Chapter 1

Lecture 3

Introduction – 3

Topics

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1.8 Simplified treatment in performance analysis

In a steady flight, there is no acceleration along the flight path and in a level flight; the altitude of the flight remains constant. A steady, straight and level flight generally means a flight along a straight line at a constant velocity and constant altitude.

Sometimes, this flight is also referred to as unaccelerated level flight. To illustrate the simplified treatment in performance analysis, the case of unaccelerated level flight is considered below.

The forces acting on an airplane in unaccelerated level flight are shown in the Fig.1.12.

They are: Lift (L), Thrust (T), Drag (D) and Weight (W) of the airplane.

It may be noted that the point of action of the thrust and it's direction depend on the engine location. However, the direction of the thrust can be taken parallel to the airplane reference axis.

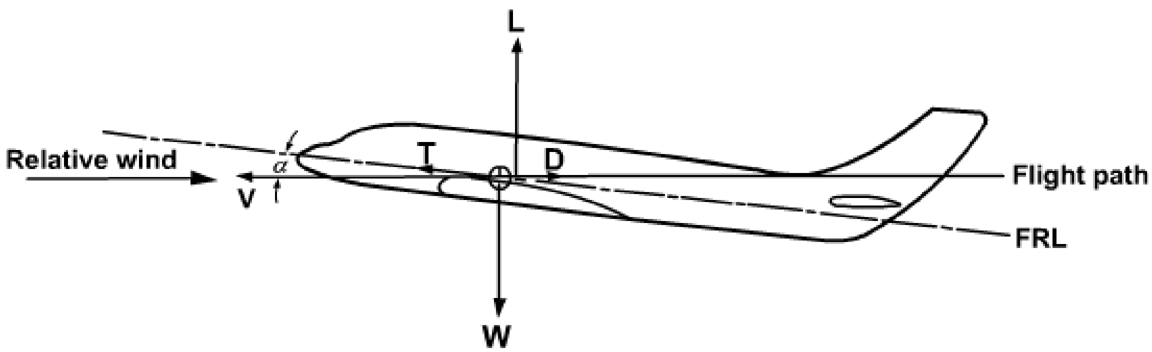

Fig.1.12 Forces acting in steady level flight

The lift and drag, being perpendicular to the relative wind, are in the vertical and horizontal directions respectively, in this flight. The weight acts at the c.g. in a vertically downward direction.

In an unaccelerated level flight, the components of acceleration in the horizontal and vertical directions are zero.

Hence, the sums of the components of all the forces in these directions are zero. Resolving the forces along and perpendicular to the flight path (see Fig.1.12.), gives the following equations of force equilibrium.

$$T \cos \alpha - D = 0 \tag{1.3}$$

$$T \sin \alpha + L - W = 0 \tag{1.4}$$

Apart from these equations, equilibrium demands that the moment about the y-axis to be zero, i.e.,

$$M_{cg} = 0$$

Unless the moment condition is satisfied, the airplane will begin to rotate about the c.g.

Let us now examine how the moment is balanced in an airplane. The contributions to M_{cg} come from all the components of the airplane. As regards the wing, the point where the resultant vector of the lift and drag intersects the plane of symmetry is known as the centre of pressure. This resultant force produces a moment about the c.g. However, the location of the center of pressure depends on the lift coefficient and hence the moment contribution of wing changes with the angle of attack as the lift coefficient depends on the angle of attack. For convenience, the lift and the drag are transferred to the aerodynamic center along with a moment (M_{ac}). Recall, that moment coefficient about the a.c. (C_{mac}) is, by definition, constant with change in angle of attack.

Similarly, the moment contributions of the fuselage and the horizontal tail change with the angle of attack. The engine thrust also produces a moment about the c.g. which depends on the thrust required.

