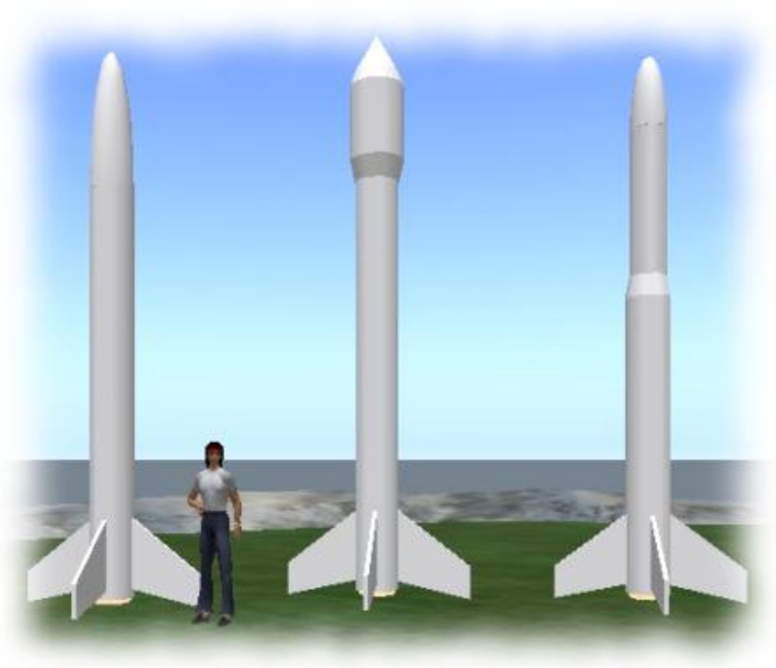
# Designing a Model Rocket

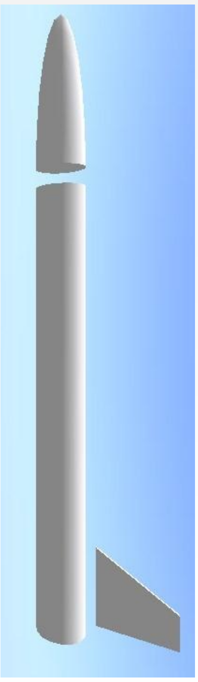


# Design Components

In the following pages we are going to look at the design requirements for a stable single stage model rocket. From the diagram here you can see that the rocket has been divided into three basic components, the nose cone, the body and the fins.

The principle considerations for our design process will be in the need to establish such parameters as the Center of Gravity, and Center of Pressure in order for our rocket to have suitable stability while at the same time minimising drag.

Throughout the examples that follow, we shall be using the shapes of various fin and nose cone in our illustrations.

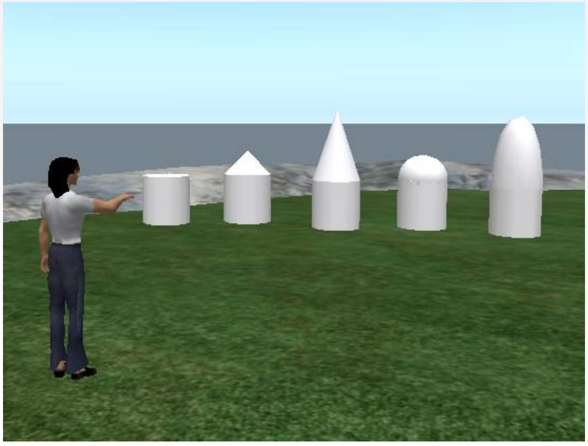


# The Nose Cone

The nose cone sits at the top of the rocket tube and serves the primary purpose of streamlining the main body of the rocket in order to reduce the resistance to its motion caused by the air resistance. As you can imagine, the effect of air resistance on any rocket will vary with altitude because as you gain height the air pressure reduces so reducing what we shall refer to as drag. The coefficient of drag is represented by the term $C_d$. In fact even the altitude of your launch site will affect the performance of your rocket.

