Efficient Underwater Surfaces

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SYNOPSIS

It is now understood that a rough underwater surface gives rise to a fuel penalty and adequate procedures exist to assess the economic consequences. Over the last 10 years about 250 hull roughness surveys have been carried out but wider adoption of the practice of routine hull roughness measurement is required. However, the choice of which roughness parameters to measure is a contentious issue, although over the last 35 years the average hull roughness $R_t(50)$ *originally proposed by BSRA has been accepted. This is adequate for quality control purposes but to improve the correlation between surface finish and drag a more detailed description of the surface may be required. A prototype instrument has been developed at the University of Newcastle upon Tyne and Teesside Polytechnic, which allows digital recording of hull surfaces for preliminary on-site analysis by its own micro-processor and more detailed statistical analysis later on a main-frame computer. This paper also discusses the present state-of-the-art in relating roughness-induced additional drag to statistical descriptions of hull surfaces and the problem of propeller roughness measurement.*

INTRODUCTION

It is now well understood that a rough underwater hull surface gives rise to a fuel penalty and adequate procedures are available to assess the economic consequences.[1] Over the last ten years about 250 hull roughness surveys have been conducted worldwide and directed from Newcastle upon Tyne. These show a small improvement in new ship finish over the decade but, more importantly, the deterioration rate has been halved. The surveys show however that there is still need for further improvement.[2]

It is self-evident that a requirement is a wider adoption of the practice of routine hull roughness measurement. An arrangement for the distribution of appropriate roughness measuring facilities worldwide would be beneficial.

A contentious issue concerns the choice of roughness parameters to measure. Over the last 35 years or so there has been quite remarkable unanimity in accepting the measure of average hull roughness $R_t(50)$ originally proposed by BSRA in connection with its *Lucy Ashton* programme. The universally adopted measuring instrument has been first the BSRA wall gauge and now the hull roughness analyser (HRA) available from BMT.

The measurement of the surface-wise distribution of $R_t(50)$ is adequate for quality control purposes, or in other words, to improve the quality of surface finish for fuel efficiency $R_t(50)$ is good enough. However, to improve the correlation between surface finish and added drag a more detailed surface description may be required. Until recently, there was no means of making detailed surface measurements at various places over a hull, apart from the tedious process of taking off replicas and measuring them in the laboratory, which has rarely been undertaken. A new prototype instrument has been developed jointly at the University of Newcastle upon Tyne and Teesside Polytechnic, which allows the digital recording of hull surfaces for preliminary analysis on-site by its own micro-processor and more detailed statistical analysis later on a main-frame computer.

The present state-of-the-art in relating roughness-induced additional drag to statistical descriptions of hull surfaces is discussed later with indications of future development.

The foregoing is meant to imply that there is plenty of scope for improving the efficiency of hull surfaces by better application and maintenance of existing antifouling products. Brief reference is made later to possible developments in antifouling provision and of drag-reducing coatings.

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Rough propeller surfaces are less of an issue, but regular surveys and maintenance both underwater and in drydock are advocated. The propeller roughness measurement problem is discussed at the end of this paper and attention is drawn to a standard procedure recently made available.[3]

THE PROVISION AND MAINTENANCE OF A SMOOTH HULL SURFACE

Present standards

Antifouling provision is essential. The better, current, self-polishing copolymer antifoulings are known to be remarkably effective antifoulants for interdock periods of three years and more, depending upon initial coating thickness. The issue with regard to their fuel efficiency is therefore their smoothness and the maintenance of the surface, especially damage avoidance.

No new technology is required in order to achieve a high standard of new ship smoothness and to maintain it in service. The requirement is to devise beneficial arrangements for the painting process and provide the resources and management to achieve a good out-turn.

A remarkably good finish (78 μm AHR) was achieved in a North East Coast yard in 1979 by launching in primer, sand sweeping at the final docking, fully staging and coating, with the contractual obligation for quality of out-turn lying with the paint supplier.[4] No new ship finish subsequently has been recorded as better but some recent finishes in Japan[5] have shown that good finishes, judged by the value of AHR, are becoming more common.

