NEW CONCEPT OF SOLAR- POWERED CATAMARAN FISHING VESSEL

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ABSTRACT: It has been considered that the availability of fossil fuels is getting rare and hence becoming more expensive. Its exploration has moved from onshore to offshore together with advanced technology involved thus causing higher cost to the fuels to be ready to use. This fact has caused (in particulars) the fishermen cannot afford to buy the fuel so that they are vulnerable to live in poverty. Recent survey shows that more than 50% of fishing boats, owned by traditional and low economic income of Indonesian fishermen, has been grounded. In addition, the use of fossil fuels has caused the increase of green house gas (GHG) effects thus its continuous use is not environmentally friendly. The current paper describes the development of catamaran fishing vessel as a part of academic contribution to help the Indonesian fishermen. Earlier work proposed the design of catamaran fishing (cat-fish) vessel using the conventional diesel engine, whilst the new design introduces the use of combination of diesel engine together with the use of solar power. Discussion includes the explanation of lay out arrangement, ship stability and seakeeping characteristics, and energy index due to the use of two power system. The later item has now become a serious matter under IMO (International Maritime Organization) regulation in order to reduce GHG effect. Economic review of the possible development of the novel concept is also taken into consideration because the investment cost of the solar powered boat is predicted to be more expensive than the diesel powered vessel but its operational cost is cheaper hence it is promising in long-term use.

Keywords: cat-fish, solar powered, stability, seakeeping, GHG.

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INTRODUCTION

It has been known currently that the availability of fossil fuels is getting rare and hence becoming more expensive. The increase cost and the scarcity of fuel oil used for fishing vessels have caused significant terrible impact to maritime sector in Indonesia including to the fishermen (Daniel and Chandra, 2010). Recent report showed that there was an increase of about 6% on the construction of fishing vessels between 2001 and 2005 in Indonesia, but approximately 50% of those vessels were not operated in the last two years attributed to the scarcity and high cost of fuel oil (Santosa and Utama, 2012).

Many efforts have been made to help the fishermen especially in order to reduce the use of fuel oil. A number of power systems have been developed such as combination of engine and sail which is later known as sail assisted engine (Daniel and Chandra, 2011). The powering vessel without using engine and fuel oil has later become more popular considering environmental issues known as green economy concept. There are several choices of power systems such as the use of sail, solar powered boat, wave power mechanism and the combination of those two and three power systems. Despite the results of those developments are still far from economic benefits, research and development of those power systems has been carried out very intensive around the world such as carried out by Satchwell (1989) dan Molland et al (2009).

The use of catamaran for fishing vessel provides wider space to put fishing equipment on deck as well as to store the catching fishes as reported by Setyawan et al (2010). The catamaran vessel has better transverse stability; this is one of the main reasons why catamaran becomes more popular compared to other types of vessel (Utama and Molland, 2001). Moreover, the seakeeping characteristics of catamaran can be as good as that of monohull in certain sea states such as reported by Molland et al (2000) and Murdijanto et al (2011).

EARLIER CAT-FISH DESIGN

Resistance Characteristics

One design of catamaran fishing (cat-fish) vessel was proposed by Setyawan et al (2010). The design was developed using database obtained from experimental model tests and CFD analysis.

Three models were built for the purpose of experimental test: (1) hard-chine of single hull, (2) round-bilge of single hull and (3) symmetric catamaran as can be seen in Figs. 1-3. The main particulars are shown in Tables 1-3.

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Table 1: Particular of hard-chine monohull

