

Techno-economic Analysis of Rotor Flettner in Container Ship 4000DWT

Agoes Santoso¹, Muhammad Badrus Zaman², Arrijal Yudha Prawira³

Abstract—rotor flettner is a kind of technology which developed and used in 21st century. This technology is very simple, cylindrical in shape, applied in the upper deck, and rotated by the electrical motor. This technology uses wind energy and applying magnus effect to create propulsion force. Rotor flettner depends on the condition of the sea wind. The designer has to check the weather condition in its route before make a design of rotor flettner. This kind of technology is not only useful for the economic side, but also, for the environment. Rotor flettner can reduce the emission of a ship. It helps to gain some power to increase in fuel saving. The emission can be decreased by the increasing of fuel saving. So, this technology is a kind of environmentally friendly technology that can be used for the future innovation.

Keywords—CFD, economic techno, emission, flettner rotor

I. INTRODUCTION¹

Green technology in need for the recent years has becomes the very first priority because it needs to create healty environment while technology grows quickly. One of the environmentally friendly technology is a green technology applied in a ship. As we know, ships need so much energy for the propulsion.

Years by years, the consumption of fuel in ship is getting bigger, see figure 1. It causes the increasing rate of CO2 in the sea surface. It showed in the graphic below, see figure 2.

not proper yet to become the main energy sources, but, it can very helpful to become an alternative energy.

Study about the application of flettner rotor analysis has already been done by some researchers. However, this study will talk about different side of flettner rotor.

This study will analyze about economical side of flettner rotor that used by container carrier with DWT 4000 ton.

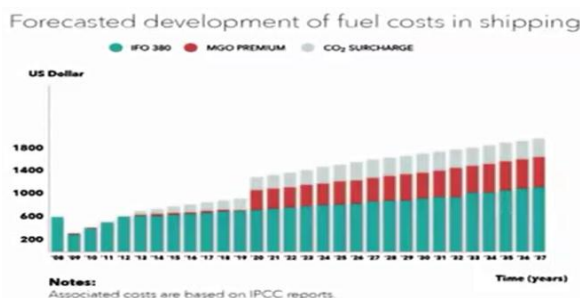


Figure 1. The increasing graphic of fuel consumption in the last few years

It needs to invent some alternative energy to decrease the impact of those much energy. One of them is rotor flettner. Rotor flettner is a wind assisted propulsion for ship that can strong enough to make some propulsion force for the ship. However, in economical analysis, it is

II. LITERATURE REVIEW

Rotor flettner is a kind of mechanical propulsor for ships that assisted by the wind. This technology is cylindrical in shape. Rotor flettner uses magnus effect to create some propulsion force [1].

Wind that blows past the cylinder will cause the pressure difference between the direction of the wind around the cylinder and opposite to the rotation cylinder that causing the thrust.

Flettner rotor is one type of mechanical propulsor vessel utilizing wind power [10]. This device consists of a large vertical cylinder. The working principle of this device utilizes magnus effect, ie, the wind that blows past the cylinder will cause the pressure difference

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between the direction of the wind around cylinder and opposite to the rotation cylinder that causing thrust for

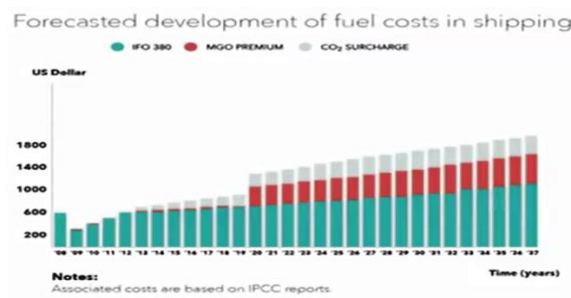


Figure 2 The increasing graphic of CO2 level above the ocean

the ship.

Installation of this rotor flettner must consider the conditions and wind direction in order to obtain optimum efficiency. Ships using Fixed Pitch Propeller has the advantage in the result of the installation of this rotor flettner than using other propeller types. At the time of sailing using flettner this rotor, steering the ship must always be controlled in order to stay on the right path.

The benefits of the application of rotor flettner on the ship is able to save on fuel usage with a percentage of 10-30% depending on the cruise line to be taken. Saving fuel will reduce the emissions such as CO₂, SO_x, NO_x and other emissions. Rotor flettner is acting as an auxiliary energy for ship propulsion system and could even perform up to 100% as a propulsion system with optimal wind conditions. Thus, the rotor flettner can serve as an independent propulsion system [2].

