The effect of a foul release coating on propeller performance

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SYNOPSIS

With the imminent ban on the application of coatings of TBT self-polishing co-polymers in January 2003 and their eventual prohibition in 2008 a great deal of research is being conducted into the performance of the possible alternatives. As part of the ongoing work investigating the hydrodynamic performance of foul release systems, being carried out at the University of Newcastle upon Tyne, a study into the possible benefits of their use on propellers has been conducted. The benefits that this method of propeller protection offers are potential fuel savings from increased propulsive efficiency as well as lower maintenance costs and a cleaner environment. Initially a literature review exploring the effect of propeller surface conditions on ship performance and previous work on propeller coatings for merchant ships was conducted. Theoretical calculations on the possible gains were then explored for a merchant ship propeller type using a propeller lifting surface analysis program. These showed that the significant losses in efficiency caused by blade roughening can be avoided by the application of a foul release coating with a surface finish equivalent to a new or well polished propeller.

INTRODUCTION

When the reduction in ship performance is associated with the condition of the ship hull, the effect of the propeller surface condition is often overlooked. Nevertheless, the effect can be significant. Mosaad[1] states that in absolute terms, the effect of the propeller surface condition is less important than the hull condition, but significantly more important in terms of energy loss per unit area. In economic terms, high return of a relatively cheap investment can be obtained by propeller maintenance. When considering the propeller surface condition a distinction has to be made between fouling and surface deterioration coupled with an increase in propeller roughness. Surface deterioration may be caused by corrosion, impingement attack, cavitation erosion or improper maintenance as described in the following.

The most common cause of propeller deterioration is corrosion. This will occur on both sides of the propeller blade and in particular in the outer half regions, where the speeds are very high relative to the water. When a new propeller is immersed in sea water it becomes the cathode in the hull-propeller electrolytic cell. Alloys such as Nikalium or Superston have about one half to one third the rate of deterioration of manganese bronze, cast steels or cast iron. The deterioration can be further minimised by the adoption of properly designed and maintained cathodic protection systems.

Impingement attack, as described by Patience[2], usually happens at the leading edge and the outer part of the propeller blades. The surface damage has a widespread distribution of fairly shallow depressions. Again the use of alloys such as Superston and Nikalium will withstand attack. Stainless steels are highly resistant to this type of attack, but mild steel and cast iron have very poor resistance to it.

Cavitation erosion is usually a concentrated and localised damage near the tip and back of the blade. It is very highly dependant on the pressure distribution of the propeller and the wake flow. With modern design techniques this can be minimised and is generally negligible even after years of service. However it is still recommended to check for indications of cavitation damage during the propeller's early service life so that, if necessary, modifications to the blade sections may be adopted. It must be noted that these modifications cannot be regarded as a routine part of the propeller surface maintenance.

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Improper maintenance such as poor grinding during cleaning may worsen the blade roughness due to scratching of the surface. Damage to the leading edge can seriously impair performance. Another aspect which needs attention during maintenance is that during hull painting splashes of conventional anti-corrosive or anti-fouling paints can drop onto the propeller, which increases the surface roughness of the blade. During maintenance periods the propeller should be protected from any grit blasting on the hull.

Fouling (the majority of marine growth on the propeller surface is of the animal type, acorn barnacles and tubeworms being the most frequent) may cause a much greater effect than roughness. However, the effects of fouling upon the propeller are difficult to quantify since little theoretical and experimental work has been done on the subject. The experimental work conducted by Kan et al.[3] investigated the characteristics of a fouled propeller using self-propulsion tests with the propeller covered in various rubber sheets to mimic the fouling. They found that small increases in roughness will cause large increases in delivered horsepower (DHP), producing a worse effect on propulsive efficiency than hull fouling but the reduction in thrust due to roughness was very small. These experiments, however, did not give very good agreement with their full-scale results. The full-scale measurements showed that the rate of increase of DHP will decrease as the roughness increases; the initial roughness has the greatest effect on performance. Because of propeller fouling, the DHP decreases by 20% and from these results, it can be seen that the effects of propeller fouling in terms of a power penalty are much greater than those of surface roughness.

