# Placement Planning of a Powered Cooling Engine on a 5 < Gross Tonnage Fishing Vessel

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## ABSTRACT

**Small fishing boats with less than 5 Gross Tonnage (GT) are commonly used for day fishing in Sendang Biru, Malang Regency, Indonesia. This study aims to design the placement of a chiller on a fishing boat. The research was conducted through observations of the fisher's workplace, fishing operations, and fishing duration, as well as by measuring the size of the boat. The results show that the addition of a solar-powered chiller increases the usable area around the fish storage box, while the solar panels are installed on the roof of the boat and also serve as a canopy. This configuration slightly reduces the open space available on the boat. The analysis of boat stability confirms that the placement of the solar-powered chiller complies with international standards, while the analysis of the boat resistance indicates only a minor increase, which does not significantly affect the boat's speed.**

***Keywords-fishing vessels; cooling machines; styling; fish freshness***

## I. INTRODUCTION

Fishing vessels with a gross tonnage of less than 5 GT and an overall length of approximately 11 m are commonly employed for single-day fishing operations in Sendang Biru, Malang Regency, Indonesia. Locally referred to as "speed boats," these vessels typically measure between 10 and 11 m in length, 1.2 to 1.5 m in width, and 0.5 to 0.8 m in depth. Each vessel is equipped with two lateral poles, known as outriggers, installed on both the port and starboard sides to enhance stability [1]. These boats predominantly operate nearshore and offshore waters and often utilize Fish Aggregating Devices (FADs) as fishing aids [2].

To maintain the freshness of the catch, fishers typically bring ice on board and place it in the fish storage box. However, during the fishing season, the large quantity of fish often exceeds the available storage capacity. As a result, the ice must be removed from the storage box and placed on the floor of the vessel, which compromises its effectiveness and leads to a decline in fish quality. To address this issue, the installation of a chiller or freezer on board is proposed as a viable alternative to the use of ice.

Tuna, one of the main species caught in Sendang Biru, Malang, undergoes a rapid increase in body temperature immediately after being captured. Therefore, it is essential to quickly reduce the internal temperature of the fish by immersing it in ice-cooled seawater for no longer than 24 h [3]. Based on this, chilled seawater produced by an onboard chiller presents a suitable alternative to conventional ice, especially considering that fishing activities conducted with vessels of less than 5 GT typically last for only one day [4].

Fishing vessels with a gross tonnage of less than 5 GT are classified as small boats and have limited space on board. The installation of a chiller further reduces the available space, particularly because it also requires an additional power supply unit, which occupies more room. This power demand can be met using solar panels installed on the vessel [5]. In recent years, solar energy has been recognized as a promising, cost-effective, and environmentally friendly power source [6]. Given the spatial constraints on small fishing boats, careful planning is essential for the integration and placement of a solar-powered cooling system on board.

## II. METHODOLOGY

The objective of this research was to design the placement of a cooling engine and solar panel on a fishing vessel with a gross tonnage of less than 5 GT. The method involved comparing the available space on an existing boat with the space required for installing both the cooling engine and the solar panels [6]. In addition, the impact of these installations on vessel performance was evaluated. Ship stability was assessed based on the International Maritime Organization (IMO) criteria [7], while changes in ship resistance were analyzed using the Holtrop method [8].

### A. *Field Study Area*

The data collection was conducted in Sendang Biru, located in Malang Regency, East Java Province, Indonesia, as illustrated in Figure 1. The fishing boats are moored along the eastern coastline of the area, which serves as the primary base for fishing activities.

### B. *Data Processing and Analysis*

Fishing boats of less than 5 GT operating in Sendang Biru generally have similar dimensions. Data were collected on various aspects, including the working area, fishing gear, fishing methods, fishing duration, as well as the size and weight of the chiller. The main dimensions of the vessel were obtained through direct physical measurements, as depicted in Figure 2. The study focused on analyzing the available deck area to determine the optimal placement of the chiller on board and to evaluate the vessel's stability and resistance following the installation.

