PEAK OF FLIGHT NEWSLETTER

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How to Determine the C_d of a Parachute

By Tim Van Milligan

We just received these newly printed parachutes in from our supplier, and already people are asking us what the Coefficient of Drag (C_d) is for the soft rip-stop nylon. The Cd is used to find the descent rate of the chute, so you can determine if the rocket will land softly, or if you need to find a larger chute so it touches down slower.

In this article, I'll go through the process of backing out the C_d of the chute based on actual flight data. This article will be most useful to TARC contestants who have to land their rockets at a specific time.

The Step-by-Step Process

This is a fun experiment because you actually get to launch a rocket. What could be more fun than that?

The general process is to launch the rocket, collect the flight data, and then do some math later to determine the C_d of the parachute. The one hitch in the process is that in order to find the C_d of a parachute, you need to first collect some data. The hardest piece of data to find is the descent velocity of the parachute. For this, I recommend using a recording altimeter that allows you to download the actual flight data to a computer after the launch. At Apogee Components, we sell a number of altimeters that will work for this experiment:

- Jolly Logic AltimeterThree
- PerfectFlight Pnut
- Altus Metrum Micro Peak

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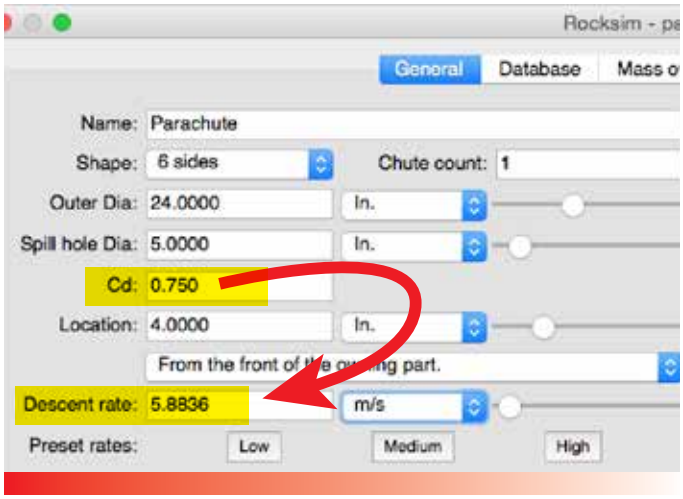

Figure 1: The C_d value of the parachute is used to determine the descent rate of the falling rocket. If you want to predict the duration of your rocket, you need to determine the actual Cd of the chute you are using.

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For my experiments, I used the Altimeter-Three because there is less work you have to do to find the descent rate (also called "descent velocity"). This altimeter automatically calculates it for you, but the others will work too. You'll have to do a little extra math if you use a different altimeter. We'll get to that part later. For now, we'll assume you have the descent rate from your altimeter. In that case, the formula to find the Cd is:

$$C_d = \left(\frac{2 \times g \times m}{\rho \times S \times V^2} \right)$$

Where:
g = Acceleration due to earth's gravity = 9.81 m/s^2
m = mass of the rocket (Kg)
r = density of air (1.225 Kg/m^3 at sea level)
S = Surface area of the parachute (m^2)
V = descent velocity of the rocket (m/s)

Note that we're using metric units here, because it gets more complicated when using Imperial Units. In the English system mass is measured in slugs, which is harder to comprehend. The only thing you'll have to do is to convert your parachute diameter from inches to meters, which is relatively simple; just multiply inches by 0.0254 to get it into meters.

It is also important to compute the surface area of the chute based on its shape. The chart below shows how to compute the area.

Parachute Shape	Area Formula
Square	D^2
Hexagon	$0.866 \times D^2$
Octagon	$0.828 \times D^2$
Circle	$1/4 \times \pi \times D^2$

Where:
D = diameter of the chute.

