Techno-Economic Review: The Use of Solar Sail On Catamaran Fishing Vessel

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Abstract

Safety and environmental issues are still to became the main concern in the roles of fishing vessel operational since directly related to costs. By conducting a technical and economical review, it is hoped that it can provide a comprehensive portraits to the ship's designers and investors so that they are expected to assist them in making decisions. Technical analysis is done by testing the ship model then the results are developed with Naval architect theories to obtain the configurations of fishing vessels designed. Meanwhile, economic analysis uses the Accounting Rate of Return (ARR) and Internal Rate of Return (IRR) methods with the value of Sensitivity. Result: Application of hybrid technology use a combination Solar-Sail has potency to save fuel usage until 95%. It is very useful when applied to catamaran fishing vessels and hence reduce emission of greenhouse gases. *The configuration has an IRR value greater than ARR and the break-even point (BEP) is smaller than service life.*

Keywords — *Fishing vessel, catamarans, technical and economic analysis, sensitivity*

I. INTRODUCTION

The mission of a fishing Vessel is to catch fish from sea to get fish that meets quality in appropriate ways and deliver the fish to land or to other vessels for the next process. From the catch, it will supply daily food needs and sustain food security for millions of people in the world. Currently fishing Vessel are still very much needed. In its operations a fishing boat must be absolutely safe because even in bad weather the ship must work so that the total resistance, driving force, fuel consumption, stability and seakeeping issues are still very important concerns, [1].

In general, the operation of a fishing vessel is always associated with safety, economic and environmental issues. Safety factors are related to stability and seakeeping, while economic and environmental factors are related to fuel costs and the level of pollution produced when the ship operates.

Reducing of ship propulsion (and fuel consumption) can be fulfilled since the ship design stage by creating more efficient hull design and propulsion systems. The weakness of a single hull fishing vessel, especially in stability and seakeeping issues is anticipated by the introduction of the catamaran hull form. There are several choices of power systems such as the use of sail, solar powered, and the combination of those two and three power systems. Despite the results of those developments are still far from economic benefits. One of it is the use of solar-sail vessels (SSV) and the concept is shown in Figure 1, [Santosa, 2017].

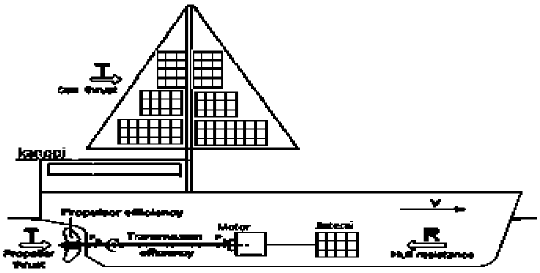

FIGURE 1. Config. of Solar-sail Catfish Vessels (SSCFV)

FIG 1. shows the configuration of the vessel with the solar-sail driver. The thrust (*T*) force generated from one or more of the ship's propulsion sources operates simultaneously or together known as the hybrid system [1]. The concept of solar vessel energy conversion is converting solar energy into the driving force required by vessels through solar panels, batteries, electric motors, transmissions and propellers at a certain speed. In detail can be explained as follows: Solar panels function to capture solar energy and convert it into electrical energy, then stored in a battery. Power stored in the battery will be used to supply the electric motor and rotate the propeller. So that the vessels can move forward due to the thrust force produced by the propeller (*Tp*). Since 2002 research on the technology of combined use of wind and solar power in the form of a Solar sail has been developed in the USA, (Herbeck et al., 2002). Solar sail is made of thin Mylar or Kapton films with a thickness of 7.6 mm and has a broad density (defining the weight of the material divided by the area of material) about 11 g / m2 as shown in fig.2

