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APOGEE PEAK OF FLIGHT NEWSLETTER

Basics of Dynamic Flight Analysis Part 6

Optimizing For Altitude

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Basics of Dynamic Flight Analysis Part 6

Optimizing For Altitude

By Tim Van Milligan

The purpose of these articles on Dynamic Flight Analysis is to learn how to adjust those parameters of a rocket's design that affect the way it behaves in flight. Of particular interest is how a rocket will react to a disturbance, such as wind. Once we know the important parameters, we can optimize the design.

At this point, we've discussed all the parameters that are used to determine the dynamic characteristics of the rocket. We'll now outline a procedure for designing a model rocket. More than that, the overall objective is to design a rocket that will achieve the highest possible altitude over a wide range of wind conditions. We will use the RockSim software, because it is the perfect tool for this design process.

If you don't have RockSim, you can download a 30-day trial edition at: http://www.ApogeeRockets.com/rocksim.asp

Step 1: Define as nearly as possible the mission of the proposed rocket.

Mission examples might be:

- Altitude Competition
- Payload carrying (egg or NAR standard 1-ounce payload). What is the proposed capacity that it should be able to loft?
- Does it need to be staged?
- Will it use a cluster of motors?
- What recovery system should be used?

The purpose of these questions is to define the overall size of the rocket. We need to know what size (diameter) of tube we need to find.

Step 2: Make a sketch of the rocket design on a piece of paper. The purpose of the sketch is just to get an overall layout of the rocket. It will also help you to enter the individual parts into RockSim, since you'll work from the tip of the nose cone down to the base of the rocket.

Step 3: Start entering your design into RockSim. Save the fins for last.

One important question you might want to ask yourself as you enter the components into the software is "can I actually get this part?"

Many young rocket designers will design an awesome rocket in RockSim and then find out that they've created many custom sized parts that they can't buy from their favorite vendor (note: I hope your favorite vendor is Apogee Components, right?). The nose cone is usually the one piece that is hardest to find if it is a custom size and shape. The point of this is that your design may be constrained by the parts that you can afford to buy. It is better to find this out now.

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When inputting the fins, just use the default fins generated by RockSim for now. You'll come back later and resize and locate them to the best position on the rocket.

Step 4: Check the static stability of the rocket so far. If the rocket is not stable, start by making the length a bit longer. DON'T add nose weight. That is a technique of the lazy. You're not *lazy*, are you?

If the static stability margin is greater than 2.0, the rocket should be redesigned.*

*The exception is super-roc style rockets. These are super-long rockets for a specific NAR contest.

While a static stability margin larger than 2.0 is fine for most rockets, it will be harder to optimize for "high altitude" flights with wind. The rocket will have a Corrective Moment Coefficient that is very large, and the rocket is going to weathercock excessively in breezy conditions.

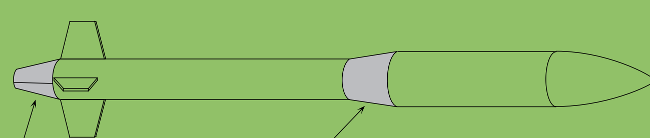
For contest rockets and altitude record attempts, the static stability margin should be as close to 1.0 as possible.

Step 5: Reduce the rocket's Drag Coefficient to the lowest possible value.

This may require a slight redesign of the design's basic configuration. Obviously it means only three fins on the model. Four or more fins only adds to the drag.

And you'll also want to get rid of the launch lug or rail buttons. They add a lot of unnecessary drag. It is interesting to note that removing the launch lugs adds expense to the rocket. Why? Because you'll need some other mechanism to guide the rocket until it reaches a sufficient speed after launch, such as a tower launcher or fly-away launch lugs. Both of these are a lot more expensive than the piddly cost of a launch lug that is removed. Now you know the reason why NASA spends so much on rockets like the Space Shuttle. High performance usually means higher cost. *No bucks, no Buck Rogers...*

If the rocket is not minimum diameter, you'll want to consider adding a drag-reducing boattail at the back end of the rocket or a reducer-transition somewhere ahead of the motor mount area of the rocket. Either item will be destabilizing to the design, so check your static stability margin again. Again, this is another item that adds to the expense of the rocket. But if you aren't willing to spend the money, you won't get the ultimate performance out of your rocket.



