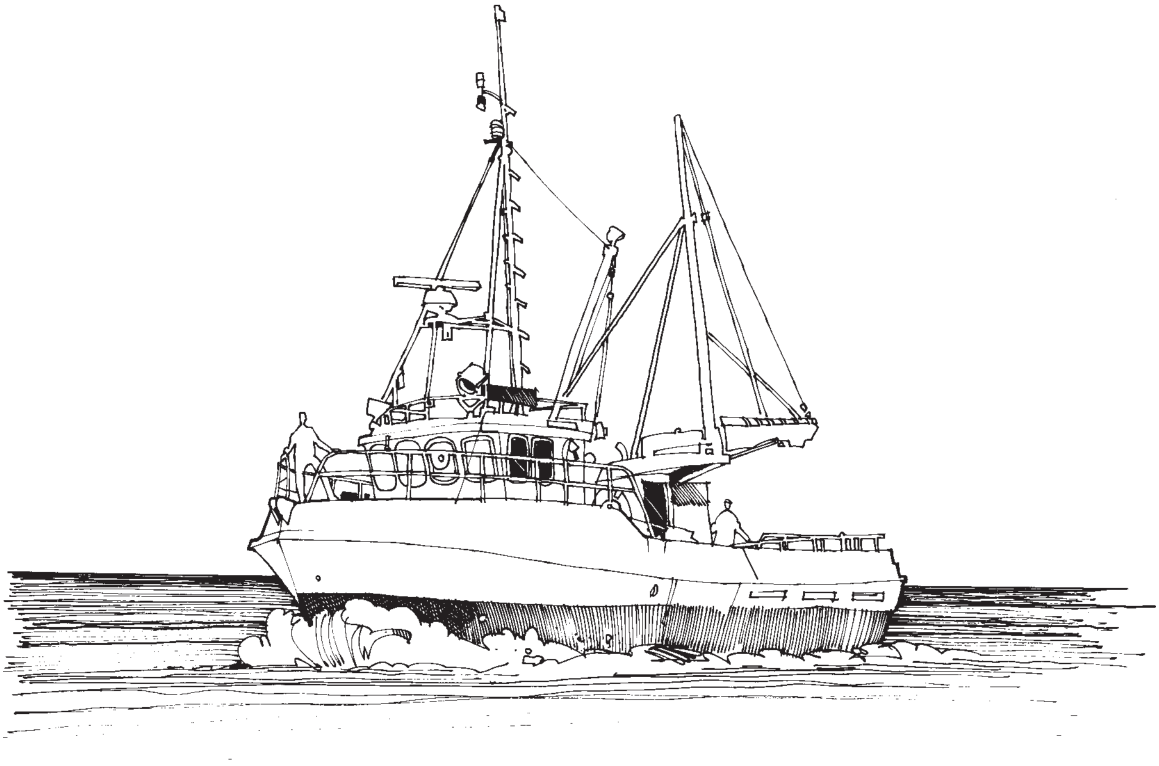
Propellers

Inboard propellers and speed calculation
Marine Engines 2.1L–16L



Foreword

The purpose of this information is to provide installers, designers or users with a simple and effective help in choosing the right propeller for a given combination of hull, engine and reverse gear and for certain operating conditions and speed range.

When calculating boat speed and choice of propeller there are many factors to be considered, from the theoretical to the very practical. There is no known formula that will automatically give the correct answer.

A number of general rules, theories and formulas are used for these calculations, all of which are more or less exact. Variations in hull shape, displacement, restriction of the water flow to the propeller and the propeller manufacturing tolerances are some of the factors influencing the result.

The only true test is the result obtained during sea trials. Adjustments, especially in the propeller size, may be necessary.

The responsibility for the design, construction and fitting of the propeller arrangement lies with the company carrying out the installation. We emphasize that our information is only for guidance and that, when used correctly gives a good general view for the choice of a suitable combination of engine, transmission, and propeller size. The final choice should be made in consultation with a propeller designer or in co-operation with Volvo Penta.

AB VOLVO PENTA

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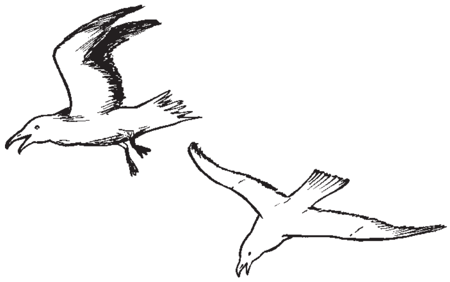
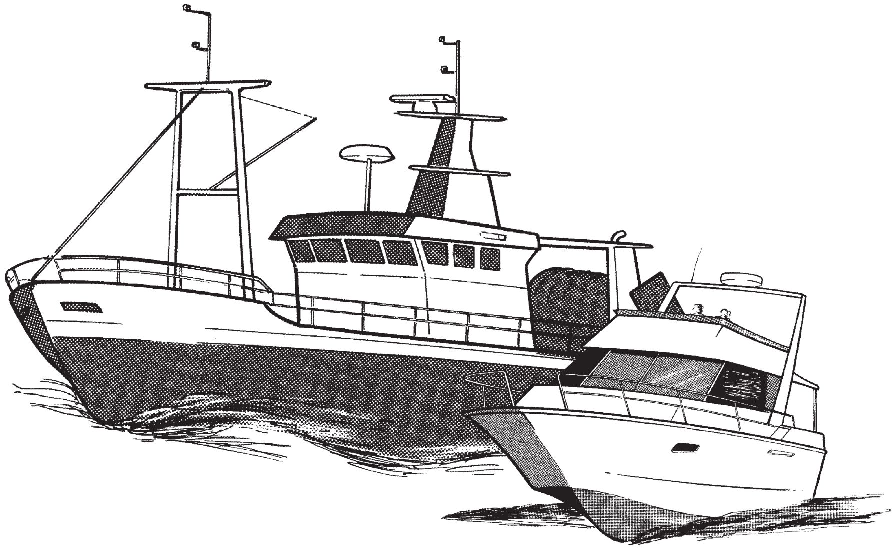
Boat propulsion

To enable a boat to make speed through water there must be some kind of propelling force. We are in this respect dealing with engines, as the source of power.

The transmission of power from the engine through the reduction gear to the water is done, with few exceptions, by using a propeller, as this has proven to give the best efficiency.





An installation where all the components are well matched, makes for a good result.

To get an optimal result for all components making up the installation, that is the boat hull, engine, reverse gear plus shaft and propeller, they must be carefully chosen to suit the intended application as far as possible.

The complete installation must be carried out properly to obtain a good result. The propeller cannot function satisfactorily if the other components have not been designed, manufactured and fitted correctly.

The propeller can be regarded as the final link in the power transmission chain and no chain is stronger than its weakest link.

Carefulness pays

It pays well to spare no effort in choosing the propeller that is most suitable for the installed combination of components. Each permillage of improved result gives lower running costs per hour.

Propeller

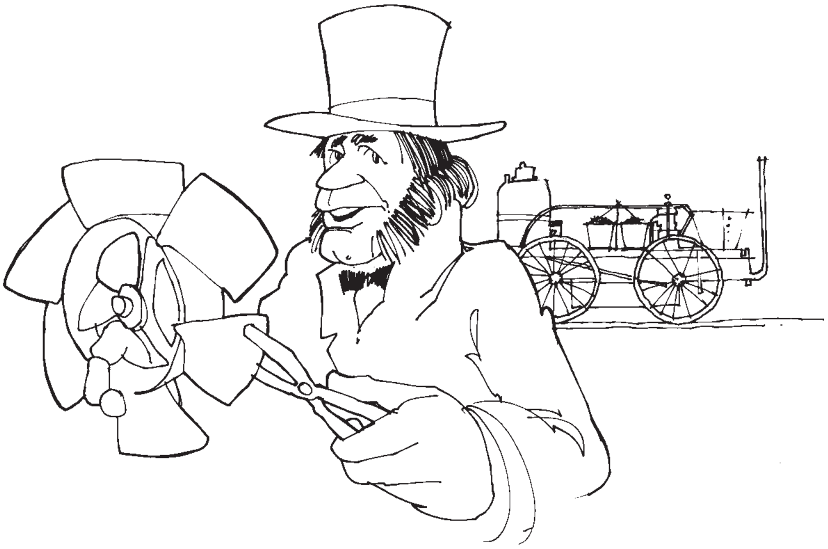


Fig. 1. Efficient propellers started to be made at the beginning of the 19th century, when the steam engine came into use.

Background

The propeller, whose name comes from the Latin "propellare" (to drive forward) is a very old idea. It was however at the beginning of the 19th century, when a suitable power source–the steam engine–was developed that an efficient screw propeller was produced.
The propeller converts the engine's output by rotation into thrust which balances the resistance against driving forward at that particular throttle speed.
Usually the engine's revolutions are too high to directly drive the propeller and therefore the engine's r.p.m. must be reduced by a reverse gear with a reduction.

How does it work?

A propeller consists of a hub and a number of blades which can be likened to the wings of an airplane.
To explain the principles, we can compare the propeller with a standard wood screw. See figure 2.
One turn of the screw results in a movement forward which compares to the **screw's pitch**. Analogously, the propeller has a pitch which can be likened to the angle of the propeller blades (pitch angle) which in the figure are drawn at the same angle for both the propeller and the screw.
A propeller will not work in a solid medium, water is a yielding medium. A table fan is an example of a propeller, and it stands (hopefully) still on the table and blows air out behind it.

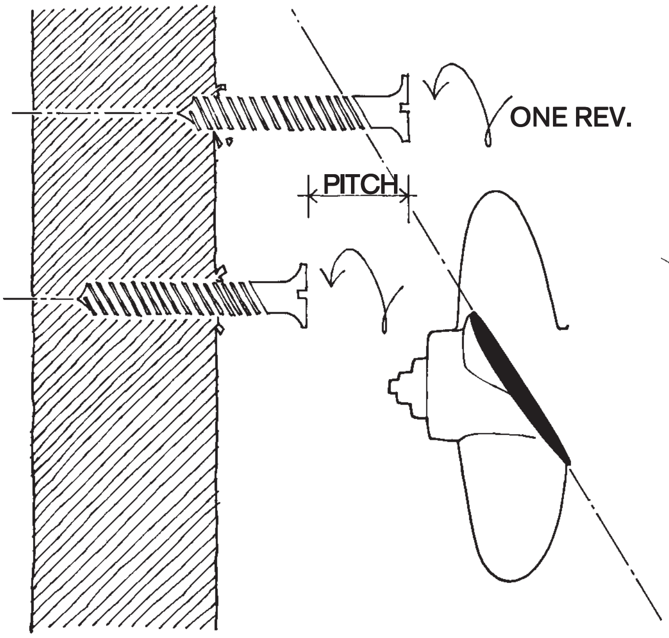


Fig. 2. One turn of the screw gives a movement forward which corresponds to the pitch.

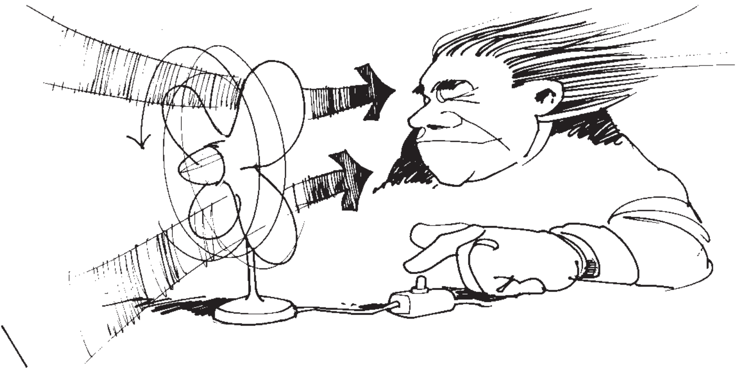


Fig. 3. A normal table fan is also a type of propeller but it works in the medium of air.

