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# APOGEE

## PEAK OF FLIGHT

N E W S L E T T E R

### BASICS OF DYNAMIC FLIGHT ANALYSIS

(PART 3) The Damping Moment Coefficient

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## Basics of Dynamic Flight Analysis Part 3

### The Damping Moment Coefficient

By Tim Van Milligan

In parts 1 and 2 in this series of articles on Dynamic Flight Analysis, we discussed the Longitudinal Moment of Inertia and the Corrective Moment Coefficient. Then we looked at the roles they played in determining the trajectory of a rocket. If you missed those articles, see Newsletters 192 and 193.

<http://www.ApogeeRockets.com/education/downloads/newsletter192.pdf>

<http://www.ApogeeRockets.com/education/downloads/newsletter193.pdf>

The next parameter I want to discuss is called the "*Damping Moment Coefficient*."

As we saw in the earlier articles, when a rocket is disturbed in flight, the disturbance causes the rocket to deflect from its path by swinging the nose into the direction of the disturbance. For example, a sudden gust of wind from the left pushes the tail of the rocket to the right, and hence the nose to the left. But as the nose swings to the left, its momentum causes it to keep swinging, and it swings past what would be the zero angle of attack. Then the fins create a restoring force in the other direction and the rocket swings back toward the original flight path. But again, the momentum of the rocket carries the rotation too far the other way, so the fins again create a restoring force in the other direction. The rocket continues to oscillate back and forth because of the original disturbance.

But the distance of each oscillation is less than the previous cycle, so that over time, the oscillations reduce to zero and the rocket continues to fly straight. This is called *damping*. The Damping Moment Coefficient is what determines how far the rocket will be deflected, and how fast the oscillations die down to zero.



**Figure 1: A rocket is hit by a gust of wind and starts pitching the nose back and forth. Damping means that the oscillation dies out over time.**

The Damping Moment Coefficient is made up of two components, one of which is aerodynamic in origin, and the other is propulsive. They are simply added together to get the total Damping Moment Coefficient.

$$C_2 = C_{2A} + C_{2R}$$

$C_2$  = Damping Moment Coefficient

$C_{2A}$  = Aerodynamic Damping Moment Coefficient

$C_{2R}$  = Propulsive Damping Moment Coefficient

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**Propulsive Component of the Damping Moment Coefficient**

The propulsive component is commonly referred to as jet damping. What happens is that the gases coming out of the nozzle seem to make the whole rocket harder to turn. This is similar to increasing the moment-of-inertia of the rocket.

The formula for the propulsive Damping Moment Coefficient is:

$$C_{2R} = \dot{m} [L_{ne} - W]^2$$

Where:

$C_{2R}$  = Propulsive Damping Moment Coefficient

$\dot{m}$  = rate of mass expulsion from the nozzle, grams/second.

$L_{ne}$  = Distance the nozzle is from the tip of the nose cone.

$W$  = Distance the CG is from the tip of the nose cone.

As you look at this formula, the first thing you'll notice is that the greater the distance the nozzle is away from the CG, the higher the Damping Moment Coefficient. Double the distance, and the value of the Damping Moment Coefficient increases by a factor of four. This tells us that a long rocket is going to dampen out oscillations much quicker than a shorter rocket.

The other thing to notice is that the Damping Moment Coefficient changes throughout the burn of the rocket. While it is not directly tied to the thrust produced by the rocket engine, the rate of mass expulsion does change with thrust level. As the motor burns more propellant, and exhaust gases are thrown out of the nozzle, the thrust goes up. So a high thrust motor is going to make the Damping Moment Coefficient a bit higher. This can be seen in Figure 2. It compares the old Apogee Components' C4 versus C10 motors. They both have approximately the same total propellant mass but the C10 expels it out of the nozzle quicker than the C4 motor.

