Transmission propeller driveline

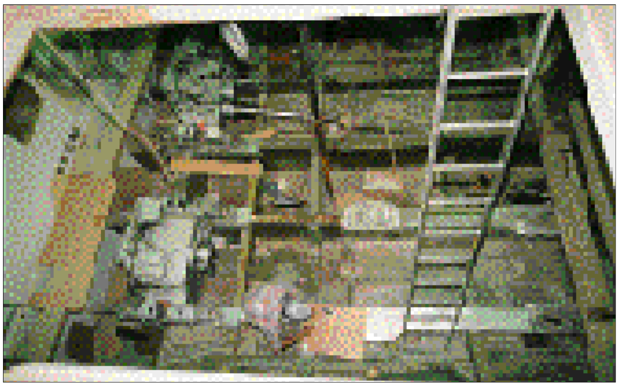
Engine horsepower, propeller diameter, and propeller pitch are often the subjects of debate concerning the performance of motor yachts equipped with conventional propeller drivelines. However, many components come into play among these elements of the propulsion system that can influence the efficiency of engine installation. A simple description of these elements, their size, and function, are useful to better understand their operation and maintenance.

The various components of a propeller driveline exist in order to convert the power of the engine into the thrust of the propeller. The conventional driveline generally incorporates the following equipment, starting from the engine: the gearbox, the coupling, the propeller shaft, intermediate bearings when needed, the stern gland or the shaft seals, the stern tube and finally, the strut with a cutlass bearing. To achieve a consistent and reliable system, all of the components must be selected and sized according to the engine horsepower, RPM, and the distance between the engine and the propeller.

THE GEARBOX

A transmission system is required to convert engine power into propeller thrust. It generally consist of a reversing gearbox mounted onto the engine housing and incorporating a reduction gear. Their main functions are to control the rotation direction of the shaft and that of the propeller to achieve reverse or neutral position, to reduce the shaft speed, increase the shaft torque, and match the engine rpm to the optimum rotation speed of the propeller to the hull type. The reversing mechanism of a gearbox can be managed by a mechanical, hydraulic or electric system. A mechanical gear box uses cone-shaped bevel gears between the input and output shafts. The epicyclic reverse/reduction hydraulic gearbox works on the same principles as an automatic gearbox in an automobile. Several alternative types of transmissions are available. Co-axial gearboxes have an output shaft that is in line with the engine crank shaft, but it can be lower, for example, as in “drop center “ gearboxes or the vee drives, and U or down-angle drives. The engine can then be mounted horizontally and/or further aft on the yacht. This gives the naval architects and designers more latitude to position the various components of the propulsion system and to optimize the weight distribution and/or the angle of the propeller shaft hence improve the efficiency of the propulsion system. It is important to remember that the location of the longitudinal center of gravity can dramatically affect the performances of a motor yacht, especially for planing hulls. The choice of

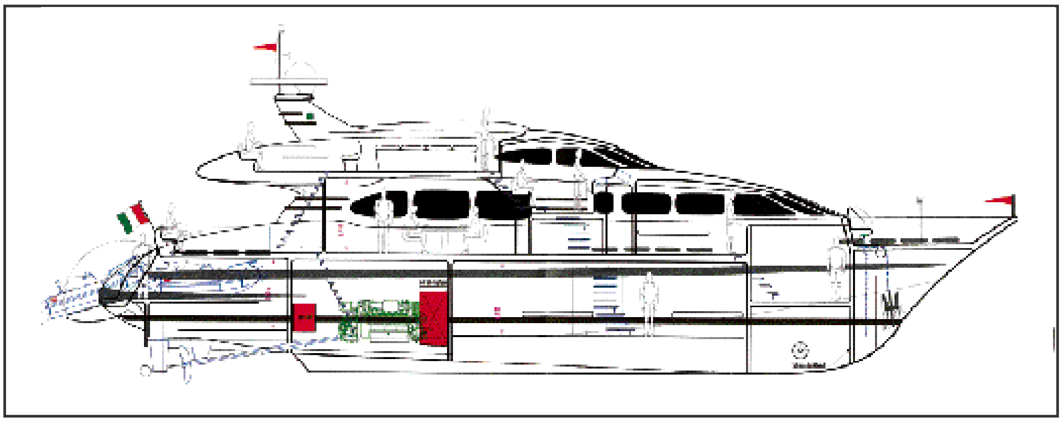
The stern tube bearing can be checked with a feeler gauge.



