NPTEL - Aircraft Design

Week 2 - Assignment 2

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Weekly recap

\[ W_0 = W_{\text{crew}} + W_{\text{payload}} + W_{\text{fuel}} + W_{\text{empty}} \]
Weekly recap

Propeller driven aircraft –

SFC = Specific fuel consumption (unit?)
Weekly recap

Propeller driven aircraft –

SFC = Specific fuel consumption (lb. of fuel/hp/h or N/W/s)
Weekly recap

Propeller driven aircraft –

Breguet equation for Range –

\[
R = \frac{\eta L}{c D} \ln \left( \frac{W_0}{W_1} \right)
\]
Weekly recap

Jet driven aircraft –

TSFC = Thrust specific fuel consumption (unit??)
Weekly recap

Jet driven aircraft –

TSFC = Thrust specific fuel consumption (wt. of fuel/s/thrust or 1/s)
Question 1

An aircraft is equipped with symmetrical aerofoil. For complete aircraft the lift curve slope is 5/rad. Stall angle is 12 deg, wing area is 10 m². What is mass during flight, whereas stall speed is observed 90 Km/hr. g=9.8m/s², density of air is 1.225kg/m³.
Solution 1

What do we know?

• Lift curve slope is 5/rad ($C_L \alpha$)
• Stall angle is 12 deg ($\alpha_{stall}$)
• Wing area is 10 m$^2$ ($S$)
• Stall speed is observed 90 kmph ($U_\infty$)
• $g = 9.8$m/s$^2$ ($g$)
• Density of air is 1.225 kg/m$^3$ ($\rho$)
Solution 1

What do we need to find out? - Mass during flight

How –
Solution 1

What do we need to find out? - Mass during flight

How –

Weight = Lift (during flight)
Solution 1

What do we need to find out? - Mass during flight

How –

Weight = Lift (during flight)

Lift to be found out using lift equation
Solution 1

Lift equation –

\[ L = \frac{1}{2} \rho U_\infty^2 S C_L \]
Solution 1

But we don’t know $C_L$ —

Use lift curve slope and stall angle-
Solution 1

But we don’t know $C_L$ —

Use lift curve slope and stall angle-

$$C_L = C_{L0} + C_{L\alpha} \alpha$$
Solution 1

But we don’t know $C_L$ —

Use lift curve slope and stall angle-

$$C_L = C_{L0} + C_{L\alpha} \alpha$$

$$C_L = 0 + 5 \times 0.2094$$
Solution 1

But we don’t know $C_L$ —

Use lift curve slope and stall angle:

$$C_L = C_{L0} + C_{L\alpha} \times \alpha$$

$$C_L = 0 + 5 \times 0.2094$$

$$C_L = 1.0472$$
Solution 1

Lift equation –

\[ L = \frac{1}{2} \rho U^2 \infty S C_L \]

\[ L = 0.5 \times 1.225 \times 25^2 \times 1.0472 \]

\[ L = 4008.8 \text{ N} \]
Solution 1

But we need to find the mass, not the weight –

\[ M = \frac{W}{g} \]
Solution 1

But we need to find the mass, not the weight –

\[ M = \frac{4008.8}{9.8} \text{ kg} \]

Ans - \( M = 409.0612 \text{ kg} \)
Question 2

For a certain angle of attack, at a given altitude, the lift will be doubled for which combination(s) of S and V?
Solution 2

Let us go back to the lift equation which we have used in Q.1 –

\[ L = \frac{1}{2} \rho U_{\infty}^2 S C_L \]
Solution 2

What parameters are changing in this equation?

