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Design of a Device for Hands-Free Tree Climbing

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Group 17: Design of a Device for Hands-Free Tree Climbing / Final Design Report

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Abstract

The URI senior capstone design Team 17 was tasked by Dr. Bahram Nassersharif to design and build a tree climbing device. It was required that said tree climbing device be: easy to operate, safe for both the operator and the tree, have hands free climbing capabilities, climb branch free trees with varying diameters between 12 and 24 inches up to 20 feet in height, have a carrying capacity up to 350 pounds, and cost less than 500 dollars to build.

Team 17 began the design process to meet these requirements by first undertaking background research into the current tree climbing devices on the market today, including patent searches and viewing found solutions from around the world. This allowed Team 17 to move forward and generate 120 design concepts, finding many potential solutions using varying power sources and mounting methodologies. From these potential solutions the team evaluated each design on the design parameters set forth. The chosen design was a human powered device with a pneumatic assistance system. This design was chosen for its ease of use, low cost to manufacture and maintain, and potential loading capabilities.

With a design chosen the team moved forward designing and redesign the device to meet the design specifications. Through testing of the various iterations of the design, engineering analysis, knowledge learned through research, the final design was built, meeting the required design specifications. This build was capable of holding 350 pounds and ascend branch less trees with varying diameter trees from 12 to 43 inches up to 20 feet. The design consists of two frame assemblies, connected through the pneumatic assistance system. A final engineering analysis was completed on this design, yielding a factor of safety of 1.5. The build cost a total of 463.95 dollars.

Additional considerations were made including manufacturability, ease of use, environmental impacts, safety, operating environments, and reasonable servicing schedules; since use in remote locations is to be expected. The design is for any individual intending to climb a tree; including but not limited to hunters, arborists, and photographers.

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List of Acronyms

URI University of Rhode Island
ROR Rate of Return
PSI Pounds per Square Inch

1 Introduction

Climbing trees has been a challenge that humans have been inventing unique solutions to for thousands of years. There are many reasons to climb a tree, from agriculture to hunting and recreation. This project aims to make tree climbing accessible and safe for everyone. The objective of the Tree Climber Project tasked to Team 17 was to design, optimize, and produce a tree climbing device that is easy to operate and safe for both the operator and the tree. Tree climbing currently has many products available on the market. A majority of these products are completely human powered, requiring the operator to expend energy in a struggle against gravity to reach the top of the tree. The few products offered that are machine powered are relatively large, heavy, and not environmentally conscious. Thus, it was decided by Team 17 that the purpose of designing this product should to solve the challenge of vertical tree ascent with low human energy expenditure. The design chosen was a two frame assembly connected through a pneumatic assistance system. This product should be able to assist an individual with 50 pounds of potential equipment safely and efficiently to the top of trees with diameters ranging from 12 to 24 inches.

The found solution to this problem is a hybrid powered[1] force couple device. This device meets all the necessary aforementioned project requirements. Additional considerations were made such as the operating environment and servicing schedule. The product was designed to operate in both recreational and commercial environments for any individual wishing to climb a tree. The current market has many two frame assembly tree climbing devices available, as the simplicity and performance make it easy to use, transport, and cost effective. This made it a great platform to start with and improve. From this platform the Team implemented a pneumatic assistance system, consisting of a double acting cylinder, 2 position air manifold, a C02 tank, and a regulator. This eliminated the need for the operator to manually move the frame assemblies up the tree, instead only required them to lift their own body weight from a seated to a standing position.

[1] Combination of human and pneumatic power

2 Patent Search

Following the literature search, we searched through the United States Patent and Trademark Office. We need to make sure, if this product is going into circulation, that we do not infringe on other patents. Though this is important to not break the law, it is also useful to look through other people's work to see what works and what doesn't. After searching through patents, we pieced together our current idea and know what we can and cannot do. All patents are present in the appendices for reference.

Figure 71: This is a product that incorporates similar ideas to the couple force were trying to apply, limited to use on coconut trees. There are two separate pieces that attach to the tree. One piece lets go of the tree and the motor pushes it up, then the piece reattaches to the tree. This process is then repeated until the robot reaches the coconuts and two arms are remote controlled to harvest them. Only with this design, it is a robot that climbs the tree. With our design a user would climb the tree with the device. They use a remote to control the six motors on the robot, two are used to climb the tree up and down, and four are used for the two arms that cut and collect the coconuts. This robot helped inspire the idea we committed to in the sense that we used two pieces that use a couple force to maintain position on the tree. But we wish to keep the device eco-friendly and avoid the use of motors, which we replace with pneumatic cylinders.

Figure 72: After finding this patent, it helped confirm that we can use a similar concept to this and it is a viable option. This product uses a couple force to maintain position on a tree. This product is also advertised as a tree stand so may not be practical for all uses. In the end, our design is var different than this ones.

Figure 73: The next patent is very similar to the concept we are pursuing. The main difference is this patented idea does not utilize pneumatic cylinders to assist the user going up the tree. Also it does not use a rope/strap system to adjust as the operator ascends up the tree. Again this product is geared towards hunting.

Figure 74: This is a tree trimmer that uses rollers to roll up the tree. This device does not carry a person up the tree but bring a saw up to trim the branches. We considered using the roller idea in our project but we decided to make an eco-friendly product, and the rollers would need a motor to turn them.

Figure 75: This uses a foot pump style system that brings you up the tree. We considered this for our project but the main concern was how can you reverse the process to come back down the tree and it came down to the issue of safety as to why we didnt decide to do something like this.

Figure 76: Another inchworm inspired idea. This again is a product mildy similar to our idea, but without the use of pneumatic cylinders.

3 Evaluation of Competition

There are many other products on the market already that accomplish the same task as our project seeks to do. Other designs use similar geometries and systems to ascend trees of various diameters. A common device uses a left and right piece that you put your feet in and hold with your respective hands, and climbs the tree one piece at a time, moving each independently. It uses the same force-couple process that our design uses, by putting your weight on the bottom where your feet rest and creating a torque around the tree that keeps it in place. A picture of this concept is shown below.

Figure 1: Example of Competitive Climbing Device

There are many variations on the same geometry that our project uses. Different sizes and materials are used to accomplish the same result. Most of these products are marketed as tree stands to be used for hunting. They use a top and a bottom piece and you slide each piece up and then re-lock them and move the other up. Most of these designs feature some place to sit on the device and a large area to stand on the bottom.

Figure 2: Example of a Competitive Climbing Tree Stand

To improve upon this, our design incorporates a double-acting pneumatic cylinder that intakes air to pressurize the cylinder, pushing and pulling the parts of the machine up the

Parameter	**Capstone Group 17**	**Competitors**	**Notes**
Retail Cost	$899.99	$89.99 to $439.99	No competitor features piston assembly
Weight	41.2 lbs.	21 lbs.	Heavier frame due to increased durability
Length	53.25”	20”	
Width	24.33” (variable)	36”	
Pressure	0 psi to 120 psi	N/A	
Max. Load	350 lbs.	350 lbs.	Device has not been tested past 350 lbs.
Tree dia.	12” to 24”	8” to 20”	Can be mounted on larger trees, ascent is impaired

Table 1: Competitive Design Specifications

tree. This assembly greatly increases the ease of ascent, and allows for the device to be heavier, sturdier, and able to hold more weight. This system is shown in detail in Figure 16 in the Detailed Product Design section of this report.

Many sporting goods stores and websites have several options for climbing tree stands, ranging from $150 to $500, according to competitive retailers including Dick’s Sporting Goods (5) and Bass Pro Shops (2). Our product has a production cost of $501, meaning that it will be marketed as a reasonably more expensive option, but will be able to hold a great deal more weight and will have the added feature of the cylinder assembly.

Other devices that accomplish the same task involve motorized or pedal-powered assemblies that use various orientations of wheels to ascend the tree. Disadvantages of these designs include the need for fuel, noise, long setup times, and relatively slow ascent speeds. Products utilizing this technology are shown in videos linked in the References section.

Market strategies will focus on showcasing the power and accessibility that the pneumatic cylinders provide, which allows us to make the machine itself stronger and more durable. The machine should be able to safely carry upwards of a 350 lb. load to the required distance up the tree, and the assistance from the cylinders will make this product able to be used by almost anyone, experience in the tree climbing industry or not.

4 Design Specifications

This project aims to make climbing up trees easy. We set out to make a device that is portable, safe, easy to use, and works with a wide array of trees. The only limitation is that it will not bypass branches on the way up. We were given a 500 dollar budget to research, design and produce this machine. Our customers will need a device that will be reliable and and functional. This device will be able to hold up to 350 pounds safely. It will also be able to carry any equipment the user has for the task theyre doing, not exceeding 350 pounds. At the same time it needs to feel effortless going up the tree. To achieve this, two pneumatic cylinders will be used to assist the user, one used to go up and the other used to go down. These cylinders will be accompanied by an air tank to maintain pressure. The cylinders must produce at least 50 pounds of pressure to optimally assist the operator without waste from the air tank.

Weight	41.2 lbs
Max. Load	350 lbs
Pressure	Range: 0-120 psi
Tree Dia.	12-24 inches
Cost	<$500
Length	53.25 inches
Width	24.33 inches

Table 2: Initial Design Specifications

5 Conceptual Design

One of the first preliminary design concepts generated for this project was a crankshaft design. This design incorporates a crankshaft mechanism using foot pedals to rotate, to create a motion that could pick up and move the body that rests on the tree and elevate it to the next position for it to be locked. The motion then continues to elevate the other locking mechanism, and the cycle repeats to ascend the tree. This design was abandoned due to lack of physical potential. An early drawing is shown below.

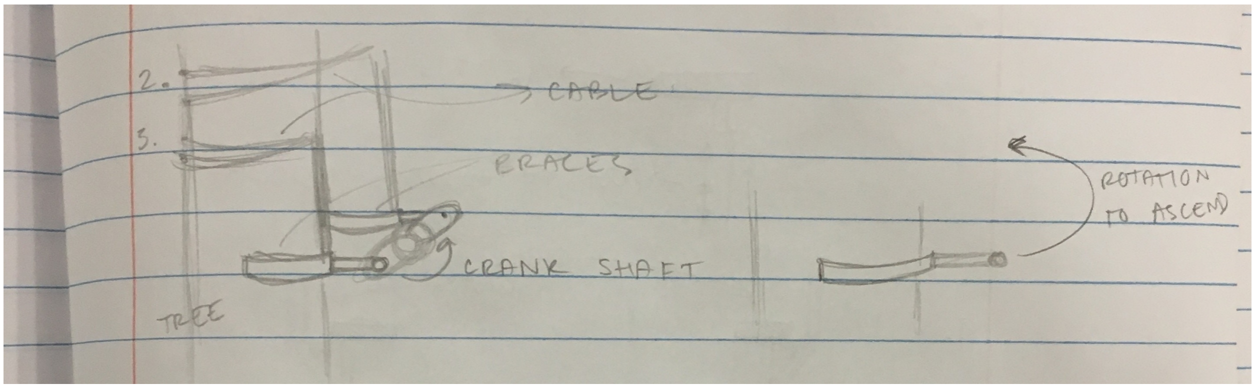


Figure 3: Crankshaft Design

Another early design idea was a wheel and brake system to rise up the tree. This concept works similarly to a bicycle, operated by pedals and with tires that lock on to either side of the tree, and held from falling by a brake system. The pedals would turn the wheels of the device to ascend the tree, and it would utilize a gear reduction system for increased mechanical advantage.

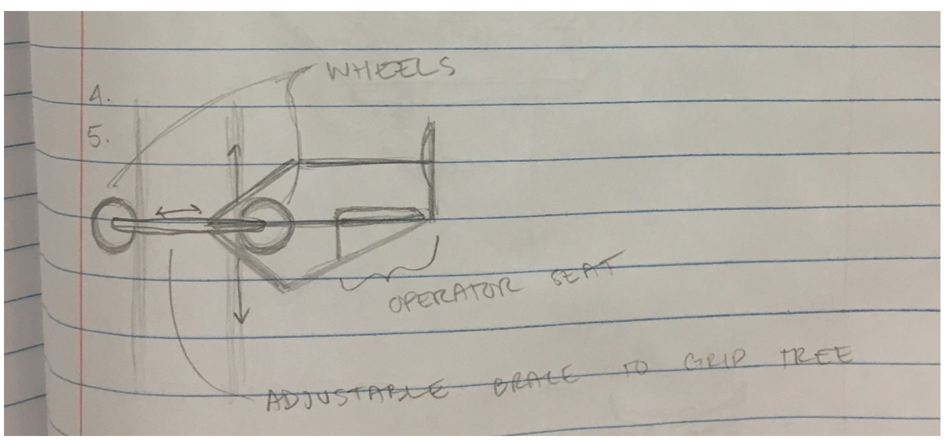


Figure 4: Wheel-Type Design

All group members' 30 Design Concepts are included in the Appendix section of this report.

Some preliminary technologies that this group came up with that ended up being used in the final design include a force-couple mounting system, and a pneumatic piston assembly.

The force-couple mounting system utilizes a support on one side of the tree to house the operator, and a cable wrapping around the tree to create tension on the tree, resulting in a high frictional force to keep the user from sliding down. Most of the designs generated and seen used this type of system to create a working device. Almost always used in pairs (top and bottom or left and right) to have two movable parts to support the user as they climb the trees.

A number of double-acting pneumatic cylinders will be installed on the device to assist in getting the heavy machine up the tree. Could be used in various geometries to create a force that does work to push the machine up, depressurize, and do work to pull the bottom of the machine up. Manual adjustments would be required to decouple the machine from the tree during the ascent.

After intense concept generation and formulation into reasonable ideas, a final design of a pneumatic-assisted stepper-style tree climbing machine was created. This concept uses a common geometry to competitive products, the y-shaped incrementally-elevating design. It improves upon those designs, however, by adding a double-acting pneumatic cylinders to assist in the ascension of the tree. This cylinder will have a compressed air intake valve on the top and the bottom, and will use that to pressurize the air inside and push the top piece of the device into extension if the bottom is filled and into compression if the top is filled. A release valve is triggered to depressurize the opposing side of the cylinder, releasing the air that was just used toward mechanical advantage. Making it a smart idea to bring a spare tank up, just to make sure the system does not need to be run manually.

The true final system follows this basic concept and it is described and shown below as (Final Design), but through cost and structure analysis, as well as problems discovered during testing; a few different designs were crafted and edited along the way.

The first design utilize two cylinders mounted to the top beam of both frames. A SolidWorks model of this ,Proof of Concept, design is shown below, and the details of this design are outlined further later in the report.

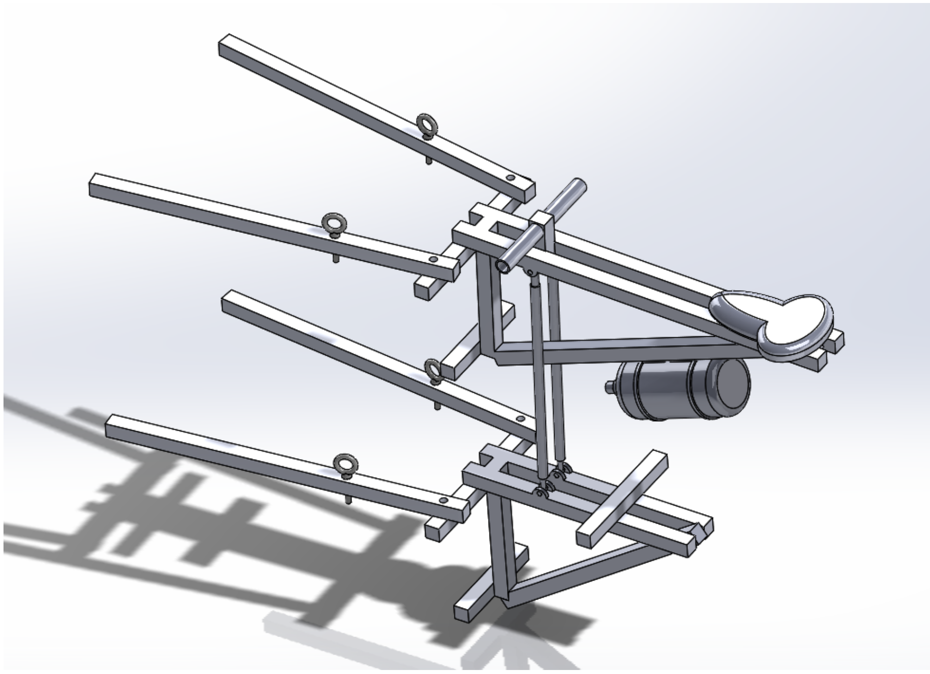


Figure 5: Pneumatic Stepper (Proof of Concept)

Due to some extra consideration, this system was never built. The double-acting pneumatic cylinders were expensive to purchase and out of our price range. The two cylinders mounted would cause the system to be overly constrained. One cylinder was determined to have enough strength and power to manage lifting the system. A SolidWorks model of this ,Test 1, design is shown below, and the details of this design are outlined further later in the report.

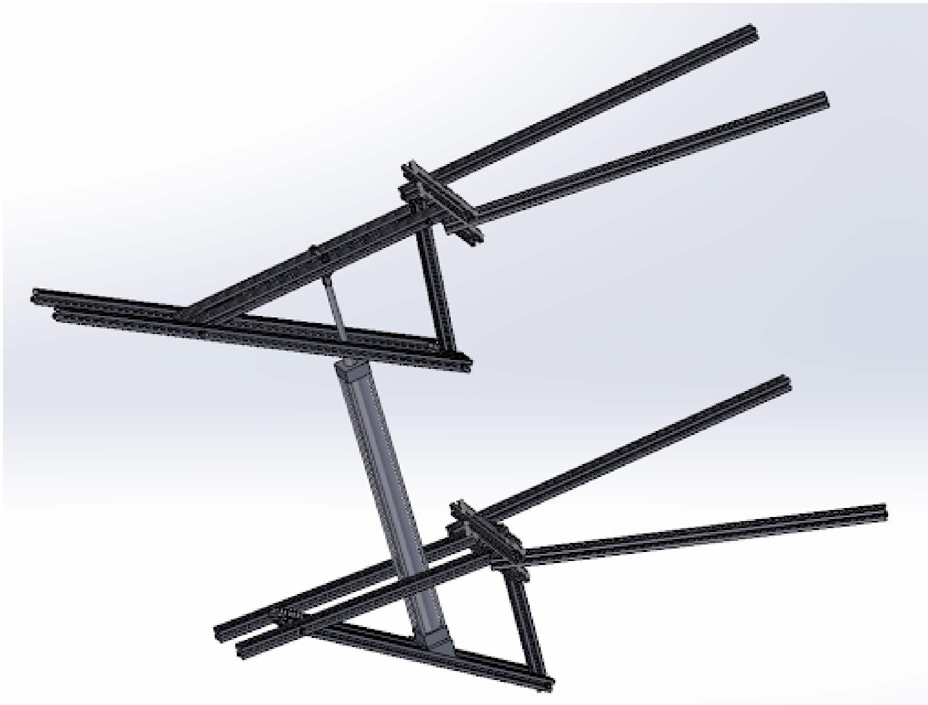


Figure 6: Pneumatic Stepper (Test Design 1)

The center of mass of the system had shifted two far forward. The system at this point was unable to hold on to the tree under its own weight. The cylinder was driving the weight of the top system into the front of the bottom system, increasing the problem of having to much weight being shifted forward. The solution was to shift the mounting of the double-acting pneumatic cylinder to the back of the system,under the seat. A SolidWorks model of this ,Test 2, design is shown below, and the details of this design are outlined further later in the report.

Figure 7: Pneumatic Stepper (Test Design 2)

The weight balance was fixed, but a new problem was revealed. The rope was wrapping around the tree to much resulting in a lose tension and the rope sagging under its own weight. This sag made it impossible to rise or descend safely because the rope could not catch. The solution was to shift the attachment zones for the ropes and to replace the rope with metal wire wrapped in plastic. A photo of the final model of this ,Final, design is shown below mounted on a tree under the load of Scott Botelho (165lbs), design is shown below mounted on the tree under its own load, and the details of this design are outlined further later in the report.

This final system allowed for the ascent and decent of the system without the ropes getting caught up or sagging to low. The was our final concept generation and our final design. Redesign idea are mentioned later in the report to further optimize this idea.

6 Quality Funtion Deployment

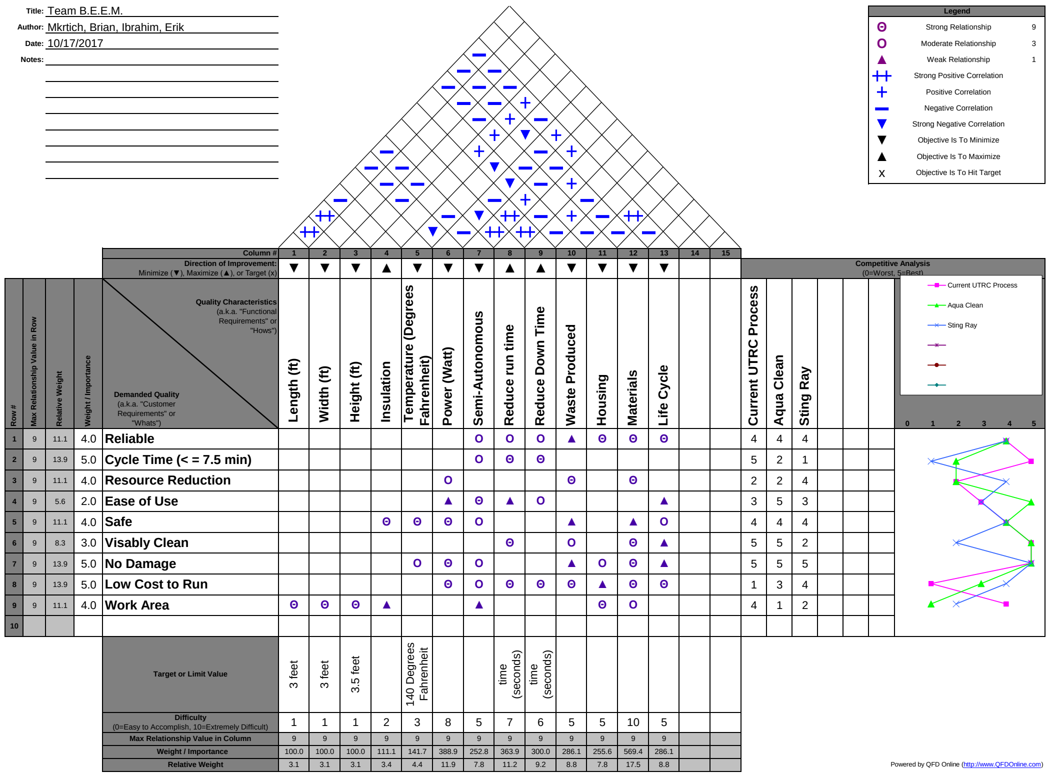


Figure 8: QFD Analysis

7 Design for X

7.1 Design for Environment

A great deal of consideration was put in to this project to make sure that they use of this machine does not damage the tree in any way. The only concern in this regard was where the base of the machine digs into the tree and provides support on each piece. To resolve this problem, rubber mats were screwed to the bottom of each section that retain the necessary friction to hold the device in place, but do not damage the bark of the tree during use, as shown below.

7.2 Design for Safety

The final structure of this device is extremely strong, having been tested with weight up to 350lbs. The aluminum frame does not bend anywhere during use, and all of the brackets remain stable. Due to this, when properly coupled and locked in to the tree, there is very little chance of the machine sliding or failing in any way. The rear-mounted pneumatic cylinder makes the user's ascent safe and easy. In the future, a comfortable seat and a safety harness will be attached to the device for safety and ease of use.

7.3 Design for Manufacturing

To improve the ease of manufacturing this product, almost all of the pieces used to make it are cut and drilled from the same aluminum bar stock. Each piece is held together with uniform bolts, brackets, and screws. When manufacturing this device, all pieces would be cut and drilled beforehand, and the disassembled machine would be shipped with all the required parts and an instruction manual for putting it together. Manufacturing and shipping are made far easier by selling the device disassembled rather than trying to assemble it at a factory and ship the completed product.

7.4 Design for Reliability

In the case that during use, the user runs out of CO2 to power the pneumatic assembly, the device works without the use of the cylinder, meaning that the user will not be stuck in the tree due to lack of power. In addition, the materials and geometry used in the design of this machine are extremely reliable.

7.5 Design for Cost

The cost of materials and manufacturing was minimized through the use of standard smooth-slotted extrusion aluminum bar stock and the accompanying brackets. This material was easily drilled and fit together to construct the two frames of the device. All materials were bought in bulk and cut and drilled efficiently to decrease material and labor costs. Design specifications stated that the device and all materials should cost less than $500, and the final design succeeded in that regard.

8 Project Specific Details and Analysis

The market for this product is extremely wide, including people in the lumber industry, arborists, hunters, recreational tree climbers, and people who are generally interested in nature. This product will run more expensive than many non-mechanized products, but for industrial applications, it is far superior. After manufacturing analysis, it is estimated that each piece will cost roughly $516 plus the price of labor, but that value will decrease as more and more units are created and the manufacturing process is optimized. This means that the retail value will be around $899.99. It was shown through the QFD Analysis and survey of potential users that the durability, weight, and carrying capacity are the most important qualities of this device. For future work, these qualities will be optimized and the manufacturing cost will be decreased.

More financial information, market information, and engineering analysis is explored in the respective sections.

9 Detailed Product Design

The process of choosing a specific design was done in batches, eliminating the unreasonable designs whether due to budget constraints or feasibility of completing the design within the given time constraints. As a team in chosen to move forward with a design that was human powered with some form of lift assistance, since a motorized design would have been difficult to keep within the $500 budget constraint. From this we narrowed our design down to either a bicycle style with chain and gear power train, or a inch worm [2] stepper design with pneumatic piston lift assistance. This left use with six design concepts that were generated. The first two were bicycle designs that can be seen in Figures 10 and 11, the remainder were piston stepper designs shown in Figures 12 , 13, and 14. After furthering our research on current models and analyzing the ease of use of each prospective model, it was decided to make a hybrid model between Alexs Designs 15 and 28. Utilizing the A-Frame inch worm from design 28 and the dual piston orientation of Design 15. With a clear preliminary design and the required design specifications displayed in the previous section Design Specifications the team was able to move forward. With the preliminary design chosen, a Solidworks model was generated with dimensions, Figure 9, and part tolerances, Figures ??. The size of the design was based of the design specification of having the capability of ascending trees 12 to 24 inches in diameter while keeping the frame as small as possible, reducing weight and making the design easier to store and handle. The design can be seen in Figure 35.

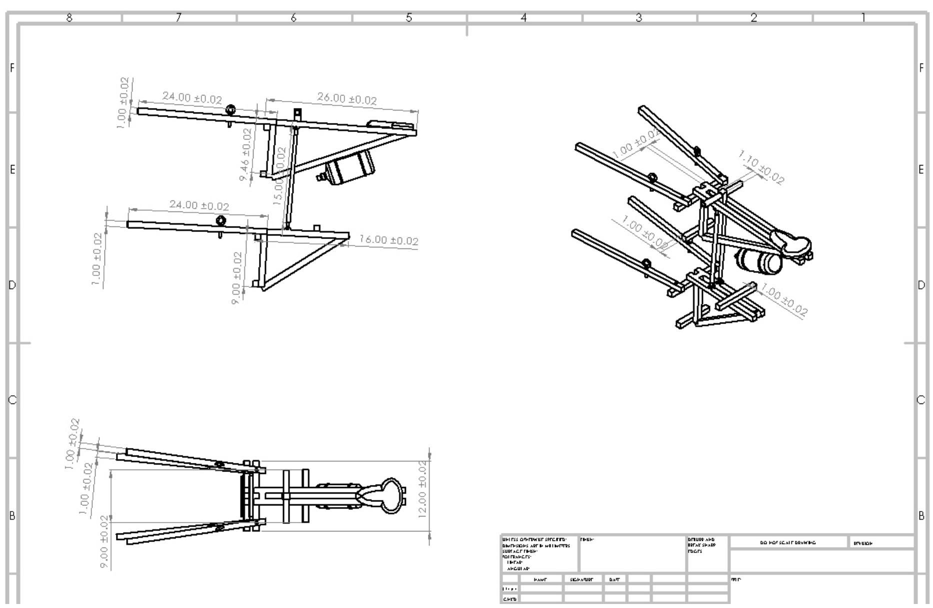


Figure 9: Assembly Drawing

[2]The inch worm stepper design is a two frame assembly utilizing force couples on each individual assembly to hold the user on the tree while maneuvering the second assembly higher up the tree, repeating until reaching the top of the tree. The top assembly is a seat which initiates the force couple and handle bars to maneuver the assembly up when the force couple is released. The second assembly is a platform to stand on with a foot catch on top. When the user is standing the force couple is initiated, then when the weight is off the assembly the foot catch allows the user to use the top of their feet to maneuver the assembly up the tree

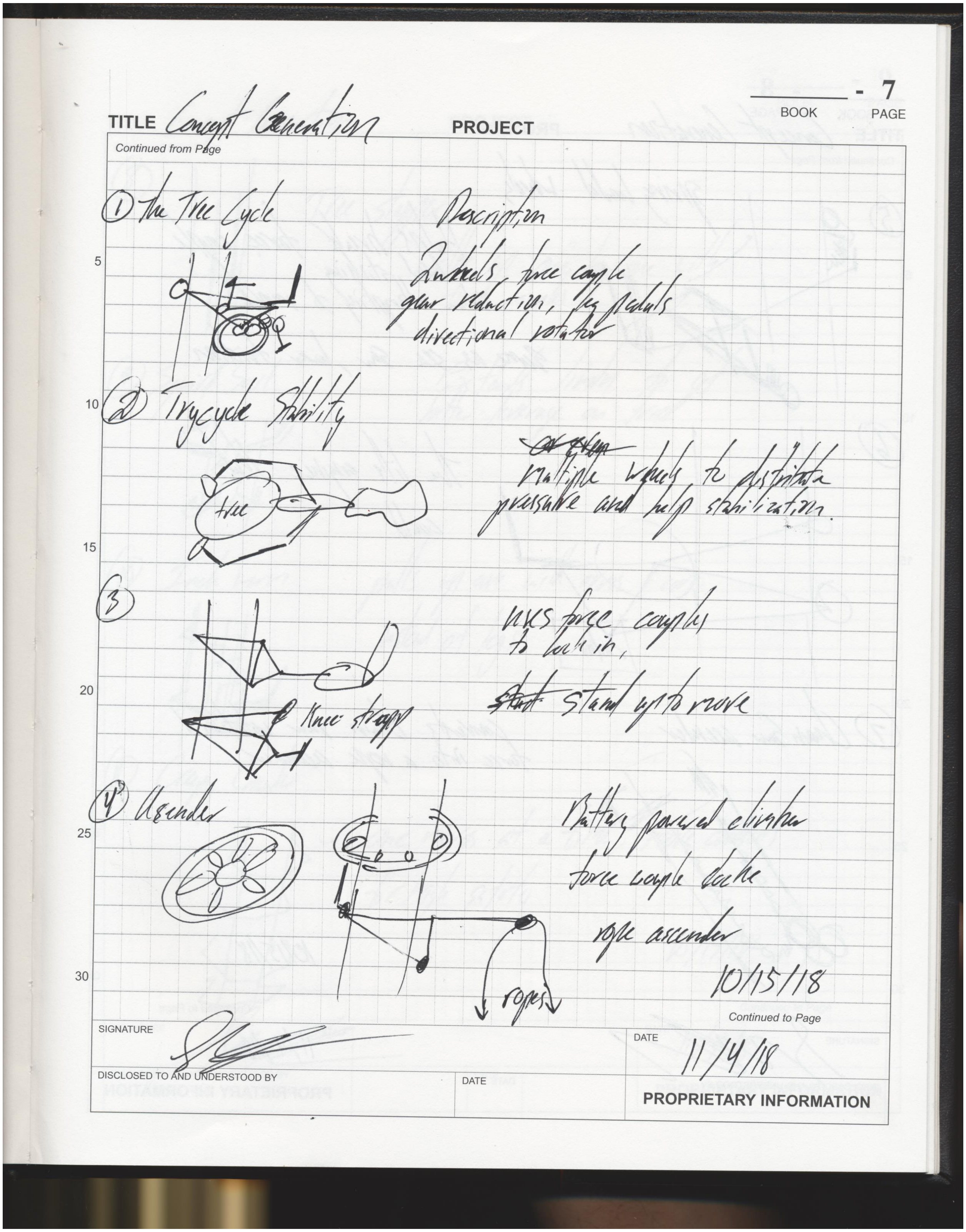


Figure 10: Scott's Designs Page 1

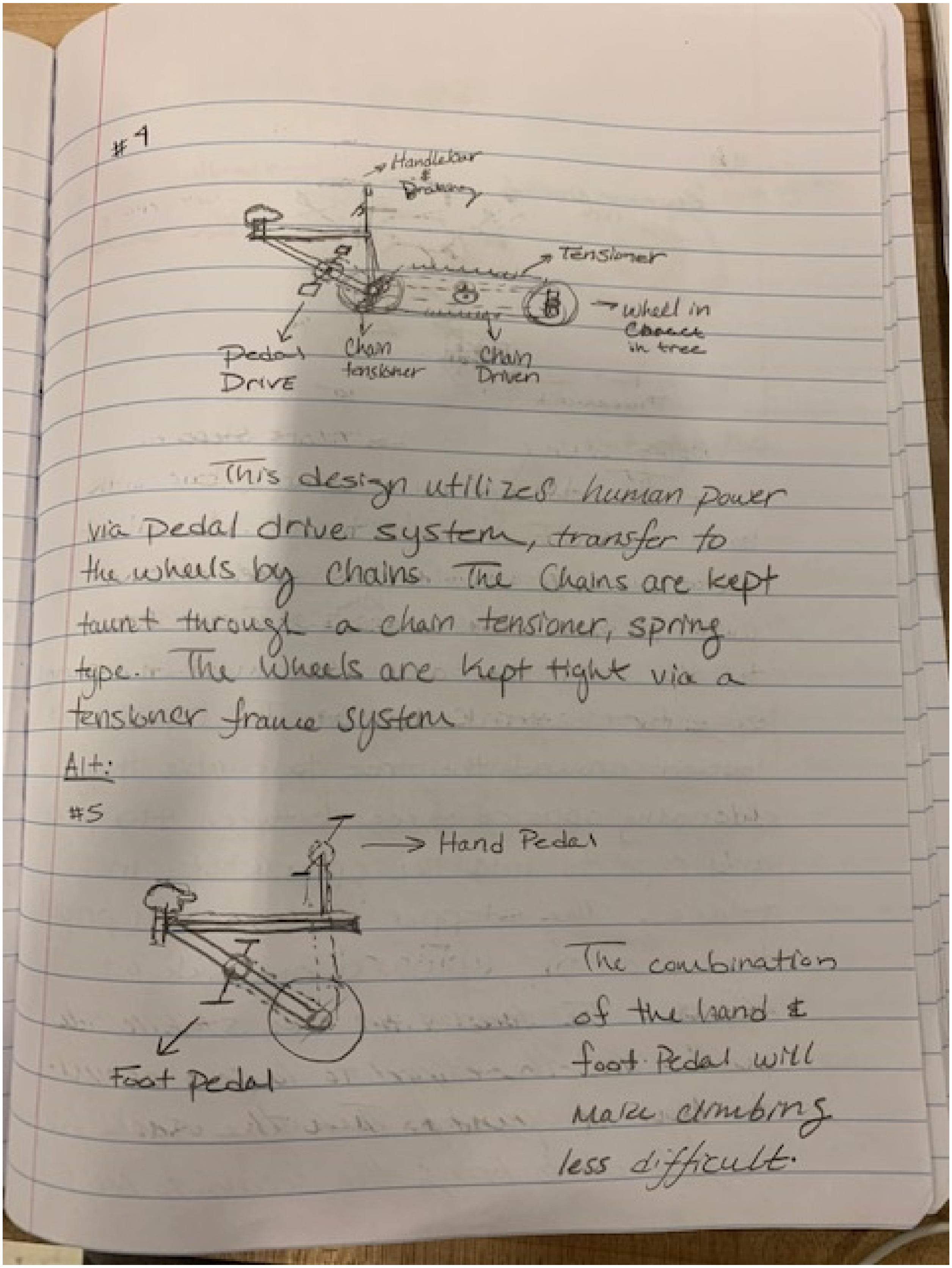
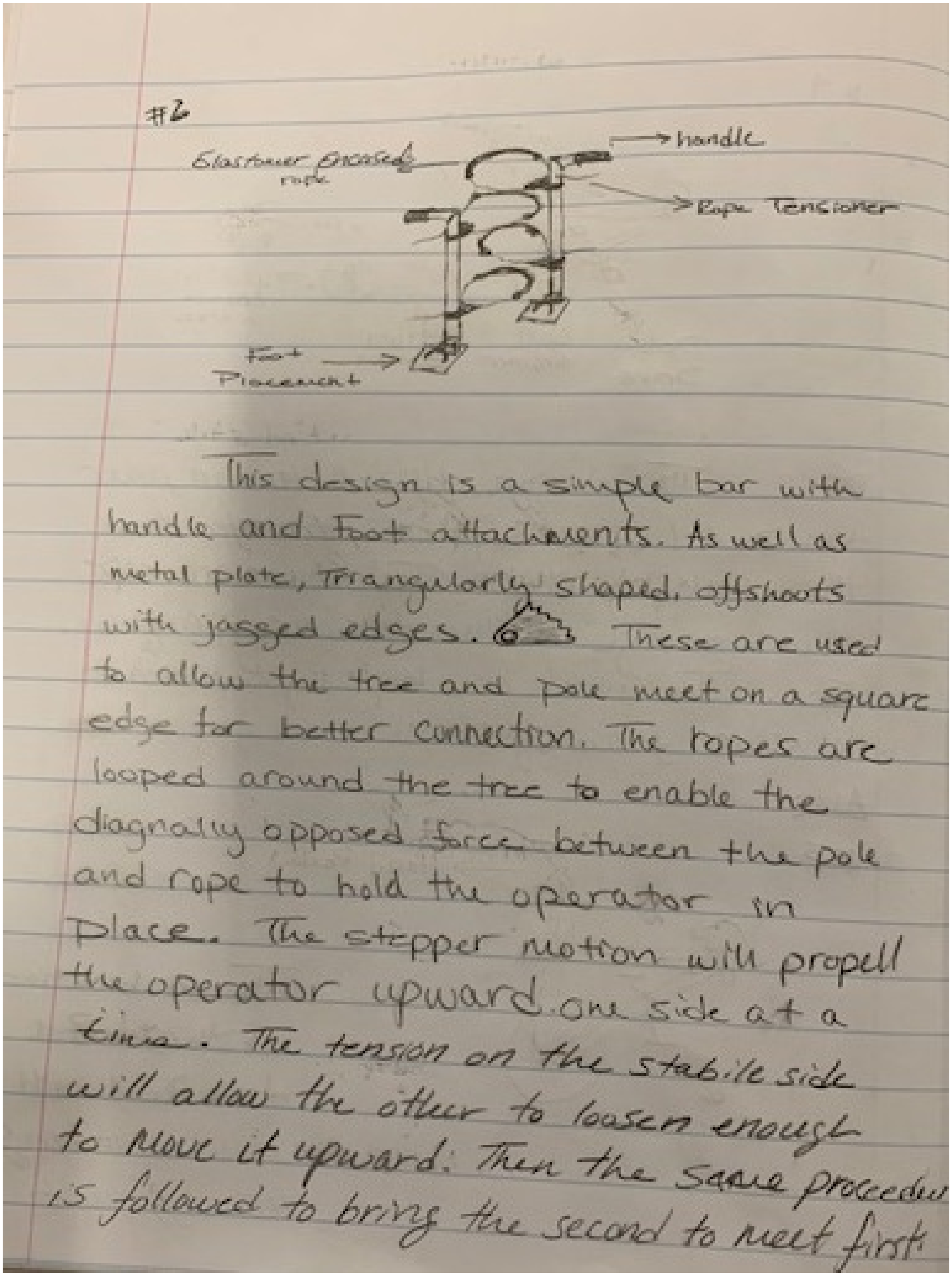


Figure 11: Alex's Designs Page 3



This design is a simple bar with handle and Foot attachments. As well as metal plate, Triangularly shaped offshoots with jagged edges. These are used to allow the tree and pole meet on a square edge for better connection. The ropes are looped around the tree to enable the diagnally opposed force between the pole and rope to hold the operator in place. The stepper motion will propell the operator upward one side at a time. The tension on the stabile side will allow the other to loosen enough to move it upward. Then the same procedure is followed to bring the second to meet first.