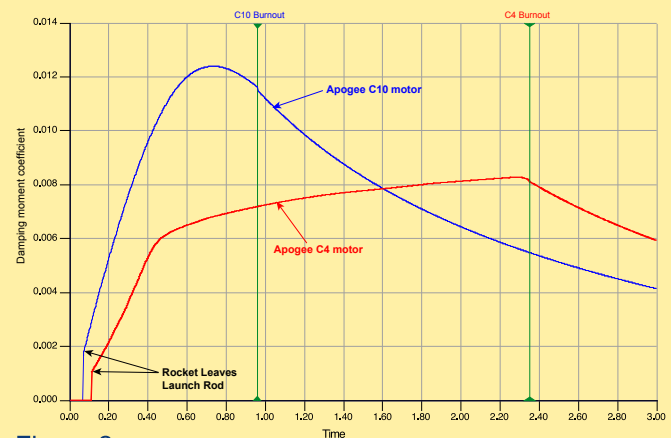


Figure 2

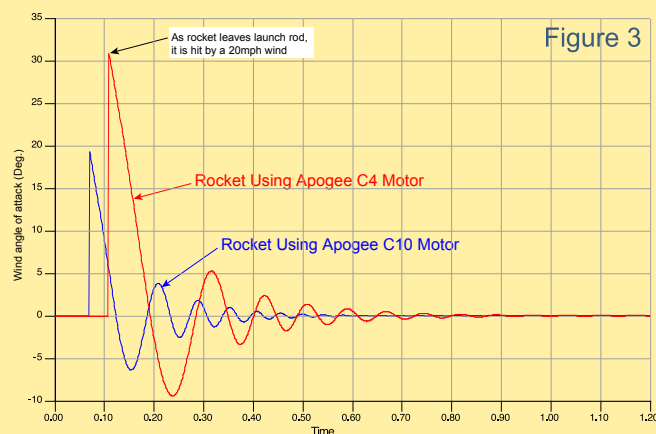
If you're observant, you'll notice from the formula that while the motor is burning, the Damping Moment Coefficient should never be zero. If this is the case, why does the RockSim generated graph (Figure 2) show it zero while the rocket is rising on the launch rod at the beginning of the motor burn?

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The reason is that this is a programming trick done internally in RockSim. We know that while the rocket is on the launch rod, it is constrained from rotating. That simplifies things and allows RockSim to run the simulations quicker. So RockSim, it is told not to calculate the Damping Moment Coefficient while the rocket is still on the rod.



In Figure 3, we compare the angle-of-attack of the same rocket using the two different rocket motors. You can see that the C10 dampens out the oscillations much more quickly than the C4 motor.

**Figure 3:** The gust of wind (a disturbance) that hits the rocket as it leaves the launch rod causes the rocket to start to oscillate. The higher Damping Moment Coefficient of the rocket using the C10 motor causes the oscillations to die down quicker.

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## Apogee News

By Tim Van Milligan

We were having a staff meeting here at Apogee Components, and it was brought up that there isn't any real "news" in our "newsletter". I thought about this a while, and I agreed that we should put something in each issue. The reason to have it is to keep a record of our own history. We have been in business over 18 years. I myself have trouble remembering what happened in the past. And maybe someday in the future, I might sell Apogee Components, and the new owner would want to know the company history too.

### In the last two weeks...

1. We have been working on a new literature package for teachers. It will be called the Rocket Reservoir for Educators. At the current time, it is over 60 pages long, consisting of overhead transparencies,

handouts, and reference materials that any teacher might be able to use. The hope is to release this as a FREE item in the next edition of the Lift-Off Letter. [http://www.ApogeeRockets.com/Lift-off\\_letter.asp](http://www.ApogeeRockets.com/Lift-off_letter.asp)

2. The Noris Rockets kits have arrived, and all the pre-orders were shipped out. This was only the second time in Apogee's history that we took pre-orders for new items. The first time was for the Saturn kits in 2000. I don't like taking customer's money without having the item to ship. I worry that I might get hit by a bus or something, and our great customers wouldn't get the items they ordered.

3. Preliminary plans for a new edition of the book "*Model Rocket Design and Construction*" were discussed. Our supply of books is dwindling, so if there is a good time to start work on this project, it is drawing near. Current projections are to have it done by Christmas of next year.





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### Aerodynamic Component of the Damping Moment Coefficient

The Aerodynamic Damping Moment Coefficient, which is added to the propulsive Damping Moment Coefficient to give us the overall Damping Moment Coefficient is a bit more complex to determine.

