Model Rocket Stability & Aerodynamic Equations

Jim Barrowman

NAR 6883

Why is stability important?

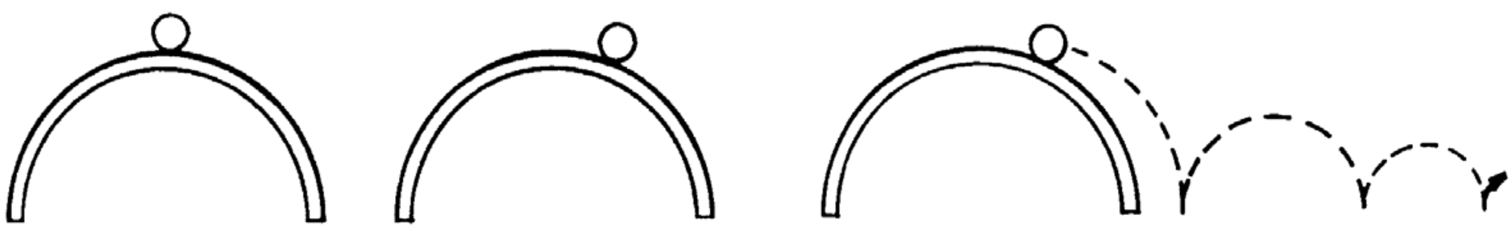
STABLE=SAFE=predictable=performance

Stability is -

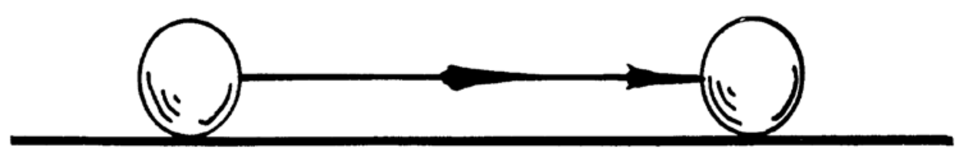
The tendency to return to a neutral position when displaced