Figure 12: Alex's Designs Page 4

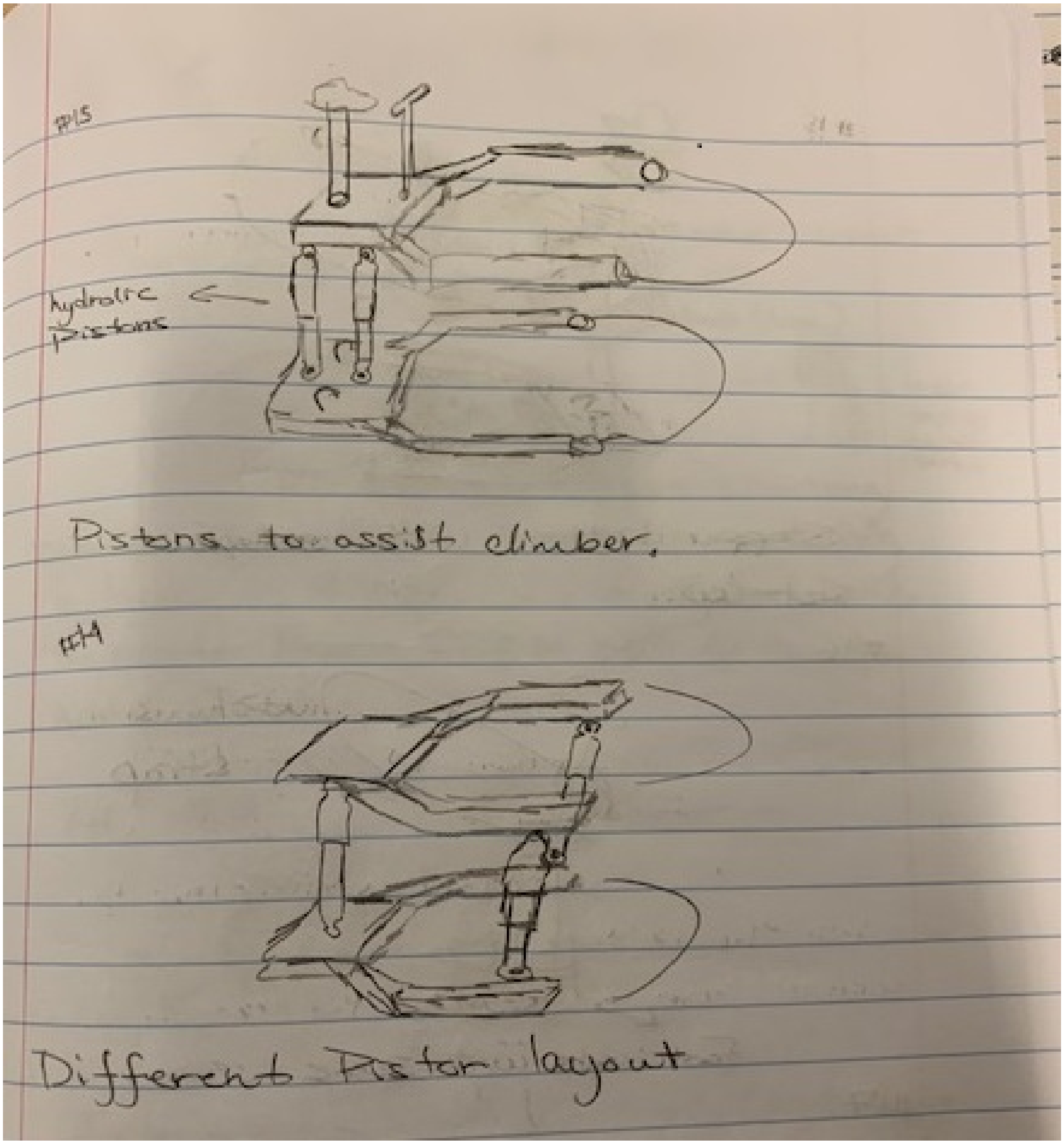


Figure 13: Alex's Designs Page 7

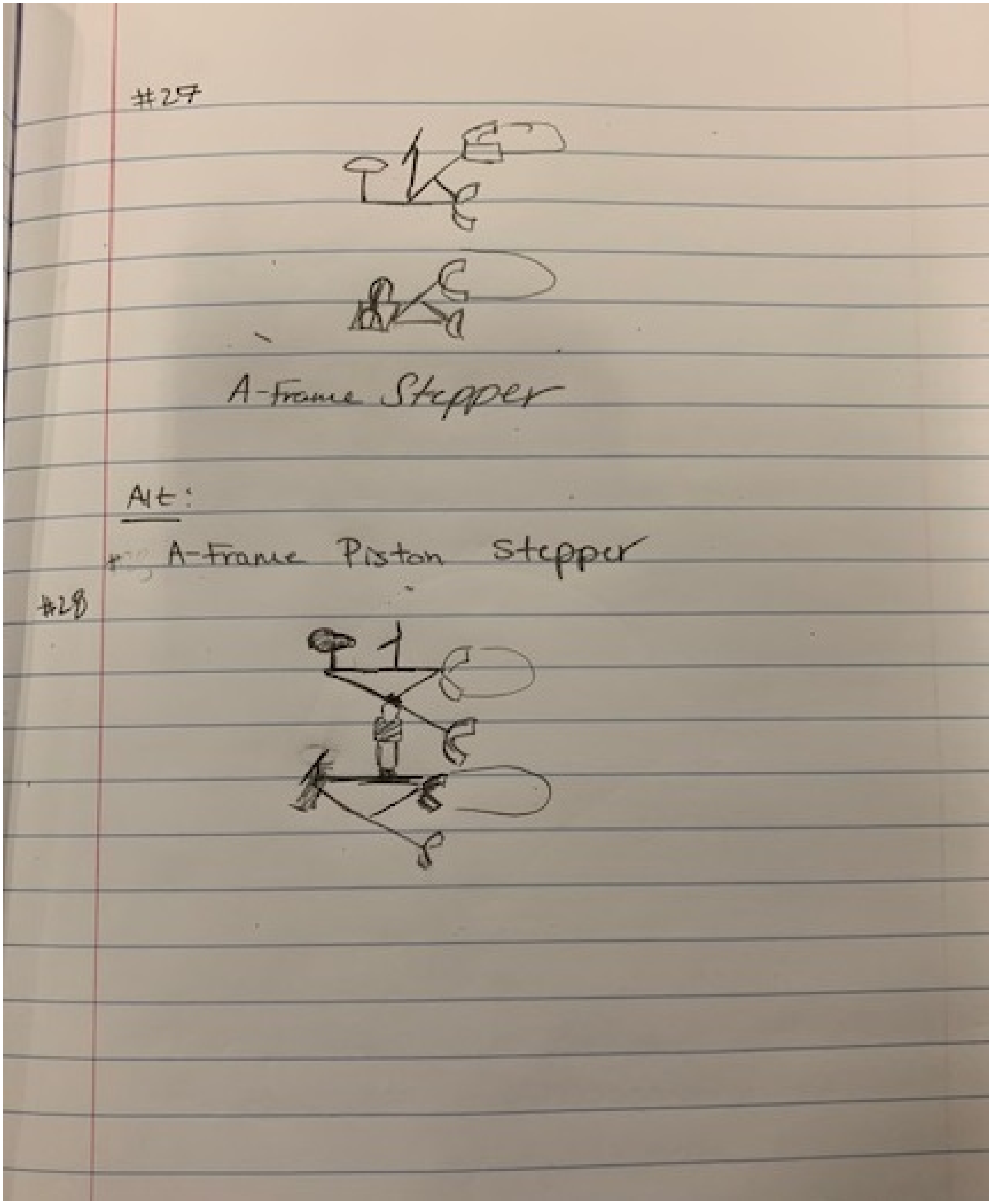


Figure 14: Alex's Designs Page 12

For generated frame design materials needed to be chosen. The materials needed to be relatively lightweight but still capable of handling the forces generated by a 350 pound load, especially within the stress concentration areas. After carrying out a static analysis on the connection point between the arms and frame, assumed to be the area of greatest stress concentration, shown in Figure 35, a material that could handle this load could be chosen. The material choices were between 1 square tube 6061 T6 aluminum and 1 plain square tube. Both met the load requirements so the choice came down to weight and pricing. The aluminum was the lighter of the two but more expensive by $ 0.43 per linear foot. The frame requires 34.08 linear feet of material, thus the aluminum would cost $ 14.65 more per frame. This extra cost comes with a significant total weight savings of 15.01 pounds. The price increase was well worth the pay off as the apparatus should be as easy as possible to operate and a lower weight puts less strain on both the user and the piston assistance system.

Now that the frame material was chosen the mounting hardware needed to be chosen. The stresses were to great to be able to use aluminum hardware, so titanium and steel hardware were priced out. The titanium hardware was significantly more expensive than the steel hardware, but the weight was less than half of steel. Considering the price vs weight payoff steel was chosen for its strength and relative low cost, the total weight increase on these small parts was not significant enough to consider the titanium a viable option. All hardware can be seen in the Bill of Materials Figure 15 With the frame design complete the two way piston system needed to chosen. The double acting cylinder, lines, manifold/regulator, directional control valve, tank, and controls all needed to be designed to be capable of lifting the frame and be intuitive for the user. Starting with the double acting cylinder choice that had a long enough stroke length to raise the frame a reasonable amount, 10 inches, and handle a 100 psi pneumatic load. After researching products the Double-Acting round body cylinder with a 7/16 inch bore, 10 inch stroke length, and 90 pounds of force at 100 psi was chosen for its performance and price point. Now knowing the requirements and operating capabilities of the double acting cylinder the pneumatic lines, manifold/regulator, and tank were all chosen together to ensure fitment and functionality. The materials chosen can be seen in the bill of materials, Figure 15, and the part diagrams in Figures 16 through **??**. Once the materials are received by the team it will be possible to design the hand controls. This being because the required pressure to activate the two air direction valve is not given in the product specifications.

The final parts to be chosen were the accessories, including the aluminum plate and rubber to protect the tree, seat, and tube end caps. The aluminum plate and rubber covering will be furnished to any point in contact with the tree. This is to meet the design specification that the product will not harm the tree while in use. The seat is for user comfort, a bicycle seat will be implemented for there low weight and they are readily available. Finally the tube end caps will be furnished at any open tube end on the product to keep water out and maintain a fit and finished look. The exact materials chosen can be seen in Bill of Materials, Figure 15.

Material	Quantity	Unit	Price per Unit	Weight per unit (LBS)	Price total	Weight Total (LBS)
1" 6061 T6 Aluminum Square Tube 0.125" Thickness	34.08	lf	$ 2.18	0.52	$ 74.29	17.7216
1/2"-13 Steel Bolts 3" length	36	ea	$ 1.05	0.11	$ 37.80	3.96
1/2"x4" Steel Bolts	10	ea	$ 1.38	0.15	$ 13.80	1.5
3/4" Steel locking Nuts	46	ea	$ 0.45	0.08	$ 20.70	3.68
5/16"-18 Eyebolt	4	ea	$ 10.02	0.125	$ 40.08	0.5
Ventura Saddle Bicycle seat	1	ea	$ 11.15	1.43	$ 11.15	1.43
2 way Cylinder	2	ea	$ 56.20	2	$ 112.40	4
Tube Caps	8	ea	$ 2.55	0.11	$ 20.40	0.88
Neopreme rubber	1	sf	$ 15.74	0.21	$ 15.74	0.21
Aluminum plate	1	sf	$ 10.71	3.53	$ 10.71	3.53
1/4" T-Handle Quick release pins w/ lanyard	4	ea	$ 11.49	0.2753	$ 45.96	1.1012
12oz C02 tank	1	ea	$ 11.49	2.33	$ 11.49	2.33
Air manifold with regulator	1	ea	$ 31.22	0.52	$ 31.22	0.52
Release Valve	2	ea	$ 13.00	0.44	$ 26.00	0.88
Hand Controls	2	ea	$ 8.53	0.333	$ 17.06	0.666
Pressurized line	2	lf	$ 6.35	0.56	$ 12.70	1.12
				Totals:	$ 501.50	42.2428

Figure 15: Bill of Materials

Due to some extra consideration, this system was never built. The double-acting pneumatic cylinders called for problems in the areas of cost and functionality. They were expensive to purchase, so purchasing two was out of our price range. Through thoughtful observation it was recognized that having two cylinders mounted would cause the system to be overly constrained; not allowing for any rotation around the tree to avoid knots. With some structural analysis, it was determined that one cylinder would have enough strength and power to manage lifting the system.

After some new thought it was determined that the one cylinder would mount the the top beam of the top system while the bottom of the cylinder would mount the the bottom the the bottom system. Gaps in the top beam of the bottom system and bottom beam of the top system had to be spaced out to make room for the cylinder to act up through the middle line of center of mass, to avoid as much unnecessary torsion of the stroke arm as possible. See Figure 5, under Concept Design.

After testing this system on a set of trees and telephone poles it the problem was quickly discovered. The center of mass of the system had shifted too far forward; reducing the moments creating the force couple and the friction force holding the system. The system at this point was unable to hold on to the tree under its own weight. If the systems were weighted in the back the system would hold. In the way we were still able to test the double-acting pneumatic cylinder and discovered the second problem. The cylinder was driving the weight of the top system into the front of the bottom system, increasing the problem of having to much weight being shifted forward.

The solution was to shift the mounting of the double-acting pneumatic cylinder to the back of the system,under the seat. See Figure **??**, under Concept Design.

The solution worked and back shift of the cylinder made it so the center of the mass of the system was in the correct place to lock the system into the tree un-weighted; which is desired for mounting. A new problem arose with the straps and their locations. The rope was wrapping around the tree to much resulting in a lose tension and the rope sagging under its own weight. This sag made it impossible to rise or descend safely because the rope could not catch.

The solution was to shift the attachment zones for the ropes and to replace the rope with metal wire wrapped in plastic. This would increase the natural tension in the rope, while the metal wire will reduce the tendency to bend or sag. Once mounted it was quickly recognized the the cage for the mounting of the cylinder to the back of the bottom system overly constrained the system; making the top system unable to touch the tree. The front two beams were removed to allow for pivot of the cylinder from the bottom and the top was already allowed to pivot. See Figure 7, under Concept Design.

This final system allowed for the ascent and descent of the system without the ropes getting caught up or sagging to low. The freedom of the cylinders made for optimal movement and versatility on the tree. The air assisted greatly in helping guild the system up and down. See Figure 55, under Concept Design.

