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Feature Article:

How To Zero In On The TARC Altitude And Duration Objectives

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How To Zero In On The TARC Altitude And Duration Objectives

Written By Tim Van Milligan

Last week, I was at Morton East High School in Cicero, Illinois, lending a helping hand to Physics Teacher Larry Houle. The task was to get his TARC teams up to speed on rocketry as quickly as possible. From my recollection, there seemed to be about 20 students organized into 5 TARC teams.

The students had already built some smaller rockets and knew quite a bit about the basics of rocketry. The credit for that goes to their teacher, Larry Houle, and to their NAR mentor Tom Pastrick.

When I was introduced as being from Apogee Components, the maker of the RockSim software, they had a couple of simple test questions for me about how to use the program. I could sense that they didn't trust me, and were trying to gauge whether or not I might be useful to their objectives. I fully expected that; as I'd do the same thing if some outsider came in and started offering me advice. But after a while, it started to become apparent that I knew how to use the software.

At the same time they were putting me to the test, I was also putting them to the test by asking them questions about what trade-offs they had made so far in their design. For example, if they asked me about the correct length of an engine mount tube, I'd answer them by asking them about the advantages/disadvantages of a long tube. Then I'd follow-up by asking the advantages/disadvantages of a short motor mount tube. This is really what engineers do all day long. They are constantly making trade-offs in the design, trying to find the optimum configuration for the task they are trying to achieve.

If you're a mentor of a TARC team, this method of answering a question with a new question is how you get them to think thing through for themselves. It puts the burden of thinking things through on to them. When they come up with their own solution, you can see their eyes light up like the bulbs on a Christmas tree.

Eventually, the students had a discussion amongst themselves about which rocket motors to use. As I was listening in on them, I could sense there was a little bit of confusion about motors and how to dial in on the right motor for the task at hand. Based on this conversation, I was able to get a good idea of what kind of obstacles that TARC teams might be running into. In fact, we at Apogee Components have had a number of teams call us up and ask what was the "hot" motor for this year's event.

Figure 1: Tim Van Milligan and the TARC students at Morton East High School gather around a computer to study their RockSim design.

I can tell you right now that there is no single engine that is a "must have." The perfect motor is completely dependant on the rocket design you're creating. If you change your design, then you'll need to change what rocket motor you'll need. In other words, like everything else in the TARC event, the motor selection is yet another trade-off study that you'll have to investigate.

Then Where Do You Start?

I know how fun it is to start designing a rocket for the TARC contest. This is the fun part for students. But if you get the cart before the horse, it is going to take a long time to reach your destination.

My suggestion on where to start is exactly the same as what is in the TARC Handbook. It lays out a very straightforward path for the students to take when designing the rocket (see page 8 of the Handbook for TARC 2010). In essence, it all starts by designing the egg capsule.

When I was at Morton East High School, I noticed that

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the students had the rocket completely designed already, and were starting to cut parts. Unfortunately, they had no idea how big of a streamer they were going to use, nor what material to make it out of. I'm not picking on the students of Morton East High School, as I'm sure that this is the case with most every team in the competition. You probably have a gut feel about how big the streamer is going to be, and you're are designing the rocket around that intuition.

Your intuition is probably wrong!

And because of that, here is the likely scenario that is going to happen. When you get into the actual launches -- because that is the goal of all the students; to have fun at the launch -- you are going to be completely surprised at how far off you were on the first flight. Your rocket is going to come down too fast or too slow – by a wide margin.

You may have designed the capsule to survive the high speed landing of a streamer descent, but it is not optimized for the time aloft.

How do you do that? By running a series of drop tests of your egg capsule with a variety of streamers.

I talked about sizing a streamer in Newsletter 244, but I think I'll go a little bit further now. We'll start by determining what is the descent rate you're trying to achieve. According to the rules, your egg capsule has to go 825 feet up into the air, and come down to the ground in a time range of about 40 to 45 seconds. Let's cut that to 42.5 seconds to give us some room for error.

For simplicity, let's say the rocket deploys the streamer right at the peak altitude of 825 feet. This is not a bad assumption to make, as it should be the slowest speed during the flight and therefore put less stress on the streamer at ejection. You can debate the merits of having the streamer deploy at a lower altitude, in which case the rocket will arc over and be heading downward before the streamer deploys.

