CHAPTER 6

THE APPLICATION OF DRAG FORCE AND LIFT FORCE

Example 01

A rectangular wing on a small airplane has a 1.3 m chord and a 10 m span. When flying in air at 220 km/h, the wing experiences a total aerodynamic force of 18 kN. If the lift to drag ratio is 3, determine the lift coefficient of the wing.

The total aerodynamic drag consists of both lift force and drag force.

$$F_{total} = \sqrt{F_L^2 + F_D^2} = (18\ kN)^2$$

Lift to drag ratio is 3.

$$F_L = 3F_D$$

Thus,

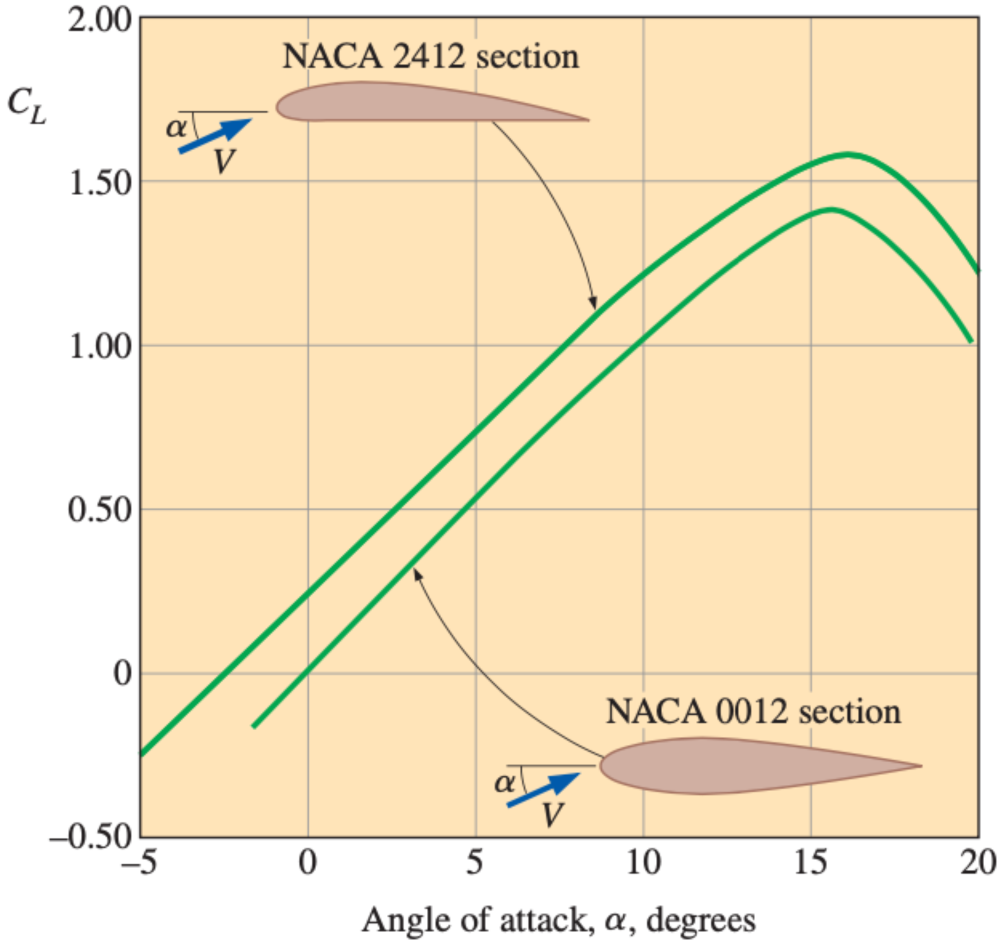
$$9F_D^2 + F_D^2 = 324$$
$$F_D = 5.69\ kN$$
$$F_L = 17.10\ kN$$

Lift coefficient :

$$C_L = \frac{F_L}{\frac{1}{2}\rho A V^2} = 0.587$$

Example 02

In a lift-and-drag experiment performed in a wind tunnel, an NACA0012 airfoil was used. The airfoil has a 15cm chord and a span length of 45cm. Using a force measuring device, a lift force of 60 N was measured on the airfoil for a Reynolds number of 4.586×10^5. The lift coefficient for this airfoil is given by $C_L = 2\pi \sin\alpha$, where α is the angle of attack. Under the given conditions, what is the angle of attack in degrees?



