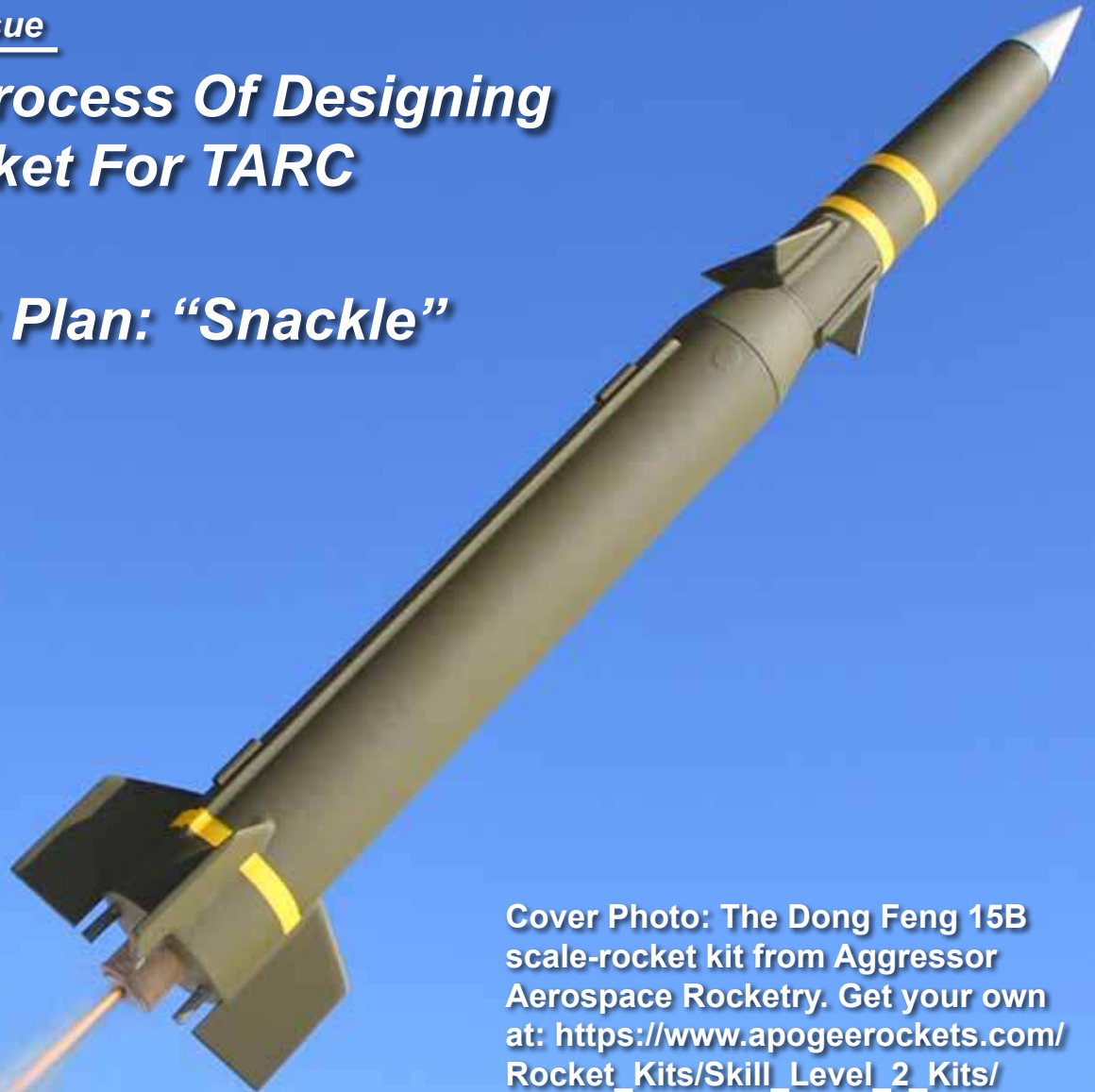


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Shrox Plan: "Snackle"



Cover Photo: The Dong Feng 15B scale-rocket kit from Aggressor Aerospace Rocketry. Get your own at: https://www.apogeerockets.com/Rocket_Kits/Skill_Level_2_Kits/Dong_Feng-15B

The Process of Designing a Rocket for TARC

By Tim Van Milligan

Recently I participated in the NAR's competition event called "Fragile Precision Payload" (<http://www.nar.org/?s=Fragile+payload+altitude>). Essentially, this event is just like the TARC (Team America Rocketry Challenge - www.rocketcontest.org). Where TARC is for students, the Fragile Precision Payload event is for any NAR member that wants to compete.

