

# The Longhorn Rocketry Association: Triton

## Team 99 Project Technical Report to the 2024 Spaceport America Cup

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**The Longhorn Rocketry Association (LRA) shall compete in the 30,000 foot Above-Ground-Level (AGL) commercial-off-the-shelf (COTS) category in the Intercollegiate Rocket Engineering Competition (IREC) at the 2024 Spaceport America Cup (SAC) on behalf of The University of Texas at Austin (UT-Austin). LRA shall launch Triton, a 5” diameter, 10.5-foot-long custom-built fiberglass rocket, propelled by a Cesaroni-Technology Incorporated (CTI) O3400-IMAX solid rocket motor on the booster. Triton will carry a payload that will measure the thermal effects of materials exposed to supersonic airflow. Triton will also carry Altus Metrum TeleMega flight computers with accelerometers, long-range radios and GPS capabilities. These flight computers will record flight characteristics, relay them to the ground in real-time and control the recovery system for the rocket. This rocket acts as LRA’s sixth entry into the Spaceport America Cup as LRA continues to grow its knowledge and experience in high power rocketry.**

### Nomenclature

$A$	= area
$a$	= acceleration
$C_d$	= drag coefficient
$\gamma$	= ratio of specific heats
$g$	= acceleration due to gravity
$M$	= Mach number
$m$	= mass
$P$	= Pressure
$P_s$	= static pressure
$Q$	= dynamic pressure
$R$	= gas constant
$\rho$	= density
$T$	= temperature

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V = volume  
v = velocity

## I. Introduction

The Longhorn Rocketry Association (LRA) is an undergraduate student-led design, build, test, and fly rocketry organization in the department of Aerospace Engineering and Engineering Mechanics (ASE/EM) at the University of Texas at Austin. This year, the LRA will compete in the 30,000-foot AGL COTS all propulsion systems category in the IREC at the 2024 SAC. The LRA will compete with Triton, a 5” diameter, 10.5-foot length, custom-built, high-powered rocket and a payload system designed to test the effects of supersonic airflow on different materials in flight. This is the LRA’s sixth entry to the IREC and is intended to improve upon Polaris I, Polaris II, and Polaris III, which are legacy two-stage rockets that the club has been developing since 2020. Polaris I was an experimental, two-stage design that flew nominally in 2021 in a test launch, while also serving to potentially position the organization to move toward its long-term goal of designing, constructing, and flying a spaceshot rocket. Polaris II was LRA’s entry into the 2022 Spaceport America Cup, where it competed in the 30K COTS division. Polaris II experienced instability during boost and did not stage but reached an apogee of 8,000 feet and successfully aborted the staging and was fully recovered. Polaris III was LRA’s rocket for the 2023 Spaceport America Cup. Polaris III successfully launched but failed to ignite the second stage to reach the nominal altitude. For the 2024 Spaceport America Cup, LRA has opted to build a single-stage rocket but install it with a more powerful motor.

### I.A. Organizational History

The LRA was founded in 2007 as an amateur rocketry club focusing on building and launching mid-powered rockets at local events around Austin. As the club grew, it began producing high-powered rockets for Level 1 & 2 certification with Tripoli Rocketry Association (TRA). Experienced members would mentor and guide newer members through the design, construction, and launch process, and this aspect of the organization continues as the Certification Group. This grounded new members in the basics of high-powered rocketry and has led to more advanced rocket design. Certification Group led to “high-power” teams which worked on more ambitious projects such as: a minimum diameter rocket, auto-rotating recovery, clustered rocket, multi-staging, and supersonic flight. The club also grew and increased its recruitment from outside the ASE/EM department, drawing students from mechanical engineering, electrical engineering, physics, and other departments.

As the ambition of the club grew, fueled by members returning from internships with valuable experience, the club began to transition to a more technical, project-based organization. Attention specifically drew towards rocket propulsion systems. The first project was a methane and gaseous oxygen Acoustic-Resonance Igniter (ARI) which was successfully fired in 2016. This was one of the first known successful acoustic resonance ignitions using these fuels. This success led to the creation of a permanent engine development team focused on the design, construction, testing, and eventual launch of a hybrid rocket engine. The first engine design, Taurus, is a Nitrous Oxide (N<sub>2</sub>O) and Hydroxyl-Terminated-Polybutadiene (HTPB) test engine designed as a proof of concept as well as a first use of the new LRA test facility at the J.J. Pickle Research Campus (PRC) at The University of Texas at Austin.

The LRA decided to enter IREC 2017 to give the organization a long-term goal of competing in the SRAD portion of IREC and producing rockets capable of flying to high altitudes on custom propulsion systems. For the past several years, the Launch Vehicle, Electronics, and Payload/Experimental teams have focused on producing rockets for the IREC competition; while for the past two years, the Propulsion and Test & Launch Operations teams have been working on the TAURUS engine and related testing infrastructure. Progress has been slow in getting the engine development program started as the necessary infrastructure for testing is both expensive and very difficult to implement safely in a city like Austin. The test stand was completed in mid-2019; however, testing stalled soon after due to the emergence of COVID-19 and subsequent in-person work restrictions which lasted for 18 months. This year, the club has been updating and refurbishing the stand to continue engine testing. The club’s long-term focus is on iterating towards a flight-weight hybrid engine design which may fly at a future IREC.

### I.B. Project Objectives

The LRA’s mission objectives for this year are to (a) design, test, and manufacture a winning rocket in the 30,000 ft AGL COTS category, (b) re-establish a strong framework for team structure, design practices and manufacturing that will serve the organization in future technical endeavors, (c) to provide members with hands-on design, manufacturing, testing, and launch experience that will be directly applicable to internships and careers in the

aerospace industry, and (d) to strengthen the LRA's network with other collegiate rocketry organizations, corporations, and the wider rocketry community.

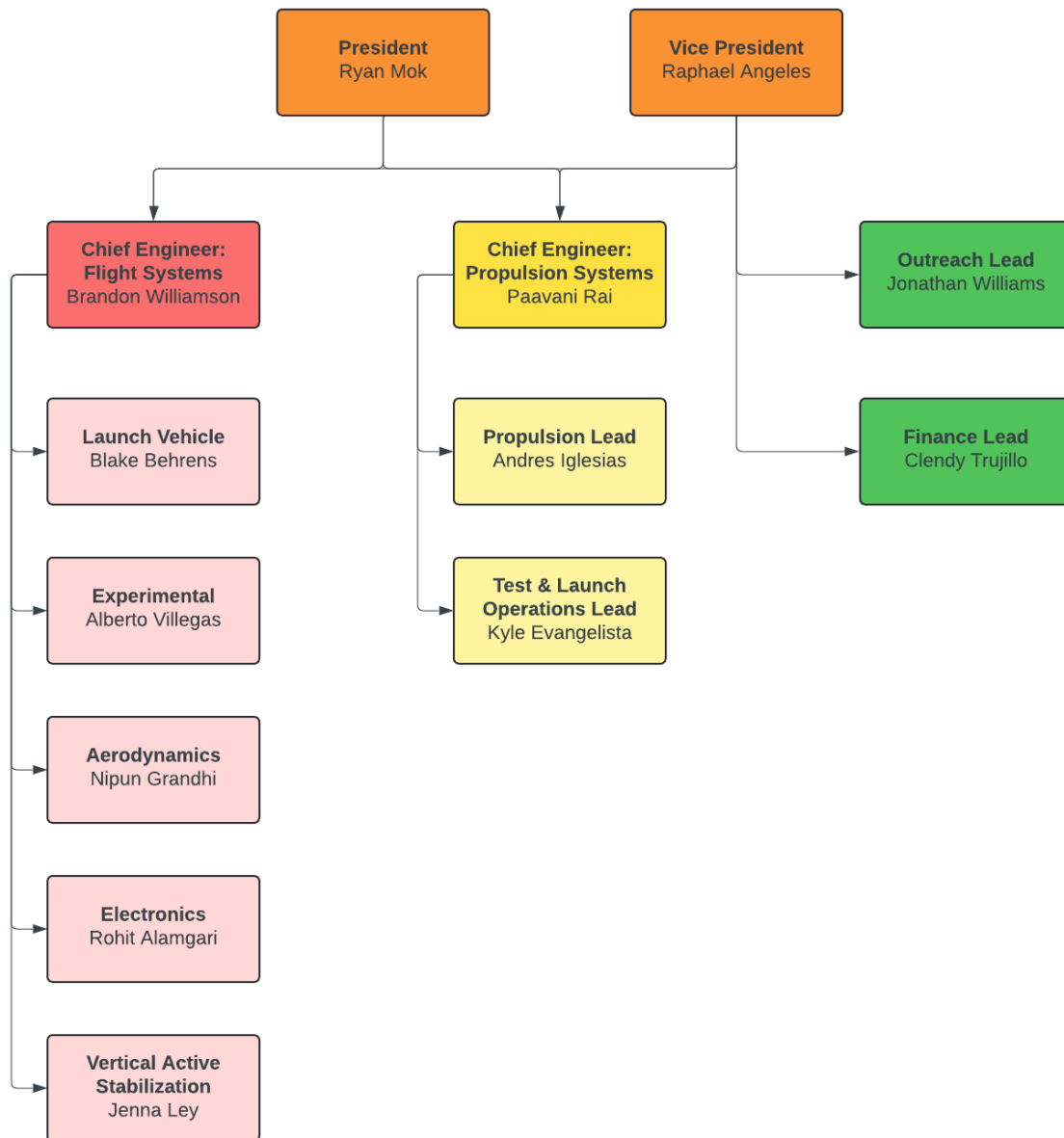
The LRA's first objective is to launch Triton to 30,000 feet AGL, while carrying a payload to analyze the effects of supersonic airflow in flight. The 2023 entry, Polaris III, failed to ignite its second stage which caused the rocket to fail to reach its nominal altitude. Furthermore, the second stage lost GPS contact and the team was unable to find the rocket in the desert. If successful, the single-stage Triton will surpass the altitude of any other rocket LRA has ever launched. The payload Triton will carry will measure the thermal effects of certain materials exposed to the atmosphere in flight. The system will use thermal cameras to look at materials placed in the nose cone and exposed slightly to the outside airflow. The results of this experiment will help engineers determine which materials give the best thermal conductivity/insulation when designing supersonic vehicles.

The organization's second objective is to improve the team's approach to solving advanced engineering challenges as the organization moves towards an SRAD propulsion system for future rockets and a potential spaceshot project. On the technical side, the organization is improving its use of Computer-Aided-Design (CAD) to better visualize components before they are made. This practice aids in avoiding complications in the interface between components, making assembly much easier and more streamlined. Better CAD practices also allow for easier design analysis using structural Finite Element Analysis (FEA) and Computational Fluid Dynamics (CFD). The team utilized SolidWorks, ABAQUS, and ANSYS software packages for producing CAD models and performing FEA & CFD analysis. The LRA utilized many manufacturing processes in the development of Triton such as composite layups, waterjet cutting, milling, laser cutting, and 3D printing. These advanced manufacturing techniques expand the realm of possibilities in manufacturing for the club, and the organization is actively seeking out new and better methods of developing high-powered rockets. On the administrative side, new organizational tools are also being explored to help improve the efficiency of information transfer within the organization and keep track of project timelines and milestones. All these tools will be essential in more technically challenging projects. The LRA has also recruited more members from varied engineering backgrounds like mechanical and electrical engineering as well as computer science, bringing more expertise to the team which will be valuable in future technical endeavors.

The third and fourth objectives for the LRA are focused on improving the organization's connections with the wider engineering world. Members of the LRA only gain value from the club when the skills they develop are applicable in their chosen field of engineering. The organization serves to act as a springboard for a career in the aerospace industry by sending alumni to internships and full-time positions at major corporations, research institutions, and government agencies. The LRA has been very successful in this regard and has many alumni nationwide who have enjoyed great success in the launch vehicle industry and who have offered their technical expertise back to the club in the form of Critical Design Reviews (CDR's) and valuable advice. Past IRECs have been great platforms for the organization to network with aerospace companies and other collegiate rocketry clubs, building relationships which have been invaluable in the development of this project.

