COMPARATIVE STUDY OF HYBRID CATAMARAN VERSUS DIESEL MONOHULL BOAT AS FERRY FOR SHORT DISTANCE ROUTES.

***[1]Ferry, M., [1]WB.Wan Nik, [1]MFAhmad, [2]Gaspersz, F. and [2]Manuputty, M.**
[1]Faculty of Maritime Studies and Marine Science, University Malysia Terengganu, Malaysia
[2] Department of Naval Architecture, Faculty of Engineering, Pattimura University, Ambon, Indonesia
*Corresponding author: ferry.m@umt.edu.my; ferdomanu@yahoo.com

SUMMARY

The increasing of fossil's fuel prices and environmental awareness urges engineers try to hybrid diesel with green energy such as solar energy. Through photovoltaic cells, solar energy is converted into electricity that could power the electric motors as the prime mover at a catamaran that has more slimmer and shallower cross-section area than single hull boat of an equivalent displacement has less draught, more deck area and more stable.. Electric motor maintains high efficiency over a wide range of loads and speeds has a small weight and need low maintenance and repair cost compared to diesel engines or outboard motors. At countries like Malaysia and Indonesia where solar energy is available during average six to seven hours a day is a quite good time range to charge the batteries until reach its full capacity, but when solar radiation is not available the battery charging is taken over by diesel generator. Such hybrid system is efficiently to be used for catamaran boat on rivers, between ports at coastal area and between closed islands due to its less the operational cost, maintenance cost and less carbon emission compare with fully diesel system, hence this is a more environmental friendly system.

Keywords: Hybrid catamaran, photovoltaic, solar energy, carbon emmision

NOMENCLATURE

C_b	Block coefficient
C_m	Midship coefficient
C_p	Prismatic coefficient
C_{wp}	Waterplane coefficient
C_T	Total resistance coefficient
EF_{CO2}	Emission factor (kg CO_2/fuel units)
GM_t	Transverse metacenter height (m)
KB	Height of center of buoyancy (m)
KG	Height of center of gravity (m)
L_{WL}	Length of waterline (m)
S	Wetted area (m^2)
SFOC	Specific fuel oil consumption (g/kWh)
R_T	Total resistance (kN)
V	Ship velocity (m/sec)
WSA	Wetted surface area (m^2)
ρ	Density of seawater (t m^{-3})

1. INTRODUCTION

A typical scenario for this study is based on sea activities in Malaysia and Indonesia, especially at regions which consists of small islands and seas. Sea transportation between the small islands within the region nowadays are mostly dominated by small monohull passenger boats powered by inboard diesel or outboard gasoline engines.

These outboard or inboard diesel engines use at the boats generate exhaust gasses which cause immeasurable negative effects on the environment, besides that the engine cooling water and waste water contains oil and fuel residue which is pumped out into the sea, cause pollution especially when there is a large number of boats operating in the region.

Moreover, due to the economic growth of these regions the number of boats will increase rapidly and consuming more fossil fuel and therefore causing more pollution. Tropical region such as in Indonesia and Malaysia having an averrage 6-7 hours free solar energy that can be utilized to achieve this transformation [1], which is a hybrid solar- gasoline/diesel generator system which may initiate interest to boat operators due to the benefits they provide. Progressively switching from fossil fuel to hybrid with alternative energy sources could reduce pollution and operational cost.

2. BOAT DIMENSION, WATER RESISTANCE AND POWER

2.1 MONOHULL BOAT

The design of a boat typically begins with analysis of the existing boats according to all of the requirements which are important to obtain general information on the type of particular boat that is the passenger boat. If the requirements will be fulfilled with the successful the design might proceed using this boat as the basis boat and, thus, involve scaling its characteristics for changes intended in the design. In this study, it is necessary bringing the design calculations and analysis of monohull and catamaran which then fulfilled the requirement as a passengers boat [2]. Also evaluate the performance including the hydrostatic, speed, resistance, and power estimation by maxsurf software.

Small passenger boats connecting closed islands most are monohull boats that carry 20-25 seated passengers, running at economical speed 10 knots, operate 300 days a year, 12 trips daily during 12 hours from 6.00 am – 6.00 pm is shown at Fig. 1.

Figure 1: Small diesel monohull boat

The body plan view of the monohull boat is shown at Fig. 2 and the main dimensions is determined by maxsurf software presented in Table 1.

