Module-2

Lecture-7

Cruise Flight - Thrust and Power available, Maximum and minimum cruise velocity, Effects of altitude on power

Thrust available

- As we have seen earlier, thrust and power requirements are dictated by the aerodynamic characteristics and weight of the airplane. In contrast, thrust and power available are strictly associated with the engine of the aircraft.

- The thrust delivered by typical reciprocating piston engines used in aircraft with propellers varies with velocity as shown in Figure 1(a).

- It should be noted that the thrust at zero velocity (static thrust) is maximum and it decreases with increase in forward velocity. The reason for this behavior is that the blade tip of the propellers encounter compressibility problems leading to abrupt decrease in the available thrust near speed of sound.

- However, as seen from Figure 1(b), the thrust delivered by a turbojet engine stays relatively constant with increase in velocity.

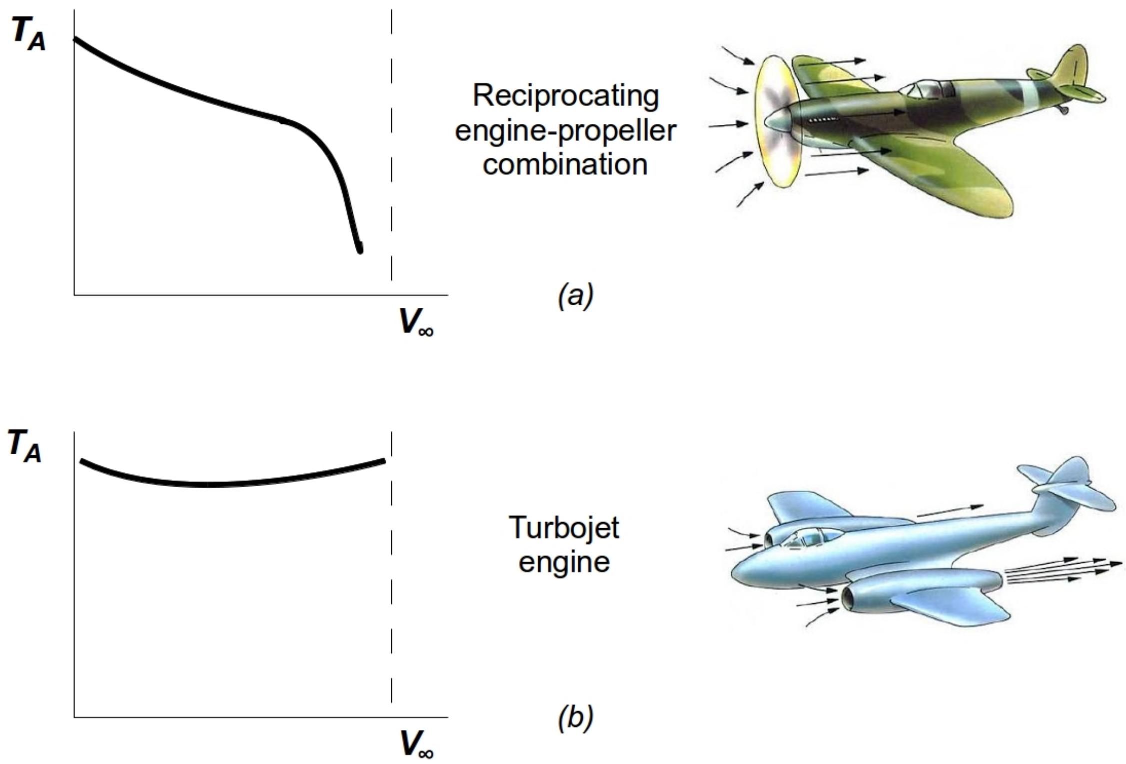

Figure 1: Variation in available thrust with velocity of the (a) reciprocating engine-propeller powered aircraft and (b) turbojet engine powered aircraft

Power

Power required for any aircraft is a characteristic of the aerodynamic design and weight of that aircraft. However, the power available, P_A is a characteristic of the power plant (engine) of the aircraft. Typically, a piston engine generates power by burning fuel in the cylinders and then using this energy to move pistons in a reciprocating fashion (Figure 2). The power delivered to the piston driven propeller engine by the crankshaft is termed

