Basic theories, airfoil design

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Most applied aerodynamic models for wind turbines still rely on airfoil data, and therefore a description of the flow past a 2-D airfoil is first given together with the needed definitions of lift, drag and moment coefficients. The text on basic theories is then followed by classical momentum theory for the flow past wind turbine rotors.

2-D Aerodynamics

Wind turbine blades are long and slender structures and the streamwise velocities are mostly much larger then the spanwise velocity component, except in deep stall, and locally the flow is assumed two-dimensional. The cross section in a wind turbine blade at a certain radius, r, is shaped as an airfoil. The aerodynamic force is created by the flow past the airfoil, and for moderate angles of attack the flow stays attached and follows the surface that will bend the flow. The angle of attack is defined as the angle between the chordline and the incoming flow, where the chordline is a line from the trailing to the leading edge of the airfoil as drawn in Figure1. Further in Figure 1 is sketched the development of the flow for increasing angles of attack.

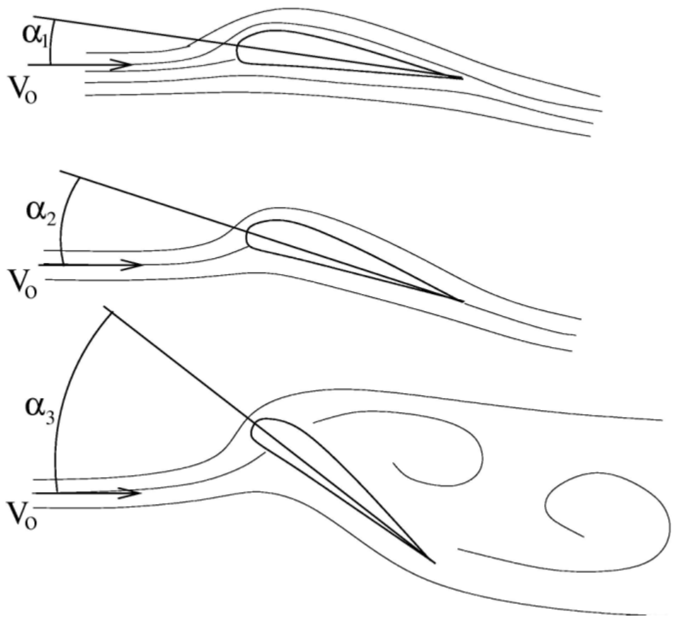

Figure 1: Sketch of flow past airfoil at increasing angles of attack

From basic physics is known that in order to change the path of a mass a force perpendicular to the motion is needed. For a bend streamline this force comes from a pressure gradient normal to the streamline as:

$$\frac{\partial p}{\partial r} = r\frac{V^2}{r} \qquad (1)$$

where, V, is the speed along the streamline, r, the fluid density and r the curvature. Far from the airfoil the pressure is the ambient pressure p_o=const, and due to the bend streamlines in Figure 1 the pressure on the upper surface (suction side) is according to equation (1) less than the ambient pressure and the pressure on the lower surface (pressure side) higher than the ambient pressure. This pressure difference gives a force, which together with the integrated local friction due to the shear stress on the surface comprises the total force [N/m] on the airfoil section. It is seen in Figure 1 that for moderate angles of attack the streamlines become more bend as the angle of attack increases and thus also the contribution from the pressure difference. However, at some point it is not possible to bend the streamlines further and the flow separates, decreasing the bending as also sketched in Figure 1. The total force, F, is often decomposed in a component normal to the incoming velocity and a parallel component, where the former is denoted the lift and the latter the drag, see Figure 2.

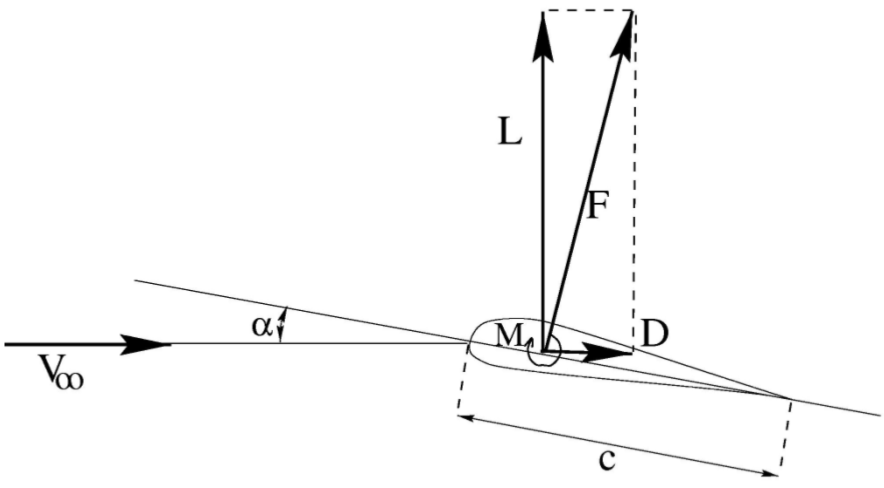

Figure 2: Definition of lift and drag

The lift, drag and aerodynamic moment are given in non-dimensional form as a lift, drag and moment coefficient:

$$C_l = \frac{L}{\frac{1}{2} r V_\infty^2 c} \qquad (2)$$