Coefficients Variation

1 Coefficient of Lift

1.1 C_p Distribution

The lift created by the airfoil is mainly affected by the distribution of pressure stress, which is different for each airfoil and is affected by camber, chord length and so on. The **pressure coefficient** C_p is defined as:

$$C_p = \frac{p - p_\infty}{\frac{1}{2}\rho_\infty U_\infty^2} \tag{1}$$

Here p is the static pressure **at the point on the airfoil**, and p_∞ is the free stream static pressure. Some C_p distribution examples are shown below:

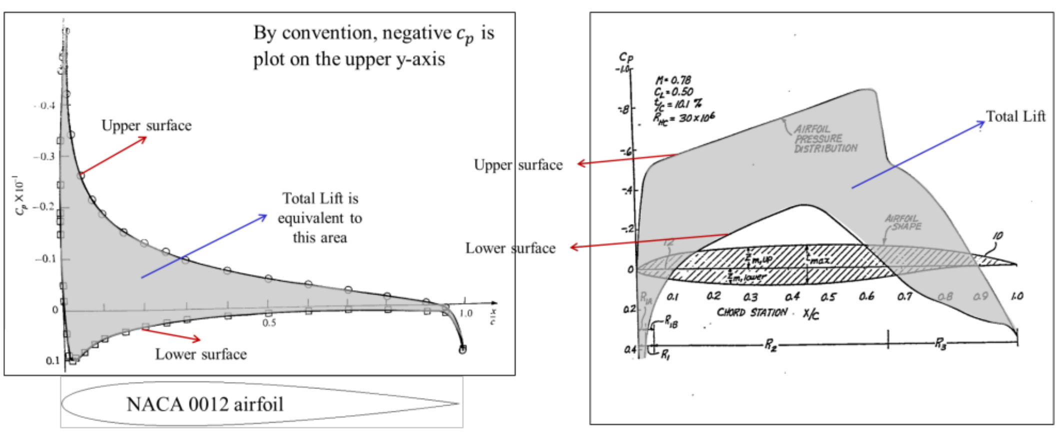

Figure 1: C_p distribution examples

Some remarks:

1. By convention, **negative** C_p (upper surface of the airfoil) is plot on the upper y-axis. This contributes most to lift.

2. Total lift is equivalent to the grey area.

1.2 Angle of Attack Dependence

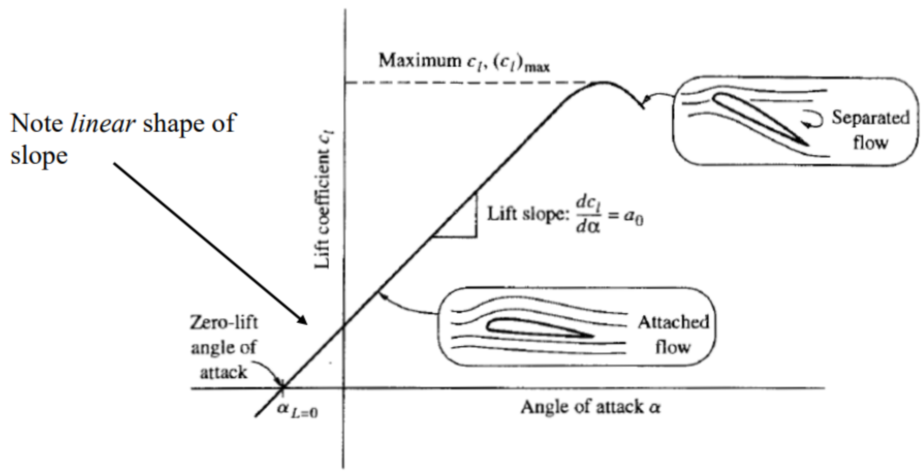

Figure 2: c_l dependence with α

Notice that here we are using section lift coefficient (c_l). Some observations:

1. Slope is mostly linear over practical range of α
2. For **thin airfoils**, theoretical maximum of lift curve slope is 2π
3. All positively cambered airfoils have **negative angle of attack**
4. A symmetric airfoil has a zero-lift angle of attack equal to **zero**
5. At high α, slope becomes non-linear and airfoils exhibits **stall due to separated flow**.

