Issue 625 / May 7th, 2024

PEAK OF FLIGHT NEWSLETTER

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

What Happened to the "Maximum Recommended Lift Off Weight"?

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COVER PHOTO

Heli-Roc

Slow descending helicopter; it seems to float in the sky. Great for competition flights for the helicopter-duration event, or just for WOW-ing your friends.

FEATURED ARTICLE

What Happened to the "Maximum Recommended Lift Off Weight"?

by Tim Van Milligan

This article discusses the historical context and limitations of maximum recommended lift-off weight values provided by rocket motor manufacturers and proposes a more comprehensive approach for determining maximum lift-off weight.

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About this Newsletter

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

Editor-in-Chief: Tim Van Milligan
Managing Editor: Michelle Mason
Content Editor: Martin Jay McKee
Layout Design: Ryan M. Conway

The Hiroc launching in Pueblo, Colorado on 04/21/2024

Martin Jay McKee

Would you like to see your launch photo featured in the ***Peak-of-Flight*** newsletter? Submit your photo at apogeerockets.com.

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What Happened to the "Maximum Recommended Lift Off Weight"?

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Decades ago, the motor manufacturers used to provide a "value" telling the maximum lift-off weight a rocket motor could handle. Old timers in rocketry still remember those values in the motor charts, and wondered where they disappeared to. In this article, I'll tell you why I don't use them, and how they've been replaced.

The reason I don't use any maximum recommended lift off weights is simple: they never accounted for the size/shape of the rocket nor the launch conditions that you may have on the day you're out on the rocket range. And it is those conditions that have a dramatic effect on the flight of the rocket.

In reality, the old charts assumed perfect conditions. They assumed that there was zero wind, and the rocket was always launched straight up. Furthermore, they assumed that the wind wouldn't affect the rocket's flight, and that the rocket would always be stable.

In essence, there really wasn't any rigorous testing of the motor to see how much it could really lift safely. And in the absence of reliable data, the motor manufacturers were faced with a dilemma.

At the core, here is what was going on. The motor manufacturers knew that customers wanted to achieve what customers called: "A slow, REALISTIC lift-off." They wanted to have their rockets take off just like the Saturn V rocket, which they saw on their TV's when they were a little kid. They did not realize that the video was almost always played in slow-motion, so it would look like it took off from the pad slower than it actually did. In actuality, the speed at which the Saturn V reached, as it cleared its launch tower (23 m/s), is about the same as a model rocket - (https://spacemath.gsfc.nasa.gov/weekly/8Page2.pdf).

Regardless of the perception or illusion of visual speed, how does a modeler slow their rocket down at launch? The easy answer is to add a lot of mass to the rocket so that it can't take off fast.

The problem that the manufacturer's faced is that their customers would load up the weight of the rocket so much in order to achieve that "REALISTIC" lift-off, that the rockets would go unstable. If the rocket would go unstable, then the manufacturer would have their own perception problem. They didn't want the general public to get the impression that model rocketry was unsafe because they were going unstable because customers wanted that slow lift-off.

Therefore, what they did was to try to limit how much mass customers would put in their rockets by giving them a number for the maximum weight of a rocket engine.

The problem didn't go away, however. Modelers just got more sly about it. In addition to loading up the rocket to what the manufacturer said was the maximum weight, they also made the rocket high drag (by making it bigger in diameter). The effect was to slow the rocket down even more, making it again unstable.

And how exactly, did the manufacturers come up with the maximum lift-off weight of the motor? No one really knows for sure. The most likely method is that they used a minimum thrust-to-weight ratio for the rocket.

As everyone knows, the thrust of the rocket motor must be greater than the weight of the rocket in order for it to leave the pad. The higher the thrust of the motor, the faster the rocket will accelerate off the pad. If the rocket has the same thrust as its weight, it will just sit on the pad. The thrust must be greater than the weight of the rocket.

The general rule of thumb that modelers used for a long time is that the maximum thrust should be at least five times the weight of the rocket. That is my guess as to what most manufacturers used when they came up with a number for the maximum recommended lift-off weight.

