2016 AFRL University & Service Academy Design Challenge

AUBURN

UNIVERSITY

Corporation 13

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Executive Summary

Auburn University's Corporation 13 has designed and developed a solution to the United States military's fast roping issues. Corporation 13 proposes a new system that consists of an assist device and a new tactical glove. The Tactical Rope Insertion Assist Device, or TRIAD, is a passive assist device utilizing a roller-damper system that eliminates rope burn, controls descent, and increases safety. TRIAD has been tested up to 450 pounds and successfully lowers the weight with a controlled descent speed as low as six feet per second. Due to the innovative design, TRIAD can utilize different viscous rotary dampers to allow for multiple descent speeds or users of different weights. One of the most attractive aspects of the design is that the TRIAD is an easy to use product and will require minimal additional training. The device is easy to engage and remove from the rope for time-sensitive missions. In addition to the TRIAD, Corporation 13 has researched and designed a new tactical glove specifically for fast roping manufactured by Ironclad Performance Wear. The new glove is ergonomically friendly, can be used while operating a weapon, and drastically reduces the heat transferred to the hand during the fast roping operation. To maximize safety, the gloves and TRIAD will be used in combination. This allows for the user's hands to be on the rope while letting TRIAD assist the user in a safe descent.

Introduction

Figure 1: Designed System

Corporation 13 proposes a fast roping system that has three subcomponents associated with the TRIAD and a fourth subcomponent that includes the designed tactical gloves. The TRIAD includes roller and roller shaft, damper, and frame subcomponents. The roller and roller shaft are made from a single piece of 6061-T6 aluminum. The rope will be fed between the two rollers ensuring that the user stays connected to the rope during descent. On the opposite end of the two shafts, viscous rotary dampers are connected to control the motion of the rollers and, in turn, control the speed of the user's descent. Corporation 13 has developed three options for damping that can be interchanged depending on the mission or user requirements: 400 inch-pounds, 200 inch-pounds, and 100-inch pounds of damping torque. The frame subcomponent of the TRIAD uses a spring-loaded hinge to support the rollers and dampers. The spring-loaded hinge keeps the rollers apart so the device can be easily loaded and unloaded from the rope. Additionally, when the user begins descent, the user's weight causes the bottom of the frame to rotate creating a path for the rope to travel safely between the rollers. This feature keeps the device on the rope.

The user's weight causes the rollers to squeeze the rope, preventing slip and engaging the rollers. When the rollers are engaged, their movement is controlled by the dampers. The fourth subcomponent of the proposed system is the tactical gloves that were designed by Corporation 13. The gloves work in conjunction with the TRIAD so that the user can have their hands on the rope. This feature serves two purposes— for the unlikely event of device failure and as a direct result of speaking with operators in the field. The combination of the two designs increases safety for the user and makes the process more efficient.

Metric	Description	Quantity	University Team's Opinion (Grade yourself on a scale of 1-10)
Total Weight (lbs)	All equipment that will be used. If replacing current rope, subtract the difference.	5.4	
Size (in^3)	All equipment combined. If replacing current rope, subtract the difference.	41.38	
Time (hrs)	Time to descend 4 people 20ft. The entire operation as if it were being performed in field	.00972	
Safety Considerations	Does it eliminate any hazards? Does it create any new ones?		8.5
Usability	Is this as usable as grabbing a rope with your hands? What are the differences and how is it better or worse?		9
Reusability	Is this a onetime use? Do I take it with me? Do I leave it behind? Is there logistical issues?		8
Innovation and Creativity	How creative do you feel your design is?		10

Functional Overview

The concept of operation for the proposed system is simple. The user will place the gloves on their hands and then attach the device to their harness using the quick-release that is tethered to the handle. The user will then approach the fast rope, attach the spring-loaded device by placing the two rollers on each side of the rope using one hand, and exit the aircraft. The weight of the user engages the hinged frame, and the user can place both hands on the rope below the device. The two rollers will then engaged on the rope causing the shafts to turn as descent begins. The dampers will be immediately engaged by the rotating shafts, slowing the descent of the user. The user should descend until he or she is in a squatting position on the ground and then stand up which will disengage the device. The squatting position allows for the device to go low enough on the rope for quick disengagement. The user will stow the device in their pack for future use. Corporation 13 suggests that the user wear a harness during operation, but an appropriate tactical belt will suffice.