The effectiveness of this rotor flettner depends on:

1. The cruise line
2. wind speed
3. Wind Direction

There are several advantages obtained from the use of rotor flettner on ships, which are:

1. Does not require additional crew
2. The system used to run automatically
3. No adverse effects occurred in charge
4. 10-30% fuel saving per year
5. Produce lower emissions than conventional vessels

III. ECONOMIC TECHNO ANALYSIS

Economic techno is about on how to make a decision (decision making) which is limited by a variety of problems associated with an engineer to produce the best choice from a wide range of alternative options. Decisions taken by a process of analysis, technical and economic calculations [3] [4].

Engineering used to say the profession / discipline where knowledge of mathematics and natural sciences gained by study, experience, and practices used wisely in developing ways to economically use materials and natural resources for the benefit of man. The definition of the economic aspects of the engineering emphasis on physical aspects. Obviously, that basically the economy is part of a well-executed engineering [5].

Alternatives arise because of the limitation of resources (human, material, money, machine, opportunity, etc.). With a wide range of existing alternatives, so it needed a calculation to obtain the best economic choice, both when comparing different design alternatives, make capital investment decisions, to evaluate the financial opportunities and so forth.

Techno economic analysis involves making a decision on the various uses of limited resources. The consequences of the results of decisions are usually impact far into the future, the consequences can not be known with certainty, a decision-making under uncertainty [8] [9]. So it's important to know:

1. prediction of future conditions.
2. The development of technology.
3. Synergies between projects funded.

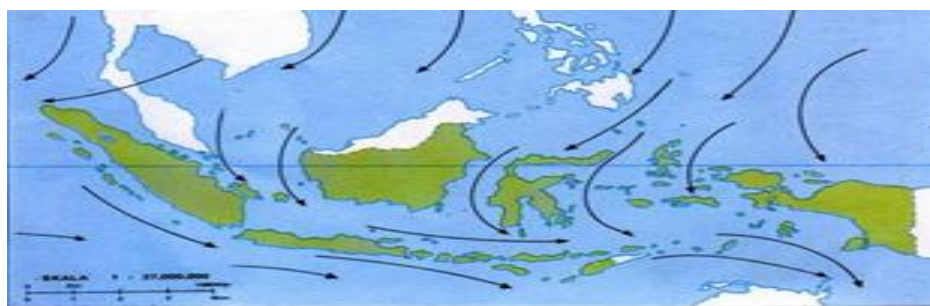


Figure 3. Wind condition on wet season in Indonesia

Because the application of engineering activities generally require relatively large investment and long-term impact on the activities of his followers, the implementation of these activities requires strategic decisions that require consideration technical and economical and rational. Therefore, Techno Economic Sciences were also considered as a means of decision support (Decision Making Support) [9].

A. Study Area

Study area of this reserach is Surabaya-Balikpapan. Based on the figure 3-5, wind conditions across the region cruise Surabaya-Balikpapan support the functions of performance of flettner rotor based on the direction and force of wind flow generated by the movement of the rotor [6].

