Apogee Components

PEAK OF FLIGHT

NEWSLETTER

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How to Trick RockSim to Simulate a 4-Stage Rocket

Cover Photo: Snarky Rocket powers it way skyward. Get your own at: www.ApogeeRockets.com/Rocket_Kits/Skill_Level_4_Kits/Snarky_Rocket_Kit

Apogee Components, Inc. — Your Source For Rocket Supplies That Will Take You To The “Peak-of-Flight”
3355 Fillmore Ridge Heights
Colorado Springs, Colorado 80907-9024 USA
www.ApogeeRockets.com e-mail: orders@apogeerockets.com
Phone: 719-535-9335 Fax: 719-534-9050

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How To Trick RockSim to Simulate a 4-Stage Rocket

By Tim Van Milligan

{This article picks up where we left off in Peak-of-Flight Newsletter #383 (www.ApogeeRockets.com/Eduction/Downloads/Newsletter383.pdf) with how to create a Rack rocket design in RockSim. We'll now turn it from 3 stages to 4 stages.}

I've had some people ask if they can fly a four stage rocket in RockSim. The typical answer is no. RockSim is not set up for a four-stage rocket. You can see that it is specifically limited to a three stage configuration.

We purposefully limited it to three stages to match the NAR safety code. The safety code specifically limits model rockets to just three stages. The reason, as we discussed in the last newsletter is for safety considerations. The more stages you add, the more the rocket will want to go horizontal than vertical.

So be aware, if you build a 4-stage rocket, your NAR insurance does not cover your flight. And therefore, it won't be allowed to be launched at a local NAR-section launch.

Having said that, the Rack rocket is the one instance that I can think of where you can trick RockSim into simulating a four stage rocket.

But you have to do some complicated trickery. So this isn't something I'd normally recommend.

Essentially, to pull off this trick, you have to create a special rocket engine file. This engine file will include the thrust curves of the bottom two D12's. We'll also need to adjust the mass depletion curve in the motor file to account for the casing dropping away at the right time.

So while RockSim still thinks it is running a three stage rocket simulation, the motor file itself will force it into running first two motors at once.

This will create a new motor file that we'll add to RockSim's engine database, based off the D12 motor. In order to prevent my current D12 motor file from getting corrupted, I'll download a D12 engine file from www.ThrustCurve.org and modify it and leave my regular D12 alone.

In this instance, I'd recommend downloading the .eng version of the motor from ThrustCurve.org instead of the .rse version. The reason is that .eng file is in a form that is more human-readable. Whereas the .rse version looks more like computer code.

I would recommend you revisit *Peak-of-Flight Newsletter #139* (www.ApogeeRockets.com/Education/Downloads/Newsletter139.pdf). It explains how to read the engine file format.

When you download the file from ThrustCurve.org, and open it in a text editor, it looks like this:

```
;
;Estes D12 RASP.ENG file made from NAR published data
;File produced October 3, 2000
;The total impulse, peak thrust, average thrust and
    burn time are
;the same as the averaged static test data on the NAR
    web site in
;the certification file. The curve drawn with these data
    points is as
;close to the certification curve as can be with such a
    limited
;number of points (32) allowed with wRASP up to v1.6.
D12 24 70 0-3-5-7 0.0211 0.0426 Estes
0.049 2.569
0.116 9.369
0.184 17.275
0.237 24.258
0.282 29.73
0.297 27.01
0.311 22.589
0.322 17.99
0.348 14.126
0.386 12.099
0.442 10.808
0.546 9.876
0.718 9.306
0.879 9.105
1.066 8.901
1.257 8.698
1.436 8.31
1.59 8.294
1.612 4.613
1.65 0
```

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Newsletter Staff

Writer: Tim Van Milligan
Layout / Cover Artist: Tim Van Milligan
Proofreader: Michelle Mason

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;

I plan on opening this file in the EngEdit software that comes bundled with RockSim. But before I do, I'm going to manually add data points on the thrust curve. What needs to be done is to duplicate the list of thrust points, and shift them over so that there are two curves that are back-to-back. We want it to look the like the first two thrust spikes in Figure 1 on page 4.

The amount of shifting on the time scale will be the burn duration of a single motor. We get that number from the last data point in the list. In this case, for a D12 motor, it is 1.65 seconds.

But I'm going to use 1.66 seconds, so that I don't lose that last zero thrust point from the first curve.

