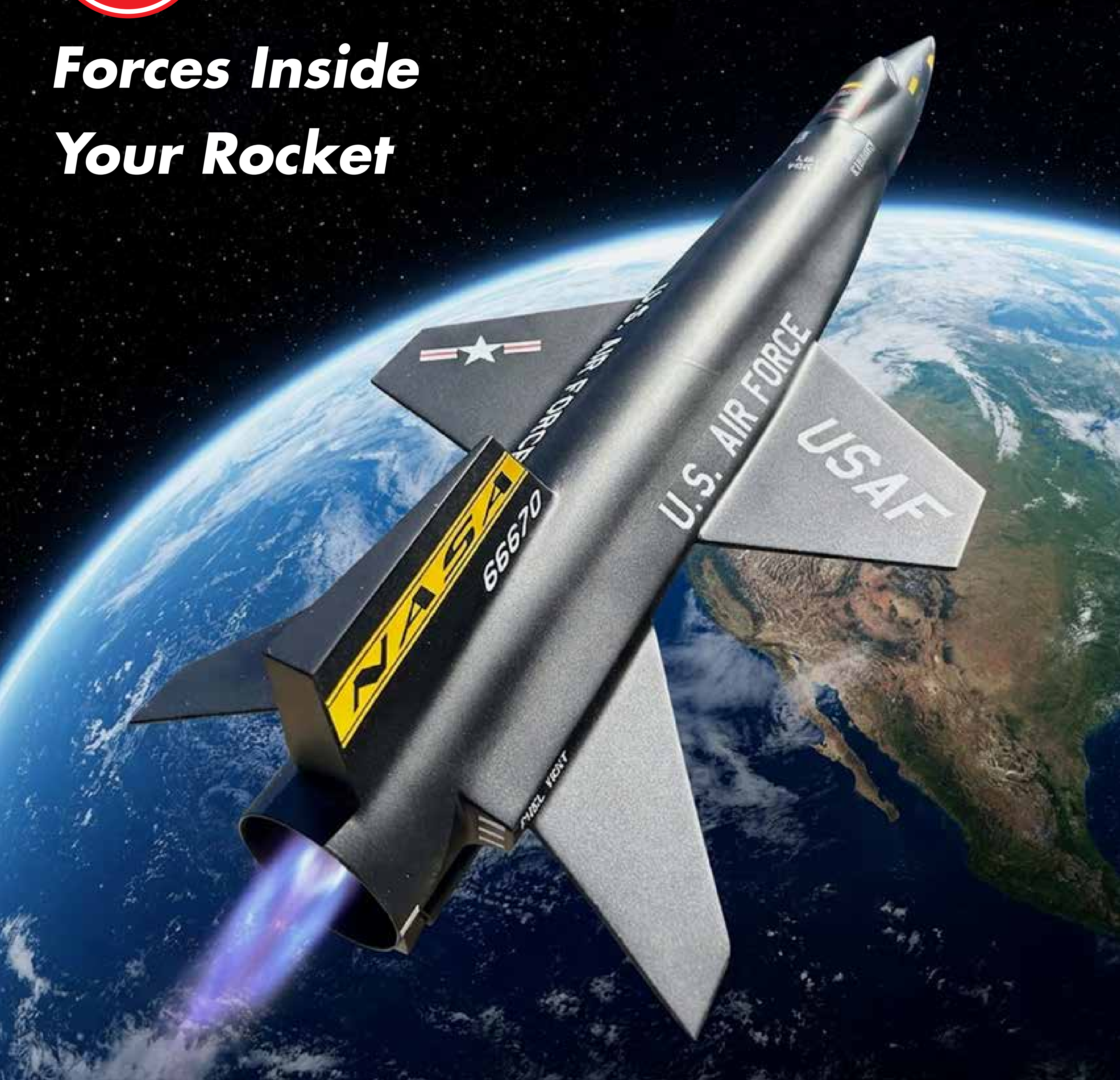
Issue 676 / April 14th, 2026

PEAK OF FLIGHT NEWSLETTER

Apogee Components, Inc. / ApogeeRockets.com / Colorado Springs, CO

Forces Inside Your Rocket



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COVER PHOTO

Apogee X-15 Kit

The X-15 is still the fastest rocket-powered manned aircraft. This beautiful kit is powered by 29mm diameter composite propellant motors, and features realistic vacuum formed fairings and canopy, wedge shaped vertical tail fins, water-slide decals, an engine ejection baffle.

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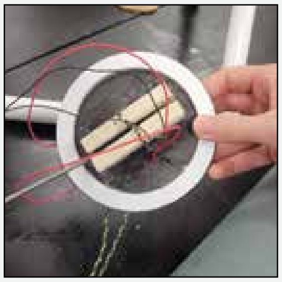

Forces Inside Your Rocket

This article explains how to make sure a rocket's nose cone fits just right. It shows how to test whether the cone is too loose or too tight so the rocket can launch safely and the parachute can come out when it should.

