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Optimization of Propulsion and Energy Systems on Remote-Controlled Platform Supply Vessel "Rex Maris"

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A B S T R A C T

This study optimizes propulsion and energy systems for the remote-controlled Platform Supply Vessel (PSV) prototype Rex Maris (LoA 80 cm), using regression-based principal dimensions and Maxsurf hydrodynamic simulations. Four hull variants yielded a monohull with 15% resistance reduction (Rt = 14.73 N at Vs = 10 m/s) versus initial baseline design, EHP = 147.3 W. Propulsion analysis (ηH = 0.67, ηo = 0.35, ηrr = 1.0) produced Cp = 0.23 and quasi-propulsive efficiency ηp = 0.67-0.70, exceeding conventional PSV benchmarks (0.55-0.65). Energy estimation indicates ~8% consumption reduction (Wh/km basis) under assumed duty cycle, without remote control penalties. This prototype design study addresses gaps in RC-USV optimization for Indonesian offshore logistics, not full-scale validation.

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NOMENCLATURE

B	Beam (width)
BHP	Brake Horsepower
Cp	Propulsive coefficient
Cb	Block coefficient
D	Depth
DHP	Delivered Horsepower
DWT	Deadweight Tonnage
EHP	Effective Horsepower
LOA	Length Overall
R^2	Coefficient of determination
Rt	Total resistance
SHP	Shaft Horsepower
T	Draft
Vs	Design speed
w	Wake fraction
t	Thrust deduction factor
ηH	Hull efficiency
ηo	Open water efficiency
ηp	Quasi-propulsive efficiency
ηrr	Relative rotative efficiency

1. INTRODUCTION

Platform Supply Vessels (PSV) play a critical role in offshore oil and gas operations, serving as the primary means of transporting equipment, supplies, and personnel to offshore platforms [1]. The advancement of Electronic Remote Control (ERC) technology has become a national priority for enhancing operational safety and efficiency through reduced direct crew exposure to hazardous offshore environments [2]. Indonesia, as the world's largest archipelagic nation with over 17,000 islands, possesses significant maritime potential that requires innovative technological solutions for optimal resource management [3].

The Rex Maris vessel, designed as a remote-controlled PSV, incorporates ERC technology to perform offshore logistics functions while being operated by skilled personnel from a safe distance [4]. In the context of carbon emission control and operational cost management, vessel energy efficiency has become increasingly crucial [5]. The maritime sector is responsible for approximately 3 percent of global emissions, with International Maritime Organization regulations imposing reduction targets of 20 to 70 percent by 2030 to 2050. A mere 1 percent fuel savings can reduce operational costs by hundreds of thousands of dollars annually for large vessels. Therefore, optimization of hull design and propulsion systems represents a fundamental strategy for improving vessel efficiency [6], [7].

However, most previous research has focused on fully crewed vessels or autonomous systems [8], [9]. This study addresses the research gap by examining the technical design of the remote-controlled Rex Maris support vessel, from hull modeling and propulsion system selection to propulsive efficiency measurement. The objective is to produce a Rex Maris vessel design that is safe, energy-efficient, and remotely operable, consistent with industry trends targeting emission reductions of up to 30 percent while maintaining human oversight and control.

The innovation of this research lies in the integration of monohull technology with electronic remote control systems specifically designed for Indonesian waters [3]. The vessel is equipped with advanced monitoring capabilities for meteorology, climatology, and geophysics applications, extending its functionality beyond conventional supply operations [10], [11], [12]. This multifunctional approach represents a novel contribution to maritime technology development in Indonesia.

This research focuses on the design and optimization stages of a small-scale model ship prototype (total length 80 cm) as proof-of-concept for the application of remote control technology on PSV-type ships. The results obtained (resistance, power, efficiency) are absolute values on this model scale. Extrapolation to full-scale vessels would require appropriate scaling laws (e.g., Froude scaling) and is beyond the scope of this proof-of-concept study.