The variation of the lift coefficient with angle of attack for a symmetrical and a nonsymmetrical airfoil.

Data from Abbott (1945, 1959).

Reynolds number : $$4.586 \times 10^5 = \frac{\rho V L}{(1.81 \times 10^{-5})} \quad \Longrightarrow \quad V = 45\ m/s$$

Lift coefficient : $$C_L = \frac{F_L}{\frac{1}{2}\rho A V^2} = 0.714 = 2\pi \sin\alpha$$

Thus, $$\alpha = 6.52°$$

Example 03

An aircraft with a mass, including payload of 1000 kg is designed to cruise at a speed of 80 m/s at height of 10 km. The effective wing area is approximately 15 m^2. Determine the lift coefficient and the angle of attack. What power is required by the airfoil during cruise? Assume a conventional airfoil.

Lift coefficient :

$$C_L = \frac{F_L}{\frac{1}{2}\rho A V^2} = \frac{1000 \times 9.81}{\frac{1}{2}(0.412) A V^2} = 0.496$$

Angle of attack :

$$0.496 = 2\pi \sin \alpha$$
$$\alpha = 4.53°$$

Drag coefficient for conventional airfoil is 0.0065.

$$Power = F_D V = \left(C_D \frac{1}{2}\rho A V^2\right)(80) = 10300\, Watt$$

Example 04

A 1500 kg aircraft is designed to carry a payload of 3000 N when cruising at 80 m/s at a height 10 km. The effective wing area is 20 m^2. Assuming a conventional airfoil, calculate:

(a) The take off speed if an angle of attack of 10° is desired

(b) The stall speed when landing

(c) The power required at cruise if 45% of the power is needed to move the airfoil

(a) Take off speed:

$$C_L = 1.22 = \frac{F_L}{\frac{1}{2}\rho A V^2} = \frac{(1500 \times 9.81) + 3000}{\frac{1}{2}(1.23) A V^2}$$

$$V = 34.5\ m/s$$

(b) Stall speed :

$$C_L = 1.72 = \frac{F_L}{\frac{1}{2}\rho A V^2} = \frac{(1500 \times 9.81) + 3000}{\frac{1}{2}(0.412) A V^2}$$

$$V = 50.0\ m/s$$

(c) Power

$C_D = 0.0065$

$\rho = 0.412\ kg/m^3$

$$Power = F_D V = \left(C_D \frac{1}{2}\rho A V^2\right)(80) = 13700\ Watt$$

$$\text{Power required} = \frac{13700}{0.45} = 30400\ Watt$$

TABLE 8.4 Drag and Lift Coefficients and Critical Cavitation Number for a Typical Hydrofoil

Angle (°)	*Lift coefficient* C_L	*Drag coefficient* C_D	*Critical cavitation number* σ_{crit}
−2	0.2	0.014	0.5
0	0.4	0.014	0.6
2	0.6	0.015	0.7
4	0.8	0.018	0.8
6	0.95	0.022	1.2
8	1.10	0.03	1.8
10	1.22	0.04	2.5