Apogee Components, Inc.
4960 Northpark Dr.
Colorado Springs, CO 80918
1-719-535-9335
www.ApogeeRockets.com

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Forces Inside Your Rocket

By Alex Magee

On a bright October day several years ago, when I was only 16, I pulled out my shiny new Electron rocket to try and earn my L1 certification. I built the rocket at home and was the only model rocketeer that I knew of, so my knowledge of high power rocketry construction went about as far as what I had learned from G. Harry Stine's Handbook of Model Rocketry and some E motor sized Estes kits. I put the rocket on the pad, the rocket flew great, and then my dreams of my L1 cert came crashing down with my rocket as one of the parachutes snapped off and flew away with all of my electronics (a Jolly Logic 2 and a MicroBeacon). Thanks to the MicroBeacon, I was able to find my stuff, but it was 100 ft up in a tree, so I never got it back. After some analysis, I found out the cause of failure was a weak attachment point on the nosecone for the shock cord, which snapped during the parachute ejection.

The next day of the launch I decided I was going to try again for my L1 certification, this time with an Apogee Zephyr. Now fortunately the folks at Apogee make much more robust nose cones (and rocket parts in general) so this flight went off without a hitch. But the moral of the story goes deeper than just using an excellent

Figure 1. My Electron Rocket. Fortunately after the aforementioned ill-fated L1 attempt I was able to fix it.

Figure 2. A comparison of the nose cone that comes with the Zephyr (in green) and the nose cone I used for my Electron (yellow and black). Look at how much more beefy the Zephyr nose cone is! After the loop for the shock cord was ripped off the Electron's nose cone, I drilled holes in the base of it to attach the shock cord.

kit to get your L1. Every launch, rocketeers all over the world get anxious if their rocket will come down in one piece. Yes, there are good practice guidelines and yes, they probably did ground testing and used some simulation tools, but what more can you do to ensure success? That requires some math and some decent testing strategies for parts you can do at home, which I hope to explain in this two-part article series.

Mathematical Analysis

Most mechanical rocket failures can be avoided starting with good mathematical analysis. Unfortunately, no rocket simulator that I am aware of is able to do this for you. If we are going to do the analysis ourselves, we need to understand what the fun-

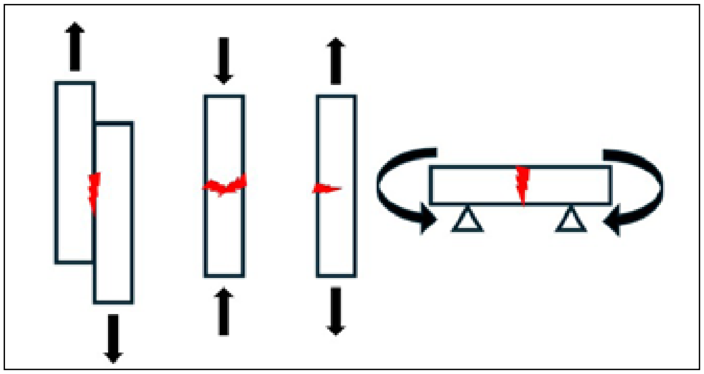

Figure 3. Types of loads a rocket is likely to experience. (Left to right: Shear, compression, tension, moments)

damental loading mechanisms that cause failure are in rockets. These loading mechanisms include shear, compression, tension, and moments, each of which has unique failure mechanisms.

Pinpointing loading types starts with understanding where these loading types occur. Shear occurs with any parallel, non-aligned forces. Compression occurs when parallel applied forces point toward each other. Tension occurs when parallel applied forces point away from each other. Moments are created by forces perpendicular to a member that are acting at a distance (basically anything that causes bending). Now that we understand these load types, we can look at where they might occur on our rockets. The biggest shear loads are usually on centering rings; there are also shear loads where the fins attach and where the shock cords attach. The largest compression loads occur on the motor mount tube, but the airframe as a whole should often be considered as well. Tension loads are highest on the shock cord and AV bay through rods. Lastly, moment loads can be large on fin attachments, bulkheads, and loops where the nose cone attaches to the shock cord.

To mathematically evaluate failure in these components we just listed, we need to look up reasonable values for the yield or failure stresses, or if that is not available, the failure load. If these come with what products you buy, use that. For example, McMaster Carr often publishes the yield stress of several of their products like threaded rods and bolts. Other times you will need to Google it or test it yourself. I had to do this with Blue Tube for a class project and discovered it had a compressive yield stress of 3580 Psi (roughly 1800 lbs failure load for a 54mm tube). Once we know reasonable failure values, we can calculate when our rockets will and will not work and can start designing them properly.

