Concept design of thin-steel purse seine fishing vessel for enhancing the safety of fishing operations

Andi Muhammad Almusadieq[1*], *Nazwa* Syafitri[1], *Reynard* Lisan[1], *Raden Sjarief* Widjaja[1]

[1] Department of Naval Architecture, Faculty of Marine Technology, Sepuluh Nopember Institute of Technology, Surabaya, Indonesia

* Corresponding author: 5018221117@student.its.ac.id

Abstract. Despite the continued use of traditional wooden fishing vessels by small-scale fishers in Indonesia, such vessels exhibit inherent limitations in durability, maintenance requirements, and seaworthiness under adverse marine conditions, which directly affect safety and operational efficiency. This study proposes a conceptual design of a 5–8 GT steel-hulled purse seiner fishing vessel constructed using thin steel plates to enhance safety, structural resilience, and sustainability. The research methodology involves the development of a conceptual vessel design with improved resistance to extreme weather conditions, while complying with applicable national and international standards, including classification rules and maritime safety regulations. The design process emphasizes overall vessel configuration, arrangement of main systems, and material selection to achieve efficient and robust construction. The use of thin steel plates is intended to support lightweight construction while maintaining structural strength and durability. The proposed design aims to reduce accident risks and improve operational safety at sea. The results of this study are expected to provide a practical reference for modern fishing vessel design and to support adoption by small- and medium-scale shipyards, contributing to improved safety and sustainability within Indonesian coastal fishing communities.

1 Introduction

Small-scale fishing vessels constitute the backbone of the global capture fisheries sector, particularly in archipelagic nations like Indonesia. However, despite their critical role in food security, this sector has historically suffered from a lack of formal engineering attention. Fyson [4] noted that the majority of fishing vessels under 30 meters have been neglected by naval architects, leaving their construction reliant on empirical methods rather than scientific design. This observation remains pertinent in the Indonesian context, where Susanto et al. [8] highlighted that domestic fishing vessels often evolve through artisanal tradition without rigorous stability evaluation. Consequently, this technical gap perpetuates the operation of fleets ill-equipped to withstand adverse marine conditions.

The continued reliance on timber for hull construction presents critical challenges regarding environmental sustainability and operational resilience. While wooden vessels have served traditional fleets for generations, they exhibit significant limitations in durability compared to modern materials. Bornmalm and Lagerqvist [2] emphasized that the historical shift from rustic boats to steel trawlers was pivotal in enhancing seaworthiness. From a safety perspective, recent quantitative assessments of marine accidents by Antão et al. [1] and Fu et al. [3] identify structural failure as a dominant Risk Influencing Factor (RIF) in severe incidents. Thus, the use of non-standardized wooden hulls poses a substantial risk to fisher safety.

Despite the structural advantages of steel, its adoption in the small-scale sector (<30 GT) is impeded by economic and manufacturing barriers. The transition from wood to steel is a complex shift in production management. Ross [6] highlights that accurate cost estimating is critical; for traditional communities, the high capital expenditure of conventional steel vessels is often prohibitive. Furthermore, conventional steel hulls require double-curvature plate bending, demanding heavy machinery scarce in small shipyards. Wibowo and Talahatu [9] argue that to make steel vessels accessible, the design must utilize simplified hull geometries, such as flat-plate designs, to reduce fabrication complexity.

Addressing these challenges, this research proposes a concept design for a 5-8 GT Purse Seine fishing vessel utilizing thin-steel plates. By integrating developable surface principles with hull form optimization, the design aims to minimize production complexity while maximizing structural integrity. The objective is to deliver a solution that adheres to Biro Klasifikasi Indonesia (BKI) and SOLAS standards, ensuring superior stability compared to wooden craft. This study seeks to provide a feasible model for small shipyards, fostering a sustainable transition towards resilient fishing fleets.