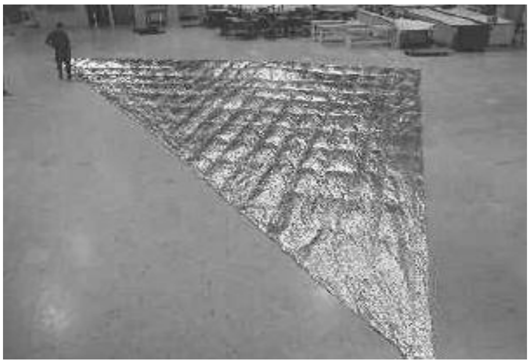

Fig. 2: Solar sail NASA JPL Type

The solar sail has 2 functions, namely: 1) As a propeller vessel, 2) As a system of Photovoltaic technology that converts sunlight into electrical energy. The existence of an efficient combination between the use of the sail and the solar panel if applied to the ship will be able to save the use of the deck of the ship. Besides functioning as a booster of vessel (in the form of sail), Solar Sail can also function as a solar panel that collects electrical energy and is very suitable to be applied as an environmental-
ly friendly vessel.

II. METHOD AND LITERATURE

1. Model test

This research is a continuing research that has been done [3]. All material data and information using the results of previous research.

TABLE I
Model Dimension

Parameter	*Catamaran*	*Demihull*
LWL (m)	14.5	14.5
B (m)	7.118	1.318
H (m)	1.44	1.44
D (m)	0.694	0.694
C_B	0.434	0.434
Displ. (ton)	11.8	5.9

Fig 3: Model ship resistance test

Fig. 3 shows the Catamaran Hull Resistance Model Test through experiments in the hydrodynamic Tank.

2. Use Formulae

- ***Ship Moving Theory***

$$T \geq R_T \quad \text{or} \quad T - R_T \geq 0 \qquad (1)$$

where: T is Thrust (kN), R_T is Resistance (kN)

- **Ship Resistance**

$$R_T = \frac{1}{2} \rho \, C_T \, (WSA) \, V^2 \qquad (2)$$

where: R_T is Resistance (kN), CT is Resistance coeff., WSA is wetted surface area (m^2), V is speed (knots).

- **Thrust**

Thrust $(T) = R_T/(1-t)$ (3) where: t is thrust deduction factor , For double screw: $t = k_R \, . \, wt$ (4)

where: k_R is 0.5 for thin rudder,

$wt = - 0.0458 + 0.3745 C_B^2 + 0.1590 D_w - 0.8635 Fr + 1.4773 Fr^2$

$$D_w = \frac{B}{\nabla^{1/3}} \sqrt{\frac{\nabla^{1/3}}{D}} \qquad (5)$$

Thrust $(T) = T\ propeller + T\ sail$ (6)

Propeller thrust, $T\ propeller = K_T . \rho . n^2 . D^4$ (7)

where: thrust coefficient (K_T), Salt water density (ρ), propeller rpm (n), propeller diameter (D)

Sail thrust, $T\ sail = q\ .\ As$ (8)

where: Dynamic wind pressure (q) = ½ x ρ x £ x V_w^2 (ton/m^2), Air mass density (ρ) = γ/g, Weight per unit volume (γ) = 1.2265 t/m^3, g = 9.81ms^{-2}, £ = wind pressure coef. (1.1), wind speed (V_w), sail area (As).

- **Powering**

Effective power (PE) = R_T x V_s (9)

Delivered power (PD) = PE/ Hd (10)

Quasi prop. coeff. (ηD) = ηP. ηH. ηR (11)

Service power (Ps) = PD/ ηT (12)

where: ηT is 0.98 with gearbox, 0.95 without gearbox

Installed power (PI) = Ps + Margin (13)

Margins (*roughness, fouling, weather*) 15 – 20% depend ship route.

- **Solar cells**

Power requirement: P = V x I (14)

Pmax = Voc x Isc x FF (15)

$$Fill\ Factor : FF = \frac{V_{mp} \times I_{mp}}{V_{oc} \times I_{sc}} \qquad (16)$$

P watt *peak* = PV area x PSI x ηpv (17)

- **Sail**

Determination of Sail Area almost as a comparison of sail area (As) with wetted surface area (WSA) is between 2.0 and 2.5. Comparison of sail area (As) with wetted surface area (WSA) known as sail ratio (SR), [6]. There is another way according to [7], where the determination of SR depends on the LWL of the ship by using the graph shown in Fig. 2.

