Spring 2021 Technical Report

Cornell Rocketry Team
Brake Line Manipulation System (BLiMS)
Recovery and Payload
Gabe Mitchell [gfm48]

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

Summary

1 Recovery and Payload Semester Summary

In accordance with its name, the Recovery and Payload subteam handles two distinct sections of the LV. The recovery systems are tasked with safely guiding the rocket to the ground after apogee, while the payload simply has to be some feat of engineering, such as a science experiment, a physical system, or anything else that the payload team can imagine. During the Spring 2021 semester, the Recovery and Payload subteam manufactured and tested the Payload system designed by Sam Noles in the Fall of 2021. Information about the system itself and the testing can be found in tech reports written by Sam Noles, Annabel Lian, and Matt Bryan. In the Spring 2021 semester, the Recovery and Payload subteam also worked on the Brake Line Manipulation System (BLiMS); the system was redesigned, manufactured, assembled, and tested. This tech report will detail that process. It should be noted that neither the payload nor recovery systems have been used in the LV, as CRT did not launch during the Spring 2021 semester.

2 Recovery Parent and Child Systems

As was previously stated, the job of the recovery system is to safely navigate the LV to the ground after apogee. Additionally, the recovery system must autonomously guide the LV to a predetermined GPS coordinate. The recovery system consists of three main subsystems: the Parachute, Parachute Dynamics, and BLiMS. The parachute is the canopy that suspends and steers the LV as it approaches the predetermined GPS coordinate. The parachute is the parent system to parachute dynamics. Parachute dynamics is not a physical system, but rather a model which will continuously determine the ideal orientation of the parachute in order for the LV to reach the predetermined GPS coordinate in the most efficient manner. Parachute dynamics will interact with the parachute through its child system, BLiMS. BLiMS stands for Brake Line Manipulation System, and it has two main functions. First, at the direction of Parachute dynamics, BLiMS will extend and retract the brake lines of the parachute, thereby guiding the LV along the most efficient path to its predetermined destination. Secondly, BLiMS will serve as a mount for both the parachute and the shock cord. This parent child tree is the exact same as that described in my Fall 2020 tech report.

3 BLiMS Requirements and Constraints

The requirements and constraints for BLiMS listed below were developed during the Fall 2020 semester. One requirement has been updated, whereas none of the constraints have changed. There is further analysis for certain requirements and constraints below the lists.

Requirements

1. Pull and release brake lines which are in 50 lbs of tension
2. Very accurately monitor the length of the brake lines
3. Serve as a mount for the parachute
4. Serve as a mount for the shock cord
5. Suspend the dry rocket during descent, notably during parachute deployment, which will require BLiMS to withstand a shock force estimated to be no more than 1000 pounds
6. Suspend the components attached to the shock cord, notably during parachute deployment, which will require BLiMS to withstand a shock force of no more than 250 pounds

Constraints

1. A portion of the forward section can not mount to the air frame
2. The system must fit within a 5.75 inch diameter cylindrical space
3. The system can not use a hollowed cylinder to mount to the air frame
4. The system must use the motors bought last year for the first iteration of BLiMS
5. The system must be as compact as possible
6. The system must be as light as possible

In requirement 1, 50 pounds of brake line tension is far in excess of what is actually predicted by an online resource, which estimates the tension in parachute brake lines to be about 15 pounds [1]. However, because the source is a website for a skydiving service and not a more formal resource, it was appropriate to require that BLiMS retract and extend brake lines in greater tension than those on a normal parachute. 50 pounds was chosen for two reasons. One, it allows for a factor of safety above three, and two, it exceeds the pulling force that most any skydiver could handle. The parachute being used is designed for people, so we can expect that the brake lines will be in a tension no greater than what a person could handle. Therefore, if BLiMS can expand and retract lines that are in 50 pounds of tension, we can be absolutely confident that it will be able to steer the LV.

In requirement 5, 1000 pounds of shock force during parachute deployment is yet another over estimate of the actual shock force that will be experienced by the LV during deployment. The estimate was done by Sam Noles for the Spring 2020 Test Readiness Review. His work is as follows:

The following equation from Jean Povtin of Saint Louis University [2] was used to estimate the maximum force upon parafoil deployment:

$$F_{max} = \frac{mV_i}{(t_f - t_i)I_F^{if}}[1 - \frac{V_f}{V_i} - \frac{g(t_f - t_i)}{V_i}] \tag{1}$$

The term I_F^{if} is known as the drag integral and is approximately equal to $\frac{1}{2}$ for high mass ratio deployments [2]. The initial velocity will be less than or equal to $150\frac{ft}{s}$, as required by the competition. The final velocity must be less than 30 $30\frac{ft}{s}$, and it will estimated at $15\frac{ft}{s}$ for our calculations. All approximations are being made to ensure that the forces on BLiMS are over estimated. By watching videos of parachutes deploying, it is determined a reasonable estimate for $t_f - t_i$ is 1 second. Entering these values gives us a maximum force of 1040 Ibf which equates to around 10g acceleration. This matches with research from the Parks College Parachute Research Group which says that personal parachute deployment acceleration can range from 3-12 g's [3]. Because the exact forces are unknown, BLiMS will be designed to withstand the upper end of this spectrum.

Requirement 6 was updated this semester. Originally, the shock cord mount was designed to withstand 80 pounds of force. This constraint was made without considering the substantial shock force on the shock cord mount that will occur when the parachute is deployed and the LV rapidly decelerates. 250 pounds was chosen as the new constraint for the shock cord mount. Because the shock force that BLiMS experiences when the entire LV decelerates during parachute deployment has an upper bound of 1000 pounds, 250 pounds was deemed a reasonable upper bound for the force exerted on the shock cord mount when the components attached to the shock cord decelerate.

Constraint 1 exists because part of the area where BLiMS will exist in the rocket will be used to mount other components. Constraint 3 exists because the previous recovery system mounted to the LV via a hollowed out cylinder, which proved to be far too troublesome to machine. Lastly, reusing the motors from last year's iteration of BLiMS was the most cost effective and efficient option, as no more motors needed to be bought, and the electrical subteam already has experience working with them. Thus, constraint 4 exists in its current form.

4 Fall 2020 overview

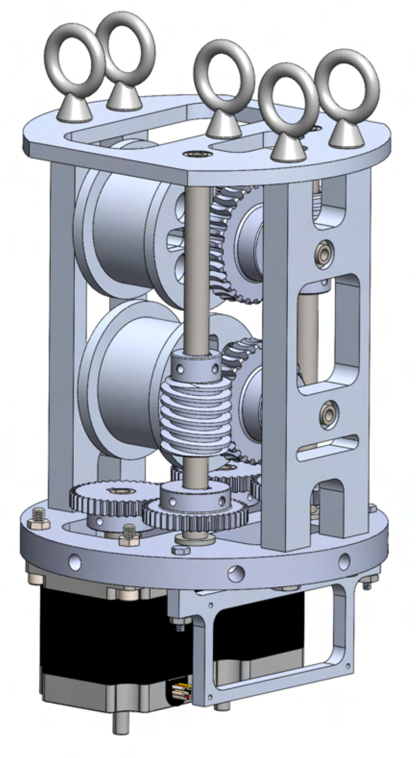

Figure 1: **Fall 2020 BLiMS CAD**

To address the requirements and constraints listed above, I designed the first iteration of BLiMS pictured above during the Fall 2020 semester. This design is detailed thoroughly in my Fall 2020 tech report, so I will only describe it briefly here. This iteration of BLiMS includes two wheel drums, one on top of the other. Each wheel drum is mounted to a horizontal shaft with a worm wheel spun by a worm gear on a vertical shaft. The two vertical shafts have spur gears attached at the aft end, which are mated with identical spur gears attached to motor shafts. Therefore, spinning the motors rotates the wheel drums and thus extends or retracts the parachute's brake lines. The design's structural components include 5 eye bolts at the forward end that serve as mounts for the parachute and shock cord. The eye bolts are mounted to the top bulkhead as well as two vertical mounts. The vertical mounts also constrain the horizontal shafts. Lastly, the mounts, vertical shafts, and motors are all attached to the bottom bulkhead, which is where BLiMS mounts to the LV.

The Fall 2020 version of BLiMS was redesigned for a few reasons. Although the height and weight of this version were deemed acceptable, we determined that both parameters could be further optimized with a redesign. Furthermore, the motor shafts being fixed at only one end was problematic, as the loads applied to the spurs gears may have caused bending in the motor shafts, which would have severely worsened the connection between the gears.

5 Spring 2021 Redesign

With these concerns and the existing requirements and constraints in mind, BLiMS was redesigned. The final iteration is pictured below.

