Feasibility of Using Solar Assisted Rigid Wind–Sail as A Power Saving Device on Boats

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Abstract

The usage of alternative energy beside fossil fuel in maritime industry is necessary due to the fluctuating fuel cost. In order to reduce the operational cost by reducing the fuel consumption, some ships are equipped with solar-wind assisted devices. The lower oils consumption in ships could reduce environmental pollutions and increase cruising range. This study investigates the feasibility of using solar assisted rigid wind–sail as a power saving device on University Malaysia Terengganu's (UMT) research boat. The attachment of solar assisted rigid wind-sail device may affect the performance, operation and stability of the boat. Generally, the performance of boat will increase when there are additional energies. Thus, the operational cost of the boat may decrease due to lower oil usage. Attempts were made to study the feasibility of using solar assisted rigid wind-sail in technical aspects including stability and performance as well as operational and economical aspects. The results of the study shown that the application of solar assisted rigid wind-sail to UMT research boat reduced the annual cost of operation from USD 20390 to USD 17815.9. It can also save up to 20% of power consumption. Further, the attachment of solar assisted rigid wind-sail to UMT research boat does not affect the stability of the boat and the stability of boat still meet the IMO requirement. Therefore, it can be summarized that the solar assisted rigid wind-sail has a high potential as an alternative to the conventional fossil fuel ships in the future.

Keywords: Boat, Stability, Operational cost, Rigid wind–sail, Solar power

1. Introduction

The usage of wind and solar energy other than fossil fuel to boats is encouraged due to fluctuation of fuel cost and damage of environment done by fuel burning. From 1994 till 2008, statistics shows that each year the price is increasing but not stable, and on July 11, 2008, the maximum price was $147.02 per barrel [1]. In addition, it was estimated that the world's shipping industry uses between 350 to 410 million tons of fuel each year, which equates up to 1.2 billion tons of carbon dioxide emissions [2].

This paper presents a study on the usage of wind and solar energy device to University Malaysia Terengganu (UMT) Research Vessel. Solar-wind assisted device for UMT boat is designed base on concept developed by Solar Sailor Holdings Ltd [3-4]. The attachment of solar rigid wind-sail device to the UMT boat may affect the performance, operation cost and stability. Generally, the performance of boat will increase when there are additional energies. Thus, the operational cost of the boat may decrease due to lower oil usage in the boat operation. However, the feasibility of using solar wind sail device to the boat may not appropriated due to stability of boat.

UMT boat is 16.5 m length, used for fishing research, discovery purpose and transportation. The boat is fitted by propeller by one single screw in engine board and equipped with all necessary facilities for 10 researchers/passengers and 3 crews. The speed of the boat during the first trial is 20 knots. The principal dimension of boat is shown in Table 1.

Table 1: UMT research boat principal dimensions

Properties	Dimensions
Length Overall	16.5 meter
Length Water Line	13.40 meter
Breadth	3.65 meter
Draft	0.6 meter
Speed	20 knots
Propulsion	1 x 360 HP Marine Engine
Block Coefficient	0.75
Fuel	1000 Liter
Water	500 Liter
Passenger and crew	13 Person

2. Methodology and Design Requirement

By using scale ration equation the new parameters of sail can be determined as shown in Equation 1. Basis Ship is taken from solar sailor hybrid-power ferry concept which is designed by Solar Sailor Holdings Ltd [3]. Full result on new sail geometry is shown in Table 2.

$$S_{NS} = \frac{S_{BS} \times \Delta^{2/3}_{NS}}{\Delta^{2/3}_{BS}} \quad (1)$$

S_{NS} = Sail Area (new sail)
S_{BS} = Sail Area (Basis sail)
Δ_{NS} = ρ x L x B x T x CB (new sail)
Δ_{BS} = ρ x L x B x T x CB (Basis sail)

Table 2: New sail dimension

Parameters	Dimension
Number of mast, N	2
Mast height (m), H	2.42
Sail area (m2), S	4.705
Sail area per mast (m2), S m	2.3525
Design wind speed (knots), VT	30
Types	NACA 4415-63

Electric power is used for onboard lighting systems, powering onboard systems and for engine starting. The examples of an electric system aboard ship are; fan-coils, alarms, lighting, tank lever, navigator device, etc [5].