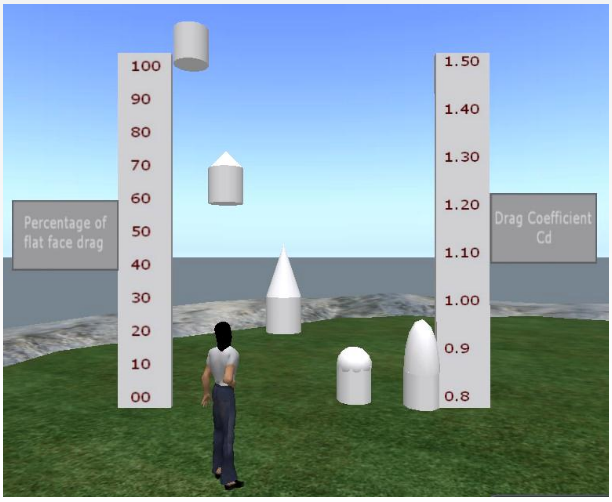
Here you can see a snapshot of the basic category types of rocket nose cone configuration. Reading from left to right they are:

- Blunt
- Blunt cone
- Cone
- Hemisphere
- Parabola



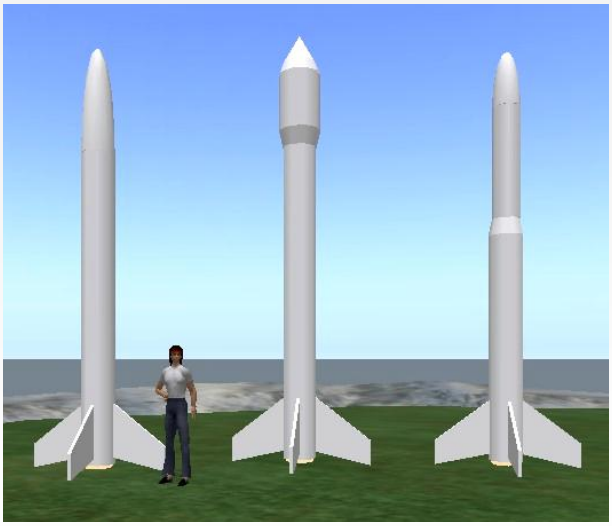
Locating each one on a scale shows the effectiveness of the various types of nose cone shape with regard to drag. On the left we have the % of flat face drag and not surprisingly the flat end nose cone has the highest value of 100% with a drag $C_d$ of 1.5; notice that the drag coefficient is just a number it has no dimensions.

If you would like to run this simulation for yourself then please feel free to visit Spaceport UK in Second Life.



# The Rocket Body

The body of a rocket is essentially a tube, whose diameter will of course determine the area of forward facing profile as it ascends through the air. In our example so far we have simply seen the rocket body in its most basic form, but its important to appreciate that there are a number of common variations on this. In the screen shot right you can see our standard model accompanied by a rocket body designed to carry a wide payload center, and a two-stage rocket on the right.

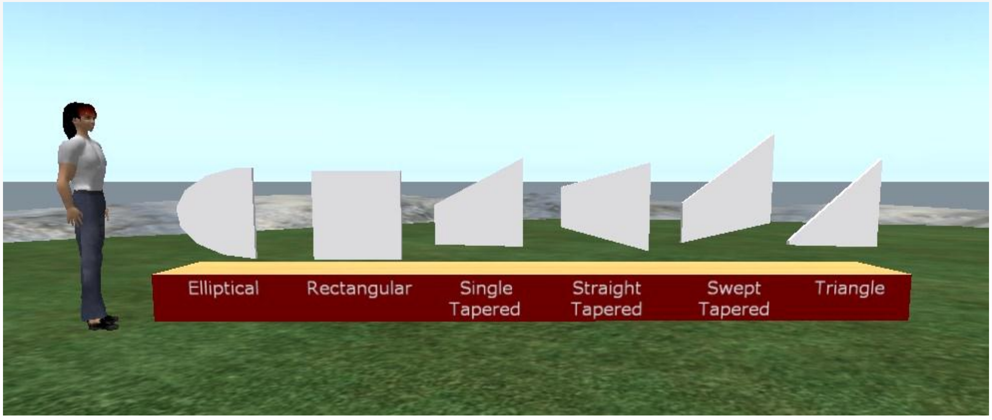


We shall see later how the shape of the rockets main body can affect factors such as center of gravity and center of pressure.