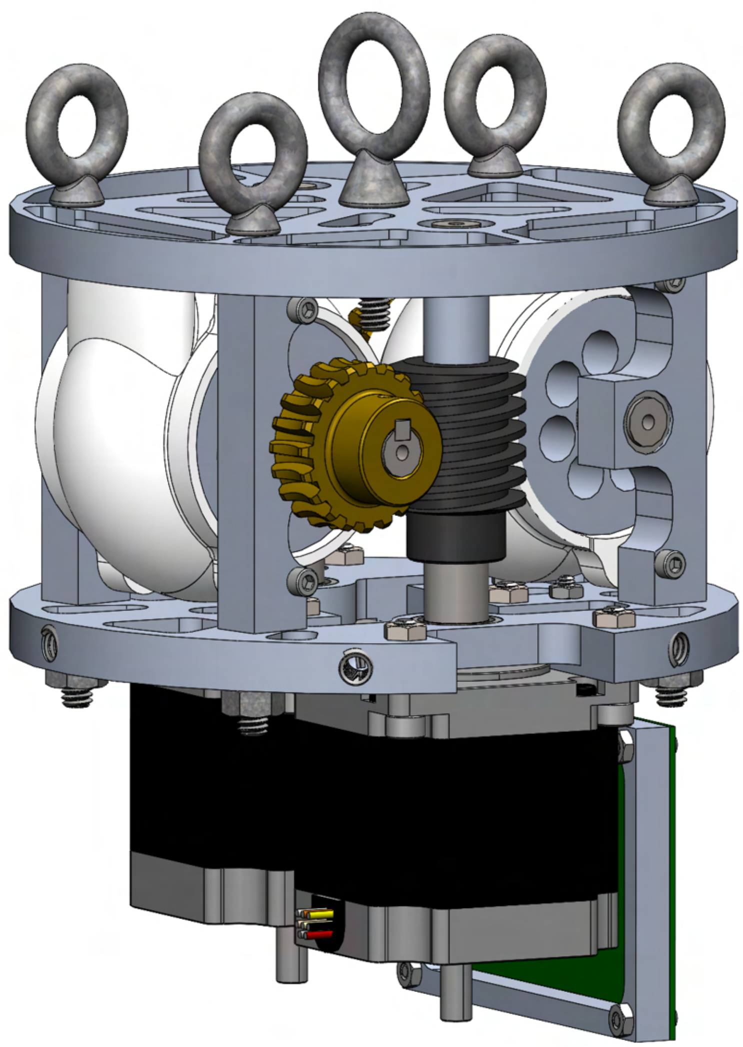

Figure 2: **Spring 2021 BLiMS CAD**

Very general design concepts were maintained in this iteration: BLiMS still consists of two wheel drums connected to a motor via shafts and worm gears; when the motors spin, the wheel drum do too, causing the brake lines to either extend or retract, thus steering the parachute. Furthermore, there are still similar structural components in place, including eye bolts, two bulkheads, and mounts in between the bulkheads. However, important changes include the removal of the spur gears and the wheel drums now being side by side. The final design is described below in color.

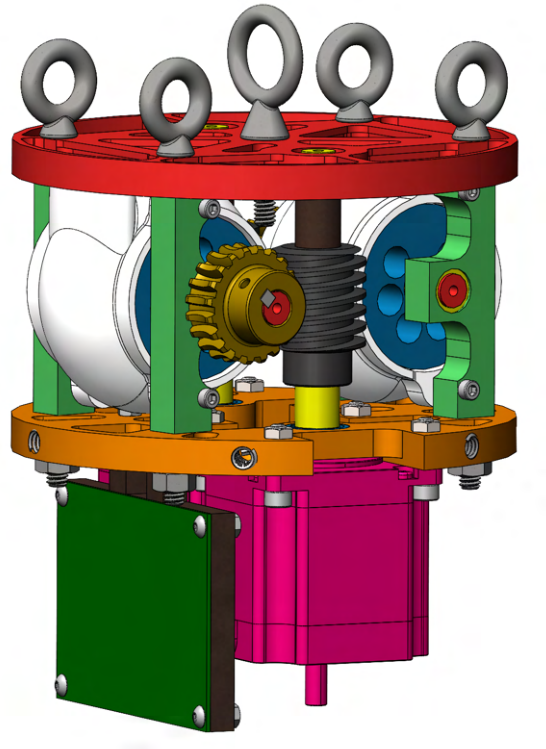

Figure 3: **BLiMS CAD in Color**

BLiMS mounts to the rocket via the aft bulkhead, pictured in orange. The bulkhead has six radial holes, each with a 2.5 D 1/4-20 helicoil inserted into them. The helicoils, along with all other fasteners, are pictured in gray. The motors, pictured in pink, mount onto the aft bulkhead via screws and nuts. The vertical worm shafts, in yellow, attach to the the aft bulkhead via bearings that are press fit into the aft bulkhead. The bearings are in blue. The aft end of the vertical shafts have a hole through which the motor shafts pass. Two set screws in the vertical shaft fasten onto the motor shaft, and the two components are completely fixed relative to each other. Attached to the yellow vertical shafts are black worm gears via key. The worm wheels are in bronze, and they are attached to the red horizontal wheel drum shafts via key. The blue wheel drums are also attached to the red horizontal shafts via key. The horizontal shafts are constrained by two mounts each. The mounts are in green, and they contain a bushing (pictured in yellow) that allows the horizontal shaft to rotate freely. Each mount has two horizontal through holes, through which screws pass the secure the wheel drum covers, pictured in white. The wheel drum covers ensure that the brake lines stay wound around the wheel drums and do not interfere with other components, notably the gears. The green mounts also have one vertical through hole, through which the four outer eye bolts pass. The parachute will mount onto the four outer eye bolts. The outer eye bolts clamp both the mounts and the forward bulkhead between their own shoulder and the bottom bulkhead. The forward bulkhead is in red. It serves as mount for the two vertical shafts via bearings press fit into the top bulkhead. Pressed against the bearings in the top bulkhead are two shaft collars, pictured in brown. The shaft collars prevent the black worm gears from moving axially.

The top bulkhead also serves as a mount for the central eye bolt, onto which the shock cord is mounted. Lastly, the board mount in brown mounts to the aft bulkhead, and it secures the recovery board to BLiMS.

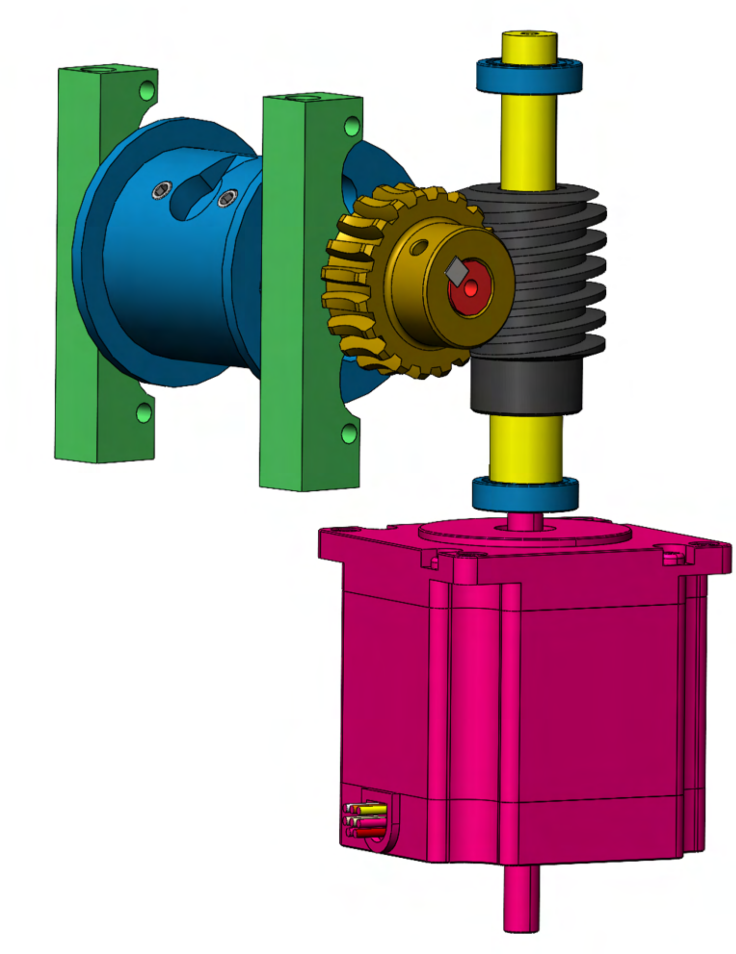

Figure 4: **BLiMS brake line manipulating components**

Understanding how BLiMS manipulates the parachute brake lines is easier when certain components are hidden. In the image above, only the components that contribute directly to rotating the wheel drum are shown. Note that in this view, the bearings that press fit into the forward and aft bulkheads are visible. Note also that it's more apparent how the motor interfaces with the vertical shaft. Lastly, much more of the wheel drum is now visible. The parachute brake line mounts to the wheel drum via a loop at the end of the brake line that wraps around a screw that is fastened into the wheel drum. The slot in the wheel drum ensures the brake line loop and mounting screw do not stick out and interfere with the rest of the brake line winding around the wheel drum.

6 Parts and Manufacturing

The parts included in BLiMS were both manufacturing in house and commercial off the shelf. The parts bought included all fasteners (helicoils, bolts, nuts, and keys), shaft components (bushings and bearings), the two sets of worm gears, and the two motors. The parts manufactured in house are pictured below.

