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Simulating a 2-Stage Saturn V in RockSim

By Tim Van Milligan

Earlier this year, a customer asked me how he should go about modifying the Apogee 1/70th Scale Saturn V RockSim file to make it a 2-stage rocket. This is an interesting topic, and I thought I'd share my strategy if I were to do it myself.

The real Saturn V rocket is classified as a 3-stage rocket, if you don't count the rocket motor in the Service Module that was used to get the Apollo astronauts back home from the moon. By looking at it, it is obvious that modifying the model rocket isn't going to be easy, since it does not have fins on the upper stages.

The solution to this problem is to make pop-out fins. That means the fins for the upper stage are hidden inside the body of the rocket, and then spring out when the rocket separates into two pieces. Now this is not as easy as it sounds, and I'll leave the mechanics of it to a future article. In fact, I'm requesting readers that have done this successfully to submit their designs to me, as I'd love to publish them here in this newsletter. I'm sure that it has been done a number of ingenious ways. But the purpose of this article is to set up the simulation in RockSim so that we can predict the performance of the model (assuming everything goes right in real life).

Figure 1: The long tube in the kit will be split to create the two stage rocket.

The other complication that I'll mention before getting started is that this is a big rocket, and the upper stage would most likely use composite propellant motors to provide the power. That means the rocket will also need to carry electronics, like the PerfectFlite Staging Unit timer (www.ApogeeRockets.com/Staging_Timer.asp) to ignite the upper stage motor. Again, I'll leave this additional complication for the builder to figure out.

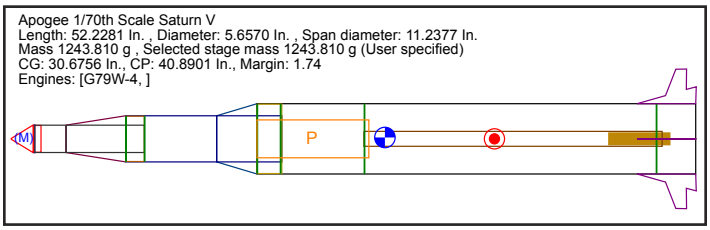

Figure 2: This is the 2D view of the Saturn V design before it is modified. Note the location of the Center-of-Pressure. We will reference this location later.

Getting Started

The first step for us in this article is to determine where to separate the stages, since the lower part of the rocket is one long tube. Ideally, we'd like to separate it at the actual joint between the stages. And this is totally possible. The upper part of the big tube will be 13.88 inches long as

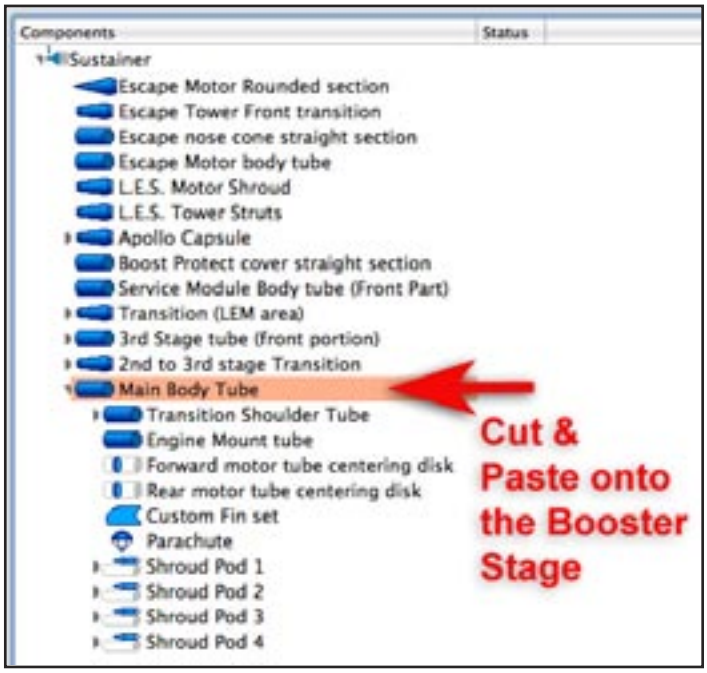

Figure 3: In the Part's Tree, "cut" the "Main Body Tube" from the Sustainer, and paste it to the Booster Stage.