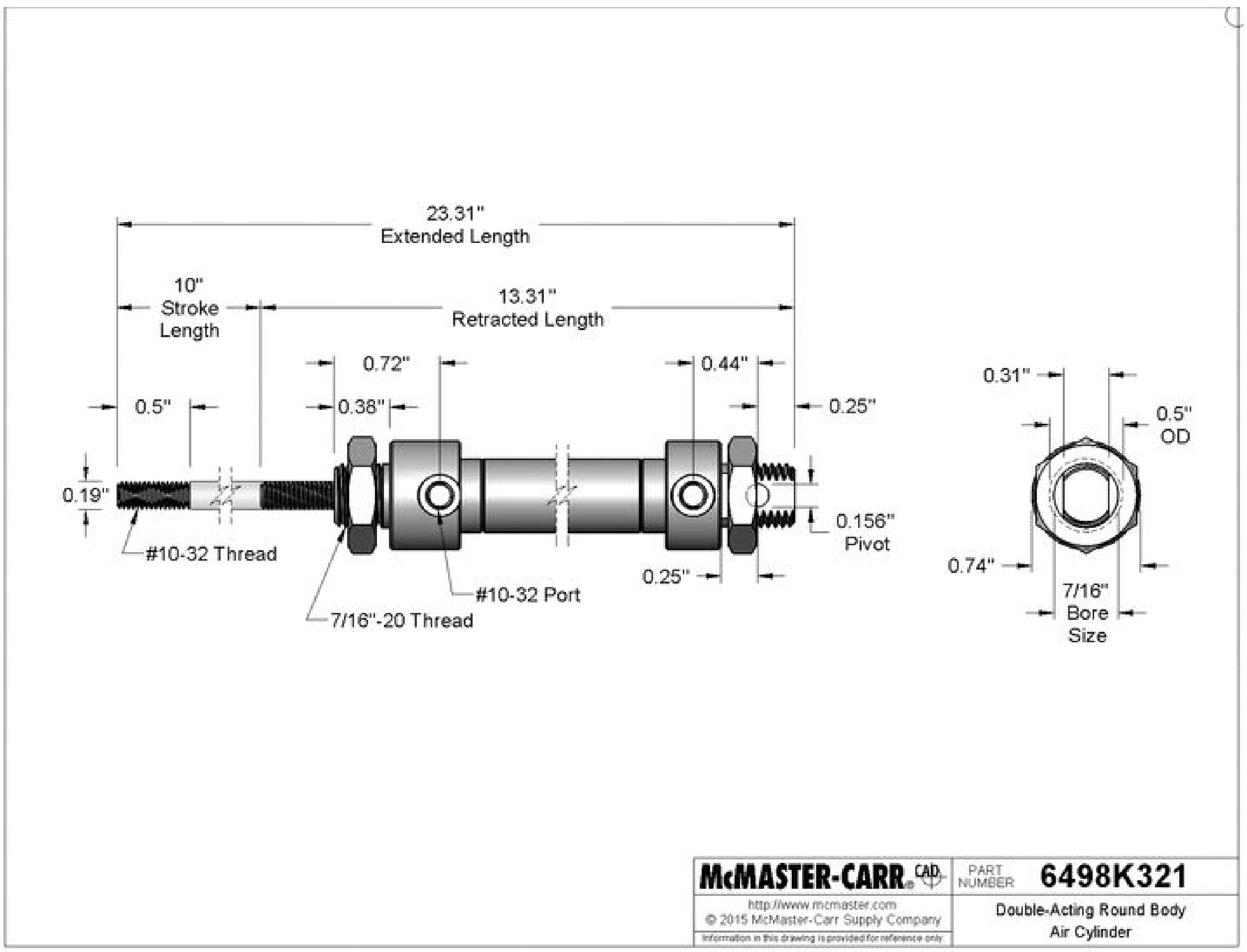


Figure 16: Double Acting Cylinder

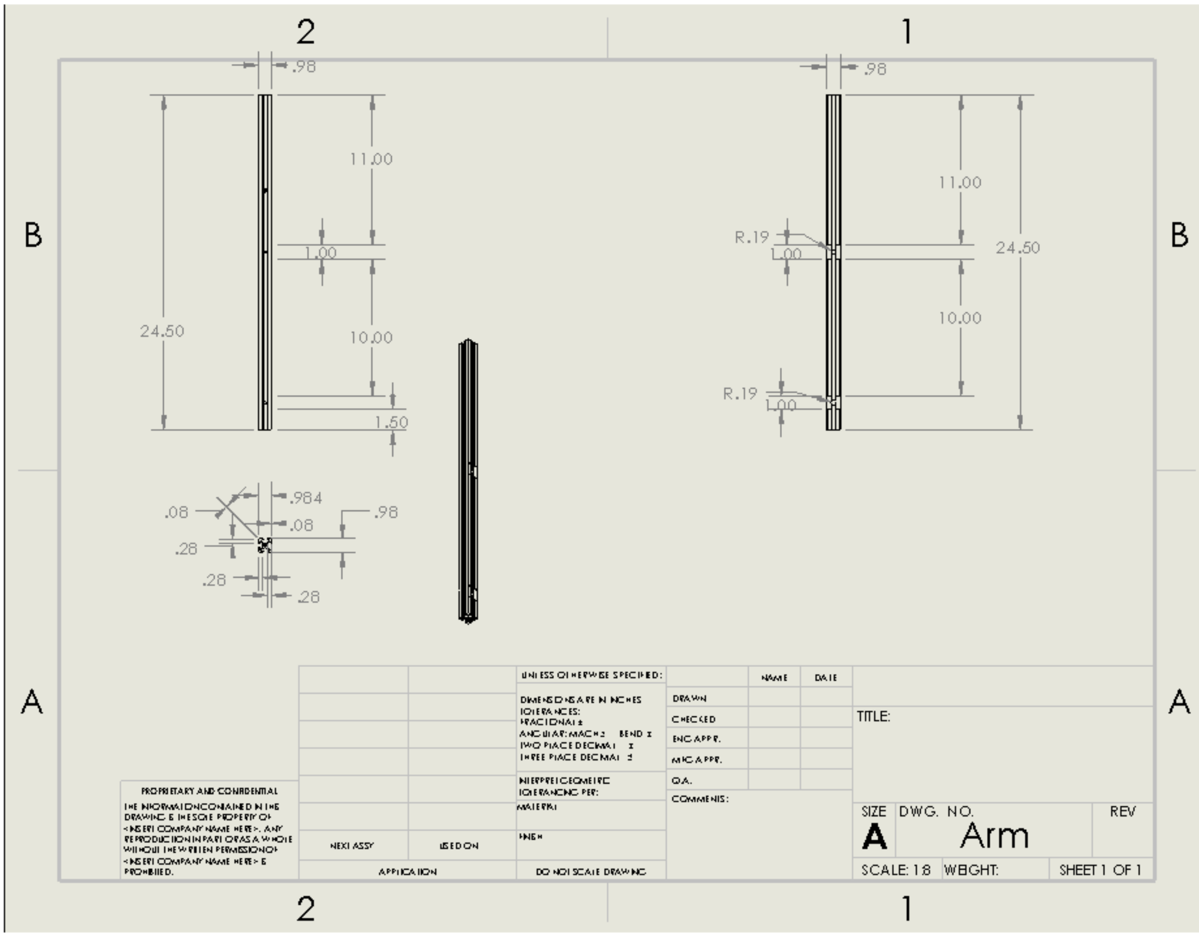


Figure 17: Air Directional valve

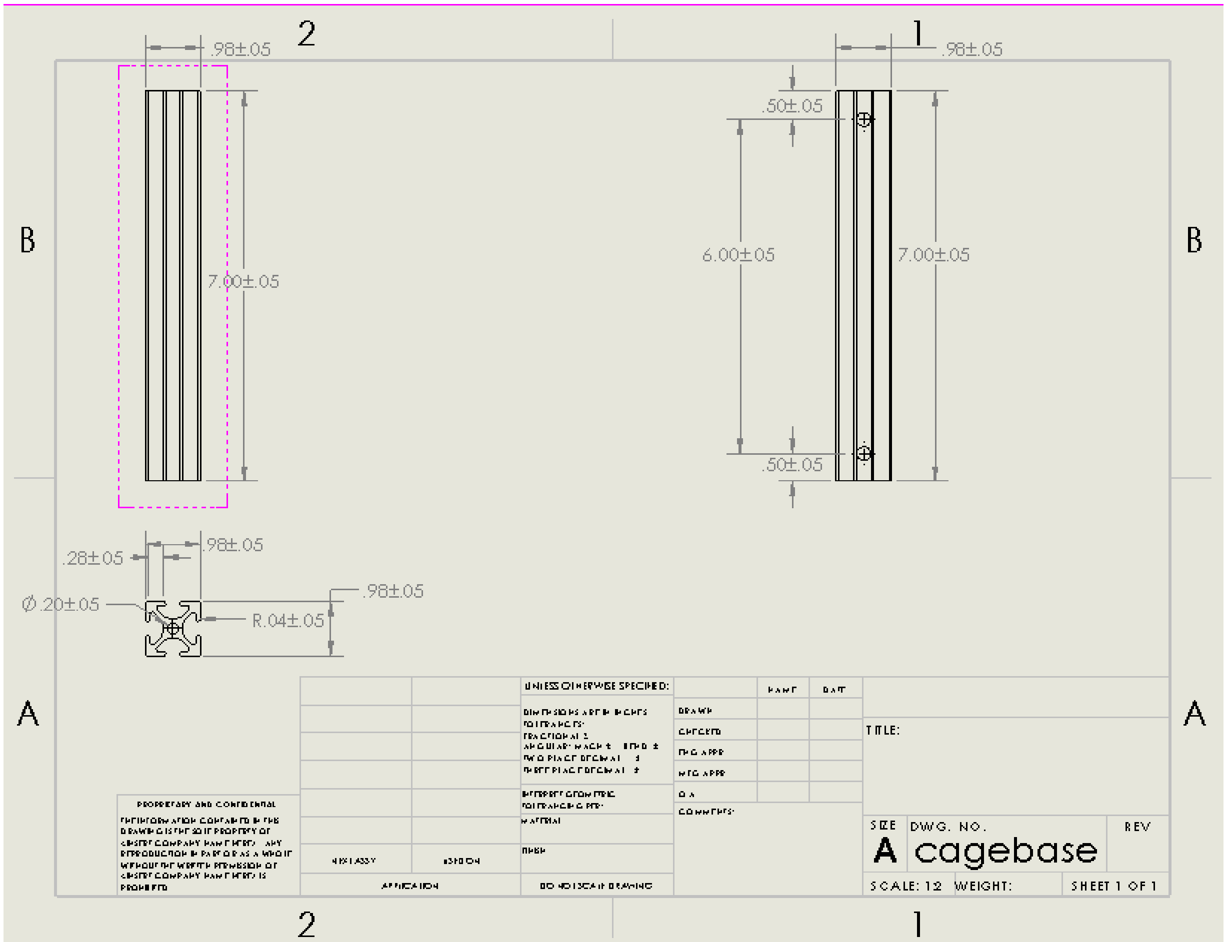


Figure 18: Cage Base Beam

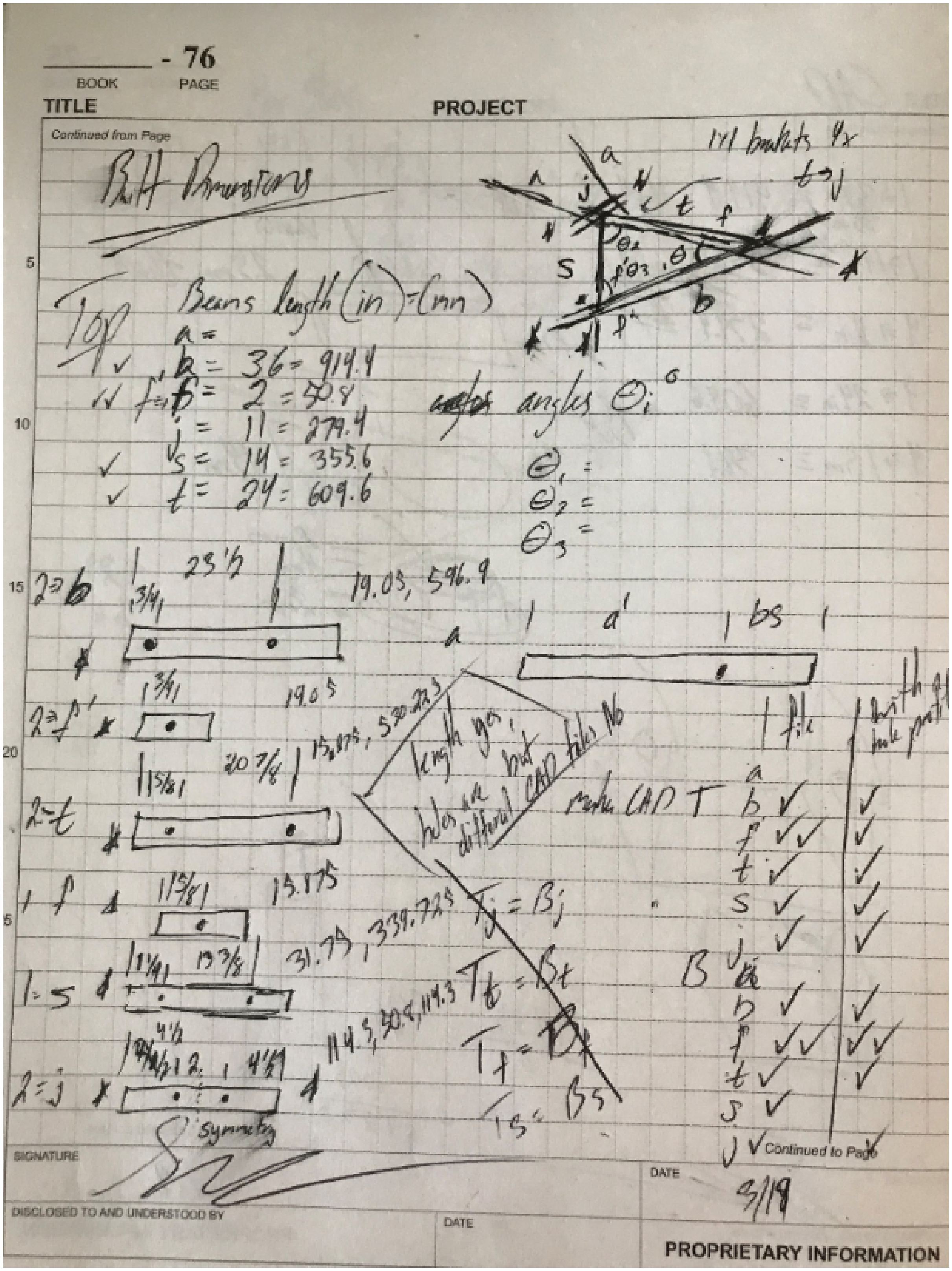


Figure 19: Reference Image for Beams

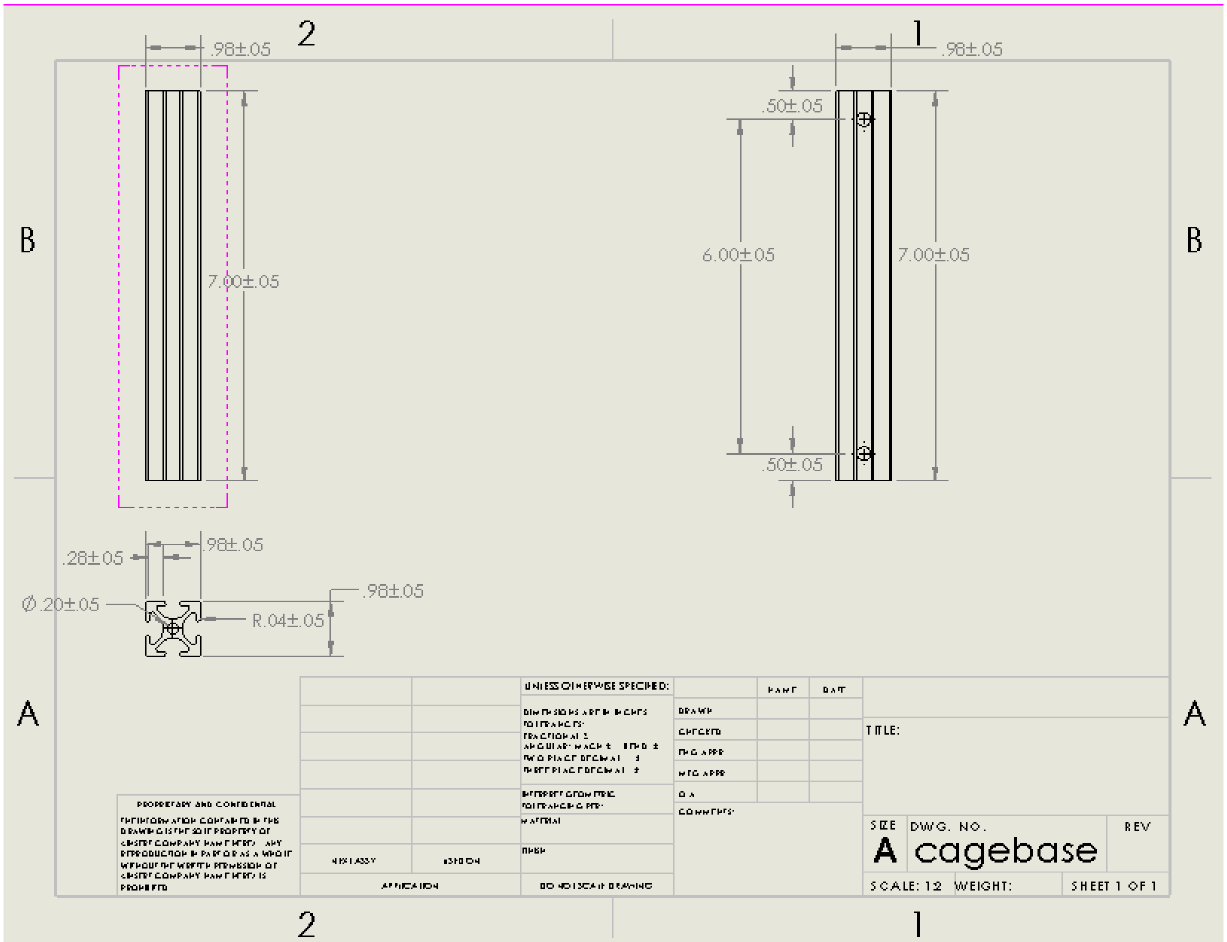


Figure 20: Cage Base Beam

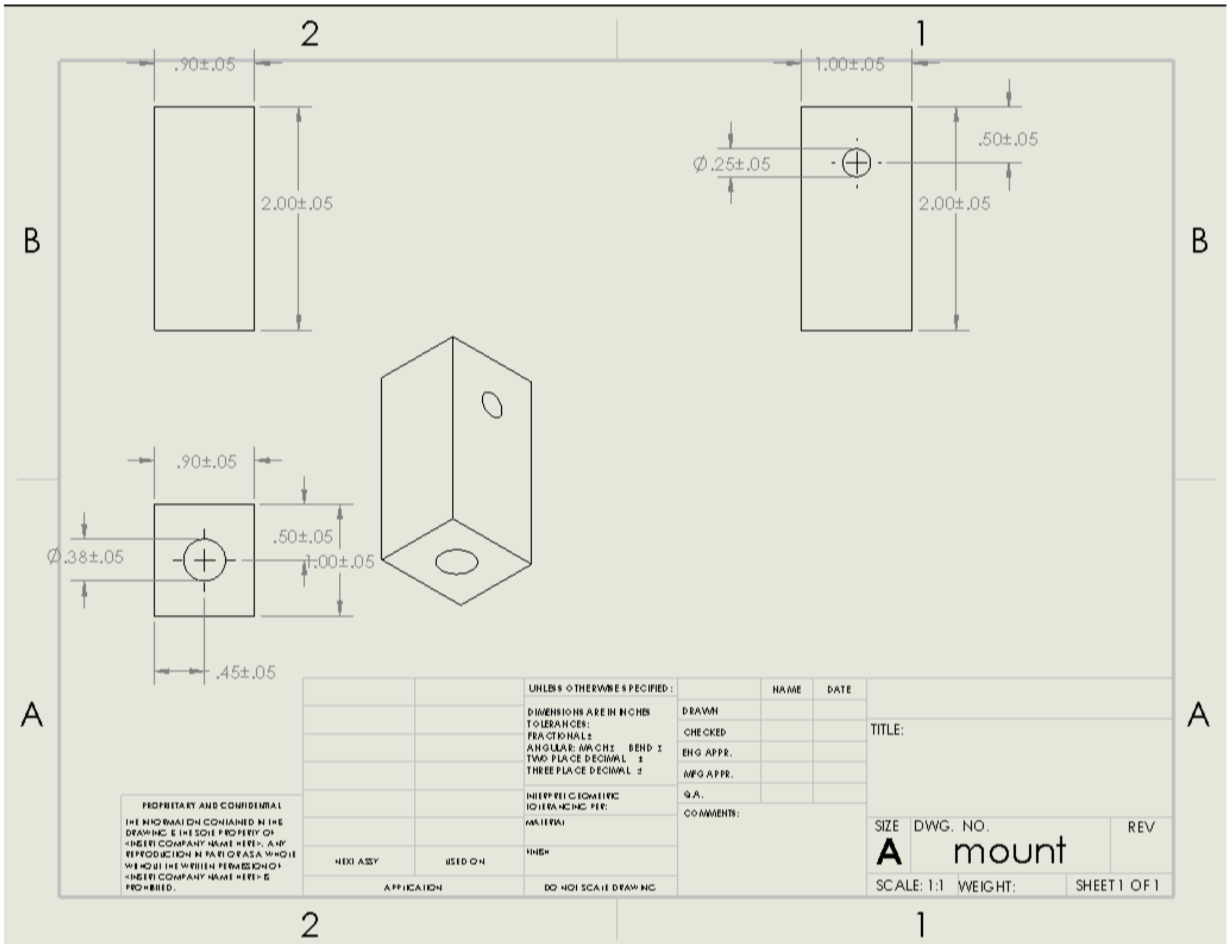


Figure 21: Cylinder Mount

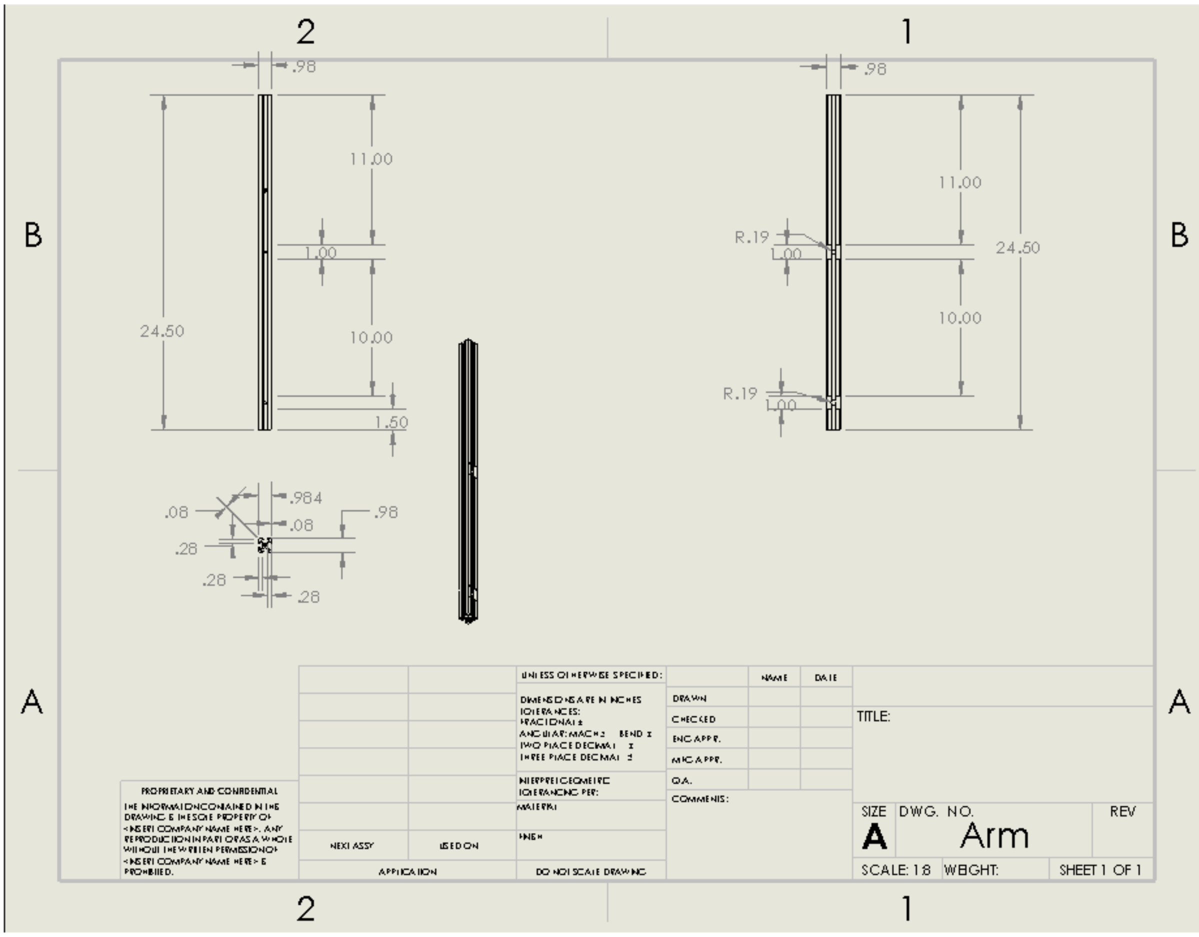


Figure 22: Arm Beam

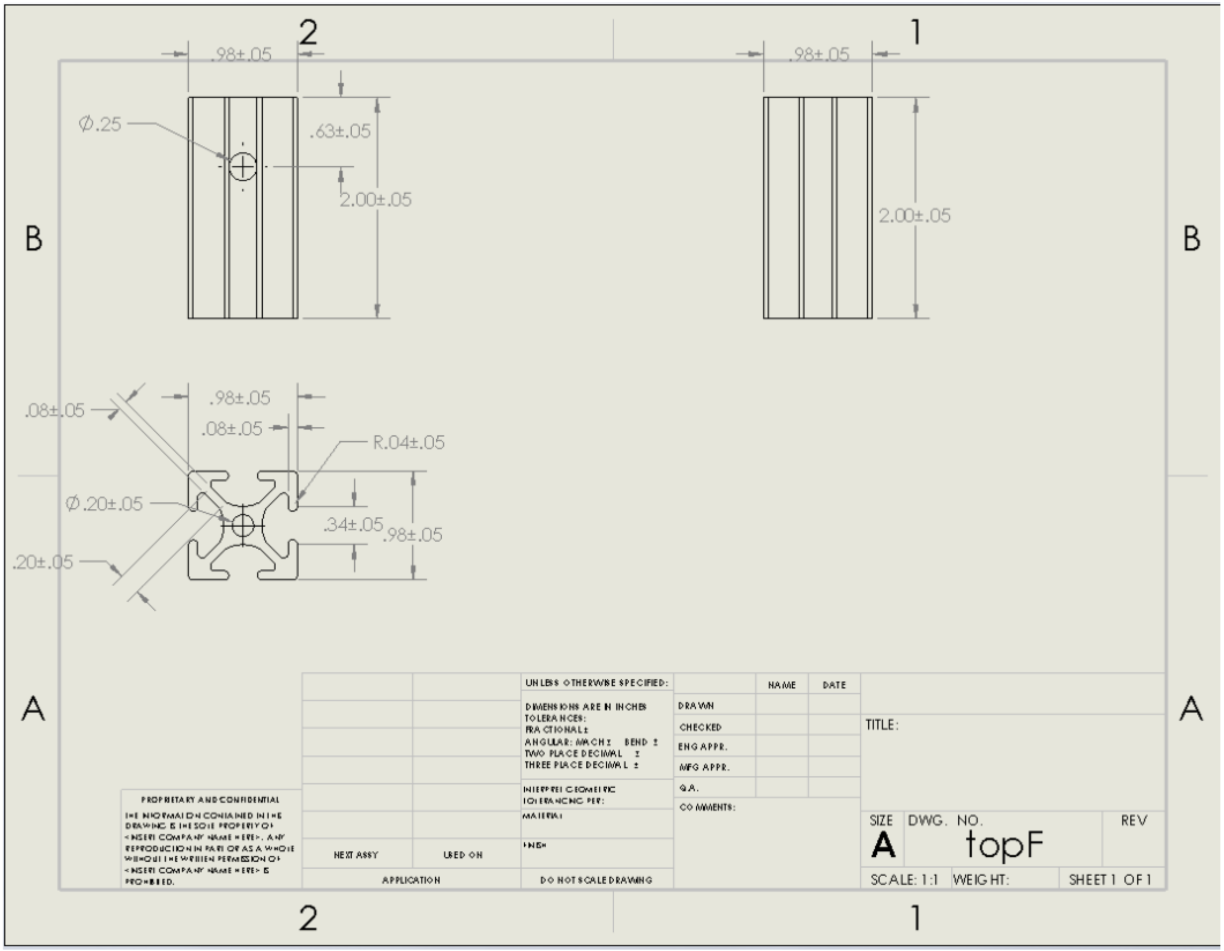


Figure 23: F Beam

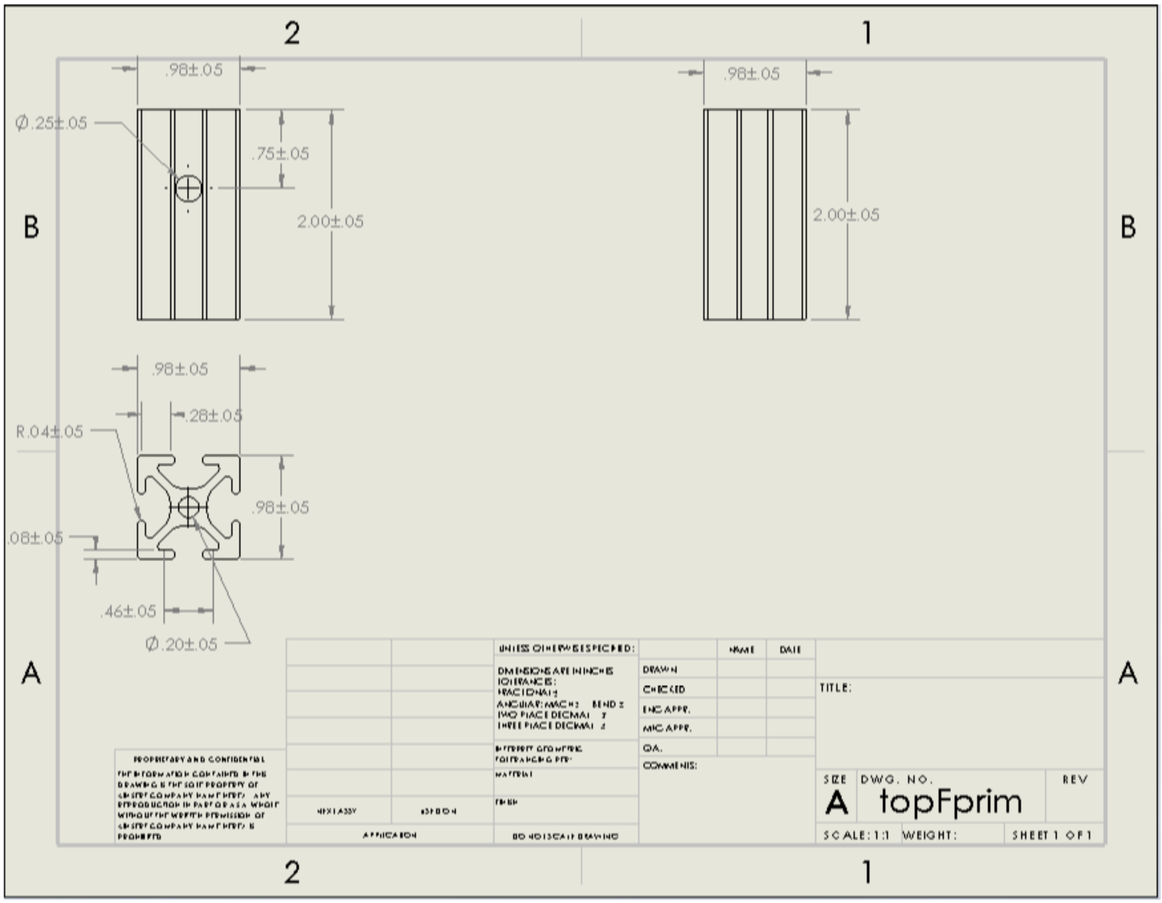


Figure 24: T Beam

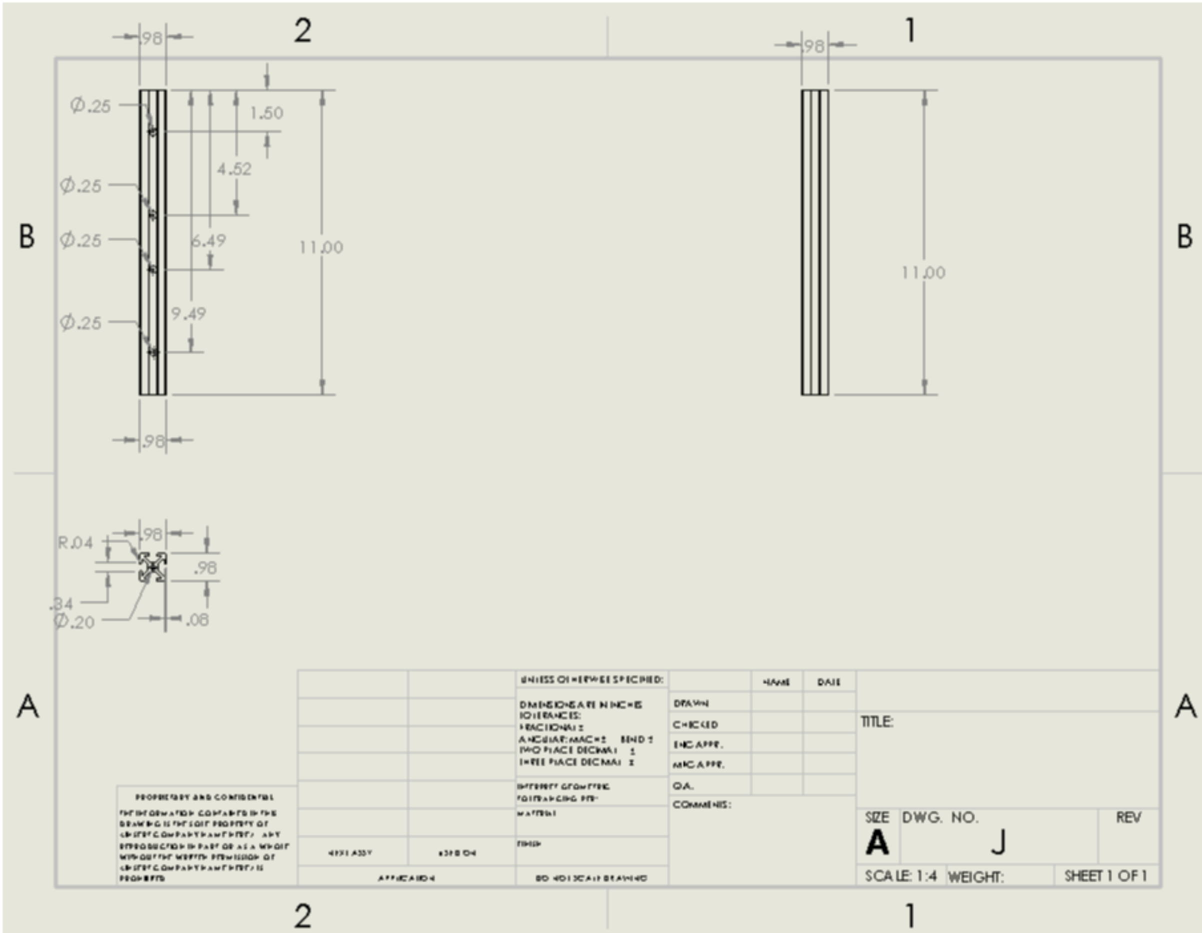


Figure 25: J Beam

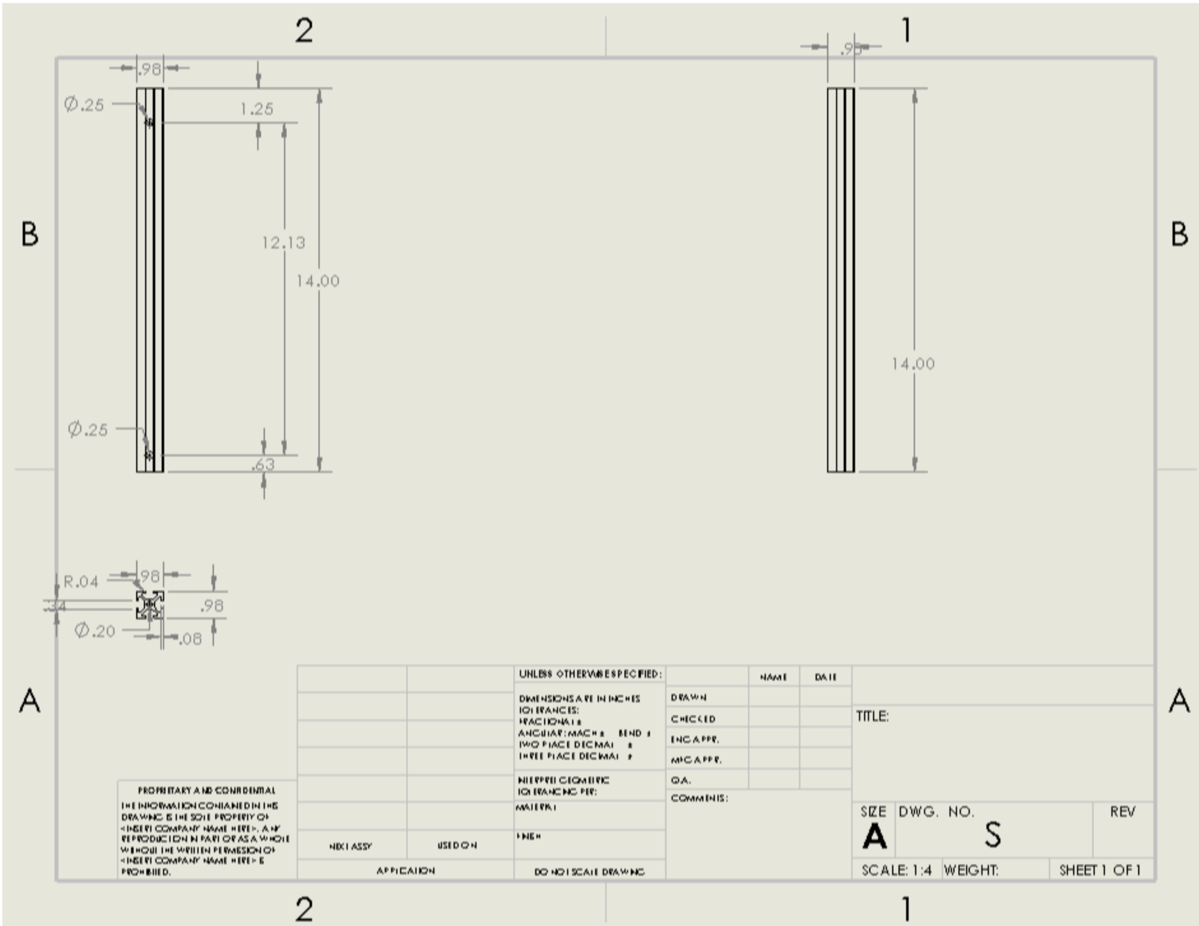


Figure 26: S Beam

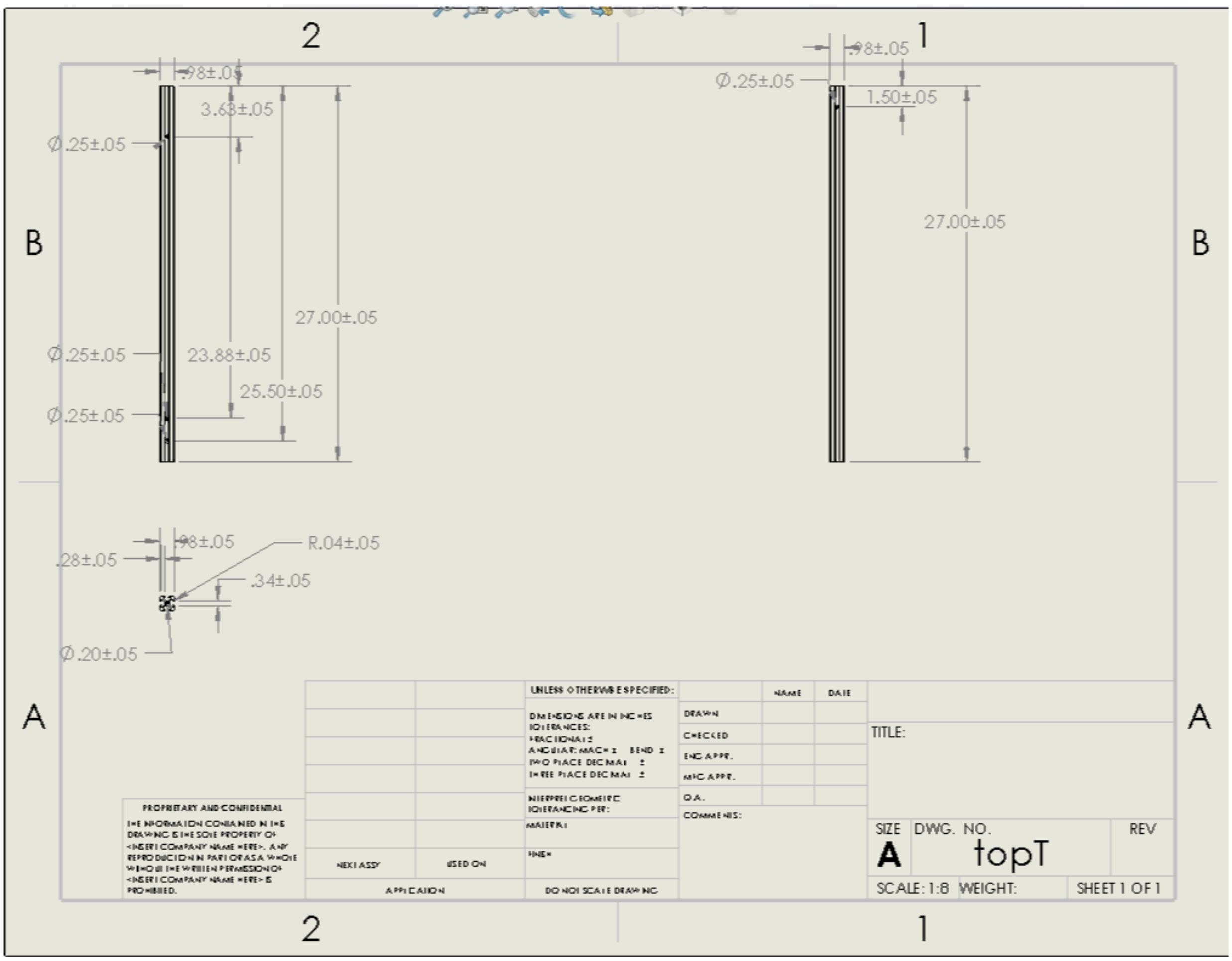


Figure 27: T Beam

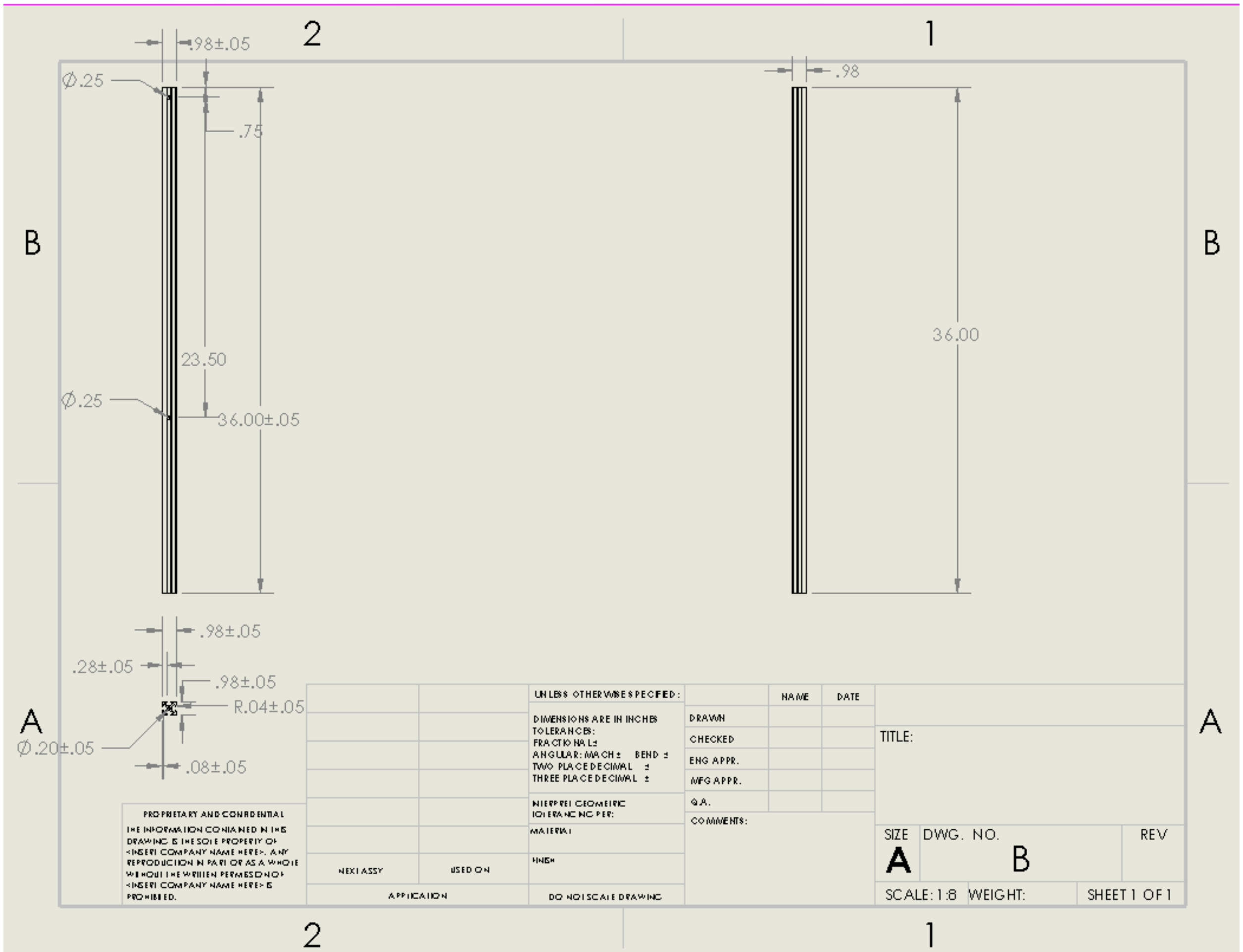


Figure 28: B Beam

Figure 29: Final Design

Figure 30: Pneumatic Stepper (Final Design, weighted my Scott Botelho)

10 Engineering Analysis

To begin analysis for our tree climbing system, first, in order to determine if our compression system would work, the potential energy needed to reach the desired goal of twenty feet,(EQ3) was balance out with the potential energy created from pressurized gas in an enclosed space, (EQ4). Knowing the potential energy needed to climb up the tree is equal to the potential needed inside of the air tank (EQ5), relationships were formed to correlate different pressures into the required volume, (EQ5). From the volume and the size of the chair, different air tank geometries were found (EQ6). From these equations a Microsoft Excel code was formatted to vary the pressure and output the need volume and radius of air tank (see figures). From these charts and graphs, pressure to volume relationships could be optimized. The derived information, it can be concluded that pressure and volume of the air tank will not be the challenge of this tree climbing system. Charts and Graphs of Air Tank analysis.

$$m = set - initial - condition \tag{1}$$

$$h = set - initial - condition \tag{2}$$

$$E = mgh \tag{3}$$

$$E = PV \tag{4}$$

$$mgh = PV \tag{5}$$

$$V = \pi r^2 l \tag{6}$$

[A, 01]$F_{D,L}$Lift and drag force N [A, 01]$C_{D,L}$Characteristic coefficient of lift and drag $-$ [A, 01]AWing platform / Surface area of the wing m^2

Height of Tree	mass	energy needed (min)	Pressures	Volume	height	radius
20	4	2576	0.1	25760	2	2049.916
20	4	2576	10	257.6	2	20.49916
20	4	2576	20	128.8	2	10.24958
20	4	2576	30	85.86667	2	6.833052
20	4	2576	40	64.4	2	5.124789
20	4	2576	50	51.52	2	4.099831
20	4	2576	60	42.93333	2	3.416526
20	4	2576	70	36.8	2	2.928451
20	4	2576	80	32.2	2	2.562395
20	4	2576	90	28.62222	2	2.277684
20	4	2576	100	25.76	2	2.049916
20	4	2576	110	23.41818	2	1.86356
20	4	2576	120	21.46667	2	1.708263
20	4	2576	130	19.81538	2	1.576858
20	4	2576	140	18.4	2	1.464225
20	4	2576	150	17.17333	2	1.36661
20	4	2576	160	16.1	2	1.281197
20	4	2576	170	15.15294	2	1.205833
20	4	2576	180	14.31111	2	1.138842
20	4	2576	190	13.55789	2	1.078903
20	4	2576	200	12.88	2	1.024958

Figure 31: Pressure, Volume, and Radius for Air Tank

Once the air tank was confirmed as a feasible idea, the frame concept was generalized and its variables were labeled(see Figures 1,2,3). From the general idea, it was determined that four different initial conditions had to be set, tree diameter, set distance from tree, seat height from lower trust point, and the angle of attack from the seat. From the initial conditions and what we know of force couples, the rest of the frames dimensions were determined as well as the static forces of the system. The static forces of the system include the upward friction forces caused by the force couple effect on the bark. If the upward friction forces become greater than the weight of the system, the system has positive holding force and our tree climbing device, sized by initial conditions, can climb a tree of the initial diameter. This chain of equations was generalized and encoded into Microsoft Excel, which allowed for the variance of the tree diameter to be equated with the locked initial conditions of the structure. This allowed us to graph the results of the holding force against tree diameter to determine the diameter that would cause system failure. Five other encoded blocked were created to view a cross comparison of the holding force to tree diameter relationship against five difference initial frame conditions. From the comparison, realistic initial conditions are put up against each other. The case with the greatest variance in climbable tree diameters is the winner and the other four are continual manually adjusted to try and beat the current best case. This static analysis confirms achieving positive holding force on trees up to two feet in diameter is trivial and we continue to tinker with our optimizing to attempt to maximize the potential of climbable trees. The chain of equations and figures used to correlate the four initial conditions into holding force are listed below in order; starting with our force coupe knowledge (Figure EQ), then the generalized frame (figure), and ends with the list of equations based on the force couple knowledge, frame generalization, and called initial conditions.

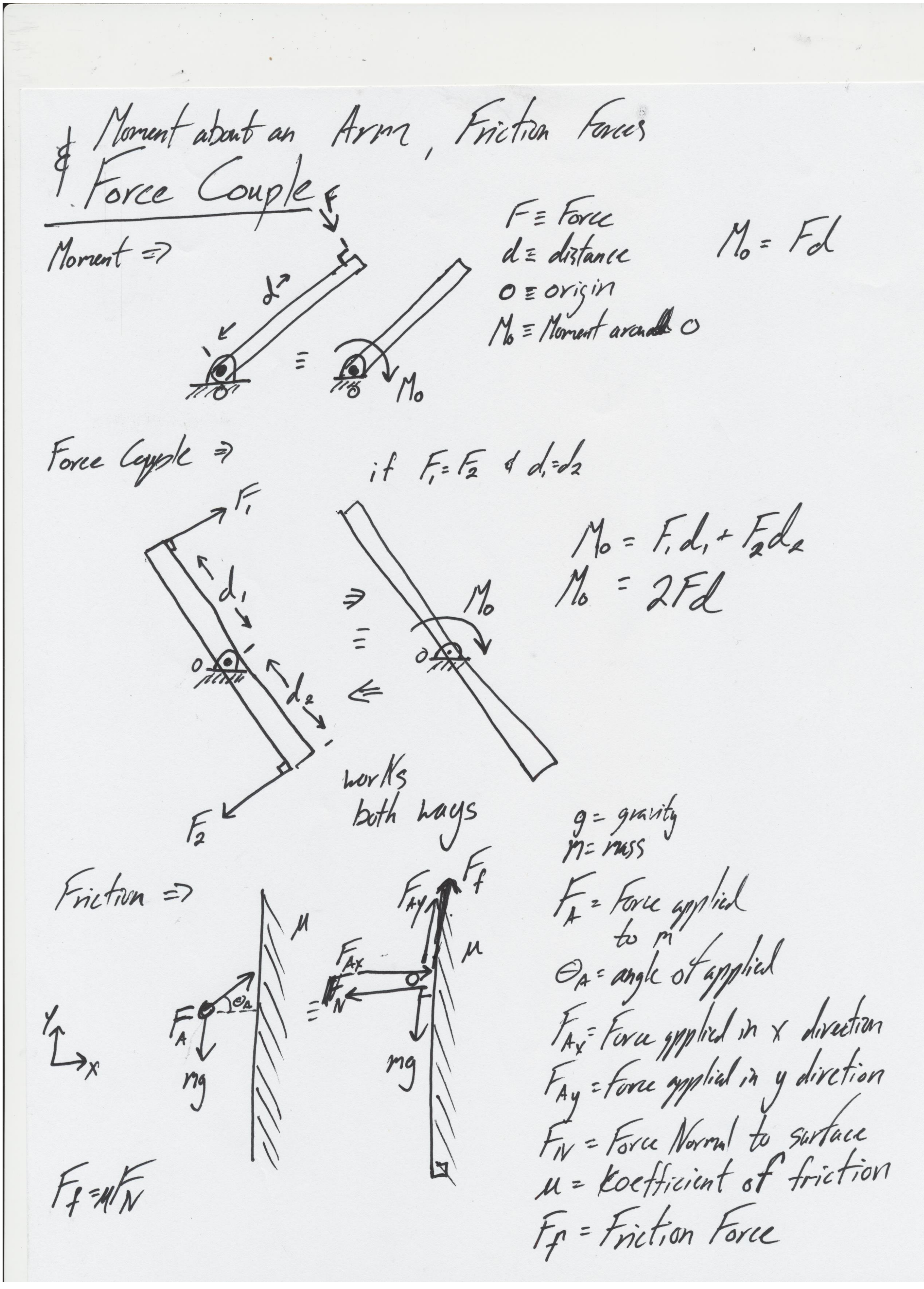


Figure 32: Moments, Force Couple, and Friction Knowledge

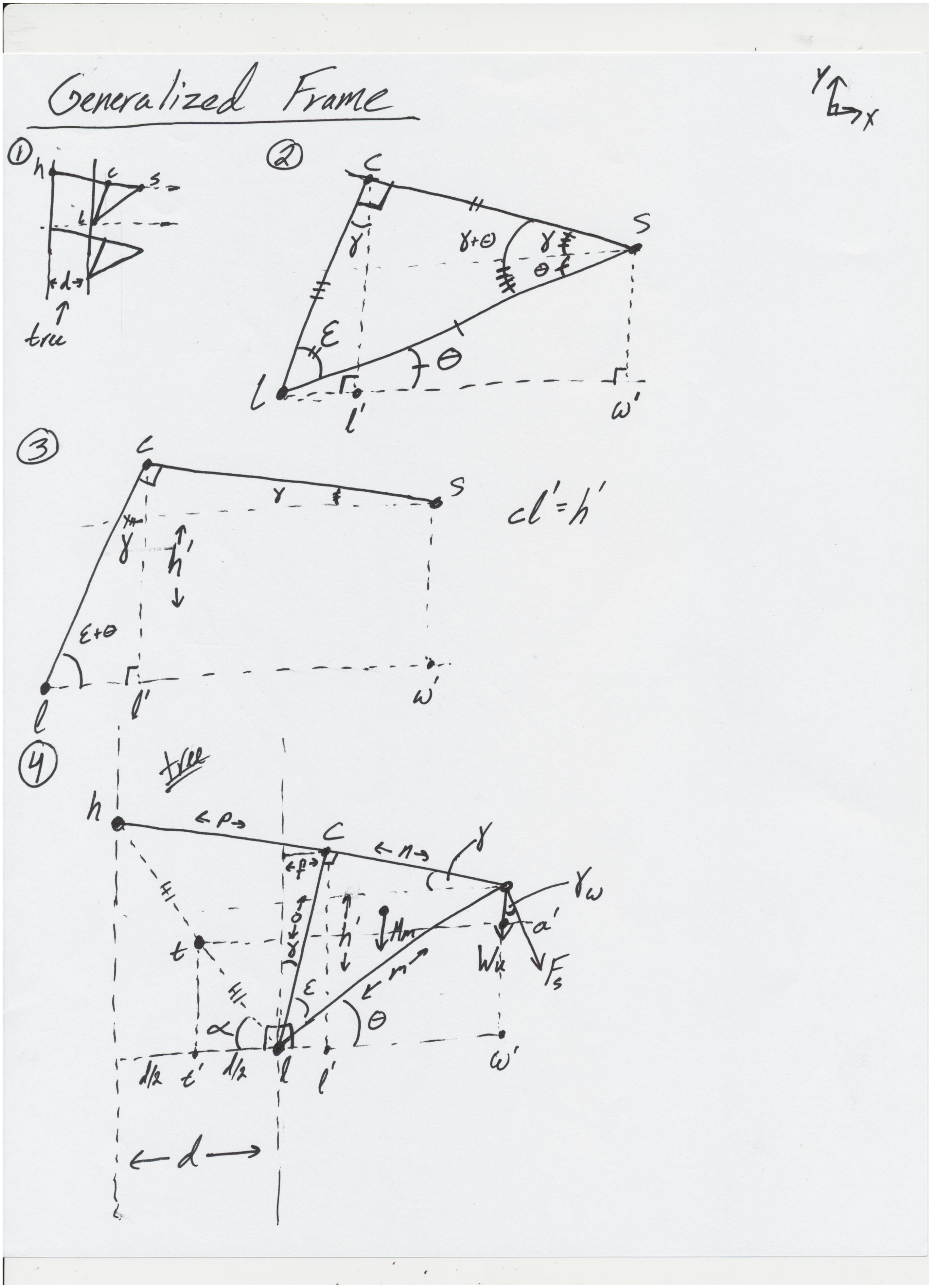


Figure 33: Generalized Frame

Geometer Equations-Angles and Lengths

$$cs = set - initial - condition \tag{7}$$

$$sw' = set - initial - condition \tag{8}$$

$$\gamma = set - initial - condition \tag{9}$$

$$\mu = set - initial - condition \tag{10}$$

$$d = set - initial - condition \tag{11}$$

$$90^{\text{deg}} = \gamma + \theta + \epsilon \tag{12}$$

$$h' = cl' = sw' + cs * sin(\gamma) \tag{13}$$

$$ll' = tan(\gamma) * h' \tag{14}$$

$$l'w' = cs * cos(\gamma) \tag{15}$$

$$\theta = tan(\frac{sw'}{ll' + l'w'})^{-1} \tag{16}$$

$$cl' = \frac{h'}{sin(\epsilon + \theta} \tag{17}$$

$$sl = \sqrt{cl^2 + cs^2} \tag{18}$$

$$ch = \frac{lw' + d - cs * cos(\gamma)}{cos(\gamma} \tag{19}$$

$$\alpha = tan(\frac{sw' + cs * sin(\gamma) + ch * sin(\gamma)}{d})^{-1} \tag{20}$$

$$f = ch * cos(\gamma) - d \tag{21}$$

$$lc = \frac{f}{cos(\epsilon + \theta)} \tag{22}$$

$$tt' = (d/2) * tan(\alpha) \tag{23}$$

$$tl = \frac{(d/2)}{cos(\alpha)} \tag{24}$$

$$sa' = sw' - tt' \tag{25}$$

$$\gamma_w = tan(\frac{sa'}{(d/2) + lw'})^{-1} \tag{26}$$

$$st = \frac{(d/2) + lw'}{cos(\gamma_w)} \tag{27}$$

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1	Set 1- Givens (constants for set m,c_f,d--Variable for sets cs,sw',gamma)							Find Sides & Angles (EQ #'s	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	Forces
2	cs	sw'	gamma (rad)	m_u	m_m	coeff_f	d-variable	At seat gamma	h'	ll'	l'w'	theta	epsilone	cl	ls	lw'	ch	alpha	f	lc	tc'	sa'	gamma_w	st	
3	2.50	1.08	0.26	4.00	0.00	0.70	0.25	15.00	1.73	0.46	2.41	0.36	0.95	1.79	3.07	2.88	2.57	1.47	2.23	8.62	1.20	-0.12	-0.04	3.00	
4	2.50	1.08	0.26	4.00	0.00	0.70	0.50	15.00	1.73	0.46	2.41	0.36	0.95	1.79	3.07	2.88	2.83	1.37	2.23	8.62	1.23	-0.15	-0.05	3.13	
5	2.50	1.08	0.26	4.00	0.00	0.70	0.75	15.00	1.73	0.46	2.41	0.36	0.95	1.79	3.07	2.88	3.09	1.28	2.23	8.62	1.26	-0.18	-0.06	3.26	
6	2.50	1.08	0.26	4.00	0.00	0.70	1.00	15.00	1.73	0.46	2.41	0.36	0.95	1.79	3.07	2.88	3.34	1.20	2.23	8.62	1.30	-0.22	-0.06	3.38	
7	2.50	1.08	0.26	4.00	0.00	0.70	1.25	15.00	1.73	0.46	2.41	0.36	0.95	1.79	3.07	2.88	3.60	1.13	2.23	8.62	1.33	-0.25	-0.07	3.51	
8	2.50	1.08	0.26	4.00	0.00	0.70	1.50	15.00	1.73	0.46	2.41	0.36	0.95	1.79	3.07	2.88	3.86	1.07	2.23	8.62	1.36	-0.28	-0.08	3.64	
9	2.50	1.08	0.26	4.00	0.00	0.70	1.75	15.00	1.73	0.46	2.41	0.36	0.95	1.79	3.07	2.88	4.12	1.01	2.23	8.62	1.40	-0.32	-0.08	3.77	
10	2.50	1.08	0.26	4.00	0.00	0.70	2.00	15.00	1.73	0.46	2.41	0.36	0.95	1.79	3.07	2.88	4.38	0.96	2.23	8.62	1.43	-0.35	-0.09	3.89	
11	2.50	1.08	0.26	4.00	0.00	0.70	2.25	15.00	1.73	0.46	2.41	0.36	0.95	1.79	3.07	2.88	4.64	0.92	2.23	8.62	1.46	-0.38	-0.10	4.02	
12	2.50	1.08	0.26	4.00	0.00	0.70	2.50	15.00	1.73	0.46	2.41	0.36	0.95	1.79	3.07	2.88	4.90	0.88	2.23	8.62	1.50	-0.42	-0.10	4.15	
13	2.50	1.08	0.26	4.00	0.00	0.70	2.75	15.00	1.73	0.46	2.41	0.36	0.95	1.79	3.07	2.88	5.16	0.84	2.23	8.62	1.53	-0.45	-0.11	4.28	
14	2.50	1.08	0.26	4.00	0.00	0.70	3.00	15.00	1.73	0.46	2.41	0.36	0.95	1.79	3.07	2.88	5.42	0.81	2.23	8.62	1.56	-0.48	-0.11	4.40	
15	2.50	1.08	0.26	4.00	0.00	0.70	3.25	15.00	1.73	0.46	2.41	0.36	0.95	1.79	3.07	2.88	5.67	0.78	2.23	8.62	1.60	-0.52	-0.11	4.53	
16	2.50	1.08	0.26	4.00	0.00	0.70	3.50	15.00	1.73	0.46	2.41	0.36	0.95	1.79	3.07	2.88	5.93	0.75	2.23	8.62	1.63	-0.55	-0.12	4.66	
17	2.50	1.08	0.26	4.00	0.00	0.70	3.75	15.00	1.73	0.46	2.41	0.36	0.95	1.79	3.07	2.88	6.19	0.73	2.23	8.62	1.66	-0.58	-0.12	4.79	
18	2.50	1.08	0.26	4.00	0.00	0.70	4.00	15.00	1.73	0.46	2.41	0.36	0.95	1.79	3.07	2.88	6.45	0.70	2.23	8.62	1.70	-0.62	-0.13	4.92	
19	2.50	1.08	0.26	4.00	0.00	0.70	4.25	15.00	1.73	0.46	2.41	0.36	0.95	1.79	3.07	2.88	6.71	0.68	2.23	8.62	1.73	-0.65	-0.13	5.04	
20	2.50	1.08	0.26	4.00	0.00	0.70	4.50	15.00	1.73	0.46	2.41	0.36	0.95	1.79	3.07	2.88	6.97	0.67	2.23	8.62	1.77	-0.69	-0.13	5.17	
21	2.50	1.08	0.26	4.00	0.00	0.70	4.75	15.00	1.73	0.46	2.41	0.36	0.95	1.79	3.07	2.88	7.23	0.65	2.23	8.62	1.80	-0.72	-0.14	5.30	
22	2.50	1.08	0.26	4.00	0.00	0.70	5.00	15.00	1.73	0.46	2.41	0.36	0.95	1.79	3.07	2.88	7.49	0.63	2.23	8.62	1.83	-0.75	-0.14	5.43	
23	2.50	1.08	0.26	4.00	0.00	0.70	5.25	15.00	1.73	0.46	2.41	0.36	0.95	1.79	3.07	2.88	7.74	0.62	2.23	8.62	1.87	-0.79	-0.14	5.56	
24	2.50	1.08	0.26	4.00	0.00	0.70	5.50	15.00	1.73	0.46	2.41	0.36	0.95	1.79	3.07	2.88	8.00	0.60	2.23	8.62	1.90	-0.82	-0.14	5.69	
25	2.50	1.08	0.26	4.00	0.00	0.70	5.75	15.00	1.73	0.46	2.41	0.36	0.95	1.79	3.07	2.88	8.26	0.59	2.23	8.62	1.93	-0.85	-0.15	5.82	
26	2.50	1.08	0.26	4.00	0.00	0.70	6.00	15.00	1.73	0.46	2.41	0.36	0.95	1.79	3.07	2.88	8.52	0.58	2.23	8.62	1.97	-0.89	-0.15	5.94	