Engineering Reality Check: Assumptions, Safety Factors, and Rules of Thumb

When we perform structural analysis on our rockets throughout this article, we are essentially building a mathematical model of a physical object. While the math is precise, the accuracy of our results depends entirely on the assumptions we make. To design a rocket that survives, you need to understand the difference between a "rule of thumb" and a hard engineering calculation. So before we start with the design, let’s review some of the concepts ahead of time.

1. The Reality of "Rules of Thumb"

In the hobby, you will often hear heuristics like, "multiply your rocket’s weight by 20 to find the shock cord load." These are useful starting points, but it is vital to understand what they actually represent.

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- **The 20g Rule (Shock Cord Load):** This is a heuristic used to estimate the "jerk" force during parachute deployment. It assumes a worst-case scenario where the parachute opens instantly at high velocity. It is not a precise calculation; it is a conservative safety buffer. If your rocket is heavy or flies at supersonic speeds, 20g might be an underestimate. Always treat this as the minimum load you should design for, not the exact load.
- **The 20x Weight Rule (Fin Impact):** This estimates the deceleration force when a rocket hits the ground horizontally. Like the 20g rule, this is a "gut check." It assumes a specific landing velocity (typically around 25 ft/s). If your rocket lands on concrete or at a higher velocity, the force will be significantly higher.

The Verdict: Rules of thumb are excellent for "sanity checking" your design, but they should never replace a proper load analysis. Use them to catch obvious errors, not to certify your rocket for flight.

2. The "Factor of Safety" (FoS)

In professional aerospace engineering, we rarely design a part to fail exactly at the expected load. If a part is calculated to break at 100 lbs, we do not build it to withstand exactly 100 lbs. We apply a **Factor of Safety (FoS).**

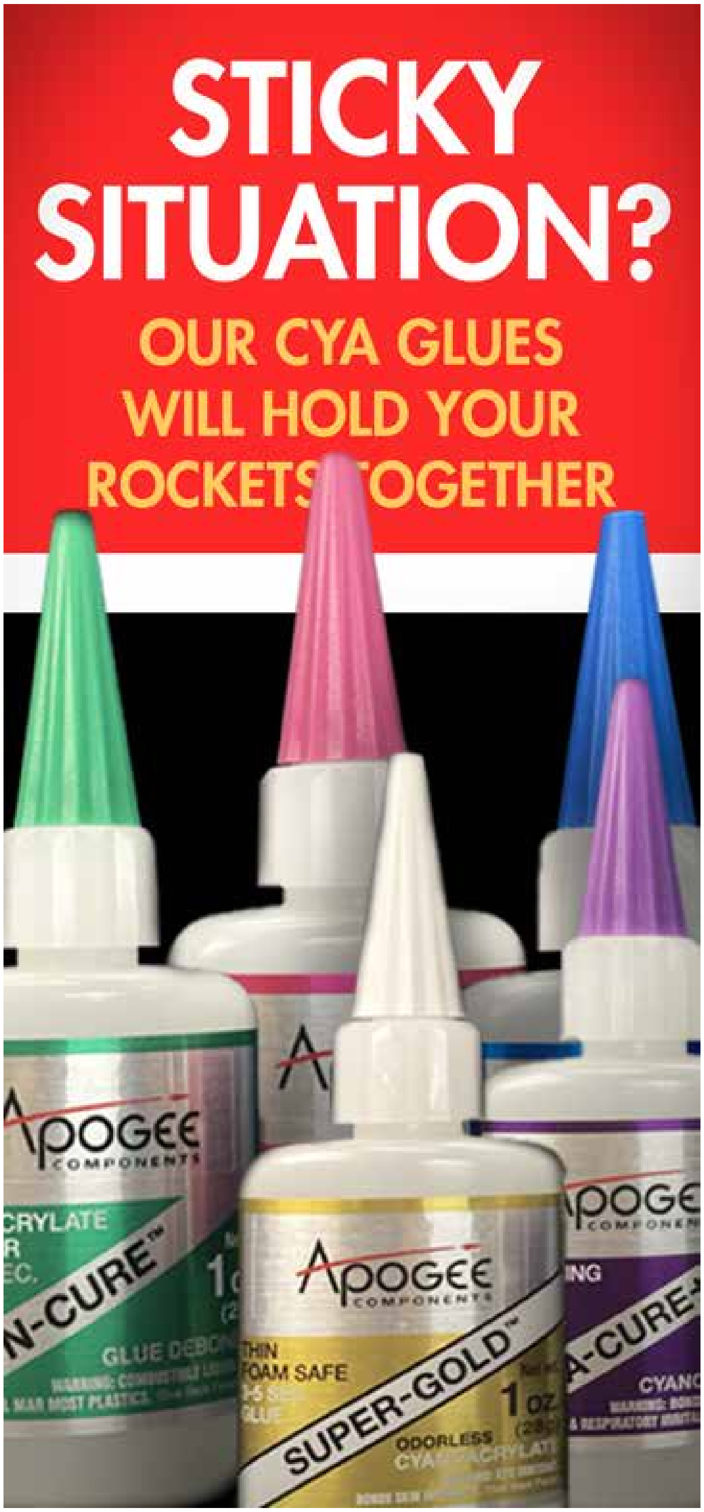
A Factor of Safety is a multiplier that accounts for the "unknowns"—variations in material quality, manufacturing defects, or unexpected flight conditions.

