The University of Texas at Austin
Aerospace Engineering
and Engineering Mechanics
Cockrell School of Engineering

7 NOVEMBER 2024

ASE 367K: FLIGHT DYNAMICS

TTH 09:30-11:00
CMA 2.306

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Topics for Today

- Topic(s):
  - Rocket (Launch Vehicle) Aerodynamics and Stability
  - Computing the Location of the Center of Pressure

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ROCKET AERODYNAMICS AND STABILITY

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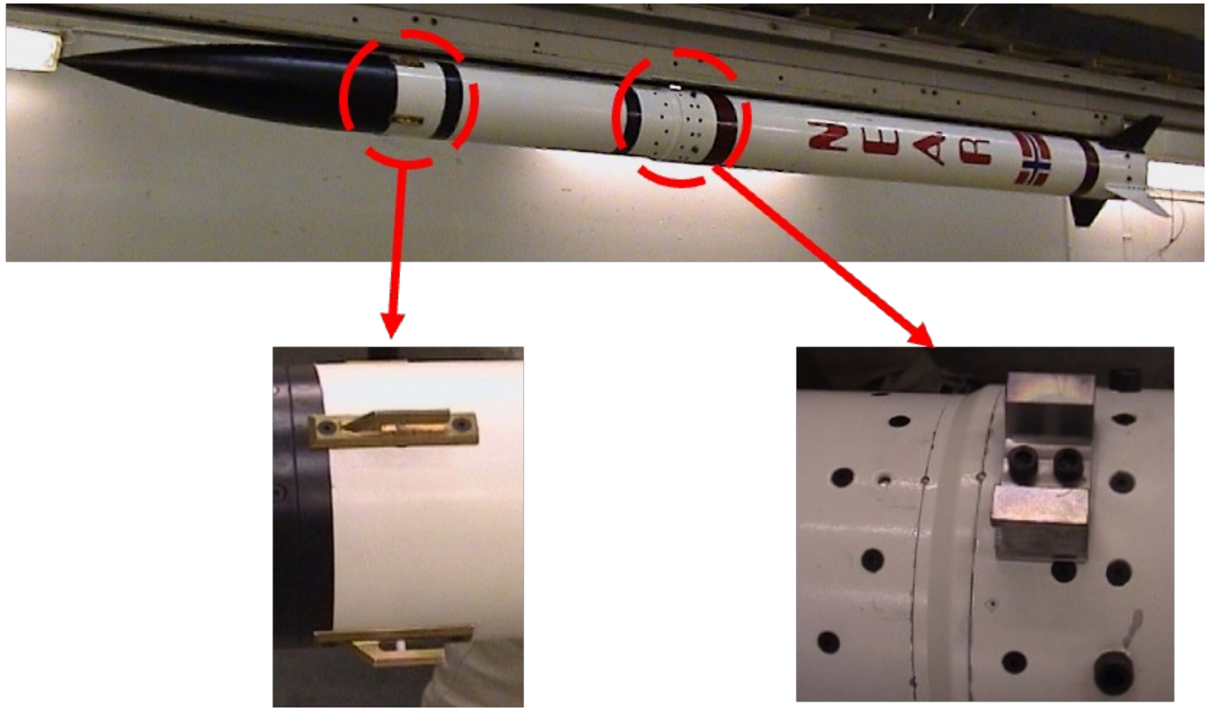
What Affects Aerodynamic Drag?

- The Object
  - Size
  - Shape
- Motion
  - Inclination
  - Speed
- Atmosphere
  - Mass
  - Compressibility
  - Viscosity



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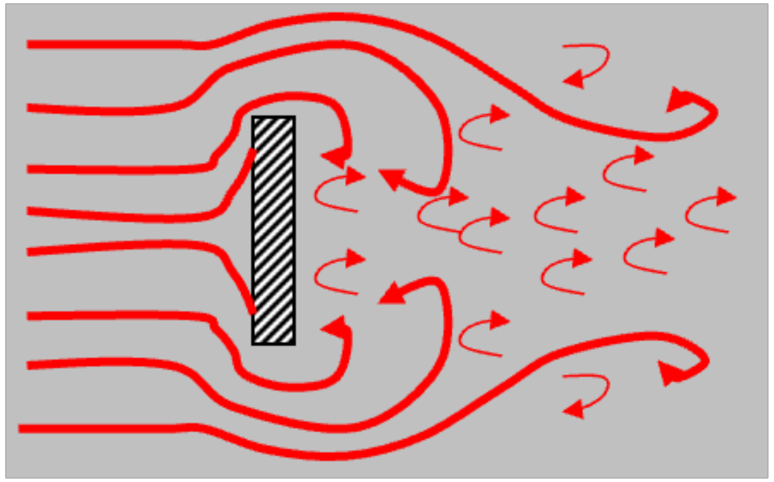
Air Flow Around Objects



eddies ~ energy

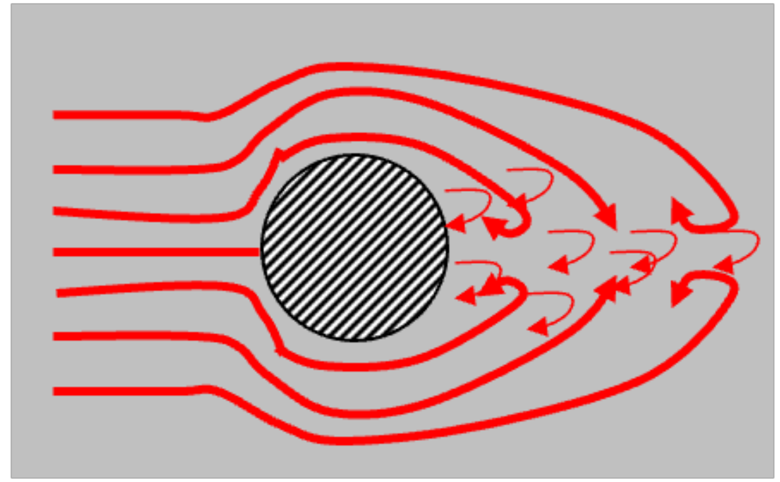
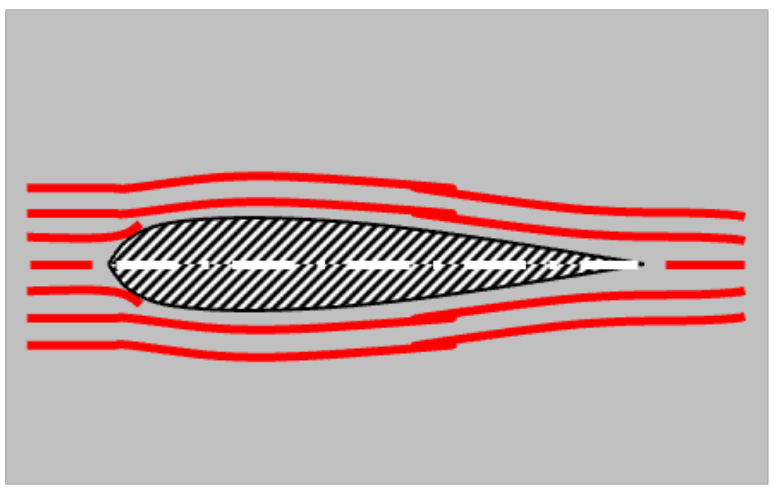


