Chapter 10
Miscellaneous topics
(Lectures 38 to 40)

Keywords : Performance estimation ; presentation of results of preliminary design ; cost analysis ; sizing and trade studies ; multi-disciplinary optimization ; concurrent engineering.

Topics

Chapter 10

Miscellaneous topics - 1

Lecture 38

Topics

10.1 Introduction

10.2 Performance estimation

10.2.1 General remarks on performance estimation

10.1 Introduction

The following topics are dealt with in this concluding chapter.

a) Performance estimation

b) Presentation of results of preliminary design

c) Cost Analysis

d) Outline of sizing and trade-off studies

10.2 Performance estimation

After carrying out the stability analysis, the major dimensions of the airplane have been arrived at. This will enable preparation of the revised three view drawing. Using this drawing and the flight conditions, a drag polar of the airplane can be estimated. For this purpose the information in Ref.4.3, Ref.1.12, part VI and Ref.1.18, chapter 12 can be used. Datcom by US Air Force(Ref.4.2) can also be used as a source of information.

The information about power output at various speeds and altitudes is known from chapter 4. With this information the performance analysis can be carried out. It is assumed that the student is familiar with methods for performance estimation. Reference 3.3 along with chapter 17 of Ref.1.18 are suggested as sources of information.

The performance analysis includes the following:

1) The variation of stalling speed (V_s) at various altitudes.

2) Variations with altitude of maximum speed (V_{max}) and minimum speed from power output consideration $(V_{min})_{power}$. The minimum speed of the airplane at an altitude will be the higher of V_s and $(V_{min})_{power}$. The maximum speed and minimum speed will decide the flight envelope.

3) Variations with altitude of the maximum rate of climb ($(R/C)_{max}$) and maximum angle of climb (γ_{max}) ; the flight being treated as steady climb. Variations with altitude of $V_{(R/C)max}$ and $V_{\gamma max}$. To arrive at these quantities choose a set of altitudes and at each of these altitudes, obtain the R/C and γ at different flight velocities. From the plot of $(R/C)_{max}$ vs. h, the values of absolute ceiling and service ceiling can be obtained. At absolute ceiling $(R/C)_{max}$ is zero and at service ceiling $(R/C)_{max}$ is 30 m/min. For multi-engined airplanes, the rate of climb with one engine inoperative must satisfy the airworthiness regulations.

4) To arrive at the cruising speed and altitude, choose a range of altitudes around the cruising altitude mentioned in the specifications. At each of these altitudes obtain the range in constant velocity flights choosing different velocities. The information on appropriate values of specific fuel consumption (SFC) can be obtained from the engine charts.

The values of range obtained at different speeds and altitudes be plotted as range vs velocity curves with altitude as parameter. Draw an envelope of these curves.The altitude and velocity at which the range is maximum can be considered as the cruising speed (V_{cruise}) and cruising altitude (h_{cruise}). These curves also give information about the range of flight speeds and altitudes around V_{cruise} and h_{cruise} at which near optimum performance is obtained.

5) The maximum rate of turn ($\dot{\psi}_{max}$) and the minimum radius of turn (r_{min}) in steady level turn depend on the thrust available, C_{Lmax} and the permissible load factor (n_{max}). The value of C_{Lmax} used here is that without the flaps. For high speed airplanes the value of C_{Lmax} depends also on Mach number. The value of n_{max} depends on the weight and the type of airplane. Reference 3.3, subsection 9.4.3 be referred to for discussion on V-n diagram.

Choose a set of altitudes and at each of these altitudes obtain the values of $V_{\psi max}$ and V_{rmin}. From plots of these quantities obtain variations, with altitude, of r_{min}, and V_{rmin}.

6) Take - off run and take - off distance: During take-off an airplane accelerates on the ground. For an airplane with nose wheel type of landing gear, around a speed of 85% of the take-off speed, the pilot pulls the stick back. Then, the airplane attains the angle of attack corresponding to take-off and the airplane leaves the ground. The point at which the main wheels leave the ground is called the unstick point and the distance from the start of take-off point to the unstick point is called the ground run. After the unstick, the airplane goes along a curved path as lift is more than the weight. This phase of take-off is called transition at the end of which the airplane climbs along a straight line. The take-off phase is said to be over when the airplane attains screen height which is generally 15 m above the ground. The horizontal distance from the start of the take off to the where the airplane attains screen height is called take off distance (Fig.3.4). The take off run and the take-off distance can be estimated by writing down equations of motion in different phases. The details are available, for example, in chapter 17 of Ref.1.18; chapter 10 of Ref.1.14 and chapter 10 of Ref.3.3.