### **I.C. Organizational Structure**

LRA is composed of seven permanent technical teams, many of which were involved in Triton's development. Technical team leads picked committed members to join and contribute important work to their team. The project hierarchy was chosen and is shown in Figure 1 below. The Propulsion and Test & Launch Operations (formerly Ground Systems) teams worked separately on the future hybrid engine development project and had no direct input to the LRA's IREC project.



**Figure 1. LRA Organizational Hierarchy Chart**

The Chief Engineer, Brandon Williamson, led the technical development of the Triton rocket and coordinated the efforts of all the sub-teams involved. He essentially acted as a systems engineer, ensuring all the different systems involved in Triton came together well.

The President and Vice President acted as the overall leads and the interface between the team, mentors, and competition authority. These leads also helped organize the logistical side of many test launches and events.

The business team (green) was primarily involved in the marketing and outreach side of the project and ran many events to help market LRA to the outside world. They also ran our Girl Day event, which was a special event to encourage girls in the Austin-area community to pursue a career in STEM.

Much of the manufacture of the actual rocket itself was done by the launch vehicle team, led by Blake Behrens. This included the design of Triton in OpenRocket, the manufacturing of the body tubes and fins, the design and manufacturing of the ebays, and the selection of parachutes.

The Experimental team, led by Alberto Villegas, designed and produced the payload. They took charge of experiment concept, design, software development, fabrication, and integration for payload. They will also work on the verification of data collected by the payload system during flight.

The Vertical Active Stabilization team, Propulsion team, Test & Launch Operations team, and the Launch Vehicle team worked on experimental projects separate from this year’s Spaceport rocket. However, their projects are to lay the foundation for future rockets, engines, and systems to fly in IREC 2025 and beyond.

#### **I.D. Team Management**

The Chief Engineer and President coordinated to schedule all major activities and deadlines which were then subdivided by technical team leads and assigned to team members. All project deliverables were coordinated by the Chief Engineer and President with help from the team leads. Financing, budgeting, and ordering of supplies was handled by the President, Vice President, and Finance Lead, and detailed records of meetings and decisions were kept by them as well. Team meetings were held every week with progress reports, milestones, deadlines, and budget updates all discussed amongst the entire officer team.

The organization primarily employed Microsoft Teams to streamline communications and improve team efficiency. Teams acted as a multi-use software product that allowed the LRA to aggregate everything it needed in one single application. It was the primary form of communication within the team, with separate channels for different elements of the project, private messaging between individuals, and document and media sharing across the team. Teams allowed for streamlined file sharing service and were used to store all documents, forms, and other files in an easily accessible location. All CAD files were also hosted in Teams, allowing all team members to view component designs and improve the efficiency of design collaboration between teams.

## **II. System Architecture Overview**

### **A. Preliminary Sizing**

The sizing for Triton was completed using the open-source programs OpenRocket. OpenRocket was used to find the preliminary sizing of the rocket components and to simulate the flight of Triton. The design was based around the constraints of the payload size, spacing for the recovery systems, and manufacturability regarding the facilities and equipment available in UT buildings. When designing the rocket, the main goal was to make the design as modular as possible to allow different sub-teams to simultaneously work on different sections of the rocket. The engine was selected with the goal of reaching an apogee of just over 30,000 feet. This year all the flight simulations were conducted using Spaceport America, New Mexico atmospheric data to account for the difference in air pressure experienced there versus in Austin, Texas, which is at a much lower elevation. Using these parameters, several motors were iterated through testing until two were chosen to be used at competition. Table 1 shows the launch conditions used in the OpenRocket simulations; Table 2 shows the flight dynamic properties of Triton; Table 3 shows the commercial engine specifications; and Table 4 shows the final structural properties.

**Table 1: Triton Launch Conditions**

White Sands, New Mexico	Spaceport America
Latitude	33°N
Longitude	107°W
Altitude	4596 ft
Launch Rail	17 ft

**Table 2: Triton Flight Trajectory Properties**

Dynamics	
Expected Altitude	30,975 ft
Thrust-to-Weight Ratio (Lift-off)	11.5:1
Maximum Velocity	2095 ft/s
Center of Pressure	95.08 in

Center of Gravity (Lift-off)	80.29 in
Static Stability Margin	2.87
Drogue Deployment Altitude	Apogee
Drogue Descent Rate	93.7 ft/s
Main Deployment Altitude	600 ft
Main Descent Rate	28.6 ft/s
Ground Hit Velocity	23 ft/s
Maximum Mach Number	1.86

**Table 3:** Triton Commercial Engine Properties

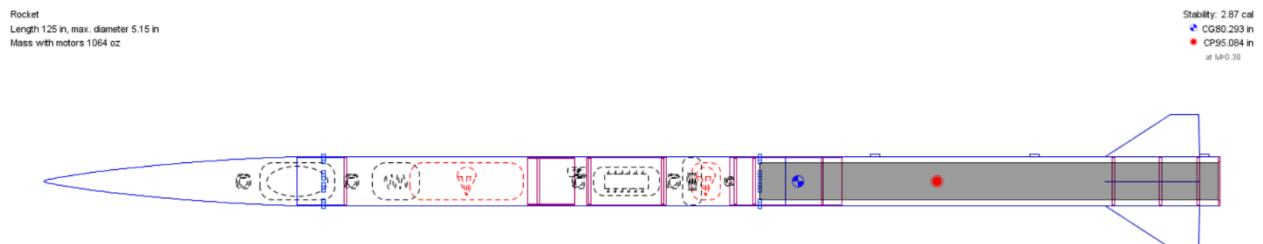
Engine	CTI O3400-IM
Type	Solid
Weight	37.05 lbs.
Average Thrust	3416.7 N
Maximum Thrust	4750.3 N
Total Impulse	21062.2 Ns

**Table 4:** Triton Structural Properties

Structures	
Material	G12 Fiberglass
Total Length	125 in
Outer Diameter	5.15 in
Inner Diameter	5.0 in
Weight (Lift-off)	66.5 lbs.
Weight (Aero-Structure)	29.45 lbs.

### II.A.1. Open-Source Software Simulations

OpenRocket is an open-source program that was used to design and simulate the Triton rocket. This program allows the user to control every aspect of a rocket, particularly various airframe geometries, and iterate through designs rapidly. OpenRocket also allows flight simulation on a selected rocket and takes into consideration launch conditions. Therefore, OpenRocket was used to simulate the flight of the rocket at the conditions that it will be experiencing at the Spaceport America Cup. The simulations for Triton used parameters of the launch conditions at Spaceport America such as launch rail length, launch angle, approximate altitude, and average wind speeds. Triton was designed to reach an apogee of ~30,000 feet, which creates a ~5% margin for mass budgeting and simulation error. During our test launch in March, OpenRocket predicted that flying with an CTI N2501-WH, our rocket would reach an apogee of ~20,430ft which it did, reaching ~20,000ft. With current simulations predicting our rocket to reach ~30,900 ft, that gives us room to account for changes in weather conditions, or any minor errors in OpenRocket that may occur during its simulations of the flight.



**Figure 2:** OpenRocket design of Triton

## B. Propulsion System

For the 30,000 feet COTS competition, many motors were considered before finalizing the decision of which to take to competition. Some key criteria used to evaluate motors included sizing, total impulse, and burn time. While many motors were considered, the primary options and basic stats are listed below in table 5. All the numbers listed are based off launch conditions at the Spaceport America Vertical Launch Site.

**Table 5: Commercial Engines Specifications and Data**

Motor	Impulse (ns)	Burn Time (s)	Apogee (ft)	Vel. Off Rail (ft/s)
CTI N5800-CS	20368	3.53	30668	71.1
CTI N3301	19318	5.86	27936	126
CTI O3400	21062	6.16	31260	127

In

selecting a motor, the expected velocity off the rail, estimated maximum velocity, and most importantly, predicted apogee were looked at in determining a suitable candidate. A high velocity off the rail was desired to ensure that Triton would be aerodynamically stable when leaving the launch rail. Upon obtaining a final design of the rocket, it became clear that the CTI N5800 had a much lower rail exit velocity, and the CTI N3301 would not reach a sufficiently high apogee. This left the CTI O3400 as the only viable motor.

One of the main considerations during motor selection was the fact that historically, LRA's rockets had hit a lower apogee than designed. This is likely due to the increased weight of certain components, such as fins (carbon fiber overlay), shock cords, and other strengthening mechanisms. While these components are crucial to ensure the structural integrity of the rocket, they also add weight and decrease the overall apogee of the rocket. Therefore, the team decided to build a rocket that went higher than the desired apogee, with the expectation that it would not reach as high.

Another strong consideration was the availability of motors. In previous years, many large high-powered rocket motors have become extremely difficult to procure, largely due to world-wide conflicts. The team was luckily able to obtain an O3400 from Animal Motor Works, but the availability of other motors like the N5800 played a large role in the decision-making process of the team.

### C. Aero-Structures Subsystem



**Figure 4: Triton lower body tube with team members**

Triton was manufactured in 4 main sections, listed in order from the bottom of the rocket to the top: the lower body tube, the zipper-less coupler, the upper body tube and the nosecone. The lower body tube holds the motor of the rocket, the upper body tube holds the recovery system, the coupler connects the lower and upper body tubes, and the nose cone holds the payload bay. The primary body and coupler material is G12 fiberglass. These components were designed based upon previous years' research in the LRA as well as structural analysis based on the maximum loads experienced during flight. The specific components will be further described in the following sections.

### *C.1 Air Frame Body*

The air frame tubes of Triton are constructed out of fiber wound G12 fiberglass sourced from Madcow Rocketry. The club used the same material last year in a 6-inch diameter configuration for the Polaris III rocket, and two years ago in a 6-inch diameter configuration for the Polaris II rocket. The body tubes were able to withstand the stress of its test flight and are reputable within the high-power rocketry community, providing confidence that the tubes will be suitable for use in Triton. Though carbon fiber is lighter and stiffer than fiberglass, radio frequencies, which are

critical for GPS tracking and relaying information from the flight computers to the ground, don't travel well through carbon fiber. The flight computers used in Triton are mounted within the upper body tube, meaning that carbon fiber is not a feasible material for Triton.

### C.2. Lower Body Tube

The booster section airframe is a 46-inch-long section of 5.15-inch diameter G12 fiberglass tube chosen to accommodate the Cesaroni 98 mm 6XL motor casing, which contains our O3400 motor. There is no motor tube in this design, the motor casing itself is supported by four plywood centering rings, a thrust plate, and a fixed bulkhead which attaches to the Cesaroni hardware. The plywood centering rings, positioned 2, 6, 11, and 42 inches from the bottom of the lower body tube were glued using epoxy and Cab-O-Sil to the inside of the lower body tube. The bulkhead, which is 3.5 inches above the top opening, was glued using epoxy and Cab-O-Sil inside the zipper-less coupler attached to the lower body tube. When assembled a 3/8" steel all-thread gets screwed into the motor casing through the bulkhead in the zipper-less coupler and gets held in place by an eye nut and lock nut on the bulkhead.

### C.3. Upper Body Tube

The upper body tube is comprised of a 52-inch-long section of 5.15-inch diameter G12 fiberglass tube sourced from Madcow Rocketry. This section holds the nose cone and the recovery system which is made up of the main 60-inch parachute in the front end, a piston, the electronics bay in the middle, and the 24-inch drogue parachute in the back end. The nose cone is attached to top of the upper body tube with shear pins and a friction fit, making sure it will only come off when the appropriate ejection charges blow. The piston, which is approximately 25 inches from the top of the tube, is a shortened coupler with a bulkhead glued to its end which is used to facilitate the deployment of the main parachute. The bulkhead in the piston has a small hole for the shock cord to run through, allowing for a seamless connection between the nose cone, main parachute, and Ebay. The Ebay, which starts 31 inches from the top of the upper body tube and ends after 8 inches, is screwed into the upper body tube and acts as an anchor for the recovery system.