Assessing the effect of the propeller surface condition on ship performance

Before the effects of roughness upon the performance of a propeller can be quantified the roughness of the surface has to be measured. There are various methods for doing this, such as using a propeller roughness comparator, by using a portable stylus instrument or by taking a replica of the surface and measuring it with laboratory equipment such as optical measurement systems. Thomas[4] describes both stylus and optical measurement systems in good detail. The propeller roughness comparator is a simple gauge by which the roughness of a propeller can be compared to a surface of known roughness. A typical example is the Rubert propeller roughness comparator that is shown in figure 1.

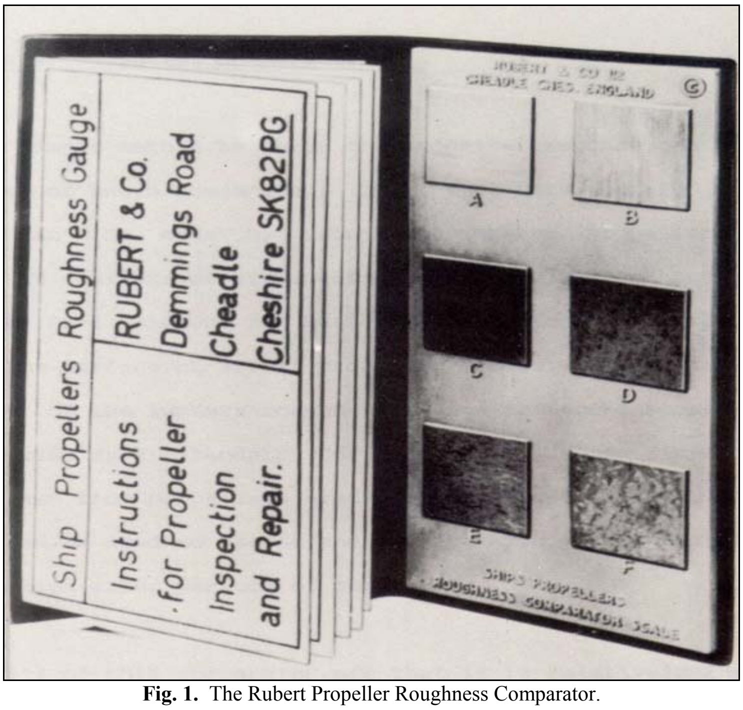
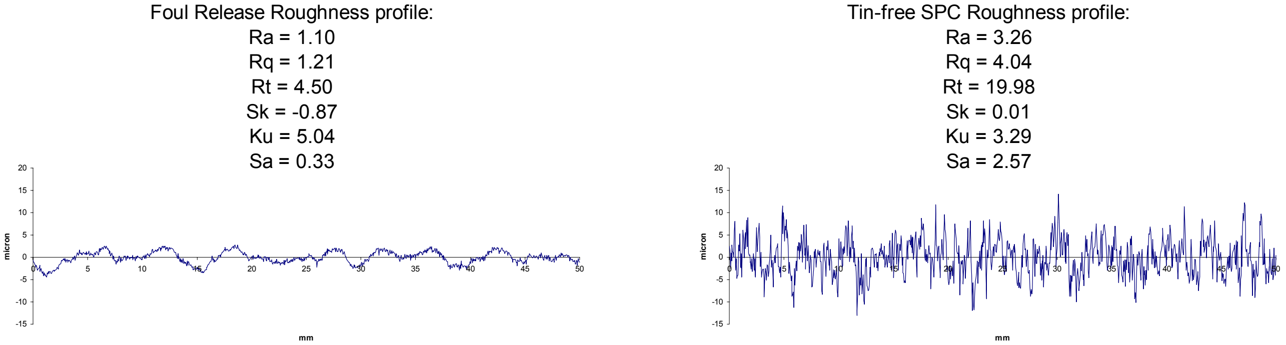


Fig. 1. The Rubert Propeller Roughness Comparator.

The gauge consists of six examples (A, B, C, D, E and F) of surface finish that range from an average roughness amplitude Ra = 0.65μm to an amplitude of Ra = 29.9μm[5]. The examples represent the surfaces of actual propeller blades. Examples A and B represent the surface roughness of new or reconditioned propeller blades while the remaining examples are replicas of surface roughness taken from propellers eroded by periods of service. C, D, E and F can be used to assess and report upon the propeller blade surface condition after periods of service.