Like TARC, the object of the Fragile Precision Payload event is to launch and recover a raw hen's egg without cracking it. What makes it challenging is the "precision" altitude and duration requirements of the event. In the NAR's event, you have to get as close as possible to 300 meters in altitude, with an overall duration (from lift-off to landing) of 60 seconds. And like TARC, you have to do it twice. Break the egg on either flight, and you're disqualified.

This is a relatively new event in NAR competition, and I guess the hidden objective is to give NAR members some experience in designing egg-lofters so that they'll become better mentors to the TARC competitors.

I thought I'd document my experience in this event, so that you'd glean some knowledge of what is involved in the design process. This will be very useful information for TARC competitors that have to design their own rockets.

Step 1: Research Past Designs

Everyone assumes that they are starting from scratch, like the competition event was never flown before. But that really isn't true. There are plenty of egg-lofter rockets that have been flown before, so you should be able to get plenty of ideas for your own rockets.

In my case, I looked through the old issues of Sport Rocketry to see the general size and configurations of the models. I also asked around to find out what size rocket engine was generally used. In this case, it was the 29mm diameter motors that were the most popular.

Step 2: Inventory your Parts Supply

Before you start designing, rummage through your current stash of rocket parts. You want to see what you have available, and what you're going to need to purchase. I had in my mind that I was going to make a 2.6" diameter



Figure 1: This photo gives you an idea of the general size of a competitive TARC-style egglofting rocket.

rocket, so I'd need a nose cone to fit that size tube. I had a couple of options, and of course, I chose the cheapest and the most convenient one in my inventory. If you can make it with the cheap one, then go for it!

Step 3: Start Designing The Rocket On Paper

Designing rockets is a cyclical process. You'll come back to it again and again in order to refine the layout and the selection of components. Don't assume that you'll get it right the first time; you won't.

Based on my own history of conversing with other modelers, I get the sense that there is a lot of uneasiness about the design process. There are a lot of variables that go into the design of a rocket, and I think that is what causes the confusion. People just don't know exactly where to start, because they are afraid of making a costly mistake right at the beginning of the process.

And in a sense, they are right. Mistakes are going to occur, and they will incur a cost of either money or time lost. But I try to look on the bright side; the cost is really an investment in knowledge and wisdom. So if you can learn something from your mistakes, then the mistake is really not that bad. And if that is the case, then make your mis-

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Designing a Rocket for TARC

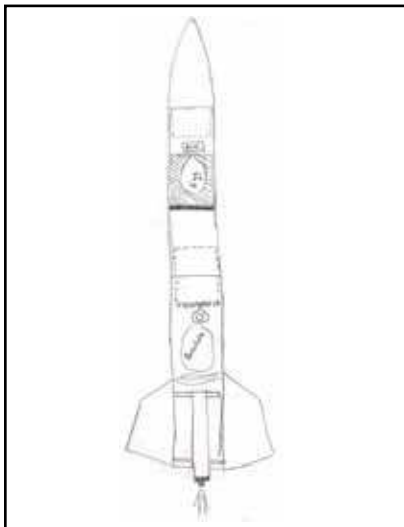


Figure 2: Sketch the layout and general position of the parts in the rocket. It doesn't need to be fancy.

in order to test my design. The goal was for the rocket that I flew in the competition to have some flight time on it. It wouldn't be flown for the first time at the competition.

The first decision you need to make during the design process is the diameter of the tube, and the size of the engine mount. And in the back of your mind, you can remember what inventory of parts you have on hand.

In my case, I had already decided on a 2.6" diameter tube (BT-80 size), and a 29mm diameter engine mount. From here, I started the outline of the rocket. You can sketch it on a piece of paper if that helps (Figure 2).

From there, you can start adding some of the internal components of the rocket, like the placement of the payload, altimeter, parachute, and the centering rings. My

takes as quickly as you can. Get them behind you so you can move forward to something that works sooner.

To reiterate, plan on making mistakes. In other words, allot some time during the process so you can recover from them. Because of this, you can't and shouldn't wait until the last minute to start the design. I started my design about two months before the actual competition, and I had two different practice launches planned

designs always start out on a sheet of paper before I start putting them into a computer. It helps me to visualize the placement of the parts, and how much room to allocate for each one inside the body tube. Usually I allocate a lot more room in the rocket than the part actually needs. That is OK. It is much easier to shorten the rocket later in the process than to make it longer.

