Module-3

Lecture-11

Stability and Control - Discussion on Equilibrium, Static and Dynamic Stability

Stability & Control

Module Road Map

- Static Stability and Trim

- Center of pressure and aerodynamic center

- Wing and tail contribution on static stability

- Static margin

- Stick fixed Neutral Point

- Stick free Neutral Point

Equilibrium

- If a system in an equilibrium state, returns to equilibrium following a small disturbance, the state is said to be stable equilibrium Figure 1.

- On the other hand, if the system diverges from equilibrium when slightly disturbed, the state is said to be an unstable equilibrium.

(a) Stable Equilibrium

(b) Unstable Equilibrium

(c) Neutral Equilibrium
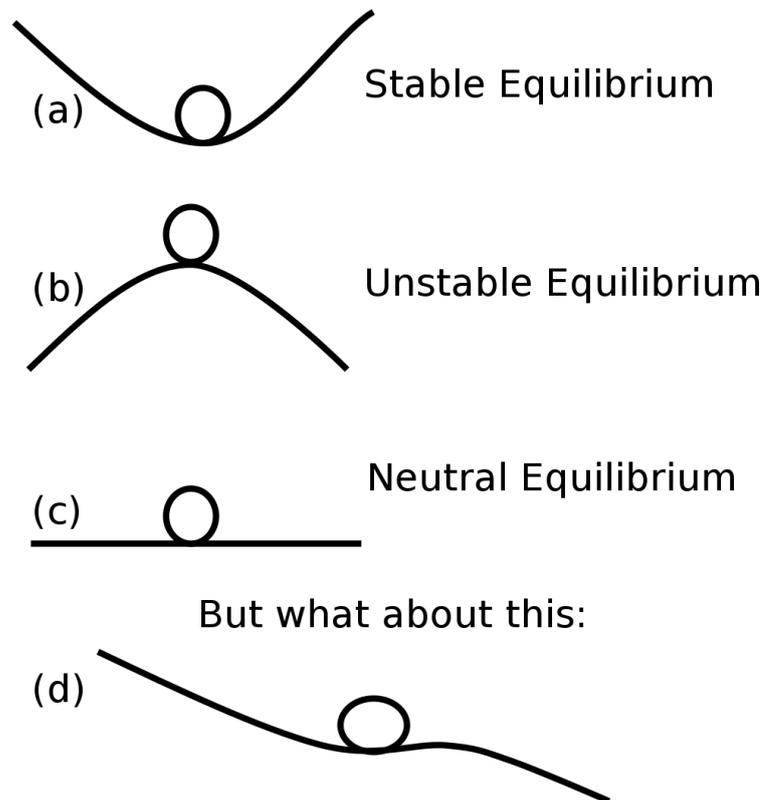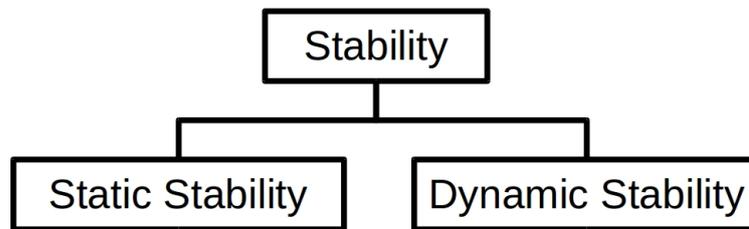
But what about this:

(d)

Figure 1: States of equilibrium

- Strictly speaking, Figure 1(d) is also a case of stable equilibrium, because a very small disturbance from equilibrium would result in a force and moment imbalance that would return the ball to its original equilibrium state.

- But a little extra disturbance, towards right could cause the ball to move past the apex, which would produce a force and moment imbalance that would cause the ball to move away from its original equilibrium state.

This type of stable equilibrium can sometime occur with an aircraft in trimmed flight: a very dangerous situation.