2 Method

2.1 Research Framework

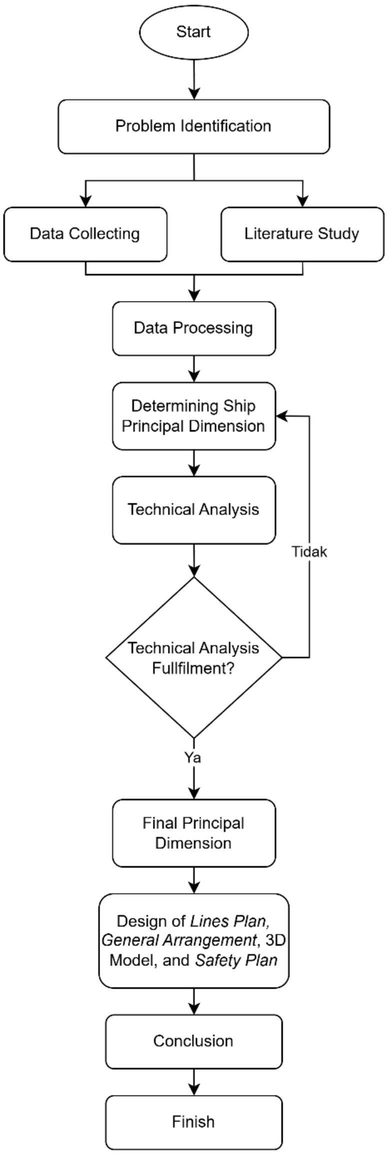


Fig. 1. Research Methodology

The methodology adopted in this study follows the iterative "Ship Design Spiral" approach as elaborated by Fyson [4]. Given the complex interdependence of naval architecture parameters, the design process is not linear but cyclical, where each decision regarding the hull form, weight distribution, and general arrangement requires continuous refinement to satisfy safety and operational constraints.

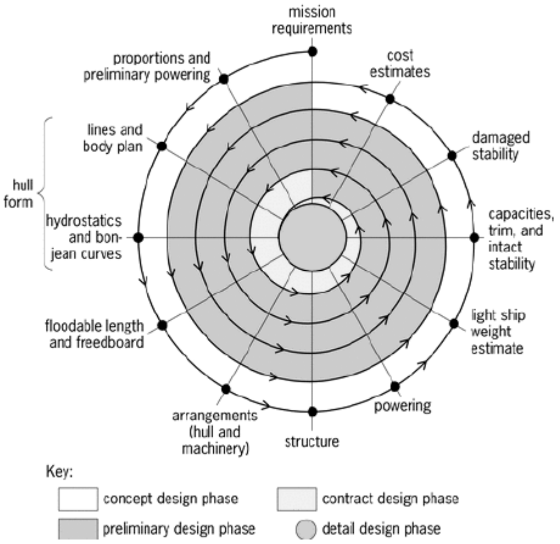


Fig. 2. Spiral Design Process

However, to address the specific challenges of adopting steel in small-scale shipyards, this research integrates the principle of Design for Production. Montwiłł et al. [5] emphasize that for efficient vessel lifecycle management, production processes must be considered during the early design phase. Consequently, the framework of this research is structured to ensure that the proposed "Thin-Steel" concept is not only hydrodynamically efficient but also technically feasible for construction in limited-resource environments. The research stages are systematically defined as follows:

1. Mission Profile Identification: Defining operational requirements based on the characteristics of Indonesian Purse Seiners.
2. Parametric Determination: Utilizing statistical regression of existing vessels to determine optimal principal dimensions (L, B, H, T).
3. Hull Form Development: Generating the lines plan using the developable surface method to accommodate thin-steel plates without complex bending.
4. Technical Assessment: Validating the design through scantling calculation (BKI Rules) and stability analysis (SOLAS criteria).

2.2 Determination of Principal Dimension

Instead of relying on a single parent ship design which may not reflect the diverse operational conditions of Indonesian waters, this study employs a statistical approach based on a comprehensive national database of fishing vessels. As highlighted by Susanto et al. [8], domestic fishing vessels often possess unique geometric characteristics evolved through traditional knowledge that must be evaluated and optimized rather than discarded. To derive the principal dimensions for the proposed vessel, a dataset of 3,732 existing fishing vessels in the 3–10 GT range was isolated from the national registry. Linear regression analysis utilizing the least squares method was performed to establish the correlation between Gross Tonnage (GT) and the main hull parameters: Length (Lpp), Breadth (B), Depth (H), and Draft (T). The regression aimed to identify the empirical geometric trends that have been proven reliable by the fishing community.