Step 4: Input The Design Into A Computer

By inputting the design into a computer, I mean that you'll need to use a specialized rocket design program. There are several programs available, but the one I choose is RockSim (www.apogeerockets.com/RockSim/RockSim_Information). The software allows you to input the individual components, and it will allow you to run flight simulations that will predict how the rocket will fly.

Initially, I start the design by inputting the nose cone and then the body tube of the rocket. Then the fins are added so that I can see if the design will be statically stable (the CP is behind the CG). Don't worry at this point about the size of the fins. They can be enlarged or reduced in size later. In fact, plan on tweaking the size and the shape of the fins later. Just get them into the design so that you can see where the CP is located on the rocket. The internal components aren't going to change the CP location, so this will give you a reference of where to position other items internally in the rocket. In other words, you'll want to position

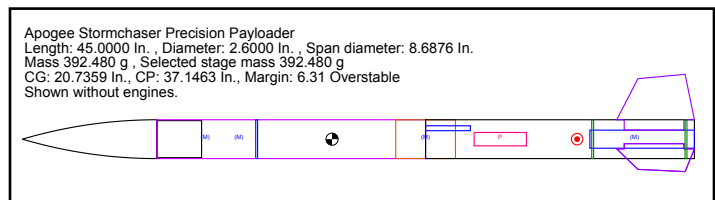


Figure 3: The basic RockSim design of the Precision Payload egglofting rocket.

Continued on page 4

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Designing a Rocket for TARC

as much as you can ahead of this location in the rocket in order to keep the rocket stable. Obviously, the motor mount and its centering rings will be aft of the CP location, and you can't do too much about that. But everything else can go in front of the CP location (towards the nose cone).

With the outer shape of the rocket input into the software, you can next start adding all the internal components. The engine mount and its centering rings are what I try to add into the design next, so I can see how much room I have left for the other components. For a 29mm motor mount, I used a tube that was 7 inches long. Why 7 inches long? Because that is what I remembered what I had in my parts bin that I inventoried earlier. It also happens to be the length of the tube used in a motor mount kit that we sell here at Apogee Components (https://www.apogeerockets.com/Building_Supplies/Motor_Mount_Kits_Adapters/Low_Mid-power_Motor_Mount_Kits/Motor_Mount_Kit_26_BT80).

With the motor mount added, I next started adding the payload mass (the egg), and the altimeter mass.

From the NAR's rulebook (<http://www.nar.org/contest-flying/us-model-rocket-sporting-code/payload-events/egg-lofting-altitude/>), the specification for the egg is that it has to have a mass between 57 and 63 grams. To be safe, I used the heavier 63 grams for the mass.

The weight of an altimeter depends on which one you use, and there are several to choose from. I used 10 grams

for the mass, because that is probably a little heavier than the Jolly Logic altimeters that we sell here at Apogee Components (https://www.apogeerockets.com/Jolly_Logic).


The next component I entered into the computer design was a parachute. "What size?" is the question. This is another one of those variables that takes some research. From what I found out asking others, the chute might be anywhere between 15 and 24 inches in diameter, depending on the size of the rocket. Since a 2.6" diameter rocket is relatively large, I decided for the initial simulations to use a 24" diameter parachute. Again, this is one of those situations where it is easier to make the chute smaller later on than to make it bigger. So I started with a larger chute than I needed in the initial design.

In reality, these are enough components to run some simple simulations to see if you're in the right neighborhood with the design. There are other components in the design, like egg protectors, bulkheads, screw eyes, launch lugs, and other small components that may need to be added. But I want to just confirm that I could get close to the target altitude of 300 meters with the shape I had.

My selection of motor for the first simulation was based on cost and convenience. I wanted to pick a motor that was relatively inexpensive, and I prefer to use a single-use motor because it is easier to swap out between flights. I have to admit, I'm lazy in that way.

Again, I went back and did some research as to what

Continued on page 5



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Penny shown for size comparison

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Designing a Rocket for TARC

motors other people had used in this event. The most common motor size was an “F” engine.

Going through the list of available single-use F motors (https://www.apogeerockets.com/Rocket_Motors/AeroTech_Motors/29mm_Motors_Single_Use), I selected the F27 motor from Aerotech. For the delay, I selected the longest one available, which is the 8-second variety. The longest delay is always my first choice for running simulations, which is described in Apogee Technical Publication #28 (https://www.apogeerockets.com/Advanced_Construction_Videos/Rocketry_Video_32). So my first motor choice for the simulation was the F27-8.