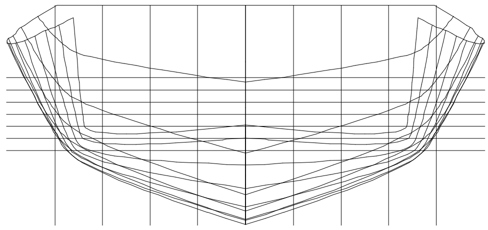

Figure 2: Body plan view of monohull boat

Table 1: Main dimension of monohull boat

Displacement	3.051	tonne
Volume	2.977	m^3
Draft to Baseline	0.462	m
Immersed depth	0.462	m
Lwl	8.786	m
Beam wl	1.977	m
WSA	16.479	m^2
Max cross sect area	0.557	m^2
Waterplane area	15.148	m^2
Cp	0.608	
Cb	0.371	
Cm	0.61	
Cwp	0.872	
KB	0.328	m
KG	1.953	m

Based on the main dimensions is determined the deck space for passengers which has length 7m and breadth 1.85m, thus the deck for passengers is 13m^2, excluded engine casing area the space for one passenger is obtained about 0.5m^2.

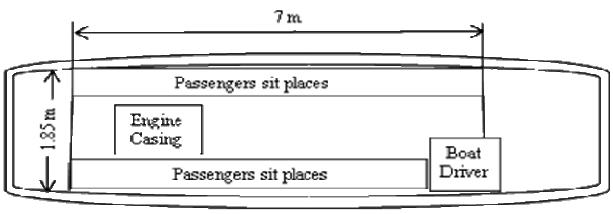

Figure 3 Layout of passengers sitting space at monohull boat

2.1 (a) Water Resistance and Power

Water resistance of a boat could be determined by fomula (1):

$$R_T = ½ C_T*\rho*V^2*S, \quad (1)$$

Where : R_T – Total Resistance (kN)
C_T – Total resistance coefficient
ρ – Seawater density (t/m^3)
V – Boat speed (m/sec)
S – Wetted surface area (m^2)

Table 2 presents the calculation result of resistance and power versus speed of the monohull boat with Holtrop method of maxsurf software, where at speed 10 knots the resistance is 2.61kN and the power is 13.6kW, then is appointed that the engine power of the monohull boat is 14kW.

Table 2: Monohull boat resistance and power versus speed

Speed, kts	Resist, kN	Power, kW
0	0	0
1	0.01	0.01
2	0.05	0.06
3	0.09	0.14
4	0.18	0.39
5	0.38	1.03
6	0.55	1.7
7	1.11	4.08
8	1.69	7.19
9	2.07	9.56
10	2.61	13.6
11	2.97	17.2
12	3.17	19.6
13	3.47	23.4
14	3.79	27.8
15	4.03	31.1

2.1 (b) Diesel Power System

On a diesel engine propulsion system the rpm of the main engine is reduced by the gearbox with certain ratio so that the propeller rpm is reduced. The main engine speed is controlled by the boat driver through the engine speed controller, see Fig. 4.

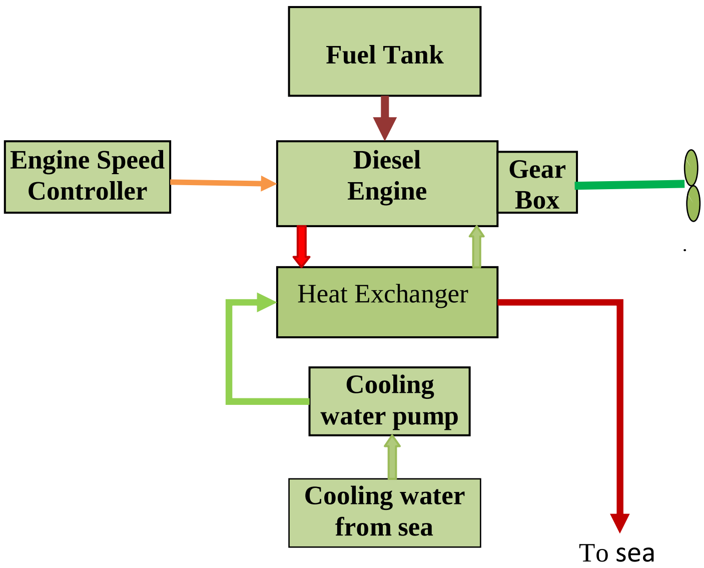

Figure 4: Diesel engine and propulsion system

2.2. CATAMARAN

At a hybrid solar-diesel generator power system, where solar energy is transformed into electricity through photovoltaic cells (PV) which runs the electric motor as prime mover on small catamaran passenger boats or for other purposes . Fig. 5 and Fig. 6 show a small catamaran boat for transportation among closed islands, where at daytime it can use solar energy and night time they could run on batteries. Diesel generator could be provided on standby to complement when alternative energy is not available.