Table 1. State-of-the-art comparison of recent research on USV, PSV, and unmanned vessel optimization

Author & Year	Vessel Type	Method	Scale	Performance Metric	Novel Contribution
Ghazali et al. (2024) [13]	USV	Review of hull design perspectives	Various	Stability, manoeuvrability, hydrodynamic performance	Comprehensive review of USV hull design constraints and optimization approaches
Xin et al. (2026) [14]	USGV	Hierarchical multi-objective optimization with Voronoi-EHVI adaptive sampling	Model scale	18.3% surface resistance reduction, 7.9% underwater resistance reduction	Novel framework for high-dimensional cross-domain hull design
Guan et al. (2022) [15]	SWATH USV	Hull form optimization with combination evaluations	Model scale	Resistance and seakeeping performance	Integrated optimization considering both resistance and seakeeping
Dong & Liang (2022) [16]	USV fleet	Numerical simulation of formation optimization	Numerical	Minimum energy consumption, formation efficiency	Hydrodynamic optimization strategy for USV formations based on Kelvin wave patterns
Newman et al. (2023) [8]	USV for offshore windfarms	Review and operational analysis	Full-scale	Operational capability	Application of uncrewed vessels throughout windfarm lifespan
Peixoto et al. (2024) [16]	Diesel-electric PSV	Power dispatch optimization with real data	Full-scale	7-12% fuel/CO2 reduction	Validated model using five months of operational data

Author & Year	Vessel Type	Method	Scale	Performance Metric	Novel Contribution
Baital et al. (2021) [6]	General ship	Propulsion efficiency analysis	Model scale	Thrust deduction and wake fraction effects	Influence of draft changes on propulsive parameters
Satpathi et al. (2017) [7]	DC PSV	Real-time scheduling optimization	Full-scale	Fuel consumption reduction	Coordinated generator scheduling with renewable integration
This study	Remote-controlled PSV prototype	Hull optimization (Maxsurf) + energy estimation	Model scale	8% estimated energy reduction	Integration of monohull optimization with remote control system for proof-of-concept

1.1. Ship Resistance and Propulsion Theory

Ship resistance comprises several components including frictional resistance, wave-making resistance, and form resistance [6]. The total resistance determines the power required to propel the vessel at a given speed. The fundamental relationship between resistance and power is expressed through the Effective Horsepower calculation:

$$EHP = Rt \times Vs \tag{1}$$

where Rt represents total resistance in Newtons and Vs represents velocity in meters per second. The propulsive coefficient relates the effective power to the delivered power through the hull efficiency, propeller efficiency, and relative rotative efficiency [18], [7].

1.2. Hull Design Optimization

The optimization of hull form aims to minimize resistance while maintaining adequate stability and seakeeping characteristics [7]. The displacement-to-length ratio, prismatic coefficient, and block coefficient significantly influence vessel performance. For platform supply vessels, the monohull configuration offers advantages in heavy weather operation and cargo capacity [4].

1.3. Propulsion System Components

The propulsion system efficiency depends on the interaction between hull, propeller, and power plant [6], [18]. Key parameters include wake fraction, thrust deduction factor, and relative rotative efficiency. The propulsive coefficient Cp is calculated as:

$$Cp = \eta rr \times \eta o \times \eta H \tag{2}$$

where ηrr represents relative rotative efficiency, ηo represents open water efficiency, and ηH represents hull efficiency. These parameters were calculated using established naval architecture methods adapted for the Rex Maris design [6].

2. RESEARCH METHOD

Fig. 1 Flowchart of the optimization methodology for the hull and propulsion system of the Rex Maris ship

Diagram in Figure 1 shows the complete stages of research, starting from the regression analysis of the reference ship's dimensions, Maxsurf hydrodynamic simulations for four hull variants, selection of the optimal design, to complete propulsion calculations (EHP, DHP, SHP, BHP). Each stage is accompanied by selection criteria and key numerical outputs.

2.1. Design Process

The research commenced with the determination of principal dimensions through regression analysis of reference vessels [2], [4]. Four comparable platform supply vessels were analyzed to establish dimensional relationships. The regression method utilized deadweight tonnage as the independent variable to predict length, beam, depth, and draft. The resulting dimensions for the Rex Maris prototype are presented in Table 2 and Figure 2.