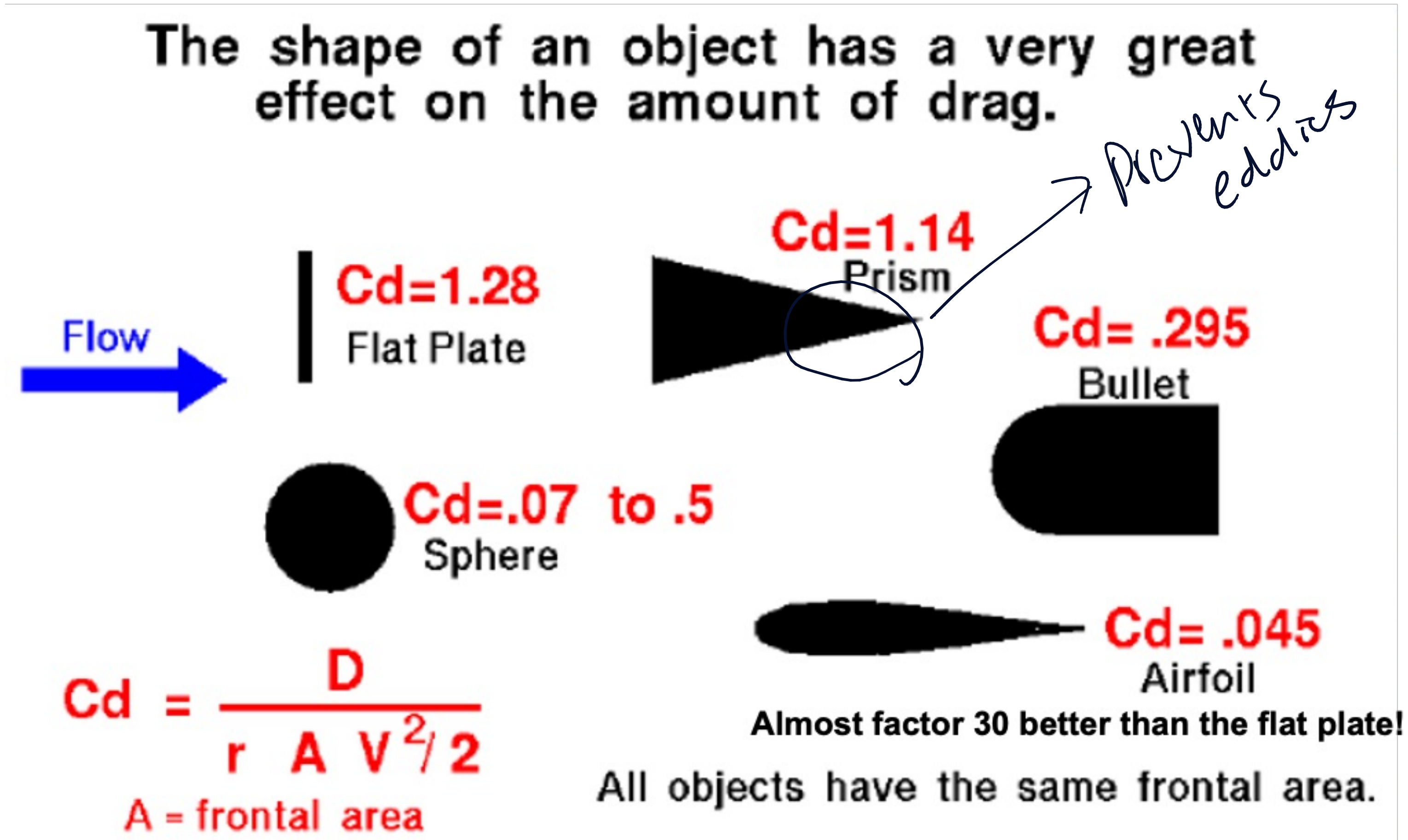
Plate - Induce large resistance

Cylindrical Rod - Lower resistance



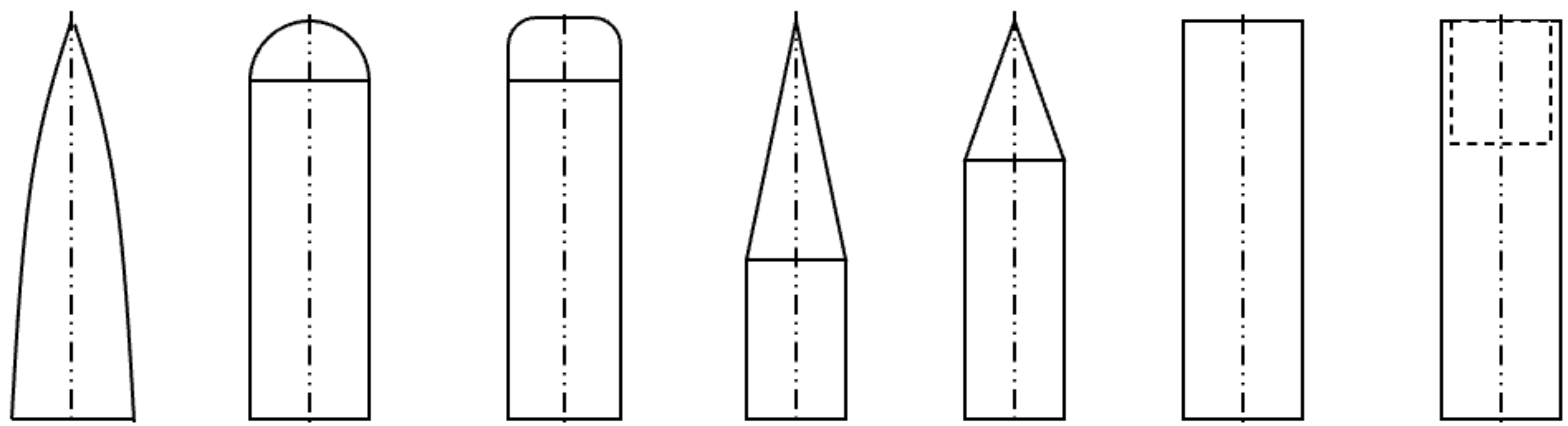
Symmetrical wing profile (Alpha = 0 °) - Least resistance

Air Flow Around Objects



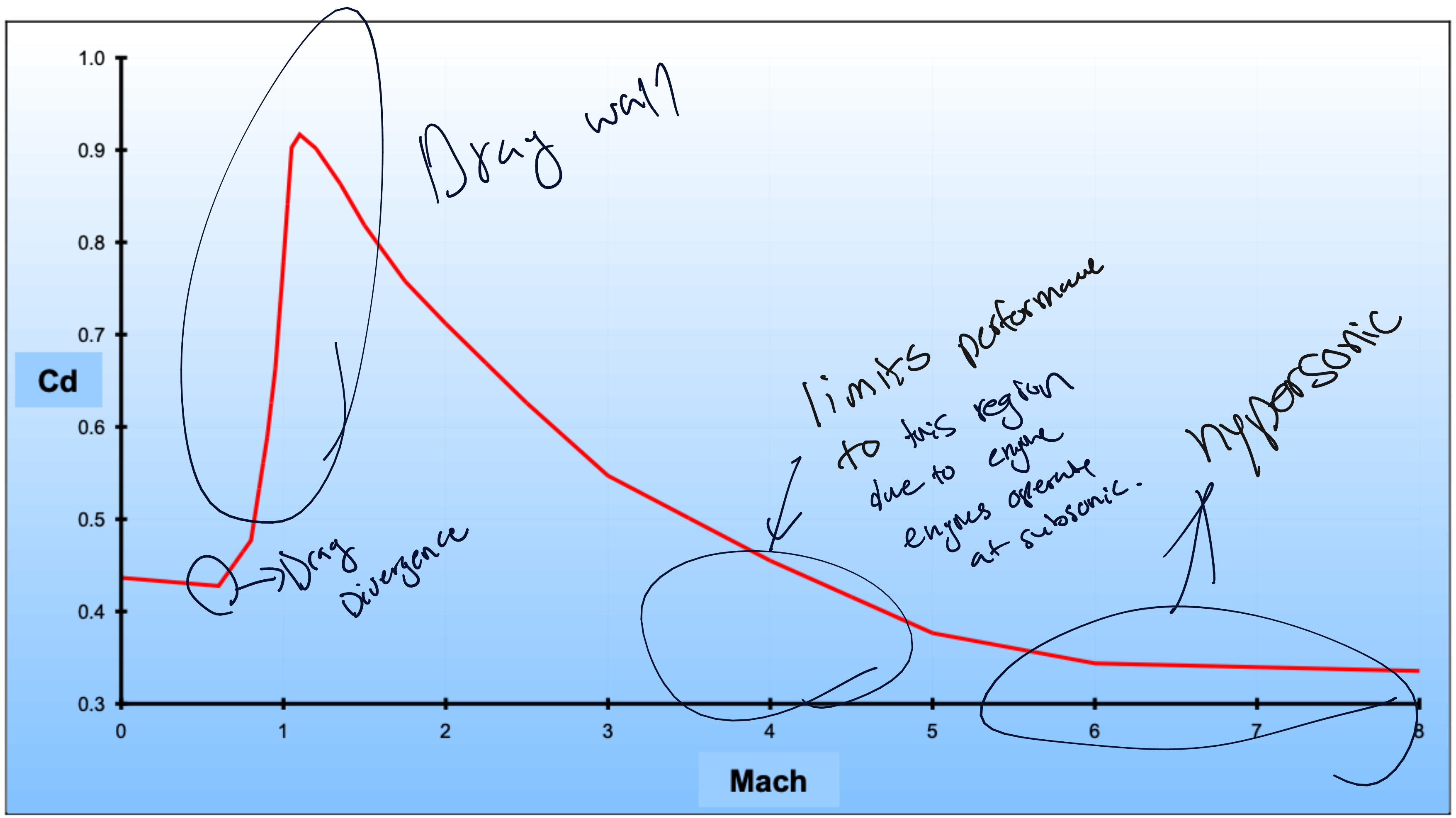
Drag Coefficients for Various Noses

Cd for different nose design (subsonic velocity) and zero alpha:

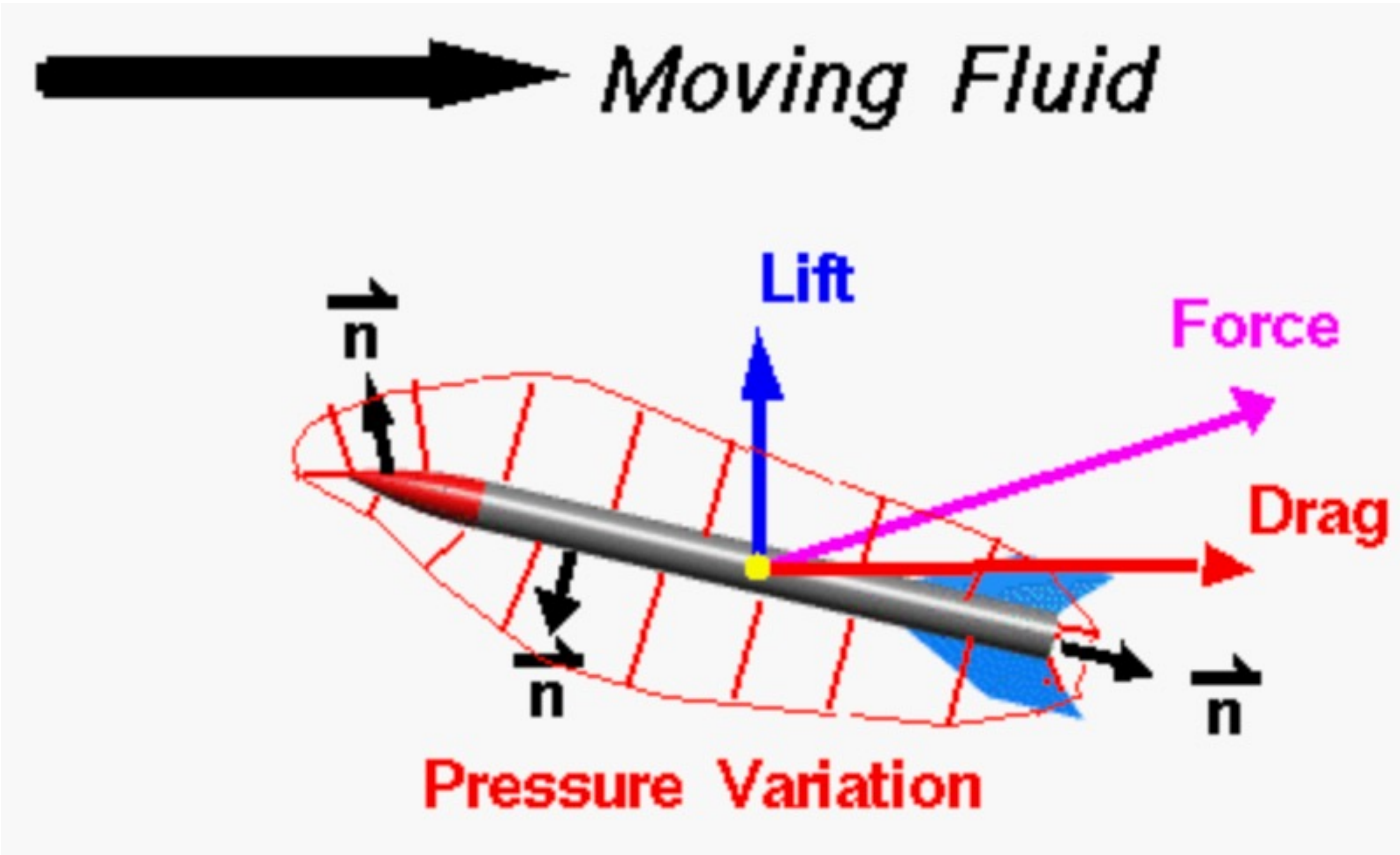


Cd:	**<0.05**	**>0.01**	**0.20**	**0.20**	**0.34**	**0.90**	**1.00**
	4:1			**3:1**	**1:1**		

