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REVIEW OF CORRELATION BETWEEN MARINE FOULING AND FUEL CONSUMPTION ON A SHIP

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ABSTRACT

Ship has been used for transportation for one hundred years and it consumed fossil fuel for its propulsion system. This then produces carbon emission to the atmosphere hence causes the air dirty and its temperature increases significantly. The ship is powered by an engine that has been already calculated for its power capacity based on its resistance and requires several tons of fuel for its trip. However, during sailing, the hull of the ship is often overgrown by marine fouling which can increases roughness of hull surface. The roughness can increase the frictional resistance and automatically the ship needs more power capacity to operate at its service speed by using its engine up to Maximum Continues Rating (MCR). However, this method can increase fuel consumption and it is an added cost that must be paid by shipping company. Meanwhile, the other method is still using Normal Continues Rating (NCR), but it will decrease ship's speed. Speed decreasing can make the sailing time longer, hence it increases fuel consumption. From the results of the estimation, some of the values are quite small, i.e. 10-20%, but if it is viewed in huge numbers and happens repeatedly, then it will be a big value and disadvantageous to the shipping company.

Keywords: marine fouling, ship hydrodynamics, ship resistance

INTRODUCTION

Shipping is one of the most important factors in global economic growth in the last one hundred years. Due to its economic of scale, the shipping industry is often considered to be more efficient in transporting goods than other mode of transportations. For many developing countries with rapid economic growth, such as India, China, Brazil, and Indonesia, the dependence on the shipping industry will only increase. This would translate in the increase of fuel demand that powers this industry.

In the last decade, the highly fluctuating fuel prices and the issue of global warming have sparked much interest in finding ways to reduce energy consumption. This is particularly important in the shipping industry, as the fuel that these ships burn is mostly of a low grade, with high sulphur content and significant carbon emissions. The International Maritime Organization (IMO) has issued regulations to minimize these emissions in MARPOL Annex VI (IMO, 2005), and recently amended by adding

Energy Efficiency Design Index (EEDI), (IMO, 2012). IMO estimates that carbondioxide (CO_2) emissions from shipping were equal to 2.2% of the global human-made emissions in 2012 (3rd IMO GHGS, 2015), and it is expected to rise by 50-250 percent by 2050 if no action is taken, (2nd IMO GHGS, 2009).

Biofouling that grow and attach to ship hull is one the main cause of increased fuel usage. The growth of marine fouling causes the hull to be rough and increases the ship hull frictional resistance (Schultz et al, 2011). Hence, it is imperative to keep the hull clean from marine fouling. This activity can keep the energy efficiency up by around 10%, (Molland et al, 2014) & (Wang & Lutsey, 2013). Biofouling growths are depending on several factors, such as temperature, salinity, etc. However, its ability to grow on a ship's hull depends on the quality of anti-fouling coating and ship's operating scheme. Currently, anti-fouling paint is still the most effective way in preventing and reducing biofouling then IMO has also regulated of harmful contents in paint that can damage the environment by issued "International Convention on the Control of Harmful Anti-fouling Systems on Ships (AFS)", (2001), like tributyltin (TBT). According to Schultz et al. (2011), the overall cost associated with hull fouling for the Navy's present coating, cleaning, and fouling level is estimated to be \$56M per year for the entire DDG-51 class or \$1 B over 15 years. Although antifouling paint seems expensive, its cost is still lower than the excess energy cost due to biofouling. Abbot et al (2000) estimate that the annual fuel saving to the world's commercial fleet due to anti fouling paint in 1989 amounts to around \$730 M. If one considers inflation and the ever increase number of ships, at present time that number can easily be much higher.

In this report, we will provide short review regarding the relationship of increased ship resistance due to marine fouling with the requirement of power and its fuel consumption. Here several recent findings from experiment in towing tanks, numerical modelling using Computational Fluid Dynamics (CFD), and fuel consumption from an operational ship that suffers from biofouling will be presented.

CALCULATION OF SHIP'S POWER REQUIREMENT

On the way to design a ship that can cruise at the requiring speed, it shall calculate the estimated power requirement of the ship engine. It also affects to how big the machine which will be installed, then how much fuel consumption and fuel tank capacity that should be provided.