Figure 34: Generalized Frame Angles and Lengths

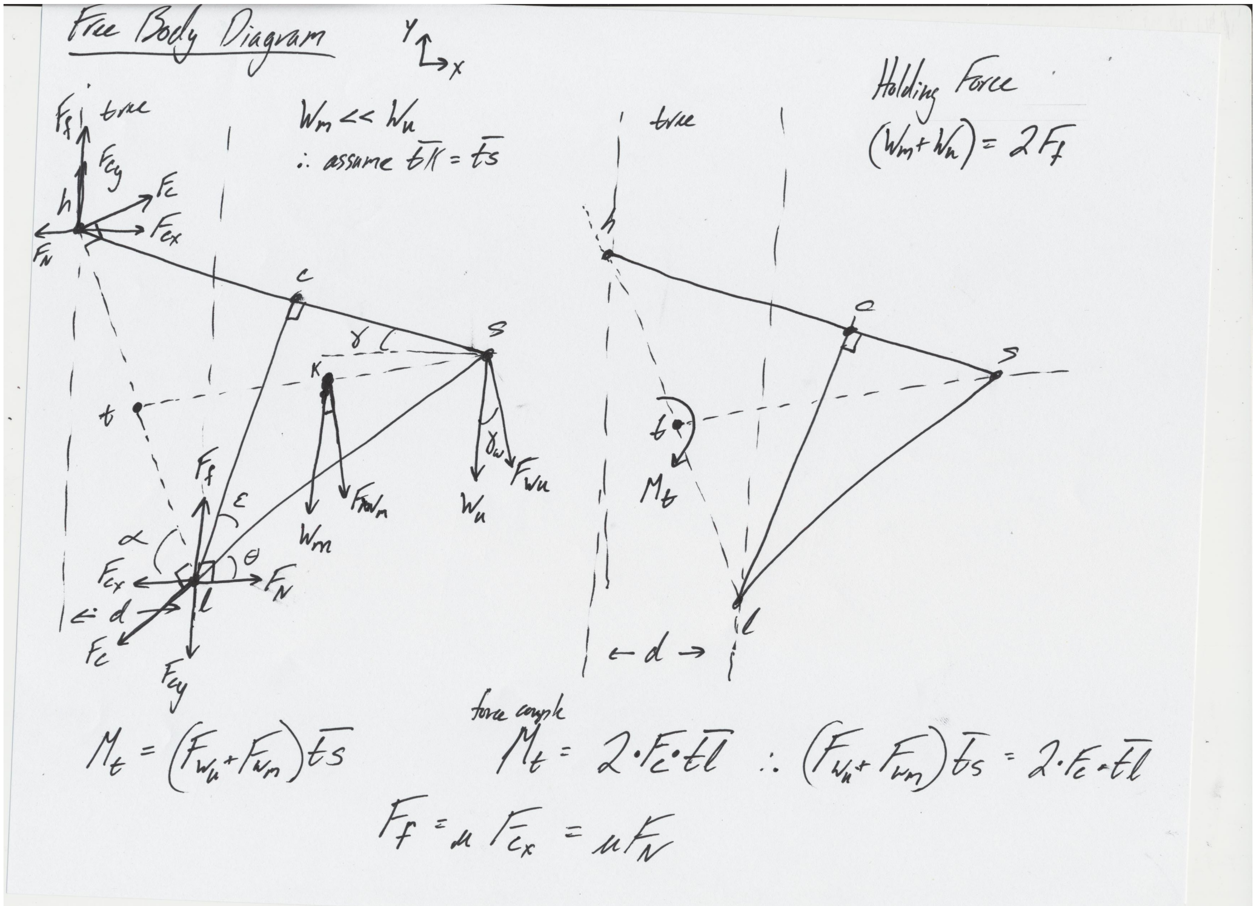


Figure 35: Free Body Diagrams

Statics Equations

$$W_M = mMg \tag{28}$$

$$W_U = m_U g \tag{29}$$

$$th = tl \tag{30}$$

$$lh = th + tl \tag{31}$$

$$F_S = \frac{cos(\gamma_w)}{W_U} \tag{32}$$

$$M_{st} = st * F_S \tag{33}$$

$$M_{st} = M_{FC} \tag{34}$$

$$M_{FC} = 2F_C d \tag{35}$$

$$F_C = \frac{M_{st}}{2d} \tag{36}$$

$$F_{C_x} = F_C * cos(90 - \alpha) \tag{37}$$

$$F_{C_x} = F_N \tag{38}$$

$$F_f = \mu * F_N \tag{39}$$

$$W_U + W_M = 2F_f \tag{40}$$

$$Staying - Power = 2F_f - (W_U + W_M) \tag{41}$$

Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL
Forces	17.00	18.00	19.00	20.00	21.00	22.00	23.00	24.00	25.00	26.00	27.00	28.00	Feasable Dimentions
	Fs	W_u	W_m	Ms	Mf_c	Fc	O_f	F_t	F_f	Weight	2*F_f	Staying Power +	Yes or No
	128.70	128.80	0.00	386.73	75.30	150.59	15.66	149.78	104.85	128.80	209.69	80.89	Yes
	128.65	128.80	0.00	402.83	71.25	142.50	28.40	139.64	97.75	128.80	195.50	66.70	Yes
	128.60	128.80	0.00	418.93	67.88	135.77	38.65	130.15	91.10	128.80	182.21	53.41	Yes
	128.54	128.80	0.00	435.03	65.04	130.07	46.81	121.36	84.95	128.80	169.90	41.10	Yes
	128.47	128.80	0.00	451.13	62.60	125.20	53.25	113.31	79.32	128.80	158.63	29.83	Yes
	128.41	128.80	0.00	467.23	60.49	120.98	58.31	106.00	74.20	128.80	148.40	19.60	Yes
	128.34	128.80	0.00	483.33	58.64	117.29	62.26	99.40	69.58	128.80	139.15	10.35	Yes
	128.28	128.80	0.00	499.43	57.02	114.03	65.34	93.46	65.42	128.80	130.84	2.04	Yes
	128.21	128.80	0.00	515.53	55.57	111.14	67.73	88.12	61.68	128.80	123.37	-5.43	NO
	128.15	128.80	0.00	531.63	54.28	108.55	69.57	83.33	58.33	128.80	116.66	-12.14	NO
	128.08	128.80	0.00	547.73	53.11	106.23	70.99	79.03	55.32	128.80	110.64	-18.16	NO
	128.02	128.80	0.00	563.83	52.06	104.12	72.07	75.15	52.61	128.80	105.22	-23.58	NO
	127.96	128.80	0.00	579.93	51.11	102.21	72.88	71.66	50.16	128.80	100.33	-28.47	NO
	127.90	128.80	0.00	596.03	50.23	100.47	73.49	68.50	47.95	128.80	95.90	-32.90	NO
	127.84	128.80	0.00	612.13	49.43	98.87	73.93	65.64	45.95	128.80	91.90	-36.90	NO
	127.78	128.80	0.00	628.23	48.70	97.40	74.24	63.04	44.13	128.80	88.26	-40.54	NO
	127.72	128.80	0.00	644.33	48.02	96.04	74.45	60.67	42.47	128.80	84.94	-43.86	NO
	127.67	128.80	0.00	660.43	47.39	94.78	74.57	58.50	40.95	128.80	81.91	-46.89	NO
	127.61	128.80	0.00	676.53	46.81	93.61	74.63	56.52	39.56	128.80	79.13	-49.67	NO
	127.56	128.80	0.00	692.63	46.26	92.53	74.63	54.70	38.29	128.80	76.58	-52.22	NO
	127.51	128.80	0.00	708.73	45.76	91.52	74.59	53.02	37.11	128.80	74.22	-54.58	NO
	127.46	128.80	0.00	724.83	45.28	90.57	74.52	51.47	36.03	128.80	72.05	-56.75	NO
	127.41	128.80	0.00	740.93	44.84	89.68	74.43	50.03	35.02	128.80	70.04	-58.76	NO
	127.36	128.80	0.00	757.03	44.42	88.84	74.31	48.70	34.09	128.80	68.18	-60.62	NO

Figure 36: Generalized Frame Forces, Weight, Friction, and Holding Force

AL	AM	AN	AO	AP	AQ	AR	AS	AT
Feasable Dimentions	Sides- (note ch for max length usable "d")				Angles			
Yes or No	ls	cs	lc	ch-variable "d"	gamma	theta	alpha	alpha
Yes	3.07	2.50	8.62	2.57	15.00	20.57	0.95	84.03
Yes	3.07	2.50	8.62	2.83	15.00	20.57	0.95	78.51
Yes	3.07	2.50	8.62	3.09	15.00	20.57	0.95	73.46
Yes	3.07	2.50	8.62	3.34	15.00	20.57	0.95	68.91
Yes	3.07	2.50	8.62	3.60	15.00	20.57	0.95	64.83
Yes	3.07	2.50	8.62	3.86	15.00	20.57	0.95	61.18
Yes	3.07	2.50	8.62	4.12	15.00	20.57	0.95	57.94
Yes	3.07	2.50	8.62	4.38	15.00	20.57	0.95	55.04
NO	3.07	2.50	8.62	4.64	15.00	20.57	0.95	52.46
NO	3.07	2.50	8.62	4.90	15.00	20.57	0.95	50.14
NO	3.07	2.50	8.62	5.16	15.00	20.57	0.95	48.07
NO	3.07	2.50	8.62	5.42	15.00	20.57	0.95	46.20
NO	3.07	2.50	8.62	5.67	15.00	20.57	0.95	44.52
NO	3.07	2.50	8.62	5.93	15.00	20.57	0.95	42.99
NO	3.07	2.50	8.62	6.19	15.00	20.57	0.95	41.60
NO	3.07	2.50	8.62	6.45	15.00	20.57	0.95	40.34
NO	3.07	2.50	8.62	6.71	15.00	20.57	0.95	39.18
NO	3.07	2.50	8.62	6.97	15.00	20.57	0.95	38.12
NO	3.07	2.50	8.62	7.23	15.00	20.57	0.95	37.14
NO	3.07	2.50	8.62	7.49	15.00	20.57	0.95	36.24
NO	3.07	2.50	8.62	7.74	15.00	20.57	0.95	35.40
NO	3.07	2.50	8.62	8.00	15.00	20.57	0.95	34.63
NO	3.07	2.50	8.62	8.26	15.00	20.57	0.95	33.91
NO	3.07	2.50	8.62	8.52	15.00	20.57	0.95	33.24

Figure 37: Generalized Frame Dimensions

Data	Staying Power +				
d-variable	Set # 1	Set # 2	Set # 3	Set # 4	Set # 5
0.25	80.89	94.28	90.24	73.98	80.88
0.50	66.70	81.11	82.20	61.09	74.80
0.75	53.41	68.97	74.68	49.52	69.06
1.00	41.10	57.79	67.62	39.03	63.62
1.25	29.83	47.53	60.99	29.49	58.43
1.50	19.60	38.13	54.72	20.79	53.49
1.75	10.35	29.54	48.81	12.85	48.77
2.00	2.04	21.70	43.22	5.61	44.24
2.25	-5.43	14.55	37.93	-1.00	39.91
2.50	-12.14	8.02	32.93	-7.03	35.75
2.75	-18.16	2.05	28.18	-12.55	31.75
3.00	-23.58	-3.40	23.69	-17.60	27.91
3.25	-28.47	-8.39	19.43	-22.22	24.23
3.50	-32.90	-12.96	15.39	-26.46	20.68
3.75	-36.90	-17.16	11.55	-30.35	17.27
4.00	-40.54	-21.03	7.91	-33.93	13.99
4.25	-43.86	-24.59	4.46	-37.24	10.84
4.50	-46.89	-27.88	1.18	-40.29	7.80
4.75	-49.67	-30.93	-1.94	-43.11	4.88
5.00	-52.22	-33.75	-4.90	-45.73	2.07
5.25	-54.58	-36.37	-7.73	-48.16	-0.63
5.50	-56.75	-38.81	-10.41	-50.42	-3.23
5.75	-58.76	-41.09	-12.97	-52.53	-5.74
6.00	-60.62	-43.22	-15.40	-54.50	-8.15

Figure 38: Holding Force Comparison of Five Generalized Frames

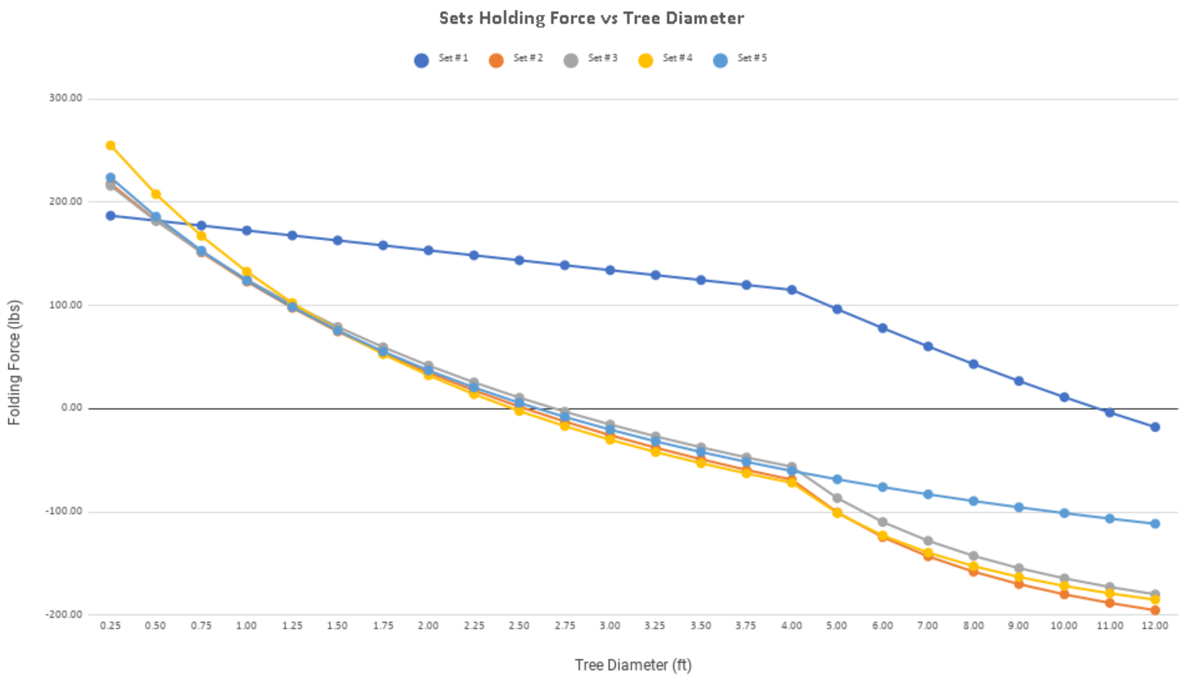


Figure 39: Tree Diameter vs Holding Force Comparison

After the final dimensions and parts of the system were decided and optimized then an ABAQUS analysis was able to be done to determine the highest forces in the system and the forces locations. The system was analysis as a 2D beam with the appropriate Young's Modulus of 20.2e6 psi, a Poisson's ration of .33, an area of 0.426 sq in, and a Moment of Inertia of 0.0425 double square inches in both the X and Y directions. All proprieties were sourced from the companies website, where properties for all parts were given. The results of the analysis showed that maximum stresses at Node 9, around the connection point from arm to tree. The stress here is 19,630lbs, but the concentration and area of the high point is small, meaning it will most likely produce less force through that area. Further analysis will be done on the arm to see what the safety factor for the arm is. The second max stress was 9,649 lbs, at node 4723, where the bottom beam meets the top beam. With a Yield Strength of 34,966 psi and a cross sectional area of 0.426 sq inches; providing a max yield force or 14,895.52lbs. Therefore the beams have a safety factor of 1.54. Analysis of the forces at the hole shows reaction forces can be approximated it different distributed loads around the circle in the X and Y directions, ranging from -148 to -4000 in the X direction and -700 to 1000 in the Y direction. These values will be used to asses the arm in more depth. Analysis of the stresses around Node 127, where the arm meets the top beam, shows internal reaction varying from 5000lbs to -28lbs. These values will be used to further analysis the bolt joining these to sections

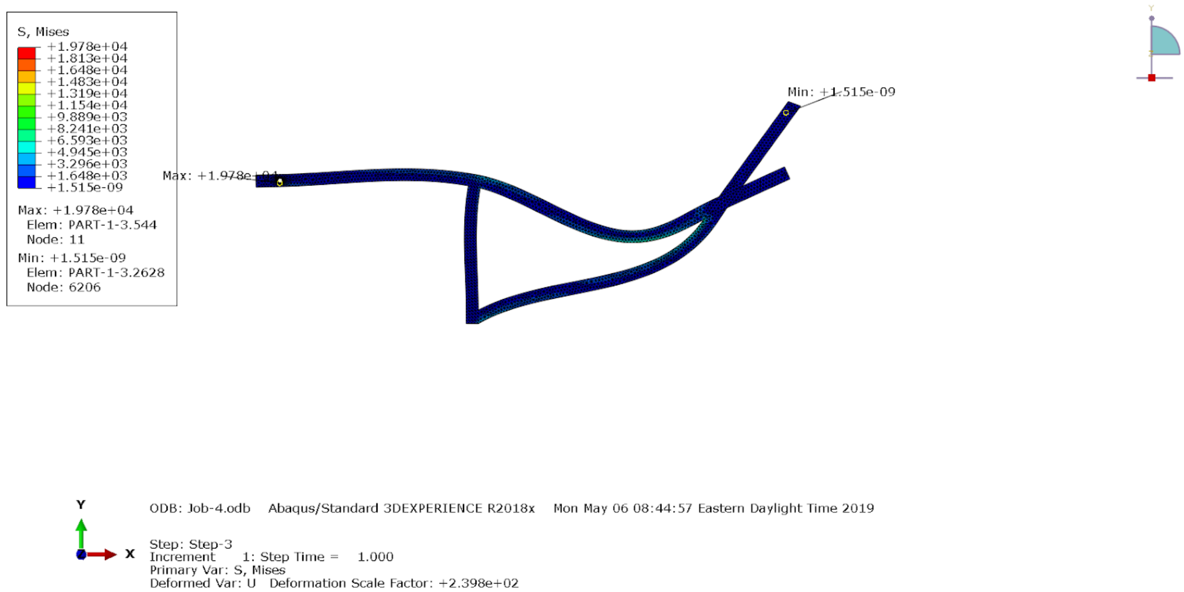


Figure 40: ABAQUS Analysis for Mounting System

This information was first used to determine if the metal frame would have the strength to hold the desired weight, and that concluded with a result of a safety factor of 1.54 Confirming the metal was safe to use for the system. The information of the stress developing in the near bolt locations was used for an ABAQUS analysis of the most stressed bolt location. The bolts Young's Modulus is 1.566e7 psi, Piossion's ratio of 0.25, cross sectional area of 0.19 sq inches, and yield strength of 35,000 psi. The max stress developed in the bolt, 12,170 lbs at Node 10. This location is under subject due to the strange boundary conditions used to simulate the bolt conditions. A more reasonable location to asses would be node 14, where there is a stress of 6,350 lbs. This was used to determine if the chosen bolts had enough holding strength to keep the system together. It was determined that the bolts had a maximum yield force of 6,860 lbs, so the safety factor of 1.08 confirming the bolts were safe for use, but way want slightly strong bolts for high stress connections.

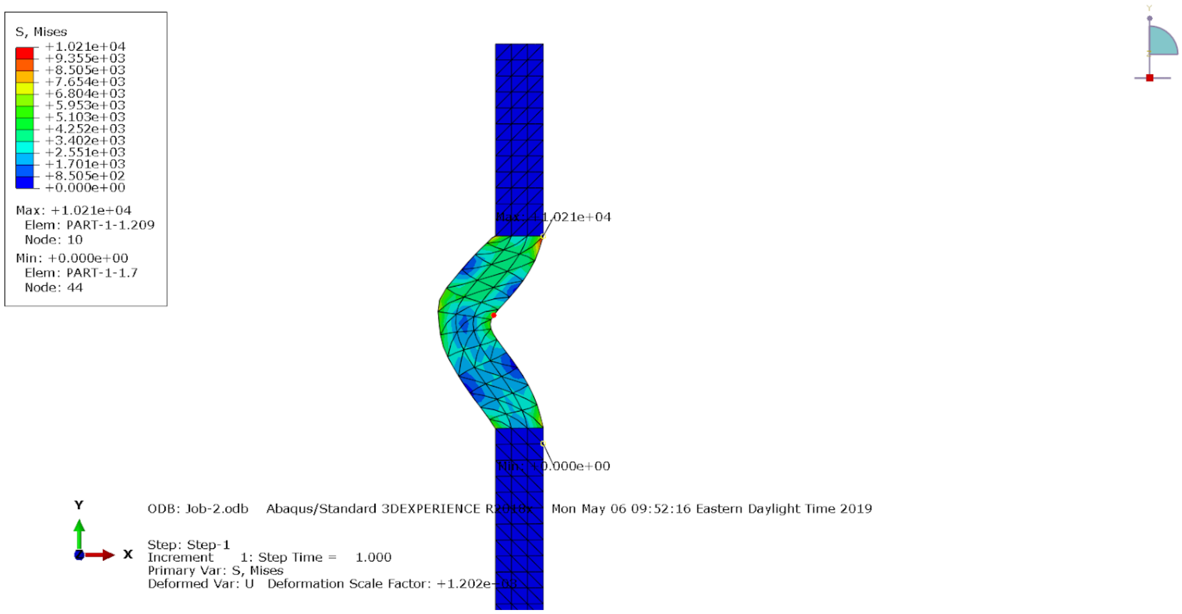


Figure 41: ABAQUS Analysis for Bolt

The ABAQUS result were not able to be compared to actual experimental results because of the complexity of the system. With mass amounts of angle changes, many different connection points, and possible slip that may occur on the tree when settling in; attempting to compare ABAQUS results to experimental results soon seems out of our league. If were had the ability and resources to do a full break test of the whole system it would have provided a lot of information about how accurate our safety factors are, but this test was not able to be done.

In the end, with the system being weighted to 350lbs, the smallest safety factor become... Leaving our team confident in the systems ability to keep its passenger safe as well as the tree.

11 Build/Manufacture

11.1 Initial Design

For the original design a year 2 required quantity of 7,700 units was assumed, from this the manufacturing cost per part was calculated. A local manufacturing expert was consulted on required overhead costs and basic operational requirements to manufacture the apparatus. With a 260 work day year and one, eight hour shift per work day, it would require the production of 29.615 units per day. This breaks down to 3.7 units per hour or 16 minutes and 12 seconds per assembly. This time constraint made a manual assembly line unreasonable. Based on figure 61, the average time to complete the manufacturing of one unit manually was 3.45 hours, totaling 603 assemblies per year. This did not meet the 7700 unit per year goal and incurred a cost of $ 97.88 per completed unit. This cost and assembly time was inapplicable so figure 63, was generated assuming a mostly automated assembly and manufacturing process. This brought the total assembly time down to under the 0.27 hours per unit and incurred a cost of $ 6.29 per unit. This cost was derived assuming a machine operating cost of $ 12.51 per hour, and a labor rate of $ 17.72 per hour. Each individual operation was allotted its required time to reach completion for the equivalent of one complete frame assembly. A manufacturing overhead cost of 100 percent, equipment overhead of 50 percent, and tolerance factor of 25 percent for miscellaneous servicing of the machines or faulty parts, were then included before calculating a final cost of $ 6.29 per part. This price does not include initial investment for machinery or area of operation, so a capital expenditure of $ 250,000 was included.

Assemblies per year	Assemblies per day	Assemblies per hour	Time per assembly (HR)	Time per assembly (min)
7700	29.61538462	3.701923077	0.27012987	16.21

Manual Assembly

	Operation 1	Operation 2	Operation 3	Operation 4	Operation 5	Operation 6	Operation 7	
	Cut bar stock to length and prepare for welding	Drill bolt holes and placement holes	Place cut pieces in jigs for the welder and remove welded frame	Tack and finish welding of prepared piece	Furnish seat	Place frame and remainder of parts into shipment package	Cleanup, inspection, etc. for 8 hour shift	Totals
Time to complete operation (per Frame)	0.5	1	0.25	1	0.1	0.1	0.5	3.45
Labor Rate	$ 17.72	$ 17.71	$ 17.72	$ 20.18	$ 17.72	$ 17.72	$ 13.38	
Cost	8.86	17.71	4.43	20.18	1.772	1.772	6.69	
Overhead Factor	1	1	1	1	1	1	1	
Equipment factor	0.5	0.5	0.5	0.5	0.5	0	0.5	
Tolerance Factor	0.25	0.25	0	0	0	0	0	
labor/ept cost	$ 15.51	$ 30.99	$ 6.65	$ 30.27	$ 2.66	$ 1.77	$ 10.04	$ 97.88

Figure 42: Manual Assembly Cost Analysis, Initial design

	Operation 1	Operation 2	Operation 3	Operation 4	Operation 5	Operation 6	Operation 7	
	Cut bar stock to length and prepare for welding	Drill bolt holes and placement holes	Place cut pieces in jigs for the welder and remove welded frame	Tack and finish welding of prepared piece	Furnish seat	Place frame and remainder of parts into shipment package	Cleanup, inspection, etc. for 8 hour shift	
Time to complete operation (per Frame in hours)	0.05	0.06	0.01	0.11	0.01	0.015	0.015	0.27
Equipment running/ labor Rate	$ 12.51	$ 12.51	$ 17.72	$ 12.51	$ 17.72	$ 17.72	$ 17.72	
Cost	0.6255	0.7506	0.1772	1.3761	0.1772	0.2658	0.2658	
Overhead Factor	1	1	1	1	1	1	1	
Equipment factor	0.5	0.5	0.5	0.5	0.5	0	0.5	
Tolerance Factor	0.25	0.25	0	0	0	0	0	
labor/ept cost	$ 1.72	$ 1.31	$ 0.27	$ 2.06	$ 0.27	$ 0.27	$ 0.40	$ 6.29

Figure 43: Semi-Autonomous Manufacturing Cost Analysis, Initial Design

11.2 Final Design

For the final design a year 2 required quantity of 7,700 units was also assumed, from this the manufacturing cost per part was calculated. The major difference in this manufacturing process versus the original is that the product would be assembled by the end user, not in the manufacturing process. This made the manufacturing process much more efficient, requiring only 4 total operations. With a 260 work day year and one, eight hour shift per work day, it would require the production of 29.615 units per day. This breaks down to 3.7 units per hour or 16 minutes and 12 seconds per assembly. This time constraint once again made a manual manufacturing line unreasonable. Based on figure 62, the average time to complete the manufacturing of one unit manually was 2.2 hours, totaling 945.45 assemblies per year. This did not meet the 7700 unit per year goal and incurred a cost of $ 60.08 per completed unit. This cost and assembly time was inapplicable so figure 64, was generated assuming a mostly automated assembly and manufacturing process. This brought the total assembly time down to under the 0.44 hours per unit and incurred a cost of $ 21.84 per unit. This cost was derived assuming a machine operating cost of $ 12.51 per hour, and a labor rate of $ 17.72 per hour. Each individual operation was allotted its required time to reach completion for the equivalent of one complete frame assembly. A manufacturing overhead cost of 100 percent, equipment overhead of 50 percent, and tolerance factor of 25 percent for miscellaneous servicing of the machines or faulty parts, were then included before calculating a final cost of $ 6.29 per part. This price does not include initial investment for machinery or area of operation, so a capital expenditure of $ 250,000 was included.

	Operation 1	Operation 2	Operation 3	Operation 4	
	Cut aluminum stock to length	Drill bolt holes and placement holes	Place frame and remainder of parts into shipment package	Cleanup, inspection, etc. for 8 hour shift	Totals
Time to complete operation (per Frame)	0.5	1	0.2	0.5	2.2
Labor Rate	$ 17.72	$ 17.71	$ 17.72	$ 13.38	
Cost	8.86	17.71	3.544	6.69	
Overhead Factor	1	1	1	1	
Equipment factor	0.5	0.5	0	0.5	
Tolerance Factor	0.25	0.25	0	0	
labor/ept cost	$ 15.51	$ 30.99	$ 3.54	$ 10.04	$ 60.08

Figure 44: Manual Assembly Cost Analysis, Final design

Automated Assembly	Operation 1	Operation 2	Operation 3	Operation 4	
	Cut aluminum stock	Drill bolt holes	Package indivual pieces	Cleanup, inspection, etc. for 8 hour shift	Totals
Time to complete operation (per Frame in hours)	0.05	0.06	0.33	0.5	0.44
Equipment running/ labor Rate	$ 12.51	$ 12.51	$ 17.72	$ 13.38	
Cost	0.6255	0.7506	5.8476	6.69	
Overhead Factor	1	1	1	1	
Equipment factor	0.5	0.5	0.5	0.5	
Tolerance Factor	0.25	0.25	0	0	
labor/ept cost	$ 1.72	$ 1.31	$ 8.77	$ 10.04	$ 21.84

Figure 45: Semi-Autonomous Manufacturing Cost Analysis, Final Design

12 Testing

The testing matrix shown in figure 46 was made by Team 17 to test the validity of the final design. The testing first began with validating our frame assemblies and straps ability to maintain position on a tree and handle loading. Once the concept of the frame was proven we needed to validate the capabilities of the pneumatic assistance system. The results from these test were critical for Team 17 as it allowed them to find the flaws in the initial design and produce the final product. These test are explained further individually below.

Component	What to test?	Parameters	Results	Resolutions
Frame	Force couple	Hold bodyweight	Pass, maintained position	
Straps	Strength and mobility	Ascension	Fail, firm hold, does not move	Round rope/cable required
Cylinder	Position	Move frames up and down	Failed, uncoupled frames	Move piston back
Arm positioning	Opening width	Ability for variable diameter	Pass, fit diameters from 12”-43”	
Air delivery system	Functionality	Air operates under load	Pass	
Air tank	Stroke count	100 strokes	64-87 strokes	Larger tank
Air manifold	Operation	Controls cylinder	Fail, need neutral position	Buy new manifold

Figure 46: Testing Matrix

12.1 Performance Testing

12.1.1 Frame Strength

The first test conducted was to validate the strength of the frame assemblies and their ability to maintain position on the tree under load. An individual frame assembly was placed on the tree, using flat tie down straps and then initially loaded with a user, this individual weighed 175 pounds. Once on the frame the user bounced up and down to induce a impact load on the frame to see how it reacted, looking for deflection in the frame or uncoupling from the tree. Frame here the frame was loaded with addition weight in 25 pound increments to a final load of 350 pounds by way of Olympic lifting metal plates. The frame maintained position and showed no deflection until 325 pounds, when a small, less than an eighth of an inch of deflection was noticed in the arms. The deflection was very minuscule and not considered an issue for the design specification of a 350 pound maximum load, if the load capacity was to be raised, a new mounting method for the arms would have been investigated. The results are tabulated below:

Added weight	result	Observations
0	Maintained position	Sturdy, no deflection observed
175	Maintained position	Sturdy
200	Maintained position	Sturdy
225	Maintained position	Sturdy
250	Maintained position	Sturdy
275	Maintained position	Sturdy
300	Maintained position	Sturdy
325	Maintained position	mild deflection in arms 1/8"
350	Maintained position	mild deflection in arms 1/8"

Figure 47: Frame Loading

12.1.2 Strap Mobility

This test aimed to see the mobility of the frame assembly on the tree. The aim was for easy ascention up the tree. The frame was mounted to the tree and a user attepted to lift the frame up the tree to a new position. This test resulted in a failure as the straps would get hung up on any tree that was not relatively smooth. The flat straps used could not pass over minor variations in the bark, thus the resolution was to implement round cable straps to allow the straps to roll over these inconsistencies in the tree bark.

12.1.3 PSI vs. Stroke Count

This test set out to see the amount to stroke cycles the pneumatic piston could complete on one 20 ounce tank of Carbon Dioxide (C02). The goal was 100 cycles loaded with 20 pounds at 20 of travel each, giving the device a theoretical assisted climbing capability of 166.66 feet, allowing a user to climb more that 8, 20 foot trees before needing another tank. The system was tested at 40 and 50 PSI to see the effect of the operating pressure as it relates to the amount of climbing before switching tanks. The results ranged from 39 to 52 cycles before exhausting the tank depending on the PSI setting. This correlates to 65 to 86.66 feet of climbing capabilities before switching tanks. While this did not meet the 100 cycle goal, it is adequate for most scenarios. This can also be easily fixed by implementing a larger tank. A larger tank is more cumbersome to climb with so the team decided to stay with the 20 ounce tank for the final design. The results are tabulated below:

Tank size	Air pressure (psi)	# Cycle unloaded	# cycles loaded
20oz	40	52	45
20oz	50	46	39

Figure 48: PSI setting vs. Stroke Count

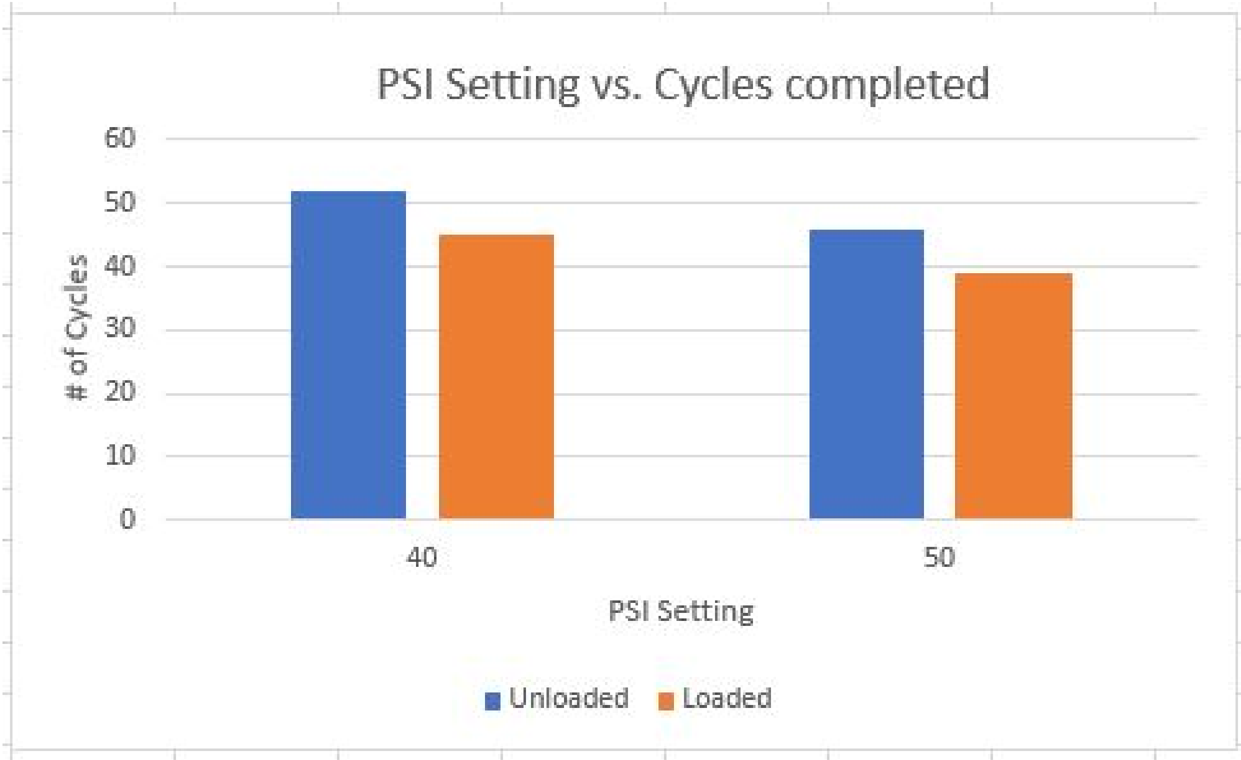


Figure 49: PSI vs. Stroke Count

12.1.4 Pneumatic Piston Loading

The pneumatic piston needs to be capable of operating under load to lift the individual frames and any equipment the user may have attached. With this in mind the loading capability versus the operating pressure was tested. The operating pressure varied from 20 to 80 PSI and the theoretical lifting capabilities were calculated. The piston was loaded with olympic lifting plates, the smallest testing interval being 2.5 pounds. The PSI was set to the given testing value and then the piston was loaded with half of the theoretical lifting capability and loaded in 2.5 pound increments until failure, defined as inability to lift the load, was achieved. This was then tabulated and graphed as shown below. It was found that the piston reached the required maximum lifting requirement at 80 PSI, lifting 70 pound which is equivalent to the 20 pound frame and 50 pounds of equipment. The results are tabulated below:

PSI Setting	Theorectical lifting Capacity (LBS)	Tested lifting capacity (LBS)
20	20.567	17.5
30	30.8505	27.5
40	41.134	37.5
50	51.4175	47.5
60	61.701	55
70	71.9845	62.5
80	82.268	70

Figure 50: PSI setting and loading capabilities

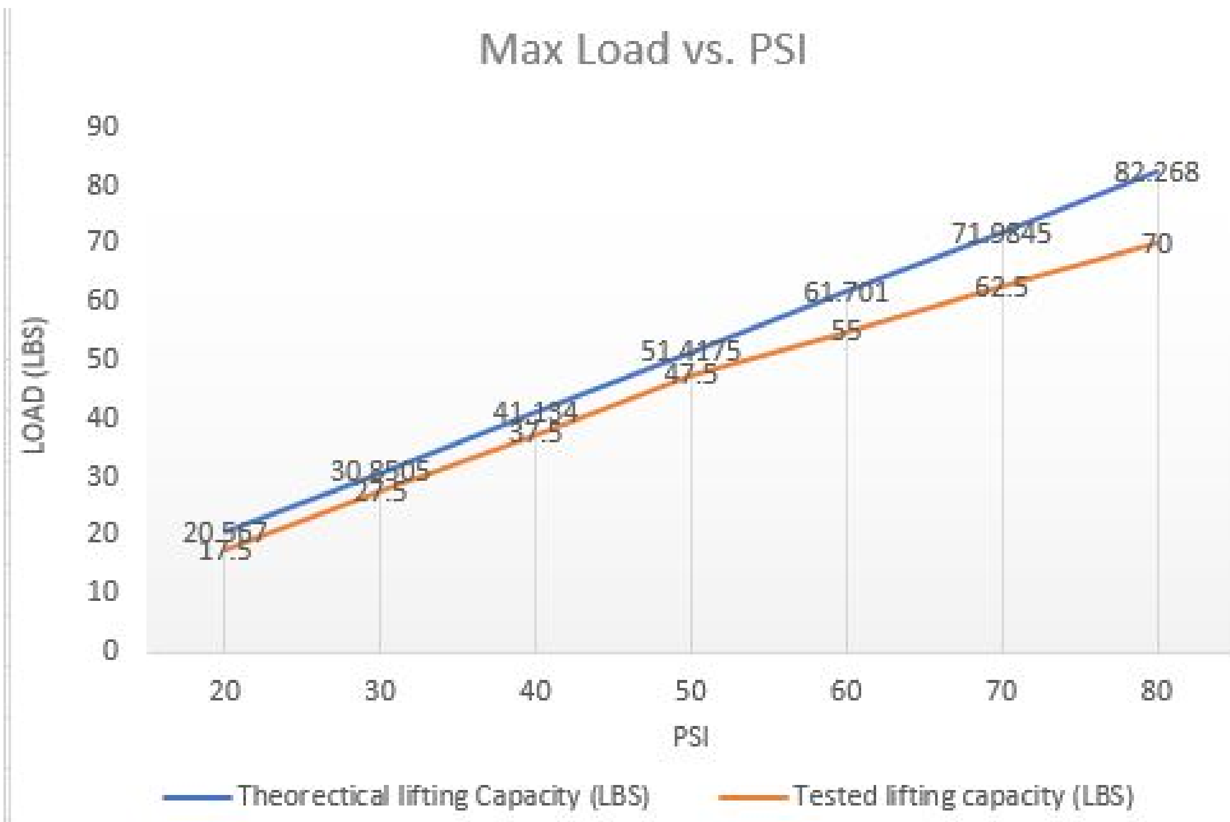


Figure 51: PSI vs. Theoretical and Tested Loading Capabilities

12.2 Design Specification Testing

12.2.1 Varying Diameter Tree Fitment

To ensure the design met the design specification of being able to climb tree varying in diameter from 12 to 24 inches the frame assembly was set up on trees with varying diameters from 12 to 38 inches. The frame was placed on the tree weighted and unweighted, it was considered successful is the frame maintained position on the tree in both scenarios. The results are tabulated below:

Diameter of tree	Fitment	Held position unweighted	Held position weighted (175lbs)
12"	Pass	Pass	Pass
16.5"	Pass	Pass	Pass
25.75"	Pass	Pass	Pass
32"	Pass	Pass	Pass
38"	Pass	Pass	Pass

Figure 52: Varying Diameter Test Results

13 Redesign

Our design has been proven to work from our Engineering analysis and a cheap prototype was created, Figures 53 and 54, based on some of our earliest positive holding force results. The energy balance analysis has proven that the space needed to pressurize potential energy will be able to fit on the tree climbing system. The force couple and static force analysis has proven our system is able to hold onto threes of the required diameter, two feet. The prototype made our theoretical concepts into experimental results and demonstrated our sitting ability on the side of a tree with a diameter greater than two feet. Our design is a classic tree climber, with a trust system frame and utilizes the stepping motion of two frames, with an engineers touch. It features and adjustable tree strap from varying tree diameters, an air compressor tank for easy assent and decent. We know it will function without the air, because there are already examples to observe. With the air compression, rising to the top of the tree should be as easy as standing up and pressing a few levers; removing almost all physical effort from tree climbing. The system kept the simple trust frame to minimize weight and material costs, added mechanical advantage in a simple one directional fashion using air pressure, and the design climbs the largest range of tree diameters compared to any other feasible designs. All while being as environmentally friendly to the air and the the tree bark.

