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PEAK OF FLIGHT

NEWSLETTER

In This Issue

How to Successfully Design and Build a Challenge Rocket

Cover Photo: Exa Rocket with its sleek shape. Get your own at: www.ApogeeRockets.com/Rocket_Kits/Skill_Level_5_Kits/Exa

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How To Successfully Design And Build a Challenge Rocket

By Tim Van Milligan

"Hello, We are a group of university students who were invited to take part in a national rocketry competition. The challenge is to design and build a multi-stage rocket capable of delivering a payload to a minimum altitude, and safely return the payload... We are beginners at best when it comes to this... . Do you have any suggestions or any idea of which kit we should use, and with which motors to optimize this? Thanks!"

This is the type of letter we get every year, so I thought it would be time to write a detailed answer.

To begin, this is a classic example of the engineering process, so it is an excellent question. I thought I'd go through the steps as if I was the designer.

Mission Objectives

The factors that determine the size of the rocket and the motors used are the size of the payload, and the mission objectives of the flight. For example, in this case, the student said that theirs is a minimum altitude that has to be achieved. That would be the *mission objective.*

In real life, this is the same thing that space launch companies have to go through. But instead of a minimum altitude, it is a specific orbit around the earth. And it may also have a specific time window for launch too. I remember a launch when I was working on the Delta II rocket, where the launch window was just 1 minute long. If we didn't get the rocket off in that window, the rocket wouldn't have been in the right spot when it reached its orbit. For us on that mission, we started the countdown about 12 hours early, just in case there was a hold for mechanical or electrical problems.

For student projects, the size and weight of the payload is typically the driving factor for the size of the rocket. In the TARC competition, the size and weight of the payload are well defined, since this is simple egg.

College level competitions have typically broader range of payloads, and they are also student designed. That makes them harder to say what size rocket you'd need for the challenge.

So if you asked me for my opinion on which rocket kit to select, I would say that I really don't know. It is going to depend on the size of your payload.

Also, I probably wouldn't tell you if I did know, because that defeats the spirit of these types of competitions. The whole purpose is for the student's learning experience. If I told you want to buy, then what did you really learn?

But I'll give you a hint…

If you want to know what size rocket to get, take a look at the size of the rockets in the prior year's competition. Typically, the mission profile doesn't change too much from year to year. So what was flown last year by other teams should give you a ballpark estimate on what size rocket you should get for this year's competition.

Obviously, that means you have to do some homework. You have to find images from the prior year's contest, or start communicating with teams from other schools. Talking with teams from other schools is ENCOURAGED! You aren't going to be penalized for it. In fact, most other teams would love to talk about their projects, and how they met the mission objectives.

I was just at the NARCON in Seattle, Washington this past weekend. I talked to several different teams that

Continued on page 3

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Continued from page 2

Design and Build a Challenge Rocket

presented talks on their projects. They were all eager to have other teams take their information and develop the concepts further. The point is, if your team isn't talking with people outside your school, you're missing one of the big objectives of the competition - "collaboration."

Designing the Rocket And Payload In Parallel

What typically happens in college level contests, is that the rocket and the payload have to be developed concurrently. So if you don't know the size of the payload, what do you do? This is the point where students freeze up, because they don't know what to do. And it basically stops the development of the rocket used to launch it.d

What you do in this case, is to sit down as a team and create a guess at the size and weight of the payload. You might say, the payload must be able to fit into an aluminum soda can, and weigh no more than 450 grams.

This again is what happens in the space industry. When you don't know the size of the payload, you have to set some constraints based on what has happened on previous launches. If you refuse to learn what happened in the past, and refuse to collaborate with others outside of your school, your project is going to take longer and be much more difficult.

One of the things you have to consider when designing the payload is the recovery system. It happens a lot that the size of the parachute is not considered until much later in the project. You need to save room for the payload's parachute when you specify the dimensions of the payload.

Think Small

In rocket design, I see that teams tend to want to leave room for everything including the kitchen sink. This tends to make the rocket HUGE. And that is cool, they think, because large rockets seem to get a lot of attention at launchers.

Additionally they desire the rocket to have the strength of a tank that can survive a crash landing.

While these are noble goals, it makes the power requirements for the rocket engine a lot larger. You'll need a bigger motor to launch that extra weight of an overbuilt rocket, and one that has a lot of excess room inside.

One of the reasons that the contest organizers have a limit on total impulse of the motor is to force the teams to reconsider their design philosophy.

I'll tell you this from my years of experience: start out with the smallest possible rocket, rather than starting out with a big one.

Smaller rockets have less logistical problems later on during the development process, even though they have less internal volume. **From my experience, it is much**

Continued on page 4

Continued from page 3

Design and Build a Challenge Rocket

easier to figure out how to make an oversize payload fit into a small rocket than it is to figure out how to remove weight from a big rocket.

