

## **SLIDE 1**

### **AN INTRODUCTION TO THE DESIGN AND SURVEY OF MARINE PROPELLERS**

by

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#### **General Introduction**

Despite its innate simplicity the propeller is possibly one of the least understood items on a boat yet, certainly on a motorboat, it is probably the most important. It is a surprisingly simple means of converting the torque drawn from the main engine into useable thrust. Although the basic form is the same – a number of blades set at an angle extending out from the central boss or hub - it comes in a number of practical forms and the marine surveyor should be able to recognise these at sight and understand their significance. A good marine surveyor's report should contain the following minimum information about the propeller(s): -

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- the number of propellers.
- the propeller type. *i.e.*, whether of folding, feathering, fixed pitch (solid), controllable pitch, contra-rotating or surface piercing type.
- the propeller's handing.
- the number of blades.
- the method of securing the propeller to the shaft.
- the propeller's colour – this need not be reported but should be recorded in the marine surveyor's private notes.
- the material of manufacture which is usually determined from the colour.

- the propeller's diameter.
- if known, or easily found, the propeller's mean pitch.
- if known, or easily found, the propeller's blade (disc) area ratio.

The first seven of these characteristics are found by simple observation and the rest by practical measurement. The actual shape of the blade is usually quite arbitrary and, at least on small craft with a few rare exceptions, not of much importance.

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Propellers are usually described in the form - blade section type – number of blades – disc or developed (blade) area ratio. Thus a Troost B4.55 type propeller would have Troost B sections, four blades and a disc or developed (blade) area ratio of 0.55. Such a propeller would be commonly found on small coasters, tugs and trawlers and the like.

**N.B.** The marine surveyor's report should, of course, also contain details about the propeller shaft(s) such as its (their) material and diameter(s).

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#### **Surveying tip 1**

- In order to check the handing of the propeller, hold it by the boss in one hand. If the thumb goes easily between the blades then that hand is the handing of the propeller. If the tip of the thumb hits the blade then the propeller is of the opposite hand.

#### **Propeller Types**

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When choosing a propeller, there are many things to consider. Several types are available and, with some research, it can be certain that the best one possible to suit the vessel is chosen. Because each propeller type offers various advantages and disadvantages, deciding between them can be perplexing and the marine surveyor should know the pros and cons. There are six basic types: -

1. feathering propellers.
2. folding propellers.
3. fixed pitch propellers often called solid propellers.
4. controllable pitch propellers often, incorrectly, called variable pitch propellers.
5. contra-rotating propellers.
6. surface piercing propellers

### **Folding and Feathering Propellers**

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Folding and feathering propellers are often referred to as low drag propellers and are alleged to offer a dramatic increase in speed under sail. Replacing an original solid propeller with a low drag unit will usually give the best performance gain for a given cost compared to other possible arrangements such as modifications to the rig. On a folding propeller, the blades are hinged and fold backwards under water pressure when not in use while relying on centrifugal force to open when driving. With the lowest drag of all, the use of a folding propeller will often increase sailing speed by between half and a full knot and reports of 1½ knots in light airs are not uncommon. Nothing else can be purchased that will make such a dramatic increase. Compared to fixed and feathering propellers, a folding propeller has a mid range price. The only caution with folding propellers is that reverse performance is usually compromised as the centrifugal force opening the blades is counteracted somewhat by the thrust of the blades trying to push the vessel sternwards. In general, folding propellers usually suit the racing enthusiast's needs best or those that are prepared to sacrifice a little reverse ability to save some of the cost. The propeller boss suffers from wear and galvanic and/or crevice corrosion in the hinge mechanism and the marine surveyor should specially look for these defects. One propeller maker also markets different types of folding or feathering propellers called by the trade names of Variprop or Varifold propellers. Other types may also be found and with these, again, the marine surveyor should check the hinge mechanisms for wear.

A feathering propeller has a mechanism that turns the blade's edge into the water flow to minimize the drag when sailing. The blades are then rotated into the required position for forward or reverse, once power is applied. Feathering propellers give control at all times and boast superior reversing ability over fixed or folding propellers. While the drag can be marginally higher than the folding propeller, it is significantly lower than a fixed propeller. The initial purchase price of these propellers is usually higher than a fixed or folding model. However, they have a long life being generally more robust in construction. Feathering propellers generally have a pitch adjustment mechanism that allows adjustment of the



**Photograph 1 Folding Propeller in Open Mode**



**Photograph 2 Folding Propeller in Closed Mode**

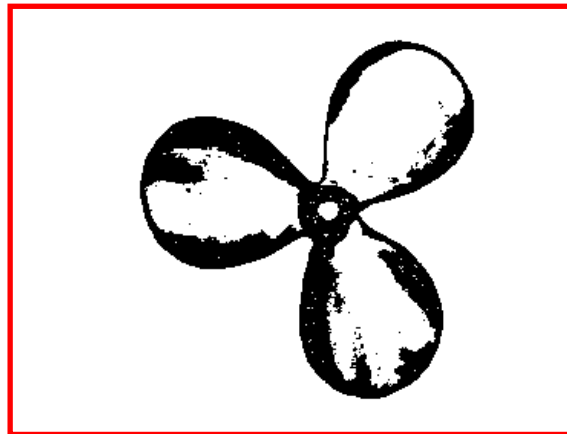
propeller to the optimum pitch for a given installation. Some high quality feathering propellers feature external pitch adjusters, which gives simple access to the adjustment for forward and reverse independently. Forward can be set for best motoring performance and reverse can be set for best manoeuvrability and thrust, which is useful when trying to back off a sandbank or stop in a marina. In general feathering propellers usually suit the Blue Water Cruisers needs best or those that have problems with difficult berthing situations and need the additional control a feathering propeller gives. It is reasonable for a racing yacht to try to minimise drag by fitting a complex propeller and/or a light but complex engine/transmission but this would be questionable practice on a cruising, family yacht of simple design. There is nothing inherently wrong with any well designed propeller of one of these types but the owner must recognise the weak spots and plan maintenance accordingly.

### **Fixed Pitch (or so-called Solid) Propellers**

Fixed propellers are the least costly and, when correctly sized, provide the best forward propulsion under power with reasonable reversing ability but have the highest sailing drag. Note that the word solid is used to distinguish an ordinary fixed (which may or may not be varied) pitch propeller from a controllable (NOT variable) pitch propeller. A solid cast fixed

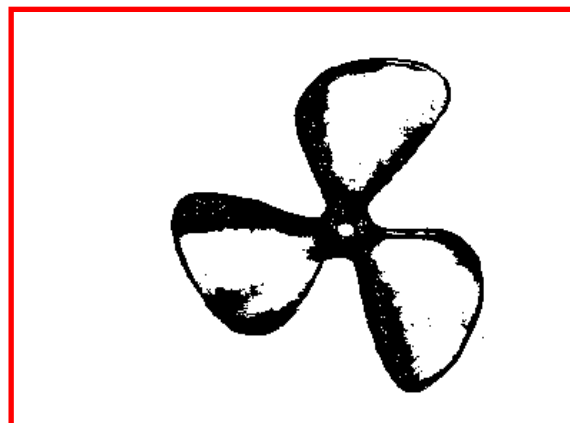
pitch propeller may have a pitch that varies along the length of its blades and, strictly, such units should more accurately be called varied pitch propellers as, once the propeller has been cast, the pitch is neither controllable nor variable. The majority of solid propellers are right handed but that is not always the case. For the best manoeuvrability control, a twin screw installations should have outboard turning propellers *i.e.* right handed to starboard, left handed to port. The marine surveyor should never take this for granted but should always check. The most common types of propeller on the average small pleasure vessel are the so-called turbine propeller, the Equipoise propeller, the highly skewed propeller (often colloquially called a weed slinger) and the two bladed sailing unit. They are all solid units, usually of constant pitch and are illustrated below in the Figures 1 a to d below.

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**Figure 1a Turbine Propeller**

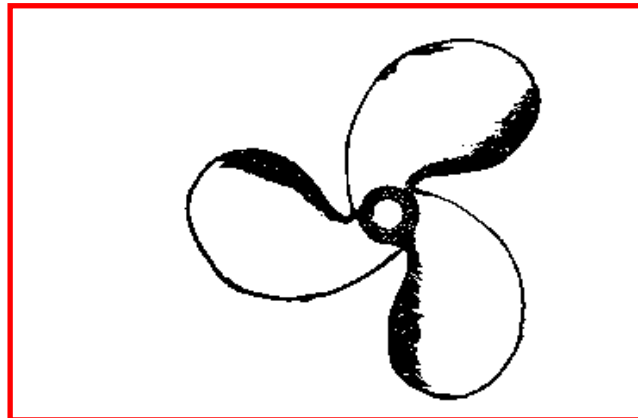
Figure 1a shows a so-called turbine type which is the typical propeller and the majority of small displacement craft will have this type fitted unless there is a very good reason not to.



**Figure 1b Equipoise Propeller**

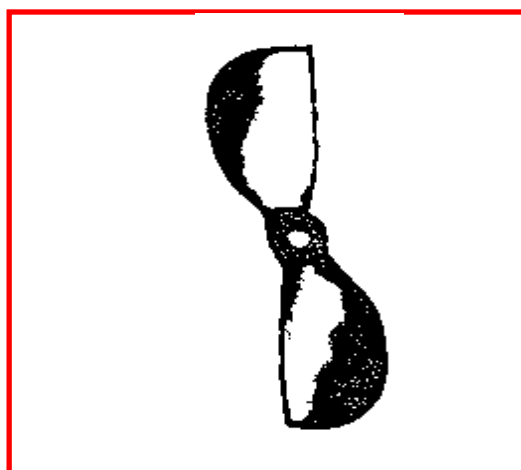
The blades of the Equipoise type have a somewhat larger surface area than those of the turbine type and therefore the pressure difference across the blade is less and that helps to reduce the possibility of cavitation. The type is normally found on high speed planing craft, although it should not be over detrimental on a low speed displacement boat.

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**Figure 1c High Skew or Weed Slinger Propeller**

The shape of the blade of the highly skewed (colloquially called a weed slinger) type of propeller is not as efficient as the turbine type but, if something catches on its leading edge, that item should be thrown off by the water resistance and the propeller's rotation. The opposite is the case, of course, when running astern. This type is often found on narrowboats.



**Figure 1d Two Bladed Sailing Propeller**

The two bladed propeller is common on sailing yachts and is designed to be locked into a vertical position behind the sternpost of a long keeled sailing boat. All sailing craft need to

stop the propeller turning when under sail because a windmilling propeller absorbs energy that would otherwise be used to increase the boat's speed. Stopping it behind the keel shields it from the water flow and helps reduce its tendency to create drag.

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### **Surveying tips 2 to 7**

- A turbine or an equipoise propeller on a displacement boat should not be a major concern.
- A turbine propeller on a planing boat should raise questions and lead to further inspection and examination for any sign of cavitation.
- A weed slinger propeller on an estuary cruiser should raise questions as to why. There might be a very good reason or it might simply be because that it was what was hanging around at the time a propeller was needed.
- A weed slinger propeller on a narrowboat should also raise questions because of the amount of time narrowboats spend in reverse and also because of the amount of weed, crud and general rubbish found in the water of the canals.
- No cruiser or narrowboat should ever have a two bladed propeller fitted because it will cost the owner fuel and engine life due to its low efficiency and the higher engine revolutions necessary.
- A two blade propeller on a fin keeled yacht with a P or A bracket should also raise questions because it will not be close enough to the keel to be shielded from water flow and so may be the cause of vibration.

