M. Candries, M. Atlar and C.D. Anderson (2000), Considering the use of alternative antifoulings: the advantages of foul-release systems, *Conference Proceedings ENSUS 2000*, pp. 88-95, Departments of Marine Technology and Marine Sciences, University of Newcastle-upon-Tyne, UK.

Considering the use of alternative antifoulings: the advantages of foul-release systems

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SYNOPSIS

Foul-release systems offer a low surface energy and non-toxic surface that work by preventing firm adhesion of fouling organisms. Above a critical threshold speed, hydrodynamic shear forces will wash off any attached organisms. Particularly for high-speed and high-activity vessels, foul-release systems currently offer an interesting alternative to toxic antifoulings.
The research, which is being carried out at the University of Newcastle-upon-Tyne, investigates whether the specific surface properties of foul-release systems have a beneficial effect on its drag. The recent flat plate towing tank experiments carried out by the authors in collaboration with CEHIPAR, Spain, 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.
These low-drag characteristics for foul-release systems may offer prospects of fuel saving and increased service speed. However, the full understanding of the drag reduction mechanism of foul-release systems and the implications for their exploitation requires further research.

INTRODUCTION

Traditional coatings control fouling by killing the settled organisms with released toxins. In contrast, foul-release systems try to prevent the adhesion of the fouling organisms by providing a low-friction, ultra-smooth surface on which organisms have great difficulty settling. Even if settling eventually occurs on the surface, there is only weak bonding between the foulants and the surface such that the organisms can easily be removed either by underwater cleaning or by the hydrodynamic shear forces against the surface, that are developed when the vessel is moving forward.
Foul-release coatings were actually conceived almost simultaneously with Self-Polishing Co-polymers (SPCs). However, SPCs were much cheaper, and the commercial development of foul-release systems only took off in the 1990s. For example, it has been reported that the application of a commercially available foul-release system on a 36-metre catamaran in 1996 resulted in an increase of 2-3 knots in all weather conditions compared to 1995 when it was coated with a Tributyltin (TBT)-free SPC. Each journey (of approx. 1 hour) was about five minutes shorter in 1996 with an overall fuel consumption reduction of 12%, more than 20,000 litres/month[1]. It was anticipated that these results were linked to the smoother surface of the foul-release paint and the University of Newcastle-upon-Tyne was contacted to carry out towing tests in order to verify the results and look for an explanation.

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FOUL-RELEASE SURFACE CHARACTERISTICS

Tackling the adhesion and release of fouling organisms

The foul-release systems that are in use today are silicone materials based on polydimethylsiloxane (PDMS). PDMS is a heterogeneous molecule with an extremely flexible backbone, which allows the polymer chain to readily adapt to the lowest surface energy configuration. The free surface energy of a surface is the excess energy of the molecules on the surface compared with the molecules in the thermodynamically-homogeneous interior. The size of the free surface energy represents the capability of the surface to interact spontaneously with other materials[2, 3]. The surface free energy and the critical surface tension are determined by comprehensive contact angle analyses. The surface tension of a variety of diagnostic liquids is related to the cosines of the angles that the liquid droplets make with the coated surface[4]. The free surface energy of PDMS in air is 23mN/m, which is a direct result of the low intermolecular forces between the methyl groups[2].

Experiments carried out in the early 1970s have examined the adhesion of barnacles and other marine organisms on substrata with different surface energy. It was found that surfaces with a free energy of 23 mN/m were least prone to foul[5, 6], as shown in Figure 1. This may be explained by the fact that a surface, of whatever composition or surface free energy, acquires a conditioning film very rapidly when placed in seawater. The film, which has the same composition for all surfaces regardless of their chemical nature, is mainly made up of glycoproteins and polysaccharides, which act as glue for fouling organisms[2, 5]. A surface free energy of 23-25 mN/m, which is equal to the minimum in Figure 1, has the lowest interfacial tension with solutions of biological macromolecules and gives the minimum driving force for adsorbtion[2].

