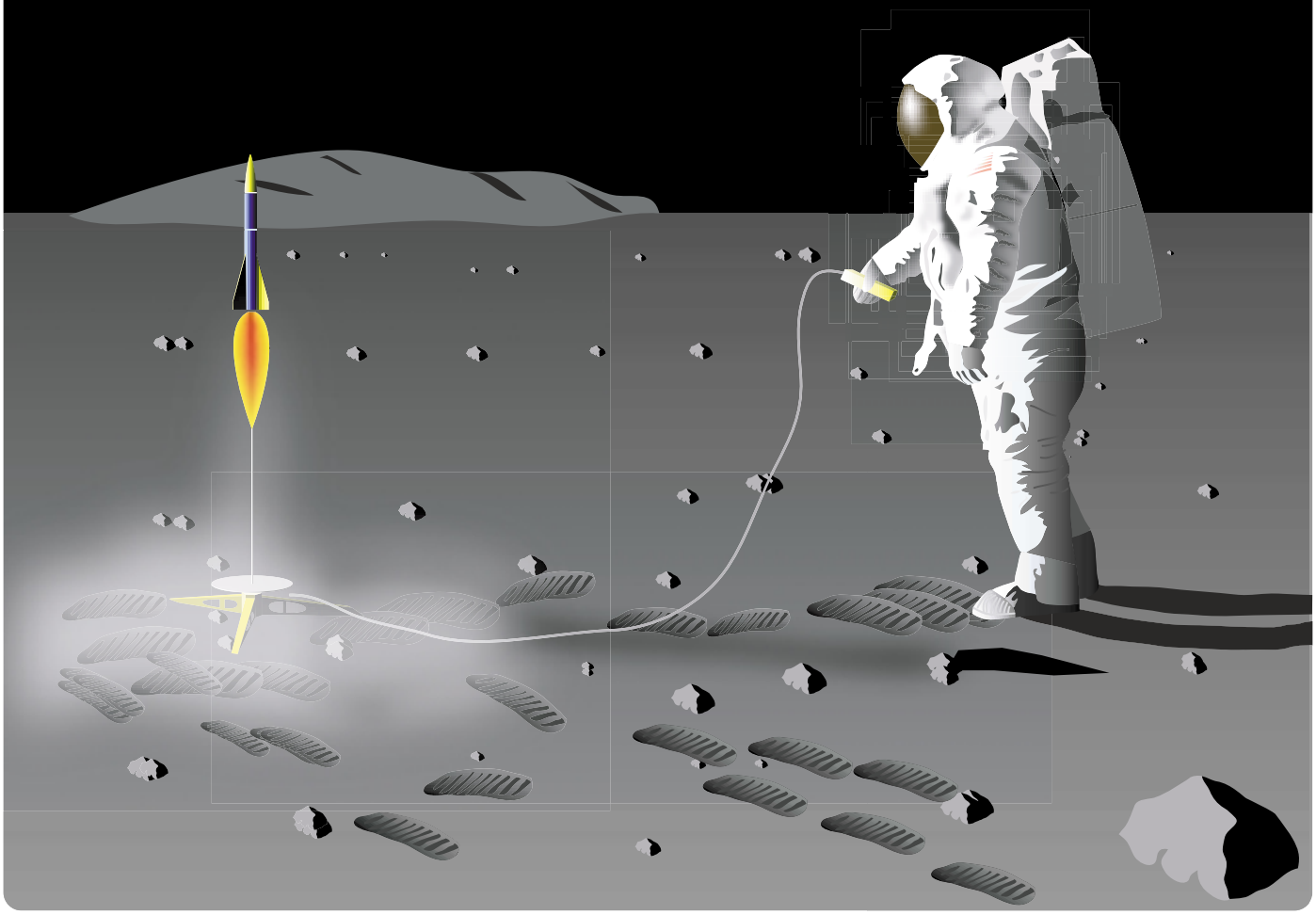
ISSUE 108, AUGUST 4, 2003

APOGEE

PEAK OF FLIGHT

NEWSLETTER

Simulating Strap-on Booster Stages In RockSim 7.0



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PEAK OF FLIGHT

Using RockSim To Simulate Strap-on Booster Stages

By Tim Van Milligan

The most requested feature that people want added to RockSim is the ability to simulate Strap-On booster stages. It seems a little bit extraordinary to me, since when I go to launches, 99% of all flights are your typical 3FNC (three fins and a nose cone) looking rockets. It is very rare that I see a model that actually has strap-on boosters. Maybe it is because you can't simulate strap-on boosters that no one flies them at large rocketry launches.

