Rocket Stability

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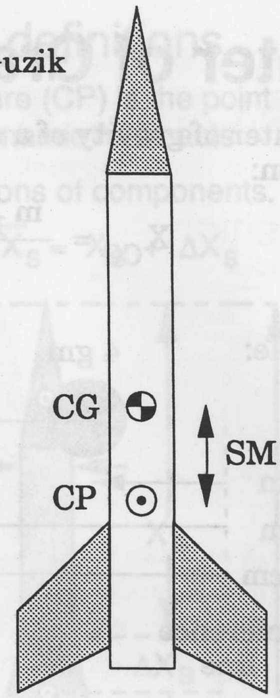
A stable model rocket will point its nose into the relative airflow. Model rockets are stabilized aerodynamically.

A stable model rocket must have its Center of Gravity (CG) ahead of its Center of Pressure (CP).

The CG is the balance point of the rocket. The model rotates about this point while in free flight.

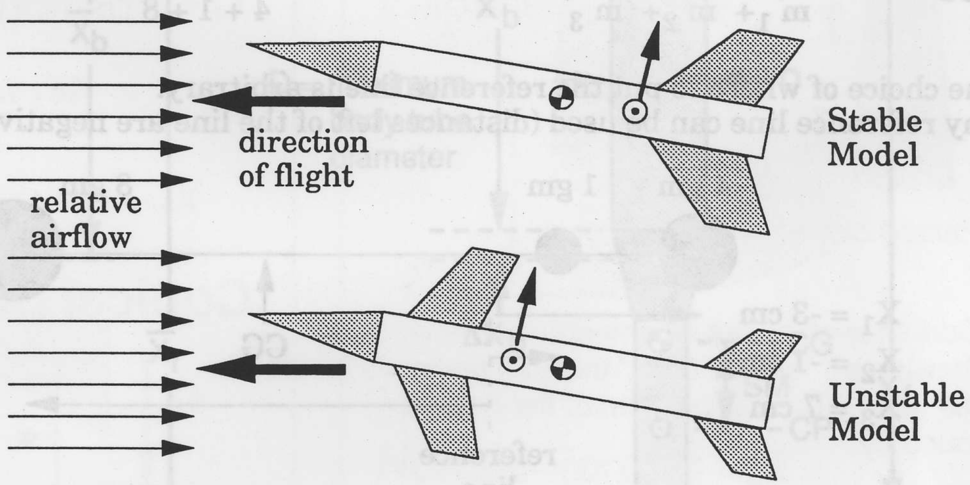
The CP is the point where the net aerodynamic force acts on the model.

The Stability Margin (SM) is the distance between the CG and CP (a positive value for a stable rocket). For a safe flight, the SM should be at least as great as the diameter of the widest tube in the model; this is referred to as "one caliber" stability.

