Issue 629 / July 2nd, 2024

PEAK OF FLIGHT NEWSLETTER

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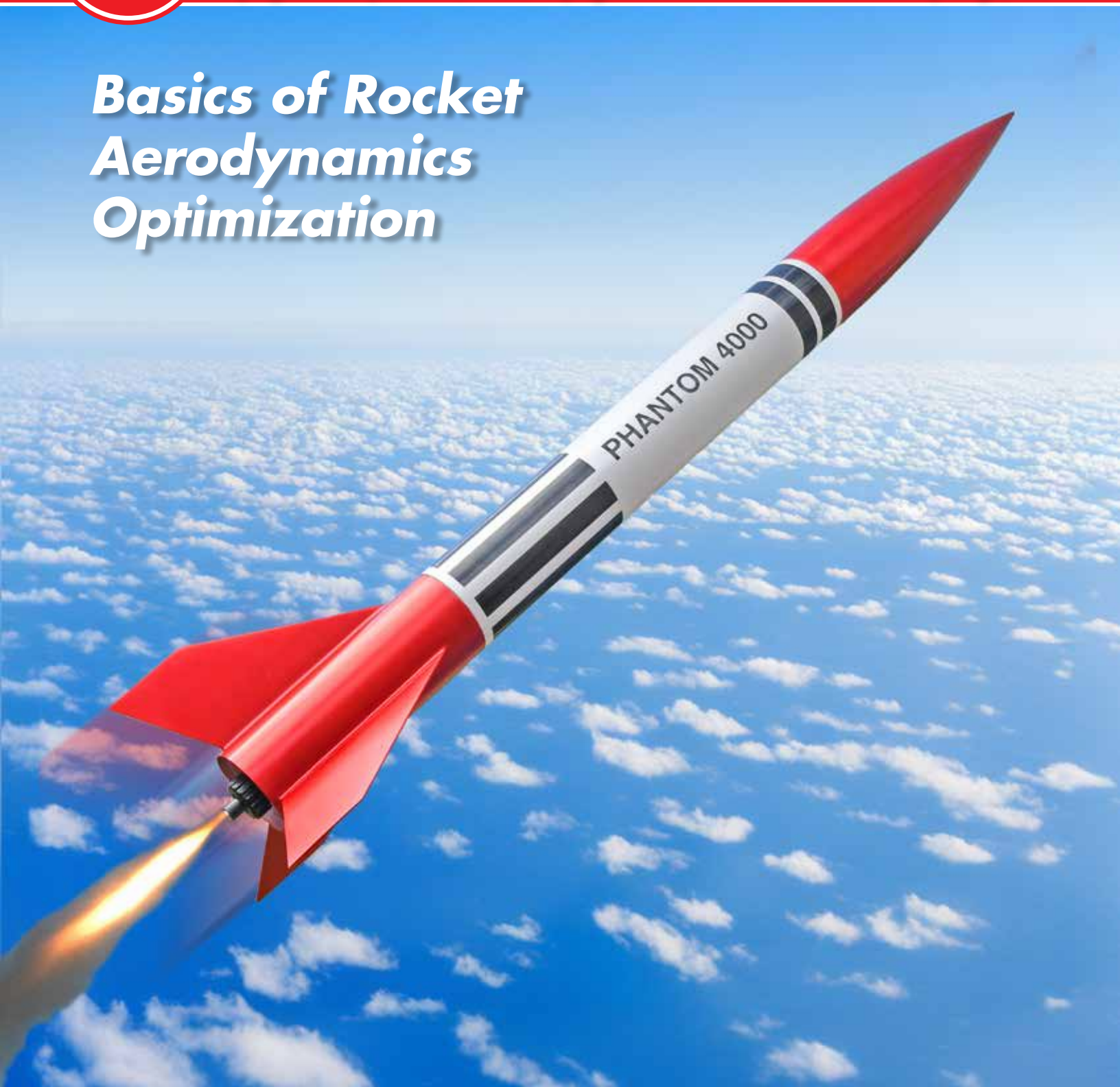
Basics of Rocket Aerodynamics Optimization



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COVER PHOTO

Phantom 4000

Discover the updated NCR Phantom 4000™, a classic model rocket kit featuring improved stability and durability with the new Gorilla Fin Lock™ design and Gorilla Shock Cord™ system. Standing at 51.5" tall and compatible with 29mm F & G class motors, this impressive rocket reaches altitudes of 1,500 feet.

