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Conceptual and Preliminary Design Innovation of a Multipurpose Palm Fruit Vessel for Inland Plantation Waterways in Muara Kaman

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ABSTRACT – Oil palm fruit production in East Kalimantan continues to increase in line with high market demand. This situation demands efficient transportation facilities to transport the harvest from plantation areas. Furthermore, annual forest fires, particularly in peatland areas, are often difficult to manage due to limited land access. Based on these two challenges, this study proposes the design of a multipurpose vessel capable of both transporting oil palm fruit and supporting firefighting. The vessel is designed with main dimensions of L = 20 m, B = 4.9 m, H = 2 m, T = 1.5 m, and an operating speed of 8 knots. The cargo hold has a carrying capacity of 67.3 tons with a single trip distance of 12.3 km. The main innovation developed is a conveyor belt with hydraulic arms to increase the efficiency of the oil palm fruit loading and unloading process in the plantation area. Furthermore, the vessel is equipped with an external firefighting system with a capacity of 90 m^3/hour with a horizontal spray range of 30 meters and a vertical height of 20 meters. The fire monitor operates using 7 kW of power to generate sufficient pressure to extinguish fires in areas difficult to reach from the riverbank. This multipurpose vessel is designed to provide an integrated solution for the oil palm plantation logistics chain while improving the response to forest fires in the Muara Kaman District.

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INTRODUCTION

Oil palm plantations represent one of the most strategic agricultural commodities contributing significantly to the economic development of local communities, particularly in East Kalimantan Province [1]. In 2020, the total area of oil palm plantations reached 1,374,543 hectares, consisting of 373,479 hectares managed by local communities, 14,402 hectares by state-owned enterprises, and 986,662 hectares operated by private companies [2], [3]. This extensive cultivation area produced approximately 3.8 million tons of Crude Palm Oil (CPO) derived from fresh fruit bunches (FFB) [4], indicating the high intensity of palm oil industry activities in the region. Muara Kaman District in Kutai Kartanegara Regency is among the areas with vast oil palm plantations, located adjacent to the Mahakam River and its tributaries [5]. The distribution of FFB in this region predominantly relies on land transportation using trucks. However, during the rainy season, plantation areas frequently experience flooding, which damages road infrastructure, reduces accessibility, and disrupts the transport of FFB to palm oil mills (PKS). These disruptions lead to delivery delays, reduced fruit quality, and substantial economic losses. In contrast, the area possesses an extensive river network that offers a stable and flood-resistant alternative transportation route capable of carrying larger loads compared to land-based transport.

In addition to logistical challenges, East Kalimantan also faces recurrent forest and land fires, which occur almost every year [6]. Historically, one of the largest forest fires occurred during the 1982–1983 period, destroying approximately 3.2 million hectares in East Kalimantan, with estimated economic losses reaching US$9 billion as reported by the World Resources Institute [7]. Over the past decades, recurring fires have contributed to severe deforestation in Indonesia for more than 30 years. According to data from the Food and Agriculture Organization (FAO), the annual deforestation rate in 1966 was 300,000 hectares, which dramatically increased to around 2 million hectares per year between 1966–2000 and continued escalating through 2010–2014 [8]. Many of the fire-affected areas are difficult to access via land routes, particularly in peatland and remote inland regions with limited infrastructure.

These two major challenges the disruption of FFB distribution in flood-prone areas and the urgent need for firefighting support in remote forest regions highlight the necessity for an innovative solution capable of addressing both logistical and emergency-response demands. This study proposes the development of a multipurpose vessel that can efficiently transport oil palm produce while also supporting fire suppression operations. The design follows standard naval architecture procedures, including the development of the lines plan [9], [10], general arrangement planning [11], [12], machinery power estimation [13], and strength, stability, and structural analysis [14]. This design approach ensures that the vessel fulfills dual operational functions: serving as a riverine transportation platform for oil palm distribution and as a unit equipped with an external fire-fighting system for forest fire mitigation in areas inaccessible by land [15]. To enhance operational efficiency, the vessel integrates a hydraulic-arm conveyor belt system to accelerate FFB loading and unloading processes and improve overall transport productivity [16], [17]. Moreover, the installation of an external fire-fighting system enables rapid response to forest fire incidents, especially in regions with limited accessibility.

