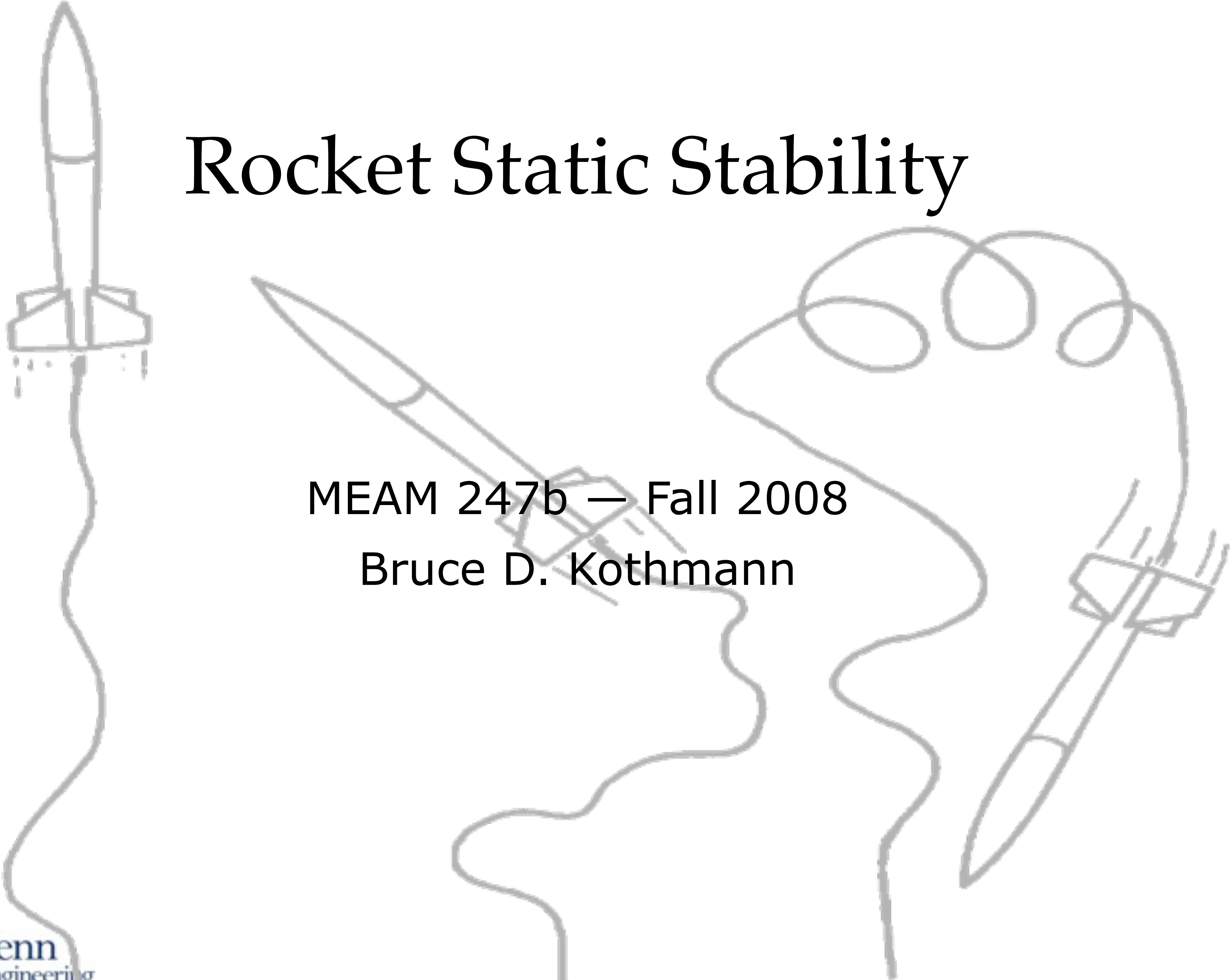
Rocket Static Stability



MEAM 247b — Fall 2008

Bruce D. Kothmann

Penn Engineering

Lecture Prepared From These Reports

THE THEORETICAL PREDICTION
OF THE
CENTER OF PRESSURE
by
James S. Barrowman (#6883)
and
Judith A. Barrowman (#7489)

Presented as a
RESEARCH AND DEVELOPMENT
Project at
NARAM-8
on
August 18, 1966

This report was reprinted on the Apogee Components web site with permission of James S. Barrowman.

www.ApogeeRockets.com

Read This One for Knowledge & Pleasure➔

🡐 *Skim This One for Equations*

Centuri

TECHNICAL INFORMATION REPORT 30

STABILITY OF A MODEL ROCKET IN FLIGHT

BY JIM BARROWMAN

This report has been written to help you understand the scientific principles that affect the stability of your model rockets. It is not a "how to" manual on calculating stability. It has been written on the assumption that every model rocketeer wants to know "why" as well as "how to".