Remark:

Balanced field length:It is the length of the run way required from, consideration of safety in the event of engine failure. If the engine fails soon after the aircraft begins to roll, the pilot can stop the airplane without difficulty. If the engine fails when the airplane is near the unstick point, then he should not have difficulty in completing the take-off. The speed of the airplane, during take-off, at which the distance to stop after an engine failure equals the distance to continue the take-off on the remaining engine (s) is called a decision speed. The balanced field length is the take-off distance to clear the screen height when one engine fails at the decision speed. Subsection 4.8.1 can be referred to for estimating the balance field length.

7) Landing Distance:The landing flight begins when the airplane is at the screen height at a velocity called the approach speed. During the approach phase the

airplane descends along a flight path of about 3 degrees. Subsequently the flight path becomes horizontal in the phase called 'flare'. In this phase the pilot also tries to touch the ground gently. The point where the main wheels touch the ground is called touch down point. Subsequent to touch down, the airplane rolls along the ground for about 3 seconds during which the nose wheel touches the ground. This phase is called free roll. After this phase the brakes are applied and the airplane comes to halt. In some airplanes, thrust in the reverse direction is produced by changing the direction of jet exhaust or by reversible pitch propeller. In some airplanes, the drag is increased by speed brakes, spoilers or parachutes. For airplanes which land on the deck of the ship, an arresting gear is employed to reduce the landing distance. The horizontal distance from the start of approach at screen height till the airplane comes to rest is called landing distance. Methods to analyze landing distance are given in Ref.1.18, chapter 17; and Ref.3.3, chapter 10.

Remarks:

i) The landing distance is considerably affected by piloting techniques. To take into account the uncertainty, the landing distance is multiplied by 1.67 to get the FAR/EASA(European Air Safety Agency) landing distance.

ii) Take-off and landing distance calculations are repeated assuming different altitudes of air fields and different atmospheric conditions e.g. A + 20^0 C i.e. the sea level temperature is 35^0 C instead of 15^0 C in the standard atmosphere.

10.2.1 General remarks on performance estimation

I) operating envelope: The maximum speed and minimum speed can be calculated from the level flight analysis. However, the attainment of maximum speed may be limited by other considerations. The operating envelope for an airplane is the range of flight speeds permissible at different altitudes. Typical operating envelope for a military airplane is shown in Fig.10.1. Explanation of the curves in this figure is as follows.

The curve ABCDE is the level flight boundary based on the engine output. The portion ABC is the V_{max} or (M_{max}) boundary. The portion CDE is the $(V_{min})_e$ or (M_{min}) boundary, limited by the engine output. For these curves, the engine output is that with the after burner on. On this boundary the specific excess power (P_s) is zero .