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### **Controllable Pitch Propellers**

The use of the word variable when describing a controllable pitch unit, although common, is sloppy English, inaccurate and technically incorrect. Controllable pitch propellers are almost

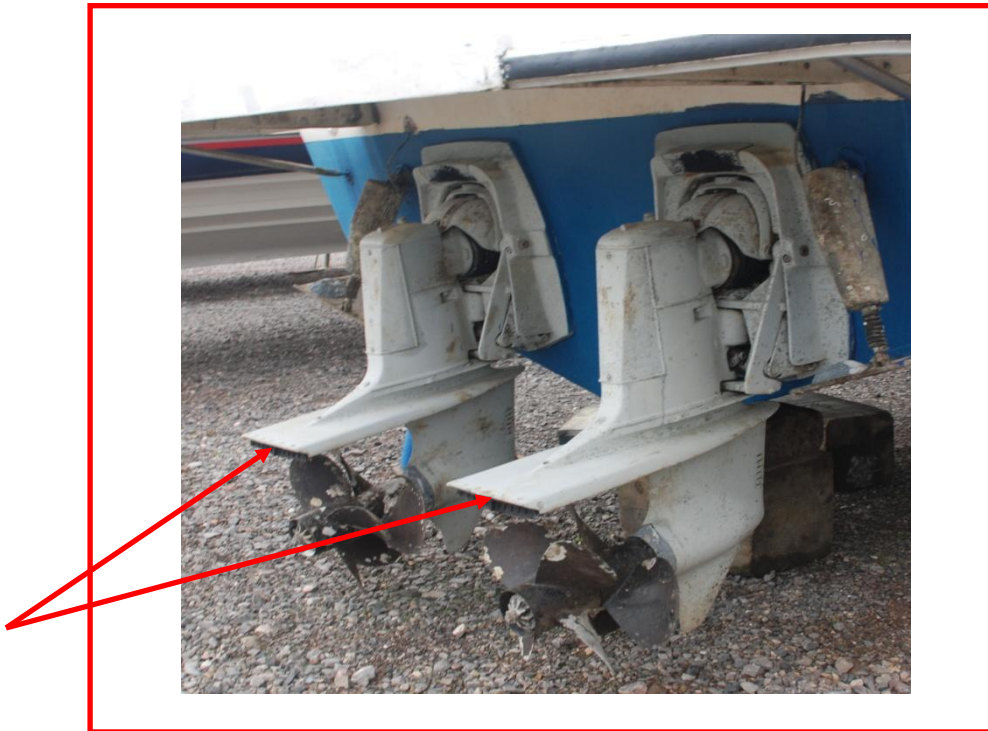


invariably left handed because making them left handed gives an opposite to usual propeller bias. With a normal solid right handed propeller when going ahead, because of the effect of the so-called propeller bias (also, in America, called the p or paddle wheel effect or propeller walk), the stern tends to turn to starboard with the reverse effect when going astern. This bias is not of much importance when running ahead but a controllable pitch propeller does not simply rotate in the opposite direction but, while maintaining the same direction of rotation, alters the angle of twist of the blades. When running astern and the blades are twisted about their rotational axis, the propeller becomes, in effect, right handed and this means that with a left handed controllable pitch propeller, when going astern, the stern slowly turns in the direction that the master or pilot expects. With a controllable pitch propeller the main gain is flexibility and the unit is an optimum compromise between two fixed pitch propellers. Controllable pitch or reversing propellers are usually operated by means of a lever controlled shaft down the centre of the main propeller shaft and all have mechanisms of varying complexity and so must be more likely to give trouble.

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### **Contra-Rotating Propellers**

Some modern yachts, particularly those with Volvo engines, will be found fitted with contra-rotating propellers usually called by the registered trade name of Duoprop with two propellers on the same shaft one mounted closely behind the other and rotating in opposite directions. Contra-rotating propellers enable the aftermost propeller to pick up the waste energy from the wake of the forward unit and increase the overall efficiency of the system. This is fine for large deep water vessels such as bulk carriers and tankers where the fuel consumption is measured in a respectable number of tons per day but on a small yacht which operates perhaps only twenty or so days a year the fuel saving is marginal and is greatly offset by the relatively high cost of the contra-rotating propeller. Surprisingly, despite the increase in efficiency but because of the high initial and maintenance costs, these units are rarely seen on big commercial ships but they are often found on Royal Navy and other military submarines. The individual units of Duoprop or other types of contra-rotating propellers will have different diameters and the aftermost propeller is always smaller in diameter than the forward unit. To gain their best advantage they need to be of somewhat coarse pitch.



**Photograph 3 A Twin Set of Contra-Rotating Propellers**

Note the anticavitation shield doubling as a cooling water discharge over the propellers.

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#### **Surveying tips 8 & 9**

- The marine surveyor should check the rotation by turning the aftermost propeller by hand and watching that the forward propeller does, indeed, rotate in the opposite direction.
- In turning the propeller a check should also be made to see that it does not turn relative to the shaft. By doing this one is checking, as far as is possible without dismounting the unit, the quality of the cone faying surface and the solidity of the key.

#### **Surface Piercing Propellers**

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Surface piercing propellers are considered to be a good option for high speeds. They are alleged to eliminate most of the drag of struts and shafts and generally provide for reduced draught.



**Photograph 4 Pantograph Arrangement on a Surface Piercing Propeller**

That that is largely an illusion can be appreciated by examining the pantograph arrangement in the slide; an arrangement which also entails considerable drag and exposure to debris. They come in two types: one extending beyond the transom and the other built into tunnels. The latter is for vessels that cannot tolerate the exposed equipment aft, such as sports fishing boats. Since they are partly exposed to air, they do not form a ventilation bubble on the back on the blade but an air bubble instead (ventilation) is dragged down from the surface and, because the air bubble does not collapse like the vapour filled cavitation bubble, surface piercing propellers are alleged not to suffer cavitation damage. They are classified by naval architects as supercavitating propeller. Unfortunately, the hydrodynamic efficiency of a ventilated propeller is considerably lower than one fully immersed (non cavitating) so, for a given diameter, they are less efficient but, in some installations, a much larger diameter can be used thus reducing the unit thrust load and getting a slightly higher ideal efficiency. The

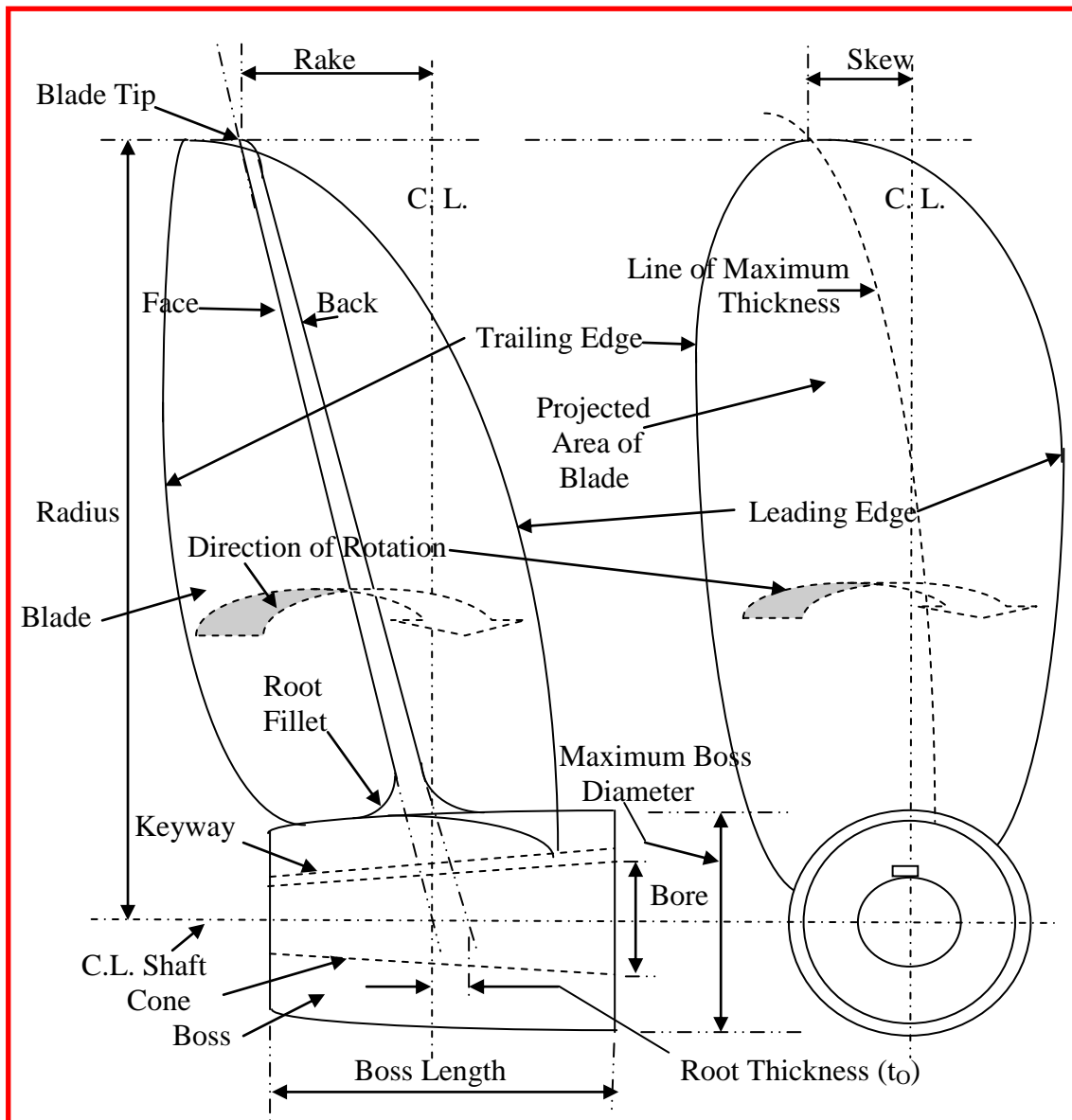
lower overall hydrodynamic efficiency is clearly demonstrated when the vessel is on a fast run by the large rooster tail of wake water at the transom. It is also important for the marine surveyor to note that a large propeller, intended to be operating at high speed while partly immersed will absorb a lot of torque at low speed when fully immersed, so careful matching is important and big gear ratios are necessary to avoid problems of getting the boat out of its hole shot up onto the plane. The gearing arrangements both inside the hull and in the outboard pantograph of twin screw units are both complex, costly in both initial capital and maintenance and open to expensive damage.

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#### **Propeller Dimensions**

In order to report his findings accurately, the marine surveyor needs to know the names and descriptions of the principal dimensions of a marine propeller. These are set out diagrammatically in Figure 2 below and are more accurately defined in the list of Propeller Terms attached to the end of this paper.

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**Figure 2 Outline of (a right handed) Propeller Dimensions**

**Propeller Ratios**

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The marine surveyor should know them and be able to define following propeller dimensions and ratios: -

Diameter, Mean Pitch, Pitch Ratio, Developed Area. Disc Area Ratio, Boss Diameter Ratio, Thickness Ratio. There are others but they are only used by propeller specialists.

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## **Propeller Materials**

Propellers are sand cast from a number of possible materials: -

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**Aluminium Alloy:** Aluminium alloy propellers are a popular and affordable option for small to medium sized boats with outboard motors. Soft and forgiving, aluminium alloy absorbs impact energy to help protect the drive components, making them a good choice for areas where propeller damage is common due to grounding or floating debris. Under load, aluminium alloy propellers actually bend when rotating thereby reducing the overall pitch size by up to one inch and limiting the maximum available pitch size to 23".

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**Aluminium Bronze:** This is a class of copper aluminium alloy containing from 5 to 11% aluminium usually used where it is necessary to increase the oxidation resistance of the metal. The metal has a tensile strength up to 58 kN/cm<sup>2</sup> and is frequently used for casting high class propellers sometimes with an admixture of nickel. Other alloying agents such as iron, manganese and silicon are also sometimes added to aluminium bronzes. When the alloy is nickel the metal is sometimes called nickel bronze. Aluminium bronzes are most valued for their higher strength and corrosion resistance as compared to other bronze alloys. They are resistant to corrosion in sea water and the metal's resistance to corrosion rests in the aluminium component of the alloys, which reacts with atmospheric oxygen to form a thin, tough surface layer of aluminium oxide which acts as a barrier to corrosion of the copper rich alloy. Another notable property of aluminium bronzes are their biostatic effects. The copper component of the alloy prevents colonization by marine organisms including algae, lichens, barnacles and mussels and therefore can be preferable to stainless steel or other non cupric alloys in applications where such colonization would be unwanted. Aluminium bronze tends to have a golden colour and is most commonly used in applications where their resistance to corrosion makes them preferable to other engineering materials. The metal tends to suffer from pitting due to the iron leaching out of the casting and semi circular grain boundary faults may also be found. Aluminium bronze can be welded using the MIG welding technique with an aluminium bronze core and pure argon gas as a shield.

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**Bronze:** Bronze is the generic name given to a large class of copper-zinc-tin alloys and the approximate limiting proportions of these are copper 70-90%, zinc 1-25% and tin 1-18% and is the material most commonly used for most modern applications. Bronze propellers are available in a wide variety of size and pitch combinations and provide excellent corrosion, salt water and fatigue resistance making the material popular for the larger open water vessels as well. Disadvantages include initial expense, damage if collision with an obstacle does occur and difficulty of repair. Propellers are usually cast from a bronze with an admixture of manganese, phosphorus, silicon or aluminium as an alloying material. Bronzes and other alloys of copper, with the exception of Monel metal, are broadly referred to as red metal whereas the brasses are referred to as yellow metal. When in contact with a ferrous metal or aluminium in seawater any of these metals will readily corrode leaving a rough green surface and they may lose their zinc content if it exceeds 16% by a leeching process called dezincification. The most common example of selective leaching is the loss of zinc from brass or bronze alloys in presence of oxygen and moisture. It is believed that both the copper and the zinc gradually dissolved out simultaneously but the copper precipitates back from the solution. The material remaining is a copper rich sponge with poor mechanical properties with its colour changed from yellow to a pinky red. Dezincification can be caused by water containing sulphur, carbon dioxide and/or oxygen. Stagnant or low velocity waters also tend to promote dezincification.

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**Manganese Bronze:** This is a form of yellow brass with a typical composition of copper 57%, zinc 41.5%, manganese 0.25%, aluminium 0.25% and iron 1%. It has a tensile strength of about 46 kN/cm<sup>2</sup> and is as strong as mild steel but considerably tougher and more resistant to corrosion.

