Performance Comparison of Fouling Control Coatings Based on Time-Dependent Biofouling Model for Ships

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ABSTRACT

The selection of the most efficient fouling control coating (FCC) for a new build ship in the design stage is significant for preventing extra fuel consumption and GHG emissions and crucial for preventing unscheduled maintenance operations. Not doing so may cause severe losses in the revenues throughout the operational life of the ship. For this reason, a tailor-made condition assessment in the design stage of the ship should be adopted while considering the ship operational profile and the target FCC performance. Such an approach becomes even more important considering the impact of the Energy Efficiency Existing Ship Index (EEXI) and Carbon Intensity Index (CII), which will come into force in 2023. The study presents the performance comparison of two fouling control coatings based on the time-dependent biofouling growth model. The analyses are conducted through two case studies in which the same ship is coated with two different fouling control coatings and operating at the same ship route and operating profile. The model first predicts the increases in the ship hull roughness in terms of equivalent sand roughness height, and then using the Granville similarity law scaling increases in the frictional resistance are calculated for a full-scale ship. Finally, penalties in the frictional resistance and power requirements due to biofouling are calculated for a year. The coating performances are compared in terms of increases in power requirements, fuel consumption and GHG emissions. The developed model enables us to select the most efficient FCC among the available FCC's for the target ship route and operational profile. Maintenance and dry-docking schedules can also be optimised according to the developed model to operate ships in the most cost-effective and environmentally friendly way.

KEY WORDS

Fouling Control Coatings, Energy Efficiency, Time-dependent biofouling, Frictional Added resistance, GHG Emissions

INTRODUCTION

Shipping plays significant role in international trade as over 80% of global trade by volume and over 70% of global trade by value are transported by sea and go through by ports worldwide. World trade demand drastically increased in the last fifty years and as anticipated it will continue to follow same trend in the future (UNCTAD 2018). It is also important to note that the increase in the international trade is not only for the cargo weight/volume, but also for the length of the route in miles with the effect of shifting trade growth to the Asia. According to the UNCTAD report, international maritime trade reached around 60 000 billions of ton-miles in 2021 despite the negative effects of COVID-19 (UNCTAD 2021). It is expected that the increase in trade demand naturally causes increase in fuel consumption and thereby Greenhouse Gas (GHG) emissions. The fourth IMO GHG study states that 1.076 million tons of GHG including carbon dioxide, methane and nitrous oxide released to the environment by the maritime transport in 2018 (IMO 2020). It is of note that 1.056 million tons of GHG emissions belong to CO_2 which grew 9.3% from 2012 to 2018. It is boldly highlighted that global warming must be reduced to under 1.5°C and urgent action is needed at COP 26 (UN Climate Change Conference, 2021) in Glasgow. Under these circumstances, a new regulations and limitations will be in force soon for maritime transport such as EEDI, EEXI and CII with aim of decreasing the

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environmental effect of maritime transport. There is no doubt that new fuel types and technologies will be assessed and investigated thoroughly to replace fossil-based fuels or to increase energy efficiency in order to catch more energy efficient and environmentally friendly shipping in line with the new regulatory rules. Electricity, hydrogen and ammonia can be given as examples of fuels on a pathway to zero-emission shipping (DfT 2019). On the other hand, some technologies/ solutions to reduce carbon footprint of ships can be listed as follows; reducing air resistance (superstructure streamlining), using wind power for propulsion (Flettner rotors, suction wings, sails, kites), solar power integration (solar panels), air lubrication, trim and ballast optimization, innovative lift producing rudders (GATE rudder), wing pods, ducted propellers, contra-rotating propellers and better hull surface management (Uzun 2019).

This paper focuses on the benefits of the better hull surface management and the effect of biofouling on ships fuel consumption and hence GHG emissions. Marine biofouling is described as the unwanted accumulation of biological matters on ships and offshore structures. Biofouling increases the ships' surface roughness, which results in increased frictional resistance up to 154% depending on the ship characteristics and biofouling type. The ship hulls covered with biofouling need more engine power in a range between 10% to 98% to cruise at the design speed compared to the clean ship hulls (Uzun, et al 2020; Uzun 2019; Demirel, et al 2017; Andersson, et al 2020; Farkas, et al 2021; García, et al 2020; Schultz 2007; Yeginbayeva et al., 2020). Increased fuel consumption causes an increase in GHG, which deteriorates the EEXI and carbon intensity indicator of existing ships. Both regulatory measures will come into force by 2023. Therefore, any operational approach for reducing GHG emissions is of paramount importance.