In order to carry out detailed calculations on the effect of propeller roughness upon ship power and hence the effect of a foul release coating, a drag-roughness correlation is needed. Mosaad[1] carried out extensive measurements upon the Rubert comparator specimens. From these measurements he calculated the characteristic roughness measure h'. This parameter was proposed by Musker[6] to characterise a surface by a single parameter, taking both the amplitude and texture of the roughness into account. It must be noted that a single parameter (such as roughness *height*) as those measured by Broersma and Tasseron[7], will not be suitable for this purpose. This is because although a surface may have a relatively large average roughness amplitude, its texture may have a long-wavelength sinusoidal texture. This type of surface may cause lower drag when compared to a surface consisting of smaller amplitudes but with a jagged texture consisting of closely packed sharp peaks[8]. When looking at coatings, a foul release system belongs to the former type, but a tin-free self-polishing co-polymer belongs to the second type, as the roughness profiles in figure 2 show[9].


Foul Release Roughness profile:
Ra = 1.10
Rq = 1.21
Rt = 4.50
Sk = -0.87
Ku = 5.04
Sa = 0.33

Tin-free SPC Roughness profile:
Ra = 3.26
Rq = 4.04
Rt = 19.98
Sk = 0.01
Ku = 3.29
Sa = 2.57

Fig 2. Characteristics of a typical foul release (Intersleek) and tin-free SPC (Ecoloflex) roughness profile.

From Figure 2 it can be seen that when long-wavelength waviness (which is unlikely to have any effect upon the drag) has been filtered out, two striking features appear: not only are the amplitudes (Ra, Rq, Rt) of the foul Release profiles typically lower, the texture of the surface (Sa) is very different. In metrological terms this type of texture is known as ‘open’ whereas the spikier texture of a tin-free SPC surface is known as ‘closed’. Using the characteristic roughness measure h’ Mosaad[1] carried out measurements in a rotating drum and established the relationship between h’ and increased torque, and hence drag. This relationship will be used later on in this work.

The coating of propellers

Coating propellers is not a new concept – several experiments have taken place from as early as World War II – but no follow-up was made on the experiments. Consequently, not much has been published in the open literature on the coating of propellers. Dashnaw et al.[10] have reported on the coating of propellers which provided protection against cavitation erosion and corrosion while providing a smooth propeller surface having lower hydrodynamic drag. They evaluated the hydrodynamic resistance of various coatings and surface finishes by means of a rotating-disk apparatus. Of the surface finishes designated for steel, a surface finish with a Root Mean Square roughness amplitude of Rq = 3.175µm was according to the authors similar to a new commercial propeller finish. This surface exhibited a higher drag than a propeller coated with a urethane system of higher roughness (Rq = 3.81µm).

Matsushita[11] tested a foul release system on both boat hulls and a propeller from the training ship ‘Yuge-Maru’. These tests showed that a foul release system can protect propellers from fouling and electrochemical corrosion, with only a small amount of fouling near the hub of the propeller and a 30% reduction in the consumption rate of the ships sacrificial anodes. Matsushita also found problems with the robustness of the coatings used past a surface time of one year. Since 1993 more development of these coatings generally has taken place, and in particular research into improving the adhesive qualities of these coatings to marine propellers[12].

THE LIFTING SURFACE ANALYSIS PROGRAM

To investigate the effect of a foul release coating on propeller performance use was made of a state-of-the-art numerical tool which predicts the performance of a propeller in a given wake flow. The computer program Unsteady Propeller Cavitation Analysis, UPCA91, was a product of collaboration between the Department of Marine Technology (now the School of Marine Science and Technology) at the University of Newcastle upon Tyne and the Institute of Fluid-Flow Machinery of the Polish Academy of Sciences. A description of an early version of the program is given by Szantyr[13].

The input to the program comprises the complete propeller geometry, details of the three-dimensional wake pattern and the ship condition, speed and propeller rpm for which the analysis is to be made. The analysis of the flow on the blades and hence the determination of the blade and shaft forces, the extent of cavitation on the blades and the resulting fluctuating hull surface pressures is carried out for a number of positions in one revolution, 36 in this case. The results produced by the program consist of:

- Pressure distribution on the propeller blade for all specified blade positions.
- Distribution of boundary layer momentum thickness, together with locations of laminar separation, laminar/turbulent transition and turbulent separation for all blade positions.
- The extent and thickness distribution of sheet cavitation for all blade positions.

