Understanding Rocket Stability Part 1 – Centre of Gravity

Learning Objective	In this lesson we will study the stability of model rockets using OpenRocket. We will discuss the forces acting upon a rocket during its flight and how its Centre of Gravity (CG) may be determined.
Grade Level	9 – 11

– Introduction –

To understand the stability of a model rocket flight it is important to visualize the rocket moving through the air during its upward trajectory.

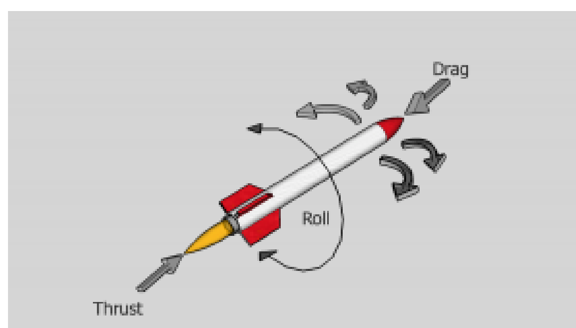

Figure 1 – Degrees of Freedom

After leaving the launch rod the rocket is essentially a free moving body in the air. The forces of wind, gravity and drag act upon the rocket affecting its intended upward flight.

Degrees of Freedom

Degree of Freedom (DOF) is defined as the number of independent parameters that define a mechanical configuration. For model rockets eight different degrees of freedom may be identified as shown in figure 1 (gravity not shown).

Thrust is the force provided by the motor and is responsible for moving the rocket upward. Drag is the force that opposes the upward motion and is determined by the aerodynamics of the rocket.

Roll is the motion that occurs when the rocket spins either left or right. The rocket may also pitch up or down, left or right and is shown by the curved arrows in the diagram.

Thrust, Drag and Gravity (not shown but affects the rocket at different points depending on the flight) are linear forces. The others are rotational forces with a rotational point. The roll rotation occurs along the axis that is straight down the centre of the rocket (assuming the rocket is symmetrical). For the pitch and yaw forces the rotational point is a point along the body of the rocket called the Centre of Gravity or CG.

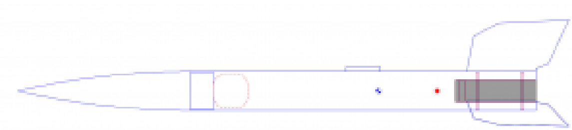

Figure 2 – Screen shot from OpenRocket

Determining CG

The easiest way to find the Centre of Gravity for your rocket is to balance it on a pivot such as a ruler. This is to be done when the preparation of the rocket is complete and it is ready to fly.

Thanks to modern software we may also use OpenRocket to determine our Centre of Gravity. Figure 2 shows a screen shot from OpenRocket of a simple rocket. The Centre of Gravity (CG) is shown by the blue circle.

You may also notice a red circle. This circle displays the Centre of Pressure of the rocket. What is important to note is that in order for a rocket to be stable it must have its Centre of Gravity ahead (closer to the nose cone) of its Centre of Pressure. We will go into more detail about Centre of Pressure in our next article.

Changing the CG

If you haven't already downloaded and run OpenRocket do so now. You may download it from http://www.openrocket.sourceforge.net. After running the program load "A simple model rocket" from the Open Example menu. Observe the Centre of Gravity and Centre of Pressure circles.

Open a component such as the Body Tube and change it's length. You will notice that the Centre of Gravity changes in relation to the Centre of Pressure as you lengthen and shorten the tube. You may even be able to shorten the tube so much that the CP moves ahead of the CG.

What we have learned so far

In this lesson we have just begun to scratch the surface in designing a stable rocket. Information regarding rocket design and stability has been with us for quite some time. Programs such as OpenRocket allow us to experiment with these concepts before we begin to build.

For part two of this lesson we will delve a little more into the balance between the Centre of Gravity and the Centre of Pressure.

Suggested Reading

The following is a list of some of the resources used in the writing of this article:

1. Handbook of Model Rocketry by G. Harry Stine and Bill Stine.
2. OpenRocket technical documentation

Understanding Rocket Stability Part 2 – Centre of Pressure

Learning Objective	In a part one we introduced the concept of rocket stability. We also discussed the centre of gravity, or CG, and how it can be found both physically and through the use of the program OpenRocket. In this lesson we will expand on rocket stability by focussing on the centre of pressure or the CP of a rocket.
Grade Level	9 – 11

– Introduction –

Figure 1 -Homemade weather vane

Imagine if you will a long tube balanced in the centre or CG on a pivot. If we were to apply a steady air stream directly to the pivot point the tube would not rotate as there would be equal force applied to both sides of the tube.

If we were then to add a piece of flat cardboard to the one end of the tube, then find the new centre of gravity and balance the tube, something interesting happens. Our air stream now pushes against the flat cardboard and causes the tube to rotate. The end with the cardboard piece is now pointed in the opposite direction of the air stream.

What we have created is a good old fashioned weather vane. Figure 1 shows a simple weather vane made with cardboard and a straw to demonstrate this concept.