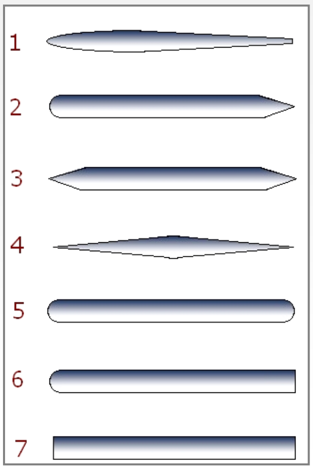
As a general rule of thumb the length of a rockets body should be in the order of ten times its diameter.

# The Fins of a Rocket

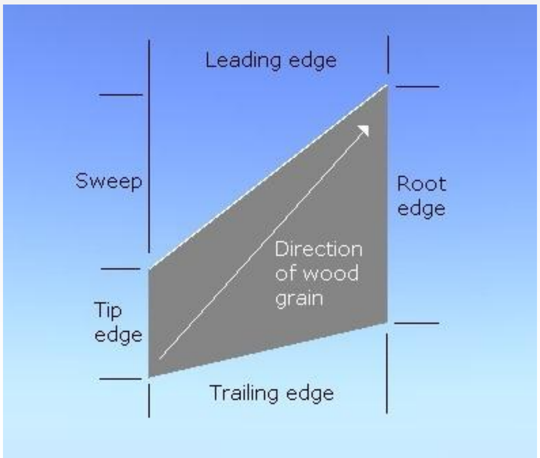
The fins are used as a means of maintaining stability and guidance for the rocket as it ascends through the air. In the diagram below you can see examples of the most common fin shapes accompanied by their name. It is also the case however that fins will introduce extra drag. The efficiency of a fin is ultimately determined by its size, type and aerofoil cross-section. In the case of a model rocket we shall assume the material being used for the fins construction will be Balsa wood.




The diagram right shows typical aerofoil cross-sections for various fin designs that rank from 1 the most efficient to 7 the least efficient with regard to surface airflow which contribute to both drag and turbulence. Looking at diagram here right, the rounded leading edge will allows the air to pass easily over it, while a pointed training edge results in low turbulence.



The diagram right shows the labelling of a fin surface. A point of particular interest here is the requirement for wood grain. Notice that it runs diagonally from the bottom of the Tip edge to the top of the root edge. The primary concern here is with regard to the ability of the fin to resist breakage when the rocket lands. If the grain runs in either the vertical or horizontal directions there is a real chance that the fin will snap of touchdown if it hits the ground first

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A rule of thumb for fin dimensions in rocket design draws upon a ratio with relation to the main body tube diameter d as shown in the diagram below

In the diagram right you can see how the fin design has been related to the diameter of the rocket body tube

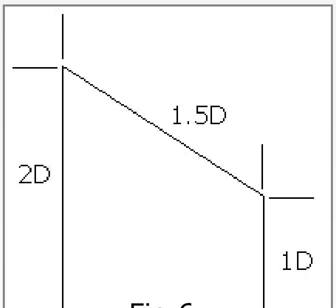
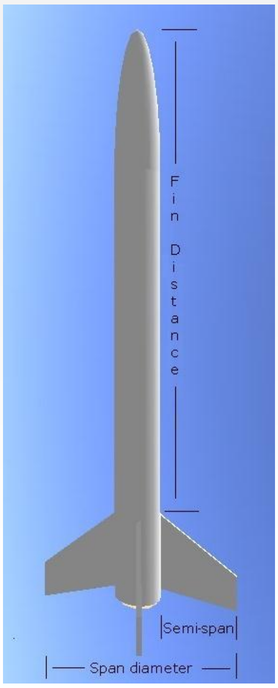



Fig 6



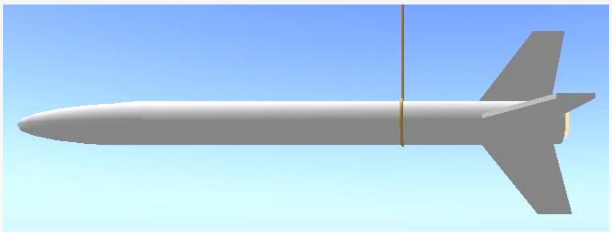

In the diagram Fig 7, the image shows some of the various names used to describe general fin terminology and placement on the body of the rocket.

