Chapter 1

Lecture 3

Introduction - 3

Topics

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1.3.5 Longitudinal and lateral stability

A relook at the stability of the pendulum, examined earlier, points out the following.

A pendulum has only one degree of freedom i.e. the rotation about the hinge. Hence, the disturbance can only be an angular displacement θ. As a result of this displacement, an unbalanced force W sin θ is created which may cause stabilizing or destabilizing moment.

On the other hand the analysis of the stability of an airplane is more complex for the following reasons.

a) An airplane in flight can move along three axes and rotate about three axes. Consequently, the disturbances can also be of various types resulting in changes in velocities along x, y and z axes and rotations about these three axes.

b) In addition to the gravitational force, an airplane is subjected to aerodynamic and propulsive forces which depend on the angle of attack and sideslip of the airplane and the linear and angular of velocities.

To make the analysis simpler, we take benefit of the fact that an airplane is symmetric about the X_b - Z_b plane (Fig.1.7).The motions along x- and z- axes and about y- axis (pitching), lie in the plane of symmetry and are called longitudinal motions. The motions along y- axis and about the x- and z- axes (rolling and yawing), which lie out of the plane of symmetry, are called lateral or asymmetric motions.

The breakup of the motion of the airplane into symmetric and asymmetric motions helps in simplifying the stability analysis. The arguments for supporting this are as follows.

A disturbance to the symmetric motions does not affect the asymmetric motions. To explain this in a better way consider an airplane in straight, level and unaccelerated flight. Let it be subjected to a disturbance in the plane of symmetry caused by either (a) a change in forward velocity or (b) a vertical velocity i.e. gust or (c) an elevator deflection. The disturbance may cause the airplane to acquire changes in u, w and q. These may cause changes in lift, drag and pitching moment. However, due to symmetry of airplane, the symmetry of the initial condition of equilibrium and the symmetry of the disturbance, the changes in lift and drag would be same on the left and right halves of the wing and the horizontal tail . Consequently, no rolling or yawing would take place i.e. the disturbances in the plane of symmetry of an airplane originally in symmetric flight, do not cause motions out of plane of symmetry.

As regards the effect of lateral disturbance on longitudinal motion, the following argument would show that the effects are very small only when the disturbance is small.

Following Ref.1.4, chapter 14, we consider that the airplane, initially in straight, level, and uncelebrated flight, is subjected to a small sideslip velocity ‘Δv’ to the right. In response to this, the airplane would tend to roll and yaw, which are motions out of plane of symmetry, but the asymmetric flow on the two wing halves and on the fuselage cause changes in pitching moment (Ref.1.5, Part II, chapter 17). Thus, a Δv produces changes in Δu, Δw and Δq. Now consider that the airplane, initially in straight level and unaccelerated flight, is subjected to sideslip Δv to the left. Besides roll and yaw, the airplane pitches but the changes are in the same direction as in the case when airplane sideslips to right. Thus, the changes in longitudinal motion Δu, Δw and Δq due to the lateral disturbance Δv do not depend on the sign of the disturbance. In other words, the changes in Δu, Δw, Δq are not proportional to Δv but to square of Δv and higher even orders of Δv. Thus if Δv is small, the changes in Δu, Δw and Δq are very small and can be ignored. But if Δv is not small, the effect on longitudinal motion would not be small.

The above arguments lead to subdivision of the stability analysis into longitudinal stability and lateral stability. The former deals with the stability of motion in the plane of symmetry and the latter deals with stability of motions out of plane of symmetry.

Remarks:

i) In static stability analysis, the perturbation in angular motions and those in the moments are predominant. Hence, in longitudinal static stability analysis the stability of motion about y-axis and in lateral static stability analysis the stability about x-and z-axes are only considered. However, in dynamic stability analysis the perturbations in linear motions are also considered.

ii) Often, the study of stability about x- axis only is called the lateral stability and that about z- axis is called the directional stability, but the two motions are interlinked and a disturbance about the z- axis produces moments about x- axis and vice versa. Hence, the lateral and directional motions are always studied together.

iii) As indicated earlier a rigid airplane has six degrees of freedom. Hence, the motion of a rigid airplane is governed by six differential equations. By separating longitudinal and lateral motions, the problem involving six equations is simplified into two problems each involving three degrees of freedom.

iv) In airplanes with features like asymmetrically swept wings and V-tail, the longitudinal and lateral motions cannot be separated. The stability analysis of these types of airplanes would require full six degrees of freedom analysis which is out of scope of the present course.

