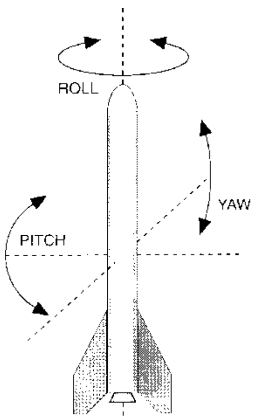
Flight Stability of Water Rocket

A rocket works by conserving momentum -- as water escapes from the rocket's nozzle, the rocket will feel a push in the opposite direction. Unless the ejected water is precisely aimed, then the rocket may not get pushed exactly in the direction you want it to go. Even a small deviation from the right direction. After launch, the rocket may start off pointing vertically into the air but eventually, some unpredictable force (uneven drag on rocket, a small gust of wind, etc.) can cause the rocket to stray from its course and take a curved path or even tumble and rotate around it center of gravity.

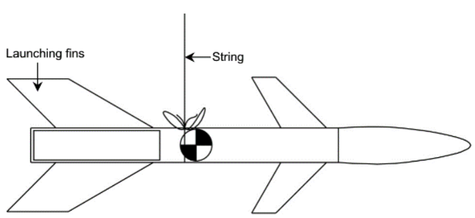


In flight, spinning or tumbling takes place around one or more of three axes. They are called *roll, pitch,* and *yaw*. The point where all three of these axes intersect is the center of mass. For rocket flight, the pitch and yaw axes are the most important because any movement in either of these two directions can cause the rocket to go off course. The roll axis is the least important because movement along this axis will not affect the flight path. Unstable motions about the pitch and yaw axes (through the center of mass) will cause the rocket to leave the planned course.

A stick thrown from holding one end, tumbles in flight in an unstable manner.

Center of Gravity

Center of Gravity (C_g) is the center of the mass of a ready-to-fly rocket (fuel included). It is the point where the rocket balances, and the point at which it rotates during flight. The center of gravity can either be by experimentation (finding the balancing point of the rocket) or calculation.



This position of the string marks the center of gravity. Measure this position on the rocket (fuel should be present)

Center of Pressure

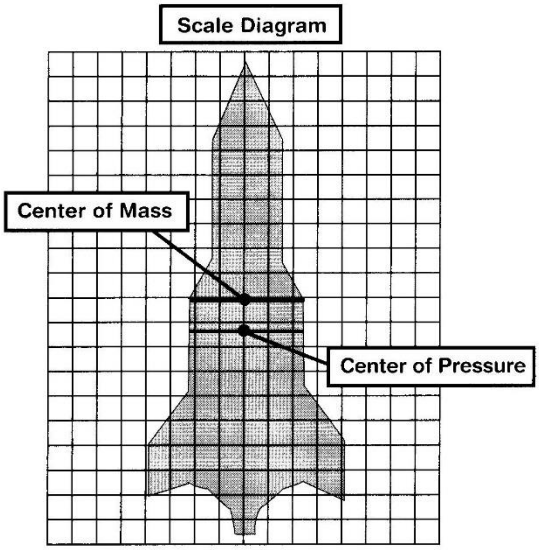
Center of Pressure (C_p) is the point at which aerodynamical (drag and lift) forces balance. The center of pressure is not nearly as easy to calculate as the center of gravity, but can be determined experimentally. The center of pressure only has meaning during flight when there are aerodynamical forces present.

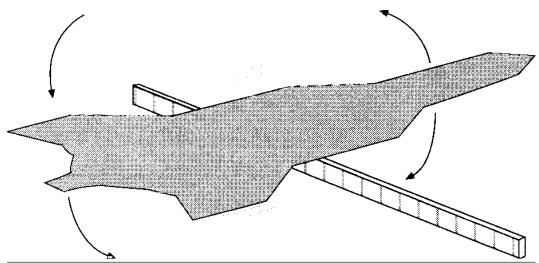
Mechanical Determination of C_p

For a model rocket, there is a straightforward method to determine the center of pressure.

First, make a two dimensional tracing of the shape of the component (or rocket) on a piece of cardboard and cut out the shape.