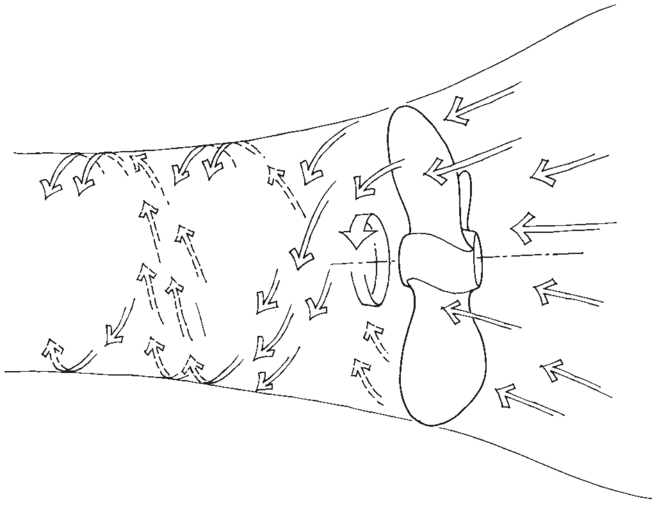


Fig. 4. The propeller creates pulling power by putting a column of water into motion.

A propeller works in the same way as the previously mentioned fan but it creates pulling power by moving water and creating a column of water behind it. See figure 4.

The difference between the propeller's pitch and the real movement is called slip and is necessary in order for the blades to grip and set the water in motion. This means that when the propeller has rotated one turn in the water it has only advanced part of the pitch (usually in the order of 75–95 %) which is shown in fig. 5.

At the same time the boat will drag water with it, somewhat in front of the propeller. The water's speed reduction which can be 5–15 % for pleasure boats is called ”wake” and affects the measured value of the slip.

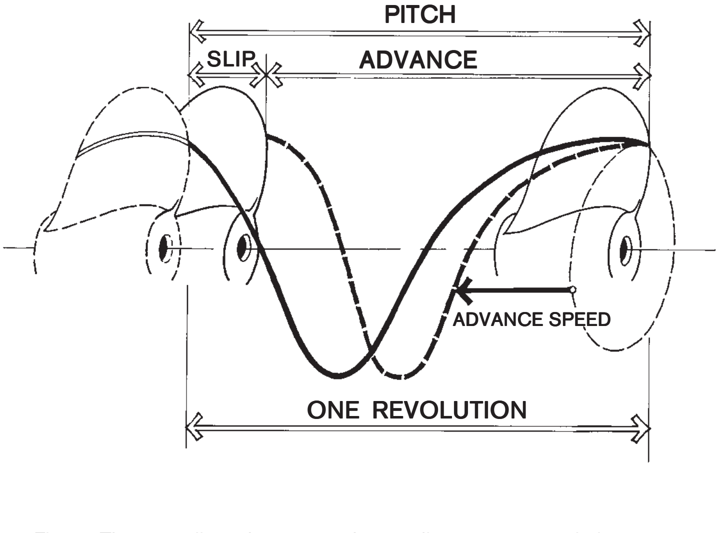


Fig. 5. The propeller advances a shorter distance per revolution than the pitch due to the ”slip”.

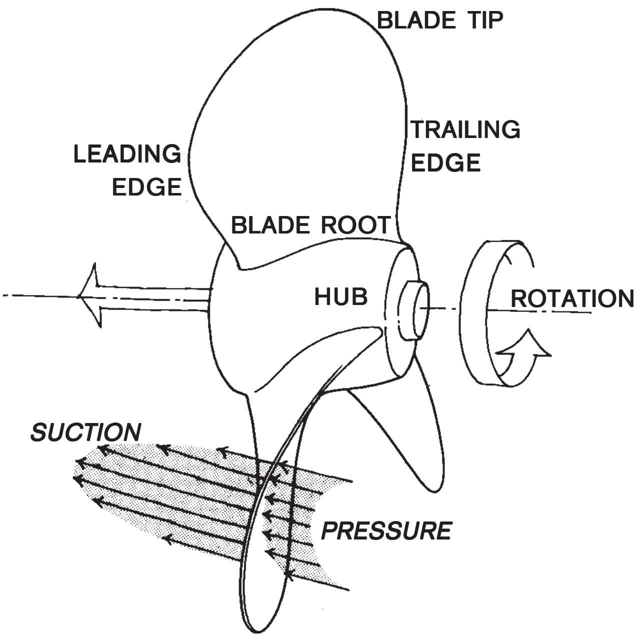


Fig. 6. Propeller blades have a pressure and a suction side.

When the propeller turns through the water the water will hit against the blade's rear side, the **pressure side**, and create a high overpressure. In the same way the propeller's leading side, the **suction side**, pulls itself through the water by creating a vacuum. See fig. 6.

The blade's suction and pressure effects start the water to move, and forces it away at almost a right angle to the blade surface.

The propeller blade's force, which is equal to the pressure difference across the blade, can be split up into two components equal to, firstly the rotation, (which gives the **torsional torque**), and secondly, the forward movement (the propeller's **thrust**). See fig. 7.

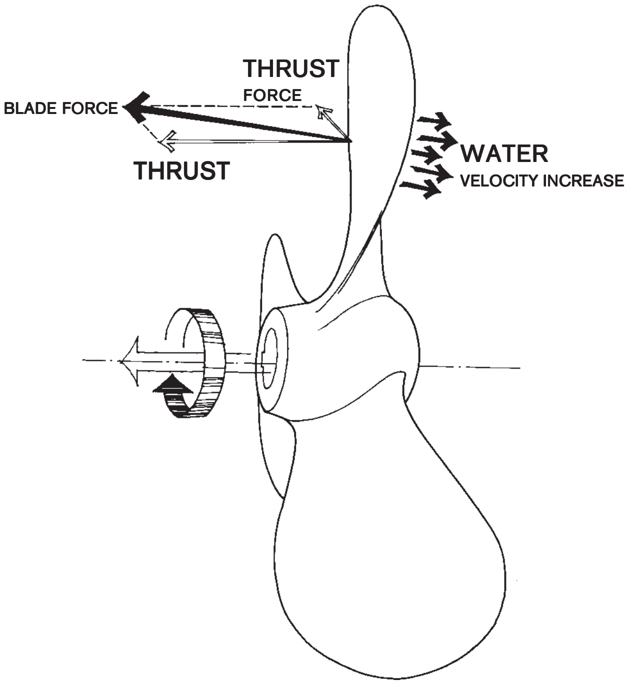


Fig. 7. Power diagram for a propeller blade.

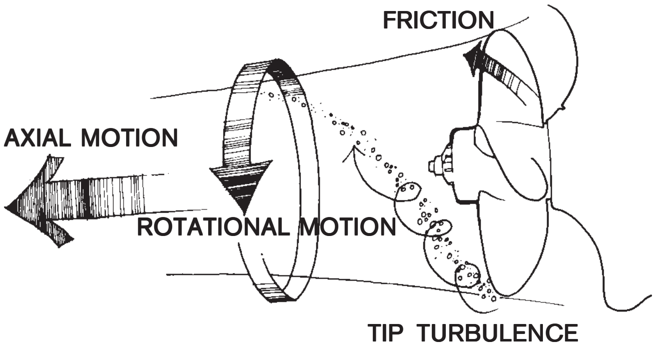


Fig. 8. The water column (or cylinder) which the propeller moves away has both an axial and a rotating movement.

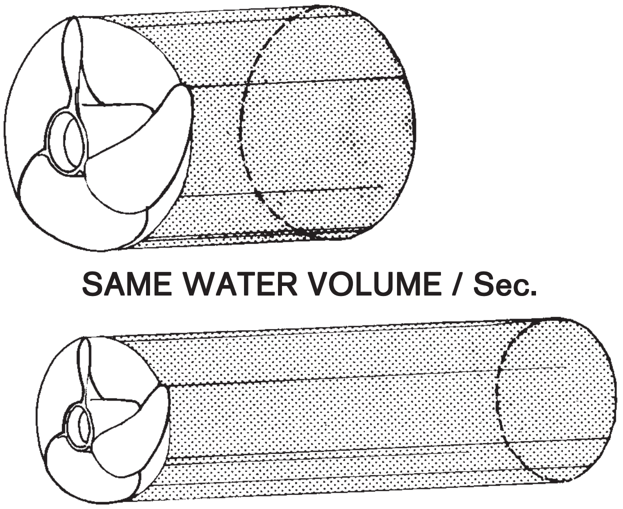


Fig. 9. A large propeller on a slow moving boat can have about the same efficiency as a small propeller on a fast going boat. The water amount/sec. is nearly equal in both cases.

One can also regard the blade force as a **reactional force**, that is the recoil effect we get when the water is forced away. Behind the propeller we get a water column which at an increased speed also reduces itself to 80–90 % of the propeller diameter. The water cylinder moves both axially (equivalent to the propeller's thrust) and in a rotational direction (equivalent to the propeller's torque). The "water cylinder" or the column has therefore a kinetic energy. See fig. 8.
The kinetic energy in the outgoing column is an important part of the propeller's losses. Other losses are friction when the blades cut through the water, turbulence eddies and cavitation bubbles at the blade. Even the release turbulence at the tip of the blade, where the water flows over from the pressure side to the suction side and is rolled into eddies when it leaves the blade tip, is a loss.

In order to reduce the energy losses in the propeller cylinder one must increase the water flow per second which passes the propeller (that is a large water cylinder which we can give a small speed increase in order to achieve better pulling power). This means that a higher propeller efficiency level is equal to a larger propeller diameter or higher boat speed which is shown in fig. 9. Normally the propeller's losses are dominated by the energy part of the outgoing column, which is shown in fig. 10 for a normal propeller (typical speed abt. 10–15 knots), with an efficiency of 50 %.

Output losses for an inboard propeller

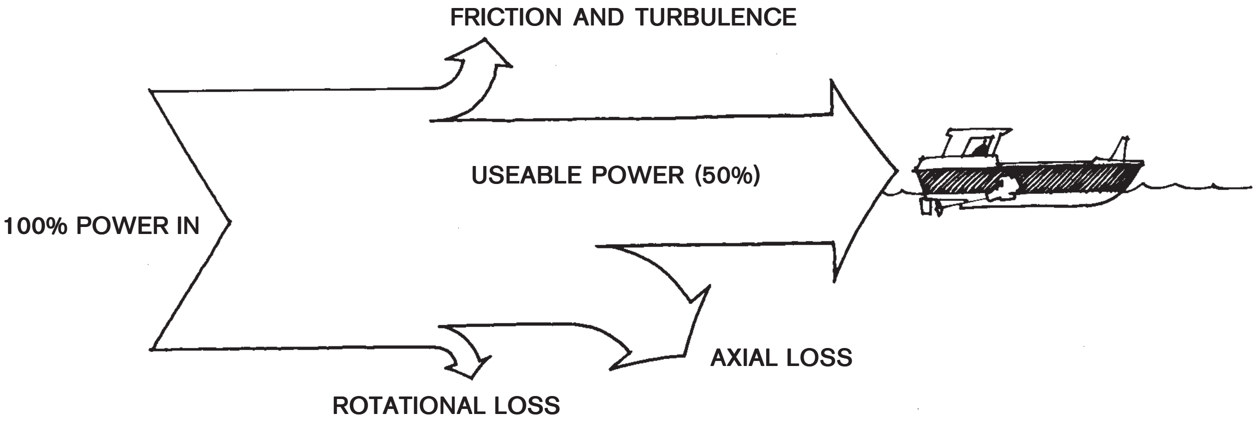


Fig. 10. The picture shows that we can only use 50 % of the applied power as driving force from the propeller.