In this study, solar energy is used for generating the electric power. Base on power requirement per day, it was estimated that power requirement to run the basic electric system for UMT boat is 4 kWh/day. The solar panels will need to supply this amount of energy to the battery each day, to accommodate total power required by electric appliances. The system efficiency was assumed as 80%.

Therefore, total power requires by panels is 4.8 kWh/day (1.2 x 4 kWh/day).

In order to supply of 4.8 kWh energy per day, the panels (assumed as the study area receive 8 hours of sunshine), will need to be rated in total at 4.8 kWh divided by 8 hour. Therefore, total power rating of the solar panels is 600 Watts (4.8kWh / 8 h).

From previous studies [6-8], by using polycrystalline silicon of solar cell type, it was found that when it is exposed to direct sunlight, a 6-centimeter diameter silicon cell can produce a current of about 0.5 ampere at 0.5 volt or 0.25Watt. Therefore, total area of solar panel can be determined as 6.785 m^2 (600 x л x 0.062/4 ÷ 0.25).

In this study, the solar panel was designed to be place on rigid sail. The solar sail area is 4.705 m^2. therefore, addition area of solar panel (need to be put to other place) is 2.08 m^2 (6.785 m^2 - 4.705 m^2).

To calculate the weight of solar panel, it is estimated that the weight for one cell of 6 centimeter diameter of silicon cell equal to 100 gram. Therefore weight of solar panel is 143 Kg (6.785 m^2 x 0.06 Kg ÷ (л x 0.062/4) m^2).

The following shows on how to determine the propulsive forces including a few parameters such as drag coefficient, C_D, lift coefficient, C_L, propulsive force/drive force, F_P, lift force, L and drag force, D. The calculation is based on wind data that provided by Department of Metrology Malaysia. As the result F_P value from each direction of wind can be determined. These values will be correlated with main engine thrust to get the percentage of power saving.

Previous research [8] shows that aerodynamic force FT (resulted from airflow through sail/wind) have to divided into two components, sideway force FH and propulsion force FP. Moreover, aerodynamic force FT also can be shown into two others component, drag force FD and lift force FL, therefore each component have interrelationship with others components. Figure 1 shows the relationship of aerodynamic forces.

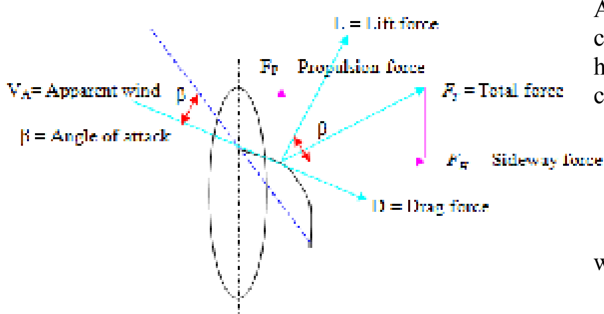

Figure 1. Relationship of aerodynamic forces

First step on determining the propulsion force is by determine the values of apparent wind speed VA and angle of attack β, which, based on the values of true wind speed, VT and ship speed VS. It is done by vector analysis. By using Foil Design Program, the NACA 4415-63 was designed to obtain the Lift coefficient, CL and Drag coefficient, CD at difference apparent wind speed. Then, Lift and Drag forces was calculate by using following Equation 1 and 2.

$$L = \frac{1}{2}\rho_{air} \cdot V_A^{\,2} \cdot S \cdot C_L \qquad (1)$$

$$D = \frac{1}{2}\rho_{air} \cdot V_A^{\,2} \cdot S \cdot C_D \qquad (2)$$

Where, ρ_{air} = Air Density, VA = Apparent Wind Speed and S = Sail Area

Base on Figure 1, propulsion force or resultant force was analyzed. It can shows on Equation 3.

