Issue 679 / May 26th, 2026

# PEAK OF FLIGHT NEWSLETTER

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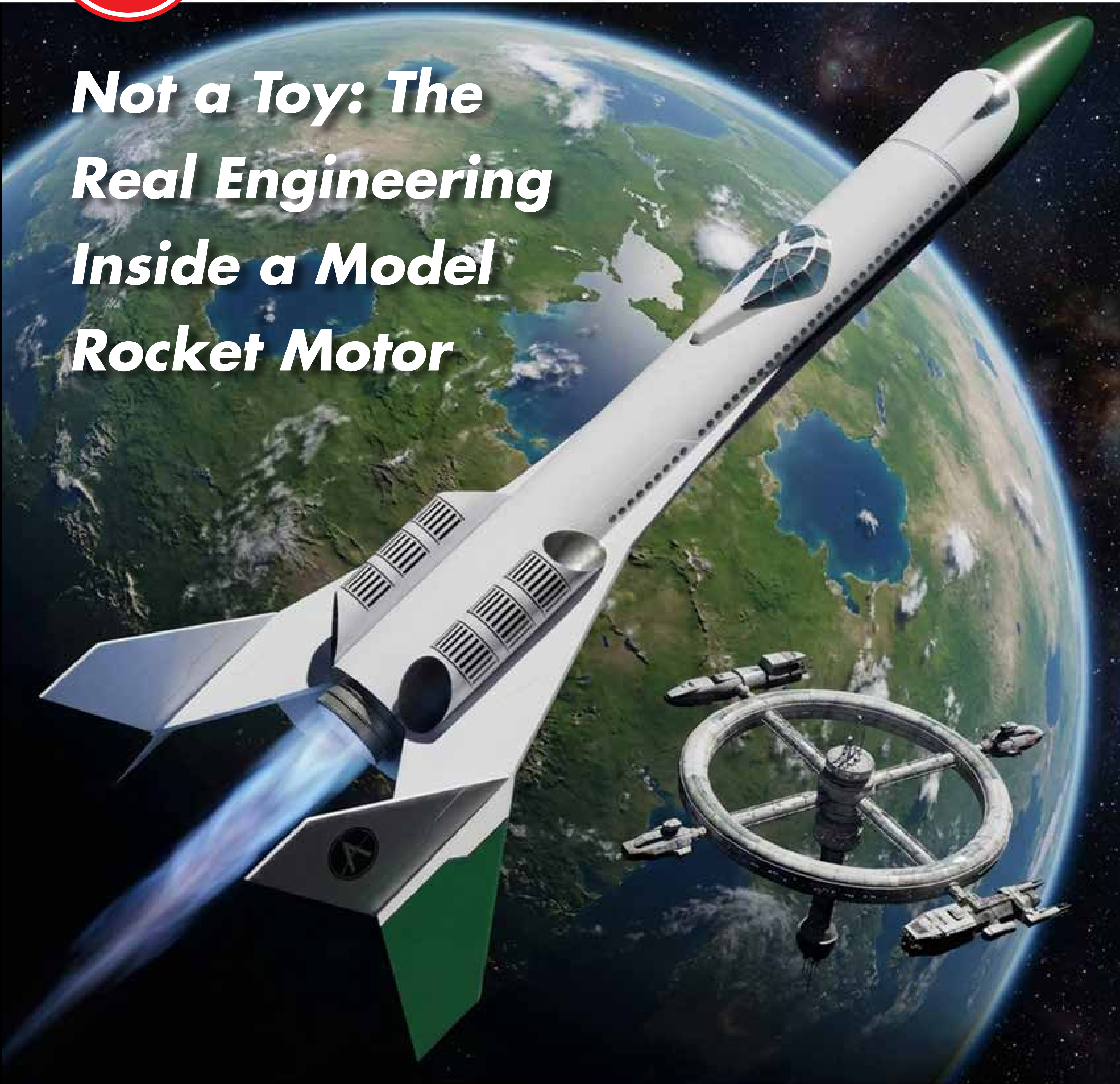

## Not a Toy: The Real Engineering Inside a Model Rocket Motor

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## COVER PHOTO

### Apogee Nebula ST

This sci-fi inspired space transport offers rewarding construction with tip fins, ejection baffles, and pro-level jigs, perfect for builders seeking standout performance and aesthetics.

## FEATURED ARTICLES

### Not a Toy: The Real Engineering Inside a Model Rocket Motor

Here is an in-depth look at the engineering, chemistry, and safety principles inside model rocket motors, bridging hobby rocketry with real aerospace science.

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## About this Newsletter

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Not a Toy: The Real Engineering Inside a Model Rocket Motor
by Tim Van Milligan

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# Not a Toy: The Real Engineering Inside a Model Rocket Motor

By Tim Van Milligan

To the casual observer, a model rocket motor looks like a simple cardboard tube plugged with clay. It is small enough to fit in the palm of your hand, light enough to be shipped in the mail, and inexpensive enough to be purchased with pocket money. Because of this accessible exterior, it is easy to dismiss model rocketry as a mere child's plaything—a step up from a firecracker, perhaps, but certainly not "real" aerospace engineering.

Nothing could be further from the truth.

Beneath that unassuming paper casing lies a carefully balanced, highly engineered thermodynamic system. A model rocket motor is a true reaction propulsion device, operating on the exact same principles of physics, chemistry, and internal ballistics as the solid rocket boosters that helped launch the Artemis rocket. The fact that millions of these motors are ignited every year with a near-perfect safety record is not a happy accident; it is the result of decades of rigorous scientific testing and quality control.