My new .eng file should look like this:

```
;
;Estes D12 RASP.ENG modified file
;File produced January 27, 2015
D12X2 24 70 0-3-5-7 0.0211 0.0426 Estes
0.049 2.569
0.116 9.369
0.184 17.275
0.237 24.258
0.282 29.73
0.297 27.01
0.311 22.589
0.322 17.99
0.348 14.126
0.386 12.099
0.442 10.808
0.546 9.876
0.718 9.306
0.879 9.105
1.066 8.901
1.257 8.698
1.436 8.31
1.59 8.294
1.612 4.613
1.65 0.01
1.709 2.569
1.776 9.369
1.844 17.275
1.897 24.258
1.942 29.73
1.957 27.01
1.971 22.589
1.982 17.99
2.008 14.126
2.046 12.099
2.102 10.808
2.206 9.876
2.378 9.306
2.539 9.105
2.726 8.901
2.917 8.698
3.096 8.31
3.25 8.294
3.272 4.613
3.31 0
```

In order that you can see what I changed, I put the new information in different colors. The red text is what was modified from the old file. I changed the name from D12 to D12X2. And the last thrust point in the old file was a zero.

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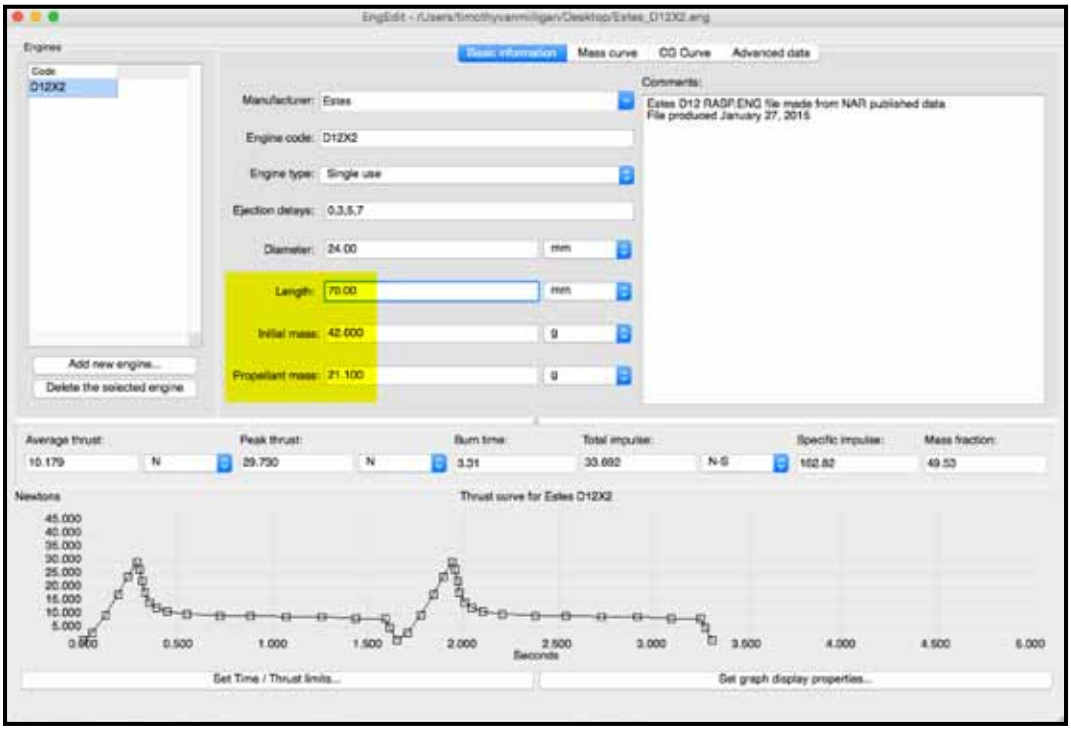

Figure 1: The new thrust curve. You can see the curve is back-to-back what a single D12 would look like. The part in the yellow block still needs minor tweaking.

Since RockSim doesn't allow you to have two zero points in the motor file, I bumped it up a smidge from 0.0 to 0.01 Newtons (shown in red color at 1.65 seconds). It is pretty insignificant added thrust, and shouldn't affect the simulation at all. The text is green is the new additional thrust curve.

The green text is the additonal portion of the thrust curve. Remember, it is the same thrust curve, but shifted over 1.65 seconds. So the thrust level is the same, but the time point has 1.65 added to each line.

Remember to resave this file in TEXT format, and then change the file extension back to .eng before you open it up in the EngEdit software.

When this file is then opened up in EngEdit, it will look like Figure 1.

We opened this file in EngEdit because we want to make some additional modifications to the file. The first is to change the length, initial mass, and propellant mass. These are easy to change, as they are right on the main screen (shown in the yellow box in Figure 1). The length simply doubles: 70mm becomes 140mm. The Initial mass also doubles from 42.6g to 85.2g to account for the two combined motors. The propellant mass doesn't double though... yes, the actual propellant changes from 21.1g to 42.2 grams. But we also have to add in the mass of the casing of one of the D12 motors. Since it drops away, it actually gets accounted for in the propellant mass.