In the next series of e-zine newsletter articles, I'm going to discuss this seemingly topic, and show you step-by-step how you can use RockSim 7.0 to simulate models that use them. I'll tell you up front; that it won't be quick. It takes a little bit of planning and forethought. And unfortunately, you won't get a nice screen image. But that effort will be worth it, as you will get reasonably accurate simulation results.

Reasons Why I'm Writing This Article

Before I start into this topic, I want to give you some reasons why it is going to be very long. It is so lengthy that you're probably going to say it isn't worth all the trouble. But please bear with me. There are some other motives that I have in writing this article, which is the reason it is so long. These reasons are:

1. To show you how you can use RockSim to simulate strap-on booster stages.
2. To advertise RockSim. Yes, this is a plug for the software. I want you to buy it. That's why I write these newsletter articles, and the reason they are free. And, there have been many people that have told me they won't buy RockSim until it can do strap-on boosters. If you are one of those people, time for you to live up to your promises...
3. To teach you the steps on how to create motors in RockSim. Why? Because manufacturers keep making new motors, and they don't send us the .eng files. If you know how to make them yourself, you probably won't need to ask me about them. By the way, you'd think those motor manufacturers would realize that having .eng files for their own motors would be great advertising. You should pester them to create them.
4. To show you how to create complex RockSim designs.
5. To show you how to use RockSim to run complex launch simulations; and then compare the results against common sense expectations.
6. To teach you a little bit about aerodynamics.
7. To teach you a little bit more about rocket stability.
8. To show you how to approach a complex problem, and break it down into smaller but manageable parts.
9. To give you some insight into how simulation software works; by explaining the constraints of the governing equations.
10. To show you how much model rocketry really mimics real rockets flown by NASA.

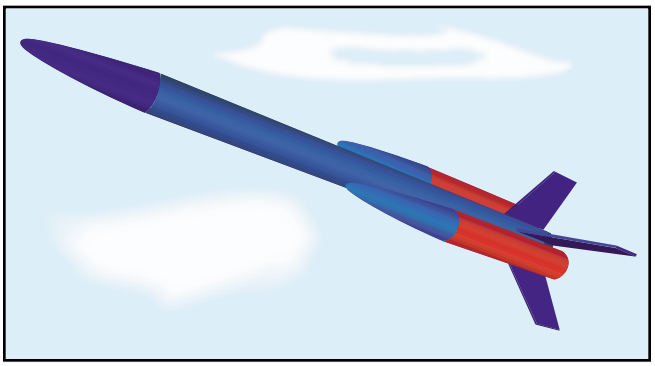

Figure 1: We want to simulate a design that looks like this. Two strap-on boosters that are attached to the core vehicle.

Yes, this will be a long series of articles. But I promise you'll learn a lot of information that will make you a better modeler.

And if my tone seems condescending or patronizing, please forgive me. I want to move slowly through the material so you can understand the "why" as well as the "how."

Let's have some fun and start by reviewing some terms.

Basics Terminology

Strap-on boosters are finless rockets attached to the sides of a normal 3FNC (Three Fins and a Nose Cone) type rocket. Many full-size space launch vehicles use strap-on boosters, such as Atlas II, Delta II, Titan IV, and even the Space Shuttle.

The reason they are used on these big rockets is because they save money. Let me explain.

Designing, building, and testing big rocket motors is expensive. VERY EXPENSIVE! So rocket manufacturers would

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rather find a way to add more power to older rockets. That's much cheaper than creating a new rocket and its engine from scratch. The way they add more power is rather simple. They attach a other motors to the side of the core.

That's how, the old Thor ICBM missile -- by adding more power to it -- turned it into today's Delta Launch Vehicle. Strap-on's give new lift to old rocket designs.

The technique is called "Parallel Staging." The motors are usually ignited at the same time as the core motor — in parallel rather than sequentially (one after the other like a typical 2-stage rocket).

Why don't big rocket makers like Boeing use multiple stages instead of parallel staging? First off, they do. Nearly all the space vehicles use multiple stages. The one that I worked on, the Delta II, used three stages to put an object the size of a VW bug into geostationary orbit around the earth.

But the more stages you put on top, the heavier the rocket becomes. The bottom rocket motor has to lift all that mass. On the Delta II, the core motor only generated 207,000 lb of Thrust. That isn't even enough thrust to lift its own weight of 223,843 lbs off the launch pad. (Source: Delta II User Manual - March 1989)

To get more thrust, you either have to add more motors; or you can create a new and bigger motor (which is expensive to do).

Solids Vs Liquids

In large rockets, the strap-on boosters are usually solid propellant motors. The core vehicle usually uses Liquid Propellants.