However, the thrust curve of a typical rocket engine varies over the duration of its burn. It may start at a high level with an initial spike, but then drop off quickly like an Estes Black Powder propellant motor. The question you have to ask is where (time-wise) do you make the comparison of the thrust to the weight of the rocket? We talked about this issue in Peak-of-Flight Newsletter #622 (**https://www.apogeerockets.com/Peak-of-Flight/Newsletter622#thrust-to-weight**).

And if you think about it, if the thrust curve of the rocket is more flat, without a high initial spike, then a thrust-to-weight ratio of at least 5 might be overkill. This is the case of a lot of Aerotech composite propellant rocket motors.

When did Things Change?

It was very soon after Rocksim was released in 1996 that I stopped looking at the manufacturer's maximum recommended lift-off weight numbers. I quickly realized that with Rocksim, I could better determine if the lift-off weight for my rocket was too heavy.

At that point I started to tell people to stop looking at that inaccurate number the manufacturers were giving. Fortunately, a lot of people listened, most importantly the "motor manufacturers" did too. They stopped putting out a number for the maximum recommended lift-off weight.

I know this approach of using RockSim doesn't sit well with a lot of old timers in the hobby, because it does involve a little bit of work. Especially compared to the simplicity of just looking up a number, it is more effort. But I'm hoping that they'll come around eventually.

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How to Find the Maximum Lift-off Weight?

First of all, MRLOW is not just about the "motor." It is critical to note that there are three main variables that have to be taken into account:

1. The rocket itself (length, diameter, CP/CG relationship, fin size)
2. The weather conditions
3. The thrust curve of the motor

Therefore, since it is a complex situation, we're going to define a process for finding the maximum lift-off weight. It is not a simple equation, because you have to define a successful flight up front.

Let's start by defining what is acceptable for the launch from a safety point of view.

First of all, we'll say that the rocket has to be pointed straight up at launch. I know that the NAR safety code (https://www.nar.org/safety-information/model-rocket-safety-code/) allows you to angle the rocket up to 30° from vertical.

What happens when a rocket is launched straight up, while a wind is blowing across the field, is that the rocket will turn into wind. This is called "weathercocking," as every rocketeer knows. This is normal, and actually a good sign that the rocket is stable. We want the rocket to be stable, because that makes its flight predictable.

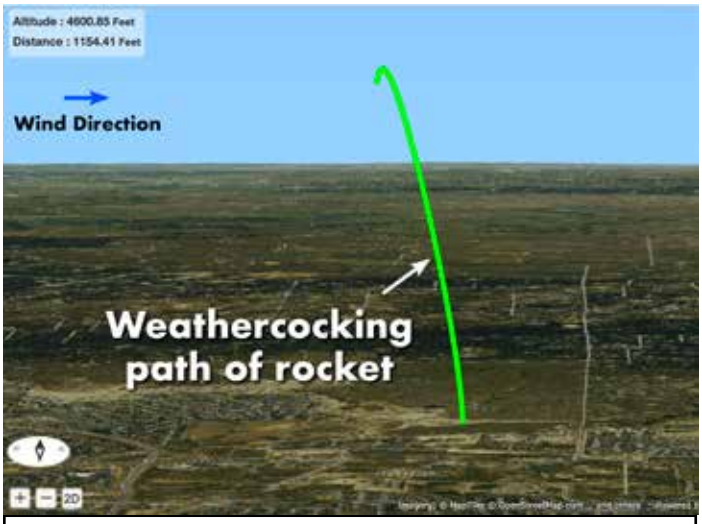

Figure 1: The classic trajectory curve of a rocket that is weathercocking (turning into the wind). It indicates that our model is stable and predictable.