If you divide 825 feet by the 42.5 seconds, you get a descent rate of 19.4 feet/sec. But this is actually wrong. The rocket took some time to get to that peak altitude during the boost phase, and you'll need to subtract it out of the 42.5 seconds. A good estimate for the boost time is somewhere around 6 to 8 seconds. For simplicity reasons, we'll say it is going to take 7 seconds to reach the peak altitude of 825 feet. Now we only have 35.5 seconds for the egg capsule to get back down to the ground. Therefore if you divide 825 feet by 35.5 seconds, you get a descent rate of 23.2 feet per second. This speed is your design objective.

Figure 2: Egg capsule on a streamer.

Knowing this, you can begin the design of your egg capsule. In order for the egg capsule to return to the earth in 35.5 seconds from an altitude of 825, feet, it is going to be coming down to the ground at a speed of around 23.2 feet per second. To put this into perspective, it is like dropping the unprotected egg from a height of about 8.4 feet in the air. Splat!

So your first step is to protect the delicate egg and keep it from cracking when you drop it from a height of 8.4 feet without anything attached to it (see Newsletter 184). This is where your capsule comes in. But remember, the heavier you make your capsule, the more energy it will have when it reaches the ground at the end of the fall. The capsule has to absorb this energy and keep it

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away from the delicate egg.

I'd suggest that you err on the conservative side and make sure your egg capsule can protect the egg in a drop from a height of 10 feet (without the streamer attached), which would give you an impact speed of 25.4 feet/sec).

By the way, figuring out the drop height to equate it to an impact speed is a simple *Conservation of Energy* problem from any physics textbook. If you need help with that, just ask your teacher.

When you get your capsule designed to cushion the egg, now you can add a streamer to it and take it to a higher drop location. This was discussed in Newsletter 244.

You're going to find that weight is a big issue when you have to bring your egg down with a streamer. A streamer doesn't slow down the egg nearly as much as the parachute did in the previous contests.

At this point, when the capsule and the streamer have been designed and are proven to protect the egg and bring it down at the correct velocity, you're ready to start designing the rest of the rocket.

Designing The Rocket

When it comes to rocket competitions, I've learned to be a pessimist about the things that could go wrong. As the old Murphy's Law states, anything that possibly could go wrong – will. This typically has me designing multiple rockets for different weather conditions. I like to be ready for when the weather is cloudy and windy.

Most competitors will design their rockets expecting the weather to be perfect. If it is, they have a great chance at doing well. But if it isn't clear blue skies with little wind, then they don't seem to have a back-up plan. In effect, they are unprepared.

My suggestion is to design the rocket expecting the wind to be blowing at 10 mph. What this means is that most rockets will weathercock (turn) into the wind as they ascend.

"Who cares?" you ask. You should care. If the rocket turns into the wind, then it isn't going to reach its target altitude of 825 feet. You'll be scrambling at the last minute to decide how you're going to make up the lost altitude. The most obvious change you can make is to swap out the rocket engine for a bigger one. But how much bigger? And more importantly, will you have that motor with you on the launch field?

When it comes to rocket designs that are more resistant to weathercocking, you have a lot of choices. There

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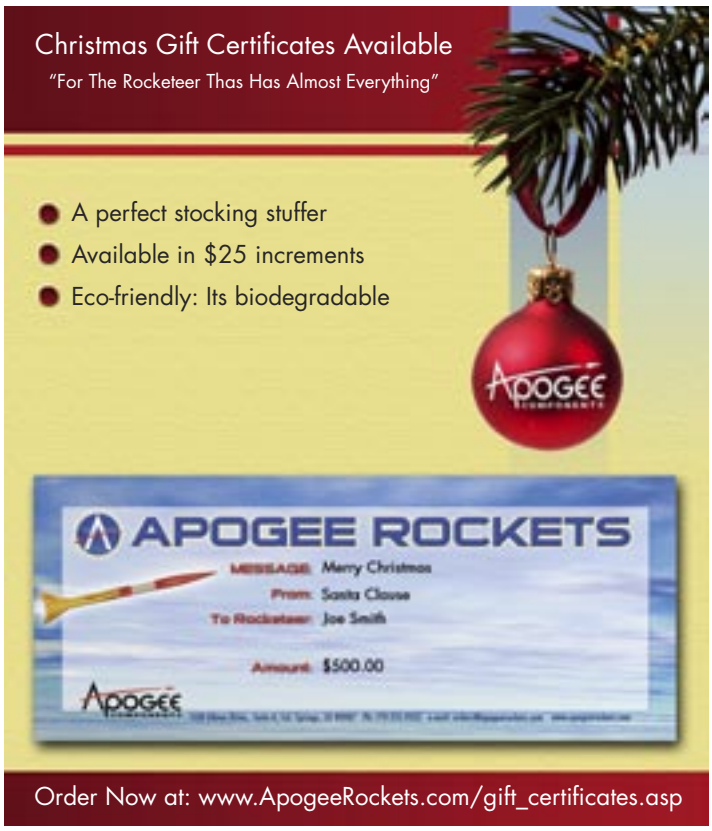