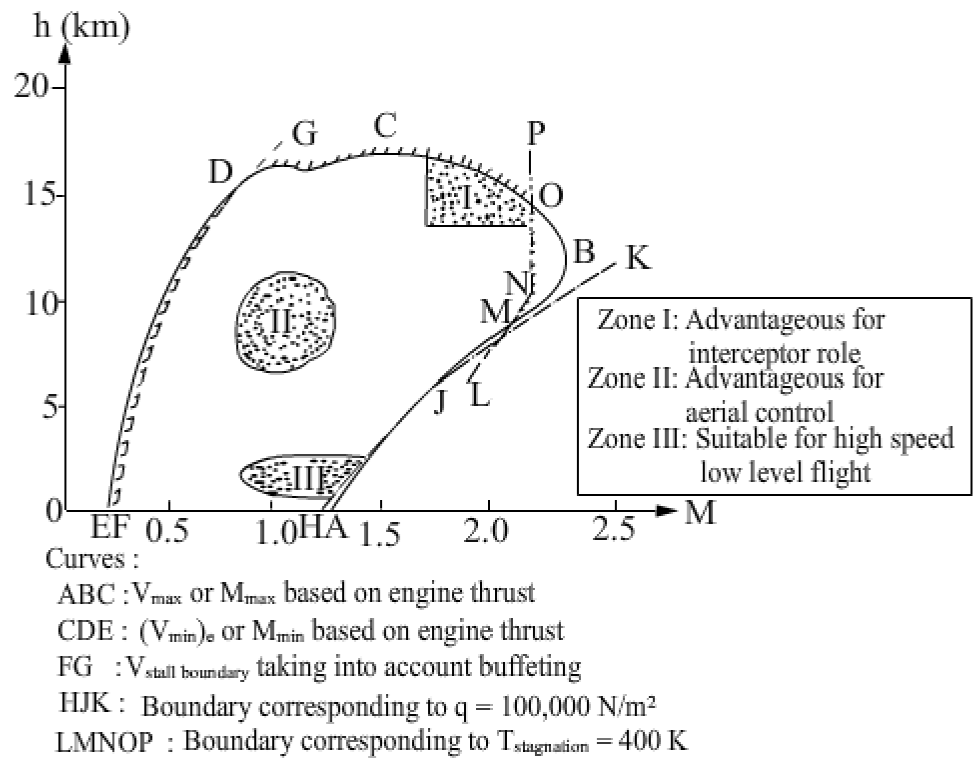

Fig.10.1 Schematic of an operating envelope of a military airplane

The curve FG is the line representing stalling speed (V_s) .

$$V_s = \sqrt{\frac{2\,W}{\rho\,S\,C_{Lmax}}};C_{Lmax}\ \text{without flap}$$

Recalling that when Mach number exceeds 0.5, the maximum lift coefficient (C_{Lmax}) decreases due to shock stall or buffetting. The line FG includes this effect when Mach number corresponds to V_s is more than 0.5. The line HJK represents the dynamic pressure (q) limit. The airplanes are designed for q around 100,000 N/m^2. As the flight Mach number increases the stagnation temperature on the surface (T_s) increases. It is given by :

$$T_s = T_{amb}\,(1 + \varepsilon\,\frac{\gamma\text{-}1}{2}\,M^2)$$

where, T_{amb} is the ambient temperature and ε is the recovery factor ; ε has a value of around 0.9 for turbulent boundary layer on the surface. The line JLMNOP represents T_s of 400 K. It may be pointed out that T_{amb} and consequently the speed of sound change with altitude in troposphere. These two quantities remain constant in stratosphere. Hence, allowable flight Mach number, for stagnation temperature to be below allowable value, changes with altitude. The flight envelope taking into account all these limits is the curve FDCONMJH.

Remark:

Reference 1.18, chapter 17, mentions about other limits like engine relight limit, pilot ejection altitude and duct pressure limit. The minimum speed from engine relight limit is encountered in some cases at high altitudes where enough air may not be available to restart the engine in the event of flame-out. The highest altitude may also be limited to the highest altitude at which ejection by pilot could be permitted (about 15 km). The duct pressure limit is imposed by the restriction on pressure inside the inlet duct of the engine.

II) Energy height technique for climb performance:The analysis of a steady climb shows that the velocity corresponding to maximum rate of climb ($V_{(R/C)max}$) increases with altitude. Consequently, climb with $(R/C)_{max}$ involves acceleration and the rate of climb will actually be lower than that given by the steady climb analysis. This is because a part of the engine output would be used to increase the kinetic energy. Secondly, the aim of the climb is to start from velocity near $V_{take\text{-}off}$ and at $h_{take\text{-}off}$ and attain a velocity near V_{cruise} at h_{cruise}. To take these aspects into account, it is more convenient to work in terms of energy height (h_e) instead of height(h). The quantity h_e is defined as :

$$h_e = h + (V^2 / 2g) \tag{10.1}$$

Multiplying Eq.(10.1) by W gives:

$$W\,h_e = W\,h + (W\,V^2/ 2g) \tag{10.2}$$

The right hand side of the Eq.(10.2) is the sum of the potential energy and the kinetic energy of the airplane. It is denoted by E. The energy height (h_e) which is E / W, is also called specific energy.

It can be shown that (dh_e / dt) = (T V – D V) / W and is referred to as specific excess power (P_s).

Using energy height concept the optimum climb path for fastest climb or economical climb can be worked out. For details, Ref.1.18, chapter 17 and Ref.3.3, chapter 7 may be referred to.

III) Range performance:For commercial airplanes the range performance is of paramount importance. Hence, range performance with different amounts of payload and fuel on board the airplane, needs to be worked out.

In this context the following three limitations should to be considered.

a) Maximum payload:

The number of seats and the size of the cargo compartment are limited. Hence maximum payload capacity is limited.

b) Maximum fuel:

The size of the fuel tanks depends on the space in the wing and the fuselage to store the fuel. Hence, there is limit on the maximum amount of fuel that can be carried by the airplane.

c) Maximum take-off weight:

The airplane structure is designed for a certain load factor and maximum take-off weight. This value of weight cannot be exceeded.

Keeping these limitations in mind a typical payload vs. range curve is shown in Fig.10.2.