For example, most people don't utilize the internal volume inside the nose cone. There is a lot of room in there that can be used for parachutes and other payloads. Use it, and you can make the rest of the rocket smaller and lighter weight.

The other advantage of small rockets is that they don't need to be built as strong as a larger one, because the forces on the rocket are lower.

Finally, smaller rockets are cheaper to fly, because the rocket motors are less expensive. That means you can fly your rocket more times to get the data you need to confirm that it will meet the mission objectives.

If your small rocket has too much performance, it is really easy to get it to fly lower. Just add ballast, like sand or water. These can easily be dumped overboard at ejection, reducing the weight of the rocket so that it comes down slower. You can also add drag to the rocket by putting on more fins, or changing the shape a little bit. It's much easier to get the rocket to fly lower than it is to get it to fly higher.

The same thing goes for the payload designers. Think small, and try to reduce weight and size as much as possible. The effort pays big dividends later in the process.

Simulations

While part of your team is working on the payload, the group that is responsible for the rocket design can start running computer simulations. RockSim (www.ApogeeRockets.com/RockSim/RockSim_Information) is a great choice for this task.

The process is to start by designing a rocket in the software, and then select the motor based on that design. You do not pick the motor first, and then try to create a rocket that will work with it. That is going to lead to all sorts of frustration.

Start with the payload dimensions first. What is the SMALLEST tube that you can get it into. Don't be conservative here and allow for excess space in the rocket. This goes against my own philosophy of having a back-up plan, but you have to hold the payload designers to the agreement they made on the size and weight of the payload. If they break the agreement, they owe the rocket design team a pizza.

It is a lot easier to make the payload bay of the rocket larger than it is to make the rocket smaller later on. Did you ever wonder why those NASA type rockets have a big nose cone (the payload fairing) on top of a skinny rocket? It is because the payload designers allowed their satellites to get big and bulky. But the fix to the rocket was easy.

The next step after you've got the rocket's dimensions into the software is to pick the rocket motor. The process is a "process."

Continued on page 5

Continued from page 4

Design and Build a Challenge Rocket

I wrote an technical publication on how to pick rocket motors that you can download and read through. You'll find it at: www.ApogeeRockets.com/Rocket_Books_Videos/Pamphlets_Reports/Tech_Pub_28 . There is also a video where I go through the steps from the report. You'll find it at: www.ApogeeRockets.com/Advanced_Construction_videos/Rocketry_Video_32 .

With that report as your guide, you should have a list of motors that might work in your design. Picking motors usually results in several motors that will work for the flight. Having options is a good thing, because sometimes your supplier will run out of the motor you want, so you have to have a back-up.

I recommend that as soon as you know which motor you want, that you order it. You don't want to get too far into construction of the rocket, and then find out that by waiting, the manufacturer has run out. There is nothing more frustrating than finding out you can't get the motor you were planning on using.

But by ordering the motor so soon in the development of the project, you are pretty much locked into the design constraints of the motor's performance. This is exactly how the space launch companies do things too. They have to order their launch vehicles early, and because of that, you can't change too much with the payload.

Building the Rocket

Your RockSim file should be your guide for building the rocket. At least, it should give you the outer dimensions of the rocket and the fin shape.

But you will undoubtably have a lot of questions about fitting everything together, and mounting the payload into your rocket. This is normal. It can be daunting, but there is a lot of information available to help give you ideas.

If you have a team mentor following your project, they should be your first choice for getting information. Don't be afraid to ask them how they would fit parts together. They will often give you great ideas, and have the experience to know where the failure point might occur. And frankly, you should ask them where they think your rocket might fail. Don't let your ego get in the way of putting together a safe rocket.

If you don't have a mentor, my next suggestion is to get the book *Model Rocket Design and Construction* (www.apogeerockets.com/Rocket_Books_Videos/Books/Model_Rocket_Design_And_Construction). It has numerous ideas on how to make strong rockets that are also lightweight.

Once you get the general idea of how to put the rocket together, there is one more "research" step to do. That is to learn the "techniques" of assembly. By this, I mean that there is more to putting the rocket together than slathering glue between the parts. For example, everyone will tell you to put glue fillets on the fins to make them stronger. But most of the fillets people put on are lumpy and produce a lot of drag. They miss the technique for applying the glue

Continued on page 6

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Continued from page 5

Design and Build a Challenge Rocket

and assembling the parts. This is where your mentor can really help you. You'll learn the techniques of assembly much quicker if you watch first-hand the process.

If you don't have a mentor, the next best thing is the videos on the Apogee Components web site. We have over 160 different assembly videos on a variety of topics, particularly those that are common to the typical model rocket. You'll find a list of videos by topic at: www.apogeerockets.com/Advanced_Construction_Videos/Topic.