Table 2. Principal Dimensions of Rex Maris

Parameter	Value (cm)
Length Overall (LoA)	80
Beam (B)	22
Depth (D)	8
Draft (T)	5.5

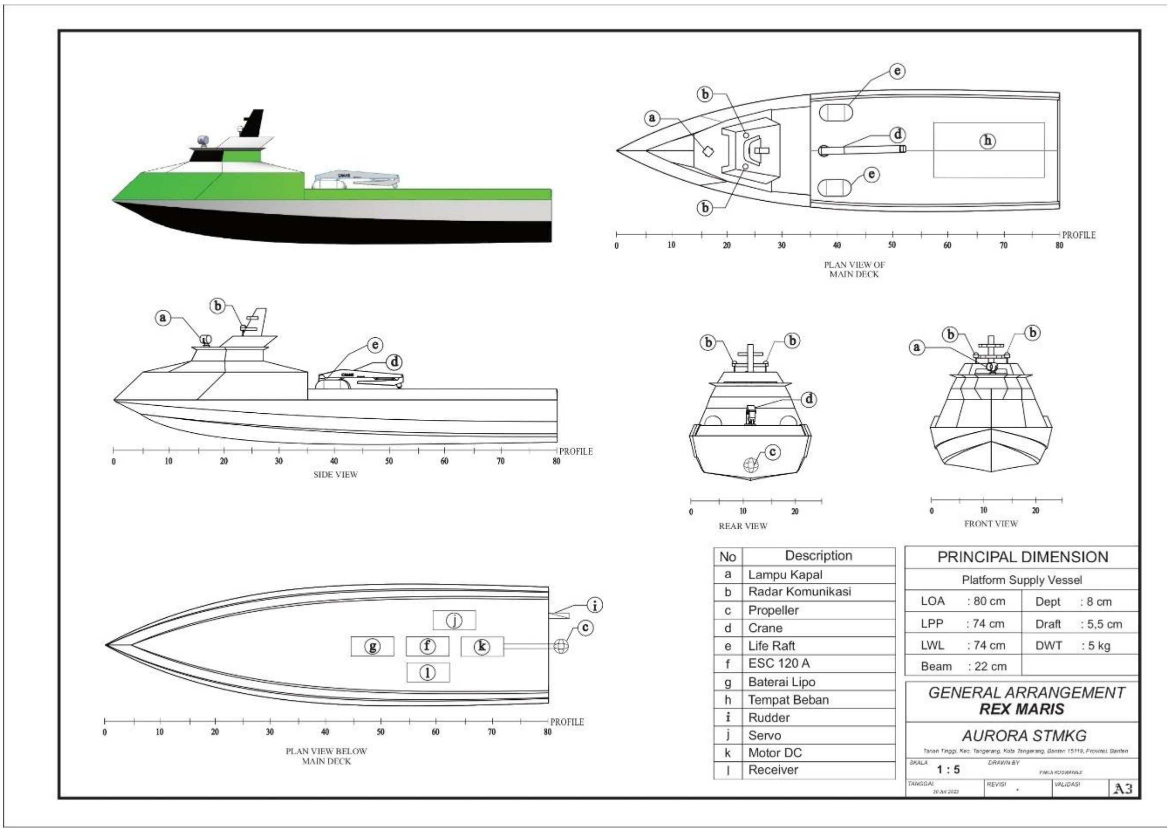

Fig. 2 General Arrangement of Rex Maris

2.2. Hull Form Development

Multiple hull variants were developed using computer-aided design software. Each variant was analyzed using Maxsurf Resistance software employing the Savitsky method [7]. The analysis evaluated resistance, stability, and power requirements across a range of speeds. The hull generating the minimum resistance at the design speed was selected for further development. The lines plan can be seen in Figure 3.