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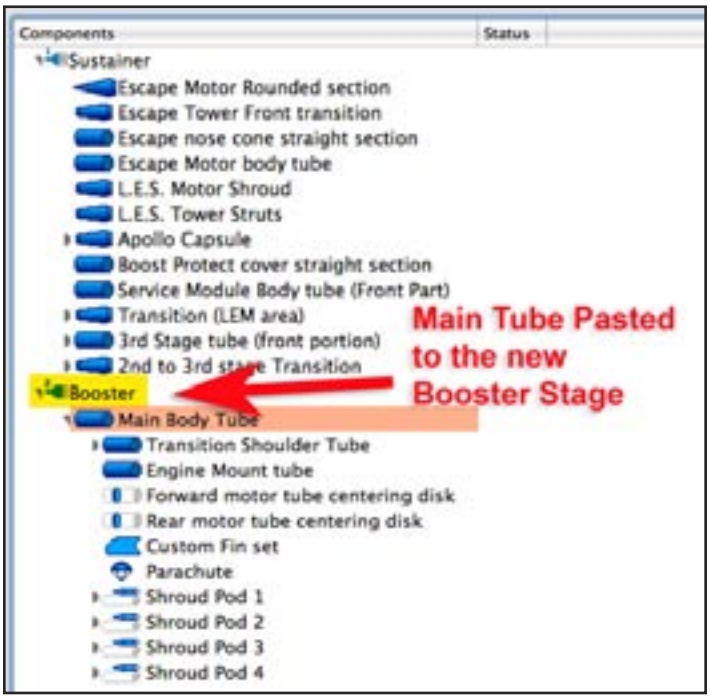

Figure 4: This is what the part's tree will look like after you've pasted the "Main Body tube" to the Booster placeholder.

shown in Figure 1. The lower part will be the remainder, which is 21.42 inches.

To reduce work and cheat a bit, I'm going to use the same trick I showed in the TARC Tutorial #3 at www.ApogeeRockets.com/RockSim_tutorials.asp . That is, I'm going to cut parts away from the Sustainer Stage, and past them into the booster stage. Figure 3 shows what the component tree looks like before the cutting operation, and Figure 4 shows what it looks like after the "cut" parts are pasted into the Booster Stage.

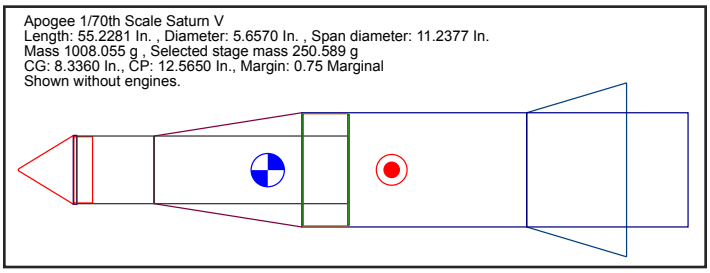

Figure 5: After the Main Body Tube is moved to the Booster section, this is what the Sustainer looks like.

At this point, if you display just the upper stage (called the *"Sustainer")*, it will look like Figure 5. Notice that at this point the upper stage is unstable. It is going to remain unstable until we add those flip out fins. But we're not quite there yet.

Now, let's start modifying and adding components to the stages.

For the upper stage, I need to add a new 2nd Stage tube. It is the same diameter as the Main Body Tube used on the booster, but only 13.88 inches long as mentioned earlier. Once that is in place, I'll tweak the lower Booster Stage before adding the extra parts into the 2nd Stage.

On the booster stage, I'm going to shorten both the Main Body Tube and the Engine Mount Tube by 13.88 inches. The forward centering ring also needs to be moved further rearward.

With the majority of the booster stage work done, I'll now concentrate on getting the main tube of the Sustainer Stage completed. This is simple, as all I need to do is add a 13.88-inch long tube below the big transition.

Once I did that, I noticed that the shoulder for the transition was part of the booster stage, so I just moved it and its centering rings back up to the top using the cut-and-

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paste method.

If you look at the outline at this point as shown in Figure 6, the design is basically back to where we had it when we started, except that it is two stages. The CP is still in the same location, so things are going well.

