HULL FOULING

STUDY OF HULL FOULING ON CRUISE VESSELS ACROSS VARIOUS SEAS

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EXECUTIVE SUMMARY

The economic and environmental effects of hull fouling on the shipping industry are well-known, and are documented by the Marine Environment Protection Committee (MEPC) of the International Maritime Organization (IMO) as part of its quest to reduce the industry’s Green House Gas (GHG) emissions. Hull fouling is of environmental and regulatory concern – not only due to its impact on emissions, but also given its inadvertent role as the transporter of aquatic invasive species.

Ship performance losses due to hull and propeller fouling can be substantial, but historically they have been difficult to quantify since ship performance measurements continuously fluctuate according to a host of variables, including draft, trim, rudder activity, wind, waves, currents and water depth. This study looked at data collected over 38,000 sea days on cruise vessels traversing different seas in order to analyze the energy efficiency losses caused by hull fouling and to identify ways of mitigating these efficiencies and alleviating maintenance costs.

INDUSTRY FOCUS

This topic is gaining increasing amounts of attention throughout the industry. A recent report from the Clean Shipping Coalition (CSC), which was submitted for consideration to the MEPC 63/4/8 in 2011, estimated that over a typical 4 to 5 year sailing interval, inadequate hull and propeller performance could be reducing the efficiency of the entire world’s fleet by 15-20%. For ships travelling at normal speeds, this equates to a directly proportionate increase in bunker consumption and GHG emissions.

Typically, the deterioration that occurs in hull and propeller performance between dry-dockings is mainly the result of biological fouling and mechanical damage. Regular hull cleaning and propeller polishing can assist in negating these effects between dry dockings depending on hull coating. In the past, many of the coatings that were used were themselves harmful to the marine environment. The IMO’s International Convention
on the Control of Harmful Anti-fouling Systems on ships, came into force in 2008; and prohibits the use of harmful elements in anti-fouling paints.

The IMO and Governments also recognize that some areas need additional protection, the Baltic Sea, Alaska and certain coastal areas for example. These are known as Emission Control Areas (ECAs) or Particularly Sensitive Sea Areas (PSSAs) which are deemed to require a higher degree of protection because of their particular significance for ecological or scientific reasons, and because they may be vulnerable to damage by international maritime activities.

**FINANCIAL FOCUS**

A fouled hull leads to increased frictional resistance which results in loss of speed or increased fuel consumption (in order to maintain speed and schedules). Fouling may cause the coating system to deteriorate; leading to premature corrosion of the hull. This, together with an increased frictional drag has both an economic and environmental impact on the ship’s operations. According to MEPC assessment, even a small amount of fouling can lead to an increase of fuel consumption of up to 40%, due to the increased resistance to movement. A clean ship can sail faster and with less energy.

High bunker costs and increased environmental regulations are forcing operators of all vessel types to search for ways to monitor fouling conditions and cost-effectively counteract its effect.

**THE STUDY AND FINDINGS**

To help ship operators better understand the impact of fouling conditions on their operations, Eniram analyzed the effect of the build-up of fouling on cruise vessels traversing different sea areas. With access to vessel performance data from over 38,000 operative sea-days, complemented with temperature and salinity databases, Eniram was able to compare and contrast data across different legs as well as consider the impact of hull cleaning and dry docking over the same period.

The results clearly show that there are differences in the rate of fouling between warmer sea areas and colder ones, with the Caribbean on average contributing most to the state of fouling followed by the Mediterranean and the Californian coastline, with the sea around Alaska contributing the least to fouling. Another noticeable highlight from the study was the effect of a ship sailing from one area into another sea area; the impact of fouling tends to decrease, before increasing again. Benchmarks for fouling were derived to help ship owners and operators to estimate the impact of operating in different areas.

Depending on the coating applied to a vessel, the financial impact of operating in areas with a high risk of developing fouling can be up to $500,000 a year for a single cruise vessel.
The study also shows that using the data collected by Eniram, it is possible to verify the effects of in-water cleanings and dry docks, as well as to detect potential problems with brushing/cleaning or anti-fouling. Operators and owners can benefit from the fouling data by using it to help to optimize treatment strategies, and to plan routes, itineraries and schedules accordingly.

1. INTRODUCTION

1.1. BACKGROUND
Shipping companies of all vessel types are being compelled to evaluate and implement fuel saving initiatives, due to increasing environmental regulations from the IMO, government and port authorities; combined with the relentless rise in bunker prices.