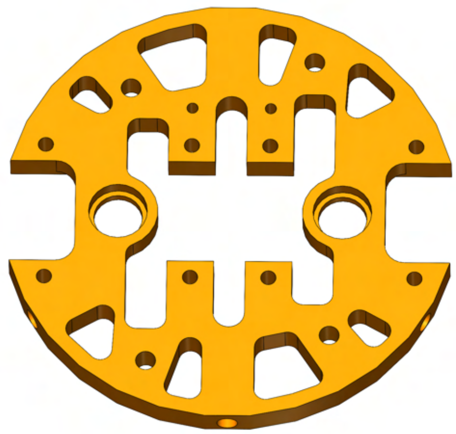

Figure 5: **Aft Bulkhead**

The aft bulkhead is made of aluminum 6061. It was manufactured primarily on the red lathes and mills, except for the mass reductions on the outside, which were done on the CNC.

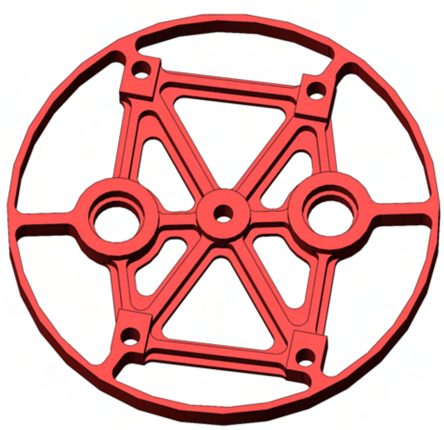

Figure 6: **Forward Bulkhead**

The forward bulkhead is made of aluminum 6061, and its boxed geometry required that it be made entirely on the CNC. The small flanges at the bottom of the beams use material in an efficient way that still maintains stiffness.

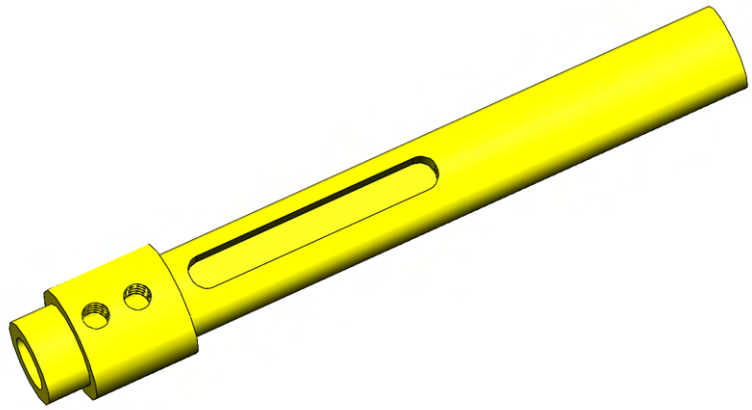

Figure 7: **Vertical Shaft**

The vertical shafts are made of steel, as is best practice. Both vertical shafts were turned on the hardinge before slots and threaded holes were added on red mills.

Figure 8: **Shaft Collar**

The shaft collars are made of Aluminum 6061 and they were manufactured on the red lathes. Its outer and inner diameter align with those of the inner race of the bearings.

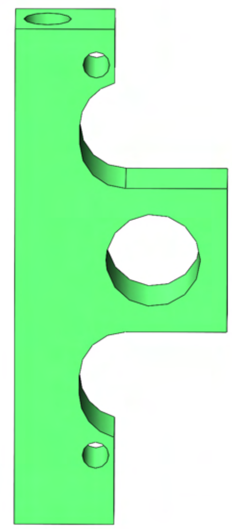

Figure 9: **Mount**

All four mounts are made of Aluminum 6061, and they were manufactured on the red mills.

Figure 10: **Wheel Drum Shaft**

Like the vertical shafts, the horizontal wheel drum shafts are made of steel; they were turned on the hardinge before slots were added on the red mills.

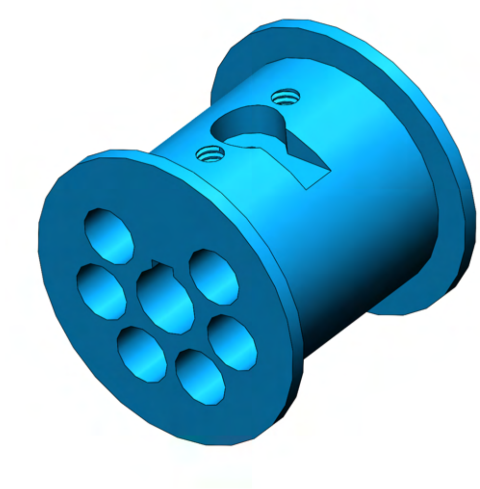

Figure 11: **Wheel Drum**

The wheel drums are made of Aluminum 6061. They were turned on the red lathes before slots, threaded holes, and mass reductions were done on the red mills. The key way was broached by hand.

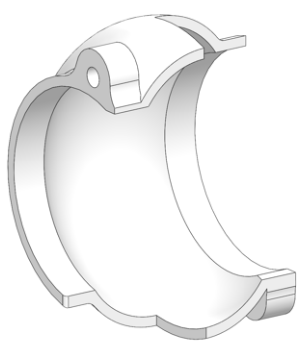

Figure 12: **Back Wheel Drum Cover**

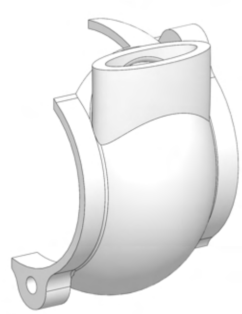

Figure 13: **Front Wheel Drum Cover**

The wheel drum covers are 3D printed, and there's two for each wheel drum. The wheel drum cover was made of two pieces so as to ensure that it could be added to BLiMS once the rest of the assembly was complete.

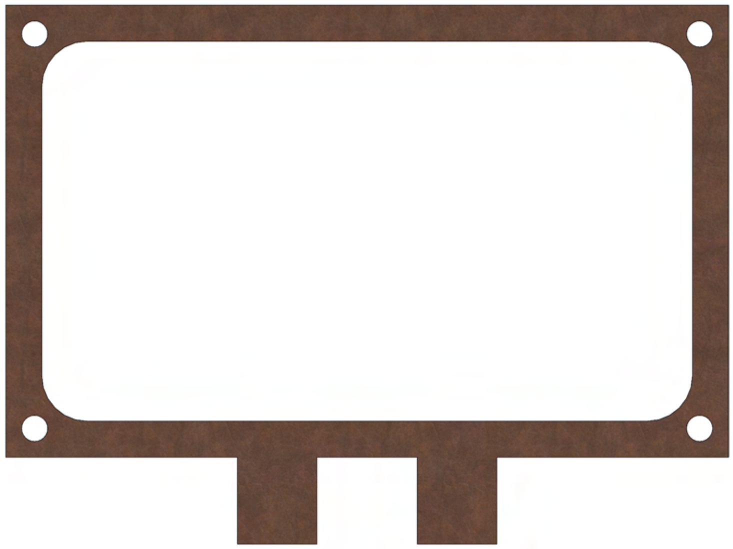

Figure 14: **Board Mount**

Because the recovery board has not yet been finalized, the board mount's dimensions are still in flux, so it hasn't been manufactured yet.

7 Bolt Pretension

Before analysis could be conducted, the pretension applied to the four main eye bolts needed to be determined. I wrote the following MATLAB script that calculates the desired preload and necessary tightening torque based upon parameters of the system. The code also outputs the load on the bolt, the load at which the bolt will yield, and the force on the members when load is applied to the bolts.

