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K-BioFouling – The Korean A to Z GloFouling Solutions

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Abstract

K-BioFouling is a one-stop A to Z GloFouling solution, developed within a Korean Ministry Oceans & Fisheries R&D project on the GloFouling initiative. K-BioFouling includes building a smart in-water cleaning (IWC) industry, smart regulatory tools for inspections, in-door and out-door test standards, addressing scientists, regulators, and operator training. AI-based inspection has reached accuracy of 96% for cleaning quality, and nearly 100% for species recognition. To accelerate the development for species recognition, we decided to open up the AI software and data for those who share their data, with goal to have eventually free access for everyone. We believe hull performance evaluation has evolved to a point where with one click one can produce ISO 19030 based performance before and after cleaning. This will also be freely shared. Robotic niche area cleaning with capture will soon be in commercial use.

1. Introduction

K-BioFouling shall provide a one-stop A to Z GloFouling solution, developed in Korea, but available for all countries:

- Within the next two years, we target to develop biofouling pre-risk assessment, hull performance monitoring, and in-water cleaning (IWC) performance evaluation to be globally available.
- IWC shall be adaptable to respond to flexible situations, short port stays, anywhere, with sufficient capacity available.
- The solution shall involve scientists, supply regulatory tools for reporting, and training for ship owners and operators.

AI (Artificial Intelligence) inspection will be at the core of many of these developments. AI based on deep learning (Artificial Neural Nets) is becoming widely available. AI analysis has reached very high accuracy on hull cleaning status and species recognition, and seems ready for robust, commercial use. However, AI is not yet widely and globally used to its full capacity. Therefore, we decided to open our AI technology and data for free to cooperating partners anywhere who are willing to provide their data.

ISO 19030 based hull performance reporting shall be available at a click to create before-and-after hull performance comparison, Fig.6. The software for this is being currently improved and will soon be able to make also total fleet estimations.

BIMCO IWC tests were carried out with monitoring by Lloyd's Register and KOMERI.

2. K-BioFouling

K- BioFouling originates from a R&D project, launched by Korea's Ministry of Oceans and Fisheries in 2021. The goal of the project was to equip Korea with an A-to-Z GloFouling solution. For that purpose, the Ministry organized collaboration among industry, research institutes, universities and registry partners, as a follow-up to the R&D project for GloBallast.

In the meantime, K-BioFouling has evolved to another level: Hull performance evaluation, global cooperation on AI inspection, offshore structure cleaning, robotic niche area cleaning. A niche area cleaning robot with arms for cleaning with capture will be introduced in 2025, Fig.3, replacing 70-80% of divers' work in hull cleaning.

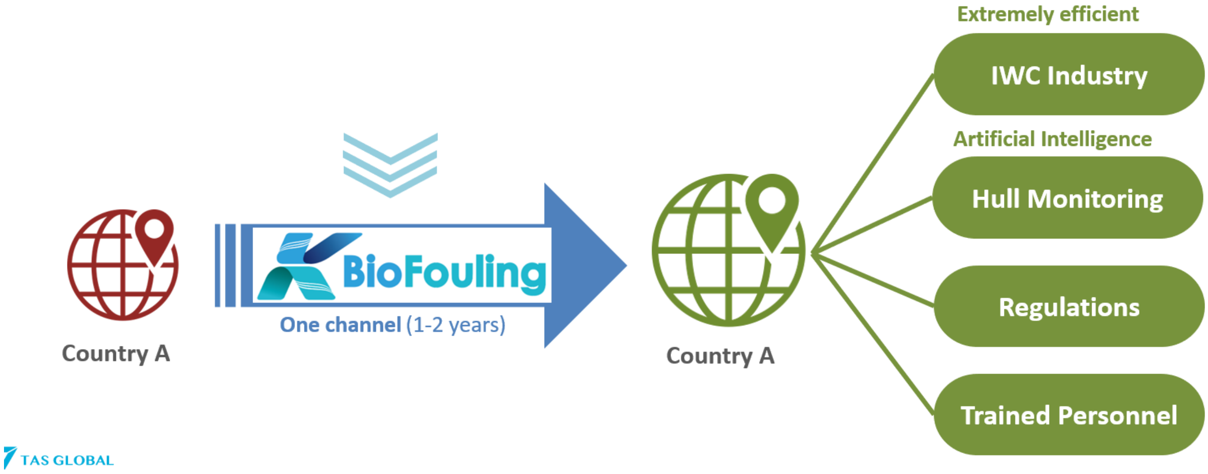


Fig.1: Concept of K BioFouling

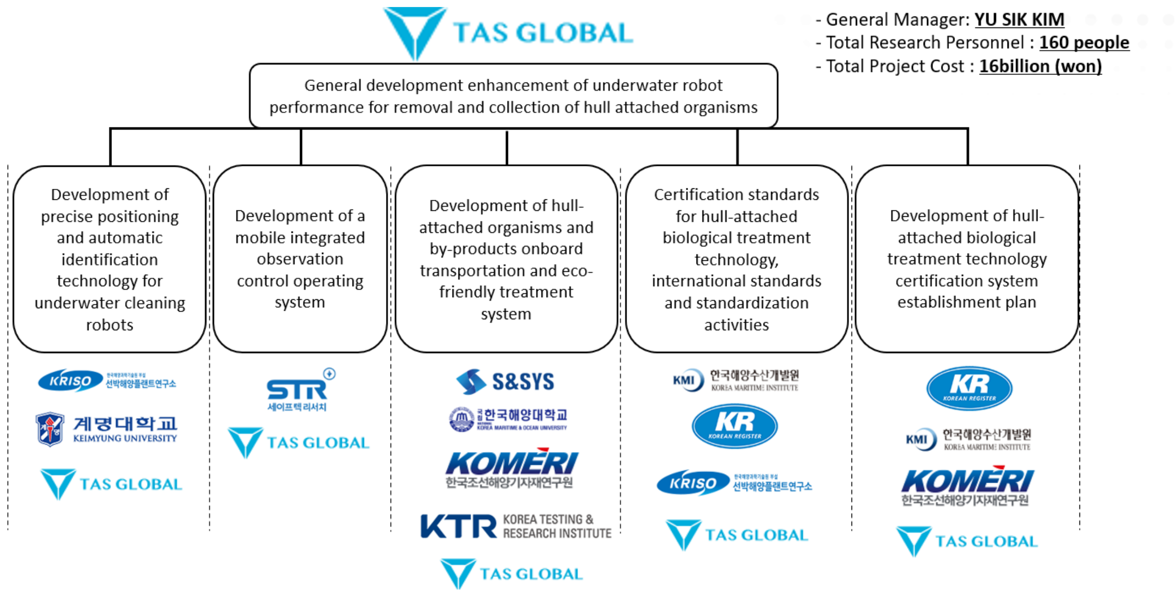


Fig.2: Development of hull fouling organism treatment (removal, collection, treatment) technology

2. AI hull Inspection

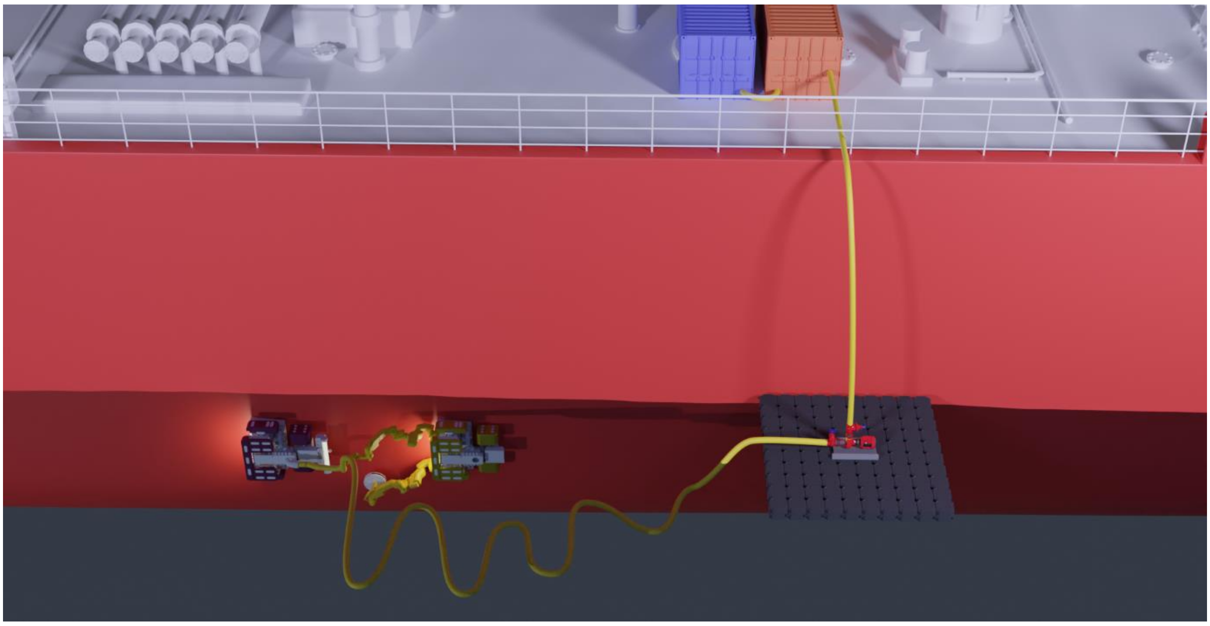
Accuracy of AI hull inspection has developed quicker than expected, Fig.4:

- Labelling of ship bottom fouling status for three categories (dense, sparse, clean)
- Transfer learning is used to develop algorithms with good performance on little data

However, regulators of countries around the globe may have invasive species of interest that we may not yet have in our data base. Therefore, we decided to launch a global collaboration initiative and to make our AI solution freely available for everyone.

3. Hull Performance evaluation

We started to gather ship data for hull cleaning performance analysis in collaboration with ship owners. There will be more explanation in *Park et al. (2023)*. We plan to provide this service for free of charge.



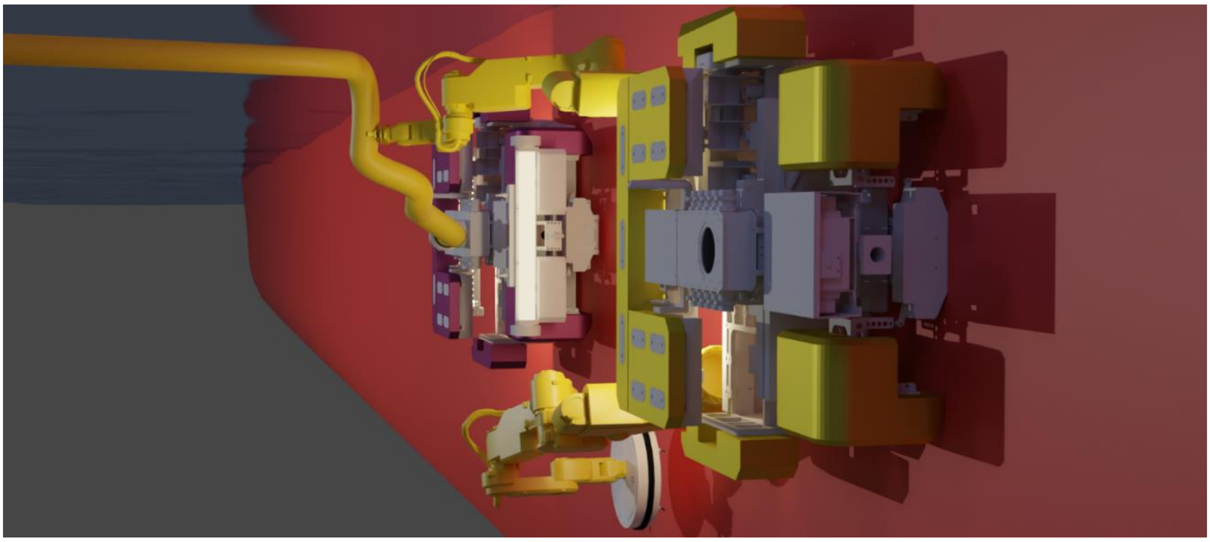


Fig.3: Hull cleaning robot with arms to be introduced in 2025

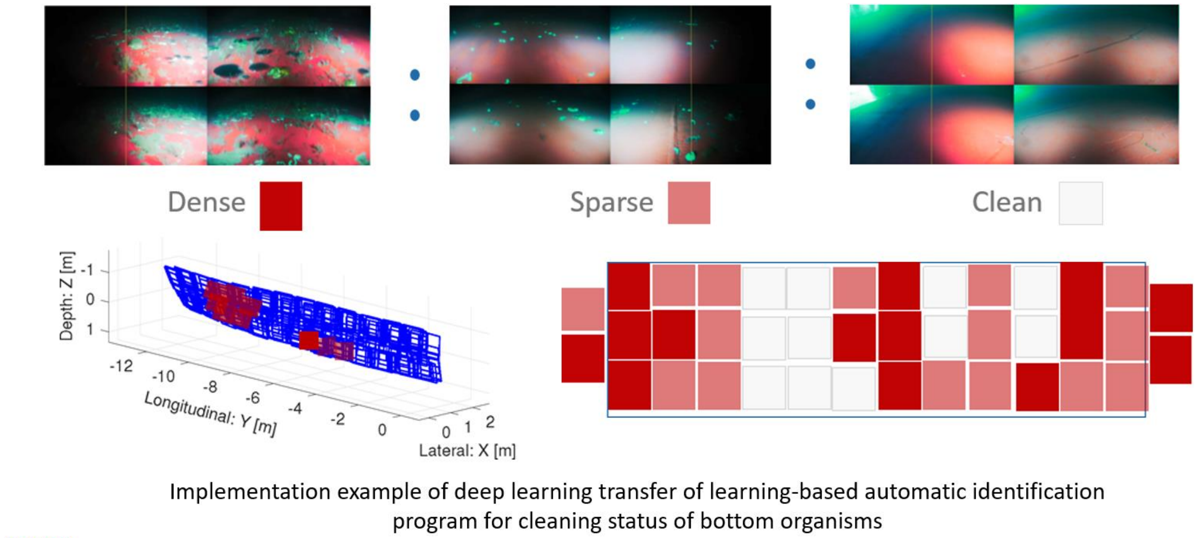


Fig.4: Implementation example of deep-learning transfer of learning-based automatic identification program for cleaning status of bottom organisms

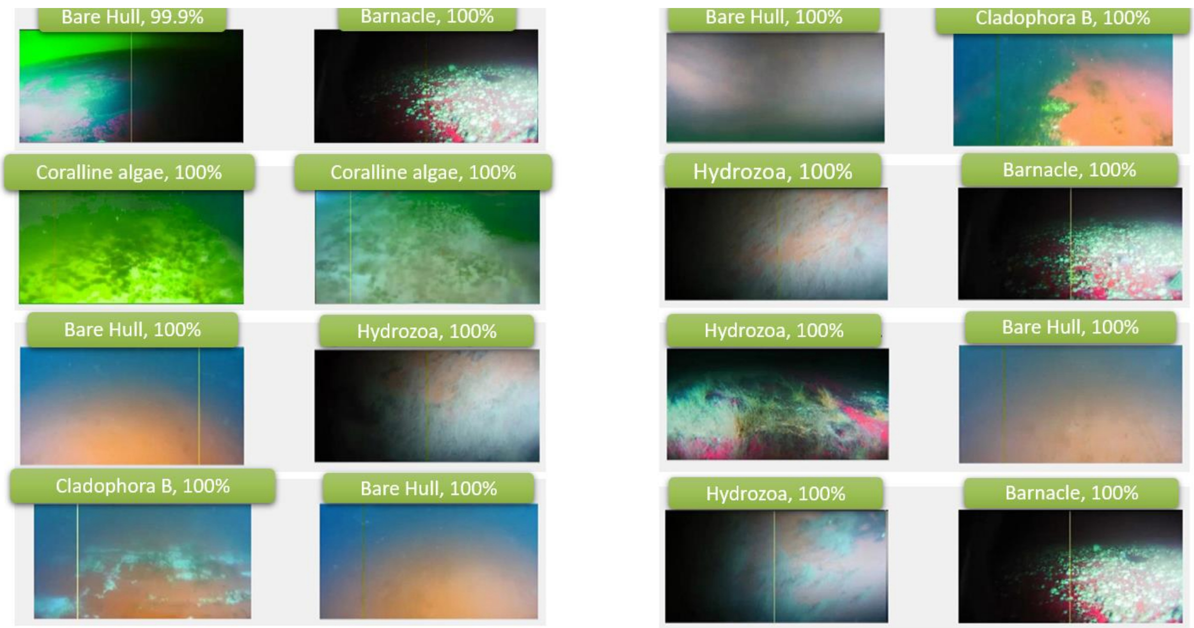


Fig.5: Results of analyzing performance of the automatic identification algorithm of ship bottom species

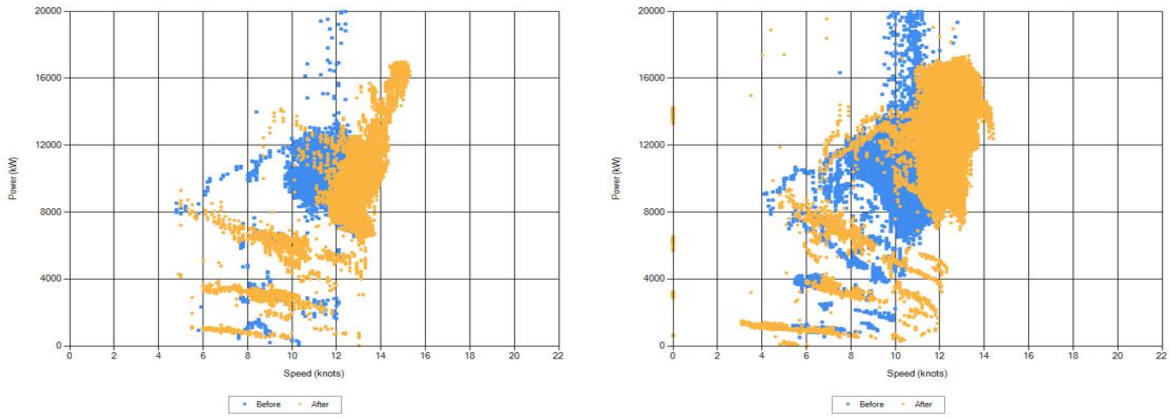


Fig.6: Before-and-after comparisons following ISO 19030

4. BIMCO IWC test results

BIMCO IWC tests were carried out, Fig.7, involving, Fig.8:

- Install hose to continuously absorb water next to the cleaning robot
- Influent: water collected before filtration (seawater and fouling)
- Effluent: purified (filtered) water
- Running water: inspection of contaminated seawater 50 m away from the cleaning area

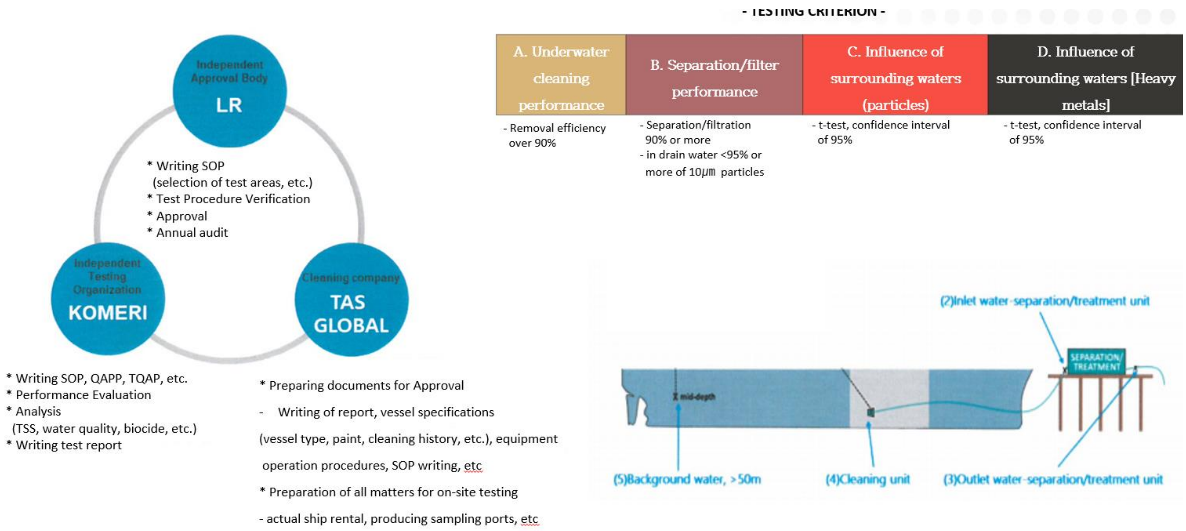


Fig.7: BIMCO tests

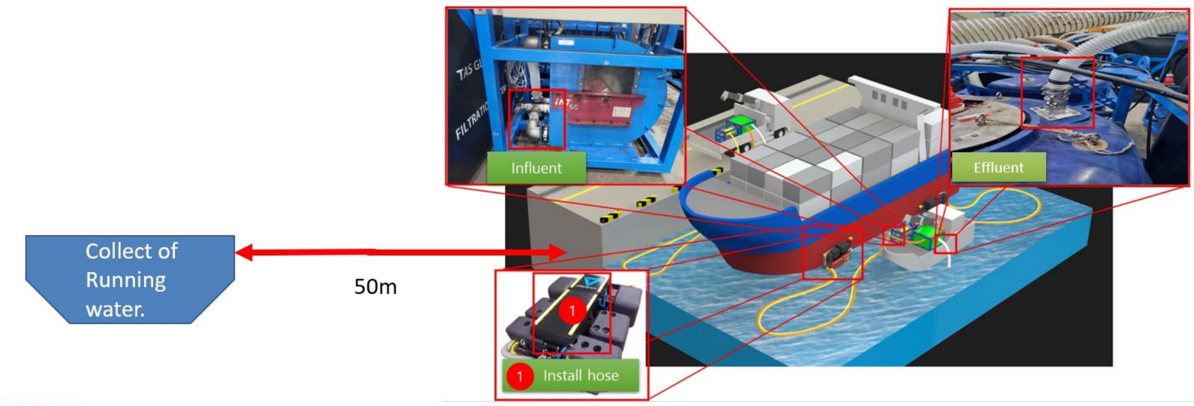


Fig.8: Details of test set-up

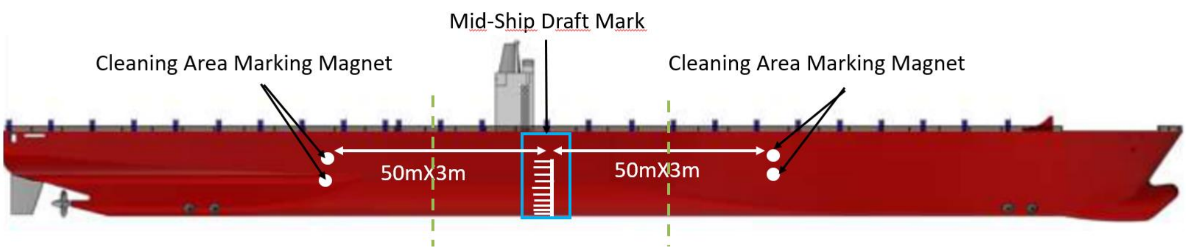


Fig.9: Location of tests

- The total test time for a BIMCO test was 1 hour.
- The range of the underwater cleaning area was 100 m x 3 m, Fig.9.
- Depending on the macro-fouling condition of the ship, it will be held 4 times for 15 min or 2 times for 30 min.

- Set the underwater cleaning start area based on midship draft mark.
- The end point of the cleaning area is marked with a magnet.

References

PARK, B.J.; KIM, M.S.; LEE, J.H.; SHIN, M.S. (2023), *Comparison of a Ship's Performance Before and After Hull Cleaning and Propeller Polishing*, 8th HullPIC Conf., Pontignano

Evaluating Technologies for Growth Prevention

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Abstract

This paper presents how to approach performance tests of antifouling systems and marine growth prevention systems. It will increase the understanding of what to consider when developing tests for systems at different technology readiness levels. Examples will be given of performed studies, e.g., experiments investigating leaching of biocide from antifouling coating and effects of in-water cleaning equipment on a self-polishing coating. The relevance of ecotoxicological tests and environmental risk assessment will be highlighted to document the expected level of environmental impact.

1. Introduction

Depending on the readiness level of a technology under development, attention should be paid to different factors influencing the technology performance. DHI develops performance tests after the methodology shown in Fig.1. Test plans are prepared and adjusted based on the manufacturer's insights into the technology and the expected market needs.

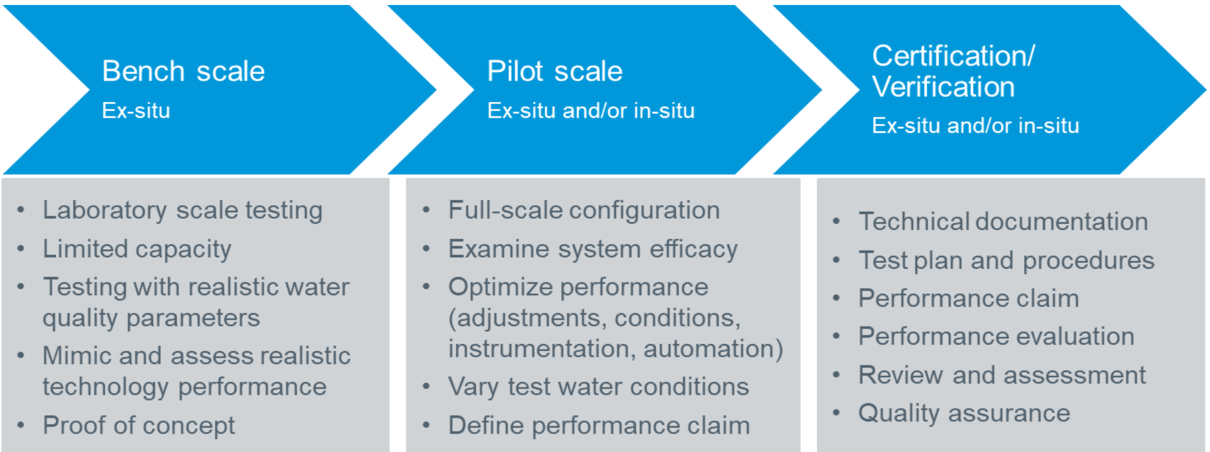

Fig.1: Technologies at different stages need different levels of testing to clarify most beneficial focus areas for further development

After having worked with ballast water management systems for more than a decade, DHI is now also looking into marine biofouling from several angles. The capture rate of an underwater remotely operated vehicle (ROV) for in-water cleaning of ship hulls has been quantified, the toxicity of the release from different coatings measured, and the efficacy of an ultrasonic technology to prevent marine biofouling investigated. As an example, the development of a test evaluating the effects of an underwater ROV used on a standard self-polishing antifouling coating will be outlined below.

