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The Configuration of Engine-Sail Catamaran Fishing Vessel

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The Configuration of Engine-Sail Catamaran Fishing Vessel

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Abstract. In the field of shipping, consumption of fossil fuel is quite large, especially as fuel to drive ship-engines. The high fuel price is not at all beneficial to the shipping industry and fishermen as users of ship-engines. The use of fuel for ship-engines is not only uneconomical but also environmentally unfriendly. The more expensive fuel is anticipated by the reuse of sail in the form of Engine-sail Vessels (ESV) as Fishing Vessels. This paper presents a study on the efficient use of fuel in ESV as a driver that does not utilize fuel to develop of environmentally friendly fishing vessels. There is a potential savings in the use of fuel 70% when compared with conventional ship-engines only.

1. Introduction

The mission of a fishing boat is to catch fish from the sea to get fish that meet the quality in appropriate ways and deliver the fish to land or to another vessel for further processing. Today, the catch of these fishing vessels supplies the daily food needs and sustains the food security of millions of people in the world [1].

From these fishing activities have an impact on the increase of air pollution levels (such as CO_2, SO_2 and NO_X) in the atmosphere, especially on fish boats that use diesel engines fuel by fossil fuels. The impact of these activities is one of the most important problems in the world to look for solutions that fish ships operating in the world become environmentally friendly fishing vessels [2].

In general, the operation of a fishing boat is always associated with economic and environmental issues. Economic factor is the cost of fuel, while the environmental factor is related to the level of pollution produced. Economic problems and strong environmental pressures force ship designers and owners to create more efficient vessels to minimize the use of ship propulsion. Reduced magnitude of ship propulsion (and fuel requirements) can be fulfilled since the ship design stage by creating more efficient hull design and propulsion systems as well as ship operational activities including ship operations, such as Engine-sail Vessels (ESV) [3].
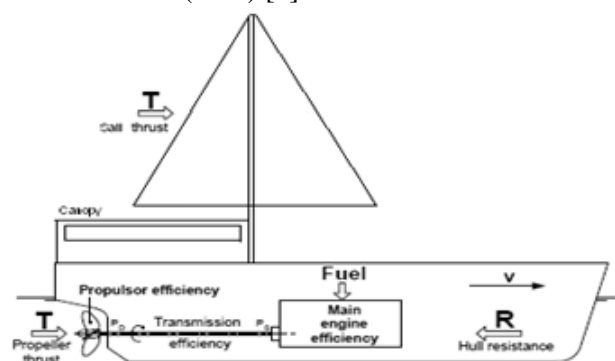

Figure 1. Configuration of Engine-sail Vessels (ESV) [1]

Figure 1 shows the configuration of the ship with the engine-sail driver. The concept of energy conversion in the ship's configuration is to convert fossil energy (fuel) and wind energy into the required thrust force of the ship through the propeller (engine) and sail. 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].

Experimental model test on a symmetrical catamaran has been carried out and reported in [3]. The experimental model test was carried out at ITS towing tank as shown in Figure 2 and the principle particular of the model and full ship was given in Table 1.

Figure 2. Experimental model test

Table 1. Principle particular

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

Table 2 showed the results of resistance test which indicated that the wider the separation between the hulls (S/L), the lower the total resistance.

Table 2. Result of resistance test [3]

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

Data's from Table 2 is further used as a basis for designing the concept of catamaran fishing boat with a combination of engine-sail [1][8].

2. Literature Review

2.1 Ship Moving Theory
The vessel may move forward due to a sufficient thrust to resist ship resistance at a certain service speed [4]. Based on the above concept, then requirement of ship can move.

$$T \geq R_T \quad \text{o r} \quad T - R_T \geq 0 \tag{1}$$

where T is Thrust (kN) and R_T is Resistance (kN).

2.2 Ship Resistance

The total vessel resistance (R_T) is calculated according to equation (2) where ρ is the sea water mass, C_T is the total resistance coefficient, WSA is the wet surface area, and V is the velocity of the vessel [4].