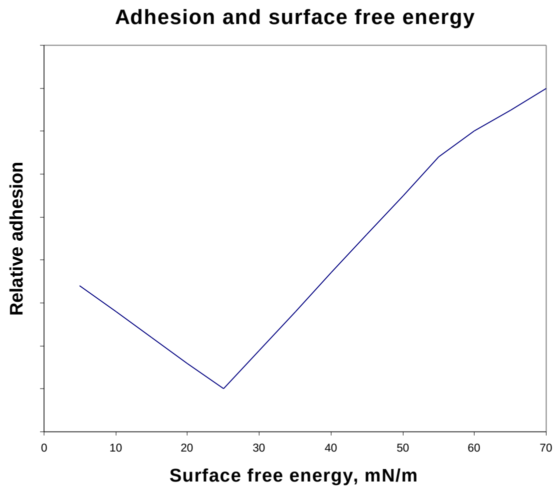

Fig. 1 The relationship between surface free energy and adhesion[after 2]

Moreover, research in the early 70s, investigating the adhesion of fouling organisms to surfaces with different free energy, found that algal fouling released more easily from silicone elastomer with a surface energy of 23 mN/m. Barnacles could be removed under the pressure of a water jet only from the silicone elastomer[5; 6]. Thus, a surface free energy of 23-25 mN/m ensures the lowest possible bonding strength of fouling organisms to surfaces and offers the possibility for easy removal of these organisms, either mechanically or hydrodynamically.

An American Standard for Testing and Materials (ASTM) to evaluate the foul-release properties of coatings is a method to measure the adhesion of barnacles in shear. Barnacles are macrofouling organisms that will eventually attach very firmly to a submerged surface and allow quantification of adhesion on surfaces. Towing experiments have been carried out with fouled test surfaces to determine the free-stream velocities required for foul-release from silicone coatings with known barnacle adhesion strength[7]. The barnacle shear adhesion strength for the foul-release test panels was an order of magnitude lower than that found on other surfaces. The speed at which the barnacles would release from the surface was predicted at 12 and 20 knots for two different foul-release systems. The results demonstrate that foul-release coatings with low barnacle adhesion strengths will hydrodynamically self-clean and that there is a good correlation between predicted and observed foul-release velocities[7, 8].

If foul-release were not to occur, fouling organisms would quickly protrude the near-wall viscous sublayer and increase the drag and roughness of the surface[9-11]. Smoothness is a very important factor for an effective non-stick / foul-release surface. Surface free energy and the surface area available for adsorption and attachment 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. Figures 2 and 3 compare the profileograms of two sample plates, one coated with a foul-release system, the other with a TBT-free SPC scheme. The measurements shown in figures 2 and 3 were taken with the optical, non-intrusive UBM Microfocus Measuring System. The wet film thickness of both coatings is 350 µm, each applied in 3 coats, and it is clear that the texture of the two surfaces is completely different. The foul-release surface in figure 2 displays a smoother surface, whereas the TBT-free SPC surface in figure 3 exhibits much steeper and closely packed roughness peaks and valleys.