Rollers and Shafts:

The rollers and shafts are made out of a solid piece of 6061-T6 Aluminum, which was chosen for its strength to weight ratio. The two components are made out of the same piece of stock to reduce the number of moving parts and to create a more structurally sound device. The rollers are knurled to increase the coefficient of friction, ensuring there is no slip between the rollers and rope. The rollers are conically shaped creating a channel to contain the rope during descent. The 2.50” width of the roller was selected so that the 2.25” fast rope would be securely contained within the roller during descent, preventing it from falling off of the rope. Corporation 13 designed the roller to be angled in at 32.0 degrees to ensure the frictional forces, created by the area of contact between the rope and rollers, prevent the rollers from slipping during descent.

Corporation 13 originally designed for a two piece roller and shaft system using a keyed shaft and keyed stock to ensure the shaft and rollers stayed in equal rotational motion. While this system worked, it left it susceptible to small manufacturing errors that would make the system feel ‘loose’. Corporation 13 decided that the single roller and shaft combination would reduce the risk of error in the system and reduce the number of moving parts.

Corporation 13 originally utilized smooth rollers. After testing the rigid, single-piece frame, the team realized the bottom roller wasn’t engaged so they took additional action beyond moving two a hinged frame that included making the rollers textured. This design change increased the friction coefficient of the wheels and helped engage dampers.

Dampers:

The TRIAD uses viscous rotary dampers from ACE Controls to control the speed of descent. These dampers were chosen due to their small size and high damping rates. These dampers have constant damping rates, so different loads will require different dampers. The torque calculations for the system are as follows:

Required Torque:

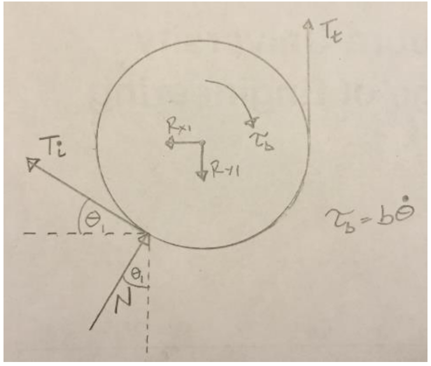


Figure 2: Free Body Diagram

Damped Roller

Sum the Moments around the axle

$$\Sigma M_{center} = J\dot{\omega} = T_t R - T_i R - b\omega \tag{1}$$

$$J\dot{\omega} = 0\ (at\ steady-state) = T_t R - T_i R - b\omega \tag{2}$$

$$b\omega = (T_t - T_i)R \tag{3}$$

$$b = \frac{(T_t - T_i)R}{\omega} \tag{4}$$

$$b = \frac{W_{user}R}{\omega} \tag{5}$$

Where b is the damping required from the ACE Controls rotary damper.

Table 1 describes the damper needed when paired with a free roller or the pair of dampers necessary to achieve the required damping, found below:

Table 1: Damper Needed Based on Weight

Weight of User (pounds)	Damping Required (in-lbs-s)	ACE Controls Damper or Combination Needed
150	0.87890625	FRT-K2-103, or two FRT-K2-502’s
200	1.171875	FRT-F2-203, or two FRT-K2-103’s

250	1.46484375	FRT-F2-203, or two FRT-K2-103’s
300	1.7578125	FRT-F2-203, or two FRT-K2-103’s
350	2.05078125	FRT-F2-203, or two FRT-K2-103’s
400	2.34375	FRT-F2-403, or two FRT-F2-203’s
450	2.63671875	FRT-F2-403, or two FRT-F2-203’s

Equations 1-5 were used to determine the information found in Table 1. Supporting calculations can be found in Appendix D. The dampers can be easily interchanged before missions by removing and reinstalling four screws. The viscous rotary dampers are connected to the shaft by a setscrew to lock the damper into rotational motion with the shaft. These dampers come in 100, 200 and 400 inch-pound damping rates. Each of the viscous rotary dampers are rated to 50,000 cycles at 50 RPM.