Whether you are a beginner looking to understand what makes

Figure 1 - The Apogee Zephyr rips skyward with a beautiful white exhaust plume from a composite propellant motor.

your rocket fly, an experienced hobbyist chasing higher altitudes, or an educator searching for a way to bring chemistry and physics to life in the classroom, understanding the internal ballistics of a model rocket motor is essential. Let's peel back the cardboard casing and explore the real engineering inside.

## Part 1: The Chemistry of Thrust

Thrust does not come from nowhere. It is the result of a rapid, controlled chemical reaction that converts solid potential energy into high-temperature, high-pressure gas. In model rocketry, we primarily deal with two types of solid propellants: Black Powder and Composite.

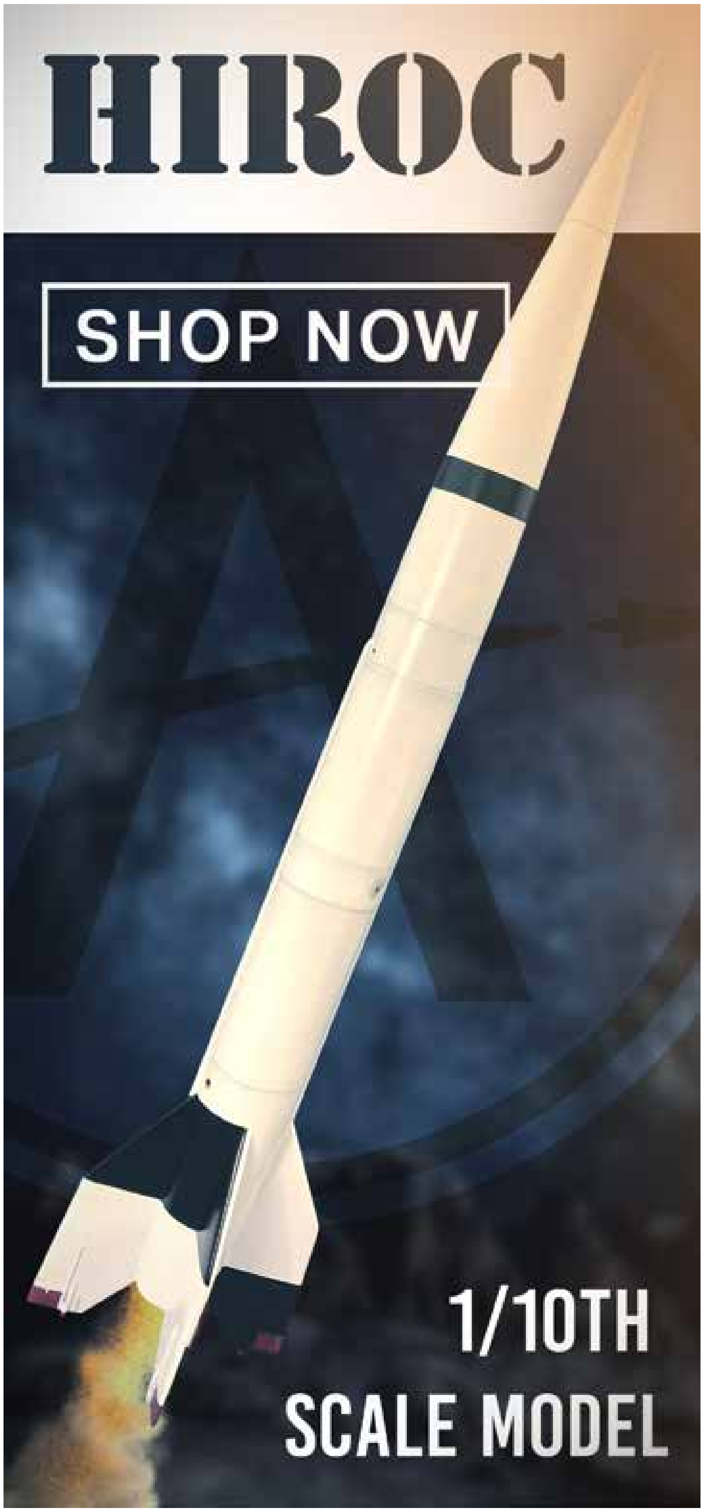
### The Classic: Black Powder Motors

For over forty years, the black powder motor has been the workhorse of the hobby. But this is not the crude gunpowder of centuries past; it is a highly refined, tightly controlled formulation.

The standard model rocket black powder propellant consists of:

- **74% Potassium Nitrate ($KNO_3$)**: This acts as the oxidizer. In the vacuum of space—or simply inside a sealed cardboard tube—a fire needs a source of oxygen to burn. Po-

Figure 2 - Chemical components of black powder.



tassium nitrate provides it.

- **15.6% Carbon (Charcoal):** This is the primary fuel.
- **10.4% Sulfur:** This acts as an additional fuel, but more importantly, it lowers the ignition temperature and increases the burn rate, acting as a binder and a catalyst.

FWhen an electrical igniter raises the surface temperature of this propellant to approximately 550°F, the reaction begins. The chemical equation for this combustion, as detailed in aerospace safety reports, is staggeringly complex. It is not a simple oxidation; it produces a mix of gases, solids, and water vapor:

$$74KNO_3+96C+30S+16H_2O \rightarrow 35N_2(g)+56CO_2\ (g)+3CH_4\ (g)+2H_2S\ (g)+19K_2CO_3\ (s)+7K_2SO_4\ (s)+K_2S+8K_2S_2O_3\ (s)+2KCSN\ (s)+(NH_4)2CO3\ (s)+S\ (s)$$

What does this mean in plain English? It means the reaction products are roughly 43% gas, 56% solid (which is why black powder motors leave a thick, white smoke trail composed of potassium carbonate and potassium sulfate).