1.2. PIONEERING DYNAMIC TRIMMING
The trim of a vessel is the difference between the ship’s draft aft and forward, and a sea-going vessel’s trim can significantly affect fuel efficiency, since it has a clear impact on propulsion resistance, and thereby the amount of fuel used. As such, Eniram has proved trim optimization to be one of the most effective methods to improve vessel efficiency and reduce operational costs. The position and angle of propellers, rudders and the shape and size of the wetted surface of the hull can all alter the trim of the vessel. Using highly accurate data readings of all the significant influences on vessel movement, Eniram’s experienced seafarers and mathematicians pioneered dynamic trimming technology for all vessel types. Based on readings from multiple sensors integrated with other onboard systems, the relations between the dynamically changing conditions and the energy requirements are mapped and transferred into a mathematical model. This then delivers onboard guidance to the crew regarding optimum trim.

Our data collection methodology, modeling algorithms and analytic skills enables Eniram to conduct deep investigations into hydrodynamic vessel performance.

1.3. FOULING
The propulsion energy required by ships represents the greatest proportion of fuel consumption onboard, and is one of the areas where significant savings can be obtained. In this way, the effects of hull fouling are important and an issue that the industry is striving to find ways to overcome. Ship owners and operators recognize that the build-up of fouling on hulls induces much larger propulsion costs, and are also a significant factor in the vessel’s maintenance costs. Fouling conditions can be exacerbated if the vessel has long idle periods or low activity, such as frequent stays in port. In an attempt to find alternative solutions, significant industry investment led by paint manufacturers, ship owners and research laboratories is focused on finding new and non-toxic coatings to minimize the direct effects of fouling.

Our data collection methodology, modeling algorithms and analytic skills enables Eniram to conduct deep investigations into hydrodynamic vessel performance in order to help customers to identify and achieve further efficiency savings. Understanding hull fouling is a key area where this has been possible.
Not only are new paints being produced to better suit each ship type, route and operation, but improved maintenance techniques – such as low-polluting hull scrubbing technologies - are also available to reduce the growth of hull fouling. As such, several ship owners have indeed introduced procedures for periodic in-water cleanings and some have even reduced the dry docking intervals to counteract the fouling growth. Finding the optimal timing to execute these procedures must be based on previous experience, as a reaction to an unexpected increase of fuel consumption.

1.4. STUDY SCOPE

It is difficult to predict how biofouling on the hull develops for a particular ship, route or coating. Eniram used real-time, dynamic, vessel-specific data during this study to form a database of over 38,000 operative sea days from a variety of cruise ships operative in different regions. Thus, a proactive approach can be taken to determine the optimal cleaning time to reduce the efficiency loss. During the study, Eniram looked at the importance of the main factors affecting the growth of vegetation on the underwater hull, including geographical location, operations of the vessel, type of underwater coating, temperature of the water, and seawater salinity. This study presents the results of the hull fouling effects experienced during the vessel’s operation in different geographical areas and of the impact of underwater cleaning and dry docking on hull fouling.

2. TECHNOLOGY

Eniram’s hull fouling study was conducted using Eniram’s own technology, which is proven to accurately collect and store vessel performance data and to be able to analyze and interpret the data collected over a period of time. It is thereby possible to identify precisely how the vessel produces and consumes energy, and determine where further fuel savings can be realized. This method is highly precise, and enables more frequent follow-up in comparison to other methods, which include trials conducted through crew members logging performance figures at certain times.

2.1. DATA COLLECTION

At the core of Eniram’s data collection and management of data is the Eniram Vessel Platform (EVP). This technology platform provides the data required for a wide range of performance analyses, and feeds Eniram’s onboard and onshore applications with all the important data that is required to provide energy efficiency solutions. The EVP is installed onboard the vessel to access real-time information of all internal and external conditions related to the vessel in order to track performance. All affecting factors need to be known in order to optimize different elements, which is why the system is integrated with both the ship’s automation and bridge systems. In addition, Eniram’s attitude sensors are installed to collect information on dynamic movements of the vessel including trim, list, accelerations, vessel bending etc. as shown in Figure 1. All collected data is filtered, organized and verified to provide accurate inputs to the Eniram applications.
2.2. DATA ANALYSIS

Using the high precision data collected from the sensors and onboard systems, the EVP processes the collected data and applies state-of-the-art modelling techniques that enable Eniram to identify all the energy consuming elements that make up the total propulsion energy consumption on board a vessel. Only by identifying and isolating the amount of energy consumed by different factors (trim, sea state, wind speed and direction, water depth and possible squat, the rudder angle, hull and propeller fouling) collectively known as Dynamic Sea Margin, are we able to identify the amount of energy lost on these factors due to suboptimal operations.

