Chapter 1
Introduction
(Lectures 1,2 and 3)

Keywords : Importance of stability and control analysis ; brief historical background ; basic concepts – static stability, dynamic stability, longitudinal, lateral and directional stability, control fixed and control free stability ; controllability; subdivisions of the subject; course outline.

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1.1 Opening remarks

In the introduction to flight dynamics-I, it was mentioned that flight dynamics deals with the motion of objects moving in earth's atmosphere. The attention in that course and the present one is focused on the motion of the airplane. Helicopters, rockets and missiles are not covered. Flight dynamics is subdivided into two main topics viz. (a) airplane performance and (b) airplane stability and control.

Airplane performance was dealt with in flight dynamics-I.This course, deals with stability and control.

Stability and control of airplane is one of the fascinating subjects in aeronautics. This is because of the following reasons.

A detailed theoretical analysis of the stability and control of an airplane requires sophisticated mathematical techniques while its experimental assessment calls for sophisticated wind tunnel and flight test techniques. Hence, this topic has an appeal for both the theoretician and the experimentalist. Further, the importance of stability and control analysis can be judged from the fact that the lack of adequate stability and control was the cause for the failure of early heavier than air machines to sustain themselves in air.

The historical developments in this subject are briefly dealt with in the next section, which is followed by (a) discussion of the basic concepts of airplane stability and control,(b) course content and (c) back ground expected from the reader.

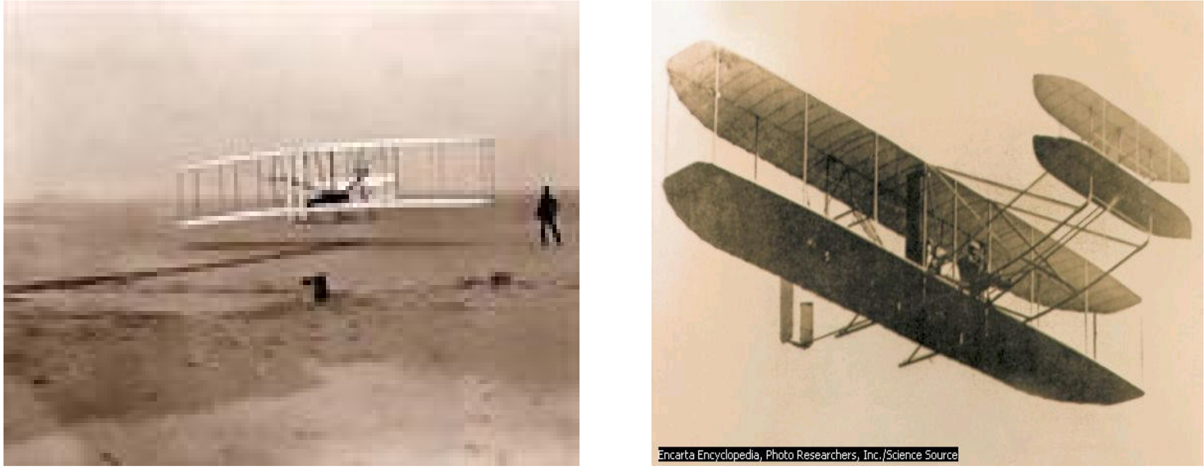
1.2 Brief outline of historical developments

1.2.1 Early developments

The first attempts to study the stability of vehicles in flight were made by Sir George Cayley (1774-1857) who also carried out experiments on models of gliders with horizontal tail and rudder.

By the 1880’s, I.C. engines were available which were lighter than the earlier engines. However, inadequate understanding of stability and control delayed the first successful flight of a powered vehicle.

Otto Lilienthal (1848-1896) during 1890-1895 and Wilbur Wright (1867-1912) and Orville Wright (1871-1948) during 1900-1903 carried out a number of experiments on hang gliders and gliders, which gave a better understanding of the stability and control. This led to the first successful flight on Dec.17, 1903. The name of this airplane was Wright flyer (Fig.1.1). It had a canard surface ahead of the wings for control of the pitching motion, vertical rudder for directional control while control in roll was obtained by warping the wings.

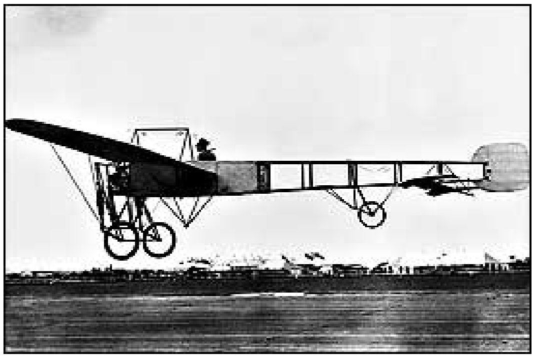


(From : http://www.old-picture.com/
wright-brothers-index-001.htm)

(From :http://fractal-vortex.narod.ru/
productive_forces/past_images/
wright2.jpg)

Fig.1.1 Two views of Wright Flyer

The first airplane with ailerons (Fig.1.2) was built in 1907 by Louis Blériot (1872-1936). It was also a monoplane. The first airplane with horizontal tail at the rear (Fig.1.3) was constructed in 1909 by A. Verdon-Roe (1877-1970).