When running the situation I always use a constant 8 mph cross wind. The reason for that is because you almost never launch on a windless day. And 8 mph is a slight breeze that is typical for a nice launch day.

My personal goal with the first computer simulation was

Result	Engines loaded	Max. altitude Meters
1	[F27R-8]	310.55
2	[F50T-9]	477.62

Figure 4: The first computer simulation came out at 310.55m!

to have a 15% margin of error. So I would have been happy with a simulated altitude anywhere within 45 meters

of the target altitude ($300\text{m} \times 0.15 = 45\text{m}$). Anywhere between 255m and 345m would have been in the range that I was hoping for.

With this in mind, the first simulation shocked me. It came in at 310 meters in altitude. I was really close to the target of 300 meters. What this told me was my rocket's overall size and fin shape was reasonable for the mission. I wouldn't have to change too much later on. You could chalk this up to good luck, or good research at the beginning. I lean towards the latter — I had done a lot of homework before I started my design.

What Do You Do If You Didn't Get Within 15%?

If your design isn't within 15% of the target altitude, and you are below the mark, you will have to do some additional homework. My first suggestion is to look at the 2D flight profile of the rocket. It could be that the rocket is weathercocking strongly into the wind, or might even be going unstable. You have to first verify that the trajectory looks reasonably straight to rule out any big stability problems.

If everything is ok with the look of the trajectory of the rocket in the simulation software, then you'll probably have to make some changes to your design. The first thing would

Continued on page 6

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Designing a Rocket for TARC

be to try to make the rocket lighter weight. A second option is to use a larger and more powerful rocket motor. In this case, I'd lean towards using a more powerful rocket motor. In my design I had hoped to use an F class of rocket motor, but there are many different G class motors that would fit the 29mm engine mount as well. The rules for the Fragile Precision Payload competition didn't specify a particular size of motor, so there are a lot of options you could go with.

It is easier if you are over the target altitude, since you can add ballast into the rocket to make it heavier. A heavier rocket isn't going to fly nearly as high as a lighter one. Additionally, one way to make a rocket heavier is to switch to stronger materials, like using plywood for the fins instead of balsa wood. You can also add beefy fillets to the fins to make them harder to break off.

I'd rather the rocket simulated too high than too low. As I mentioned, it is easy to reduce the altitude later, even at the last second during the design process. Just add more ballast.

Step 5: Finalize the Initial Design

Did you notice that I used the word "initial" when describing the rocket design? I anticipated that I would be changing the design later on, and I had to make tweaks to it later. But what was important was that I made enough decisions that I could go forward with the plan.

To complete the design in the software, I added all the other little bits, like mass for the egg protectors, the shock cord, and the launch lugs. I wanted to account for all the mass that would be in the rocket at launch.

Step 6: Start Building the Rocket

The rocket, while it looks simple on paper, is a bit more complex. I decided on through-the-wall fins for the rocket, which meant I had to cut slots into the body tube for the fin tabs. I also decided to tilt the fins at 3° so that they would induce a spin at launch. I wanted to use this strategy as an extra effort to get a straight up flight. I didn't want the rocket to weathercock into the wind, because that makes it more difficult to achieve consistency in flights.

What this meant to my design was that there would be some construction challenges for slotting the tube. The technique that I recommend for doing this is found in my Advanced Construction Videos at: https://www.apogeerockets.com/Advanced_Construction_Videos/Rocketry_Video_3

The payload bay was the other challenge. It had to hold both the egg and the altimeter. I ended up putting a bulkhead in the



Figure 5: The altimeter mount for my egglofter.

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Designing a Rocket for TARC

middle of the upper part of the rocket in order to prevent the egg from sliding rearward. And on top of the egg, I laid the altimeter. I used a simple bulkhead with an Altimeter Mount from Jolly Logic (https://www.apogeerockets.com/Electronics_Payloads/Electronics_Accessories/Altimeter_Mount). Finally, to keep the altimeter from butting up against the bottom of the nose cone, I put some vertical pieces of plywood on the bulkhead. This forced a little gap between the altimeter and the nose cone.

Step 7: Flight Tests

The first set of flight tests was to get some data on the rocket's performance. The big unknown in any rocket design is the coefficient of drag. While the simulation software can get you some preliminary values, you need actual flight data to confirm the predictions.