1.3.6 Control fixed and control free stability

As mentioned earlier, the airplane is treated as a rigid body for the purpose of stability analysis. This implies that the distortion of the airplane, due to aerodynamic and other loads, is small and does not change appreciably the aerodynamic characteristics of the airplane. However, the control surfaces viz. the elevator, rudder and aileron (see Fig.1.16) are movable surfaces. When they are free to move during the disturbed motion, they would bring about significant changes in the aerodynamic forces and moments in addition to those due to the disturbance. Hence, the stability of the airplane with controls fixed and controls free are analysed separately. It would be further pointed out in section 8.15 that the number of degrees of freedom increases when controls are free to move during the disturbed motion.

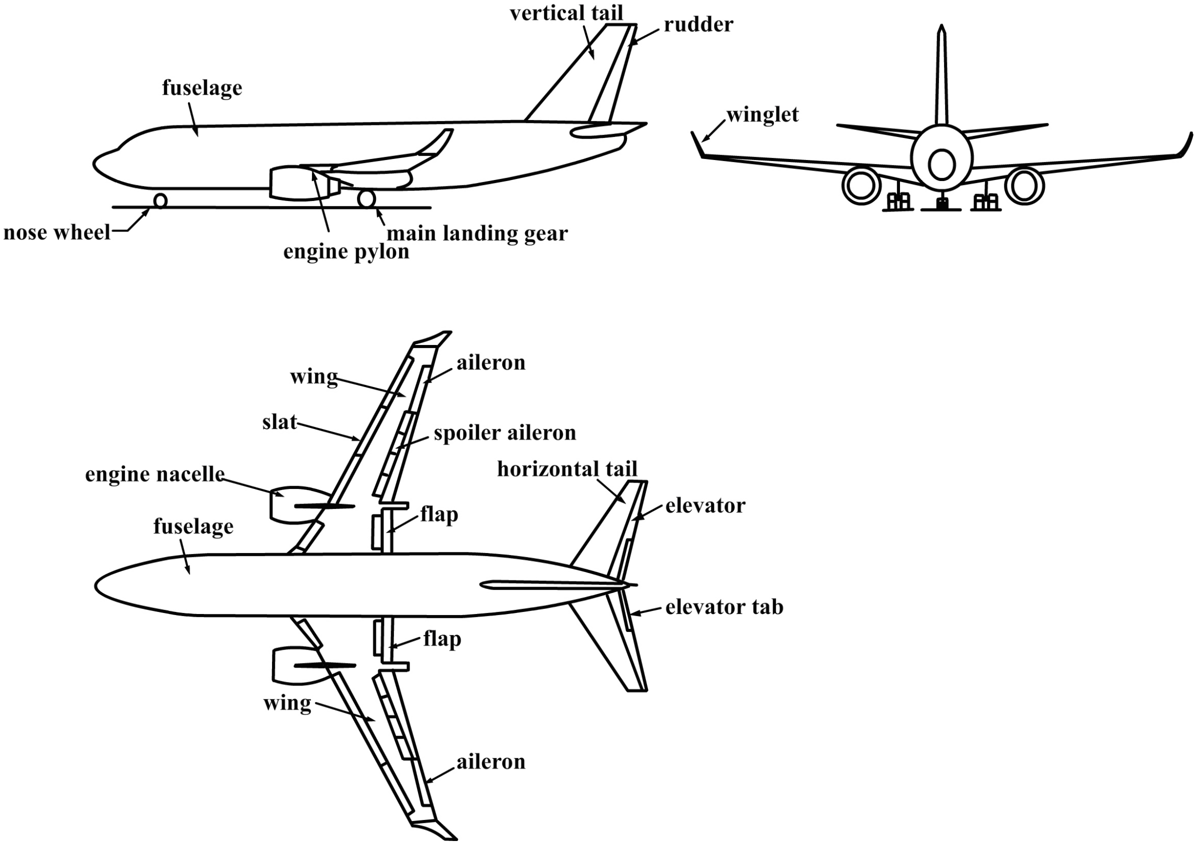

Fig.1.16 Major components including control surfaces (aileron, elevator and rudder) of an airplane

1.3.7 Subdivisions of stability analysis

Based on the aforesaid discussion, the subject of stability analysis can be subdivided as presented in Fig.1.17.

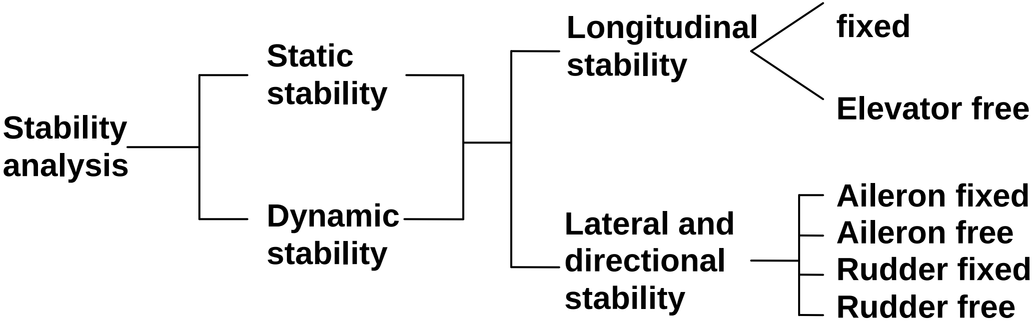

Fig.1.17 Subdivisions of stability analysis

Remark:

Since, the movement of the elevator is controlled by stick movement, the elevator fixed and elevator free stability are also called stick-fixed and stick-free stability.