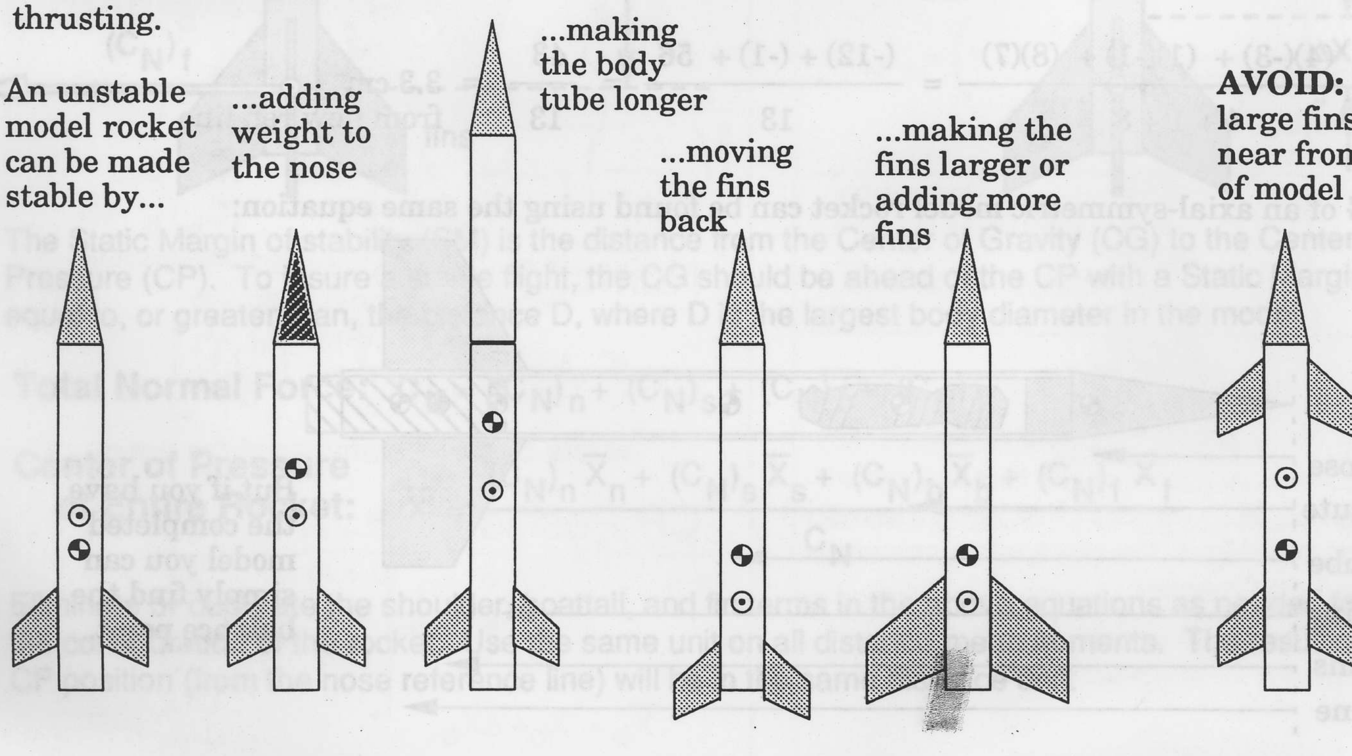


The net aerodynamic force, which acts through the CP, produces a torque that acts to turn the nose cone back into the relative airflow.

On an unstable model, the aerodynamic force will tend to push the nose of the rocket further off to the side. This causes the model to thrash wildly around the sky while the motor is thrusting.



An unstable model rocket can be made stable by...

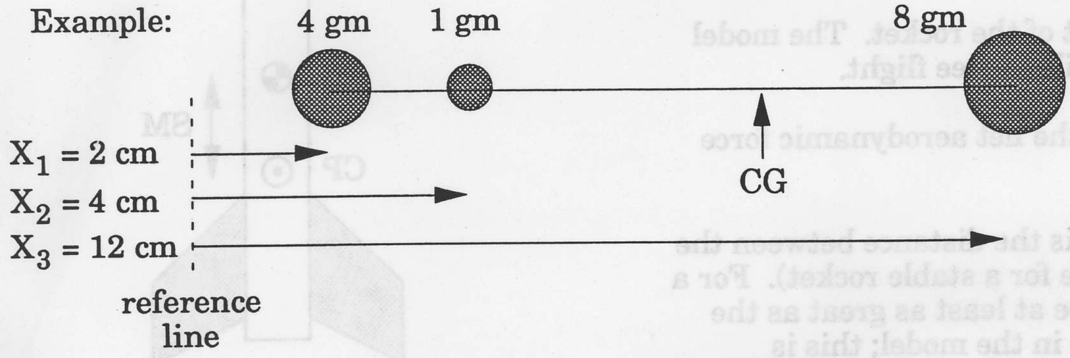


Center of Gravity (Center of Mass) (Balance Point)

The center of gravity of a set of masses arranged along a line can be calculated from the equation:

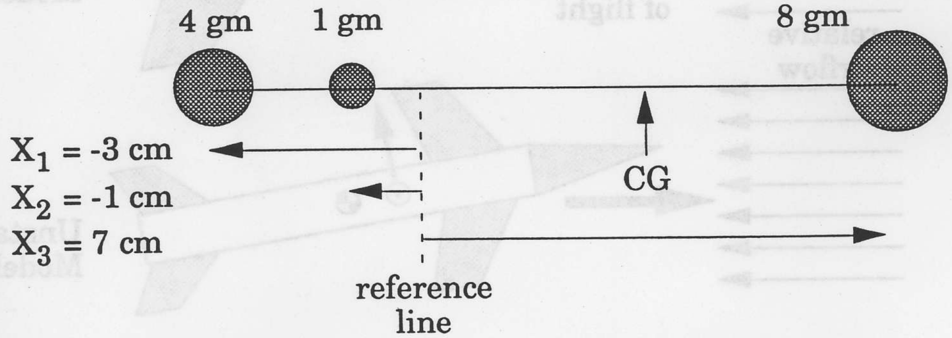
$$X_{CG} = \frac{m_1X_1 + m_2X_2 + m_3X_3 + \ldots}{m_1 + m_2 + m_3 + \ldots}$$

Example:



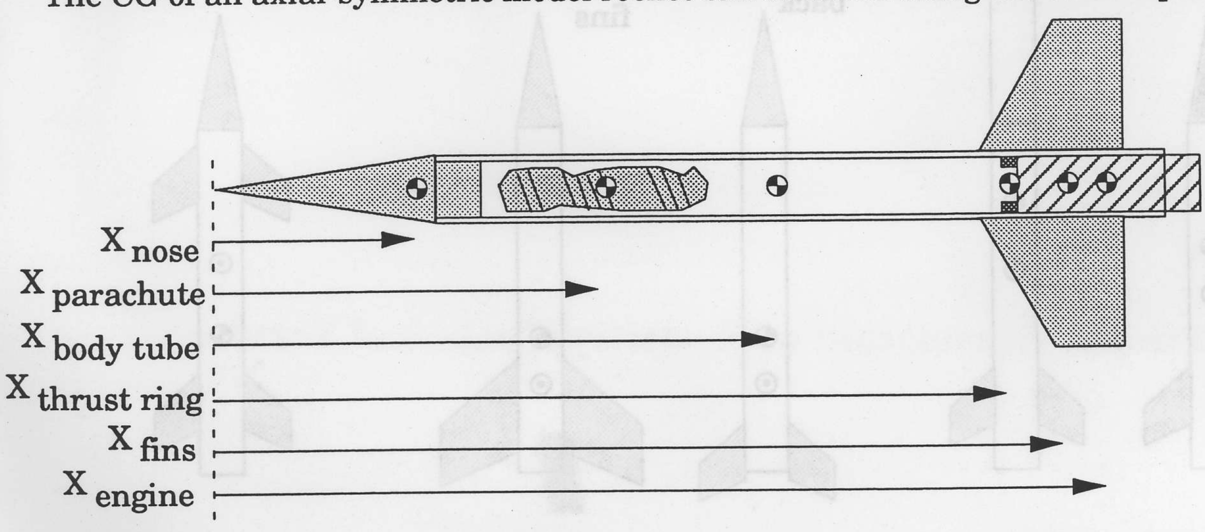
$$X_{CG} = \frac{m_1X_1 + m_2X_2 + m_3X_3}{m_1 + m_2 + m_3} = \frac{(4)(2) + (1)(4) + (8)(12)}{4 + 1 + 8} = \frac{8 + 4 + 96}{13} = 8.3 \text{ cm from ref. line}$$

The choice of where to put the reference line is arbitrary.
Any reference line can be used (distances left of the line are negative).



$$X_{CG} = \frac{(4)(-3) + (1)(-1) + (8)(7)}{4 + 1 + 8} = \frac{(-12) + (-1) + 56}{13} = \frac{43}{13} = 3.3 \text{ cm from new ref. line}$$