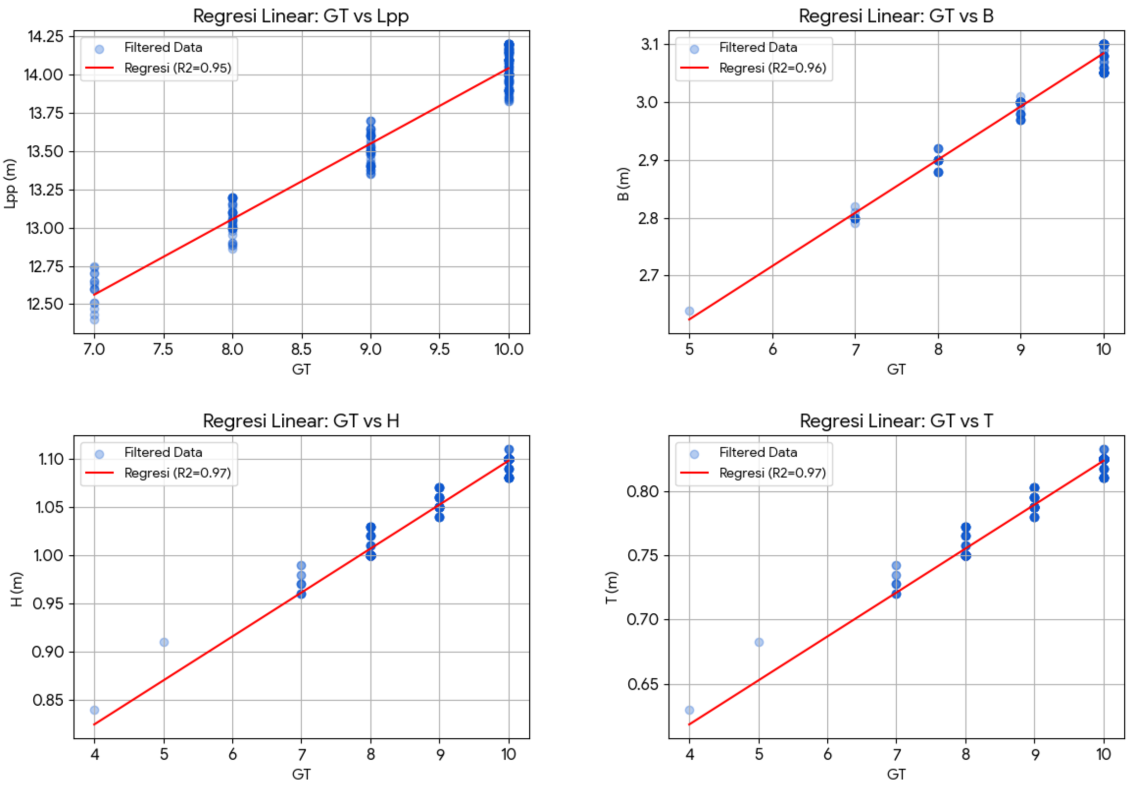


Fig. 3. Result of Linear Regression

The analysis employed an iterative outlier removal process to ensure high statistical significance ($R^2 > 0.95$). The resulting regression equations, which serve as the initial design baseline, are presented in Equations (1) to (4):

$$L = 0.4932(GT) + 9.1092 \quad \text{(R\^{}2 = 0.95)} \tag{1}$$

$$B = 0.0919(GT) + 2.1648 \quad \text{(R\^{}2 = 0.96)} \tag{2}$$

$$H = 0.0455(GT) + 0.6426 \quad \text{(R\^{}2 = 0.97)} \tag{3}$$

$$T = 0.0341(GT) + 0.4820 \quad \text{(R\^{}2 = 0.97)} \tag{4}$$

These equations provide the statistical foundation for the vessel's sizing. However, specific design interventions particularly regarding the vessel's breadth (B) are subsequently applied to enhance stability beyond these traditional averages, as detailed in the results section. Place the figure as close as possible after the point where it is first referenced in the text. If there is a large number of figures and tables, it might be necessary to place some before their text citation.

2.3 Hull Form Generation

The adoption of thin-steel plates (thickness < 4 mm) for the hull structure introduces significant constructability challenges, particularly regarding welding distortion and plate forming. Conventional fishing vessels typically employ compound curvature hull forms, which require extensive line heating or mechanical bending. As noted by Montwiłł et al. [5], the complexity of these manufacturing phases directly impacts the production cost and lifecycle efficiency. Furthermore, applying thermal forming to thin plates carries a high risk of material buckling and structural deformity.

To mitigate these risks, this research utilizes the Developable Surface Method as the core geometric strategy. Referencing the work of Wibowo and Talahatu [9], the hull is generated using ruled surfaces where the Gaussian curvature is zero. This geometric property allows the steel plates to be unrolled into 2D flat patterns without stretching or shrinking, thereby effectively eliminating the need for thermal forming processes.

