Royal Belgian Institute of Marine Engineers

DRAG PREVENTION COATINGS
for marine propellers

This paper presents some results of the research being conducted into the use of silicone based foul release coatings to prevent the increases in roughness and hence drag, caused by fouling on marine propellers In service. It explores previous research conducted within the School of Marine Science and Technology at Newcastle University Into the hydrodynamics of Foul Release coatings.

The paper describes the early work that has been conducted to investigate the effect of the coating on propeller performance, included computer simulations and a series of sea trials conducted using the research vessel ‘Bernicia’. Results from these trials include the conditions of the coating after 12 months In service, where the coatings was found to be intact and free from hard shell fouling.

The paper presents the Initial results from a series of model tests using the Emerson Cavitation tunnel at Newcastle University. These tests show that the coating has no detrimental effects on the propeller performance until the coatings is subjected to intense damage. The full scale propeller on which the model Is based is also shown to be in good condition and free from fouling.

The work presented In this paper Is part of a post-graduate project sponsored by International Paint Limited.

INTRODUCTION

Following the phasing out of TBT-SPCs imposed by the International Maritime Organisation, a new generation of antifouling paints are currently In the process of replacing about 80% of the existing antifouling market
Two main types of coatings claim to have satisfactory performance over 5 years.
These are tin free SPC technologies and Foul Release systems. The Foul Release systems are particularly suited for fast scheduled vessels. The first full coating on a fast furry was In March 1996 on a 33 knot aluminium catamaran that had previously been coated with a low copper TBT-free antifouling system and required regular in-water scrubbing during the summer months to prevent excessive fouling (Millett and Anderson, 1991).

After the application of the Foul Release coating, the vessels operating crew noted an immediate improvement the performance with an increase of 2-3 knots in all weather conditions compared to when the previous system was first applied. Each Journey (usually lasting about 1 hr) was 5mins shorter in 1996 than in 1995. This led to an overall fuel consumption reduction of 12% more than 20,000 litres per month.

In order to investigate and provide scientific proof of these claims the coating manufacturer initiated a research programme within the School of Marine Science and Technology at Newcastle University to look at the frictional drag of surfaces coated with their Foul Release Systems and compare them to standard type antifouling coatings (Candries, 2001).

Flat plate resistance tests were conducted in both the school's towing tank and the much larger facility at CEHIPAR in Spain. These tests showed that depending upon the application quality of the surfaces, the Foul Release coatings exhibit between 2% and 23% less drag than Tin-free SPC coatings (Candries and Atlar, 2003).

To further investigate this reduction in drag, detailed boundary layer measurements conducted using the Emerson Cavitation Tunnel at Newcastle and the CEHIPAR tunnel in Spain, using LDA measurements. These tests showed that the function velocity for Foul Release surfaces is significantly lower than for Tin-free SPC surfaces and that at the same stream wise Reynolds number the ratio of the inner layer to the outer layer of the boundary layer is smaller for the Foul Release surfaces.
The inner layer is the part of the boundary layer where major turbulence (and hence drag) production occurs. These factors lead the Foul Release surfaces to have significantly lower roughness functions when compared to the Tin-free SPC coatings (Candries and Atlar, 2005).

Detailed roughness measurements of both the Foul Release and Tin-free SPC surfaces show that they have very different surface roughness characteristics. The Foul Release coating has what Is termed an 'open' texture while the Tin-free SPC has a 'closed' texture. It is this open texture that is thought to promote the lower drag of the Foul Release coatings (Candries, 2001).

Following the results of this research, further research is being carried out to investigate how the drag benefits of Foul Release schemes can be exploited. One such area is that of propeller coatings in addition to the hull.

Due to the large amounts of power being delivered through the propeller any improvement in the blade surface condition and its maintenance has the potential to provide significant reductions in fuel consumption and the associated benefits (Mosaad, 1986).

COMPUTER SIMULATI0NS

The first attempts to understand the effect of Foul Release coatings on propellers were to use state-of-the-art numerical propeller performance analysis tool to investigate the effect the coating would have on marine propellers.