Through this dual-function approach, the study aims to provide a practical contribution to improving plantation transportation systems and strengthening forest fire mitigation capabilities in Muara Kaman District and remote areas of East Kalimantan in general.

METHOD

ship design approach

The design process of the proposed multipurpose vessel begins with the application of the Parent Design Approach [18],[19], a method that utilizes the characteristics and performance data of existing vessels as reference models. This approach ensures that the selected principal dimensions fall within a proven and operationally reliable range, particularly for vessels operating in riverine environments and transporting plantation commodities in East Kalimantan. The reference design is then systematically analyzed and modified to meet the specific objectives of this study, namely the capability to transport fresh fruit bunches (FFB) of oil palm and the additional function of supporting forest fire-fighting operations.

A comprehensive literature review is incorporated to strengthen the design foundation, covering aspects of river vessel performance, stability requirements, maneuverability in narrow waterways, shallow-water limitations, and load-handling characteristics. These considerations serve as the basis for determining the vessel's principal dimensions, including length (L), breadth (B), depth (H), and draft (T). By employing the Parent Design Approach, the design process becomes more efficient, reduces iterative uncertainty, and ensures that the resulting dimensions and configurations remain technically feasible, environmentally appropriate, and operationally optimized for the unique challenges of inland river transportation in Kalimantan.

Lines Plan Modeling and Hydrodynamic Analysis

The next stage of the design process involves developing the lines plan, which represents the three-dimensional hull geometry of the vessel. The sheer plan, body plan, and half-breadth plan were generated using Maxsurf Modeler Advanced [20], ensuring a smooth and well-proportioned hull form that satisfies hydrodynamic design criteria. The resulting hull model was subsequently used as the basis for hydrodynamic evaluation through resistance analysis. Total resistance at the operating speed of 8 knots was calculated using Maxsurf Resistance, which decomposes resistance into its principal components, including frictional resistance, residuary resistance, and air drag. The obtained total resistance values form the foundation for determining the required propulsion power. Engine power estimation was performed using the Watson method, which accounts for the influence of hull form characteristics, operating speed, propulsion efficiency, and typical riverine environmental conditions. This stage ensures that the vessel achieves optimal hydrodynamic performance, enabling efficient operation in relatively calm river environments that may exhibit variable currents and depth constraints.

Calculation of Weight, Stability, and Freeboard

The ship's weight calculation is carried out by separating the components into Light Weight (LWT) and Dead Weight (DWT). LWT includes the weight of the hull structure, machinery systems, navigation equipment, and additional installations such as the conveyor system and external fire-fighting equipment. Meanwhile, DWT consists of the cargo capacity of palm oil fresh fruit bunches, fuel, freshwater, provisions, and crew load. The estimated total weight is used to determine the ship's displacement and to evaluate its compliance with the predetermined principal dimensions. The stability analysis refers to the Principles of Naval Architecture Volume II and IMO standards to calculate the metacentric height (GM), GZ curve, stability area, and the ship's ability to return to an upright position after experiencing external disturbances [21]. The freeboard calculation follows the provisions of the International Convention on Load Lines (ICLL) 1966/1988 to ensure that the vessel has sufficient reserve buoyancy in accordance with safety standards [22]. This stage is crucial considering that the ship will operate in river waters with potential variations in loading conditions and dynamic water characteristics.

General Arrangement (GA)

The final stage of the methodology is the preparation of the General Arrangement (GA), which organizes the layout of all spaces and major installations onboard. The cargo hold arrangement is adjusted to the dimensions and capacity of fresh fruit bunches (FFB) to ensure fast loading and unloading operations. The conveyor system is positioned strategically and equipped with a hydraulic arm to facilitate cargo transfer from the jetty or plantation to the ship's cargo hold. The engine room is designed according to the required propulsion power and additional systems such as generators for fire pump operation. Crew accommodation is placed in a safe and ergonomic area in accordance with safety and comfort standards. In addition, the installation of the external fire-fighting system is arranged in locations that provide maximum spray coverage for combating forest fires along the riverbanks. The preparation of this GA ensures that all vessel functions both as a palm oil carrier and as a fire-fighting support vessel can operate effectively, efficiently, and safely [23].