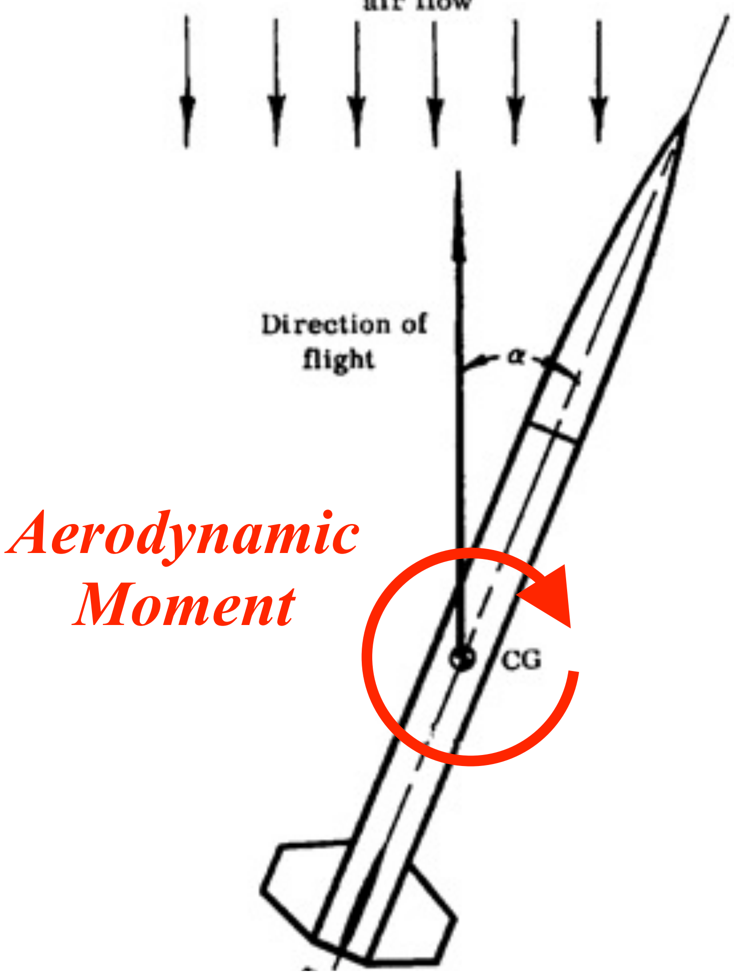
The best technique for accurately determining the stability of model rockets is given in CENTURI'S TIR # 33.