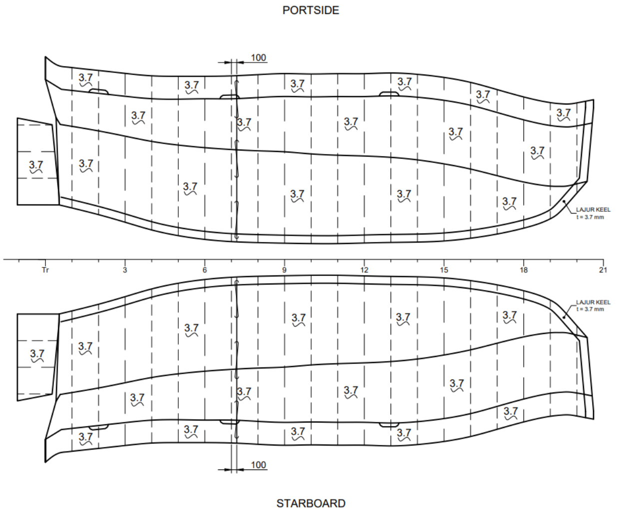


Fig. 4. Shell Expansion

The hull modeling was executed using computer-aided design (CAD) tools to optimize the developability of each panel. The design prioritizes a simplified chine configuration, enabling the integration of standard Flat Bars (FB) for stiffeners instead of the angle bars or bulb flats typically required for curved hulls. This integration ensures that the structural integrity of the thin-steel plating is maintained while significantly reducing fabrication man-hours and material scrap.

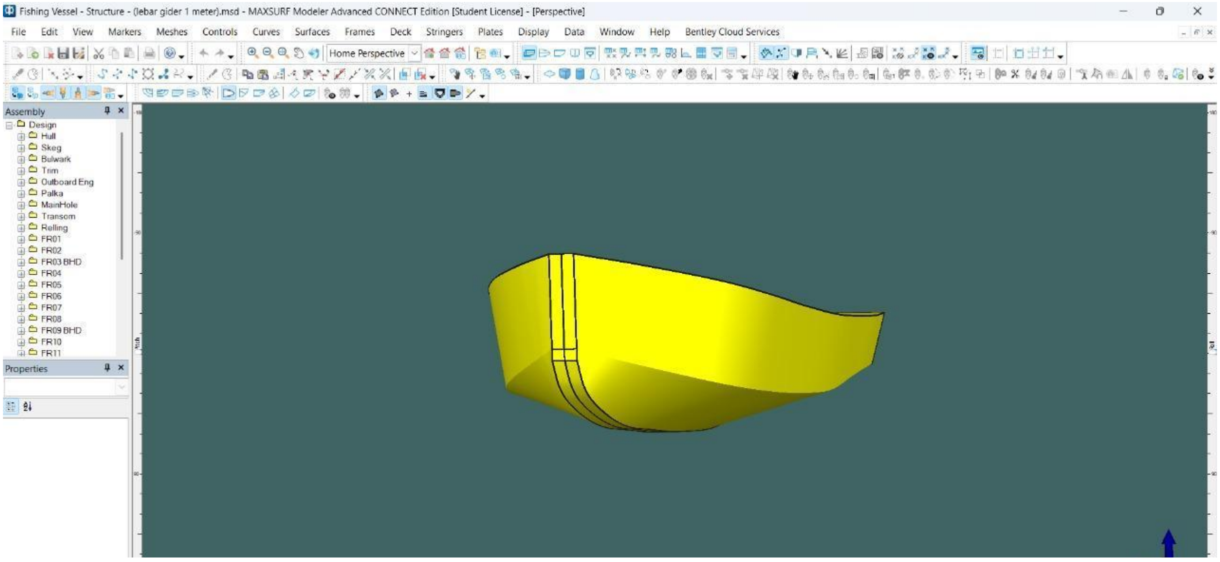


Fig. 5. 3D Hull Model

2.4 Evaluation Criteria

The proposed concept design is subjected to a rigorous technical assessment to ensure it meets the dual objectives of safety and manufacturing feasibility. Unlike traditional wooden vessel construction which often relies on empirical estimation, this study strictly adheres to deterministic regulations to mitigate the Risk Influencing Factors identified by Antão et al. [1]. To validate the feasibility of "Thin-Steel" application, the structural members—specifically the 3.7 mm hull plating and Flat Bar (FB) stiffeners—are calculated against the Rules for Small Vessels issued by Biro

Klasifikasi Indonesia (BKI). This structural assessment focuses on ensuring that the section modulus and plate thickness meet the minimum requirements for local strength, confirming that the significant reduction in material weight does not compromise hull girder integrity as emphasized in the historical transition analysis by Bornmalm and Lagerqvist [2].