### C.4. Zipper-less coupler

The zipper-less coupler is a 12-inch coupler located above the motor that serves to prevent the shock cords of the drogue parachute from zippering the upper body tube during deployment. It works by being glued to the lower body tube in a way to make it stick out 6 inches, so that the shock cord connections from the drogue parachute to the lower body tube would sit inside the upper body tube when the rocket is assembled. The zipper-less coupler will be experiencing three main forces, the thrust of the motor pushing up during ascent, the tension under the shock cord of the drogue parachute pulling up during descent, and the moment of the upper body tube to the lower body tube that is present during flight. To withstand these forces, the zipper-less coupler was cut from a G12 Fiberglass tube and had a 1/4" G-10 fiberglass bulkhead attached to the top end of the coupler using epoxy and Cab-O-Sil. A 3/8" hole was drilled through the center of the bulkhead prior to installment to allow a zinc plated steel all-thread to be threaded through it for a connection to the motor casing. The zipper-less coupler was designed to be more than 2 calibers long to counter bending due to the large length to diameter ratio of the rocket.

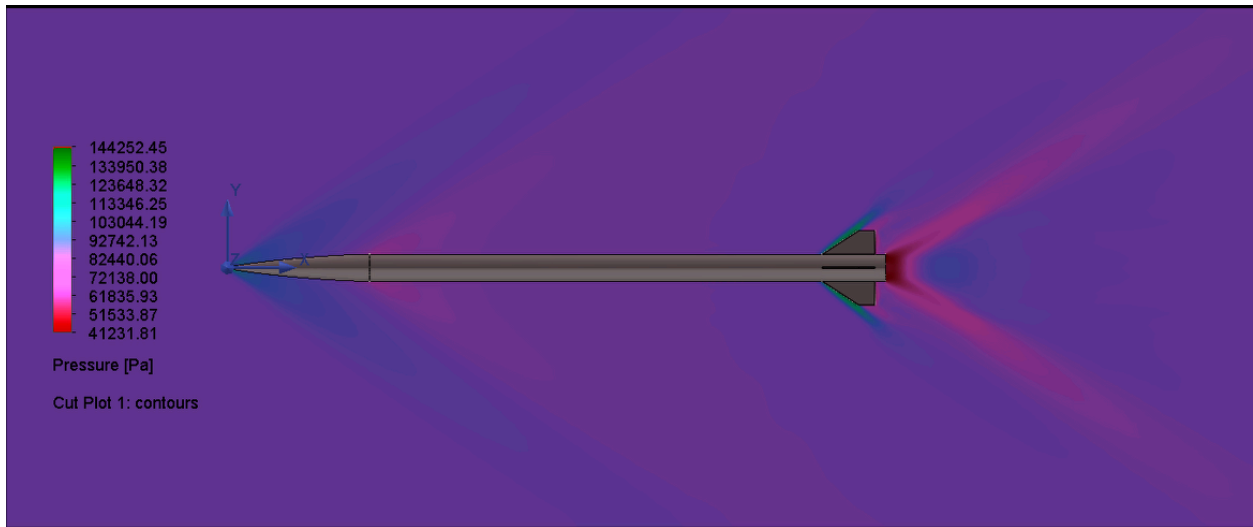
### C.6. Nose Cone

The nose cone geometry selected for use in Triton was the 5:1 Von Karman geometry. According to the International Research Journal of Engineering and Technology, Von Karman geometry consistently provides the lowest coefficient of drag across transonic and supersonic speeds. This will help ensure that the rocket remains as stable as possible during supersonic flight, as well as helping the rocket achieve the target apogee of 30,000ft. The nose cone used for Triton is manufactured by Wildman Rocketry and is made of filament wound Carbon Fiber with a metal tip to protect against aerodynamic heating at supersonic speeds.

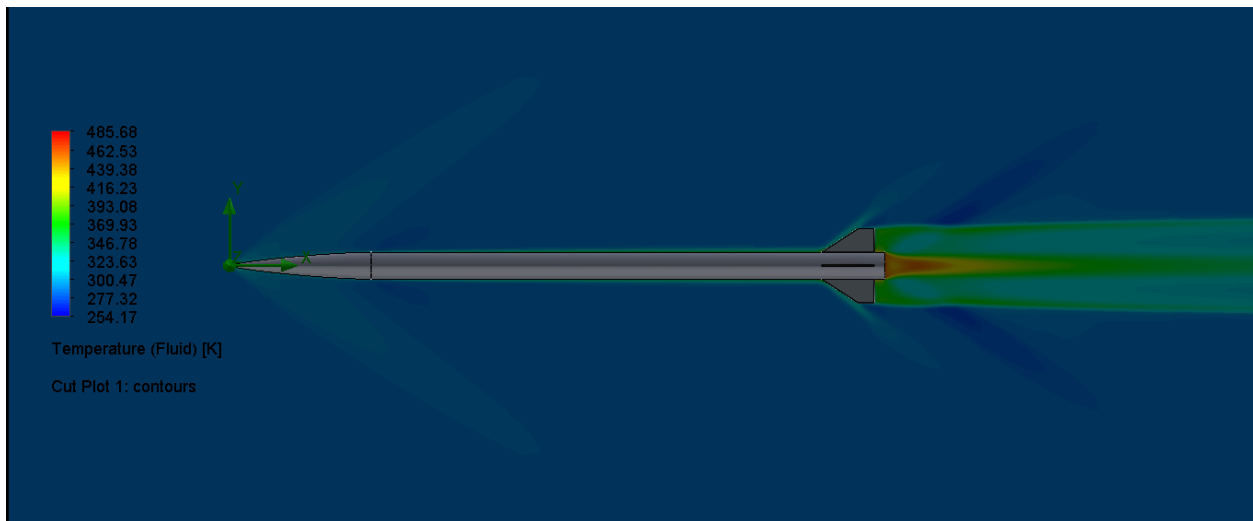
In order to ensure a suitable nosecone material, a CFD simulation was run in ANSYS Fluent to model the pressure and temperature on the nosecone throughout flight.  $T_0$  is defined as the temperature when a flow is isentropically brought to rest, or the maximum temperature given some flow Mach number. It is given by Equation 1 below, where M is the Mach Number, T is the static temperature, and  $\gamma$  is the ratio of specific heats.

$$T_0 = T \left( 1 + \frac{\gamma-1}{2} M^2 \right) \quad \text{Equation (1)}$$

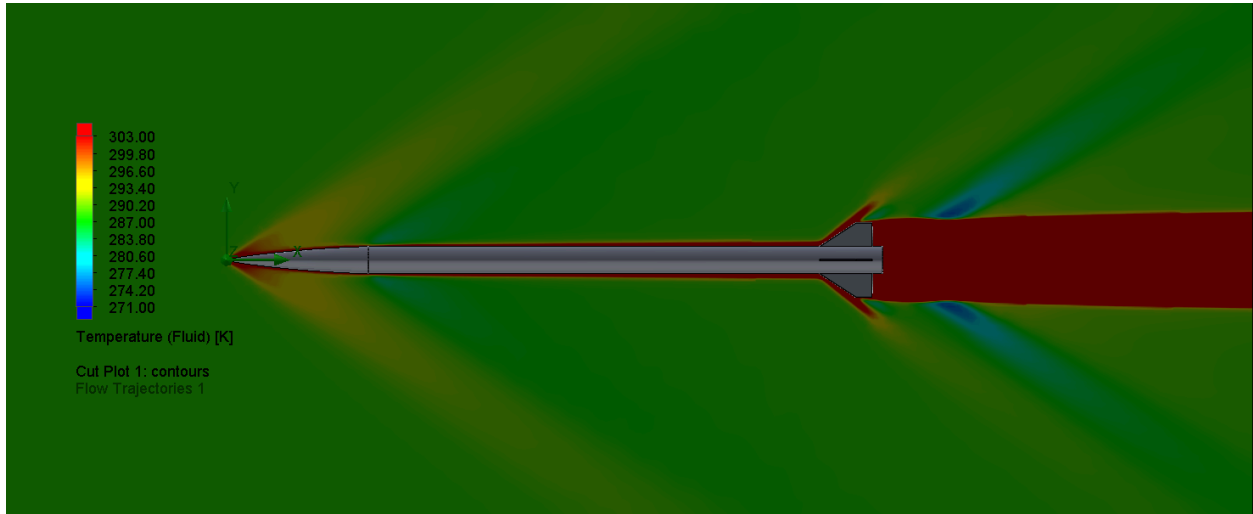
Simulated flight velocity and altitude data from OpenRocket are inputs for the model. Static temperature is calculated from the altitude value at each timestep from the Standard Atmosphere model. Static temperature and velocity are then used to calculate Mach Number and  $T_0$ .



**Figure 6: Pressure contours from computational fluid dynamical analysis of Triton at maximum velocity (Mach 1.81)**

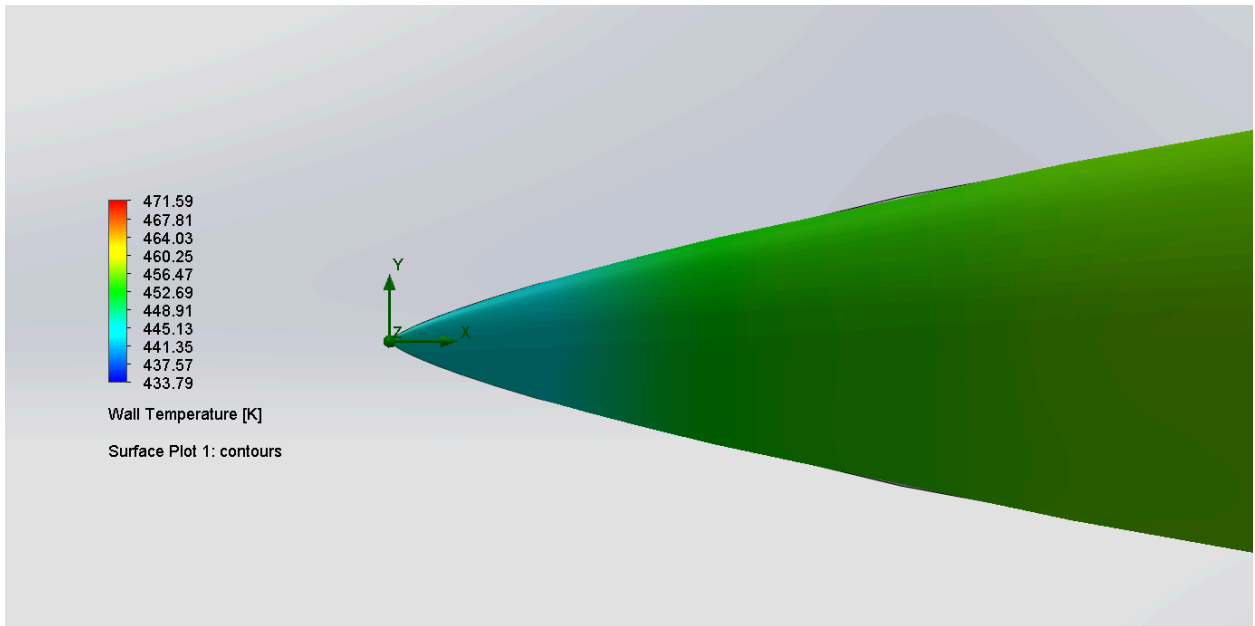


**Figure 7: Temperature contours from computational fluid dynamical analysis of Triton at maximum velocity (Mach 1.81)**



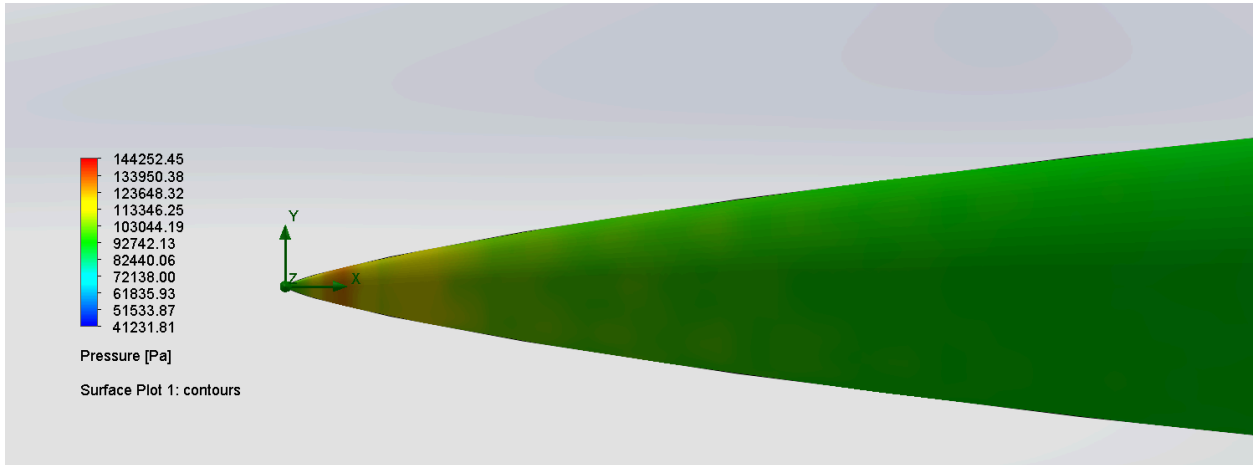
**Figure 8: Temperature contours with modified range**

As seen above, CFD analysis was performed on the whole rocket body at the maximum velocity achieved by the rocket during flight, Mach 1.81. The pressure contours show us expected results, such as oblique shocks near the nose and the fins. The max pressure is exerted on the fins at 144,252 Pa. The temperature contours in Figure 7 also show us oblique shocks as expected. Figure 8 was changed the color scale so that the temperature across the shocks is more visible.