2. Testing ROV operations on antifouling coating

After a meeting with the developer behind the NakAI ROV (hereafter the developer), it was agreed that no existing standard for testing could be followed, and parameters for evaluation of the equipment had to be determined. The developer wanted to investigate the possible effects caused by underwater cleaning by the ROV. The following parameters were examined:

- Visual effect on the coating such as scratches
- Effect of the coating thickness
- Effect on the biocidal leaching rate
- Water quality parameters for indirect effects: Salinity, temperature, dissolved oxygen, and pH

The developer had different configurations of the ROV (different options for wheels and brushes), and, the experiments were therefore designed to test a small-scale ROV model in a confined test system mimicking the surface of a ship hull, Fig.2.

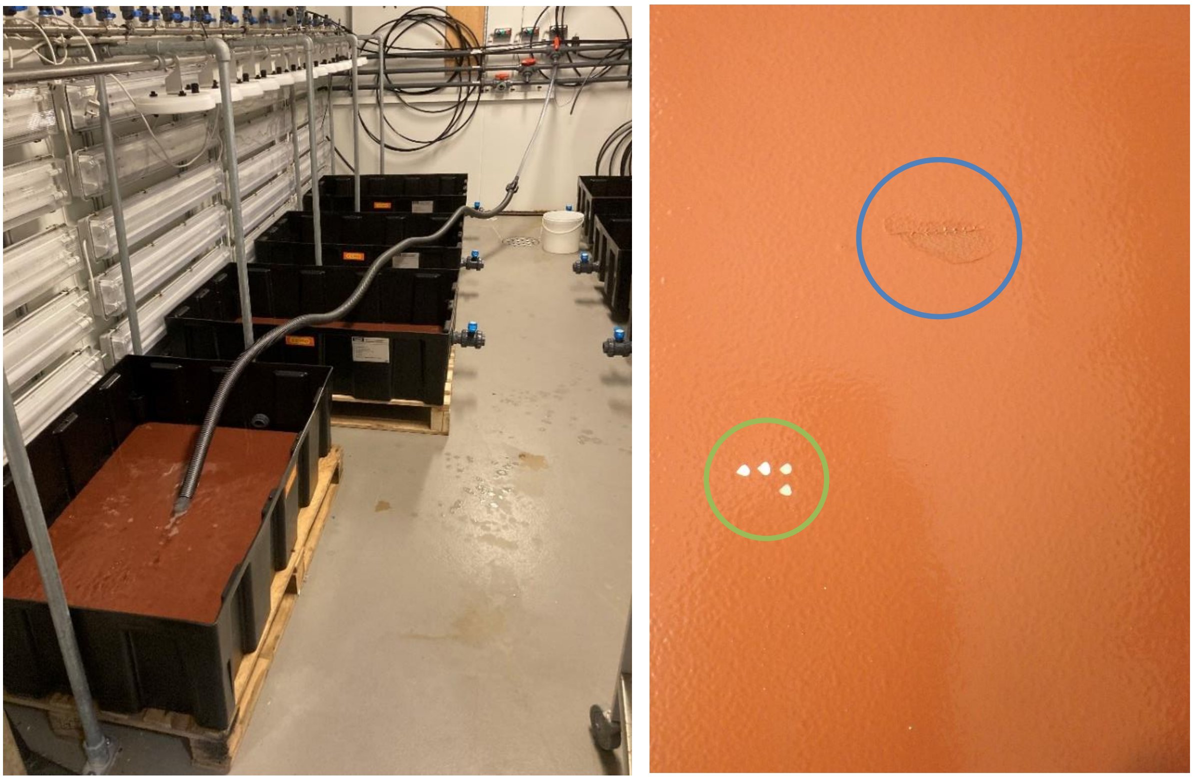

Fig.2: Steel plates used as surrogate for a ship hull for the testing of the ROV. Left: Seven plates were immersed in seawater which was replaced weekly after sampling of water for copper analyses. Right: Plate prior to testing with variations in the surface structure (blue circle) and marked with droplets of coating without copper (green circle) to simplify identification in later photo documentation.

Visual effects such as scratches were documented by photography. Even in an indoor environment it was a challenge to obtain the same light on the test systems, and differences in light exposure add uncertainty in the interpretation of colour differences observed on the pictures. Underwater macro pictures were taken of parts of the plates as the water depth did not allow for pictures of the full plate under water. This was deemed acceptable to document scratches through the coating layers that were possibly caused by the ROV. However, the macro pictures were not used as no scratches on the surface of the plates went through the top coating layer. Good macro pictures require a skilled photographer and lighting to overcome shading effects from the photographer or the camera. The droplets on the plate surface, Fig.2, functioned well, but more contrast between the droplet colors would help when light and shading effects make the pictures difficult to interpret.

The coating thickness was measured with approximately 15 replicate measurements per plate transect, i.e., on average one measurement after every 4 cm of transect. No measurements were made outside the outer 5 cm of the plates to avoid edge effects. The number of replicates was considered high; however, the results were nevertheless difficult to interpret as there were no trend in the measured coating thickness. It could be considered to increase the number of replicates or determine the position of each measurement more closely, however, the variation between measurements might be relatively high even with increased number of replicates.

The content of copper was determined in the discarded (discharge) water before refilling the tank with new (inlet) seawater. The procedure for renewal of the water above the plates followed the same procedure during the entire test period. The analyses of copper were performed by an accredited laboratory according to DS/EN ISO 17294-2:2016. Results for water above the control plate (not exposed to ROV activity) are shown in Fig.3 and give an impression of the calculated leaching rate, as the time of exposure was approximately one week, and the dimensions of all the plates were the same. The copper concentrations in the water above the test plates (exposed to ROV activity) did not significantly differ from the analyses of the water above the control plate.

The observed change in copper leaching rate, Fig.3, therefore, was apparently not connected to the ROV activity, but could maybe be due to different leaching mechanisms taking over after each other. The ROV operation happened once during the test, which was on day 43 after first immersion of the plates. It would be very interesting to see how long time the leaching rate would stay high, however, due to the costs of maintaining the weekly renewal of water, it could be considered to renew only every second week after the first two months. Other coatings could also show a different leaching pattern even under the same conditions.

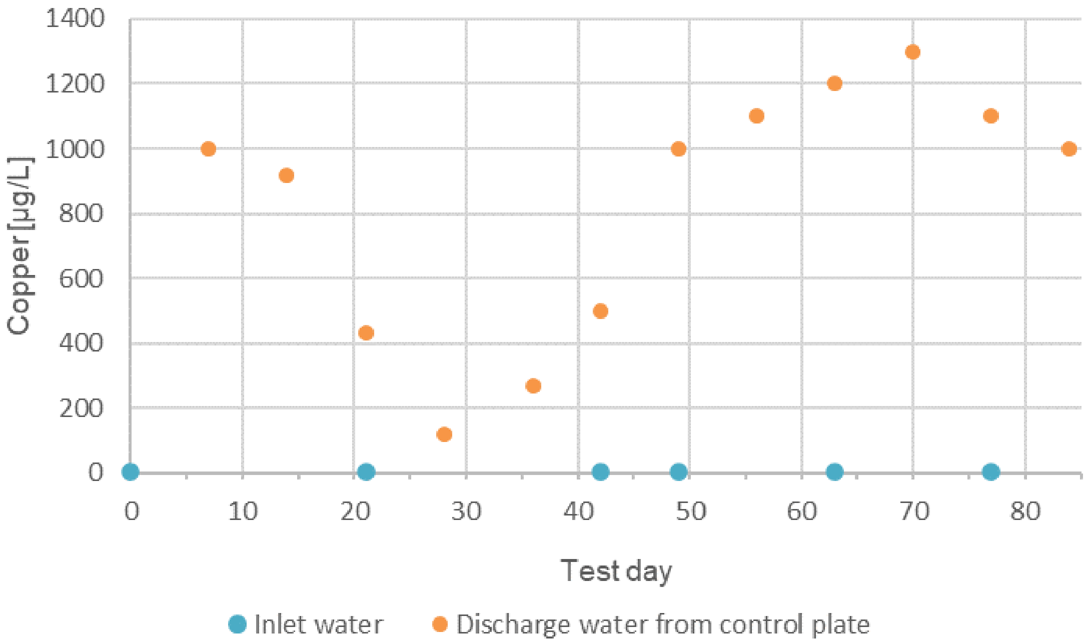

Fig.3: Total copper concentrations measured in the seawater above the control plate. One replicate was sampled and analyzed.

The salinity, temperature, dissolved oxygen, and pH did not change in a manner that would be expected to affect visual effects on the coating, coating thickness, and biocidal leaching rate. The temperature of the water increased from 15 °C to 16 °C during the ROV operations, and dissolved oxygen decreased over the week where water was still-standing, but none of these changes were expected to influence the above-mentioned parameters.

3. Perspectives

Knowing the effects that an underwater ROV may have on the coating is highly relevant to make informed choices among antifouling coatings, in-water cleaning, and other hull protection technologies that may be used in combination. This is where technology performance evaluation by a party independent of the manufacturer has its role. However, the previously published methods for performance evaluation are dominated by comprehensive and expensive studies in the field. A laboratory-based or smaller scale procedure, as applied in the present study, could be a pragmatic and affordable approach for developers and manufacturers requesting performance evaluation of antifouling and in-water cleaning technologies. The current tests could be a valuable input to early testing of some of the aspects of applying in-water cleaning technologies to keep biofouling and thus vessel fuel costs to a minimum.

Another interest is to assess the environmental effects of discharges during in-water cleaning of weathered, overgrown antifouling coating, possibly containing a mixture of biocidal substances. One way of assessing the adverse effects of this chemical cocktail is to perform ecotoxicological tests with whole effluents. A broad range of marine algae and invertebrates can be used in ecotoxicological tests that may also include early life stages of fish or adult fish. For ethical reasons, however, tests using vertebrates (like fish) should be avoided or limited to the extent possible. In general, tests with whole effluent provide an insight into how species might respond to also unknown substances in the effluent, or substances not deemed important on its own.

Data on the toxicity of chemicals to marine organisms can be used in environmental risk assessment of commercial products (e.g., an antifouling coating) or services (e.g., in-water cleaning of vessels). The risk assessment may include exposure modelling to evaluate the size of the aquatic area which may be impacted by effluents containing toxic substances.

The modelling approach may also be used for the sound emitted by ultrasonic growth prevention systems. Depending on the frequency of the ultrasonic transducers, the sound waves are emitted in the hearing range of various aquatic mammals. Although authorities might be more used to regulate chemical emissions, the possible impact on the environment from exposure to noise is also relevant. Inspiration can be found in the consideration of other kinds of offshore noise management. However, consideration of the varying frequency ranges (and sound levels) is important, and a model environment for a standardized risk assessment would benefit the possibility of comparing different technologies.

Hydrodynamics of Biofouling: Blending Hull Inspections to High-Fidelity Computations and Experiments

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Abstract

We have an incomplete understanding as to how biofouling contributes to generation of hydrodynamic drag. The main roadblock in reliable prediction of drag penalties is the absence of correlations relating biofouling topography to the resulting drag forces. To address this problem, we utilize topography resolving direct numerical simulations coupled to laboratory experiments. Surfaces are synthesized using individual biofouling organisms as building blocks to produce topographies that are representative of ship hull roughness, while simultaneously varying surface statistics (e.g. planar solidity, frontal solidity) within a set of ranges. Results suggest that there is a high correlation between the roughness function and the frontal solidity, while the latter showed strong correlation with both the viscous and pressure forces as well.

1. Introduction

Biofouling is the unwanted accumulation of marine organisms on the hull of vessels, which can result in increased drag and fuel consumption. The economic significance of the biofouling has been discussed in great detail in *Schultz et al. (2011)*, where it is underlined that the total cost associated with just one specific class of US Navy vessels (DDG-51) can rise up to $1B over a 15-year period cycle. *Schultz (2007)* has conducted laboratory-scale ship experiments to assess the biofouling impact to the required shaft power of a full-scale ship due to various fouling conditions and concluded that in the case of heavy calcareous fouling the powering penalty can increase up to 86%, compared to a hydraulically smooth hull. It is therefore an evident need for the marine community to focus on developing effective antifouling coatings that would prevent the marine organisms from attaching on the ship hulls.

Over the last decades multiple studies have focused on the interaction of wall-roughness with turbulent boundary layers, but only few of them targeted specifically biofouling-type roughness and their impact on the hydrodynamic drag. Analyses of scanned biofouled surfaces indicate that such roughness is in the high skewness (Sk>1) and low effective slope (ES<0.5) regime, *Dehn et al. (2017)*. Working toward that direction, *Schultz (2004)* conducted a study to investigate the frictional resistance of different antifouling coatings utilizing actual barnacle-fouled topographies and found that the silicon-based surfaces where the ones to result in the highest skin-friction values. *Monty et al. (2016)* presented experimental measurements over boundary layers with light calcareous fouling (tubeworms surfaces) and estimated the final drag penalty on a ship using scaling analysis. In order to reconstruct a realistic biofouling surface, they assembled the final roughness by using repeated tiles of scanned fouled coupons. In an effort to assess the drag impact of barnacle-type topographies *Kaminaris et al. (2023)* by employing direct numerical simulations over boundary layers with spatially inhomogeneous roughness concluded that the highest contribution to the total drag arose mainly from the pressure force imposed by the organisms (even up to ≈88%). Furthermore, *Sarakinos and Busse (2022)* performed direct numerical simulations of turbulent channel flows over barnacle-type topographies with light clustering and observed that the frontal solidity, λ_f, has the highest impact on the roughness function for low planar solidity, λ_p, topographies.

The motivation of the current work is to generate controlled rough surfaces that resemble actual biofouled topographies and to investigate which surface parameters best correlate to hydrodynamic drag. We will report Direct Numerical Simulations (DNS) of turbulent boundary layers over barnacle and tubeworm populated surfaces, which are carefully synthesized to mimic actual biofouled topographies. To cover a wide parametric space a highly efficient, in-house, Navier-Stokes solver based on an immersed boundary formulation is utilized, alongside a sophisticated algorithm encharged with the surface generation.

2. Approach

2.1. Direct Numerical Simulations

In the present study four different planar solidity (10%, 17%, 39%, 57%) random topographies of barnacle-type were studied, alongside a staggered one with 39% planar solidity. In addition, three different random topographies of tubeworm-type were studied all at the same 10% planar solidity, with varying frontal solidity levels ($\lambda_{f,min}$=3.8%, $\lambda_{f,med}$=4.3%, $\lambda_{f,max}$=6.2%). All the flows with barnacle-type topographies were simulated on a 200D x 28D x 20D domain (D is the base diameter of the truncated cone), in the streamwise (x) and spanwise (z) and wall-normal (y) directions with 6002 x 1202 x 348 points respectively, while the tubeworm-type topographies were simulated on a 150D x 28D x 20D domain, with a finer resolution of 7202 x 1802 x 370 points to accurately resolve the smaller size tubeworms. The barnacle-type topographies are exactly the same as the ones reported in *Womack et al. (2022)* and *Kaminaris et al. (2023)*. The computational domain matches exactly the dimensions of the experimental domain. The Reynolds number of the computations matches the one of the experiments at a distance of 30D upstream of the leading edge of the roughness. The friction Reynolds number just before the leading edge of the roughness is equal to $Re_{\tau(LE)}$ = 750.

The Navier–Stokes equations for incompressible flow are solved on a structured Cartesian grid using an in-house finite-difference solver coupled to an immersed-boundary (IB) formulation, *Yang and Balaras (2006)* to impose the no-slip boundary condition on the roughness surface.

2.2. Topography generation algorithm

The novelty of the present study mainly lies upon the generation of rough surfaces representative of commonly observed configurations of biofouling organisms. Such topographies are identified by high skewness and low effective slope values. The topography generation in the present study is handled by our in-house, object-oriented Python algorithm. The algorithm is composed of three main parts, which are summarized in Fig.2:

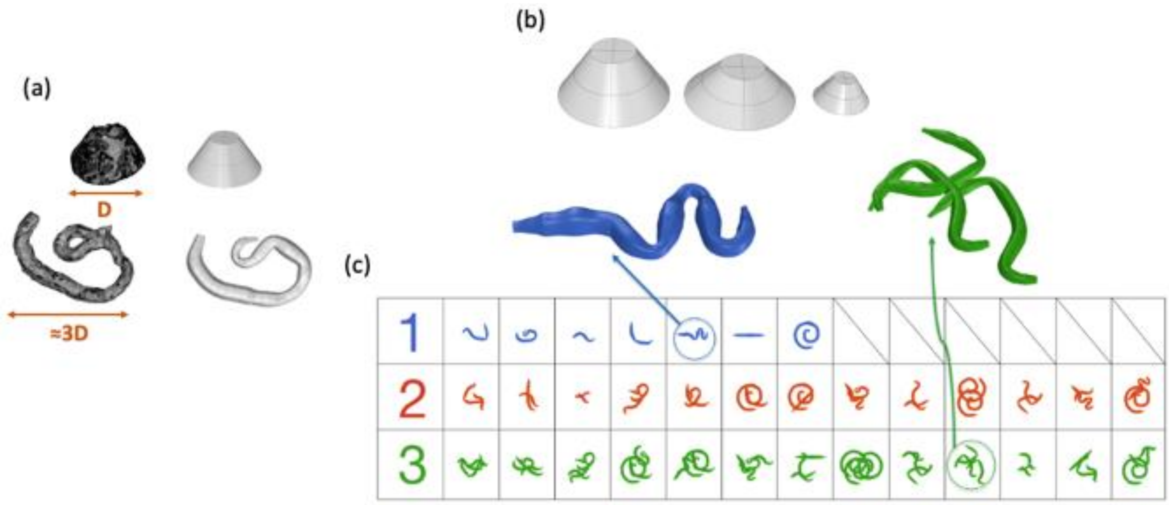

Fig.1: a) Scanned and modeled organisms, b) database of barnacle-type organisms and c) database of tubeworm-type organisms

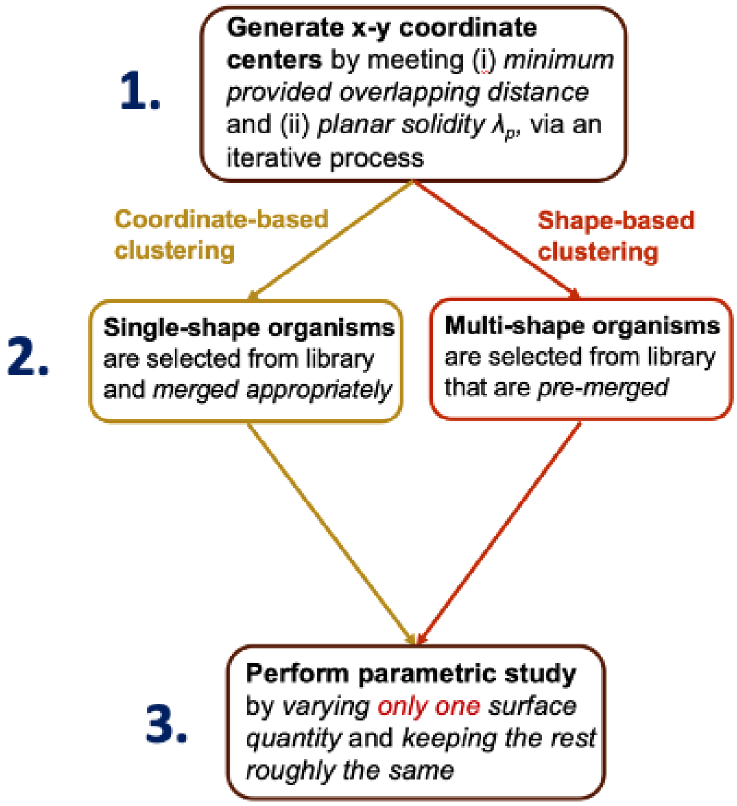

Fig.2: Diagram of the topography generation algorithm

1) Generation of the xy centre-coordinates of the marine organisms. In this step the desired planar solidity, λ_p, as well as the minimum overlapping distance, d_{min}, are satisfied via an iterative process. A random (x_o,y_o) set of coordinates is initialized followed by a second (x_1,y_1) set. The Euclidian distance, d_E, is found between the two sets of coordinates and compared to the minimum overlapping distance. If $d_E \geq d_{min}$ then the second pair is accepted and proceed to the generation of the third coordinate set, if not then another (x_1,y_1) set is generated and re-compared. This process continues until the desired planar solidity is met.
2) Organism-shape assignment to every xy set of coordinates and the resulting clustering level. There are two options that can be selected in this step. The first option ("Coordinate-based clustering") uses single-shape organisms, Fig.1b-c, and gives more flexibility and randomness to the resulting topographical field, but on the contrary, if one wants to produce physical biofouling surfaces then a significant organism-overlapping should be present, which creates two main issues. Firstly it imposes an increased computational challenge for the merging of the overlapping organisms; a continuous surface is needed for the IB formulation; and secondly it makes the control of the topographical statistics of the resulting topography almost impossible, since the merged organism statistics will significantly differ compared to the single ones. The second option ("Shape-based clustering"), however, efficiently bypasses that issue by using pre-merged multi-shape organisms, Fig.1c, with a priori known topographical statistics. In this way one can maintain high d_{min} values, without compromising the statical control. It is mentioned, though, that the extent of the organism configuration library becomes then a crucial parameter for the randomness conservation. Here, 33 different organisms are used under various directional orientations to ensure randomness, which is post-verified by the Morisita index of dispersion (I_δ) quadrant method (not shown here). In the future we aim to expand this library with more shapes and combinations. It is noted that all the organisms used herein were designed in such a way to mimic the shape of actual organisms obtained via detailed scans, Fig.1a.
3) Parametric modification of the topography. In this step only one topographical statistic is varied, while the rest are kept the same. In a pre-processing step a library of various angles (with

regard to the flow-axis) and their corresponding frontal solidities is generated and stored, Fig.3. Then, once the main algorithm reaches the third step, all the organisms are individually rotated by an angle, φ, extracted from the stored library in such a way to create three different topographical arrangements - one with the lowest possible frontal solidity ($\lambda_{f,min}$), one with an intermediate frontal solidity ($\lambda_{f,med}$), and one with the maximum frontal solidity ($\lambda_{f,max}$). In this way one can conduct a systematic investigation by isolating the influence of each surface statistic to the resulting drag force. Currently, the frontal solidity variation is the only option, but in the future, we aim to expand to other statistical quantities as well.

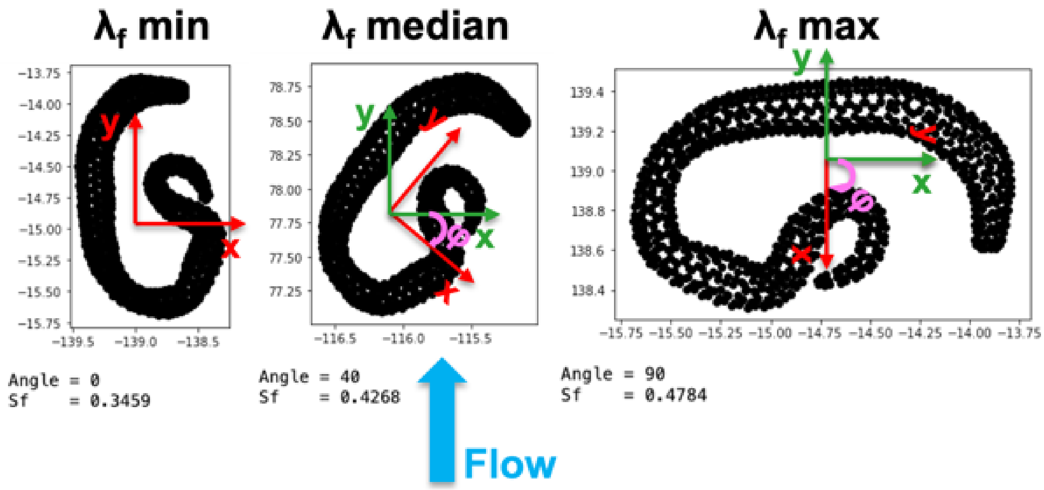

Fig.3: Visualization of the generation process of the frontal solidity, λf, parametric library

As a quick refence the planar and frontal solidity are defined as follows:

$$\lambda_p = \frac{S_p}{S_o}, \quad \lambda_f = \frac{S_f}{S_o},$$

where $S_p = \hat{n}_o \cdot \underline{S}$, $S_f = \hat{n}_u \cdot \underline{S} < 0$, $\underline{S}$ the surface area vector, $\hat{n}_o$ the vertical unit vector and $\hat{n}_u$the unit vector in the direction of the flow.

3. Validation

To assess the accuracy of the DNS set-up we directly compare the mean streamwise velocity and normal Reynolds stresses profiles at the experimental measurement station, Fig.4.

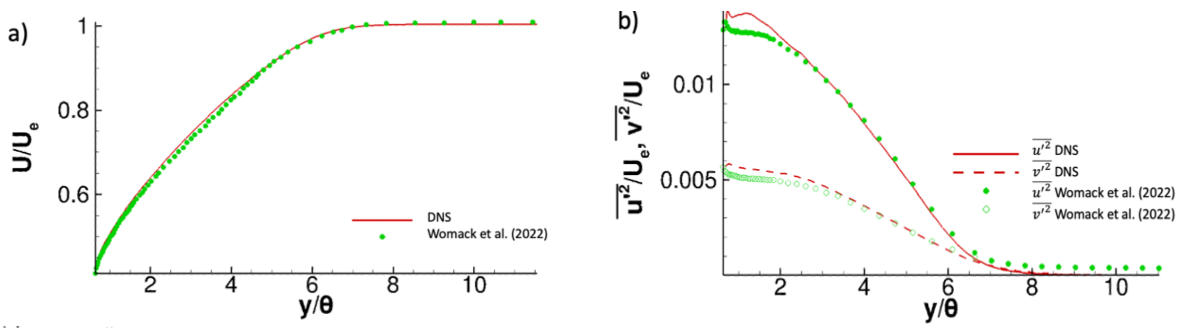

Fig.4: a) Mean streamwise velocity and b) normal Reynolds stresses at the experimental measurement location for the case of the barnacle-type roughness with λ_p=17%.