# Center of Gravity

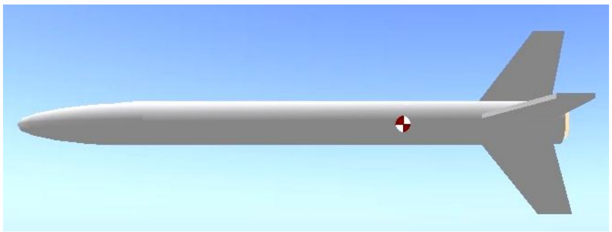
As you will already have read in the introduction, the primary design considerations with regard to the stability of a rocket are center of gravity and center of pressure.

The rockets center of gravity is that point at which the whole assembly is in equilibrium, or balance. In determining the center of gravity, it is important to prepare the rocket to the same state as pre-launch, so engine, parachute, wadding and any payload installed.

To determine center of gravity, simply suspend the rocket from a loop of string and adjust its position along the body tube until the rocket is balanced, then make a small mark on the body tube either side of the string.



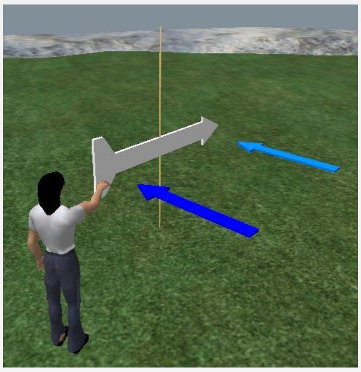
For the purpose of this example I have shown the center of gravity marked by a circle with a cross. It is possible to adjust the center of gravity by simply placing clay weights in the nose cone, but remember an increase in weight will directly impact upon our rockets performance



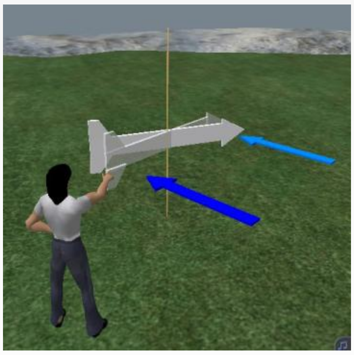
# Center of Pressure

The center of pressure for a model rocket, is that point at which all aerodynamic forces are equal, in other words aerodynamic forces on both sides of this point are the same.

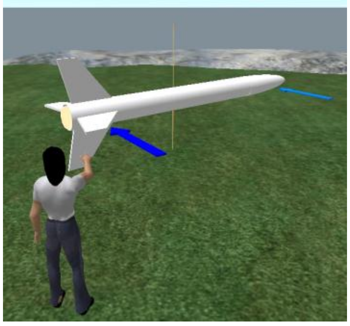
I want to start looking at the center of pressure by drawing an analogy with Weathervanes. In a Weathervane, similar to the one shown here, the rear has a larger surface area than the front. When the wind blows, the greater surface area, which translates to resistance at the rear, produces a turning force.



Here you can see how the unequal distribution of wind resistance at either end of the weathervane has caused it to face into the direction of the wind.

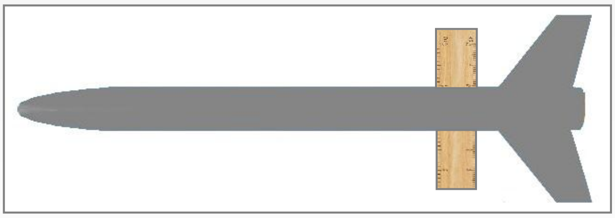


You should now be able to imagine that our rocket will act in a similar way to a standard weathervane. While the rocket has been balanced around its Center of Gravity, the point where the wind pressure will balance out becomes the center of pressure and for a stable rocket design this should lye, as you will see behind the center of gravity.



I you imagine now that aerodynamic forces can only act upon an exposed surface, the center of pressure must come at a point of equal area. In other words increasing fin area will shift the center of pressure toward the rear of the rocket while reducing fin area will shift the center of pressure toward the front of the rocket. There are clear implications here also for the number of fins on the rocket reducing from four to three will clearly reduce the surface area they contribute and so again the center of pressure will move toward the rear of the rock.

A simple method for determining the center of pressure is to create a cardboard cut-out of the rocket, notice how much it looks like the weathervane, then balance this on the edge of a ruler. This point is also known as the Center of Lateral Area or CLA.