The installation of an engine room with the fitting of the Vee-Drives and one shaft.

The role of a strut is to support the shaft forward of the propeller. Therefore its shape is very important.

Because of the lack of space, the removal of a shaft or gearbox have to be thought out at the design stage.



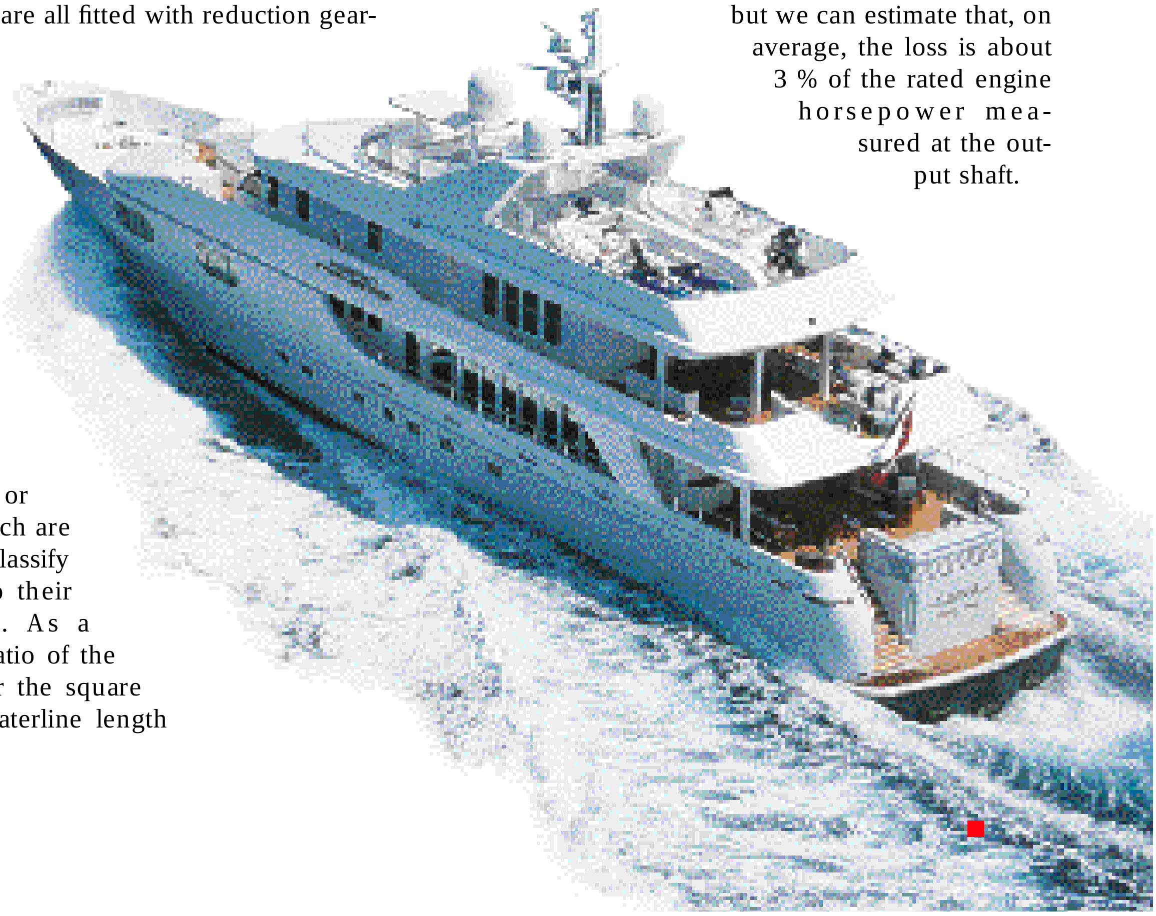
A direct line installation moves the engine and the center of gravity forward.

reduction ratio is particularly important to optimize performance and is dictated by the three following parameters:

- The rated RPM
- The operating speed of the yacht
- The maximum allowable diameter for the propeller.