There are some exceptions, but as a general statement, solid -propellant motors have a short burn time, and produce a lot of thrust. Contrasting this, a liquid-propellant motors have a long burn time, but produces less thrust. Overall, liquid propellant motors are higher efficiency than solid motors, so engineers like to use them whenever economically possible.

So what typically happens is that all the motors are usually ignited on the ground to create maximum thrust. The solid

Figure 2: The Delta III rocket uses nine strap-on booster motors. Six are lit on the ground.

motors burn out first, and are dropped off the rocket. This accomplishes two things. First, the empty cases are useless mass. Second, they are hanging out in the breeze, causing a lot of drag. So getting rid of them as soon as possible makes a lot of sense. The core vehicle becomes lighter, and doesn't have excess drag.

On the Delta II rocket uses 9 solid rocket motors. Six of them were ignited on the ground along with the main engine. They burned for about 56 seconds. After they burned out, the remaining three strap-on boosters were ignited and burned for another 56 seconds. Meanwhile, the main core motor (a liquid-propellant motor) burned for a total of 264 seconds, which was another 152 seconds after the last set of strap-on boosters

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had fallen away.

Parallel Staging On Model Rockets

Is there and advantage to use parallel staging on smaller rockets?

Not really. In model rocketry, if you want more power, you just go out and buy a bigger motor.

A bigger motor has an advantage over a cluster of smaller motors. That advantage is a simplification of the rocket, which results in a higher reliability rate. It is much easier to get one big motor to ignite, than to try to get all the motors in a cluster to ignite successfully. True?

Also, since we're generally using solid-propellant motors for all our launches, there isn't much of an advantage to having strap-on boosters. All the motors, including the core motor, would burn out at approximately the same time. You might as well just use sequential staging. It will be more efficient and less complex than strap-on boosters.

There are, however, some cases where there is an advantage to using parallel staging.

Situation 1: Scale Models. If you are building a replica of a rocket that NASA uses, like a Titan IV, you'd want it to operate just like the real thing.

Situation 2: When you are using a long burn motor, such as the Apogee F10 motor in the core. Since this motor burns for nearly 8 seconds, it could be used with other "short duration" motors that burn out in two or three seconds. It is a real cool looking effect to see the strap-ons fall away while the main core keeps going. Especially when it happens real close to the ground where you get a real good view of it. Additionally, hybrid motors can be used in the core vehicle, since their burn time can be tailored to act like a liquid propellant motor.

Situation 3: Large rockets. When you start getting above N size motors, you are at the threshold where there just aren't bigger motors that are commercially available. You have to start clustering or staging them.

Situation 4: Legal Aspects. If you don't want to get a Low Explosives User's Permit (LEUP), you are in a similar boat to Situation #3. There is a maximum size motor you can legally own and use. But you can cluster them, or parallel stage them.

Situation 5: Physical size limitations. When you stage rockets conventially, the rocket gets longer in length. But if you own a short rail or launch tower, you need to keep the overall length of the rocket to a minimum. Otherwise, you may not have sufficient speed when you clear the tower for the fins to be effective. I admit, this last one is stretching it, but it does illustrate that there may be special cases where it makes sense to parallel stage.

What does the flight profile look like?

I want to talk about theoretical stuff before we get into the "how-to" part where I show you the RockSim simulations. Why? We'll need to compare RockSim's results later, to make sure that it matches our theoretical expectations. Otherwise, our simulation results won't do us any good.

First, let's discuss the flight profile of a simple model. I don't want to get into the Delta II rocket with 9 strap-ons, as that would be really complicated. Let me say that even a "simple" parallel-stage model is quite complex in its flight profile.

Case Study #1: Our "simple" parallel stage rocket will look like the image shown in Figure 1. Two strap-on boosters, and a single motor in the core vehicle -- all using the same type of motor. For the sake of familiarity, let's say they are Estes C6 model rocket motors.

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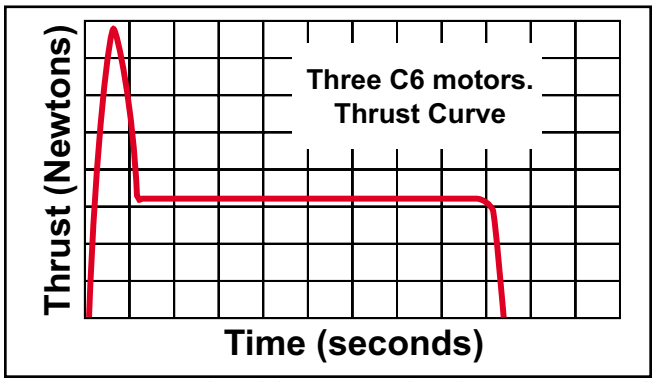

Figure 3: We should expect the thrust curve of our example (CASE #1) to look like this.

