Fall 2024 Technical Report

Thomas Rimer tr382
Cornell Rocketry Team
BLiMS
Recovery and Payload

Cornell University
Sibley School of Mechanical and Aerospace Engineering
124 Hoy Road
Ithaca, NY 14850

1 System Overview

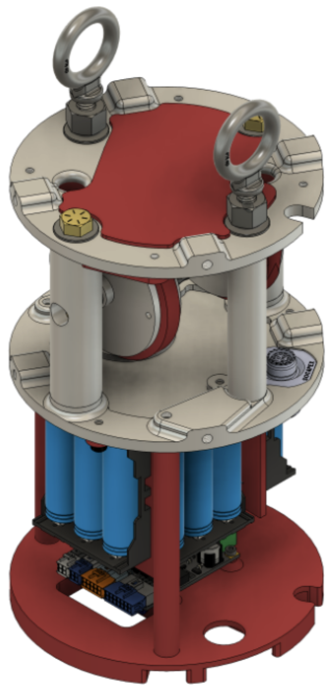


Figure 1: **Complete BLiMS assembly**

Cornell Rocketry's Brake Line Manipulation System "BLiMS" pulls on the brake lines of the rocket's main parachute, adjusting the trajectory of the rocket while descending from apogee, similar to how a descending skydiver navigates to a landing site. Ultimately, the goal of BLiMS is to navigate the rocket to a predetermined GPS waypoint, easing the rocket recovery process. BLiMS has been in development by Cornell Rocketry for several years, but despite at least three complete redesigns and attempted constructions, the system has never flown. This is the first year with a working BLiMS mechanism, which is scheduled to launch on an L3 rocket in January 2025 before final integration into the 2025 competition LV.

This year's version of BLiMS uses a single, BLDC motor to rotate a pair of spools on which the parachute's brake lines are wound. The motor is driven by an appropriately specced motor driver, and powered by a series of high-current rechargeable Li-Ion batteries. The design's driving constraint is simplicity; this year's version of BLiMS is intended to be a minimally viable product, with the intention of improving the design and capabilities in future years.

While conceptually simple, the challenge of BLiMS comes from two primary sources. First, loads from the parachute are significant during initial deployment, meaning BLiMS must be resilient to tens of thousands of Newtons. Secondly, with no experimental data to draw on, the required performance envelope for BLiMS is still large to accommodate as many scenarios as possible. Therefore, many components on this version of BLiMS are over-capable with the expectation that subsequent versions will narrow requirements.

2 Images of Design

2.0.1 System Pictures

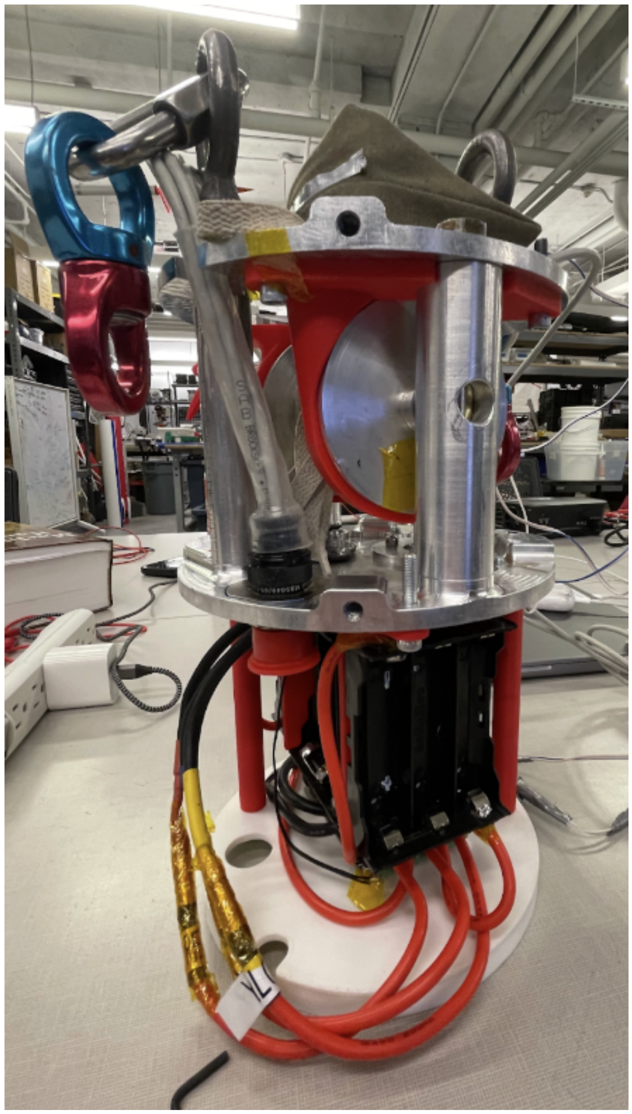


Figure 2: **BLiMS assembly closeup**

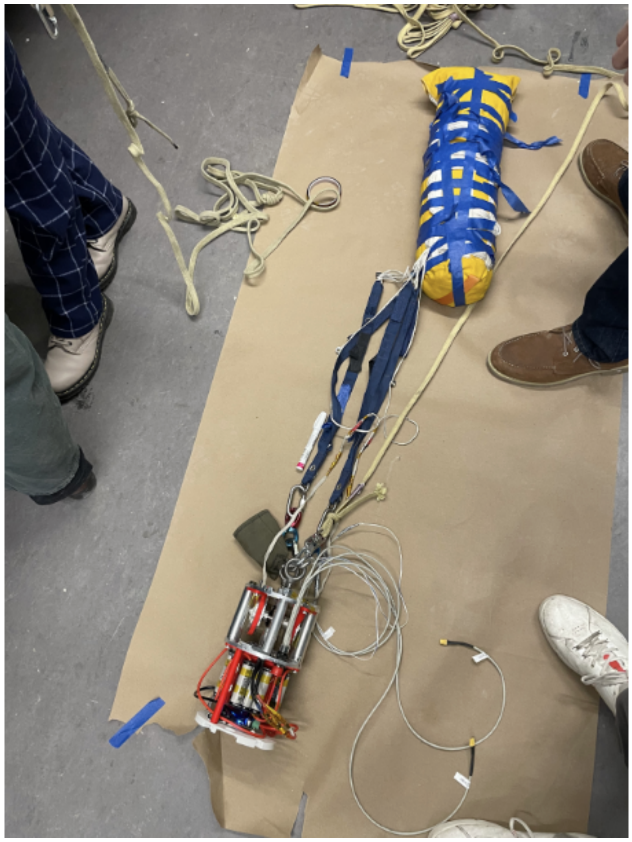


Figure 3: **Complete BLiMS assembly laid out and connected to the parachute before loading into the L3 rocket for launch.**

Figure 4: **BLiMS installed in the L3 air frame, from below. The green LED visible through the bottom slot indicates the status of the system. The umbilical (white) containing all BLiMS power and control signals runs through its designated port.**

2.1 CAD Assembly

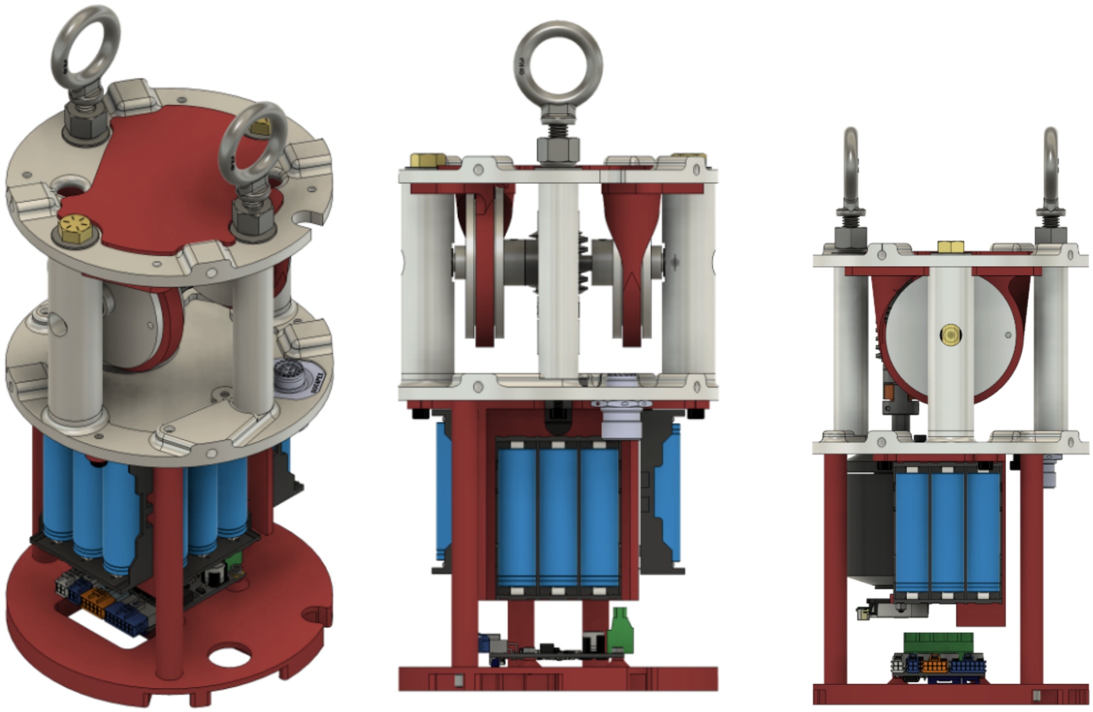


Figure 5: **Complete BLiMS assembly rendered at different angles**

Figure 6: **Close up of the BLiMS assembly upper section**

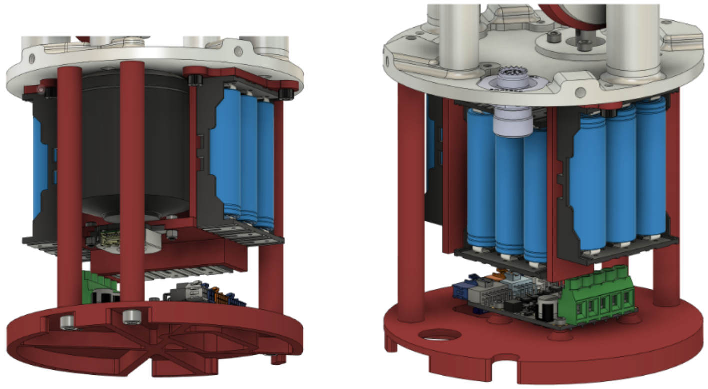


Figure 7: **Close up of the BLiMS assembly lower section**

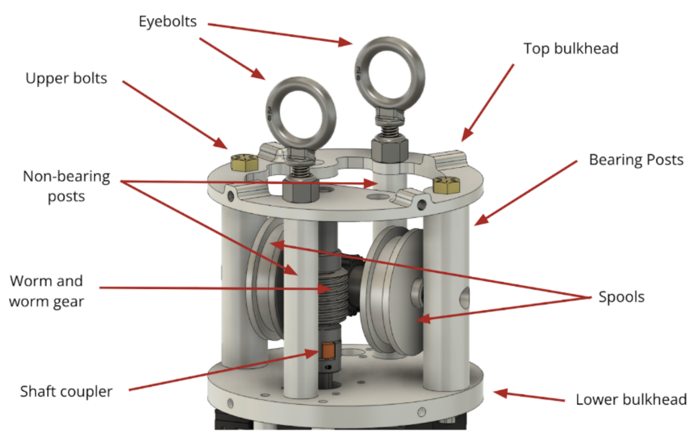


Figure 8: **Annotated BLiMS assembly upper section**

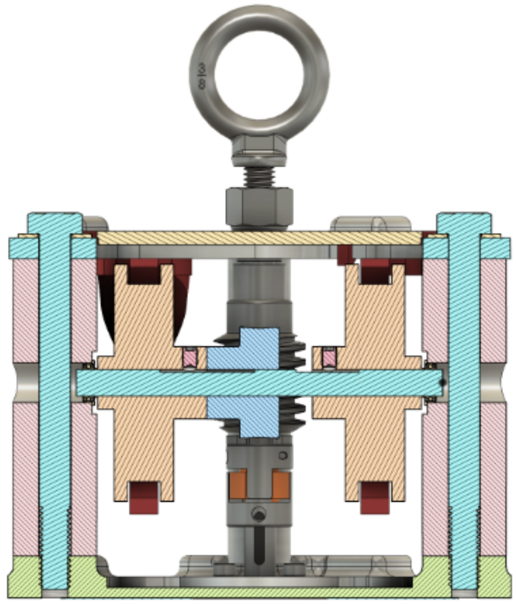


Figure 9: **Cross section through the shaft of the BLiMS assembly upper section. In orange are the two spools. In light blue is the worm gear. In teal is the horizontal shaft and bolts. In pink are the bearing posts.**

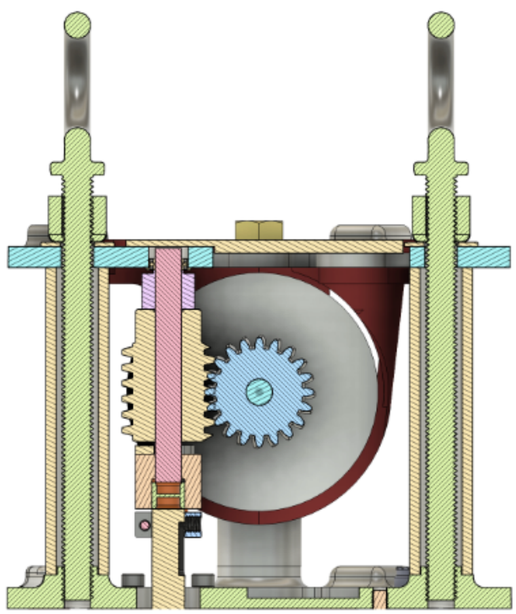


Figure 10: **Cross section perpendicular to the shaft of the BLiMS assembly upper section. In tan is the worm. In blue is the worm gear. In green are the eyebolts. In pink is the vertical shaft.**