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are a number of things you can do, such as spinning the rocket using canted fins or adding spinerons (http://www.apogeerockets.com/Rocketry_Videos/Rocketry_Video_01.asp). You can also use tube fins or ring tails, which seem to resist weathercocking a lot more than normal fins.

There are a lot of other tips for designing rockets that fly straighter. These are found on the Apogee Web site in Newsletter 198 (www.ApogeeRockets.com/education/downloads/Newsletter198.pdf), or in the book *Model Rocket Design and Construction – third edition* (www.ApogeeRockets.com/design_book.asp).

If you are able to design a rocket that flies straight and meets the requirements of achieving 825 feet on a breezy day (10 mph), you're in good shape. That same rocket will fly a little bit higher on a calm day with perfect weather conditions, but it is easier to lower a rocket's altitude later during the competition than to try to increase the altitude.

Selecting the Motor

Selecting the motor for the flight is where it starts getting more complicated. You do need as basic understanding of rocket motors and how they work. For that information, I'll point you to a number of references. First is Newsletter 131 (www.ApogeeRockets.com/education/downloads/Newsletter131.pdf). If you don't like to read, and are more of a visual person, then the same information is in the Apogee DVD: *" Rocketry Education #1"* (www.apogeerockets.com/Teacher_DVD.asp). Another good reference is the booklet *"Model Rocket Propulsion"* (www.ApogeeRockets.com/mod_rocket_propulsion_bk.asp).

You may gloss over this and think it isn't important. But it is critical. From my experience with the students at Morton East High School, and from other high schools that I've had contact with, most students don't fully grasp how rocket engines are classified. Without this, it is really hard to select the right rocket motor. You'll end up ordering the wrong motors, which will waste a lot of your limited financial resources.

Learn about rocket motors now! With any of those references listed previously, your students will gain a good understanding of how rocket engines are classified, which is the foundation on which they'll select the right rocket motors for the contest.

Selecting Rocket Engines versus Selecting Engines for Competition Models

You wouldn't think there is a difference between the selection process, but there is. In the basic step-by-step process of selecting motors for rockets, you will come away with a whole host of motors that might work. But when selecting for competition, you'll narrow that list down considerably to maybe just three or four that might get the job done.

The step-by-step process for picking motors for regular models is listed in Apogee Components *Technical Publication #28* (www.ApogeeRockets.com/education/downloads/Tech_Publication_28.pdf). I do suggest that you download