I decided to take two different motors with me for the first set of flight tests. There was the F27R-8, which I mentioned before, and the F50T-9 (https://www.apogeerockets.com/Rocket_Motors/AeroTech_Motors/29mm_Motors_Single_Use/Aerotech_29mm_Motor_F50T-9). I chose the F50 as a back-up for a couple of other reasons. First, it has high lift-off thrust. And secondly, it has more total impulse than the F27. The F50 has 76.8 N-s of power, where the F27 has 49.6 N-s of power. Think of the total power as the size of the gas tank in a car. The bigger the tank, the further the car can travel. So if the F27 didn't get the rocket to the 300m altitude, then there would be a better chance that the F50 motor would.

By the way, the Total Impulse of the motors has to be looked up on a motor chart. Fortunately, they are listed with each motor on Apogee's web site. So if you look of the motor, you'll find its total impulse too.

The result of the first flight (see Figure 6) using the F27



Figure 6: The bright red flame tells us that this is the flight of the rocket using the F27 motor.

was an altitude of 258.8 meters. The F50-9 screamed right through the goal, and achieved an altitude of 420.6 meters.

I wasn't expecting the second altitude to be so high!

But that is what flight tests are meant to be about - finding the problems.

But this is actually a good thing, as I've bracketed the goal of 300 meters in altitude. I've got data from two different motors where one didn't have enough power, and the second had too much. This tells me that an F size motor is going to work for the design. The problem is, I still didn't

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Designing a Rocket for TARC

know which particular F motor would get me close to the altitude goal.

Step 8: Finding the Rocket's Coefficient of Drag

The one variable we need to find, which we mentioned previously, is the rocket's Coefficient of Drag. Without this number nailed down, we're not going to be able to get our computer simulations to match up with the actual flight results. But with the flight data collected from the first round of test flights, we can begin the process of identifying this important parameter.

There are a few ways to find the Coefficient of Drag. These methods are described in detail in Peak-of-Flight Newsletter #303 (www.ApogeeRockets.com/education/downloads/Newsletter303.pdf). I was actually using one of the Jolly Logic AltimeterThree (https://www.apogeerockets.com/Electronics_Payloads/Altimeters/Jolly_Logic_Altimeter_Three) altimeters during my test flights, so I had a lot of data available. But as I said, I'm lazy, so I used the basic data of peak altitude to get a ballpark figure for the Cd.

What I did to find the Cd was to use the standard backtracking technique. I simply went into RockSim and manually entered different Cd values until the simulated altitude matched the actual flight altitude.

Using this process I finally settled on a Cd of approximately 0.55 for the design I had used. Remember, this

design was designed to spin on the way up, so the Cd will be higher than a typical rocket that doesn't spin.

Step 9: Choosing New Rocket Motors

Within the F engine group, there are actually a lot of motor choices I could pick from (more than 50 of them). The brute force way to pick a motor that would get me to my goal of 300 meters would be to run a launch simulation of each one in the RockSim software using a Cd of 0.55. But that would take too long, and fortunately there is a way to eliminate a lot of the F power motors. That way is to look at the total impulse of the motors.

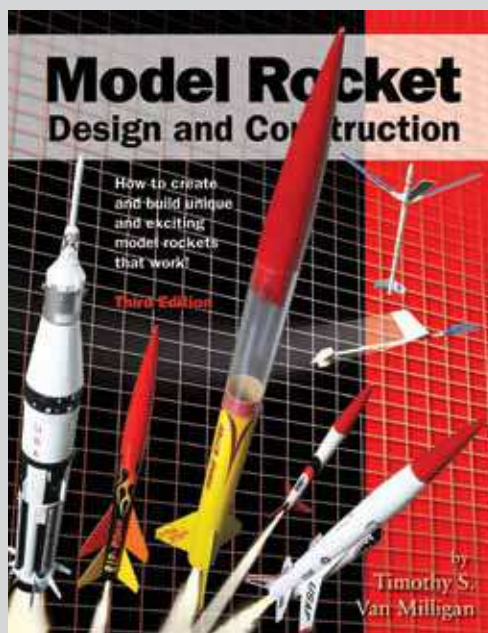
We said earlier that the test flight results had bracketed the goal of 300 meters. So what I can do is make a chart of altitude versus the engine power (measured in Total Impulse). Such a chart is shown in Figure 7.

With the results of each motor plotted on the chart, I drew a line connecting them. Then I looked for where the line crossed the 300m altitude line. From there, I dropped down to see the corresponding total impulse of the motor. In this case, it came out to be around 56.5 Newton-seconds.