After performing many different tests during the last few months on our device, the most impactful being the tests on the frame and strap systems. The only major redesigns were focused around these parts. First we tested the original frame design and satisfied the test criteria at that given time. Although, when weight was added, deformation occurred and became an issue. This was resolved by replacing the brackets that held everything together with bolts that went through the entirety of the bars. This was successful because it gave the ability to tighten the different connection points as much as needed. Then, after adding the cylinder to the structure, the center of mass was disrupted causing the whole test the fail. After discovering the weight was unbalanced, the frame went under reconstruction. The cylinder was best put in the back of the frame, rather than the front. This improved both the center of mass and the force couple which held both the frames in place, unweighted, and also the angle the piston pushed up on the top frame when the cylinder was activated. The main design for the frames were to have the ability to hold itself on the tree while unloaded and the redesigns implemented granted success to this requirement.

The biggest issue with the strap system, was they would get stuck on the tree and impede the ascent/descent ability of the device. The first raw test included generic rope, but this was simply a temporary idea just to prove the force couple methodology. Eventually that rope snapped and showed rope was not an option for the final design. The second solution to this issue was to use ratchet straps. These straps worked for holding the device on the tree, and proved to be easily manipulated for set up, but failed when movement was tested because they would not slide on the bark well and hung down too far to make any kind of progress for ascent. After this test, an idea was sparked to use rubber coated cable rope because it was stiff enough to hold its shape at the appropriate length and was significantly stronger than ratchet straps. Again the cable rope passed the mount test on the tree, but still showed issues with movement up the tree. The last redesign for this part of the device was moving the hook points on the arms of the frame. After moving them up the arms this showed promising results to smoothly move up the tree. Sadly, this was minimally tested because redesigns were made during the last days of the semester.

Another minor redesign made includes changing the two position manifold to a three position manifold. The two position manifold made it awkward to move on the tree because there was always pressure given on one side of the cylinder. To solve this a three position manifold must be implemented to give a neutral setting where no air is supplied to the cylinder.

Future design teams should look more into a more efficient, cheaper and lighter material to build the frames with but still be easy to manipulate. Doing this will allow the device to be more portable, easier to construct and in turn become more marketable. The big stress points of the system could be reinforced if there become issues with deformation. Also the issue with the strap/cable system needs to be further investigated. Maybe use a quick connect system with the cable ropes to tighten and loosen the cables with ease. Also there is the unsolved issue with the length of the arms placement of the hooks for the cables. And of course as mentioned in the last paragraph, the manifold needs an upgrade. Since this was built as a prototype any of these issues can be improved to bring this device into production.

Figure 53: Proof of Concept Design

Figure 54: Proof of Concept Design

Figure 55: Pneumatic Stepper (Final Design, weighted my Scott Botelho)

14 Project Planning

The project management plan was the same for both the Fall 2018 and Spring 2019 sections of this project. The overall goal was to maintain a consistent and achievable schedule based off the respective Gantt charts for each section, both created in Microsoft office. The Gantt charts were necessary as each project section spanned over several months with four team members, making a concise and clear schedule is crucial. The major milestones and tasks were broken down to make weekly achievable goals allowing the Gantt chart to generate our projects current completion percentage at any time. The major milestones for each semester were set and within these major milestones the individual tasks were broken down and correlated to one another, creating a critical path. The critical path allowed the team to have keep a current list of critical objectives throughout the project, allowing for a critical tasks to be completed in a timely fashion. Each week the team members were tasked with their individual critical tasks based on the Gantt chart schedule.

14.1 Fall 2018

For the fall section of the project the major milestones included the Critical Design review, Proof of Concept Presentation, and finishing the Preliminary Design Report. Within these major milestones the individual tasks were broken down and correlated to one another, creating a critical path. The critical path allowed the team to have keep a current list of critical objectives throughout the project, allowing for a critical tasks to be completed in a timely fashion. Each week the team members were tasked with their individual critical tasks based on the Gantt chart schedule, Figure 57.

The first major milestone completed was the critical design review. Leading up to this the required critical tasks were completed on schedule. Each week the team reflected on the task completed in the previously and looked forward to the upcoming critical tasks. During the meetings a work breakdown structure could be created, utilizing each team members strengths. After successfully reaching 100 percent completion on the first major milestone the same system was implemented for the remainder of the project, moving forward to 100 percent completion on the project section.

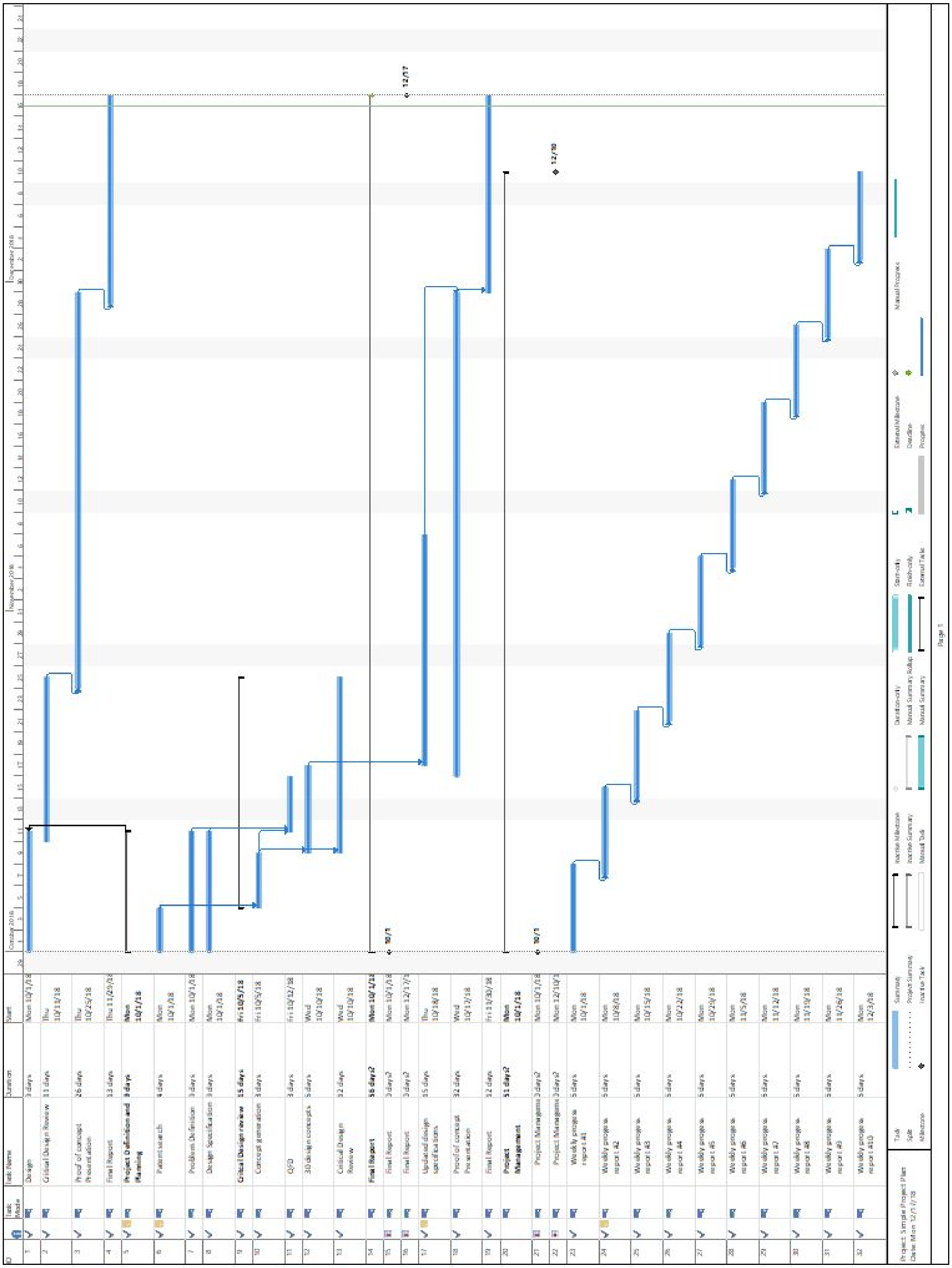


Figure 56: Project Plan Fall 2018

14.2 Spring 2019

The same scheduling methodology was followed for the Spring semester. The major Milestones included Building the Tree Climber, Testing, and the Final Presentation and Report. Each major milestone included tasks that needed to be achieved within there set time span, following the critical path, in order to keep the project on schedule.

Building the tree climbing was broken down into 5 tasks leading up to the goal of completion by March 18th, starting with redesigning the frame assemblies to account for the new material choice, 80/20 aluminum extrusions. Now that there was a new frame design it required redesigning the mounting positions for the pneumatic assistance system. With the redesigns complete it was then critical to order the new required materials to physically build the product. The first iteration of the new design was built on time, allowing the team to move onto testing.

Testing was given a 14 day span to complete, overlapping with the building timeline, as components were completed they were tested individually. As testing commenced issues with the design were found, causing the team to step back into the build and resign process once again setting the project behind schedule for a two week period leading up to the Presentation and Report milestone section. The testing milestone was reached by the set Milestone date, but not exactly how it was originally planned.

The final 31 days leading up to the 05/06/2019 project deadline was dedicated to the presentations and final report. This section was completed as planned but team simultaneously continued to do several tests on the final product. These were functionality test to try and optimize ease of use. The Team achieved the goal of completion by 05/06/2019, on schedule and under budget.

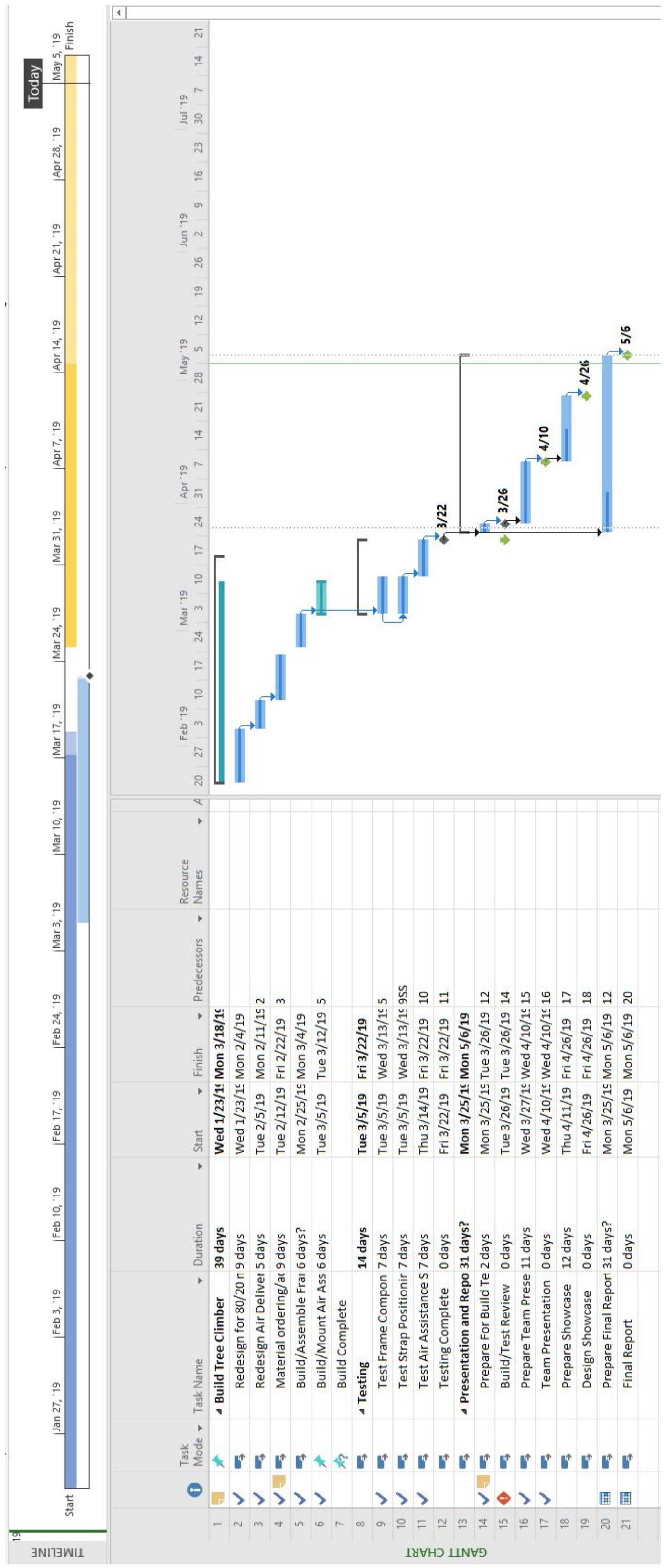


Figure 57: Project Plan Spring 2019

15 Financial Analysis

The set project budget for Team 17 to build a tree climbing device was 500 dollars. This budget was strictly for materials to build the device itself, the cost of the engineering team and associated consultants were theoretically figured based on current pay rates in the engineering field today. With this budget restraint in mind the team set out to complete a financial analysis to ensure the project stayed under budget.

15.1 Bill of Materials

The initial bill of materials for the first design can be seen below, Figure 58. This design utilized 6061 aluminum square tube, larger bolts, and different products to build the pneumatic assistance system, including 2 pneumatic cylinders. This model came out to cost 501.50 dollars, a majority of the cost was incurred in the 2 pneumatic cylinders and the assembly had a theoretical total weight of 42.25 pounds.

Material	Quantity	Unit	Price per Unit	Weight per unit (LBS)	Price total	Weight Total (LBS)
1" 6061 T6 Aluminum Square Tube 0.125" Thickness	34.08	lf	$ 2.18	0.52	$ 74.29	17.7216
1/2"-13 Steel Bolts 3" length	36	ea	$ 1.05	0.11	$ 37.80	3.96
1/2"x4" Steel Bolts	10	ea	$ 1.38	0.15	$ 13.80	1.5
3/4" Steel locking Nuts	46	ea	$ 0.45	0.08	$ 20.70	3.68
5/16"-18 Eyebolt	4	ea	$ 10.02	0.125	$ 40.08	0.5
Ventura Saddle Bicycle seat	1	ea	$ 11.15	1.43	$ 11.15	1.43
2 way Cylinder	2	ea	$ 56.20	2	$ 112.40	4
Tube Caps	8	ea	$ 2.55	0.11	$ 20.40	0.88
Neopreme rubber	1	sf	$ 15.74	0.21	$ 15.74	0.21
Aluminum plate	1	sf	$ 10.71	3.53	$ 10.71	3.53
1/4" T-Handle Quick release pins w/ lanyard	4	ea	$ 11.49	0.2753	$ 45.96	1.1012
12oz C02 tank	1	ea	$ 11.49	2.33	$ 11.49	2.33
Air manifold with regulator	1	ea	$ 31.22	0.52	$ 31.22	0.52
Release Valve	2	ea	$ 13.00	0.44	$ 26.00	0.88
Hand Controls	2	ea	$ 8.53	0.333	$ 17.06	0.666
Pressurized line	2	lf	$ 6.35	0.56	$ 12.70	1.12
				Totals:	$ 501.50	42.2428

Figure 58: Initial Bill of Materials

The final design bill of materials can be found below, Figure 59. This revised bill of materials included the change in frame material choice to the 80/20 smooth slotted aluminum extrusions, only one pneumatic cylinder, and revised bolt and strap connector choices. This design cost a total of 463.95 dollars.

Material	Quantity	Unit	Price total
1" x 1" Smooth surface T slotted profile Aluminum	53.6	lf	$ 160.26
1/2"-13 Steel Bolts 3.5" length	12	ea	$ 11.76
1/4"x.55" Bolts	6	ea	$ 8.28
3/4" Steel locking Nuts	18	ea	$ 8.10
3/8" schackle	4	ea	$ 19.28
Double acting pneumatic cylinder, 20" stroke	1	ea	$ 56.20
Neopreme rubber	2	sf	$ 7.30
20oz C02 tank	1	ea	$ 29.98
5 valce, 4 way, 3 position air manifold	1	ea	$ 31.22
1/4" pneumatic line	10	lf	$ 5.20
1/4 C02 cylinder regulator kit	1	ea	$ 66.99
1/4" pneumatic fittings	4	ea	$ 3.56
1/4" female NPT quick connect coupling	1	ea	$ 4.24
1.5" tie down strap	2	ea	$ 15.98
Gusseted inside brackets	10	ea	$ 35.60
			$ 463.95

Figure 59: Final Bill of Materials

15.2 Human Resource Allocation

The table below, Figure shows the total amount of man hours to complete this project throughout the year. Each team member on the four man team averaged 10 hours of work a week over the duration of the project. Assuming overhead cost and the average hourly wage of a design engineer each team member was assumed to have costed 55.00 dollars an hour. In addition to team member work professor and manufacturing consultation was included in the cost and tabulated below, Figure 60.

Item	Cost per unit	Units	Total	Total cost
Engineer #1	$ 55.00	hr	144	$ 7,920.00
Engineer #2	$ 55.00	hr	144	$ 7,920.00
Engineer #3	$ 55.00	hr	144	$ 7,920.00
Engineer #4	$ 55.00	hr	144	$ 7,920.00
Manufacting Consultation	$ 80.00	HR	4	$ 320.00
Professor consultation	$ 120.00	hr	10	$ 1,200.00
			Total Cost	$ 33,200.00

Figure 60: Human Resource Incurred Cost

15.3 Cost to Manufacture

Below are the cost to manufacture the initial and final designs. The first two figures 61 and 62 show the cost for a manual assembly, while Figures 63 and **??** show the semi-autonomous cost to manufacture. The price difference between these two methodologies is 91.41 and 38.24 dollars per assembly respectively, which are substantial. The semi-autonomous methodology has more start up cost, but this investment would pay dividends in the long run. This manufacturing process assumes that the costumer would receive the parts required to assemble the product themselves. This was chosen to maintain low manufacturing and shipping cost.

Assemblies per year	Assemblies per day	Assemblies per hour	Time per assembly (HR)	Time per assembly (min)
7700	29.61538462	3.701923077	0.27012987	16.21

Manual Assembly

	Operation 1	Operation 2	Operation 3	Operation 4	Operation 5	Operation 6	Operation 7	
	Cut bar stock to length and prepare for welding	Drill bolt holes and placement holes	Place cut pieces in jigs for the welder and remove welded frame	Tack and finish welding of prepared piece	Furnish seat	Place frame and remainder of parts into shipment package	Cleanup, inspection, etc. for 8 hour shift	Totals
Time to complete operation (per Frame)	0.5	1	0.25	1	0.1	0.1	0.5	3.45
Labor Rate	$ 17.72	$ 17.71	$ 17.72	$ 20.18	$ 17.72	$ 17.72	$ 13.38	
Cost	8.86	17.71	4.43	20.18	1.772	1.772	6.69	
Overhead Factor	1	1	1	1	1	1	1	
Equipment factor	0.5	0.5	0.5	0.5	0.5	0	0.5	
Tolerance Factor	0.25	0.25	0	0	0	0	0	
labor/ept cost	$ 15.51	$ 30.99	$ 6.65	$ 30.27	$ 2.66	$ 1.77	$ 10.04	$ 97.88

Figure 61: Manual Assembly Cost Analysis, Initial design

	Operation 1	Operation 2	Operation 3	Operation 4	
	Cut aluminum stock to length	Drill bolt holes and placement holes	Place frame and remainder of parts into shipment package	Cleanup, inspection, etc. for 8 hour shift	Totals
Time to complete operation (per Frame)	0.5	1	0.2	0.5	2.2
Labor Rate	$ 17.72	$ 17.71	$ 17.72	$ 13.38	
Cost	8.86	17.71	3.544	6.69	
Overhead Factor	1	1	1	1	
Equipment factor	0.5	0.5	0	0.5	
Tolerance Factor	0.25	0.25	0	0	
labor/ept cost	$ 15.51	$ 30.99	$ 3.54	$ 10.04	$ 60.08

Figure 62: Manual Assembly Cost Analysis, Final design

	Operation 1	Operation 2	Operation 3	Operation 4	Operation 5	Operation 6	Operation 7	
	Cut bar stock to length and prepare for welding	Drill bolt holes and placement holes	Place cut pieces in jigs for the welder and remove welded frame	Tack and finish welding of prepared piece	Furnish seat	Place frame and remainder of parts into shipment package	Cleanup, inspection, etc. for 8 hour shift	
Time to complete operation (per Frame in hours)	0.05	0.06	0.01	0.11	0.01	0.015	0.015	0.27
Equipment running/ labor Rate	$ 12.51	$ 12.51	$ 17.72	$ 12.51	$ 17.72	$ 17.72	$ 17.72	
Cost	0.6255	0.7506	0.1772	1.3761	0.1772	0.2658	0.2658	
Overhead Factor	1	1	1	1	1	1	1	
Equipment factor	0.5	0.5	0.5	0.5	0.5	0	0.5	
Tolerance Factor	0.25	0.25	0	0	0	0	0	
labor/ept cost	$ 1.72	$ 1.31	$ 0.27	$ 2.06	$ 0.27	$ 0.27	$ 0.40	$ 6.29

Figure 63: Semi-Autonomous Manufacturing Cost Analysis, Initial Design

Automated Assembly	Operation 1	Operation 2	Operation 3	Operation 4	
	Cut aluminum stock	Drill bolt holes	Package indivual pieces	Cleanup, inspection, etc. for 8 hour shift	Totals
Time to complete operation (per Frame in hours)	0.05	0.06	0.33	0.5	0.44
Equipment running/ labor Rate	$ 12.51	$ 12.51	$ 17.72	$ 13.38	
Cost	0.6255	0.7506	5.8476	6.69	
Overhead Factor	1	1	1	1	
Equipment factor	0.5	0.5	0.5	0.5	
Tolerance Factor	0.25	0.25	0	0	
labor/ept cost	$ 1.72	$ 1.31	$ 8.77	$ 10.04	$ 21.84

Figure 64: Semi-Autonomous Manufacturing Cost Analysis, Final Design

15.4 Return on Investment

This section of the financial analysis for the tree climbing apparatus was done regarding the initial design at the onset of the project to calculate the net present value and potential internal return rate on investment over an eight year span, and decide whether the project is a smart financial investment. The methodology aims for a project that has a higher internal ROR than hurdle rate[3]. The spreadsheet, figure 65, below is summarizing of the ensuing written documentation of methodology.

The derived net present value of $ 12,160,000 with an internal ROR of 177 percent was based off a selling price of $ 899.99 in an initial operating market size of 10,000 units per year, jumping to 20,000 in year 2 and then continuing to increase at a 10 percent per year growth rate. Operating within this market, the goal is to gradually increase the products market share for the first 4 years of operation. Starting at zero percent market share while in development for year zero, ten percent in the first operating year, 35 percent in the second year, and then leveling out at 50 percent for years three through eight. This yielded a manufacturing quantity required for each respective year, 2,000 units for year one, 7,700 units for year two, increasing relative to market size until reaching a final value of 19,487 units in year eight. With these given values, it is now possible to calculate a manufacturing cost per unit.

Assuming the year 2 required quantity of 7,700 units, the manufacturing cost per part was calculated. A local manufacturing expert was consulted on required overhead costs and basic operational requirements to manufacture the apparatus. With a 260 work day year and one, eight hour shift per work day, it would require the production of 29.615 units per day. This breaks down to 3.7 units per hour or 16 minutes and 12 seconds per assembly. This time constraint made a manual assembly line unreasonable. Based on figure 61, the average time to complete the manufacturing of one unit manually was 3.45 hours, totaling 603 assemblies per year. This did not meet the 7700 unit per year goal and incurred a cost of $ 97.88 per completed unit. This cost and assembly time was inapplicable so figure 63, was

[3] The hurdle rate is the required amount of internal return to move forward with a project

generated assuming a mostly automated assembly and manufacturing process. This brought the total assembly time down to under the 0.27 hours per unit and incurred a cost of \$ 6.29 per unit. This cost was derived assuming a machine operating cost of \$ 12.51 per hour, and a labor rate of \$ 17.72 per hour. Each individual operation was allotted its required time to reach completion for the equivalent of one complete frame assembly. A manufacturing overhead cost of 100 percent, equipment overhead of 50 percent, and tolerance factor of 25 percent for miscellaneous servicing of the machines or faulty parts, were then included before calculating a final cost of \$ 6.29 per part. This price does not include initial investment for machinery or area of operation, so a capital expenditure of \$ 250,000 was included.

Based off the bill of material, figure 58 manufacturing cost, and a freight out cost of \$ 15.00 per unit, the final cost per part was \$ 516.51. Based off our market share and the correlated units sold per year, a gross profit margin of 43 percent was generated for each year. Afterwards project expenses and sales cost were added. It was assumed that two sales representatives each with a \$ 60,000 annual salary, \$ 10,000 of market research, and \$ 20,000 of advertising would be required for launch. Including the already incurred cost of prototyping, \$ 42,760, which is broken down in figure **??**, the earnings before tax were generated. From here a business tax rate of 39 percent and depreciation of machinery assumed to be \$ 25,000 per year were deducted, to yield the operating cash flow. From this the working capital rate of 15 percent was deducted to yield the products free cash flow generation. The start up capital, or the free cash flow of year 0, totaled \$ 367,584; this would be recuperated by the second quarter of year two on the market. Using the net present value formula with a 10 percent cost of capital and subtracting out the start up capital, the \$ 12,160,000 valuation was calculated. The internal ROR was calculated using the free cash flow values for years 0 through 8, returning a 177 percent value. Since our internal ROR was greater than our hurdle rate, or required internal ROR to move forward with the project, this project is considered a GO based on this investment decision methodology. The projected statement of income were also generated for 2019 and 2020, assumed to be year 1 and 2 on the market, and shown in figure 66.

Tree Climber Valuation Final

Cash Flow Valuation Model
(in 000s, except Average Selling Price)

			Yr. 0 (Pre-Launch)	Projected Yr. 1	Yr. 2	Yr. 3	Yr. 4	Yr. 5	Yr. 6	Yr. 7	Yr. 8
Sales / Marketing Information (From Research)											
Global Market Size			10,000	20,000	22,000	24,200	26,620	29,282	32,210	35,431	38,974
Market Growth Rate			100%	10%	10%	10%	10%	10%	10%	10%	
Share of Market			0%	10%	35%	50%	50%	50%	50%	50%	50%
Tree Climbing Apparatuses Sold			-	2,000	7,700	12,100	13,310	14,641	16,105	17,716	19,487
Average selling price / apparatus				$899.99	$899.99	$899.99	$899.99	$899.99	$899.99	$899.99	$899.99
Net sales				**1,799,980**	**6,929,923**	**10,889,879**	**11,978,867**	**13,176,754**	**14,494,429**	**15,943,872**	**17,538,259**
	Per Apparatus										
Cost of goods sold	$ 501.51			1,003,020	3,861,627	6,068,271	6,675,098	7,342,608	8,076,869	8,884,556	9,773,011
Freight-out	$ 15.00			30,000	115,500	181,500	199,650	219,615	241,577	265,734	292,308
Total Cost	**$ 516.51**			**1,033,020**	**3,977,127**	**6,249,771**	**6,874,748**	**7,562,223**	**8,318,445**	**9,150,290**	**10,065,319**
Gross profit				**766,960**	**2,952,796**	**4,640,108**	**5,104,119**	**5,614,531**	**6,175,984**	**6,793,582**	**7,472,940**
Gross margin				*43%*	*43%*	*43%*	*43%*	*43%*	*43%*	*43%*	*43%*
	Sales Reps	Mkt. Rsrch									
S,G,&A (direct)	$ 120,000	$ 10,000	130,000	120,000	120,000	120,000	120,000	120,000	120,000	120,000	120,000
	Prototyping	Pre-Launch Advertising									
Project expenses	$ 42,760	$ 20,000	62,760	0	0	0	0	0	0	0	0
Earnings Before Interest & Taxes (EBIT)			**(192,760)**	**646,960**	**2,832,796**	**4,520,108**	**4,984,119**	**5,494,531**	**6,055,984**	**6,673,582**	**7,352,940**
EBIT margin				*36%*	*41%*	*42%*	*42%*	*42%*	*42%*	*42%*	*42%*
Tax benefit (cost)	39.0%		75,176	(252,314)	(1,104,790)	(1,762,842)	(1,943,806)	(2,142,867)	(2,361,834)	(2,602,697)	(2,867,647)
Net Operating Profit After Taxes (NOPAT)			(117,584)	394,646	1,728,006	2,757,266	3,040,312	3,351,664	3,694,150	4,070,885	4,485,294
Add back, depreciation on M&E				25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
Operating cash flow			**(117,584)**	**419,646**	**1,753,006**	**2,782,266**	**3,065,312**	**3,376,664**	**3,719,150**	**4,095,885**	**4,510,294**
Less,											
Working capital % of Sales (Inventory & Accounts Receivable)		15%		269,997	1,039,488	1,633,482	1,796,830	1,976,513	2,174,164	2,391,581	2,630,739
(Increase) / decrease in working capital				(269,997)	(769,491)	(593,993)	(163,348)	(179,683)	(197,651)	(217,416)	(239,158)
Capital Expenditures for Manufaturing Plant	$250,000		(250,000)	0	0	0	0	0	0	0	0
Free cash flow			**(367,584)**	**149,649**	**983,514**	**2,188,272**	**2,901,964**	**3,196,981**	**3,521,499**	**3,878,469**	**4,271,136**

Discount rate (Cost of Capital)	10%
Net present value (NPV)	**$12,160,000**
Internal rate of return (IRR)	**177%**
Hurdle rate	30%
Investment decision	**GO**

Figure 65: Cash Flow Model

Tree climbing apparatus PROJECTED STATEMENTS OF INCOME FOR THE YEARS ENDED DECEMBER 31, 2019 AND 2020 *USD in thousands*			
		2019	2020
Net sales		$ 1,799,980	$6,749,925
Cost of goods sold		1,033,020	3,873,825
Gross Profit		766,960	2,876,100
Selling Expenses		120,000	120,000
General & Administrative Expenses		240,000	240,000
Operating Income		406,960	2,516,100
Income Before Taxes		406,960	2,516,100
Income Taxes	39%	(158,714)	(981,277)
Net Income		$ 248,246	$1,534,823

Figure 66: Projected Statements of Income

16 Operation

One of the main design requirements was ease of use/operation. This device is portable and can be set up by one person. After the frame is built and all the bolts are tightened, it is recommended to travel with the cylinder mounted on both frames to facilitate portability. After the device is brought to the desired tree to be climbed, the operator should set the whole device on the ground as close to the tree as possible. Then the bottom frame can be strapped to the tree and slightly lifted. This will set the bottom frame in place and the top frame can now be strapped to the tree and lifted so the tree climbing device is stationary at full stroke. This process should only take a few minutes. With the CO2 tank clipped to the operator as desired, whether it is clipped to a belt or elsewhere, they can step onto the bottom frame to then climb up to sit on the top frame. Once on the top frame, the operator connects the air system to the manifold and desired pressure can be set using the dial on the regulator (recommended 20-70 psi depending on how much weight is applied to the system). Now the operator is ready to being ascent. The right position on the manifold pushes the top from up and the left position lifts the bottom frame. The middle position acts as neutral where no air is applied. Firstly, put the manifold in the left position and the bottom frame should be lifted and locked into place since the device was originally set at full stroke. Once the bottom frame is set in place, the operator clicks the manifold to the right. If done correctly the operator will stand up and the top from will follow. Sitting on the top frame and putting the manifold in the left position will now raise the bottom frame. After the force couple is applied to the bottom frame the process is ready to be repeated until the operator reaches the desired height. Once at that height the manifold should be kept in the middle position and the air regulator can be dialed to the off setting and the operator can fulfill their purpose in the tree. When the job is done in the tree, the descent may begin. The air system can remain off to save CO2 since gravity will substantially assist descent. The operator must do opposite of how they ascended, and begin with uncoupling the bottom frame to where they can stand on the bottom and likewise uncouple the top frame and let it fall. Once the top is dropped down, the force couple can be set and the operator can sit. Then the bottom can move down and this process is repeated until they reach the bottom of the tree. To finish the process, unhook the cables and the device can be carried to the next tree. Extra CO2 tanks can be carried if multiple trees need to be climbed before refills. To refill the tanks, they must be brought to professionally trained personnel.

17 Maintenance

Maintenance to individual parts will include replacement parts. If any of the bars break or shows signs of deformation (bending, cracking or chipping), they must not be put under any additional load and need to be replaced. The same goes to the bolts and brackets. It is imperative to check the device for bar deformation before each use. If the frames have any loose connections they must be tightened and remain tightened. If problems occur to the air delivery system the lines can be reinserted to the quick connect fixtures. If the lines have any leaks they should be replaced. The CO2 tanks may be brought to any refill station to be fixed by a professional, but O-rings can be replaced by the operator. Under the circumstance of manifold or regulator malfunction they also should be replaced before reuse of the device. If there is an air system failure during operation on the tree, the device is safe to use without it, but there will be less or no supplementary air assistance. The cylinder must not be tampered with, if there are any issues with the cylinder, it can be brought to a professional to fix of if necessary can be replaced.

Disposal of metal parts goes as desired. Air delivery lines may be disposed as desired as well. CO2 tanks must be disposed of properly at any refill station.

18 Additional Considerations

18.1 Economical Impact

There are many ways products introduced into the market can impact economics. Our product was not made final, but if our design were to be implemented to the targeted professions, there could be an impact to arborists prices and possibly the price of coconuts and other harvested resources. The market for hunters wouldnt be affected too much simply because there are many other competitive products being sold for cheaper. Although our design is a little more innovative than most. Overall there would not be outstandingly noticeable impact to the economy from this product.

18.2 Societal and Political Impact

There seems to be no society of political impact. This device has be made for a very niche sector of the market.

18.3 Ethical Considerations

This product is ethically sound. It was designed around safety to the environment, specifically the trees it is used on.

18.4 Health, Ergonomic and Safety Considerations

Once a seat is implemented the two frames will be ergonomically satisfactory. Of course with a product like this, there are some safety concerns. The operator must practice caution using this device, there is always a risk factor while working in high places. Although the design has a sufficient safety factor for the integrity of the frames, the safety concern lies on the risk of falling off the device.

18.5 Environmental and Sustainability Considerations

There is no risk to the environment from this device. The pneumatic cylinder uses CO2 which is naturally produced. This will not create an impact on the environment. Because this product can be operated without the cylinder it is completely sustainable, but if considering the CO2 usage, that is a minor issue and can easily be refilled.

19 Conclusions

The design we have manifested works and it meets the desired design specifications, but areas of the system could use some improvement. The ABAQUS analysis determined a safety factor of... for the frame, so thinner lighter metal could be used. Also, it was determined that the bracketing system of the aluminum bar we used was tedious and not worth the effort. Meaning holes were drilled and bolts used to connect the parts. This made the intricate design of the beams to be unnecessary and to strong. It would be recommend to do another analysis using the same frame dimensions to determine the thinnest and lightest metal that could be used. Then drill holes and use bolts to connect all parts. This should save on money and weight of the system; while making machining and assembly much easier.

The arm should also have another analysis done, mentioned in the analysis section, to increase the number of arm slots to optimize the ranger of trees that can be climbed while minimizing the change of the pitch of the seat between different size trees. The arm should also be made longer to make it easier to mount and ascend/descend larger trees. The system should be able to work on larger trees according the the analysis, but it was not able to be put into practice due to the short arms.

The longer arms and more holes will allow the rope to be tensions straight across the back side of the tree. Minimizing the amount the rope needs to wrap around the tree, it's length, and with it it's weight. With less weight and more tension there will be less sage and the rope will follow the system up and down; allowing for optimal catching. The arm angle should also be made adjustable and also lockable. Right now the arms are allowed to swing when stressed, causing the arms to squeeze the tree. This adds more fiction and holding force, but cause the system to get caught and damage the tree.

A series of safety straps could be recommended. The most important one would be a strap connected the two systems together. It was observed during testing that it the piston is opened all the way, the to systems could become to far apart to operate; leaving the user suspended on the tree. With that in mind another strap could be used to allow the arms to assist the bottom system up instead of the legs, since using the legs was a struggle.

We don't believe it to be a wise idea to strap into the system, because if it were to fall the user would be strapped to it and forced to land on top of the system or have the system land on them. As a backup safety precaution, it could be a good idea to mount a repel point of the back and go up with a rope. If the system got caught up or became to separated and the air system and manual operation both failed; the user would not be trapped, but instead could repel down with ease if they brought a safety rope and repel gear.

If these changes are added made to the manufacturing of the system we believe our functioning system would be even better; sleeker, lights, more optimal, easily adjustable, easy to transport easy to use and learn how to use, while keeping the user, the tree, and the environment in general safe.