Figure 5: Fore view of a small catamaran boat

Figure 6: After view of a small catamaran boat

The body plan drawings of the catamaran is done with maxsurf software shown at Fig. 7. The displacement of the catatamaran is designed similar to the displacement of the monohull boat at Fig. 1.

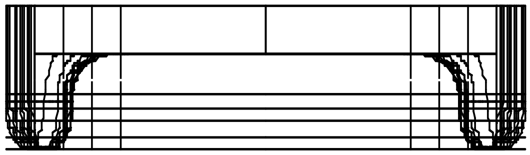

Figure 7: Body plan view of catamaran

By software maxsurfpro is determined the main dimensions of the boat presented in table 3, then from the main dimensions is determined the deck area for the sitting passengers space (Fig. 8) where the length is 7.5m and breadth 3.5m, which allows each passenger to occupy an area of about 1.05m2, that is twice than the area available for one passenger at the monohull boat, hence on catamaran boat the passengers can sit more conveniently.

Table 3: Main dimension of catamaran boat

Displacement	3.047	tonnes
Volume	2.973	m^3
Draft to Baseline	0.51	m
Immersed depth	0.51	m
Lwl	9.273	m
Beam wl	3.85	m
WSA	23.164	m^2
Max cross sect area	0.423	m^2
Waterplane area	9.126	m^2
Cp	0.757	
Cb	0.491	
Cm	0.648	
Cwp	0.768	
KB	0.287	m
KG	2.15	m

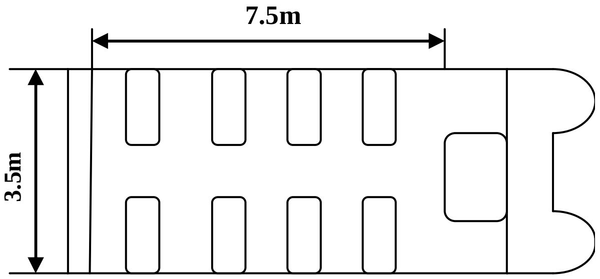

Figure 8 Layout of passengers sitting space at catamaran boat

2.2 (a) Water Resistance and Power

At Table 4 is presented the result of the water resistance and power versus speed of the catamaran determined with maxsurf hullspeed software, where at speed 10 knots the catamaran resistance is 2.42 kN and power 12.62 kW ≈ 13 kW, which is about 7% less than the power of the monohull boat.

Table 4: Resistance and power versus speed

Speed kts	Resist kN	Power kW
0	0	0
1	0.05	0.03
2	0.17	0.2
3	0.29	0.45
4	0.52	1.1
5	0.79	2.14
6	1.01	3.1
7	1.35	4.96
8	1.74	7.38
9	2.01	9.31
10	2.42	12.62
11	2.84	16.41
12	3.09	19.09
13	3.51	23.7
14	4.06	29.76
15	4.45	34.33

2.2 (b) Hybrid Power System

Catamaran boats that used as ferry between closed islands generally are small in tonnage, ferrying about 20 - 25 passengers which is similar as being carried by the monohull boats. The characteristics of these cat boats are suitable for installation of the solar panels at the roof which supply energy to the hybrid power system. The propose hybrid power system is shown in Fig. 9. The DC current produced at this system by the solar panels will run the electric motor before being channeled to the propeller. Part of the current is going to charge the batteries for running the boat during shortage of solar energy, in particular during the night when the capacity of batteries is low then the generator will perform its duty [3].

During the daytime the hybrid power system cat boat can be powered by solar energy which should save fuel that will reduce the operational cost and the maintenance/repair cost of the diesel generator. Generally, solar panel has an operation life of 20 years, while E-motor has efficiency over 90 %. Under this arrangement, the propulsion system does not require a thrust bearings as the electromotor bearings will directly deliver the propeller thrust to the boat hull. Electric motors maintain high efficiency over a wide range of loads and speed. At 48 V DC electric motors will generate power up to 15 KW (≈ 20 HP) and with low speed and high torque in most applications they are capable to use a simple, cheap and efficient transmission system. These electric motors are enable to get the best possible performance powering from the batteries or directly from the solar cells panels/diesel generator . High efficiency gives longer running time and less frequent battery replacement.

The generator and the solar cell panels have the same capacity which is 300 A, 48V DC and the battery capacity is 1000Ah.