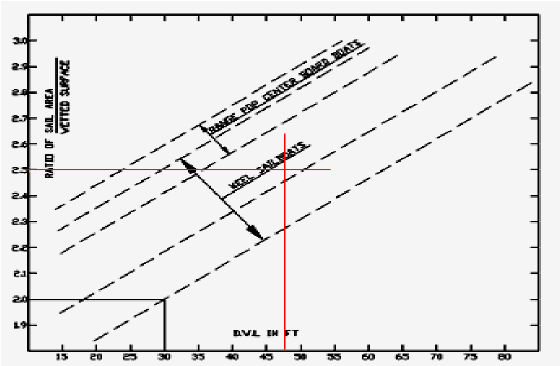

Fig 4: Graph of *SR* – *LWL* Relationship

Fig. 4 shows graph of relation between SR with LWL which can be used to determine Sail Area with 15 - 80 feet or 5 - 25 m LWL limitation.

- **Service life**

To calculate future income and investment costs, people need to know how long it will last.

- **Investment cash flow**

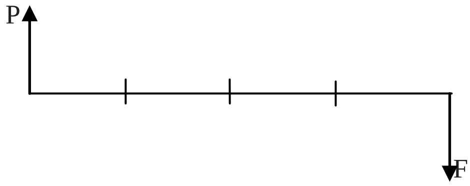

Fig 5: Cash flow Diagram

Expenditures and income which are measurable units and related to certain investments can be illustrated in the design of cash flows as shown in Fig. 5.

- **Accounting Rate of Return (ARR)**

An economic method that uses normal accounting and budgeting techniques to measure profits generated from new investments. ARR is the ratio of the percentage of annual profit (Net Profit) to investment costs.

$$\text{Profit} = \text{Revenue} - \text{Cost} \quad (18)$$

- **IRR Internal rate of return (IRR)**

An economic method is used to calculate positive income values based on cash flow and expenditures which are considered negative items by considering interest rates so that getting the discounted algebraic value is zero.

- **Present value**

According to the ARR method, time has no money value, that is, one dollar earned in year 1 is equal to one dollar in year n. Whereas according to the IRR method which is based on the concept of present value, a dollar sometime in the future is worth less than one dollar today (calculated using press. 19, 20 and 21). The basic reason underlying the concept of present value is that money has an income capacity. Income capacity varies according to how the money is used. Money can be deposited into a bank, loaned, used to buy shares, etc.

$$\text{Present Value Factor} = (1 + i)\ N \quad (19)$$

$$F / P = (1 + i)\ N \quad (20)$$

$$F = P\ (F / P,\ i\%,\ N) \quad (21)$$

Where: F (future value), P (present value), i (interest), N (time)

- **Rate of interest**

To calculate the present value of money to be received in the future, it is necessary to determine the Appropriate Interest Rate (ARI). The ARI value should not be lower than the interest that must be paid for the loan. If investors plan to use their own capital, ARI must not be lower than what the money can generate in the use of alternatives (opportunity costs) at the same risk.

- **Discounting of future cash flows**

The procedure used to calculate the present value of the amount of future money is called discount

- **Decision Making**

Performed by comparing the ARR and IRR values.