1.4 Controllability

It was pointed out earlier that for each flight condition, a definite lift coefficient and hence angle of attack is required. When the airplane is at an angle of attack the components of the airplane like wing, fuselage and tail would also be at angles of attack, and produce lift and drag which would cause pitching moments about c.g.. The sum of these pitching moments will be counter-balanced by the elevator. Hence, a suitable elevator deflection is needed for each angle of attack. Similarly, suitable rudder and aileron deflections are also needed to balance rolling moment and yawing moment during the flight. In this background, the range of speeds at which controlled flight is possible and the rapidity with which a desired attitude can be achieved, are the important factors that determine the controllability of an airplane. In general, the term controllability can be defined as the influence which the pilot or the controlling agency can exert on the equilibrium state of the airplane; this state is characterized by the variables u, v, w, p, q and r.

1.5 General remarks

In this section a few remarks are presented to supplement the description given in the earlier sections.

1.5.1 Examples of stability in day-to-day life

Examples of systems displaying different types of stability can be found in many devices in common use. For example, we can observe three different types of doors in offices. The most common type of door is neutrally stable, i.e. once opened; it remains open till someone closes it.The second type, the pair of doors with springs at the hinges, once opened and left, return to the closed position after performing a damped oscillation. The third type, the door with a hydraulic damper, when opened, returns to the closed position without oscillating and displays subsidence.

1.5.2 Airplane stability depends on flight condition

Unstable systems are difficult to observe as most of the practical systems are designed to be stable. However, systems need not be stable under all situations, e.g. an airplane that is stable in steady level flight may be unstable during an inverted flight condition. Further, an airplane which is stable at high speeds may show instability at low speeds. Hence, the stability of the airplane needs to be examined under various flight conditions.

1.5.3 Stability and controllability are not the same

Stability and controllability must be clearly distinguished for each other. The former is the ability to return to the equilibrium states after a small disturbance, whereas the latter is the ability to change from one equilibrium state to another. Therefore, a very stable airplane will resist changes in its attitude and hence, will be difficult to control. Accordingly, military airplanes, for which rapid maneuverability is one of the requirements, have lower levels of stability than civil airplanes.

1.5.4 Stability is desirable but not necessary for piloted airplanes

Stability is desirable but not a necessary for piloted airplanes. In these types of airplanes, neutral stability or a slight instability under some conditions can be tolerated if the disturbance does not grow rapidly and the pilot has enough time to correct the situation. However, an unstable airplane requires constant attention and is a source of fatigue to the pilot.

1.5.5 Small disturbance analysis of stability

In conventional stability analysis we consider the forces and moments brought about by the disturbance as transient and small. This simplification converts the non-linear dynamic stability equations into a set of linear equations (see chapter 7).

1.5.6 Rigorous definitions of terms

The discussion on stability presented above, is somewhat simplified as this is an introductory course. Reference 1.6 , chapter 15 may be referred to for mathematical definitions of the terms like (a) system, (b) equilibrium state (c) stability, (d) asymptotic stability , (e) asymptotic stability in large and (f) instability .

1.6 Course content

The subject matter here is divided into the following topics.

Chapter 2. Longitudinal stick-fixed stability and control

Chapter 3. Longitudinal stick-free static stability and control

Chapter 4. Longitudinal static stability and control – effect of acceleration

Chapter 5. Directional static stability and control

Chapter 6. Lateral static stability and control

Chapter 7. Dynamic stability analysis – I – Equations of motion and estimation of stability derivatives

Chapter 8. Dynamic stability analysis – II – Longitudinal motion

Chapter 9. Dynamic stability analysis – III – Lateral motion

Chapter10. Miscellaneous topics – stability after stall, automatic control and response.

Sample question paper –Hints for solutions

Sample question paper –Model answers

Appendix ‘C’ presents drag polar, stability derivatives and characteristic roots for a jet airplane.

1.7 Background expected

It is expected that the student has undergone course on Flight mechanics-I i.e. airplane performance which calls for background of (a) vectors, (b) rigid body dynamics (c) aerodynamics and (d) airplane engines.

Remark:

In addition to Refs.1.1 to 1.6 mentioned earlier, references 1.7 to 1.13 may be consulted for further information on stability and control analysis.