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University Engineering Design Challenge

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BRIGHAM YOUNG UNIVERSITY

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Final Report

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FINAL REPORT
For: University Engineering Design Challenge (Brigham Young University)

In each of the previous three years (2012, 2013, and 2014) a small group of senior engineering students from Brigham Young University (BYU) were selected to compete in the Air Force Office of Scientific Research (AFOSR) Engineering Design Challenge. The teams were part of BYU's Capstone Program. As such, each team participated in two semesters of engineering design courses; the first of which was generic, and the second of which was tailored to their specific project. Each team was coached by an industry professional working as an adjunct professor.

A detailed report was prepared by each team and is included as appendices to the present document. These reports describe the requirements, the solution architecture, the engineering methods used, validation methods used, and the final design.

In 2012, the team designed, built, and tested a grappling hook like device to accent walls. The team received a significant amount of local news coverage and some national coverage. The team earned 3rd place in the 2012 competition. In 2013, a different team, designed, built, and tested a portable bridge. Again, the team earned 3rd place. In 2014, yet another team designed, built and tested a para jumper's emergency lift kit. Again the team earned 3rd place. In each case, each design team came to appreciate the complexities of the real-world design challenges faced by the Air Force and learned to develop a valuable product in that setting.

The following news outlets covered the BYU teams' designs and performances at the competition:

- Design News
- Discovery Channel's Daily Planet
- Daily Herald
- Deseret News
- KSL TV
- Slashgear.com
- Gizmoto.com

The most significant outcome, however, is the growth of the engineering student. Our goal to do the following has been accomplished because of the AFOSR funding and competition. Each student has:

1) Understood and applied a structured design process to create a competitive design;
2) Understood and applied principles of project management to ensure the project is completed on time and on budget;
3) Integrated prior learning and experience to achieve high-quality engineering designs that meet the AFOSR's needs;
4) Participated synergistically as a team member to help the team succeed at the highest level;

5) Took the responsibility to learn and work independently, seeking outside help and advice as needed to complete the design project; and
6) Worked hard on a challenging project and couple that work with faith to accomplish an outstanding solution.

Throughout the two-semester project the students were individually and collectively mentored, and their progress was evaluated in terms of both project outcomes and their personal professional development.

Appendices
The final technical report is includes as an appendix for each of the three competitions.

Ira A. Fulton College of Engineering and Technology
Brigham Young University Capstone – Team 1
Air Force Research Labs
April 05, 2012

AFRL Climbing Competition

Climbing Assistance to Allow Troops with Equipment to Scale Buildings or Mountain Faces under Various Conditions.

Team Alpha

Team Members:

Aaron Ford

Brady Morton

Bryan Braun

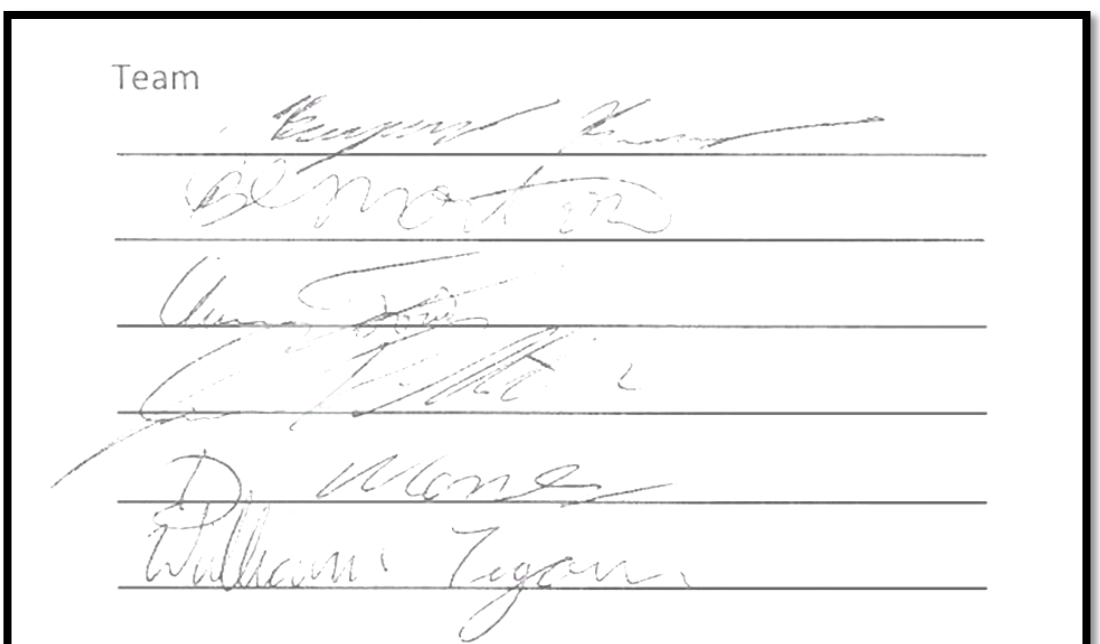
Dave Monk

Jason Rindlisbacher

William Tryon

Team Coach:

Greg Bishop



Executive Summary

The Air Force Research Laboratory (AFRL) is a scientific research organization that does R&D work to improve the technology and war fighting capabilities of the United States. In April 2012, the AFRL is sponsoring an engineering design competition between 15 universities. Our team has been selected to represent BYU in this competition. The competition task is to design a system to allow troops, with their equipment, to scale buildings or mountain faces under a variety of conditions, efficiently and effectively. At the competition, each team will demonstrate the operation of their climbing system and be scored on a variety of criteria.

Our team has developed a three-stage climbing system that can be deployed from a standard military rifle and used to climb a variety of surfaces. The device is operated by sliding a rocket-shaped projectile over the barrel of an M-4 rifle. The rocket contains a bullet trap, allowing the soldier to aim the device and fire a single rifle round to launch the projectile. The nose of the rocket can be swapped out with one of three modular attachment devices: A grappling hook, an adhesive-based attachment, or an anchor driver. Each device has inherent strengths and weaknesses allowing each to excel at specific use cases. This allows the soldier to use whichever option best fits the circumstances. Regardless of the attachment method used, the attachment will trail a 3mm climbing rope. This rope can be fed through a motorized battery-powered ascension device which attaches to a soldier's harness. Using the ascender, soldiers can be hoisted up walls, cliffs, or buildings.

Each aspect of our solution was chosen through a process of concept selection and rigorous testing, which is detailed in the body of this report. As we were testing, many of our selected concepts did not meet the target specifications we had defined, causing us to rapidly iterate through several designs. We soon learned that the constraints of our challenge made a one-size-fits-all solution impractical. Our final solution uses modular design to achieve the desired flexibility and manage the necessary tradeoffs.

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Section I: Project Summary and Results

Project Objective Statement

To honorably represent BYU by building a climbing system to allow troops to scale vertical surfaces by April 21st, using $2500.

Project Introduction

The Air Force Research Laboratory (AFRL) is a scientific research organization that does R&D work to improve the technology and war fighting capabilities of the United States. In April 2012, the AFRL is sponsoring an engineering design competition between 15 universities.

Our team has been selected to represent BYU in this competition. This report will describe the problem definition, the design solution, and the process we used to develop our solution.

Description and Scope

The competition task is to design a system to allow troops, with their equipment, to scale buildings or mountain faces under a variety of conditions, efficiently and effectively. At the competition, each team will demonstrate the operation of their climbing system and be scored on a variety of criteria, including:

- Time to complete climb
- Size and weight of packaged device
- Ease of operation
- Usability
- Stealth
- Innovation
- Other criteria

This demonstration will include student presentations and an operational climb performed by military personnel whom we must train to use our system.

Our team was instructed to assume that the end-user of our solution would have access to the equipment contained in a standard military assault backpack. Utilizing this equipment would help reduce the additional weight and complexity of our solution. As we developed our solution, we planned to use the following equipment (see the full equipment list in Appendix B1):

- Two BA5590 batteries
- M4 carbine rifle
- A Yates rappelling harness
- Carabineers

Review of Customer Needs & Metrics

We developed a list of customer needs based on three main sources:

1. Competition Scoring
2. Anticipated End user criteria
3. Latent Needs

From these sources, we compiled a list of customer statements and interpreted needs (which can be found in Appendix B2). Some of the most important customer needs we discovered included the following:

The device…

- can support an adult carrying military gear (300lbs)
- facilitates scaling of 90 feet or higher
- functions on vertical or near vertical surfaces
- is usable on rock, adobe, and concrete surfaces
- is usable in extreme weather
- allows soldier mobility
- is safe

With this list of needs, we developed functional specifications and quantifiable metrics for measuring specification. These metrics helped us test our prototypes and designs and ensured that we would meet the customer's needs. Table 1 (below) includes several of the most critical metrics with their target values. For a full list of the metrics and their target values, refer to Appendix B3.

Metric No.	Need No.	Metric	Import.	Units	Marginal Value	Ideal Value
1	1	Climbing height for a single deployment	5	ft	at least 90 ft	at least 100 ft
2	2	Grade/incline of surface	5	Degrees	at least 90°	at least 100°
13	14	Rate of ascension	4	ft/s	at most 11	at most 8
21	20	Functional day and night	5	Binary	Yes	Yes
30	27,29	Device weight (not including pre-existing gear)	4	lbs	at most 50	at most 35

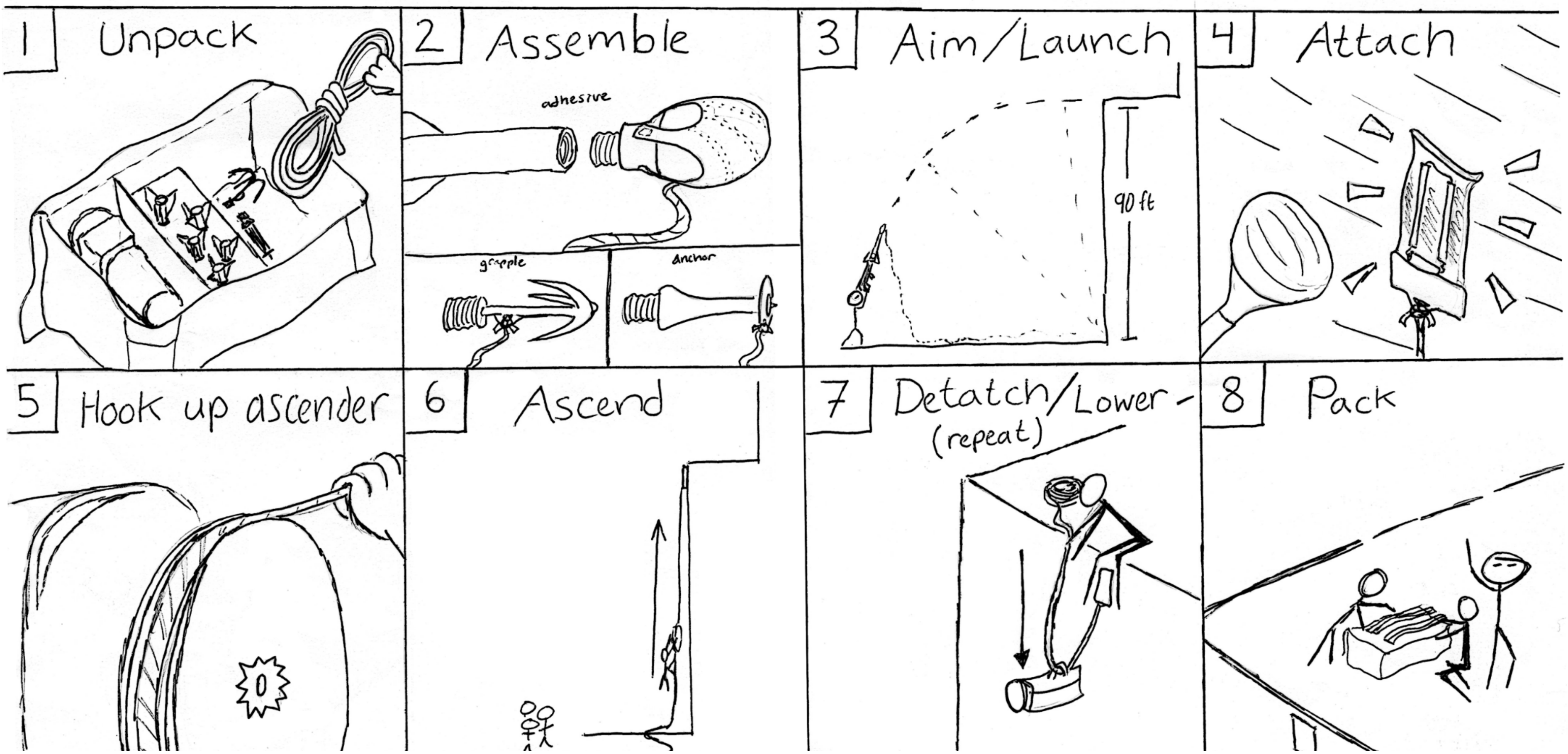
Table 1 - A listing of several critical metrics with their target values

Project Results

Design Solution

Our solution is designed to assist a troop of four individuals in climbing a 90 ft vertical surface in less than twenty minutes. The solution consists of a device that can be deployed from a standard military rifle and used to climb a variety of surfaces. A simple visual description of the operation of our design is included in the storyboard below.

TEAM 1 STORYBOARD



As shown in Figure 1 above, all the equipment is packed in a bag for convenient carrying. When it is time to use the device, some minor assembly will be necessary. The main device consists of a rocket-shaped projectile with a threaded nose region. The threads allow the nose of the rocket to be swapped out with one of three modular attachment devices: A grappling hook, an adhesive-based attachment, or a powder-actuated anchor driver (cell 2 above). Each attachment device carries its own advantages, and may be the ideal choice depending on the climbing surface and its condition. This will be discussed in detail later.

The climbing system is prepared by sliding the rocket-shaped projectile over the barrel of an M-4 rifle. The rocket contains a bullet trap, allowing a soldier to aim the device using their gun and fire a single rifle round to launch the projectile (cell 3 above).

Each attachment device uses a different mechanism to attach to the wall and specific instructions are given for operating each one in Appendix D1. Regardless of which device is used, the attachment will end up trailing a 3mm climbing rope. This rope can be fed through a motorized battery-powered ascension device (cell 5 above) which attaches to a soldier's harness. Using the ascender, soldiers can be hoisted up walls, cliffs, or buildings.

This system lends itself to being divided into three major subfunctions: Deployment, Attachment, and Ascension. Much of our detailed design process was handled by treating these subfunctions separately and then bringing them together for a final integrated solution. The upcoming three sections will discuss the technical aspects of each subfunction in detail.

Detailed Deployment Design

When determining the best way to deploy our system we wanted to minimize any additional weight that the soldiers may need to carry in the field. Considering that military personnel are often equipped with an M-4 rifle, it seemed the obvious choice to utilize the rifle's energy as a way to propel our system to the attachment point. The main question we had was whether or not the force from the rifle would be sufficient to deliver our payload the 90' distance required by our customer needs.

We decided to test the plausibility of our design by starting on a smaller scale. We fabricated an attachment for a .22 LR handgun to launch a golf ball with a rope attached to it. The preliminary tests were successful. We were able to launch the golf ball approximately 75' with the rope, and close to 250' without the rope. Considering the energy from an M-4 is about 9x more powerful than the .22, the idea seemed very possible.

Figure 2 – A .22 handgun used to prove the bullet-powered projectile concept

The next step was to design and test for an M-4. We did not have access to an M-4, so we used an AR-15, which is almost identical, but has a slightly longer barrel than an M-4. In our research for this project we found a door breaching grenade the military uses, known as a GREM (or SIMON). The

GREM is designed to slide over the barrel of an M-4, and is launched off with the force of a bullet. The GREM has a bullet trap inside that captures the bullet. This design seemed ideal for our project, as it would allow us to deploy our system without the additional step of loading a blank into the M-4, and it would provide more energy than a blank. We designed a rocket, known as JARF, based off of the GREM concept.

Figure 3 - An early concept model of our deployment solution

The first test with the JARF was unsuccessful. The prototype was built out of PVC and was easily broke when trying to launch. After some redesign and better material, we were able to successfully launch JARF from an AR-15. Our 90' goal was easily surpassed without additional payload. As long as the additional weight of our system stays relatively low, launching from an M-4 rifle is an excellent option.

After figuring out how to launch our system, we began to work on integrating the attachment set up with JARF. We added threads to the front of JARF so that the attachment system can be modular, allowing the user a choice of different attachment mechanisms for different surfaces or conditions that may be encountered.

After settling on our solution, we were informed that the competition would take place in an area where we would not be allowed to use an M-4 to deploy our system. Our final solution still incorporates the use of an M-4, but for competition purposes, we were tasked with finding a way to simulate the force from the rifle in an alternate manner. To do this, we have built a compressed gas cannon that has successfully launched our system. We performed pressure tests on the cannon by pressurizing it with water at 1.5x the working capacity for over ten minutes. We tested it at 900 psi, allowing us to safely operate it up to 600 psi, which is well above the calculated pressure needed. The cannon is not one of our deliverables, so its weight will not be counted against us.

Detailed Attachment Design

As we developed our attachment solution, our decisions were greatly influenced by the competition criteria and customer needs we gathered. These needs were very demanding. For example, a few of the needs which applied directly to the attachment solution included:

- functions on vertical or near vertical surfaces
- is usable on rock, adobe, and concrete surfaces
- is usable in extreme weather

As our team prototyped various attachment methods, we began to see that no single attachment method would work in all situations. However, while each method had strengths and weaknesses, taken together, they covered all the needs we were trying to satisfy. This is best represented by the decision matrix in figure 2. This matrix graphically displays our selected attachment methods and the major customer needs we needed to fulfill. For every green check mark on this matrix, we were able to prove successful functionality for the attachment method. For every X, the method fell short.

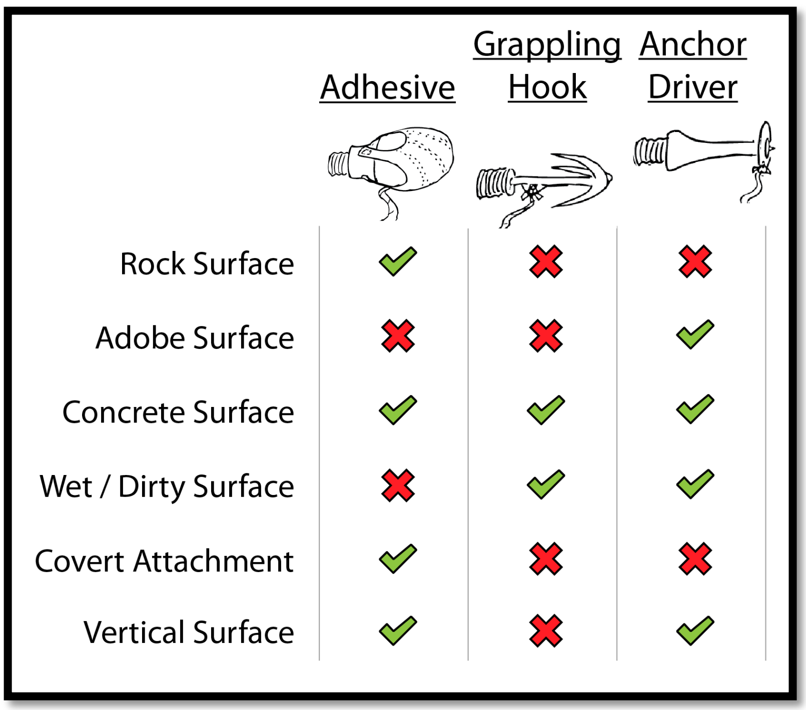


Figure 4 - A decision matrix for showing which attachment device best suits each climbing environment

Clearly, the best way to cover all the customer needs is to design a way to use a combination of these different methods. Our modular rocket nose serves that exact purpose.

This matrix can also be used to help you determine which solution to use in a specific situation (for example, if you have a wet, vertical, concrete surface, use an Anchor Driver).

Embedded Anchors

Our choice to use embeddable steel anchors as a method comes from several successful testing experiences. To prove the concept of an anchor driver, we used a Hilti EX D72 powder actuated nail driver, which is often used in construction. The tool uses .22 cartridges to drive nails into solid concrete (which is what we wanted to do). To test it, we drove nails into concrete at a variety of nail lengths, and angles. Then we attempted to pull the nails out in both shear and tensile loading conditions. The full results are in Appendix C1, but it's sufficient to say that for nails

Figure 5 – A test fixture for embedded anchors.

driven at angles from 60°-90 °, the average peak force to remove was about 400lbs. This easily meets our target value of 300lbs for maximum load on the anchor.

While we didn't have the chance to do a full proof of concept on Adobe, we spoke several times to Russell J. Bezette, Utah's award-winning adobe expert recognized by the Heritage foundation. He expressed confidence that the only way to scale an adobe building or wall in the way we intended to do was to use embedded anchors. With this feedback, we chose to focus in on proving the adhesive based techniques.

Using Adhesives

Several weeks of iterative testing using a variety of adhesives caused us to settle on the Loctite 3979 *UV* cure adhesive as our adhesive of choice (see the MSDS and Specs for Loctite 3979 in Appendix D4-D5). Tests for this adhesive under a variety of loading conditions demonstrated that it was the only option that could cure to the strengths we needed in just a few short minutes (see Appendix C5 for the full dataset).

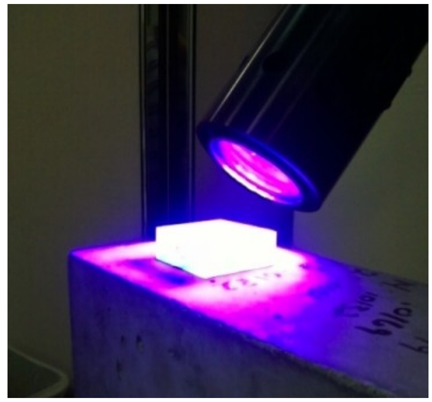


Figure 6 - A UV light cures our adhesive, binding our test pieces together.

One downside to Loctite 3979 is that we'd have to provide a high power *UV* source for remote curing. As we became more confident in this specific adhesive, we grew less confident in how we were going to get the adhesive applied to the wall. This brought us back to our structured design process, where we brainstormed 34 concepts for orienting the attachable unit and creating a preliminary attachment as an intermediate step to our permanent attachment. Through a process of scoring, screening, and prototyping these concepts (see Appendix C7-C9) we discovered that the best way to apply a preliminary adhesive is to apply a very tacky material to a piece of fabric, and then press it up against the wall. We also discovered that this pressure can easily be delivered by an impulse force like a beanbag. As we refined the concept, we learned that using a sticky synthetic adhesive for a preliminary attachment (like the adhesives used in sticky mousetraps) can hold the cloth in place while the UV adhesive has time to cure. The UV light can be delivered by a light-weight, remote array of battery powered LED's. By designing reinforced fabrics that can support hundreds of pounds, yet, still allow ultraviolet light to pass through and cure the adhesive, we had a working concept (see Appendix C6 for acceptance tests). This turned our adhesive based concept from a fragmented idea to a concrete

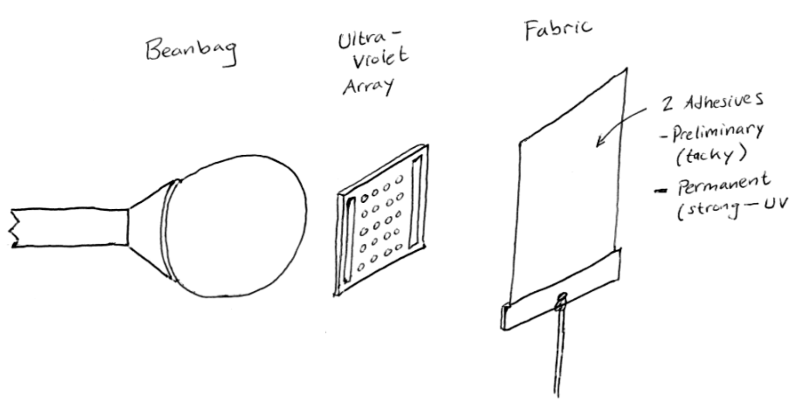


Figure 7 - The components of our attachment solution as a concept sketch

solution.

Using a Grappling Hook

While a Grappling Hook device wasn't part of our original design solution, we soon realized that the modular design of our attachment unit made adding a grappling device very easy. While the purpose of our competition is to scale vertical surfaces without grappling over the edge, situations in military activity do exist where a grappling hook attachment would be the best solution. It is for these situations that we built an example grappling attachment for demonstrative purposes.

Detailed Ascension Design

While the other subfunctions within our team tested multiple solutions and ideas, only one concept was run with for the solution as to how to ascend up the wall to the height of 90 feet. A few of the metrics that drove the concept selection are seen below in *Table 2*;

Table 2 – Driving metrics in selection of ascension system

Metric	Marginal Value	Target Value
Ascension Speed	12 ft/s	45 ft/s
System Weight	< 20lbs	
Strenuousness	Easier than current	
Use of limbs during ascension	yes	

Appendix B5 shows the selection matrix used, which determined that an automated winch would be the best solution. It was also determined that a spooling mechanism on the winch would not be desirable because it would carry the rope up with each climber. The only feasible solution was to design a sort of friction winch which would use friction to grip the rope sufficiently to wind itself up the rope without slipping, and while leaving the free end of the rope at the base of the wall. Two concepts seemed feasible to accomplish this; First, a motor driven shaft which looped rope around several time to provide adequate friction, and Second - a friction pulley which used deep grooves to pull the rope tight and provide enough friction to wind itself up the rope. It was determined through analysis that the friction pulley method would be the better solution.

Figure 3 – Initial testing of friction shaft

Friction Pulley

The friction pulley concept was determined to be the most feasible solution. This concept is used by several companies that manufacture commercially available ascension systems. The idea is that a deep, narrow groove is cut into a disk. As the rope wraps around the disk (pulley), it fits tightly into the groove. The weight or force on the rope pulls it tighter into the groove and the greater this force, the more squeezed the rope becomes in the groove. This provides the friction which allows the rope not to slip in the pulley as it climbs the rope. The

Figure 5 – Friction pulley

torque output of the motor required to lift a load of 300 lbs. is quite large and most small DC motors capable of outputting this torque will operate at very low RPM. If the winch is to climb the rope at an adequate speed, a reasonably large diameter pulley is required. It took less material to make a pulley of a larger diameter than for a friction shaft and therefore saved significant weight. The motor found to produce sufficient torque, while operating at low voltage and adequate RPM was a commercially available 1hp ATV winch made by Badlands Winches. The easiest solution was to purchase the actual winch and modify it by stripping off unnecessary parts and replacing them with parts allowing it to operate as a friction winch. This transformation from an ATV winch to a ascension devise is seen in Figure 5.

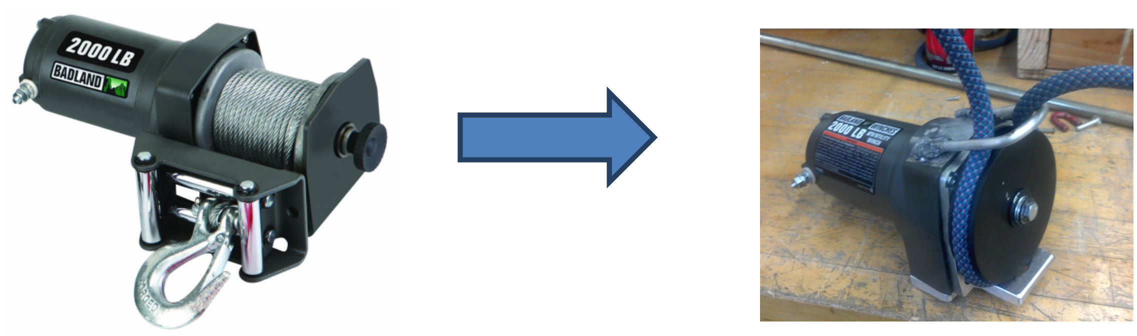


Figure 5 – Transition from commercially available ATV winch to friction pulley climbing devise

This design has shown to work on multiple occasions and has demonstrated successful climbs to a height of roughly thirty feet.

Engineering and Technical Analysis

The first aspect of the solution to be analyzed is the electrical and power aspects. Because the winch was modified and the small diameter drum was replaced with a larger diameter pulley, the torque output of the motor will be larger for the pulley and the maximum load smaller. Switching from a 1.25" diameter drum to a 3" diameter pulley decreases the maximum load from 2000 lbs. to roughly 850 lbs. This also means that the motor will draw more current in order to output a higher torque. According to the motor specifications listed in Appendix D3, lifting a load roughly one-third of the maximum load limit will draw a current of about 30 amps. The military battery carried by troops has a capacity of 7.5 Ah at 24V or 15 Ah at 12V, which even at 24V will allow for a continuous operation of 15 minutes, much longer than the necessary time to ascend 90 feet.

Additionally, the increased torque output required to turn the larger diameter pulley decreases the output speed of the motor. Initial tests measured the lift speed to be approximately 20-25 ft/min. Although this does meet the minimum requirements for speed, it is preferred to increase the lift speed to over 30 ft/min. This can be accomplished by increasing slightly the diameter of the friction pulley and also by increasing the input voltage to the motor.

As for the mechanical strength of the system, the component that undergoes the highest stress is the shaft which transmits power from the motor to the pulley. This shaft was machined out of Aluminum 6061-T6 round stock. It was not believed that the machining operations compromised the strength to any significant degree. The outer diameter of the shaft is a constant ¾", but with both ends having gear teeth cut into them, a safe estimate of 0.53” for the outer diameter was used for calculations. The major stresses developed in the shaft are due to bending stresses and torsional stresses. In essence, the shaft can be modeled as a cantilevered beam with the force being applied at the end through the pulley. To minimize the bending stress developed, the shaft was designed so that the pulley fits almost flush against the face plate of the motor, ensuring a small moment arm for the force to be applied. This design helped keep the developed bending stress well below the yield limit. Table 3 shows the mechanical properties of the material as well as the estimated stresses developed in the shaft.

Table 3 – Mechanical analysis of aluminum shaft

Tensile Yield Stress	40 ksi
Shear Strength	30 ksi
Bending stress developed in shaft	19,773 psi
Torsional stress developed in shaft	15,719 psi

The only other two components that see a significant force are the bearing plate, which is held in place by 4 M4 screws and supported by the motor housing, and the bottom plate which connects the winch to the climbers harness. This plate is ½” thick, allowing it to easily hold the 300 lbs. and the moment created through the connection. Two M6 screws attach this plate to the motor base and easily carry the weight of the climber. An exploded view of the winch showing all components is seen in Section II – Drawing Package.

As stated above, this ascension devise has shown to be successful in lifting a climber up a vertical surface. With virtually no rope slippage in the winch, ascension rates fell between 20-25 ft/min. It is anticipated that these rates can be increased to 30 ft/min, which is well above the marginal value listed in the project metrics. The military battery supplies sufficient power to operate the winch for up to 15 minutes, much longer than the time needed for ascension. A mechanical analysis of the ascension devise confirms that all components can handle the stresses developed without critical failure.

Conclusion

Our design process has been focused on meeting customer needs… even when they have seemed impossibly challenging. This has guided our decisions, like when deciding to use modular attachment devices when no single attachment method alone would satisfy customer needs.

As we compared our solution to the functional specifications we created, we realized that while we did not meet all of them, we were able to meet the ones with highest importance rating. Several of these specifications are listed in the table below, with their final values after testing.

Metric	Import.	Units	Marginal Value	Ideal Value	Final Value
Climbing height for a single deployment	5	ft	at least 90 ft	at least 100 ft	90 ft
Grade/incline of surface	5	Degrees	at least 90°	at least 100°	90°

Rate of ascension	4	ft/min	at least 20	at least 30	25 ft/min
Functional day and night	5	Binary	Yes	Yes	Yes
Device weight (not including pre-existing gear)	4	lbs	at most 50	at most 35	20 lb (est.)
Usablilty on Concrete, Adobe, and Rock	5	Binary	Yes	Yes	Yes
Physical Exertion Score (survey)	4	#	at most 2.5	at most 1	1

Much has been done to conceptually prove each aspect of our project (data is found in the appendices). The individual components of our solution have been tested independently and all function properly under ideal conditions. We sought the advice of subject matter experts to find solutions beyond our understanding. Analytical models were developed that supported the behaviors we anticipated. From rough prototypes to polished products, we tested and improved our solution every step of the way. The degree to which we can cause our solution's integrated subfunctions to work together seamlessly will determine our success at the competition site.

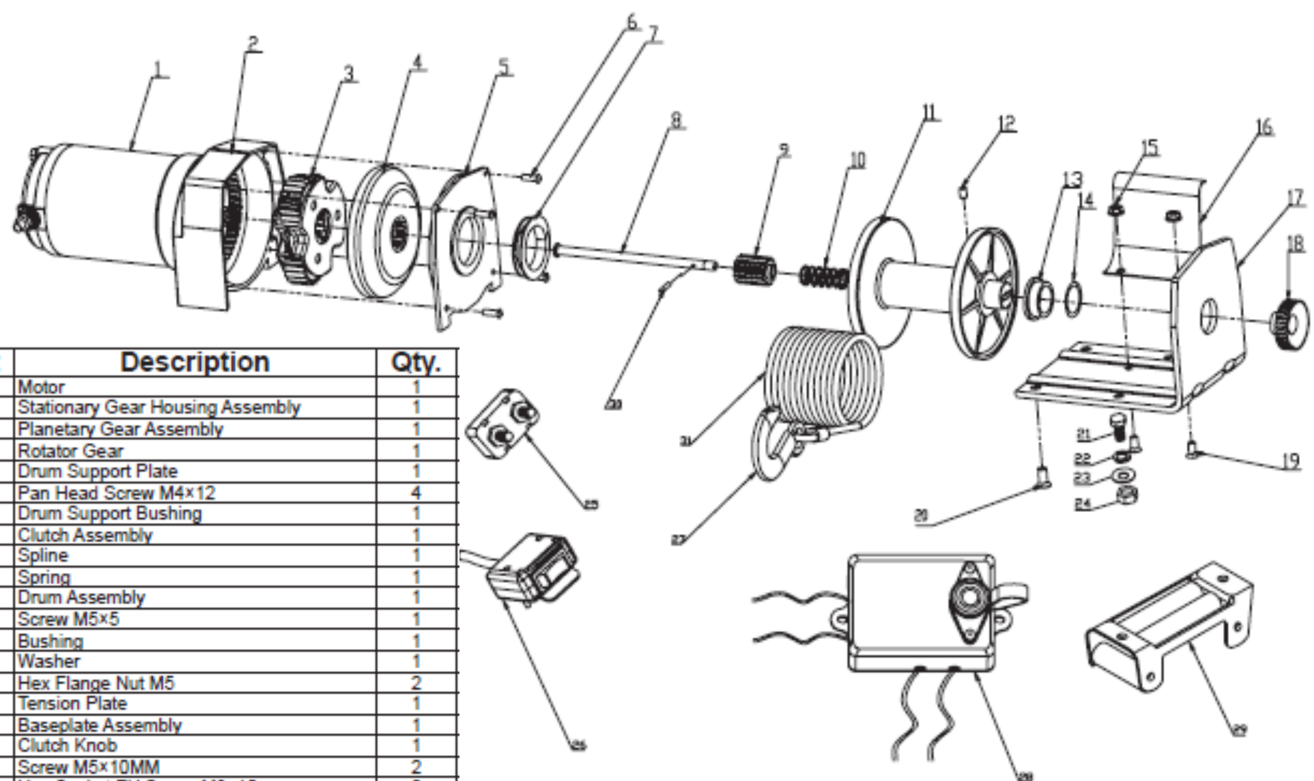
Section II: Drawings and Definitions

Drawing Package

This section contains the technical drawings require to reproduce the hardware of our solution. It includes technical drawings for the deployment, attachment, and ascension aspects of our solution. Other on-site assembly instructions may be found in the operations manual in appendix D1.

Winch Modifications

Starting with the Badlands Winches , 2000 lb Model 68146, a new ascension device will be created. The following details the Badlands winch preparation.



Part	Description	Qty.
1	Motor	1
2	Stationary Gear Housing Assembly	1
3	Planetary Gear Assembly	1
4	Rotator Gear	1
5	Drum Support Plate	1
6	Pan Head Screw M4×12	4
7	Drum Support Bushing	1
8	Clutch Assembly	1
9	Spline	1
10	Spring	1
11	Drum Assembly	1
12	Screw M5×5	1
13	Bushing	1
14	Washer	1
15	Hex Flange Nut M5	2
16	Tension Plate	1
17	Baseplate Assembly	1
18	Clutch Knob	1
19	Screw M5×10MM	2
20	Hex Socket FH Screw M6×10	2
21	Screw M8×20	4
22	Lock Washer φ8	4
23	Washer-Flat φ8	4
24	Nut M8	4
25	Circuit Breaker	1
26	Switch Controller	1
27	Hook	1
28	Solenoid Box	1
29	Roller Fairlead	1
30	Pin 3 x 11	1
31	Cable Assembly	1

Modifications to Winch

Note: All wiring components remain unaltered.

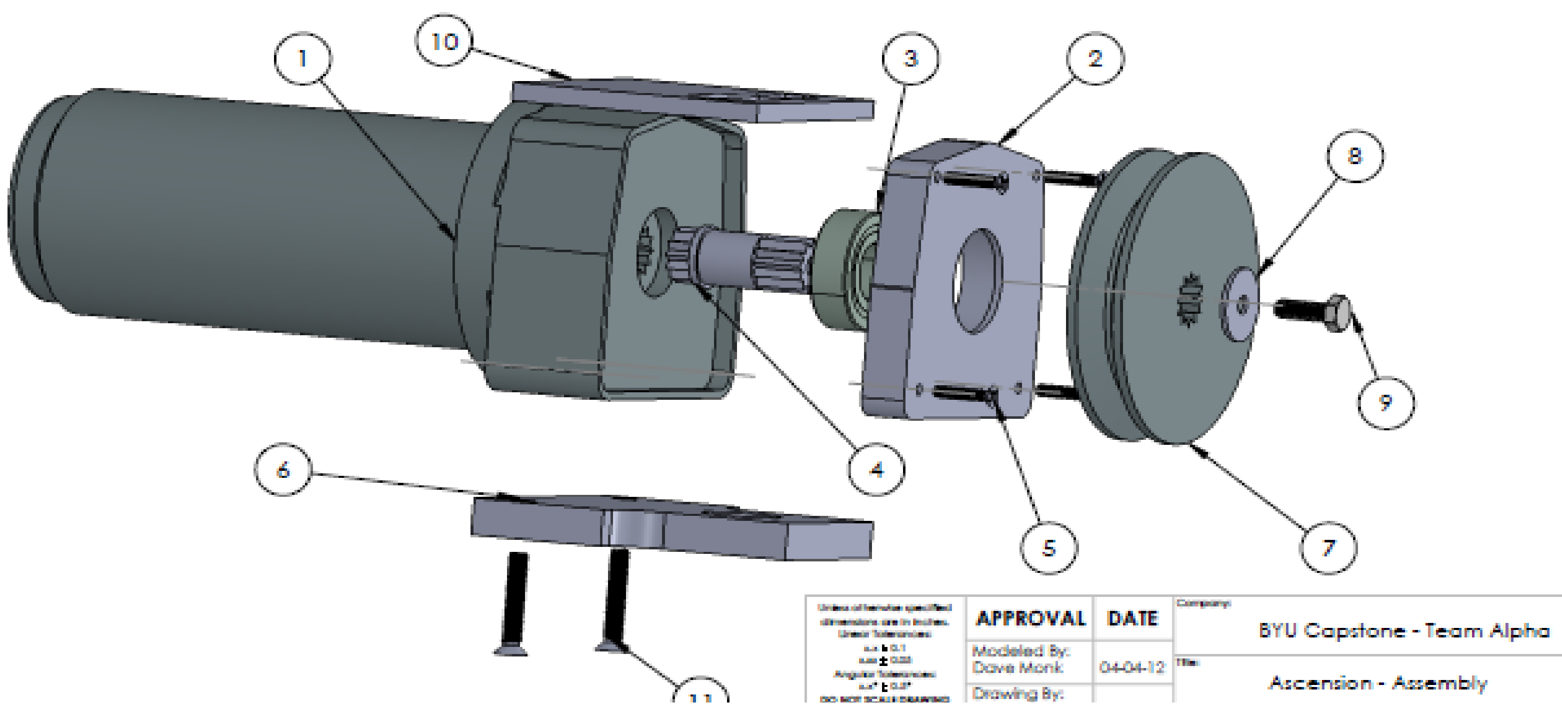
Remove parts 5-24. This includes all Drum support plate and entire drum assembly, Baseplate assembly, and the Clutch and shaft assembly.

All that should be remaining are motor, Stationary gear housing assembly, Planetary gear assembly, and Rotary gear. Also, wiring and electrical components should remain separate and unaltered.

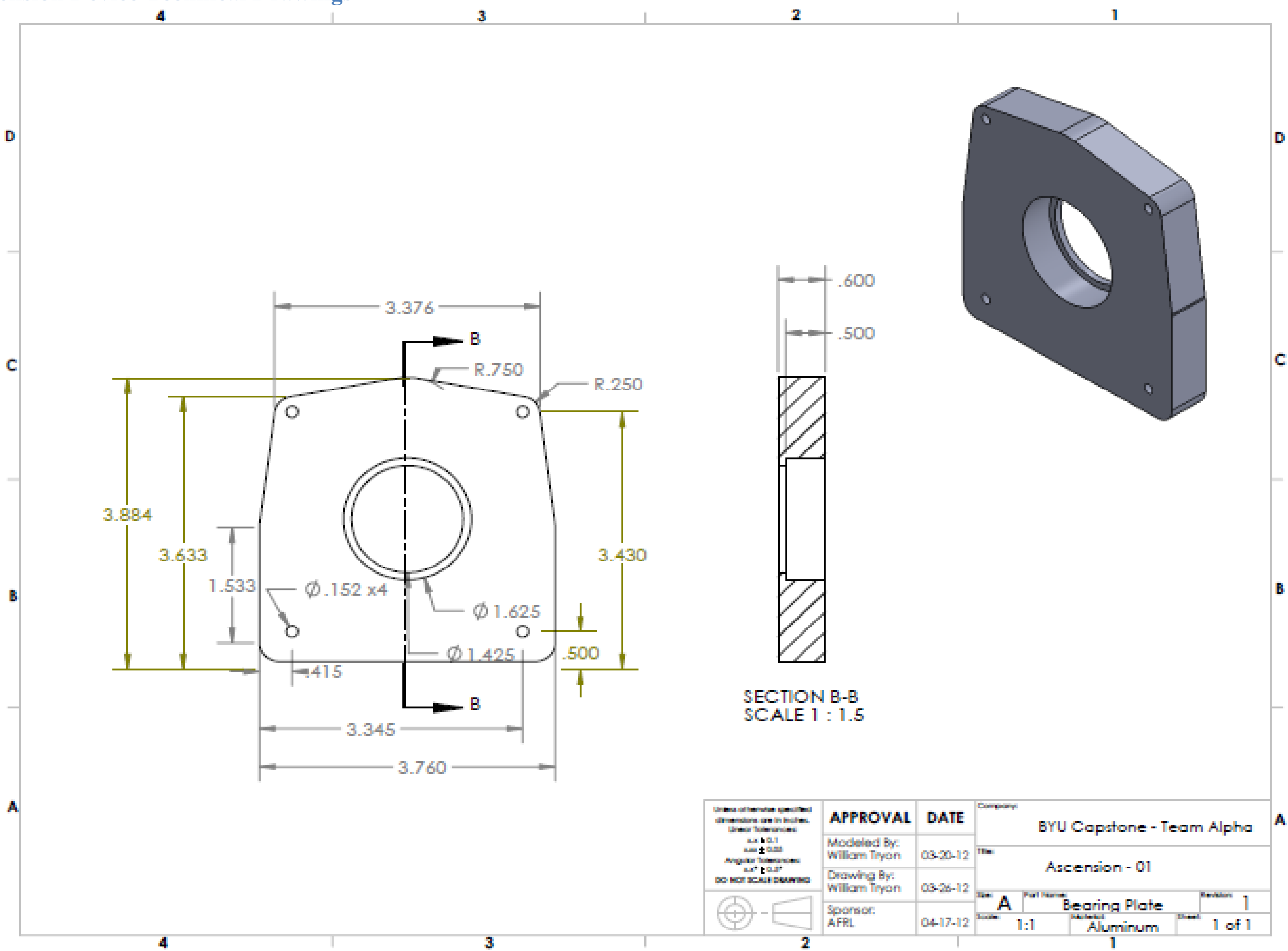
For assembly of new parts, refer to exploded view of ascension assembly seen below.

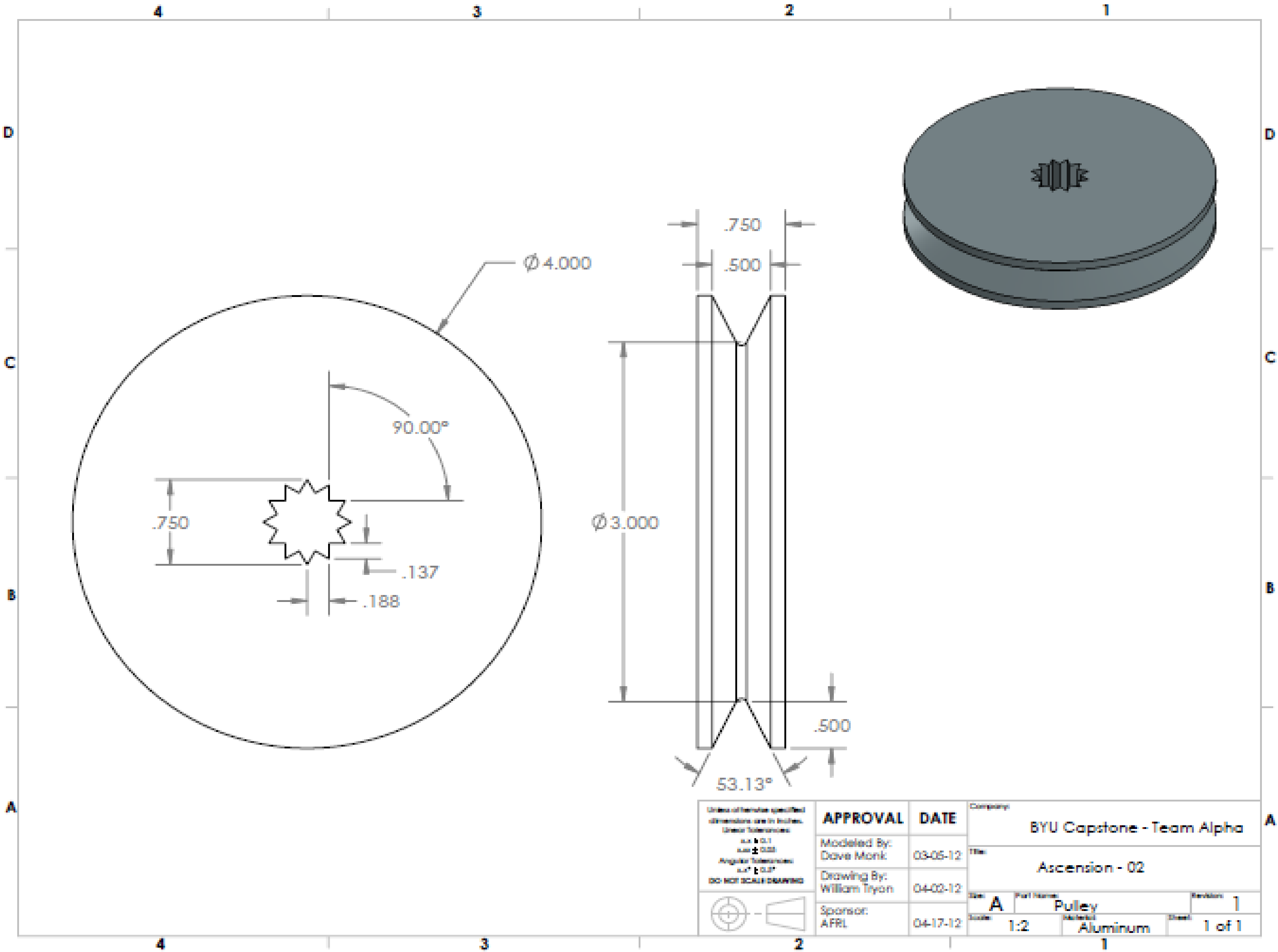
Ascension Device Assembly

ITEM NO.	PART	MANUFACTURER/PART NUMBER	DESCRIPTION	QTY.
1	Motor	Badlands Winches, #68146	Modified Badlands 2000lb ATV winch	1
2	Bearing Plate	Ascension - 01		1
3	Bearing	McMaster-Carr, # 6384K67	3/4" ID, 1 5/8" OD, Double shielded	1
4	Shaft	Ascension - 03	Milled gear heads on both ends	1
5	M4 screw	McMaster-Carr, # 91801A227	M4 x 25mm	4
6	Bottom Plate	Ascension - 05	Allows carabiner connection to harness	1
7	Pulley	Ascension - 02	Friction pulley, climbs up rope	1
8	Washer		Any washer will work	1
9	.25in-20 screw	McMaster-Carr, #92620A540	1/4"-20 x 0.75 in	1
10	Rope Guide	Ascension - 04	Welded to motor casing	1
11	M6 screws	McMaster-Carr, #92010A444	M6 x 45mm	2



Ascension Device Technical Drawings





Ø 4.000
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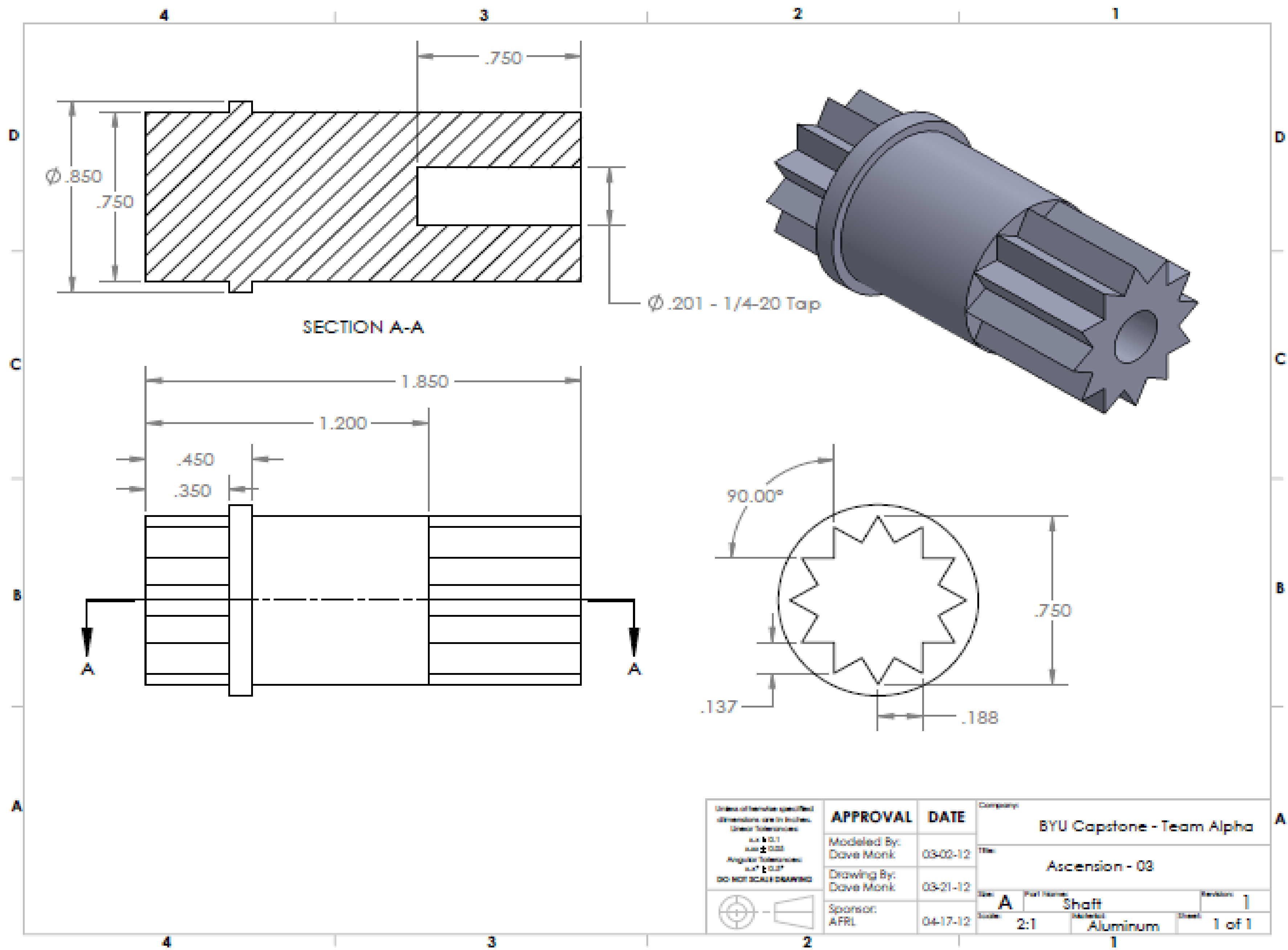
APPROVAL
DATE
Modeled By:
Dave Monk
03-05-12
Drawing By:
William Tryon
04-02-12
Sponsor:
AFRL
04-17-12
BYU Capstone - Team Alpha
Ascension - 02
A
Pulley
1
1:2
Aluminum
1 of 1