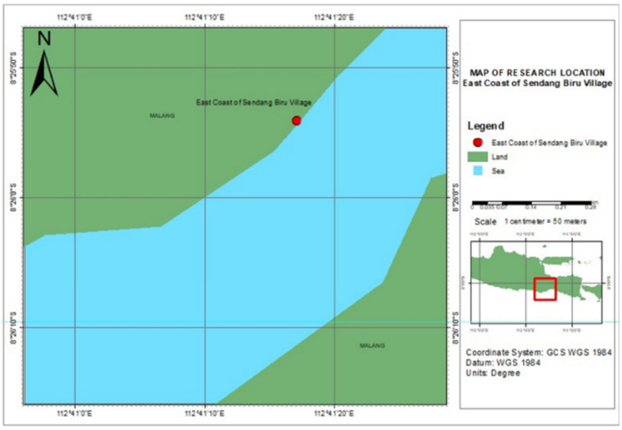

Fig. 1. Research location map.

Fig. 2. Dimensional measurement of the fishing boat.

#### 1) *Assessment of Deck Area Availability*

Data on the area of the solar panels and the area of the cooling engine are required to calculate the space requirements on board the boat. Simpson's formula is then applied [9]:

$$A_{ad} = \frac{h}{3}(y_0 + 4y_1 + 2y_2 + \cdots 4y_n + y_n + 1) \quad (1)$$

$$h = \frac{LoA}{n} \quad (2)$$

where $A$ denotes the width of the area, $h$ the spacing between stations, $y_0$ the ordinate of the first station, $y_1$ the second station, $y_2$ the third station, $y_n$ the last station, and $LoA$ the overall length of the boat.

#### 2) *Boat Stability*

Stability assessment is a crucial process used to evaluate whether a vessel meets the established safety standards. Fishing vessels must exhibit adequate stability and maneuverability to ensure safe operation [9]. In this study, stability calculations were conducted by simulating several loading conditions, also known as load cases [1–11]. These loading conditions were categorized into two main scenarios:

##### a) *Loadcase 1*

Existing ship condition with fisher, fishing gear, and ice load with empty fish load.

### *b) Loadcase 2*

The condition of the boat with a chiller and solar panel, fisher, fishing gear, and full load of fish. The analysis was carried out in accordance with the stability criteria contained in/specified by the IMO regulation [**Error! Reference source not found.**, 7]:

1. The area under the GZ curve at an angle of 0° - 30° (deg) should not be less than or equal to 3.151 m deg.
2. The area under the GZ curve at an angle of 0° - 40° (deg) should not be less than or equal to 5.157 m deg.
3. The area under the GZ curve at an angle of 30° - 40° (deg) should not be less than or equal to 1.719 m deg.
4. The maximum GZ value should not be less than or equal to 0.2 m at an angle of 30° or more.
5. The angle at the maximum GZ value should not be less than or equal to 25° (deg).