Each external component of the rocket (such as nose cone, body tube, fins, and adapters) add to the overall damping of the rocket. And like the Moment of Inertia and Corrective Moment Coefficient, the location of each of these parts in relation to the CG affects their values. The formula for the Aerodynamic Damping Moment Coefficient is:

$$C_{2A} = \frac{\rho V A_r}{2} \sum \left( C_{N\alpha_{\text{component}}} \left[ Z_{\text{component}} - W \right]^2 \right)$$

$C_{2A}$  = Aerodynamic Damping Moment Coefficient

$\rho$  = Density of Air

$V$  = Velocity of the rocket

$A_r$  = Reference Area (usually the area of a circle at the maximum diameter of the rocket).

$C_{N\alpha(\text{component})}$  = Normal Force coefficient of the individual component (nose cone, body tube, fins, etc)

$Z_{\text{component}}$  = Distance from the nose tip to the CP of the component

$W$  = Distance from the nose tip to the CG of the rocket

Let's look at these variables to see how they affect the overall Aerodynamic Damping Moment Coefficient.

$\rho$  = Density of Air. The density of air decreases as the rocket goes higher into the sky. In space, there is no air, so at this point there is NO damping.

$V$  = Velocity of the rocket. The faster the rocket goes, the greater the aerodynamic damping. The term is not squared though, so the damping moment is only directly proportional to the speed the rocket travels. If you look at Figure 4, you'll recognize that the peak



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damping moment for the entire flight occurs pretty close to the maximum speed of the rocket.

**Figure 4: The Damping Moment Coefficient closely follows the speed of the rocket, so that maximum damping occurs when the rocket is near its fastest speed.**

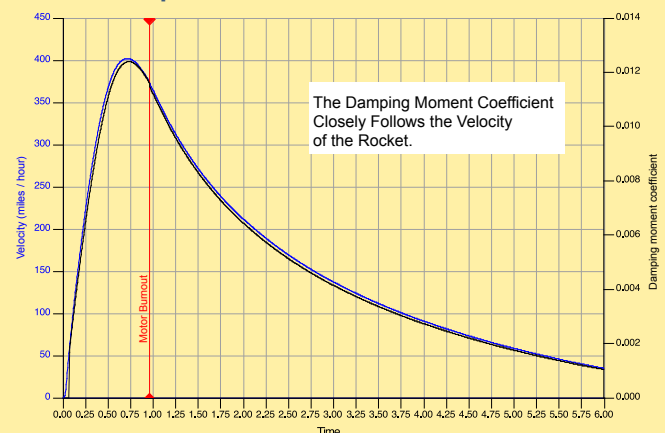


Figure 4

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$A_r$  = Reference Area (usually the cross-sectional area at the maximum diameter of the rocket. This term just tells us that the bigger the rocket, the greater the Aerodynamic Damping Moment Coefficient will be.

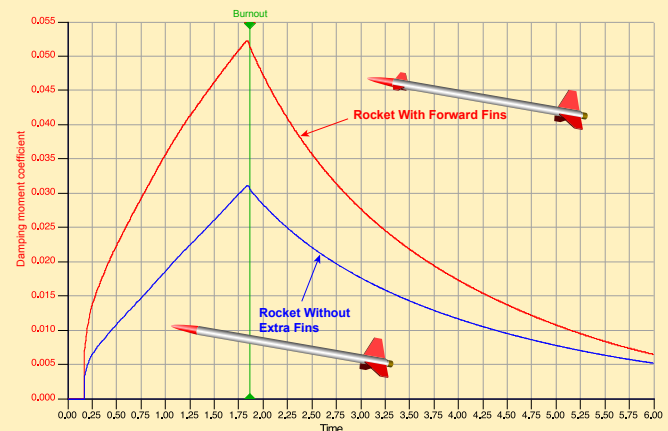
$C_{N\alpha(\text{component})}$  = Normal Force coefficient of the individual component (nose cone, body tube, fins, etc). The magnitude of the part's normal force coefficient makes some components, notably "fins" play a larger role in damping than other parts, like body tubes.

$[Z_{\text{component}} - W]^2$ , which relates how far the component is from the CG of the rocket, has a huge effect on the part's contribution to the Damping Moment Coefficient. The further the part is away from the CG, the more effect it has.

It should be noted that since the distance term is squared, that the value will always be positive. For example, a fin placed near the front of the rocket will have the same damping effect on the rocket as a fin placed near the back end of the rocket. Even though forward

fins are destabilizing, they can help dampen out oscillations!