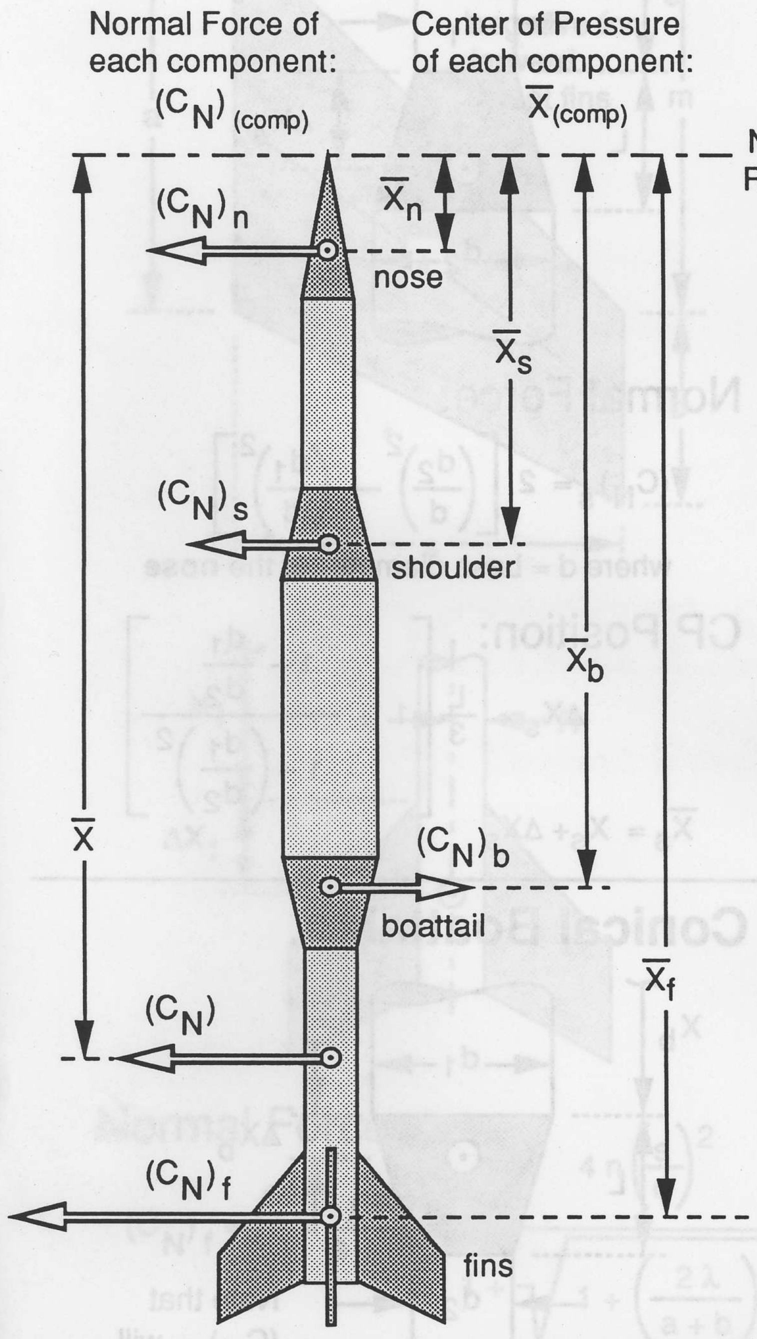
The CG of an axial-symmetric model rocket can be found using the same equation:



But if you have the completed model you can simply find the balance point.

Center of Pressure

(Barrowman Method)

