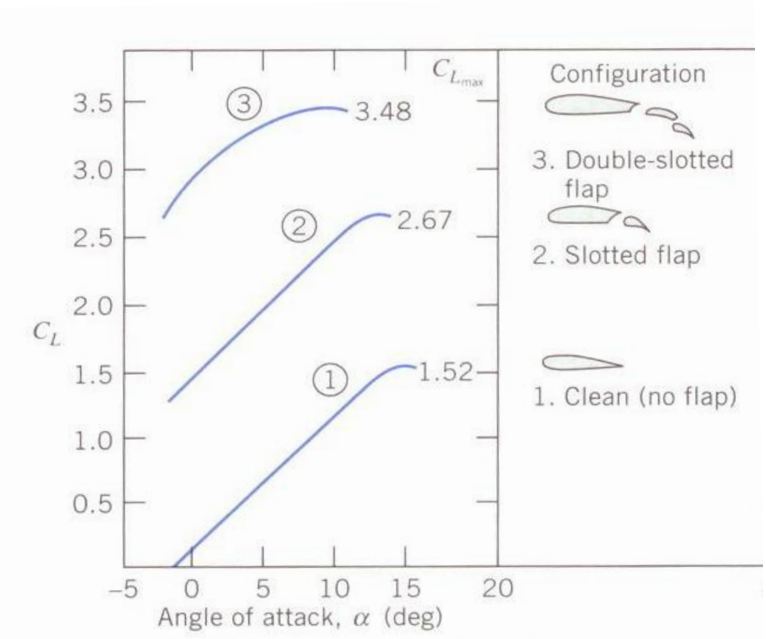
LIFT & DRAG

SELF ASSESSMENT SHEET 5

1. The Aero Boero 115 uses the NACA 23012 [1] airfoil for its wings. At take-off its weight is 802kg [2] and the wing area 17.4m^2. Assuming the wing C_L is the same as the aircraft C_L by how much is the minimum landing speed reduced if a single-slotted flap is deployed? (Assume wing area increases by 33%). Take air density at ground level to be 1.2 kg/m^3.



(a) Lift coefficient versus angle of attack

Ans: 9.3 m/s or 35%

2. The drag coefficient for a wing of finite span is given by:

$$C_D = C_{D,infinite} + \frac{C_L^2}{\pi A_{Ratio}}$$

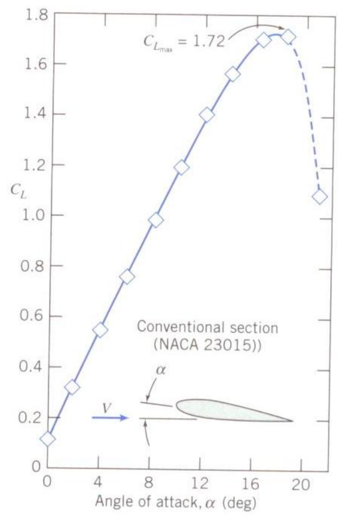
a) Using the data for NACA 23015, what is the drag coefficient for a wing of aspect ratio (b/c) of 6.5 at an angle of attack of 8°?

b) If the planform area is 150m^2, what is the drag force on the aerofoil when flying at an altitude of 5,000m and a speed of 500 mph?

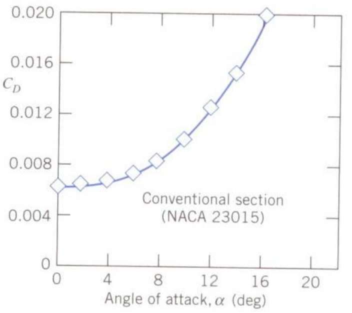
c) How much thrust is required to overcome this drag?

d) Remembering that:

$$C_D = \frac{D/A_p}{\frac{1}{2}\rho V^2}, \qquad C_L = \frac{L/A_p}{\frac{1}{2}\rho V^2}$$



