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Low-energy surfaces on high-speed craft

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Abstract

Foul Release systems offer a low-energy surface that prevents firm adhesion of fouling organisms on underwater hulls. Above a critical threshold speed, hydrodynamic forces against the ship hull wash off any attached organisms. Particularly for high-speed, high-activity vessels, Foul Release systems offer an environmentally attractive, long-term, cost effective alternative to toxic biocidal antifoulings.
A research project has been set up to investigate whether the specific surface properties of Foul Release systems have a beneficial effect on its drag. Flat plate towing tank experiments have confirmed that the total resistance of a 6.3m plate coated with a Foul Release coating system was 1.4% lower than when it was coated with a Tributyltin-free Self-Polishing Co-polymer (SPC).
Surface analysis carried out with an optical measurement system has indicated that the mean absolute slope and the correlation length of the Foul Release sytem can differ from those of other coatings by an order of magnitude. Part of ongoing research has been trying to correlate the roughness parameters with the observed drag reduction.

1. Introduction

The majority of antifoulings controls fouling settlement through the release of biocides from the coating surface. Foul Release coatings work quite differently, and prevent the settlement of the fouling by providing a low-energy surface onto which organisms have great difficulty attaching. If vessels are stationary for extended periods, settlement can occur, but there is only weak bonding between the fouling and the Foul Release coating surface and so the organisms can be relatively easily removed, by the hydrodynamic forces against the surface when the vessel is travelling fast enough.

The first full fast ferry application of a Foul Release coating was on a 33 knot aluminium catamaran, in March 1996 (Millett and Anderson, 1997). Prior to this, the vessel concerned had been coated annually with a low-copper TBT-free antifouling, suitable for use on aluminium. After the application of the Foul Release coating, an increase of 2-3 knots was observed in all weather conditions. Consequently, each journey (of approximately 1 hour) was about five minutes shorter in 1996 than in 1995, and the overall fuel consumption was reduced by 12%, more than 20000 litres/month. It was thought that these results were linked to the surface properties of the Foul Release system and a research project was set up to investigate this. As the first stage of this project, towing tests were carried out with flat planes in order to verify if Foul Release systems exhibited less drag than tin-free SPC systems. The results of these tests are presented in Section 2 of this paper.

Foul Release systems are chemically very different from toxic antifouling systems and are formulated in such a way that they exhibit low surface energy, which in turn has repercussions on the surface metrology. Measurements have been carried out with an optical measurement system to compare the roughness parameters with those of other coating systems, and are presented in Section 3 of this paper. Finally, preliminary conclusions and an outline of the ongoing research are presented in Section 4.

2. Drag measurements

Two sets of flat plate towing experiments were carried out. The first set of experiments involved a 2.55m long plate that was towed in the 40m long, 3.75m wide and 1.2m deep tank of the University of Newcastle-upon-Tyne. The aluminium plate, as shown in Figure 1, was towed over a speed range up to 2m/s.

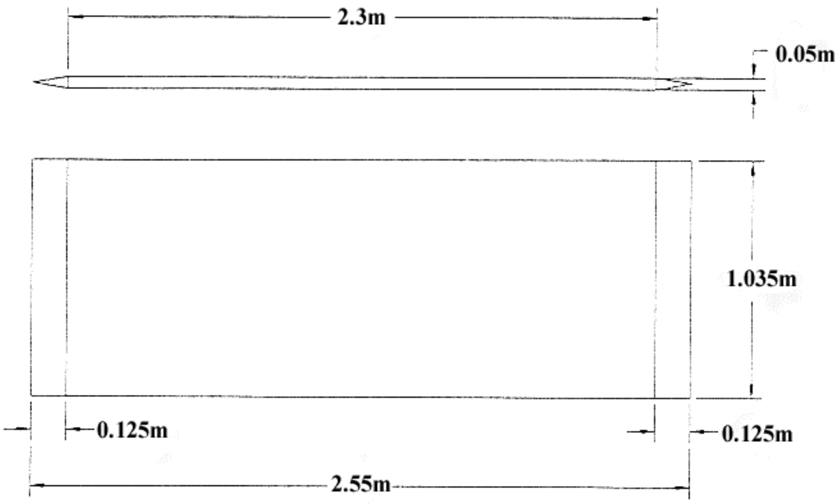


Figure 1. Dimensions of the plate used in the Newcastle University towing experiments