## Heat Liberated by Black Powder

The chemical reaction of standard model rocket black powder liberates approximately 3 kilojoules of heat energy per gram of propellant (roughly 715 to 750 calories per gram).

To put that into perspective: a standard "C" class motor contains about 12.5 grams of propellant. When ignited, it releases roughly 37.5 kilojoules of thermal energy in just over a second. This massive, sudden release of heat is what causes the rapid expansion of the gaseous reaction products. By forcing this rapidly expanding, superheated gas through the de Laval nozzle, the motor converts thermal potential energy directly into the kinetic

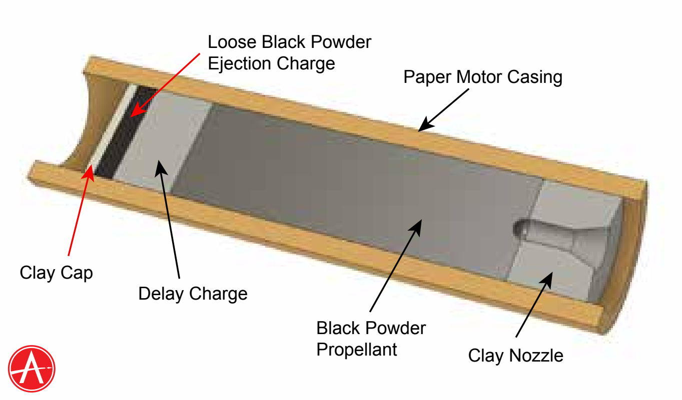


**Figure 3 - Cross section of a black powder propellant rocket motor.**

energy that imparts motion to the exhaust.

*Educator's Angle: This is a perfect real-world application of stoichiometry. Students can calculate the molar masses of the reactants and see exactly why the 74/15.6/10.4 ratio is required to ensure complete combustion without leaving unburned fuel or oxidizer behind.*

### The Powerhouse: Composite Motors

While black powder is reliable, it has the lowest energy content per unit weight of commercially available propellants. For heavier rockets and higher altitudes, aerospace engineers—and model rocketeers—turn to composite propellants.

Composite motors use a fundamentally different chemistry:

- **~82% Ammonium Perchlorate ($NH_4ClO_4$)**: A highly efficient oxidizer.
- **~18% Elastomers (Synthetic Rubber)**: This serves a dual purpose. It is the fuel that burns, and it is the physical binder that holds the propellant grain together, giving it the consistency of a hard pencil eraser.

The combustion of a composite motor is much cleaner, producing almost 100% gaseous exhaust (primarily carbon monoxide, carbon dioxide, water, nitrogen, and hydrogen chloride). Because almost all the mass is converted to gas rather than solid particulate, composite motors are vastly more powerful.

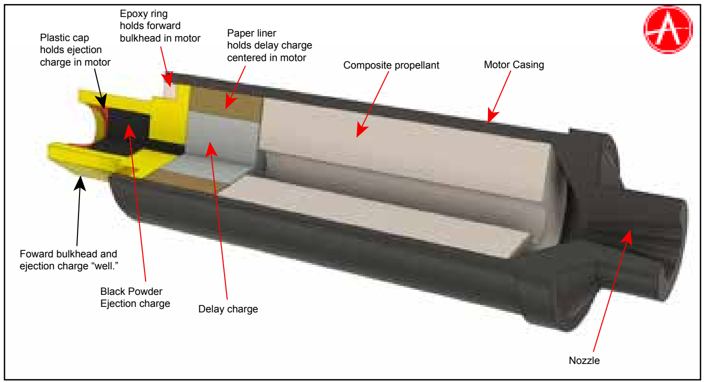


**Figure 4 - Cut-away showing the components of a single-use composite propellant rocket motor.**

## The Chemistry of Composite Propellants (Stoichiometry and Energy)

Unlike black powder, which is a homogeneous mixture, composite propellants are heterogeneous systems: solid oxidizer crystals embedded in a polymer fuel binder. The most common formulation used in hobby and high-power rocketry is Ammonium Perchlorate Composite Propellant (APCP).

A typical near-stoichiometric formulation is approximately:

- **~80–82% Ammonium Perchlorate ($NH_4ClO_4$)** — oxidizer
- **~16–18% polymer binder (such as HTPB)** — fuel
- **~1–3% additives** (curatives, iron oxide burn-rate catalysts, plasticizers)

For simplicity, if we represent the polymer binder approximately as a hydrocarbon repeating unit such as $C_4H_6$, a simplified stoichiometric combustion reaction can be expressed conceptually as:

$$10\,NH_4ClO_4+C_4H_6 \rightarrow N_2+H_2O+CO+CO_2+HCl_{10}NH_4ClO_4+C_4H_6 \rightarrow N_2+H_2O+CO+CO_2+HCl$$

In reality, the reaction is far more complex and proceeds through multiple intermediate decomposition steps:

1. Ammonium perchlorate thermally decomposes into reactive oxygen species.
2. The polymer binder pyrolyzes into smaller hydrocarbon fragments.
3. These fragments oxidize in the high-temperature combustion zone.

The final exhaust typically consists primarily of:

- $H_2O$ (water vapor)
- CO and $CO_2$

**Figure 5 - Blue Thunder Propellant has very wispy tracking smoke because there are little solids in the resultant reaction during the combustion process.**

- $N_2$
- $HCl$

Unlike black powder, composite motors convert nearly all reaction mass into **gaseous products**, which is a key reason for their dramatically higher performance.

However, this high efficiency comes with a practical drawback: with nearly 100% gaseous exhaust, composite motors produce very little tracking smoke during ascent (see figure 5). To ensure visibility for tracking and recovery, manufacturers add smoke-producing additives, such as metal salts or titanium powder, to the propellant mixture. These additives convert into dense white particulate matter upon combustion, creating the necessary tracking smoke.