Fig. 11. The water flows evenly around the blade without bubbles.

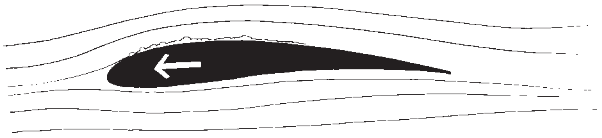


Fig. 12. The blade is relatively thick and the water does not have time to come around the blade. Bubbles are formed, in this case on the suction side.

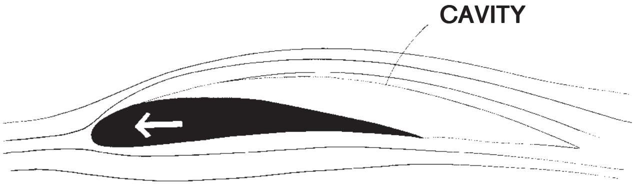


Fig. 13. Continuous bubbles (cavity) with even contact area, on super-cavitation propeller.

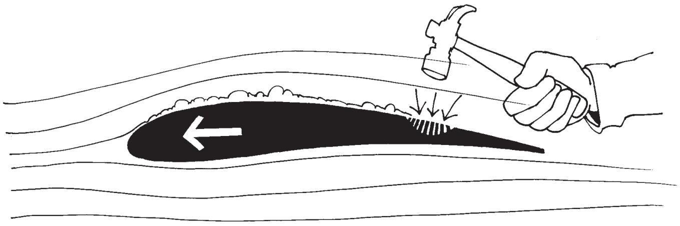


Fig. 14. Particles are "hammered" away from the propeller when the bubbles collapse. (In this case, on the suction side of the propeller).

Cavitation

A propeller blade screws itself through the water with a rather high speed. Measured at 70 % of the propeller radius, the speed is about 60–80 knots. The speed in this case is the blade speed, not the boat speed. If the blade is too thick (in relation to the blade width) the water which is pushed away from the blade edge has such a high speed from the blade that it does not flow back over the blade before it has passed. One gets a space (cavity), which is filled with steam and air, which is always present in the water. See figs. 11 and 12.

Cavitation at a propeller blade will gradually form and starts with bubbles and possible small eddies around the areas with low pressure.

As the speed increases the bubbles get larger and at higher speeds float out in a continuous gas bubble with an even contact surface (super-cavitation) as per fig. 13.

Speeds equal to the transformation zone "little cavitation" should be avoided. The reason is that the blade's profile resistance increases at transformation and therefore reduces the propeller's efficiency at the same time as there are risks for erosion damage at those places where the bubbles collapse. At the collapse, large pressure pulses are created which can quickly hammer away particles from the metal surface (erosion). See fig. 14.

Erosion starts on the suction side if the propeller works with a too high load (high output, high revolutions and low speed), alternatively, if the blade's leading edge is damaged or if the blade passes through a dead zone (for example behind a thick but not tapered keel).

The erosion on the pressure side (which can be intensive) can be the result of too low propeller loading, that is low output, low revolutions and high speed, too high blade arching or the forward edge of the suction side has been badly ground. Fig. 15.

The propeller should be designed so that cavitation on the pressure side never occurs. Cavitation on the suction side can be accepted to a certain level, if it is of the so called "layer type".

Many propellers have a small diameter in relation to the output, so that cavitation will more or less always occur. This, in combination with the water flow from a not so well designed stern (which gives eddies and release zones), initiates cavitation bubbles whose volume at the blade pulsates when the propeller rotates. One can get powerful propeller noise, partly through the pressure pulses in the water against the hull (this power is equivalent to about 5 % of the propeller's thrust), and partly through bending vibrations in the propeller shaft.

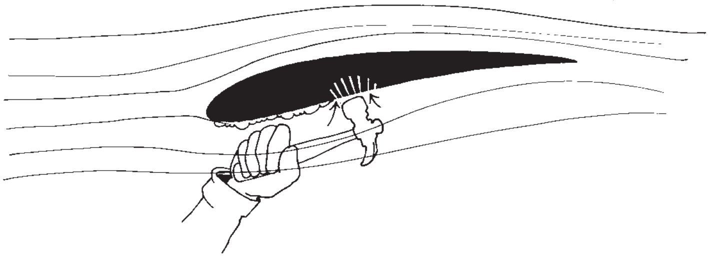


Fig. 15. Erosion damage on the propeller's pressure side. Particles are hammered away.

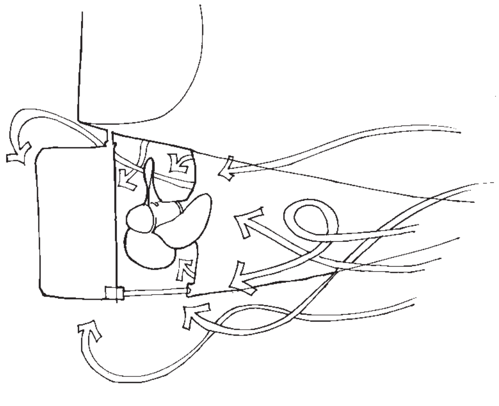
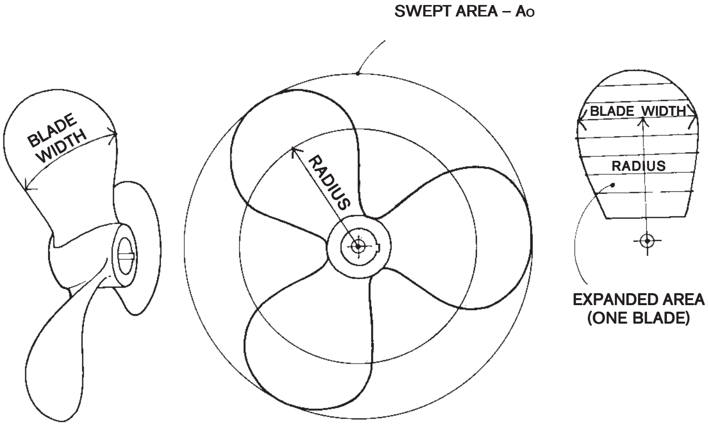


Fig. 16. The risk of erosion damage on propellers is greater if the stern is of a bad design. Eddies and release zones cause cavitation.



● RELATIVE EXPANDED BLADE AREA $A_E / A_O = \frac{\text{TOTAL BLADE AREA } A_E}{\text{SWEPT AREA } A_O}$

Fig. 17 Blade area and swept area.

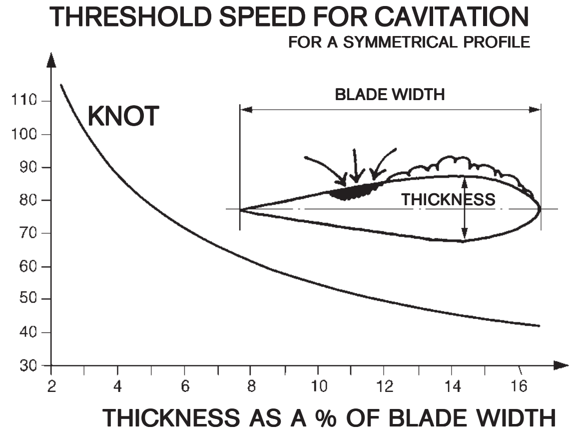


Fig. 18. In order to avoid cavitation the ratio between the blade thickness/blade width is limited by the blade speed.
Blade thickness expressed as a % of the blade width.

Blade area/Cavitation

The propeller's blade area is calculated in relation to the circle scribed when the propeller rotates. In order to simplify the blade area calculation, one can draw the blade width with straight lines equivalent to the different radii according to fig. 17. One then has **the expanded blade area A_E.**

The swept area is called A_O.

If one knows the blade width at 70% of the propeller radius then the **blade area** is about:

$$\boxed{\frac{A_E}{A_O} = 0.43 \times \text{No. of blades} \times \frac{\text{Blade width}}{\text{diameter}}}$$

The blade area is governed by the fact that cavitation should not occur on the blade surface, absolutely not on the pressure side, but possibly some cavitation on the suction side.
Cavitation which occurs at low pressure (almost zero) is a result of a combination of:

- propeller force gives a pressure difference over the blades
- the propeller blade's profile in itself creates a vacuum during speed in the water
- the angle of the propeller shaft, eddies and release zones from the boat hull give pulsing contact flow angles against the blades.

A guide for the blade area is 0.17 m^2 per ton pulling power for a slowly rotating propeller (for every additional blade above three, add at least 10%–15% to the area).

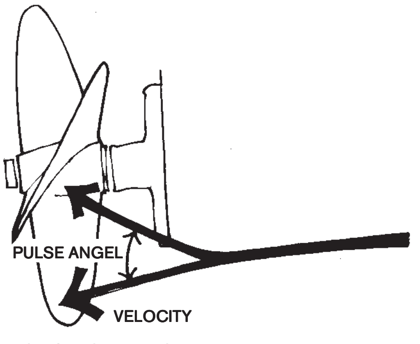


Fig. 19. Pulsations in the flow angle.

Usually the propeller blade has a high speed when it cuts through the water (60–80 knots). The blade thickness then becomes important and affects the vacuum at a blade. Fig. 18 shows that the threshold speed for cavitation gets a thin symmetrical profile. One sees that at the blade speed of 70 knots the blade thickness should be max. 6% of the blade width (that is the blade width should be 17 times the thickness). The combination of pressure force and blade thickness, gives the rule that the blade area should be at least 6 to 8 cm^2 per kW propeller output (if the flow area before the propeller is rather even).
If the flow area is pulsating (measuring is sometimes necessary), it might be necessary to increase the blade area. Two propeller types are shown below (slow moving boat with a propeller efficiency of 40%, and a fast moving boat with a propeller efficiency of 60%) and the blade areas one must have for the propeller to withstand the pulsing in the flow angle when the propeller is in other respects, correctly chosen. See fig. 19.
For example, a blade speed of 70 knots and a slow moving boat with a propeller efficiency of 40%, the blade area 60 % is sufficient for 4 degrees of angle pulsation. Already at 5 degrees an 80% blade area is required. Our 6–8 cm^2 per kW can rise to be both 15 and 20 cm^2 per kW.
It is therefore very important that the stern is well designed and to avoid the propeller being subject to heavy loading (that is high blade speed above 65 knots).

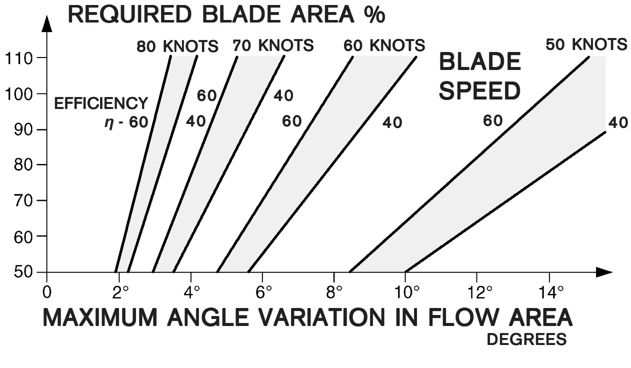


Fig. 20. Blade area in relation to the maximum pulsations in the flow angle at different blade speeds and efficiency 40–60 %.