Figures in Lecture Taken from this Excellent Report

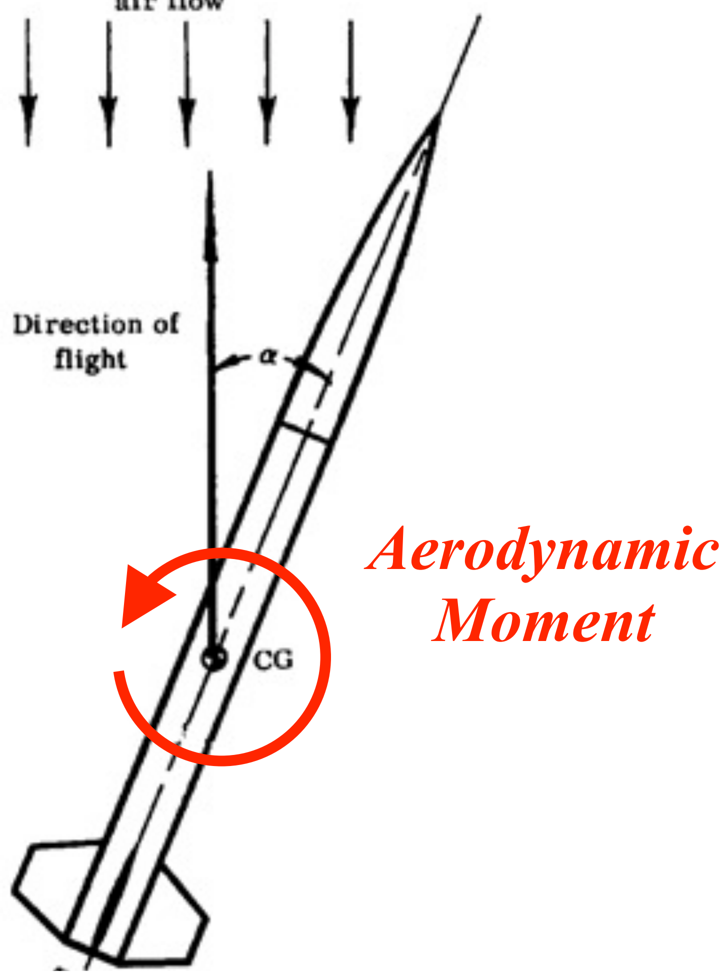
Basic Concept of *Static* Stability

Figure 5

Static Stability Applied to Rockets

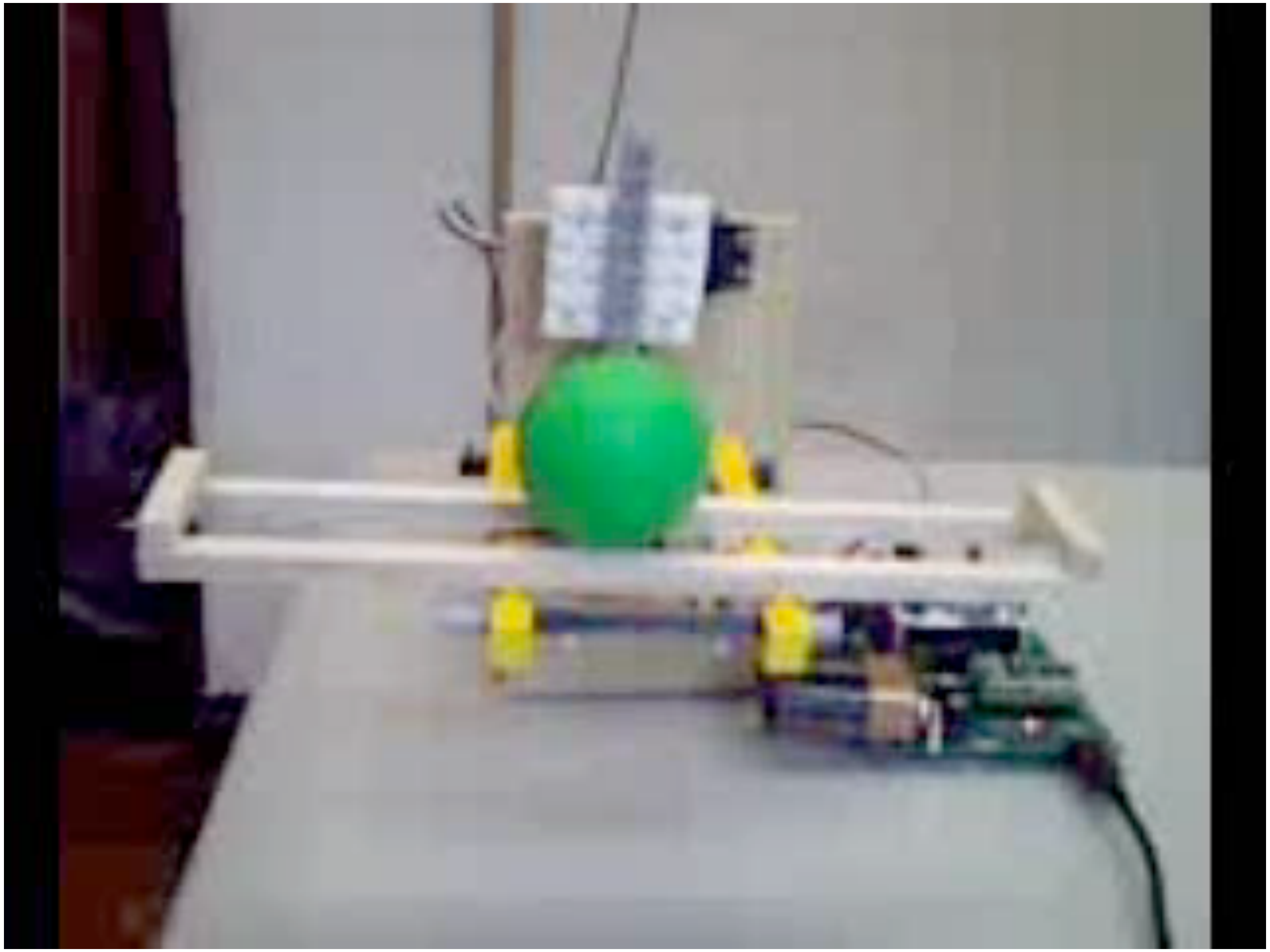


UNSTABLE



STABLE

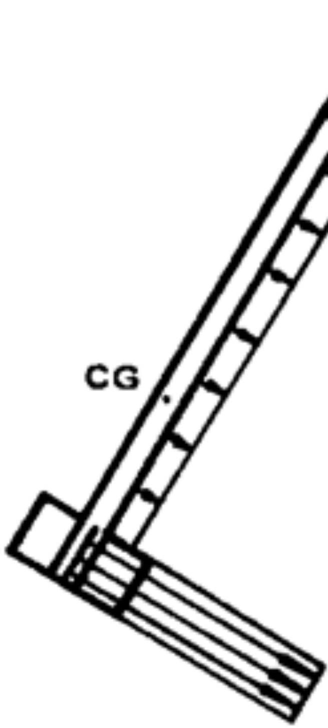
Careful : Static Stability != Dynamic Stability



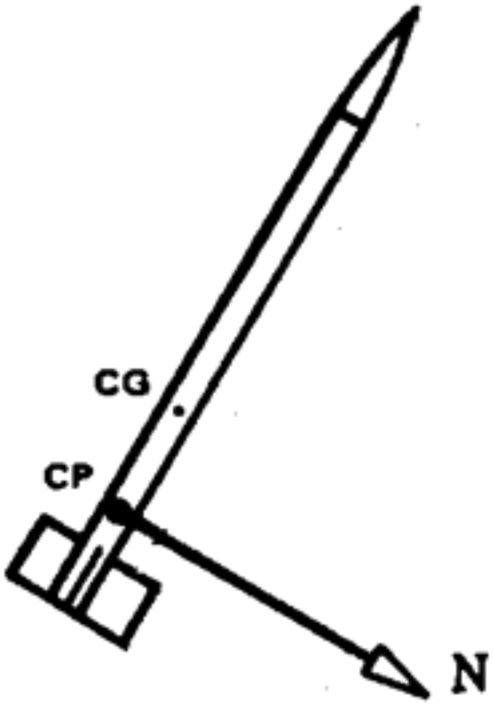
Microcontroller Uses Feedback of Ball Position to Achieve *Static* Stability & *Dynamic* Instability!