(From: http://www.lva-moto.fr/forum/ topic-12149-anzani-motor-page-1.html)

(From: http://davideo4301.blogspot.in/2010_06_01_archive.htm)

Fig.1.2 Two views of Louis Blériot’s airplane

Fig.1.3 Airplane of A. Verdon-Roe

(From: www.leavalleyexperience.co.uk)

As regards the theoretical analysis, F.W. Lanchester (1868-1946) gave ideas about stability in his book entitled "Aerodonetics" published by Archibald Constable in 1908. He also mentioned about motion following longitudinal disturbance and called it phugoid.

In 1911, G H Bryan published a book entitled 'Stability in aviation', published by Macmillan in which he presented the mathematical analysis of the flight following a disturbance. It may be added that in the equilibrium state the resultant forces and moments acting on the airplane are zero. Any event altering this state is a disturbance. It could be for example, (a) movement of airplane controls by the pilot or (b) inputs beyond pilot's control like gust of air.

The equations derived by Bryan still form the basis of stability analysis.

1.2.2 Subsequent developments

In the 1930's, the flying qualities of the airplane were studied. These (flying qualities) are based on the opinion of the pilots regarding the amenability of the airplane to perform chosen tasks with precision and without undue effort on the part of the pilot. These were correlated to features of the motion like frequency of oscillation, damping etc. and finally to the geometric features of the airplane like area of horizontal tail, area of vertical tail and dihedral.

In the 1940's automatic control of airplanes became possible. An airplane with automatic control has sensors to detect the linear and angular accelerations and changes in flight path. Once the changes have been detected, the control surfaces are deflected automatically depending on the quantity sensed and the corrections needed. An airplane with automatic control is equivalent to an airplane with a different level of stability. By changing the ratio of input to the output of the automatic control system, it was possible in 1950's to have airplanes with variable stability.

Supersonic flight became possible in 1950's after gaining an understanding of the changes in drag coefficient, lift coefficient and pitching moment coefficient when flight Mach number (M) changes from subsonic to supersonic. These changes also affect the stability of the airplane. It was also understood that the adverse effects of these changes can be alleviated by use of wing sweep (Fig.1.4).

In 1980's airplanes with fly-by-wire technology were available. In this technique the movement of the control stick or pedals by the pilot is transmitted to a digital computer. The input to the computer is processed along with the characteristics of the airplane and the actuators of the controls are operated so as to give optimum performance.

(a)Supersonic transport- Concorde (From : www.aido3n.blogspot.com)

(b) Fighter-MIG- 29M (From: www.defenseindustrydaily.com)

Fig.1.4 Supersonic airplanes

Recent developments include relaxed static stability and control configured vehicle (CCV). Relaxed static stability is used in fighter airplanes to improve their performance. The light combat aircraft (LCA) designed and developed in India has this feature. In a control configured vehicle, the control surfaces and flaps are automatically deployed when the airplane changes from one flight to another. With CCV the structural weight, size of the wing and size of control surfaces can be reduced to an optimum level while achieving greater maneuverability of the airplane.

For further details see Refs. 1.1 and 1.2.

1.3 Basic concepts about airplane stability and control

While carrying out the performance analysis in flight mechanics-I, various equilibrium states were considered. For example, in a steady level flight, an airplane is considered to be flying at a constant altitude along a straight line at constant speed. The equilibrium equations for this flight give the lift and the thrust required during the flight. Subsequent analysis of these equations gives important items of performance. It may be pointed out that these analyses tacitly assume that the airplane will continue to fly in the equilibrium state. However, in actual practice it is noticed that among the various equilibrium states that we can imagine, some are not observable. To illustrate this, consider the following example.

