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

JOHN-PAUL CLARKE
Ernest Cockrell, Jr. Memorial Chair in Engineering, The University of Texas at Austin

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

JOHN-PAUL CLARKE
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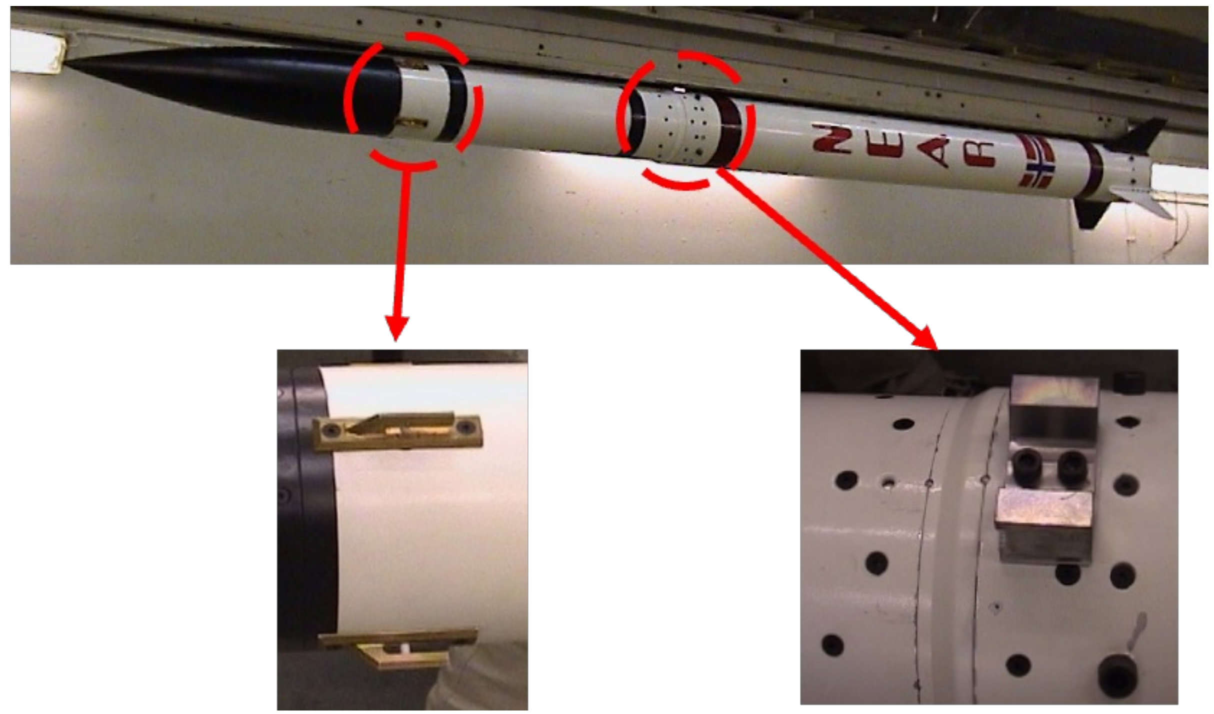
What Affects Aerodynamic Drag?

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



Air Flow Around Objects

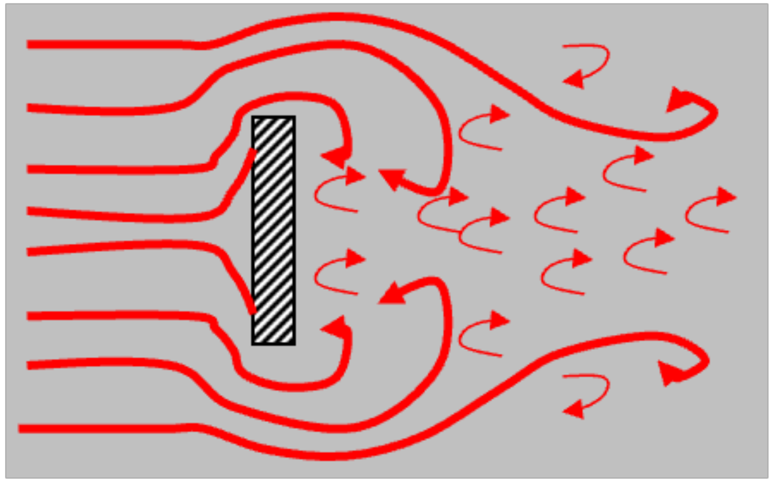
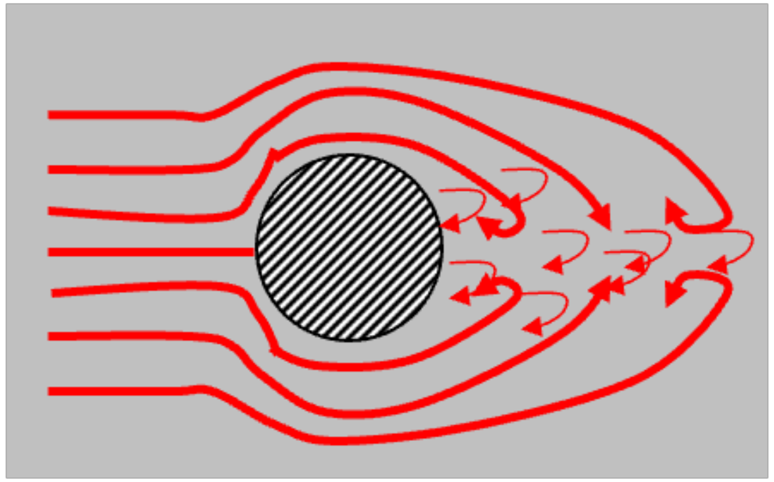
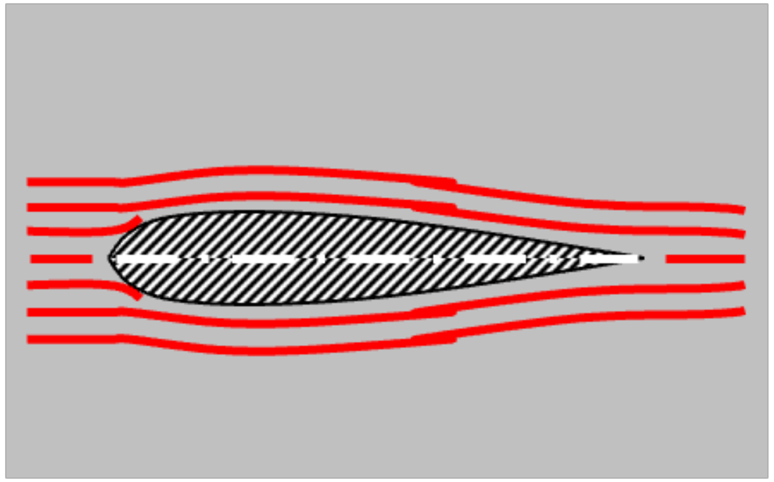