2.2 CAD Components

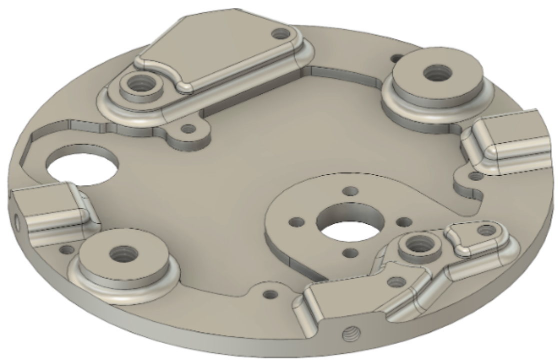


Figure 11: **Bottom bulkhead**

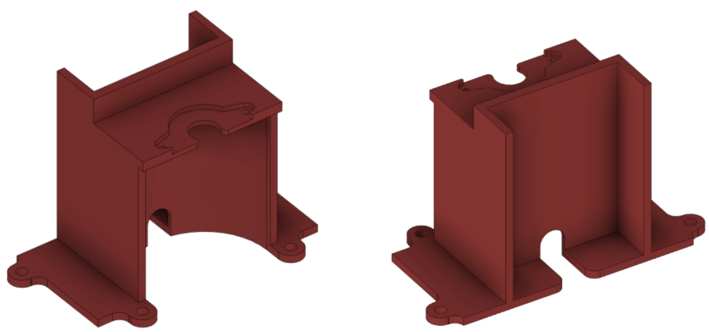


Figure 12: **Motor enclosure and battery mounting superstructure (image upside relative to its installed position on BLiMS**

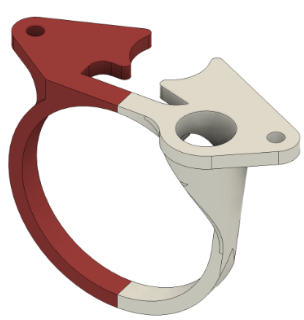


Figure 13: **One set of wheel drum covers. Each piece is colored differently to highlight their boundaries**

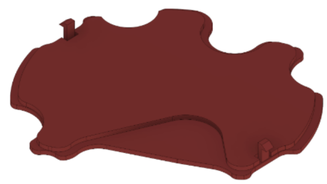


Figure 14: **Top bulkhead seal**

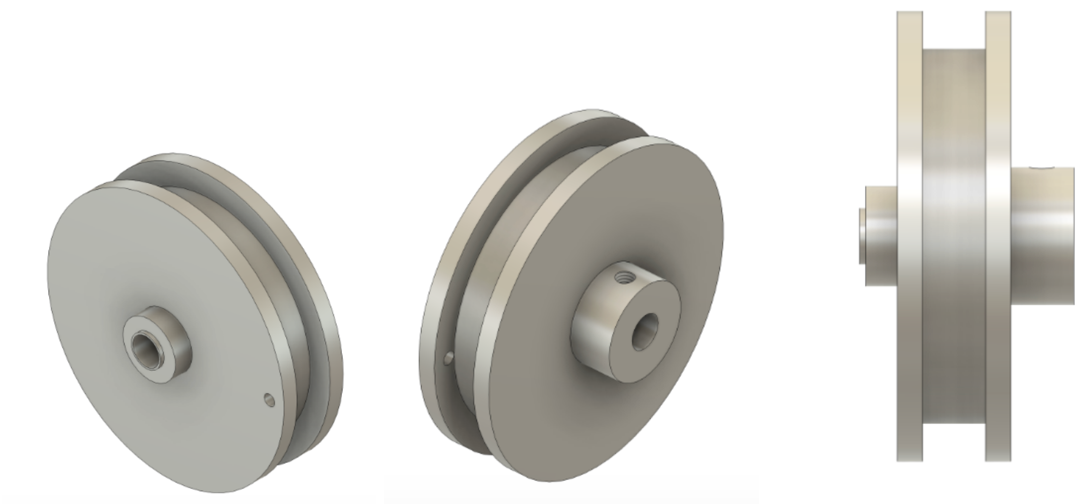


Figure 15: **Spool**

Figure 16: **Bearing Post**

Figure 17: **Non bearing post**

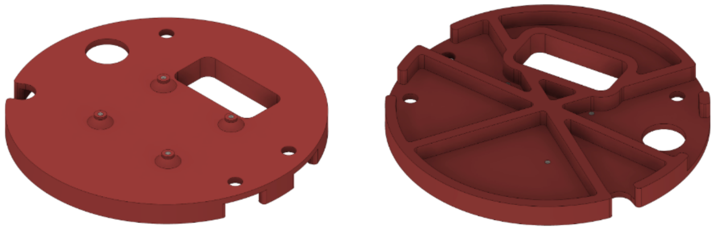


Figure 18: **Bottom plate**

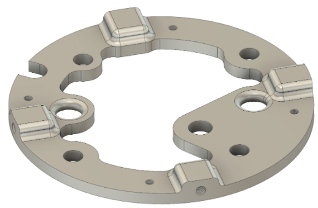


Figure 19: **Top bulkhead**

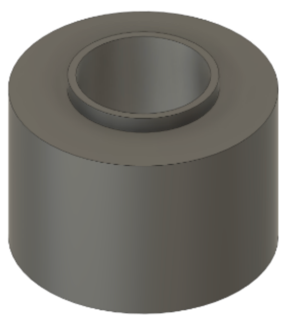


Figure 20: **Vertical bearing spacer**

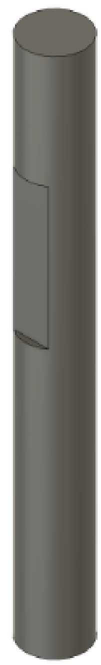


Figure 21: **Vertical Shaft**

Figure 22: **Bottom plate standoff**

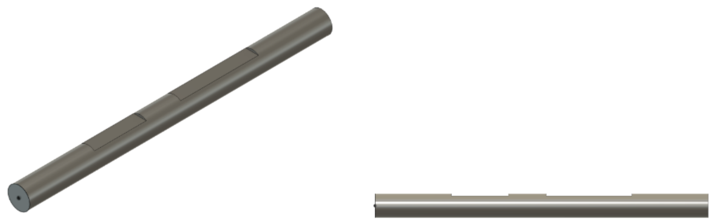


Figure 23: **Horizontal shaft**

3 System Function

A typical, un-guided model rocket deploys a main parachute several thousand feet above the ground and completes the final minute of descent subject to local wind patterns. Not only does this mean the rocket could potentially land on and injure someone, but even when the landing is safe, the rocket is usually miles from the original launch site. At Spaceport America, where Cornell Rocketry launches our competition each year, rocky desert terrain and extreme temperatures makes recovery challenging.

The purpose of BLiMS is to actively guide the rocket to a prespecified GPS waypoint during its traditionally unguided descent stage. If successful, the rocket would land in a known safe and easily accessible location, allowing fast and easy recovery.

There are many ways to guide a rocket during descent that are technically possible, but Spaceport America competition requirements mean there's only one feasible choice; a parachute guidance system which manipulates the shape of the main parachute causing it to drift in a certain direction. This, in combination with a control system capable of factoring in wind and other exogenous effects, enables the rocket to guide itself to a location in a manner functionally identical to a skydiver.

3.1 Relation to Other Systems

BLiMS has no child systems. The only parent to BLiMS is the launch vehicle itself.

4 Requirements

4.1 Exogenous Requirements

Exogenous requirements are constraints set by other systems that any BLiMS design must work around or take into account. Any and every approach to designing BLiMS is subject to the same exogenous requirements.

4.1.1 Airframe

BLiMS must mount within the 6″ airframe of the Cornell Rocketry 2024 launch vehicle. As such, all components must fit within a 6″ diameter circle. The vertical requirements of BLiMS were less strict, though a complete system <2 feet long was highly desirable to minimize overall rocket length. Additionally, any mounting of BLiMS to the fiberglass airframe was to be done through radial ¼”-20 bolts (preferably through four equally spaced holes) as it’s a proven strategy that Cornell Rocketry is comfortable with.

4.1.2 Parachute

BLiMS is connected to the main parachute through two pairs of lines, totaling four connections. The first two connections are with the left and right static lines. These lines transfer the drag force generated by the parachute to the rocket, and are therefore under significant tension during initial parachute deployment. The static lines are connected with quick links which must be factored into any mounting point design.

Parachute deployment is a notoriously challenging system to model. In other words, it is very difficult to predict the expected loads during parachute opening from first principles. Fortunately, experimental data collected from Cornell Rocketry’s competition launch at the 2024 Spaceport America Cup featured a ripped drogue chute, meaning the main parachute deployed as the rocket was falling at terminal velocity. This was a worse case scenario for parachute loading (a properly working drogue chute reduces terminal velocity significantly decreasing main deceleration rates) and therefore a good example of the worst-case-scenario that BLiMS would see through the static lines. Onboard IMU data processed after the launch revealed peak combined accelerations (in all directions) were 30G (300 m s-2).

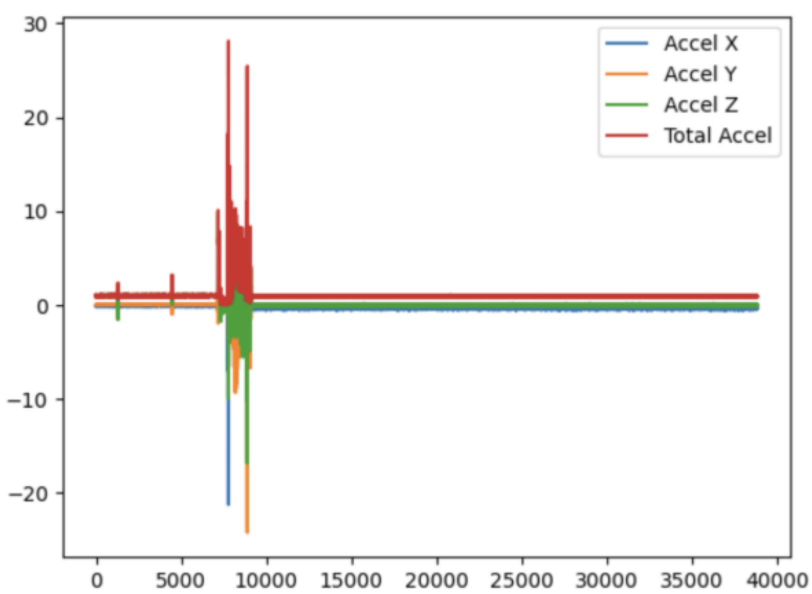


Figure 24: **Graph of the recorded acceleration vs time. X axis is seconds, Y axis is m s-2. Total acceleration is the X, Y, and Z accelerations in quadrature.**

Given a rocket weight of 150 lbs, 30Gs corresponds to 4,500 lb-force (20,000 N) generated by the parachute which was transmitted through the static lines. Therefore, each static line mounting point must be capable of withstanding 10,000N without significant deformation.

This loading scenario value is not perfect; different parachute sizes, types, and packing techniques significantly impact opening loads. However, 10,000N is a reasonable worst-case-scenario estimate; during normal operating conditions, this loading is never expected. The 2025 deployment main scheme using a Tender Descender eliminates the chance of a no-drouge, main-opening, meaning this value is especially conservative.

The quicklink used to attach the static line requires at least ½″ clearance from the inside air frame to mount to any ring.

The second two connections to BLiMS from the parachute are the left and right brake lines. When these small cables are pulled, they change the shape of the parachute causing it to drift in certain directions. The brake lines are thin (¼″ diameter) dynama and simply terminate in a frayed end. While not load bearing, the brake lines still require a nontrivial amount of force to hold in place. To perform certain airborne maneuvers, like corkscrews, the brake lines must also be pulled or released at non-trivial speeds.

To determine both the force and retraction velocity requirements, members of Cornell Rocketry skydived several times to build an institution for parachute control. From these tests, it was estimated that the brake lines require up to 20 lb-force each (90N) to retract. High speed maneuvers required release the brake lines up to 0.5 m s-1.

Once again, these requirement estimates are imperfect. All skydives were performed as tandems, meaning total falling mass was almost double that of the rocket. This leads to higher brake line forces necessary in the tandem skydive compared to what the rocket actually needs. Furthermore, the maneuvers requiring the upper limits of the aforementioned speed were "tricks" like flat spins, and are unlikely to ever be needed during a controlled parachute descent. However, because the numbers cited above overestimates, they are appropriate for a first version of BLiMS with the understanding that a future version of BLiMS may require only a fraction of this capabality.

4.1.3 Parachute Insertion

The section of air frame allotted to the parachute is directly above BLiMS. Therefore, when the parachute is loaded it is stuffed against BLiMS. Any BLiMS design must be robust enough to withstand the force of packing, and avoid tangling with the many wires and lines emerging from the parachute. While this may feel redundant in the face of the 20,000+ N anticipated from main deployment, this requirement rules out certain 3D printed brake line routing components on previous BLiMS designs, which were prone to breaking.