**Nial Bronze:** Known in America as Nibral this is an alloy that combines bronze, aluminium and nickel for superior strength, durability and corrosion resistance and combines the effectiveness of bronze and aluminium with the strength of nickel. It is a common choice for large merchant ships, warships and stern drive boats wanting to upgrade from aluminium propellers. This has a silvery yellow colour.

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**Phosphor Bronze:** This is a copper/tin metal containing up to about 0.1% phosphorus. It is a hard, fine grained, red metal having great toughness and high tensile strength. Low tin bronzes contain from about 3.5 to 5% tin while high tin bronzes contain 4.5 to 7% tin. For special purposes bronzes up to 9% tin are available. This has a yellow colour with a red tinge.

**Silicon Bronze:** This is used as a high strength casting metal and is mainly a copper silicon alloy containing small amounts of manganese, zinc and iron. Typical compositions are copper 95%, silicon 4%, manganese 1% or copper 88%, silicon 5%, iron 5% and zinc 2%. These alloys have tensile strengths in the region of 38 kN/cm<sup>2</sup>. The metal is sometimes used for high class marine propellers and for the propellers of submarines.

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**Cast Iron:** Cast iron will rapidly form a rusted surface which does not readily flake off and which also provides corrosion protection to the underlying metal. The rust is brown coloured but will turn black when submerged in seawater. The best cast irons have a nickel or silicon content. Graphitic corrosion is selective leaching of iron from grey cast iron, where iron gets removed and graphite grains remain intact. Affected surfaces develop a layer of graphite, rust and metallurgical impurities that may inhibit further leaching. The effect can be substantially reduced by alloying the cast iron with nickel. Cast iron propellers are often found on Continental barges, tugs and similar working craft.

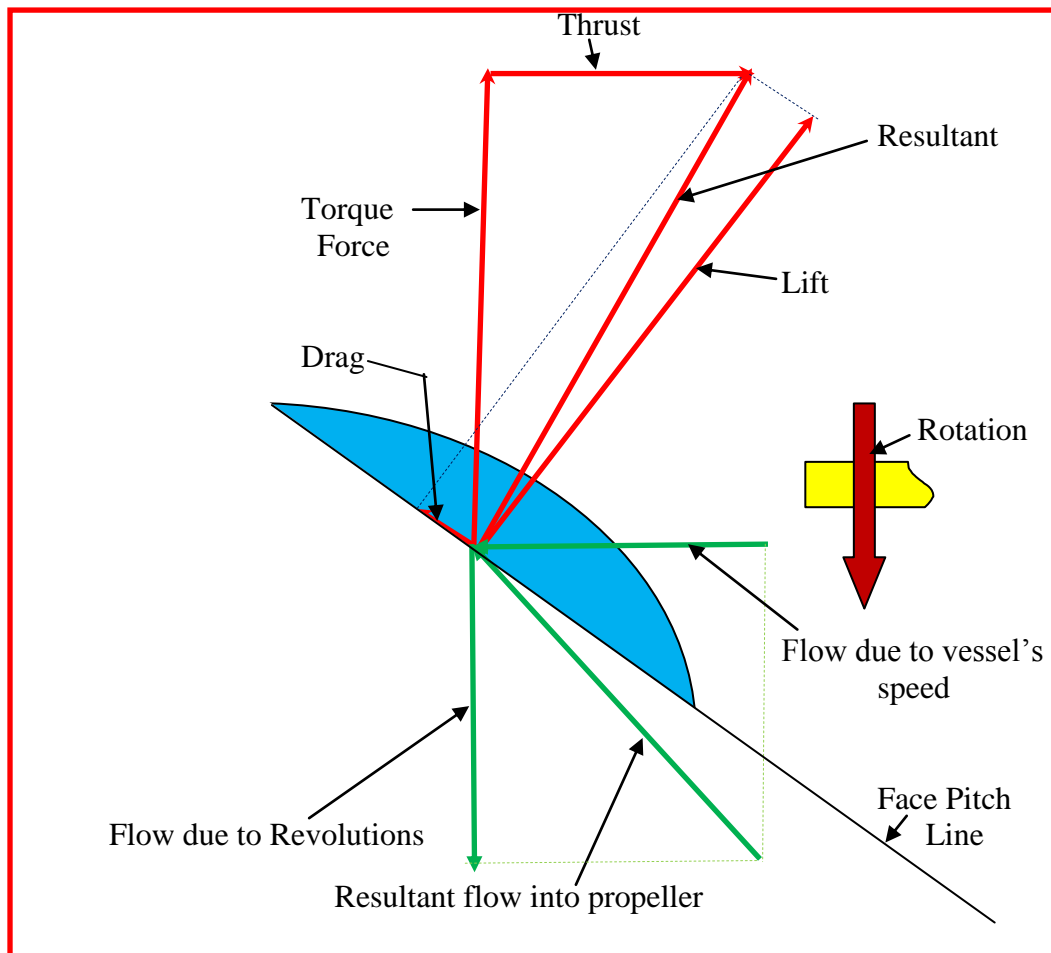
**Stainless Steel:** This material in each of the austenitic, ferritic and martensitic forms is subject to severe pitting and crevice corrosion and those with low chromium or nickel or high carbon content are the most susceptible in this regard. Either AISI 316 or 318 austenitic stainless steels that contain 3% molybdenum are the best for use in a marine environment. These materials are often used for propeller shafts but the marine surveyor should not be lulled into a false sense of security by the use of this metal. Modern propellers often use Duplex H51 stainless steel which is magnetic but much stiffer and stronger than the AS materials. Because stainless steel propellers do not flex under power, they are also available



in larger pitch sizes. The metal is commonly found on American built boats and on boats fitted with controllable pitch or contra rotating propellers.

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**Propeller Action**



**Figure 3 Water Flow Components into and Force Components on a Blade Section**

It is not necessary to go deeply into the highly mathematical theories of propeller action but the marine surveyor should, as part of his general background knowledge, have a simple understanding of how a propeller works. In Figure 3 above is shown a section through a propeller blade. It is the simplest type of section called a circular back section. Shown in green are the two basic lines of flow: that due to the advance of the propeller through the water and that due to the propeller rotating. These can be resolved into a single line of water flow which will be found to be at an angle different to that of the face pitch line. The

angle between the face pitch line and the water flow resultant is called the angle of incidence. The resultant line of flow is split into two sections: One running along the face pitch line and the other along the back of the propeller. The line of flow running round the back of the propeller flows faster than that running along the the face pitch line resulting in a difference of pressure between the two propeller blade surfaces. The law that explains this is called Bernoulli's law affter the man who first investigated it and gave its mathematical background. It is the same law that explains how a heavier than air aeroplane can fly.

The change in pressure and the friction of the water on the propeller blade results in two forces acting on the blade section: a positive force called the lift and a negative force called the drag. The resultant of these two forces can be resolved into two further forces called the thrust and the torque force. The torque force multiplied by its distance from the propeller shaft centreline is the torque or twisting moment that is supplied by the engine and the thrust is what pushes the boat through the water.

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### **Propeller Design**

Since this Lecture is only an introduction to the art of propeller design and by far the majority of propellers on small craft are of the solid or fixed pitch type, it is intended to concentrate on that type. The methods used for the design of other types is basically the same and varies only in details and in the design charts or computer programmes used.

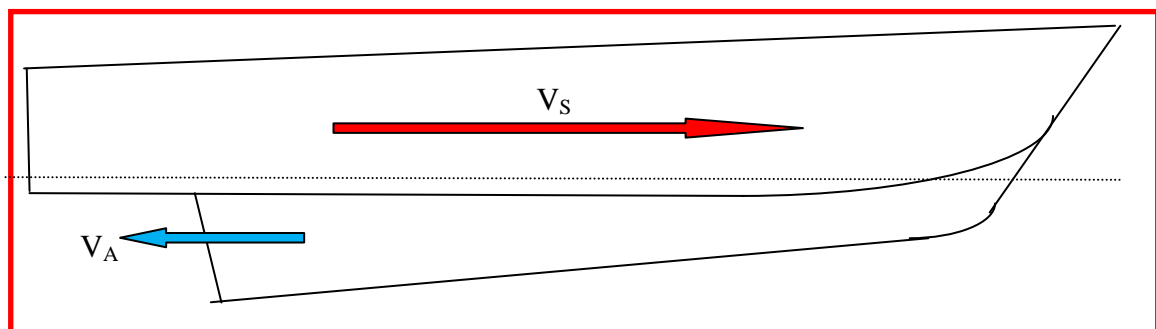
The basic data needed to design a propeller are: -

1. The speed of advance of the propeller through the water.
2. The power to be absorbed.
3. The propeller revolutions per minute.

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## Wake and the Speed of Advance

As the boat moves through or across the water it achieves a given speed which is usually symbolised as  $V_S$ . For various hydrodynamic reasons, skin friction, wave making, eddy making *etc* the water, as it passes the propeller is substantially less than that and the water passing by the propeller is said to be at the speed of advance symbolised by  $V_A$ . See Figure 1 below. The difference between the two is called the wake and is, generally, a function of the vessel's hull fullness or block coefficient.



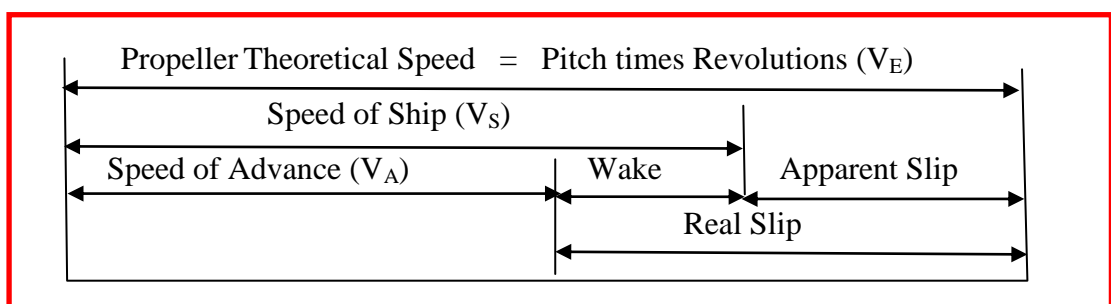
**Figure 4 Illustration of Wake**

The propeller design charts are based on the speed of advance and, therefore, it is necessary to estimate the value of the wake fraction so that the correct speed can be calculated.

$V_S$	=	vessel's speed	knots
$V_A$	=	speed of advance	knots

Both speeds can, of course be given in feet per second or metres per second as long as the units used are consistent. The relationship between the two speeds and the wake is shown graphically in Figure 5 below.

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**Figure 5 Wake Fraction Bases**

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### Slip

Before considering the wake we need to consider this term. The theoretical speed that a propeller can achieve is the product of its mean pitch times the revolutions per unit time ( $V_E$ ). For various reasons which we need not go into, the vessel does not achieve that theoretical speed and the difference between the theoretical and actual speed is called the apparent slip. When compared to the speed of advance of propeller's inflow it is called the real slip. Older methods of propeller design were based on slip theory but they have long been abandoned and the term is now really only of historical interest. Nevertheless the marine surveyor should know of it and understand it as it will often be found mentioned in older books on yacht propeller design.

### The Wake Fraction

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There are two methods of calculating the wake fraction, one due to Froude ( $w_F$ ) based on the speed of advance and the other due to Taylor ( $w_T$ ) based on the ship's speed, the latter being the more logical from the propeller designer's point of view. These are given mathematically in the formulae below.

	<b>Froude</b>		<b>Taylor</b>	
	$w_F$	$= \frac{V_S - V_A}{V_A}$	$w_T$	$= \frac{V_S - V_A}{V_S} \quad (1)$
hence				
	$V_A$	$= \frac{V_S}{1 + w_F}$	$V_A$	$= V_S(1 - w_T) \quad (2)$

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- For most small craft it is accurate enough to take the Taylor wake fraction to be a linear function of the boat's block coefficient. Thus for a single screw boat.
- $w_T = 0.5C_b - 0.05$
- For a twin screw boat the wake values are somewhat smaller i.e. multiply the above formula by 0.60.

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#### **Units to be Used**

There are a number of different types of design charts available to the naval architect using various formulae for the ordinates and abscissa (the x and y axes) most of which are non dimensional, but the most commonly used one for small craft propeller design is the so-called  $B_P - \delta$  chart which plots curves of  $\delta$  (diameter function) and  $\eta_o$  (open water efficiency) values on a chart showing pitch ratio as the ordinate or x axis against various values of  $B_P$  or power coefficient on the abscissa or y axis. These charts are available for propellers ranging from 2 to 7 blades and disc area ratios from 0.3 to 1.40. These terms will be explained later and a large number of propeller terms are also defined in the attached glossary.

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#### **The Power to be Absorbed**

Since we are using the  $B_P - \delta$  method of design in this Lecture the power has to be in units of horse power not kW. Allowance has also to be made for the presence of a gear box and friction losses in the stern tube and propeller bracket bearings and the following are the usual allowances made: -

**Table 1**

<b>Item</b>	<b>Power Loss %</b>
Rev/Red Gearbox	5
Stern Tube	2
Shaft Bracket	2

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The definitions of power used in propeller design are: -

*Indicated Power (IHP)* The power developed in the engine's cylinders and usually confined to steam engines

*Brake Power ( $P_B$ )* The power measured at the engine output coupling and *before* the gearbox.