The agreement is very good, and it is within the experimental uncertainty and sampling error of the DNS. Here, the barnacle-type roughness with λ_p=17% (R17) is shown, but similar trends were observed for all of the topographies studied.

4. Topography-flow correlation

The barnacle-type topographies considered but not shown in the present study can be found in *Kaminaris et al. (2023)*. The three different tubeworm-type topographies with the same planar but different frontal solidity levels, alongside the barnacle-type topography with the same planar solidity are shown in Fig.5.

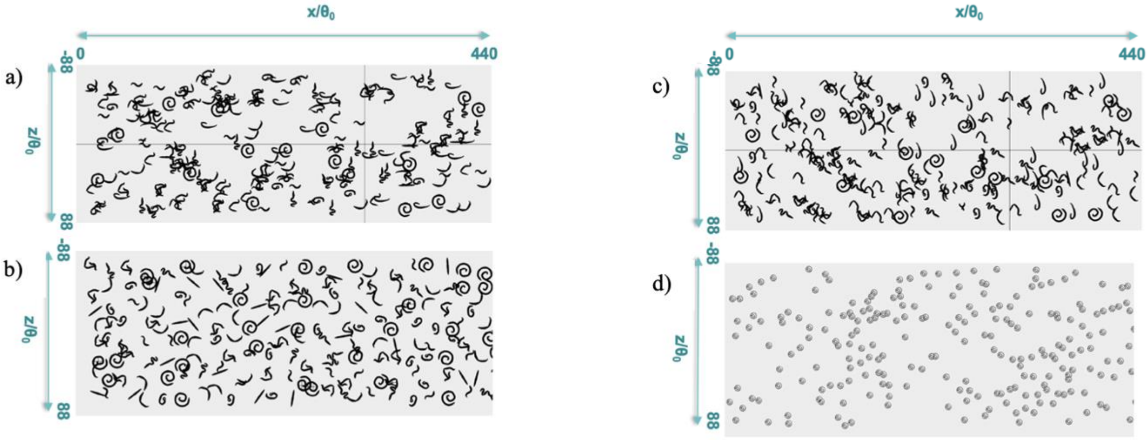

Fig.5: Biofouling synthesized topographies with λ_p=10%. Tubeworm-type topographies with a) $\lambda_{f,min}$=3.8%, b) $\lambda_{f,med}$=4.3% and c) $\lambda_{f,max}$=6.2%. d) Barnacle-type topography with λ_f=3.6%.

The streamwise evolution of the momentum thickness, θ/D (D: the barnacle base diameter), over the full extent of the boundary layer for the topographies shown in Fig.5 can be seen in Fig.6. Looking at Fig.6a it is evident that the frontal solidity clearly affects the growth of the boundary layer in topographies with same planar solidity. Specifically, it seems that the growth rate increases as the frontal solidity increases. In contrast, when topographies of different organism type but of same planar and frontal (almost) solidities are compared, the mean height, $\bar{h}$, seems to be the defining factor regarding the boundary layer growth, Fig.6b. In this case the greater the mean height the faster the boundary layer growth, which means that the boundary layer grows faster over the barnacle-type topographies. We should note though, that other topographical statistics or even the shape of each organism type may play an important role on the growth and should be further investigated.

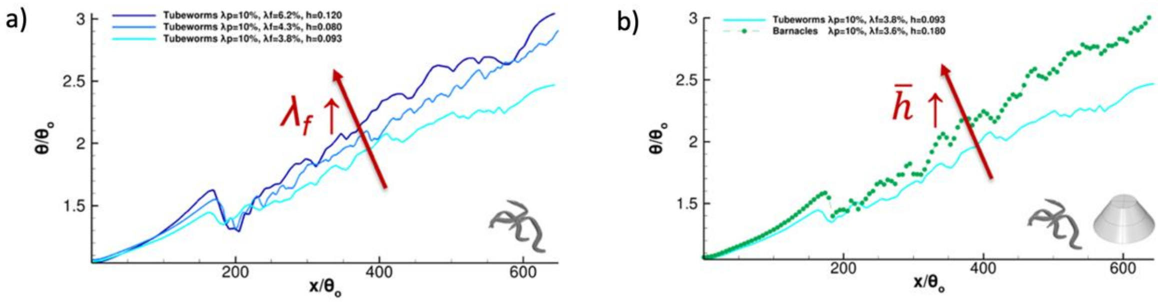

Fig.6: Streamwise evolution of the momentum thickness, θ/D, over surfaces with λ_p=10%, for the case of a) tubeworm-type topographies, b) tubeworm- and barnacle-type topographies.

Interestingly, the frontal solidity impact to the friction velocity evolution, u_τ/U_e, does not follow the same trends as the boundary layer growth. Specifically, Fig.7a indicates that the mean height, $\bar{h}$, constitutes a very important factor in the friction velocity magnitude and it is speculated that the decrease in the mean height "balances out" the increase in the frontal solidity (cases $\lambda_{f,med}$=3.8% and $\lambda_{f,max}$=4.3%). On the other hand, when the statistically similar barnacle- and tubeworm-type topographies are compared the same trend of the mean height scaling is observed as in the boundary layer growth.

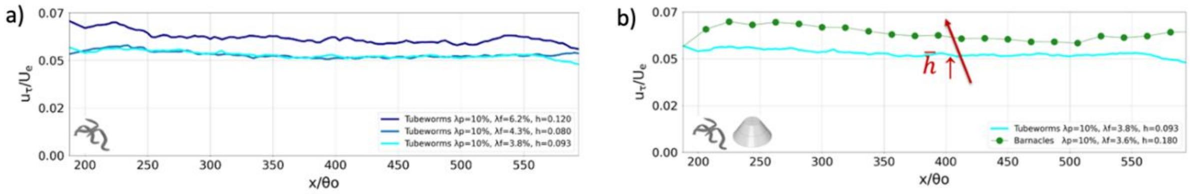

Fig.7: Friction velocity, u_τ/U_e, with regard to the streamwise distance, x/θ_o for a) tubeworm-type topographies, b) tubeworm- and barnacle-type topographies.

It is well established in the literature that the mean velocity profiles can be split into two layers, the inner and outer layer. In the overlapping region of those a logarithmic region exists, which is called the "log-law" and in the case of rough-wall flows it is expressed as follows:

$$U^+ = \frac{1}{\kappa} ln(y^+) + B - \Delta U^+ \qquad \text{Eq.(1)}$$

The same equation is valid in the smooth wall flows as well, without the presence of the roughness function, ΔU^+. The downwards shift inserted by the roughness function, ΔU^+ is used in the rough-wall flows to represent the momentum deficit caused by the roughness compared to a smooth-wall case.

The roughness functions, ΔU^+, according to *Hama (1954)* can be found by the equation below at the same displacement thickness Reynolds number Re_{δ^*}:

$$\Delta U^+ = \sqrt{\frac{2}{c_{f\,S}}} - \sqrt{\frac{2}{c_{f\,R}}} = U^+_{e\,S} - U^+_{e\,R} \qquad \text{Eq.(2)}$$

Eq.(2) implies that the outer-layer similarity has to be satisfied in order to be used, as it happens to be in *Flack et al. (2005)*, *Schultz and Flack (2005)*, and *Wu and Christensen (2007)*. In the present, however, outer-layer similarity is not achieved (not shown) and therefore the ΔU^+ is assessed directly via the more robust graphical method, where the smooth log-law is shifted downwards to match the one of the rough-wall.

In Fig.8 the velocity profiles are shown in inner coordinates, allowing the estimation of ΔU^+. For the tubeworm-type and same planar solidity topographies, it seems that frontal solidity significantly affects the momentum deficit, similar to what was found in *Sarakinos and Busse (2022)* and specifically the higher the frontal solidity the higher the roughness function, Fig.8a. When comparing the cases of different organism type with same planar and frontal (almost) solidity topographies the mean height $\bar{h}$ seems to be the defining factor, consistently with the impact to the boundary layer growth discussed previously.

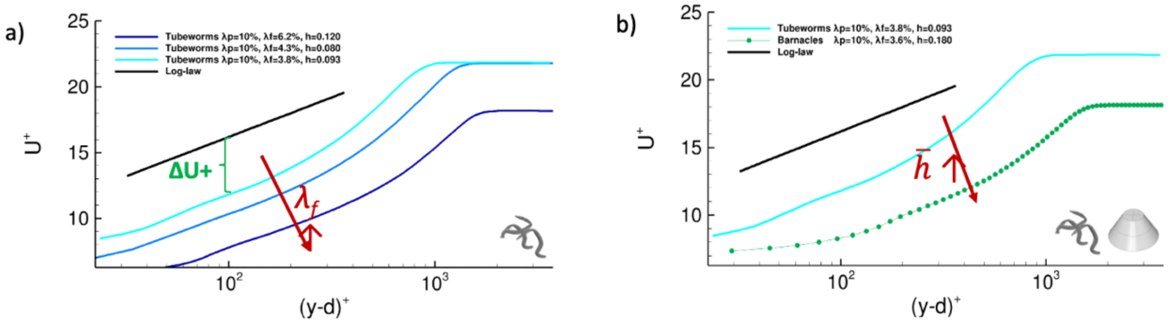

Fig.1: Mean streamwise velocity profiles in inner coordinates for the a) tubeworm-type topographies, b) tubeworm- and barnacle-type topographies

Once the roughness function is assessed the equivalent-sandgrain roughness height k_s, can be estimated via Eq.(3). The equivalent sandgrain roughness height, k_s represents the height of uniform, closely packed sand that results in the same roughness function, ΔU^+ as it does the roughness of our interest in the fully rough flow regime, *Schlichting (1979)*. In this way all kind of topographies can be expressed into the same length-scale, allowing us to "universalize" the impact any given roughness can have to the flow.

$$\Delta U^+ = \frac{1}{\kappa} ln(k_s^+) + B - 8.5 \qquad \text{Eq.(3)}$$

Finally in Fig.9 the equivalent sandgrain roughness height, k_s/D, is shown against the planar solidity for various topographies studied, as estimated via Eq.(3) for the constants of B=4.17 and κ=0.384. It is clear that as the planar solidity increases the k_s/D (D: the barnacle base diameter) increases as well (blue arrow in the figure). On the other hand, for the tubeworm-type topographies with the same planar solidity the k_s/D increases as the frontal solidity increases (red arrow in the figure). Therefore, the former observations suggest that the drag exerted on a ship hull is a function of both the planar and frontal solidities.

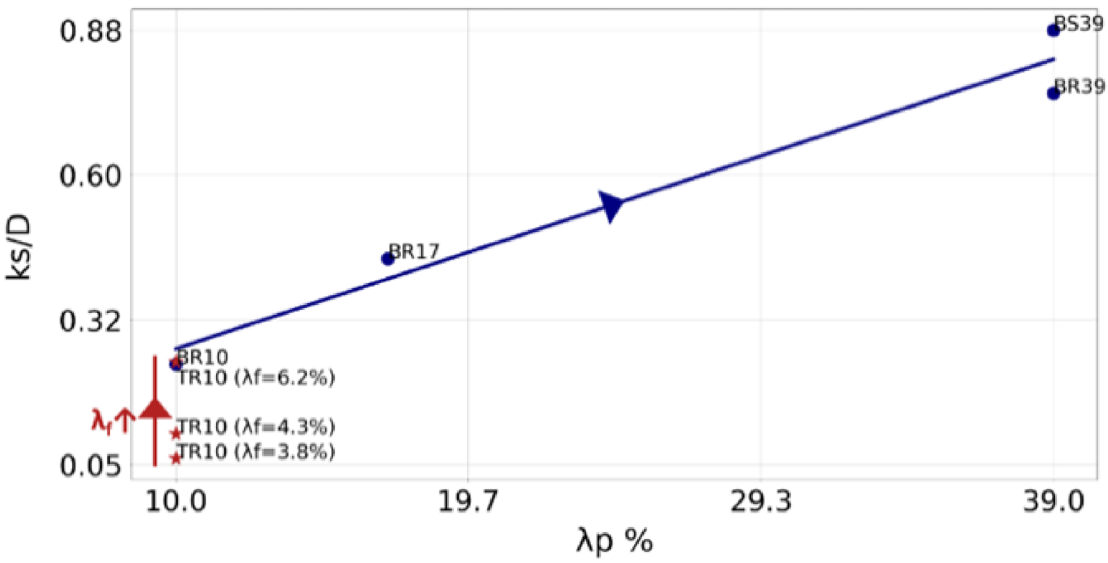

Fig.9: Equivalent sandgrain roughness height, k_s/D, with regard to planar solidity, λ_p, for a variety of topographical arrangements

To thoroughly investigate the drag-topography relationship the pressure and viscous forces are separately evaluated on the discretized surface of the roughness. To allow more generalized arguments to be made the forces alongside the main topographical statistics are evaluated inside a cluster of sample bins. In this way local singularities are significantly restricted from biasing the overall trends. As can be seen from Fig.10 there is a weakly linear increase of the pressure force, F_{px}, with the increase of the frontal solidity, which seems to hold for all the topographies studied herein. The respective trends to ES and $\bar{h}$ found similar to the λ_f for the barnacle-type topographies, but significantly weaker for the case of the tubeworm-type topographies.

With regard to the relationship of the viscous forces with the frontal solidity, the opposite trend is obtained -as the frontal solidity increases the viscous force decreases. *Schultz (2004)* made a similar argument, by contending that the higher the planar solidity of the barnacles the lower the viscous drag will become. Interestingly, the slope of the decrease is weaker in the case of the λ_p=10% barnacle arrangement. As for the pressure forces trends, the respective viscous force trends to ES and $\bar{h}$ found similar to the λ_f for the barnacle-type topographies, however clearly weaker for the case of the tubeworm-type topographies.

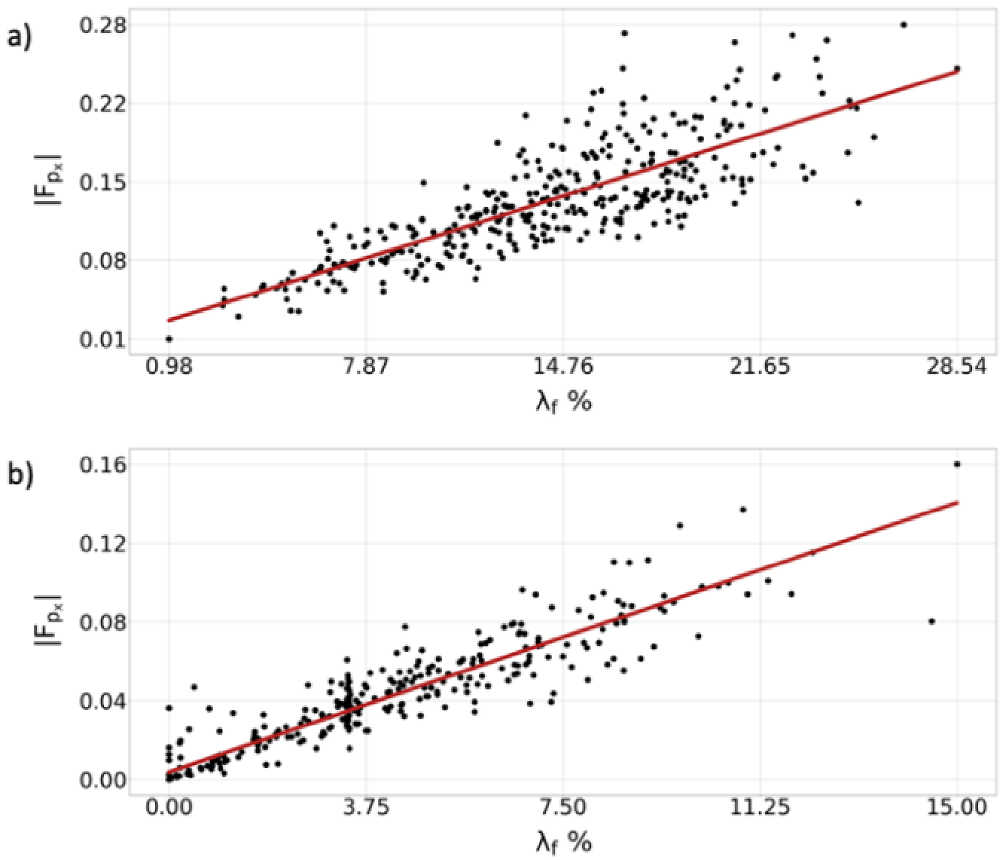

Fig.2: Pressure force, $F_{px,}$ with regard to frontal solidity, λ_f, using sample bins for the barnacle-type topographies for the a) λ_p=39% and b) λ_p=10%

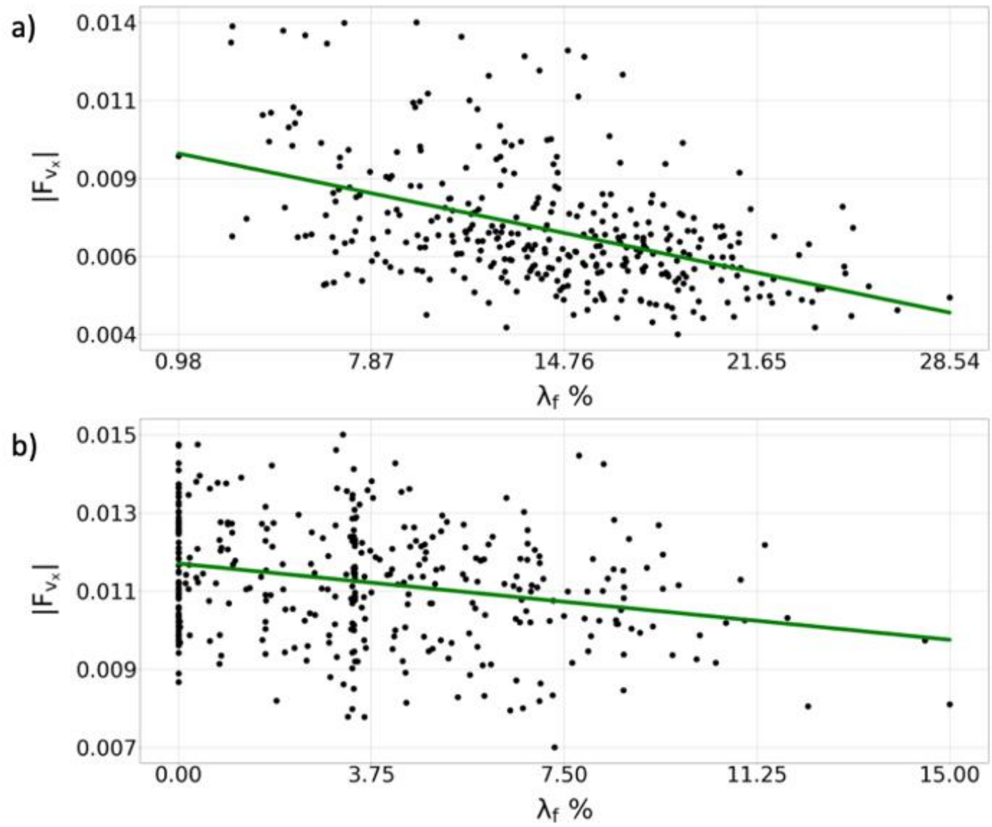

Fig.3: Viscous force, $F_{px,}$ with regard to frontal solidity, λ_f, using sample bins for the barnacle-type topographies for the a) λ_p=39% and b) λ_p=10%

5. Conclusion

Direct numerical simulations were performed over a range of different barnacle- and tubeworm-type topographies and their correlation with the flow statistics was presented. It is concluded that increased values of frontal solidity led to both increased values of boundary layer growth, as well as roughness function, ΔU^+ and consequently to increased drag. Surprisingly, mean surface height, $\bar{h}$, seemed to be important only in the skin friction magnitude. The parametric study that was employed in the tubeworm-type arrangements revealed underlying correlations that otherwise would be very difficult to be stated. Moreover, significant correlation between the pressure and viscous forces and the frontal solidity was detected, with the former found to increase as frontal solidity increases, while the latter to decrease.

Acknowledgement

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Testing of In-Water Hull Cleaning Equipment, the Know-How

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Abstract

This paper intends to share the experience of testing In-Water Hull Cleaning Equipment. The factors determining the choice of standards/requirements, development of test plan, logistics / conducting of the test, data recording and analysis. Insight into lesson learned and best practices for future testing.

1. Introduction

Biofouling have been identified as a major vector for transfer of invasive aquatic species. Biofouling also has a major impact on the hull/propeller efficiency resulting higher fuel consumption thus increase the operational costs and GHG emissions. Bio fouling management has become crucial in the present-day shipping and has drawn attention of the stakeholders such as vessel owners, managers, charterers, local port authorities and various environmental agencies.

Maintaining a clean hull being the objective, in water hull cleaning has become vital component of vessel operation. Various cleaning technologies and practices are being used to maintain clean hulls. However, it has been a challenge for vessel operator to conduct In-water hull cleaning (IWHC) services during port stay (withing the port limits) as such operations generally not allowed. Port locations where IWHC permitted, is of a type ''with capture'.

Local authorities expect high suction ratios, high separation grades of effluent (collectively known as capture ratio in some publications).

Consequently, the impact of IWHC on the coating lifespan is another matter to be looked at as compatibility of cleaning technology / method has varying impact on the condition of the coating across different coating types.

Testing the performance of IWHC devices, in terms of cleaning, efficacy of capturing debris while cleaning, separation grades and level of disinfection, as applicable has not being conducted in larger scale with a consistence methodology.

2. In-water hull cleaning

Depending on the level of fouling and stage of use, cleaning operations can be broadly categorized in to two parts.

- Proactive cleaning - Proactive In-Water Cleaning is the periodic removal or reduction of biofilm growth (i.e., microfouling or slime layer) on ship surfaces. Proactive In-Water Cleaning also removes newly settled or attached microscopic stages of macrofouling organisms, to ultimately minimize macrofouling. Growth, *ACT-MERC (2023)*.

- Reactive cleaning **-** Reactive In-Water Cleaning is used to remove already established macrofouling organisms, *ACT-MERC (2023)*.

Both above operations could include debris capture, separation, treatment, and disposal. However, it is more common in the reactive cleaning technologies.

2.3. Local environmental impact

Number of port authorities (eg. New Zealand) have impose bans prohibiting the in-water hull cleaning in their territorial waters, mainly due to the potential release of debris during cleaning. The number of countries impose these restrictions tends to increase.

In the current industry trends of IWHC, we could observe that there are number of technology/service providers emerging with the claims of varying level of Cleaning efficacy, Capture rates, Separation efficacy, Coating compatibility (possibility of using the system without damaging the coating) etc.

Some port authorities have introduced their own testing regime to evaluate IWHC technologies and allow In water hull cleaning service providers to carry out hull cleaning. (eg: Flemish ports, Australia)

2.4. Standards for In-Water Hull Cleaning

Industry association and Academia also have come up with testing regium, approval standards for IWHC.

BIMCO has published ‘approval procedure for in-water cleaning companies’ and ‘standards for ship hull cleaning’.

Maritime Environmental Resource Centre (MERC) under the Alliance for Coastal Technologies published a paper *ACT/MERC (2022)*, “Guidelines for Testing Ship Biofouling In-Water Cleaning Systems” to provide guidance to concern parties to test and approve In water hull cleaning companies.

These guidelines provide test procedures for performance assessment of IWHC technologies, but the lack of clarity on the authority issued approval and certification, degree of assessment of the reliability and compatibility of the technology, details for evaluation of performance claims and limitations, assessment of the operator is noticeable.

Lloyds Register believe any assessment of IWHC should consist of both the technology and operation. Understanding the limits of the technology and level of sophistication/competence to operate machinery are both in separable for optimum performance. For that regard, LR have developed a test specification to assess and approve In Water Hull Cleaning Technologies depending on their technology claim in both proactive and reactive in water hull cleaning. In combination with LR approved service provider scheme, the technology and the operation can be evaluated and certified.

LR test specification has been developed taking into account following industry standards and guidelines,

1. BIMCO Approval procedure for in-water cleaning companies
2. ACT/MERC, 2022. Guidelines for Testing Ship Biofouling In-Water Cleaning Systems.
3. Procedure for Hull cleaning in Flemish ports
4. Australian in-water cleaning standards

In addition, we have included a “controlled test” in the Test Specification to determine the efficacy of the system in a controlled environment which would assist to compare the various cleaning technologies under the same physical/environmental conditions.

Our intention is to provide an approval scheme to the in-water hull cleaning systems after a robust but practicable test regime which would provide technology providers and operators a recognition of an approval by an independent party.

This certification aims to provide the industry stake holders to build confidence on the certified equipment. Further, it may assist port authorities or local governments to consider allowing the certified service providers to operate in their waters by reducing the burden of conducting testing and evaluating results by themselves.

3. LR Test Specifications for Approving In Water Hull Cleaning Systems

This test specification specifies the LR requirements to approve In Water Hull Cleaning Systems with Capture and the Associated equipment. This test specifications will aid the equipment manufacturer to develop their products to meet LR type approval requirements and obtain type approval for their products after going through design review, type testing and verification of the manufacturing facilities.

The certification process consists of the followings,

3.1. Design review

Manufacturer is to submit the design aspects of the system including the components used, P&ID diagrams, wiring diagrams, control philosophy and functionality details.

Review of IWHC system components and equipment will be conducted in accordance with LR rules, accepted industry standards or National/International standards as applicable.

Mechanical, electrical and control components are to be suitable for their intended purpose and accordingly are to be selected from the list of Type Approved Products published by LR where applicable.

The intention of the thorough design review is to assess and confirm the equipment is suitable for the intended purpose whilst meeting the required safety standards. (Ref: LR test specification Stage A)

3.2. Control Test (For equipment with capture)

Hull cleaning equipment will be broadly devised in to two parts (Cleaning head and Separation unit) and the performance in the aspects of efficacy of each part will be assessed during the controlled test.

A test in a controlled environment would facilitate a fair and accurate assessment and recording of the cleaning system in the efficacy characteristics.

Further, a result of the control test should provide a fair comparison between two systems as the testing conditions will be the same for the similar systems being tested.

During the controlled test, the system should be performed at the declared operational parameters of the technology provider.

3.2.1. Capture efficiency of the cleaning head during the cleaning

Capture efficacy of the cleaning head is to be evaluated under control condition. This can be achieved by using a plate with harvested biofouling in a tank and sampling arrangements at required locations. The tank is to be sized appropriately to accommodate operation of the cleaning head and water volume required for the function.