We need to go back to the original D12 motor file to figure out the empty case weight. For a single D12, the Initial mass is 42.6 grams, and the propellant mass is 21.1 grams. Subtracting the propellant from the initial mass gives us the weight of the empty case.

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42.6 grams - 21.1 grams = 21.5 grams.

Therefore, we'll add 21.5 grams to the total propellant weight for the new motor:

21.1 g + 21.1 g + 21.5 g = 63.7 grams

Next comes the hard part. We have to change both the Mass Curve and the CG curve of the motor. This is where EngEdit is crucial, because it is needed to match what happens in real life.

Our goal is to make something that looks very similar to the mass curve shown in Figure 2. We want to include the steps where the entire case ejects out of the rocket.

EngEdit by default creates a mass depletion curve as shown in Figure 3. What this shows is how the propellant is consumed as it burns and is ejected through the nozzle.

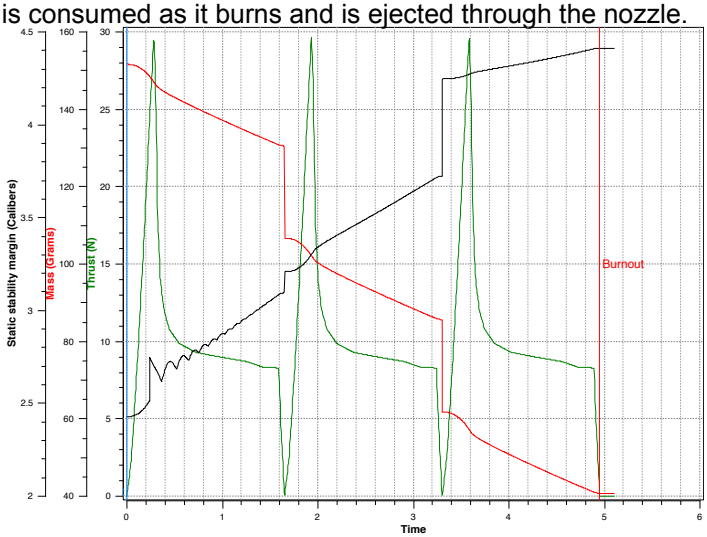

Figure 2: Graph of thrust, mass, and static stability margin of a 3-stage Rack rocket discussed in the last issue of this newsletter. Note the red line, and how the mass drops dramatically after each motor is ejected from the rocket.

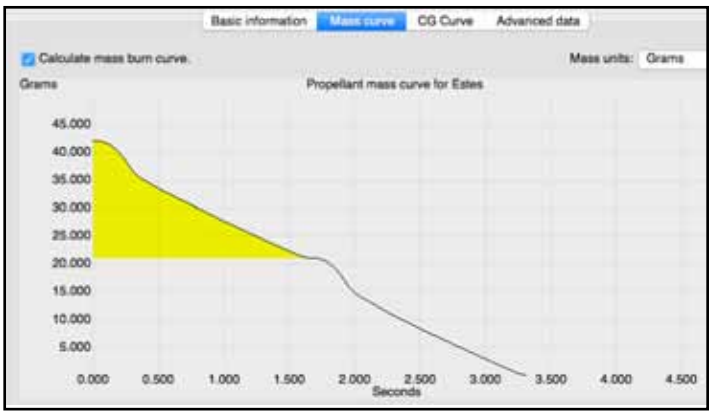

Figure 3: The default mass depletion curve as generated by EngEdit. The portion of the line above the yellow area needs to be shifted up by the weight of a single D12 empty casing.

Notice it isn't a smooth line. It is derived from the thrust curve of the motor. When the thrust is high, the motor is consuming propellant at a fast rate, so the depletion curve has a steeper slope. When the thrust is constant, you have a constant slope.

We don't really want to change the slope of this curve, we just want to shift it to account for the mass of the casing.

The portion of the curve above the yellow area in Figure 3 is where we want to shift. The mass of the casing is the difference between the initial weight and the propellant weight. We already determined that the empty casing is 21.5 grams.

If you deselect the box "Calculate mass burn curve" you'll see all the points that can be shifted (see Figure 4 on the next page). You'll immediately notice that there is a editable point for every point you have on the thrust curve (refer to Figure 1).

