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The BYU Rocketry High Power Rocket Process Workbook: Establishing enduring engineering practices

Physics 492R Capstone Project Report

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ABSTRACT

BYU Rocketry is a student-led organization for students to learn how to work in teams to design, build, and fly high power rockets. The objective of the organization is to enable students to become leaders and innovators in the space industry. It is essential for the progression of the organization that incoming students are able to learn from more experienced students before they graduate and leave the club ecosystem. Therefore, the effective tutelage of incoming students is a foundational goal of the organization. This report discusses the creation of process documentation for the purpose of instruction in the practices of high power rocketry. The use of this process workbook enables students to follow well-researched, repeatable methods that ensure the safe and predictable performance of their rockets. The result of this is the establishment of good engineering practices among the rising generation of BYU Rocketry students.

INTRODUCTION

BYU Rocketry is a student-led organization with the objective of providing students with hands-on experience that will enable them to become leaders and innovators in the space industry. It was founded in 2015 by a group of students who were excited by the rapid development of private space companies and the promise of expanded space exploration. BYU Rocketry entered the first annual Spaceport America Cup competition, the world's largest intercollegiate rocket engineering competition, in 2017. A major goal of the club was to win the Spaceport America Cup, as this would lend legitimacy and security to BYU Rocketry in the eyes of the international community as well as within BYU campus. In 2018 BYU won second place in its category, which was a promising development.

In the meantime, BYU Rocketry was growing among the students. It quickly became one of the most popular clubs in the engineering college. The annual Student Launch Competition invited students to build teams and build rockets with rules that mimicked the Spaceport America Cup; whichever team shows the best engineering practice and proves their rocket by flying nearest the target apogee wins coveted bragging rights. The great number of attendees prompted the club leadership to create more activities to keep students involved. Ryan Garrison, the founding president of BYU Rocketry, arranged this set of activities into a so-called "pipeline." A student following the pipeline would have meaningful activities to grow their skills in rocketry for every semester they are in school. Participants would be able to progress and prepare for the next upcoming activity, eventually culminating in the Spaceport America Cup competition team.

The pipeline was well-received by BYU faculty, including Mechanical Engineering Department Chair Dr. Dale Tree. He applauded BYU Rocketry for creating an extracurricular program that could maintain meaningful student engagement. The pipeline was also a mechanism to ensure the longevity of the club; as experienced seniors participate in the upper-level teams, they can mentor incoming students. That way, when the experienced students graduate, the club is left with a rising generation ready to pick up where the previous left off. This responsibility to teach skills to the rising generation led to the Manufacturing and Engineering Process Team.

In 2019, the club leadership determined a need to compile the knowledge gained by students over years of trial and error. The Manufacturing and Engineering Process Team, or MEPS Team, was formed with the goal of teaching incoming students skills that graduating seniors have practiced in their years of rocketry. The MEPS team spent a year and a half researching, writing, and publishing a 138-page handbook. 1 This handbook covered topics including club structure and activities, rocketry regulations, design and build tips, and examples of past builds. The handbook is carefully referenced, drawing information from 51 sources. The handbook was well received, with several first-year students referring to it while building their first rockets.

LEARNING HOW TO BUILD HIGH POWER ROCKETS

The first generation of BYU Rocketry students consisted of a few students who had been involved in high power rocketry for many years before their college experience, and many students who learned step-by-step as college students. To learn the skills involved in high power rocketry involves a great deal of research, trial and error, and tenacity. There are numerous resources to be found on the internet in this field. Some of it is very well organized. Most so are resources like NASA's Glenn Research Center, which has numerous lessons in aeronautics. 2 The Apogee Components Peak of Flight Newsletter has decades of articles written to promote an understanding of the technicalities of rocketry. 3 Some instructions are shared on personal blogs, like that of John Coker and Richard Nakka, who also share their decades of experience in trial and error in amateur rocketry. 4 5 Less organized, but often very enlightening is information from online forums like The Rocketry Forum and rocketry related Facebook groups. 6 These resources are the avenues from which the first generation of BYU Rocketry students learned. As these students learned these skills, they began teaching new incoming students the same skills in a mentorship position.

The process of learning how to build high power rockets is at once both an individual endeavor and a collective one. The regulatory bodies for amateur rocketry are the National Association of Rocketry (NAR) and Tripoli Rocketry Association (TRA). Both these groups require individuals undergo a certification process to be allowed to fly high power rockets. High power rockets are defined under the National Fire Protection Association Code as rockets that weigh more than 1.5 kg, have a motor with more than 125 grams of propellant, have greater than 80 Newtons of thrust or more than 160 Newton-seconds of total impulse. 7 NAR and TRA are given the ability to authorize their members to fly under NFPA and FAA rules if they are certified members. To certify, an individual must build a rocket, then safely launch and recover that rocket using a motor that is in the level of classification for which they are certifying. In the highest class of certification, Level 3, a prospective must design and build their rocket under the oversight of an experienced mentor, who guides the design and build process and offers their knowledge and expertise. In this way, the amateur rocketry community ensures there is some amount of collaborative learning, however each rocketeer must learn the skills for themselves. This also shows the value of the pipeline structure instituted at BYU Rocketry. The pipeline allows students to enter the hobby and work collaboratively under the tutelage of more experienced rocketeers, while also encouraging individual projects and learning activities.

There are also original skills that the students at BYU Rocketry have developed that have now been taught to incoming generations. Foremost of these is the process of manufacturing carbon fiber body tubes. In the aerospace industry, carbon fiber needs no introduction. Strong, lightweight and rigid, it fits the requirements of flight vehicle airframes to a tee. As BYU students, the club has had access to the Composites lab, along with their store of donated pre-impregnated carbon fiber. In early attempts, students used chemical release agents to prevent the resin from binding the carbon tubes to the mandrel, and heat-shrink tape to apply compressive pressure to the outside of the material. In the early years, making carbon fiber tubes was an uncertain endeavor. Some of the tubes would bind to the mandrel so completely that the carbon tube needed to be cut off and scrapped. Many tubes would have deep wrinkles, but were otherwise usable, so the wrinkles would be filled with epoxy and sanded smooth. These early pre-preg tubes were messy, but BYU Rocketry students learned through trial and study of composites how to improve. Using precisely cut Mylar sheaths to cover the mandrel along with proper coats of chem release solved the binding problem. Carefully wrapping the carbon around the mandrel mitigated the warping and wrinkling problem. Further along, the club invested the time and money into turning the mandrels on a lathe to polish the surface and add a draft, almost eliminating the need for Mylar and chem release. Over the span of five years, BYU Rocketry students have gone from needing to throw out one in three tubes to consistently producing high quality tubes that serve as the core of the airframe of their rockets. This is one of the skills that is important to teach incoming students. If it is not taught, it could easily be lost. Recording the process makes it more accessible to future generations of students.