*Shaft Power ( $P_S$ )* The power measured at the gearbox output coupling or at the forward end of the stern tube gland.

*Delivered Power ( $P_D$ )* The power measured at the outer end of the stern tube.

*Effective Thrust ( $P_{ET}$ )* The power delivered by the propeller thrust.  
*Power*

It is the last of these that pushes the boat through the water and is a function of the propeller design.

In order to design the propeller, the naval architect needs to know the value of the delivered power and this is calculated from: -

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$$P_D = P_B \times \text{Transmission efficiency } (\eta_T) \quad (\text{hp}) \quad (3)$$

*i.e.*

$$P_D = P_B \times (100 - \text{Power Loss Percent})/100 \quad (\text{hp}) \quad (4)$$

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#### **The Propeller Revolutions per Minute**

This is the value of the revolutions of the propeller shaft *i.e.* the engine revolutions divided by the gearbox reduction ratio.

$$N_P = N_E / \text{gbr} \quad (1/N) \quad (5)$$

### **SLIDE 36**

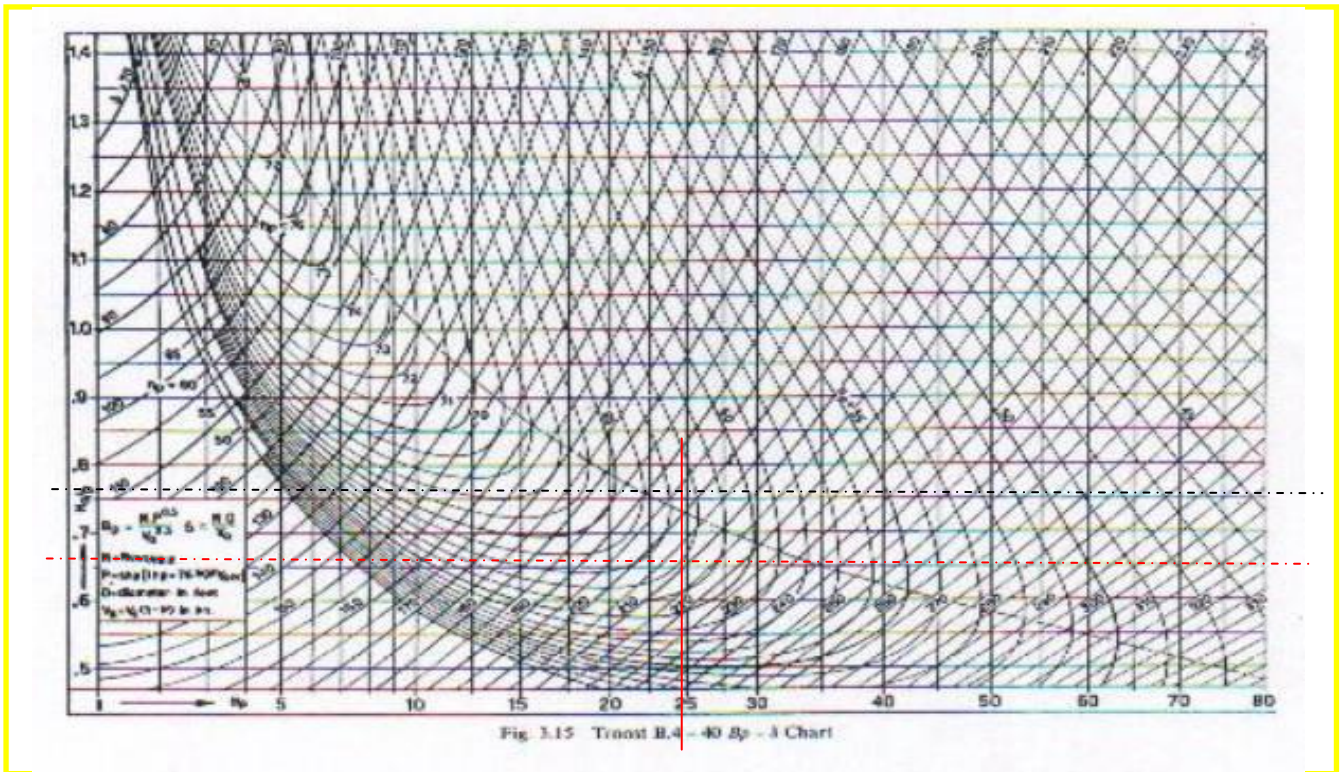
#### **Calculation of the Power Coefficient ( $B_P$ ) and Numerical Example**

This coefficient was introduced by the American Admiral David W. Taylor and is given by: -

$$B_P = \frac{N_P \times P_D^{1/2}}{V_A^{2.5}} \quad (-) \quad (6)$$

The reader is now referred to the chart for a B 4.40 propeller below.

### **SLIDE 37**



Along the ordinate (x) axis will be seen the mean pitch ration while along the abscissa (y) axis the scale of the power coefficient  $B_p$ . The curved lines running from top right to bottom left are values of the diameter coefficient ( $\delta$ ) and the loops hanging from the top left hand corners are curves of open water efficiency ( $\eta_o$ ). The long, curved, dotted line running from top left to bottom right is the line showing the curve of *maximum* efficiency.

The designation B4.40 means that the propeller whose performance is given in the chart is of the Troost (or Wageningen) B type with four blades and a disc area ratio of 40%.

To illustrate the chart's use a numerical example must be given.

### **SLIDE 38**

We assume the following data: -

### **SLIDE 39**



Ship's speed	10	knots
$P_B$	100	bhp
gbr	2:1	-
Engine RPM	1200	1/m
Taylor wake fraction	0.10	-
Overall transmission efficiency	0.93	-

**Calculate  $P_D$**

$$P_D = 100 \times 0.93 = 93 \text{ hp}$$

**Calculate shaft rpm**

$$N_S = 1200/2 = 600 \text{ 1/m}$$

**Calculate speed of advance**

$$V_A = 10(1 - 0.1) = 9 \text{ knots}$$

$$V_A^{2.5} = 9^{2.5} = 243 \text{ knots}^{2.5}$$

**Calculate  $B_P$**

$$B_P = \frac{N_P \times P_D^{1/2}}{V_A^{2.5}} = \frac{600 \times 93^{1/2}}{243} = 23.81$$

**SLIDE 40**

Plotting that value on the chart above and lifting off the information where it crosses the line of maximum efficiency we get the following values: -

$\delta$	=	195
P/D	=	0.79
$\eta_o$	=	0.435

## SLIDE 41

### **However**

If the efficiency values for a given mean pitch ratio ( $P_M/D_P$ ) are plotted out horizontally, it will be found that the point chosen will sit nearly at the top of the graph. That means that, if the conditions alter slightly, the propeller can move over the top of the curve and the efficiency would then be found to plunge sharply. Such a situation is undesirable and, to avoid it, good designers reduce the  $\delta$  value lifted from the chart by about 5%. Clearly this will alter the other values also so that the final figures would then be: -

$\delta$	=	185.25
$P_M/D_P$	=	0.84
$\eta_o$	=	0.432

A rule of thumb method of doing the same thing is to reduce the diameter by, say, 5% and to increase the pitch by the same amount so that the value of the diameter in inches or mm plus the pitch in inches or mm stays constant.

## SLIDE 42

Now  $\delta$  is defined as propeller revolutions per minute ( $N_P$ ) [or shaft revolutions ( $N_S$ )] times the diameter in feet ( $D_P$ ) divided by the speed of advance in knots ( $V_A$ ). So that: -

$$D_P = \delta \cdot V_A / N_P \quad \text{feet} \quad (7)$$

*i.e.*

$$D_P = 185.25 \times 9 / 600 = 2.78 \quad \text{feet}$$

$$\rightarrow \underline{\underline{33.35}} \quad \text{inches}$$

and the mean pitch

$$P_M = 0.84 \times 33.35 = \underline{\underline{28.01}} \quad \text{inches}$$

### SLIDE 43

### SLIDE 44

### Cavitation

As the propeller works it absorbs the torque developed by the engine at given revolutions *i.e.*, the delivered horsepower - and converts that to the thrust which pushes the boat through the water. The ratio of the absorbed power or the thrust to the total blade area of the propeller are called, respectively, the power and the thrust loading. If either of these exceeds a certain value which depends upon a complex relationship between the propeller type, the flow in which it works and its mean depth below the water relative to its diameter then the flow pattern of the water over the propeller blades breaks down causing a severe loss of thrust and, eventually, physical damage to the surface of the propeller blades. The flow breakdown is called cavitation and is similar to the water hammer often heard in old plumbing systems. On trials, it sounds like gravel being thrown against the stern of the vessel. It is a highly complex phenomenon and the pitting damage it causes usually appears on the back of the blade following a clear radial pattern. It can also appear as similar damage on the driving face of the propeller in which case, almost certainly, a further factor has entered the problem in the form of an incorrect pitch distribution along the length of the blade. Most small craft propellers are usually of constant pitch over the blade length and this regime is accurate enough for 99% of boats but on high speed boats with large propeller loading factors the

pitch should vary over the length of the blade *i.e.*, the boat should be fitted with a *varying* pitch propeller. The effects of cavitation including loss of speed and damage to the propeller blades can be minimised by ensuring that the propeller has sufficient blade area relative to the area of the circle described by the propeller blade tips. There are different patterns of cavitation that can occur on a marine propeller and these are usually grouped as: -

### **SLIDE 45**

- face cavitation.
- sheet cavitation.
- bubble cavitation.
- tip vortex cavitation.
- hub vortex cavitation

Face cavitation occurs on the driving face of the propeller and is often due to an incorrect pitch distribution along the length of the blade resulting in the tip pitch being too small. Sheet cavitation occurs when large suction pressures build up near the leading edge of the blade resulting in the back of the blade being covered with a sheet of bubbles. The greatest pressure reductions occur on the back of the blade and this is where most sheet and bubble cavitation takes place and high tip speeds increase the possibility of such cavitation. Tip vortex cavitation is due to low pressure within the vortices shed at the blade tips. Boss or hub vortex cavitation is usually due to a high angle of incidence between the direction of flow of the water and the blade leading edge in way. A propeller is said to be fully cavitating when the whole of the back is covered in sheet cavitation. This phenomenon is also called super cavitation. According to Bernoulli's law the passage of a hydrofoil (propeller blade section) through the water causes a positive pressure on the face of the blade and a negative pressure on its back. It is the resolution of the pressures that results in the torque requirement and the thrust development of the propeller. The negative pressure causes any gas in solution in the water to evolve into bubbles similar to those found when opening a bottle of lemonade or champagne. These bubbles collapse and can cause hammer like

impact loads on the blades in excess of 7 kg/cm<sup>2</sup> (100 lb/in<sup>2</sup>). It is the collapse of those bubbles that results in the observed damage to the propeller blade surfaces. Cavitation can also be caused by the placement of any object that would obstruct or cause turbulence to the clear unobstructed water flow to the propellers which includes items that protrude below the bottom of the hull such as strainers, skin fittings and transducers. It is important that such items should not be placed in the line of the water flow to the propellers. Air drawing or ventilation is a different but related phenomenon and occurs when the propeller tips are too near the water surface and the screw sucks down air from that water surface.

In order to avoid cavitation, irrespective of the number of blades (Z), the minimum blade or disc area ratio (dar), using metric units, the disc area ratio may be estimated from the empirical formula: -

**SLIDE 46**

	dar	=	$[1.245(P_D/A_P)^{2/3}/T_S^{0.72}] \times 10^3$	-	(8)
where					
	dar	=	disc area ratio	-	
	P <sub>D</sub>	=	delivered power	kW	
	A <sub>P</sub>	=	propeller disc area	cm <sup>2</sup>	
	T <sub>S</sub>	=	propeller tip speed	cm/s	

**SLIDE 47**

The disc area of the propeller in the numerical example above is: -

$$(33.35 \times 2.54)^2 \times \pi/4 = 5635.71 \text{ cm}^2$$

and the power loading on the propeller: -

$$(93 \times 0.746) / 5635.71 = 0.0123 \text{ kW/cm}^2$$

and that loading raised to the  $2/3$  power

$$0.0123^{2/3} = 0.0533 \text{ -}$$

The tip speed of the propeller is: -

$$\pi \times 33.35 \times 2.54 \times 60 / 600 = 631.46 \text{ cm/s}$$

and that speed raised to the 0.72 power

$$631.46^{0.72} = 134.36 \text{ -}$$

The disc area ratio should then be: -

$$[(1.245 \times 0.0533) / 134.36] \times 10^3 = \underline{\underline{0.494}} \text{ -}$$

Strictly, a correction should be made to the pitch ratio for the increase in area but it is usually so small that it can be ignored.