UN's GloFouling Partnership project published a report which summarises the existing studies showing the effect of marine biofouling on the GHG emissions in the COP26 conference. The report indicated that the increase in GHG emissions might go up to 55%, even at minimal surface area coverages (GloFouling 2021). Moreover, biofouling is also considered one of the main drivers for the translocation of invasive aquatic species, which may establish a reproductive population in the host environment. This poses threats to humans and the life under the water. The risk of environmental harm due to biofouling is recognised by the IMO and the Convention on Biological Diversity. Minimising the environmental effects of marine biofouling is also in line with the UN Sustainable Development Goals, particularly Climate Action (Goal 13) and Life Below Water (Goal 14).

Fouling Control Coatings (FCC) are the most viable approach for reducing the ship biofouling which could be either biocidal or non-toxic coatings. Fortunately, there is a range of commercially available FCCs which efficiently can be utilised on the ship and increase the ship energy efficiency. The main challenge here is the selection of the most appropriate FCC, which depends on several factors. According to the resolution MEPC.207(62), these factors are dry-docking periods, ship speed, operating profiles and ship type. However, there are no standards, or models exist to predict FCC performance for ships in operation. Therefore, FCC is selected based on information supplied by the manufacturer, by word of mouth, and by salesperson considering only the economic aspects of FCC (Swain, et al 2007). This leads to the potential incorrect FCC selection resulting in penalties in fuel consumption, GHG emissions as well as unscheduled hull cleaning and dry-docking. In order to fill this gap, Uzun, et al (2019) developed a time-dependent biofouling prediction model which allow us to predict biofouling growth in time and therefore increases in the effective power, fuel consumption and GHG emissions. Therefore, if the required data is utilised, this model enables us to compare the performances of different coatings in terms of fuel consumption and emissions.

In this study, performances of two different coatings are compared based on 3 years of a ship operation using the time-dependent biofouling model developed by Uzun, et al (2019). The results were presented in terms of increases in the effective power, fuel oil consumptions and CO_2 emissions within the total operation time. The paper is organised as follows: The model methodology and extrapolation processes are explained along with the ship details selected for this case in Section 2. The results and discussions are presented in Section 3 and finally conclusions are drawn in Section 4.

TIME DEPENDENT BIFOULING PREDICTION MODEL

Time dependent biofouling prediction model is a decision support tool that bridges FCC field tests, the ship operating profiles and biofouling roughness data to make tailor-made condition assessments for ships. The model is innovative as the literature contains very little similar work, and this is likely because previous investigators viewed the modelling of time-dependent fouling build-up as a problem that was too complex and intractable. However, the proposed model takes a rather innovative and practical approach and shows satisfactory predictions of the effect of biofouling on powering penalties and, therefore, GHG emissions.

Methodology

Figure 1 summarises the general methodology of the time dependent biofouling growth model. The model's inputs are ship operating profile (trade routes, idle and sailing periods), ship features (ship speed and dimensions), FCC field test data, roughness function data on biofouling. Paint manufacturers generally conduct their field tests in limited areas, which are environmentally diverse in terms of the chemical and physical properties of the seawater. If the limited field test data is available for the FCC in question, the model predicts the performance of the FCC in different regions on the shipping route using the sea surface temperature (SST) as an extrapolation parameter. Biofouling growth is strongly dependent on SST (Crisp and Bourget 1985; Epelbaum, et al 2009; Farhat, et al 2016; Qiu and Qian 1998; Thiyagarajan, et al 2003). Detailed information about the model can be found in Uzun, et al (2019).