**Figure 9: The wall temperature around the nosecone of Triton at Mach 1.81**

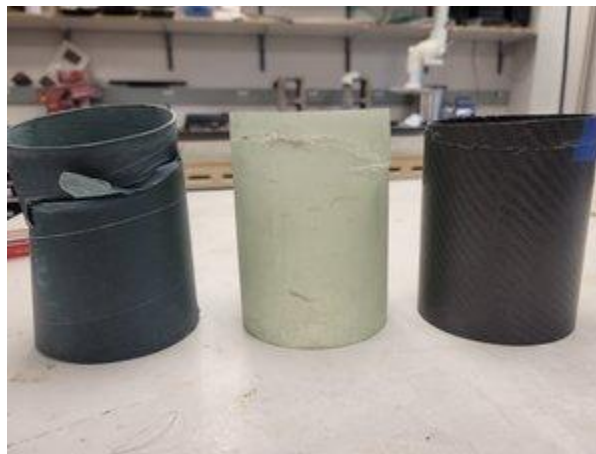
Figure 9 shows an estimate of the wall temperature using the adiabatic assumption for model simplifications. The CFD analysis shows the nosecone temperature of Triton at its maximum speed at around 445 K. This is lower than the stagnation temperature, but also consistent with the idea that the temperature at the stagnation point would be the maximum temperature. While 445 K is certainly not low, as mentioned earlier, most of the heat energy will not be transferred to the airframe.



**Figure 10: Pressure at the tip of the nosecone at Mach 1.81**

Finally, the CFD study shows that the maximum static pressure that the nosecone will experience during flight is around 133950 Pa, which occurs at the surface of the aluminum nosecone tip. This is much lower than the failure pressure of aluminum. The static pressure around the rest of the nosecone is around 9200 Pa, which is also much lower than the failure pressure of fiberglass.

LRA tested various materials such as Blue Tube, fiberglass, and carbon fiber on an Instron machine, and found that fiberglass failed at 14,000 lbs of force. Therefore, there is very little cause for concern that the fiberglass nosecone will shred during flight.

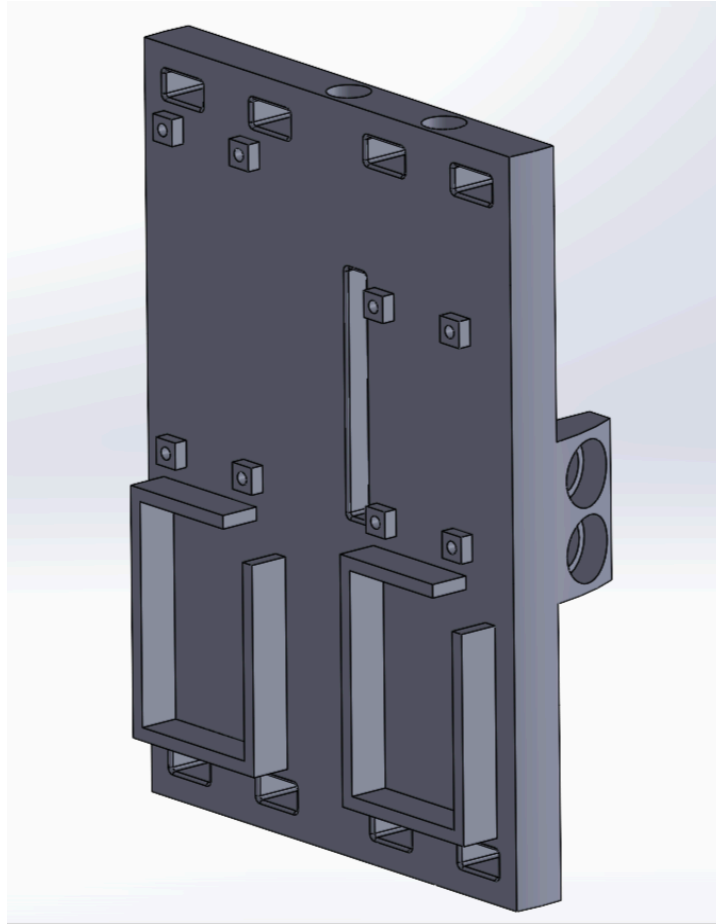


**Figure 11: Blue Tube, fiberglass, and carbon fiber body tubes after being tested on an Instron machine**

### C.7. Electronics Bays

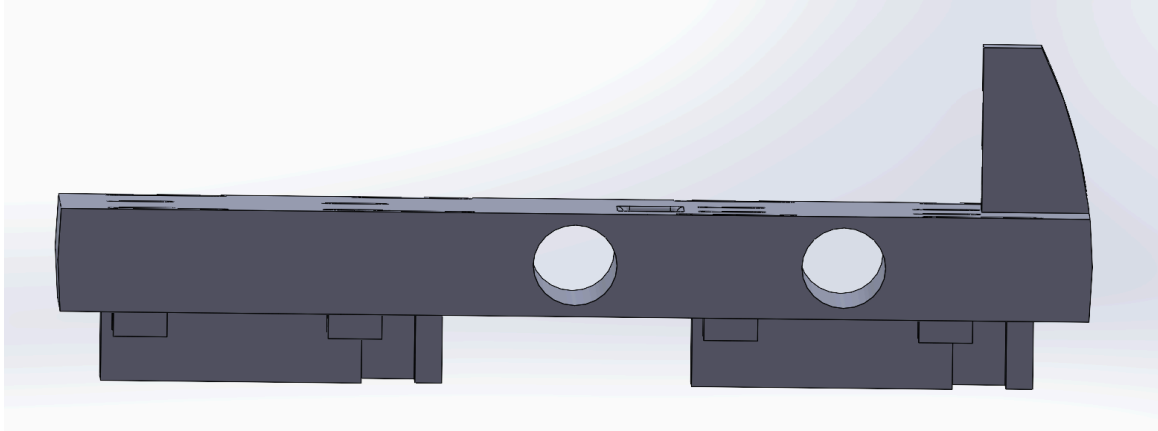
The electronics bay, which houses the flight computers, is in the upper tube. The bay itself is a red fiberglass tube, 8 inches in length. The tube is enclosed on each side with fiberglass bulkheads, connected by two 3/8-inch all-thread rods. Each bulkhead is made of two G10 fiberglass sheets epoxied together. The outer piece is cut to the exact measurement of the inner diameter of the main body tube, and the inner bulkhead is the exact measurement of the inner diameter of the electronics bay tube. An eye bolt screwed onto the all-thread on either side of the bulkheads holds them together against the tube. This ensures that the avionics are protected from the ejection

charges that deploy the recovery system. The electronics bay is held in position using countersunk screws, which are drilled through the main body tube and bay.



**Figure 12: SolidWorks illustration of the sled**

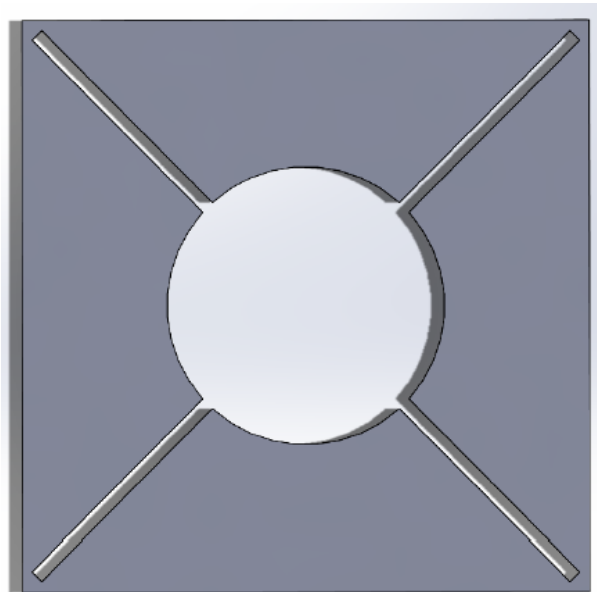
Inside the bay, a sled made of 3D-printed PETG houses the electronics for Triton. Two all-threads run through the center of the bay and are threaded through the center of the sled to prevent rotation during flight. The sled is designed to house two flight computers (an Altus Metrum TeleMega and an Altus Metrum EasyMega), two manual key switches, and two official Altus Metrum lipo batteries. Each flight computer will be connected to one switch and one battery for redundancy in case of the failure of a component in the primary flight computer (TeleMega). The computers will be screwed into the sled, while the batteries will be held in place by their housing walls and zip ties. The electronics sled is shown in figures 12 and 13.



**Figure 13: Top view of sled**

*C.8. Fins*

There are four fins on Triton mounted 90 degrees apart from each other. The fins are made from 1/4" G-10 fiberglass, and the fins are laid up tip-to-tip with carbon fiber to create a stronger attachment to the body tubes. The fins have a semispan of 7 inches, with a root chord of 10 inches, and a tip chord of 3 inches. The leading edge of both the fins is swept to 60 degrees, as our research has shown that the 60-degree leading edge sweep is best for supersonic flights. The fin leading and trailing edges were sanded to produce an "airfoiled" geometry. The sharper edges reduce supersonic shocks and transonic instability of the vehicle. G-10 fiberglass was selected due to its high strength and stiffness<sup>6</sup>, which was derived from LRA heritage data<sup>4</sup>.



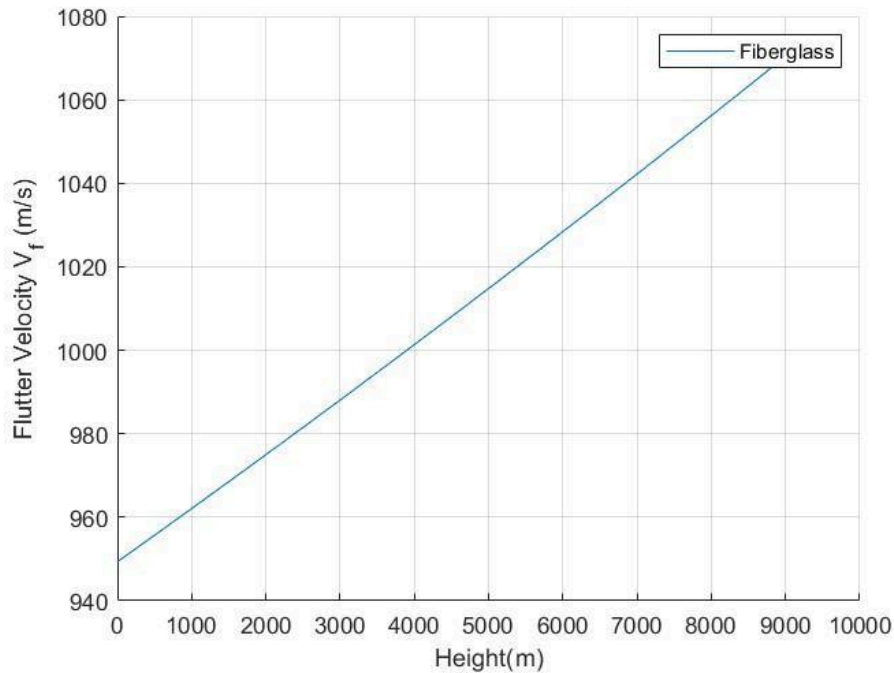
**Figure 14: Fin slot alignment tool**

To precisely attach the fins – especially important for supersonic flights – a custom fin jig and stand were designed and manufactured to ensure proper alignment. The fin jig was constructed from 1/4" plywood and was machined in house.