.750
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SECTION A-A
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DATE
Modeled By: Dave Monk
03-02-12
Drawing By: Dave Monk
03-21-12
Sponsor: AFRL
04-17-12
BYU Capstone - Team Alpha
Ascension - 03
A
Shaft
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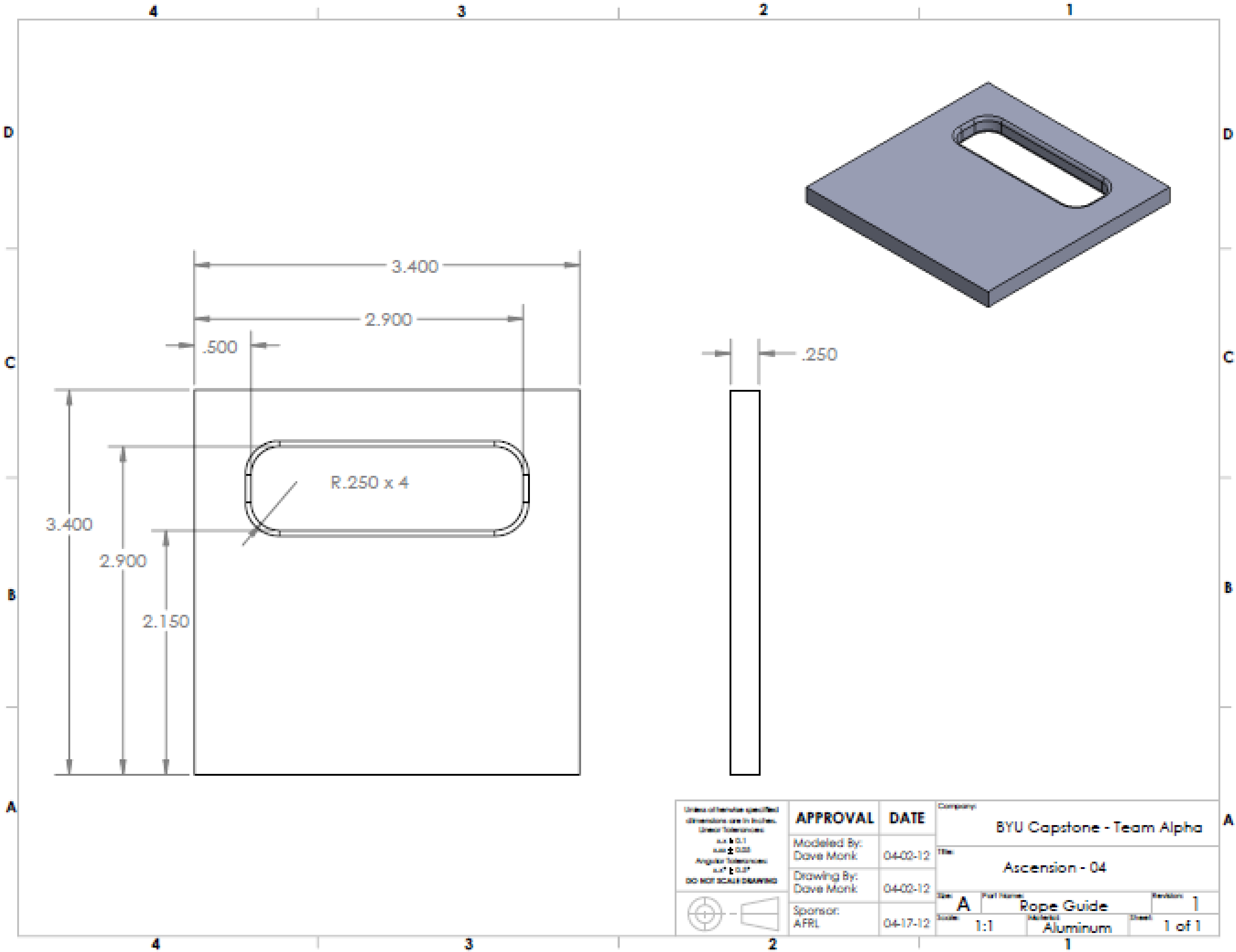
2:1
Aluminum
1 of 1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.250
R.250 x 4
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2.900
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APPROVAL
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04-02-12
Drawing By: Dave Monk
04-02-12
Sponsor: AFRL
04-17-12
BYU Capstone - Team Alpha
Ascension - 04
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Rope Guide
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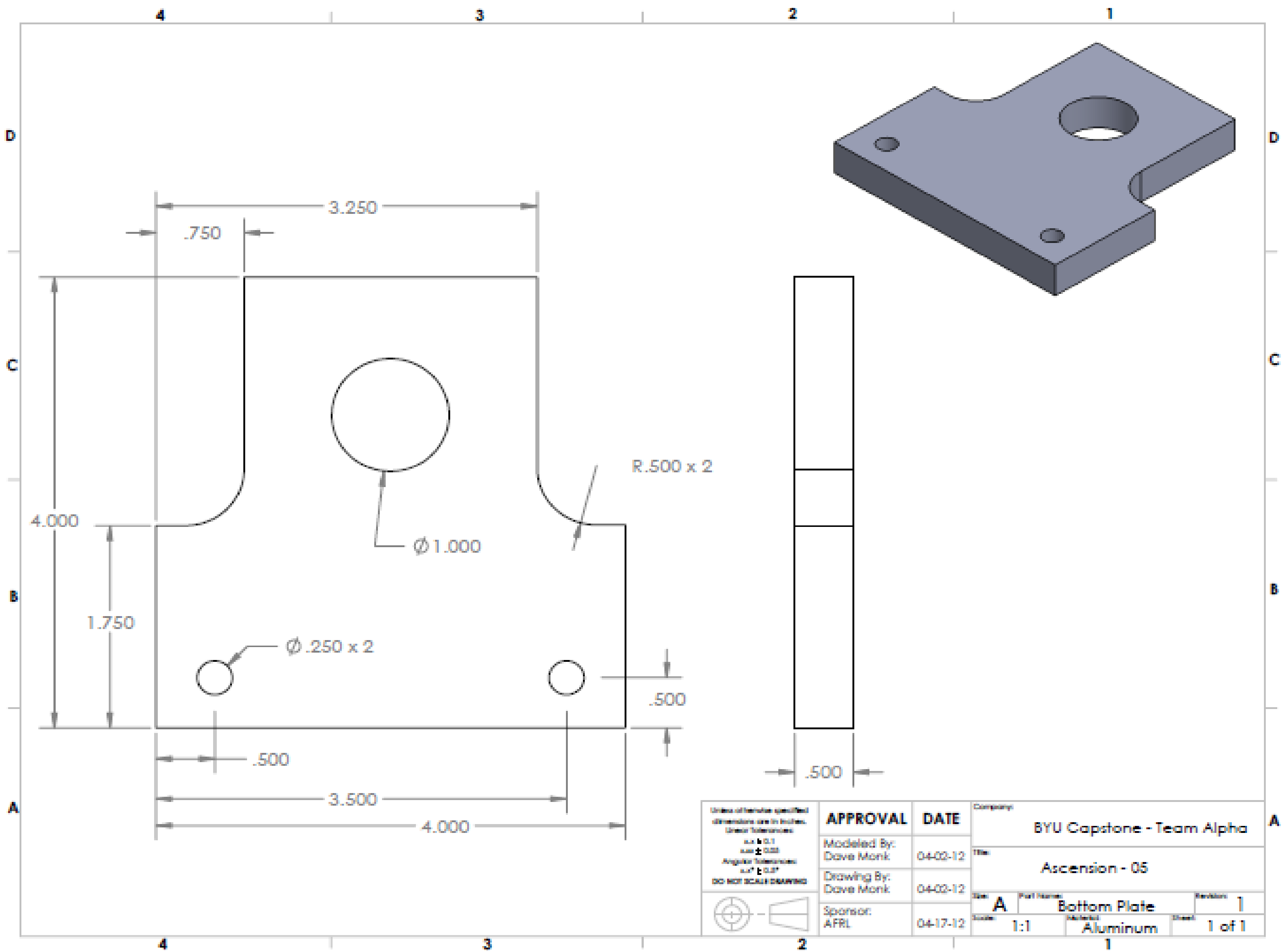
1:1
Aluminum
1 of 1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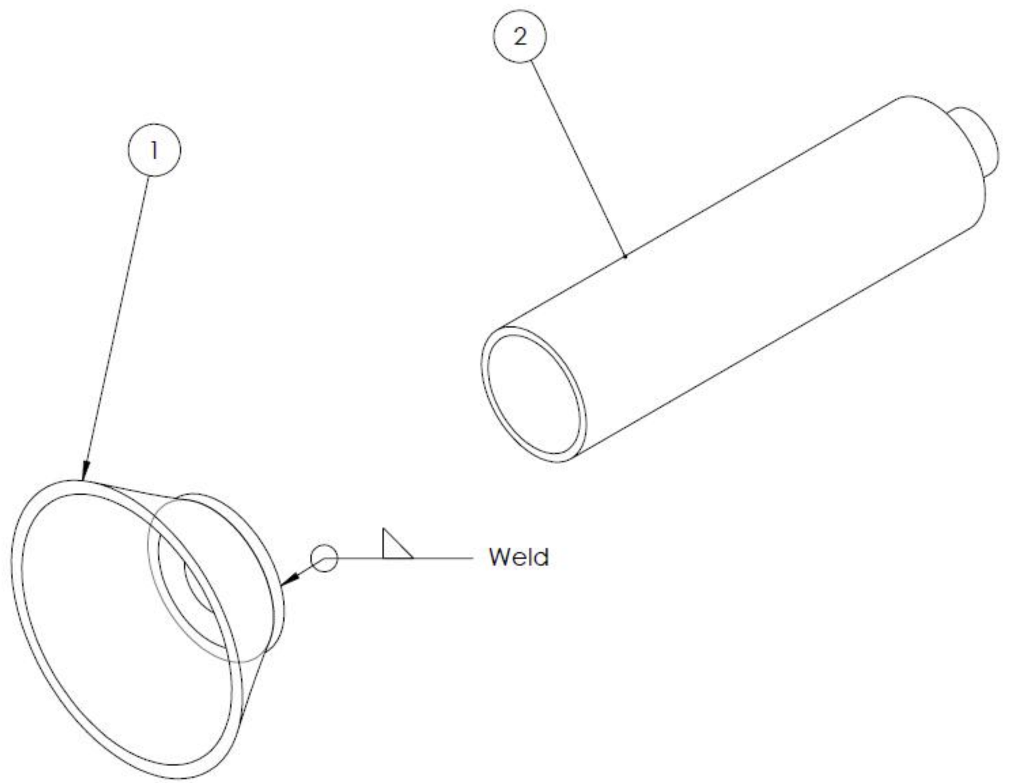
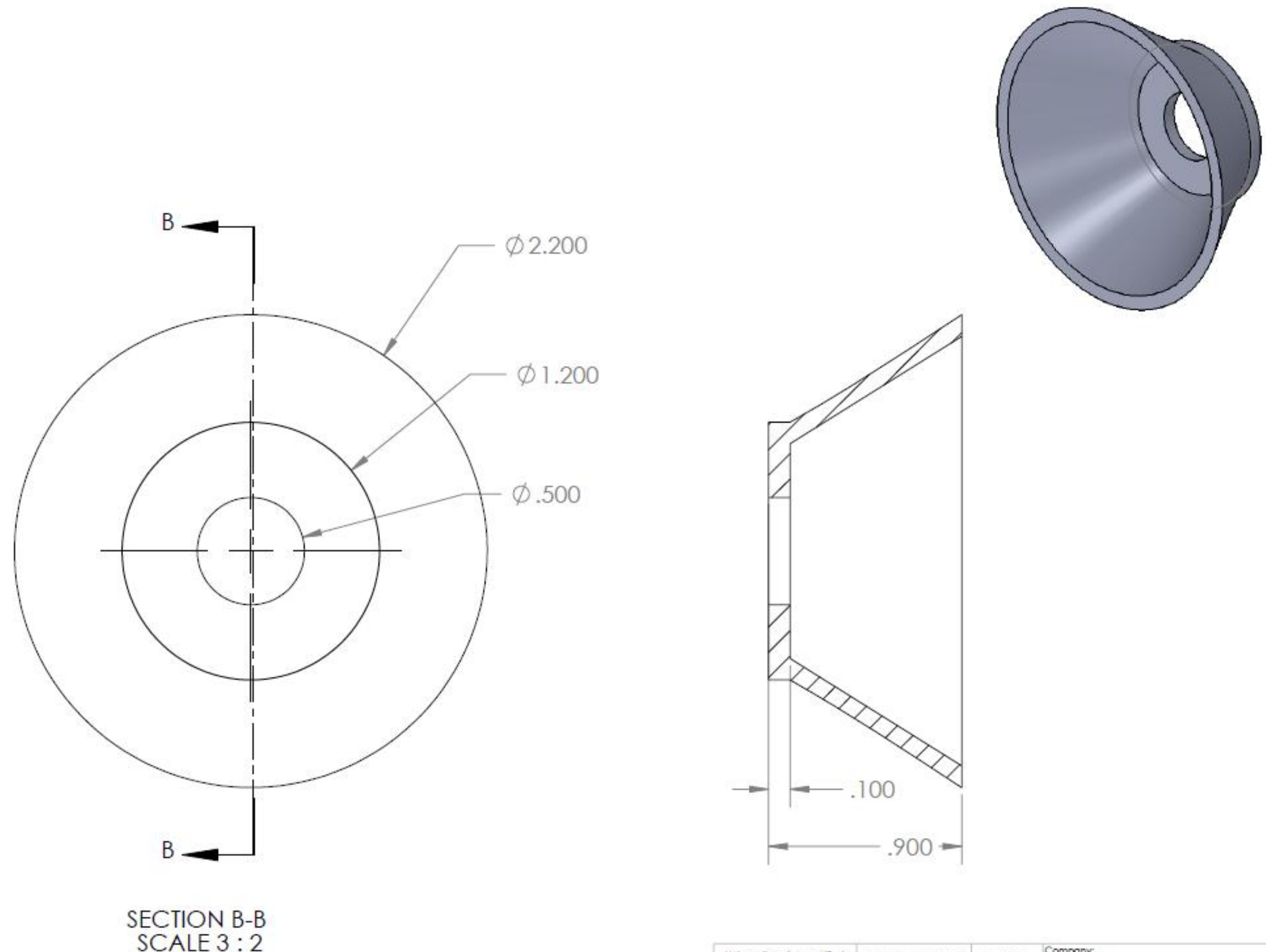
APPROVAL
DATE
Modeled By: Dave Monk
04-02-12
Drawing By: Dave Monk
04-02-12
Sponsor: AFRL
04-17-12
Company:
BYU Capstone - Team Alpha
Title:
Ascension - 05
Size:
A
Part Name:
Bottom Plate
Revision:
1
Scale:
1:1
Material:
Aluminum
Sheet:
1 of 1

Attachment Device Technical Drawings

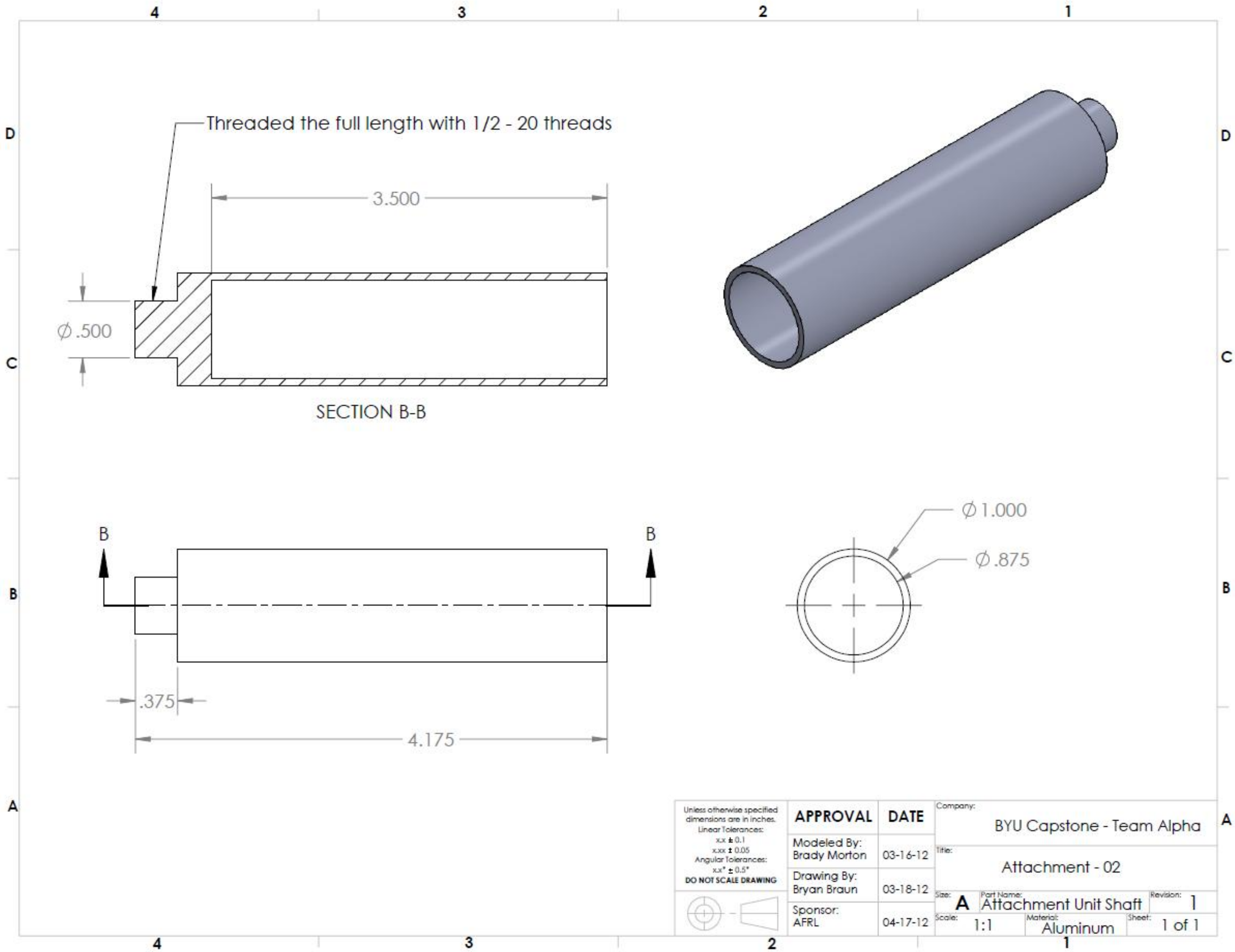
Item No.	Part	Description	Qty
1	Cup	Cup for supporting bean bag	1
2	Shaft	Shaft for attaching adhesives to rocket.	1



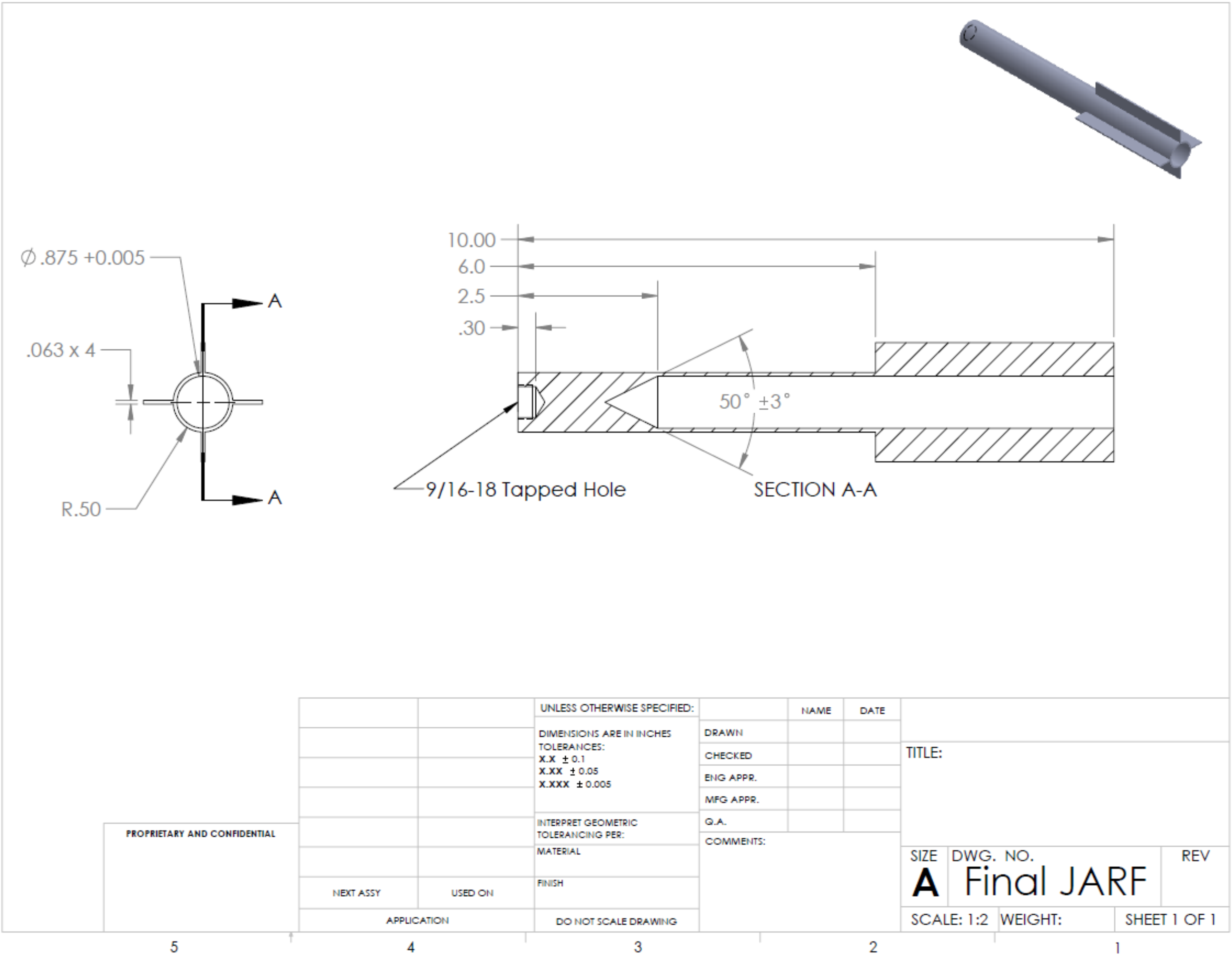
Unless otherwise specified dimensions are in inches. Linear Tolerances: x.x ± 0.1 x.xx ± 0.05 Angular Tolerances: x.x° ± 0.5° DO NOT SCALE DRAWING	APPROVAL	DATE	Company: BYU Capstone - Team Alpha			
	Modeled By: Bryan Braun	03-22-12	Title: Attachment Assembly			
	Drawing By: Bryan Braun	03-24-12	Size: A	Part Name: Assembly		Revision: 1
	Sponsor: AFRL	04-17-12	Scale: 1:4	Material: Various	Sheet: 1 of 1	



Unless otherwise specified dimensions are in inches. Linear Tolerances: x.x ± 0.1 x.xx ± 0.05 Angular Tolerances: x.x° ± 0.5° DO NOT SCALE DRAWING	APPROVAL	DATE	Company: BYU Capstone - Team Alpha		
	Modeled By: Bryan Braun	03-16-12	Title: Attachment - 01		
	Drawing By: Brady Morton	03-18-12	Size: A	Part Name: Adhesive Unit Cup	Revision: 1
	Sponsor: AFRL	04-17-12	Scale: 1:1	Material: Aluminum	Sheet: 1 of 1


Threaded the full length with 1/2 - 20 threads
3.500
Ø .500
SECTION B-B
B
B
Ø 1.000
Ø .875
.375
4.175
Unless otherwise specified dimensions are in inches.
Linear Tolerances:
x.x ± 0.1
x.xx ± 0.05
Angular Tolerances:
x.x° ± 0.5°
DO NOT SCALE DRAWING
APPROVAL
DATE
Modeled By: Brady Morton
03-16-12
Drawing By: Bryan Braun
03-18-12
Sponsor: AFRL
04-17-12
Company: BYU Capstone - Team Alpha
Title: Attachment - 02
Size: A
Part Name: Attachment Unit Shaft
Revision: 1
Scale: 1:1
Material: Aluminum
Sheet: 1 of 1

Deployment Device Technical Drawings



Bill of Materials

Bill of Materials for : AFRL Vertical Ascension

Team: Team: Alpha Team #: 1 Date: 4/5/2012
City: Provo State: Ut

Item	Part #	Description	Raw Mat'l	Source	Qty	Unit of Meas	Unit Price ($)	Total Price
Major System Names Here	*if available*	*Describe the Part (Axle, Bearing, Lifter, Solenoid)*	*What is it made from*	*Where can you buy it (Home Depot, AndyMark, Supply House, Etc.)*	*How Many*	*Piece, Inch, Etc.*	*Cost Per Unit*	
Deployment								
JARF	-	1" diameter, 10" long bar stock for projectile body	Steel	Metal/hardware shop	1	Piece	$3.00	$3.00
JARF	-	.5" by 3" Fins	Steel	Metal/hardware shop	4	Piece	$0.50	$2.00
JARF	-	1" diameter, 1.5" long bar stock for bullet trap	Steel	Metal/hardware shop	1	Piece	$1.00	$1.00
JARF	-	1" diameter, 5" long bar stock for bullet trap	Aluminum	Metal/hardware shop	1	Piece	$0.50	$0.50
							Subtotals:	$6.50
Attachment								
Rope		3 mm boat rope	Rope	Internet/boat shops	1	Piece	$86.00	$86.00
Grappling hook	-	Grappling hook	Steel	Amazon.com	1	Piece	$13.00	$13.00
Nail driver	-	Nail gun attachment	Steel	ebay.com	1	Piece	$20.00	$20.00
Attachment system	3979	Loctite 3979 light cure adhesive	-	Loctite	1	Bottle	$45.00	$45.00
Attachment system		UV LED array	-	Internet	1	Piece	$375.00	$375.00
Attachment system		Mousetrap glue	-	Home Depot	1	Piece	$5.00	$5.00
Attachment system	-	Cloth	Berlap	Michaels	1	Piece	$5.00	$5.00
Attachment system	MN21B2PK	12V Energizer A23 battery	-	Internet	1	Piece	$5.00	$5.00
Attachment system	-	1" diameter, 4" long bar stock for head fixture	Aluminum	Metal/hardware shop	1	Piece	$2.00	$2.00
Attachment system	-	Sand bag for attachment head	-	Machined	1	Piece	$5.00	$5.00
Attachment system		Switch for UV array	-	Radio shack	1	Piece	$3.50	$3.50
Attachment system	-	Cup head	Aluminum	Rapid prototype/sand cast	1	Piece	$65.00	$65.00
							Subtotals:	$629.50
Ascension								
Lift system	68146	Badlands Winch	-	Harbor freight	1	Piece	$60.00	$60.00
Lift system	6384K67	Bearings	Steel	McMaster-Carr	1	Piece	$12.00	$12.00
Lift system	-	Bearing Plate	Aluminum	Metal/hardware shop	1	Piece	$5.00	$5.00
Lift system		Switch		Home Depot	1	Piece	$6.00	$6.00
Lift system	-	Shaft	Steel	Metal/hardware shop	1	Piece	$5.00	$5.00
Lift system	91801A227	M4 x 25mm Screw	Steel	McMaster-Carr	4	Piece	$0.50	$2.00
Lift system	-	Bottom plate	Aluminum	Metal/hardware shop	1	Piece	$5.00	$5.00
Lift system	-	Pulley	Aluminum	Metal/hardware shop	1	Piece	$5.00	$5.00
Lift system		Washer	Aluminum	Metal/hardware shop	1	Piece	$0.50	$0.50
Lift system	92620A540	.25in-20 x 0.75 in screw	Steel	McMaster-Carr	1	Piece	$0.50	$0.50
Lift system	-	Rope guide	Aluminum	Metal/hardware shop	1	Piece	$5.00	$5.00
Lift system	92010A444	M6 x 45mm screws	Steel	McMaster-Carr	2	Piece	$0.50	$1.00
								$0.00
							Subtotals:	$95.00
							Totals:	**$731.00**

Section III: Appendices

Appendix A: Project Information

A1: Team Information

Team Contact Information Sheet		
Name	**Email**	**Phone**
Aaron Ford	aaronquazar@aol.com	(720) 937-7667
Brady Morton	bradymorton@hotmail.com	(801) 885-4326
Bryan Braun	bbraun7@gmail.com	(571) 274-7135
Dave Monk	dave.jw.monk@gmail.com	(801) 690-5184
Jason Rindlisbacher	jasonrindy@gmail.com	(801) 357-9753
William Tryon	connleytryon@gmail.com	(940) 765-8811
Greg Bishop(Coach)	greglbishop@gmail.com	(801) 916-5229

A2: References

- Military Mountaineering, Pentagon (June 1, 1995)

A3: Glossary

Project Glossary

Term	Definition
AFRL	Air Force Research Laboratory
AR-15/M-4	Standard military rifles which can be used to deploy our system.
UV	Ultra Violet – Low wavelength light which can be used for curing adhesives.
UV Adhesive	An adhesive that cures when exposed to ultraviolet light.
Anchor	A fixed attachment connected to a climbing rope.

A4: Project Milestones

Project Milestones	Completion Date
Team Contact List	Sep-2011
Team Name and Logo	Sep-2011
Project Objective Statement	Sep-2011

Project Schedule	Sep-2011
List of Customer Needs	Oct-2011
Functional Specifications	Oct-2011
Concept Generation	Oct-2011
Concept Screening & Scoring	Oct-2011
Preliminary Prototypes	Nov-2011
Detailed Testing	Feb-2012
Concept Selection	Feb-2012
Parts Purchase Info	Mar-2012
Bill of Materials	Mar-2012
Assembly Drawing	Mar-2012
Detailed Part Drawings	Mar-2012
FMEA	Mar-2012
Hardware Completion	Apr-2012
Competition	Apr-2012

Appendix B: Project Definition

The items in this section were used by the team to fully define the project. This includes a lot of early stage design work like research, determining customer needs, and generating concepts.

B1: Standard Equipment Carried by Troops

Standard Equipment Carried By Troops

Item #	Name	Price ($)	Quantity	Cost
1373	Slimline Elite Rope		120	$132.00
1146	Steel D 3 Stage Autolock	$32	4	$128
1011	ISC Rescue Ascenders	$200	1	$200
7016	Petzl Croll	$57	1	$57
6106	Yates Mini Haul 4:1 Kit	$243	1	$243
312	SAR Harness	$139	4	$556
1026	BlueWater Large Aluminum 8	$39	1	$39
	3 Day Assult Pack	$201.95	1	$201.95
	BA5590 Battery	$114.99	2	$229.98
7010	Petzl Vertex Best (helmet)	$110	4	$440
1015B	Rescue Rigger	$48	1	$48
			Total Cost:	$2,274.93

B2: Customer Statements

Customer Statements

Customer Statements		Interpreted Needs
"The ability to accommodate troops and their gear, approximately 300 lbs."	The device	can support an adult carrying military gear
"Capability to climb rock faces and concrete/adobe walls of 60 ft or taller that are vertical or near vertical."	The device	is usable on rock, adobe, and concrete surfaces
	The device	functions on vertical or near vertical surfaces
	The device	facilitates scaling of 60 feet or higher
"The ability to provide climbing assistance without the need to grapple over the top edge of the structure is desired."	The device	assists in climbing without needing to grapple over the top edge of the structure.
"The ability for the device to permit multiple pitches during the climb or to allow use by multiple troops is desired (reusable)."	The device	can be deployed several times in the same climb.
	The device	can be used by multiple troops.
	The device	is reusable.
"Minimize the weight of the system that needs to be carried by the operator(s)."	The device	is light-weight
"It is desirable that the system allows the operator to do other tasks while climbing, including holding and using his weapon, radio, or other equipment."	The device	allows the operator to perform other tasks while climbing.
"Device/System should be easily carried by a single troop, ideally fitting in an assault/tactical backpack with volume of roughly 20"x10"x8", or attaching to backpack in a way that allows soldier mobility or fitting in a larger rucksack with dimensions of approximately 24"x14"x10"."Standard Alice pact, 20x10x10inch, or strapped to outside of the pack."	The device	allows soldier mobility
"Rate of climb should be faster than what is done today or less strenuous than current operations at comparable speeds."	The device	allows for fast ascension
	The device	minimizes the strenuousness of the climb
"Elevations up to 10,000 ft"	The device	operates in elevations up to 10,000 ft
"We would like to minimize detectability, visibility, and audibility."	The device	is covert.
"Flame resistance - not critical"	The device	is flame resistant.

"Safety is a primary consideration – need to be safe during development and test. Final product must be safe for operators." "it must pass your schools' safety standards, and the safety of the device will be judged prior to the competition. If it is deemed unsafe by a safety review committee sometime before or during the competition, the device will not be allowed to be used."	The device	is safe.
"Adaptability is allowed (e.g., modular elements that allow use on different surfaces)."	The device	is adaptable to different surfaces (modular)
"Time to complete climb (includes unpacking, setup time, and retrieval of equipment, if required)"	The device	can unpack quickly
	The device	can be set up quickly (includes deployment and attachment)
	The device	can be retrieved quickly
"Scoring: Size of packaged device" "Dimensions may be one element of the scoring criteria, smaller is better. Ideally, the device should be easy to carry by one person and not hinder his/her movement on trails etc."	The device	can be contained in a small package
"Scoring: Restarts required"	The device	facilitates successful climbing without the need of multiple attempts
"Ease of operation (strenuous of operations, number of steps/time to set-up system, number of personnel required, number of tools required, training time)" "average fit person, 175 lbs (not couch potato, not Olympic athlete)" "We are considering using DoD personnel to demonstrate each team's prototype design. With this concept, each team must adequately train their DoD climber on how to use their design."	The device	can be set up with few steps
	The device	can be operated with a reduced number of operators
	The device	can be operated with reduced number of tools
	The device	requires little training to use
"Usability: Applicability to a range of rural/urban climbing situations, frees operator to do other tasks concurrently, packages conveniently for transport, ability to tolerate extremes (weather/wind, night/day, hot/cold, rough handling)" "Operates between -10 and 100 °F"	The device	packages conveniently for transport
	The device	is usable in extreme weather
	The device	is usable in wind
	The device	is usable both night and day
	The device	is usable in extreme temperatures (for outdoor use)
	The device	operates normally despite rough handling

"Stealth: Low detectability by human senses, during all phases of operation -- distance from which device can be detected, size signature, acoustic signatures, no traceability (leaving parts behind)." "Also, as noted in previous answers, noise of the device is desired to be low."	The device	evades visual detection
	The device	evades audio detection
	The device	has a small size signature
"Parts can be left behind, although in some cases it is desirable to leave no trace" "Can the climbing mechanism be destructive to the surface? Yes, although in some cases it is desirable to leave no trace."	The device	minimizes the evidence left behind
"Innovation/Elegance/Craftsmanship in Design: functional changes compared to existing systems, aesthetics, simplicity, design clarity, design continuity, style, robustness, visual precision, layout." "Are we able to incorporate existing, perhaps commercially-available, rope climbing devices in our design? Yes, although one of the scoring criteria will be innovation, which will factor in the novelty of the system developed."	The device	is innovative
	The device	is stylish and aesthetically attractive
	The device	is simple
	The device	is designed clearly
	The device	has a continuous design
	The device	is robust
Factor of safety to be used in the design? – "need to consider dynamic loads and extreme conditions, also potential for some component wear."	The device	can handle dynamic loads
	The device	resists wear
"Teams will be allowed a fixed time to complete their demonstration (20 min)."	The device	facilitates a quick operation
"These faces may have some structure (fissures, ledges, windows, etc), but the ability to accommodate a variety of conditions is desired."	The device	is flexible

B3: Functional Specifications

Metric No.	Need No.	Metric	Import.	Units	Marginal Value	Ideal Value
1	1	Climbing height for a single deployment	5	ft	at least 90 ft	at least 100 ft
2	2	Grade/incline of surface	5	Degrees	at least 90°	at least 100°
3	3	Physical Exertion Score (survey)	4	#	at most 2.5	at most 1
4	4	Total cost (to build final prototype)	3	$	at most $1000	at most $1500
5	5	Usability on Concrete, Adobe, and Rock	5	Binary	Yes	Yes
6	5,7	Number of deployments in a single climb	4.5	#	at least 1	at least 3
7	5,8	Number of climbers in a single deployment	4.5	#	at least 2	at least 4
8	5,9	# of deployments before resupply	4.5	#	at least 3	at least 10
9	5,10	# of free limbs	4.5	#	at least 1	at least 2
10	11	Total time of climb (from packed device to device retrieval)	4	min	at most 20	at most 12
11	12	Time to unpack	3	min	at most 2	at most 0.5
12	13	Time to set up (deployment and attachment)	3	min	at most 5	at most 3
13	14	Rate of ascension	4	ft/s	at most 11	at most 8
14	15	Time to retrieve device	3	min	at most 2	at most 0.5
15	16	Climbing success rate (# successful climbs/ # attempted climbs)	4	%	at least 60%	at least 90%
16	17,18,36	Minimum # of deployment cycles without failure	3.66	#	at least 15	at least 40
17	17,18,36	Minimum # of attachment cycles without failure	3.66	#	at least 15	at least 40
18	17,18,36	Minimum # of ascension cycles without failure	3.66	#	at least 15	at least 40
19	17,18,36	Minimum # of rope cycles without failure	3.66	#	at least 15	at least 40
20	17,19	Height of drop without receiving damage	3.75	ft	at least 10	at least 25
21	20	Functional day and night	5	Binary	Yes	Yes
22	21	Functions when wet (wetness scale)	5	#	at least 2	at least 4
23	21,22	Wind speed	4.5	mph	at least 10	at least 35
24	21,23	Minimum Functional Temperature	4.5	C	–23°	–30°
25	21,23	Maximum Functional Temperature	4.5	C	38	45
26	21,24	Cycles in "Sand Chamber"	4.5	cycles	at least 2	at least 10
27	25	Corrosion Resistance	3	Binary	Yes	Yes
28	26	Maximum functional elevation	3	ft	at least 10,000	at least 15,000
29	27,28	Device package volume	3	in^3	at least 3300	at least 1500
30	27,29	Device weight (not including pre-existing gear, from question #8)	4	lbs	at most 50	at most 35
31	27,30	Carrier mobility	4.5	Subj.	at least 2	at least 4
32	31,32	Visibility from 200 ft.	3	Binary	No	Yes
33	31,33	Audible Volume of Operation	3.5	Db	94*	84*
34	31,34	Projected area from 200 ft.	3	in^2	720	288
35	31,35	Traceability (traceability rating)	3	#	at most 3	at most 2
36	31,35	# of parts left behind	3	#	at most 6	at most 10
37	37	Time under direct flame (w/out combustion)	2	s	at least 5	at least 20
38	38	Minimum iterations of 300lb drop test from 1 m w/out failure	5	#	at least 1	at least 3
39	39	Minimum Weight of Payload	5	lbs	at least 300	at least 500
40	41	Average training time needed until proficiency levels are met	4	min	at most 60	at most 15
41	42	# of steps to set up	3	#	at most 6	at most 3
42	43	# of operators needed to use it	4	#	at most 4	at most 1
43	44	# of tools needed	3	#	at most 3	at most 0
44	45	Clarity of design (clarity rating)	3	#	at least 2	at least 4
45	40,46	Number of parts (unassembled)	3.5	#	at most 200	at most 10
46	40,46	Number of parts (assembled)	3.5	#	at most 10	at most 5
47	47	# of commercially available elements in climbing system	4	#	at most 6	at most 3
48	48	Use of Grapple	4	Binary	Yes	No
49	49	Aesthetics Rating (aesthetics rating)	3	#	at least 2	at least 4
50	50	Can climb without having someone secure the rope from below	4	Binary	No	Yes

The keys below help explain the rating or scaled based metrics on our spec sheet.

Wetness Scale - A Ranking of Wetness from 0 - 5

0 - Dry
1 - Lightly sprinkled with water
2 - Damp
3 - Light Rainfall
4 - Heavy Rainfall
5 - Immersed in Water

Physical Exertion Score - A ranking from 1.0 - 5.0

1 - Minimal Exertion. Comparable to walking.
2 - Light Exertion. Starts to increase pulse and breathing. Rest is unneccessary.
3 - Moderate Exertion.
4 - Heavy Exertion. Rest is desireable.
5 - Maximum Exertion. Comparable to sprinting. Requires rest afterwards.

Aesthetics Rating
The system is stylish and aesthetically pleasing .

1 - Strongly Disagree
2 - Disagree
3 - Nuetral
4 - Agree
5 - Strongly Agree

Proficiency Level Definition

The operater can successfully deploy, attach, and ascend with the system without assistance, completing the operation in 150% of the time taken by an experience opearator.

Carrier Mobility
The device can be comfortabley carried and allows soldier mobility.

1 - Strongly Disagree
2 - Disagree
3 - Nuetral
4 - Agree
5 - Strongly Agree

Tracability Rating
Troops using the system can be easily traced.

1 - Strongly Disagree
2 - Disagree
3 - Nuetral
4 - Agree
5 - Strongly Agree

Clarity of Design Rating
The device has a clear and comprehensible design.

1 - Strongly Disagree
2 - Disagree
3 - Nuetral
4 - Agree
5 - Strongly Agree

B4: Concept Generation List

Deploy	Attach	Ascend	Pack/Unpack
Explosive Charge	***Adhesive***	***Motorized***	Everything attaches to the rifle/weapon
Bullet Powered Rifle Barrel Attachment	Spray-able Velcro	Friction winch (prevents spooling the rope)	Stored in a holster
M203 Grenade Launcher Attachment	UV light that illuminates on impact and cures adhesive	Motorized (spooling) ascension	Folds into a case (briefcase)
Ignite O2 (gas) to launch out barrel	-Laser beam curing from ground	Winch in hand	Self-contained cartridge that fires from a
Small handheld launcher (like M203)	Quick setting air hardening Epoxy	Mechanical Winch pulls from the top	Can be inflated/deflated
Gas Powered	Epoxy bi-chamber that mixes (and cures) on impact	Electric winch attached to the waist	Put it in a box
Compressed gas rifle magazine	Glue man (run and stick to wall)	Hookshot	Shoulder Strap
Compressed Air Gun	Post-it note climbing system	***Man Powered***	Backpack
Compressed C02	Tape	Single Pully System	Rolled in a tarp/folded like paper
Man Powered	Sticky rope (on side of wall)	Bike Pedal system	Spring loaded unpack (like parachute)
Throwing device (clay pigeon)	Sticky Octopus Rope (many strands)	Rope Ladder	In backpack, deploys right from the bag
Bow/Crossbow	Sticky Rope (on top of wall)	Cargo Net	Device wrapped in the climbing rope
Giant bow/Crossbow	***Creating/Anchoring in Holes***	Two ropes with knots tied at intervals (foot loops)	Packed as a hat
Launch person with Giant bow/Crossbow	Powder actuated anchor driver	Semi sticky glue shoes	Bag turns into a harness
3 man Water Balloon Launch	Projectile embeds in surface and expands in the hole	Hand crank (American Gladiator)	
3 man person launch (large water balloon)	Explodes and fires many sharp pins that embed in the surface	Ladder	
Swing Rope w/elastic section	Mechanical Drill for drilling stud into wall	Two foot ascender (looks like pogo stick)	
Swing a rope	Secondary Explosion	Single Foot ascender	
David & Goliath Sling	Drywall anchor	Classic Ascender	
Atlatl	Hoberman Sphere (expands in a crevice)	Partner uses pulley system to lift his friend	
Guy throws his friend (acrobats)	Spike ball that shoots out with secondary explosion	Pull self up with series of pulleys	
Ladder	Expanding friend	Metal Ascension Gloves	
Elastic Rope Stretch and Release	***Hooks to surface***	Bicycle Ascender	
Magnetic	Electro rheological/Magneto rheological Fluid (hardens rope core)	Upside down bicycle ascender	
Magnets	Bimetallic strip inside rope that coils	Two foot ascender with elastic attachment	
Rail gun	Grappling hook	***Other***	

Aerial

Rocket Propelled Projectile (like Kp6)

Robotic Quad-copter with camera feed

Remote Helicopter

Balloon carries rope (pop it at top)

Hot air balloon

Candle lantern

Inspector Gadget Helicopter

Model rocket launch (disposable engine)

Helicopter drop off

Kite (or directional stunt kite)

Other

Robotic Surface Climber (Gekko)

Compressed spring device (linear)

Robot climbs the wall (trailing rope)

Teleporter

Anti-gravity device

Lasso

Fishnet attachment

Bolo (rope w 2/3 heavy balls that wrap around target)

Remote Clamp

Other Surface Attachment

Strong Magnet

Uni-directional Gecko pads on hands and feet

Gecko pad gloves

Suction cups on hands and feet (mechanical passive) Suction cup lever (can be fired)

Fish hook pads

Suction cup Octopus Rope

Other

High Friction, air mattress pumped with water

Hydrochloric Acid

Monkey

Peg board climbing (or ladder)

Really heavy object on top

Carpet Roll

Blow up the wall

Fan and Parachute

Trampoline (or the blob)

Jetpack

Pogo stick

B5: Scoring Matrices

Concept Screening Matrix - Deployment

		Concepts									
		Bullet Powered Rifle Attachment		M203 Grenade Launcher		Compressed Air Launcher		Bow/Crossbow		Remote Helicopter	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
facilitates scaling of 90 feet or higher - 5	13%	**4**	0.52	5	0.65	3	0.39	3	0.39	4	0.52
functions on vertical or near vertical surfaces - 5	10%	**5**	0.5	5	0.5	5	0.5	5	0.5	5	0.5
is inexpensive - 3	6%	**4**	0.24	3	0.18	3	0.18	3	0.18	2	0.12
is flexible - 5	10%	**4**	0.4	3	0.3	3	0.3	5	0.5	4	0.4
facilitates a quick operation - 4	10%	**4**	0.4	4	0.4	3	0.3	4	0.4	2	0.2
is robust - 3	6%	**5**	0.3	5	0.3	3	0.18	4	0.24	2	0.12
is convenient to transport - 4	8%	**5**	0.4	4	0.32	2	0.16	3	0.24	4	0.32
is covert - 3	8%	**3**	0.24	3	0.24	4	0.32	5	0.4	4	0.32
is safe - 5	12%	**4**	0.48	3	0.36	4	0.48	4	0.48	5	0.6
is simple - 4	9%	**5**	0.45	5	0.45	4	0.36	5	0.45	4	0.36
is innovative - 4	8%	**5**	0.4	4	0.32	4	0.32	3	0.24	4	0.32
Total Score		**4.33**		**4.02**		**3.49**		**4.02**		**3.78**	
Rank		**1**		**3**		**4**		**2**		**5**	
Continue?		Yes		Possibly		No		Possibly		No	
Total Weight:	100%										

Concept Screening Matrix - Attachment

		Concepts							
		Epoxies		Embeds in surface and expands		Secondary explosion		Fish-hook pads	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
functions on vertical or near vertical surfaces	15%	**4**	0.61	3	0.46	4	0.61	4	0.61
is inexpensive	7%	**3**	0.22	4	0.29	3	0.22	5	0.37
is flexible	11%	**3**	0.34	4	0.45	3	0.34	4	0.45
facilitates a quick operation	9%	**3**	0.28	4	0.37	4	0.37	4	0.37
is robust	7%	**2**	0.15	4	0.29	4	0.29	3	0.22
is convenient to transport	9%	**3**	0.28	4	0.37	3	0.28	2	0.19
is covert	7%	**5**	0.37	4	0.29	2	0.15	4	0.29
is safe	13%	**3**	0.4	4	0.53	4	0.53	3	0.4
is simple	10%	**4**	0.41	4	0.41	4	0.41	3	0.31
is innovative	9%	**5**	0.47	4	0.37	5	0.47	5	0.47
Total Score		**3.53**		**3.83**		**3.67**		**3.68**	
Rank		**4**		**1**		**3**		**2**	
Continue?		No		Yes		No		Possibly	
Total Weight:	100%								

Concept Screening Matrix - Ascension

		Concepts							
		Motorized Winch (winding or friction)		Bike Pedal System		Rope Ladder		Two foot ascender w/Elastic attachment	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
functions on vertical or near vertical surfaces	8%	5	0.4	4	0.32	5	0.4	4	0.32
minimizes the strenuousness of the climb	14%	5	0.7	3	0.42	4	0.56	3	0.42
is inexpensive	6%	3	0.18	3	0.18	5	0.3	4	0.24
is flexible	10%	5	0.5	4	0.4	4	0.4	4	0.4
facilitates a quick operation	13%	5	0.65	4	0.52	4	0.52	3	0.39
is robust	6%	3	0.18	4	0.24	5	0.3	4	0.24
is convenient to transport	8%	5	0.4	3	0.24	2	0.16	4	0.32
is covert	6%	5	0.3	4	0.24	4	0.24	4	0.24
is safe	12%	5	0.6	4	0.48	3	0.36	4	0.48
is simple	9%	4	0.36	3	0.27	5	0.45	4	0.36
is innovative	8%	4	0.32	5	0.4	1	0.08	4	0.32
Total Score		**4.59**		**3.71**		**3.77**		**3.73**	
Rank		**1**		**4**		**2**		**3**	
Continue?		Yes		No		Possibly		No	
Total Weight:	100%								

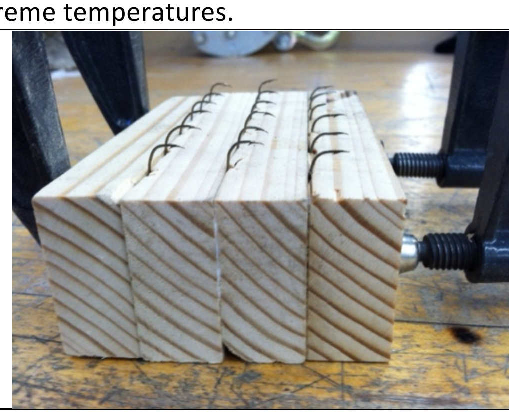
Appendix C: Prototyping and Test Data

C1: Deployment Prototypes

Prototype Name:	Golf Ball Launcher	**Projected Date** 11/14	**Completion Date** 11/14
Purpose:	A quick prototype used to determine if a gun could launch our climbing system 90 ft vertically and to find out if trapping a bullet fired from a live round would propel the system farther than a blank cartridge.		
Assignments:	Jason and Aaron: Machine and weld a golf ball launcher that will screw onto 1/2x28 threads.		
Prototype plan:	Initial tests will be with a .22lr handgun with the golf ball launcher attached to the barrel. We will test blank cartridges and then real .22lr rounds and record our findings. Later we plan to test the launcher with an AR-15 or M-4 rifle.		
Results:	With .22lr blank rounds, we were able to fire the golf ball (with a rope attached) approximately 60ft, with live .22lr rounds, however, the distance increased to 80ft. Using a 5.56mm blank in an AR-15 rifle we were able to achieve over 100ft (we only had 100ft of rope). A live round was not tested with the AR-15 because a golf ball will not trap a 5.56 bullet.		
Conclusion:	Using a rifle to launch our system 90ft seems like a very viable option and is one that we will likely pursue. Also, trapping the bullet seemed to work much better than using blanks.		
Questions:			

Prototype Name:	JARF	Projected Date Dec 2, 2011	Completion Date
Purpose:	Create a better rifle mounted launch system that manages the rope and can adapt to multiple payloads.		
Assignments:	Jason and Aaron: Build a and test a prototype working prototype		
Prototype plan:	The JARF (a mix of Jason's and Aaron's initials) is designed to launch greater distances and effectively manage the rope, which will be coiled inside of it. The JARF is also designed to trap a live round fired from a soldier's weapon, increasing the maximum distance it can travel, and eliminating the need for a soldier to unload his weapon to chamber a blank cartridge in a battle situation.		
Results:	Our initial prototype, made from PVC and steel, flew nearly 300ft when fired horizontally with a blank. It did not, however, have rope attached to it. It also tumbled through the air, reducing the distance it would have traveled otherwise. When tested with a live round, the PVC body shattered into several pieces, and we could not find the steel bullet trap to verify that it had done its job.		
Conclusion:	More testing needs to be done and we are working on better prototypes that will not break when used.		

C2: Attachment Prototypes

Prototype Name:	Wooden Fishhook plate	Projected Date 10/28/2011	Completion Date 10/28/2011
Purpose:	**For the "fishhook pads" concept:** To validate a score of flexibility = 4, and robust = 3. Specifically, we want to confirm that it can be used on rock, adobe, and concrete, (need 6) and under various weather and surface conditions (needs 21-24).		
Assignments:	Bryan to get fishhooks, Brady to get glue.		
Prototype plan:	Build it during Capstone hours "see sketch in Bryan's Record Book". Then use a concrete, adobe, and rock test surface (along with a cinder block, for validation of model) to ensure that our prototype can grip it. Test its ability to grip under dry, wet, and sandy conditions as well as under extreme temperatures.		
Results:	**Best gripping:** Cinder block, rough concrete, rough rock (dry, wet, or sandy doesn't make a difference). **OK gripping:** Smooth rock (if wet, it doesn't grip as well). **Poor gripping:** Smooth concrete (if wet, it doesn't grip well at all)		

Conclusion:	We will need a higher fidelity prototype to determine if we can grip smoother surfaces. We should probably see results from our other prototypes before investing more time in a higher fidelity prototype. To further validate "robust = 3" we need to test the wear properties and drop-test it.
Questions:	Will this be able to grip adobe? Would a higher fidelity model grip the smooth surfaces? How much weight can be supported by a "fish hook system" Do we make a higher fidelity model?

Prototype Name:	Greg's Powder Actuated Nail Driver	**Projected Date** 11/02/2011	**Completion Date** 11/02/2011
Purpose:	**For the "embeds in surface and expands" concept:** To validate a score of flexibility = 4, robust = 4, and safety = 4. We want to confirm that it can be used on rock, adobe, and concrete (need 6), under various weather and surface conditions (needs 21-24), and that it can support dynamic forces up to 300 lbs. **For the "secondary explosion" concept:** To validate a score of flexibility = 3, robust = 4, and covert = 2. We want to confirm that it can be used on rock, adobe, and concrete (need 6), under various weather and surface conditions (needs 21-24), at low audio levels (need 33), and that it can support dynamic forces up to 300 lbs.		
Assignments:	Brady picks up the nail driver from Greg's house. Get concrete slab by Monday.		
Prototype plan:	Borrow a nail driver from Greg. Use the driver to drive nails into concrete, adobe, and rock test surfaces under dry, wet, and sandy conditions as well as under extreme temperatures. Attempt to remove the nails to see what forces are required to pull them out.		
Results:	(see below)		

Nail Driving Test Results

Test #	Material	Penetration (")	Sound Level (dB)	Angle (°)	Comments
1	Concrete	1 3/4	98	90	It cracked the concrete a little.
2	Concrete	1 9/16	93.7	90	
3	Concrete	1 3/4	103.9	90	
4	Limestone	0	?	90	It bent and damaged the nail.
5	Wood	2 5/8 +	104.7	90	Would have gone deeper but for the washer.
6	Limestone	0	117	90	It bent and damaged the nail.

The nails penetrated the concrete but not the limestone. The nails embedded in concrete required over 150 lbs force to remove (we maxed out the force gauge).

Assumptions:
- Surface conditions (dry, wet, sandy) will not have a significant impact on this test.
- Material temperature will not have a significant impact (test this assumption later?)

Conclusion:	Using a "secondary explosion" or an "embed in surface" system may be a challenge for rock surfaces. More research on rock hardness is needed.
Questions:	Do we need to test on other varieties of rock? Which varieties? Do we need to test this on other varieties of concrete? Which varieties? Do we need to test this with more powerful rounds? Should sound levels be measured outside? How will this affect adobe? - Further testing should include trying other angles of entrance. - Removing the nail with Instron grippers pulling on opposing nails in a concrete test cylinder may yield more accurate results.

C3: Ascension Prototypes

Prototype Name:	Friction Winch	**Projected Date** Dec 2, 2011	**Completion Date**
Purpose:	Design shaft to act as friction winch. Discover if rope will slide to center of shaft and not spool over edge of shaft. Discover benefits of larger vs smaller shafts.		
Assignments:	Dave and William, machine different shaft designs.		
Prototype plan:	Machine straight tapered shafts and parabolic tapered shaft. Create test fixture to attach shaft to motor in order to test load limitations of motor.		
Results:	**Still waiting for motor. No tests run yet.		
Conclusion:			
Questions:			

Prototype Name:	Electric Motor	**Projected Date** Dec 2, 2011	**Completion Date**
Purpose:	Find load limitations and carrying capacity of motor. Also find lifting speed of motor.		
Assignments:	Dave and William – Research motors and gear motors. Find most efficient and cost effective way to achieve 600 in-lbs torque and over 100 rpm.		
Prototype plan:	Talk to experts in field of motors. Research online motor and gear motor vendors. Purchase motor. Attach to friction winch and test how much weight the motor will lift vertically and measure the speed at which it lifts 1000 lbs.		
Results:	** Still waiting on motor purchase. No tests run yet.		
Conclusion:			
Questions:			

C4: Nail Driving Test Results

Nail Driving Test Results

Test #	Date	Nail	Material	Penetration Depth (")	Sound Level at 3 ft(dB)	Angle (°)	Mode	Peak Force to Remove (lbf)	Comments
1	11/1/2011	2.5 in	Concrete (64 hrs cured)	1 3/4	98	90			It cracked the concrete a little.
2	11/1/2011	2.5in	Concrete (64 hrs cured)	1 9/16	93.7	90			
3	11/1/2011	2.5in	Concrete (64 hrs cured)	1 3/4	103.9	90			
4	11/1/2011	2.5in	Limestone	did not penetrate	?	90			It bent and damaged the nail. It chipped the rock.
5	11/1/2011	2.5in	Wood	2 5/8 +	104.7	90			Full penetration and would likely have gone deeper but the washer distributed the force.
6	11/1/2011	2.5in	Limestone	did not penetrate	117	90			It bent and damaged the nail. It chipped the rock.
7	1/8/2012	2.5in	Concrete (2 months cured)	0.875		90	Tension	305	Surface had previously been glued
8	1/8/2012	2.5in	Concrete (2 months cured)	1		90	Tension	48	
9	1/8/2012	2.5in	Concrete (2 months cured)	0.625		90	Tension	220	Surface had previously been glued
10	1/8/2012	.75in	Concrete (2 months cured)	1"		90			Nail buried in the concrete
11	1/8/2012	.75in	Limestone	did not penetrate		90			
12	1/24/2012	1.5in	Concrete (full cure cylinder)	destroyed the sample		90			Driving into the end of the round test cylinder destroys the sample. Too brittle? Too small?
13	1/24/2012	1.5in	Concrete (2 months cured)			90			Tall Sample
14	1/24/2012	1.5in	Concrete (2 months cured)			70	Shear	370+	Tall Sample... some of the nail was exposed by chipping of the concrete.
15	1/24/2012	2in	Concrete (full cure column)			90			

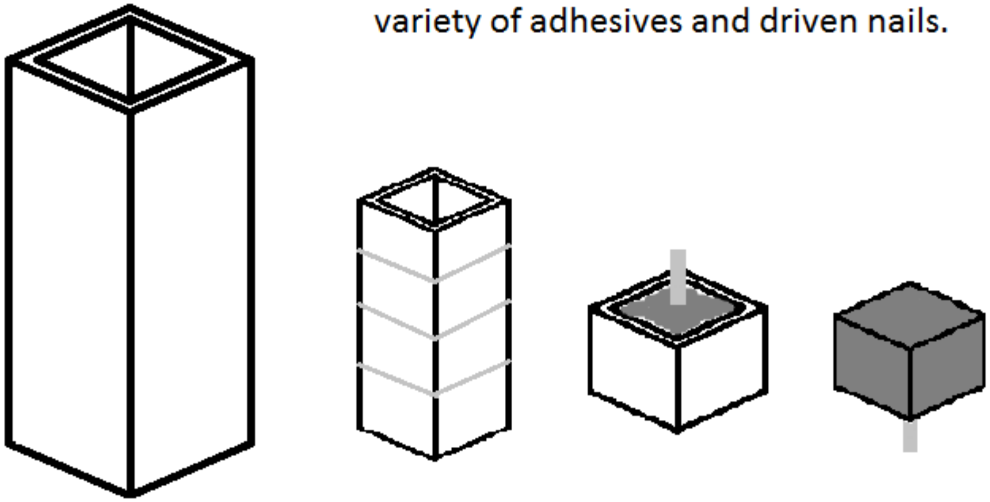
16	1/24/2012	1.5in	Concrete (full cure column)			90	Shear	460	This was pulled twice. The first test was scratched because the fixture failed at 375 lbs.
17	1/24/2012	.75in	Concrete (full cure column)			90			

C5: Adhesive Test Results

Adhesive Test Results									
Test #	**Date**	**Adhesive**	**Material**	**Cure-Time**	**Tensile / Shear**	**Peak Force (lbs)**	**Area (in^2)**	**lbs/in^2**	**Notes**
1	12/2/2012	Fixmaster Metal Magic	Acryllic - Concrete	10 min	Tensile	19	7.8	2.435897	
2	12/2/2012	Mixer Cups	Acryllic - Concrete	10 min	Tensile	127	7.8	16.28205	
3	12/2/2012	331 Magnet Bonder	Acryllic - Concrete	10 min	Tensile	293	7.8	37.5641	
4	1/8/2012	3974 - UV Cure	Acryllic-Rock	1 min	Tensile	0	1.5	0	Minimal contact with the rock
5	1/8/2012	3974 - UV Cure	Acryllic-Rock	2 min	Tensile	25	1.5	16.66667	Minimal contact with the rock
6	1/8/2012	3979 - UV Cure	Acryllic-Rock	1 min	Tensile	90	2	45	
7	1/8/2012	3970 - UV Cure	Acryllic-Rock	2 min	Tensile	140	2	70	
8	1/13/2012	3974 - UV Cure	Acryllic-Concrete	4 min	Tensile	560	7.8	71.79487	
9	1/13/2012	3979 - UV Cure	Acryllic-Concrete	4 min	Tensile	175	7.8	22.4359	
10	1/13/2012	Loctite 331	Acryllic-Concrete	10 min	Tensile	75	7.8	9.615385	
11	1/16/2012	3979 - UV Cure	Acryllic-Concrete	1 min	Shear	Maxed: 300+	3	100	Original test failed still need to complete.
12	1/16/2012	3979 - UV Cure	Acryllic-Concrete	4 min	Shear	Maxed: 300+	3	100	Original test failed still need to complete.
13	1/16/2012	Loctite 331	Acryllic-Concrete	10 min	Tensile	25	7.8	3.205128	
14	1/16/2012	Loctite 331	Acryllic-Concrete	15 - 20 min	Shear	215	7.8	27.5641	Detached from the cement, not the acryllic.

Attachment Test Set-up

For testing the hold strength of a variety of adhesives and driven nails.

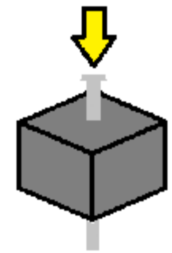


1 Get square PVC tubing.

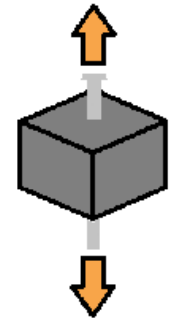
2 Cut the tubing into segments.

3 Pour concrete into the segment and lodge a bolt in the mixture.

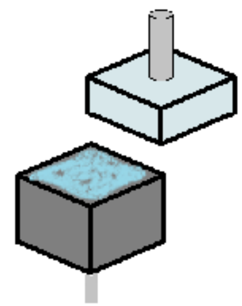
4 Remove test piece from the mold.



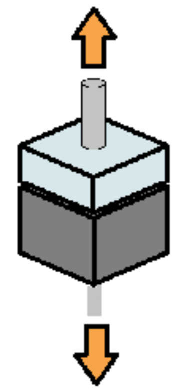
5a Drive a nail into the test piece.



5b Use Instron to record tensile test data.



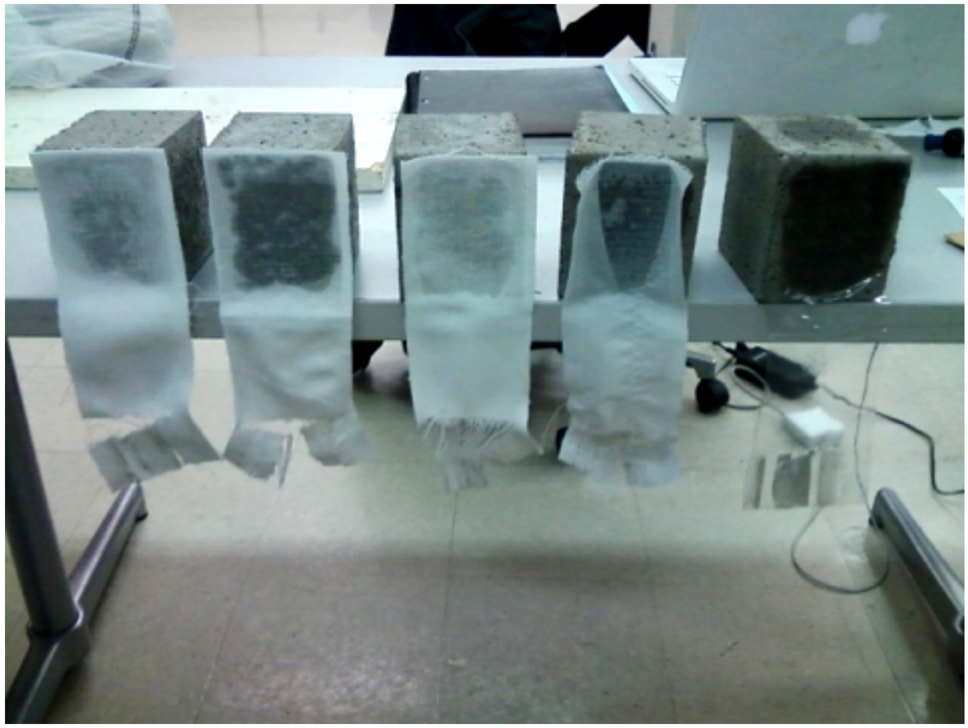
6a Apply adhesive and build a test surface.



6b Bond the pieces and record tensile test data.

C6: Fabric Test Results

UV Cure Fabric Testing									
Test #	**Adhesive**	**Material Name**	**Material Description**	**Cure Time**	**Max Load (lbs)**	**Area (in^2)**	**psi**	**Ramp Rate (in/s)**	**Notes**
1	Loctite 3979	White Screen Cloth	Plain	2:00 min	72	8.13	8.86	0.004	Fabric began to tear
2	Loctite 3979	White Duck Cloth	Plain	2:00 min	135	8.13	16.61	0.004	Fabric began to tear near the clamp
3	Loctite 3979	No-Rip Nylon	Plain	2:00 min	93	8.13	11.44	0.0045	Started to have some peel around the edges of the adhesive patch, began tearing near adhesive and near grip as well.
4	Loctite 3979	High Quality Cotton	Plain	2:00 min	97	8.13	11.93	0.0045	Fabric began to tear near the bottom grip.
5	Loctite 3979	Vinyl	Plain	2:00 min	83	8.13	10.21	0.005	Plastic deformation, very slight peel, pulled the part 4 inches, ran out of room.
6	Loctite 3979	High Quality Cotton	Double Layer	2:00 min	109	8.13	13.41	0.005	Tore at bottom grip.
7	Loctite 3979	Reinforced Duck Cloth	Duck cloth reinforced with 2 pleather strips (strips on outside)	2:00 min	160	8.13	19.68	0.005	Adhesive failed = peel. Lots of concrete can off with the adhesive. UV light doesn't penetrate this material as well as others espcecially through the pleather strip. I think a factor was that since the adhesived didn't cure under the pleather, the effective surface area was much smaller.
8	Loctite 3979	Reinforced Burlap	Burlap reinforced with 2 twill tape strips (strips on outside)	2:00 min	226	8.13	27.80	0.005	Tearing at clamp, tore through the twill strips. The strips ultimately failed.
9	Loctite 3979	Reinforced No-Rip Nylon	Double layer nylon sheet, with reinforced stitching	2:00 min	208	8.13	25.58	0.005	Hydraulic fluid got shut off and killed the test, continued test, and failed in peel.
10	Mixer Cups	Red Duck Cloth	Plain	10 min	30	4.5	6.67	-	Failed in the adhesive. Used the electronic fish scale and manpower.
11	Mixer Cups	Floral Fabric	Plain	10 min	45	6	7.50	-	Failed in the adhesive. Used the electronic fish scale and manpower.



