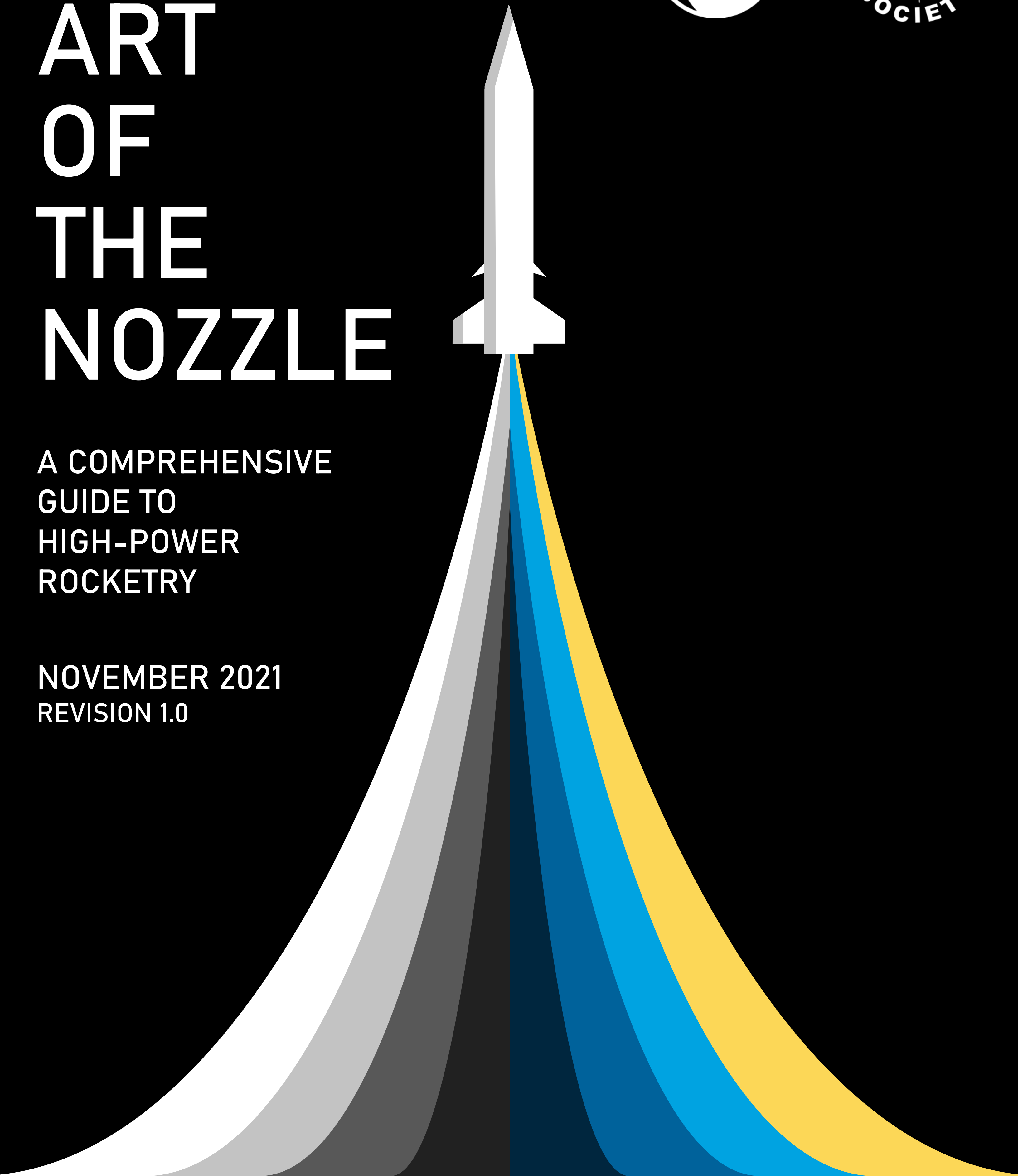
THE ART OF THE NOZZLE

A COMPREHENSIVE GUIDE TO HIGH-POWER ROCKETRY



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INTRODUCTION: FIRE IN THE SKY

Since the dawn of time, humanity has marveled at the stars and sought to determine the nature of the universe. This yearning for knowledge has driven incredible scientific discoveries and earth-shattering technological breakthroughs.

The world of high-power rocketry is full of the same drive to reach new heights. Sitting down to design, build, test, and fly a vehicle that gets launched into the sky in a fiery column is an exhilarating process. Seeing a rocket take off in a cloud of smoke after months of effort inspires an extraordinary feeling of accomplishment. Rocketry has something to offer everyone; it is an ever-evolving field in which knowledge is continually built on, experimentation is encouraged, and resources are shared freely among rocketeers.

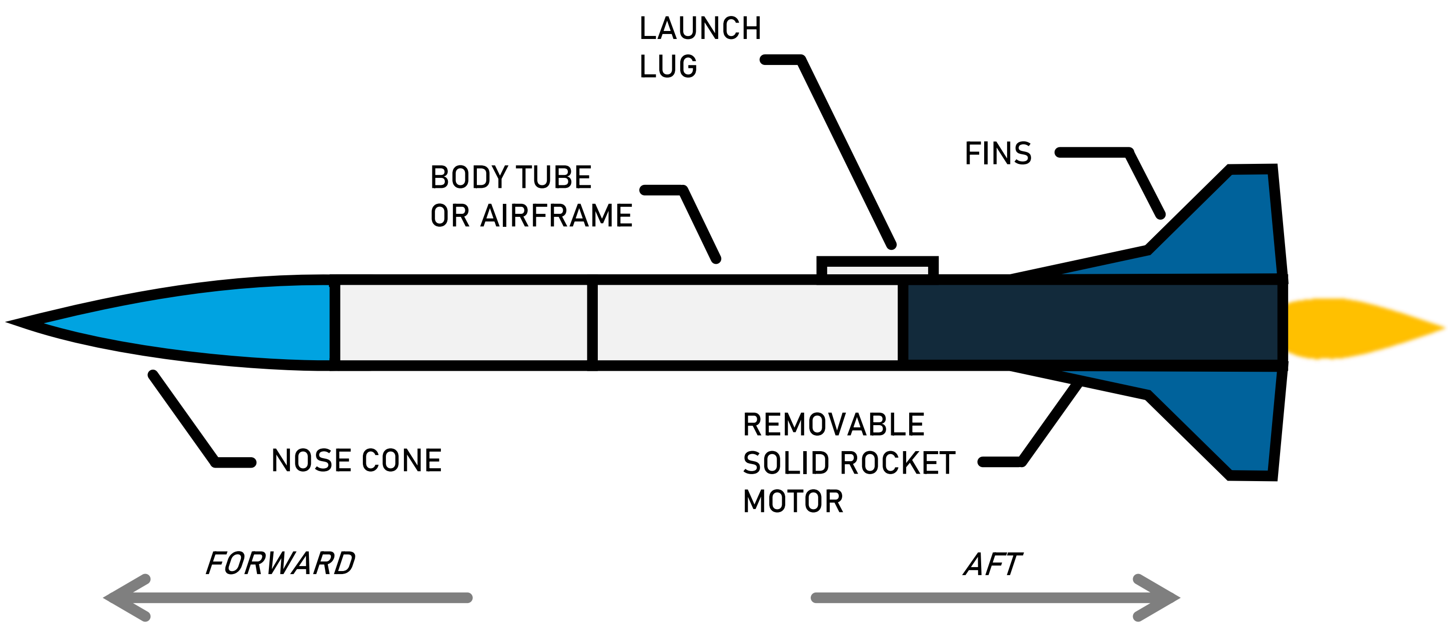
However, rocketry can seem intimidating to anyone getting started. This guide is an introduction to the rocketry certification process and landscape for anyone looking to begin designing, building, and flying their own high-power vehicles. If you're looking for more information on any terms or phrases, hyperlinked terms are defined in detail in Appendix C and linked to their definitions.

1 | GETTING STARTED

1.1 WHAT IS ROCKETRY?

Rocketry is the practice of designing, building, and flying rockets. The field of rocketry involves many different disciplines of science and engineering, such as aerodynamics, thermodynamics, chemistry, and more. An understanding of these fields is important as you get further in rocket design, but you don't need to be a scientist or engineer to make a rocket fly!

Fundamentally, a rocket is a self-contained vehicle that expels some of its own mass to produce thrust. In high-power rocketry, most rockets have the basic components shown in the image below.