$$Fp = (L \cdot \sin\beta - D \cdot \cos\beta) \cdot N \qquad (3)$$

where, L =Lift Force, D = Drag Force, β =Angle of Attack and N = Number of sail

Force resultant from wind energy will be linked to engine ship to determine how much horsepower can be saved. Like those known, speed of vessel depends to horsepower supplied by the main engine. But then, the horsepower of engine is proportion to thrust power (power produce by propeller) [8-10]. The following Equation 4 is commonly used to calculate thrust power.

$$P_T = R_T V_S \qquad (4)$$

where, P_T = Thrust Power, R_T = Ship Resistance and V_S = Ship Speed

Therefore, normal operation data of UMT boat was study, where, resistance and thrust power at various boat speeds were investigated. In this study, Hullspeed software was used to calculate that data. After that, engine horsepower at various boat speeds can be determined by estimate the loss of engine horsepower to thrust power is equal to 67%[9]. This can shows with Equation 5.

$$P_{HP} = \frac{R_T V_S}{0.67} \qquad (5)$$

where, P_{HP} = Break Horsepower

By knowing interrelationship between horsepower, boat resistance and speed, therefore, force resultant from wind energy can be connected to engine horsepower. This is because, resistance to boat is reaction force which opposite forward movement of boat, while force resultant from wind is reaction force which helps forward movement of boat [9-10]. Following is relationship Equation 6 between force resultant from wind and resistance;

$$R_T - F_p = R_{Tnew} \qquad (6)$$

where, R_T = Ship Resistance, F_P = Resultant Force and R_{Tnew} = New Ship Resistance

Therefore, it shows the resistance (R_T) is decrease with increasing of resultant force (Fp). This is directly reducing horsepower (P_{HP}) which need to be generated by engine. The difference between horsepower P_{HPnew} (with sail) and horsepower P_{HP} (without sail) at constant speed is shows how many energy saving can be achieved. The percentage of power saving at constant speed can be calculated as Equation 7;

$$\frac{P_{HP} - P_{HPnew}}{P_{HP}} \times 100 = \%PowerSaving \quad (7)$$

For stability, there are various methods to calculate the large angle of stability of a vessel, such as the Wall Sided Formula, Integrator Method, Isocline Method, Barnes Method and Reech Methods. However, in this study Hydromax Professional program was used. This programme used to analyze the stability of boat in fulload and lightship conditions.

For economical aspect of this study the annual average cost (AAC) and net present value (NPV) methods between actual boat (operate with main engine) and wind assisted boat (operate with combination between wind sail and main engine) will be studied. Equations 8 and 9 show formula related to calculating NPV. In this study the life time of the UMT boat was assumed as 20 years and interest rate (i) is 10%.

NPV (without sail) = ∑PV(maintenance cost) + PV(operation cost) - PV (salvage value) (8)

NPV (with sail) = ∑PV(maintenance cost) + PV (operation cost) + PV (investment cost in sail) - PV(salvage value) (9)

Table 3 is shows the present costs of the system elements.

Table 3: Overall cost estimation

Cost	Properties	With Sail (USD)	Without Sail (USD)
Investment Cost	Boat	64000	64000
	Solar Sail	9318.05	non
Maintenance Cost (increase 2%/ each year)	Machinery and Hull	6400 /year	6400 /year
	Solar Sail rig	774.48/ year	non
Operation Cost	Fuel Oil	6957.03 /year	9139.41/year
	Lube Oil	145.74 /year	191.46//year
Salvage Value		27868.14	23052.04
Others Cost		1000 /year	1000 /year

3. Result and discussion

Figure 2 shows the relationship between true wind velocity values with propulsion force at different true wind direction. In this case, ship velocity (Vs), ship direction, angle of attack (α) and sail area is constant to 15 knot, 5 deg, 14 deg and 4.702 m^2 respectively.