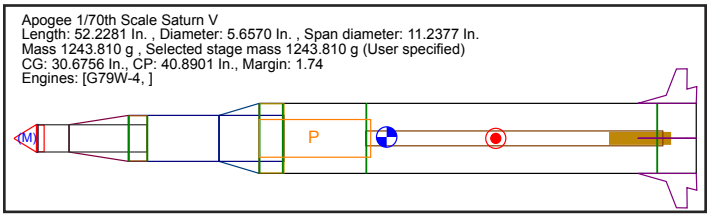

Figure 6: At this point in the modification, the 2-stage version looks like the single-stage. Compare the CP location with that shown in Figure 2 (they're the same).

Adding the motor tube for the sustainer stage is the next step. Since this is a big rocket, I'm guessing that I'll want to put in a 29mm motor, and probably use an F or G engine to power the rocket. The engine mount tube will be relatively short. The reason is that I envision the parachute compartment being in the front portion of the big tube. In other words, the upper stage will still separate into two parts so that the capsule comes down on its own parachute away from the section that holds the motor. So I'm thinking that at this stage, I want the entire rocket to come down in three parts. This allows me to follow the assembly steps as much as possible when actually building the rocket.

Fortunately, the tube is so large in diameter that there should still be plenty of room around the engine mount tube for an ebay to house the electronics and the battery to ignite the upper stage motor.

The back end of the engine mount tube will extend down into the top of the booster stage. I envision the pop-out fins acting as a centering ring, of sorts. This should

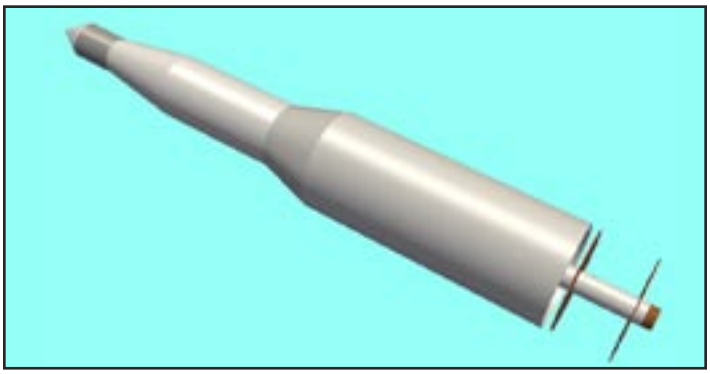

Figure 7: A 3D view of the upper stage. The flip-out fins will be placed between the aft two centering rings.

allow the two stages to couple together. I'll put a centering ring both ahead and behind the fins to make sure that the two stages engage fully and there is no wobble. What this looks like in 3D is shown in Figure 7.

Up until this point, we have only been concerned about placement of parts. Now we need to start to worry about the aerodynamics. We already know where the CP of the rocket is without fins on the upper stage. The CP was shown in Figure 1 at 40.89 inches from the tip of the Command Module nose cone. We need to remember this number, because when we add fins to the 2nd stage, it is going to change, since they will be sticking out in the design file. But in real life, once we launch the rocket, the value is going to be at the 40.89 inch location. We just need to be sure our CG is in front of this point at lift-off.

Adding the fins to the upper stage gets tricky. I'm going to use the pod feature of RockSim to attach them in mid-air between the two coupling centering rings that extend out the base of the upper stage. With the pod feature, you can actually attach the fins anywhere, even out in free space. In real life, they will be attached to some sort of dowel that

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spans between the two centering rings. The first dowel Pod is shown in Figure 8 below.

I'm not goint to put in the other dowl pods yet. I'll attach fins to them first, and then do a copy-paste later on. That will save me a lot of time rather than having to do them one at a time.

The next question is, how big are the fins going to be? The root chord is easy to determine, since that is going to be the distance between the two coupling centering rings. But what about the span?