Plate - Induce large resistance

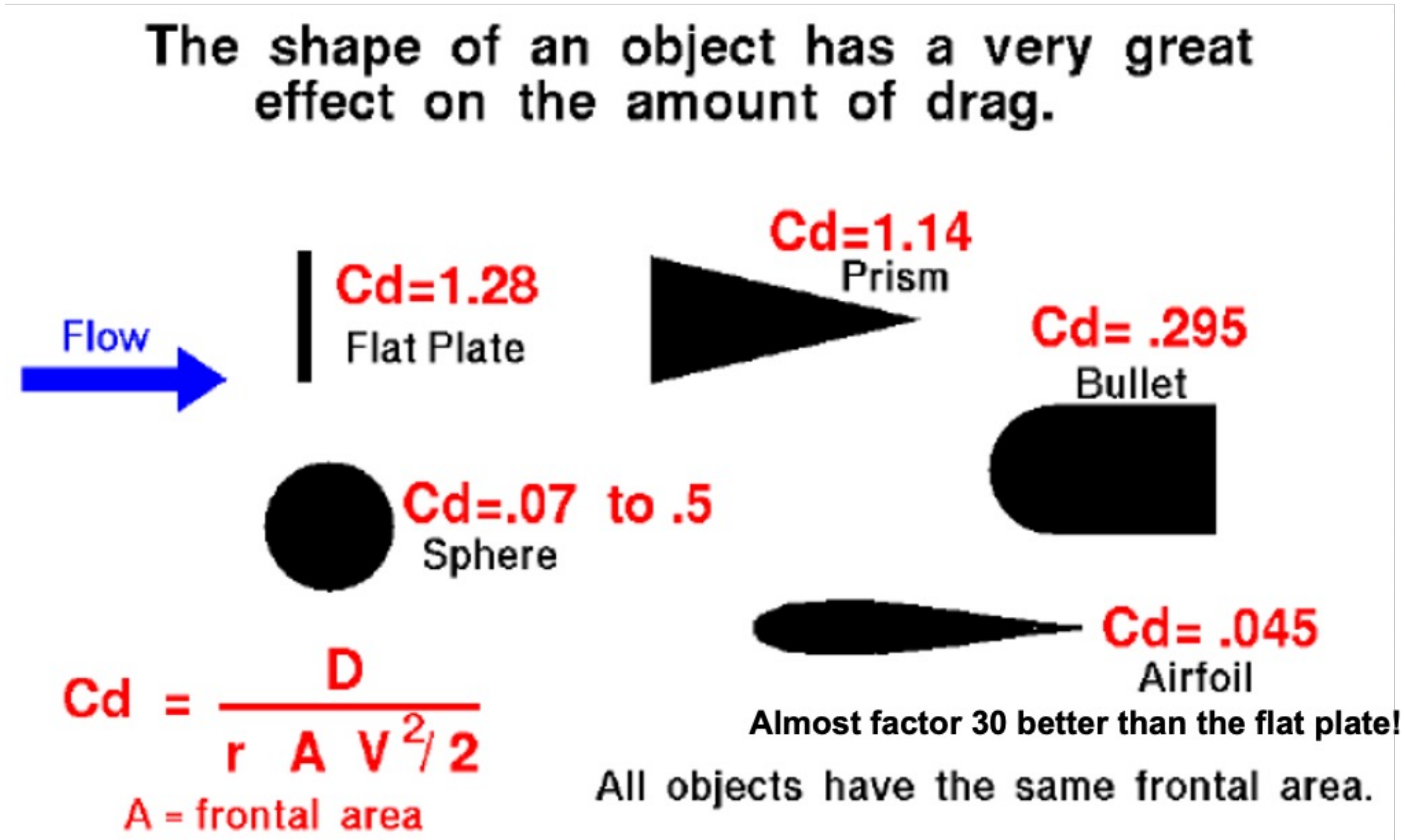


Cylindrical Rod - Lower resistance



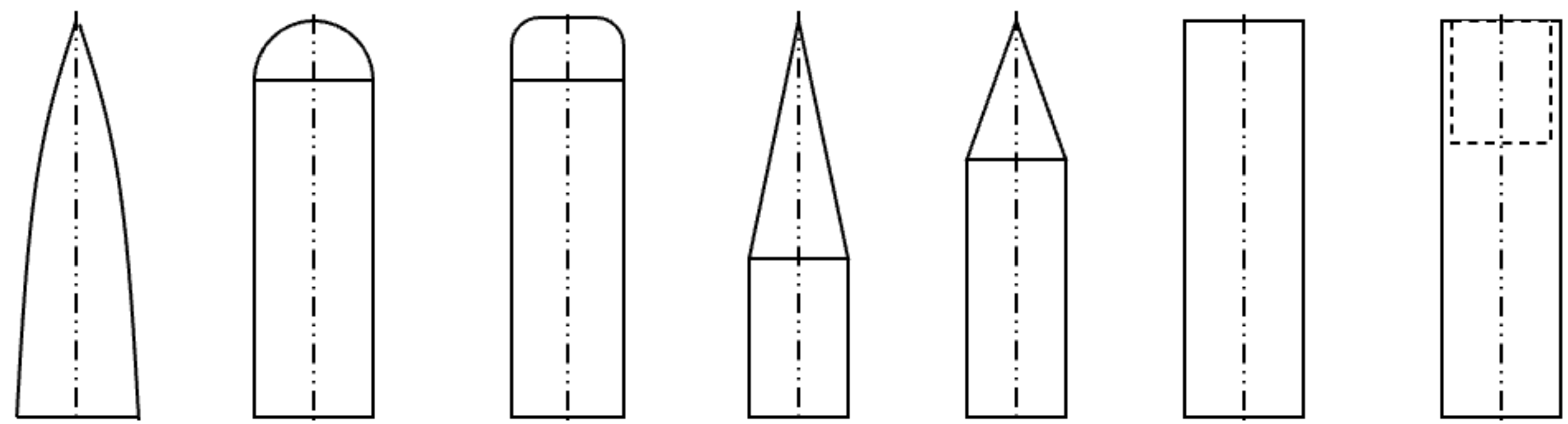
Symmetrical wing profile (Alpha = 0 °) - Least resistance

