

2022-2023



# Launch 2 Learn

## Introductory Rocket Workshop

### Handbook

Brought to you by Wisconsin Space Grant Consortium, Tripoli Rocketry Association and AIAA  
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## 2. Workshop Supply List

### 2a. Virtual Workshop

If you are attending a virtual workshop, you have received a supply box with all of the items required to build your rocket. **IT IS YOUR RESPONSIBILITY TO ATTEND THE LAUNCH 2 LEARN KIT REVEAL MEETING TO VERIFY YOUR SUPPLY KIT IS COMPLETE.** WSGC will issue missing components based upon the reveal meeting. A checklist is provided on the next page.

*If you are missing any items, email the Connie Engberg as soon as possible at [cengberg@carthage.edu](mailto:cengberg@carthage.edu) with the Subject Line: "Launch 2 Learn Workshop – Missing Supplies."*



Figure 2-1: Parts included with the LOC Precision – 3.10" Caliber ISP Rocket Kit (not including parts supplied by WSGC)

In addition to the supplies we provided, you will also need to secure a quiet workspace with ample table space, a computer with a camera and microphone, and reliable internet. If you have concerns about your ability to participate in the workshop, please contact us as soon as possible at [spacegrant@carthage.edu](mailto:spacegrant@carthage.edu).

### 2b. In-Person Workshop at your Campus

If you are attending an in-person workshop, the WSGC workshop leader will coordinate delivery of the supplies to your college/university and/or bring the materials and supplies listed below with an asterisk (\*). **You/Your Team will be responsible for providing all other materials and supplies:**

- Classroom/Workspace
- Computers
- RockSim (1-2 licenses)
- Table coverings
- Internet Access
- Projector
- Yard Stick
- Ruler(s)
- Drill(s)
- Screw Driver Set(s)
- Paper Towel

## 2c. Workshop Supply Check-List

ITEM DESCRIPTION:	QUANTITY:	RECEIVED:
Launch 2 Learn Handbook*	1	
Alcohol Wipes	15	
Awl, drill and bits	1	
Craft Sticks, Wooden	15	
Cups, Plastic	15	
18" Wooden Dowel	1	
Epoxy	1	
Nitrile Gloves	6 pr.	
Masking Tape	1	
Paper Plates	2	
Paper Towels	bundle	
Pencil	1	
Ruler	1	
Sandpaper	1	
Screwdriver set	1	
Table Covering	1	
Utility Knife	1	

*Table 2-1 Workshop Supply Checklist*

Workshop Supply Check-List (Continued)



PK-60

# **CALIBER-ISP™** **38MM**

**Height: 59.25"**  
**Weight: 29 oz.**  
**Diameter: 3.100"**

Flights to over 6,100 ft.

**Motor Suggestions:**  
**G80-4\*, H128-6\*,**  
**H242-8\*\*, I161-10\*\*, J90-10**

## **Kit Features Include:**

- Heavy Duty Airframe Tubing
- Precision Cut Plywood Fins & Rings
- Pre-slotted Airframe
- Plastic Nose Cone
- Payload Section
- Nylon Parachute Recovery
- Shock Cord Mount/Baffle System

VISIT [WWW.LOCPRECISION.COM](http://WWW.LOCPRECISION.COM)

- Assembly Instructions for all kits
- KITS & ACCESSORIES
- VINYL DECALS
- UPDATES



435A Factory Street . Plymouth, WI 53073  
920.892.0557  
[LOCprecision.com](http://LOCprecision.com)

**THANK YOU FOR CHOOSING LOC/PRECISION!**

Since LOC/PRECISION Cannot Control The Use Of Its Products Once Sold, The Buyer Assumes All Risks And Liabilities There From, And Accepts And Uses LOC/PRECISION Products On These Conditions.



**NOTE:** Schools, Clubs, & other groups  
LOC/PRECISION MULTI-PACKS are now available for this and other LOC/PRECISION models. For more information on launching model rockets in your area contact the National Association of Rocketry (NAR) at [www.nar.org](http://www.nar.org) or the Tripoli Rocketry Association at [www.tripoli.org](http://www.tripoli.org)

## **OTHER KITS AVAILABLE:**



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Figure 2-2: Caliber ISP 38 mm Kit from LOC Precision

ITEM DESCRIPTION:	QUANTITY:	RECEIVED:
<b>LOC Precision – 3.10” Caliber ISP Rocket Kit*:</b>	1	
Booster Airframe	1	
Nose Cone	1	
Coupler	1	
Payload Section	1	
38mm Motor Mount Tube	1	
Recovery Strap	1	
Parachute	1	
Parachute Protector	1	
Fin	4	
Quick Link	2	
<i>Centering Ring Bag:</i>		
Centering Ring with 2 Small Holes	1	
Centering Ring with 1 Small Hole	1	
Centering Ring with 0 Small Holes	1	
Eyebolt	1	
Washer	2	
T-Nut	2	
Machine Screw	2	
Motor Retention Cap	1	
<i>Rail Button Bag:</i>		
Rail Button	2	
Nut	2	
Machine Screw	2	
Wood Screw	2	
<i>Bulk Plate Bag:</i>		
Bulk Plate	1	
Eyebolt	1	
Nut	2	

Table 2-2 Workshop Supply Checklist ISP Rocket Kit



### 3. Workshop Objectives

The *Launch 2 Learn Introductory Rocket Workshop* has multiple objectives:

- Introduce teams to the design, build, fly stages of high-powered rocket
- Build a Level 1 high-powered single deploy kit rocket
- Develop basic understanding of rocket flight simulation
- Understand Tripoli Level 1 certification

## 4. High-Powered Rocketry Overview

### 4a. Rocketry History and Organizations

Amateur high-powered rocketry (HPR) began in the 1950's following the launch of Sputnik and coinciding with the Space Race.

There are two national organizations governing high-powered rocketry:



Tripoli Rocketry Association (TRA) <http://www.tripoli.org>



National Association of Rocketry (NAR) <https://www.nar.org>

To launch an HPR safely and legally, you must belong to one of these clubs, and follow the necessary procedures as determined by the club.

### 4b. Launch Profile Overview

The typical launch profiles for high-powered rockets are:

1. Launch
2. Powered Ascent
3. Coasting Flight
4. Ejection Charge/Drogue Deploy
5. Slow Descent
6. Ejection Charge/Main Deploy
7. Recovery

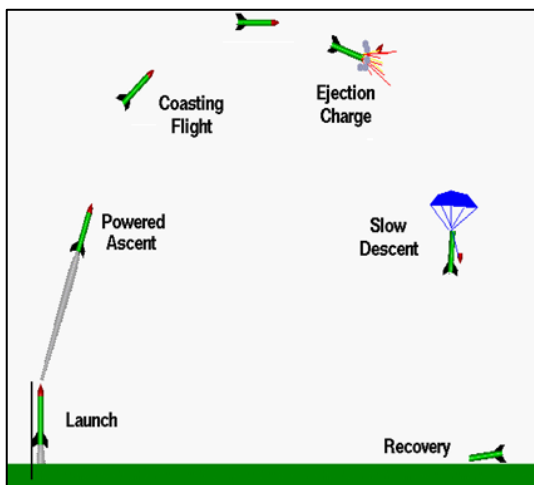


Figure 4-1: Single Deploy Flight Profile

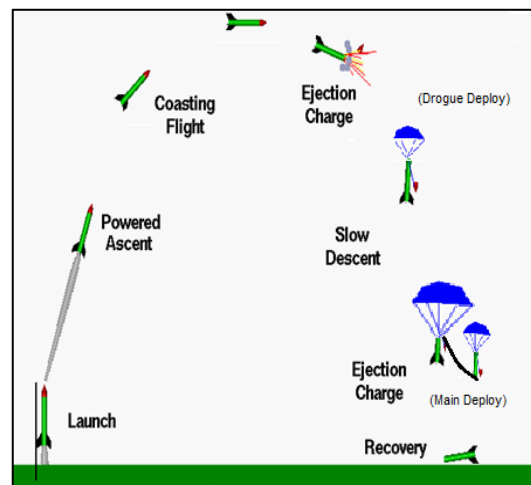


Figure 4-2: Dual Deploy Flight Profile

#### 4c. Rocketry Resources

There are many resources available online for the new amateur rocket enthusiast. Many manufacturers make rocket kits that you can build for HPR. Some of these include:

- Aerotech
- LOC Precision
- Madcow Rocketry
- Public Missiles Limited (PML)

Many vendors distribute HPR kits along with other necessary rocketry supplies (think one-stop shopping):

- Apogee Rockets
- Giant Leap Rocketry
- Wildman Rocketry

The Tripoli Rocketry Association website contains links to many rocket vendors at:

<http://www.tripoli.org/Vendors>.

Kits come in a range of materials for a range of skill levels and budgets. Paper, phenolic, blue tube, fiberglass and carbon fiber are all popular choices. Recovery hardware, electronics and motors can be found at the vendors listed on the Tripoli website also. At the end of this workshop, we will recap the procedures of how to design, build, and fly an HPR.

#### 4d. High-Powered Rocketry Overview Notes

## 5. Structures

The main component of a high-powered rocket build is the airframe structure itself. Other systems include recovery and propulsion. The size and internal structure of an amateur high-powered rocket is different from actual rockets that attain suborbital and orbital trajectories. This section discusses the main structural components of high-powered rockets.

### 5a. Parts and Subassemblies (*Build Reference 13.a*)

All high-powered rockets have a few key elements that are easily recognized from the exterior: fins, a body tube, and a nose cone. There are also other external elements such as rail buttons and motor retainers. There are other features in the interior of the rocket; couplers, bulkheads, centering rings, motor mount tubes, recovery hardware etc.

A typical high-powered rocket will consist of an aft section (the booster) and a forward section (the sustainer) joined by a coupler.

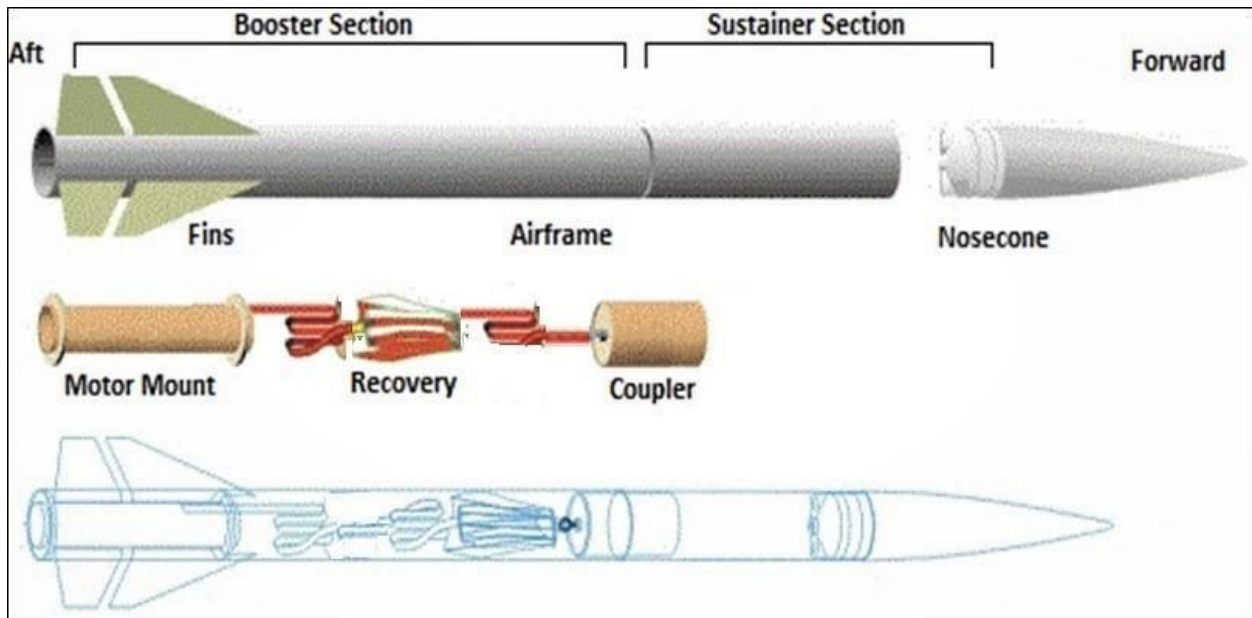


Figure 5-1: High-Powered Rocket with Coupler

For more details about high-powered rocket structures, please see the NASA High-Powered Video Series Counterpart document, pages 3 – 16.

[https://www.nasa.gov/audience/forstudents/studentlaunch/hp\\_rocketry\\_video\\_series](https://www.nasa.gov/audience/forstudents/studentlaunch/hp_rocketry_video_series)

[https://www.nasa.gov/sites/default/files/atoms/files/sl\\_video\\_instruction\\_book.pdf](https://www.nasa.gov/sites/default/files/atoms/files/sl_video_instruction_book.pdf)

### 5b. Nose Cone (*Build references 13.b.vi*)

The nose cone subassembly consists of the nose cone and any interior features that would attach it to the rest of the rocket (such as bulkheads, eyebolts, etc.). In certain cases, the nose cone can be part of the payload/experiment that the rocket vehicle is carrying or can contain the recovery or tracking electronics.

Nose cones are usually made of molded injection plastic, fiberglass or carbon fiber.

### 5c. Airframe (*Build reference 13.a.iv*)

Rocket airframes are generally smooth thin walled cylinders with a high length to diameter ratio and encompass the rocket's propulsion system, recovery system, electronics, and payload.

Generally, rockets have a nose cone fitted to the forward end of the airframe and a set of fins mounted towards the aft end. On a *minimum diameter* rocket, the airframe also serves as the motor tube. This design eliminates the need for centering rings and a motor tube, but presents new challenges because the fins must be surface mounted.

High-powered rocket airframes are typically made of non-metallic, high strength to weight ratio composite materials like carbon fiber, fiberglass, phenolic and PVC (NAR rules). Paper and cardboard will not handle the loads of high-powered rocket motors unless they are sufficiently reinforced with composite materials.

### 5d. Coupler (*Build references 13.a.ii; 13.b.iii, iv*)

A coupler can be used to join multiple segments of the airframe. A coupler is a tube that's outer diameter (OD) is equal to the inner diameter (ID) of the airframe, allowing for a snug fit inside. When joining airframes with a coupler, the coupler should extend at least one airframe diameter into each joined segment. Hence, if you were to join two 4-inch diameter airframes, you would need a coupler at least 8 inches long.

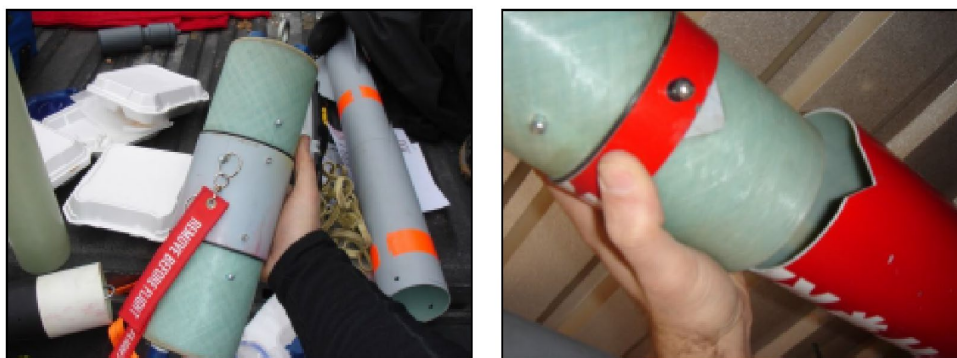
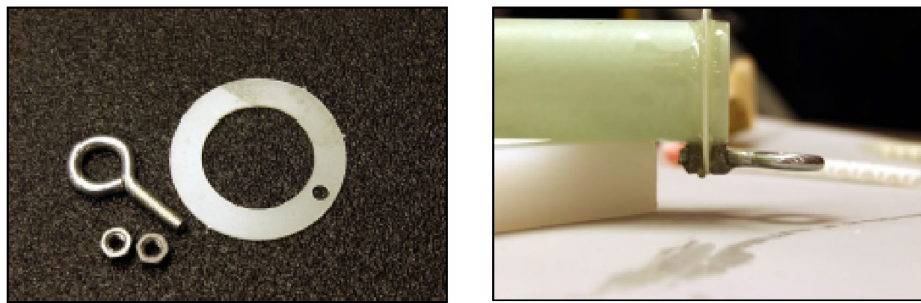


Figure 5-2: Avionics Bay / Airframe Coupler Tube Assembly

Couplers, because of their required lengths to join airframe sections, make a good place to store electronics such as altimeters, batteries, switches, and so on. The coupler section makes an ideal avionics bay. The *avionics bay* in Figure 5-2 is built from a 12-inch long *coupler* with a 4-inch *collar* in the center. The collar is a segment of airframe that is epoxied to the middle of the coupler. The collar allows direct access to the switches that power on the altimeters after the rocket is fully assembled. This coupler joins two airframe segments that contain the recovery system by clicking into place with plastic rivets or screws.

### 5e. Centering Rings / Bulkplates (*Build references 13.a.i, ii, iii; 13.b.ii, iii, x*)

*Centering rings* are used to align small tubes concentrically, like motor tubes, inside of an airframe. Centering rings can be made of many different materials and take many shapes depending on the number of inside tubes that are to be aligned.



*Figure 5-3: Centering Ring and Recovery Hardware*

*Bulkplates* are circular disks that fit inside of tubes to separate volumes. Typically, centering rings and bulkplates are either made out of plywood (i.e. birch), or from composite materials (i.e. fiberglass) and serve as the mounting structure for other systems' components such as recovery hard mounts, payloads, and electronics. Typically, there exists one centering ring above the fins and one below. Centering rings act as the primary load path, to transfer the motors thrust to the airframe.

### 5f. Motor Tube (*Build references 13.a.iii; 13.b.ii, v*)

A motor tube is any tube inside of a rocket that is intended to fit a rocket motor. Motor tube diameters are typically called out in millimeters and refer to the motor size they are designed to hold. A typical high-powered rocket may have a 38mm, 54mm, 75mm, or 98mm motor tube.



Figure 5-4: Motor Mount Tube Assembly (Left); Motor and Motor Casing (Right)

Recall that on a *minimum diameter* rocket, the airframe is the motor tube. Generally, on smaller rockets, the motor tube encompasses the entire rocket motor case. Larger rocket motor tubes may only encompass half of the motor tube with the rest freely suspended inside the rocket airframe. That is because a full-length motor tube can be heavy, adding unnecessary weight.

### 5g. Motor Retention (*Build reference 13.a.i; 13.b.x*)

A motor retainer is a device that positively retains the rocket motor case inside of the rocket prohibiting it from falling out during flight. There are many commercial motor retainers available for every size motor. It is also very common for rocket builders to fashion their own motor retainer from common screws and washers from a hardware store.

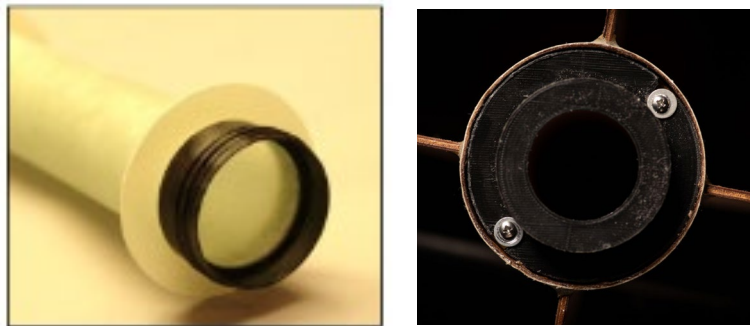


Figure 5-5: Motor Mount Tube Assembly (Left); Motor and Motor Casing (Right)



### 5h. Rail Buttons (*Build references 13.b, vii, xi*)

Most high-powered rockets launch from a rail rather than a rod and require a rail button to attach the rocket to the launch rail. Rail buttons are not to be confused with launch lugs (small cylinders attached to the sides of most low-powered rockets) which attach the rocket to a launch rod. The most commonly used launch rails are 6' tall 1010 rails (1"x1"x6') and 10' tall 1515 rails (1.5"x1.5"x10'). A rail can be seen in Figure 5-6.

A rail button is an 'H' shaped component usually made of a hard, smooth plastic, that mounts to the airframe of a rocket and slides freely inside of a channel along an extruded aluminum launch rail. This system constrains the rocket's movement until sufficient velocity is achieved that the fins become effective for flight stability.

Rail buttons should not be an afterthought of the design process. Their location should be documented as part of the vehicle's design requirement. The rocket should have one rail button near the bottom of the booster, and another near the center of gravity. It is beneficial if both rail buttons are located on the same airframe section.