## Heat of Reaction: Energy Density of Composite Propellant

Composite propellants liberate approximately:

3.8–4.5 kJ per gram

This is significantly higher than black powder, which releases about 3 kJ per gram.

To put this into perspective:

A 200-gram composite motor grain (roughly an “I” size motor) releases roughly 800 kJ of thermal energy during its burn.

That is comparable to the chemical energy contained in over 0.02 liters of gasoline, released in just a few seconds.

This energy raises chamber temperatures to: 3,000–3,500°C

At these temperatures, the combustion products become highly pressurized gas. The de Laval nozzle then converts this **thermal energy** into **directed kinetic energy**, producing exhaust velocities between: 1,900–2,200 m/s

**Figure 6 - Components that go into a composite propellant rocket motor.**

This higher energy density — combined with nearly complete gas production — explains why composite motors achieve specific impulses in the 190–220 s range, compared to roughly 82 s for black powder.

### Why the Stoichiometry Matters

The oxidizer-to-fuel ratio in composite propellant is carefully balanced:

- Too much oxidizer → lower flame temperature and wasted mass.
- Too much fuel → incomplete combustion and soot formation.
- Near-stoichiometric balance → maximum flame temperature and optimal chamber pressure.

Because the burn rate of APCP increases with chamber pressure (a pressure-dependent burn law), small changes in composition directly affect thrust curves, total impulse, and motor stability. This is why composite propellant manufacturing requires tight mass-fraction tolerances and rigorous quality control.

## Part 2: Thermodynamics and Internal Ballistics

To understand why a rocket motor doesn't simply melt or explode, we have to look at thermodynamics—the study of heat, work, and temperature.

When the propellant burns, it generates an immense amount of heat and gas. In a black powder motor, the chamber temperature reaches a staggering 2,300°F. In a composite motor, it is even hotter, reaching up to 4,283°F.

To put that into perspective, iron melts at 2,800°F. So how does a cardboard or thin plastic casing survive temperatures that would liquefy steel?

The answer lies in two engineering principles: **ablation** and **insulation**.

- **The Casing:** The convolutely-wound paper casing of a black powder motor is an excellent insulator. Heat transfers through paper very slowly.
- **The Burn Pattern:** Black powder motors are typically "end-burning." They ignite at the rear and burn forward. The unburned propellant ahead of the flame front acts as an insulator, protecting the forward sections of the rocket. Composite motors often use a "core-burning" design, where a hole runs down the center of the propellant. The propellant burns from the inside out, meaning the unburned fuel insulates the outer casing until the very last fraction of a second of the burn. Additionally, the propellant is often inserted into a paper liner to further insulate the outer casing from the direct heat of the combustion chamber.

As the temperature spikes, so does the pressure. A black powder motor operates at a chamber pressure of about 106 psia (pounds per square inch absolute). A composite motor may operate at around 500 psia.

*Educator's Angle: This is an ideal way to teach the Ideal Gas Law (PV=nRT). As the chemical reaction creates more moles of gas (n) and the temperature (T) skyrockets, the pressure (P) inside the fixed volume (V) of the motor casing must increase. The only way to relieve this pressure and prevent an bursting of the casing is to give the gas an exit.*

## Part 3: The De Laval Nozzle and the Physics of Speed

If you just poked a hole in the bottom of the motor casing, the high-pressure gas would vent, but it wouldn't create efficient thrust. To turn pressure into speed, you need a nozzle. Specifically, you need a de Laval nozzle.

Invented by Swedish engineer Gustaf de Laval in the late 19th century for steam turbines, this nozzle design features a converging section (getting narrower), a throat (the narrowest point), and a diverging section (getting wider). Every single model rocket motor uses this exact geometry.

Here is how the physics work:

1. **Subsonic Convergence:** As the high-pressure gas moves toward the throat, the narrowing walls force it to accelerate. At this point, the gas is moving slower than the speed of sound (subsonic).
2. **Sonic Throat:** The throat is mathematically sized so that the

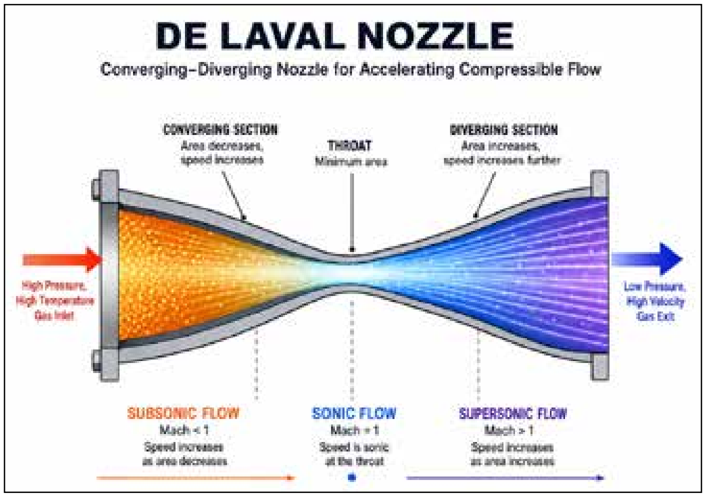


**Figure 7: The deLaval Nozzle converts high pressure gasses into high velocity flow to create thrust.**

gas reaches exactly the speed of sound (Mach 1) right as it passes through the narrowest point. The size of this throat dictates the internal chamber pressure. If the throat is too small, the pressure builds until the casing ruptures. If it is too large, the pressure drops, and the motor produces little thrust.