The maximum total pressure is 20.92 psi. The maximum shear stress is just 0.30 psi, demonstrating that shearing of the fin is highly unlikely if the fin is oriented correctly on the rocket body.

A Matlab code was written to determine the fin flutter velocity ( $V_f$ ) at a given height during the flight.  $V_f$  is defined as the velocity at which the fins of the rocket experience heavy oscillations and eventually failure of fin medium. It is given by Equation 2 below, where  $a$  is the speed of sound,  $G$  is shear modulus,  $AR$  is the aspect ratio of the fin,  $P$  is pressure,  $\lambda$  is the taper ratio,  $t$  is the thickness of the fin, and  $c$  is the root chord length:

$$V_f = a \sqrt{\frac{\frac{G}{1.337AR^3P(\lambda+1)}}{2(AR+2)\left(\frac{t}{c}\right)^3}} \quad (2)$$



**Figure 15: Matlab Plot of Fin Flutter**

The shear modulus of G10 fiberglass was found to be  $2.7 \times 10^6$  psi (dielectric manufacturing). Using the data taken from OpenRocket, the max velocity of the sustainer stage is expected to be 2095 ft/s at 9598.9 feet altitude. At this altitude, the sustainer stage fins are expected to experience fin flutter at 3243.83 ft/s, giving the fins a safety factor of 1.55. The above calculation uses conservative assumptions too, as it assumes the fins are made from fiberglass, when they have a carbon fiber tip-to-tip finish.

### C.9. Centering Rings

The booster centering rings were made from  $\frac{1}{4}$ " plywood, which was manufactured in house. The selection of plywood was due to the fact that the centering rings do not experience any axial load during the launch as they are just connected to the lower body tube and not the motor casing as they are only intended to keep the motor straight and not support any force. There are four rings attached to the lower body tube, one two inches, one six inches and one 11 inches, and one 42 inches from the bottom of the rocket. The outer surfaces of the ring were fixed to the lower body tube with Cab-O-Sil in order to prevent their displacement during launch and keep the motor straight.

### C.9. Bulkheads

A total of five bulkheads were used in manufacturing Triton. All five bulkheads are made of  $\frac{1}{4}$ " G-10 fiberglass. One bulkhead is placed at the zipper-less coupler to serve as attachment points for the drogue recovery

system. Two bulkheads are used in the avionics bay, serving as platforms on which to attach shock cords and ejection charges. These two bulkheads also have smaller interior bulkheads also made from 1/8" G-10 to ensure a smooth, tight connection to the avionics bay. Another bulkhead is used to make the piston. The final bulkhead is used in the nose cone as an endcap to the payload bay.

#### C.10. Retention System

The retention system in place for Triton is a commercial 98mm motor top retainer made from anodized aluminum. The retainer has a 3/8" threading that a stainless steel all-thread will be screwed into. The other end of the all-thread will be inserted through the top of the zipper-less coupler G10 bulkhead, attached on the other side with an eye nut and lock nut. A small eye nut will be attached to the bulkhead of the zipper-less coupler and a piece of Kevlar will be connecting the small eye nut to the all-thread so that the all-thread does not unscrew itself from the motor top retainer. This will ensure the motor stays attached to the rocket after burnout, as well as acting as an anchor for the recovery system after drogue deployment.

#### C.11. Rail Buttons

Due to the weight of the rocket – 66.5 lbs. – a traditional rail-button method will not suffice to support the weight of the rocket on the launch rail. Therefore, a set of 3 linear rail buttons of the standard 1515 size will be used to attach to the rocket. To ensure that the rail buttons were perfectly aligned, a string was attached to the top rail button and a weight was added to the end of the string so that gravity held the string in a straight line and the marks for the bottom rail button could be added. Screws and epoxy were used as an attachment to bond the rail button to the airframe, and the screws will be cut as to not screw into the motor.

#### C.12. Test Flights

A test flight was performed on March 23<sup>rd</sup>, 2024 at Seymour Texas. A Cesaroni N-2501 was used as the booster and the launch was successful with the rocket reaching an altitude of ~20,000ft and a speed of Mach 1.45 before landing and having a successful recovery with minimal damage to the Rocket.

### II.D. Flight Computer Subsystem

The two flight computers' primary purposes are to control parachute deployment and to transmit the rocket's telemetry back to a ground station in real time. Each flight computer is mounted to a 3D printed sled, as mentioned previously in section C.7. Triton takes advantage of a redundant flight computer system so that both computers have apogee and main parachute deployment control.



**Figure 16: TeleMega Flight Computer**

The Altus Metrum TeleMega was selected as the primary flight computer. This computer has a built-in barometer, 3-axis accelerometer, magnetic sensor, GPS receiver, and 3 axis gyroscope to allow for accurate flight monitoring and automatic stage-of-flight determination. In addition, it includes a 70cm band radio transmitter for active telemetry downlink, allowing for easy recovery as it transmits the known GPS position until line of sight is lost with our handheld receiver (Yagi antenna). For the secondary flight computer, an Altus Metrum EasyMega will also be utilized. It has all the same capabilities as the TeleMega, without GPS or radio telemetry capabilities. Each flight computer utilizes a separate official Altus Metrum lipo battery.



Figure 17: EasyMega Flight Computer

## II.E. Recovery Subsystem

Polaris' recovery system utilizes dual deployment recovery. There are two parachutes - drogue, and main. At stage apogee, the flight altimeters ignite a black powder charge, deploying the drogue parachute. The drogue lowers the descent velocity allowing for less deceleration when the main parachute deploys. When the launch vehicle reaches 600 feet altitude, the main charge will ignite, pushing out the main parachute with the assistance of a piston. A pilot chute will first deploy, which will open the chute bag for the main chute and release the main.

### II.E.1. Avionics

An Altus Metrum Tele Mega will be used to control the ejection events for apogee drogue deployment and for main deployment at 600 feet AGL. An Altus Metrum Easy Mega will be used as backup flight computer with a 2 second delay for the apogee and 200-foot delay for the main parachute. We chose these flight computers as they have active altitude checking as well as their ability to check continuity after integration to allow for easier troubleshooting.

### II.E.2. Parachutes

Two primary parachutes are used in Polaris' recovery system. The first is the drogue, which is responsible for slowing the initial descent of the rocket, as well as controlling the descent trajectory. The descent rate for the drogue was chosen to be <100 ft/s to meet the requirements of the IREC rules. The preliminary sizing of a parachute can be done using the basic aerodynamic relationship for drag given in Eq. (3).

$$S = \frac{2mg}{v^2 C_d \rho} \quad (3)$$

where  $m$  is the mass,  $g$  is the acceleration due to gravity,  $v$  is the descent velocity,  $C_d$  is the coefficient of drag, and  $\rho$  is the density of air<sup>7</sup>.

Assuming the parachute is toroidal with a  $C_d$  of 2.2, the diameter of the drogue was found to be 24 inches for the sustainer. Final sizing was performed with OpenRocket as the algorithm it uses is believed to be quite accurate. Using OpenRocket the drogue was sized at 24 inches resulting in a descent velocity of 93.7 ft/s for the rocket.

The main parachute was also sized using OpenRocket. The size was based off the IREC rules stating that the descent velocity should not exceed 30 ft/s. Based on this value, the diameter of the main for the booster was chosen as a 60 in. Toroidal parachute resulting in a 28.6 ft/s ground hit velocity for the booster stage. velocity for the sustainer stage.

Lastly, 50 feet of 1/2" Kevlar shock cord will be used to connect the main, pilot and drogue parachutes to both the motor can and the payload bay. This was derived from a reasonable assumption that around five times the rocket's total length is an appropriate shock cord size.

In addition to the main chute and drogue chute, Triton will be equipped with a chute bag for the main chutes. The chute bag will have a 3-inch pilot chute attached to them to deploy the main parachute from the chute bag.

### II.E.3. Parachute Protection

A piston will be used for the main parachute in. This has a dual purpose, as it both protects the parachute from ejection gases, and more effectively pushes the parachute and shock cord out of the body tube. In addition, it should

have a much higher chance of protecting the parachutes, as it is very hard to improperly assemble this protection system. As mentioned, the main parachute is also protected by the recovery bag.

#### II.E.4. Ejection Charges

The nose cone and the upper body tube are connected at the coupler with eight 4-40 shear pins. The average peak load required to break all the shear pins is 202.67 lb<sup>s</sup>. Goex 4F black powder was used for separation of these two sections and to eject the recovery system. With a peak load safety factor of 2.6, the pressure required to exert this peak load is 26 psi. Using Eq. (4), the required black powder mass was calculated to be 4.6 grams. The housing for the ejection charge is made of 1/4" aluminum tubing, with epoxy filled in the bottom of the tube. The black powder is ignited with a firewire initiator e-match igniter. There are two ejection charges per stage: a primary and a backup. The backup ejection charge is set to fire 2 seconds after apogee, which will ensure that the rocket is still moving slow enough for safe separation. An additional 1.75-gram black powder charge will be connected between the upper and lower body tubes to release the drogue shoot. Additionally, there will be a second, backup black powder charge with 50% more black powder that will be ignited two seconds after the initial charges to ensure separation.

$$m = \frac{PV}{RT} \quad (4)$$

### II.E. Payload

#### Experimental Design

Triton's 8.8 lb. payload (Infrared Radiation Detection for Thermal Resistivity) utilizes an Infrared camera to collect data from 4 different material samples that emit different levels of infrared radiation intensity. The design consists of an infrared camera (and its breakout board), Raspberry Pi, and power bank. The main idea is to be able to collect readings of different materials within the payload bay and measure/test the thermal resistivity of different materials to conclude which acts as the best insulator. This data is then going to be streamed and stored on a Raspberry Pi, from where it will be retrieved, analyzed and turned into video footage.

Vent holes have been drilled into the body of the rocket to prevent pressure build up. This also allows for more of a change to the inside temperature of the rocket due to the atmospheric conditions, allowing us to measure infrared radiation intensity as if the materials were exposed to the outside. We have strategically placed the camera to be as far away from the material samples as possible to allow for the largest field of view, and thus the largest sample sizes, possible.

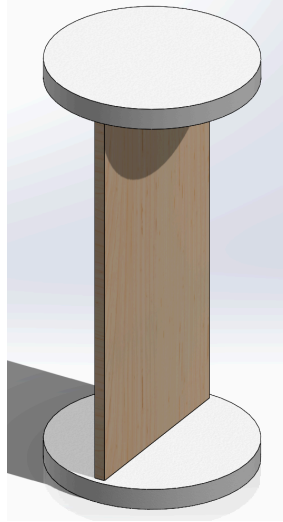
We have chosen four samples to add to our testbed. These include PLA filament, Styrofoam, aerogel insulation, and rubber. Our goal is to test the thermal resistivity of each of these materials. To have a uniform test environment, we are using 1x1-inch squares for all the materials and spacing them on our testbed. All these materials are exposed to the outside environment through the drill holes.



**Figure 18: Thermal Image from Payload**

*Housing, Subsystems (manufacturing and design):*

Figure 19 shows that the payload has a top and bottom plate that differ slightly with the bottom having two additional through holes to mount a U-Bolt holding the payload stationary, not allowing it to experience turbulent motion. We will also have holes cut out from the end plates for a tab slot design for the two side plates to be able to slide securing them in place. The final model of the payload will be made from 1018 carbon steel to help react to the force from impact due to the engine ignition and stage separation.



**Figure 19: Payload Cad**

Our initial prototype model was created with laser cut birch for the two side panels and 3D printed PLA filament for both endplates. Additionally, the end plates have a 0.5” semicircle cut out to help with integration to avoid some bolts in the payload bay. The same design with tab slots was used and mounting holes were later drilled to secure electronics into place. This option was chosen to garner a rough estimate of how the panels and integration would come together. Based on our testing we gathered that the materials selected were not able to adequately react to the force of impact as shown in figure 20 which led us to choosing a stronger material in steel.