LOA=12.9m	LBP=11.8m	B=3.0m
H=1.5m	T=0.6m	Vs=8 knots

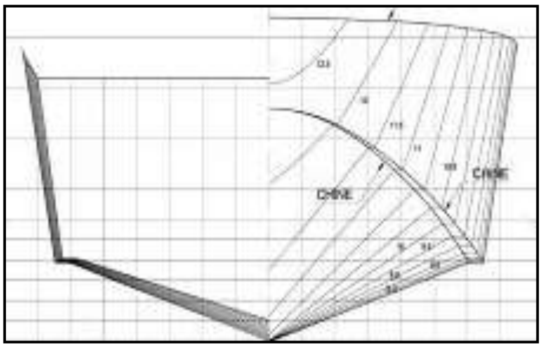

Fig. 1 Hard-chine monohull

Table 2. Particular of round-bilge monohull

LOA=12.9m	LBP=11.8m	B=3.0m
H=1.5m	T=0.6m	Vs=8 knots

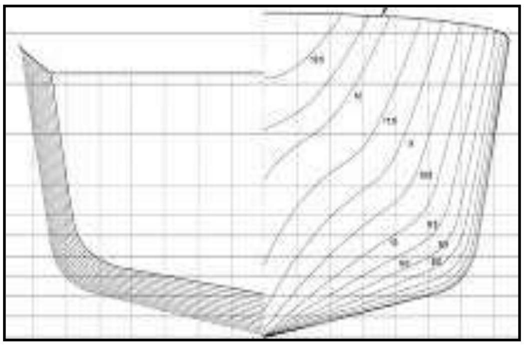

Fig. 2 Round-bilge monohull

Table 3. Particular of symmetrical catamaran

LOA=12.9m	LBP=11.85m	B=4.0m
H=1.5m	T=0.7m	Vs=8 knots

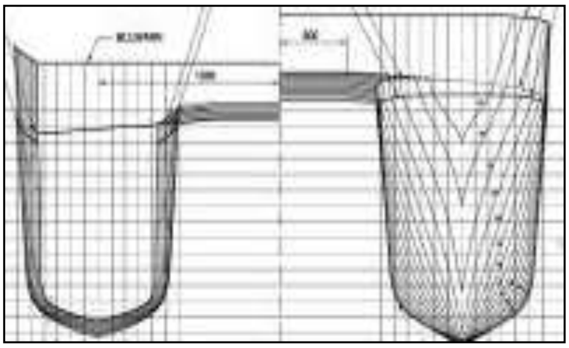

Fig. 3. Symmetrical catamaran

The most popular formulation to estimate the resistance of catamaran is the method proposed by Insel and Molland (1992). The hull of catamaran contains 2 isolated demihulls. It produces wave and viscous resistance interaction and expressed as:

$$C_T = (1+\phi k)\sigma C_F + \tau C_W \tag{1}$$

Where C_T is total resistance coefficient; C_F is frictional resistance coefficient, obtained from ITTC-1957 correlation line; C_W is wave resistance coefficient of isolated demihull; (1+k) is form factor value of isolated demihull; ϕ is used to estimate the change of pressure around demihull; σ represents additional velocity between demihulls and calculated from the summation of local frictional resistance around wetted surface area.

In reality, the factors of ϕ and σ are difficult to measure hence for practical point of view, the two factors can be combined to form viscous resistance interference factor β where $(1+\phi k)\sigma = (1+\beta k)$ hence:

$$C_T = (1+\beta k)C_F + \tau C_W \tag{2}$$

Where for monohull or demihull in isolation the value of β=1 and τ =1.

The resistance results of these hull forms were compared to know whether the power efficiency of catamaran could be gained for the development of catamaran fishing vessels. This power efficiency will in turn, save the use of fuel energy.

Results of the tank tests are tabulated in Tables 4-6, which explain the correlation between resistance and speed (and hence Froude numbers).

Table 4. Resistance of hard-chine monohull

Run Number	Speed (knots)	Froude Number	Resistance (kN)
1	5	0.239	0.64
2	6	0.287	1.13
3	7	0.335	2.28
4	8	0.382	2.97
5	9	0.430	5.24
6	10	0.478	8.37

Table 5. Resistance of round-bilge monohull

Run Number	Speed (knots)	Froude Number	Resistance (kN)
1	5	0.239	0.84
2	6	0.287	1.28
3	7	0.335	1.93
4	8	0.382	2.52
5	9	0.430	4.01
6	10	0.478	5.79

Table 6. Resistance of symmetrical catamaran

Run Number	Speed (knots)	Froude Number	Resistance (kN)		
			S/L=0.2	S/L=0.3	S/L=0.4
1	5	0.239	1.11	1.12	1.12
2	6	0.287	1.59	1.59	1.59
3	7	0.335	2.30	2.28	2.26
4	8	0.382	2.96	2.94	2.92
5	9	0.430	4.06	4.00	3.95
6	10	0.478	5.50	5.37	5.28