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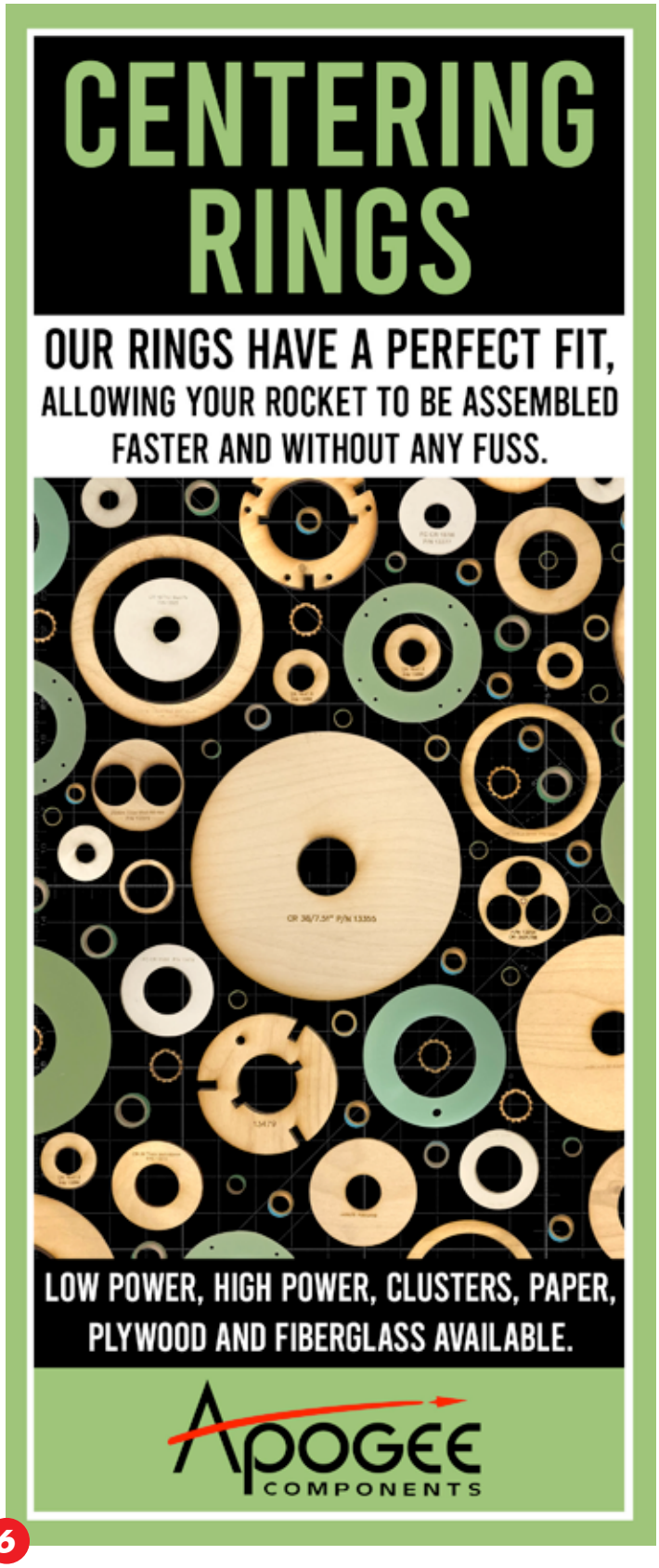

Most rocketeers, if there is a wind blowing, will angle the rocket into the wind. Why? Because this will make it land closer to the pad. Who wants to walk to retrieve your rocket? I totally get why they do this.

But actually, if you were to launch a heavier rocket, you should point the rocket down-wind, not into the wind (see Figure 2). There is a reason for this, which is that the rocket will fly more upward because it will turn into the wind. However, I've almost never seen anyone angle their rocket away from the direction the wind is blowing. It isn't intuitive, and may be something that you forget about if you were trying for that "slow realistic" lift-off of a heavy weight rocket.

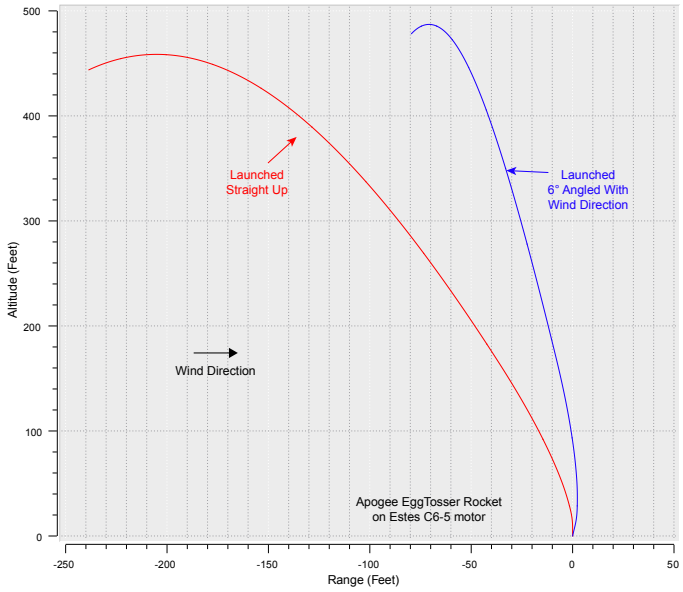

Figure 2 - By angling the launch rod with the direction of the wind, we can get a straighter flight. The downside is the rocket will drift further away.