Air Flow Around Objects



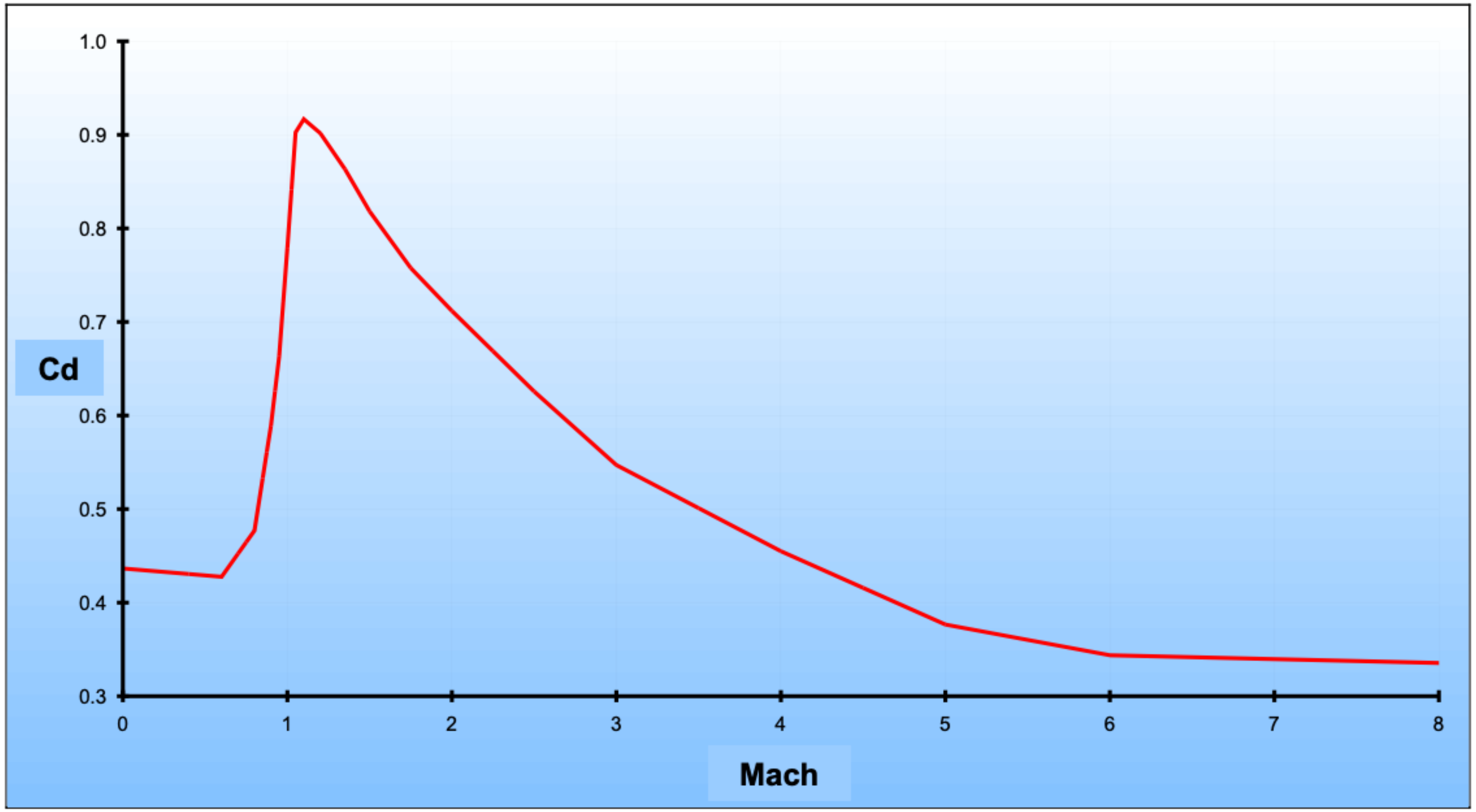
Drag Coefficients for Various Noses

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

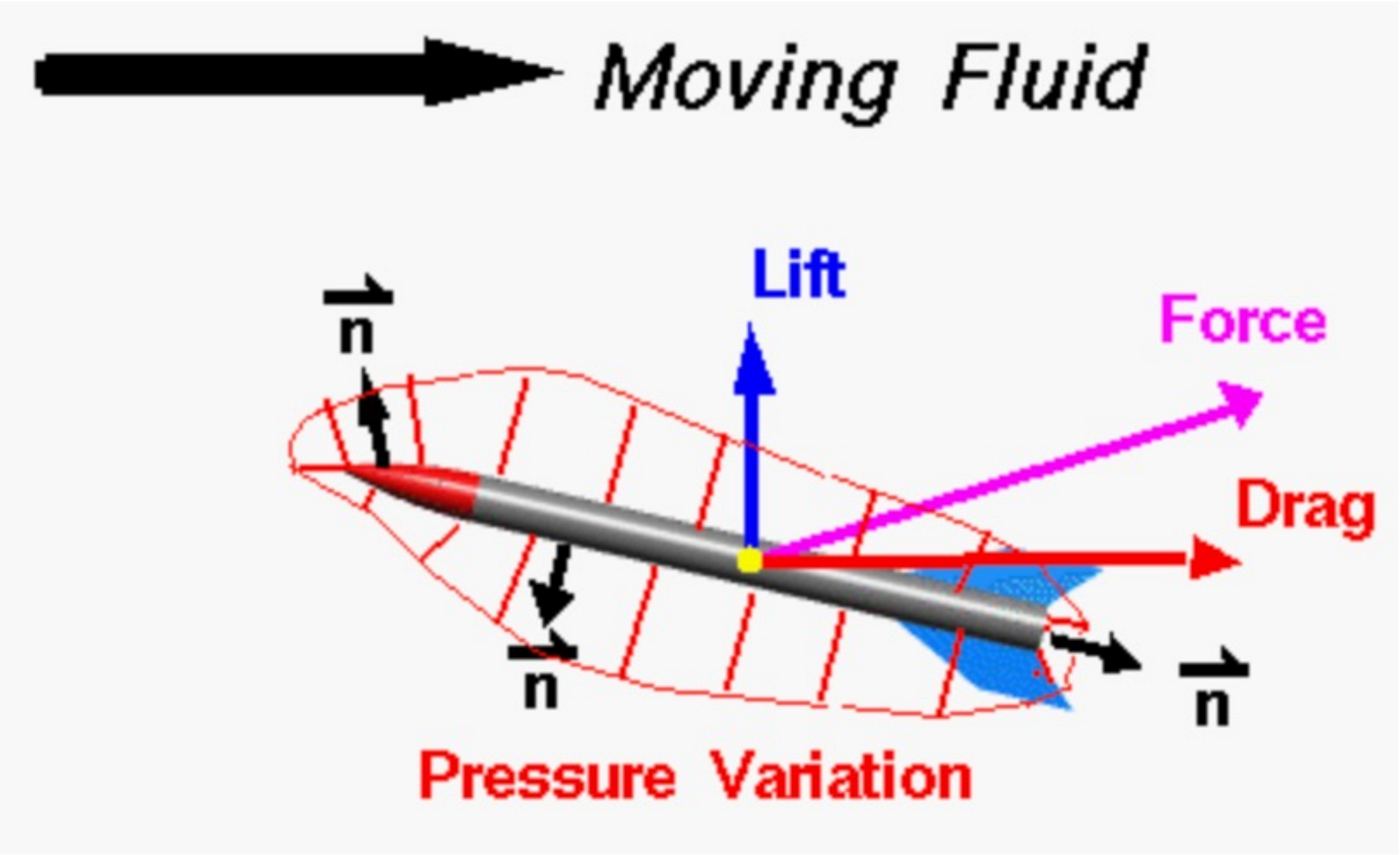


Cd:	**<0.05**	**>0.01**	**0.20**	**0.20**	**0.34**	**0.90**	**1.00**
	4:1			**3:1**	**1:1**		

Drag Coefficient v. Mach Number



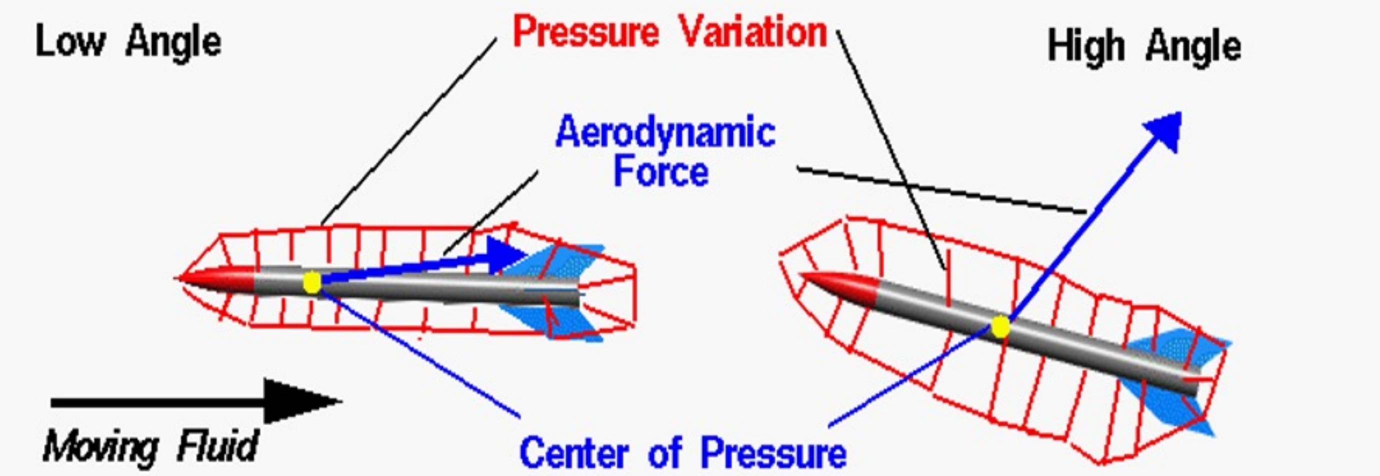
Aerodynamic Forces



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

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

Center of Pressure



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

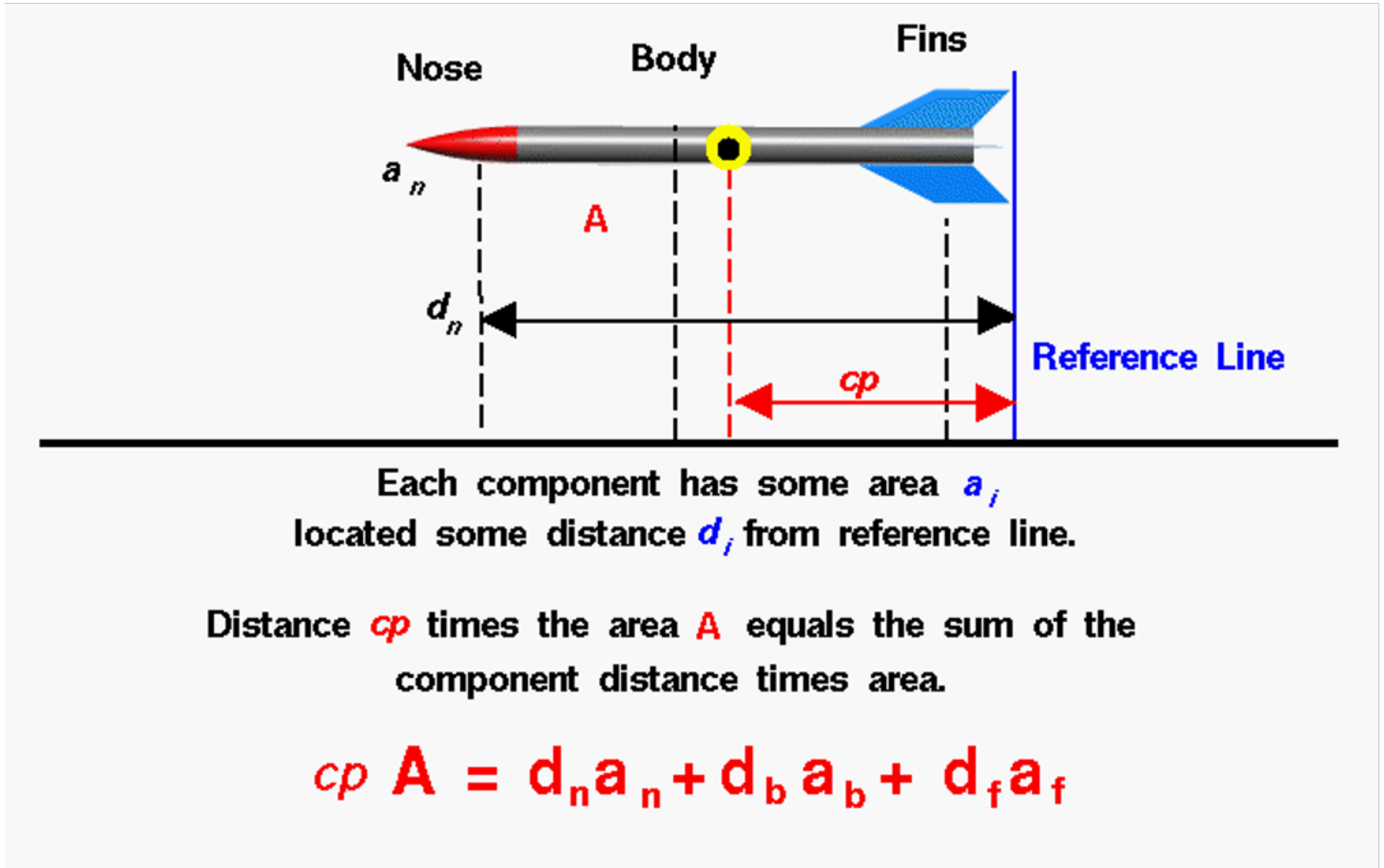
$$\boxed{C_P = \frac{\int x \cdot p(x) \cdot dx}{\int p(x) \cdot dx}}$$

Aerodynamic force acts through the center of pressure.

Center of pressure moves with angle of attack.