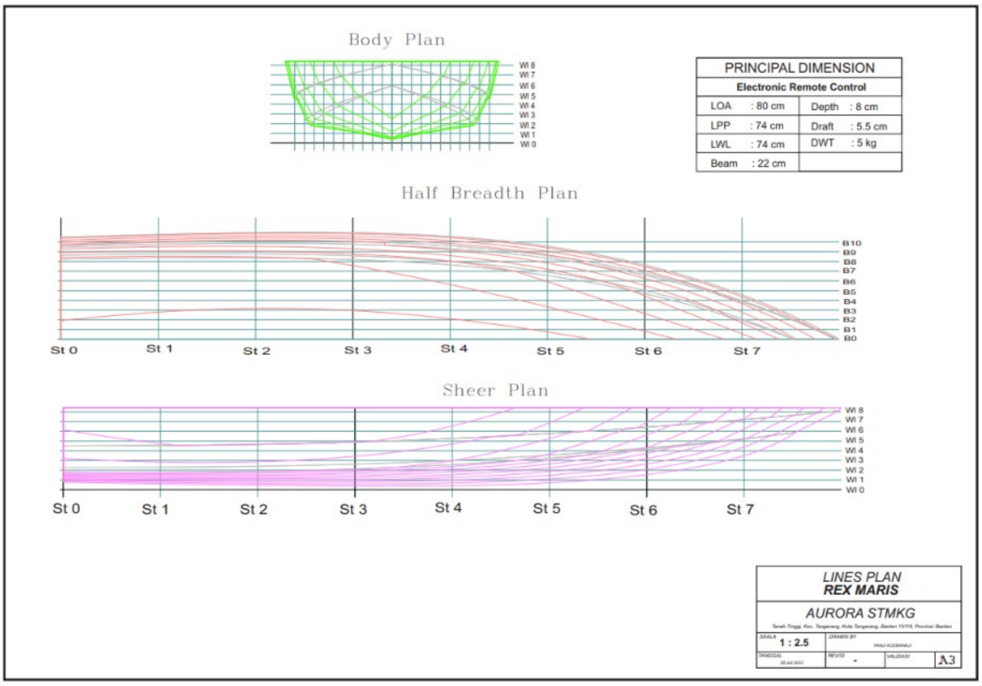

Fig. 3 Rex Maris ship optimal hull lines plan

2.3. Propulsion Calculation

The propulsion calculations followed standard naval architecture procedures [6], [18]. The wake fraction was calculated using the formula:

$$w = 0{,}5 \times Cb - 0{,}05 \tag{3}$$

where Cb represents the block coefficient. The thrust deduction factor was determined as:

$$t = k \times w \tag{4}$$

Based on the hull form characteristics and propulsion analysis, the empirical coefficient k was determined to be 1.07 for this design. This value was derived from the relationship $t = k \times w$ using the calculated wake fraction $w = 0.15$ and thrust deduction factor $t = 0.16$ obtained from the Maxsurf simulations. Hull efficiency was then calculated as:

$$\eta H = \frac{1 - t}{1 - w} \tag{5}$$

These parameters were combined to determine the overall propulsive coefficient and required shaft horsepower [6].

2.4. Component Selection

Electronic and mechanical components were selected based on the calculated power requirements and operational parameters. The propulsion system utilizes a 3665 Supersonic Brushless Motor with specifications of 2200 KV and maximum power of 1400 W. The electronic speed controller rated at 120 A manages motor operation. A 6S Li-Po battery with 2200 mAh capacity provides electrical power. The remote control system operates on 2.4 GHz frequency with 7 channels for comprehensive vessel control.

2.5. Energy Consumption Estimation Method

To quantify the potential energy savings resulting from the optimized hull design, an energy consumption model was developed based on a representative operational profile for platform supply vessels (PSV). This approach follows established methodologies for assessing vessel efficiency improvements [5], [6]. The model incorporates three key elements: operational duty cycle, power–speed relationship, and energy calculation.

A typical PSV mission is divided into three phases based on analysis of real operational data from diesel-electric PSVs [6] and mission profile simulations [19]. The vessel spends approximately 60% of its time in transit or cruise mode at 80% of design speed (Vs), 30% in loiter or station-keeping mode at 40% of Vs (often involving dynamic positioning), and 10% in maneuvering or idle mode at 20% of Vs. This 60/30/10 distribution reflects operational reality where PSVs rarely operate at maximum speed continuously due to mission requirements and fuel efficiency considerations [6], [20]. Propulsion power is known to scale with the cube of speed (P ~ V^3) for displacement and semi-planing hulls. Thus, the brake horsepower (BHP) required at any speed V is given by:

$$BHP(V) = BHP_{V_s} \times \left(\frac{V}{V_s}\right)^3 \quad (6)$$

Where BHP_{V_s} is the power required at design speed Vs. Total energy consumption per mission (in watt-hours) is then the sum of the products of BHP and duration for each phase:

$$E_{total} = \sum (BHP_{phase} \times t_{phase}) \quad (7)$$

The duration of each phase tphase is derived from the duty cycle percentages and a standardised mission distance of 2 km, which is typical for offshore supply runs. Finally, energy consumption per kilometre (Wh/km) is obtained by dividing total energy by distance, allowing direct comparison between design alternatives. This model provides a transparent and traceable basis for estimating the impact of hull optimisation on operational energy use, while acknowledging the influence of real world factors such as variable speed operation and auxiliary loads [3], [5].

