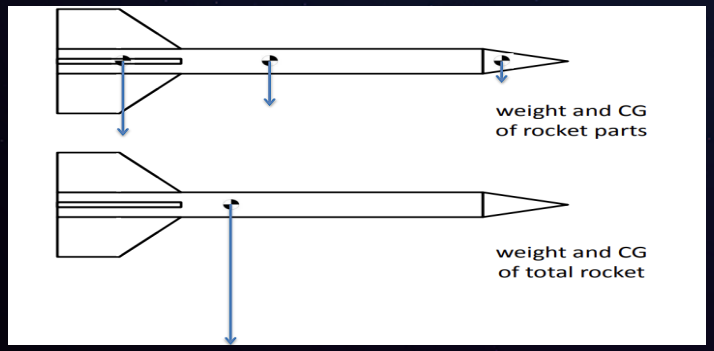
ROCKET STABILITY (VIA C.P. & C.G.)

Centre of Gravity (C.G.)

- The C.G. is the point at which the **rocket's mass is balanced**.
- It is like the point where we can balance a rocket model on our finger.
- Adding weight to the nose-cone moves the C.G. forward.
- Adding weight to the tail moves the C.G. backward.

Centre of Pressure (C.P.)

- The C.P. is the point where the **overall aerodynamic forces assumed to be act** on the rocket.
- Aerodynamic forces which acts on rockets are – Drag & Lift.
- It depends on the shape of the body and fins.
- Bigger fins and longer tail section moves the C.P. backward.



Why CP and CG important for stability ?

Role of C.G. :-

- It determines how the **rocket responds to forces and moments.**
- Forward C.G. increases resistance to rotation, makes the rocket to stay on the predicted trajectory.
- **C.G. controls how easily the rocket can rotate.**

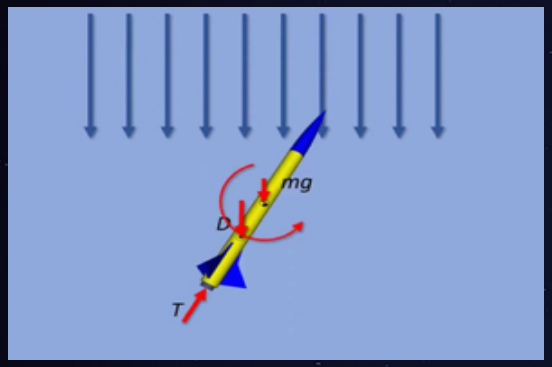
Role of C.P. :-

- It determines where the **air pushes the rocket during flight.**
- Aerodynamic forces increase with increase in angle of attack.
- **C.P. controls where the aerodynamic forces are applied.**

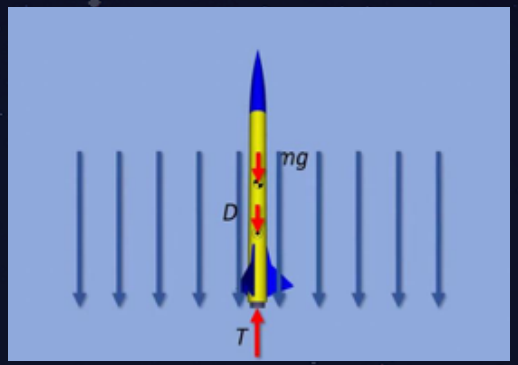
Relative position of C.P. and C.G. :-

- For stable rocket, **C.G. must be ahead of C.P.** .
- C.P. & C.G. together determine **whether aerodynamic forces stabilize or destabilize the rocket.**
- **Correct C.P. & C.G. placement ensures straight ascent, minimal oscillation and safe flight.**

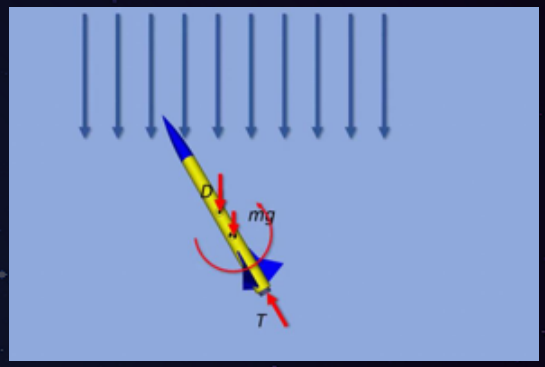
Relative position of CP and CG for stability ?