So by defining our rules that the rocket has to be launched straight up, we're actually increasing the safety of the trajectory. That will give us more margin-of-error just in case our process isn't perfect.

Our second safety criteria is that the rocket's apogee (the highest point in the trajectory) must be within the "weathercocking cone" defined in RockSim.

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People ask us all the time if their rocket is weathercocking too much because the rocket is overstable. So we built a very simple visual tool into RockSim called the "weathercocking cone."

This imaginary cone concept was first devised by Trip Barber (a previous president of the NAR), and then we integrated it into RockSim because it was such a brilliant idea. The "weathercocking cone" is an imaginary cone of 40° projected up vertically from the launch pad. As long as the "apogee point" of the flight stays within that cone, the weathercocking of the rocket is acceptable. If the apogee point is outside the cone, the rocket has weathercocked (arc over) too far, and the rocket shouldn't be flown with the motor or the weather conditions listed. In RockSim, you'll see the weathercocking cone show up in the 2D flight profile screen.

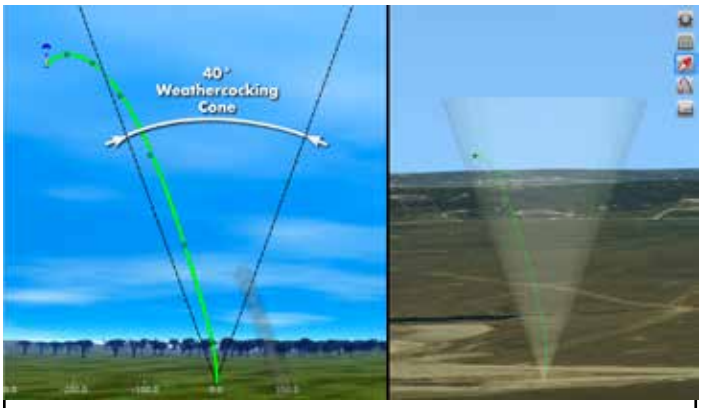

Figure 3 - The Weathercocking cone can tell us if the rocket has arced over too much. Rocksim screen shown on left, and the 3D version of RS-PRO screen shown on right side.

The third criteria is that the deployment speed of the rocket must be under 50 mph. We chose this because we want the parachute (or whatever recovery device we use) to survive the deployment. This criteria limits us to how strong your rocket and the parachute are. And I'm sure you could make a bulletproof rocket that could survive a deployment that is a lot higher than that speed. But for most normal rockets, this maximum speed of 50 mph is a reasonable compromise.

The deployment speed is going to be dependent on the ejection delay of the rocket motor. The heavier and slower the rocket flies, the shorter the ejection delay you'll need for your rocket. For example, for a heavier rocket, you'd use a C6-3 motor rather than a C6-5 motor because the rocket will reach apogee sooner in the flight. You always want to deploy near apogee because that is the slowest point in the trajectory.

This indicates to us that the maximum weight a rocket motor can lift is dependent on the delay. A shorter delay motor will allow us to make the rocket heavier.

Our fourth criteria is that there is a minimum lift-off speed that the rocket has to reach. Now this is the hardest variable to figure out, because it is the one that we want to optimize for in order to get the lowest lift-off speed. The goal of many modelers is to get the slowest lift-off speed possible.

What is the slowest speed the rocket can leave the launch pad, and still put the apogee point of the trajectory in the weathercocking cone? I can tell you it depends on the size of the fins and the CG/CP relationship.

The fins create the restoring force that keeps the rocket flying a stable trajectory. If the fins are too small, the restoring force isn't going to be enough to overcome the disturbing forces acting on a rocket (like a gust of wind hitting from the side). The way to make the rocket have

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enough restoring force is either to fly faster (so more air flows over the fins to create a lift force) or to make the fins bigger. So there will be a minimum speed for every rocket. And it depends upon the rocket itself.

