Longitudinal Stability and Neutral Point

Vijay Gaikwad
VJTI, Mumbai
Reaction of aircraft when disturbed

- **Stable**
  - Returns to its initial position

- **Static Instability**
  - Departs from equilibrium

- **Dynamic Instability**
  - Oscillates with larger amplitude

[https://www.nasa.gov/centers/glenn/home/](https://www.nasa.gov/centers/glenn/home/)
Initial Reaction on disturbing an aircraft!

STATIC STABILITY
Static Stability

Definition:
When disturbed from an equilibrium position, the aircraft tends to return to its original position, without any action from the pilot.

Types:

I. **Positive static**

II. **Neutral static**

III. **Negative static**
Neutral Static Stability

NEUTRAL

Ball remains in new position when disturbed

Equilibrium encountered at any point of displacement
Positive Static Stability

STABLE

Ball returns to starting position when disturbed

Figure 1

original state

disturbed state

final state after a few oscillations
Negative Static Stability

**UNSTABLE**

Ball moves away from starting position when disturbed

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**Figure 2**

- **Original state**
- **Disturbed state**
- **Unstable** (ball is rolling downhill)
Flight Conditions

Lift = weight
Thrust = drag
No net moments

(a) Equilibrium flight.

No moments - airplane holds disturbed condition

(c) Neutral static stability.

http://history.nasa.gov

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Example of an unstable aircraft
Final Outcome of disturbing an aircraft!

DYNAMIC STABILITY
Dynamic Stability

**Positive**
Oscillations decrease in amplitude

**Neutral**
Oscillations constant in amplitude

**Negative**
Oscillations increase in amplitude
Positive Static Stability:
Their relative location affects Stability

THE 3 CENTRES OF AN AIRCRAFT
The Three Key Centers


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CENTER OF GRAVITY

Centre of Gravity CG
- Point where the moments act;
- Depends only on the plane's mass distribution, not its aerodynamics

Centre of Pressure CP
- Point where the resulting aero force applies
- Depends on the model's aerodynamics and on the angle of attack

CENTER OF PRESSURE

CENTER OF GRAVITY

THREE
Centre of Pressure

Low Angle of Attack

Aerodynamic Force

Pressure Variation

High Angle of Attack

Moving Fluid

Center of Pressure

Center of Pressure is the average location of the pressure. Pressure varies around the surface of an object. \( P = P(x) \)

\[
\begin{align*}
 cp &= \frac{\int x \ p(x) \ dx}{\int p(x) \ dx} \\
 \text{Aerodynamic force acts through the center of pressure.}
\end{align*}
\]

https://www.nasa.gov/centers/glenn/home/AE-705%20Introduction%20to%20Flight

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NEUTRAL POINT

Neutral Point NP
= Reference point for which the pitching moment does not depend on the angle of attack $\alpha$

Depends only on the plane's external geometry

Neutral Point

- position of CG where the aircraft would be **Neutrally stable**.
All three Centers together!

THE FOURTH CENTRE!
Aerodynamic Centre

For low speed, thin airfoils (flat plate):

\[ ac = \frac{c}{4} \]

Moment about the aerodynamic center is constant with angle. Aerodynamic center does not move with angle.
Example of a toy plane

EFFECT OF RELATIVE LOCATION

Perturbation in flight increase Angle of Attack

\[ \text{L}_{\text{wing}} \uparrow \text{ but } \text{L}_{\text{tail}} \downarrow, \text{ hence net Nose down Moment created} \]

Aircraft is **Stable** due to this *restoring* torque

When CG is at NP

Position of AC is independent of angle of attack

Moments due to $\uparrow L_{\text{wing}}$ & $\uparrow L_{\text{tail}}$ balance

There is no restoring torque

Aircraft is neutrally stable due to this balance of moments

As the nose pitches up, $\uparrow L_{\text{wing}} > \uparrow L_{\text{tail}}$   \hspace{1cm} \textbf{WHY ??}

The aircraft nose pitches up further

Aircraft is unstable due to unbalanced moments

EFFECT OF CG POSITION w.r.t. AC and NP
CG ahead of AC and NP

1. Very Stable

CG Positions → 5% MAC

Saucers

Steel Ball

Wing's MAC

Aerodynamic Center → 25% MAC

Neutral Point → 35% MAC

Aircraft is HIGHLY stable!


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Aircraft is stable!


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Aircraft is LESS stable!


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CG behind AC and at NP

Aircraft is NEUTRALLY STABLE!

In summary: Effect of CG Position

1. Very Stable: 5% MAC
2. Stable: 25% MAC
3. Less Stable: 30% MAC
4. Neutral: 35% MAC
5. Unstable: BEHIND THE NP

CG Positions → 5% MAC
Saucers
Steel Ball

Wing’s MAC →

Aerodynamic Center → 25% MAC
Neutral Point → 35% MAC

Effect of CG on Longitudinal Stability of plane

EFFECT OF CG ON FLIGHT
Longitudinal stability

Payload position

CG Position

TOP VIEW

BOTTOM VIEW

1  2  3  4  5
CG Position at 2

TOP VIEW

Payload Location

CG Location

BOTTOM VIEW

BACK

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CG Position at 3

Payload Location

TOP VIEW

BOTTOM VIEW

CG Location

![Graph showing CG position at 3](image)

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CG Position at 4

[Top View and Bottom View Images]

Payload Location

CG Location

Graph showing CG Position at 4

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CG Position at 5

Payload Location

CG Location

TOP VIEW

BOTTOM VIEW

1. CG Location
2. Payload Location

Graph:

- X-axis: 0 to 600
- Y-axis: 0 to 300
- Graph shows a curve with peak at around 200.
Flights with different CG position

![Graph showing flights with different CG position]
Why ??

Let's see!
\( \frac{C_L}{C_d} \) Vs \( \alpha \) graph
Comparison of Flight Path with Graph

Different CG positions

Corresponding $\alpha$ positions

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Longitudinal stability concept explanation

NEUTRAL POINT
Longitudinal stability

- Payload position
- CG Position
Comparison of flights (CG at 1)

without Vertical Gust

with Vertical Gust
Comparison of flights (CG at 3)

without Vertical Gust

with Vertical Gust
Comparison of flights (CG at 4)

- without Vertical Gust
- with Vertical Gust
Comparison of flights (CG at 4)
Comparison of flights (CG at 5)

- **without Vertical Gust**
- **with Vertical Gust**

![Graphs showing comparison of flights with and without vertical gust](image-url)
Comparison of flights (CG at 5)
Flights with changing AOA

- Angle of attack = 0°
- Angle of attack = 4°
- Angle of Attack = 8°
- Angle of Attack = 12°
Comparison of flights

Flight path comparison for different Launch angles (Glider 2)