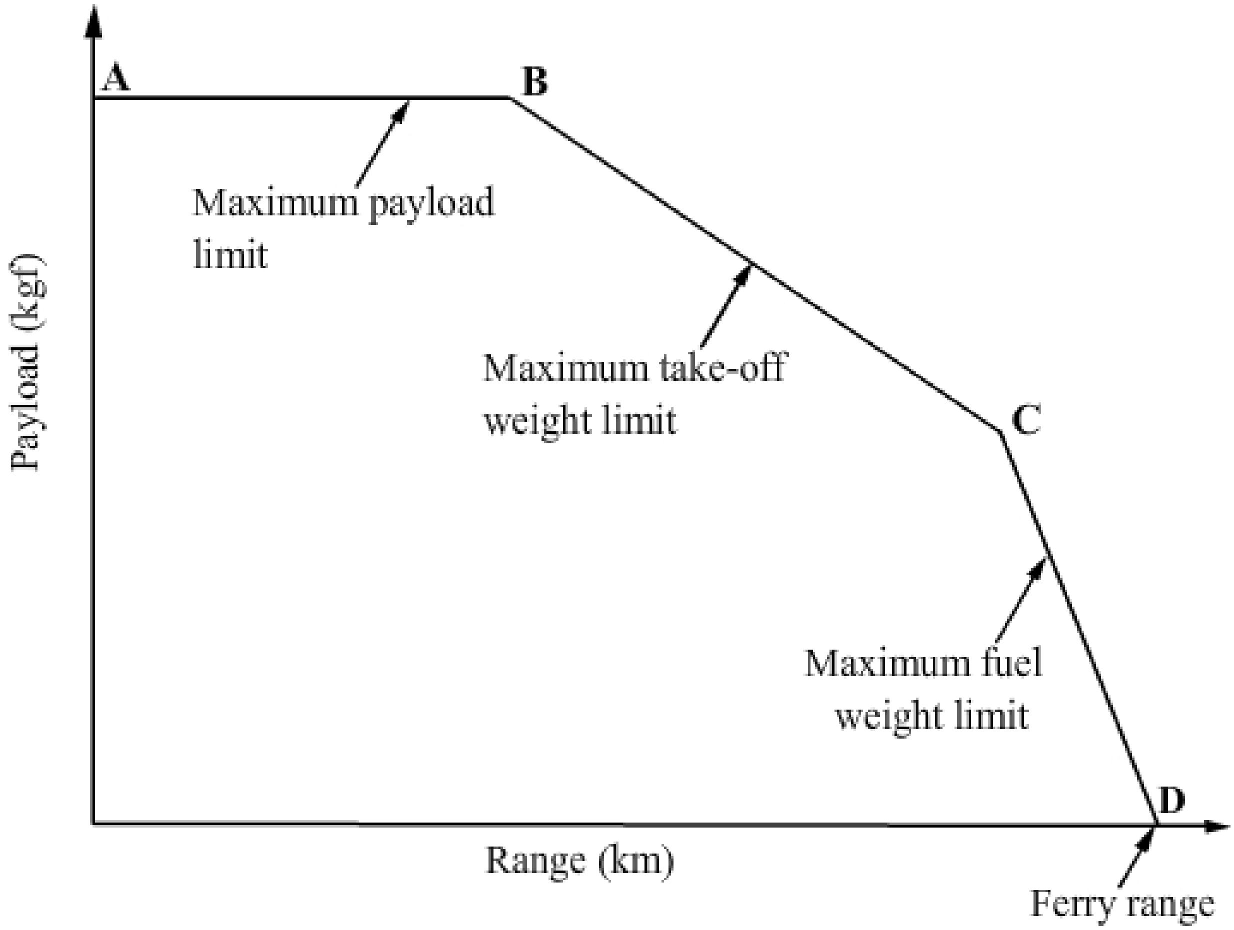

Fig.10.2 Payload – range diagram

A brief explanation of fig.10.2 is as follows.

Point A represents the maximum payload. As the fuel is added the range can increase as represented by line AB. At point B, the limit of the maximum take-off weight is reached. If it is desired that the range should increase further, then the payload has to be decreased so that the maximum take-off weight limit is not exceeded as represented by line BC. At point C, the maximum fuel capacity limit is also reached. If it is desired to increase the range further, the payload has to be decreased as fuel volume cannot be increased. Point D represents zero-payload condition. The range represented by point D is called 'ferry range'.

This type of analysis is used to obtain various combinations of payload and range under different flight operations.

(IV) Other performance items: In case of fighter airplanes, enhanced level of turning performance can be obtained by relaxing the requirements of level turn. Similarly, the fighter airplanes may engage in post-stall maneuvers. For further information on these topics, Ref.1.18, chapter 17 may be referred to.