It can be seen from Tables 4 and 5 that hard-chine monohull has slightly higher resistance than roound-bilge one at higher speed (Froude number above 0.30) and this is believed to be due to the existence of spray and wave breaking at higher speed. This is in agreement with the facts found by Hogben and Standing (1975) and Utama et al (2008). Meanwhile, the catamaran shows its potency to produce less resistance at the same speed as the monohull (see Table 6). It is apparently shown that the higher S/L ratio the lower the resistance of catamaran and this is in a good agremeent with the work done by Insel and Molland (1992), Utama and Molland (2001) and Jamaluddin et al (2013). This is a good indication, if applied as cat-fish, to produce vessels with lower resistance (and hence less power). Thus, this is believed to be very useful to the fishermen in term of low consumption of fuels as well as to the environment in connection with lower emission caused by smaller engines.

Layout arrangement of the monohull and catamaran fishing vessels are shown in Figs. 4 and 5. It is obvious that the catamaran provides wider deck area hence gives more freedom to set-up the layout arrangement on the deck of ship such as having more space for fish hold and putting more fishing equipment.

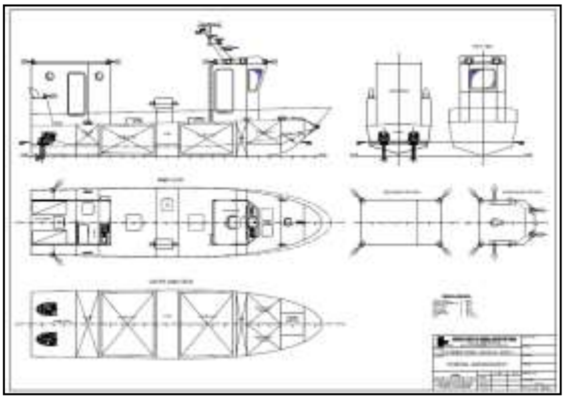

Fig. 4 GA of monohull fishing vessel

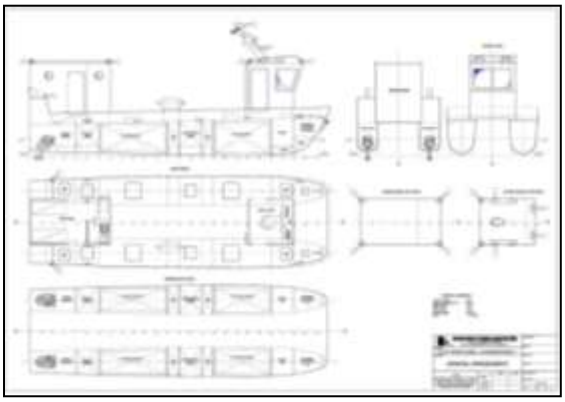

Fig. 5 GA of cat-fish vessel

Stability and Seakeeping

Ship stability is an area of naval architecture that deals with how a ship behaves at sea, both in still water and in waves. Stability calculations focus on the center of gravity and center of buoyancy of vessels and how these interact. When a ship hull is designed, stability calculations are performed for the intact and damaged states of the vessel (Rawson and Tupper, 1994). Intact stability calculations are relatively straightforward and involve taking all the centers of mass of objects on the vessel and the center of buoyancy of the hull. Cargo arrangements and loadings, crane operations, and the design sea states are usually taken into consideration. Meanwhile, damage stability calculations are much more complicated than intact stability. Finite element analysis is often employed because the areas and volumes can quickly become tedious and long to compute using other methods.

Among others, catamaran or twin-hull vessel has better transverse stability compared to monohull vessel. Fig. 6 shows that GZ value of catamaran is higher than that of the monohull and this is an indication of better stability. This is one of the main reason why catamaran becomes more popular compared to other types of vessel. This vessel type has been applied successfully as passenger carriers, oceanographic research vessels, and leisure boats (Utama, 1999). Recent work shows that catamaran is feasible as fishing vessel, particularly for coastal waters operation as reported by Setyawan et al (2010).