The Diameter in this chart is measured across the flats sides, not corner-to-corner. Therefore, if you have an 18-inch hexagon parachute from Apogee Components (https://www.apogeerockets.com/Building-Supplies/Parachutes/Up-to-24in/18in-Printed-Nylon-Parachute), the area is found by:

S = 0.866 x (18 x .0254)^2
S = 0.4572 m^2

The next variable to solve the C_d equation is the mass of the falling object. As mentioned before, this is the mass of the rocket including the parachute. The easiest thing to do is to pick up the rocket after it touches down on the ground and weigh it immediately. That is exactly what I did in this process because it includes both the parachute and the "spent" rocket engine.

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The "spent" engine is the name we give to the rocket engine after all the propellant has burned. They can vary a few grams from one engine to the next, so I weigh the rocket immediately after the launch so that I'm not using an approximate value and it matches the flight data from the altimeter.

As soon as you make the weight measurement, annotate the data you collected from the altimeter. For the AltimeterThree, I go to the app on my phone and type in the weight in the "Notes" section on the "Info" screen. I also make note of the size of the parachute used in the same text field, so I don't forget later. If you're like me and you don't write it down, you'll forget it later and then the data is useless.

I next made a spreadsheet table to enter the data and do the simple math for me.

For example, the number shown in Column C of **Table 1** is set up to convert the diameter from inches to meters by multiplying the value in Column B by 0.0254.

Similarly, the values in Column D are set up to take the value in Column C, square it and then multiply it by 0.866 (since it is a hexagon shaped parachute).

Creating a table like this is probably the hardest task in computing the C_d of the parachute, but over time it will save you a lot of time. The reason is that you'll need to fly the rocket many times to find an average C_d value.

If you are in TARC, you should be capturing data like this for every flight you make, so that you can determine what rocket mass you should have to get the final descent rate you need for the contest (hint, hint).

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Cd Chart

Description	Diameter (inch)	Diameter (m)	Area = S (m^2)	Mass (Kg)	V (m/s)	Cd
Flight #5	24	0.6096	0.3218	0.3209	5.00	0.639
Flight #4	18	0.4572	0.1810	0.3543	6.50	0.742
Egg Tosser	15	0.381	0.1257	0.0724	3.00	1.025
TARC Rocket 7-29-2017	24	0.6096	0.3218	0.3543	4.10	1.049

Table 1: Setting your data up in a chart makes it easy to perform the experiment multiple times.

www.apogeerockets.com/Rocket-Kits/Skill-Level-2-Model-Rocket-Kits/SkyMetra

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Finding the Descent Velocity

When you get your flight data from your recording altimeter downloaded to your computer, you want to look at the plot of altitude vs time, like the one shown in **Figure 2** from an AltimeterThree.

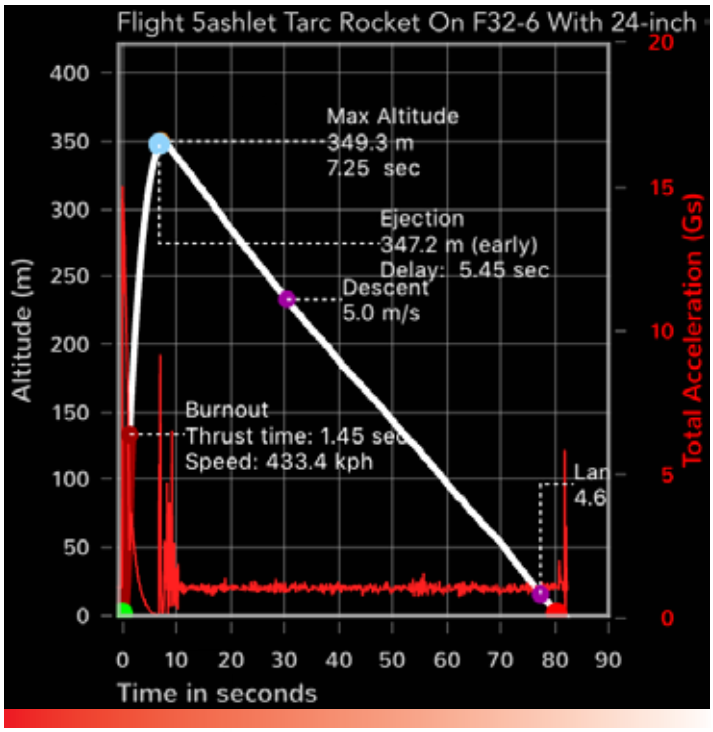

Figure 2: Typical flight data as recorded by the AltimeterThree altimeter.

