PEAK OF FLIGHT NEWSLETTER

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DESIGNING AND BUILDING FOR SUPERSONIC FLIGHT

https://www.apogeerockets.com/Model-Rocket-Kits/Skill-Level-4-Model-Rocket-Kits/AGM-157-Scorch

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PEAK OF FLIGHT

Designing and Building for SuperSonic Flight

By Walter Lohmueller

Introduction

In 1947 Chuck Yeager broke the sound barrier in an X-1 rocket plane. Now less than 100 years later hobbyists can do the same for less than 30 dollars. This is the only hobby in which you can break the sound barrier without spending 100 million dollars on a fighter jet. That said, it is still a big challenge to break the sound barrier with cardboard rockets. It certainly was for me. I wrote this article to summarize and share all the things I learned and I hope it will make breaking the sound barrier easier for you! This article will be targeted at people that are looking to design small-scale supersonic rockets that are around 29 to 24mm in diameter and who only have access to basic adhesives and tools.

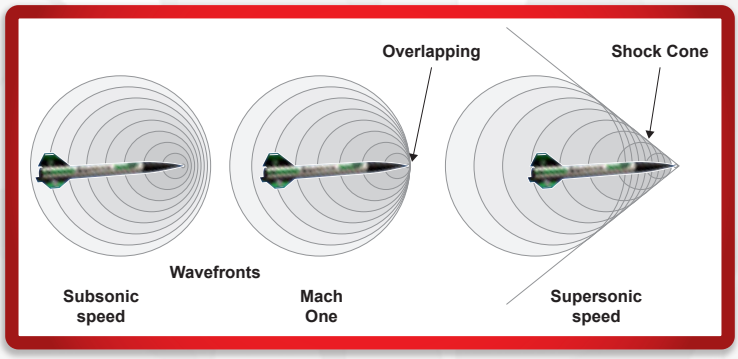

FIGURE 1: DEMONSTRATION OF WAVEFRONTS

What does it mean when something goes supersonic?

Before we try to break the sound barrier, we should first understand what the sound barrier is.

Here is a basic description of what it means when something goes supersonic. When an object starts moving, the air can move out of its way. But when that object starts to pass a speed of 500 miles an hour, the air can't get out of the object's way quickly enough. As a result of this, the air starts building up around the object (shown in Figure 1). When this happens, the object is "transonic". Eventually, at around 768 miles per hour, the air built up around the object breaks off and creates a shockwave and a sonic boom (also in Figure 1). Once this happens, the air in front of the object is no longer being warned of the object's approach and the said object is now considered to be "supersonic". A lot of drag is created as a result of the air building up, and as a result, it takes a lot of force to get something to go supersonic. The speed of sound can also change because of factors like temperature, humidity, and pressure. For example, at an altitude of 10,000 feet, the speed of sound is 734 miles per hour while at sea level, the speed of sound is 768 miles an hour.

Simulation Software

Simulating a rocket's flight is a very important part of rocketry. It will give you information about the rocket's maximum speed and altitude so you will know if your rocket will break the sound barrier. More importantly, it will tell you if your rocket is stable. You need to find a simulation software that is capable of simulating supersonic flights. There are many good options out there, but one that works well is RockSimPro (https://www.apogeerockets.com/index.php?main_page=product_software_info&cPath=13_205&products_id=726).

Design

When designing your rocket, you want to keep a couple of things in mind. First, for supersonic flights, you should target a speed of at least 800 miles an hour. This will give you some room for error and anomalies and still allow you to break mach. When you launch rockets, not everything goes exactly according to the simulations. For example, the motor could deviate from the simulated thrust curve, and air temperature, wind, and humidity might not be what you simulated. Also, the rocket's coefficient of drag might not be what you thought, and your simulations might also be incorrect. By going at 800 miles an hour, you can afford some mistakes. Second, make sure your stability margin is above 2.25. You might ask "why have such a

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You can subscribe to receive this e-zine FREE at the Apogee Components website www.ApogeeComponents.com, or by clicking the link here Newsletter Sign-Up

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large stability margin"? Well, when your rocket approaches Mach 1, the air building up causes the center of pressure to shift forward which makes your rocket less stable. I learned that the hard way. (https://www.youtube.com/watch?v=XkTIyu950TI&t=193s)

You can design your rocket to be 24 or 29mm in diameter. 24mm is going to be much more challenging though because your motor options are limited.