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

2.3 Thrust

Thrust (T) is the energy or force required to drive the vessel and can be expressed as equation (3) [4]

$$T = R_T / (1 - t) \tag{3}$$

where t is thrust deduction factor. For double screw [3], the t is defined as

$$t = k_R \cdot wt \tag{4}$$

where k_R is 0.5 for thin rudder. The wt could be found using

$$wt = -0.0458 + 0.3745 \, C_B{}^2 + 0.1590 \, D_w - 0.8635 \, Fr + 1.4773 \, Fr^2$$

where $\quad D_w = \dfrac{B}{\nabla''^3} \sqrt{\dfrac{\nabla''^3}{D}}$

To move itself, the thrust (T) force generated through the propeller and the sail must be greater than the existing total vessel resistance which is mathematically expressed in equation (5) [4].

$$T \, propeller + T \, sail > R_T \tag{5}$$

where $T \, propeller$ is the propeller thrust which could be defined as

$$T \, propeller = K_T . \rho . n^2 . D^4 \tag{6}$$

where K_T is the thrust coefficient, ρ is the salt water density, n is the propeller Rpm, and D is the propeller diameter. The sail thrust defined as

$$T \, sail = q . As \tag{7}$$

where q is the dynamic wind pressure. The q could be defined as

$$q = \tfrac{1}{2} \times \rho \times \pounds \times V_w{}^2 \; (ton/m^2)$$

where ρ is the air mass density which is equal to γ/g. γ is the weight per unit volume which is equal to 1.2265 t/m^3, g is equal to 9.81 ms^{-2}, £ is the wind pressure coefficient, V_w is the wind speed, and As is the sail area.

2.4 Powering

Engine conventional is the prime mover of the vessel which works by converting the fuel energy to rotate the blades thereby producing sufficient thrust to resist ship resistance at certain service speeds. One of the most fundamental methods of power sharing in this conventional driving force is to distinguish between the effective power (P_E) required to drive the ship and power delivered (P_D) on the ship propulsion unit [4]. The formulations used according to [4] are as follows

$$\text{Effective power (PE)} = R_T \text{ x } V_s \tag{8}$$

$$\text{Delivered power } (PD) = PE/ Hd \tag{9}$$

$$\text{Quasi propulsive coefficient } (\eta D) = \eta P. \eta H. \eta R \tag{10}$$

$$\text{Service power } (Ps) = PD/ \eta T \tag{11}$$

where ηT is 0.98 (with gearbox) or 0.95 (without gearbox).

$$\text{Installed power } (PI) = Ps + Margin \tag{12}$$

where Margins (*roughness, fouling, weather*) is ranged by 15 – 20% depending on the ship route.

Sail is one of the propeller props without a propeller on the ship that can work due to the wind force (catch the wind) on the surface of the sail, resulting in a drifting force on the ship at a certain speed. The Sail is one of the propulsion devices on the ship. As with other propulsion devices such as propellers, the sail is attempted to produce an optimal thrust force, in order to produce maximum velocity of the ship. The forces on the Sailing Ship, as the ship moves due to the thrust of the propeller or sail there will be a lift that will lift the hull from the water. In addition, obstacles caused by the aerodynamic resistance of the sail are the forces acting on the sailboat, [5].

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 Figure 3.
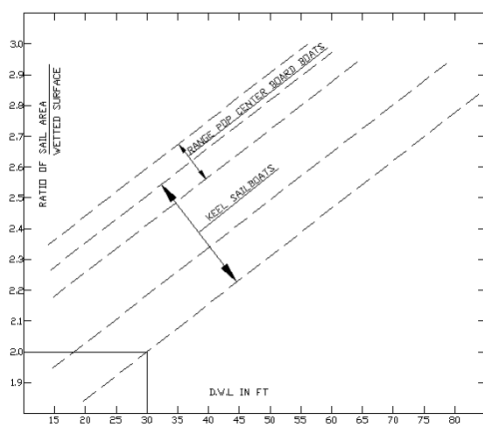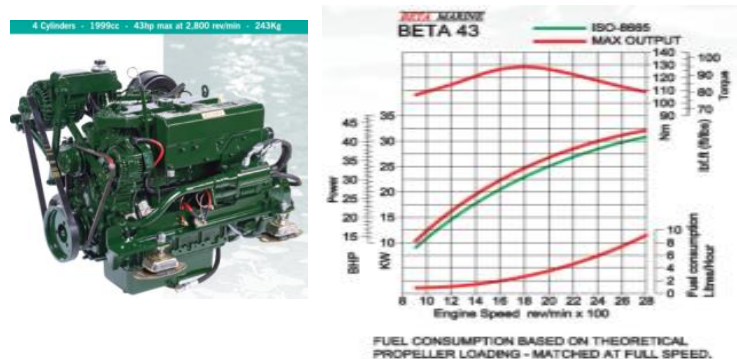

Figure 3. Graph of *SR-LWL* relationship which can be used to determine Sail Area with 15 - 80 feet or 5 - 25 m LWL limitation.

