Study of catamaran fishing vessel based on wind energy

P Santoso¹, I Utama²

¹) Institut Teknologi AdhiTama Surabaya-Indonesia.
²) Professor Hydrodynamics of Naval Architect Dept., FTK, ITS, Surabaya-Indonesia.

pramudya05@itats.ac.id

Abstract. Amid the Covid19 Pandemic, the world is currently experiencing a difficult time. The impact of the chain due to soaring crude oil prices on world markets has been felt by all levels of society. Responding to this, austerity movements in various sectors are needed in order to create alternative solutions to the dependence of FO to get through difficult times. In the sea transportation sector, the use of fuel for motorized vessels is not only uneconomical but also environmentally unfriendly. The dependence on fossil fuels energy has led to the development of the concept of energy efficient vessels that use alternative energy sources in moving ships. This is anticipated by the re-use of sails in the form of Sailboats (SB) which are applied as fishing vessels. This paper presents a study of the efficient use of wind energy in SB as a boat mover that does not utilize fuel for the development of environmentally friendly fishing vessels. Technical analysis is done through testing the ship model in the Towing Tank then the results are explored by Naval Architect theories. In conclusion, there is a potential savings in fuel consumption by 100% when compared to ships that have only engine-driven.

1. Introduction

Amid the Covid19 Pandemic, the world is currently experiencing a difficult time[1]. The impact of the chain due to soaring crude oil prices on world markets has been felt by all levels of society. Subsidies by the government to ensure the supply of fuel oil (FO) in the country actually becomes an increasingly heavy burden[2]. Responding to this, austerity movements in various sectors are needed in order to create alternative solutions to the dependence of FO to get through difficult times[3].

At present fishing vessels are still urgently needed to support and sustain food security for billions of people in this world. We know that the mission of a fishing boat is to catch fish from the sea to get fish that meet the quality in appropriate ways and take the fish ashore or to other ships for further processing. In operation a fishing boat must be absolutely safe because even in bad weather the ship must work, so that the problem of total resistance, driving force, fuel consumption, stability and seakeeping are very important concerns.

In general, the operation of a fishing boat is always associated with economic and environmental issues[4]. The economic factor is the cost of fuel because the consumption of fossil fuels (fossil) is quite large, especially for ships primemover, while environmental factors are related to the level of pollution that occurs due to ship operations[5]. The high price of fuel oil is not at all profitable for ship operators. The use of fuel for motorized ships is not only uneconomical anymore, but it is also not environmentally friendly. Economic problems and strong environmental pressure forced ship designers and owners to create more efficient ships so as to minimize the use of boat propulsion[5]. Reduction in the amount of propulsion (and fuel requirements) can be met since the design phase of the ship by creating a more
efficient hull design and propulsion system and ship operational activities including ship operations, such as: Sailing Boats, Solar Electric Ships, Engine Sails Ships[4].

The impact given from the operational activities is very important to be studied and, in the future, it will be used as a basis for developing ship drivers using renewable energy that is efficient and effective[6]. The Catamaran hull is very potential to be used as a fishing vessel because it has a large deck area and also has good resistance performance, stability and ship motions (seakeeping) as well as the potential to reduce exhaust emissions and subsequently will be used as a basis for non-fossil energy applications on ships[7].

Figure 1. Sailboats Configuration [9].

Figure 1 shows the Sailboats configuration, which the concept of energy conversion in the configuration is to convert wind energy into the required thrust force of the ship through the sail.

2. Methodology

Experimental model test on a symmetrical catamaran has been carried out and reported in[8]. 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.

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    |
| CB        | 0.434     | 0.434    |
| Displ. (ton) | 11.8   | 5.9      |

Figure 2. Experimental model test

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

| Run No. | V (Knots) | Fr | Catamaran 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     |
Further, the Data’s in Table 2 used to explore the Sail catamaran fishing vessel.