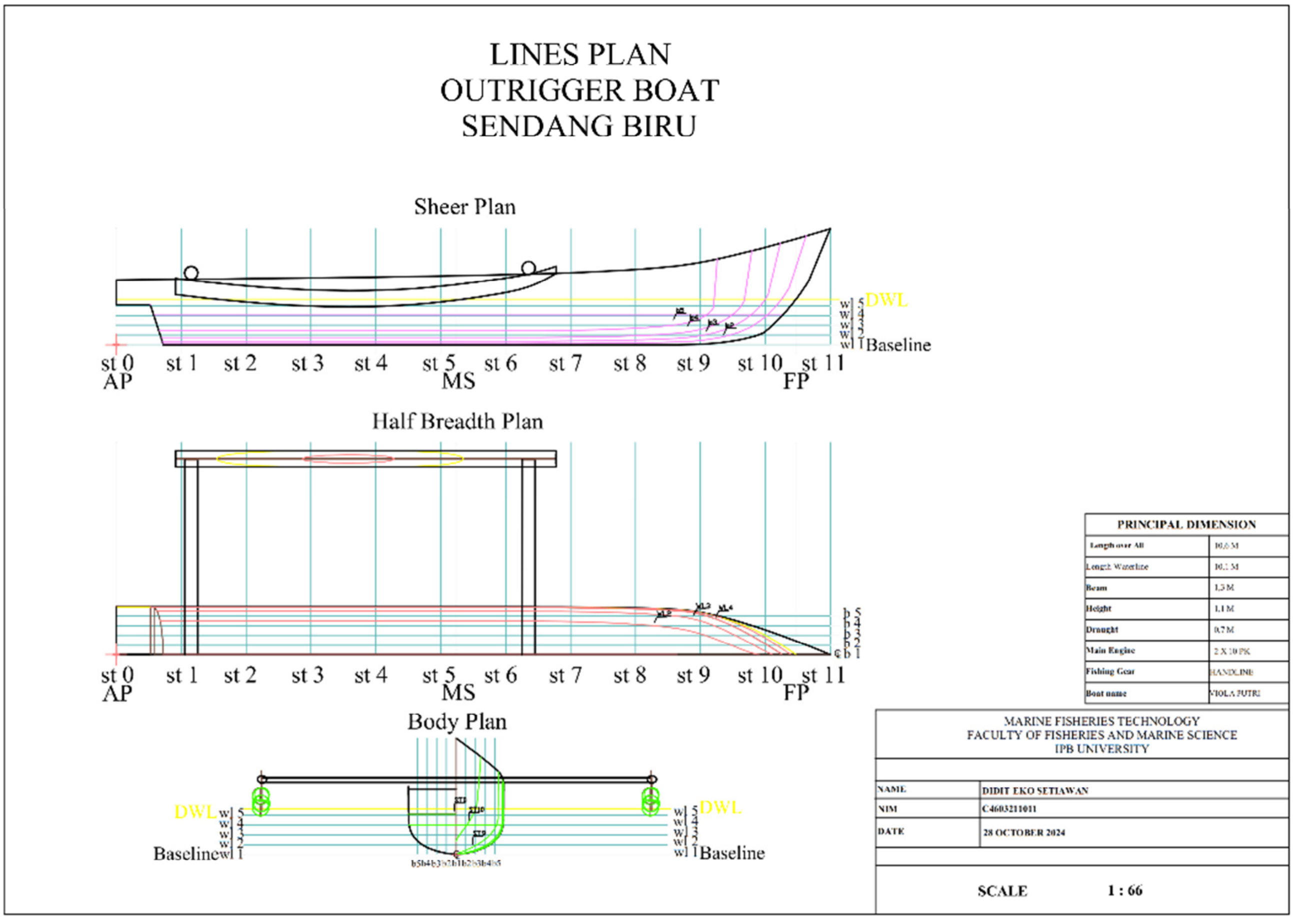

Fig. 3. Fishing boat line plan.

### *3) Boat Resistance*

A boat resistance test was carried out to evaluate the extent to which the additional onboard load affects the vessel's resistance. For fishing boats of ≤ 5 GT, safety considerations must include an assessment of whether the vessel remains operational and buoyant under added load conditions, or whether the load poses a risk of loss of maneuverability or potential sinking. The resistance analysis was performed using the Holtrop method, which accounts for the total resistance as the sum of various contributing components. These include viscous resistance, wave-making resistance, and air resistance, with the latter often considered negligible due to its relatively small magnitude [11-13]. In this method, the total resistance ($R_t$) is calculated as the sum of frictional resistance ($R_f$) and wave resistance ($R_w$):

$$R_t = \sum R_f + 4R_W \tag{3}$$

$$R_f = \frac{1}{2}\left(\rho * C_f * S * V^2\right) \tag{4}$$

$$R_w = \frac{1}{2}\left(\rho * C_w * S * V^2\right) \tag{5}$$

where $\rho$ is the fluid density, $C_f$ is the coefficient of friction , $C_w$ is the wave coefficient, $S$ is the wet surface area, and $V$ is the boat speed.