**Figure 5:** Even though forward fins are destabilizing and not recommended, they can help dampen out oscillations.



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**Aerodynamic or Propulsive: Which has a greater effect on the Damping Moment Coefficient?**

You may be wondering as I did, which component, aerodynamic or propulsive, has a greater effect on the damping of the rocket? For a typical model rocket, the aerodynamic component is much larger. This can be seen in Figure 4 if you look at the Damping Moment Coefficient at any given flight speed (compare the value while the rocket is thrusting, and when it is coasting). The value of the Damping Moment Coefficient is almost identical, which means that the propulsive damping is negligible for this design. The conclusion is that you shouldn't count on the rocket thrust to dampen out any oscillations.

**Conclusion**

In this article, we looked at a third term that affects the dynamic characteristics of our rockets called the Damping Moment Coefficient. It controls how fast the oscillations, that are a result from a disturbance such as a gust of wind, die down.

What I suggest you do is take some of your favorite RockSim designs and modify things like the location of the fins and the length of the tubes. You can then plot out the Damping Moment Coefficient and see how the changes you made affect the shape of the graphs. Don't be afraid to play around, as you can't break anything. Have some fun.

**About The Author:**

Tim Van Milligan (a.k.a. "Mr. Rocket") is a real rocket scientist who likes helping out other rocketeers. 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 a 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 the curator of the rocketry education web site: <http://www.apogeerockets.com/education/>. He is also the author of the books: "Model Rocket Design and Construction," "69 Simple Science Fair Projects with Model Rockets: Aeronautics" and publisher of a FREE e-zine newsletter about model rockets. You can subscribe to the e-zine at the Apogee Components web site or by sending an e-mail to: [ezine@apogeerockets.com](mailto:ezine@apogeerockets.com) with "SUBSCRIBE" as the subject line of the message.



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## Question & Answer

### Which Delay Time Should I Use In RockSim?

By Tim Van Milligan

There has been some confusion among new users of RockSim as to which delay time to select from the drop-down menu list. The problem seems to occur most frequently with high-power motors. Here's why...

All motors will have the following available delays in the dropdown list: NONE, All, plus the numeric values available in the motor data file - such as shown in Figure 1 for the Estes C6 rocket motor.

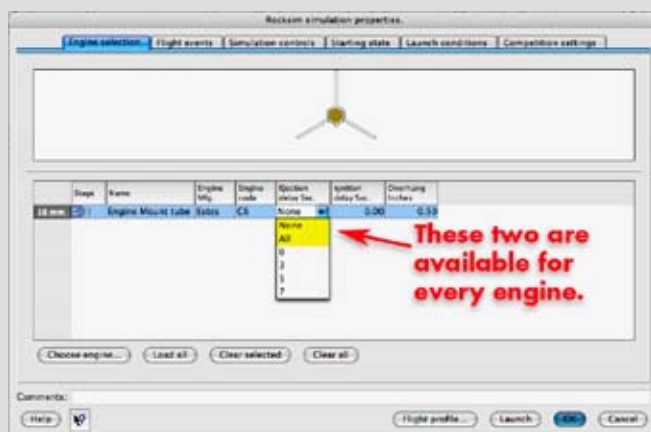


Figure 1

**Figure 1:** The choices in the "Engine delay, Sec" drop-down-menu for the Estes C6 engine include: None, All, 0, 3, 5, and 7.

Most modelers understand how the "numeric-value" engine ejection delays work (see newsletter #131 <http://www.ApogeeRockets.com/education/downloads/Newsletter131.pdf> if you don't understand the engine code for model rockets). But the delay times of None and All are not numbers. You're smart to notice that.

### What does "ALL" do?

To explain what the "All" ejection delay does, you need a little history lesson on the evolution of the RockSim software. I'm not sure when it was, but somewhere between version 2.0 and 4.0 we got a request from a RockSim customer to show on the graphs when each ejection charge delay would occur. That user was pretty smart to know that if you looked at the velocity graph, you could and should try to pick the closest delay available to the minimum speed.

What we did is put a vertical line on the graph to show when each ejection charge delay would occur. See Figure 2. To display this on the graphs though, you have to select the "All" delay.