Therefore, what I needed to do was to find an F motor with a power level of around 56.5 Newton-second.

This is where you have to do some homework and search the engine charts either in the simulation software, or on the Apogee Components web site.

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Model Rocket Design and Construction

By Timothy S. Van Milligan

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Designing a Rocket for TARC

I started my search by looking at the 29mm diameter single-use motors from Aerotech. As mentioned before, I like the convenience of a single use motor. From the chart,

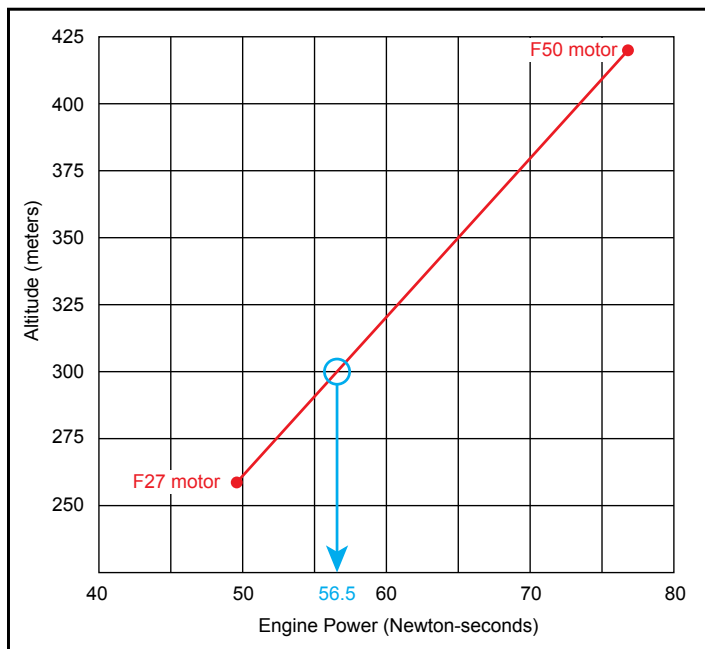


Figure 7: Using the data from the previous launches, this simple chart was made. We use it to find the estimated total impulse we need to reach the goal of 300m.

the closest single-use motor would be the Aerotech F42 motor (see Figure 8 on the next page).

I was going to make that motor my choice for the next round of test flights, but at the time, I was out of stock. When you can't get the motor, you have to have a back-up plan. So I had to expand my search to include reloadable motors. This time, I only looked at what was available (in stock). From this list, I decided to test both the Cesaroni F29 (55.0 N-s) and the Cesaroni F59 (57.0 N-s). These were both close to the 56.5 N-s that my chart predicted would get me closer to the 300m goal.

Step 10: Test Flights To Confirm the Motor Choice

The goal of my second round of test flights was to get closer with my motor choice. The secondary goal was to start looking at the descent rate of the model. The target from lift-off to landing had to be as close to 60 seconds as possible.

The final objective of the test flights, since I was using the reloadable motors, is that I had to determine the delay time to set with the Delay Adjustment Tool (https://www.apogeerockets.com/Rocket_Motors/Cesaroni_Accessories/Pro-38_Delay_Adjustment_Tool). Running a quick simula-

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PEAK OF FLIGHT

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Designing a Rocket for TARC

AeroTech 29mm Propellant										
Click the headers to sort up and down. Shift-click to sort multiple columns. Use the drop down boxes below the headings to filter the list to specific criteria.										
Motor	P/N	Case	Max Del. (s)	Color	Burn Time	Tot. Imp. (N-s)	Max Thrst (N)	Mass Tot/ Prop. (g)	Len. (mm)	Pr
All		Air	All	All	All				All	All
F20W-4	62004	AeroTech Single Use	N/A	White Lightning	2.8	64.0	40.9	80.0 / 30.6	83	2
F20W-7	62007	AeroTech Single Use	N/A	White Lightning	2.8	64.0	40.9	80.0 / 30.6	83	2
F23F-4	62304	AeroTech Single Use	N/A	Black Max	2.2	41.2	29.8	80.0 / 30.6	83	2
F23F-7	62307	AeroTech Single Use	N/A	Black Max	2.2	41.2	29.8	80.0 / 30.6	83	2
F27R-4	62704	AeroTech Single Use	N/A	Red Line	2.0	49.6	37.7	80.0 / 28.4	83	2
F27R-8	62708	AeroTech Single Use	N/A	Red Line	2.0	49.6	37.7	80.0 / 28.4	83	2
F42T-4	64204	AeroTech Single Use	N/A	Blue Thunder	1.3	52.9	62.3	77.0 / 27.0	83	2
F42T-8	64208	AeroTech Single Use	N/A	Blue Thunder	1.3	52.9	62.3	77.0 / 27.0	83	2
F50T-4	65004	AeroTech Single Use	N/A	White Thunder	1.4	76.8	79.6	84.9 / 37.9	98	2
F50T-8	65006	AeroTech Single Use	N/A	White Thunder	1.4	76.8	79.6	84.9 / 37.9	98	2
F50T-9	65009	AeroTech Single Use	N/A	White Thunder	1.4	76.8	79.6	84.9 / 37.9	98	2