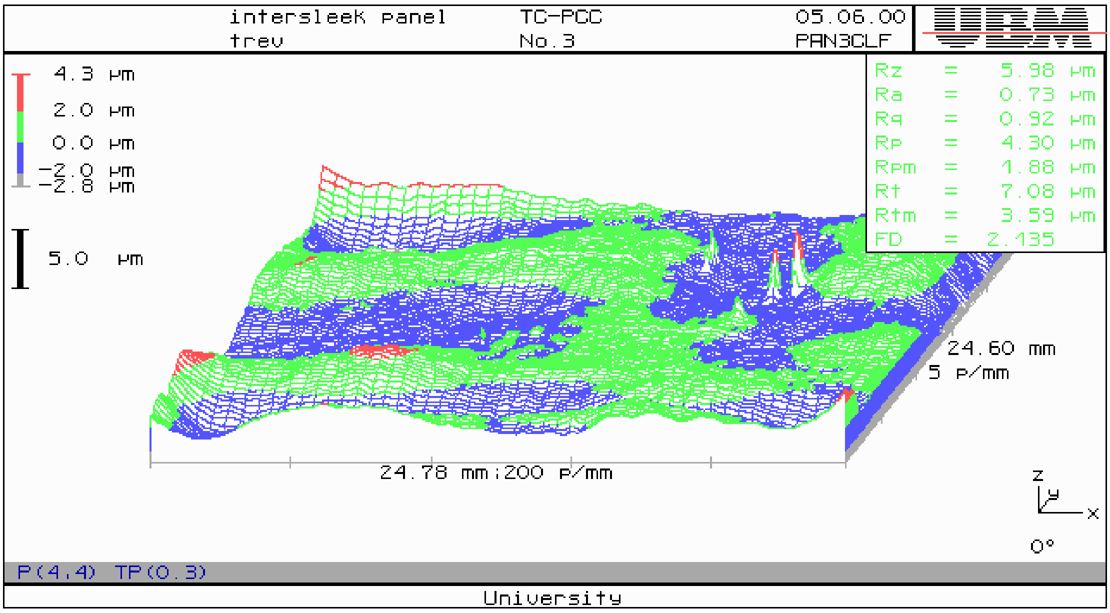

Fig. 2. Laser profileogram of a sample aluminium plate coated with a foul-release scheme

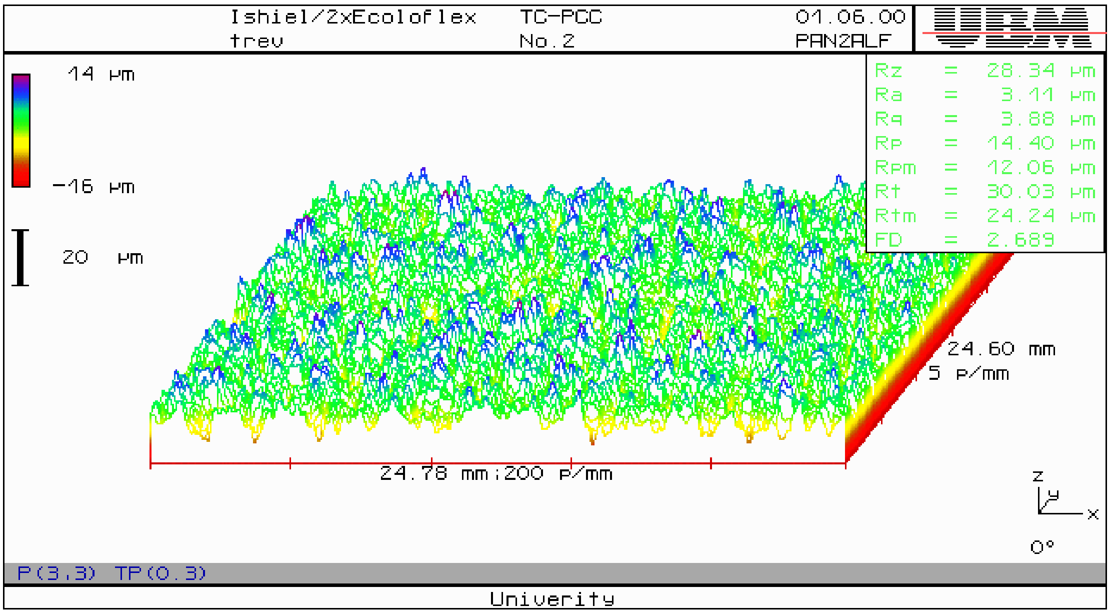

Fig. 3. Laser profileogram of a sample aluminium plate coated with a TBT-free SPC scheme

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THE DRAG AND ROUGHNESS OF FOUL-RELEASE SYSTEMS

Measuring the drag: Flat plane towing tank experiments

The inherent smoothness of foul-release surfaces will have an important effect on its resistance. An ongoing research project at the University of Newcastle-upon-Tyne has been investigating the correlation between the drag and surface characteristics of foul-release systems in comparison with a TBT-free SPC alternative. Two sets of towing tests with flat planes have established that, compared to a TBT-free SPC coating scheme, a foul-release system exhibits lower drag.