STABLE MOTION

UNSTABLE MOTION

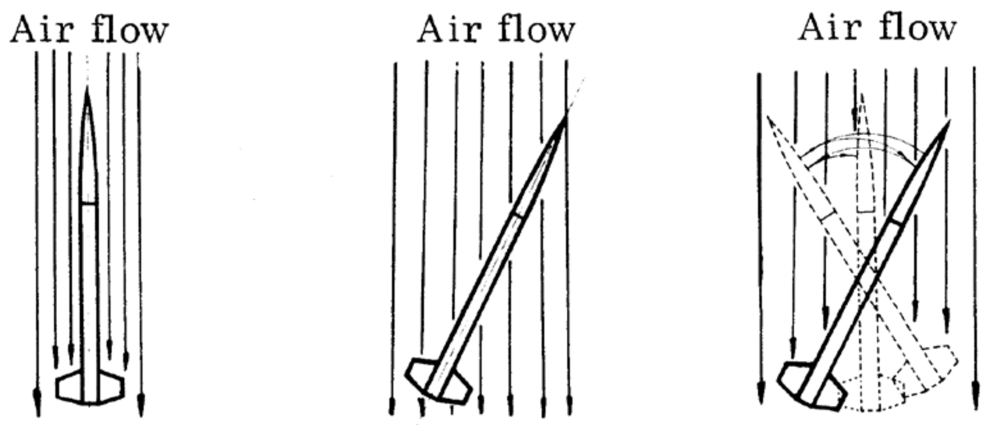


NEUTRALLY STABLE MOTION

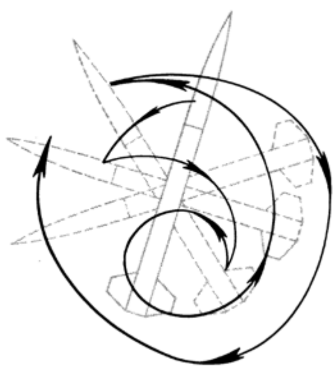


Stability for a Rocket is -

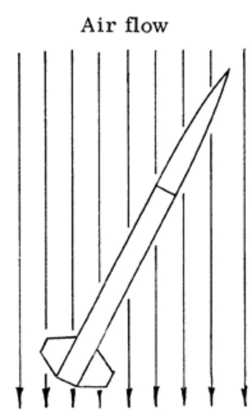
STABLE