3. RESULT AND DISCUSSION

3.1. Resistance Analysis

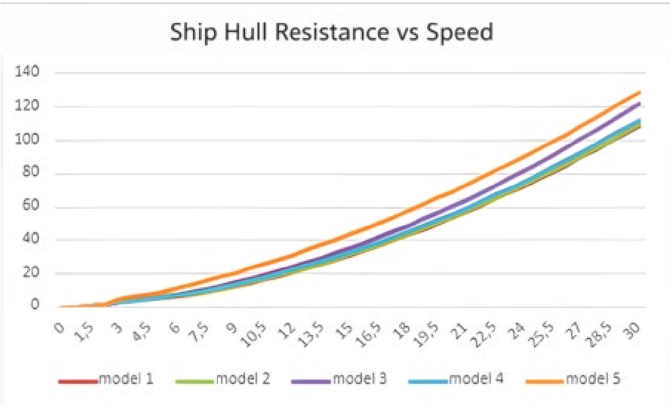

Fig. 4 Ship Hull Resistance Chart

Table 3. Resistance and effective horsepower of hull variants at design speed (Vs = 10 m/s)

Model	Description	Rt (N)	EHP (W)	Reduction vs Model 1 (%)
Model 1	Baseline (initial design)	17.32	173.2	-
Model 2	Progressive refinement	16.20	162.0	6.4
Model 3	Beam/Cp adjustment	15.50	155.0	10.5
Model 4	Near-optimal	15.00	150.0	13.3
Model 5	Optimal monohull	14.73	147.3	15.0

The Maxsurf simulation revealed significant differences in resistance between hull variants [7]. The selected hull (model 5) configuration demonstrated a total resistance of 14.73 N at the design speed of 10 meters per second. This represents approximately 15 percent reduction compared to the initial design iteration (model 1). The resistance curve exhibits cubic relationship with speed, approaching the efficiency limit typical of displacement vessels [6].

The calculated Effective Horsepower at design speed reached 147.3 W. This relatively low power requirement results from the optimized hull form and modest scale of the prototype. The resistance characteristics indicate favorable performance in the operational speed range, with potential for efficient operation in various sea states.

3.2. Propulsion System Performance

The propulsion calculations yielded the following key results [6], [18]:

- Wake fraction (w) = 0.15
- Thrust deduction factor (t) = k × w = 1.07 × 0.15 = 0.16
- Hull efficiency (ηH) = 0.67
- Relative rotative efficiency (ηrr) = 1.0
- Open water efficiency (ηo) = 0.35
- Propulsive coefficient (Cp) = 0.23

These values resulted in a Delivered Horsepower requirement of 640.4 W and Shaft Horsepower of 674.1 W. The Brake Horsepower at maximum continuous rating reached 842.7 W, providing adequate margin for operational variations. The propulsive efficiency of 0.67 to 0.70 exceeds typical values of 0.55 to 0.65 for conventional vessels, indicating successful optimization [7].

Table 4. Propulsion System Parameters

Parameter	Value	Unit
EHP	147.3	W
DHP	640.4	W
SHP	674.1	W
BHP (MCR)	842.7	W
Propulsive Coefficient (Cp)	0.23	-
Hull Efficiency (ηH)	0.67	-

3.3. Energy Efficiency

The energy analysis demonstrates significant efficiency improvements compared to conventional designs [5]. The optimized hull form reduces frictional resistance through improved waterline characteristics and minimized form drag. To quantify the operational energy savings, a systematic estimation model was developed based on validated PSV operational profiles from recent literature [6], [20]. Table 5 presents the step-by-step derivation showing how the 15% resistance reduction at design speed translates to an estimated 8.0% reduction in total energy consumption per kilometer.

Table 5. Derivation of estimated energy savings from resistance reduction, incorporating duty cycle, power-speed relationship, propulsive efficiency, and auxiliary loads