**Figure 20: Payload bay**

*Assembly:*

The assembly began with the 3D printed PLA endplates. After getting a working model to fit inside the payload bay, we used our measurements to laser cut birch wood to create two distinct panels, one to house all the electronics and the camera and the other to hold up the material samples in front of the camera. Cases for the material samples were designed and 3D printed to securely fit into slits on the panel, holding the samples up. Our electronic components were screwed onto the second panel while the camera was positioned to look toward the materials through a cutout.

The two endplates and two assembled panels were then inserted into the payload bay one at a time, each piece fitting into the last to create our final assembled product. A portable power bank was slid behind the electronics panel and secured with tape and Velcro to power the Raspberry Pi throughout flight.

*Electronics:*

The system consists of a computer (Raspberry Pi 5), an infrared camera (FLIR Lepton), and a battery (USB power bank). The power bank powers the Pi and the Pi powers the camera breakout board, which has the camera connected to it. All payload electronics operate independently of flight control systems. The FLIR Lepton 3.1R is an excellent thermal camera, boasting a resolution of 160x120 pixels and a 119-degree diagonal field of view. It has a thermal sensitivity of 0.05K and is designed to capture long wave infrared (LWIR) ranging from 8 to 14  $\mu\text{m}$  in length. Testing at room temperature indicates that its absolute temperature sensing abilities are accurate to at least within 1 degree Celsius (at least at temperatures near room temperature). However, we are most interested in the relative changes in temperature—which the manufacturer promises we can see up to 0.05K.

*Software:*

A Python script automatically executes when the Pi is powered on, which infinitely loops until power is removed or the process is manually killed. All output from the script is piped into a log file to make identifying causes of failure easier. The Pi acts as a wireless access point to enable easy monitoring and troubleshooting in the field. During the flight, the camera repeatedly takes pictures and stores the raw output of the camera (integers saying hundredths of kelvin) in a directory, with each file being named based on the time it was taken. Around 4-5 pictures are taken every 5 seconds, with the time slightly varying due to occasional garbage frames; this is accounted for by naming each file with a timestamp.

After the flight, the raw data is transferred from the Pi to a PC, being converted to JPG files, and processed using a Python script we coded. This script consisted of several different sections with a final goal of creating a video to analyze the temperature changes in each of the materials over the course of the flight.

The first section was to trim excess frames. The Pi was active for large periods of time before and after the actual flight, so we excluded data captured while on the ground. There were also some instances of corrupted files within the thousands remaining, and we manually filtered those out to get a smooth video.

Next, we normalized each frame to account for outliers and make the resulting video smooth. This was necessary because in each frame, the temperature values were coded black to white relative to the other pixels/values in that frame. Future frames could have vastly different ranges, meaning the same value doesn't translate to the same temperature across different frames. Creating a standard range across all frames helped to solve this issue.

Finally, we stitched each resulting frame into a coherent video and were able to analyze the variations of infrared radiation throughout flight. Using specifically selected points in the frames, we were also able to draw up graphs that tracked the temperature changes for each material so we could associate numerical values with our video.

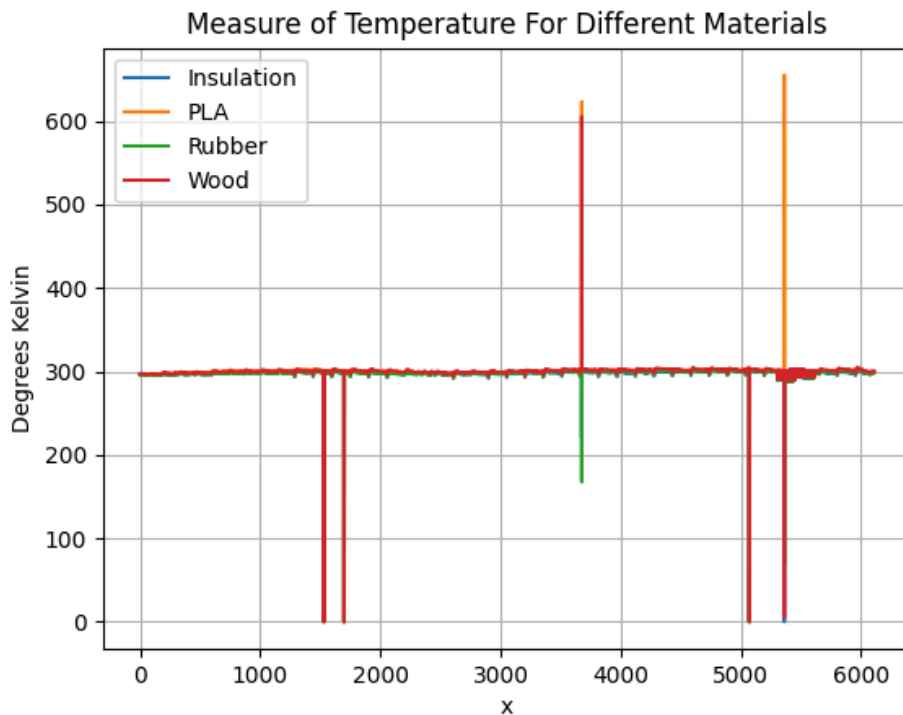


Figure 21: Original Temperature data

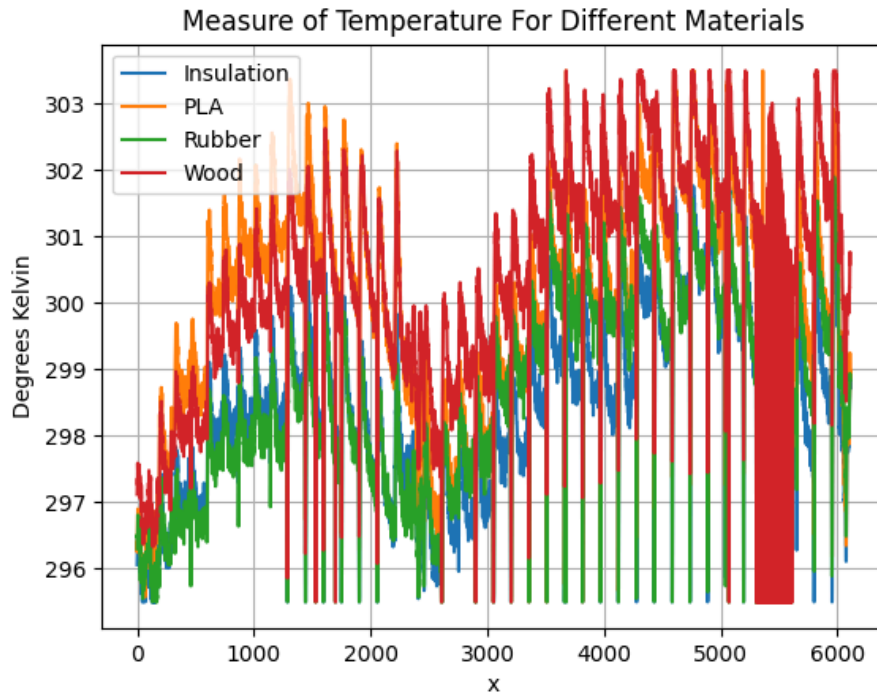
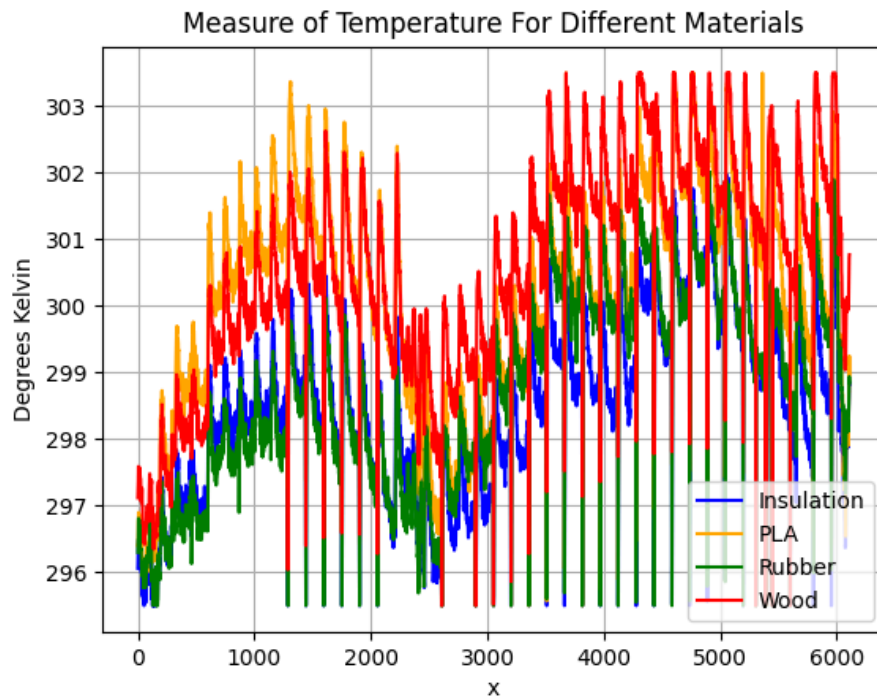


Figure 22: After Removing Outlier (can see variance a lot better)

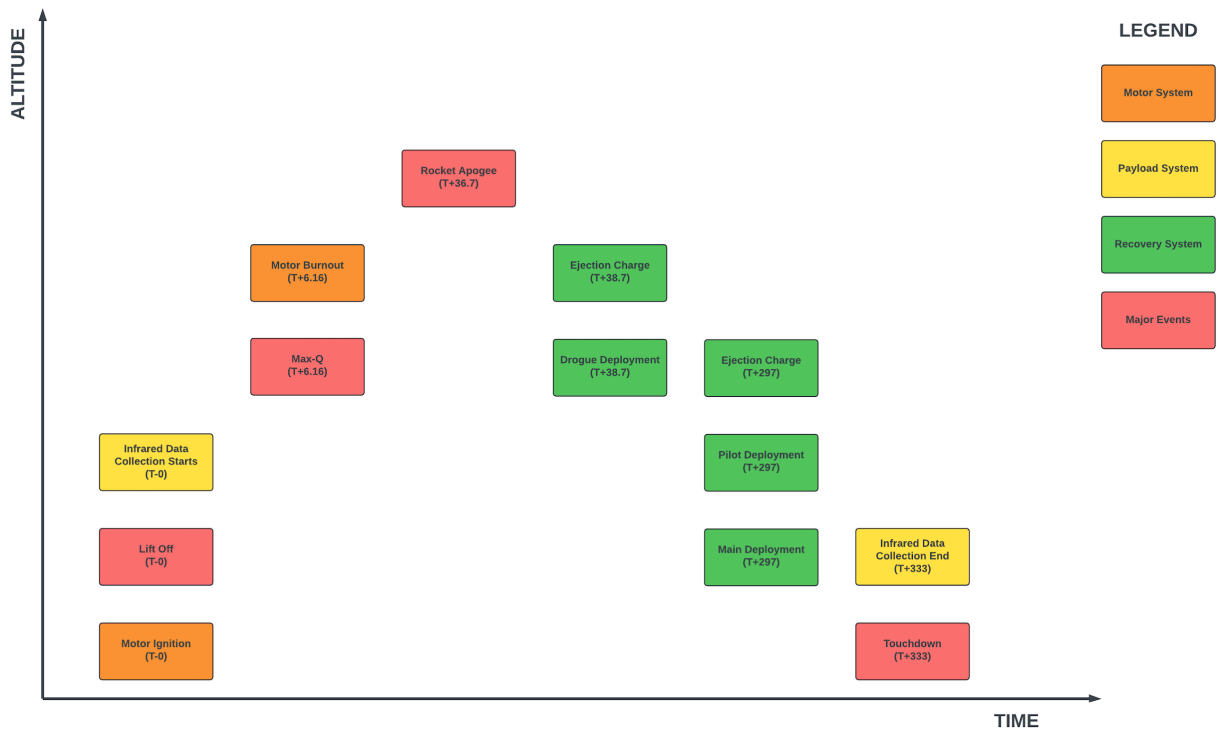


**Figure 23: After Normalizing data**

### III. Mission Concept of Operations Overview

At the 2024 Spaceport America Cup, the Longhorn Rocketry Association will launch the Triton rocket, carrying an 8.8 lb. payload to 30,000 feet. During ascent, the payload will collect data pertaining to the thermal effects of materials exposed to the atmosphere during supersonic flight.