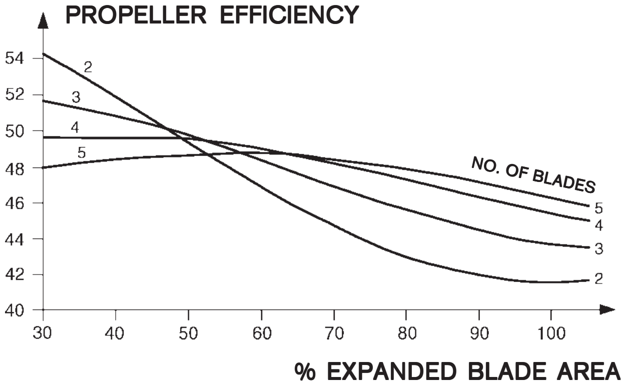


Fig. 21. The efficiency for a propeller with 2, 3, 4 or 5 blades respectively.

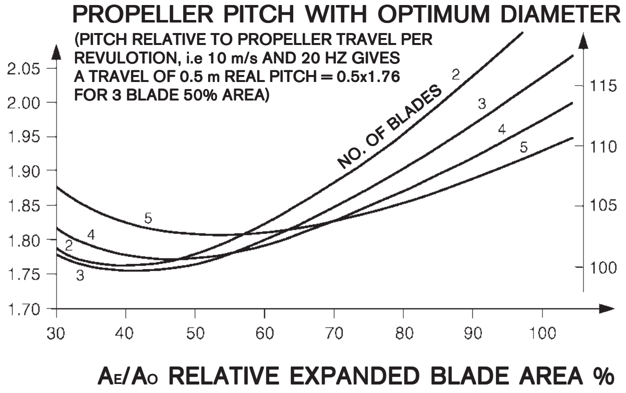


Fig. 23. Pitch in % for propellers with a different number of blades and optimal diameter.

Number of blades

A propeller blade only functions well until the blade width starts to be greater than its height from the root to the tip. This corresponds to an area per blade in the range 16–18%. This means that for a small blade area of 30–40% two blades are enough, up to 55% three blades, and so on. This is shown in fig. 21 for the number of blades 2, 3, 4, and 5 with a load so that a 3-bladed propeller with an area of 48% should have an efficiency of 50%.

More propeller blades have a tendency to "help" each other. The optimal diameter is reduced by about 4% when an additional blade is added at the same time as more blades tend to even out the speed range and any layer cavitation on the suction side is reduced. An optimal chosen diameter, according to the above corresponds also to an optimal pitch, see fig. 23.

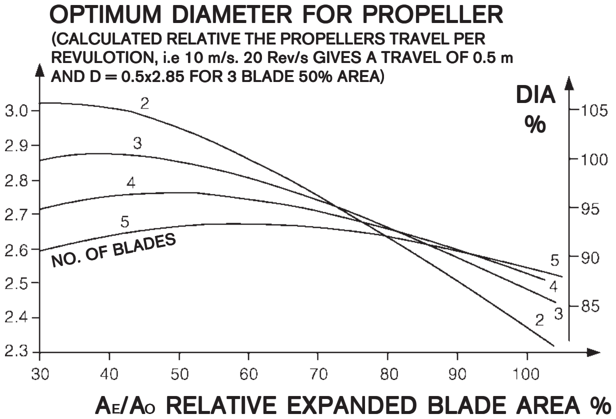


Fig. 22. Optimal diameter is reduced with larger number of blades, for a blade area below 75%.

The number of blades **(Z)** affect the frequency for the vibrations (but also the vibration strength). Measurements show that frequencies equivalent to the propeller shafts revolutions **(n)** are often very strong (this has to do with unbalance and that the propeller blades are not exactly alike, so called hydro-dynamic unbalance). Also water is thrown against the boat bottom every time a blade passes, i.e. the frequency is equal to the blade frequency **(Z×n)** (also double blade frequency **2×Z×n** is often noticeable).

For a propeller which is located behind the keel as in fig. 24, a three-bladed propeller will give more powerful bending vibrations to the propeller shaft (and even to the hull) than a four-bladed propeller. The three-bladed propeller will pass one blade at a time through the dead zones behind the keel creating a power pulse,

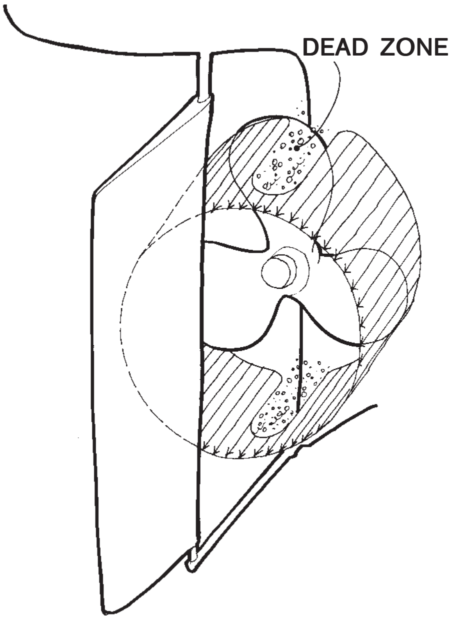


Fig. 24. This boat keel has 2 dead zones.

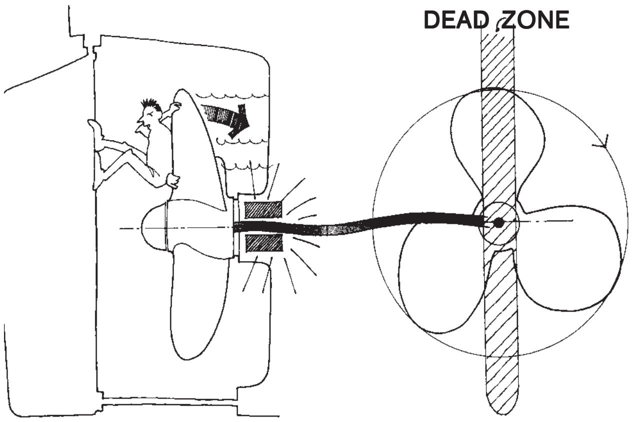


Fig. 25. When a blade passes a dead zone the shaft is subject to a bending effect.

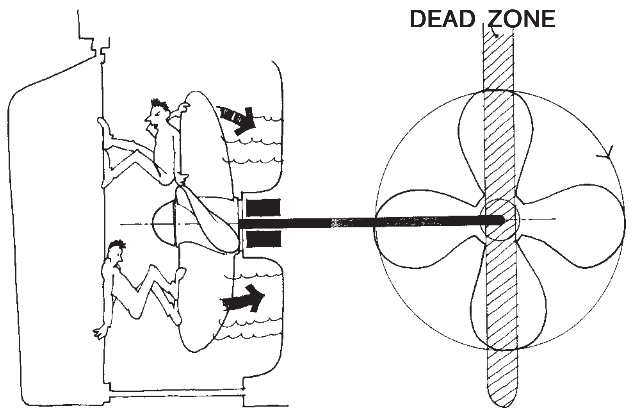


Fig. 26. If two blades pass at the same time through the dead zones they almost balance each other.

which has a lever effect, bending the shaft. For the four-bladed propeller, two blades will pass at the same time through the dead zones where the blade's power pulses will almost balance each other (as regards bending). However, the power pulses along the shaft are often larger for a four-bladed propeller, but it does not give the same effect at the vibration level as the bending of the propeller shaft for a 3 bladed propeller. The change of blade frequency can also affect the noise level (depending on where the boat's resonance is).

Choice of the number of blades consequently affects the flow area at the propeller. **One should never allow the number of blades to be the same as the number of the dominating dead zones (which are really waves in the speed range) which the blade passes during one revolution. In the example above two "waves" are formed which means that a two-bladed propeller should not be used.**

Selecting the propeller's main dimensions

We have mentioned earlier that an important parameter for a cavitation-free propeller is the speed at which the propeller blade cuts through the water. If we can keep the speed to 60 knots (we then see that the effective part of **the blade is at 70 % of the radius**), the blade thickness is reasonable (somewhat less than 8%) and the blade withstands pulse angle variations of 6–7 degrees.

(Depending on the load, the permitted thickness is "used" in order to take up the pressure difference over the blade, which is why an 8 % thickness for a lightly loaded propeller becomes 5% for a heavily loaded propeller).

If instead we choose a blade speed of 80 knots problems can arise where the blades have to be made very thin, less than 5 % of the width, and they will only withstand pulse angles of maximum 2–3 degrees (manufacturing faults included). The demand of higher manufacturing precision is increased.

The boat designer's dilemma is often that the hull's limitations (the necessary propeller inclination, the maximum propeller diameter, etc.) forces the use of a propeller with high blade speed. A practical limit is about 70 knots for propellers with normal precision, otherwise lower.

Extremely high blade speeds (say 100 knots) is equivalent to super cavitation propellers, i.e. almost the whole blade is cavitating on the suction side. These propellers are not covered in this book.

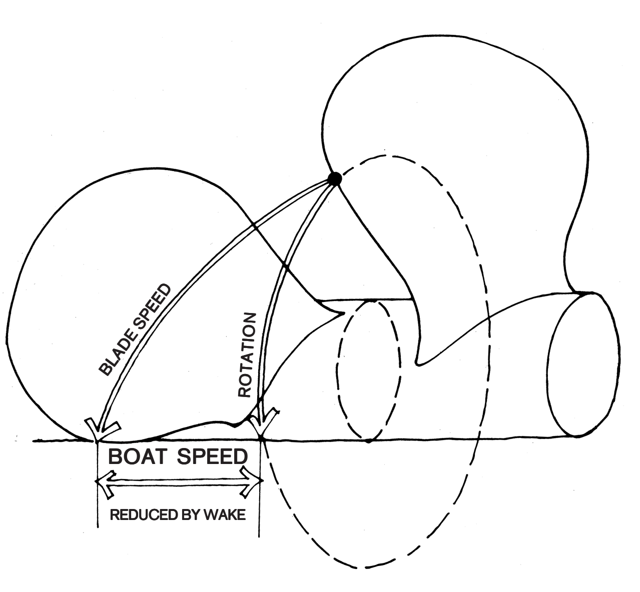


Fig. 27. The propeller blade speed, which is also measured in knots, is not to be confused with the boat's speed.

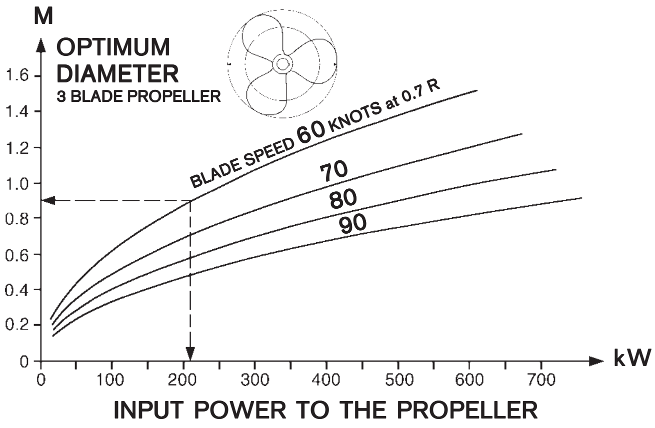


Fig. 28. Propeller diameter depends on the output it shall absorb.

In order to understand the selection of the propeller's main dimensions we show here an example of how one can, using simple rules, obtain a good indication regarding the propeller's diameter, ratio, etc. More exact information can be obtained from the propeller tables in section B.

The output which the propeller is to absorb determines its diameter. We use the blade speed to determine the propeller's characteristics, 55–60 knots gives a slowly rotating propeller, 60–65 a faster and 65–70 a fast rotating propeller.