What this means, is that if you want a more *'accurate'*

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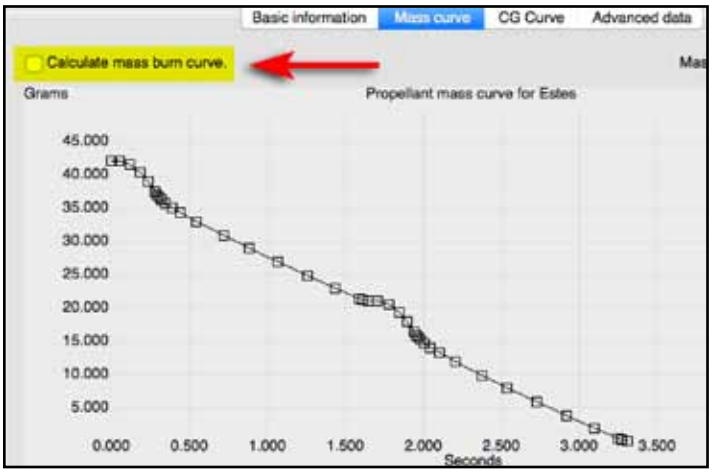

Figure 4: The mass burn curve can be edited once you deselect the box that says: "Calculate mass burn curve."

thrust curve with lots and lots of data points, the more work you'll have to do to shift the mass depletion curve.

So in this example, all the points prior to 1.65 seconds have to be shift up 21.5 grams on the plot. Unfortunately, this is hard to do with accuracy by moving each point in EngEdit. It can be done reasonably well, but if you want the best accuracy, you'll have to open the raw engine file in a text editor. This is similar to what we did earlier when we edited the .eng file in a text editor. But this time, we have to save the file in the RockSim Engine format first, and then open that file in the text editor.

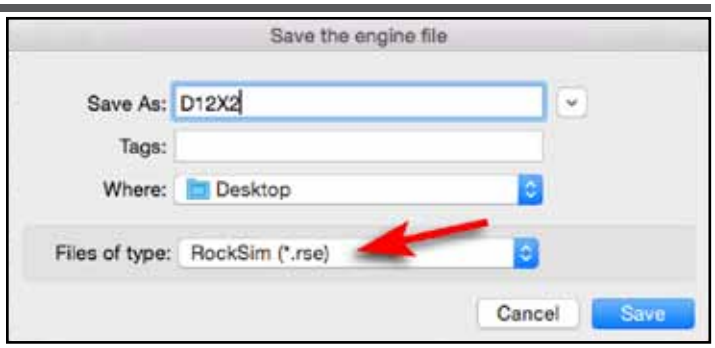

Figure 5: Save the file in the RockSim (*.rse) file type.

So choose File<Save As, and be sure to change the file type to RockSim format (see Figure 5).

You can close EngEdit, and then open the file in a text editor (word processing) program. You'll see something like this:

```
<engine-database>
  <engine-list>
    <engine  mfg="Estes" code="D12X2" Type="single-use"
    dia="24." len="140." initWt="85.2"
propWt="42.2" delays="0,3,5,7" auto-calc-mass="0" auto-
    calc-cg="1"
avgThrust="10.179" peakThrust="29.73" throatDia="0."
    exitDia="0." Itot="33.692"
burn-time="3.31" massFrac="49.53" Isp="81.41" tDiv="10"
    tStep="-1." tFix="1"
FDiv="10" FStep="-1." FFix="1" mDiv="10" mStep="-1."
    mFix="1" cgDiv="10"
cgStep="-1." cgFix="1">
    <comments>Estes D12 RASP.ENG file made from NAR pub-
    lished data
File produced January 27, 2015</comments>
```

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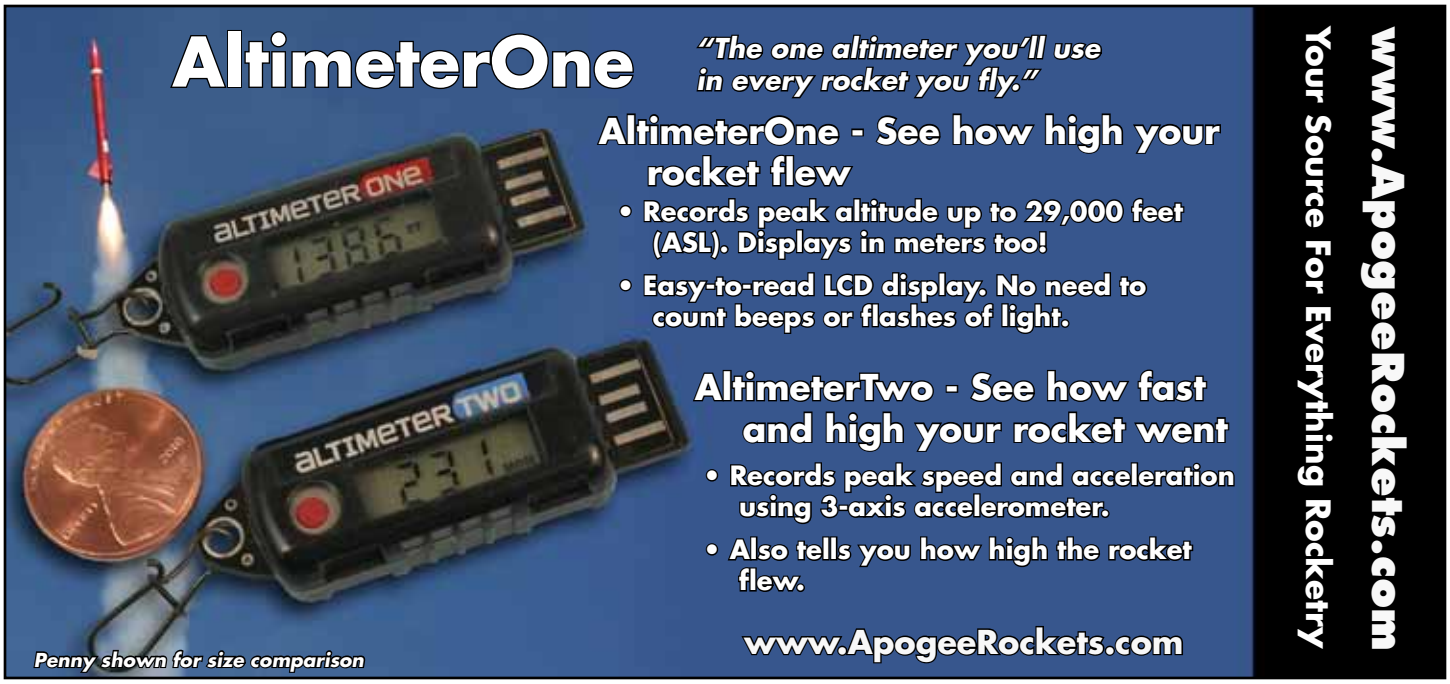