Based on Molland et al. (2011), calculation of ship power demand estimation described in equation 1. Where total resistance (R_T) is the value of the ship's resistance at a speed (V) in calm water conditions which obtained by empirical, analytical, numerical (CFD) or towing test calculations. Effective power (P_E) is power required to tow the ship at the required speed, where P_E is the multiplication of R_T and V. Deliver power (P_D) is power required to be delivered to the propulsion unit (at the tail shaft), where Quasi-propulsive coefficient (QPC) (η_D) is a losses factor due to from changing rotational power to be translational by propeller. From the propeller to machine, power supply is connected by a shaft which also has a power loss (η_T). Then it need to be given a margin due to factor of roughness, fouling and weather, because the R_T calculation was calculated in calm water condition (15-30%).

$$\text{Installed power } (P_I) = \frac{P_E}{\eta_D} \times \frac{1}{\eta_T} + \text{margin (roughness, fouling and weather)} \quad \ldots (1)$$

From equation 1, if there is an increase in resistance due to fouling or decreasing speed and if value $\eta_D = 0.55$, $\eta_T = 0.95$ and margin 30 %, then equation 1 becomes:

$$P_{I(R_T,V)} = \frac{R_T \times V}{\eta_D} \times \frac{1}{\eta_T} + \text{margin} \qquad \text{... (2)}$$

$$P_{I(R_T,V)} = R_T \times V \times 250\% \qquad \text{... (3)}$$

INCREASED RESISTANCE DUE TO MARINE FOULING

Studies on increasing resistance due to marine fouling have been conducted. Towing tank experiments using sandpaper as marine fouling roughness model has been carried out (Yusim & Utama, 2016). In a set of model test consist of 3 treatments, namely smooth hull, regular roughness, and irregular roughness. Figure 1 is an irregular roughness model with difference distribution in each section of hull. Sandpapers with specific roughness values (k_s) are arranged in the model based on survey results in the real ship. For the bow section is 0.283 mm, midship side shell is 0.302 mm, midship bottom is 0.339 mm, stern side shell is 0.434 mm and stern bottom is 0.377 mm. Then the results of the difference in total resistance of the smooth model compared irregular roughness is up to 41.88%.

Figure 1 Irregular roughness model, (Yusim & Utama, 2016).

Besides physical modelling, numerical modelling using CFD has also been analyzed (Baital & Utama, 2016). In this study, CFD is used to analyses the difference drag between smooth hull, regular roughness hull with 0.72 mm of the biofouling height, and irregular roughness where there is a height difference on certain part, namely 0.6 mm on bow, 0.72 mm on mid and 0.92 mm on stern, as shown in Figure 2. The simulation used 3D model with 1:25 scale and has been convergences with root mean square (RMS) criterion with residual target 10^{-5}. Steady state flow method with total element about 1.8 million elements to satisfy grid independence criterion has been applied. The result shows that roughness due to biofouling has significant increase for resistance up to 40% at cruising speed.

Other experiments have been conducted by several experts, i.e. Hutchins et al (2016) & Utama et al (2017) compared rough surfaces with hydrodynamically smooth surfaces by wind tunnel testing to predict an increase of frictional coefficient (C_F) and the results are about 25-31%. Turan et al (2016) did experiment and obtained an increase of C_F about 20%. Demirel et al (2017) calculated CFD simulations and discovered the increase of ship resistance due to fouling about 38%.