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

Center of Pressure



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

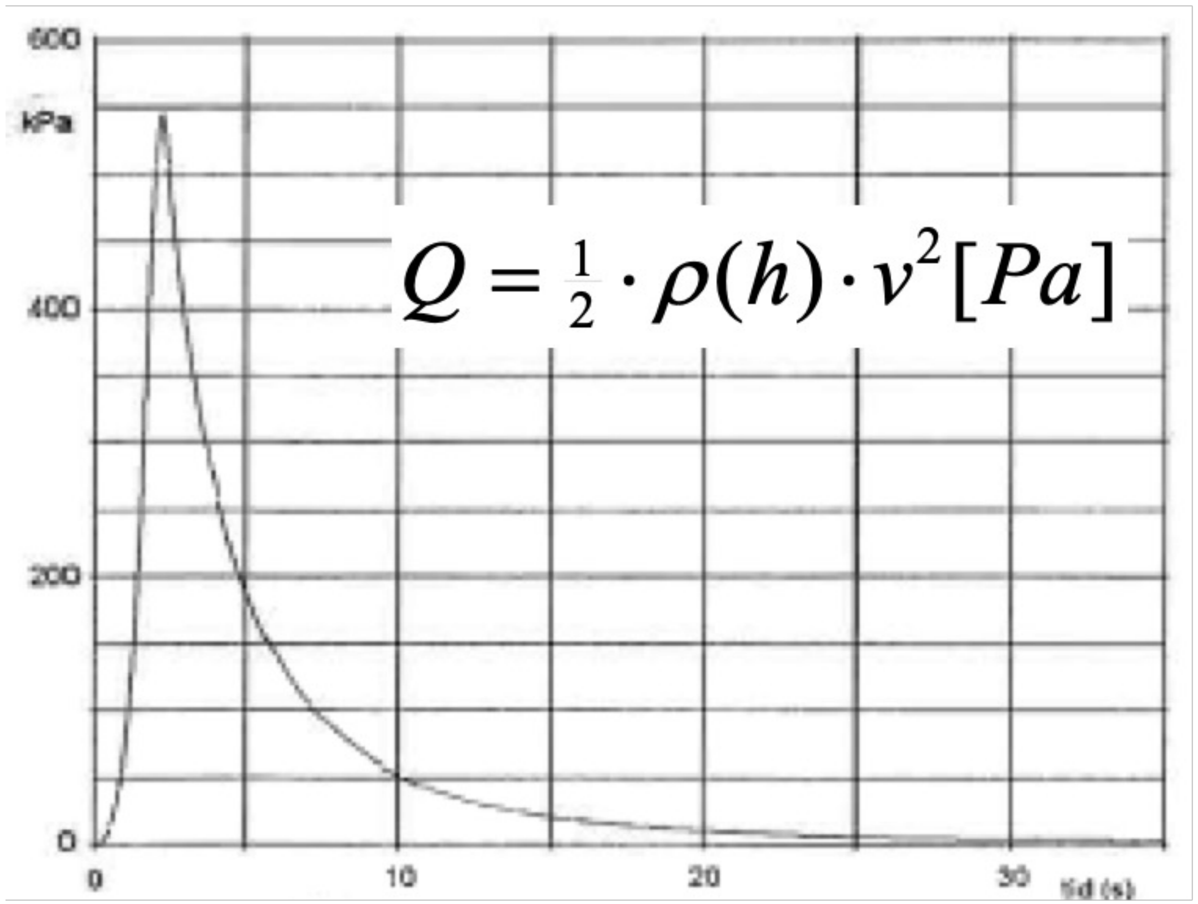
Rocket Drag Equation

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

Dynamic Pressure

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 $1.23 kg/m^3$ for air at sea-level).
v	: Rocket speed

Dynamic Load



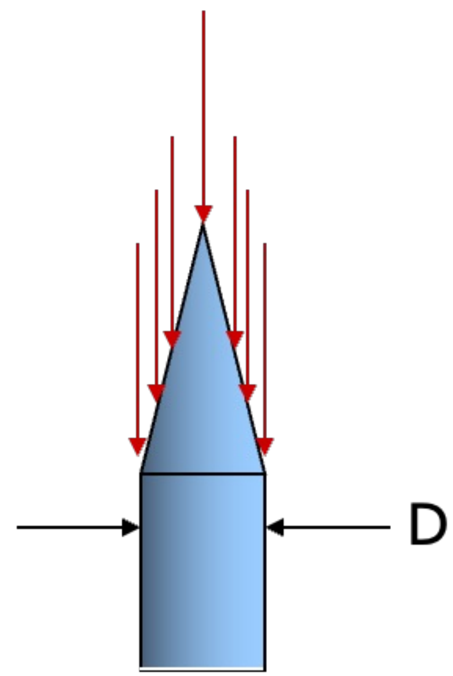
$$Q = \frac{1}{2} \cdot \rho(h) \cdot v^2 [Pa]$$

Student Rocket:

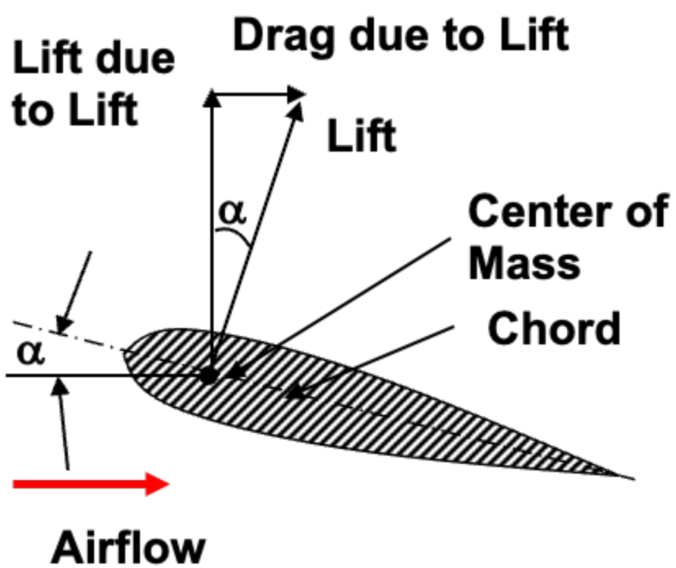
D=ø70mm➔0.07m

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

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



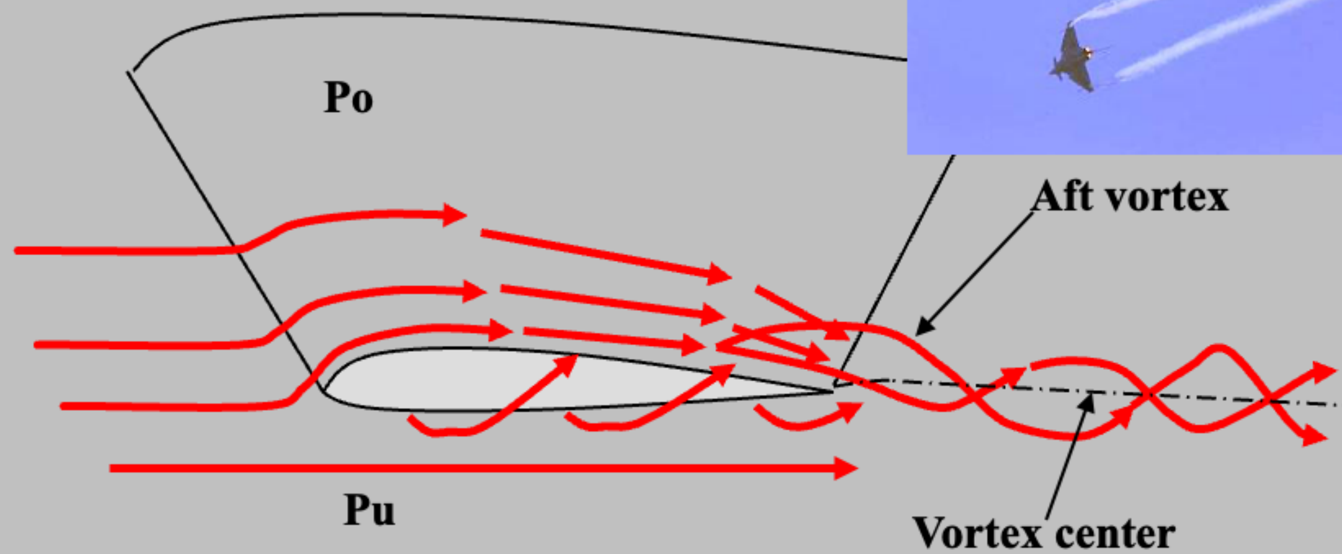
Induced Drag



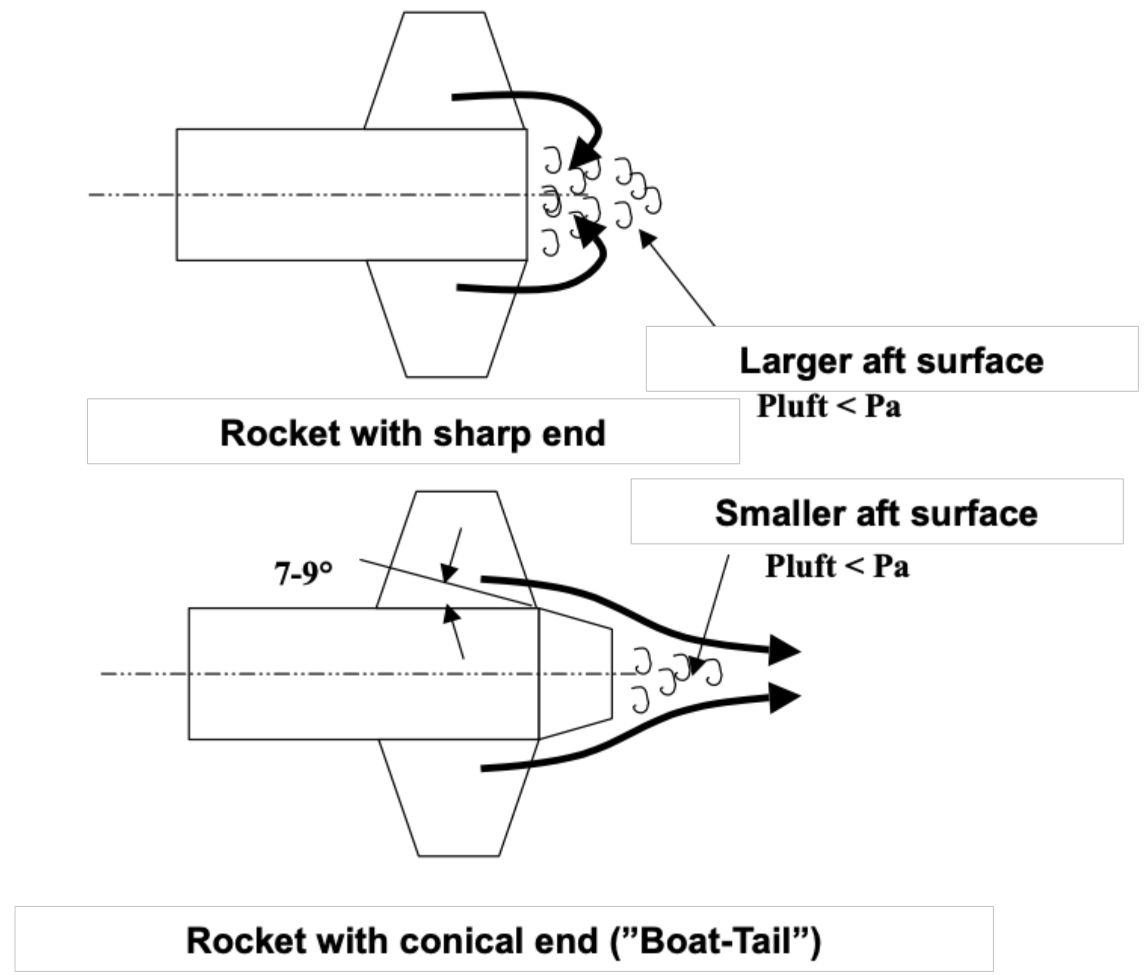
A symmetrical wing/fin will generate lift when | α > 0° |