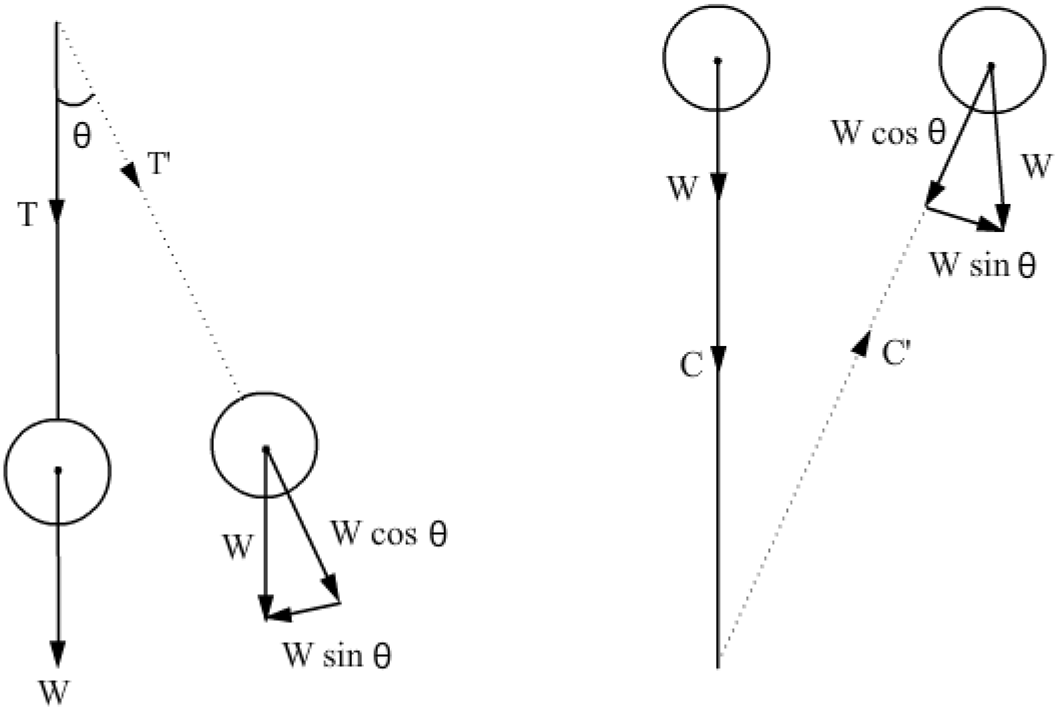
One can imagine a chalk piece to rest in equilibrium on its narrow rounded end on a smooth horizontal table. However, no one has seen this equilibrium. The reason for this is that while imagining the equilibrium it is tacitly assumed that the chalk piece is rotationally symmetric about the center point of the rounded end and that there are no disturbances (e.g. small current of air). On the other hand, the chalk piece can be made to stand on the table on its flat, broad end. It will remain standing even in the presence of a small current of air like a gentle blowing. Of course, blowing hard at the chalk piece will topple it. This brings us to the following important observations.

(a) There are equilibrium states from which, when a system is disturbed slightly over a short period, it will return to the equilibrium state. In other case it will not. The former are termed stable states of equilibrium and the later as unstable states of equilibrium.

(b) When the disturbance is large, the system may not come back to the equilibrium state. Further, analysis of the case of large disturbance is more complicated.(section 7.7 may be referred to for further details)

1.3.1 Stable, unstable and neutrally stable states of equilibrium

To explain the concepts of stable and unstable equilibria, let us consider the example of a pendulum.



(a) Bob at the bottom – state ‘A’ (b) Bob at the top – state ‘B’

Note : The bobs in the figure are circular in shape. Please adjust the resolution of your monitor so that they look circular.

Fig.1.5 Equilibrium states and stability of a pendulum

Figure 1.5a shows the pendulum in a state referred to as ‘A’. In this state, the weight (W) of the bob is supported by the tension (T) in the rod. Let the pendulum be disturbed, so that it makes an angle θ to the original position. In this disturbed position, the weight of the bob has components Wcosθ and Wsinθ. The component W cos θ is balanced by the tension (T') in the rod whereas the unbalanced component W sin θ causes the pendulum to move towards the undisturbed position. While returning to the equilibrium position, the bob may overshoot that position. However, when there is friction at the hinge and/or damping due to the medium in which the pendulum moves, it (pendulum) will eventually come back to its original equilibrium position. Thus, the equilibrium ‘A’ is a case of stable equilibrium.