3. **Supersonic Divergence:** Once the gas passes the throat and enters the widening bell of the nozzle, something counterintuitive happens. Because the gas is now moving at the speed of sound, the widening area causes it to accelerate to supersonic speeds while its pressure and temperature drop.

By the time the exhaust leaves the nozzle of a black powder motor, its temperature has dropped from 2,300°Fto 540°F, and it is traveling at an incredible 2,650 feet per second (about 1,800 miles per hour).

Composite motors push this even further. Their exhaust leaves the nozzle at velocities between 6,112 and 7,077 feet per second (over 4,000 miles per hour).

*Educator's Angle: The nozzle is a masterclass in fluid dynamics and conservation of mass. It demonstrates how thermal energy (heat and pressure) is converted directly into kinetic energy (velocity), which is the fundamental mechanism of rocket propulsion.*

## Part 4: Specific Impulse (Isp) - The MPG of Rocketry

When hobbyists and aerospace engineers talk about how "good" a propellant is, they don't just talk about total thrust. They talk about efficiency. In rocketry, efficiency is measured by Specific Impulse, denoted as IspIsp.

Specific impulse is essentially the "miles per gallon" of a rocket motor. It measures how much thrust is produced per unit weight of propellant consumed per second. The mathematical definition is:

$$I_{sp} = \frac{F}{\dot{m} \cdot g_0}$$

Where:

- $F$ is the thrust produced.
- $\dot{m}$ is the mass flow rate of the propellant.
- $g_0$ is standard gravity.

Specific impulse is measured in seconds (technically $lb_f$-sec/$lb_m$).

- The $I_{sp}$ of a standard model rocket black powder motor is about **82 seconds**.
- The $I_{sp}$ of a composite model rocket motor ranges from **190 to 220 seconds.**

For comparison, the massive Solid Rocket Boosters on the Artemis rocket have an $I_{sp}$ of about 269 seconds. This shows just how remarkably close composite model rocket motors are to pro-

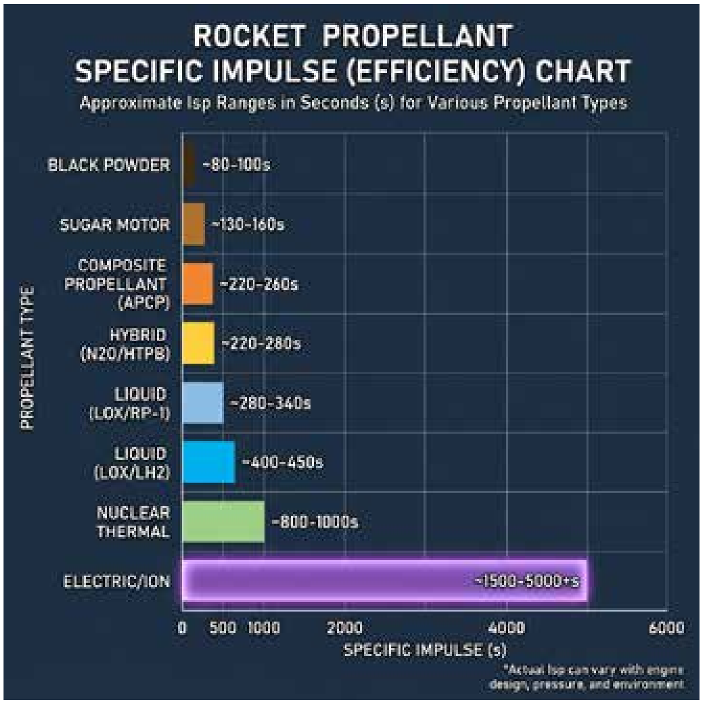


**Figure 8 - Comparison of the efficiencies of various types of rocket propellant**

fessional, space-grade hardware.

Because composite motors have a specific impulse nearly three times higher than black powder, they can lift heavier rockets to higher altitudes using a fraction of the propellant mass. This is why high-power rocketry relies almost exclusively on composite technology.

## Part 5: Engineering for Safety

With chamber temperatures exceeding 4,000°F and exhaust velocities breaking the sound barrier, it is natural to ask: *Why is this safe?*

The safety of model rocketry—boasting hundreds of millions of safe flights over forty years—is not due to luck. It is due to the principle of "fail-safe" engineering.

**Controlled Burn vs. Detonation:**

A firecracker is designed to explode. Its casing is sealed tight, and the powder inside is loose. When ignited, the pressure builds instantly until the casing violently ruptures, creating a shockwave.

A model rocket motor is designed to burn. The propellant is hydraulically dead-pressed into a solid block (a "grain"). It can only burn on its exposed surface. Because the burn rate is known

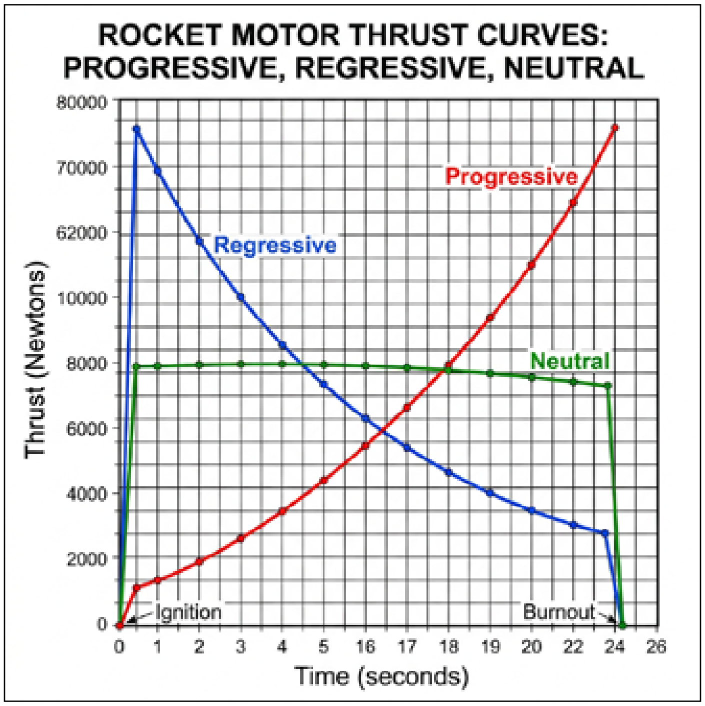


**Figure 9 - Thrust curves shapes can be Progressive, Regressive, or Neutral. What would you think the are the advantages/disadvantages of each?**