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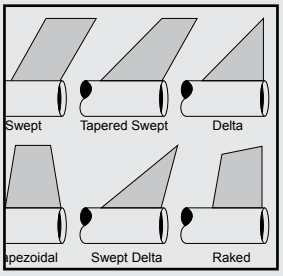

Basics of Rocket Aerodynamics Optimization

by Matthew Harkey

This article discusses the basics of aerodynamics in the context of model rocketry. It covers the importance of understanding drag, stability, and velocity to optimize rocket performance. It also explores the design and selection of fins, nose cones, and body tube configurations, providing insights into their impact on aerodynamics and stability. The article emphasizes the need to match the appropriate components to the rocket's size, desired stability, and aerodynamic efficiency.

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

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The Apogee Star-Lift Mega Lander roars skyward on an awesome white thunder rocket motor.

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Basics of Rocket Aerodynamics Optimization

by Matthew Harkey

{Ed. This article comes from a young rocketeer that is beginning his exploration of model rocketry, and how to make them fly higher. It covers some of the basics that you'll need to know to make higher performing models. If you want to go deeper, be sure to go through the bibliography at the end, which links to some of our more advanced articles on aerodynamics and stability.}

So you're building a model rocket and you are wondering, how can I improve its stability and efficiency? A great place to start is to consider the components that combine to improve your rocket's aerodynamics.

It is well known that aerodynamics plays a crucial role in minimizing drag and maximizing thrust so rockets can reach the highest apogee possible. But you may be wondering which parts contribute to what and which parts matter more than others?

Let's start with the most visible components: fins, nose cones, and body tube configurations. Fins are positioned along the bottom of a rocket to stabilize its flight. Nose cones help to streamline a rocket's geometry. Body tubes comprise the most surface area on your rocket. This article will help you get an idea of how to choose the right parts to improve the success of your model rocket launches!

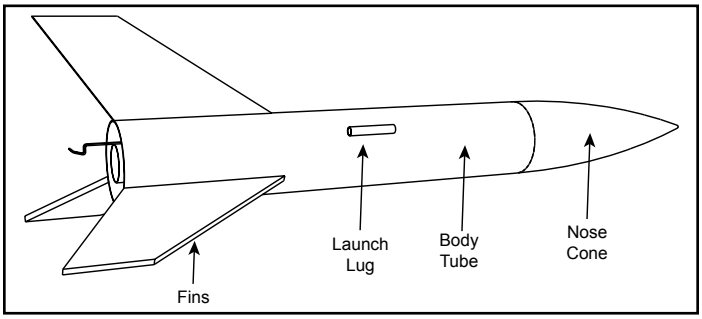


Figure 1: Diagram of the different parts of a rocket.

Being able to understand aerodynamics in the context of model rocketry is crucial for optimizing the performance and stability of your rockets during flight. One must familiarize themselves with drag, stability, and velocity concepts to better understand aerodynamics as a whole. Drag is the resistance of the air against a rocket's motion (see Figure 2), so minimizing drag allows your rocket to reach higher altitudes. Stability ensures that a rocket maintains a consistent trajectory, which is essential for achieving successful and more predictable launches. Once your rocket goes supersonic, additional complexities such as shock waves, boundary layer separation, and increased drag are introduced, which can also significantly impact aerodynamics. It is important to know that most aerodynamic enhancements aim to minimize drag and increase stability but may have limitations, especially at higher speeds.

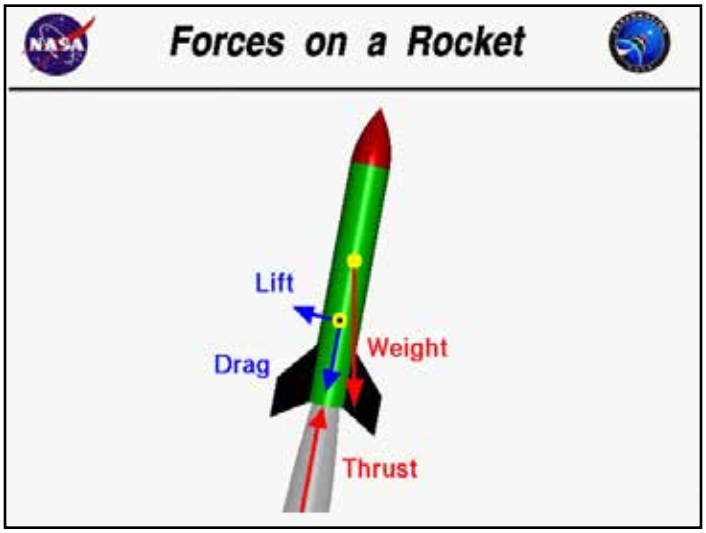
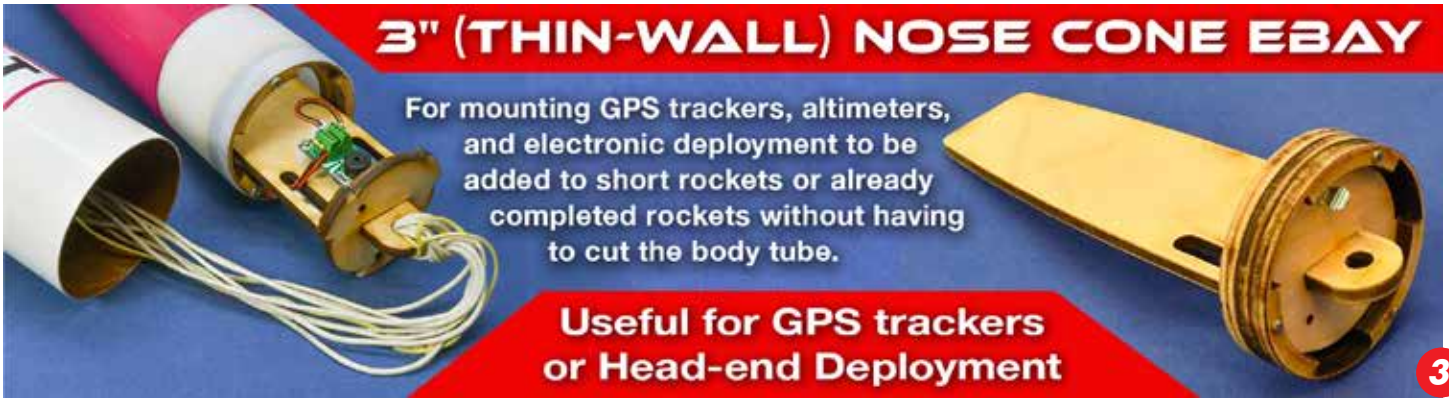