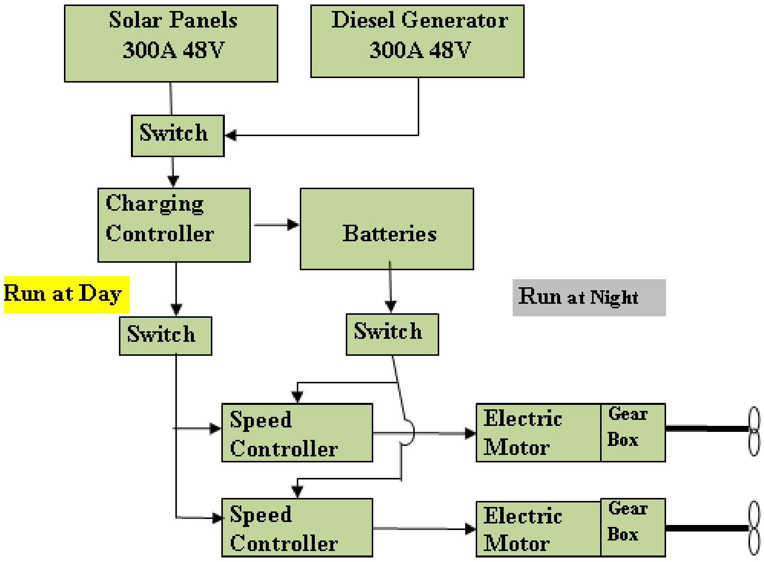

Figure 9: Hybrid solar-diesel generator electric propulsion system

3. RESULT AND DISCUSSION

This study focus is on implementing the alternative energy for powering small catamaran boat in place of monohull passenger boat where nowadays operating in these areas in a large number thus utilizing large quantities of fossil fuel. According to Muzathik et al. [4][5], the daily average sun shines hours are about 6-7 hours for the study area. In addition these vessels mainly operate during the day time thus can benefit power from solar energy for the propulsion of the boat. Normally these vessels operate around 12 hours in a day, out of this about 6 hours power requirement should be derived using generator from 6.00 am – 9.30 am and from 3.30 pm -6.00 pm where the solar radiation is low and is used only to charge the batteries and at the other six hours it is ferrying by solar power. With this mode of operation the hybrid power system could save fuel usage of the diesel-generator and at the same time reduces it maintenance and repair cost.

3.1 INCOME

Short distance routes between closed islands is assumed about 2 miles, which will be reached in 14 minutes by boat with speed 10 knots included the manuevring time. The boat will stay at the jetty for 16 minutes.Totally time for two ways trip and waiting time at the jetties will be 1 hour, the ferry boats will undergo about 12 trips daily. During 16 minutes waiting
time at the jetty the number of passengers at each trip will be variously, assumed that the average number of passengers on one way trip is 50% of the boat capacity that is 10 people, so average total daily passengers during 12 trips is 12 x 2 x 10 passengers is 240 pass daily. If the boats will operate 300 days yearly and the the ticket price for one way trip is $0.50, the income from ticket price for both types of boats will be 300 x 240 x $0.50 = $36,000.

3.2 FUEL AND LUB OIL CONSUMPTION

Yearly fuel consumption of the mono-hull boat and the hybrid cat depends on the number of trip and number of yearly sailing hours of the boats. But for the hybrid cat boat the fuel consumption depends on the number of hours when the boat is powered by the diesel generator which are summarized in Table 5. The specific fuel consumption of small diesel engines and small generators are about 250g/kWh and specific lub oil consumption is 0.7g/kWh [6]. To obtain the daily fuel consumption it is depend on the engine power, specific fuel oil consumption (SFOC) and total daily sailing hours. The daily operational time of the mono hull and catamaran is 12 hours, but the cat boat will sail under solar power only about 6 hours daily that is from 09.30pm – 3.30pm and at the other 6 hours the cat boat will be powered by the diesel generator, from 6.00am – 09.30am and 3.30pm – 6.00pm, while during these hours the solar radiation is low and the electricity from the solar cells is used to charge the batteries [7]. If the cat boat is planning to operate at night, the diesel generator must always be on standby for charging the batteries and powering the boat, besides that at night the boat needs electricity for lighting. About six hours daily the hybrid cat boat uses the solar power, that is why the sailing hours of the hybrid cat using diesel-generator is less than of the monohull, hence the yearly fuel and lub oil consumption of hybrid cat is less than of the monohull, the result is summarized in Table 5.

Table 5: Yearly sailing hours, fuel consumption and lub oil consumption.