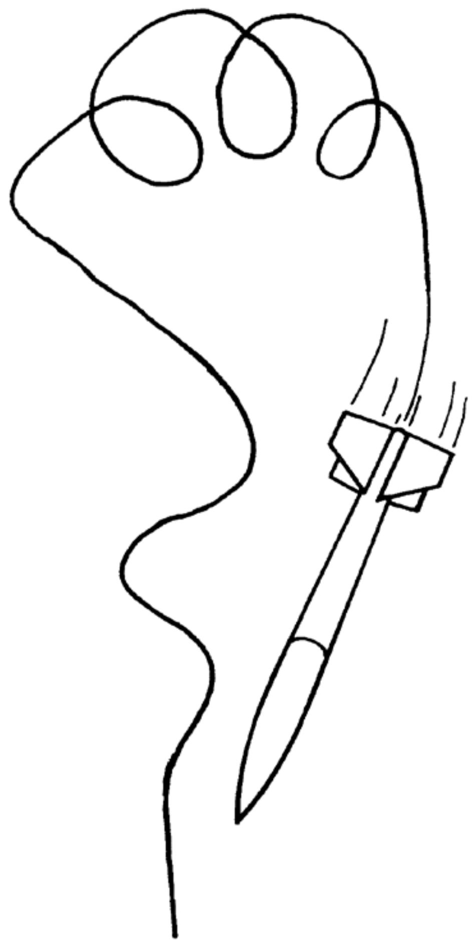
UNSTABLE



NEUTRALLY STABLE



STABLE



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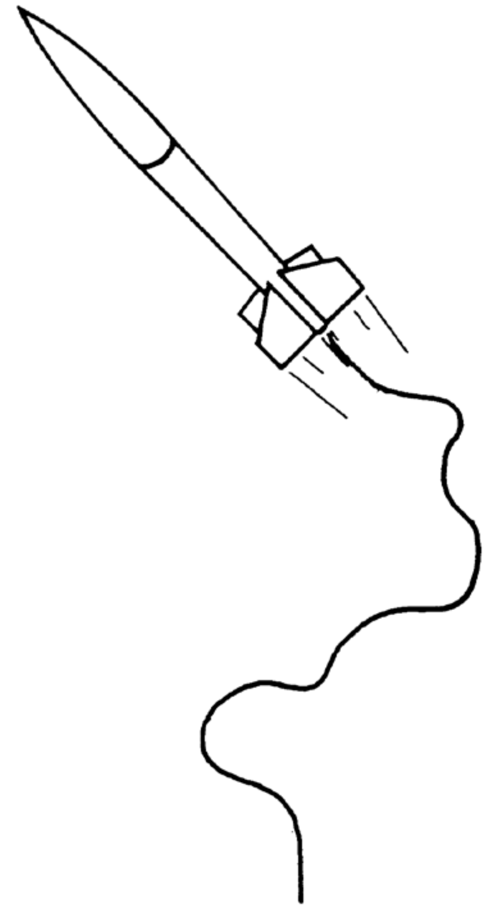
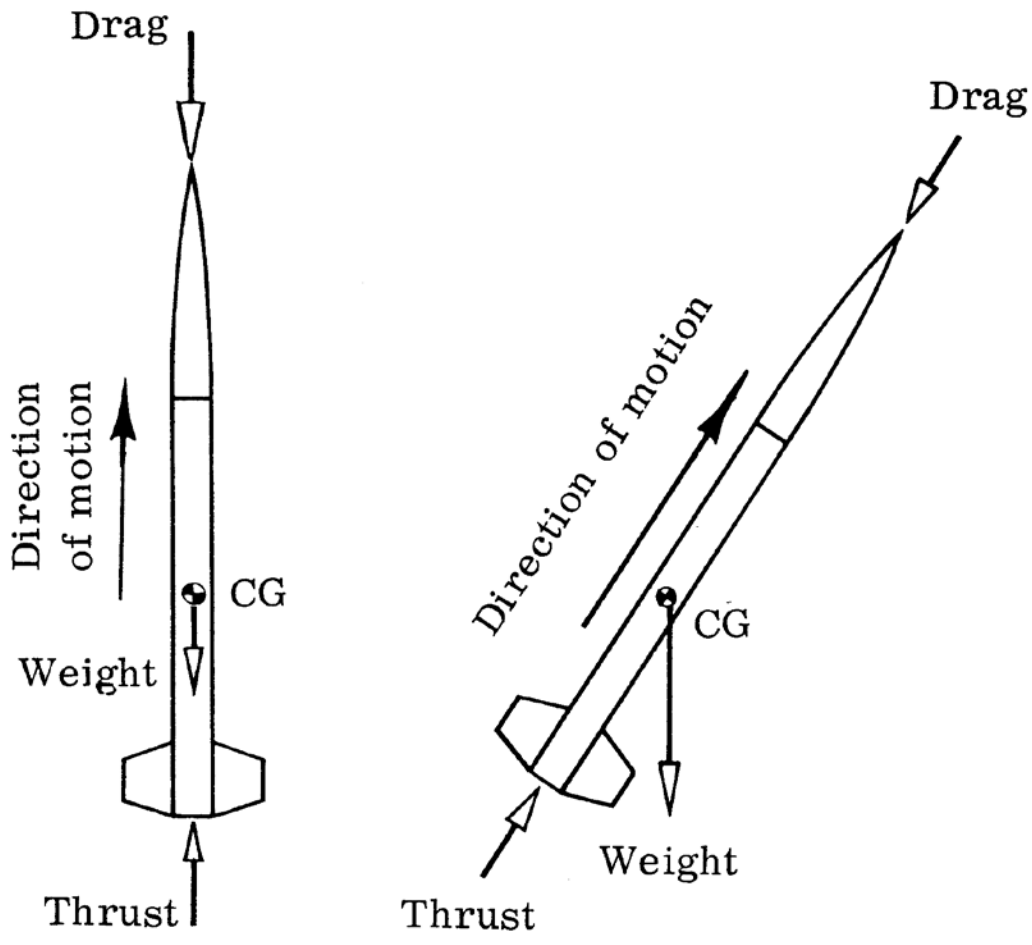