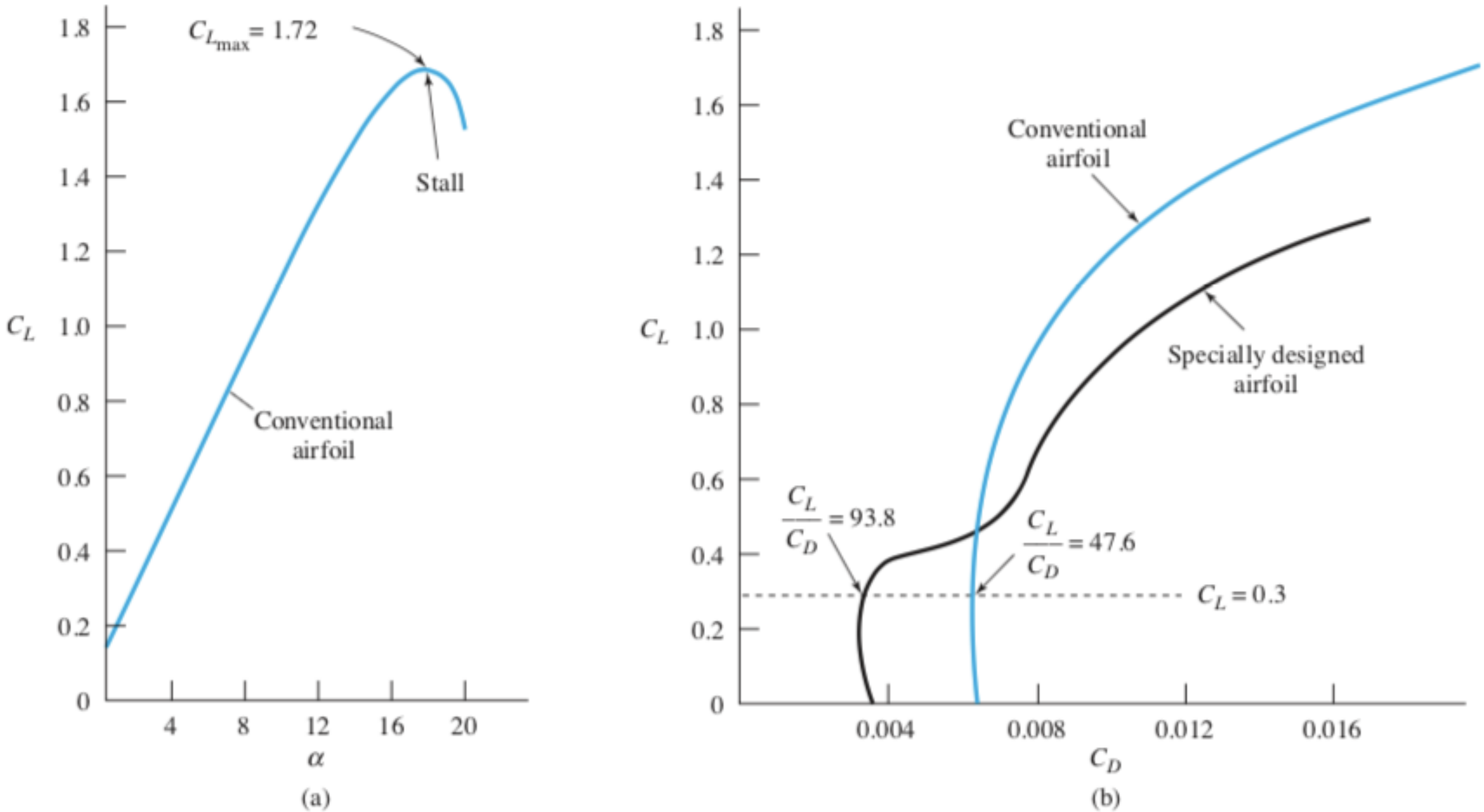


Fig. 8.13 Lift and drag coefficients for airfoils with $\mathrm{Re} = Vc/\nu \simeq 9 \times 10^6$.

Example 05

A proposed aircraft is to resemble a huge airfoil, a flying wing as shown below. Its wingspan will be 200 m and its chord will average 30 m. Estimate, assuming a conventional airfoil, the total mass of the aircraft, including payload, for a design speed of 800 km/h at an elevation of 8 km. Also, calculate the power requirement.

For a conventional airfoil, From Figure 8.13, we can assume that

$$\frac{C_L}{C_D} = 47.6 \qquad at \qquad C_L = 0.3$$

$$C_L = \frac{F_L}{\frac{1}{2}\rho A V^2} = \frac{m \times 9.81}{(0.5)(0.526)(200 \times 30)(222^2)} \qquad \Longrightarrow \qquad m = 2.38 \times 10^6 \;\; kg$$

$$\frac{1}{2}\rho A V^2$$

$$Power = F_D \times V = \left(C_D \frac{1}{2}\rho A V^2\right) V = 490{,}000 \;\; W = 657 \;\; hp$$

The power require for the aircraft is 657 hp.