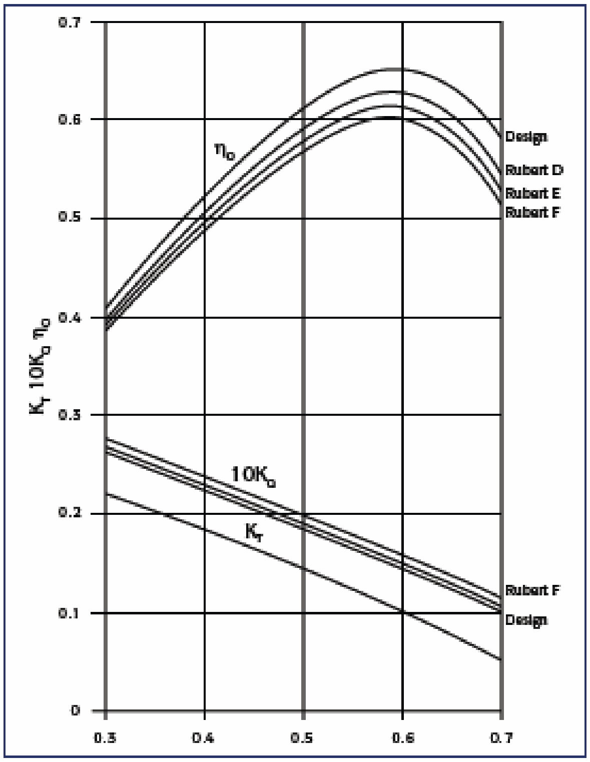

Figure 1: The effect of blade surface roughness on propeller performance. The propeller in this case is that used in the later model tests. Rubert values of D, E and F correspond to increasing levels of roughness. It can be seen that the biggest effect is an increase in the propeller torque. The Foul Release coating has similar results to the Design condition, corresponding to a new or well polished propeller.

Overall length	metres	16.2
Beam	metres	4.72
Draft	metres	2.59
Gross tonnage	tons	46.25
Service speed	knots	8.0

Tabel 1: The general particulars of RV 'Bernicia'

The effect of the coating was represented by varying blade sectional drag coefficients within a lifting surface based unsteady propeller performance analyses software. The method used for relating the sectional drag to the surface characteristics of the blade was Musker's equivalent roughness height parameter (Musker,1977). This was used as it takes account of both the variation In roughness amplitude and surface texture.

This is particularly important when looking into silicone based Foul Release coatings with their completely different type of surface texture. The results of these showed that a Foul Release coating had approximately the equivalent blade section drag of a new or well polished propeller (Atlar et al., 2002). *Figure 1* shows the effect of increasing roughness on the thrust torque and efficiency curves of a marine propeller. The increase In blade surface roughness has the effect of increasing the torque of the propeller and thereby lowering the efficiency.

Figure 2: The Research vessel 'Bernicia'.

Diameter	1.14m
Blade area ratio	0.466
Number of blades	4
Maximum shaft speed rpm	440
Direction of rotation	Right

Tabel 2: Details of the 'Bernicia' propeller

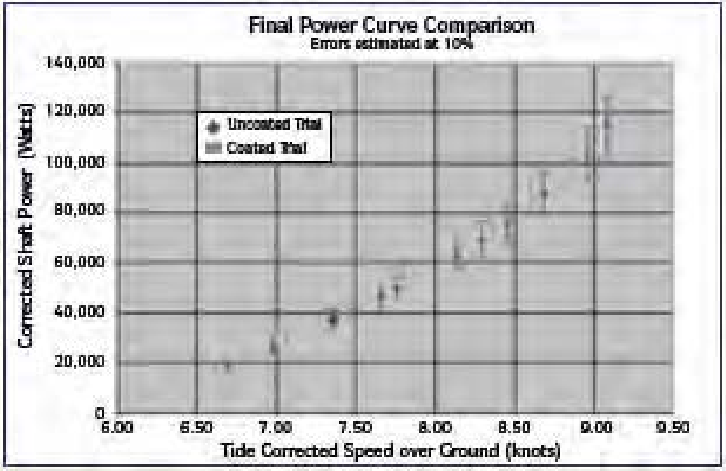

Figure 3: The final results of the 'Bernicia' sea trials show no statistical difference between the two curves. The trials were particularly affected by the weather leading to large error estimates am making the results inconclusive.

SEA TRIALS

To investigate the effect of the coating in full scale it was decided to run a series of sea trials over a measured. mile. These were conducted with the school research vessel 'Bernicia' (Figure 2), which is a 16m ship based on the design of a fishing vessel and is mainly used for estuarine and coastal research. The general particulars are shown in Table 1 and the propeller details are shown In Table 2. The vessel was used to conduct a series of trial measurements with the propeller uncoated before being placed on the ship and its 1,14m diameter propeller removed to be coated using a silicone based Foul Release marine coating. Another series of measured mile trials was then conducted. Despite the weather affecting the coated trial the results showed little difference between the performance of the coated and uncoated propellers (Figure 3). Detailed results of these trials can be found In (Mutton et al., 2003).