To develop design requirements for Triton, a concept of operations (CONOPS) was developed to specify the various phases of the mission. Figure 24 shows this concept of operations, with altitude as the Y-axis and time as the X-axis. Figure 25 shows a visualization of the rocket throughout its flight path. The following subsections detail each mission phase. A full list of possible failures for each phase, along with corresponding mitigation approaches, will be included in Appendix D.



**Figure 24: Triton CONOPS Diagram**

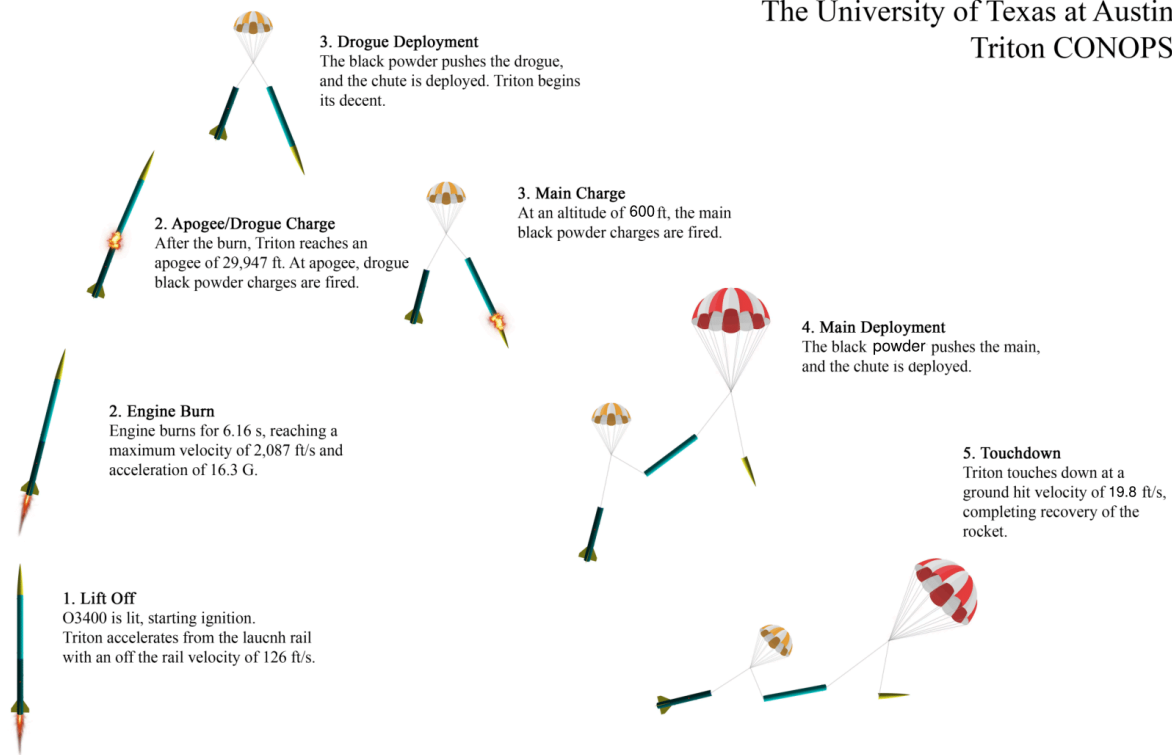


Figure 25: Triton Flight Profile Diagram

### III.A. Pre-Launch Setup

Pre-launch, the electronics sled will first be assembled, and all the components will be tested for battery voltage, and correct wiring. Then, the components will be turned off, and loaded into the electronics bay. The black powder charge wells will then be loaded with 2 grams of black powder and an electronic match each, including the interstage coupler charge. Next, the electronic match leads will be attached to the terminal blocks attached to the bulkheads on the electronics bay and the interstage coupler, and the second stage ignition line will be shorted. The electronics bays will then be set down on the ground, and after all personnel are 15 feet away from the bay, the electronics will be turned on to check for continuity. After continuity on all lines has been verified, the electronics bay will be turned off, and loaded into their respective body tubes.

All pistons, parachutes and shock cords will then be inserted into their respective bays, and mounting points. Each section of the rocket will then be shear pinned to ensure they do not separate until the flight computers give the signal to fire the recovery charges. The rocket will then be fully assembled to determine the total loaded weight, and center of mass to report to officials.

The rocket will then be taken to the pad. First, the launch area will be cleared of all non-necessary personnel, after which the rocket will be loaded horizontally on the rail. Once the rocket is secure, the rocket will then be raised vertical. The flight computers will then be armed, and continuity for the Telemega will be checked using the Teledongle receiver. If this is checked, then the team will continue. The motor will then have its igniter attached, after which the team will perform a final continuity test of the motor igniter. Once continuity and nominal behavior from the flight controllers is confirmed, the pad will be evacuated, and the launch vehicle will be ready for launch.

### III. B. Payload Mission

The payload will be loaded into the rocket during pre-launch set up. With an extended battery life, the payload will be able to record data for up to 3 hours after initial set up. This is enough time for the team to weigh the

payload at the pre-launch station, drive out to the pad, and launch the rocket. The payload will record data throughout the rocket's flight, completely internally (no payload piece will be ejected out). During descent, the payload will be ejected from the rocket's body along with the main parachute, as part of the nose cone. Once landed and the recovery team recovers the rocket, the payload will be disarmed, and the data pulled from the onboard computers. Should the recovery team not find the payload within the 3-hour time frame, the data will be saved to a hard drive before the payload loses power.

### III.C. Ignition

Ignition will only occur when all team members remotely monitor the flight computers report nominal operation. At motor ignition, the force of the motor starts to exert force on the thrust plate. This load will then be distributed to the airframe via the thrust plate. Also, three centering rings will ensure the motor tube stays in position throughout the flight.

### III.D. Liftoff

At liftoff, the flight computers will record an initial acceleration, and switch to flight mode. The launch rail the rocket is mounted on will ensure that the rocket maintains a straight trajectory until the rocket is sufficiently fast to maintain trajectory via passive stabilization. The rocket will continue to accelerate up to 127 feet per second when it clears the launch rail, with a stability margin of 2.06 at 19 feet AGL (T+0.32 s).

### III.E. Motor Burnout

The next section of the flight will encompass the remainder of the powered ascent, beginning once the rocket leaves the launch rail and ending once the motor burns out. Once ignited, the booster motor will continue to burn for 6.16 seconds. During this time, the rocket will continue to accelerate upwards, and will begin to decelerate once the motor burns out. As this is the main portion of the powered ascent, there is substantial risk to the rocket during this phase - for example, this section of the flight will contain the moment of maximum dynamic pressure, or Max Q.

### III.H. Max-Q

Throughout the rocket's ascent, its motion will be resisted by dynamic pressure, given by Eq. (5).

$$Q = \frac{1}{2}\rho v^2 = \frac{1}{2}\gamma P_s M^2 \quad (5)$$

where  $\rho$  is the density of the air around the rocket,  $v$  is the rocket's wind speed,  $\gamma$  is the specific heat ratio of air,  $P_s$  is the static pressure and  $M$  is the Mach number. The second form of the dynamic pressure equation assumes an ideal gas, which air can be approximated to for atmospheric conditions and Mach numbers under 5.

Using simulation data obtained from OpenRocket simulation, the maximum velocity of 2114 feet per second is obtained at 6194 feet altitude, which is at 10790 feet of elevation above sea level. This occurs approximately 5.12 seconds after liftoff. Using the 1976 standard atmospheric model, this corresponds to a local pressure of 9.8 psi and air density of 0.055 lb/ft<sup>3</sup>. Using equation (4) above, one can obtain the dynamic pressure at this point. Assuming that the point of maximum velocity is maximum dynamic pressure, this gives a max dynamic pressure of 26.6 psi.

### III.I. Drogue Parachute Deployments

Triton is expected to reach apogee, the highest altitude in its flight path, around 39.5 seconds after ignition. Once the rocket reaches apogee, the main on-board altimeter, located in the electronics bays, will send an electrical charge through an igniter to a carbon fiber ejection charge tube. This will ignite the black powder inside of the tube, pressurizing the parachute bay and separating the parachute bay and nosecone/staging coupler from the motor can at the coupler junction by breaking the 4-40 nylon shear pins. For the sake of redundancy, a secondary altimeter will

ignite a secondary black powder charge two seconds after apogee to ensure separation. A Kevlar shock cord will connect the two sections to the parachutes, which will all be ejected at once. The drogue parachute will fully deploy upon separation to slow the descent of the rocket to roughly 91.5 feet per second, in addition to keeping the motor can section above the parachute/payload bays and away from the main parachute assembly. The high drogue descent rate is necessary to ensure the rocket does not drift too far into the desert. The main parachute assembly, which includes the pilot parachute, will not deploy but remain inside the upper body tube.

Should the two sections of the rocket fail to separate the first time, the secondary altimeter should force separation. However, if both altimeters fail, the rocket will continue to travel along its ballistic trajectory, ending with its inevitable destruction when it hits the ground. A successful black powder ignition would separate the sections, so this failure mode would most likely occur if the altimeters were wired incorrectly - however, the pre-flight checklist (in Appendix E) includes altimeter wiring confirmation steps to prevent this. Alternatively, the Kevlar cord could become tangled, causing issues for later chute deployment. As such, the risk of mission failure is high, but mitigatable, during this phase of the flight.

### **III.J. Main Parachute Deployments**

At 600 ft AGL for both stages, the main piston will be ejected, allowing the pilot parachute to unfurl from the main parachute assembly. This will mark the beginning of the Main Parachute Deployment phase of the flight, with the end denoted by the unfurling of the main parachute.

During Triton's descent, the main parachute and a pilot parachute will be contained within the rocket. Once the piston is ejected by the black powder and releases the chute bag, the pilot chute will unfurl and provide tension to one end of the main parachute bag. This tension will pull the main parachute out of the bag, allowing the main parachute to fully deploy.

Main parachute deployment will exert significant decelerating forces on Triton. For example, the jolt from the force of deployment could cause the Kevlar cord to tear through the airframe, causing considerable damage. This force could also cause the quick links that attach the cord to the body of the rocket to break, leading to a detached section of the rocket to fall from a bit under 800 feet. To mitigate these risks, the quick links and Kevlar cord have been sized to withstand the expected deceleration loads with ample safety factors.

### **III.K. Touchdown**

With the successful deployment of the main parachute assembly, Triton will decelerate until it is falling at a velocity of around 21.8 ft/s. This is where the Touchdown phase of the flight shall begin. Under a minute later, the lower section will land, followed by the upper section and the main parachute assembly. The UT ground crew will monitor the rocket's location visually and electronically to ensure a speedy recovery. This phase, along with the entirety of the flight, shall end once the UT ground crew ensures that the rocket poses no danger to itself or surrounding personnel, and is safely retrieved.

There is some risk involved with the rocket landing, as it is possible that the forces involved with impacting the ground could damage the rocket. Perhaps more importantly though, the falling rocket could strike and damage property, or even worse, a person. To mitigate this possibility, the launch rail will be angled at 85 degrees to the horizon away from the launch zone, causing the rocket to fly away from personnel and property.

## IV. Conclusion

The IREC project has pushed the LRA to tackle the challenges of large, multifaceted engineering projects as the organization continues to transition from a hobbyist culture to a fully-fledged, project-oriented engineering program. Building on the mistakes of the last competition entry, the IREC team has undergone many changes over the year. The competition forced team members to face engineering problems and learn how to run and manage a large, interconnected project successfully. Members have gained a lot of technical knowledge and valuable management and organizational experience. These kinds of projects emphasize the importance of experience beyond the classroom as the solutions to real-world problems can't always be looked up in textbooks.