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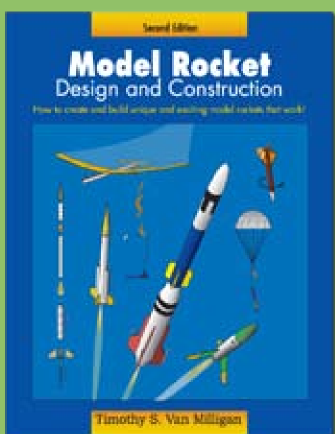
For other drag reducing techniques, see my book: *Model Rocket Design and Construction*. You can order a copy at: http://www.ApogeeRockets.com/design_book.asp

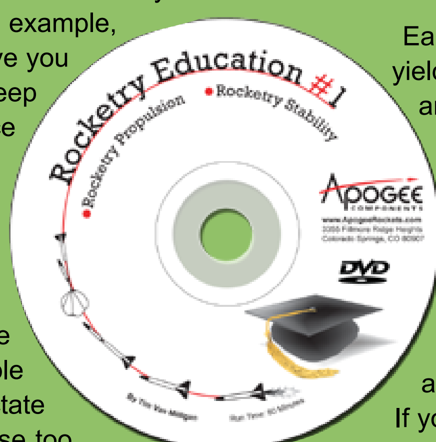
Step 6:
Perform a preliminary launch simulation



At this point, make an initial guess at the engine you might use in the rocket. It will usually be based on the "power" that is allowed. For example, if you were attempting an "F"-engine altitude rocket, then you would pick an "F" size motor, and not a "G" size motor.

The purpose of this first simulation is to create a starting point to begin the optimization process. In your simulation, launch the rocket straight up with no wind.

If you can make a good guess at the engine you might be using for the actual flight, then it will save you time by installing that motor now. For example, a low-thrust motor is often going to give you the highest altitude because it will keep the speed of the rocket low, and hence the drag to a minimum.



However, if you are launching a heavy payload, then you may have to come back and switch to a motor with a higher initial thrust level to get the rocket moving. Additionally, being able to actually buy the motor will also dictate what engine you might be forced to use too. Example: Aerotech might have discontinued the perfect motor, and now you can no longer purchase it.

The time you spend in getting to know the different types of rocket engines will pay off. Not all motors of the same power class are equal. There are better motors for achieving maximum altitude. I highly recommend the new DVD called *Rocketry Education #1* for an in-depth review of the different types of rocket engines. You'll find it at: http://www.ApogeeRockets.com/Teacher_DVD.asp

Once you know the different motor types, the next task is how to select the best one. If you don't know the step-by-step process of selecting a good rocket engine for your model, then I highly recommend reading Apogee Technical Publication #28. http://www.apogeerockets.com/technical_publications.asp#TP28_anchor

While our engine selection process will be slightly different from the method in this report, it is worth reading because it lays out the steps in a logical sequence. I like step-by-step instructions, because it takes the *guessing* out of the process.

Step 7: Use RockSim to perform an optimum mass calculation for the rocket engine you just used in the simulation.

The optimum mass will be your target when it actually comes to building the rocket. You need to find out how far away your current design is from the mass needed for peak altitude.

Each rocket design and motor choice will yield a different optimum mass. For example, an Apogee Aspire on a F10 will have a different optimum mass than the same rocket using an F42 motor.

Sometimes you will actually have to add weight to your rocket. This is usually for high power rockets (G size and bigger), or for the ones that are very small ("A" power and smaller). If you find you have to add weight to bring your model up to the optimum weight, then you are in a good position. It opens up more choices later when it comes to actually building the rocket.

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For example, you can spend more time and effort on achieving a super-duper paint finish on your rocket. Paint adds weight, and it also helps to smooth out the rocket and lower its drag. You can also use building techniques that add extra strength, durability and redundancy to the rocket, even though they would add a ton of weight. Finally, you can add a lot of tracking powder to help you spot the rocket in the sky when it reaches that record-setting altitude.

However in most cases, for B to F size rocket engines, your initial design will probably be too heavy and you'll need to remove weight to get down to the optimum mass. In particular, you may find that for B and C size engines it may be physically impossible to remove enough weight to get to the optimum value. But you should try anyway.

Go back to your design and see if you can change out components and bring the weight down. At the ApogeeRockets.com web site, you'll find many ultra-light rocket parts created specifically for this task of weight reduction.

I also recommend that you look at the mass versus altitude chart that can be generated in RockSim. This chart will show you how much altitude you'll lose if your rocket is too heavy or too light. See Figure 1.