A full discussion of propeller design - which is a very interesting subject in its own right - is outside the scope of this paper. Nevertheless, the marine surveyor may also find the following approximations useful. The propeller diameter suitable for a given power installation may be estimated from one of the formulae: -

	$D_P$	$=$	$kP_B^{1/2}$	mm	(9)
or					
	$D_P$	$=$	$(11,300/N_S^{1/2})P_B^{1/4}$	mm	(10)
where					
	$D_P$	$=$	propeller diameter	mm	
	$P_B$	$=$	brake power of main engine	bhp	
	$N_S$	$=$	shaft revolutions	1/m	
	$k$	$=$	constant	-	

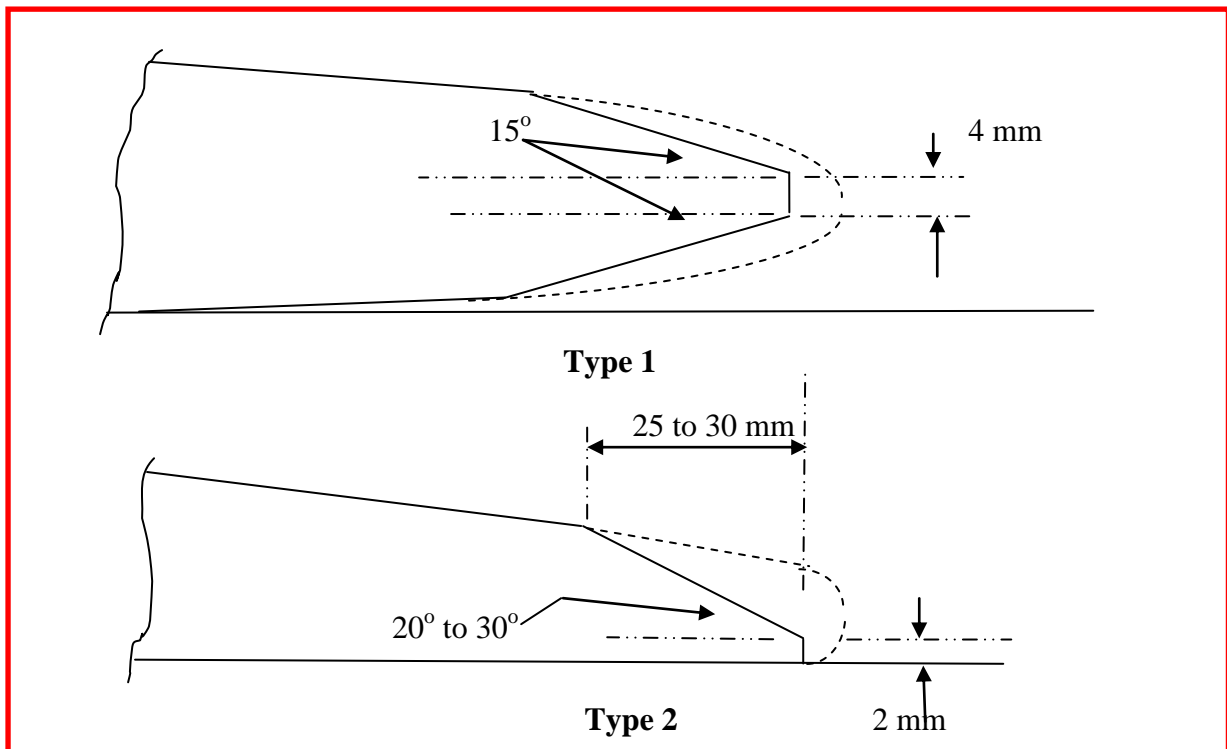
From such limited information as is available  $k$  is approximately 70. It is recommended that, where possible, the marine surveyor calculate the value of  $k$  for his own records.

**SLIDE 48**

**Propeller Singing**

Eddy shedding off the trailing edge of the blades is related to cavitation and can, under certain circumstances, cause the blades to flutter at a resonant frequency resulting in the propeller producing either a single clear note typically a clear harmonic tone much like a humming or ringing wine glass or a low grumbling sound. Either sound is very audible and a cause of annoyance although not otherwise harmful. The phenomenon is called propeller singing and appears to be affected by critical factors for which current explanatory theories make no allowance. For example, a twin screw vessel may have one propeller that sings and another that does not and the noise may be eliminated just by simply altering the position of the propellers or a singing propeller may be replaced by an identical unit which is found to be silent. Experience shows that the lower the number of blades on a propeller the less the chances are of singing.

**SLIDE 49**



**Figure 6 Detail of an Anti-Singing Edge**

The singing is a result of propeller diameter, revolutions, boat speed, trailing edge thickness and shape or roundness. While, in most of the cases, the diameter, revolutions and boat speed have to remain the same, it is possible to modify the propeller blade trailing edge geometry. This is the usual strategy for all efforts to eliminate singing and it is achieved by grinding the *trailing* edge to a sharp V shape typically on the suction side. See Figure 6 above where Type 2 is to be preferred. The shape avoids the creation of curving flow eddies by cleanly separating the water flow off the blade. However, the adoption of unduly thin edges can result in erosion or fracture of the blade near the edges and the author recommends a minimum of 2 mm. An anti-singing edge should be considered as a last resort to minimize the singing of an existing propeller although, in most modern propellers, the anti-singing edge is usually, these days, designed in *ab initio*. There is also some evidence that trailing edge blade cup can be an effective anti-singing technique. Cupping, however, changes the thrust and power characteristics of the propeller whereas an anti-singing edge does not measurably alter the propeller's performance. Many sources recommend that the anti-singing edge be applied from the 40% radius fully to the blade tip or even slightly beyond depending on the tip shape. The same effect can also be caused by the leading edge of the blade but that is rare.

The B-Series charts give the open water characteristics of conventional fixed pitch propellers with various numbers of blades and blade area ratios for different pitch ratios. Today many ships are equipped with controllable pitch propellers (CPPs) and use is also made of ducted



CPPs. The thrust-torque performance of these units is not only of importance for ship designers but also for accurate analysis of speed trial results. Due to lack of this systematic information for CPPs in such cases, it is current practice to use the B-series data. The hydrodynamic characteristics of CPPs, however, differ substantially from those of fixed pitch propellers and for that reason the Wageningen propeller C- and D- series was started for CPPs and ducted CPPs respectively. In addition to the propeller thrust and torque, the hydrodynamic characteristics of the blade spindle torque will also be measured. The series will provide open water characteristics in two complete quadrants for modern CPP designs, including measurement of the blade spindle torque and both open and ducted CPPs will be considered. At this stage it is expected that the following series C4-40, C4-55, C4-70, C5-75, D4-40, D4-55, D4-70 will be tested in both 19A and 37 ducts and the tests will cover the complete range of pitch settings as well as both flow directions so that the two complete quadrants can be derived. The ducted series will be of personal interest to the author as he was the designer of the original Kort nozzle from which the 19A model was derived.

### **The Survey of Propellers**

With the smaller outboard and stern drive units, the first step is for the marine surveyor to examine the propeller close up and if there are any obvious signs of damage *i.e.* big dents, severe bends, missing pieces or even missing blades, then the propeller definitely needs repairing. He should then run his fingers around the propeller blades taking particular attention to the leading edge. The blade should be smooth and if any damage in the form of burrs, pieces missing or bends however minimal can be felt it will signify that the propeller has at some stage come into contact with a submerged object. Many marine surveyors think that a small amount of damage is acceptable but that is not so as damage to the blades will affect the propeller's performance in two ways.

1. any damage will affect the propeller's dynamic balance.
2. any damage will also affect the hydrodynamic performance of the propeller.

The marine surveyor must remember that the blades are, in effect, small wings spinning at very high speed in fact anything up to three or four thousand RPM and at such speeds the water flowing over them is travelling extremely fast and, therefore, even slight damage will have a very significant effect on the water flow and reduce the overall efficiency.

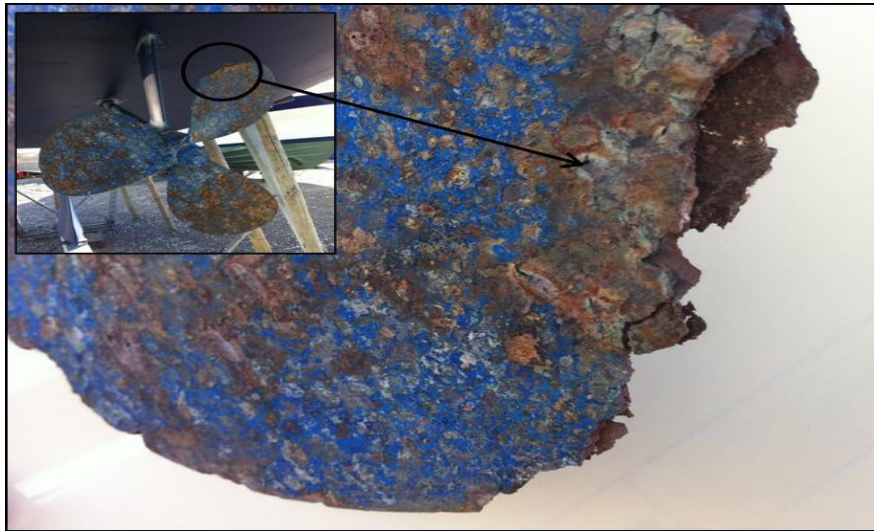
If there is any damage, the next step is to remove the propeller from the shaft and arrange for it to be sent together with the tail end shaft to a specialist workshop where the following process would be carried out. There, the propeller and shaft will be serial numbered to ensure that it is returned to their rightful owner. On arrival the workshop engineers would perform a visual inspection of the damage to the blades. Next the blades would be straightened by using the appropriate pitching block. If the propeller has any pieces missing or the edges are rough then it would be welded to bring the blades up to the correct profile. Special care will be taken to ensure there is no heat transference to the rubber bush or any plastic/composite parts and the propeller would be shaped into profile by grinding while keeping continuity between each blade. The minimal amount of material would be removed to ensure strength and to prolong the life of the propeller. The propeller would then be checked for pitch and any adjustments will be made after which it would be dynamically balanced to give smooth power and economy from the engine and to ensure that it runs vibration free. The propeller would then be finished: aluminium alloy propellers are usually painted and stainless steel and bronze ones satin finished.

If no signs of damage are noted, the author would still commend that the propeller be removed. Any growth on the propeller should be removed. If the propeller is of aluminium alloy, check the paint finish and, if necessary, apply a new coat making sure that the paint is suitable for the propeller material. If the propeller is stainless steel, it may have an amount of calcium build up on the blades which can be removed by using a scouring pad or a descaler. If a descaler is used, it should be ensured that it does not come into contact with any of the rubber or plastic parts of the propeller. Once cleaned, refit the propeller. It is recommended that the propeller should be removed from the shaft once a year and the shaft cone cleaned and greased before the propeller is refitted to ensure that the propeller does not become seized onto the shaft.

The marine surveyor may come across the term blue printing which is a hand process which involves thinning the blades and sharpening the leading edges. The advantage of blueprinting is that it improves the overall efficiency of the propeller although the gain is minimal. The disadvantages of this same thinning and sharpening are reduced blade strength, fatigue resistance and being more subjective to stress raisers occurring at the sharpened leading edge. A sharp leading edge is very prone to minute nicks which create stress raisers which often result in cracks that originate from the nick at the leading edge and

propagate through the blade. The same thing is true for any nicks at the trailing edge. To reduce the risk of corrosion, propellers and stern gear must never be coated with standard metal based paints.

### **SLIDE 50**



**Photograph 5 Propeller with Broken Blade and Bad Dezincification**

Photograph courtesy of Eur. Ing. Nic Fieldhouse C.Eng.