4.1.4 Separation

Above BLiMS is a CO_2 separation system that uses compressed CO_2 to split the rocket in half and release the drogue parachute. As a result, BLiMS must form an airtight seal across the air frame somewhere along its length.

4.1.5 AV Bay

Beneath the allocated section of airframe for BLiMS is the AV Bay, which houses all the central flight control electronics. From the AV bay is an umbilical which carries the control data from the flight controller to BLiMS. BLiMS must ensure that all relevant wire terminals within the mechanism are easily accessible to this umbilical.

Additionally, wires for the CO2 separation system and the Tender Descender are routed through a separate umbilical which needs to pass through the entirety of BLiMS. These wires necessarily must pass through the sealed section of BLiMS, and therefore a convenient and easily disconnectable wiring pass through is needed somewhere along the sealed section of BLiMS.

4.1.6 Mass

At the time of development, the hybrid motor powering the 2025 launch vehicle was underperforming, making weight reduction of utmost importance. While there was no specific maximum mass, every effort possible to reduce weight of the system (within reason) was to be taken.

4.1.7 Temperature

BLiMS must be capable of operating in 150F without significant degradation of performance on any front.

4.2 Endogenous Requirements

Endogenous requirements are constraints specific to BLiMS, which are directly linked to its design. Any and every approach to designing BLiMS is subject to unique exogenous requirements determined by its design.

4.2.1 Guaranteed Performance

Due to Cornell Rocketry's historical incapacity to successfully build and fly a parachute guidance system (despite several previous attempts), this year's design was heavily influenced by a desire to build a mechanism that was guaranteed to work. This manifested as frequently overspeccing systems, like the motors, batteries, or bulkheads. While not optimal in many regards, the certainty offered by these overperforming members.

4.2.2 Simplicity

Similar to the guaranteed performance requirement, in an effort to ensure BLiMS flew in 2025, the capabilities were descoped to simplify the MVP. Namely, independent brake line control was abandoned, instead favoring a single-motor design which couples the brake line extension and retraction to one another.

4.2.3 Assembly

BLiMS must be easy to assemble and disassemble in the field. By extension, it must be able to be assembled and reassembled without replacing or damaging components (i.e. no/minimal permanent adhesives or glues).

4.2.4 Backdrive

Though forces through brake lines for parachute maneuvers are only in the tens of pounds, the mechanism must be resilient to double or triple that in the case of a line tangle. For a motor-powered design, this means either speccing the motor to handle these extreme loads, or simply preventing backdrive through mechanical means.

4.2.5 Battery Life

The batteries in BLiMS must be capable of powering BLiMS on standby for 12 hours with enough remaining charge to power the motor at full power for 15 minutes.

4.2.6 Eyebolt Position

The angular position of the eyebolt must be easily adjustable.

5 Design

5.1 Design Overview

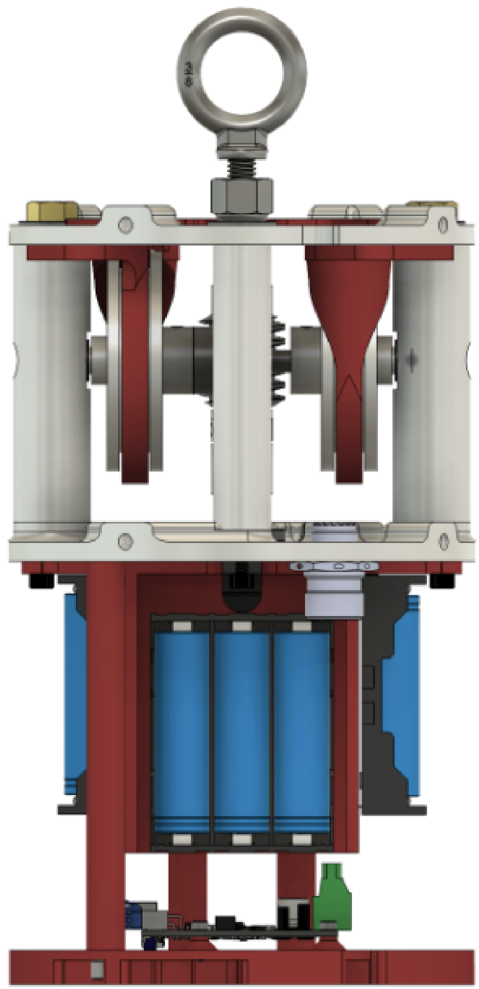


Figure 25: **CAD assembly of BLiMS**

The overarching 2025 BLiMS design was inspired by previous Cornell Rocketry BLiMS designs. However, it has significant improvements in both simplicity and robustness which make it better suited to the task. To control the parachute, each brake line is wound or unwound on its own spool. Due to the requirement of only one motor, the two spools are rigidly mounted to the same shaft. The left and right brake lines are spooled in opposite directions, meaning as one brake line extends, the other retracts. This allows the mechanism to smoothly turn left and right with single motor.

A worm gear connected to a brushless DC motor is used to turn the shaft and thus the spools. The worm gear not only offers a convenient and low profile mechanism to transfer mechanical work from the vertical motor (which must be vertical due to horizontal space constraints) to the horizontal shaft, but the worm gear also prevents backdriving. Therefore, when the brake lines are tugged, the system remains rigid—even when powered off—yet the motor meets little resistance when spinning the spools. Preventing backdriving addresses the backdrive requirement, and decreases the power requirements of the motor as it doesn't need to stay powered when holding a fixed position.

Surrounding the motor, worm/worm gear, and spools is the BLiMS superstructure. This includes an upper and lower bulkhead (of which the latter provides the airtight seal necessary for the CO2 separation) and four posts between them. Atop the upper bulkhead are two eyelights allowing the parachute's static lines to attach, as well as guides for the brake lines. The bottom bulkhead also houses the sealed wire pass through.

Beneath the lower bulkhead is the motor body and the batteries which are mounted on a plastic frame. Finally, three additional, non load bearing posts beneath the bottom bulkhead attach a bottom plate beneath the batteries, on which the motor driver is mounted. The bottom plate includes multiple pass throughs for the various wires which control BLiMS and the deployment electronics above it.

BLiMS weighs 3.6kg. The specific mass breakdown is shown below.

Component Name	Weight (grams)	Quantity	Sub-Mass (g)
DC Motor	800	1	800
18650 Batteries	45	9	405
Pulleys	172	2	344
Top Bulkhead	199	1	199
Bottom bulkhead	305	1	305
Eyebolts	112	2	224
Bearing posts	99	2	198
Long screws	36	4	144
Upper Bolts	66	2	132
Bottom Standoffs	31	4	124
Worm	121	1	121
Worm gear	88	1	88
Non-bearing post	39	2	78
Battery holders	25	3	75
Shaft coupler	70	1	70
Amphenol connector	50	1	50
Bottom plate	50	1	50
Battery/driver 3D printed mounts	15	3	45
Horizontal shaft	42	1	42
Stepper driver	40	1	40
Bearing	13	3	39
Lock nuts	18	2	36
Vertical shaft	26	1	26
		Grand total	3635

Figure 26: **Table of all components and their masses**

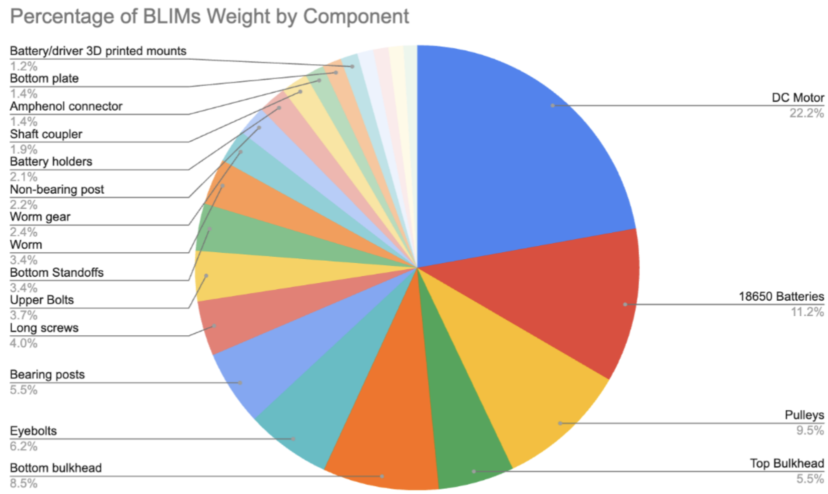


Figure 27: **Percentage breakdown of weight by component**

The layout of BLiMS was driven by the selected motor. A motor trade study, incorporating the pull and speed requirements expressed above, was performed before any design took place to identify the appropriate motor for the system.

5.2 Motor Trade Study

As a reminder, BLiMS must be capable of exerting 20 lb-force (90N) on each of the brake lines (not simultaneously). It must also be capable of retracting or extending either brake line at up to 0.5 m s-1. It's worth mentioning that electric motors typically have an inverse stall torque to rpm relationship. In other words, at higher angular velocities, motors produce less torque. To ensure the widest possible operating envelope of BLiMS, the motor selected must be capable of delivering 90N of force to the brake lines while retracting them at 0.5 m s-1.

However, BLiMS' maximum retraction speed and force are equally influenced by BLiMS' spool radius and worm gear ratio. An increase in spool radius would increase retraction speed while lowering force applied to the line. An increase in worm gear ratio would decrease retraction speed, while increasing force applied to the brake lines. Whatsmore, worm gears have nonlinear decreases in efficiency with ratio, meaning higher ratio worms are less effective at transmitting torque from the motor to the spools. As a result, choosing a motor cannot be done without also choosing both the spool radius and worm gear ratio.

To identify an appropriate motor in this highly nonlinear, three dimensional solution space, a Python model (available in this Google Colab link here) was built to simulate performance and identify valid combinations of motor, spool, and worm gear. The model accepts the motor's torque curve as input. As output, it generates a 3D plot with color-coded points corresponding to valid and invalid combinations of motor speed, gear reduction, and spool radius. The color of a point corresponds to the validity of that combination of parameters:

Green: Combination works. It has sufficient torque and speed Yellow: Combination does not work. It has sufficient speed, but does not have sufficient torque. Orange: Combination does not work. It has sufficient torque, but does not have sufficient speed. Red: Combination does not work. It does not have sufficient torque or sufficient speed.

Using back-of-the-envelope physics, a large array of stepper and brushless DC (BLDC) motors were screened. Of the 2 dozen motors considered, three motors were simulated, resulting in a single obvious choice. Below are the results from each simulation.

5.2.1 StepperOnline 23HE45-4204S Nema 23 Stepper Motor (nickname: "Medium Powered Stepper")

This motor is a medium size stepper motor. It weighs 1.83 kg (4.03 lbs). It has a top speed of 20 rps or 1,200 rpm. It requires a high-powered stepper motor driver, likely the Stepper Online DM556T which weighs 0.44kg (0.97 lbs). Below are the model results for the Medium Powered Stepper motor. All axes represent the absolute physical limits on each of the parameters.

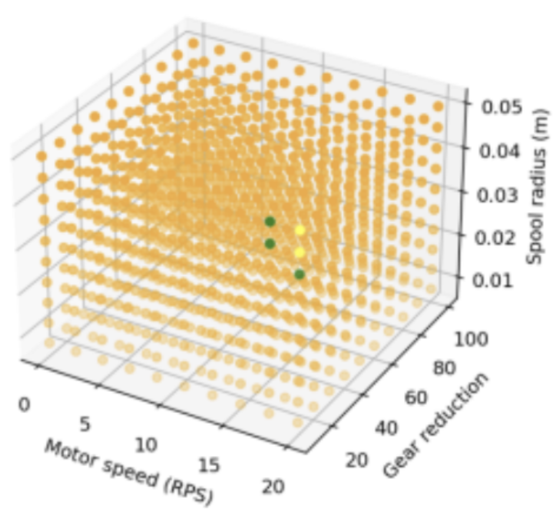


Figure 28:

Based on these results, a 4.5 cm radius spool run at 17.5 rps with a 10:1 worm gear is the best combination for BLIMs.

This combination is seriously pushing the limits of the stepper motor, and therefore is not recommended. Additionally, this motor weighs a lot. Thus, there is reason to explore alternatives.

5.2.2 ODrive M8325s 100KV BLDC (nickname: “High Torque BLDC”)

Specification	Value	Unit	Notes
Speed Constant [1]	100	RPM/V	
Torque Constant [2]	0.083	Nm/A	
Speed / Torque Gradient	43.53	RPM/Nm	
Pole Pairs	20		
Phase Resistance	24	mΩ	Phase-neutral
Phase Inductance	9.9	uH	Phase-neutral
Continuous Current	40 60	A A	Free Air Forced Air
Peak Current	80	A	3-second
Thermistor	NTC 10k 3435		

Figure 29: **Table of parameters for the High Torque BLDC**

This motor weighs 840 grams. As a side note, it has an approximate density of 0.00621 grams per mm 3. Based on the speed constant, the top free-speed of the motor will range between 2,250rpm and 3,780. Based on the torque constant, the batteries can provide a maximum of 2.905 Nm of torque (assuming 35A draw). Below are model simulations of the DC motor, full axis.