7.0.1 MATLAB Code

```
Ad=0.04987; %in^2 %area of bolt shank
At=0.0318; %in^2 %thread area/ tensile stress area of bolt
lt=1.6159; %in %length of threads being clamped
ld=2; %in %length of bolt shank

%listing young's modulus of different materials, to be used throughout
E_Gsteel=29007547.5; %psi
E_al=10000000; %psi

%calculating stiffness of eye bolts
kb=(Ad*At*E_Gsteel)/(Ad*lt+At*ld); %lb/in

%calculating stiffness of first member, a portion of the mount
```

```
%assume load is transferred through entire component
A_one=0.45*0.368-pi*(0.257/2)^2; %in^2
L_one=1.37; %in
k_one=A_one*E_al/L_one; %lb/in

%calculating stiffness of second member, a portion of the mount
%assume load is transferred through entire component
A_two=0.45*0.35-pi*(0.257/2)^2; %in^2
L_two=0.425*2; %in
k_two=A_two*E_al/L_two; %lb/in

%calculating stiffness of third member, a portion of the mount
%assume load is transferred through entire component
A_three=0.45*0.5-pi*(0.257/2)^2; %in^2
L_three=0.9465; %in
k_three=A_three*E_al/L_three; %lb/in

%calculating stiffness of fourth member, the bottom bulkhead
%assume load is transferred through frustum
alpha=pi/6; %rad, angle of frustum
t=0.2; %in, thickness of frustum
d=0.257; %in, diameter of bolt hole
D=0.625; %in, diameter of the smaller end of the frustum

%using eqn for stiffness of component when load is transferred via a
%frustum
denominator=log(((2*t*tan(alpha)+D-d)/(2*t*tan(alpha)+D+d))*((D+d)/(D-d)));
k_foura=(pi*E_al*tan(alpha))/denominator; %lb/in

%stiffness of other frustum in bottom bulkhead
k_fourb=k_foura; %lb/in

%calculating stiffness of fifth member, the washer
%assume load is transferred through entire component
E_washer=3*10^7; %psi
A_five=pi*((0.625/2)^2-(0.257/2)^2); %in^2
L_five=0.045; %in
k_five=A_five*E_washer/L_five; %lb/in

%calculating total stiffness of members clamped
OneOverk_tot=1/k_one+1/k_two+1/k_three+1/k_foura+1/k_fourb+1/k_five;
k_tot=1/OneOverk_tot;

%calculating desired preload
YS_steel=30000; %psi %yield strength galvanized steel
Yield_strength_bolt= YS_steel; %psi %stress at which bolt will yield
proof_Strength_bolt=0.9*Yield_strength_bolt; %psi %proof strength of the bolts
```

```
percent_of_proofS=0.25; %preload the bolt to 25% of the proof strength
preload_F=percent_of_proofS*proof_Strength_bolt*At %lbf %calculate desired
    preload

c=kb/(kb+k_tot); %unitless, joint constant
p=250; %lbf, load applied to bolt

%force that bolt experiences after preload and external load applied
%CAN NOT BE LARGER THAN THE FORCE AT WHICH THE BOLT WILL YIELD
Fb=c*p+preload_F %lb

%force at which bolt will yield
F_bolt_yield=At*Yield_strength_bolt %lbf

%force that the members being clamped by the bolt and the nut
%experience
%CAN NOT BE GREATER THAN ZERO, OTHERWISE MEMBERS NO LONGER CONSTRAINED
F_members_clamped=(1-c)*p-preload_F

%definining parameters needed to determine tightening torque

%a circle in the middle of the outer and inner edges of the threads
%where friction forces are assumed to act on threads
pitchD=0.218; %in

%mean washer diameter
%where friction forces are assumed to act when nut tightened onto washer
dc=(0.625+0.257)/2; %in

%Lead = distance between the same thread
%= to pitch in this case b/c only one thread
Lead=0.05; %in

%coefficients of friction b/w nut, thread, and washer
MuThreadNut=0.3; %unitless
MuWasherNut=0.3; %unitless

%applying tightening torque formula.
TorqueNumerator=preload_F*pitchD*(Lead+pi*MuThreadNut*pitchD*sec(alpha));
TorqueDenominator=2*(pi*pitchD-MuThreadNut*Lead*sec(alpha));
TorqueSecond=preload_F*MuWasherNut*dc/2;
Tightening_Torque=TorqueNumerator/TorqueDenominator+TorqueSecond
```

The code output the following numbers when parameters for the four BLiMS eyebolts and members clamped are input:

```
>> BLiMS_pretension

preload_F =

  214.6500


Fb =

  327.7652


F_bolt_yield =

   954


F_members_clamped =

  -77.7652


Tightening_Torque =

   24.2667
```

Figure 15: **MATLAB output**

Notice that when 25% of the bolt's proof strength is applied as preload, the internal forces in the bolt that occur when the external load is applied do not exceed the internal forces that would cause the bolt to yield. Notice also that the force acting on the members is negative, which means that a clamping force remains at all times and the members stay constrained. This means that a preload output by the code, 214.65 pounds, is satisfactory. Notice lastly that to get this preload, a tightening torque of 24in*lb must be applied. It should be noted that 25% of the bolt's proof strength applied as preload is much lower than typical values, which hover around 70%. A much lesser value was applied in this situation because higher values were getting low factors of safety on ansys.

8 BLiMS Pulling Force Analysis

Two sets of analyses will be conducted on BLiMS, as the system has two main functions: pulling the break lines and serving as a mount for the parachute and shock cord. First, BLiMS pulling force will be analyzed

The motors on BLiMS have a maximum torque output of 175 oz-in, which is equivalent to 10.9375 pound inches. This torque will be transferred to the vertical worms shafts via set screws. The torque from the worm shaft is then transferred to the wheel drum shaft via the worm gears. However, because the worm gears have a gear ratio of 1:10, the torque transferred to the wheel drum shaft must be multiplied by 10. Therefore, the maximum torque applied to the wheel drum shaft from the motor will be

$$\tau_{wds} = \tau_m * GR = 10.9375 * 10 = 109.375 lbs * in \tag{2}$$

Where τ_{wds} is the torque applied to the wheel drum shaft, and τ_m is the torque output by the motor. The torque applied to the wheel drum from the break line is equal to

$$\tau_{wd} = T * R = 50 * 0.95 = 47.5 lbs * in \tag{3}$$

Where τ_{wd} is the torque experienced by the wheel drum from the brake line, T is the tension of the brake line, and R is the radius of the wheel drum.

Because the maximum output torque of the system (that which can be applied to the wheel drum shaft from the motor) far exceeds the maximum torque that the brake line will apply to the wheel drum, it is confirmed that BLiMS will be able to extend and retract the brake lines, even if there are power losses in the system.

9 BLiMS Load Bearing Analysis

BLiMS is also required to be a mount for both the parachute and shock cord. This means that any components that bear the load when the parachute deploys will need to withstand a shock force of 1000 pounds. Parachute deployment will also cause the components attached to the shock cord to rapidly decelerate and therefore exert a substantial shock force on the shock cord. The shock cord mount must therefore be able to withstand that shock force, which is estimated to be no greater than 250 pounds. These conditions were applied to a simplified assembly of BLiMS in ansys static structural. The assembly was made less complex so as to reduce solution time.

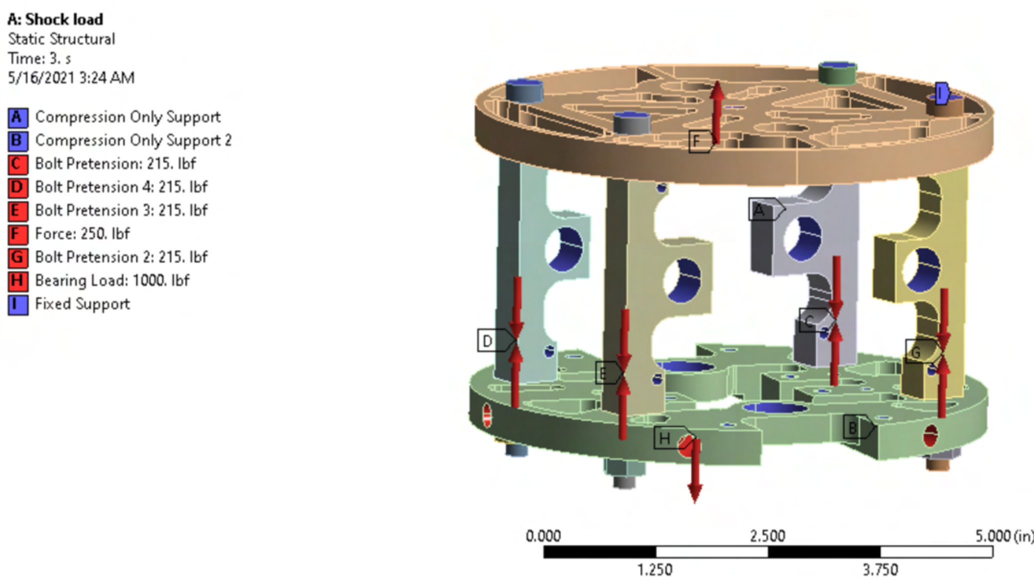

Figure 16: **Ansys Loading Conditions**

The loads applied varied over 3 time steps. In the first time step, fixed supports (I) were applied to the heads of the eye bolts, compression supports (A and B) were applied to all through holes where a bolt would be, and pretension (C,D,E, and G) was applied to the eye bolts. In the second time step, a 1000 pound bearing load (H) was applied to the six radial holes in the bottom bulkhead to mimic parachute deployment. Lastly, in the third time step, a 250 pound force (F) was applied to the top bulkhead to mimic the shock cord force.

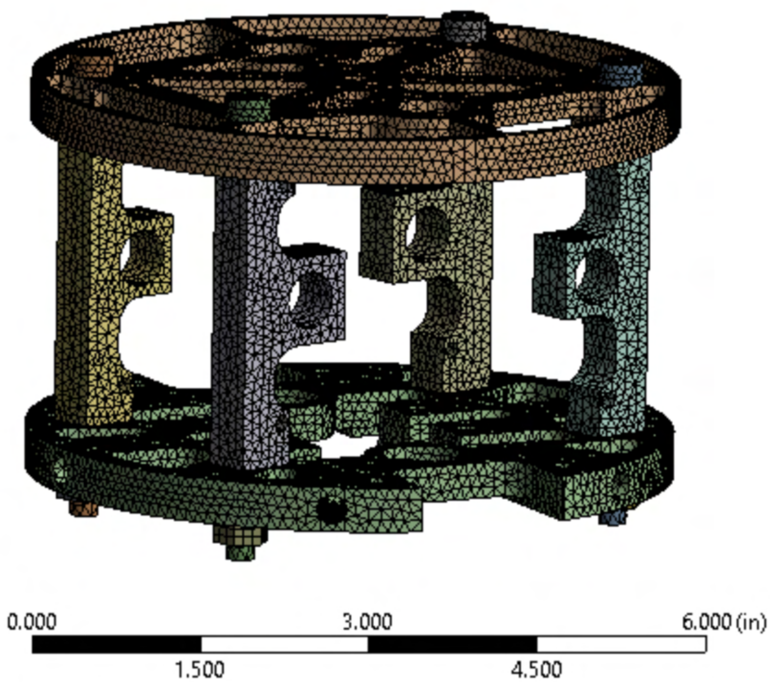

Figure 17: **Ansys Mesh**

The mesh above was produced before ansys solved.