STABLE



NEUTRAL



UNSTABLE

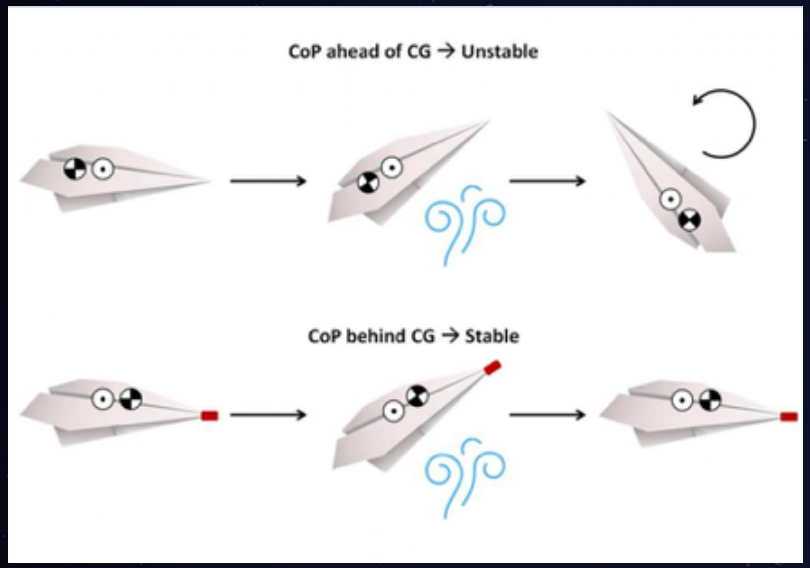
STABLE ROCKET

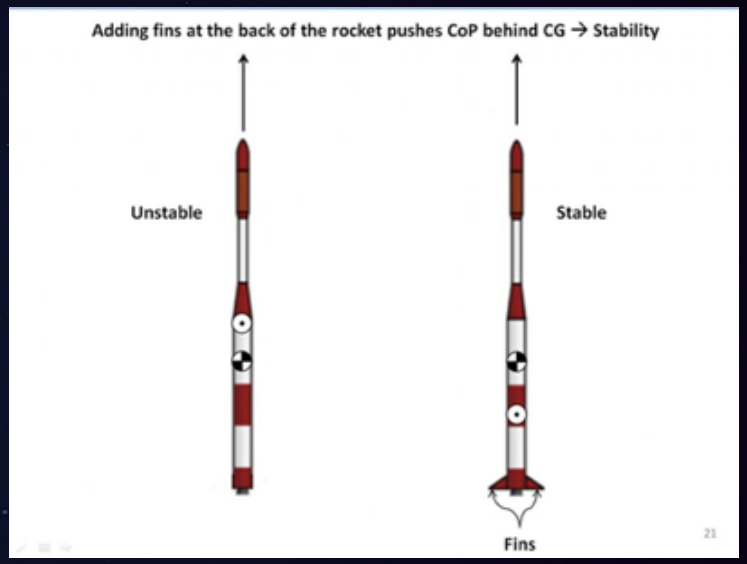
- In stable rocket, **C.P. must be ahead of C.G..**
- The aerodynamic forces produces **a restoring moment**.
- The rocket naturally turns back into the direction of motion.
- This is **positive static stability**.

UNSTABLE ROCKET

- In unstable rocket, **C.P. may behind C.G..**
- The **tilt** due to gust of wind, **increases** instead of self-correcting.
- This leads to **tumbling or loss of control** from desired trajectory.

How to achieve desired position of CP and CG for stability ?





For C.G.

MOVE C.G. FORWARD (MORE STABLE)

- Add weight to nose cone.
- Use lighter fins.
- Move heavy internal components forwards.

For C.P.

MOVE C.P. BACKWARD (MORE STABLE)

- Increase fin size.
- Move fins farther back.
- Use more balanced swept or longer fins.

What if CP & CG coincide?

Neutral static stability

- If the rocket is perfectly aligned and undisturbed, it will continue straight path.
- If rocket experiences even a small disturbance, it will continue to new disturbed path, means it will not reach the mission site and land somewhere else.
- Rocket will not self-correct and will not diverge further.

Why not desirable?

- No restoring force exists to correct disturbance.
- Oscillation may grow due to thrust variation, leading to path deviation.
- In real atmospheric flight, perfect neutrality is not possible.

What is Static Margin?

Static margin is the quantitative measure used to assess how stable a rocket is.

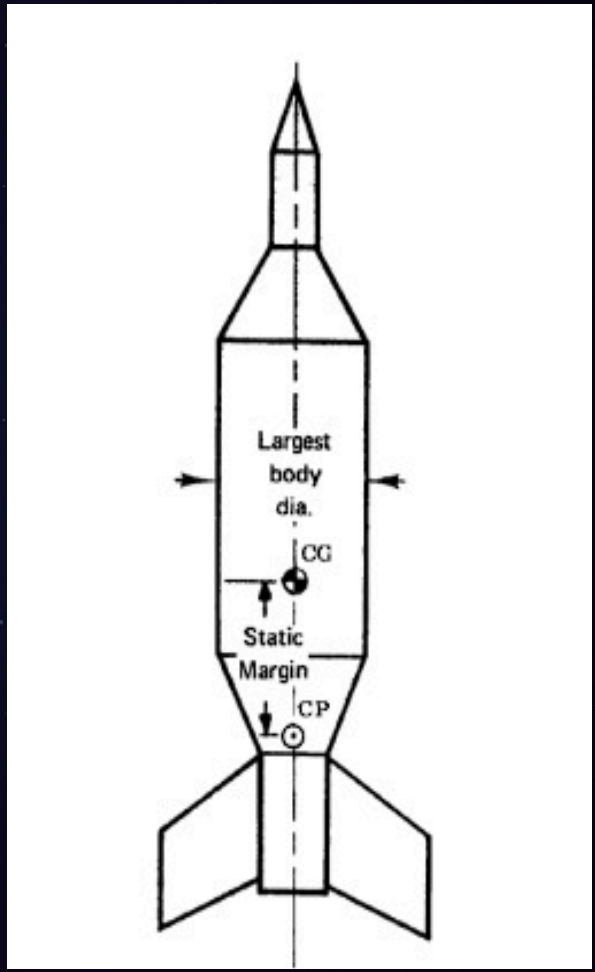
$$\text{Static margin} = \frac{C.G.position - C.P.position}{Body\ diameter}$$

Typical static margin is around 1-2 Caliber.

- Usually expressed in **caliber**, where **1 Caliber= one body diameter(widest).**
- Marginally stable: < 1 Caliber.
- Over-stable: > 3 Calibers (rare but possible).

Conditions :-

- Higher static margin -> C.P. is far behind C.G. -> strong restoring moment -> very stable.
- Very high static margin -> turn into winds too aggressively.
- Low to zero static margin -> poor stability.



BEGINNER MODEL ROCKET