Figure 5-6: Rail Guide



Figure 5-7: Rail Button

### 5i. Fins (*Build references 13.a.v; 13.b.ix*)

Fins are flat fixed stabilizing structures extending from the body of a rocket that give stability in flight. The effectiveness of fins depends mainly on the size, shape, and surface finish. Fins can be many different shapes. Four common shapes are tapered, simple delta, cropped delta, and elliptic.

Fins have several features used to parametrically characterize its design; tip chord (ct), root chord (cr), span (b), leading edge (LE), trailing edge (TE), aspect ratio (AR), and tang. The aspect ratio is just  $b/ct$ . Most fins are tapered or delta type due to ease of manufacturing. Most rocket fins are designed with low aspect ratios ( $AR < 4$ ) and taper ratio ( $ct/cr$ ) between 0.2 and 0.4 is ideal for minimum induced drag ( $\delta$ ). The tang is the part of the fin that extends inside of the airframe.



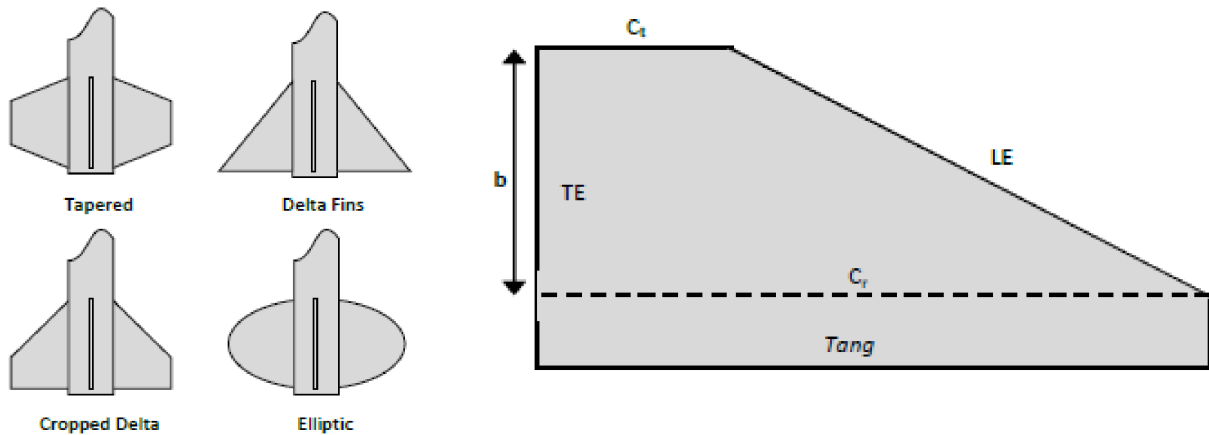


Figure 5-8: Fin Types (left) Fin components (right)

Fins are attached to a rocket using one of two methods – surface mounted (minimum diameter rockets) and through the wall (TTW). Some rockets employ removable fins. Removable fins are difficult to successfully design but you would gain multi-mission capability or just the simple ability to replace a damaged component.

Typically, fins are constructed of G10 fiberglass, carbon fiber, plastics, and/or plywood sheets cut to size. High-powered rocket fins should not be made from Plexiglas or any other non-rigid material. More complex fins can be composites of two or more of these materials.

## 5j. Structures Notes

## 6. Propulsion Systems

Rocket propulsion is a complex subject matter. Traditional propulsion systems rely on thermodynamic expansion of a supersonic gas to produce thrust. Non-traditional propulsion systems still rely on Newton, but get creative in how they produce thrust.

This workshop will only cover the basics of propulsion as they pertain to high-powered rocketry. Any aerospace propulsion textbook can be consulted for a more detailed explanation.

### 6a. HPR Definition and Classifications

Rockets use a propulsive device called a rocket motor that generates thrust by exhausting hot gases at high velocities. The momentum of the hot exhaust gases produces a net force in the opposite direction causing the rocket to move upwards. This happens because the rocket obeys *Newton's 3rd Law of Motion*, which states that for every action there is an equal and opposite reaction.

A rocket exceeds the definition of a model rocket under NFPA 1122 and becomes a high-powered rocket under NFPA 1127 if it:

- Uses a motor with more than 160 Newton-seconds of total impulse (and 'H' motor or larger) or motors that all together exceed 320 Newton-seconds
- Uses a motor with more than 80 Newtons average thrust (see rocket motor coding)
- Exceeds 62.5 grams of propellant
- Weighs more than 1,500 grams including motor(s)
- Includes any airframe parts of ductile metal

HPR motors approved for sale in the United States are stamped with a two-part code that gives some basic information about the motor's power and behavior: A letter specifying the total impulse ("H"), and a number specifying the average thrust ("225"). *Average thrust* is a measure of how slowly or quickly the motor delivers its total energy and is measured in Newtons. *Total impulse* is a measure of the overall total energy contained in a motor and is measured in Newton-seconds.

Impulse Class		Category
H	160.01Ns to 320.01Ns	Level 1
I	320.01Ns to 640.00Ns	
J	640.01Ns to 1280.00Ns	Level 2
K	1280.01Ns to 2560.00Ns	
L	2560.01Ns to 5120.00Ns	
M	5120.01Ns to 10240.00Ns	Level 3
N	10240.01Ns to 20480.00Ns	
O	20480.00Ns to 40960.00Ns	

Table 6-1: HPR Motor Impulse Classes and Categories

HPR motors cannot be purchased over the counter.

Members must be certified by either the National Association of Rocketry (NAR) or the Tripoli Rocketry Association (TRA) to the appropriate level to purchase motors from vendors. As part of this workshop, you may be certified NAR Level 1 pending a successful flight. You can then purchase 'H' and 'I' motors, and one 'J, K, or L' on the day you intend to certify Level 2. To certify Level 2, you must pass a written test as well as conduct a successful flight.

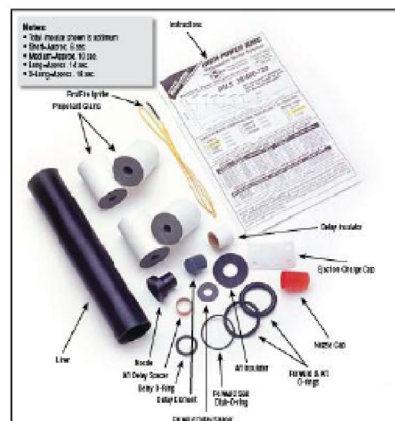
### 6b. Commercial Motors

For WSGC rocket teams, you are required to use a certified commercially manufactured motor. The certifying agencies are the National Association of Rocketry (NAR) and Tripoli Rocketry association (TRA). Some of the more popular solid rocket motor manufacturers are Cesaroni Technology Inc. (CTI) and Aerotech (AT). Each manufacturer produces a wide variety of commercially certified rocket motors in all different impulse and thrust ranges.

Reloadable solid rocket motor systems are composed of a reusable motor case and a reload kit. All HPR motor cases come standard in 38mm, 54mm, 75mm, and 98mm diameters.

Most cases have three standard parts: the case, a forward closure, and an aft closure. A forward closure and a removable aft closure may be built in where the reload is loaded from on some motor cases. The closures are usually interchangeable between cases of the same diameter but in different lengths.

Solid rocket motor reload kits include the assembly instructions, the propellant, the nozzle, and all other one-time use hardware for the flight. A typical reload kit will include: a phenolic or paper liner that acts as thermal protection for the motor case; a series of O-rings that will seal the reload inside of the motor case; a set of phenolic disks that act as thermal protection for the aft and forward closures; a delay grain for the motor ejection charge or a tracking smoke element if the motor does not use an ejection charge; and an igniter. You will also need O-ring grease for the assembly of the reload. It is very important not to deviate from the manufacturer's direction for motor assembly.



*Figure 6-1: HPR Motor Components*



Figure 6-2: Cesaroni HPR Reloadable Motors

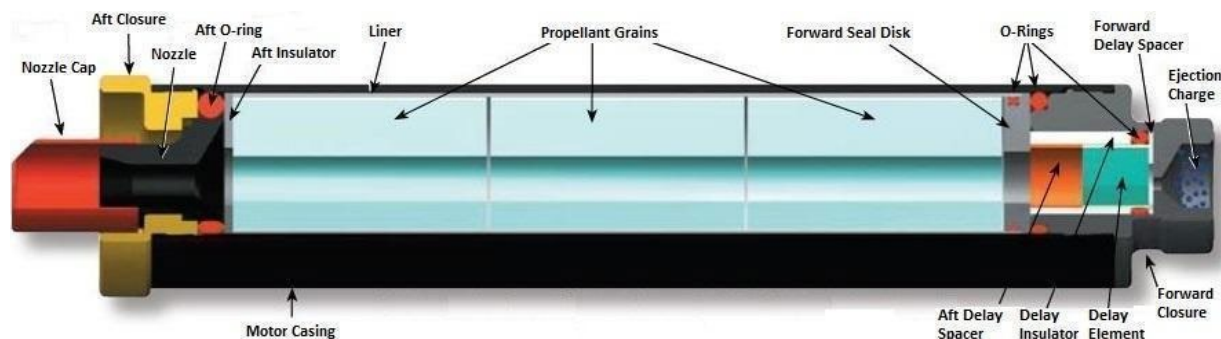


Figure 6-3: Cutaway Drawing of Typical Assembled RMS-Plus Motor

## 6c. E-Matches / Motor Ignitor

Electric matches, commonly called “*E-Matches*,” are a universal initiator of many rocketry pyrotechnics and motors. A typical e-match is made from a thin nichrome (nickel-chromium) wire laminated to a small non-conductive flake of fiberglass. Each end is soldered to one wire of a two-conductor solid core copper shooter wire. The nichrome bridge is dipped into a pyrogen solution that dries hard and looks like a match, hence the name.



Figure 6-4: Aerotech Single Use Motor with Ignitor

E-matches are typically high current or low current. Kits for making your own e-matches can be purchased on the internet, or you can purchase them from most vendors on launch day. E-matches can be augmented to serve as motor igniters also.

## 6d. Thrust to Weight Ratio

In order for a rocket motor to lift a rocket, it must produce enough thrust to overcome the force of gravity. This means a rocket motor, at a minimum, must produce enough mechanical energy to achieve a *thrust-to-weight ratio* of just over 1.0. For example, if your rocket has a thrust to weight of 5:1, that means the rocket motor must produce 5 times the force of the weight of your rocket. If your rocket weighs 20 lbs. then the motor needs to produce at least 100 lbs. of thrust. <http://www.thrustcurve.org/>

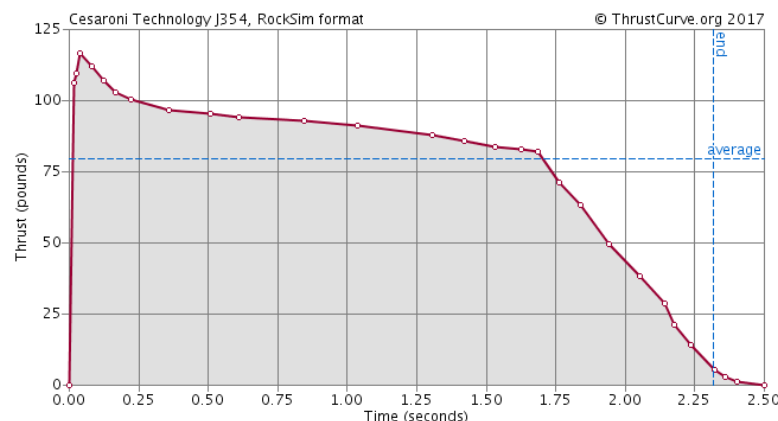


Figure 6-5: Thrust to Weight Curve from Commercial Software Package

## 6e. Trajectory Analysis

Below is an example of a completed trajectory analysis. The analysis displays important events in the flight such as maximum altitude, velocity, and acceleration. It may also display the rocket's recovery events and descent rate.

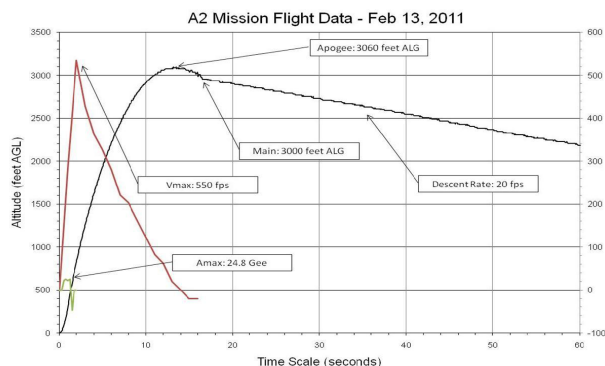


Figure 6-6: Plotted Trajectory Data from Commercial Software Package

## 6f. Commercial Software Packages

The easiest way to perform a trajectory analysis is to purchase a commercially produced trajectory analysis program like RockSim, or RASAero. There are also free software packages available like OpenRocket. These programs have simple CAD programs that allow a user to build a model of the rocket in the program. The programs can help calculate many rocket parameters like weight, length, and stability in addition to performing a three degrees of freedom (3DOF) flight analysis.

These commercial programs offer the user a lot of control over the simulation environment also. The user can manipulate the winds, the launch angle, temperature, and many other parameters to match the simulation environment to the real world.

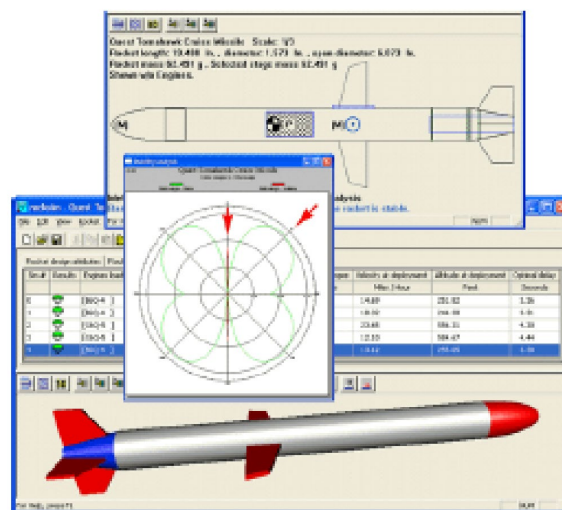


Figure 6-7: RockSim Flight Simulation Software

Commercial software can be found at the following links:

- RockSim: <http://www.apogeerockets.com/rocksim.asp>
- RASAero: <http://rasaero.com/>
- OpenRocket: <http://openrocket.sourceforge.net/>

Submission of RockSim file simulation is required for all WSGC rocket programs.

## 6g. Propulsion System Notes

## 7. Stability

An important component of rocket vehicle design, and a safe and successful flight, is ensuring vehicle stability.

An object is directionally stable if it tends to return to its original direction in relation to the oncoming medium (water, air, etc.) when disturbed away from that direction. Directional stability is also called “weathervaning or weathercocking” because a directionally stable vehicle free to rotate about its center of mass is similar to a weather vane rotating about its pivot. Without stability, a rocket would tumble end over end, spin, or orient itself at a high displacement angle. At high displacement angle, drag forces may become excessive and the rocket may experience structural failure.

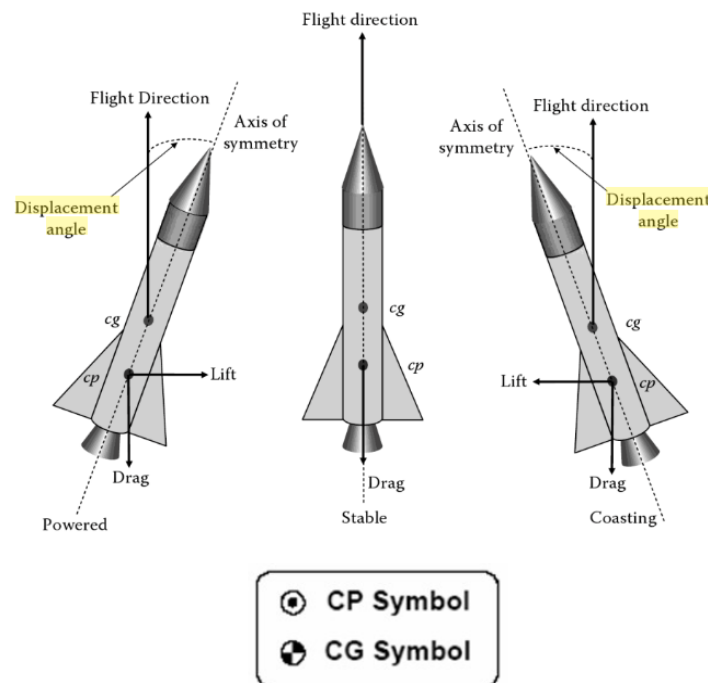


Figure 7-1: Rocket Stability Diagram

Generally, a rocket is considered stable if its center of gravity (CG) is at least one body diameter in front of its center of pressure (CP). A practical approach to efficient rocket design is to allow the structural design to mature to the point where the CG location is stable (does not vary much with tweaks to the configuration) and then tailored for the desired stability margin by selecting where you want your CP to be located.

## 7a. Center of Gravity

The *center of gravity* (*CG* or  $\underline{X}_{CG}$ ) of a rigid body is the mean location of all the masses in a system. The position of the CG is fixed in relation to the body and does not coincide with the geometric center generally. The CG can be determined analytically or empirically. The standard CG symbol in Figure 7-1 should be added to the rocket via stickers or pen.

The *Analytical Approach* requires accounting for all of the individual point masses that compose the system and their location in the system as measured from a common datum plane, typically the tip of a rocket's nose cone. The average of their positions weighted by their masses is the location of the center of gravity. The basic assumptions used in calculation of the theoretical center of gravity for this rocket are uniform gravitational field ( $g = \text{constant}$ ) and that the components have uniform density ( $\rho = \text{constant}$ ). Simulation programs, such as RockSim, would use this method.

The *Empirical Approach* relies on observation and experience. An example of determining the CG empirically would be a simple balance method. Find the point on the rocket where it balances and you have found the CG. Although accurate, this method is not practical on very large and heavy rockets and is not useful during the design phase of your student launch project. It can be an easy check just to verify your analytical model once your rocket is complete.

## 7b. Center of Pressure (*Build reference 13.b.viii*)

As a rocket flies through the air, aerodynamic forces act on all parts of the rocket. In the same way that the weight of all the rocket components acts through the center of gravity (CG), the aerodynamic forces act through a single point called the *center of pressure* (*CP* or  $\underline{X}_{CP}$ ). The standard CP symbol in Figure 7-1 should be added to the rocket via stickers or pen.

You can calculate the CP, but this is a complicated procedure requiring the use of calculus. The aerodynamic forces are the result of pressure variations around the surface of the rocket. In general, you must determine the integral of the pressure times the unit normal, times the area, times the distance from a reference line. Then divide by the integral of the pressure times the unit normal, times the area. Lots of work!

A simple empirical method is the cardboard cutout method. This method assumes that the center of pressure coincides with the centroid, or geometric center, of the rocket. Make a cardboard cutout of the rocket silhouette and find the balance point. This method is an easy approximation of the area where the CP might be located. This method could be useful early on in the preliminary design of your student launch projects, but is not recommended as your primary method for determining your rocket's CP.



### 7c. Static Margin

*Static margin (SM)* or *margin of stability* describes the directional stability of a rocket. Recall that an object is directionally stable if it tends to return to its original direction in relation to the oncoming medium (water, air, etc.) when disturbed away from that direction and that a rocket is considered stable if its *CG* is at least one body diameter in front of its *CP*.

$$SM = \frac{\underline{X}_{CP} - \underline{X}_{CG}}{\text{Body Diameter}} \geq 1.0$$

*Equation 7-1: Static Margin*

Generally, it is desirable to have a static margin of 1.5 to 2.0. A rocket is considered over stable if it has a static margin of 3.0 or greater. An over stable rocket will lean or “weather vane” further into the wind and not travel as high. It is important to note that a rocket’s *CG* will change as the motor exhausts combusted fuel. Generally, the *CG* will move forward as a solid rocket motor burns, causing the rocket to become more stable.

### 7d. Stability Notes

## 8. Recovery Hardware (*Build references 13.b.v, xii*)

High-powered rockets are required to have a recovery system. In this section, you will learn about the hardware needed to build a recovery system, how to apply Newton's 2<sup>nd</sup> Law of Motion to calculate the size parachute needed to safely recover your rocket and how to use the *Ideal Gas Law* to appropriately size black powder ejection charges to deploy your recovery systems.

High-powered rockets typically have one of two types of recovery systems - *Single Event Recovery* or *Dual Event Recovery*.