With an output of 300 kW at the propeller (and boat speed below 27 knots), diagram fig. 28 provides the following relationship between the output and the propeller.

Blade speed (at 70 % radius)	Propeller diameter
Knots	Meter (Ins)
60 70 80	1.08 (42.5") 0.85 (33.5") 0.70 (27.6")

When we have selected the optimal diameter we can then directly obtain the best propeller revolutions (13.1) from fig. 29 and place it in the table.

Our diagrams best apply when the boat's speed is less than 20–25 % of the blade speed.

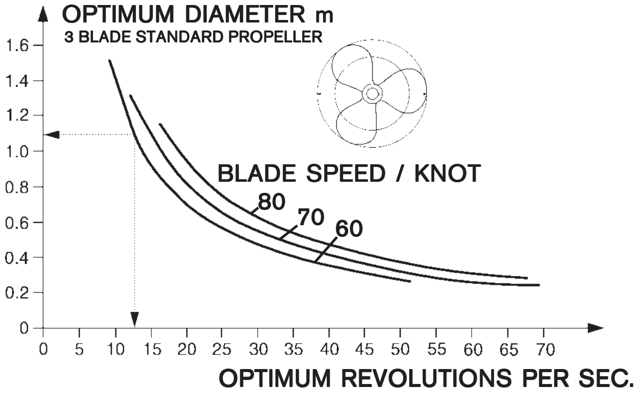


Fig. 29. The propeller revolutions per second depend on the optimal diameter and blade speed.

Required ratio, U, is calculated for an engine with a speed of 2400 r.p.m. = 40 Hz. The blade speed in the example is 60 knots.

$$U = \frac{40}{13.1} = 3.1$$

Blade speed	Propeller-diameter	Revolutions	Ratio
Knots	Meter (Ins)	Hz = r.p.s.	
60 70 80	1.08 (42.5) 0.85 (33.5) 0.70 (27.6)	13.1 19.4 26.9	3.1:1 2.1:1 1.5:1

The estimated efficiency is shown in fig. 30 for different boat speeds, including an assumed **wake of 15 %,** i.e. the propeller is subject to a speed which is 85 % of the boat's speed.

We can now add to our table for propeller data a reading of the efficiency, fig. 30, and enter these values to the right.

Blade speed	Propeller diameter	Revolutions	Ratio	Efficiency
Knots	Meter (Ins)	Hz = r.p.s.		
60 70 80	1.08 (42.5) 0.85 (33.5) 0.70 (27.6)	13.1 19.4 26.9	3.1:1 2.1:1 1.5:1	0.53 0.48 0.44

The power which is given is output × efficiency (e.g. here 300 kW × 0.53 which gives an output power of 159 kW). Therefore we can also calculate **the thrust, T**, from the propeller.

$$\boxed{\textbf{T Newton} = \textbf{efficiency } \times \frac{\textbf{output in kW}}{\textbf{speed in knots}} \times \textbf{1944}}$$

Our values inserted in the formula give:

$$T\ (\text{Newtons}) = 0.53\ \frac{300}{12}\ 1944$$

N = 25758

which completes the previous table:

Blade speed	Propeller diameter	Revolutions	Ratio	Efficiency	Thrust
Knots	Meter (Ins)	Hz = r.p.s.			N
60 70 80	1.08 (42.5) 0.85 (33.5) 0.70 (27.6)	13.1 19.4 26.9	3.1:1 2.1:1 1.5:1	0.53 0.48 0.44	25758 23330 21380

The efficiency also gives us the possibility to estimate the pitch as the propeller's slip is related to the efficiency. See fig. 31.

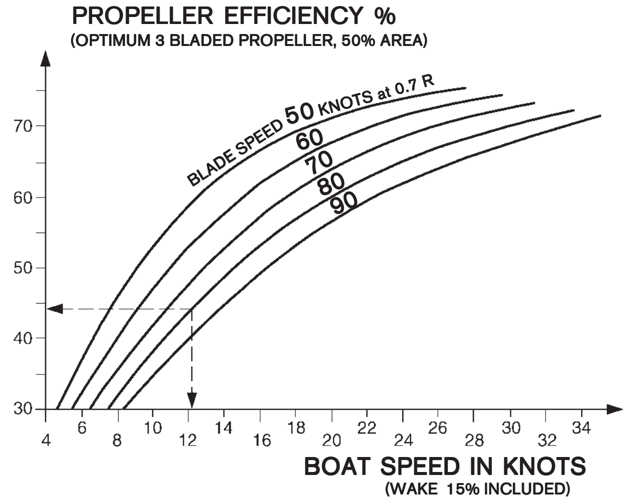


Fig. 30. The propellers efficiency at different boat speeds and blade speeds. In the example the boat speed is assumed to be 12 knots.

The pitch is always somewhat higher than the propeller travel per revolution, i.e.:

$$\text{Pitch (meter)} = \frac{0.514 \times \text{boat speed in knots}}{(\text{rev. Hz})\ (1\text{-slip in boat})}$$

When we enter the values in the formula we get:

$$\text{Pitch} = \frac{0.514\text{x}12}{13.1\text{x}(1-0.355)} =$$

$$\frac{0.514\text{x}12}{13.1\text{x}0.645} = \frac{6.168}{8.499} = 0.73$$

We enter the value in the table:

Blade speed Knots	Efficiency	Slip in boat (wake 15 %)	Pitch, m (ins) (for 12 knots)
60	0.53	0.355	0.73 (28.7")
70	0.48	0.405	0.53 (20.9")
80	0.44	0.450	0.42 (16.5")

We have now got an idea of the main dimensions and shall now **choose the blade area**. We already know that the blade speed very much affects the smallest allowed blade width, see page 7.

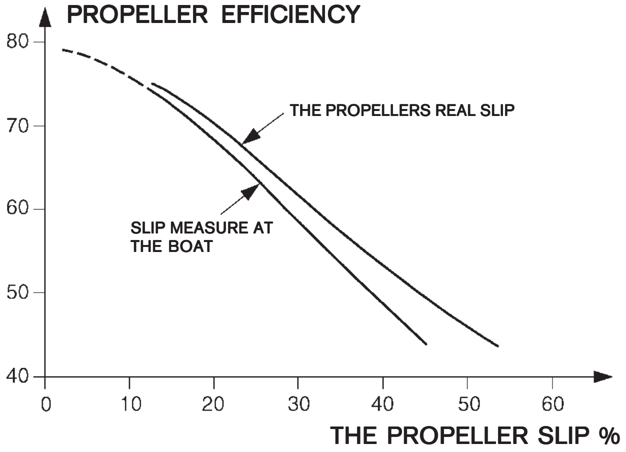


Fig. 31. The propeller's efficiency and slip. The boat speed is assumed to be 12 knots.

As part of the cavitation free permitted vacuum has been "used" by the propeller's thrust, the blade must be made even wider.

For a slowly rotating propeller it is easy to obtain the necessary blade area, partly because the propeller is large and partly because the blades can be thicker in relation to the blade width, see fig. 32.

Our rough rules for the blade area, 0.17 m^2 per ton thrust for lower speeds and a minimum of 6–8 cm^2 per kW for higher speeds (up to 15–20 cm^2 at irregular speed ranges) can be tabulated as per fig. 33 next page.

The boat's speed, 12 knots, divided by the blade speed, 60 knots, gives 0.2 or 20 %. The reading from fig. 33 gives us the blade area of 0.48 for 60 knots.

Blade speed Knots	Boat speed Blade speed	Blade area
60	0.2	0.48
70	0.17	0.68
80	0.15	0.93

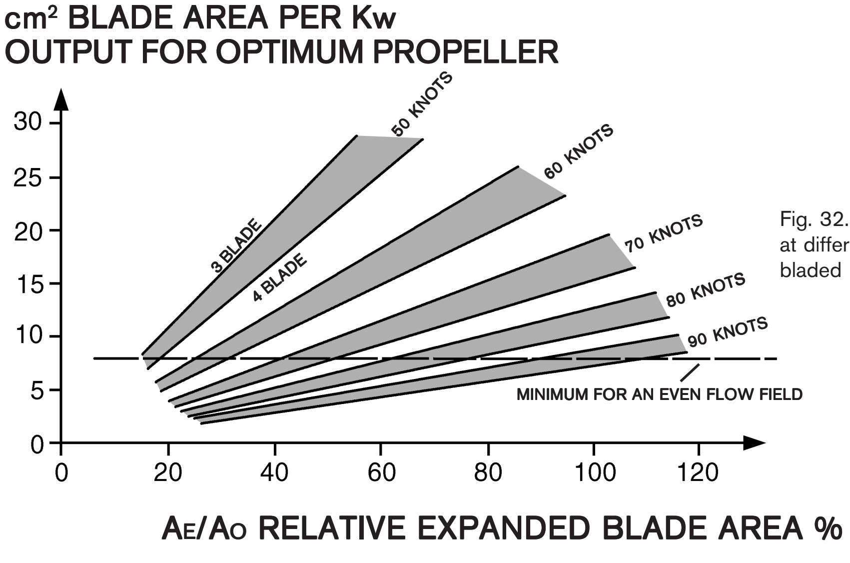


Fig. 32. Blade area in cm^2 per kW at different speeds for 3- and 4 bladed propellers.

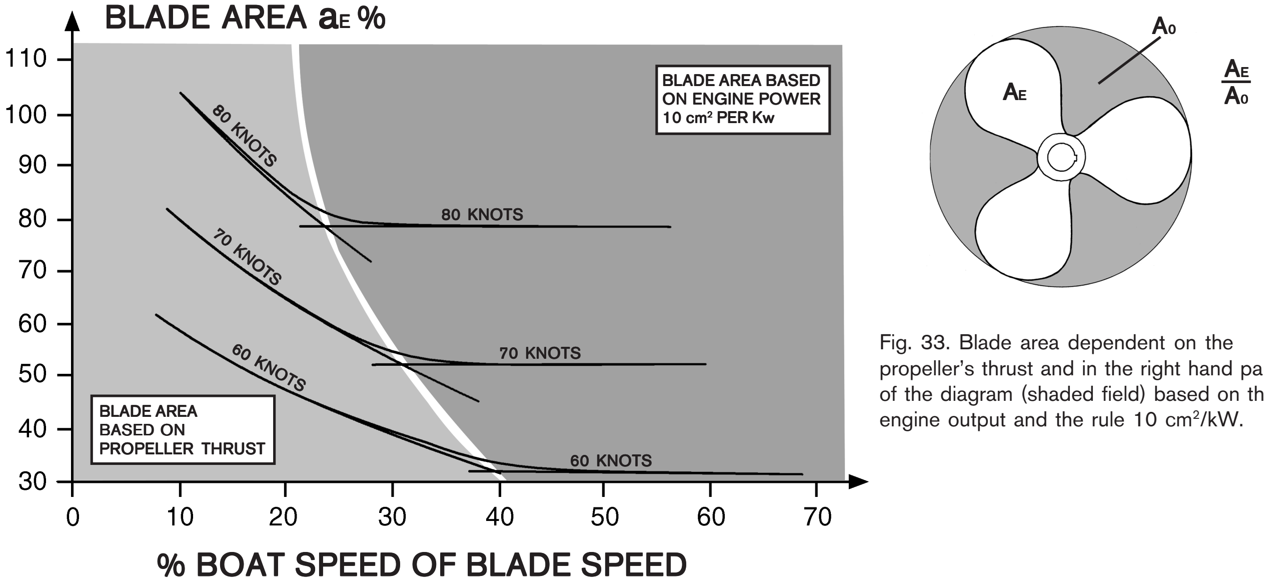


Fig. 33. Blade area dependent on the propeller's thrust and in the right hand part of the diagram (shaded field) based on the engine output and the rule 10 cm^2/kW.