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```
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  <eng-data t="0." f="0." m="42.2" cg="70."/>
  <eng-data t="0.049" f="2.569" m="42.1212"
cg="70."/>
  <eng-data t="0.116" f="9.369" m="41.6202"
cg="70."/>
  <eng-data t="0.184" f="17.275" m="40.4856"
cg="70."/>
  <eng-data t="0.237" f="24.258" m="39.107"
cg="70."/>
  <eng-data t="0.282" f="29.73" m="37.5855"
cg="70."/>
  <eng-data t="0.297" f="27.01" m="37.0525"
cg="70."/>
  <eng-data t="0.311" f="22.589" m="36.6176"
cg="70."/>
  <eng-data t="0.322" f="17.99" m="36.3381"
cg="70."/>
  <eng-data t="0.348" f="14.126" m="35.8151"
cg="70."/>
  <eng-data t="0.386" f="12.099" m="35.191"
cg="70."/>
  <eng-data t="0.442" f="10.808" m="34.3876"
cg="70."/>
  <eng-data t="0.546" f="9.876" m="33.0405"
cg="70."/>
  <eng-data t="0.718" f="9.306" m="30.9742"
cg="70."/>
  <eng-data t="0.879" f="9.105" m="29.1178"
cg="70."/>
  <eng-data t="1.066" f="8.901" m="27.0091"
cg="70."/>
  <eng-data t="1.257" f="8.698" m="24.904"
cg="70."/>
  <eng-data t="1.436" f="8.31" m="22.9973"
cg="70."/>
  <eng-data t="1.59" f="8.294" m="21.396"
cg="70."/>
  <eng-data t="1.612" f="4.613" m="21.2181"
cg="70."/>
  <eng-data t="1.65" f="0.01" m="21.1081"
cg="70."/>
  <eng-data t="1.709" f="2.569" m="21.0128"
cg="70."/>
  <eng-data t="1.776" f="9.369" m="20.5119"
cg="70."/>
  <eng-data t="1.844" f="17.275" m="19.3772"
cg="70."/>
  <eng-data t="1.897" f="24.258" m="17.9987"
cg="70."/>
  <eng-data t="1.942" f="29.73" m="16.4772"
cg="70."/>
  <eng-data t="1.957" f="27.01" m="15.9441"
cg="70."/>
  <eng-data t="1.971" f="22.589" m="15.5093"
cg="70."/>
  <eng-data t="1.982" f="17.99" m="15.2297"
cg="70."/>
  <eng-data t="2.008" f="14.126" m="14.7068"
cg="70."/>
  <eng-data t="2.046" f="12.099" m="14.0827"
cg="70."/>
  <eng-data t="2.102" f="10.808" m="13.2793"
cg="70."/>
  <eng-data t="2.206" f="9.876" m="11.9321"
cg="70."/>
  <eng-data t="2.378" f="9.306" m="9.86586"
cg="70."/>
  <eng-data t="2.539" f="9.105" m="8.00949"
cg="70."/>
  <eng-data t="2.726" f="8.901" m="5.90077"
cg="70."/>
  <eng-data t="2.917" f="8.698" m="3.79562"
cg="70."/>
```


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```
      <eng-data  t="3.096" f="8.31" m="1.88899"
    cg="70."/>
      <eng-data  t="3.25" f="8.294" m="0.287613"
    cg="70."/>
      <eng-data  t="3.272" f="4.613" m="0.109781"
    cg="70."/>
      <eng-data  t="3.31" f="0." m="0." cg="70."/>
    </data>
  </engine>
</engine-list>
</engine-database>
```

The column in yellow show all the data points prior to 1.65 seconds. The green column are the mass points we have to edit by adding 21.5 grams to it. So the first point at t=0 would be changed to m=63.7 grams, and the last point at t=1.65 seconds would be 42.6081 grams.