(about 1.15 inches per second for black powder at 106 psia), the volume of gas produced at any given millisecond is perfectly predictable. The nozzle is sized to vent this exact amount of gas, maintaining an equilibrium.

## Burn Rate, Grain Geometry, and the Deflagration Distinction

As just mentioned, black powder in a model rocket motor burns at approximately:

1.15 inches per second at 106 psia

It is relatively fast-burning and pressure-sensitive. For this reason, black powder motors are typically **end-burning.** The propellant ignites at the rear and burns forward at a nearly constant surface area, producing the familiar flat thrust curve of small model motors. The chemistry and the geometry are simple—and elegantly matched.

Composite propellant behaves very differently.

Ammonium Perchlorate Composite Propellant (APCP) burns much more slowly—typically on the order of:

0.2 to 0.4 inches per second depending on formulation and chamber pressure. At first glance, this slower burn rate might seem like a disadvantage. In reality, it is one of the keys to composite propulsion.

Because APCP burns more slowly, igniting only one end of the grain would not generate sufficient gas to build chamber pressure efficiently. Instead, composite motors are designed to burn *from the inside out*. A cylindrical core—or more complex geometries such as star or *finocyl* (fin in a cylinder) patterns — is cast into the propellant. Combustion begins along the internal surface and progresses outward toward the casing.

This geometry accomplishes two critical objectives:

1. **Surface Area Control** – The internal core dramatically increases the initial burning surface, compensating for the slower burn rate and producing the required mass flow for high-thrust rocket motors.
2. **Thrust Shaping** – By tailoring the internal geometry, engineers can design neutral, progressive, or regressive thrust curves (see Figure 10). In composite motors, thrust control is achieved as much by grain architecture as by chemistry. For more information about the common grain geometry used in model rocket motors, see Peak-of-Flight Newsletter #341 (https://www.apogeerockets.com/education/downloads/Newsletter341.pdf)

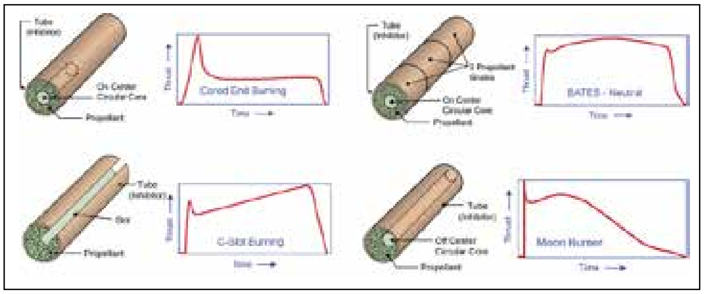
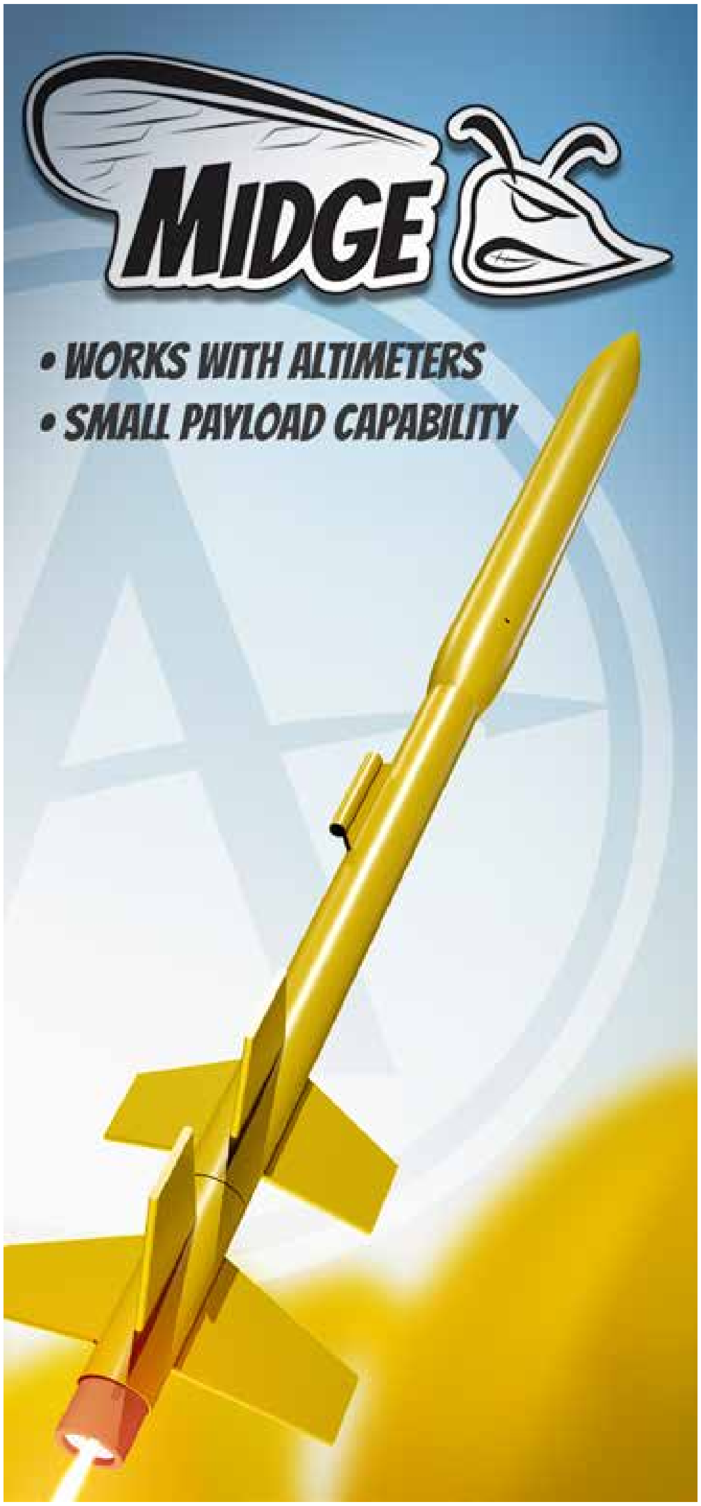