Fouling is one of the most difficult factors to quantify accurately because the energy changes due to the build-up of frictional resistance are slow, as there is a large number of highly variable measurements, as well as a range of affecting factors to consider. Eniram has nonetheless made significant headway in measuring fouling development.

3. THE STUDY

Real-time dynamic data collected from over 38,000 operative sea days of approximately 60 cruise ships across different regions of the world was analyzed by Eniram using its own methodology.

3.1. FOULING

For the purposes of this study hull fouling includes biofouling as well as the ageing and degradation of the hull and coating. Biofouling is the settlement and accumulation of micro-organisms, plants, algae and even animals on an underwater surface. The organisms usually attach and form in areas of the hull where sunlight can reach, which is why significant growth is rarely found on the flat bottom of a ship. Fouling can be further divided into to two basic forms, micro (slime and weed) and macro fouling (larger organisms).
The rate of accumulation of fouling depends on factors such as geographical location, temperature of the water, nutrients in the water and seawater salinity and water depth. In addition, the quality and type of underwater coating as well as operation of the vessel has an influence on fouling. The wide range of factors that influence fouling condition of the hull are summarized in Figure 2.

![Figure 2. Variables affecting vessel fouling](image)

### 3.2. DATA SPECIFICATION

Currently, fouling reduction strategies are based on limited information. Although fouling is a well-recognized issue that has always affected the shipping industry, the extent to which fouling affects propulsion power performance is not widely known and is difficult to quantify. In dealing with this issue, Eniram has two distinct advantages: firstly, our own processing methodology, and secondly, the vast amounts of data collected that forms part of the analysis. For this study, Eniram collected and analyzed over 38,000 sea days of data with a frequency of up to 25 observations per second.

While data from approximately 60 cruise vessels sailing in different parts of the world was used, only data where the vessel was operating for a minimum of 30 days across the same sea area was taken into account, in order to avoid overlapping of vegetation larger from other areas. Since the volume of selected data is significant, it gives a fairly good representation of operational vessels in the cruise sector in general. In particular, the vessels studied have a range of different propulsion systems, itineraries, and treatments; as well as being serviced differently. However, the common factor across all of them is that they are equipped with Eniram’s Vessel Platform (EVP), the data collection and management platform and Eniram’s Dynamic Trimming Assistant (DTA), our pioneering technology to help the crew to maintain optimum trim in all dynamic conditions. As such, the variety of vessels and conditions generates results that can be applied to a more diverse set of vessel types, not just cruise specific.
Additional data was collected and analyzed; including changes in sea area, cleanings and other behavioral aspects. The data is further complemented by sources such as salinity and sea temperature databases, information on brushings, paints and GPS data for shallow waters.

<table>
<thead>
<tr>
<th>Variable</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wash / coating information</td>
<td>Data not always available</td>
</tr>
<tr>
<td>Speed through water</td>
<td>Measurable</td>
</tr>
<tr>
<td>Time</td>
<td>Measurable</td>
</tr>
<tr>
<td>Location</td>
<td>Measurable</td>
</tr>
<tr>
<td>Salinity</td>
<td>Database</td>
</tr>
<tr>
<td>Water temperature</td>
<td>Measurable / database</td>
</tr>
<tr>
<td>Draft</td>
<td>Measurable</td>
</tr>
<tr>
<td>Trim</td>
<td>Measurable</td>
</tr>
<tr>
<td>Hull roughness</td>
<td>Not available</td>
</tr>
</tbody>
</table>

*Table 1. Summary of data used in the study*
Air temperature, illumination and nutrients play a role in fouling, but due to a lack of accurate estimates for these variables, they are not included in the model used for this study. To create the most accurate models possible, data on wash dates was taken into account. Table 1 summarizes the collected data.

4. RESULTS

4.1. FOULING ACROSS DIFFERENT SEA AREAS
This study used data on cruise vessels sailing in the sea areas of Alaska, California, Caribbean, Mediterranean and other areas. In Figure 4, we can see the effect of changing sea areas on power consumption over 9 months.