While some of the small fast planing crafts can be fitted with a direct drive and small diameter propellers, this arrangement cannot be used on the heavier vessels. To achieve the necessary lift to go over the hump and then plane, the heavier yachts need more thrust. It can be achieved by the installation of a larger diameter propeller which transmits a higher torque. The propeller torque increases proportionally to the reduction ratio. The displacement and semi-displacement yachts are all fitted with reduction gearboxes to achieve an optimum propulsive output. To simplify, the lower the speed of a yacht, the lower the rotation speed of the propeller shaft needs to be. The reduction ratio is determined according to speed/length ratio, or Froude number, which are universally used to classify yachts according to their operating speed. As a reminder, it is the ratio of the speed in knots over the square root of the static waterline length in feet. For crafts with speeds under 35 knots, the increase of the reduction ratio generally allows the use of a propeller with a larger diameter while keeping the same engine power and weight achieving about the same fuel consumption. The reduction ratio used on yachts are generally between 2:1 and 3:1 with numerous intermediate ratios. During the design process of a propulsion system, it is a lot simpler and more economical to optimize the diameter of the propeller according to the standard reduction ratio available from the gearbox manufacturers rather than to order a one-off gearbox with a custom ratio.

As with any mechanical system, a gearbox absorbs energy and thus generates power losses. The losses vary according to the gearbox type, the reduction system employed, and other factors such as the oil viscosity, temperature and quantity. The wide band of varying efficiency makes it difficult to give a precise figure for gearbox efficiency, but we can estimate that, on average, the loss is about 3 % of the rated engine horsepower measured at the output shaft.



THE COUPLING

The gearbox and the propeller shaft are connected with a coupling that can be either rigid or flexible. The rigid coupling is assembled with two flanges bolted together. The alignment of the shaft is made by taking measurements of the gaps between the gearbox output and the propeller shaft coupling flanges. These gaps cannot exceed certain tolerances to limit the possibility of excessive wear or damage of the gearbox. These tolerances for angular misalignment, expressed in thousandth of an inch, are measured with a feeler gauge and should not exceed 0.0005 inches per inch of the flange's outside diameter. This alignment should be carefully and methodically carried out by trained technicians. A poor alignment can generate high stresses on the various elements of the driveline and result in their premature wear and even breakage of some elements. High vibrations of the propeller driveline are generally associated with misalignment. To eliminate or compensate these alignment defects, it is possible to install a flexible coupling or constant velocity joints in place of this rigid coupling described above. Several models are available on the market. Their selection must be carried out with great care to match the power and torque to be transmitted and the rotation speed of the shaft.

THE PROPELLER SHAFT AND BEARINGS

This central element of the propeller driveline must be able to withstand the torsional stress created by the engine torque and the propeller resistance. Propeller shafts used to be made of mild steel or bronze. Today, they are made of various grades of stainless steel whose mechanical properties, and perhaps more importantly, whose corrosion resistance can vary dramatically. During the inspection of a propeller shaft, crevice corrosion can be found at the stern tube and/or strut bearings. It is therefore recommended that the shafts be drawn and checked at least every five years. Nowadays, carbon fiber composite shafts can be manufactured and fitted on board some high tech crafts.
The following formula can be used to calculate the shaft diameter :

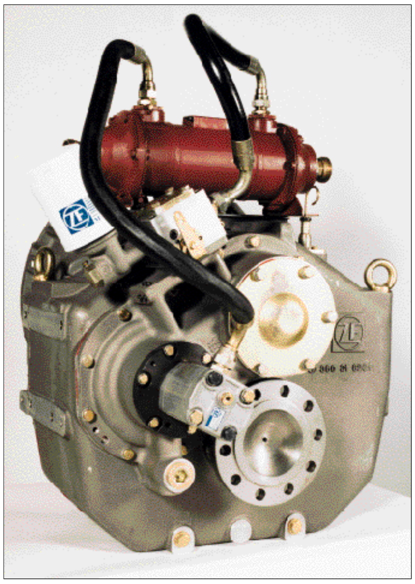
$$D = 685C\sqrt[3]{\frac{P}{N}}$$

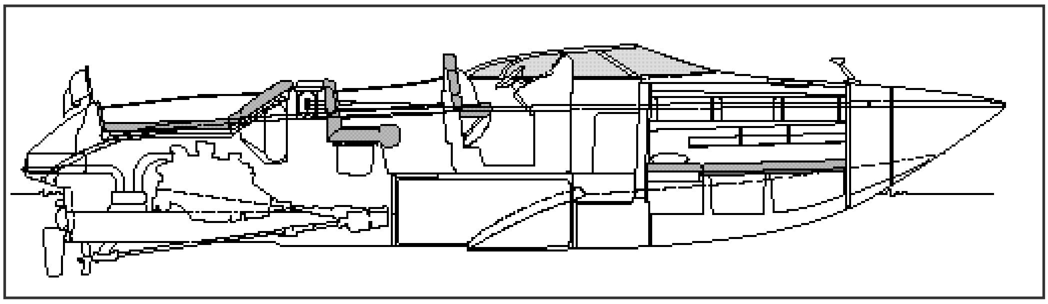
D : diameter in inches
P : engine output in horsepower
N : shaft rpm
C : material factor varies with grade of stainless steel used