### 8a. Single Event Recovery System (SERS)

A typical *Single Event Recovery System* ejects a parachute at apogee. This can most commonly be achieved by using a motor ejection charge. Most low- to mid-powered rocket motors have this capability. At motor ignition, the propellant and a delay grain begin to burn. The delay grain burns slowly. Once it burns through, the ejection charge is set off and the parachute is deployed. If the timing is good, this happens near apogee. SERS is the simplest recovery system and is good for low altitude flights on small launch fields and high-altitude flights on large launch fields.



Figure 8-1: Single Event Recovery System

The plot shows the trajectory of a rocket with a single event recovery system. The rocket reaches apogee and deploys a parachute using the motor ejection charge. The rocket then descends slowly at 20 fps. With an apogee of 3000 feet, it takes two and a half minutes for the rocket to touch down.

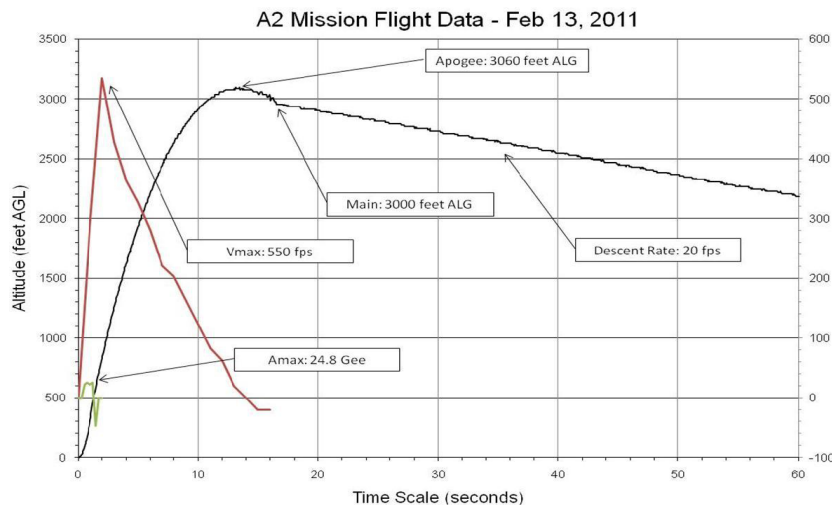


Figure 8-2: Single Event Trajectory Plot

## 8b. Dual Event Recovery System (DERS)

A typical *Dual Event Recovery System* has one event at apogee and the second at a much lower altitude, typically 700 feet or more *Above Ground Level (AGL)*, and requires electronics to do so. This recovery technique significantly reduces the recovery area by allowing the rocket to fall much faster from apogee and deploying a main parachute much closer to the ground. The first event recovery system is typically a long length of shock cord and perhaps a drogue parachute. The second event recovery system is the main parachute, which slows the rocket down considerably for a safe touchdown.



Figure 8-3: DERS Example

The following plot shows the trajectory of a rocket using a dual event recovery system. The rocket reached an apogee of 4800 feet. It then deployed a drogue that slowed the descent to 90 fps. At 1100 feet, the main parachute deployed further slowing the descent rate to 18 fps. It takes only one-and-a-half minutes for the rocket to touch down.

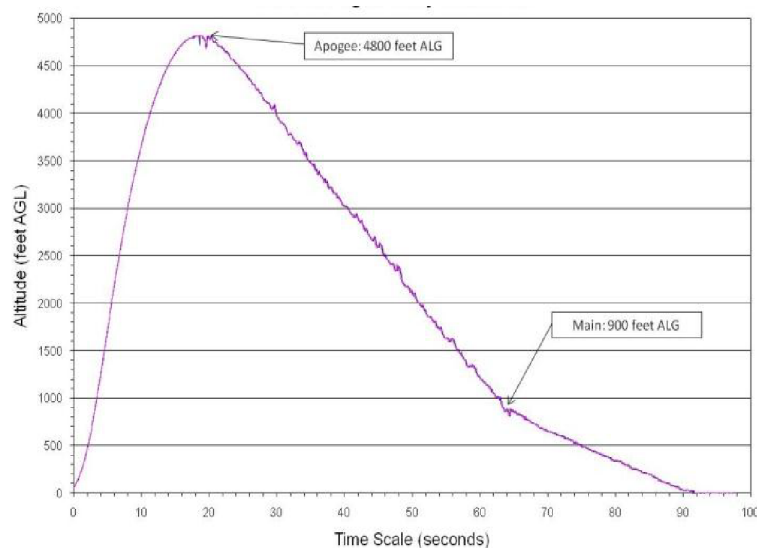


Figure 8-4: Dual Deploy Trajectory Plot

A rocket equipped with a typical dual event recovery system has the following general layout. The main parachute is generally forward of the avionics bay. This adds advantage to the rocket's center of gravity and hence the rocket's stability margin by having the larger and heavier of the recovery devices far forward.

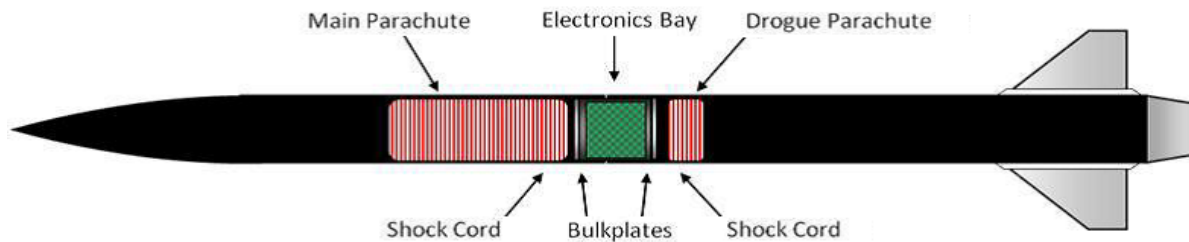


Figure 8-5: Possible Layout of a Rocket with DERS

The avionics bay is generally between the two parachutes. This adds advantage to the locations of the recovery ejection charges. The charges are generally placed in cups on the avionics bay's end closures or bulkplates. Avionics bays are discussed further in Section 9.

### 8c. Parachutes

Parachutes are the most commonly used recovery device in high-powered rocketry. A parachute is a high drag device that reduces the high-speed descent of the rocket by producing a force that opposes the weight of the rocket. The effectiveness of a parachute depends on velocity, air density, surface or "reference" area, and a drag coefficient. A drag coefficient is a dimensionless quantity that is used to quantify the drag or resistance of an object in a fluid environment such as air. For non-streamlined objects like parachutes, the drag coefficient can be greater than 1.

High-powered rocketry parachutes typically have three major features:

1. Canopy
2. Shroud lines
3. Steel connector link



Figure 8-6: Dual Deploy Recovery System

The canopy is made of several rip-stop nylon cloth panels, or gores, sewn together to form a round, cruciform, annular, or other shape. The shroud lines are attached to the outer edge of the canopy. The steel connector link gathers all the shroud lines together and can be connected to the rocket's recovery harness. Some of these connectors also have a swivel built in to aid in stability. Some parachutes have a spill hole or apex vent - a small hole in the top of the canopy that allows small amounts of air to spill out from the top of the canopy adding to its stability. Otherwise, the parachute will rock from side to side to dump air out from the bottom sides of the canopy, which would cause the rocket to swing like a pendulum.

## 8d. Parachute Selection

There are two criteria to assist with parachute selection. The descent velocity, or ground-hit velocity, should be at or under 20 ft/s for minimal body damage upon landing. The expected drift range should also not exceed 2500 feet downrange. Most rocket simulators will determine the descent velocity for you if the model is accurate.



Figure 8-7: Parachute Selection with Simulation Data

## 8e. Parachute Protectors

Nylon cloth is susceptible to melting and charring. It is necessary to protect your recovery system from the hot gases and any burning debris that are generated by the ejection charge. A flameproof Aramid cloth or Kevlar cloth will protect the parachute from these hot gases and burning debris. Other options include deployment free bags (D-bags). D-bags provide parachute and support line protection and can ensure a reliable and orderly deployment. Another option is to utilize wadding (dog barf) when packing the parachute. Great care should be taken to not tightly wrap the parachute with both techniques.



Figure 8-8: Parachute Protector

## 8f. Recovery Hardware

A *recovery harness* is a generally long length of static cord that attaches structural components that separate as part of the recovery system. Typical materials for a recovery harness are Aramid/Kevlar, Kevlar/Fiberglass, and nylon. Each end is secured by a quicklink typically to a *U-bolt* or *eyebolt* that is rigidly mounted to a bulkplate on an avionics bay, nose cone, or booster. The main parachute is generally attached to a loop in the shock cord tied just below the nose cone by a quicklink. The length of recovery harness required will be the subject of empirical testing and evaluation. Your workshop rocket has 12 feet of shock cord. A Level 3 type rocket may require more than 100 feet of shock cord.



Figure 8-9: Recovery Hardware

The recovery harness can be bundled into groupings using rubber bands or masking tape. This technique helps to dissipate the momentum of the separating components when they are ejected. In the photo above, the shock cord was bundled into four 10 feet long lengths that were



Figure 8-10: Recovery Harness

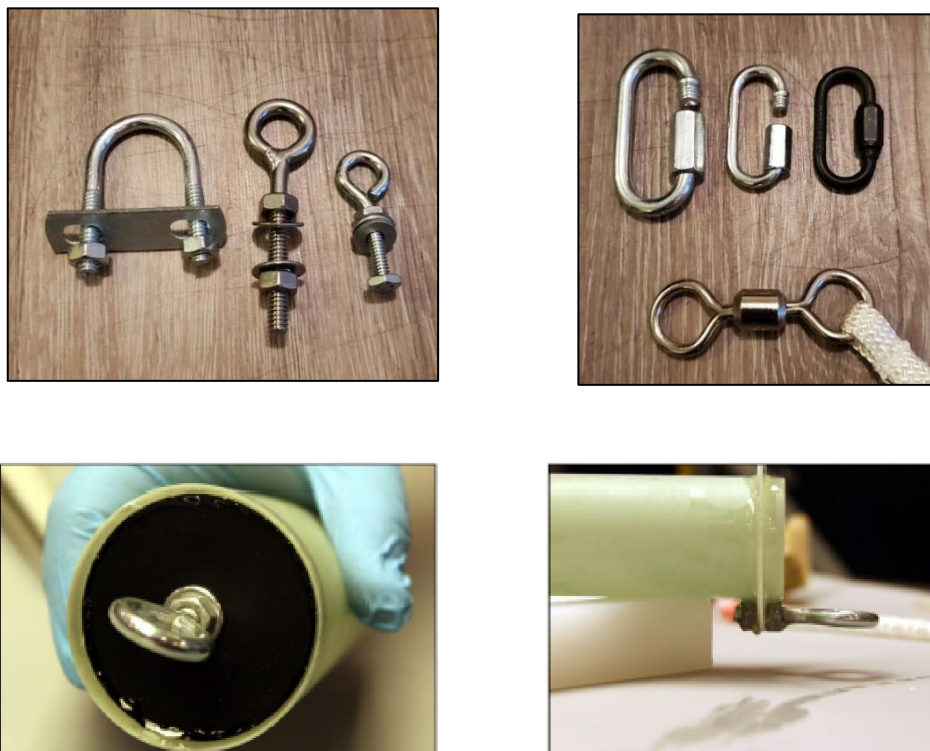


folded in 8" - 10" lengths and wrapped a couple of times with masking tape. During deployment, energy is used up to tear the tape to release more cord. This technique performed very well in-flight dissipating momentum of the two 25 lbm rocket sections that were ejected at 200 lbf before the shock cord became taught. Recall that nylon is susceptible to melting and charring. Take measures to protect nylon cords and inspect all shock cords before flights.

### 8g. Quicklinks / Eyebolts

Quicklinks make connecting and rigging a recovery system very easy. There are many different types of quicklinks available commercially. Always use quicklinks with a locking gate. In addition, the bi-products of black powder ejection charges are acidic. While zinc-plated steel quicklinks are safe for many flights, inspect the levels of corrosion and clean all metallic hardware between flights. Take care in choosing a quicklink that will safely carry the maximum expected load that will be experienced. Too small of a quicklink may yield under heavy loading when the main parachute opens.

The quicklinks attach the recovery system to the rocket's structures. There are several hard points on the rocket's bulkplates and/or centering rings. These hard points are generally made using eyebolts or U-bolts. U-bolts are preferred on large rockets. Eyebolts should be closed and/or welded closed.



*Figure 8-11: U-Bolts and Eyebolts (Upper Left); Quicklinks (Upper Left); Closed Eyebolts (Bottom)*

## 8h. Recovery Notes

## 9. Avionics System

Every dual deploy rocket will require recovery electronics, to control the ejection charges for the recovery events. Recovery electronics are optional for single deploy rockets, where the ejection charge is usually contained within the motor, and is on a timed fuse.

Recovery electronics will usually be contained within the electronics (avionics) bay, but can be in other locations within the rocket. Recovery electronics also cover the tracking electronics that are used to locate a rocket that lands over the horizon (out of sight).

### 9a. Avionics Bay

Avionics refers to any electronic systems flown on a rocket, whether they are flight computers, guidance and control systems, telemetry systems or payloads. These systems are typically built into an Electronics Bay. An 'E-Bay', is a subsystem of a high-powered rocket that typically contains altimeters, batteries, and switches. A typical E-Bay consists of three structural components: the housing, a forward and aft end-cap, and an avionics sled.



*Figure 9-1: Avionics Bay*

### 9b. Avionics Bay Housing / Coupler

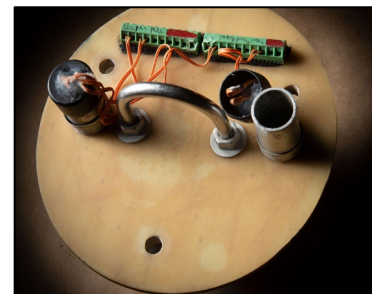
The E-Bay housing is typically built from a coupler tube and can have a collar made from a segment of airframe that is epoxied to the middle of the coupler and allows direct access to the switches that power on the altimeters. The collar also supports static pressure ports that equalize the housings interior pressure with the exterior atmosphere. Generally, rocket builders follow the convention that when joining airframes with a coupler, the coupler should extend at least one airframe diameter into each joined segment.



*Figure 9-2: Coupler Tube*

### 9c. End Caps

The E-Bay end-caps close out the housing, separating the rocket's volumes, and support the recovery harness hard mounts, charge cups, and all-threads. Typically, end-caps are made from G-10 fiberglass bulkplates, or plywood. The all-threads act as a two-force member that connect both end-caps and carry the recovery harness load through the E-Bay. End-caps should create a good seal around the end of the housing to prevent hot gas seepage from the ejection charges.



*Figure 9-3: End Cap/Bulkplate*



## 9d. Avionics Sled

Typically, the avionics sled is a G-10 fiberglass board or boards that mount in the avionics by sliding onto the all threads that connect the end plates; like a sled. The avionics electronics, batteries, and switches are mounted to the sled and wired together to form systems. The avionics sled in the photo to the right is slid onto  $\frac{1}{4}$ " diameter all-threads using  $\frac{1}{4}$ " I.D. G-10 fiberglass tubes that are epoxied to the corners on the G-10 boards. This simple sled supports only altimeters, batteries, and switches. The sled was designed to slide into the avionics bays of several different rockets.

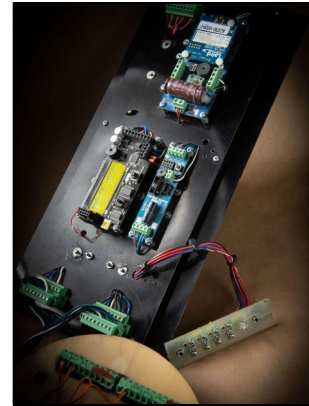


Figure 9-4: Avionics Sled on G-10 Fiberglass Tubes

The system level diagram below details the dual event recovery system's configuration. This system is a fully redundant recovery system. There are two altimeters, which each have a dedicated battery and switch. Each altimeter has its own set of recovery charges to fire. There are four in total in the rocket. Although not required, redundant setup is a nice feature.

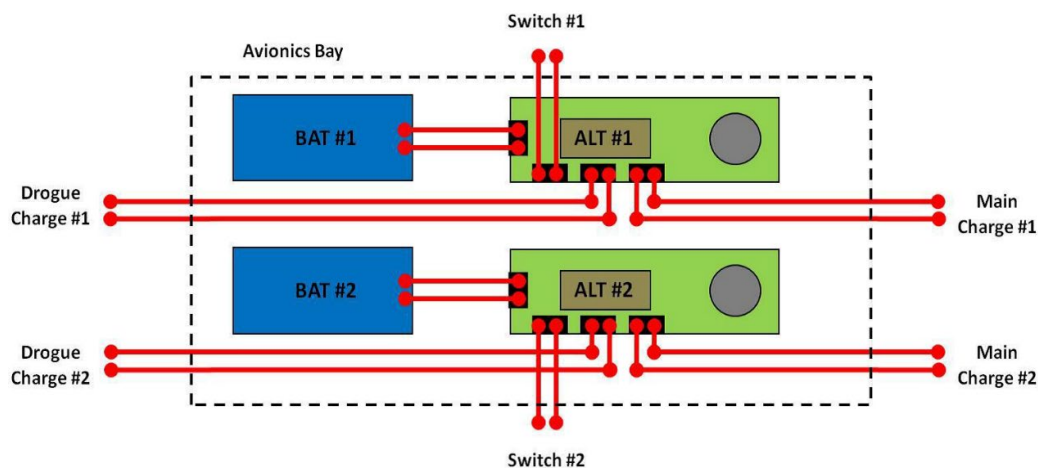


Figure 9-5: System Level Diagram of DERS Configuration

## 9e. Recovery Electronics

*Dual Event Recovery Systems* require the use of electronic devices called *Altimeters* that can determine altitude and initiate events at desired altitudes.

Altimeters, usually mounted in the rocket's avionics bay, need to sample the outside air pressure. Your rocket will need a static pressure port along the outside to allow the inside pressure to equalize to the outside pressure.

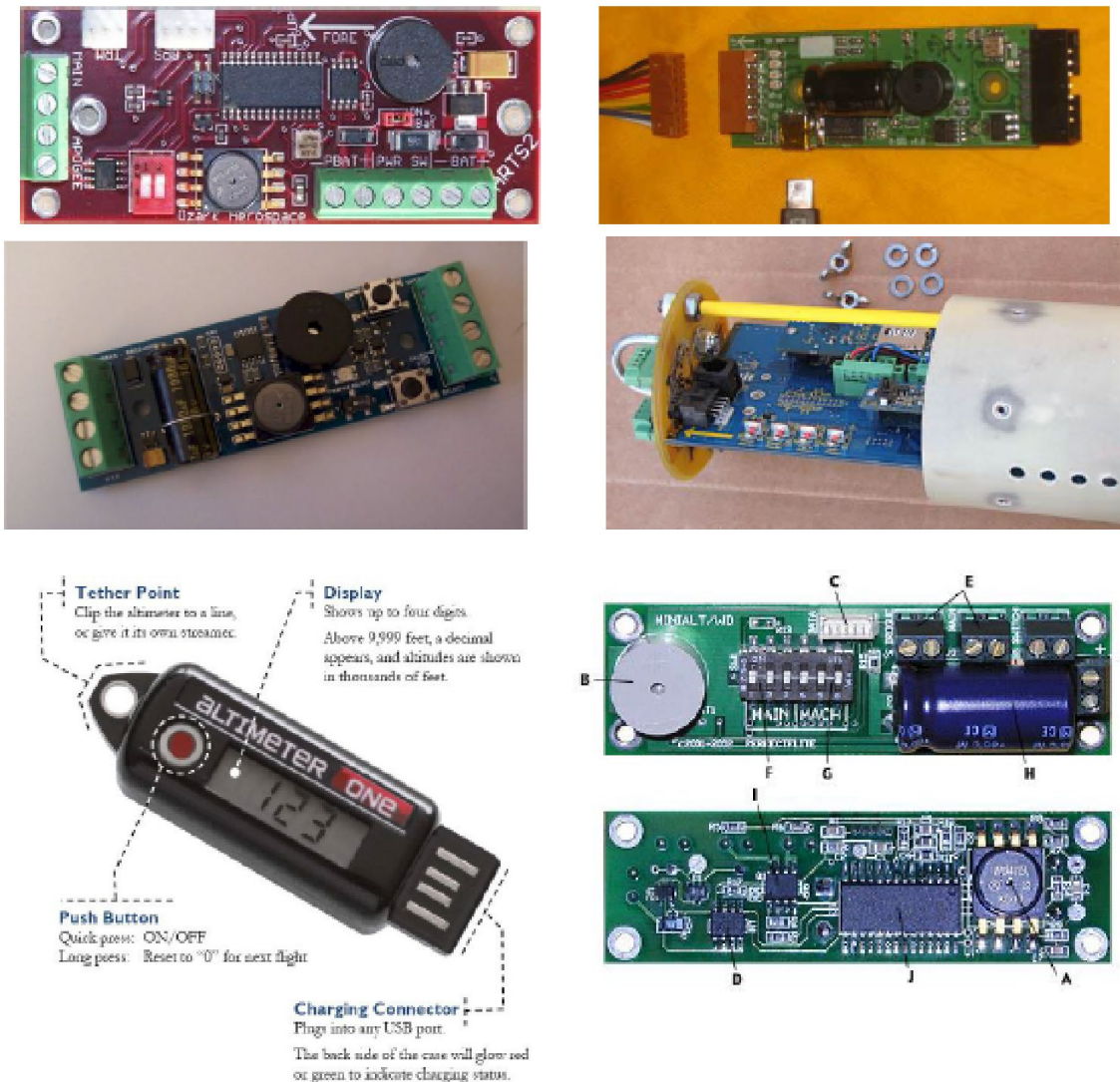


Figure 9-6 Clockwise From Top Left: RRC2 Mini Alt, G-WIZ Av Bay, AED R-DAS Tiny, Perfectflite MAWD, Apogee Altimeter One, ARTS2 Flight Computer

## 9f. Batteries

Typically, rocket builders prefer each altimeter has a dedicated battery. Your electronics should be able to remain switched on and reliably operate if the rocket remains on the pad for an extended duration before launch.