Concurrently, given the operational profile of purse seiners which involves heavy lifting and dynamic loads, the vessel's intact stability is evaluated against the International Maritime Organization (IMO) Intact Stability Code (2008). The design must satisfy key parameters derived from the Righting Lever (GZ) curve, specifically the area under the curve at 0°–40°, the maximum GZ value occurring at an angle of no less than 25°, and a minimum Initial Metacentric Height (GM_0) of 0.35 m. Finally, aligning with the cost estimation principles outlined by Ross [6], the design is qualitatively evaluated for constructability, focusing on the minimization of double-curvature plates and the utilization of standard profiles to ensure the vessel remains economically accessible for small-scale fishers.

3 Result and Discussion

3.1 Evaluation Criteria

Based on the statistical regression methodology referenced from Susanto et al. [8], the final principal dimensions were established and subsequently adjusted to meet specific stability criteria. The comparison between the statistical regression baseline and the proposed design is presented in Table 1.

Table 1. Comparasion between Regression Result and Taken Design

Parameter	Regression Result (8 GT)	Proposed Design (7.89 GT)	Deviation & Analysis
Length (Lpp)	± 13.06 m	9.76 m	More compact to enhance maneuverability in crowded ports.
Breadth (B)	± 2.90 m	3.64 m	+25% Wider. Deliberately designed as a "beamy" hull to maximize the righting moment during hauling operations.
Depth (H)	± 1.01 m	1.79 m	+77% Higher. Provides substantial freeboard to ensure a dry deck condition and improve resilience against waves.
Draft (T)	± 0.76 m	1.00 m	Optimum draft for stability and cargo capacity balance.

Following the dimensional determination, the hull form was generated using the Developable Surface Method proposed by Wibowo and Talahatu [9]. This geometric strategy ensures that the 3.7 mm steel plates can be formed into the required hull shape without thermal bending, thereby preventing material buckling and significantly reducing production complexity, a critical factor emphasized by Montwiłł et al. [5]. The visualization of this hull form is presented in the Lines Plan (Fig. 6) and the 3D isometric view (Fig. 7).

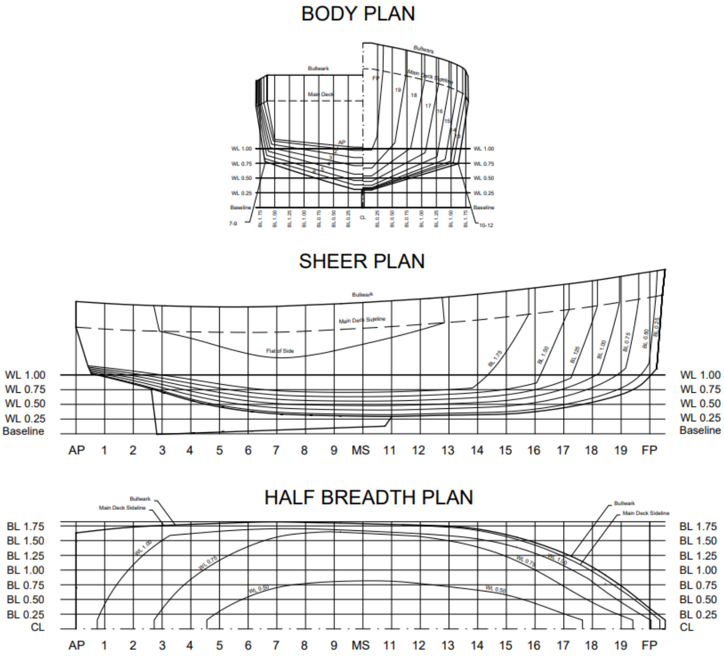


Fig. 6. Lines Plan

Fig. 7. 3D Isometric view

The analysis of the Lines Plan reveals a hard-chine (V-bottom) configuration. While this form theoretically exhibits slightly higher frictional resistance compared to a round bilge hull, it offers significantly better roll damping. This characteristic is crucial for crew safety and comfort, particularly when operating in the dynamic marine conditions typical of Indonesian fishing grounds.

3.2 General Arrangement and Capacity Configuration

The General Arrangement (GA) is strictly configured to maximize the working deck area required for purse seine operations. As illustrated in Fig. 8, the accommodation superstructure is positioned at the aft to provide the skipper with an unobstructed view of the working deck and net handling activities.