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.

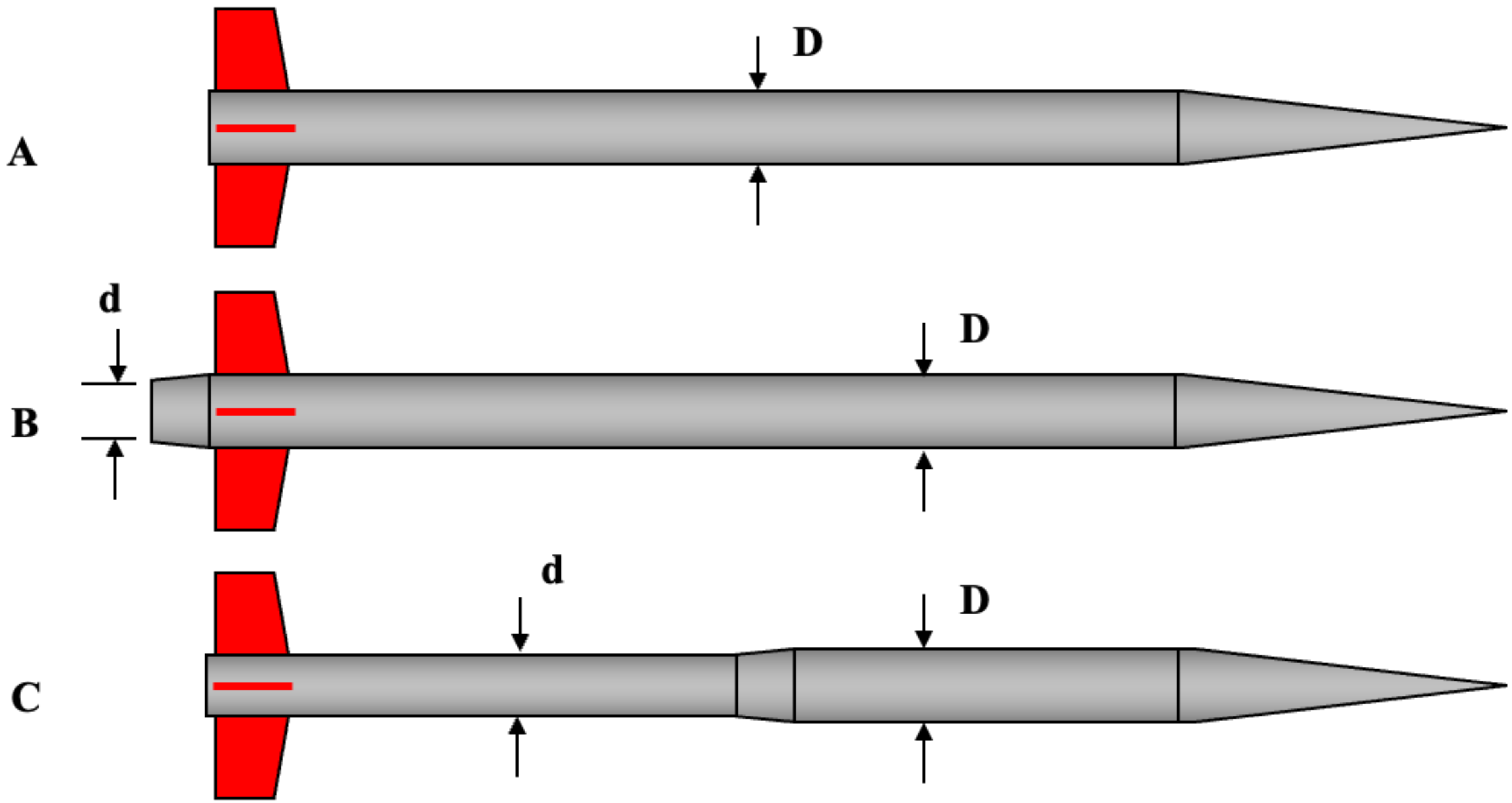
Po > Pu ⇒ Positive Lift



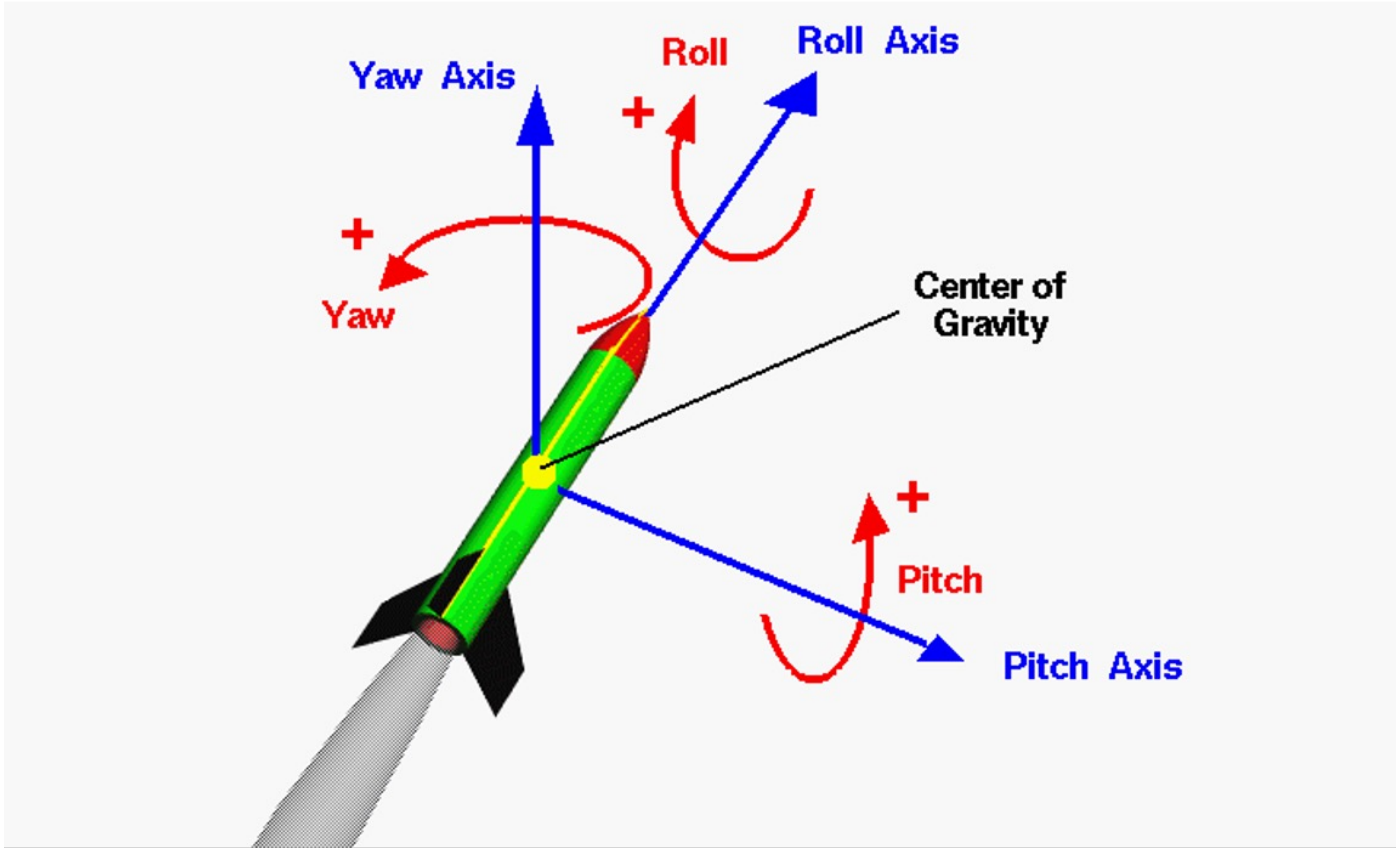
Drag Reduction



What Rocket Shape has the Highest Drag?