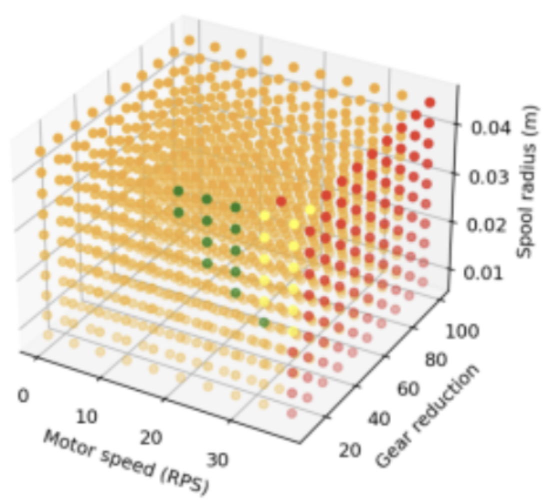


Figure 30:

The 10:1 worm gear ratio remains the best gear reduction. Regenerating the plot with a 10:1 gear reduction on the gear reduction axis creates the following 2D plot.

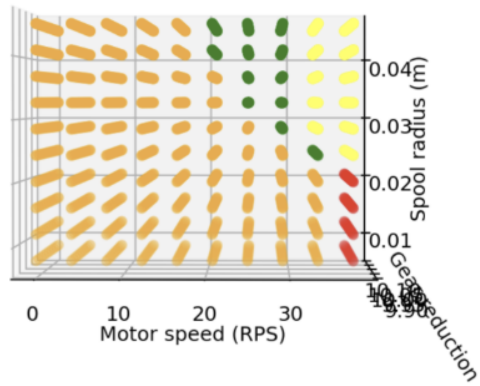


Figure 31:

Therefore, this motor can provide enough torque given a 10:1 worm gear and a 3 cm radius spool (from existing design). However, the motor body is quite wide and will likely cause packaging challenges, so further analysis of other motors is worthwhile.

5.2.3 ODrive D6374 150KV BLDC (nickname: "6374")

Specification	Value	Unit	Notes
Speed Constant [1]	270	RPM/V	
Torque Constant [2]	0.031	Nm/A	
Speed / Torque Gradient	515.67	RPM/Nm	
Pole Pairs	7		
Phase Resistance	39	mΩ	Phase-neutral
Phase Inductance	16	uH	Phase-neutral
Continuous Current	45 65	A A	Free Air Forced Air
Peak Current	85	A	3-second
Thermistor	NTC 10k 3435		

Figure 32: **Table of parameters for the 6374**

The motor does not have a listed weight, but similar motors online weigh about 900 grams. Based on the speed constant, the top free-speed of the motor will range between 3,375 and 5,670 rpm. Based on the torque constant, the batteries can provide a maximum of 1.925

Nm (assuming 35A draw). Below are model simulations of the DC motor, with each axis representing the absolute limits of each physical parameter.

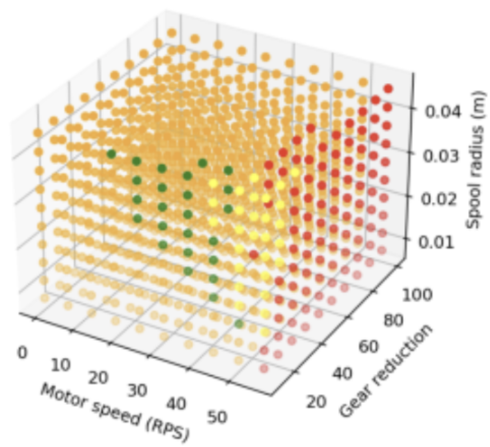


Figure 33:

Once again, the 10:1 worm gear reduction appears to be the most viable. Cropping the plot gives the following 2D plot.

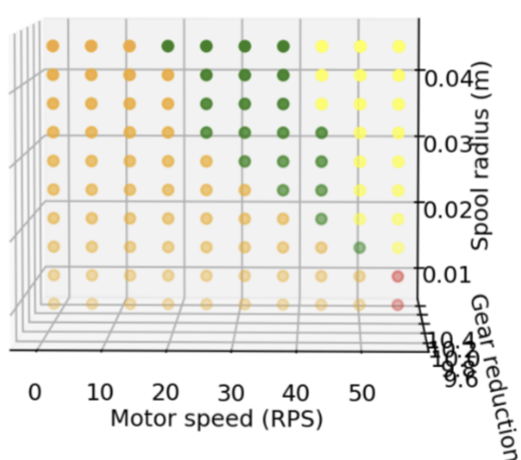


Figure 34:

There is a relatively spacious valid solution region. For example, given a 3 cm radius spool, the motor needs only spin between 25 and 45 rps.

5.2.4 Motor Trade Study Results

Based on the analysis of the three motors above, the ODrive D6374 150KV BLDC with a 10:1 worm gear and 3 cm radius spool was selected as the best combination for BLiMS.

At 25 rps (0.47 m/s surface speed), the motor produces 1.06 Nm of torque, which works out to 282 N (63 lbf) of surface force. At a slow (0.1 m/s, 5.3 RPS) retraction speed, the motor produces 1.74 Nm of torque, which works out to 464 N (104 lbf). At a fast (1 m/s, 53 RPS) retraction speed, the motor will produce 0.10 Nm of torque, which works out to 27 N (6 lbf). Note, the fast speed is double the maximum necessary; however it is included to demonstrate the motors capacity to handle unexpected edge cases or a potentially expanded performance envelope for future versions if necessary.

5.3 Supporting Motor Hardware Selection

ODrive, the supplier of the 6374, recommends the 16384 CPR Absolute RS485 Encoder for the 6374. It offers 14 bit encoding up to 12,000 rpm which is more than sufficient for BLiMS. It is also designed to work with the ODrive Pro motor controller, which is also compatible with the 6374. Therefore, the motor driver and encoder were selected.

Specification	Min.	Typ.	Max.	Units	Conditions and Notes
DC Voltage	15		58	V	
Maximum Modulation Depth		99%			Utilizable percentage of DC bus
AUX Logic Voltage	10	12	14	V	Optional
Operating Motor Current			20 80 120	A A A	Free air (T_A 25°C) Active cooling (T_A25°C) Peak (3 second max)
ESD Protection		±30 ±8 ±8 ±8 ±8 ±6		kV	Power Lines, IEC 61000-4-2 CAN Lines, IEC 61000-4-2 Isolated Lines, IEC 61000-4-2 RS485 Lines, IEC 61000-4-2 USB Lines, IEC 61000-4-2 All Other Lines, IEC 61000-4-2
CAN baudrate			12	Mbit/s	Additional firmware limitations apply, see `baud_rate`.

Specification	Value	Units	Notes
Mass	140 72 32	g	Full Case Heat Spreader Bare Board
Width Length Height	51 64 17.5	mm	
Mounting	PCB Heat Spreader		4x M3, 42mm x 45mm pattern (horizontal, vertical) 4x M4, 60mm x 60mm pattern

Figure 35: **Tables of parameters for the ODrive Pro motor driver.**

Included in the scope of the BLiMS project is the battery for the motor. The motor's torque curve is directly linked to the battery's voltage and peak current capabilities, therefore it's essential that the batteries meet the power requirements of BLiMS. The ODrive Pro (selected motor driver) can handle voltages between 15 and 58 volts. Most systems operate around 36-48 volts, so that was selected as the target range of any battery pack to be used. A number of batteries were qualitatively evaluated on the following features:

- Capacity (total amp hours)

- Voltage (voltage of the entire battery pack, including variation from max charge to max discharge)
- Current (peak and sustained current ratings)
- Volume (volume of the entire pack, including dead space due to non-ideal geometry)
- Mounting (how the batteries can be durably affixed to the BLiMS structure, while still remaining easily removable during deconstruction)
- Recharging (easy to recharge, in a shop environment and out in the field)
- Safety (some battery chemistries discouraged due to risk of starting fires)
- Temperature resilience (capable of withstanding 150°F indefinitely without degradation of performance)

Battery packs were eliminated due to their often bulky layout and challenge of mounting within the constraints above. However, this was an unfair assumption and a future version of BLiMS should reevaluate battery packs as they often contain overcurrent protection and other features which make them desirable over individual cells.

Nonetheless, a battery system consisting of nine Molicel P28A 18650 Li-Ion batteries wired in series was identified as the best possible option. Below are the battery system stats:

Physical stats: 45 grams per battery, 406 grams for entire system Capacity: 2,800 mAh per battery, 2,800 mAh for entire system (wired in series) Current: 35A peak, +10A continuous Voltage per Cell: 2.5V discharge cutoff, 3.6V nominal, 4.2V charge cutoff Voltage of Entire System: 22.5V discharge cutoff, 32.4V nominal, 37.8V charge cutoff Heat resilience: 140°F with no significant performance degradation

The batteries are mounted in three plastic packs, each with capacity for three cells, allowing each battery to be individually installed and removed from BLiMS. The plastic packs themselves are permanently adhered to the battery mounting superstructure with 3M RP+110GF VHB double-sided tape. The tape is 1.1mm thick (1 mm when compressed), and can withstand sustained temperatures up to 350°F with >50% strength remaining. Unlike glues, which are messy and require time to set, VHB offers a near immediate bond and is easier to use.

To charge the 18650s, two generic external 18650 chargers (each with slots for 6 batteries) were purchased. To recharge BLiMS, the batteries are removed by hand from the plastic packs and inserted into the charger. This requires BLiMS to be fully powered down and removed from the rocket to be recharged. This is not ideal, and a future version of BLiMS should ideally allow charging from an external port, allowing for the batteries to be permanently mounted.

5.4 Superstructure Design

With the motor, spool radius, worm gear ratio, motor driver, motor encoder, and batteries selected, the packaging and superstructure design could begin.

Fundamentally, the superstructure is based on two bulkheads connected by four posts. A pair of opposing posts have aligned radial holes allowing for a bearing to be press fit in, which supports the horizontal shaft. On the shaft are the two appropriately size spools

Both spools are slid onto the horizontal shaft and fixed in place with set screws. Note that the spools have a small lip on their outer side to prevent rubbing against the pulleys. In between the spools, the worm gear is also mounted on the horizontal shaft with a set screw. A set of 3D printed spool covers guide the brake lines from the holes in the top bulkhead to the spool. This minimizes the chance of tangling or inadvertent unspooling if/when brake lines go slack. The spool covers are printed in two pieces and designed to be easily installed after the brake line has been spooled using two screws into the upper bulkhead.

This layout drives the position of the motor (whose axis must be aligned relative to the worm gear to enable appropriate meshing of the worm). It also drives the location of the two exit holes in the top bulkhead, which guide the brake lines out of BLiMS with a smooth, filited hole to prevent snagging or wear on the cables.

The top bulkhead, bottom bulkhead, and posts are held together using an intuitive but purposeful bolting technique that uses a mix of long, pretensioned bolts and eye bolts with jam nuts to hold the entire assembly together. Below is a cross section of bolts, which pass through the top bulkhead and entire length of posts without thread engagement. Instead, they thread directly into the bottom bulkhead.

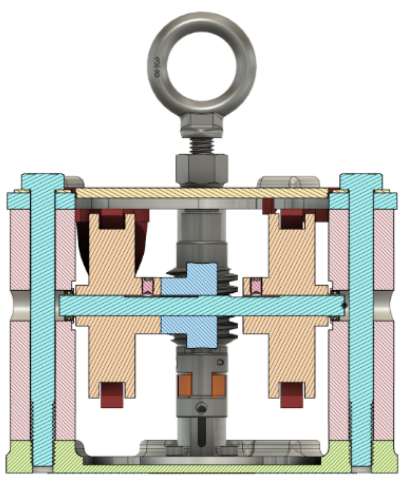


Figure 36:

Below is a cross section of the two eyebolts, with jam nuts on top.

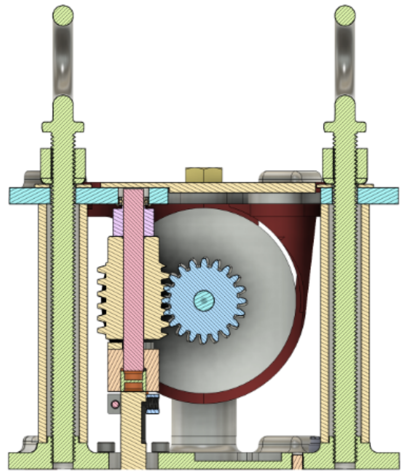


Figure 37:

To tighten the eyebolts, they are twisted into place with the jam nuts threaded all the way to the top. Once the eyebolt is almost entirely screwed in and the eye is oriented tangent to the airframe, the eyebolt is held firm while the jam nut is torqued down the top bulkhead. As the jam nut is tightened, it pretentions the bolt, holding the assembly together. The non-eye bolts are simply bolts tightened with a wrench.

This mounting strategy offers several advantages. Because the bolts/eye bolts thread directly into the bottom bulkhead, no nut is needed on the opposite side and thus the holes can effectively be blind (which is ultimately what happens when the motor and batteries are installed). A single bolt spanning the entire length of the BLiMS upper section also reduces the part count. It also means disassembly of the upper section only requires loosening 4 bolts. Lastly, pretensioning the bolts allows the posts to be placed in precompression prior to launch. Therefore, when loads are applied to the eyebolts, the load goes into reducing the preload rather than stretching the post.

Note the inclusion of a shaft coupler, which joins the shaft of the motor to the vertical shaft. It has small bits of plastic inside which allow for minor axial misalignment, reducing the chance of damaging the motor and minimizing vibrations from the motor. Shaft couplers are commonplace for direct shaft-to-shaft coupling.