## III. RESULTS AND DISCUSSION

Fishing vessels of less than 5 GT in Sendang Biru exhibit similar dimensional characteristics. The data collected include the main vessel dimensions, working areas, types of fishing gear, fishing operations, and the duration of fishing activities, and are presented as follows:

### *A. Boat Dimensions*

The initial stage of ship design involves determining the main dimensions of the boat. The latter are then processed in the software and become the basis for calculations or analysis in the next stage. A line plan drawing of the Sendang Biru fishing boat was made usingcomputer software, as shown in Figure 3. The main dimensions of Sendang Biru speed, which will serve as the research material, are presented in Table I:

TABLE I. DIMENSIONAL CHARACTERISTICS OF SENDANG BIRU SPEEDBOAT

| **Dimensions** | |
|---|---|
| Overall length (LoA) | 10.6m |
| Width (B) | 1.3m |
| Height (H) | 1.1m |
| Draft | 0.7m |

The catamaran arms measure 5.9 m in length, while the floating arms are 5.8 m long. The vessel is powered by a 10 HP engine, positioned on both the port and starboard sides of the stern. The hull of the Sendang Biru speed boat is constructed from fiberglass, whereas the deck and masts are made from wooden planks. The catamaran structure itself is built using wooden beams.

### *B. Working Area*

The fishermen work at the back of the boat to drive, refuel, and catch fish, as evidenced in Figure 4. The middle area of the boat was the fish storage area, where the coolbox was placed. During fishing operations, fishers are at the back of the ship and throw their fishing gear. If a fish is caught, it is immediately pulled towards the middle of the ship and then put into the fish storage area.

Fig. 4. Working area of fisher on boat.

### *C. Fishing Gear Specifications*

The handline is a type of fishing gear often used by traditional fishers to catch fish in the sea. The former is the simplest type of fishing gear. Its main structure consists of a fishing rod, fishing line, and a weight or bait. The fishing grounds for operating the handline are quite open and varied because it can be operated around the surface to the bottom of the waters, around coastal waters, or deep sea. The handline utilized by speedboat fishers in Sendang Biru is the coping handline. The hook used to catch fish has various sizes, adjusted to the size of the fish to be caught. The bait used was an artificial bait made of fine threads in the form of tassels that function to attract fish attention, as displayed in Figure 5. The fishing gear was put in a box of 0.48 m$^2$ on a boat, as portrayed in Figure 6.

Fig. 5. Fishing hooks and artificial bait.

### *D. Fishing Method*

The operation of handline fishing gear involves several practical stages, all of which are typically carried out by a single fisher. The process begins with the preparation phase, where the fisher gets everything ready before setting out—this includes preparing the bait, refueling the engine, packing ice and food, and making sure that the boat is fully operational. Subsequently, the decision on where to fish is made. This choice is usually based on the fisher’s prior experience, often relying on the knowledge of areas that have previously yielded good catches. Once a suitable fishing spot is reached, the setting and immersion phase begins. The bait is attached to the hooks, the anchor is dropped to keep the boat steady, and the handline equipped with a sinker and multiple hooks is lowered into the water. Fishing at each location usually lasts between 15 and 30 min, depending on how active the fish are. When bites are felt, the fisher begins hauling the line, bringing the catch on board. The fish are then stored in a chiller located in the middle of the vessel. Most of the fishing activity takes place at the stern of the boat, where the fisher steers, manages gear, and monitors the lines. The bow area remains mostly unused during operations.

### *E. Fishing Duration*

Fishing activities conducted by speedboat fishers in Sendang Biru rely on handline fishing gear. This method is simple and typically operated by a single individual, consisting of basic components, such as a fishing rod, line, sinker, and bait. In Sendang Biru, handline fishing operations are carried out at night, with preparation beginning earlier in the day. Fishers usually depart from the coast around 16:00 WIB (Western Indonesian Time) or as early as 02:00 WIB, and return to the eastern shore of Sendang Biru at approximately 07:00 WIB or 16:00 WIB, depending on the specific schedule and fishing conditions.