We must also check if the propeller can withstand the speed range's irregularity. We assume in our example that the pulse angle is 5 degrees and examine if any further increase of the blade area is required.
We use fig. 34 and go in with an angle of 5 degrees and the actual efficiency and then read off the information given in the next table.

Blade speed Knots	Efficiency	Smallest permitted blade area	Comments
60	0.53	0.48	is approved
70	0.48	0.88	raised from 0.68
80	0.44	1.96	unreasonably high

One sees that only the slowly rotating propeller can have an unchanged area of 48 %.
A blade speed of 70 knots requires here an 88 % blade area which is too much for a three-bladed propeller compared with fig. 21. which shows that we should use a four-bladed propeller.

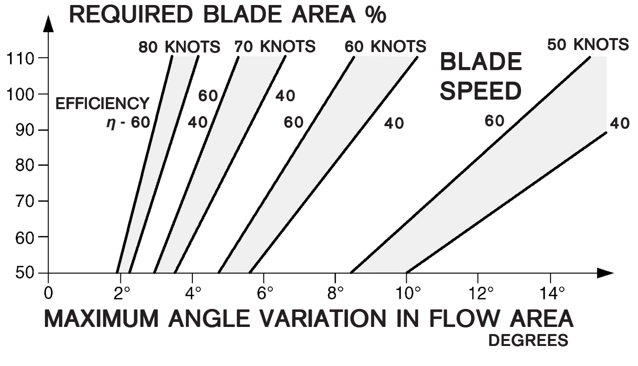


Fig. 34. Blade area in relation to the max. pulsation in the contact flow angle, at different blade speeds and efficiency 40–60 %.

A high speed propeller at 80 knots seems unreasonable. An alternative is to go over to an extreme propeller with a blade speed of 90–100 knots (super-cavitating). Our study shows that we should look at a propeller with a blade speed of 60 or 70 knots, and possibly the range in-between should be studied.

The two suggested propellers which represent a reasonable lower and upper limit can be summarized in a table for further study, as below.

Blade speed, knots	60	70
Diameter, meters appr.	1.08	0.85
Pitch, meters appr.	0.73	0.53
Pitch, diameter (P/D)	0.68	0.62
Efficiency	0.53	0.48
Thrust, Newton	25758	23330
Revolutions, Hz	13.1	19.4
Reduction (engine 40 Hz)	3.1	2.1
Blade area	0.48	0.88
Number of blades	3	4

Carefully note that the table's value is an indication and that a new more detailed study must be done. For example, we speak of a 48 % efficiency for our propeller at 70 knots blade speed, perhaps a truer value is 46%.

More accurate values are given in the propeller tables in booklet B, but even here it applies that they should not be regarded as binding or that the values are exact. Propeller data is also related to design philosophy, (release at the tip of the blade), material, manufacturing precision, the cavitation margin, matching of the propeller to the total loading, etc.

Hull forms

From the descriptions of propellers we continue here with a short presentation on hull forms in general and definitions of the hull types.
The majority of boats can be divided into three main groups, they are:

Displacement boats, Semi-planing boats, Planing boats

There are variants within these main types but they cannot be covered by our general recommendations.

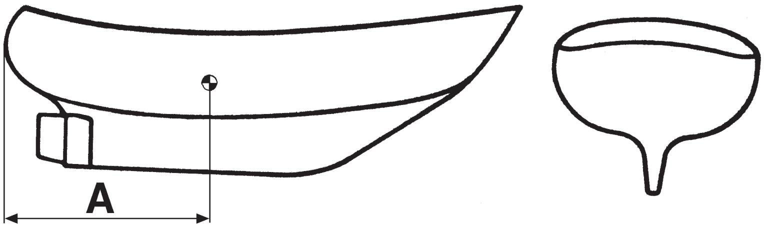
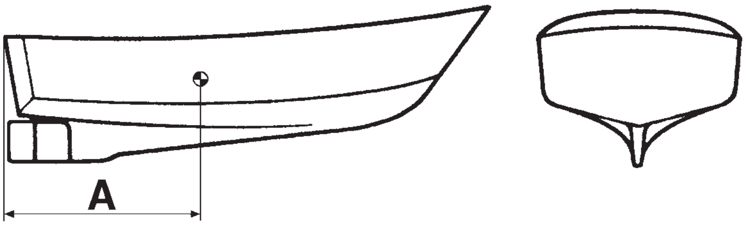


Fig. 35.
Displacement boat hull type
A = the distance from the centre of gravity to the stern is relatively long.

Displacement boats are, as the name implies, boats that displace water, that is during running they push away as much water as they weigh. They often have a tapering stern with a small support area. At speed, the water is forced to the sides. These boats run smoothly but the speed is always below the so called speed limit curve, L page 16, even if a very powerful engine is used.

Fig. 36.
Semi-planing boat hull type
A = the distance from the centre of gravity to the stern is moderate.



Semi-planing boat hulls have a relatively wide and supporting stern which allows the boat to be partly lifted from the water at speed. The wetted area is reduced and the resistance to the forward movement reduced too. This type of hull is a compromise between a purely displacement hull and a planing hull and it combines the characteristics of a smooth running hull with rather good speed possibilities.

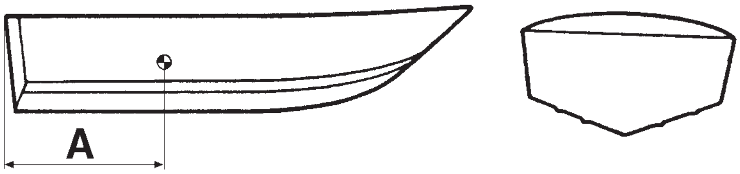


Fig. 37.
Planing boat hull type
A = the distance from the centre of gravity to the stern is relatively short.

The planing hull is designed so that at a certain minimum speed it is lifted and planes on the water. As soon as the planing speed is reached the resistance against the forward driving power is reduced and the boat then attains a high speed with a relatively low output requirement. To be able to come up to planing speed the so-called planing step must be passed, which requires a relatively high engine output.

Hull definitions

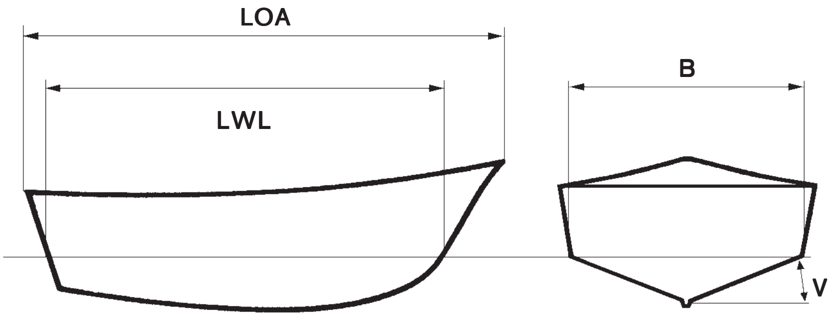
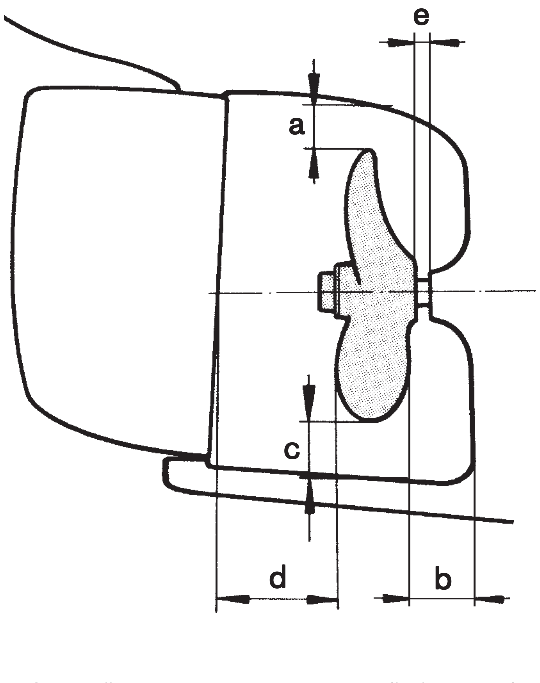


Fig. 38. Hull definitions
LOA = Total length
LWL = Length at waterline
B = Width at waterline
V = Bottom angle at the stern

This picture and the abbreviations explain the more common measurement definitions for a boat hull.

The correct choice of all the components, that is the hull, engine, reverse gear (with reduction) and propeller give the optimal result–a basic requirement for the maximum usage from the separate components. The best economical result also follows if these requirements are fulfilled.

Propeller space



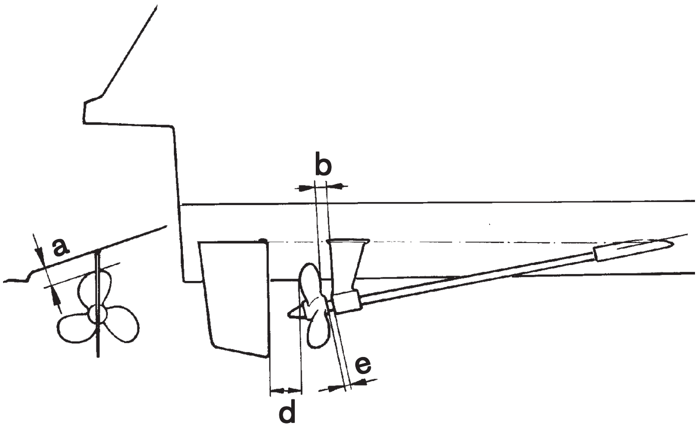


Fig. 39. A propeller arrangement, common for displacement boats
R = the propeller radius
D = the propeller diameter
a = 0.10D.

Fig. 40. The common propeller arrangement for a planing hull
b = 0.15D
c = 0.03D
d = 0.08D
e = approx 1 x shaft diameter

In order for the propeller to work in the intended way, the hull must be formed so that it does not disturb the water flow and that sufficient space exists between the propeller and the surrounding parts.

The pictures and texts above give the propeller's minimum distance to the hull, keel, skeg and rudder. When classing, there are special rules that must be followed.

Single and twin installations

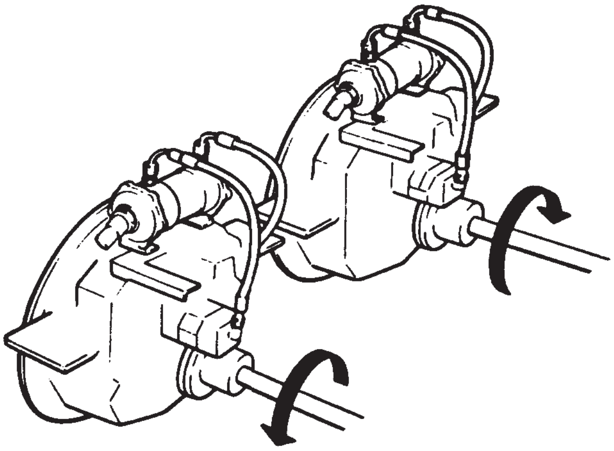


Fig. 41. Propeller rotation in a twin installation seen from the aft.

The most effective method of propulsion is generally achieved with a single installation. If more power is required than what is possible with a single installation, then two engines, each with a separate propeller shaft can be fitted.

Two (or more) engines which are coupled to a common transmission and one propeller is another possibility. Improved manoeuvring is achieved with twin installations and separate propellers as the power output can be controlled separately and independently for each engine. One engine can be run ”reverse” and the other ”forwards” when entering moorings, for example.