(a) Lift coefficier



(b) Drag coefficien

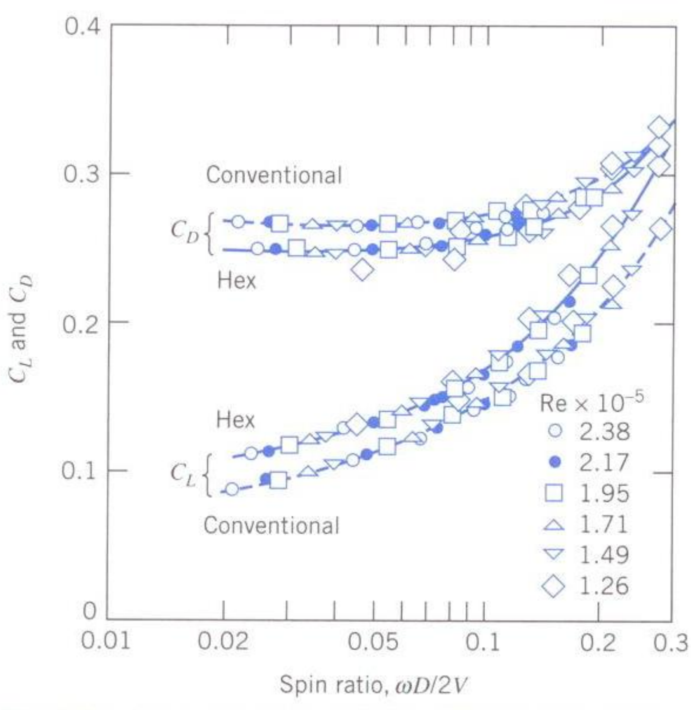
1 http://www.ae.illinois.edu/m-selig/ads/aircraft.html
2 http://www.airliners.net/aircraft-data/stats.main?id=4

What mass can this aerofoil support?

Ans: 0.057, 154 kN, 34 MW, 275T

3. Under the Rules of Golf, a golf ball weighs no more than 1.620 oz (45.93 grams), has a diameter not less than 1.680 in (42.67 mm)[3]. When a conventional golf ball is travelling at 100 mph what spin speed corresponds to a lift coefficient of 0.1? By how much does the spin rate need to increase if the lift is to be doubled?

Ans: 73 rad/s, 323 rad/s



[3] http://en.wikipedia.org/wiki/Golf_ball

SOLUTIONS

1. Find U_{stall} for "clean" case:

$$W = mg = 802 \times 9.81 = 7868N$$

For clean case C_{Lmax} is 1.52

$$U_{stall} = \sqrt{\frac{2W}{\rho C_{L_{max}} A}} = \sqrt{\frac{2 \times 7868}{1.2 \times 1.52 \times 17.4}} = 22.3 m/s$$

Acceptable safe minimum speed is therefore

$$U_{safe} = 1.2 \times 22.3 = 26.8 m/s$$

With single slotted flap, wing area is increased:

$$A_{with\ flap} = 1.33 \times 17.4 = 23.1 m^2$$

From chart, $C_{Lmax,\ flap}$ is 2.67

$$U_{stall,with\ flap} = \sqrt{\frac{2W}{\rho C_{L_{max,flap}} A_{with\ flap}}} = \sqrt{\frac{2 \times 7868}{1.2 \times 2.67 \times 23.1}} = 14.6 m/s$$

Acceptable minimum speed is therefore

$$U_{\text{safe, with flaps}} 1.2 \times 14.6 = 17.5 m/s$$

Minimum landing speed is reduced by 9.3 m/s or 35%

2. From the charts, At 8° C_L is 1.0 and $C_{D,infinite}$ is 0.008

$$C_D = C_{D,infinite} + \frac{C_L^2}{\pi A_{Ratio}} = 0.008 + \frac{1.0}{6.5\pi} = 0.057$$

$$C_D = \frac{D/A}{\frac{1}{2}\rho U^2}$$

Find ρ from ISA table in steam tables. At 5,000m ρ/ρ_o = 0.6012. (Note ρ_o is given at the bottom of the page, 1.225 kg/m^3)

$$\rho = 0.6012 \times 1.225 = 0.735$$

500 mph = 223m/s

$$D = 0.057 \times 0.5 \times 0.725 \times 223^2 \times 150 = 154kN$$

Thrust = drag force x velocity

$$P = DU = 154 \times 10^3 \times 223 = 34MW$$

$$C_D = \frac{D/A_p}{\frac{1}{2}\rho V^2}, \qquad C_L = \frac{L/A_p}{\frac{1}{2}\rho V^2}$$