The first set of these 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[12]. The aluminium plate, as shown in Figure 4, was towed over a speed range up to 2m/s. The total drag of the plane 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 three different surfaces which were the aluminium reference surface, the surface coated with a 3-coat TBT-free SPC scheme and the surface coated with a 3-coat foul-release scheme. Figure 5 shows the total resistance coefficients for the three surfaces as well as the ITTC-57 friction line plotted against the Reynolds number and shows the significant difference between the two coatings.

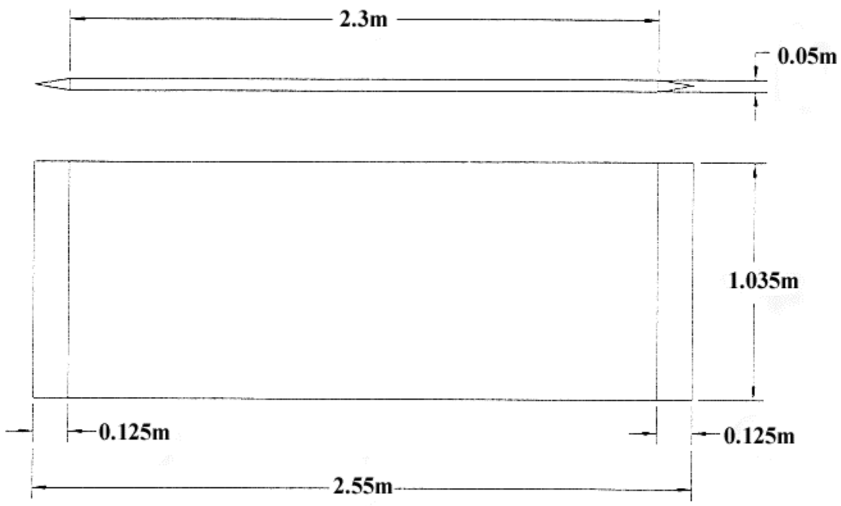

Fig. 4. Dimensions of the plate used in the Newcastle towing experiments

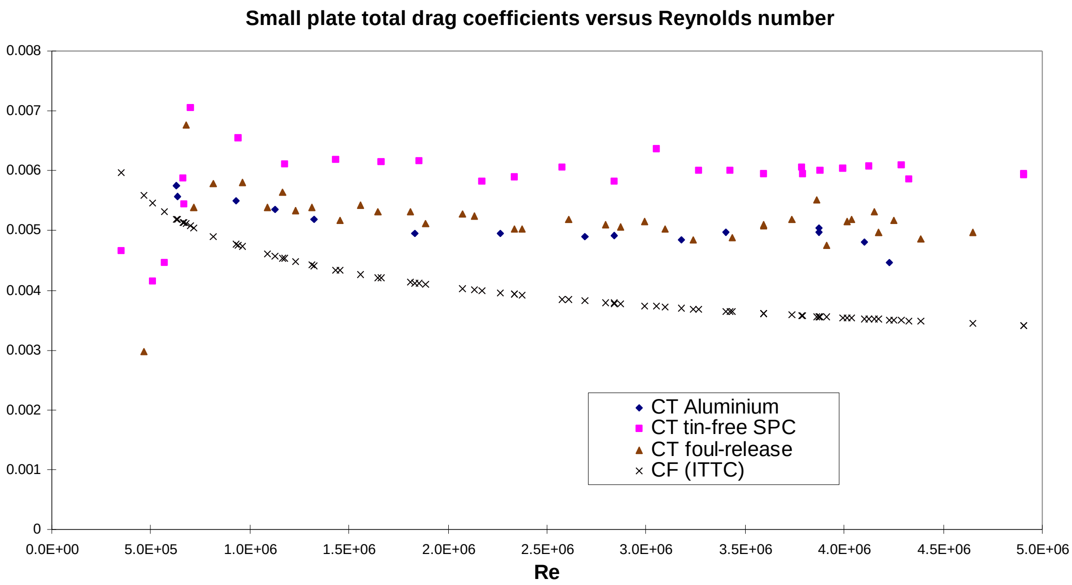

Fig. 5. Total resistance coefficients against Reynolds number of the three tested surfaces in the Newcastle towing tank

Because of the limited speed range and the run-length of the Newcastle tank, the maximum Reynolds number in the first set of experiments was restricted to Re = $5{\cdot}10^6$ and the time-span over which measurements were taken was only 3s for the highest speed. In order to confirm the favourable trends observed in the first set of tests, it was decided to carry out further experiments over a much larger speed range up to 8m/s using a 6.3m long plate in the 320m long El Pardo Calm Water Tank, shown in figure 6. The aluminium plate, as shown in figure 7, was based on the NSRDC friction plane model 4125, which was used for similar experiments at the David Taylor Model Basin[13].