- **How to apply it:** If your analysis shows a maximum expected load of 80 lbs, you should aim for a design that can handle at least 120 lbs to 160 lbs (an FoS of 1.5 to 2.0).
- **Why it matters:** If your calculated stress is 2,660 PSI and your material's yield strength is 3,320 PSI, your margin is extremely slim. In the real world, a small bubble in your epoxy or a slight misalignment during assembly could cause that part to fail. Always design with a buffer.

3. Understanding Our Assumptions

Every calculation in this article relies on simplifying assumptions. When you run your own numbers, you must be aware of the "blind spots" in your model:

- **The "Uniform Column" Assumption:** When we use the Johnson-Euler buckling equations, we treat the rocket as a uniform, solid column. In reality, a rocket is a complex assembly of airframes, bulkheads, and motors. While this assumption is a safe, conservative approximation, it ignores the fact that drag is concentrated at the nose cone and thrust is concentrated at the motor mount.



- **Material Consistency:** We often use "handbook" values for materials like plywood or Blue Tube. However, these properties can vary based on the manufacturing batch, humidity, and temperature. When in doubt, always use the lower end of the published strength range to be safe.
- **Static vs. Dynamic Loading:** Most of our math treats forces as "static" (applied slowly). Rocketry is inherently "dynamic" (forces are applied in milliseconds). While static analysis is a great baseline, it is inherently less accurate in a dynamic simulation.

Hypothetical L2 Rocket Design

To help you get a feel for mathematically testing your rocket designs, let's design a hypothetical L2 rocket together, just like one you could make in a simulator like RockSim. The components, in order are: 1 4:1 3 in diameter LOC plastic nose cone, 60 inches of blue tube joined with a 8 inch blue tube coupler, 3 ¼ in plywood fins (45 deg sweep, 20 cm root cord, 10 cm height and tip cords, 2 ¼ in plywood centering rings, 2 #8 aluminum through rods, 2 ¼ in plywood bulkheads for your AV bay, ½ inch tubular nylon shock cords, a 30 cm long, 38 mm blue tube motor mount, a 48 inch main parachute and last, but not least, a 15 inch drogue parachute. We will try to fly it on a J425R from Aerotech. When assembled, it might look something like the rocket below:

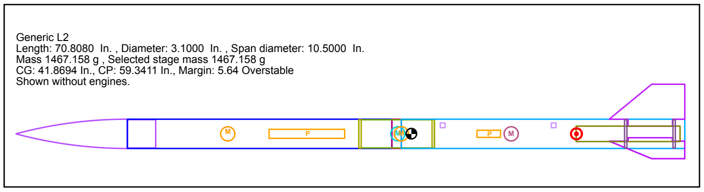

Generic L2
Length: 70.8080 In. , Diameter: 3.1000 In. , Span diameter: 10.5000 In.
Mass 1467.158 g , Selected stage mass 1467.158 g
CG: 41.8694 In., CP: 59.3411 In., Margin: 5.64 Overstable
Shown without engines.

Figure 4. A reasonable L2 rocket design.

Now that we have made this beautiful rocket in our simulator, let's see if it can handle the stress and loads of flight. If not, we need to change some stuff.

Shear

Let's start with shear loads, looking at where the shock cord connects to the bulkhead and where the centering rings connect to the motor mount tube. To get a reasonable value for the force of the shock cord on the connection, multiply the weight of your rocket by 20 or calculate the drag force from your main parachute opening at about 20 m/s. (If your parachute is opening at speeds higher than that you did something wrong). Our hypothetical L2 rocket is about 4 lbs, so the load on the connection between the bulkhead and shock cord will approach 80 lbs. The load is applied over the area formed by the outer circumference of the washer used times the thickness of the wood or if the shock cord is tied to the wood, it is along the length between the holes in the wood times twice the wood thickness. Using ¼ in plywood with a ½ in washer, the area in shear is 0.393 in², so the shear stress is 204 Psi. A reasonable yield shear strength for plywood is 1015 Psi, so we are probably okay, but remember that ¼ in plywood is usually not a ¼ in thick. In scenarios where the factor of safety isn't as good, we may need to consider using ½ in plywood or a wider washer.