After a year with the coating in service 'Bernicia' was again docked and the state of the propeller coating inspected (Mutton, 2004). The coating was found to be in good condition with only light slime present on the inner part of the blades. The coating was 95% intact, except slight removal of the coating at the edges of the blades. Figure 4 shows the uncoated propeller after a previous period of 14 months in service. Hard shell fouling, mainly barnacles, was present to about half the blade radius. This can be compared to figure 5 which shows the state of the coated propeller after 12 months in service.
During the trials, roughness measurements were taken on the propeller using a 'Surtronic 3 +' roughness gauge before and after the coating was applied. This unit was selected because of its small size and automated traverse make it more suitable for use on small propellers and foul release coatings than other devices.

Figure 4: The propeller of 'Bernicia' after 14 months in service before coating. Hard shell fouling is present to half the blade radius.

Figure 5: The propeller of 'Bernicia' after 12 months in service after coating. 95% of the coating is intact, except some detachment of the blade edges. Light slime fouling is present in the inner half of the blades (grey material in the red coating is the dried bio film]. This could be easily removed by hand or with a damp cloth.

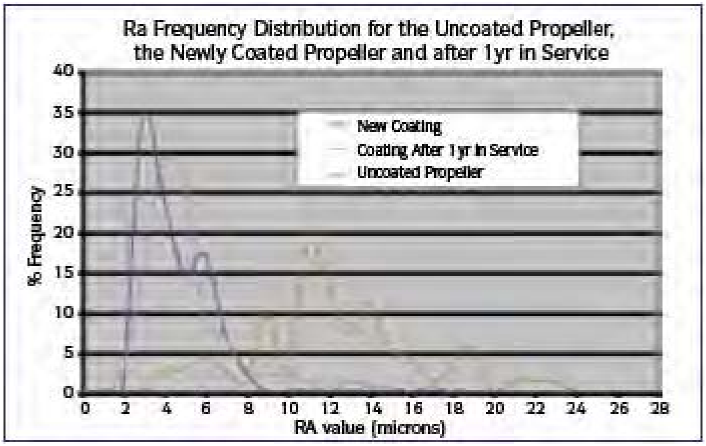

Figure 6: The mean roughness amplitude, Ra Frequency distributions (with a cut off length of 2.5mm). Measured on the propeller of 'Bernicia' before coating, after coating and after a period with the coating in service.

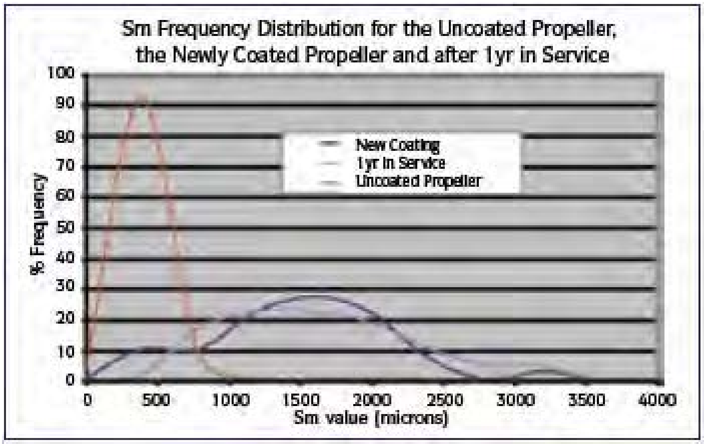

Figure 7: The mean spacing between profile peaks, Sm, frequency distribution.. Measured on the propeller of 'Bernicia' before coating, after coating and after a period with the coating in service.

Figure 6 shows the results for the mean roughness amplitude (Ra, with a cut-off length of 2.5mm). It can be seen that there is a significant difference between the roughness distribution of the uncoated (roughened slightly after about 8 months in service) and the newly coated propeller.
It can also be seen that the coating does not return to a roughness frequency distribution similar to the uncoated propeller after a period of service with the coating. There was some measured difference between the newly applied coating and the coating after 12 months in service. This is mostly due to the presence of the slime layer on the blades, which can easily be removed by hand or a damp cloth and mechanical damage to the coating. That slime layers can attach to Foul Release coatings is a known phenomenon (Candries et al, 2003) and their effect on the coating performance is currently being investigated as part of this research project.

Figure 7 shows the mean spacing between profile peaks frequency distribution, Sm, measured on the 'Bernicia's' propeller. This is a measure of the surface texture where the larger the value, the more 'open' the texture. It shows a significant difference between the uncoated and newly coated propeller. The coated propeller exhibits a much wider range of mean spacing, where the uncoated propeller had a much smaller range.

After a period of the coating being in service the frequency distribution of Sm has changed little and still exhibits the wider range. In a similar manner to the Ra distribution In Figure 6 the mean spacing distribution is still fundamentally different to the uncoated propeller distributions after a period of service.

Figures 6 and 7 both show that the coating significantly changes the roughness characteristics of the propeller blade surface and that the roughness does not change significantly alter 12 months in service.

The coating has the effect of preventing the increases in roughness usually seen with uncoated propellers after time in service (Mutton, 2004).