C7: Preliminary Attachment Brainstorming Matrix

Orientation/Initial Attachment Combination Matrix

:Scores	Orientation / **Preliminary Attachment**	Nail belt	Net	Nail with washer and epoxy	Sticky Fabric	Spring Loaded Rocket	Multi-direction glue/clay	Spit Wad	Breakable Egg/Humpty Dumpty	Multi-nail Button actuator	Epoxy/Pressure	Suction with Grip	Nail	Explosive/armor piercing	Silly String	Peanut Butter
	Scores:	5	5	5	4	4	3	3	3	2	2	2	2	1	1	0
~~6~~	~~360 degree multi attachment with rope~~	~~N~~	~~N~~	~~Y~~	~~Y~~	~~N~~	~~Y~~	~~Y~~	~~N~~							
~~6~~	~~Ball Swing~~	~~N~~	~~N~~	~~Y~~	~~Y~~	~~Y~~	~~N~~	~~Y~~	~~Y~~							
~~6~~	~~Pyramid~~	~~Y~~	~~N~~	~~Y~~	~~Y~~	~~N~~	~~N~~	~~Y~~	~~Y~~							
~~5~~	~~2 balloon plane~~	~~Y~~	~~Y~~	~~Y~~	~~Y~~	~~Y~~	~~Y~~	~~Y~~	~~Y~~							
5	2 pt anchor	Y	Y	Y	Y	Y	Y	Y	Y							
~~4~~	~~Helicopter~~	~~Y~~	~~Y~~	~~Y~~	~~Y~~	~~Y~~	~~Y~~	~~Y~~	~~Y~~							
4	Top Heavy	Y	Y	Y	Y	Y	Y	Y	Y							
~~4~~	~~Ball~~	~~Y~~	~~Y~~	~~Y~~	~~Y~~	~~Y~~	~~Y~~	~~Y~~	~~Y~~							
4	Flight Spin	Y	Y	Y	Y	Y	Y	Y	Y							
3	2 tiered, 2 anchor															
3	1 pt anchor															
3	Wire Catch															
3	360 multi with sensor															
2	Balloon															
2	Vacuum															
1	Target Guided															
1	Parachute															
1	Sensor Rotation															
1	Crawler															
0	Glider															

C8: Preliminary Attachment Scorings/Screenings

		1 pt Anchor	2 pt anchor	Rocket	Streamer
Selection Criteria	**Weight**	Rating	Rating	Rating	Rating
functions on vertical or near vertical surfaces	15%	**5**	**5**	**5**	**5**
is flexible	12%	**3**	**2**	**4**	**4**
facilitates a quick operation	10%	**3**	**3**	**5**	**4**

is robust	8%	**5**	**4**	**4**	**5**
is convenient to transport	10%	**5**	**4**	**4**	**5**
is covert	8%	**3**	**3**	**4**	**4**
is safe	14%	**4**	**4**	**4**	**4**
is simple	11%	**3**	**2**	**4**	**3**
is innovative	10%	**4**	**4**	**5**	**4**
	100%				
	Total Score	**3.92**	**3.51**	**4.36**	**4.23**
	Rank	**3**	**4**	**1**	**2**

Selection Criteria	Weight	Nail belt		Net		Nail with washer and epoxy		Sticky Fabric		Spring Loaded Rocket		Multi-direction glue/clay		Spit Wad		Breakable Egg/Humpty Dumpty	
		Min Rating	Max Rating	Min Rating	Max Rating	Min Rating	Max Rating	Min Rating	Max Rating	Min Rating	Max Rating	Min Rating	Max Rating	Min Rating	Max Rating	Min Rating	Max Rating
functions on vertical or near vertical surfaces	15%	5	5	3	5	5	5	4	5	5	5	4	5	5	5	5	5
is inexpensive	7%	1	3	2	4	1	3	3	5	1	4	1	3	3	5	1	4
is flexible	11%	2	4	2	3	2	4	2	4	2	4	2	4	2	4	2	4
facilitates a quick operation	9%	3	5	4	5	4	5	3	5	1	4	2	4	2	5	3	5
is robust	7%	4	5	1	3	3	5	3	4	3	4	2	3	2	3	1	3
is convenient to transport	9%	1	2	4	5	1	3	4	5	2	3	2	4	5	5	3	4
is covert	7%	1	2	4	5	1	3	4	5	1	4	4	5	4	5	3	5
is safe	13%	2	5	3	4	2	4	3	4	3	5	2	4	2	4	2	4
is simple	10%	2	3	2	4	2	4	4	5	3	5	3	5	4	5	3	5
is innovative	9%	3	4	3	5	2	4	1	3	3	5	3	4	1	3	3	5
Total Score		2.55	3.94	2.82	4.32	2.48	4.08	3.12	4.50	2.62	4.39	2.58	4.18	3.07	4.42	2.77	4.44
Average		3.25		3.57		3.28		3.81		3.51		3.38		3.75		3.61	
Avg. Rank				4				1						2		3	
Max Rank									1		4				3		2
Min Rank				3				1						2		4	
Continue?		NO				NO				NO		NO					

Selection Criteria	Weight	Nail belt		Net		Nail with washer		Sticky Fabric		Spring Loaded		Multi-direction		Spit Wad		Breakable	
		Min Rating	Max Rating	Min Rating	Max Rating	Min Rating	Max Rating	Min Rating	Max Rating	Min Rating	Max Rating	Min Rating	Max Rating	Min Rating	Max Rating	Min Rating	Max Rating
functions on vertical or near vertical surfaces	15%	5	5	1	4	5	5	4	5	5	5	4	5	2	3	1	2
is inexpensive	7%	1	3	2	4	1	3	3	5	1	4	1	3	3	5	3	4
is flexible	11%	2	4	2	3	2	4	2	4	2	4	2	4	2	4	2	4
facilitates a quick operation	9%	3	5	4	5	4	5	3	5	1	4	2	4	2	3	3	5
is robust	7%	4	5	1	3	3	5	3	4	3	4	2	3	2	3	1	3
is convenient to transport	9%	1	2	4	5	1	3	4	5	2	3	2	4	5	5	3	4
is covert	7%	1	2	4	5	1	3	4	5	1	4	4	5	4	5	3	5
is safe	13%	2	5	3	4	2	4	3	4	3	5	2	4	2	4	2	4
is simple	10%	2	3	2	4	2	4	4	5	3	5	3	5	4	5	3	5
is innovative	9%	3	4	3	5	2	4	1	3	3	5	3	4	1	3	3	5
Total Score		2.55	3.94	2.52	4.17	2.48	4.08	3.12	4.50	2.62	4.39	2.58	4.18	2.61	3.93	2.30	3.98
Initial Max Rank									1		4				3		2
Initial Min Rank				3				1						2		4	
Initial Average		3.5		4		3		2		4		3.5		2		4	
Initial Avg. Rank				4				1						2		3	
Continue?		NO		YES		NO		YES		NO		NO		YES		YES	
New Average		3.248		3.342		3.2795		3.809		3.5055		3.379		3.2705		3.1425	

Preliminary Attachment Testing

Preliminary Attachment Method	Test Surface	Effectiveness (0-5)	Notes
Breakable Egg			
filled w/ hot glue and netting	Concrete	0	The net held the bulb pieces together, preventing sticking.
filled w/ hot glue and screw anchor	Concrete	0	Some blobs of glue stuck, but dripped off. It also wasn't a direct hit on the wall.
filled w/ foam insulation	Concrete	0	Foam held broken glass together, prevening sticking.
filled w/ roofing pitch	Concrete	0	Pitch held broken glass together, preventing sticking.
Spitwad			
Newspaper and roofing pitch	Concrete	0	Left a splat on the wall, but promptly fell off.
Newspaper, WD-40, and roofing pitch	Concrete	0	Left a splat on the wall, but promptly fell off.
Newspaper, water, and roofing pitch	Concrete	1	Stuck to the wall, but could not hold a load. Most of the liquid was water.
Adhesive-Filled Net			
insulation foam inside pantyhose	Concrete	0	Bounced off the wall.
Sandbag w/ Adhesive on Fabric			
w/ roofing pitch on duck cloth	Concrete	3	Fabric stuck. It held 2-3 lbs.
w/ insulation foam on duck cloth	Concrete	2	Held < 1 lb.This holds more weight as it hardens but it takes 30min+ to get decent hardening .
w/ Loctite "Mixer Cups" epoxy on duck cloth	Concrete	4	5 minute cure. It held the weight of the concrete block (around 25 lbs).
w/ magnet bonder on duck cloth	Concrete	2	5 minute cure. It held < 2 lbs.
w/ superglue metal epoxy on duck cloth	Concrete	4	5 minute cure. It held about 10 lbs.
w/ hot glue on duck cloth	Concrete	4	Cures in seconds. It held the concrete block (≈25 lbs). Great in shear, but worse in tension.
w/ hot glue on duck cloth	Cinder Block	5	Cures in seconds. Held the whole cinder block and more (up to 40 lbs?)
w/ VHB tape on duck cloth	Concrete	2	
W/ Loctite Sprayable Adhesive on duck cloth	Concrete	1	
W/ Gorilla Tape on duck cloth	Concrete	1	
w/ gorilla glue (white) on duck cloth	Concrete	1	

w/ gorilla glue (brown) on duck cloth	Concrete	1	
w/ mousetrap goop on duck cloth	Concrete	5	Held the concrete block even when shaking it.
w/ mousetrop goop on duck cloth	Concrete	2	
w/ strong stick (cream) on duck cloth	Concrete	1	
w/ Loctite instant epoxy on duck cloth	Concrete	4	
Very High Bond Tape			
VHB	Concrete	2	It performs poorly with both with and without surface cleaning.
VHB	Cinder Block	2	
VHB	Masonry	2	
VHB	Rock	2	
Spider Ball			
Spiderball with insulation adhesive	Concrete	0	Didn't remain stuck to the wall

Preliminary Orientation Testing

	Method	Power Source	Angle	Ground Distance	Success?	Notes
1	Rocket	blanks	45	257.48 ft	Yes	Flew straight
2	Rocket	blanks	60	39.9 m	Yes	Flew straight (landed after 3s)
3	Rocket	blanks	45	196.8 m	Yes	Flew straight
4	1 pt anchor	blanks	70	75 ft (line length)	No	Line didn't stay taut, but it wasn't shot directly up.
5	1 pt anchor	blanks	90	75 ft (line length)	No	Line didn't stay taut, but the projectile fell short.
6	1 pt anchor	bullet	90	75 ft (line length)	Yes	Worked very well.
7	2 pt anchor	blanks	90	75 ft (line length)	Yes	It worked but it was more taut on one side, and drifted to one side.
8	2 pt anchor	blanks	90	75 ft (line length)	Yes	It worked but it was more taut on one side, and drifted to one side.
9	Streamer	blanks	45	177 ft	Yes	Flew straight
10	Rocket w 1 pt anchor	blanks	90	12.83 m		We intentionally put slack in the line, which caused the rocket to bounce.
11	Rocket	bullet	0	-	No	The rocket broke to pieces.
12	Streamer	black powder	30	?	Yes	Flew straight

C11: Motor Requirement Calculations

3-0235 — 50 SHEETS — 5 SQUARES
3-0236 — 100 SHEETS — 5 SQUARES
3-0237 — 200 SHEETS — 5 SQUARES
3-0137 — 200 SHEETS — FILLER

COMET

Motor Requirements

Design for 1000 lbs.

Torque = r × F

For 1½" diameter shaft
T = .75 in × 1000 lbs

$\boxed{T = 750 \text{ in-lbs.}}$

For V = 12 ft/min

$12 \text{ ft/min} = \pi\left(\frac{1.5}{12}\right) \omega$

$\boxed{\omega = 30.6 \text{ rpm.}}$

For V = 45 ft/min

$45 \text{ ft/min} = \pi\left(\frac{1.5}{12}\right)\text{ft } \omega$

$\boxed{\omega = 114.6 \text{ rpm}}$

* A 1½" diameter shaft for 1000 lb load

T > 750 in-lbs.
For V ≥ 12 ft/min, ω > 30.6 rpm
V > 45 ft/min, ω > 114.6 rpm

For 2" diameter shaft
T = 1" × 1000 lbs.

$\boxed{T = 1000 \text{ in. lbs}}$

For V = 12 ft/min

$12 \text{ ft/min} = \pi\left(\frac{2 \text{ in}}{12}\right) \omega$

$\boxed{\omega = 22.9 \text{ rpm.}}$

For V = 45 ft/min

$45 \text{ ft/min} = \pi\left(\frac{2}{12}\right)\text{ft } \omega$

$\boxed{\omega = 85.9 \text{ rpm}}$

* A 2" diameter shaft for 1000 lb Load

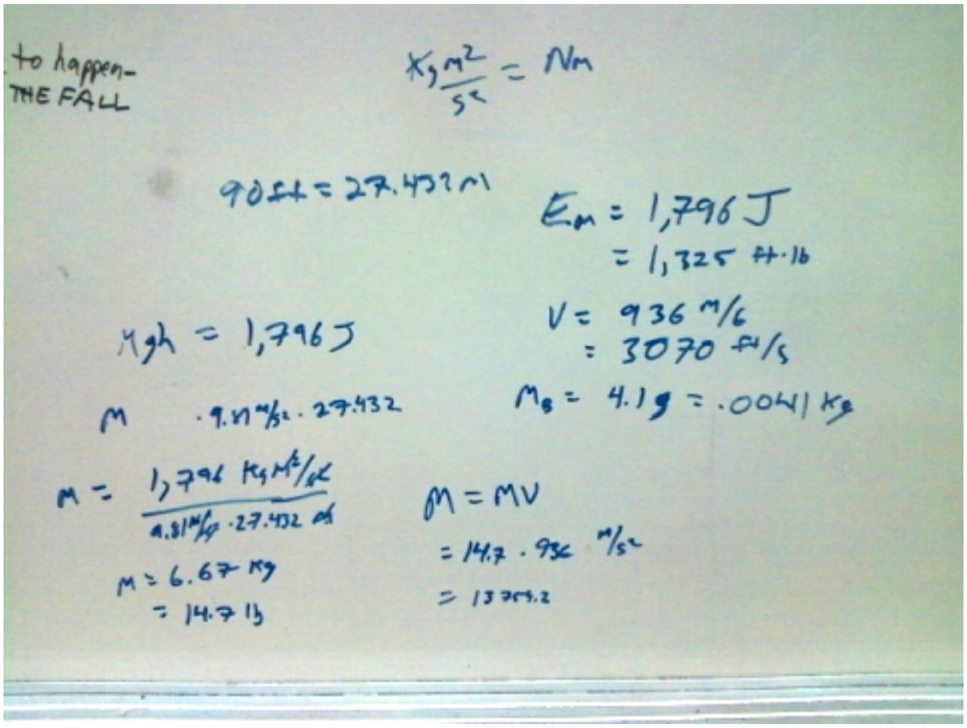
T > 1000 in-lbs
For V = 12 ft/min, ω > 22.9 rpm
V = 45 ft/min, ω > 85.9 rpm.

We have 15 V DC Battery, which can be amplified to 30 V.

We need a motor which operates at under 30 V, has between 750-1000 in-lbs torque and 86-115 rpm.

C12: Deployment Power Calculations

Using reasonable assumptions and data available online, we were able to calculate that in the absence of friction, our deployment device could carry a payload of 14.7 lbs up ninety feet. The calculations are given below.



C13: Audio Level Calculations

Assumptions:

- Outdoor sound attenuation can be described by half-spherical attenuation in a direct sound field
- An outdoor sound of 50 db next to you is detectible

$$L_2 = L_1 - 20 \cdot \lg\left(\frac{r_2}{r_1}\right)$$

r_1 = *Distance from source to a nearby reference point*
r_2 = *Distance from source to a distant observer*
L_1 = *Sound level at a nearby reference point*
L_2 = *Sound level for distant observer*

Ideal value: At 200 ft, a source sound level of 84 db has attenuated* to 50 db (level of an average home)
Marginal value: At 200 ft, a source sound level of 94 db has attenuated* to 60 db (level of a hair dryer)

Appendix D: Product Manuals

D1: Operations Manual

ATTACHMENT / ASSEMBLY	
Images	**Steps**
	Remove the rocket-projectile from the pack and thread an attachment device onto the nose (screw it in until it doesn't rotate any further)
	For Adhesive Device: 1. Remove a prepared cloth from the pack (ensure the circuit is already attached and the primary adhesive is applied). 2. Attach the line to the cloth (via carabineer, or bowline knot) 3. Peel off the wax paper protecting the primary adhesive. 4. Secure the cloth on the beanbag assembly 5. Apply the UV adhesive (Loctite 3979liberally to the cloth opposite of the LED array on the other side of the fabric 6. Flip the timer switch 7. Load the projectile onto the gun barrel (or pneumatic launcher), being careful to keep adhesive end pointing up 8. Launch before the twenty second timer is up 9. Wait the full cure time (2-4 minutes) before putting force on the line
	For Anchor Driving Device 1. Load one .22 cartridge into the chamber of the anchor driver 2. Load a nail into the barrel of the anchor driver according to this criteria: • Softer than concrete: anchor length > 1" • Concrete: anchor length = 1" • Harder than concrete: anchor length < 1" (or don't use anchors) 3. Ensure that the line is connected to the anchor washer 4. Load the projectile onto the gun barrel (or pneumatic launcher), being careful to keep the barrel pointing up. 5. Aim and Launch
	For Grappling Hook 1. Ensure that the line is connected to the hook, via carabineer, or knot. 2. Aim above the target destination and Launch.
DEPLOYMENT	
Images	**Steps**
	1. Slide the projectile over the barrel of the gun 2. Ensure that attachment device is fully connected 3. Aim the device by aiming the gun 4. Pull the trigger to launch the device
ASCENSION	
Images	**Steps**
	1. Remove the ascension winch from the pack. 2. Fasten electrical connections from the battery to the winch. 3. Put on climbing harness; be sure all straps are secure and tight. 4. Use carabineer to attach ascension winch to harness. 5. Be sure switch controller is free and easily accessible. 6. Feed end of rope through rope guide, around pulley, and back through rope guide. 7. Run winch forward to remove any slack in rope. 8. Grab free end of rope and place tension on it.

	9. Ascend to desired height using switch controller.

D2: Troubleshooting Table

DEPLOYMENT	
Issue	**Resolution**
The projectile will not launch 90 ft.	1. Ensure that you are using a live round with a bullet instead of a blank round. 2. Ensure that the projectile can easily slide on and off the barrel of the gun without sticking.
The projectile stops functioning properly.	Check all parts to make sure they are intact. If the parts appear to be compromised after several uses, consider replacing the unit.
ATTACHMENT	
Issue	**Resolution**
The preliminary adhesive will not stick to the wall at all.	Check to make sure the preliminary adhesive is still tacky (it can dry out over long periods of time). If it is tacky and the fabric still doesn't stick, you may need to apply more adhesive.
The permanent adhesive isn't sticking properly (often this means the fabric pulls of under weak loading).	1. Check the onboard battery to see if it needs to be replaced. 2. Check for any loose wires or broken LEDs that may contribute to an open circuit. 3. Ensure that you are loading the fabric in shear (it isn't designed to handle large forces in tension or peel) 4. Ensure that you are giving the adhesive enough time to cure, up to doubling the normal cure time. If it still doesn't appear to cure properly, check the other steps below. 5. Ensure that the device is approaching the wall at about a 90 deg angle and has enough force to strike the wall forcefully and directly. 6. The surface may be too wet or dirty to keep a good adhesion. In this case, try to climb a different surface, or use a different modular attachment device. 7. Ensure that you have applied enough UV cure adhesive (appx. 1Tbsp, or enough to spread a 0.1" thick layer onto the cloth). 8. Ensure that the UV adhesive is being properly stored and sealed while not in use (see Loctite MSDS for more details)
The anchor isn't being properly driven into the surface.	1. Make sure that the anchor device strikes the wall about a 90 deg angle and impacts forcefully and directly (this is easier if you stand back from the wall to deploy the device) 2. Make sure a blank .22 round and nail have been loaded into the gun.
The rope becomes untied.	Tie the rope to the attachment device by using a bowline knot (See Military Mountaineering, Pentagon (June 1, 1995)
ASCENSION	
Issue	**Resolution**
The rope is slipping through the ascension device	1. Be sure to put tension on the rope as you feed it into the device 2. Start the rope gripping and feeding through the device, before you put your full weight on the system
The motor runs too slowly	Test the battery and replace it if it is exhausted
The motor will not run	Test the battery and replace it if it is exhausted

D3: Ascension Motor Spec Sheet

68146 2,000 lb. Winch Specifications

Rated Single Line Pull	2,000 lb. (907 kg.)
Application	Utility/Shop/ATV
Motor	12VDC 1 HP Permanent Magnet
Power IN & Power OUT	Yes
Duty Cycle Rating	5% (45 sec at Max Rated Load; 14 min, 15 sec Rest)
Handlebar Controller	Wired, 7 ft (2.1m) long Optional Wireless Remote Available (SOLD SEPARATELY)
Geartrain	Planetary
Gear Ratio	153:1
Freespool	Yes
Brake	Auto. Load Holding Dynamic
Drum (Dia. X L)	1.25″ X 2.8″ (32mm X 71mm)
Hook	1/4″ Eye Hook
Fairlead	Roller with nylon bushings

Wire Rope Size / Type	Ø5/32″ x 50′ (Ø4mm X 15.2m) Nominal strength=2,800 lb 7X19 Galvanized Steel Aircraft Wire Rope Battery
	12VDC, Minimum 12 Ah
Battery Cables	10 gauge, 5.8′ (1.78m) long
Mounting Pattern	3.15″ (80mm)
Mounting Hardware	**Winch:** 2x G8, M8-1.25 X 35mm **Fairlead:** 2x G8, M8-1.25 X 19mm
Overload Protection	In line Circuit Breaker
Sound Rating	85 dB
Overall Dimensions (L X D X H)	11.25″ X 3.88″ X 4.25″ (286 X 99 X 108mm)
Weight	14.7 lb. (6.7 kg.)
IP Rating	IP 65 - Winch and Controls (resistant to water jets)
Winch Certification	CE

First Layer of Wire Rope Performance

Line Pull lb. (kg.)	**Line Speed** fpm (mpm)	**Amp Draw** (@ 12V)
0 (0)	13.3 (4.1)	10
500 (227)	10.8 (3.3)	30
1000 (454)	8.3 (2.5)	55
1500 (680)	6.2 (1.9)	80
2000 (907)	4.1 (1.2)	106

Material Safety Data Sheet

Revision Number: 001.1 **Issue date:** 01/06/2010

1. PRODUCT AND COMPANY IDENTIFICATION

Product name:	**LOCTITE® 3979™ LIGHT CURE ADHESIVE**	**IDH number:**	1402562
Product type:	Acrylic Adhesive	**Item number:**	1402562
		Region:	United States

Company address:
Henkel Corporation
One Henkel Way
Rocky Hill, Connecticut 06067

Contact information:
Telephone: 860.571.5100
Emergency telephone: 860.571.5100
Internet: www.henkelna.com

Contains one or more components for which a Toxic Substances Control Act (TSCA) Low Volume Exemption (LVE) applies. See Section 15.

2. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW

HMIS:

Physical state:	Liquid, Gel	**HEALTH:**	*2
Color:	Translucent, Off white	**FLAMMABILITY:**	2
Odor:	Mild	**PHYSICAL HAZARD:**	1
		Personal Protection:	See MSDS Section 8

WARNING: COMBUSTIBLE LIQUID AND VAPOR.
HARMFUL IF SWALLOWED, ABSORBED THROUGH SKIN OR INHALED.
DO NOT SPRAY. DO NOT HEAT.
MAY CAUSE ALLERGIC SKIN REACTION.
CAUSES EYE, SKIN AND RESPIRATORY TRACT IRRITATION.

Relevant routes of exposure: Skin, Inhalation, Eyes, Ingestion

Potential Health Effects

Inhalation: Modified acrylamide is harmful if inhaled. Causes respiratory tract irritation. Vapors and mists will irritate nose and throat and possibly eyes. Headache. Nausea. DO NOT heat or spray as this increases the inhalation hazard.

Skin contact: Modified acrylamide may be absorbed through skin in harmful amounts. Toxic. May cause allergic skin reaction. Causes skin irritation.

Eye contact: Contact with eyes will cause irritation.

Ingestion: Modified acrylamide is harmful if swallowed. Toxic.

Existing conditions aggravated by exposure: Eye, skin, and respiratory disorders.

This material is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200).

See Section 11 for additional toxicological information.

3. COMPOSITION / INFORMATION ON INGREDIENTS

Hazardous components	CAS NUMBER	%
Urethane Polymer	Proprietary	30 - 60
Acrylate monomer	Proprietary	30 - 60
Modified acrylamide	2680-03-7	10 - 30
Treated fumed silica	67762-90-7	5 - 10
Photoinitiator	Proprietary	1 - 5
2-Hydroxyethyl acrylate	818-61-1	0.1 - 1

4. FIRST AID MEASURES

Inhalation: Move to fresh air. If breathing is difficult, give oxygen. If not breathing, give artificial respiration. Get medical attention.

Skin contact: Immediately flush skin with plenty of water (using soap, if available). Remove contaminated clothing and footwear. Wash clothing before reuse. If symptoms develop and persist, get medical attention.

Eye contact: Flush with copious amounts of water, preferably, lukewarm water for at least 15 minutes, holding eyelids open all the time. Get immediate medical attention.

Ingestion: Do not induce vomiting. Never give anything by mouth to an unconscious person. Keep individual calm. Get immediate medical attention.

5. FIRE FIGHTING MEASURES

Flash point: 86.0 °C (186.8 °F) Pensky Martens closed cup

Autoignition temperature: Not available

Flammable/Explosive limits - lower: Not available

Flammable/Explosive limits - upper: Not available

Extinguishing media: Water spray (fog), foam, dry chemical or carbon dioxide. Do not use high volume water jet.

Special firefighting procedures: Wear self-contained breathing apparatus and full protective clothing, such as turn-out gear. Water may be unsuitable as an extinguishing media, but may be helpful in keeping adjacent containers cool.

Unusual fire or explosion hazards: Uncontrolled polymerization may occur at high temperatures resulting in explosions or rupture of storage containers.

Hazardous combustion products: Oxides of carbon. Oxides of nitrogen. Oxides of phosphorus. Irritating organic vapours. Formaldehyde. Isocyanates. Hydrogen cyanide. Amines. Hydrocarbons.

6. ACCIDENTAL RELEASE MEASURES

Use personal protection recommended in Section 8, isolate the hazard area and deny entry to unnecessary and unprotected personnel.

Environmental precautions: Remove all sources of ignition. Do not allow product to enter sewer or waterways.

Clean-up methods: Refer to Section 8 "Exposure Controls / Personal Protection" prior to clean up. Ensure adequate ventilation. Soak up with inert absorbent material (e.g. sand, silica gel, acid binder, universal binder, sawdust). Store in a partly filled, closed container until disposal.

7. HANDLING AND STORAGE

Handling: Prevent contact with eyes, skin and clothing. Do not breathe vapor and mist. Wash thoroughly after handling. Do not taste or swallow. DO NOT heat or spray. Use only with adequate ventilation. Refer to Section 8. Use only in area provided with appropriate exhaust ventilation.

Storage: Keep in a cool, well ventilated area away from heat, sparks and open flame. Keep container tightly closed until ready for use.

For information on product shelf life contact Henkel Customer Service at (800) 243-4874.

8. EXPOSURE CONTROLS / PERSONAL PROTECTION

Employers should complete an assessment of all workplaces to determine the need for, and selection of, proper exposure controls and protective equipment for each task performed.

Hazardous components	ACGIH TLV	OSHA PEL	AIHA WEEL	OTHER
Urethane Polymer	None	None	None	None
Acrylate monomer	None	None	None	None
Modified acrylamide	None	None	None	0.1 mg/m3 TWA (Skin) 0.025 ppm TWA (Skin)
Treated fumed silica	10 mg/m3 TWA Inhalable dust. 3 mg/m3 TWA Respirable fraction.	15 mg/m3 TWA Total dust. 5 mg/m3 TWA Respirable fraction.	None	None
Photoinitiator	None	None	None	None
2-Hydroxyethyl acrylate	None	None	None	None

Engineering controls: Local exhaust ventilation is recommended when general ventilation is not sufficient to control airborne contamination below occupational exposure limits.

Respiratory protection: Use NIOSH approved respirator if there is potential to exceed exposure limit(s). If this material is handled at elevated temperatures or under mist forming conditions, without engineering controls, a NIOSH approved respirator must be used.

Eye/face protection: Safety goggles or safety glasses with side shields. Full face protection should be used if the potential for splashing or spraying of product exists. Safety showers and eye wash stations should be available.

Skin protection: Use impermeable gloves and protective clothing as necessary to prevent skin contact. Neoprene gloves.

9. PHYSICAL AND CHEMICAL PROPERTIES

Physical state: Liquid, Gel
Color: Translucent, Off white
Odor: Mild
Odor threshold: Not available
pH: Not applicable
Vapor pressure: Not available
Boiling point/range: Not available
Melting point/ range: Not available
Specific gravity: 1.1194
Vapor density: Not available
Flash point: 86.0 °C (186.8 °F) Pensky Martens closed cup
Flammable/Explosive limits - lower: Not available
Flammable/Explosive limits - upper: Not available
Autoignition temperature: Not available
Evaporation rate: Not available
Solubility in water: Not available

Partition coefficient (n-octanol/water):	Not available
VOC content:	1.26 %

10. STABILITY AND REACTIVITY

Stability:	Stable under normal conditions of storage and use.
Hazardous reactions:	May occur.
Hazardous decomposition products:	Oxides of carbon. Oxides of nitrogen. Oxides of phosphorus. Formaldehyde Irritating organic vapours. Isocyanates. Hydrogen cyanide. Amines. Hydrocarbons.
Incompatible materials:	Strong oxidizing agents. Strong reducing agents. Strong bases. Strong acids. Peroxides. Alkalis. Copper. Copper alloys. Amines. Carbon steel. Iron. Rust. Free radical initiators. Other polymerization initiators.
Conditions to avoid:	Keep away from heat, spark and flame. Store away from incompatible materials. Ultraviolet radiation. Exposure to sunlight. Freezing conditions.

11. TOXICOLOGICAL INFORMATION

Acute oral product toxicity:	Modified acrylamide LD50 (rat) 316 mg/kg
Acute dermal product toxicity:	Modified acrylamide LD50 (rabbit) 518 mg/kg
Acute inhalation product toxicity:	Modified acrylamide LC50 (rat) 1 h > 776 ppm (vapor)

Hazardous components	NTP Carcinogen	IARC Carcinogen	OSHA Carcinogen (Specifically Regulated)
Urethane Polymer	No	No	No
Acrylate monomer	No	No	No
Modified acrylamide	No	No	No
Treated fumed silica	No	No	No
Photoinitiator	No	No	No
2-Hydroxyethyl acrylate	No	No	No

Hazardous components	Health Effects/Target Organs
Urethane Polymer	No Records
Acrylate monomer	Irritant, Allergen
Modified acrylamide	Irritant, Eyes, Mutagen, Kidney, Less weight gain and food intake.
Treated fumed silica	Irritant
Photoinitiator	No Records
2-Hydroxyethyl acrylate	Allergen, Central nervous system, Heart, Irritant, Kidney, Liver, Lung, Some evidence of carcinogenicity, Spleen

12. ECOLOGICAL INFORMATION

Ecological information:	Not available

13. DISPOSAL CONSIDERATIONS

Information provided is for unused product only.

Recommended method of disposal:	Dispose of according to Federal, State and local governmental regulations.
Hazardous waste number:	Not a RCRA hazardous waste.

14. TRANSPORT INFORMATION

The shipping classification in this section are for bulk packaging only. Shipping classification may be different for non-bulk packaging as exceptions may apply. Refer to shipping documents for package specific transportation classification.

U.S. Department of Transportation Ground (49 CFR)

Proper shipping name:	Combustible liquid, n.o.s. (N,N-Dimethylacrylamide)
Hazard class or division:	Combustible Liquid
Identification number:	NA 1993
Packing group:	III

International Air Transportation (ICAO/IATA)

Proper shipping name:	Environmentally hazardous substance, liquid, n.o.s. (Isobornyl acrylate)
Hazard class or division:	9
Identification number:	UN 3082
Packing group:	III

Water Transportation (IMO/IMDG)

Proper shipping name:	ENVIRONMENTALLY HAZARDOUS SUBSTANCE, LIQUID, N.O.S. (Isobornyl acrylate)
Hazard class or division:	9
Identification number:	UN 3082
Packing group:	III
Marine pollutant:	Isobornyl acrylate
Exceptions:	Classified per IMDG Amendment 34; Effective Jan 1, 2010.

15. REGULATORY INFORMATION

United States Regulatory Information

TSCA 8 (b) Inventory Status:	All components of this product are listed on the U.S. Toxic Substances Control Act (TSCA) inventory or are exempt from listing because a Low Volume Exemption (LVE) has been granted in accordance with 40 CFR 723.50.
TSCA 12(b) Export Notification:	None above reporting de minimus
CERCLA/SARA Section 302 EHS:	None above reporting de minimus
CERCLA/SARA Section 311/312:	Immediate Health, Delayed Health, Fire
CERCLA/SARA 313:	None above reporting de minimus
California Proposition 65:	This product contains a chemical known in the State of California to cause cancer. This product contains a chemical known to the State of California to cause birth defects or other reproductive harm.

Canada Regulatory Information

CEPA DSL/NDSL Status:	One or more components are not listed on, and are not exempt from listing on either the Domestic Substances List or the Non-Domestic Substances List.
WHMIS hazard class:	B.3, D.1.B, D.2.B

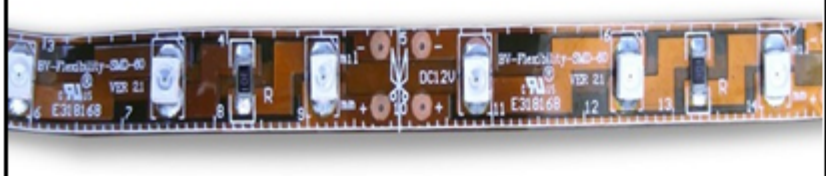
16. OTHER INFORMATION

This material safety data sheet contains changes from the previous version in sections: 1,5,7,8,9,10,14

Prepared by: Tricia Voghell, Regulatory Affairs Specialist

DISCLAIMER: The data contained herein are furnished for information only and are believed to be reliable. However, Henkel Corporation does not assume responsibility for any results obtained by persons over whose methods Henkel Corporation has no control. It is the user's responsibility to determine the suitability of Henkel's products or any production methods mentioned herein for a particular purpose, and to adopt such precautions as may be advisable for the protection of property and persons against any hazards that may be involved in the handling and use of any of Henkel Corporation's products. In light of the foregoing, Henkel Corporation specifically disclaims all warranties, express or implied, including warranties of merchantability and fitness for a particular purpose, arising from sale or use of Henkel Corporation's products. Henkel Corporation further disclaims any liability for consequential or incidental damages of any kind, including lost profits.

D5: UV Spec Sheet



UV Light Source Specification Sheet

Flexible Ultraviolet LED Strip Light (UV)	
Frequency	382-385 nm
Beam Angle	120°
Power	1.6 W.
Voltage	12 V DC
Power Consumption	1.6 W/134 mA per ft.
Weight	0.1 oz.
Width	0.3 in.
Depth	0.1 in.
LED Spacing	2 LEDs per inch/0.65 in. between centers
Cuttable	every 3 LEDs/ 2 in.
Bulbs per ft.	18
Lifespan	50,000 hours

Appendix E: Safety Information

E1: Hazard Analysis

Description of job tasks being performed & the location of the work:
Job Tasks: Capstone Project: Replacement of Military Grappling Hook. This project will launch a UV cured epoxy laden weaved material out of a homemade 300psi inert gas cannon approximately 90' onto a substantial structure. The epoxy has a set up time of 3-4 minutes and a projected minimum tensile strength of 500lbs. The weaved material envelops a 1/2 - 5/8" climbing rope for a climber to ascend the structure. The climber attacesh a 2000lb capacity, 12 volt/30 amp (peak) electric winch attached to a climbing harness to the rope. The winch will then be electrically operated by the climber to ascend the wall. A preliminary test will be conducted Wednesday, March 28, 2012 at the Provo City Fire Department Training Facility. The test will consist of a cannon shot or two and a fully loaded manned winch test not connected to the material. Potential hazards associated with test: 1. Epoxy – The epoxy is a Loctite 3979 UV activated acrylic adhesive that has special precautions that should be followed when handled by technicians. They are: a. Inhalation: Modified acrylamide is harmful if inhaled. Causes respiratory tract irritation. Vapors and mists will irritate nose and throat and possibly eyes. Headache. Nausea. DO NOT heat or spray as this increases the inhalation hazard. b. Skin contact: Modified acrylamide may be absorbed through skin in harmful amounts. Toxic. May cause allergic skin reaction. Causes skin irritation. c. Eye contact: Contact with eyes will cause irritation. d. Ingestion: Modified acrylamide is harmful if swallowed. Toxic. Here the controls for these items: a. Move to fresh air. If breathing is difficult, give oxygen. If not breathing, give artificial respiration. Get medical attention. <u>If significant amounts are used wear a NIOSH approved respirator.</u> b. Skin contact: Immediately flush skin with plenty of water (using soap, if available). Remove contaminated clothing and footwear. Wash clothing before reuse. If symptoms develop and persist, get medical attention. <u>Use Nitrile gloves</u>. c. Eye contact: Flush with copious amounts of water, preferably, lukewarm water for at least 15 minutes, holding eyelids open all the time. Get immediate medical attention. <u>Use safety glasses or splash proof googles.</u> d. Ingestion: Do not induce vomiting. Never give anything by mouth to an unconscious person. Keep individual calm. Get immediate medical attention. (Information furnished by Henkel Corporation) **http://hybris.cms.henkel.com/henkel/msdspdf?matnr=1402562&country=US&language=EN**

2. Cannon – At 300psi, the cannon may have some recoil or may catastrophically fail. Recommend:
   a. The operators manufacture a stand that will hold the cannon in place and limit the amount of handling by personnel.
   b. The operators wear leather gloves to minimize potential hazards from handling the cannon.
   c. The operators wear double hearing protection to minimize hearing issues.

3. Winch – The winch is substantial enough to hold a two hundred plus pound person, however, I recommend:
   a. The operators be 100% tied off, that is to say, besides the simulated rope being tied off they should have a secondary tie off and lanyard in case the simulated rope fails. The secondary tie off should be on another anchorage point independent of the simulated rope and the operator have on a full body harness that has a "D" ring on the back pad similar to the one in the picture below.

Photo furnished courtesy of DBI/Sala

   b. The operators should also wear leather gloves to keep from getting rope burns as they feed rope through the winch.
   c. The operators should be careful of the pinch point the winch creates when feeding the rope through the pulley system.
   d. The operators should watch out for loose clothing or hair that may get caught in the pulley wheel.
   e. The operators should not have anything in their pockets while wearing fall protection.
   f. The winch electrical connections should be covered either with electrical tape or an actual terminal cover.

Location of the work: Provo City Fire Department Training Facility

Supervisor of the job tasks being performed:				
Faculty Supervisor:	Bob Todd	Click here to enter text.	Assessment Date:	March 26, 2012
Department:	Engineering			

Machines, equipment, and portable powered hand-tools that will be used to perform the job tasks:

Make:	Badland Winch	**Model**:	Click here to enter text.
Make:	Click here to enter text.	**Model**:	Click here to enter text.
	(add more rows as needed)		

Have the machines, equipment, and portable powered hand-tools been assessed for proper guarding, and are all guards in place? *If you have questions regarding proper guarding please contact the campus Safety Officer2-4184.*

☐Yes All assessments had been completed by (date): Click here to enter text.

Indicate the safety hazards that are present when the job tasks are being performed:		
☒	Flying Debris	
☒	Falling Objects	
☒	Individuals could fall 4 feet or more	
☒	As applicable, indicate the machine hazards that exist while performing the job tasks: (The machines should be properly guarded when evaluating hazards)	
	☒	Machine part(s) could smash, compress, or penetrate body parts
	☒	The machine(s) present a cutting or shearing hazard **Possible**
	☒	Individuals could have loose clothing or hair caught by rotating parts
	☒	Other: Electrical terminals should be covered so now operator is shocked accidentally.
☐	Exposed energized parts (> 50 volts)	
☒	Pressure	
	☒High positive pressure (indicate pressure): 300psi	
	☐Vacuum (indicate pressure): Click here to enter text.	
☐	Temperature (indicate temperature): Click here to enter text.	
☐	Other: Click here to enter text.	

Indicate the health hazards that are present when the job tasks are being performed:	
☒	Noise
☒	Skin and eye hazard(s)
☒	Inhalation Hazard(s)
☐	Laser Hazards (Class IIIB and IV laser products)
☐	Other: Click here to enter text.
	The degree of the health hazards must be evaluated. Health hazard evaluation and exposure control selection must be performed by

the campus Safety Officer 2-4184 or Industrial Hygenist 2-2943. The evaluation must be recorded for future reference.

-Engineering Controls- e.g. local exhaust ventilation while welding			
List all necessary engineering controls needed to perform the job tasks safely:			
1.	See listing under "Job Tasks" at top.	**4.**	Click here to enter text.
2.	Click here to enter text.	**5.**	Click here to enter text.
3.	Click here to enter text.	**6.**	Click here to enter text.

-Personal Protective Equipment (ppe)- e.g. safety glasses			
The following online tool is available to determine what personal protective equipment is needed: http://risk.byu.edu/safety/ppe/ppe.php.			
List all necessary items of personal protective equipment (ppe) needed to perform the job tasks safely:			
1.	See listing under "Job Tasks" at top.	**4.**	Click here to enter text.
2.	Click here to enter text.	**5.**	Click here to enter text.
3.	Click here to enter text.	**6.**	Click here to enter text.

E2: FMEA Analysis

Item and Function	Potential Failure Mode	Potential Effects of Failure	Severity	Potential Causes of Failure	Occurrence	Current Controls	Detection	RPN	Recommended Action	Responsibility and Target Completion Date
Attachment	Attachment fails during ascent	Climber falls	10	Bad surface adhesion	3	None	8	240	Increase surface area for adhesives, Test consistency	Bryan/Brady, March 20

	Attachment doesn't attach initially	The system is not useable	2	Failure in attachment/deployment integration	3	None	4	24	Test consistency	Attachment team, continual testing, March 20
	Rope becomes unattached from the anchor	Climber falls	10	Poor connecter design. Knot fail.	4	None	8	320	Test under extreme conditions (wet, cold, etc). Test for knot slippage.	Bryan/Brady Attachment design - March 20
Winch	Battery Exhaustion	Winch fails	5	Extended use of winch	2	None	3	30	Design battery monitor. Design a brake and release mechanism	Dave - April 1
	Rope slips in winch	Person slips down rope	3	Using wrong size rope, poor design	2	None	5	30	Use proper rope, Have braking devise	Dave/William - April 1
	Rope severs and breaks	Climber falls	10	Rope wear.	4	Pre-mission rope inspections	8	320	Inspect as you climb. Increase safety factor	Dave/William - April 1
Deployment	Rifle barrel explodes due to attachment weight	User Injury	8	Trying to launch too much mass	2	None	4	64	Testing and research Reduce weight of attachment system	Aaron/Jason - April 1

Severity	**10** - Death or serious injury likely **5** - Significant hassle to user, personal injury possible **1** - Little to no affect on user
Occurrence	**10** - Liklihood of failure occuring is almost guarenteed. **5** - The risk of failure is moderate **1** - Risk of failure very low
Detection	**10** - Failure impossible to detect **5** - Moderate ability to detect failure **1** - Defect easily detected

	Rifle attachment doesn’t fly 90 ft	Will not be able to climb 90ft	3	Attachment/rope is too heavy	2	None	3	18	Reduce weight and select good rope	Aaron/Jason - April 1

E3: Air Pressure Certification

Hi,
I am with the BYU team. I spoke with Devon Parker on the phone about the pressure certification, and I believe this is what you need. We were instructed to pressurize our launcher to 1.5 times the desired operating pressure with water and hold it there for 10 minutes. We pressurized our launcher to 900 psi, and held it there for over 10 minutes without any problems. That means that we should be good to run at up to 600 PSI, which is significantly higher than we are currently planning to run it. I have forwarded you an email that was sent to Greg Bishop, our team coach, from Kevin Cole, the BYU faculty member that worked with me on this. In the email, located below, Kevin confirms that he witnessed the test. If you have any questions or need any more information for the pressure certification please let me know.

Thank You,
Jason Rindlisbacher

---------- Forwarded message ----------
From: Kevin Cole <cole@byu.edu>
Date: Fri, Apr 6, 2012 at 5:03 PM
Subject: Launcher hydro test
To: "greglbishop@gmail.com" <greglbishop@gmail.com>
Cc: "Jason Rindlisbacher (jasonrindy@gmail.com)" <jasonrindy@gmail.com>

To whom it may concern:

I witnessed a hydro test of Capstone team #1's launcher. It was pressurized to 900 PSI and held there for 15 minutes with no visible leakage or damage.

Kevin Cole

Appendix F: Fall Report (Body)

Project Objective Statement

Honorably represent BYU by building a climbing system to allow troops to scale vertical surfaces by April 21st, using $1500.

Introduction

The Air Force Research Laboratory (AFRL) is a scientific research organization that does R&D work to improve the technology and war fighting capabilities of the United States. In April 2012, the AFRL is sponsoring an engineering design competition between 15 universities.

Our team has been selected to represent BYU in this competition. Through this report, we will describe the results of the concept selection and prototyping work that we have done so far. We hope that this report will give an accurate picture of where we are in the design process and the challenges we face in the upcoming months.

Description and Scope

The competition task is to design a system to allow troops, with their equipment, to scale buildings or mountain faces under a variety of conditions, efficiently and effectively. At the competition, each team will demonstrate the operation of their climbing system and be scored on a variety of criteria, including:

- Time to complete climb
- Size and weight of packaged device
- Ease of operation
- Usability
- Stealth
- Innovation
- Other criteria

This demonstration will include student presentations and an operational climb performed by military personnel whom we must train to use our system.

The scope of our project is defined by the competition and the assumed end use by the US armed forces. Our contacts at the Air Force Research Laboratory have been intentionally ambiguous with regards to the climbing site, climbing conditions, and details regarding potential systems and designs. This was done to encourage each team to design an innovative and flexible system that would work under a variety of conditions. However, to give us an idea of how to move forward, they provided this statement in one of our early documents:

> Potential Solutions could involve ideas such as:
>
> - Automated rope climbing device
> - Harpoon grapples
> - 'suction cup' climbing system
> - Sticky grapples deployed via air gun

We were also given a list of equipment in a standard assault backpack, which can be used to assist in the operation of our system. We have been told to assume that the end user will have access to the following items:

- Two BA5590 batteries
- M4 carbine rifle and ammo
- M9 handgun and ammo
- Kernmantle static climbing rope (either 9mm or 11mm)
- A Yates rappelling harness
- CMC rescue gear
- A figure 8 belay device
- Several carabineers
- A Leatherman type multi-tool
- An assault vest
- Food / Water
- A back mounted rucksack for transporting this equipment

With this information, we are free to use any means to design the system that will perform and score best in the competition.

Project Results

Research

Our research has been focused on 1) learning about existing climbing systems and 2) searching for groundbreaking research and experiments into alternative methods.

In researching existing climbing systems, we met with Sgt. Williamson of the BYU ROTC. He took our team to a climbing facility at Camp Williams Army Base. Here, he showed us much of the current equipment in use and demonstrated several ascension techniques. He also loaned us a copy of the US Army climbing training manual *Military Mountaineering*. Through this and other conversations with rock climbers and our sponsor, we were able to get a quick understanding of the most common existing climbing systems.

We also found that there were several groups that were researching alternative climbing systems. Students at Stanford University have built robots that climb surfaces using a variety of different technologies like tiny physical hooks, electro-adhesion, and tiny hairs or silicone stalks that create adherence through van der walls forces. Several of these and other technologies are used to attempt human ascension on episodes of television shows like "Prototype This" and "Mythbusters" (see Figure 1). By exploring these avenues, we were able to evaluate an exhaustive set of technologies and options for our climbing system.

Figure 8 – A woman on the television series "Prototype This" uses pads with thousands of embedded fishhooks to climb a cinder block wall.

Customer Needs & Metrics

We developed a list of customer needs based on three main sources:

4. Competition Scoring – The sponsor has designed the rules and scoring of the competition to direct each team towards building the ideal system. For example, the need of "stealth" is established by assigning a possible "stealth score" of up to 20 points. We use this and other scoring criteria as customer needs for our design.

5. End user criteria – The competition is a vehicle for furthering research in climbing technology. Successful systems are wanted for eventual use by US troops. Other customer needs can be determined by recognizing the needs of an Army end user. For example, the competition will not be held in extreme weather but we have been asked by our sponsor to design for use in extreme weather because this may be important for use further down the road.
6. Latent Needs – We have determined several latent needs that we believe may be important to the sponsor, though they have not specifically mentioned them. For example, in our research we learned that most climbing systems require a man on the ground to secure the rope from below. This is inconvenient and we believe that if we can solve this problem, we could further delight our sponsor.

From these sources, we have created a list of customer needs, including the following:

The device…

- can support an adult carrying military gear (300lbs)
- facilitates scaling of 90 feet or higher
- functions on vertical or near vertical surfaces
- is usable on rock, adobe, and concrete surfaces
- is usable in extreme weather
- allows soldier mobility
- is safe

For a full list of customer statements and interpreted needs, refer to the appendix (A.1). Given a list of needs, we developed quantifiable metrics for measuring each of those needs. These metrics will help us test our prototypes and designs to ensure that we meet the customer's needs. For each metric we have developed marginal and ideal target values based on the competition guidelines and our personal research. Table 1 (below) includes several of the most critical metrics with their target values. For a full list of the metrics and their target values, refer to the appendix (A.2).

Metric No.	Need No.	Metric	Import.	Units	Marginal Value	Ideal Value
1	1	Climbing height for a single deployment	5	ft	at least 90 ft	at least 100 ft
2	2	Grade/incline of surface	5	Degrees	at least 90°	at least 100°
13	14	Rate of ascension	4	ft/s	at most 11	at most 8

21	20	Functional day and night	5	Binary	Yes	Yes
30	27,29	Device weight (not including pre-existing gear)	4	lbs	at most 50	at most 35

Table 2 - A listing of several critical metrics with their target values

Concept Generation and Selection

With our customer needs and metrics defined, we began working to identify concepts and select the best ones. Our concept generation and selection process included the following steps:

1. Concept Decomposition
2. Concept Generation
3. Concept Selection

Concept Decomposition Results

Our project posed a problem for concept decomposition because the scope of possible climbing systems was so broad that it was difficult to find subfunctions that would be used in every instance. For example, a system using a giant trampoline would not have the same subfunctions as a system that facilitated climbing using suction cups. Consequently, we created a very basic decomposition to use until we selected a specific climbing option. This decomposition included four subfunctions: deploy, attach, ascend, and pack/unpack (see Figure 2).

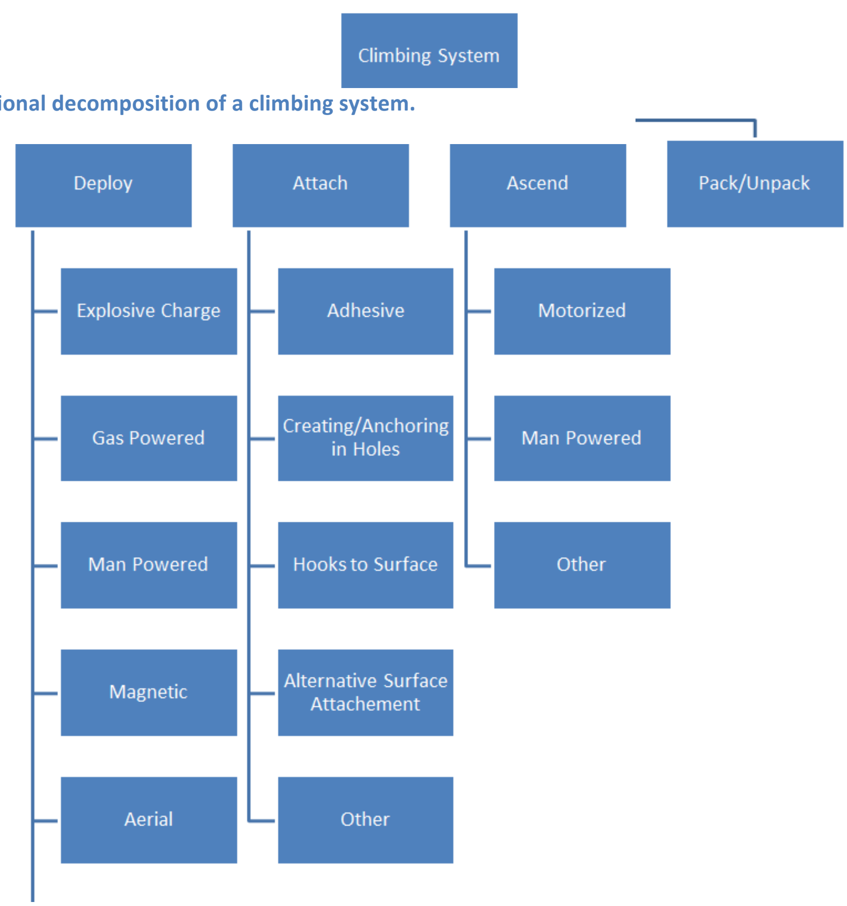


Figure 9 - Our functional decomposition of a climbing system.

Concept Generation Results

Through individual and group concept generation, our team identified 118 potential concepts for elements of our climbing system. Each concept fell under one of the four subfunctions listed above. We categorized our ideas under these subfunctions based on the technologies they used, as shown in Figure 3. For the full list of potential concepts and selected concept sketches, see the appendix (B.1).

Concept Selection Results

Our concept list was so large that we used two rounds of multi-voting to eliminate the concepts that appeared unfeasible. These included concepts that were beyond the scope of our project, like jet packs and personal helicopters, as well as concepts that were in direct violation of customer needs, like a cannon that fires humans into the air (clearly violating the customer need of safety). The result was a list of 14 concepts which we evaluated through a weighted scoring process. To see the quantitative results of our scoring, see the appendix (B.2).

Figure 10 – A concept classification tree for our concepts

The results of the scoring led us to consider the following eight subfunctions for our final design (listed in their respective categories):

	Deployment	Attachment	Ascension
Highest Score	Bullet-powered M4 rifle attachment	Projectile that Embeds in the Surface	Friction Winch
2nd Highest Score	M203 Grenade Launcher powered	Embeds via Secondary Explosion	
3rd Highest Score	Bow / Crossbow	Fish hook attachment	
4th Highest Score		Adhesive / Epoxy	

Table 3 – A summary of our scoring results, organized by design subfunction

These concepts scored close enough to each other to merit further prototyping as a means of determining which ones should be selected. We decided not to evaluate any concepts for the pack/unpack subfunction at this time because we felt it was more appropriate to determine how to pack the device after we settled on a final choice. The whole concept selection process can be summarized in the following diagram.

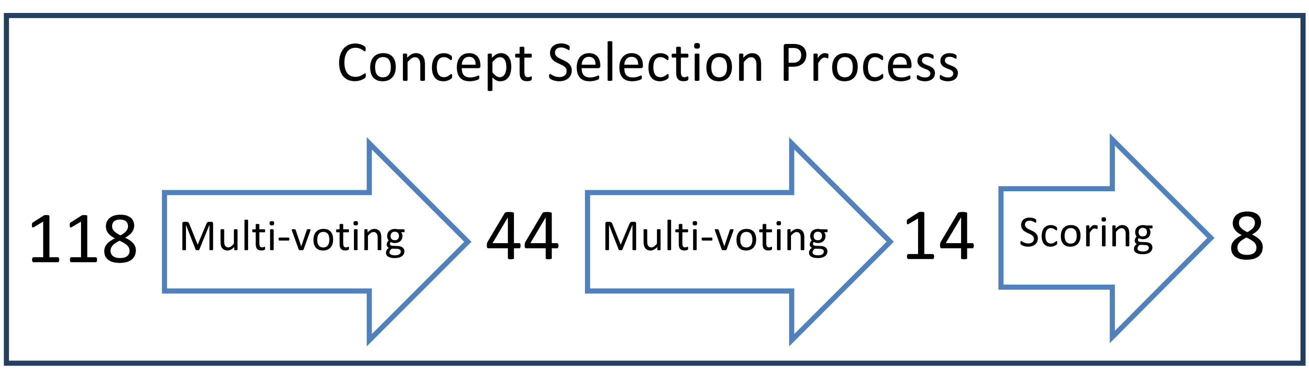


Figure 11 - A summary of the concept selection process

Prototyping

With eight potential concepts remaining, we decided to engage in a process of fast iterative prototyping so we could quickly eliminate concepts that will not be as successful. To do this, we broke our team into the following three mini-teams of two people each:

- Deployment – Jason Rindlisbacher and Aaron Ford
- Attachment – Brady Morton and Bryan Braun
- Ascension – Dave Monk and William Tryon

The prototyping results of each mini-teams' efforts will be given in the next three sections.

Deployment Prototyping Results

Figure 12 –Golf ball launcher attached to a .22lr handgun

Prototyping began with determining whether or not it would be feasible to launch a payload using the equipment already carried by the troops. To test this, we built a golf ball launching attachment that can screw on to both an M-4 and a .22lr pistol. Not having access to an M-4, we decided to carry out our tests with an AR-15 as it is basically the same gun (the main differences being it has a longer barrel and is semi-automatic). We couldn't find any local retailers that carried blanks for the AR-15, so we had to special order them online. While we waited for them to come, we decided to do preliminary testing using a .22lr handgun (see Figure 5). We attached a rope to a golf ball and used blanks to launch it. The .22lr was able to launch the golf ball a distance of 60 ft. with a blank, and 80 ft. with a bullet. With the AR rounds at about 9 times more powerful, these results were very encouraging. Once we were able to test with the AR rounds, we found that they were sufficient to propel the golf ball over 100 ft. (we only had a hundred feet of rope).

Figure 13 – CAD model of JARF launching system

Having determined that the force of the standard troop's gun is sufficient to launch a payload the necessary distance, we began to design a barrel mounted deployment system. We designed our model based on GRIM, a door breaching system that is launched from an M-4. Using their design as a starting point, we created our CAD model, known as JARF (See Figure 6). We built a simple model of JARF out of PVC and tried launching it with the AR-15. This crude prototype was able to launch up to 300 ft. The biggest factor in the distance we are able to launch is the rope. We are currently working on determining the best way to launch our system without the rope causing unnecessary amounts of drag.

Attachment Prototyping Results

Fish hook pad

We chose to test the merits of a fishhook system by building a simple fish hook pad using fish hooks and a block of wood (see Figure 7). We used this prototype to test the difference of grip between our control surface (cinder block), rough varieties of rock and concrete, and smooth varieties of rock and concretes. We also tested the grip of each of these surfaces under wet and sandy surface conditions. Each surface was given a rating by users based on how well the pad would grip to it. The full results of our tests are given in the appendix (C.3). In summary, we learned that our fish hook pad has a stronger grip on rough surfaces like cinderblock and rock than smooth surfaces like a smooth cement floor. We also learned that in most cases, the surface conditions (like wetness or sand) failed to have a significant effect on how the fish hook system gripped.