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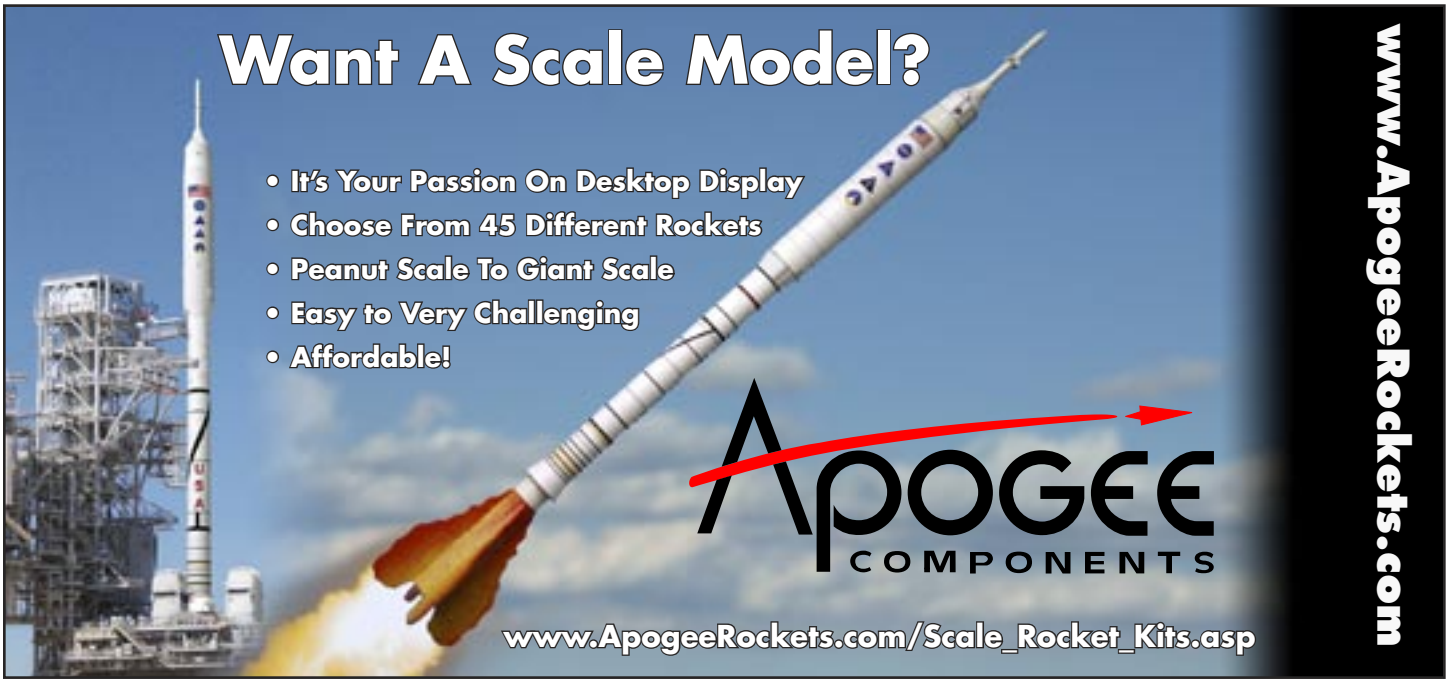

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this document and read it through. It will save you a lot of agony and much money by preventing you from picking the wrong motors.

From the big list of motors returned by the process shown in *Technical Publication #28*, your next step is to whittle it down to the motors that will actually loft your rocket to at least the 825 foot altitude.

Your First Launches

At this point, you should be ready to run your first actual real launch. The purpose of this launch is to gather some rudimentary data about your rocket's flight characteristics. For the first few launches, I recommend using the *Apogee Flight Record* data sheet (www.ApogeeRockets.com/data_sheets.asp). There is also a copy of it in the book *Model Rocket Design and Construction – Third Edition.*

Notice that nowhere did I say to launch your altimeter or the egg on the first flight. You can (and should) simulate the weight of the egg with some ballast weight (sand), but flying the altimeter in the rocket when you don't know how it is going to behave is an invitation to a disaster (which might happen if the rocket is smashed to bits because of a unstable flight).

Regardless of what happens on the first flight, with the *Apogee Flight Record,* you're going to get back a ton of data about how the rocket flies. If possible, video tape the flight so you have something additional to study if you don't catch the subtle characteristics of your rocket's flight.

The *Apogee Flight Record* comes with a report that explains how you can use the information you've collected to make the next flight better. If you don't use that information, you've only got yourself to blame. It is really good, and I strongly urge you to make use of this excellent tool to make your flights better (more consistent). Consistency, after all, is the key to winning the TARC competition.

An unstable rocket presents a big dilemma. However, don't revert back to step one quite yet. There could be any number of reasons why the rocket--which was designed stable in RockSim--could have gone unstable. See Peak-of-Flight Newsletter #42 for a discussion of this (www.ApogeeRockets.com/education/downloads/Newsletter42.pdf).

If the rocket flies well and you are confident that it will continue to fly well on the next flight, you might consider flying the altimeter in the rocket on the next flight. Don't fly the altimeter until you are sure you have a stable rocket that seems to work ok. I don't want you to smash up the altimeter and have to buy a new one.