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Dieter, George. 5th Ed., 2012, McGraw-Hill

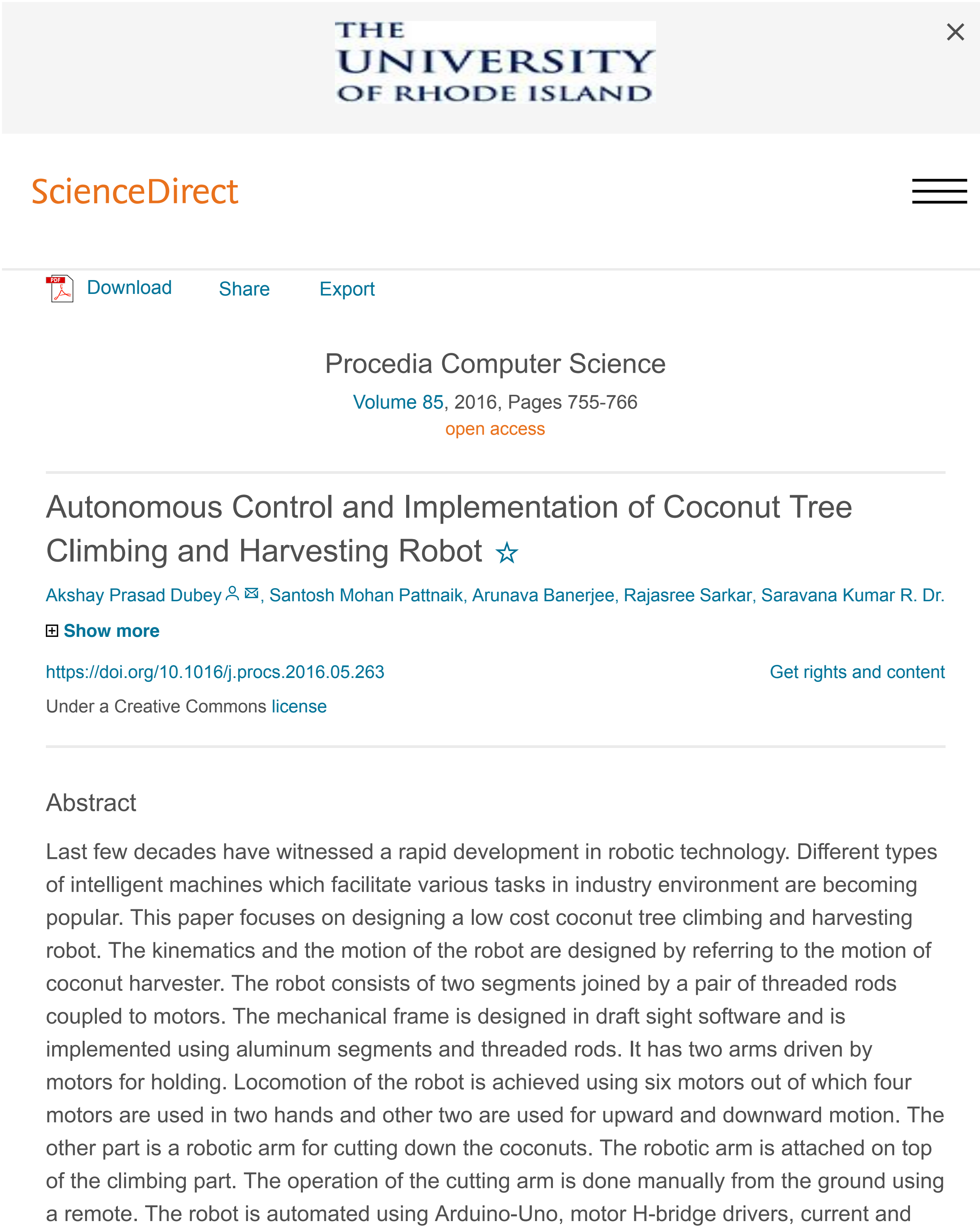
[2] Bass Pro Shops Website
http://www.basspro.com/

[3] Competitive pedal-powered climbing machine.
https://www.youtube.com/watch?v=MnYzlm_qZjU

[4] Competitive motor-powered climbing machine.
https://www.youtube.com/watch?v=pnyN7qYZEw

[5] Dick's Sporting Goods Website
http://www.dickssportinggoods.com/

[6] Website for all part ordering and price information
https://www.mcmaster.com/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Procedia Computer Science

Volume 85, 2016, Pages 755-766

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Autonomous Control and Implementation of Coconut Tree Climbing and Harvesting Robot ☆

Akshay Prasad Dubey, Santosh Mohan Pattnaik, Arunava Banerjee, Rajasree Sarkar, Saravana Kumar R. Dr.

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Abstract

Last few decades have witnessed a rapid development in robotic technology. Different types of intelligent machines which facilitate various tasks in industry environment are becoming popular. This paper focuses on designing a low cost coconut tree climbing and harvesting robot. The kinematics and the motion of the robot are designed by referring to the motion of coconut harvester. The robot consists of two segments joined by a pair of threaded rods coupled to motors. The mechanical frame is designed in draft sight software and is implemented using aluminum segments and threaded rods. It has two arms driven by motors for holding. Locomotion of the robot is achieved using six motors out of which four motors are used in two hands and other two are used for upward and downward motion. The other part is a robotic arm for cutting down the coconuts. The robotic arm is attached on top of the climbing part. The operation of the cutting arm is done manually from the ground using a remote. The robot is automated using Arduino-Uno, motor H-bridge drivers, current and

Figure 67: Autonomous Control and Implementation of Coconut Tree Climbing and Harvesting Robot

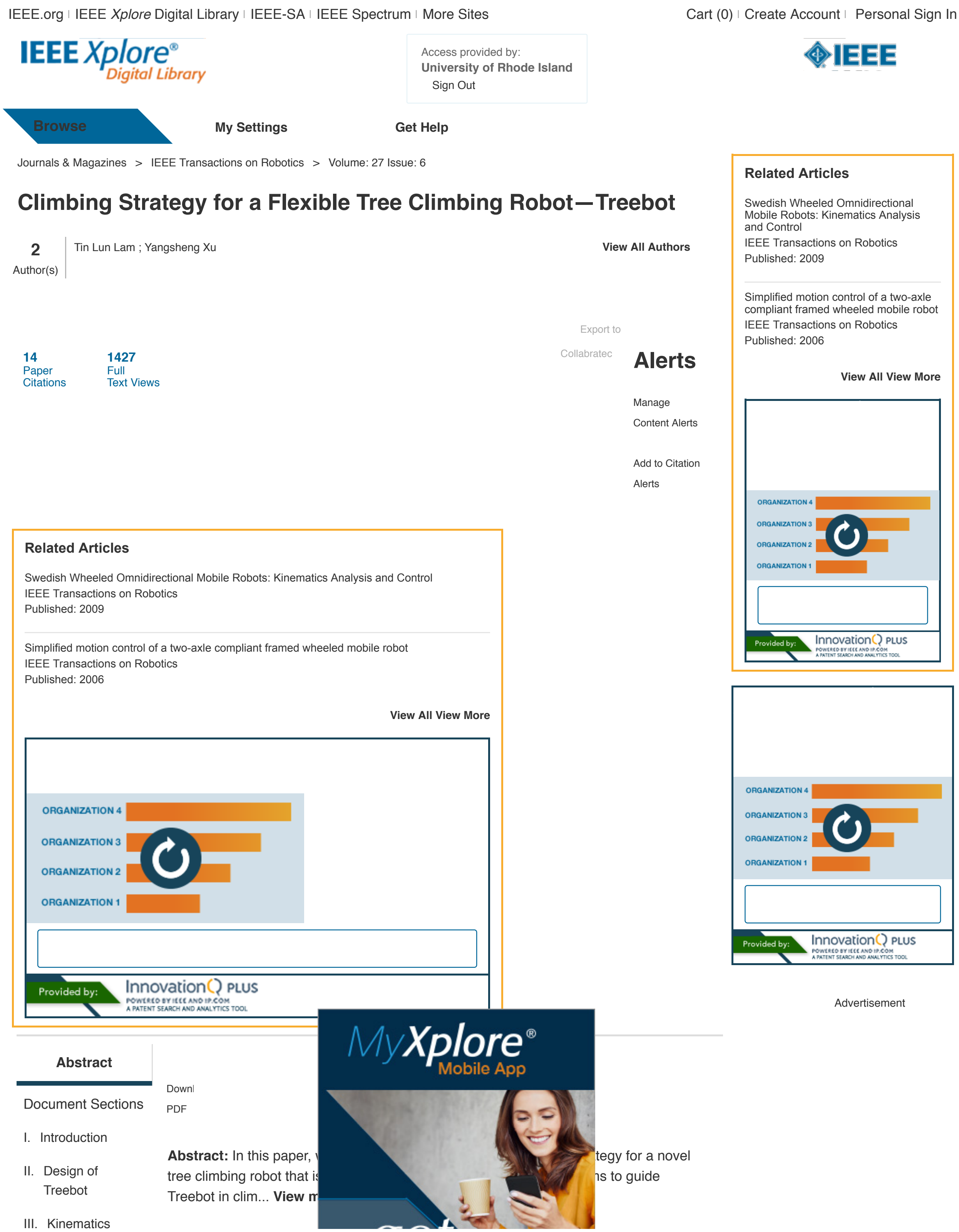

Figure 68: Climbing Strategy for a Flexible Tree Climbing Robot

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Indian Applicant Files Patent Application for Coconut Tree Climbing Machine

Indian Patents News; New Delhi [New Delhi]25 June 2011.

Full text | Abstract/Details

Abstract Translate

According to the Controller General of Patents, Designs & Trade Marks, A coconut tree climbing machine which is meant for climbing the Coconut tree with out climbing the coconut tree has three important parts one is the Multi-purpose trolley carrier which is meant for transporting the coconut climbing machine from one place to another which can also be used to transport the plucked coconut from one place to another and it also has two catching mechanism which is intended to catch the coconut tree in its stem; at first one catching device hold the stem and the second ascend up in the climbing device; when this ascend and hold, the former detach from the stem and moves up, this process keep on happening and the device has a climbing device which is attached with the catching device, the main purpose of it is to enable the machine to climb up; and the machine has a robotic arm which enables it to pluck the coconut from the top after the MoreMore

Full Text Translate

New Delhi, June 25 -- Sajeev Singh M K of Thiruvanathapuram, India filed patent application for coconut tree climbing machine. The inventor is Sajeev Singh M K.

Sajeev Singh M K filed the patent application on Dec. 9, 2009. The patent application number is 3029/CHE/2009 A. The international classifications are B25J5/00 and B25J9/00.

According to the Controller General of Patents, Designs & Trade Marks, "A coconut tree climbing machine which is meant for climbing the Coconut tree with out climbing the coconut tree has three important parts one is the Multi-purpose trolley carrier which is meant for transporting the coconut climbing machine from one place to another which can also be used to transport the plucked coconut from one place to another and it also has two catching mechanism which is intended to catch the coconut tree in its stem; at first one catching device hold the stem and the second ascend up in the climbing device; when this ascend and hold, the former detach from the stem and moves up, this process keep on happening and the device has a climbing device which is attached with the catching device, the main purpose of it is to enable the machine to climb up; and the machine has a robotic arm which enables it to pluck the coconut from the top after the climbing is over. It is a four folded arm which can be stretched to nearly two meters and forty centimeters at the end of the robotic arm there is a razor sharp and undulated blade which is known as cutting mechanism

Figure 69: Indian Applicant Files Patent Application for Coconut Tree Climbing Machine

More like this ›

KERALA AGRI VARSITY COCONUT CLIMBING MACHINE POPULAR IN INDIA

Asia Pulse; Rhodes [Rhodes]29 Mar 2012.

Full text | Abstract/Details

Abstract Translate

[...] it is essential to pluck the ripe nuts at least once in 45 days.

More

Full Text Translate

THRISSUR, March 29 Asia Pulse - With coconut climbers
becoming a rarity in the state, an innovative mechanical
coconut climbing device developed by scientists of the Kerala
Agricultural University (KAU) at nearby Mannuthy is fast
gaining popularity.

The device, KAU Kera Suraksha Coconut Climbing Machine, is
practically risk-free for the operator and prevents him from
falling down from the tree when he accidentally looses balance,
head of the Agricultural Research Station (ARS) at KAU U
Jaikumaran said.

The device consists of a seat and pedal units and the entire
unit is capable of fitting on the coconut tree with the seat
unit above the pedal, he said.

Figure 70: Kerala Agri Varsity Coconut Climbing Machine Popular in India

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Procedia Computer Science 85 (2016) 755 – 766

Procedia Computer Science

International Conference on Computational Modeling and Security (CMS 2016)

Autonomous control and implementation of coconut tree climbing and harvesting robot

Akshay Prasad Dubey[a], Santosh Mohan Pattnaik[b], Arunava Banerjee[c], Rajasree Sarkar[d], Dr. SaravanaKumar R.[e]

[a,b,c,d,e] *School of Electrical Engineering, VIT University, Vellore, Tamilnadu, 632014, India*

Abstract

Last few decades have witnessed a rapid development in robotic technology. Different types of intelligent machines which facilitate various tasks in industry environment are becoming popular. This paper focuses on designing a low cost coconut tree climbing and harvesting robot. The kinematics and the motion of the robot are designed by referring to the motion of coconut harvester. The robot consists of two segments joined by a pair of threaded rods coupled to motors. The mechanical frame is designed in draft sight software and is implemented using aluminum segments and threaded rods. It has two arms driven by motors for holding. Locomotion of the robot is achieved using six motors out of which four motors are used in two hands and other two are used for upward and downward motion. The other part is a robotic arm for cutting down the coconuts. The robotic arm is attached on top of the climbing part. The operation of the cutting arm is done manually from the ground using a remote. The robot is automated using Arduino-Uno, motor H-bridge drivers, current and level sensors and other supporting circuits. The forward and the reverse motion of the motors are controlled by the Arduino through driver modules. Robot has automatic and manual functions fully controlled by the end-user. This paper has taken into account of the safety, reliability and the ease of use. A locomotion algorithm is developed to provide the robot with an autonomous capability for climbing. The prototype of the robot is implemented and tested successfully.

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*E-mail address:*akshayprasaddubey@gmail.com

Peer-review under responsibility of the Organizing Committee of CMS 2016
doi:10.1016/j.procs.2016.05.263

Figure 71: Autonomous Control and Implementation of Coconut Tree Climbing and Harvesting Robot

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(**7** of **7**)

United States Patent	**7,748,497**
Tolliver , et al.	**July 6, 2010**

Portable climbing tree stand

Abstract

A foldable climbing tree stand platform includes a first section having a first arm rotatably coupled to the first section and a second section having a second arm rotatably coupled to the second section. A hinge rotatably couples the first section to the second section, wherein a platform position is obtained when the first section and the second section are substantially coplanar, and a packed position is obtained when the first section and the second section are rotationally folded onto each other and the first arm and the second arm are contained therein. A securing member is connected between the arms, wherein the sections may selectively engage an upright support and the securing member selectively surrounds the upright support for providing cantilevered support when folded into the platform position. A foldable climbing tree stand system is also provided.

Inventors: **Tolliver; Randy** (Carleton, MI)**, Tolliver; Robert** (Carleton, MI)
Family ID: **38573966**
Appl. No.: **11/279,120**
Filed: **April 10, 2006**

Prior Publication Data

Document Identifier	**Publication Date**
US 20070235259 A1	Oct 11, 2007

Current U.S. Class:	**182/136**; 182/135
Current CPC Class:	A63B 27/00 (20130101); A01M 31/02 (20130101)
Current International Class:	A63B 27/00 (20060101)
Field of Search:	;182/136,135,187

References Cited [Referenced By]

Figure 72: Portable Tree Climbing Stand

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(**11** of **11**)

United States Patent	**5,842,540**
Mancini, Jr.	**December 1, 1998**

Rotary tree climbing stand

Abstract

A rotatable tree stand that allows a hunter or wildlife photographer to comfortably and safely shoot or photograph approaching wildlife. The tree stand has two primary components. The first is an upper support which contains the seat structure and an assembly for attaching the seat structure to the tree, comprised of an upper brace and lower brace. The second is a lower support which contains a platform and an assembly for attaching the platform to the tree. The supports engage opposite sides of a tree trunk in offset transverse planes of the trunk, thereby allowing a cantilevering action when the seat structure is occupied allowing the downward force of gravity to act through the braces and in opposing directions against the tree trunk, thereby firmly gripping the tree. The platform is positioned directly below the seat structure, such that, when the user is situated within the seat structure, his feet can rest comfortably on the platform. A tubular frame is attached at its outer side to both the upper and lower brace and is attached, via rollers, on its inner side to a rotatory track. The rollers are disposed within the rotatory track and are attached to the tubular frame. Attached to the inner side of the rotatory track is a seat. The roller and rotatory track assembly allow the user to rotate the seat assembly 360 degrees, allowing the user to face approaching game regardless of the direction.

Inventors: **Mancini, Jr.; Julius P.** (Greenville, MS)
Family ID: **26723094**
Filed: **April 30, 1998**

Current U.S. Class:	**182/136**; 182/187
Current CPC Class:	A01M 31/02 (20130101)
Current International Class:	A45F 3/26 (20060101); A45F 3/00 (20060101); A45F 003/26 ()
Field of Search:	;182/135,136,187,188

References Cited [Referenced By]

U.S. Patent Documents

4069891	McClung

Figure 73: Rotary Tree Climbing Stand

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(**4** of **4**)

United States Patent	**8,517,066**
Van De Mortel , et al.	**August 27, 2013**

Multi-axis controlled self-climbing tree trimmer

Abstract

A multi-axis controlled self-climbing tree trimmer used for shaping and severing peripheral growth from a tree is provided herein. The trimmer typically includes a structural segment hinged together to form a rigid chassis that surrounds a tree trunk climbing segment and a trimming portion. The climbing portion is retained within the structural segment in the form of a number of inward-extending carriages containing one or more rollers for gripping the tree trunk during climbing, and the trimming portion may include a rotatable split ring gear containing centrifugally rotating trimming blade members and/or a cutting tool on a positionable arm. When rotated, the blade members unlatch and pivot, into the trunk of the tree to effect controlled trimming. The system may utilize a multi-axis control system that uses linear interpolation, circular interpolation and coordination of all axes to enable the trimmer to follow an XYZ contour selected by a user.

Inventors: **Van De Mortel; Mike** (Yorba Linda, CA)**, Hipwell; Christopher A.** (Torrance, CA)

Applicant:

Name	City	State	Country	Type
Van De Mortel; Mike	Yorba Linda	CA	US	
Hipwell; Christopher A.	Torrance	CA	US	

Assignee: **Vandypalm, Inc.** (Irvine, CA)
Family ID: **48999606**
Appl. No.: **13/591,131**
Filed: **August 21, 2012**

Current U.S. Class:	**144/24.13**
Current CPC Class:	B27L 1/06 (20130101); A01G 23/0955 (20130101)
Current International Class:	A01G 23/095 (20060101)
Field of Search:	;144/208.2,343,24.13

References Cited [Referenced By]

Figure 74: Multi-Axis Controlled Self-Climbing Tree Trimmer

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(**6** of **6**)

United States Patent	**7,971,685**
Simone , et al.	**July 5, 2011**

Pump jack tree stand

Abstract

The invention comprises, in one form thereof, a pump jack tree stand including a platform and a seat engaging a pump jack. The pump jack cooperates with a pole that is supported by an adjacent tree. The user actuates a foot lever on the pump jack to climb the pole. The pump jack's release is hand actuated as opposed to the commonly used foot-actuated release.

Inventors: **Simone; Anthony** (Webster, NY)**, Garcea; Frank** (Churchville, NY)
Family ID: **38320926**
Appl. No.: **11/670,222**
Filed: **February 1, 2007**

Prior Publication Data

Document Identifier	Publication Date
US 20070175702 A1	Aug 2, 2007

Related U.S. Patent Documents

Application Number	Filing Date	Patent Number	Issue Date
60764231	Feb 1, 2006		

Current U.S. Class:	**182/133**; 182/136; 182/187; 182/221
Current CPC Class:	A01M 31/02 (20130101)
Current International Class:	A63B 27/00 (20060101)
Field of Search:	;182/133,134,135,136,221,222,223,187

Figure 75: Pump Jack Tree Stand

United States Patent	**5,097,925**
Walker, Jr.	**March 24, 1992**

Tree walker

Abstract

A lightweight, portable, tree-climbing device to provide a stable, elevated, horizontal, platfrom utilizing two separate elements for a hunter or observer. The uppermost element accommodates the user in a sitting position while the lower element accommodates his feet. The user faces the tree during the ascending and descending processes but has the option of facing the tree or leaning his back against the tree during his hunting or observing activity. Each element has tubular supporting members, which, along the the ends of the supporting cables, have predrilled holes, thus allowing for the selective adjustment of each element during initial attachment. The device further provides for selective adjustment of the support cables as the user ascends and descends the tree. The device further allows the user to climb past limbs without first having to cut them from the tree.

Inventors:	**Walker, Jr.; George T.** (Dothan, AL)
Assignee:	**Walker, Jr.; George T.** (Dothan, AL)
Family ID:	**24143484**
Appl. No.:	**07/537,636**
Filed:	**June 14, 1990**

Current U.S. Class:	**182/135**; 182/187
Current CPC Class:	A63B 27/00 (20130101); A01M 31/02 (20130101)
Current International Class:	A47C 9/10 (20060101); A47C 9/00 (20060101); A01M 31/02 (20060101); A01M 31/00 (20060101); A63B 27/00 (20060101); A01M 031/02 (); A63B 027/00 ()
Field of Search:	;182/187,188,134,135 ;108/152

References Cited [Referenced By]