Additionally, it depends on the wind force trying to turn the rocket. The slower the wind speed, the less restoring force is needed from the fins. Unfortunately, you can't assume perfect conditions where there aren't any wind forces acting on the rocket. Why? Because you can never predict when a gust of wind is going to pop up. It is better to design for the worst case situation, and use that for the basis of your algorithm. I personally like to use a wind speed of 8mph during my simulations, because that gives me some margin for error.

So assuming some wind blowing past the rocket, how do you find that minimum speed where the fins become effective? That is the million-dollar question that everyone has.

But we do have decades of experience flying rockets to make a "rule-of-thumb" for the minimum lift-off speed. The general consensus is that most rockets with a stability margin of greater than 1.0, that leave the launch rod going between 30-50 feet/sec (9-15 m/s), are going to fly OK {reference: https://www.rocketryforum.com/threads/minimum-liftoff-velocity-or-velocity-off-rod.68514/}.

Unfortunately, 30 feet/sec still seems lightning fast, and isn't that "slow realistic speed" that everyone wants.

We wish there was a better way to calculate the minimum lift-off speed of a rocket than to use 30mph, but no one has come up with an easy way to calculate it yet. If you have ideas, we'd love to hear them.

Another rule-of-thumb is never let the air flowing over the fins exceed a 12° angle-of-attack (see Figure 4). For most airfoils, if the angle-of-attack exceeds about 12°, the

airflow separates and creates what is called a "stall." At that point, the fins don't produce any lift force to correct the rocket should a gust of wind hit it from the side.

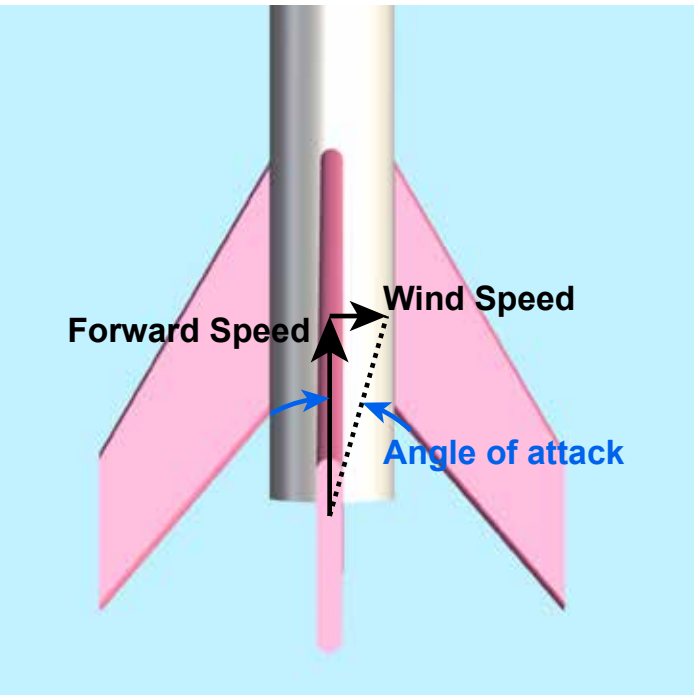

Figure 4: The angle-of-attack defined for a single fin. This angle-of-attack shouldn't exceed 12° or the fin will stall.

It is possible to plot out the wind angle of attack in RockSim, as shown in figure 5. But, we could simplify this angle-of-attack situation by following what is called the "20% rule". We would state it as: "The wind speed blowing across the rocket must be less than 20% of the lift-off speed of the rocket."