Figure 2: Forces on a Rocket (Source: https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/rocket-aerodynamics)



The design of a rocket's fins plays a major role in ensuring stability and minimizing drag during flight. Model rocket builders have explored unique fin shapes and configurations for decades to optimize performance. Each fin has its advantages and disadvantages, so it is very important to pick the right fin shape for your rocket. Theoretically, the elliptical fin offers the lowest induced drag for full-size rockets but may not be the ideal choice for smaller rockets due to difficulty in constructing them.

Parallelogram fins are easy to manufacture with consistent airfoil shapes. Compared to elliptical fins, they can be more effective at low Reynolds numbers but may have slightly higher induced drag.

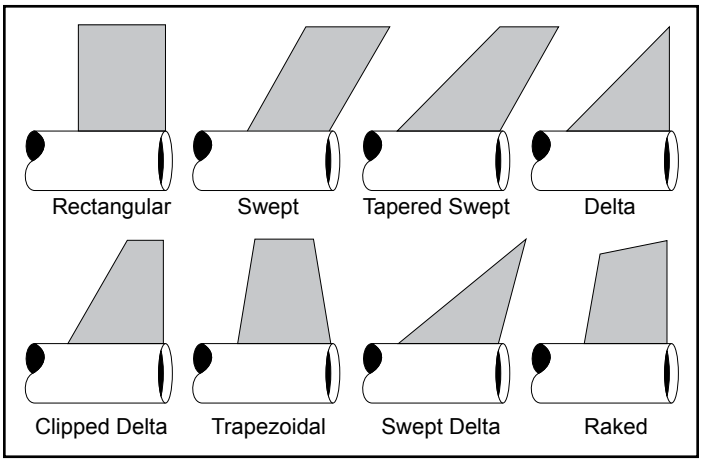


Figure 3: Different types of fin shapes.

Tapered swept tip fins are good for keeping a rocket lightweight and aerodynamic, but they offer less stability than other designs. The advantage of being lightweight is that a rocket's motor has less weight to push, so the rocket can accelerate at a faster speed.

Trapezoidal fins are a good choice for mid-sized rockets because they provide excellent stability but may be too bulky for smaller models. A good way to think about how stable a rocket's fins are is by looking at their width. Fins with more width are more stable, but also add weight to a rocket. Fins that are thinner are lighter, but can't counteract forces caused by turbulent airflow.

Similarly, clipped delta fins provide excellent stability but may not be as aerodynamic as other shapes for maximizing flight distance.

Tube fins are a very experimental design that can generate additional lift and stability, but their effectiveness decreases with longer rockets as they can create high drag due to the venturi effect and disrupted airflow. It is not recommended to use tube fins if you are new to model rocketry because they can severely impact the stability of your rocket.

The choice of fin shape for a model rocket depends on several factors, including the rocket's size, desired stability, and aerodynamic efficiency. In my opinion, parallelogram fins are the best for most small model rockets because of their high performance at low Reynolds numbers, providing sufficient stability without excessive drag.

Nose Cones

There are many types of nose cones in model rocketry, each with its advantages and disadvantages. For example, the parabolic/rounded nose is optimal for subsonic speeds (below Mach 0.8) as it minimizes drag to increase altitude. Unfortunately, this configuration performs less well at supersonic speeds due to wave drag. Wave drag is the formation of shockwaves around a rocket when it goes supersonic.