U.S. Patent Documents

3961686	June 1976	Starkey

Figure 76: Tree Walker

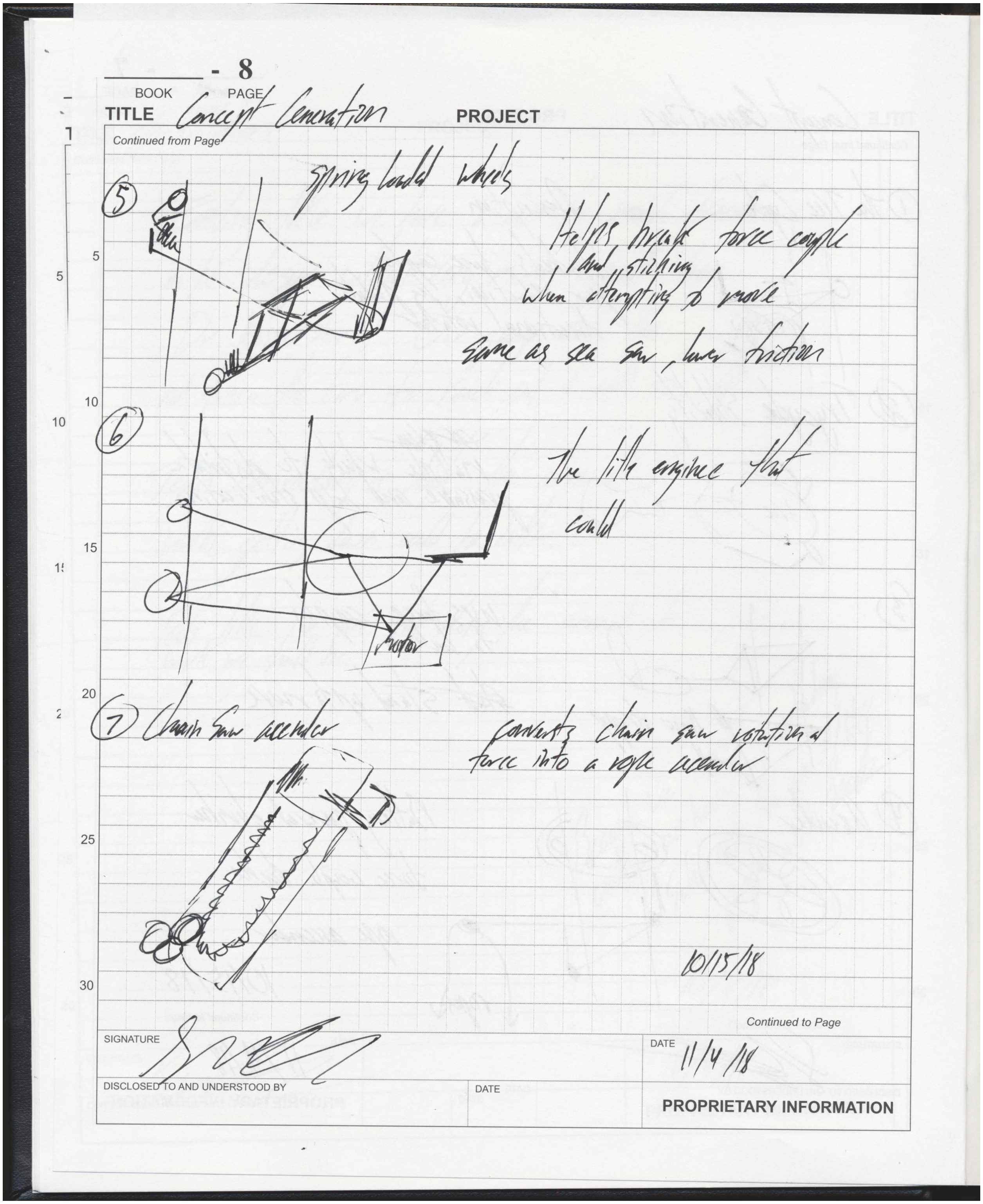


Figure 77: Scotts Design Page 2

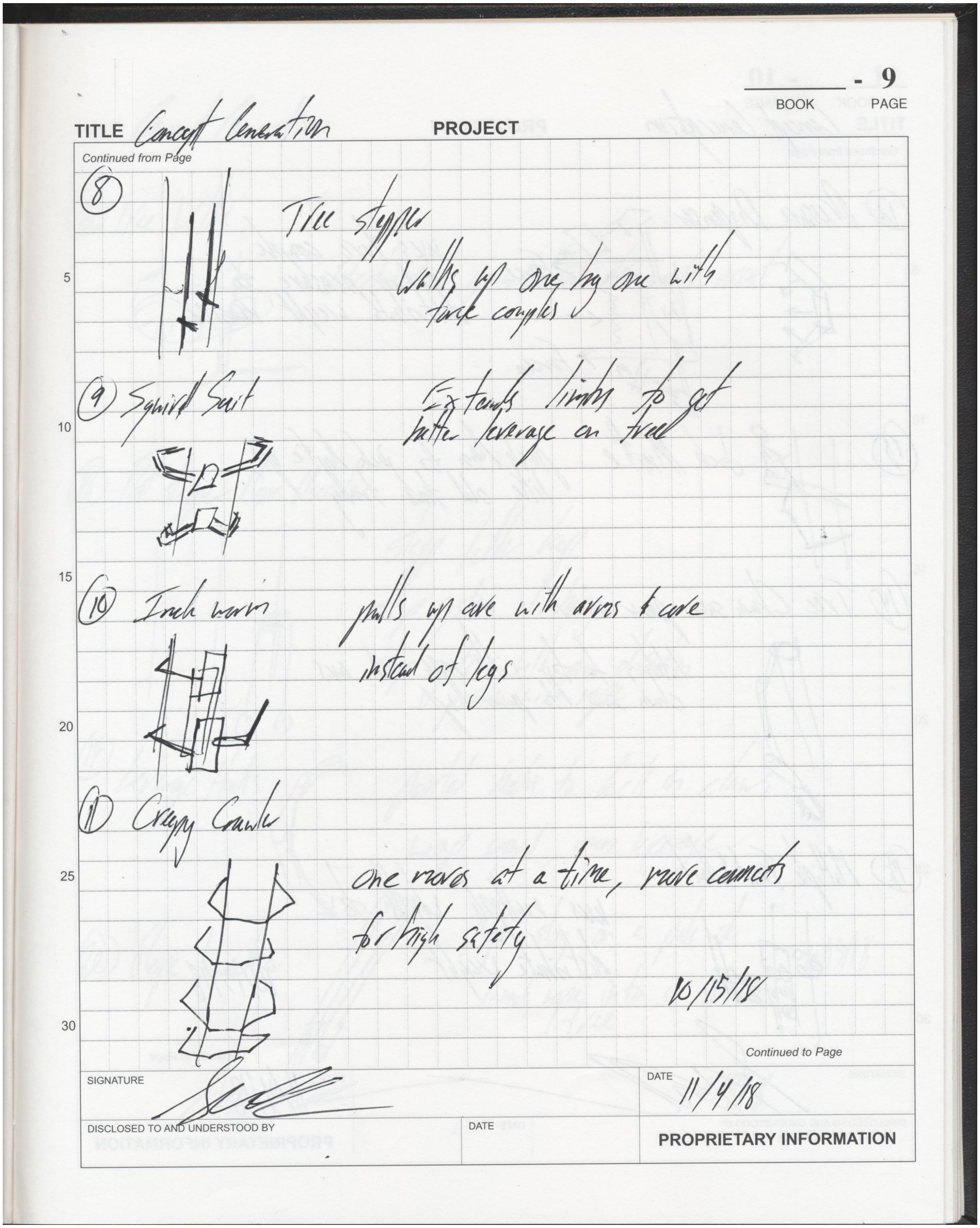


Figure 78: Scott's Designs Page 3

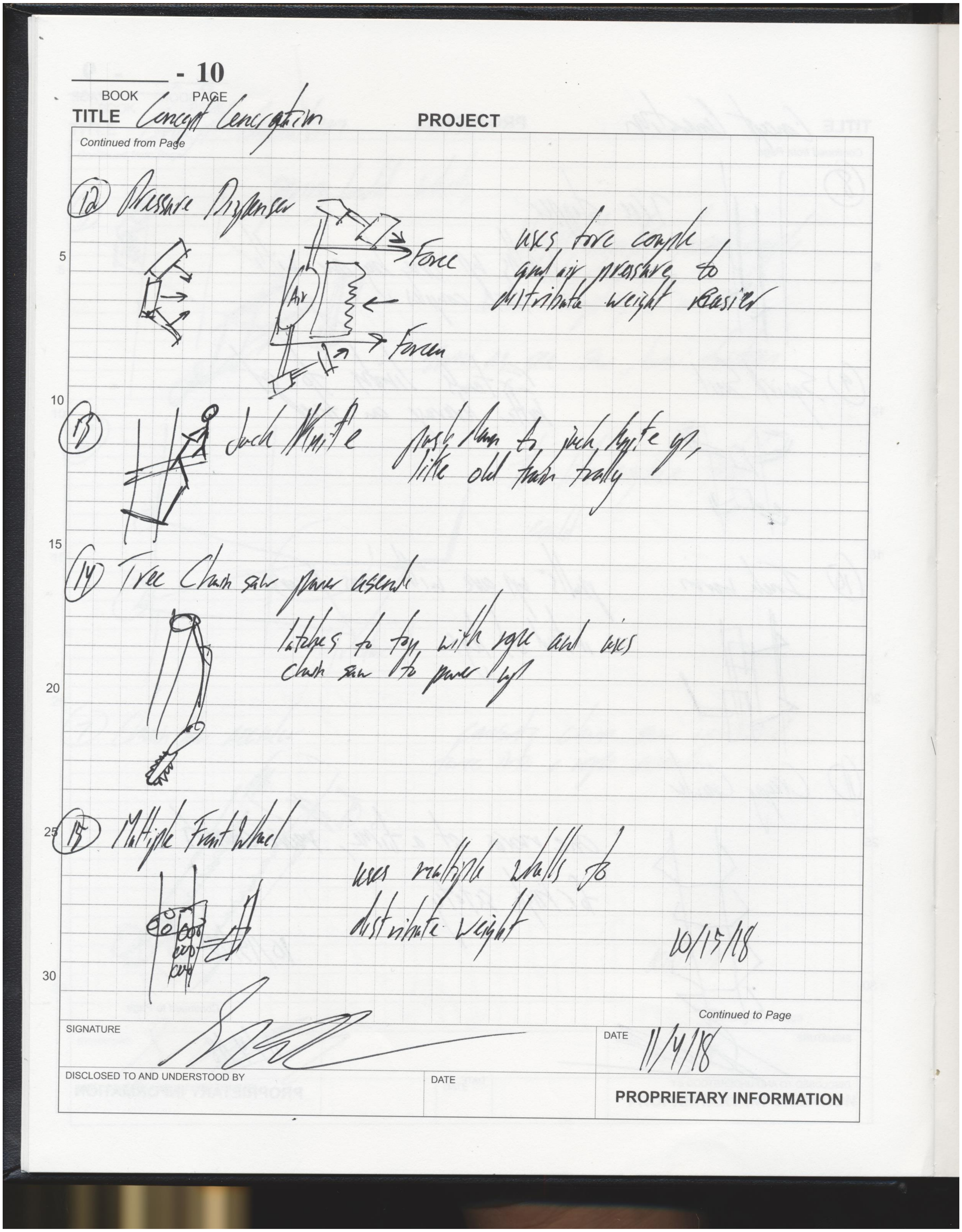


Figure 79: Scott's Designs Page 4

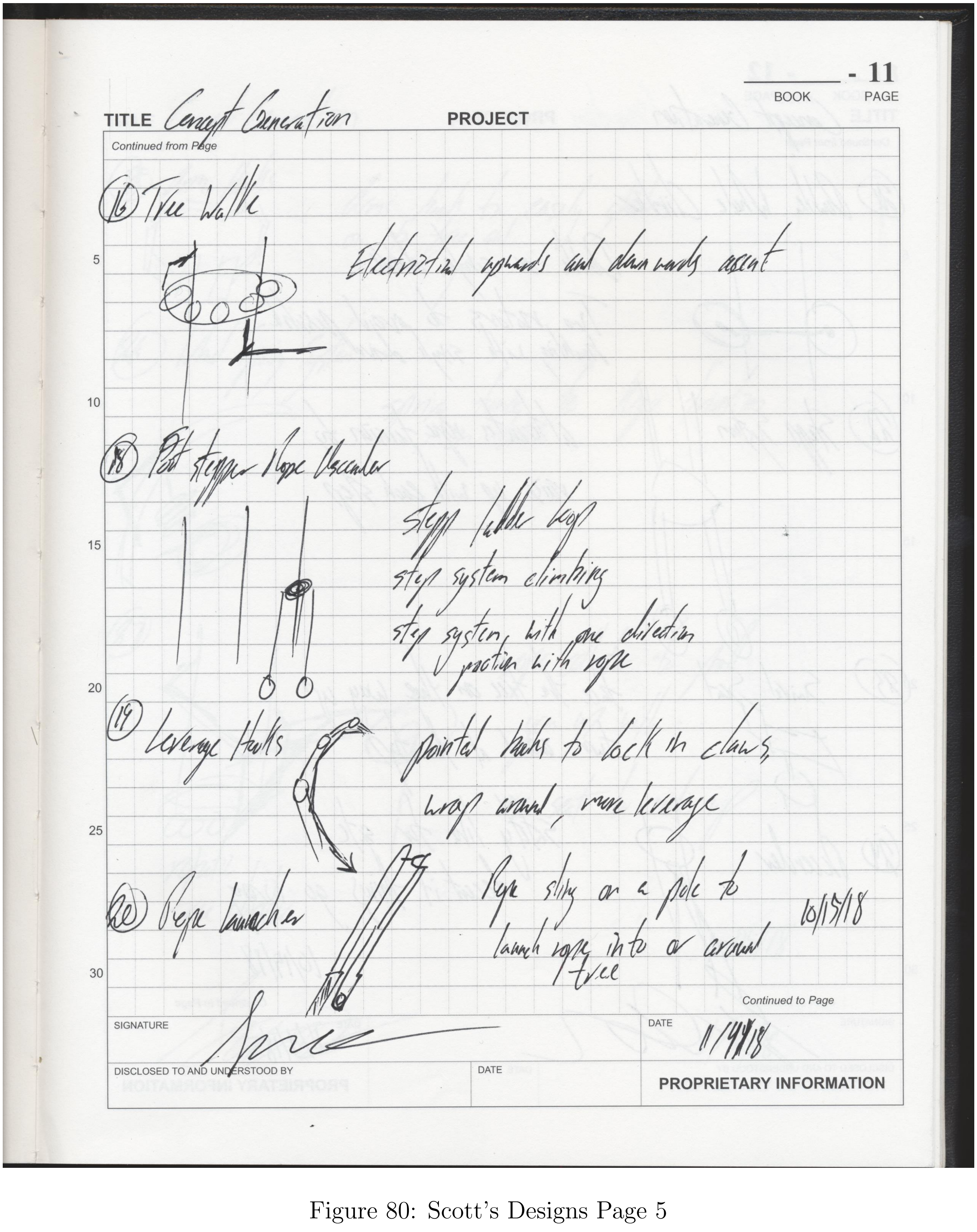


Figure 80: Scott's Designs Page 5

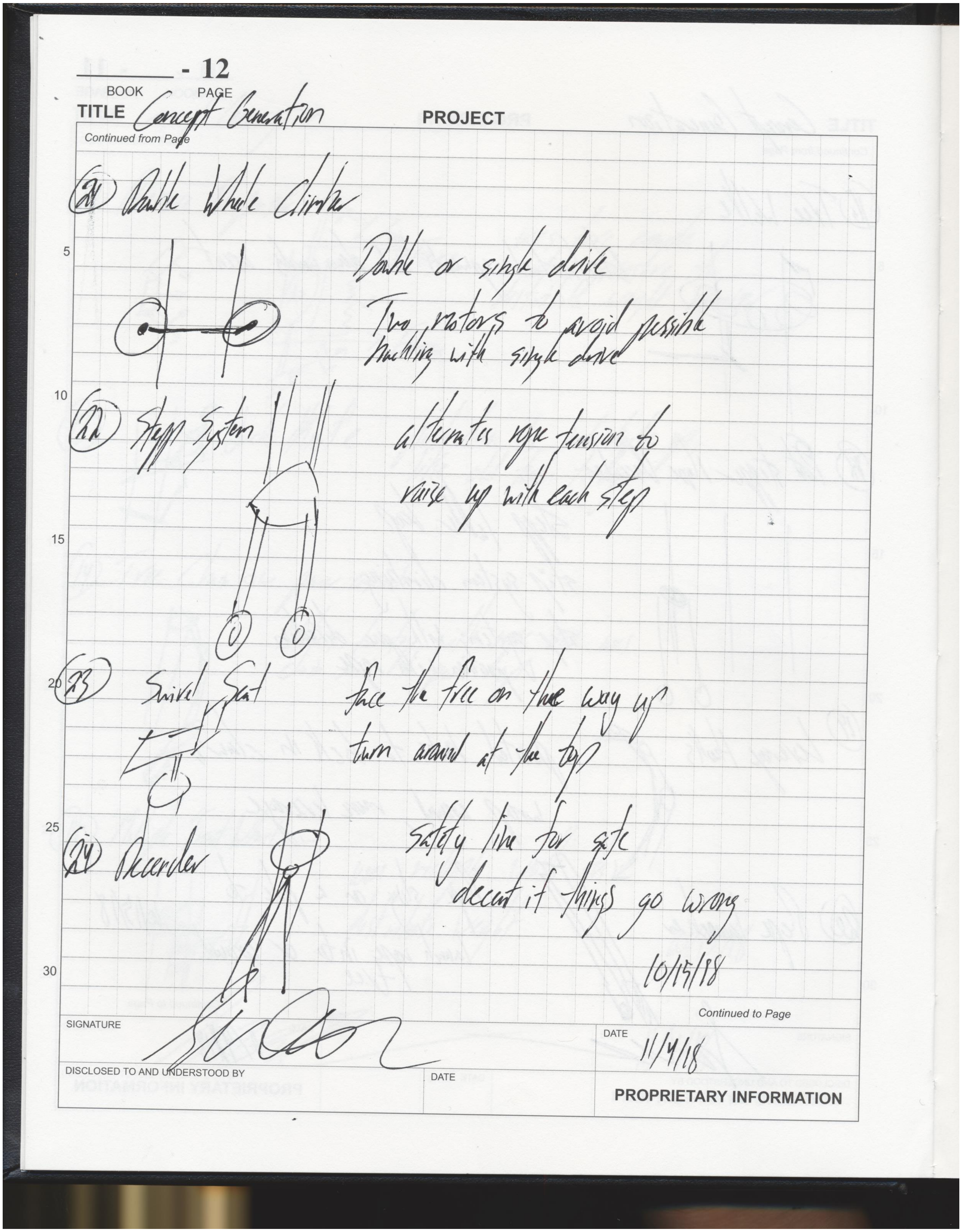


Figure 81: Scott's Designs Page 6

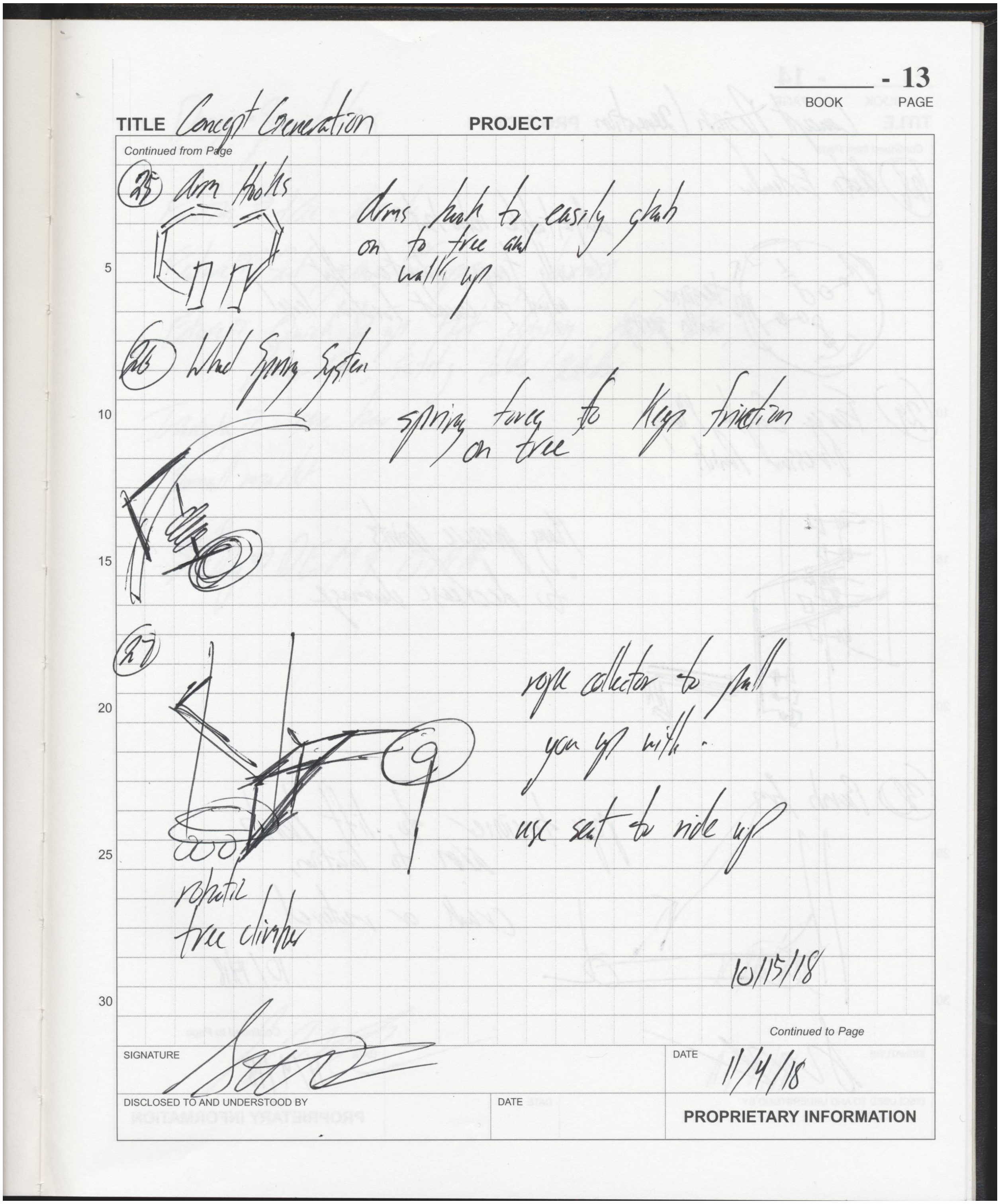


Figure 82: Scott's Designs Page 7

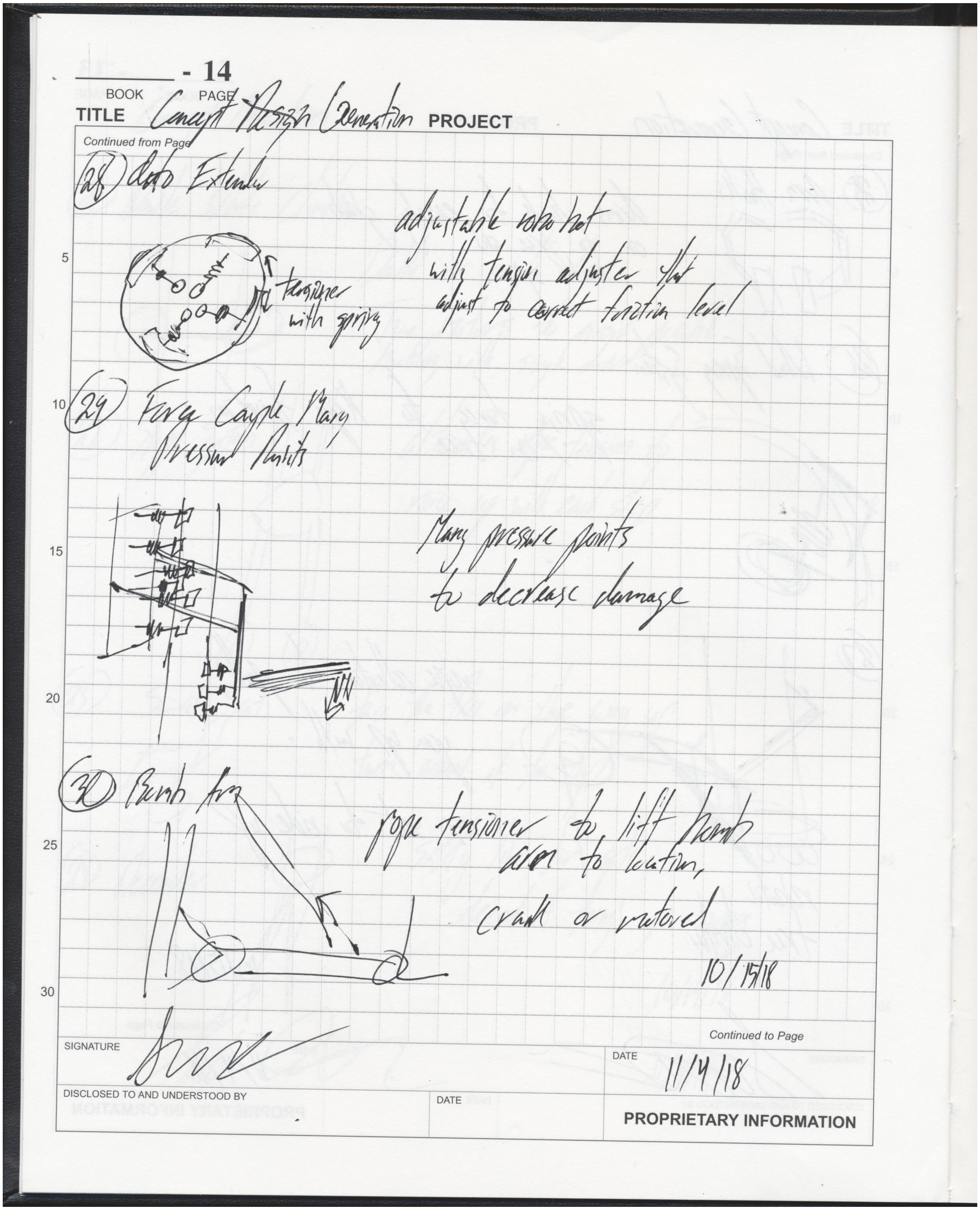
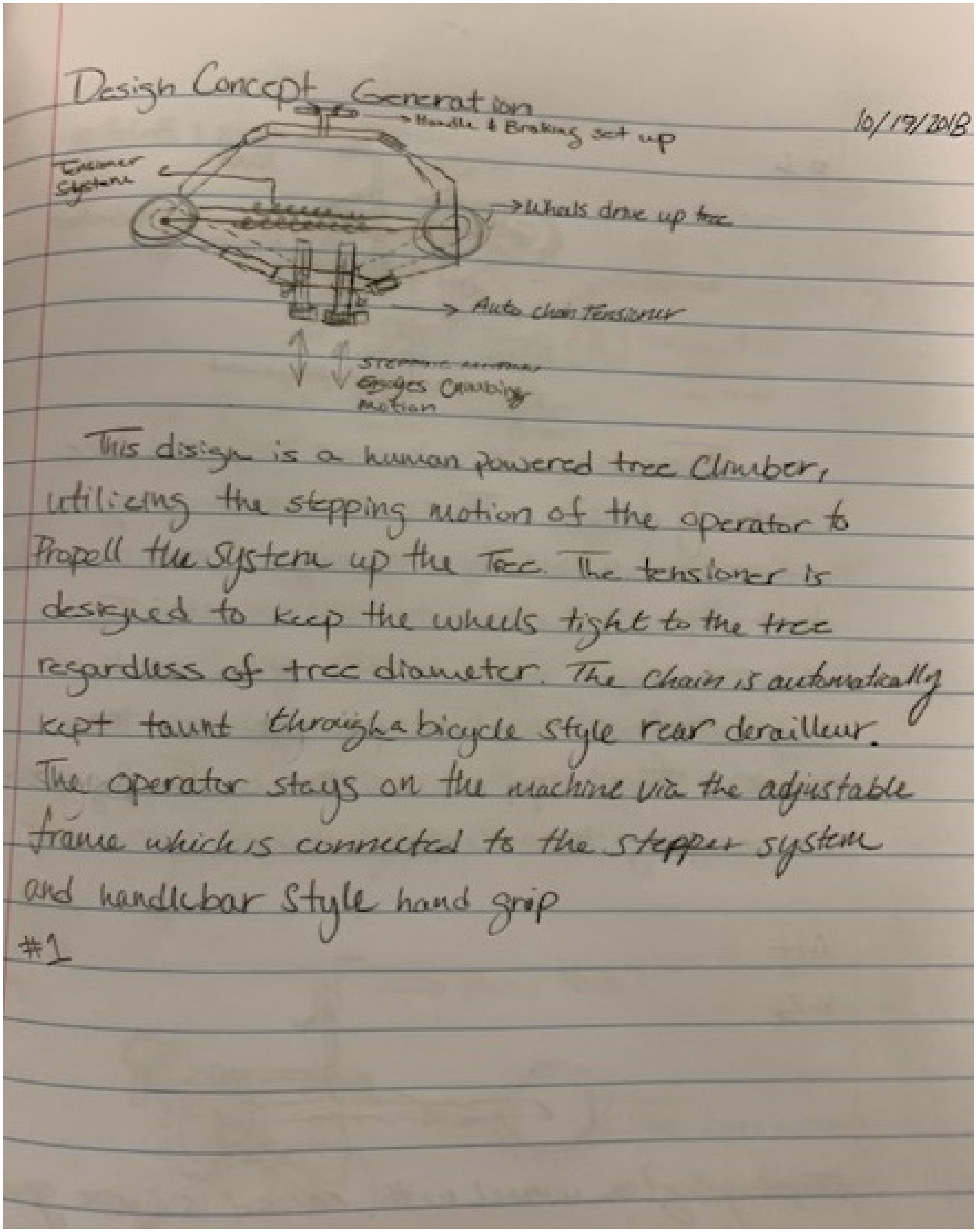


Figure 83: Scott's Designs Page 8



This disign is a human powered tree Climber, utilizing the stepping motion of the operator to Propell the System up the Tree. The tensioner is designed to keep the wheels tight to the tree regardless of tree diameter. The Chain is automatically kept taunt through a bicycle style rear derailleur. The operator stays on the machine via the adjustable frame which is connected to the stepper system and handlebar Style hand grip

#1

Figure 84: Alex's Designs Page 1

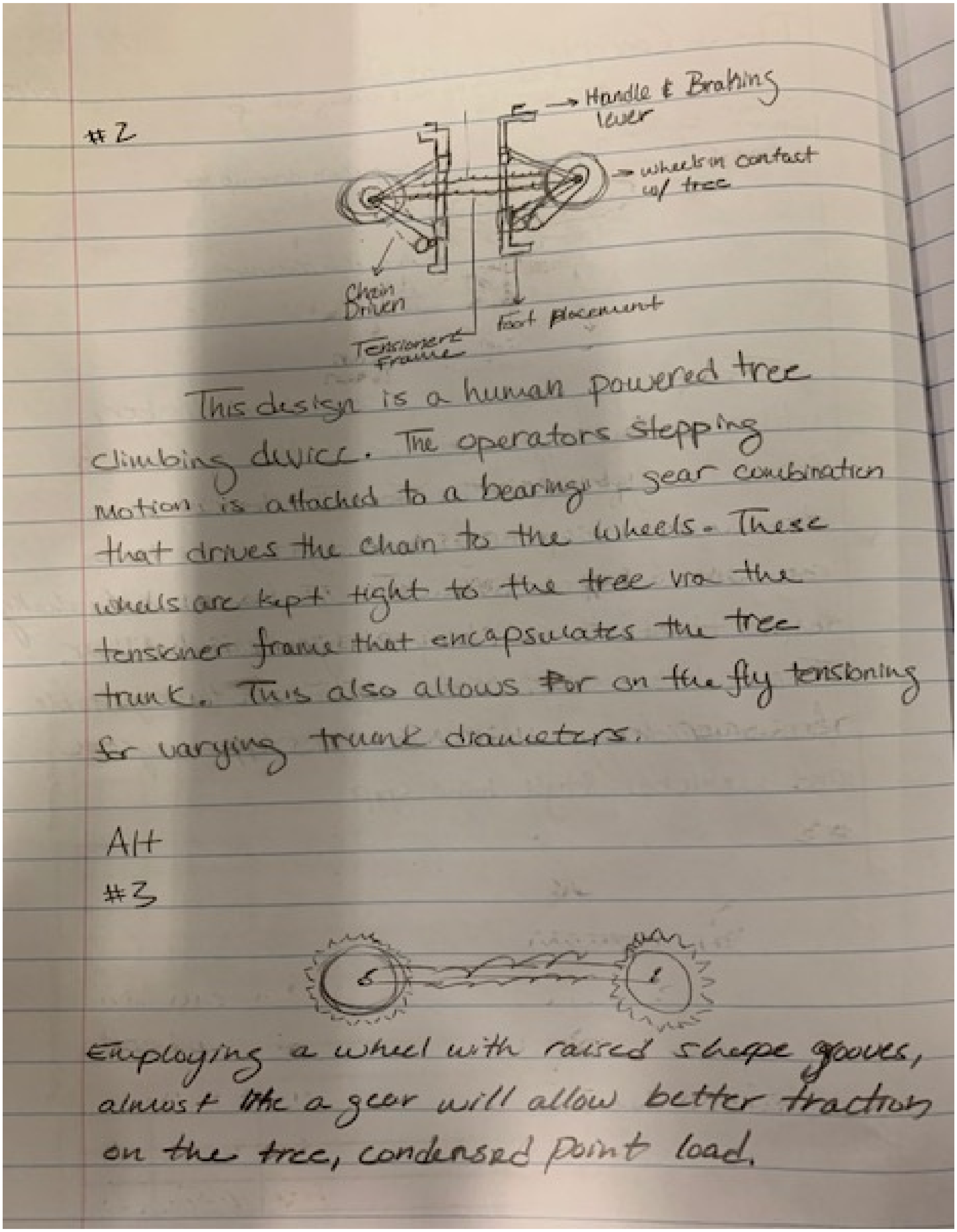


Figure 85: Alex's Designs Page 2

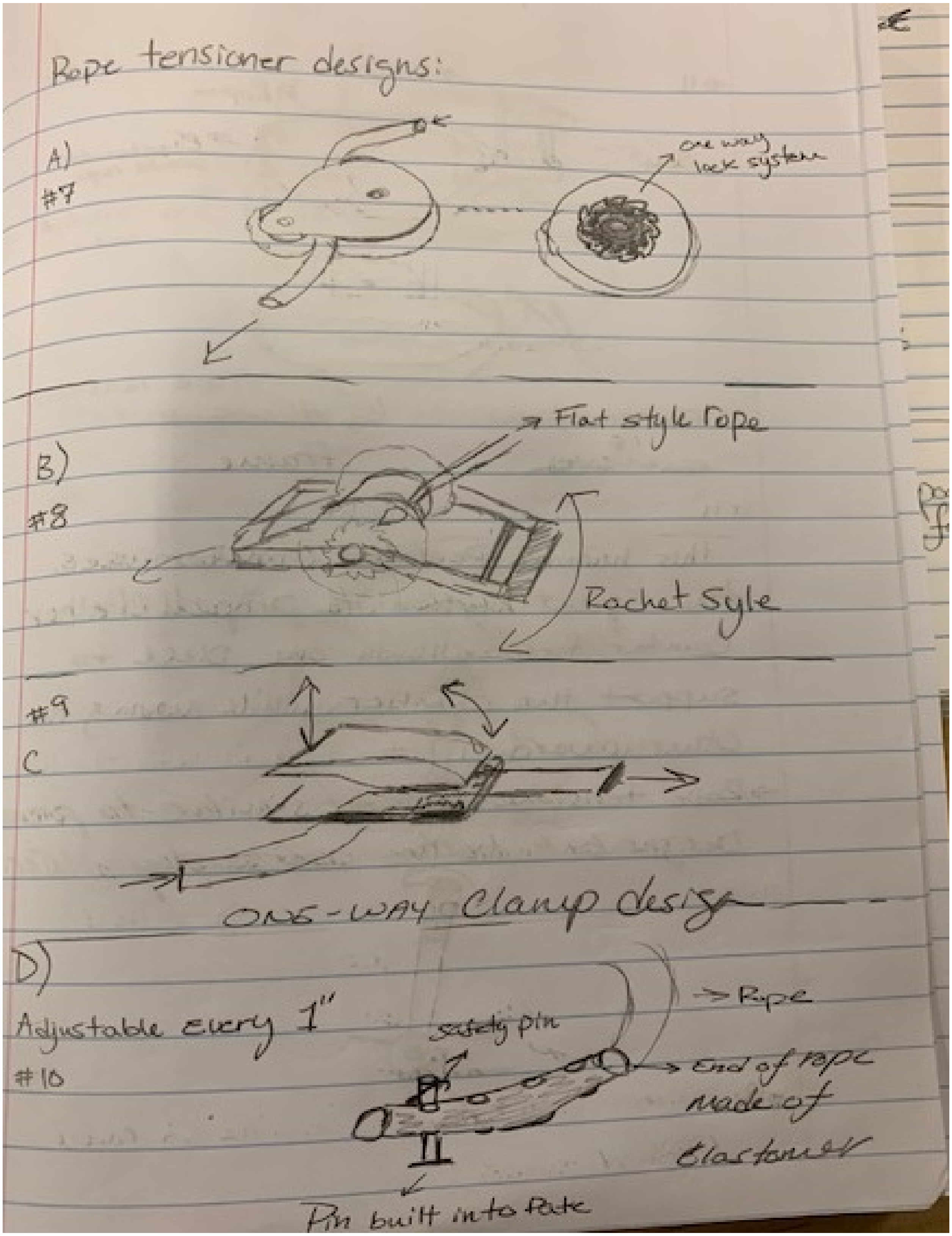


Figure 86: Alex's Designs Page 5

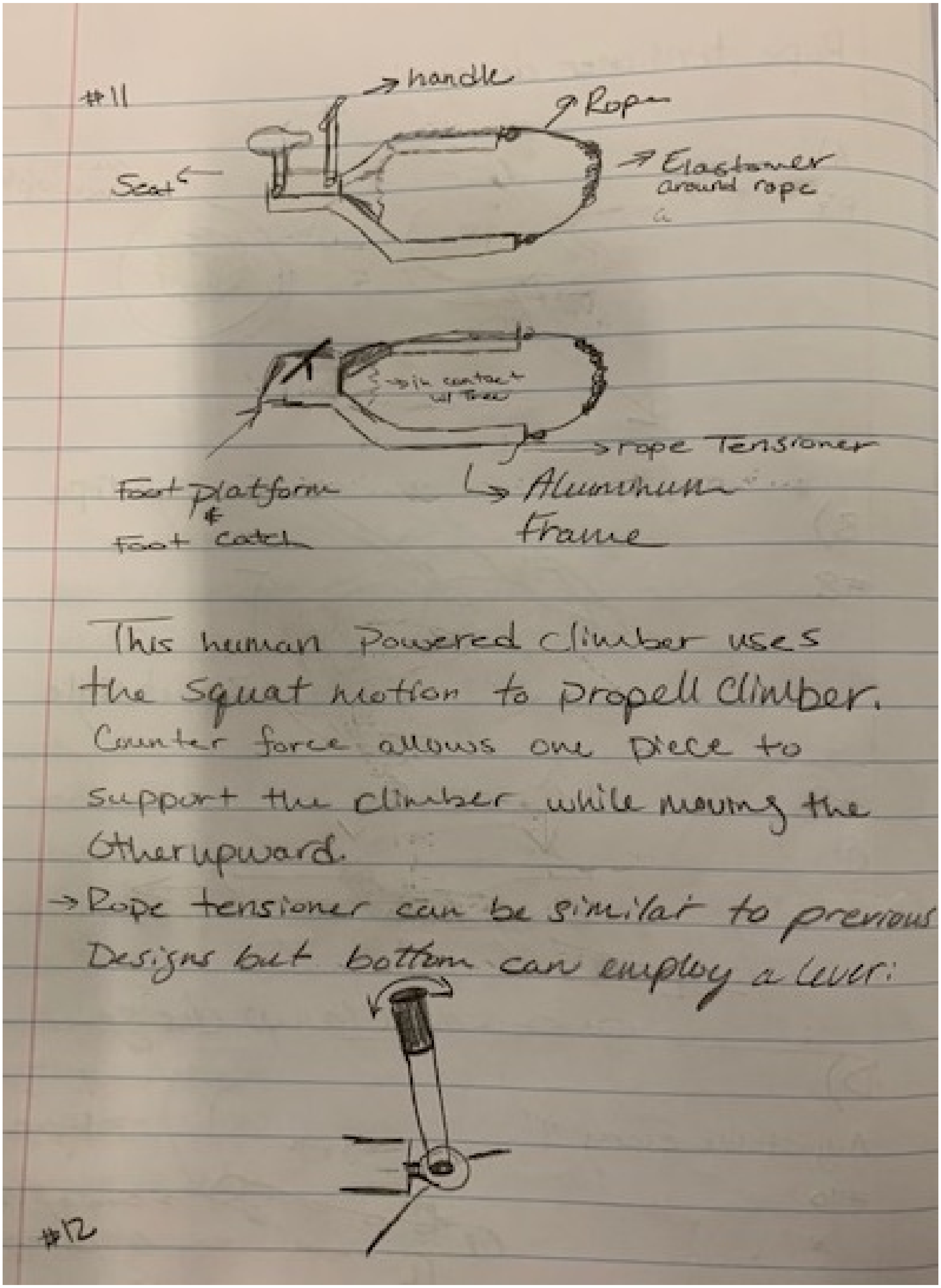
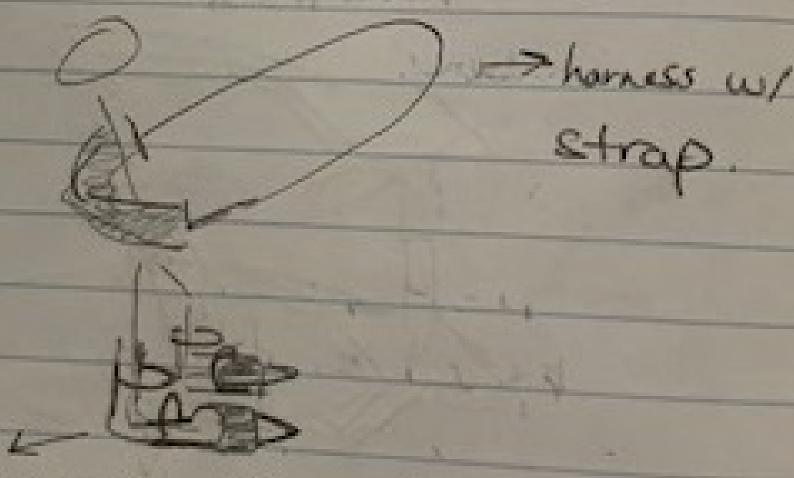


Figure 87: Alex's Designs Page 6

#15

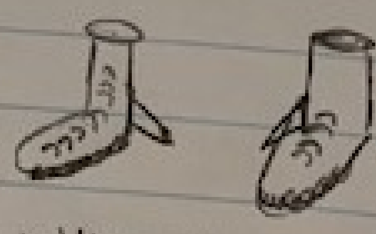
Stepper bottom with strap harness set-up.

#16



Foot insert with spike

#17



Boot with spikes on inside of ankle
(Use w/ harness)