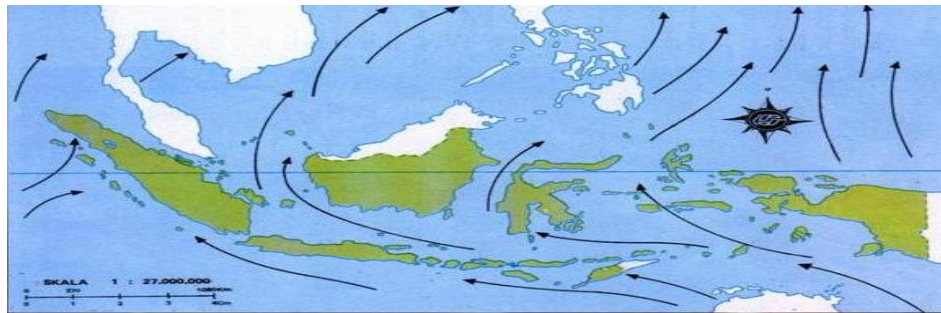


Figure 4. Wind condition on dry season in Indonesia

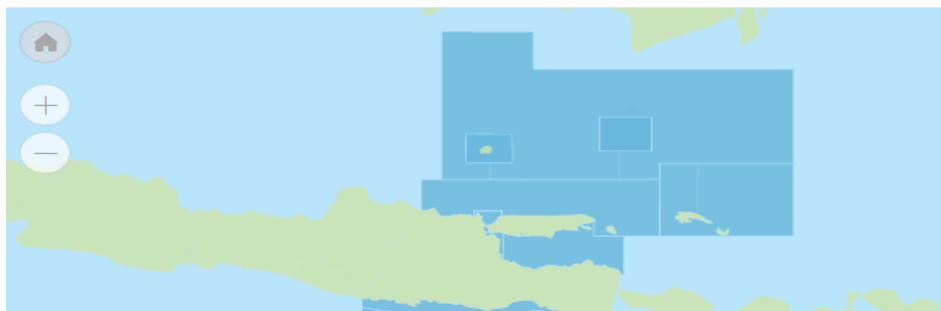


Figure 5. Selected area of the study

A. Numerical Performance Model

Numerical performance model. The power consumed by the motor, and the lift and drag forces acting on the cylinder determine the amount of main engine power the rotor is able to replace. The thrust gained from the rotor is calculated as the projection of the sum of the lift and drag force and, respectively, onto the course of the ship. The magnitudes of the lift and the drag force, and the power delivered by the rotor and to the rotor, respectively, are given by the following equations:

$$l = \frac{1}{2} \rho A v_a^2 C_L \quad (1)$$

$$d = \frac{1}{2} \rho A v_a^2 C_D \quad (2)$$

$$p_{l\&d} = (l + d) \cdot V_{ship} \quad (3)$$

$$p_{motor} = \frac{1}{2} \rho A v_a^3 C_M \alpha \quad (4)$$

The defining parameters are the lift, drag, and moment coefficient, C_L , C_D and C_M (in line with anecdotal evidence and preliminary CFD results, see below), respectively; the rotor is a plain cylinder, without end plates, and it has a vertical cross sectional area A , which

is the height $h = 18$ m times the diameter $d = 3$ m, and the spin ratio (the ratio of the rotor surface speed and the apparent wind speed) $\alpha = 5,23$. V_{ship} is the ship's velocity vector, V_a is the apparent wind speed, and ρ is the density of air. If the power contribution is smaller than that from the drag force alone it is assumed that the rotor is switched off. The power contribution p_{prop} is calculated as the difference between the power delivered by the Flettner rotor and the power that is consumed by the motor to rotate it:

$$p_{prop} = p_{l\&d} - p_{motor} \quad (5)$$

B. Ship Resistance Calculation

B.1 Volume Displacement

Displacement volume is the volume of water displaced by the hull. Where the formula used to find the volume displacement are:

$$\nabla(m^3) = C_b W_L \times L_{WL} \times B \times T \quad (6)$$

B.2 Displacement Weight

Displacement weight is the weight of the volume of water displaced by the hull. So the weight of displaced

water volume of the weight of the ship. Where the formula used to find the weight displasmen are:

$$\Delta(\text{Newton}) = \nabla \times \rho \text{ air laut} \quad (7)$$

B.3 Wet Surface Area

B.4 Froud Number

Froud number (Fn) need to know to define that linear function of the Fn is a standard LCB. Fn itself will be used to read a chart 5.5.25 on the book Resistance and Propulsion of Ships [7]. The following formula to find Fn:

$$Fn = V/\sqrt{gLwl} \quad (9)$$

B.5 Reynolds Number

Reynolds number needs to be known, because it will serve to seek frictional resistance later. The following formula to find Rn:

$$Rn=(V \times Lwl)/\nu k \quad (10)$$

B.6 Friction Resistance (Friction Coefficient)

Frictional resistance (CF) is a resistance because of the friction caused by the fluid which has a viscosity, and the viscosity is a cause of friction with the surface ship. Actually, to look for frictional resistance, there are two ways, namely by calculating according to the formula, and by looking at the picture on the book Resistance and Propulsion of Ships (Harvald, 1992) by entering the value of the speed of the ship, and also the length of the ship. But in this design, will use the formula, because it more closely.

B.7 Residual Resistance(Coefficient resitance)

Residual drag coefficient (CR) for a standard vessel can be taken from the diagram fig.5.5.5 - 05/05/13 on the book Resistance and Propulsion of Ships (Harvald, 1992). Before looking for the rest of the resistance in the diagram, should determine the value, the value of β , and the value of ϕ .