Centre of Pressure

Why did adding a piece of cardboard to the tube suddenly cause this rotation? What we have essentially done when we added the cardboard was change the centre of pressure (CP). An object such as a weather vane will rotate along its centre of pressure when air flow or wind is introduced.

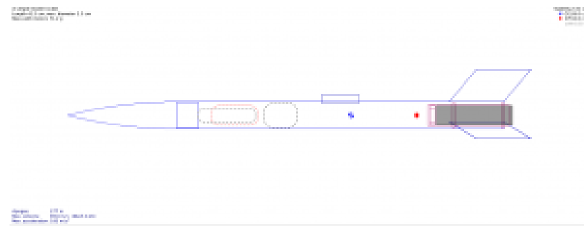

Figure 2- OpenRocket Example Rocket

Without the cardboard piece the centre of pressure equals centre of gravity and thus the tube (in our example, a straw) does not rotate when a direct flow of air is introduced. This concept of centre of pressure is very important in rocket flight.

You may see an example of a rocket design in figure 2. If the CP is ahead of the CG (in relation to the nose cone) the rocket will not be stable in its flight.

You can visualize this by imagining a gust of wind hitting the rocket sideways on its way up. The wind will force the rocket to swivel along the CP, however, the thrust of the rocket upwards will balance out this force as the rocket will swivel on its CG. A good rule of thumb is to have the CP the distance of a body diameter or more behind the CG.

Finding the Centre of Pressure

An old trick to finding the CP of a model rocket is to trace a profile of the rocket onto cardboard, cut the profile out and then balance this profile on a pencil or pen. The balance point will be the CP. This is quite logical if you think about it because a sideways wind hitting the rocket on its way up acts upon the profile of the rocket.

In 1966, James S. Barrowman, an aeronautical engineer at NASA, came up with a simplified method for calculating the centre of pressure of a model rocket. Barrowman's calculations are used in rocket design and flight simulation software such as OpenRocket.

Another way to determine CP is to use these simplified calculations on this web page from the NASA web site.

We will use OpenRocket to determine CP for the rest of this article.

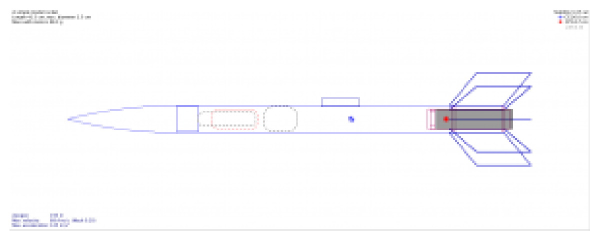

Figure 3 – Rocket design after changes

Changing the Centre of Pressure

If you do not have a copy of OpenRocket you may download one by clicking on this link. From the file menu of OpenRocket you may open up the example rocket by selecting Open example. Figure 2 shows the sample rocket.

You may observe in figure 2 that the CG is 26 cm from the nose cone and the CP is 32 cm from the nose cone (you may have to click on the picture to see this information). Having the CG ahead of the CP means that this design is a stable one.

Let's now change the CG of the design. We can change the weight of the nose cone by clicking on Nose cone | Override | Override mass. For our example we add 20 grams to the Override mass value. Now if we look at our CG value it is 24 cm instead of 26 cm. The CP did not change.

To change the CP lets add fins to our design. Double click on Trapezoidal fin set to open up the fin configuration. Change the Number of fins value to 8. The CP of our rocket is now 34.7 cm. Figure 3 shows our new design.

Suggested Reading

The following is a list of some of the resources used in the writing of this article:

1. Handbook of Model Rocketry by G. Harry Stine and Bill Stine.
2. OpenRocket technical documentation by Sampo Niskanen.
3. Model Rocket Stability by Rick Weber

Flight Pattern of a Model Rocket Launch

Learning Objective	In this lesson we will look at the flight path of a model rocket. By the end of the lesson the student should understand the various stages of a model rocket flight.
Grade Level	9 – 11

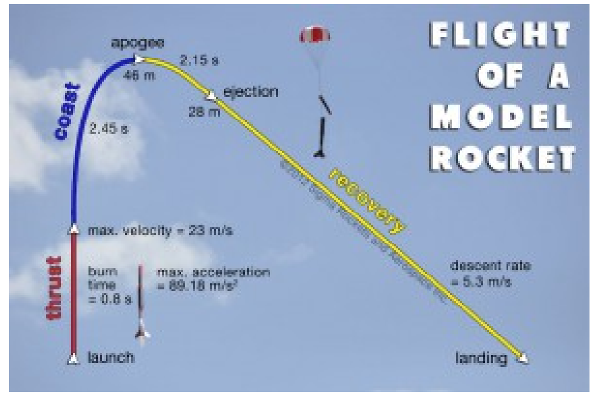

Figure 1 - Flight Path of a Model Rocket

– Introduction –

In the diagram on the right we can see a graphic of a typical model rocket flight. As you may see in the diagram the four main stages of a model rocket flight are thrust, coast, apogee and recovery. We used our electronic altimeter to record data for each of these stages. We have included the data collected from our test flight with our rocket flight path graphic.

Our test rocket was launched using an Estes B6-4 rocket motor.