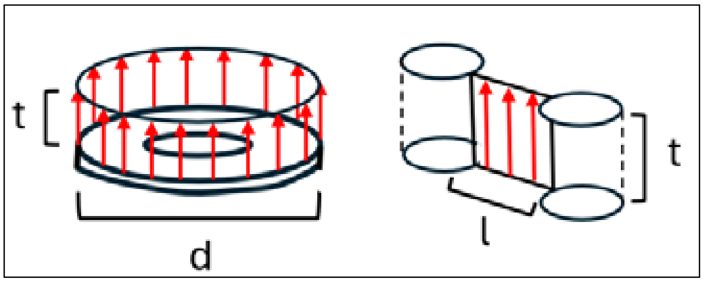


Figure 5 - Left: An illustration of the shear area in a bulkhead from force on a washer. The height of the red arrows corresponds to the thickness of the bulkhead. Right: Shear area in a bulkhead from force on a shock cord tied to the bulkhead.

We now look at the connection of the centering rings to the motor mount tube, the maximum load here is the peak motor thrust. Looking at this 4 lb rocket, we decide to use a J425 motor with a peak thrust of 102 lbs. The shear area in this location is the circumference of the motor mount tube times the combined height of the centering rings. The J425 needs a 38 mm motor mount tube, so its circumference is about 5.19 inches. With two quarter inch plywood centering rings, that means the shear area is 2.59 in² and the shear stress is 38.3 Psi. With the bond strength of JB Weld being advertised at over 5000 Psi, this part is very safe.

Compression

To analyze possible compression failures, we will look at the motor mount tube and the entire rocket as a column. Starting with the motor mount tube, we take the thrust of the motor and divide it by the cross sectional area of the motor mount tube. For our 4 lb rocket using the J425, the compressive stress is 330 Psi on the motor mount tube, well below the 3580 Psi limit of Blue Tube. One thing that is nice about this part is that failure in this location doesn't tend to be catastrophic. The tube will typically crumple until the motor gets close enough to the lower centering ring. This happened to a motor mount adapter that I made, which is shown in Fig. 6.

Figure 6. A poorly designed motor mount adapter made from paper. Notice how crushed it is at the base. It couldn't handle the H87 motor I used.

Now we look at the entire rocket as a column under a compressive load. A long time ago, some really smart people figured out that the longer a beam is, the more likely it will fail. They derived a formula we now call the Johnson-Euler Buckling Formula. Figure 7 shows a typical Johnson-Euler curve. Anything above the lower of the red or blue lines for a point has a >99% chance of failure. Finding the failure load requires 6 equations shown in Fig 8.

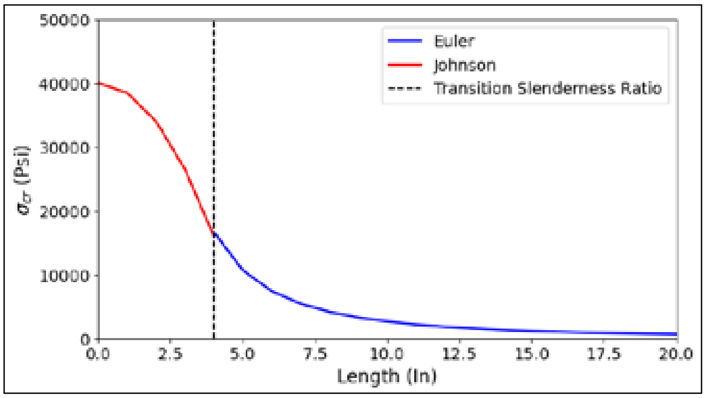


Figure 7 - Johnson-Euler curve for a 1 inch diameter column of 6061-T6 Aluminum under free-free loading conditions. Notice how after 10 in or so it doesn't cost much strength to make the column longer.

This may appear overwhelming, but Omnicalculator has a buckling calculator that can do this all for you [1]. The process starts with finding the radius of gyration or the rocket and using that to determine the slenderness ratio. Then we find the transition slenderness ratio using a K of 1.2 (this is the free-free condition in Omnicalculator) and see if our rocket's slenderness ratio is bigger or smaller than the transition slenderness ratio. if it's smaller, we use the Johnson formula (Eq. 5) and if it's bigger, we use the Euler formula (Eq. 6) [2]. In the case of our rocket, let's say it has a 3 inch diameter body and the distance from the first centering ring to

(1) $$I_{x,\,circle} = \frac{\pi R^4}{4}$$

(2) $$r = \sqrt{\frac{I_x}{A}}$$

(3) $$R_s = L/r$$

(4) $$R_{trans} = \sqrt{\frac{2\pi^2 E}{K^2 S_y}}$$

(5) $$\sigma_{cr} = S_y - \left(\frac{S_y}{2\pi} \cdot \frac{KL}{r}\right)^2 \left(\frac{1}{E}\right)$$