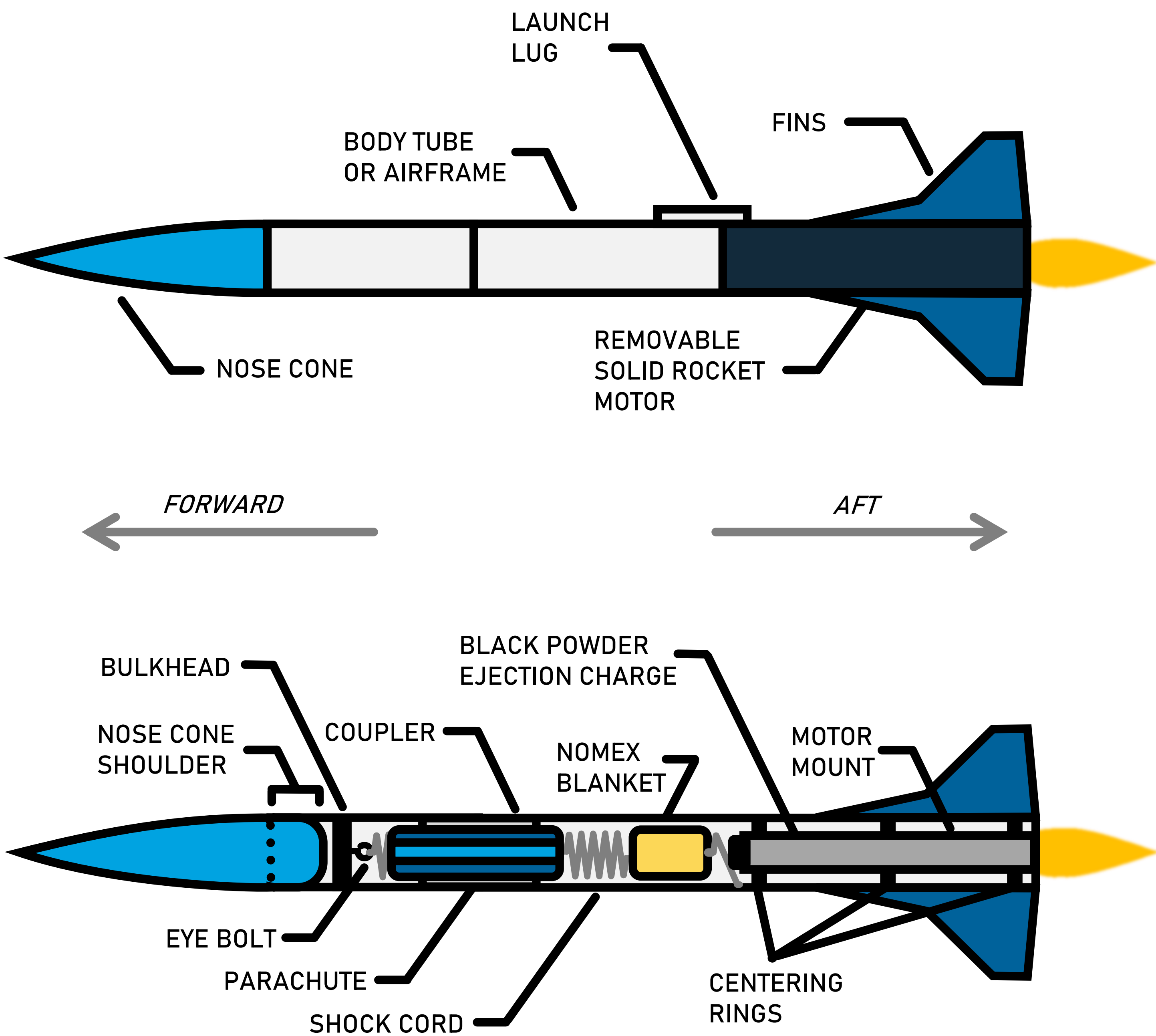


All rockets need a motor or engine to produce thrust, which is generated by burning propellant, or rocket fuel. The motor is typically located at the bottom of the rocket. The primary tube of the rocket is called the body tube or airframe; it holds the motor and all other components of the rocket. Fins and a nose cone are attached to the body tube to make the rocket aerodynamically stable, and a parachute is stored inside the body tube to allow the rocket to land safely. Many rockets include other components to achieve different goals, but most will include at least these five basic components.

2 | ROCKETRY BASICS

2.1 ROCKET ANATOMY

Rockets have a set of parts that work together to safely launch and relaunch. These parts each have a different shape and purpose. This section explains many common parts and how they interact with each other. The pictures below show common rocket components both inside and outside the vehicle.



2 | ROCKETRY BASICS *(continued)*

NOSE CONE - The top of the rocket, shaped so air will flow smoothly around the rocket. Nosecones typically follow a conical, tangent ogive, elliptical, or Haack shape.

BODY TUBE - The main structure of the rocket, which holds the motor, parachute, electronics and related components inside.

BULKHEAD - A plate that blocks transfer of gases between sections of the rocket, or to be used for mounting of components such as recovery hardware or electronics.

COUPLER - A piece of tube that connects two sections of the rocket which are generally the same diameter; the outer diameter matches the inner diameter of the body tube.

PARACHUTE - Slows the descent of the rocket as it falls from its apogee. Some rockets may use multiple parachutes to slow the rocket even further, where a drogue chute is a smaller parachute that allows the rocket to fall faster and is accompanied by a main parachute that deploys closer to the ground.

SHOCK CORD - Holds the sections of the rocket together after an ejection charge has been set off, generally between the nose cone and a bulkhead inside the body tube. It is usually 3-5 body lengths long. It is also usually the attachment point for the parachute.

EYE BOLT - A metal part that connects the shock cord to the rocket body, often attached to a centering ring or a bulkhead.

CENTERING RING - Used to hold the motor mount in the middle of the rocket. They are mounted inside the body tube and around the motor mount.

MOTOR CASE - Contains the combustion gases as the propellant burns, protecting the rocket and allowing pressure to build, such that hot gases will be sent through the nozzle.

THRUST RING - Typically added as part of the motor, whether it be a single-use 3D printed thrust ring or a reloadable casing. Transfers the force of the motor's thrust into the rocket.

MOTOR RETENTION - Motor retention is used to keep a rocket motor safely inside the rocket, especially once the ejection charge fires and deploys the parachute. Without proper motor retention, the ejection charge could cause your motor to be ejected as well, which disqualifies a certification.

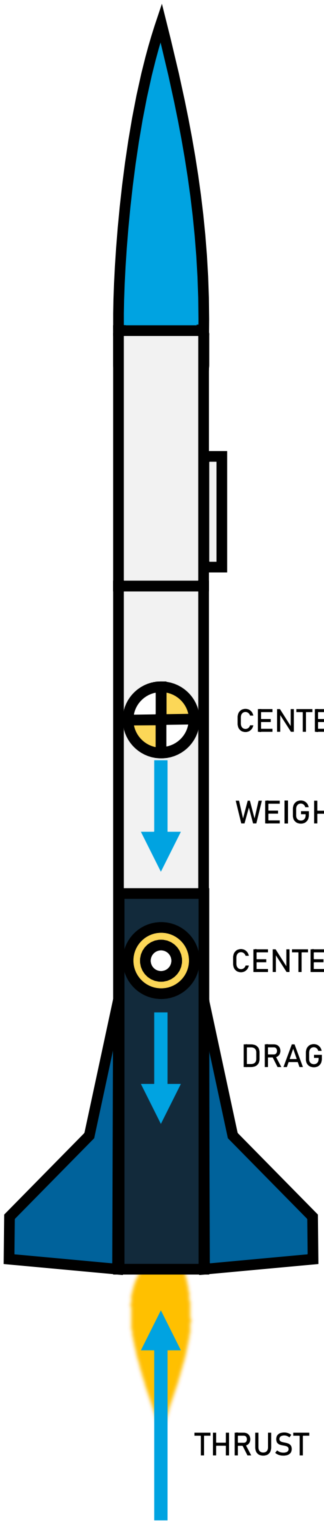
MOTOR MOUNT - A smaller tube mounted in the rocket to hold the motor inline with the body tube.

FINS - Provide aerodynamic stability while the rocket is in motion, such that the rocket will fly straight. Fins can come in many shapes and sizes, where some are designed for performance and others for aesthetics. Fins usually go through the wall of the body tube for extra strength.

LAUNCH LUG/RAIL BUTTON - Interfaces the rocket with its rod or rail and keeps the rocket flying straight as it takes off. Comes in a few main styles and sizes depending on the launch pad. 1010 rails are the standard for high-power rocketry and are used with "rail buttons" mounted to the rocket.

AVIONICS *(flight computer)* - Used to measure altitude and deploy parachutes. They are NOT required for a Level 1 certification and are not shown above, though they can be used in more advanced flights.

2.2 FORCES OF FLIGHT



When a rocket is flying, it experiences forces that push on the rocket in multiple directions. These forces are called thrust, drag, and weight.

Thrust from the rocket motor pushes the rocket off the ground and into the sky. Drag is created by the air flowing around the rocket, and increases when a surface is rough.

Weight is the force created by the rocket being pulled to earth by gravity.