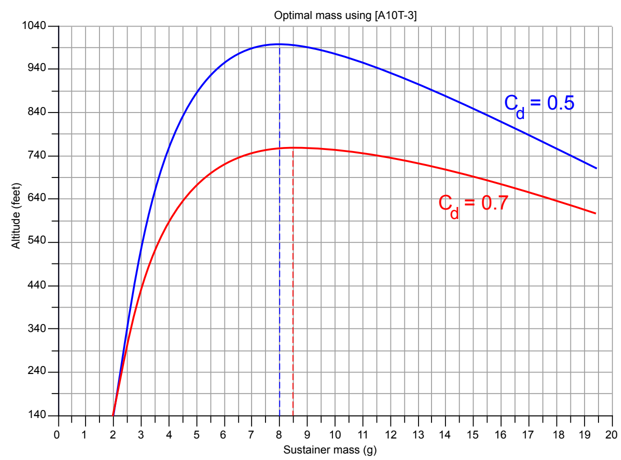

Figure 1: Optimal Mass Charts like this one can be generated by the Rocksim software.

The shape of the curve is what you want to pay attention to; If it is very steep on either side of the optimum mass, then you'll have to work extra hard to try to get the rocket very close to the best mass.

On the other hand, if the curve is very flat on either side of the optimum mass, then you have a little extra margin for building errors. And it may actually be worth putting more effort into getting a slick paint finish on the rocket, even though it adds a bit extra weight. The reason is that you'll be lowering the Drag Coefficient, and that will actually help your rocket go higher.

In Figure 1, you'll see that the rocket with the C_d of 0.7 has a very flat top of the curve. You could be overweight by two grams and not lose much altitude at all! Isn't that great news? You wouldn't know this un-

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less you used RockSim and looked at the shape of the optimal mass chart.

Why a Lower Drag Coefficient is Even Better

Lowering the Drag Coefficient by a significant amount is far more important than the extra weight you may have to add by painting a good finish on the rocket. In the Figure 1 chart, you'll see that lowering the C_d of rocket from 0.7 to 0.5 adds a LOT of altitude to the rocket. And consider this... you could add 9 extra grams of weight to this particular rocket, and still get a higher altitude than building at the optimum mass if it had a higher Drag Coefficient. In the chart, the rocket with a C_d of 0.5 and at a weight of 17 grams will still go higher than the model with a C_d of 0.7 with a weight of 8 grams.

So go back to Step 5 and really reduce the drag on your rocket as much as possible. It has the biggest impact on the height that your rocket will achieve.

How To Build Low-Drag Rockets

That brings up an important point that I can't stress enough (TARC teams and mentors pay attention if you want to win the contest). The point is that Drag Coefficient will play a huge role in the TARC contest, and it is absolutely imperative that you control it as best as you can. How do you do this?

You do this by using the best and most consistent building techniques. But you can only learn those by watching an expert build a rocket. Therefore, GET my two video books on building model rockets. You'll find them at: http://www.ApogeeRockets.com/Building_1_2_videos.asp.

You're probably rolling your eyes at this right now thinking something like: "I know how to build a rocket, what more is there to learn?" If you are thinking that, you've already lost the TARC competition. You just haven't taken the "loser's walk" off the field yet.

The techniques I show you in the two video books are optimized for building the slickest, strongest, yet lightest weight rockets. More importantly, you'll build high-quality rockets. And if you're building multiple rockets, like you would have to do for a TARC competition, you'll find that they are consistent. You need consistency if you want any chance of winning. The rocket you use on a qualifying flight is not likely to be the same one you use at the finals. But they should be so similar that you can expect the same performance out of each of them.

You next question might be: "Can't I learn the techniques in the book *Model Rocket Design and Construction*?" That is a good question. The book is great for learning how to place parts, but it doesn't show techniques, like how to hold the part and how to use the tools for best results. You can only learn that by watching an expert or by years and years of trial-and-error.

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It is disheartening to me that people don't take my advice on this key point about getting the two video books. I've been building rockets since 1976, and I've qualified for two trips to the World Spacemodeling Championships, representing Team USA by building ultra-high performing rockets. And look at my trail of articles that have appeared in this newsletter to see if there is anyone in the world that is more interested in building super-efficient model rockets. So when I say that these video books are worth it, they really are! The techniques shown in the video books are the final product of years of trying to optimize a rocket's performance. These are the techniques you'll need if you want to build those ultra-efficient rockets.

And yet, I can tell by the number of video books that I sell that people still don't believe me. Just like they didn't believe me about superior usefulness of RockSim. People have scoffed at my advice about using RockSim for the TARC competition. They thought that "cheaper" software could help them to win the event. Of course they have been proven wrong. Every year, a RockSim user wins the TARC competition. Because of that record, now everyone knows that if you don't have RockSim there is a good chance you'll be sitting in the spectator seats at the finals.

