PART 1 : SECTION 1

CHAPTER 15

PROPELLER THEORY

Basic Considerations

1. The propeller blade has an aerofoil section and when in motion is subject to the same basic forces as the wing. It advances through the air along a spiral path which is the resultant of the rotational component and the forward speed of the aircraft. In doing so it experiences a total reaction which can be resolved into a forward-acting thrust and a torque force which opposes the rotary motion.

2. Because the propeller moves forward in a spiral path the blades are set at a large angle (known as the blade or pitch angle) to the plane of rotation so that the actual angle at which the blades meet the air is small—in the neighbourhood of 3° or 4°, the angle of attack for best L/D ratio.

3. The distance a propeller moves forward in one revolution (the advance per revolution) is not a fixed quantity, but depends on the forward speed of the aircraft and the speed of rotation of the propeller. The path of a blade can be split into two components :—

(*a*) A component due to the forward speed (BA in Fig. 1)—this is the same for all portions of the blade from root to tip.

(*b*) A component (CB) due to the rotation of the propeller. This component is least at the root of the blade, increasing progressively towards the tip ; it is proportional to the radius of the blade at any given section.

When these two components are combined, the resultant path of the blade lies along AC. The angle of advance, ACB, is small at low speeds, and large at high forward speeds.

Total Reaction

4. Fig. 1 shows that the blade travelling in the direction CA, with an angle of attack ACD, produces the usual total reaction, inclined slightly rearwards of the path CA. (For clarity the forces are shown as originating from C instead of the centre of pressure.) The total reaction can be split into the normal lift force, acting at right angles to CA and the drag force acting in the opposite direction to CA. It can also be split into two other components, one the *thrust*, acting in the direction of flight BA, and another the *torque force* opposing the rotation and acting in the opposite direction to the plane of rotation CB. Torque, reacting through the driving shaft, tends to rotate the airframe in the opposite direction to the propeller. The thrust is the force which propels the aircraft along the flight path.

Pitch

5. Because the speed of the blade increases towards the tip, the blade angle (Fig. 2) near the root is large, gradually diminishing towards the tip. This is the reason for the helical twist of the blade, and the means by which all parts of the blade are made to meet the air at about the same angle of attack. If the blade is rotated at 0° angle of attack for one revolution it will advance a certain distance, known as the *geometric pitch*

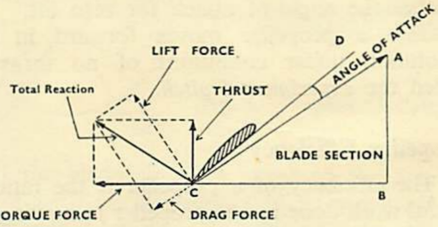

Fig. 1. Forces Acting on a Propeller Blade

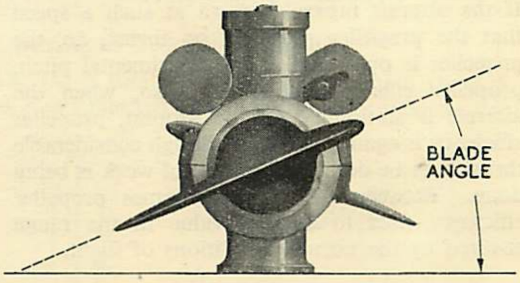

Fig. 2. Blade Angle

line AB. This can be resolved into two components ; AC, in the plane of rotation and parallel to the centre line of the blade (this force is simply end thrust), and CB, also in the plane of rotation but at right angles to AC. The first component places a tension on the blade, while the second tends to reduce the blade angle. For a given solidity this centrifugal twisting moment is less for four blades than for three, decreasing as the number of blades increases.

19. Therefore, in view of the lower efficiency of wide blades and the increased centrifugal turning moment experienced with them, it is preferable to increase solidity by increasing the number of blades. Where this is impracticable owing to blade interference the same effect can be achieved by the use of counter-rotating propellers (para. 25).

Variation of Blade Angle—Constant-Speed Propellers

20. In para. 13 it was stated that increasing the blade angle was not an efficient method of increasing the ability of a propeller to absorb the power delivered to it. This should not be confused, however, with the action of a constant-speed propeller in compensating for decreased air density at height. Under these conditions, for a given blade angle of attack, both the lift and drag of the blade will fall in the less dense air, with the result that the propeller would tend to race if engine output remained constant. By increasing the blade angle, the constant-speed mechanism counteracts this tendency and enables the propeller to absorb the power delivered to it, although at high altitudes it is probable that the blades will not be operating at the optimum angle of attack. It will be appreciated that a fixed-pitch propeller driven by a supercharged engine can realize its highest efficiency only at the altitude for which it is designed, above or below which a loss of efficiency must occur.

Slipstream

21. The column of air forced backwards by the propeller is called the slipstream, the diameter of which approximates to that of the propeller disc. The speed of the slipstream relative to the aircraft exceeds the air speed of the aircraft by as much as 100 per cent. at low speeds or as little as 10 per cent. at high speeds. Because of this faster airflow over the tail and other parts of the aircraft in the slipstream, the drag of these parts may be much greater than if they were located outside the slipstream.

22. The slipstream increases the effectiveness of the tail surfaces at low speeds, but the directional and lateral balance of the aircraft may be upset because the propeller imparts a rotary motion to the air, resulting in the airflow meeting the fin and rudder at an angle of attack. (During the early stages of a take-off the tendency to swing because of such swirl may be strong.)