Drag Coefficient v. Mach Number



Aerodynamic Forces



L = Lift, net force normal to air flow
D = Drag, net force parallell to air flow

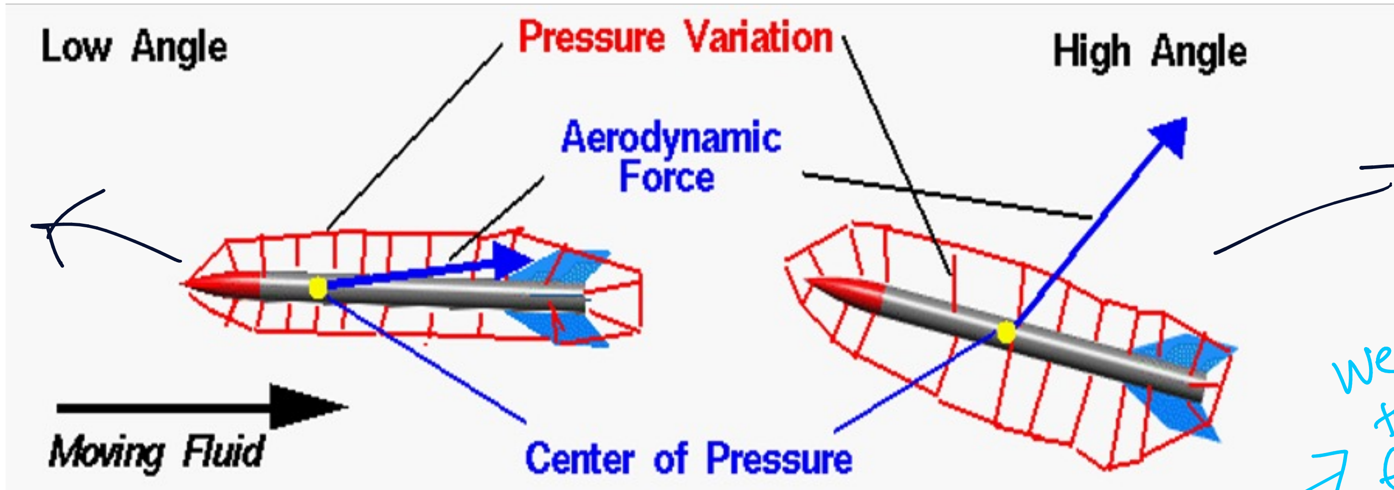
Surface integral

$$\vec{F}_{Aero} = \sum_{Surface} p \cdot \vec{n} \cdot A = \oint p \cdot \vec{n} \cdot dA$$

Symmetrical Rockets

Center of Pressure

Assumes pressures are distributed equally over the area. surface



Cp upfront
Most pressure at front

Cp back

Rockets are symmetric too, so we can do this. into and out of page about axis

We are looking at thin foil, just to find location of Cp. also assuming the airfoil is symmetric about its roll axis.

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

$$C_P = \frac{\int x \cdot p(x) \cdot dx}{\int p(x) \cdot dx}$$

$\frac{\Sigma A_i x_i}{A_{total}}$

Cp = Weighted sum of pressure.

"Moment" = (pressure x Area) x distance (x) Force

"Force" = pressure x "Area"

Normalization by net pressure

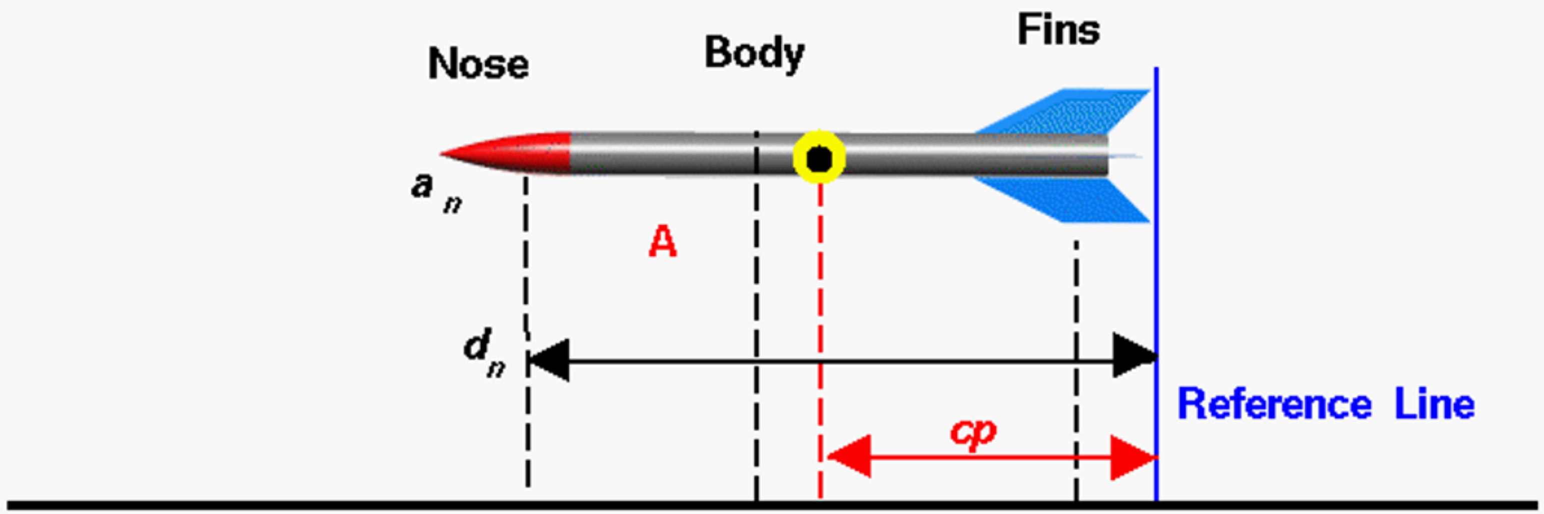
Aerodynamic force acts through the center of pressure.

Center of pressure moves with angle of attack.

Not aerodynamic center

Taken from ref.: http://exploration.grc.nasa.gov/education/rocket/cp.html

Center of Pressure



Each component has some area a_i
located some distance d_i from reference line.

Distance cp times the area A equals the sum of the
component distance times area.

$$cp\,A = d_n a_n + d_b a_b + d_f a_f$$

Taken from ref.: http://exploration.grc.nasa.gov/education/rocket/cp.html

Rocket Drag Equation

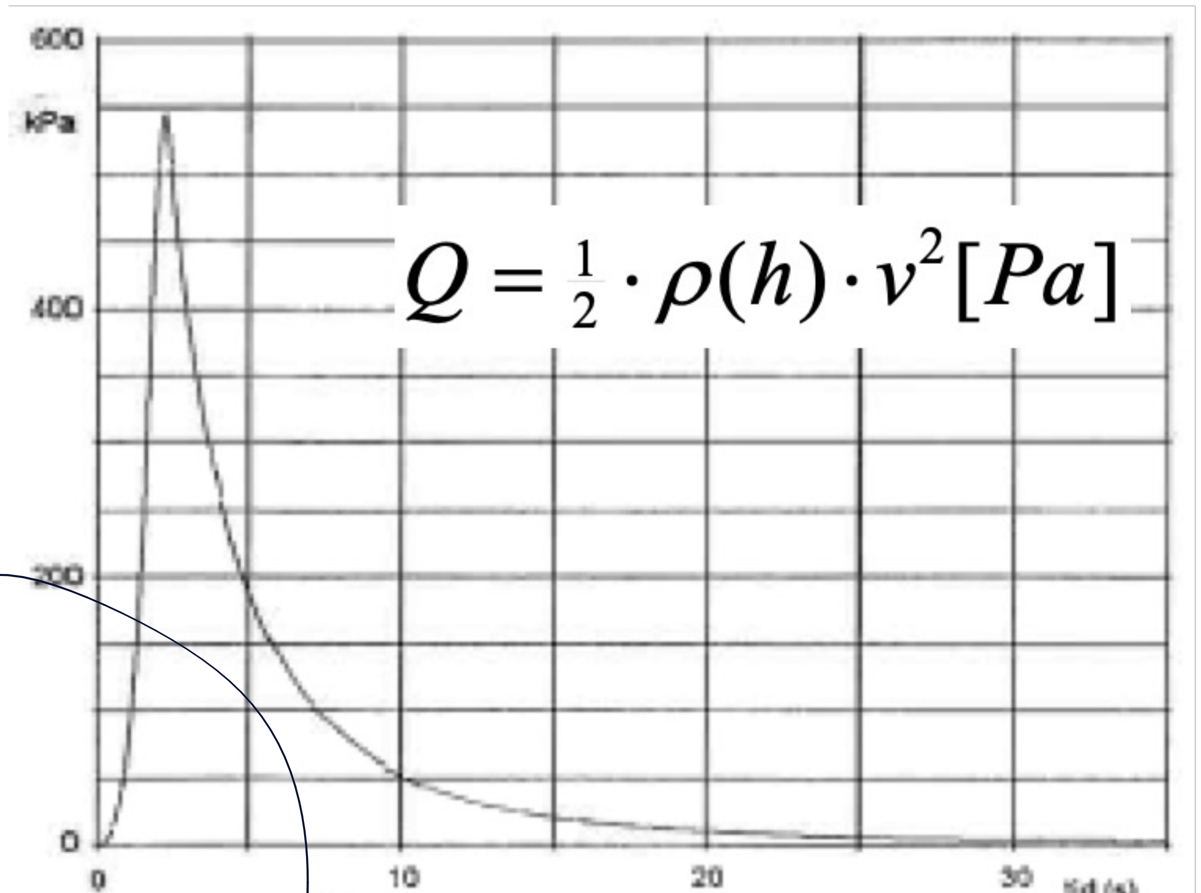
$$\boxed{D = C_D(M,\alpha)\cdot A\cdot \underbrace{\frac{\rho\cdot v^2}{2}}_{\text{Dynamic Pressure}}[N]}$$

frontal area

C_D	: Drag coefficient. Contains all complex dependencies like air compressibility, viscosity body shape and angle-of-attack.
A	: Reference area, typically the base diameter of the nose. Different A, affect the value of C_D.
ρ	: Density of the atmosphere of consideration (typically 1.23kg/m^3 for air at sea-level).
v	: Rocket speed