3. Result

Figure 3 shown The lines plan of vessel, is a vertical cross section of the ship (body plan), vertical elongated (buttock line) and horizontal elongated (water line) equipped with absent ordinate information of the ship. Information on this line plan data as shown in Figure 3 is an input for depicting and calculating the Hydrostatic Curve. The making of Lines Plan is carried out using the Design re-use method by entering the main size data’s available.

| Draft Amidships m | 0.000 | 0.050 | 0.100 | 0.150 | 0.200 | 0.250 | 0.300 | 0.400 | 0.500 | 0.600 | 0.694 |
|-------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Displacement t     | 6.677 | 0.288 | 2.443 | 2.239 | 2.348 |       |       |       |       |       |       |
| Heel deg           | 7.051 | 0.304 | 2.852 | 2.678 | 2.947 |       |       |       |       |       |       |
| Draft at FP m      | 7.560 | 0.326 | 3.460 | 3.568 | 3.547 |       |       |       |       |       |       |
| Draft at AP m      | 8.032 | 0.347 | 4.467 | 3.954 | 3.766 |       |       |       |       |       |       |
| Draft at LCF m     | 8.384 | 0.362 | 4.844 | 4.345 | 4.341 |       |       |       |       |       |       |
| Trim (+ve by stern) | 8.818 | 0.380 | 5.149 | 4.790 | 4.662 |       |       |       |       |       |       |
| WL Length m        | 9.233 | 0.398 | 5.807 | 5.592 | 5.515 |       |       |       |       |       |       |
| Beam max on WL m   | 9.813 | 0.423 | 7.101 | 6.448 | 6.138 |       |       |       |       |       |       |

**Table 3 The Hydrostatic Properties**
Table 3 shown Hydrostatic properties, is the ordinate data of the ship line plan used to determine the characteristics of the ship to be designed. The results of the hydrostatic calculations are used for the purpose of: 1) Crosscheck main size data provided from previous studies, 2) Besides that it is also used to complete the data needed for development the Configuration of Sail catamaran fishing vessel.

3.1. Ship Moving Theory
The vessel may move forward due to a sufficient thrust to resist ship resistance at a certain service speed [6].

\[ T > RT \quad \text{or} \quad T - RT > 0 \]

where \( T \) is Thrust (kN) and \( RT \) is Total ship resistance (kN).

\[ R_T = \frac{1}{2} \rho C_T (WSA) V^2 \]

where: \( t = k_R \cdot \frac{w}{t} \)

\[ wt = -0.0458 + 0.3745 C_B^2 + 0.1590 D_w - 0.8635 Fr + 1.4773 Fr^2 \]

\[ D_w = \frac{B}{\pi} \sqrt{\frac{E^\infty}{D}} \]

where: \( t \) is thrust deduction factor for single screw, \( k_R \) is 0.5 for thin rudder.

3.2. The sail
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[9]. 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[10]. 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[9].

The sail force \( (F_s) \) defined as[11],

\[ F_s = q \cdot A_s \]

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

\[ q = \frac{1}{2} \rho \cdot E \cdot V_w^2 \text{ (ton/m²) } \]

where \( \rho \) is the air mass density which is equal to \( \gamma/g \), \( \gamma \) is the weight per unit volume which is equal to 1.2265 t/m³, g is equal to 9.81 ms⁻², \( E \) is the wind pressure coefficient, \( V_w \) is the wind speed, and \( A_s \) is the sail area.
Figure 4. Graph of SR-LWL [11]

Figure 4 shown SR-LWL relationship which can be used to determine Sail Area with 15 - 80 feet or 5 - 25 m LWL limitation[11]. Determination of Sail Area almost as a comparison of sail area (As) with wetted surface area (WSA) is between 2.0 and 2.5[10]. Comparison of sail area (As) with wetted surface area (WSA) known as sail ratio (SR). There is another way according to[11], where the determination of SR depends on the LWL of the ship by using the graph.

3.3. Stability

Figure 5. The stability balance of Catamaran Sailboat, [18].