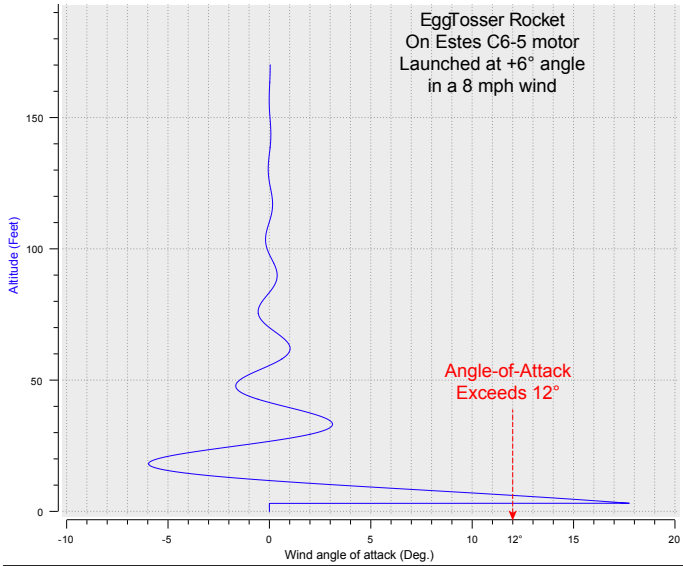

Figure 5 - A plot of angle-of-attack versus altitude. Here the rocket's fins are at such a high angle of attack, that a stall is possible.

Let's say for example, say the wind speed is 5 mph. The minimum lift-off speed for the rocket then must be at least 25 mph. (5 mph / 0.2 = 25 mph). The downside of this, is that someone could make the fins very tiny which reduces their effectiveness. Small fins on a rocket that is flying very slow aren't going to produce enough lift to correct the rocket.

This means it comes back to the size of the fins and the distance between the Center-of-Gravity (CG) and the Center-of-Pressure (CP).

At this point, let's run some simulations in RockSim and see how heavy we can make the rocket (which reduces the lift-of-speed), and see if the rocket meets

our other criteria of having the apogee point inside the weathercocking cone, with it launched straight up in a 5 mph wind. For this simulation, I used the Apogee Kronos rocket kit (see figure 6).

Figure 6 - Kronos rocket as seen in RS-PRO.

Before adding weight to the rocket, I looked at the static margin, which is the relationship distance of the CG and CP. To make an apples-to-apples comparison, I had to move the weight around in the rocket to keep the static margin the same. For this first run of simulations, the static margin was 2.48.

From Figure 7, the baseline weight of the Kronos rocket was 687.5 grams. When launched on a F20W-4 motor, it reached an altitude of 696.72 feet. Everything looks great, with the apogee point within the weathercocking cone, and a deployment speed of 21.97 ft/sec (14.98mph). It was actually deploying on the upward portion of the trajectory, so that is also a good sign that I can add a lot more mass to the rocket.

KRONOS Rocket lift-off speeds at various weights. The Static Margin is held constant at 2.48

Sim#	Engines loaded	Thrust to weight ratio at launch guide departure	Altitude at deployment Feet	Max. altitude Feet	Max. velocity Feet / Sec	Velocity at deployment Feet / Sec	Velocity at launch guide departure Feet / Sec	Comments
0	[F20W-4]	6.52	696.18	696.72	193.89	21.97	42.73	687.5g Margin 2.48 CG 34.2256
1	[F20W-4]	5.14	492.77	495.57	147.30	19.35	36.71	800g Margin 2.48 empty CG 32.3221
2	[F20W-4]	4.61	401.86	411.75	128.33	24.05	34.33	900g Margin 2.48 empty CG 32.94
3	[F20W-4]	4.18	320.89	342.41	112.46	34.16	32.20	1000g Margin 2.48 empty CG 33.05
4	[F20W-4]	3.82	248.99	286.04	99.25	45.37	30.26	1100g Margin 2.48 empty CG 33.16
5	[F20W-4]	3.53	183.77	239.84	88.33	57.11	28.58	1200g Margin 2.48 empty CG 33.24

Figure 7 - The Kronos Rocket simmed with different lift-off mass, but with a fixed CG point, the apogee of each flight was within the weathercocking cone.

KRONOS lift-off Speeds at variable CG Location

Sim#	Engines loaded	Thrust to weight ratio at launch guide departure	Altitude at deployment Feet	Max. altitude Feet	Max. velocity Feet / Sec	Velocity at deployment Feet / Sec	Velocity at launch guide departure Feet / Sec	Comments
6	[F20W-4]	5.71	577.80	577.86	166.62	23.79	39.19	787.57 g Margin 3.79 empty CG 34.1806
7	[F20W-4]	5.06	474.26	477.52	144.30	28.22	36.36	887.57 g Margin 4.81 CG 27.2458
8	[F20W-4]	4.55	383.85	394.78	125.73	35.17	34.04	987.57 g Margin 5.62 CG 24.81
9	[F20W-4]	4.13	304.93	327.18	110.05	43.85	31.95	1087.57 g Margin 6.28 CG 22.8331
10	[F20W-4]	3.78	235.59	272.52	96.66	52.78	30.05	1187.57 g Margin 6.83 CG 21.1841

Figure 8: The Kronos rocket loaded up with nose weight. All these flights stayed within the weathercocking cone.