The rate of fouling development differs noticeably from one area to another, with the Caribbean Sea area representing the highest rate for fouling. Although the exact magnitude of fouling for different sea areas is not clear, the effect of changing sea area can be seen on all the ships that sail between different sea areas as shown in Figure 4. Another noticeable effect is seen when the ship has sailed in one area for a while and then enters a different area; the fouling decreases for a while and then starts to increase again. The possible reason for this is that species living in a specific ecosystem started to perish in a foreign environment; thus allowing species in the new region take over.

The fouling levels across different sea areas are summarized in Table 2. The average amount in the table indicates how the resistance of fouling developed. This is calculated according to energy consumption increase per day. The total time in days and sample size (which refers to periods or legs be-
tween washes or dry dock) shows the basis for calculating the averages. As a general rule, the more days and samples in the data set, the more representative the data is. The deviation in fouling among sea areas can be attributed to a variety of factors such as individual ship characteristics, differences in type and age of the coatings, as well as a lack of washing data.

On average, operating in the Caribbean causes the most fouling, while the waters around California and the Mediterranean coming second and the third on the list respectively. The high variation of fouling in the Caribbean, for example, might be caused by ships that visit fresh water ports from time to time, year-round cruises in various areas, or variation in speed; all of which alter the accumulation of fouling. The results indicate that the waters around Alaska cause the least amount of fouling, which may be due to cruise vessels visiting nearby glaciers which have lower water temperatures and variation in salinity.

<table>
<thead>
<tr>
<th>Area</th>
<th>Average</th>
<th>Standard deviation</th>
<th>Time in area (days)</th>
<th>Samples</th>
<th>% increase in fouling in 90 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska</td>
<td>2.00</td>
<td>1.35</td>
<td>3 371</td>
<td>25</td>
<td>0.9</td>
</tr>
<tr>
<td>California</td>
<td>2.47</td>
<td>1.56</td>
<td>1 405</td>
<td>14</td>
<td>1.1</td>
</tr>
<tr>
<td>Caribbean</td>
<td>3.35</td>
<td>3.55</td>
<td>9 228</td>
<td>74</td>
<td>1.5</td>
</tr>
<tr>
<td>Mediterranean</td>
<td>2.59</td>
<td>3.87</td>
<td>2 938</td>
<td>22</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Table 2. Average fouling cruise ships across different sea areas

4.2. DRY DOCK IMPACT

Major maintenance work on a vessel is carried out during dry dock. When the ship is not in water, it is easier to wash, repaint or re-coat the hull as well as other tasks such as sanding or hydro blasting. The impact of cleanings during a dry dock on an individual vessel is shown in the graph in Figure 5. The graph clearly highlights the impact of the dry dock on a specific ship; in this case only high pressure cleaning of the hull and touch up as needed was carried out. As can be expected, this dry dock had a significant impact on fouling, reducing it by 5%. The ship in question had been operated soundly so no major fouling has occurred after the dry dock.

Verifying the results of in-water cleanings as well as dry docks enables ship owners and operators to choose the most appropriate and cost-effective cleaning methods and schedules for that particular vessel, based on actual operational data.
4.3. OTHER EXAMPLES ON USING FOULING DATA

PROBLEMS WITH ANTIFOULING

As previously stated, fouling increases the power consumption of a vessel. Figure 6 shows a graph that represents the power consumption caused by additional drag for a cruise ship before and after washes. The wash dates can be clearly seen in the diagram as the power consumption drops after the wash. It is evident that during the months of August and September the fouling increased propulsion power consumption by nearly 4% over this two month period. Since fouling usually develops at a slower rate, it may suggest that the coating of the ship was damaged.
UNSUCCESSFUL WASH

Cleaning vessels under the sea surface is a challenging process, and can sometimes remove part of the coating. An example of this case can be seen in Figure 7. In January, the hull of the vessel was washed. However, the growth of fouling accelerated rapidly, and the power consumption increased by nearly 4% over the following three month period; suggesting that brushing had damaged the anti-fouling treatment.

![Figure 7. The impact of a failed wash on power consumption](image)

5. CONCLUSION

5.1. FINANCIAL IMPACT OF FOULING

As a ship’s hull condition degrades due to marine fouling, more power and fuel are needed to maintain service speeds; resulting in increased GHG emissions. Rising fuel costs, hull maintenance expenses, and mounting environmental regulations make the monitoring of the condition of the hull an important part of vessel management to reduce energy and emissions.