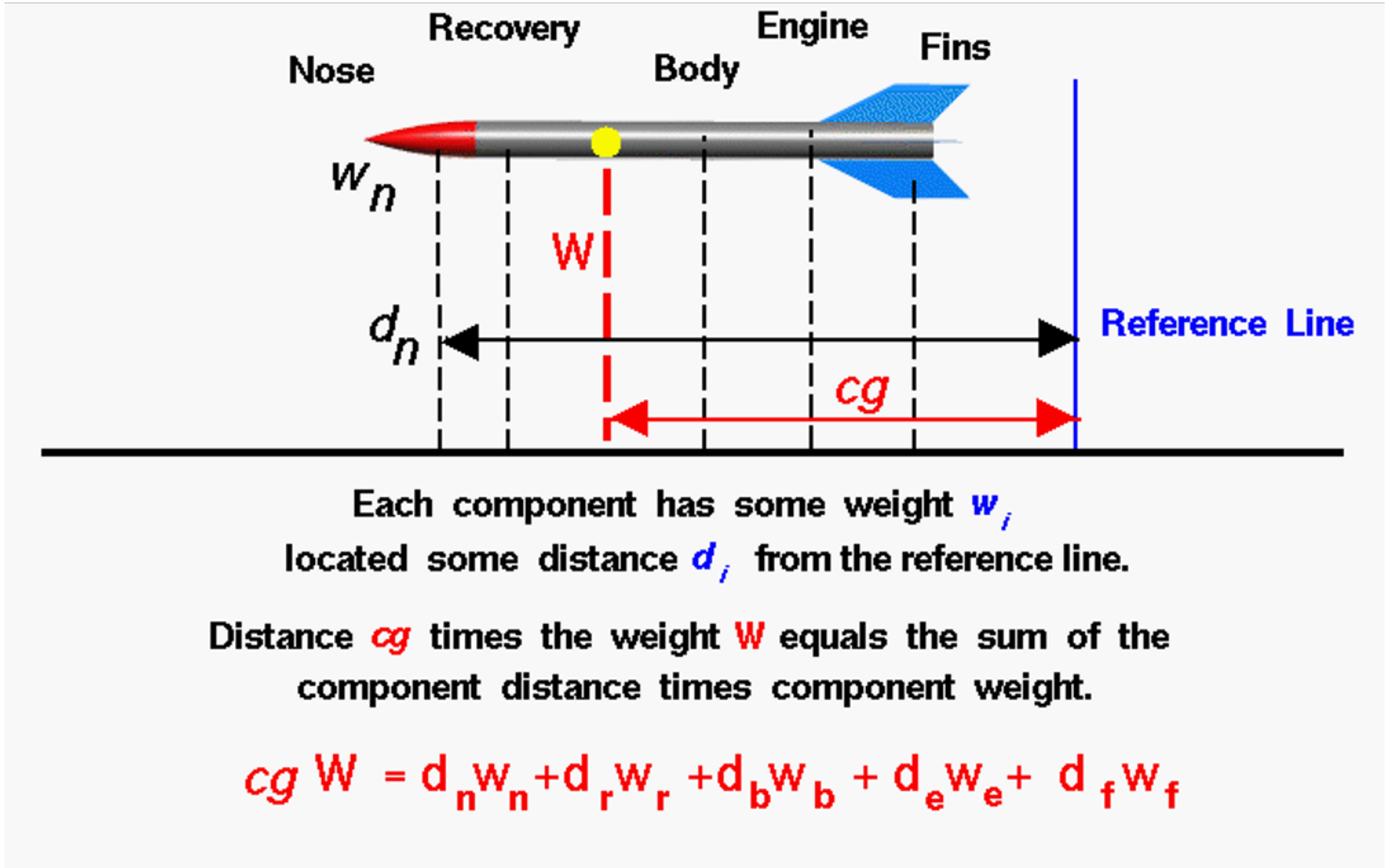


Axes

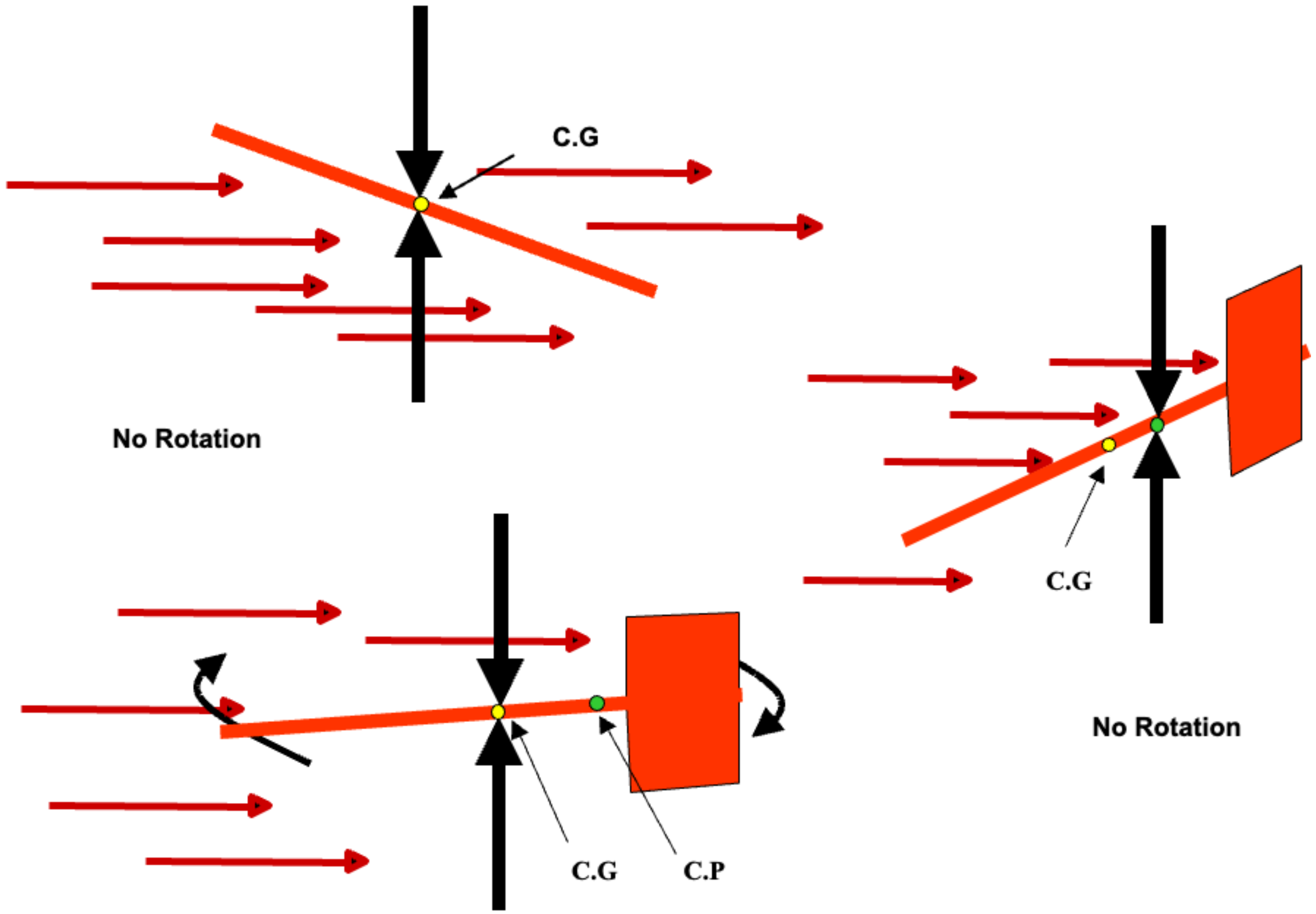


Yaw Axis
Roll
Roll Axis
+
+
Yaw
Center of
Gravity
+
Pitch
Pitch Axis

Center of Gravity

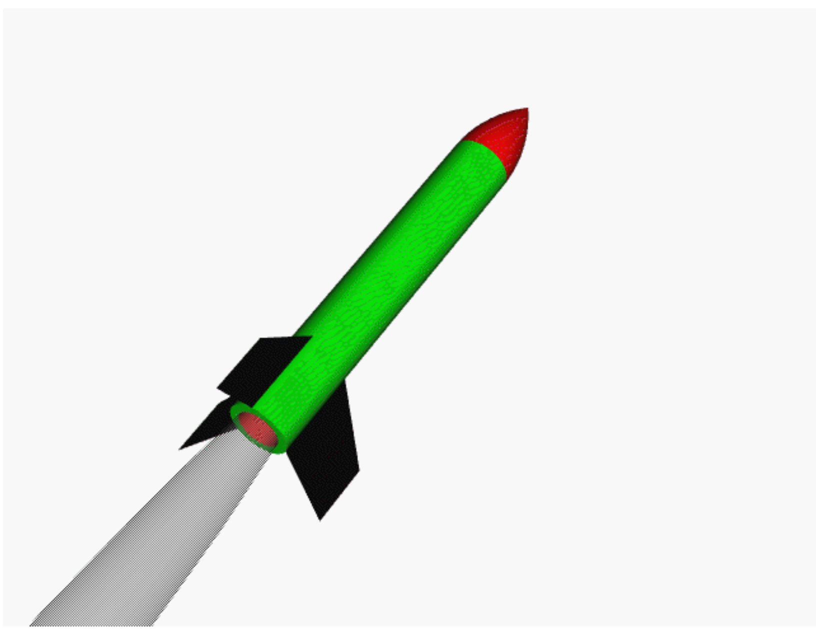


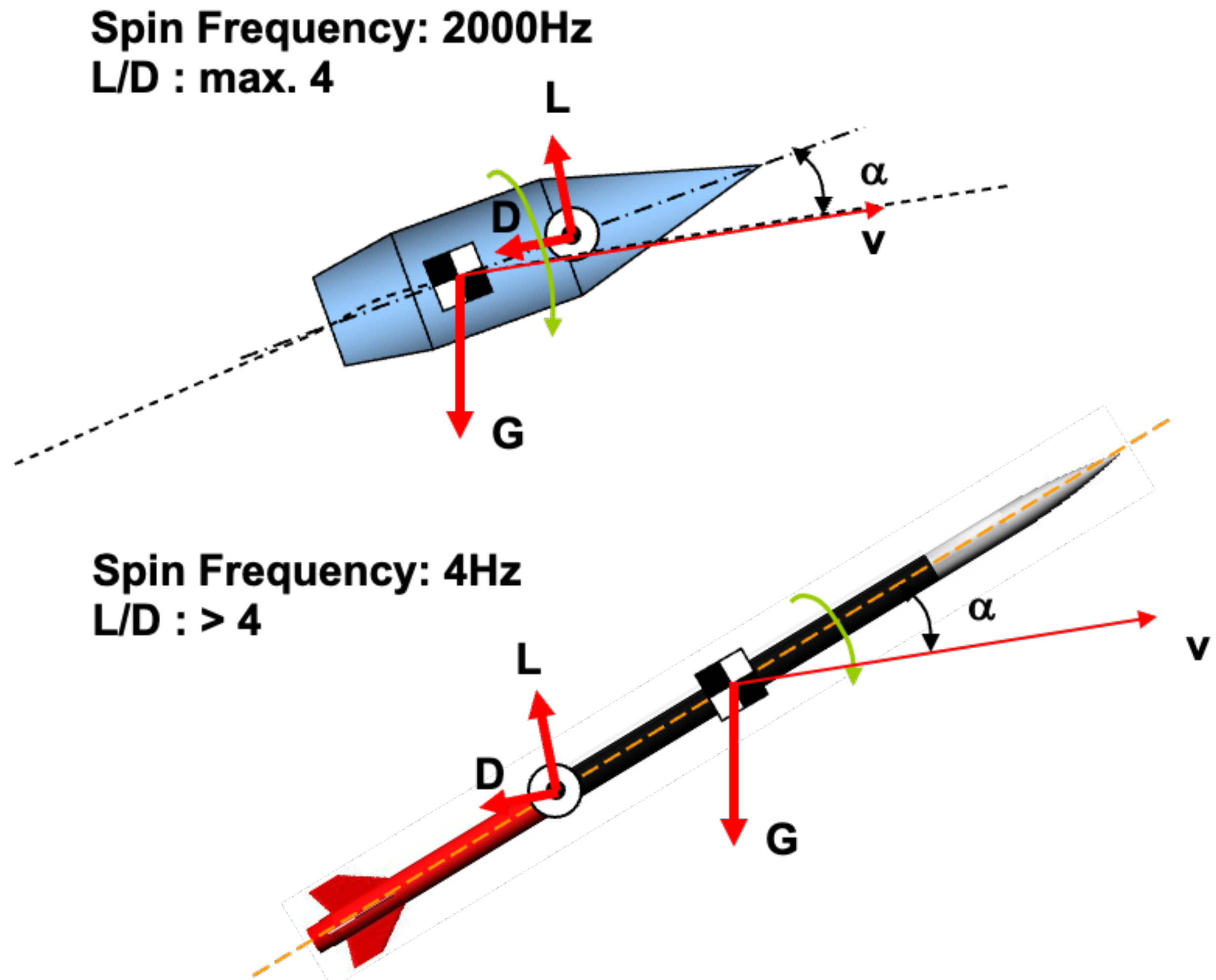
Weathercock (Passive) Stability