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                    ┌───────────┐
                    │ Stability │
                    └───────────┘
              ┌───────────┴───────────┐
    ┌──────────────────┐   ┌────────────────────┐
    │  Static Stability │   │  Dynamic Stability │
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Static Stability and Trim

> **Static Stability**
>
> *If an airplane disturbed from equilibrium state has "Initial Tendency" to return to its equilibrium state, then the aircraft is assumed to have static stability.*
>
> **Dynamic Stability**
>
> *Not only initial tendency, but also the amplitudes of the response due to disturbance decay in finite time to attain the equilibrium state.*

In general, when aircraft is being referred to be in stable equilibrium, we mean dynamic stability. However, it so happen that for most of the cases, for conventional aircraft, if it is statically stable, it also automatically satisfies dynamic stability criterion – but not all aircraft! Handling qualities may be different.

- Static equilibrium occurs whenever there is no acceleration (linear or angular) of the aircraft. Un-accelerated flight requires that the summations of forces and moments acting on the aircraft are zero.

- Static equilibrium also requires that the side force acting on the airplane is also zero.

- Additionally, the summation of moments about the centre of gravity (CG) in roll, pitch and yaw must all be zero for equilibrium (Trimmed flight).

Stable Trim - Longitudinal (Axial)

Small translational disturbances in axial, normal or side slip velocity must all result in a return to the original trimmed equilibrium condition. This is also referred to as pitch stability.

- An object moving through the air will experience drag that opposes the motion.

- If angle of attack remains fixed, this drag will increase with speed. (**Drag opposes increase in speed**)

- Thrust developed by engine is either constant with airspeed or decrease with increasing air speed. (**Drag increase in speed**)

- In static equilibrium with regard to translational in the direction of motion, the forward component of thrust must balance the drag $(T = D)$

- At constant angle of attack, a small increase in airspeed will result in

  ○ Increase in Drag

  ○ Either a decrease in Thrust or No change in Thrust

- Therefore, this force imbalance in the axial direction will result in a deceleration, which will tend (initial tendency) to restore the airspeed to the original value.

- Conversely, if airspeed is decreased by a small disturbance with no change in angle of attack, the drag will become less than the thrust and the aircraft will accelerate back (tends to) to the equilibrium airspeed.
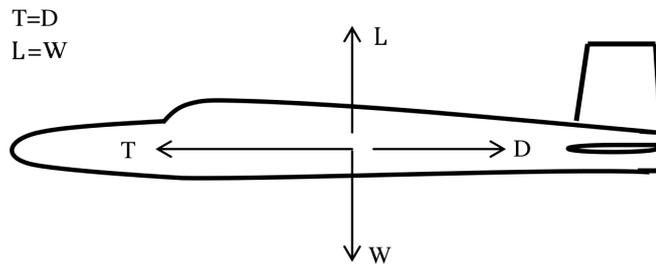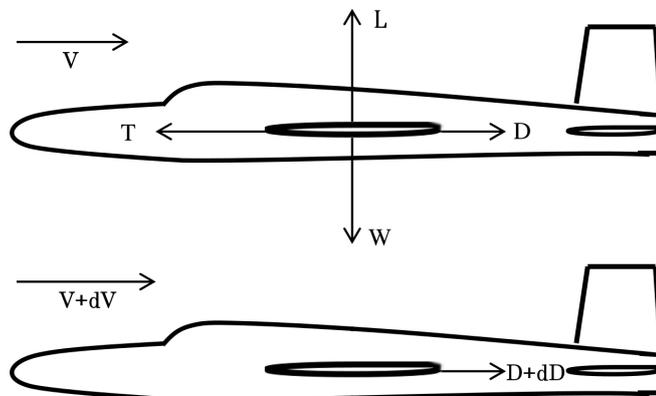

Figure 3: Pitch Stability

Figure 4: dD will oppose dV. If dV is positive; dD will act to reduce/marginalize dV.If dV is negative; dD will tend to increase the speed as in that case $T > D$.