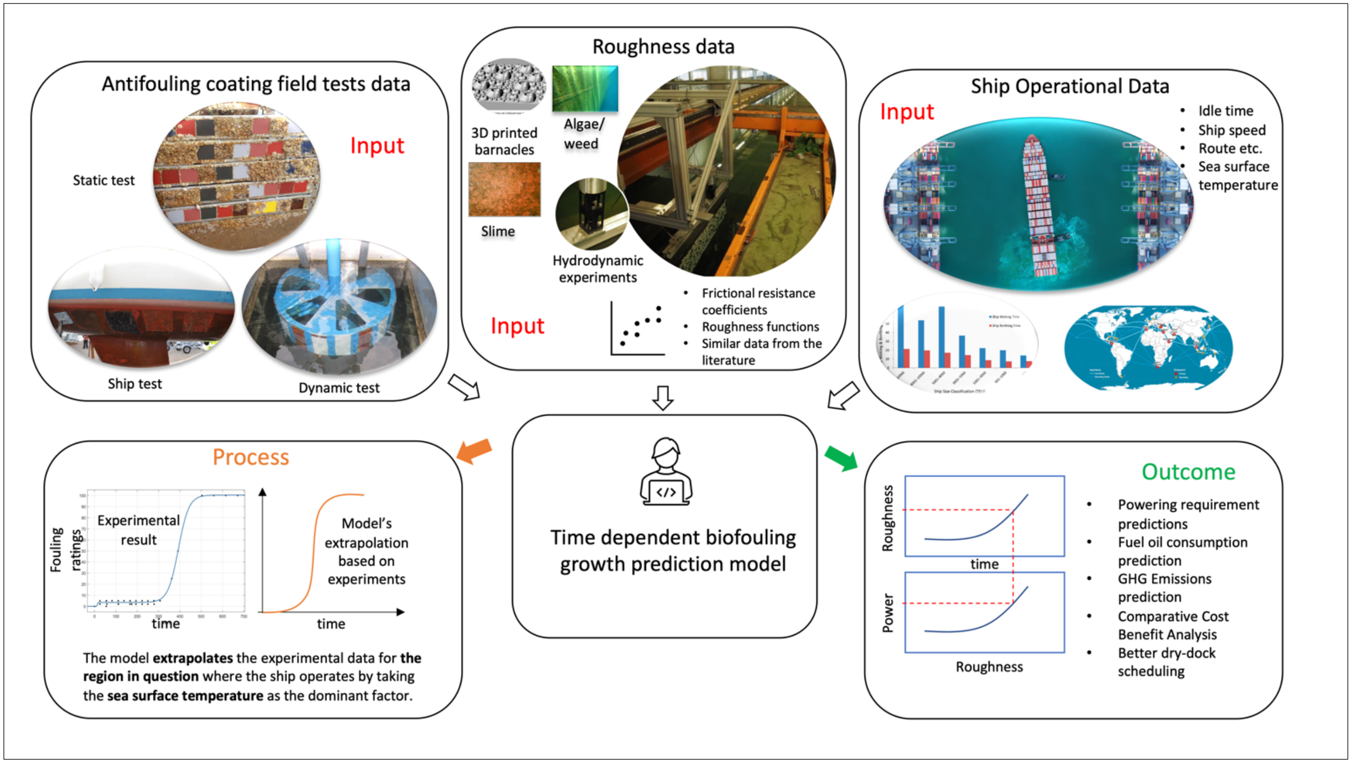

Figure 1 The methodology of the model

Once the model predicts the biofouling growth in terms of equivalent sand grain roughness, predictions can be used whether in a Granville similarity law scaling procedure (Granville 1958) or can be employed in the wall function of a computational fluid dynamics (CFD) software. In both way full-scale predictions for increase in frictional resistance (ΔC_F) can be made accurately for the specific ship cruising at the ship speed in question. Granville similarity law scaling approach is selected for this study as it is more practical to use for a duration analysis as the model predicts new roughness values for each ship operation day by day.

Calculation of the Effective Power

The biofouling accumulation on the ship hull causes a roughness which increases the frictional resistance and the effective power (P_E). The P_E is a function of the total resistance and ship speed as given in equation 1.

$$P_E = R_T V \qquad [1]$$

where R_T is total resistance and equation 1 can be written as below:

$$P_E = 0.5 \rho S C_T V^3 \qquad [2]$$

where ρ is sea water density, S is the wetted surface area, C_T is the total resistance coefficient and V is the ship speed.

The percentage increase in P_E due to roughness can be expressed by equation 3 which is similarly used by Demirel, et al (2017).

$$\Delta P_E\% = \frac{\Delta C_F}{C_{TS}} \times 100 \qquad [3]$$

where C_{TS} is the total resistance coefficient of the ship.