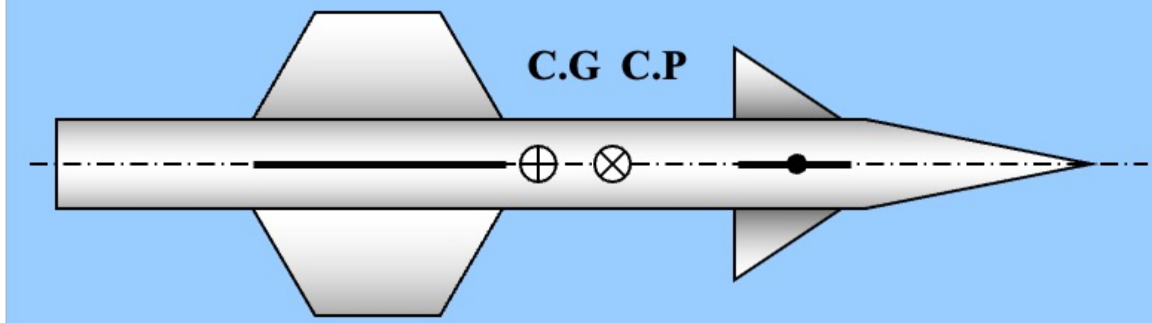
Rotation about C.G since C.P offset of the C.G location

Spin Stabilization

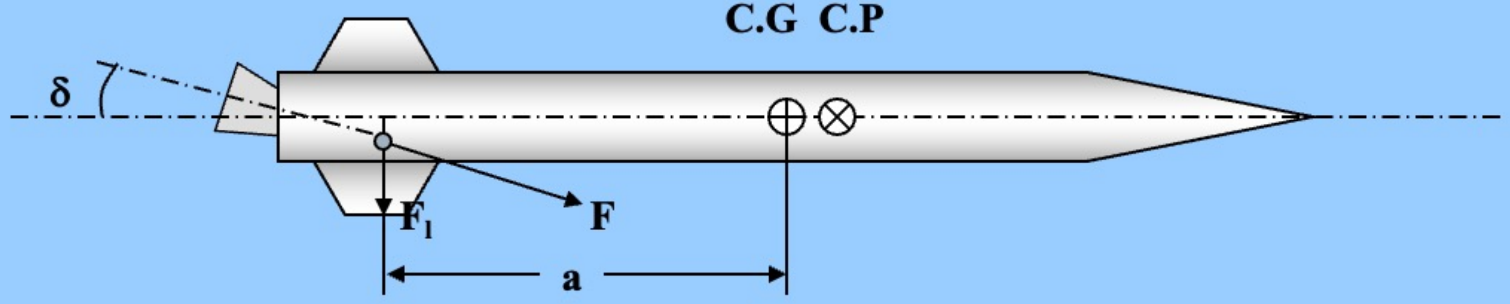


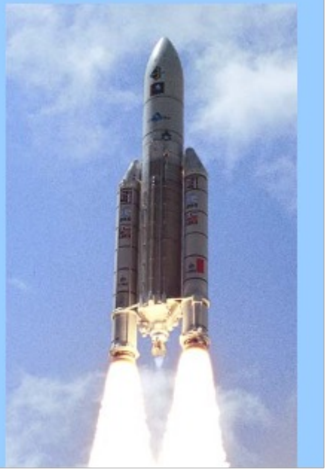


Active Stabilization



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.