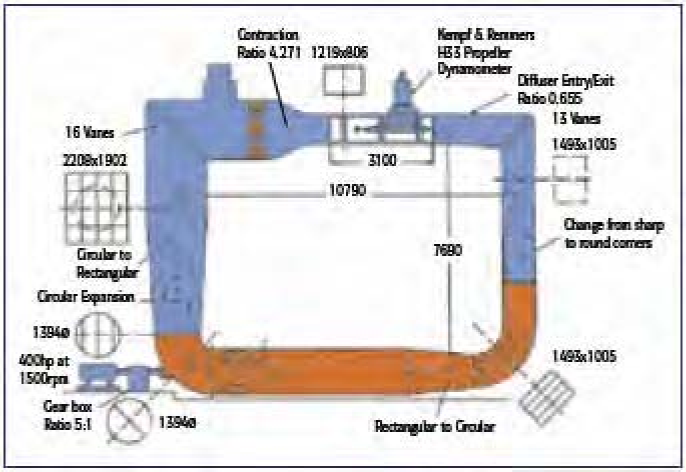

Figure 8: layout of the Emerson Cavitation Tunnel at the University of Newcastle upon Tyne

MODEL TESTS

To complement the computer simulations and sea trails a series of propeller open water test with and without the Foul Release coating have men carried out in a cavitation tunnel under controlled conditions. These tests have men conducted using the Emerson Cavitation Tunnel within the School of Marine Science and Technology at the University of Newcastle upon Tyne.

The facility consist of a 60 tonne water capacity, vertical plane, enclosed, recirculating water tunnel and the associated control and measurement systems. The measuring section of the tunnel is 3m x 1.2m x 0.8m. The measurement system to be used for these test consist of a Kempf and Remmers H45 dynamometer mounted to the lid of the measuring section. This enables measurements to be taken up to 3000N Thrust and. 150Nm Torque. Speed of rotation for the propellers up to 3000rpm.

Water speed is generated by a 4 bladed impeller mounted in the lower arm of the tunnel generating tunnel speeds up to $8ms^{-1}$. A vacuum can 00 applied to the tunnel allowing it to test at scaled pressure conditions. The layout of the tunnel can be seen in Figure 8. other testing facilities available include digital noise and pressure measurements. high speed photography and laser velocity measurement systems (LDN / PDA and PIV). A complete description of the facility can be found in Atlar (2000).

The model used for the tests is a scale model of the propeller of an existing medium sized tanker of about 100.000 dwt. The vessel was being monitored to investigate the performance of its coated propeller. This model is representative of typical modern merchant propellers, which are both the most numerous and seen as the most likely candidates for coating application at full scale. The model has been constructed from aluminium to a scale of 1: 19.57 (this unusual ratio was used to provide a model with the maximum diameter feasible for the tunnel) so that multiple sets of blades, manufactured with great accuracy can be installed or replaced quickly and easily. This allows rapid and reversible changes between the coated and uncoated. Condition. The blades used in these tests were previously tested and were shown to be statistically similar: The details of the basis vessel and its propeller are shown in Table 3.

Detailed measurements were made of botl1 the thrust and torque on the model propeller at different rotational speeds In both the uncoated and coated conditions and at both atmospheric and a reduced pressure condition corresponding to the fully loaded condition of the full scale vessel.

From these measurements the efficiency of the propeller can be obtained. Once the intact coating measurements had been taken the coating was artificially damaged to simulate typical In service conditions seen in full scale propellers.

Three separate damage conditions were simulated and tested in the reduced pressure condition (equivalent to the full scale loaded condition of the vessel). All tests were repeated a number of times to allow for 95% confidence limits to be calculated. Noise measurements and cavitation observations were also recorded and will be published in due course.

Vessel data	
Ship Type	Medium Tanker
Deadweight	96920 tonnes
Length Overall	243.28 metres
Max Draught	13.616 metres
Speed	14.86 knots
Power (installed)	9893kW
Built	1992
Full Scale Propeller Dimensions	
Diameter	6.85m
Mean Face Pitch	4.789m
Number of Blades	4
Expanded Blade Area Ratio	0.524
Design Advance Coefficient, J	0.48

Table 3: The main particulars of the basis vessel and propeller.

The particulars of the model can be seen in Table 4. The uncoated and coated propeller model can be seen in figure 9 and 10 respectively.

Model Scale Propeller Dimensions	
Diameter =	0.35 m
Blades =	4 (multiple sets)
Expanded Area Ratio =	0.524
Pitch Ratio =	0.699
Material:	Aluminium Alloy
Direction of Rotation:	Right

Table 4:Model scale propeller details

DATA PRESENTATION

The results of the open water tests are given in the standard manner using the non dimensional confidents that are shown here:

Figure 9: The mode! propeller with uncoated blades.