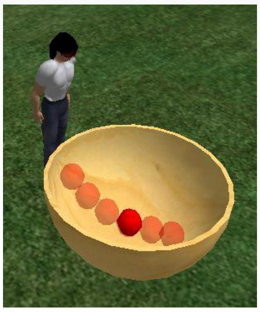
A second method is to take your cutout and place it over graph paper draw the outline and simply count squares, that point on the main body that has as many squares on either side will represent the center of pressure.

# What is stability?

In order for a rocket to fly in a predictable trajectory it must be stable, so lets begin by clarifying stability. In this example I am going to make use of a ball and basin.

In the image shown below left, the ball is, as you would expect lying at the bottom of the basin in what is referred as its neutral position, and unless some force acts upon the ball this is were it will remain. Now imagine that a force is applied to the ball such that it moves up the side of the basin to occupy what is called the disturbed or displaced position. The final image lower right shows what happens if the applied force holding the ball at the side of the basin is removed. The ball rolls or oscillates back and forth across the bottom of the bowl until finally coming to rest once more in the neutral position. When an oscillation returns an object to its neutral position the oscillation is referred to as be positively stable; any body that returns to its neutral position following a disturbance is said to be stable.





Look now at the sequence of images from left to right below. If we invert the basin and balance the ball at a neutral position on the top, any disturbance will cause the ball to roll down the side and bounce away, unable to return to its neutral position and when this happens we refer to the ball as being unstable

Finally we place our ball onto a flat surface, now no matter where the displacement moves it too, it will remain stable and so is said to have neutral stability.

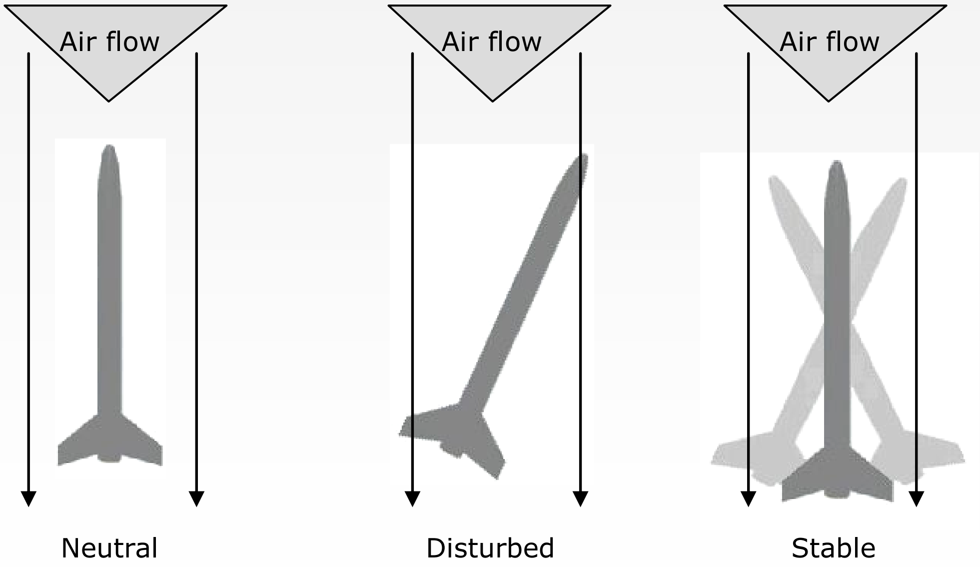
In conclusion then we can deduce that there are three types of stability; positive, negative and neutral.

Stable (positive)

Unstable (negative)

Neutral

Applying these definitions of stability to a rocket in flight, from the left we have a rocket in neutral position, a rocket on Disturbed position and finally right a oscillating about its neutral position and so has stable oscillation.