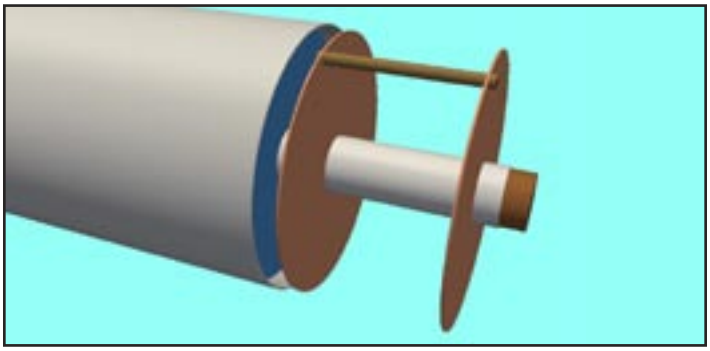

Figure 8: A pod was attached to the 2nd-Stage tube. Then a dowel (a solid body tube) is attached to that. Finally, the pod was positioned between the rings and its radial position was adjusted to what is shown here.

This is where you're going to put on your thinking cap. That's what I did. To determine the span distance, I needed to draw a full size base-view pattern of where the fins will be (see Figure 9). I needed to spin the fins inward so I could see how they might look in their stowed configuration. When I drew this out, it looks like they can have a span no greater than 3.3 inches.

I'll make the planform a simple rectangle, to get as much fin surface area as possible. I want that upper stage to be as stable as I can make it.

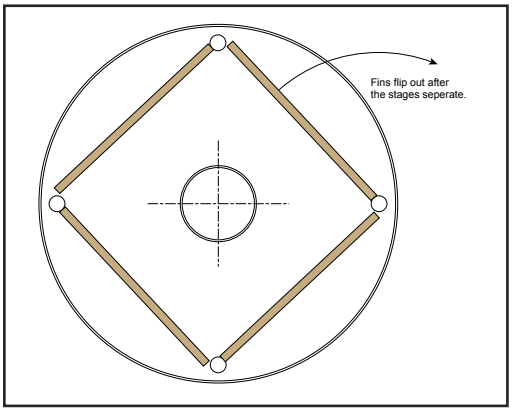

Figure 9: Base view that I drew to figure out how much room there was for the fins, so that I could find the maximum length of each flip-fin.

So, attaching the fins to the dowels (pods), and then duplicating them three times, the rear of the upper stage will look something like Figure 10.

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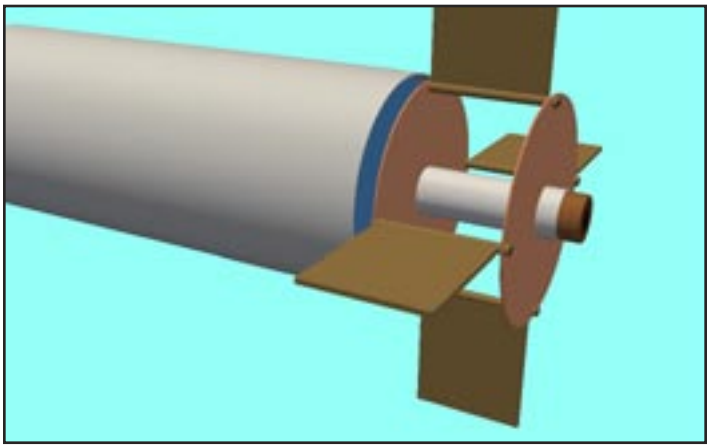

Figure 10: The flip-out fins as modeled in RockSim.

As I said before, I'll leave it to you to figure out how to activate the fins so that they rotate outward during flight. It may be as simple as some rubber bands wrapped around the dowels.

The important part is that we now have a CP location for the upper stage. This is shown in Figure 11. We're in a pretty good position right now, as the CG of the upper stage is still in front of the CP. However, there is probably some weight in the back end by the fins that still isn't accounted for, and we haven't added the weight of our electronics needed for staging this rocket. As a guess, I'll throw in 50 grams for this unaccounted mass, and put it between the centering rings that hold the engine mount tube in the rocket. Doing this moves the CG and the CP much closer together, as is shown in Figure 12.