MY ROLES IN BYU ROCKETRY

I became involved in BYU Rocketry in 2018. I built my level one certification rocket that winter semester, then was elected to my first club leadership position as Outreach Coordinator. In the fall semester of that year I started on the Structures sub-team of the Junior High Power Team, where I first experienced working on a BYU Rocketry team. We successfully flew our rocket Tachyon in Spring 2019. I then joined the High Power Team to compete in the 2020 Spaceport America Cup competition. Though this was a great team experience, our work was cut short in Spring of 2020 due to the COVID-19 lockdowns, and we were never able to complete that rocket. It was during this time the MEPS Team was first created, and I worked to write the first MEPS Handbook, which was published in Spring 2021. I joined the High Power Team once more for the 2021 Spaceport America Cup. We built our rocket Sundance, but we were unable to fly it due to a number of circumstances, not least of which was the change of the 2021 Spaceport America Cup competition to a virtual event, rather than a week-long launch event. In 2022 I took the lead role of the MEPS team, and took the initiative to produce a new Process Workbook for BYU Rocketry.

METHODS OF CREATING THE MEPS PROCESS WORKBOOK

The idea for creating the MEPS process workbook came from working with a professional engineering firm and observing their processes. In Summer 2022, I interned with HyperComp Engineering. HyperComp is an engineering firm that designs and manufactures Composite Overwrapped Pressure Vessels for aerospace customers. In my experience at HyperComp, I worked with a number of process sheets and shop instructions. The purpose of these instructions is to ensure the parts being produced follow a repeatable pattern set during the design and testing phase. If a set of instructions is tested thoroughly, and if those instructions are followed closely, the manufacturer can have some confidence that the final product will match the capabilities of the tested article.

When I returned to school, I considered how to improve the work previously done on the MEPS Handbook. The Handbook presents its information in a verbose, encyclopedic style. It is thorough, yet it could be difficult to follow if used as a rocket-building guide. I wanted to create an aid that could be a simple, easy to follow, yet thorough and complete step-by-step guide to design and build a high power rocket. As I considered how to best accomplish this, I recalled the process documentation I worked with in my internship. Those process sheets outline key details necessary to complete tasks in a consistent method. 8 A person who follows the steps outlined in process documentation can quickly understand how to complete a task. I determined that the best way to present this information was as a series of process sheets that outline the numerous tasks required to design and build a rocket. This series of process sheets would form a High Power Rocketry Process Workbook.

The use of a collection of process sheets fulfills several objectives. First, process documentation explains technical procedures in short, clear, messages. This both appeals to the inexperienced student approaching rocketry for the first time, as well as the seasoned builder looking for a checklist to ensure build quality. Second, process sheets allow a builder to document the manufacturing process of their rocket. Having an annotated record of the manufacturing process is especially helpful because there are many occasions when the design and manufacture of a rocket are inspected. When a rocketeer is applying for certification, a NAR or Tripoli representative will ask them for details on their build process. Every time a rocket is flown, the Range Safety Officer will ask questions about the construction. When presenting at a competition like Spaceport America Cup, the officials will expect a full report on the design and manufacture of the rocket. Keeping a record of each step of the process is crucial to keeping good engineering practice, and process documentation for each step helps BYU Rocketry students learn how to keep that kind of a record. Therefore I, along with the club leadership, determined the MEPS project should seek to create a set of process documentation.

The next step of the MEPS project was to build the team. I put together an application for the MEPS team and took responses for a few weeks. I asked applicants a few questions about their history with rocketry, then asked them what they envision the future of the MEPS team to be. I then met with each applicant and discussed their goals concerning BYU Rocketry. It was important to me that team members understood the importance of encouraging progress in the club. I selected a team of five students, including Tyson Butterfield, Sam Francis, Barry Creighton, Noah Cahill, and myself.

I then put together the list of processes that need documentation. I met with the new team, as well as with BYU Rocketry leadership to brainstorm a list. We drew from chapters that had been included in the first MEPS Handbook, and from our own knowledge of rocket building. It was important to break down the whole endeavor of rocket building into simple, summarized processes. We ended up with a list of a few dozen processes for which we could write documentation. The list of sections I then divided into chapters of Design, Review, Build, Test, and Launch. These chapter summarize the general process of engineering a project like a high power rocket.

The next task was to create a standardized format for the pages of this process workbook. With several team members writing pages, some level of uniformity in the writing style was important. To establish this format, I wrote up the first page, describing how to design a rocket using the OpenRocket program. First, I determined what the sequence of steps is to design in OpenRocket, and arrange these steps in chronological order. 9 These steps need to include a single instruction per step, otherwise the process would become too complicated. Next was to identify what steps would benefit from an explanatory figure. For the OpenRocket page, the figures included screenshots of the program window that highlight the step. Finally, I read through the whole document as though I were using OpenRocket for the first time. I determined whether I could follow the instructions with only the context provided. Once I was satisfied with the document, I took it to the team and discussed these steps with them. We divided the list of processes among the team members, and set a writing schedule. Each team member would be responsible for writing one process every other week. The team would then meet biweekly, where we could review and edit the pages written. Generally, each process was meant to fill no more than a page of writing.

The next step was to design the layout for the pages. I wanted to reflect that this was a workbook meant for the user to keep their own record. To encourage that, I included on each page a place for the user to fill in their name, the name of their rocket, the name of a mentor, and the date the process was completed. Each page has a place for the title of the process, and a text box for a 3 to 4 line statement about the process. This statement should explain the importance of the process to the construction of the rocket, as well as any general notes on how to accomplish the process. Once the layout was finalized, I shared this with the team to use in their pages.

One section that was particularly important was “Rolling Pre-preg Carbon Fiber Tubes.” This was a skill first taught to me by an upperclassman in the club, and through my years on the Structures Team, I invested countless hours in the Composites Lab improving this process. Writing this page was important because I wanted to ensure the process was clearly taught, so the skill will not be forgotten by future BYU Rocketry students. To teach this skill clearly, I needed to photograph the process. I scheduled a time when several experienced rocketry students could help me to go through the process to make a carbon fiber tube, and sent an open invitation to any students who wanted to learn to come observe and assist. Before we went to make the tube, I wrote out the sequence of steps I would write in the page, and determined which steps would benefit the most from a picture. Then, when the day came to make the tube, I photographed every step I could manage. I picked out the most instructive pictures, inserted them alongside the steps, and completed the process page. Because of the number of figures and the number of steps, this turned out to be several pages long, longer than other, simpler processes.