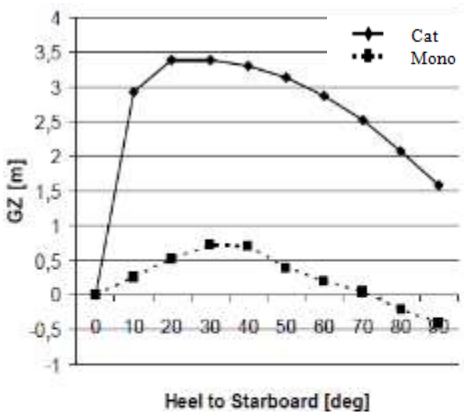

Fig. 6 Comparison of GZ (Setyawan, 2010)

Seakeeping ability is a measure of how well-suited a watercraft is to conditions when underway (Lloyd, 2001). A ship or boat has good seakeeping ability is said to be very seaworthy and is able to operate effectively even in high sea states. St. Denis, in Lewis (1988), suggested four principal terms needed to describe a seakeeping performance and these include the mission of ship, environmenal conditions, ship responses, and seakeeping performance criteria. It is obviously that a passenger ship and a fishing vessel have different missions and operated in different environments. The performance criteria will be different as well. Both may be considered seaworthy, although for different reasons based on different criteria. Furthermore, seakeeping directly impacts the design of a vessel. Ship motions are considered when determining the principal dimensions of the ship and in developing the general arrangements of the ship's internal spaces. For example, in most vessels the far forward parts of the ship experience the worst ship motions and are commonly un-acceptable for berthing passengers or crew.

Overall, ship stability and seakeeping evaluation are considered for fishing vessels because of the placement of sail and (later) solar panel can reduce the ship stability and seakeeping qualities. Also, fishing vessels are usually operated in more open sea hence this vessels are prone to capsize.

Several surveys indicated that fishing vessel has reached the highest accident rates among othe types of vessel (Rawson and Tupper, 1994). Dynamic stability analysis, which is known as seakeeping has been carried out by Murdijanto et al (2011) which demonstrated that the catamaran mode shows almost similar motion characteristics as compared to the monohull type. This is true for sea state up to 3 which then indicated that catamaran is as comfortable as the monuhull. In detail, it was reported that heave and pitch motions of catamaran are more excessive under following sea condition (see Figs. 7 and 8), whereas the roll motion is more extreme under quartering and beam sea conditions. The responses of roll motions of catamaran was given in Fig. 9 indicating that catamaran has slightly better rolling motion that than of the monohull. It implies that catamaran is, in fact, slightly more comfortable than the monohull.

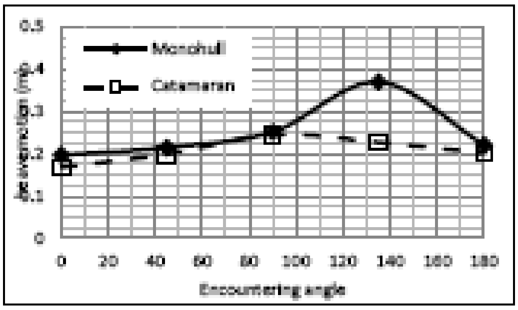

Fig.7 Heaving motion characteristics

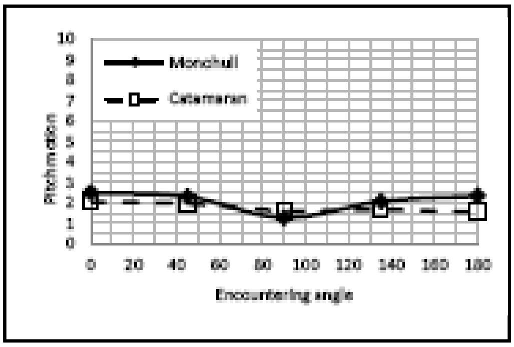

Fig. 8 Pitching motion characteristics

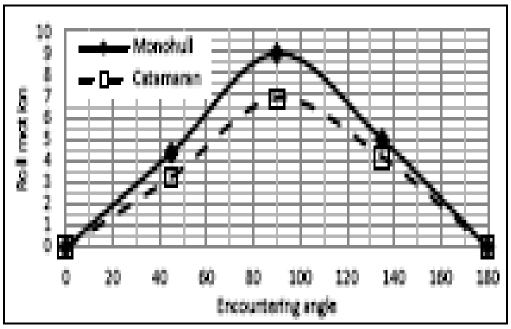

Fig. 9 Rolling motion characteristics

SOLAR POWERED BOAT

The use of solar energy as a clean source of energy has been well-known for more than 20 years. This has been used to power water heater at homes, road lights, and so on. This is later developed to power small ships under a combined power known as hybrid engine. In this case, the boat is powered by battery and the solar power is applied to charge the battery during the operational of the boat at sea. The first electric boat powered by solar energy, was developed in England in the 1970s (Santosa and Utama, 2013). Further developments have been carried out around the world. One of the most phenomenal progress was the launching of PlanetSolar, the biggest solar powered vessel so-far owned by Switzerland. It has length up to 31 m and sails around the world successfully.