### *F. Fish Storage Box*

The fish storage box is located in the middle of the boat, as shown in Figure 6. Its capacity is 200 kg, and its size is 0.58 $m^2$.

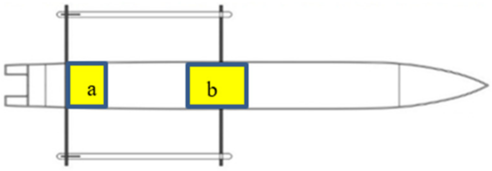

Fig. 6. The placement of fishing gear box (a) and fish storage box (b) on the boat.

### *G. The Chiller*

To maintain the freshness of the catch without relying on ice, a chiller was used as an alternative cooling solution. In this study, a chiller with a cooling capacity of 9,000 Btu/h was selected as a suitable option for use on board. The unit, along with its supporting components, measures approximately 0.6 m in length and 0.06 m in width, making it compact enough for installation on a small fishing boat. The chiller is tasked with cooling around 75 kg of seawater down to 4 °C, which is the proposed temperature for preserving fish freshness. This temperature standard is based on the Indonesian National Standard (SNI) No. 2729:2013, which outlines the best practices for handling and storing freshly caught fish. As a basis for consideration in the arrangement of equipment onboard, one of the factors is the proximity of the related equipment and the efficiency of the connecting pipes [14]. The chiller was attached to the fish storage box considering that the function of the chiller was to cool the fish and seawater in the fish storage box. It maximizes its function and minimizes the cost of piping, as depicted in Figure 7.

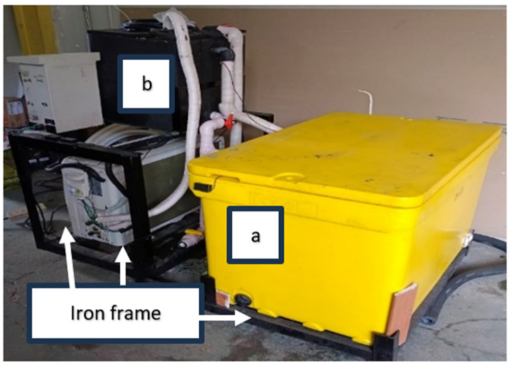

Fig. 7. Fish storage box (a) and chiller (b).

TABLE II. DECK COVERAGE AREA

| **Load** | **Existing deck on boat** | | | **Addition of chiller on deck** | | |
|---|---|---|---|---|---|---|
| | **Length (m)** | **Width (L)** | **Area ($m^2$)** | **Length (m)** | **Width (L)** | **Area ($m^2$)** |
| Fishing gear storage | 0.6 | 0.8 | 0.48 | 0.6 | 0.8 | 0.48 |
| Fish cool box | 0.72 | 0.81 | 0.58 | - | - | - |
| Cooling machine (included) | - | - | - | 1.32 | 0.81 | 1.15 |
| Total area | | | 1.06 | | | 1.63 |

The presence of a cooling machine attached to the fish storage box reduces the deck area, as presented in Table II. The potential occupied area with the addition of a chiller on board was 1,63 $m^2$. This adds occupancy by 0.57 m compared to the area of the existing deck on the boat.

### *H. Solar Panel*

Since the cooling machine is intended for use by local fishers, this study prioritized the selection of components that are readily available on the market. This approach is meant to make it easier for fishers to assemble and maintain the system on their own in the future. A chiller with a cooling capacity of 9,000 Btu/h was selected for this purpose. The compressor used in the system, which matches this cooling capacity, is commonly available and operates with an electric power input of 760 W. To meet these electricity needs, solar panels and their components are prepared to generate electrical energy onboard. It requires two solar panels, each with a capacity of 545 W peak, which produces 1.090 W [4]. The total size of the solar panel was 4.55 m in length and 1.13 m in width, as portrayed in Figure 8.