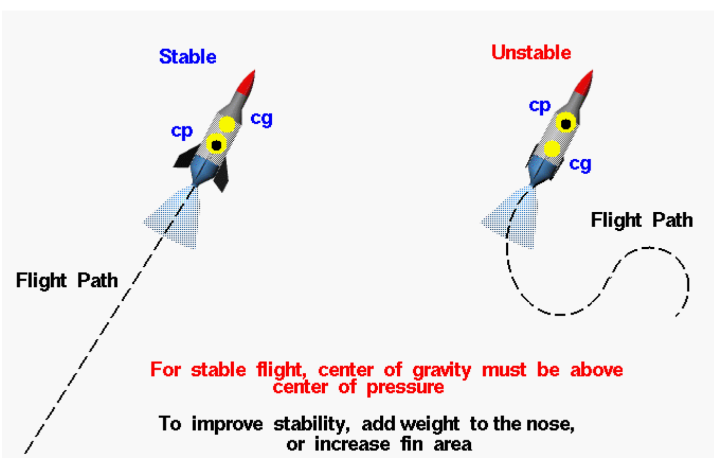
Then, hang the cut out shape by a string, or balance it on a ruler and determine the point at which it balances. (Just like balancing a pencil with a string!) The point at which the cut-out balances is the center of pressure.

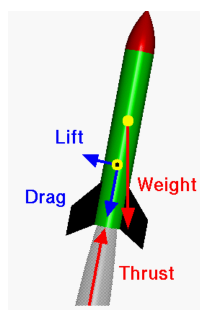




Condition of Stability

For stability, the center of mass should be toward the rocket's nose and the center of pressure should be toward the rocket's tail. If the center of gravity is located above the center of pressure, the rocket will return to its initial flight conditions if it is disturbed.





Explanation:

During the flight of a model rocket small gusts of wind, or thrust instabilities can cause the rocket to "wobble", or change its attitude in flight. Like any object in flight, a model rocket rotates about its center of gravity Cg, shown as a blank dot on the figure. The rotation causes the axis of the rocket to be inclined at some angle a to the flight path. Whenever the rocket is inclined to the flight path, a lift force is generated by the rocket body and fins, while the aerodynamic drag remains fairly constant for small inclinations. Lift and drag both act through the center of pressure Cp of the rocket, which is shown as the black dot in the figure.

If the center of pressure is above the center of gravity, the lift and drag forces maintain their directions but the direction of the torque generated by the forces is reversed. Any small displacement of the nose generates forces that cause the displacement to increase. Such a flight condition is shown on the right of the figure where the rocket is unstable.

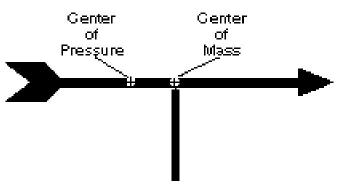
Experimental Determination of Stability

After the center of pressure has been marked on the scale diagram, add the position corresponding to the center of mass. C_m should be well above the C_p. If it is not the design must be modified.

Stability with fins

The addition of fins to bottle rockets contributes to the stability of the rocket in flight. The fins counteract sideways motion of the rocket. Air flows smoothly past them if the rocket is traveling along its axis. If there is any sideways motion, then the air striking the fins pushes the rocket back towards straight motion. It's not perfect -- the rocket may still go around in circles, but the idea is to make the path straighter than it otherwise would be.
http://van.physics.illinois.edu/qa/listing.php?id=2140

Extension to Weather Vanes



The reason that the weather vane arrow points into the wind is that the tail of the arrow has a much larger surface area than the arrowhead. The flowing air imparts a greater force to the tail than the head, and therefore the tail is pushed away. There is a point on the arrow where the surface area is the same on one side as the other. This spot is called the center of pressure.

The center of pressure is not in the same place as the center of mass. If it were, then neither end of the arrow would be favored by the wind and the arrow would not point. The center of pressure is between the center of mass and the tail end of the arrow. This means that the tail end has more surface area than the head end.
http://quest.arc.nasa.gov/space/teachers/rockets/rocketry.html

If your center of mass is well in front of the center of pressure, your rocket should be stable. Proceed to the swing test. If the two centers are close together, add more clay to the nosecone of the rocket. This will move the center of mass forward. Repeat steps 2 and 3 and then proceed to the swing test.