Once you get altitude data back from the follow-on flights, you can now dial in on that magic altitude of 825 feet. By this, I mean make the subtle changes necessary to the rocket and the motor choice so that you consistently launch to the correct altitude and you're deploying the streamer right where you want it (at the peak?).

Dial In On the Exact Altitude

How do you do this?

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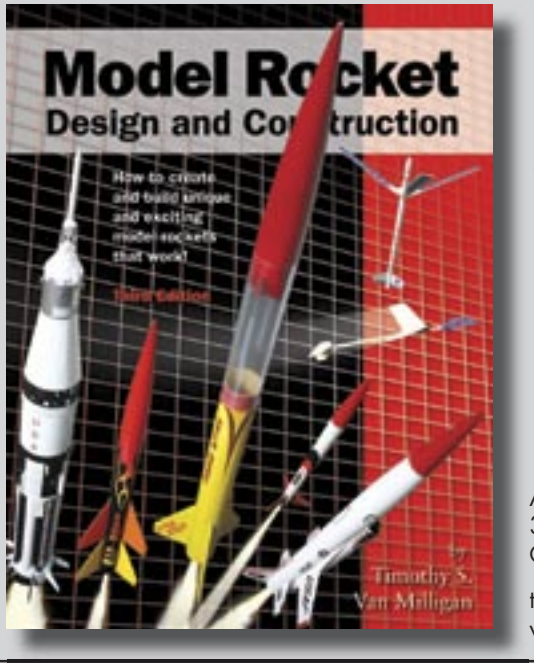

Model Rocket Design and Construction

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First, take the altitude measurements you've got from the altimeter, and back out the *Coefficient of Drag* (C_d) for the rocket. The C_d is unique to the specific configuration of each rocket, and you'll need an accurate value to make quality predictions of the final altitude when using RockSim.

You'll plug the Cd into RockSim on your future simulations and you'll get much closer results on your test flights. This process of finding the unique Coeficient of Drag is called "Cd Back-Tracking." For a detailed explanation of how this is done, see Peak-of-Flight Newsletter 130 at: www.ApogeeRockets.com/education/downloads/Newsletter130.pdf. It is important to note that you should always plug in your actual launch conditions into RockSim. That way the software can take into account the other factors so you can isolate the C_d value more clearly.

Once you have your C_d value nailed down, you shouldn't have to change the value in RockSim in subsequent launch simulations. It should be fairly accurate from here on out. But if you run additional launches, you should always perform your C_d back-tracking just to verify things and to make minor tweaks if necessary.

If everything was working perfectly, what should happen? This will be a test of how well you've been keeping records of your flight and how well you've entered data into RockSim. But what you want to happen is for the RockSim pre-flight predictions to be very close to the actual altitude as recorded by the altimeter. If RockSim predicts 850 feet, and the altimeters reports back 850 feet after the flight, then you know you're dialed in pretty good. Will you ever get to this level of perfection? Well, nothing is perfect. But in the 7 previous years of TARC, the winning teams got very good at getting really close (just a few percent difference).

Tweak the Parameters For Optimum Altitude

What do you do if your rocket is flying too low or two high? This is probably what you wanted to know, right? Before I tell you how to do this, it is important that you're dialed in on the C_d of the rocket as listed previously. Otherwise, what I tell you next won't do any good.

When the rocket flies too high; say your rocket is flying to 850 feet instead of 825 feet. What modifications can you make to the rocket to drop the altitude down?

1. Add weight to the rocket. Adding weight is easy to do. You can simply pour a little bit of powdered chalk into the rocket body tube as the ballast. This is typically called tracking powder. The advantage is that the powder, when ejected by the engine, will create a big puffy cloud in the

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sky so you and your tracking team can see it more easily. That is a big benefit in this event.

The only caution that you need to be aware of is that sometimes the tracking powder can clog up the tube and prevent the nose from coming out cleanly. I'd suggest that you test this prior to the actual contest day so that you know how much tracking powder is too much and you can no longer reliably eject the nose from the rocket.

Another way to add weight is to paint the rocket, since paint has mass. But I recommend you don't add paint if the rocket wasn't painted prior to the test flights to determine the C_d of the model. By painting the rocket at this point, you're going to affect the C_d of the model, and basically you'll need to start your test flights all over again.