Power Requirement Calculation

The calculation of the ship's propulsion power requirement involves several interconnected analytical stages [24]. The first stage is determining the Delivered Horse Power (DHP), which is the power transmitted through the propeller shaft, obtained from the ratio between Effective Horse Power (EHP) and the propulsion coefficient using the equation:

$$DHP = EHP / Pc \quad (1)$$

Thrust Horse Power (THP) is calculated as the effective thrust power of the propeller, representing the ratio between EHP and hull efficiency:

$$THP = EHP / \eta h \quad (2)$$

The power chain is then traced through the transmission system by determining the Shaft Horse Power (SHP), obtained from DHP divided by the shaft transmission efficiency of 0.98, considering that the engine is located at the aft section of the ship:

$$SHP = DHP / \eta s \eta b \quad (3)$$

The next stage calculates the Brake Horse Power (BHP_scr), which represents the required power at the engine shaft before mechanical losses in the gear transmission system, using:

$$BHP\_scr = SHP / \eta G \quad (4)$$

The final calculation yields BHP_mcr, the maximum continuous rating (MCR) of the engine that must be provided to ensure optimal ship operation under all loading conditions, expressed by:

$$BHP\_mcr = BHP\_scr / 0{,}85 \quad (5)$$

These calculation steps are essential to ensure that the selected main engine has sufficient capacity to meet the ship's operational requirements and complies with propulsion system efficiency standards.

A. RESULTS AND DISCUSSION

Determination of Payload

The determination of payload on the vessel must be based on the harvested volume of oil palm fruit produced in a specific area. With the availability of harvest yield data, the design of the cargo hold or payload capacity can be appropriately defined according to the existing data

Table 1. Oil Palm Fruit Harvest Data

Year	Mature Plantation Area (Ha)	Total Area (Ha)	Production (Tons)	Productivity (Kg/Ha)	Number of Farmers (Households/ID Holders)
2020	1.020.468	1.374.543	17.721.970	17.367	218.023

The determination of the cargo hold capacity for transporting oil palm fruit on the Self-Propelled Barge is based on a rectangular configuration with predetermined dimensions, consisting of two modified cargo holds. Considering the substantial oil palm harvest in the Muara Kaman area, the planned cargo hold dimensions are as follows:

Cargo hold 1

P = 5 m, L = 3,5 m, T = 3,6 m

V_1 = P x L x T

V_1 = 5 x 5 x 2

$V_1 = 50\ m^3$

Cargo hold 2

P = 5,5 m, L = 3,5 m, T = 3,6 m

V_2 = P x L x T

V_2 = 5 x 2 x 2

$V_2 = 50\ m^3$

$P = 0{,}67\ kg/m^3$

$$V_{Total} = V_1 + V_2$$
$$V_{Total} = 51 + 50$$
$$V_{Total} = 101\ m^3$$
$$m = P\ x\ V$$
$$m = 0{,}67\ x\ 101$$
$$m = 67.3\ ton$$

Determining the Main Dimensions

Based on the river specification data above, the dimensional limits for the vessel can be identified. The design method used in this study is the Parent Design Approach, which utilizes comparative data from previously researched vessel designs. The ship data used in this design is referenced and compared with modifications based on the predetermined size of the cargo hold (payload) of 67.3 tons, resulting in a recommended ship length of L = 20 m. After obtaining the ship length, the next step is to determine the vessel's breadth (B), depth (H), and draft (T), which are calculated using the principal dimension ratios of the ship

Table 2. Ship Size Comparison Ratio

Comparison	Ratio	Description
L/B	(4) 3,0 - 6,5	*Accepted*
B/T	(3) 2,8 – 5,7	*Accepted*
L/H	(9.8) 9,0 - 14	*Accepted*
H/T	(2) 1,5 – 2,0	*Accepted*

After determining the ratio, the following data measurements are obtained.