Metal plates with the required foul rating should be prepared as per the declared performance claim by the manufacturer. Artificially or natural growing or accelerated growing of biofouling can be used as per the approved test plan.

3.2.2. Efficiency of the separation unit

Degree of separation will be assess using an influent flow with predefined TSS and PSD loading at flow rate similar to the manufacture's declaration. The separation unit should be in normal operational condition to the limits of flow and particle loading.

3.2.3 Challenges during the controlled test.

- The actual cleaning unit might not fit in the water tank or the cleaning surface due to the size limitations. In this case, scaled down version of the cleaning unit would have to be used. Manufacturer should verify the scaling down would not impact favourably or adversely compared to the full-scale version in normal operation.
- Growing/simulating of the fouling on the plate could be challenging as it takes time to grow biofouling naturally. Different options can be considered such as accelerated growing, 3D printing, etc.
- Size and position of sampling is crucial in order to collect representative samples and to accurately quantify the constituents.
- Conversion factor of wet/dry fouling is also unique to the type of fouling and material.

3.3. Coating condition assessment (Optional)

One of the major concerns of In water hull cleaning is the impact it might have on the coating. If a technology provider claims that their system does not or have a minimum impact on particular type of coating and that claim need to be evaluated. This particularly important for Hull grooming/ proactive cleaning technologies that advocates high frequency of clean/groom.

A test plan is to be developed to assess the impact on the coating. The coating specification and the criteria of assessment should be agreed and confirmed by the coating manufacturer. A set number of repeated cleaning runs need to be conducted to analyze the topography of the coating specimen and measure thickness, as applicable. Sample of water column for biocides, TSS, microplastic as applicable can also provide input to the assessment criteria.

3.4. In situ testing (Full scale testing)

Objective of the full-scale testing is to verify the performance of the system under real life operation conditions.

This part of the testing procedure is similar to local port requirements, BIMCO standards and the guidance document published by Maritime Environmental Resources centre (MERC).

The in-water hull cleaning equipment will be considered as a one unit while performing the test. Overall efficiency of the unit will be assessed in terms of,

1. Cleaning efficacy
2. Capturing efficacy
3. Separation efficacy
4. Impact on the surrounding environment

Some test parameters such as TSS, micro plastics, biocides, organism viability of the effluent etc. have been added according to the technology claim provided by the cleaning system manufacturer/operator.

The test procedure has been developed to facilitate the service provider to obtain BIMCO accreditation for In Water Hull Cleaning with Capture upon successful completion of initial audit.

Further, it is expected to cover most of the current requirements imposed by the local port authorities on In Water Hull Cleaning Operations.

3.4.1, Challenges of In situ testing

- In situ test is to be done with the collaboration of several parties such as Vessel owner, cleaning company, Testing Organisation, Class surveyor, Underwater inspection team etc.
- Conditions such as visibility, Sea state, tides, currents etc. can adversely affect the testing and sampling.
- Preparing a suitable vessel which meet the schedule and requirements of all the parties could be a difficult task. The condition of fouling should be assessed prior cleaning and suitable representative areas of the Hull are to be selected for testing as per the declared technology claim by the equipment manufacture or Service provider.
- Assessment of the cleaning performance is done comparing the before and after photos/videos. As of now we use NSTM 2006 guidelines to assess the fouling rating. However, the comparison is done visually. The ideal way should be to develop a software/machine learning method to assess the cleaning performance to maintain the uniformity of the assessment.
- Quality of the still pictures for the assessment of before and after cleaning is very important. It is preferred to use a picture taken perpendicular to the focus area than parallel. Recommend using professional underwater photography or Biofouling inspection ROV's for this purpose.
- In situ verification testing is involved with the sample collection, preparation, transportation and analysing etc. Engaging a skilled Testing Organisation with the required proficiency was a challenge. Most of the local laboratories are only performing analysis of the samples and not comfortable taking the role of 'Testing organisation'. Due to the limited number of suitable Test Organisations, the testing could be a financial challenge to the equipment manufacturer/service provider.

3.5. Quality Assessment of Operator

Prerequisite for approval, LR would verify the technology provider/Service supplier possesses an adequate quality assurance system and a documented quality system which complies with the current version of ISO 9000 series.

The technology provider/Service supplier should submit the relevant documents for review as per the requirements of LR and BIMCO Approval procedure for In- water hull cleaning systems.

Further an initial audit of the facility will be conducted to assess the quality management system and production quality assurance.

Further, the technology provider/service supplier will be subjected to periodic renewal audits after the approval.

4. Survey, Certification and Audit

The testing will be conducted in accordance with an approved test plan. IWHC manufacturer working with a Test Organization for the development and the execution of the testing. Test Organization shall have the means and expertise in the development of the test plan, conduct testing, sampling & analysis and reporting results.

Lloyds Register will be involved in every step of the approval phase by approving the test plans, witnessing testing, assessing efficacy criteria, auditing facilities and conducting design review. After successful completion, a type of approval certificate for the equipment and approved service supplier certificate for the operator may be issued.

A full report of test data and results will be made available. IWHC provider would be able to present the report and result to relevant authorities, where applicable in order to assess the different performance criteria according to their own regulations/requirements.

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A Smarter Approach to Maintenance and Inspection

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Abstract

Smart robots, meaning those that know their position and can be programmed to operate autonomously, can significantly alter how hull inspection and hull husbandry is conducted, ultimately leading to better planning and operational decisions. Frequent inspection via a subsea robot equipped with precision sensors can provide an unprecedented level of information about hull condition; visual imagery processed through AI to assess fouling and coating condition, ultrasonic thickness mapping, sonar anomaly detection, roughness testing, 3-D scanning. All are possible and can greatly enhance trend analysis and facilitate maintenance planning, as well as be fed into existing vessel monitoring programs. Coupled with frequent, gentle cleaning of the hull, vessel owners and operators can maximize vessel performance through near real time knowledge.

1. Introduction

Hull condition matters. Whether it is the state of biofouling or the condition of the coating, it is information that someone cares about. The International Maritime Organization recently published guidelines for biofouling management (IMO). The guidelines were clear about the need for periodic inspections to determine the state of biofouling and the condition of any antifouling systems or coatings in use. This information can help drive maintenance decisions and may even factor into whether or not vessels are allowed into a given port. It is crucial that these inspections be thorough, and accurately document the condition of the hull. Equally important is that the inspections be done efficiently, so as not to be a disruption in the vessels, or ports routine. Inspections have been the domain of divers for years, although the use of remotely controlled vehicles (ROVs) is becoming increasingly common. There have been tradeoffs with the two solutions; however, technological advances in smart robotics are greatly increasing the efficacy of ROV solutions and can provide an unprecedented level of detail from an inspection, and do so without disrupting vessel operations.

2. Why inspect

In simple terms, biofouling matters for two reasons; risk of transporting aquatic nuisance species (biosecurity) and increasing hull resistance leading to increased fuel usage and emissions released (performance). Performance impacts of biofouling can be assessed via close monitoring of multiple indicators on the vessel; fuel usage, engine power commanded vs speed achieved, and many small details from the engines themselves (pressures, temperatures, rack position, etc.). If the biofouling on the hull is significant enough, vessel performance will suffer, and eventually will be apparent to the operators. Vessel monitoring solutions are designed to identify performance degradation early, and allow decisions about hull cleaning to me made. However, biofouling does not instantly appear on the hull, nor does it instantly provide a performance impact once it grows to a certain level. Instead, biofouling slowly accumulates over time, and will eventually reach a point where the performance degradation manifests itself with a degree of certainty for the monitoring system to flag. In other words, at some point in the process, biofouling is affecting performance without being detected.

In terms of biosecurity, there are areas of the hull that can become fouled without impacting performance, most notably the niche areas, but there may be other areas that due to hydrodynamics have less impact on performance than others. This means that performance monitoring is not necessarily adequate to actually determine the level of biofouling on the hull. The only way to know that actual amount of biofouling on the hull is to look at it. And look at it thoroughly and completely. Inspecting representative areas can only provide so much information. It is also important to note that performance monitoring solutions are not designed for determining coating condition. Damage or wear rates for coatings must be assessed visually.

This is not to say that inspection can replace performance monitoring. Inspection can, and should, supplement performance monitoring. Incorporation of inspection data into the performance monitoring algorithms will provide a more complete understanding of the vessels' performance and will likely yield new insights into how to optimize performance and maintenance practices.

3. Intelligent Robotics

Inspections are traditionally completed via divers or small ROVs. Both solutions document the condition of the hull using a combination of still and video imagery, and rely on the diver, the ROV pilot and other topside observers to assess the condition of the hull. New advances with artificial intelligence (AI) now allow for the imagery to be processed through an AI engine, with the aim of providing a more complete and objective assessment of the hull condition. This should result in more uniform reporting of fouling, and could be integrated into performance monitoring solutions. However, assessment of imagery alone is not sufficient. Position information for the imagery is equally critical, where is the fouling or coating damage actually on the hull.

Divers and ROVs can provide some information on where a given observation is made, but it will lack precision. Depth is straightforward to report, but otherwise the position is likely to be described in relative terms in relation to some known feature on the hull, if at all. Video imagery can contain a narrative, but reviewing hours of video footage is tedious. Still imagery is easy to use in reports, but subsea georeferencing data has traditionally been very limited. A more intelligent solution is required.

Armach Robotics has developed an intelligent robotic solution that can provide a comprehensive inspection and perhaps more importantly a comprehensive inspection report that thoroughly and precisely documents the condition of the hull.

Armach's solution uses a small, autonomous robot (known as a Hull Service Robots (HSR)) to conduct these inspections. The HSR is a hybrid flying and hull crawling robot, approximately 1 meter long and weighs less than 35 kg that can operate on any hull material. The HSR can be equipped with a forward-looking sonar and forward, rear, and downward looking cameras to document the condition of the hull. These inspections can be conducted independently, or more likely as part of a proactive cleaning regimen (discussed later), with pre and post cleaning condition recorded in one evolution. The inspection of the hull surface is conducted by the HSR crawling along the hull, while its free flying capabilities can be employed to inspect the niche areas of the propeller(s) and rudder(s).

Fig.1: Armach HSR and early prototype

Armach’s ultimate differentiator is the use of autonomy and precision on-hull navigation to deliver these reports.

If the HSR knows exactly where it is on the hull at all times, it can be programmed to cover the entire hull efficiently and prove that it provided 100% coverage of the hull. Efficiently providing 100% coverage of the hull is critical to a successful inspection program. If spots are missed, it is an incomplete inspection. Further, the HSR needs to be efficient. Inspections tend to be disruptive to a vessel’s operations, so a full inspection that can be completed during a normal in-port period, without causing any delays if going to be greatly preferred over other approaches.

Because the HSR is autonomous, no one is needed to actively pilot it. The HSR can be monitored by a single person actually multiple HSRs can be monitored by a single person, allowing for two or more robots to perform a single inspection, cutting down on time required. Because of the small size of the HSR, no significant infrastructure is required for its launch, operation, and recovery. As Multiple HSRs can be operated from a single operations unit, typically a commercial van or small trailer, located on the pier near the bow and/or stern of the vessel the inspection can be done while still allowing routine pier operations to continue, avoiding any impact to the vessel's operational schedule.

For a hull inspection or cleaning application, typical GPS based earth relative positioning doesn't really provide any valuable information - what matters is where the robot is on the ship. Ships move. Even tied at a pier, a ship can move slightly, and that movement could exceed the required accuracy to ensure complete coverage of the hull. The HSR is designed with a proprietary system to identify and maintain it “hullographic” position; that is where is on the hull relative to the bow and waterline. Armach Robotics’ sister company, Greensea Systems, has been developing and evolving this hull relative positioning technology for the past 5+ years in partnership with the US Navy’s Office of Naval Research. Built on Greensea’s industry leading OPENSEA open architecture software platform for marine robotics, the hullographic positioning system utilizes a fiber optic gyroscope based Inertial Navigation System (INS), Doppler Velocity Logger (DVL), precision odometry and forward-looking multi-beam sonar to establish and maintain positional accuracy within 15 cm regardless of distance traveled.

After launch, the HSR is flown into position near the hull, rolled 90° and attached to the hull, held into position by a low-pressure adhesion system (no magnets needed!). The HSR then builds a map of the hull with the sonar as it crawls along the vessel. The INS, DLV and track odometry work together, monitoring precise alignment and distance traveled to update the vehicle’s position relative to the hull. Even the best INS-based systems will inherently develop an error over time, so a novel feature based sonar navigation capability enables the system to reference its position against previously identified features on the hull to update the vehicle’s position periodically, correcting for any accumulated error. The sonar also provides for obstacle detection and avoidance. With this positioning capability, inspection and cleaning patterns can be programmed within the control software, and the HSR can be turned loose to perform its work. Video, sonar and all positional information is logged during the evolution, providing a complete report on the pre and post cleaning condition of the hull.

The downward looking cameras can provide a mosaic, Fig.2, of the hull of the ship, allowing creation of a zoomable image of the hull. Operators and maintainers will no longer need to only review select representative imagery from the inspection, or spend hours reviewing extended video files. Running the imagery through a suitable AI engine will allow for the objective assessment of the fouling and coating conditions, while still allowing it to be reported out with a high degree of precision. And owners and operators will have the added benefit of knowing exactly what was, and if applicable was not, inspected.

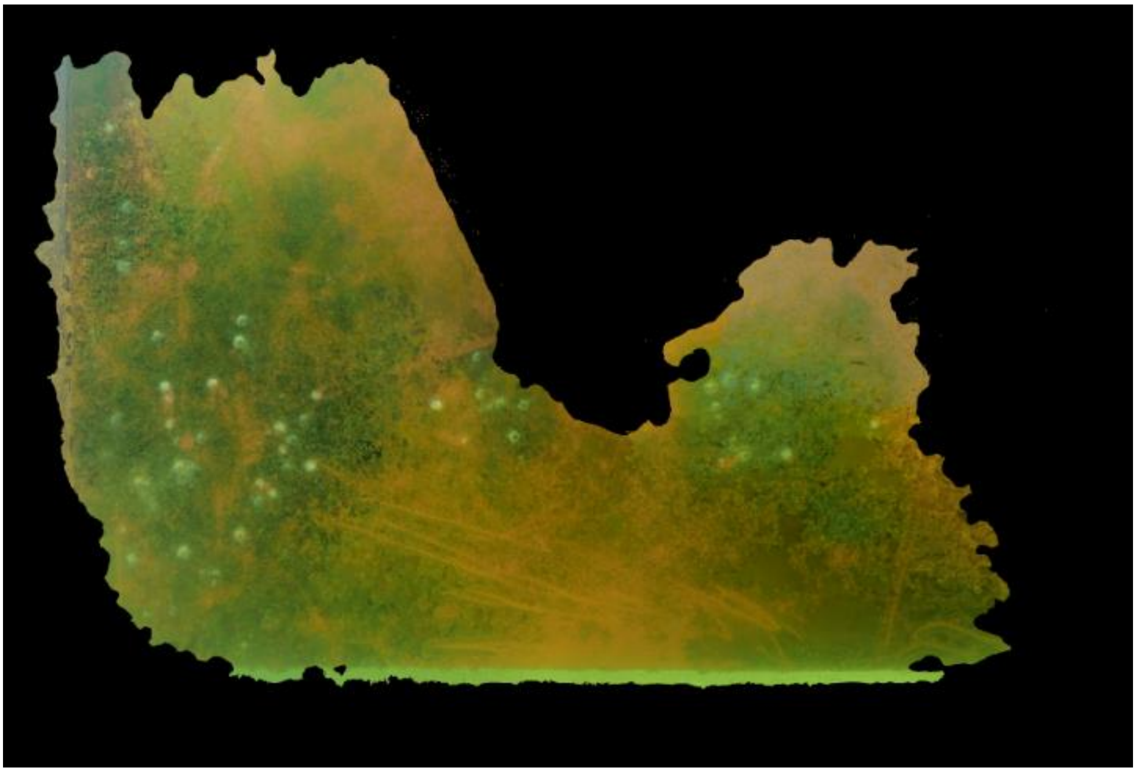

Fig.2: Mosaic image of hull plating showing fouling

This precise information could then be incorporated into a vessel performance monitoring solution, with fouling conditions and any identified coating damage being accounted for.

Additionally, more sensors can be added to the vehicle for specialized inspections, such as ultrasonic thickness testing of the hull plating. Fig.3 shows the mission view of an HSR conducting a survey of a water tank, with each dot representing a location a reading was taken. The information can then be post processed to provide the thickness readings directly overlayed with position, and can be color coded to provide a "heat map" of conditions and potential issues.

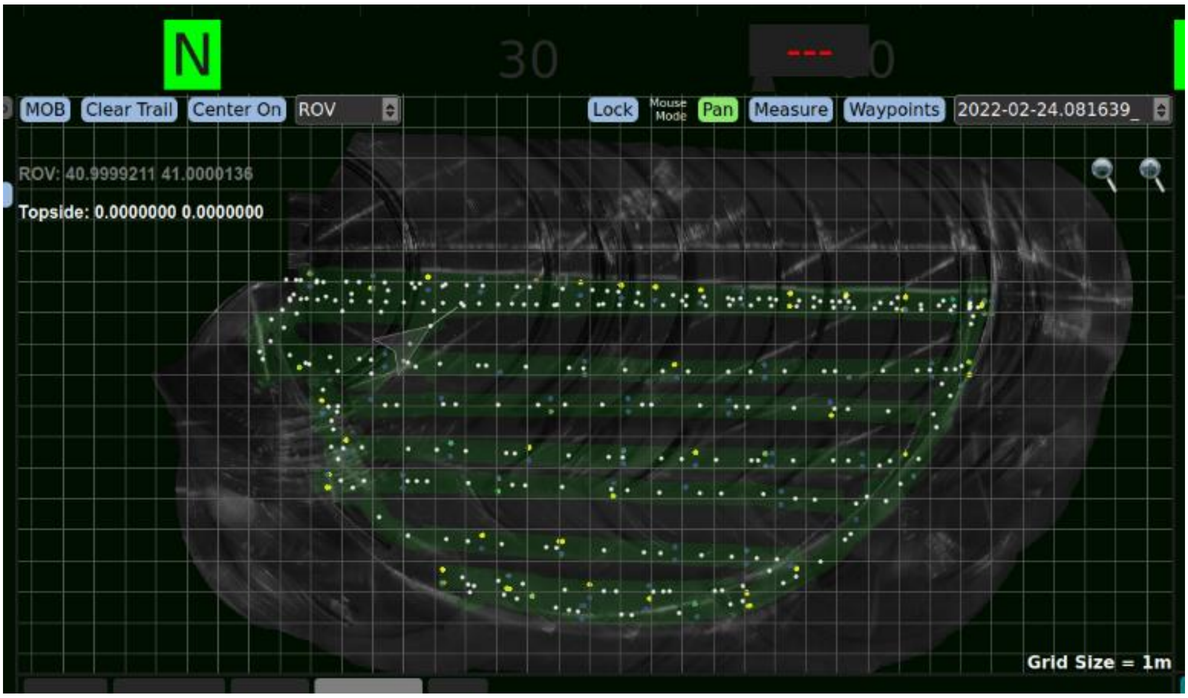

Fig.3: Mission view showing locations of ultrasonic thickness readings in a water tank

This inspection technology is actually an outgrowth of Armach's ongoing work to provide proactive cleaning services with the HSR. As noted, every cleaning evolution will collect the full inspection data for the areas cleaned. The end result will be a post cleaning report that meets or exceeds any existing requirements for inspection.

4. Proactive Cleaning

While the IMO's Biofouling Guidelines do not specify the details of how hull cleanings are to be performed, they do highlight the need to keep hulls clean for biosecurity reasons, and encourage cleanings to be done.

Biofouling accumulation starts as soon as ship enters the water, Fig.4. The rate of accumulation will vary extensively considering environment, operations, and coating system, among other factors. Frequent removal of biofouling, at the microfouling level, via mechanical means is one way to prevent the buildup of fouling organisms. The critical words here are frequent and microfouling. This is what the HSR was designed to do. The HSR's small size and autonomy make "frequent" an economically viable option. The logistics required for use of an HSR (or multiple HSRs) are low compared to many other cleaning systems. Equally important is that the HSR was designed for the removal of microfouling, and only microfouling. Much like a dish cloth differs from a Brillo pad for cleaning pots and pans, the HSR is optimized for its job of removing microfouling. It doesn't require much power, and uses soft brushes that are only good a removing slime and biofilm. This means it is gentler on the coating systems, which in turn means multiple cleanings can occur with less impact than what a traditional reactive cleaning would impart. This is good both for an individual cleaning evolution and its impact on the local waters, as well as over the lifetime of the coating. Field and laboratory testing has show that on select, commercially available and commonly used coatings, no damage occurred after 1,000 brush passes.

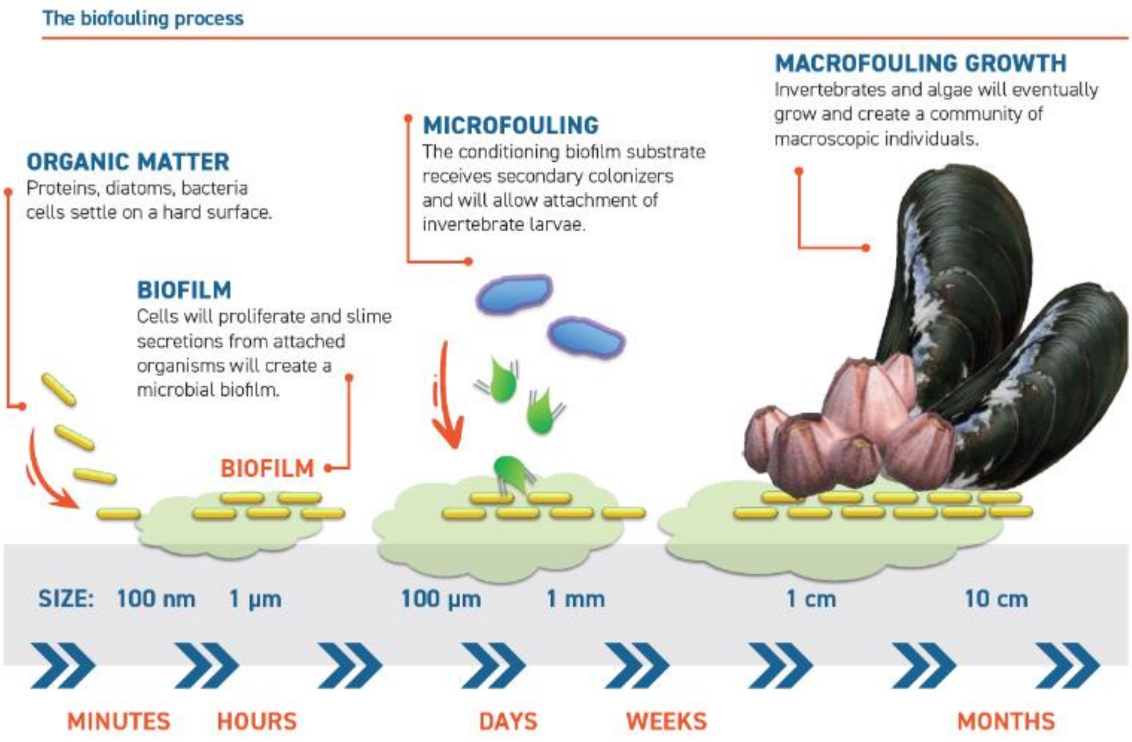

Fig. 4: Progression of Biofouling Growth

With a system that is gentle on coatings, and efficient and economic to use, frequent cleaning should become commonplace. If a ship is cleaned right before departing port, the risk of it carrying any potentially invasive species from that port is low. Transiting the high seas is also considered low risk for biofouling accumulation. This means that a recently cleaned ship should arrive at its next port with a low biosecurity risk. Any biofouling accumulation that occurs while the vessel is in its next port will be local (and thus not a biosecurity risk), and another proactive cleaning event can occur. The result being clean vessels sailing the high seas and not leaving ports as a vector for invasive species.

With the biosecurity risk managed, shipowners will also realize efficiency savings as they will be sailing with an always clean hull. With the aggressive greenhouse gas (GHG) reduction targets in place for the maritime industry, proactive cleaning should be part of any organizations plans for carbon reduction. And for those operators looking beyond fossil fuels, the efficiency benefits of a clean hull will still matter. New alternative fuels are likely to be more expensive, and may be less energy dense, meaning more frequent refueling. Efficiency will continue to matter.

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Developing Canada's Policy on Biofouling & In-Water Cleaning of Vessels: Addressing Challenges and Opportunities as a Regulator

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Abstract

This paper describes Canada's multifaceted approach to the development of biofouling and in-water cleaning policy, through international leadership, outreach and education, and filling knowledge gaps. By commissioning science, engaging with industry, supporting the establishment of a Canadian in-water cleaning industry, and actively participating at the IMO Canada is informing future measures and ensuring science-backed policy. Through strategic assessment of challenges and seizing opportunities Canada is incorporating the information learned to develop a way forward.

1. Introduction: The Canadian Context

Transport Canada (TC) has a mandate to serve the public interest through the promotion of an environmentally responsible transportation system in Canada. With the world's longest coastline to protect, TC is working to reduce the risk of vessels introducing and spreading aquatic invasive species (AIS) and marine pathogens in Canada as the regulating authority of shipping mediated AIS.

AIS can be introduced and spread by biofouling, which refers to the organisms that build-up on underwater surfaces and structures exposed to an aquatic environment, such as a vessel's hull. TC is working to ensure that methods used to reduce these risks, like in-water cleaning and use of anti-fouling systems, are not harming the environment.

In 2022 the Government of Canada announced the next phase of the Oceans Protection Plan which involves a new investment in ocean protection initiatives to proactively combat emerging threats while expanding existing initiatives. This next phase includes funding to prevent the introduction and spread of AIS, allowing TC to advance its efforts in addressing biofouling-related risks.

In Canada, legislative framework of biofouling and in-water cleaning of vessels is a shared jurisdiction between several federal government departments and ports, and is based on the length of a vessel, willingness of ports to permit cleaning activities, and water quality requirements of the jurisdictions where the ports reside.

The biofouling of recreational vessels up to 24 metres in length, is legislated through the 'Aquatic Invasive Species Regulations', under jurisdiction of Fisheries and Oceans Canada. By contrast, biofouling and in-water cleaning of large vessels over 24 m in length is not specifically regulated.