Plan acceler

Dynamic Load



$$Q = \frac{1}{2} \cdot \rho(h) \cdot v^2 [Pa]$$

have specific acc. plan to manage heat load,

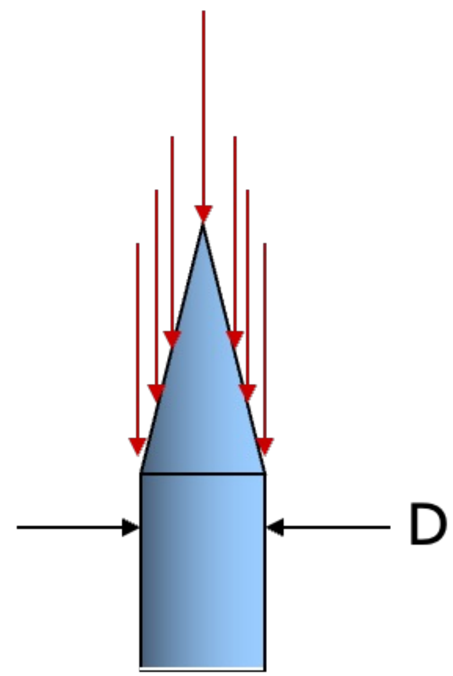
Student Rocket:

dynamic load affect heat load,

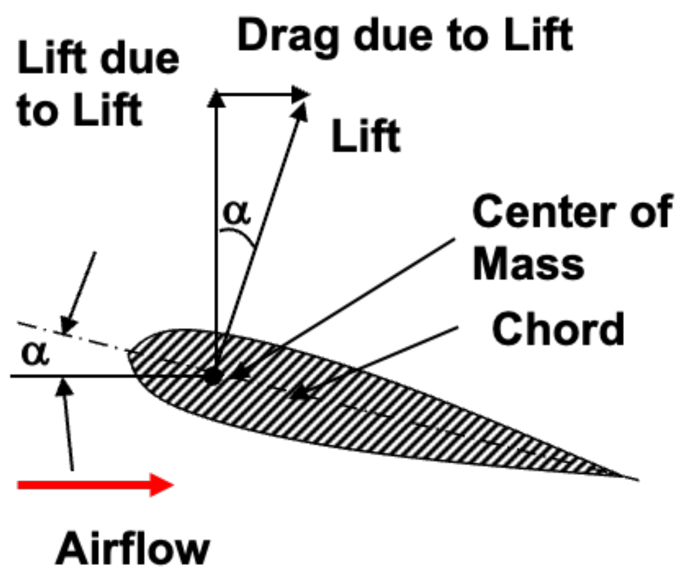
D=ø70mm➔0.07m

$$A = \frac{\pi \cdot D^2}{4} \Rightarrow \underline{0.00385m^2}$$

$$F_{max} = Q_{max} \cdot A \Rightarrow 550000 \cdot 0.00385 = \underline{\underline{2117.5N \approx 216.0kg}}$$



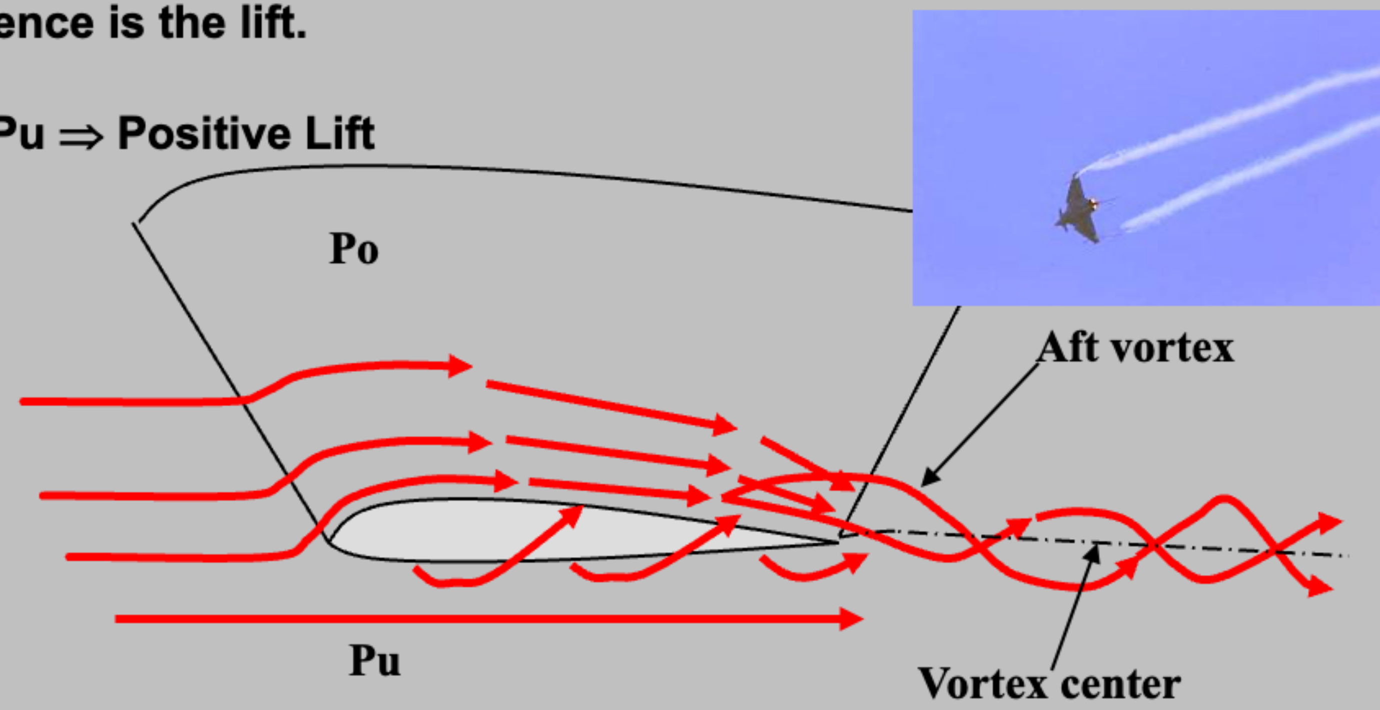
Induced Drag



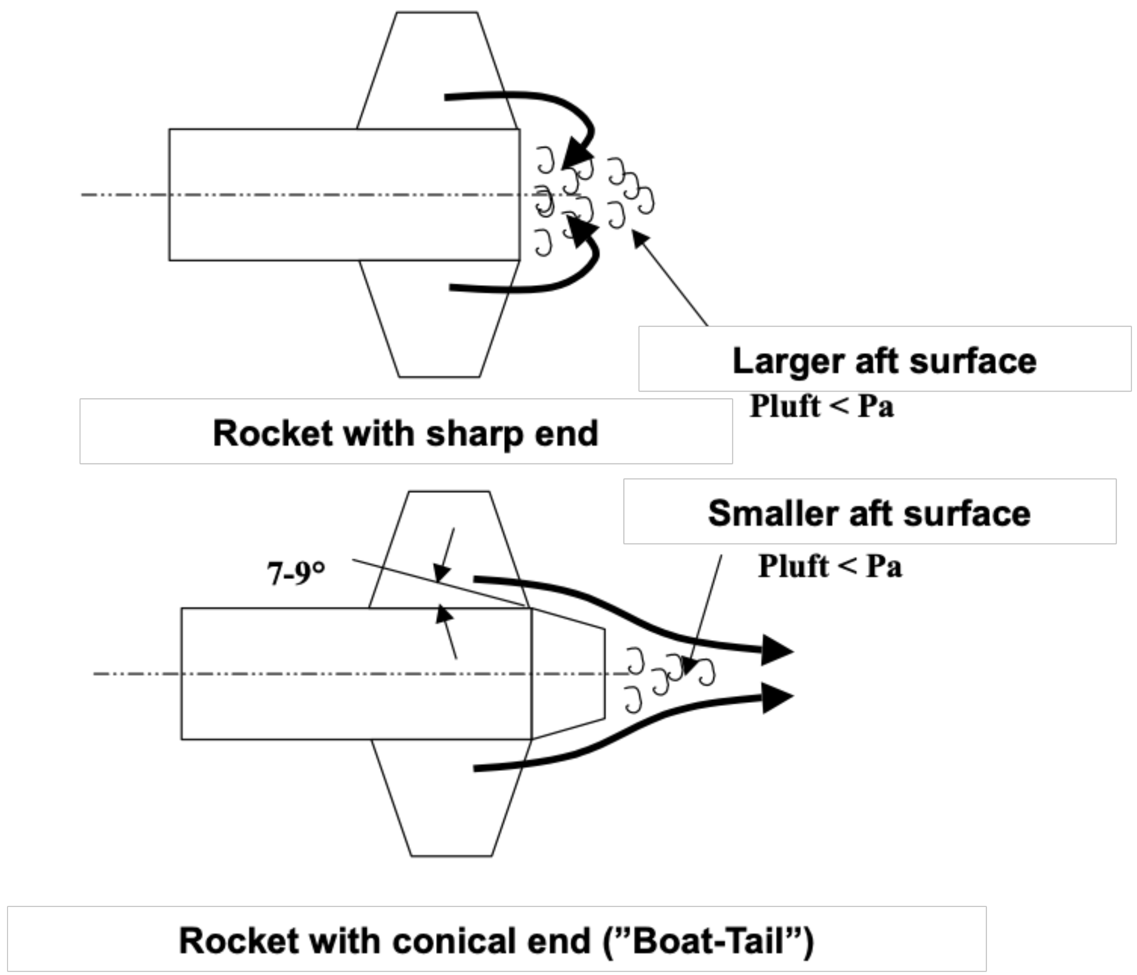
A symmetrical wing/fin will generate lift when | α > 0° |

A unsymmetrical fin / wing in an airflow will have excess pressure on the face with least surface (often on the side facing down) and low pressure on the opposite face with largest surface. The pressure difference is the lift.