Figure 5. shows the balance of forces and moments acting on a catamaran sailboat. This balance occurs because the values of the moment of return when the ship is shaken (displacement multiplied by the righting arm) is the same as the moment of wind (the force of the wind multiplied by the heeling/capsize arm). Sailboats have two types of stability arms, the static arm is the moment of return when the ship is shaken (righting arm) and the wind force moment arm is working at the centre of the sail (heeling/capsize arm)[12].

W Boat x Right arm = Wind press x Capsize arm
(Righting moment) (Capsizing moment)  

\[ \text{(9)} \]

3.4. Ship motion

Ship motion is the motion response of ship when it receives a disturbance from the outside (external) which in this case is caused by wave blows[13] or in other words is one aspect of hydrodynamics that studies the behaviour of ships on the waves.

Figure 6. Ilustration of Ship Motion response

Figure 6 shows the illustration of the response of the ship, where waves as the input of the ship hit the ship causing dynamic movement of the ship as its output[13].
Figure 7. Dynamic Ship Motion with 6 Degrees of Freedom,

Analysis of the dynamic motion of this ship is very dependent on the characteristic wave information where the ship will be operated. The dynamic motion of ship tends to cause a return force that functions to return the ship to its original position. The dynamic motion of the ship is shown in six degrees of freedom, namely: three are linear / translational motion and three are rotational, all movements are based on three axes (x, y, z) as in Figure 7[13]

In ship operations at sea, there are three of the most dominant movements that can cause changes in displacement, namely:

Heave
\[(m + a) \ddot{z} + b \dot{z} + cz = F(t)\]  \hspace{1cm} (10)

Pitch
\[(mk^2 + a) \ddot{\theta} + b \dot{\theta} + c\theta = M(t)\]  \hspace{1cm} (11)

Roll
\[(mk^2 + a) \ddot{\phi} + b \dot{\phi} + c\phi = 0\]  \hspace{1cm} (12)

In the dynamic motion of the ship parameters measured include: the response of heaving, pitching and rolling movements and the possibility of slamming and deck wetness.

Limits regarding seakeeping performance criteria relate to specific aspects of the ship's response to sea conditions, such as the amplitude of the roll / pitch / heave motion at a certain point (area) on the ship. Every aspect of the movement, if it has a high value will be able to allow the element of the ship to degrade to an unnatural level.

Response Amplitude Operators (RAO) is calculated by following Equation:

\[RAO(\omega) = \frac{X}{\zeta_a}\]  \hspace{1cm} (13)

4. Results and Discussion

In general, the normal operational of fishing vessels according to[14], 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).
**Figure 8.** Operational simulation of Sailboat Catamaran Fishing Vessel

Figure 8. Operational simulation of Sailboat Catamaran Fishing Vessel. 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.

**Table 4.** Results of data development

| No. | Parameter              | Symbols | Results | Units   |
|-----|------------------------|---------|---------|---------|
| 1   | Displacement           | $\Delta$ | 11.8    | ton     |
| 2   | Lightweight            | $LWT$   | 7.070   | ton     |
| 3   | Payload                | $DWT$   | 4.730   | ton     |
| 4   | Resistances            | $R_T$   | 6.138   | kN      |
| 5   | Thrust                 | $T$     | 6.685   | kN      |
| 6   | Sail Areas             | $SA$    | 125     | m$^2$   |
| 7   | Cubic number           | $CUNO$  | 55.04   | m$^3$   |
| 8   | Cargo hold Capacity    | $Cap.$  | 8.5     | m$^3$   |
| 9   | Fish cargo             | $W_c$   | 1851    | kg      |
| 10  | Gross tonnage          | $GT$    | 15      | tonnage |
| 11  | Gross tonnage          | $GT$    | 14.45   | tonnage |
| 12  | Nett tonnage           | $NT$    | 3.03    | tonnage |
| 13  | Weight of Sail Eqpt.   | $W_{m}$ | 243     | kg      |
| 14  | Weight of Ship Eqpt.   | $W_{SE}$| 727     | kg      |
| 15  | Weight of Fish Proc.Eqpt.| $W_{FPE}$| 339   | kg      |
| 16  | Weight of Fishing gear | $W_{FE}$| 554     | Kg      |

Table 4 shows Results of data development as a engineering analysis is done through testing the ship model in the Towing Tank then the results are explored by Naval Architect theories.