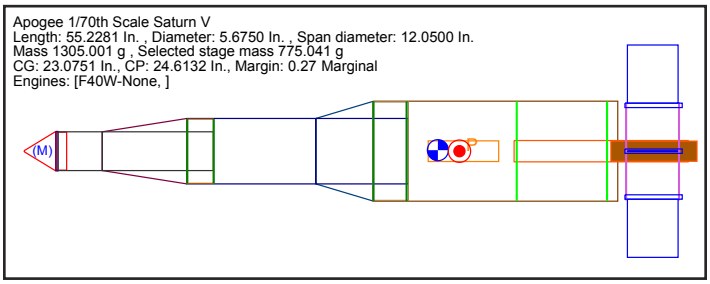

Figure 11: With the fins added to the Sustainer stage, we can now see if it will be stable. Unfortunately, it is barely marginal, and we haven't added the heavy electronic ignition system yet.

Unfortunately, I still need to add the weight of the third parachute. After adding the chute, I realized that this didn't move the CG far enough ahead, which is bad. As a last resort, I added another 50 grams into the service module tube to get that CG-CP relationship a bit better. At this point, the static margin of just the upper stage portion is

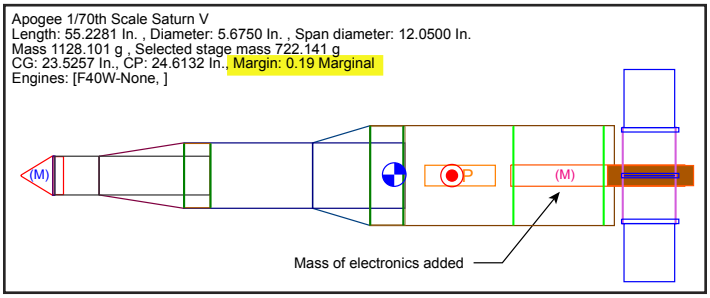

Figure 12: With 50 grams of electronics in the rear of the rocket, the Static Margin drops to 0.19. Not good...

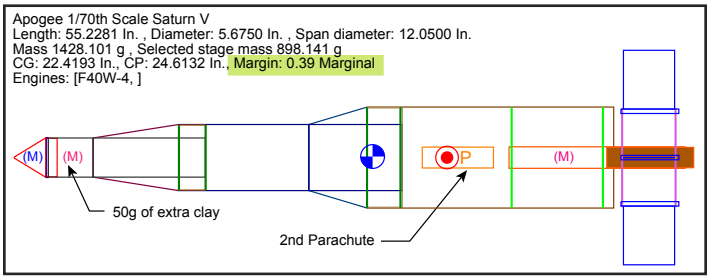

Figure 13: After adding another parachute, I was forced to add more clay in the nose to make the rocket more stable. This should only be done as a last resort.

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0.39 (as shown in Figure 13).

The design is done. Before we launch it, let's take one last look at the final CP position of the complete rocket. Remember, we said that the actual CP position is going to be at the 40.89 inch location (as shown in Figure 2 on page 2). In our final drawing, it shows the CP position at 38.6304 inches. It moved slightly forward, but not enough to cause too much concern. The reason it stayed so close, even with the extra fins on the upper stage, was that those new fins are actually positioned somewhat close to the original CP location.

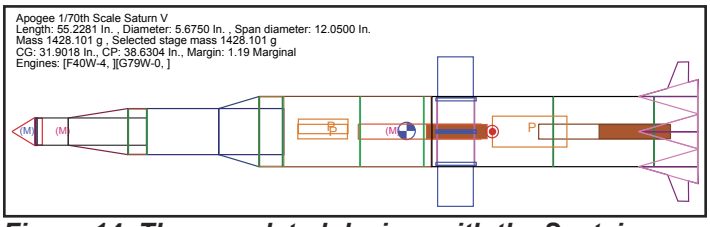

Figure 14: The completed design, with the Sustainer fins extended. The CP is still in a good location in this configuration. In the actual flight model, the CP will be at 40.89 inches, which makes the model even more stable. "More Stable" is always good.

Basically, I'm pretty confident flying the rocket like this even with those upper stage fins sticking out in the wind, when actually they will be inside the rocket until they flip out when the rocket stages.

The margin of stability is still greater than one, and this is a worst-case situation. In real life, the stability margin will be greater, I calculate it to be 1.58 calibers.

On a complex project like this, I'd like the higher stability margin. It may mean that the rocket might weathercock a little bit more, but I would only attempt this flight on a fairly calm day.

