the vessel's design and operational parameters to enhance safety, efficiency, and overall performance in fishing activities.

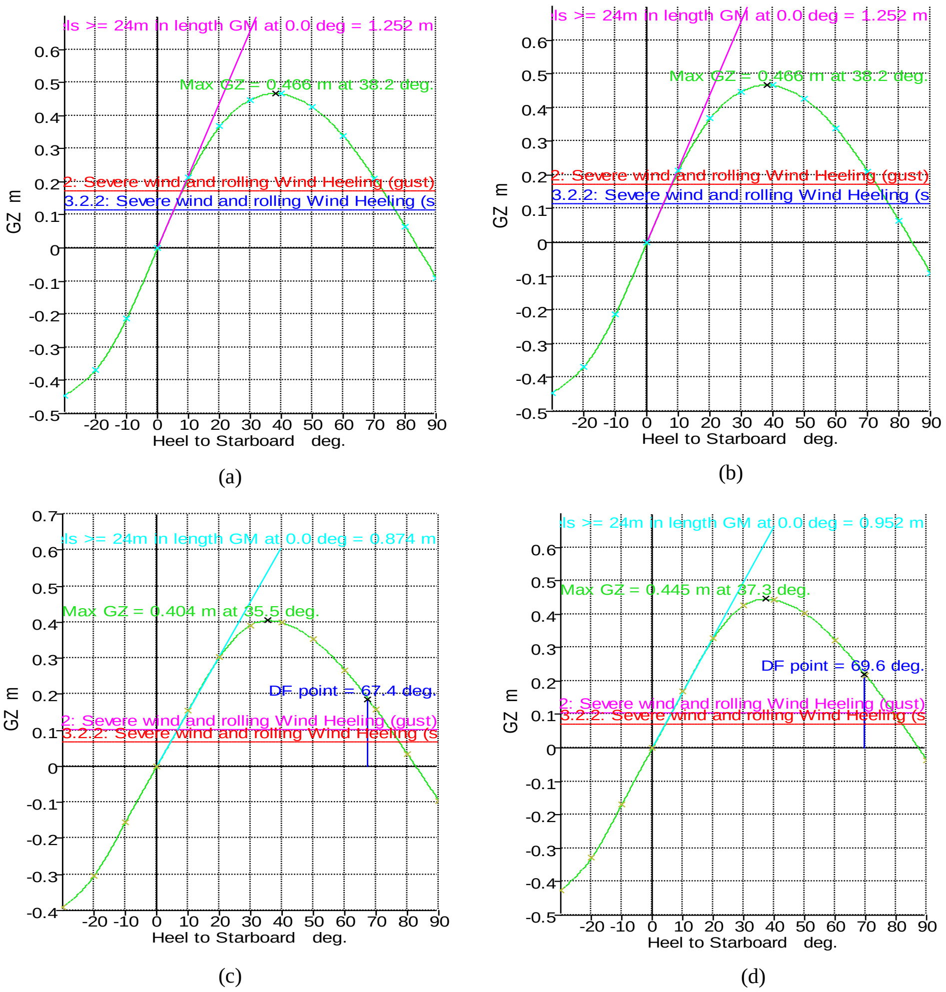

Figure 5. Stability Arm and Wind Criteria (a) Loadcase 1 (b) Loadcase 2 (c) Loadcase 3 (d) Loadcase 4

Observations from the diagram indicate a remarkable similarity in the GZ arms across loadcases 1 to 4. This consistency underscores the need for meticulous adjustments to align the GZ arms with the stringent standards set forth by the International Maritime Organization (IMO). By adhering to these established norms, we ensure that the vessel's stability characteristics meet the requisite safety thresholds mandated for maritime operations.

The forthcoming corrections, outlined in the accompanying table, will serve to fine-tune the GZ arms 1 to 4, thereby optimizing the vessel's stability profile. This meticulous process not only enhances the vessel's overall seaworthiness but also mitigates potential risks associated with unstable conditions at sea.

Through these corrective measures, we aim to uphold the highest standards of safety and regulatory compliance, reaffirming our commitment to safeguarding the well-being of crew members and the integrity of maritime operations.

TABLE 5.
CORRECTION RESULT

Code	Criteria	Value	Units	Load case1	Load case2	Load case 3	Load case 4	Status
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.1: Area 0 to 30	0.0550	m.deg	8.1706	7.3958	6.6300	7.1801	Pass
	3.1.2.1: Area 0 to 40	0.0300	m.deg	12.7766	11.4785	10.6417	11.5805	Pass
	3.1.2.1: Area 30 to 40	0.0900	m.deg	4.6059	4.0827	4.0116	4.4004	Pass
	3.1.2.2: Max GZ at 30 or greater	0.200	m	0.466	0.411	0.404	0.445	Pass
	3.1.2.3: Angle of maximum GZ	25.0	deg	38.2	36.4	35.5	37.3	Pass
	3.2.2: Severe wind and rolling							Pass
	Angle of steady heel shall not be greater than (<=)	16.0	deg	5.2	5.5	4.4	4.2	Pass
	Angle of steady heel / Deck edge immersion angle shall not be greater than (<=)	80.00	%	19.30	20.81	21.61	20.12	Pass
	Area1 / Area2 shall not be less than (>=)	100.00	%	116.58	105.36	170.21	178.55	Pass
4.2 Fishing vessel	4.2.3.1: Initial GMt for vessels >= 24m in length	0.350	m	1.252	1.130	0.874	0.952	Pass