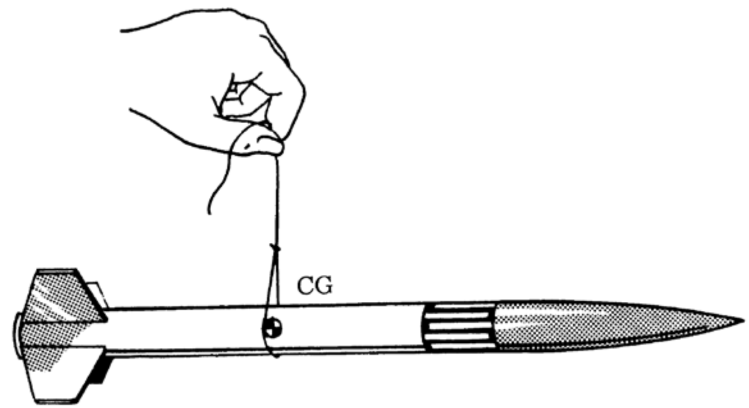
NEUTRALLY STABLE

Translational Forces on a Model Rocket

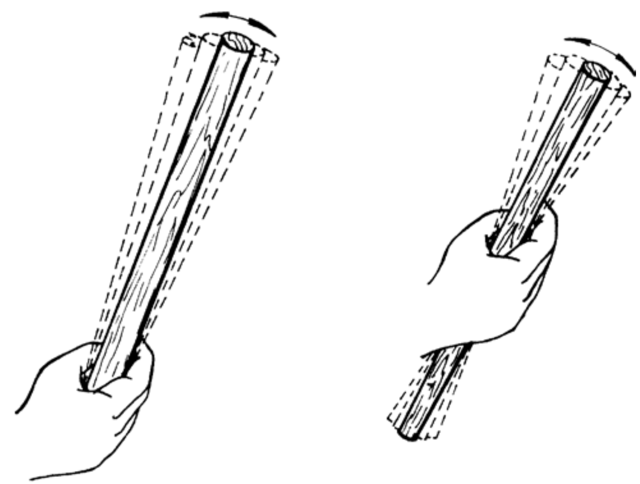


The Center-of-Gravity (CG) is a Special Place

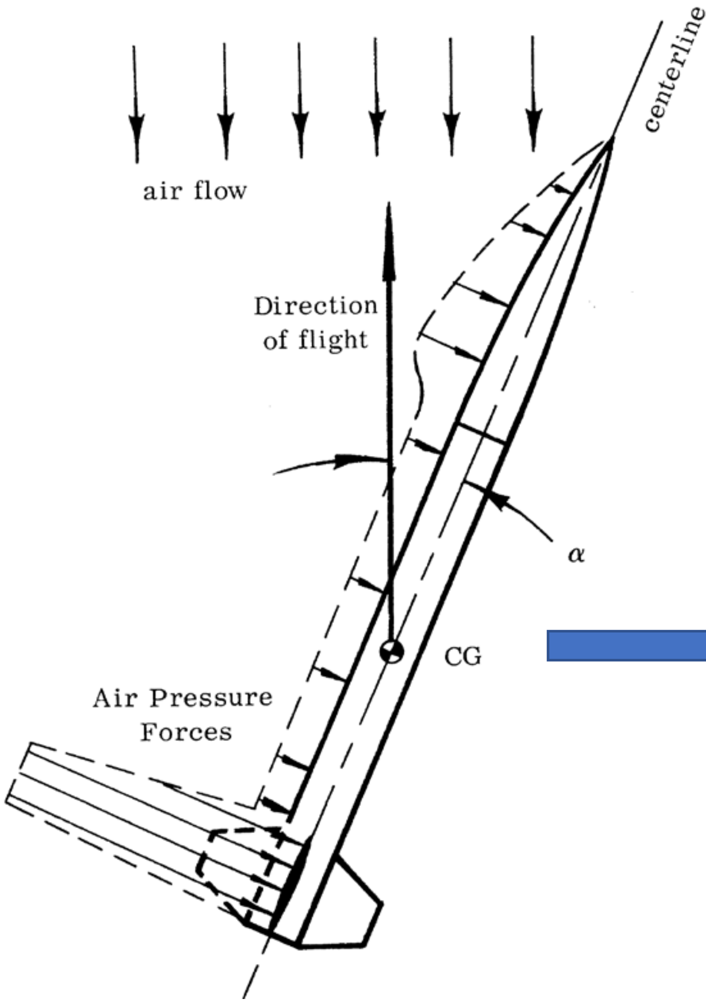
- All translational forces always act through the Center-of- Gravity.