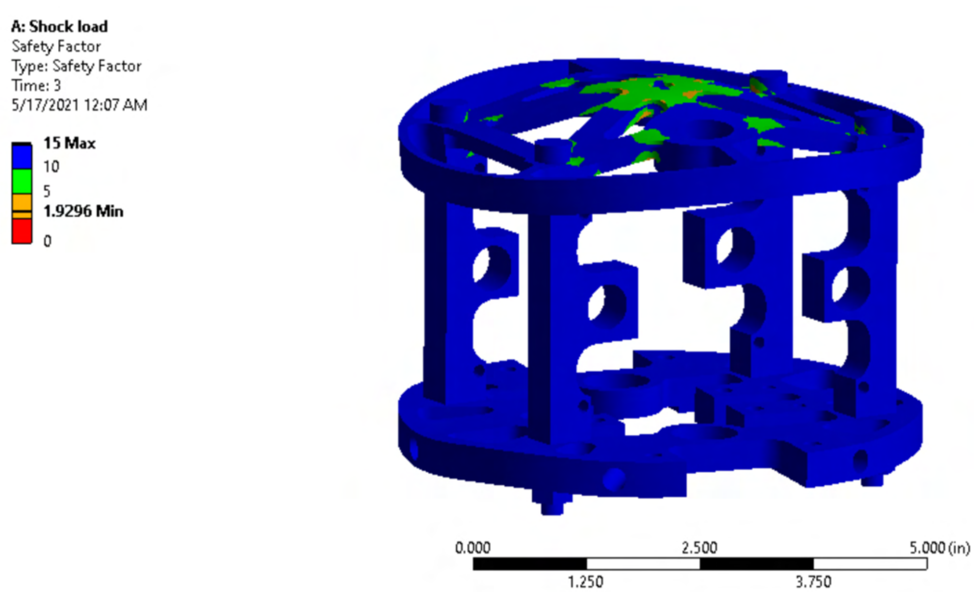

Figure 18: **Factor of Safety**

To give an overview of the solution, here is the factor of safety output by ansys. Note that the factor of safety is lowest in the forward bulkhead and two of the eye bolts. The stress in each part is analyzed individually below.

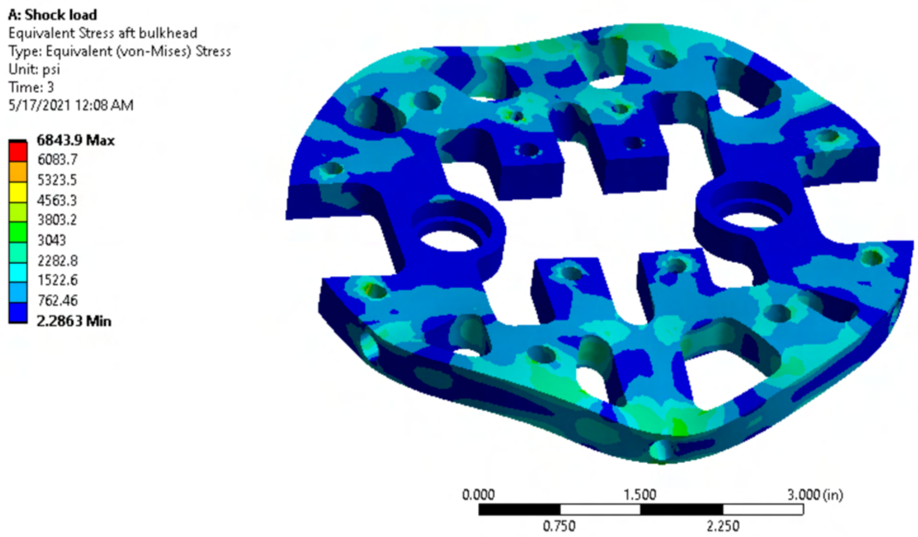

Figure 19: **Aft Bulkhead Von Mises Stress**

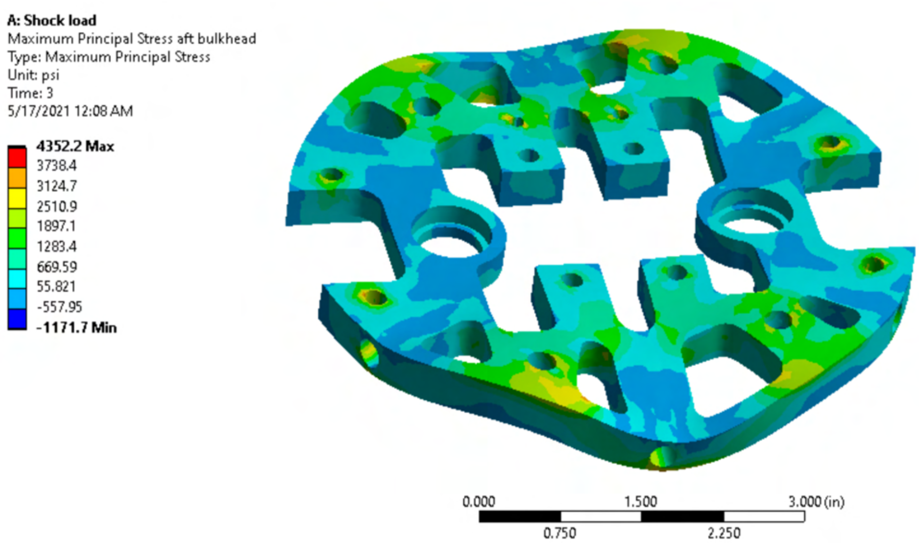

Figure 20: **Aft Bulkhead Maximum Principle Stress**

The yield stress of aluminum 6061 is 40030 psi [5]. The highest stress experienced by the aft bulkhead is 6843.9 psi, meaning the factor of the safety of the aft bulkhead is

$$FoS = \frac{\sigma_y}{\sigma_{max}} = \frac{40030}{6843.9} = 5.849 \tag{4}$$

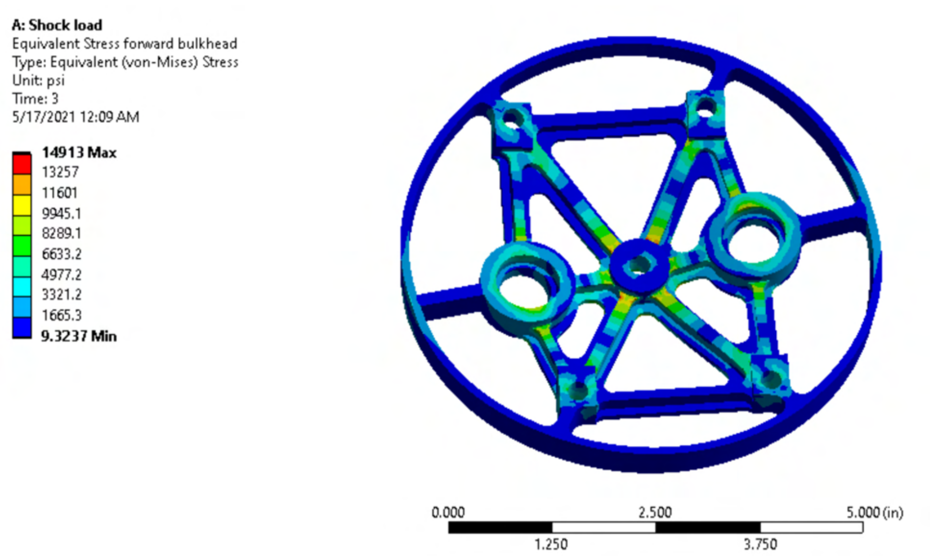

Figure 21: **Forward Bulkhead Von Mises Stress**

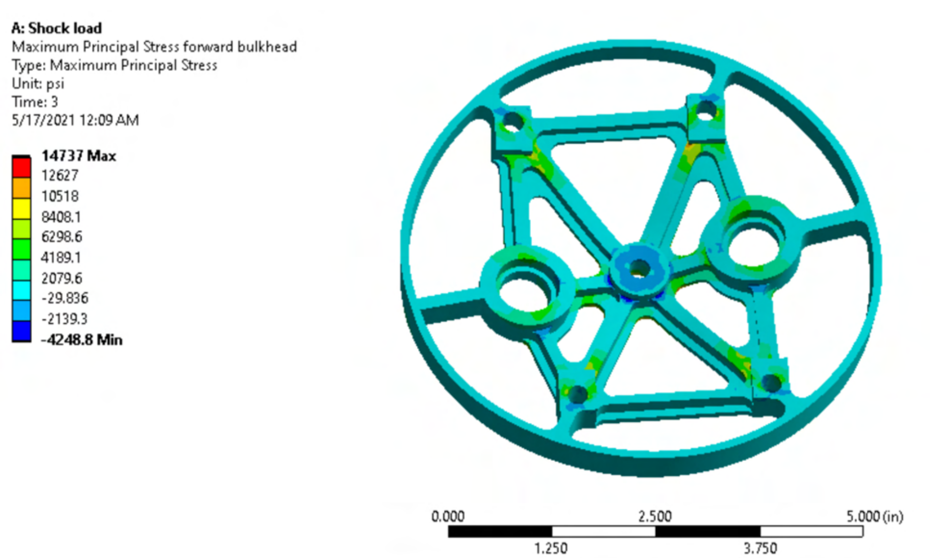

Figure 22: **Forward Bulkhead Maximum Principle Stress**

The highest stress experienced by the forward bulkhead is 14737 psi, and this bulkhead is again made of aluminum, which has a yield stress of 40030 psi [5]. The factor of the safety of the forward bulkhead is