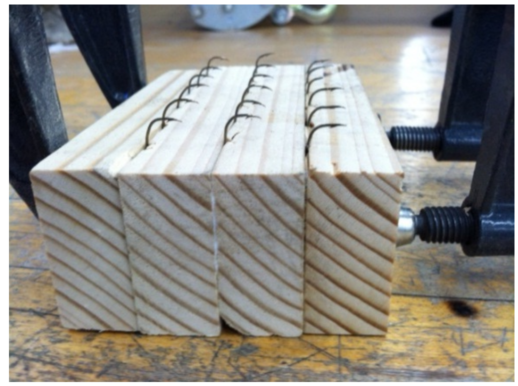


Figure 14 - The fish hook pad prototype

Embedded Anchors

Next, we tested an embedded anchor system by using a powder actuated nail gun to drive nails into a variety of solid surfaces including wood, rock, and concrete (see Figure 8). While we did this, we collected a variety of data relevant to our customer needs, including sound levels, depth of penetration, and force to remove. We analyzed our sound level results with a physics-based analytical model for determining sound attenuation outdoors in a direct sound field (see Figure 9). The full results of our tests are given in the appendix (C.4). We had several major takeaways from these tests:

- It will be far more difficult to drive an anchor into solid rock than any other material.
- We will need a quieter system than a powder actuated nail driver if we want to reach our marginal sound level target value.
- An anchor driven into concrete can support over 150 lbs.

$$L_2 = L_1 - 20 \cdot \lg\left(\frac{r_2}{r_1}\right)$$

r_1 = Distance from source to a nearby reference point
r_2 = Distance from source to a distant observer
L_1 = Sound level at a nearby reference point
L_2 = Sound level for distant observer

Figure 15 - Our model for outdoor sound attenuation in a direct sound field

We hope to continue to do more tests in the future to determine the following things:

- How does this method work on adobe?
- What are other ways (or more powerful systems) for driving anchors into rock?
- Exactly how much force does it takes to remove the anchor (from concrete, rock and adobe)?
- How will the approach angle affect the ability to drive anchors into these surfaces?

Industrial Grade Adhesives

Figure 16 – Several of our test nails embedded in concrete

We are preparing to test a variety of ultra-fast cure industrial grade adhesives to see how they perform on the surfaces we are designing our system for. In our preparations, we were able to acquire the following five sample adhesives for testing on rock, concrete, and adobe:

1. Loctite 331 Structural Adhesive (uses an activator)
2. Loctite 3974 Light Cure Adhesive
3. Loctite 3979 Light Cure Adhesive
4. Loctite Fixmaster Metal Magic Steel (an epoxy)
5. Loctite Fast Cure Mixer Cups (an epoxy)

We have designed a fixturing system that will allow us to get an accurate tensile force measurement for each test by using an Instron tensile test machine (see appendix C.5, for a full description of our test setup). The torsion capabilities of this machine will help us get data for shear forces as well. In addition, we will be able to get accurate measurements of the forces required to remove nails from these surfaces.

Ascension Prototyping Results

Figure 17 – Rough prototype of friction winch design

The friction winch concept was further broken down into two sub-concepts; namely the design of the friction winch and the motor to power it. The first concept tested was a design in which rope was looped several times around a cylindrical shaft. Each loop of rope around the hollow shaft added more friction force and reduced slippage. This initial, rough design is shown in Figure 10. Primary tests of this rudimentary design of a smooth aluminum pipe and slick nylon rope showed that when loaded with roughly 350 lbs, the shaft held with no rope slippage. The concept of this design is to have a motor turn the shaft, and as the shaft rotates it will wind itself up the rope. One difficulty, however, is that as the friction winch moves up the rope, the rope naturally winds across the shaft and will eventually wind off the side of it. To prevent this from happening we have modeled two designs to try to keep the rope centered on the shaft as it turns. These designs can be seen in

Figure 11. Tests to determine the effectiveness of preventing spooling off the side of the shaft will be completed upon arrival of the motor.

Although the minimum load requirement for the ascension system is only 300 lbs., we have decided to design the system to carry at least 1000 lbs. in order to maintain a sizable factor of safety. This means that if the diameter of the shaft is roughly 1.5" at the location of highest weight, the torque needed to turn the shaft is at least 750 in-lbs. Calculations for motor requirements at different shaft diameters can be seen in Appendix C8. Few motors have the power to produce these magnitudes of torque while still keeping system weight to a minimum. However, recent research has revealed that small motors used in cordless power drills can have as much as 650 in-lbs. torque while weighing less than 3 lbs. These motors run on 18 V batteries which will allow us to utilize the batteries already carried by military troops. We plan to mount two motors, one on each end of the shaft to produce the necessary torque and speed requirements but are still in the process of obtaining these motors to verify these expectations experimentally.

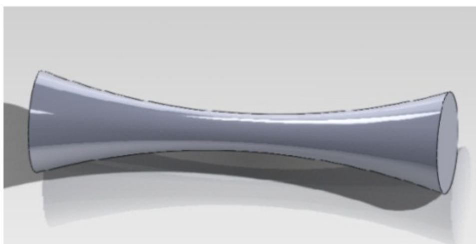


Figure 18 – Center-spooling friction winch designs.

We are very optimistic that the winch design will prevent the rope from spooling off the side of the shaft and also that a motor can be obtained which will yield the necessary torque to lift 1000 lbs. vertically. Results should be obtained within the coming weeks.

Status and Upcoming Challenges

As of now, we are still in the prototyping phase of our project. It is our goal that each mini-team will have done sufficient testing to select a final concept by December 9th. This will allow us to complete our research and order all the necessary materials for our final design before the winter break.

Despite our great progress so far, we still have several challenges to overcome, including the following:

- Addressing the difficulty of launching rope 90 ft. vertically
- Attaching to a surface from vertical angle
- Developing an attachment method that is simple and repeatable
- Optimizing motor torque vs. speed
- Integrating the subfunctions into one unified system
- Minimizing the system weight

Despite these challenges, the team is on schedule to meet our goals and move into the development of a final design. We have demonstrated excellent team work and overcome several challenges along the way. We are confident in our abilities to succeed in the project and competition.

Summary and Conclusion

In closing, we want to remind the reader of the big picture surrounding our project. We are designing a climbing system which will be entered into a 15 university competition hosted by the Air Force Research Laboratories. Using the competition guidelines and scoring criteria, we have developed an exhaustive list of customer needs, which is driving the development of our solution. Through research and brainstorming, we identified 118 potential concepts from which we eventually selected 8 to continue prototyping and testing.

Since then we have been heavily involved in prototyping and testing these 8 concepts in order to determine their feasibility. Our prototypes have included a combination of analytical calculations and physical testing. The deployment team has tested the concept of using a US military weapon attachment to deploy our system. All signs show that these methods will provide power sufficient to launch a small payload 90 ft. The attachment team has been testing a variety of attachment methods (including adhesives, miniature hooks, and anchors) with mixed results. The ascension team has identified and tested several potential winch designs for automatic powered ascension. Their rough prototypes have proven the concept and they will soon test their higher fidelity prototypes.

While many challenges remain, we have identified those challenges and we are preparing ourselves to meet them. By following a structured design process and working together as a team, we are confident that we are poised for success in this project and competition.

Ira A. Fulton College of Engineering and Technology
Brigham Young University
2012-2013 Capstone – Team 1 Final Report
Air Force Research Laboratory
April 16, 2013

AFRL Obstacle Traversing Competition

Obstacle Traversing Device to Allow Troops with Equipment to Cross Rooftops, Canals, Crevices, and Other Gaps

Flying Aces

TEAM MEMBERS:

Andrew McQuay	Date	Sean Johnson	Date
James Stewart	Date	Daniel Newquist	Date
Luke Rasmussen	Date	Nathaneal Hill	Date
Greg Bishop	Date		

Executive Summary

The Air Force Research Laboratory (AFRL) is a scientific research organization that does R&D work to improve the technology and war fighting capabilities of the United States. In April 2013, the AFRL is sponsoring an engineering design competition between 17 universities. Our team has been selected to represent BYU in this competition. The competition task is to design a traversing device to allow troops, with their equipment, to cross canals, gaps between rooftops, glacier crevasses, and similar obstacles under a variety of conditions. At the competition, each team will demonstrate the operation of their traversing device and be scored on a variety of criteria.

The team has developed a traversing system that can be deployed quickly and used to cross a variety of obstacles. The device, called the "scissor bridge" (pictured below), is operated by extending the structure to a given span on one side of the obstacle, locking it in place, and then lowering it to span the necessary gap. In developing the scissor bridge, it was convenient to divide the design into its components: structure, joints, planking, and attachment. Each aspect of the solution was chosen through a process of concept selection and rigorous testing, which is detailed in the body of this report.

The objective scoring criteria of the competition and the corresponding values of the scissor bridge are included in the table below. Subjective criteria include multipurpose, ease of operation, usability, innovation and creativity, presentation, and judges' bonus.

It quickly became apparent that the constraints of the competition rendered "the perfect design" almost impossible. Decisions had to be made regarding sacrifices in weight or volume, time to set up or strength, and others throughout the creation of the scissor bridge. The final solution integrates the most desirable aspects of each criterion to achieve the desired flexibility and manage the necessary tradeoffs.

Metric	Points	Units	Marginal Value	Ideal Value	Final Value
Span	20	ft	5	20	20.33
Volume	20	ft^3	5	1	1.88
Weight	20	lbs	20	5	24
Load Capacity	20	lbs	350	350	350
Time to use, set up, and pack with four people	20	min	6	4	0.75

Judging criteria compared to the performance of the scissor bridge.

Scissor Bridge

Table of Contents

Section I: Project Summary and Results

Project Objective Statement

To design and build a device by April 18th to allow Special Tactics Airmen to easily maneuver the battlefield terrain obstacles that are encountered in diverse missions executed in environments all across the world. These obstacles can include canals, gaps between rooftops, glacier crevasses, compound walls and others.

Project Introduction

The Air Force Research Laboratory (AFRL) is a scientific research organization that does R&D work to improve the technology and war fighting capabilities of the United States. In April 2013, the AFRL is sponsoring an engineering design competition between 17 universities.

Our team has been selected to represent BYU in this competition. This report will describe the problem definition, the design solution, and the process we used to develop our solution.

Description and Scope

The competition task is to develop and build a traversing device to allow troops, with their equipment, to cross canals, gaps between rooftops, glacier crevasses, and similar obstacles encountered by Special Tactics Airmen. At the competition, each team will demonstrate the operation of their traversing device and be scored on a variety of criteria, including:

- Time to complete course (20 pts)
- Span when fully deployed (20 pts)
- Size when packed (20 points)
- Weight (20 points)
- Load capacity (20 points)
- Multipurpose (10 points)
- Ease of operation (10 points)
- Usability (10 points)
- Innovation and creativity (10 points)
- Presentation (10 points)
- Judges' bonus (10 points)

The final score awarded will be determined by three major aspects of the competition. The three aspects are: a presentation featuring the design process and a detailed explanation of the product, a timed obstacle course where three students and one battlefield airmen use the device to cross multiple obstacles, and a pass/fail static load test of 350 lbs. Points will be awarded during each of the three parts of the competition.

Review of Customer Needs & Metrics

The team developed a list of customer needs based on two main sources:

1. Competition Scoring as defined by the AFRL.
2. Anticipated end user criteria, gathered from talking to other special forces.

From these sources, a list of customer statements and interpreted needs was compiled (which can be found in Appendix B1). Some of the most important customer needs discovered included the following:

The device…

- facilitates crossing an obstacle of 20 feet or longer
- can support an adult carrying military gear (350lbs)
- is light-weight (less than 20 lbs)
- is compact when stored, can fit within a 1-5 cubic feet container
- facilitates a quick operation
- is safe

With this list of needs, functional specifications and corresponding quantifiable metrics for measuring each specification were developed. These metrics helped in concept selection and ensured that the customer's needs would be met by the final product. Table 1 (below) includes several of the most critical metrics with their target values. For a full list of the metrics and their target values, refer to Appendix B2.

Metric	Import.	Units	Marginal Value	Ideal Value
Span	5	ft	5	20
Volume	5	ft^3	5	1
Weight	5	lbs	20	5
Load Capacity	5	lbs	350	350

Table 1: A listing of several critical metrics with their target values. The full list is found in Appendix B2.

Project Results

Design Solution

Our solution is designed to assist a troop of four individuals in crossing a twenty foot gap in less than five minutes. The solution consists of a device that can be extended from a span of less than two feet to more than twenty feet. The extended device is locked in place and then lowered across the gap. Figure 1 shows the method of using the scissor bridge. The selection of the scissor bridge concept was completed and verified as outlined in the previous report. For convenience, the section of the report addressing the concept selection and verification is included in Appendix F.

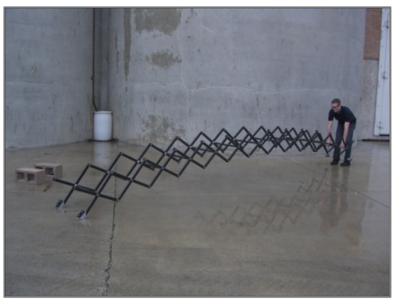
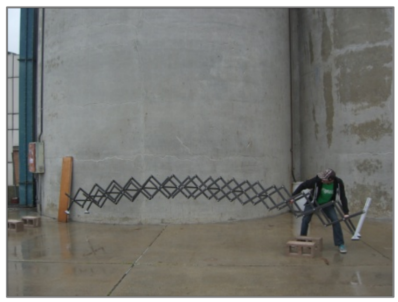
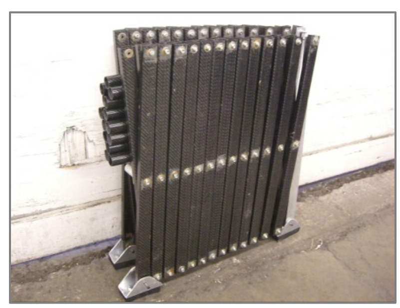
		
1. **Unpack:** remove the scissor bridge and connecting rungs from the bag.	2. **Assemble:** with one side of the scissor bridge on its side, place one rung on each protruding nub. Line up the other side of the bridge and insert the nubs into the rungs.	3. **Level:** If the ground is uneven on the surface you want to cross, adjust the attachment as necessary on each side of the scissor bridge using the slotted c-beam.
		
4. **Extend:** pull the bridge to its extended length and lock the sides at each corner of the bridge, similar to step 3.	5. **Lower:** place the bridge across the gap.	6. **Cross:** it is easiest to cross by lowering yourself and using the sides to balance as you cross.
		
7. **Collapse:** pull the bridge over, unlock the sides, and collapse the bridge.	8. **Disassemble:** remove one side of the bridge from the rungs and remove each rung	9. **Pack:** place the two sides of the bridge into the bag and then the rungs. Cinch the bag.

Figure 1: Description of how to use the scissor bridge to cross a gap.

As shown in the first cell in Figure 1, all the equipment is packed for convenience in carrying the device. When it is time to use the scissor bridge, some minor assembly will be necessary. The rungs of the bridge are attached to the supporting structure which can then be extended across the gap. The attachment device at each corner of the bridge can be modified to attach to different terrain and uneven surfaces.

This system lends itself to being divided into four main components: Structure, Joints, Attachment, and Planking. Much of the detailed design process was handled by treating these components separately and then integrating them into the final solution. The remainder of the report discusses the detailed design and performance of each component in detail.

Detailed Structure Design

One of the most important aspects of the design is the choice of structural beams. These beams have been optimized for strength, weight, and volume. Many variables were considered in this optimization including cross sectional shape, cross sectional dimensions, beam thickness, beam length, max angle of scissor extension, and curvature. Likely due to the novelty of the scissor bridge concept, no governing equations were found that could relate strength or deflection to the variables mentioned above. For this reason the FEA program Z88 Aurora was used to optimize the design. An Excel Macro was developed with the help of Dr. Carl Sorensen which greatly increased the speed and efficiency of running the FEA iterations. The macro, in Appendix C7, receives values for the key variables mentioned above and then creates a structural file which is then used by the FEA program. A specified load is also applied to the center of the bridge.

Aluminum properties were used in this analysis because carbon fiber is difficult to model accurately due to its anisotropic properties. All the potential suppliers of carbon fiber who were contacted stated that carbon fiber is known to be at least as strong as aluminum. The use of aluminum properties then provided a conservative baseline of worst possible performance.

With the development of these tools, it was relatively easy to run many iterations of testing. The method of isolation of variables was then used to find trends. The first design features that were tested were beam length, max angle of extension, and curvature. A cross sectional shape, dimension, and thickness were arbitrarily chosen. To find the strength trend based on beam length, a max angle of extension and curvature were also arbitrarily chosen. Several beam lengths were tested and the max bridge deflection was recorded for each iteration. An example of the FEA output is shown below in Figure 2.

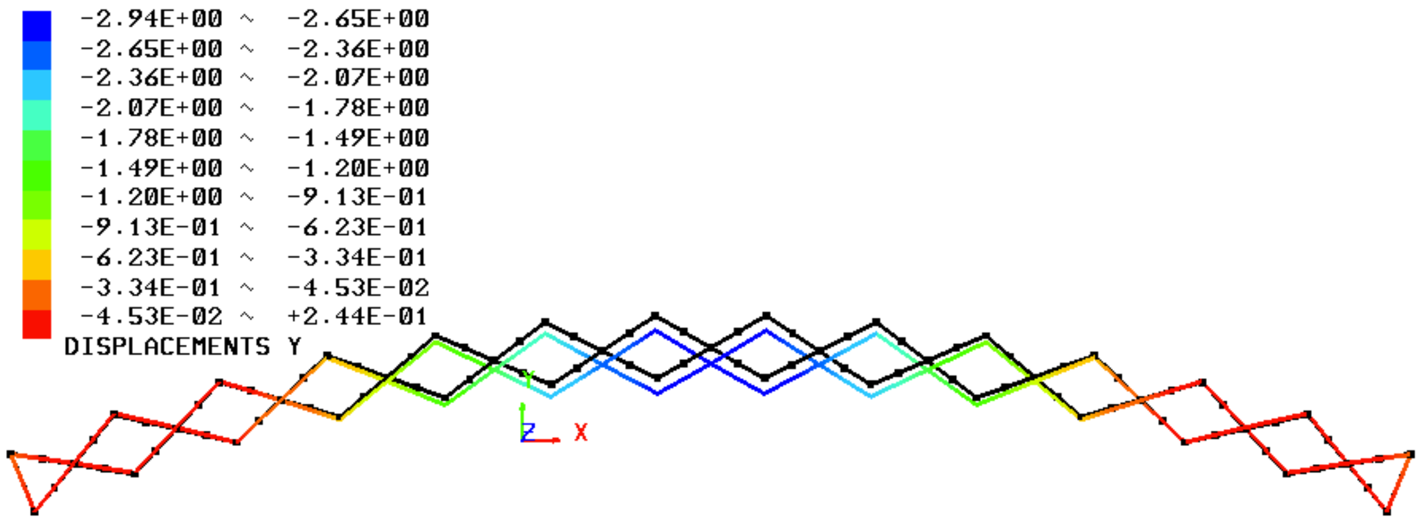


Figure 2: FEA Model output showing deflection based on the dimensions of the beam and the maximum extended angle.

Maximum deflection of the bridge was the measured output for every test. This was chosen to quantify the strength of the bridge because deflection will bend the beams to breaking, and also indicates the ease of use when walking. It was decided that if the bridge moves up and excessively when applying loads, it would be undesirable to walk on.

The results of testing deflection at various beam lengths can be seen in Table 1. Additional testing results can be seen in Tables 2 and 3. Once an ideal value was chosen for a certain variable, that value was used for future tests of other variables. Following this method of testing, the design converged to optimal parameters.

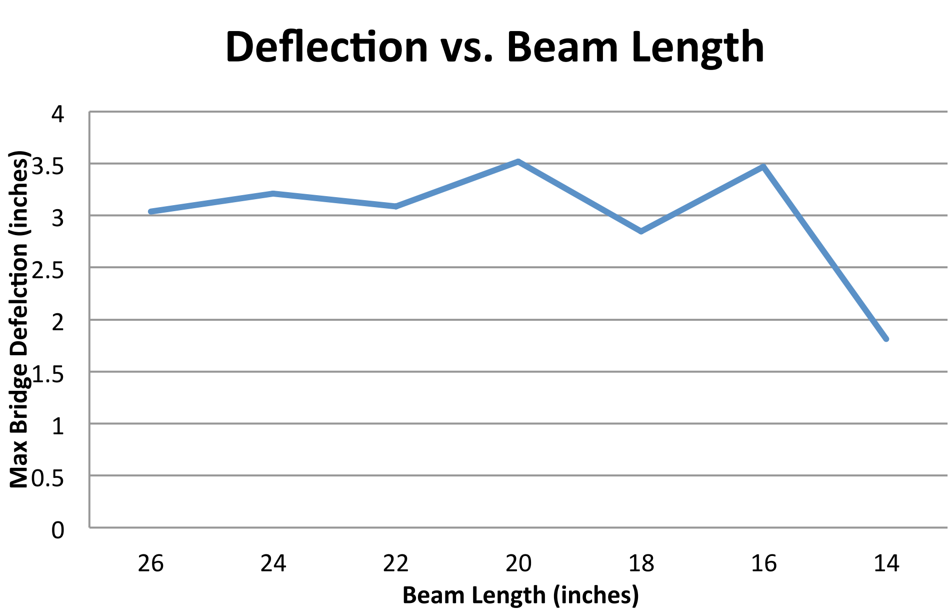
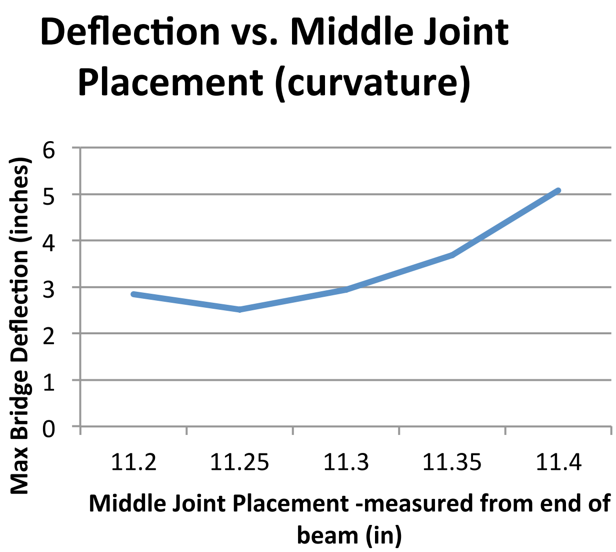


Table 2: The outputs from the FEA model revealed the relationship shown in the graph above between the beam length and overall deflection.



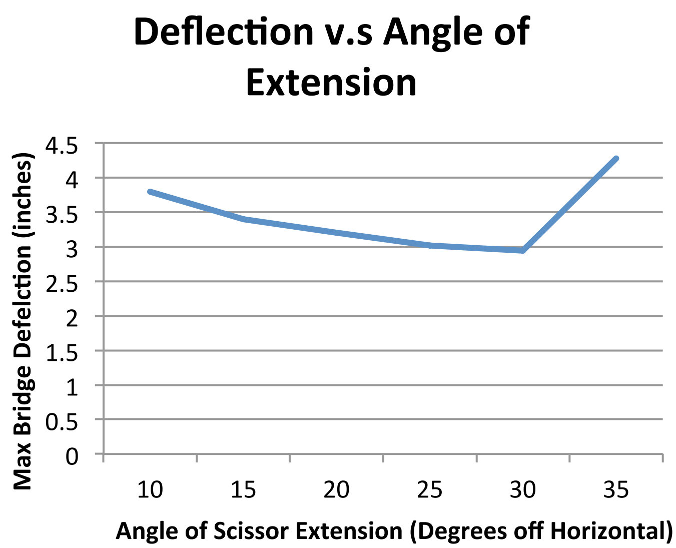


Table 3: Relationship between middle joint placement and bridge deflection.

Table 4: Relationship between maximum angle of extended beams and bridge deflection.

The volume of the bridge was also affected by variables such as beam length and cross-sectional area and shape. Early on, it was determined that by staying in a reasonable design space with these variables, the scissor bridge would easily stay under 5 cubic feet of volume. For this reason, the volume of different designs was not a limiting factor.

The weight of the bridge was another key performance characteristic that needed to be optimized. Several trends on the graphs above show increased strength with added weight. Beam thickness is the variable with one of the most dramatic relationships between strength and weight. With an increase of thickness, strength quickly increases but weight does as well. Through iterations of the FEA, it was determined that by using the minimum thickness carbon fiber suppliers use (0.05”) and increasing strength through cross-sectional dimensions, the final solution weight would be optimized. Changing the cross sectional dimensions of the beams instead of thickness was much more effective in adding strength while maintaining a low weight. The FEA model also revealed that strength performance begins to plateau around 45 degrees from the horizontal plane and that an extension of 30 degrees would allow for fewer scissor sections, greatly reducing weight. The beam length also gave an inverse relationship between weight and strength. The beam lengths determine how many scissor sections are needed to span a 20’ gap, so the longer the beam, the less weight. Inversely, the longer the beam, the weaker the bridge became. Through weight calculations and observing deflection trends, the best length was determined to be 24 inches.

From the results presented in the graphs, the final dimensions of the structural beams were chosen to be 24" long with cross-sectional inner dimensions of 1.25"x0.625" with a 0.05" thickness. It was decided that they would have a maximum extension of 30 degrees and have a curvature that resulted in 30 inches of height at the center. An image of the final structural beam is seen in Figure 3.

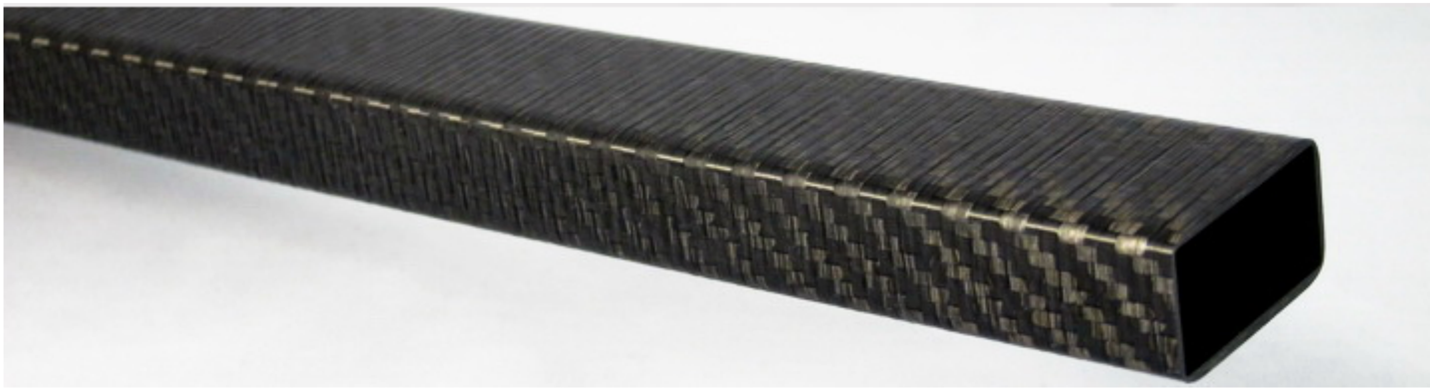


Figure 3: Structural Beams used in the scissor bridge. These beams were optimized to give the most strength with the least amount of weight and volume.

In order to verify the performance of the beams, one section of the scissor bridge was tested on the Instron machine to find its load capacity (Figure 4). The beams did not fail during testing; the bolts began to bend at 1900 pounds, before the beams failed. This test validated the use of these beams in the scissor bridge application.

Figure 4: Load test done on structural beams.

The FEA model described above was first validated by comparing its output with the performance of a full scale aluminum prototype. The prototype, pictured in Appendix C1, deflected about twenty inches under its own weight. The FEA model showed this as well and verified that the results it provided were reliable.

Detailed Joint Design

The joints are a critical part of the design. The joints hold all the beams together and enable the structure to retract and expand. There are two different joint designs in the scissor bridge: the top/bottom joints and the middle joints. The middle joints serve an additional purpose of supporting the planking. Many designs were presented as possible solutions; however, the current method was chosen for its light-weight, simple, and easy to repair design.

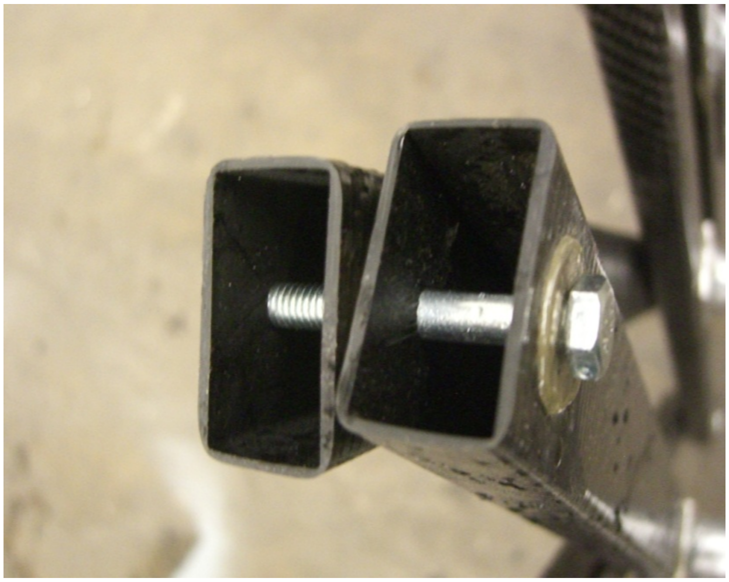


Figure 5: The top/bottom joints enable the scissor bridge to collapse and extend easily.

The top/bottom joints have a hole drilled in the carbon fiber beams, a half an inch from the ends, with a bolt going through both beams. This connects the beams and allows the motion needed to extend and retract the bridge. Figure 5 shows this joint design. Early prototyping of this concept brought up concerns with the holes weakening the overall strength of the structure as well as possible wear and deformation in the holes overtime. To avoid these possible problems, the bolt size was analyzed to provide the needed strength while minimizing the bolt diameter. Minimizing the bolt diameter reduced the loss of strength in the beams due to the drilled hole. Washers were also epoxied to the carbon fiber beams around each hole to give added strength as well as to prevent wear and deformation caused from the contact between the bolt and carbon fiber.

The middle joints followed a similar design using epoxied washers and bolts going through both beams. The only difference is the interaction with the planking which was accomplished by replacing the innermost washer on each side with a plate and tube design shown in Figure 6. The flat plate acts as a washer and is epoxied to the beams. The protruding tube slides inside the rungs for the planking.

The tube and plate were welded together and tested for strength. Initial prototypes used a 1/8 inch plate with a 1 ½ inch outer diameter and a 1/8 inch thickness. This was overdesigned and eventually, through further testing, the outer diameter was reduced to 1 inch and the thickness to 1/16 inch. This cut weight and provided the needed strength being able to withstand at least 1400 lbs without failure. The method of testing and results are shown in Figures 7 and 8.

Figure 6: Incorporating a protruding nub into the joint design allows it to interface with the planking.

Figure 7: The testing method used to ensure the welds were sufficiently strong.

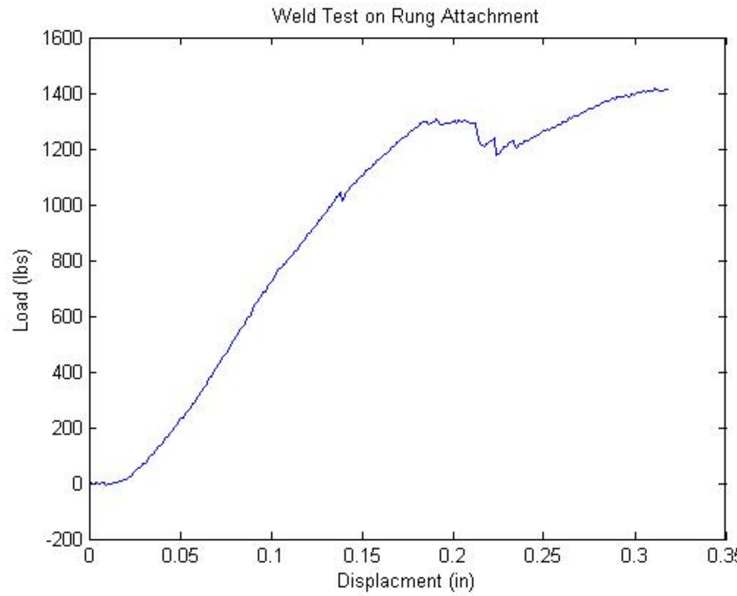


Figure 8: Strength testing data for the nubs in the middle joint design.

Detailed Attachment Design

The design of the attachments (end pieces) has been optimized to grip any surface and keep the scissor bridge level while someone is crossing. It is also designed to be able to be used in different environments such as mud, dirt, concrete, snow, etc. The foot of the attachment (Figure 9) comes straight from the design of a foot of a ladder. It is capable of being placed on the ground in two different orientations because it swivels on a bolt connected to the rest of the structure. The foot has a gripped rubber bottom that will hold the structure steady on hard grounds such as concrete or rock. To grip softer surfaces such as grass, dirt, snow, and mud, the foot also consists of a jagged side that allows the foot to dig into the surface and act as an anchor.

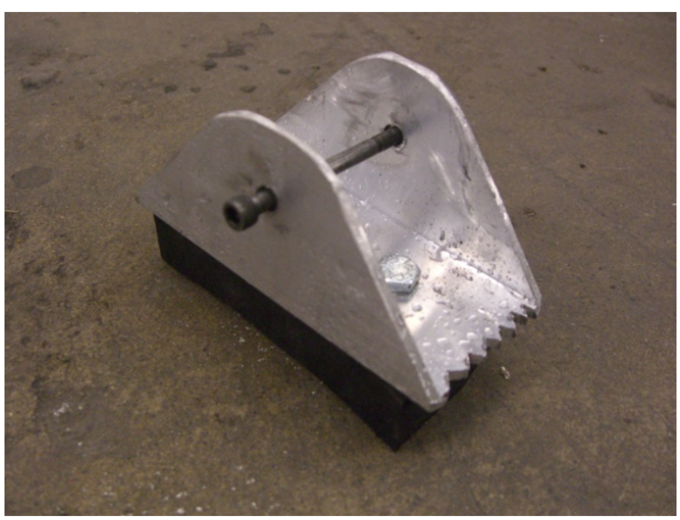


Figure 9: The foot of the bridge is designed to grip both hard and soft surfaces.

The last beam of the scissor bridge is attached to a c-beam with a slot in it that allows it to be lengthened up to nine inches. This allows the user to lengthen one side of the structure making the bridge level when trying to cross gaps that have uneven ground.

Figure 10: The attachment can be adjusted to lengthen one side of the bridge, enableing it to be used on uneven surfaces.

Detailed Planking Design

Many different planking attributes were discussed throughout the course of the year. The team decided that the most important attributes for planking were:

1) weight
2) volume
3) load capacity

These three attributes are important to consider for planking methods because they are essential in helping the bridge meet the overall specifications for the competition. Unfortunately, other important attributes had to be sacrificed to accommodate these three *most* important attributes. Attributes that had to be sacrificed include ease of setup, setup time and usability. The weight, volume, and load capacity are discussed below:

1) **Weight:** Weight was seen as the most concerning issue for planking, since the main structure of the bridge was already approaching the maximum for the weight specification. To address this issue, the team decided to eliminate solid planking that would allow the user to cross the bridge without paying very much attention to feet placement. Instead, it was decided that the planking would consist of "rungs," like ladder rungs, that would be spaced out at 1.5 foot increments across the bridge. This

solution requires the user to pay much more heed to foot placement and also increases the risk of falling off of the bridge. This design is adequate for an able bodied person. However, to carry injured or others across the bridge modifications are necessary. A sled type device can be used to pull an injured person across the bridge as well. Another aspect of reducing weight within the planking came from optimizing the material. Carbon fiber was chosen because of its high strength to weight ratio. The total weight of the planking is just under 3 lbs.

2) **Volume:** In order to provide a sufficient amount of room for the user to comfortably walk across the bridge, the rungs needed to be about 18 inches wide. This would make the bridge far too big with regard to volume, so concepts had to be generated for making the planking more compact. The final idea allows the planking to be completely detached from the main scissor assembly. Each rung is a fixed length of 18 inches and all of them fit snugly in the bag along with the scissor sides. In packing, the rungs can be individually removed and placed in the bag, allowing the bridge to be at a collapsed width of about 8 inches.

3) **Load Capacity**: The planking needed to hold at least 350 lbs in the center of the bridge, but still be as lightweight as possible. The solution was to use circular carbon fiber tubing for the rings, which optimized the strength-to-weight ratio. The tubes used for the thirteen rungs on the structure are 1 inch inner diameter with a wall thickness of .0625 inches. An 18 inch section of this tubing was tested (Figure 12) on the tensile test machine and held a point load of 320 lbs in a simply supported setup before cracking. This may seem to be insufficient to hold 350 lbs; however, the testing was done with a point load as shown in the figure. The edge of the instrument used to place a force on the beam seemed to crush and almost cut through a thin section of the rung. The load will also be distributed through the joints and into the structure when the bridge is put together. Thus, the rungs do not need to support the entire load by themselves.

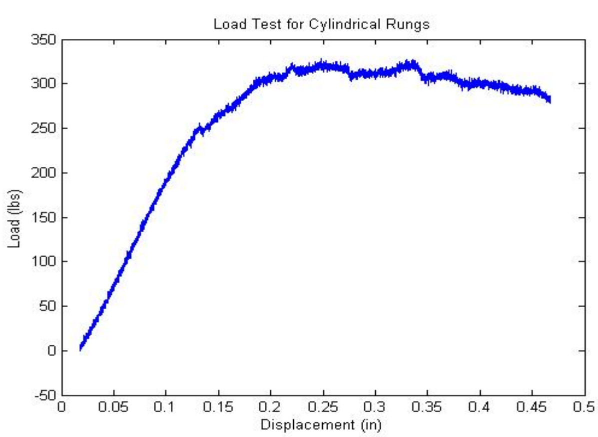


Figure 11: Testing data for the rungs

Figure 12: The rungs were tested as shown in the figure.

Product Performance

To determine the overall success of the scissor bridge, the design is compared to the product specifications below. These specifications were referred to throughout the creation of the product.

Metric	Import.	Units	Marginal	Ideal Value	Scissor Bridge Performance
Span	5	ft	5	20	20.33
Volume	5	ft^3	5	1	1.88
Weight	5	lbs	20	5	25
Load Capacity	5	lbs	350	350	350
Ease of crossing with gear and/or injured person	3	Scale #4	2	5	4
Physical exertion required to unpack, use, and pack	4	Scale #3	2	5	5
Number of gaps crossed by team of four in competition	5	#	5	Unlimited	Unlimited
Training required	4	minutes	10	3	2
Personnel required to set up	4	#	4	1	1
# of free limbs while using	4	#	1	2	0
Time to use, set up, and pack (with 4 people)	5	minutes	6	4	2
Can be used with tactical gloves	3	Scale #4	3	5	5
Field repairable	4	Scale #4	3	5	4
Safety	5	Scale #5	3	5	3
Dynamic Load Capacity	4	Safety Factor	1.5	3	1
Can be used with limited visibilty (smoke, darkness, etc.)	4	Scale #4	2	3	3
Minimum temperature	4	F	-30	-130	≤20
Maximum temperature	4	F	115	134	≥134
Can be used in heavy precipitation (wind, rain, and snow)	4	Scale #4	3	5	4
Cross canals/streams, rooftops, minefields	5	Scale #4	3	5	4
Cross glacier crevasses, rock formations, unstable/collapsed structures, w	3	Scale #4	3	5	4
Tools required	4	#	5	0	0
Aesthetic	4	Scale #6	3	5	5
Appeal in PR campaign	4	Scale #6	3	5	5
Operator Excitement	4	Scale #6	3	5	5
Can be used when depth perception is compromised by NVG's	3	Scale #4	3	5	5

Scale #1- Importance Rating
1. Feature is undesirable. I would not consider a product with this feature.
2. Feature is not important, but I would not mind having it. Not AFRL specified but might be worth points.
3. Feature would be nice to have, but is not necessary. Not AFRL specified but likely worth points.
4. Feature is highly desirable, but I would consider a product without it. AFRL specified this is worth 10 or 15 points.
5. Feature is critical. I would not consider a product without this feature. AFRL specified this is worth 20 points.

Scale #2- Ease of crossing with gear and/or an injured person
1. Cannot cross with either gear or injured person.
2. Can cross with gear or injured person with difficulty (Physical Exertion Score 4-5).
3. Can cross with gear or injured person easily (Physical Exertion Score 1-3).
4. Can cross with gear and injured person with difficulty (Physical Exertion Score 4-5).
5. Can cross with both gear and injured person easily (Physical Exertion Score 1-3).

Scale #3- Physical Exertion Score
1. Maximum Exertion. Comparable to sprinting. Requires rest afterwards.
2. Heavy Exertion. Rest is desireable.
3. Moderate Exertion.
4. Light Exertion. Starts to increase pulse and breathing. Rest is unneccessary.
5. Minimal Exertion. Comparable to walking.

Scale #4- Utility Rating
1. Cannot be accomplished.
2. Can be accomplished with much difficulty with extra equipement or special technique.
3. Can be accomplished easily with extra equipement or special technique.
4. Can be accomplished with some difficulty with no extra equipment or special technique .
5. Can be accomplished easily wiith no extra equipment or special technique.

Scale #5- Safety Rating
1. Injury unavoidable.
2. High risk of injury or harm even with level of concentration.
3. Small chance of harm if operator maintains high level of concentration.
4. Very small chance of injury or harm, requires little concentration to maintain safety.
5. No chance of injury or harm, requires no concentration to maintatin safety.

Scale #6- Excitement Rating
1. Extremely disappointing.
2. Disappointing, misses some expectations.
3. Adequete and meets all expectations.
4. Moderately exciting exceeds some expectations.
5. Very exciting. Exceeds all expectations.

Table 5: Scissor bridge performance compared to the product specifications developed at the beginning of the project.

The specifications were targeted at the criteria provided by the AFRL. The scoring criteria compared to the performance of the scissor bridge will be discussed:

- **Weight**

By using carbon fiber wherever possible and aluminum when necessary, the weight of the scissor bridge was minimized to 24 lbs.

- **Volume**

Removing the middle rungs allows the sides of the scissor bridge to collapse inward to 6 inches. The individual beams are 2 feet long and when the scissor bridge is collapsed each side is less than 2 feet long. This results in a packed volume of 1.88 cubic feet.

- **Span**

The scissor bridge is capable of extending up to 20 feet and 4 inches.

- **Load Capacity**

While each component of the scissor bridge was tested individually as detailed in the preceding sections, it was unclear how the components would distribute the load. Thus, the extended scissor bridge was also tested to hold 350 lbs.

- **Time to Complete Course**

A team of four able bodied persons can consistently unpack, assemble the bridge, and cross a gap in less than one minute.

- **Multipurpose**

The scissor bridge was designed to be able to attach to both hard and soft surfaces. The attachments can be adjusted to maintain the bridge level while crossing on uneven surfaces. The scissor bridge is capable of being used to traverse irrigation canals, rooftops, minefields, mountain streams, glacier crevasses, compound walls, and other obstacles. The bridge can also be extended partway and used as a stretcher to carry an injured person.

- **Usability & Ease of Operation**

One of the advantages of carbon fiber is that it can be used in almost any environment. Its strength and other properties don't change much from hot to cold temperatures. It is also robust and durable. The interaction of the aluminum and carbon fiber may be a concern at extreme temperatures since aluminum will expand and contract more than carbon fiber. However, aerospace and biking industries have used carbon fiber/aluminum interfaces in extreme conditions with no adverse effects. This lends confidence to the ability of the scissor bridge to be used in similar conditions.

The scissor bridge packs conveniently for transport. The bag can be clipped to the outside of a backpack or carried by its handle.

Due to the planking design of the rungs, the users must focus on crossing and are unlikely to perform other tasks while crossing the bridge. It would be difficult to cross with a heavy pack or carrying someone across.

- **Creativity and Innovation**

The design team considers the scissor bridge to be a simple, user-friendly design with an aesthetic appeal. The design is innovative but similar in some ways to a ladder which is commonly used in similar applications.

Expected Schedule

The bridge was completed by the deadline of April 18th, 2013. The milestones set and achieved by the team are included in Appendix A3.

Financial Implications

After evaluating the cost of the bridge once the design had been finalized, the team concluded that more money was needed. The budget for the bridge was approved in early March and the team remained within this revised budget. The cost of the bridge was not part of the scoring criteria of the AFRL.

Conclusion

The design process has been focused on meeting the product specifications. By meeting these specifications to the fullest extent possible, the Flying Aces have developed a product that has a strong chance of performing well at the competition. In comparing the final solution to the functional specifications created, it is apparent that not all the requirements were met. However, the large majority of the specifications were met, including almost all the ones with highest importance rating. Several of these specifications are listed in the table below, with their final values after testing.

Metric	Import.	Units	Marginal Value	Ideal Value	Final Value
Span	5	ft	5	20	20.33
Volume	5	ft^3	5	1	1.88
Weight	5	lbs	20	5	24
Load Capacity	5	lbs	350	350	350
Time to use, set up, and pack with four people	5	min	6	4	0.75

Table 6: Final value of functional metrics of the scissor bridge compared to the product specifications.

The team is pleased with many of the final characteristics of the bridge. It collapses to almost the ideal volume specification, as seen in the table above. The bridge weighs a mere 24 lbs, which is outside of the specification range for weight, but is still light when considering its strength. The bridge can be set up in less than one minute and it takes less than 8 seconds for one person to cross it. It is multipurpose, in that it can be used to cross not only canals, but also roof-to-roof gaps, glacier crevasses, uneven surfaces, and even compound walls.

As detailed in the report, each aspect of the final product has been verified to meet the product performance criteria. The individual components have been tested independently and all function properly even under extreme conditions. Expert opinions, analytical models, FEA models, prototypes, and testing have all have been instrumental in developing the scissor bridge. The Flying Aces strongly believe that the scissor bridge will perform impressively at the competition in April.

Recommendations

Due to time and financial constraints, the scissor bridge is not fully optimized. The design aspect that has the most potential to improve the overall performance of the scissor bridge is planking. Walking over spaced out rungs is possible but not as comfortable as desired. Designing a collapsible and solid planking system would greatly increase the ease of operation and usability of the bridge. This would eliminate the need to crawl across rungs and improve the overall performance of the bridge.

The scissor bridge could also be improved by creating self-locking leveling attachments and end pieces. This would reduce the number of steps in using the scissor bridge as well as make the design more user-friendly. Further work could also be done to minimize the weight and volume.

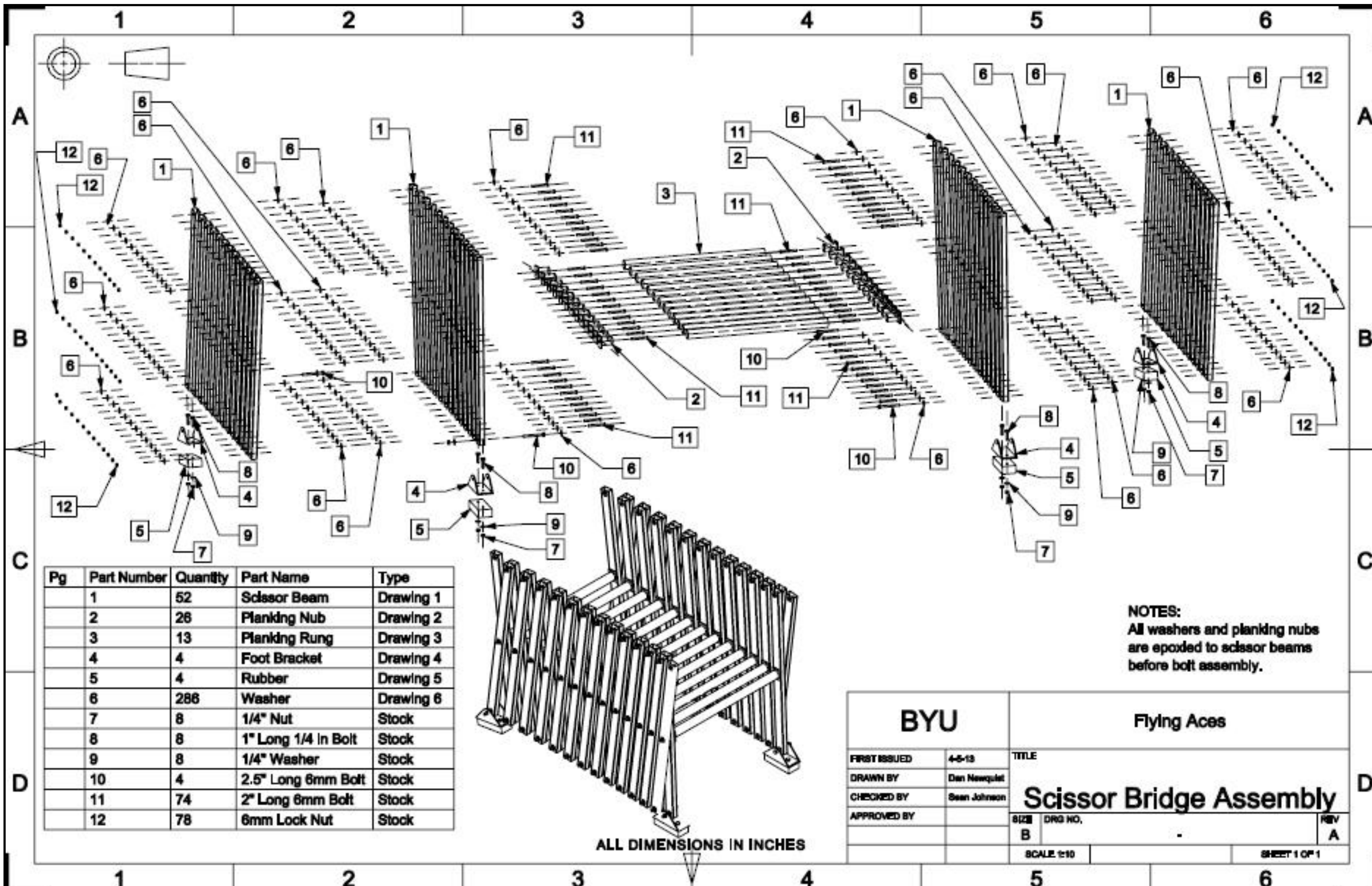
Another area of concern in the scissor bridge is the “bounce.” Currently, the fastest and easiest method of crossing is by hunching over and using the sides to balance. This is because the bridge deflects downward as it is stepped on and then springs back as the user lifts their foot to step forward. Solving this problem would eliminate the need to hunch over when crossing the bridge. A possible solution to this would be to increase the stiffness of the structural beams; however, this would likely mean increasing the thickness which would mean an overall increase in weight.

Section II: Drawings and Materials

Drawing Package

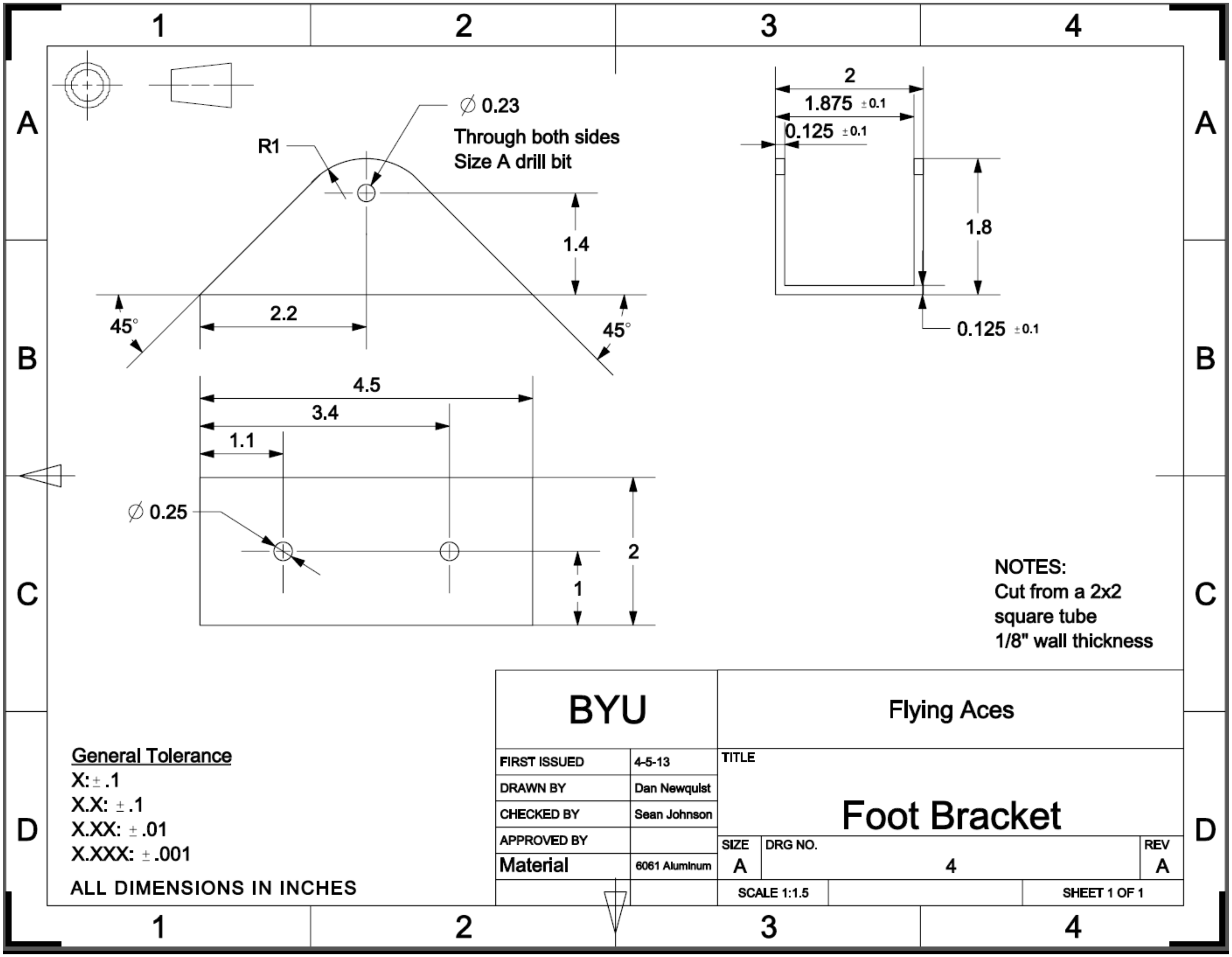
This section contains the technical drawings require to reproduce the hardware of the solution. It includes technical drawings for the structure, joints, attachment, and planking aspects of our solution. Other on-site assembly instructions may be found in the operations manual in appendix D1.