Two sets of four radial ¼″-20 bolt holes—one set in the upper bulkhead and one set in the lower bulkhead—enable BLiMS to be mounted to the airframe.

In the bottom bulkhead is a TVS07RF-11-35SC Amphenol connector. Amphenol is an industry standard for electrical connectors. The TVS07RF-11-35SC seals against the bottom bulkhead, ensuring the success of the CO2 separation system. It also allows wires from one side to easily be connected and detached, aiding in the integration of BLiMS into the rocket. The exact model was chosen by members managing the rocket's wiring harness.

All components beneath the bottom bulkhead are nonstructural 3D prints held together with standard bolt schemes. Note that the flat bottom of the bottom plate (on which the motor driver is mounted) allows the entire BLiMS to stand vertically during testing and assembly/disassembly—another intentional design decision to further aid in any field work that may need to take place.

5.5 Materials

All Cornell Rocketry-manufactured components are either machined 6061 aluminum or 3D printed PLA-PC blend. The justification for 6061 is provided in the analysis section.

The PLA-PC filament is not ideal for inside the rocket; with a softening temperature of 55°C the PLA components will lose structural integrity at Spaceport America where outside temperatures alone are in excess of 45°C. Future designs of BLiMS will avoid 3D printed components as much as possible, and in cases where they prove necessary, utilize higher temperature ABS-type filaments.

6 Analysis

Ansys Static Structural analysis was performed on the system to ensure it could withstand a peak loading (30G) event. Note that while hand calculations were attempted, the behavior in question (assembly deformation during peak loading) was an emergent property of the complex dynamics of the assembly, including bolt pretensioning, which could not be neatly calculated. While further simplification and effort could have yielded usable hand calculations, it was determined it would be a better use of time to jump straight to Ansys. This comes with risks of Ansys providing unverifiable results.

First, a simplified CAD of the assembly was prepared. Threads from the bolts were removed, leaving only the minor diameters. The eyes of the eye bolts were removed leaving a flat surface on which the loads could be applied. Finally, both the vertical and horizontal shaft assemblies were removed. Below is a screenshot of the simplified assembly.

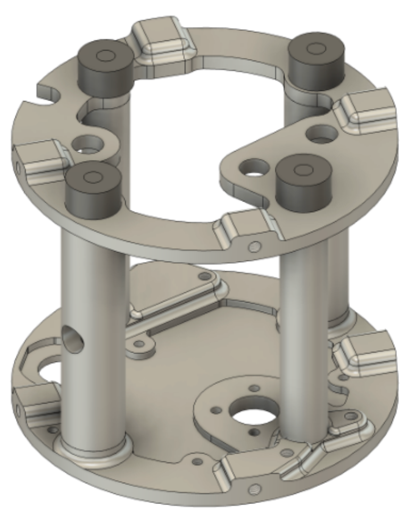


Figure 38: **Simplified BLiMS assembly for Ansys**

6.1 Ansys Setup

10,000N was applied to the top of each truncated bolt in the upward direction, resulting in a total parachute loading of 20,000N. Note that this simulation assumed equal weight distribution during a peak loading event which may not necessarily be the case.

Bolts were preloaded with a variety of forces in different simulations to test the impact on the structural integrity of BLIMs during both peak parachute loading, and under no parachute load.

The inside surface of the eight radial bolt holes (4x in top bulkhead, 4x in bottom bulkhead) were set as fixed supports.

All post-to-bulkhead joints were set as friction, u=0.5. All bolt-to-bottom bulkhead joints were set as fixed (note the pinball radius was increased to 1mm to ensure Ansys recognized it as a joint).

Materials were simulation dependent, see simulation details for specifics.

6.2 Simulation 1

Model Description: Previous version of BLIMs model (different from the one described above).

Load description: 10,000 N parachute load on each eyebolt. 11,000 N bolt preload on all four bolts.

Material: 7075 for both bulkheads, bearing posts. 6061 for non-bearing posts. 316 stainless for eyebolts.

6.2.1 Results

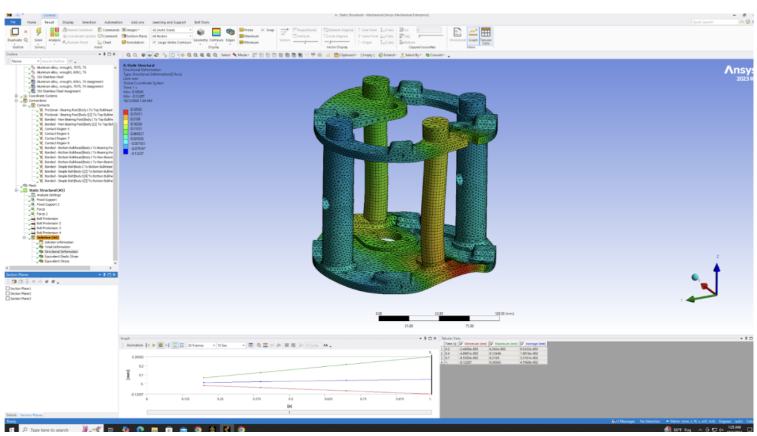


Figure 39: **Directional displacement in z**

Image X: Directional displacement in z

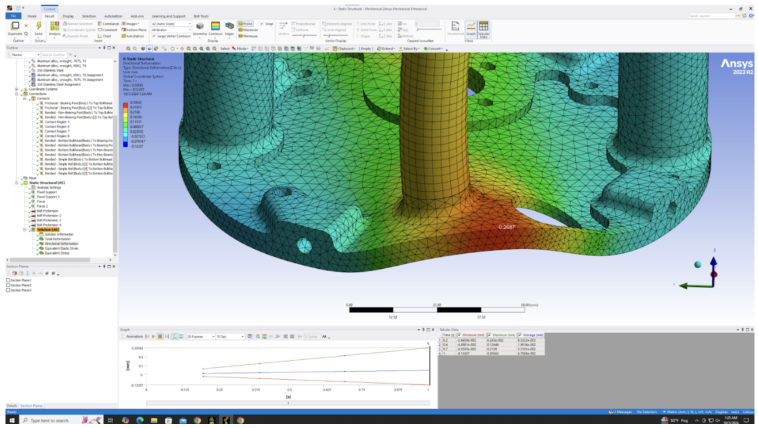


Figure 40: **Closeup of directional displacement in Z of problem zone**

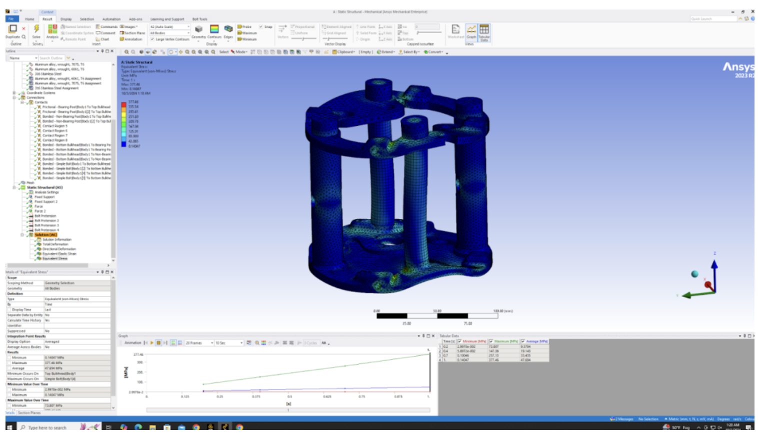


Figure 41: **Von-Mises stress, complete assembly**

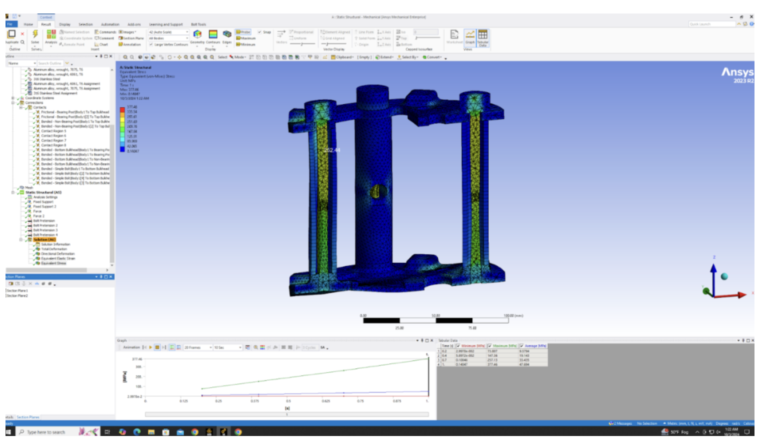


Figure 42: **Von-Mises stress, cross section**

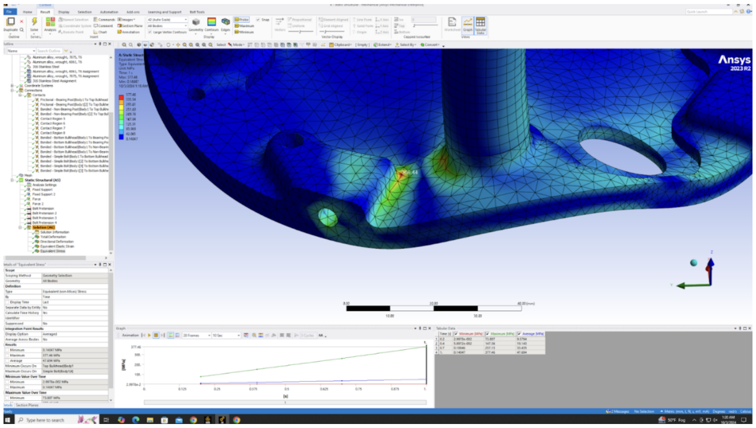


Figure 43: **Von-Mises stress, closeup of problem region 1**

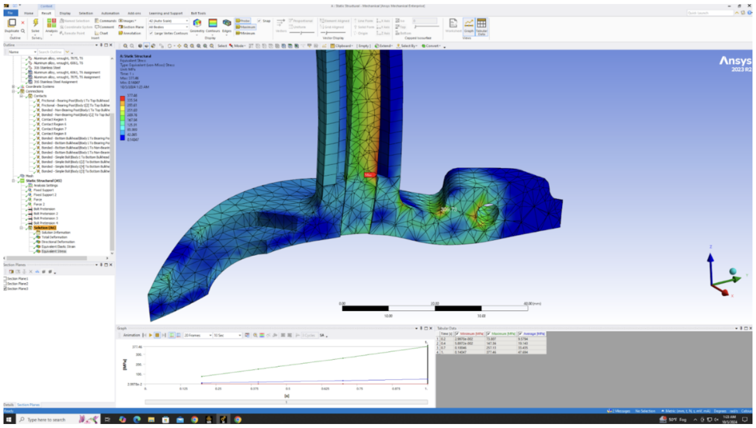


Figure 44: **Von-Mises stress, cross section of problem region 1**

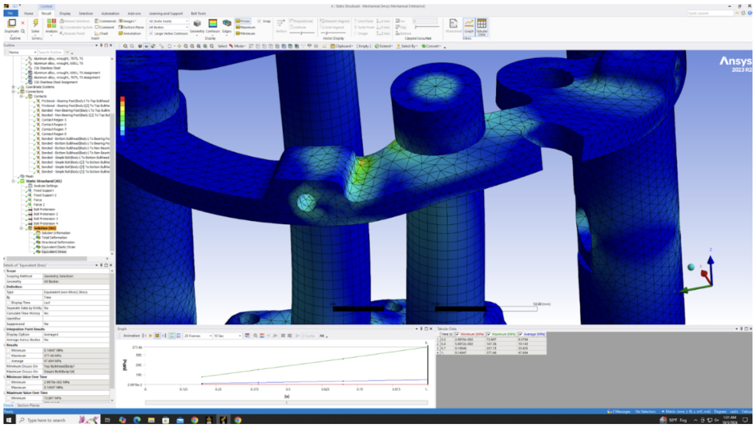


Figure 45: **Von-Mises stress, closeup of problem region 2**

6.2.2 Conclusion

There was a problematic region on the bulkhead between one of the non-bearing posts and radial bolt holes. It exhibited high stress and was likely a source for the large deformation observed nearby. Thus a design change was proposed which added an aluminum bridge in the problem area. The extra material was hypothesized to alleviate these issues.

6.3 Simulation 2

Model Description: Current version of simplified BLiMS assembly.

Load description: 0 N parachute load on each eyebolt. 11,000 N bolt preload on eyebolts, 5,000 N preload on bearing posts.

Material: 7075 for both bulkheads, bearing posts. 6061 for non-bearing posts. 1010 annealed carbon steel for eyebolts (somewhat close to material properties listed on the ASTM standard that our eye bolts fulfill).

Mesh: 148,000 elements.

