The Flat Plate Airfoil

While there are some basic problems with its practical use, the simplest airfoil that can be envisaged is an infinitely thin, flat plate at an angle of attack, α, to an oncoming uniform stream of velocity U as depicted in Figure 1. The solution to this steady planar potential flow was presented in section (Bgee) and we review it here for convenience.

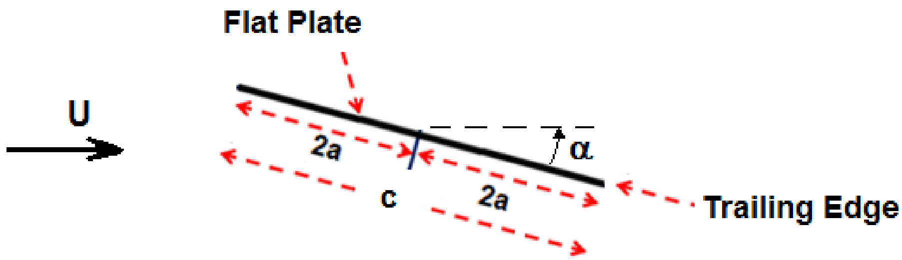

Figure 1: A two-dimensional, flat plate airfoil of chord, c, at an angle of attack, α, to a steady uniform stream of velocity, U.

As shown in section (Bgee), the steady planar potential flow around a flat plate at an angle of attack is one of the simplest of the Joukowski airfoil solutions. In the notation of section (Bged) the Joukowski airfoil solution is generated in the limit $R/a \rightarrow 1$, $\beta = 0$ in which the chord of the plate, $c = 4R$. As in all the Joukowski airfoil solutions it was argued that, in practice, the flow could not negotiate the sharp trailing edge (a condition called the Kutta condition) and it followed that this required a specific value of the circulation, namely $\Gamma = -4\pi UR\sin\alpha$ (for only with this Γ does the flow leave the trailing edge smoothly). This value of the circulation means that the lift coefficient based on the planform area is $C_L = 2\pi\sin\alpha$. Note that it is, however, assumed that the flow negotiates the sharp leading edge.

Real viscous flows cannot negotiate a sharp leading edge as this potential flow has been permitted to do. In practice at any finite angle of attack, such a foil would experience separation of the flow at the leading edge resulting in a separated region or wake on the upper suction surface and much less lift than the potential flow would predict. The foil would in fact be "stalled". To avoid this, at least at small angles of attack (typically less than about 12^o), the leading edge of practical airfoils is carefully rounded in order to ensure that the flow remains attached to the surface until much further aft. As we shall see in the next section, the resulting lift is then close to that of the potential flow prediction. Much care with the design is needed to achieve this end and details such as the effect of small irregularities in the surface of the leading edge can have substantial effects. The leading edges of the wings of small, general aviation aircraft are sometimes fitted with profile-changing additions known as "wing cuffs" in order to alter the location of boundary later separation and therefore improve performance and/or the angle of attack at which stall occurs.

As we shall see in the sections that follow, the above result for a flat plate airfoil, namely $C_L = 2\pi\sin\alpha$, is remarkably accurate for almost any shape of airfoil provided the foil has not stalled and an appropriate effective angle of attack, α, is used. In normal operation the angle, α, is quite small and $\sin\alpha \approx \alpha$ where α is measured in radians. Then $C_L \approx 2\pi\alpha$ and

$$C_L \;\approx\; 2\pi\alpha \qquad \text{and} \qquad \frac{\partial C_L}{\partial\alpha} \;\approx\; 2\pi \tag{Dcd1}$$

where this last quantity, $\partial C_L/\partial\alpha$, is called the lift slope and is an important factor in flight design.