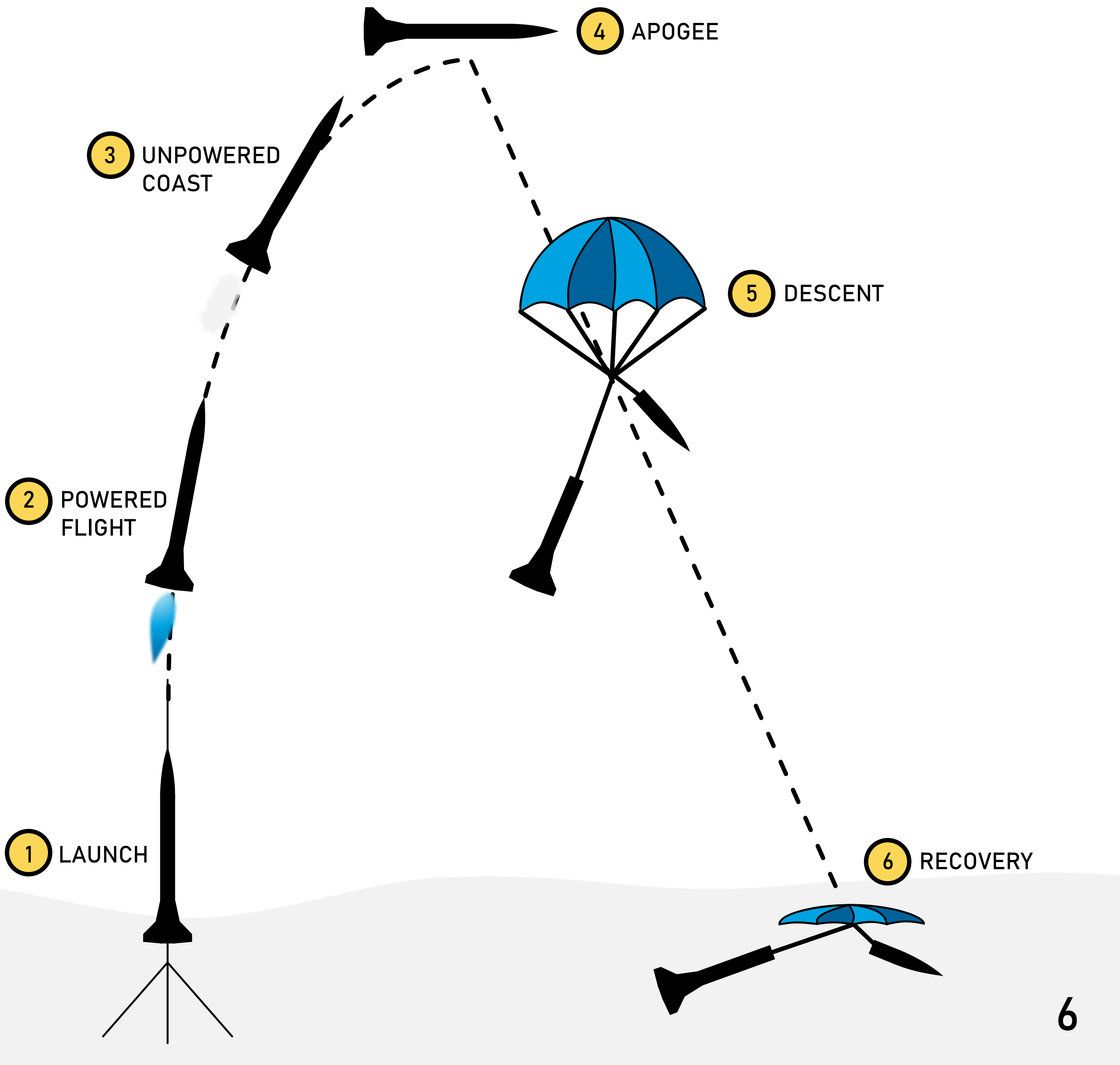
The picture here also shows the location of two important points on a rocket: the Center of Gravity (CG) and Center of Pressure (CP). The CG of a rocket is the location of its average weight, which you can measure by balancing a rocket lengthwise. Thrust and drag act at the CP of a rocket, which can be found using a simulation. The rocket's CP is similar to the Center of Gravity, but it measures the average location of the pressure forces instead of the average location of gravitational forces.

A rocket's stability margin is found by measuring the distance between the CG and CP and dividing by the rocket's diameter. For stable flight, your rocket should have a stability margin of 1.0 - 2.0 and the CP must be behind the CG.

Stability can be altered in several ways. If you increase your fin size, add more fins, or move your fins aft, the CP moves aft. If you increase the weight of the nose, the CG moves forward.

2.3 PHASES OF FLIGHT

High-power rocket flights have very defined stages from their launch to their recovery. When you see your first launch, these steps will be incredibly clear! Each stage is associated with different interactions happening between rocket components. The figure below shows a typical flight profile for a single-stage rocket. Each step will be discussed in more detail below.



2 | ROCKETRY BASICS *(continued)*

1. IGNITION AND LAUNCH

Once your rocket is on the pad, it will be ignited from a distance. As the rocket lifts off from the launch pad, it is kept straight using the launch rail (or rod). As the rocket speeds up, it leaves the rail (or rod) and is stabilized using its fins.

2. POWERED FLIGHT

During this phase, the rocket motor continues to push the rocket into the sky. The fins keep the rocket stable by ensuring the CG is forward of the CP at all times. Many rockets spin as they fly into the clouds; this is completely normal.

3. UNPOWERED COAST

After all the fuel in the rocket motor runs out, the rocket begins to slow down as it continues to battle gravity and drag. During this phase, the nose cone and body tube keep the flight smooth. As the rocket climbs in altitude, the air pressure decreases, and air is vented out of the rocket using small holes in the body tube.

4. APOGEE

Apogee is the highest point in the rocket's flight. Near this time, the parachute will be deployed using an ejection charge, which creates pressure in the rocket that separates it and pushes the parachute into the open air. Insulation or fireproof fabric protects the shock cord and parachute from getting charred.

5. DESCENT

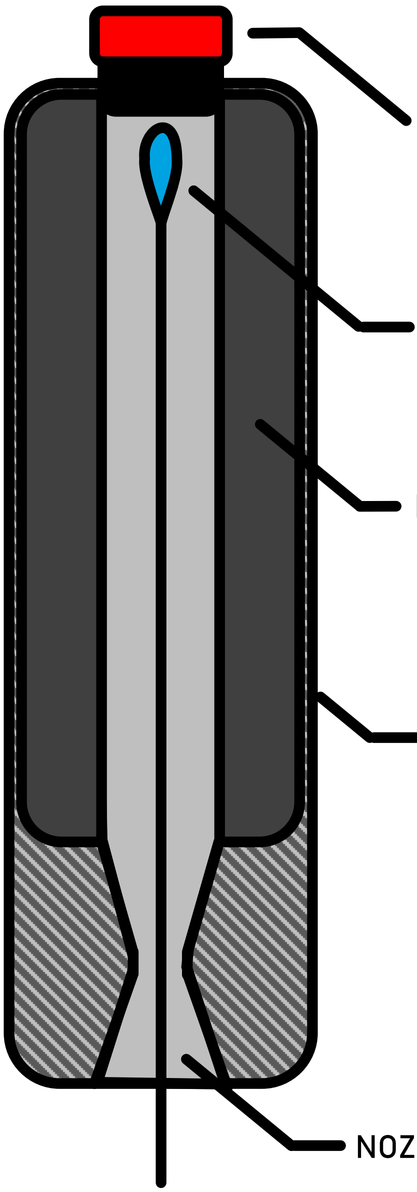
After the parachute is deployed, it creates drag that slows the rocket as it falls back to Earth. The shock cord holds everything together so you can find and recover all the pieces of your rocket at one time.

6. RECOVERY

Once the rocket lands, it is safe to recover. After recovering the rocket- hopefully in one piece!- you can replace the motor and fly again!

3 | MOTOR CLASSES AND CERTIFICATION

A rocket motor is a self-contained propulsion system (creates thrust) that burns propellant and ejects the resulting hot gases through a nozzle, which provides energy to push a rocket off the ground. It does not spin, like a car motor or electric motor. A diagram of a simple solid rocket motor is shown here.



This section goes over rocket motor sizing, the certification levels required for each size, who certifies the use of rocket motors, and where to find someone to help you get a Level 1 Certification (and beyond).

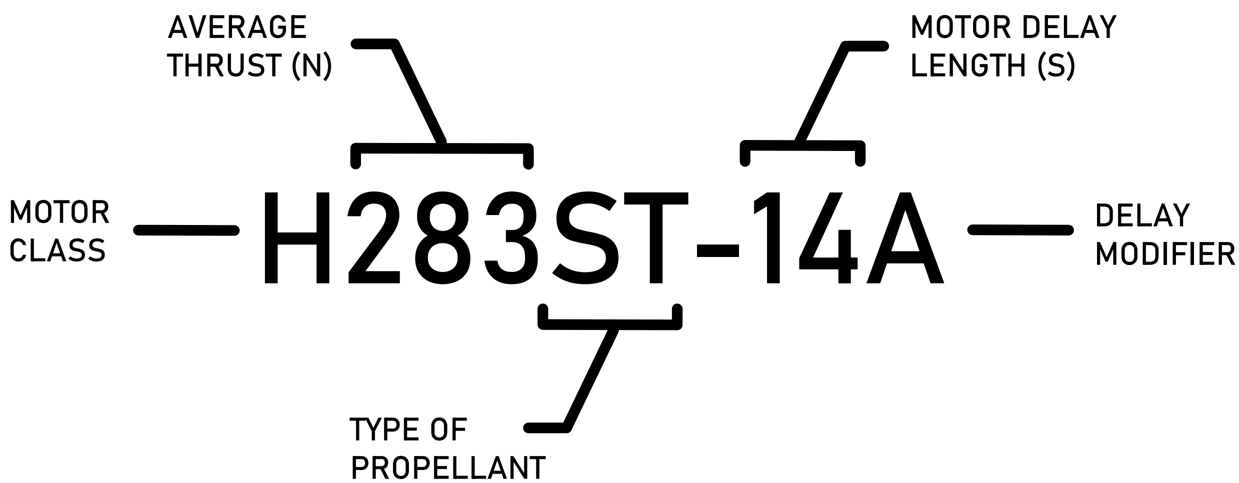
3.1 ROCKET MOTOR CLASSIFICATIONS

Motors are grouped based on their total impulse. This is the total amount of energy the motor can provide to the vehicle. The letters assigned to motors are based on their total impulse, starting with A-class motors, which are defined as any motor with a total impulse between 1.25 and 2.50 Newton-seconds (N-s). A table of solid rocket motor classifications can be found at https://en.wikipedia.org/wiki/Model_rocket_motor_classification. A shortened version of this table is shown on the following page.

Each subsequent letter doubles the total impulse in the range, with high-power starting at an H motor with 160.01 N-s or more. Motor classifications are given as a range (e.g., an H motor is anything with 160.01 N-s to 320 N-s). Motors on the lower end of the range are referred to as “baby” or “low” H’s, and motors near the top of the end are considered “full.”

3 | MOTOR CLASSES AND CERTIFICATION *(continued)*

When browsing motors, other information is given on the label. Take Aerotech's H283ST-14A for example. The H given provides the total impulse range the motor falls in. The 283 refers to the average thrust of the motor, given in Newtons. ST stands for Super Thunder, which is the propellant type used in the motor. 14 is the length of the motor ejection charge delay after motor burnout. A refers to the delay modifier. The two most common modifiers are A, for adjustable, and P, for plugged. Adjustable delays can be drilled to a desired delay length. Plugged motors have no ejection charge. A detailed table can be found on this Wikipedia page.