The other thing we need to change is the CG location points in the engine file. This step takes some thought, so let me explain how RockSim calculates the CG location. Remember, the CG location of the engine is the balance point. As the rocket burns propellant, it is getting lighter in weight. The balance point shifts depending on where the propellant was in the motor when it burned.

On a black powder propellant motor, the motor burns propellant from the back end towards the front end. We call these end-burn motors, because it burns similar to a cigarette. The CG for these motors then shift forward as the motor burns, because the back end is getting lighter in weight.

For composite propellant motors, the motor burns from the inside core to the outside edge (like a ring that gets bigger on the inside). For these motors, the CG doesn't shift much, because the propellant is burned along the entire length of the motor.

For hybrid motors, the tank in the front holding the oxidizer gets lighter than the section containing the fuel, so the CG of those types of motors moves rearward as it burns.

Do you see how complicated it is to figure out how the CG of the motor shifts?

It is complicated. So when we set up RockSim, we had to simplify things, because we didn't want to make CG curves for every available rocket engine (we sell over 1000 motors at Apogee). The simplification we made was to put the CG at the midpoint of the length of the motor. So for a 70mm long D12 motor, the CG is at 35mm from the front, and doesn't change at all. You see this in Figure 6.

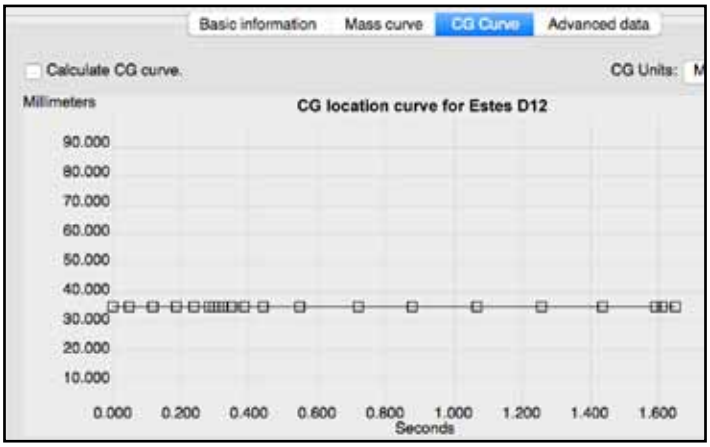

Figure 6: The CG location is assumed to stay in the same spot as the motor burns.

But in our doubled-up motor thrust curve, the CG shift will be significant when the empty casing drops away after it burns out. So we should try to mimick this in the CG curve as closely as possible.

What we know, is that at the end of the burn (after 1.65 seconds), the CG of the motor should be at 35mm. This is half the length of a single D12 motor casing.

The big question is where should the CG be for the first part of the thrust curve. The answer is that you should put it

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at half the length of the new motor casing. In our example, the two D12 that are butted together, the overall length is 140mm; half that would be 70mm.

With this estimation of the CG location, go back and edit the .rse file in the text editor. For burn time prior to 1.65 seconds, the CG is 70mm. After 1.65 seconds, the CG should be 35mm. Save the motor file as TEXT format as you close the word processor. Then go back and change the file extension to .rse.

To save space in this newsletter, I won't reprint the modified data file, but you can download it from the Apogee web site at: www.ApogeeRockets.com/Education/Downloads/Rack_rocket.zip

If you want, you can go back into EngEdit and open the modified thrust curve. What we want to see is the drop in mass after the motor burns halfway, and also see the CG shift at the same point in time. What we should see is shown in Figures 7 and 8.

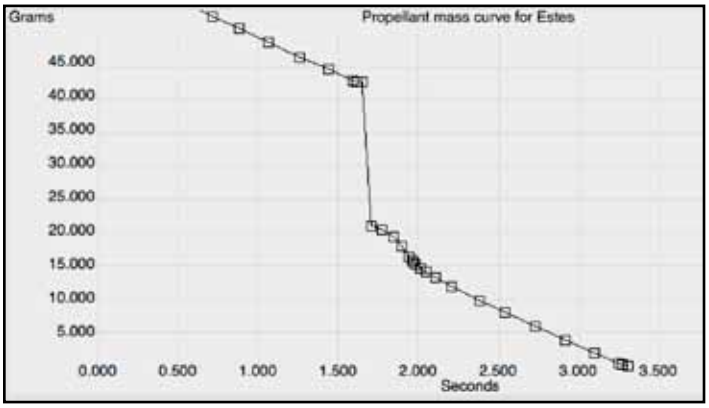

Figure 7: Using the EngEdit software, you can see that the engine file now has been modified to account for the dropped mass of the engine casing after the first motor burns out (compare to Figure 3).