Figure 8: This is a motor chart from the Apogee web site. You want to look at the total impulse column to find a motor that matches what your rocket needs.

tion in RockSim told me that the optimum delay for the F59 should be set to 6.77 seconds. Using the D.A.T., the available options were either 7 seconds or 5 seconds. The obvious choice was to make it a 7 second delay.

I also ran the simulations for the F29, and the software predicted that the delay should be around 5.91 seconds.

With these numbers, I went out the launch range and fired off the rocket with each of the different motors. The

data came back great.

Both the F29 and the F59 were really close. The F29 reached 307.8m and the F59 reached 303.6 meters.

To be honest, I could live with either of these numbers.

The second objective was to see how close to the 60-second duration the rocket was achieving with the 24-inch diameter parachute. The duration for the F29 launched flight was 46 seconds, and the F59 was 72 seconds.

The difference was caused by the altitude where deployment occurred. The F29 was set for a delay of 7 seconds instead of 5 seconds. Therefore, it deployed lower

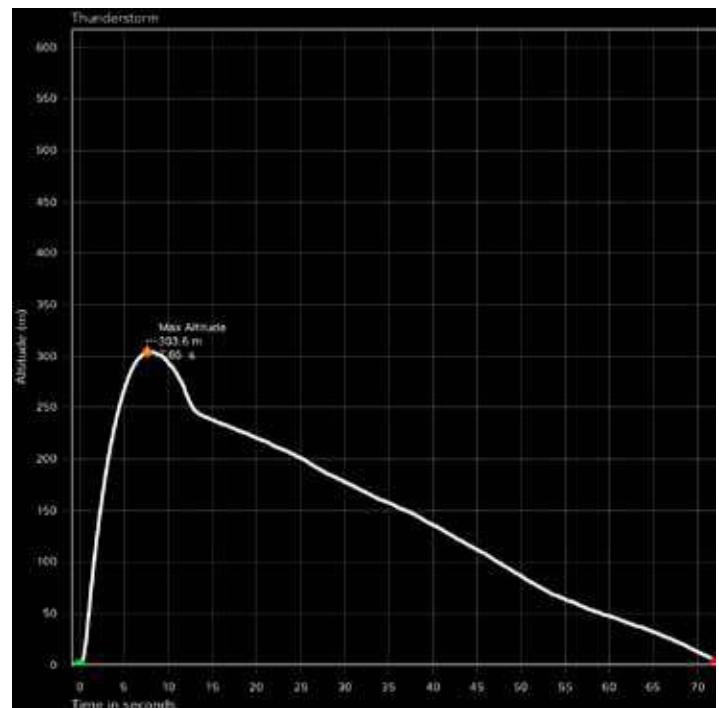


Figure 9: Flight data from the flight using the F59 motor (from the AltimeterThree altimeter). The peak altitude was 303.6 meters.

Continued on page 11



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PEAK OF FLIGHT

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Designing a Rocket for TARC

than anticipated (at about 210 meters). Since it was low at deployment, it didn't have as far to fall.

The flight with the F59-7 deployed higher up, at about 245 meters. Being higher up, it had further to fall, and took longer. Additionally, if you look at the graph in Figure 9, you might notice that the descent line isn't straight. The rocket looks to have caught a small thermal and the descent rate slowed down for a bit. So it was 12 seconds longer in the air than anticipated.

Step 11 - Analyzing the Data, Making Modifications

At this point, you have to go back and analyze the data and see if you need to make any corrections.

For my rocket, I ran out of time, and I didn't have the opportunity to make any more test flights. I made the one critical mistake of not allowing more time for tweaking the design and the motor selection.

One thing that I would have done, had I allotted more time, was to go back and dial in the ejection charge and reduce the size of the parachute. My RockSim simulations showed me that if the rocket would have ejected at apogee, the parachute's size would have to be reduced to around 21 inches in diameter. I prefer to have the parachute come out at apogee, because it puts less stress on the rocket body and reduces the chances of zippering the body tube.