The total drag was measured with 2 suitably designed load cells, which were fitted to the plane and then to the two towing pins at the fore and aft of the plane. The measurements were taken with the three different surfaces, which were the aluminium reference surface, the 3-coat SPC antifouling scheme and the 3-coat Foul Release system. Figure 2 shows the total resistance coefficients for the three surfaces as well as the ITTC-57 friction line plotted against the Reynolds number, and displays the significant difference between the two coatings.

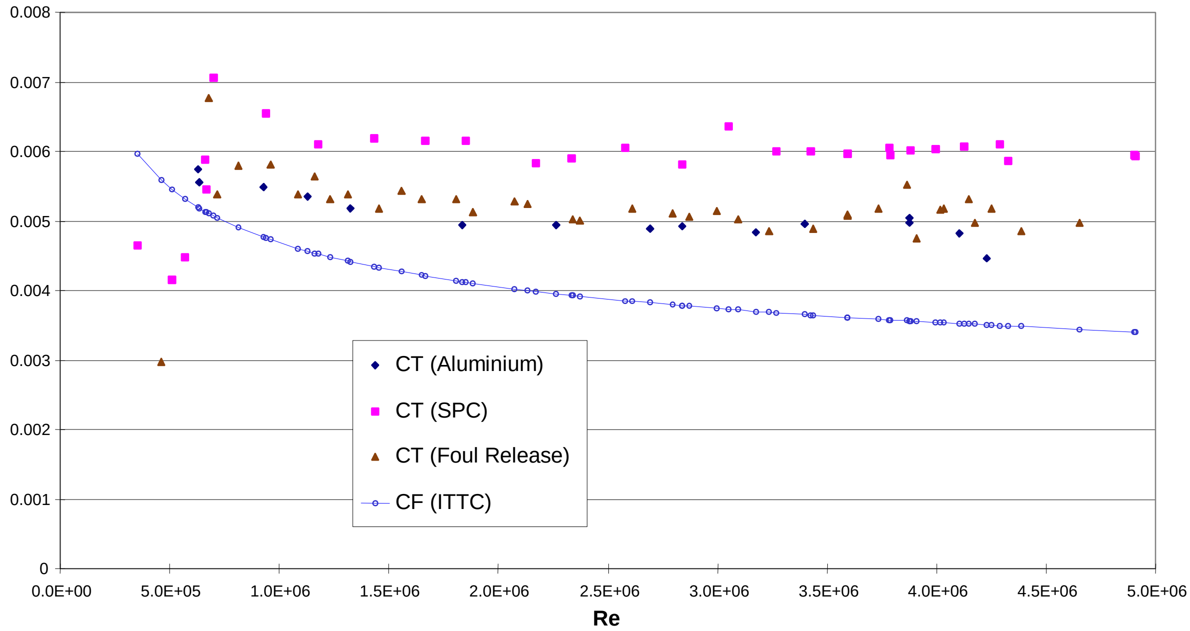


Figure 2. Total resistance coefficients against Reynolds number of the three tested surfaces in the Newcastle University towing tank

Because of the limited speed range and run-length in the first set of experiments, the maximum Reynolds number was restricted to $5{\cdot}10^6$, and the time-span over which measurements were taken was only 3 seconds for the highest speeds (Candries et al., 1998).

The second set of experiments was carried out over a much larger speed range, up to 8m/s, with a 6.3m long plate, in the 320m long El Pardo Calm Water Tank, shown in Figure 3. The design of the aluminium plate, as shown in Figure 4, was based on the NSRDC friction plane model 4125, which has been used for similar experiments at the David Taylor Model Basin (West, 1973).