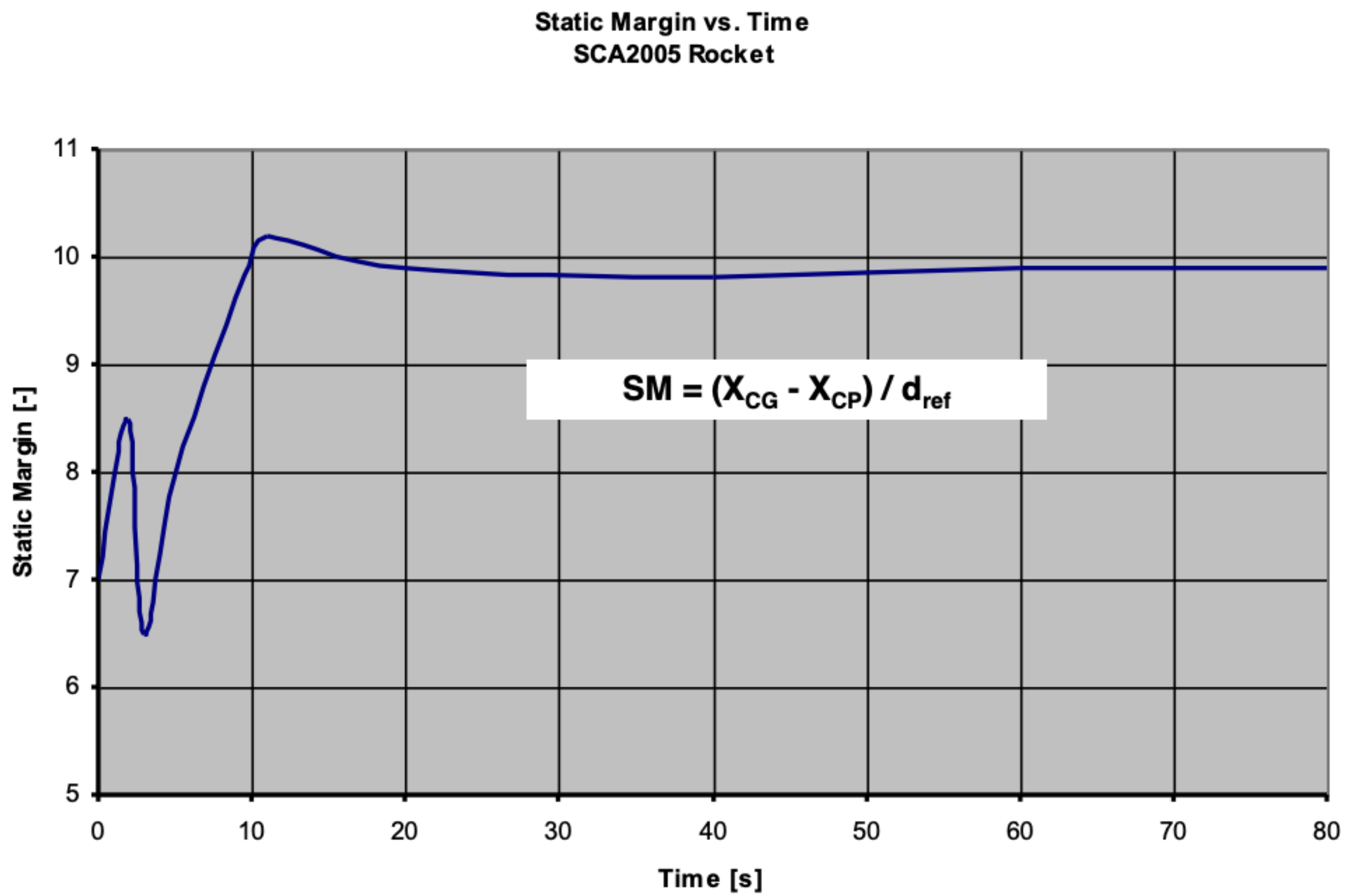




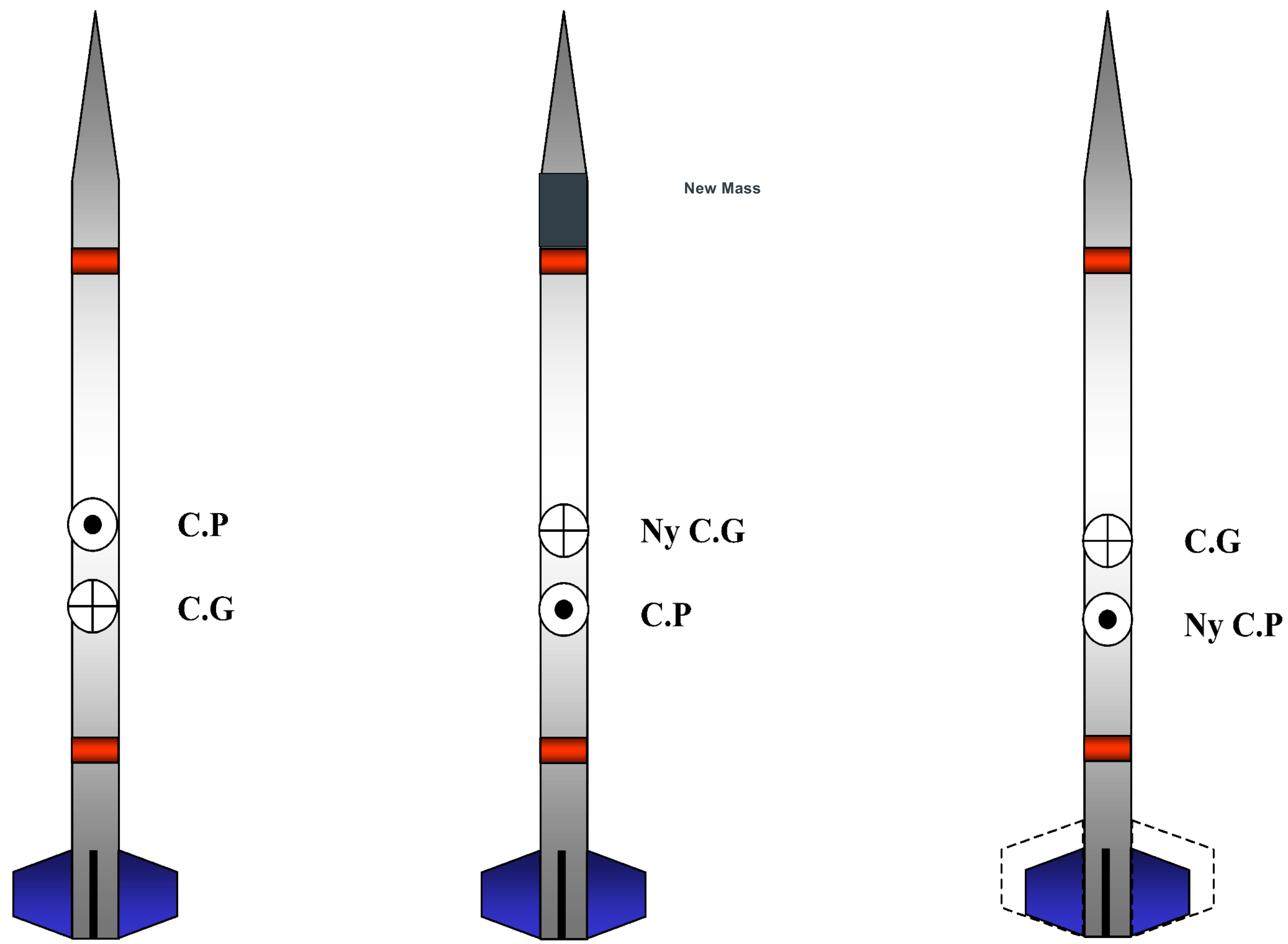
Thrust Vectoring

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

Static Margin



Which of these are stable? And why?



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COMPUTING LOCATION OF THE CENTER OF PRESSURE

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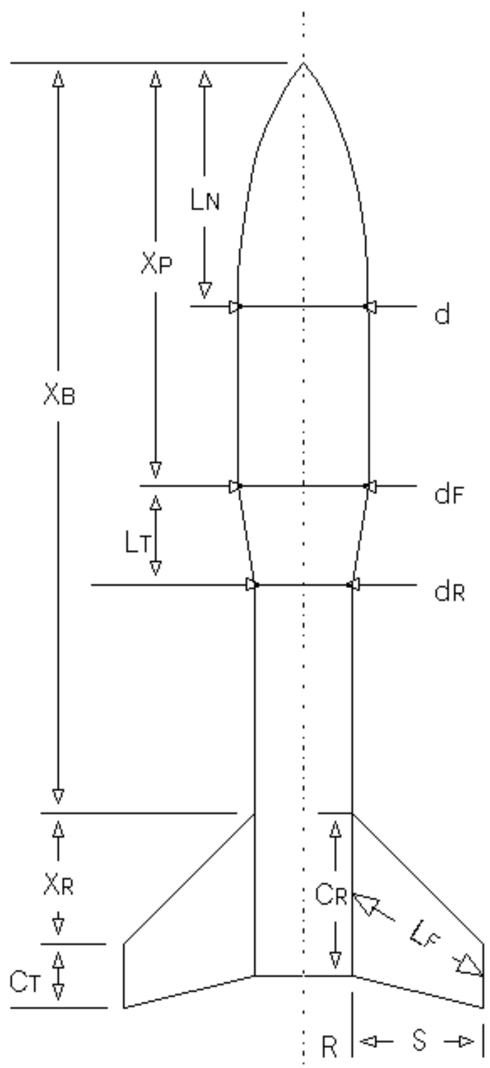
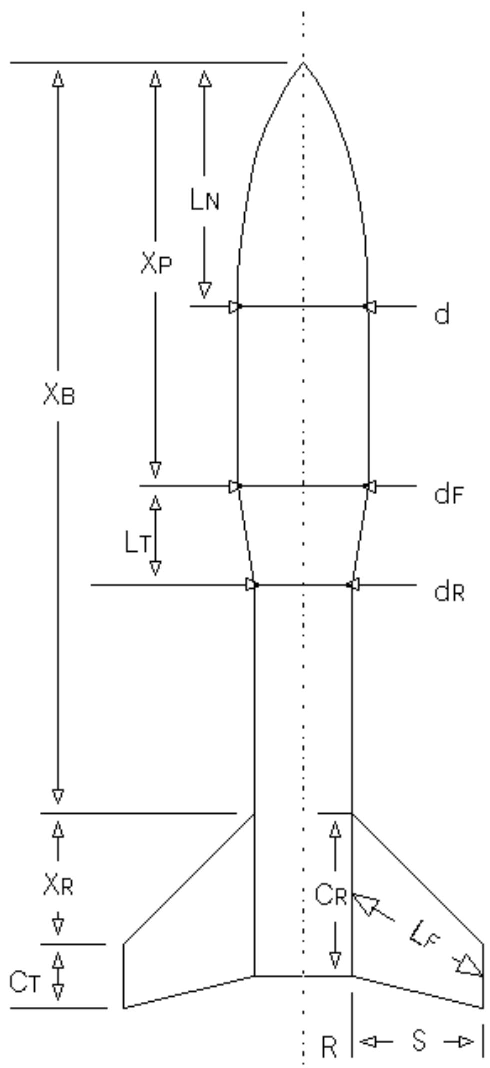
Barrowman Equations



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



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

NOSE

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

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

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

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

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