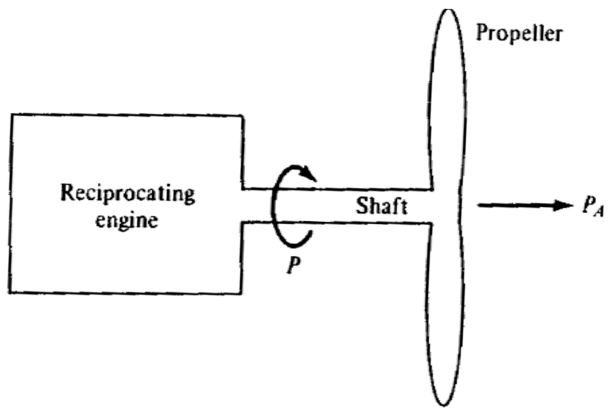

Figure 2: Schematic of a reciprocating engine

as the shaft brake power P. Actual power available is always less than the shaft brake power i.e. $P_A < P$. In fact, power available is modeled as

$$P_A = \eta P$$

Here η is propeller efficiency, $\eta < 1$. It is a direct product of the aerodynamics of the propeller. Both η and P are considered to be known quantities for a given aircraft. Figure 3 graphic the relationship between power available and power required with respect to speed for a propeller driven engine. A jet engine derives its thrust from compressing incoming air and then mix it with fuel to burn it and then exhausting the hot gases at high velocities through a nozzle. The power available from a jet engine is given by Equation:

$$P_A = T_A V$$

Referring to Figure 1(b), it can be seen that the thrust from a jet engine remains reasonably constant with respect to velocity. Thus the power-available curve varies linearly with V as shown in Figure 4.

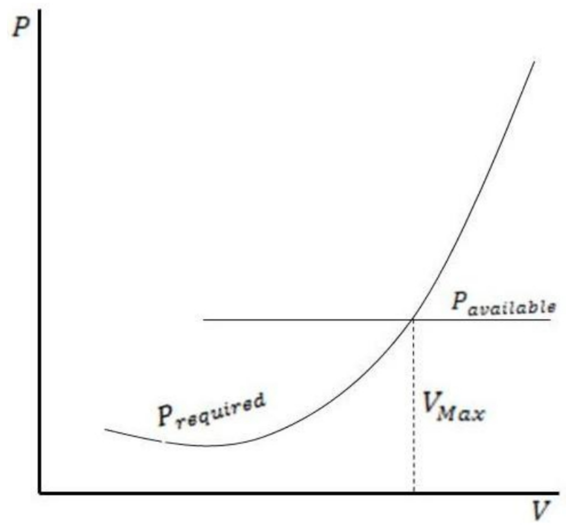

Figure 3: Power required and power available variation with velocity (propeller driven aircraft)

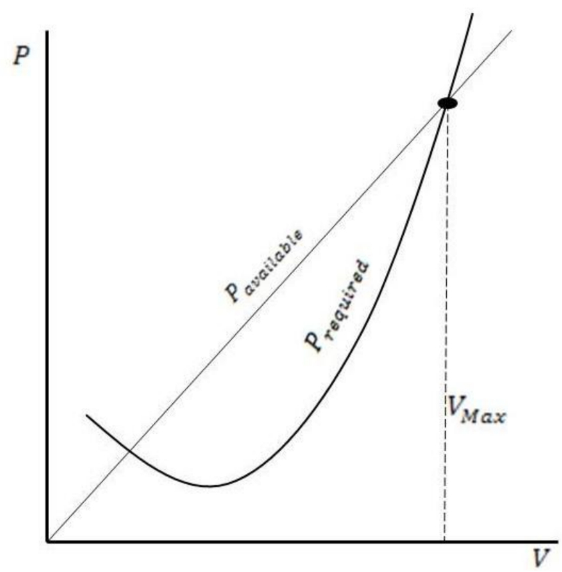

Figure 4: Power required and power available with velicity (jet engine)

Maximum flight velocity

For both the propeller and jet-powered aircrafts, the maximum flight velocity at a given altitude is determined by the high speed intersection of the maximum power available, $P_{available}$ and the $P_{required}$ curves as depicted in Figure 3 & 4.