# A rockets motion and flight forces

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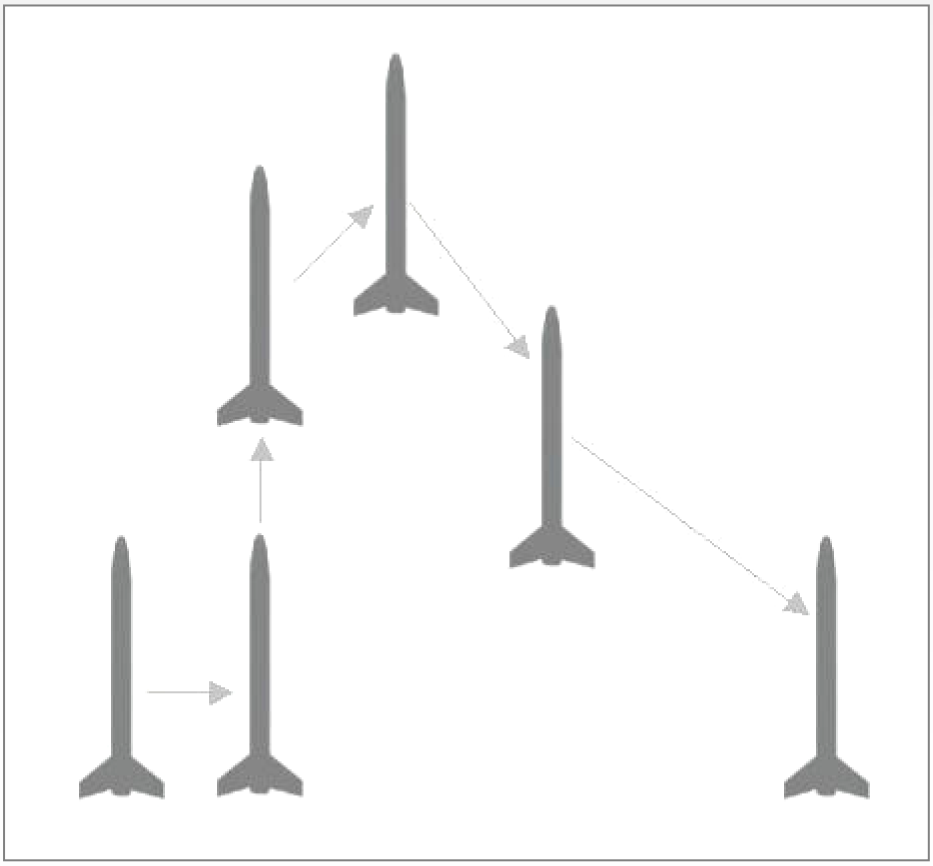
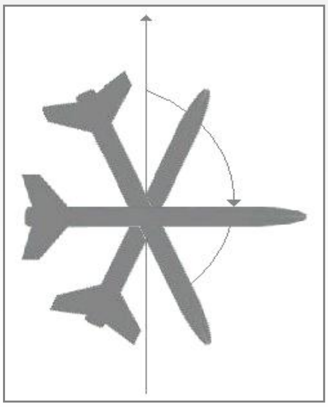
Two discrete types of motion can represent the flight of a rocket or for that matter the motion of any object: Transitional and Rotational.

In the diagram below our rocket has moved sideways, up and down, but always faces in the same direction.



When considering how high a rocket or far a rocket can travel then we are referring to its transactional motion, but considering stability then we must consider this in terms of rotational motion.

In the case or rotational motion, the rocket will point in different directions about a central axis, while remaining in the same place



Below you will see that I have summarised some rules of thumb that apply to the stability of your rockets

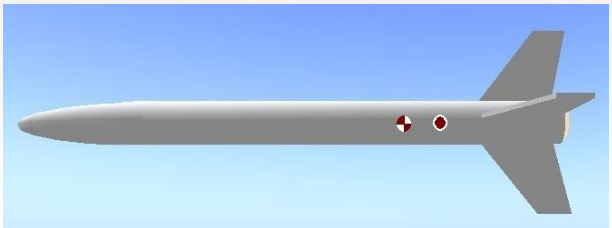
- With no other forces acting on a rocket other than the engines thrust propelling it a rocket will fly directly into the airflow.
- Should a side wind hit the rocket during it ascent then the rocket will begin to fly at an angle known as the angle-of-attack to the airflow, in what we now know to be it disturbed position.
- If the rocket then oscillates back to its neutral oscillation then it is considered as stable.
- If the angle-of-attack becomes wider with oscillations then the rocket may eventually flip over completely and so enters a state of instability.

# The point of stability

At the start of this section on stability I stated that *The primary design considerations with regard to the stability of a rocket are center of gravity and center of pressure.* And of course there must be a relationship between these two parameters.

As a rule of thumb the center of gravity should always be ahead of the center of pressure by about one main tube diameter. If you find that this is not the case then either increase the tube length or weight the nose cone with clay to move the center of gravity forward

In the image here you can see that I have placed the center of pressure mark a bullet circle, behind the mark for center of gravity.