B.8 Additional Resistance

Although there have been previous CF correction, but the correction has not been included in the correction of the surface roughness of the ship. Because remember that the surface is not as smooth with the surface ship models. Extra correlation coefficient custody for ship models are generally determined by various forms of correction, there is a direct set a price of $CA = 4$, and there is also dependent on the length of the vessel is designed. This time the book Resistance and Propulsion of Ships (Harvald, 1992) recommends to correct by referring of displasmen designed vessels, because some argue that the correction is designed according to the reference displasmen more appropriate vessel. Here below is the value of CA is given in accordance with the reference of displasmen ship:

In the book Resistance and Propulsion of Ships (Harvald, 1992), a wet surface for normal merchant ship can be calculated using the following formula:

$$S = 1,025Lpp (Cb \times B + 1,7T) \quad (8)$$

Since the value of displasmen designed vessels this time located at between 1,000 t - 10,000 t, it must be done interpolation. So that later we will get the value of CA correctly.

B.9 Air Resistance

The amount of air resistance is generally not very important, and efforts should be made to get the exact calculation may not be adequate to the importance of the influence of the air. According to the book Resistance and Propulsion of Ships (Harvald, 1992), if the data on the wind in the design is not known it is recommended for the correction of air resistance as follows:

$$CAA = 0.00007 \quad (11)$$

B.10 Steering Resistance

For steering resistance value is no special formula to look for it, in the book Prisoner and Propulsion of Ships (Harvald, 1992) is given a value as follows:

$$CAS = 0.00004 \quad (12)$$

But the actual value of the steering resistance could be ignored in a stable ship in reasonable condition. It looks above correction value is very small, because in the initial design, the correction is generally already included in the additional resistance.

B.11 Total Resistance

To calculate the total resistance of ships, it should be added together before all the coefficients had been sought and has also been obtained. For the total coefficient value is as follows:

$$CT = CF + CR + CA + CAS + CAA \quad (13)$$

After a total coefficient value is obtained, then the next can be calculated from the value of total resistance vessels as follows:

$$RT = CT (1/2 \rho V^2 S) \quad (14)$$

$$RT \text{ service} = (1+15\%) \times RT \quad (15)$$

C. Propulsion Force Calculation

Before obtaining power saving, it needs to obtain propulsion force calculation first. The formula is shown below :

$$Fp = (L \times \sin \beta + D \times \cos \beta) \quad (16)$$

While L is lift force, D is drag force, and β is the apparent wind.

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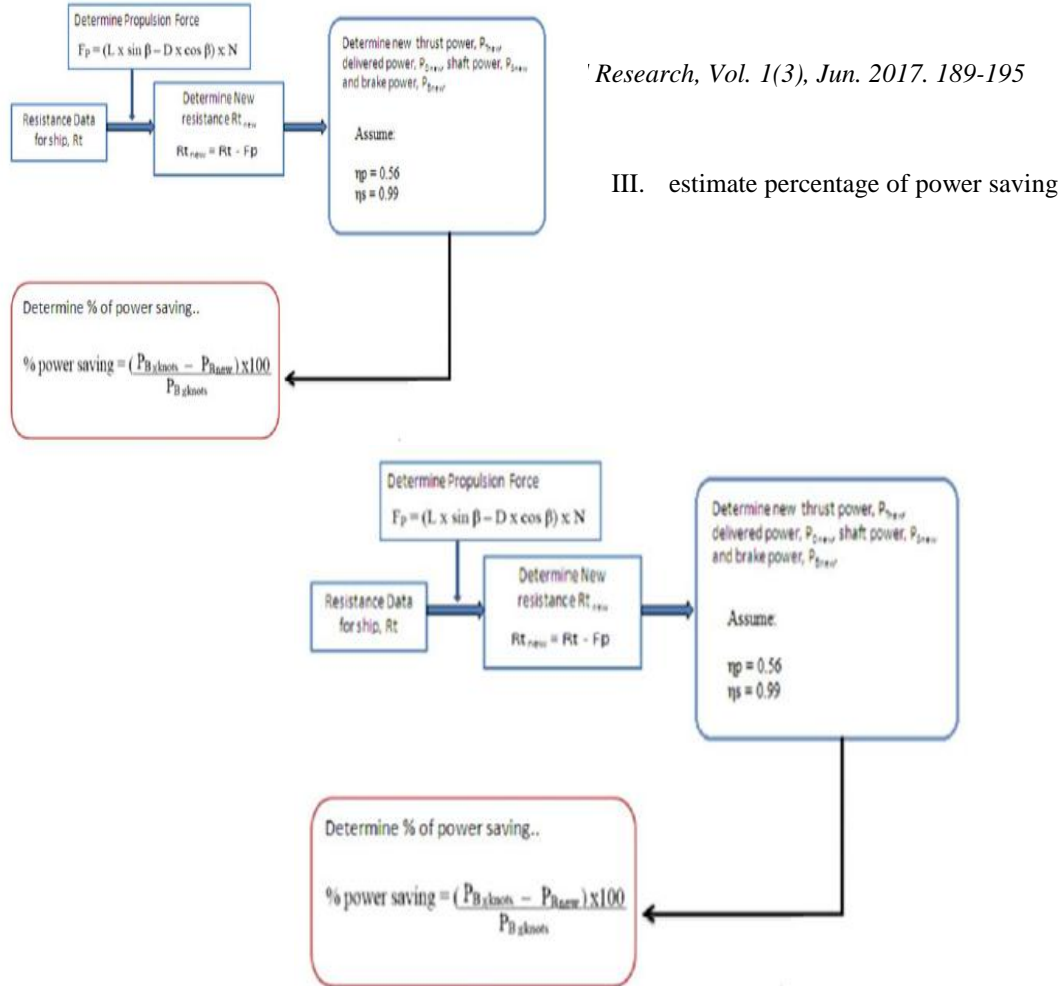