$$FoS = \frac{\sigma_y}{\sigma_{max}} = \frac{40030}{14737} = 2.716 \tag{5}$$

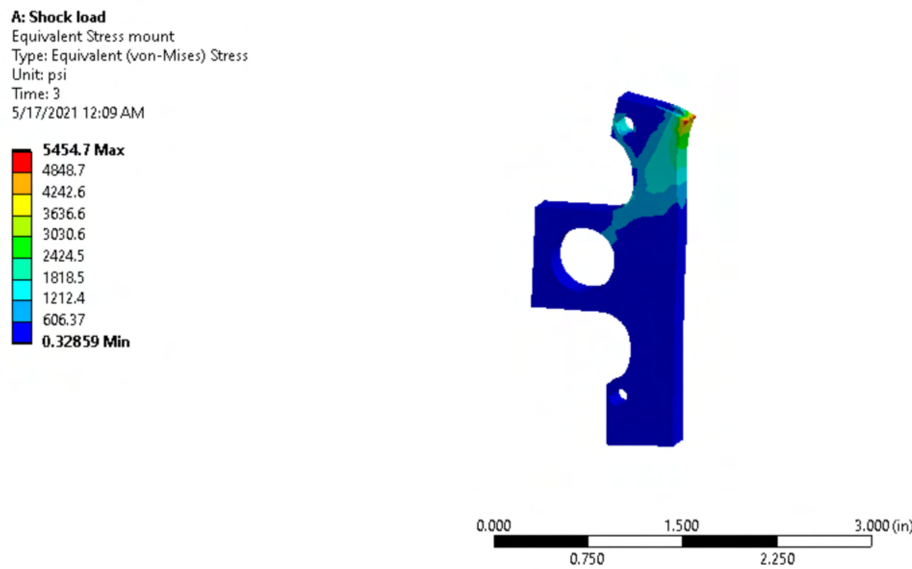

Figure 23: **Mount Von Mises Stress**

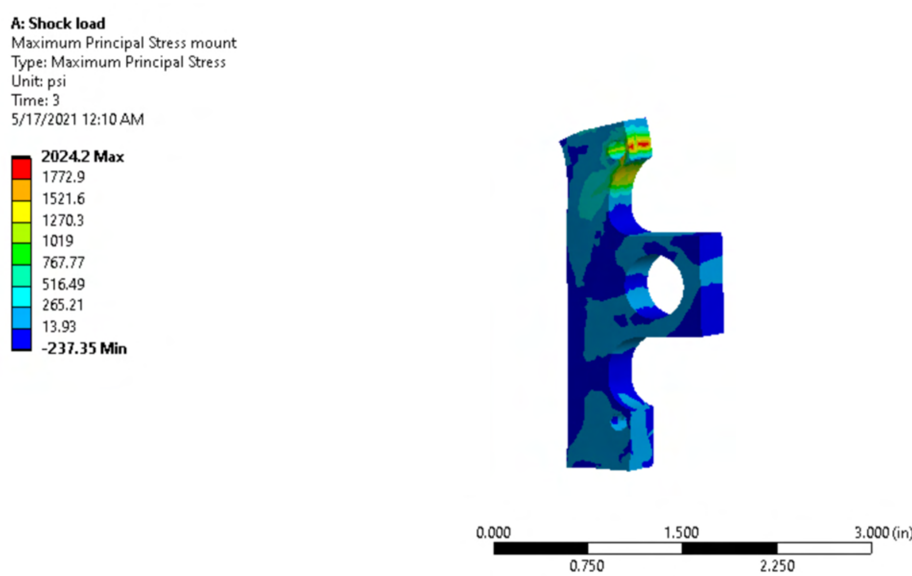

Figure 24: **Mount Maximum Principle Stress**

The highest stress experienced by any mount is 5454.7 psi, and the mounts are also made of aluminum. The factor of safety of the mount is therefore

$$FoS = \frac{\sigma_y}{\sigma_{max}} = \frac{40030}{5454.7} = 7.339 \quad (6)$$

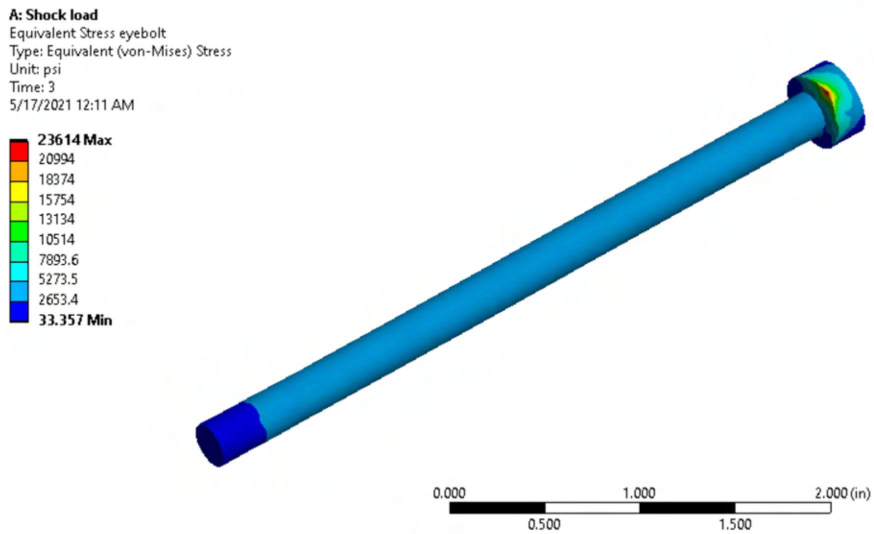

Figure 25: **Eye Bolt Von Mises Stress**

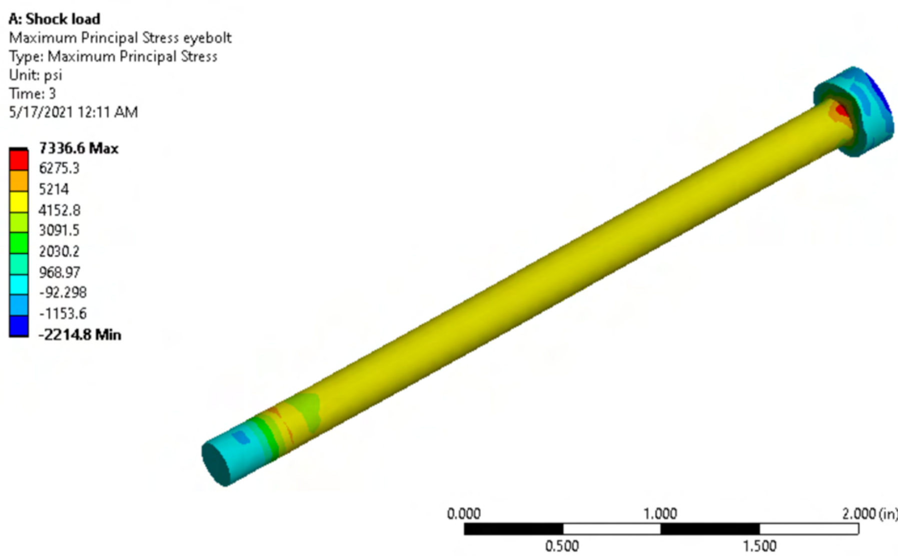

Figure 26: **Eye Bolt Maximum Principle Stress**

The yield stress of galvanized steel is guaranteed to be at least 33000 psi [4]. The highest stress experienced by the eye bolts is 23614 psi, meaning the factor of the safety of eye bolts is

$$FoS = \frac{\sigma_y}{\sigma_{max}} = \frac{33000}{23614} = 1.397 \tag{7}$$

10 BLiMS Assembly

With analysis complete, we proceeded with manufacturing and assembly. Below is an image of the finished product.