6.3.1 Results

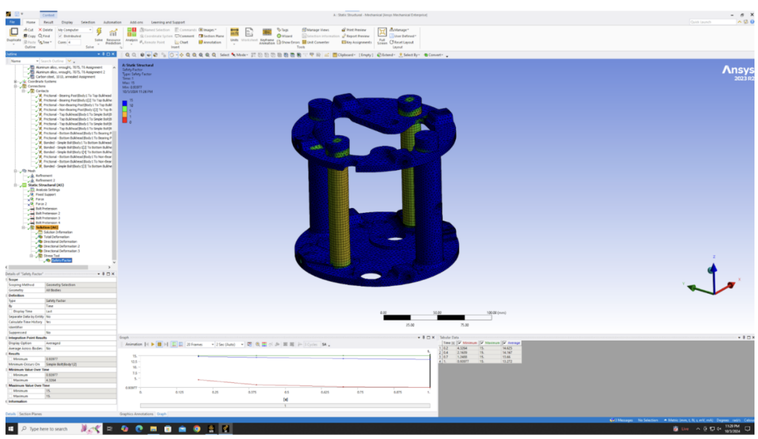


Figure 46: **Safety factor, full assembly frontside**

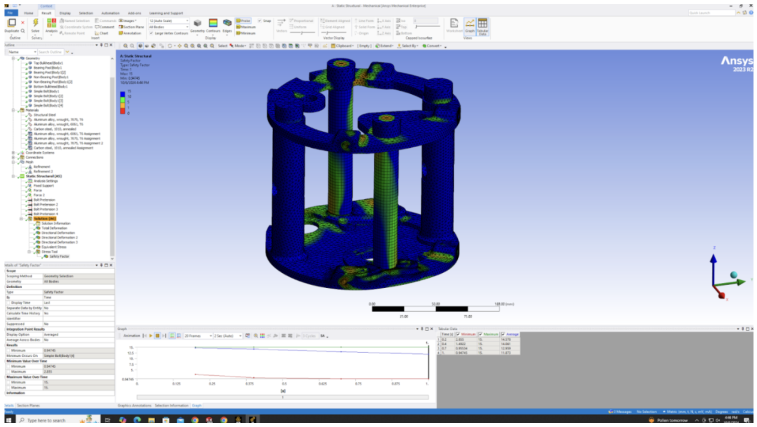


Figure 47: **Safety factor, full assembly backside**

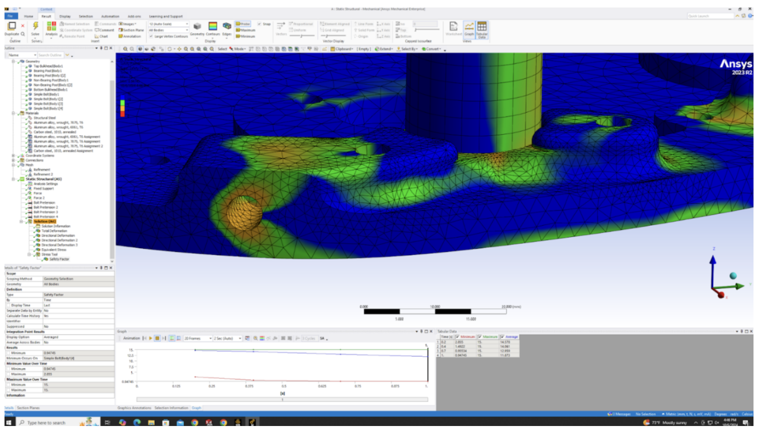


Figure 48: **Safety factor, problem region closeup**

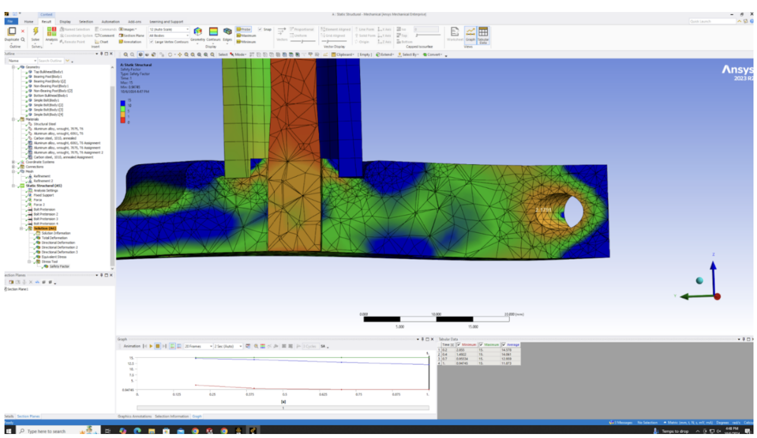


Figure 49: **Safety factor, problem region cross section**

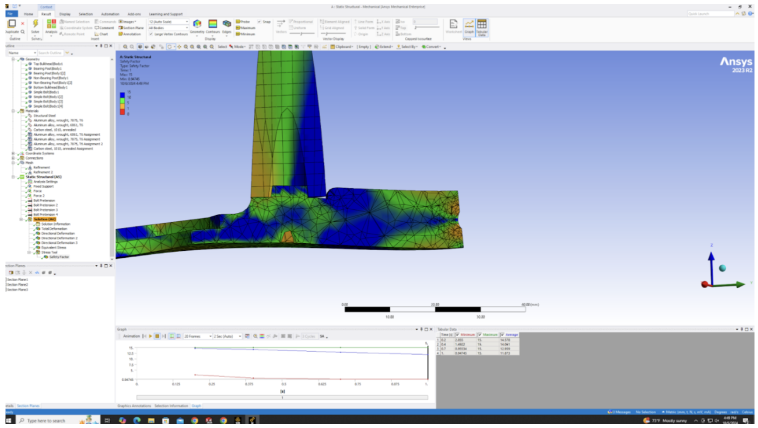


Figure 50: **Safety factor, problem region cross section (other side)**

6.3.2 Analysis

This simulation represents the state which BLIMs will typically be in; sitting inside the rocket, fully pretensioned, with no load from the chute. The safety factor on the non-bearing posts (under the 11,000 preload) is in the high 3s (relative to yield). This is okay. So we will proceed with simulating the actual loading scenario.

6.4 Simulation 3

Model Description: Current version of simplified BLiMS assembly.

Load description: 10,000 N parachute load on each eyebolt (20,000 N total). 11,000 N bolt preload on eyebolts, 5,000 N preload on bearing posts.

Material: 7075 for both bulkheads, bearing posts. 6061 for non-bearing posts. 1010 annealed carbon steel for eyebolts (somewhat close to material properties listed on the ASTM standard that our eye bolts fulfill).

Mesh: 148,000 elements.

6.4.1 Results

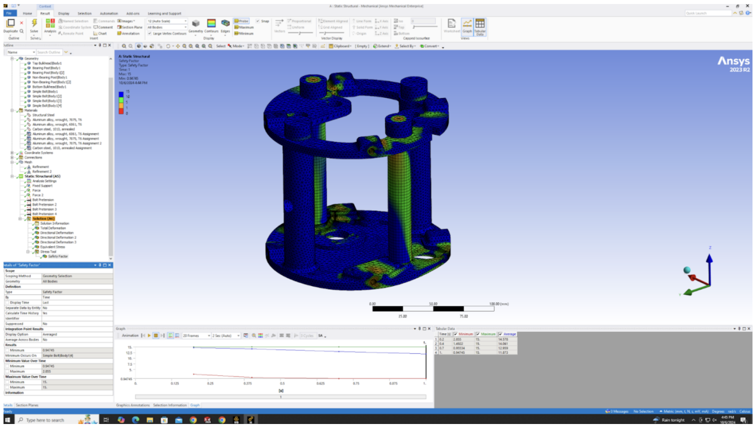


Figure 51: **Safety factor, full assembly frontside**

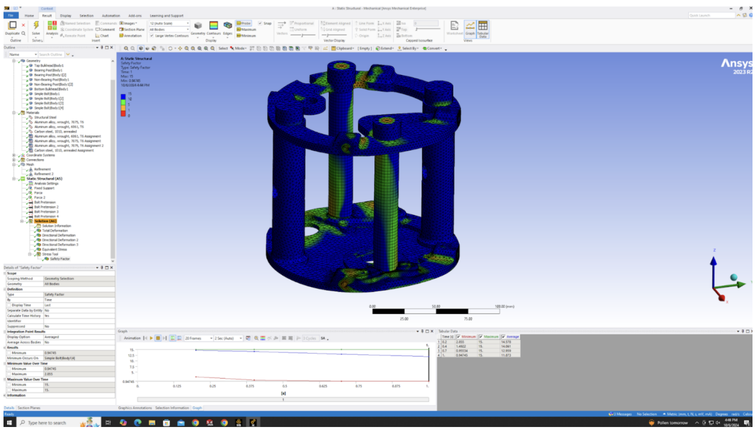


Figure 52: **Safety factor, full assembly backside**

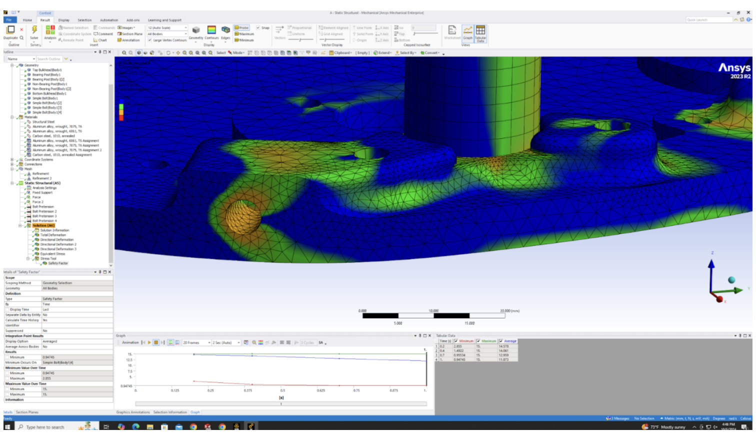


Figure 53: **Safety factor, problem region from simulation 2, closeup**

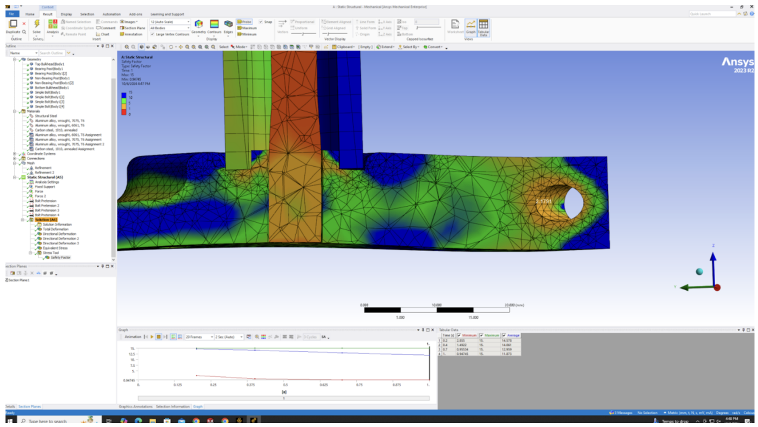


Figure 54: **Safety factor, problem region from simulation 2, cross section**

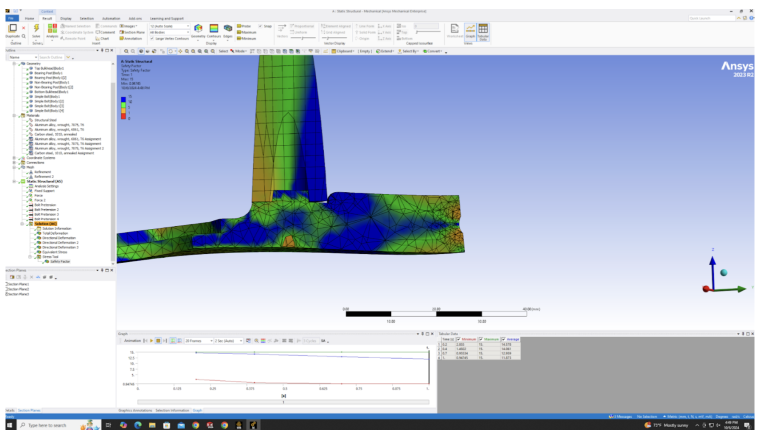


Figure 55: **Safety factor, problem region from simulation 2, cross section, opposite side**

6.4.2 Results

This simulation represents the extreme loading case of BLIMs during a 30g shock loading event from main deploying with no drogue. There are two hot spots, each one forming between one of the eyebolt mounting points and the nearest radial bolt hole (to the left). Most of the hot spots are in the low 3 for safety factor. Within the radial bolt holes, it dips down to mid 1s for safety factor. In the most concerning spot, it reaches around 0.95. While this is technically a failure accordinging to Ansys, I am comfortable proceeding with the design because I believe mismatches between reality and the Ansys model are leading to unrealistically low safety factors in this area.

Namely, the interior, cylindrical surface of the radial bolt holes are all set as "fixed supports" meaning they can not move. In reality, they will actually be coincident with a steel bolt, which in term will be mounted within the fiberglass airframe. Both the steel bolt and air frame will deform under these extreme loads, meaning the localized stress concentration in the corner of the sharp cylinder will not be present. The large safety margin (3+) in surrounding areas suggests that the overall part is capable of handling the loads and these 1 safety factor regions are the result of the model.

Additionally, the load cased used in this simulation assumes a 30g shock loading event, which will only occur if drogue fails to deploy and main pops out. For the anticipated operation of BLIMs, these high acceleration values are not expected.

7 Testing

BLiMS will undergo, at the very minimum, extensive benchtop testing and a single flight test before being installed in the competition launch vehicle. If the first flight test proves unsuccessful, additional drop tests may be performed.

7.1 Benchtop Testing

Though BLiMS is highly integrated with the rocket's airframe, parachute, and AV bay, it can still be effectively tested on its own. These "benchtop" tests will be determined by software members responsible for programming BLiMS. However, they will certainly include:

- BLiMS spinning in pre-programmed manner under no load, with no brake lines attached. This separates potential mechanical issues from the validation of electronics and software.
- BLiMS spinning in pre-programmed manner under load, applied to spooled brake lines with weights or springs. Ensures that behavior of BLiMS observed in the un-loaded benchtop testing remains consistent even when the lines are loaded.