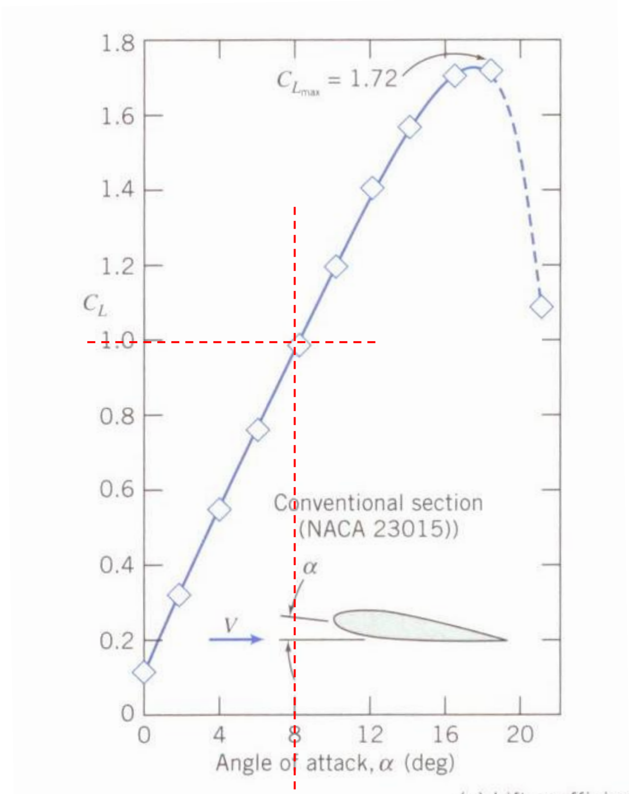
So:

$$\frac{C_D}{C_L} = \frac{D}{L}$$

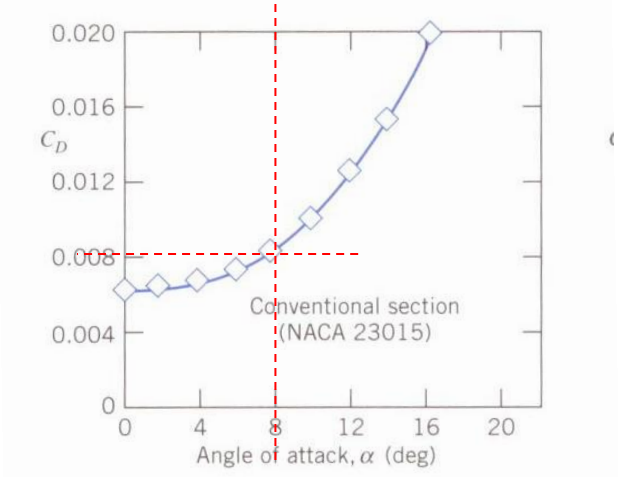
Hence:

$$L = 154 \times 10^3 \times \frac{1.0}{0.057} = 2.7MN$$

Mass = 275x10^{3}kg = 275 T

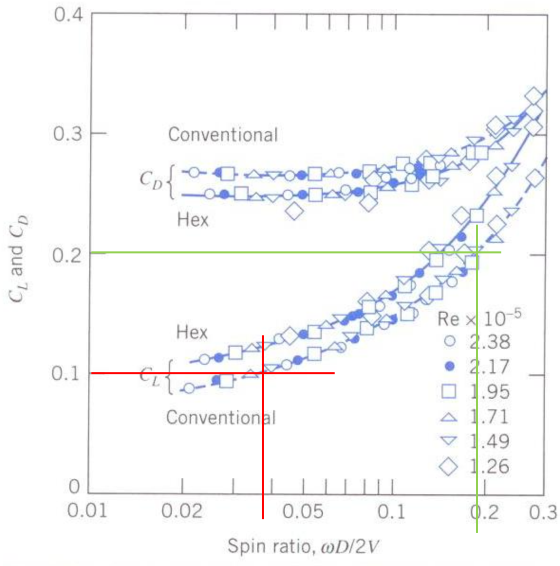


(a) Lift coefficier



(b) Drag coefficien

3. Calculate Reynolds number:



$$Re = \frac{\rho v d}{\mu}$$

$$V = 100 \times \frac{1609}{3600} = 44.5m/s$$

$$Re = \frac{\rho v d}{\mu} = \frac{1.2 \times 44.5 \times 42.67 \times 10^{-3}}{1.8 \times 10^{-5}}$$
$$= 1.26 \times 10^5$$

This is the diamond symbols on the graph.

Reading from the graph, for C_L = 0.1, spin ratio = 0.035

$$Spin\ ratio = \frac{\omega D}{2V}$$

$$\omega = \frac{0.035 \times 2 \times 44.5}{0.04267} = 73rad/s$$

If the lift is to be doubled then for the same ball the lift coefficient must be doubled. Reading from the graph, when C_L is 0.2 the spin ratio is 0.19.

$$\omega_{new} = \frac{0.19 \times 2 \times 44.5}{0.04267} = 396rad/s$$

Alternatively, this can be obtained from the ratios: $\omega_{new} = \frac{0.19}{0.035} \times 73 = 396\ rad/s$

Apparently this is easily possible in golf as speeds up to 6,000 rpm (628 rad/s) are not unusual.