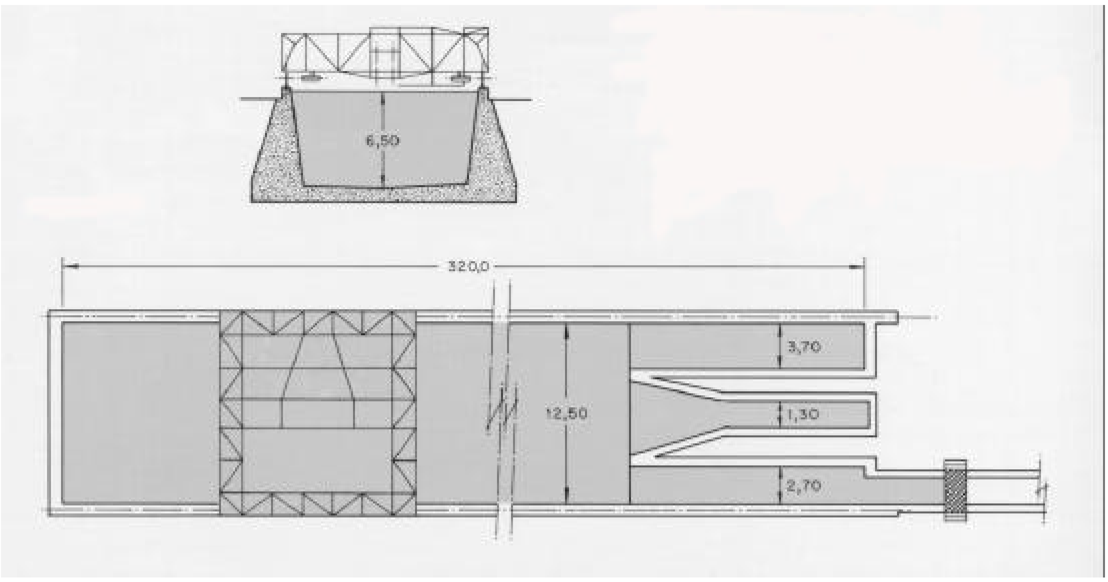


Figure 3. Dimensions of the CEHIPAR Calm Water Tank

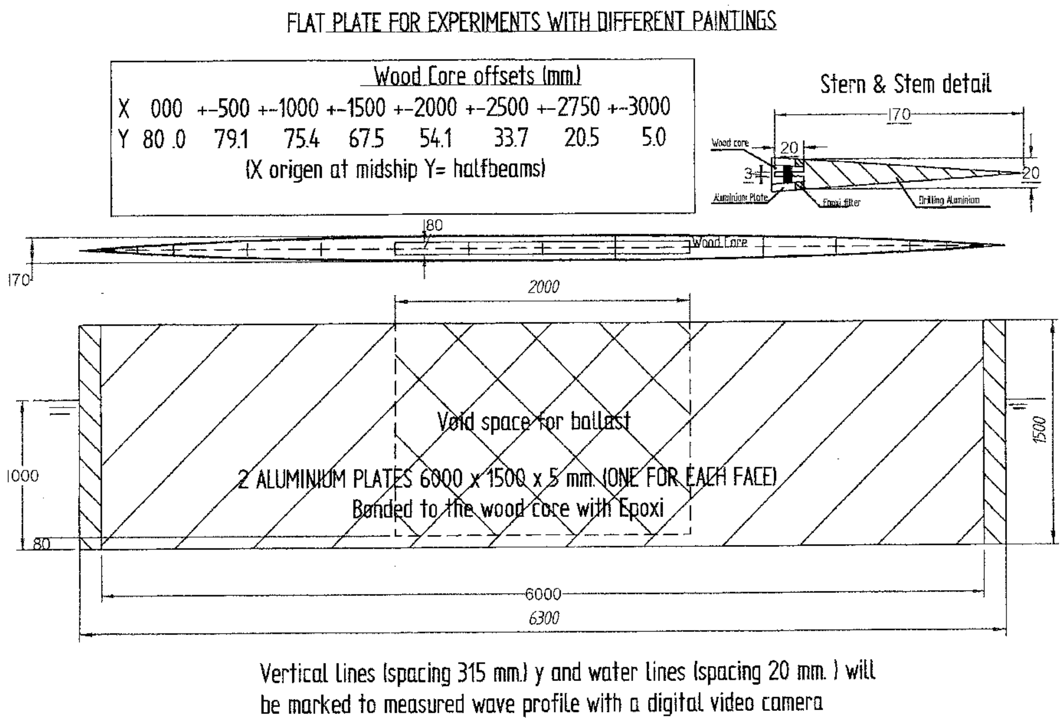


Figure 4. Dimensions of the plate used in the CEHIPAR/Newcastle University towing experiments

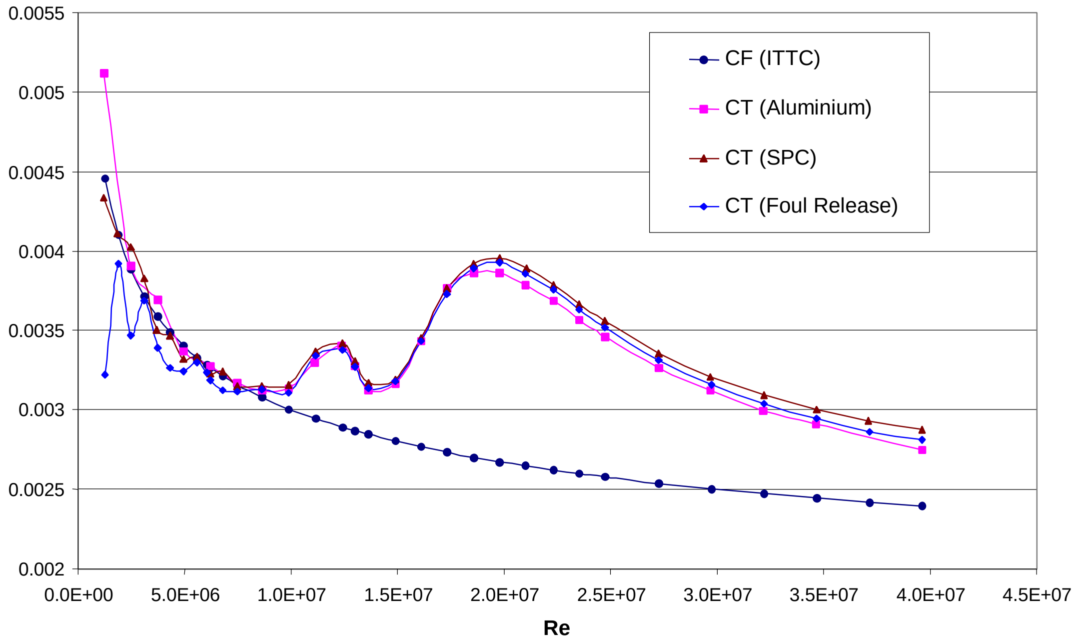


Figure 5. Total resistance coefficients against Reynolds number in the CEHIPAR Calm Water Tank

The total resistance of the plane was measured with the dedicated dynamometer of the carriage for the same three different surfaces: the aluminium reference surface, the surface coated with a 3-coat SPC antifouling scheme and the surface coated with a 3-coat Foul Release system. Figure 5 shows the total resistance coefficients for the three surfaces plotted against the Reynolds number. Above a Reynolds number Re = $2 \cdot 10^7$, the Foul Release surface exhibits a drag which is on average 1.56% higher than the aluminium surface, and the SPC surface exhibits a drag which is on average 2.91% higher than the aluminium reference. In other words, the total drag coefficient of the Foul Release surface was on average 1.41% lower than the SPC surface (Candries and Atlar, 2000).