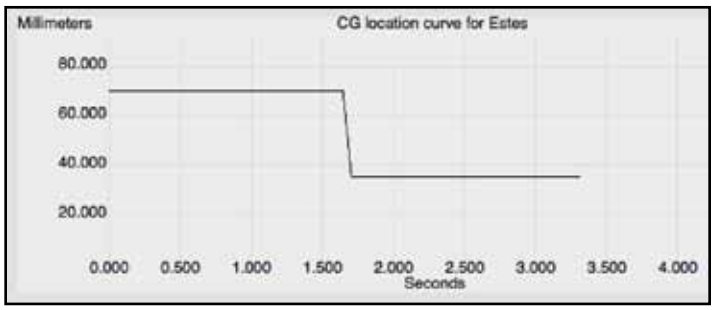

Figure 8: The engine file now has been modified to account for the dropped mass of the engine casing after the first motor burns out. The top graph shows how the mass changes with time, and the bottom one shows the CG position during the burn.

Now we're ready to go back into RockSim and load this new motor file. But now the rocket is another 70mm longer thanks to the fourth stage. So you have to remember to extend the fin section to be longer (see Figure 9).

Loading the new motor file is pretty easy. If you've never done it before, see the video #26 at: http://www.apogeerockets.com/RockSim/Rocksim_Video_Tutorials. Loading new motor files is probably the most frequently asked question about RockSim, which is why we created this video.

Figure 9: The new 4-stage Rack rocket. The bottom motor, the brown one, represents two motors from our new engine file.

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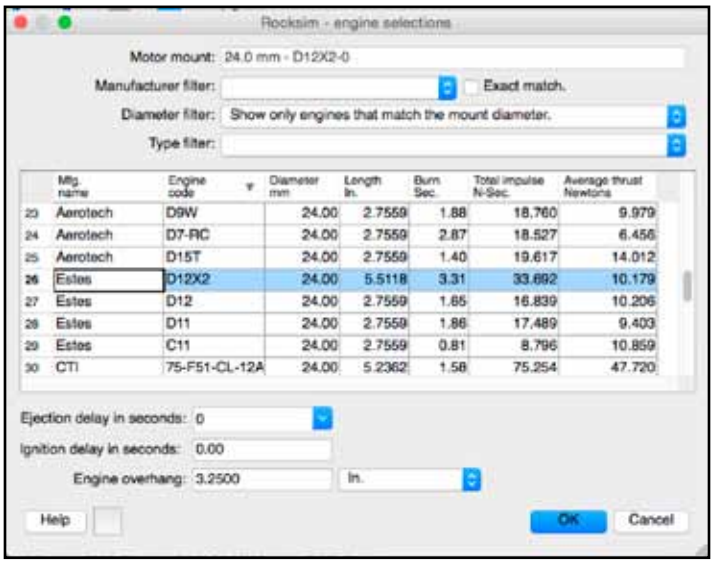

	Mfg. name	Engine code	Diameter mm	Length in.	Burn Sec.	Total impulse N-Sec.	Average thrust Newtons
23	Aerotech	D9W	24.00	2.7559	1.88	18.760	9.979
24	Aerotech	D7-RC	24.00	2.7559	2.87	18.527	6.456
25	Aerotech	D15T	24.00	2.7559	1.40	19.617	14.012
26	Estes	D12X2	24.00	5.5118	3.31	33.692	10.179
27	Estes	D12	24.00	2.7559	1.65	16.839	10.206
28	Estes	D11	24.00	2.7559	1.86	17.489	9.403
29	Estes	C11	24.00	2.7559	0.81	8.796	10.859
30	CTI	75-F51-CL-12A	24.00	5.2362	1.58	75.254	47.720

Figure 10: The new motor (the light-blue line) shows up in the engine selection table.

If you imported the motor file correctly into RockSim, the new motor will show up when you go to select a motor (as seen in Figure 10). The only other change you need to make is to adjust the "Engine Overhang." Typically, the motor sticks out the back of the rocket by 0.5 inches. In this case, I added to that length 2.75 inches, for a total engine overhang of 3.25 inches. If you forget to do this, you'll figure it out quickly, because the motor won't reach all the way back to the fins in the side view image.