III. RESULT

TABLE 2
Result of Resistance Test

Run No.	V (knots)	Fr	Catamaran Resistances (kN)		
			S/L=0.2	S/L=0.3	S/L=0.4
1	5.788	0.250	1.821	1.659	1.659
2	6.218	0.268	2.141	1.851	2.061
3	6.677	0.288	2.443	2.239	2.348
4	7.051	0.304	2.852	2.678	2.947
5	7.560	0.326	3.460	3.568	3.547
6	8.032	0.347	4.467	3.954	3.766
7	8.384	0.362	4.844	4.345	4.341
8	8.818	0.380	5.149	4.790	4.662
9	9.233	0.398	5.807	5.592	5.515
10	9.813	0.423	7.101	6.448	6.138

Table 2 shows the experimental results of catamaran Resistance in towing tanks. Furthermore, from this data will be developed as a basis for designing the concept of catamaran fishing boat with a combination of solar-sail, [1], [8]. Powering: Effective power (PE) 32,435 kW, quasi-propulsive coefficient (ηD) 0.664, delivered power (PD) 50.21 kW, transmission losses (ηT) 0.98 without gearbox, service power (Ps) 51.235 kW and installed power (PI) of 60 kW with total efficiency (PE / PI) is 54%. Engine specifications used 2 x 43 hp or 2 x 30 kW.

Sail Area obtained approximately 125 m^2.

Thrust is obtained for 6.685 kN with thrust deduction factor (t) of 0.038. Propeller thrust (*Tp*) is achieved at 9.8 knots service speed (*Vs*) and Sail thrust (*Ts*) is reached at 19.2 knots wind speed (*Vw*).

The result of recent study is the layout of Solar sail catamaran fishing vessel are presented in Fig. 5.

Fig 6: The Layout of SSCFV

Fig.6 shows the arrangement of fish holds and area for crew activities on the main deck, The wider space area for fishing activities on main deck is the main concern for the commercial fishing industry now. The Data's of Solar sail Catamaran Fishing Vessel (SSCFV) is LWL=14.5m, B=7.118 m, H=1.44 m, T=0.694 m, Tonnage 15 GT, Fish hold 1.723 ton, Electric power 2 x 30 kW at 2800 rpm.

TABLE 3
The SSCFV System work at *Vs* 9.813 kts

Sail		Propeller		Prime mover
Vw (Knots)	*Ts (kN)*	*Tp (kN)*	*Electric motor Rpm*	
0.0	0	6.685	1700	Propeller
4.0	0.5	6.185	1550	Propeller-sail
8.0	1.2	5.485	1480	Propeller-sail
12.0	2.4	4.285	1300	Propeller-sail
16.0	5.4	1.285	1000	Propeller-sail
19.2	6.685	0	0	Sail

Table 3 describes the propeller and sail can work individually/separately or together as a hybrid system when the ship moves and shows the Hybrid System (SSCFV) work

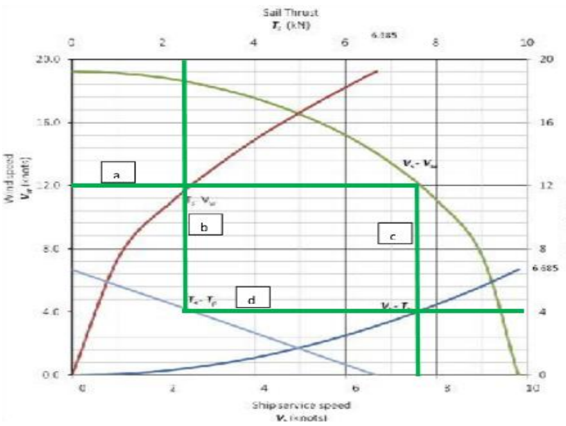

Fig7: Applied of Hybrid System (SSCFV) work,[17]

IV. DISCUSSION

- **Technical review**

The design process begins with determining the design conditions (mission design requirements) which will then produce a good ship design. The results of the design will be used as a basis for analyzing all issues related to ship operational costs (accounting). A model for testing the resistance of ships in Towing Tank is made as shown in Figure 6 with the results of the resistance test (*RT*) in accordance with Table 3. Ship resistance are used to determine the size of the prime mover (powering) and the thrust (*T*) that it produces. In this study more focused on the design mission as a function of catamaran fishing vessels with hybrid drives (a combination of, solar sail). the aims of technical reviews are to make sure mainly matters of the design configurations fishing vessels that relating to safety and the environment, such as: stability, seakeeping shipbuilding criteria, quantification of air pollution, etc.