Effect of altitude on power required

- From the relations obtained in the previous discussions, i.e,

$$P_{req} = T_{req}V = DV = \frac{WV}{\frac{C_L}{C_D}} = \sqrt{\frac{2W^3C_D^2}{S\rho C_L^3}}$$

and

$$P_{req} = \frac{1}{2}\rho V^3 SC_{D_o} + \frac{\frac{W^2}{\frac{1}{2}\rho VS}}{\pi ARe}$$

for sea level conditions, we have:

$$V_o = \sqrt{\frac{2\left(\frac{W}{S}\right)}{\rho_o C_L}} \tag{1}$$

$$P_{R,o} = \sqrt{\frac{2W^3C_D^2}{S\rho_o C_L^3}} \tag{2}$$

- At an altitude where density is ρ, these relations are:

$$V_{alt} = \sqrt{\frac{2\left(\frac{W}{S}\right)}{\rho C_L}} \tag{3}$$

$$P_{R,alt} = \sqrt{\frac{2W^3C_D^2}{S\rho C_L^3}} \tag{4}$$

- For a fixed value of C_L and C_D between sea level and altitude, dividing Equation 3 by Equation 1 and Equation 4 by Equation 2, we obtain

$$V_{alt} = V_o\sqrt{\frac{\rho_o}{\rho}} \tag{5}$$

$$P_{R,alt} = P_{R,o}\sqrt{\frac{\rho_o}{\rho}} \tag{6}$$

- So, from the known values of power required, $P_{R,o}$ and velocity, V_o of an aircraft at sea level we can obtain power required, $P_{R,alt}$ and velocity, V_{alt} at an altitude.

- A typical variation of P_R v/s V for various altitudes has been presented in Figure 5. It could be seen that power required curves experience an upward and rightward translation and as well as slight clockwise rotation as altitude increases.

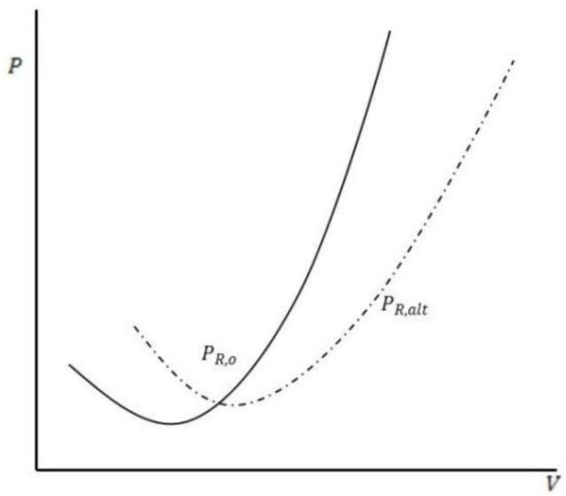

Figure 5: Change in the power required curve with altitude

In this discussion we will assume that P_A and T_A are directly proportional to the altitude density. The variation of maximum power available and power required both at sea level and at an altitude is shown in Figure 6. It can be understood that by plotting power available and power required as function of velocity for various altitudes, one can quickly estimate the maximum speed at a given altitude.

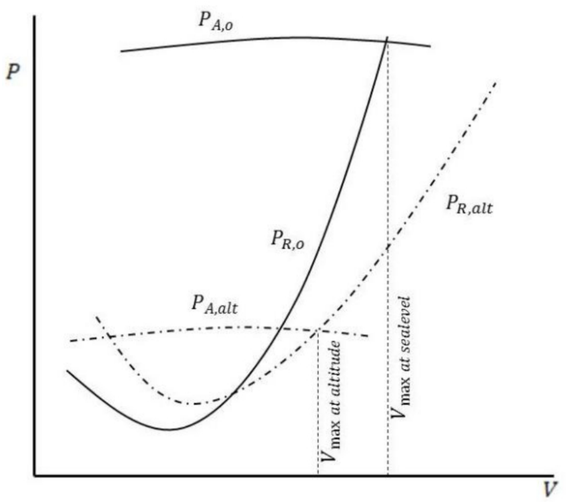

Figure 6: Change in the power required and power available curve with altitude