Similarly for re-coating, management must ensure that specification, access and supervision are adequate to ensure a good result. If it is argued that such provision is costly, then techno-economic justification is possible.[1]

Apart from the few special cases referred to above, Ref. (2) shows that the average new ship roughness has improved by only a small amount over the recent decade (129 to 113 μm), but the average deterioration rate has improved substantially (40 to 20 μm p.a.). The decade covers the period when self-polishing copolymers were introduced but also it was a period of growing awareness that smooth underwater surfaces would result in substantial bunker cost savings.

New paints and application techniques

It is worth pointing out that the chemistry and rheological aspects of marine paints are a response to customer requirements; for example, there is, for obvious reasons, a requirement for thick airless spray application, minimum number of coats and quick-drying properties, but these are not the best characteristics for a good finish, since drips, sags, runs and overspray can result.

Robotic painting and other advances in application methods are likely to call for new paints. Any customer insistence on a measured and improved contractual standard of finish is also likely to have an influence.

Butt weld dressing

A technical and economic case has been made for the removal of outer hull butt weld beads.[6] Calculations were made for five ship types and it is not difficult to make similar estimates in other particular cases. The technique of weld dressing itself deserves investigation to ensure that it is cost-effective.[7]

Cupro-nickel technology

Three systems have been proposed:

1. Cu-Ni wire mesh embedded in plastic such that the knuckles of the mesh are exposed. The plastic sheets are applied to steel plate using an epoxy adhesive.
2. Cu-Ni sheeting applied with an adhesive.
3. Cu-Ni cladding of steel in a hot rolling process.

There have been some recorded successes but a serious difficulty is the problem of first cost. Additionally the repair of damage in cases 1 and 2 presents difficulties. The integrity of the Cu-Ni surface is important for electrolytic considerations. There are some doubts about the effectiveness of the wire mesh on a moving ship since it is known that fouling will attach and survive on the tiniest of inert areas in an otherwise toxic surface. A techno-economic study of alternative 3 showed no substantial return on the invested capital, even supposing the technology was developed.[8]

It should be pointed out that if organo-metallic biocides are internationally banned for environmental reasons, then Cu-Ni technology might be a more attractive proposition.

Fendering systems

Ship berthing forces have been studied extensively.[9] The emphasis was to provide data for fender and quay design. The report recognises that stronger quay and fender construction implies more likelihood of ship damage. The ship damage referred to however is structural, whereas from the point of view of fuel efficiency it is the surface which should remain undamaged.

If considerable sums of money are invested in the preparation of smooth antifouling surfaces then fendering systems should be designed to avoid surface damage as well as structural damage. Even pneumatic fenders will remove coatings over a large area if there are substantial draft and tide changes.

Berthing and mooring practice

The surface damage, especially at the fore end, due to anchors and cables deserves consideration alongside the fendering problem. Changes in practice and design could reduce such damage. Whilst the new anti-abrasive coatings can alleviate the problem as far as anticorrosive protection is concerned, they do not, as yet, constitute an antifouling provision and hence a result of anchor and cable damage, as well as fender damage, is a colonisation of fouling.

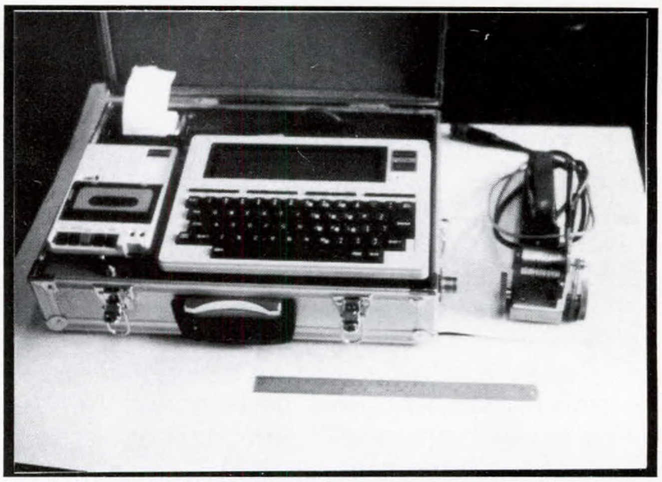

FIG. 1: Modified hull roughness analyser capable of recording a surface digitally