In contrast, the conical nose cone is relatively simple and inexpensive to manufacture. It performs reasonably well at transonic and supersonic speeds but is not optimized for

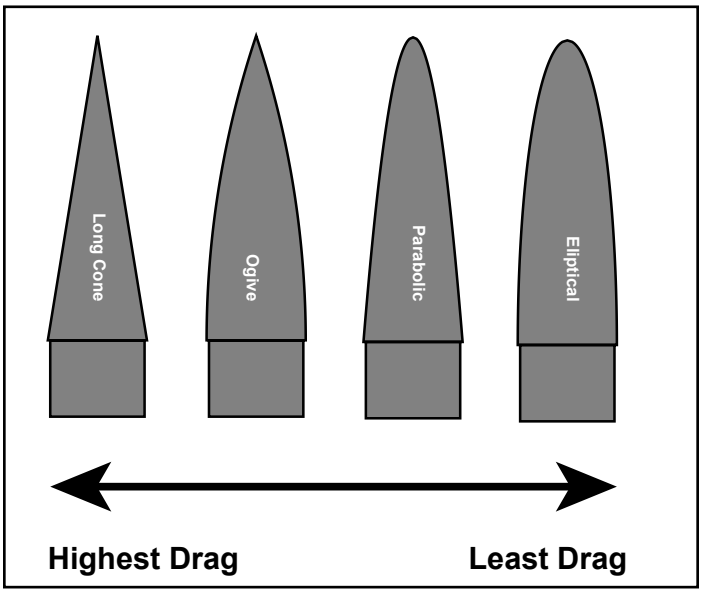


Figure 4: Common nose cone shapes

either.

Ogive nose cone performs very well at transonic and supersonic speeds. Ogive nose cones are more slender to decrease wave drag, which makes them great for providing more internal volume than a conical nose. It is more complex to manufacture than a conical nose, but many stores have them in stock. I would recommend the ones at Apogee because they are made with high quality materials and equipment.

Another nose cone is the Von Kármán Nose Cone, which was optimized for transonic speeds and significantly decreases drag in this range. Unfortunately, at high angles of attack, rockets with this nose cone can become unstable. This is because, at high angles of attack, the airflow around the rocket becomes more turbulent, increasing drag and causing unpredictable forces on the rocket's body. This, combined with a shift in the center of pressure, causes the Von Kármán nose cone to induce instability in a model rocket. Since it is pretty blunt, its performance decreases at supersonic and hypersonic speeds. Overall, choosing the right nose cone for your application is crucial to ensuring your rocket's stability and operation during flight.

Body Tubes

Although not as impactful as the other features, body tube configurations still influence aerodynamics and play a major role in determining stability. Determining the length of your body tube is challenging, but hopefully this will provide you with some insights.

Longer body tubes increase a rocket's moment of inertia, enhancing stability by resisting rotation during flight. Since they are longer, they provide more internal volume for payloads and recovery systems. This means that you can put flight computers with components such as cameras, altimeters and accelerometers to analyze your flight after retrieving your rocket. Another benefit is that they are more aesthetically appealing to some rocketeers because of their appearance. However, longer tubes add weight and generate more aerodynamic drag, which can negatively impact performance and stability.

Whereas, shorter body tubes offer reduced weight and lower drag, improving overall performance and making