The analysis presented in Table 5 shows that both the IMO stability criteria and the severe wind and rolling criteria consistently meet the established standards for all load cases 1 to 4. This alignment represents a successful outcome for each load case, indicating compliance with the required safety thresholds and regulatory benchmarks.

These results underline the robustness and reliability of the ship's stability characteristics in different operational scenarios. By meeting both the IMO Stability Criteria and the Severe Wind and Rolling Criteria, the vessel demonstrates its ability to withstand challenging maritime conditions with resilience and efficiency.

Such comprehensive validation provides assurance of the structural integrity and operational viability of the vessel and instils confidence in its ability to navigate safely and effectively in a variety of sea states. This confirmation of compliance reinforces the vessel's suitability for maritime operations and underlines its compliance with global safety standards.

4.2 Vessel motion to Safety of Catching Operations

Safety and the fulfillment of fishing objectives depend on the seaworthiness of the vessel before it sets sail. In order to accurately assess the vessel's seaworthiness, simulations are carried out with the vessel in a fully loaded condition, mirroring the conditions used in stability calculations.

This comprehensive analysis includes the JONSWAP wave equation, which accurately models wave behavior, together with consideration of the angle of wave entry into the vessel. The wave entry angle is segmented into three distinct parts, each of which is critical in determining the vessel's response to the prevailing sea conditions. These segments include following seas, beam seas and head seas, capturing the full spectrum of potential wave interactions.

The accompanying figure provides a visual representation of these angles and illustrates their importance in maritime operations. In particular, there are

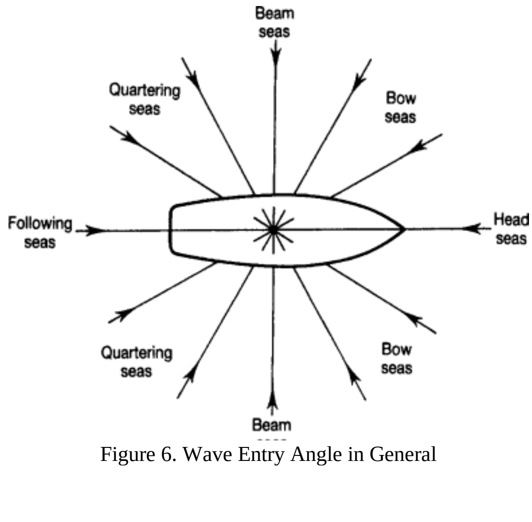

Figure 6. Wave Entry Angle in General

typically five angles of wave entry, with each angle presenting unique challenges and implications for the stability and maneuverability of the vessel.

It is also important to note that the vessel operates at a maximum speed of 9 knots when underway, navigating through waves ranging in height from 0.5 to 3 meters. This variability in wave height underlines the dynamic nature of the maritime environment and requires a thorough understanding of the vessel's capabilities and limitations in different wave conditions.

Movement conditions, both with and without solar panels, are standardized to account for minimal variations in water content. These adjustments ensure consistency across scenarios, allowing a fair comparison of the vessel's performance under different conditions. Specifically, the analysis includes situations with a full load as well as scenarios where the vessel is operating with no cargo on board. By studying both loaded and unloaded conditions, we gain a comprehensive understanding of how the presence or absence of solar panels affects the vessel's motion dynamics. This meticulous approach allows us to accurately assess the impact of solar panel installations on the stability and maneuverability of the vessel, contributing to informed decision making in maritime operations.

TABLE 6.
FOLLOWING SEAS FULL LOAD

Wave Height (m)	RMS of Vertical Acceleration (at Working Deck AP & FP)	RMS of Lateral Acceleration (at Working Deck Ap & FP)	RMS of Pitch	RMS of Roll	Status
0,5	0,039 & 0,041	0	0,66	0	Pass
1	0,078 & 0,082	0	1,32	0	Pass
1,5	0,117 & 0,123	0	1,98	0	Pass
2	0,155 & 0,164	0	2,64	0	Pass
2,5	0,194 & 0,205	0	3,3	0	Fail
3	0,233 & 0,246	0	3,96	0	Fail