(6) $$\sigma_{cr} = \frac{\pi^2 E}{(K\frac{L}{r})^2}$$

Figure 8. Equations for Johnson-Euler Buckling

Symbol	Meaning
A	Cross sectional area of body tube
b	Diameter of bulkhead/width of rectangular cross section
c	Distance to centerline
d	Diameter
E	Modulus of Elasticity
h	Height
I_x	Area moment of inertia
K	Length adjustment factor (usually 1.2)
L	Body length (Johnson-Euler)
l	length
P	Applied load
R	Radius of body tube
R_s	Slenderness ratio
R_{trans}	Transition slenderness ratio
r	Radius of gyration
S_y	Yield strength
t	Thickness
σ_{cr}	Critical/Failure Stress

Table 1 - Variables

the shoulder of the nose cone is 60 inches. After running all of the calculations using the modulus of elasticity and yield stress of Blue Tube (120 Ksi and 3580 Psi respectively) we get that the critical load is 163 lbs. Your rocket is safe. Now honestly the critical load given is kind of an underestimate because a decent fraction of the motor thrust is distributed along the length of the rocket based on the weight of given segments and their drag. This makes it not a true column. However, drag tends to be concentrated in the nose cone. This means if you are going fast enough that ~80% or more of the thrust is used to overcome drag, then the critical load given

by these calculations should be used as a hard value.

Tension

Tension in a rocket is relatively rare and generally only occurs during parachute ejection. That means that we only need to analyze things attached to the shock cord, like AV bay through rods. Their yield strengths are generally 50 Ksi for steel and 40 ksi for aluminum. Looking at our hypothetical rocket that weighs 4 lbs, this means that there will be a max of 80 lbs on the shock cord, and therefore 80 lbs will go through the AV bay. If our rocket has 2 #8 through rods, the cross sectional area of which is 0.014 in², then the tensile stress is 2860 Psi. This is plenty of margin of error. A bonus is that if a threaded rod can support the load, a single nut can generally support that same load. So you don't need to worry about doubling up with the nuts, but it isn't a bad idea if you are using thin through rods.

Figure 9 - Look at all the tension in that shock cord. If you have an AV bay, it will need to support that load.

Moments

We have finally arrived at the last kind of load! You are almost done with engineering checks on your rocket's design. Now we just need to check out if our bulkheads, fin attachments and where the shock cord attached to the nose cone are strong enough. Let's start with the bulkheads. Note we assume that the bulkhead has 2 through rods holding it in place, if you are using 3 or more, you need to look at Kirchoff-Love plate theory, which I am not going to explain here. Anyway, the peak stress is always where the load is applied. To find it, we use Eq 7., Eq 9. And Eq. 10. If the bulkhead is ¼ in plywood and we keep the 80 lb load, then stress is 1200 Psi but the yield stress in bending of plywood is 5800 psi. So we are probably okay and don't need to make the bulkhead any thicker.

$$M = \frac{Pl}{4} \tag{7}$$

$$M = Pl\sin(\theta) \tag{8}$$

$$I_{x,\,rectangle} = \frac{bh^3}{12} \tag{9}$$

$$\sigma = \frac{Mc}{I_x} \tag{10}$$

Figure 10 - Equations for stress in bending.

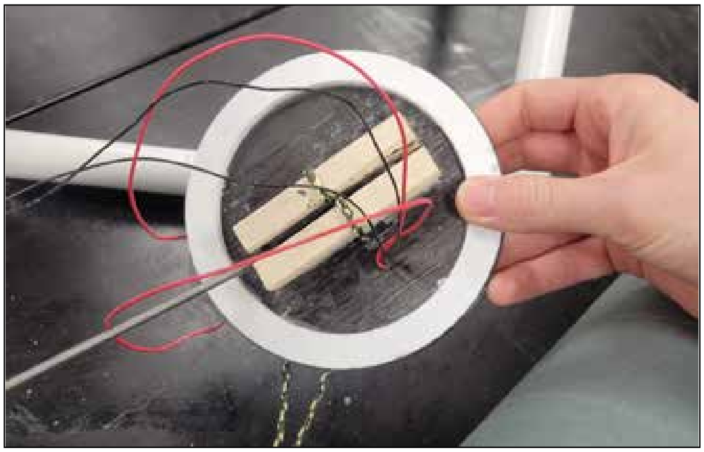


Figure 10. One of the bulkheads used in my L3 attempt. I was made with super thin sheets of carbon fiber and was too weak. Hence the two sticks of wood as thick as my thumb to reinforce it. In addition, you can see the through rod on the left of the image. Even though the rocket was 17 lbs, I only needed #8 size through rods.