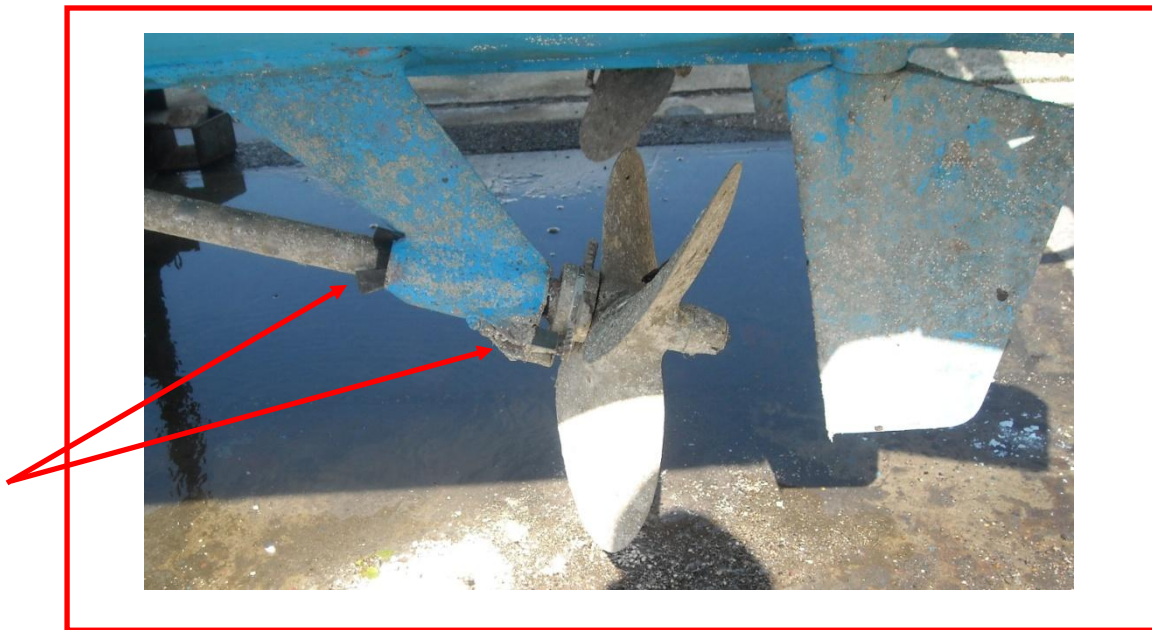
With the bigger propellers, the same basic procedure should be followed but the pressure face (the aft side face) of all blades should be closely examined for surface roughness and pitting. If found this will probably but not necessarily be due to cavitation. The leading and trailing edges of all blades and the blade tips should be examined for physical damage, chips, bent areas and general condition. If the propeller of whatever type is of bronze its colour should be noted carefully. If it appears to be unduly pinkish in colour this may be due to dezincification of the bronze due to galvanic or electrolytic action and should be reported and, if found, the anodes and their bonding to the shaft should be specially examined and sight taken of any bronze skin fittings to see if the same defect is present in those. The first sign of electrolytic action are small surface ringlets of corrosion scattered over the blades. If these are found it probably means the propeller is not properly bonded to the cathodic protection system and that corrosion is taking place while the propeller is static. It could be due to a stray current from the boat next door or from the quay. The propeller should be

removed and the shaft withdrawn and examined for crevice or pitting corrosion even if it is stainless steel.

With really bad cases of dezincification propellers have been known to pit badly and look like a sponge. The propeller blades should also be lightly hammer tested. A good sound propeller gives out a clear ringing sound - like a bell. The marine surveyor should also look for crevice corrosion of the shaft at its entry to and exit from the propeller boss and any P or V bracket bearings. If the propeller has been dismantled the marine surveyor should carefully examine the bore in the boss looking for internal cracks. He should also examine the shaft cone and look for cracks using a dye penetrant at the ends of the key way. He should also check the cone of both propeller and shaft for fretting corrosion. He should examine the key for shear effects making sure that he does not lose the key or drop it into a place from which it cannot be recovered. The propeller should be an interference fit over the key which is best secured to the shaft by means of a pair of tap screws. Loose keys are a menace. With twin screw vessels measure the diameter of both shafts – they may be different. One of the things that tend to get overlooked in the survey of the propeller is the effect of bio fouling. The marine surveyor should be aware that hard bio fouling puts the system out of balance and this, in turn, leads to wear and tear on the bearings and other components of the drive train. Propellers degrade not only through cavitation and galvanism/electrolysis but also through oxidation. Paint coatings last a few weeks at best and resin coatings constantly degrade through impact and other damage and are fairly expensive to supply and maintain.

The marine surveyor should be aware that all stainless steel and even Monel metal shafts unlike plain carbon or mild steel ones are cathodic to all the bronzes used in the manufacture of propellers and this can lead to dezincification of the bronze. All such shafts should, therefore, be fitted with shaft anodes.

## **SLIDE 51**



**Photograph 6 Typical Twin Screw Propeller and Spade Rudder**

Note the Cutless bearing being squeezed out of the P bracket and the scissor type rope cutters.

The marine surveyor should also check for a DC potential at the stern gear because that can in some circumstances do more damage than an AC one unless the latter is half or wholly rectified by a poor connection somewhere, which is not as uncommon as it sounds. However, it is unlikely that a stray current will be found when the boat is ashore as it will be necessary to be able to measure down to 0.1 mA AC and 1.0 mA DC in order to be able to find it. A dezincified propeller might, of course, have just been manufactured from a bad alloy in the first place or may have spent time in the past without the protection of an anode. If there is still a serious stray current to earth, it might be expected that the new anode will have been very active with a bright and heavily corroded surface. If there is rapid anode consumption then stray current or poor bonding should be suspected and the marine surveyor should consider recommending the owner to instruct a recognised competent marine electrician to carry out a survey to eliminate the circuits one by one. He should also be aware that, if the boat does not have a galvanic isolator, she may have become the cathodic protection for the one next to it. The USA favours bonding while isolation is preferred on this side of the big pond. If the marine surveyor is asked to carry out a corrosion survey when the boat is afloat then a marine reference cell (usually silver/silver chloride) is a necessity.

From the time that they are immersed into a marine environment, propellers are prone to attack by marine organisms such as barnacles, slime and algae, which attach themselves to the metallic surface, creating a rough surface on the propeller which a reduction in the propeller's efficiency and adversely affect its balance resulting in vibration of both the

propeller and the boat. Propellers will often be found to be so fouled and this markedly reduces their efficiency. In the case of bronze units, various people have suggested the use of a copper based antifouling epoxy paint which is fairly easy to apply as the copper is held in suspension in the epoxy. Antifouling paints, however, are either often too toxic for the marine environment or lack surface smoothness. One product currently on the market is called Propshield which is a lanolin based grease/wax product which needs an application of heat to get a good finish. These problems can be overcome by a combination of polishing the propeller to prepare it for electroplating, cleansing to remove all traces of dirt and grease, electroplating with copper to a depth of at least 0.005 inches (0.15 mm) followed by spraying with a standard 5% solution of sodium hypochlorite and sodium chloride in a suitable container to form a firmly adhering conversion coating of basic cupric chloride and then sealing the container for at least twenty four hours. The preferred procedure for polishing is to use number 60 grit size at 325 square metres per minute for roughing, followed by number 180 grit size at 500 square metres per minute for finishing using grease as a polishing aid. Electroplating with copper to the suggested minimum depth provides a smoothing effect ranging from 70 to 90 per cent. The container in which the hypochlorite spraying is carried out should be kept sealed until just before the fitting of the propeller and launching. A life expectancy of five years can be anticipated with minimal maintenance every time the vessel is slipped. In at least one case known to the author, the owner proposed to clean his bronze propeller by washing it in sulphuric acid but applying such an acid to a propeller would do the kind of damage that marine surveyors try to prevent by fitting the hull with cathodic protection. The acid leaves porous copper behind making an excellent substrate for the attachment of fouling due to the extra wetted surface area created. Copper is not too badly affected by sulphuric acid although there would be a slow deterioration forming copper sulphate but the use of nitric acid could be catastrophic. When the author was serving his time, a dirty propeller was, after scraping off any barnacles or other crustaceans, cleaned of the general biofouling by washing the propeller in vinegar and washed off afterward with copious supplies of fresh water. The method was usually fairly effective. There are a variety of products available today that have been proven effective for the antifouling protection of propellers, bow thrusters, shafts, shaft brackets, rudders, trim tabs and keel coolers. The most popular one is a product called Propspeed which works well but is a bit expensive. It is an environmentally safe product and does not contain copper, tin or any other toxic substances which may cause environmental pollution. For powerboats with

planing hulls, it usually will pay for itself with improved fuel economy due to lack of fouling. In the past couple of years some owners have been using zinc spray, which comes in an aerosol can and is applied similarly to spray paint and this, it is alleged, gives good results but the author has no firsthand experience of the product.

**SLIDE 52**



**Photograph 7 A Bent Propeller Shaft**

The 32 mm diameter shaft was of AS316 austenitic stainless steel and the propeller silicon bronze. The propeller was undamaged and showed no scores, edge damage or scars. The propeller and shaft on the other side of the boat were undamaged. There were no marks on the underside of the (frp) boat and the bronze P bracket and Cutless bearing were undamaged. The shaft was bent approximately 16°. The owner reported no underwater contacts and it was suggested that the damage was caused when the boat sat down at low tide on a rock in the mud berth where she was moored. Such a bent shaft cannot be straightened satisfactorily and had to be renewed. Note also the painted condition of the both anodes.



**Photograph 8 A Torn rubber Glove on a Surface Piecing Propeller Pantograph**

Such a tear would be difficult to find and it would be necessary to strip the whole pantograph down to renew the glove.

### **SLIDE 53**

#### **Measurement of the Propeller Dimensions on a Survey**

The marine surveyor should *measure* the radius of *all* the blades and take the average noting that they may sometimes be found to vary by as much as 5 or 6 mm. Excessive difference in blade radii can be the cause of severe vibration in the hull. Many propellers will have the diameter and the pitch stamped onto the boss either between two of the blades or on the forward face of the boss and the marine surveyor should look for these. These figures will usually be in inches and will be in the form of diameter x pitch. The marine surveyor should note that there is an ISO Standard for propeller dimensions.

In order to measure the pitch of a propeller on site the following procedure should be adopted. The propeller should be rotated so that the blades are, one at a time, horizontal. The radius of that blade is then measured and a plumb bob hung down from the top of the propeller blade at 70% of that radius from the centreline of the shaft. This is done on each of the blades in turn. The dimensions a and b are then measured as in Figure 8 below. The marine surveyor must not forget to allow for the declivity of the slipway. The procedure should be carried out for all blades and the mean of the readings taken. The pitch thus obtained should be quoted as approximate due to shipyard conditions as the only truly



accurate way to measure the pitch is on a flat bed table in a factory machine workshop using a device called a pitchometer.

### Surveying tip 10

It is usually assumed that all propeller blades are cast on the same boss circumference and at the same rake angle. That assumption is not *necessarily* valid and it is good practice for the marine surveyor to line one blade up with the rudder or the stern post and attach a wooden marker to rudder or stern post with the free end just touching the nearest point of the blade's trailing edge. If the propeller is true, as it is *slowly* rotated the trailing edges of the other blades should, each in turn, just touch the free end of the wooden marker. Any gaps or overlaps should be noted, recorded and reported as the propeller is probably out of dynamic balance and the cause of vibration.