However, provisions of the Fisheries Act, https://laws-lois.justice.gc.ca/eng/acts/f-14/FullText.html, and the 'Canadian Environmental Protection Act', https://laws-lois.justice.gc.ca/eng/acts/c-15.31/FullText.html, apply to water quality as it relates to biofouling management measures, including in-water cleaning of vessels. TC has authority over shipping, and can regulate biofouling management for commercial vessels over 24 m, under Section 190 of the 'Canada Shipping Act, 2001', https://laws-lois.justice.gc.ca/eng/acts/c-10.15/FullText.html. In the absence of federal regulations, Canada Port Authorities can establish their own practices and procedures to promote environmental protection in the waters of the port as outlined in the Canada Marine Act, https://laws-lois.justice.gc.ca/eng/acts/c-6.7/FullText.html. This allows Canada Port Authorities to set rules for in-water cleaning in their respective waters. This adds to the complexity of developing potential policy and regulations in a Canadian context.

To gain a better understanding of biofouling management practices in Canada, a study of ports and shipowners was comissioned in 2018. The results revealed low implementation of biofouling management measures, with one-third of surveyed Canadian shipowners not undertaking preventative measures and one-fourth not managing biofouling at all, neither preventatively or reactively.

Additionally, the study found 64% of surveyed Canadian shipowners did not have biofouling management plans or record books for any of the vessels in their fleet.

In conjunction with the limited legislative framework and Canadian industry's still-developing knowledge, currently there are few in-water clean and capture companies operating in Canadian waters. This poses a challenge for implementing responsible biofouling management practices in Canada. The lack of available in-water clean and capture services makes environmentally responsible decision making difficult for vessels. TC is aware that in-water cleaning and propeller polishing is undertaken in some Canadian ports without capture which may pose risks to local ecosystems.

2. Canada's 4-pillar Approach

Canada has adopted a 4-pillar approach to the development of an evidence-based framework on control and management of vessel biofouling. This approach involves international leadership, outreach and education, filling knowledge gaps, and developing policy options.

2.1. International Leadership

Canada actively participates in the International Maritime Organization (IMO), the United Nations specialized agency responsible for marine shipping. In early 2020, a Biofouling Correspondence Group was formed under the coordination of Norway to undertake the review of the '2011 Guidelines for the Control and Management of Ships' Biofouling to Minimize the Transfer of Invasive Species'. Canada was an active participant in the Biofouling Correspondence Group reviewing the IMO's Biofouling Guidelines to facilitate increased uptake and effectiveness.

Through the correspondence group's work, there were several themes of discussion that emerged, and many submissions with proposals on how to make the guidelines more user friendly. The group supported Canada's proposal to develop standardized Biofouling Management Plan & Biofouling Record Book templates. The IMO template draws inspiration from and is similar to the templates Canada developed for domestic stakeholders. The revised 2023 Biofouling Guidelines, which were adopted at MEPC 80 in July 2023 increase the user-friendliness by including standardized Biofouling Management Plan & Biofouling Record Book templates. The revised IMO Biofouling Guidelines also include methods to assess biofouling, biofouling management actions and timelines, re-organization to reflect the life of a vessel, as well as additional and redefined key terms for greater clarity.

The IMO will be undertaking a new work output to develop guidance on in-water cleaning of vessels. Canada intends to continue its international leadership by being an engaged participant and collaborating with other Member States on developing guidance on in-water cleaning. Biofouling inspections are anticipated to be another key issue with Member States and international organizations invited to submit relevant information on best practices for biofouling inspections and cleaning actions to the IMO.

In addition to IMO work Canada is contributing internationally to the ongoing development of standard methods for performance and documentation of proactive hull cleaning through participation in the Working Group on in-water cleaning of ship's biofouling under the International Organization for Standardization (ISO).

2.2. Outreach and Education

To develop effective policies TC recognizes the need to incorporate a wide variety of viewpoints through outreach and education. TC has presented at and attended numerous forums, like PortPIC, and hosted many stakeholder engagement sessions on domestic and international biofouling policy issues.

To discuss concerns and understand viewpoints TC has met with: Canada Port Authorities, academia, the shipping industry, other government departments, international governments, in-water cleaning service providers, and Indigenous communities.

Engagement revealed that there are still some misconceptions about biofouling risks in Canada, especially in regards to the Great Lakes-St. Lawrence River (GLSLR) region. The GLSLR region is unique as a salt water to fresh water transition zone, which creates complex ecosystems adapted to the changing salinity levels. Commercial shipping plays a vital role in the region connecting Canada to global markets and careful management practices are necessary to prevent the introduction and spread of AIS as some species may survive and thrive in the change of salinity.

Industry has raised concerns about biofouling management costs and the lack of environmentally responsible in-water cleaning services available in Canada with stakeholders expressing interest in more detailed testing, inspection, and approval procedures. In response, TC is working with other government departments to address this feedback through policy development and procurement processes to help bring in-water cleaning with capture to Canada.

Feedback from these engagement opportunities raised questions about the permissibility of in-water cleaning in Canadian waters. This has enabled subsequent engagement to focus on education about Canada's legislative framework. Feedback has been incorporated into Canada's engagement and policies throughout their development.

In fall of 2022, TC launched new web pages on *Aquatic Invasive Species from Marine Transportation* and *Managing Biofouling*, which included the publication of our 'Voluntary Guidance for Relevant Authorities on In-Water Cleaning of Vessels'.

2.3. Filling Knowledge Gaps

To address knowledge gaps and inform future policy measures, TC has partnered with Fisheries and Oceans Canada to establish a baseline assessment of the risk vessel biofouling poses to Canadian waters. This partnership supports TC and the Department of Fisheries and Oceans Canada's joint interest in the development of science-based policies to prevent the introduction and spread of AIS.

A national assessment was conducted using advanced modelling methods, incorporating best-available shipping, environmental, and biological data to estimate the number of non-indigenous species (NIS) establishments per year across Canadian regions from international shipping activity. Results showed that the expected probability of NIS establishment from niche areas is greater than from the main hull, despite being proportionally smaller in area, highlighting the importance of niche areas for establishment of NIS. At current rates of shipping, Canada can expect, on average, eight new NIS establishments from biofouling per year in each of the Atlantic and Pacific regions, five in the GLSLR region, and two in the Arctic. These rates of establishment correspond with vessel traffic volumes. Vessel biofouling is recognized as a dominant vector for the global transport and introduction of NIS and the probability of NIS establishment by vessel biofouling is considerable.

Future collaborative work with Fisheries and Oceans Canada will provide scientific support to TC through biological sampling of vessel biofouling to identify dominant risk factors, environmental modelling to anticipate the influence of climate change, and risk assessment.

Additionally, TC will be developing testing methodology for in-water clean and capture technologies, and testing the efficacy of in-water clean and capture technologies.

2.4. Developing Policy Options: Voluntary Guidance as an Interim Measure

In fall 2022 TC published 'Voluntary Guidance for Relevant Authorities on In-Water Cleaning of Vessels.' Developed over a two-year period with extensive stakeholder engagement, the Voluntary

Guidance serves as an interim policy measure in the absence of regulations. In order to protect the environment, it is based on the best available science and follows the precautionary principle in areas where knowledge gaps exist.

To facilitate international consistency, Canada's Voluntary Guidance draws inspiration from the policy and regulatory frameworks of other countries. It incorporates best practices and standards to develop a comprehensive approach that aligns with international norms. The Voluntary Guidance also takes into account the United States' legislative framework to harmonise policies and effectively manage our shared waters.

Overall, the Voluntary Guidance recommends that in-water cleaning ideally be performed when only "microfouling" (a build-up of slime on a vessel's hull made up of tiny organisms) is present, rather than waiting until there is a build-up of "macrofouling" (an easy-to-see build-up of large organisms like barnacles and grass). Vessels with macrofouling pose a higher-risk of transporting invasive species.

However, Canada understands that vessels may require the cleaning of macrofouling from their hulls. As such, the guidance proposes best practices for cleaning both microfouling and macrofouling, using two methods: clean with capture and clean without capture.

The Voluntary Guidance includes best practices that can be employed to manage the risks associated with cleaning vessels in-water. Relevant authorities who are responsible for deciding whether service providers should be allowed to operate in their waters are encouraged by the Voluntary Guidance to review requests for vessel cleanings on a case-by-case basis. Service providers are responsible for any research, testing, verifying, and documenting of the in-water cleaning technology and coordinating with vessel owners and operators on cleaning requests. Vessel owners and operators are responsible for arranging underwater inspections and preparing all documentation related to biofouling.

Vessels seeking clean without capture services should meet one of two strict criteria: either the macrofouling buildup originates locally, or the buildup consists solely of microfouling (slime layer). The former carries a low risk of introducing new AIS since it contains only organisms already present at the cleaning location.

Regarding the cleaning of macrofouling, the Voluntary Guidance recommends that service providers demonstrate that their technology has undergone testing at a facility that is approved, certified, and audited by an independent accreditation body. Testing should be done on at least 3 separate cleanings on at least 3 different types of vessels that have different types of anti-fouling system, levels of biofouling and ideally, environmental conditions. Independent testing should also confirm that the technology does not damage the anti-fouling coating. If a cleaning technology is approved for use by a coating manufacturer, the service provider should provide this information.

In terms of water quality, testing should demonstrate that the system removes contaminants prior to discharging the effluent to comply with all relevant Canadian legislation.

As clean with capture technologies may be utilized for cleaning macrofouling with an unknown or non-local origin (which is a higher risk activity), the voluntary guidance recommends additional testing criteria and procedures that are more stringent regarding capture capability, physical separation, secondary treatment, and continuous monitoring of the cleaning process.

Although Canada requests third party testing of technologies in the Voluntary Guidance, Canada has faced challenges with the lack of internationally standardised testing for in-water cleaning technologies. In order to facilitate the development of a standardised testing methodology Canada has participated in the development of the 2022 ACT/MERC 'Guidelines for Testing Ship Biofouling In-Water Cleaning Systems' as well as the ongoing ISO standard on in-water cleaning testing.

A ‘Biofouling Management Plan and Record Book Template’ is included in the Voluntary Guidance which is available for download from the government of Canada’s form catalogue. This template is designed to be a user friendly and easy to fill out PDF.

In addition to the Voluntary Guidance, Canada is working on more initiatives to increase environmentally safe in-water cleaning. Public Services and Procurement Canada has established a supply arrangement for in-water cleaning with capture services for the Government of Canada’s fleet. The first cleaning of a Naval vessel occurred in July 2023. The requirements outlined in the supply arrangement closely mirror the Voluntary Guidance for intra-governmental consistency. Qualified suppliers may apply to become supply arrangement holders at anytime through Canadabuys.

Although there has been significant progress on policy development in recent years, Canada has faced challenges in implementation. Industry is learning best practices for biofouling management in Canadian waters, but capacity of the in-water clean and capture industry is limited in Canada, which impedes the adoption of the Voluntary Guidance and the usage of the supply arrangement. Ports find the lack of standard testing and certification of in-water cleaning technologies to be an impediment in decision making for allowing or disallowing in-water cleaning of vessels in their waters.

3. Next Steps

Canada’s plan is to develop a comprehensive evidence-based policy framework by 2027 on the control and management of vessel biofouling, including on in-water cleaning of vessels. This policy framework may include new voluntary measures and/or new or expanded domestic regulations.

More specifically, Canada will continue to take a 4 pillar approach to the development of Biofouling Policy. Through international leadership and being an active participant in IMO discussions Canada will contribute to the development of international standards to facilitate global consistency including reviewing the non-mandatory nature of the IMO Biofouling Guidelines. Through hosting stakeholder engagement sessions, participating in forums, and facilitating education opportunities on biofouling management plans and record books TC will undertake more outreach and education. To fill knowledge gaps TC is working with our partners at Fisheries and Oceans Canada using scientific research to establish the risk that vessel biofouling poses to Canadian waters and factors that may be used to improve biofouling management. Other research initiatives will look at in-water clean and capture technologies and development of a testing methodology. Finally, TC will develop policy options on the control and management of vessel biofouling that target vessel owners/operators, ports, and in-water cleaning service providers. This includes reviewing the existing Voluntary Guidance, and exploring new voluntary and mandatory policy options that could be implemented within the Canadian context, noting the internationally shared waters with the United States.

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How Robotics Can Contribute to Greater Fuel and Maintenance Efficiency with More Frequent Monitoring Schedules

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Abstract

This paper discusses the advantages of using underwater robotics for hull inspections, by comparing the traditional method of using divers against the time, quality, and cost of using ROVs. The analysis will detail both advantages and disadvantages, quantifying the findings based on case studies of customer experiences who have used ROVs to replace or complement divers for hull inspections, such as Foss Maritime and SAAM Towage Canada. Foss Maritime predicted a savings of $68,500 in the first year of using robotics to diagnose damage response and equipment failure inspections. The actual, measurable savings were $135,650.

1. Introduction

Hull inspections play a critical role in the maritime industry, serving as an examination and assessment of the structural integrity, condition, and overall health of a ship's hull. From colossal ocean liners to nimble fishing vessels, the hull, as the very foundation of a ship, demands meticulous examination.

These inspections, conducted through visual assessments, non-destructive testing, thickness measurements, and coating inspections, are essential for identifying damages, corrosion, or weaknesses that may compromise the integrity of the vessel and the efficiency of operations.

By ensuring the seaworthiness and compliance of ships, hull inspections contribute to the smooth operation, longevity, and safety of maritime vessels.

2. The Importance of Frequent Monitoring

Frequent monitoring through hull inspections is essential for maintaining the safety, compliance, operational efficiency, and cost-effectiveness of ships. By regularly assessing the hull's condition, ship owners and operators can identify and address problems early, ensuring the integrity of the vessel, the safety of the crew, and the protection of the marine environment. Conducting regular inspections has also proven to be a key factor in optimal ship performance, saving substantial time and operating costs.

2.1. Traditional Methods of Hull Inspection

Traditional methods of hull inspections encompass a range of techniques, including visual inspections, divers, and dry docking. Each method has its own costs, challenges, advantages, and disadvantages.

2.2. Visual Inspections

Visual inspections are relatively cost-effective compared to other methods. They require trained personnel to visually examine the hull for any damages or irregularities. However, they can be limited by accessibility to certain areas of the hull. In some cases, scaffolding, ladders, or ROVs may be required to access difficult-to-reach areas. Additionally, relying solely on visual inspections may not provide detailed information on the internal condition of the hull.

One advantage is that visual inspections provide immediate visual feedback on the condition of the hull, allowing for quick identification of visible damages or corrosion.

2.3. Divers

Using divers for hull inspections can be more expensive due to the need for trained and certified divers, specialized equipment, and diving support vessels, with costs starting at approximately $5,000 per day and more, https://www.researchgate.net/figure/Costs-associated-with-the-three-inspection-methods-The-dive-team-and-free-flying-ROV_tbl4_283273705. The costs also include the deployment and retrieval of the divers. Divers face challenges such as limited visibility in murky waters, potential hazards from underwater structures or marine life, and limited time underwater due to decompression requirements. They may also encounter difficulties accessing certain areas or facing adverse weather conditions. An advantage of hiring divers is that they can perform detailed visual inspections and tactile assessments, allowing for a closer examination of the hull, and can identify and document damages, marine growth, and coating conditions.

2.4. Dry Docking

Dry docking involves taking the ship out of the water and placing it in a dry dock facility. It is a substantial expense and requires planning, coordination, and downtime for the vessel. Costs include the dry-docking facility charges, labor, equipment, and any necessary repairs or maintenance, and can range anywhere from hundreds of thousands of dollars to millions, depending on the size of the vessel and the scope of work needed. Dry docking is also a time-consuming process, requiring careful scheduling to minimize disruption to the vessel's operations. It also requires coordination with various parties involved, such as shipyards, classification societies, and repair teams. Dry docking may not be feasible for certain types of vessels or in remote areas without suitable facilities. One advantage is that dry docking provides the opportunity for a comprehensive inspection of the entire hull, including both external and internal surfaces. It allows thorough examinations, repairs, and maintenance work that cannot be easily accomplished in water.

Overall, the choice of method depends on factors such as the vessel type, budget, urgency, and the desired level of detail in the inspection. Many ship operators combine different methods to maximize the effectiveness and efficiency of their hull inspection processes.

3. How ROVs Can Improve Hull Inspections

Remotely Operated Vehicles (ROVs) have revolutionized hull inspections by offering significant improvements over traditional methods.

ROVs provide quick deployment, allowing for rapid and efficient inspections without the need for extensive preparation.

Equipped with enhanced 4K cameras, these advanced underwater robots capture high-definition imagery, providing inspectors with clear and detailed views of the hull's condition.

The inclusion of specialized reporting software streamlines the inspection process, enabling inspectors to document findings, annotate images, and generate comprehensive reports.

Furthermore, ROVs offer the flexibility of modular add-ons, such as sonar systems, advanced positioning and stabilization systems, and manipulators, enhancing their capabilities for inspections, mapping, measurement, 3D modeling, and repairs.

While the advantages of ROV-based hull inspections include improved safety, cost-effectiveness, detailed assessments, and inspection efficiency, there are limitations to consider, such as the lack of human judgment and reduced dexterity to perform tactile assessments. However, overall, ROVs have proven to be valuable assets in enhancing the effectiveness and accuracy of hull inspections.

4. Case Studies

4.1. Foss Maritime

As part of an approved Continuous Improvement Initiative, Foss purchased a Deep Trekker ROV in order to reduce the costs of using divers for diagnosis of damage response and equipment failure inspections, blocking/pre-drydocking checks, pre-operation/charter vessel surveys, quality assurance information among other potential options such as UWILD external specialist certification for basic barge inspections.

The predicted savings was $68,500 for the first year and $87,500 annually thereafter.

However, after tracking the first year of ROV use, Foss realized an astounding actual and measurable impact of saving/earnings of a total of $135,650, which was twice the original prediction (not including immeasurable costs, such as losing a tow job due to waiting on divers, or the potential cost of increased equipment damage due to inadequate underwater information).

"We used divers and only minimally because of the cost. We have used the ROV way more than anticipated due to how easy it is to transport and deploy and it has saved the company a lot of money, in one case even to verify that divers were needed when there was reluctance to call them!" explains Amanda Dayton, Manager of Contracts and Estimating at Foss Maritime.

The Foss Shipyard began to use the ROV on a weekly basis, whether it was called in to perform block checks during a drydocking, inspecting the hull and running gear of moored vessels coming off-hire or ramping up for work, or providing helpful information on equipment failure. The ROV was light enough to be manually carried from pier-to-pier or office-to-pier by one person and did not require an onshore power connection; so it was easy to transport to the vessel location, which is important when dealing with working vessels.

"The specific features that we found most useful were first, the low cost of the ROV, then the small size and the light weight for transportation and deployment, the ability to capture photos & video with DVR, the ease of operation (not too many buttons or extra equipment or confusing features), the neutrally buoyant tether (we use it to find the way back to the operator! It's easy to get lost underwater!), and the quick operational speed and maneuverability. Deep Trekker specifically has also been particularly wonderful with its sales and customer service team!"

In addition to alleviating diver costs, Foss also notes that external vendors can impact overall project timelines due to the dependence on fitting into their schedules of availability and also having to wait until the dive team can organize themselves to the same time and place.

Also, due to safety concerns of having divers in the water, sometimes there are delays to ensure that the vessel is in a condition that is stable and safe enough for dive operations. Since the ROV can be operated by one person, it can be deployed much faster than divers and has more schedule flexibility as well as operational flexibility since diver health is not a concern.

They only had to use the ROV twice instead of calling divers in order to realize a return on investment. They also appreciated the simple and waterproof design so that if anything broke or needed maintenance, it would not be a financial burden or disable it from service for very long.

"The biggest surprise to me was how extremely skeptical co-workers and customers were at first with we used the ROV and how quickly their minds changed to solid believers after witnessing a couple of jobs," Dayton explains. (See https://www.deeptrekker.com/resources/customer-success-story-foss-maritime-and-amanda-dayton for more details.)

4.2. SAAM Towage Canada

With a fleet of 22 tugboats servicing 7 ports in British Columbia, SAAM Towage Canada is primarily focused on ship docking and escort duties for oil & gas tankers.

Stuart Jones, Technical Superintendent, Maintenance Department for SAAM Towage Canada explains, “We use our ROVs for scheduled underwater inspections of vessels to monitor the underwater condition of components and structures. We also use them for quick inspections of vessels’ underwater components - lots of debris exists on the West Coast so it is not uncommon to strike logs sitting just below the surface.”

“The video and photo features are our most used feature,” said Stuart.

Stuart noted specifically how the use of ROVs allows the SAAM Towage team to streamline and accelerate their processes. DTG3s allow Stuart to “follow up immediately on reports of suspected underwater damage to vessels. If a Captain reports possible contact with a submerged object, we can immediately assess the vessel and expedite its return to service if no significant damage is found during the inspection with the ROV. Previously we would have to wait for an available dive team.”

“The introduction of the DTG3 as a tool for inspection of our fleet has been an exciting and rewarding process,” shared Stuart. “I’m looking forward to the continued success of the units to complement our operation.” (See https://www.deeptrekker.com/resources/rov-saam-towage-canada for more details.)

4.3. Verreault Navigation

Based out of Les Méchins, Québec, Verreault Navigation specializes in ship repair and maintenance. One of the top shipyards on the Atlantic Seaboard, Verreault Navigation is strategically located to work on the full range of vessels that travel the St. Lawrence Seaway.

Verreault Navigation uses the DTG3 for underwater inspection of the vessels brought in for repair and maintenance.

“We are a ship repair facility complete with drydock and wharf. We are proud to repair vessels of up to 800 ft in length and 90 ft in width. We use the Deep Trekker for inspections of the ship’s hull before docking. The main reason we need to inspect the hull is to see if the bottom is free of ice or other obstructions. We also use our Deep Trekker to confirm vessel position over blocks in the drydock prior to removing water and to ensure the vessel's drawings are up to date with any possible hull modifications prior to settling the vessel on the blocks.”

The use of the DTG3 allows the Verreault Navigation team to quickly and conveniently inspect hulls and blocks to ensure safe and effective drydocking and repairs.

“We can more readily ensure vessel safety prior to settling on the dock blocks. In the past, we would have had to have divers come to do certain inspections if we had doubts. The Deep Trekker allows us much more autonomy in this aspect and allows us to intervene much quicker and ensure our clients do not lose precious time in dock.”

Time is money, especially in the shipping industry. By utilizing the DTG3 to inspect blocks and ensure the ship is stable in the drydock, the Verreault Navigation team can minimize the time needed for necessary drydocking.

The Verreault Navigation team also noted that the “camera and recordings” were the most used feature on their DTG3 and that the Deep Trekker “customer service has been excellent.” (See https://www.deeptrekker.com/resources/simplifying-operations-verreault-navigation for more details.)

5. The Deep Trekker Difference

Deep Trekker offers innovative systems to protect divers from harm and to allow hull inspections to be completed safely and in sufficient time. Take a look at our top 3 robotic systems for hull inspections in the marine industry:

Deep Trekker offers three submersible ROVs:

- DTG3
- PIVOT
- REVOLUTION

These vehicles are purpose built for versatility and customization, and engineered to meet a broad range of needs across many industries. In challenging hull inspection operations, they provide operators with a convenient and straightforward way to get eyes underwater. Equipped with sonar and a 4K camera, Deep Trekker's ROVs deliver high quality underwater footage in nearly any environment.

The battery-operated robots are designed for ease of portability. Portability of an ROV is extremely important for inspecting confined areas and difficult-to-reach locations. Deep Trekker vehicles come housed in their own convenient Pelican carrying cases, allowing them to be easily transported and deployed in virtually any environment.

The DTG3 is a mini observation-class underwater ROV built to provide operators the ability to quickly deploy and visually inspect underwater environments within a matter of minutes. Battery-operated, with a depth rating of 200m (656ft), the DTG3 is versatile, durable, and extremely portable.

The PIVOT and REVOLUTION are completely re-imagined ROVs with six vectored thrusters for massively enhanced maneuverability and stability. The patented revolving head of the REVOLUTION allows operators to rotate the camera, manipulators, and sonar, all while station holding in moving water. Depth-rated to 305m (1000ft) with field-swappable lithium-ion batteries, both the PIVOT and REVOLUTION are tough, portable, and adaptable.

When you choose Deep Trekker, you get more than a top-quality ROV - you also gain access to our experienced, best-in-class senior robotics team members and 5-star customer support. Our team is just an email or phone call away, ready to provide guidance, answer questions, and offer technical support whenever you need it.

We believe in being a true partner to our customers, providing more than a premium quality product, but also the expertise, ideas, and vision necessary to succeed in your underwater operations.

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Developing a Novel Fully Autonomous In-Transit Hull Grooming Platform

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Abstract

This paper provides an overview of the process of developing a new, proactive in-transit cleaning platform consisting of an autonomous, tether-free robot. Several solutions for cleaning biofouling off ships exist, but the majority are limited to when ships are stationary. This means the cleaning process happens at long intervals after significant accumulation on the hull. The new platform requires a reliable, robust solution for staying attached while the ship is sailing. The paper will discuss the motivation for developing such a platform and describe the milestones of reaching a completed product, while focusing on the current progress. Finally a new testing protocol for grooming effects on anti-fouling coatings will be presented and proposed as a benchmark test.

1. Introduction

Biofouling is the accumulation of microorganisms and plants on surfaces such as ship and submarine hulls. Its effects on the shipping industry are well known by now - affecting both ships' performance in the form of excess drag and marine biodiversity in the way of transporting invasive species. According to an *IMO (2022)* report on biofouling, even a thin layer of slime (a layer of biofilm up to 0.5 mm in thickness) covering up to 50% of a hull surface can increase greenhouse gases (GHG) emissions by 25-30%. *Swain et al. (2022)* estimated roughly that if all internationally operating vessels were kept clean of biofouling, the shipping industry could reduce its GHG emissions by 19%. *Schultz (2007)* quantified the effects of biofouling on the performance of US Navy ships and found that biofouling can reduce the speed of an Oliver Hazard Perry class frigate (FFG-7) by 2.7-10.7%, depending on the biofouling stage and compared to a hydraulically smooth surface when sailing speed of 30 kn. *Davidson et al. (2014)* describe in a report to the Marine Invasive Species Program in California another aspect of biofouling, which is its role as a leading vector in the transportation of invasive species. Because of all the above, a myriad of solutions exist, and are continuously developed, for the biofouling problem.