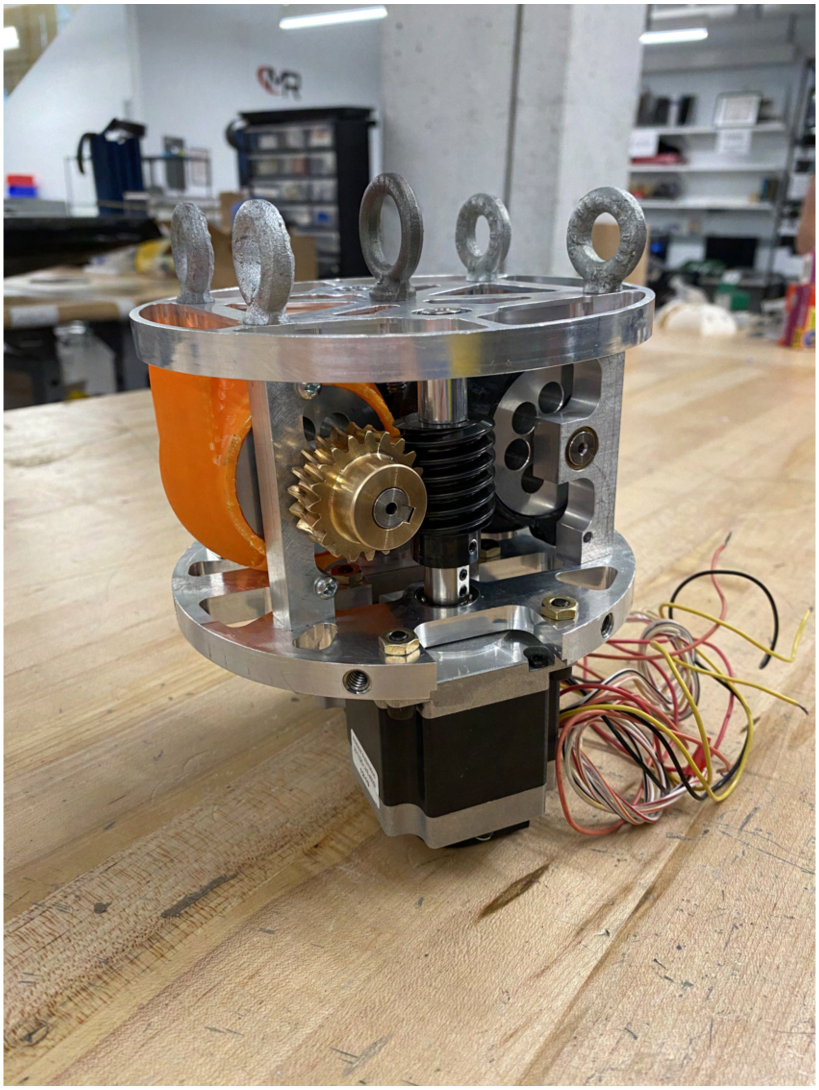

Figure 27: **BLiMS Assembled**

11 BLiMS Testing

Once analysis was complete and BLiMS was assembled, the system's functionality needed to be tested. The two tests conducted determined whether BLiMS could withstand expected shock loads and pull brake lines with sufficient force. The brake line pulling test is detailed below, and the BLiMS shock force testing is described afterwards.

11.1 Brake Line Manipulation Testing

Test Name: Brake Line Manipulation Test	**Subsystem:** BLiMS
Test Description The objective of this test is to determine whether BLiMS can pull brake lines that are in as much as 50 pounds of tension. This requirement was detailed further in the BLiMS Requirements and Constraints section. If BLiMS is able to pull lines that are in 50 pounds of tension, then the system will pass.	
Test Setup BLiMS will be oriented upside down for this test. A string will be wrapped around the wheel drum as a brake line would be. The other end of the string is attached to a bucket where weights will be placed. The motors will be actuated to see if BLiMS is able to lift the bucket and the weight within. With each trial, an increasing amount of weight will be put in the bucket. Lastly, because BLiMS has two line-pulling subsystems, both will be tested.	

<table>
<tr><td colspan="2">Test Procedure
☑ Acquire all items needed for testing
  ☑ BLiMS
  ☑ Lab weights
  ☑ Bucket with known mass
  ☑ String
  ☑ Carabiner (to help string interface with bucket fluidly)
  ☑ Controller to automate BLiMS
☑ Set up BLiMS in test configuration
  ☑ Find a testing area to invert BLiMS and safely suspend and pull weight
  ☑ Fasten string to wheel drum and wrap it around the wheel drum
  ☑ Attach the bucket to the other end of the string
  ☑ Hook up BLiMS motors to controller
☑ Code the motors to pull the bucket up a certain distance at a certain speed with no weight in the bucket.
☑ Do subsequent trials with increasing weight. During each trial, take note of the distance traveled, the travel time, and whether the motors skipped steps.
☑ When the motor begins to skip steps, lower the speed (and therefore increase the torque). Redo the trial with the same weight and the lower speed.
☑ Continue the process of increasing the weight and decreasing the motor speed until all weights have been tested.
☑ Repeat the entire test but with the other motor subsystem</td></tr>
<tr><td>Expected Data
BLiMS will be able to pull 50 pounds of force at a reasonable speed.</td><td>Obtained Data
See Tables Below</td></tr>
<tr><td>Result: FAIL</td><td>Reason: BLiMS could not pull more than 15 pounds at a reasonable speed</td></tr>
<tr><td>Date of Test: 4/13 and 4/14
Date of Re-Test (if failed): NA</td><td>Person(s) Involved: Gabe Mitchell</td></tr>
</table>

Test Reflection

Although BLiMS was able to pull brake lines that were in about 15 pounds of tension, testing was terminated. Pulling speeds were at this point about 0.15 inches per second, which was a crawl. It would not have made sense to test higher pulling weights, as the slow pulling speed would have made any result irrelevant.

Note again that per earlier calculations, BLiMS should have a maximum pulling force of about 100 pounds. Clearly that was not reached. The divide between the system in theory and in reality exists because I don't have a complete understanding of the motor's torque-speed curve. I assumed that because the required pulling force of the system (50 pounds) was far off from the maximum pulling force (100 pounds) of the system, there would be no issues with pulling speed. Clearly that assumption was erroneous. Furthermore, we are guessing that there were substantial power losses in the worm gears, as we did not use lubricant in the design.

Lastly, remember the actual estimate of the tension in the brake lines is about 10-15 pounds. However, our goal was to over engineering BLiMS just in case our actual prediction was incorrect. Therefore, although the test was a failure, BLiMS still may be able to pull brake lines on an actual parachute.

Testing BLiMS B side motor subsystem

speed setting	weight (kg)	distance up (in)	time up (s)	speed (in/s)	steps skipped?
50 of 100	carabiner only	6	14.59	0.411	No
	carabiner & bucket	6	15.29	0.392	No
	0.5	6	15.28	0.393	No
	1	6	15.23	0.394	No
	1.5	6	15.2	0.395	No
	2	6	15.23	0.394	No
	2.5	6	15.19	0.395	No
	3	6	15.2	0.395	No
	3.5	6	15.31	0.392	No
	4	4.5	15.45	0.291	Yes
40 of 100	4	6	19.07	0.315	No
	4.5	6	19.02	0.315	No
	5	6	19.16	0.313	No
	5.5	3.75	19.21	0.195	Yes
30 of 100	5.5	6	26.18	0.235	No
	6	6	25.59	0.235	No
	6.5	4.75	25.79	0.189	Yes
20 of 100	6.5	6	38.55	0.156	No
	7	6	38.11	0.157	Barely

Testing BLiMS A side motor subsystem

speed setting	weight (kg)	distance up (in)	time up (s)	speed (in/s)	steps skipped?
50 of 100	carabiner only	6	15.19	0.395	No
	carabiner & bucket	6	15.23	0.394	No
	0.5	6	15.3	0.392	No
	1	6	15.21	0.394	No
	1.5	6	15.26	0.393	No
	2	6	15.28	0.393	No
	2.5	6	15.3	0.393	No
	3	6	15.32	0.393	No
	3.5	6	15.36	0.391	No
	4	0	NA	0	Stalled
40 of 100	4	6	19.21	0.312	No
	4.5	1	19.21	0.052	Yes
30 of 100	4.5	6	25.58	0.234	No
	5	6	25.63	0.238	No
	5.5	6	25.59	0.235	No
	6	6	25.64	0.235	No
	6.5	0	NA	0	Stalled
20 of 100	6.5	6	38.34	0.156	No
	7	6	38.41	0.156	Barely