The nice feature of the AltimeterThree is that it tells you the descent rate of the rocket right on the plot. In this case, the descent rate is indicated by the purple dot and is labeled as 5.0 m/s.

This is the value you would use in the C_d equation (or in the spreadsheet table you made). If you are using one of the other altimeters, you'll have to determine the descent rate by picking off two points from the chart and doing a little math.

First, take the raw plot, like the one shown in **Figure 3**, and draw a straight line to smooth out the data.

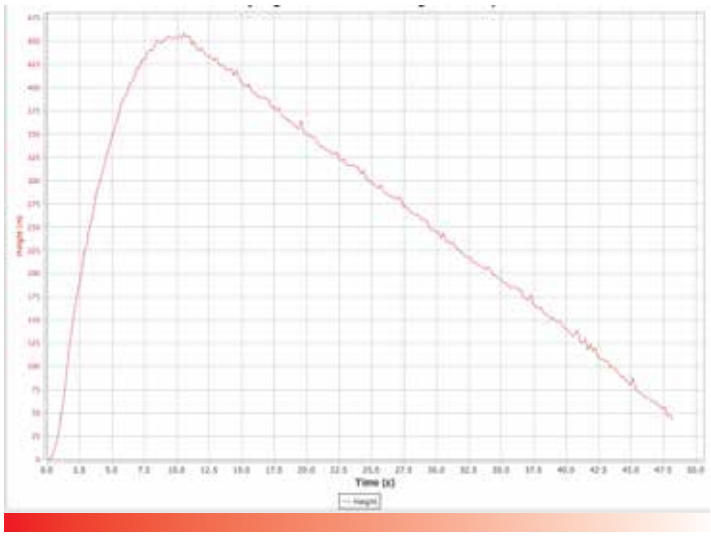

Figure 3: This is the raw data from the MicroPeak altimeter plotted out on a graph. The data looks jagged because the atmosphere is not as perfectly uniform as we'd like. It needs to be smoothed out.

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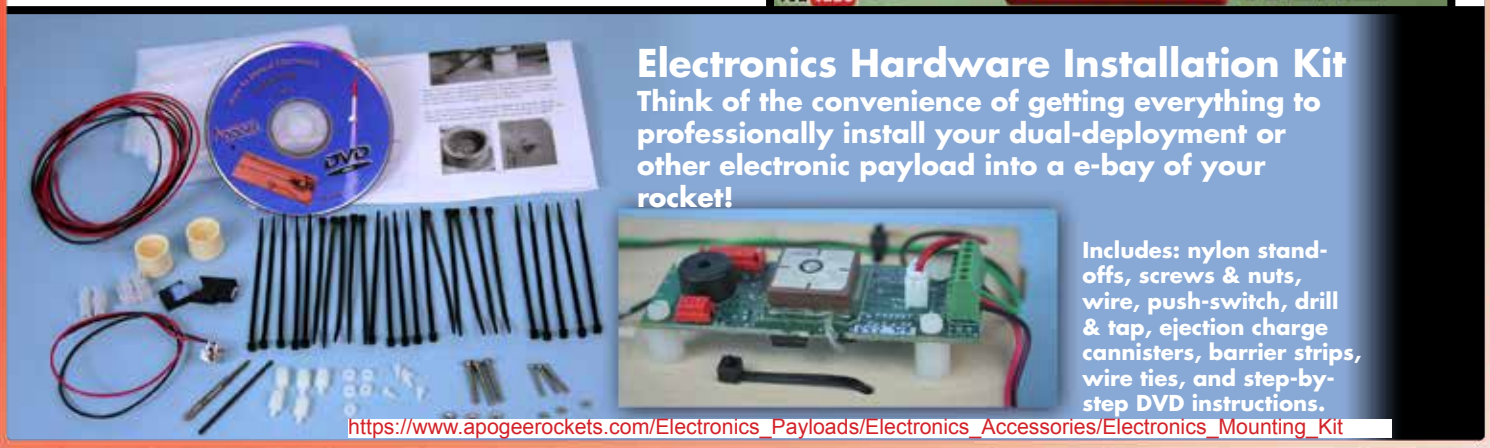