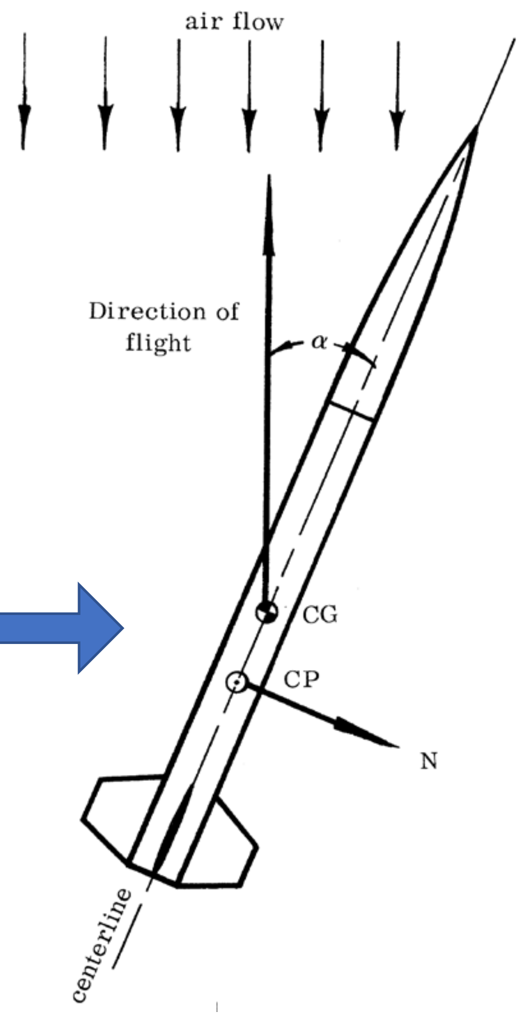


- Any free-flying body - like a rocket - always rotates about the Center-of-Gravity.