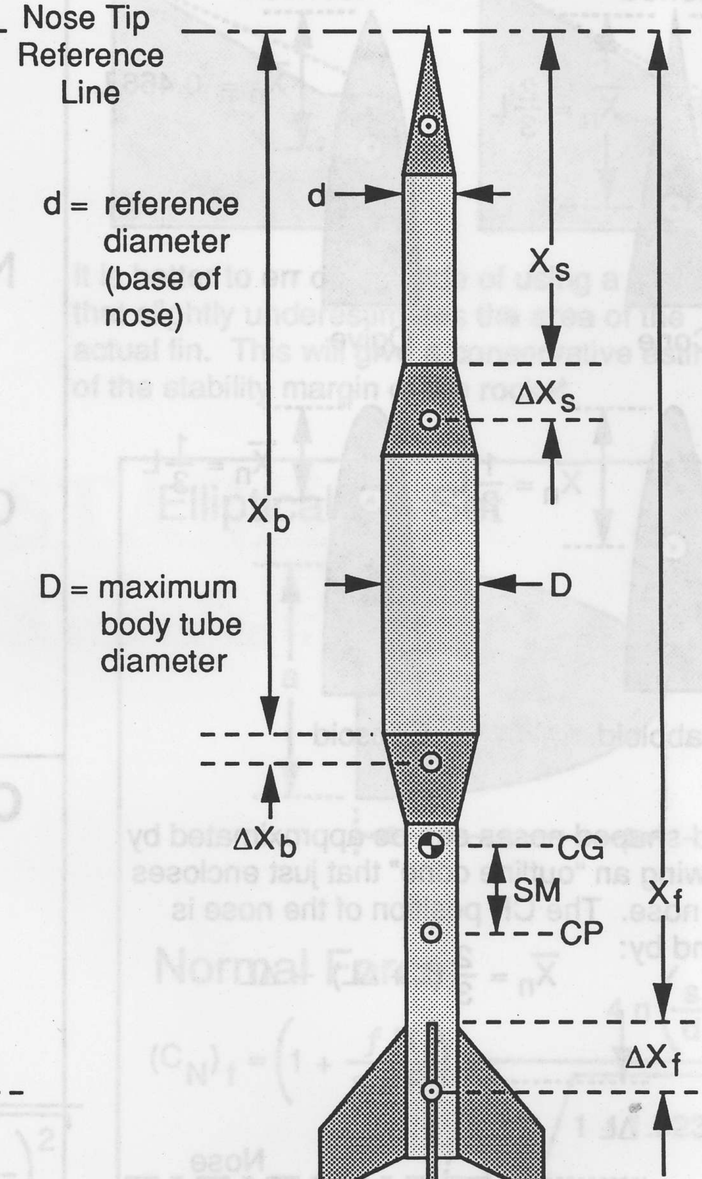


Overview and definitions

The Center of Pressure (CP) is the point where the net aerodynamic force acts

C.P. positions of components.

Example: $\overline{X}_s = X_s + \Delta X_s$



The Static Margin of stability (SM) is the distance from the Center of Gravity (CG) to the Center of Pressure (CP). To insure a stable flight, the CG should be ahead of the CP with a Static Margin equal to, or greater than, the distance D, where D is the largest body diameter in the model.

Total Normal Force: $C_N = (C_N)_n + (C_N)_s + (C_N)_b + (C_N)_f$

Center of Pressure of Entire Rocket:

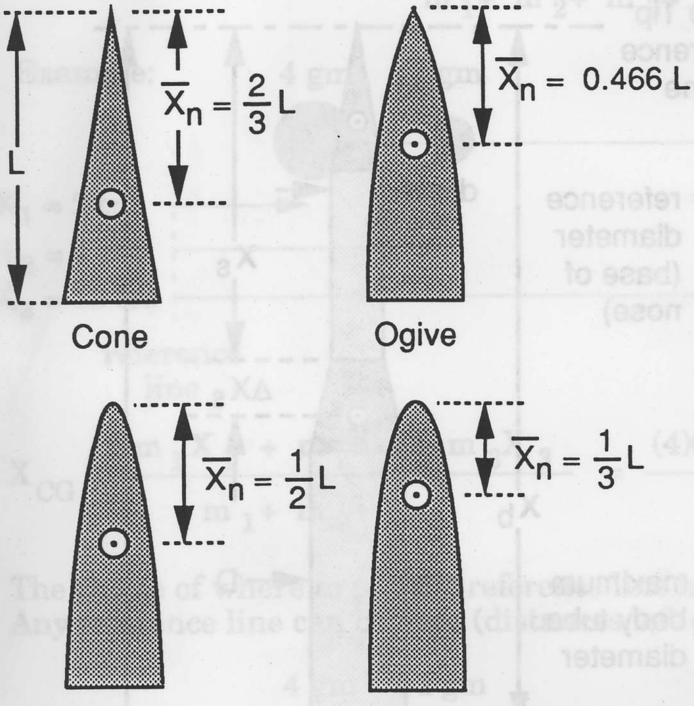
$$\overline{X} = \frac{(C_N)_n\overline{X}_n + (C_N)_s\overline{X}_s + (C_N)_b\overline{X}_b + (C_N)_f\overline{X}_f}{C_N}$$

Eliminate or duplicate the shoulder, boattail, and fin terms in the above equations as needed for the configuration of the rocket. Use the same unit on all distance measurements. The resulting CP position (from the nose reference line) will be in the same distance unit.