3.1a MOTOR CLASSIFICATION TABLE

CLASS	IMPULSE (N-s)
A	1.26 – 2.50
B	2.51 – 5.00
C	5.01 – 10.0
D	10.01 – 20.0
E	20.01 – 40.0
F	40.01 – 80.0
G	80.01 – 160.0
H	160.01 – 320.0
I	320.01 – 640.0
J	640.01 – 1,280.0
K	1,280.01 – 2,560.0
L	2,560.01 – 5,120.0
M	5,120.01 – 10,240.0

3 | MOTOR CLASSES AND CERTIFICATION *(continued)*

3.2 GOVERNING BODIES IN ROCKETRY

In rocketry, several primary organizations govern different aspects of the hobby. The National Association of Rocketry (NAR) and Tripoli Rocketry Association (Tripoli) are the largest amateur rocketry groups in the world, with thousands of members each. NAR has more members, focuses more on low-power, and does not allow experimental motors. Tripoli has fewer members, and focuses on high-power and experimental rocket motors. In order to get certified in high-powered rocketry, you must be a member of either NAR or Tripoli.

Both NAR and Tripoli provide their members with resources, such as a community to learn from, launch insurance, and events across the United States. These events are usually run by local clubs, which can be found here: NAR, Tripoli. Both organizations work with government agencies, including the National Fire Protection Agency (NFPA), Bureau of Alcohol, Tobacco, and Firearms (ATF), and Federal Aviation Administration (FAA). Both also advocate for amateur rocketry hobbyists and do some of the regulatory work required for safe, legal launches. Generally, the FAA governs where, when, and how high rockets can fly, and the ATF and NFPA govern the storage and use of propellants.

3.3 CERTIFICATIONS

LOW-POWER

Most motors that have an impulse class from A to G can be flown without a certification. A few F and G motors require certifications, but cannot be used for a certification flight because their average thrust exceeds 80 N. These launches do not require a waiver. In order to acquire a higher level certification, a rocket must be flown by a member of Tripoli or NAR with a designated impulse class motor associated with each level, as well as some other requirements which can be found below.

JUNIOR CERTIFICATION PROGRAMS

For rocketeers between 14-17 years old, NAR offers a Junior Level 1 certification, which is nearly identical to a typical Level 1, but requires a written test to be passed. Tripoli has a similar program, with a few differences: The age range of this program is 12-17 years old, and any motor that is below the certification of the mentor can be flown with the mentor present at the launch.

3 | MOTOR CLASSES AND CERTIFICATION *(continued)*

LEVEL 1

A motor with an impulse class of H or I, as well as any motor up to I with over 80N of average thrust, can be flown with an Level 1 certification. In order to get a Level 1 certification, a rocket must be flown by a Tripoli or NAR member with a motor of impulse class H or I, it must have a successful parachute deployment, must be recovered successfully, and must land in a condition where it could get a new motor and re-fly with very few modifications. A typical Level 1 rocket is 2.5 to 4 in. in diameter, 3 to 5 ft. tall, and will fly to anywhere between 1,500 and 4,000 ft.

LEVEL 2

A motor with an impulse class of J through L can be flown with a Level 2 certification. The requirements to get this certification are the same as a Level 1, with the addition of a written exam that must be taken prior to the flight.

LEVEL 3

The process of getting an L3 is significantly more involved and expensive than the preceding levels. Like a Level 1, a rocket must be successfully built & flown, but the impulse class of the motor must range between M-O. Additionally, Level 3 certification includes an application process and certification package that must be approved before launching the rocket. More detailed information on the requirements for certifications can be found on the Tripoli and NAR websites.

CERTIFICATION REQUIREMENTS

Check the links below to find certification requirements for NAR and Tripoli!

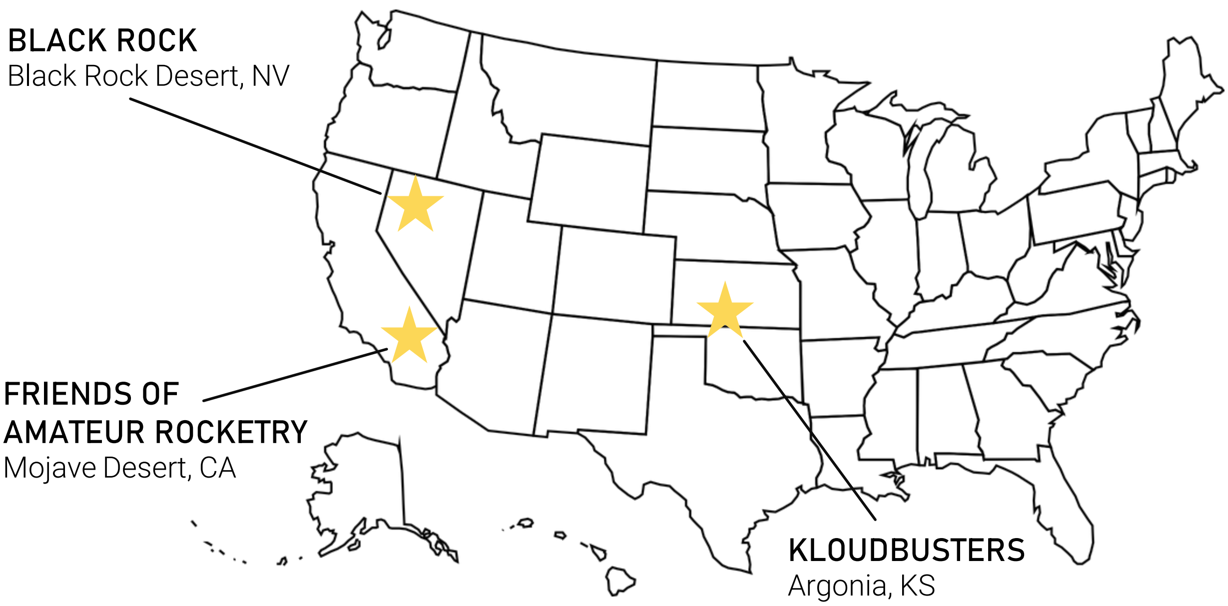
NAR: https://www.nar.org/high-power-rocketry-info/

TRIPOLI: http://www.tripoli.org/Certification

3 | MOTOR CLASSES AND CERTIFICATION *(continued)*

3.4 ROCKETRY CLUBS

Both Tripoli and NAR have local clubs across the United States that provide communities for rocketeers and organize launches. All Tripoli clubs hold high-power launches, but some NAR clubs are low-power only. Be sure to check their website to confirm. Typically, local clubs host launches monthly. Each launch will have something called a launch waiver, an agreement with the FAA that dictates the maximum launch altitude (ranging from hundreds to thousands of feet) and the launch window, which is the range of time launches are allowed. Check a club's website to see when they take place. Rocket launch sites generally have to be far away from major population centers, so driving 1-4 hours is typical for a "local" launch. If a club's website looks like it hasn't been updated in a while, don't hesitate to reach out to the club leadership via email. Often, the people running the actual launches are different from those maintaining the website. A map of some well-established launch sites is shown below.



FINDING CLUBS AND EVENTS

Check the links below to find a club or rocketry event near you!

CLUBS

NAR: https://www.nar.org/find-a-local-club/nar-map-locator/

TRIPOLI: http://www.tripoli.org/Prefectures

EVENTS

NAR: https://www.nar.org/events/

TRIPOLI: https://bit.ly/398Rh8G

4 | PREPARING TO BUILD YOUR ROCKET

To build a rocket, you can choose to purchase a **kit** with almost all of the parts ready for you, or do a **scratch-build**, which requires more design work up front. This section will discuss which parts to get, where to find them, making your own build plan, safety information, and buying motors. It does NOT go over exact details of building the rocket, which can be found in the upcoming build guide or in some resources below.

4.1 SOURCING PARTS AND TOOLS

For a basic Level 1 certification rocket, typical materials include: cardboard tubes, plywood fins and centering rings, and a plastic nose cone. Many rocketeers choose use a kit for their certification rockets.

If you choose to scratch build a Level 1 vehicle, components can be purchased at LOC Precision, Madcow Rocketry, and Balsa Machining. To lower the costs of your rocket, making rockets from shipping tubes is a viable option. 3 in. and 1.5 in. shipping tubes typically have the same inner diameter as 3 in. and 38mm standard rocketry tubing, respectively. Uline provides bulk shipping tubes, safety gear, and other build equipment.

Kits are available from a variety of suppliers and include most of the parts required to build the rocket. Vendors of cardboard kits include: LOC Precision, Madcow, and Apogee. Some common Level 1 certification kits are an Apogee Zephyr or a LOC EZI-65. These vendors are not necessarily affiliated with HNS, and there are many more options to choose from.

Epoxy, a two-part adhesive stronger than typical glues, is typically not included with kits. For a basic cardboard rocket, essentially any structural epoxy will do and can be purchased at most hardware stores.

Sheet parts (fins, centering rings) are cut from plywood, typically ¼ in. or 6mm thickness with 5 or more plys. 3D printed nosecones are the standard for DIY builds where commercial nosecones are not used. 3D printed centering rings are also a viable option.

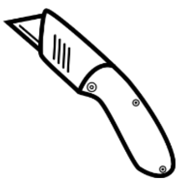
Kevlar shock cord is recommended; typically with 1,000-1,500 pound breaking strength (about ⅛ in. in diameter) for a basic Level 1, weighing 3-5 lbs. EmmaKites is a good source. Mirror clips are a good, cheap option for motor retention, so long as metal ones are used.

Parachutes can be hand made from ripstop nylon, but a commercial parachute is highly recommended. Top Flight Recovery is a good source for cheap, high-quality parachutes. It is possible to 3D print rail buttons/guides, but buying them from a rocketry vendor is recommended.