1.3 Reynolds Number Dependence

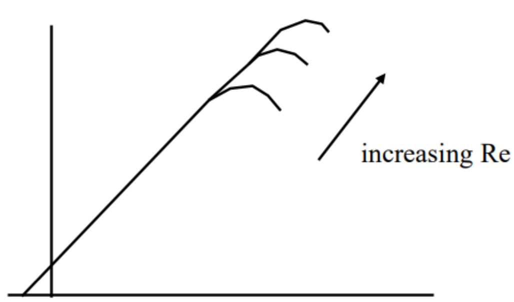

Figure 3: c_l dependence with Re

Some observations:

1. No effect on lift curve slope in linear region
2. Important Re effect on max c_l due to viscous effect.

1.4 Mach Number Dependence

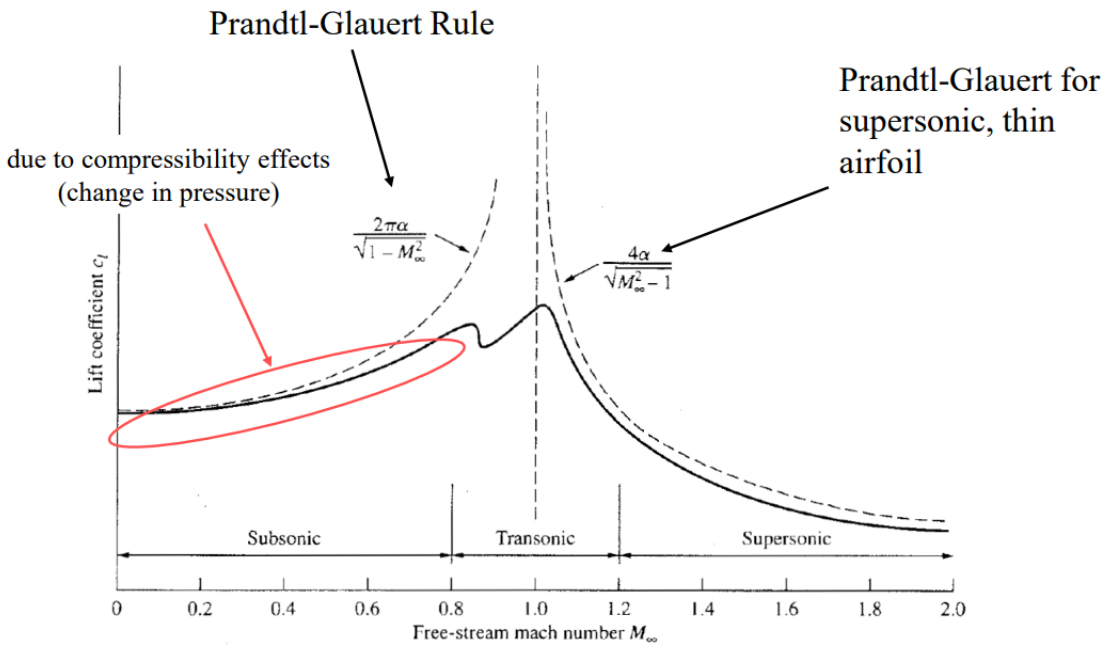

Figure 4: c_l dependence with M_∞

2 Coefficient of Drag

2.1 Angle of Attack Dependence

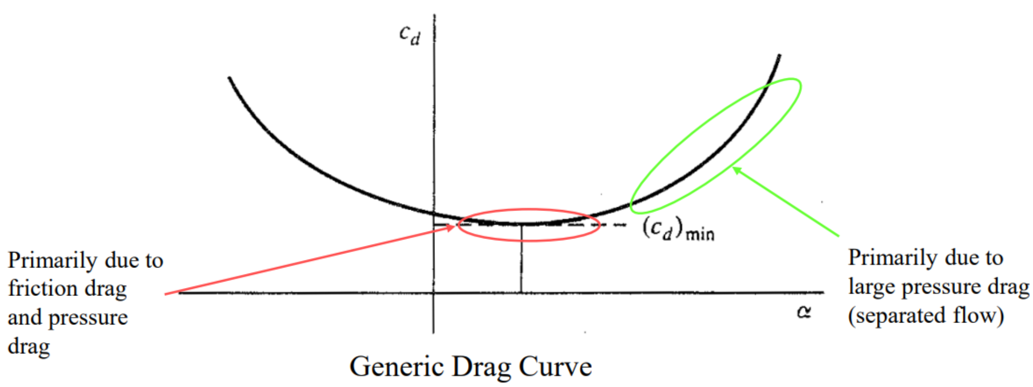

Figure 5: c_d dependence with α

Some observations:

1. High c_d at high α due to separated flow
2. For a cambered airfoil, minimum drag value may not occur at **zero angle of attack**, but may be at some small α

2.2 Reynolds Number Dependence

The drag coefficient is mainly affected by the **skin friction coefficient** c_f. For **laminar flow**:

$$c_f \propto \frac{1}{\sqrt{Re}} \tag{2}$$

For **turbulent flow**:

$$c_f \propto \frac{1}{(Re)^{0.2}} \tag{3}$$

Therefore, c_d is sensitive to Re, and is larger at **lower Re**.

2.3 Mach Number Dependence

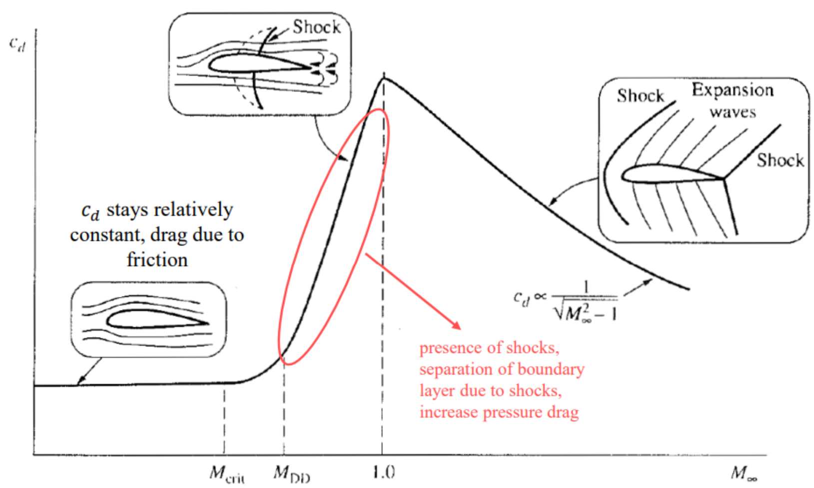

Figure 6: c_d dependence with M_∞

1. M_{crit}: Mach number at which sonic flow is **first encountered** at some location on the airfoil

2. M_{DD}: free stream Mach number at which drag rapidly diverges

3 Coefficient of Moments

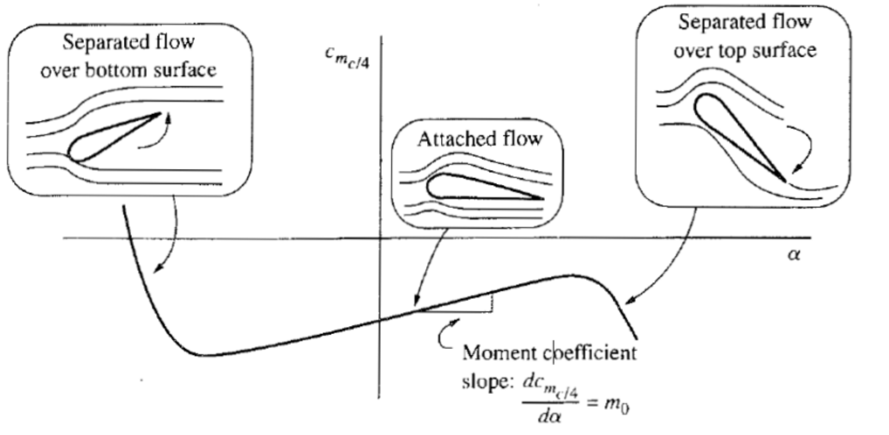

Figure 7: $c_{m_{c/4}}$ dependence with α

Some remarks:

1. Linear over practical range of angle of attack
2. But the slope is positive for some airfoils, negative for others
3. Non-linear at high α, when flow separates
4. Linear portion of curve is independent of Re