The development of a small solar power boat in Indonesia was reported by Chandra and Daniel (2010). Body of catamaran is used due to its advantages such as providing wider deck area and having better transverse stability (Insel and Molland, 1992). The solar panel was situated above the hull as canopy as can be seen in Fig. 10. An electric engine of 6 HP was installed at the stern part in order to investigate the successful combination of solar panel and electric engine (see Fig. 11).

Fig. 10 (Chandra and Daniel, 2010)

Fig. 11 (Chandra and Daniel, 2010)

Further progress was conducted by Ko and Chao (2012) on the development of photovoltaic (PV) generation as one of the most essential renewable energy resources. This invention demonstrates plentiful merits such as cleanness, low cost of repair and no noise. Several applications utilizing this technology have been developed such as satellite power systems, solar power generation, solar battery charging station, and solar vehicles such as cars, ships and airplanes.

NEW DESIGN OF CAT-FISH

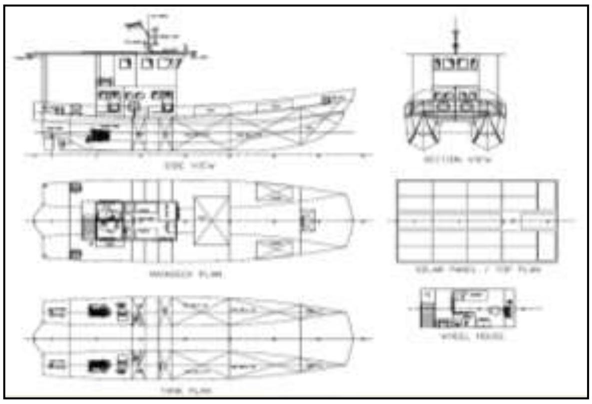

Fig. 12 GA of solar-powered cat-fish vessel

A study about solar powered catamaran fishing vessel was developed and still carried out in ITS. Body of catamaran was selected attributed to its attractive benefits such as providing wider deck area and having better transverse stability.

The result of recent study is the layout of catamaran fishing vessel are presented in Fig. 12. The solar panel was placed above the hull as canopy with an electric engine of 2 x 55 kW was installed at the stern part in order to investigate the effectiveness of solar-cell panel and electric engine combination. The principle particulars of the boat are: LOA =18 m, B_{OA} = 5.6 m, B-demihull = 1.9 m, H = 2.25 m, T = 1.2 m, deck area about 75.2 m^2, Disp = 31 ton, GT = 48.5 ton, Hold 1 = 2 x 20.21 m^3, Hold 2 = 2 x 23.09 m^3), The service speed of boat is 10 knots (Fr = 0.38) and its total resistance is 18.56 kN. This catamaran provides wider deck space and bigger volume capacity compared to the monohull, see Table 7.

Tabel 7 Comparison of monohull fishing vessel

No	GT	L (m)	B (m)	H (m)	T (m)	Deck Area (m^2)
1	19	17.5	3.8	1.8	1.1	46.55
2	20	18	3.8	1.9	1.2	47.88
3	20	18	3.8	1.8	1.2	47.88
4	20	18	3.9	1.9	1.2	49.14
5	20	18	3.8	2	1.2	47.88
6	20	18.2	3.7	1.8	1.2	47.14

The wider space area for fishing activities on main deck is the main concern for the commercial fishing industry now. The space area on main deck for catamaran is mostly related to the separation length ratio (S/L). Therefore this ratio need to be investigated and discussed into the resistance performance to estimate the ship speed and power required. The large deck space is a key feature of catamaran fishing vessel, which provides an incredible amount of spaces for accommodation, bridge, engine room and massive fish storage.