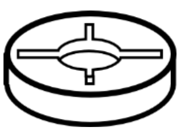
4 | PREPARING TO BUILD YOUR ROCKET *(continued)*

Some common **tools and equipment** required to build high-power rockets are:

DISPOSABLE CUPS AND POPSICLE STICKS to mix and apply epoxy

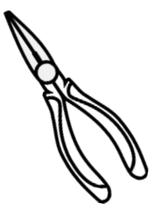


UTILITY KNIFE to make precise cuts in body tubes, tape, or other materials

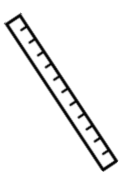


FIN ALIGNMENT JIG to ensure your fins are straight and evenly spaced

POWER DRILL for vent holes and shear screws

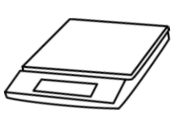


PLIERS for installing eye bolts and general use



RULER to ensure centering rings are installed correctly

MASKING TAPE for preventing epoxy from getting where it does not belong

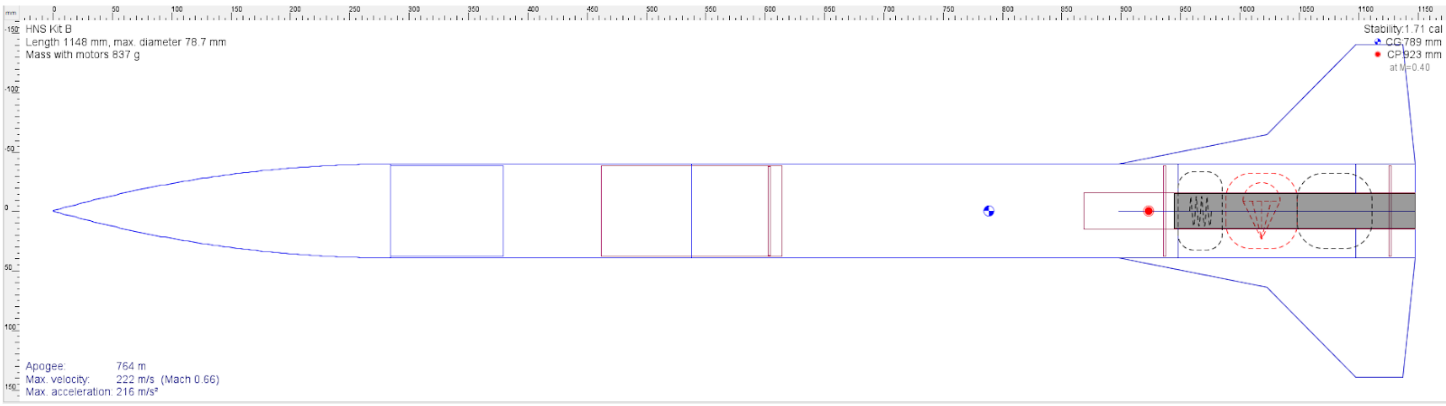


FOOD SCALE, for measuring epoxy mixtures

4 | PREPARING TO BUILD YOUR ROCKET *(continued)*

4.2 ROCKET SIMULATION SOFTWARE

Rocket simulation software is used to keep track of a rocket design and ensure that the rocket will fly well with different sizes and types of motors. This should be used for kits and scratch-builds, although for scratch-builds it is *required* to check the rocket's stability *before* buying parts. Two common simulators are Rocksim and OpenRocket. Some resources and tutorials are at the end of this section. OpenRocket is one of the only free rocket simulation tools and is widely used in the community.



Manufacturers may have a simulation file provided for their kits. OpenRocket can open files with either .RKT and .ORK extensions, while Rocksim can only open .RKT files. If a simulation file for a kit is not available from a manufacturer, it can commonly be found on https://www.rocketreviews.com/.

While building, update your simulation based on the actual weight of your components, their location in the rocket, motor availability, and any additional components or features you added during the build. Re-running simulations is important to ensure you can accurately predict CP and CG locations, maximum altitude, and speed.

For higher, faster flights, fins should be as straight as possible and the body tube should be sanded smooth. In simulations, try changing the fin profile to "rounded" instead of "square." Slight fin misalignment or a camera attached to the side of a rocket do not cause major issues, but will increase the overall drag on the rocket and reduce performance.

- Comparison between OpenRocket & Rocksim: http://wiki.openrocket.info/Feature_comparison
- OpenRocket Tutorial: http://wiki.openrocket.info/
  Rocksim Tutorial: https://www.apogeerockets.com/RockSim/RockSim_Video_Tutorials.

4 | PREPARING TO BUILD YOUR ROCKET *(continued)*

SIMULATION QUICK LINKS

Check the links below to learn more about the software discussed here!

- Comparison between OpenRocket & Rocksim: http://wiki.openrocket.info/Feature_comparison
- OpenRocket Tutorial: http://wiki.openrocket.info/
- Rocksim Tutorial: https://www.apogeerockets.com/RockSim/RockSim_Video_Tutorials.

4.3 SCRATCH-BUILD DESIGN RULES

Rocketeers learn a lot from experience, and some knowledge is widely known in the community. This list of rules of thumb is meant to give you some of the key points. Most of these are design rules for use in scratch-builds.

- Body tube diameter and length are some of the first design decisions; if the diameter of the motor is known, a rocket diameter is generally about twice the motor diameter

- Use parts that are easy to find or *slightly* modify; for example, body tubes have set sizes, and motor mount tubes have set sizes (29mm, 38mm, etc.)

- Double check your units- tube diameters are sold in both inches and millimeters

- The largest concern when designing a rocket is the stability of the rocket in flight; size the fins *after* deciding the tube length and diameters

- A thrust-to-weight ratio (TWR) of ≥ 5 is recommended for stable flight; this affects motor selection

- Minimum off-the-rail velocity should be 45 ft/s (~14 m/s)

- A stability margin of 1.0 - 2.0 is recommended for subsonic flight

- Typical length for a shock cord is between 3-5x airframe length

- Safe descent rate under parachute is typically 20-24 ft/s (6 - 7.5 m/s)

- A typical Level 1 rocket is 3 or 4 in. in diameter with a 29mm or 38mm motor mount.

- Generally, more rocketeers use OpenRocket to run simulations.

4 | PREPARING TO BUILD YOUR ROCKET *(continued)*

4.4 PLANNING YOUR BUILD

Planning each step of the build helps save time later in the build process, reduce stress, and help you be more flexible if something goes wrong. Manufacturing plans will also help ensure that you know what materials you need and how long each task will take.

TO DEVELOP A BUILD PROCEDURE:

Read the rocket kit instructions and watch any associated videos. This will help familiarize you with building the rocket and you'll be able to get a sense of how all the parts fit together. Some examples include:

1. Apogee Components HPR Intro Video: https://youtu.be/FbLVOOfxvig
2. Apogee Components Level 2 Build Series:
3. https://www.youtube.com/playlist?list=PLmJQzoMsBYwPHD4tYvA3ipvWfFkQybsqZ
4. John Coker Assembly Video: https://youtu.be/Xtr3758PvzA

Even if your kit comes with instructions, you should use what you learned to make your own plan! This can be as simple as a written checklist or Google document. If the instructions you're using need more detail, you can add this to your own plan.

Timing is key. For each step, think about how much time you think it will take to complete, and think ahead about time-sensitive components. For example, if you're gluing on a fin with 5-minute epoxy, make sure everything is easy to reach, including a way to wipe it off before it dries if you mess up. Consider attaching only one fin at a time. Also, if it's your first time, it'll probably take twice as long as you think, and that's ok! You'll get faster as you get more experience. If you're not sure how long something will take, you can watch YouTube videos or ask someone who's done it before.

Make sure you have all the materials you need before starting a step. If you're ordering parts, keep track of how long they will take to arrive as this may affect the order in which you can build different parts of your rocket.

4 | PREPARING TO BUILD YOUR ROCKET *(continued)*

4.5 SAFETY

Rockets are lots of fun, but with great fun comes great responsibility. It's important to get familiar with the materials being used and to make sure the correct safety measures are taken during assembly. A commonly-used term for safety gear is personal protective equipment (PPE), such as gloves or safety goggles. It's essential to know what PPE is required for each material you work with, so that you can stay safe while building your rocket. Another phrase you're likely to hear often is Safety Data Sheet (SDS), which contains information on materials, what dangers and risk they pose, and what to do in case of an incident.

Common safety risks of rocket construction include:

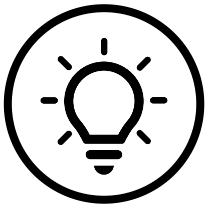
- Breathing in particulate matter from sanding
- Breathing in chemical vapors
- Skin/eye contact with solvents
- Working with power tools
- Working with razors

A lot of risk in rocketry can come from exposure to harmful materials. The table below describes some common rocket materials and how their risks can be mitigated.

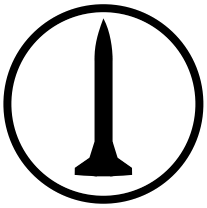
MATERIAL	USE	REQUIRED PPE	RISK WITHOUT PPE	EXAMPLE SDS
Acetone	Epoxy cleanup	Gloves	Skin contact: irritation Inhalation: dizziness and headaches	Acetone SDS
Black powder	Ejection charges	Gloves, safety glasses, spark-free tools	Fire hazard	BP SDS
Carbon fiber	Body tubes, fin reinforcement, bulkheads	Gloves, respirator, long sleeves	Carbon fiber dust can cause skin and lung irritation	CF SDS
Epoxy	Composite bonding and layups	Respirator, gloves	Extremely sticky; can develop an allergy with time	Rocket Poxy SDS
Fiberglass	Body tubes, fin reinforcement, bulkheads	Gloves, respirator, long sleeves	Fiberglass dust can cause skin and lung irritation	Fiberglass SDS

4 | PREPARING TO BUILD YOUR ROCKET *(continued)*

Another incredibly important safety area is rocket motor handling. Rocket motors store a lot of energy and should be handled with caution. The safety practices listed below will ensure that your motor maintains its quality and remains safe.