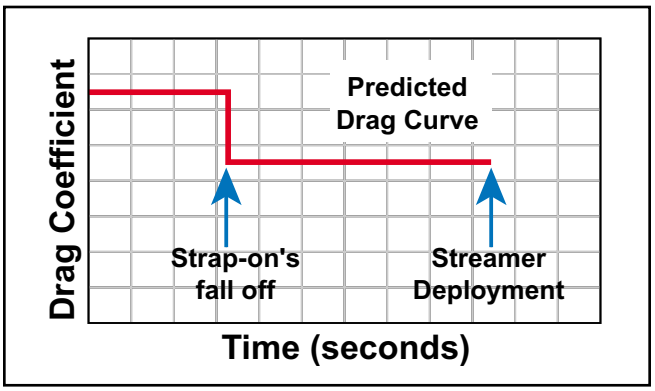

Figure 4: Our predicted Drag plot for our rocket.

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We'll specify that all the motors will ignite when the launch button is pushed (no air-starts). Since they all have the same type motor, we better expect the outboards to burn out at the exact same time as the core vehicle motor.

Our theoretical thrust curve will look like the one shown in Figure 3. You'll notice that the final curve is just the sum of the three individual motors. The spike is three times as high, but the burn time is the same as just a single motor.

What will be different though, is the Drag plot and the mass depletion plot. The C_d plot should look like something similar to Figure 4. At lift-off, the C_d is very high, because of the strap-ons. When the strap-ons are jettisoned, we expect the C_d of the rocket to go down instantly and dramatically.

The mass depletion graph should also give us an indication that something dramatic happens when the strap-on boosters fall off. For our simple rocket, we anticipate that it should look similar to Figure 5.

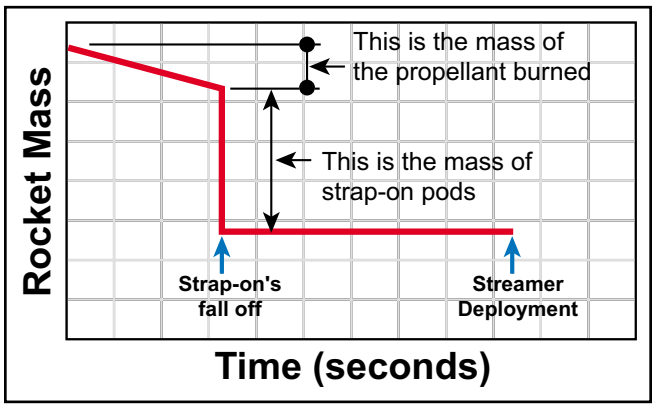

Figure 5: When the strap-ons fall off, the rocket suddenly gets a lot lighter in weight.

Case Study #2: As a second case study, let's now assume that the core motor is air-started, but only after the strap-on's burn out. Figure 6 shows what we would expect the Thrust, C_d, and the Mass depletion graphs to look like.

This second case study is actually simpler than the first case. The thrust curve looks strikingly similar to a conventional two-stage rocket. Doesn't it?

The mass depletion curve also looks like something you'd expect from a 2-stage rocket.

The only curve that is different is the C_d graph. But even this could be similar to a conventional 2 stage rocket; if the booster stage was big and fat. For example, in Figure 7, I've illustrated what the 2-stage rocket might look like that could make a C_d graph like in Figure 6.

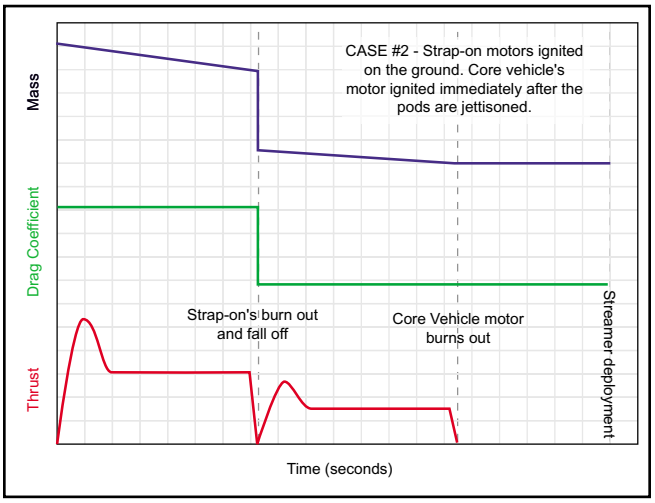

Figure 6: In this example, the core motor doesn't ignite until after the pods fall away. Doesn't this resemble a typical two-stage rocket like the one in figure 7?