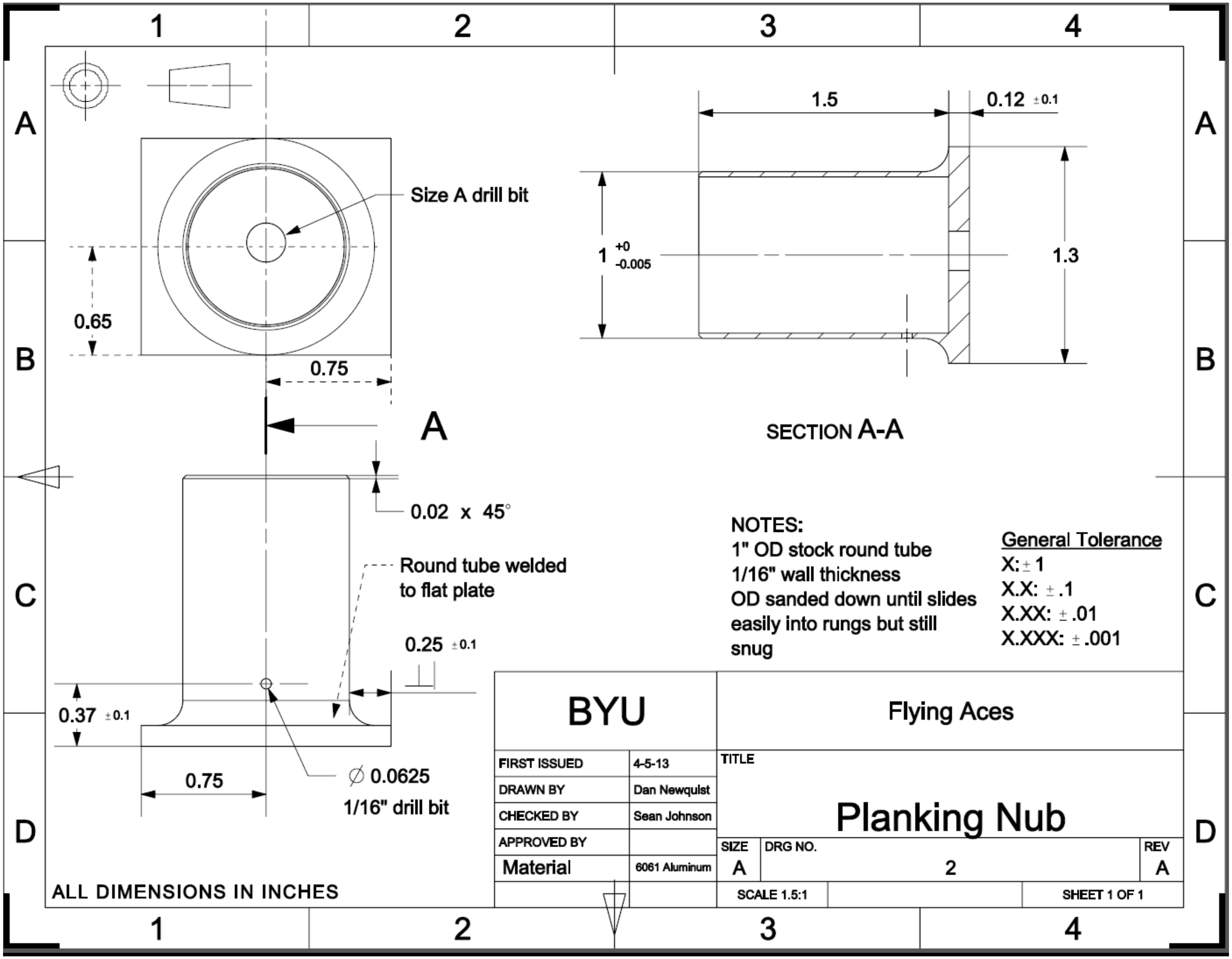
Assembly Drawings

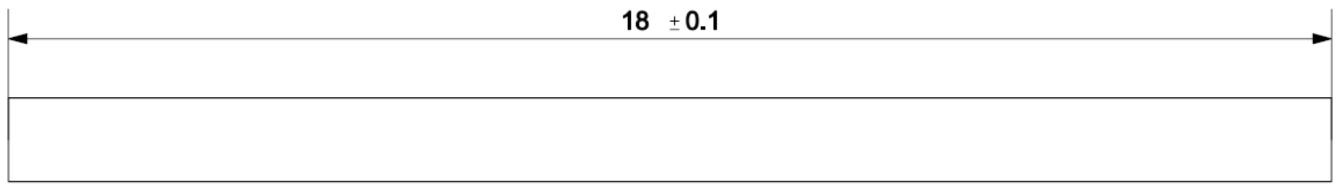


Pg	Part Number	Quantity	Part Name	Type
	1	52	Scissor Beam	Drawing 1
	2	26	Planking Nub	Drawing 2
	3	13	Planking Rung	Drawing 3
	4	4	Foot Bracket	Drawing 4
	5	4	Rubber	Drawing 5
	6	286	Washer	Drawing 6
	7	8	1/4" Nut	Stock
	8	8	1" Long 1/4 in Bolt	Stock
	9	8	1/4" Washer	Stock
	10	4	2.5" Long 6mm Bolt	Stock
	11	74	2" Long 6mm Bolt	Stock
	12	78	6mm Lock Nut	Stock

Part Drawings




Size A drill bit
1.5
0.12 ±0.1
1 +0 -0.005
1.3
0.65
0.75
A
SECTION A-A
0.02 x 45°
Round tube welded to flat plate
0.25 ±0.1
0.37 ±0.1
0.75
∅ 0.0625
1/16" drill bit
NOTES:
1" OD stock round tube
1/16" wall thickness
OD sanded down until slides easily into rungs but still snug
General Tolerance
X: ± 1
X.X: ± .1
X.XX: ± .01
X.XXX: ± .001
BYU
Flying Aces
FIRST ISSUED 4-5-13
DRAWN BY Dan Newquist
CHECKED BY Sean Johnson
APPROVED BY
Material 6061 Aluminum
TITLE
Planking Nub
SIZE A
DRG NO. 2
REV A
SCALE 1.5:1
SHEET 1 OF 1
ALL DIMENSIONS IN INCHES

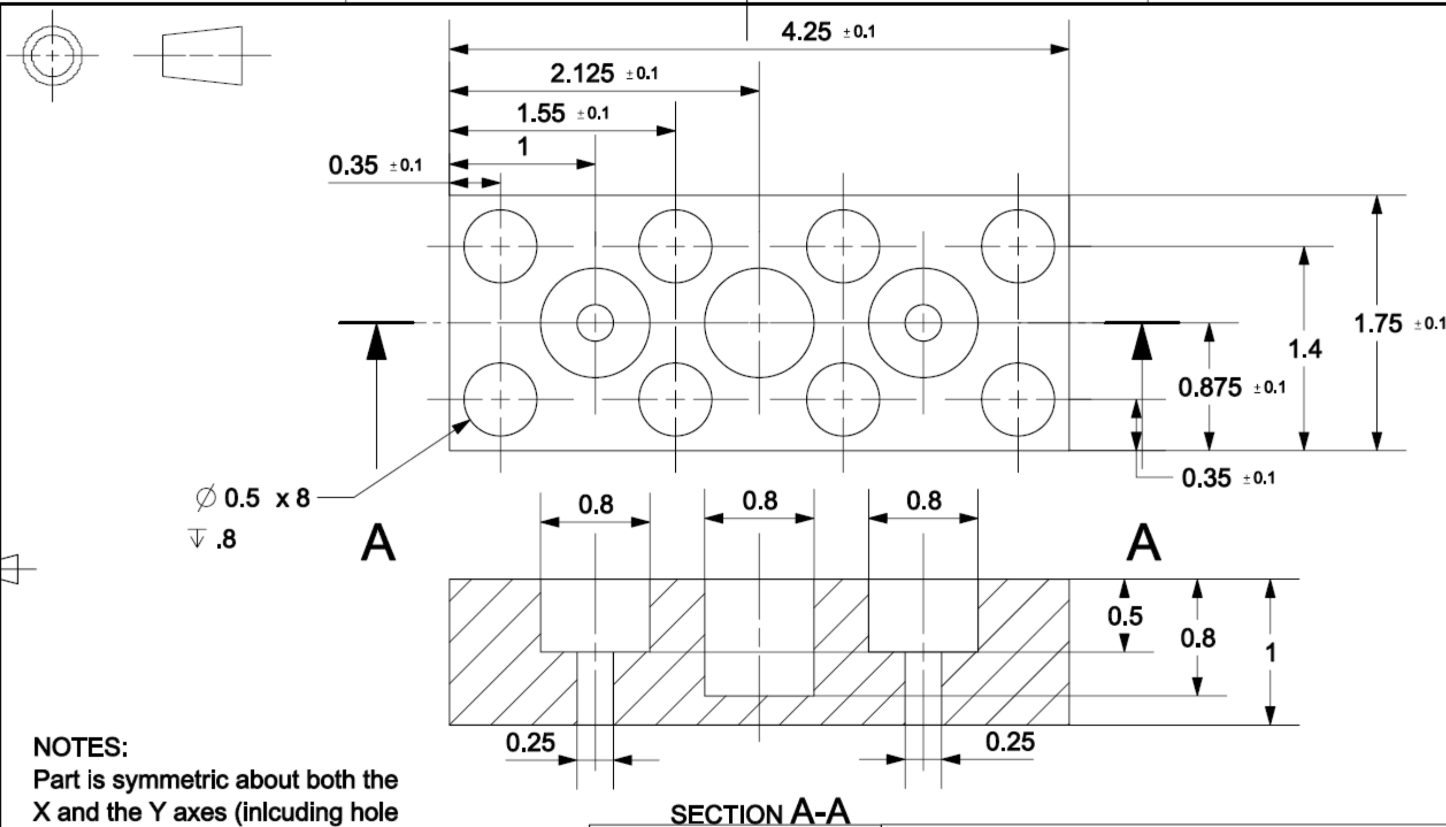


NOTES:
Stock Carbon Fiber Round Tube
1" (ID)
.0675" wall thickness

<u>General Tolerance</u>
X: ±1
X.X: ±.1
X.XX: ±.01
X.XXX: ±.001

ALL DIMENSIONS IN INCHES

BYU		Flying Aces		
FIRST ISSUED	4-5-13	TITLE Planking Rung		
DRAWN BY	Dan Newquist			
CHECKED BY	Sean Johnson			
APPROVED BY		SIZE A	DRG NO. 3	REV A
Material	Carbon Fiber	SCALE 1:2		SHEET 1 OF 1

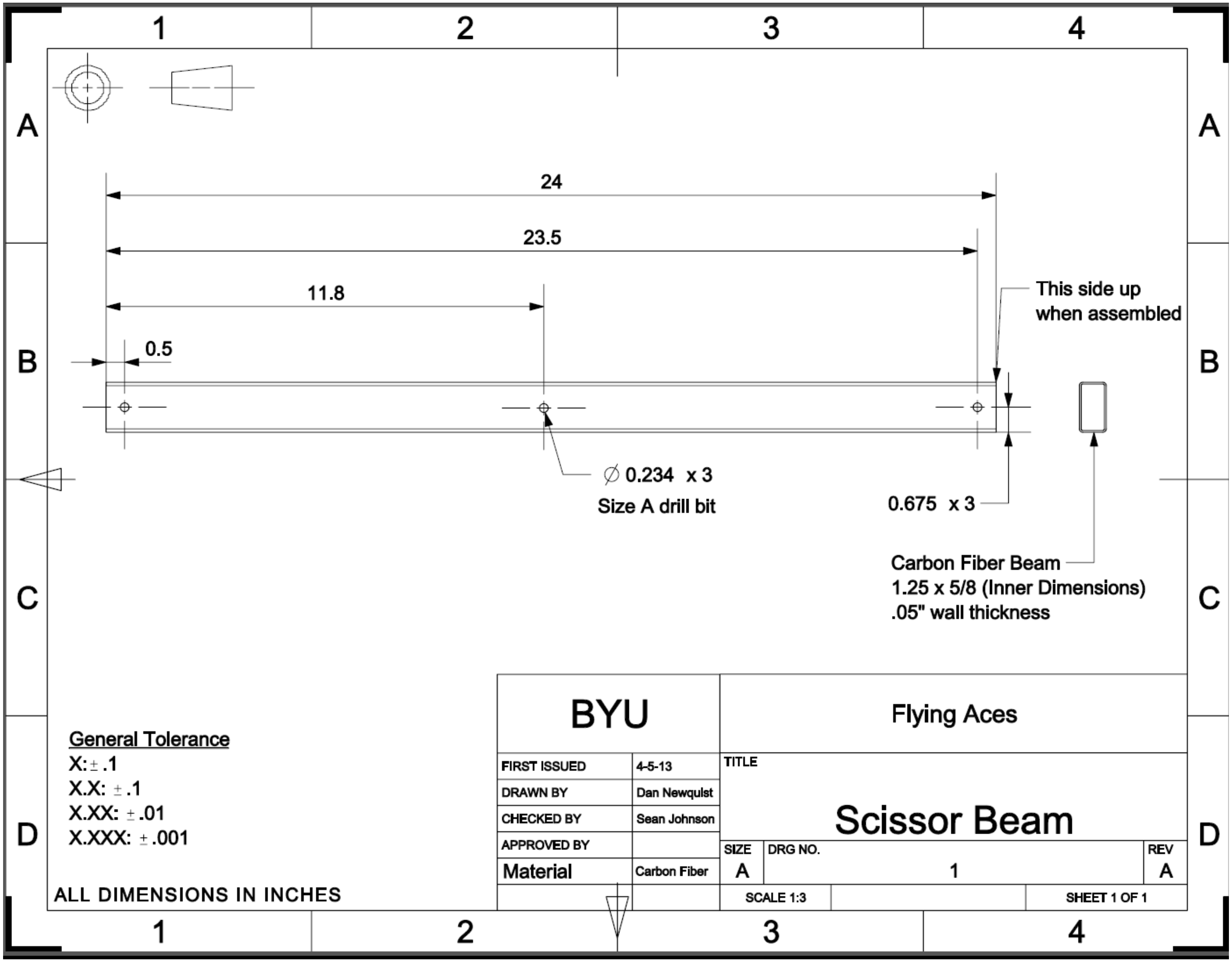


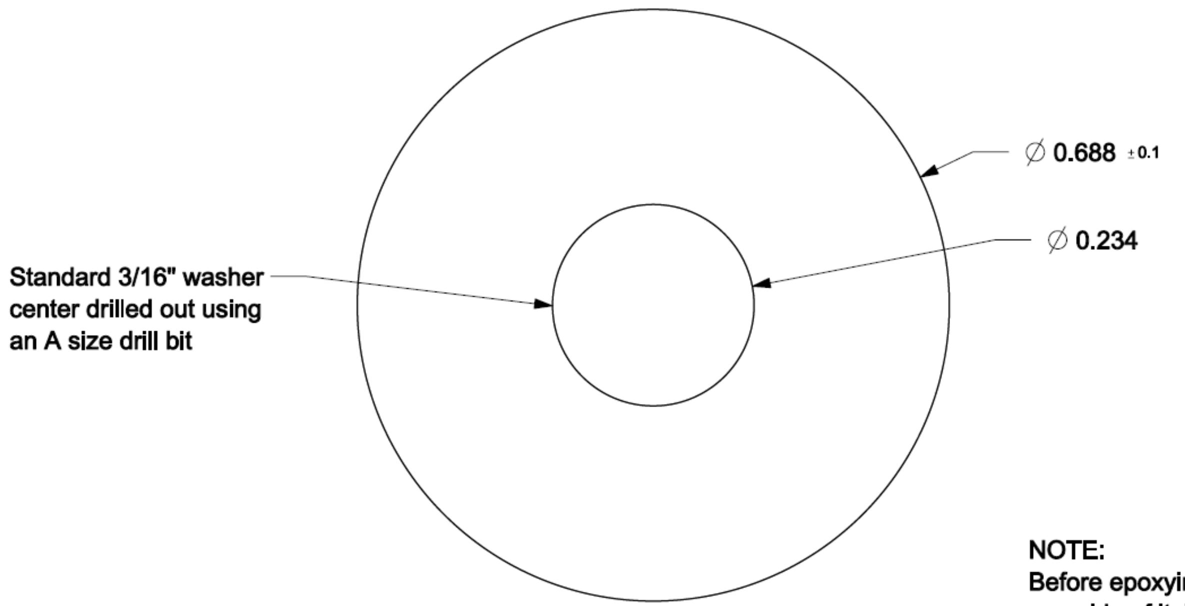
NOTES:
Part is symmetric about both the X and the Y axes (inlcuding hole locations).

General Tolerance
X: ± .1
X.X: ± .1
X.XX: ± .01
X.XXX: ± .001

ALL DIMENSIONS IN INCHES

BYU		Flying Aces	
FIRST ISSUED	4-5-13	TITLE	
DRAWN BY	Dan Newquist	Rubber Pad	
CHECKED BY	Sean Johnson		
APPROVED BY		SIZE A	DRG NO. 5	REV A
Material	Neoprene Spring Rubber	SCALE 1:1	SHEET 1 OF 1


24
23.5
11.8
0.5
This side up when assembled
∅ 0.234 x 3
Size A drill bit
0.675 x 3
Carbon Fiber Beam
1.25 x 5/8 (Inner Dimensions)
.05" wall thickness
General Tolerance
X: ± .1
X.X: ± .1
X.XX: ± .01
X.XXX: ± .001
ALL DIMENSIONS IN INCHES
BYU
Flying Aces
FIRST ISSUED 4-5-13
DRAWN BY Dan Newquist
CHECKED BY Sean Johnson
APPROVED BY
Material Carbon Fiber
TITLE
Scissor Beam
SIZE A
DRG NO. 1
REV A
SCALE 1:3
SHEET 1 OF 1



NOTE:
Before epoxying washer, rough up one side of it. This will allow the epoxy to bond better.

<u>General Tolerance</u>
X: ± 1
X.X: ± .1
X.XX: ± .01
X.XXX: ± .001

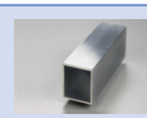
ALL DIMENSIONS IN INCHES

BYU		Flying Aces		
FIRST ISSUED	4-5-13	TITLE		
DRAWN BY	Dan Newquist	Washer		
CHECKED BY	Sean Johnson			
APPROVED BY		SIZE	DRG NO.	REV
Material	6061 Steel	A	6	A
		SCALE 6:1		SHEET 1 OF 1

Bill of Materials

Air Force Traversing Device

Assembly Name :	Scissor Bridge
Assembly Number :	1
Assembly Revision :	3
Approval Date :	08-Apr-13
Part Count :	81
Total Cost :	$4,727.97

Part #	Part Name	Description	Qty	Units	Picture	Unit Cos
45530	Carbon fiber rungs	RockWestComposites1.000 X 1.132 X 72IN	4	72IN		$ 135.9
Custom	Carbon fiber beams	RockWest Composites 0.625 - 1.25 x 0.73 - 1.35IN	60	24IN		$ 65.9
M82550025A20000	M6 bolts	Fastenal 1.0 x 25mm DIN 933 Class A2 Stainless Steel Cap Screw	2	25/ea		$6.4
1138571	M6 bolts (long)	Fastenal 1.0 x 50mm DIN 931 Class 8.8 Zinc Cap Screw	1	50/ea		$24.5
MW6360000A20000	M6 Steel Washers	Fastenal DIN 125 Stainless Steel A2 Flat Washer	1	100/ea		$4.6
N/A	Aluminum nubs	6061 Aluminum round tube 1.00 X 1.225 OD X	1	20ft		$ 55.2
N/A	Aluminum bars	6061 Aluminum bars 1.50 X .125 X 30IN	5	2.5ft		$ 14.0
1L2550000A20000	M6 Nylon lock nuts	M6-1.0 DIN 985 A2 S/S Nylon Insert Lock Nut	1	50/ea		$12.7
N/A	Aluminum square tube	2.00 X 2.00 X 1/8 IN WT	1	30 IN		$ 20.7
8630K118	Neoprene spring rubber	McMaster-Carr 6.00 X 6.00 X 1.00 IN	1	1/ea		$ 22.3
11100449	1/4" bolts	1/4-20x1" 18-8 S/S w/1/16"Hole Drilled Head Hex Cap Screw	4	1/ea		$1.7
	Total		81			

Section III: Appendices

Appendix A: Project Information

A1: Team Information

Team Contact Information Sheet		
Name	**Email**	**Phone**
Andrew McQuay	mcquaya@gmail.com	(801) 623-8400
Daniel Newquist	daniel_newquist@yahoo.com	(801) 473-5792
James Stewart	jramptons@yahoo.com	(801) 404-2297
Luke Rasmussen	lukejrasmussen@gmail.com	(801) 631-7825
Nathaneal Hill	natehill71@gmail.com	(404) 353-9027
Sean Johnson	seanjohn26@gmail.com	(949) 228-3532
Greg Bishop(Coach)	greglbishop@gmail.com	(801) 916-5229

A2: Glossary

Project Glossary

Term	Definition
AFRL	Air Force Research Laboratory
Planking	The walking surface/design of the traversing device
Joints	The connecting method/design of the individual beams of the scissor bridge

A3: Project Milestones

Project Milestones	Completion Date
Team Contact List	Sep-2012
Team Name and Logo	Sep-2012
Project Contract	Sep-2012
Project Schedule	Sep-2012
List of Customer Needs	Oct-2012
Functional Specifications	Oct-2012
Concept Generation	Oct-2012
Concept Screening & Scoring	Oct-2012
Preliminary Prototypes	Nov-2012
Concept Selection	Dec-2012
Full Scale Prototype	Dec-2012
Structural Design Completion	Jan-2013
Joint Design Completion	Jan-2013
Planking Design Completion	Feb-2013
Attachment Design Completion	Feb-2013
Verification of Structural/Joint Design	Mar-2013
Verification of Planking	Mar-2013
Verification of Attachment	Mar-2013
Parts Purchase Info	Mar-2013
Bill of Materials	Mar-2013
Assembly Drawing	Mar-2013
Detailed Part Drawings	Mar-2013
FMEA	Mar-2013
Hardware Completion	Apr-2013
Competition	Apr-2013

Appendix B: Project Definition

The items in this section were used by the team to fully define the project. This includes a lot of early stage design work such as research, determining customer needs, and generating concepts.

B1: Customer Statements

Need No.		Customer Need	Import.
1	The device	facilitates crossing/climbing an obstacle of 20 feet or longer	5
2	The device	is compact when stored/ can fit within a 1-5 cubic feet container	5
3	The device	is light-weight (less than 20 lbs)	5
4	The device	Can hold a load of 350 lbs	5
5	The device	is easy to use	4
6	The device	is robust	4
7	The device	is simple	4
8	The device	can be used by multiple troops	5
9	The device	is reusable	5
10	The device	allows the operator to perform other tasks while using it	4
11	The device	facilitates a quick operation	5
12	The device	can pack quickly	5
13	The device	can be set up quickly (includes deployment and attachment)	5
14	The device	can be deployed while wearing tactical gloves	3
15	The device	is field repairable	4
16	The device	is safe	5
17	The device	operates normally despite rough handling	4
18	The device	is usable both night and day	4
19	The device	is usable in extreme weather	4
20	The device	is usable in extreme temperatures (for outdoor use)	4
21	The device	is usable to cross canals and streams	4
22	The device	can be used to cross rooftops	4
23	The device	can be used to cross snow and glacier crevasses	4
24	The device	can be used to cross desert rock formations	4
25	The device	can be used to cross unstable/collapsed structures	4
26	The device	can be used to cross compound walls	4
27	The device	can be used to cross minefields	4
28	The device	would do well in a PR campaign	2
29	The device	makes operators excited to use it (Awesome factor)	2
30	The device	can handle dynamic loads	4
31	The device	requires little training to use	4
32	The device	can be set up with few steps	4
33	The device	can be operated with a reduced number of operators	4
34	The device	can be operated with reduced number of tools	4
35	The device	is innovative	4
36	The device	is stylish and aesthetically attractive	4
37	The device	is able to be used with impaired depth perception as when using NVG's.	3
38	The device	can be used within a short timespan	5
39	The device	can carry gear and/or an injured person	3

Importance Rating
1. Feature is undesirable. I would not consider a product with this feature.
2. Feature is not important, but I would not mind having it. Not AFRL specified but might be worth points.
3. Feature would be nice to have, but is not necessary. Not AFRL specified but likely worth points.
4. Feature is highly desirable, but I would consider a product without it. AFRL specified this is worth 10 points.
5. Feature is critical. I would not consider a product without this feature. AFRL specified this is worth 20 points.

B2: Functional Specifications

Need No.	Metric	Import.	Units	Marginal	Ideal Value	Source
1	Span	5	ft	5	20	AFRL PPT, specified exactly
2	Volume	5	ft^3	5	1	AFRL PPT, specified exactly
3	Weight	5	lbs	20	5	AFRL PPT, specified exactly
4, 6, 16	Load Capacity	5	lbs	350	350	AFRL PPT, specified exactly, awaiting clarification
5,39	Ease of crossing with gear and/or injured person	3	Scale #4	2	5	AFRL Problem Statement PPT
5	Physical exertion required to unpack, use, and pack	4	Scale #3	2	5	AFRL PPT, minimize "strenuousness of operation"
8, 9, 13	Number of gaps crossed by team of four in competition	5	#	5	Unlimited	Number of expected obstacles in competition
5, 7, 31	Training required	4	minutes	10	3	AFRL PPT, interpretation of reasonable training time
5, 7, 11, 33	Personnel required to set up	4	#	4	1	AFRL PPT, minimize "number of personnel required"
5, 10	# of free limbs while using	4	#	1	2	AFRL PPT, "frees operator to do other tasks concurrently"
5, 7, 11, 12, 13, 32, 38	Time to use, set up, and pack (with 4 people)	5	minutes	6	4	PPT, 20 min total competition
14	Can be used with tactical gloves	3	Scale #4	3	5	AFRL PPT, mentioned but no specific points
7, 15, 34	Field repairable	4	Scale #4	3	5	AFRL PPT, specified exactly
10, 16	Safety	5	Scale #5	3	5	AFRL PPT
6,16, 17, 30	Dynamic Load Capacity	4	Safety Factor	1.5	3	AFRL PPT
5, 18	Can be used with limited visibilty (smoke, darkness, etc.)	4	Scale #4	2	3	AFRL PPT, specified exactly
19, 20	Minimum temperature	4	F	-30	-130	Avg. temp in Alaska, coldest recorded land temp. (wrcc.dri.edu)
19, 20	Maximum temperature	4	F	115	134	Avg. temp in Egypt's deserts, hottest recorded land temp.
5, 19	Can be used in heavy precipitation (wind, rain, and snow)	4	Scale #4	3	5	AFRL PPT implies to be used in extreme weather
1, 21, 22, 26, 27	Cross canals/streams, rooftops, minefields	5	Scale #4	3	5	AFRL PPT, specified exactly, likely to be in competition
1, 23, 24, 25	Cross glacier crevasses, rock formations, unstable/collapsed structures, w	3	Scale #4	3	5	AFRL PPT, specified exactly, not likely to be in competition
5, 7, 15, 34	Tools required	4	#	5	0	AFRL PPT
7, 28, 35, 36	Aesthetic	4	Scale #6	3	5	AFRL PPT, specified exactly
28, 29, 35, 36	Appeal in PR campaign	4	Scale #6	3	5	Interpretation of "Judges Bonus"
28, 29, 35, 36	Operator Excitement	4	Scale #6	3	5	Interpretation of "Judges Bonus"
18, 37	Can be used when depth perception is compromised by NVG's	3	Scale #4	3	5	AFRL PPT, specified exactly
	deflection	4	inches			Interpretation of "Judges Bonus"

Scale #1- Importance Rating
1. Feature is undesirable. I would not consider a product with this feature.
2. Feature is not important, but I would not mind having it. Not AFRL specified but might be worth points.
3. Feature would be nice to have, but is not necessary. Not AFRL specified but likely worth points.
4. Feature is highly desirable, but I would consider a product without it. AFRL specified this is worth 10 or 15 points.
5. Feature is critical. I would not consider a product without this feature. AFRL specified this is worth 20 points.

Scale #2- Ease of crossing with gear and/or an injured person
1. Cannot cross with either gear or injured person.
2. Can cross with gear or injured person with difficulty (Physical Exertion Score 4-5).
3. Can cross with gear or injured person easily (Physical Exertion Score 1-3).
4. Can cross with gear and injured person with difficulty (Physical Exertion Score 4-5).
5. Can cross with both gear and injured person easily (Physical Exertion Score 1-3).

Scale #3- Physical Exertion Score
1. Maximum Exertion. Comparable to sprinting. Requires rest afterwards.
2. Heavy Exertion. Rest is desireable.
3. Moderate Exertion.
4. Light Exertion. Starts to increase pulse and breathing. Rest is unneccessary.
5. Minimal Exertion. Comparable to walking.

Scale #4- Utility Rating
1. Cannot be accomplished.
2. Can be accomplished with much difficulty with extra equipement or special technique.
3. Can be accomplished easily with extra equipement or special technique.
4. Can be accomplished with some difficulty with no extra equipment or special technique .
5. Can be accomplished easily wiith no extra equipment or special technique.

Scale #5- Safety Rating
1. Injury unavoidable.
2. High risk of injury or harm even with level of concentration.
3. Small chance of harm if operator maintains high level of concentration.
4. Very small chance of injury or harm, requires little concentration to maintain safety.

Scale #6- Excitement Rating
1. Extremely disappointing.
2. Disappointing, misses some expectations.
3. Adequete and meets all expectations.
4. Moderately exciting exceeds some expectations.

B3: Concept Generation List

45

- Hoverboard
- Plane tow
- Pole vault — NATE
- Bungee jump
- Jet pack
- Slingshot
- Balloons
- Tripod slide — SEAN
- Interlock arms and lay across
- Garbage shoot collapsable — JAMES
- Roller skate skis
- Static blanket
- Glue/dirt
- Air drop trampolines — DAN
- Scissor lift bridge
- Springboard
- Glider
- Human cannon — LUKE
- High wire bike
- Swing
- Shooting net
- Telescoping one pole ladder
- Single pole wheel cart
- Winch
- Squirrel suit
- Mag lev
- Whip
- Pre tension poles
- Tripod pulley

- Power zipline
- Chain link
- Blow up bridge
- Section arch bridge
- Slap bracelet
- Compliant rod launcher
- Retractable flyer
- Backpack heli
- Power paraglide
- Carbon fiber bridge puzzle
- Quadrotor with ropes
- Telescoping two pole ladder
- Hanging rope bridge
- Cargo ladder
- Slider
- Gogo gadget
- Tire swing
- Catapult

B4: Screening Matrices

		Suspension Bridge		Tripod Swing/Pulley		Scissor Bridge		Alunminum Ladder
Category	Weight	Min 2	Max3	Min 4	Max5	Min 16	Max17	Column20
Volume	5	4	5	3	5	4	5	3
Weight	5	4	5	3	5	2	4	3
Load Capacity	5	2	5	2	5	1	3	3
Time to use, set up, pack	5	1	3	1	3	1	3	3
Safety	5	3	5	3	5	1	3	3
Cross canals/streams, rooftops, minefields, compound walls	5	1	4	3	5	1	3	3
Physical exertion required to unpack, use, and pack	4	1	3	1	2	2	4	3
Training required*	4	1	3	1	3	3	5	3
Personnel required to set up*	4	2	4	2	4	4	5	3
# of free limbs while using	4	2	4	1	2	3	5	3
Field repairable	4	1	3	1	3	1	5	3
Dynamic Load Capacity	4	1	4	2	5	1	3	3
Can be used with limited visibilty (smoke, darkness, etc.)	4	3	5	3	5	1	3	3
Use in extreme temperatures	4	2	5	2	4	1	3	3
Can be used in heavy precipitation (wind, rain, and snow)	4	3	5	2	5	2	3	3
Tools required*	4	2	5	1	5	1	5	3
Aesthetic	4	3	5	2	5	3	5	3
Appeal in PR campaign	4	3	5	1	4	2	5	3
Operator Excitement	4	3	5	4	5	3	4	3
Can be used with NVG's	3	3	4	4	5	3	5	3
Can be used with tactical gloves	3	3	5	2	5	3	5	3
Cross glacier crevasses, rock formations, unstable/collapsed structures	3	3	5	2	5	2	3	3
		210	401	191	393	182	364	273
1- Much worse than aluminum ladder	Difference (max-min)		191		202		182	
2- A ilttle worse than aluminum ladder								
3- Same as aluminum ladder	Sum (max+min)		611		584		546	

Appendix C: Prototyping and Testing Data

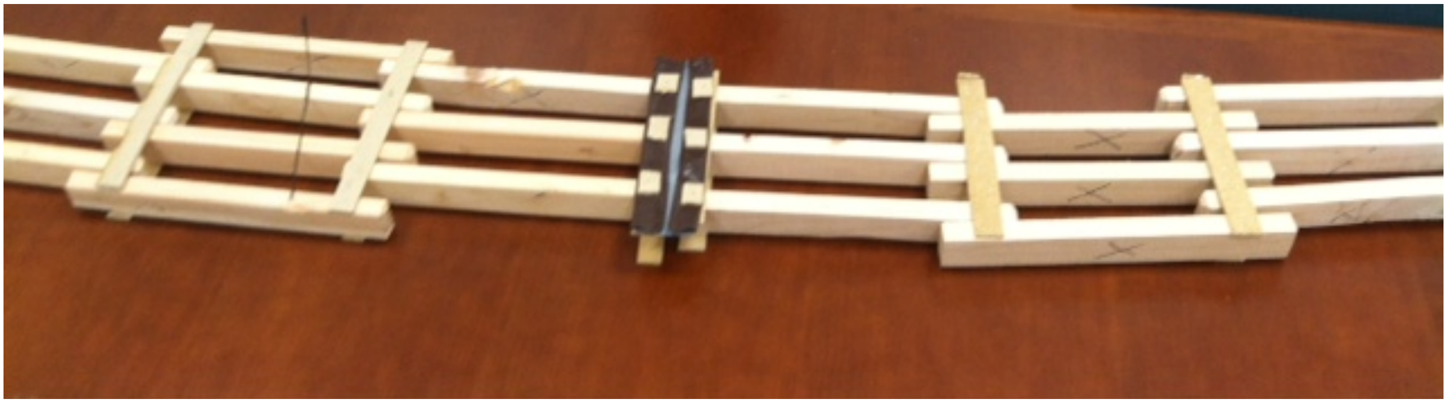
C1: Traversing Prototypes

Figure iii- Suspension Bridge Concept

Figure ii- Scissor Bridge Concept

Figure iv: Tripod Swing/Pulley

C2: Planking Prototypes



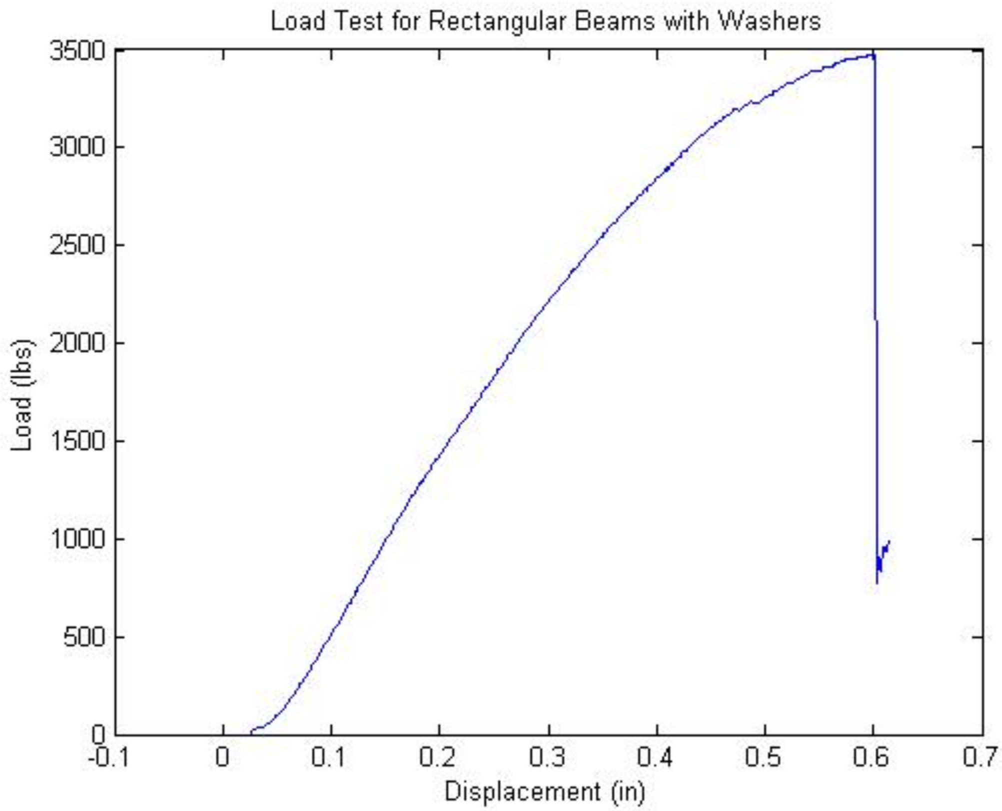
An extendable planking system.

Packable solid planking

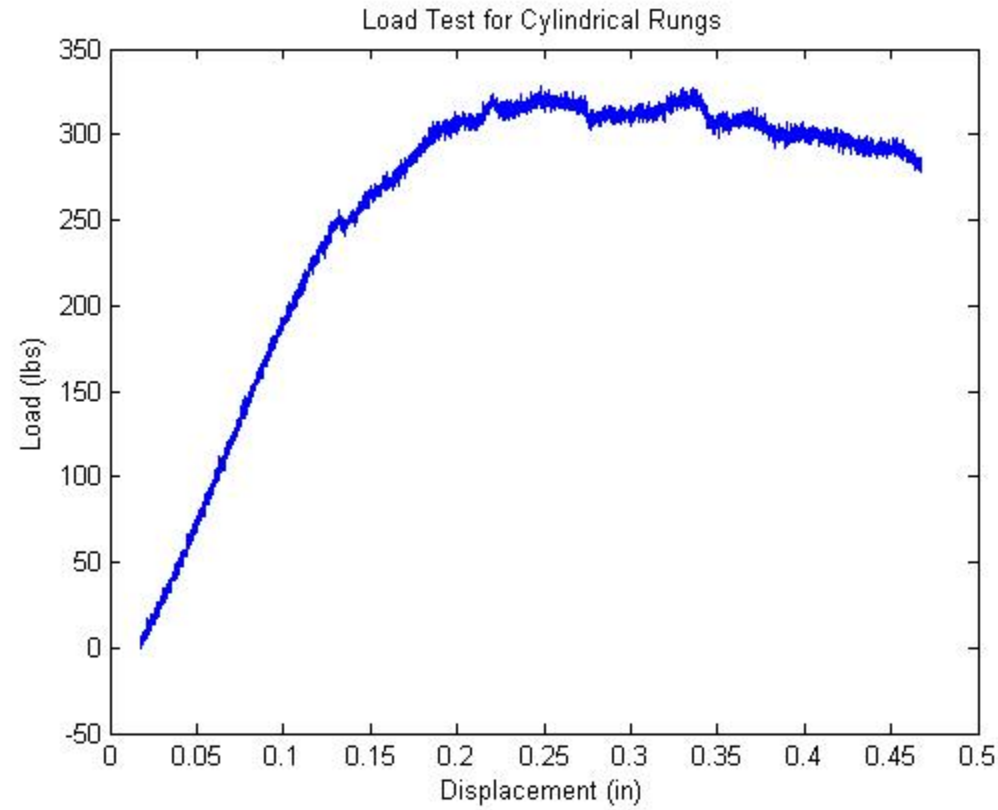
C3: Attachment Prototypes

Prototype of attachment that could be used to adjust the bridge so as to be used on uneven surfaces.

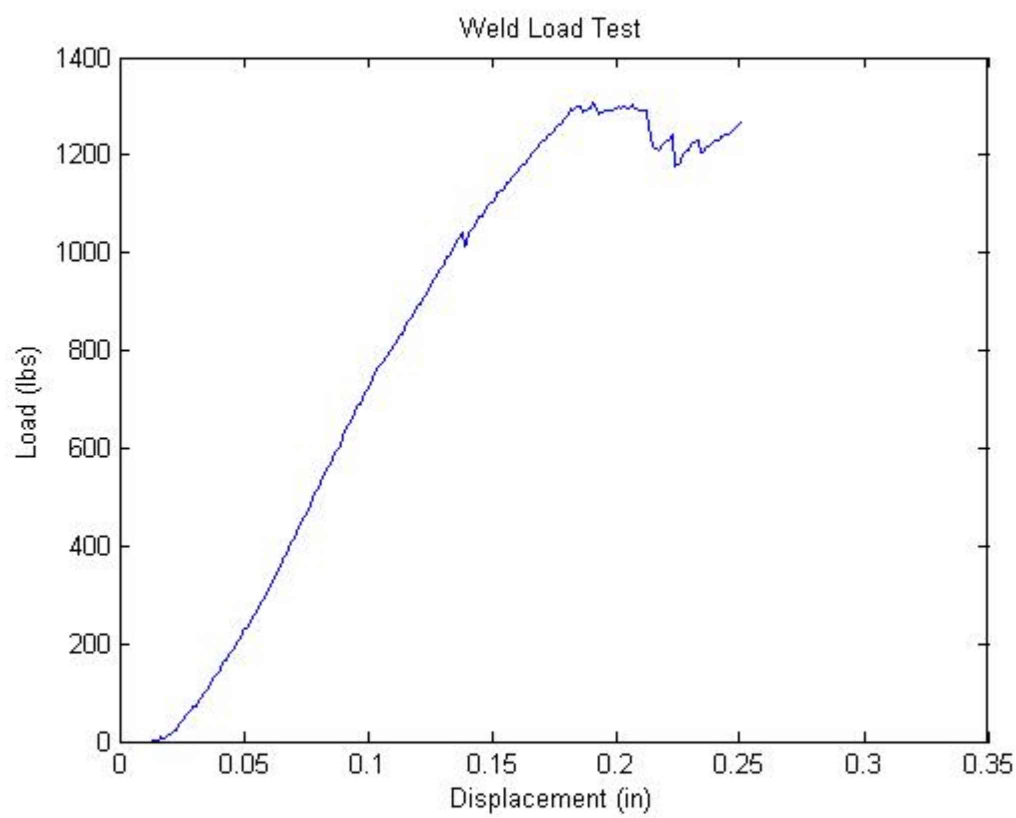
C4: Carbon Fiber Beam Strength Test Data



C5: Rung Strength Test Data



C6: Joint Test Data



C7: Excel Macro for FEA

```
Const MaxNodes = 45000
   Const MaxElements = 45000
   Const MaxUnits = 200

   Dim XCoords(MaxNodes) As Double, YCoords(MaxNodes) As Double, ZCoords(MaxNodes) As Double
   Dim Elements(MaxElements, 2) As Long
   Dim OuterHinges(MaxUnits, 2) As Double
   Dim InnerHinges(MaxUnits, 2) As Double
   Dim CenterHinges(MaxUnits, 2) As Double

Sub RotatePoint(XCoordinate As Double, YCoordinate As Double, Theta As Double)
   Dim Radius As Double, Angle As Double
   Radius = Sqr(XCoordinate ^ 2 + YCoordinate ^ 2)
   If XCoordinate = 0 Then
     Angle = 2 * Atn(1) * Sgn(YCoordinate)
   Else
      Angle = Atn(YCoordinate / XCoordinate)
      If XCoordinate < 0 And YCoordinate < 0 Then Angle = Angle - 4 * Atn(1)
      If XCoordinate < 0 And YCoordinate > 0 Then Angle = Angle + 4 * Atn(1)
   End If
   Angle = Angle + Theta
   XCoordinate = Radius * Cos(Angle)
   YCoordinate = Radius * Sin(Angle)
End Sub



Sub GenerateNodesAndElements()
'Generate the node coordinates and the element connectivity for the scissor mechanism

   Dim BarRadius As Double
   Dim BarLength As Double
   Dim WallThickness As Double
   Dim ScissorAngle As Double
   Dim ElementsPerHalfBar As Integer
   Dim NodesPerBar As Integer
   Dim ElementLength As Double
   Dim NumberOfUnits As Integer
   Dim K As Double
   Dim UnitHeight As Double
   Dim Phi As Double
```

```
    Dim BaseDistance As Double
    Dim BaseHeight As Double

    Dim FirstUprightNode As Long

    Dim CurNode As Long, CurElement As Long
    Dim RepeatUnit As Integer

    Dim NumElements As Long
    Dim NumNodes As Long

    Dim I As Integer

    Dim MySheet As Object

'Read the parameters of the scissor truss
'Set MySheet = ActiveWorkbook(Worksheets("Parameters"))
With ActiveSheet
    BarRadius = .Cells(1, 2)
    WallThickness = .Cells(2, 2)
    BarLength = .Cells(3, 2)
    ScissorAngle = .Cells(4, 2) * Atn(1) / 45   'Convert to radians
    ElementsPerHalfBar = .Cells(5, 2)
    NumberOfUnits = .Cells(6, 2)
    K = .Cells(7, 2)
End With

'Calculate the unit geometry
UnitHeight = BarLength * Sin(ScissorAngle)
Dim Delta As Double
Delta = (1 - 2 * K) * BarLength * Cos(ScissorAngle)
Phi = Atn(Delta / UnitHeight)

'Set up the initial Hinge Points
InnerHinges(0, 1) = 0   'set x coordinate of inner hinge 0 to 0
InnerHinges(0, 2) = 0   'set y coordinate of inner hinge 0 to 0
OuterHinges(0, 1) = 0   'set x coordinate of outer hinge 0 to 0
OuterHinges(0, 2) = BarLength * Sin(ScissorAngle) / Cos(Phi) 'set y coordinate to starting coordinate

'Set up the hinge points for each unit
Dim TrussUnit As Long
For TrussUnit = 1 To NumberOfUnits
```

```
   InnerHinges(TrussUnit, 1) = InnerHinges(TrussUnit - 1, 1) + 2 * K * BarLength * Cos(ScissorAngle) * Cos((2 * TrussUnit -
1) * Phi)
   InnerHinges(TrussUnit, 2) = InnerHinges(TrussUnit - 1, 2) - 2 * K * BarLength * Cos(ScissorAngle) * Sin((2 * TrussUnit -
1) * Phi)
   OuterHinges(TrussUnit, 1) = OuterHinges(TrussUnit - 1, 1) + 2 * (1 - K) * BarLength * Cos(ScissorAngle) * Cos((2 *
TrussUnit - 1) * Phi)
   OuterHinges(TrussUnit, 2) = OuterHinges(TrussUnit - 1, 2) - 2 * (1 - K) * BarLength * Cos(ScissorAngle) * Sin((2 *
TrussUnit - 1) * Phi)
   CenterHinges(TrussUnit, 1) = InnerHinges(TrussUnit - 1, 1) + K * (OuterHinges(TrussUnit, 1) - InnerHinges(TrussUnit - 1,
1))
   CenterHinges(TrussUnit, 2) = InnerHinges(TrussUnit - 1, 2) + K * (OuterHinges(TrussUnit, 2) - InnerHinges(TrussUnit - 1,
2))
   Debug.Print InnerHinges(TrussUnit, 1), InnerHinges(TrussUnit, 2), OuterHinges(TrussUnit, 1), OuterHinges(TrussUnit,
2)
Next TrussUnit

'Find the rotation needed for the truss
Dim Alpha As Double
Alpha = Atn(InnerHinges(NumberOfUnits, 2) / InnerHinges(NumberOfUnits, 1))

'Rotate the Hinge Points to the Level Position

Call RotatePoint(OuterHinges(0, 1), OuterHinges(0, 2), -Alpha)
For TrussUnit = 1 To NumberOfUnits
   Call RotatePoint(OuterHinges(TrussUnit, 1), OuterHinges(TrussUnit, 2), -Alpha)
   Call RotatePoint(InnerHinges(TrussUnit, 1), InnerHinges(TrussUnit, 2), -Alpha)
   Call RotatePoint(CenterHinges(TrussUnit, 1), CenterHinges(TrussUnit, 2), -Alpha)
Next TrussUnit


'Now set up to create the enodes and elements
NodesPerBar = 2 * ElementsPerHalfBar + 1
CurNode = 1
CurElement = 1

' Do the primary bars for each unit
For RepeatUnit = 1 To NumberOfUnits
   'Do the front bar (angled up)
   Call SaveBar(InnerHinges(RepeatUnit - 1, 1), InnerHinges(RepeatUnit - 1, 2), _
               OuterHinges(RepeatUnit, 1), OuterHinges(RepeatUnit, 2), BarRadius, K, _
               CurNode, CurElement, ElementsPerHalfBar)
   'Do the back bar (angled down)
   Call SaveBar(OuterHinges(RepeatUnit - 1, 1), OuterHinges(RepeatUnit - 1, 2), _
               InnerHinges(RepeatUnit, 1), InnerHinges(RepeatUnit, 2), -BarRadius, 1 - K, _
```

```
                    CurNode, CurElement, ElementsPerHalfBar)
Next RepeatUnit

'Do the uprights
FirstUprightNode = CurNode
Call SaveNode(CurNode, InnerHinges(0, 1), InnerHinges(0, 2), 0)
CurNode = CurNode + 1
Call SaveNode(CurNode, OuterHinges(0, 1), OuterHinges(0, 2), 0)
Call SaveElement(CurElement, CurNode - 1, CurNode)
CurNode = CurNode + 1
CurElement = CurElement + 1
Call SaveNode(CurNode, InnerHinges(NumberOfUnits, 1), InnerHinges(NumberOfUnits, 2), 0)
CurNode = CurNode + 1
Call SaveNode(CurNode, OuterHinges(NumberOfUnits, 1), OuterHinges(NumberOfUnits, 2), 0)
Call SaveElement(CurElement, CurNode - 1, CurNode)
CurNode = CurNode + 1
CurElement = CurElement + 1

'Make the hinges for each unit
For RepeatUnit = 1 To NumberOfUnits
  Debug.Print RepeatUnit, NumberOfUnits, NodesPerBar, ElementsPerBar
  Call SaveElement(CurElement, _
    (RepeatUnit - 1) * 2 * NodesPerBar + ElementsPerHalfBar + 1, _
    (RepeatUnit - 1) * 2 * NodesPerBar + NodesPerBar + ElementsPerHalfBar + 1)
  CurElement = CurElement + 1
  If RepeatUnit < NumberOfUnits Then
   'Put Hinges between units
    Call SaveElement(CurElement, _
      (RepeatUnit - 1) * 2 * NodesPerBar + NodesPerBar, _
      RepeatUnit * 2 * NodesPerBar + NodesPerBar + 1)
    CurElement = CurElement + 1
    Call SaveElement(CurElement, _
      RepeatUnit * 2 * NodesPerBar, _
      RepeatUnit * 2 * NodesPerBar + 1)
    CurElement = CurElement + 1
  End If
Next RepeatUnit

'Make the hinges for the uprights

Call SaveElement(CurElement, 1, FirstUprightNode)
CurElement = CurElement + 1
Call SaveElement(CurElement, NodesPerBar + 1, FirstUprightNode + 1)
CurElement = CurElement + 1
```

```
Call SaveElement(CurElement, NodesPerBar * NumberOfUnits * 2, FirstUprightNode + 2)
CurElement = CurElement + 1
Call SaveElement(CurElement, NodesPerBar * NumberOfUnits * 2 - NodesPerBar, FirstUprightNode + 3)

NumElements = CurElement
NumNodes = CurNode - 1


'Write the node file
Dim fs As Object, OutFile As Object

Open "z88structure.txt" For Output As #99

Print #99, 3, NumNodes, NumElements, 6 * NumNodes, "0 # AURORA_V2"

For I = 1 To NumNodes
   Print #99, I, 6, XCoords(I), YCoords(I), ZCoords(I)
Next I
For I = 1 To NumElements
   Print #99, I, 2
   Print #99, Elements(I, 1), Elements(I, 2)
Next I

Close #99

End Sub


Sub SaveBar(StartX As Double, StartY As Double, EndX As Double, EndY As Double, Z As Double, K As Double, _
            CurNode As Long, CurElement As Long, ElPerHalfBar As Integer)

   'Save the nodes and elements necessary for a bar going from StartX, StartY, Z to EndX, EndY, Z
   'K is the offset of the center point (the center point is at a fraction K from the start to the end
   'CurNode and CurElement will be updated by this sub
   'ElPerHalfBar is the number of elements per half bar (i.e. the number of elements on each side
   '   of the center hinge point
   Dim BaseX As Double, BaseY As Double
   BaseX = StartX
   BaseY = StartY
   SpanX = EndX - StartX
   SpanY = EndY - StartY
   Call SaveNode(CurNode, BaseX, BaseY, Z)
   CurNode = CurNode + 1
   'First Half of Bar
```

```
   For I = 1 To ElPerHalfBar
      Dim MyX As Double, MyY As Double
      MyX = BaseX + K * SpanX * I / ElPerHalfBar
      MyY = BaseY + K * SpanY * I / ElPerHalfBar

      Call SaveNode(CurNode, MyX, MyY, Z)
      Call SaveElement(CurElement, CurNode - 1, CurNode)
      CurNode = CurNode + 1
      CurElement = CurElement + 1
   Next I
   BaseX = BaseX + K * SpanX
   BaseY = BaseY + K * SpanY
   'Second Half of Bar
   For I = 1 To ElPerHalfBar
      Call SaveNode(CurNode, BaseX + (1 - K) * SpanX * I / ElPerHalfBar, BaseY + (1 - K) * SpanY * I / ElPerHalfBar, Z)
      Call SaveElement(CurElement, CurNode - 1, CurNode)
      CurNode = CurNode + 1
      CurElement = CurElement + 1
   Next I
End Sub

Sub SaveNode(Node As Long, Xcord As Double, Ycord As Double, Zcord As Double)
   XCoords(Node) = Xcord
   YCoords(Node) = Ycord
   ZCoords(Node) = Zcord
End Sub
```

Appendix E: Safety Information

Hazard Analysis

Hazard	Cause	Effect	RPC	Countermeasures	RPC After
Bridge unstable and flips over	Insufficient footing, tangling of cables, swaying of bridge, attachment slips on surface	User falls 8 feet or higher from bridge	1	Wide attachment on sides Functional testing of full scale prototype with offset load. 350 lbs placed on one side rail of bridge to verify the bridge footing maintained 100% contact with the ground.	3
Bridge Collapse	Structural failure of major component (rung, beam, cable, joint), attachment slips on surface	User falls 8 feet or higher from bridge	1	Dyanmic load tests on full scale prototype Static load test on full scale prototype to 2 times required load, add grip surface to attachment	2
User loses balance and falls of bridge	Insufficient footing or bouncy bridge or slips on rungs	User falls from bridge or onto bridge	1	Add a rope along sides to help the user balance, add grip surface to rungs	2
User falls through bridge	Fabric tears	User falls from bridge or onto bridge	1	Static load test on full scale prototype to 2 times required load	2

Appendix F: Selection and verification of scissor bridge concept

Product Development Process

Crossing canals, rivers, rooftops and any other type of gap has been an ongoing problem for the Air Force and other military groups. This problem clearly needs a better solution and forms the basis of the opportunity development stage for this project. This project began in the opportunity development stage and will end somewhere in the middle of the design integration stage. Since our team has spent this semester mostly in the opportunity and concept development stages, these two stages will be expounded upon in the following two sections.

Opportunity Development

After compiling a list of customer needs (see appendix A), a product specification sheet was created to document the performance criteria for the final product. Table 1 contains a list of performance characteristics obtained from conversations with and documents provided by the Air Force. The “Need No.” in the first column of the table references the numbers in the customer needs (Appendix A) that the metric correlates to. For example, the “Span” metric correlates to Customer Need #1, which reads “The device facilitates crossing/climbing an obstacle of 20 feet or longer.” The “Import.” column shows a number between 1 and 5 which is the importance level that the team assigned to the characteristic. The rating scales are explained in detail in Appendix B. Several of the most important metrics are the span, volume, weight and load capacity of the device. The marginal value is the lowest acceptable value for the metric and the ideal value is the ultimate goal for the metric. The units for both of these values are shown in the “Units” column.

Table 2- Required Performance Characteristics

Need No.	Metric	Import.	Units	Marginal Value	Ideal Value
1	Span	5	ft	5	20
2	Volume	5	ft^3	5	1
3	Weight	5	lbs	20	5
4, 6, 16	Load Capacity	5	lbs	350	350
5,39	Ease of crossing with gear and/or injured person	3	Scale #4	2	5
5	Physical exertion required to unpack, use, and pack	4	Scale #3	2	5
8, 9, 13	Number of gaps crossed by team of four in competition	5	#	5	Unlimited
5, 7, 31	Training required	4	minutes	10	3
5, 7, 11, 33	Personnel required to set up	4	#	4	1
5, 10	# of free limbs while using	4	#	1	2
5, 7, 11, 12, 13, 32, 38	Time to use, set up, and pack (with 4 people)	5	minutes	6	4
14	Can be used with tactical gloves	3	Scale #4	3	5
7, 15, 34	Field repairable	4	Scale #4	3	5
10, 16	Safety	5	Scale #5	3	5

6,16, 17, 30	Dynamic Load Capacity	4	Safety Factor	1.5	3
5, 18	Can be used with limited visibility (smoke, darkness, etc.)	4	Scale #4	2	3
19, 20	Minimum temperature	4	F	-30	-130
19, 20	Maximum temperature	4	F	115	134
5, 19	Can be used in heavy precipitation (wind, rain, and snow)	4	Scale #4	3	5
1, 21, 22, 26, 27	Cross canals/streams, rooftops, minefields	5	Scale #4	3	5
1, 23, 24, 25	Cross glacier crevasses, rock formations, unstable/collapsed structures, walls	3	Scale #4	3	5
5, 7, 15, 34	Tools required	4	#	5	0
7, 28, 35, 36	Aesthetic	4	Scale #6	3	5
28, 29, 35, 36	Appeal in PR campaign	4	Scale #6	3	5
28, 29, 35, 36	Operator Excitement	4	Scale #6	3	5
18, 37	Can be used when depth perception is compromised by NVG's	3	Scale #4	3	5

Concept Development

The team started the concept development stage by holding a brainstorming session. Originally, the brainstorming session was a decomposition for several different aspects of the product. It quickly became apparent, however, that all the components depended on the method of travel across a gap. Thus, the remainder of the concept development stage focused solely on traveling while ignoring the attachment, walkway, and actuation. The session resulted in the creation of fifty unique concepts for travel. After evaluating the fluency, variety, and originality of the candidate set, the team determined to begin eliminating the concepts.

First, using intuition-based judgment, the fifty ideas were then narrowed down to ten. In order to eliminate additional concepts, a screening matrix was created (see Table 2). The screening matrix allowed a quantitative evaluation of the concepts and helped determine which designs would best meet the product specifications.

Table 3- Screening Matrix

Category	Weight	Suspension Bridge Min 2	Suspension Bridge Max3	Tripod Swing/Pulley Min 4	Tripod Swing/Pulley Max5	Scissor Bridge Min 16	Scissor Bridge Max17
Volume	5	4	5	3	5	4	5
Weight	5	4	5	3	5	2	4
Load Capacity	5	2	5	2	5	1	3
Time to use, set up, pack	5	1	3	1	3	1	3
Safety	5	3	5	3	5	1	3
Cross canals/streams, rooftops, minefields, compound walls	5	1	4	3	5	1	3
Physical exertion required to unpack, use, and pack	4	1	3	1	2	2	4
Training required*	4	1	3	1	3	3	5
Personnel required to set up*	4	2	4	2	4	4	5
# of free limbs while using	4	2	4	1	2	3	5
Field repairable	4	1	3	1	3	1	5
Dynamic Load Capacity	4	1	4	2	5	1	3
Can be used with limited visibility (smoke, darkness, etc.)	4	3	5	3	5	1	3
Use in extreme temperatures	4	2	5	2	4	1	3
Can be used in heavy precipitation (wind, rain, and snow)	4	3	5	2	5	2	3
Tools required*	4	2	5	1	5	1	5
Aesthetic	4	3	5	2	5	3	5
Appeal in PR campaign	4	3	5	1	4	2	5
Operator Excitement	4	3	5	4	5	3	4
Can be used with NVG's	3	3	4	4	5	3	5
Can be used with tactical gloves	3	3	5	2	5	3	5
Cross glacier crevasses, rock formations, unstable/collapsed structures	3	3	5	2	5	2	3
Total		210	401	191	393	182	364

Importance Rating
1. Much worse than aluminum ladder
2. A little worse than aluminum ladder
3. Same as aluminum ladder
4. A little better than aluminum ladder
5. Much better than aluminum ladder

Plan
Make Prototype, do some more research and find ways to improve volume, weight, load capacity.

Questions to answer
How would you tension the poles? Are telescoping poles feasible? How much tension is required? What is the set up time? Can it be used on walls/ changes in elevation?

In Table 2, the category column corresponds to the product specifications and the weight was based on the importance rating for each category. Each of our concepts were given a minimum value and a maximum value based on an estimated worst and best case scenarios in comparison with an aluminum ladder (the current method). The screening matrix showed that each concept could potentially be better than an aluminum ladder. To proceed with the decision-making process, a plan of learning more details of each concept was formed.

The three final concepts were the scissor bridge, the tripod, and the suspension bridge. See Figures 1-3 for pictures of these concepts. To evaluate these remaining three concepts, a simple prototype was built for each one. A prototype of the tripod made it clear that this concept is not robust nor is it a user friendly design. The suspension bridge and scissor bridge both seemed to have structural integrity, so it was more difficult to eliminate one of these concepts.

Figure v- Suspension Bridge Concept

Figure vi- Scissor Bridge Concept

Figure vii - Tripod Swing/Pulley

In a design review, the capstone professors preferred the suspension bridge while more students from other capstone teams preferred the scissor bridge. However, a design review with the AFRL made it clear that the scissor bridge was more likely to win at the competition. They suggested that the time it takes to set up and retrieve the device is very important and pointed out that the scissor bridge concept exhibited potential to have a very short setup and retrieval time. They were extremely excited about the scissor bridge and were impressed with the design as well as the amount of progress the team had made on the project.

The approval from the AFRL along with the potential of the scissor bridge to meet the product specifications was considered the verification of the concept development stage.

2014 AFRL Design Challenge Report
Brigham Young University
Heavy Lifters

<u>Team Members</u>
Taylor Eatough
Ethan Grabau
Nathan Harris
Jakob Later
Trey Nelson
Matthew Palmer

<u>Team Coach</u>
Van Rogers

By signing, we indicate that we have reviewed this report and approve of its submission.

Heavy Lifters

____
Taylor Eatough

____
Ethan Grabau

____
Nathan Harris

____
Jakob Later

____
Trey Nelson

____
Matthew Palmer

____
Van Rogers (Coach)

Executive Summary

The Air Force Research Laboratory (AFRL) is a scientific research organization that does R&D work to improve the technology and war fighting capabilities of the United States. In April 2014, the AFRL is sponsoring an engineering design competition between 19 universities and service academies. Our team has been selected to represent BYU in this competition. This report will describe the problem definition, the design solution, and the process we used to develop our solution.

Over the course of the school year, the team has been tasked to develop a device that can be deployed quickly to aid Air Force Pararescue Jumpers (PJs) in rescue and recovery of individuals or items trapped by heavy vehicles, aircraft, structures, or objects. One primary device has been developed to meet this need and a secondary device, though not required by the competition, was developed to meet an end user need not fulfilled by the primary device.

The primary device is an air bag capable of heavy lifting which is operated using compressed air and a regulator. In developing the air bag, the design was divided into the components of material, air hoses and attachments, regulator, and air tank. Each aspect was researched extensively and put through a process of concept selection and testing which is detailed in the report.

The secondary device, dubbed the “Ninja”, is a mechanism placed underneath the object being lifted which rises with the object as the air bag inflates. Its purpose is to provide safe shoring to avoid injury should the airbag fail. It is operated by placing it underneath the object to be lifted and releasing the ratcheting mechanism. It will then automatically rise with the lifted object and lock into place when weight is placed upon it. In developing the Ninja, the design was divided into the components of its beams, pins, top and bottom plates, and ratcheting mechanisms. Each aspect was researched, put through concept selection, modeling, and testing which is detailed in the report.

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List of Table and Figures

Project Summary and Results

Project Introduction

The Air Force Research Laboratory (AFRL) is a scientific research organization that does R&D work to improve the technology and war fighting capabilities of the United States. In April 2014, the AFRL is sponsoring an engineering design competition between 19 universities and service academies.

Our team has been selected to represent BYU in this competition. This report will describe the problem definition, the design solution, and the process we used to develop our solution.

Scope

The competition task is to design and build a device that is capable of lifting building structures, aircraft, and armored vehicles between 45,000 and 50,000 lbs on uneven and sloping, wet, slippery, muddy, rocky, sandy (or a combination thereof) terrain to extricate equipment and personnel in situations where the scene is actively on fire or burnt and has exposed sharp metallic surfaces and oils and lubricants on the ground. According to the AFRL, "the current constraint is the inability to make kits available small enough in volume and weight; SWaP (Size, Weight, and Power) enhancements are a must from the current version. A successful rescue is a controlled operation that is immediately deployed to prevent crushing or further damage to equipment and personnel. The mindset is "lift an inch, shore an inch" for stability of heavy load lifting. The kit should be rapidly repackaged and redeployed during secondary phases of military operations and require little to no training to use.

At the competition, each team will demonstrate the operation of their lifting device and be scored on a variety of criteria, including:

- Time to complete lift(s) (20 points)
- Size (when broken down and packed) (20 points)
- Solution weight (all supporting equipment) (20 points)
- Lift Capacity (20 points)
- Reusable (10 points)
- Ease of operation (10 points)
- Usability (10 points)
- Innovation & creativity (10 points)
- Presentation (10 points)
- Judges' bonus (10 points)

The final score awarded will be determined by a panel of 5-7 engineers and operators. The team is scheduled to present the lifting device at the competition on Thursday April 17, 2014 at Arnold Air Force Base in Manchester, Tennessee.