Next, run the simulation, and take a look at the graph of thrust, mass, and stability margin. I want to look at this graph, to see that it looks similar to Figure 2 on page 5.

The new chart is shown in Figure 11. What you want to look for is that the first two thrust curves (the green line) are identical to the last two. Then you want to verify that the mass drop (the reddish-orange line) steps down uniformly after the motor burns out.

To be honest, when I was writing this article, the first time I ran the simulation, the chart looked like Figure 12. Something didn't look right, as the mass drop between the

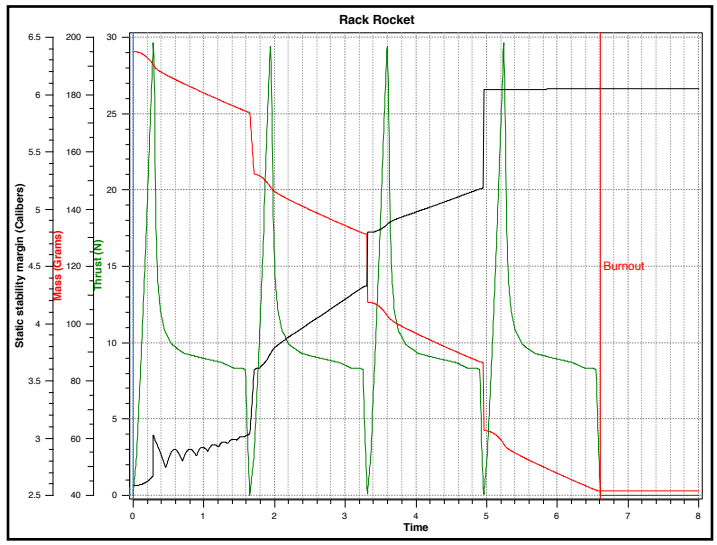

Figure 11: This graph allows us to verify that the new engine file was set up correctly. Compare to Figure 2.

Continued on page 11

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Simulating 4-Stage Rockets in RockSim

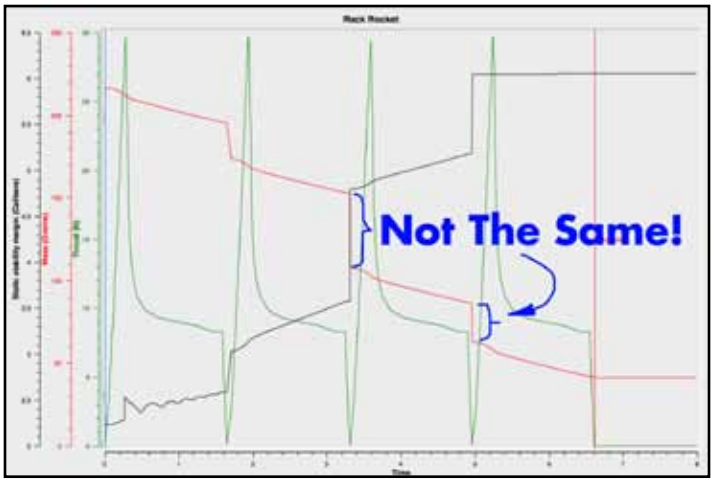

Figure 12: My first attempt at changing the engine file gave me the wrong mass depletion curve.

second and third stages was larger than the drop between the third and fourth stages. This shouldn't have happened, so it alerted me that something was wrong in my new engine file. It was only after fixing my engine file that the chart looked correct, as shown in Figure 11.

With the engine file confirmed to be correct, we can now make some comparisons between the three stage Rack rocket and the four stage version.

To be frank, I wasn't too shocked when I saw the results of the four stage rocket in the simulation summary. The four stage rocket actually flew lower than the three stage version by 117 feet (see Figure 13).

	Resul	Engines loaded	Max. altitude Feet	Velocity at launch Miles / Hour
1		[D12-0] [D12-0] [D12-7]	3249.91	31.85
2		[D12X2-0] [D12-0] [D12-7]	3132.44	29.44

Figure 13: A comparison of the three stage rocket and the four stage version. The four stage rocket lifted off slower and didn't fly as high.

Why is that? Shouldn't more motors equate to a higher flight?

There are a couple of reasons. First, the fins on the three stage rocket were not as far aft when it was simulated. Remember, we had to stretch the rocket to account for the fourth motor. Making this change affects the stability margin of the rocket. The three stage rocket has a reduced stability margin. Essentially, the three stage rocket doesn't react to the wind in same way.

The four stage rocket has a massive static stabilty margin at lift-off. And the extra motor adds weight, which means it takes off slower. The slower flying rocket, with a higher stability margin, reacts much more to the wind than the three stage rocket. So it weathercocks more in the wind. It uses up its propellant going sideways rather than upwards.

Pretty interesting results? I think so.

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.