**Figure 9.** Relationship between $V_w - V_s$

Figure 9 shows the graph of the relationship between the wind speed ($V_w$) and the Ship service speed ($V_s$). When the wind speed is captured by the sail to move ship, it will produce the ship service speed. Figure 10 shows the graph of the relationship between the thrust of the ship $T$ with the speed of the ship $V_s$ and the wind speed $V_a$. This graph can be used to calculate the speed of a sailboats. For example, 8 knots (see red line) then the boat's thrust value $T$ will be around 4.5 kN and then use the graph Fig.2 enter the $T$ value of 4.5 kN, then the wind velocity ($V_w$) value is obtained around 15 more knots and 8 knots Ship service speed ($V_s$), or vice versa.
The results of the calculation of Response Amplitude Operators (RAO) for heave and pitch motions as presented in Figures 11 and 12.

Motion of catamarans is very dependent on the choice of the distance between the hull (S/L) and in S/L = 0.2 is 18% smaller than the catamaran S / L = 0.4 in the direction of wave 120°, as obtained from the results of experimental studies by [16].

The results of the calculation of the static stability of catamaran fishing vessels with sail propulsor under various operational conditions as shown in Table 5.

| No | Ship Conditions       | LWT (kg) | DWT (kg) | Displ. ∆ (kg) | Fishcatch (kg) | SA/∆ | Centre Gravity (m) | Draught, d (m) |
|----|----------------------|---------|----------|---------------|----------------|------|--------------------|----------------|
| 0  | Design               | 7070    | 4730     | 11800         | 2880           | 10.59| 7.142              | 1.308          |
| 1  | Departure from port | 7070    | 1850     | 8920          | 0              | 14.01| 6.523              | 1.360          |
| 2* | Outward bound        | 7070    | 1540     | 8610          | 0              | 14.52| 6.554              | 1.370          |
| 3  | On fishing ground    | 7070    | 2670     | 9740          | 1440           | 12.83| 6.953              | 1.346          |
| 4  | Homeward bound       | 7070    | 3675     | 10745         | 2880           | 11.63| 7.288              | 1.331          |
| 5  | Arrival at port      | 7070    | 3335     | 10405         | 2880           | 12.01| 7.341              | 1.339          |

Note: Condition 2* is the conditions that are considered the most critical stability. However, after checking the stability, it still meets fish catch requirements.
Figure 13. Sailboat stability

Figure 13 shows Sailboat stability when the ship is operational. In condition 2 (outward bond), to achieve 9.8 knots service speed ($V_s$) required 17.15 knots wind speed ($V_w$). There is a balance at an angle of about 9° and the value of Sail force ($F_s$) is 5.467 kN. But when the ship is in condition 4 (homeward bond), to achieve 9.8 knots service speed ($V_s$) required 19.16 knots wind speed ($V_w$). There is a balance at an angle of about 4° and the value of Sail force ($F_s$) is 6.823 kN.

Table 6. Fish vessel stability requirements according to The Fishing Vessels (Safety Provisions) Rules 1975 and HSC annex 7. IMO 2016.

Table 6 shows the results of calculating the stability requirements of sailboat catamaran fishing vessels under various conditions. The results all meet requirements according to The Fishing Vessels (Safety Provisions) Rules 1975 and HSC annex 7, IMO 2016.

The economic value of FO use on Engine fishing vessels is shown in Figure 14 below, [14].

Figure 14. Relationship between $V_s$-FC-T at 60 kW power.