The increases in fuel consumption are proportionally calculated based on the increase in the effective power. It is of note that propulsive efficiencies were not considered as only one ship is used in the case study.

Case Study

A crude oil tanker was selected to be used in the case study. Three year of real ship operation was taken into account. The ship characteristics and required parameters are given in the Table 1.

Table 1 Ship Characteristics

Vessel type	Crude Oil Tanker
Deadweight	151k tons
Length	269 m
Breadth	45 m
Draft	16.2 m
Ship Speed	13.5 knots
Main Engine Power	16,395 kW
FO consumption (t/day) at design draft and speed	48 tons/day

Operating profile is tabulated in Table 2. As can be seen from the table idle days (static times), sailing days and total operating days are given in the table. It is important to note that three years of noon reports were used for obtaining ship operating profile.

Table 2 Ship Operational data

Idle days including port stays in 3 years	284 days
Sailing days in 3 years	811 days
Operating days in 3 years	1095 days

Figure 2 represents the ship route of operations which are plotted by using GPS coordinates of ship reported in the noon data. The ship operation and ship characteristics is kept same to be able to understand the performance differences of FCC in the same conditions. It is accepted that no hull cleaning operation was undertaken during the 3 years of operation.

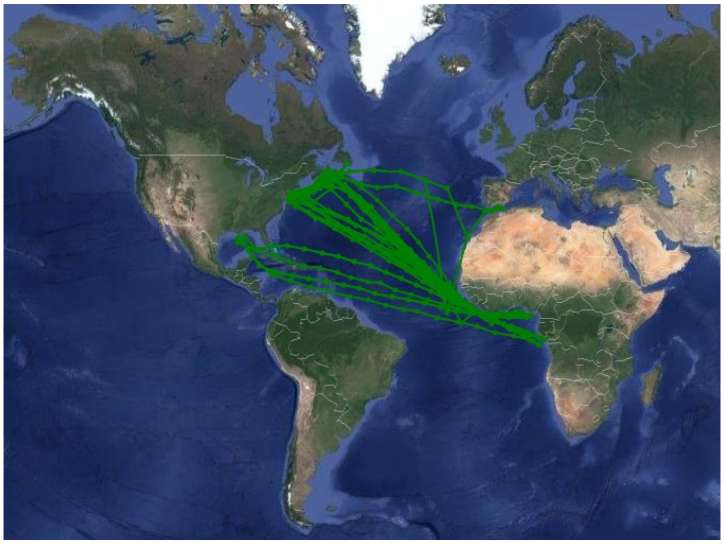

Figure 2 Plot of coordinates on ship route

The noon data includes operational modes of manoeuvring, loading, unloading, sailing, and port stays. However, as the aim of this study is modelling biofouling growth during idle times, operational modes were divided into two groups as sailing (if the operation involves speed) and idle times (if there is no speed).

RESULTS

The increases in the effective power were calculated at the design speed of 13.5 knots for a 3 years of ship operation using the time dependent biofouling growth model developed by Uzun, et al (2019). It can be seen from the figure that coatings show different performances in time. Coating B achieved to keep ship hull smooth nearly 15 months whereas the increase in the effective power due to biofouling were around 13% for Coating A. In the first 3 months, increase reached to around 9% and then remained until 04/2011 for Coating A. Following that increase in the effective power rose to 13% in the following 4-month period and then gradually increased to 18% by the end of 3 years of operation. After keeping the ship hull clean for a 15-month period Coating B showed steep increase in the effective power and reached to around 18% in 05/2012. In the following period the increases in the effective power went up to 20.5 for Coating A.