Type: Beta Marine, Power engine   : 43 hp max at 2,800 rev/min, Fuel consumption : 10 Lt /hr (at continuous Ratting), Engine Dimension : L=978 mm, B=622 mm, H=740 mm, weight=243 kg

Figure 4. Specification of BETA43 engine series

2.5 Fishing Vessel

In general, the normal voyage profile of fishing vessels according to [9] are: (1) the ship departs and operates in the port (*departure from port*), (2) the ship goes to the location of the fishing ground (*outward bound*), (3) the ship arrives at the location fishing ground and fishing (*on fishing ground*),   (4) the ship leaves the location of the fishing ground to the port (*homeward bound*), and (5) the ship arrives at the port and docked at the port (*arrival at port*).

In its operation, a fishing vessel must be completely safe (*very seaworthy indeed*). Even in bad weather, the ship must work. All work on the fishing boat must be done quickly, starting from the process

of catching until the processing of the catch is a function of time. The slow catching process causes the fish to run all (migration), while the sluggish processing of the catch causes the fish to be damaged [1].

3. Method and Result

This research is a continuing research that has been done by [3]. All material data and information are using the results of previous research to support scientific/academic and its application.

Based on the results in Table 2, it can be calculated and thus provided the effective power (PE) of 32.4 kW. With the *quasi-propulsive coefficient* (ηD) of 0.664, then the *delivered power* (PD) will be of 50.21 kW and with the *transmission losses* (ηT) without gearbox of 0.98 will give *service power* (Ps) of 51.2 kW. Finally, if the *total efficiency* (PE / PI) is 54%, it yields the *installed power* (PI) of 60 kW. The engine specifications used is 2 x 43 HP or 2 x 30 kW as shown in Figure 4.

Furthermore, by using Figure 3 it can be found that the boat with 14.5 m LWL will have approximately 125 m^2 of sail area. Meanwhile, the calculation of *thrust* (T) is obtained from Table 2, which is 6.685 kN and with thrust deduction factor (t) of 0.038. The Propeller thrust (Tp) is obtained at the service speed (Vs) of 9.8 knots while the thrust force (Ts) is calculated using equation (7) and reached at *wind speed* (Vw) of 19.2 knots. A hybrid curve chart was further derived from the above calculation and shown in Figure 6. The curve can be used to estimate the efficiency of ESV.

4. Discussion

It can be found from the tank test work as reported in [3] that at the service speed (Vs) of 9.81 knots, the total resistance (R_T) is 6.14 kN, thus the installed engine power (PI) required is 60 kW or 2 x 30 kW to adjust the shape of catamaran. The specifications of engine was shown in Figure 4 which shows the characteristics of the BETA43 engine connecting the engine running (rpm), engine power (P), fuel consumption (FC) and engine torque (Q). The maximum engine speed is 2800 rpm with fuel consumption of about 10 litres/hour and 110 Nm engine torque. Furthermore, Figure 5 can be used as a reference to calculate the efficiency of fishing vessel.

By using equation(4), it can be determined that the magnitude of thrust deduction factor (t) is 0.038, hence the thrust of ship (T) is 6.685 kN, whilst the total ship resistance is 6.138 kN. It means that as the thrust is greater than total ship resistance thus the boat will move, sea also equation (1).