RESULTS

While writing the process sheets, we wanted to test out the functionality of the instructions. I contacted a student who was in the early stages of designing his level one certification rocket, and had him follow through the processes. We found that he was much more confident in the design process, because he had a general understanding about how each step fit into the last. He still required some more direct training on some of the more complicated processes, but he could follow along and take ownership of his rocket more so than if he simply had a mentor complete the tasks for him. He completed the rocket and launched it successfully, earning his level one certification.

We were able to determine some changes to make to the handbook from this test. First was that we identified more processes to write. There are more steps in the review process that are already exist in the club structure, such as Preliminary and Critical Design Reviews, and Flight Readiness Reviews. It would be beneficial to the builder to outline the elements of these so they can be prepared to present their rockets at the review. There are also more tests that could be included, mainly the Parachute Ejection Test and Electronics Continuity Test. Including these new pages will improve the reliability of the rockets produced. The workbook would also benefit greatly from more illustrations. Many of the build documents would be more clearly understood with effective diagrams.

Moving forward, the workbook needs to be implemented to fulfill its purpose. At the beginning of each school year BYU Rocketry holds its Student Launch Competition, where incoming freshmen get their first experience in collegiate rocketry. Introducing the workbook at this level will set it as a standard practice for this incoming generation, ensuring its influence. It can also assist the club leaders who preside over the Student Launch Competition, who are often overwhelmed by the volume of assistance that is expected of them. A new MEPS Team lead has been appointed. I have communicated with him concerning the past of the MEPS project, and hope to assist him in planning new phases. I hope to see the aforementioned changes implemented, so the workbook can continue to improve along with the skills of BYU Rocketry students.

DISCUSSION

The High Power Rocket Workbook fills two roles at once. First, it is an instructive resource that guides the student through the steps to make a scratch-built rocket, whether for the first time or not. This demystifies the process and ensures no steps are missed. Second, it is a record the student can keep track of the work completed on the rocket, and how it was done. If a student keeps notes of when work was done and how it was done and has their work checked off by someone in a mentor position, the workbook becomes an amplifier of the factor of safety on the rocket. This follows a pattern of good engineering practice which is invaluable to teach to young engineering students.

In my research into high power rocketry, I was unable to find a single, chronological pathway to instruct how to build a high power rocket. The workbook fills this role. The internet is full of advice, most of it very helpful, but it is unorganized. This workbook allows a rocketeer to understand from the outset what the steps are to create an originally designed, ready to fly high power rocket. In this way, it is like a syllabus for a course. As BYU Rocketry teaches students how to build high power rockets, the students can look through the workbook and understand what skills are going to be practiced next. This becomes a springboard for their personal study, and helps them master the skills of rocketry.

The workbook is a resource that can be kept in BYU Rocketry for many years to come. The skill level of the students in the club has increased over time. This is proven by BYU's first place win at the 2023 Spaceport America Cup. 10 Therefore, the mentors of today will be more effective at bringing up the incoming students, and helping them succeed in even greater ways. A resource like the process workbook will only help both mentor and student to become better engineers. As the students become better engineers, BYU Rocketry will see greater success and progress to more difficult projects. This workbook can serve as foundation, and it can be expanded to relay newfound skills developed by the future generations.

CONCLUSION

BYU Rocketry faces a potential crisis each year. As a student-led organization, it depends on the ascendance of a new generation of dedicated students to carry the torch once experienced students graduate. The process workbook described in this report is designed to be a tool to assist club leaders in raising a strong generation in the skills necessary to succeed in rocketry. Through collaborative research and testing, the workbook has been found to teach good engineering practices of iterative design, collaborative review, tight manufacturing guidelines, and rigorous test. By doing this, the process workbook fulfills BYU Rocketry's objective of providing students with hands-on rocketry experience to enable them to become leaders and innovators in the space industry. By developing strong engineers with a sense of responsibility for their fellow student, the annual crisis is avoided, and replaced with growing success.

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APPENDIX

BYU Rocketry High Power Rocket Process Workbook

High Power Rocket Workbook

MEPS

Manufacturing Engineering Process

The purpose of this workbook is to guide a rocketeer through the steps of designing and building a high power rocket. Many of the pages assume the user has access to the resources available to BYU Rocketry students, but anyone can accomplish the tasks herein with the correct tools. This workbook is intended to be both a resource and a record for the rocketeer to keep track of the work accomplished and the techniques used to build their rocket. Therefore, each page has a space to record the name of the rocket, the builder, a mentor overseeing the build, and the date completed. As the builder works through these pages, keeping notes of their work, a trackable record of the work done is created. In addition to being good engineering practice, this record will help the rocketeer when presenting their rocket, whether to the Range Officer or at the IREC Conference.

BYU Rocketry Manufacturing and Engineering Process Team, 2023
Contact Adam Dunford at dunford.ae@gmail.com

High Powered Rocket Process Sheet		MEPS Manufacturing Engineering Process	
Design – OpenRocket			
Name of Rocket:	Name of Builder:	Name of Mentor:	Date Completed:

OpenRocket is a Computer Aided Design suite that helps you design your rocket. It is loaded with data about materials commonly used, including Commercial Off-the-Shelf motors. It provides important data based on your design like expected stability, velocity, and apogee.

1. Open OpenRocket.
   a. At the top are three tabs: Rocket Design, Motors and Configuration, and Flight Simulations.
2. Rocket Design
   a. Add parts by clicking on the icon under "Add new component"
   b. Add a nose cone, body tube, and inner tube using the database under the "Select Preset" menu. See Figure 2.
   c. If the parts are out of order on the design, change the order by clicking and dragging in the parts list in the top left of the screen.
   d. Add fins. Adjust general dimensions as desired. Go to Fin Tabs, click "Calculate automatically"
   e. Add centering rings, editing the material and thickness
   f. Position the centering rings so they lie within the fin root chord.
   g. Add Parachute and Shock Cord.
   h. Add Mass Component: Motor Retainer

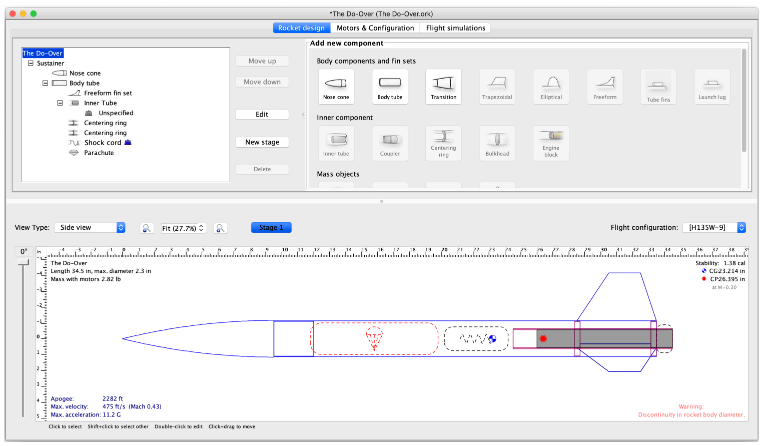


Figure 1 - The Rocket Design page of OpenRocket. The Parts List shows the parts that have been added to the design, and the View Window shows an outline of the current design.