Experience Suggests That Static Stability is Usually Sufficient for Dynamic Stability on a Model Rocket

“Center of Pressure” Concept

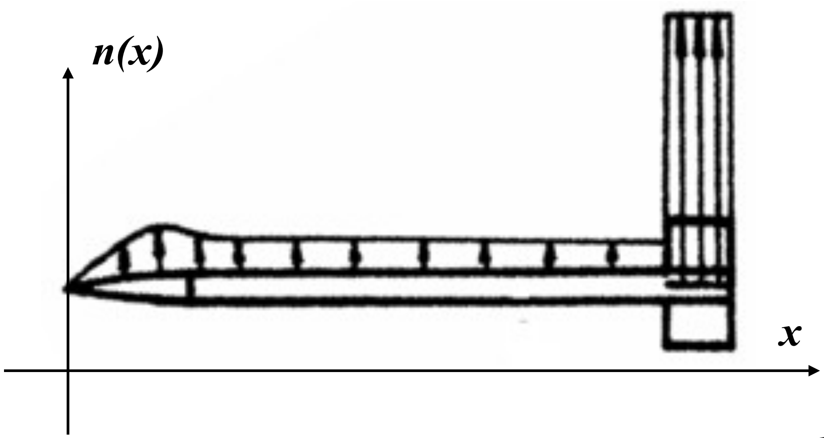


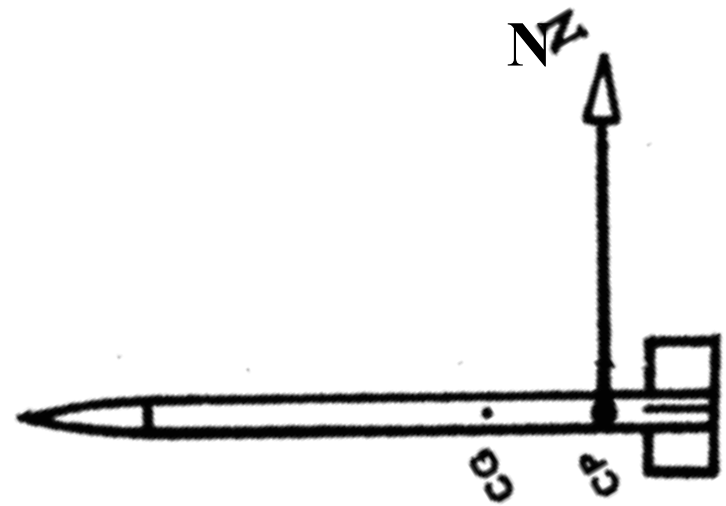
Actual Distributed Pressure Forces on Body Surface