**Figure 10 - Common grain geometries used in model rocketry. It is the grain geometry that determines the shape of the thrust curve that is produced (from POF Newsletter 341).**

## Deflagration vs. Detonation

The slower burn rate of composite propellant is not merely an engineering curiosity—it is a defining physical characteristic.

APCP undergoes **deflagration** (the process where a flame front travels through a flammable mixture at speeds slower than the speed of sound, relying on heat transfer to the unburned material rather than a destructive shock wave), not detonation. The combustion front travels subsonically through the material and is strongly pressure-dependent. Unconfined, the propellant burns vigorously but does not explode. It requires containment to build pressure and produce thrust.



This scientific distinction became central in the 1990s legal challenge brought by the Tripoli Rocketry Association (TRA) and the National Association of Rocketry (NAR) against the Bureau of Alcohol, Tobacco, and Firearms (BATF). The regulatory classification of APCP hinged on whether it met the statutory definition of an explosive material.

The courts ultimately ruled that composite propellant's measured burn rate, lack of detonation capability, and controlled, pressure-dependent combustion placed it outside that definition. The result was the removal of APCP from the federal explosives list—an outcome grounded not in advocacy alone, but in combustion science.

## Engineering, Not Explosion

There is a subtle but important contrast here:

- Black powder burns faster.
- Composite propellant burns slower.
- Yet composite motors produce far greater total impulse.

The difference lies not in explosive violence, but in controlled thermodynamics. Composite propulsion relies on deliberate geometry, sustained gas generation, and efficient nozzle expansion—not rapid shock-driven decomposition.

In the end, both systems obey the same physical laws. But composite motors demonstrate something deeper: that power in rocketry is not about how fast something explodes. It is about how precisely energy is released, shaped, and directed.

**Fail-Safe Casings:**

Even with perfect manufacturing, anomalies can happen. A microscopic void in the propellant grain can increase the burning surface area, causing a sudden spike in pressure.

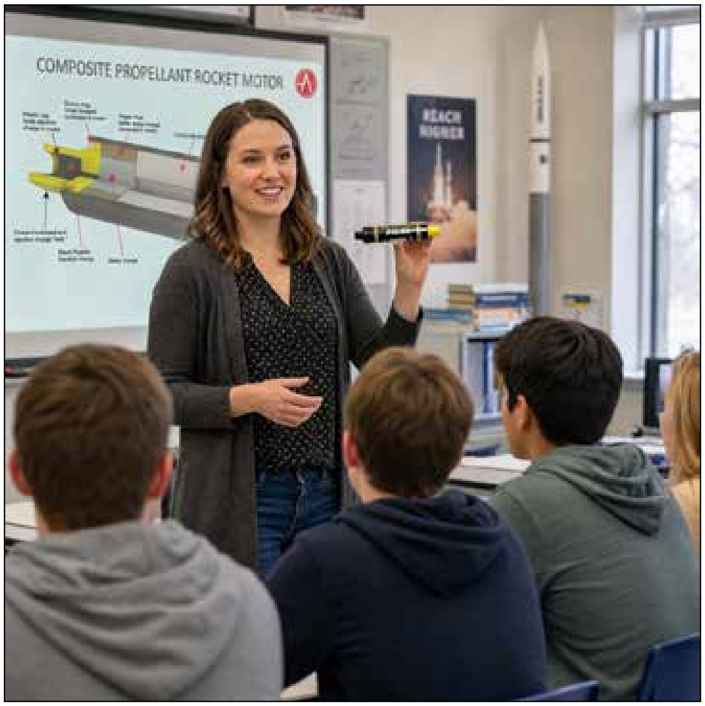
If a model rocket motor experiences an overpressure event, it is designed to fail safely. Traditional paper or plastic casings are engineered to have a lower burst strength than the pressure required to create a dangerous fragmentation explosion. They split longitudinally, venting the pressure instantly without producing sharp shrapnel.

In modern mid- and high-power rocketry, where motors are significantly larger, reloadable aluminum casings, high-temperature thermoplastics, or fiberglass are frequently used. These materials are also rigorously engineered with fail-safe mechanisms. Aluminum casings, for example, do not shatter; the aluminum deforms or threaded closures specifically designed to yield, strip, to vent safely at the ends if over-pressurized. Fiberglass casings are designed to delaminate or split along their weave, releasing pressure without generating dangerous metallic fragmentation.