Since I had a choice of two motors, F29-5 and the F59-7, I had to pick one for the contest. I decided on the F59-7. It wasn't because it was closer in altitude than the F29. The reason was that the motor has a higher average thrust level. The higher the average thrust, the faster the rocket travels. The advantage of this is that it is less susceptible to weathercocking in the wind. I didn't know what the winds would be like on the contest day, so I would recommend a

higher thrust motor just in case the winds might be blowing stronger than average.

Contest Results

For the actual contest, the rocket design flew well. The first flight reached 286.5 meters, and had a duration

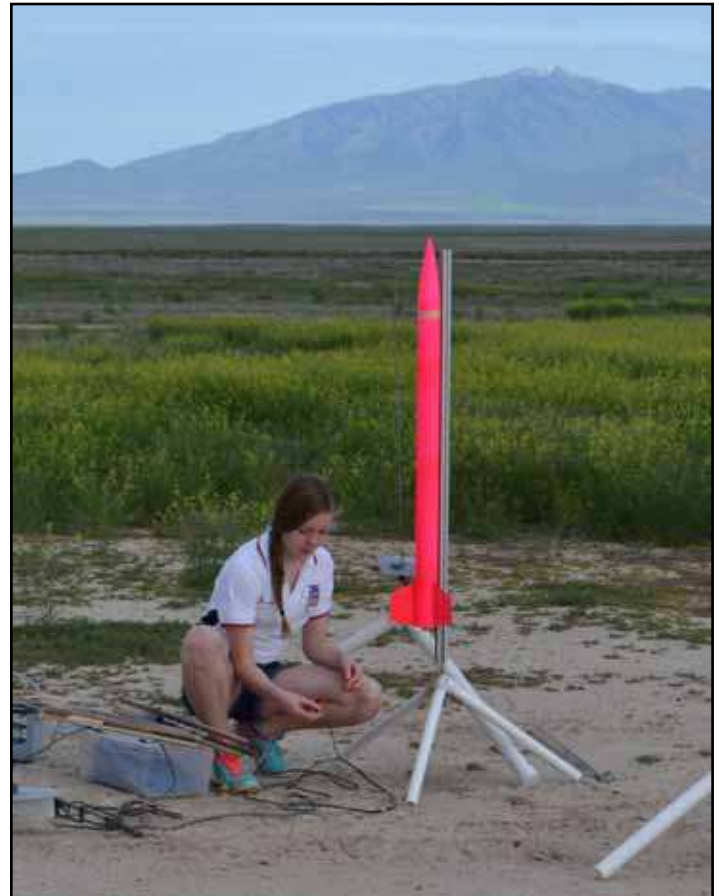


Figure 10: My daughter Allison hooks up her contest egglofter that used the identical design as mine.

Continued on page 12



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Designing a Rocket for TARC

of 51 seconds. The second did better at 297.5 meters and a duration of 65 seconds. That was pretty good if I say so myself.

Unfortunately, on the second flight, the egg broke. Ugh!!! An instant disqualification...

How did that happen? That is something that I'm still trying to figure out. My best guess is that the rocket hit a hard patch of ground on touchdown. I wish I had been paying more attention to the launch. I should have taken a video of the flight to analyze later.

In any case, if I were to fly this again, I'd probably make a change and add more foam to the payload bay, or switch to the 2.6" diameter foam nose cone that we sell for TARC participants (https://www.apogeerockets.com/Building_Supplies/Nose_Cones/Low_Mid_Power_Nose_Cones/66mm_TARC_Foam_Nose_Cone).

I relearned a couple of lessons on these flights. First, have a checklist of preparation items. On one test flight I forgot what delay to use for the flight, which resulted in a delay that was too long. Second, video tape the launches so you can go back and see what happened. And finally, plan further ahead. You have to allot more time for test flights to confirm the changes you make will work. I wanted to reduce the delay and test a different size chute, but I didn't have the time available.

Conclusions

With this article, I just wanted to document the process of how you'd go about designing and testing a TARC style rocket. The process isn't hard. The key is to get started early so that you have time to make corrections to the design before the contest. It also allows you to get all the components and the rocket motors ordered so you have time to test fly the designs.

For more on TARC rockets, see Peak-of-Flight Newsletter 249 (www.apogeerockets.com/education/downloads/newsletter249.pdf).

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

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