S and V
Solution 2

This means we can write -

\[ L = k \times U_{\infty}^2 S \]
Solution 2

Let’s check option (a) -

\[ L(\text{old}) = k \times U_\infty^2 S \]
\[ L(\text{new}) = k \times (\sqrt{2})^2 U_\infty^2 S \]
Solution 2

Let’s check option (a) -

\[
L(\text{old}) = k \times U_\infty^2 S
\]
\[
L(\text{new}) = k \times (\sqrt{2})^2 U_\infty^2 S
\]
\[
L(\text{new}) = 2 \times k \times U_\infty^2 S
\]

Correct!
Solution 2

Let’s check option (b) -

\[ L(\text{old}) = k \times U_\infty^2 S \]

\[ L(\text{new}) = k \times \left(\frac{1}{2}\right)^2 U_\infty^2 \times 2S \]
Solution 2
Let’s check option (b) -

\[ L(\text{old}) = k \times U_\infty^2 S \]

\[ L(\text{new}) = k \times \left(\frac{1}{2}\right)^2 U_\infty^2 \times 2S \]

\[ L(\text{new}) = \frac{1}{2} \times k \times U_\infty^2 S \]

Incorrect!
Solution 2

Let’s check option (c) -

\[ L(\text{old}) = k \times U_\infty^2 S \]
\[ L(\text{new}) = k \times U_\infty^2 \times 2S \]
Solution 2

Let’s check option (c) -

\[ L(\text{old}) = k \times U_\infty^2 S \]
\[ L(\text{new}) = k \times U_\infty^2 \times 2S \]
\[ L(\text{new}) = 2 \times k \times U_\infty^2 S \]

Correct!
Solution 2

Let’s check option (d) -

\[ L(\text{old}) = k \times U_\infty^2 S \]
\[ L(\text{new}) = k \times (2)^2 U_\infty^2 \times \frac{1}{2} \times S \]
Solution 2

Let’s check option (d) -

\[ L(\text{old}) = k \times U_\infty^2 S \]
\[ L(\text{new}) = k \times (2)^2 U_\infty^2 \times \frac{1}{2} \times S \]
\[ L(\text{new}) = 2 \times k \times U_\infty^2 S \]

Correct!
Question 3

Drag polar of an aircraft is given by:

\[ C_D = 0.020 + 0.019 \, C_L^2 \] and

\[ C_{L\alpha} = 4.5/\text{rad} \]

What are the values of parasite drag coefficient and coefficient of lift when the aircraft is operating at its max. L/D?
Solution 3

Parasite drag coefficient is $C_D = 0.020 + 0.019 \, C_L^2$

Coefficient of lift is $C_L = \sqrt{\frac{C_D}{k}} = 1.025$
Question 4

An airplane has a weight of 180,000 N at the beginning of the flight and 20% of this is the weight of the fuel. In a flight at a speed of 800 km/h, the lift to drag ratio (L/D) is 12 and the TSFC of the engine is 0.8. Obtain rough estimates of the range in km and endurance in hr.
Solution 4

\[ W_1 = \text{Weight at the start of the flight} = 180,000 \text{ N} \]

\[ W_f = \text{Weight of the fuel} = 0.2 \times 180,000 = 36,000 \text{ N} \]

\[ W_2 = \text{Weight of the airplane at the end of the flight} = 180,000 - 36,000 = 144,000 \text{ N} \]

Hence, the average weight of the airplane during the flight is:

\[ W_{\text{avg}} = \frac{(180000 + 144000)}{2} = 162,000 \text{ N} \]
Solution 4

Consequently, the average thrust ($T_{avg}$) required during the flight is:

$T_{avg} = \frac{W_a}{(L/D)} = \frac{162,000}{12} = 13,500 \text{ N}$

The average fuel consumed is:

$T_{avg} \times TSFC = 13500 \times 0.8 = 10,800 \text{ N/h}$
Solution 4

Fuel consumed per hour is 10,800 N. Then how much time will 36,000 N of fuel take to burn?

\[ E = \frac{36,000}{10,800} = 3.33 \text{ h} \]
Solution 4

How far will the aircraft go in 3.33 h?
It will go distance = time*speed

\[ R = 3.33 \times 800 = 2667 \text{ km} \]
Any doubts?