I'm giving you this advice about buying the video books because I want you to succeed. Not only for those in TARC, but in all rocketry challenges. The secrets that took me 30 years to learn -- including 6 years in engineering college -- you could know in just a few hours by watching the videos. There is a shortcut to success, but you have to be smart enough to invest in it.

I guarantee that by following my advice on the video books will make you a better modeler. You will build lighter, stronger, more consistent, high quality, and more efficient rockets.

By the end of step 7, you should have run a number of RockSim simulations, and have come up with your final choice for the best rocket engine based on the size and Drag Coefficient of your design.

You should also have determined the minimum launch guide length that the design needs for stability in zero wind conditions.

Dynamic Stability Optimization

Here is where you'll really refine your design by tweaking the size and shape of the fins and moving parts around to get the dynamic parameters into the ranges that yield a rocket with good flight characteristics.

You'll recall that the goal when designing a rocket from the standpoint of "dynamics" is to create a rocket that: 1) is not easily deflected from the intended direction of flight, and 2) the rocket quickly returns to a straight and true flight path once the disturbance has passed AND does it so that it is as close to the original flight path as possible.

During this step, you'll be tweaking the shape of the fins, so you may want to read my free Technical Publication on the best shape for fins. This may give you some insight on what you might do to get lower drag on your rocket. You'll find it at: http://www.apogeerockets.com/technical_publications.asp (look for Technical Publication #16).

Step 8: Natural Frequency Optimization

Recall from Peak-of-Flight Newsletter #196 that it is recommended that the most desirable Natural Frequen-

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cies for *model rocket-sized* vehicle lie between 0.2V and 1.0V (where "V" is the velocity of the rocket in m/s).

Step 9: Damping Ratio Optimization

And from Peak-of-Flight Newsletter #197, we learned that the recommended Damping Ratio should be between 0.05 and 0.30.

I'll refer you back to those two newsletters so you can get some hints and tips on optimizing the dynamic characteristics of the rocket.

Step 10: Build the rocket

Your rocket, at this point, is pretty much designed. But as mentioned before, you will still face some challenges when you actually build the model. You'll have to pay attention to weight, aligning the fins, and making sure you have good airfoils on your fins.

If you are sloppy during construction, you'll have wasted all that effort you've done during the design portion of your project. So take your time and do it right.

Now you've built your rocket, and it is a work of art. It is a highly efficient machine designed to cut through the air to awesome altitudes. But your optimization project is still not done. You can still do a couple of things as you get ready to launch that may squeeze some more altitude out of the rocket.

Step 11: Give your rocket a kick-start.

Rocket competitors have known for decades that the use of a piston launcher will probably get you another 5 percent of higher altitude from the design. They work better on the smaller rockets than the bigger ones, but you may consider using one. See the additional reference information at the end of this article to locate information about piston launchers.

Step 12: Optimize your launch angle – Ground Support Equipment and Flying Skills

When you get out to the field to launch your rocket, you'll want to take notice of the wind conditions. The wind is always going to reduce the altitude of your rocket from the zero wind conditions in your Rocksim simulations.

On way to reduce the affect of the wind is to use a longer launcher. While most competitors will use a short launch rod/rail/tower, you want to use a longer one if there is any wind. *Really…when is there not wind*? Since that is so rare, you might as well be ready for it ahead of your launch day by having a good long launcher (even if you are using a piston launcher in combination with your launch tower).

At this point, we can do our best to minimize that effect by launching at the correct angle (as measured from vertical). I hope you have a laptop with you when you get to the field. Finding the optimum launch angle for a specific wind speed is another good use of RockSim.

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What I'd suggest is to make a table showing the optimum launch angle for your rocket design versus wind speed. If you do this ahead of time, you can save yourself some set-up time when you get to the field.

Finding the optimum launch angle can be tedious because it involves running a lot of simulations. If you want to save the time and manual labor of changing the launch angle between each simulation you run, then I highly recommend investing in the SMARTSim software (http://www.ApogeeRockets.com/smartsim.asp). It allows you to run batches of simulations using RockSim to find the optimum conditions.

Now that I think about it, you should be able to use SMARTSim during the design phase when you are tweaking the design to optimize the dynamic characteristics too.

Conclusion:

There you have it. A procedure for designing high performance rockets. You'll find that it is an iterative process, where you'll have to repeat steps to get to a final configuration. And the more performance you want, the more money it will cost you.