7.2 L3 Flight Testing

To test BLiMS in an actual flight environment, it is going to be launched on an L3 rocket in early January 2025. The L3 is 6" (like the competition launch vehicle) and will be 12 feet tall, weighing in at 60 lbs. This launch test is ideal targeting three aspects of BLiMS.

Firstly, an L3 test launch will reveal whether the current scheme for connecting the parachute's brake and static lines to BLiMS will lead to tangling. This is a major concern, given there are also wires running to the tender descender main parachute deployment device mixed in with all the parachute lines. If any lines cross over one another, it can very easily lead to catastrophic parachute failure and ballistic re-entry.

Secondly, an L3 test launch will ensure BLiMS can perform movements under actual loads from the parachute. While weights in a lab are a good starting place, actual parachute loads are not perfectly symmetrical nor constant over time. If the BLiMS motor is unable to manipulate the parachute on the significantly-lighter L3, it is unlikely to perform well on the 130lb launch vehicle.

Finally, an L3 test launch will give software members the ability to tune their flight model. Currently, the flight routine for BLiMS during the L3 launch is a series of increasingly aggressive banks. By performing these banks to the left and right, a relationship between brake line retraction distance and bank angle/turn radius can hopefully be established. This "tuning" is essential to developing a successful guided BLiMS scheme.

Validation of test results during a launch is challenging given the rocket is necessarily thousands of feet away when these tests are taking place. Therefore, for the L3 launch, a camera module was designed (described in detail in a separate technical report) to mount on the outside of the rocket and capture footage of both the parachute (looking up) and BLiMS mechanism (facing inside). Below is an image capture from the camera looking at the inside of BLiMS while on the ground preparing for launch.

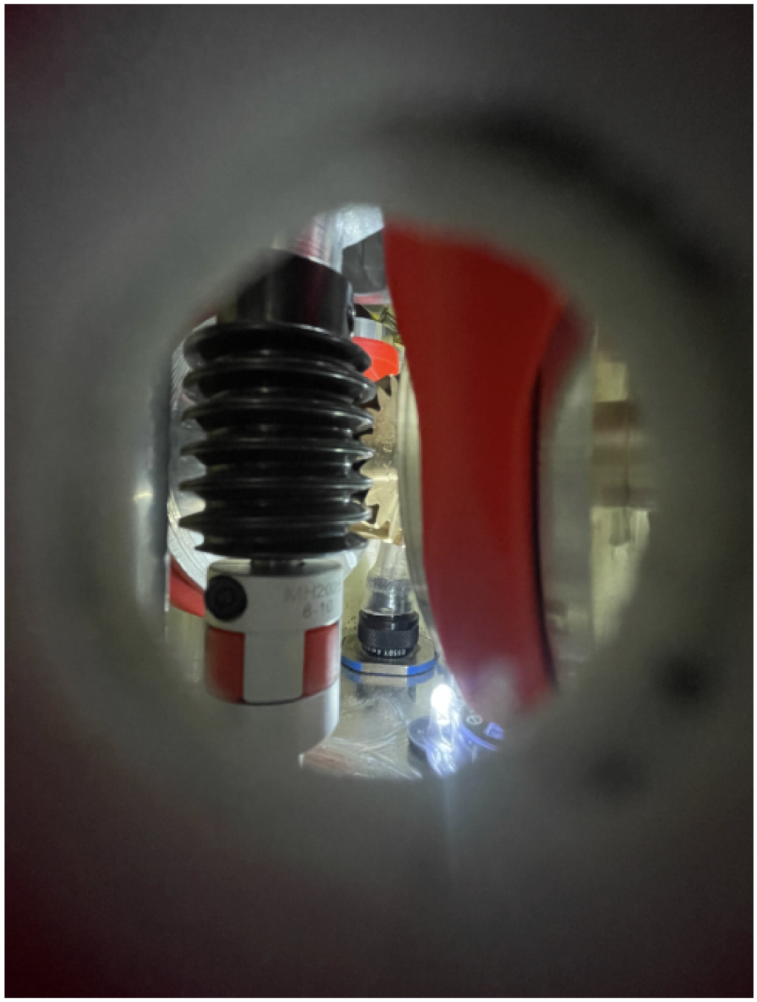


Figure 56: **View of BLiMS from the external camera system. Note the white LED which was installed prior to the L3 launch to provide consistent light for the cameras.**

Note, the original L3 launch was scheduled for December 2024. BLiMS was installed and ready to operate, but a nozzle failure on the launch pad ended up leading to the rocket partially destroying itself. The BLiMS mechanism was unaffected and will be remounted in the January 2025 L3 with little modification.

7.3 Subsequent Drop Tests

If the L3 launch demonstrates successful main parachute deployment, BLiMS manipulating the brake lines, and usable bank angle information for software, then BLiMS is unlikely to require additional testing before launching on the competition launch vehicle. However, if any of those conditions are not may, further drop tests may be warranted. These tests will likely be targeted at particular weaknesses identified through the L3, though it's fruitless to speculate what they may specifically be without the L3 launch result.

7.4 Structural Testing

The Ansys Static Structure analysis was deemed sufficient to fly BLiMS on the launch vehicle without further structure testing. It's worth highlighting that many objectively weaker bulkheads have been flown and single-handedly, successfully managed parachute loads. While BLiMS' superstructure's unusual bolting arrangement could theoretically introduce unexpected failure modes, the system is by most standards overbuilt and therefore very unlikely to succumb to rocket-threatening damage.

8 Manufacturing

Components for BLiMS were manufactured using manual milling, manual lathing, CNC milling, and 3D printing.

The top and bottom bulkhead were done almost entirely on the Haas. CAM preparation, workholding, etc.. was managed by our team's machinists and not within the scope of this technical report. The only parts of the top and bottom bulkhead not CNC machined were the threaded holes which were tapped by hand after the fact.

The pulleys, posts, and shaft spacers were all lathed on manual lathes. All components are relatively straightforward to lathe.

The flats on the horizontal and vertical shafts were machined on a manual mill.

All 3D printed components were made on a Bambu Labs P1S printing PolyMaker Polymax PLA with 100

See the appendix for all machining drawings.

9 Supply Chain

Below is a table containing a complete BOM for BLiMS. All prices are accurate as of December 2024.

Item	Price Per Unit	Quantity	Sub Price	Order Location	Serial #
Eyebolts	11.01	4	44.04	McMaster	3014T974
Upper Bolts	11.79	1	11.79	McMaster	91257A651
Lock Nuts	14.67	1	14.67	McMaster	90648A215
Washers	6.59	1	6.59	McMaster	92141A031
Bearings	9.43	6	56.58	McMaster	7804K145
Shaft	13.6	2	27.2	McMaster	4143N18
Set Screws	15.21	1	15.21	McMaster	91375A438
Shaft Coupler	3.26	3	9.78	Stepperonline	MH2025-8-10
Motor	119	1	119	ODrive Robotics	
Motor Driver	229	1	229	ODrive Robotics	
Battery Holders	9.99	2	19.98	Amazon	
Batteries	3.55	30	106.5	18650batterystore	
Battery Chargers	29.99	2	59.98	18650batterystore	
Lower Bolts	10.26	1	10.26	McMaster	90128A575
Aluminum Tubing	16.61	2	33.22	McMaster	89965K377
VHB Tape	32.9	1	32.9	McMaster	3744A33
		Grand total	796.7		

Figure 57:

Most components were ordered from McMaster-Carr without issue.

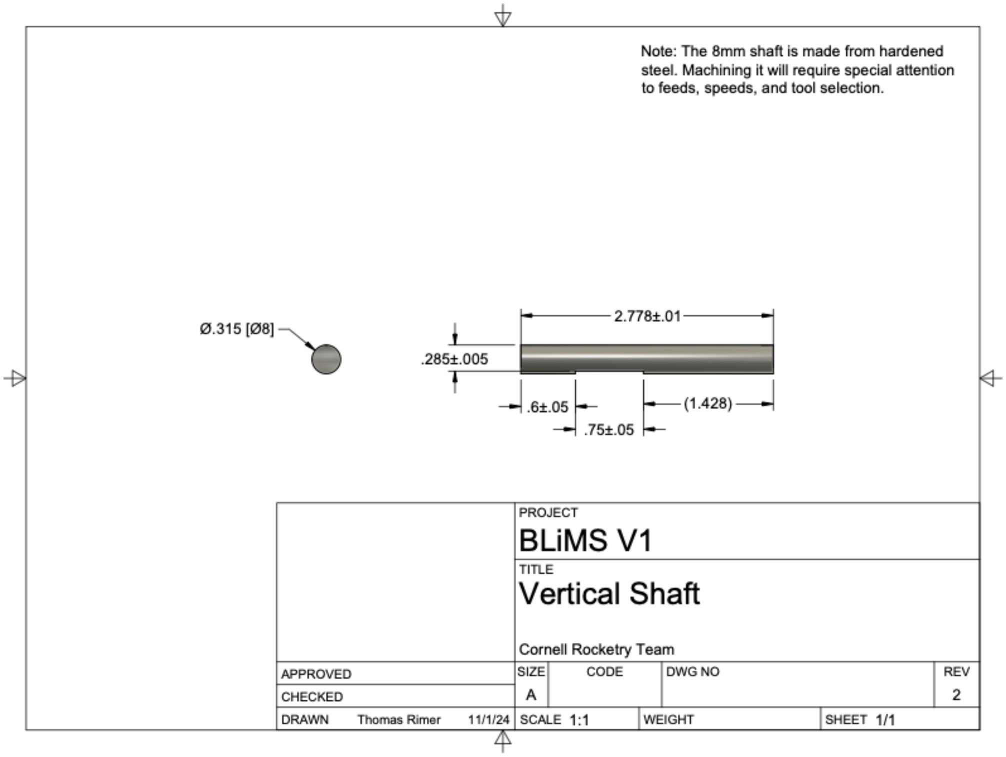
A single shaft coupler was ordered from Stepperonline—a reliable source for stepper motors, stepper motor drivers, and motor related hardware. At the time, an order was going in for a separate project so it was reasonable to purchase from them, however, shaft couplers are fairly ubiquitous and can be found just about anywhere.

ODrive Robotics provided a 25

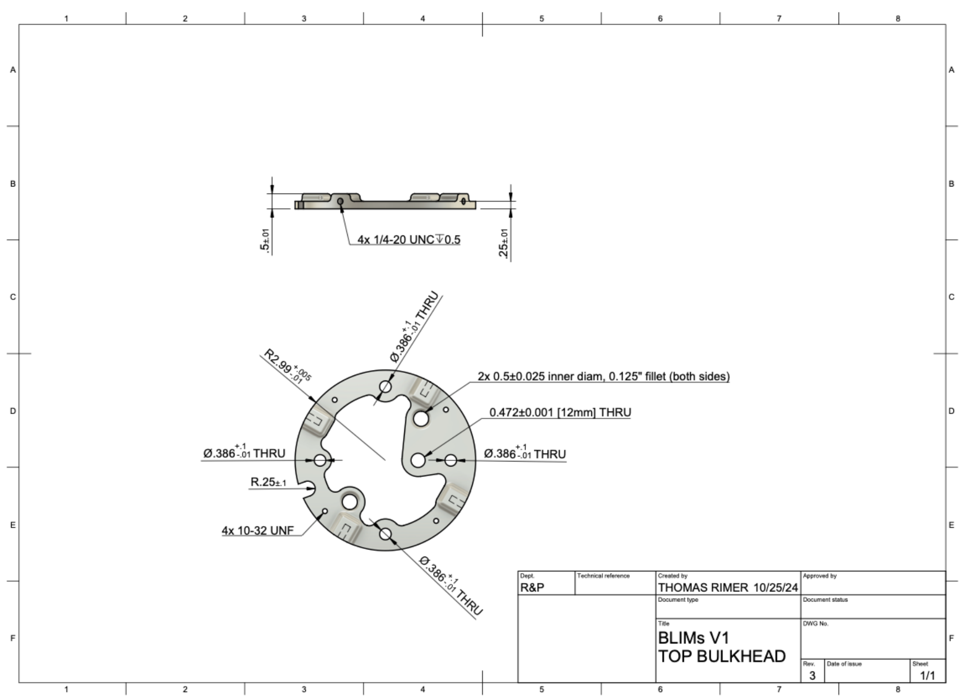
The total system comes in around $800 not including the 6061 stock used in the machine, the bulkheads, pulleys, and various shaft spacing hardware.