A final practical pre-flight assessment of your rockets stability is the swing test. Here you secure a tether to the main rocket body at the center of gravity mark and the rocket swing through the air to simulate the aerodynamic pressure during a flight. Any up or downward tendency of the nose should be corrected by wind pressure on the fins so pushing the CP back in line behind the CG

If your rocket goes into a tumble and cartwheels, this is a strong indication that the CG and CP are too close, try inserting clay weights into the nose cone to shift the CG forward from the CP

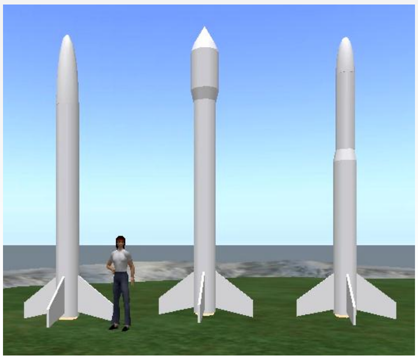
The relationship between the center of gravity and center of pressure, is expressed by Static Stability, or Calibre of Stability, this is a dimensionless number that can be derived from the formula

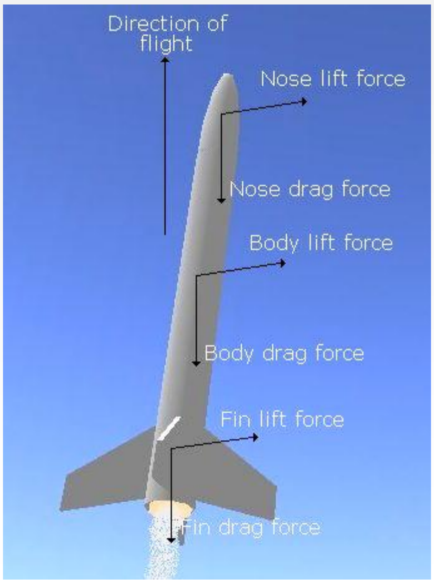
$$\text{Static Stability} = \frac{\text{Body diameter}}{\text{Distance CP to CG}}$$

For a rocket that has a CP to CG distance of 0.85 inches and a tube diameter of 0.84 inches, the rocket will be said to have Single Calibre Stability, and for a rocket with a constant body diameter a Calibre of Stability of 1 or below should be fine.

The situation will change however when the rocket body diameter is not constant such as the cases shown earlier where the rocket has a wider payload bay of two stages each of different diameter.

Its probably worth emphasizing here that the Caliber of Stability measure does not inform us as to how the rocket will fly but how stable it is likely to be in flight.






From our understanding of Static Stability we can now appreciate that during the course of a rockets flight all the major components; nose cone, body and fins are able to produce both lift and drag. The point of balance for all of these combined forces is the Center of Pressure

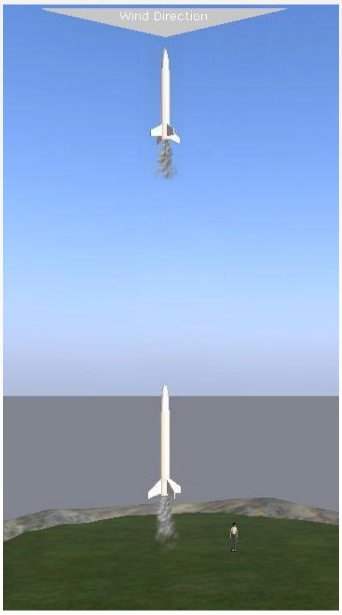
Some rules of thumb

- Ensure that you have a static stability that is equal to diameter of the rockets largest body tube section
- The CP will move rearward when you increase the thickness of the fin.
- At some point, increasing the thickness will cause lift force to go down, and the CP will shift forward dramatically.
- Increasing the thickness has the adverse effect that it also increases the overall drag on the model. The model will not fly as high.
- We want to reduce the fin thickness to decrease the drag. But the minimum thickness will depend on when the fin becomes too weak, or if it moves the CP too far forward.