Running Simulations and Results

I ran the simulation using a G79-0W motor in the booster stage, and a F40-4W motor in the sustainer. I ran two sims, the first being in calm wind, and the second in the situation where the wind was blowing at 5 mph. The results were pretty similar, meaning my rocket didn't weathercock too much. Remember, in real life the rocket may weathercock a little more because the stability margin is going to be greater. So you'll want to be prepared for that.

The only other concern that I have is the lift-off speed

Figure 15: Simulation results. On a calm day, the 2-stage rocket reaches an altitude of 768.65 feet. In a 5mph wind, the top altitude is 743.86 feet. The one concern is the lift-off speed of 26.83 mph. It should be above 30 mph.

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on this particular motor-combination is a little slow at 26 miles per hour. I always recommend at least 30 miles per hours.

There are two ways to get up to this speed. Either use a longer launch rod, or go with a motor with higher initial thrust. For reference, I used a 72 inch long rod in the simulations. The Saturn is such a big rocket that I'd probably launch it off a 96 inch long rail anyway. So I could still get away with this motor combination. But there are some higher thrust motors available as a back-up.

These are my tips on flying a 2-stage Saturn V. You can see there is a lot of prep work necessary even before you start building. If you do make one, be sure to send us some photos!

If you would like to see the RockSim files used in this article, download them at: www.ApogeeRockets.com/Education/Downloads/2-Stage_Saturn_V.zip

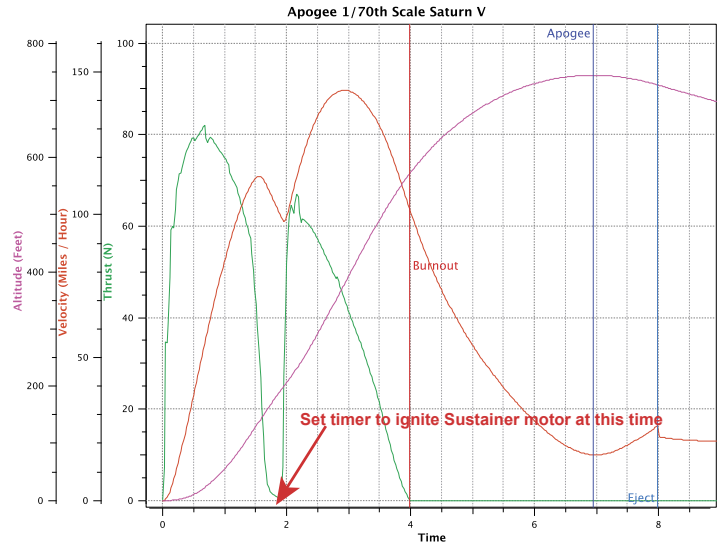
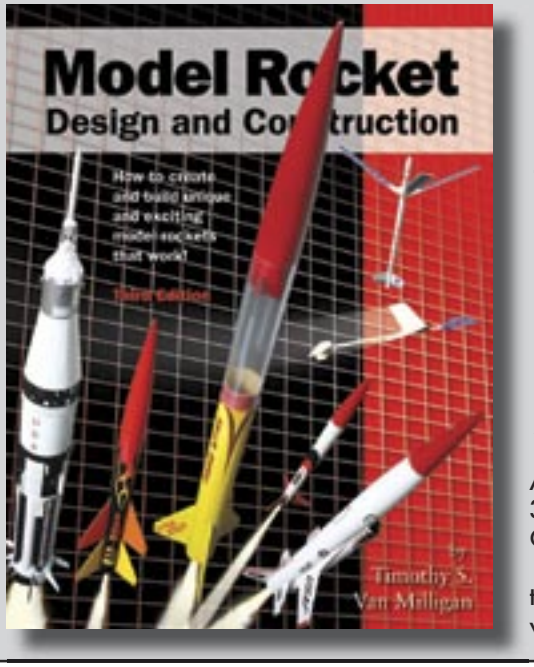


Figure 16: From the thrust curve, we can pick how long to set the timer to start the sustainer motor. Here it looks like we'd set it at 1.8 seconds.

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 with "SUBSCRIBE" as the subject line of the message.



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