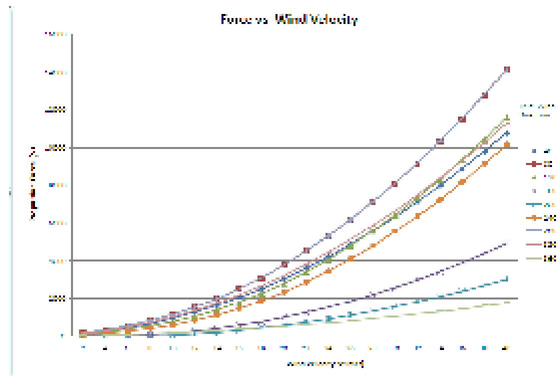

Figure 2. Relationship between true wind velocity values with propulsion force

From the figure 2, propulsion force is slightly increased when wind velocity increased. It can also be seen that the different direction of wind acting on sail will produces different propulsion force. The different values of wind velocity (Vt) and wind direction (φ) will affect relative velocity (apparent wind velocity), consequently, the higher of apparent wind velocity will produce a higher propulsion force. Moreover, the increased of wind velocity will increase the pressure different between inward and backward of the sail, therefore the Lift force that is produced by the sail is much higher.

Figure 3 shows the relationship between ship velocity values with propulsion force at difference true wind direction. In this case, wind velocity (Vt), ship direction, angle of attack (α) and sail area is constant to 12 knot, 5 deg, 14 deg and 4.702 m^2 respectively.

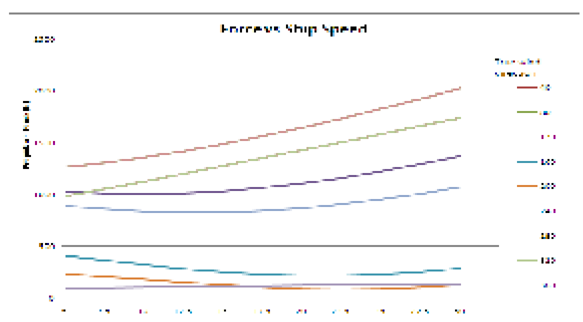

Figure 3. Relationship between ship velocity values with propulsion force

From the figure 3, propulsion force slightly increased when ship velocity increased. But, it depends on the direction of wind, the different direction of wind acting on sail will produces different propulsion force. As discussed, the differences value of ship velocity will affect relative velocity, the higher of apparent wind velocity will produce the higher propulsion force. Therefore, increasing the ship velocity will increase the propulsion force. Figure 4 shows the relationship between power saving and ship speed according to the different angle of true wind.

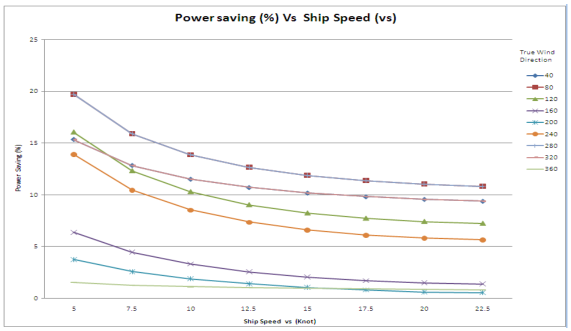

Figure 4. Relationship between percent of power saving with ship velocity

From the figure 4, percentage of power saving was between 1 to 20% based on the direction of true wind. Percentage of power saving slightly decreased when the speed of the ship increased. Although increasing ship speed will produce much more lift force, the increase in power saving is not proportion to the increasing of the lift force. It is because with the increasing speed, the boat will use much more engine power (brake power) when compared with lower speed. The power saving is disproportion to engine power and proportional to lift force. So, power saving is related with engine power and ship speed.