- **Economic Review**

The mission of a fishing boat is to catch fish from the next sea from the catch which will supply daily food needs. The catch is income from a fishing boat. So the selling value of a fishing boat is how much net load capacity (cargo space) to carry the catch. The Data's of Solar sail Catamaran Fishing Vessel (SSCFV) is 15 GT Tonnage and 1.723 ton Fish hold. The economical review discusses the problem of fishing vessels related to economic aspects, such as: value of investment, income (costs), costs (cost), break-even point, age of ship service, etc.

a. Determine the Value of Investment

The method used in determining the investment value is the inquiry method based on market prices for typhoon vessels. As shown in Tab 4.

TABLE 4
Value of Investment (in millions)

Items of SSCFV investment	10 GT	15 GT	20 GT
1. Hull Equipment	360	480	600
2. Prime mover Inst.	315	360	525
3. Vessel Cost	675	840	1125
4. Fishing Gear	75	100	125
5. Total Investment	750	940	1250
Investment Cost			

*Source:www.majubangkit.com

According to market prices: 10 GT / 80 HP fishing vessels have a price of 750, while 20 GT / 120 HP fishing vessels have a price of 1250. Designed fishing vessels (SSCFV) 15 GT / 86 HP with an interpolation calculation obtained at 940 with details such as Table 7. In this case the price of 940 is the investment value of the configuration of conventional diesel engine fishing vessel.

Furthermore, it is will be used as the basis for determining the investment of SSCFV by Accounting Rate of Return (ARR) method.

b. Accounting Rate of Return(ARR) Calculation

TABLE 5
The ARR Method, [18]

INVESTMENT COST OF SSCFV	Values
1. Hull and Equipment	480
2. Prime mover and Installation	180
3. Vessel Cost	660
4. Fishing Gear	94
5. Total Investment	754
Operating revenues 1 /	544
Operating cost :	
Fixed :	
6. Depreciation = 10% of 3	66
7. Average cost of capital = 12% of 0.6 x 5	54
8. Insuramce = 5% of 3	33
9. Hull maintenance = 5% of 1	24
10. Crew basic salary	60
11. Fixed management	45
Total fixed cost	283
Variable :	
12. Fuel oil (10 ltr/hr)	0
13. Lubricants = 5% of 12	0
14. Ice = 30% of catch 30/t	4
15. Engine Repair - 7% of 2	13
16. Hull Repair - 3% of 1	14
17. Gear Repair & Replacement - 50% Of 4	47
18. Miscellanous - 10% of 12-17	8
19. Crew Bonus - 20% of Net Profit	59
Total Variabel cost	145
20. Total Annual Costs	428
21. Net Profit	116
22. Profit Before Deduction Interval (21+ 7)	170
23. Accounting Rate Of Return (22 as % of 5)	23
24. Fixed Costs (US$/ton Of Catch)	283
25. Variable Costs - US$/ton Of Catch	145
26. Total Costs (20) US$/ton Of Catch	428
1 / Catch rate, kg per hour	62
Catch/day, 8 hours per day (kg)	495
Annual catch, 200 days per year (t)	99
Average vessel price of fish (US$ per t)	8
2 / = 40% of Investment cost - 12.2 assumed to correspond to the average capital Invested during the service life	

A normal accounting and budgeting method that is used to measure profits generated from new investments. Whereas ARR is the ratio of the annual percentage profit (Net Profit) to investment costs, as shown in Table 6.

TABLE 6
Cash flow

SSCFV	0	1	2	3	4	5
Investment Cost	754					
Cash Revenue		679	679	679	679	679
Cash Outlays		497	497	497	497	497
Depreciation		66	66	66	66	66
Net profit		116	116	116	116	116

Values of ARR = 20 %

All data's in Table 6, such as: the value of Investment Cost, Depreciation, Net profit and ARR are taken from the calculation of Table 8. The ARR value is always greater than the value of profit (net profit). While the projected projection of return on investment capital as shown in Figure 8 below.