Figure 14. shows the graph of the relationship between ship speed ($V_s$) - fuel consumption ($FC$) - thrust ($T$). To reach the official speed $V_s$ 9.8 knots with 60 kW engine power ($P$), 6.685 kN thrust ($T$) requires 57.9 liters/hour fuel consumption ($FC$). So it can be said that the economic value of the ship speed ($V_s$) of 9.8 knots, the thrust ($T$) of 6,685 kN is equivalent to the cost of fuel consumption of 57.9 liters/hour. Furthermore, if the economic value of the use of wind energy is equated with the economic...
value of the use of fossil energy, the results obtained are a sailboat speed of \( (V_s) \) 1 knot equivalent to wind speed \( (V_w) \) of 1.96 knots which also has an equivalent value to the force thrust \( (T) \) of 0.68 kN which is equivalent to FO of 5.9 liters / hour. So it can be simply concluded that wind speed \( (V_w) \) of 1 knot is equivalent to FO of 2.95 liters / hour.

5. Conclusions
Application of sail on catamaran fishing vessels is very useful has potency of cost saving about 100% fuels consumption and can reduce the emission of greenhouses gases. The present work apparently portraits of study into the development of more energy efficient and less polluted fishing vessel.

6. References
[1] Keputusan Presiden Republik Indonesia Nomor 12 Tahun 2020 tentang Penetapan sebagai Bencana Nasional - Regulasi | Satgas Penanganan COVID-19, https://covid19.go.id/p/regulasi/keputusan-presiden-republik-indonesia-nomor-12-tahun-2020 (accessed 28 October 2020).
[2] PERPRES No. 47 Tahun 2017 tentang Penyediaan Lampu Tenaga Surya Hemat Energi bagi Masyarakat yang Belum Mendapatkan Akses Listrik [JDIH BPK RI], https://peraturan.bpk.go.id/Home/Details/72904/perpres-no-47-tahun-2017 (accessed 28 October 2020).
[3] Imawan Santosa P, Utama IKAP, D.A W. A Study into the Development of More Energy Efficient and Less Polluted Fishing Vessel. IJOER 2017; 3: 75–79.
[4] Santtosa PI. The Configuration of Solar Sail Catamaran Fishing Vessel. Global Journal of Research In Engineering, https://engineeringresearch.org/index.php/GJRE/article/view/1961 (2019, accessed 28 October 2020).
[5] PI S. Techno-Economic Review: The Use of Solar Sail On Catamaran Fishing Vessel. International Journal of Mechanical Engineering 2019; 6: 32–37.
[6] Santosa PI. The Configuration of Engine-Sail Catamaran Fishing Vessel. IOP Conf Ser: Mater Sci Eng 2019; 462: 012008.
[7] Setyawan D, Utama IK a. P, Murdijanto M, et al. Development of Catamaran Fishing Vessel. IPTEK The Journal for Technology and Science; 21. Epub ahead of print 1 November 2010. DOI: 10.12962/j20882033.v21i4.90.
[8] Samuel S, Iqbal M, Utama IKAP. An Investigation into the Resistance Components of Converting a Traditional Monohull Fishing Vessel into Catamaran Form. DOI: https://doi.org/10.14716/ijtech.v6i3.940.
[9] Marchaj CA. Sail Performance : Techniques to Maximize Sail Power. 2nd Edition. Camden, Me: International Marine/Ragged Mountain Press, 2002.
[10] Larsson L, Eliasson R, Orych M. Principles of Yacht Design. 4th Edition. Camden, Maine: International Marine/Ragged Mountain Press, 2014.
[11] Kinney FS. Skene’s Elements of Yacht Design, Eighth Edition. Dodd, Mead & Co., 1983.
[12] Catamaran Stability | James Wharram Designs, https://www.wharram.com/articles/how-we-design/catamaran-stability (accessed 28 October 2020).
[13] Bhattacharyya R. Dynamics of marine vehicles. New York: Wiley, 1978.
[14] Hind JA. Stability and Trim of Fishing Vessels and Other Small Ships, 2nd Edition | Wiley. Wiley.com, https://www.wiley.com/en-us/Stability+and+Trim+of+Fishing+Vessels+and+Other+Small+Ships%2C+2nd+Edition-p-9780852381212 (accessed 28 October 2020).