Chapter 10

Lecture 34

Performance analysis VI – Take-off and landing – 3

Topics

10.4.8 Balanced field length and its estimation

Take-off is a critical phase of flight operation and various eventualities are taken into account to arrive at the length of the runway required for the operation of the airplane. In the case of multi-engined airplane, the possibility of the failure of one of the engines during take-off is an important consideration. If the engine failure takes place during initial stages of ground run, then the pilot can apply the brakes and bring the airplane to halt. If the engine failure takes place after the airplane has gained sufficient speed, then the following two alternatives are available.

(a) Apply brakes and stop the airplane, but this may need much longer runway length than in the case of take-off without engine failure.

(b) Instead of applying brakes, continue to fly with one engine inoperative and take-off; but the take-off distance would be longer than when there is no engine failure.

These two alternatives indicate the possibility of a speed, called “Decision speed”. If the engine failure occurs at the decision speed, then the distance required to stop the airplane is the same as that required to take-off with one engine inoperative. The take-off distance required when engine failure takes place at the decision speed is called 'Balanced field length (BFL)'. It is estimated as follows.

FAR 25 (see Ref.10.1) is used as a set of regulations for obtaining the take-off distance of jet airplanes. The regulations also prescribe a procedure to calculate the balanced field length (BFL). Reference 10.2 has estimated BFL for many jet airplanes and observed that BFL is a function of TOP defined in Eq.(10.21).

Based on this data, the BFL in feet, when W/S in lbs / ft^2 is given as (Ref.3.18, Pt.I, chapter 3):

$$\text{BFL (in ft)} = 37.5\ \text{TOP (in lbs / ft}^2\text{)} \tag{10.23}$$

When SI units are used, Eq.(10.23) takes the following form.

$$\text{BFL (in m)} = 0.2387 \frac{\left(\frac{W}{S}\right)_{TO}}{\sigma\, C_{LTO} \left(\frac{T}{W}\right)_{TO}} \tag{10.24}$$

where W / S is in N / m^2.

Remark :

(i) Effect of number of engines on BFL :

The data in Ref.10.2, on which Eq.(10.23), is based, shows some scatter (Fig.3.7 of Ref.10.2). However, the data for airplanes with two, three and four engines show some definite trend; the BFL is more as the number of engines decrease. This is expected, as for a two engined airplane, when one engine is inoperative, the thrust available would decrease to half of the full thrust, whereas for an airplane with four engines, with one engine inoperative, the thrust available would be three fourth of the full thrust. Consequently, BFL would be less for a four engine airplane as compared to that for a two engined airplane. Perhaps, based on this argument, Ref.3.9, chapter 5, suggests three different lines for BFL vs TOP curve for airplane with two three and four engines. In SI units these lines can be expressed as:

For two engined airplane: BFL (in m) = 0.2613 TOP (in N / m^2) (10.25)

For three engined airplane: BFL (in m) = 0.2387 TOP (in N / m^2) (10.26)

For four engined airplane: BFL (in m) = 0.2196 TOP (in N / m^2) (10.27)

Example 10.4

Consider the airplane of example 10.3 and obtain the balance field length.

Solution:

In this case :

$W / S = 5195\ N/m^2$, $\sigma = 1.0$, $C_{LTO} = 2.16$ and $T/ W = 0.3$.

Consequently, TOP is 8017 N/m^2.

Using Eqs (10.25) to (10.27) the BFL would be (a) 2095 m for an airplane configuration with two engines, (b) 1914 m for three engine configuration and (c) 1761 m for four engine configuration. Comparing s_{to} and BFL in examples 10.3 and 10.4, it is seen that is BFL is nearly twice of s_{to} .

(ii) See Appendices A and B for calculation or take-off distance for a piston engined airplane and a jet airplane respectively.

10.5 Landing performance

10.5.1 Definition of landing distance

While describing the take-off distance it was mentioned that the airplane should clear the screen height before it leaves the airport environment. For the same reason, the landing flight begins when the airplane is at the screen height. The landing distance is defined as the horizontal distance that the airplane covers in descending from the screen height and to come to halt. In actual practice, the airplane does not halt on the runway. After reaching a sufficiently low speed the pilot takes the airplane to the allotted parking place.