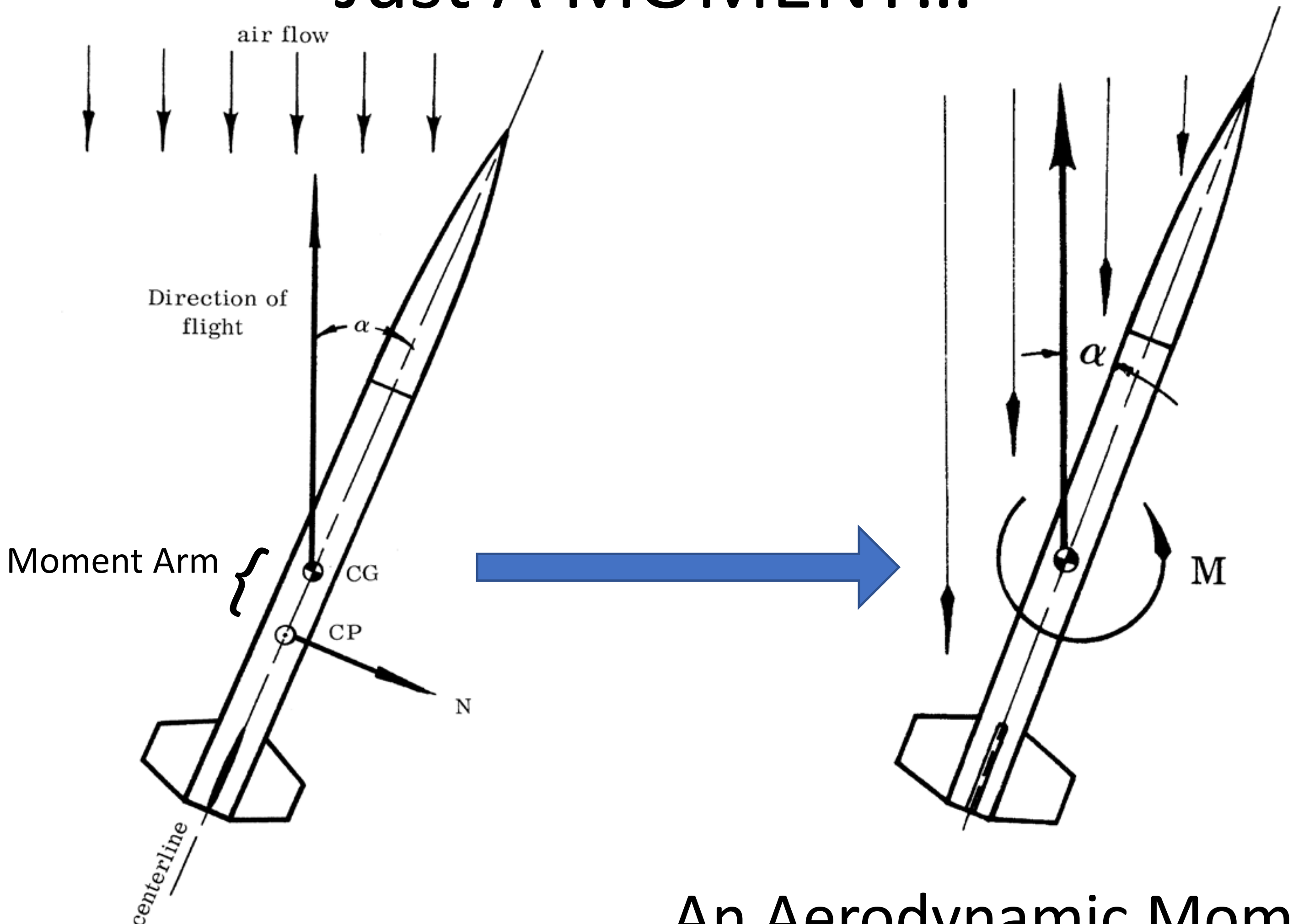


Model Rockets are Aerodynamically Stabilized by Rotational Forces





Just A MOMENT…

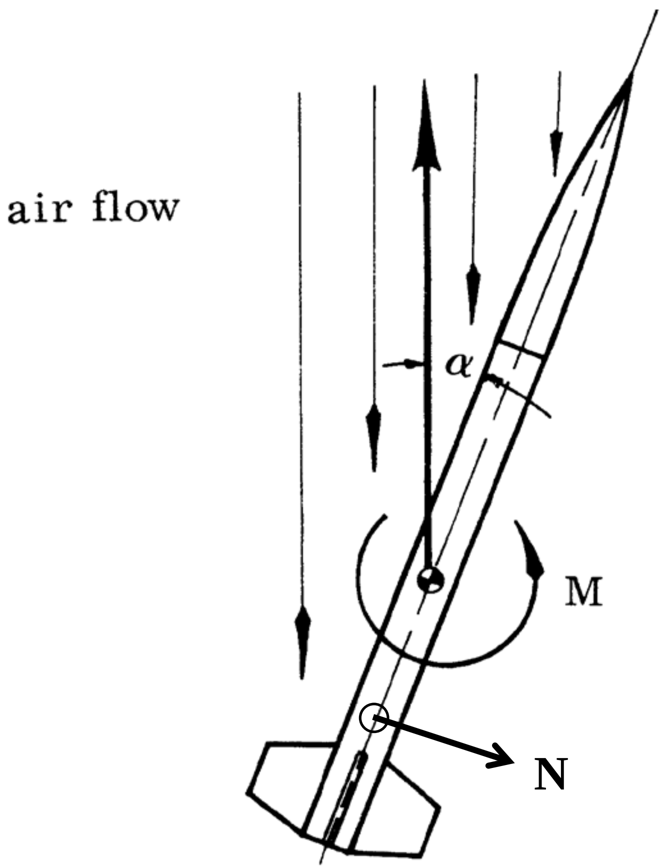


An <u>Aerodynamic Moment</u>

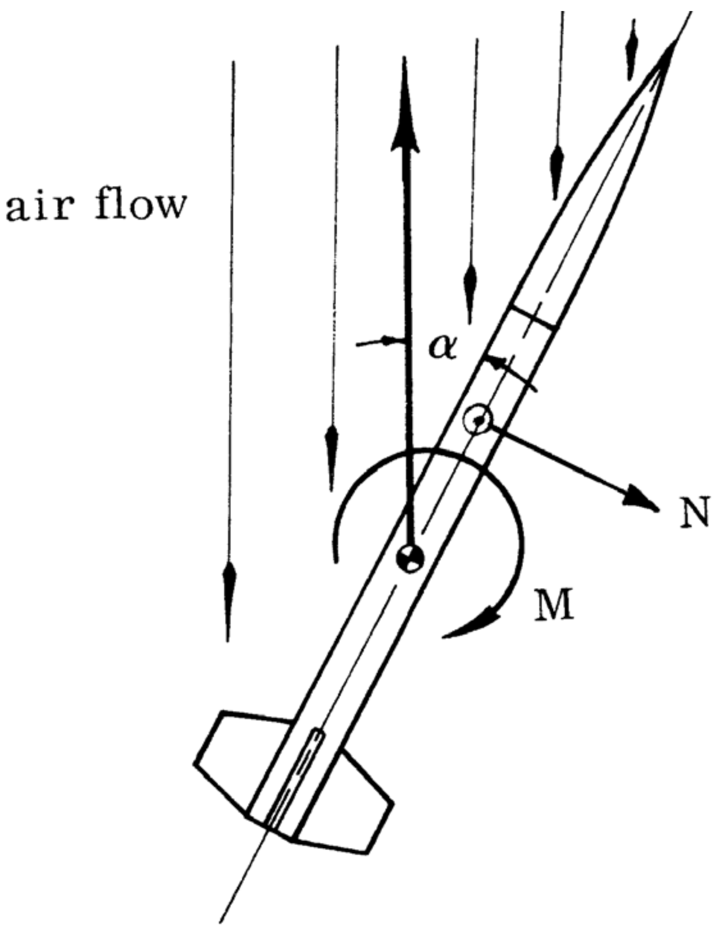
Aerodynamic Moment

Depends on the Locations of the Center-of-Gravity (CG) and Center-of-Pressure (CP)