Corporation 13 had many iterations with different modes of damping. The first system that was investigated was Stihl chainsaw clutches. These chainsaw clutches were relatively small compared to other clutches, and were beneficial to the design because as the speed increased, the damping would also increase. As the team progressed through testing, it became apparent that these clutches weren’t providing enough damping. To adjust to this, the team deconstructed the clutches and stretched the springs inside of the dampers. When the spring was stretched, this caused the dampers to be immediately engaged. Corporation 13 tested the clutches with the stretched springs and had more successful results. This mode of damping lowered approximately 300 pounds around 12 feet per second.

The team wanted to increase the damping to reach a target velocity of seven to nine feet per second. The team ordered Hilliard Extreme Duty centrifugal clutches, but once received, the clutches were too large to fit onto the frame and too heavy to maintain a small and light design. The team returned to research again and found the ACE Control’s viscous rotary dampers that are currently on the system.

Frame, Handle, Harness and Quick Releases:

The frame and handle of the TRIAD are made of 6061-T6 Aluminum to increase the strength and minimize weight. As shown in Figure3, the TRIAD’s frame consist of a hinge which allows the roller to rotate 59 degrees when the weight of the user is applied. This allows more surface area to be engaged, creating a larger normal force between the rope and the rollers. When the rollers are hinged during descent, there is no longer a gap for the device to come off of the rope. To keep the shaft concentric with the holes in the frame and to reduce friction between the two surfaces, tapered bearings are placed in recessed holes. The frame also consists of a torsional spring that ensures separation of the rollers at rest allowing easy placement on the rope. This spring creates 10 in-lb of torque, which is more than double the weight of the moment created from the top portion of the frame. The TRIAD’s handle is 0.75 inches in diameter and 7 inches long. The handle’s length directly correlates with the moment occurring between the two rollers. There is a hole in the handle for the user’s tether to connect. The 6” tether is 18mm nylon webbing and has a strength of 4945 lb_f. On the user end of the tether is a 316 stainless steel quick release, which is similar to the quick releases currently used by the military. Corporation 13 suggests that the user wears a harness to ensure safety and act as the primary

Figure 3: Hinged Device

attachment point for the user-device interface. The standard issue tactical belt is a possible attachment point, but a harness provides greater support.

Corporation 13's design was iterated many times before reaching the hinged frame concept. Initially, the frame consisted of two rectangular plates that were bolted together. Figure 12 in Appendix C has a picture of the original square frame. This system relied on the whole device rotating to ensure engagement on the rope. After testing the rigid shaft, the team noticed the bottom roller wasn't engaged during descent. The team designed the hinged frame concept during a testing operation to ensure the bottom roller engaged the damper and roller due to the normal force supplied by the other roller and rope. The handle on the system also incurred significant changes. Initially the handle was approximately eleven inches long and square in shape. After receiving feedback from operators, the team decided that everything should be round to prevent injuries during operation. The team then shifted to a round stock as the handle and optimized the handle to a length of seven inches to provide an adequate moment to engage the bottom of the hinged frame.

Tactical Gloves:

The gloves use heat resistant materials to redirect the heat generated by friction away from the user's hands. The glove is made up of three main components: the back construction, palm base layer, and pads. The dexterity and feel of traditional tactical gloves is maintained by using 0.8-0.9 mm goatskin leather as the palm base material of the glove. Pads of Aerofoam that are 3mm thick are used in areas with the most concentrated heat. Materials with low thermal conductivities were used to create a path of higher thermal resistance. The padding is covered by a proprietary Kevlar blend with high abrasion resistance. The Aerofoam was chosen based on the following equations:

$$q = \frac{kA(T_{rope} - T_{hand})}{L} \tag{6}$$

$$T_{hand} = T_{rope} - \frac{q^{"}L}{k} \tag{7}$$

Where q is heat produced by friction, k is thermal conductivity, A is the area of the operator's hand, T_{rope} is the temperature of the rope, T_{hand} is the temperature of the palm of the hand, L is the thickness of the palm of the glove, and q'' is heat flux. In Equation 4, A, T_{rope}, q, and q'' are constant. It is necessary for q to remain constant since it is produced by friction, the stopping force in this instance. Therefore, k must be as small as possible. Additional calculations for the gloves can be found in Appendix D. Aerofoam was chosen to act as insulation due to its low thermal conductivity of 0.0294 $\frac{W}{mK}$. The composition of each material used is found below in Table 2:

Table 2: Glove Material Composition

Material	Composition
Leather	Goatskin
Padding—Aerofoam	Silica, Nitrile Butadiene Rubber
Overlay—Kevlar blend	Kevlar, Nylon, Spandex, Polyurethane
Backing—Ribbed Knit Nylon	Nylon, Spandex
Cuff—Neoprene	Neoprene, Nylon

Aerofoam was chosen for the glove application to maintain flexibility and comfort without compromising the effectiveness of the material. An overlay material was chosen to be extremely abrasion resistant, rated to 8679 cycles on an H 18 wheel, in order to withstand the wear of the rope and protect the Aerofoam. The leather base material for the palm was chosen in part because of its relatively low thermal conductivity, but mostly to maintain the traditional feel of a tactical glove. Comfort and similarity to tactical gloves soldiers use to train guided the ergonomic design. The knitted nylon backing was chosen for breathability and stretch in order to keep the glove dry and taut on the hand. The cuff material was selected for its stretch and sweat wicking ability. A carabineer hole was added for convenience in stowing the gloves.

Material selection was the first part of the design process for the gloves. Materials including SuperFabric, Aerogel, Aerofoam, various leathers, nylon lycra, neoprene, silicone, Nomex, and many others were researched. SuperFabric, Aerogel, nylon lycra, and goatskin leather were chosen for the first iteration of the glove. This iteration was sewn in-house, but was not a quality product even though its thermal properties were good. The glove did not fit as intended and the industrial sewing machine was only able to produce one type of stitch and was unreliable. There were doubts about the longevity of this product. The glove team then outsourced manufacturing to Ironclad Performance Wear. Ironclad took our designs and created technical drawings which were sent to their factory for production. The company was able to manufacture three of our designs—lightly padded, medium padded, and heavily padded prototypes. A picture of the three designs can be seen below in Figure 4.

Figure 4: Design Variations

A cross-section of the glove materials can be found in Figure 5. From these three designs the glove team conducted testing to choose which glove to take to competition. Operators at Fort Benning also reviewed the three prototypes and provided feedback. Ultimately, the heavily padded design was chosen because it provided the most heat protection and dexterity was not compromised according to operators.