As a rule of thumb, it is considered that the shaft diameter must not be less than the diameter of the propeller divided by 14, and the maximum distance between two bearings must not be more than 48 times the diameter of the shaft. These rules of thumb are to be used with the great care and cannot replace an engineering calculation. However they can be useful for a quick check or estimate of the sizing of a


Silent propeller vee struts.

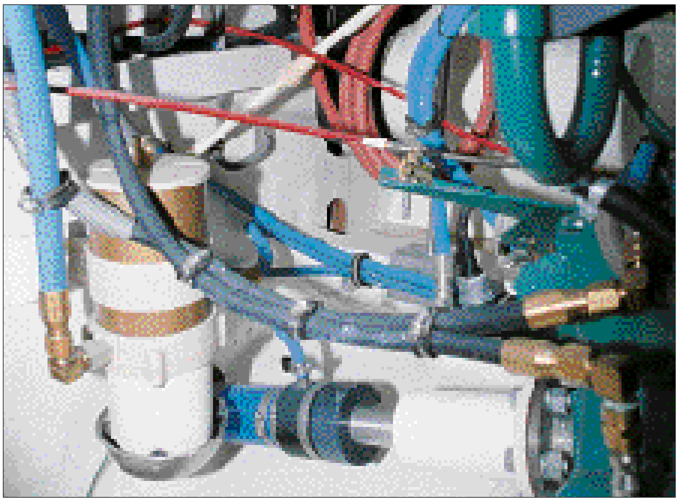

Cast struts.


Hydraulic reverse / reduction gearbox.



The V-drive allows the installation of the engine further aft while preserving the advantages of a conventional driveline.

conventional propeller shaft. To avoid creating a hard spot with the associated stress concentrations, it generally recommended that the bearings should be located at least 20 or more shaft diameters apart. An intermediate thrust bearing, or pillow block, can be installed to absorb the propeller thrust while relieving the gearbox of an important stress and increasing its life expectancy. We must know that for each horse developed by the engine, the shaft bears a thrust of about 30 pounds. The propulsion system must be able to withstand a thrust of about 15 tons for a 1000 hp engine. In terms of efficiency, it is generally admitted that each bearing generates a power loss of about 1%.



The stuffing box must not be leaking and is to be frequently monitored.

THE STERN TUBE

The stern tube allows the passage of the propeller shaft outside the hull. It can be fitted with a cutless bearing but it is always equipped with a stuffing box or shaft seal. This drive train component must be the object of special attention, checked regularly and adjusted to avoid water ingress or even worse, a breaking of the whole. The conventional stuffing boxes are mounted on the stern tube with a rubber hose attached with metal hose clamps. This hose must be made of a good quality rubber and maintained in good condition, without any crack or other defect. The clamps must be stainless steel and mounted by pairs. A single clamp can become loose or break and them create substantial ingress of water causing dramatic consequences. In the last few years these stuffing boxes have been gradually replaced by shaft seals or lip seals. These systems are easier to maintain, but they must be regularly checked and the bellows replaced as soon as defects are detected.

THE STRUT

Outside of the hull, the propeller shaft is normally supported by one or two struts. These brackets are generally made of bronze or stainless steel, they can be of the single arm or vee strut type. On FRP hulls, the struts can be through-bolted and/or laminated, but in all cases these areas have to be reinforced to achieve suitable rigidity and strength. The water-lubricated cutless bearings on the struts have a shell manufactured from a metal (stainless steel, naval brass or bronze) or non-metallic phenolic resin, with a grooved rubber sleeve. This rubber, although very tough and resistant, must withstand high loads and chemical attack. Therefore, the condition and wear of the rubber sleeve must be monitored on a regular basis. A maximum clearance, between the shaft and the sleeve should not exceed 0.6 inch for shafts between 2 and 4 inches in diameter. Here again, excessive wear will generate vibrations and fatigue of the various components of the drive train.

The gearbox and all the components of the shaft play an important part in the performance and reliability of a motor yacht. They must be selected with good judgment and be maintained with care to preserve safety and comfort while cruising.

By Eric A Ogden.
Photos : Renaud Jourdon