As you can see in the chart of Figure 7, I stopped at 1200 grams lift-off mass for the rocket. At that point, my velocity at deployment was about 39 mph, and the altitude was only 183.7 feet in the sky. Lift off velocity was at 28.5 feet/sec. Personally, I'd be getting uncomfortable to add any more weight even though the apogee point was still within the weathercocking cone.

In my second simulation experiment, I allowed the CG to float. In other words, if I was going to add weight, I'd probably add more mass to the nose cone. This will make the rocket more overstable, and should affect the weathercocking. What I did was add nose weight to the rocket in 100 gram increments. In Figure 8, you see that the rocket doesn't quite fly so high, so it is weathercocking a little more. But no matter what the weight, this particular rocket doesn't seem to weathercock a lot, as its apogee point is always within the weathercocking cone in the 2D flight profile.

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Conclusion

In this article, we explored the complex interplay of various factors that influence the successful launch and flight of a model rocket. We introduced the concept of the "weathercocking cone" as a visual tool to assess the acceptable range of apogee points for a rocket's trajectory. Additionally, we discussed the criteria for deployment speed, lift-off speed, and angle-of-attack. Finally, we provided some rule-of-thumb guidelines based on decades of rocketry experience to help modelers determine the minimum lift-off speed and avoid stalls during flight.

Understanding these factors and applying them effectively can significantly improve the chances of a successful rocket launch. While there may not be a one-size-fits-all solution, our aim is to provide modelers with a framework to make informed decisions about their rocket designs and launch conditions. By continually refining our understanding of rocket dynamics and using tools like RockSim, we can push the boundaries of model rocketry and achieve new heights while maintaining safety.

About The Author:

Tim Van Milligan (a.k.a. "Mr. Rocket") is a real rocket scientist who likes helping out other rocketeers. He is an avid rocketry competitor and is Level 3 high power certified. He is often asked what is the biggest rocket he's ever launched. His answer is that 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 an 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 also the author of the books: Model Rocket Design and Construction, 69 Simple Science Fair Projects with Model Rockets: Aeronautics and publisher of the "Peak-of-Flight" newsletter, a FREE ezine newsletter about model rockets. You can email him by using the contact form at https://www.apogeerockets.com/Contact.

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Article Submission Guidelines
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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.