Compared to Figure 2, the differences in drag are much smaller in Figure 10, and the scatter of Figure 5 is absent. The latter is explained by the fact that during the CEHIPAR experiments, Bessel-function filters were applied immediately during measurement to filter out the vibrations caused by the passing of the carriage over the railway and its undesirable effects on the measured drag values. The reduced difference between the SPC and the Foul Release surfaces can be partly attributed to the difference in roughness of the two surfaces, as discussed in Section 3.

3. Surface analysis

The majority of Foul Release systems that are in use today are based on silicone technology, with an extremely flexible backbone, which allows the polymer chain to readily adapt to the lowest surface energy configuration. The size of the free surface energy represents the capability of the surface to interact spontaneously with other materials. It was found experimentally that the relative adhesion of fouling organisms on a material is directly proportional to $\sqrt{E \gamma_c}$, whereby E is the elastic modulus of the material, and γ_c its surface energy. This parameter for silicone materials is at least an order of magnitude smaller than for other materials (Brady and Singer, 2000). Moreover, if organisms eventually do attach to the surface, it has been shown that they attach less strongly than on other materials (provided the coating is applied thickly enough), which explains why fouling organisms can release from the surface under the influence of hydrodynamic forces. The speed at which most fouling organisms can release from Foul Release surfaces has been measured at the Florida Institute of Technology by towing experiments (Kovach and Swain, 1998). These trials have shown that, with the current Foul Release technology, speeds in excess of 15 knots are required to prevent most fouling types settling.

An effective Foul Release system relies on the smoothness of its surface. Surface free energy and the surface area available for adsorption and attachment of fouling organisms increase with roughness. The valleys of rough surfaces are penetrated by marine adhesives and hence foulants will more readily attach. Moreover, the foulants also find shelter from shear and abrasion in the crevices and thus roughness also poses a threat to the hydrodynamical removal of the organisms. Because of the fact that fouling organisms attach less quickly and less strongly on Foul Release surfaces it could be expected a priori that the material is in some way smoother than most surfaces. In turn this could explain why Foul Release surfaces exhibit less drag than other ship surfaces.

Townsin and Dey (1990) correlated the roughness and drag of a range of coated surfaces and found that the resistance of a newly painted surface correlated well with the parameter Rt_{50}, which is measured on a ship hull with the BMT Hull Roughness Analyser.

Figure 6. The Hull Roughness Analyser

Figure 7. The optical measurement system

This stylus instrument, as shown in Figure 6, measures Rt_{50}, which is the highest peak to lowest valley perpendicular to the mean line over a length of 50mm sampled at intervals of 50µm. When the stylus has traversed the evaluation length, fifteen readings of R_{t50} and an average, the Mean Hull Roughness (MHR) are printed out.

The instrument was used throughout both sets of the towing tank experiments reported in Section 2. In general, 10 and 20 MHR values for the small and large plate respectively were averaged to obtain the overall Average Hull Roughness (AHR). It was observed from the beginning that the measurement of the Foul Release surface required a special treatment in that the coated surface had to be wetted slightly in order to get meaningful readings. If the surface was dry, the stylus hopped over the rubber-like material, whereas if the surface was too wet, the gauge skidded very easily; both practices would give erroneous readings (Anderson et al., 1999). Table 1 presents the average roughness in microns for the three surfaces obtained from both sets of experiments.