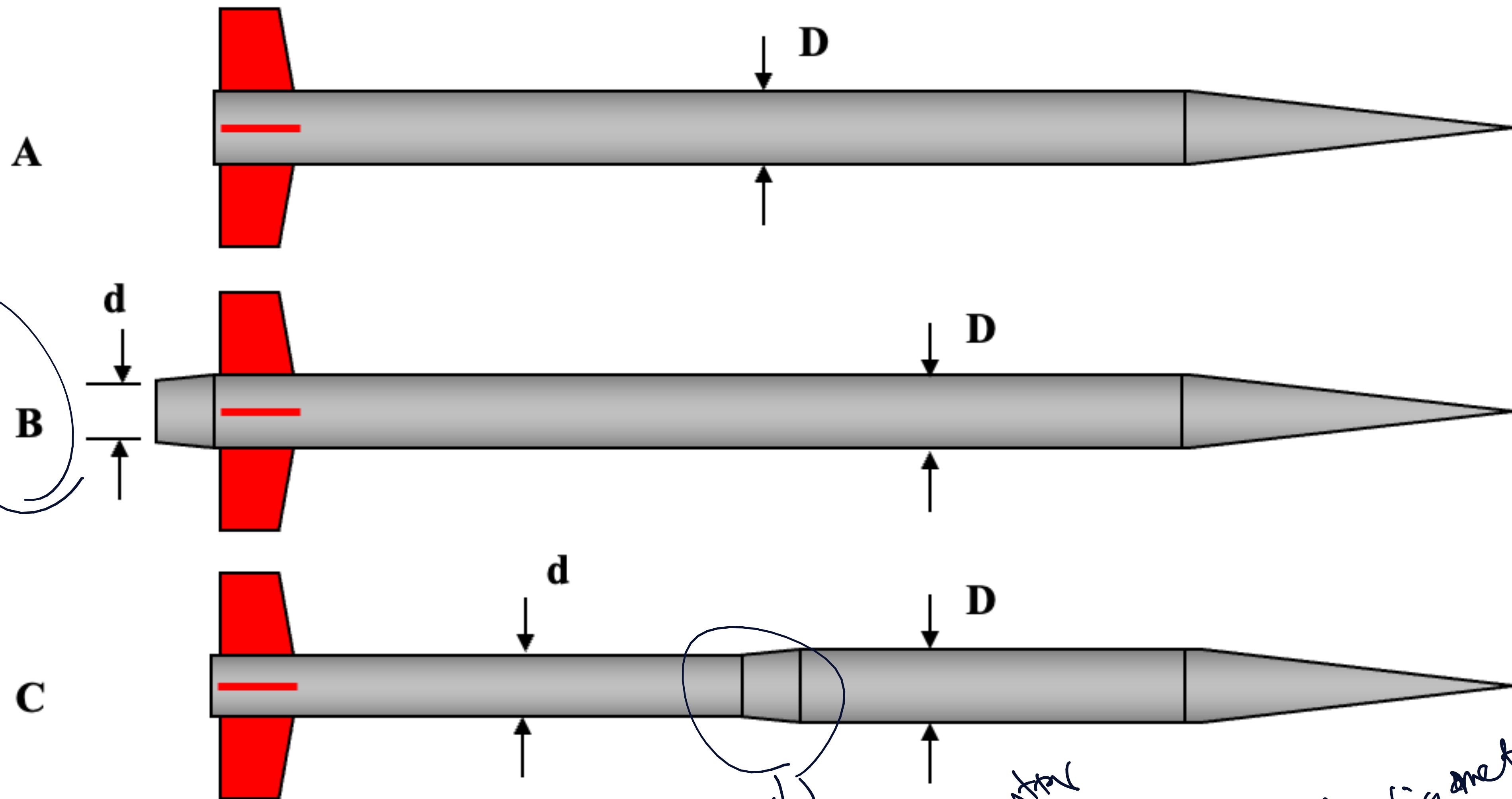
Po > Pu ⇒ Positive Lift



Drag Reduction



What Rocket Shape has the Highest Drag?