2. Angle the launch rod by a few degrees into the wind. This non-vertical launch will lower the overall altitude of the rocket. The rocket will also weathercock a little bit more, which is also going to lower the overall altitude. But RockSim will help you to find the optimum launch angle to point the rocket. The good news is that this will also help the rocket to land closer to the launch pad so you won't have to chase it as far.

3. Switch to an engine with lower average thrust. For example, if you were using an E30 motor in your test flights and it was going too high, you might be able to drop an E15 motor into the rocket. While typically an E15 would make the rocket fly higher, on a breezy day, the rocket will

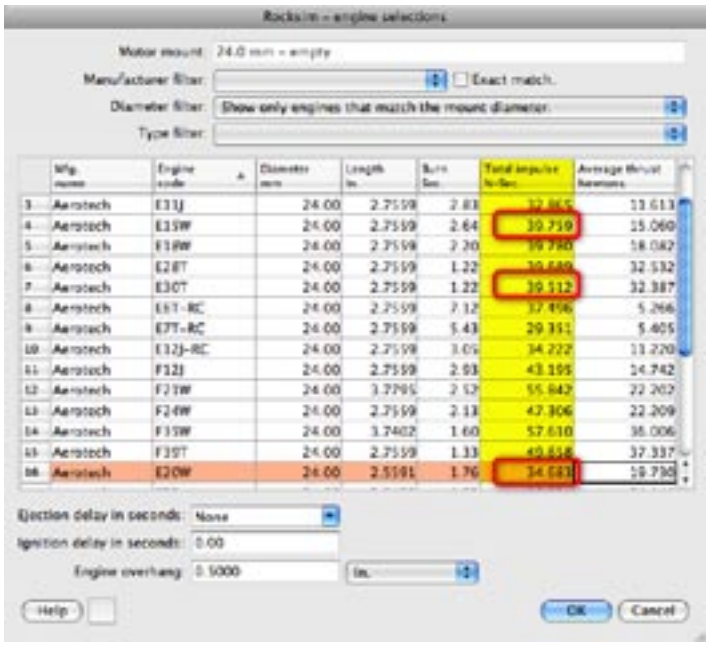

Figure 3: Within RockSim, you can see the total impulse for each of the different rocket motors.

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weathercock more and would fly lower. So this is a weather-condition dependant change.

4. Switch to a motor with a lower total impulse. I like to tell people to think of total impulse as the size of the gas tank in the motor. The bigger the tank, the further the vehicle can travel. So by lowering the size of the tank (the total impulse of the motor), the rocket is not going to travel as high.

As strange as it sounds, not all motors in the same classification have the same amount of energy. In fact, they are usually all different because of the type of propellant that they use. For example if your rocket was using a 24mm diameter E-motor, by NAR definition it could have anywhere from 20.1 Newton-seconds of power, all the way to 40 Newton-Seconds. The E30 and the E15 are pretty close to that upper limit of 40 Newton-Seconds with a little over 39 N-s of total power. But the new E20 and the Estes E9 are a lot lower. The E20 has 34.6 N-s of power, and the E9 has 27.8 N-s of power.

If the rocket is flying way too high, by hundreds of feet, then you'll have to take more drastic actions. You can try one of these:

5. Add drag to the rocket by attaching something to the outside of the rocket. I've seen TARC teams add bits of balsa glued to the outside of their rocket. And that works. Anything extra on the outside of the rocket is going to add drag. But remember, as soon as you do this, your C_d value that you've worked hard to nail down through a series of test flights is now going to be incorrect. You really should start all over with those test flights. This is not an option I would recommend on the day of the contest.

6. Drop down in motor size. For example, if you were using an F motor before, and it was going hundreds of feet too high, then it would be logical to drop down to an E motor. Again, this is a major change, and is not something you'd do on the day of the contest.

Strategies to Get More Altitude From Your Rocket

Getting more altitude from the rocket is a bit trickier than getting it to fly lower. But in general, to get more altitude from the rocket, you'd do the opposite things that lowered your rockets altitude.

1. Remove weight from the rocket. This is hard to do if your rocket is already constructed. You might consider building is some ballast weight into the rocket design, just in case you need to remove some weight after your test flights.