These challenges will be invaluable as the club continues to increase its ambition and reach for more advanced challenges. While the integration of all the Triton subsystems was complicated this year, an SRAD rocket will be even more sophisticated and will require a very strong grounding in systems engineering and project management. Additionally, the efficient transfer of information from year to year, between officers, and to all team members is constantly being improved and worked on as the club tries to build and improve. All these skills and practices will serve members well in whatever field they pursue, whether it is the launch vehicle, aerospace, or any other industry.

### IV.A. Lessons Learned – Management

LRA benefitted greatly from the management practices passed down by previous officers although there were still many challenges to address during the project. One of the most difficult aspects was dealing with frequent changes to project timelines as designs went through several iterations and issues were discovered. Almost all delays and setbacks were avoidable with the benefit of hindsight. One of the issues faced by technical student organizations is that of administrative and management duties, many leads and members were less excited by the non-technical elements of the project which led to poor recruitment, rushed design, and a general problem of maintaining strict deadlines. Time was also spent on experiments and side projects that turned out to be unnecessary or not useful for the final rocket, further slowing down progress.

Next year's project will be approached with a better understanding of the inter-reliance of teams working on a complex project. The project will be better planned out from the beginning with clearer milestones and objectives so that the organization doesn't coast or lose momentum during the year. Better engagement on Teams along with increased usage of CAD will help ensure that all team members are kept updated on project plans and changes. Better project management tools such as Agantty will improve the efficiency and visualization of project tasks and milestones.

Finally, one of the biggest management changes occurring in LRA is the streamlining of teams into larger project groups. Many members could agree that there was a lack of unity amongst LRA members, largely because there were so many different teams with different goals. By combining teams into larger project groups with an overarching goal, a greater sense of teamwork and comradery could be achieved since goals were more similar across teams. For the 2024-2025 school year, LRA will be divided into 3 different project groups: the Spaceport Competition Group, the Advanced Research Group, and the Hybrid Engine Group.

### IV.B. Lessons Learned – Technical

The Triton rocket borrowed heavily from design elements used in both the Polaris series of rockets (previous year's IREC entries), and the dozens of certification rockets built in the past. At the beginning of the project, since the LRA has a history in the 10,000 and 30,000 COTS category of IREC, along with previous experience in the Polaris series of rockets, it appeared that the technical challenges this year would be minimal. While much of the design was technically like projects from the past, many lessons were learned regarding the complexity of multidisciplinary projects containing several independent but related subsystems.

Firstly, unlike certification rockets, Triton is not meant just to launch and land, but also to carry scientific payload and more sophisticated flight electronics. The integration of all these components proved to be more complicated than initially thought and led to several roadblocks during the development of the rocket. This was the main motivation for the creation of an officer position to specifically oversee this element of the project.

In addition, the planning and scheduling of three separate projects, the airframe, flight computer and payload, was difficult to coordinate. Having all three systems ready for testing and launch was challenging as they each had their own technical and manufacturing issues to overcome. This is part of a larger problem the LRA is trying to solve to keep all the five permanent technical teams, propulsion, launch vehicle, test & launch operations, payload,

and electronics, working in tandem instead of separately. Teams were given the freedom to work independently for much of the year, which only created problems at the integration and testing phase of the project as leads had differing ideas about how their components were supposed to connect. This led to the creation of a much more involved timeline showing the development of all subsystems as part of the overall project as opposed to each group working independently.

Secondly, a large amount of time and money was wasted on purchasing supplies without exact dimensions or quality assurance which led to problems in manufacturing and component integration. Many high-powered rocketry suppliers don't give exact product dimensions online and mandrels, nose cones, and other equipment were ordered incorrectly as a result. These kinds of problems can be solved by doing more research when ordering and by calling suppliers and manufacturers for product specifications before ordering, something that wasn't considered this year, but which will be adhered to going forward.

Lastly, the hybrid engine project sucked up a large amount of time and resources from the club which will be beneficial in the long run. The IREC project didn't always get the emphasis it deserved but the hope is that a successful propulsion system can be developed by the end of Spring 2025 so that the LRA can compete in the SRAD category of IREC in 2026.

#### **IV.C. Knowledge Transfer and Transition**

This year was complicated in knowledge transfer, both from previous members and between different technical teams. Much knowledge was lost with graduating seniors from the previous year as well as leads who left the org over the summer.

Additionally, any important team members were lost to internships and co-ops, complicating the design process and the project. Several key officers left in the Spring, creating confusion as new officers assumed positions halfway through the project, having to deal with the learning curve of the position while also keeping the project on schedule. This made it difficult to keep track of what had been done or not done and what was left to accomplish. While these problems are a reality for student organizations, the LRA is trying to find better ways to handle abrupt changes during the year by having more members who are involved at a high level within each team so there can be smoother transitions in the future.

Also, as mentioned previously, the communication between sub-teams was sometimes less than desirable which led to very stressful attempts at component integration and many redesigns of system interfaces. The large number of teams within LRA as well as the wide spread of goals effectively siloed many teams into their own groups, creating very limited communication between teams. As a result, many members only knew the other members in their own team and had little knowledge of other teams' projects.

Looking towards the future, the structural changes of LRA aim to create a more unified organization with each project group looking towards a certain project goal. The hope is to help everyone in LRA feel valued as a critical member in a mission, whilst learning the technical and team skills to make them a better engineer.

## Appendix

### A. System Weights, Measures, and Performance Data

**Table 1:** Triton Launch Conditions

White Sands, New Mexico	Spaceport America
Latitude	33°N
Longitude	107°W
Altitude	4596 ft
Launch Rail	17 ft

**Table 2:** Triton Flight Trajectory Properties

Dynamics	
Expected Altitude	30,975 ft
Thrust-to-Weight Ratio (Lift-off)	11.5:1
Maximum Velocity	2095 ft/s
Center of Pressure	95.08 in
Center of Gravity (Lift-off)	80.29 in
Static Stability Margin	2.87
Drogue Deployment Altitude	Apogee
Drogue Descent Rate	93.7 ft/s
Main Deployment Altitude	600 ft
Main Descent Rate	28.6 ft/s
Ground Hit Velocity	23 ft/s
Maximum Mach Number	1.86

**Table 3:** Triton Commercial Engine Properties

Engine	CTI O3400-IM
Type	Solid
Weight	37.05 lbs.
Average Thrust	3416.7 N
Maximum Thrust	4750.3 N
Total Impulse	21062.2 Ns

**Table 4:** Triton Structural Properties

Structures	
Material	G12 Fiberglass
Total Length	125 in
Outer Diameter	5.15 in
Inner Diameter	5.0 in
Weight (Lift-off)	66.5 lbs.
Weight (Aero-Structure)	29.45 lbs.

## **B. Hazard Analysis**

### *B.1. Rocket Motor*

Sufficient care will be taken when handling, transporting, and storing the APCP propellant to prevent any potential hazards. The propellant will be kept away from any source of heat, or ignition in a cool dry place. When handling the propellant during assembly of the engine, safety goggles will be worn, and care will be taken to avoid contact with the APCP to avoid any potential skin irritation. Furthermore, the igniter and any other source of heat or ignition will be kept away from the engine both during and after assembly. Only when the rocket is on the pad will the igniter be placed inside the engine.

### *B.2. Black Powder*

The handling and storage recommendations provided in the MSDS by the manufacturer of the black powder we will be using, GOEX, will be followed. As standard for any explosive, the powder will be stored in a cool dry place away from any source of ignition. The black powder will also be stored away from other combustibles and care will be taken to avoid any electrostatic charges. Furthermore, any sudden shocks to the storage containers will be avoided. When handling the black powder, safety goggles and gloves will be worn. Electrostatic charges will be avoided by grounding igniters and all other handling tools.

### C. Risk Analysis Matrix

Team 99 – Univ. of Texas		Triton		5/09/2024	
Stage of Flight	Hazard	Possible Causes	Risk of Mishap & Rationale	Mitigation Approach	Risk of Injury after Mitigation
Pre-Launch Assembly	Recovery charge ignites prematurely; risk to personnel	Static charge results in a current running through the ematch	Low; The probability of a current strong enough to set off the ematches is extremely low	Have all circuits with energetics disconnected until the rocket is vertical	High
	Motor ignites or otherwise burns during assembly or packing into rocket; significant risk to personnel & other teams				
Pre-Launch Pad Operations	Rocket falls off rail during pad operations; risk to pad personnel	Structural failure in the rail buttons	Medium; Primary danger comes from the weight of the full rocket (100+ lbs.) and danger to pad personnel	3 total rail buttons will be used, and all rail buttons will feature structural anchors on the interior of the airframe where they attach with a through-the-wall metal backing	Low
		Improper procedures during mounting of rocket onto rail		Proper procedures will be stressed to avoid overly torquing the rail buttons or inducing similar adverse stresses	
	Recovery system deploys prematurely; risk to pad personnel	Static charge results in a current running through the ematch	Low; The probability of a current strong enough to set off the ematches is extremely low	Have all circuits with energetics disconnected until the rocket is vertical	High
	Motor ignites prematurely; risk to pad personnel				
Liftoff	Motor fails to ignite	Improper installation of igniter	Medium; Igniters used on motors of this size have been known to fail	Igniter installation will be observed by other pad personnel to ensure proper procedures are followed	Low
		Igniter is faulty or otherwise fails due to defect		Backup igniters will be available on site	
		Igniter has a faulty		Connections will be checked as an	

		connection to the launch circuit		item of the launch checklist and continuity tested through the launch circuit before leaving the pad area	
A motor CATO or other significant structural failure occurs during boost; injuries to people on ground possible	Cracks in the propellant grain	Medium; Motor CATOs have happened to LRA in the past - albeit sparingly - with one case being on a 75 mm motor several years ago	All propellant grains will be inspected before assembly into the motor casing/liner	Low	
	Gaps between propellant grains, motor liner, or the nozzle / endcap				
	Motor end closures fail to hold				
	Motor casing unable to contain normal pressure				
	Motor casing unable to contain normal pressure				
Off-nominal trajectory off the launch rail; risk of rocket hitting	Failure of the rail buttons as the rocket accelerates	Low	3 rail buttons will be used on the rocket, theoretically	Low	

	people or objects on the ground	along the launch rail		allowing a limited redundancy should one fail The rail buttons are attached to fiberglass block anchor points attached to the interior of the airframe, with a through-the-wall metal backing securing the button	
Apogee & Recovery Deployment	Drogue parachute(s) fail to deploy	Flight computer fails to deploy the ejection charges	Medium; Even commercial computers can have software bugs that can cause failed deployment	Installing redundant flight computer systems – in the case one fails to deploy either parachute, the other can fully recover the rocket	Low
		E-match igniter fails to ignite ejection charges, or the ejection charges fail to properly deploy the drogue parachute	Medium; pyrotechnic charges are extremely reliable if installed correctly, but can have electrical issues	Installing redundant flight computer systems – in the case one fails to deploy either parachute, the other can fully recover the rocket	Low
		The drogue parachute fails to fully inflate or becomes tangled with the shock cords	High; with the high winds at apogee, there is a large chance the drogue parachute can become tangled	Folding the drogue parachute properly will minimize the chances the parachute tangles with the shock cord	High
	Main parachute(s) fail to deploy	Main parachute gets tangled in the parachute bag	Medium; the parachute bag is designed to use the pilot chute to pull it out, but there is a chance of tangled chutes and shock cord even with this.	Using a bigger pilot chute – this will give more force to pull the parachute bag out of the rocket and pull the parachute out.	Medium
Touchdown	Landing rocket falls on a person or other property; risk to personnel	Rocket fails to deploy parachute or spectators do not have a visual on the rocket	Medium; even in the vast expanse of the New Mexico desert, it is possible to be impacted by a falling rocket	The Spaceport ground control will announce all rockets launching and all spectators should watch the launch to see if	Low

				anything goes non-nominally.	
	Rocket lands with unburnt propellant	Flight computer fails to fire recovery charge	Medium; with a single stage rocket, it is unlikely the motor will have unburnt propellant, but one or more recovery charges may fail to fire	Disarming all flight computers before picking up the rockets – this will disconnect the black powder charges from any source of electrical power before accessing the ebays	Medium

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