As an aside, it was when I was thinking about this case study, that it dawned on me how RockSim could simulate this configuration.

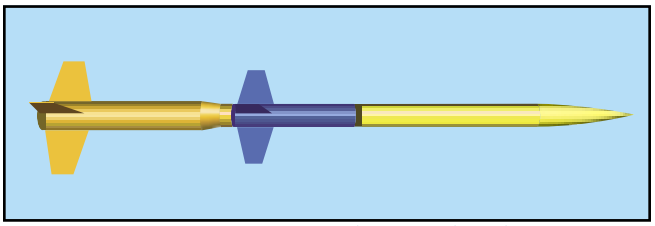

Figure 7: A two-stage rocket, with a large diameter booster stage, could be confused with the graphs shown in figure 6.

If we can trick RockSim into simulating these three curves, for Case #2, we can get reasonable altitude prediction numbers. More important, we'll be on our way to developing a trick to simulate all cases of parallel staging.

Not So Fast... There's More To Consider.

Actually, there are two more variables (more graphs) that we need to get right too. They are the CG position, and the CP location.

When we create the RockSim design file to show these strap-on boosters, we have to get the CG in the right spot. But since RockSim will only allow us to make conventional 2 stage

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rockets, how do we do this? RockSim forces us to put the booster below the sustainer motor.

Coming Next Issue

In the next issue, I'll continue this article by showing you step-by-step how to set up the rocket design in RockSim. You'll also learn about the CP affects and the Cd effects of the strap-on booster tubes, and what we're going to do about the nose cones on the pods.

About the Author:

Tim Van Milligan 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 the FREE e-zine newsletter about model rockets. You can subscribe to the e-zine at the Apogee Components web site, or sending an email to: ezine@apogeerockets.com with "SUBSCRIBE" as the subject line of the message.

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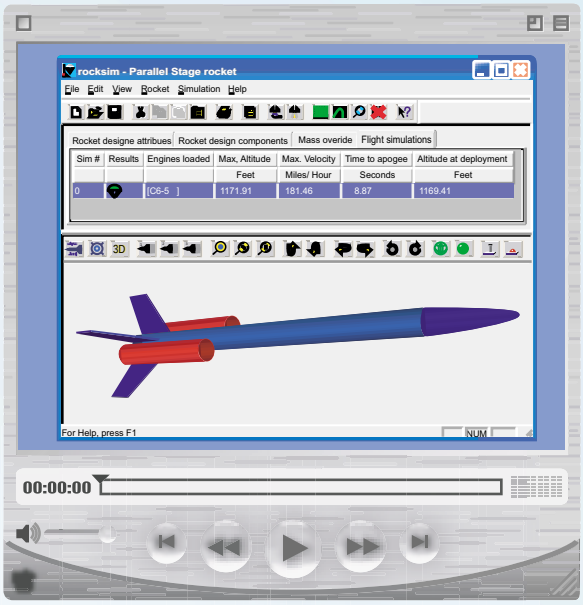
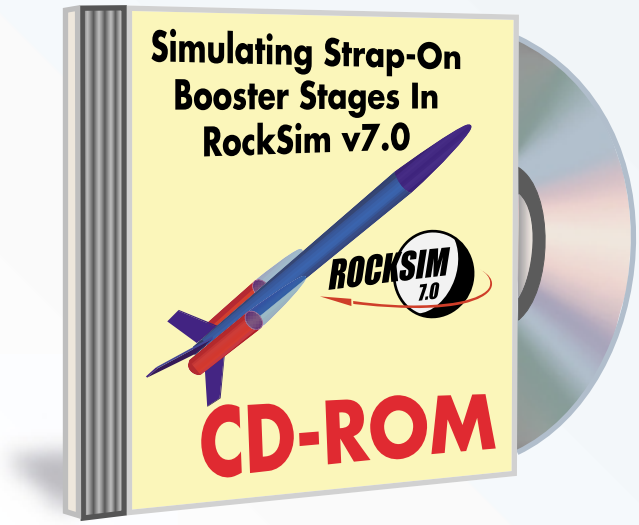
Learning the techniques to simulate strap-on booster stages in RockSim offers me the opportunity to demonstrate to you some of the advaced features that I use every day. I can teach you how to make your RockSim simulations more accurate, and how to create your designs quicker.

This new CD-ROM has over 34 minutes of how-to instructional videos on it that will teach you: how to use the Engine Editor software, compiling the engine database, analyzing the simulation results, and lots of tricks and tips.





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