Fig. 8. Solar panel.

When installing the solar panel to power the chiller, it is important to place it as close as possible to the cooling unit. This makes the wiring and piping much simpler and more efficient, and also helps reduce the risk of electrical problems caused by long or poorly arranged cables. In this study, the solar panels were mounted directly above the chiller and the fish storage box, supported by four vertical poles. This setup not only ensures that the panels receive maximum sunlight without obstruction, but also acts as a roof that shades the fish storage area. By protecting the box from direct sun exposure, it helps keep the fish cooler and preserves their quality. The layout of the chiller, solar panel, fish storage box, and fishing gear is illustrated in Figure 9.

The system comprises several key components, each of which is labeled accordingly in the corresponding Figure to facilitate identification and understanding. Component A refers to the Solar Charge Controller (SCC) and battery box, which manage the flow and storage of the electrical energy. Component B denotes the switch box used to control power distribution. The chiller is labeled as C, while its internal refrigeration components are marked as D. The fish storage box is indicated as E, the main engine as F, and the propeller as G. Structural support for the solar panels is provided by vertical poles labeled as H, with the panels themselves marked as I. Finally, component K represents the fishing gear box, where the handline equipment is stored.

The arrangement of space and shipboard equipment is depicted in Figure 9. The fish storage area is positioned at the center of the vessel, adjacent to the cooling machine, allowing for an efficient transfer of the catch. The SCC and its battery storage box are placed directly behind the cooling unit, near the fisher's working area. This placement provides convenient access, making it easier for the operator to monitor and control the SCC and battery system. The solar panels are mounted above these components, supported by vertical poles with a height of 1.7 m from the top of the boat's structure. Authors in [14] stated that the addition of solar panels on the ship deck does not have a significant impact on vessel stability.

The design and placement of the cooling machine and solar panels on fishing vessels of ≤ 5 GT, particularly those equipped with outriggers or classified as speedboats, considered the spatial limitations and working conditions experienced by fishers. Most fishing activities are concentrated toward the rear of the vessel, where fishers operate and manage their equipment. The working area on the vessel is typically divided into two zones: the deck cover area and the free area [7]. The deck cover area is primarily used for storing the fishing gear, the catch, and other essential equipment. In contrast, the free area refers to the remaining open space outside the covered zones, where crew members carry out their operational tasks during fishing activities.

### *I. The Ocupied Deck Area*

The deck area on the board was calculated using Simpson's rule. To simplify the calculation, the ship was divided into 11 ordinates, as shown in Figure 10.