Equivalent Point Load with Identical Moment About CG

"Center of Pressure" Concept

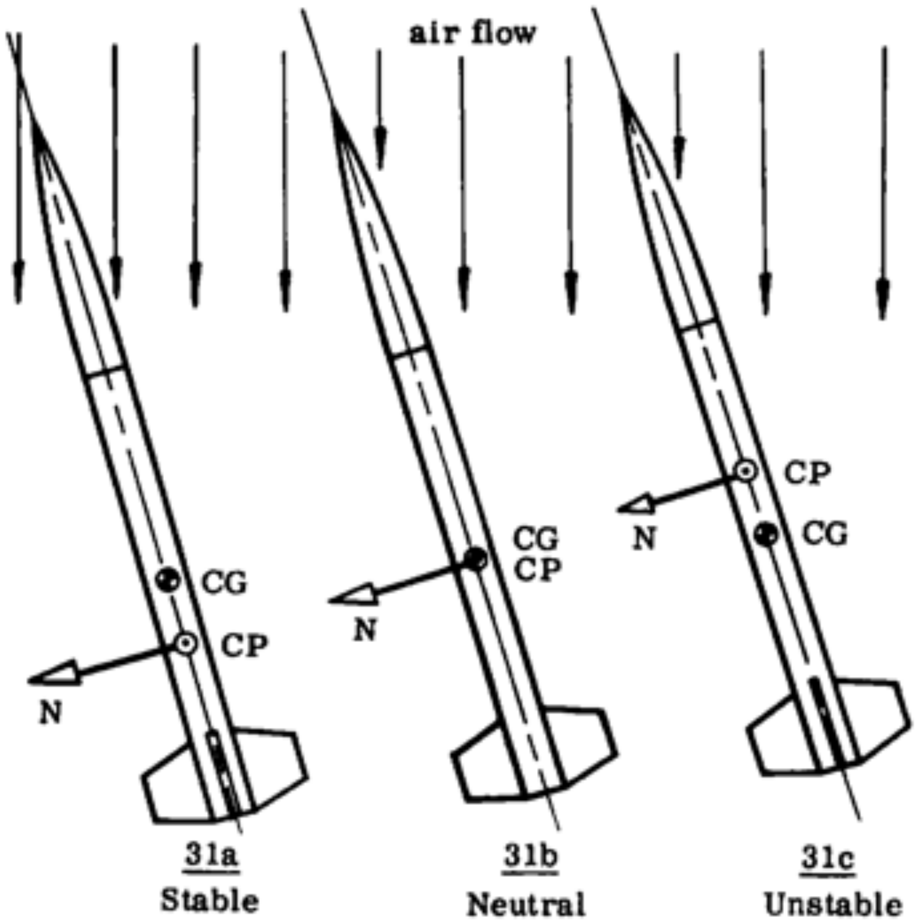




$$N = \int_{x=0}^{x=L} n(x)dx$$

$$x_{CP} = \frac{1}{N}\int_{x=0}^{x=L} x \times n(x)dx$$

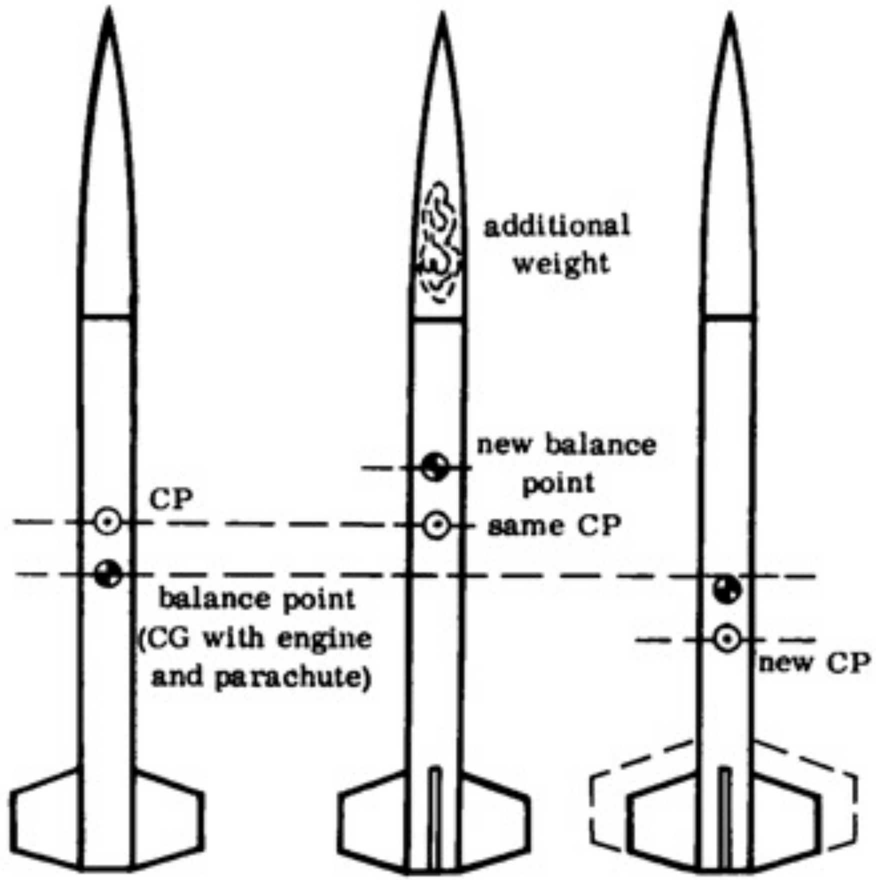
Static Stability ➔ CP Aft of CG



Types of stability

Figure 31

Achieving Static Stability



40a
Unstable configuration

40b
Add weight to nose

40c
Increase fin area (note that CG shifts slightly to the rear)