The impact on the fins when the rocket lands is one of the toughest points in a flight. I know this has killed a number of rockets (mine included), and almost always the failure point is where

the fins attach to the wall of the body tube and not the actual fin. There are many different ways this loading can occur, but we will assume the rocket hits parallel to the ground so the fin is loaded on its side. The max force when the rocket hits like this at this point with a safe descent rate of 25 ft/s is likely to be around 20 times the weight of the rocket, so in the case of our hypothetical L2 rocket, 80 lbs. However the moment produced depends on the angle in which the hit occurs, which is up to 60 degrees for a 3 fin rocket and 45 for a 4 fin rocket. The moment produced here is given by Eq. 8, and comes out to 222.7 lb*in for our rocket. The area moment of inertia comes from Eq. 9 using the length of the fin for b and the thickness for h. This results in a stress of 2715 Psi. The plywood fins will be fine because their tensile strength is 5800 Psi.

This is a good time to explain why we do through-wall-mounting for high power rockets. If you are joining the fins just to the rocket body, the epoxy might be fine at 2715 Psi, but since epoxies are terrible with moment loads the epoxy may crack. Blue tube will definitely delaminate at 2715 Psi and paper tubes will be absolutely cooked. This is why we always do through wall mounting for high power rockets. It puts the moment load on the fin material and not the body tube lamination or epoxy, keeping your rocket safe when it hits the ground.

To finish off our mathematical analysis, we return to the anecdote about my L1 failure. On a standard LOC 3 inch nose cone made of polypropylene, the loop for your shock cord is 3/16 in in diameter and 1 in long. My rocket weighed 2 lbs but separated in half so the shock cord force approached 20 lbs. Using Eq. 7, 9 & 10 for the stress, we get a stress of 7,720 Psi. Polypropylene fails at 4500 Psi, so my L1 certification was doomed from the start. I should have done the math before I flew.

Now let's look at the nosecone on the Apogee Zephyr. The loop where the shock cord attaches is about ⅜ in in diameter, but it is 1.25 in long. The Zephyr also weighs 2.75 lbs, so that means more force on the shock cord, 55 lbs. Using Eq. 7, 9, and 10 again, we get a maximum stress of 3320 Psi, but because the kit comes with a nice wide shock cord, the maximum stress is actually closer to 2660 Psi. In any case, it’s a reasonable safety factor, enabling people like me to get their L1 certification without any worry.

Conclusion

So now that we have gone through how to mathematically test your rocket design, hopefully you have a better idea of both how to design your rocket and where the weak points might be. You also hopefully understand how to determine the loading types at different locations. Clearly, the analysis here was not comprehensive, so there may be other areas of your rocket you need to test. Knowing how to do this analysis well will not only help you avoid the embarrassing moments when your rocket shreds itself during flight in front of your friends, but also build higher performance rockets and move the hobby forward.

Citations:

[1] Dhari, R., “Buckling Calculator,” Omni Calculator, accessed March 30, 2026, https://www.omnicalculator.com/physics/buckling

[2] “Column Buckling,” MechaniCalc, accessed March 30, 2026, https://mechanicalc.com/reference/column-buckling

About the Author

Alex Magee, has been flying model rockets ever since his parents gave him one when he was six. He currently lives in Provo, Utah and attends Brigham Young University where he is studying mechanical engineering. He has a part time job researching heat transfer in ablative materials and when he is not working on his next rocketry project he is out riding his bike or swimming.

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When you have an idea for an article you'd like to submit, please use our contact form at https://www.apogeerockets.com/Contact. After review, we will be able to tell you if your article idea will be appropriate for our publication.

Always include your name, address, and contact information with all submissions. Including best contact information allows us to conduct correspondence faster. If you have questions about the current disposition of a submission, contact the editor via email or phone.

CONTENT WE ARE LOOKING FOR

We prefer articles that have at least one photo or diagram for every 500 words of text. Total article length should be between 2000-4000 words and no shorter than 1750 words. Articles of a “how-to” nature are preferred (though other types of articles will be considered) and can be on any rocketry topic: design, construction, manufacture, decoration, contest organization, etc. Both model rocket and high-power rocket articles are accepted.

CONTENT WE ARE NOT LOOKING FOR

We don't publish articles like "launch reports." They are nice to read, but if you don't learn anything new from them, then they can get boring pretty quick... Example: "Bob flew a blue rocket on a H120 motor for his certification flight." As mentioned above, we’re looking for articles that have an educational component to them, which is why we like “how-to” articles.

You can see what articles and topics we’ve published before at: https://www.apogeerockets.com/Peak-of-Flight?pof_list=archives&m=education. You might use this list to give you an idea or two for your topic.

Here are some of the common articles that we reject all the time, because we’ve published on these topics before:

- How to get a L1, L2, or L3 Cert
- Building cheap rockets and equipment (pads & controllers)
- How to 3D print parts, or a Rocket Kit
- How to Build a cheap Rocket Kit
- Getting Back Into Rocketry After a Long Hiatus

ARTICLE & IMAGES SUBMISSION

Articles may be submitted by emailing them to the editor. Article text can be provided in any standard word processor format, or as plain-text. Graphics should be sent in either a vector format (Adobe Illustrator, SVG, etc.) or a raster format (such as jpg or png) with a width of at least 600 pixels for single column images or 1200 pixels for two-column images. It is preferable for images to be simple enough to be readable in a two-column layout, but special layouts can be used.