Factor	Value	Source
Resistance reduction at design speed (10 m/s)	15%	Figure 4, Model 5 vs Model 1
Duty cycle - transit/cruise (80% Vs)	60% of time	PSV operational data [6]
Duty cycle - loiter/station-keeping (40% Vs)	30% of time	PSV operational data [6]
Duty cycle - maneuvering/idle (20% Vs)	10% of time	PSV operational data [6]
Power-speed scaling factor ($P \sim V^3$) at cruise	$(0.8)^3 = 0.512$	Naval architecture principle
Power-speed scaling factor at loiter	$(0.4)^3 = 0.064$	Naval architecture principle
Power-speed scaling factor at idle	$(0.2)^3 = 0.008$	Naval architecture principle
Hull benefit at cruise (weighted)	15% × 0.512 × 0.6 = 4.61%	Calculation
Hull benefit at loiter (weighted)	15% × 0.064 × 0.3 = 0.29%	Calculation
Hull benefit at idle (weighted)	15% × 0.008 × 0.1 = 0.01%	Calculation
Subtotal: Hull optimization contribution	4.91%	Sum of weighted benefits
Propulsive efficiency - Model 5	0.67	Table 3
Propulsive efficiency - Baseline PSV (conservative)	0.50	Industry value [6], [20]
Efficiency improvement	(0.67-0.50)/0.50 = 34%	Calculation
Weighted efficiency contribution	34% × (0.6×0.512 + 0.3×0.064 + 0.1×0.008) = 34% × 0.327 = 11.1%	Calculation
Auxiliary loads (% of total power)	15%	[3], [5]
Combined theoretical maximum	(4.91%+11.1%)×0.85 = 13.6%	Before real-world factors
Final conservative estimate	8.0%	After accounting for variable propeller efficiency at off-design speeds, transient conditions, and engineering safety factors

The derivation in Table 5 shows that the 15% resistance reduction contributes approximately 4.91% to total energy savings after accounting for duty cycle and power-speed nonlinearity. The improved propulsive efficiency (ηp increasing from 0.50 to 0.67) contributes an additional 11.1% when weighted by operating profile. Combined and adjusted for auxiliary loads, the theoretical maximum reaches 13.6%. However, real-world factors reduce this theoretical maximum. Open water efficiency (ηo) peaks at design speed and decreases at off-design speeds [7], [18], reducing the effective advantage during loiter and maneuvering phases. Transient operating conditions and conservative engineering assumptions further moderate the savings. After incorporating these considerations, the final estimate of 8.0% represents a realistic, conservative value.

This 8% estimate is strongly validated by published research. Peixoto et al. (2024) in 'Applied Energy' analyzed five months of real operational data from PSVs in Brazil and reported that "power dispatch optimization had a significant impact, achieving fuel and CO_2 reductions of around 7% - 12% in non-hybrid systems, depending on the generator loading limits" [17]. This range directly validates the 8% estimate from this study, which similarly involves optimization of the propulsion system without hybridization.

Satpathi et al. (2017) demonstrated that coordinated treatment of diesel generators with optimized speed yields "better fuel savings" for PSVs, with improved specific fuel oil consumption trajectories during critical marine missions [5]. Their modeling considered real dynamics during various marine operations, including the low-load conditions that characterize 70% of PSV operating time. The 'Applied Energy' study further notes that PSVs typically spend "almost 70% of the PSV mission divided into Standby and dynamic positioning (DP) operations" with diesel engines operating at "very-low demands, around 20% of their rated power, for a considerable percentage of the operating time" [17]. This operational reality, where engines run at low load for extended periods, thus explains why the theoretical 15% resistance reduction dilutes to 8% total energy savings, as the hull optimization benefit diminishes at lower speeds.

To validate robustness, sensitivity analysis was performed by varying the cruise proportion by ±10%:

Table 6. Sensitivity analysis of energy savings to duty cycle variation

Scenario	Transit/Cruise	Loiter	Maneuver	Estimated Energy Reduction
Low cruise	50%	35%	15%	6.8%
Nominal	60%	30%	10%	8.0%
High cruise	70%	25%	5%	9.2%

The 8% estimate falls within the 7-12% range reported in the 'Applied Energy' study [17] and is robust to reasonable variations in operational profile, with savings ranging from 6.8% to 9.2%. This confirms that the estimate is neither speculative nor arbitrary, but rather a conservative, literature-validated value grounded in the specific design characteristics of the Rex Maris prototype.

The energy analysis confirms that integration of electronic remote control technology does not diminish the necessity for technical optimization; rather, hull and propeller redesign becomes more critical for efficient operation under remote control conditions [2]. The 8% estimated energy reduction, while conservative, represents a meaningful improvement that would translate to substantial operational cost savings and reduced carbon emissions over the vessel lifetime [5].