Thrust Phase

The Thrust Phase is the first phase of the flight and begins right after ignition. It is during the Thrust Phase where the model rocket gets all its upward acceleration. The length of the Thrust Phase is determined by the burn time of the motor. For our test flight the burn time was measured at 0.8 seconds.

The acceleration and maximum velocity the rocket reaches is determined by the total impulse of the motor and the weight of the rocket. And it occurs during the thrust phase. For our test flight the maximum acceleration was recorded as 89.18 m/s^2. The maximum velocity that our test rocket reached was 23 m/s.

Total impulse simply means the product of the average force of the motor and the burn time. In other words:

$$\text{Total Impulse} = \text{Force}_{average} \text{ X } \text{Time}_{burn}$$

Since force is measured in Newtons and time in seconds, Total Impulse would be measured in Newton-seconds. We will not determine Total Impulse in this article. In future articles we will go into more detail with regards to this parameter.

Coast Phase

After the burn time of the Thrust Phase the delay or Coast Phase begins. It is during this phase where there is no thrust coming from the motor. It is here where the rocket begins to decelerate. It may reach its apogee during this stage. The Coast Phase gives way to the ejection of the recovery device. For our test flight the Coast Phase was broken up into two values. The first one was the time taken from the end of the Thrust Phase to the apogee of the flight. This was recorded as 2.45 seconds. The second time was the time taken for the rocket to go from apogee to ejection. It was recorded as 2.15 seconds. Thus the total time the model rocket coasted for before ejection was 4.6 seconds. This time is known as the delay time.

You may find the delay time in the model rocket classification as well. It is the last number shown. For example a B6-4 motor has a delay of 4 seconds which is pretty close to the actual time we recorded.

Apogee and Ejection

On our graphic in figure 1 we show the ejection charge coming after apogee or the highest altitude in the flight. This is the case for most rocket flights. This is also the most desirable flight pattern. However, in some situations the ejection of the parachute comes before the apogee of the flight. This is caused by a delay that is too short.

It may be dangerous for ejection to happen before apogee as the rocket is traveling at a high speed when the parachute is deployed. This may damage the parachute and the rocket. As well, the opposite is true. A delay that is too long may make for a deployment too close to the ground. Or in some cases so late that the rocket crashes.

For our test flight the apogee was recorded at 46 meters. Our ejection altitude was recorded at 28 meters above the ground. Apogee occurred 2.45 seconds after the end of the trust phase or 3.25 seconds after the rocket lift off. The ejection happened at 4.6 seconds after the burn phase or 5.4 seconds after the rocket left the ground.

Recovery Phase

Nothing brings more relief when launching model rockets than to see the parachute glide the rocket to a soft landing. The speed at which the rocket returns to the ground depends on the size and efficiency of the recovery device. Generally it is good to bring a model rocket down gently so that it will not be damaged. The recovery phase starts once the ejection charge is fired and the parachute is pushed out. For our test flight the rocket descended at 5.3 m/s.

Our Test Model Rocket

The test rocket we built was done using OpenRocket. The rocket has 3 fins, is 63 cm long with a 34 mm diameter. A B6-4 motor was loaded into the rocket as well as an electronic device to take measurements for our flight analysis. We used an electronic altimeter to record flight data.

Flight Analysis

Our model rocket was launched on a calm day. The flight was smooth and the nylon parachute deployed as expected. We have included a table of our flight measurements below to correspond with our graphic in figure 1 above.

Table 1 – Rocket Flight Analysis

Parameter	Actual Measurement
Apogee	46 m
Maximum Velocity	23 m/s
Maximum Acceleration	89.18 m/s^2
Time to Apogee from End of Thrust Phase	2.45 s
Time from Apogee to Ejection	2.15 s
Ejection Altitude	28 m
Flight Duration	9.9 s
Descent Rate	5.3 m/s

In the video of our flight analysis the model rocket is stopped and held in place at its various points in the flight path. As mentioned above, the measurements were taken using an electronic altimeter.

Test your knowledge

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What are the four main stages of a model rocket flight?

thrust, recovery, land, altitude
takeoff, recovery, loiter, stabilize
thrust, coast, apogee, recovery
takeoff, coast, altitude, recovery
Correct! Wrong!
The four main stages of a model rocket flight are thrust, coast, apogee and recovery.

Continue >>

What is the name of the parameter used to measure the recovery phase of a rocket flight?

burn time
maximum acceleration
descent rate
minimum velocity
Correct! Wrong!
The recovery phase starts once the ejection charge is fired and the parachute is pushed out. The rocket descends at the decent rate and is usually measured in metres per second.

Continue >>

The Thrust Phase of the rocket flight is determined by the burn time of the rocket motor?

True
False
Correct! Wrong!
The Thrust Phase is the first phase of the flight and begins right after ignition. It is during the Thrust Phase where the

model rocket gets all its upward acceleration. The length of the Thrust Phase is determined by the burn time of the motor.

Continue >>

Apogee is the term given to the highest point of the rocket flight?

True
False
Correct! Wrong!

Continue >>
Flight Pattern Quiz
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