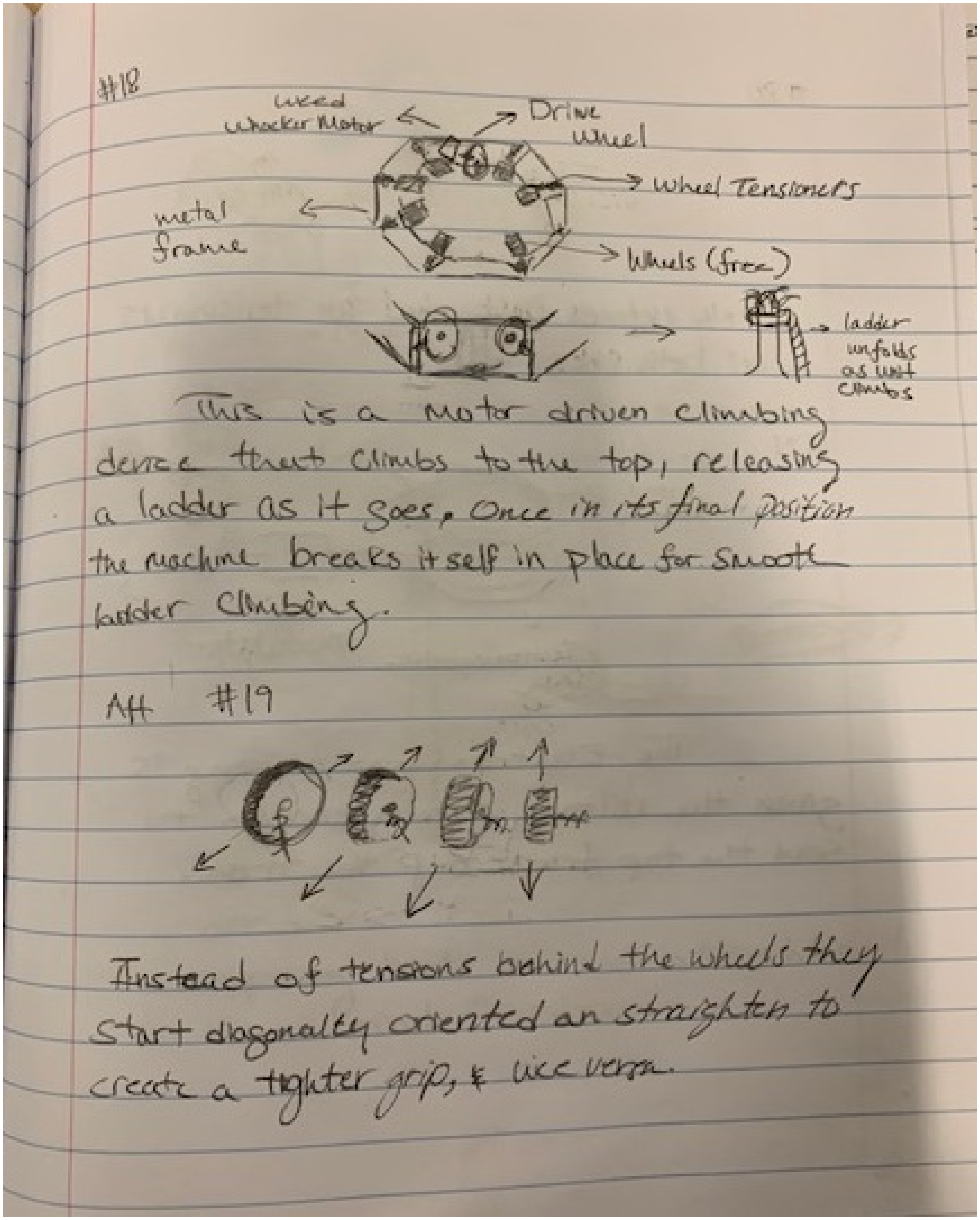


Figure 89: Alex's Designs Page 9

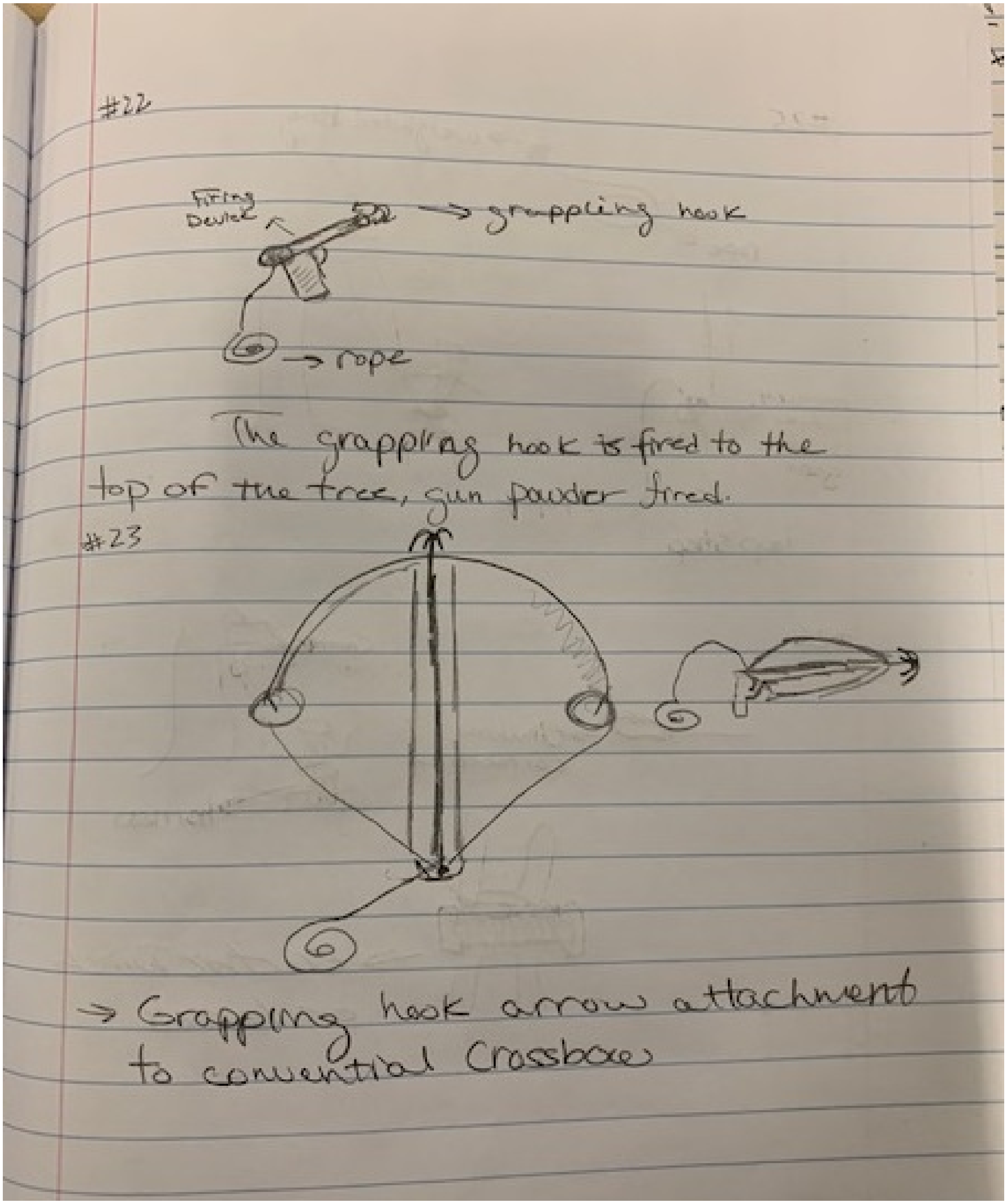


Figure 90: Alex's Designs Page 10

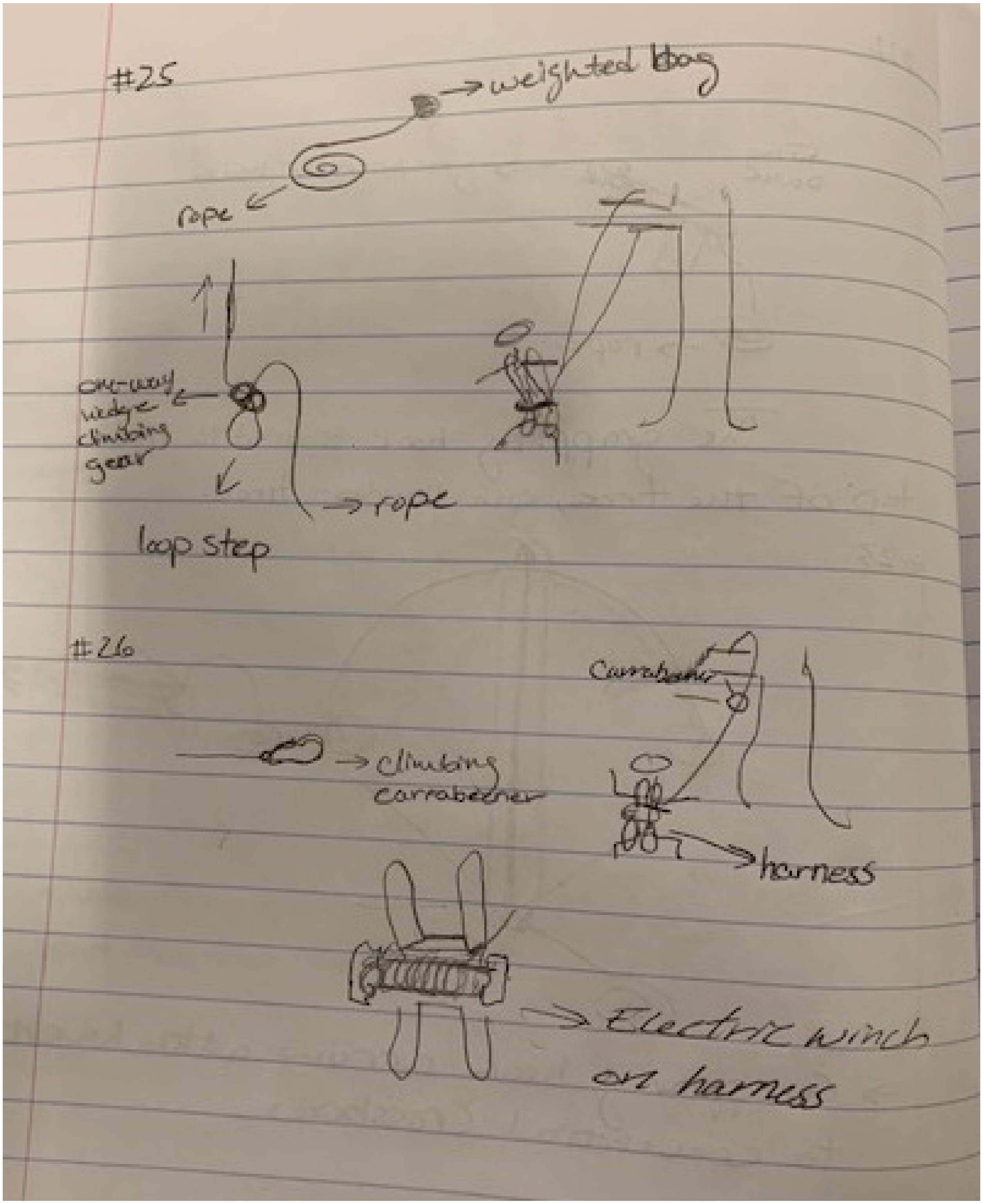


Figure 91: Alex's Designs Page 11

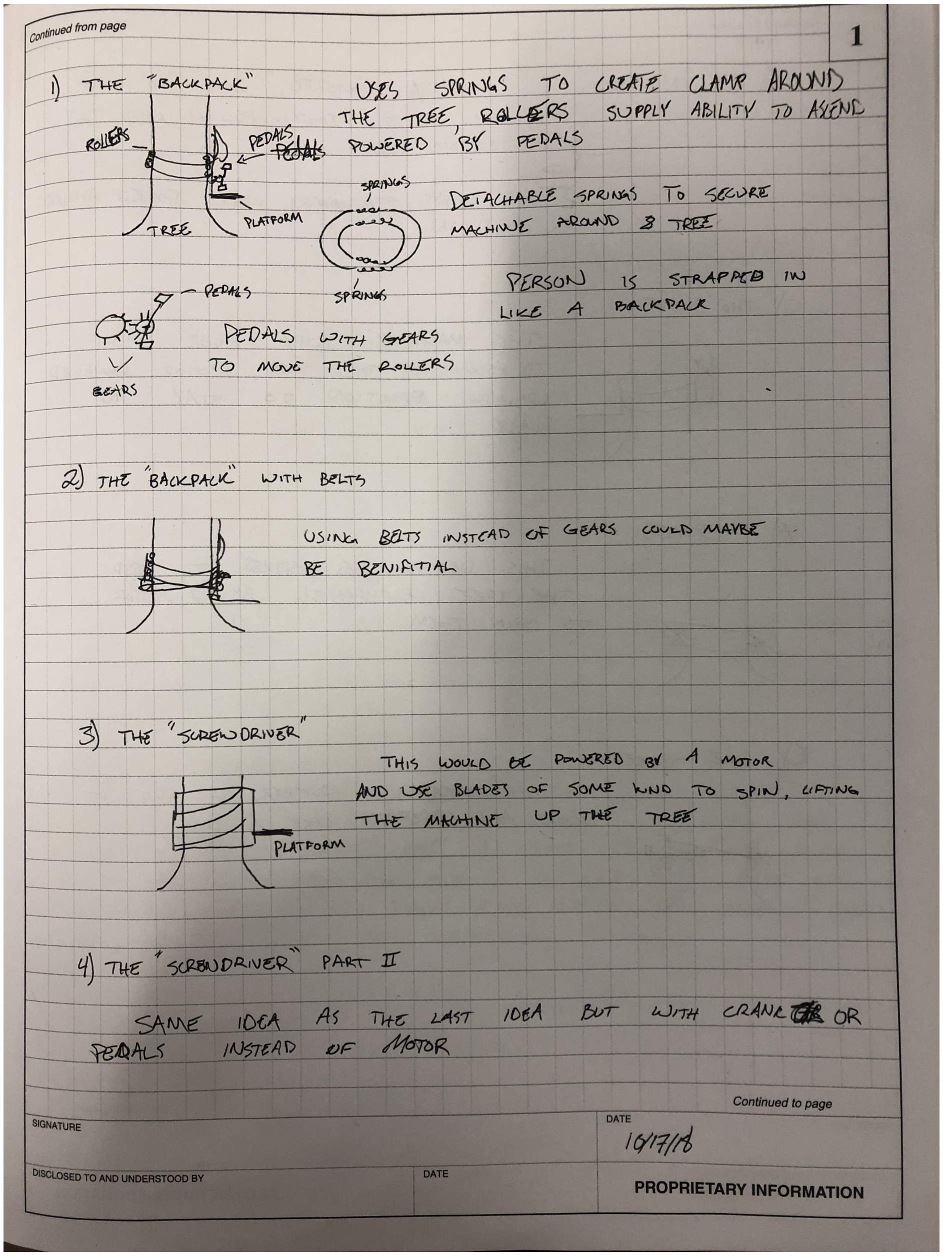


Figure 92: Nick's Designs Page 1

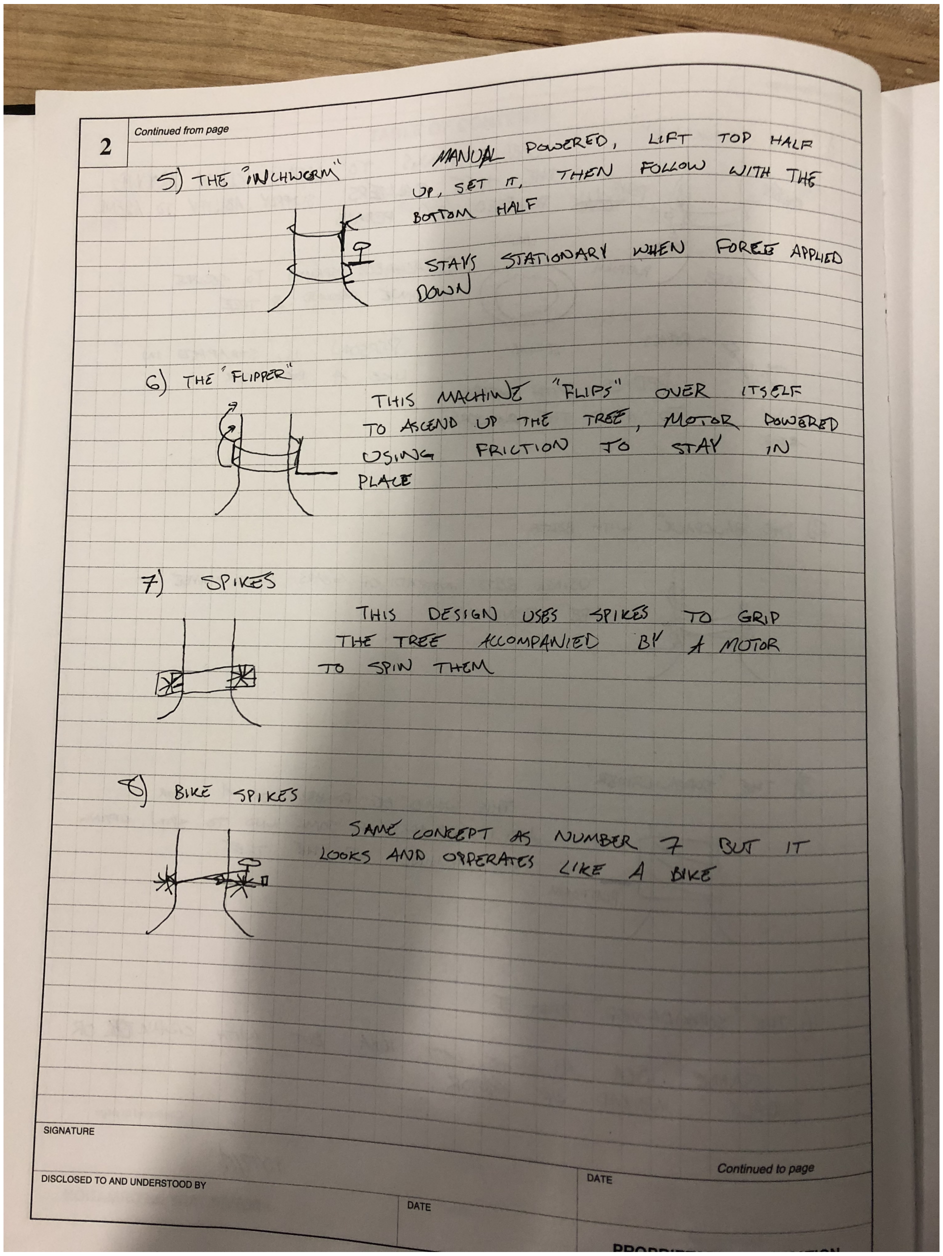
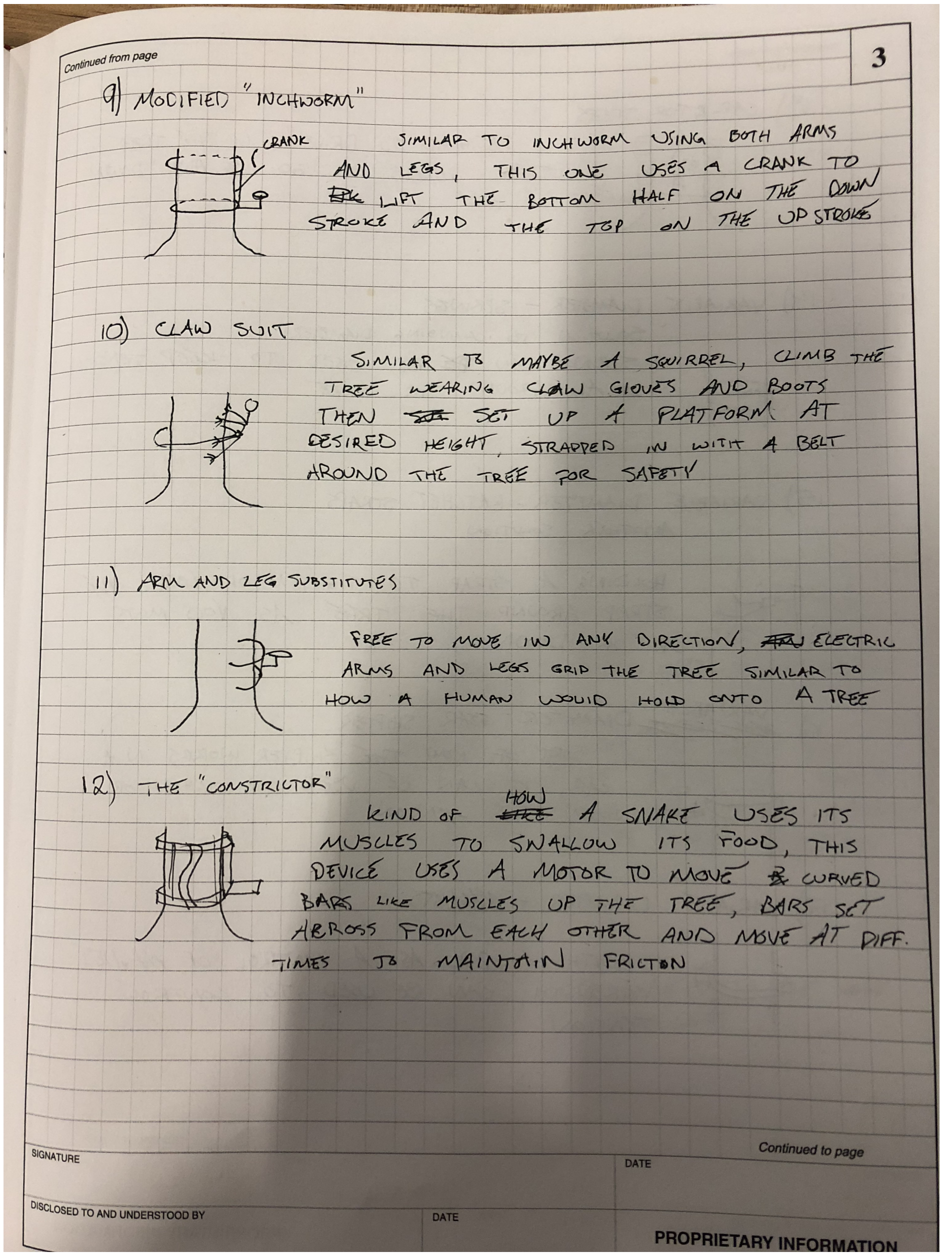


Figure 93: Nick's Designs Page 2



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3

9) MODIFIED "INCHWORM"

CRANK

SIMILAR TO INCHWORM USING BOTH ARMS AND LEGS, THIS ONE USES A CRANK TO ~~BR~~ LIFT THE BOTTOM HALF ON THE DOWN STROKE AND THE TOP ON THE UP STROKE

10) CLAW SUIT

SIMILAR TO MAYBE A SQUIRREL, CLIMB THE TREE WEARING CLAW GLOVES AND BOOTS THEN ~~SET~~ SET UP A PLATFORM AT DESIRED HEIGHT, STRAPPED IN WITH A BELT AROUND THE TREE FOR SAFETY

11) ARM AND LEG SUBSTITUTES

FREE TO MOVE IN ANY DIRECTION, ~~AR~~ ELECTRIC ARMS AND LEGS GRIP THE TREE SIMILAR TO HOW A HUMAN WOULD HOLD ONTO A TREE

12) THE "CONSTRICTOR"

KIND OF ~~EREE~~ HOW A SNAKE USES ITS MUSCLES TO SWALLOW ITS FOOD, THIS DEVICE USES A MOTOR TO MOVE ~~B~~ CURVED BARS LIKE MUSCLES UP THE TREE, BARS SET ACROSS FROM EACH OTHER AND MOVE AT DIFF. TIMES TO MAINTAIN FRICTON

SIGNATURE | DATE | Continued to page

DISCLOSED TO AND UNDERSTOOD BY | DATE

PROPRIETARY INFORMATION

Figure 94: Nick's Designs Page 3

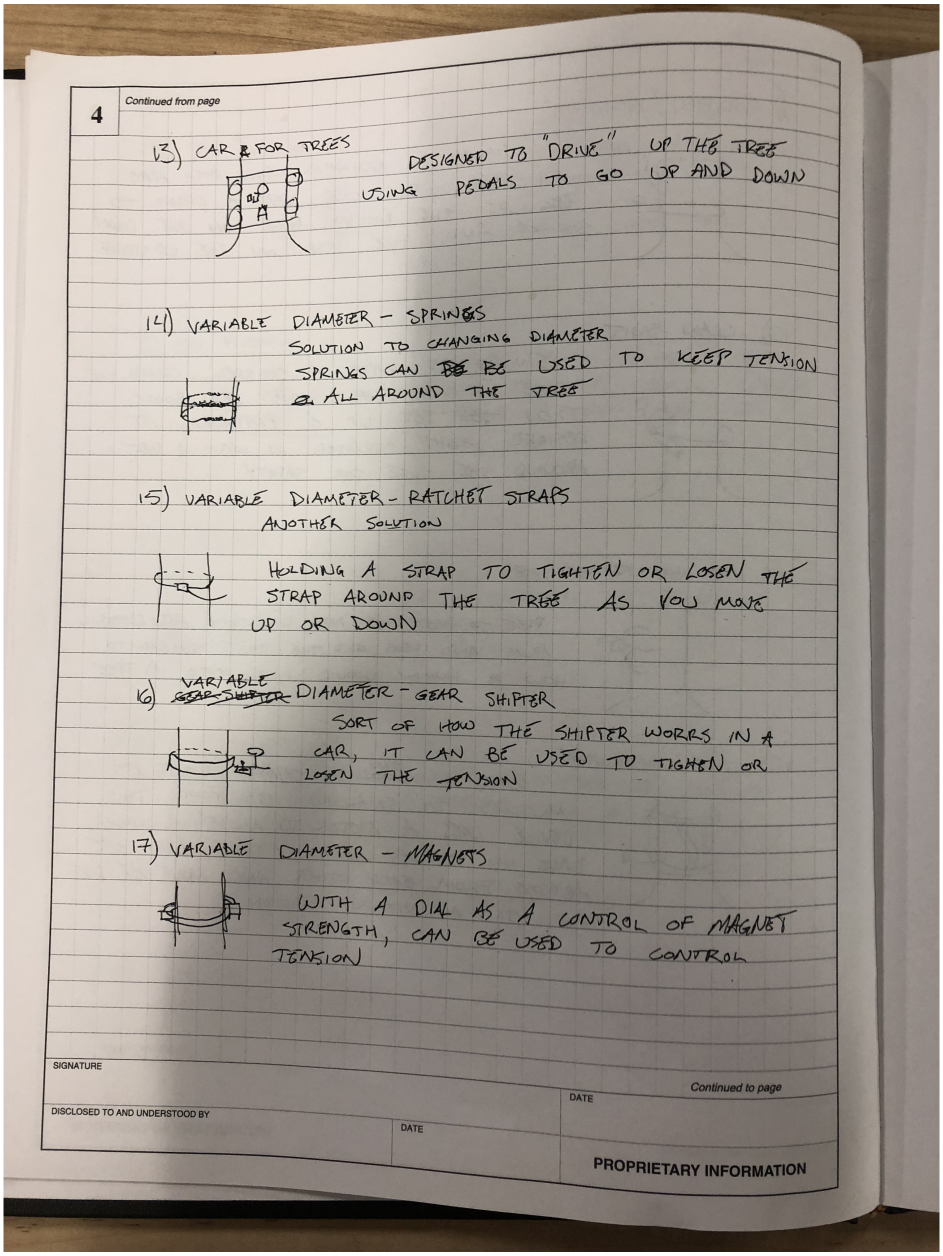


Figure 95: Nick's Designs Page 4

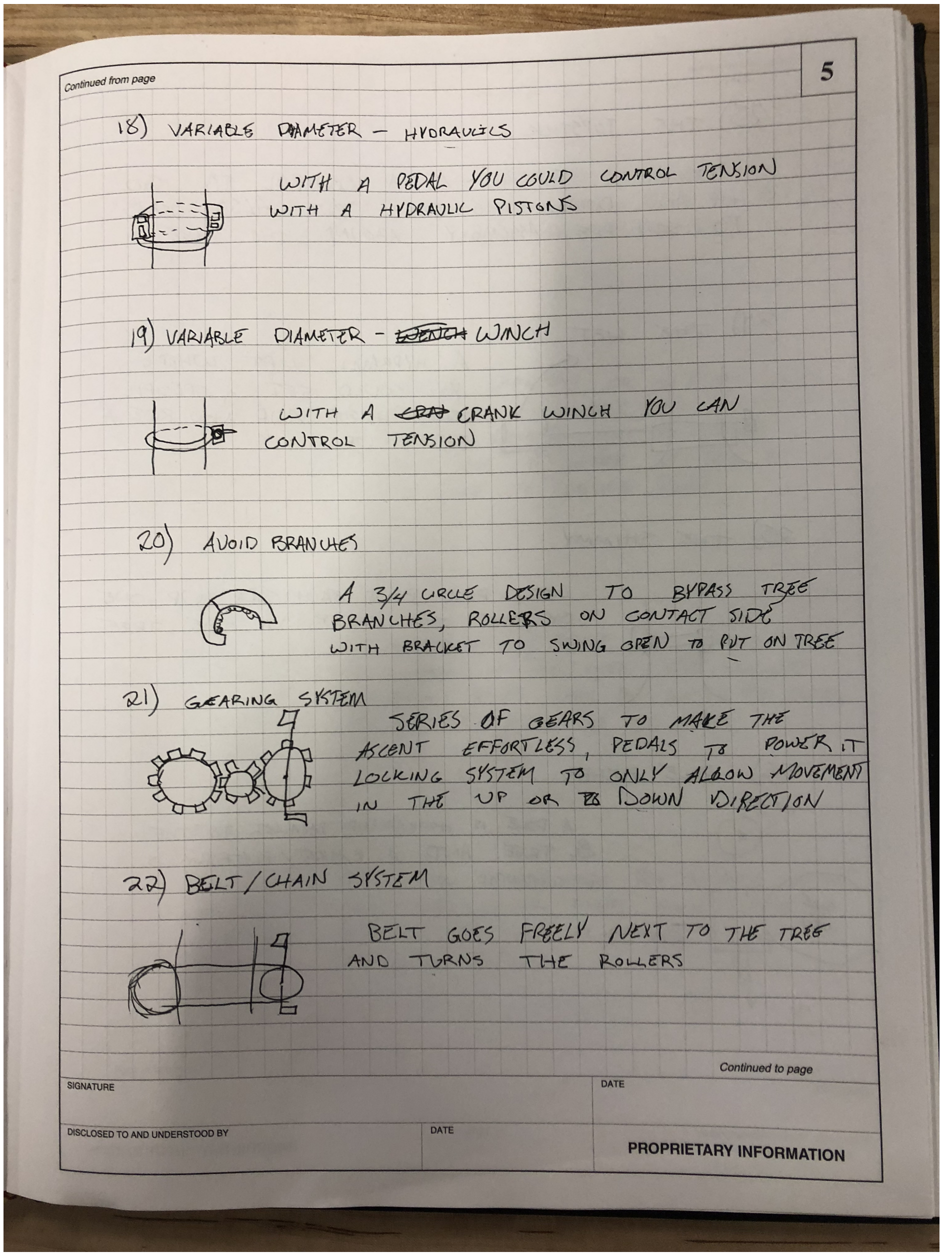


Figure 96: Nick's Designs Page 5

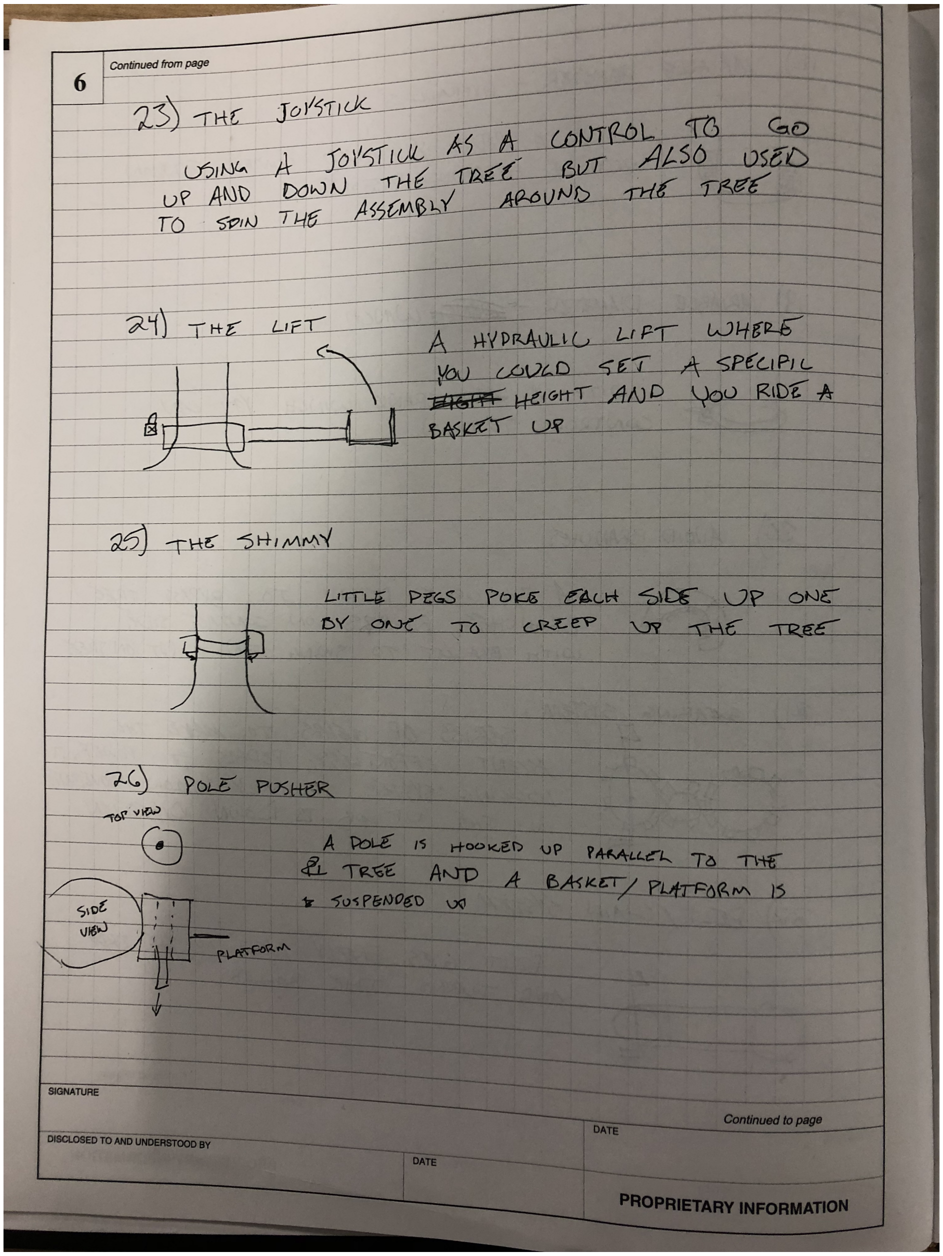
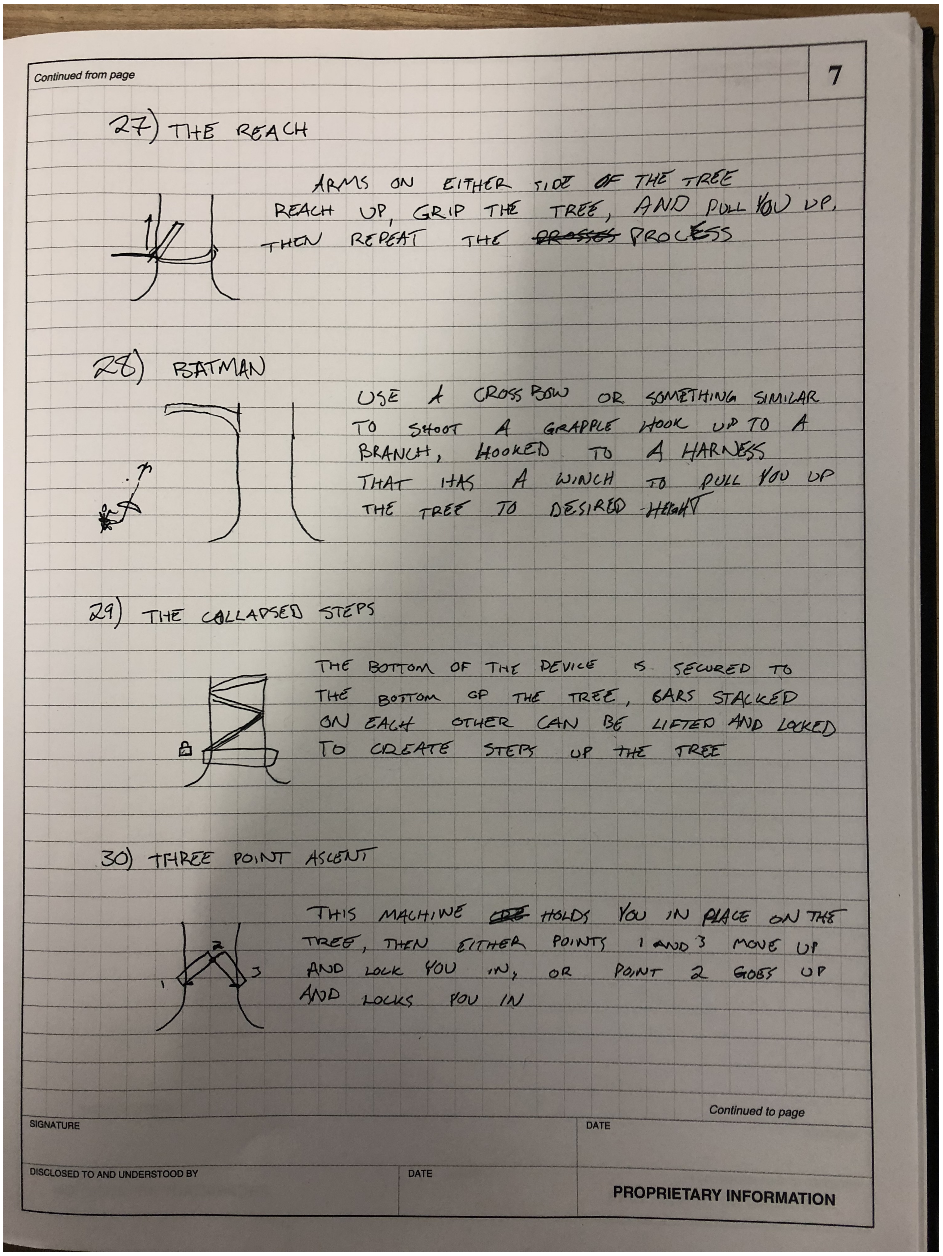


Figure 97: Nick's Designs Page 6



Continued from page

7

27) THE REACH

ARMS ON EITHER SIDE OF THE TREE REACH UP, GRIP THE TREE, AND PULL YOU UP, THEN REPEAT THE ~~PROSSES~~ PROCESS

28) BATMAN

USE A CROSSBOW OR SOMETHING SIMILAR TO SHOOT A GRAPPLE HOOK UP TO A BRANCH, HOOKED TO A HARNESS THAT HAS A WINCH TO PULL YOU UP THE TREE TO DESIRED HEIGHT

29) THE COLLAPSED STEPS

THE BOTTOM OF THE DEVICE IS SECURED TO THE BOTTOM OF THE TREE, BARS STACKED ON EACH OTHER CAN BE LIFTED AND LOCKED TO CREATE STEPS UP THE TREE

30) THREE POINT ASCENT

THIS MACHINE ~~[illegible]~~ HOLDS YOU IN PLACE ON THE TREE, THEN EITHER POINTS 1 AND 3 MOVE UP AND LOCK YOU IN, OR POINT 2 GOES UP AND LOCKS YOU IN

Continued to page

SIGNATURE

DATE

DISCLOSED TO AND UNDERSTOOD BY

DATE

PROPRIETARY INFORMATION

Figure 98: Nick's Designs Page 7

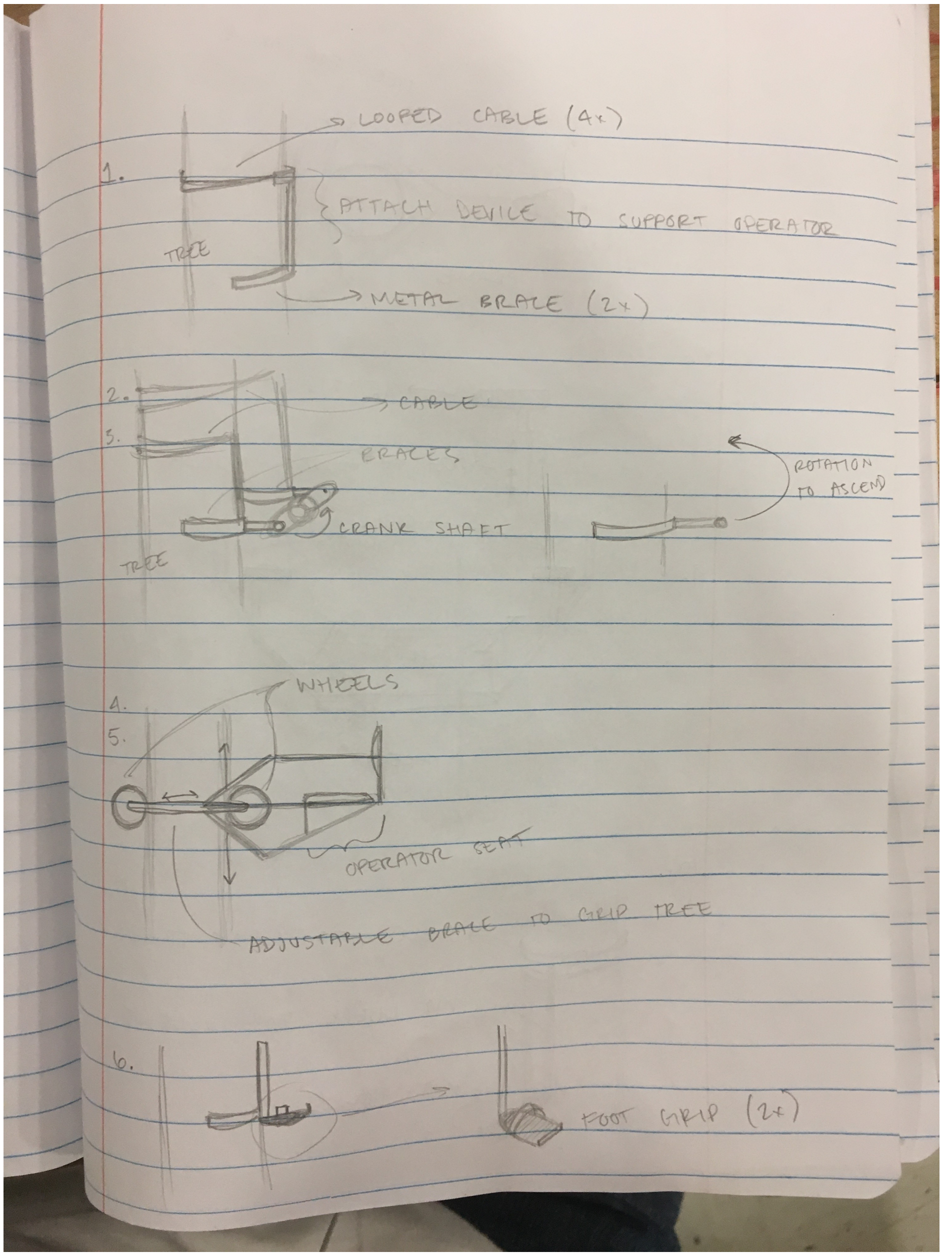


Figure 99: Cam's Designs Page 1

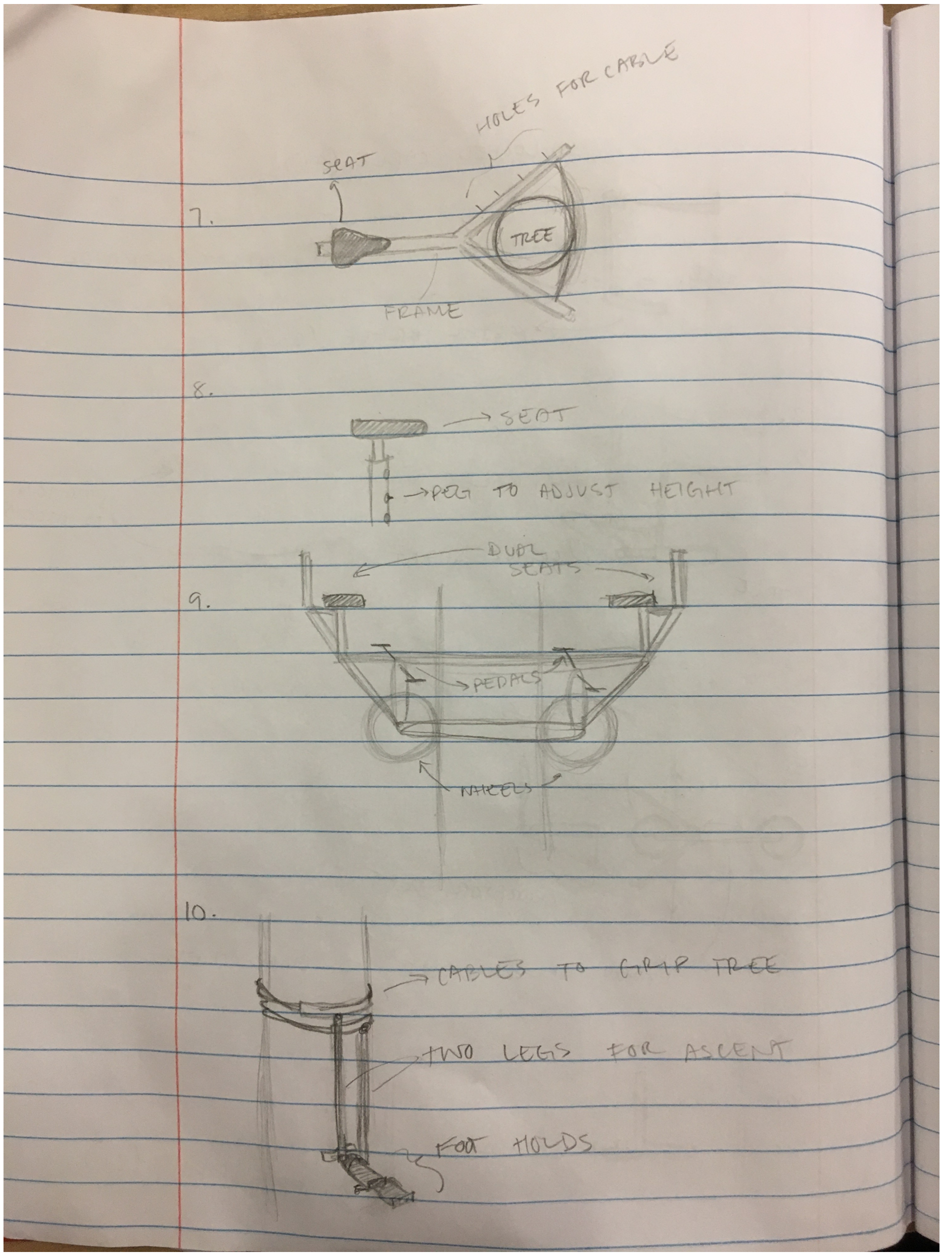


Figure 100: Cam's Designs Page 2

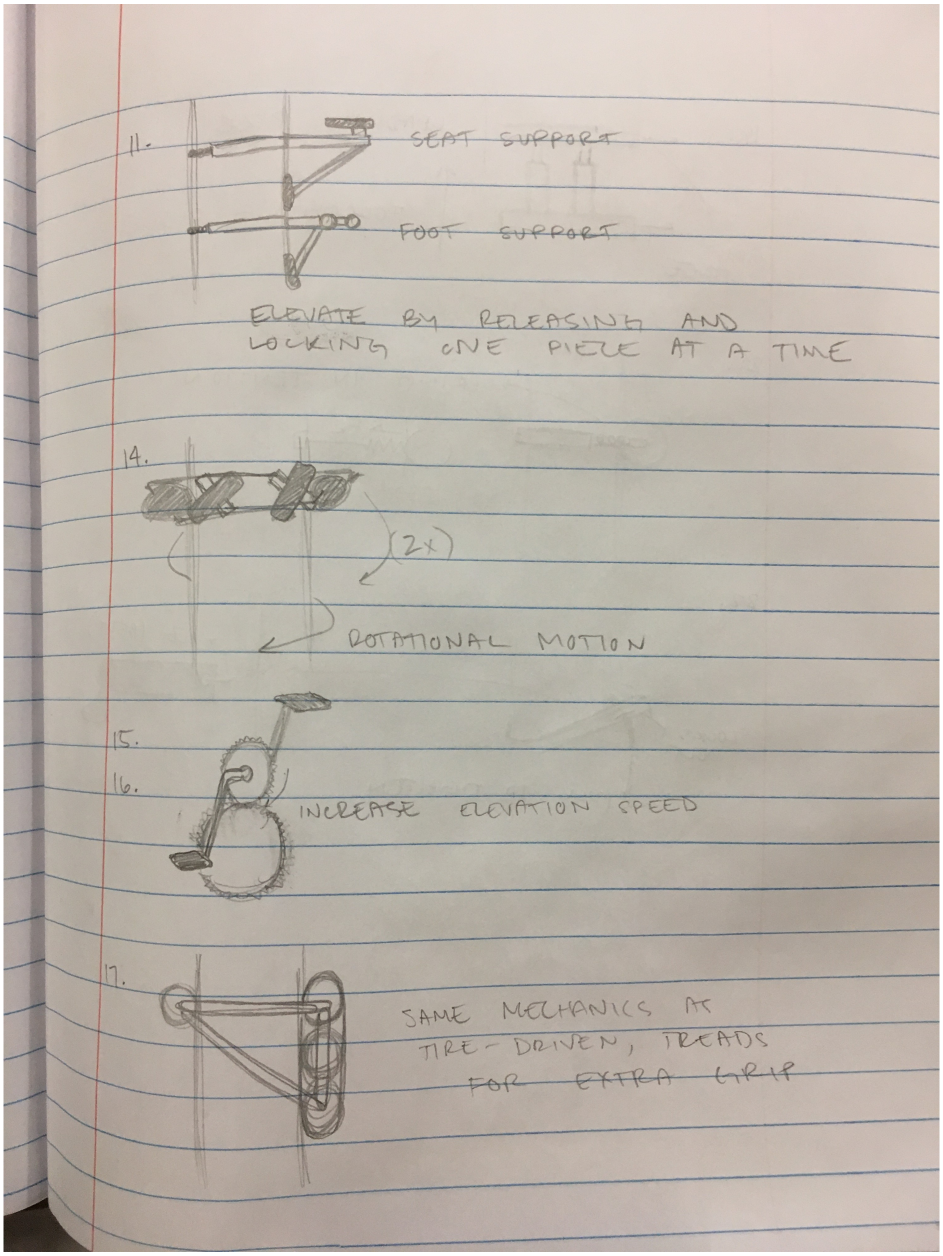


Figure 101: Cam's Designs Page 3

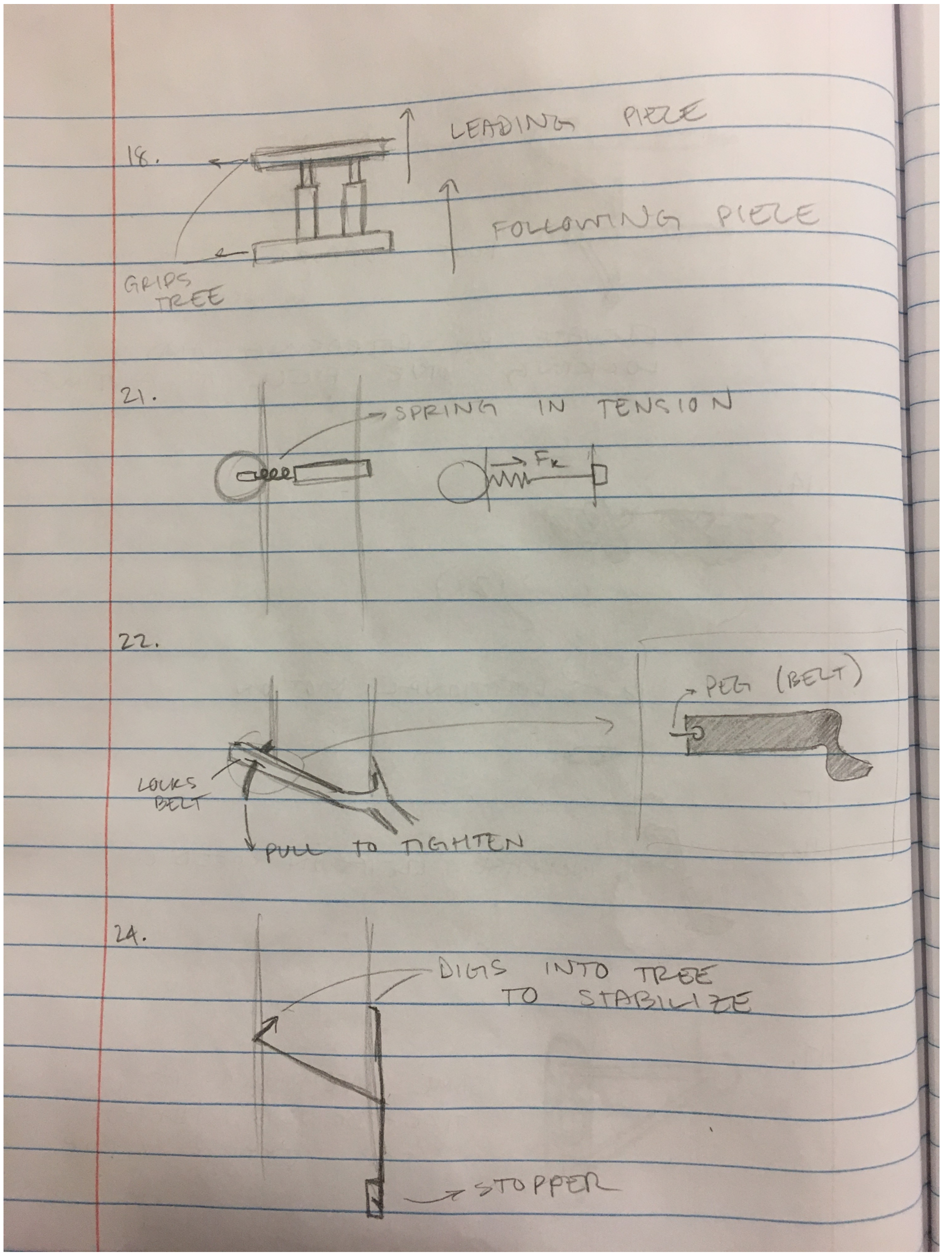


Figure 102: Cam's Designs Page 4