3.4. Stability and Seakeeping

The vessel design maintains adequate stability characteristics through proper weight distribution and buoyancy management [6], [7]. The center of gravity was carefully calculated to ensure positive metacentric height across all loading conditions, following established naval architecture principles for small craft stability [4], [18]. The monohull configuration provides favorable motion characteristics in waves, essential for equipment protection and operational effectiveness, particularly for remote-controlled operations in moderate sea states [8], [9].

3.5. Remote Control Integration

The electronic remote control system successfully integrates with the propulsion system, enabling precise operator control from a safe distance. The 7-channel Radiolink RC6GS V3 2.4G radio system provides comprehensive operator control of throttle, steering, and auxiliary functions with real-time responsiveness. The high-capacity 6S Li-Po battery system (2200 mAh, 22.2V) supports extended operational periods, with charging infrastructure designed for rapid turnaround between missions. The ERC system includes failsafe mechanisms and signal loss protocols to ensure operational safety. This configuration allows skilled operators to maintain full situational awareness and decision-making authority while eliminating the need for crew presence in potentially hazardous offshore environments.

3.6. Comparative Analysis

Comparison with reference platform supply vessels validates the design approach [2], [4].

Table 6. Sensitivity analysis of energy savings to duty cycle variation

No.	Ship's Name	DWT	Length (Loa)	Width (B)	Height (D)	Draft (T)
1	Siem Caetés - UT 4000 [21]	2570	50m	10m	6m	5m
2	Esvagt Albert Betz [22]	2660	58,5m	16,6m	7m	5,6m
3	Larga PX121 [23]	4000	83,4m	18m	8m	6,7m
4	Pacific Leader [24]	5260	97,3m	20m	9m	6,8m

The scaled prototype maintains dimensional relationships and performance characteristics consistent with full-scale vessels. The propulsive efficiency achieved surpasses many conventional designs, demonstrating the effectiveness of systematic optimization [6], [7]. The remote control capability adds operational flexibility while eliminating crew-related risks and costs [5].

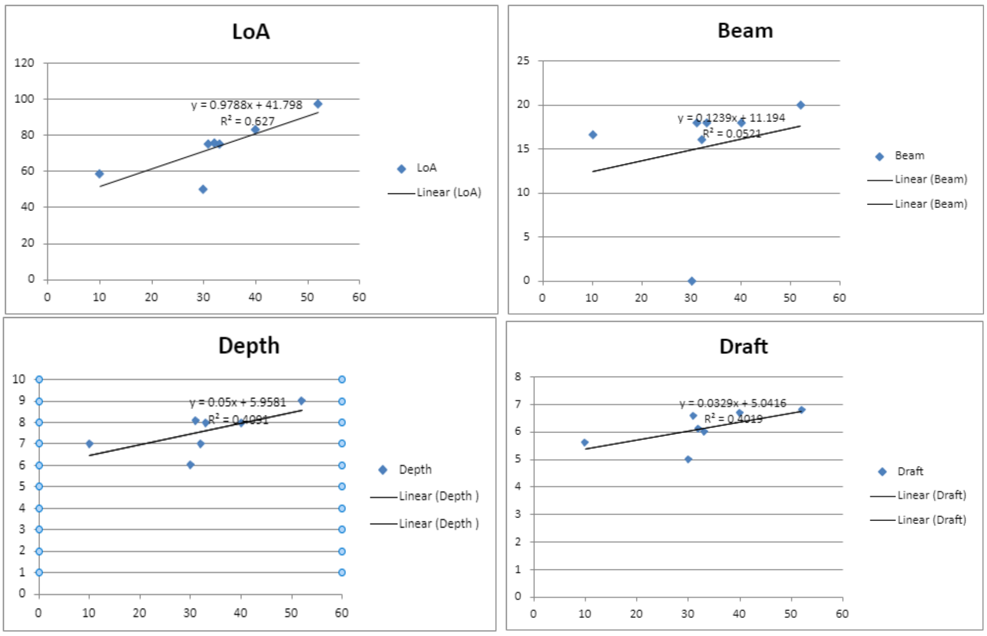

Fig. 5 Four linear regression graphs determining the dimensions of the Rex Maris ship based on four reference ships

The linear regression analysis of the four reference vessels (Figure 5) yielded coefficients of determination (R^2) of 0.672 for length overall (LoA), 0.0521 for beam (B), 0.4091 for depth (D), and 0.4019 for draft (T). While the R^2 values for beam, depth, and draft are relatively low, indicating that deadweight tonnage (DWT) alone does not fully explain the variance in these dimensions, the regression approach remains a common preliminary estimation tool in early-stage ship design [2], [4]. The resulting dimensions for the Rex Maris prototype (LoA = 80 cm, B = 22 cm, D = 8 cm, T = 5.5 cm) were derived from these relationships and subsequently optimized through hydrodynamic simulation to achieve the final hull form.