As the fishing vessel is designed to use engine and sail drive (*ESV*), the generation of thrust to move the ship comes from propeller and sail. When the ship moves, the propeller and sail can work individually/separately or together as a hybrid system both with service speed (Vs) of 9.813 knots.
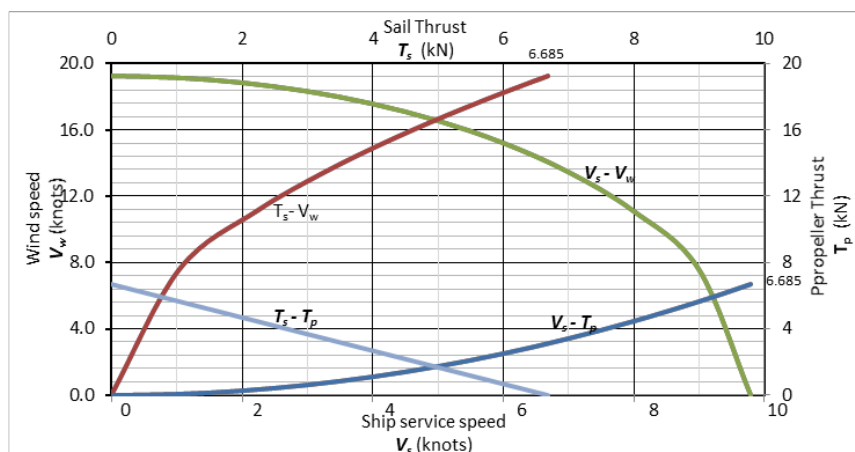

Figure 5. Hybrid curve chart [1]

The relationship between propeller thrust (T_P), see equation (3) and sail thrust (T_S), see Equation (7) is shown in Figure 6 called T_P–T_S curve. Meanwhile, the relationship between wind speed (V_W) with the sail thrust (T_S) is shown in Figure 6 called the V_W–T_S curve. Likewise, the relationship between ship

service speed (V_S) and propeller thrust (T_P) is also shown in Figure 6, namely the V_S–T_P curve. The relationship between wind speed (V_W) and ship service speed (V_S) is called the V_W–V_S curve.

Table 3. Remark of hybrid curve chart

No	Number of Axis	Relationship Between
1	Axis [1] is T_s Sail Thrust (kN),	T_s – T_p Curve use ordinate [1] and abscise [2]
2	Axis [2] is T_p Propeller Thrust (kN)	V_s - V_w Curve use ordinate [3] and abscise [4]
3	Axis [3] is V_s Ship speed (knots)	V_s – T_p Curve use ordinate [3] and abscise [2]
4	Axis [4] is V_w Wind speed (knots)	T_s - V_w Curve use ordinate [1] and abscise [4]

Table 3 shows the number of axis and relationship of *Hybrid Curve Chart* as shows in Figure 6. If the economic value of the use of wind energy is equated with the economic value of fossil energy use, then to calculate the ESV efficiency and how the hybrid system at ESV will be explained in detail in the following case study. In order to test the validity of the present approach as summarized in Figure 6, 2 case studies are given, Case Study 1 and Case Study 2.

4.1 Case study 1 (CS1)
It is assumed that a fishing vessel uses hybrid driving force (engine, sail) and operated at a service speed (V_S) of 9.8 knots, whilst the sea breeze blows (V_W) with a speed of 12 knots. Furthermore, estimate thrust caused by T_S screen/sail, thrust generated by T_P propeller, the propeller contribution to V_S hence the vessel can be operated at the service speed of 9.8 knots, and the fuel consumption (F_C).
The answers is described as follows:
For completion of CS1 using Figure. 6 *Hybrid Curve Chart*, Fig. 8 *Rpm-Vs Chart,* and Fig. 9 *Rpm-FC Chart.* Choice value of 12 kts *Vw* Wind speed in the axis [4] and then generate horizontal line [a] through pass the *Ts – Vw* curve and the *Vs- Vw* curve, next from the intersection it drags the vertical line [b] and [c] From the intersection of the line with the curve *Ts-Tp* drag a horizontal line [d]   , (*see green line in Figure 6*).
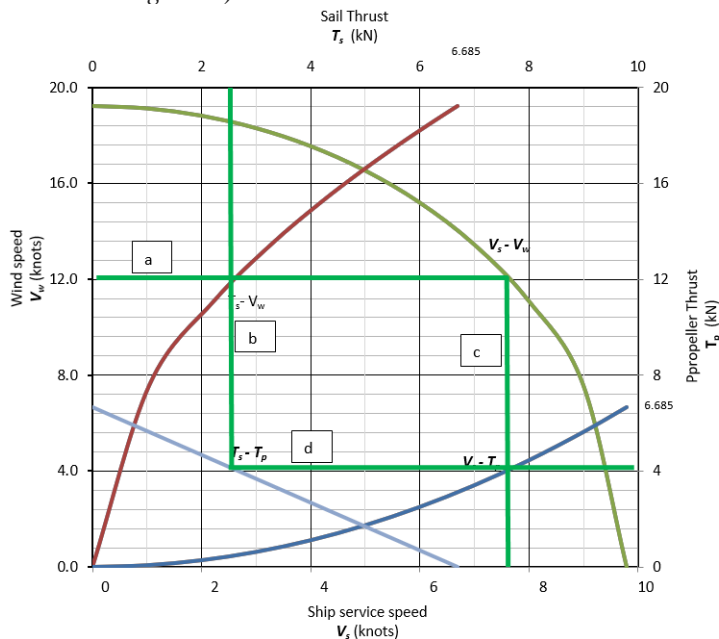