10.5.2 Phases of landing

Figure 10.2 shows the phases of landing flight for an airplane with tricycle type landing gear.

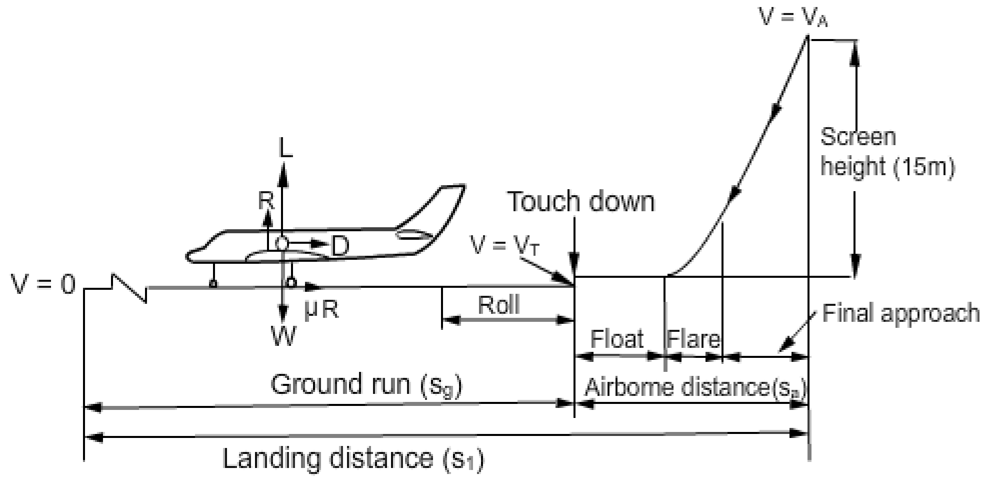

Fig.10.2 Phases of landing flight

During the final approach phase, the airplane performs a steady descent. The flight velocity in this phase is called approach speed and denoted by V_A. During the flare, the pilot makes the flight path almost horizontal. In the float phase the pilot gently touches the main wheels to the ground. This is done gradually so that the vertical velocity of the airplane is not more than about 4 m/s. The flight speed at the point of touch down is denoted by V_T. It is about 90% of V_A. After the touch down, the airplane rolls for a period of about 3 seconds during which the nose wheel is gently lowered to touch the ground. Brakes are not applied in this phase as their application would produce a large decelerating force which would cause a large nose down moment and the nose wheel may hit the ground with a bang. After the three wheels have touched the ground, the brakes are applied as well as other devices like reverse thrust or reversed pitch of propeller are deployed. The ground run is said to be over when the airplane comes to halt or attains a low speed when it can turn off the runway and go to the parking place.

10.5.3 Estimation of landing distance

This can be done in a way similar to the estimation of the take-off distance i.e., by writing down equations for each phase of the flight. However, the estimation cannot be done accurately as the flare and float phases depend very much on the judgment of the pilot.

Royal Aeronautical Society Data sheets (presently called Engineering Science Data Unit or ESDU) have given a simple method which amounts to assuming a constant deceleration and calculating the distance to decelerate from V_A and to come to a halt i.e.

$$s_{land} = - (V_A)^2 / 2a \tag{10.28}$$

where, a = $-1.22\ m/s^2$ (or $4 ft/s^2$) for simple braking system

= $-1.52\ m/s^2$ (or $5\ ft/s^2$) for average braking system.

= $-1.83\ m/s^2$ (or $6\ ft/s^2$) for modern braking system and

= -2.13 to $3.0\ m/s^2$ (or 7 to 10 ft $/s^2$) for airplane with modern braking system and reverse thrust or reverse pitch propellers.

The approach speed (V_A) depends on factors like stalling speed under approach conditions, minimum speed at which adequate control is possible and the type of approach viz. visual landing or instrumented landing system or aircraft carrier deck approach. As a first estimate V_A can be taken as 1.3 V_S.