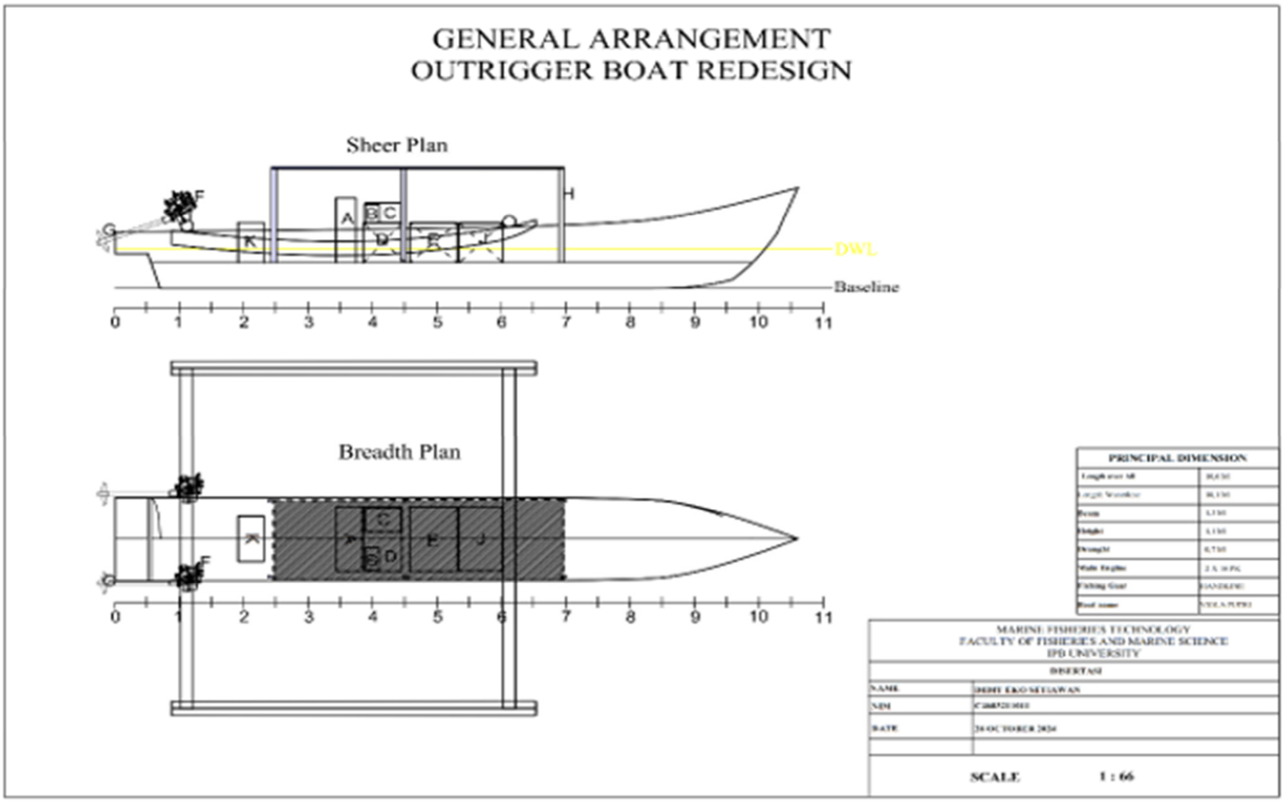

Fig. 9. General plan of a solar-powered chiller on boat.

The boat deck was divided into a series of ordinates for measurement purposes [14]. The width of the boat was recorded at each ordinate point, ranging from ordinate 0 at the stern to ordinate 10 at the bow, as illustrated in Figure 10. The distance between each ordinate was determined by dividing the total length of the vessel into ten equal segments. To calculate the deck area, Simpson's First Rule was applied, as the number of ordinates used was odd. The corresponding coefficients were assigned to each point, and the results are listed in Table III. Based on this calculation, the total estimated deck area was 37.9 m².

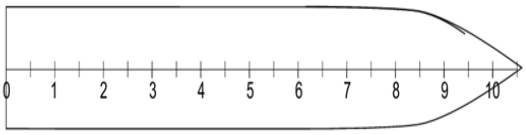

Fig. 10. Speed boat ordinate.

### *J. Boat Stability*

Based on calculations performed using computer software, the addition of the refrigeration unit, solar panels, and fish catch weight meets all the stability criteria outlined in IMO Resolution A.749. All loading conditions evaluated resulted in a pass status, as presented in Table IV.

TABLE III. DECK AREA SIZE

| Ordinate | Width (m) | Simpson's coefficient | Area ($m^2$) |
|---|---|---|---|
| 0 | 1.3 | 1 | 1.3 |
| 1 | 1.3 | 4 | 5.2 |
| 2 | 1.3 | 2 | 2.6 |
| 3 | 1.3 | 4 | 5.2 |
| 4 | 1.3 | 2 | 2.6 |
| 5 | 1.3 | 4 | 5.2 |
| 6 | 1.3 | 2 | 2.6 |
| 7 | 1.3 | 4 | 5.2 |
| 8 | 1.2 | 2 | 2.4 |
| 9 | 1 | 4 | 4 |
| 10 | 0.8 | 2 | 1.6 |
| Total | | | 37.9 |