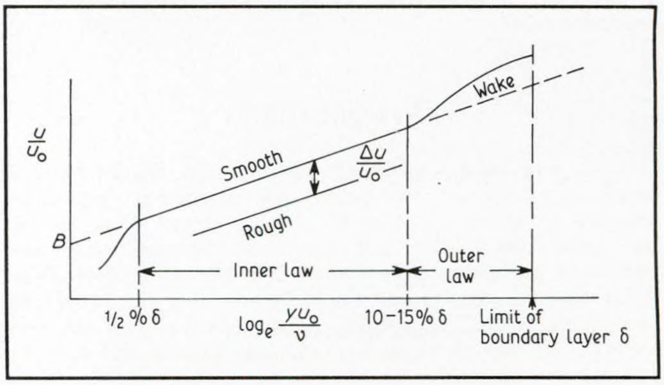

FIG. 2: The roughness function $\Delta u/u_o$

Other issues

Among the other resources to improve and maintain smooth wetted surfaces are: impressed current systems, which help prevent corrosion pitting of surface damaged areas; underwater maintenance by specialist divers, especially in connection with propeller inspection and polishing; codes of good coating practice, eg Ref. (10); better management and training for those concerned with outer bottom coating.

ROUGHNESS MEASUREMENT AND QUALITY ASSURANCE

Two measures which help to indicate the quality of application of outer bottom coatings are the distribution of paint thickness over the hull, which is of particular importance for self-polishing paints, and the distribution of roughness as measured by the HRA. Both thickness and roughness distributions present similar statistical presentation problems.

$R_t(50)$ is considered to be an adequate parameter for quality control purposes especially when coupled to a description of the local surface recorded in a standard form. A standard procedure is available for the measurement and presentation of results using the BMT instrument.[11] A potential surveyor would require a three day training programme.

If trained surveyors and suitable instruments were distributed worldwide, this resource could be used by ship operators to ensure that the quality of hull surface maintenance is improved, with the associated saving in bunker costs, continuing the trend identified in Ref. (2).

AN ADVANCED ROUGHNESS MEASURING INSTRUMENT

For research purposes there is a need to have digital recordings of hull surfaces. In a joint SERC-sponsored study, Newcastle University and Teesside Polytechnic have modified the HRA so that it will record hull surfaces digitally and through its own micro-processor can undertake preliminary analysis of results on the spot.

Digitising is effected by a shaft encoder coupled to redesigned wheels of the hand-held measuring head which can traverse the hull over about 0.5 m length. The minimum digitising interval is just over 50 µm, although power spectral density plots of surfaces have shown that there is little loss of information for intervals of 125 µm. The original ball stylus diameter of 1.56 mm was retained in the prototype which means a short wavelength cut off just less than this value and dependent upon the profile slope. The original skid of the HRA has been retained so that the long wavelength cut off remains at about 50 mm.

Figure 1 shows the complete instrument.

Table I: Roughness parameters used for hull and propeller surfaces

Parameter	*Long wavelength cut off* (mm) *used in Ref.*	*Reference*	*Comment*
$R_t(50)$	50	11	Most authorities have discussed this parameter
$R_t(1)$	1	15	This approaches the value of the short wavelength cut off determined by a stylus instrument
R_q	2, 50	13 & Karlsson	It links the standard deviation of the height distribution and $\sqrt{m_o}$
m_n		12	The *n*th moment of the power spectrum. m_o is the area
$\alpha = m_o m_4 / m_2^2$		11	It is important to have both a long and a short wavelength limit when defining this bandwidth parameter
s_k, k_u	2.0	13	Owing to statistical inefficiency practical application of skewness and kurtosis is difficult for profile characterisation
β	2.0	3	Correlation length depends upon high pass cut off and so is not an intrinsic property of the surface. Long wavelenght cut off must be considered carefully
λ_{pc}	2.0	3	Peak count wavelength
P_c	2.0	3	Peak count
R_a	2.0	3	Mean roughness height

The values of roughness parameters are materially affected by the cut off values; texture parameters are also affected by the digitizing interval. Both these features should be carefully considered and defined in particular cases.

HULL SURFACE ROUGHNESS PARAMETERS AND DRAG

A cross-section of a hull painted surface is a broad-banded random function. There are a considerable number of well known statistical parameters which can be used to typify such a surface,[12] including the moments of the spectral distribution.