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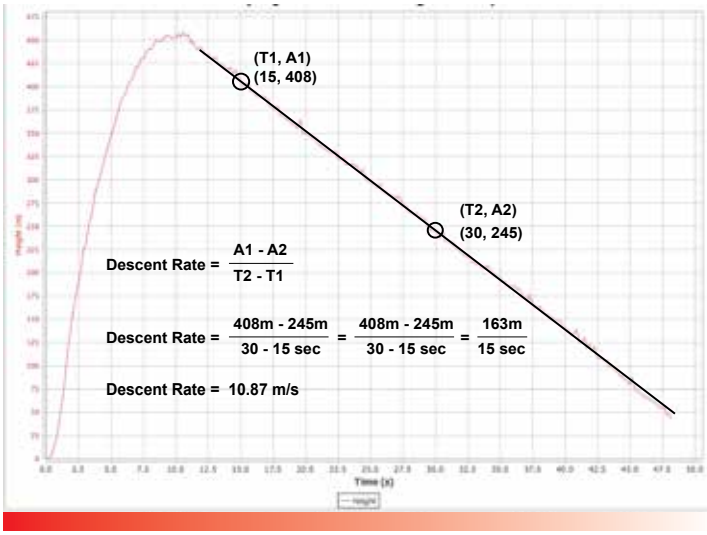

Figure 4: The straight line drawn through the rough data makes it easier to pick two points off the chart. The descent rate is calculated from the two points.

Once the data has been smoothed (called a "best-fit line"), two points are selected from the line. As shown by the simple formula in **Figure 4**, the descent rate is determined by the change in altitude divided by the time difference between the two point.

This descent rate value is then input into the C_d formula.

Some Important Things to Remember

When pulling data off the graph of altitude vs time, you have to make sure you pick points where the parachute is actually open fully. Sometimes you will get false readings if you just rely on the stated descent rate. For example, look at the graph in **Figure 5**.

This chart is typical of a rocket that uses dual-deployment or a Chute Release (https://www.apogeerockets.com/Electronics-Payloads/Dual-Deployment/Chute-Release). The rocket's parachute is delayed in opening until it is closer to the ground. Initially it falls at a high rate of descent and then transitions to a low rate for final touchdown.

If you used the stated descent rate of 10.3 m/s you would be fooled to thinking that is the rate associated with the parachute. Therefore, you should always look at the graph of the