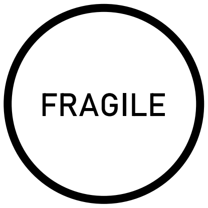


Store in a cool, dry environment. Cycling motors between hot and cold can degrade the motor.

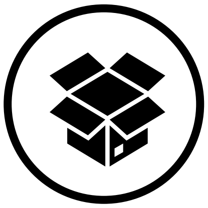


Never insert a rocket motor ignitor until the rocket is on the launch pad.

Do not store near heat sources, open flames, or electrical devices that could create sparks.



Handle the motor with care. Dropping the motor can damage it, and older rocket motors should be used with caution.



Keep the rocket motor in its original packaging until needed. It prevents static electricity and is safer to store in.

4.6 OBTAINING MOTORS

There are three major manufacturers of high-power rocket motors: **Aerotech**, **Cesaroni**, and **Loki** (*Note: Loki motors are not sold in California*.) Most high-power rocket motors are "reloadable," meaning that they require a reusable casing as well as a "reload" containing propellant and single-use components (i.e. a nozzle). Single-use motors are usually pre-assembled, just like their low-power counterparts. Reloadable motors are generally cheaper per launch, but require the upfront cost of the casing. A single reloadable casing usually takes about ten flights to break even on cost compared to an equivalent disposable motor, however, reloadable motors tend to also have a wider selection of motors with different effects and thrust profiles. Aerotech is the only manufacturer that makes single-use high-power rocket motors with their "DMS" (Disposable Motor System) line.

Note: There is a second category of single-use motors known as "loadable" motors. These motors must be assembled by the user, but are usually even cheaper than pre-assembled single-use motors. On a motor's designation, they are sometimes denoted by a "/L" at the end. Example: G77-R7/L

Most clubs have a local vendor that sells rocket motors at launches, but it is recommended to reach out to the club or vendor ahead of time to inquire about availability. Buying from a local vendor is far more convenient and avoids hazardous material shipping charges (HAZMAT charges) on larger motors.

4 | PREPARING TO BUILD YOUR ROCKET *(continued)*

If there isn't a vendor at your launch site, you will have to buy a motor online . Buying online is usually significantly more expensive because most high-power motors are subject to HAZMAT shipping fees. However, both Loki and Aerotech have options for Level 1 and even some Level 2 motors that can be shipped without paying HAZMAT fees. For motors that do require it, the fee is typically $35 and independent of the number of motors ordered. Paying $35 in mailing fees on top of overall cost for one motor isn't ideal, but if a group is ordering 10 motors at once, $3.50 per motor is more reasonable. HAZMAT fees are charged by the shipper, there is nothing that the vendor can do about it.

Below are links to pages from each high-power motor manufacturer listing all their dealers:

ROCKET MOTOR DEALERS

Check the links below to find motor dealers for each of the major manufacturers!

- Aerotech: http://www.aerotech-rocketry.com/dealer.aspx
- Cesaroni: http://pro38.com/dealers.php
- Loki: https://www.lokiresearch.com/page/Dealers

5 | LAUNCH DAY

Launch Day can be both a thrilling and chaotic experience. Throughout the day, rocketeers will launch from several pads to punch their ticket to the sky. Most rockets will return to fly again, some will fly for the last time, and a few fail in spectacular fashion. Embrace it, enjoy it, and be safe.

This section discusses getting ready for a launch, doing final preparations, flying the rocket, and earning your L1.

5.1 BEFORE YOU LEAVE

When preparing for launch day, a packing list is essential. Assume the rocket will break -- somehow -- before getting to the pad, and it will need to be fixed at the launch site. Here are some of the common things to bring (see Appendix A for a full list):

• Rocket stuff: The Rocket, all the tools (*seriously, all of them*), razor blades, drill, epoxy, extra bowls for epoxy, tape, spare parts, motor drilling tool, etc..
• NAR / Tripoli membership card or ID #, Certification paperwork, launch fees.
• Human stuff: a friend (or several), trash bags, water, lunch, boots, sun hat, jacket, folding table, chairs, sunscreen, bug spray, pen and paper, etc..

Some of this information will require some research on a local site. Double check that the site will have a motor vendor there (if needed), and if any launch fees are necessary.

Launch day will be outdoors for most of the day. Check the weather for the launch to gauge temperatures and winds (important for launch too). Consider bringing gear for the weather and the terrain (e.g. a jacket and pants make searching for rockets in a cornfield much easier). It is often a long day so snacks, extra water, and a caffeinated beverage can go a long way.

Write a packing list and check everything when it enters the car. Almost everyone has a story of the time they forgot a critical tool and started driving, and it's never any fun!

5.2 ARRIVAL AND MEETING CLUB MEMBERS

After arriving at the launch site, find some members of the club you're launching from and figure out how to register and pay launch fees, if necessary. Most clubs log who comes and flies during a given launch weekend. Find the vendor (if any) to pick up any last-minute items, including the motor. Last, find the Range Safety Officer (RSO) and Launch Control Officer (LCO) and introduce yourself. They will give you a flight card and be a useful resource in finding someone to certify your flight.

For NAR, two Level 1 members or one Level 2 member can certify a Level 1 flight. The certification team will conduct a pre-flight certification check to verify with the flier that the rocket is safe and flight-ready. They also review the rocket immediately after flight to make sure it is reflyable, and if so, sign the paperwork for certification. Tripoli is very similar, except the certification team is a single Prefect, Director, or TAP (Technical Advisory Panel) Member, and the paperwork is slightly different. Both are linked below:

CERTIFICATION FORMS

Check the links below to get a blank certification form!

NAR: https://www.nar.org/wp-content/uploads/2020/10/HPR-APPL-2020-V1.pdf
TRIPOLI: http://www.tripoli.org/Portals/1/Documents/Certification/Universal_Certification_Form.pdf

5.3 SETTING UP AND COMPLETING YOUR ROCKET

Once all the club logistics are sorted, you're free to finish preparing your rocket. It's important to set up a useful workspace to finish the rocket and/or assemble the motor in. The following will help:

- If using the back of a car, try to put down a protective layer. Black powder residue after launch can get stuck in fabric and will leave an odor.
- During the day, have someone remind you to take breaks to eat, drink, and put on sunscreen.
- Somewhere shady to rest from time to time.

Once the workspace is set up, complete your pre-flight checklist (See Appendix B).

When your rocket is ready, present it to the Range Safety Officer and the person certifying the flight so they can confirm the rocket is flight-ready. They will check things such as: the motor retention, coupler fit, rail guide security, and fin strength. This is not a test; this is just to make sure the flight will be safe. If you are attempting a certification flight, there will be some additional questions and a certification form to fill out.

5.4 LAUNCH

After the pre-flight check, find the LCO or pad assignment table to receive your pad number. Wait for the range to be "open" to walk to the pad. To put the rocket on the pad, most rails tilt at the base or the entire base moves. Tilt the rail away from the crowd, never towards the spectators. Slide the rocket onto the rail, making sure not to let go (this helps protect the rail guide attachment points). Tilt the rail back to a vertical position. The rail should be as straight as possible, or facing a couple of degrees away from the crowd.

At this point, turn on the flight computers (if any) and confirm all charges are connected correctly inside. The last thing to do before leaving the launch pad is install the ignitor. Strip the leads about 4", then push the ignitor up into the motor carefully until it stops. Use tape or the motor cap to hold the ignitor in place. Finally, clip the ignitor leads into the launch system, making sure the clips are not making contact with any metal materials. Most launch systems have a continuity check feature; use that feature to make sure the ignitor is properly connected. Make sure to take a picture with the rocket before leaving!

The LCO will typically wait for several rockets to be ready and launch them one after the other, announcing each. During the flight, it's usually more fun to watch with your own eyes rather than focus on getting the perfect video. Keep a close eye during flight, and watch for "events" like chute deployment. Pointing at the rocket makes it easier for people around you to also follow it if it drifts far away. Once you see the rocket land, mark a long line in the dirt or sand (or other method) so that you know what direction to go for recovery.

5.5 RECOVERY AND POST-LAUNCH OPS

Once the rocket lands, assess how far away it is and plan accordingly. Most Level 1 rockets land within a 30-minute walk (round-trip), unless it's a windy or high flight. If you know where it landed, post-launch is a very good time to take a few minutes' rest after the adrenaline of launch. Bring water, some snacks, a friend, and a phone. Wait for the range to be opened by the LCO, tell the LCO where you're going, and pick up the rocket! Once the rocket is found, take some pictures of it and carefully reassemble it enough to carry it back. Immediately bring over the people certifying the flight for a post-flight inspection and they will do the same set of checks as pre-flight.

6 | LEVELING UP

6.1 NOW WHAT?

Congratulations, and welcome to high-power rocketry!

From here, you can learn lots of different skills. Fly using flight computers, go for a supersonic flight, fly to higher altitudes, design fantastic art for your rockets, add cameras, and fly sentimental or science payloads in an enclosed section. Build documents from successful Level 3 projects are a good source for design ideas and methods for future build skills. Some skills to learn include:

- Fiberglass and/or carbon fiber manufacturing techniques
- Simulation software for supersonic flights: RASAero
- Avionics (electronic flight computers)
- Dual deployment (deploy a small chute, then a big one to reduce drift distance)
- 3D printing rocket parts
- Artful designs, add LEDs (light-emitting diodes)
- Multi-stage rockets

Using avionics to deploy parachutes is the next major skill in high-power rocketry. There are several commercially available flight computers and avionics bays to help store them on a rocket. Making custom avionics is possible, but difficult.