Table 3. Main Dimension of the Ship

Main Dimension	
Ship Name	MV. Queen Diana 1
LOA	20 m
B	4.9 m
H	2 m
T	1.5 m
V	8 Knot

Lines Plan

After determining the ship's main dimensions from the comparison, the next step is to create a design model using Maxsurf Modeler Advanced software to design the ship according to the specified dimensions. Here are the steps for designing a lines plan using Maxsurf Modeler Advanced.

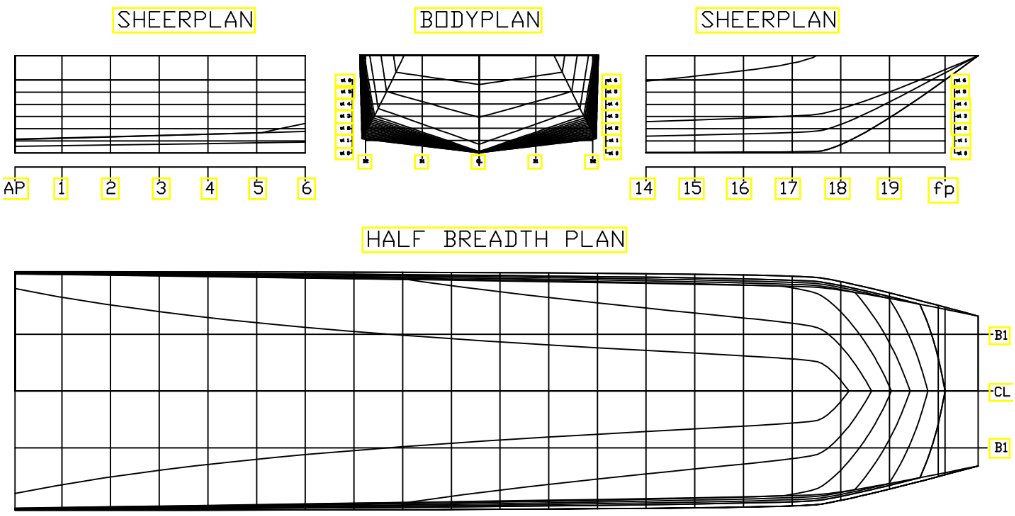

Figure 1. Line Plan of the Ship Design

Resistance Calculation

The resistance calculation for the vessel uses the Holtrop analytical method through the Maxsurf Resistance software. After running the simulation using the Holtrop method at a speed of 8 knots, the ship's resistance was found to be 14.4 kN, with a required power of 72.45 kW.

Main Engine Selection

Based on the engine power requirement, the Effective Horse Power (EHP) obtained from Maxsurf Resistance is 59.2 kW, while the calculation using the Watson method results in 72.45 kW.

Table 4. Main Engine Specifications of the Ship

Main Engine Specifications	
Model	6CHE3
Type	4-scycle, vertical, natural aspirated water cooled diesel design
Bore x Stroke	6 in-line 105 x 125 mm
Displacement	4.330 mm
Ratedoutput	L: 84.6 KW (115 Hp)/2550 Rpm
Fuel consumption	242 gr/kW.hr
Cooling FW cpty	20 + 0.8 L (Resevior tank)
Lo cpty	18.5 lit
Starting system	Electric starting motor (DC 24V-4kW)
Dry Weight	630 kg

Weight Calculation

In the ship's weight calculation, there are two types of weight components: Dead Weight (DWT) and Light Weight (LWT). The DWT calculation includes components such as payload, crew, fuel weight, and crew weight.

Table 5. Ship DWT Weight Calculation

No	Heavy Components	Quantity	Unit
1	Weight of Main Engine Fuel	0.23	ton
2	Weight of Lubricating Oil	0.001	ton
3	Weight of Fresh Water	1.48	ton
4	Crew and Personal Belongings	0.7	ton
5	Payload	67.3	ton
	Total	69.711	ton

LWT calculations include ship components, namely machinery, outfitting, and construction weight. Construction weight can be calculated using Autocad software.