TABLE 7.
BEAM SEAS FULL LOAD

Wave Height (m)	RMS of Vertical Acceleration (at Working Deck AP & FP)	RMS of Lateral Acceleration (at Working Deck Ap & FP)	RMS of Pitch	RMS of Roll	Status
0,5	0,152 & 0,107	0,301 & 0,246	0,29	1,68	Pass
1	0,305 & 0,214	0,601 & 0,492	0,59	3,36	Pass
1,5	0,457 & 0,322	0,902 & 0,738	0,88	5,04	Pass
2	0,610 & 0,429	1,203 & 0,984	1,18	6,72	Fail
2,5	0,762 & 0,536	1,504 & 1,229	1,47	8,4	Fail
3	0,915 & 0,643	1,804 & 1,475	1,76	10,08	Fail

TABLE 8.
HEAD SEAS FULL LOAD

Wave Height (m)	RMS of Vertical Acceleration (at Working Deck AP & FP)	RMS of Lateral Acceleration (at Working Deck Ap & FP)	RMS of Pitch	RMS of Roll	Status
0,5	0,251 & 0,437	0	0,52	0	Pass
1	0,502 & 0,874	0	1,04	0	Pass
1,5	0,753 & 1,311	0	1,56	0	Pass
2	1,004 & 1,748	0	2,08	0	Pass
2,5	1,255 & 2,185	0	2,60	0	Pass
3	1,506 & 2,622	0	3,12	0	Fail

TABLE 9.
FOLLOWING SEAS EMPTY

Wave Height (m)	RMS of Vertical Acceleration (at Working Deck AP & FP)	RMS of Lateral Acceleration (at Working Deck Ap & FP)	RMS of Pitch	RMS of Roll	Status
0,5	0,042 & 0,071	0	0,69	0	Pass
1	0,081 & 0,092	0	1,35	0	Pass
1,5	0,147 & 0,153	0	1,98	0	Pass
2	0,185 & 0,194	0	2,67	0	Pass
2,5	0,224 & 0,235	0	3,33	0	Fail
3	0,263 & 0,276	0	3,96	0	Fail

TABLE 10.
BEAM SEAS EMPTY

Wave Height (m)	RMS of Vertical Acceleration (at Working Deck AP & FP)	RMS of Lateral Acceleration (at Working Deck Ap & FP)	RMS of Pitch	RMS of Roll	Status
0,5	0,182 & 0,137	0,331 & 0,266	0,32	1,68	Pass
1	0,335 & 0,244	0,631 & 0,492	0,62	3,39	Pass
1,5	0,487 & 0,352	0,932 & 0,778	0,92	5,07	Pass
2	0,640 & 0,459	1,233 & 0,984	1,22	6,75	Fail
2,5	0,792 & 0,566	1,534 & 1,259	1,50	8,43	Fail
3	0,945 & 0,673	1,834 & 1,505	1,79	10,08	Fail

TABLE 11.
HEAD SEAS EMPTY

Wave Height (m)	RMS of Vertical Acceleration (at Working Deck AP & FP)	RMS of Lateral Acceleration (at Working Deck Ap & FP)	RMS of Pitch	RMS of Roll	Status
0,5	0,281 & 0,467	0	0,55	0	Pass
1	0,532 & 0,874	0	1,07	0	Pass
1,5	0,783 & 1,341	0	1,59	0	Pass
2	1,034 & 1,778	0	2,11	0	Pass
2,5	1,285 & 2,185	0	2,63	0	Pass
3	1,536 & 2,652	0	3,12	0	Fail

Based on the analysis presented in the six tables above, it is clear that certain conditions do not meet the criteria established by Tello. Specifically, in the following sea conditions, the vessel only shows optimal performance when encountering wave heights below 2.5 metres. This limitation is due to the fact that the Root Mean Square (RMS) of the pitch exceeds the standard at heights above 1.5 metres.

Similarly, in beam seas characterised by wave heights exceeding 1.5 metres, the ship's roll motion does not comply with the Tello criteria. Tello requires that roll motion should not exceed 6 degrees, but in this scenario the vessel exceeds this standard and can only operate satisfactorily in wave heights below 1.5 metres. Consequently, the safety of the vessel's operation is ensured when encountering waves of 1.5 metres or less.

In addition, the RMS of the vertical acceleration exceeds the Tello standard when encountering waves of more than 2 metres. This discrepancy underlines the importance of adhering to safety protocols, as the vessel's ability to handle head sea conditions is compromised when encountering waves above this limit. Previous studies have indicated that the placement of solar panels on the deck of a ship does not affect the ship's stability and motion, provided that the ship's weight point remains intact, the weight of the solar panels is not excessive, and the laying of solar panels does not impede fishing activities [31].

IV. Conclusion

1. The Fishing Vessel's performance in terms of stability is not affected by laying solar panels on the deck. Under full load conditions, the vessel still complies with IMO regulations.
2. The vessel in this study can operate in wave heights of up to 3 metres, but performs better in wave heights of less than 2 metres. The successful fishing operation of the vessels studied will only have a good performance at 1.5 metres, according to the seakeeping analysis.

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