You also need to pay attention to reinforcing your model so it can withstand supersonic speeds without shredding. More detailed guides are linked later in this article.

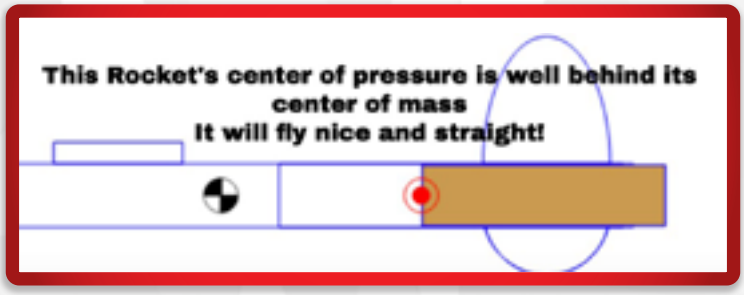

FIGURE 2: THE DISTANCE THE CP IS FROM THE CG FOR SUPERSONIC ROCKETS SHOULD BE 2.25 TIMES THE TUBE DIAMETER.

To start, you should reinforce your fins with regular copy paper. This will not only polish the surface, but will also drastically increase strength. To do this, first cut out your fins and then trace the shape of the fin on regular copy paper. Cut out the image 6 or 8 times depending on how many fins your model has. Then, give the fins themselves a light sanding. Thinly spread out wood glue on half of one side of the fin, making sure a thin layer of glue covers the whole side of the fin. Next, attach the paper and line up the edges. After the edges are aligned, quickly do the other side. Once the glue has dried, take some thin CA glue and seal the edges. Make sure the edges of the paper bond well to the wood. Also make sure not to seal the edge of the fin that you will glue to the body tube! If you are using balsa wood, your fin thickness should be around 1/10 C grade balsa with paper skins.

FIGURE 3: PAPER THE FINS FOR EXTRA STRENGTH

Because our rocket will be traveling so fast, it is important to keep our fins as aligned as possible. To mark the tube, I print out the base view of the model and trace the edges of the fin shape onto the body tube. Then, I extend them down the length of the tube by using a door frame. The elegance of this technique is that I end up with 2 lines for each fin, which will allow me to

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glue the fin in between the two lines. This is preferable to just one line as it is harder to align them that way. You should use a fin alignment jig as well and the ones sold by Apogee Components are perfect for this (https://www.apogeerockets.com/Building-Supplies/Fin-Alignment-Jigs).

You will also want to add epoxy clay (https://www.apogeerockets.com/Building-Supplies/Adhesives/FIXIT-Epoxy-Clay) fillets to your model. Before you do this, make sure to sand down the surface you will epoxy with 400 grit sandpaper. Then mix equal portions of the epoxy. Once the clay is one uniform color, roll it into a worm. Then wrap the worm around the fin. Press the epoxy clay against the fin. For now, just press the clay directly into the fin and body tube joint. Once you've pressed the fillet against the joint, use a popsicle stick or your finger to gently smooth the fillet. Make sure you don't pull the clay out of the joint. If you do, just press it back into place. Use water to assist with smoothing the fillet. When doing this, try to make sure your fillets are symmetrical as well. Then, let the fillet dry completely. If the fillets are asymmetric, now is a good time to use some high grit sandpaper and sand the fillets until they are symmetrical. Then add a little bit of water to Elmer's wood filler and mix the two up. Once it is at the consistency of toothpaste, take a paintbrush and use it to apply the wood filler onto the epoxy clay fillets. This will fill in all the gaps and bumps on the fillet. The filler is very easy to remove so it is okay to be generous when applying it. Make sure you cover the entire fillet and a little of the body tube and fin as well. Once it is fully dry, start with some 150 grit sandpaper to sand off some of the filler; try to smooth the filler but don't sand it off completely. Once the filler is in the general shape, continue to smooth the filler with some 220 grit sandpaper. With this 220 grit, you can also sand some of the excess filler off the body tube and fin.

FIGURE 4: ADD EPOXY FILLETS TO INCREASE FIN STRENGTH

After you are done your fillets will have a nice professional look to them (Figure 4)! More importantly, that fin is not coming off!