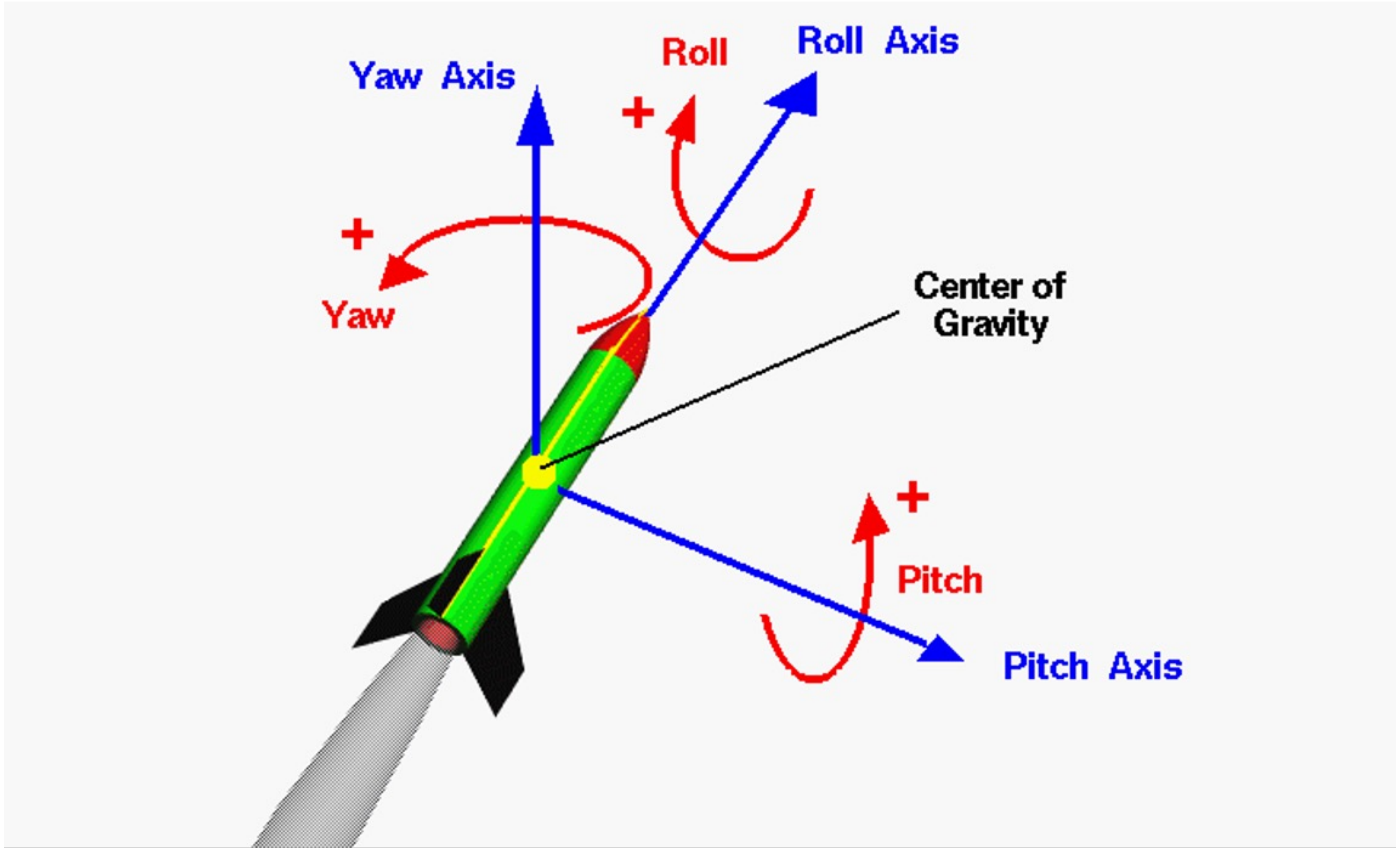


Stable

Doesn't matter

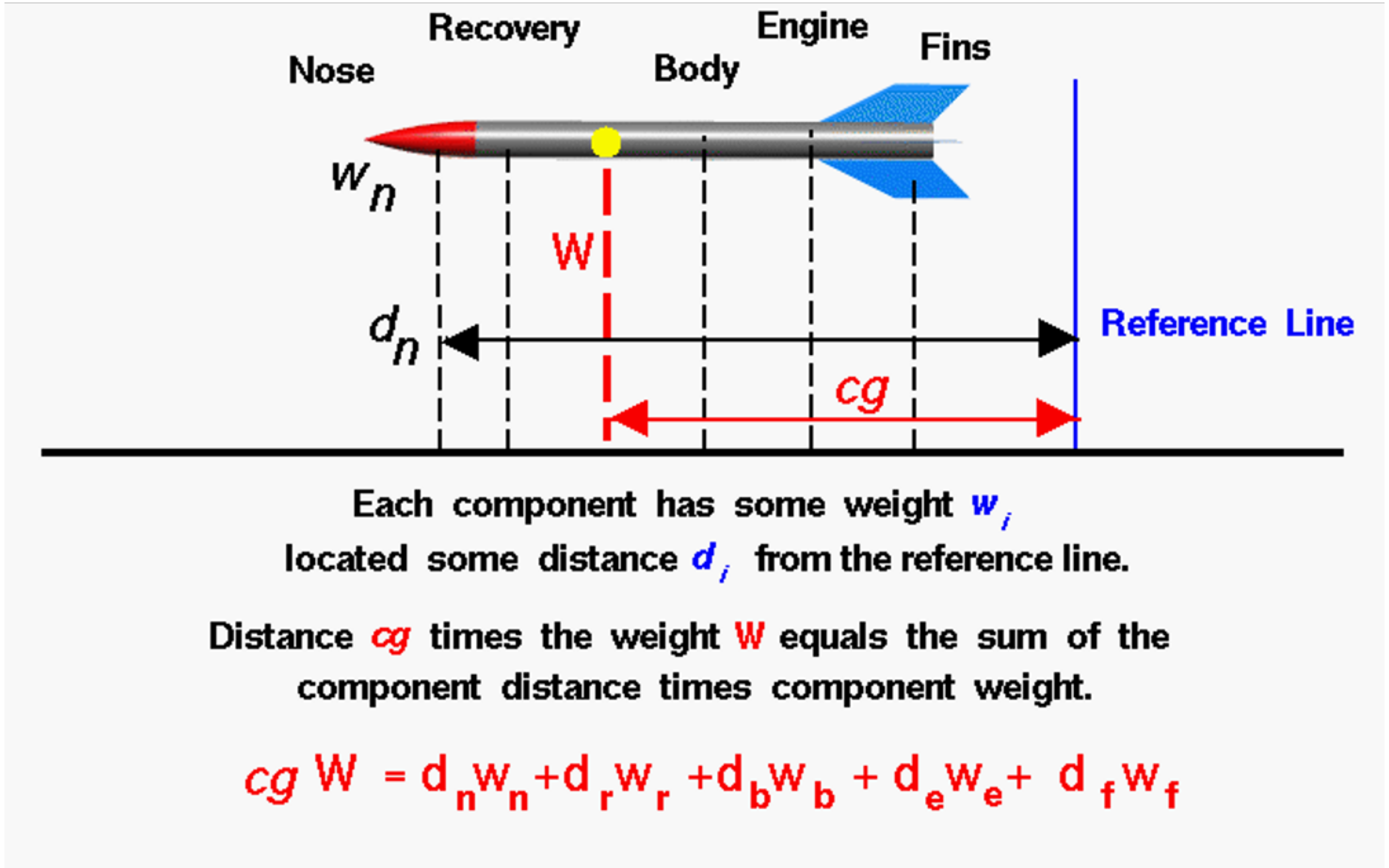
it's the biggest diameter that affects drag.

