LEVEL FLIGHT

Introduction

1. During flight four main forces act upon an aircraft : lift, weight, thrust, and drag. In level flight there must be no residual force tending to move the aircraft from its straight and level path, *i.e.* the forces must be in equilibrium.

The Four Forces

2. With the aircraft in steady level flight the four forces and their points of action are :—

(*a*) The resultant of the lifting forces of the wing (lift), which acts at right angles to the path of flight through the centre of pressure (C.P.).

(*b*) The weight of the aircraft, which acts vertically downwards through the centre of gravity (C.G.).

(*c*) The thrust of the engine or propeller, which may be taken to act approximately parallel to the direction of flight. This assumption, although not strictly valid, will suffice for the purposes of this chapter.

(*d*) The drag, which acts horizontally backwards from a point which varies with the flight attitude of the aircraft.

3. For straight and level flight the opposing forces must be equal and opposite, so :—

Lift = Weight
Thrust = Drag

The lift must, therefore, be adjusted by altering the angle of attack until it is exactly equal to the weight which it must support. Similarly the thrust and drag must balance, for if the thrust is greater the aircraft will accelerate, if less the speed will decrease. Although the opposing forces are equal, there is a considerable difference between each pair of forces. The lift or weight figure, for example, may be 50,000 lb. while the drag or thrust may be as low as 5,000 lb., depending on the speed and the power used.

Pitching Moments

4. The positions of the C.P. and C.G. are variable and under most conditions of level flight they are not coincident. The C.P. changes its position with change in angle of attack and the C.G. with reduction in fuel or when stores are dropped. The outcome is that the opposing forces of lift and weight set up a couple causing either a nose-up or a nose-down pitching moment depending on whether the lift is in front of or behind the C.G., as illustrated in Fig. 1. The same consideration applies to the position of the lines of action of the thrust and drag. Ideally the pitching moments arising from these two couples should neutralize each other in level flight so that there is no residual moment tending to rotate the aircraft.

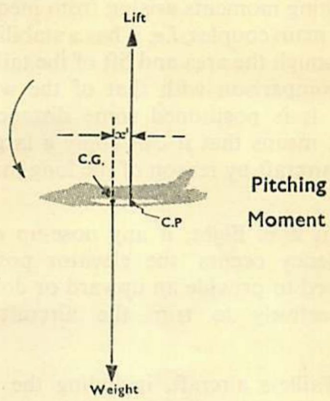

Fig. 1.

5. This ideal is not easy to attain by juggling with the lines of action of the forces alone but, as far as possible, the forces are arranged as shown in Fig. 2. With this arrangement the thrust/drag couple produces a nose-up and the lift/weight couple a nose-down moment, the lines of action of each couple being positioned so that

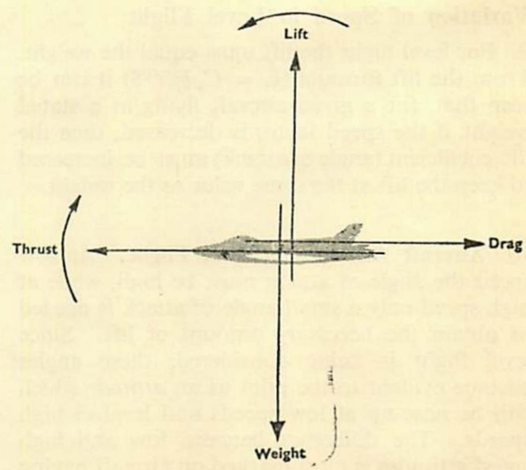

Fig. 2. Disposition of the Four Forces

the strength of each couple is equal. If the engine is throttled back in level flight the thrust/drag couple is weakened and the lift/weight couple pitches the nose down, so that the aircraft assumes a gliding attitude. If power is then reapplied the growing strength of the thrust/drag couple raises the nose towards the level flight attitude.

Tailplane and Elevator

6. The function of the tailplane and elevator is to supply any force necessary to counter residual pitching moments arising from inequalities in the two main couples, *i.e.* it has a stabilizing function. Although the area and lift of the tailplane is small in comparison with that of the wings, the fact that it is positioned some distance behind the C.P. means that it can apply a large moment to the aircraft by reason of the long moment arm.

7. In level flight, if any nose-up or nose-down tendency occurs, the elevator position can be altered to provide an upward or downward force respectively to trim the aircraft.

8. Tailless aircraft, including the tailless delta-wing types, use the tips or rear portions of their swept-back wings to carry out the function of a separate tailplane. This portion of the total wing area, being behind both the C.P. of the complete wing and the C.G., adjustment of control surfaces at the tips or, with delta wings, along the trailing edge, stabilizes the aircraft in the same way as a tailplane.

Variation of Speed in Level Flight

9. For level flight the lift must equal the weight. From the lift formula ($L = C_L \frac{1}{2}\rho V^2 S$) it can be seen that, for a given aircraft flying at a stated weight, if the speed factor is decreased, then the lift coefficient (angle of attack) must be increased to keep the lift at the same value as the weight.

10. **Aircraft Attitude in Level Flight.** At low speed the angle of attack must be high, while at high speed only a small angle of attack is needed to obtain the necessary amount of lift. Since level flight is being considered, these angles become evident to the pilot as an *attitude* which will be nose-up at low speeds and level at high speeds. The difference between low and high speed attitudes is most marked on aircraft having swept-back wings or unswept wings of low aspect ratio for the reasons given in Chapter 6.

11. **Variation of L/D Ratio.** Examination of the lift formula shows that for a given weight, or lift, each value of I.A.S. must be accompanied by a specific angle of attack ; the one decreasing as the other increases. The angle of attack at which the wing is operating is an important aerodynamic consideration when flying for range, for to obtain the maximum range the wing must be at the angle of attack for the best L/D ratio. The pilot, having no indication of angle of attack, must perforce use the A.S.I. to tell when the aircraft is in the correct attitude. The recommended range speed given in Pilots' Notes is that which realizes the angle of attack for best L/D ratio. Therefore by flying at the recommended range I.A.S. for the appropriate weight, the aircraft will be at the angle of attack that will enable it to fly furthest for a given amount of fuel. Flying for range is dealt with in detail in Vol. 2, Part 3.

Effect of Weight on Level Flight

12. If an aircraft is flying level at a given angle of attack, for example that for best L/D ratio (about 4°), and at a known weight and I.A.S., then if the weight is reduced by dropping stores the lift must also be reduced to balance the new weight. To maintain optimum conditions with the angle of attack at 4° the speed must be decreased until the lift falls to the same value as the new weight.

13. The lower the weight the lower is the I.A.S. corresponding to a given angle of attack, the I.A.S. at the required angle being proportional to the square root of the all-up weight.

Effect of Altitude on Level Flight

14. The $\frac{1}{2}\rho V^2$ factor of the lift formula is the total air pressure experienced during flight. As has been stated in Chapter 2, the magnitude of this factor depends on the I.A.S. and not on the T.A.S. As height is increased at a given I.A.S., the increasing T.A.S. is offset by the reduction in density so that the total value of $\frac{1}{2}\rho V^2$ is also constant. Since not only the speed but also the lift and drag vary with the $\frac{1}{2}\rho V^2$ factor, the relationship between I.A.S. and angle of attack is unchanged at altitude, provided of course that the weight is constant.

15. At high altitudes, however, compressibility effects tend to alter the relationship by reducing the C_L appropriate to a given angle of attack. This aspect is dealt with in Chapter 14, "Transonic and Supersonic Aerodynamics".