Table I. Average hull roughness (in microns) of the three tested surfaces in both sets of experiments

Average Hull Roughness	*Newcastle Experiments (2.55m long plate)*	*CEHIPAR experiments (6.3m long plate)*
Aluminium	17	18
TBT-free SPC	75	39
Foul Release	48	62

As shown in Table 1, the roughness of the aluminium reference surface was virtually identical for both sets of experiments, but in contrast to the first experiments, the roughness of the Foul Release surface was higher than the roughness of the SPC surface in the second set of experiments. This oddity can be explained by the poor surface condition prior to application of the Foul Release surface in the second set of tests. The SPC coating had been stripped off with the intention of leaving the primer on, but there were large patches where the aluminium was exposed. Thus, instead of applying the Foul Release system on a smooth aluminium surface like in the first set of experiments, the Foul Release tie- and topcoat were applied on an uneven primer surface with an average roughness of 37 microns. In contrast, the SPC surface was much smoother for the second set of experiments due to a better paint application than in the first set of experiments.

If one compares Table 1 with Figures 2 and 5, one notices immediately that the resistance of a surface coated with a Foul Release system does not correlate with the roughness parameter Rt_{50}.

Consequently, an optical measurement system was used to analyse small sample plates (20 by 25cm) coated with the different paint systems described in Section 2. A photograph and diagram of the UBM non-intrusive optical measurement system are shown in Figures 7 and 8 respectively. The instrument works by the focus-detection principle whereby the vertical displacement of the objective is measured by an infrared laser diode as light source. The instrument has a vertical range of 0.5mm and a resolution of less than 50nm.

The roughness of the surface has been investigated by analysing a wide range of parameters The amplitude parameters, characterising how the roughness varies at right angles to the surface, can be subdivided into extreme-value parameters (e.g. Rt), average parameters and properties of the height distribution . Texture parameters, which describe how the roughness varies in the plane of the surface, included counts of extrema and crossings with the mean line, the average absolute slope Sa, and the correlation length τ. A fractal approach, which essentially scrutinises the surface for self-similarity, was included by computing the fractal dimension.

The measurements were carried out for a range of long wavelength cut-offs and sampling intervals (equal to half the Nyquist short wavelength cut-off). In accordance to the standards for roughness measurement as suggested by Medhurst (1990), 3 transversal and 3 longitudinal measurements were taken for each set of bandwidth parameters.

Two typical examples of the measured roughness profiles of the SPC and the Foul Release surface are shown in Figures 9 and 10 respectively for a long wavelength cut-off of 5mm and a sampling interval of 50µm, filtered by a 81-part moving-average method. All parameters have been averaged over 10 cut-off length intervals.

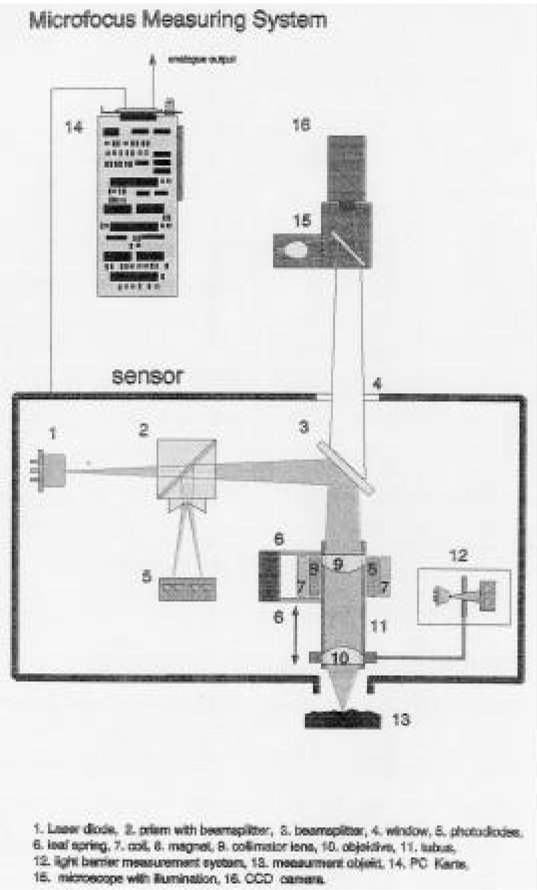
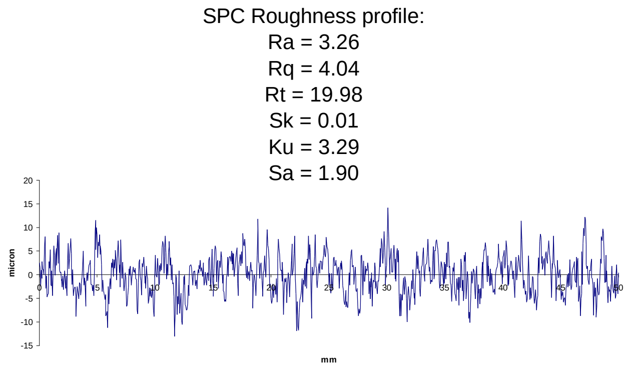