The different direction of wind acting on the sail will produce different propulsion force. The wind direction acting on sail will produce different values of apparent wind. Therefore the different values of apparent wind will affect the aerodynamic and also propulsive force. Figure 5 shows the relationship between percentages of power saving with route situation. The ship speed, angle of attack (α) and sail area is constant to 15 knot, 14 deg and 4.702 m^2 respectively.

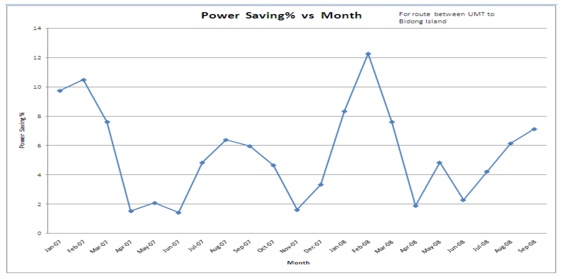

Figure 5. Relationship between percent of power saving with route

From the figure 5, the highest power saving is during North – East monsoon, which is from November until March, because, the wind speed is higher compared to others months. the lift force is proportion to wind speed and wind direction (base on vector analysis). Since, power saving is proportional to lift force, power saving in this month is higher than others months.

By using the Hydromax Professional program, the stability can be obtained at different angles of the heel. The result was shows in GZ vs Heel angle graph. It can be shown in Figure 6 and Figure 7. From the graph, it can be seen that the maximum GZ for light ship is 0.229 at angle 50 deg, whilst, the maximum GZ for full load ship is 0.314 at angle 47 deg. It can be seen that, the boat still complies the International Maritime Organization stability requirement although it was attached by solar sail.

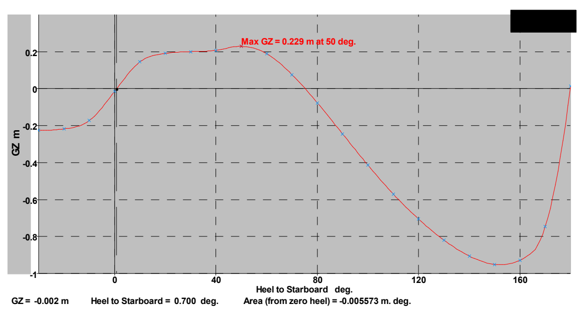

Figure 6. GZ curve for light ship

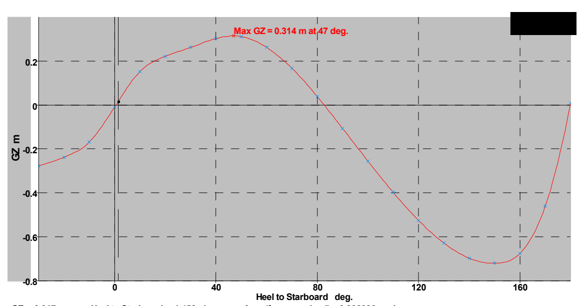

Figure 7. GZ curve for full load ship

Base on economical calculation for both cases, with solar sail and without solar sail, the AAC are negative, which mean that both alternatives are not profitable. This is due to the function of this boat which is only used for research purpose. The result finds that, the total annual average cost (without sail) is higher than total annual average cost (with sail). Where, AAC without sail is equal to 20390 USD per year, while, AAC with solar sail equal to 17815.9 USD per year. This result shows that the boat which has been fitted with solar sail is more economical compared to the boat without the solar sail.

Sensitivity analysis is the simplest way of investigating uncertainties in main parameters. The procedures involve repeating the calculation with different values of key parameters and assess how sensitive the results are to such changes. The effect of increasing of oil price percentage is shown in Figure 8. The oil price increase 20% until 220% from current value (USD 0.5053 per Liter).

Figure 8 shows the effect of oil price percentage for boat with solar sail and without solar sail. From the graph, annual average cost slightly increased when percentage of oil price increased. According to the economic calculation, AAC depends on operation cost. Basically, operating cost depends on fuel cost. By cutting out usage of fuel will reduce the operating cost and annual average cost.