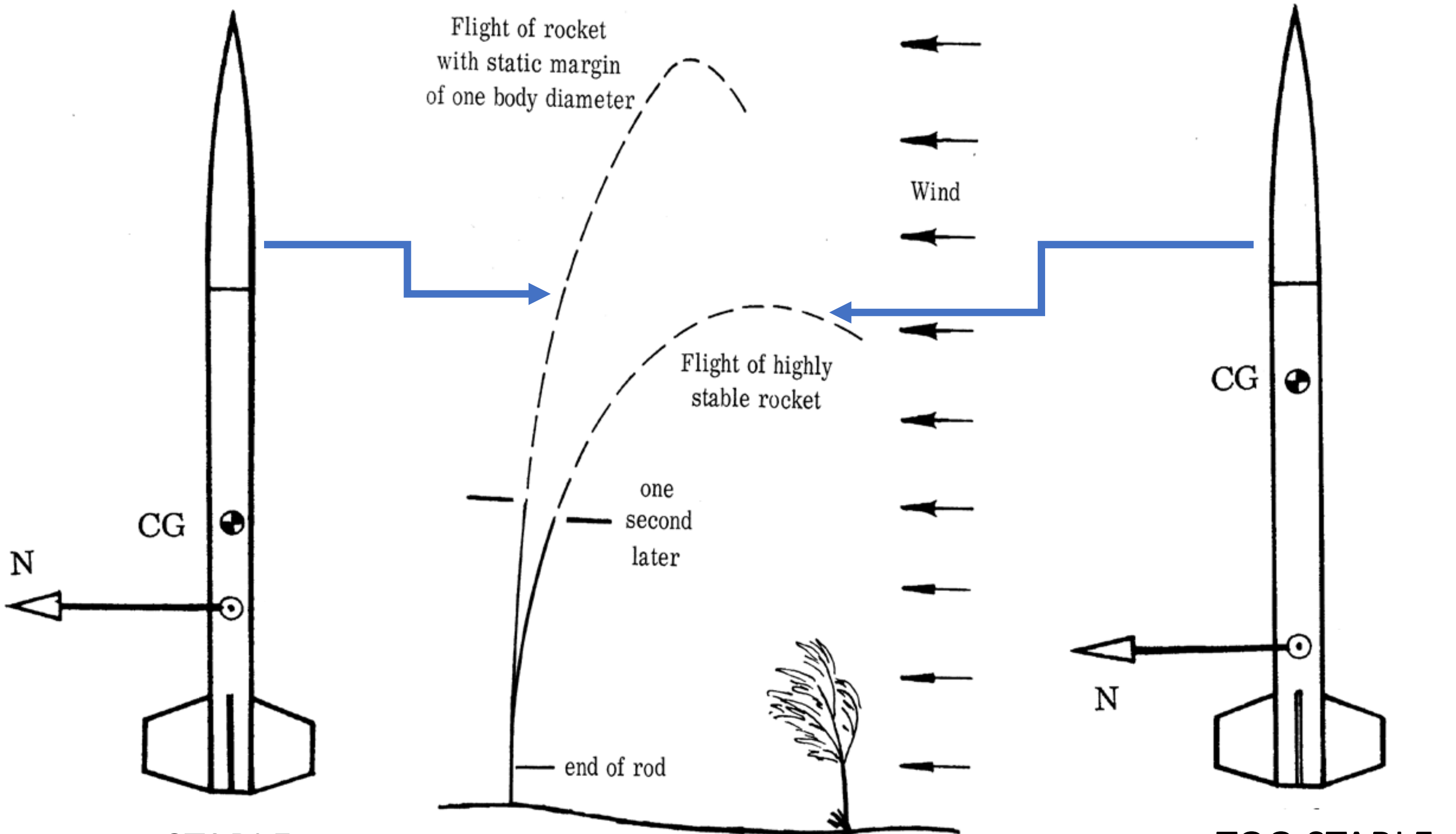
STABLE



UNSTABLE



Stable, but not too Stable

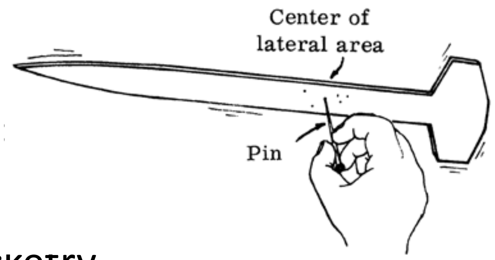


STABLE

TOO STABLE

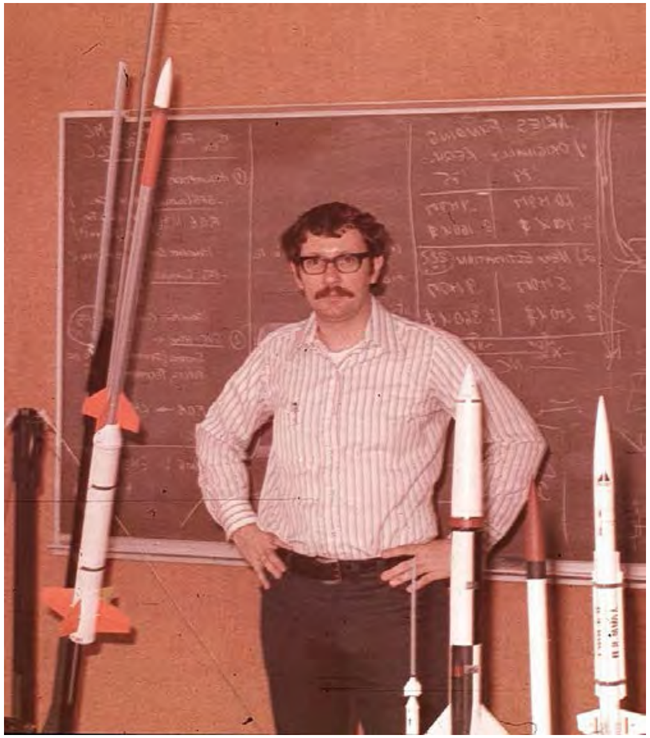
Ways to Determine Model Rocket Stability

- For designs that are already built:
  - Swing Test
    - Done carefully, it's the ultimate test.
    - NAR Handbook of Model Rocketry and Internet sites describe how.
    - Doesn't help with unbuilt designs.
- For unbuilt designs:
  - Determine the CG ◕ - done in many design programs.
  - Determine the CP ⊙
    - Cardboard Cut-out
      - Provides a conservative answer (α=90°).
      - Your rocket will likely be too stable.
    - Aerodynamic Equations
      - Published in the NAR Handbook of Model Rocketry.
      - Many design programs, such as Rocksim and OpenRocket, include the appropriate equations.



Aerodynamic CP Equations

- Initially derived for NASA Sounding Rockets.
- Sounding rockets and Model Rockets are both aerodynamically stabilized.
- Based on key aerodynamic research and engineering done by NACA.
- Too complex for use without significant computer capability.
- Appropriate assumptions made them much simpler and applicable to model rockets.



Simplifying Assumptions

1. The Rocket is a rigid body.
2. The rocket is axially symmetric.
3. Flow over the rocket is potential flow.
   I.e., no turbulence, vortices, or friction.
4. The nose is not flat, but comes to a point.
5. The fins are thin flat plates with no cant.
6. The angle-of-attack is very near zero ($< 10^o$).
7. The flow is steady state.
8. The flow is subsonic.

Nose Center of Pressure

By Definition:

$$\bar{X} = d\left(\frac{C_{m_\alpha}}{C_{N_\alpha}}\right)$$

Where:

$$C_{m_\alpha}(x) = \left.\frac{\partial C_m(x)}{\partial \alpha}\right|_{\alpha=0} = \frac{8}{\pi d^3}\int_0^L x \frac{\partial S(x)}{\partial x}\,dx$$

And The normal force coefficient is independent of nose shape as long has it an initial area of zero and varies smoothly:

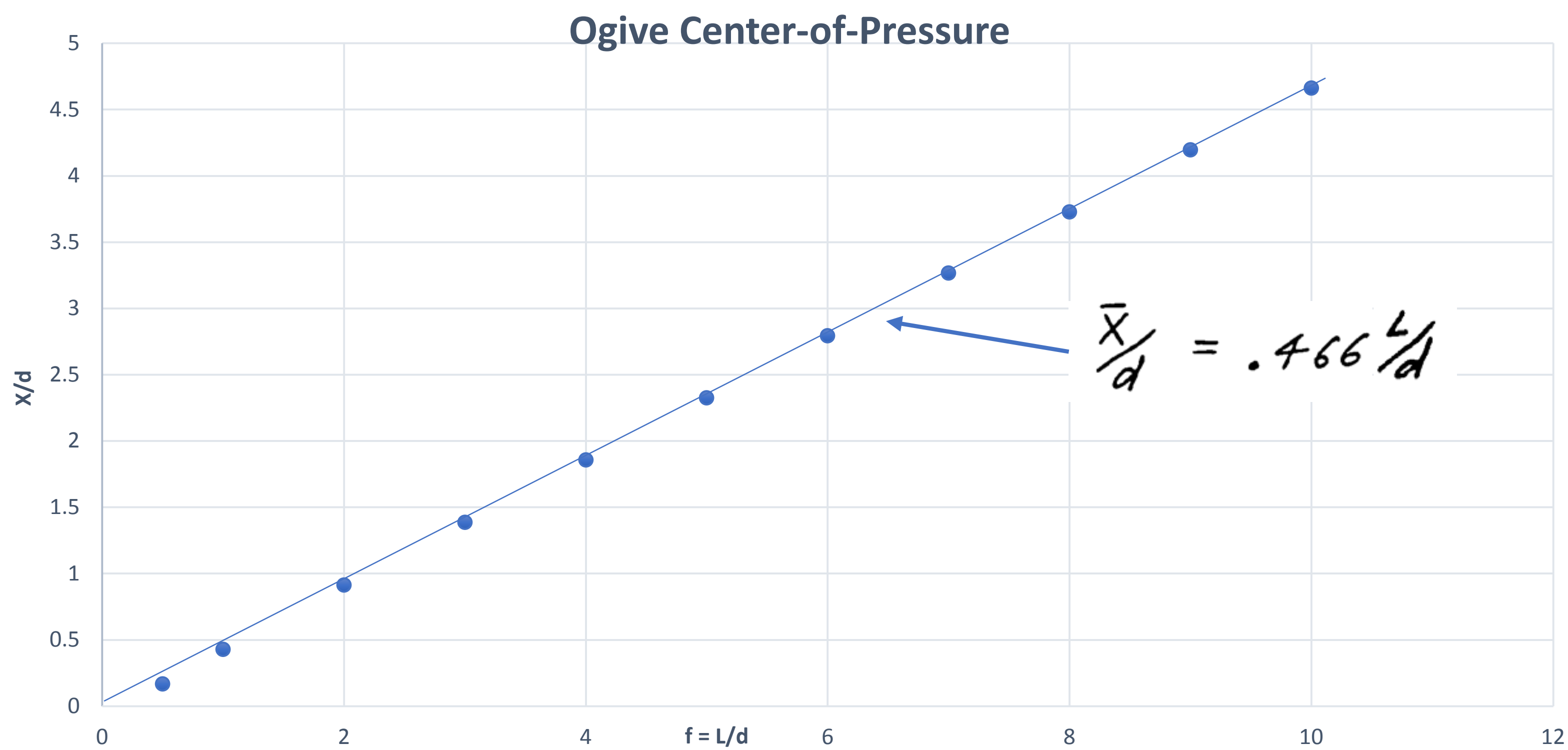
$$(C_{N_\alpha})_N \doteq 2$$

After some careful calculus, it turns out that the nose CP depends only on it's volume:

$$\bar{X} = L - \frac{V}{S(L)}$$

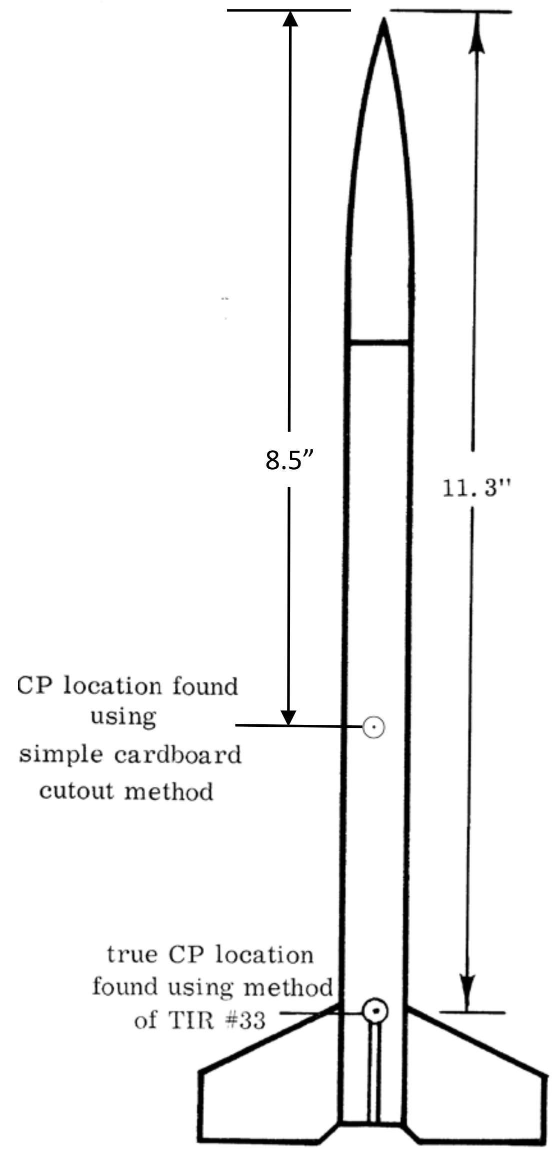
Tangent Ogive CP

$$\frac{\bar{X}}{d} = f + f\left[f\left(f^2+\tfrac{1}{4}\right)^2 + \tfrac{1}{3}f^3 + \left(f^2-\tfrac{1}{4}\right)\left(f^2+\tfrac{1}{4}\right)^2 \sin^{-1}\left(\frac{f}{f^2+\frac{1}{4}}\right)\right]$$



Aero Equations Proven

- By comparison with sounding rocket windtunnel data
- By flying Test Models like the Centuri Javelin
- Over 50 years:
  - Thousands of stable model rockets
  - Higher contest performance



Are You Stable?

STABLE=SAFE=predictable=performance

Know it before you fly it!