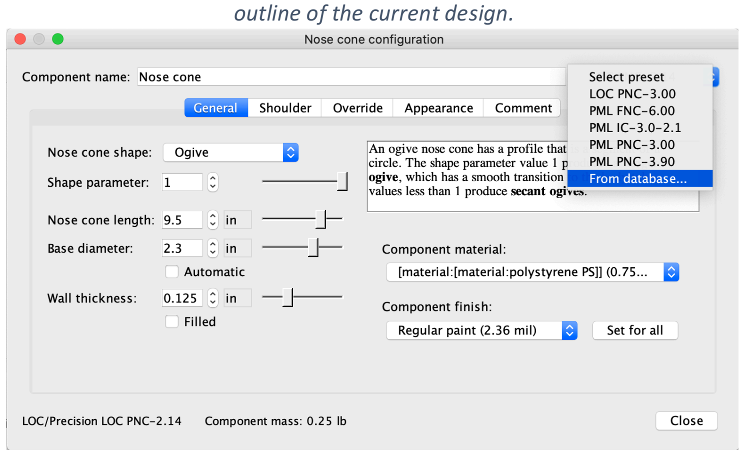


Figure 2 - A Nose Cone Component Configuration page. Here you can edit parameters about the Nose Cone, or you can open the drop-down menu at "Select Preset" and choose "From database..." This will open the present database that matches many Commercial Off-the-Shelf products. Use the database for nose cones and body tubes, as these will be fairly accurate.

3. Motors & Configuration
   a. Find your list of available motors (in another section of MEPS)
   b. Select Inner Tube as the motor mount
   c. Select “New Configuration,” then “Select Motor.”
   d. Return to Rocket Design, check each item in the parts list that its material is correct.
   e. Edit fin dimensions and body tube length until stability is between 1.5 – 2 calibers.
4. Flight Simulations
   a. Click New Simulation.
   b. Click “Edit Simulation,” Set Launch Site Altitude to 5000 ft and Launch Rod Length to 8 ft
   c. Click “Run Simulation.” OpenRocket will return a set of data, some of which are vital to safe flight.
   d. Velocity off Rod: If this value is below 50 ft/s, you should consider a different motor or a lighter rocket.
   e. Optimum Delay: This gives the expected delay from motor burn-out to apogee. You will need this to set the correct delay on your motor.
   f. Ground-hit Velocity: If this value is above 25 ft/s, you should consider a larger parachute.

NOTE: For further help on how to use OpenRocket, go to wiki.openrocket.info

High Powered Rocket Process Sheet		MEPS Manufacturing Engineering Process	
Design – Choice of Materials			
Name of Rocket:	Name of Builder:	Name of Mentor:	Date Completed:

There is a wide variety of materials used in rockets, from plywood fins, balsa nosecones and paper body tubes to full-composite construction. Each of these have varying qualities that make them useful, such as price, ease of use, weight, and strength. Use this matrix as an aid when designing a rocket.

	Mid Power	**Level 1**	**Level 2**	**Level 3**	**Cost**	**Difficulty**
BODY TUBES						
Cardboard	X	X			$	X
Glassed Paper	X	X	X		$$	XXX
Blue Tube		X	X	X	$$	XX
Phenolic Tubing		X	X	X	$$	XX
Carbon Fiber			X	X	$$$	XXX
FINS & CENTERING RINGS						
Balsa	X				$	X
¼” Plywood	X	X	X		$$	X
Polycarbonate	X	X			$$$	X
3/8” Plywood		X	X		$$	X
G10 Fiberglass			X	X	$$	XX
Composite-reinforced Plywood			X	X	$$$	XXX

<table>
<tr><td colspan="2">High Powered Rocket Process Sheet</td><td colspan="2" rowspan="2">MEPS
Manufacturing Engineering Process</td></tr>
<tr><td colspan="2">Design – Parachute Sizing</td></tr>
<tr><td>Name of Rocket:</td><td>Name of Builder:</td><td>Name of Mentor:</td><td>Date Completed:</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Safe recovery of the rocket, and therefore recovery system design, is extremely important. Two factors should determine your parachute size. First is the desired descent rate. Second is the space available in the parachute bay. OpenRocket's Flight Simulation function can predict descent rate with reasonable accuracy.</td></tr>
</table>

In a dual deploy rocket, your drogue descent rate should be fast enough to allow the rocket to lose altitude quickly, but slow enough to allow for safe main parachute deployment. This can be between 50 – 100 ft/s. Be aware that as this velocity is higher, your rocket will undergo greater stresses at main deployment. These stresses can be mitigated by using longer shock cord, and using harness shock cord attachment techniques.

The main descent rate should be slow enough to allow your rocket to softly touch down. This should be below 25 ft/s. Be aware that in windy conditions, the slower the descent rate, the danger of drift increases.

<table>
<tr><td colspan="2">High Powered Rocket Process Sheet</td><td colspan="2" rowspan="2">MEPS
Manufacturing Engineering Process</td></tr>
<tr><td colspan="2">Review – Check Component Weight</td></tr>
<tr><td>Name of Rocket:</td><td>Name of Builder:</td><td>Name of Mentor:</td><td>Date Completed:</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">It is essential to maintain accurate simulation input to ensure accurate output. Garbage in, garbage out. One of the key inputs in OpenRocket is component weight. When completed components are received, input weights into OpenRocket before affixing them to other parts.</td></tr>
</table>

1. Before permanently affixing any parts (such as the fins to the motor mount), gather all parts, and a scale.
2. Open the OpenRocket file of the rocket.
3. Check that there is one part in the OpenRocket parts list for each physical part.
4. Double click on the name of the part in OpenRocket.
5. Click on the “Override” tab
6. Check the box for “Override mass”
7. Weigh the part using the scale.
8. Record the weight in the Override window, and press close.
9. Repeat Steps 3 – 8 for each part in the rocket.