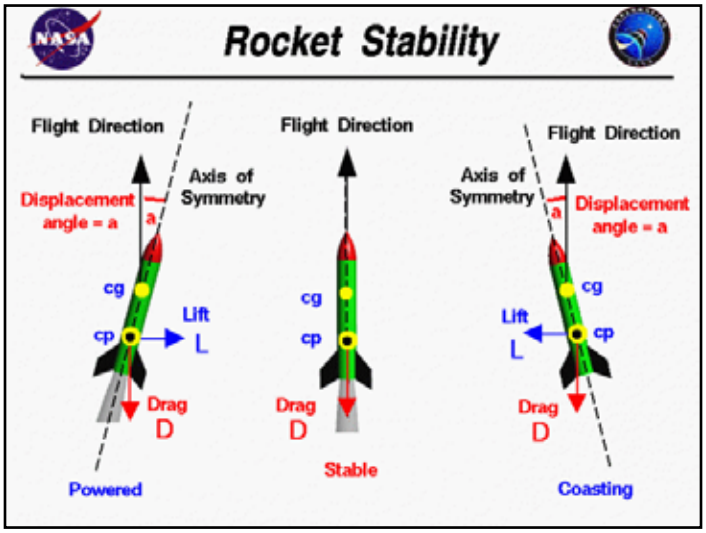


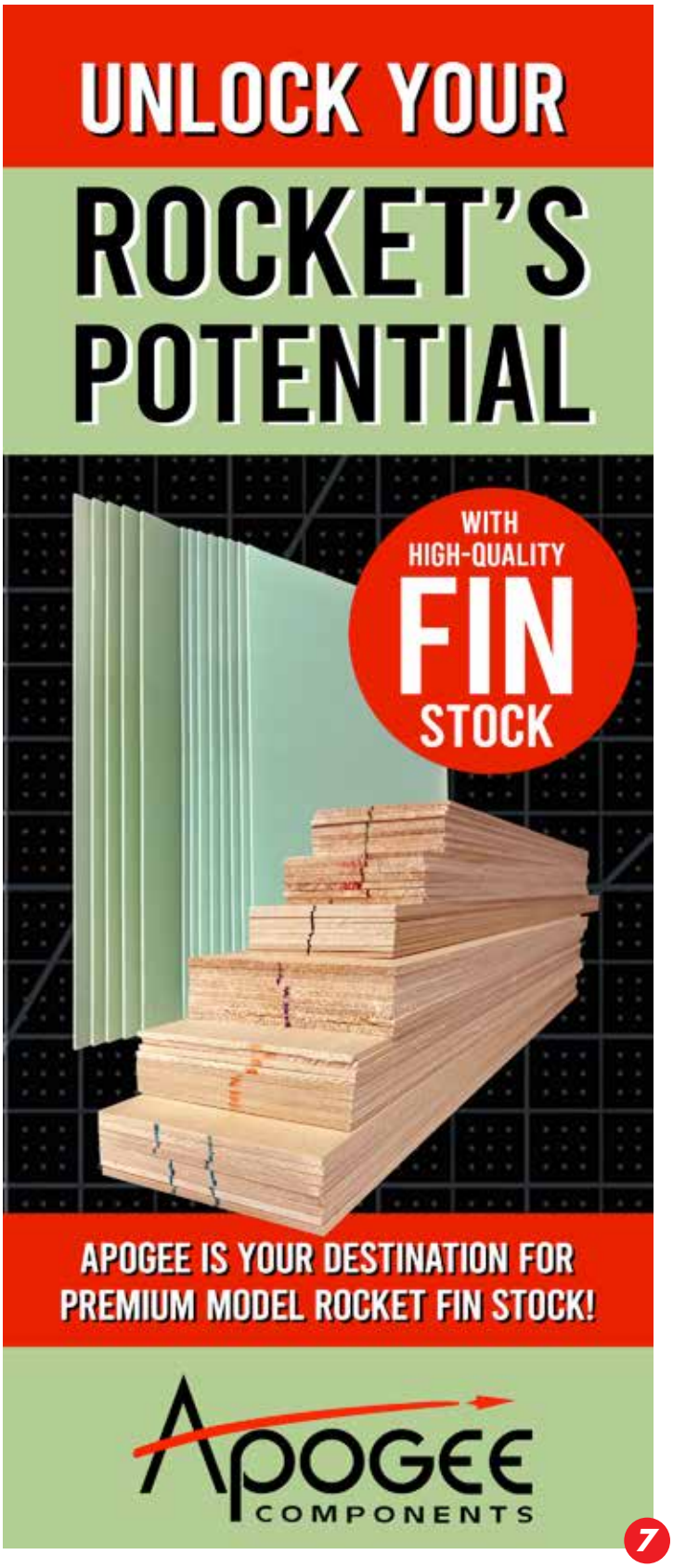
Figure 5: Stability of a model rocket (Source: https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/rocket-stability/)

construction simpler. These advantages allow rockets with shorter tubes to achieve higher altitudes with less powerful propulsion systems. However, the reduced moment of inertia decreases stability, making the rocket more susceptible to wind, rotation as well as perturbations that a rocket is exposed to at higher speeds. Additionally, the limited internal volume restricts space for payloads and recovery systems, which makes more complex systems such as dual deployment challenging. Another limitation of shorter body tubes is that increased speed doesn't help if your rocket is unstable.

Choosing the appropriate body tube configuration involves balancing these factors to meet your performance goals. Longer tubes are ideal for stability and payload capacity, while shorter tubes are preferred for higher performance and easier construction. Personally, I find longer body tubes to be better because they make stability and construction much easier.

Putting it all together

One commercial rocket that optimizes the shape of fins, a body tube, and a nose cone to maximize performance is the Apogee Aspire (https://www.apogeerockets.com/Rocket-Kits/Skill-Level-2-Model-Rocket-Kits/Aspire). This kit is incredibly efficient and can break the sound barrier for only 26 dollars. It has a long, slender body tube to increase stability at the supersonic speeds it reaches.