The final part of the research is figuring out how to mount the payload into the rocket. This is called payload integration, and it is a big issue, even in rockets launched into outer space.

At this point, since the payload may not be complete yet, you don't know how it is going to be mounted in the rocket because you may not know the size. Don't worry too much about this yet. Sure, it is an issue. But if you get the rocket built quickly, you'll have time to make modifications later in the process. The good news is that the front section of the rocket, where the payload will be installed, is the easiest part of the rocket to modify.

Another good source of information on integrating your payload, particularly electronic payloads, can be found in the book: Modern High Power Rocketry 2 (www.apogeerockets.com/Rocket_Books_Videos/Books/Modern_High_Power_Rocketry_2).

I know this has been a lot of research up to this point in

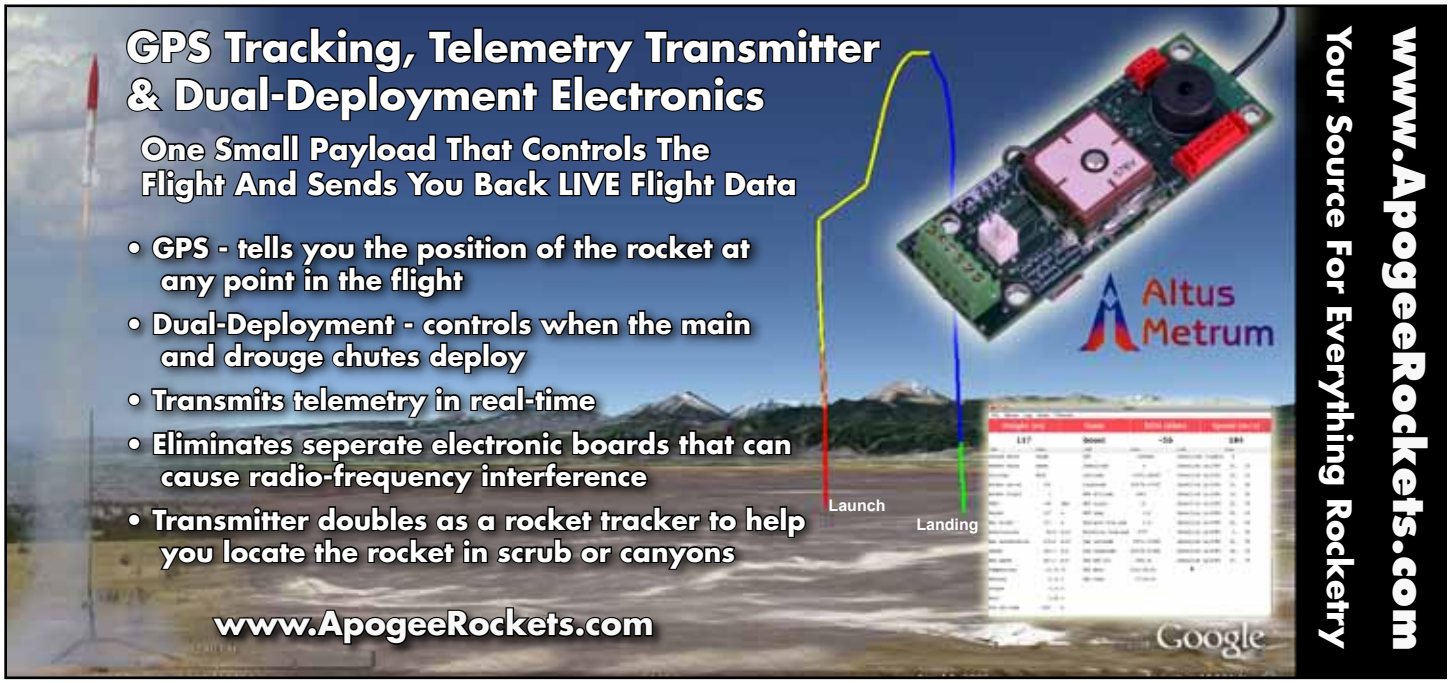
the development of your rocket. It is an investment of time that pays huge dividends when you actually begin the assembly of your rocket.

Now that you are knowledgeable about your design, you're at a good point to start gathering up all the parts. Many parts you can get locally. And if you can't find them in your town, give Apogee Components a look. Our web site contains a lot of hard-to-find items that you may need. And it also contains a lot of information on how to use those parts to their maximum effectiveness.