Torque Reaction

23. As has already been stated, there is a tendency for the aircraft to rotate in the opposite direction to the propeller. One method of counteracting this tendency, no longer used on high performance aircraft, involves the use of *wash out* (a decrease in incidence towards the tip) on the wing that tends to rise, accompanied by *wash in* on the other wing, the difference in lift causing a rolling moment opposing the torque reaction. Uneven disposition of the load can also provide the same effect. On some aircraft the propellers are *handed* to rotate in opposite directions, the torque reaction of one cancelling that of the other. Such an arrangement also makes for an even distribution of slipstream over the tail unit.

Gyroscopic Effect

24. A rotating propeller has gyroscopic properties which become apparent when the plane of rotation of the propeller is changed. If the propeller is rotating in a clockwise direction—as seen by the pilot—the nose will tend to fall during turns to the right, and to rise during turns to the left. Similarly, if the tail is raised sharply during a take-off the nose will tend to swing to the left, and in a loop it will tend to yaw to the right. For anticlockwise rotation the effect will be in the opposite direction. However, gyroscopic effects are not usually significant and are easily countered.

Counter-Rotating and Co-Axial Propellers

25. When two propellers are mounted in tandem and rotated in opposite directions several advantages are obtained. If both halves make up a single unit driven by one engine (*e.g.* Wyvern aircraft) the complete installation is known as a *counter-rotating propeller*. If the two propellers are separate units, independent of each other, and each being driven by its own engine (*e.g.* Gannet aircraft), then the installation is known as a *co-axial propeller*.

26. The co-axial propeller, under normal flight conditions with both engines running at equal power, can be compared to the counter-rotating type. The power output from the engine(s) is

absorbed by a propeller of high solidity having a small diameter and thus low tip speed, so avoiding compressibility effects and loss of efficiency at the tips. Torque and gyroscopic effects are cancelled by the opposite directions of rotation and the rotary motion of the slipstream is largely removed. When either unit of the co-axial propeller is feathered the operation of the remaining unit would result in the reappearance of the undesirable effects ; however, the adverse yawing moment that occurs in the usual type of twin-engine aircraft is eliminated by the common thrust line of both engines.

Braking Propellers

27. By extending the pitch range of a propeller beyond the normal fine-pitch limit so that a large negative angle of attack is obtained, it is possible to make the propeller provide a powerful decelerating force. When employed in this way it is called a *braking propeller*.

28. This should not be confused with the windmilling action of all propellers when meeting the airflow at a small negative angle of attack. This condition, shown in Fig. 8, is that obtained when the engine is throttled back in flight. The angle of attack (ACD) is slightly negative and the total reaction is therefore also negative. The total reaction can be split into one component acting rearwards against the direction of flight and a torque force acting in the same direction as the direction of rotation ; under the influence of the torque force the propeller continues to windmill in the normal direction but exerts a braking force on the aircraft.

29. Although a windmilling propeller provides a strong decelerating force at high speeds, it is not satisfactory at low speeds. In Fig. 9 the blade has been rotated further to a large negative angle of attack. The negative thrust remains but the propeller torque is reversed and must be opposed by engine torque if rotation in the correct direction is to be maintained. It is clear that the magnitude of the braking force will depend on the engine power applied. High negative thrusts are possible and can be used after landing to shorten the run, or to assist in manœuvring on the ground.

30. In changing the pitch from normal to a power-on reverse thrust position, the windmilling position has to be traversed. At this point engine torque and propeller torque are acting in the same direction, and it is essential that the pitch change be made at a very high rate if overspeeding is to be avoided.

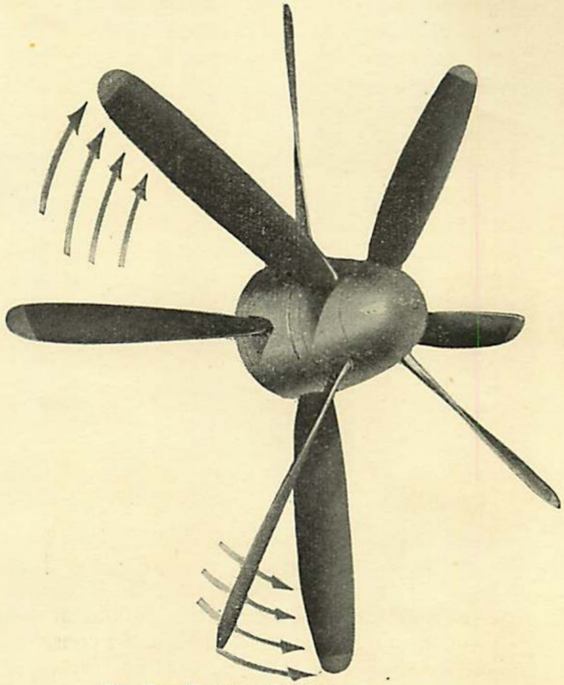

Fig. 7. Counter-Rotating Propeller

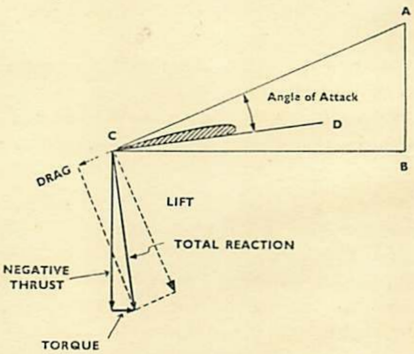

Fig. 8. Braking Action of Windmilling Propeller

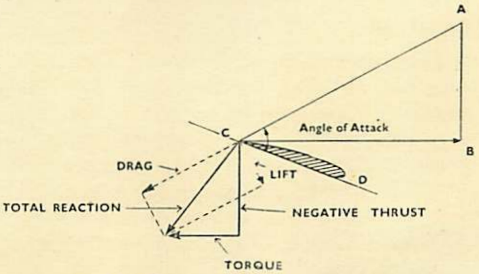

Fig. 9. Power-on Braking Propeller


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