The fins are very swept and have a low aspect ratio to reduce drag compared to the traditional flat fins that other commercial model rockets use. It uses a plastic ogive nose cone to minimize wave drag at transonic and supersonic speeds. Overall, the Apogee Aspire is designed for reaching the maximum speed possible, which correlates to high altitudes. Its design features a long body tube, airfoiled fins, and a slender nose cone, all of which contribute to its optimized aerodynamic performance, allowing it to break the sound barrier with G Class and higher Motors. This rocket could be used for your L1 certification attempt, or you could just use an F-class motor that needs no license to purchase (you have to be over 18) and still reach over a mile in altitude which is very impressive for a small model rocket such as itself. Overall, this marvel of engineering is incredibly well-designed and is worth considering purchasing if you are interested in model rocketry.

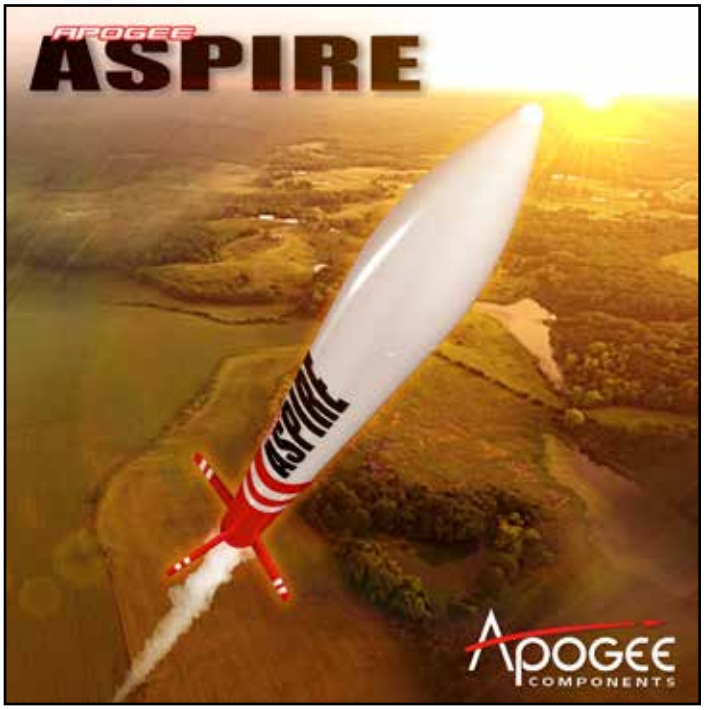


Figure 6: The high flying Apogee Aspire rocket is a good optimized rocket.

Designing an efficient and successful rocket requires careful consideration of various factors, including aspect ratio and fin dimensions. The height-to-width ratio, also known as the aspect ratio, determines the overall shape and aerodynamic characteristics of the rocket. A higher aspect ratio generally results in lower drag and better efficiency, while a lower ratio may result in greater stability but increased drag. For model rockets, an aspect ratio between 10:1 and

15:1 is considered optimal.

As discussed previously, fins are essential for stability and control during flight. Proper fin sizing is vital for optimal aerodynamic performance. On their website, UC Berkeley's competitive rocketry team provides a comprehensive tutorial on sizing fins, covering fin area, shape, and placement at: **https://rocketry.gitbook.io/public/tutorials/airframe/sizing-fins**. By following these guidelines, you can optimize fin dimensions for your desired stability and control.

To simulate rocket designs to estimate their performance, RockSim (**https://www.apogeerockets.com/RockSim/RockSim_Information**) is very helpful. RockSim is a powerful rocket design and simulation software that allows users to model and analyze various aspects of their designs. By following the tutorials and guides on the RockSim website (**https://www.apogeerockets.com/RockSim/RockSim_Video_Tutorials**) as well as the live tutorials (**https://www.apogeerockets.com/RS-Live-Training**) hosted by Tim Van Milligan on YouTube, one can easily utilize the software to simulate and iterate upon their rocket designs, taking into account factors such as aerodynamics, stability, and thrust. Utilizing these tools can be crucial for achieving