The *IMO (2022)* report describes anti-fouling (AF) coatings on ships' hulls as the most widespread solution for the biofouling problem. AF coatings work by releasing biocides into the water, which slows the growth of slime. These coatings help mitigate the problem to a certain extent. However, they have limited efficiency, need to be reapplied every few years, and release toxins into the water, *Soroldoni (2017)*. Another preventative method is using ultrasonic waves emitted from transmitters attached to the hull. According to *IMO (2022)*, this method is especially effective in niche areas. Since these two methods don't completely eliminate biofouling, periodic in-water cleaning is done at ports, and complete dry-docking of vessels is done approximately every 5 years. Because none of the mitigation ways mentioned above are good enough, proactive cleaning methods are becoming the most viable solution in the market.

The significant advantage of Proactive In-Transit Cleaning of the Hull (PITCH), when done at short intervals, is maintaining a clean hull while sailing. This helps in reducing drag penalties, leading to increased performance and less fuel consumption. Moreover, proactive cleaning helps to reduce the migration of invasive species since slime gets removed soon after it is formed, which prevents its development to the microfouling stage (layers 100 µm to 1 mm thick which include invertebrate larvae). Maintaining a clean hull also has significant financial benefits for ship operators, combining the reduction in fuel expenses and increase in ship efficiency by decreasing down-time for cleaning. While PITCH cannot reach certain niche areas around the hull, for example the propeller, the benefits of maintaining the majority of the hull clean are substantial and justify moving towards such solutions.

Despite the advantages of in-transit cleaning, few attempts at creating a robust, reliable and efficient solution have been successful. This is due to the massive challenge of remaining attached to the hull while the ship is sailing, caused by a complex and extremely turbulent flow. The ship's movement consists of 6 degrees of freedom and is one of the causes for the complexity of the flow. Additionally, because of the water's viscosity and the size and speed of a ship sailing through it, turbulence occurs all around it. This means that the momentum associated with the flow comes from a constantly varying direction. The water's density leads to a significant amount of force on any object trying to move through it, and because of the turbulence, the direction of this force is constantly changing. Furthermore, any object that moves through water experiences drag. In order to create an effective platform, it must experience less drag than the biofouling it is cleaning. Another challenge is the operational aspect of such a platform: A ship's crew barely has any excess time while sailing to contribute towards operating a cleaning device. Finally, the platform should not damage the AF coating, and should be cost effective.

2. A Novel Autonomous Solution

NakAI Robotics is developing a fully autonomous robot that cleans hulls in transit, Fig.1. NakAI's robot remains attached to the ship's hull while sailing by using a combination of magnets and an adjustable hydrodynamic profile. The hydrodynamic shape means the robot can generate forces that push it towards the ship's hull by utilizing the flow's characteristics, while the adjustable portion allows it to remain attached when unexpected forces, resulting from sporadic flow directions, act on it. The robot will operate untethered, meaning it completely relies on its adhesion mechanisms to prevent detachment. It is deployed automatically when sea conditions allow and remains underwater for the duration of the cleaning period, utilizing a slim profile and the hydrodynamic design to reduce the drag penalty on the ship.

Fig.1: NakAI's robot during one of the large-scale tests

The robot incorporates a set of sensors to allow autonomous navigation. After a calibration and initial learning phase, the robot automatically optimizes the cleaning pattern with every run to improve efficiency and ensure it covers its designated area. At the end of each cleaning session, a report is sent to the ship's operator, detailing operation time, area covered, and insights. This means the robot is fully autonomous during its operation, leaving the interaction with the crew only to when reports are sent, allowing the crew to choose when to interact with it.

The system in its whole includes three parts: Robot, Carrier and Docking. The Docking is where the robot recharges and waits for appropriate sea conditions while out of the water. The docking station includes a communication module to transmit and receive information from the bridge, a connection to the ship's electricity for charging purposed, and a cleaning system to prevent biofouling on the robot.

The Carrier is in charge of transporting the robot from the Docking to a safe depth below the waves. The transition area between air and water is an area of extremely turbulent flow regime, where the hydrodynamic advantages of the robot's structure do not come into play yet. Therefore, the carrier was designed to be robust, durable and apply a strong magnetic force to ferry the robot in and out of the water.

The cost effectiveness of PITCH can be broken down into a few elements: (1) Fuel costs; (2) Ship's performance - Maintaining higher velocities and thus increasing efficiency; (3) Less down time in ports for in-water cleaning; (4) Extended time between dry dockings. Taking all the above into consideration, savings can reach up to millions of dollars per year, which is a significant return on investment for a platform that is expected to cost $100k.

3. Development Milestones

As discussed above, placing a platform on a sailing ship involves overcoming significant challenges, and so a robust testing process must be created to ensure these challenges are met. The testing process is broken down into 3 phases: modeling, small-scale testing, large-scale testing. To model the physical aspects of the problem a Computational Fluid Dynamics (CFD) simulation was designed. In addition, a navigation simulation was conducted to test the autonomic algorithm and conduct "dry-runs" before integrating it into the robot's components. Small-scale tests were created to check different aspects of the platform, such as sensors, drivetrain or specific features of the hydrodynamic design and can be done within the company's workshop. Large-scale tests were designed to check the full scale of the robot and the integration of systems.

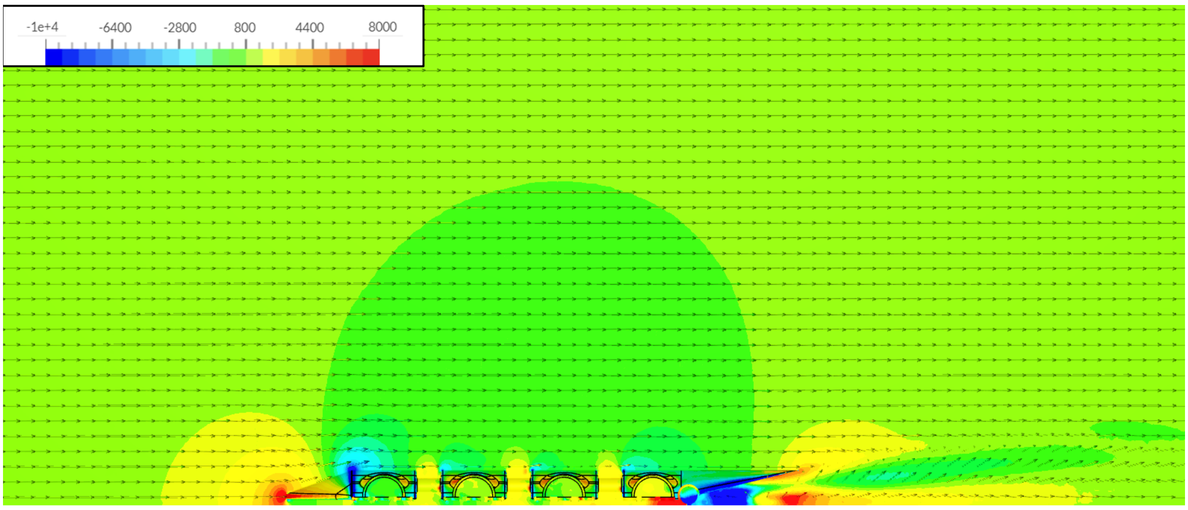

Fig.2: Example of results from a CFD simulation. Vectors depicting the fluid's velocity are visible, and the pressure field is shown, the scale for which is presented in [Pa] at the top left corner

CFD is an effective tool and has been used extensively throughout the development process. Initially the selected platform was SimScale, at which point different design concepts were tested with relatively simple flow conditions. Once a satisfactory design was reached, a new tool - Ansys Fluent, was selected to simulate more complex flows. Using the new tool enabled the achievement of more accurate results for complex flow conditions such as oscillating flow or surface waves. At the final step of CFD simulations, a full integration of the dynamic aspects of the robot was simulated. CFD results were promising and showed that adhesion is possible using hydrodynamic forces. While CFD is a powerful and versatile tool, the simulation results always require validation, which is one of the purposes of the small-scale and large-scale tests.

An approach for testing in the fluid dynamics world is dimensional analysis. It is a helpful tool that allows testing at reduced size and thus saves time and space. The approach relies on Buckingham's Pi Theorem, *Buckingham (1914)*. The physical characteristics of a problem are laid out, and dimensionless numbers, comprised of those parameters, are defined. In order to produce a reliable test, the value of these dimensionless numbers must be kept. A prominent number in fluidic problems is the Reynolds number, which describes the ratio of inertial forces to viscous forces. The inertial term in the number is a product of the fluid's density (ρ), its velocity (U) and a characteristic length (L), the viscous term is the fluid's dynamic viscosity (μ). Thus, the equation defining the Reynolds number is:

$$Re = \frac{\rho U L}{\mu}$$

The value of the Reynolds number is pertinent to the understanding of the flow regime. An open flow regime is considered turbulent from $Re = 5 \times 10^5$, and the flow is considered more turbulent as the value increases. For a 2-meter robot attached to a ship sailing at 24 kn through sea water, the Reynolds number is in the order of 10^7, which is deep in the turbulent regime. Replicating this number in a workshop while maintaining the full size of the robot requires immense amounts of horsepower because of the amount of water or air that needs to be propelled. For a small start-up with limited resources, there was a need to come up with other solutions.

One of NakAI's solutions is an in-house wind tunnel, which is a common tool in the fluid dynamics field. For the purpose of small-scale physical tests, one was built in the company's workshop, designed to test only specific parts of the robot, both in a stationary and dynamic setting. The wind tunnel can generate an air flow of up to 33 m/s, which is the equivalent of water moving at approximately 5 kn, when considering a similar Reynolds number (~1.5×10^6). At such a high Reynolds number, the coefficients of lift and drag do not vary much, and so an extrapolation could be done to find the relevant forces in higher simulated flows. The tests produced promising results and simulations were validated through them.

Fig.3: The wind tunnel that was built at the company's workshop

Alongside the wind tunnel, a variety of other small-scale tests were carried out. Steel plates were mounted on a wall in the workshop to test the magnetic adhesion force and experiment with driving algorithms. A children's pool was brought into the workshop to assist with calibrating cameras, which are part of the navigation system. The water's salinity was matched to that of the Mediterranean Sea to simulate the correct diffraction properties. Different wheels were tested to find the combination of material and pattern with the highest friction. These tests were done on a steel plate in three different conditions - dry, wet, and oiled. All the above are just part of the small-scale tests that are an essential part of the development process.

To perform initial large-scale tests, a test rig was built to tow a full-scale model of the robot behind a vehicle on a highway. A model of the robot was attached to a board with two sets of load cells, with 3 cells in each set to allow for 3D recording of forces. The contraption was then loaded and strapped onto a trailer, and IMUs were placed both on the trailer and the model to allow for noise reduction in the data-processing stage. The whole rig was towed behind a vehicle on a highway, leading to a Reynolds number in the order of 10^6. The added value of such a test is a sporadic flow regime, which simulates the conditions underwater. While the results were noisy, they were reliable enough to interpret, and a good agreement with the CFD simulations was found.

The next step for full scale measurements is to place the model on a sailing ship. This is achieved thanks to a collaboration with one of NakAI's business partners and will be conducted on a route between Israel and Cyprus. The model will be attached again to a board, using two sets of load cells and the contraption will be attached to the hull using a set of powerful magnets. Additionally, an IMU sensor will be implemented to measure the movements of the ship, which will eventually help with adjustments to the navigation software. The setup is designed to float in case of disengagement from the hull, and a GPS is incorporated to allow retrieval.

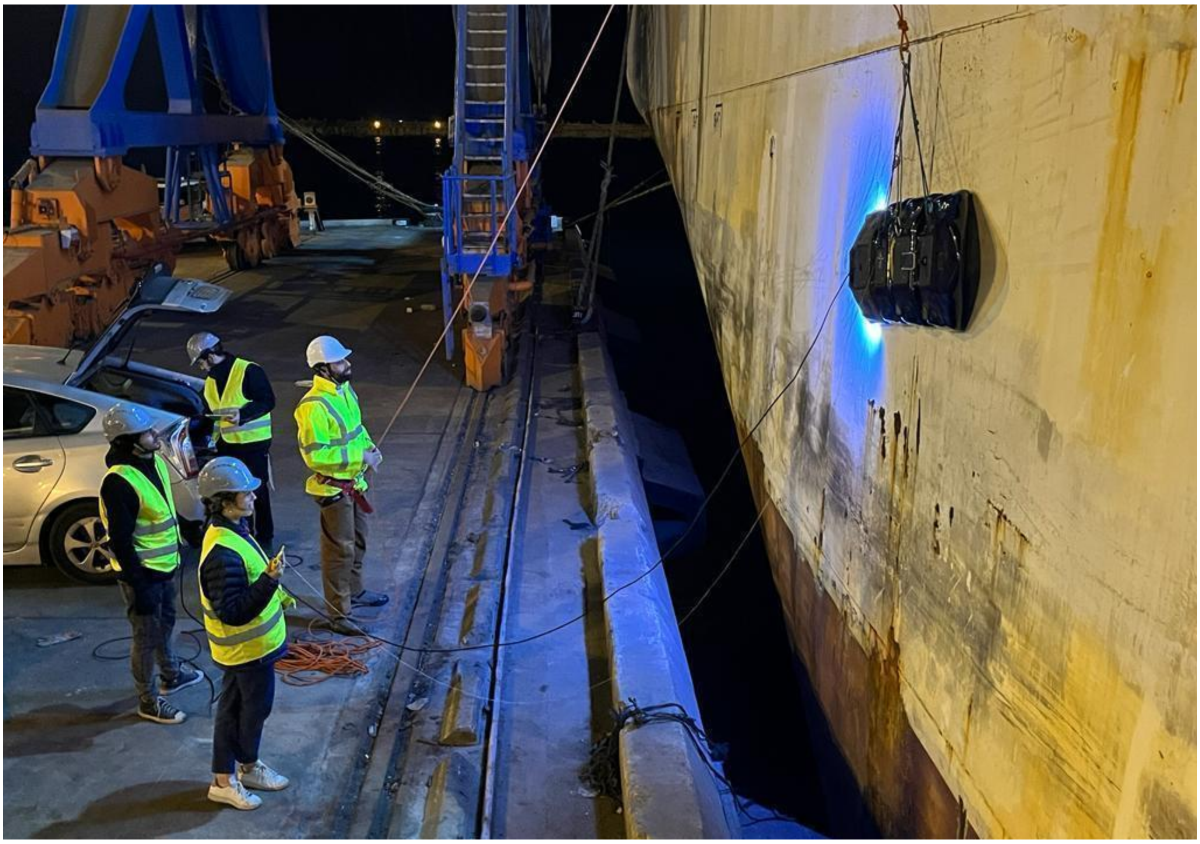

Fig.4: NakAI's crew during one of the full-scale stationary tests

The final form of large-scale tests is conducted on ship, both stationary (in-port) and moving. These tests provide the opportunity to test all the systems at once, and the integration between them. A number of tests on stationary ships have already been conducted, with improvements implemented after each one. Tests on moving ships are anticipated to begin after the model tests on a moving ship are completed.

4. Testing for Effects on Hull

Besides operational testing, NakAI was asked by commercial partners to evaluate the effects of the robot on AF coatings. This comes primarily to ensure protection of the paint over time since grooming a hull requires significantly more passes than other cleaning methods. Damaging the coating would lead to excess amounts of toxins in the water and loss of antifouling protection.

In cooperation with DHI in Denmark, a test system was built, using seven plates covered with self-polishing copolymer AF coating (Globic 9000). The plates were painted and once the paint was dry, they were submerged for six weeks. This ensured initial leaching of copper into the water before the robot's effects were tested. To make the process more efficient, a small model was used that only incorporated the pertinent components – wheels and brushes, alongside all the relevant control systems. Two types of wheels and three types of brushes were tested. The full test process is shown in Table I.

Table I: The procedure used for testing the effects NakAI's robot has on AF coatings. The estimated time to complete is based on the process of the test conducted through a collaboration between NakAI and DHI.

	Step	Time to complete
a	Design and produce a small-scale model that includes the driving and cleaning mechanisms which will be used with the cleaning platform	~2 weeks
b	Apply AF coating on steel plates and submerge them once it has dried. Plates and coating should resemble realistic conditions in terms of material and paint thickness	~1 week
c	Measure leaching into the water over 6 weeks, testing on a weekly basis	~6 weeks
d	Perform tests – 100 passes per test, which simulate approximately three years of operations at a frequency of 1 pass every 11 days	~1 day
e	Analyze initial results - visual effects and paint thickness	~1 day
f	Maintain plates submerged for 6 more weeks and keep testing for leaching on a weekly basis	~6 weeks
g	Analyze contaminant existence results from all 12 weeks	~1 week

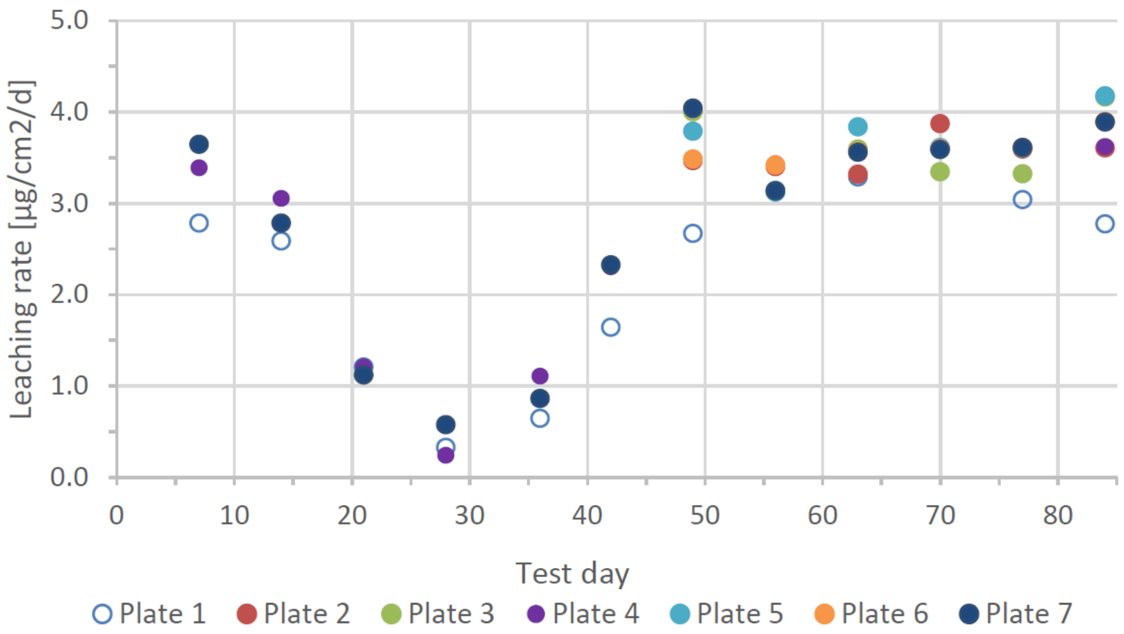

Fig.5: Copper leaching rate throughout the test period, calculated by analyzing a sample of discharge water from each plate. Plate 1 is the control plate, and samples from it, along with samples from plates 4 and 7, were collected throughout the entire test period. Samples from the rest of the plates were taken only after the robot's activity (day 43).

The test results showed no measurable effects on the paint (visual and thickness) by the activity of NakAi's robot. Additionally, no excess copper was found in the water where the robot cleaned in comparison to the test plate, as can be seen in Fig.5, which presents the copper leaching rate from the different plates throughout the test period. These results are satisfactory to proceed with the understanding that the robot's activity does not harm the paint under similar conditions to those that were tested.

To the extent of our research, there is no standard for quantifying the effect of cleaning methods on the AF coating. This means there is no regulation over the amount of residue and toxins released during the cleaning process. With the growing awareness of the environmental impacts of cleaning methods, it is only fitting that the amount of paint released during a cleaning cycle be measured in a controlled environment. NakAI along with DHI propose the procedure described in Table I as a baseline for a benchmark industry-side test for any in-water hull cleaning platform.

5. Summary

The problem of biofouling and the need for Proactive In-Transit Cleaning of the Hull (PITCH) was discussed, alongside its advantages and development challenges. This hull grooming method could reduce each ship's GHG by approximately 20% and save the ship operator up to millions of dollars thanks to lower fuel costs and improved ship performance. Additionally, PITCH could help reduce the transfer of invasive species.

NakAI's novel, autonomous in-transit hull grooming platform was presented. The platform uses a combination of magnets and an adjustable hydrodynamic design to stay attached to the hull. The development stages of such a platform were outlined, focusing on different types of tests required, dividing them into three: Simulations, small-scale, large-scale. The simulations assist in testing concepts, and the tests validate the results. The results from the tests so far have corroborated the simulations' results, and large-scale dynamic tests at sea are about to commence.

In addition, the need for testing the effects the platform has on AF coatings was discussed, while making the point that no standardized test exists. A protocol involving 7 steps was suggested as a benchmark test to answer this need. This test should be conducted in a controlled environment, and takes approximately 16 weeks to complete, where the vast majority of the time the test is passive.

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Fully Autonomous Port Asset and Ship Hull Inspection for Structural Integrity and Biofouling Management

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Abstract

This paper shows the capabilities of fully autonomous data collection with minimized user interaction in confined environments, plus the use-case specific automatized data processing and labeling. Subdron's proprietary technology for highly accurate subsea positioning in confined environments allows generating 3D reconstructions of any structure at an unique level of accuracy even in zero visibility. This creates added value for port authorities in monitoring underwater assets and applying predictive maintenance on it. For ship owners, it provides the possibility to monitor the status of the hull and receive accurate information about the fouling status: a 3D map of biofouling – exact position and quantity of it. This service offered by subdron, will significantly increase quality of the hull monitoring process, that will be executed in shorter time and at lower cost.

1. Robotics as a Service

The increasing demand for remotely conducted in-water surveys (IWS) requires sophisticated automated concepts. Subdron GmbH, www.subdron.com, has initiated 'Robotics as a Service' applications that can support infrastructure monitoring in ports and on waterways, offshore structures, and ships, Fig.1. Subdron specialises in the development of navigation algorithms, autonomous underwater vehicle (AUV) navigation in the object-relative range, and the collection and evaluation of inspection data. The idea was to develop an AUV as an application-related overall system.

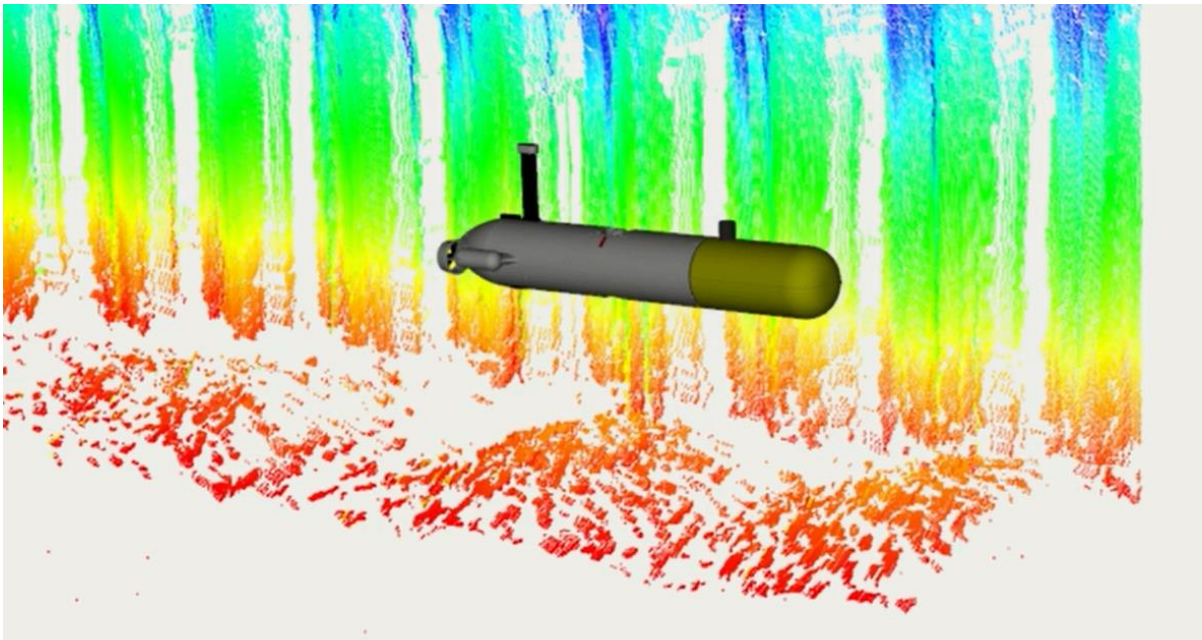

Fig.1: Display of a real mission in simulation environment

The use of proprietary relative object navigation (RON) allows dispensing with cost-intensive external positioning systems. Currently, subdron is in the process of offering the mission expertise it has accumulated over the past years as a project related service. The resulting advantage for port authorities and diving companies is that technology and underwater robotics expertise are available exactly when and where they are needed, without having to develop their own technologies. This also eliminates the clients' need for specialists who need to be continuously trained and retained within the company. As partial aspects of the service offering, 3D sheet pile surveying and ship hull inspection are presented here as examples.

In present and future transportation planning, ports play a key role as hubs of goods handling and globally networked value chains. Crucial to their 24/7 performance is the seamless monitoring and maintenance of the infrastructure in the port area, which has often developed over decades.

An important focus here is on sheet pile structures. Particularly at the quay edges, the ever-larger crane systems required for loading and unloading container ships cause a substantial increase in loads *Schallück (2012)*. Regular analysis of the heavily stressed modular sheet pile walls is necessary, especially from the aspect of detecting lock blasts. Scanning of ship hulls regarding smuggled goods or other unwanted foreign objects is also becoming a focus of attention when it comes to safe transport routes. The same applies to the increasing demand for remotely conducted in-water surveys (IWS) for hull inspections to comply with classification regulations.

Traditionally, divers have been used for such tasks, often performing their analysis under great time and cost pressure in sometimes murky visibility in the sediment-laden waters of inland ports. Remotely operated vehicles (ROVs) are now increasingly used for these tasks, but only qualified pilots can perform the measurements. They depend on sight – so optimal positioning is also a challenge. In the future, these tasks will be ideal areas of application for specially equipped AUVs.