Measurement of Emission

International Maritime Organization (IMO) adopted a new chapter to MARPOL annex VI in order to reduce GHG emission from international shipping by improving the energy efficiency for ships. The hull design, propulsion techniques and operational practices are expected technology that can be improved in order to increase the energy efficiency for ships. The Marine Environment Protection Committee (MEPC) approved the interim guidelines on the method of calculation of Energy Efficiency Design Index (EEDI) towards determining minimum energy efficiency level for new ships. It is mandatory to all merchant ships of 400 GT and above regardless the nationality of the owners IMO (2000). However, it is considered in the near future to apply to other type of vessels using fossil fuels.

Furthermore, the EEDI formula provides a specific figure for an individual ship design, as proposed by IMO (Guidelines on the Method of Calculation of the Attained Energy Efficiency Design Index (EEDI) for new ships resolution of the Marine Protection Environment Committee (2012), IMO. Guidelines on Survey and Certification of the Energy Efficiency Design Index Environment Committee (2012), as given in Equation (3):

$$\text{EEDI} = \frac{P \times sfc \times C_F}{C \times V} \text{gm } CO_2\text{/tonne mile} \quad (3)$$

Where P is power (kW), sfc is specific fuel consumption (gm/kW.hr), C_F is a CO_2 conversion (tonne CO_2/tonne fuel), C is the capacity of the ship (DWT or GT) and V the speed (knots). As such, EEDI can be seen as a measure of a ship's CO_2 efficiency.

When considering the overall form of EEDI, it is clear that in order to reduce the index for a given ship at a given speed, a decrease in propulsive power must be achieved and/or improvements made in engine efficiency with a reduction in *sfc*. The EEDI formula can later be simplified to Equation (4):

$$EEDI = CO_2 \text{ emission / transport work} \quad (4)$$

The CO_2 emission represents total CO_2 emission from combustion of fuel at design stage, including propulsion and auxiliary engines, taking into account the carbon content of the fuels in question. If shaft generators or innovative mechanical or electrical energy efficient technologies are incorporated on board a ship, these effects are deducted from the total CO_2 emission. If wind or solar energy is used to board a ship, the energy saved by such measures will also be deducted from the total CO_2 emissions, based on the actual efficiency of the system. The transport work is calculated by multiplying the ship's capacity as designed (DWT for cargo ships and GT for passenger vessels) with the ship's design speed measured at the maximum design load condition and at 75% of the rated installed shaft power. Speed is the most essential factor in the formula and may be reduced to achieve the required index.

Application to smaller size of vessel such as fishing vessel is still being carried out.

Economic Viability

There are two factors driving research and investigation in order to improve the overall efficiency of the ships propulsion, namely economic and environmental factors (Utama and Molland, 2012). Fundamentally, improvements in efficiency of propulsion should lead directly to improvements in the economic return and a decrease in greenhouse gas (GHG) emissions. There are many ways that can be done to achieve the optimum efficiency: the use of catamaran type of vessel hence causing the use of smaller size of engine and the use of non-fossil energy such as sails, solar panel and wave power mechanism.

Despite there is no proven work of alternative energy development that can replace the use of marine engine together with fossil fuels, many research on this development are still carried out around the world. One of the good examples is such a system called Greenline Hybrid. This is a powerful answer to this concern as it uses up to four times less fossil fuel than a planning powerboat in similar condition and it is completely emission-free in electric mode. The hybrid (diesel-electric) and solar powered drive systems have proven themselves both reliable and cost effective. Furthermore, Greenline Hybrid is more cost-effective to buy and use than any comparable boat, thereby offering incredible value for money and without polluting environment with smoke, noise or waves.

CONCLUSIONS

The rare and high cost of fossil fuels has pushed naval architects and people in the maritime sector to develop more efficient ships. There are many ways to achieve that such as development of catamaran fishing vessel that can produce lower resistance and hence lower power of engine. The current research shows that catamaran is not only efficient but also causes less emission compared to the monohull with the same displacement.

Development of alternative energy is another possibility to reduce the use of fossil fuels and hence minimize GHG effect. However, the complete replacement of engine and fossil fuels seems to be impossible at present. The use of the combination of those energy resources is the appropriate choice hence it can satisfy both high efficiency and low carbon emission

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