Static Margin = Degree of Static Stability

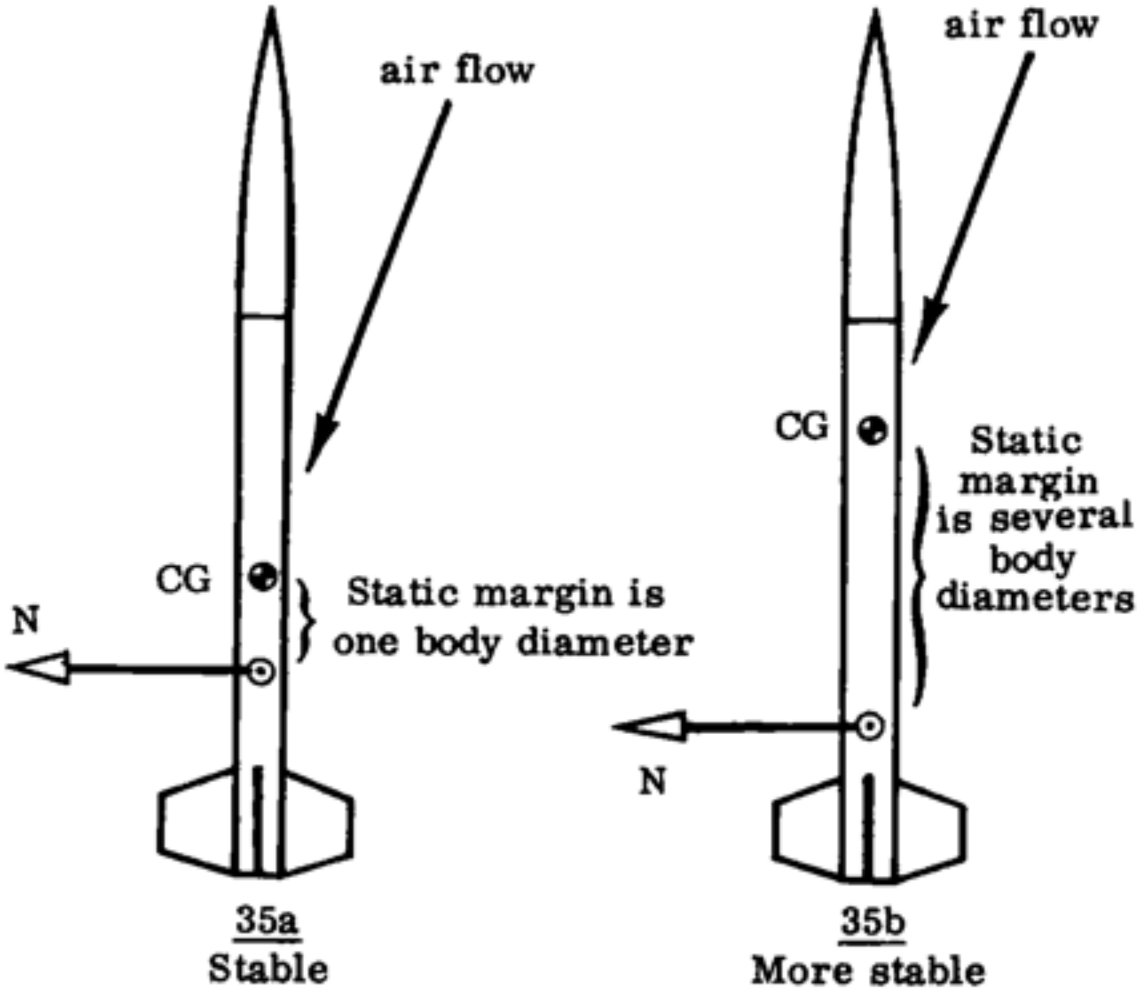
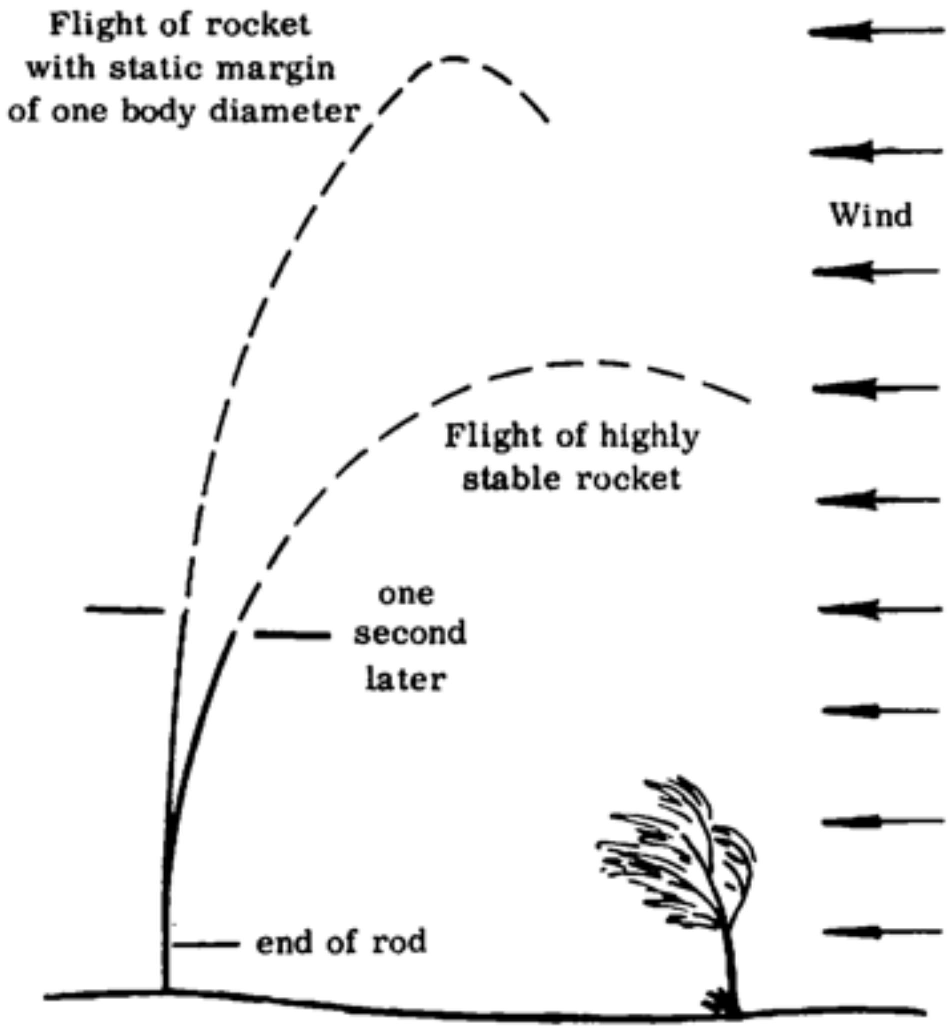


Figure 35

How Much Static Margin is Too Much?