Example 10.5

Obtain the landing distance for the airplane in example 10.1. Assume that the airplane has modern braking system with reverse thrust and that $V_A = 1.3\ V_S$.

Solution:

From example 10.1, W = 441, 450 N, S = 110 m^2 ,

C_{Lmax} during landing = 2.7.

Hence, $V_S = \left(\frac{2 \times 441450}{1.225 \times 110 \times 2.7}\right)^{1/2} = 49.24\ m/s$

Consequently, $V_A = 1.3 \times 49.24 = 64.01$ m/s.

Taking a = $-2.13\ m/s^2$, the estimate of landing distance is :

$$s_{land} = -\frac{64.01^2}{2 \times (-2.13)} = 961.9 \text{ m}$$

Answer : Landing distance = 961.9 m

Remarks:

i) Appendix A also estimates the landing distance using Eq.(10.28). Appendix B uses a different formula.

ii) The landing distance is proportional to $(V_A)^2$ and consequently it is proportional to $(V_S)^2$. The following observations can be made by noting that $(V_S)^2$ equals $2W/(\rho SC_{Lmax})$.

(a) The landing distance increases with increase of (W/S) and the altitude of landing field. (b) The landing distance decreases with increase of C_{Lmax}.

iii) The use of reverse thrust and reverse pitch propeller to reduce the landing distance has been mentioned earlier. The landing run can also be decreased by using (a) arresting gear, (b) drag parachute and (c) spoilers.

The arresting gear is used for airplane landing on the deck of a ship.

The drag parachute, when opened, increases the drag significantly and reduces the landing run.

The spoilers are located on the upper surface of the wing. When deflected up, the spoiler disturbs the flow, resulting in reduction of lift and increase of drag. Spoiler ailerons are shown in Fig.1.2c. When used as a device to produce a rolling moment, the spoiler aileron is deflected only on the left or the right wing half. The lift on that wing half is reduced and the airplane rolls. Whereas, during landing, the spoiler ailerons on both the wing halves are deployed simultaneously. This results in a large reduction in lift and increase in drag. Both these effects help in reducing the landing run.

iv) Like take-off distance the landing distance is also reduced by head wind.

10.6 Flap settings during take-off and landing

It is mentioned in subsection 10.4.1, that the C_{Lmax} during take-off is 80% of that during landing. The flap setting during take-off is lower than the setting during landing. The reasons for this difference are as follows.

Equation (10.17) shows that the take-off run depends on ambient density(ρ), wing loading (W/S), maximum lift coefficient (C_{Lmax}) and the average accelerating force. Out of these parameters, as pointed out earlier, the values of (W/S) and (T/W) are chosen based on considerations of cruise, maximum speed etc. In this situation, the choices available to reduce the take-off distance are (a) C_{Lmax} and (b) average accelerating force during the take-off.

It may be pointed out at this juncture that a high value of C_{LTO} would reduce V_1 and hence the take-off run (Eq.10.17). However, the high value of C_{LTO} would also result in high value of C_D and consequently high value of drag and a lower accelerating force. This would tend to increase the take-off run (Eq.10.17). On account of these two opposing effects, there is an optimum value of C_{LTO} and the corresponding flap setting, that would result in lowest take-off run.

On the other hand, during landing the approach speed and the touch down speed would be lowest when the C_{Lmax} is highest. Further, the high value of C_D associated with high value of C_{Lmax} would also increase the decelerating force during landing run and consequently reduce it. Thus a high value of C_{Lmax} is beneficial for reducing the landing run & distance.

Keeping these two aspects in view, the flap setting during the take-off is lower than that during the landing. As a guideline it is mentioned in Ref.3.15, chapter 5, that the flap deflection for take-off $(\delta_f)_{TO}$ is about half of that during landing $(\delta_f)_{Land}$.The deflection of the leading edge slat during take-off, is about two-thirds of that during landing.

It may be further added that during landing run, after all the landing gear wheels have touched ground, the lift is not needed. Hence, in airplanes with provision of spoilers, they (spoilers) are deployed during the landing run to reduce the lift and increase the drag.

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