The results of *Hybrid Curve Chart* readings obtained:
1) Line [b] with the axis [1] is obtained 2.4 kN *Ts*
2) Line [c] with the axis [3] is obtained 7.6 knots *Vs*
3) Line [d] with the axis [2] is obtained 4.3 kN *Tp*

Figure 6. Application of CS1 use *Hybrid Curve Chart*

Furthermore, use Figure 7 to find when *the rotation of engine* abt. 1300 Rpm obtained 7.67 / 2 = 3.835 knots *Vs*. (*See red line*), and then use Figure 8 to find when the rotation of engine about 1300 Rpm

obtained magnitudes of *fuel consumption* (*FC*) is abt. 1.8 liter/hour/engine or 3.6 liter/hour (*see red line*).

Results of the completion of CS1:

When 12 knots wind speed (*Vw)* blows on the sail generates 2.4 kN sail thrust (*Ts*) and automatically propeller thrust (*Tp*) is abt. 4.285 kN with the contribution of servicing ship speed*Vs* of 7.67 kts and 3.6 ltr / hour fuel consumption (*FC*).
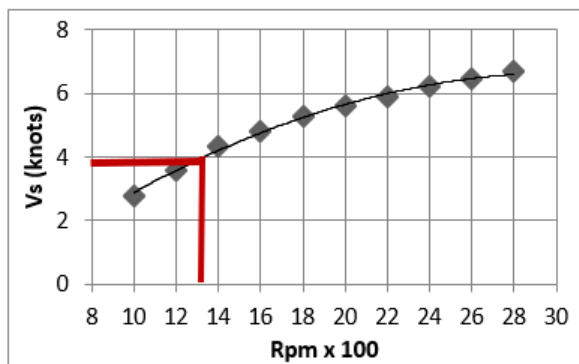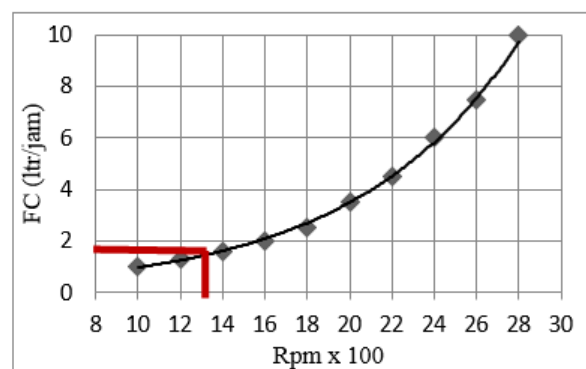

Figure 7. *Rpm-Vs Chart*

Figure 8. *Rpm-FC Chart*

4.2 Case Study 2 (CS2)
When ESV is operated the sea breeze blows (*V_W*) with the varying speeds of 0.0, 4.0, 8.0, 16.0, and 19.2 knots. By using *Hybrid Curve*, *Rpm-V_S*, and *Rpm-F_C*, estimate: thrust of sail (*T_S*), thrust of propeller (*T_P*), contribution of propeller to *T_S* thus the vessel can be operated at the service speed (*Vs*) of about 9.813 knots, and the fuel consumption (*F_C*). In the same way as in CS1, the following results obtained are: (see Figure 9 and 10)

Table 4. The hybrid system work at the service speed (*Vs*) 9.813 knots

Sail		Propeller		FC/Engine (Liter/hour)	Prime mover work
Vw (Knots)	Ts (kN)	Tp (kN)	Engine Rpm		
0.0	0	6.685	1700	4.5	Engine
4.0	0.5	6.185	1550	3.8	Engine-sail
8.0	1.2	5.485	1480	3.7	Engine-sail
16.0	5.4	1.285	1000	2	Engine-sail
19.2	6.685	0	0	0	Sail

Table 4 shows the Hybrid System (ESV) work, the propeller and sail can work individually/separately or together as a hybrid system when the ship moves.