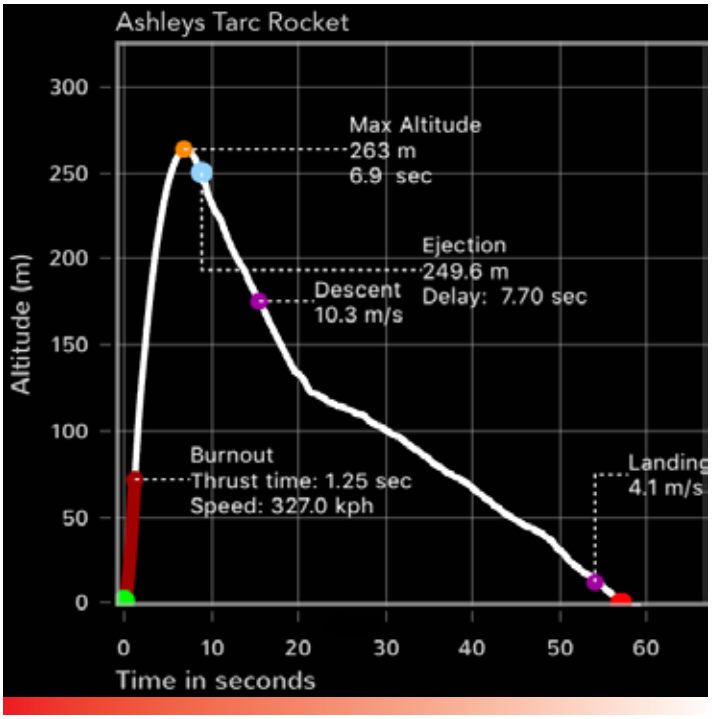

Figure 5: This chart indicates that the descent rate for the rocket was 10.3 seconds. But the chute didn't open until around 20 seconds in the flight.

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flight to make sure you are seeing the true descent rate.

In this example, you can still get the true descent rate, but you have to do the math like you would if the rocket used one of the other recording altimeters (see example in **Figure 3**).

The second point I'd like to make is to ignore the landing speed that is reported by the AltimeterThree device. The reason is that it is the final touchdown speed, and is often lower than the rate of the parachute as it falls through still air. One reason for this is that usually the heavy part of the rocket (like the fins and the rocket motor) lands first on the ground, which changes the mass that is suspended by the parachute. It only may be a brief second, but it is enough to make the altimeter think it is falling slower than it is.

Another reason for the slower descent rate at landing is because of a cushioning effect in the thicker layer of air near the surface of the ground. It is more noticeable in airplanes as they come in for a landing, and they seem to glide further as they get into the cushion of air near the ground. If you used this as the descent rate, then your total time aloft predictions will be too long.

It is also important that when determining the C_d of a parachute, you need to repeat the process through many tests. Each time you do the flight test, you will get slightly different results. The reason for this again is that the air that the rocket falls through is not consistent from flight to flight. The other reason the results vary is that sometimes the parachute will oscillate as it descends. Each time it sways, it spills a little air out of the chute and it falls faster.

If you want more consistent results, you want to limit the oscillations of the parachute. This can be aided by making sure you all the suspension lines are the same length. It is possible for them to be off a little bit just from the way you attach the chute to the rocket.

Figure 6: The lines of this chute are beginning to twist, which pulls the canopy closed. That makes the rocket fall faster.

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Figure 7: A swivel helps prevent the strings from twisting and collapsing the canopy.

You should also use a swivel (https://www.apogeerockets.com/Building_Supplies/Parachutes_Recovery_Equipment/Swivels) to prevent the chute from twisting the lines which shortens the lines and reduces the canopy diameter. Remember, the smaller the diameter, the faster the chute will fall. A parachute with twisted lines will have a lower C_d than one that is fully open.

Another thing that causes the descent rates to vary is the rocket that hangs below the chute. Its surface area also contributes to the drag of the falling chute and makes the chute appear to be more effective than it really is.

Figure 8: This rocket is oriented sideways so that it increases the drag. If you used the Cd computed from this flight, it would think the parachute was more effective than it really is.

The suspended rocket can also oscillate under the canopy, which again affects the steadiness of the descent rate. The greater the oscillation, the lower the C_d value the chute will appear to have.

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Figure 9: If you use a small mass instead of a rocket, you'll get more consistent descent rates because the payload doesn't affect the air flowing into the canopy as much.

To eliminate this variable when testing, you should detach the chute you are testing from the rocket. This is done by having the test chute eject completely from the rocket. Obviously it will need its own mass, so hang a weight from the canopy as shown in **Figure 9**. Some things you can hang are a heavy nose cone, a sack full of sand, or some lead weights — and don't forget to include the altimeter too.

The rocket itself will have to have its own chute to bring it down separately. The reason for doing this again is that the smaller weight has lower surface area and, therefore, lower drag than a rocket body, so it won't effect the descent rate of the parachute as much. You'll get a more consistent C_d value when you compute its value after the flight.