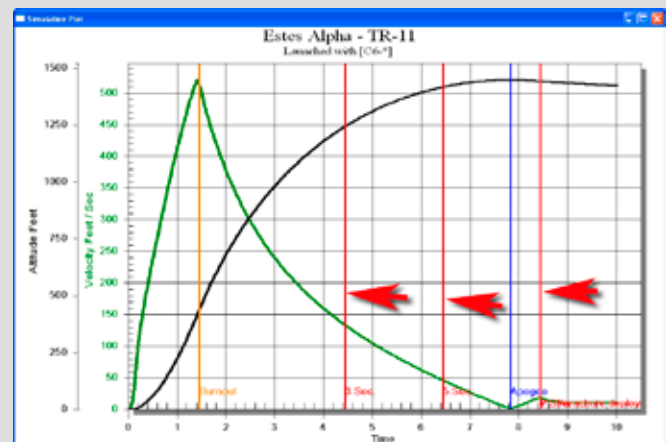


Figure 2

**Figure 2:** Selecting the "All" delay from the available delays menu will only draw a line on the graph showing where the other available delays will occur during the flight.

You'll note that looking at the graph in Figure 2 that an Estes C6-\* motor was chosen. The asterisk actually means that the delay called "All" was selected from the drop-down menu. On the graph, you see vertical lines (red) that show us where the other available delays would occur during the flight.

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It is important to note that the Estes C6 motor has other delays available. You can see this in Figure 1. They are 0, 3, 5, and 7 seconds. The zero second delay is the burnout line (orange). So our graph does show ALL the available delays.

In the simulation summary screen, the motor in the list will also have the asterisk shown, as is seen in Figure 3.

Sim	Result	Engines loaded	Max. altitude Feet	Max. velocity Miles / Hour	Max. acce Gees	Time to apogee	Velocity at deploy Miles / Hour
1	0*	[C6-*	1260.33	311.38	30.36	7.46	41.34

Figure 3

**Figure 3:** When you see the asterisk in the motor designation, that tells you that the delay called "All" was selected from the drop-down menu.

You'll notice one last thing when comparing the graph in Figure 2 with the simulation summary in Figure 3. The actual delay that was used to calculate the

results was the longest delay time from the drop-down menu. The longest happens to be 7 seconds. So the summary screen will be showing data for a 7.0 second delay (see Figure 3 again).

The confusion comes from HIGH-POWER motors. Most high power motors do NOT have any ejection delays available. They are capped off on the front end. This is commonly referred to in model rocketry as a "plugged" motor. The engine does not push off the nose cone and eject the parachute. If you select a plugged motor for your rocket and did not have other means to deploy the parachute, the rocket is going to crash.

When you load a high power motor into a design and go to the delay dropdown menu, you're only going to see two choices: None and All.

What do you suppose will happen if you choose the "All" choice?

We just said that "All" will display the other delay choices on the graph, and it tells RockSim to use the delay choice with the highest value for the summary screen values. THERE ARE NO OTHER DELAY TIMES AVAILABLE, so it treats the flight as if the motor is plugged – NO ejection charge at all.

As we just said, a plugged motor is going to cause the rocket to arc over and continue its trajectory right into the ground. This is known as a crash or lawndart. In the summary screen, you'll see a little icon that shows a rocket with its nose buried into the ground. See Figure 4.

Sim	Result	Engines loaded	Max. altitude Feet	Max. velocity Miles / Hour	Max. acce Gees	Time to apogee	Velocity at deploy Miles / Hour
1	0*	[C6-None]	1260.33	311.38	30.36	7.46	n/a

Figure 4

**Figure 4:** The bent rocket icon in the summary screen means your rocket crashed.

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How do you get around this if your desired rocket motor does not have any available delay times?

There are actually two ways. The first way is to highlight the delay field and simply type in a number, such as is shown in Figure 5. And yes, you can use decimal values!

	Stage	Name	Engine Mfg.	Engine code	Ejection delay Sec.	Ignition delay Sec.	Overhang Inches
1.6 mm		Engine Mount tube	Estes	C6	2.5	0.00	0.50

Figure 5

**Figure 5:** You CAN type in any delay number you want when selecting a rocket engine!

**IMPORTANT:** After typing in the number, you MUST hit the TAB key or the ENTER (not RETURN) key on your computer. This forces RockSim to accept the new value you have typed in for the delay time.

### Some RockSim History

Another history lesson... In previous versions of RockSim (through version 7), the delay choices in the drop-down menu included a zero for every single motor, including plugged motors.

Either our customers didn't realize they could type in a delay number in the selection box, or they couldn't get past the fact that they were actually flying a plugged motor with no delay. But whatever it was, some people were still confused. So what do you think they did?