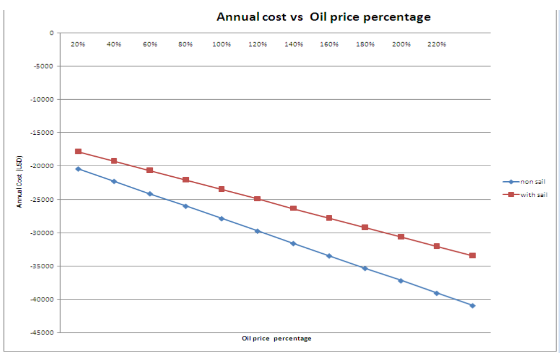

Figure 8. Sensitivity of oil price.

The graph shows the gradient of boat without solar sail is higher than boat with solar sail which mean; the boat without solar sail is more sensitive due to increasing of oil price percentage rather than boat with solar sail. Therefore, it shows that the boat that is fitted with solar sail is more economical compared with the boat without solar sail. The return investment of the boat (fitted by wind -solar assisted boat) is determined by the numbers of years that the investment will be recovered. It is known that, AAC for without sail and with sail is equal to 20390 USD and 17815.9 USD per year respectively. Therefore, cost saving (per year) = (20390 - 17815.9) = 2574.1 USD. Assuming that; oil price, interest rate (i) and others value that influence on calculation of economic is constant each year. So, the capital investment recovery can be determined. Investment cost for boat with solar sail is; 9547.643 USD. Therefore, investment will be recovered with in 4 year (9547.643 / 2574.1= 3.7 year).

4. Conclusion

The usage of alternative energy beside fossil fuel in maritime industry is necessary due to the fluctuating fuel cost. In order to reduce fuel consumption and cut the fuel cost, studies have been conducted in which one of the methods is by using solar wing sail assisted ship. This study presents the usage of wind assisted device in UMT boat. The study is carried out in different aspects such as stability, design, mechanical system, propulsion, economic and etc. From the research, it shown that there are many variables to influence power saving, such as angle of attack, Vs, VT, and directions. It also has been shown that the application of Solar-Rigid wing sail to UMT boat reduced the annual cost operation from 20390 USD to 17815.9 USD. It can also save up to 20% of power. The research also shows that the attachment of solar rigid sail to UMT boat does not affect the stability of UMT boat. The result shows that the stability of boat still meet the IMO requirement. Therefore, it was summarized that the project has a high potential as an alternative to be developed in the future.

Reference

[1] Oil increasing. http://en.wikipedia.org/wiki/oil_price_increasing_since 2003.

[2] Ships'CO2 'twice that of planes. http://news.bbc.co.uk/1/hi/sci/tech/7052037.stm.

[3] Powering the transport needs of the future with clean efficient hybrid marine power. http:// www.Solarsailor.com.

[4] Ronald O'Rourke, (2006). Navy Ship propulsion Technology; Option for reducing Oil Use. CRS Report for Congress. December 11.2006.

[5] Electrical system onboard ship http://www.boatdesign.net/wiki/Electrical_system#onbord_power_usage.

[6] Solar panel. http://www.speedace.info/solar panels.htm.

[7] William H. Avery, Walter G. Berl, (1999). Solar Energy from Tropical Ocean. International Journal of Hydrogen Energy 24, 295-298.

[8] CJ Satchwell,(1985). Wind Ship Technology. Proceeding of the International symposium on WindShip Technology (WINDTECH'85), Southampton, U.K., April 23-25, 1985. Part A and B.
[9] Saiful Bin Salim, (2006). Design of wind Propulsion System for Ship, Final Year Project Thesis, Universiti Teknologi Malaysia.
[10] Shahrizman Effendi Bin Hashim, (2005). "A design of wind powered propulsion system", Final Year Project Thesis, Universiti Teknologi Malaysia.