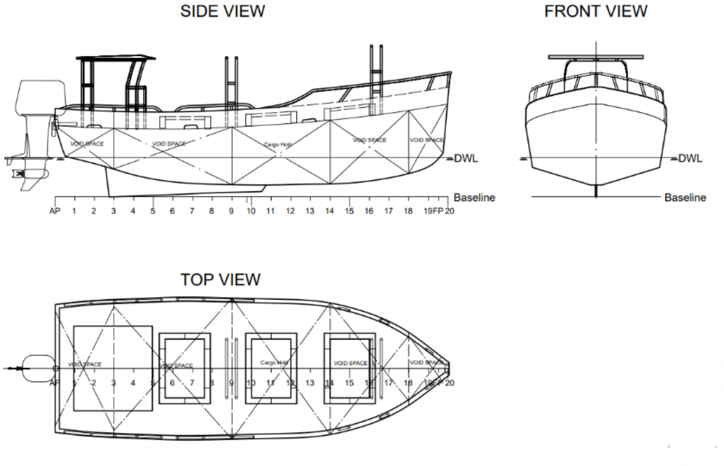
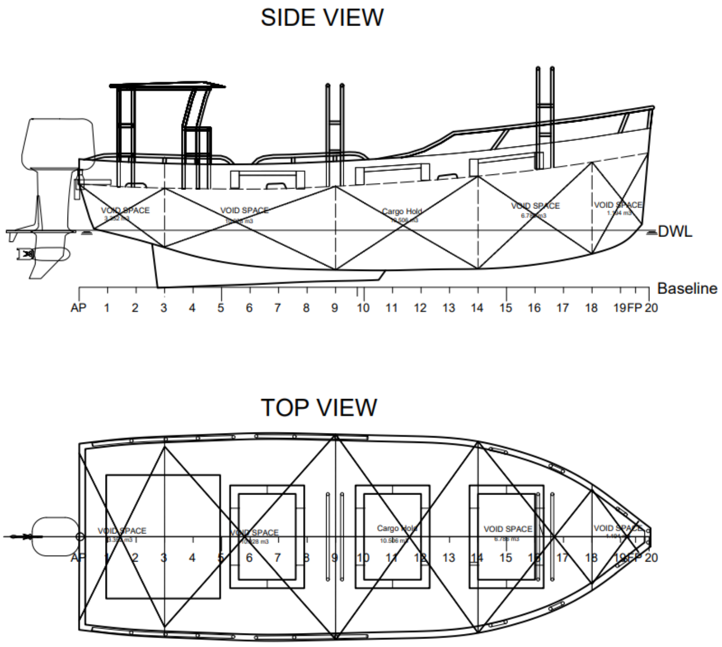


Fig. 8. General Arrangement

Regarding cargo capacity, the Capacity Plan shown in Fig. 9 details a fish hold with a total volume of 2.5 m³, which translates to an effective capacity of approximately 2 tons of fish and ice. Furthermore, the portable fuel tanks and fresh water tanks are strategically positioned along the longitudinal axis to maintain an even keel trim condition under full load, ensuring optimal hydrostatics during transit.

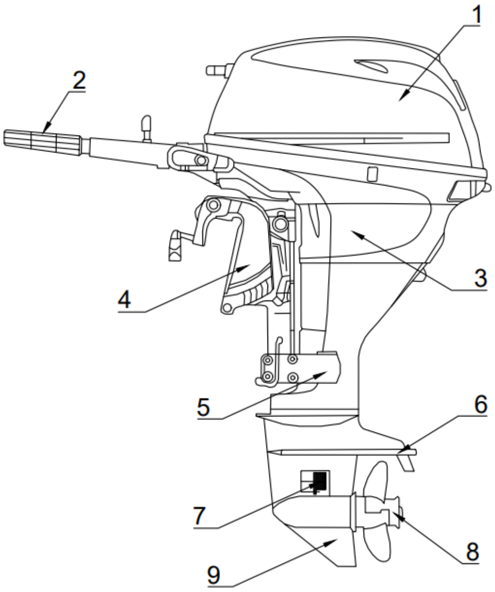


No	Name	Frame (aft)	Frame (fore)	Capacity (m^3)	Long Arm (m)	Trans Arm (m)	Vert Arm (m)
1	Storage	0	3	3.529	0.84	0	1.383
2	Void Space 1	3	9	11.503	3.087	0	1.171
3	Cargo Hold	9	14	11.059	5.754	0	1.189
4	Void Space 2	14	18	7.143	7.899	0	1.35
5	Void Space 3	18	20	1.257	9.357	0	1.594