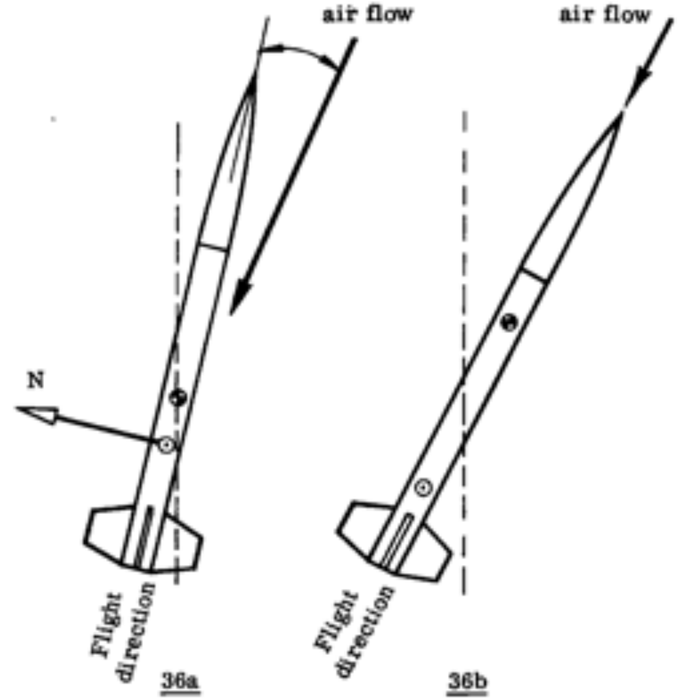


Figure 36

One Second After Launch

Effect of Stability on Trajectory & Simulation

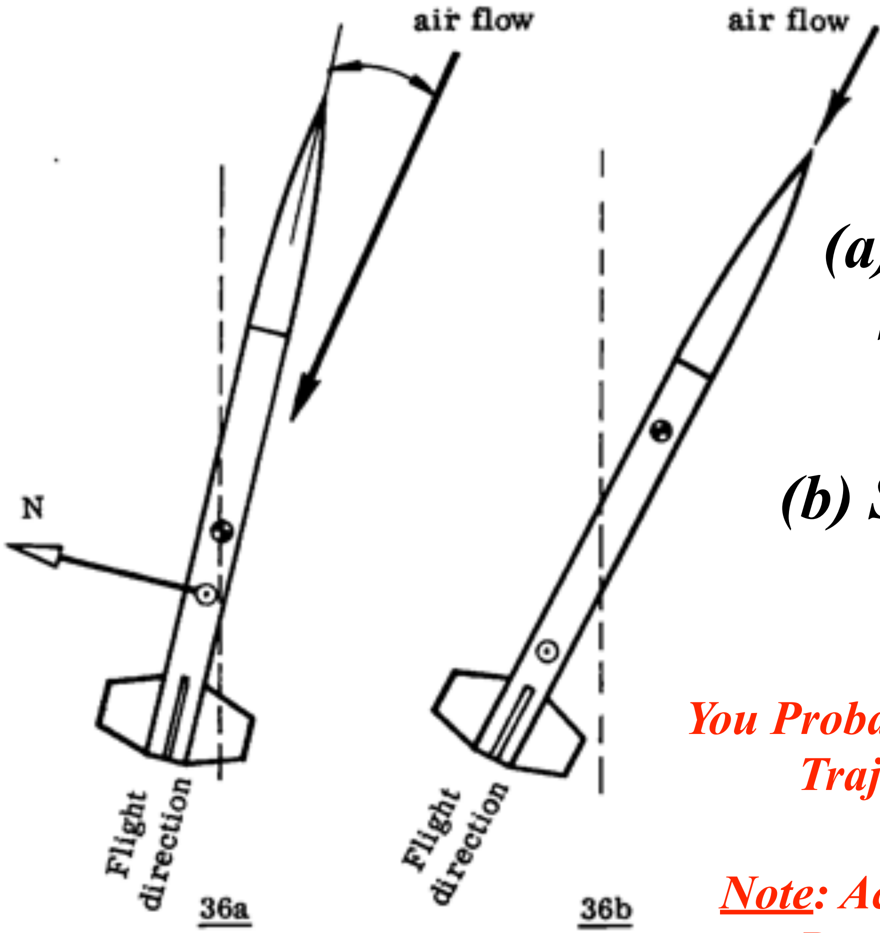


Figure 36

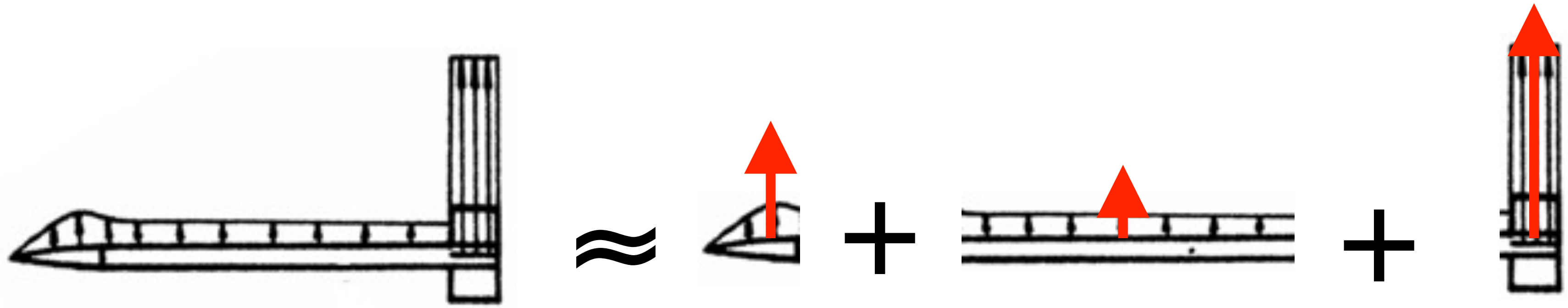
(a) Modest Stability → N May Have Significant Effect on Trajectory

(b) Strong Stability → N Small (Rocket Quickly Reorients to α = 0)

You Probably Want Strong Stability to Enable Accurate Trajectory Calculation Without Modeling N

<u>Note</u>: Achieving Suitable Crosswind Flight Might Require Weaker Stability = More Difficult Simulation = More "Expensive "Rocket

Estimating N and Xcp



- Neglect Small Contribution of Body (Valid for Small Angles Only)
- Compute Point Force and "Center of Pressure" For Nose and Tail Distributed Loads Independently (Assume No Aerodynamic Interactions / Interference)

$$N = \int_{x=0}^{x=L} n(x)dx \approx \int_{NOSE} n(x)dx + 0 + \int_{TAIL} n(x)dx$$