Thrust Coefficient $K_T = \frac{T - To}{\rho n^2 D^4}$ (1)

Torque Coefficient $K_Q = \frac{Q - Qo}{\rho n^2 D^5}$ (2)

Advance Coefficient $J = \frac{V}{nD}$ (3)

Efficiency $\eta = \frac{JK_T}{2\pi K_Q}$ (4)

Where:
T = Thrust (N)
To = Frictional thrust of the propeller shaft (N)
Q = Torque value (Nm)
Qo = Frictional torque of the propeller shaft (Nm)
n = Rotation rate of the propeller model (rps)
V = Water speed (ms^{-1})
D = Diameter of the propeller model (m)
ρ = Density of the water (kgm^{-3})

Figure 10: The model propeller with mated blades.

TESTS IN ATMOSPHERIC CONDITION

The propeller was first tested in atmospheric conditions (no vacuum applied to the tunnel).The tests were conducted at a water speed of 4ms $^{-1}$. This water speed is used as it is fast enough to mitigate Reynolds number effected (the propeller Reynolds number varies between 1x106 and 2.5 x 106 depending on the rpm. but still allows small advance coefficient (J) values to be achieved within the loading limits of the dynamometer and the propeller motor drive system. The resul1s can be seen in Figure 11.

The results show a slightly higher efficiency for the coated propeller than the uncoated one at the higher advance coefficient values, although the difference between the two lies with the range of experimental accurate of the tests. It does however appear to confirm the results of the computer simulations, that the coated blades have the same drag as new or well polished blades, The slight change in the efficiency is due to the slight decrease in the measure torque values as applied in the computer simulations mentioned earlier.

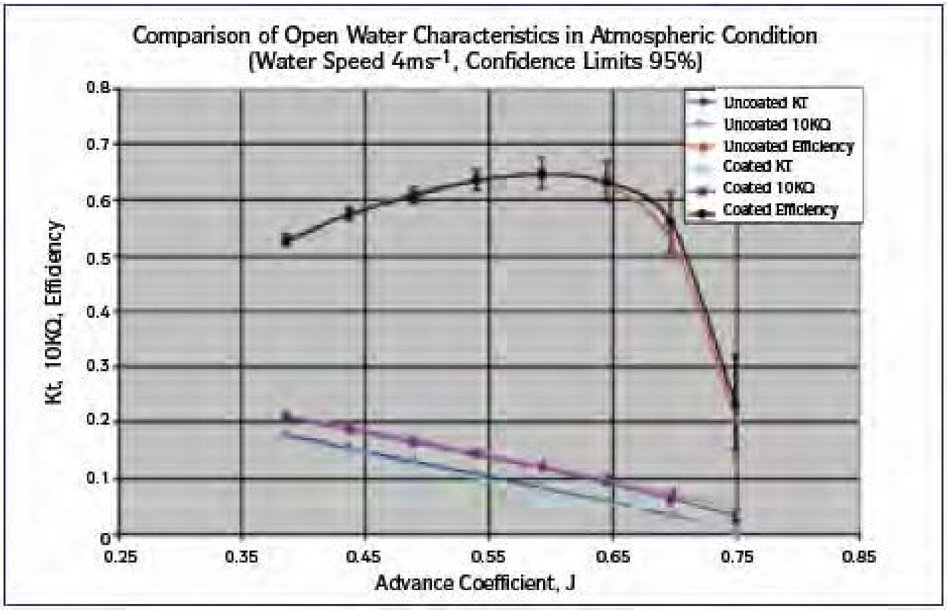

Figure 11 : Thrust torque and efficiency in the atmospheric condition.