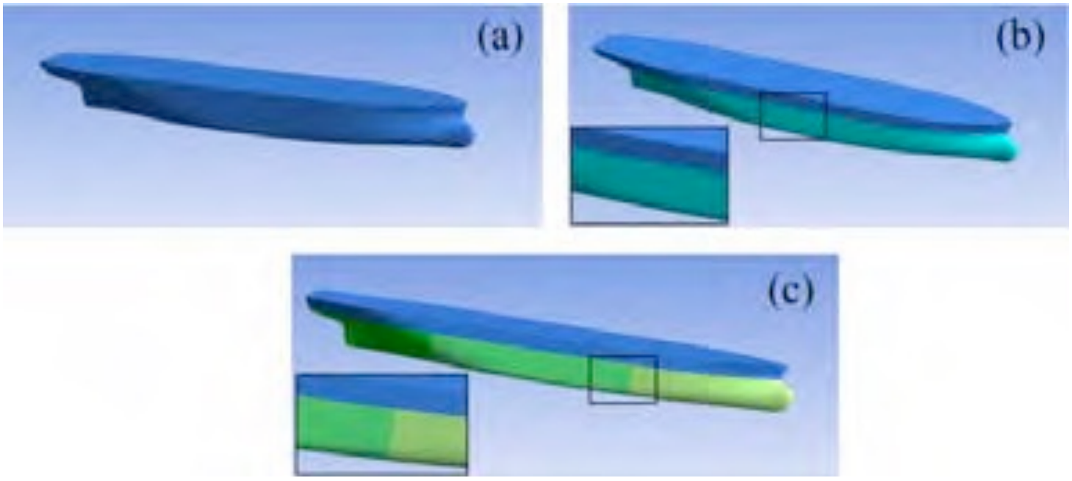

Figure 2 CFD models (A) Smooth; (B) Regular Roughness; and (C) Irregular Roughness, (Baital & Utama, 2016).

ESTIMATION OF INCREASED FUEL CONSUMPTION

Figure 3 is an example of the engine characteristic diagrams, i.e. YANMAR 12AYM-WGT-L rating, 1340 kW @1822 RPM (YANMAR CO., 2016). Usually the ship's engine is operated at Normal Continues Rating (NCR), namely 85% from Maximum Continues Rating (MCR), then the NCR is 1548 RPM.

If the ship resistance increases, then to maintain its speed, the vessel must raise the power by raising the engine speed to MCR. Based on the diagram, it will increase up to about 50 kW or 3.37%, unfortunately the fuel consumption will increase from 160 L/h up to 260 L/h, that is an increase of 100 L/h or 62.5%.

This is because the trend of the maximum power output curve increases significantly in the low RPM and becomes slightly flat at 1200 - 1900 RPM or it looks curved downwards. While the fuel consumption curve has contrary trend, it increases significantly in high RPM rotation or it looks curved upwards. Hence, increasing the engine rotation from NCR upward, to get extra power due to marine fouling impact, can cause a rise in fuel consumption significant.

Figure 4 is a graph of increasing the ship's frictional resistance (R_F) when C_F increases 30%, using equation 4, (SNAME, 1988). From the curve it can be seen if the ship operator still stays at NCR, then the ship's speed will decrease from the 14 knots to 12 knots or decrease 14.3%. Speed reductions will have an impact on the longer sailing time, cause fuel consumption increases too. If calculated, there will be an increase about 16.7% of the sailing time and it will increase its fuel consumption as well.

$$R_{F(V)} = \frac{1}{2} \times \rho \times S \times V^2 \times C_{F_{(V)}} \qquad \text{... (4)}$$

where:

ρ = density of sea water

S = wetted surface area

V = ship's speed
C_F = coefficient of friction

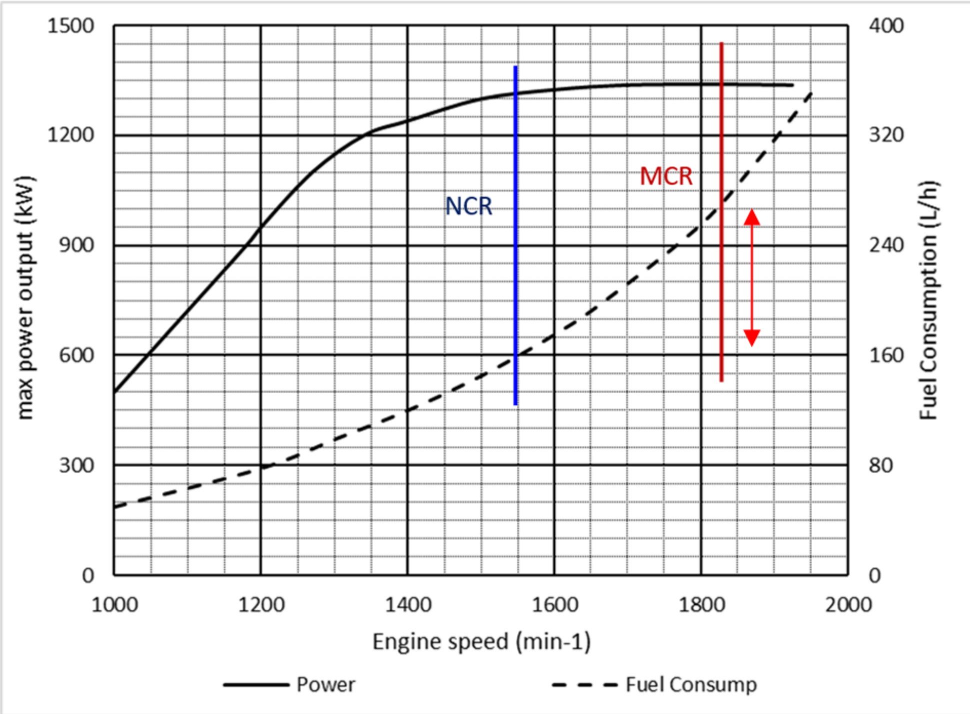

Figure 3 Engine characteristic of YANMAR 12AYM-WGT-L rating, (YANMAR CO, 2016)