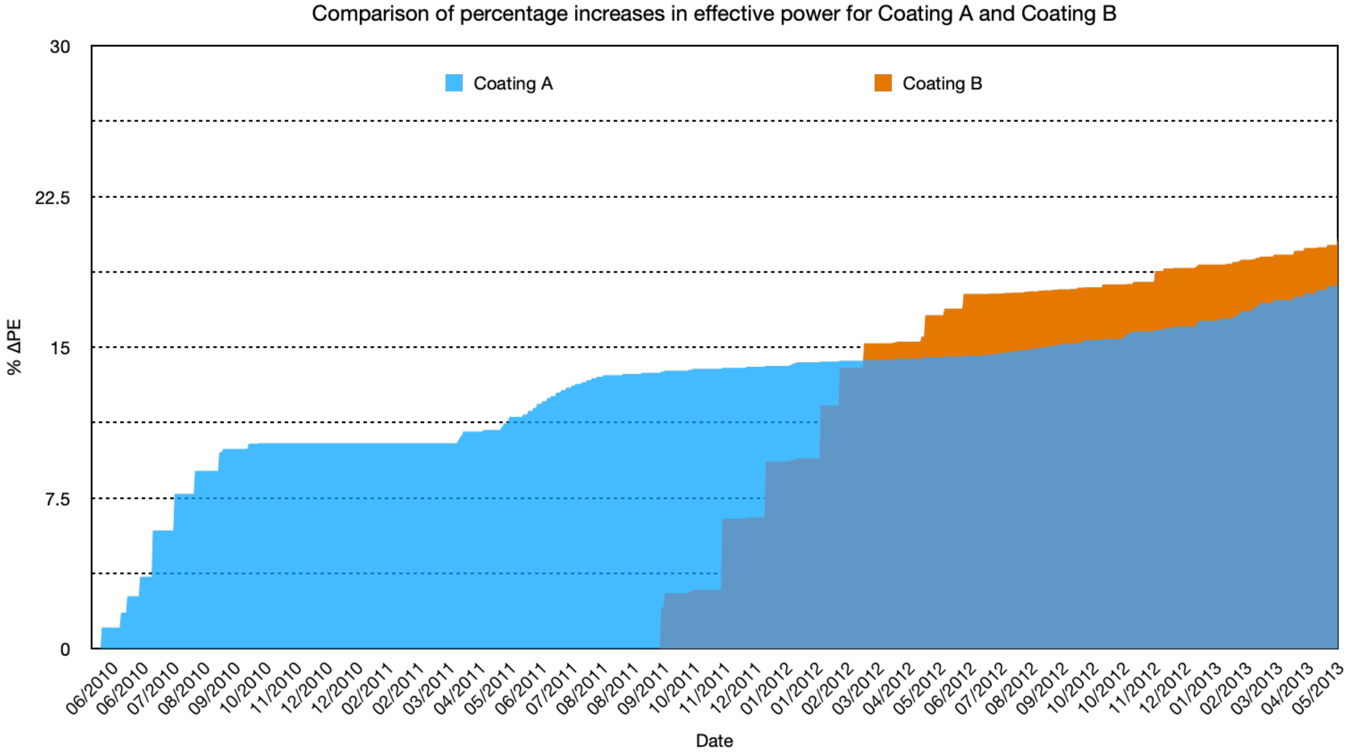

Figure 3 The percentage increases in the effective power for Coating A and Coating B

Figure 4 illustrates the fuel oil consumption for the smooth hull (reference condition), Coating A and Coating B in 3 years of ship operation. Fuel oil consumption calculations are conducted based on the assumption that daily fuel consumption of the ship 48 tons in smooth hull condition at design draft and design speed. The effect of biofouling can be seen from the figure, the increase in fuel consumption was calculated to be around 13% for Coating A whereas the increase in the fuel consumption was around 7% for Coating B compared to the smooth hull.