Drop Testing

If you have access to a high platform and are able to perform drop tests, that's even better than launching (though nowhere near as fun). The advantages are that it reduces the chances of losing the model you are testing and you have more control on thermals that would vary the descent rate of the rocket. You can control the thermals by picking the time of day to perform the tests for when they are not present.

For drop tests, you know the height of the release point, and you can use a simple stopwatch to determine how long it takes to touch down.

Using altimeters for drop tests is a little more complicated because they are typically designed to trigger data recording by sensing an increase in altitude (like a rocket taking off upward).

The only altimeter we carry that will measure in the downward direction is the JollyLogic AltimeterThree (https://www.apogeerockets.com/Electronics-Payloads/Altimeters/Jolly-Logic-Altimeter-Three). To make it work for drop testing, you do have to configure it for either kite mode or "experimental" mode to capture the data. I haven't tried this myself yet because I haven't found a good "high-place" to stand and release the parachutes. But it should record data as soon as you turn it on.

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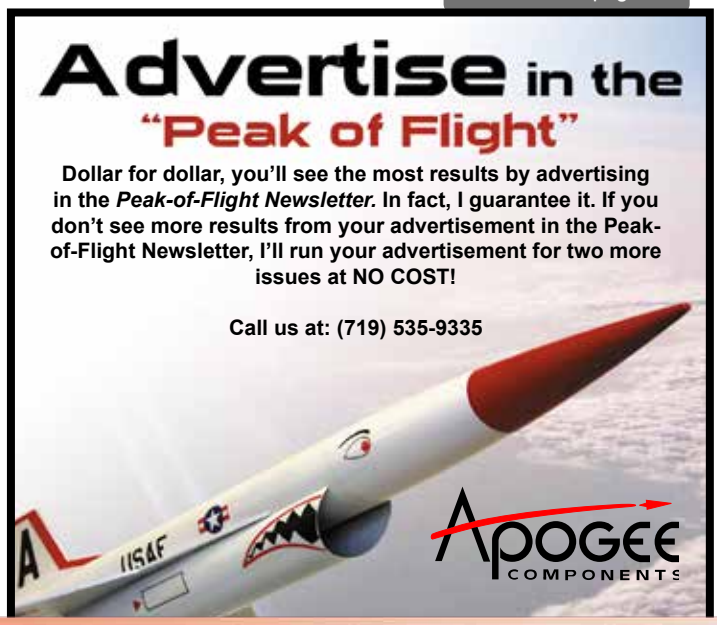

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Conclusion

The process of finding the C_d of a parachute is simple and a lot of fun. I hope you try it rather than trusting the numbers that parachute manufacturers supply customers. If you do perform this, please let us know your results for the chutes you are testing. I'd love to see some flight data to compare against. I haven't done enough flight tests with the printed nylon chutes yet to know their C_d values, but I suspect they are in the typical range of 0.75, which is what most flat hexagon shaped parachutes have. So that would be a good starting point if you wanted to use RockSim to determine the total flight time of your rockets.

References:

Properly Sizing Parachutes for Your Rockets - Apogee Peak-of-Flight Newsletter #149 (https://www.apogeerockets.com/education/downloads/Newsletter149.pdf).

About The Author:

Tim Van Milligan (a.k.a. "Mr. Rocket") is a real rocket scientist who likes helping out other rocketeers. He is an avid rocketry competitor, and is Level 3 high power certified. He is often asked what is the biggest rocket he's ever launched. His answer is that before he started writing articles and books about rocketry, he worked on the Delta II rocket that launched satellites into orbit. He has a B.S. in Aeronautical Engineering from Embry-Riddle Aeronautical University in Daytona Beach, Florida, and has worked toward an M.S. in Space Technology from the Florida Institute of Technology in Melbourne, Florida. Currently, he is the owner of Apogee Components (http://www.apogeerockets.com) and also the author of the books: *Model Rocket Design and Construction*,*69 Simple Science Fair Projects with Model Rockets*: *Aeronautics* and publisher of the *Peak-of-Flight Newsletter*, a FREE e-zine newsletter about model rockets. You can email him by using the contact form at: https://www.apogeerockets.com/Contact.

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