Figure 6. Overview of process to determine power saving

IV. RESULT AND DISCUSSION

A. Total Resistance

According to the calculation, the result of resistances shown in Table 1. From the result of ship's resistances above, then, the power of the ship can be determined.

B. Ship's Power

In designing a ship, the important thing to note is that when choosing Main engine. In the selection of the main engine should be known in advance how much power is needed, the choosen main engine must be fit to the needs

of power. Because the engine generated power not fully to be used as a producer, eventually there will be a definite obstacles that the main engine power is reduced. Therefore, in this chapter calculation engine needs to be removed from the start (BHP) and whether the later output (EHP) can be used to run the ship in accordance with its VS. In this calculation, using two reference books, namely Resistance and Propulsion of Ships (Harvald, 1992) and Prinpciples of Naval Architecture (Lewis, 1988).

Based on the calculation, the power of ships shown in Table 2.

TABLE 1.
SHIP'S RESISTANCE

Resistance	Value
Friction resistance coefficient (Cf)	0,000802
Residual resistance coefficient (Cr)	0,00212
Additional resistance coefficient (Ca)	0,000213
Steering resistance coefficient (Cas)	0,00004
Air resistance coefficient (Caa)	0,00007
Ship's total resistance (Rt service)	110,24 kN

RPM Flettner Rotor vs Force

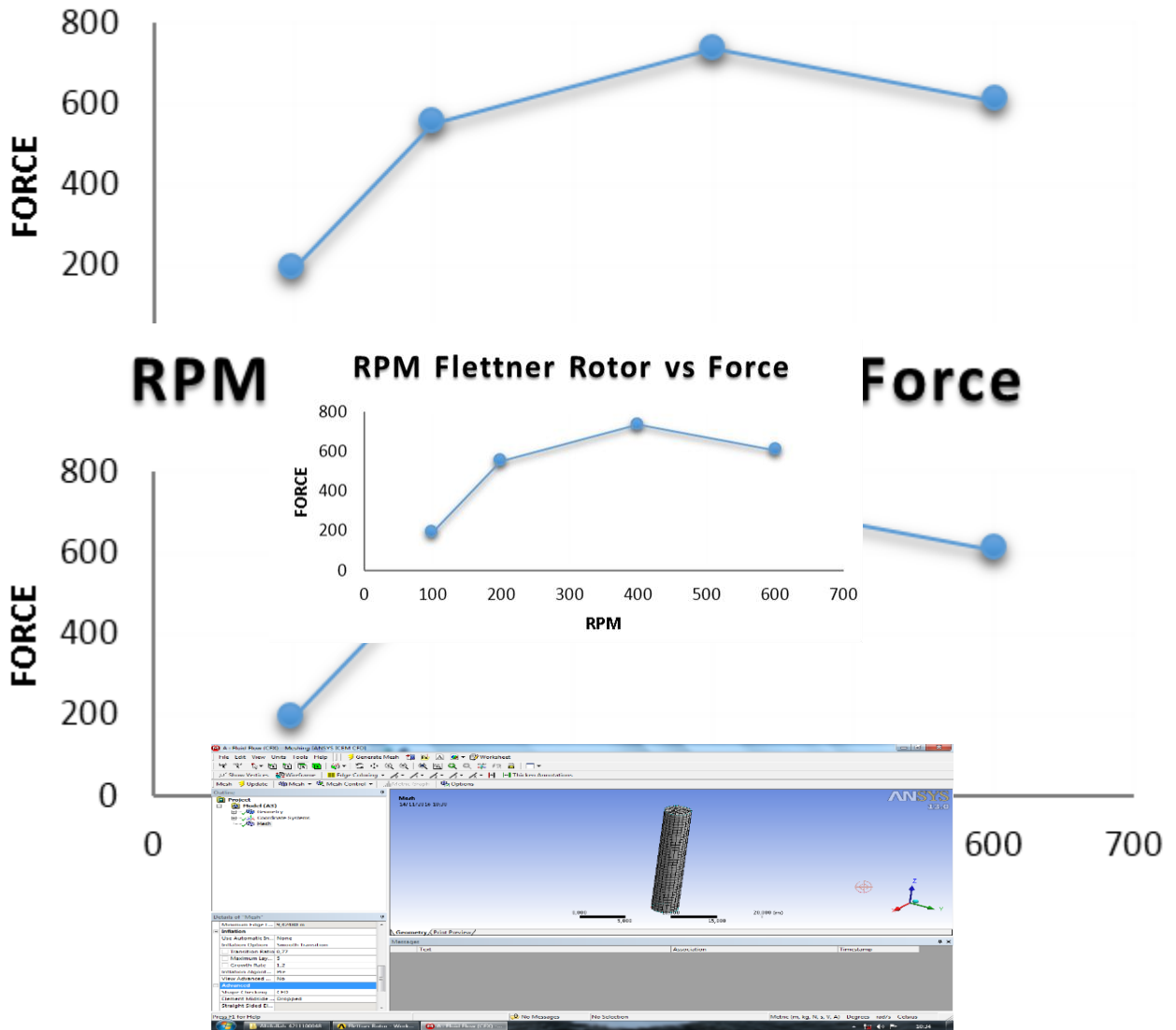


Figure 8. CFD Simulation of Flettner Rotor

C. Rotor Flettner's Calculation

Based on the chart in figure 7, the higher the rotation flettner rotor, then, the greater the force generated. However, when the rotation reaches 600 RPM, the force generated has decreased.

The value of RPM used for the analysis based on the results of the largest thrust force, namely when flettner rotor is rotated at 400 RPM and generate a force of 736 N.

From the simulations in CFD in figure 8, there are some data that can be collected to calculate the power of rotor flettner. The data:

1. Height of rotor flettner = 18 m
2. Diameter of rotor flettner = 3 m
3. RPM = 400
4. Lift = 736 N
5. Drag = 11,776