TABLE IV. BOAT STABILITY

| No | Criteria | Value | Units | Boat with ice and without fish load | | Boat with solar powered chiller and full load of fish | |
|---|---|---|---|---|---|---|---|
| | | | | Actual | Status | Actual | Status |
| 1 | 3.1.2.1: Area 0 to 30 | 0.0550 | m.rad | 0.2639 | Pass | 0.2475 | Pass |
| 2 | 3.1.2.1: Area 0 to 40 | 0.0900 | m.rad | 0.4381 | Pass | 0.3809 | Pass |
| 3 | 3.1.2.1: Area 30 to 40 | 0.0300 | m.rad | 0.1742 | Pass | 0.1334 | Pass |
| 4 | 3.1.2.2: Max GZ at 30 or greater | 0.200 | m | 1.001 | Pass | 0.766 | Pass |
| 5 | 3.1.2.3: Angle of maximum GZ | 25.0 | deg | 35.5 | Pass | 34.5 | Pass |

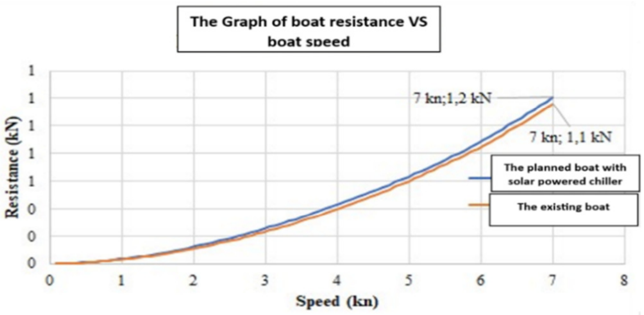

Fig. 11. Boat resistance

### *K. Boat Resistance*

The boat resistance analysis, also referred to as drag analysis, is used to determine the engine force required to propel a vessel through a fluid along its axis of motion. The effective power output from the engine is referred to as thrust. As the vessel moves forward, any opposing force acting against this thrust is considered resistance [15]. In this study, the main dimensions of the fishing vessel used in the analysis were approximately 10.6 m in length, 1.3 m in width, and 0.7 m in depth. These measurements were processed to generate a boat model, as illustrated in Figure 1. Vessels of this size, typically equipped with outriggers, are commonly referred to as speed ships by the local fishers in Sendangbiru. To estimate hydrodynamic resistance, the Holtrop method was employed, which considers the shape of the hull. For this analysis, the vessel's maximum speed was assumed to be seven knots. Figure 11 presents the comparison of resistance values between the redesigned and the existing vessel. The results indicate that at a speed of 7 knots, the redesigned vessel exhibited a resistance of 1.2 kN, compared to the 1.1 kN for the existing configuration.

## IV. CONCLUSION

Several studies have explored the use of solar-powered chillers or freezers on fishing vessels. However, the novelty of the present research lies in its specific focus on the implementation of a solar-powered cooling system on small fishing boats with a gross tonnage of less than 5 GT. Due to the limited size of such vessels, a careful planning of the cooling system's placement was essential to ensure operational safety and to prevent issues, such as instability or overloading, which could compromise the vessel's seaworthiness.

The design of the chiller and the integration of solar panels were based on various practical considerations, including the working space available to the fishers, their routines regarding the storage of the fishing gear, and the location of the fish cool boxes. The addition of the solar-powered chiller increased the usable occupancy area on board from 1.06 $m^2$ to 1.63 $m^2$, as a result of a 0.57 $m^2$ extension surrounding the fish storage box. The solar panels were mounted on the upper part of the vessel and also served as a protective roof, which slightly reduced the open deck area from 12.24 $m^2$ to 11.67 $m^2$.

The stability analysis confirmed that the installation complied with the criteria set by the International Maritime Organization (IMO). Furthermore, the resistance analysis revealed only a slight increase of 0.1 kN in hydrodynamic resistance, which was not significant enough to impact the vessel's speed.

These findings contribute to the advancement of small-scale fisheries in Indonesia and demonstrate the feasibility of integrating green energy technologies, such as solar power, into traditional fishing operations.

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