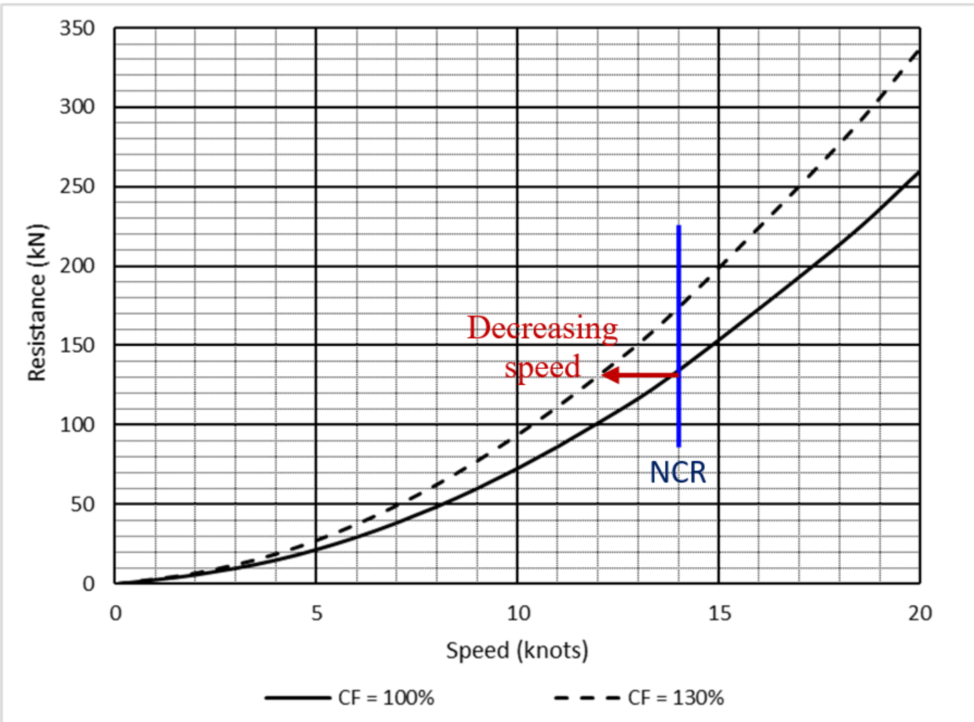

Figure 4 Resistance curve due to increase of C_F

FUEL CONSUMPTION OBSERVATION

A measurement on the amount of fuel consumption per trip on a ferry which operated in the Sunda Strait for about a year has been carried out, as shown in Figure 5. The investigated ship left dock in November 2016, where the hull is freshly cleaned and painted, and the data was recorded until the end of August 2017. This is a rough data without statistical treatment, so the data is not solely influenced by one cause. The causes may be the effect of the payload that varies each trip, thus causing the data going up and down. If the payload is small, then the draft will decrease and the resistance will be smaller and the fuel consumption as well.