High Powered Rocket Process Sheet		MEPS Manufacturing Engineering Process	
Build – Rolling Pre-Preg Carbon Fiber Tubes			
Name of Rocket:	Name of Builder:	Name of Mentor:	Date Completed:

BYU Rocketry students have access to the BYU Composites lab, which has pre-preg carbon fiber and a large oven to build composite high-power rocket body tubes from scratch. This process has been refined by generations of BYU Rocketry students to reliably produce high-quality body tubes capable of placing at the top of the Spaceport America Cup.

1. Schedule a time in the Composites and Plastics Lab to use the space. Arrange to have at least three people helping in this process.

2. Carry these materials to the lab: Mandrel, Dunstone shrink tape, mylar sheeting, cotton or microfiber cloths, safety glasses, and gloves.

3. Put on safety glasses and gloves.

4. Hang the mandrel on a bar, and clean it with alcohol using a clean cloth. No paper towels as these contribute to foreign object debris.

5. Wipe the cutting table with alcohol, roll the mylar sheet out, and wipe it with alcohol.

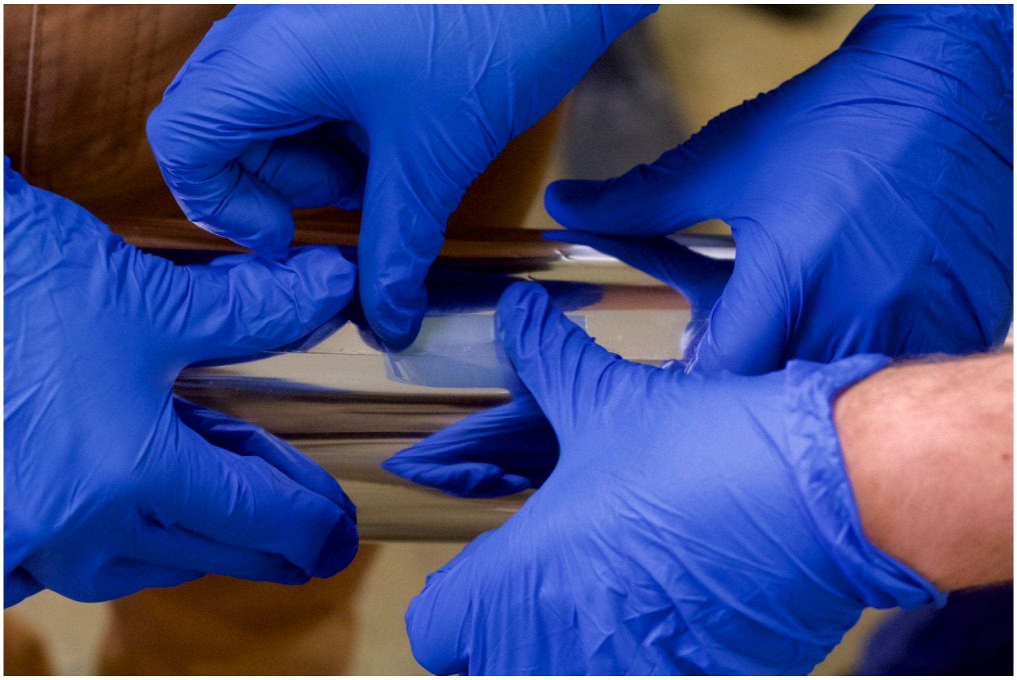
6. Calculate the circumference of the mandrel.

7. Using a long straightedge ruler, measure and mark the mylar sheet at least two inches longer than the carbon fiber sheet length, and as wide as the circumference of the mandrel. The carbon fiber sheet length should be at least two inches longer than the finished length of the body tube.

8. Using a sharp razor, cut the mylar along the marks from Step 7.

9. Fit the mylar onto the mandrel, ensuring the edges of the mylar are square. There should be very little overlap of mylar where the edges meet.

10. Using 1 inch lengths of blue flash tape, cinch the mylar tightly around the mandrel.



11. Use one piece of tape for every 6 inches of length, and at the edges, tape the mylar to the mandrel. The edges should be square at this point, and the mylar should have no kinks or folds.

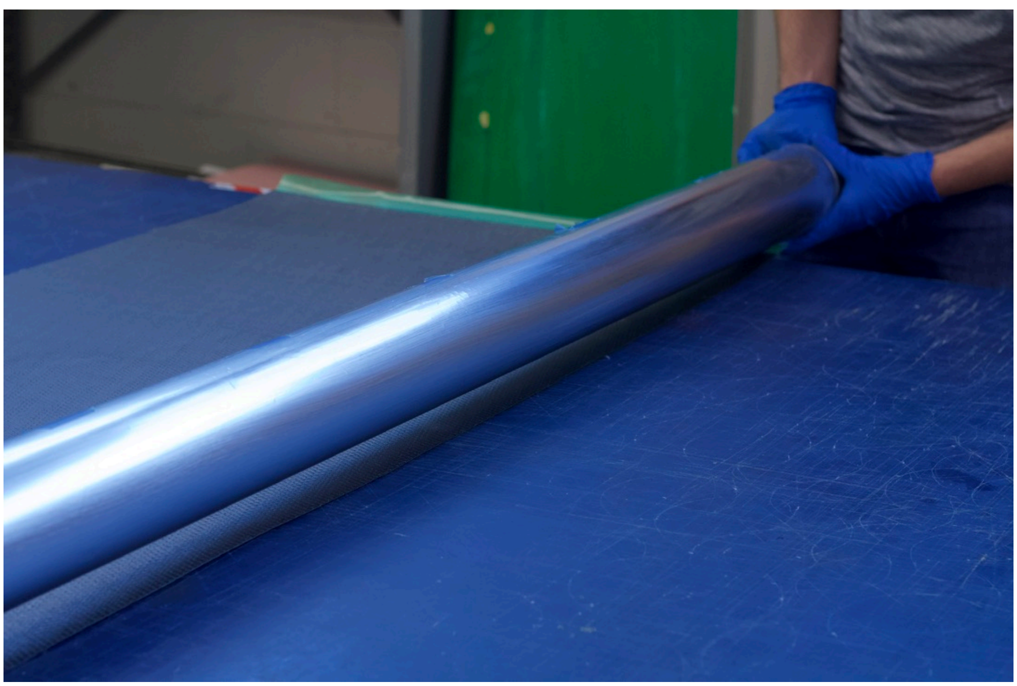
12. Using a clean cloth, wipe the surface of the mylar with Chemlease Mold Primer. Allow time to cure, and repeat at least once.

13. Calculate the width of carbon fiber needed. This is the circumference of the mandrel multiplied by the number of layers in the wall thickness. Again, the length should be at least two inches longer than the finished body tube.