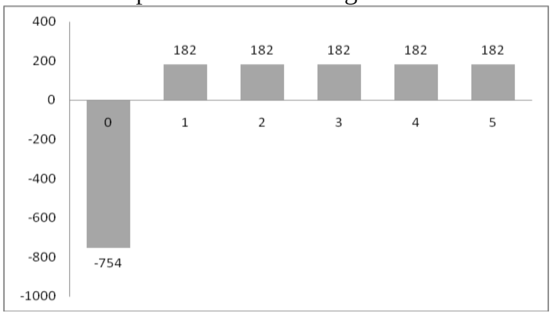

Fig 8: Cash flow Diagram

- **Calculation of Internal Rate of Return (IRR)**

TABLE 7:
The IRR Method,[18]

n	Cash flow	Present Factor		Present value	
		20%	25%	20%	25%
0	-754	1.00	1.00	-754	-754
1	182	0.83	0.8	152	146
2	182	0.69	0.64	126	116
3	182	0.58	0.51	105	93
4	182	0.48	0.41	88	75
5	182	0.40	0.33	73	60
6	182	0.33	0.26	61	48
7	182	0.28	0.21	51	38
8	182	0.23	0.17	42	31
9	182	0.19	0.13	35	24
10	182	0.16	0.11	29	20
				9	-104

To calculate the IRR value the determination of the interest rate (interest rate) is based on the preference (expectation) of the investor and is always greater than the percentage ratio of profit (net profit) to the value of the investment. For example: In calculating the IRR value of a SSCFV investor preference vessel configuration with interest rates of 20%, and 25%. While the value of the ratio of profit to investment about 15%, so that the SSCFV IRR value is obtained at 20+(5x20)/(9-(-104)) = 21% with a service life of around 10 years.

- **Break Event Point**

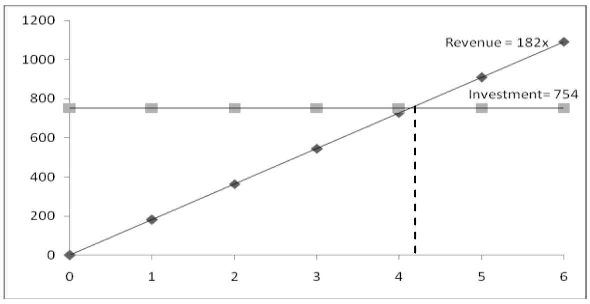

Fig 15: Break Even Point Diagram

The break-even point of SSCFV is obtained about 4.2 years with a service life of 10 years.

TABLE 8
Resume of SSCFV

	Values
Investment	754
NP (%)	15
ARR (%)	23
IRR (%)	25
Sensitivity (%)	20-30
BEP (years)	5
Service life	10

Table 8. shows resume of NP, ARR, IRR. From the results of reading the diagram that the configuration of fishing boats that meet the criteria of the IRR> ARR values.

- **Decision making**

Decision making is done by comparing the IRR and ARR values. When the IRR is smaller than ARR, the decision is UNWORTHY, but when the IRR value is greater than the ARR, the result of the decision is WORTHY. From Table 8, it is clear that the configuration of SSCFV can be called WORTHY because break-even point is 4.2 years and service life is 10 years, its means in future the SSCFV will be produces profit until 5.8 years later.

- **Sensitivity**

A result of a decision is not always absolutely true and cannot be separated from the error factor, especially when there are many assumed parameter values. Changing a decision as a result of the assumptions means that the decision is sensitive to change. To anticipate the changes that occur (in this case) related to the IRR value which is very closely related to the determination of the service life of the ship, then the margin value is +/- equal to 20% of the IRR value which is the upper and lower limit of IRR value. The values of range sensitivity are 16.8 up to 25.2%.