Surprisingly, the thin wall body tubes the Apogee Components provide are strong enough for this, https://www.apogeerockets.com/Building_Supplies/Body_Tubes/Low_Power_Tubes/29mm_x_13_Body_Tube_Holds_FG_Engines.

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www.apogeerockets.com/Rocket-Kits/Skill-Level-2-Model-Rocket-Kits/SkyMetra

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My only recommendation here is that before you start building, seal the edges of the tube with CA and rough up the tube itself with 400 grit sandpaper. This will get rid of the gloss on the tube, which will make it much easier for adhesives to bond to it.

Choosing a Motor

You can't launch a rocket without a motor to power it. Here are some basic recommendations for motors. Because our rocket is going so high and so fast there is a non-negligible chance you will lose it. Because of this, I don't recommend using reloadable motors as if you lose the rocket, you also lose the expensive aluminum casing.

If your rocket is 24mm in diameter, I recommend the Aerotech F44W. If your rocket is 29mm in diameter, you have many more options. Most high thrust G motors will work for you. The best way to find a motor that will push your rocket past the speed of sound is just to simulate.

Minimizing Drag

You also want to try to minimize drag and weight as much as possible to increase speed. Here are a few tips to do that. More detailed guides to some of these tips are linked below.

1. Polish your surfaces: There are many ways to do this, but my favorite is to take some high build sandable primer and heavily apply it to the body tube. Then start with 180 to 250 grit sandpaper and sand the tube until you start to see the white of the tube again. At this point, be very careful and sand gently because you don't want to cut into the tube. After sanding, you should see all the spirals filled with primer and a little more primer around the tube. Then, apply another coat of primer and this time sand with 400 to 600 grit wet sandpaper. This sandpaper is meant to get wet and we plan to do just that! But before you start sanding, make sure the edges of the tube are sealed with Cyanoacrylate glue to prevent water from getting on the

FIGURE 5: ALTIMETER TWO FROM JOLLY LOGIC

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cardboard. If the edges are sealed, start sanding. You shouldn't sand down to the tube as that would expose the paper to water, which is not good. Once you've smoothed the surface with your wet-dry sandpaper, wipe the water off and finish the tube off with a few layers of paint. You want to make sure that you compensate for the extra weight the paint and primer will add to your simulated rocket. The specific weight added depends on how big your model is, but it is approximately an extra 12 to 20 grams. To add the extra weight to your simulations, use the "Mass override" feature on each component in RockSimPro.

2. Airfoil fins: Airfoiled fins are pretty standard for most high-performance models. To make them, start by rounding off the leading edge of the fin. Once that is done, make a mark ⅔ from the fins trailing edge. Then take your time gently sanding the back ⅔ of the fin. Make sure the airfoil is symmetrical, as shown in Figure 6.

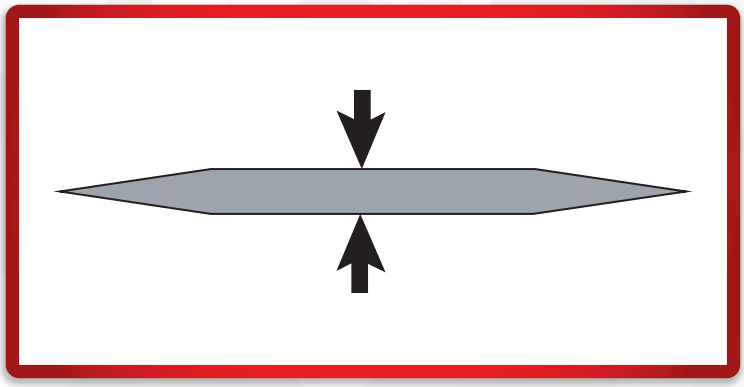

FIGURE 6: A GOOD SUPERSONIC AIRFOIL

FIGURE 7: AN OGIVE SHAPED NOSE CONE

3. Nose cone shape: By optimizing your nose cone design and shape, you can increase your top speed by a surprising amount. This might differ from rocket to rocket but I found an Ogive shape to be the best (Figure 7). I also tried to keep the nose cone pretty short, to decrease drag and increase speed. But you don't want it to be too short, as that will increase drag. To find the best nose cone shape and size, you will just have to play around with your design. Also if you 3d print or make your nose cones, don't be afraid to print them with very thin walls, I got away with 0.5 mm walls of PLA. Thinner walls will reduce weight and increase speed.