14. Using a long straightedge ruler, measure and mark the carbon fiber sheet on the cutting table.

15. Using a sharp razor, cut the carbon fiber sheet along the marks from Step 14.

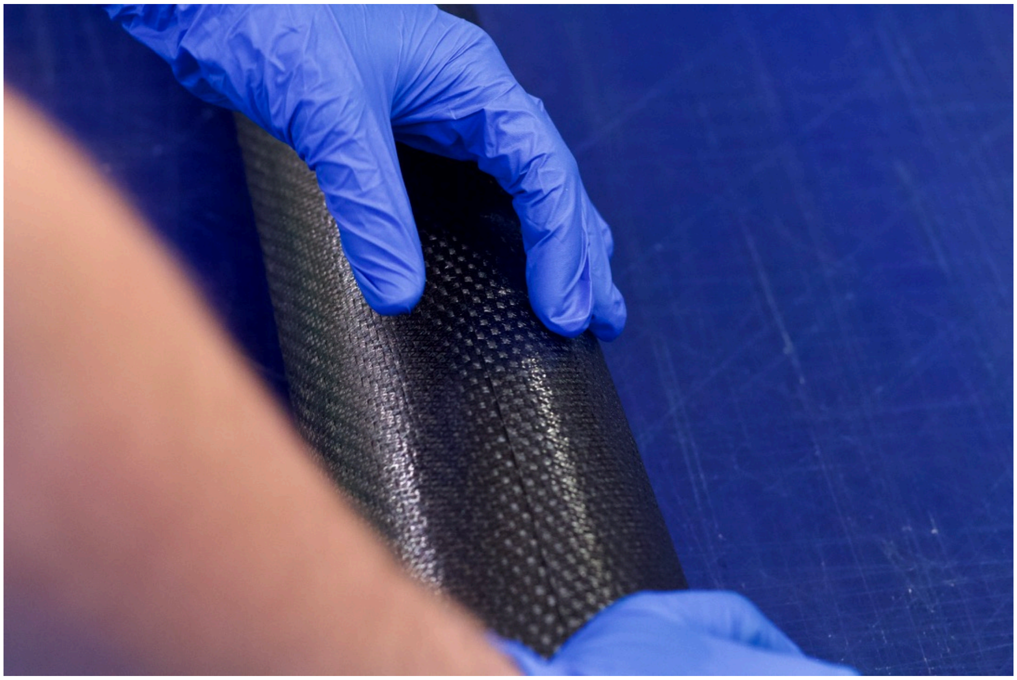
16. With the carbon fiber sheet on the cutting table, rest the mandrel on the edge of the carbon fiber sheet.



17. Pass the heat gun across the edge of the carbon fiber sheet and the bottom of the mandrel until the carbon becomes tacky. Do not allow the heat gun to rest at any one spot on the carbon as the heat can cause it to begin curing.

18. With the carbon fiber sheet tacky, roll the mandrel over the sheet. This is best done with one or two people on the cutting table, applying pressure on the mandrel and evenly rolling it, while one or two more people apply pressure to the sheet on the table, being careful not to distort the weave of the carbon fiber.

19. While rolling the mandrel over the sheet, feel the tube for any air bubbles or wrinkles in the carbon fiber. Gently press these out by warming the spot with the heat gun and massaging the carbon fiber.



20. With the sheet completely rolled onto the mandrel, hang the mandrel on a bar.

21. Gather the shrink tape and Partall Paste #2.

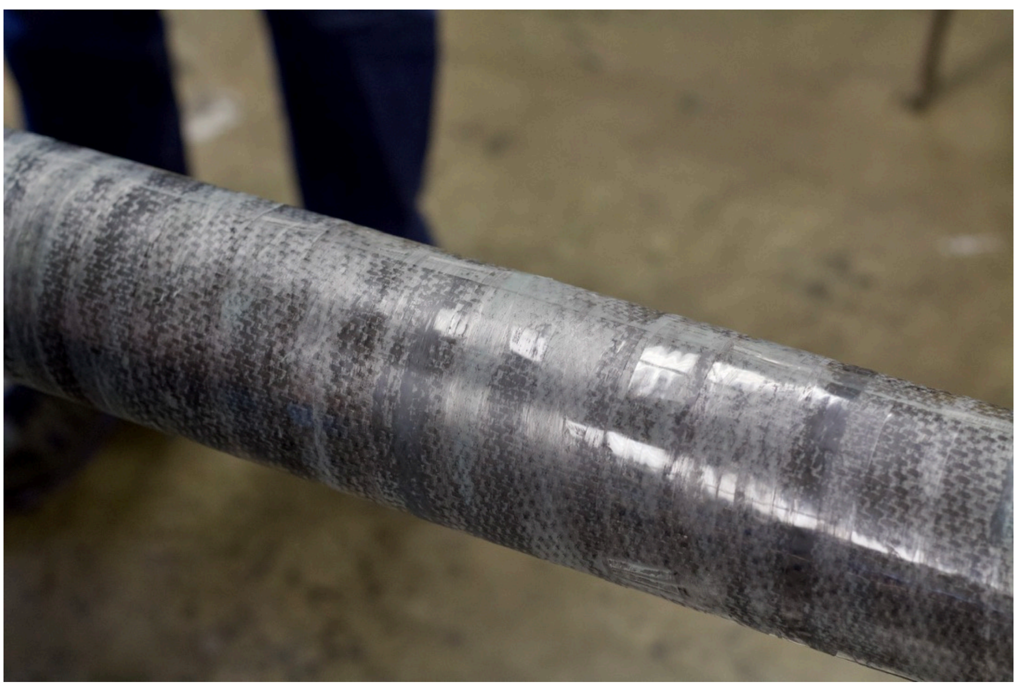
22. Using blue flash tape, tape the end of the shrink tape to the edge of the mandrel, off the edge of the carbon fiber.

23. Apply the shrink tape with the outer edge facing the carbon fiber. Dunstone shrink tape typically has a release coating on the outer side of the roll of tape.

24. Wrap the shrink tape around itself for one revolution, then angle the shrink tape so it begins to cover the carbon fiber. This can be done with one person holding the shrink tape, and one person spinning the mandrel.

25. Apply a thin layer of mold paste to the side of the shrink tape facing the carbon fiber. This can be done by one more person holding a cloth.

26. Wrap the shrink tape across the carbon fiber, being careful to consistently overlap the previous pass of tape.



27. With the carbon fiber covered, wrap the shrink tape one full revolution around itself at the other edge of the mandrel.

28. Cut the shrink tape and use blue flash tape to secure it.

29. The tube is now ready to be cured in the oven. Take note of the product information of the pre-preg carbon fiber, and inform a Composites Lab Assistant of its curing profile.