Axes

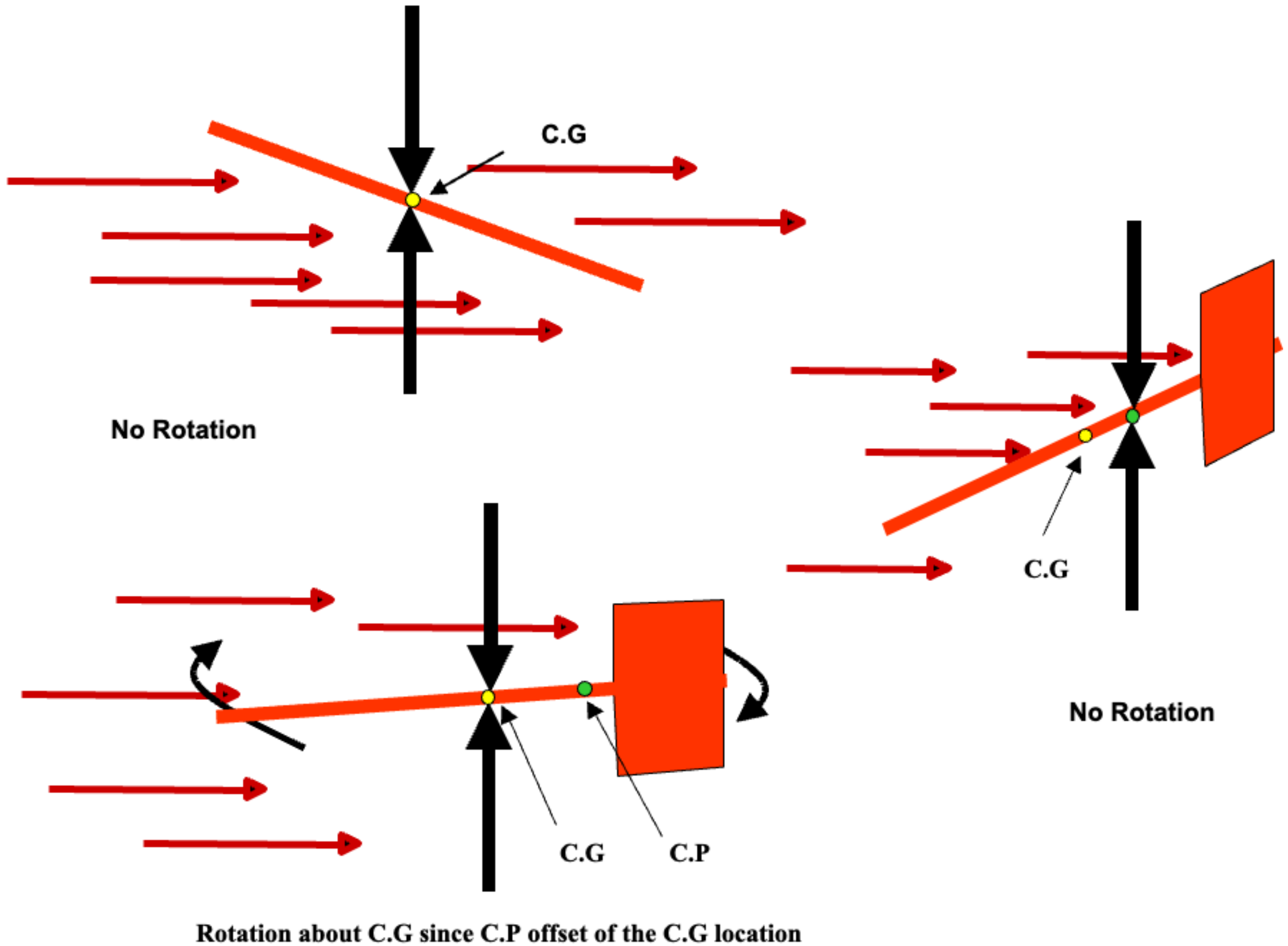


Yaw Axis
Roll
Roll Axis
+
+
Yaw
Center of Gravity
+
Pitch
Pitch Axis

Center of Gravity



Weathercock (Passive) Stability

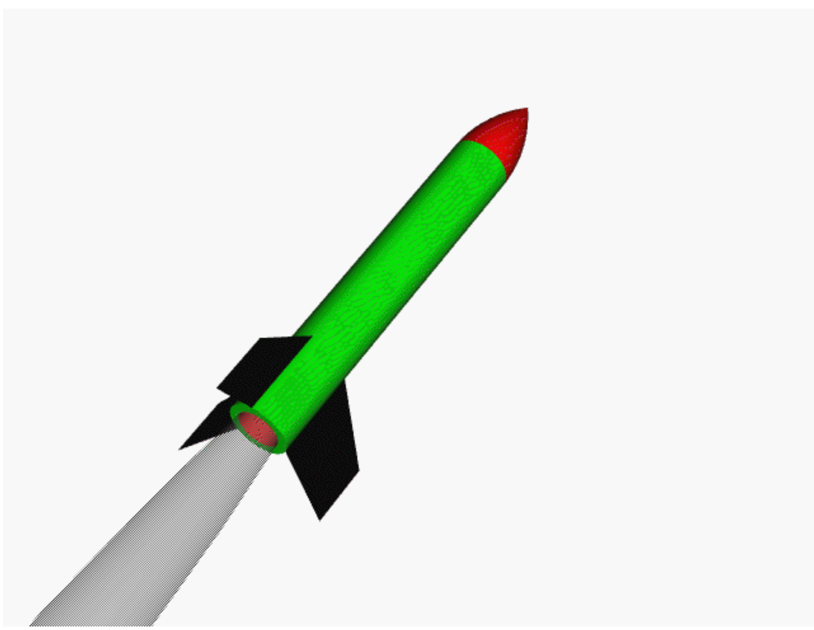


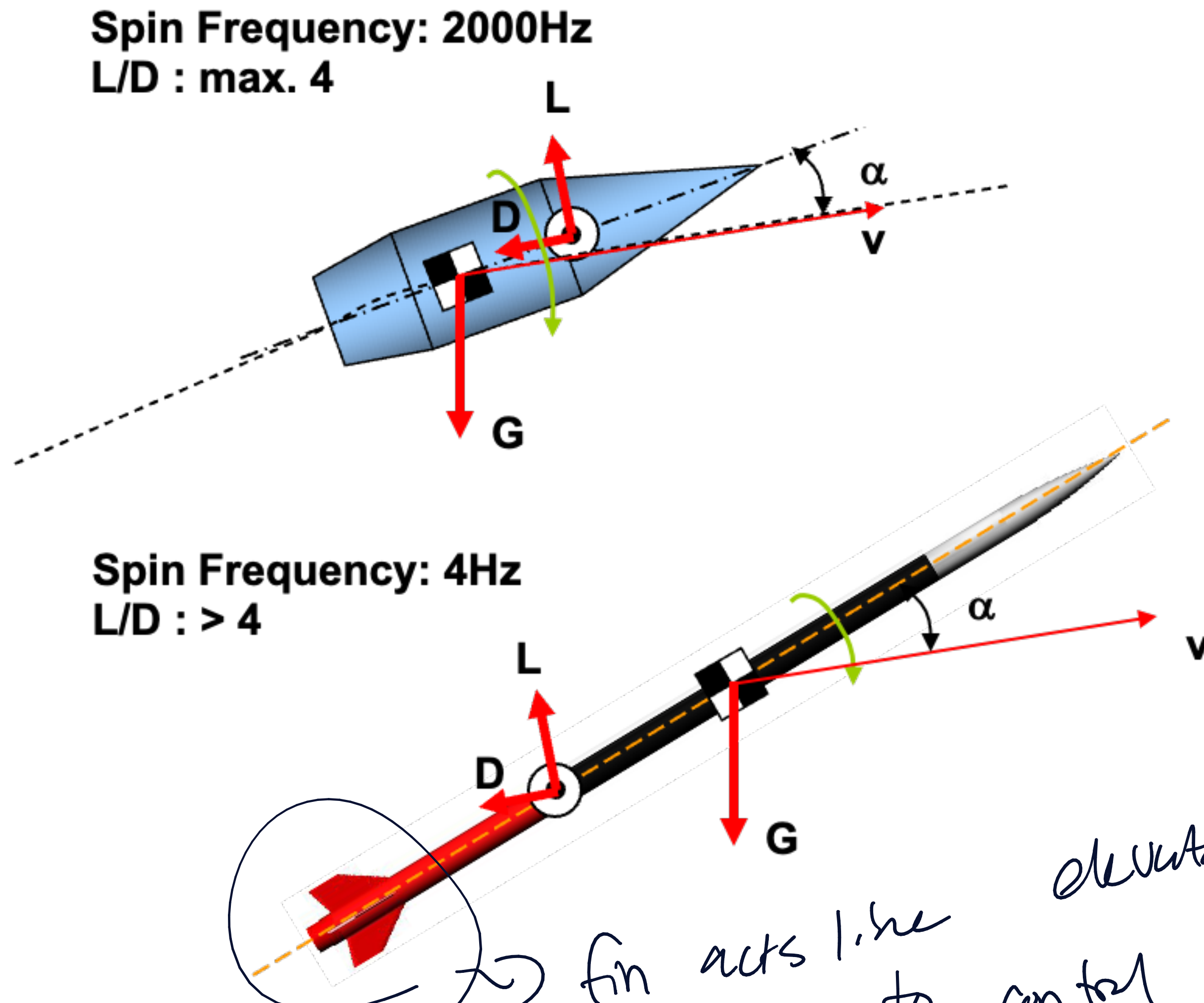
fins to provide weathercock stability.

Spin Stabilization

h is constant
w rt inertial space

Rocket body symmetry
helps





fin acts like elevators
to control α.

Cabin

what control scheme do you use?

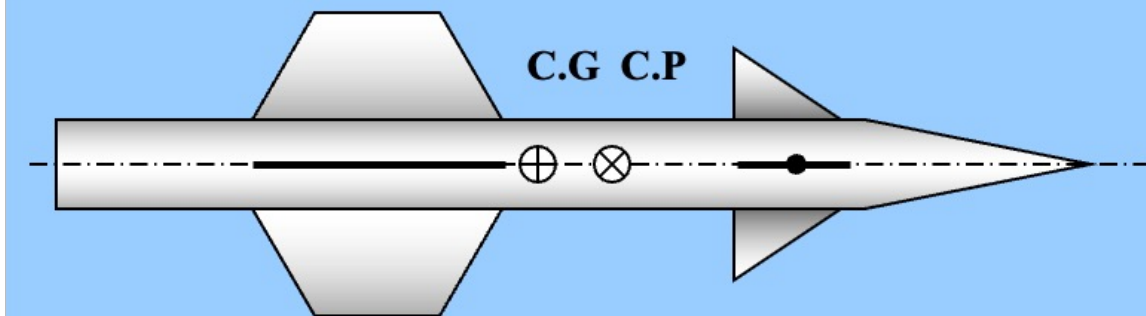
non minimum phase problem with rockets

Active Stabilization

Control

How good is my model? How fast is my feedback, good sensor, good actuator,

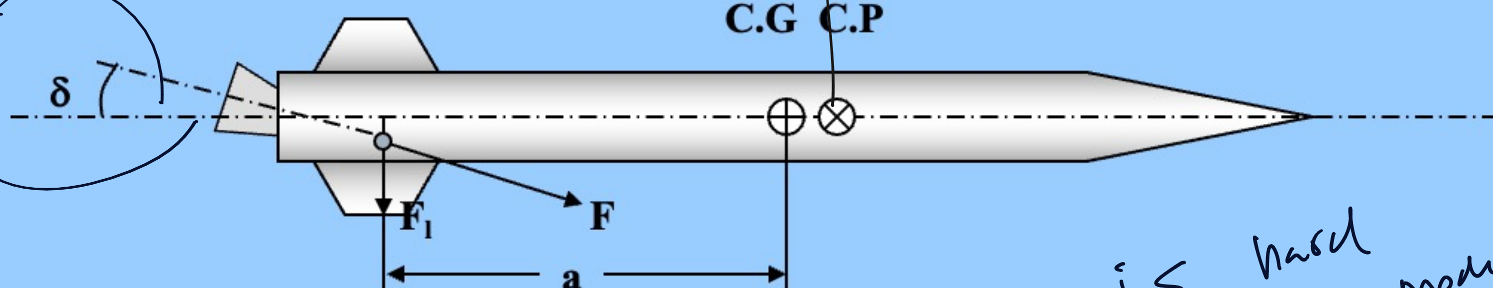
to keep CG in front of CP for con cone



gymbal faster

Naturally dynamic unstable, but maintained stable due to an automatic attitude system. Trajectory and stability can be maintained by moving servo controlled fins or by use of side thrusters. A thrust vectoring system (TVC) can also be used. A TVC system is a device that can change the thrust vector by changing the orientation of the nozzle or by deflecting the plume.

C.G can be moved back and forth during its flight



gymbal is hard
you need good model
it is a nonminimum phase system.