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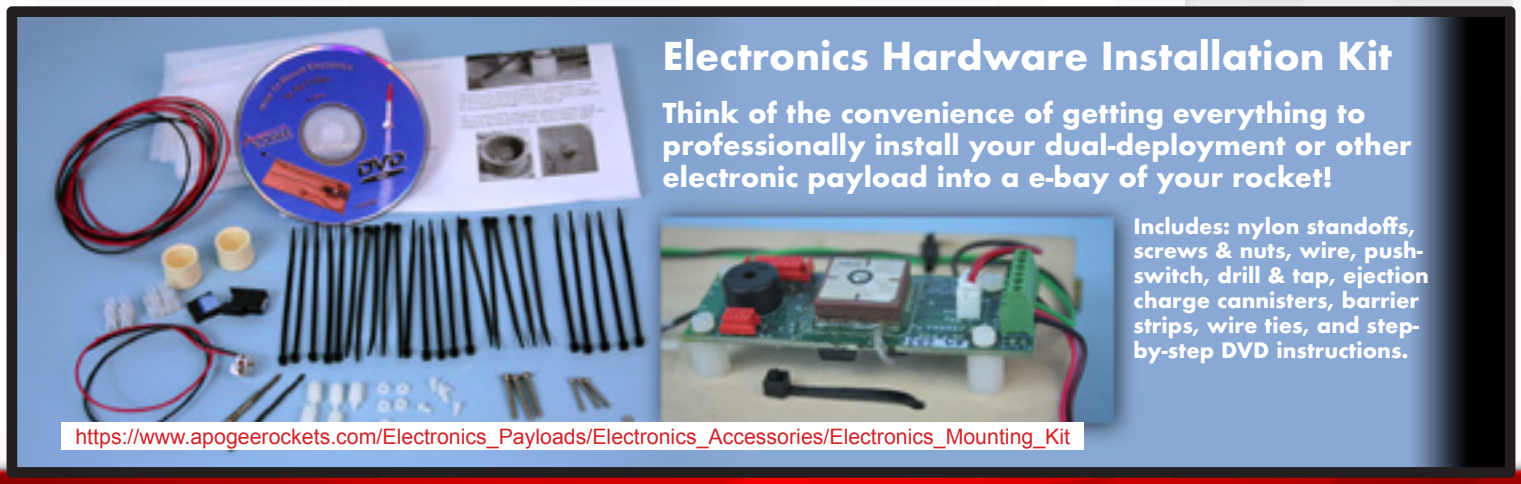

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4. Use 3 fins on your model: This one is pretty simple, just design your rocket with only 3 fins and keep them as small as you can while still keeping the stability margin above 2.25.

5. Use fly-away rail guides: This is another simple one. Launch lugs contribute up to 30 percent of a rocket's drag, and a fly-away rail guide will eliminate this unnecessary drag. You could also solve this problem with a launch tower or piston launchers. The problem with launch towers is that they can be quite big and difficult to transport. Piston launches have other complicated problems. The rail guide seems to be the simplest and best option.

6. Fin material: By using stronger materials, you can make your fins thinner and decrease drag. Balsa wood is easy to work with but is not the strongest wood out there. About 1/10 C grade balsa with paper skins should be sufficient for Mach 1 flights. Plywood is another option, and is much stronger than balsa wood. About 1/20 Birch plywood with paper skins should be good. Fiberglass is even stronger than plywood. But I haven't worked with fiberglass yet, so I don't have any recommendations as to how thick the fiberglass should be. If you use fiberglass, you will also have to use epoxy to bond it to the airframe.

7. Make the design minimum diameter: Make your rocket airframe just big enough to house the motor to reduce drag.

Check out our Facebook page
www.facebook.com/ApogeeRockets

Recovery

One of the most important parts of model rocketry is getting your rocket back safely. I used 300-pound braided Kevlar cord as a shock cord that was cut to be 3 times as long as the rocket. I highly recommend a streamer over a parachute for this type of rocket. Because the rockets are so light and will fly so high, a parachute will allow them to drift pretty far. This can be a big problem especially if your launch site has roads, trees, tall grass, etc. Drifting can make it very easy to lose the rocket. I also find that parachutes can get easily tangled, which is another reason to use a streamer. I used some mylar streamers sold at Apogee Components (https://www.apogeerockets.com/Building_Supplies/Parachutes_Recovery_Equipment/Streamers). They hold creases nicely, which is helpful when you fold them in an accordion style to increase drag. These streamers are shiny, which will make them easily visible to the ground. Make sure that you pack the recovery wadding tightly enough so no air can pass through as these streamers burn easily. To attach the streamer and shock cord, I just used some masking tape. As a general rule of thumb, I like to keep my rocket's descent rate around 18 mph. This rate keeps it coming in fast enough to avoid lots of drift, but also slow enough to prevent damage to the rocket.