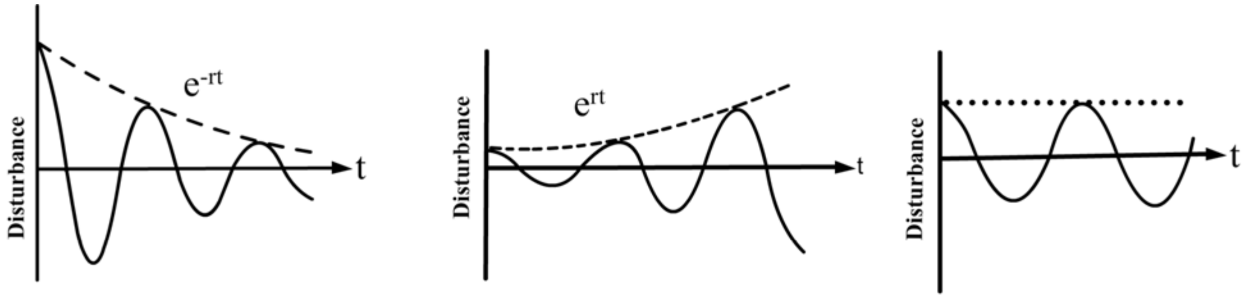
In equilibrium state 'B' as shown in Fig.1.5 (b), the weight of the bob is balanced by compression (C) in the rod. Let the pendulum be disturbed, so that it makes an angle θ to the original position. In this disturbed position, the weight of the bob has components W cos θ and W sinθ. The component W sinθ in this case tends to move the pendulum away from its equilibrium position. Hence, equilibrium 'B' is unstable.

Apart from the stable and unstable equilibria, there is a third state called neutrally stable equilibrium. It is defined as follows.

If a system, when disturbed slightly from its equilibrium state, stays in the disturbed position (neither returns to the equilibrium position nor continues to move away from it), then, it is said to be in neutrally stable equilibrium. In the above example of the pendulum, if the static friction at the hinge is very large, then, on being disturbed from the equilibrium position, it will remain in the disturbed position.

1.3.2 Possible types of motions following a disturbance – subsidence, divergence, neutral stability, damped oscillation, divergent oscillation and undamped oscillation

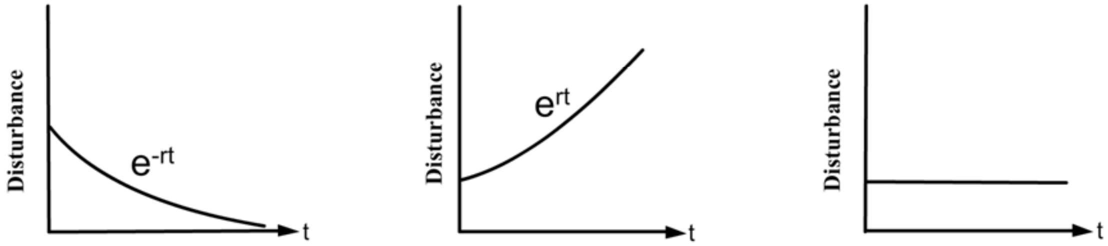
After a system has been disturbed from it's equilibrium position, it's subsequent motion will be like any one on the six types shown in Fig.1.6. For the sake of the subsequent discussion, it is assumed that initially the disturbance is positive.



(a) Damped oscillation

(b) Divergence oscillation

(c) Undamped oscillation



(d) Subsidence

(e) Divergence

(f) Neutral stability

Fig.1.6 Types of motion following a disturbance

i) Figure 1.6a shows a damped oscillation. In this case the system while returning to the equilibrium position goes beyond the undisturbed state towards the negative side. However, the amplitude on the negative side is smaller than the original disturbance and it (amplitude) decreases continually with every oscillation. Finally, the system returns to the equilibrium position. The time taken to return to the equilibrium position depends on the damping in the system. An example of this is the motion of pendulum (Fig.1.5 a) when there is friction at the hinge or the pendulum moves in a fluid (air or water). The friction at the hinge or that between the bob and the fluid results in damping.

ii) Figure 1.6b shows the divergent oscillation. In this case also the system shows an oscillatory response but the amplitude of the oscillation increases with each oscillation and the system never returns to the equilibrium position. It may even lead to disintegration of the system. An example of this is the divergent oscillation of telephone cables. During winter, in cold regions, ice forms on the telephone cables. Sometimes the cross section of the cable with ice becomes unsymmetric. Such a cable when it starts oscillating may some times get into divergent oscillation leading to snapping of cables. Divergent oscillations are seldom encountered. The practical systems are designed such that they do not get into divergent oscillations.

iii) Figure 1.6c shows the undamped oscillation. In this case also the system shows an oscillatory response but the amplitude of the oscillation remains unchanged and the system never returns to the equilibrium position. An example of this situation is the ideal case of the pendulum motion (Fig.1.5a), when the hinge is frictionless and the pendulum oscillates in vacuum.

iv) When a system returns to its equilibrium position without performing an oscillation, the motion is said to be a subsidence (Fig.1.6d). An example of this could be the motion of a door with a hydraulic damper. In the equilibrium position the door is closed. When some one enters, the equilibrium of the door is disturbed. When left to itself the door returns to the equilibrium position without performing an oscillatory motion.

v) Conversely, when the system continuously moves away from the equilibrium position, the motion is called divergence (Fig.1.6e).

vi) If the system stays in the disturbed position (Fig.1.6f), then the system is said to have neutral stability.