Figure 9 shows the relationship between *wind speed (Vw)* and *fuel consumption (FC)*. Figure 10 also shows the efficiency/savings of fuel usage in ESV operations which alternately and fully utilize wind energy.

Service speed (Vs) on fishing boats is a major requirement because fishing vessels must arrive at the fishing ground as quickly as possible so as not to lose the right time to catch fish. This fishing vessel sailed with operational speed of around 9.8 knots. At this speed the ship will experience a drag force

(*RT*) of 6,423 kN with the need for thrust (*T*) of 6.685 kN. To meet the needs of the thrust force is supplied from propeller propulsion (*Tp*) with a 2x30 kW engine and sail (*Ts*) with an area (*As*) 125 m^2.
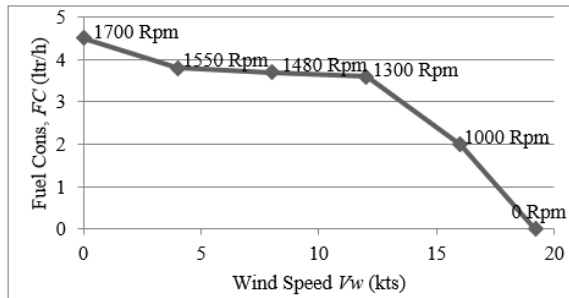

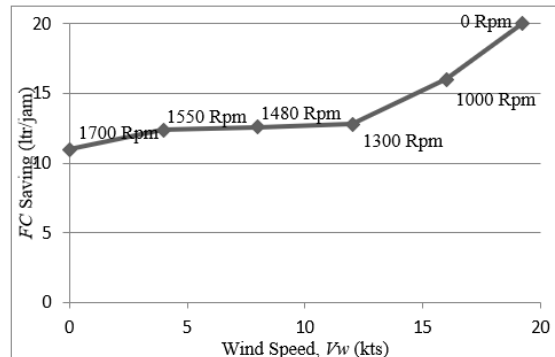**Figure 9**. Result of CS2 use *Vw - FC Chart*   **Figure 10**. Result of CS2 use *Vw-FC Saving Chart*

The optional of service speed is adjusted to the voyage profile of the fishing vessel itself. When the ship operates in the port area (*departure from port*) in an empty load state, the ship will only use a speed of about 2 to 3 knots. At this time the use of engines and sail is highly recommended. When the ship goes to the location of the fishing ground (*outward bound*) in an empty load state and after the ship is on the high seas it will use full service speed of 9.813 knots, because the fishing vessel must arrive at fishing ground according to the planned time (on time) by using the engine and sail simultaneously. When the ship arrives at the location of the fishing ground in an empty load state and then doing the fishing operation on the fishing ground will tend to use a speed of about 4 to 7 knots because the fishing equipment set up requires a rather fast time and if it is not quickly worried the fish will run all. At this time the use of machines and sail simultaneously / alternately is highly recommended depending on the situation. When the ship leaves the fishing ground location (*homeward bound*) to the port in full load condition with the catch, fulfilment of thrust force is generated from the use of the engine and sail simultaneously to reach speed service 9.813 knots. And when the ship arrives at the port (*arrival at Port*), the ship only uses its speed of about 2 to 3 knots by using the engine and sail alternately. The use of wind energy to drive ESV with service speed of Vs 9.813 knots requires a *Vw* wind speed of 19.2 knots to produce a thrust force of T of 6.685 kN.

5. Conclusion

Application of hybrid technology is very useful when applied to catamaran fishing vessels. The development of hybrid vessel gives a promising expectation in order to reduce the use of fossil fuels. It has been found that the use of sail in combination with the operation of engine (ESV) was to be very useful. Economic review indicates the potency of cost saving and could be save about 70% fuels consumption. The system can reduce the emission of greenhouses gases. There is shown a good promise that can lead to significant savings in fuel consumption and hence reduce emission of greenhouse gases. The present work apparently portraits of study into the development of more energy efficient and less polluted fishing vessel.

6. References

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