Test Flights

Now your rocket is ready to fly. Hopefully you've left time in your schedule to do some test flights. The purpose

Continued on page 7



Continued from page 6

Design and Build a Challenge Rocket

of these flights is to test the system to make sure everything will perform as intended. Start slowly. Fly the rocket without the payload on the first attempt, just to make sure the rocket is stable and functions correctly. Instead of using the actual payload, use a dummy payload. In the space industry, the dummy payload is usually water. But you can use clay or sand to simulate the weight of your payload.

Then, I'd highly suggest that you add an altimeter to the rocket to get back some actual flight data. The important piece of information you need is the drag coefficient of the rocket. This number will help you make your simulations more accurate.

The first time you fly your rocket, you should be prepared for the rocket to reach a different altitude than you expected. The reason is the default drag coefficient that the software calculated is going to be a little bit off. It is a hard number to predict ahead of the time, but as soon as you have actual flight data, you can find it pretty easily.

See Peak-of-Flight Newsletter #303 (www.apogeerockets.com/Education/Downloads/Newsletter303.pdf) for the process of backing out the drag coefficient.

Once you determine the C_d, your next step is to go back to the computer and run some more simulations. You can learn a lot from the simulations, so don't skip this step.

You may have to go back and make some modifications to your rocket. Hopefully your rocket flew too high. It is easier to get it to come down to a lower altitude than to get it to fly higher. If you need some tips of getting more altitude from your rocket without changing to a larger motor, see the *Model Rocket Design and Construction* book.

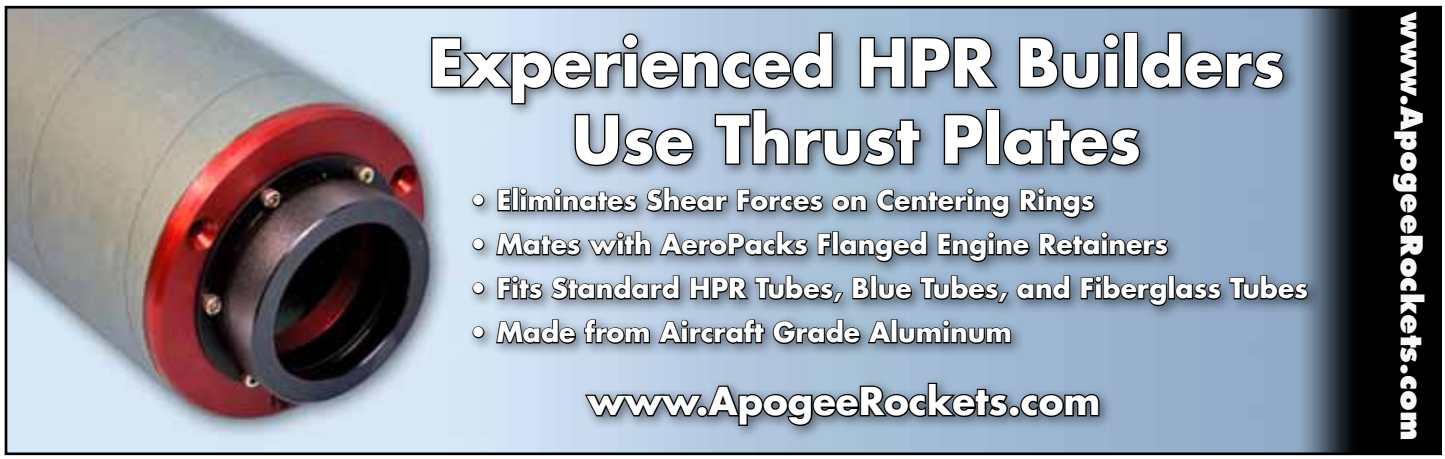
Finally, you're ready to add your payload to the rocket after you've got it flying safely and to the right altitude. Things should be working great at this point with the rocket, and the only thing to worry about is the payload. That is what the ideal situation is, anyway.

After each flight, immediately write down your observations of the flight. It doesn't hurt to video record the flight either, so you can review it later. If you're not going to write down your thoughts, then I suggest that you video yourself doing a post-flight analysis of the launch. You'd be surprised what things you'll forget about between the time you fly the rocket, and the time you get it back to the workbench. Especially if you launch several times in one day, and all the flights seem to merge together in your mind. Going back to the video will help refresh your memory of the actual events, and may help you see things that you didn't notice in real-time.

When all is said and done, the greater number of test flights you can get in, the better. You'll end up having a more consistent rocket flight, and you'll learn a lot of flying skills.

Whether you're competing in TARC, the Student Launch Initiative, or any of the other rocket design chal-

Continued on page 8



Continued from page 7

Design and Build a Challenge Rocket

lenges, the process is identical to what is here. It is identical to what the big aerospace companies do when they have a new rocket to create. But that shouldn't be a surprise, as what we do in model rocketry is the same as what happens with big rockets. The only difference is the size of the rocket, and the size of the budget.

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.