6. Coefficient Moment = 0,335

From the datas above, it can be calculated for the rotor flettner's power using the calculation in section 3. The result of the calculation shown in table 3.

1. The combination of power from the lift and drag amounted to 5002.621 watt

2. Power required to rotate the rotor flettner of 400 RPM is 825.286 watt
3. Power contributed by flettner rotor amounted to 4177.336N.

Once the value of BHP's new is collected (see table 4), power saving calculation can be determined according to figure 6, then, gained power saving amounting to 0.038%.

TABLE 3.
 ROTOR FLETTNER'S CALCULATION

$P_{l\&d}$	5002,621 N
P_{motor}	825,286 N
P_{prop}	4177,336 N

TABLE 4.
 SHIP'S POWER AFTER ROTOR FLETTNER HAS BEEN MOUNTED

Ship's total resistance (R_t service)	106,06 kN
EHP	709,54 kW
DHP	1210,09 kW
SHP	890,02 kW
BHP	1210,094 kW

V. CONCLUSION

Based on the results of the discussion above has been referring to the data and relevant references, then, it can be deduced for the results of studies that have been carried out is as follows:

1. Power required to rotate the rotor flettner with a speed of 400 RPM is equal to 825.286 watts
2. Power Contribution generated amounted to 4177.336 watts
3. The higher the rotation flettner rotor, then, the greater the force generated. However, when the rotation reaches 600 RPM, the force generated has decreased.
4. According to the techno economic analysis calculation of the power saving has been done on the cruise lines Surabaya-Balikpapan, Rotor Flettner less contributes to fuel savings as an alternative energy because it provides the effectiveness of 0.038%.

Based on the results of the discussion and conclusions that have been obtained regarding the techno economic analysis rotor flettner on container ships with cruise lines Surabaya-Balikpapan, still required some further action in order to achieve effective use flettner rotor, including:

1. The cruise line extended. Suggested taking samples of international shipping
2. Increase the number of rotor and carried out further analysis of variations in the number of rotor.

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