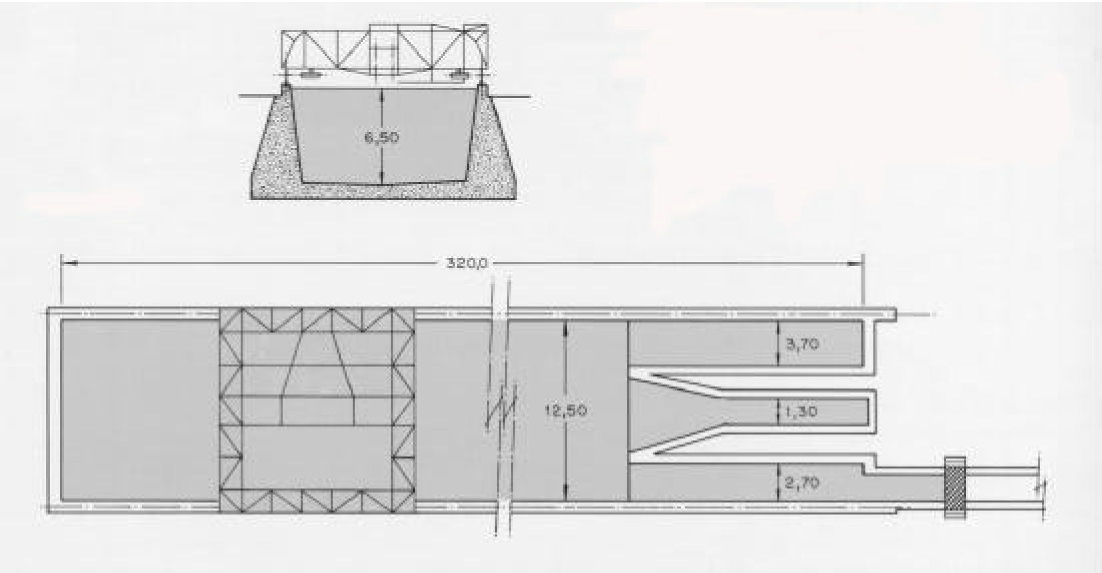

Fig. 6. Dimensions of the CEHIPAR Calm Water Tank

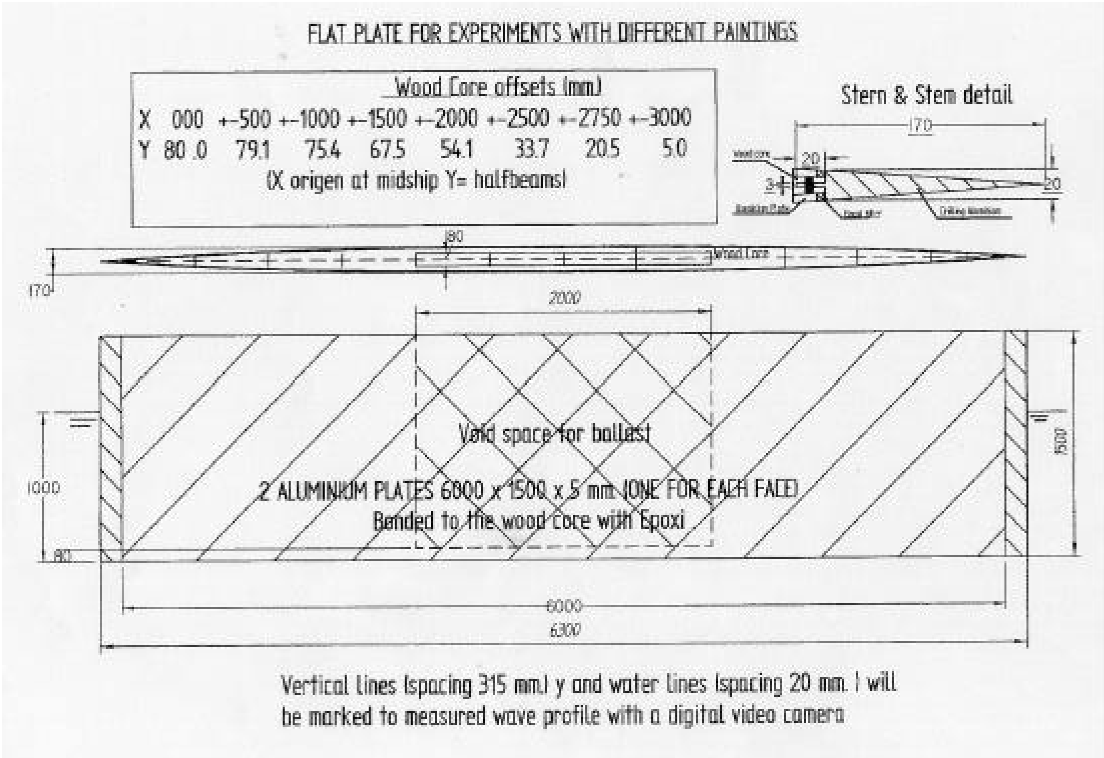

Fig. 7. Particulars of the plate used in the CEHIPAR towing experiments

The total resistance of the plane was measured with the dedicated dynamometer of the carriage for the same three different surfaces used in the first tests. These were the aluminium reference surface, the surface coated with a 3-coat TBT-free SPC scheme and the surface coated with a 3-coat foul-release scheme. Figure 8 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 surface. In other words, the total drag coefficient of the foul-release surface was 1.41% lower than the SPC surface on average. Compared to figure 5, the differences in drag are much smaller than in figure 8, and the scatter of the data, which can be observed in figure 5, is absent. The removal of the scatter in the data 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 carriage over the railway and its undesirable effects on the measured drag values. On the other hand, the reduced difference between the measured drag of the SPC and the foul-release surface can be partly attributed to the difference in the roughness of the two surfaces, as discussed in the following section.