That's right, they chose the zero second delay (which was the only other option besides "All" in prior versions of RockSim). That is the wrong choice, since a "0" for the ejection charge delay always means one thing. That means to deploy the parachute immediately after the propellant is consumed in the motor. A zero does NOT mean plugged.

I would get dozens of emails a month asking me why their simulation only went to 100 feet in altitude on

a M-class motor. It only went that high because they didn't allow their rocket to coast upward for any amount of time. Deployment occurred way too soon because of the zero second delay.

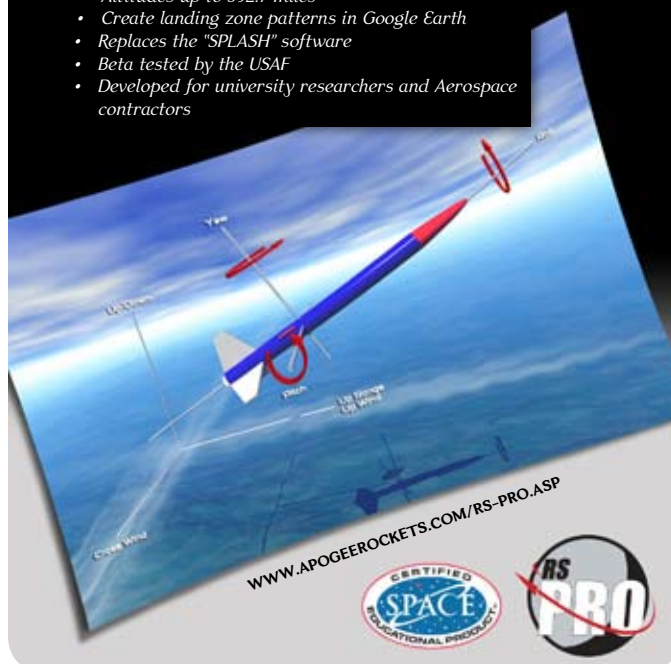
What I would have to tell people to do is *type in a very long delay*, such as 100 seconds, and then run a simulation. Most rockets would be back on the ground before that, which effectively makes the motor a "plugged" variety. Obviously, the rocket would crash on the ground. But that was OK, since this was going to be a two-step process.

The next step would be to look at the flight summary screen. RockSim would tell them what the optimal delay would be. Using that information, I'd tell them to run a second simulation, but this time "type in" the optimum delay value from the summary screen. Now the simulation would deploy the chute at the apogee point in the flight.

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It was a two-step approach that would help them to set the electronics that they'd be using to control the actual parachute deployment out of the rocket.

### The "None" Delay Choice

When version 7.0 came out in 2003, we got a lot smarter. We got rid of the "0" for a delay choice for all high-power motors, and instead, we replaced it with the "None" choice that you see now. That leads us to the second way to tell RockSim when to deploy a parachute.

Remember, that the "None" delay choice means the motor is plugged (has NO delay). This is typical for most high-power motors.

Also in version 7.0, we added a new tab in the "prepare for launch" screen. This tab is called "Flight Events." It is on this screen that you tell RockSim when to deploy the parachute. With each parachute in the rocket, you can tell the software when you want it to be ejected out of the model.

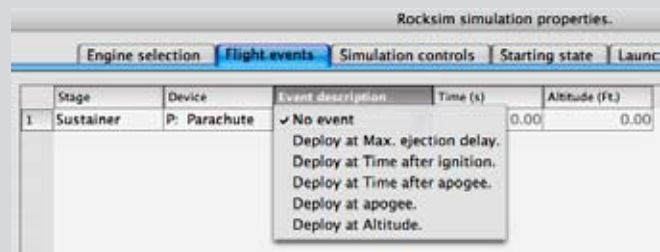


Figure 6

**Figure 6:** The "Flight Events" tab allows users to control when the parachute is ejected out of the model.

In hindsight, the flight events tab was a stroke of genius. It has been much more intuitive for users to figure out how to deploy parachutes at the correct time in the flight for high power rockets. I no longer get emails asking me how come their rocket only went to 100 feet up on a M-class motor.

But I still occasionally get emails asking what "None" means. That is the purpose of this article. None, in regards to ejection delay, means: "you won't get none."