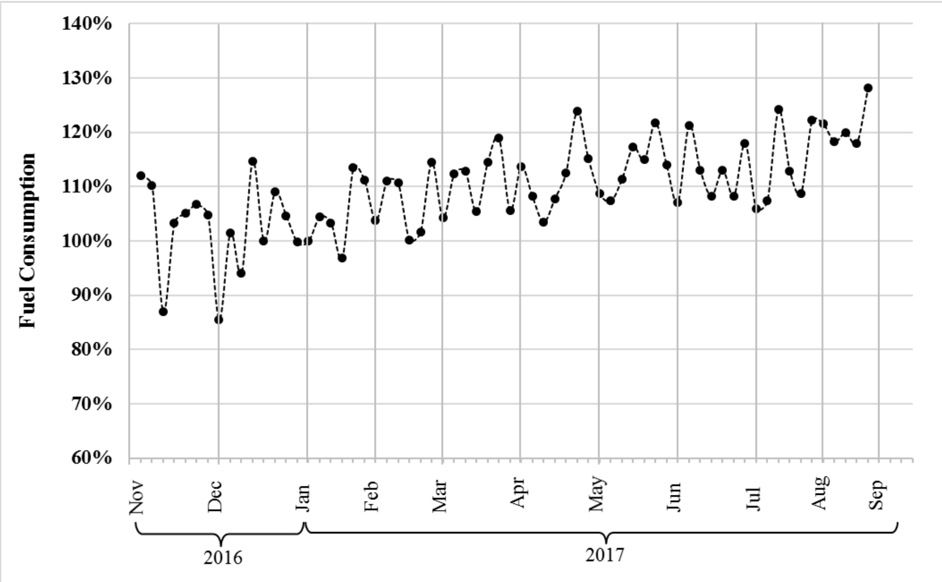

Figure 5 Rough data of the fuel consumption per trip

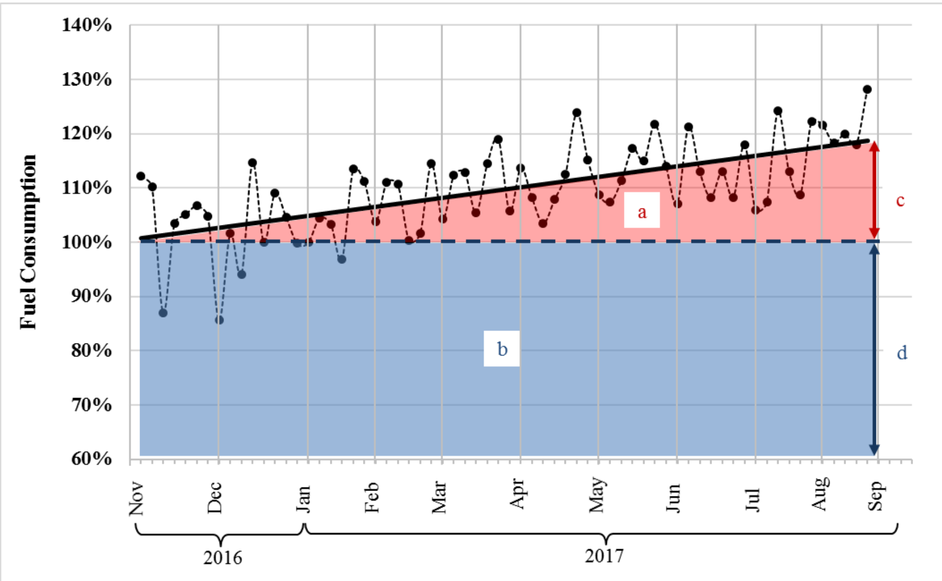

Figure 6 Regression linier on fuel consumption per trip

The data is processed using linear regression as shown in Figure 6. It is found out that there is an increasement of fuel consumption from month to month and this is believed to be the increase of marine fouling on the ship hull. It can be seen based on the trend line, the fuel consumption increase about 20% (see line c) when the ship operates at the last trip on about a year (see line d). If integrated from the first trip when the investigated ship just left dock until about a year, the added fuel consumption due to marine fouling (area a) compared with the smooth hull (area b) is about 10%. If the ship does not immediately go to the drydock to clean its hull back into smooth, then the increase will be greater. However, ship's operator is necessary to take into consideration from economic calculation whether deciding when the ship have to enter drydock or keep sailing, as long as the regulations are not violated.

CONCLUSION

Marine fouling can increase the ship resistance, and concluded from towing tank experiment, the added resistance reach about 42% and using CFD modeling reach about 40%. To maintain the service speed of ship due to marine fouling, if it uses MCR, the increase of fuel consumption is up to about 62.5%. However, if stays on the NCR, it increases about 16.7% of fuel consumption and the sailing time. Because the fuel consumption curve is generally curved upward, so if needing extra power at high RPM will consume very much fuel. The measurement of a Sunda Strait’s ferry fuel consumption has added fuel consumption about 20% on a trip by the end of the year and the comparison of fuel consumption for about a year of sailing for smooth hull and due to marine fouling is about 10%.

From the calculation of the addition of fuel consumption above some of the value is small, i.e. 10-20%. But if it is viewed in a huge numbers and happens repeatedly, then it will be a big value and disadvantageous to the ship operator, as exposed by Schultz et al (2011) above.

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