Fig. 9. Capacity Plan

3.3 Propulsion Arrangement Strategy

Diverging from conventional steel vessels that typically employ inboard diesel engines, this design adopts a 20 HP Outboard Engine propulsion system, as illustrated in Fig. 10. The selection of this propulsion method is predicated on three strategic advantages. Firstly, regarding space efficiency, it eliminates the need for an internal Engine Room, thereby maximizing the hull volume available for the fish hold and directly contributing to revenue generation. Secondly, it simplifies maintenance routines; the engine can be easily detached for onshore repair, effectively addressing the scarcity of skilled diesel mechanics in remote coastal areas. Finally, aligning with the cost estimation principles outlined by Ross [6], this configuration eliminates the expensive shafting system, stern tube, and rudder assembly, significantly reducing the initial Capital Expenditure (CapEx).



STEERING SYSTEM	
NO	DESCRIPTION
1	Engine
2	Tiller Handle
3	Upper Case
4	Bracket Unit
5	Tilt Adjustment
6	Anti Ventilation Plate
7	Water Intake Hole
8	Propeller
9	Skeg

Fig. 10. Steering System

3.4 Cargo Hold Insulation System: Structural and Thermal Analysis

Given the high thermal conductivity of the steel hull $K\approx 50\ W/mK$, the fish hold is designed with a composite sandwich system whose dimensions are determined through two deterministic calculation stages, integrating structural stiffness equivalence and thermal load analysis. The analysis begins by determining the thickness of the Fiberglass Reinforced Plastic (FRP) skins t_{frp} to ensure the inner hold walls possess impact resistance equivalent to the outer steel hull when subjected to heavy fish baskets and ice blocks. The Equivalent Stiffness principle is applied, expressed as

$$E_{st}\cdot I_{st} = E_{frp}\cdot I_{frp}$$

with the moment of inertia III proportional to t3t^3t3, leading to the required FRP thickness

$$t_{frp} = t_{st}\times\sqrt{3}\frac{E_{st}}{E_{frp}}$$

By substituting $t_{st} = 3.7\ mm,\ E_{st} = 206\ GPa,\ and\ E_{frp} = 10\ GPa$ the calculation becomes

$$t_{frp} = 3.7\times\sqrt{3}\frac{206}{10}t_{frp} = 3.7\times 2.74 = 10.14\ mm$$

so the FRP skin thickness is rounded to 10 mm10~\text{mm}10 mm for both layers. This parameter is then used to determine the required Polyurethane (PU) foam core thickness t_{core} to meet thermal standards, using a design target heat transfer coefficient of $U_{design} = 0.46\, W/m^2k$ derived from the recommended limit of $0.60\, W/m^2k$ by applying a safety factor of 1.3. The corresponding required thermal resistance is

$$R_{req} = 2.17 m^2k/W$$

The two FRP skins contribute a thermal resistance of

$$R_{skins} = 2\times\left(\frac{t_{frp}}{k_{frp}}\right)R_{skins} = 2\times\left(\frac{0.01}{0.23}\right) = 0.087\, m^2k/W$$

so the required resistance from the PU core becomes

$$R_{core} = R_{req} - R_{skins} = 2.17 - 0.087 = 2.083\, m^2k/W$$

With PU foam conductivity $k_{pu} = 0.024\, W/mK$, the corresponding thickness is

$$t_{core} = 2.083\times 0.024 = 0.0499\, m$$

which is rounded to 50 mm for manufacturing efficiency. Thus, the final insulation configuration becomes 10 mm FRP − 50 mm PU Foam −10 mm FRP, providing structural protection equivalent to the steel hull while achieving thermal performance approximately 30% superior to the minimum FAO tropical standard.