Customer Needs and Requirements

The pararescue jumpers (PJs) are some of the most highly skilled special operators in the United States military. Originally, PJs were specifically trained to rescue a pilot who has been shot down behind enemy lines. Despite their extremely specialized role, PJs have an extremely valuable skill set that has been applied to a large variety of military and non-military situations.

Many PJ missions are conducted in combat situations where speed and mobility are key factors in not only mission success, but in staying alive. PJs will often enter a situation by means of airlift which stipulates that whatever equipment is necessary to accomplish in that mission has to be strapped to their backs as they jump out of an airplane or helicopter. When entering the field, PJs rarely know all the details beforehand. They must adapt as the situation demands. The scenarios they encounter are constantly changing at a rapid pace. This unique work environment drives the parameters and objectives of this product development.

Often, large armored vehicles, giant pieces of buildings, or other structures need to be lifted in order to recover a victim or vital piece of equipment, or sometimes a vehicle simply needs to get unstuck from the mud. There are already such devices available to perform these tasks, but the PJs need an improved device. The current system employed by the PJs (see Figure 1) includes two medium-pressure, cylindrical air bags. Each bag has a 10,000 lbs lifting capacity for a total lifting capacity of 20,000 lbs. In order to ensure that the lifted object is safe to go under, it is also stabilized using either sandbags that are filled on-site or anything else that can be found nearby.

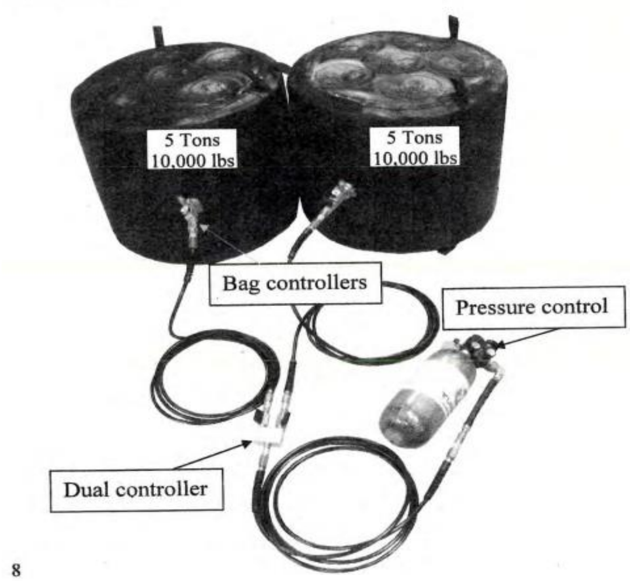

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Figure 1: Current Pararescue Airbag System

The total system weighs roughly 40 lbs and has an operating pressure of 27 psi. Each bag is 22" in diameter and has a lift height of 20"(see Figure 1). This pneumatic system allows for versatility in what types of objects the PJs can lift as well as what types of terrains can be lifted on.

The motivation for the new product development is to improve upon the current system's capabilities (though by no means is this limited to a similar pneumatic design). The objectives for the competition are:

- Lift building structures, aircraft, and armored vehicles
- Lift on uneven and up to sloping, wet, slippery, muddy, rocky, sandy (or a combination of) terrain
- Lift where the scene is actively on fire or burnt and have exposed sharp metallic surfaces and oils and lubricants on the ground.
- The kit should be rapidly repackaged and redeployed during secondary phases of military operations and require little to no training to use
- Dimensions 12” x 12” x 6” (Threshold), 6” x 6” x 2” (Objective)
- Weight: 30 lbs. (Threshold), less than 10 lbs. (Objective)
- Capable of being carried by a single person.
- Lift Capacity: 45k lbs. 18-20” (Threshold), 55k lbs. 20-25” (Objective)

In addition to the above requirements, the system should have the following characteristics:

- Capable of being set up and employed rapidly
- Standoff controllable lift capability to increase/decrease load height
- Low operating pressure (if using a pneumatic solution)
- Operational in varying extreme cold/hot temperatures
- Operational at high altitude (minimum 10,000 ft MSL)
- Operational when exposed to various hazards such as aircraft/vehicle wreckage
- Must be able to withstand puncture/fire hazards during operation

To supplement these design parameters, PJs have been contacted and interviewed in order to get customer statements that help clarify the market desires. We discovered that the actual end user has specific requirements which are slightly different than the competition requirements. These were gathered, evaluated, and summarized in a requirements matrix (see **Appendix F**). The most critical requirements for each component are detailed in the report below. Development budget and milestones were created and summarized in a project contract that can be seen in **Appendix F** as well. These parameters and objectives, as well as a clear understanding of what the end user desires, has driven the development of this new product.

Airbag Selection and Performance

After going through the processes of concept generation and selection (see **Appendix D**), it was determined that an improved airbag system would accomplish the competition objectives and end user requirements.

As guidelines for the competition, the AFRL issued certain standards of performance. The AFRL has made it clear that they do not expect every standard to be met, and they understand that compromises will have to be made. According to our research and end user validation, we made tradeoffs that were deemed most beneficial in the creation of a desirable product. **Table 1** provides a summary of the Airbag's performance directly compared to the AFRL Threshold Standards and the current system's performance. These were validated through extensive testing which can be seen in **Appendix I**.

Table 1: Airbag Performance Matrix

Requirement	AFRL Standard	Current System	Goal	Team System	Validation Method	Goal Fulfilled
Lift Capacity	45-55k lbs	20,000 Lbs.	51,200 Lbs	51,200 Lbs	See Appendix I	Yes
System Size	12" x 12" x 6"	Fits in a Duffle Bag/Backpack	Fits in a Duffle Bag/Backpack	Fits in a Duffle Bag/Backpack	Verification in bag	Yes
System Weight	30 Lbs	42 Lbs	<30 Lbs	41 Lbs	Dig. Scale	No
# of Personnel to Operate	1	1	1	1	Testing (Appen. I)	Yes
Lifts Height	20" - 24"	18"-20"	20"	24"	See above	Yes
Operation Time	N/A	2-3 Min	<3 Min	<3 Min	See above	Yes

Airbag Design

The final airbag, as seen to the right in **Figure 2,** was created through a design selection process that was a complicated balancing of many different factors; geometry, overall volume, lifting surface area, material strength, material flexibility, operating pressure and portability all had to be considered.

Figure 2: Completed Airbag capable of lifting 25,000 lbs

A cylinder is the best geometry for a pressure vessel to equally apply loading to the material of the bag in order to reduce hoop stress. However, we found several advantages of a cuboid bag design that made it the optimal geometry for this heavy lifting application. The first is its ratio of usable area to storage area. The way we plan to store the bag is to simply roll it up and place it in the PJ's backpack. If you roll up a circle with a diameter equal to the side length of a given square, once rolled up, the two shapes will take up essentially the same amount of usable space. Once unfolded though, the square will have roughly a 27% larger surface area, which will allow for greater lift capacity. This greater surface area and geometry choice would also allow for better stability, one of the critical requirements of the PJ. This was validated (as seen in **Appendix J**) with testing of current airbags from vendors, interviews with PJs, real demonstrations with firefighters, and extensive prototyping and testing (as seen in **Appendix I**).

Volume, the area of the lift surface and operating pressure were all closely linked in the design process. Using a simple spreadsheet (**Appendix H**), we concluded that a 32" x 32" x 20" cube shape gave us the most optimized results. This optimization was constrained by our air tank volume, the needed lifting capability, and the strength of the material used (which restricted our overall achievable operating pressure).

Material strength and flexibility were two more interdependent variables. Many of the current airbags on the market that have the lift capacity that we need are made of a thick vulcanized rubber. This allows for high lift weights, but greatly hinders portability. We picked a 32 oz/yrd^2 urethane coated polyester. The material is abrasion resistant and strong, yet it is easily folded and rolled which makes for easy porting (see **Appendix A**). This material is not strong enough on its own to withstand the needed operating pressure to achieve our target lift weight, so we designed a system of external straps that would add extra strength to the bag, without compromising its portability. The manufacturing process for these straps can be seen in **Appendix A** under the Airbag Design Package. The straps did add several pounds of extra weight to the bag, but their effects on rolling and packing were negligible. The webbing is 2" polyester webbing with a 6,000 lbs tensile strength. We added as few as straps as were possible that would still sufficiently reinforce the bag in order to reach the desired burst pressure (see **Appendix G** for the handwritten strap calculations).

Air Cylinder and Regulators

For the system's air supply, the decision was based on the air requirements for the airbags. A 'Scott Safety' brand carbon wrapped SCBA cylinder was selected. This is a cylinder that is typically used for providing breathable air to firefighters. The cylinder weighs 9.75 lbs empty, 14.61 lbs full, and has a capacity of 65 cubic feet at 4500 psi. The standard valve that comes with the cylinder has been replaced with a model T-100 regulator/shut off valve by Turanair Systems.

The air cylinder was chosen because a supply of at least 60 cubic feet of air is needed to fully inflate both bags. This was one of the most lightweight options on the market that met that requirement. The standard valve was removed from the tank in order to allow for the valve and regulator to be integrated into one unit for simplicity, ease of use, and to save on size and weight of the overall lift kit. To operate, the user simply has to connect the hose to the regulator and open the valve. The cylinder can be refilled anywhere SCBA or paintball style cylinders are filled. Both the regulator and the cylinder have been proven in harsh environments. The regulator will also be familiar to many PJs because it is currently in use on many of their lifting kits.

Control System

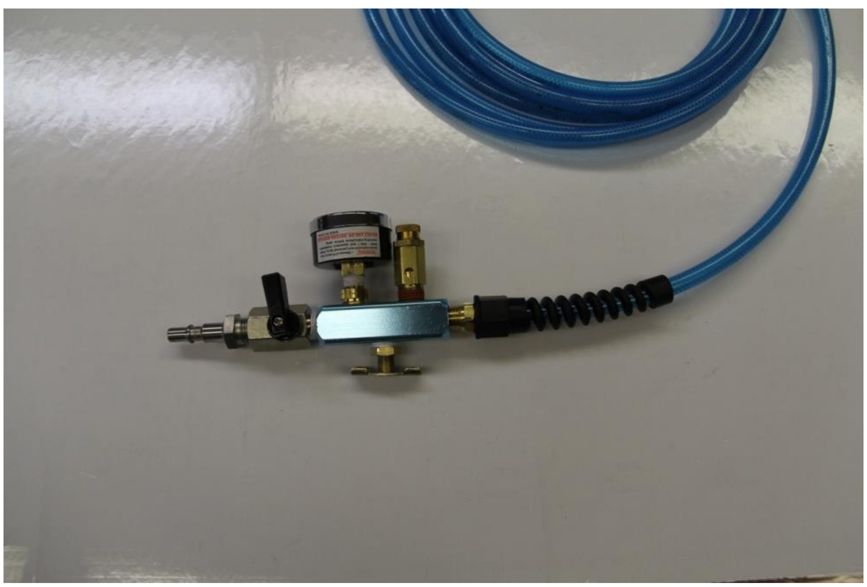


Figure 3: Control System

The control system (see **Figure 3**) of the lift kit is what allows the airbag to be operated quickly and accurately from a distance. It allows the PJs to direct the speed and height of the lift. Many off-the-shelf rescue airbag systems offer some form of control system that performs these functions, however, in order to optimize the system for the PJs, the team chose to develop a custom system.

The whole system was designed to be simple, lightweight, and require a minimum number of parts and connections. The system is centered on a 15-foot long ¼ inch polyurethane hose. The hose uses push button quick couplings at the ends. One side connects directly to the airbag while the other side of the hose connects to the air tank and also has the control components. As seen in **Figure 3**, the control has an inline ball valve that is used to control the inflation of the airbag. It also has a valve that can be used deflate the airbag and control the lowering of the load. The system implements two safety features. The first is an inline low profile pressure gauge used to monitor the pressure in the airbag. The second is an overpressure relief valve that is set to release air when the system begins to exceed the safe operating pressure of 27 psi. This prevents the airbag from being over inflated and possibly causing a catastrophic failure such as an explosion. The control system also includes an optional splitter that allows for the simultaneous operation of two airbags. All the components used in the control system were selected based on reliability and minimal weight. To see complete instructions on the assembly and use of the airbag kit, see **Appendix K**.

Auto-Shore Design

Shoring is a major safety concern for the PJs as they use their lifting system. Shoring provides a means that should the primary lifting system fail or need to be used to lift elsewhere, the object being lifted has something to settle on that keeps the object at its height when the primary lift stopped. The current methods used by PJs involve filling sand bags on-scene for shoring or using whatever can be acquired from the surrounding environment. After interviews with PJs and going through concept generation and selection (see **Appendix D**), the team designed and built what will be referred to hereafter in the report as the "Ninja". The Ninja (see **Figure 4**) was built purely to satisfy end user needs and was not part of the competition's requirements.

Figure 4: The Ninja Auto-Shore Device

Performance

The Ninja is designed from lightweight 6061 aluminum with grade 9 bolts and pins to hold its components together. It is designed to hold 25,000 lbs at a safety factor of 2. Two ninjas combined will shore a total weight of 50,000 lbs. To use the Ninja, simply place it underneath the load you wish to provide shoring for, and release its latch on the end. The Ninja automatically rises as you lift the load to provide shoring up to 20 inches in height. When finished lifting, simply raise the load with you main lift system, and pull the cord on the end of the Ninja to extract if from underneath the load. Collapse and latch it for safe storage and use. **Table 2** below shows a comparison of the teams' goals in developing the Ninja and the fulfillment of those goals. Calculations and validation of these data are provided in **Appendix C**.

Table 2: Autoshore Ninja Performance Matrix

Requirement	End User Standard	Current System	Goal	Team System	Validation Method	Goal Fulfilled
Shoring Capacity	45-55k lbs	None	50k lbs	50k lbs	Instron Testing (See Appendix B)	Yes
System Weight	20-30 lbs	None	30 lbs	84 lbs	Digital Scale	No
# of Personnel to Operate	1	None	1	1	Testing (Appendix B)	Yes
Shore Height	20"	None	20"	20"	Measuring Tape	Yes
Operation Time	<30 seconds	None	<30 seconds	<30 seconds	Testing (Appendix B)	Yes

Ratcheting Mechanism

The design of the ratcheting mechanism has been optimized to allow upward movement of the Ninja while maintaining stability and security. It has been designed to automatically adjust to surfaces at different angles and shifting weight. It is capable of being placed under a vehicle with at least 6 inches of clearance and has been designed to hold 25,000 lbs. with a safety factor of 2 . When fully extended the Ninja can support a load at 20 inches. The ratcheting mechanism does not add any extra weight or size to the shoring device.

The ratchet is made from 6061 aluminum bars and grade 9 steel bolts. The base beams have holes milled out to create ratcheting teeth (see **Figure 5**). An annealed steel bar passes through the ratchet hole and is bolted to the support beam. The load is passed through the leg, into the bolt, and onto the base through pure shear. The bolts are grade 9 steel and are able to withstand the shear forces being applied to it by the downward force. The ratcheting mechanism is activated by springs with a total tensile force of 250 lbs to overcome the weight and leverage of the ninja at its lowest height. The springs constantly pull the beams to the next highest position. From results from Instron testing, it was decided by the team that two ratcheting mechanisms, one on top and one on bottom, would be required to maintain the static load and force distribution; having two ratcheting mechanisms will allow the Ninja to adjust to different slopes and angles.

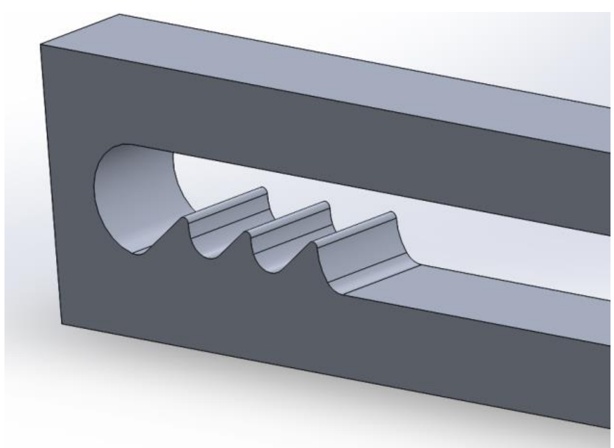


Figure 5: Auto-Shore Ratcheting Teeth

Plate

A plate is bolted onto the top of the Ninja to link the two sets of legs; this causes the legs to rise at the same rate and to distribute the load evenly. A ½" 6061 aluminum plate was selected to take the 25000 lb capacity bending loads placed on the top of the ninja. Holes have been drilled in the top to reduce weight.

Spring

The spring is hooked into the sliding bar of the ratchet and to the far side of the Ninja. When fully extended the springs apply the 250 lbs. of required force to cause the Ninja to rise.

Bolts

The Ninja has bolts in key locations to hold different components together, allow movement of those components where needed and to transfer the load between components. Large shear loads pass through the bolts and cross bars in the ratchet; because of this grade 9- ½" bolts and bar stock was selected to withstand these loads. In order to hold the two legs in symmetry when lifting a ⅜" bolt was placed in the middle of the two beams to link them systematically.

Beams

The beams that form the scissor portion of the Ninja have been carefully selected based upon extensive analysis, modeling, and experimental evidence. The final design selected for the detailed design of the beam can be seen in **Figure 6.**

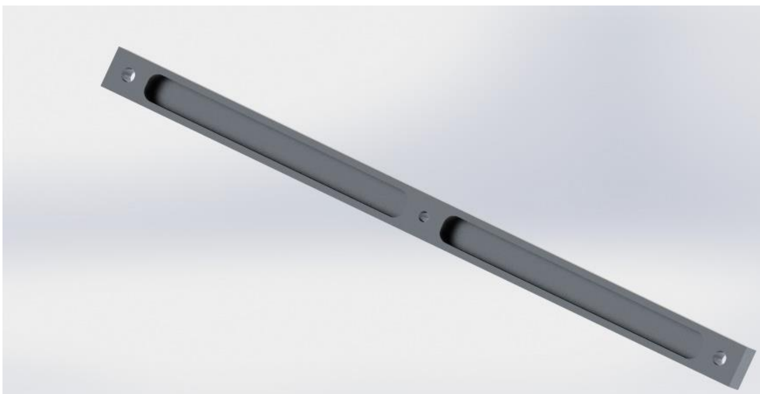


Figure 6: Beam Detail

The beam material is 6061 Aluminum. This was selected because of its high strength-to-weight ratio, in addition to its manufacturability. Other materials considerations and experimental and analysis evidence can be seen in **Appendix B.**

The final beam geometry is a 1.5" x 1.0" x 25.5" 6061 aluminum bar. There is a channel milled into the bar stock through 23 inches of the beam in order to reduce weight and maximize the weight-buckling failure ratio. During analysis and testing, it was determined that this was the most significant factor for failure on a long thin beam with heavy loading. In order to arrive at this final geometry, an excel spreadsheet with equations embedded was created to compare various beam geometries and the forces they would encounter in buckling in the x-direction, y-direction, and compressive shear. That spreadsheet can be seen in **Appendix C.** As can be seen highlighted in this spreadsheet, the channel beam is the geometry that produces the lightest weight beam that has a minimum buckling force higher than the compressive force applied to the beam. Also, since the compressive force used for these calculations is already two times higher than the actual applied force, it follows that these conservative estimates give the beam a safety factor greater than 2 in buckling. It can also be seen that the beam has a safety factor of over 10 in shear compression. This is why 6061 aluminum was chosen rather than titanium or 7075 aluminum. This material had the most significant cost advantage for its size and weight, and is safe in all possible failure modes.

The specific drawings of this beam can be seen in the **Appendix A, Part Ninja-001.** As can be seen from this drawing, the holes to attach the beam to the ratchet, which are 0.5" diameter, are located 24 inches apart in order to achieve the target lift height of 20” with an angle of less than 50 degrees in order to reduce compressive forces felt on the beam. Also, a 0.25” hole is drilled in the center of the beam in order to connect to ratchet beams together to prevent bending in the beams and also to ensure symmetric motion of the device. The channel is 0.75” deep, leaving only a 0.25” wall thickness along the milled channel in order to reduce weight.

Recommendations

We recommend more extensive testing on the lift bag. When dealing with high pressures, certain safety precautions must be taken which causes tests to take longer, so we primarily conducted hydrostatic testing. It would also help to iterate the airbag design further with a greater budget and more time. Other variations to the airbag geometry could be considered in order to optimize performance. The team also highly recommends research into other materials, especially Vectran or Dyneema, to improve lifting capabilities and decrease weight of the kit; the cost to obtain this material simply did not fit into our budget.

Due to time constraints, more research could be done to improve the weight of the Ninja. The team is confident that our prototype is a successful start to creating a light weight auto-shore device, however additional research could be conducted in alternative material choices. The key issue ran into in the Ninja’s development was trying to use carbon fiber to decrease weight. We were unable to create lightweight fittings and joints to connect the carbon fiber beams to the ratcheting supports. These lessons are detailed in **Appendix B**. The auto-shore could be improved by experimenting with different sizes of carbon fiber beams or making beams with different fiber lay-up patters to optimize the strength capabilities, and finding a better way to interface with aluminum. Also, further research should be conducted in producing a high density plastic ratchet which would greatly reduce the weight of the aluminum ratchet. Similar material-selection changes could be investigated for the top plate in order to decrease the weight of the shoring device.

Conclusions

Our design process has been focused on meeting the specifications of the end user. We have checked this document as team to ensure that it contains all of the vital information for the reproduction and testing of the prototypes we have created. We have also included a DVD with all of our critical documents organized for reuse by our sponsor. We have verified the entire system to ensure that it has fulfilled the critical design requirements, and we have thoroughly validated this system with fire rescuers from the Provo Fire Department and with professional Pararescue Jumpers. By meeting these specifications to the fullest extent possible, the Heavy Lifters have developed a product that will performing extraordinarily well at the competition. Although we do not fulfill all of the AFRL Standard Requirements, we have followed the requirements of the end user and reached or exceeded almost every design requirement. These are outlined once again below in **Table 3**.

Table 3: Comprehensive Performance Matrix

Airbag Performance					
Requirement	**AFRL Standard**	**Current System**	**Goal**	**Team System**	**Goal Fulfilled**
Lift Capacity	45-55k lbs	20,000 Lbs.	51,200 Lbs	51,200 Lbs	Yes
System Size	12" x 12" x 6"	Fits in a Duffle Bag/Backpack	Fits in a Duffle Bag/Backpack	Fits in a Duffle Bag/Backpack	Yes
System Weight	30 Lbs	42 LBS	<30 Lbs	>40Lbs	No
# of Personnel to Operate	1	1	1	1	Yes
Lifts Height	20" - 24"	18"-20"	20"	24"	Yes
Operation Time	N/A	2-3 Min	<3 Min	<3 Min	Yes
Autoshore Performance					
Requirement	**End User Standard**	**Current System**	**Goal**	**Team System**	**Goal Fulfilled**
Shoring Capacity	45-55k lbs	None	50k lbs	50k lbs	Yes
System Weight	20-30 lbs	None	30 lbs	70 lbs	No
# of Personnel to Operate	1	None	1	1	Yes
Shore Height	20”	None	20”	20”	Yes
Operation Time	<30 seconds	None	<30 seconds	<30 seconds	Yes

The team is pleased with many of the final characteristics of the lift kit, and this solution is a great improvement over the system currently in use. The individual components have been tested independently and all function properly even under extreme conditions. Expert opinions, analytical models, FEA models, prototypes, and testing have all have been instrumental in developing the lift kit. The Heavy Lifters believe that the lift kit will excel at the competition in Tennessee.

Competition Update: System Validation

Although extensive validation had been conducted through demonstrations with the Provo Fire Department and phone interviews with PJs, we had not had an opportunity to physically meet with the end user until the AFRL Competition. Due to their specialized role and high demand, all of our efforts to meet with PJs within any distance were frustrated. This interaction was a crucial step in our product development because it gave us an opportunity to receive real validation from hands on interaction of the end user with our product. We flew out to Tennessee for the AFRL Design Challenge, where we met with over 10 retired and active duty Pararescue Jumpers. They interacted with our device, questioned our testing and verification, and actually used our product to conduct a heavy lift scenario.

The lift they performed, as seen to the right in **Figure 7**, was conducted on a Caterpillar D6 Bulldozer which weighed 48,000 lbs. The dozer was positioned on a slight hill with somewhat loose soil. A crane was used to support the load as a safety precaution and it also had a force sensor to read how much of the load the lift kit was lifting with. We were asked to lift one side of the dozer which weighed 26,000 lbs in required lifting force.

Figure 7: Heavy Lift Kit Implementation on D6 Bulldozer

We trained the PJs how to use our system in just a few minutes, and they helped us to implement it in order to lift the load. The autoshore Ninjas were placed on either side of the bulldozer underneath the treads so that they could shore the load as the airbag lifted it. The area underneath the load was too small to insert two bags, so only one bag was used. They placed the bag on a wooden cribbing base they had built in order to get the bag as close as possible to the load. As the bag inflated and lifted the load 4 inches, we realized the base was too small so the part of the bag that was hanging off the side caused the load to shift. This shifting load caused the bag to puncture slightly on the edge of the wooden base, causing a slow release of air pressure. The autoshore devices were still in their initial closed position and they held the entire weight of the bulldozer, while the second airbag was placed under the load. The second airbag was then pressurized and held the entire weight of the dozer and lifted it to a height of 16 inches before the over pressure safety valve began releasing air, which ended our lift. The autoshore Ninjas had automatically ratcheted to the load position and were able to hold the load as the airbag deflated. Once the weight of the load was entirely on the Ninjas and the airbags were removed, all of the pararescue jumpers started clapping, which was a good validation of their acceptance and excitement about the product.

An image of the Ninjas holding the bulldozer can be seen to the right in **Figure 8**. The PJs were visibly thrilled with the performance of the Ninjas and expressed their excitement to us by telling us how well they performed and automatically shored the load. The pararescue jumpers also liked the airbag because of its ease of use, low insertion height, and protection from bursting due to the web cage straps.

Figure 8: Autoshore Ninjas shoring D6 Bulldozer

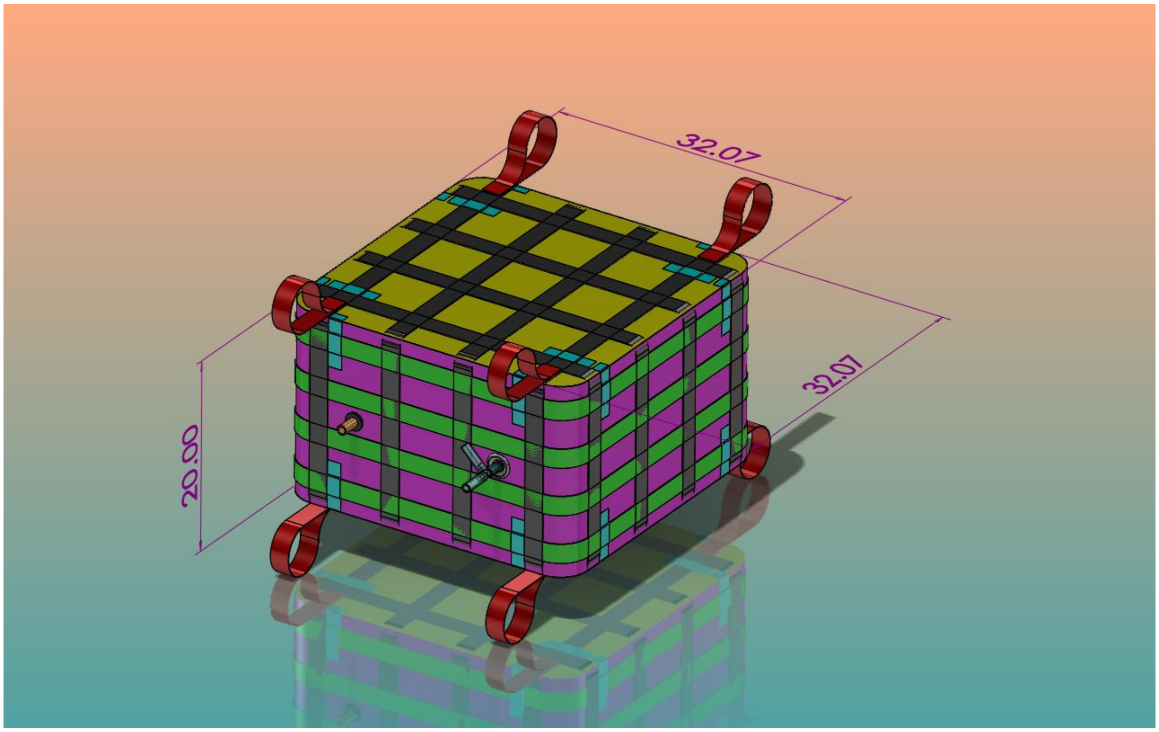
For recommendations, the PJs told us that the autoshore should have a reduced weight which could be accomplished by using plastic for the ratchet beams. They also wanted a more robust airbag that was resistant to puncture. We recommend conducting much more extensive testing on heavy lifts with this system to discover the best insertion and cribbing methods. The PJs also wanted to know if the airbags could be stacked on top of each other and still be stable so we recommend conducting that test.

Overall, the Pararescue Jumpers and other Air Force personnel were excited with our product, and with the verification and testing we had performed. One PJ came up to us and said that we were the only team who actually talked to the end users and received their feedback and validation as we developed the device. He said he was so thrilled about it and was very impressed with the end product.

Appendices

Appendix A: Design Package

Airbag



Bill of Materials

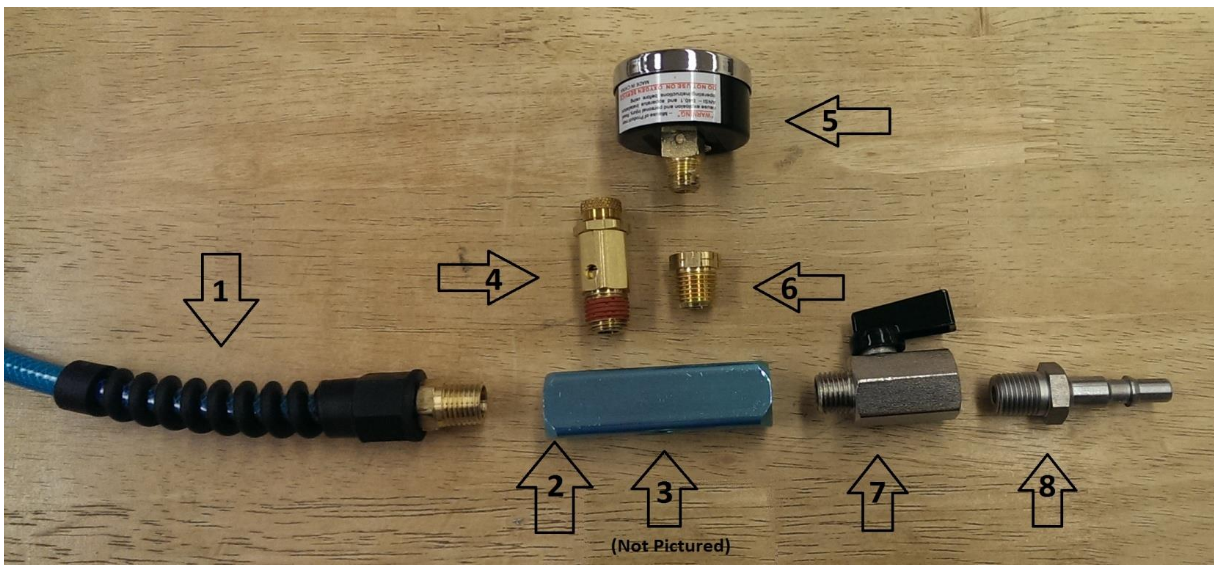
Kit Contents	
Subsystem	**Quantity**
Airbag	2
Hose/Controller Assembly	2
Cylinder/Regulator Assembly	1
2-way Splitter	1

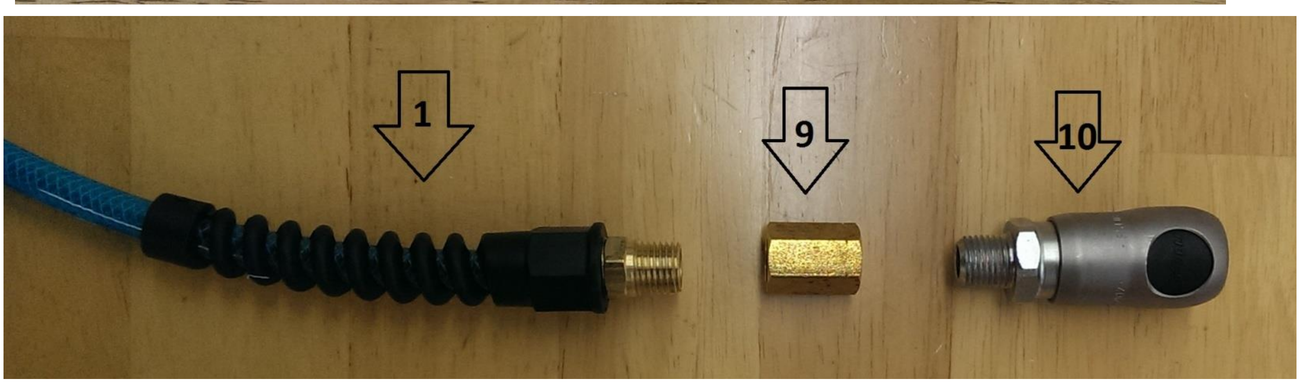
Subsystems:

Airbag				
Item #	**Description/Part #**	**Material**	**Quantity**	**Manufacturer/Supplier**
1	E 1055 Coated Fabric	32 oz PVC Coated Polyester	4 linear yards	EREZ Thermoplastic Products
2	2" Seatbelt Webbing	Polyester	50 yards	Jack's Plastic Welding
3	UR-1087 Adhesive			Clifton Adhesive

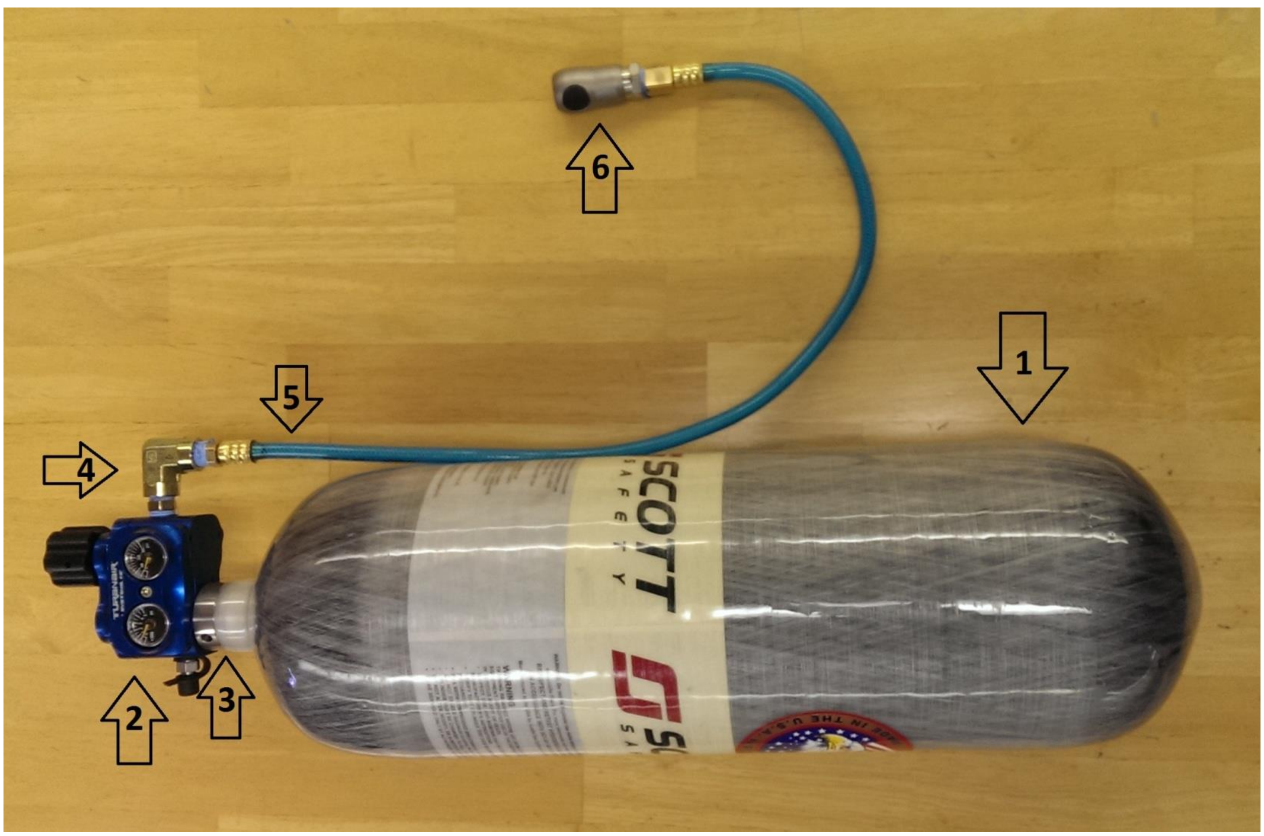
4	LA4009 Accelerator			Clifton Adhesive
5	Heat Tape for seams	PVC Coated Polyester	10 yards	Jack's Plastic Welding
6	3/4" NPT threaded fitting	Aluminum	2	Jack's Plastic Welding
7	1/4" x 3/4" NPT bushing		1	
8	3/4" NPT threaded plug	PVC	1	
9	Staubli Connector RBE06.6251		1	Staubli

Hose/Controller Assembly				
Item #	Description/Part #	Material	Quantity	Manufacturer
1	1/4" Flexeel Air Hose with 1/4" MPT and strain relief on each end	Polyurethane	15 feet	Coilhose Pnumatics
2	1/4" threaded 2-way air hose manifold	Aluminum	1	Amico
3	1/4" NPT blue anodized aluminum internal plug	Aluminum	1	
4	NC series safety valve 25-200psi adjustable (set to 25psi)	Brass	1	Control Devices
5	G-060 mini air pressure gauge		1	Air-Logic
6	1/4" x 1/8" pipe bushing	Brass	1	
7	1/4" mini ball valve (male on one end, female on other)		1	
8	Staubli Connector RBE06.6251		1	Staubli
9	1/4" NPT coupling	Brass	1	
10	Staubli Socket RSI06.1251		1	Staubli
11	PTFE tape (used on all threaded connections)	PTFE		

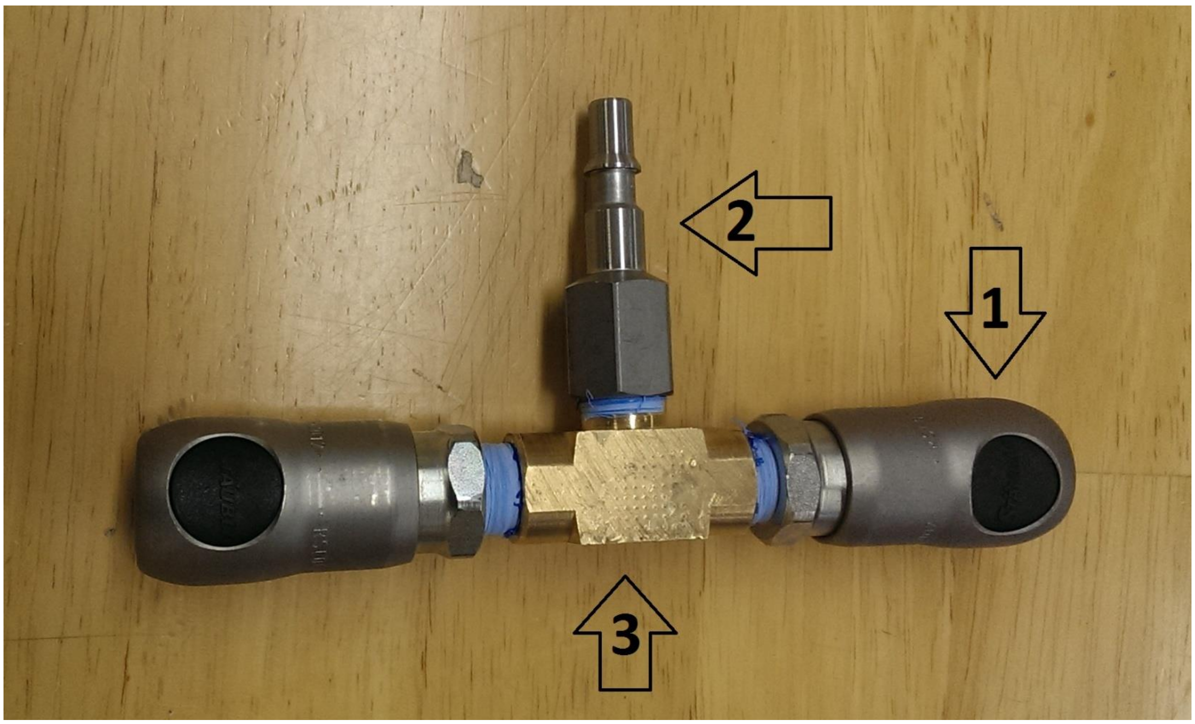




Cylinder/Regulator Assembly				
Item #	Description/Part #	Material	Quantity	Manufacturer
1	Carbon wrapped air cylinder 804722-01	Carbon Wrapped Aluminum	1	Scott Safety
2	T-100 Regulator	Aluminum	1	Turanair Systems
3	Small S.S. Collar		1	Turanair Systems
4	1/4" NPT street elbow	Brass	1	
5	1/4" Flexeel Air Hose with 1/4" female on one end, male on other	Polyurethane	2 feet	Coilhose Pnumatics
6	Staubli Socket RSI06.1251		1	Staubli
7	PTFE tape (used only on threaded connections of hose and elbow)	PTFE		



2-way Splitter				
Item #	Description/Part #	Material	Quantity	Manufacturer
1	Staubli Socket RSI06.1251		2	Staubli
2	Staubli Connector RBE06.6201		1	Staubli
3	1/4" NPT tee, 2x female, 1x male	Brass	1	
4	PTFE tape (used on all threaded connections)	PTFE		



PRODUCT DATA SHEET

E 1055

TEST & METHOD	TYPICAL CHARACTERISTICS	
	STANDARD	**METRIC**
Fabric, Type	Polyester 1OOQ Den 7 Ozlyd²	Polyester 1100 Dtx 240 *gml* m²
Total Weight ASTMD 751	31.9 *Ozl* yd²	1080 gm/m²
Breaking Strength (Strip) ASTM D 751 p.B	440 / 396 lbs / inch	400 / 360 Kg / 5 em
Tear Strength ASTM D 751 p.B	66 / 66 lbs	30 / 30 Kg
Adhesion ASTM D 751 / HF Welding	17.6117.6 lbs / inch	16116 Kg / 5 em
Puncture Resistance Fed.Std. 101-2031	220 lbs	100 Kg
Air Porosity BS. 4F.100 Clause 32.1	Pass (10 minutes at 7 psi)	
Blocking Resistance ASTM D 751- 70°C(l60°F)6 hrs.	#1	
Abrasion Resistance ASTM D 3389 (TABER H-22 Wheel1000 gm Load)	> 1200 Cycles to expose the cloth.	
Weft Distortion	1.6 inch max. (on 60 inch widthwise)	40mmmax. (on 150 em widthwise)
Clod Crack / Bend ASTM D 2136	- 31°F	- 35°C

: Update January , 2010

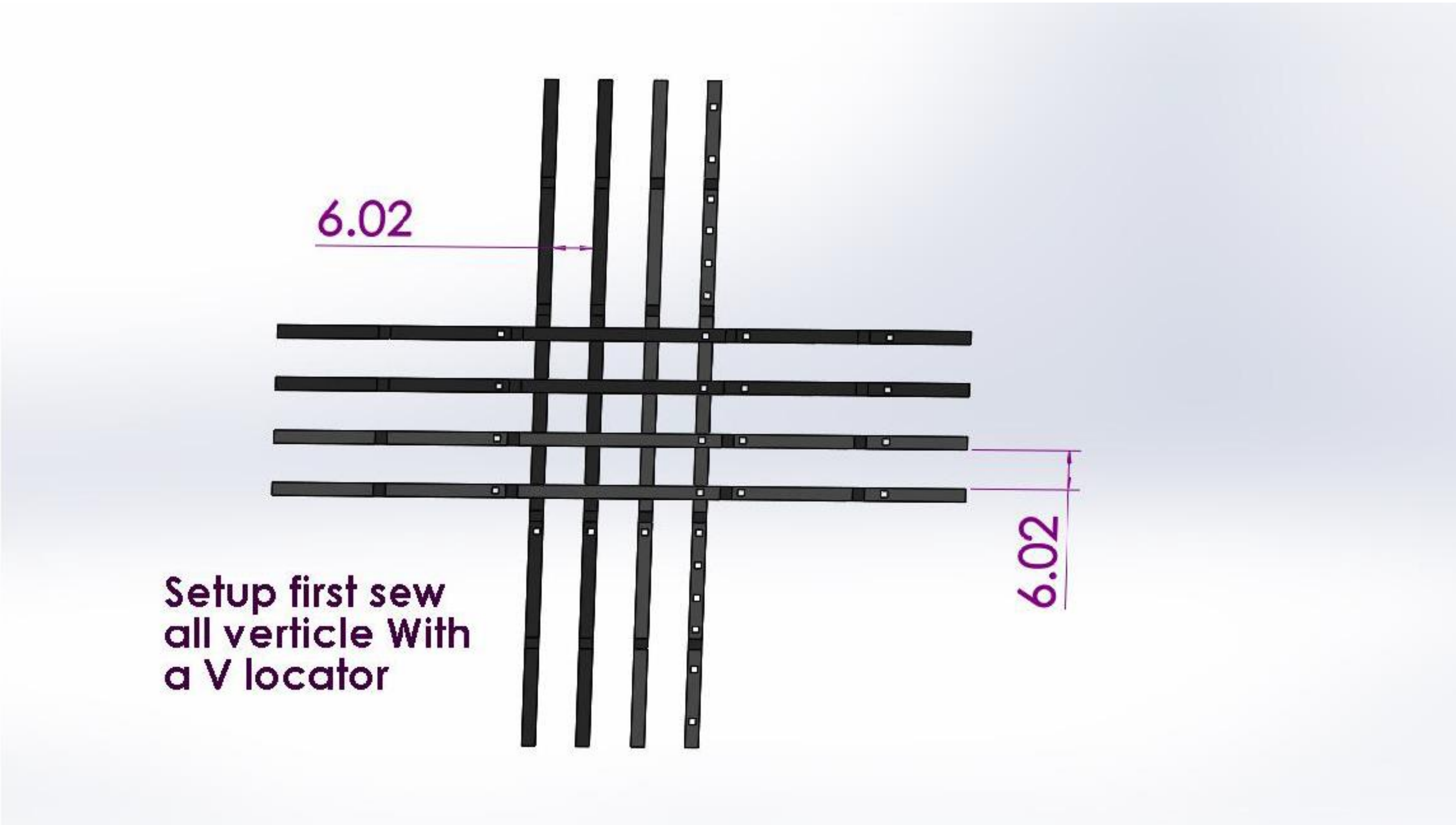
Recommended end use: Inflatable Boats

We believe this information is the best currently available.
It is subject to revision once additional know-how is gained. We make no guarantee of results
and assume no obligation liability whatsoever in connection with this information.

KIBBUTZ EREZ M.P. ASHKELON COAST 79150 ISRAEL, Tel: 972-8-6801200 Fax: 972-8-6801208 WWW.EREZ-THERM.COM

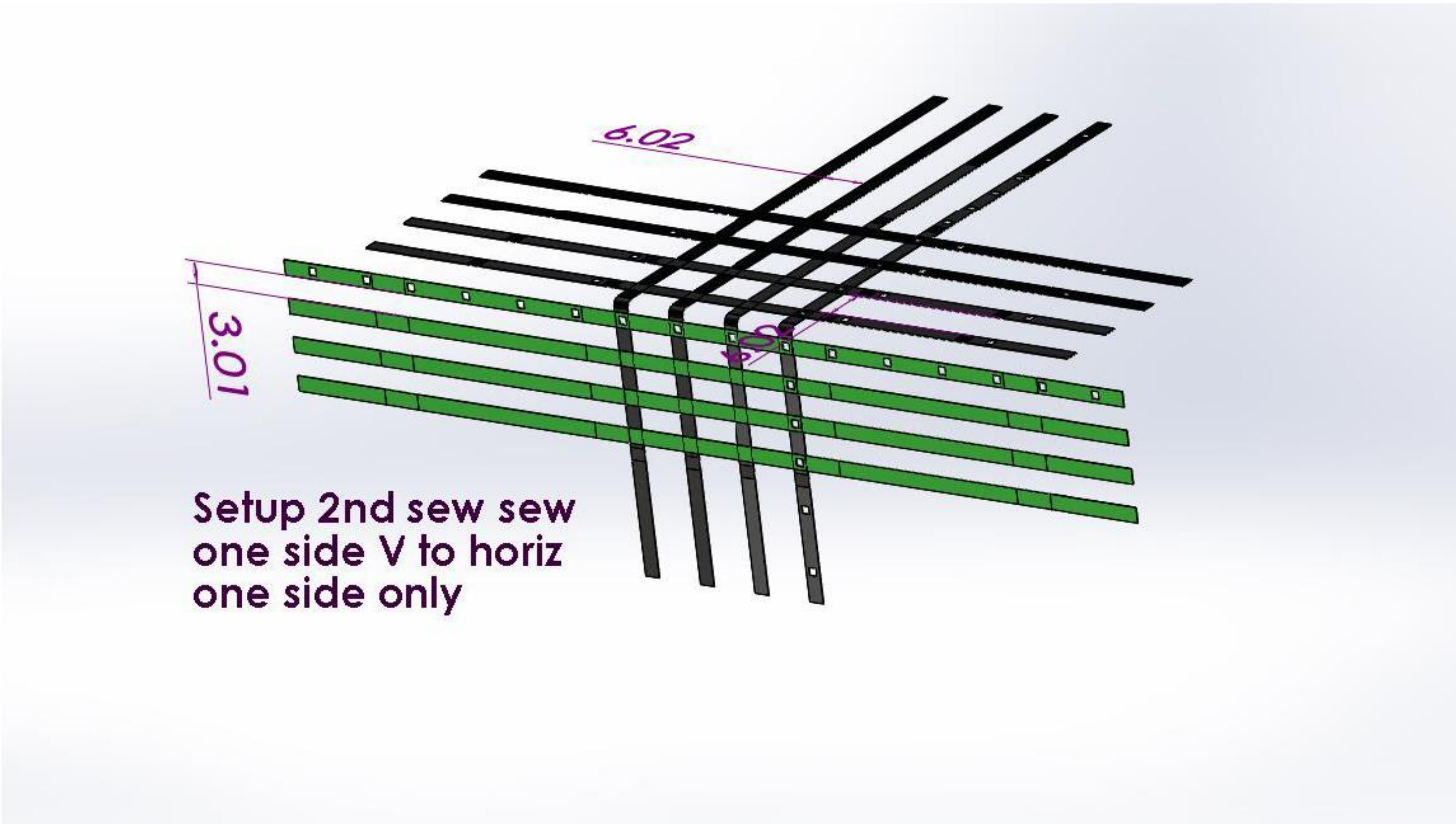
How to accurately sew the lift bag web cage

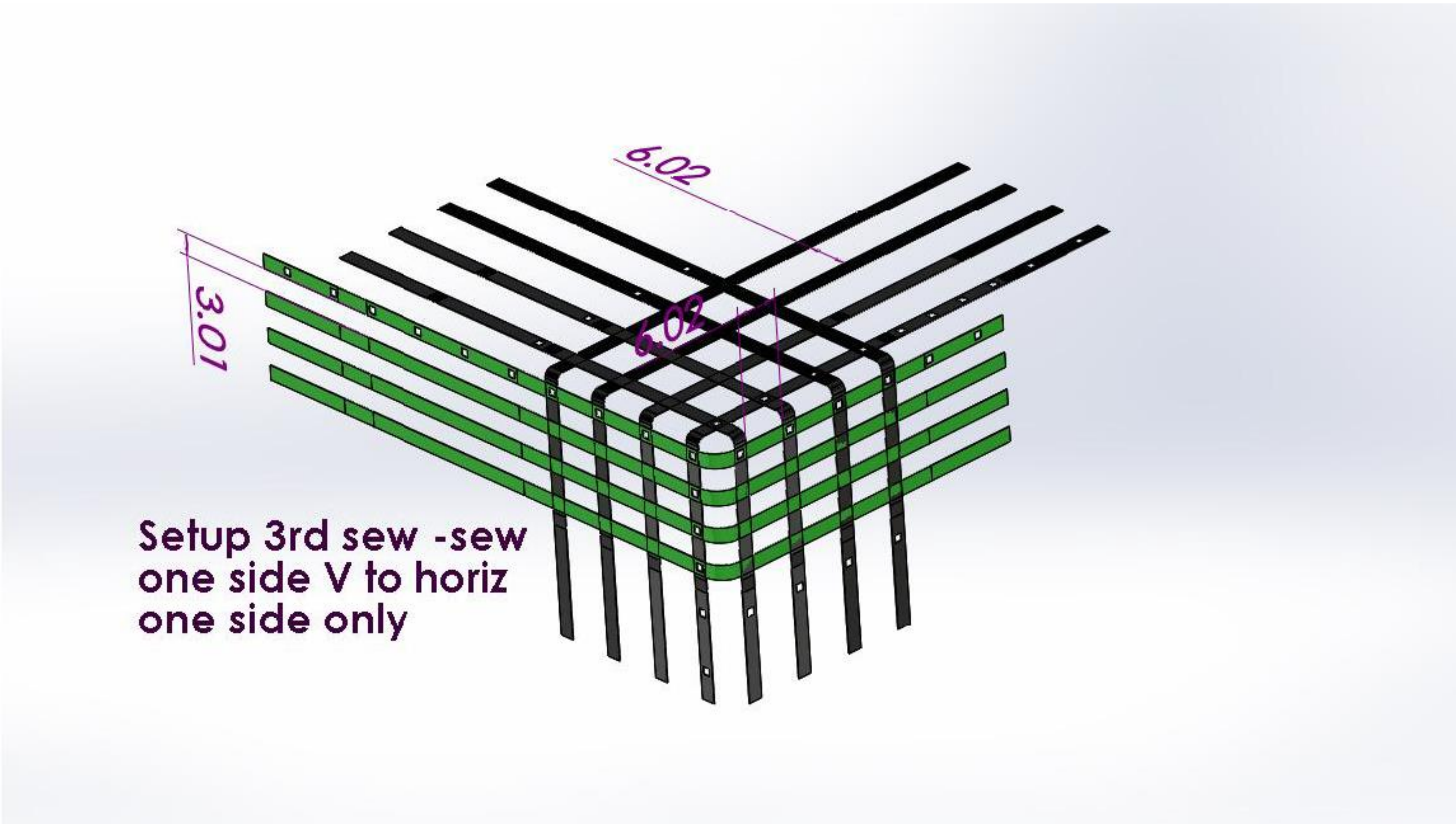
The lift bag cage is made of 6,000 lb burst polyester web. Polyester does not stretch like nylon, so we think this is the best choice. The engineers at BYU did math and gave the thumbs up on this design. However it needs to take all the inflation stress and here are the things we are doing to make that happen.