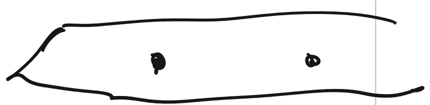
Thrust Vectoring

IRIS-T Air-To-Air Jet Vane TVC System

↑ SM = more stability

Static Margin = distance btwn CG and C.P. for this case

Neutral point: aerodynamic center
the pitch moment
due to α stays
constant

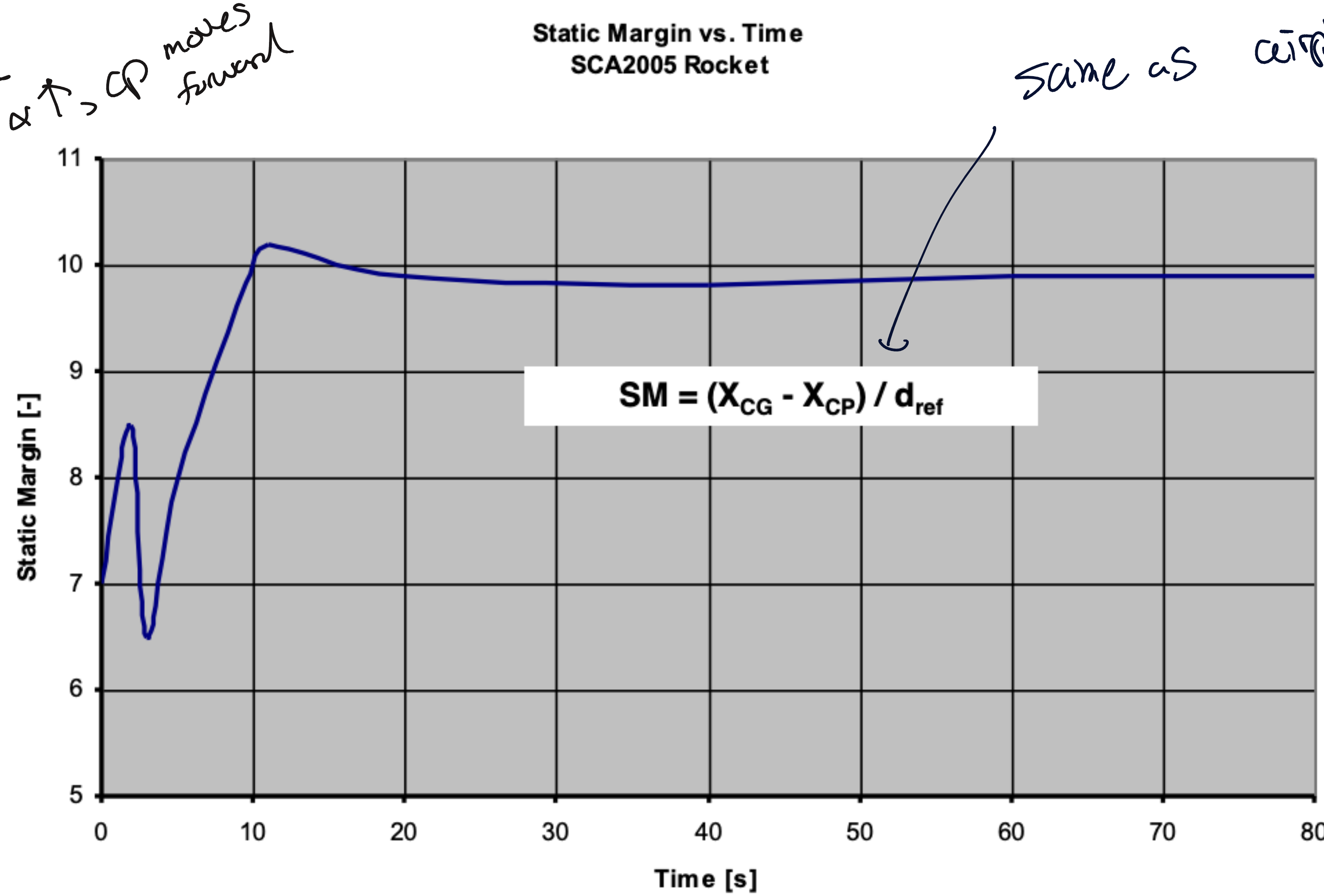


↳ as α ↑, CP moves forward

↳ we want this to move forward for stability

same as airplane

C.P. is where
L and D occurs

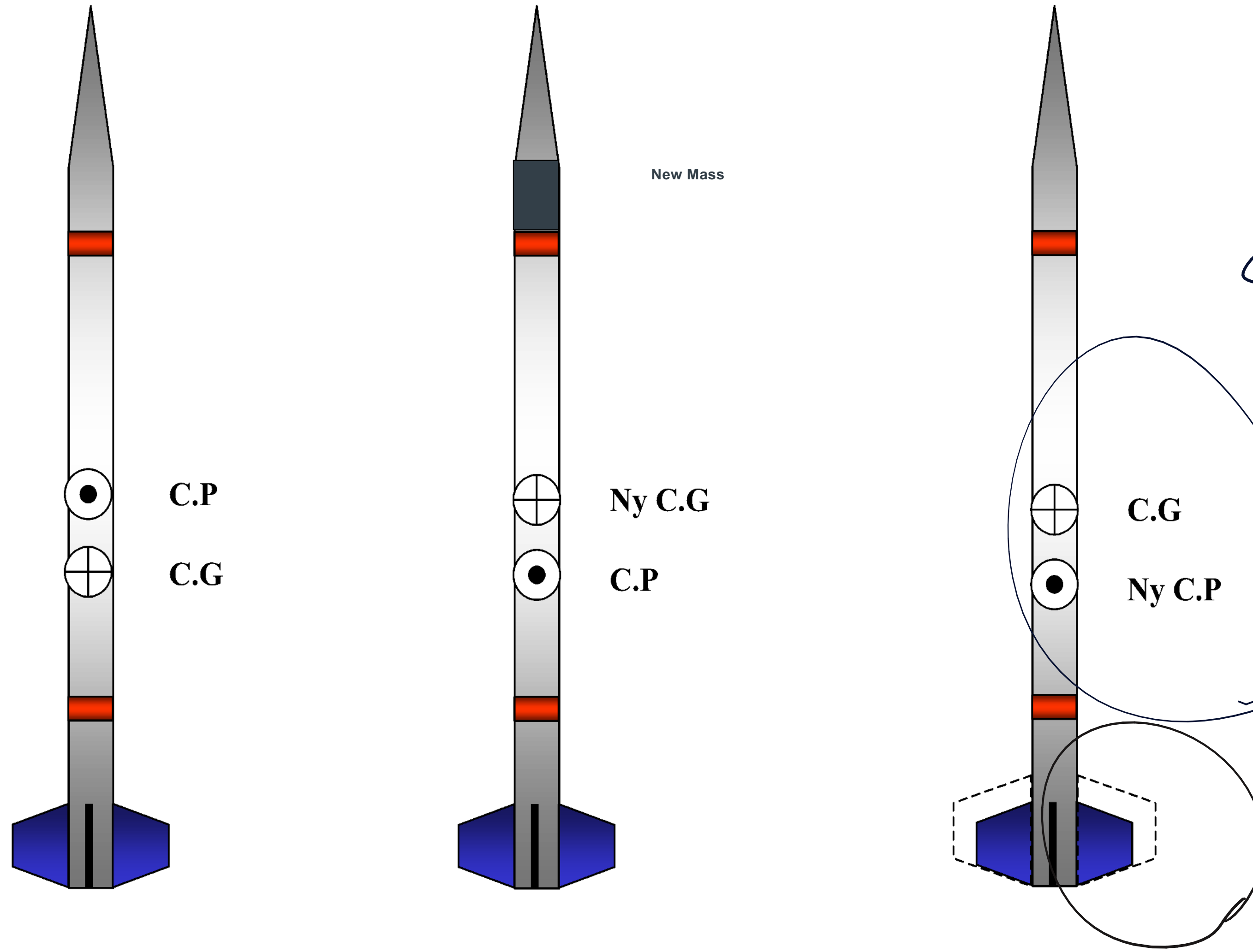


* This is showing how SM changes throughout its flight

a.c. is used for longitudinal stability.

Which of these are stable? And why?

More Weathercock stability means ↑ drag.



Stable

bigger fin shifts C.P. towards the tail this ↑ S.M.

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COMPUTING LOCATION OF THE CENTER OF PRESSURE

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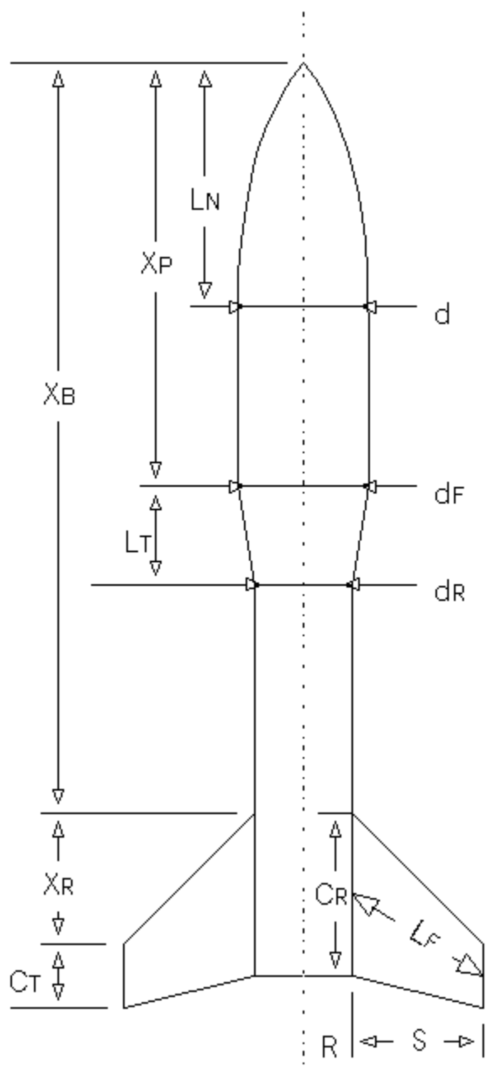
Barrowman Equations

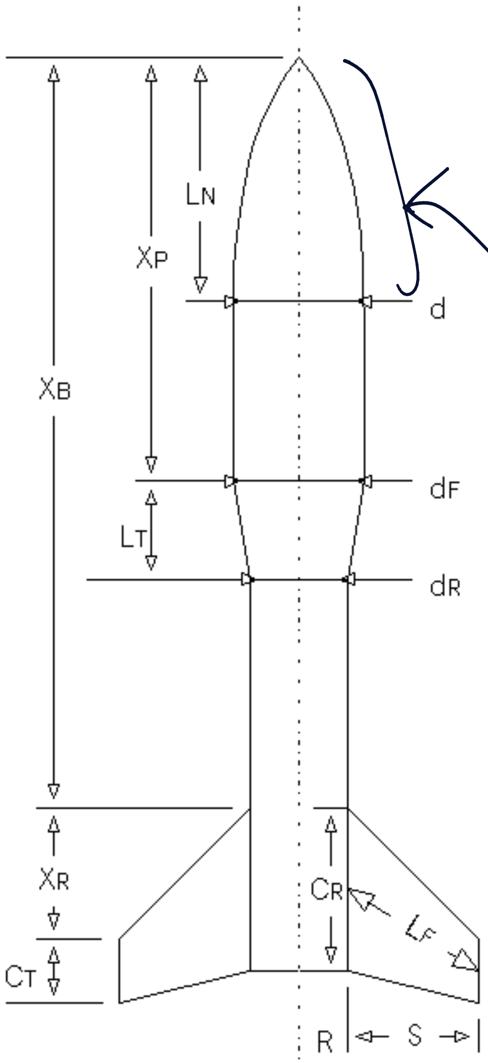
useful for C_p



L_N = length of nose
d = diameter at base of nose
d_F = diameter at front of transition
d_R = diameter at rear of transition
L_T = length of transition
X_P = distance from tip of nose to front of transition
C_R = fin root chord
C_T = fin tip chord
S = fin semispan
L_F = length of fin mid-chord line
R = radius of body at aft end
X_R = distance between fin root leading edge and fin tip leading edge parallel to body
X_B = distance from nose tip to fin root chord leading edge
N = number of fins

Barrowman Equations

good estimate of Cp



this shape

$$\bar{X} = \frac{(C_N)_N X_N + (C_N)_T X_T + (C_N)_F X_F}{(C_N)_R}$$

OML
outer Mold line

NOSE

$(C_N)_N = 2$
For Cone: $X_N = 0.666L_N$
For Ogive: $X_N = 0.466L_N$

ogive

TRANSITION

$$(C_N)_T = 2\left[\left(\frac{d_R}{d}\right)^2 - \left(\frac{d_F}{d}\right)^2\right]$$

$$X_T = X_P + \frac{L_T}{3}\left[1 + \frac{1 - \frac{d_F}{d_R}}{1 - \left(\frac{d_F}{d_R}\right)^2}\right]$$

FIN

$$(C_N)_F = \left[1 + \frac{R}{S+R}\right]\left[\frac{4N\left(\frac{S}{d}\right)^2}{1 + \sqrt{1 + \left(\frac{2L_F}{C_R + C_T}\right)^2}}\right]$$

$$X_F = X_B + \frac{X_R}{3}\frac{(C_R + 2C_T)}{(C_R + C_T)} + \frac{1}{6}\left[(C_R + C_T) - \frac{(C_R C_T)}{(C_R + C_T)}\right]$$

Dutch Roll

Lateral stability > directional stability

As the airplane rolls to the right, there is sideslip toward lower wing, there is more lift on the right wing to restore its roll, but at the same time there is more drag on the right wing too, causing yawing to the right. Weaker directional stability attempts to restore the yaw, while roll overshoots to the left again.

p and r are out of phase of each other.

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Spiral: Directional > lateral

1. Gust from right
2. causes yaw to the left "Nose to the left" "right sideslip"
3. More lift on right wing since you get more direct wind on the right wing than left wing.
4. Now this rolls airplane to the left

5. Strong directional stability returns airplane to its original direction but airplane is still rolled to the left. Weak lateral stability doesn't allow the airplane to recover its roll
6. yawing back to its original direction