Fig.2: Vehicle after mission completion of customs ship hull inspection in the Port of Hamburg

2. Autonomy for Underwater Robotics

The subdron team consists of European experts in underwater robotics. With the goal of autonomously collecting underwater survey data independent of depth and processing it as needed, the company has been putting the idea of 'Robotics as a Service' into practice. A complete system developed by subdron can move stably, safely, and autonomously in the object-relative range of 1-2 m based on proprietary navigation algorithms.

Field tests of the systems were performed at the subdron test facility on Lake Constance, and in the ports of Hamburg and Bremerhaven, Fig.2. First commissioned investigations have also already delivered convincing results.

Navigating in very confined environments is also possible. Specific environmental perception sensor technology integrated into the vehicle generates and processes data that is directly incorporated into the navigation algorithm. This is the core of subdron's proprietary relative object navigation (RON). RON can ensure that the vehicle always moves in the desired position and orientation to the object.

RON as a software and hardware package makes it possible to dispense with cost-intensive external positioning systems. The imaging sensor system is aligned in an ideal position and orientation to ensure the best possible data acquisition. This, in turn, results in every analysed structural area being imaged at the same resolution.

Thus, even demanding inspection tasks can be undertaken and evaluated with a high level of detail, Fig.3.

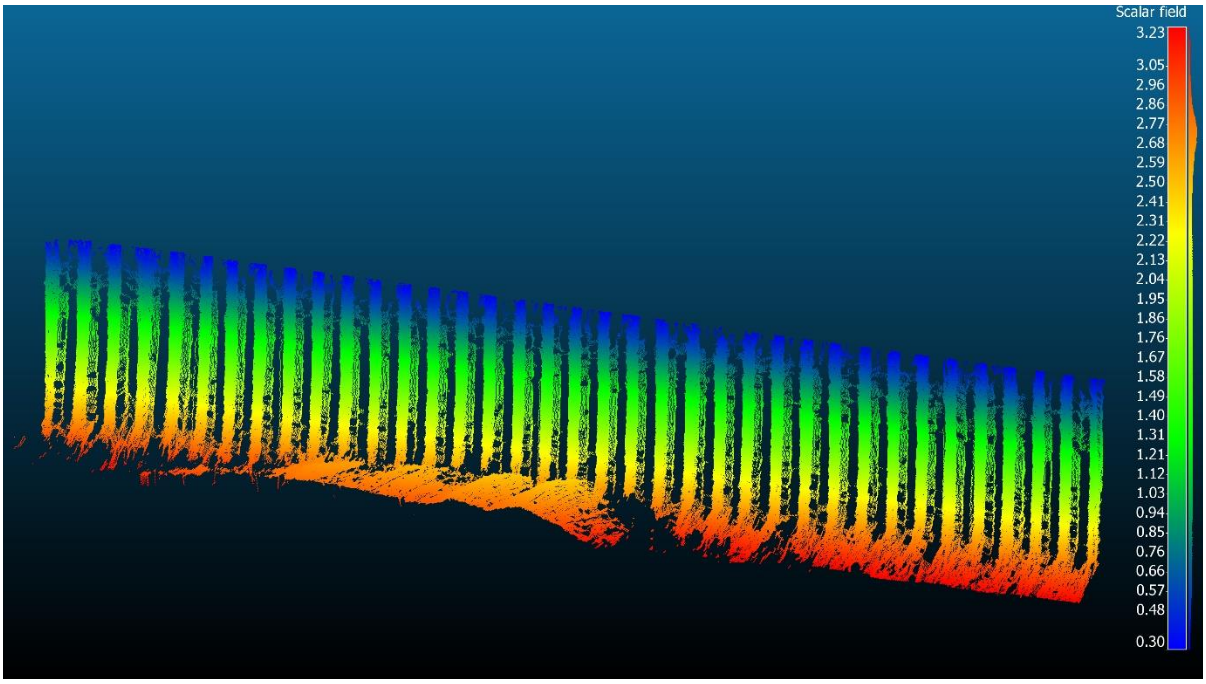

Fig.3: Accumulation at the bottom of the base area of a sheet pile in the Port of Stuttgart

3. High-Performance Underwater Carrier Vehicle

The carrier vehicle is a high-performance Sparus II AUV from IQUA Robotics, https://iquarobotics.com/, with software and hardware modified by subdron GmbH. It is a torpedo-shaped hovering vehicle with mission-specific payload range and efficient hydrodynamics for long autonomous operation time.

The hovering AUV is designed to operate in open water, has a length of 160 cm, a fuselage diameter of 23 cm and a weight of 52 kg in air. This makes it small, light, and manoeuvrable. With a speed of up to 3 kn and an operating time of 8-10 h, even extensive missions can be planned daily. An open software architecture based on a robot operating system (ROS) is used for mission programming, *Carreras et al. (2015).*

Fig.4 shows the orderliness of the sheet pile wall in the Port of Stuttgart. Results of the sheet pile survey included:

- Measurement of the rear trough width (28cm)
- Measurement of the front trough width (27cm)
- Interlock width (5cm)

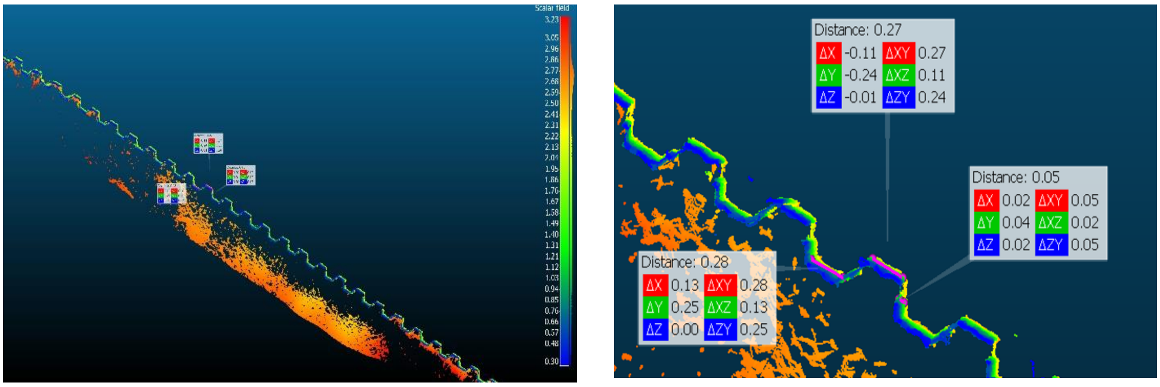

Fig.4: Top view of the sheet pile wall in the Port of Stuttgart, overview (left) and close-up (right)

4. Technical Specifications

For navigation on the water surface, the AUV uses a GPS antenna to determine its position. Underwater navigation uses an inertial navigation system (INS) to determine the AUV's acceleration and angular velocity in three-dimensional space. A downward-looking doppler velocity log (DVL) coordinates the exact direction of travel and speed over ground.

Classic sensor technology is also used for this AUV. A pressure sensor reports the current depth of the AUV. For open water operations, an ultra-short baseline (USBL) system is available to position the submerged AUV and maintain communication. However, due to frequency (multipathing, etc.), the USBL has limited use in a harbour area. All data acquired here is used to validate the position data during post-processing of the point clouds.

Depending on mission requirements and desired data quality, subdron can survey 1-2 km of a harbour wall within 8-12 h on a single battery charge. For such a mission, usually two or three subdron staff members are deployed to enter parameters such as the desired scan length and depth into the system. As the user interaction is continuously developed, it will be possible in perspective to perform a mission with a "non-robotics expert" and an assistant on site.

5. Demand-Driven Data Density

For maximum resolution, the optimum distance between the vehicle and the object to be measured is 1.5-2.5 m. If greater area performance is desired, this distance can be increased. However, greater area performance will result in lower resolution.

Before a mission begins, the sensors of the entire system are calibrated to provide precise measurement results for up to one day. Should the mission require it, recalibration can be carried out quickly.

With a resolution of 1cm, the measurement accuracy is excellent for resolving even small structures. On the relevance of high-resolution 3D data in building geometry, *Hesse et al. (2019).*

6. Legal Requirements

Depending on the location and purpose of the measuring AUV, permits must be obtained from the port authorities. Approvals from river and shipping police may also be required. Due to the close cooperation of all institutions involved in safe port operations, these permits are usually issued within a few days.

7. Quickly Ready for Action

The usual lead time for survey tasks is sufficient to get an AUV to intra-European deployment locations. Likewise, missions outside European waters can be quickly initiated. Transport of the AUV by air freight is given by a certification of the lithium-ion battery for air transport. Depending on the environmental conditions, the AUV can be easily launched from a small boat or comfortably deployed from the water's edge.

8. Imaging Sensor Technology

For bathymetry and side-scan applications, a 260 KHz multibeam echosounder (MBES), a 1.1 MHz side-scan sonar, and a 2.25 MHz MBES are available as a separate payload with full functionality. Depending on the environmental conditions, the AUV can be equipped with additional technologies such as cameras or lasers.

9. Processing Algorithm provides Data Format

Depending on customer's requirements, the acquired data can be prepared and transferred as a point cloud in xyz or by common processing programs. For this purpose, after completion of the mission, the data pass through a specially developed processing algorithm in which the fan data are correlated with the navigation data and thus geo-referenced.

With a density of 10000 measurement points per m^2 (= 1 measurement point per cm^2), the subdron technology delivers a high resolution that is currently higher by a factor of 100 than that of the multibeam installed on board the survey vessel 'Seeadler' in 2016 with a maximum point density of 100-120 measurement points per m^2 at the container quay in the lower area, *Döscher* (2019). With the current resolution, even small deformations can be detected. Once the AUV has undertaken its mission and the processing has been completed, clients receive data in the desired format.

10. 3D Sheet Pile Survey with 10000+ Measurement Points

Fig.5 shows results of a sheet pile wall survey over a length of 30 m and a depth of 3 m in Stuttgart. Note the level of detail of a subdron survey on sections of the structure.

The p.dron measurement system was used for the recordings. The AUV was controlled via subdron's proprietary RON and served as a carrier vehicle for the navigation and the 2.25 MHz multibeam echo sounder. The measurement results from survey, undertaken in September 2021, show a high-resolution 3D point cloud with approximately 10000 measurement points per m^2 and no irregularities. The system was verified by determining the resolution of the images of an intact section of the structure as well as the locks. The rectangular flanks and the rear slope area are not imaged.

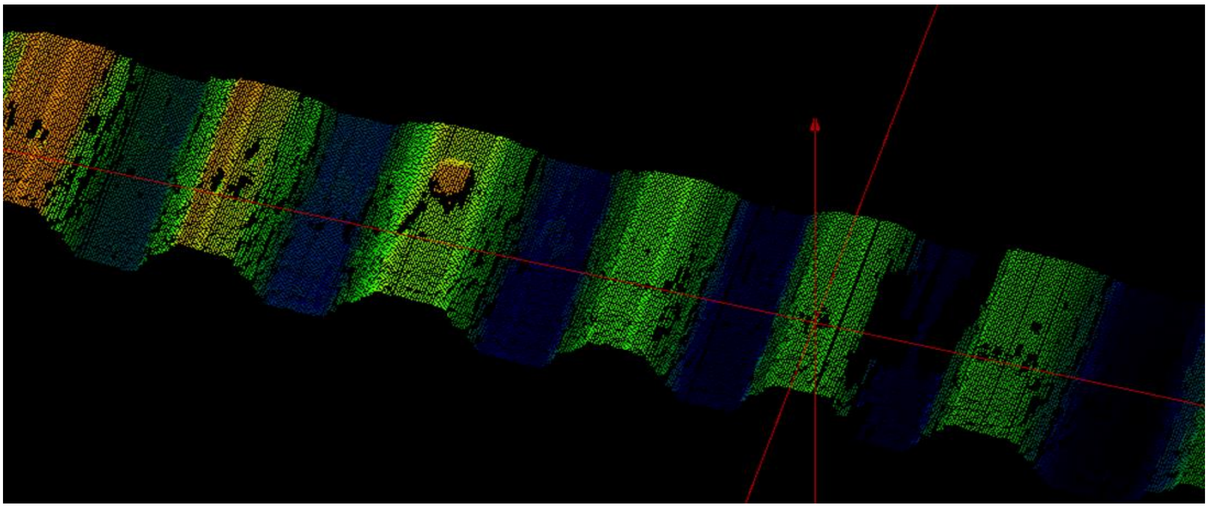

Fig.5: Raw data of sheet pile wall scan. The left section shows a concrete block as a test object. Dimensions of the concrete block: 20x20cm

11. Detection of Foreign Objects during Ship Hull Inspection

The fact that the high-resolution imaging of a system developed by subdron is also suitable for scanning ships' hulls was demonstrated in the Port of Hamburg. In the sediment-laden waters of the port, with a visibility of 30-50 cm, a foreign object measuring 55×35×15cm was detected that had been attached to the hull of a 20 m-long customs ship. In the section of the point cloud, the 3D reconstruction of the foreign object on the hull can be clearly seen by orange-coloured dots, Fig.6. Disregarding the mission setup, the acquisition time for this scan from ferrying to recovery of the AUV was approximately half an hour.

This test under the customs vessel provided valuable insights for further development of stable navigation under large commercial vessels. These will be applied during in-water surveys. Likewise, they will be a valuable support in the preparation of out-of-tour damage inspections after groundings or damage due to mooring manoeuvres.

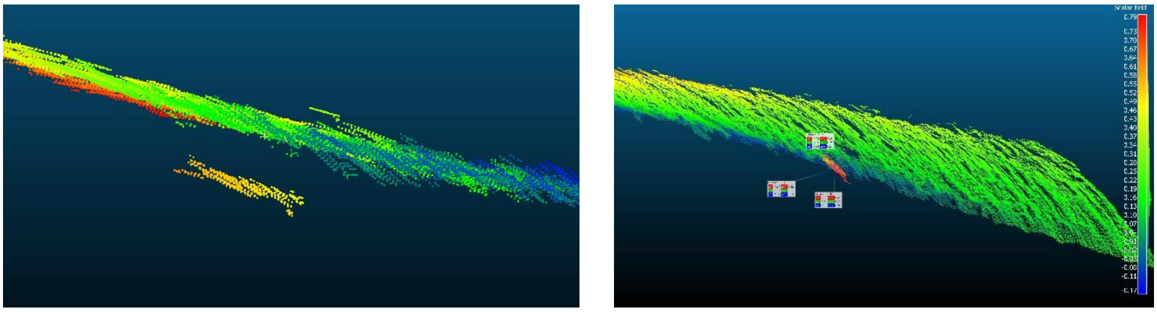

Fig.6: Overview of foreign object on the hull (left) and close-up (right)

12. Conclusions

In port operations, the service package of subdron GmbH has already proven to be a useful support for survey tasks that can be realised quickly. Even though subdron is pushing the development of IWS deployments, the p.dron measurement system is to be seen as complementary to surface- or ship-based autonomous measurement systems in current applications.

Furthermore, the generically deployable and adaptable system control via RON creates a multitude of additional application fields. Examples of future 'Robotics as a Service' applications include infrastructure monitoring in ports and on waterways, port security, and inspections of offshore structures and ships.

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OpenHull Cooperative Platform for Hull Data

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Abstract

The Open Hull project introduces a collaborative platform designed to facilitate the exchange, comparison, and enhancement of coating and cleaning strategies among shipping companies, all while factoring in their vessel operations. Through the sharing of proprietary hull data, participants gain access to anonymized insights and experiences contributed by their industry peers. This article offers an update on the ongoing progress and vision of the Open Hull project, shedding light on its pioneering approach to fostering industry-wide cooperation and highlighting the initial lessons drawn from this innovative initiative.

1. Introduction

Significant strides have been taken in recent years to enhance the energy efficiency of ship hulls. The emergence of hull optimization algorithms has provided a framework to fine-tune cleaning schedules, and the rapid deployment of sensors aboard vessels starts to effectively enable shipowners and managers to achieve even more precise optimizations. The impetus behind the growing emphasis on cleaner hull solutions stems from multiple factors, including the upward trajectory of bunker prices (Fig.1), the enforcement of the CII regulation commencing in January 2023, the enforcement of stricter local mandates to curb the spread of Non-Native Species, and a mounting global awareness of the challenges posed by climate change.

Despite these advancements, the majority of optimization efforts have concentrated on refining cleaning schedules, leaving a notable gap in research pertaining to harmonizing and optimizing the interplay between cleaning technologies and coatings, as well as their alignment with the operational profiles of diverse vessels.

Fig.1: Global Average Bunker Price for VLSO between 10.8.2020 and 9.8.2023, https://shipandbunker.com/prices/av/global/av-glb-global-average-bunker-price#VLSFO

2. The limit of current cleaning & coating optimization methods

2.1. Performance-based optimization

The switch from time-based cleanings to performance-based cleanings have allowed for a better monitoring of hull performance.

Performance algorithms rely on noon reports or on sensors data to keep track of the corrected speed loss over time, the residual error being explained by added hull resistance, ie, fouling.

Showing the curve of corrected speed loss over time, with idle periods and hull cleanings, allow to recognise the effect of these cleanings, as we can see in the examples below, *Morobe (2023)*, *Oliveira (2017)*.

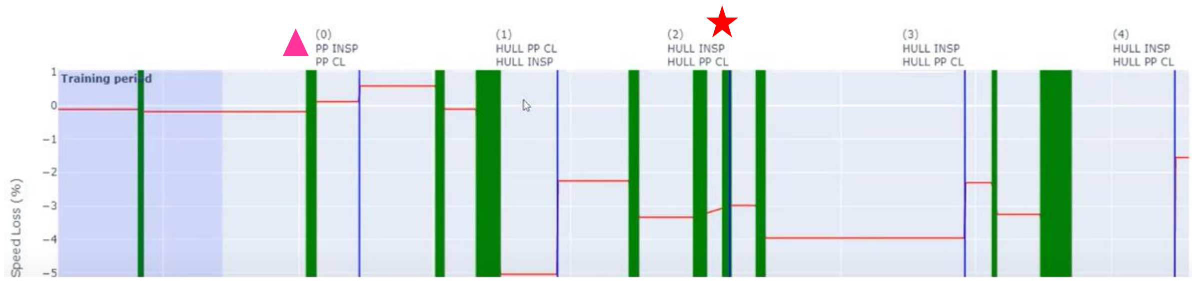

Fig.2: Corrected Speed Loss over time, with idle periods marked in green and cleaning events in blue, *Morobe (2023)*

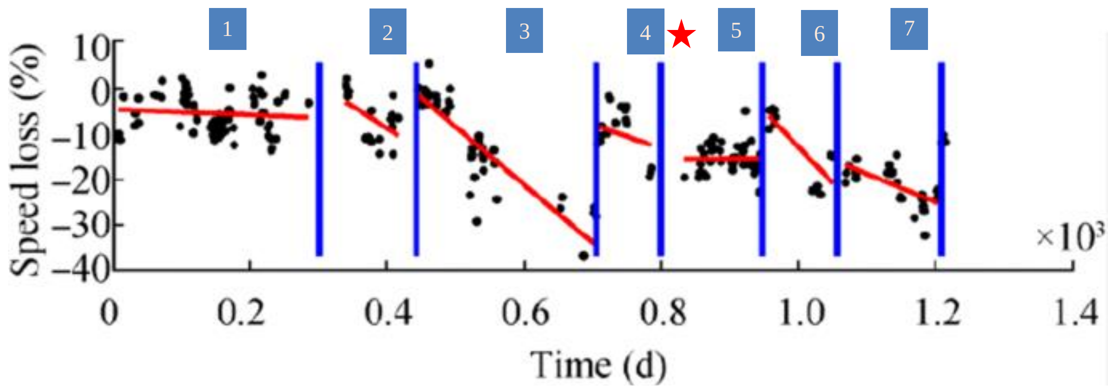

Fig.3: Corrected Speed Loss over time, with cleaning events in blue, *Oliveira (2017)*

However, in these two examples, some questions remain unanswered:

- Cleaning events have varying impact on the speed loss: some being very effective to decrease speed loss, other with little to no effectiveness (marked with red stars in Fig.2 and Fig.3).
- The slope of performance loss over time differs greatly from one cleaning event to the next. See for example the pink triangle in Fig.2, and the difference between periods 1 and 3 in Fig.3.

Some authors from shipping companies have also described that they would delay the first cleaning event as long as possible, because the paint would have a lessen efficiency afterwards and subsequent cleaning events would need to be planned much more regularly. *Karagiannidis et al. (2021)* showed an example where the first cleaning event would be planned 3 years after dry dock, and then every 3 to 6 months until the next dry dock.

These examples show that the impact of cleaning is still largely unknown, both in terms of efficiency and regarding the impact on the coating.

2.2. Tailor-made coating and cleaning solutions

Some coating developers have developed specific paints matching specific technology development, like Jotun Seaquantum Skate which is designed to work with Jotun Hull Skater. However, the necessity to purchase a unique cleaning solution tailored to a unique coating solution, doesn't answer the need for optimization for all the other paints and the other cleaning technologies, which represent most of the coating applications and cleanings realized in the world.

According to *Swain et al. (2022)*, proactive cleaning technologies should also be tailored to the type of anticoating which has been applied on the hull. Therefore, a biocide-based coating should be activated by a proactive cleaning, while a cleaning on a Fouling Release Coating should focus on fouling removal.

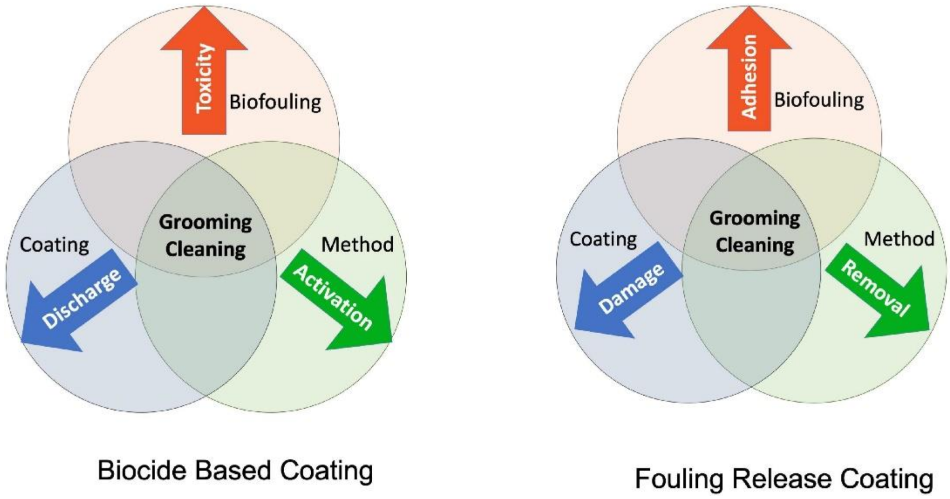

Fig.4: *Swain et al. (2022)*, varying coating technologies call for different proactive cleaning methods

However, these recommendations remain largely difficult to action from a cleaning service perspective. Little is known about the technological implication between Activation and Removal of biofouling when it comes to cleaning full scale vessels.

3. The opportunity of large-scale cleaning and coating optimization

3.1. Limitations of fleet-scale optimizations

The reason why most performance algorithms focus on noon reports and on sensors data, is that they can be optimized at the scale of one vessels and/or of a limited number of sister vessels. High or medium (daily) frequency data give enough information to find optimization levers and correct the speed loss curve in a satisfactory manner.

However, when it comes to cleaning events, the large amount of variables (technology used, conditions and location, specs, operation, zones of the hulls, type and age of coating, previous cleaning events, operation parameters…) comes with a very limited number of cleaning events to study – generally less than 10 in a 5-year dry dock cycle.

Thus, it is impossible to optimize these parameters at the scale of one or a few vessels.

Even a 100 vessels fleet would create too much variables and too few cleaning events to allow a deep understanding of all the variables.

Creating big data for very low frequency cleaning events would mean to pool together data from 1000+ vessels with all types and brands of coatings, and many different cleaning technologies used.

3.2. The vision for a cooperative platform for hull data

The vision of OpenHull is to create a large-scale repository of hull data, that would gradually build knowledge about the effectiveness of cleanings in various conditions, and the compatibility between cleaning techniques and coating parameters. This data lake will enable to also optimize the biofouling management plan of a vessel and adapt it to its actual operating conditions, and to compare special antifouling techniques, for example for niche areas. Fig.5 summarizes the success factors.

EASY – leverage service provider data and automatically uploads

INDEPENDENT – All coating and cleaning technologies are analyzed on the same basis

NEUTRAL – The platform benefits all participating shipping companies alike

STRUCTURED – OpenHull gathers and structures hull data, improving its reliability and compatibility

Fig.5: Success factors of the OpenHull approach

What's more, a failed test on an innovative coating or cleaning solutions leads to heavy consequences, such as earlier dry dock and new coating application. As a result, shipping companies are cautious when testing new coating and cleaning innovations, and usually test them on small scale for one or several dry dock cycles before expanding a given solution to several pools of vessels.

As a result, innovative solutions for hull performance (coating and cleaning) are long to penetrate the market.

This is true, even if the technology has already been extensively tested by other shipowners in similar condition.

Pooling data together will enable shipping companies to build independent knowledge faster, relying on previous data in relevant conditions to make better informed decisions.

The foreseeable advantages of such an open repository platform would be:

1) Assess the fouling state of any vessel, based on coating & operational data
2) Estimate the hull coating efficiency rate of any given vessel based on passed data
3) Predict the impact of cleaning on:
    a) Fuel performance
    b) Coating degradation
4) Predict the impact of idle times on
    a) Fuel performance
    b) Coating degradation
5) Choose coating technologies adapted to the vessel operational profile
6) Calculate the impact of more advanced Anti-Fouling Systems over the whole paint lifecycle

4. Industry consultation about OpenHull

4.1. General method for consultation

From February 2023 to June 2023, a total of 25 interviews were conducted to assess the interest of players of the industry in such a platform.

Organizations surveyed included shipping companies, service and technology providers, institutions (NGOs, government bodies, associations…), as well as coating companies, Fig.6.

Among Shipping companies, most interviewees were tanker companies, and the others were distributed between Container lines, Cruise line, and other goods, Fig.7.

Interviews took the form of one to several hours of remote meetings, where the main interest and main concerns about OpenHull were debated.