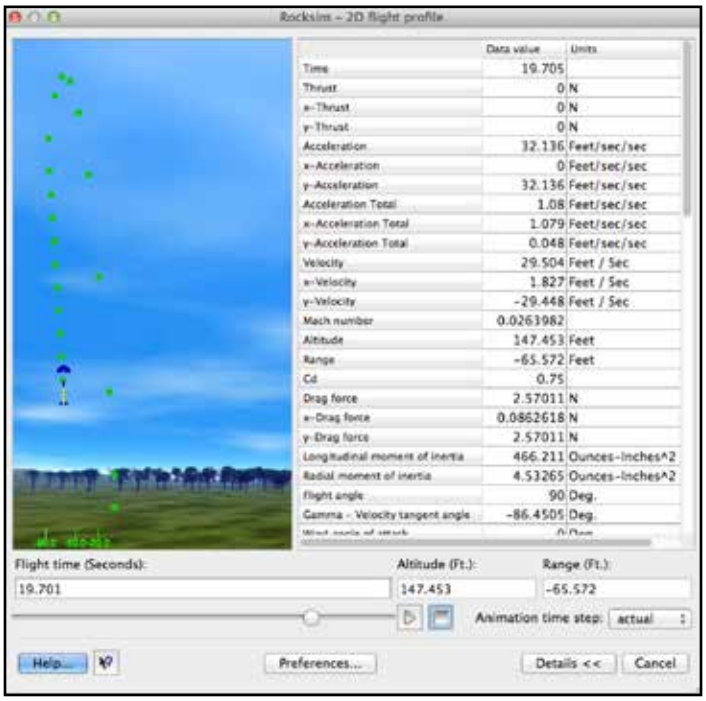
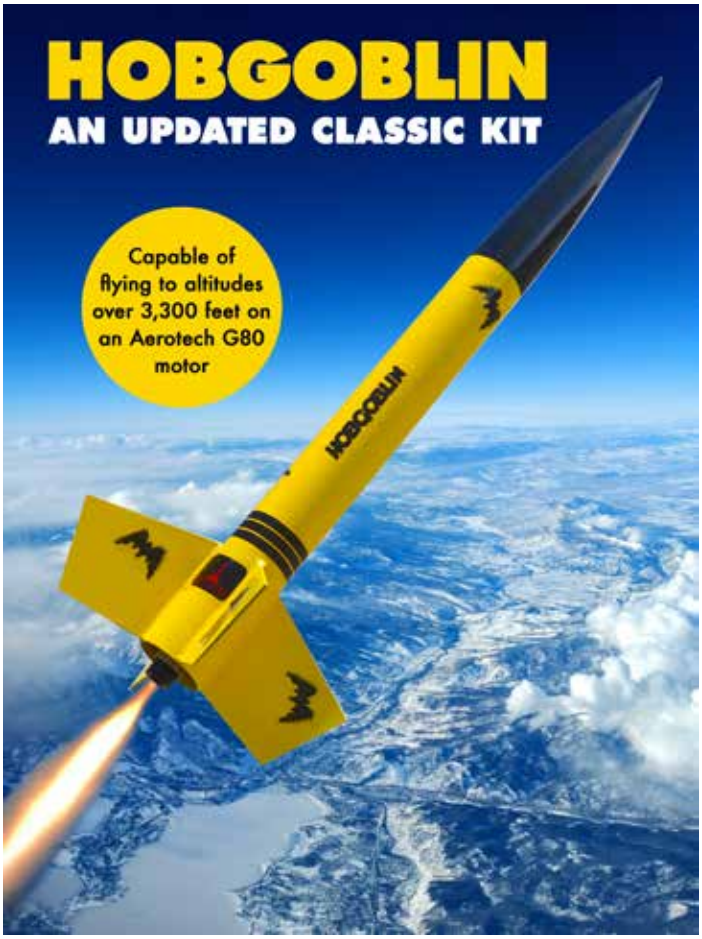


Figure 7: Screen shot of a RockSim simulation.

aerodynamic efficiency and ensuring the stability of your rocket. This can save you time and money if your design could be more stable. Accurate modeling and analysis of design parameters ensures that your rocket has optimal shape, fin dimensions, and overall configuration for maximum performance and stability. It is very important to get an idea of how stable your rocket is going to be during flight regardless of whether you are launching an experimental rocket or not.



Conclusion

Understanding and optimizing aerodynamics can have a significant impact on performance and stability in model rocketry. Key elements such as fins, nose cones, and body tube configurations greatly influence a rocket's aerodynamic efficiency. Fins stabilize flight, nose cones minimize drag, and body tubes balance stability and performance. Choosing the right fin shape and nose cone design depends on the rocket's size and desired speed, while body tube length affects stability and payload capacity. The Apogee Aspire serves as a prime example of a commercially available rocket optimized for aerodynamic performance. Utilizing tools like RockSim can aid in designing and refining rocket configurations, ensuring aerodynamic efficiency and stability. By mastering these aspects, rocket enthusiasts can achieve successful launches and reach impressive altitudes!