### SLIDE 54

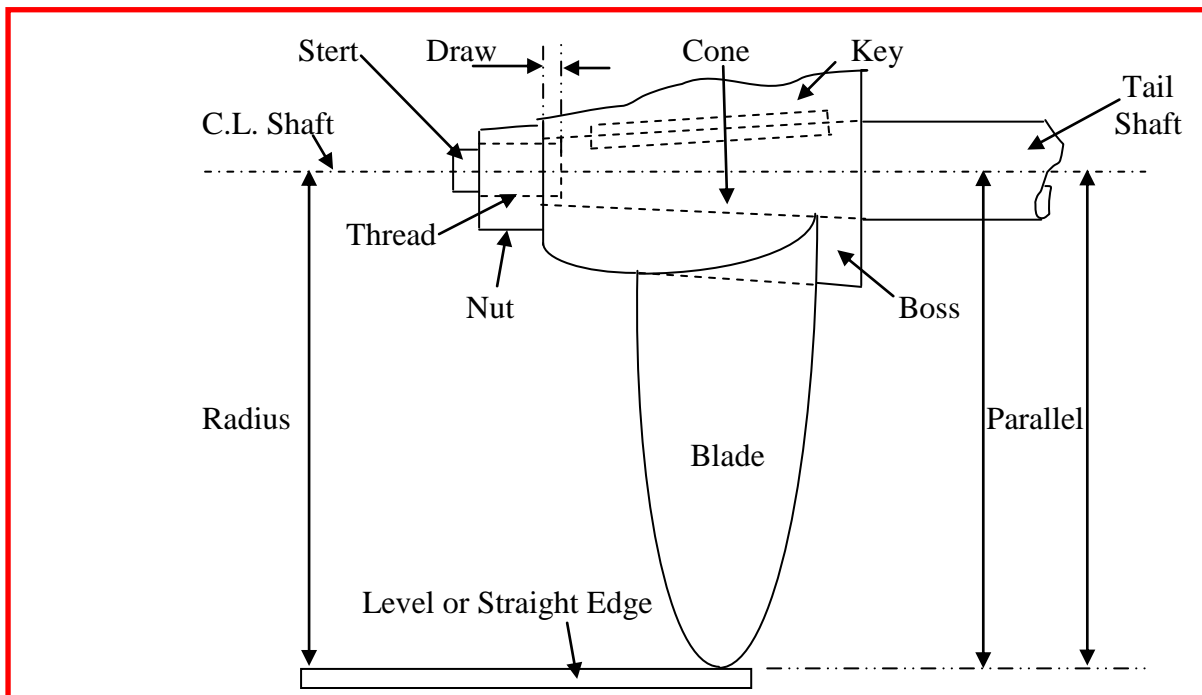


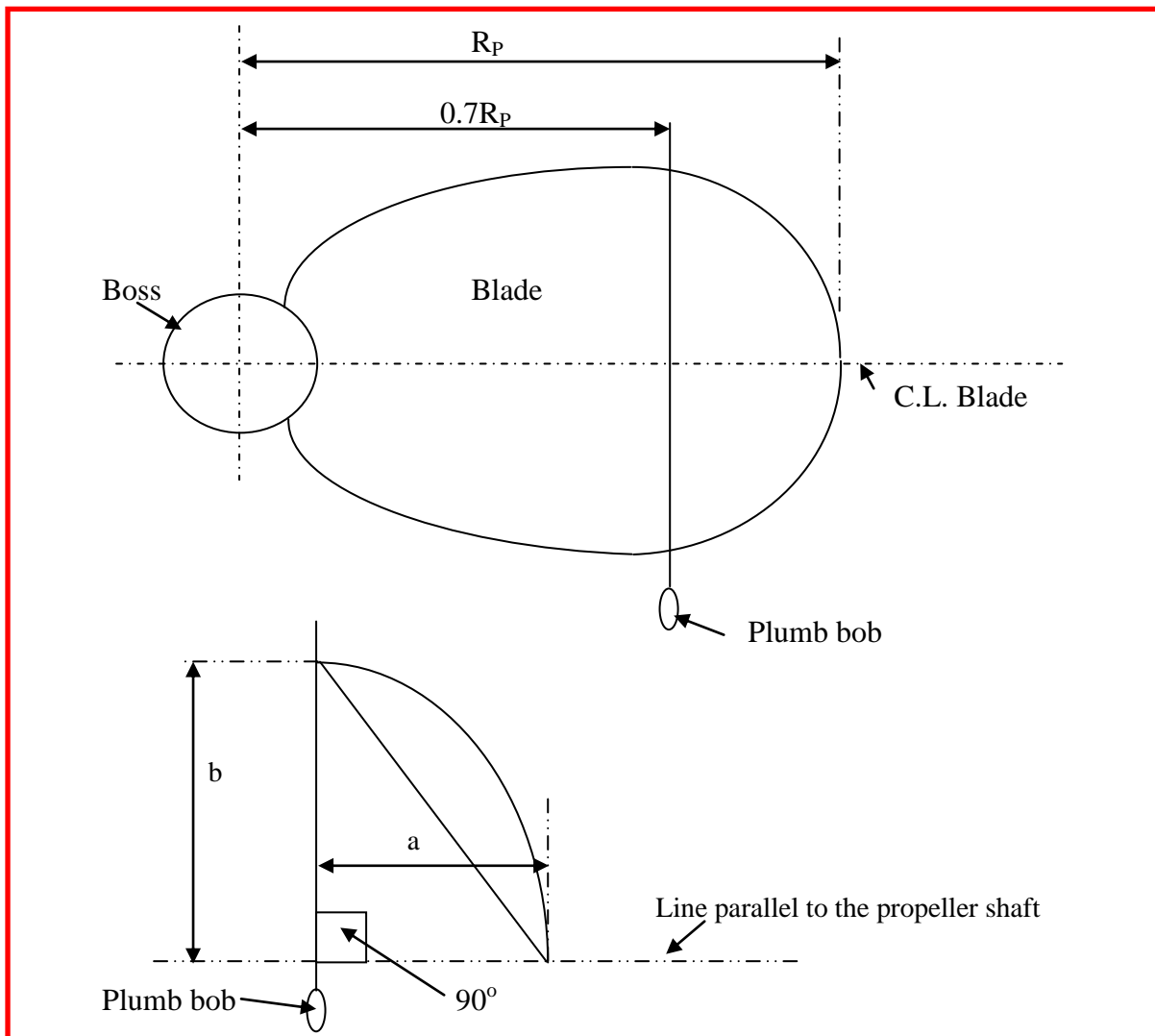
Figure 7 Measuring the Propeller's Diameter

### SLIDE 55

**SLIDE 56**

It is usually assumed that all propeller blades are cast on the same boss circumference and at the same rake angle. That assumption is not *necessarily* valid and it is good practice for the marine surveyor to line one blade up with the rudder or the stern post and attach a wooden marker to the rudder or stern post with the free end just touching the nearest point of the blade's trailing edge. If the propeller is true, as it is *slowly* rotated the trailing edges of the other blades should, each in turn, just touch the free end of the wooden marker. Any gaps or overlaps should be noted, recorded and reported as the propeller is probably out of dynamic balance and the cause of vibration.

**SLIDES 57 TO 59**



**Figure 8 Measuring the Propeller Pitch**

**SLIDE 60**

The pitch of the propeller is then calculated from the formula: -

$$P_p = 0.7 \times 2\pi \times R_p \times a/b \quad \text{mm} \quad (11)$$

For most practical purposes  $\pi$  can be taken to be equal to  $22/7$ . Hence: -

$$P_p \approx 4.4R_p a/b \quad \text{mm} \quad (12)$$

where

$$P_p = \text{propeller pitch at the point measured} \quad \text{mm}$$

$$\pi = 3.1416 \quad -$$

$$R_p = \text{propeller radius to blade tip} \quad \text{mm}$$

$$a = \text{measurement as above} \quad \text{mm}$$

$$b = \text{measurement as above} \quad \text{mm}$$

## **SLIDE 61**

### **Surveying tip 11**

- A builder's try square is useful for these measurements on propellers up to about two metres in diameter.

The marine surveyor if he needs more accuracy can, of course, take a series of readings at different radii along each blade and calculate the mean pitch by the moment mean method but this is usually an unnecessary refinement. This method does, however, enable him to draw a curve of pitch up the length of the blade if the propeller is of the variable pitch type *i.e.*, the pitch varies along the length of the blade. If the pitch is measured thus on a controllable pitch propeller *i.e.*, one where the pitch can be altered or controlled by means of a lever in the wheelhouse the marine surveyor should ensure that the readings are all taken at the same lever setting and note exactly what that was in his report.

## **SLIDE 62**

The part of the shaft to which the propeller is attached and which extends outside the hull is called the tail end shaft. It is subject to a number of defects of which the marine surveyor must be aware. It is good practice to measure and record its diameter and to note the material from which it is made. Common materials are mild steel, stainless steel, bronze and Monel metal (a form of bronze).

### **SLIDE 63**

The diameter of the shaft at the point where it enters the propeller boss should comply with the formula: -

$$d_s = \text{constant} \times (P_D/N_s)^{1/3}$$

where

$$d_s = \text{diameter of shaft in mm}$$

$$P_D = \text{developed power in kW}$$

$$N_s = \text{propeller shaft revolutions per minute}$$

The constant varies with the material. It is good practice for the marine surveyor to calculate the constant and keep the value in his private notes.

### **SLIDE 64**

It is also good practice to measure and record in his report the wear down i.e. how much gap there is between the shaft and the bearing. The gap encourages crevice corrosion which is usually invisible to a superficial examination and the marine surveyor should include in his report a note to the effect that he has not seen the shaft drawn and cannot guarantee its condition inside the bearing.

### **SLIDE 65**

He should **RECOMMEND** that the shaft be drawn and given a close up examination in way of the bearing at no more than two year intervals.

Shafts are known to groove heavily in way of the vessel's internal packing gland. A defect invisible on a normal pre purchase survey. So **BEWARE**

### **SLIDE 66**

## PROPELLER TERMS

A marine propeller is a fan like mechanism that transmits power by converting the engine's torque into thrust. Usually consisting of two, three, four or more blades, the propeller spins around a central shaft to create dynamics similar to a rotating screw or hydrofoil. When the blades spin, a pressure difference between the forward and after surfaces is produced, accelerating the water behind the blade to create force.

*Azimuth Propulsor* A propulsion unit consisted of a shroud attached to the vessel's rudder stock with a pod inside fitted with an ordinary propeller and capable of delivering its thrust through 360°.

*Blade* The blade is an ellipse shaped leaf that extends outward from the propeller boss or hub. The majority of pleasure craft propellers are available in two, three and four blade configurations. Multi-blade propellers offer advantages for high horsepower outboard engines mounted high on the transom with the propeller providing additional bite and stability at higher speed. They can also improve acceleration while maintaining plane with fewer engine revolutions. Because there is more drag, multi-blade propellers do, however, tend to reduce the vessel's top end speed. A high end three bladed propeller usually runs a few miles per hour faster than the same pitched multiple blade design.

The marine surveyor should be familiar with the following terms that attach to the blades of a marine propeller.

- *Blade Back:* This is the suction side or forward side of the blade.
- *Blade Centre Axis:* Linear reference line that indicates propeller rake.
- *Blade Centre Line:* Reference line that intersects each cylindrical section at the midpoint of the blade section width. Is used to indicate propeller skew.
- *Blade Face:* This is the pressure side, pitch side or after side of the blade.
- *Blade Number:* The number of blades attached to the propeller boss, number one blade being that over the key way. The blades are then numbered in accordance with the direction of rotation of the propeller.
- *Blade Root:* This is also called the fillet area and is the area where each blade attaches to the boss, the region of transition from blade surfaces and edges to the boss periphery.

- *Blade Sections*: These are the shape of a cylindrical section through the blade and are often referred to as Cylindrical Sections. The boss and fillet area account for about the first 20-30% of the propeller's diameter.
- *Blade Sections* are of five different basic types: -
  1. *Circular back sections*: Flat faced with symmetrically rounded back.
  2. *Hydrofoil sections*: Resembling traditional aeroplane wing sections *i.e.*, a rounded leading edge with the section's maximum thickness at about one third of the section's length abaft the leading edge.
  3. *Troost B sections*: Sections that are hydrofoil from 0.20 to 0.40 r/R and circular back from 0.65 r/R to the tip and transitional between. The most common modern commercial sections.
  4. *Ogival sections*: Elliptical in shape.
  5. *Supercavitating sections*: A high speed application with a sharp leading edge with the maximum thickness near the trailing edge. Found on surface piercing propellers.
- *Blade Section Length and Station*. The section length is the same as blade cylindrical width and each station is expressed as a percentage of the propeller's radius increment.
- *Blade Thickness*: For structural integrity, the blade is thickest at the root. Within each radial section, the point of maximum thickness may not necessarily coincide with the midpoint of the chord length.
- *Blade Thickness Fraction or Ratio*: The maximum blade design thickness as extended to the propeller centre line and divided by the propeller diameter. Blades must have enough thickness to achieve both the desired sectional shape and to provide sufficient strength under loading. Blades that are too thick produce a lower propeller efficiency.
- *Blade Tip*: This is the point of maximum radius of the blade from the centre of the boss and is also the point of separation between the leading and trailing edges.
- *Leading Edge*: This is the edge of the propeller blade adjacent to the forward end of the boss and leads into the flow of water when the propeller is providing forward thrust.
- *Trailing Edge*: This is the edge of the propeller adjacent to the after end of the boss and is the closest when viewing the propeller from aft. The trailing edge retreats from the flow of water when providing forward thrust.

<i>Blade Area Ratio</i>	The British Admiralty name for the developed or disc area ratio
<i>Bore</i>	The maximum diameter of the hole bored into the boss to take the propeller shaft.
<i>Boss</i>	This is the solid cylinder located at the centre of the propeller to which each propeller blade is attached. Boss shapes include cylindrical, conical, radius and barrelled. The centre of the boss is bored to accommodate the engine propeller shaft. In America the boss is called the hub.
<i>Boss Diameter</i>	The diameter should be measured and recorded at each end of the boss.
<i>Boss Diameter Ratio</i>	The mean diameter of the boss divided by the propeller diameter. Usually about 0.18 to 0.25.
<i>Boss Length</i>	The distance between the forward and after faces of the boss.
<i>Camber</i>	Often used but usually misunderstood. It is defined as the curvature of the mean thickness line of a given blade section.
<i>Cavitation</i>	This term is primarily used in conjunction with propellers and rudders. Often confused with ventilation, cavitation is the phenomenon of water vaporizing or <i>boiling</i> due to the extreme decrease in pressure on the forward, or, suction side of the propeller blade. Partial cavitation is normal on most propellers but excessive cavitation can result damage to the propeller's blade surface. Cavitation can be caused by nicks in the leading edge of the blade, bent blades, too much cup, sharp corners at the leading edge, incorrect matching of propeller to the vessel and engine or propeller imbalance. It is usually measured in terms of a non dimensional cavitation number and can be reduced by an adjustment of blade area and/or pitch distribution. When cavitating, the propeller will speed up but power is lost and/or the rudder may lose steering action. Cavitation often occurs when turning and results from a loss of a constant solid water flow. Power catamarans usually require deflectors when a single motor is used, to direct a flow of water to the propeller.
<i>Contra Rotating Propellers</i>	A pair of propellers fitted in tandem on the same shaft and rotating in opposite directions. The after propeller is usually somewhat smaller in diameter than the forward propeller.
<i>Cup</i>	A propeller is said to have a cup if the trailing edge of the blades formed or cast with the edge curled. Cupped blades are stated to improve the grip of the propeller onto the water thereby reducing ventilation, providing better out of the hole acceleration and allowing the boat to reach higher top speed. Cupping benefits are so desirable that almost all modern recreational, high performance propellers have some degree of cup. Compared with an uncupped propeller with the same pitch, the cupped one will reduce the full throttle engine speed, a single cup by 100-200 rpm and a double cup by 300-400 rpm. Cupping also helps to

reduce slip by increasing the hydrodynamic pitch as opposed to the face pitch and thus increases the thrust developed by the propeller.