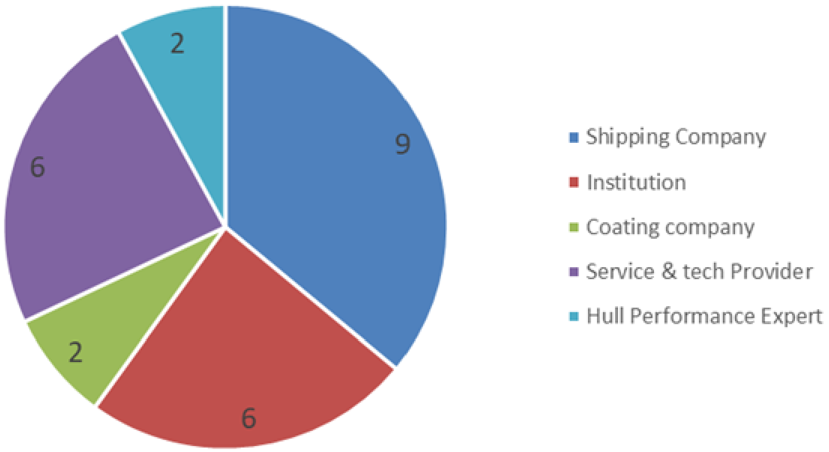

Fig.6: Number and types of organizations interviewed about OpenHull

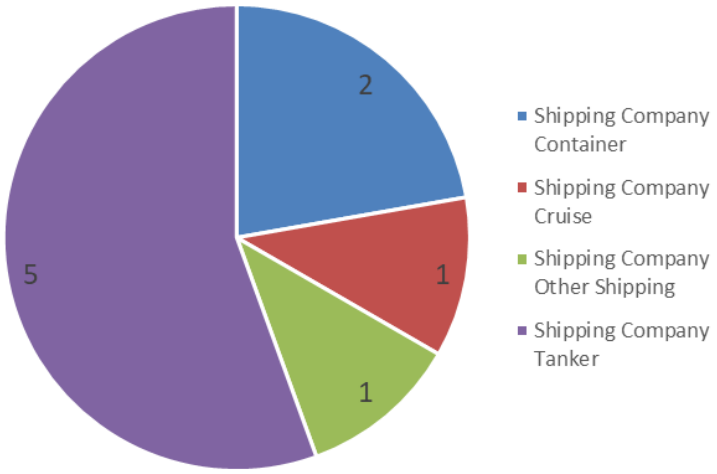

Fig.7: Detail about Shipping company type

4.2. Learnings from interviews

After the interviews, interest in OpenHull was determined on a scale from 1 (no interest at all) to 5 (immediately ready to commit). The results are presented Fig.8.

Overall, the project was looked at favorably by most people interviewed. The main positive feedbacks were:

- Useful for the fight against biofouling (most institutions and a distribution of other types of company)
- Help to find new, qualified service providers (1 shipowner)
- Help to choose the relevant cleaning technology depending on coating (2 shipowners)
- Help to choose the relevant AFS depending on the vessel (1 shipowner)
- Prove the efficiency of a proprietary technology (2 coating and 2 cleaning providers)

Among the 25 interviews, 20 were not ready to immediately commit. Their main concerns were:

- No resources to allot at the moment (13 organizations)
- Fear of losing a competitive advantage (6 organizations)
- Competing with internal performance models (1 organizations)

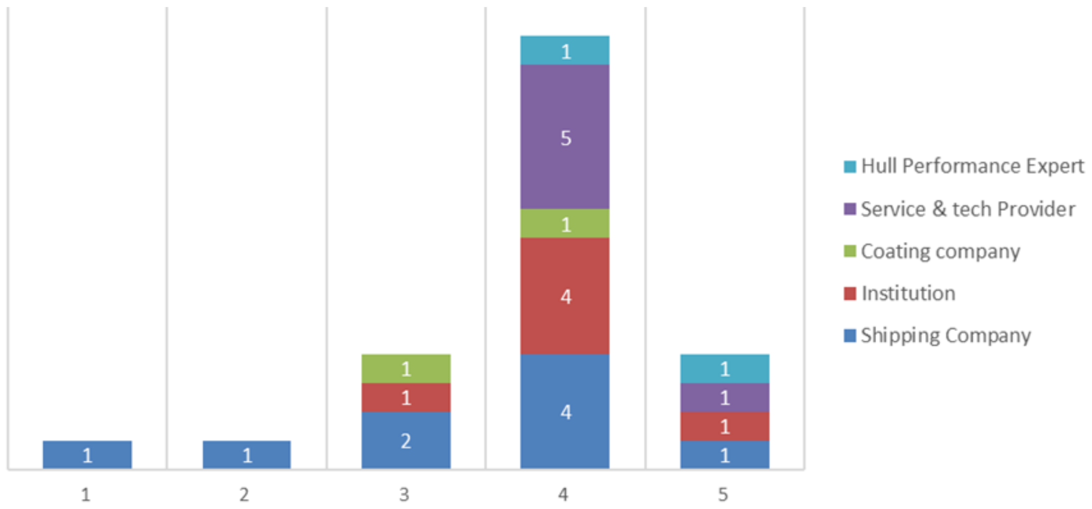

Fig.8: Score of interest in OpenHull from 1 (no interest at all) to 5 (immediately ready to commit), with detail of organization types

Four companies were immediately ready to commit. Among them was 1 shipping company, who started sharing data from various pools of vessels (antifouling parameters, cleaning events, and noon reports) to kickstart a first proof of concept for OpenHull.

4.3. Learnings from first data set

Data was shared from 11 vessels with two groups of sister ships, with all the data from the date of the last dry dock. For these vessels, 3 different coatings brands were applied, Fig.9 - all self-polishing paints and 26 cleanings or inspection events were recorded, Fig.10.

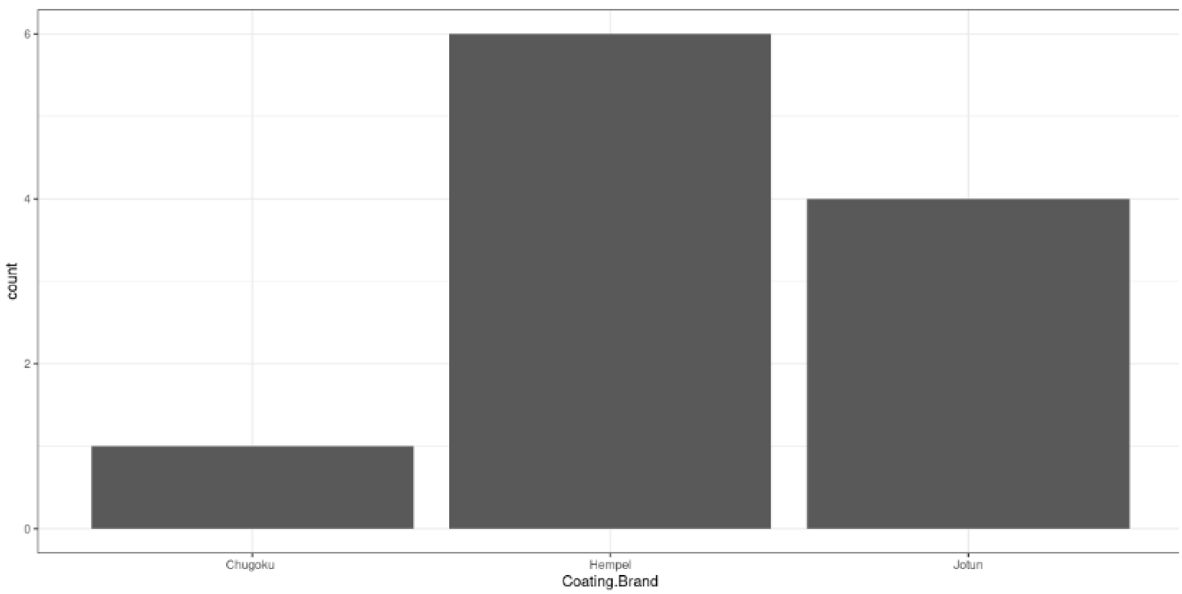

Fig.9: Brands of paints applied in the 11 vessels studied for the proof of concept

The preliminary results showed that the age of the last cleaning event was significantly impacting the fuel efficiency of the vessel. Unsurprisingly, the data studied was too scarce to draw meaningful learnings about the coating or cleaning efficiency, as well as the paint degradation factor.

Taking into account the visual images of the hull before and after a cleaning event was important to check on the actual state of the hull and assess the level of Anti Fouling efficiency.

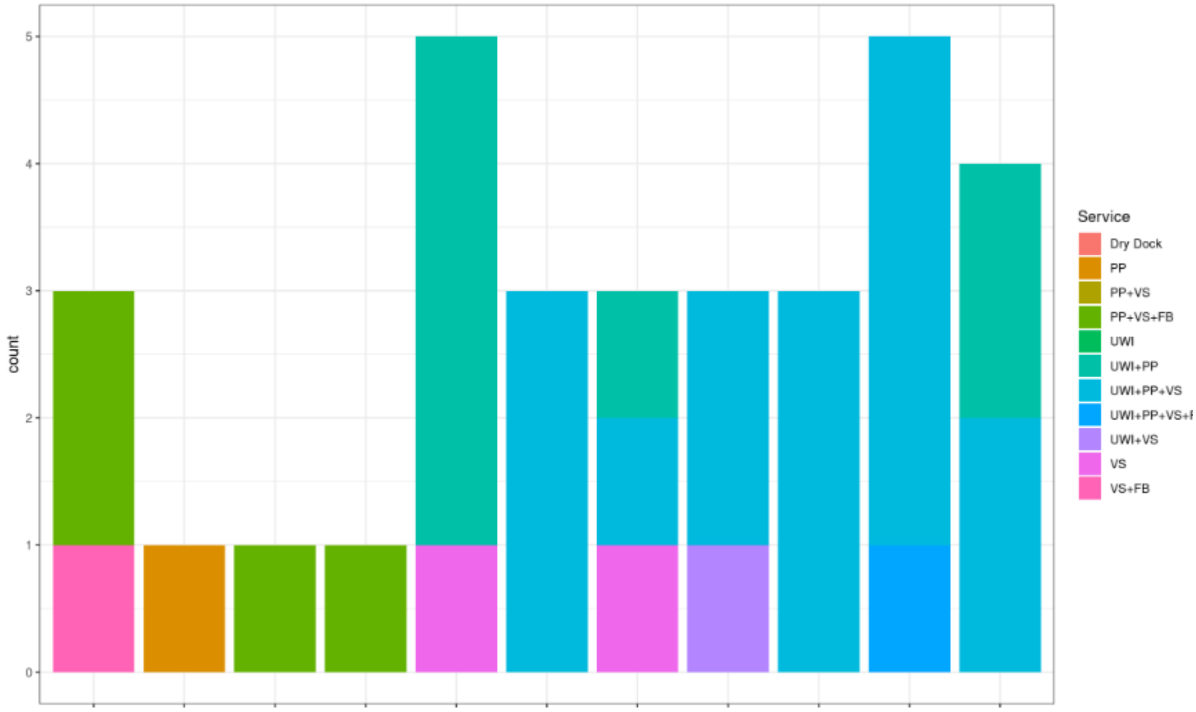

Fig.10: Recorded cleaning events for each of the 11 vessels studied for the proof of concept, with details on type of report

The reports shared by the shipping company have shown a high variability in their forms and in the content, which made comparison at large scale all the more difficult.

5. Overcoming the challenges

5.1. Creating consistency in inspection and cleaning reports: the Digital Fouling Report

OpenHull cooperative platform for hull data aims at analyzing visual images of the hull and adding them with Antifouling and with cleaning parameters to estimate paint degradation. The initial proof of concept for the platform has shown that a high variability in the form and content of cleaning and inspection reports would make it more difficult to extract their value.

Many cleaning companies create high quality, extensive reports with pictures and/or videos, following the BIMCO or AMPP standards and complying with the state of the art of the profession. However, even in this case, different frameworks and different scales are used to assess the level of biofouling.

With OpenHull emerged the idea to create a Digital Fouling Report format, that will be a common ground between several existing PDF standards, and include the minimum meaningful information that will be compared from one report to another.

A survey of the cleaning and inspection companies was conducted on this project, and a first meeting was held during Norshipping event in June 2023. It enabled to set up the outline of such a Digital Fouling report, that would rely on the Glofouling scale of fouling and include a selection of zones around the hull and hull images.

This project was presented for support at the 11th meeting of the Global Industry Alliance (GIA) for Biosafety on April 27th, 2023. There was an overall support from the members, and a willingness to move forward, but the amount of financial support asked for in this first presentation was deemed too high compared to the means of the GIA. A new application will be made with reduced scope of project.

The AMPP – Association for Material Protection and Performance – has expressed its interest to create a working group dedicated to working on this format, as a complementary tool to the existing standard procedure for inspecting and reporting Antifouling Systems' condition during underwater inspection on ships *AMPP (2021)*.

Such Digital Fouling Report will enable the OpenHull platform, but also all performance software products, to include standardized inspection data into their own algorithms and to improve their recommendations.

5.2. Getting a foot on the ladder of cooperation: A map for Service Providers and Paint reviews

As seen in 4.2, one of the main concerns of surveyed people was that OpenHull would require resources that they did not have at the time being. Overall, we could sense a general positive opinion about the project and its usefulness, but a concern that it would be difficult to make it work and create the right momentum in the industry.

Out of 9 shipping company, only one was ready to immediately share some data. This was favored by several factors: access to high level decision makers, willingness to improve performance models, positive opinion about industry cooperation.

However, sharing data is a decisive step for a shipping company, that usually take time and resources to allow.

These interviews enabled to draw a first version of the OpenHull platform, that will not require any specific data sharing, but rely on ship owners and ship managers reviews about paint and cleaning events. This platform will enable cooperation around hull results, but decorrelate it from actual data sharing.

It is expected to be live in September 2023 on the website openhull.com.

6. Conclusion and impact

OpenHull began with a big idea - bringing the maritime industry together to work as a team and share information about ship hulls. This helps everyone and makes cleaning and coating ships better. In the first few months, we learned a lot from talking to people in the real world.

It was the start of two complementary initial projects, the Digital Fouling Report format and and the establishment of an online platform for peer reviews concerning cleaning technologies and Anti-Fouling Systems.

From here on, the support from industry organizations and international institutions, as well as participation for industry players, will be decisive to make both projects adopted and useful. If successful, they will be a first step moving towards the long-term vision. In other places, working together has shown how powerful it can be. For instance, the shipping industry decided to share safety information instead of competing. Now we face a big question: should we compete or work together to protect the environment and fight climate change?

Optimizing hull performance thoroughly will also increase the financial feasibility of alternative fuel technologies: to drive the energy transition of the industry, every percent of energy efficiency will be needed.

At a time when global trade is deemed as a concern for its environmental impact, we have the power and the responsibility to lead the way into more cooperation, for the benefit of all.

Acknowledgement

The warmest thanks go to the many industry players who have open their doors and networks, and who have shared their insights for the OpenHull project over the last few months. They have allowed the learnings shared in this article.

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Recent and Important Steps towards Harmonized Regulations on Hull Cleaning

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Abstract

In the future, hull performance strategies may have to align with the International Maritime Organization's (IMO) guidelines or regulations on biofouling management, as well as international standards on hull cleaning developed by the International Organization for Standardization (ISO). This paper reports on the latest developments on the topic of hull cleaning in these two mentioned organizations, through the lens of the Clean Hull Initiative. The paper argues that the recent developments in the IMO and the ISO are important new steps towards harmonized regulations of hull cleaning.

1. Introduction

Biofouling on ships spreads invasive aquatic species, and the translocation of such organisms is a recognized global threat to coastal environments. Hull cleaning that is conducted safely reduces these biosecurity risks. Furthermore, biofouling increases frictional drag on hulls and decreases the propeller efficiency, which in turn increases fuel consumption and emissions from vessels. While the IMO's calculations showed that biofouling accounts for 9% of emissions from global shipping in 2020, *IMO (2020)*, recent research by *Swain et al. (2022)*, estimate 19%, equalling 198 million tons of CO2.

Biofouling on ships' hulls should be a core concern to anyone developing and improving hull performance strategies. During the first half of 2023, hull cleaning was firmly placed on the international agenda in two parallel processes: The International Maritime Organization (IMO) finalized their revised guidelines for the management of biofouling for the first time since 2011, and an international group of experts initiated the work of developing a standard for hull cleaning under the supervision of the International Organization for Standardization (ISO).

This paper will report on these two processes in the IMO and the ISO from the point of view of the Clean Hull Initiative. The Bellona Foundation "soft launched" the Clean Hull Initiative at PortPIC in 2021, and since then, the Bellona Foundation has been actively following the debates at the IMO, and has also been convening the standard development work conducted by a group of experts in the ISO.

2. The Clean Hull Initiative

The Clean Hull Initiative (CHI) aims to address the lack of comprehensive biofouling management policies worldwide, and to address the confusion caused by operational variations among the few jurisdictions that have such policies. CHI aims to provide a level playing field for a range of stakeholders, thereby contributing towards harmonized regulations. Through the promotion of more consistent policies, CHI aims to make it easier for the shipping industry to manage biofouling proactively, and to arrange for in-water cleaning service providers to smoothly operate in several locations. Working towards this goal, CHI has made efforts to enable an ISO standard for hull cleaning, which has succeeded: The development of such a standard was formally initiated in 2023.

As of August 2023, the Clean Hull Initiative has almost 40 stakeholder members, and the group includes global ship owners, operators, regulators, port authorities, cleaning technology developers and service providers, test facilities and the scientific/research community.

Before returning to the topic of the ISO standard, this paper will make an account of recent developments in the IMO, since the organization arguably sets the stage for the work done on the ISO standard.

3. Hull cleaning on the agenda of the IMO

In 2023, the IMO revised the Guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species from 2011. The revised guidelines will henceforth be referred to as the revised IMO guidelines, *IMO (2023)*.

The revised IMO guidelines were developed in a Correspondence Group, and turned into a final draft at the 10th meeting of the Sub-Committee on Pollution Prevention and Response (PPR 10) in April 2023. In July the same year, MEPC 80 adopted the guidelines. The revised guidelines provide important definitions, clarifications and recommendations, and they are more detailed compared to the 2011-version, which makes the revised guidelines far more actionable. However, there is still work left to be done on the guidelines: A separate guidance on matters relating to in-water cleaning is to be developed at PPR 11 in 2024, and the target completion year of that output is 2025.

The revised IMO guidelines provide relatively precise definitions of proactive and reactive hull cleaning, and states that proactive cleaning is the periodic removal of microfouling on ships' hulls to prevent or minimize attachment of macrofouling, while reactive cleaning is a corrective action during which biofouling is removed from a ship's hull and niche areas either in-water with capture or in drydock, *IMO (2023)*.

One of the most interesting parts of the guidelines is a rating scale referred to as "Table 1" in the revised IMO guidelines. This table recommends proactive cleaning on microfouling, and here refers to a section of the guidelines called "section 9.4", a section which states that proactive hull cleaning without capture cannot be conducted on rating ≥ 2, *IMO (2023)*. On light macrofouling and above, the table recommends cleaning with capture. It may be argued that "cleaning with capture" should be specified as reactive cleaning, since proactive cleaning cannot be conducted on macrofouling, but the table and section 9.4. nonetheless provides important clarifications on when in-water cleaning with non-capture and capture may be conducted.

Table 1: Rating scale to assess the extent of fouling on inspection area

<table>
<tr><th>Rating</th><th>Description</th><th>Macrofouling cover of area inspected (visual estimate)</th><th>Recommended cleaning</th></tr>
<tr><td>0</td><td>No fouling.
Surface entirely clean. No visible biofouling on surfaces.</td><td>-</td><td>-</td></tr>
<tr><td>1</td><td>Microfouling.
Submerged areas partially or entirely covered in microfouling. Metal and painted surface may be visible beneath the fouling.</td><td>-</td><td>Proactive cleaning may be recommended as further specified in paragraph 9.4</td></tr>
<tr><td>2</td><td>Light macrofouling.
Presence of microfouling and multiple macrofouling patches. Fouling species cannot be easily wiped off by hand.</td><td>1-15% of surface</td><td rowspan="3">Cleaning with capture is recommended as further specified in paragraph 9.9.

It is recommended to shorten the interval until next inspection. If the AFS is significantly deteriorated, drydocking with maintenance and re-application of AFS is recommended.</td></tr>
<tr><td>3</td><td>Medium macrofouling.
Presence of microfouling and multiple macrofouling patches.</td><td>16-40% of surface</td></tr>
<tr><td>4</td><td>Heavy macrofouling.
Large patches or submerged areas entirely covered in macrofouling.</td><td>41-100% of surface</td></tr>
</table>

Fig.1: "Table 1" excerpt from IMO's revised guidelines, *IMO (2023)*

From the perspective of the Clean Hull Initiative, the revised IMO guidelines are a promising first step towards international regulations, which is important since there is an urgent need to develop such regulations.

4. Hull cleaning on the agenda of the ISO

As reported in *Oftedahl and Skarbø (2021, Skarbø (2022)*, the Clean Hull Initiative was established to develop an international and industry-wide recognized standard on proactive hull cleaning. In January 2023, such a standard was approved for development after the initial proposal received an overwhelming number of YES votes by the voting countries in the ISO. Shortly after, a working group, called WG ISO/TC 8/SC 2/WG 13, was established to develop the standard. (In addition to working on the standard on hull cleaning, the working group (WG 13) also covers another standard on guidelines for testing ship biofouling in-water cleaning systems.) The Bellona Foundation is the convenor of the working group. The group includes experts from the science/research community, cleaning service providers and technology developers, the coating industry, the port sector and the shipping industry and NGOs.

The objective of the standard for hull cleaning is to provide a "best practice" methodology to assist and facilitate the implementation of environmentally responsible hull cleaning procedures and methods for documentation of the operations. The proposed scope of the standard was originally to "[…] specify standard methods for performing and documenting safe and environmentally sound proactive hull cleaning." The standard will most likely describe the hull cleaning process, including all relevant aspects such as fundamental conditions, preparations, the cleaning operation itself, and post-inspection routines. By specifying required documentation and measures, the standard will help ports and other jurisdictions evaluate requests for in-water cleaning of ships' underwater hull areas while in port or at anchorage, and help shipowners ensure that cleaning services are performed according to a specific standard regardless of location.

In March 2023, the working group met for the first time, and by June the working group had already held three meetings, one of which was a three-day long hybrid meeting with several members meeting in Oslo, Norway. The plan is to submit a Working Draft to ISO in September 2023.

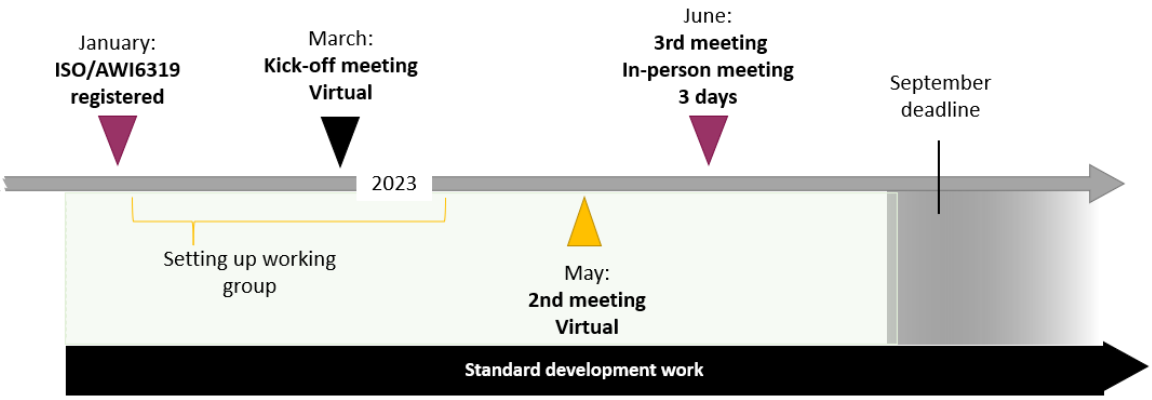

Fig.2: The timeline for the first three quarters of 2023. AWI stands for Approved Work Item. The September deadline is the deadline for the Working Draft.

In the initial phase of this work, the involved stakeholders expressed the importance of aligning the standard with the IMO's guidelines on the topic of biofouling management, hence, the final standard will most likely be compatible with these guidelines, and use many of the same definitions. In light of the revised version of the IMO guidelines, changes to the original scope of the standard may occur.

As the work progresses, there are several hypothetical scenarios that need to be assessed, and questions to be answered. Should the standard expand by including new parts that address cleaning with capture, to align as much as possible with the scope of the IMO guidelines? (If parts are added to the standard, these parts will have their own timeline.) How much focus should there be on inspection? What does it mean to for a standard to indicate "best-practices" for hull cleaning? There will hopefully be time to discuss all these questions since the standard development has a timeline of 36 months. At the end of 2025, the standard must be finished, and it will be published in January 2026.

Fig.3: The timeline for the standard development and finalization

5. Conclusions

In the first half of 2023, the topic of hull cleaning fully entered the international agenda, both through the work done at the IMO to revise its biofouling management guidelines, and through the work done at the ISO to develop new standards on hull cleaning. The Clean Hull Initiative sees the recent IMO guidelines as a clear sign that hull cleaning is increasing its level of importance in the international shipping community, and predicts that hull cleaning will continue to increase its importance to ship owners, to ports, and other stakeholders in the years to come. The Clean Hull Initiative is also content to see that a new standard on hull cleaning has been approved for development, and that the standard is already ready to submitted to the ISO as a Working Draft. In light of these recent developments, anyone concerned with hull performance should align their strategies with the revised IMO guidelines, and prepare for the new standards and regulations that hopefully will arrive a few years from now.

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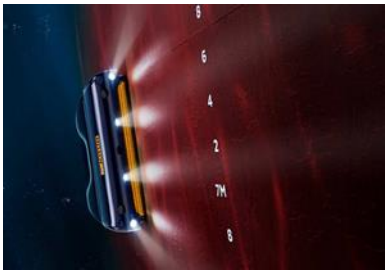
5th In-Port Inspection & Cleaning Conference (PortPIC)

Pontignano/Italy, 30.9-2.10.2024

Topics: Aquatic Invasive Species / Diver operations in port / Next-generation antifouling technologies / Operator perspective on cleaning / Performance-based cleaning / Regulations & Guidelines / Robotic cleaning & inspection

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The proceedings will be made freely available to the general public.

Deadlines:

anytime	Optional "early warning" of interest to submit paper / participate
30.05.2024	First round of abstract selection (1/3 of available slots)
30.06.2024	Second round of abstract selection (remaining slots)
30.08.2024	Payment due for authors
30.08.2024	Final papers due

Admin. Fees: **800 €** – early registration (by 30.06.2024)
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