Hence, the sum of the moments about the c.g. contributed by the wing, fuselage, horizontal tail and engine changes with the angle of attack. By appropriate choice of the horizontal tail setting (i.e. incidence of horizontal tail with respect to fuselage central line), one may be able to make the sum of these moments to be zero in a certain flight condition, which is generally the cruise flight condition. Under other flight conditions, generation of corrective aerodynamic moment is facilitated by suitable deflection of elevator (See Fig.1.2a, b and c for location of elevator). By deflecting the elevator, the lift on the horizontal tail surface can be varied and the moment produced by the horizontal tail balances the moments produced by all other components.

The above points are illustrated with the help of an example.

Example 1.1

A jet aircraft weighing 60,000 N has it's line of thrust 0.15 m below the line of drag. When flying at a certain speed, the thrust required is 6000 N and the center of pressure of the wing lift is 0.45 m aft of the airplane c.g. What is the lift on the wing and the load on the tail plane whose center of pressure is 7.5 m behind the c.g.? Assume unaccelerated level flight and the angle of attack to be small during the flight.

Solution:

The various forces and dimensions are presented in Fig.1.13. The lift on the wing is L_W and the lift on the tail is L_T. Since the angle of attack (α) is small, it may be considered that $\cos \alpha = 1$ and $\sin \alpha = 0$. Thus, the force equilibrium (Eqs. 1.3 and 1.4), yields :

$$T - D = 0$$

$$L_W + L_T - W = 0$$

i.e. D = T = 6000 N and $L_T + L_W$ = 60000 N

From Fig. 1.13., the moment equilibrium about the c.g. gives:

$M_{cg} = T (z_d + 0.15) – D.z_d – 0.45.L_W – 7.5.L_T = 0$ where z_d is the distance of drag below the c.g; not shown in figure as it is of no significance in the present context.

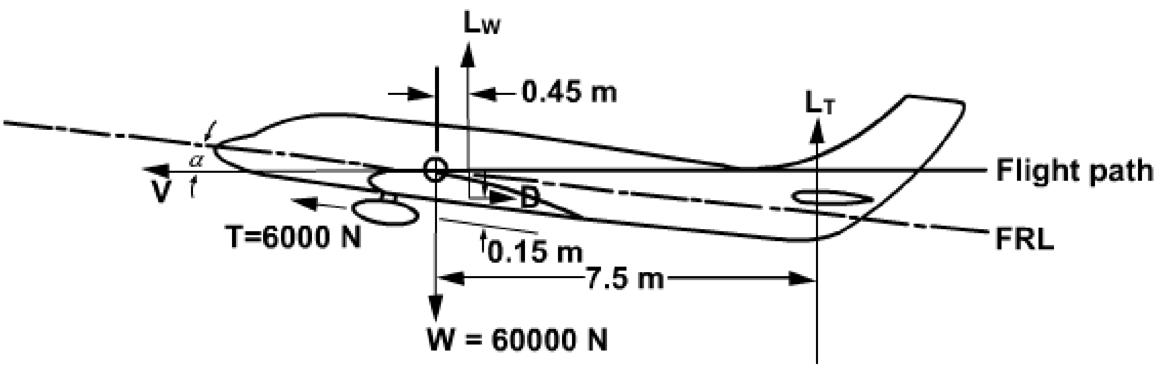

Fig.1.13 Forces acting on an airplane in steady level flight

Solving these equations, gives :

L_W = 63702.13 N and L_T = -3702.13 N

Following observations can be made.

A) The lift on the wing is about 63.7 kN. The lift on the tail is only 3.7 kN and is in the downward direction.

B) The contribution of tail to the total lift is thus small, in this case, about 6% and negative. This negative contribution necessitates the wing lift to be more than the weight of the airplane. This increase in the lift results in additional drag called trim drag.

C) The distance z_d is of no significance in this problem as the drag and thrust form a couple whose moment is equal to the thrust multiplied by the distance between them.