6.2 LEVELS 2 AND 3

With a Level 2 certification, it's possible to take on more challenging and exciting projects. Flying J, K, and L-class motors opens up LOTS of options (e.g., rockets up to ~50 lbs and altitudes up to ~40,000 ft are possible). At this level, it will be harder to find launch sites for higher flights. A Tripoli Level 2 certification is required to start doing experimental propulsion. To earn a Level 2 certification, both NAR and Tripoli require a written exam in addition to a near-identical build and launch process as the Level 1.

A Level 3 certification allows experienced rocketeers to fly heavier, faster, and/or more complex rockets. The types of projects flown are similar to a Level 2, but to a higher degree of difficulty. It's recommended to do several flights of a Level 2 scale before moving to a Level 3. At this scale, rockets have the capacity to reach the edge of space.

Earning a Level 3 will require a lot of planning, preparation, and some new skills. A flight using flight computers to deploy parachutes is required prior to certification flight, and the Level 3 rocket will likely have fiberglass parts. Level 3 certification also requires a written project plan to be submitted ahead of time to certified rocketeers: either a Level 3CC member (NAR) or two TAPs (Tripoli). Your approver must also attend the launch.

LEVELS 2 AND 3 INFO

Check the links below to learn more about Level 2 and 3 certifications from NAR and Tripoli!

LEVEL 2

NAR: https://www.nar.org/high-power-rocketry-info/level-2-hpr-certification/
TRIPOLI: http://www.tripoli.org/Level2

LEVEL 3

NAR: https://www.nar.org/high-power-rocketry-info/level-3-hpr-certification/
TRIPOLI: http://www.tripoli.org/Level3

6.3 YOUR JOURNEY

Rocketry is an incredibly rewarding activity, one that brings together art, science, design, and nature in a spectacular display of ingenuity and perseverance. The sport has grown and incredibly strong and supportive community whose members are dedicated to their collective progress. As you begin or continue your journey in high-power rocketry, keep asking questions. The answer just might be among the stars.

APPENDIX A: EXAMPLE LAUNCH PACKING LIST

- Membership card (NAR or Tripoli)
- Certification paperwork
- Completed rocket
    - Nose cone, fin can, parachute, shock cord, quick links
- Motor, not loaded
    - Motor casing, if applicable
    - White lithium grease if reloadable motor
    - Delay tool (if you need to adjust your delay grain)
- Parachute protector
    - Nomex or dog barf
- Small screwdrivers
- Cordless drill, charged
- Sharpie
- Painter's tape
- 5-minute epoxy (with gloves, paper cups and popsicle sticks for mixing)
- Electronics, if applicable
- Charged batteries, if applicable
- Shear screws, if applicable
- Folding table
- Folding chairs
- Pop-up canopy, recommended
- A friend (or several)
- Trash bags
- Water
- Extra water
- Caffeinated beverage
- Lunch
- Paper Towels
- Sunglasses
- Sunscreen
- Boots
- Sun hat
- Jacket
- Bug Spray
- Pen & Paper

APPENDIX B: EXAMPLE PRE-LAUNCH CHECKLIST

1. Before doing final preparations on the rocket, find who will be certifying your rocket. Discuss what parts, if any, of the final preparations they would like to witness. If this is your first time using a reloadable motor, they may want to offer guidance on the process.

2. Prepare the motor according to the directions. As needed, drill the delay grain and add the proper amount of black powder to the charge well.

3. Install the motor in the rocket, securing it with the motor retention method.

4. Fold the parachute so it slides smoothly out of the body tube.

5. Put as much of the shock cord as possible in the parachute bay before the parachute. You want the parachute to be the first thing coming out of the tube.

6. Add “dog barf” recovery wadding if needed, or wrap the Nomex cloth around the parachute to protect it.

7. Add the parachute to the rocket, then seal the parachute bay with the friction fit coupler or shear screws.

    a) If using a friction fit, hold the top of the rocket and shake. The rocket should not separate. If it does, add tape to the coupler to make the fit tighter.

8. Once the rocket is ready for flight, re-measure your Center of Gravity (CG) just in case you missed anything in your initial estimates. You can do this by balancing the rocket lengthwise on your hand to see if the CG location matches your simulation.

9. Make sure a flight card is filled out properly for the flight, and the rocket is ready!

APPENDIX C: DETAILED GLOSSARY OF TERMS

Acetone – Volatile, colorless liquid solvent. Used commonly in nail polish remover and other household products, to dissolve epoxy, and to thin paint and other solutions.

Adhesive – Substance used to bond objects/materials together; glue.

Aerodynamics – The study of how air interacts with moving bodies.

Aft – Away from the rocket's nose; the opposite of forward.

Altitude – Height above a certain level, especially sea level.

Apogee – The maximum altitude the rocket reaches during flight.

Avionics (flight computer) – Used to measure altitude, deploy parachutes, and do thrust vector control for advanced flights. They are NOT required for a Level 1 certification.

Black powder (gunpowder) – Explosive made of a mixture of sulfur, carbon, and potassium nitrate. Used commonly in ejection charges. The most common and reliable method of ejecting a parachute from a high-power rocket.

Body length – Total length of the rocket, from the tip of the nose cone to the end of the rocket.

Body tube (airframe) – The main structure of the rocket, which holds the motor, parachute, electronics and related components inside.

Bulk – Items that are sold in large quantities, usually at a reduced price.

Bulkhead – A plate that blocks transfer of gases between sections of the rocket, or to be used for mounting of components such as recovery hardware or electronics.

Burn time – Refers to the length of time that a rocket motor burns once ignited, measured in seconds.

Carbon fiber – A strong, lightweight material made of carbon atoms bonded together to form a long chain. Commonly used in aerospace structures.

Center of gravity (CG) – The CG is the average location of the weight of a rocket. As a model rocket flies through the air, it rotates about its CG.

Center of pressure (CP) – The CP is the location along a rocket's body where the sum of aerodynamic forces acts. This is important for understanding the stability of a rocket.

Centering ring – Used to hold the motor mount in the middle of the rocket. They are mounted inside the body tube and around the motor mount.

Certification – The process of building, flying and recovering a rocket in reflyable condition in order to get certified by a governing organization (i.e., NAR or TRA). Certification permits individuals to purchase and use rocket motors for high-power rockets.

APPENDIX C: DETAILED GLOSSARY OF TERMS

Composite – A material produced from two or more constituent materials that have different chemical/physical properties. In rocketry, common composite materials are fiberglass and carbon fiber.

Coupler – A piece of tube that connects two sections of the rocket which are generally the same diameter; the outer diameter matches the inner diameter of the body tube.

Delay modifier – A tool used to remove material from an ejection charge, which changes the ejection.n charge delay

Deployment – The ejection of a parachute from a rocket, which is then used to recover the rocket.

> *Single deployment* – consists of a single parachute, deployed from inside the rocket
>
> *Dual deployment* – deployment of a small drogue parachute, followed by a larger, main parachute

Descent – Rocket's motion from apogee until landing, slowed by a parachute.

Descent rate – The rate at which a rocket moves from apogee to the ground, usually measured in meters per second (m/s) or feet per second (ft/s).

Diameter – Length of a straight line passing from side to side through the center of a circle or sphere.

Director – In charge of local clubs associated with certification organizations (NAR/TRA).

Drag – The force of the air on the rocket opposite the direction of motion.

Drogue chute – Small parachute used to slow the descent of a rocket; used for higher altitude flights because they have low drag, which allows the rocket to descend quickly before the main chute is deployed.

Ejection charge – An ejection charge is a small pyrotechnic device that deploys your parachute.

Ejection charge delay – Delay between burnout of the motor and firing of the ejection charge (measured in seconds).

Energy – The capacity for doing work; exists in many forms, including potential, kinetic, thermal, electrical, and chemical (in the case of rocket motors).

Epoxy – A two-part adhesive stronger than typical glues. It is sold with different cure times, ranging from 5 minutes to 24 hours. Longer cure times are usually stronger.

> *Structural epoxy* – type of epoxy that forms bonds that will bear considerable loads

Eye bolt – A metal part that connects the shock cord to the rocket body. These are often attached to a centering ring or a bulkhead.

APPENDIX C: DETAILED GLOSSARY OF TERMS

Fiberglass – Textile (fabric) made from woven glass filaments, commonly used as a material in aerospace.

Fins – Provide aerodynamic stability while the rocket is in motion, such that the rocket will fly straight. Fins can come in many shapes and sizes, where some are designed for performance and others for aesthetics. Fins usually go through the wall of the body tube for extra strength.

Fin alignment jig – Device used to keep fins aligned when bonding them to the rocket's airframe

Flight profile – Graph or diagram showing the expected flight parameters of a rocket based on its geometry, motor used, and weather conditions. Includes altitude (and expected apogee) and speed vs. time.

Force – That which can cause an object with mass to change its velocity (i.e., to accelerate).

Forward – Towards the rocket's nose; the opposite of aft.

High-power rocketry – Hobby similar to model rocketry, but higher impulse range motors are used.

Ignitor – Device through which current is passed, to electrically ignite a rocket motor.

Impulse – A rocket motor's impulse is calculated by multiplying its thrust (measured in Newtons (N), a unit of force) by its burn time (measured in seconds). This value is used to classify the motor's power and define its impulse class. Impulse is reported in units of Newton-seconds (N·s) or lb-seconds (lb·s). For example, A 10N force applied over 10 seconds would have an impulse of 100 N·s.

Impulse class – The letter that represents a certain impulse range. From letter to letter (starting from 'AA'), the impulse doubles. For example, a "G" class motor ranges from 80.01 to 160 N·s. An "H" class motor ranges in impulse from 160.01 to 320.0 N·s.

Kevlar – Synthetic heat-resistant fiber with high tensile strength, commonly used as shock cord.

Launch Control Officer (LCO) – The person at a launch who operates the launch pads. They also announce when a launch is about to happen, and whether the range is open or closed for rockets.