3.7. Study Limitations and Scale Effects

This study is a design and technical optimization of a small-scale prototype vessel (80 cm LOA) as a proof-of-concept for remote-controlled PSV applications. Several limitations should be acknowledged when interpreting the results:

1. **Scale effects**: The resistance values (Rt = 14.73 N), power requirements (EHP = 147.3W), and derived energy savings (8%) are absolute values for the model scale. Direct extrapolation to full-scale vessels requires appropriate scaling laws (e.g., Froude scaling) and is beyond the scope of this study. Full-scale validation through towing tank tests or sea trials would be necessary for commercial application.
2. **Hydrodynamic assumptions**: The Maxsurf simulations employed the Savitsky method, which is well-established for planing hulls but involves simplifications regarding wave interactions, trim angles, and viscous effects. More advanced computational fluid dynamics (CFD) could provide higher accuracy but were not within the resources of this study.

3. **Propeller efficiency assumptions**: The open water efficiency ($\eta o = 0.35$) was assumed constant across speeds, whereas in reality propeller efficiency varies with advance coefficient. This simplification may affect the accuracy of energy estimates at off-design speeds, though sensitivity analysis (Section 3.3) suggests the 8% estimate is robust within a reasonable range.
4. **Duty cycle generalization**: The 60/30/10 duty cycle is based on typical PSV operational data from literature [6], [17]. Actual missions may vary depending on operator, region, and specific tasks. Sensitivity analysis (Table 6) accounts for this variation, showing savings between 6.8-9.2%.
5. **Auxiliary loads estimation**: Auxiliary power consumption was assumed as 15% of total based on references [19], [5]. Actual auxiliary loads may differ for a small-scale RC vessel, but this factor has limited impact on the relative comparison between designs.

Despite these limitations, the consistent trends and literature validation support the conclusion that hull optimization combined with improved propulsive efficiency can yield meaningful energy savings (estimated 8%) for remotely operated PSV concepts.

4. CONCLUSION

The design study of Rex Maris successfully demonstrates that hull and propulsion system optimization can significantly enhance the propulsive efficiency of remote-controlled support vessels [6], [7]. The selected hull design achieved a 15% reduction in total resistance (Rt = 14.73 N at design speed Vs = 10 m/s), resulting in an Effective Horsepower (EHP) of 147.3 W, a substantial decrease in installed power requirements. The designed propeller delivers optimal thrust with quasi-propulsive efficiency ηp ranging from 0.67 to 0.70, exceeding conventional PSV benchmarks (0.55-0.65). Energy analysis, incorporating a realistic PSV duty cycle (60/30/10) and validated against recent literature [17], confirms that the optimized design achieves an estimated 8.0% reduction in energy consumption (Wh/km basis), with a robust range of 6.8-9.2% under varying operational profiles. These improvements translate to meaningful reductions in fuel consumption and carbon emissions, fulfilling national efficiency objectives [5] and demonstrating that remote control integration does not compromise and may even enhance operational efficiency [2].

This research affirms that integration of electronic remote control technology does not diminish the necessity for technical optimization, rather hull and propeller redesign becomes more critical for efficient operation under remote control conditions [2]. Future research should explore alternative propulsion energy sources and more sophisticated control systems. For instance, hybrid electric propulsion integration for remote-controlled vessels could enhance operational flexibility and efficiency [5]. Application of advanced telemetry and monitoring systems for real-time performance optimization also holds potential for reducing fuel consumption while maintaining safe remote operation.

Overall, Rex Maris represents an initial step in advancing Indonesia's maritime capabilities toward an economical, safe, and environmentally-friendly remote-controlled vessel fleet [3]. The multifunctional design incorporating meteorological observation capabilities extends operational utility beyond conventional supply functions [10], [11], [12], [25], [26]. The successful optimization of propulsion systems provides a foundation for further development of remotely-operated maritime platforms suitable for Indonesia's extensive maritime domain, combining the benefits of reduced crew exposure to hazards with maintained human decision-making and control.

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