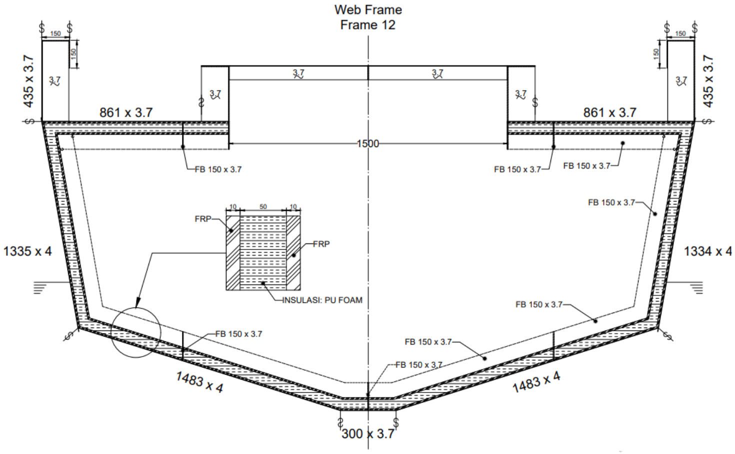
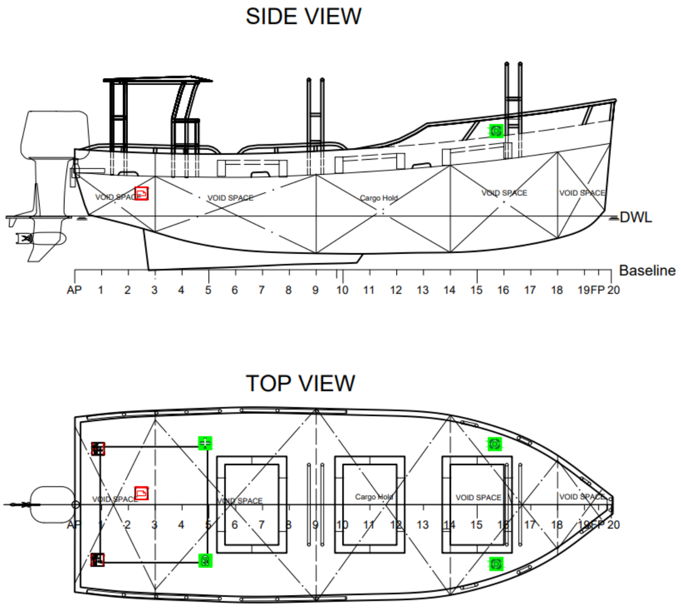


Fig. 11. Cargo Hold Constrction (Frame 12)

3.5 Safety Plan and SOLAS Compliance

The Safety Plan is designed in strict adherence to SOLAS regulations for vessels under 24 meters to mitigate the Risk Influencing Factors highlighted by Antão et al. [1]. As depicted in Fig. 12, the arrangement ensures rapid deployment of safety gear in emergencies. Standard equipment includes Life Saving Appliances such as a 4-person Life Float positioned on the wheelhouse top and Life Jackets stored in accommodation areas. Regarding fire safety, ABC-type Fire Extinguishers are strategically placed near the galley and portable fuel tank area, supplemented by a Fire Blanket. Furthermore, the vessel is equipped with standard COLREG navigation lights (Masthead, Sidelights, Sternlight) powered by a dedicated accumulator. This comprehensive safety arrangement addresses the structural and operational vulnerabilities of traditional vessels discussed by Bornmalm and Lagerqvist [2], ensuring a higher survival probability in adverse marine conditions.



LIFE - SAVING			
SYMBOL	DESCRIPTION	QTY	LOCATION
✚	First Aid Box	1	Main Deck
🟩	Life Jacket	3	Main Deck
◎	Lifebuoy	2	Main Deck

FIRE - FIGHTING EQUIPMENT			
SYMBOL	DESCRIPTION	QTY	LOCATION
P 5KG	5 KG Powder Fire Extinguiser	2	Main Deck
🟥	Fire Blanket	2	Storage

Fig. 12. Safety Plan

4 Conclusion

This research successfully proposes a resilient concept design for a 7.89 GT "Thin-Steel" Purse Seiner to modernize Indonesia's small-scale fishing fleet. Validated by a statistical regression of 3,732 existing vessels, the design features a distinctively stable hull geometry (L/B = 2.68) with a 25% increase in breadth to strictly satisfy IMO Intact Stability criteria for heavy lifting operations. Crucially, the application of the Developable Surface Method confirms the manufacturing feasibility of the 3.7 mm steel hull; by utilizing ruled surfaces and standard Flat Bar stiffeners, the design eliminates the need for complex thermal forming, thereby offering a cost-effective and constructible solution for local shipyards with limited infrastructure.

Operationally, the vessel integrates a strategic 20 HP outboard propulsion system to eliminate the inboard engine room, maximizing the cargo hold capacity to 2.5 m³. The deterministic thermal analysis establishes a specific sandwich insulation specification—comprising 10 mm FRP skins and a 50 mm Polyurethane foam core which achieves a Global Heat Transfer Coefficient (U-value) of 0.46 W/m²K, surpassing FAO tropical standards by 30%. Consequently, this study provides a feasible technical model for sustainable fleet modernization, balancing the rigorous safety standards of BKI and SOLAS with the practical constraints of production and cost.

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