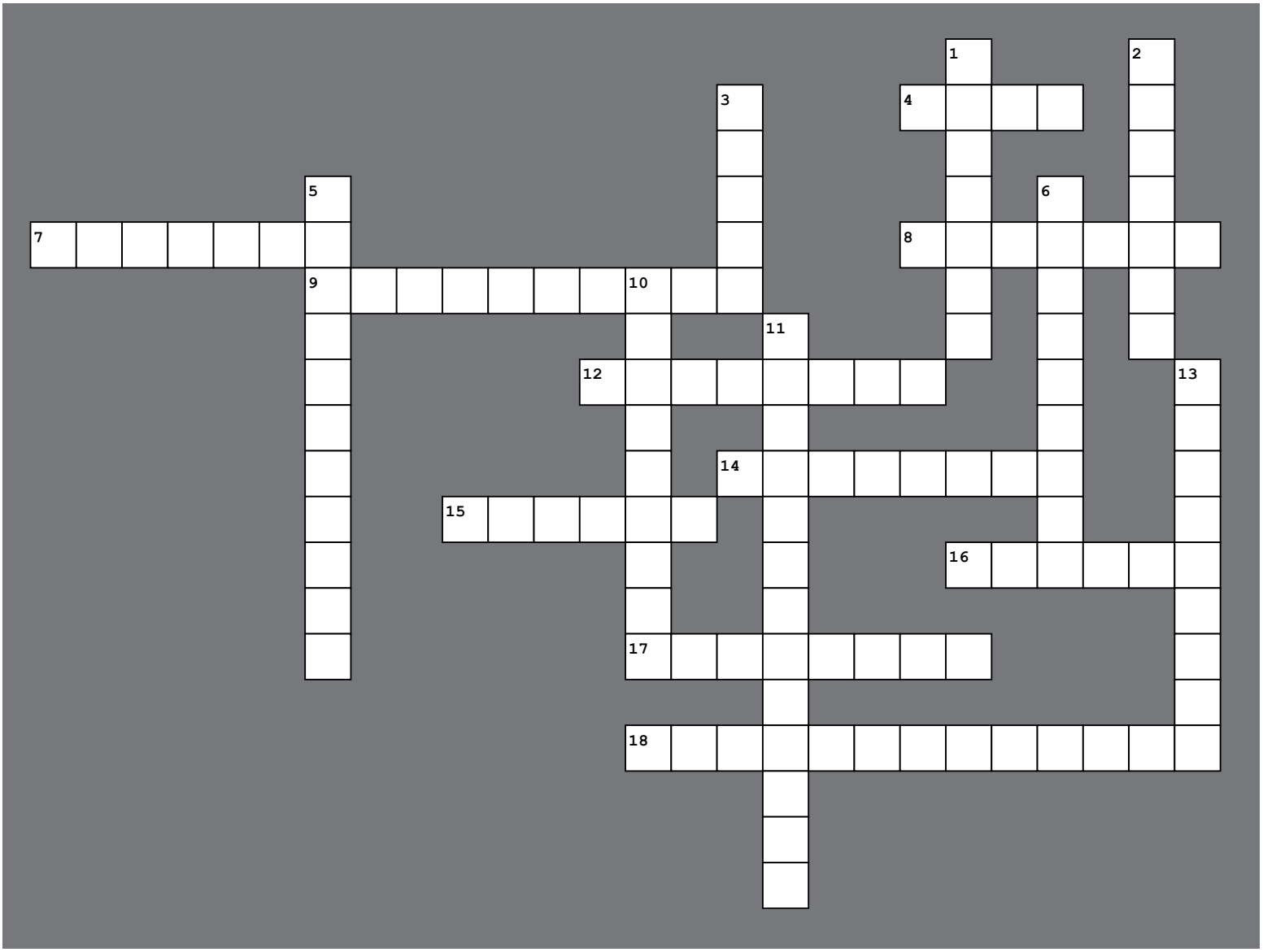
RATES

Apogee Components offers $300 for a quality-written article over 2,000 words in length. Payment is pro-rated for shorter articles.

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.

CROSSWORD



QUESTIONS

ACROSS

4. The ratio of aircraft speed to the speed of sound through the medium where the aircraft is traveling.
7. Failure of a model to make an official flight when its launch is attempted. Failure to launch caused by a malfunction of a meet-provided launch system must not be considered a misfire.
8. The line marking the apparent junction of Earth and sky.
9. 299,792 km per second, the constant c.
12. A streak of condensed water vapor in the air due to the heat produced by aircraft engines at high altitudes.
14. The number of seconds for which the motor burns.
15. Jupiter-like planets, the gas giants Jupiter, Saturn, Uranus, and Neptune.
16. A force that aims to produce rotation.
17. A device that controls the amount of power outputted by the engine.
18. The average thrust during the first half second of the burn

DOWN

1. The weight of the content carried in an aircraft, including passengers, pilots, cargo, etc.
2. The cross-sectional shape of a wing, blade, turbine, or rotor that produces lift
3. North American Aerospace Defense Command
5. The space within the boundary of the heliopause, containing the Sun and solar system.
6. An abrupt change in horizontal or vertical wind direction.
10. Extrasolar planet. A planet orbiting a star other than the Sun.
11. the personnel, radar, computers, etc, on the ground that monitor the progress of aircraft or spacecraft.
13. The weight of the rocket ready to fly, but without any motor loaded

ACROSS
4. Mach 7. Misfire 8. Horizon 9. Speed of Light 12. Contrail 14. Burn Time 15. Jovian 16.Torque 17. Throttle 18. Initial Thrust

DOWN
1. Payload 2. Airfoil 3. NORAD 5. Heliosphere 6. Wind Shear 10. Exoplanet 11. Ground Control 13. Dry Weight

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