How to know if you pass the speed of sound?

This is a question that is fairly hard to answer. In most normal circumstances, just putting a cheap altimeter in the rocket will work. But, because our rockets get going so quickly, the gee forces will likely overload the altimeter's accelerometers and render its readings useless. You will

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PHOTO 8: USE A HIGH-THRUST COMPOSITE PROPELLANT MOTOR

need to find an acceleration-based altimeter that has a gee limit that is above what your rocket will experience. There are many good options out there that you can use for 29mm designs (Figure 5). For 24mm designs, you will need a lightweight altimeter that has a high gee limit and will need to fit in a 24mm airframe. Such a device might be difficult to find. Instead of an altimeter, you can try to listen for the sonic boom that will result when a rocket breaks mach. However, there is a low chance that you will hear it, because the shockwave forms horizontally. I also tried an indirect approach that might not be the best, but was adequate. I flew my rocket with a Jolly Logic AltimeterTwo (https://www.apogeerockets.com/Electronics-Payloads/Altimeters/Jolly-Logic-AltimeterTwo).

The Jolly Logic AltimeterTwo has a gee limit of 24 gees and my rocket quickly passed that. (Extend the limit of the AltimeterTwo to 40.56 G's in P.O.F. issue 293 - https://www.apogeerockets.com/education/downloads/Newsletter293.pdf)The altimeter did measure max altitude and time to apogee, however. By dividing max altitude by time to apogee I found the rocket's average speed in feet per second. Then, I compared my average speed with the predicted average speed from the simulations. If the two averages match, it suggests that the simulations are accurate. Then, I could infer that the simulated top speed is likely to be the top speed in the flight. Once again this strategy is not perfect, and requires additional assumptions. But, it is better than nothing.

FIGURE 9: A TRACKER CAN HELP YOU LOCATE YOUR ROCKET AFTER THE FLIGHT

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Extra tips and tricks

These are some extra tips that I wanted to share, but did not fit neatly into another category.

For 29mm designs, GPS trackers are a good idea if you have the mass budget for them (shown in Figure 9). They will be worth it to help recover your rocket. The minimum diameter rockets fly extremely high and it can be very easy to lose sight of them, especially in cloudy weather. Dual deploy computers aren't really necessary at this scale and with a GPS tracker, dual deploy computers are just extra weight. I also highly recommend tracking powder for these high-stakes flights. Like the GPS, this powder will help you locate the rocket and decrease your chances of losing it. I don't recommend using an engine block in your rockets. The engine block limits the size of motors you can use and most composite motors already have a thrust ring that will keep the motor from sliding forward. To retain the motor, I like to wrap a few layers of masking tape around the body tube and motor. This tape will keep it from sliding backward.

Helpful Links and resources

Paper skinning
https://www.apogeerockets.com/Advanced_Construction_Videos/Rocketry_Video_16

Epoxy clay fillets
https://www.youtube.com/watch?v=TD0s4H9X37Q

Polishing surfaces with sand able primer
https://www.youtube.com/watch?v=sigDwXV-UHw&t=221s

Air Foiling fins
https://www.youtube.com/watch?v=7NTX-4-LeTk&t=164s

About the author

Walter Lohmueller is a middle school student who lives in South Pasadena, CA and enjoys building model rockets as well as coding electronics. He has been building model rockets for over a year now and has a YouTube channel DIY Aerospace (https://www.youtube.com/channel/UCCU-ateE1v0U3PAIyV3XVsJA) where he shows all his projects. He became interested in rocketry after watching YouTube videos of model rockets. He found electronics as another good way to expand his passion and is working on DIY altimeters. He hopes to make more complex flight computers and model rockets in the future. When he is not designing model rockets, he is playing bass guitar and going to school.

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