Daily Trips	Yearly total sailing time, hours		Yearly fuel consumption, tonnes		Yearly lub oil consumption, liters	
	Monohull	Hybrid cat power by generator	Monohull	Hybrid cat power by generator	Monohull	Hybrid cat power by generator
4	560	0	2.45	0	7	0
5	700	0	3.07	0	9	0
6	840	0	3.68	0	10	0
7	980	140	4.29	0.48	12	1.18
8	1,120	280	4.91	0.96	14	2.35
9	1,260	420	5.52	1.44	15	3.53
10	1,400	560	6.13	1.93	17	4.70
11	1,540	700	6.75	2.41	19	5.88
12	1,680	840	7.36	2.89	21	7.06

3.3 MAINTENANCE COST

The average maintenance cost for diesel engine and diesel engine-driven generators is \$0.005-\$0.010 per kWh, according to the GTI (Gas Technology Institute), so this cost is depending on the power and the sailing hours of the boat during a year, hence the maintenance cost is increased by increasing of the trip numbers. In Table 6 is shown that the maintenance cost of the hybrid cat boat when ferrying daily (4 – 6) trips are zero because during these trips the diesel generator is not on duty, as the boat is powering by the solar panels due to high solar radiation, but during trips more than six the generator must be in function due to not enough solar radiation.

Table 6: Yearly maintenance cost

Number of daily trip	Monohull, $	hybrid cat, $
4	78	0
5	98	0
6	118	0
7	137	13
8	157	27
9	176	40
10	196	54
11	216	67
12	235	81

3.4 OPERATIONAL COST

Operational cost consists of: fuel and lub oil cost, crew salary, maintenance cost and other costs but in this study is assumed that the maintenance cost and the fuel cost will have the most significance effect to the profit.

Table 7: Yearly operational cost

Number of daily trip	Monohull, $	hybrid cat, $
4	1,373	0
5	1,717	0
6	2,060	0
7	2,403	266
8	2,747	532
9	3,090	797
10	3,434	1,063
11	3,777	1,329
12	4,120	1,595

3.5 PROFIT

Profit before tax is income minus operational cost. Hybrid cat boat has low operational cost than monohull boat, hence its yearly profit is higher (see Fig. 11)

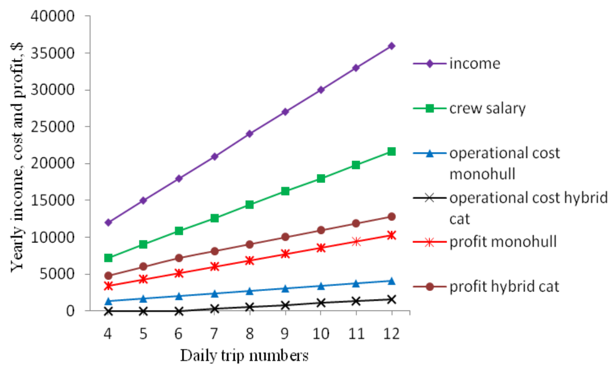

Figure 11: Yearly income, operational cost and profit of both boat types

3.6 CARBON EMMISION

With a good approximation we can say that burning a litre of diesel fuel oil produces 2.63 kg CO_2, the value depends on
the mixture of hydrocarbons and the engine, but does not vary much. The weight gains due to the fact that we have considered only the combustible, but we need to add oxygen in the combustion.
Formula for carbon emission is: CO_2 emission = Fuel Combusted (fuel units) * EF_{CO2} (kg CO_2/fuel units), where $EFco_2$ is emission factor of diesel fuel oil the magnitude is 10.14 kg/gallon [8][9]
At Table 5 is presented yearly fuel consumption of hybrid cat boat which is more less than of the monohull boat, hence that lead to the larger occurrence of yearly carbon emission of the monohull boat compare to hybrid cat boat, which is shown in Fig. 12.

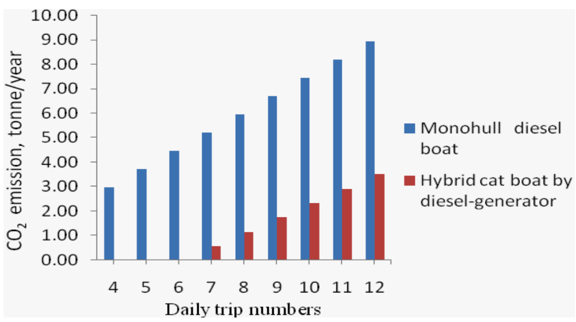

Figure 12: Yearly carbon carbon emission

4. CONCLUSION

Based on the study is revealed that hybrid cat boat:

- Has less resistance and less power.
- Has less operational cost due to less fuel and maintenance cost, hence has less operational cost.
- Is more convenient for the passengers due to more space, good sight to the surroundings; no noise interference.
- Has less carbon emission and less waste water, hence less effect on the environment pollution .

As a conclusion, using hybrid power system beside fossil fuel for small and medium catamaran boats is encouraging based on operational costs and environmental issues.

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