NOTES:

- The Composites Lab typically has the following materials in stock that are useful for this process: razor knives, markers, alcohol, acetone, Chem Trend Chemlease, Partall Paste #2, blue flash tape

- If the mandrel has been prepared and polished, the mylar can be skipped. In this case, apply Chemlease directly to the mandrel, and proceed to step 13.

- This process should allow the carbon fiber tube to easily break free from the mandrel. If there is any difficulty removing the tube, try keeping the tube in the walk-in freezer to shrink the mandrel.

- Do not use metal tools to remove the tube from the mandrel, as this can damage both the mandrel and the part.

<table>
<tr><td colspan="2">High Powered Rocket Process Sheet</td><td colspan="2" rowspan="2">MEPS
Manufacturing Engineering Process</td></tr>
<tr><td colspan="2">Build – Cut Fins (Band Saw)</td></tr>
<tr><td>Name of Rocket:</td><td>Name of Builder:</td><td>Name of Mentor:</td><td>Date Completed:</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">It is a great skill to be able to make parts by hand. It allows the builder to have a certainty the part matches the design. This process is most useful for wood fins. This process should only be used for composite fins in a lab set apart for composites cutting.</td></tr>
</table>

1. On OpenRocket: Print as many Fin Templates as there are fins.
2. Prepare materials: Safety glasses, wood material, fin templates, white glue, band saw, belt sander.
3. Spread a thin layer of glue on the wood.
4. Lay the template over the glue, gently squeezing any bubbles out till the template is flat.
5. Let the glue dry, put on safety glasses, and take the wood to the band saw.
6. Cut out the fins on the bandsaw, carefully following the lines on the template.
7. On the belt sander, carefully sand off the paper template
8. On the belt sander, round the edges of the fins to finish.

High Powered Rocket Process Sheet		MEPS Manufacturing Engineering Process	
Build – Cut Fins (Laser Cutter)			
Name of Rocket:	Name of Builder:	Name of Mentor:	Date Completed:

The laser engraver is a useful tool in the BYU Engineering Prototyping lab. Wood fins can be easily cut into complex shapes, as well as centering rings and bulkheads. The Prototyping Lab Assistants are a great resource for any questions when working with this machinery.

1. On a CAD program, draw the shape of the fin in a sketch.
2. Be aware of the kerf of the laser cutter, which is the width of material lost in cutting. This is typically a few thousandths of an inch, which is negligible for this purpose.
3. Export the sketch as a DXF file, and save it on a flash drive.
4. Schedule a time on the Laser Engraver at byuprojectslab.simplybook.me
5. Cut your wood material to fit the 40” x 28” laser engraver bed.
6. Turn on the laser engraver.
7. Follow the instructions found on the computer attached to the laser engraver.
8. Import DXF file to CorelDraw.
9. Export file from CorelDraw to laser engraver
10. Set appropriate power and speed for the material.
11. Check the lens of the laser engraver is clean.
12. Lay material in the bed of the laser engraver.
13. Set the focus of the laser engraver using the focus device.
14. Set the home point on the upper left corner of the material.
15. Close the door on the laser engraver, ensure the exhaust fan is running.
16. Start the job on the laser engraver.
17. Once the laser finished running, without moving the material, check that the cuts have run through the thickness of the material.
18. If the cuts have not cut through the entire material, change the power, speed, or focus of the laser, and run the program again.
19. Once the fins are cut out, round the edges on a belt sander.

High Powered Rocket Process Sheet		MEPS Manufacturing Engineering Process	
Build – Cut Fins (CNC)			
Name of Rocket:	Name of Builder:	Name of Mentor:	Date Completed:

The CNC router is a useful tool in the BYU Engineering Prototyping lab. Wood, composite, and even metal fins can be easily cut into complex three-dimensional shapes. The Prototyping Lab Assistants are a great resource for any questions when working with this machinery.

1. On a CAD Program, create a part in the shape of the fin.
2. Export the part as an STL file, and save it on a flash drive.
3. Schedule a time for CNC Router Toolpath Programming at byuprojectslab.simplybook.me
4. Once the toolpath programming is complete, schedule a time with the Lab Assistant who completed the programming to run the router.
5. The Lab Assistant will control most of the process using the router.
6. The fins may require some finishing after routing.

High Powered Rocket Process Sheet		MEPS Manufacturing Engineering Process	
Build – Cut Fin Slots By Hand			
Name of Rocket:	Name of Builder:	Name of Mentor:	Date Completed:

This process prepares the body tube for Through-The-Wall fins. If the body tube is made of a composite material, this process should be done in the composites finishing lab.

1. Gather materials: Fin Slot Template, Body Tube, tape, dremel, clamps.
2. Print Fin Slot Template from OpenRocket.
3. Tape Template securely around the body tube, ensuring the template is straight and flush.
4. Ensure the Template will place the fin slots at the correct place along the length of the tube.
5. If Body Tube Material is composite, any cutting must be done in the composites finishing lab. Fiberglass and carbon fiber dust can be very harmful.
6. Clamp body tube so it cannot slide or rotate, with one slot in an easily reachable position.
7. Turn on dremel, and carefully cut through the tube wall along the template.
8. Turn off dremel, and rotate tube so the next slot is easily reachable.
9. Repeat until all slots are cut.
10. Clean the edges of the cut surface.
11. If there are any imperfect cuts, fin fillets will be able to cover those up.

High Powered Rocket Process Sheet		MEPS Manufacturing Engineering Process	
Build – Alignment Jig			
Name of Rocket:	Name of Builder:	Name of Mentor:	Date Completed:

An alignment jig is a tool which holds the fins in the correct position while they are being glued to the body. This is essential to ensure an accurate and safe flight.

1. Open a CAD software, and get the tube diameter, number of fins, fin thickness, and fin height for the rocket.
2. Draw a sketch in CAD showing a cross sectional outline of the fin area of the rocket. It should have a circle that matches the body diameter, and a number of rectangles along the circle that match the fin thickness and fin height.
3. Export this sketch as a DXF filetype, then follow the process to cut out the jig on the laser cutter.
4. The alignment jig can typically be made of cardboard to save on cost, but it can also be made from plywood.

High Powered Rocket Process Sheet		MEPS Manufacturing Engineering Process	
Build – Motor Mount Assembly			
Name of Rocket:	Name of Builder:	Name of Mentor:	Date Completed:
The motor mount section can be assembled before it is permanently fixed in the body of the rocket. This is the power center of the rocket, so it is essential that all connections here are solid.			