V. CONCLUSION

After conducting a technical and economical review , it can be concluded that the SSCFV suitable for fishing vessel.

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REFERENCES

[1] Pramudya IS, IKAP Utama, Wasis DA, 2017, Kapal Ikan Katamaran : Tinjauan Aspek Kebutuhan Energi, Fungsi dan Performa Kapal yang Ramah Lingkungan, Disertasi – MT093350.

[2] Korol I. and Latorre, R., 2010, Development of Eco-Friendly Fishing Vessel An ecological vehicle powered by renewable energy, EVER Monaco.

[3] Utama IKAP., Setyawan, D, Jamaluddin, A, Sugiarso, A., 2010, Development of Catamaran Fishing Vessel, IPTEK, Journal for Technology and Science, Vol.21, No.4.

[4] Molland AF., Turnock SR., Hudson DA., 2011, Ship Resistance and Propulsion – Practical Estimation of Ship Propulsive Power, ISBN:978-0-521-76052-2 Hardback, CUP, USA.

[5] Marchaj, 2003, C A, *Sail Performance, Techniques to Maximize Sail Power*, Revised Edition, ACl, London.

[6] Larson L., 2007, Principles of Yacht design, 3rd ed.,ISBN-13: 9780071487696, Mc Graw Hill

[7] Kinney, F.S., 1977, Skene's Element of Yacth Design, ISBN: 071361823x, ACB Ltd, London.

[8] Richard Benny Luhulima, I Ketut Aria Pria Utama, Aries Sulisetyono, 2016, CFD Analysis inti the Resistance Interference of Displacement Trimaran, Australian Journal of Basic and Applied Sciences (AJBAS).

[9] Richard Benny Luhulima, I Ketut Aria Pria Utama, Aries Sulisetyono, 2016, Experimental Investigation into the Resistance Components of Displacement Trimaran at Various Lateral Spacings, International Journal of Engineering Research & Science (IJOER), 2016.

[10] Utama, I K A P, , An Investigation into the Viscous Resistance Components of Catamarans, PhD Thesis, University of Southampton, UK, 1999.

[11] Richard Benny Luhulima, Sutiyo, and I Ketut Aria Pria Utama, 2017, An Investigation Into The Correlation Between Resistance and Seakeeping Characteristics of Trimaran at Various Configuration and with Particular Case in Connection with Energy Efficiency.

[12] P.I. Santosa, I.K.A.P Utama and W.D Aryawan, 2016, *Power Estimation of HCFV Based on Voyage Profile*, International Journal of Science and Research (IJSR), ISSN (Online): 2319-7064.

[13] Hind, JA., 1982, Stability and Trim of Fishing Vessels - second edition, Fishing News Book Ltd, Farnham, Surrey, England.

[14] P.I. Santosa, I.K.A.P Utama, W.D Aryawan, 2016, Power Estimation of HCFV Based on Voyage Profile, International Journal of Science and Research (IJSR) ISSN (Online): 2319-7064.

[15] Pramudya Imawan Santosa, IKAP Utama, Wasis DA, 2017, A Study into the Development of More Energy Efficient and Less Polluted Fishing Vessel, International Journal of Engineering Research & Science [IJOER], ISSN: 2395-6992, Vol-3, issue-10, October-2017.

[16] P I Santosa, I K A P Utama, W D Aryawan, D B Purwanto, R-M Chao, and A Nasirudin, 2014, An Investigation into Hybrid Catamaran Fishing Vessel: Combination of Diesel Engine, Sails and Solar Panels, IPTEK, Journal of Proceeding Series, Vol. 1, 2014 (eISSN: 2354-6026).

[17] PI Santosa, 2018, AN INVESTIGATION INTO THE USE OF SOLAR-SAIL ON CATAMARAN FISHING VESSEL, International Journal of Mechanical Engineering (IJME) Vol.5 Issued 8 August 2018, Page: 1-6 ISSN: 2348-8360

[18] J Fyson, 1986, Fishing Vessel Design, FAO of the United Nations