The speed is calculated in the same way for twin (or more engines) installation as with a single installation but using the sum of the engines output.

Propeller rotation

For a single installation a right or left hand rotating propeller can be chosen. The rotation direction is, however, often dependent on the type of reverse gear being used.

For twin installations the starboard propeller should always rotate clockwise and the port propeller anti-clockwise seen from the aft forward. Otherwise there is a risk that air bubbles are drawn down into the water between the two propellers which can cause cavitation.

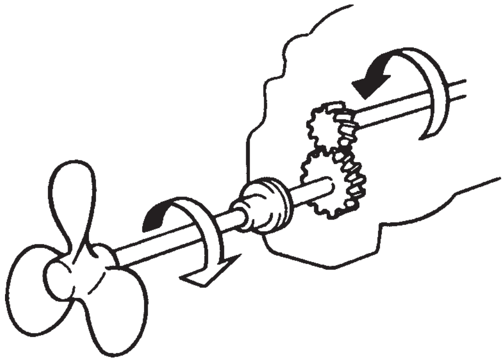


Fig. 42. The propeller shaft usually has lower revolutions than the engine.

Choice of reduction ratio

As a rule the largest possible ratio should be chosen for slow-going displacement boats. It then follows that the propeller diameter can also be relatively large with high thrust within the applicable speed range.

Depending on the hull type and speed range a smaller ratio can be chosen for higher speed, if required.

This is based on the best possible thrust within the respective speed range. If the ratio is chosen outside of the recommendations the thrust will be lower than the optimum calculated power. The boat’s top speed is not necessarily affected.

A check must always be done that the hull has sufficient space for the propeller according to figs. 39 and 40.

Diagrams and examples: Displacement Boats

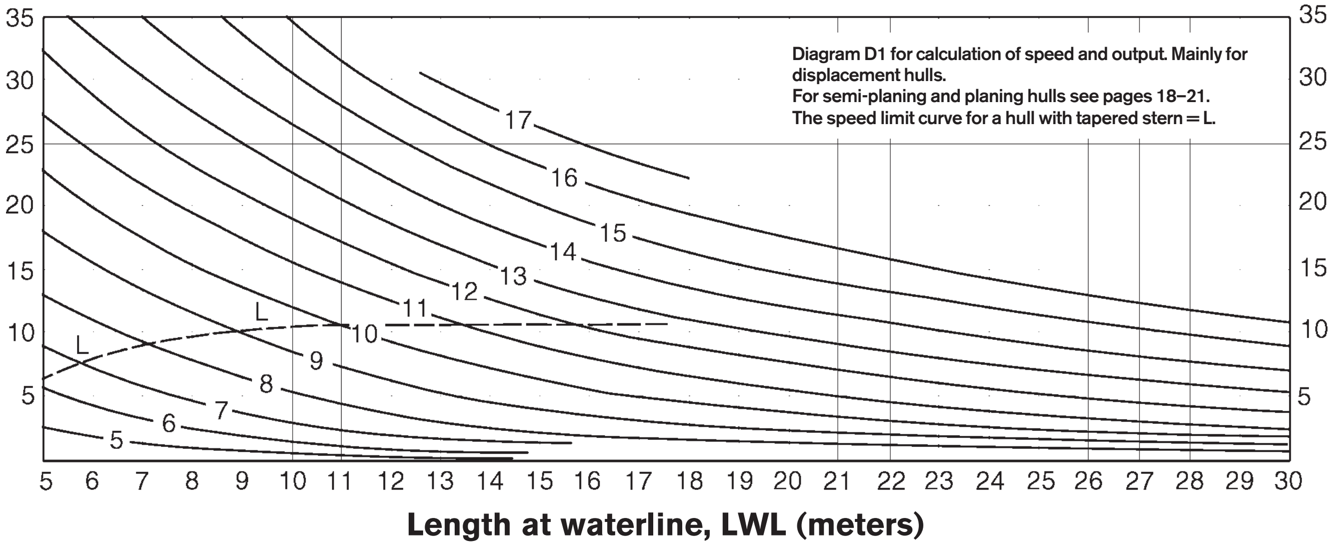


Diagram D1 for calculation of speed and output. Mainly for displacement hulls.
For semi-planing and planing hulls see pages 18–21.
The speed limit curve for a hull with tapered stern = L.

Required output and speed

The boat's data, operation conditions and required speed can be known but **the required output is unknown** for the intended speed range. This situation is covered in examples A1, B2, B4 and B5.

In another case where the boat's data and output are known, the question **What speed can be reached?**, is covered by examples A2, B1, B3 and B6. For all cases, the diagrams D1, D2, D3 and D4 can be used.

Using the diagrams

When using our diagramsone can relatively simply calculate the boat speed for that particular hull. In order to arrive at the correct result, the boat's main operating conditions must be determined. A number of examples are included in the following text.

Example A1
The required output is to be found.

Displacement hull

Boat data LWL = 15 m
Displ = 54 tons (metr)
Required speed about 10 knots.

Follow the line LWL = 15 (in the diagram D1) straight upwards, until the meeting point on the 10 knot line. Go straight out to the left, and Q = 6.1 can be read on the Q scale.

Definition:

$$Q = \frac{\text{Hp}^{\ 1)}}{\text{Displ (metr)}}$$

1) Available output at the propeller

Where it follows:

$$6.1 = \frac{\text{Hp}}{54} \qquad \text{Hp} = 6.1 \times 54 = 329{,}4$$

This output requirement is given as available output at the propeller. In our tables we have quoted the flywheel output. The difference is that the losses in the reverse gear (abt. 4%) and in the propeller shaft sleeve (abt. 3 %) (total 7 %) have been deducted from the flywheel output to arrive at the "available output" at the propeller. When we are looking for the flywheel output in this case we divide 329.4 by 0.93 which gives **354.2.**
An engine that has a **flywheel output = 365 hp or 340 hp at the propeller and can be very suitable. It also has a small excess output.**

Example A2
The boat speed is to be calculated.

Displacement hull

Using the diagram (D1) the estimated speed can be calculated when the boat's data and the available output are known. **Note, that the diagram applies mainly for displacement boats.**
The diagram applies only if the ratio has been chosen so that optimal propeller revolutions for the required speed can be reached and that the boat hull has sufficient space for the propeller.

For a boat with data LWL = 13.0 m
Displ = 16 tons
Recommended engine has 240 hp on propeller shaft.

1) Calculate the factor $Q = \frac{\text{Output (hp)}}{\text{Displ (tons)}}$

i.e. $\frac{240}{16} = 14.99$

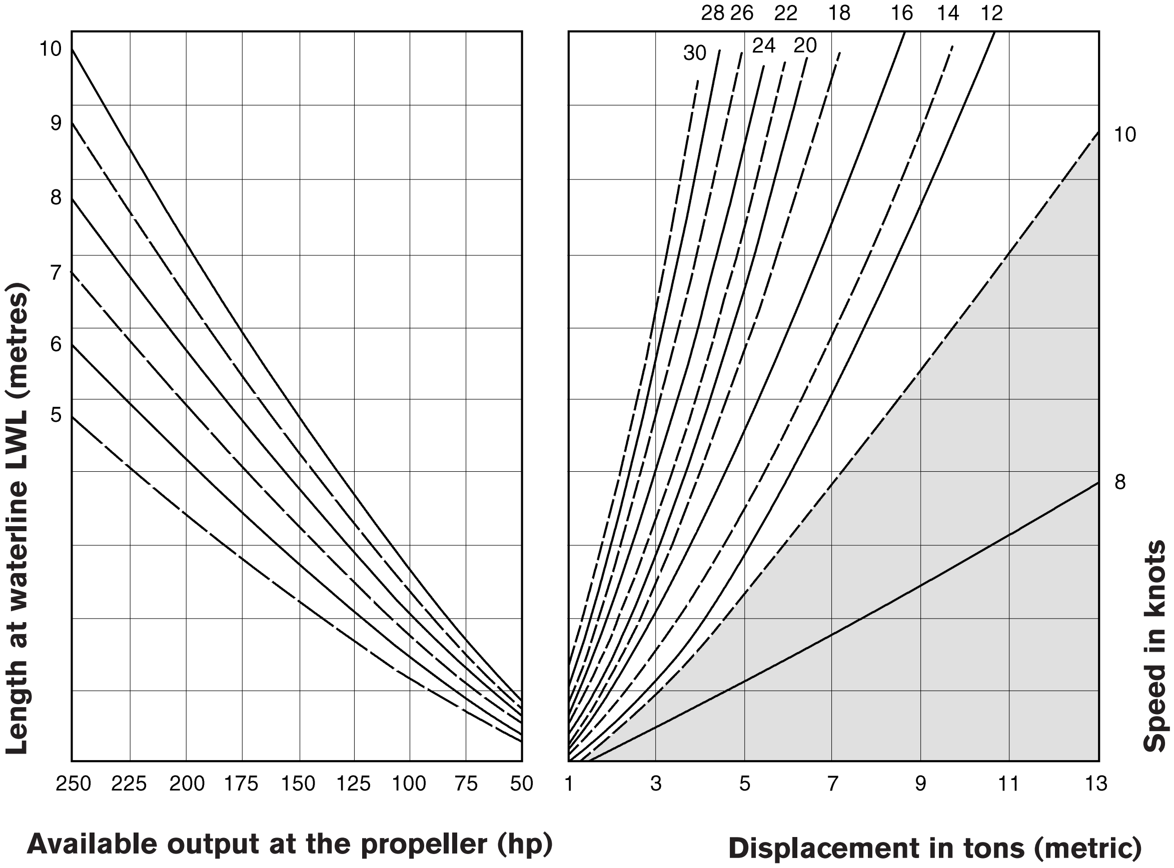
2) Draw a line horizontally from the obtained Q value to the line in question for LWL in the diagram D1.
3) Read off the speed at the meeting point between the two lines. In our example, about 12.3 knots.
4) NOTE! The calculated speed 12.3 knots is valid only on the condition that the boat has a relatively "speed suitable" hull. If the boat has a tapered stern the speed limit curve "L" is applicable which means that the boat's maximum speed will be about 11 knots. A certain output reserve will in the latter case be available.

Diagram D2 for calculating the speed and/ or output.
Planing and semi-planing hulls.
Output range 50–250 hp.

The diagram applies for speed calculations for conventional hulls.

Basic factors

–LWL should be = LOA × 0.85
–The relationship LOA/Width = 2.8–3.2
–The maximum hull angle at the transom shield = 15°–17°
–The displacement should include load and passengers
–The total output at the propeller = flywheel output × 0.93
–Hull form–V-bottom with round or sharp chines



Example B1
The boat speed is to be determined

Semi-planing hull (double-ender)

Engine 100 hp at Flywheel
Boat data LWL = 7.5 m
Displ = 3.7 tons (metric)

For the engine the output is 100 hp. Available output at the propeller, is 100 × 0.93 = 93 hp.
Use diagram D2 to find the speed range.
Draw a line straight upwards from the output number 93 hp until it cuts a hypothetical curve line for LWL = 7.5 m. From this point straight to the right to a vertical line for the displacement 3.7 tons. The latter meeting point will be on the curve line for approx. 12.5 knots.