1. Gather the body tube, inner tube, epoxy, centering rings, fins, and fin alignment jig.
2. Clean all surfaces that will be epoxied with alcohol and a cloth.
3. Determine the length of inner tube required. This should typically be around the length of the motor used. Mark this length on the inner tube.
4. Cut the inner tube to length. If the tube is made of fiberglass or carbon fiber, this should be done in the composites finishing lab. If not, this can be done on a miter saw.
5. Mark on the tube where the centering rings will sit.
6. Slide the centering rings on the tube, one by one. Using masking tape, tack the centering rings in their place.
7. Check the space between centering rings. The fin tabs should be able to fit between the rings.
8. Mix a small batch of epoxy according to its instructions.
9. With the tube standing on one end, spread the epoxy where the tops of the centering rings meet the tube.
10. Before epoxy sets, adjust the centering rings to ensure they are aligned perpendicular to the inner tube.
11. Let stand until epoxy sets.
12. Mix another small batch of epoxy.
13. Stand the tube on the opposite end, and spread the epoxy as in step 8.
14. Let stand until epoxy sets.
15. The entire interface between the centering rings and inner tubes should be joined by epoxy.
16. With the fin slots cut, prepare to mount the inner tube in the body tube.
17. Stand the inner tube with the top side facing up.
18. Mix a batch of epoxy.
19. Spread the epoxy on the outer edges of the centering rings.
20. Push the inner tube assembly into the body tube until the centering rings rest in the correct position.
21. Let stand until epoxy cures.
22. Check the fins set flush in their slots. Try sanding the corners of the fin tabs if they do not set flush against the inner tube.
23. Mix a batch of epoxy.
24. Spread epoxy on the edge of the tab of one fin.
25. Place the fin in a slot, being sure the tab rests on the inner tube.

26. Repeat steps 24 and 25 until all fins are epoxied in place.
27. Place the fin alignment jig over the fins so they do not move out of place.
28. Let stand until epoxy cures.

High Powered Rocket Process Sheet		MEPS Manufacturing Engineering Process	
Build – Fin Fillets			
Name of Rocket:	Name of Builder:	Name of Mentor:	Date Completed:
The fin fillets serve as the strong bond that holds the fins in place during flight. This is important as the fins face extreme stress. Well-finished fin fillets can also improve the aesthetic finish of the rocket.			

1. Gather the completed motor mount assembly, a dowel or PVC pipe that matches your fillet radius, epoxy, silica epoxy thickener, gloves, masking tape, sandpaper. Epoxy with a pot life of longer than 5 minutes is essential, longer than 10 minutes is recommended.
2. Set the motor mount assembly in a stand with two fins pointing upward.
3. Using the dowel as a measuring device, mark the radius of the fillet on both the body tube and the fins.
4. Use masking tape to mask off the marks made in step 2. This will prevent excess epoxy from bonding on the tube and fins.
5. Put on gloves.
6. Mix a batch of epoxy according to the instructions. Little by little, add silica thickener while mixing, until the epoxy has a consistency of smooth peanut butter.
7. Fill the fillet space with epoxy.
8. Using the end of the dowel, scrape along the fillet to smooth the epoxy into the radius shape.
9. Let stand until epoxy sets. Be careful of excess epoxy in the mixing pot, as this can heat quickly when it cures.
10. Repeat steps 6 to 9 until all fillets are filled.
11. Once all epoxy has set, but before it fully cures, remove masking tape.
12. Sand any rough edges of the epoxy until any edges are taken off.

High Powered Rocket Process Sheet		MEPS Manufacturing Engineering Process	
Build – Rail Buttons			
Name of Rocket:	Name of Builder:	Name of Mentor:	Date Completed:

Rail Buttons are the part on a rocket that attaches to the launch rail. The rail buttons must be aligned, and securely fastened to ensure the rocket's initial ascent is straight.

1. Gather the assembled motor mount assembly, rail buttons, a long angle bracket, a drill, machine screws, washers, and nuts.
2. Make a mark halfway between two fins.
3. Using the long angle bracket, extend the mark along the body tube.
4. Mark the height along the body tube where the rail buttons will be placed. One rail button should be just a few inches from the tail of the rocket, and another should be near the center of gravity of the complete rocket.
5. Drill a hole that matches the width of the machine screw.
6. Insert the machine screw through the rail button into the hole.
7. Fasten the screw with a washer and nut on the inside of the tube.
8. Ensure the screw is not excessively long inside the body tube, as this can impede the parachute.

High Powered Rocket Process Sheet		MEPS Manufacturing Engineering Process	
Launch – Parachute Folding			
Name of Rocket:	Name of Builder:	Name of Mentor:	Date Completed:
Safe recovery is one of the most important goals in rocketry. Effective deployment of the parachute requires the rocketeer to consider how the parachute is packed. There are many types of parachutes. This process is an example of how to fold a simple flat parachute.			

1. Fold the parachute in half. See Figure 1.

Figure 1

2. Take the upper right most corner and fold inwards to the middle corner which is closest to the rocketeer. See Figure 2

Figure 2

3. Repeat Step 2 for the left side. The parachute should now have a nearly triangular shape. See Figure 3.

Figure 3

4. Fold the right most corner of the triangle to the left most corner. See Figure 4

Figure 4

Launch – Parachute Folding	Name of Rocket	Name of Builder

5. Gather the shroud lines and fold them, laying them over the parachute. See Figure 5.

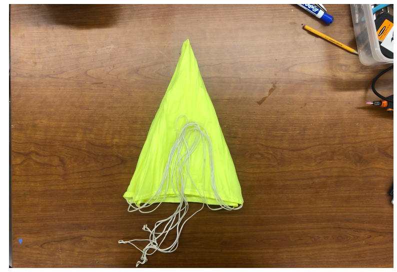


Figure 5

6. With the shroud lines in the center, fold the top point of the triangle down to the bottom of the triangle, forming a trapezoid. See Figure 6.

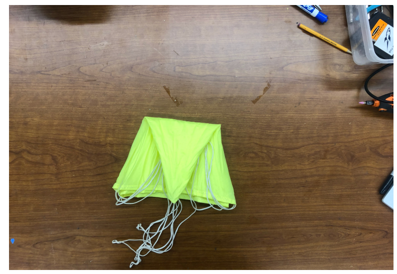


Figure 6

7. Fold the right side of the trapezoid to the left side of the trapezoid. See Figure 7.

8. Roll the parachute and push the it into the body tube. Note that the folded parachute should slide freely within the body tube.

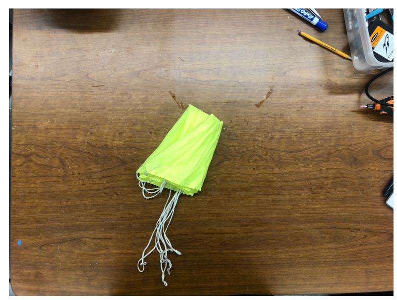


Figure 7