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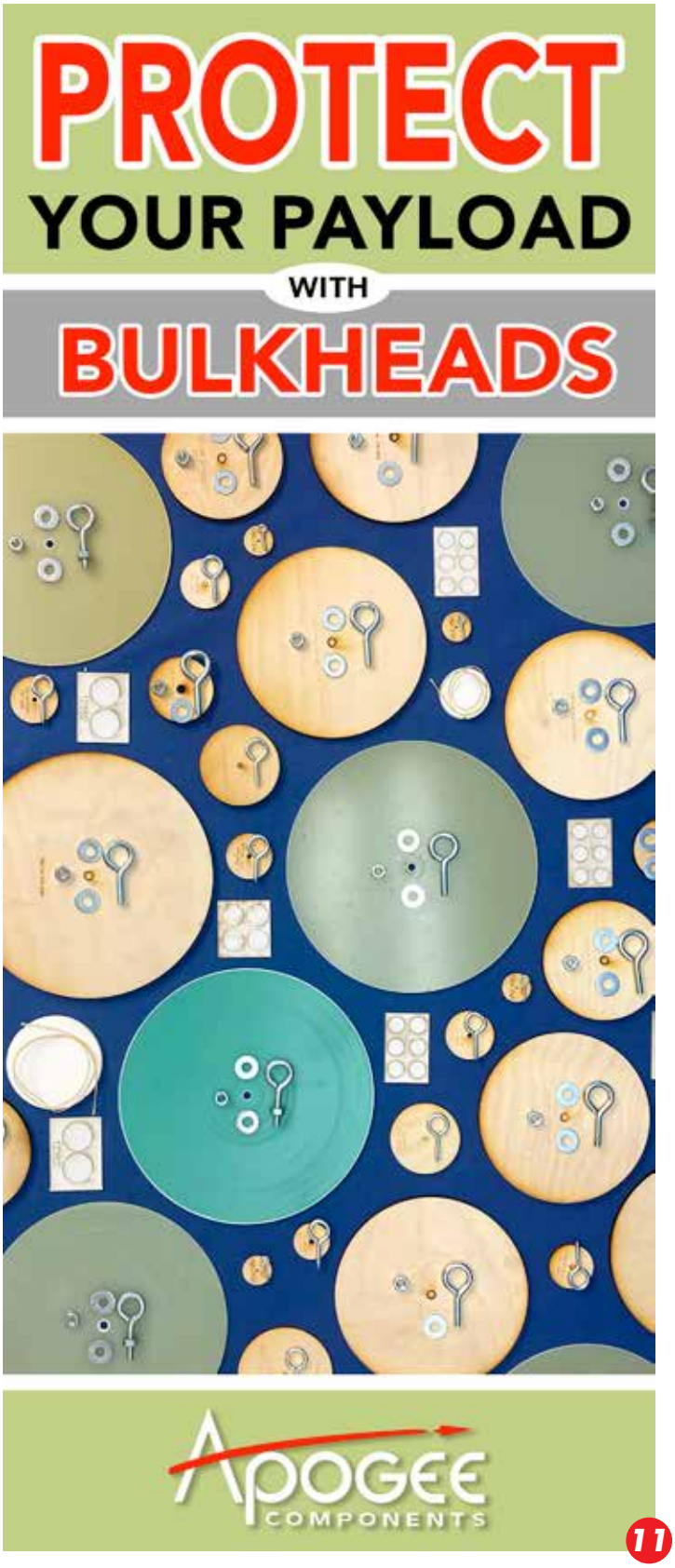
About The Author:

Matthew Harkey was born in San Francisco and currently attends high school in the Bay Area. Driven by curiosity, Matt has developed a strong passion for 3D modeling and printing, model rocketry, and robotics. He is currently working towards achieving his Junior Level 1 certification in model rocketry, allowing him to launch even bigger rockets. His curiosity drives him to explore new technologies and learn more about them.



SUBMITTING ARTICLES TO APOGEE

We are always looking for quality articles to publish in the *Peak-of-Flight* newsletter. Please submit the "idea" first before you write your article. It will need to be approved first.

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 nice 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 more common articles that we reject all the time, because we've published on these topics before:

- How to get a L1 Cert
- How to get an L2 or L3 Cert
- Building cheap rockets
- How to 3D print parts
- Building Low Cost Launch Equipment (pads and controllers)
- Getting Back Into Rocketry After a Long Hiatus
- How to Build a Rocket Kit
- How to Build a Computer (too technical)

ARTICLE & IMAGES SUBMISSION

Articles may be submitted by emailing them to the editor. Article text can be provided in any standard word processor format (MS Word, Libre Office, etc.) or as plain-text. Graphics, meanwhile, should be provided 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 a width of 1200 pixels for two-column images. If possible, it is generally preferable for images to be simple enough to be readable in a two-column layout, but special layouts can use the whole page width if required.

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

ACCEPTANCE

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 have been run in another publication before inclusion in the *Peak-of-Flight* newsletter, but it may be based on another work such as a prior article, R&D report, project report, etc. After we have published and paid for an article, you are free to submit them to other publications.

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WHERE WILL IT APPEAR?

These articles will mainly be published in our free newsletter, *Peak-of-Flight*. Occasionally some of the higher-quality articles could potentially appear in one of Tim Van Milligan's books that he publishes from time to time.

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