There are two main types of batteries used in high-powered rocketry, primary and secondary. Primary batteries such as a 9V alkaline battery are designed for a one-time use and then discarded when they are exhausted. Even if never taken out of the original package, primary batteries can lose 8% - 20% of their original charge every year when stored at room temperature. This “self-discharge” rate is known to occur due to a non-current producing side chemical reaction, which occurs within the cell even if no load is applied.

Secondary batteries, like Nickel Cadmium (NiCad) or Lithium Polymer (Li-Po) batteries are designed to be rechargeable and used multiple times. Secondary batteries weigh less than primary batteries and manufacturers can shape them; however, they please. They are more expensive than primary batteries. Some require sophisticated chargers to recharge them safely. Improper use or charging of some secondary batteries can result in fire or explosion.

Secondary batteries self-discharge more rapidly than primary batteries. A freshly charged NiCad battery can lose 10% of its initial charge in 24 hours, and discharges at a rate of about 10% every month thereafter. Most Li-Po batteries have reduced self-discharge-rates to a relatively low level but are still poorer than primary batteries. Even though secondary batteries have their energy content restored by charging, some deterioration occurs on each charge/discharge cycle. Secondary batteries like Li-Po batteries are gaining favor in the work of high-powered rocketry where the advantages of both lower weight and greatly increased run times can be sufficient justification for the price.

## 9g. Switches

Typically, rocket builders prefer to power up their electronics from the outside of the rocket once it is placed on the launch pad. This method maximizes battery life. The switches can either be surface mounted to the airframe of the rocket or mounted inside the rocket with an access hole or panel. The two categories of switches used on high-powered rockets are the *Single Pole Single Throw (SPST)* and the *Dual Pole Single Throw (DPST)*. The *Single Pole Single Throw (SPST)* is a simple on-off switch where the two terminals are either connected together or disconnected from each other.

The *Dual Pole Single Throw (DPST)* is equivalent to two SPST switches controlled by a single mechanism. In these two categories, there are toggle switches, push button switches, and selector switches.



Figure 9-7: *Single Pole Single Throw (Top); Dual Pole Single Throw (Bottom)*

## 9h. Tracking

There are three main types of tracking: audible, GPS, and RF.

In general, FCC certification is required for any electronic device that can oscillate above 9 kHz. Manufacturers must make sure that their products will not interfere with other products or cause risk and harm to the public. All electrical devices must be tested and fulfil the emission requirements to receive FCC certification. If manufacturers sell products without the appropriate approval, they will receive a monetary fine and their products will be recalled.

Teams purchasing a tracker must be aware if the tracking unit requires an FCC certificate or equivalent. The manufacturer or seller should abide by these rules also and require that the consumer have a certificate or will acquire one.

For introductory rocketry, it is recommended to use an electronic tracking device that does not require licensing.

### i. Audible

This is the cheapest and simplest option. There are commercial products produced for high-powered rocketry that emit a high-pitched audible sound that are activated when the parachute is ejected from the rocket. The sound will help you to locate the rocket, but the range is not very large, so you must know the general vicinity of the rocket upon landing.

### ii. RF Tracking

This is an option to assist with rocket recovery. There are commercial products for high-powered rocketry, which produce an RF pulse on a distinct frequency. The device is installed in the rocket, and using a Yagi antenna tuned to the frequency, the rocket can be homed in on.

### iii. GPS Tracking

This is the most expensive option, but is the easiest and most reliable. Again, there are commercial products for high-powered rocketry, which emit GPS coordinates (position) in real time to a receiver.

## 9i. Ejection Charges

A black powder charge is the most common and reliable method of ejecting a parachute from your rocket. In your rocket, the motor's ejection charge will ignite and generate hot gases that pressurize the rocket's airframe and exert a net force on the bulkplate of the nose cone. This net force will eject the nose cone, shock cord, and parachute out of the rocket airframe. This all happens because the rocket is obeying the *Ideal Gas Law*.

The *Ideal Gas Law* is the equation of state for a hypothetical incompressible or "ideal" gas. The state of an amount of gas is determined by its pressure, volume, and temperature.

The modern form of this equation is  $PV = NRT$  where  $P$  is the absolute pressure of the gas,  $V$  is the volume occupied by the gas,  $N$  is the amount of substance (in this case the substance is black powder),  $R$  is the gas constant, and  $T$  is the absolute temperature. The equation can be reordered to solve for  $N$  directly and known values substituted. The design pressure is determined by the desired net force on a surface divided by the area of that surface. Typical net force values for a 4-inch diameter rocket range from 100 lbf - 200 lbf. This translates to a typical pressure range of 8psi – 16psi. In addition, black powder charge amounts are typically reported in the unit grams. Recall there are 454 grams in 1 pound. So for a rocket with  $r = 2$  inch:

$$P = \frac{F}{A} = \frac{F}{\pi r^2} = \frac{200 \text{ lbf}}{\pi(2 \text{ in})^2} = 16 \text{ psi}$$

Equation 9-1: Pressure

$$V = \pi r^2 L = 12.56 \text{ in}^2 \cdot L$$

Equation 9-2: Volume

The volume is a function of the length of the rocket tube being deployed (left as a variable).

$$N = \frac{PV}{RT} = \frac{(16 \text{ psi})(12.56 \text{ in}^2 \cdot L)}{\left(266 \frac{\text{in} \cdot \text{lbf}}{\text{lbm}}\right)(3307^\circ \text{R})} \left(\frac{454 \text{ grams}}{1 \text{ lbf}}\right) = (0.1 \cdot L) \text{ gram}$$

Equation 9-3: Black Powder

We see, the reduced equation for this case, states that 0.1 grams of black powder is needed for every 1-inch length of airframe containing the recovery system. Therefore, if  $L = 20$  in, then 2.0 grams of black powder is needed to eject the recovery system with 200 lbs. of force. This theoretical value should now be tested.

Typically, rocket builders use a charge cup or well to contain the measured amount of black powder for the ejection charges. Everything from PVC end caps, brass pipefittings, to a rolled length of blue masking tape can be used. Some fixed volume charge cups will require a filler of some type to occupy the empty volume in the cup once the black powder and e-match have been installed. Rocket builders typically use soft foam earplugs or shredded housing insulation material more commonly called “dog barf.” Cannon plug covers, electrical tape, masking tape, and duct tape can be used to seal the charge cups.

Alternatively, ejection charges can be contained in a prefabricated plastic container (canister), with a built-in filament to ignite the charge. These containers will come in small and large sizes,

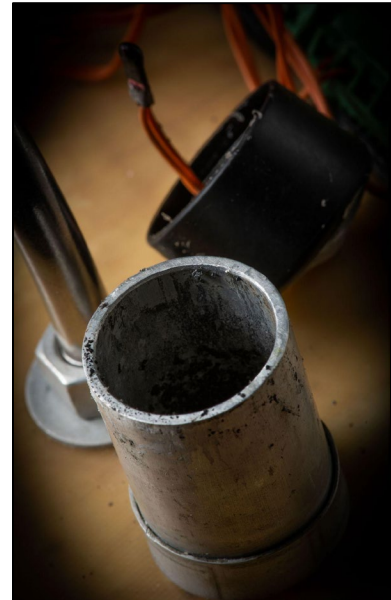
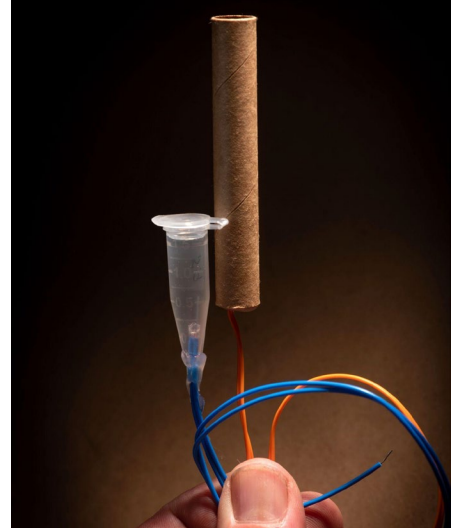


Figure 9-8: Ejection Charge Cup

and a foam plug needs to be used to fill the remaining empty space in the container, so that the black powder remains in contact with the filament at the bottom of the container. Wire leads extend from this ejection canister, which are then simply wired to your wiring block on the outside of your avionics bay, or can be wired directly to the altimeter. Care must be taken to direct the charge along the length of the rocket airframe tube.

#### **9j. Avionics Notes**



*Figure 9-9: Ejection Canister*

## 10. Recovery Exercise: Ejection Charge Sizing

A black powder charge is the most common and reliable method of ejecting a parachute from your rocket. This exercise will teach you how to determine the ideal amount needed for your rocket by using the *Ideal Gas Law*.

$$PV = NRT$$

*Equation 10-1: Ideal Gas Law*

$$P = \frac{F}{A}$$

*Equation 10-2: Pressure*

The constants for 4F black powder are:

$$R = 266 \frac{\text{in}\cdot\text{lbf}}{\text{lbm}} \text{ (Gas Constant)} \quad T = 3307^\circ\text{R} \text{ (Temperature – Rankine)}$$

The variables for your rocket are:

$$F = 100 \text{ lbf (Ejection Force)}$$

$$A = 5.0 \text{ in}^2 \text{ (Area)}$$

$$V = 100 \text{ in}^3 \text{ (Volume)}$$

Use the *Ideal Gas Law* and Pressure formula to determine the required amount of black powder to eject a parachute from your rocket. **Note: There are 454 grams in 1 lb.**

## 10a. Ejection Charge Calculation Worksheet



## 11. RockSim Overview

### 11a. Creating a Model

Simulations are THE key component to high-powered rocket design. Models can be created of an existing rocket in RockSim 10. We will create a simple model of your as-built LOC Precision Caliber-ISP.

- RockSim: <http://www.apogeerockets.com/rocksim.asp>

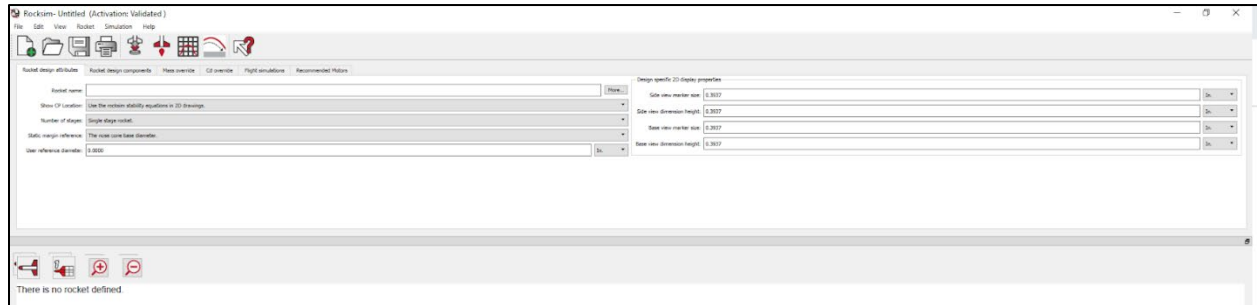


Figure 11-1: RockSim 10

### Learning to use RockSim

- Rocket Design Attributes
- Rocket Design Components
- Mass Override
- CD Override
- Flight Simulations
- Recommended Motors

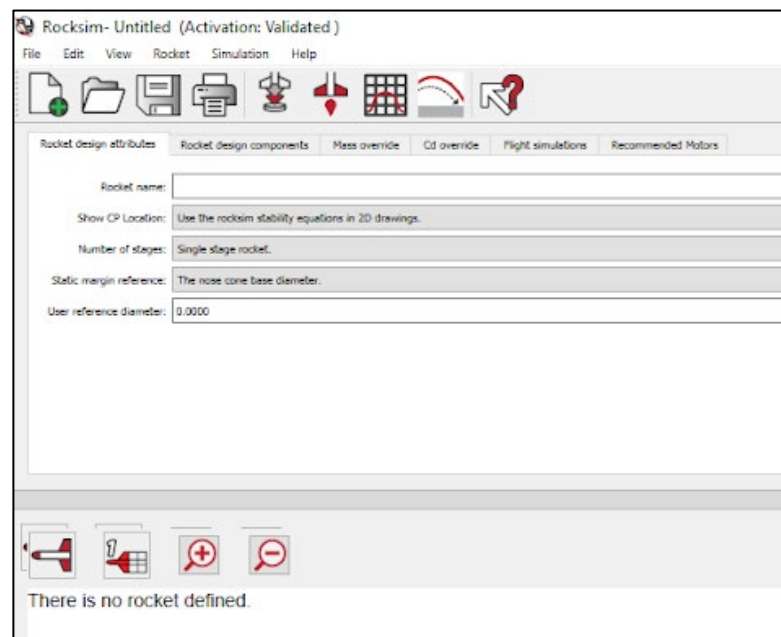


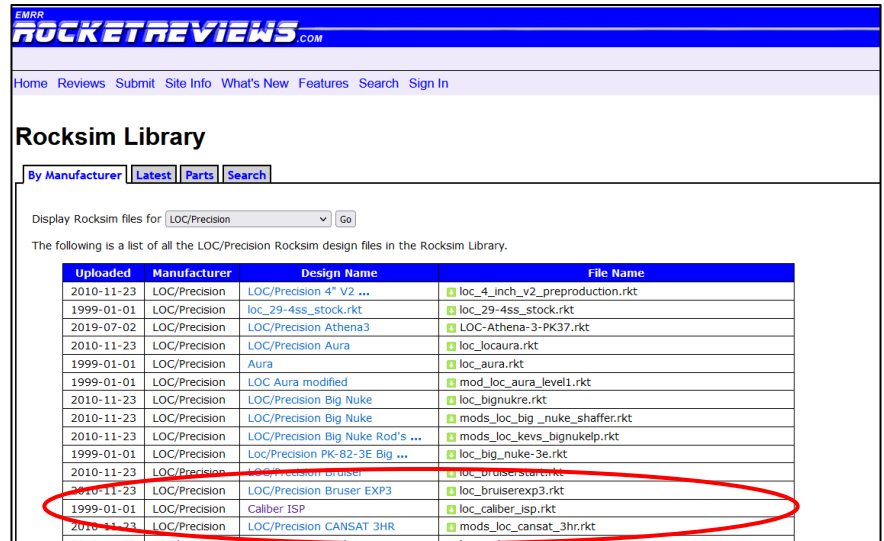
Figure 11-2: RockSim 10 Folders

## 11b. Importing a Model

Models of kit rockets can be imported into RockSim. This feature is useful to perform simple analysis to ensure the kit is suitable for the competition parameters. It is quick to import a model and run a simulation of that model. Most rocket vendors/suppliers will offer a free RockSim model, such that you can perform analysis first, prior to purchasing the kit. We will search for and import a detailed model of the LOC Precision Caliber-ISP. There are databases online, where users can upload and share or download RockSim models.

### i. Selecting a Kit

1. Download a pre-existing model of a LOC Precision-Caliber ISP kit
  - a. <https://www.rocketreviews.com/rocksim-library.html>
  - b. Sort by Manufacturer
  - c. Display RockSim files for LOC/Precision
  - d. Download Caliber ISP file
0. Import rocket file into RockSim 10
  - a. Open the existing design file folder (Import Folder)
  - b. Select loc\_caliber\_isp file from download folder
3. View the LOC Caliber ISP



Uploaded	Manufacturer	Design Name	File Name
2010-11-23	LOC/Precision	LOC/Precision 4" V2 ...	loc_4_inch_v2_preproduction.rkt
1999-01-01	LOC/Precision	loc_29-4ss_stock.rkt	loc_29-4ss_stock.rkt
2019-07-02	LOC/Precision	LOC/Precision Athena3	LOC-Athena-3-PK37.rkt
2010-11-23	LOC/Precision	LOC/Precision Aura	loc_loaura.rkt
1999-01-01	LOC/Precision	Aura	loc_aura.rkt
1999-01-01	LOC/Precision	LOC Aura modified	mod_loc_aura_level1.rkt
2010-11-23	LOC/Precision	LOC/Precision Big Nuke	loc_bignukre.rkt
2010-11-23	LOC/Precision	LOC/Precision Big Nuke	mods_loc_big_nuke_shaffer.rkt
2010-11-23	LOC/Precision	LOC/Precision Big Nuke Rod's ...	mods_loc_kevs_bignukelp.rkt
1999-01-01	LOC/Precision	LOC/Precision PK-82-3E Big ...	loc_big_nuke-3e.rkt
2010-11-23	LOC/Precision	LOC/Precision Bruser	loc_bruserstar.rkt
2010-11-23	LOC/Precision	LOC/Precision Bruser EXP3	loc_bruserexp3.rkt
1999-01-01	LOC/Precision	Caliber ISP	loc_caliber_isp.rkt
2010-11-23	LOC/Precision	LOC/Precision CANSAT 3HR	mods_loc_cansat_3hr.rkt

Figure 11-3 Rocket Reviews RockSim Library, Caliber ISP

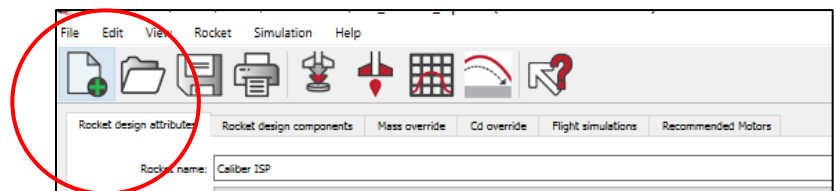


Figure 11-4: RockSim Import Folder

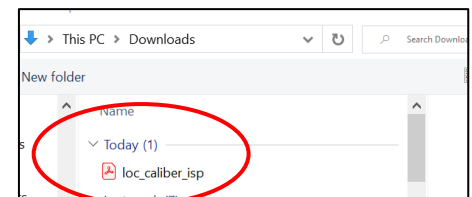


Figure 11-5: Select Rocket File from Download Folder on Computer

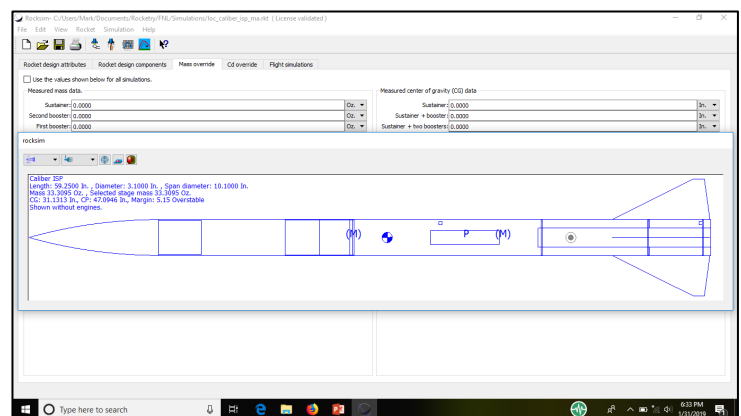


Figure 11-6: Caliber ISP Stock File

ii. Selecting an Engine

- 1. Select the 'Prepare for Launch' icon
- 2. Select the 'Choose Engine' tab

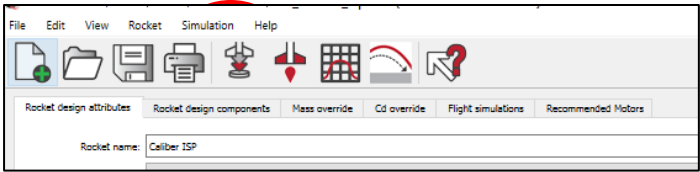


Figure 11-7: Select Prepare for Launch

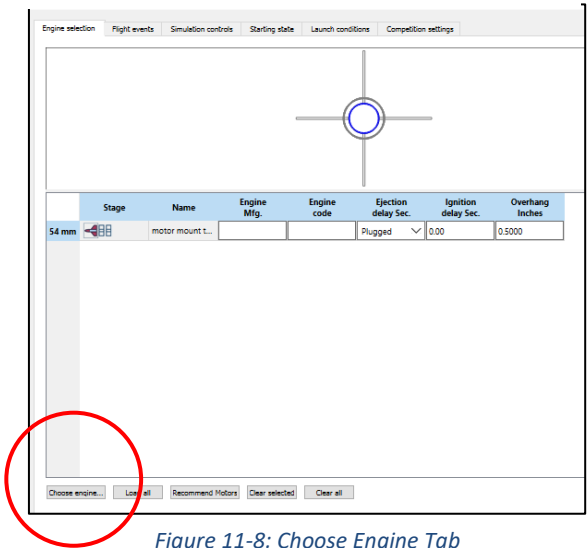


Figure 11-8: Choose Engine Tab

- 3. Select 'Aerotech' in the Manufacturer Filter field
- 4. Select the 'Show all engines' in the Diameter Filter field

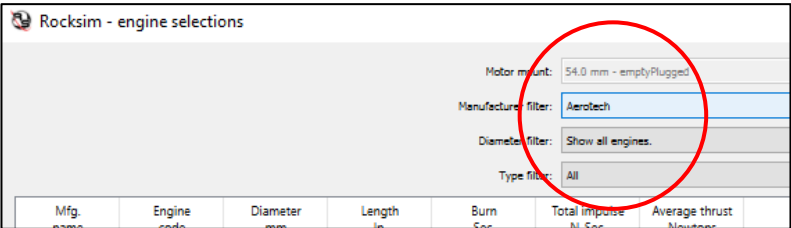


Figure 11-9: Manufacturer Field and Diameter Filter

- 5. Double click on the H219T motor

The AeroTech H219T will automatically load into the RockSim software.