- The extent of bubble cavitation for all blade positions.
- The diameter of the cavitating tip vortex for all blade positions.
- The six components of hydrodynamic forces acting on a single propeller blade
- The six components of the total hydrodynamics forces and moments acting on the propeller shaft.
- The fluctuating pressures induced at specified points on the hull surface by a single propeller blade (including the effects of cavitation).
- The fluctuating pressures induced at specified points on the hull surface by the whole propeller.

The last four results undergo harmonic analysis and, in addition to their total values, they are presented in the form of harmonic amplitudes and associated phase angles. For the work reported here, cavitation and hull surface pressure fluctuations are of little interest and the only significant output from the program is the values of propeller thrust and torque corresponding to each specified operating condition.

INPUT DATA

The computer calculations were carried out for a typical, fixed pitch, merchant ship propeller that has the following main particulars:

Diameter = 6850mm
Mean Pitch = 4789mm
Number of blades = 4
Expanded Area Ratio = 0.524

The propeller geometry was taken from the appropriate manufacturer's drawings.

The calculations were made for the propeller in open water, with the wake corresponding to a uniform axial stream. The assumption that the propeller works in a uniform stream rather than a 3-dimensional ship wake is considered to have little effect on the conclusions drawn from this present study. To suppress the effects of cavitation a high, fictional value of the shaft centre-line immersion was inputted.

BLADE SECTION DRAG COEFFICIENTS

In a similar way to most propeller design and analysis procedures, the effects of blade drag are accounted for by the inputting of the appropriate blade section drag coefficients usually denoted by the term, C_D. The drag coefficients that correspond to a new or freshly polished propeller were taken from Burrill[14]. These values would normally be used in the propeller design calculations, and are thus referred to here as Design C_D's. They will be used to form the basis for the calculation of the drag coefficients corresponding to various degrees of blade roughness. The increase in section frictional resistance due to roughness can be represented by the expression[1]

$$1000\Delta C_F = 8.1\,\mathrm{Re}^{0.093}\left[\frac{1}{3}\left(h'/c\right) - 4.5\,\mathrm{Re}^{-1/3}\right] \qquad (1)$$

Where Re is the blade section Reynolds' Number
c is the section chord length
h' is the roughness parameter as defined by Musker[6]

Values for h' for the various Rubert surfaces were calculated by Mosaad[1] and are given in table I.

Table I. Musker's characteristic roughness measure of Rubert gauge surfaces.

Rubert Surface	*h' (μm)*
A	1.32
B	3.4
C	14.8
D	49.2
E	160
F	252

The sum of the frictional drag and the form drag will give the increase in total drag. This is given by:

$$\Delta C_D = 2(1 + t/c)\Delta C_F \tag{2}$$

where t is the maximum thickness of the blade section.

It is the opinion of a major UK propeller manufacturer[15] that a roughness equivalent to Rubert A represents a degree of smoothness unlikely to be achieved in practice. Rubert B is considered characteristic of a new or well polished propeller and Rubert D to E would be equivalent to the blade roughness after 1 to 2 years in service. For this investigation it has been assumed that the new or polished propeller has Rubert B blade surfaces, the drag of which is represented by the design C_D values. The increase in C_D caused by blade roughening is then given by the difference between the ΔC_D values corresponding to the Rubert surface in question and that for Rubert B. If we take for example Rubert D

$$C_D D = Design C_D + (\Delta C_D D - \Delta C_D B) \tag{3}$$

The effect of the increased roughness on the drag coefficient for the section at r/R = 0.7 is shown in table II.

Table II. Drag coefficients of Rubert surfaces (Design = Rubert B).

Surface	*Design*	*Rubert D*	*Rubert E*	*Rubert F*
C_D	0.00838	0.01003	0.01138	0.01206
% Increase		19.7	35.8	43.9

Candries carried out experimental work with various surfaces coated with a foul release system[16]. The surface characteristics of 5 different applications were studied using a UBM Optical Measurement System from which it was found that the roughness measure h' varied between 0.5 and 5µm. The quality of application ranged from excellent to good, so that it was considered appropriate to assume a value of h' = 5µm. The calculated values were negligibly different form those calculated when using the Design C_D values. From this it can be inferred that a foul release coated blade surface is equivalent to the new or well polished blade surface.