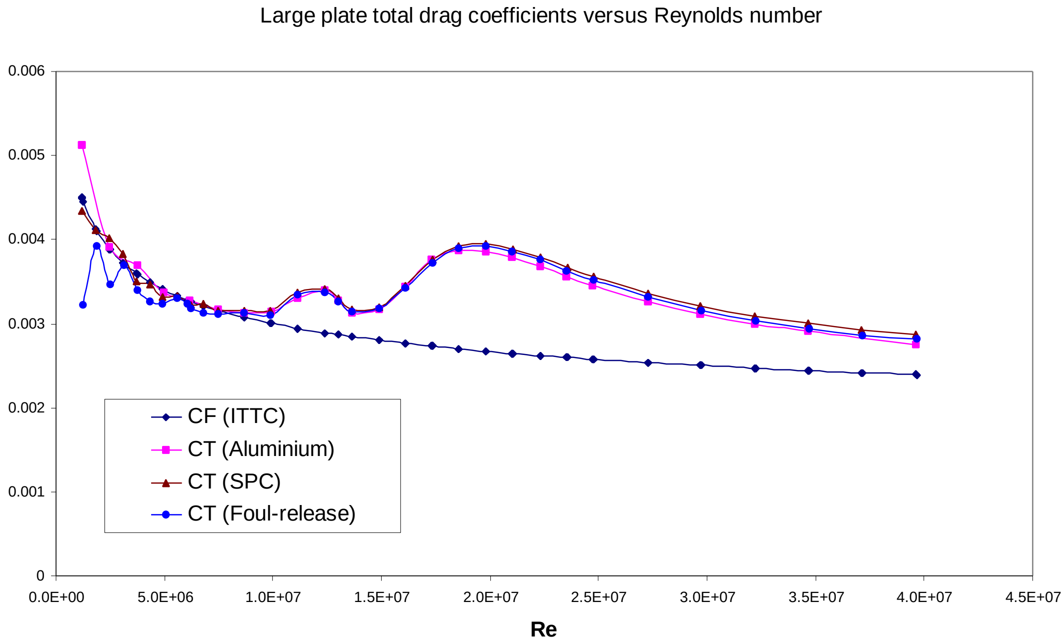

Fig. 8. Total resistance coefficients against Reynolds number of the three tested surfaces in the CEHIPAR Calm Water Tank

Measuring the roughness: Using a Hull Roughness Analyser

Throughout both sets of flat plane experiments, the roughness of the different surfaces was measured using the BMT (previously known as BSRA) Hull Roughness Analyser, which is the standard equipment used for this purpose in marine technology. The ball stylus of this hand-held equipment measures the highest peak to lowest valley perpendicular to the mean line over a 50mm interval, R_{t50}. When the head has traversed the surface over about 0.5m, fifteen readings of R_{t50} and an average, the Mean Hull Roughness (MHR) are printed out. For the small and large plate experiments reported here, in general, 10 and 20 values for MHR 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[14]. 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. 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.

R_{t50} can be used to correlate the roughness of newly painted surfaces with their drag[15]. However, as explained above, laser profileometry has shown that the surface texture of foul-release coatings is fundamentally different from traditional antifoulings and thus it is possible that R_{t50} may not be a suitable parameter to adequately describe the roughness of foul-release surfaces. Further investigation is required and at the time this paper was submitted, the laser profileometry analyses of the second set of tests were underway.

CONCLUSIONS

- Both sets of flat plane towing tank experiments have shown that a foul-release surface exhibits lower drag than a TBT-free SPC surface. What is extraordinary, is that the foul-release surface exhibited lower drag in the second set of experiments when measurements had shown that its roughness compared to the SPC surface, was actually higher, due to poor surface preparation.
- Laser profileometry measurements have shown that the texture of a foul-release surface is significantly different from the texture of a TBT-free SPC surface. The ongoing research will now compare the roughness measurements done with the BMT Hull Roughness Analyser and with the laser profileometer.

In any case, the investigation presented in this study so far is an indirect way of explaining the physical mechanism behind the inherent drag reduction mechanisms of the foul-release system. A more direct approach to understand this mechanism is to look into the near-wall characteristics of the foul-release system using state-of-the-art flow measuring technology. Therefore, as the next stage of the research programme, water tunnel experiments using laser-doppler velocimetry are being prepared to measure the boundary-layer velocity profile over the different surfaces and to establish the hydrodynamical roughness function of the different surfaces.

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