This is a stark contrast to amateur "basement bomber" rockets made from plumbing pipes, which act as lethal shrapnel hazards if over-pressurized. The National Association of Rocketry (NAR) safety codes mandate these specific design tolerances to engineer the hazard out of existence.

## Conclusion: A Classroom in a Cardboard Tube

A model rocket motor is a triumph of miniaturized engineering. It takes the violent, chaotic energy of chemical combustion and harnesses it through the elegant laws of thermodynamics and fluid mechanics.



For the beginner, understanding this process turns a simple hobby into an appreciation for how humans reach the stars. For the experienced hobbyist, mastering these concepts is the key to designing custom rockets, staging complex flights, and optimizing payload capacities.

And for the educator, there is perhaps no better teaching tool. Inside that small cardboard tube lies applied chemistry, stoichiometry, thermodynamics, the Ideal Gas Law, fluid dynamics, and Newtonian physics. It is a tangible, exciting, and profoundly safe way to prove to students that the math and science they learn on a whiteboard actually govern the physical world.

Model rocketry is not a toy. It is an aerospace laboratory that fits in your pocket, waiting for a spark.

## References:

Information in this article was adapted from *"Forty Years of Model Rocketry - A Safety Report"* prepared for the National Association of Rocketry by G. Harry Stine in 1979, a pioneer of model rocketry and author of the *Handbook of Model Rocketry.*

## 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 (www.apogeerockets.com) and the author of the books Model Rocket Design and Construction and 69 Simple Science Fair Projects with Model Rockets: Aeronautics, as well as the publisher of the "Peak-of-Flight" newsletter. You can reach him through the contact form at www.apogeerockets.com/Contact.

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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 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.

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

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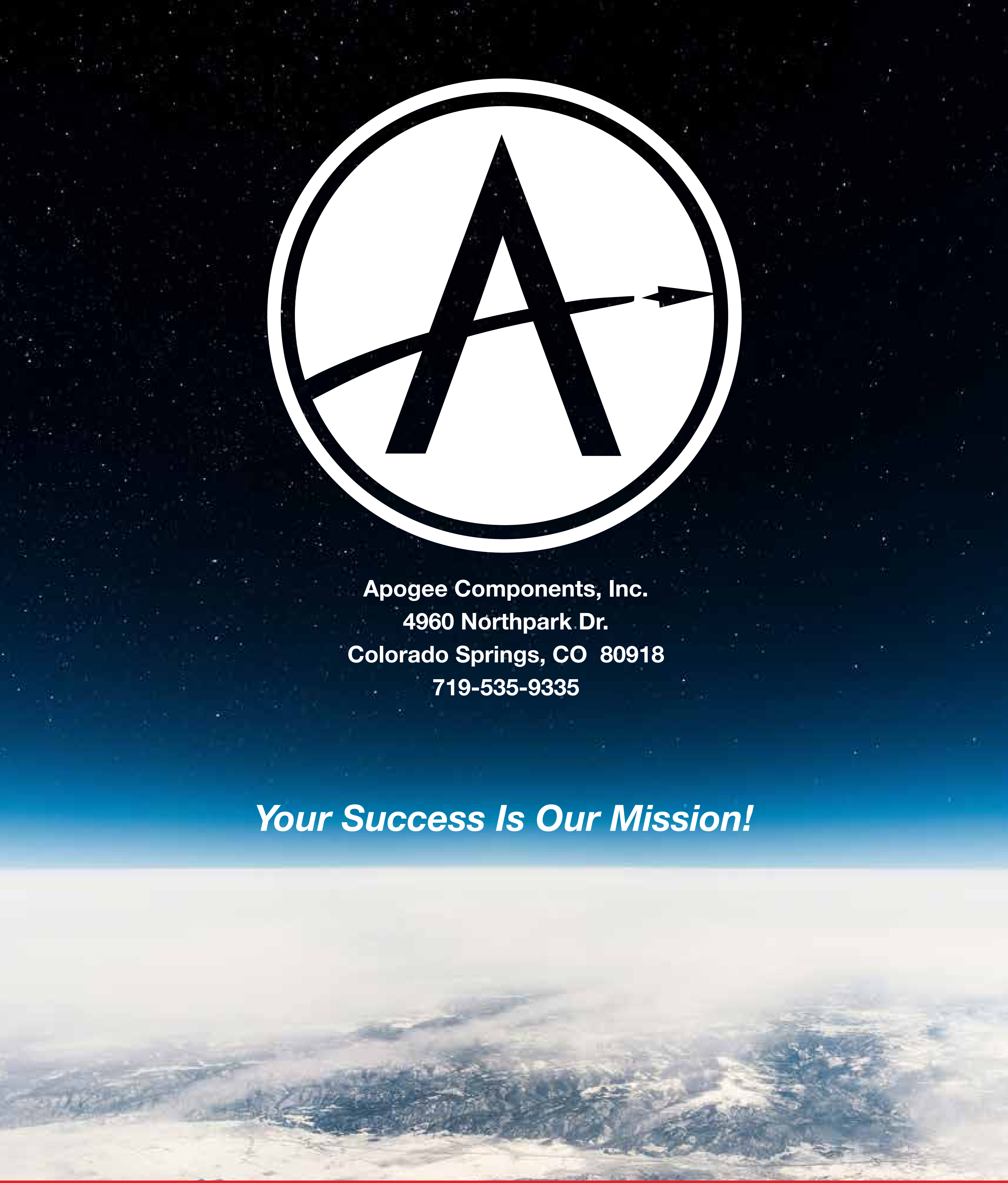
These articles will mainly be published in our free newsletter, *Peak-of-Flight*. Occasionally some of the higher-quality articles could potentially appear in one of Tim Van Milligan's books that he publishes from time to time.



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