Table 6. Ship LWT Weight Calculation

No	Heavy Components	Quantity	Unit
	Engine		
1	Main Engine	0,63	Ton
	Outfitting		
1	Navigation equipment	0,04	Ton
2	Equipment & Supplies	0,007	Ton
3	Conveyor Equipment	0,34	Ton
4	Extinguishers	0,11	Ton
	Construction Component		
1	Construction	7.2	Ton
2	Plate weight	25	Ton
	Total	31.2	Ton

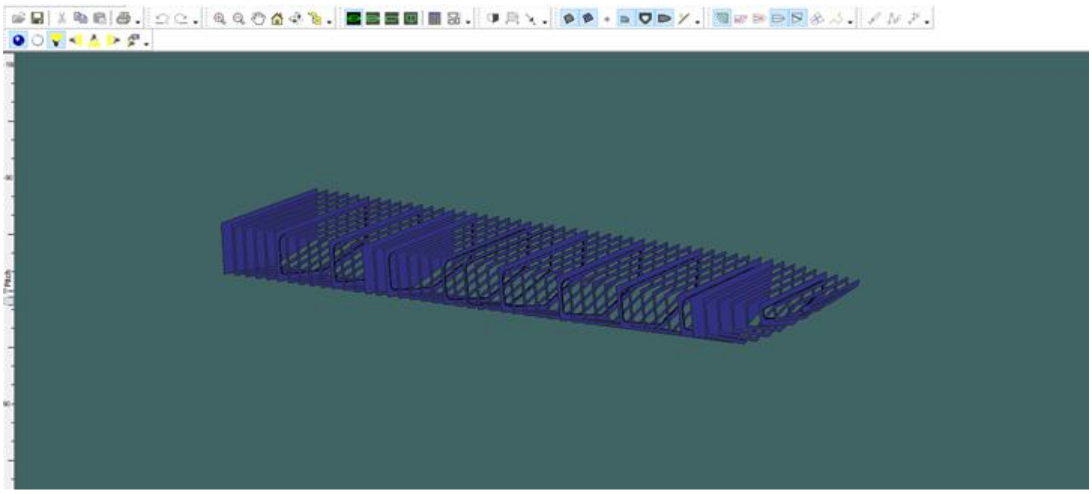

Figure 2. 3D ship construction frame view

Table 7. Displacement Correction Table

Displacement Correction		
Total Weight	103.50	ton
Displacment(Δ)	103.5	ton
The requirement Δ must be greater than 0% by 5%		
Difference	0.002	
% of Difference	0.00%	qualify

Conveyor Calculation

The conveyor design is determined based on the cargo capacity that the vessel can carry and the required loading time. The calculation is conducted to determine the conveyor capacity and subsequently specify the conveyor system to be used, as follows:

Calculation of the conveyor's carrying capacity per hour.

$$Q = 3.6 \cdot 5.4/1 = 72 \text{ Ton/h}$$

Therefore, from the calculation of the loading and unloading speed of palm oil in 1 hour, the conveyor is capable of moving 72 tons of palm oil and the conveyor specifications used can be determined based on the displacement speed of 4 m/s which is equal to 1.216 ft/s and converted into minutes of 72.96 ft/min. Therefore, conveyor specifications are needed with a displacement speed of 72.96 ft/min or more.

External Fire Fighting Calculation

$$P_m = P(1+a) / \eta_t$$

when :

a : 0,15 for large combustion engines

η_t : Transmission Efficiency 0.95 for 1-stage bevel gear

The results of the calculations above show that the pump power required to spray water 30 meters is 7.16 kW.

General Arrangement

The general arrangement determines the layout and space on the designed ship. The general plan for a ship transporting oil palm fruit is as follows:

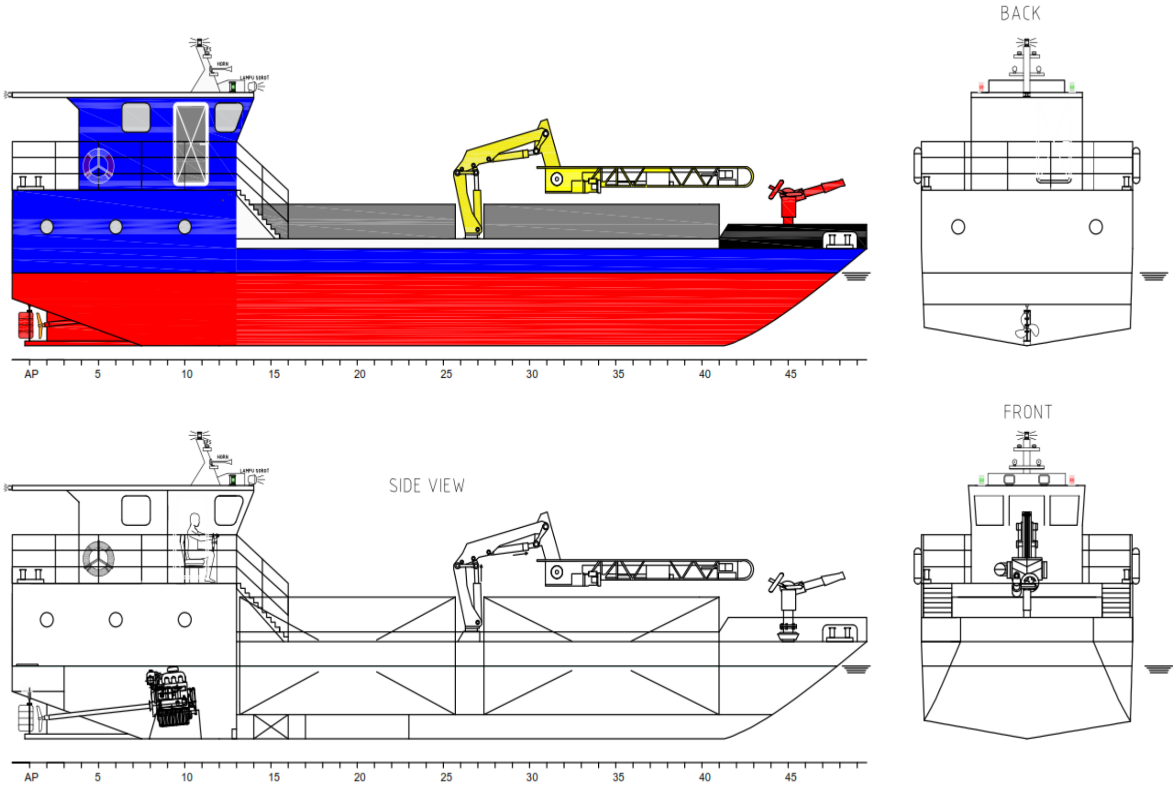

Figure 3. General Arrangement of the designed ship

CONCLUSION

The principal dimensions of the vessel were determined using the Parent Design Approach, resulting in a ship length of 20 m, a beam of 4.9 m, a depth of 2 m, and a draft of 1.5 m. The vessel is powered by a 72.45 kW diesel engine and equipped with two modified cargo holds providing a total payload capacity of 67.3 tons. The ship also features a belt conveyor system, an external fire-fighting installation, two pairs of life buoys, and is designed to operate along a 12.3 km route from the plantation loading jetty to the PT. TJA processing facility, M.P. Evans Group. Based on the payload capacity of 67.3 tons, a belt conveyor was selected with a transfer capability of 72 tons per hour. The conveyor specifications include a 16-foot belt length, a total weight of 650 lbs, a 110/220V single-phase electric motor, and a 3500-watt generator. The system is complemented with a hydraulic arm to facilitate efficient loading and unloading operations. The external fire-fighting system was designed according to the vessel's operational environment—riverine areas near forested regions. With a required capacity of 90 m³/hr, the selected fire-fighting unit provides a throw length of 30 m, sufficient to reach riverside forest areas, and a throw height of 20 m, accommodating the relatively low tree canopy along the riverbanks. The system requires a 7 kW pump, enabling a compact and lightweight installation that optimizes the limited onboard space.

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This research was initiated to address the challenges of distributing palm oil from plantation areas that are difficult or impossible to reach using land-based transportation. By integrating naval architecture principles with an understanding of the geographical characteristics of Kalimantan particularly its wide and deep river systems this study provides a relevant and practical solution for improving logistical accessibility. The author would like to express sincere gratitude to all colleagues and students involved in this project, as well as to the faculty members of the Department of Naval Architecture, Institut Teknologi Kalimantan, for their continuous support throughout the data collection, data processing, design development, and publication stages. Their contributions have been essential to the successful completion of this research.

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