Nose

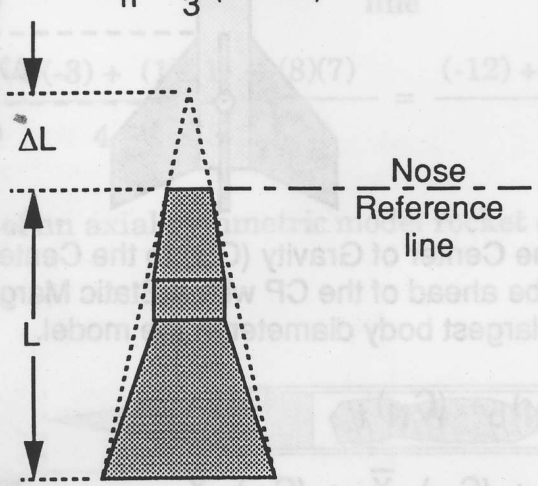
Normal Force: $(C_N)_n = 2$ for all shapes.

CP Position:



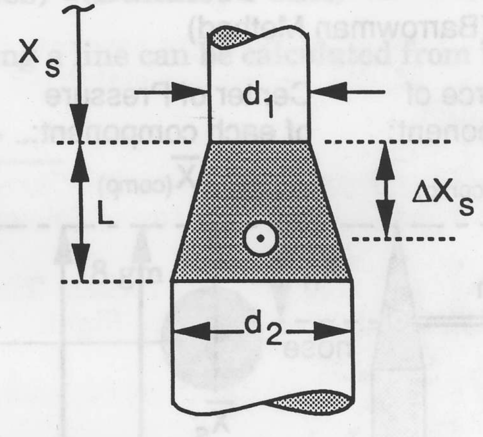
Odd-shaped noses can be approximated by drawing an "outline cone" that just encloses the nose. The CP position of the nose is found by:

$$\overline{X}_n = \frac{2}{3}(L + \Delta L) - \Delta L$$



All other position measurements on the model are measured from the nose reference shown in the normal manner.

Conical Shoulder



Normal Force:

$$(C_N)_s = 2\left[\left(\frac{d_2}{d}\right)^2 - \left(\frac{d_1}{d}\right)^2\right]$$

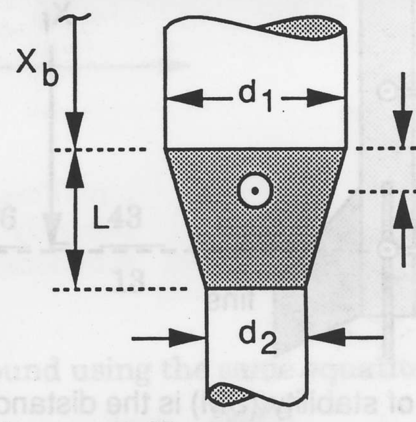
where d = base diameter of the **nose**

CP Position:

$$\Delta X_s = \frac{L}{3}\left[1 + \frac{1 - \frac{d_1}{d_2}}{1 - \left(\frac{d_1}{d_2}\right)^2}\right]$$

$$\overline{X}_s = X_s + \Delta X_s$$

Conical Boattail



Note that $(C_N)_b$ will be negative

Normal Force:

$$(C_N)_b = 2\left[\left(\frac{d_2}{d}\right)^2 - \left(\frac{d_1}{d}\right)^2\right]$$

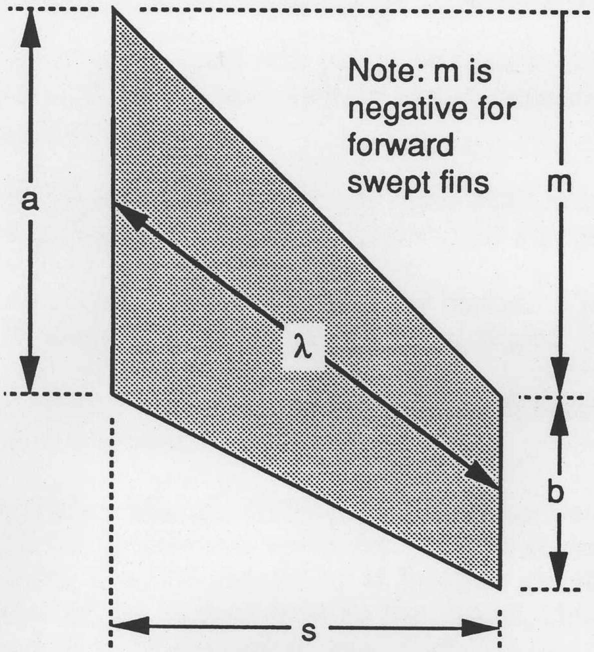
where d = base diameter of the **nose**

CP Position:

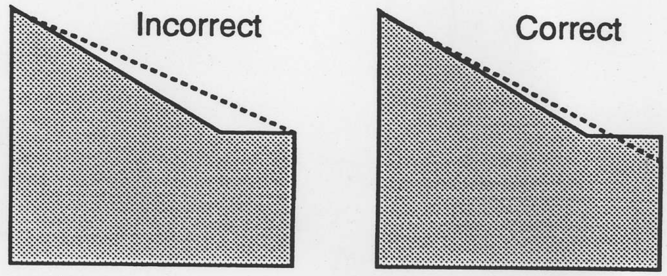
$$\Delta X_b = \frac{L}{3}\left[1 + \frac{1 - \frac{d_1}{d_2}}{1 - \left(\frac{d_1}{d_2}\right)^2}\right]$$

$$\overline{X}_b = X_b + \Delta X_b$$

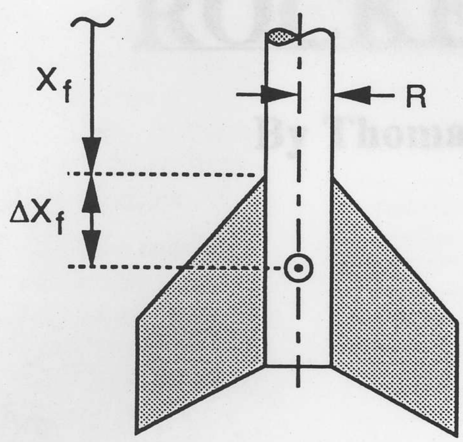
Fin Set Trapezoidal Shape



Apply this to each set of identical fins on the model. The fin shape must be approximated by a trapezoid, making sure the area of the trapezoid closely matches that of the original fin.



It is better to err on the side of using a trapezoid that slightly underestimates the area of the actual fin. This will give a conservative estimate of the stability margin of the rocket.



Normal Force:

$$(C_N)_f = \left(1 + \frac{f R}{s + R}\right) \frac{4n\left(\frac{s}{d}\right)^2}{1 + \sqrt{1 + \left(\frac{2\lambda}{a + b}\right)^2}}$$

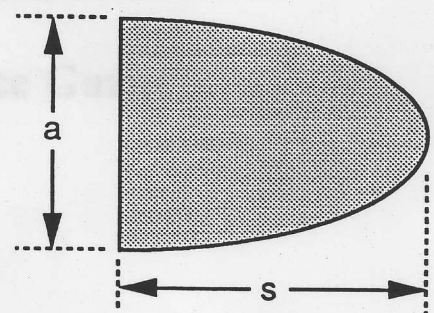
where n = the number of fins in the set
d = base diameter of **nose**
f = 1.0 for 3 or 4 fins
f = 0.5 for 6 fins

CP Position:

$$\Delta X_f = \frac{m(a + 2b)}{3(a + b)} + \frac{1}{6}\left(a + b - \frac{ab}{a + b}\right)$$

$$\overline{X}_f = X_f + \Delta X_f$$

Elliptical Fin Set



Normal Force:

$$(C_N)_f = \left(1 + \frac{f R}{s + R}\right) \frac{4n\left(\frac{s}{d}\right)^2}{1 + \sqrt{1 + 1.623\left(\frac{s}{a}\right)^2}}$$

CP Position:

$$\overline{X}_f = X_f + 0.288\,a$$

References

Calculating the Center of Pressure of a Model Rocket, Centuri Technical Report TIR-33, by James Barrowman

Barrowman Equations for Elliptical Fins, by James Barrowman, Model Rocketry Magazine, January 1971.

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