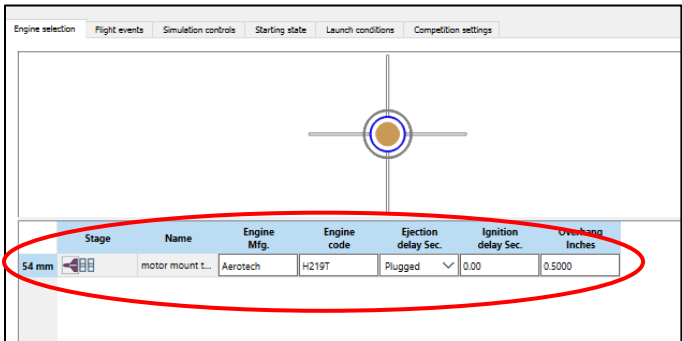


Figure 11-11: H219T Motor Uploaded to RockSim

Mfg. name	Engine code	Diameter mm	Length in.	Burn Sec.	Total impulse N-Sec.	Average thrust Newtons
Aerotech	M1780NT	75.00	26.1811	3.04	5341.079	1759.828
Aerotech	M1809FJ	98.00	29.5669	4.95	8212.700	1658.461
Aerotech	M1845NT	98.00	23.5039	4.73	8093.458	1711.452
Aerotech	M4500ST	98.00	23.5039	1.69	7307.365	4321.328
AT	M6000ST	98.00	29.5669	1.74	9606.003	5533.412
Aerotech	N1000W	98.00	41.1811	16.14	14138.407	876.235
Aerotech	N2000W	98.00	41.1811	7.68	13263.435	1727.235
Aerotech	N3300R	98.00	41.7323	4.52	14035.152	3105.809
Aerotech	N4800T	98.00	47.2835	5.21	19273.861	3702.240
Aerotech	O5280X	98.00	59.0157	4.52	22223.948	4920.068
Aerotech	H2835T	38.00	6.1024	0.74	199.083	269.031
Aerotech	I175W5	38.00	8.4252	1.97	333.196	169.135
Aerotech	G80T	29.00	4.8819	1.50	116.252	77.501
Aerotech	D22W	24.00	3.4252	1.01	19.243	19.053
Aerotech	E26W	24.00	3.4646	1.22	27.619	22.583
Aerotech	F52C	29.00	4.3701	1.33	66.311	49.895
Aerotech	G125T	29.00	6.1417	12.60	145.847	11.574
Aerotech	H135T	29.00	6.1417	15.43	214.935	13.928
Aerotech	G85T	29.00	6.1417	19.96	129.868	6.509
Aerotech	H400C	54.00	14.1339	3.26	1307.257	401.122
Aerotech	H219T	38.00	6.1024	1.08	234.561	216.985
Aerotech	F52C	29.00	4.3701	1.33	66.311	49.895
Aerotech	I130-300CC09B	54.00	20.9716	4.00	477.075	119.269

Figure 11-10: Aerotech H219T Motor Selection

### **11c. Running a Flight Simulation**

Once a model is created or imported, RockSim can be configured to perform simulations of your rocket, under various conditions, with various motors. We will set up and perform a flight simulation of the LOC Precision Caliber-ISP.

### **11d. Interpreting Results**

Interpreting and understanding the results of a flight simulation are important, to ensure requirements are satisfied. If the results do not satisfy requirements, then modifications to either the simulation conditions, the motor selection or the parachute selection should be made, and the flight simulation repeated. If the results still do not satisfy requirements, then perhaps a different kit/model should be imported and the whole process repeated.

Interpreting the results properly will also ensure that the simulation was set up and performed properly.

### **11e. Simulation Tips**

In the proposal and preliminary phase of the FNL, many simulations should be run, examining as many kits as possible, to determine the best kit-motor-parachute combination that will satisfy requirements. By the time of the submission of the PDR, the team should have narrowed the choice to one kit-motor-parachute combination.

Once the kit arrives, and the build progresses, keep in mind that modification will most likely be made to the stock kit, in order to accommodate your challenge payload/solution. Simulations must be updated to match the existing rocket, to ensure any changes will not violate vehicle performance requirements.

### **11f. RockSim Notes**

## **12. Designing and Acquiring Your Rocket**

As a new rocket builder, designing and building your first high-powered rocket for competition may seem like a daunting task. This section will highlight some of the key components to help you with a safe and successful flight.

### **12a. Rocket Selection / Rocket Simulation**

The first step is selecting which kit you will purchase to build your competition rocket. To be successful, it is beneficial to view the widest array of kits possible so you know what's out there. Selection of the kit is not trivial; be sure to spend some time researching the capabilities and allow the payload design to mature.

FNL does not set restrictions on material or size usually, only motor and altitude range achieved. Thus, the main driver for kit selection will be the size of the motor tube and the altitude the rocket can achieve with that size of motor.

### **12b. Simulations**

Simulating the flight performance of the kit, on the expected motor (or similar) is beneficial prior to buying your kit. Usually, vendors and manufacturers will provide a RockSim file such that you can simulate accurately. A range of kit and motor combinations should be considered. Once the kit is narrowed down and selected, it is a good idea to have a backup motor selection in mind, as the weight increases on your rocket over the course of the design/build.

In conjunction with initial simulations to help select a kit, payload design should begin. Discuss concepts and ideas, while looking at cost, weight and size. The rocket kit should not be selected until it is determined the maximum size of the payload that will fit inside (aka: don't let a random kit diameter choice dictate how small your payload should be).

Conversely, the estimated payload weight should be known as early as possible (or an upper limit set), as this will also determine the motor choice, since this estimated weight will need to be added to the stock simulations and affect the altitude requirement.

### **12c. Weight (Simulation vs. Stock Kit vs. Modified Kit with Payload)**

It is usually a rule of thumb that initial simulations will under predict the final weight of the fully loaded rocket. Drag considerations will also likely be under predicted. This should lead to an initial higher than required altitude estimate (or stated differently, the initial predicted altitude can be conservatively high, with the assumption that weight will increase by final design). If the weight increase is too much however, then an increase in motor size may also have to occur.

Keep in mind there is a deadline for motor selection, after which you can no longer change the motor you will be using for competition flight!

### **12d. Recovery**

Determining the size of the parachute and the size and how much recovery hardware should be completed prior to the kit is purchased. The size of the parachutes is not trivial as they will need to satisfy descent rate requirements and will add weight to the rocket vehicle.

### **12e. Miscellaneous Design Tips**

Don't just randomly buy a kit too early, because it says it reaches a certain altitude! A stock kit can likely be assembled within a week by a team of students. A modified kit may take an extra week or so. If you want to be built by FRR, then set aside all of March to build, and that should be plenty of time. If your design looks good at PDR, you can begin ordering parts in February.

Be sure to understand how changes to the design affect the performance. For example, if your build weight increases to the point where you need to choose a bigger motor, this will in turn add more weight toward the rear of your rocket, which will change your stability margin (CG vs. CP) thus, weight may have to be added towards the nose of the rocket to satisfy the required stability margins.

Changing to a bigger motor will also increase the overall weight, which will increase the descent rates and kinetic energy upon landing, such that larger parachutes may then need to be selected (to satisfy descent rate requirements) which will further increase weight and change your stability margin.

During simulations, it is good to select a 'nominal' motor, and a 'backup' motor. The nominal motor is used with the stock or modified kit model, and simulations satisfy all requirements. As the build progresses, the backup motor would be used if the weight started to increase beyond what the nominal motor simulations expected and reaching minimum altitude becomes an issue. It is best however, to try to 'shave' weight by any means necessary (or reduce the drag, by polishing to surface somehow).

Don't forget to verify and understand all of the requirements!

### **12f. Design & Acquisition Notes**

## 13. Rocket Build

### 13a. Pre-Fit Check

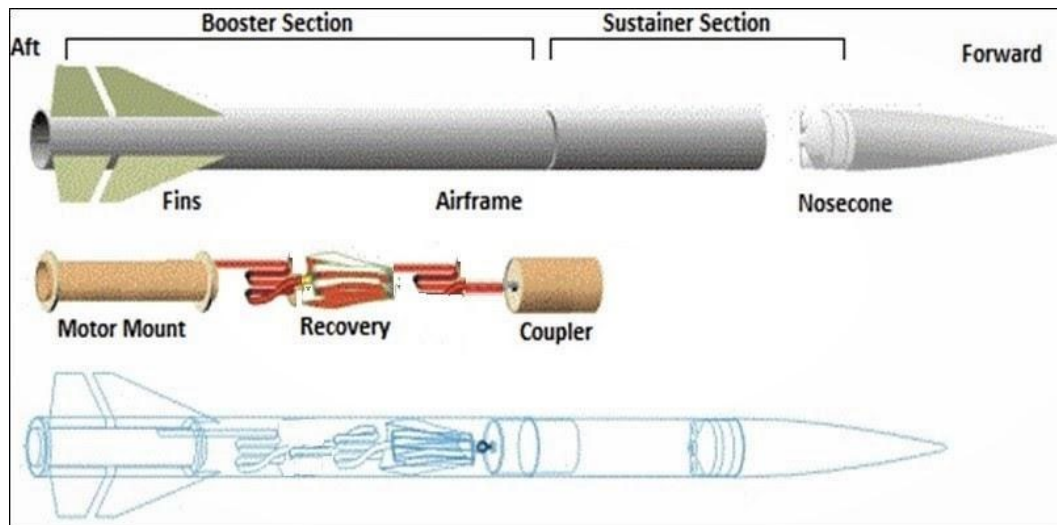


Figure 13-1: High-Powered Rocket Diagram

The key to proper fit and adhesion is to **DRY-FIT** all rocket parts **BEFORE** applying any epoxy to parts. Do not over-sand your parts, a snug fit is required.

#### Parts to dry-fit (DETAILED ON FOLLOWING PAGES):

- Centering Rings
- Coupler and Bulkplate
- Motor Mount Tube (MMT)
- Airframe
- Fins
- Nose cone

#### Notes:

## i. Centering Ring

Reference: 5e. Centering Rings / Bulkplates

1. Identify and label centering rings
  - a. Add the word “out” to one side of the Aft Centering Ring
2. Rough sand entire length of motor mount tube (for adhesion) just enough to remove glassine
3. Sand inside of centering rings so they fit into MMT
4. Install small eyebolt into the **Forward** centering ring
  - a. One nut and small washer on the eyebolt side of the centering ring (depends on hardware)
  - b. Small washer and nut on the back end of the centering ring
5. Install motor retention threaded T-Nuts onto **Aft** centering ring
  - a. May need to gently hammer the T-Nuts into place

### Notes:



13-2: Aligned Centering Rings (top – Forward, middle – Center, bottom – Aft)



Figure 13-3: Forward Centering Ring with Eyebolt Installed



Figure 13-4: Aft Centering Ring with T-Nuts Installed



## ii. Bulkplate

Reference: 5e. *Centering Rings / Bulkplates*

1. Install an eyebolt into the bulkplate
  - a. One large washer and one nut on the eyebolt side of the centering ring
  - b. One large washer and nut on the back end of the bulkplate (*If you only have one washer, the washer should be placed on the back side of the bulkplate*)
2. Dry-fit bulkplate into coupler tube (using eyebolt as handle)
3. Sand outside of bulkplate for proper fit
4. Place the **Coupler Bulkplate** 1/4" from end of the coupler

### **Notes:**



Figure 13-5: Bulkplate and Eyebolt

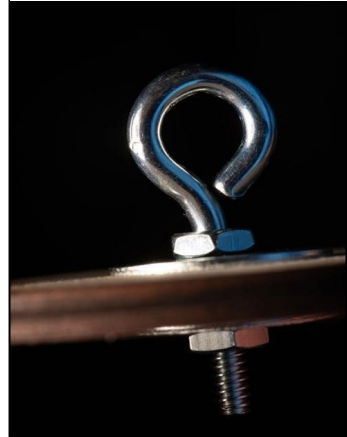


Figure 13-6: Eyebolt Installed in Bulkplate



Figure 13-7: Eyebolt installed in Bulkplate

### iii. Centering Ring Alignment

Reference: 5e. Centering Rings / Bulkplates, 5f. Motor Tube

1. Centering rings should fit on motor mount tube
2. Mark the forward end of motor mount tube at  $1/8''$ - $3/16''$  for forward centering ring placement
3. Measure distance from aft end of airframe to the forward fin slot for center motor mount ring placement
4. Draw a line at the same distance on the motor mount tube for center motor mount ring placement. NOTE: Measure from aft end of motor mount tube
5. Mark the middle of motor mount tube at  $5-1/4''$  from aft end for mid-centering ring placement;



Figure 13-8: Centering Rings Fitted on Motor Mount Tube



Figure 13-9: Center Motor Mount Ring Distance from End of Motor Mount Tube



Figure 13-10: Center Motor Mount Ring Located above Fin Slot (Left); Measure the Length of the Fin Slot for Accuracy (Center); Draw a Line on the Motor Mount Tube around the Center Motor Mount Ring (Right)

### Notes:

#### iv. Airframe

Reference: *5c. Airframe*

1. Rough sand around fin slots of airframe tube (for adhesion)



#### v. Fins

Reference: *5i. Fins*

2. Fit fins into airframe tube slots – sand as needed to fit



#### Notes:



*Figure 13-11: Fin Slot (Top); Relation to Motor Mount Tube and Mid/Aft Centering Rings (Center); Fin Sanding Technique (Bottom)*

## 13b. Assembly

### i. Epoxy Overview

1. Normally a two-part chemical mixture
  - a. A resin
  - b. A hardener
  - c. Usually mixed in a 1:1 ratio
2. Various Types Based on Material and Strength
  - a. Time, Strength
  - b. JB Weld – metallic bonding
  - c. Silica additive can be used for fin fillets
3. Epoxy Fillets
  - a. Creates a strong bond between two surfaces
  - b. Applied with a craft stick in single smooth line to create a valley between two surfaces
4. Safety
  - a. Always wear gloves prior to mixing and applying epoxy
  - b. Work quickly and with small amounts of epoxy at each step

Learn more about epoxy:

<https://www.apogeerockets.com/education/downloads/Newsletter186.pdf>

Or see the NASA Handbook for construction tips.



Figure 13-12: Epoxy Resin and Hardener



Figure 13-13: Epoxy Application

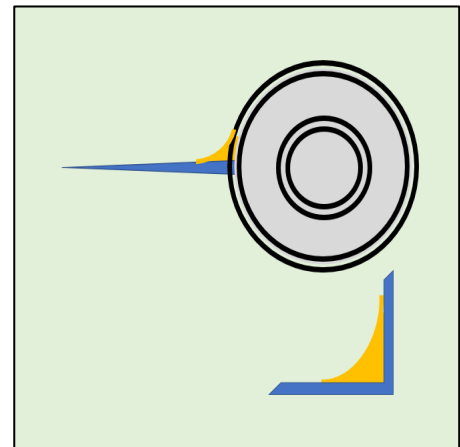


Figure 13-14: Epoxy Fillets

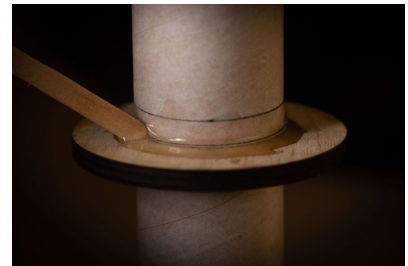
### **Notes:**

## ii. Motor Mount Assembly

Reference: 5e. Centering Rings / Bulkplates, 5f. Motor Tube

1. Dry-fit Step: Fit the mid-centering ring at the measurement marked in previous steps
  - a. Slide ring down below lines
  - b. Put on gloves before preparing epoxy
  - c. Prepare small amount of epoxy 1:1 ratio
  - d. Apply epoxy to the motor tube on the lines drawn for mid-centering ring
  - e. Slide the mid-centering ring just ahead of the forward fin slot on the marked line, using twisting motion
2. Dry-fit Step: Fit the forward centering ring at the measurement marked in previous step
  - a. Slide ring down below lines
  - b. Put on gloves before preparing epoxy
  - c. Prepare small amount of epoxy 1:1 ratio
  - d. Apply epoxy to the motor tube on the lines drawn for forward centering ring
  - e. Slide the forward centering ring to the marked line(s), using twisting motion
3. Apply fillet on aft side of forward centering ring
4. Apply small dabs of epoxy to eyebolt threads and T-nuts
  - a. Do not get epoxy on the outside of the motor mount tube
5. Set motor mount assembly aside, allow epoxy to dry

### Notes:



*Figure 13-15: Motor Mount Placement with Line (Top); Applying Epoxy to the Mid-Centering Ring (Center); Completed Mid-Centering Ring (Bottom)*



*Figure 13-16: Epoxy Eyebolt Thread and T-Nuts (Top); Complete Motor Mount Assembly (Bottom)*



### iii. Coupler Assembly

Reference: 5d. Coupler, 5e. Centering Rings / Bulkplates

1. Dry-fit Step: Fit bulkplate inside coupler, ensuring level fit ~1/4" from the edge
2. Remove bulkplate after ensuring fit
3. Put on gloves before preparing epoxy
4. Prepare small amount of epoxy
5. Dab the threads and nut of eyebolt with epoxy
6. Apply epoxy around inside coupler ~ 1/4" from the end
7. Twist the bulkplate into the coupler leaving 1/4" gap from the edge of the coupler
8. Apply fillet on forward side of bulkplate
9. Set coupler assembly aside, allow epoxy to dry



#### Notes:



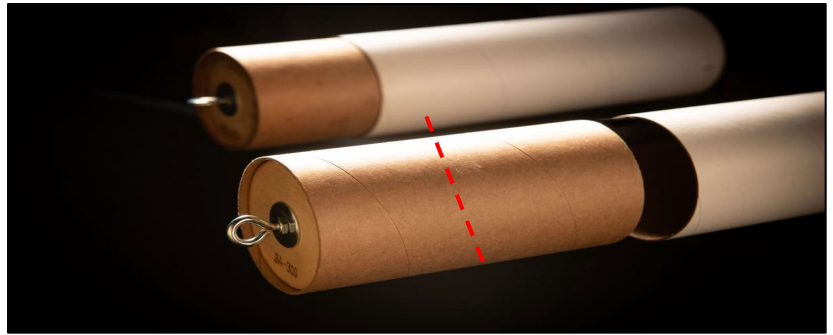
*Figure 13-17: Bulkplate Installed in Coupler (Top);  
Applying Epoxy around Inside of Coupler (Middle);  
Bulkplate Installed in Coupler (Bottom)*