The purpose of selecting parameters is to choose those which can be shown to correlate with the measured roughness function $\Delta u/u_o$ of typical painted surfaces (see Fig. 2). It is not of prime importance to effect a correlation with very rough hull surfaces, which result from bad surface damage, since even the crudest analysis shows them to result in unacceptable bunker penalties. It is of prime importance however to ensure that the parameters chosen are statistically reliable.

Table I lists a number of parameters which have been used by various authorities to describe hull and propeller surfaces, together with some comments on their characteristics.

There are few data which give statistical descriptions of typical hull painted surfaces together with their measured roughness function. Among the most valuable data are those of Musker.[13]

Musker found that the measured roughness function of five replicated ship surfaces did not correlate well with $R_t(50)$. By trial and error he found that a combination of four other parameters resulted in a satisfactory correlation. The parameters were σ_r, the standard deviation; s_p, the average local slope; s_k, the skewness of the height distribution; and k_u, the kurtosis of the distribution. The combination yielding an 'equivalent height' h', which correlated with the measured roughness function for all five surfaces ($R_t(50)$ ranging between 550 and 173 µm) was

$$h' = \sigma_r\,(1 + a\,s_p)(1 + b\,s_k\,k_u)$$

It should be noted however that all four parameters were determined from a filtered profile with a 2 mm long wavelength cut off by subsequently evaluating the parameter over a 50 mm length.[13] More conventional statistical computer packages yield different, lower values for the four parameters of the five surfaces.

Recent work by Walderhaug and Kauczynski[14,15] takes $R_t(50)$ and $R_t(1)$ as the parameters to define the painted surface. Results from seven painted plates are presented. Six of the plates have $R_t(50)$ values less than 250 µm, ie moderately rough hull surface finish values. All six plates yield $R_t(1)$ values between about 20 and 40 µm. The seventh plate is particularly rough, $R_t(50)$ = 675 µm, and is reported as having a surface of 'particles suspended in paint' which is not typical and would not be acceptable as a reasonable hull surface. The $R_t(1)$ value at 160 µm is not in accord with the other six plates.

A similar analysis at Newcastle University has shown that four of Musker's surfaces, R173, 253, 345 and 420, and three laboratory sprayed plates yield similar $R_t(1)$ values between 20 and 35 µm. Musker's roughest surface, R550, provides a higher value at $R_t(1)$ = 60 µm; this plate is beyond the range that could be called moderately rough.

Three 'more or less sandy rough' plates are also included in Walderhaug's data and they are those studied by Musker and Sarabchi.[16] One surface was abrasive paper and the other two were abrasive paper painted over. The $R_t(50)$ values of these three plates lie between 770 and 970 µm. The $R_t(2)$ values given in Ref. (16) and reproduced by Walderhaug[14] were calculated using Musker's filtering procedure. Estimates have been made of the likely $R_t(2)$ values by conventional procedures, which are about one-third those given by Musker, and then, by extrapolation, the corresponding $R_t(1)$ values have been determined. Again the painted plates yield $R_t(1)$ values less than 50 µm. The unpainted surface has a higher value.