Example B2
The required output is to be determined

Semi-planing hull

Boat data
LWL = 7.0 m
Displ = 3.2 tons (metric)
Required speed 16–18 knots

Use diagram D2. Go in with a vertical line from displacement 3.2 tons straight upwards to the meeting point for a hypothetical speed curve between 16 and 18 knots.
Go from this meeting point straight to the left to the curve for LWL = 7 m. Straight downwards from the latter point the output 125 hp can be read, which is the available output at the propeller.
To get the flywheel output one should divide by 0.93

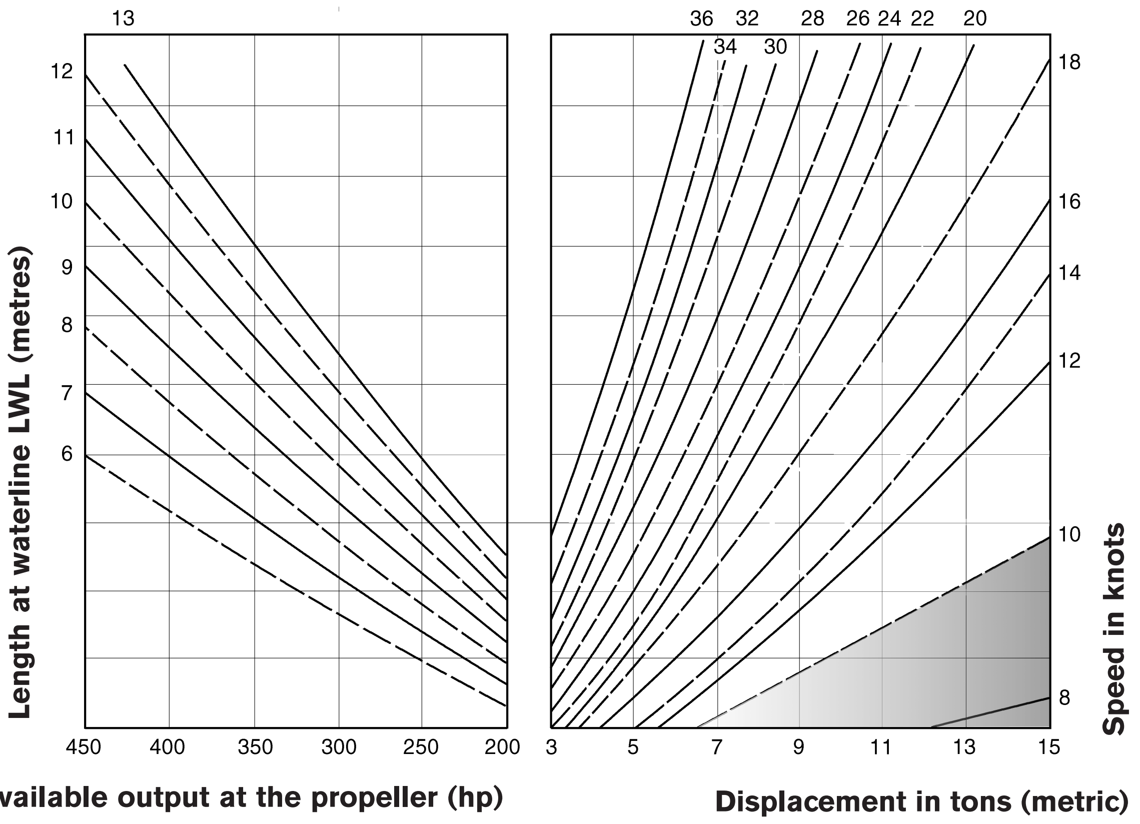
$$\frac{125}{0{,}93} = 134.5 \text{ hp}$$

Diagram D3 for calculating the speed and/ or output.
Planing and semi-planing hulls.
Output range 200–450 hp.

The diagram applies for speed calculations for conventional hulls.

Basic factors

–LWL should be = LOA × 0.85
–The relationship LOA/Width = 2.8–3.2
–The maximum hull angle at the transom shield = 15°–17°
–The displacement should include load and passengers
–The total output at the propeller = flywheel output × 0.93
–Hull form–V-bottom with round or sharp chines



Example B3
The boat speed is to be determined

Planing hull

Boat data LWL = 8.8 m
Displ = 6.0 tons (metric)
2 engines 200 hp each at Flywheel are to be fitted

Two engines give 2 × 200 = 400 hp. Available output at the propeller will be 400 × 0.93 = 372 hp.

In this case diagram D3 should be used.

From the left lower edge a line is drawn from output = 372 hp straight upwards to the curve for LWL = 8.8. From this meeting point straight to the right to a line for the displacement = 6.0 ton. The latter meeting point shows the speed = approx. 28.5 knots.

Example B4
The required output is to be determined

Semi-planing boat

Boat data LWL = 9.0 m
Displ = 8.0 tons (metric)
Required speed = approx. 16 knots

Use diagram D3. Draw a line from displacement = 8 tons straight upwards until it cuts the speed curve for 16 knots. Then go straight to the left to the curve for LWL = 9.0 m.

Read off, straight downwards, the required output at the propeller = 250 hp.

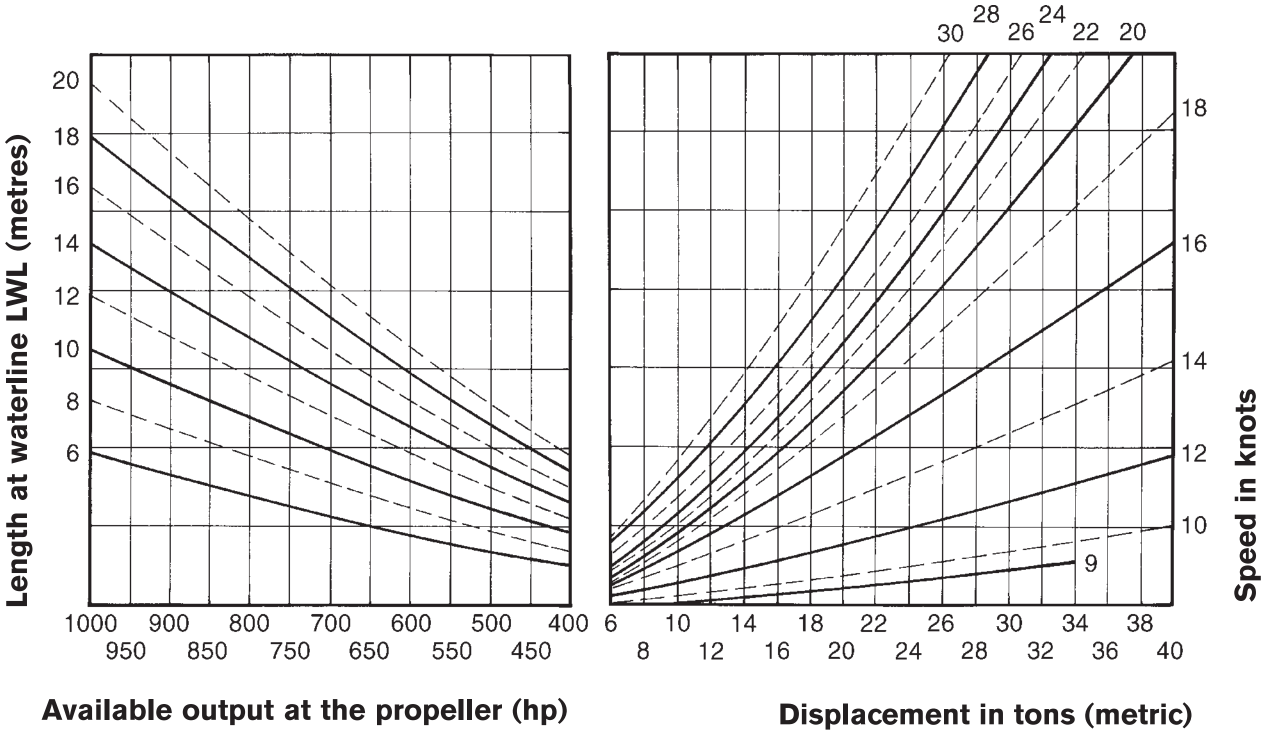
Converted to flywheel output $\frac{250}{0.93} = 168.8$ hp

In this case one can choose two engines which gives approx. 2 × 140 = 280 hp.

This gives a reserve output which could be suitable with regard to driving extra equipment (pumps, alternators etc.).

Diagram D4 for calculating the speed and/or output. Planing and semi planing hulls.
Output range 400–1000 hp.
The diagram applies for speed calculations for conventional semi-planing and planing hulls. Tolerance 5 % within the speed range 12–28 knots where correct data is used.

Basic factors for the boat
–LWL should be = LOA × 0.87
–The relationship LOA/Width = 2.8–3.2
–The maximum hull angle at the transom shield = 15°–17°
–The displacement should include load and passengers
–The total output at the propeller = flywheel output × 0.93
–Hull form = V-bottom with round or sharp chines.



Example B5
The required output is to be determined

Semi planing hull

Boat data LWL = 14 m
Displ = 28 tons
Required speed = 15 knots

In this case the diagram D4 is used. This diagram permits calculation for outputs up to 1000 hp. In all other respects the diagram is read in the same way as diagram D2.
Required output is read off at 640 hp, which expressed in flywheel output is $\frac{640}{0.93} = 688$ hp
Divided between two engines we get 344 hp for each.

Example B6
Speed is to be calculated

Semi planing hull

Engines 2 × 367 hp at Flywheel
Boat data LWL = 13.5 m
Displ = 25 tons

As in example B5 diagram D4 is used as the engine output requires this.
For each engine the flywheel output is 367 hp. Expressed in available output at the propeller 367 × 0.93 = 341.3 hp. For both engines 682.6 hp. Mark a point for 682.6 hp in the left part of the diagram and draw a line straight up from this point to a constructed line for LWL = 13.5.
Thereafter draw a line from this meeting point straight to the right (parallel with the diagram's lines) to the line for 25 tons displacement. The lines meet each other somewhat above the 16 knots curve.

Operation conditions

For each engine there is an output setting for three different types of operation conditions called Rating 1–5. It is important that the right condition is chosen in each case. We quote here our general recommendations.

Marine Propulsion Engine Rating Definitions

Rating 1

Heavy Duty Commercial
For commercial vessels with displacement hulls in heavy operation.

Typical boats: Bigger trawlers, ferries, freighters, tugboats, passenger vessels wit longer journeys.

Load and speed could be constant, and full power can be used without interruption.

Rating 2

Medium Duty Commercial
For commercial vessels with semiplaning or displacement hulls in cyclical operation.

Typical boats: Most patrol and pilot boats, coastal fishing boats in cyclical operation, (gillnetters, purse seiners, light trawlers), passenger boats and coastal freighters with short trips.

Full power could be utilized maximum 4 h per 12 h operation period. Between full load operation periods, engine speed should be reduced at least 10% from the obtained full load engine speed.

Rating 3

Light Duty Commercial
For commercial boats with high demands on speed and acceleration, planing or semiplaning hulls in cyclical operation.

Typical boats: Fast patrol, rescue, police, light fishing, fast passenger and taxi boats etc.

Full power could be utilized maximum 2 h per 12 h operation period. Between full load operation periods, engine speed should be reduced at least 10% from the obtained full load engine speed.

Rating 4

Special Light Duty Commercial
For light planing craft in commercial operation.

Typical boats: High speed patrol, rescue, navy, and special high speed fishing boats. Recommended speed at cruising = 25 knots.

Full power could be utilized maximum 1 h per 12 h operation period. Between full load operation periods, engine speed should be reduced at least 10% from the obtained full load engine speed.

Rating 5

Pleasure Duty
For pleasure craft applications only, which presumes operation by the owner for his/ her recreation.

Full power could be utilized maximum 1 h per 12 h operation period. Between full load operation periods, engine speed should be reduced at least 10% from the obtained full load engine speed.

Notes

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