#### iv. Coupler/Sustainer

Reference: 5a. *Parts and Subassemblies*, 5d. *Coupler*

1. Dry-fit coupler to upper airframe
2. Draw a line/mark around the center of the coupler
3. Put on gloves before preparing epoxy
4. Prepare small amount of epoxy
5. Apply epoxy around inside of the sustainer (about 1" from edge)
6. Place coupler into sustainer section aligning aft section of the sustainer with the center line drawn on the coupler
7. Use a twisting motion, to evenly distribute the epoxy
8. Set aside, let epoxy dry

#### Notes:



*Figure 13-18: Example of Where to Draw Line on Coupler (Top); Epoxy Application (Middle); Coupler Placement (Bottom)*

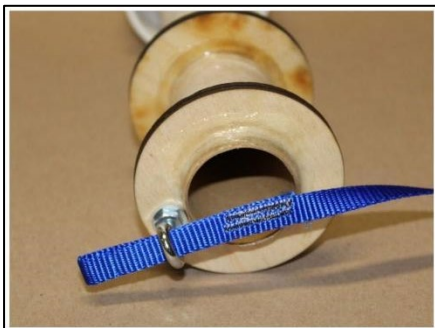
## v. Motor Mount

Reference: 5f. Motor Tube, 8. Recovery Hardware

1. Attach the shock cord to the forward centering ring eyebolt using a quicklink in the shock cord loop and the eyebolt
  - a. A [double slip square knot](#) can be used if a loop is not on the shock cord
    - i. Attach shock cord by feeding the cord through the eyebolt
    - ii. Feed the opposite end of the shock cord through the sewn loop
    - iii. Pull shock cord tight



Figure 13-19: Cord and Quicklink



2. Re-coil shock cord in ~8 - 10" in length, securing with masking tape when done
3. Leave enough length on the eyebolt end of the shock cord such that it will come out the end of the forward opening on the airframe

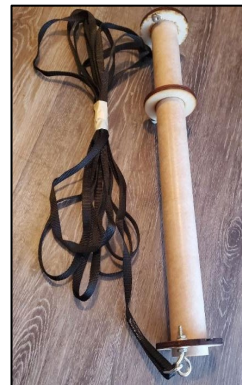


Figure 13-20: Shock Cord Attached to Eyebolt

4. Stuff the bundle of cord inside the motor mount tube

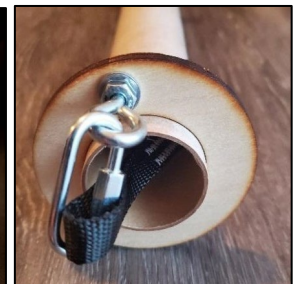
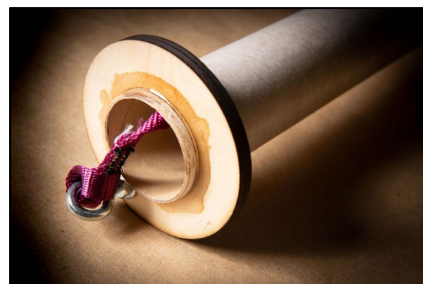


Figure 13-21: Shock Cord Installed Inside Motor Mount Tube Using Eyebolt (Left) and Quicklink and Eyebolt (Right)



5. Dry-fit Step: Make sure motor mount tube fits into airframe properly, sand outer edge of centering rings as needed
  - a. Avoid making burrs on the inner edge of the airframe
  - b. If a burr occurs, gently sand the inner edge of the airframe
6. Slide motor mount tube into airframe forward the mid-centering location
7. Remove MMT after ensuring proper fit
8. Put on gloves before preparing epoxy
9. Prepare small amount of epoxy
10. Epoxy inside parameter of the airframe just in front of the forward center ring location using craft stick taped onto dowel rod
11. Slide the motor mount tube into position
  - a. The **Mid-Centering** must be just forward of the forward fin slot. If the mid-centering does not clear the slot, fins may not fit into the slots properly
  - b. The **Motor Mount Tube** should be flush with the aft side of the airframe
12. Allow epoxy to dry

**Notes:**



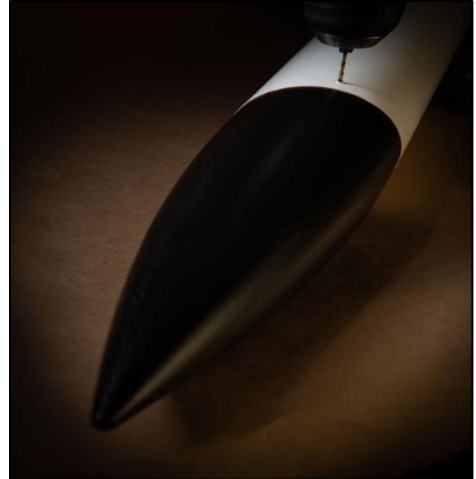
*Figure 13-22: Relative Position of MMT Assembly Once Installed in Airframe (Top); Mid Centering Ring Should Sit Forward of Fin Slots (Bottom)*

#### vi. Nose Cone

Reference: *5b. Nose Cone*

1. Fit the nose cone to the sustainer
  - a. Should not require sanding
2. Drill a single hole at location shown, through both airframe and nose cone with awl or 1/8" drill bit
3. The nose cone is then attached to the airframe with a sheet metal screw (longer pointed screw) to keep the nose cone from separating in flight (but allow for removal of nose cone)
4. Seam along nose cone (flash) may be sanded with fine grain sandpaper (while waiting for fin epoxy to set)

#### **Notes:**



*Figure 13-23: Drilling the Airframe and Nose Cone*



*Figure 13-24: Nose Cone Fitted on Sustainer, Red Dot Indicates Drill Mark*

## vii. Rail Button Alignment

Reference: 5h. Rail Buttons

### Rail Guide System

- 1010 rail guide (it's a 1.0" x 1.0" rail)
- 6' (or 72 inches) in length

### Rail Button Measurement

1. Temporarily position a 4" - 5" length of tape between the fin slots. Place a mark on tape, just inside of both fin slots.
2. Remove the masking tape
3. Fold masking tape in half on non-stick side, matching the two fin slot reference marks
4. Make a crease at the middle location
5. Place the strip of masking tape back on the airframe matching lines to the fin slots
6. Mark the center point at the crease line, making a line half way between the two fin slots on the aft portion of the booster section
7. Place the line marked on the airframe parallel to a door jam
8. Draw a line halfway up the airframe, creating the rail button centerline
9. This is the line the rail buttons will be installed on after the fins have been installed

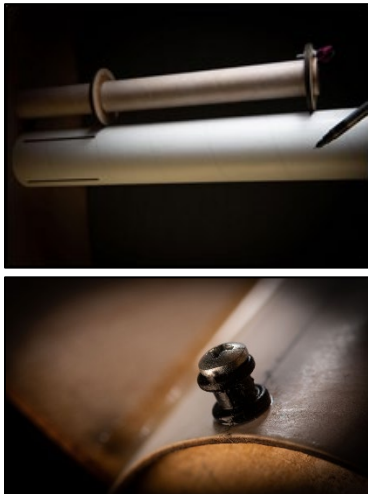


Figure 13-26: Rail Buttons are Drilled into the Mid-Centering Ring (Top) and Aft-Centering Ring (Bottom)

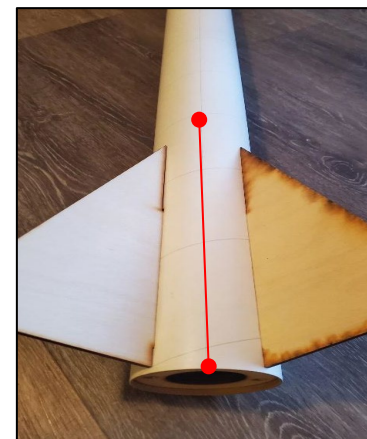
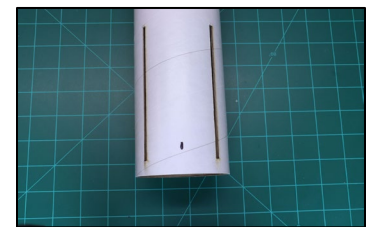
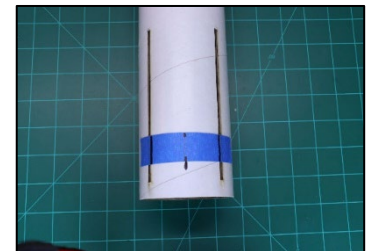
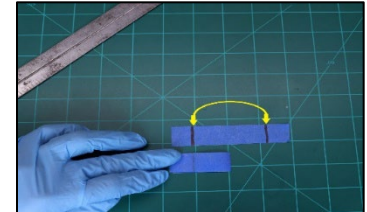
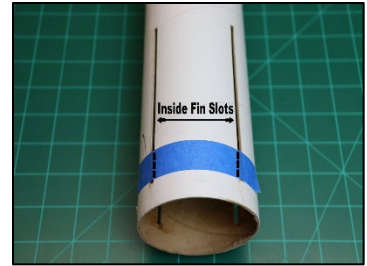


Figure 13-25: Measuring Fin Slots (Top); Measuring Half Way between Two Fin Slots (Top Center); Drawing a Line at the Half Way Mark on Tape (Center); Drawing the Half Way Mark on the Air Frame (Bottom Center); Markers to Indicate Rail Button Placement/Alignment (Bottom)

### viii. Vent Holes

Reference: 7b. *Center of Pressure*

- Vent (pressure relief) holes allow the pressure inside the rocket to equalize to the external atmosphere.
  - Usually 1/8"-1/4" in diameter
1. Drill first hole with an awl or 1/8" drill bit in the middle region of the sustainer
  2. Drill second hole an awl or 1/8" drill bit in the booster region above the motor mount tube/fins

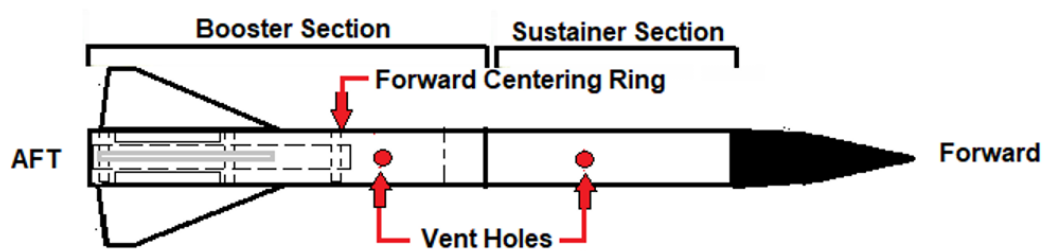


Figure 13-27: Vent Holes Indicated in Red on Rocket Airframe

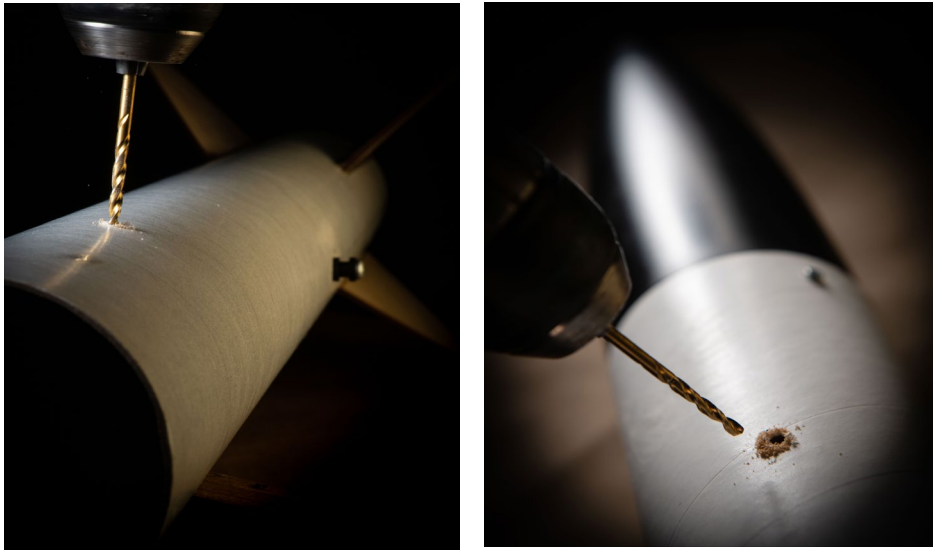


Figure 13-28: Drilling Vent Hole in Booster Section to Not Interfere with Rail Buttons Alignment (Left); Drilling Vent Hole in Sustainer Section (Right)

Notes:

## ix. Fin Installation

Reference: *5i. Fins*

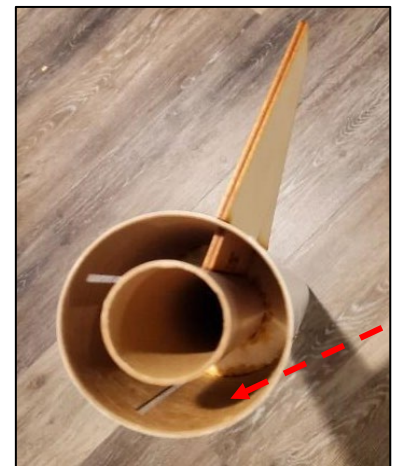
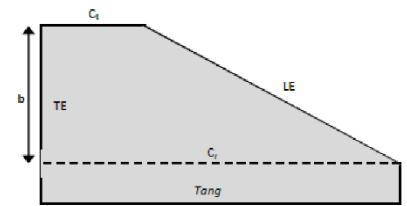
### Dry-fit and Tack

1. Dry-fit fins into slots
2. Retrieve fin installation guide from binder, and place guide on floor
3. Set airframe on the center circle on the guide
4. Align each fin to the crosshair lines
5. Put on gloves before preparing epoxy
6. Prepare small amount of epoxy
7. Apply epoxy to “Tang” side of fin #1 (light tack)
8. The span (b) is placed at the aft end of the airframe
9. Insert fin into fin slot – repeat for each fin
  - a. Ensure the tang touches the motor mount tube
10. Place assembly on fin installation guide, and align fins - tape fins to the airframe as needed
11. **Do these steps quickly to get all fins tacked/aligned before the first fin cures**

### Notes:



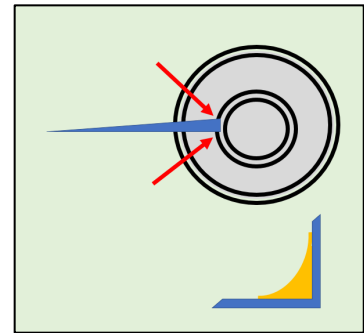
*Figure 13-29: Align Each Fin to Crosshair Lines*



*Figure 13-30: Tang Example (Top);  
Apply Epoxy to Tang (Center); Insert  
Tang in Fin Slot (Bottom)*

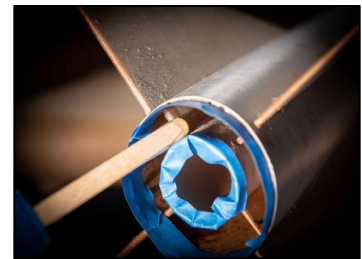
### Inner Fin Fillets

1. Preparation: Apply masking tape to outside diameter of motor mount tube and airframe (up to fin tab)
2. Apply epoxy fillet to seam between motor mount tube and “tang” side of the fin
3. Use long dowel to apply along full length
4. Apply quickly with large dollops
5. Apply a total of 8 fillets (on each side of 4 fins)
6. Allow epoxy to set, remove tape while wet (within 15 minutes)



*Figure 13-31: Epoxy Fillet to Seam Motor Mount and Tang*

### Notes:



*Figure 13-32: Use Craft Stick or Long Dowel to Apply Epoxy Fillet between Motor Mount and Fin*

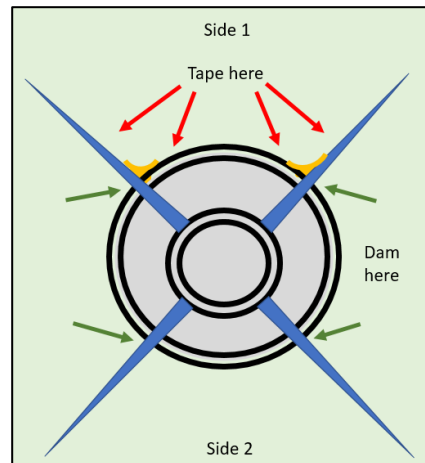


*Figure 13-33: Fully Applied Epoxy Fillet between Motor Mount and Fin*



### Outer Fin Fillets (Prep)

1. Fillet tape must be installed parallel to fin, along the full length about 1/4" away from corner
  - a. On both fin and tube (red arrows)
2. Repeat fillet tape for all four fins
  - a. Will be 16 strips of tape for entire rocket for fillets
3. With the rocket positioned as shown, place 4 pieces of tape to create 4 dams to fill in the small gap between the fin and tube, on top of fillet tape
4. Place tape under fin long enough to cover gap
  - a. Must be tight in corner, so epoxy does not leak through (green arrows)



*Figure 13-34: Tape and Dam Diagram*



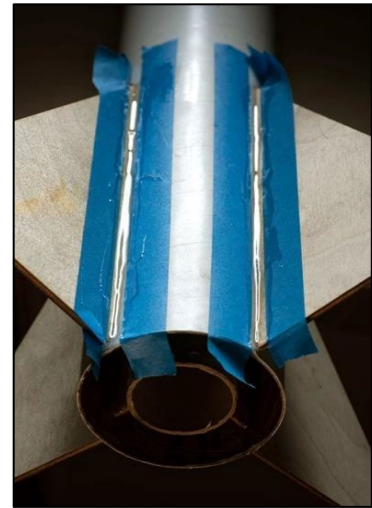
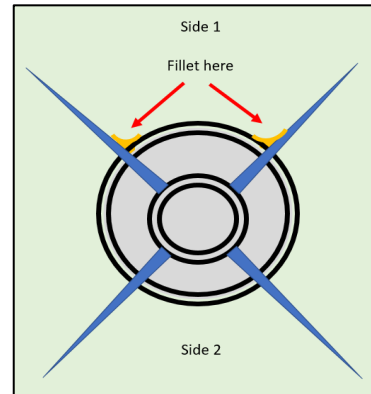
*Figure 13-35 (Left); Tape Locations for Epoxy Fillets (Center); Dam Locations Right)*

### Notes:

### Outer Fin Fillets (Epoxy)

1. For Side 1 (as shown):
  - a. Put on gloves before preparing epoxy
  - b. Prepare small amount of epoxy
  - c. Fill in gap with epoxy (both fins) – let set few minutes, ensure epoxy is not leaking past dam on underside
  - d. Epoxy along entire length of fin root, create smooth fillets (both fins)
  - e. Remove dam tape from underside after 10 minutes
  - f. Remove fillet tape from Side 1 (tube and fins)
  - g. Let set up for 10 – 15 minutes
2. Rotate rocket 180 degrees, and repeat for Side 2
3. Sides 3 and 4 do not require a dam step, fillet only

### Notes:



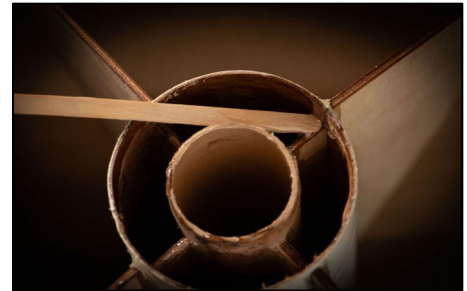
*Figure 13-36: Fillet Diagram (Top);  
Fin Fillet Fill (Bottom)*