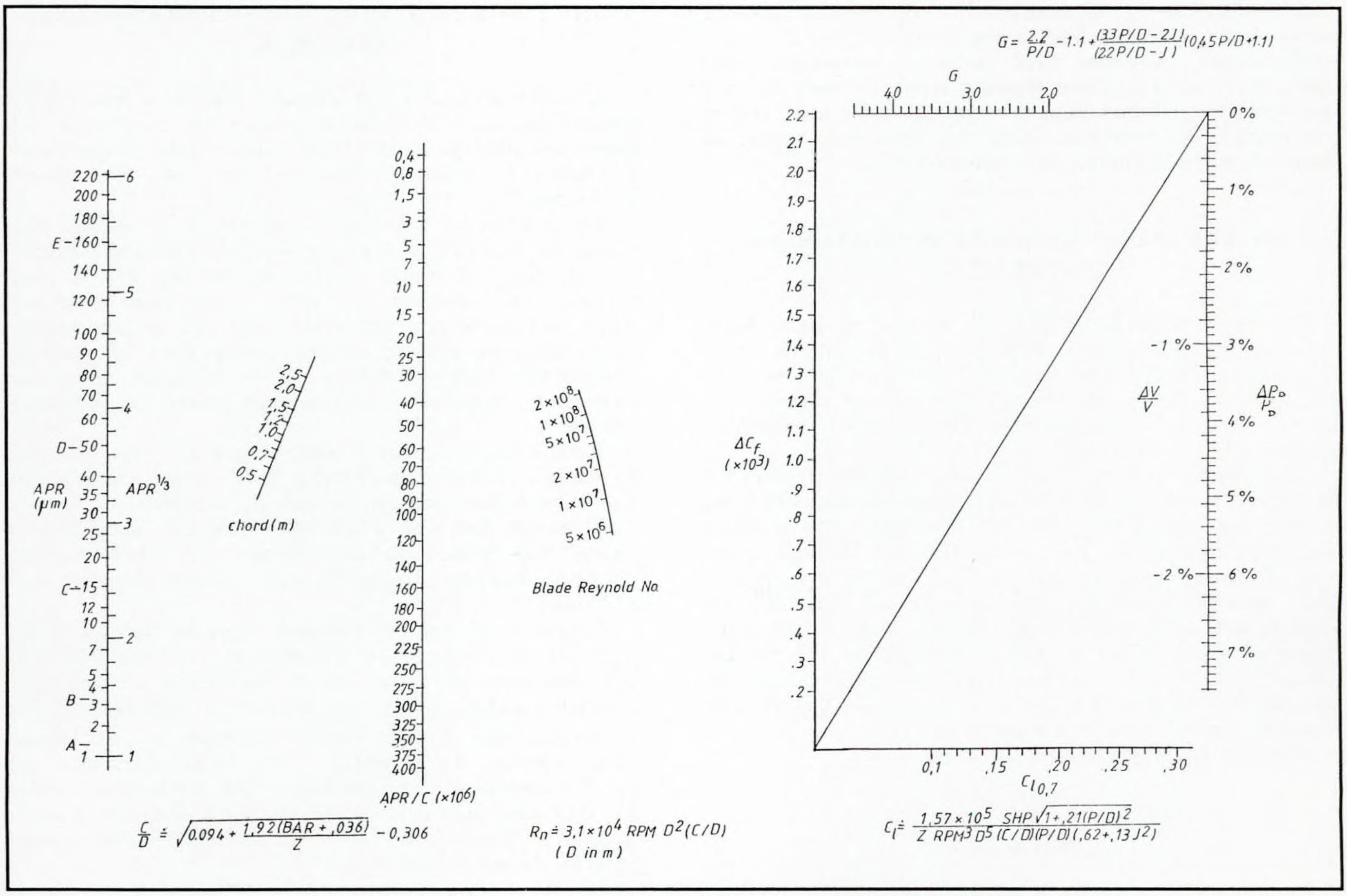

FIG. 3: Nomograph for determining propeller blade roughness penalties

The significance of the above arguments is in relation to the drag measurements reported in Refs (14) and (15) which seem remarkably to confirm the approximate formula below, given in Ref. (17), provided $R_t(1)$ lies between 20 and 40 µm:

$$10^3\,\Delta\,C_F = 44\left[\left(\frac{k}{L}\right)^{1/3} - 10\,\left(R_n\right)^{-1/3}\right] + 0.125$$

Whilst it may be argued, as above, that typical, ship painted surfaces which are not excessively rough do have $R_t(1)$ values between 20 and 40 µm, this must be the subject of extensive investigation. Such work is now possible using the modified HRA as described earlier. The significance lies in the possibility that $R_t(50)$ is a good description of a moderately rough ship painted surface to correlate with drag.