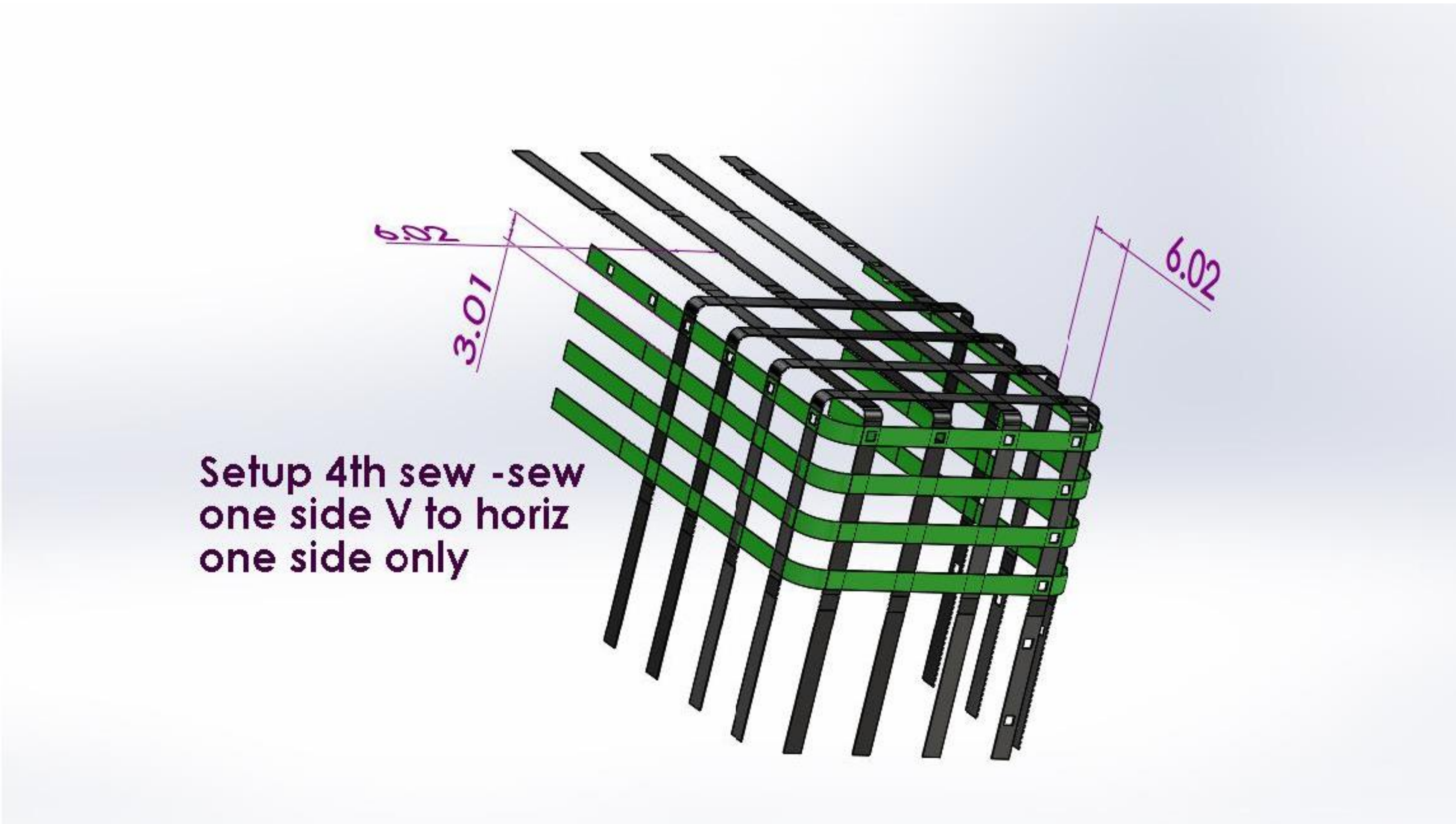

6.02
6.02
Setup first sew
all verticle With
a V locator

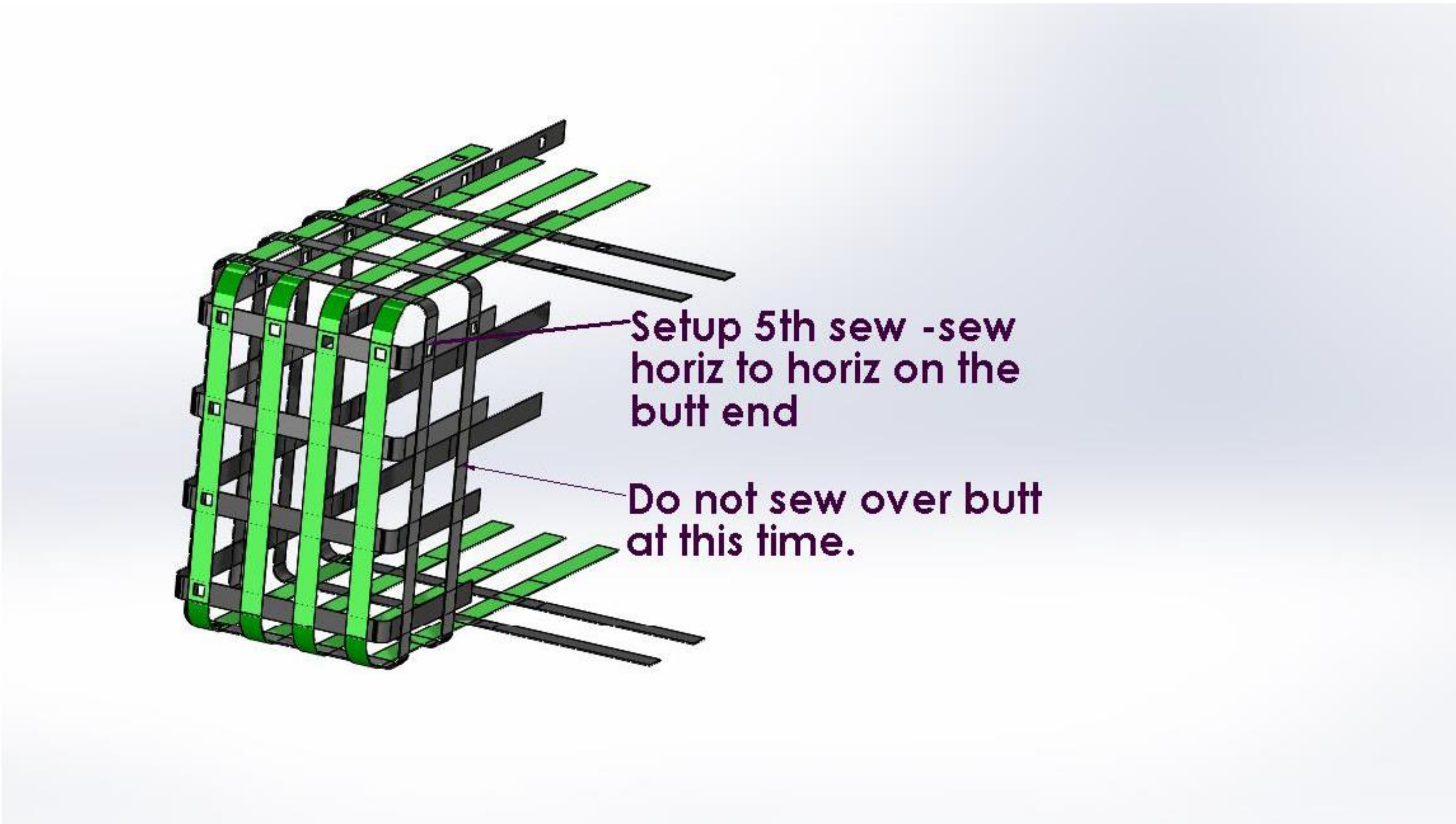
verticle and horizontal web

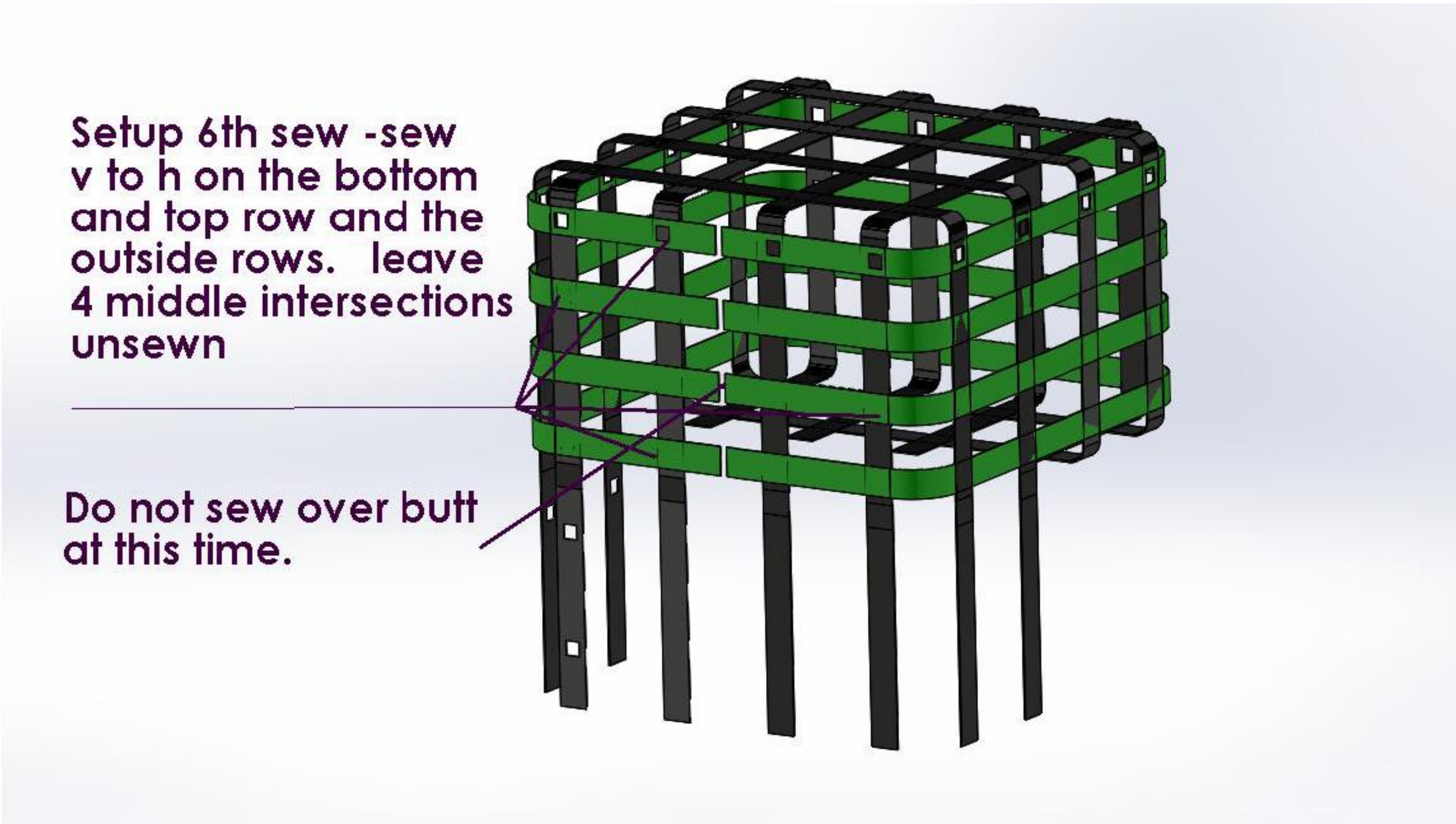
verticle web and horizontal webs are different colors. The verticle webs actually wrap around the top the sides and the bottom. They are dargk grey in color. Horizontal webs only wrap around the sides. They are green in color. First we lay out the Verticle webs and sew them where they intersect.

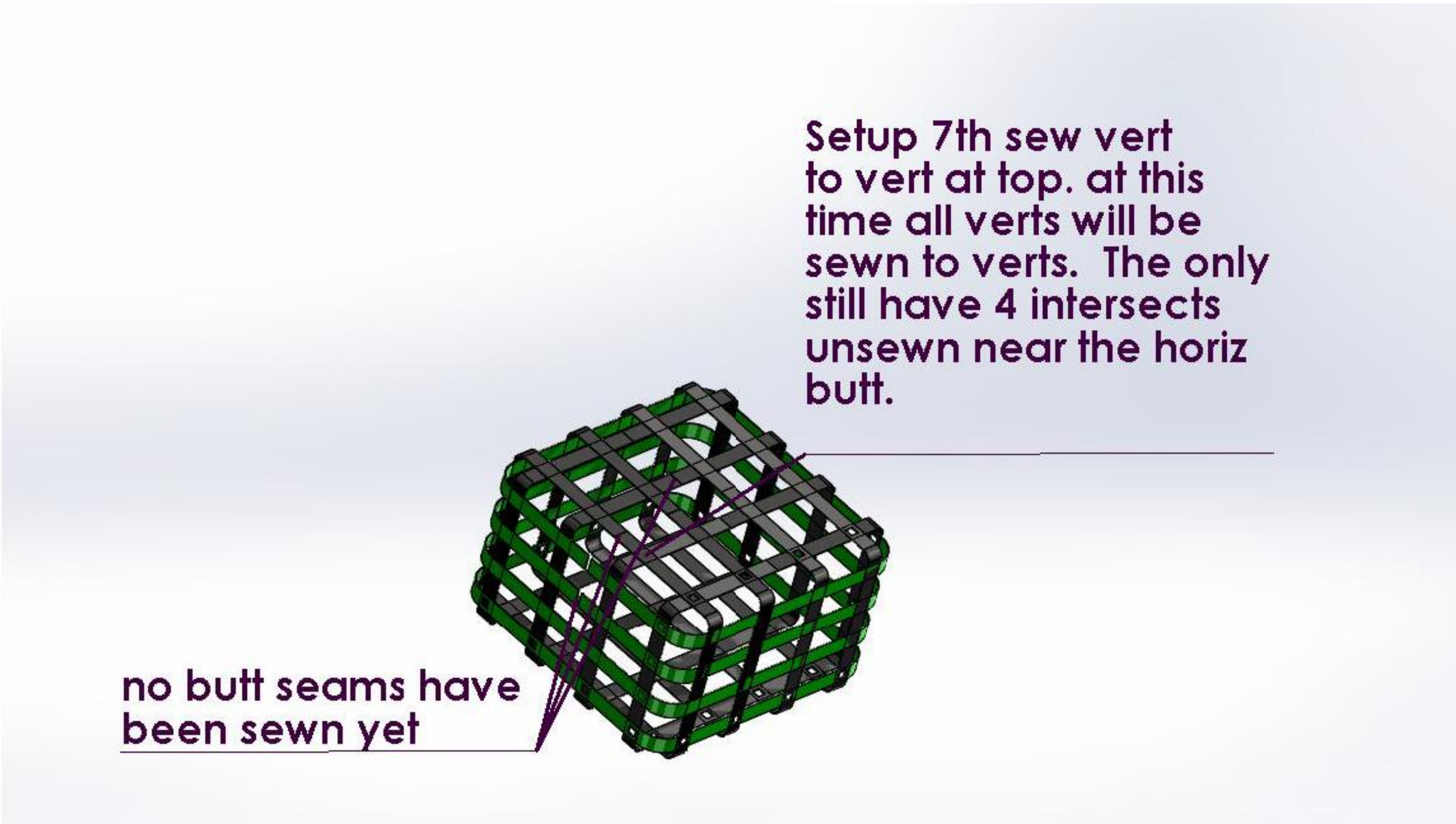

6.02
3.01
Setup 2nd sew sew
one side V to horiz
one side only

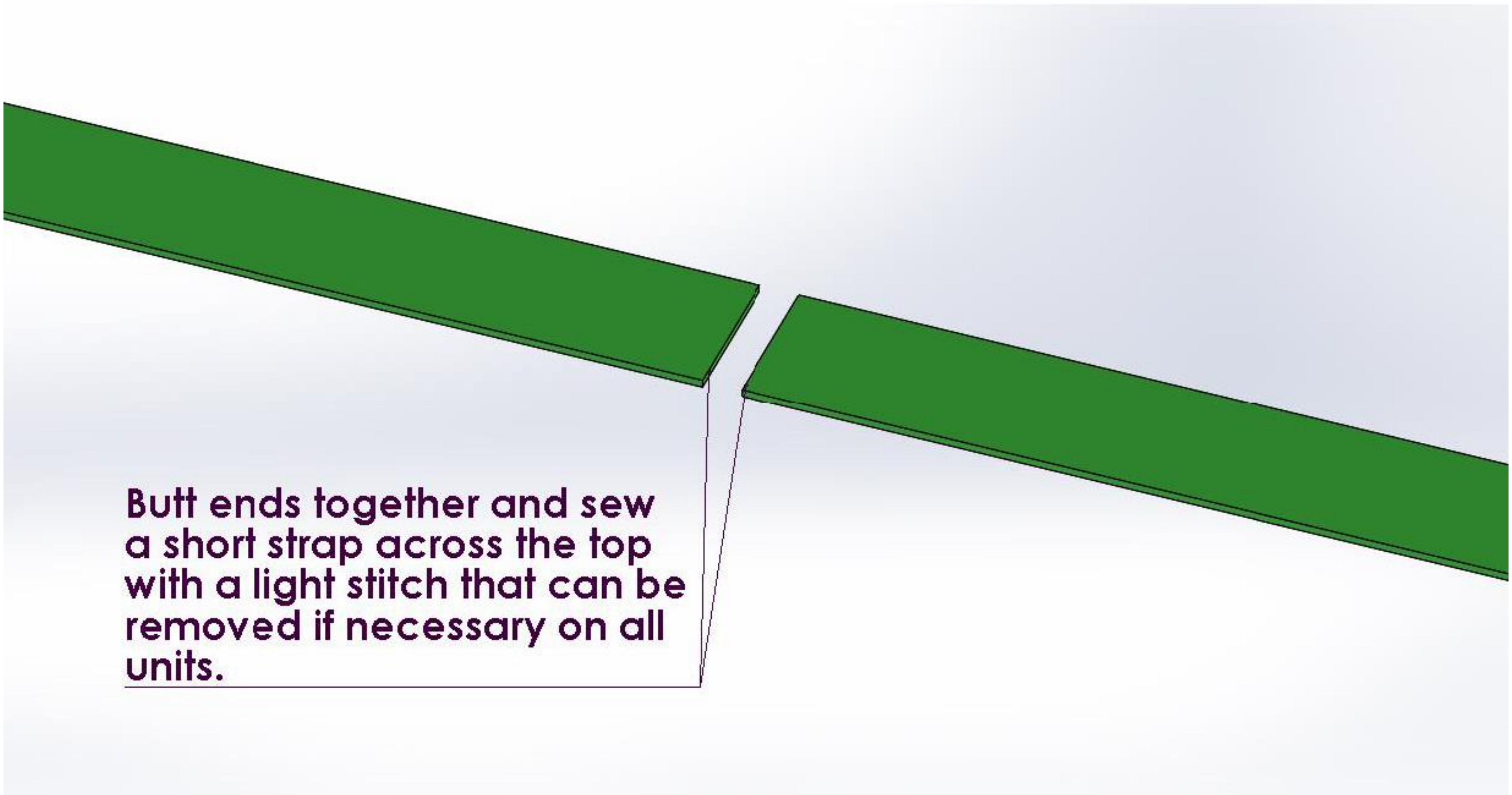

6.02
6.02
3.01
Setup 3rd sew -sew
one side V to horiz
one side only

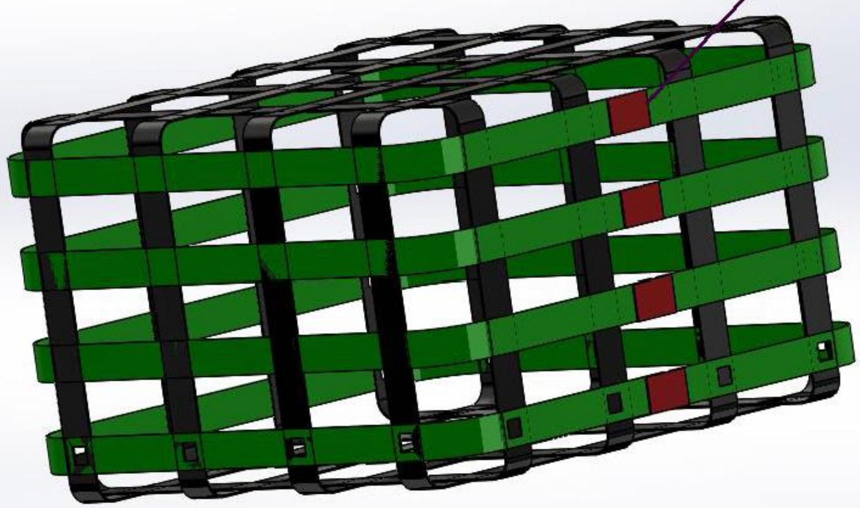

6.02
3.01
6.02
Setup 4th sew -sew
one side V to horiz
one side only


Setup 5th sew -sew
horiz to horiz on the
butt end
Do not sew over butt
at this time.


Setup 6th sew -sew v to h on the bottom and top row and the outside rows. leave 4 middle intersections unsewn
Do not sew over butt at this time.

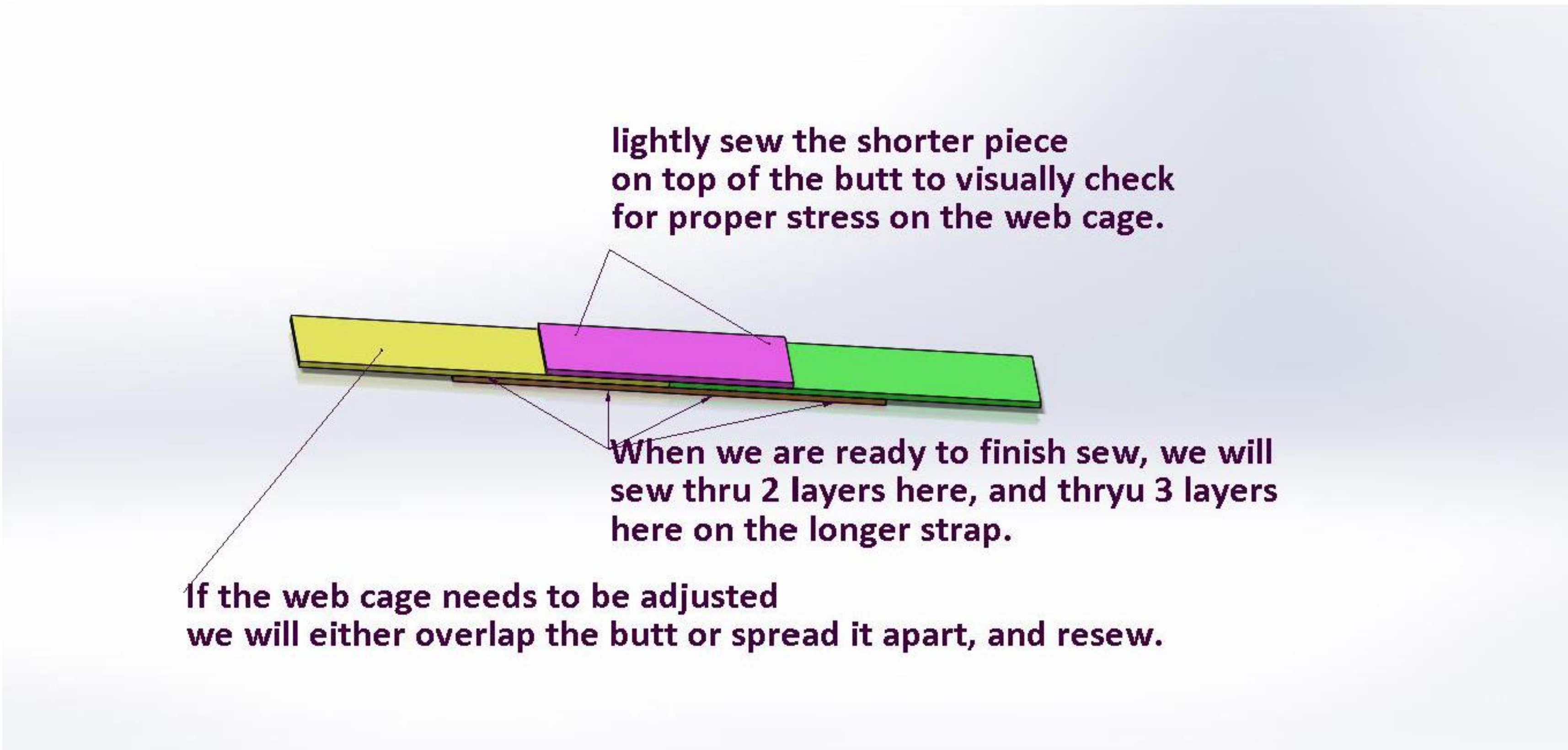

Setup 7th sew vert
to vert at top. at this
time all verts will be
sewn to verts. The only
still have 4 intersects
unsewn near the horiz
butt.
no butt seams have
been sewn yet


Butt ends together and sew a short strap across the top with a light stitch that can be removed if necessary on all units.



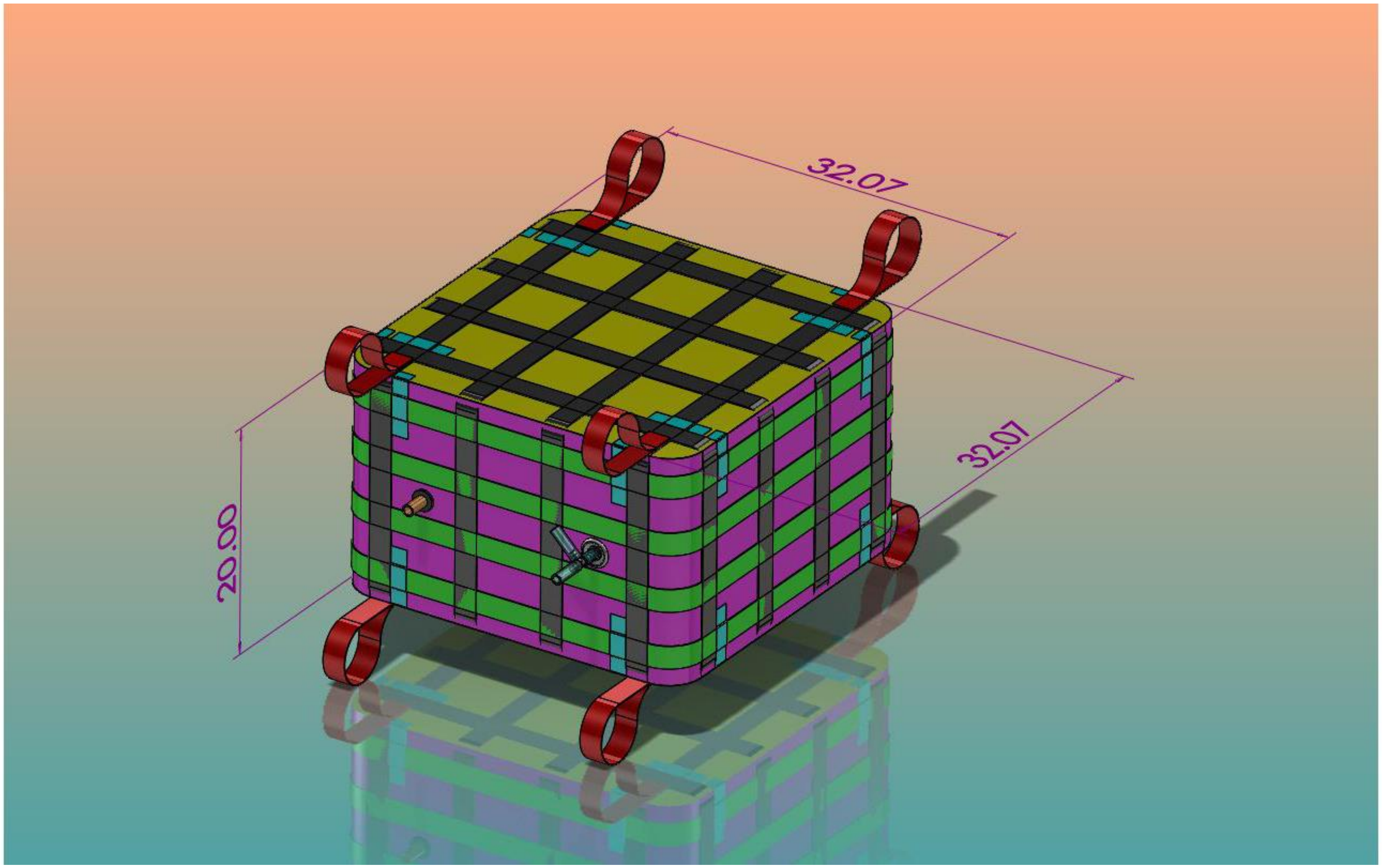
Sew 9 and 10, and 11- after the light sew is done on the butt connections, we will test the inflation and stress on the straps at 5 psi. If we need to adjust the strap tension we can cut the stitch and re sew. If not we will back up the butt connections with a longer strap and sew them hard see sew 12.

We will stuff the inflatable back in the web cage and sew the 4 intersects that remain unsewn.


lightly sew the shorter piece
on top of the butt to visually check
for proper stress on the web cage.
When we are ready to finish sew, we will
sew thru 2 layers here, and thryu 3 layers
here on the longer strap.
If the web cage needs to be adjusted
we will either overlap the butt or spread it apart, and resew.

Summary

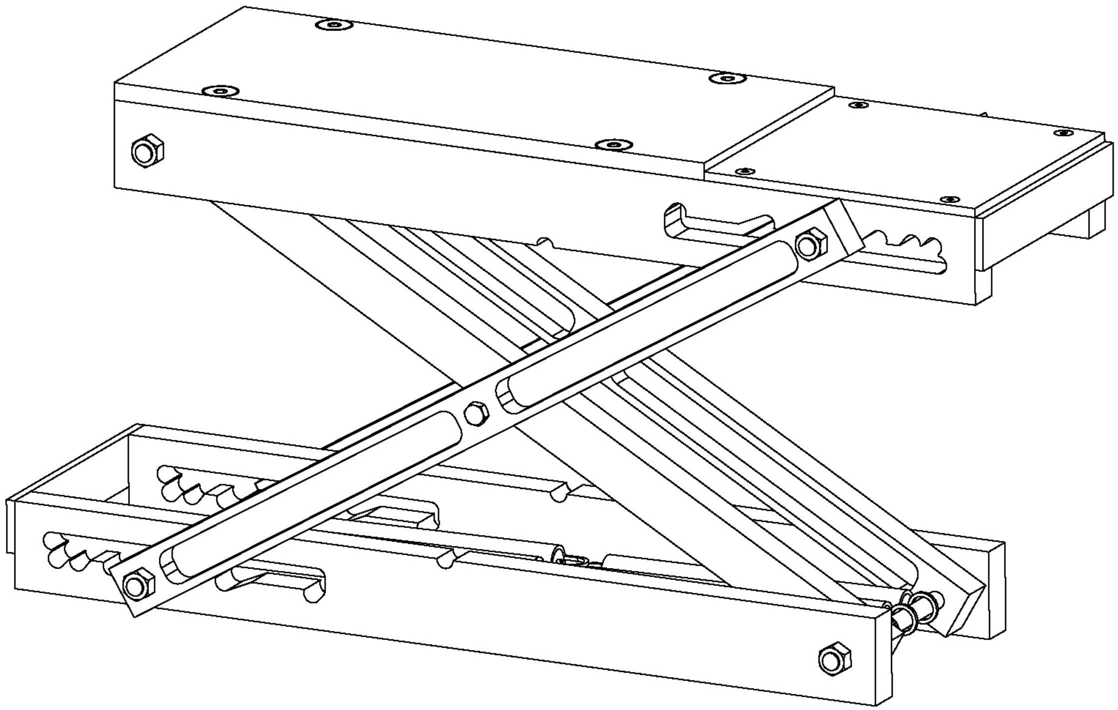
we intend to make this as safe and strong as possible. We are doing that by accurately cutting and locating the parts with sewing, then checking the stress on the web to insure that the web will be taking as much inflation pressure as possible without putting a unknown stress on the fabric. The last immage shows how we intend to locate the inflatable so the web inflates in exactly the right position each time.


32.07
32.07
20.00

web tie downs

The light blue web tie downs will locate the web in the right spot so that inflation will stress the web exactly the right way each time it is inflated.

Any questions call me at work 800 742 1904 or on my cell 970 759 8715 or email info@jpwinc.com



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

NEXT ASSY	USED ON
APPLICATION	

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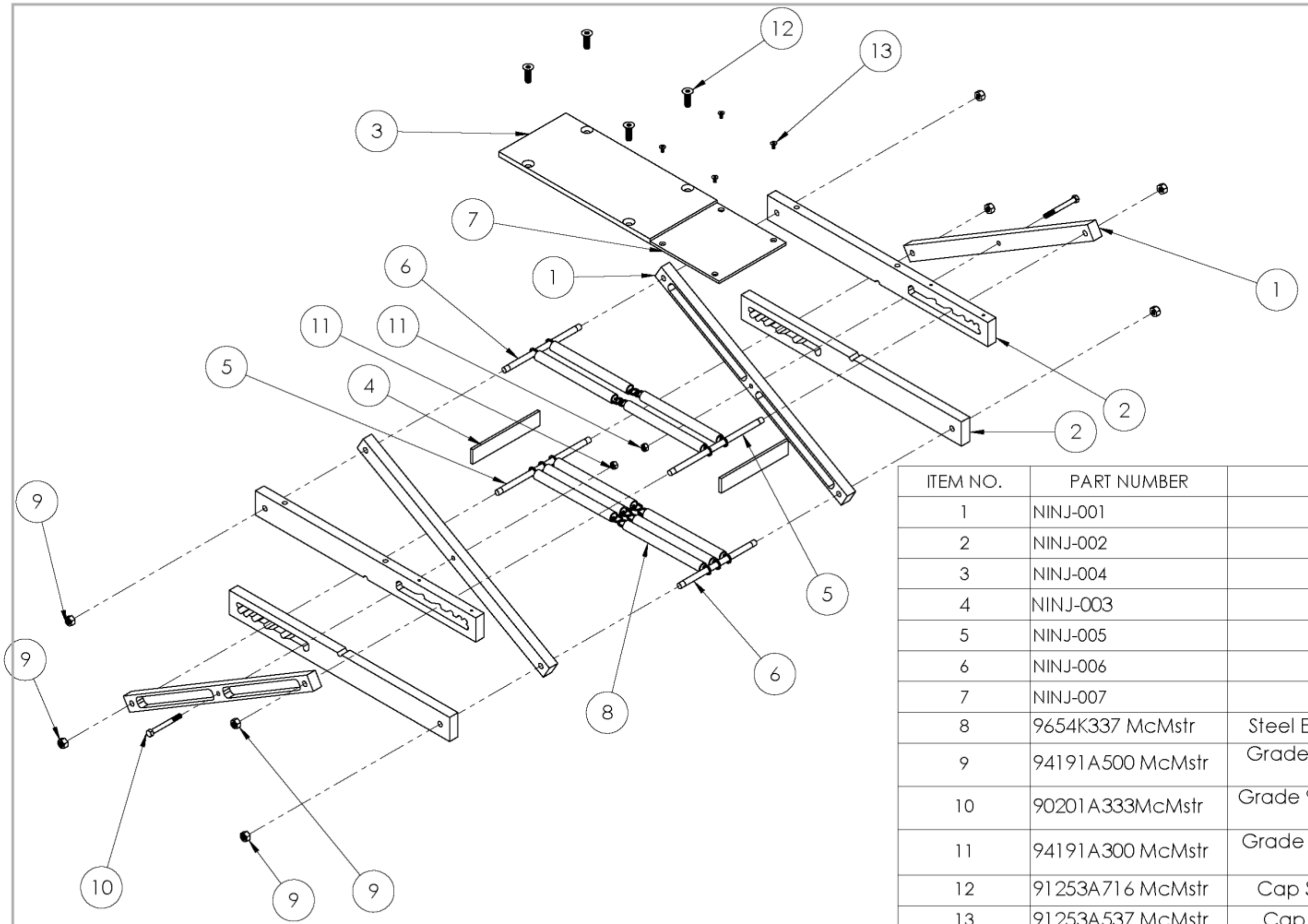
TITLE:

Auto-Shore Ninja

SIZE **A** DWG. NO. NINJ-A01 REV

SCALE: 1:4 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	NINJ-001	LEG	4
2	NINJ-002	BASE RATCHET	4
3	NINJ-004	PLATE	1
4	NINJ-003	BRACKET	2
5	NINJ-005	RATCHET BAR	2
6	NINJ-006	FIXED BAR	2
7	NINJ-007	PLASTIC PLATE	1
8	9654K337 McMstr	Steel Extension Spring, 7.75" L	10
9	94191A500 McMstr	Grade 8 Hex Nut 1/"-13, 7/16" High	8
10	90201A333McMstr	Grade 9 Cap Screw, 3/8"-16, 3-1/2" L	2
11	94191A300 McMstr	Grade 8 Hex Nt 3/8"-16, 21/64" High	2
12	91253A716 McMstr	Cap Screw 1/2'-13, 1-1/2' L	4
13	91253A537 McMstr	Cap Screw, 1/4"-20, 1/2" L	4

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING | REVISION 1

BYU Heavy Lifter

	NAME	SIGNATURE	DATE
DRAWN	J. LATER		04/07/14
CHK'D	E. GRABAU		04/07/14
APPV'D			
MFG			
Q.A			

MATERIAL:

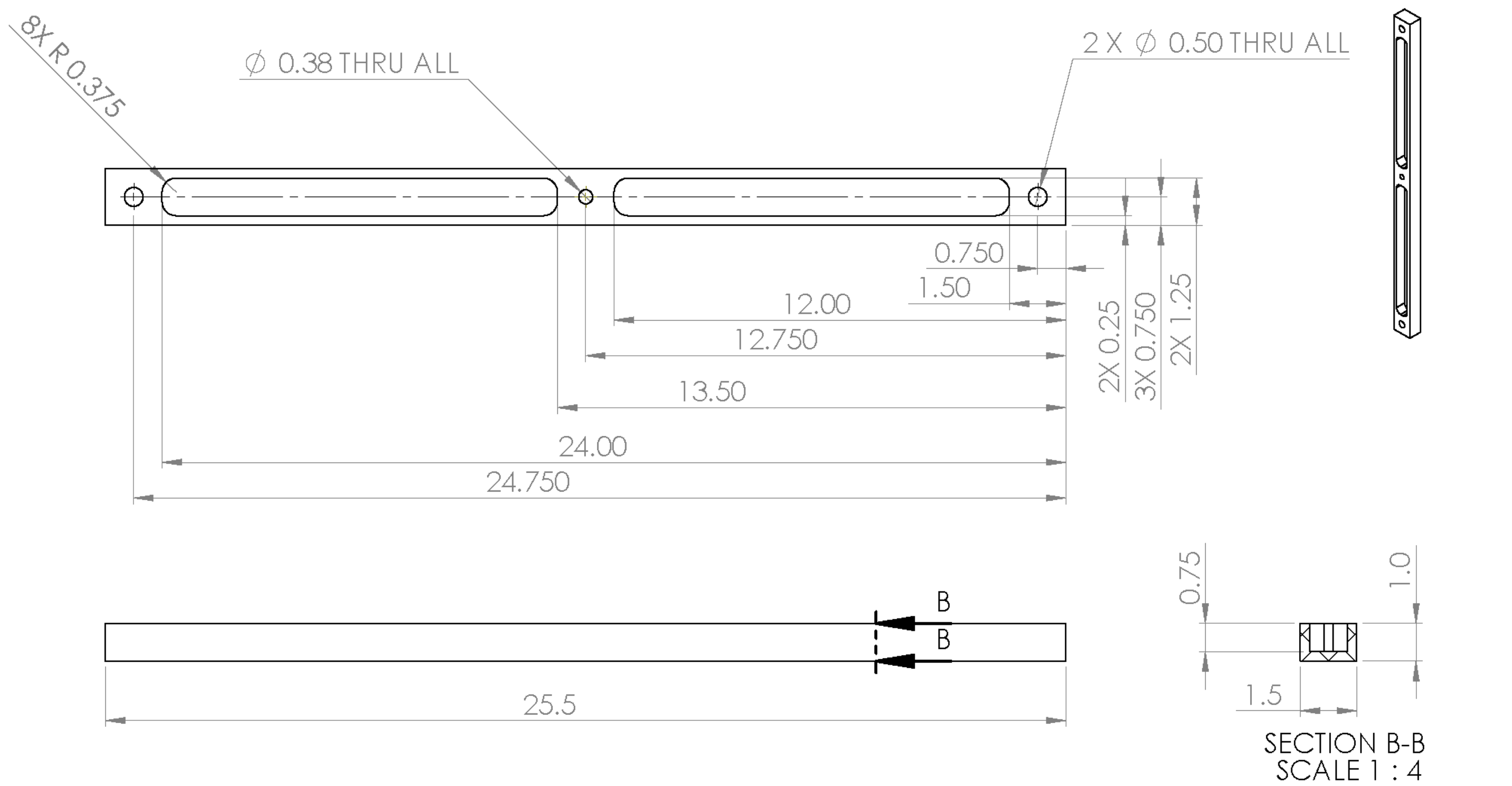
WEIGHT:

TITLE:

Auto-Shore Ninja

DWG NO. NINJ-A01 | A3

SCALE:1:9 | SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	BYU Heavy Lifters	
DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±.02 THREE PLACE DECIMAL ±.002	DRAWN	JBL	03/24/14		
	CHECKED	EAG	04/07/14	TITLE:	
	ENG APPR.			LEG	
	MFG APPR.				
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.				
MATERIAL 6061 AL	COMMENTS:			SIZE A	DWG. NO. NINJ-001 REV A
FINISH N/A					
DO NOT SCALE DRAWING				SCALE: 1:3 WEIGHT:	SHEET 1 OF 1

NEXT ASSY	USED ON
APPLICATION	

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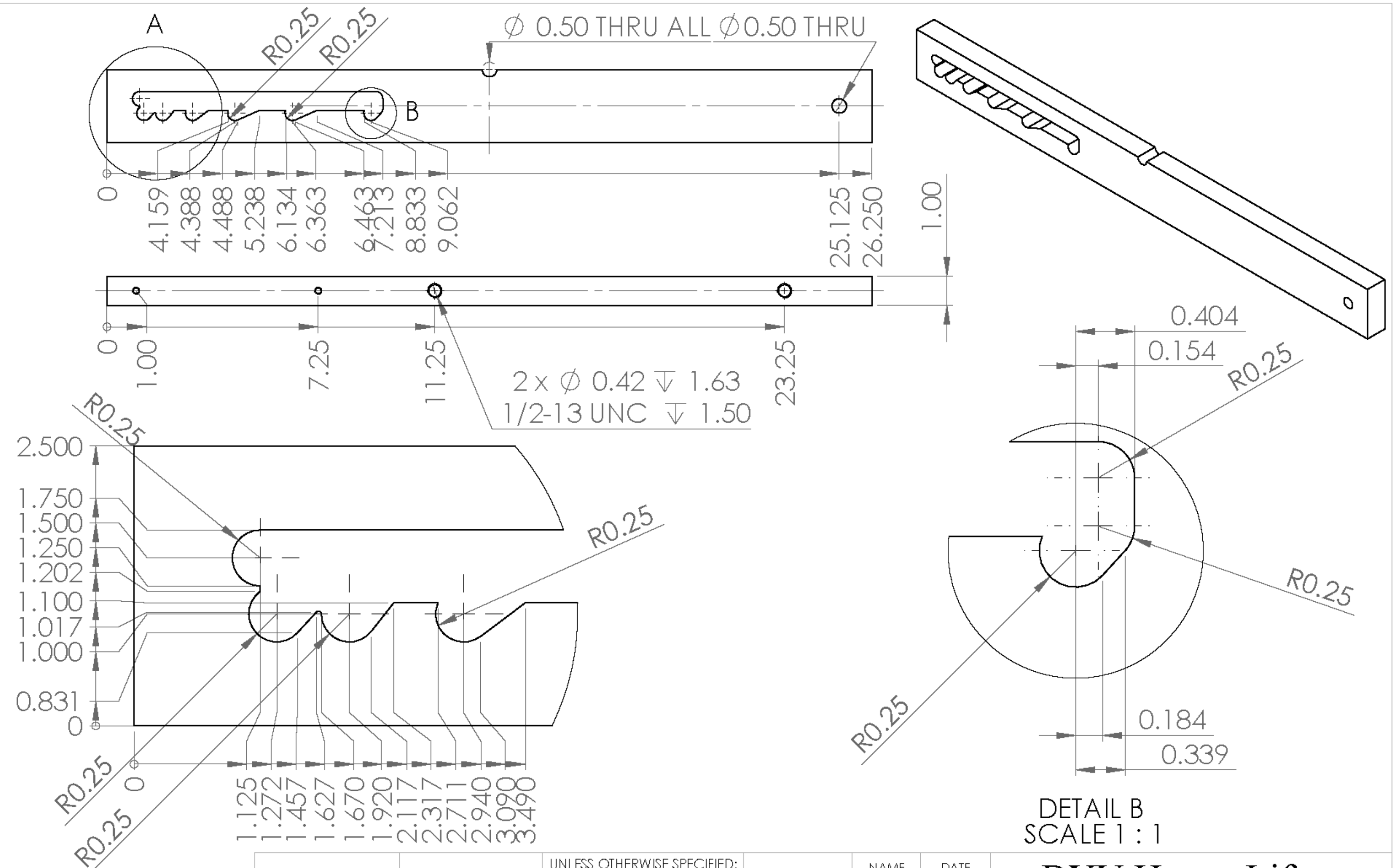
5 4 3 2 1



DETAIL B
SCALE 1 : 1

DETAIL A
SCALE 1 : 1.3

UNLESS OTHERWISE SPECIFIED:		
DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±.02 THREE PLACE DECIMAL ±.002		
INTERPRET GEOMETRIC TOLERANCING PER:		
MATERIAL	6061 AL	
FINISH	N/A	
NEXT ASSY	USED ON	
APPLICATION		DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	EAG	04/07/14
CHECKED	JBL	04/07/14
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

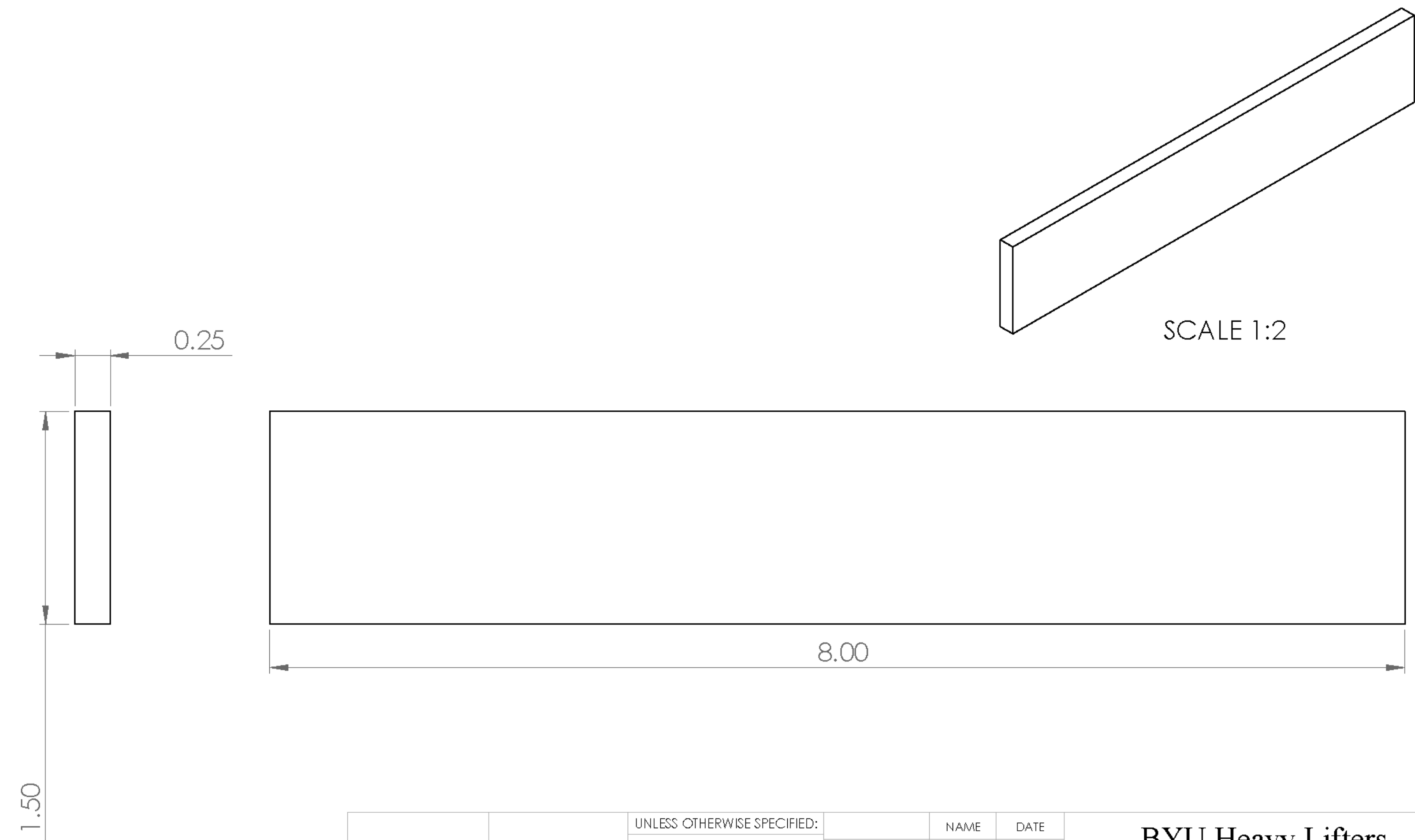
BYU Heavy Lifters

TITLE:

BASE RATCHET

SIZE	DWG. NO.	REV
A	NINJ-002	A
SCALE: 1:5	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	BYU Heavy Lifters
		DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±.02 THREE PLACE DECIMAL ±.002	DRAWN	EAG	04/07/14	TITLE: BRACKET
			CHECKED	JBL	04/07/14	
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL 6061 AL	COMMENTS:			SIZE A DWG. NO. NINJ-003 REV A
NEXT ASSY	USED ON	FINISH N/A				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:1 WEIGHT: SHEET 1 OF 1

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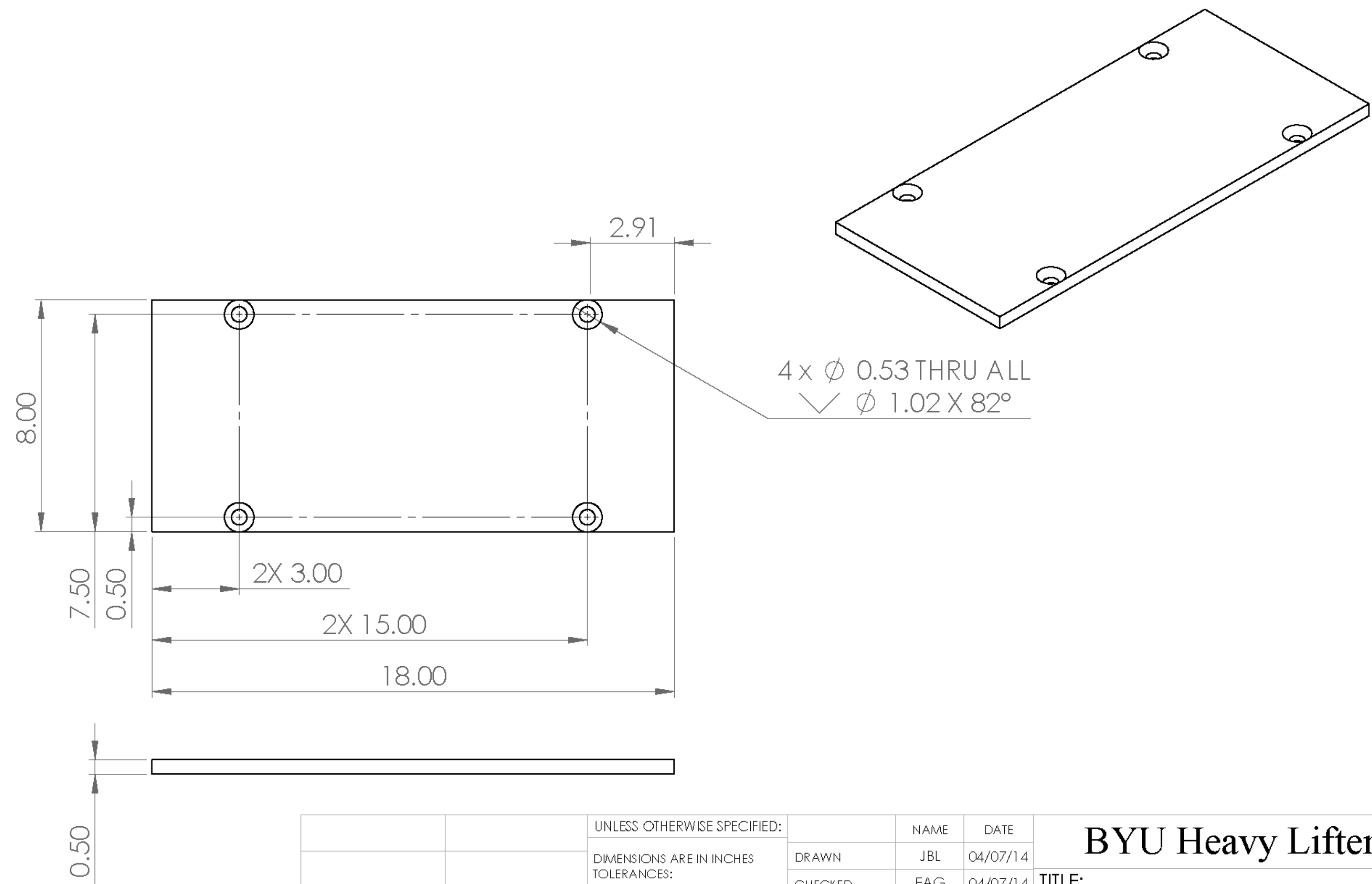
5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±.02 THREE PLACE DECIMAL ±.002	DRAWN	JBL	04/07/14
	CHECKED	EAG	04/07/14
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL 6061 AL	COMMENTS:		
FINISH N/A			
DO NOT SCALE DRAWING			

NEXT ASSY	USED ON
APPLICATION	

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BYU Heavy Lifters

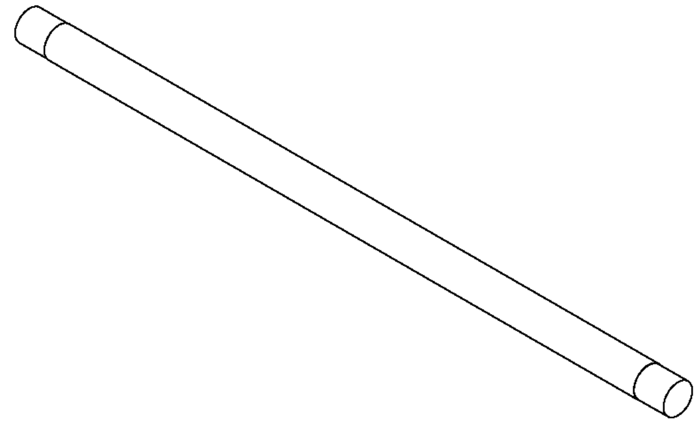
TITLE:

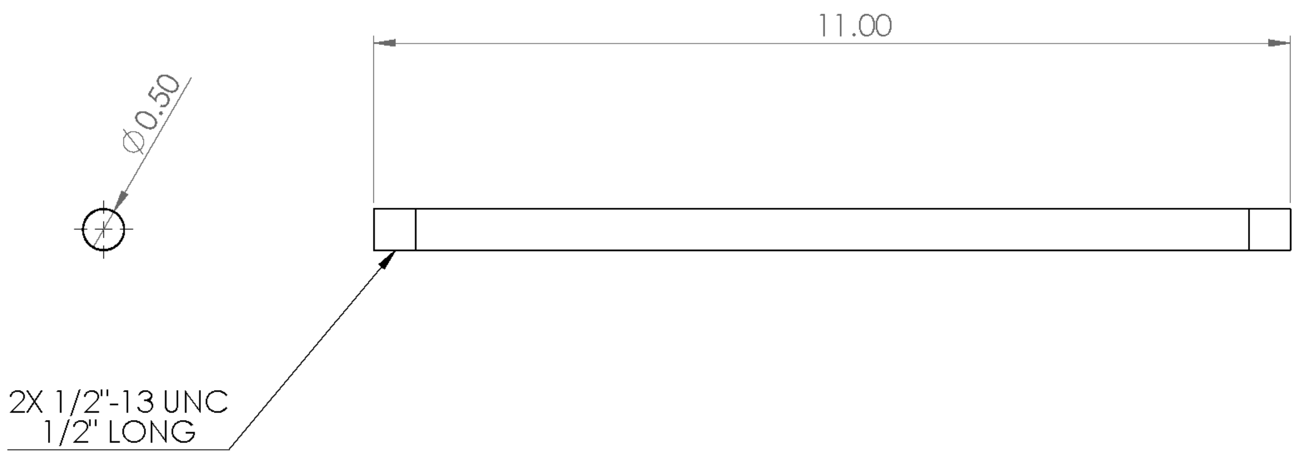
PLATE

SIZE	DWG. NO.	REV
A	NINJ-004	A

SCALE: 1:5 WEIGHT: SHEET 1 OF 1

5 4 3 2 1





		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±.02 THREE PLACE DECIMAL ±.002	DRAWN	JBL	04/07/14
			CHECKED	EAG	04/07/14
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL 4140 STEEL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

PROPRIETARY AND CONFIDENTIAL

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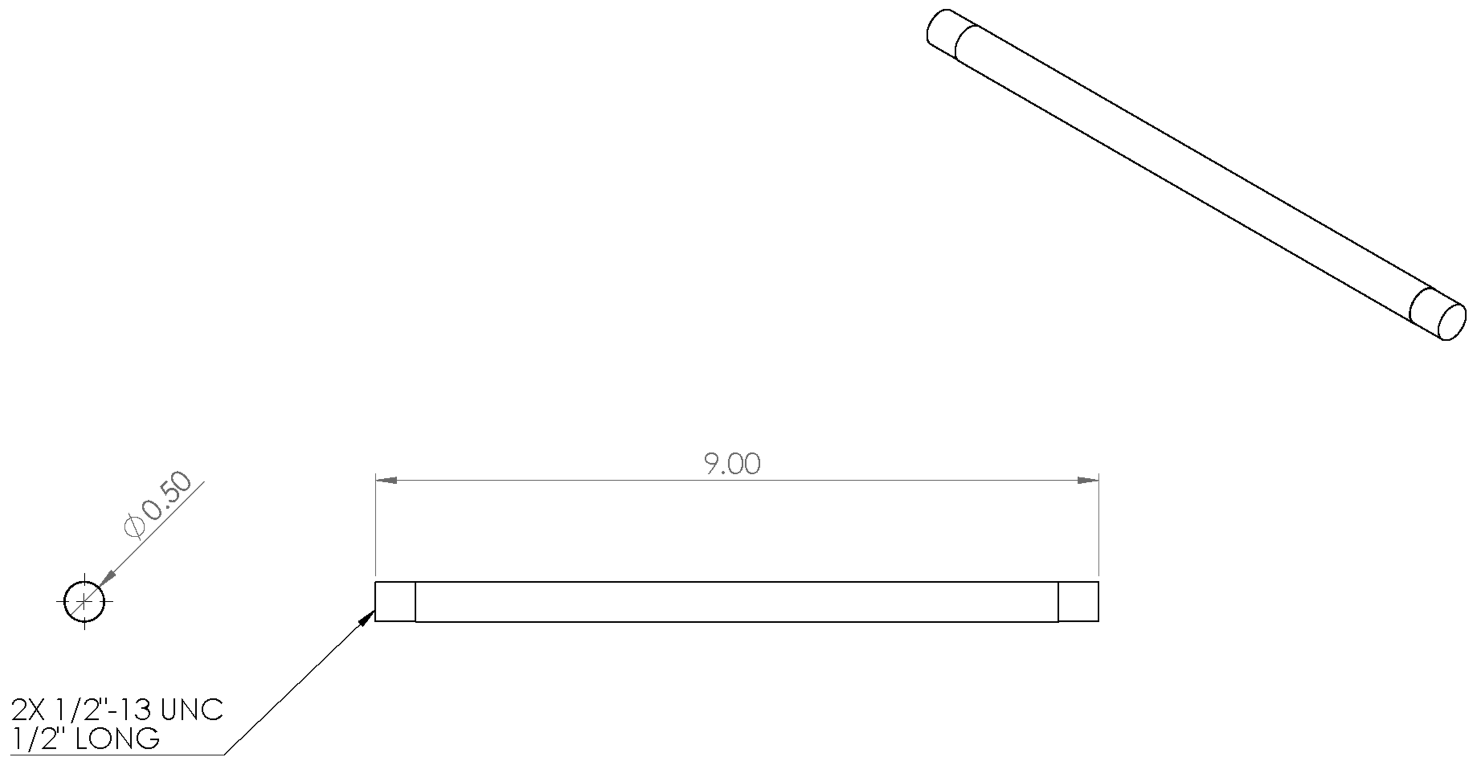
BYU Heavy Lifters

TITLE:

RATCHET BAR

SIZE	DWG. NO.	REV
A	NINJ-005	A
SCALE: 1:2	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1



BYU Heavy Lifters

TITLE: **FIXED BAR**

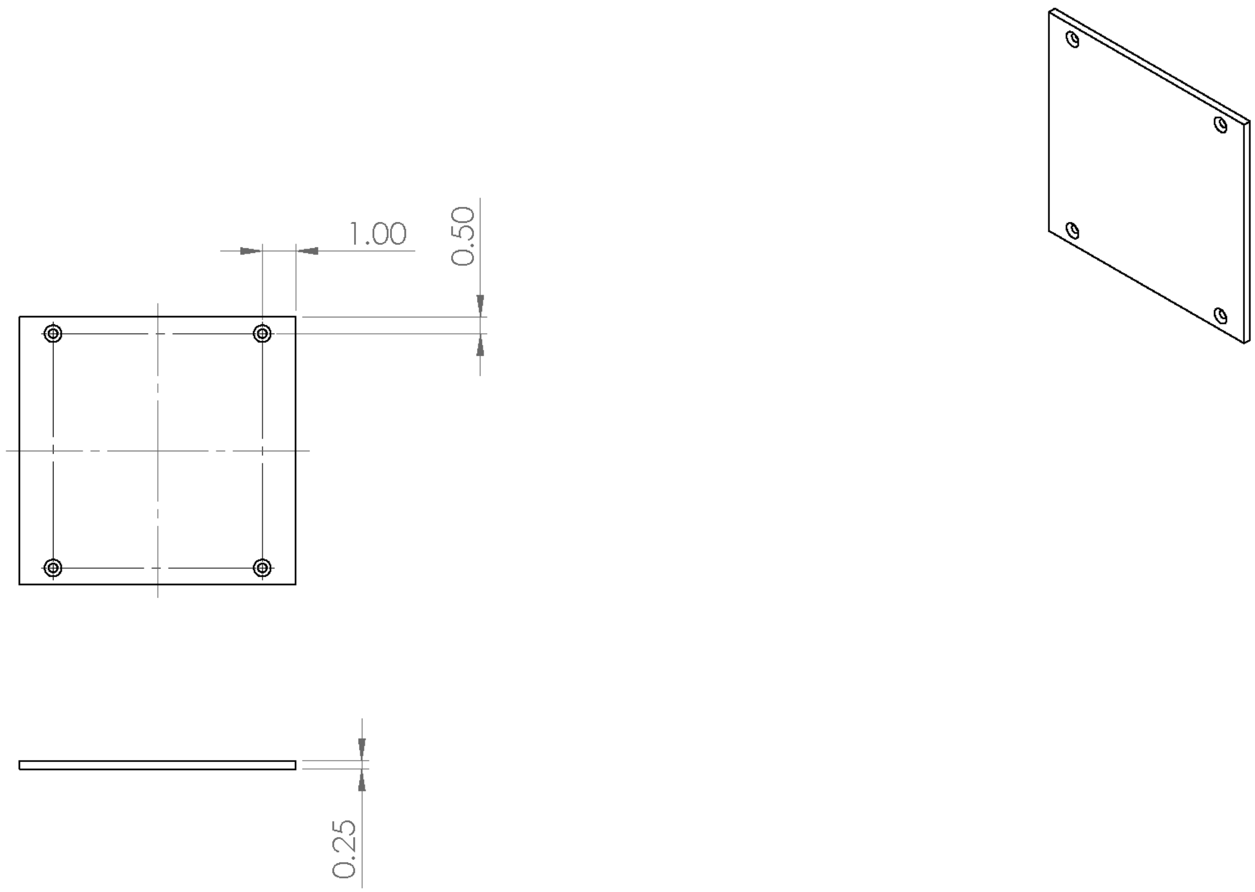
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±.02 THREE PLACE DECIMAL ±.002	DRAWN	EAG	04/07/14	
	CHECKED	JBL	04/07/14	
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL 4140 STEEL	COMMENTS:			
FINISH				
DO NOT SCALE DRAWING				

NEXT ASSY	USED ON
APPLICATION	

SIZE A | DWG. NO. NINJ-006 | REV A

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±.02 THREE PLACE DECIMAL ±.002	DRAWN	EAG	04/07/14
			CHECKED	JBL	04/07/14
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL POLYCARBONATE PLASTIC	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

BYU Heavy Lifters

TITLE:

PLASTIC PLATE

SIZE	DWG. NO.	REV
A	NINJ-007	A

SCALE: 1:5 WEIGHT: SHEET 1 OF 1

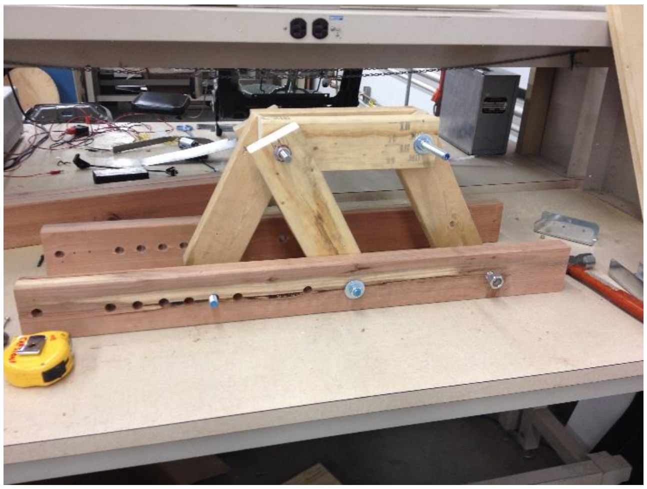
5 4 3 2 1

Appendix B: Auto-Shore Ninja Prototypes and Testing

The purpose of this document is to describe each prototype made, its purpose, and the reasons for failure.