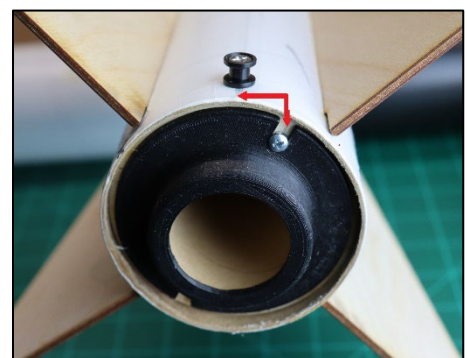
## x. Aft Centering Ring Installation

Reference: 5e. *Centering Rings / Bulkplates, 5g.*

1. Install long machine screws into retaining nuts for use as handle
  - a. Dry-fit Step: Ensure the aft end of booster is free of epoxy, for ease of fit (sand or wipe with alcohol)
  - b. Dry-fit Step: Ensure CR fits in tube, all the way until contact with fin tabs (will be an edge as shown) – sand as needed
  - c. Remove aft CR after dry-fit
2. Put on gloves before preparing epoxy
3. Prepare a small amount of epoxy
4. Apply a band of epoxy around outside of MMT and inside of airframe
5. Twist centering ring into place, pushing in all the way until it stops against fin tabs
6. **Ensure T-nut is offset from rail button mark**
7. Apply fillet on aft end of aft CR
  - a. Avoid getting epoxy in MMT and in motor retention system



## Notes:



*Figure 13-37: Slide Aft Ring to Fins (Top); Epoxy Outside of MMT (Top Center); Epoxy Inside of Airframe (Middle Center); Rail Button, T-Nuts and MMT Cap Installed (Bottom Center); Offset between T-Nut and Rail Button (Bottom)*

## xi. Rail Button Installation

Reference: *5h. Rail Buttons*

Rail Buttons are installed so that your rocket can be fit to a standard launch rail

The bottom rail button will be installed into the aft centering ring, while the top rail button will be installed into the airframe (with backing nut – or into forward centering ring)

1. Mark an 'X' on the vertical line where it intersects the aft CR
2. Mark an 'X' on the vertical line near the forward CR
  - a. Attach dowel to your ruler, insert into forward end of airframe until it touches the forward CR
  - b. Mark line on dowel indicating end of airframe, remove and place on top of airframe to use as "measuring tape"
3. Drill holes using a 1/8" drill bit – ensure hole is perpendicular to surface
4. Dab epoxy in hole
5. Attach rail buttons and pointed screws into place



*Figure 13-38: Rail Button Alignment on Launch Rail (Top); Marking an 'X' on the Vertical Line Where the Line Intersects with the Aft and Forward Centering Ring (Bottom)*

### Notes:

## xii. Recovery Installation

Reference: 8. Recovery Hardware

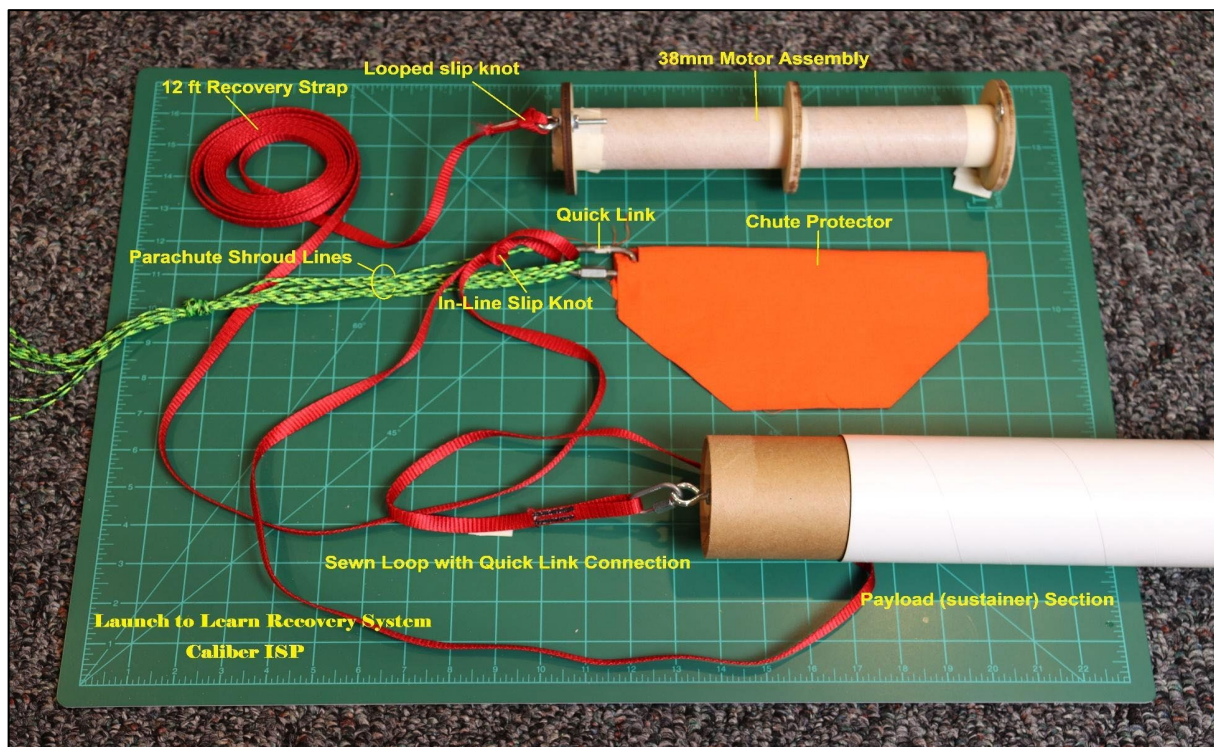


Figure 13-39: Recovery Supplies

Failed parachute deployment: <https://www.youtube.com/watch?v=M2G-UVCO7u0>

1. Push a shock cord out through forward end of airframe, remove masking tape
2. Tie an in-line slip knot in the shock cord (1/3 point of the total shock cord length)
3. Untangle parachute shroud lines
4. Place arm through the shroud lines

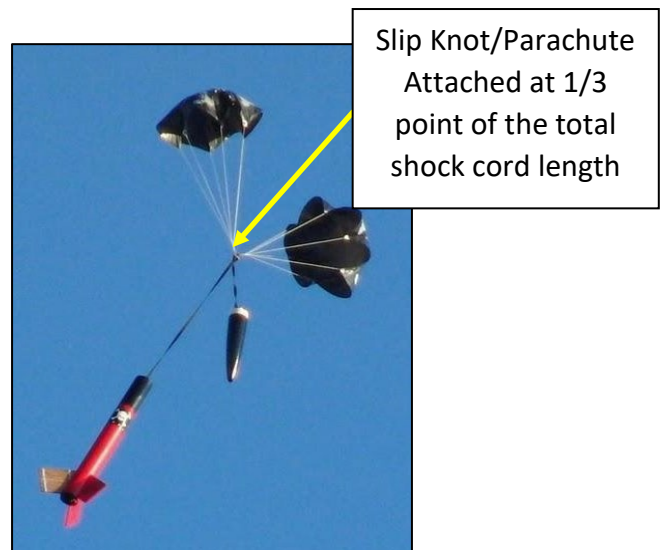


Figure 13-40: Masking Tape and Shock Cord (Left); Knot Location on Shock Cord (Right)



5. Attach the parachute to the parachute with a looped slip knot
  - a. Feed shroud lines through sewn loop in shock cord end
  - b. Pass parachute through shroud lines
  - c. Pull parachute tight



Figure 13-31: Overview Knot Step 1

**Notes:**



Figure 13-42: Overview Knot Step 2



Figure 13-43: Overview Knot Step 3

### xiii. Parachute Preparation

1. Make sure the parachute shroud lines are untangled, and then lay it flat on the table.



*Figure 13-44: Step 1 of Parachute Prep*

2. Position one shroud line nearest you, then start folding the parachute gores into angular sections by bringing each consecutive shroud line over the first and evening out the fold up to the tip.



*Figure 13-45: Step 2 of Parachute Prep*

3. Once all gores are folded with all shroud lines together, it should appear like this.



*Figure 13-46: Step 3 of Parachute Prep*

4. Fold the parachute like a zigzag.



*Figure 13-47: Step 4 of Parachute Prep*

5. Tightly roll the parachute into a cylinder. Ensure all shroud lines are still untangled and together.



*Figure 13-48: Step 5 of Parachute Prep*

6. Neatly bring the shroud lines together in a zigzag fashion and place them next to the parachute at one corner of the parachute protector or Nomex cloth.

a. Watch demo of alternate method of small Nomex cloth



*Figure 13-49: Step 6 of Parachute Prep*

7. Start rolling the Nomex over the parachute and shroud lines. Keep it snug. Then place the shock cord onto the Nomex using the same method as the shroud lines.



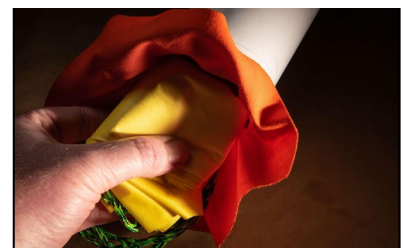
*Figure 13-50: Step 7 of Parachute Prep*

8. Fold the left and right corners of the Nomex inward, then continue rolling the bundle tightly, keeping all of the shroud line inside the Nomex cloth.



*Figure 13-51: Step 8 of Parachute Prep*

9. Place the newly wrapped parachute bundle into the booster section of the rocket14. Certification Launch Preparation



*Figure 13-52: Step 9 of Parachute Prep*

## 14a. Safety Overview

Launch operations require TRA or NAR personnel in order to complete a launch safely. At a minimum, the personnel required are:

1. Range Safety Officer (RSO)
  - a. The goal of the RSO is to minimize the risks to personnel and property involved in the handling, preparation, and launch operations of model and high-powered rocket launches
2. Launchpad Safety Officer (LSO)
  - a. The LSO is responsible for determining the status of range operations: site, airspace, and weather.
3. Launchpad Manager
  - a. The Launch Pad Manager will assist you with the launch prep
4. Rocketry Mentor
  - a. TRA/NAR certified at a level equal to or above the motor you will use to certify
  - b. May guide, direct, and assist you as you prepare your rocket and go to the launch pad

## 14b. Launch Site Materials and Supplies

Materials and supplies that may be helpful at the launch site:

- Drill
- Screwdriver
- Dog Barf
- Epoxy
- Masking Tape
- Screw
- Washer
- Nut
- Etc.



*Figure 14:1 Launch Site Preparation Area*

## 14c. Pre-Launch Rocket Preparation

Prior to the certification launch, you will need to prepare the motor and the parachute. Once you are assigned a launch pad, you will need to place your rocket on the launch rail and prepare the rocket for launch.

- Motor
- Recovery
- Launch Pad

## 14d. Motor Preparation

For a certification launch, you will need to prepare your own motor under supervision of the club RSO (or your mentor).

1. Obtain your motor from the RSO
  - a. WSGC provides one certification motor
2. Perform your own motor prep
  - a. Remove certification motor from protective cardboard tube
  - b. Delay Adjustment
  - c. Black Powder
  - d. Motor Installation
3. RSO will observe your motor prep
  - a. It is not a test, it is a hands-on learning experience
  - b. If you don't understand something, ask questions
4. Insert your motor in rocket and install motor retainer
5. Suggest you tape the ignitor to the outside of the rocket for later



Figure 14-2: Certification Motor and Packaging

### i. Remove from Container

Your certification motor will come in a protective cardboard tube when shipped. Basic motor specs are found on the label. You will remove the motor from the tube – it may also be sealed in a plastic bag, so remove that as well.

The motor will have parts contained within:

1. Motor
2. Ignitor Leads
3. Pyrogen
4. Vial of Black Powder
5. Red Forward Plug
6. Baffle Washer



Figure 14-3: Certification Motor Parts



Ensure the motor is intact and there is no obvious damage from shipping. You will note the nozzle end and the forward charge well end (see figure 6-3 in Commercial Motor section on page 25). You will need to adjust the motor ejection charge delay, using an Aerotech ejection delay tool.

## ii. Delay Adjustment

You will need to determine the expected time to apogee. The motor should come with a standard 14-second delay. You will need to remove the amount of time (in seconds) from the standard delay, for your rocket flight.

For example, you simulate your flight to reach apogee in 12 seconds. You would then remove 2 seconds from the standard delay. The tool will have various adjustments; you will find the one that removes 2 seconds. This will ensure the parachute deploys at the proper time.

1. Adjust the motor ejection charge delay
  - a. Use the delay adjust tool to remove seconds from delay
    - i. Adjust the tool for proper amount
    - ii. Screw the tool into the end
  - b. Shake flakes out – discard
  - c. Install Baffle Washer



Figure 14-4: Delay Tool



Figure 14-5: Removing seconds from delay

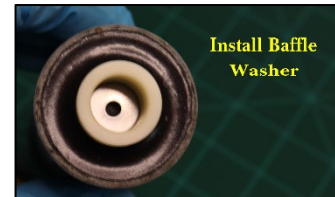


Figure 14-6: Install Baffle Washer

## iii. Black Powder

Once the delay is adjusted properly, you will remove the shavings. You will then pour the black powder from the vial into the end, and cover with the red rubber cap.

- d. Pour black powder into deployment well
- e. Insert Plug Cap on end

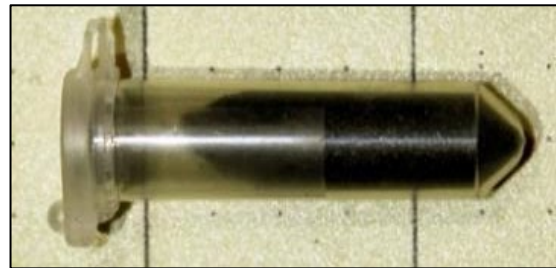


Figure 14-7: Black Powder Vial

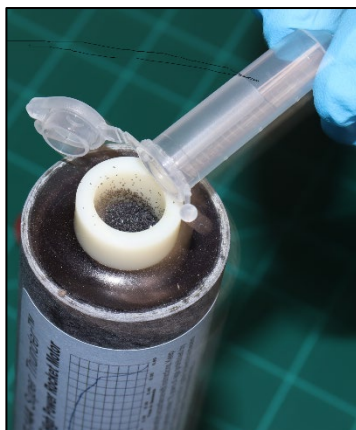


Figure 14-8: Pour Black Powder into Deployment Well



Figure 14-9: Insert Plug Cap

#### iv. Motor Installation

Finally, you can insert your motor into your rocket. Ensure that it inserts smoothly. **DO NOT** apply too much force. If the motor cannot be installed smoothly, check for epoxy inside the motor mount tube. If there is epoxy, you may need to clean the tube.

Once the motor is installed, ensure it is flush with the aft motor mount tube (all the way in). You can then install your motor retainer.

We recommend that you tape the motor ignitor (keep in bag), to the exterior of your rocket. This ensures that you do not misplace the ignitor before you reach the launch pad. You will also need the tape once you get to the launch pad.

Fill out your launch card with the motor details.

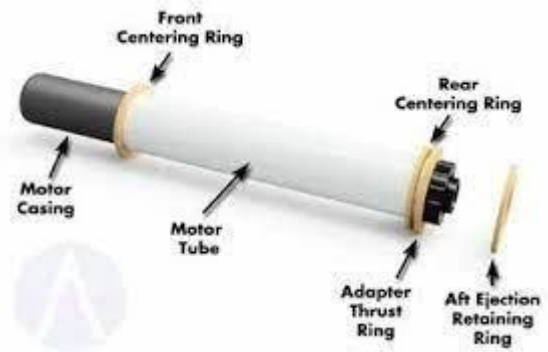


Figure 14-10: Motor Installation

#### 14e. Recovery Preparation

##### i. Parachute

1. Know how to fold / install your parachute into your rocket (as previous demo)
  - Ensure parachute and protectors are **attached** inside of quick-links
  - a. Ensure your quick-links are attached to rocket and **closed**
  - b. Ensure to use parachute protectors and/or 'dog barf' to protect your nylon parachute from the hot ejection charge gases
    - Ensure parachute protection is on bottom (where ejection charge is) and parachute is on top
2. If your certification flight occurs in adverse conditions
  - a. Consider using a smaller parachute than the stock parachute provided, to prevent drift



Figure 14:11: Parachute and Protectors Attached Inside of Quicklinks (Top); Quicklink Attached to Rocket and Closed (Bottom)

- i. Your Rocketry Mentor may be able to assist you
- b. You may 'reef' your shroud lines using tape (or by tying a knot part way up the shroud lines)
  - . This will decrease the parachute open diameter
  - i. This will increase descent rate (decrease drift)
- c. Ensure your mentor or RSO is aware of any adjustments you have made prior to flight
- 3. At Tripoli Wisconsin (only) - additional recovery techniques are used for certification flights (when flying in adverse conditions)



Figure 14-12: "Reef" the Shroud Lines Using Tape

## ii. Jolly Logic

Although unlikely, in the case of high wind conditions on certification day, you will be using a Jolly Logic parachute release (for Tripoli Wisconsin certifications).

The Jolly Logic device will prevent your parachute from opening at motor ejection. The parachute still deploys (exits the rocket), but the canopy does not open. The Jolly Logic can be used to 'release' the canopy at a lower altitude. This prevents unwanted drift in high wind conditions, allowing you to recover it sooner and eliminate the chance of losing it.

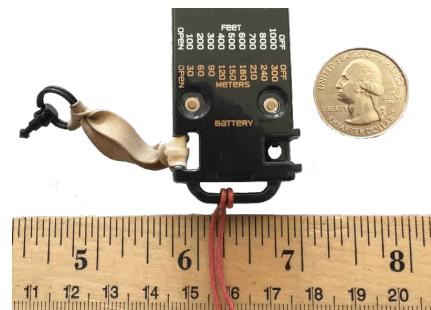


Figure 14-13: Jolly Logic Parachute Release

<https://jollylogic.com/products/chuterelease/>

- a. Jolly Logic Parachute Release
  - i. This device will be loaned to flyers
  - ii. This device will not open the parachute until a much lower altitude
    - 1. AKA streamer (or tumble) recovery from apogee

## iii. RF Tracker and Antenna

For Tripoli Wisconsin certification flights, we may also have RF tracking devices available for use. This small device goes inside your rocket (or simply tape to your shock cord). The device emits a radio signal (transmitter) on a specific frequency that a hand-held device, sometimes called a Yagi antenna (receiver) can track. The transmitter has a range of one mile.

You will need to remember the frequency of the transmitter (which is on the inside cap of the device). The antenna needs to be tuned to this frequency. The antenna will emit an audible pulse that is louder in the direction of the transmitter, and softer if pointed away from the transmitter.



Figure 14-14: RF Tracking Device (Left); Yagi Antenna (Right)

<https://www.com-spec.com/rcplane/index.html>

- a. RF Tracker and Antenna
  - i. This device will be loaned to flyers
  - ii. This device will emit an RF signal that allows you to track on ground
    - 1. It can be flown in your sustainer section or taped to shock cord

These devices ARE NOT REQUIRED for certification flight

- a. If you plan to use a device be familiar with its operation prior to flight
- b. Ensure your mentor or RSO is aware of any devices used in flight

## 14f. Launch Pad Preparation

Once you are prepared your rocket for the certification launch and have completed the pre-launch checklist check in with the LCO for your pad assignment. Turn in the launch card and proceed to the Launch pad when the “Range is Open.” The Launch Pad Manager (or Mentor) will assist you with the launch prep.

### i. Steps to Prepare Launch Pad

1. The rail will be tilted over for loading
  - a. Slide your rocket on the rail, aligning your rail buttons in the grooves in the rail
2. Your rocket should be on top – your rail buttons down
  - a. Slide all the way down until it hits the stops
3. Remove the ignitor from the bag
  - a. Pull the exposed ends apart a few inches
  - b. Strip an inch of wire covering from the exposed ends
4. Insert the bulb end of the ignitor into the motor
  - a. Push the bulb as far as it can go, until you feel it stop
  - b. Tape the kinked end to the bottom
  - c. Ensure that the wire is secure and will not fall out
5. Grab the alligator clips (on the ground)
  - a. Wrap each ignitor lead around each clip
  - b. Ensure the leads do not contact each other or the rail



*Figure 14-15: Ignitor (Top); Alligator Clip (Bottom)*

## 14g. Rocket Retrieval

There are several things you should be aware of prior to your rocket retrieval (for certification at Tripoli Wisconsin).

### i. Landmarks / Hazards

It is always a good idea to scout out the area (at least look at a map) to see where your rocket may land, and the best way to get there. There are a few roads in the launch area that you may drive on for better access to where your rocket may have landed.

In good conditions, certification flights at Tripoli Wisconsin usually land within 2500 feet radius of the launch pads (the green circle). In less-than-ideal conditions, certification flights have landed up to 4000 feet from the launch pads (the yellow circle).