Send the images separately via email as well as show where they go by placing them in the word processor document.

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Submitted articles will be evaluated against a rubric (available here on our website). All articles will be evaluated and the results will be sent to the author. In the evaluation process, our goal is to ensure the quality of the content in *Peak-of-Flight*, but we want to publish your article! Resubmission of articles that do not meet the required standard are heavily encouraged.

ORIGINALITY

All articles submitted to Peak-of-Flight must not run in another publication before inclusion in the *POF* newsletter, but it may be based on another work such as a prior article, R&D report, etc. After we have published and paid for an article, you are free to submit them to other publications.

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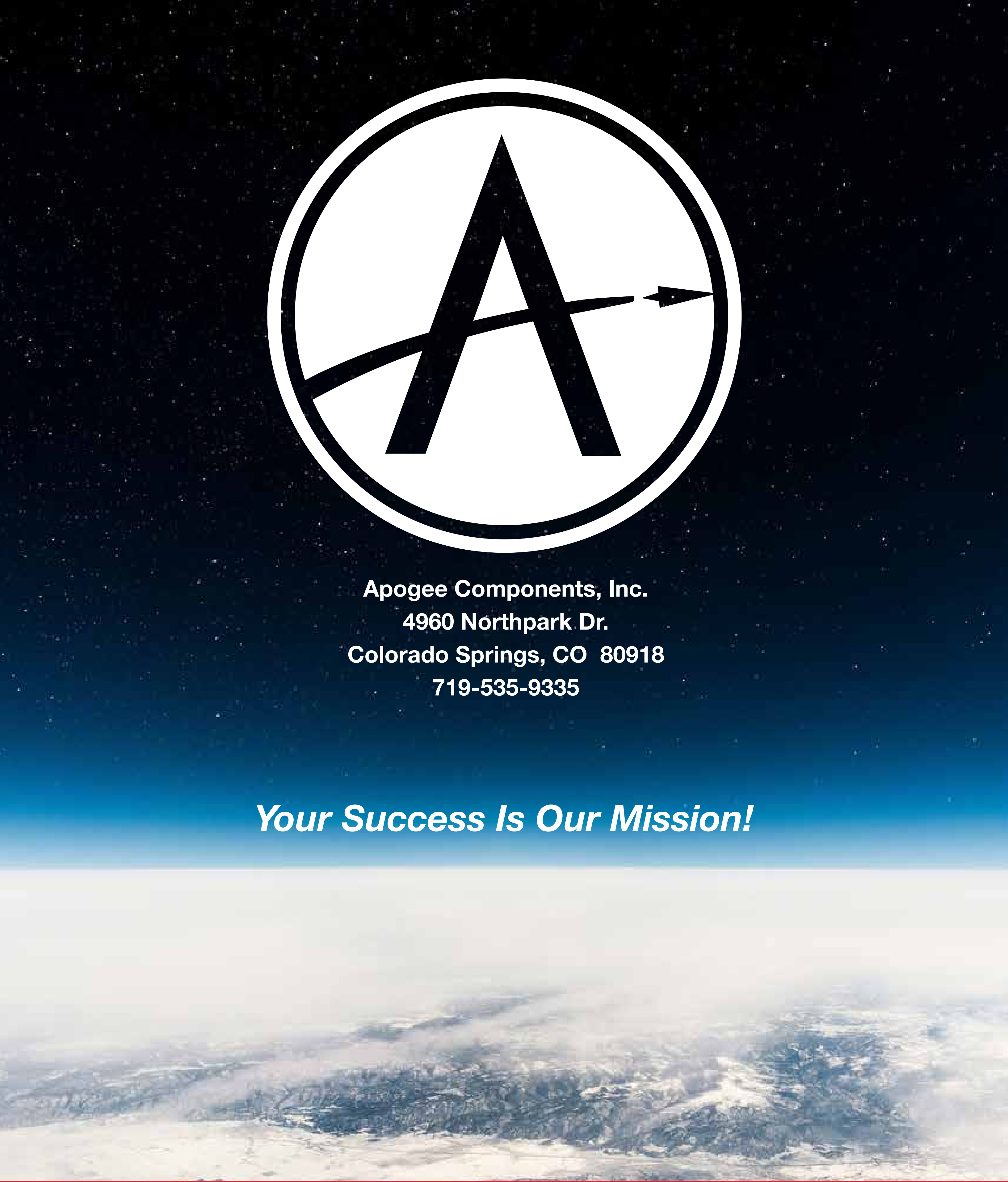

Apogee Components, Inc.
4960 Northpark Dr.
Colorado Springs, CO 80918
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