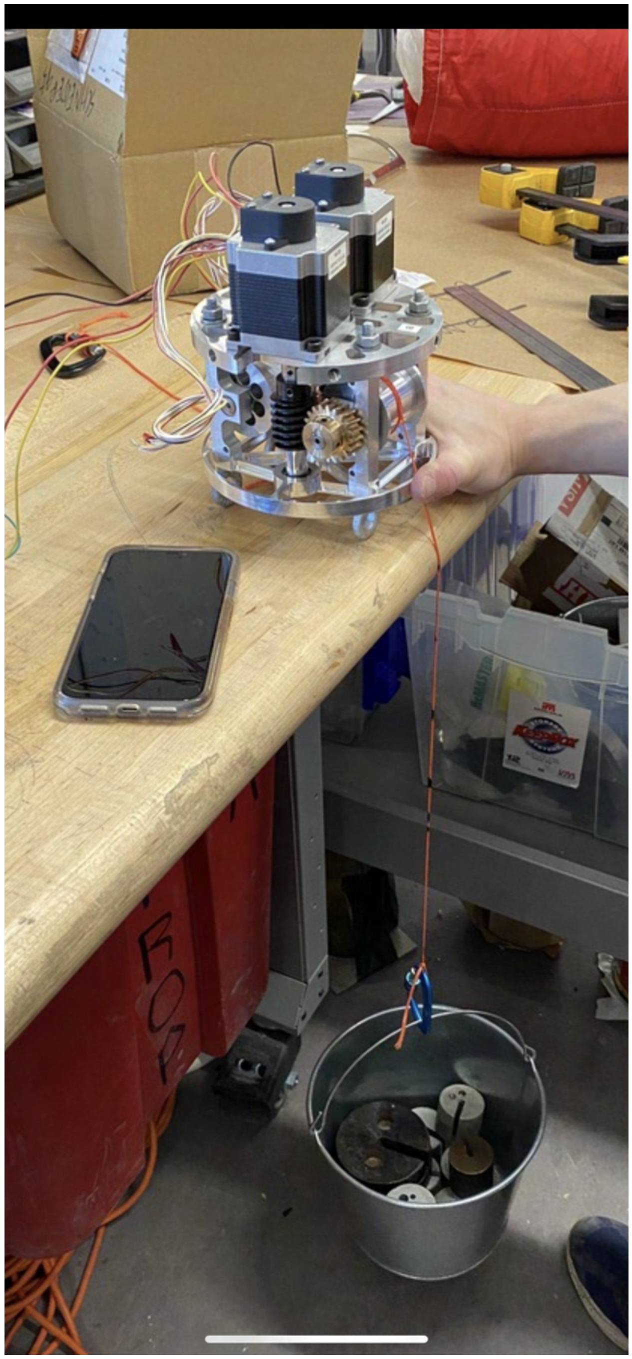

Figure 28: **BLiMS During Pulling Force Test**

11.2 Shock Testing

Test Name: Bovay Lab shock load test	**Subsystem:** BLiMS
Test Description The objective of this test is to determine whether BLiMS can withstand the force of the parachute deploying. That load is estimated to be as much as 1000 pounds. This requirement was detailed further in the BLiMS Requirements and Constraints section. If BLiMS is able to withstand 1000 pounds of force applied to the parachute mounts, then it will pass the test.	
Test Setup This test will be done in Cornell's Bovay Lab, where we will be using a tensile testing device and a load cell. BLiMS will be mounted to the load cell via mounts that we machine and assemble in house. Once the testing apparatus is set up, the machine will exert an increasing tensile load on BLiMS until 1000 pounds of force are reached. After the test, BLiMS we be inspected for yielding.	

Test Procedure	

☑ Acquire all items needed for testing
  ☑ BLiMS (without motors so that it can fit in the bottom test mount)
  ☑ Upper test mount (assembled)
  ☑ Bottom test mount
  ☑ Six 1/4-20 1" bolts
  ☑ Torque wrench and 7/16" socket
  ☑ Thread lube
  ☑ WD-40 (usually necessary to insert BLiMS into bottom testing mount)
☑ Set up BLiMS in test configuration
  ☑ Fasten bottom testing mount to tensile testing machine
  ☑ Fasten assembled top testing mount to tensile testing machine
  ☑ Attach BLiMS to bottom testing mount with six radial 1" 1/4-20 bolts
  ☑ Apply lube to each bolt and apply a fastening torque of 10 in*lb to each bolt (notice this value is low because the load applied to BLiMS will not interfere with the clamping force of the bolts, so a high preload is unnecessary)
  ☑ Attach BLiMS eye bolts to the carabiners of the top test mount
☑ Apply an increasing tensile load with the tensile test machine until 1000 pounds is reached
☑ If the load suddenly drops, it indicates that a component may have yielded. Stop the test at this point
☑ Let the load sit at 1000 pounds if that point is reached
☑ Lower the tensile load back to zero
☑ Inspect BLiMS for any substantial deformation or yielding	

Expected Data BLiMS will be able to withstand 1000 pounds of load applied to the parachute mounts without substantial deformation.	**Obtained Data** BLiMS was able to withstand the load, and there was no apparent deformation or yield.
Result: Pass	**Reason: BLiMS met test requirements**
Date of Test: 5/10 **Date of Re-Test (if failed): NA**	**Person(s) Involved: Gabe Mitchell**

Test Reflection

Another avenue to test whether BLiMS could handle a shock force similar to parachute deployment is to drop a weight that is attached to the eye bolts by a string. When the weight is suddenly stopped by the tension in the string, that tension will exert a shock force on BLiMS. That loading condition will likely do a better job of simulating parachute deployment. We did not conduct such a test this year, as the Bovay lab tensile test was more straight forward. However, a drop test is something to consider in the future.

The top image below includes BLiMS in its shock testing configuration (back right), the bottom test mount (back left), and the top test mount (front center). The bottom image is of BLiMS during the shock force testing.

Figure 29: **BLiMS Shock Test Components**

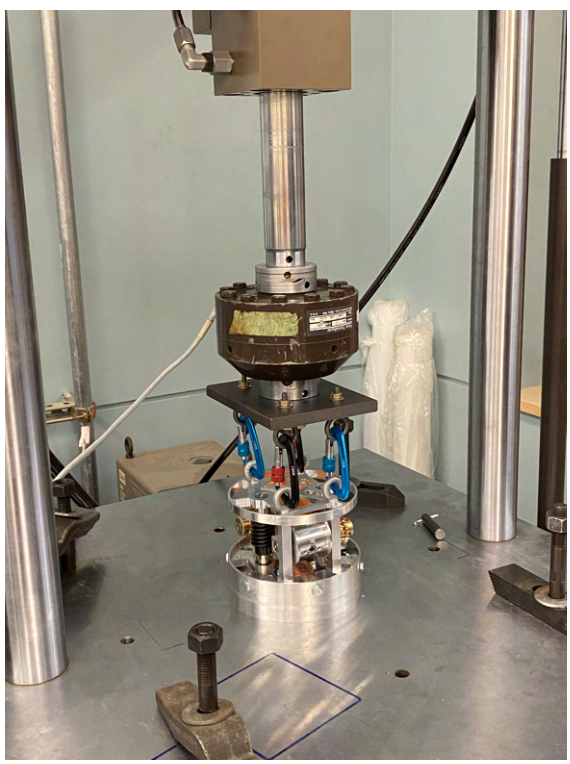

Figure 30: **Shock Test**

12 Reflection

I had another fantastic semester on CRT. My two main jobs this spring were to continue engineering BLiMS and to be a mentor for new recruits; both roles went well. As detailed in the tech report, engineering BLiMS included an entire redesign, FEA, manufacturing, assembly, and testing. I was heavily involved in each portion except for the manufacturing unfortunately, as the machine shop was only open to the CRT machining pod. Next year, I will be in the shop much more than this semester, so I'm looking forward to making up for lost time and improving my machining skills.

Besides a lack luster machining experience, engineering BLiMS this semester was fantastic. The redesign was at first difficult, as I was very excited about moving forward with the BLiMS iteration that I created first semester. However, when concerns about weight, volume, and functionality were brought up, it became clear to me that a redesign would be advantageous. My big take away from that process was that CAD often does a poor job of indicating the functionality of a design and that it takes a very careful and persistent eye to pick out design flaws. Another lesson was that it's never too late to make improvements to a design. After completing my Fall 2020 tech report, my mind moved immediately to manufacturing BLiMS and completely away from any design improvements. My mindset was based upon an assumption that we were too far ahead in the engineering process to make any design changes; that's why I was surprised when team mates brought up the idea of redesigning BLiMS. However, I'm very glad that they did so, as this most recent iteration it by far the best.

Manufacturing BLiMS actually proved to be quite educational, which was surprising. I originally imagined that the assembly process would only involve loosely tightening some nuts and bolts without much thought, but it ended up being much more than that. My biggest take away from the assembly process was learning about pretension and how it should be applied based upon the parameters of a system. That will be an especially useful lesson for further rocketry work. Another educational experience was learning how to properly implement bearings into a system and how to press fit shafts into them.

The biggest lesson from testing BLiMS is that there is still a lot more that can be done to improve the system, especially when it comes to the brake line manipulating components. Key steps will be to gain a better understanding of the stepper motors and implementing lubricant into the gear connections. I'm excited to make improvements and deepen my understanding of the system.

To reiterate, the other major role I played on the team was that of a mentor for new members. I mentioned in my last reflection that this job was especially important to me, as my success in rocketry has been in large part due to the support of other members. I really wanted to be a guide to new members in a similar way. I'm confident that the subteam was very successful in on boarding new members. I contributed to this process by making new CAD lessons, being available for zoom calls whenever issues popped up, and, most importantly, giving freshmen meaningful tasks that allowed them to find their way and learn by doing. Our success in on boarding new members is already visible in the great work that new members are doing. I'm really excited to see the progress that they make next year.

As for myself, I am also excited to be a subteam lead and undergo personal growth of my own. I think that going into next year, I will be just the right amount of nervous: I'll be concerned enough about rocketry to work hard as a lead, but not worried enough to where I'll be overly stressed. Overall, I'm just excited about the direction that my teammates and I are going to take CRT.

References

[1] Do You Have to Be Physically Fit to Skydive?" Chattanooga Skydiving Company, 31 Aug. 2020,www.chattanoogaskydivingcompany.com/blog/do-you-have-to-be-physically-fit-to-skydive/.

[2] Jean Potvin. *Opening Shock and Shape of the Drag-vs-Time Curve*, Physics Department, Saint Louis University, St. Louis, MO. https://www.pcprg.com/aiaa07extratalk.pdf

[3] Parks College Parachute Research Group. *Skydiving Canopy Opening G-Forces*.https://www.pcprg.com/g-forces.htm

[4] Cascadia Metals. GALVANIZED STEEL Grade Data Sheet, www.cmetals.com/wp-content/uploads/2020/03/Galvanized_Steel_Grade_Data.pdf.

[5] "Aluminum Alloys - Mechanical Properties." Engineering ToolBox, www.engineeringtoolbox.com/properties-aluminum-pipe-d_1340.html.