CALCULATIONS WITH UPCA91

The propeller performance with the design C_D values was calculated for five operating conditions corresponding to J = 0.3, 0.4, 0.5, 0.6 and 0.7. This will provide a basis for comparison. J is the non-dimensional advance coefficient given by

$$J = \frac{V_A}{nD} \tag{4}$$

where V_A is the propeller advance in m/s
n is the propeller rate of rotation in rps
D is the propeller diameter in metres.

This procedure was then repeated with the drag coefficients corresponding to Rubert D, E and F surfaces and for all the above advance coefficients.

Thrust and Torque values that are derived from these calculations were made in non-dimensional terms as shown below

$$\text{Thrust Coefficient, } K_T = T/(n^2 D^4 \rho) \tag{5}$$

$$\text{Torque coefficient, } K_Q = Q/(n^2 D^5 \rho) \tag{6}$$

where T is the propeller thrust in kN
Q is the propeller torque in kN.m
ρ is the mass density of sea water in kg/m^3

The efficiency of the propeller for each case is calculated from

$$\eta_0 = J/2\pi \times K_T/K_Q \tag{7}$$

The values of K_T, $10K_Q$ and η_0 are plotted against J and the results are shown in figure 3.

From this figure it can be seen that the predominant effect of an increase in the roughness of the propeller blades is an increase in the propeller torque. The decrease in propeller thrust that accompanies the increased torque is too small to be obvious on the figure's scale.

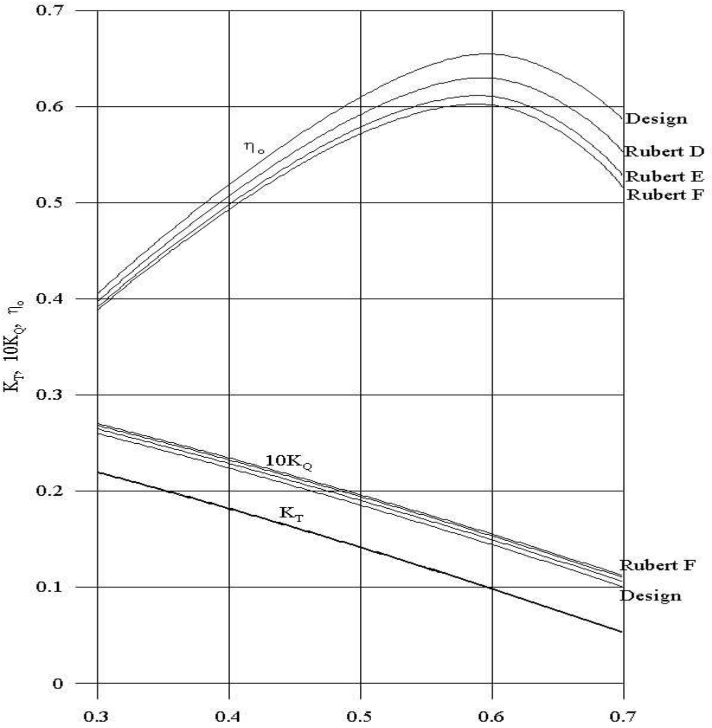


Fig 3. Propeller open water characteristics for various values of blade surface roughness.

The loss in propeller efficiency as the propeller blades roughen, to a base J, is shown by figure 4. It is defined by

$$\%\text{Efficiency Loss} = (\eta_0\,\text{Design} - \eta_0\,\text{Rubert}) / \eta_0\,\text{Design} \times 100 \tag{8}$$