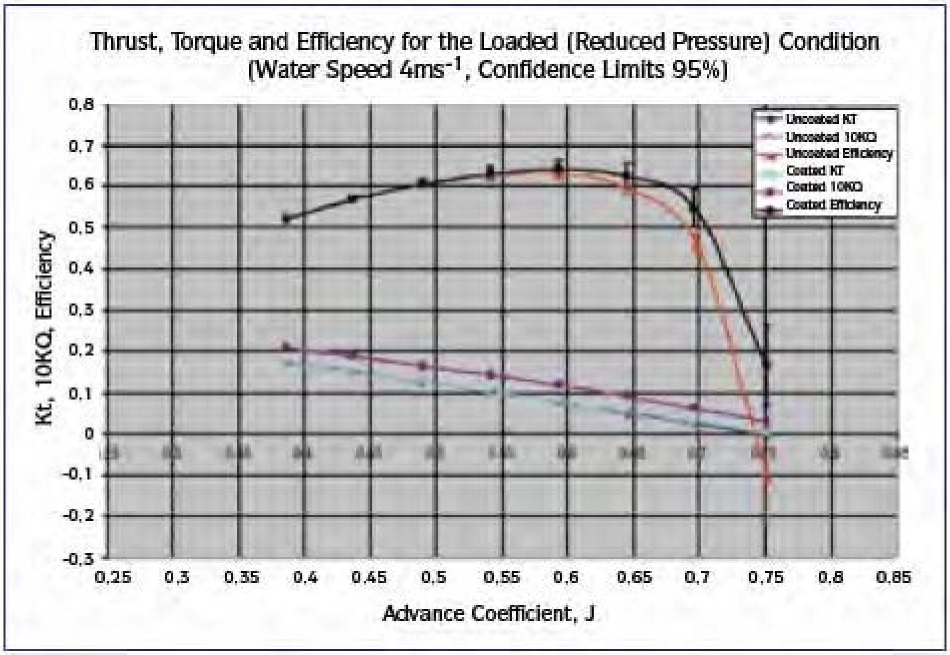

Figure 12: Thrust, torque and efficiency in the loaded (reduced pressure] condition,

TESTS IN LOADED CONDITION (REDUCED PRESSURE)

A vacuum was then applied to the tunnel in order to scale the pressure, and hence the cavitation effect to the equivalent values for the full scale fully loading condition. The cavitation number at **σ** 70% of the blade radius, **σ** = 0.498. Figure 12 shows similar results to the tests run in atmospheric conditions. There is some evidence of minor efficiency gains at higher **J** values with the coated blades but not sufficient evidence to say that the coating produces a drag reduction effect at anything but the highest values of advance coefficient (corresponding to low values of rpm). The coating again gives the same efficiency at the operating condition as the uncoated propeller (operating point is **J** = 0.48).

TESTS IN DAMAGED CONDITION

Examination of full-scale propellers coated with Foul Release systems has demonstrated that, like all propeller coatings, the Foul Release coating is prone to suffering damage from cavitation and impact with object in the water: This is usually about 5-10% of the coating surface area and predominantly on the blades leading edge, trailing edge and tip regions. It was suggested that this damage may signiftcanl1y affect the performance of the propeller, promote early cavitation inception and encourage further cavitation development in the damaged areas.
To investigate this it was decided to impart typical damage onto the model propeller coating to investigate the damage effect. Details of the damage effect on cavitation will be published in due course. The work presented here concentrates on the effect of the damage to the propeller performance.
Once all the testing for the intact coating had been completed, the coating was artificially damaged to replicate typical damage scenarios based on observation of full scale vessel propellers in service. These scenarios were simulated in 3 stages. All of the these were conducted at a water speed of 4mS $^{-1}$ and for the loaded condition.

The damage inflicted in each scenario is as follows.

Damage Scenario 1

Blade 1: 15% tip coating removal at back of blade.
Blade 2: 10% tip coating removal at back of blade.
Blade 3: 5% tip coating removal at back of blade.
Blade 4: Left Intact as a reference blade.

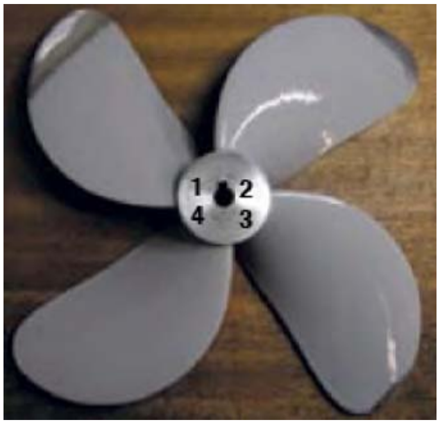

Figure 13: Damage Scenario 1 [view from the back],

The most common form of damage seen in full scale is removal of the coating on the back of the blade around the tip region. Three different extents of damage have been simulated on the blades 1 to 3 while blade 4 has been left intact in order to act as the reference for the other three during cavitation comparisons. The 10% damage is approximately the extent of cavitation when the propeller is in the loaded condition and operating at it's design **J** of 0,48. This is shown in Figure 13.

Damage Scenario 2

Blade 1: Large coating detachment In centre, back of blade.
Blade 2: Scratched to remove coating, back of blade.
Blade 3: Damage extended to remove leading and taming edge, back of blade.
Blade 4: Left intact as a reference blade.

The second damage condition builds on the first to represent further damage that is possible on the blades. Blade 1 has a large area of the coating removed. The amount removed is considered a worst case scenario of severe impact damaged to the coating and is more extensive than that yet seen on a full scale application. B1ade 2 had a number of scratches and abrasions inflicted upon the coating on the back of the blade.
This is typical full scale damage usually caused by foreign bodies impacting on the propeller. They were studied carefully to determine what types of damage and where will have the most impact upon the cavitation pattern of the propeller blade. Blade 3 has had the coating removed along the leading and trailing edges of the back of the blade. This is typical of damage that is often seen in full scale propellers Blade 4 was again left intact to act as a controller the other three blades. This is seen in Figure 14.