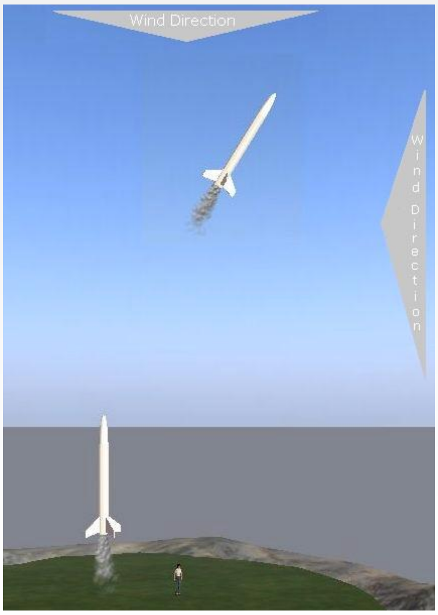
The airfoils on a rocket are symmetrical, and produce no lift when flying at a zero degree angle-of-attack. When the rocket hits a disturbance, such as a gust of wind, the fins are now at an angle of attack, and start producing lift and induced drag.
The lift force cause the rocket to rotate about the CG to zero out the angle-of-attack so it continues to fly straight. But the drag always slows the rocket down, and reduces the altitude it is capable of achieving.

# The effects of wind and drag

The image here right shows a rocket ascending upward without any appreciable wind, and so the only drag the rocket will experience is the perceived direction of wind as it races vertically through the air. In this somewhat idealised example the rocket will rise vertically.




The picture on the right however, shows what will happen if we introduce a across wind. The wind now pushes against the fins causing the rocket to rotate to face toward the wind direction until the two forces become equalised, in an effect known as Weathercocking. With enough wind force the rocket could turn horizontal, clearly an undesirable effect and a good reason not to launch on windy days. One way to reduce this effect is of cause to reduce fin area by making them smaller, however a smaller fin will be less effective with regard to its ability to stabilise our rocket. Another effect of reducing fin area will be to move the center of pressure closer to the center of gravity, which in turn can be compensate for by weighting the nose cone, often achieved by including clay weights, but remember an increase in weight will directly impact upon our rockets performance. It becomes a compromise



# Induced drag and turbulence

On the previous page you saw how a side wind will cause the rocket to weather cock over into the wind, however even in low or no wind conditions a rocket can still be adversely affected by poor assembly and finishing.

Just as we have broken down the simultaneous motions of transaction and rotation of a rockets flight, in a similar way we can also divide the forces acting on the rocket.

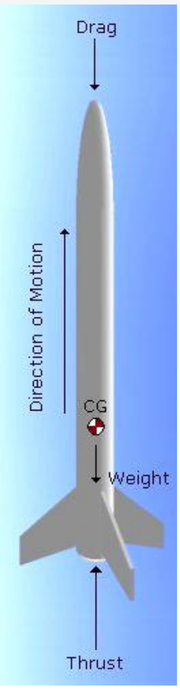
**Translation associate forces:** Weight, Thrust and forward Drag: Notice in particular that all these forces act through the CG

Rotational associate forces:

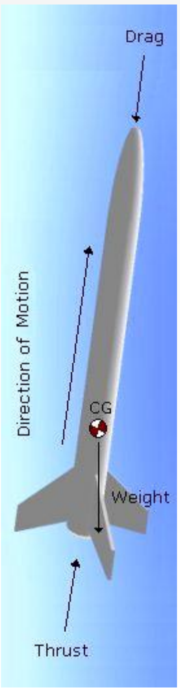
**Translation associate forces:**
Weight, Thrust and forward Drag

Notice in particular that all these forces act through the CG

**Rotational associate forces:**
Those forces due to air pressure such as those that result from induced lift from the nose and fins




Translational forces
in vertical flight




Translational forces
in angled flight

# Finishing Touches

The image here right shows a rocket that is to all intents and purposes ascending in what appears to be a clean vertical path, however its overall performance may be diminished through the induced drag of a rough textured surface. In putting the finishing touches to a rocket and before a coat of paint is applied all surfaces should be sanded flat to remove and rough edges and particularly in the case of the fins wood grain.

In this image the rocket is clearly veering away from a vertical path, but this is not necessarily caused through the influence of weather cocking to a side wind. Here its possible that fins have been installed that poorly aligned and positioned. An equally dramatic effect may arise from rough un-smoothed joints such as those between the fin and body causing airflow turbulence.