We debated whether or not to change the name to "plugged." But from my conversations with newbies to high power, they don't understand initially what plugged means either. Technically, there is no "plug" in a reloadable engine casing. The end is capped off by the forward closure. The word "plugged" comes from the world of black powder rocket engines, where there was an actual plug of clay on the top of the motor that prevents gases from coming out the top end of the motor (such as the Estes D11-P engine). Because high power motors are not really plugged, we left the word as "None."

### What Does The Future Look Like?

We're constantly trying to figure out how to make engine selection easier and more intuitive for customers. So what can we do in future versions? My thinking is that changing the Flight Events tab would be the place to concentrate our energy. As I mentioned previously, our customers have grasped the concept of flight events quite easily. I get far fewer emails about engine selection now than I got in the past.

One area where I still get questions is how to set up staging of complex high-power rockets. You can't use None or All - and those are the only two choices for most high power rockets. If you select either of them, the rocket will not ignite the upper stage and it will crash land. In RockSim version 8, you MUST type in a number in the delay selection field. There is no other option at this point.

We have taken some initial steps at eliminating the confusion of staging in our new RS-PRO software. Besides using the flight events to tell when the parachutes are deployed on the rocket, we have a separate "flight

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events' choice to tell when a multistage rocket fires the upper stage. See Figure 7.

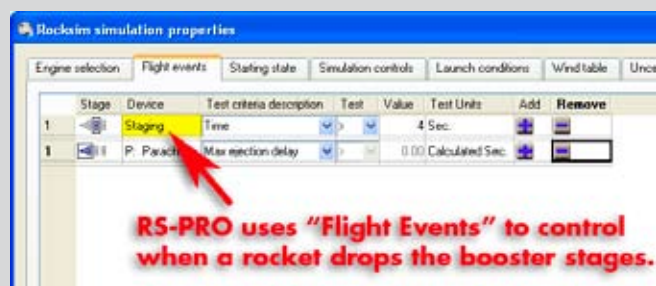


Figure 7

**Figure 7:** In RS-PRO, you can set when a multi-stage rocket "stages" by using the flight events. This gives you more control, since it is actually done with electronics carried in the rockets.

Personally I already love this feature, as it seems more intuitive to me too. So in the next version of RockSim, we'll probably add something similar to what we do with RS-PRO. The difference, though, is that we'll probably limit the number of choices available compared to what is possible in RS-PRO. The RS-PRO software has a level of complexity that isn't needed in sport rocketry. I'm pretty sure that you may not care about what gamma angle your rocket is at when the model stages, let alone even know what that means. In fact, the feedback we've gotten from RS-PRO customers has shown us that there are too many choices, even for highly complex research rockets. Seems like everyone wants simple options like: "stage at flight time XYZ."

The other change we'll probably make in the next version of RockSim is to get rid of the "All" delay choice. I don't know of anyone that still uses it. Everyone seems to go with the optimum delay value shown in the summary table on the main screen of RockSim. In fact, I've discovered that it doesn't work properly in version 8. And yet no one has reported it even though RockSim

v8 has been out for 2-1/2 years. That is about as much proof as I need that no one uses the feature, and it should be eliminated.

## Conclusion

There is one last thing that I'd like to say about picking the correct delay choice from the engine selection menu: Confirm everything in the 2D Flight Profile!

I've said this in just about every RockSim article that I've written because it is so very important. You have to look at the 2D Flight Profile to see the animation of the flight to make sure that events are happening at the correct times throughout the flight. The numbers on the summary screen won't tell you the full story of what will happen in your flight. You have to see the events actually happen with your eyes to confirm you've gotten everything set up properly in your simulations.

Picking the right delay choices in RockSim is not too difficult if you sit down and think things through. I've asked similar questions in the past, so I'm just as guilty of looking for the quick answer instead of engaging my brain to do its job. But in watching the 2D Flight Profile, I've found my mistakes and the solutions to fix them. I've come to rely on it for that extra information that is the difference between a successful launch and a failure.

## Additional Information:

**Using the 2D Flight Profile** – Peak-of-Flight Newsletter #163 <http://www.ApogeeRockets.com/education/downloads/Newsletter163.pdf>

**How to Set Up Multiple Flight Events in RockSim** – Peak-of-Flight Newsletter #176  
<http://www.ApogeeRockets.com/education/downloads/Newsletter176.pdf>