Figure 8. The optical measurement system used for the surface analysis (Taken from the UBM User Manual)



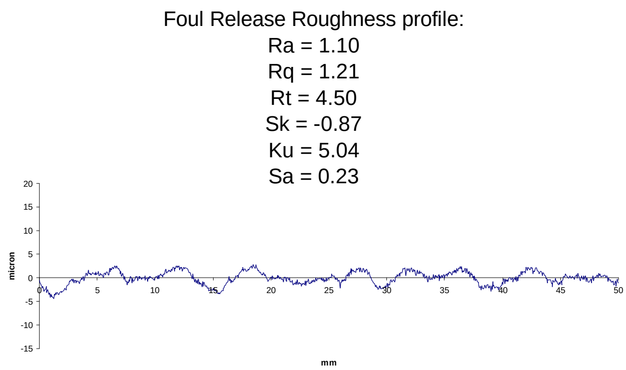


Figure 9 (Top). Typical profile of the SPC surface
Figure 10 (Bottom). Typical profile of the foul-release surface

Figures 9 and 10 show that the amplitude parameters (centre-line average roughness Ra, RMS roughness height Rq and maximum peak to valley height Rt) are in this case lower for the Foul Release surface than for the SPC surface. Moreover, the "spiky" SPC surface clearly exhibits a great deal more of short-wavelength roughness. In other words, the "open" texture of the Foul Release surface is very different from the "closed" SPC surface, as partially indicated by the average absolute slope Sa (in degrees), which differs by an order of magnitude. Further computations show that the correlation length is also an order of magnitude larger for the Foul Release surface than for the SPC surface. This further indicates that, in association with the SPC surface, the Foul Release surface exhibits relatively more long than short wavelength components.

4. Ongoing research

Foul Release systems are very effective antifoulings for high-speed high-activity craft on which fouling organisms do not have the opportunity to attach strongly and from which they are washed off easily by the hydrodynamic forces against the hull. The coatings do not rely on toxins and are therefore not under any environmental scrutiny. They do not degrade chemically over time, and provided no mechanical damage occurs, have an extended lifespan.

Both sets of towing tank experiments have shown that the resistance of the Foul Release surface was lower than the SPC surface. This proves an additional argument in favour of the use of Foul Release systems for high-speed craft, where a modest decrease in resistance results in significant savings of fuel.

Further tests are underway to measure the boundary layer velocity profile of the above coating systems, using laser doppler velocimetry (LDV) equipment in the Emerson Cavitation Tunnel at the University of Newcastle-upon-Tyne. These tests will provide further insight into the drag characteristics of Foul Release systems. The roughness function of the different surfaces, which is a measure of the increase of frictional resistance compared to a smooth surface and which will be derived from the boundary-layer velocity profiles using the modified Clauser method.

Surface profilometry of coated sample plates has shown that the texture of a Foul Release surface is significantly different from the texture of a tin-free SPC surface. In order to correlate the roughness functions measured from the drag experiments with the surface characteristics, it will be necessary to find a suitable combination of the available roughness parameters, which not only takes the height of the roughness into account but also includes a measure of the surface texture.

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