10 Appendix

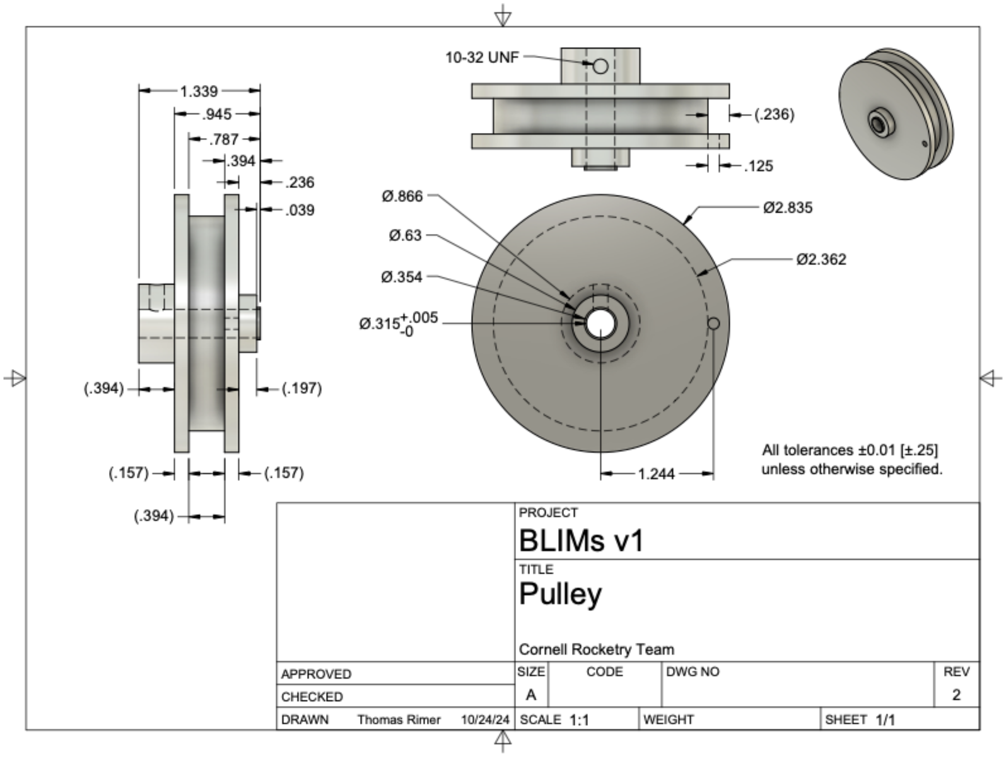
Mechanical drawings of all machined components.

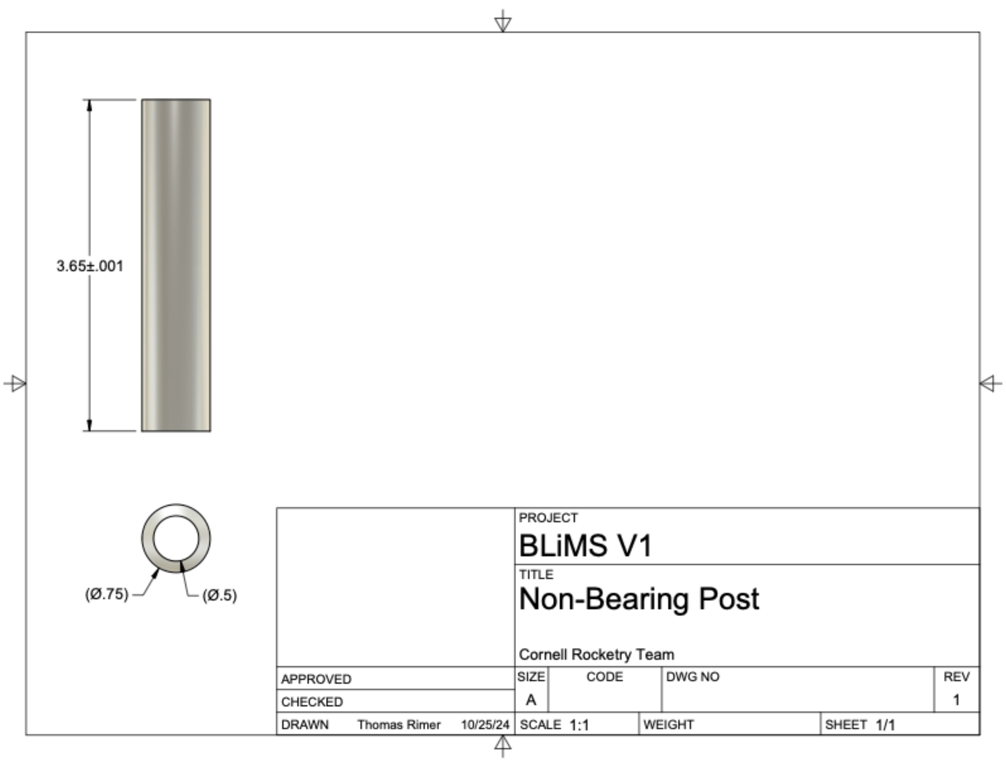


Note: The 8mm shaft is made from hardened steel. Machining it will require special attention to feeds, speeds, and tool selection.
Ø.315 [Ø8]
2.778±.01
.285±.005
.6±.05
.75±.05
(1.428)
PROJECT
BLiMS V1
TITLE
Vertical Shaft
Cornell Rocketry Team
APPROVED
CHECKED
DRAWN Thomas Rimer 11/1/24
SIZE
A
CODE
DWG NO
REV
2
SCALE 1:1
WEIGHT
SHEET 1/1

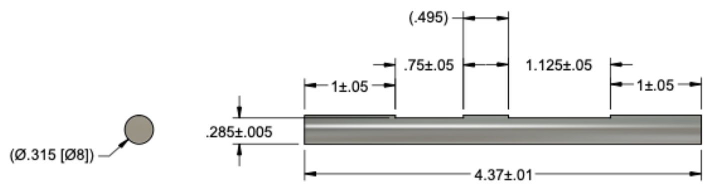


4x 1/4-20 UNC 0.5
.5±.01
.25±.01
Ø.386 THRU
R2.99
2x 0.5±0.025 inner diam, 0.125" fillet (both sides)
0.472±0.001 [12mm] THRU
Ø.386 THRU
Ø.386 THRU
R.25±.1
4x 10-32 UNF
Ø.386 THRU
Dept.
R&P
Technical reference
Created by
THOMAS RIMER 10/25/24
Approved by
Document type
Document status
Title
BLIMs V1
TOP BULKHEAD
DWG No.
Rev.
3
Date of issue
Sheet
1/1

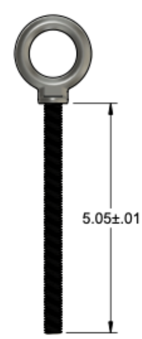

10-32 UNF
1.339
.945
.787
.394
.236
.039
(.236)
.125
Ø.866
Ø.63
Ø.354
Ø.315+.005 -0
Ø2.835
Ø2.362
(.394)
(.197)
(.157)
(.157)
(.394)
1.244
All tolerances ±0.01 [±.25] unless otherwise specified.
PROJECT
BLIMs v1
TITLE
Pulley
Cornell Rocketry Team
APPROVED
CHECKED
DRAWN Thomas Rimer 10/24/24
SIZE A
CODE
DWG NO
REV 2
SCALE 1:1
WEIGHT
SHEET 1/1


3.65±.001
(Ø.75)
(Ø.5)
PROJECT
BLiMS V1
TITLE
Non-Bearing Post
Cornell Rocketry Team
APPROVED
CHECKED
DRAWN Thomas Rimer 10/25/24
SIZE A
CODE
DWG NO
REV 1
SCALE 1:1
WEIGHT
SHEET 1/1

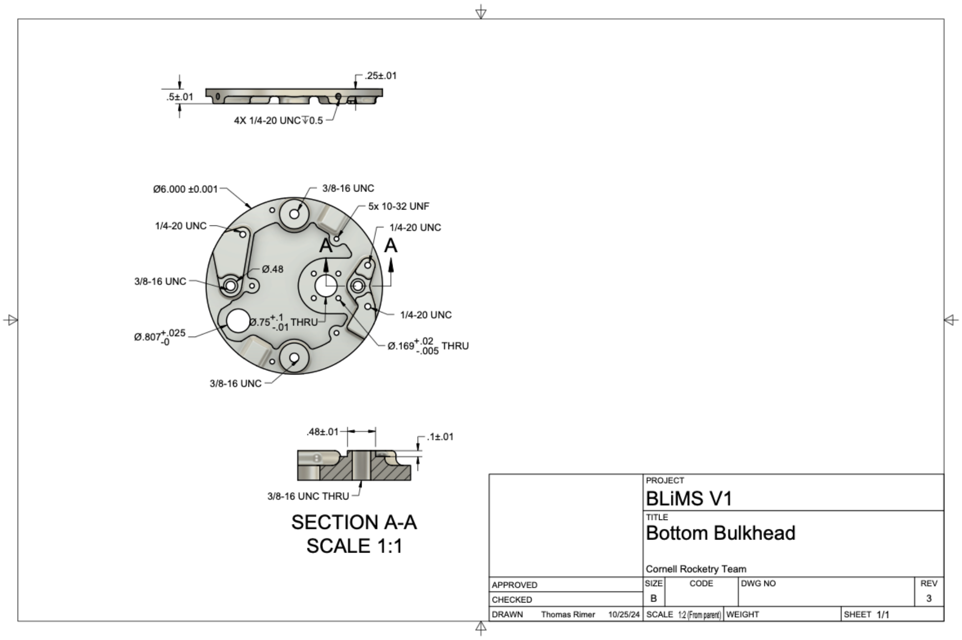
Note: The 8mm shaft is made from hardened steel. Machining it will require special attention to feeds, speeds, and tool selection.

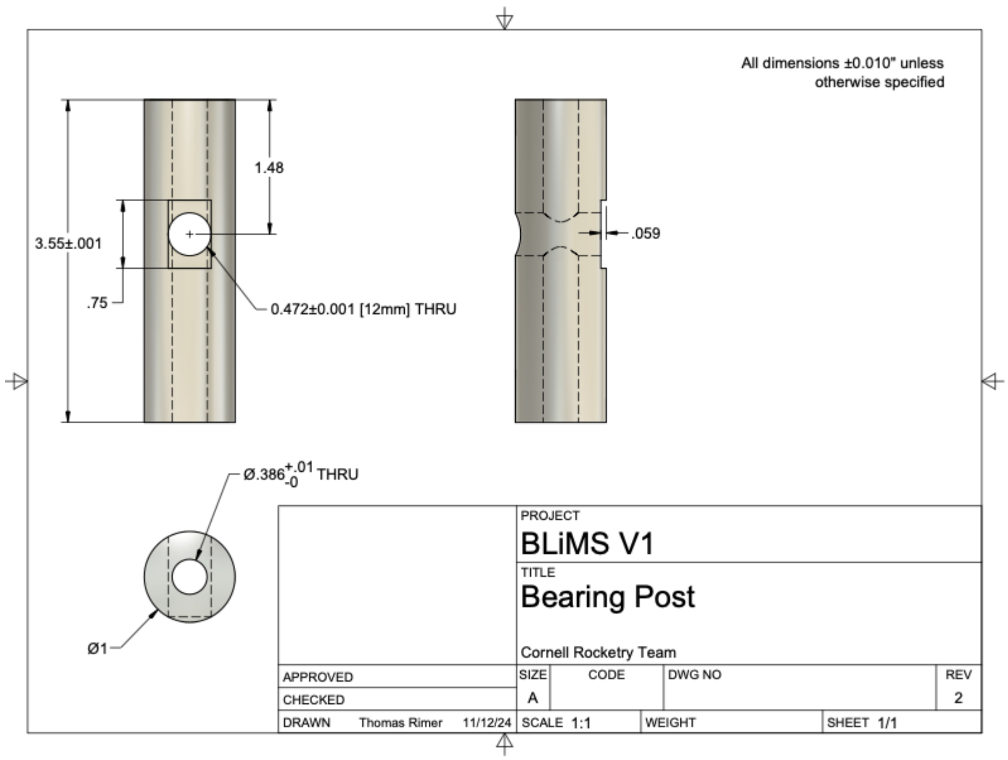


PROJECT	BLiMS V1			
TITLE	Horizontal Shaft			
	Cornell Rocketry Team			
APPROVED	SIZE A	CODE	DWG NO	REV 2
CHECKED				
DRAWN Thomas Rimer 11/1/24	SCALE 1:1	WEIGHT	SHEET 1/1	



PROJECT	BLiMS V1			
TITLE	Eyebolt			
	Cornell Rocketry Team			
APPROVED	SIZE A	CODE	DWG NO	REV 1
CHECKED				
DRAWN Thomas Rimer 10/25/24	SCALE 1:2	WEIGHT	SHEET 1/1	


.5±.01
.25±.01
4X 1/4-20 UNC↧0.5
Ø6.000 ±0.001
3/8-16 UNC
5x 10-32 UNF
1/4-20 UNC
1/4-20 UNC
A
A
Ø.48
3/8-16 UNC
1/4-20 UNC
Ø.75 +.1 -.01 THRU
Ø.807 +.025 -0
Ø.169 +.02 -.005 THRU
3/8-16 UNC
.48±.01
.1±.01
3/8-16 UNC THRU
SECTION A-A
SCALE 1:1
PROJECT
BLiMS V1
TITLE
Bottom Bulkhead
Cornell Rocketry Team
APPROVED
CHECKED
DRAWN Thomas Rimer 10/25/24
SIZE B
CODE
DWG NO
REV 3
SCALE 1:2 (From parent)
WEIGHT
SHEET 1/1


All dimensions ±0.010" unless otherwise specified
1.48
3.55±.001
.75
0.472±0.001 [12mm] THRU
.059
Ø.386 +.01 -0 THRU
Ø1
PROJECT
BLiMS V1
TITLE
Bearing Post
Cornell Rocketry Team
APPROVED
CHECKED
DRAWN Thomas Rimer 11/12/24
SIZE A
CODE
DWG NO
REV 2
SCALE 1:1
WEIGHT
SHEET 1/1