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2. Angle the launcher "WITH" the wind. Since the rocket is going to want to weathercock into the wind, you'll actually gain a few feet of altitude by doing this.

3. Use a longer launch rod. The faster the rocket leaves the launch pad, the straighter it will fly because it will be less effected by the wind (it won't weathercock as much). So instead of using a 5 foot long launch rod, use a 6 or 7 foot rail launcher. The longer the better, as there is really no such thing as a rod that is too long. The longer the rod, the more distance the rocket has to build up a lot of speed to counteract any side-wind hitting it.

4. Switch motors to a higher average thrust. This is also going to make the rocket fly faster, and therefore straighter because it is less affected by the wind.

Figure 4: Tim explains how a rail launcher works.

5. Switch to motors of higher total impulse.

6. Use a piston launcher to give the rocket a kick-start into the air. You might be able to gain about 2-to-5 percent more altitude by using a piston launcher. This is going to add some complexity to the launch process, but it doesn't change the rocket in any way. For more on piston launchers, visit: www.ApogeeRockets.com/Sunward_Piston_launcher.asp.

7. Reduce drag on the rocket. This could be as simple as removing the external launch lugs and using fly-away rail guides (see Peak-of-Flight Newsletter 247 at: www.ApogeeRockets.com/education/downloads/Newsletter247.pdf). Note that changing the outside of the rocket is going to change the C_d value of the rocket. This is not advisable to do on the contest day, because you'll have to perform some test flights to back-track a new C_d value.

8. Use a bigger motor, going from one size to the next, such as going from an E motor to an F size. This is a big change to the rocket, and should only be used when you'll have time to retest the rocket to see how high it is going to go.

Conclusion

Armed with this information, you should be able to dial in on that 825 foot target altitude with greater certainty. And you should be able to hit that correct descent rate too in order to get your rocket back down to the ground between

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40 and 45 seconds. But don't be fooled. It will take a lot of work on your part, as there are a lot of decisions you'll have to make. Most of them occur during the design phase of the project. But once you get your design locked in, the techniques of dialing in on the target altitude in this article can be used.

References Not Mentioned Previously:

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Newsletter 196 - How do you know if your payload bay is big enough to carry your egg? - www.ApogeeRockets.com/education/downloads/Newsletter196.pdf

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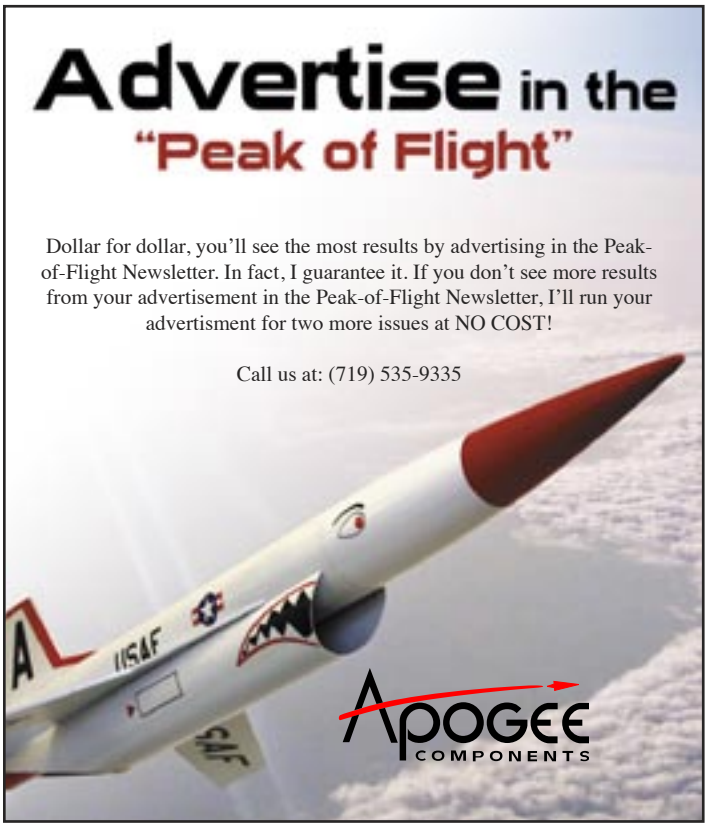
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