*Cycloidal Propeller* A device fitted to vessels requiring a high degree of manoeuvrability and consisting of a number of fairly narrow vertical blades rotating round their own centres which, in turn, rotate around the vertical centre of the device. Hence they perform a cycloidal motion. Sometimes fitted with a horizontal hydrofoil form shield below the blade tips. Often found under the propriety trade name of Voith Schneider.

*Cylindrical Section* A cross-section of a propeller blade cut by a circular cylinder whose centreline is the axis of rotation. See *Sections*.

*Diameter* Diameter is twice the distance from the centre of the boss (hub) to the tip of the blade and is the diameter of the circle scribed by the blade tips as the propeller rotates.

*Disc Area* This is the area of the circle described by the propeller blade tips *i.e.*: -

$A_D$	=	$\pi D_p^2/4$	$m^2$	(12)
where				
$A_D$	=	disc area	$m^2$	
$D_p$	=	propeller diameter	m	

The marine surveyor should be aware that there are three area ratios in common use by naval architects and these are: -

*Projected Area Ratio* The projected area of propeller blades divided by the disc area and is the smallest area ratio in common use.

*Developed Area Ratio* The area of the blades rotated to zero pitch divided by the disc area and the most widely used of the ratios.

*Expanded Area Ratio* Similar to the disc area ratio with the sections unwrapped from the boss. It is the largest of the area ratios.

*Ducted Propeller* See *Shrouded Propeller*.

*Exhaust Propellers* In many small installations, particularly outboard units the engine exhaust is routed through the propeller boss or hub. There are three main arrangements usually described using American terminology.

1. *Thru Hub*: where the propellers are designed with an open barrel hub that serves as an outlet for engine exhaust to escape without making blade contact thereby improving acceleration.
2. *Non Thru Hub*: which is the normal arrangements used for vessels fitted with inboard engines with shaft driven propellers and through hull exhaust, and on some outboards that don't route the exhaust through the lower unit torpedo.



3. *Over Thru Hub*: propellers that allow a controlled combination of thru hub and over hub exhaust flow at lower revolutions, boosting propeller performance during initial acceleration and allowing for a better bite on some engine/boat combinations.

<i>Geometric Pitch Angle</i>	The angle between the pitch reference line and a line perpendicular to the propeller's axis of rotation.
<i>Gill Jet Thruster</i>	An electrically driven axial pump fitted to the bottom of a vessel with a rotating delivery head and capable of delivering the thrust through 360°.
<i>Handing</i>	See <i>Rotation</i> .
<i>Hub</i>	The American name for the boss.
<i>Inboard/Outboard</i>	Also, in America, called a <i>Stern Drive</i> . A propulsion system that uses an inboard motor, mounted at the transom, with a propeller assembly, similar to the bottom of an outboard motor, mounted on the outside of the transom, bolted to the motor with the transom sandwiched between. In most designs it can be used optionally with a V or <i>Jet Drive</i> .
<i>Keyway</i>	A slender rectangular slot broached into both the interior of the boss and the cone on the propeller shaft. It is fitted with a key which helps to secure the propeller to the shaft and to prevent torsional slipping on the shaft.
<i>Kort Nozzle</i>	See <i>Shrouded Propeller</i> .
<i>Leading Edge</i>	The edge of the blade that is forward when the propeller is rotating according to its handing. The opposite of the <i>Trailing Edge</i> ( <i>q.v.</i> ).
<i>Mead Width Ratio</i>	This is largely of American use and is the mean width of the propeller blade divided by the propeller diameter. It is related to the developed (or disc) are ratio dar by the formula: -

$$mwr = \pi D_p (dar - 0.04) 4Z$$
 where  
 $D_p$  is propeller diameter and Z the number of blades.

The formula assumes that the mean boss diameter is 0.20 x the propeller diameter.

<i>Outdrive</i>	Where an inboard motor drives a propeller unit mounted outboard on a vessel's transom through a system of shafts and bevel gears. Also called a <i>Z-Drive</i> , <i>Stern Drive</i> or an <i>Inboard-Outboard Drive</i> .
<i>P-effect</i>	Also called Propeller Bias, Paddlewheel Effect, Transverse Thrust or Propeller Walk. See <i>Transverse Thrust</i> .

*Paddlewheel Effect* See *Transverse Thrust*.

*Pitch* Pitch is the theoretical forward movement that a boat propeller travels during one revolution through a solid medium and is measured as the angle at which a propeller cuts through the water and which is calculated from the dimensions and geometry of its blades.

*Pitch Angle* Angle of the pressure face along the pitch line with respect to the plane of rotation measured in degrees. Not to be confused with pitch. Pitch angle decreases from the blade root to the tip in order to maintain constant pitch. The marine surveyor should understand the relationship between the pitch and the pitch angle which is given by: -

$\tan \theta = \frac{\text{Pitch}}{2\pi r}$	degrees	(13)
where		
$\theta$	=	pitch angle degrees
r	=	propeller radius inches or mm

*Pitch Distribution* The variation of the pitch over the length of the blade. The different types of pitch distribution are: -

1. *Constant (fixed) pitch* – the pitch is equal for each radius.
2. *Progressive pitch* – the pitch increases along the cylindrical line from the leading to the trailing edge.
3. *Regressive pitch* – the pitch decreases along the cylindrical line from the leading to the trailing edge.
4. *Variable pitch* – the pitch is different at each radius.
5. *Controllable pitch* – the blade angle can be mechanically varied. C.P. propellers are nearly always left handed.

*Pitch Line* This is a line that passes through the leading and trailing edges of the blade and used as a reference for pitch angle.

### Surveying tip 10

- A simple rule of thumb to follow when experimenting with propeller pitch. At wide open RPM, increasing the pitch reduces the revolutions by roughly 200 per inch of pitch. So that switching from a 21 inch to a 23 inch pitch propeller, for example, will lower the maximum revolutions by approximately 400. Going down the same amount in pitch size will have the opposite effect and increase maximum achievable revolutions.

*Pitch Ratio* This is the most fundamental of the various propeller ratios and is the mean pitch divided by the propeller's diameter.

*Propeller* A propeller is a type of fan of radial, spiral shaped blades attached to a central boss usually situated at the after end of a vessel that transmits

power by reason of their rotation in water and the blade section angle of attack, converts the torque provided by the engine and gearbox into thrust. A pressure difference is produced between the forward and after surfaces of the hydrofoil sectioned blade and the water is accelerated behind the blade. A right handed propeller is designed to rotate clockwise (when viewed from astern) which, and vice versa for a left handed unit. Larger diameter propellers with greater pitch and producing more thrust are usually needed by narrowboats powered by slow revving traditional engines but at the cost of greater *Transverse Thrust* (*q.v.*). A propeller is sometimes colloquially known as a *Screw*.

<i>Propeller Centre Line</i>	Linear reference line passing through hub centre on the axis of propeller rotation.
<i>Propeller Centre Axis</i>	Linear reference line that locates the blade on the boss and is perpendicular to the Propeller Centre Line.
<i>Propeller Effect</i>	See <i>Transverse Thrust</i> .
<i>Propeller Shaft</i>	See <i>Line Shaft</i> .
<i>Propeller Singing</i>	A phenomenon occurring in boat propellers at certain rates of revolutions. A strong, almost pure tone is radiated from the propeller into the water but rarely heard on deck because of engine noise. Where this becomes a nuisance the volume or pitch of the tone can be reduced or altered by slightly altering the sectional shape of the trailing edge of the blades.
<i>Propeller Stripper</i>	A pair of blades, one on the propeller shaft and one on the stern tube, with sharp leading edges, to chop up any rope, plastic, tough weeds etc before it becomes tightly wrapped around the propeller or shaft causing vibration, loss of thrust and poor steering or even stalling in severe cases. Sometimes called a weed cutter.
<i>Propeller Walk</i>	See <i>Transverse Thrust</i> .
<i>Radius</i>	The distance from the axis of rotation to the blade tip. The radius multiplied by two is equal to the diameter.
<i>Rake</i>	<p>Rake is the angle of attachment of the blade to the boss of the propeller and affects the flow of water through the propeller. Rake has implications with respect to boat performance. Higher rake can improve performance in higher engine elevation and/or ventilating or cavitating situations.</p> <p>A propeller blade may rake either aft or forward from the blade centre axis.</p>

*Aft or Positive Rake* the blade tip rakes towards the after end of the boss and such rake is common for planing and combination hulls as it provides increased top end speed while assisting in trimming the bow upward for less wetted surface and frictional drag.

*Forward or Negative Rake* the blade tip rakes towards the forward end of the boss and such rake is rare but may be found in commercial craft with displacement hulls as it trades speed for steady power that can aid in holding the bow of the boat down and level.

The rake may be specified either in mm or inches at the blade tip or in degrees.

*Rotation* The direction in which the propeller rotates when viewed from astern.

*A right handed* propeller rotates clockwise.

*A left handed* propeller rotates anti clockwise.

Twin screw applications utilize both left handed (port side) and right handed (starboard side) rotating propellers and are said to be outboard handed. Left handed propellers are primarily used on twin engine boats to cancel the steering bias that would be caused if both propellers spun in the same direction.

*Screw* A colloquial name for the propeller.

*Size* The size of a propeller is usually described by two numbers which indicate the sizes of diameter and the pitch respectively.

*Shrouded Propeller* A hydrofoil sectioned steel ring fitted round a specially designed propeller and found in two forms: -

- The fixed nozzle which is permanently welded to the vessel's hull.
- The nozzle rudder which is attached to the vessel's rudder stock and replaces the rudder.

*Skew* A blade centre line transverse curvilinear sweeping back from the direction of rotation. The contour of the blade is not radially symmetrical about blade centre axis. Skew forms an asymmetrical shape that can be viewed by looking at the prop blades directly from the fore or aft: -

- *Aft or Positive Skew*: The blade sweeps in the direction opposite to the propeller rotation when moving the craft forward.
- *Forward or Negative skew*: The blade sweep in the same direction to the propeller rotation when moving the craft forward.

<i>Slip</i>	Because under actual operating conditions the propeller's absolute forward movement (actual pitch) is less than theoretical pitch and the difference is called the slip. It varies from boat to boat, depending on the weight of the boat and blade surface of the propeller.
<i>Stern Drive</i>	See <i>Outdrive</i> .
<i>Stern Gland</i>	An arrangement usually by means of greased packing in a <i>Stuffing Box</i> ( <i>q.v.</i> ) or <i>Stern Tube</i> ( <i>q.v.</i> ) whereby water is prevented from entering a vessel at the point where the <i>Propeller Shaft</i> ( <i>q.v.</i> ) passes through the hull. Also usually contains the <i>Propeller Shaft's</i> aftermost bearing. Some modern pleasure narrowboats have stern glands that are lubricated by water drawn by the propeller's action through the gland by a pipe from the weed hatch.
<i>Taper</i>	The slope of the bore inside the boss. Usually 1 in 12 in Imperial units and 1 in 10 in metric.
<i>Track</i>	This is the measurement of the axial position of all blades with respect to each other and represents the spread distance between individual blade rake distributions. Always a positive value, track is the absolute difference of one blades actual individual blade rake distributions to the corresponding blade rake distributions on a neighbouring blade.
<i>Trailing Edge</i>	The opposite of the blade to the leading edge ( <i>q.v.</i> ).
<i>Transverse Thrust</i>	A propeller not only thrusts a boat forward, it also causes the stern to turn to one side, which side depends on whether the propeller is right or left handed. This transverse thrust (also called the p-effect, paddle wheel effect or propeller bias or walk) results in the tendency of the propeller to create a transverse force causing the stern of the vessel to creep either to port or starboard side depending on the handing of the propeller. The effect is especially noticeable when the vessel is on a stern board where there is greater vessel resistance to move sternwards thus making it easier for the propeller to push the vessel's stern sideways. If the propeller is right handed ( <i>i.e.</i> it revolves clockwise in forward gear when viewed from astern), the vessel will normally veer to port going ahead and clockwise going astern and <i>vice versa</i> for a left handed propeller. Thus it is impossible for a single propeller boat to go dead straight without constant minor adjustments to the rudder. When fully understood, good use of this effect can benefit close manoeuvres. Not to be confused with <i>Interaction</i> ( <i>q.v.</i> ).
<i>Under Propped</i>	Said of a propeller having too small or too fine a pitch to produce enough thrust to efficiently drive the boat.
<i>Ventilation</i>	Sometimes the term <i>cavitation</i> is used when in reality <i>ventilation</i> or <i>air drawing</i> is actually occurring. Ventilation is air being drawn down

from the water surface or the introduction of exhaust gases into the propeller blades both of which cause the propeller to race and lose thrust. Ventilation can be useful in the bottom end acceleration by allowing the propeller to slip a regulated amount, allowing the engine to revolve higher during initial acceleration. It is usually achieved by ventilation holes at the root of each blade or the use of an over hub design. Ventilation is for through hub exhaust propellers only. Causes of ventilation include excessively tight cornering, over trimming of the engine and mounting an outboard motor too high on the transom.

*Voith Schneider* See *Cycloidal Propeller*.

*Z-drive* See *Outdrive*.