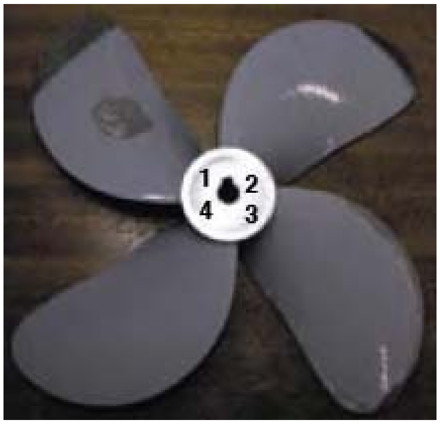

Figure 14: Damage Scenario 2 [view from the back].

Figure 15: Damage Scenario 3 [view from the back].

Damage Scenario 3

Blade 1: As stage 2 but repeated on the blade face
Blade 2: As stage 2 but repeated on the blade face, more scratches to back.
Blade 3: As stage 2 but repeated on the face
Blade 4: Left intact as a reference blade.

The third scenario of damage test repeated the damage, inflicted upon the back of the blade during scenario 2, to the face of the blades. In addition more scratches and abrasion were inflicted upon the back of Blade 2. The root of Blade 2 on both the back and the face were abraded to simulate the damage to the coating that occurs due to a rope or chain being wrapped around the propeller.
The face of Blade 1 has a similar large detachment to that inflicted upon the back of the blade in damage scenario 2. It is however larger and extends closer to the leading edge.
The face of Blade 2 has a number of scratches and abrasions. They are concentrated towards the leading edge of the blade as this is an area that was identified in the earlier tests as being most susceptible to cavitation when damaged.
The face of Blade 3 has the leading and trailing edges removed in a similar manner to the damage inflicted on the back of the propeller: Blade 4 is again left as a reference with which to compare the previous blades. This is shown in Figures 15 and 16.
From Figure 17 it can be seen that only damage scenario 3 shows any significant difference from the intact coating at tile operating advance coefficient Damage scenario 1 would actually appear to improve the performance slightly. This is most likely due to the removal of the coating, thereby thinning the apparent blade section

Figure 16: Damage Scenario 3 [view from the face].

This loss of thrust would suggest that the damage to the coating is disturbing the flow past the propeller. It can also be seen that the maximum efficiency remains above 60% for all of the damage scenarios. The maximum damage generates less than a 5% loss in maximum propeller efficiency between the intact coating and the worst damage scenario.

These results suggest that damage to the propeller coating does not lead to large losses in efficiency, even when the damage is quite severe.

It also has to be remembered that the coating system has not men scaled with the model (due to the minimum attainable thickness of the coating). This leads the coating to be proportionally thicker on the model than on a full scale application.
This would increase the effect of the damage on the efficiency. particularly the effect of damage on the thrust. These damage scenario results should therefore be seen as a worst case scenario. Detailed uncertainty estimates and pair wise statistical analysis are being conducted to demonstrate the extent and reliability of the results observed in these tests.

FULL SCALE PERFORMANCE

Figures 18 and 19 show the full scale coating on the basis propeller after a period in service of 37 months. This shows that about 90% of the coating is still attached to the propeller despite some losses round the tip and the leading and trailing edges. It can also be seen that little or no fouling is present on the blades (the prop had not been cleaned during the 37 months in service). This shows that the coatings are able to prevent the build up of fouling and its associated increases in drag for extended periods (to date coatings have been trial led successfully for periods of over 3.5 years).
In addition to the savings gained by the prevention of fouling drag, further savings are achieved by the reduction in the number of occasions that a diver has to be used to clean the propeller. In high fouling environments it has been seen that some slime fouling can attach to the propeller on the inner half.
To maintain the propeller at maximum efficiently it is still recommended that the propeller is still periodically cleaned by a diver.