Force Coefficients

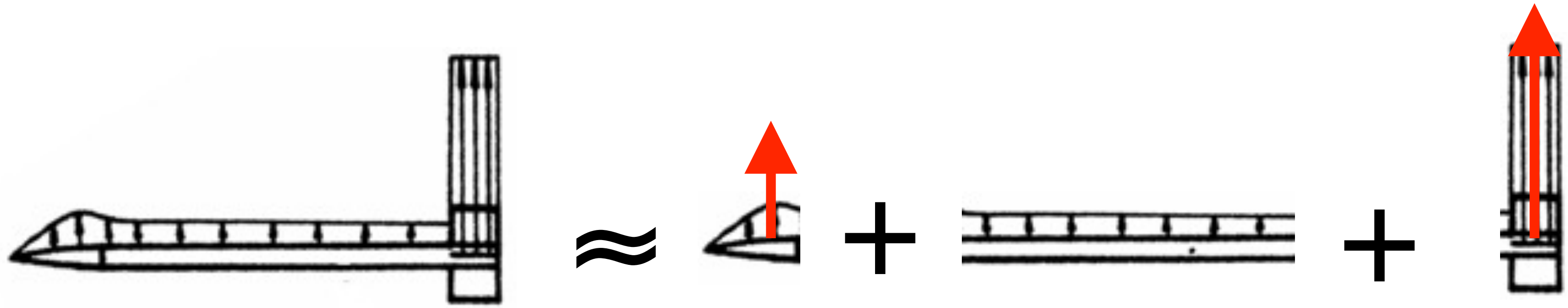
$$C_N \; @ \frac{N}{\frac{1}{2}\rho V^2 A} \approx \frac{N_{NOSE} + N_{TAIL}}{\frac{1}{2}\rho V^2 A} = C_{N_{NOSE}} + C_{N_{TAIL}}$$

For Small Angles of Attack, α, Force Coefficients Are Linearly Related to α

$$C_N = C_{N_\alpha}\alpha = \left(C_{N_{\alpha,NOSE}} + C_{N_{\alpha,TAIL}}\right)\alpha$$

Simplified "Barrowman Equations" Give Formulas for Derivatives on RHS in Terms of Nose & Fin Geometry

Center of Pressure Calculations



$$x_{CP,NOSE} = \frac{1}{N_{NOSE}} \int_{NOSE} x \times n(x)\,dx$$

$$x_{CP,TAIL} = \frac{1}{N_{TAIL}} \int_{TAIL} x \times n(x)\,dx$$

Simplified "Barrowman Equations" Give Formulas for Nose & Tail CP Locations in Terms of Nose and Fin Geometry

$$x_{CP} = \frac{C_{N,NOSE}\,x_{CP,NOSE} + C_{N,TAIL}\,x_{CP,TAIL}}{C_{N,NOSE} + C_{N,TAIL}}$$

Do We Have to Calculate Stuff to Get a Stable Rocket?

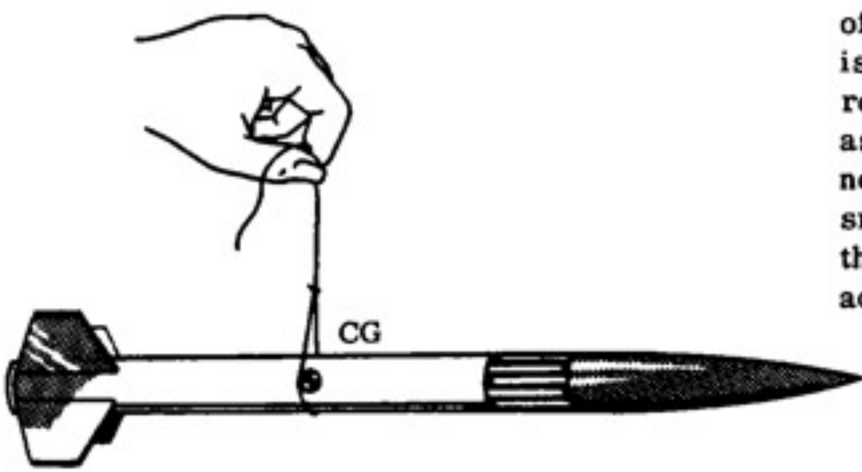
In the "Real World" of Aerospace Engineering…

- "Build-and-Check" is Much Too Expensive
- Development Cycle Time = Critical for Success
- Carefully Designed Scale Model Tests Often Used
- Computational Models Almost Always Used
- Analytical Insights From Simple Models Essential

- And…

Calculating Stuff is Fun!

Okay, You Don't Actually Have to Calculate Stuff…



Balanced rocket

Figure 15

SWING TEST

The best experimental method is to swing the fully prepared rocket (parachute and engine inserted) on a string attached to the rocket at its center of gravity. First, balance test the rocket to find its C.G. Then secure the string firmly at the C.G. with a piece of tape or straight pin. Check to see if the area is clear so you won't hit anyone or smash the rocket when you swing it. Be careful to start the rocket so that it is pointing in the direction that it is moving. Remember that if it has a large angle-of-attack, it may be unstable at that angle even though it is actually stable at smaller angles-of-attack. If the rocket tends to stay pointed in the direction it is moving as you swing it, then it is stable. Several tries may be necessary before you can start the rocket swinging smoothly; but if the rocket simply will not stay pointed in the direction it is moving, then it probably doesn't have adequate stability.