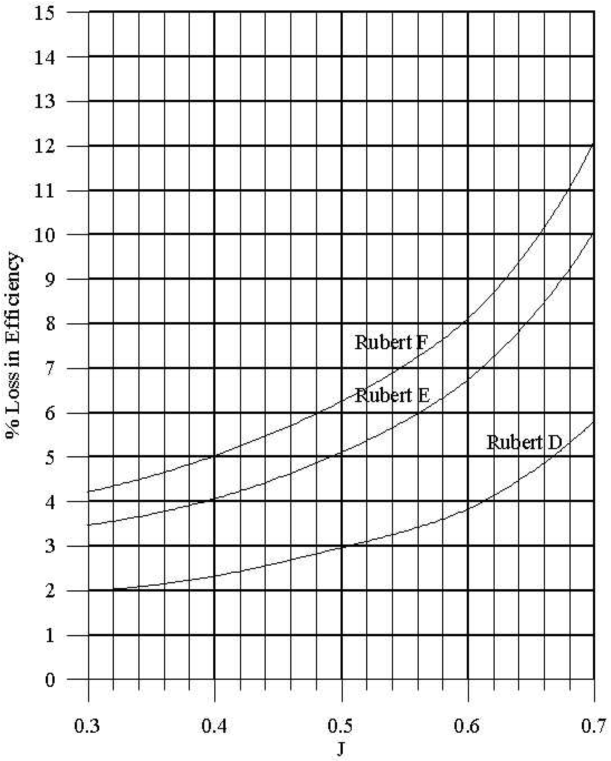


Fig 4. Loss in efficiency in going from Design Drag Coefficient to specified Rubert Surfaces.

In a similar way the gains in efficiency possible due to the blade being polished are shown in figure 5. It is defined by

$$\%\text{Efficiency Gain} = (\eta_0\,\text{Design} - \eta_0\,\text{Rubert}) / \eta_0\,\text{Rubert} \times 100 \qquad (9)$$

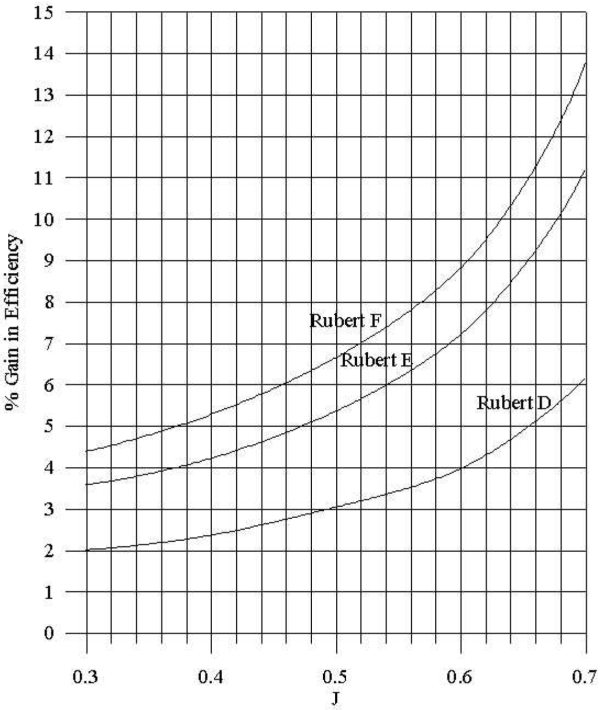


Fig 5. Gain in efficiency in going from specified Rubert Surfaces to Design Drag Coefficient

The gains in efficiency by polishing are, of course, slightly greater than the losses in efficiency with blade roughening. There is an increase in efficiency with the increase in J because as the propeller forces decrease in magnitude, the section drag will comprise a larger proportion of the total energy that is lost. Performance data for the ship from which the propeller that was modelled is taken shows that on average the propeller works at a value of J = 0.48. From figures 4 and 5 it is shown that the propeller efficiency losses and gains are about 3%, 5% and 6% for surfaces of roughness represented by Rubert D, E and F respectively.

CONCLUSIONS

The results of the calculations described above show that significant losses in propulsive efficiency resulting from blade roughening can be regained by cleaning and polishing of the blades. Alternatively, the efficiency losses could be avoided, perhaps indefinitely, by the application of a paint system that gives a surface finish equivalent to that of a new or well-polished propeller. A foul release coating is such a paint system.

This research is ongoing and the calculations presented above are to be validated in the near future with model tests using the Emerson Cavitation Tunnel at the University of Newcastle upon Tyne. The model will also be used to consider the effects of coating thickness and investigate the durability over time of the coating as there is some concern of detachment at the blade tips. For full-scale evaluation sea trials are to take place using the University research vessel 'Bernicia' and a number of larger commercial vessels. These results will be published in due course.

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