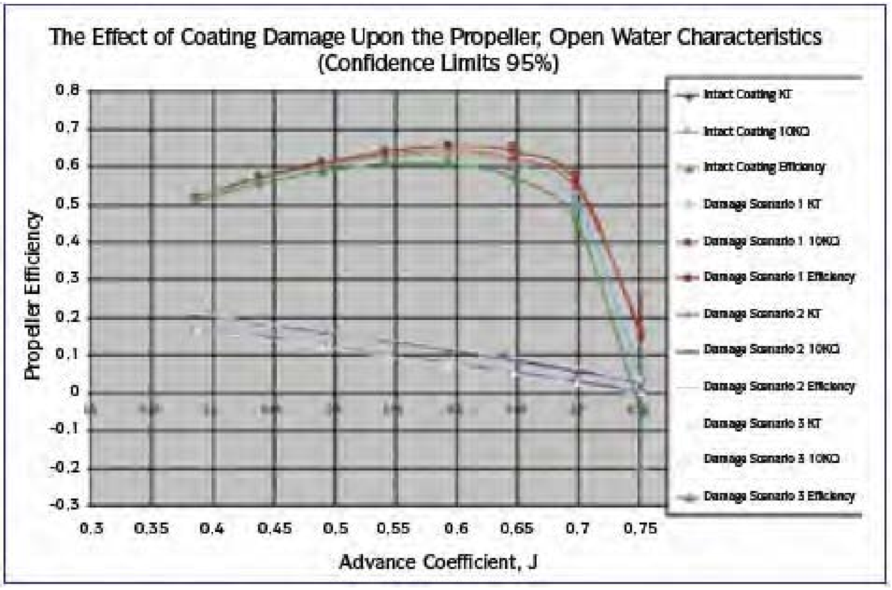

Figure 17: A comparison of the changes in open water characteristics with progressive damaged scenarios.

Figure 18: The full scale propeller after 37 months of service

Figure19: The back of the full scale propeller after 37 months of service.

This however would be at a reduced frequency and would not involve any hard abrasive cleaning (a damp cloth is generally sufficient to remove slime fouling from the Foul Release coatings).

ONGOING RESEARCH

In addition to the work described in this paper, a number of other measurements have been taken using the model propeller in both the coated and uncoated condition. The results will be published in due course. These include thrust, torque and efficiency measurements with a reduced loading condition equivalent to the full scale ballast condition. Extensive cavitation inception and noise measurements have been collected for all conditions of the propeller. The noise measurements are of particular relevance to naval vessels and cruise ships where noise reduction is a significant feature of the design process. Extensive video records of the cavitation patterns have also been collated for all conditions. Comparisons will be made to investigate the effect of the coating upon cavitation extent in all conditions.

FUTURE RESEARCH

The research presented here is part of an ongoing research programme into the hydrodynamics of Foul Release coatings. With regards to the work looking into their use on propellers a number of future research topics have been identified. The extrapolation of these results to full scale has to be investigated in order to demonstrate that the results are applicable in full scale conditions.

It is proposed that a series of model tests using models of different sizes should help to clarify the requirements. A major requirement that is being investigated at the moment Is the need for a standardised method of roughness estimation for Foul Release coated propellers.

For uncoated propellers the standard method is the Rubert gauge and it is proposed that a similar style system will be developed for the coated propellers. To finally conclude whether the coating does produce a drag reduction beyond the new or well polished propeller, It is proposed to use a Laser Doppler Anemometry (LDA) system to measure the boundary layer over the propeller blades in both the coated and uncoated condition. This Is feasible though technically challenging due to reflections of the laser from the coated surface.

The effect of the slime films present on a number of full scale propellers is being investigated, using flat plates, rotating disks and propellers. The effect of the slime film on the coated propeller performance is complex and difficult to evaluate.

Research is already being conducted into the effect of slime on Foul Release coatings on flat plates using the LOA system to accurately measure the boundary layer over slime films. Further research in this area including extending it to propellers is planned. Research is also being conducted into defining the attributes of an ideal propeller coating and identifying future materials that could provide enhanced performance beyond that of the Foul Release coatings.

CONCLUSIONS

It has been suggested that Foul Release coatings would provide drag benefits when applied to marine propellers in a similar manner to their application to ship hulls. This paper details research being conducted by the School of Marine Science and Technology at Newcastle University to Investigate and substantiate these claims. Early work and some computer simulations suggested circumstantial evidence that this may indeed be the case.

Further computer studies, sea trials and model tests have now been conducted to investigate the effect of the coating. While finding no evidence to positively conclude that Foul Release coatings give a drag reduction beyond that of a new or well polished propeller, no detrimental effect for having the intact coating present on the blades has been found in both the atmospheric condition and the full scale loaded condition.

It is understood that some damage will always occur at full scale so the effect on the propeller efficiency of typical damage conditions have been investigated. It was found that damage to the coating has to be extensive before significant reductions in efficiency begin to occur.

Investigation of full scale propellers in service has shown that the coatings are effective In preventing the deterioration and associated increases in blade drag that usually occur on an uncoated propeller after a period of service. It has also shown that the vast majority of the coating remains attached to the blade, apart from around the tip and the leading and trailing edges.

Research into this topic is ongoing and further results of the model tests will be presented in the future. These results will include the effect of the coating on cavitation and noise.

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