Launch lug– Tubular component attached to the airframe of a rocket, used to interface the rocket with its launcher and keep the rocket flying straight as it takes off from the rod. Comes in a few main styles and sizes depending on the launch pad being used.

Launch pad – Platform from which a rocket is launched.

Launch rail – Metal structure that holds a rocket upright before it launches; 1010 rails are the standard for high-power rocketry. Rockets that use rail buttons slide over the rail.

Launch rod – Metal structure that holds a rocket upright before it launches. Rockets that use launch lugs slide over the rod.

APPENDIX C: DETAILED GLOSSARY OF TERMS

Launch waiver – Each launch club submits a waiver which allows rocketeers to fly at their launch site to a certain height above ground level for a certain window of time. "How high is the waiver?" usually refers to the *maximum altitude allowed at a site*.

Launch window – The times launches are allowed on launch day.

Low-power rocketry – Rocketry involving lower impulse class motors; doesn't have any age or ability requirements.

Main chute – Larger than the drogue chute, deploys after the drogue chute to slow the rocket until it lands (for dual deployment).

Mass – A measure of the amount of matter in an object, usually measured in grams (g) or kilograms (kg).

Motor – Rocket component consisting of fuel and an oxidizer, ignited to produce hot exhaust that creates thrust, propelling the rocket forward. See also: ***Propellant.***

Motor case – Contains the combustion gases as the propellant burns, protecting the rocket and allowing pressure to build, such that hot gases will be sent through the nozzle; usually an aluminum or steel.

> *Reloadable casing* – Motor case that can be reused.

Motor mount – A smaller tube mounted inside the rocket to hold the motor inline with the body tube.

Motor retention – Motor retention is used to keep a rocket motor safely inside the rocket, especially once the ejection charge fires and deploys the parachute. Without proper motor retention, the ejection charge could cause your motor to be ejected as well, which disqualifies a certification.

National Association of Rocketry (NAR) – One of the two major organizing bodies for high-power rocketry, gives individuals certifications to be able to fly high-power rockets. See also ***Tripoli Rocketry Association.***

Newtons – *Unit of force (unit = N for Newton); equal to the force that would give a mass of 1 kilogram an acceleration of 1 meter per second per second (1 m/s^2).*

> *Newton-seconds* – *(unit = N*s) The unit used for impulse.*

Nose cone – The top of the rocket, shaped so air will flow smoothly around the rocket. Nosecones typically follow a conical, tangent ogive, elliptical, or Haack shape. For more information, see https://en.wikipedia.org/wiki/Nose_cone_design.

Nose cone shoulder – Section of the nose cone (usually straight) that holds the nose cone to the top of the rocket.

Nomex (dog barf) – Heat-resistant material commonly used to protect parachutes from the hot gases generated from a rocket motor.

APPENDIX C: DETAILED GLOSSARY OF TERMS

Nylon – Synthetic polymer; durable, flexible, with excellent strength. Commonly used material for parachutes and shock cord.

> *Ripstop nylon* – Lightweight nylon fabric with threads in an interwoven pattern; commonly used in shock cord.

Off-the-rail velocity – The velocity that the rocket reaches when it leaves the launch rail or rod.

OpenRocket – Free model rocket simulator software that allows one to design and simulate rockets before actually building and flying them.

Pad – see ***Launch pad.***

Parachute – Slows the descent of the rocket as it falls from its apogee. Some rockets may use multiple parachutes to slow the rocket even further, where a drogue chute is a smaller parachute that allows the rocket to fall faster and is accompanied by a main parachute that deploys closer to the ground.

Particulate matter – Mixture of solid particles and liquid droplets found in the air; exposure to such particles is harmful for lungs and other organs. Examples include dust, dirt and smoke.

Personal protective equipment (PPE) – Equipment worn to minimize exposure to hazards that would otherwise cause injuries. Examples of PPE include gloves, safety goggles, lab coats, and respirators.

Plywood – Material made of thin layers or “plies” of wood veneer. Common material for model rocket fins.

Prefect – Member of certification organizations (NAR/TRA) with the authority to certify individuals (L1-L3).

Pressure – Perpendicular force per unit area.

Propellant – Rocket fuel. For high-power rockets, this is almost always APCP (Ammonium Perchlorate Composite Propellant).

Rail – see ***Launch rail.***

Rail buttons – Button-shaped component attached to the airframe of a rocket, used to interface the rocket with its launcher and keep the rocket flying straight as it takes off from the rail. Comes in a few main styles and sizes depending on the launch pad being used.

Rail guides – Romponents secured to the airframe of a rocket that help guide the rocket during its first few feet of flight until the rocket is moving fast enough to be stabilized by fins. See also ***Rail buttons.***

Range Safety Officer (RSO) – The person at a launch makes sure if each rocket is safe to fly. They have the authority to not allow flights if they are deemed unsafe.

RASAero – Simulation software for model and high-power rockets; used for both aerodynamic analysis and flight simulation.

APPENDIX C: DETAILED GLOSSARY OF TERMS

Recovery – The process of getting a rocket back after launch, including tracking and retrieving the rocket.

Respirator – Type of PPE worn over the head; protects individuals by removing contaminants from the air. There are two types: particulate respirators, which filter out airborne particles, and "gas masks" that filter out chemicals and gases.

Ripstop – see *Nylon.*

Rocket fuel – see *Propellant.*

Rocksim – Simulation software for designing and simulating rocket flight. Free for a 30-day trial period, then costs $124.

Rod – see *Launch rod.*

Safety Data Sheet (SDS) – A document that lists information relating to safety and health.

Shear screws – One-time use screws used to attach parts of a rocket together until the parachute is deployed.

Shock cord – Holds the sections of the rocket together after an ejection charge has been set off, generally between the nose cone and a bulkhead inside the body tube. It is usually 3-5 body lengths long. It is also usually the attachment point for the parachute.

Simulation software – computer program used to design model rockets and output information on a rocket's flight profile, aerodynamic properties, motor performance, etc. The exact capabilities depend on which software you're using. See *OpenRocket, RASAero,* and *Rocksim.*

Staging (rocket stage) – the combination of one or more rocket sections that fire in a specific order and then detach. Rockets with one section are single-stage, and two or more sections are multi-staged.

> *Single-stage rocket* – rocket that uses a single rocket motor or cluster of motors to reach its desired altitude
>
> *Multi-stage rocket* – rocket that uses two or more rocket stages, each of which contains its own propellant. Once the first stage is ignited and the motor finishes burning, it separates from the vehicle and the second stage lights, and so on. Rockets contain multiple stages in order to go higher than single-stage rockets, since the total weight of the rocket reduces greatly as the rocket ascends.

Solvent – A substance that dissolves another substance (solute), resulting in a solution.

Stability – A rocket's level of stability refers to its ability to maintain a safe, straight flight. A rocket's *stability margin* is the distance between the rocket's center of pressure and center of gravity, divided by the diameter of the rocket. This number should be greater than 1 in maximum expected wind conditions.

Structural epoxy – see *Epoxy.*

APPENDIX C: DETAILED GLOSSARY OF TERMS

Subsonic – Refers to speeds less than the speed of sound, or Mach 1.0.

Supersonic – Refers to speeds greater than the speed of sound, between Mach 1.0 and Mach 5.0.

Technical Advisory Panel (TAP) – Members associated with a certification organization (NAR/TRA) to provide technical assistance and guidance to individuals building an L3 certification rocket. One TAP member must be present and witness the certification flight, and must witness the rocket ascend in a stable manner and descend in a stabilized manner controlled by the recovery system.

Thermodynamics – The study of the relationship between heat, work, temperature and energy.

Thrust – Thrust is the force generated by the rocket motor that propels a rocket upwards. Thrust is typically measured in Newtons (N), which represents the amount of force needed to accelerate 1 kilogram of mass at the rate of 1 m/s^2. Thrust can be quantified in pounds of thrust, in which a pound of thrust represents the amount of force needed to accelerate 1 pound of material at 32 ft/s^2.

Thrust ring – Typically added as part of the motor, whether it be a single-use 3D printed thrust ring or a reloadable casing. Transfers the force of the motor's thrust into the rocket.

Thrust-to-weight ratio (TWR) – Found by dividing the rocket's thrust by its weight. Values greater than 1 mean that the thrust is greater than the weight of the rocket. A TWR of 3 or more is required to fly under Tripoli, and at least 5 is recommended.

Thrust vector control (TVC) – The ability of a rocket (or other vehicle) to change the direction of the thrust from its motor in order to control the attitude or angular velocity of the vehicle.

Tripoli Rocketry Association (TRA) – One of the two major organizing bodies for high-power rocketry, gives individuals certifications to be able to fly high-power rockets. See also *National Association of Rocketry.*

Utility knife – Type of knife used for general manual work purposes, such as opening boxes. Generally have a retractable blade.

Velocity – The rate at which position changes, usually measured in meters per second (m/s).

Vent holes – Holes in the airframe of a rocket whose purpose is to allow the pressure inside the rocket to equalize to the outside (atmospheric) pressure.

Waiver – see *Launch waiver.*

Weight – The product of an object's mass multiplied by the acceleration acting on that mass (for objects on Earth, weight is their mass multiplied by the force of gravity, ~9.82 m/s^2).

3D printing – The action or process of making a physical object from a 3-dimensional digital model, typically from laying down many thin layers of material in succession.

ABOUT THE AUTHORS

This document was created through a collaboration between Hot Nozzle Society (HNS) and Students for the Exploration and Development of Space (SEDS). Hot Nozzle Society was formed as a result of a movement within the amateur rocket community that seeks to make rocketry more accessible to others, regardless of their skill or training. SEDS is an international student organization that aims to promote space exploration and development through educational and engineering projects. SEDS is fostering the development of future leaders and contributors in the expanding space industry.