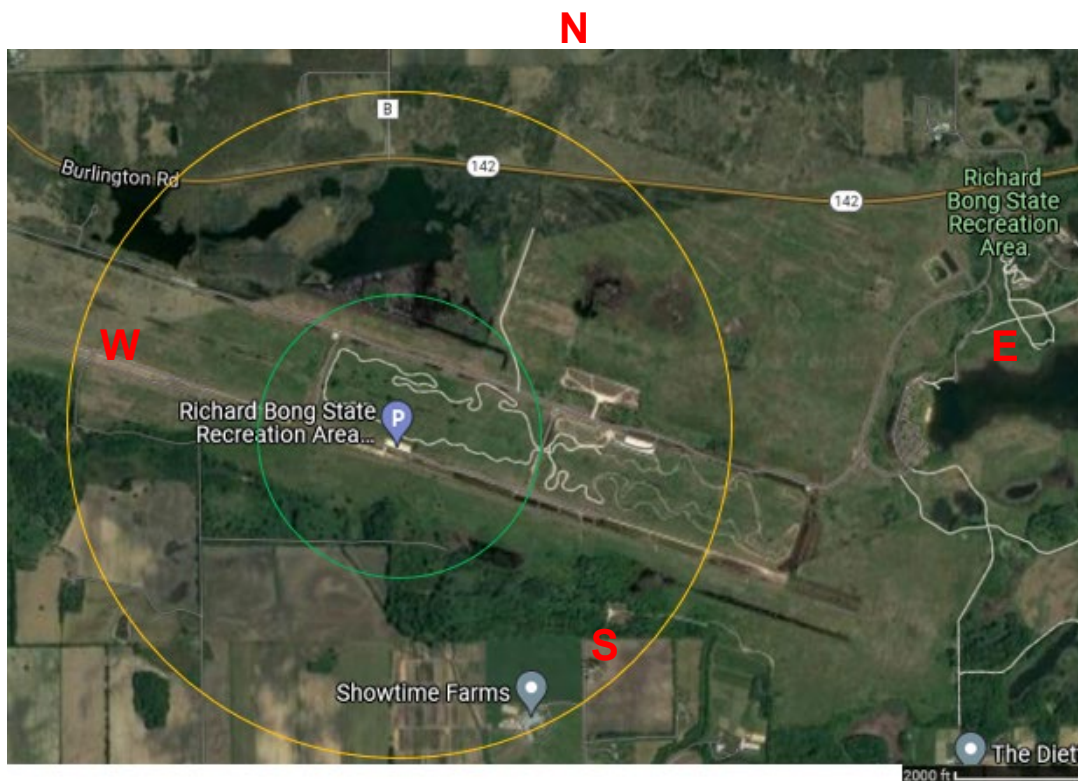
You should also try to note the hazards in the area, which your rocket may land in or nearby. Be aware of the water hazards to the north. There are also numerous tall trees and tall grass in the area. The ground can be soft and muddy as well, so be prepared.

### ii. Range and Line of Sight

If you are lucky, in real calm conditions, your rocket may land within a few hundred feet of the launch pad. This area contains some tall grass but is otherwise free of hazards. You will simply be able to walk



out and collect your rocket – your parachute is brightly colored to assist you with spotting it from a distance on the ground.



*Figure 14-16: Richard Bong State Recreation Area Aerial Map*

When your rocket is descending, you should try to ascertain a range and a line of sight. You can try to use the tree lines to determine the range. You should also use other objects to determine a line of sight. As you get closer to the area where you suspect your rocket has landed, you can use the objects to look back to the launch site, to get your bearing.

Next, you would need to determine if you can simply walk directly towards your rocket, or if you should drive around to another road / access point and walk from there. We also suggest you go in pairs to recover, assisting each other.

For your own safety, please do not enter the water to recover your rocket. Please do not attempt to climb trees either. Tripoli Wisconsin has poles that you can borrow to help recover your rocket. Worst case, it may be unrecoverable even though it is in plain sight.

### **iii. Post-Flight Inspection**

You must return your rocket to the RSO for inspection following your flight. Your rocket must be free of any damage for your certification to be complete. If your rocket is unrecoverable, notify the RSO.

## 15. Certification Launch Overview

Level 1 certification allows flyers to fly high-powered rockets with a total installed impulse up to 640 newton-seconds. WSGC simulates the LOC Precision Caliber ISP with an Aerotech H219T DSM.

### 15a. Certification Launch Requirements

#### i. Steps for Completing Your Launch:

1. When arriving at the launch site, you are expected to abide by the presiding organizations safety procedures
  - **COVID restrictions:** Limitations on # of people at the launch site/pad, social distancing, mask mandates and temperature check regulations may be in place
  - a. Presiding organization may require a COVID release form be signed
2. Requirements at the certification launch
3. Review pre-launch checklist
  - a. Complete launch card and submit to TRA/NAR
  - b. After rocket recovery, return to HPR Launch Operations area
  - c. Properly dispose motor
  - d. Sign and submit TRA Membership Application to Frank Nobile (Wisconsin only)
  - e. Pack rocket for return home
4. Fees associated with certification launch
  - a. FNL reimbursable by WSGC using reimbursement form or coordinated with local TRA/NAR
    - i. Flight/Ground Transportation/Meals
      1. \$45 maximum meal allowance per day
      2. Ground transportation: When personal vehicles are utilized, either gas or miles can be reimbursed, but not both
    - ii. Original receipts with names of individuals on each receipt
  - b. CRL certification launches will take place during launch competition weekend
  - c. Complete and submit a reimbursement request to Connie Engberg no later than 30 days after certification launch

## **15b. Certification Rocket Overview**

### **Tripoli Requirements**

- Register
- Airframe
- Recovery
- Motor
- Electronics – Not required
- Certification Flight
- Post flight inspection

#### **i. Airframe**

The rocket must be built by the flyer. The rocket shall have a display on the exterior identifying the calculated center of pressure. The rocket must be of "conventional rocket design". "Odd Rockets" including flying pyramids, saucers and flying spools will not be allowed for any certification flight. The rocket may be either a kit or scratch built. Scratch built rockets may contain commercially built components.

#### **ii. Recovery**

Standard parachute recovery is required. Non-parachute recovery methods (e.g. tumble, helicopter, gliding, etc.) are not permitted for certification flights. If the rocket is using dual deployment, the first recovery event may be via a drogue-less or streamer as long as the main or second event uses a standard parachute.

#### **iii. Motor**

The certification flight must be with a single certified H or I motor (tested total impulse between 160.01 and 640.00 n-sec). Staged and/or clustered rockets may not be used for certification flights. The flyer shall be observed during the assembly (if a reload or hybrid) and preparation of the motor by the certifying member or their designated representative.

#### **iv. Electronics**

Electronics are not required for Level 1 certification flights.



## 15c. Certification Pre-Flight

After completing construction of your Level 1 rocket, the next task is to locate the nearest launch site. Level 1 certification flights may take place at any insured launch that is sponsored by TRA or NAR. It is recommended to call the club launch coordinator beforehand to verify the FAA waiver, field conditions, and if Level 1 certification flights are honored.

The certifying member (i.e. Prefect, TRA Director, or TAP Member) must be present and witness the certification flight. The certifying member must witness the rocket ascend in a stable manner and descend in a stabilized manner controlled by the recovery system.

You can find U.S. launch locations at:

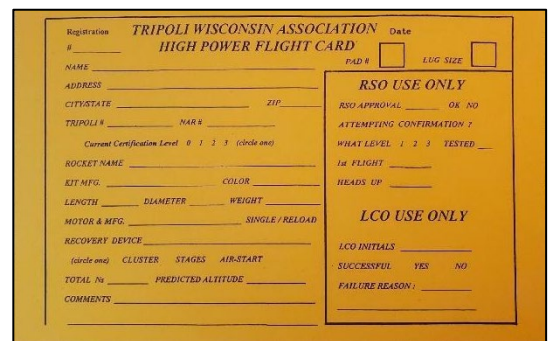
<http://www.tripoli.org/Prefectures>

<https://www.nar.org/find-a-local-club/nar-club-locator/>

### i. Pre-Flight Overview

When you arrive at the launch site on launch day, you will need to:

1. Obtain a launch card from the club organizer table
2. Prepare your rocket for flight
3. Ensure all of your bonds/fillets are intact
  - a. Ensure all of your parts fit – no excess epoxy
4. Prepare your parachute as instructed in the workshop
5. Ensure your nose cone is attached
  - a. You may fly a 'payload' if you wish
6. Ensure you have a piece of tape with you
7. Prepare your motor (see the RSO/Rocketry Mentor for motors)
8. Ensure you have your motor retainer with you and tools to tighten it
9. Fill out / turn in your launch card to the Launch Control Operator (LCO)
  - a. LCO will assign you a launch pad (numbered)
10. Proceed to launch pad when range is open
  - a. Usually, a Launch Pad manager (or rocketry mentor) will assist you with launch prep
11. Return to pit area to watch your launch!
12. Observe and recover your rocket
13. Return rocket to Range Safety Officer (RSO) for inspection and sign off



The image shows a yellow launch card for the Tripoli Wisconsin Association. The card is titled "TRIPOLI WISCONSIN ASSOCIATION HIGH POWER FLIGHT CARD". It contains various fields for registration information, including Name, Address, City/State, ZIP, Tripoli #, NAR #, and Current Certification Level. There are also fields for Rocket Name, Kit Mfg., Length, Diameter, Weight, Motor & Mfg., Single/Reload, Recovery Device, Total No., Predicted Altitude, and Comments. The card is divided into sections for "RSO USE ONLY" and "LCO USE ONLY". The RSO section includes fields for RSO Approval, Attempting Confirmation, What Level, and Heads Up. The LCO section includes fields for LCO Initials, Successful, and Failure Reason. There are checkboxes for "PAD #", "LUG SIZE", "1st FLIGHT", and "HEADS UP".

Figure 15-1: Tripoli Wisconsin Launch Card

## **ii. Pre-Flight Inspection**

Prepare the following information for the LCO when you turn in your launch card.

1. TRA/NAR Membership #
2. Kit Manufacturer
3. Center of Gravity (CG) and Center of Pressure (CP) – Mark the CG and CP on the rocket
4. Motor Type and Manufacturer
5. Type of Recovery Device
6. Length, Diameter, and Weight of Rocket
7. Predicted Altitude (Remember to conduct a simulation in RockSim)

## 15d. Certification Post-Flight

The rocket must be presented to the certifying member for inspection. If the rocket cannot be recovered, but can be inspected in place (power lines, tree, etc...), this is acceptable. The certifying member shall inspect the rocket for excessive damage. Excessive damage shall be considered damage to the point that if the flyer were handed another motor, the rocket could not be put on the pad and flown again safely. Damage caused by wind dragging will not cause a disqualification.

### i. Certification

Upon a successful flight and retrieval of your rocket, the following steps will take place:

1. The RSO will inspect your certification rocket
2. The RSO will sign your certification form
  - a. WSGC will reimburse L2L participants for the first year of TRA or NAR membership
3. WSGC will pay L2L participants TRA or NAR membership for *certification flights* conducted at Richard Bong Recreation Area
4. Tripoli Membership cards will be mailed to participants address provided on form
  - a. Membership is valid for one year
  - b. Membership must be renewed by participant annually
  - c. TRA Certification is valid at NAR launches
  - d. Participants may obtain level II

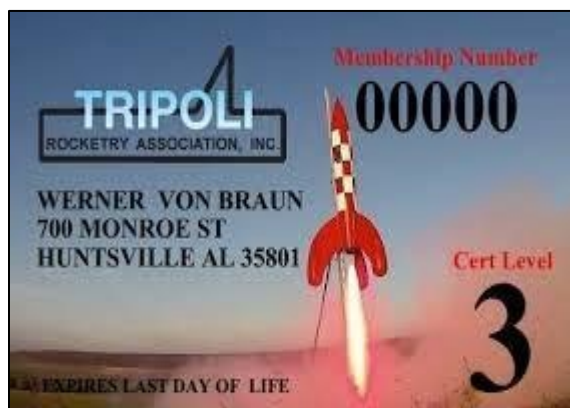


Figure 15-2: Tripoli Membership Card Example

Certification; however, WSGC does not cover the cost of certification.

Individuals certifying at a local launch site may certify through the National Association of Rocketry. NAR and TRA certification/membership procedures are different. Please consult your team's mentor for further information.

### ii. Non-Certification

Any of the following will result in non-certification for a certification flight:

1. Motor CATO (CATastrOphic failure of a rocket engine)
2. Excessive damage
3. No recovery system deployment or tangled recovery system deployment
4. Rocket drifting outside the specified launch range
5. Components coming down not attached to the recovery system
6. Any other violation of TRA safety code associated with this particular flight
7. Any other legitimate reason the certifying member deems merits non-certification

### **15e. Rocket Transport**

When preparing to bring your certification rocket home, you will need to take the necessary steps to clean your rocket and prepare for the transport.

1. Cleaning and packaging rocket for public transportation
  - a. Remove / dispose of the motor
  - b. Wipe out any black powder residue
  - c. Disassemble any components
2. Transporting rocket from Kenosha, WI
  - a. Checked bag for airline flights
  - b. Ship from hotel (confirm this option with the hotel)
    - i. Boxes, bubble wrap and labels will be available for shipping for certification launches conducted at Richard Bong Recreation Area
3. Shipping costs may be submitted with Launch 2 Learn travel expenses

### **15f. Certification Launch Notes**

## 16. Reference Sheet

### 16a. WSGC Resources

Wisconsin Space Grant Consortium (WSGC)

<https://spacegrant.carthage.edu/>

WSGC Website Registration Page (Login/Registration)

<https://spacegrant.carthage.edu/about/login/>

### 16b. NASA Resources

NASA Space Grant Consortium(s)

[https://www.nasa.gov/stem/spacegrant/home/Space\\_Grant\\_Consortium\\_Websites.html](https://www.nasa.gov/stem/spacegrant/home/Space_Grant_Consortium_Websites.html)

NASA Systems Engineering and Project Management Resources

[https://en.wikipedia.org/wiki/Verification\\_and\\_validation](https://en.wikipedia.org/wiki/Verification_and_validation)

### 16c. Collegiate Rocket Launch (CRL) Resources

CRL Website

<https://spacegrant.carthage.edu/funding-programs/undergraduate/rocket-competitions/collegiate/>

CRL Tools & Tips

<https://spacegrant.carthage.edu/students/tools-and-tips/>

### 16d. First Nations Launch (FNL) Resources

FNL Website

<https://spacegrant.carthage.edu/first-nations-launch/>

FNL Tools & Tips

<https://spacegrant.carthage.edu/first-nations-launch/tools-and-tips/>

HPR Launch Sites near TCUs

<https://www.google.com/maps/d/edit?mid=13Wq7Qtb7hcsWM3S96L0SOVERugRnjuKo&ll=39.190340596364734%2C-103.43167299999999&z=5>

### 16e. Apogee Resources

Apogee Rockets – RockSim Information

[https://www.apogeerockets.com/RockSim/RockSim\\_Information](https://www.apogeerockets.com/RockSim/RockSim_Information)

Apogee Rockets – RockSim Quick Start Guide

[https://www.apogeerockets.com/RockSim\\_Quick\\_Start\\_Guide?pg=quickside](https://www.apogeerockets.com/RockSim_Quick_Start_Guide?pg=quickside)

Apogee Rockets – RockSim Discounted Temp License

[https://www.apogeerockets.com/Rocket\\_Software/RockSim\\_Educational\\_TARC](https://www.apogeerockets.com/Rocket_Software/RockSim_Educational_TARC)

## **16f. Tripoli Rocketry Association (TRA) Resources**

TRA Website

<http://www.tripoli.org/>

TRA Membership

<http://www.tripoli.org/Membership>

TRA Certification Overview

<http://www.tripoli.org/Certification>

TRA Universal Certification Form

[http://www.tripoli.org/Portals/1/Documents/Certification/Universal\\_Certification\\_Form.pdf](http://www.tripoli.org/Portals/1/Documents/Certification/Universal_Certification_Form.pdf)

TRA Prefectures

<http://www.tripoli.org/Prefectures>

## **16g. National Association of Rocketry (NAR) Resources**

NAR Website

<https://www.nar.org/>

NAR Membership

<https://www.nar.org/my-membership/>

NAR Clubs

<https://www.nar.org/find-a-local-club/nar-club-locator/>

FAA Waiver on NAR Website

<http://www.nar.org/high-power-rocketry-info/filing-for-faa-launch-authorization/filing-for-faa-waiver/>

## **16h. HPR Launch Information - Canada**

[http://www.calgaryrocketry.org/forms/CAR\\_hpr\\_level\\_1-3\\_certification\\_program\\_v2.5.pdf](http://www.calgaryrocketry.org/forms/CAR_hpr_level_1-3_certification_program_v2.5.pdf)

## **17. WSGC Rocket Workshop Evaluation Questionnaire**

Thank you for participating in our Launch 2 Learn workshop. Please fill out the workshop evaluation questionnaire here:

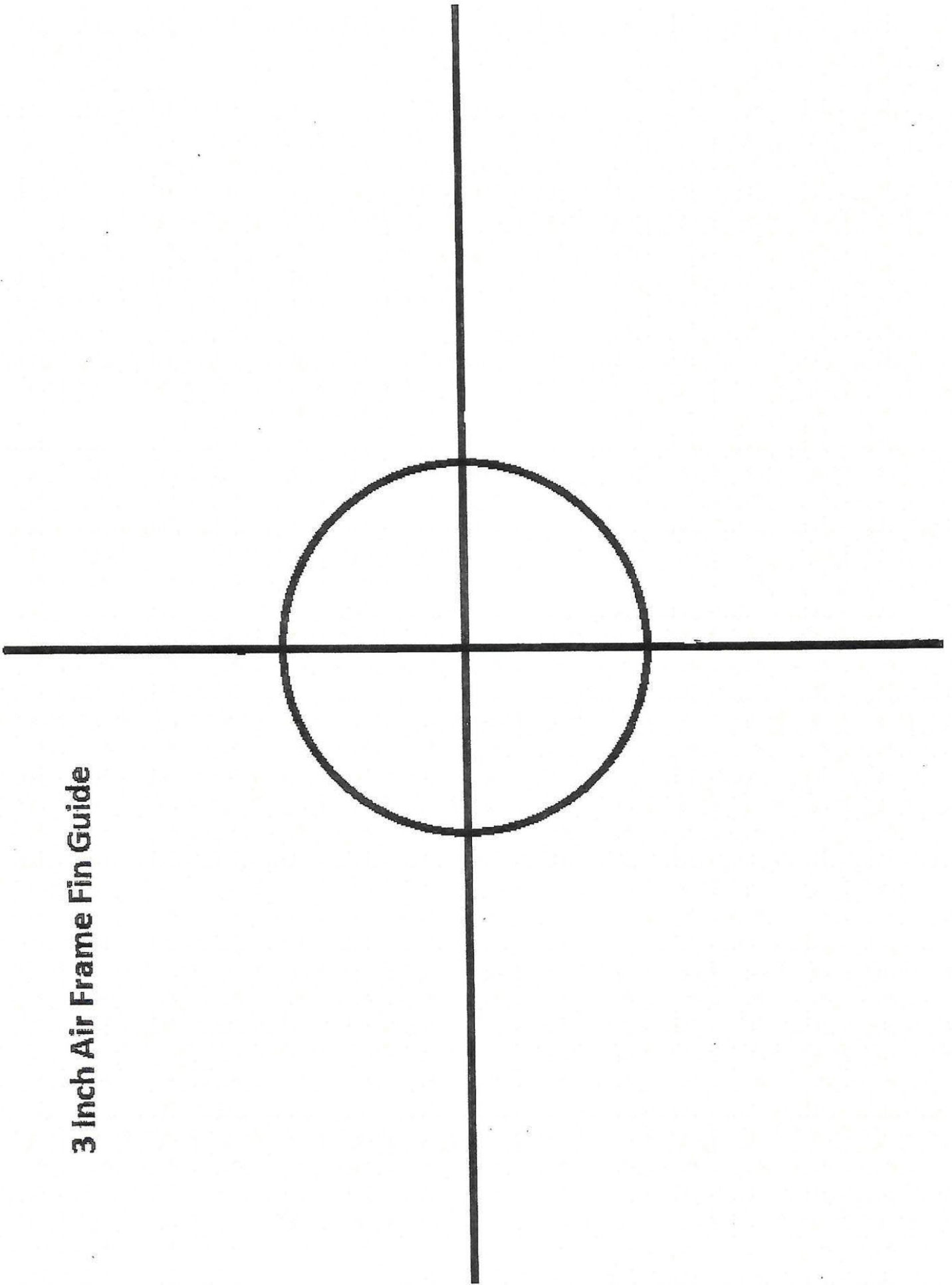
<https://forms.gle/HfyoLWQUru2uq85c6>

FNL participants will also complete a survey for the Everett group as part of NASA's independent evaluation of the program.



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**3 Inch Air Frame Fin Guide**



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