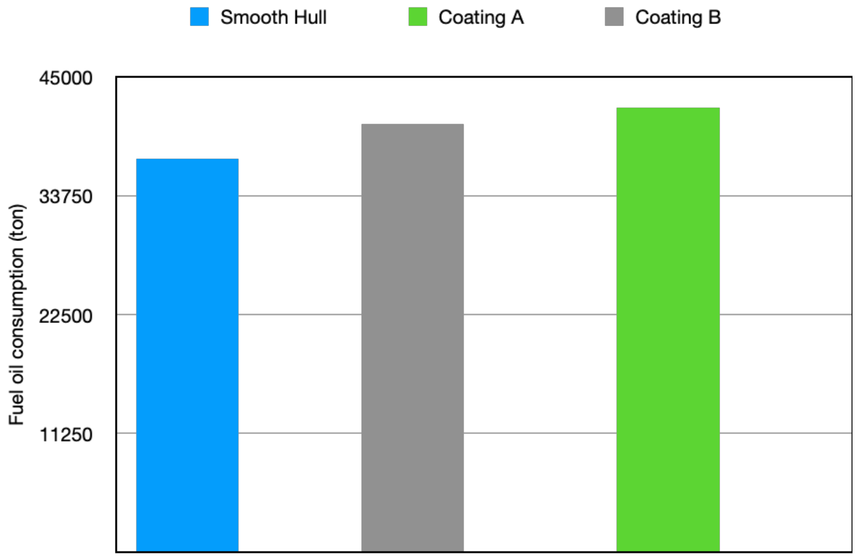

Figure 4 Comparison of fuel oil consumption in tons for Coating A and Coating B

The difference in fuel oil consumption between Coating A and Coating B was calculated to be around 1550 tons which is equivalent of 32 days of fuel oil consumption of the ship in smooth condition. It is important to note that although the fouling control coatings performances were close to each other, appropriate selection saves notable amount of fuel. The cost of the fuel oil consumption for Coating A was calculated to be $30 million whereas this value changed to $29 million for Coating B. The cost difference between Coating A and Coating B was around $1.1 million. The average market price for heavy fuel oil is taken as 717.5 $/ton, according to the March of 2021 prices (Global 20 ports average, 2021).

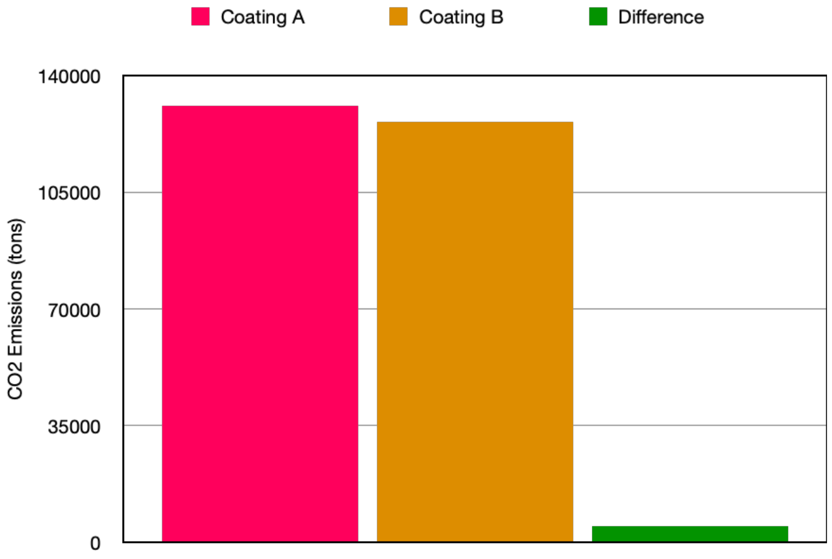

Figure 5 CO_2 Emissions of Coating A and Coating B

The Figure 5 illustrates the comparison of CO_2 emissions and the difference between the Coating A and Coating B. The CO_2 emissions were calculated as 131k ton for Coating A and 126k ton for Coating B. The difference in CO_2 between Coating A and Coating B was found around 4.8k ton for a 3 year of ship operation.

CONCLUSIONS

The performances of two different fouling control coatings were compared in terms of increases in effective power, fuel consumption and GHG emissions. Three year of real ship operation data of a tanker was used in the time dependent biofouling growth model. Once the time dependent biofouling growth is predicted via the model, full-scale predictions for increase in the frictional resistance were conducted based on the Granville similarity law approach and increases in the effective power, fuel oil consumption and GHG emissions were predicted. The increases in the effective power were obtained at design speed of 13.5 knots. The increases in the effective power were predicted to be 20.5% for Coating B and 18% for Coating A at the end of the 3 years of operation. Although Coating B reached to a higher value in terms of increased power, it has been found that Coating B showed relatively better performance than Coating A when the results are compared. This can be attributed to the fact that although Coating A has relatively less increase in the effective power, Coating B achieved to keep ship hull clean for a notable amount of time. The fuel oil consumption difference between coatings is found to be 1550 tons in total which costs around $1 million dollar and causes 4.8 k ton CO_2 emission in total. This approach can be used in selecting the most appropriate FCC for the ship in question regarding ship characteristics and ship operational profile. In addition, it can be used as decision support tool for deciding most suitable time for hull cleaning/maintenance operations.

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