Recent work in the Ship Performance Group at Newcastle University has been directed towards the applicability of spectral moments as parameters to correlate with drag. In studying Musker's five surfaces and a set of laboratory sprayed antifouled surfaces, the following conclusions have been reached using a 50 mm long wavelength cut off:

m_o correlates with $R_t(50)$, R_q and R_a — as height measures

m_2 correlates with slope — as a texture measure, but it does not correlate with $R_t(50)$, ie texture does not correlate with height

$m_2{}^3/m_o$ correlates with Musker's h'

The foregoing discussion is supported by the hope that simple hull surface measurements can be correlated with the drag penalty they cause. As has been pointed out by Grigson however, and certainly where roughness is severe, it may be necessary to measure the velocity loss function on a replicated surface in the laboratory and he has devised a suitable procedure.[18]

PROPELLER SURFACES

Propeller surfaces can be polished underwater and arguably this is the best way of undertaking the work, using specialist divers. The cost can be two orders of magnitude less than recoating a hull and whilst the potential gain is less, the small sum involved makes regular blade polishing a sensible routine maintenance.

A standard procedure for measuring blade surfaces, calculating average propeller roughness (APR), and calculating the power penalty has been made available.[3] For maintenance purposes the six Rubert comparator gauges are adequate to determine surface condition. For more detailed examination in dry dock, a two parameter stylus instrument is available, as used by the propeller industry to check new finish standards. The instrument can produce the mean roughness height, R_a, with a long wavelength cut off at 2.5 mm and the peak valley pairs per 2.5 mm, P_c. It has been shown that a good correlation with Musker's h' can be made using these reliable statistics:

$$h' \approx 0.0147\,R_a{}^2\,(2.5)\,P_c$$

A simple nomograph is available to estimate power penalties (see Fig. 3).

FUTURE DEVELOPMENTS

Hovering in the background is the possibility, however remote, that environmental legislation will affect the nature of antifouling biocides. Already coatings with organo-tin biocides have been banned for certain small craft in certain ports. In consequence, paint technologists are even more busy searching for alternatives. It should be pointed out however that where shellfish are at risk near the mouth of an estuary and where that river has drydocks, more toxin is likely to come from the unfiltered flushing of dry docks than from the ships and boats using the harbours.

In the search for alternatives it is noted that, generally, fish don't foul. Furthermore many fish that are prey or predators also seem to have drag reducing properties. It seems likely that in the next decade considerable attention will be paid to slime coatings not only as potential antifoulants but also as drag enhancers and in some cases drag reducers.

There is a need to know much more about the surface topology of typical painted hull surfaces of moderate roughness to help in the roughness to drag correlation. The availability of digitising stylus instruments will make simple what otherwise is a tedious laboratory process.

The standard of surface maintenance is likely to improve over the next decade beyond that reported in Ref. (2). This will certainly be the case if a worldwide surveying facility becomes available as a quality assurance procedure.

More drag to roughness correlation experiments will be undertaken in recirculating channels, rotor apparatus, pipe flows and flat plane tests. Too little data are presently available in the literature in which there is both reliable data to determine the roughness function and also adequate statistical data defining the typical moderately rough antifouled surface.

In the end, the goal of the decade should be 'all ships smooth' and the dissemination of information should be a major part of the research workers' programme to achieve this goal.

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NOMENCLATURE

In addition to the roughness parameters given in Table I, the following symbols are used.

k = AHR = Average hull roughness

$= \frac{1}{n}\sum \text{MHR} \ldots n \approx 100$ stations

MHR = Mean hull roughness

$= \frac{1}{m}\sum R_t\,(50) \ldots m$

$\approx$ dozen or so readings at each station

$R_t(50)$ = highest peak to lowest valley perpendicular to the mean line over a 50 mm interval

The roughness function (Fig. 2)

u = boundary layer velocity
y = distance from surface in boundary layer
u_o = $(\tau_o/\rho)^{0.5}$ = 'friction velocity'
τ_o = wall shear stress
ρ = fluid density
ν = kinematic viscosity
δ = boundary layer thickness
κ = Karman constant

Propeller roughness penalty nomograph (Fig. 3)

A-E = Rubert propeller blade roughness comparator surfaces
APR = average propeller roughness, μm
BAR = propeller blade area ratio
ΔC_F = increment in skin friction drag coefficient due to roughness
C = propeller blade chord, m
D = propeller diameter, m
G = propeller roughness power penalty 'geometry' factor
J = advance constant
P_D = delivered power, kW
P = pitch
R_n = Reynold's number
V; ΔV = ship speed; change in speed due to roughness, m/s
Z = number of blades