Fouling has a significant impact on vessel performance. This study suggests that the effect of fouling varies substantially in different geographical areas, and that changing from one area to another can clean the hull. From the data we have been able to develop benchmarks for determining fouling development and comparing individual vessels. The fouling development benchmark is calculated according to how many megawatts the energy consumption increases per day on a vessel with total power of 20MW.
Using these benchmarks as indications of the differences between areas, we can estimate the financial impact to ship owners and operators when no cleanings are made during the year:

Operating in areas of heavy development of fouling can therefore increase operations costs by close to $500,000 per year for a single cruise vessel. Since the deviations are large, the effect on a single vessel may be multifold. With an effective and timely cleaning strategy, fouling related costs can be reduced.

**Table 3. Calculating the financial cost of fouling**

*Calculations based on utilization rate 60%, 360 days per year, USD 700 per ton, 110,000 GT with 20 MW propulsion power.*
5.2. HOW FOULING DATA CAN HELP
Operators and owners can benefit from the fouling data by providing them with the transparent data they need to help to determine the optimum hull treatment strategy, including the planning of routes and itineraries. Here are some examples of areas where the results of data analysis can help when considering a range of energy efficiency drives—such as validation of any dry dock changes, hull ageing or deflection, propeller efficiency, etc:

- **When and how often to clean**: optimize the timing of hull maintenance to reduce costs
- **Type of treatment**: choose the suitable anti-fouling for the vessel in question and measure effects of brushings and polishing on propulsion power
- **Optimize routes and itineraries**: using the data analysis of the differences in fouling rates across different sea areas as part of vessel routing to help reduce the effect of fouling
- **Verify results**: use data analysis to verify any anti-fouling actions taken, either through cleaning or dry dock activity.

5.3. STUDY LIMITATIONS AND FUTURE RESEARCH
This study focused on examining the hull fouling impact on cruise vessels across different geographical areas. The findings presented here represent average percentage values of the observations made. The level of resistance due to fouling occurs at a different rate at various operational speeds. The actual degree of fouling has not been measured, only its impact on energy consumption. No measurement of actual fouling (just the impact) has been conducted and any information with regards to the type of paint/coating and its method of application is based on the information provided by the vessel operator.

The benefit of Eniram’s methodology is that we can identify energy consumption changes due to fouling, thus helping to adopt mitigating strategies. By being able to identify the impact of fouling on propeller or any other structural modifications to the hull, steps to make the vessel more efficient can be taken. Eniram continues to carry out further research on fouling, as this is clearly an area of great environmental significance and has considerable economic impact on operating margins. Some factors found to require more research are the effects of speed profiles and water temperature (relating to seasons) which may impact the development of fouling. There is also a wide variation in coatings for vessels; some may use self-polishing paints, others may use foul release paints, and some may use a combination of these or some totally different solution. This may therefore result in a varying rate of fouling development, and an effect on the results of in-water cleaning.

These issues, among others, will be considered in future research into hull fouling, including the potential to match the results with actual measures of hull roughness. This can be coupled with further examples on the cost implications of untimely cleaning and analysis on how different in-water cleaning techniques and coating systems can affect the development of fouling on the hull.
6. ABOUT ENIRAM

Established in 2005, Eniram provides the maritime industry with decision support and data analytics technology that reduce fuel consumption and emissions. The product portfolio, created by experienced seafarers and technologists, ranges from single onboard applications to comprehensive fleet analysis and is used by both small and large shipping companies on vessels ranging from cruise liners, tankers, container ships, bulkers, LNGs and ferries. These companies rely on Eniram’s technology to enhance their vessel efficiency and operation and benefit from significant environmental savings and enhanced information intelligence.

ENIRAM PROVIDES SHIP OPERATORS WITH

• Onboard applications delivering real-time guidance to maintain optimum vessel performance for maximum fuel efficiency
• Fleet performance management tool to monitor and compare the actual performance of each equipped vessel across an entire fleet
• Analytics services exploring the breadth, depth and velocity of the data collected to further improve efficiencies and validate the results of other energy saving initiatives such as propeller changes, hull modifications and antifouling measures.

Visit our website www.eniram.fi or contact us to find out more about our products and services.

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