Propellers

As mentioned in the introduction, propellers come in a wide variety of shapes and sizes and are fabricated from a wide range of materials. Some of the terminology used in describing these widely different geometries is identified in Figure 1. The details of the geometry and, more generally, the overall design, are important in determining the performance, ruggedness and reliability of the propeller. A well-designed propeller can achieve an efficiency of 80% at the design speed though that value declines under off-design conditions. As with all turbomachinery it is important not only to determine the design conditions and to make appropriate design decisions, but also to determine how much operating time is to be spent at off-design conditions. The latter can often determine the frequency of maintenance required.

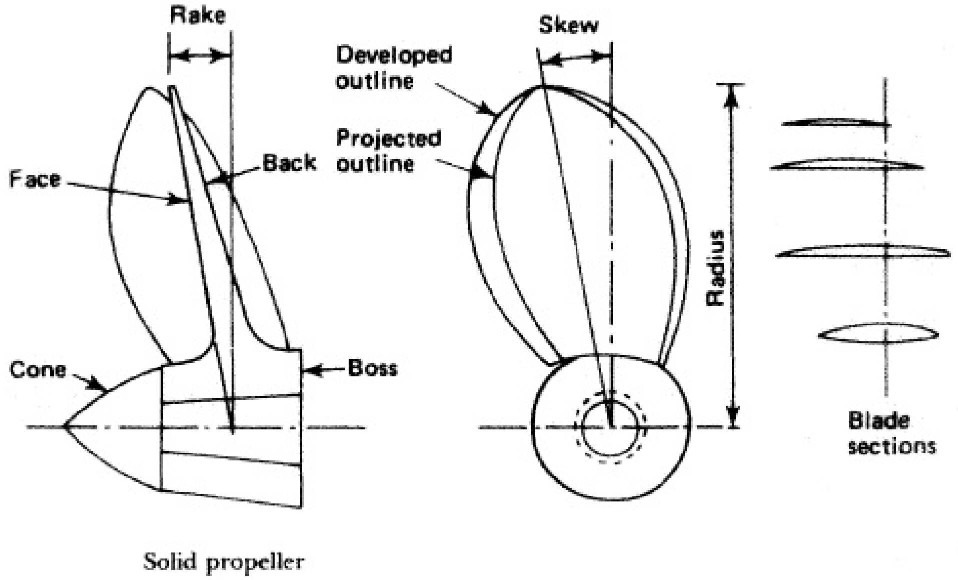

Figure 1: Geometric propeller characteristics.

Here we provide a brief summary of some of the design considerations. Both aircraft and marine propellers come in a variety of numbers of blades, anywhere from two to six or more. With larger numbers of blades the effect of the wake of one blade on the following blade can significantly reduce performance. Furthermore, both ships and planes can have a number of propellers. Though the modern trend in both instances is toward the fewest practical number of propellers (namely one), ships are sometimes equipped with three and commercial passenger aircraft have at least two for safety reasons.

As well as the number of blades, the propeller radius and blade planform area are primarily determined by the rotational speed and the thrust needed to propel the airplane or ship. As well as this fluid mechanical performance analysis, a structural analysis is needed to ensure the integrity, reliability and durability of the propeller. Often the competing requirements demanded by the fluid and structure analyses force design compromises and often help determine the material from which the propeller is made. In the context of aircraft propellers, the weight is often an additional constraint and today these are often formed from aluminum or carbon-fiber sheeting. In contrast, marine propellers are usually fabricated from bronze (or stainless steel) in order to be both structurally sound and less susceptible to cavitation damage (see section (Mfe) and (Mff)). However, for cost reasons small marine propellers are increasingly made from plastics.

The manner in which the blade chord and thickness varies with radial location is also an important design feature. Moreover, the blade angles usually decrease with radius so that the lift produced is distributed over the length of the blade (since the incident velocity increases with radius) rather than being focussed at the tip. The flow at the blade tip is often of critical importance. On aircraft propellers it is the source of much noise and so the tip is sometimes completely unloaded (zero design incidence angle) in order to minimize the noise. With marine propellers, cavitation (see section (Mfe)) often occurs first at the tip and, as with aircraft propellers, the tip is unloaded to minimize this deleterious effect. All of these cavitation and structural constraints mean that marine propellers come in a wide variety of different shapes as illustrated by Figure 2 in the Introduction.

The need to operate efficiently over a range of speeds (or advance ratios, see section (Mfc)) means that some propellers are equipped with mechanisms that allow adjustment of the blade angles. These are known as variable pitch propellers and are widely used on modern aircraft. The adjustment mechanism must, of course, be incorporated in the propeller shaft. In the marine context, this strategy is rarely employed because of the risk of fouling and the increased need for maintenance

Sometimes ducted propellers such as that in Figure 2 (right) are used to improve performance. These can be useful for vertical or short take-off aircraft where they are useful for strategies involving variable-thrust orientation. In the marine context they can provide a marginal performance improvement but their susceptibility to fouling and damage can be a vulnerability.

Figure 2: Left: Typical ship propeller. Right: Ducted marine propeller.