D) Generally, the angle of attack (α) is small. Hence, sin α is small and cos α is nearly equal to unity. Thus, the equations of force equilibrium reduce to

$$T – D = 0 \text{ and } L – W = 0.$$

E) It is assumed that the pitching moment equilibrium i.e. $\Sigma M_{cg} = 0$ is achieved by appropriate deflection of the elevator. The changes in the lift and drag due to elevator deflections are generally small and in performance analysis, as stated earlier, these changes are ignored and the simplified picture as shown in Fig.1.14 is considered adequate.

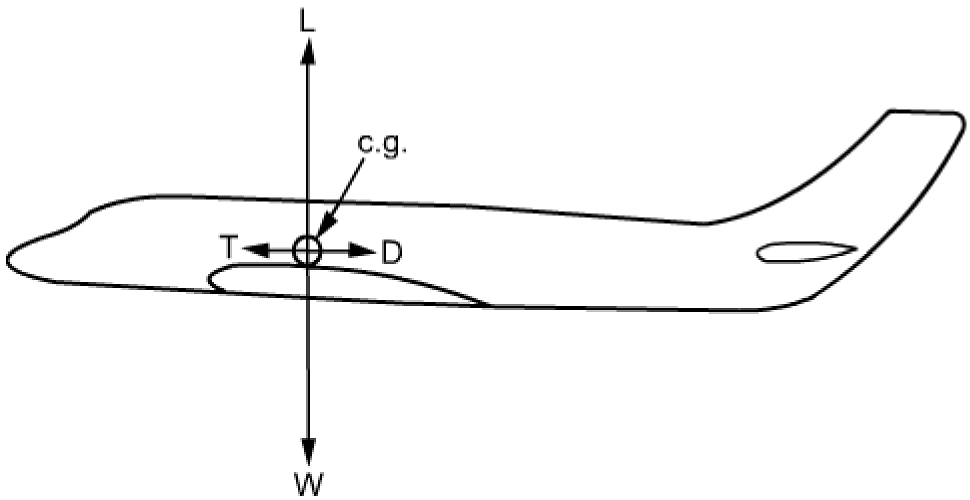

Fig.1.14. Simplified picture of the forces acting on an airplane in level flight.

1.9 Course outline

Let us consider the background material required to carry-out the performance analysis. It is known that :

$$L = (1/2)\,\rho\, V^2\, S\, C_L$$

$$D = (1/2)\,\rho\, V^2\, S\, C_D$$

where C_L and C_D are the lift and drag coefficients; S is the area of the wing. The quantities C_L and C_D depend on α, Mach number (M = V / a) and Reynolds number ($R_e = \rho V l/\mu$); where l is the reference length. Thus

$$C_D = f\,(C_L, M, R_e) \qquad (1.6)$$

The relation between C_L and C_D at given M and R_e is known as the drag polar of the airplane. This has to be known for carrying the performance analysis. The density of air (ρ) depends on the flight altitude. Further the Mach number depends on the speed of sound, which in turn depends on the ambient air temperature. Thus, performance analysis requires the knowledge of the variations of pressure, temperature, density, viscosity etc. with altitude in earth's atmosphere.

The evaluation of performance also requires the knowledge of the engine characteristics such as, variations of thrust (or power) and fuel consumption with the flight speed and altitude.

Keeping these aspects in view, following will be the contents of this course.

Earth's atmosphere (chapter 2)

Drag polar (chapter 3)

Engine characteristics (chapter 4)

Performance analysis. (chapters 5 to 10)

These topics will be taken up in the subsequent chapters.

The Appendices 'A' and 'B' present the performance analyses of piston-engined and jet airplane respectively.

1.10 Back ground expected

The student is expected to have undergone courses on (a) Vectors (b) Rigid body dynamics (c) Aerodynamics and (d) Aircraft engines.

Remark: References 1.5 to 1.14 are some of the books dealing with airplane performance. They can be consulted for additional information.