If you enjoyed this article, or you've learned something new, I would appreciate it if you could send me a note. I'm interested in your opinions about our newsletter and how we can make it better.

Additional Resources:

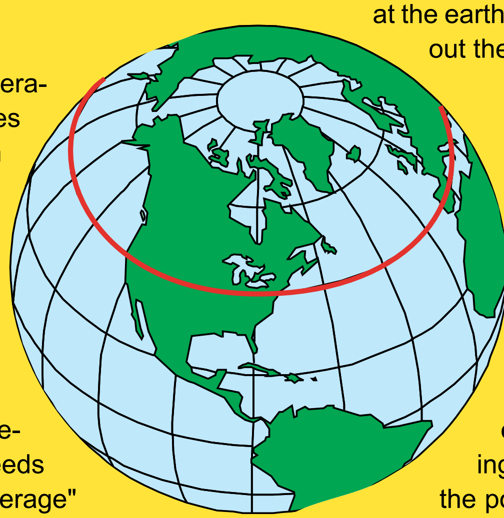
1. Piston Launchers Explained. By Scott Johnsgard Jr. Peak-of-Flight Newsletter #47.
2. Piston Launcher Plans. Apogee Technical Publication #11. http://www.apogeerockets.com/technical_publications.asp Publication #16).
3. Contest Flying Preparations. Peak-of-Flight Newsletter #6
4. Altitude Flying Strategies. Peak-of-Flight Newsletter #10.
5. How to use Tracking Powder. Peak-of-Flight Newsletter #76, page 5.
6. Optimizing Your Design Using SMARTSim. Peak-of-Flight Newsletter #130
7. What is "Static Margin?" Peak-of-Flight Newsletter #133

About The Author:

Tim Van Milligan (a.k.a. "Mr. Rocket") is a real rocket scientist who likes helping out other rocketeers. Before he started writing articles and books about rocketry, he worked on the Delta II rocket that launched satellites into orbit. He has a B.S. in Aeronautical Engineering from Embry-Riddle Aeronautical University in Daytona Beach, Florida, and has worked toward a M.S. in Space Technology from the Florida Institute of Technology in Melbourne, Florida. Currently, he is the owner of Apogee Components (http://www.apogeerockets.com) and the curator of the rocketry education web site: http://www.apogeerockets.com/education/. He is also the author of the books: "Model Rocket Design and Construction," "69 Simple Science Fair Projects with Model Rockets: Aeronautics" and publisher of a FREE e-zine newsletter about model rockets. You can subscribe to the e-zine at the Apogee Components web site or by sending an e-mail to: ezine@apogeerockets.com with "SUBSCRIBE" as the subject line of the message.

Question & Answer

In the launch conditions of RockSim, why does the software ask you for the latitude of the launch site?



The reason is that the acceleration force due to gravity changes with latitude. You may recall from your school physics class that "g" is equal to 9.8 m/s^2. Actually, that is just an average value. It is greater at the north and south poles than it is at the earth's equator.

For RockSim to accurately predict the flight of the rocket, it needs something better than just the "average" value. That is why you need to enter your latitude coordinates prior to launch.

Your next question is why is the force of gravity less at the earth's equator. I went to Wikipedia and dug out the answer for you.

"Gravity is weaker nearer the equator, for two reasons. The first is that in a rotating non-inertial or accelerated reference frame, as is the case on the surface of the Earth, there appears a 'fictitious' centrifugal force acting in a direction perpendicular to the axis of rotation. The gravitational force on a body is partially offset by this centrifugal force, reducing its weight. This effect is smallest at the poles, where the gravitational force and the centrifugal force are orthogonal, and largest at the equator. This effect on its own would result in a range of values of g from 9.789 m/s^2 at the equator to 9.832 m/s^2 at the poles.

The second reason is that the Earth's equatorial bulge (itself also caused by centrifugal force), causes objects at the equator to be farther from the planet's center than objects at the poles. Because the force due to gravitational attraction between two bodies (the Earth and the object being weighed) varies inversely with the square of the distance between them, objects at the equator experience a weaker gravitational pull than objects at the poles.

In combination, the equatorial bulge and the effects of centrifugal force mean that sea-level gravitational acceleration increases from about 9.780 m/s^2 at the equator to about 9.832 m/s^2 at the poles, so an object will weigh about 0.5% more at the poles than at the equator."

Source: http://en.wikipedia.org/wiki/Earth%27s_gravity