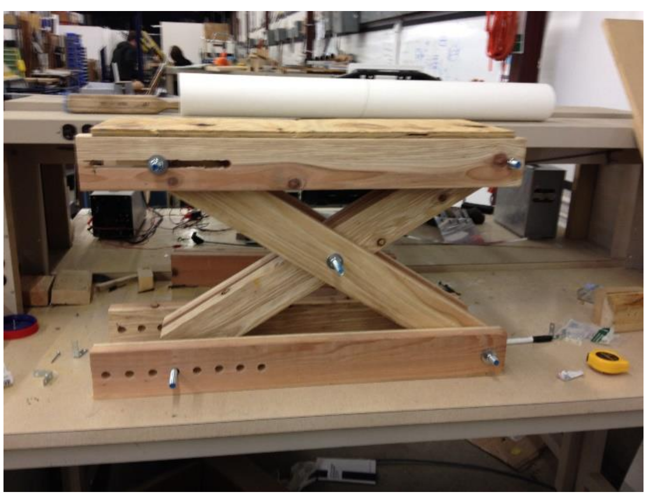
<u>Wooden Crib-It</u>

The purpose of this was to determine the stability and scale for how the large the final prototype could be. The prototype, built to a 1:2 scale, represented a final product that would be 6 feet long and therefore too large to meet the target dimensions.



<u>Wooden Scissor Ninja</u>

The purpose of this was to determine the stability and scale for how the large the final prototype could be. The prototype was built to full scale in terms of length, width, and height, but is not representative of how the final product should lay flat nor the size of the beams to be used. It was determined that it was a stable design and to move forward with further prototyping.

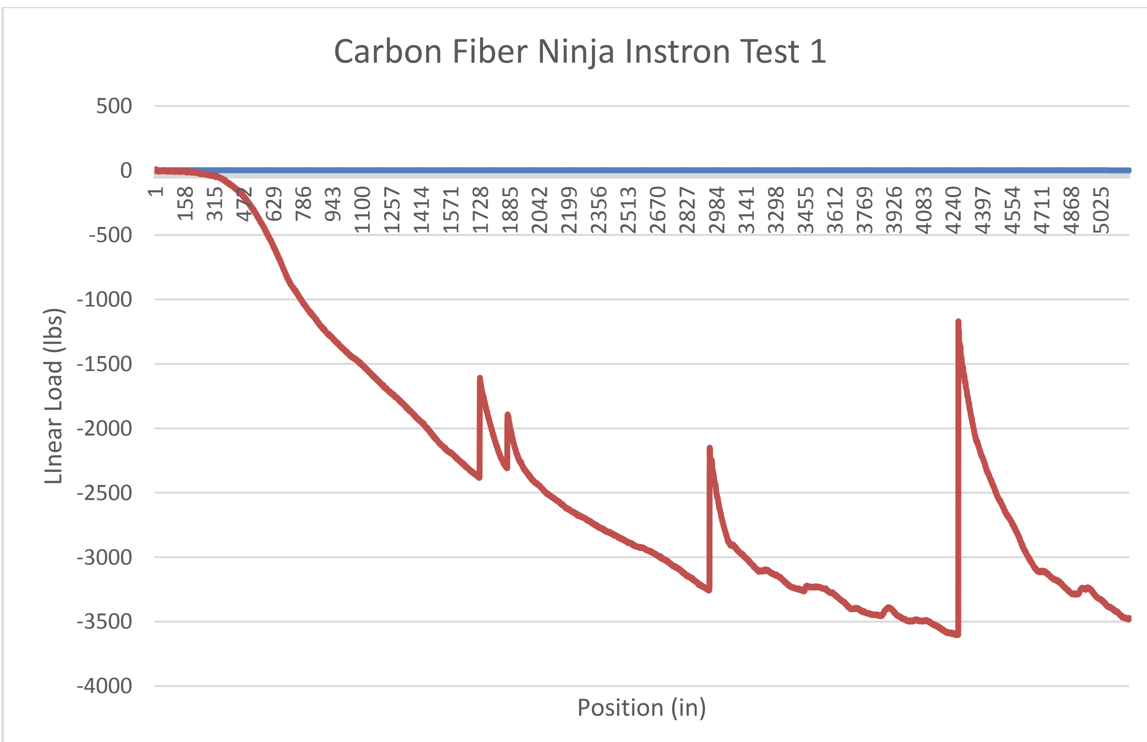


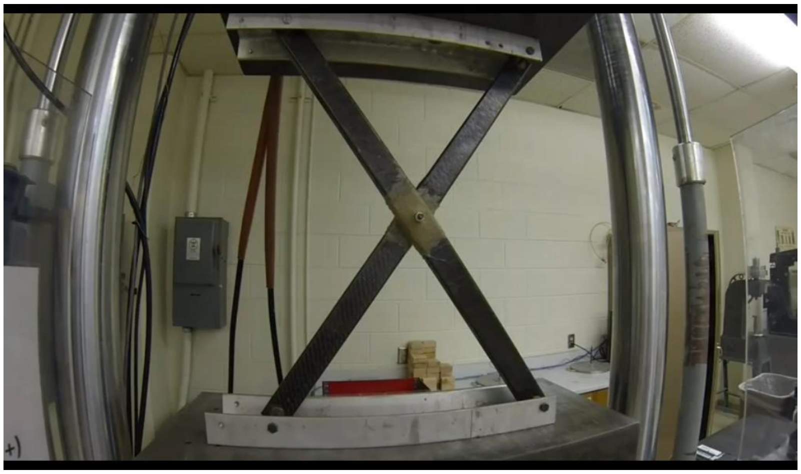
Carbon Fiber Pinned Beams Half Ninja

The purpose of this prototype was to test how much weight 2 carbon fiber pillars could stand at full lift height. Because of this purpose, the prototype was not given adjustable height ability. It is built from 2”x1”x24” carbon fiber pillars. The prototype held roughly 2400 lbs before shearing in the carbon fiber began at the pin joints. It held up to 3600 lbs before the test was stopped to prevent possible damage/injury to surrounding machinery and people. Each drop in capacity after 2400 lbs was due to the pins beginning to shear through the carbon beams.

We learned from this prototype that the carbon fiber will need to be protected from the pins so that shearing will not limit the capacity.

This graph represents the load vs. position. Shearing can be seen as the line suddenly jumps and as its slope becomes erratic towards the end of the test.



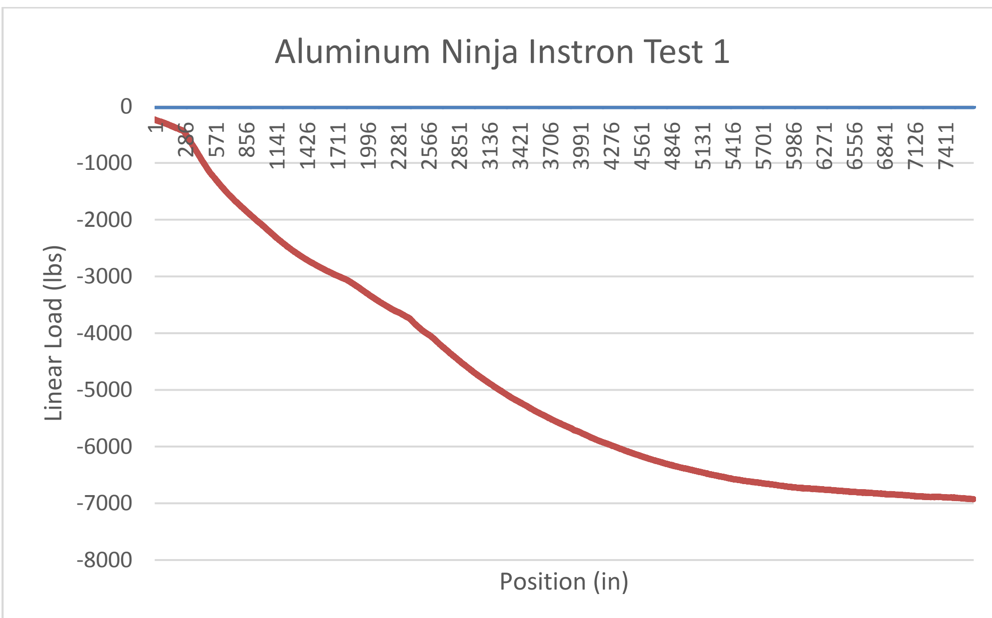


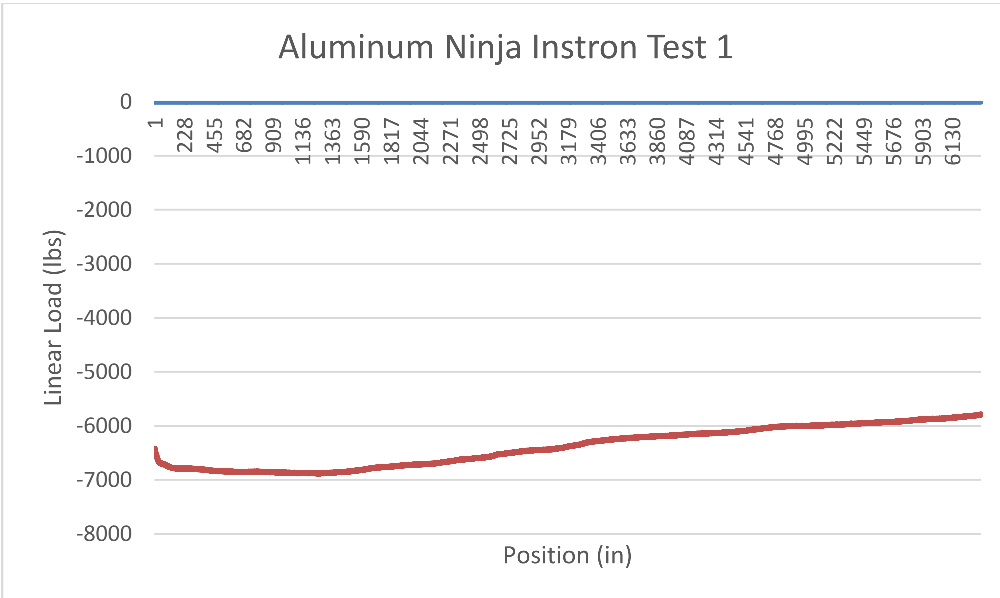
Aluminum Pinned Beams Half Ninja

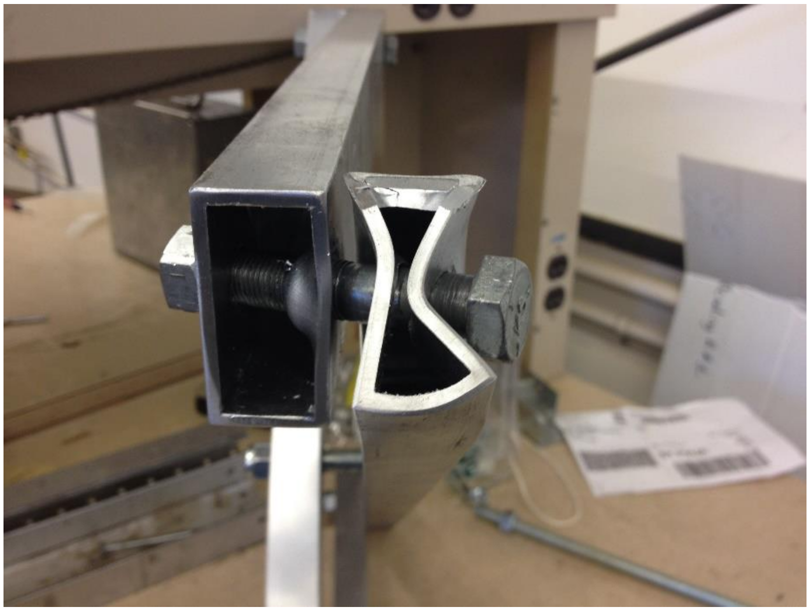
This prototype was built to determine if using aluminum and larger diameter pins would improve the ninja's ability to withstand shear at the pins. It was built using ½" bolts and 1"x2" 6061 aluminum hollow pillars. This prototype was also designed to sit at 20" without height adjustability.

It held roughly 7000 lbs before plastic deformation began. The test was allowed to continue past this point in order to create visually noticeable deformation so that we could see the areas needing modification. Deformation is concentrated at the pinned joints of the prototype with the pins themselves remaining intact.

We learned that the pins are still the greatest weakness thus far. However, the aluminum held a greater capacity and we are moving forward with creating an aluminum sleeve at the pins for the carbon pillars. This should hopefully allow the stress to pass through the pillars without stress concentration at the pins.




Aluminum Ninja Instron Test 1
0
-1000
-2000
-3000
-4000
-5000
-6000
-7000
-8000
Linear Load (lbs)
1
228
455
682
909
1136
1363
1590
1817
2044
2271
2498
2725
2952
3179
3406
3633
3860
4087
4314
4541
4768
4995
5222
5449
5676
5903
6130
Position (in)



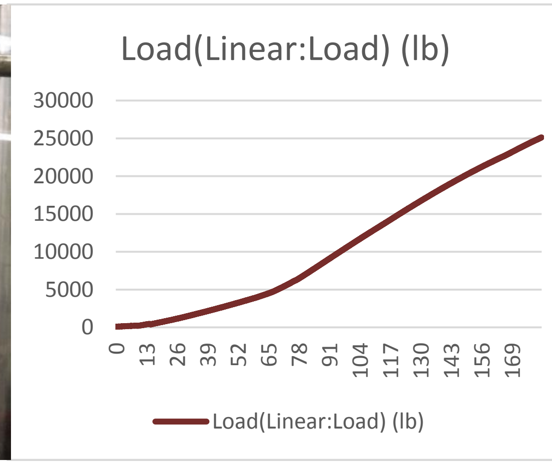
Final Selected Carbon Fiber Beam Compression Testing

This single beam was used to test the compressive strength of the carbon fiber beam that was going to be used in the final Ninja as well as to determine if the aluminum end caps designed to eliminate the need for drilling in the pillar.

The beam failed in compression at 7,000 lbs which did not meet the compression requirements desired. Also, with the solid aluminum end caps attached, the total beam weighed more than simply using an all-aluminum beam with no end caps. The beam will be all 6061 aluminum with pockets machined out to reduce weight.

Final Prototype Testing:

We loaded the final prototype in the Instron (see image below) and loaded it at various shoring heights. We loaded the Instron up to 26,00 lbs and the Ninja was able to hold the load without major deflection or any failures. We opted not to load the Ninja to the full 50,000 lbs in order to preserve the prototype for the final competition in Tennessee, however we are confident that it can hold much higher than the 26,000 lbs before failure due to the failure analysis we conducted (in **Appendix C**).



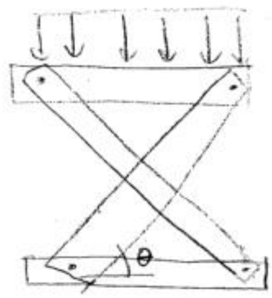
We weighed the final design with a digital scale and found that it weighs 42 lbs, which is higher than our initial goals. We also practiced operating the device, and it is simple to use. Once you place it under the load, it automatically shores to the height of the lift, and it can be easily retracted and closed by one operator, thus fulfilling those key design requirements.

Overall, we have verified that the autoshore has fulfilled all except for the weight requirements of our key design requirements. We have checked the information in this document and found that it contains all pertinent transferrable information for someone to recreate this device, and we have validated this final design with fire rescuers and Pararescue Jumpers.

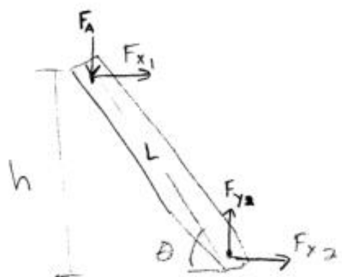
Appendix C: Auto-Shore Beam Force Analysis

The hand calculations for failure in the legs or beams of the Auto-shore Ninja can be seen below. This first calculation is to determine the forces that the main leg beams experience, and then to determine its possible failure modes by inputting values into an excel document.

Autoshore Force Analysis



$F_{Total} = 50{,}000$ lbs



Z-Axis at (1)

$F_{y_2} L\cos\theta + F_{x_2} L\sin\theta = 0$ (1)

Y-Direction

$F_{y_2} - F_A = 0$

$F_{y_2} = F_A = \frac{F_T}{2} = \frac{50{,}000}{2} = 25{,}000$ lbs (2)

sub (2) into (1)

$25{,}000 \text{ lb } L\cos\theta + F_{x_2} L\sin\theta = 0$

$F_{x_2} = -\frac{25{,}000\cos\theta}{\sin\theta} = \frac{-25{,}000}{\tan\theta}$ (3)

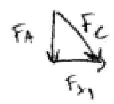
X-Direction

$F_{x_1} + F_{x_2} = 0$

$F_{x_1} = -F_{x_2}$ (4)

$\theta = \sin^{-1}\left(\frac{h}{L}\right)$

Compression Force



$$F_A^2 + F_{x_1}^2 = F_C^2$$

$$F_C = \sqrt{F_A^2 + F_{x_1}^2} \quad (5)$$

$$F_C = \sqrt{25{,}000^2 + \left(\frac{25{,}000}{\tan\theta}\right)^2} \quad (6)$$

Compressive Stress:

$$P_c = \frac{F}{A} = \frac{F_c}{A}$$

Buckling

$$P_{cr} = \frac{C\pi^2 EI}{L^2}$$

$C = 1$ for Pinned-Pinned

$$I_x = \frac{bh^3}{12}$$

$$I_y = \frac{hb^3}{12}$$

This table was used to determine the minimum and maximum angles the leg would move through in order to achieve full motion from rest to a shoring height of 20 inches.

Ratchet Length Table				
Shoring Heights	Actual Height	Theta	Ratchet Length	Delta
3	5	7.18	23.81	0.15
4	6	9.59	23.66	0.65
6.8	8.8	16.46	23.02	1.02
9.6	11.6	23.58	22.00	1.45
12.4	14.4	31.11	20.55	1.98
15.2	17.2	39.30	18.57	2.70
18	20	48.59	15.87	

As can be seen from the table above, the minimum angle the legs would experience is 7.18 degrees, and the maximum angle is 48.59 degrees, which we will conservatively round up to 50 degrees.

We know that each of the 4 beams of the device need to hold 1/4th of the load, so each beam needs to hold 12,500 lbs in the y-direction to reach the total applied force of 50,000 lbs for each auto-shore. Using statics from the above hand calculations, we were able to determine what compressive forces the beam will feel at various degrees. Here are the results.

Theta (degrees)	Theta (rad)	Fy	FX	Calculated Compressive Force
7.18	0.125	12500	99226.23	6299.397415
10	0.175	12500	70891.02	6346.416324
15	0.262	12500	46650.64	6470.476128
20	0.349	12500	34343.47	6651.111078
25	0.436	12500	26806.34	6896.111994
30	0.524	12500	21650.64	7216.878365
35	0.611	12500	17851.85	7629.84118
40	0.698	12500	14896.92	8158.795558
45	0.785	12500	12500	8838.834765
50	0.873	12500	10488.75	9723.273918

From this, you can see that the maximum compressive force that each leg or beam will feel is 9,723 lbs which we will once again round up to 10,000 lbs to be conservative.

Using these applied forces, we analyzed potential beam geometries for possible failure modes in:

1) Shear Compression (at maximum stress concentrations where the pins will be located)
2) Buckling in the x-axis
3) Buckling in the y-axis

The results can be seen below:

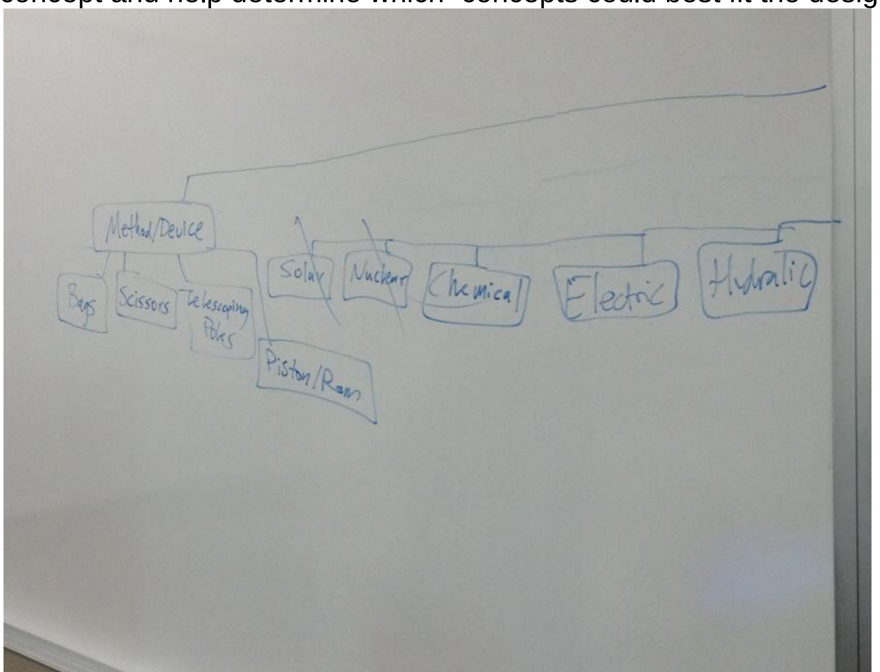
Failure Analysis on Possible Beam Geometries				
	Square I-beam	Channel Beam	Rectangular Stock	Units
b	1	1	1.5	in
h	1	1	1	in
E	10000000	10000000	10000000	psi
L	24	24	24	in
t	0.25	0.25	n/a	in
d	1.5	1.5	n/a	in
s	0.25	0.25	n/a	in
C (pinned-pinned)	1	1	1	n/a
Area	0.75	0.75	1.5	in^2
Volume	18	18	36	in^3
Density	0.0975	0.0975	0.0975	lb/in^3
Extra volume for bolt material	3.75	3.75	3.75	in^3
Extra weight for bolt material	0.366	0.366	0.366	lb/in^3
Weight/leg	2.121	2.121	3.876	lb
Weight for 4 legs	8.483	8.483	15.503	lb
Ixc	0.219	0.219	0.281	in^4
Iyc	0.043	0.066	0.125	in^4
Pcr(x)	37482.22	37482.22	48191.43	lb
Pcr(y)	7362.58	11378.53	21418.41	lb
Compressive Load (Max)	10000.00	10000.00	10000.00	lb
Compressive Stress (Max at Hole)	14545.45	14545.45	6956.52	psi
Compressive Yield Strength	40000	40000	40000	psi
Compressive Failure Factor of Safety	2.75	2.75	5.75	n/a
Critical Buckling (x axis) safety factor	3.75	3.75	4.82	n/a
Critical Buckling (y axis) safety factor	0.74	1.14	2.14	n/a

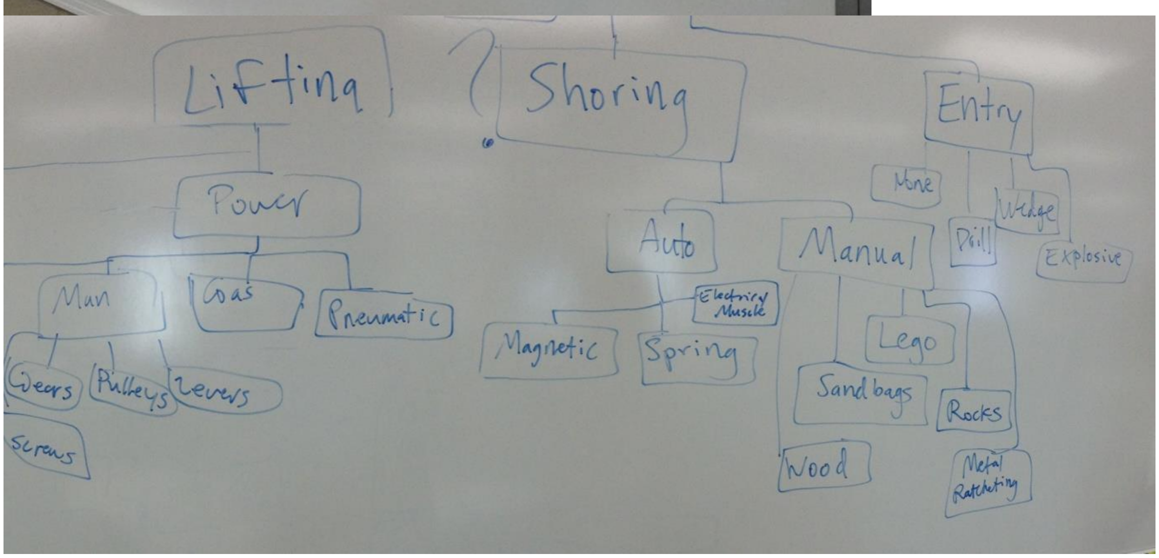
In the above table, you can see the areas in red which preclude the two beam geometries from being an ideal candidate for the beam. The square I-beam cannot withstand the buckling load in the y-axis direction. The rectangular stock far exceeds the maximum allowable weight, which is

15 lbs for the entire assembly. As can be seen above, the channel beam is the ideal candidate for the beam geometry because it can withstand all possible failure modes, with a safety factor of more than 1. Also, since the calculated loading is already twice the applied loading, there is a built in safety factor of 2 already.

Appendix D: Concept Generation and Selection

After establishing the problem, the team moved forward to the concept development stage. In this stage, the team used methods including benchmarking, various brainstorming methods and communication with experts in several lifting technologies. After generating a large solution set, the team used a Concept Classification Tree to organize the concepts and to expand unexplored paths. From this, we were able to narrow down the concepts by pruning less promising branches. After getting the concepts down to the top 5 ideas, the team utilized a screening matrix to rate each concept and help determine which concepts could best fit the design requirements.





From this, we narrowed our solution set down to the top three concepts of pneumatic, hydraulic, mechanical), which we further investigated with engineering modeling, prototyping, and testing.

After extensive modeling, prototyping, and testing, the team selected to use an airbag for the final lifting concept with the aid of a decision matrix (see figure 8). The reasons for selecting an airbag are:

- Large lifting capacity
- Can achieve desired lift height in one single lift
- Distributes forces over large surface area on the load (this is critical when lifting vehicles that don't have a solid lift point readily accessible, or when dealing with aircraft that are relatively fragile)
- Large footprint gives stability under load
- Very collapsible and portable
- Can be used multiple times
- Versatile (can be stacked to gain greater height, can spread as well as lift, can lift on various surfaces)
- Can be operated at safe distances from load

The relatively few disadvantages to this kind of system are that it is limited to whatever compressed air source is available on hand and the airbags can be punctured by any number of possibilities and rendered useless. These conclusions made it clear that an airbag was going to be the optimal lifting concept.

	Benchmark (Current System)	Mechanical Device (Tripod)	Triangle Hydraulic	High Pressure Smores	Jack Stands powered by Jaws	High Pressure Bags
t lIfts a variety of large objects	=	-	=	+	=	=
t has high lift weight capability	=	+	+	+	+	+
t lifts objects to adjustable height	=	+	+	+	+	+
t lifts objects to a useful height	=	=	=	=	=	=
sertion Height	=	=	-	=	-	+
t can operate lift and lowering quickly	=	=	-	=	=	=
t has adjustable lift and lowering rate	=	=	=	=	-	=
t is operational in extreme temperatures	=	+	+	=	+	=
t is operational at high altitude	=	=	=	=	=	=
t withstands damage during operation	=	+	+	+	+	=
t functions on extreme terrains	=	-	=	=	-	+
t functions on extreme slopes	=	-	+	+	-	=
t operable by one person	=	=	=	=	=	=
t is capable of being carried by one person	=	=	=	=	=	=
t is light weight	=	+	=	=	+	+
t has compact packaging	=	+	+	+	=	+
t is safe for operator use	=	-	=	=	-	=
t distributes load over an larger area	=	-	-	-	-	-
t can be quickly packed and unpacked	=	=	=	=	=	=
t is reusable	=	+	+	=	+	=
t is easy to use	=	=	=	=	=	=
umber of +'s	0	7	7	6	6	6
umber of ='s	21	9	11	14	9	14
umber of -'s	0	5	3	1	6	1
et Score	0	2	4	5	0	5
ecision		Develop with Bags				Pursue

Figure 5: Decision Matrix

Appendix E: Failure Modes and Effects Analyses

Airbag

Hazard	Cause	Effect	RPC	Countermeasure	RPC after
Airbag deflation	Puncture from sharp/abrasive load	Load falls gradually, personnel under load killed or severely disabled	1, catastrophic, occasional	Chose abrasion resistant material for airbag material and examine lift site to ensure no sharp protrusions exist.	2, Catastrophic, Remote
	Ruptured hose	Load falls gradually, personnel under load killed or severely disabled	1, catastrophic, occasional	Visually inspect hoses before lift to detect any ruptures. Pressure tests will be conducted on system prior to competition.	3, Catastrophic, extremely improbable
	Connection failure resulting in quick deflation	Load falls gradually, personnel under load killed or severely disabled	2, catastrophic, remote	Visually inspect couplings before lift to detect any defects or damage. Pressure tests will be conducted on system prior to competition.	3, Catastrophic, extremely improbable
	Material failure from contact with corrosive chemicals	Load falls gradually, personnel under load killed or severely disabled	1, catastrophic, occasional	Bag material will be made of chemically resistant materials. And if possible, place bag on lift surface free of chemicals.	3, Catastrophic, extremely improbable
	Defect in material	Load falls gradually, personnel under load killed or severely disabled	2, catastrophic, remote	Visually inspect airbag material before lift to detect any defects. Pressure tests will be conducted on system prior to competition.	3, Catastrophic, extremely improbable
Airbag burst	Regulator fails	Airbag bursts, load falls rapidly, personnel under load killed or severely disabled	1, catastrophic, occasional	Overpressure valve will be installed that will allow for an amount of air equal to the greatest amount of air that flows through regulator to be passed through it.	3, Catastrophic, extremely improbable

		Airbag bursts, personnel in proximity to airbag severely injured by flying debris	1, catastrophic, occasional	Overpressure valve will be installed that will allow for an amount of air equal to the greatest amount of air that flows through regulator to be passed through it. Operators will also stand behind the blast shield.	3, Catastrophic, extremely improbable
	Over pressure valve fails	Airbag bursts, load falls rapidly, personnel under load killed or severely disabled	1, catastrophic, occasional	Should the overpressure valve not function as the correct pressure, there will be shutoff valves that allow for the termination of air flow into the bag, preventing continued over inflation. There will be a pressure gauge that will indicate whether or not the airbag is above the prescribed safe operating pressure.	3, Catastrophic, extremely improbable
		Airbag bursts, personnel in proximity to airbag severely injured by flying debris	1, catastrophic, occasional	Should the overpressure valve not function as the correct pressure, there will be shutoff valves that allow for the termination of air flow into the bag, preventing continued over inflation. There will be a pressure gauge that will indicate whether or not the inflatable is above the prescribed safe operating pressure. Operators will also stand behind the blast shield.	3, Catastrophic, extremely improbable

	Severe puncture from load	Airbag bursts, load falls rapidly, personnel under load killed or severely disabled	1, catastrophic, occasional	Airbag material will be abrasion resistant. If at all possible, upon visual inspection, the bag will not be used to lift the load in an area with sharp protrusions.	2, Catastrophic, Remote
		Airbag bursts, personnel in proximity to airbag severely injured by flying debris	1, catastrophic, occasional	Airbag material will be abrasion resistant. If possible, lift area will be checked and determined free of sharp protrusions. Finally, operators will stand behind blast shield.	2, Catastrophic, Remote
Load shifts	Poor bag placement	Load falls, personnel under load killed or severely disabled	1, catastrophic, reasonably probable	Load will be lifted slowly with continual assessment to insure stability. Load will also be shored with provided shoring materials.	2, Catastrophic, Remote
	Uneven terrain	Load falls, personnel under load killed or severely disabled	1, catastrophic, reasonably probable	Load will be lifted slowly with continual assessment to insure stability. Load will also be shored with provided shoring materials.	2, Catastrophic, Remote
Air cylinder ruptures	Damage from impact	Explosion, personnel injured/killed	2, catastrophic, remote	Care will be used in the transport and handling of the air cylinder.	3, Catastrophic, extremely improbable
	Material flaws	Explosion, personnel injured/killed	1, catastrophic, occasional	Air cylinder will be pressure tested before the competition.	3, Catastrophic, extremely improbable

Air hose fails	Sharp/abrasive edges	Bag deflates - personnel under load injured/killed	1, catastrophic, occasional	Lift area will be checked for sharp protrusions and air hose will be kept clear of those areas. Hose material will be abrasion resistant.	3, Catastrophic, extremely improbable
		Free hose causes minor injury to personnel	1, catastrophic, occasional	If at all possible, upon visual inspection, the hose will be operated away from any sharp protrusions. Hose material will be abrasion resistant. Operators will stand behind blast shield.	3, Catastrophic, extremely improbable
	Overpressure	Bag deflates - personnel under load injured/killed	1, catastrophic, occasional	Hose will be rated to withstand pressures greater that airbag. Air cylinder will also have a regulator that will ensure the hoses are not pressured above what they are safely rated for. There will also be a pressure gauge for visual monitoring as well as an overpressure valve that will ensure the pressure is not too great.	3, Catastrophic, extremely improbable

		Ruptured hose causes mild injury to personnel	3, marginal, occasional	Hose will be rated to withstand pressures greater that airbag. Air cylinder will also have a regulator that will ensure the hoses are not pressured above what they are safely rated for. There will also be a pressure gauge for visual monitoring as well as an overpressure valve that will ensure the pressure is not too great. Operators will stand behind the blast shield.	3, marginal, extremely improbable
Personnel Pinned between bag and load	Operator error	Sever injury/death to pinned personnel	2, catastrophic, remote	Before any lifting, operators will inspect the lift site to ensure that all personnel are clear before operating lift bag.	3, Catastrophic, extremely improbable

Auto-Shore Ninja

Hazard	Cause	Effect	RPC	Countermeasures	RPC After
Overload of auto shore	Failure of components	Load falls and injures rescue personnel	1	Place sand bags as backup shoring in competition setting.	3
Tip over of auto shore	Imbalanced load	Load falls/shifts and injures rescue personnel	1	Personnel stand off a safe distance of 22 feet. Lifted object is secured using ropes and stakes.	3
Auto shore does not lift with the load	Failure of auto lift or ratcheting mechanisms	Auto shore does not shore load	1	Place sand bags as backup shoring in competition setting.	3
Auto shore cannot be removed	Airbag cannot lift auto shore sufficiently to be unlocked	Load cannot be lowered evenly. Possible tipping causing injury to rescue personnel.	1	Have additional airbag on hand to lift load off of auto shore locks	3

Appendix F: Project Contract

Project Contract

Team 1 - BYU Heavy Lifters

Air Force Research Laboratory

October 1, 2013

Capstone 2013-2014

Ira A. Fulton College of Engineering and Technology

Brigham Young University

Contract Version 1.3

This contract defines the arrangement between AFRL and the Brigham Young University Capstone Team #1, also called BYU Heavy Lifters. This contract outlines a plan where the AFRL Heavy Lift Rescue and Recovery Competition requirements can be met by BYU Heavy Lifters. This plan includes a timeline of milestones which will guide the team to progress through the phases of product development; it also includes a product budget and a requirements matrix.

Project Objective Statement

Design, build, and test a heavy lifting device that can lift vehicles, aircraft, and fallen structures up to 45,000 lbs and weighs less than 30 lbs by April 17, 2013 for less than $14,000.

Stakeholder Information

Project Owner: Air Force Research Laboratory

Name	Title	Email	Phone
Devon Parker	Senior Manager Turbine Test Facility Planning	jonathan.parker.14@us.af.mil	931-454-5291

Project Team: BYU Heavy Lifters

Name	Title	Email	Phone
Ethan Grabau	Mechanical Engineer	ethangrabau@gmail.com	713-560-4102
Jake Later	Mechanical Engineer	jakoblater27@gmail.com	801-580-5220
Matthew Palmer	Mechanical Engineer	palmer.matthew88@gmail.com	702-985-7385

Nathan Harris	Applied Physics	Nathan.g.harris@gmail.com	801-703-4355
Taylor Eatough	Manufacturing Engineer	tayloreatough@gmail.com	801-310-8851
Trey Nelson	Manufacturing Engineer	trey.d.nelson@gmail.com	801-473-4045
Van Rogers	Coach	vrog1019@gmail.com	801-372-5546

Project Organizer and Sponsor: BYU Capstone

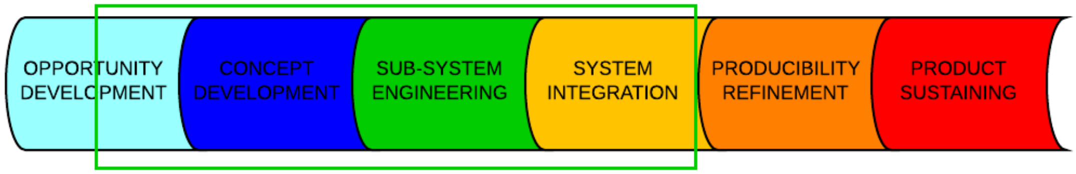
Name	**Title**	**Email**	**Phone**
Chris Mattson	Capstone Director	mattson@byu.edu	801-422-6544
Carl Sorensen	Capstone Co-Director	carl_sorensen@byu.edu	801-422-0516
Paula Harper	Capstone Administrative Assistant	paulah@byu.edu	801-422-2894
Jim Trent	External Relations Manager (Sponsor)	jim.trent@byu.edu	801-830-5225

Project Scope

BYU Heavy Lifters plan to develop this product from the opportunity development stage through system integration. The team plans to deliver a fully functional prototype for the AFRL Heavy Lift

Rescue and Recovery Competition on April 20th, and the transferable documentation to fully reproduce the product.

Product Development



Market Surrogates

Provo Fire and Rescue:

Deputy Chief Tom Augustus

Firefighter/paramedic Jason Branson

Para rescue Jumpers

Search and Rescue

Development Milestones:

2013	Date

Project Contract Submitted for Heavy Lifting Device	October 4
Review Concept Prototype for Heavy Lifting Device with Capstone Faculty	October 18
Select Lifting Concept and Review Transferability of Concept with Capstone Coach	October 30
Review Lifting Mechanism Prototype with Capstone Faculty	November 15
Calculated concept load capacity of 45,000 lbs	November 20
Safety Validation with Provo Fire Department to approve lifting of small car	December 4
Lift a small car with prototype	December 11
Review report that captures desirability and transferability with two coaches	December 12
2014	**Date**
Air Force design review	January 10
Submit lifting and shoring design to manufacturing	January 30
Lift Semi Truck	March 20
Fire Rescuers test lifting mechanism on rolled car	March 27
Review report capturing desirability and transferability with Capstone Faculty	April 3
Win optimized lifting competition	April 17

Requirements Matrix

See next page for full requirements matrix.

Subsystem:	Surrogate Evaluation Criterion (How to measure)	Load weight	Load distribution area	Adjustable Height	Time to deploy	Time to repack	Rate of Lowering	Rate of lifting	Highest Temperature Use	Lowest Temperature Use	Usable altitude	Resistant to petroleum chemicals	Operation Slope	Device works on loose gravel	Required number of operators	Weight of product	Volume of kit when packed	Longest Dimension	Operator Distance from Vehicle	# of potential hazard areas on device	Number of avg. lifts before energy source is exhausted	Displacement from original position	Time to learn to use	# of steps during use	Cost of Materials + Manufacturing
#	Market Requirement (What is wanted)	#	1	2	3	4	5	6	7	8	9	10	11	12	13	12	15	16	17	18	19	22	23	24	25	26
1	Kit lifts a variety of large heavy objects		X	X																						
2	Kit lifts objects to adjustable height				X																					
3	Kit lifts objects to a useful height																									
4	Kit can be operated quickly				X	X	X																			
5	Kit has adjustable lift and lowering rate							X	X																	
6	Kit is operational in extreme temperatures									X	X															
7	Kit is operational at high altitude											X														
8	Kit withstands damage during operation												X								X					
9	Kit functions on extreme terrains and slopes													X	X											
10	Kit operable by one person															X										
11	Kit is capable of being carried by one person																X	X	X							
12	Kit is light weight																X									
13	Kit has compact packaging																	X	X							
14	Kit is safe for operator use																			X						
15	Kit distributes load over an large area			X																						
16	Kit can be quickly packed and unpacked					X	X																			
17	Kit is reusable																					X				
18	Kit allows for safe shoring							X	X																	
19	Kit is easy to use					X																		X	X	
20	Kit has a reasonable cost																									X
21	Vehicle remains stable																						X			
		Unit of measurement	lbs	in ^2	in	Min	Min	in/ sec	in/ sec	deg F	deg F	feet above sea level	Bool	deg F	Bool	# of users	lbs	in^3	in	ft	count	count	ft	min	count	dollars
	Market desired values	Marginal	45k	36	20	5	3	0.3	0.1	130	-40	10k	No	30	Yes	2	50	1750	20	2	1	1	1	5	15	5000
		Ideal	55k	576	24	2	1	6	2	300	-100	15k	Yes	50	Yes	1	10	72	12	8	0	100	0.5	3	3	1500
		Target	45k	?	20	3	2	2	1	250	-40	15k	Yes	30	Yes	1	30	1750	20	6	0	2	0.5	3	15	5000

Development Budget:

Material/Manufacturing	Cost	Credit	Balance
Capstone Allotment		14,000	14,000
Pre-Competition Prototypes	5000		9,000
Competition Prototype	4000		5,000
Travel Expenses to Final Competition	5000		0

Fall and Winter Grading Criteria:

Fall Semester:

Critical Design Requirement (1-3 Scale of Importance)	**A**	**B**	**C**
1 Concept Load Capacity	20k+ lbs	10-19k lbs	5-9k lbs
1 Concept Lift Kit Size	Design can be carried by one person	Design can be carried by two people	Design is carried by 3 or more people
2 Concept Lift Kit Weight	Design has a final weight of 30 lbs or less	Design has a final weight of 31-60 lbs	Design has a final weight of 60lbs+
3 Concept Kit Deployment Time	Design has deployment time of 3 min or less	Design has deployment time of 5 min	Design has deployment time of more than 5 min
3 Concept Ease of Use for End User	Market surrogate is excited using design	Market surrogate are satisfied with the design	Market surrogate is not interested in the design

Winter Semester:

Critical Design Requirement (1-3 Scale of Importance)	**Element Importance**	**A**	**B**	**C**
Load Capacity	1	Kit lifts and shores 45k lbs +	Kit lifts and shores 20-44k lbs	Kit lifts and shores 10-19k lbs
Lift and Shoring Kit Size	1	Carried in one Pararescue Jumper Backpack	Carried in two Pararescue Jumper Backpack	Carried in three Pararescue Jumper Backpack
Lift Kit Weight	2	30 lbs or less	31-60 lbs	60-90 lbs
Shore Kit Weight	2	15 lbs or less	25 lbs or less	40 lbs or less
Kit Deployment Time	3	3 min	5 min or less	10 min or less
Ease of Use for End User	3	Market surrogates are excited with the function, packaging and controls of kit.	Market surrogates find kit and function acceptable.	Market surrogates are not interested in functionality or controls of the kit

Signatures

BYU Heavy Lifters

____

Ethan A. Grabau

____

Jake Later

____

Nathan Harris

____

Taylor Eatough

____

Trey Nelson

____

Van Rogers (Coach)

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Matthew Palmer

Capstone Administration

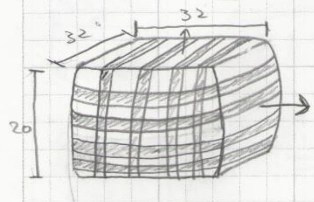
____

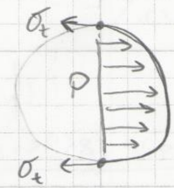
____

Jim Trent (Sponsor)

Appendix G: Airbag Hand Calculations

Assume bag is cylindrical





Perimeter of air bag = Circumference of cylinder

$4(32") = \pi D$

$D = 40.74$ in (Equivalent diameter)

Assume: Nylon strap: width = 2in
thickness = .07in
breaking strength = 6000 lbs

4 straps each direction, neglect strength of coated fabric

Hoop stress (Around Circumference of air bag)

Force = Pressure x Diameter x height

$F_{hoop} = 50\,psi\,(40.74\,in)\,20\,in = 40740\ lb$

Breaking strength of horizontal straps = $4\ straps\,(2\ points/strap)\ 6000\ lbs/point = 48000\ lb$

Factor of safety $n = \frac{\text{Breaking strength}}{\text{force at } 50psi} = \frac{48000}{40740} = \underline{1.18}$ horizontal straps will not fail until after 50psi

Pressure * Area = Breaking strength

$P(D*h) = \#\text{of straps} * 2\ points/strap * \text{breaking strength}/strap$

$P(40.74*20\ in) = 4(2)\,6000\ lbs$

$\underline{P = 58.91\ psi}$ ← Pressure at strap failure

BYU | CAPSTONE

Signature Date

Appendix H: Airbag Cuboid Optimization

Cube Shaped Bags													
L	W	H	Volume (Cu Ft)	Psi to lift 10,000 lbs	Volume @ 10,000 lbs (Cu Ft)	Psi to lift 15,000 lbs	Volume @ 15,000lbs (Cu Ft)	Psi to lift 20,000 lbs	Volume @ 20,000 lbs (Cu Ft)	Psi to lift 22,500 lbs	Volume @ 22,500 lbs (Cu Ft)	Psi to lift 25,000 lbs	Volume @ 25,000 lbs (Cu Ft)
36	36	24	18.00	7.72	27.45	11.57	32.17	15.43	36.90	17.36	39.26	19.29	41.62
34	34	24	16.06	8.65	25.50	12.98	30.23	17.30	34.95	19.46	37.31	21.63	39.68
32	32	24	14.22	9.77	23.67	14.65	28.39	19.53	33.12	21.97	35.48	24.41	37.84
30	30	24	12.50	11.11	21.95	16.67	26.67	22.22	31.40	25.00	33.76	27.78	36.12
28	28	24	10.89	12.76	20.34	19.13	25.06	25.51	29.79	28.70	32.15	31.89	34.51
26	26	24	9.39	14.79	18.84	22.19	23.56	29.59	28.29	33.28	30.65	36.98	33.01
24	24	24	8.00	17.36	17.45	26.04	22.17	34.72	26.90	39.06	29.26	43.40	31.62
22	22	24	6.72	20.66	16.17	30.99	20.89	41.32	25.62	46.49	27.98	51.65	30.34
20	20	24	5.56	25.00	15.00	37.50	19.73	50.00	24.45	56.25	26.81	62.50	29.18
36	36	20	15.00	7.72	22.87	11.57	26.81	15.43	30.75	17.36	32.72	19.29	34.68
34	34	20	13.38	8.65	21.25	12.98	25.19	17.30	29.13	19.46	31.10	21.63	33.06
32	32	20	11.85	9.77	19.73	14.65	23.66	19.53	27.60	21.97	29.57	24.41	31.54
30	30	20	10.42	11.11	18.29	16.67	22.23	22.22	26.16	25.00	28.13	27.78	30.10
28	28	20	9.07	12.76	16.95	19.13	20.88	25.51	24.82	28.70	26.79	31.89	28.76
26	26	20	7.82	14.79	15.70	22.19	19.63	29.59	23.57	33.28	25.54	36.98	27.51
24	24	20	6.67	17.36	14.54	26.04	18.48	34.72	22.41	39.06	24.38	43.40	26.35
22	22	20	5.60	20.66	13.48	30.99	17.41	41.32	21.35	46.49	23.32	51.65	25.29
20	20	20	4.63	25.00	12.50	37.50	16.44	50.00	20.38	56.25	22.35	62.50	24.31
32	32	18	10.67	9.77	17.75	14.65	21.30	19.53	24.84	21.97	26.61	24.41	28.38
21	21	10	5.20	22.68	13.22	34.01	17.23	45.35	21.24	51.02	23.25	56.69	25.25

Appendix I: Airbag Prototyping and Testing

The purpose of this document is to describe each prototype made, its purpose, and the reasons for failure.

<u>Mylar Balloons</u>

These prototypes were used to get a visual and conceptual idea of what the airbags would generally look like. They also gave us an idea of how they could stack together in order to increase the lift height. These were never intended for more than a visual aid.

<u>Pillow Bag #1</u>

This was purchased from an underwater salvage company. They made some modifications for us (removed the overpressure valves) since this was being used in a highly unconventional way. This pillow shape design was our initial choice for geometry since it would be able to be compacted tightly. This prototype was also used to give the team some experience lifting items; the team gained great insights into the lifting process. This bag reached a burst pressure of 33 psi.

Pillow Bag #2

(see picture for Pillow Bag #3)

This bag served much the same purpose as the first pillow bag, though the workmanship was not up to par - it had multiple leaks and ultimately failed around 13 psi.

Pillow Bag #3

This pillow bag was custom made to fit our ideal dimensions. Our plan for our kit was to have four of these pillow bags in order to have two lifting points that would be able to attain the 20" lifting height desired. Ultimately this design failed for multiple reasons. We didn't want the complication of four bags and four hoses; the team felt that the amount of air required to fill all four bags was not worth carrying the required size air tank and the geometry of the bag meant that as you lifted in height you lost lifting area (much like a high pressure spherical lift bag). This burst at 44 psi.

Web-Enclosed Bag #1

After scrapping the pillow bag idea, we pursued a web cage design that would theoretically serve the purpose of constraining the bag and allowing for greater pressures as well as a more cubic geometric shape. The main purpose of this bag was to validate our calculations. It is over the team's desired weight and size, but the main idea was to see if the web cage actually gave an advantage. This bag burst at 34 psi due to failure in the sewing of the web cage. If the sewing had been stronger than this bag would have been able to hold much for air. During tensile strength validation tests of the webbing and the sewing job, we found the webbing material to break at roughly 5500 lbs. We found the sewed seems with butt joints to break anywhere between 1600 and 2400 lbs. This gave further emphasis to the fact that the sewing was the failure mode.

Web-less Bag

This is the exact same inflatable that was found in the first web-enclosed bag, except without the webbing. This prototype served to benchmark our previous prototype. If this bag burst before the webbed bag did, than we would know that our design offered an advantage. This bag burst at 23 psi - validating our calculations (see **Appendix G**) and proving that our web design works.

Web-Enclosed Bag #2

During tensile strength validation tests of the webbing and the sewing job, we found the webbing material to break at roughly 5050 lbs. We found the sewed seems with overlapped joints to break at roughly 4450 lbs (some samples broke around 3550 lbs, but we feel this was due to poor placement of the straps in the machine - we don't feel these results are relevant to the actual performance of the bag under normal conditions).

Appendix J: Customer Requirements and Validation

In order to determine the customer (or end user) requirements, we determined multiple avenues for securing such information and validation. We started by contacting our local heavy lifting airbag vendors who supplied the same system as is currently used by the PJs and the army. We invited them to demonstrate their products and critically interviewed them to determine pain points, and to fully understand their solution more. This pictures below shows a demonstration from one vendor, Vetter, where he showed us some of his high pressure airbags and shoring devices.

From this, we learned about the benefits of a high pressure bag, and also the issues with stability that they can cause. It is from this interview that we first conceived the idea for an auto-shore device. We took these lessons and feedback, and then scheduled a briefing from the Provo Fire Department.

The fire chief and his officers were more than happy to show us their heavy lifting devices and even scheduled a demonstration for us where they lifted an overturned vehicle with several different methods. Some images of that trip can be seen below.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During this visit, we understood that firefighters are not our direct end users, however, they were a great market surrogate that was readily available for us to work with. One of the main differences between firefighters and PJs is their ability to carry lots of equipment, as can be seen from the photos above. Despite this, we still learned valuable information, such as the incredible amount of time it takes to shore a vehicle. This once again reinforced our concept of an auto-shore device, and we received good feedback from the fire department about it. We also learned the difficulty in balancing a load while lifting which eventually led to our decision to lift with 2 separate airbags. This all contributed to give us valuable information about customer requirements, however, the best validation came from our real end user, the pararescue jumper.

We were unable to locate any pararescue jumpers in our local area, so we scheduled conference calls with pararescue jumpers in Florida, Georgia, and Tennessee. From this, we gained extremely valuable insight about our assumptions and testing. We learned that PJs would be willing to carry extra weight for an auto-shore device and that they were excited about the idea. We also learned that they preferred having two lifting points, and that they were impartial about the method used to lift as long as it was quick, safe, and stable. We continued to validate with them as we progressed in our design, until we arrived at our final design. The ultimate validation will come when we compete in April with real PJ end user judges.

Appendix K: Basic Operating Instructions

1. Unpack kit
2. Attach controller-hose to airbag, fitting is push-to-connect (see Figure 1). Make sure that over-pressure valve plug is in place and at least hand tight (see Figure 2).
3. Slide airbag under object to be lifted. Lift on area that allows for most contact with airbag, while being sturdy enough to lift on. WARNING: Avoid sharp objects that could puncture the airbag.
4. Connect controller-hose to air cylinder (see Figure 3). If wanting to fill two airbags simultaneously first connect two-way splitter to air cylinder then connect controller hoses to each end of the splitter (see Figure 4).
5. When ready to lift, slowly open the valve on the regulator (see Figure 5). The valve on the regulator or the valve on the controller-hose can be used to control rate of lift (see Figure 6). WARNING: Do not allow more than 60 psi of pressure in the hose (see Figure 7), this may damage the pressure gauge and cause it to read improperly. WARNING: Do not exceed 25 psi in the airbag, this may cause bag to rupture. The pressure in the airbag should be checked periodically while inflating by closing the valve on the controller-hose and reading the pressure gauge. The overpressure valve will begin to release pressure from the airbag if 25psi is exceeded. If overpressure valve begins to release air, STOP filling airbag.

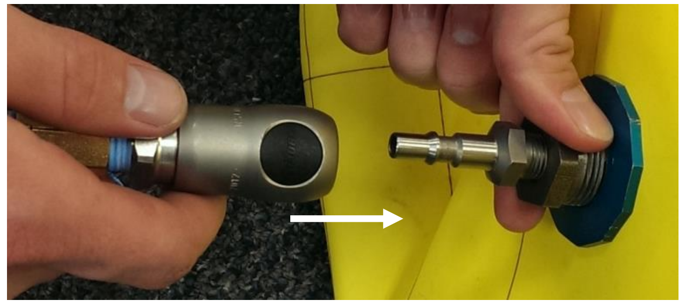

Figure 1

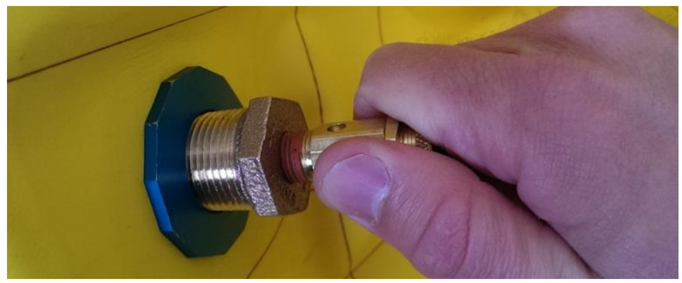

Figure 2

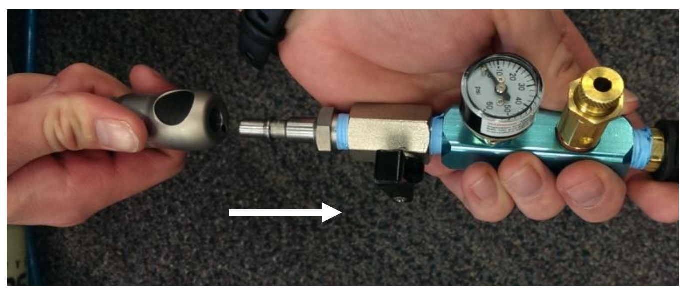

Figure 3

Figure 4

Figure 5

6. To lower the bag: remove the controller-hose from the air cylinder connection (or splitter if being used) by pushing the button on the quick-connect then use the valve on the controller-hose to control the release of air from the bag. Once bag is no longer supporting the load you may remove the over-pressure valve plug for more rapid deflation. Once deflated, be sure hand tighten plug back in place (see Figure 2).

Figure 6

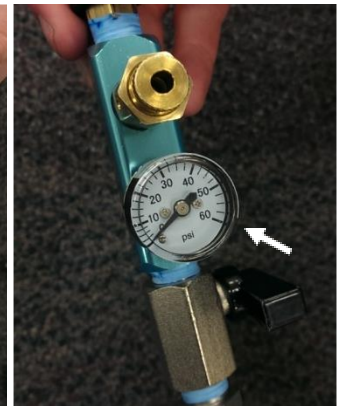

Figure 7

1.

1. Report Type

Final Report

Primary Contact E-mail

Contact email if there is a problem with the report.

mattson@byu.edu

Primary Contact Phone Number

Contact phone number if there is a problem with the report

+447517538527

Organization / Institution name

Brigham Young University

Grant/Contract Title

The full title of the funded effort.

University Engineering Design Challenge

Grant/Contract Number

AFOSR assigned control number. It must begin with "FA9550" or "F49620" or "FA2386".

FA9550-11-1-0329

Principal Investigator Name

The full name of the principal investigator on the grant or contract.

Christopher Mattson

Program Manager

The AFOSR Program Manager currently assigned to the award

Julie Moses

Reporting Period Start Date

08/01/2011

Reporting Period End Date

09/29/2014

Abstract

In each of the previous three years (2012, 2013, and 2014) a small group of senior engineering students from Brigham Young University (BYU) were selected to compete in the AFOSR Engineering Design Challenge. The teams were part of BYU's Capstone Program. As such, each team participated in two semesters of engineering design courses; the first of which was generic, and the second of which was tailored to their specific project. Each team was coached by an industry professional who worked as an adjunct professor. In 2012, the team designed, built, and tested a grappling hook like device to accent walls. The team received a significant amount of local news coverage and some national coverage. The team earned 3rd place in the 2012 competition. In 2013, a different team, designed, built, and tested a portable bridge. Again, the team earned 3rd place. In 2014, yet another team designed, built and tested a para jumper's emergency lift kit. Again the team earned 3rd place. In each case, each design team came to appreciate the complexities of the real-world design challenges faced by the Air Force and learned to develop a valuable product in that setting.

The most significant outcome, however, is the growth of the engineering student. Our goal to do the following has been accomplished because of the AFOSR funding and competition. Each student: 1) Understood and applied a structured design process to create a competitive design; 2) Understood and applied principles of project management to ensure the project is completed on time and on budget; 3) Integrated prior learning and experience to achieve high-quality engineering designs that meet the AFOSR's needs; 4) Participated synergistically as a team member to help the team succeed at the highest level; 5) Took the responsibility to learn and work independently, seeking outside help and advice as needed to complete the design project; and 6) Worked hard on a challenging project and couple that work with faith to accomplish an outstanding solution.

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None

Extensions granted or milestones slipped, if any:

None

AFOSR LRIR Number

LRIR Title

Reporting Period

Laboratory Task Manager

Program Officer

Research Objectives

Technical Summary

Funding Summary by Cost Category (by FY, $K)

	Starting FY	FY+1	FY+2
Salary			
Equipment/Facilities			
Supplies			
Total			

Report Document

Report Document - Text Analysis

Report Document - Text Analysis

Appendix Documents

2. Thank You

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