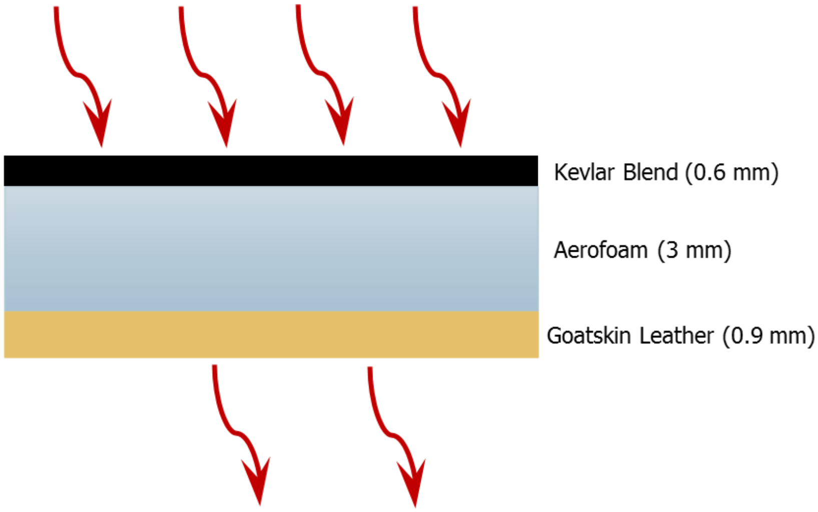


Figure 5: Glove Material Cross-Section

Possible Future Improvements

While the TRIAD is very functional, safe, and effective, the team suggests a few areas to be further researched. As previously noted, specifically sized dampers provide sufficient breaking force for certain loads, dependent on user weight and mission requirements. This could be improved upon by developing adjustable dampers. With adjustable dampers users could potentially adjust a dial to match their specific weight, rather than replacing entire dampers. When designing adjustable dampers, life cycle considerations should be considered to ensure a reusable, reliable device. The team also suggests researching and incorporating lighter and more advanced materials for the frame and handle. Although the device is robust, more advanced materials could decrease weight and size making the device even more advantageous to the user. In addition, the TRIAD could also be redesigned to be ambidextrous, eliminating the need for a right or left-handed device creating a more ergonomic device.

With respect to the glove design, further research in pad placement could be done specifically for the trigger finger. Additionally, the exact lifecycle of the glove should be determined with testing.

Appendix A

Table 3: Operator Information

Name of Operator	Contact Info	Operator's Current Job	Operator Dislikes	Operator Likes
Lieutenant Kyle Stammer	401-368-9872	US ARMY	Operator disliked color. Operator suggests camouflage.	Operator likes the versatility of the use for shooting and roping.
Nicholas Pietka	773-551-8037	US ARMY	Operator disliked that the device was not adjustable to different rope diameters.	Operator liked the functionality of the TRIAD.
Chris Hunter	706-580-4741	US ARMY	Operator suggests moving pad off top of trigger finger and move to the pinky.	Operator liked the ergonomics and dexterity of the gloves.
SFC Jason Day	334-844-5649	US ARMY	Operator disliked auto-belay concept. Disliked preloading device.	Operator liked the idea device that is attached to rope quickly.

Figure 6: Hands-On Visit Photos

Appendix B

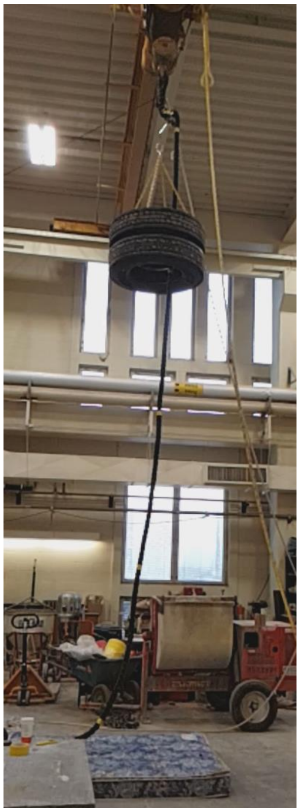


Figure 7: Preliminary Test Set-Up

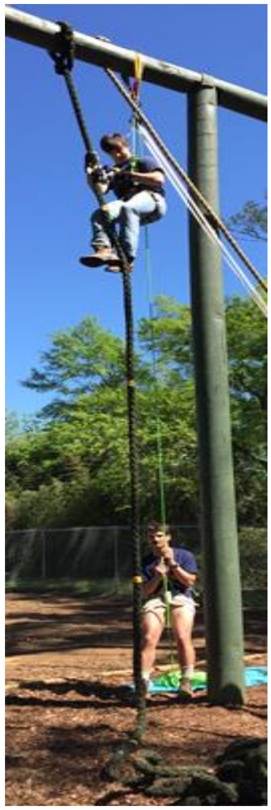


Figure 8: Full Scale Test Set-Up

Corporation 13 has conducted testing with various configurations. The initial testing was completed in the Harbert Civil Engineering building on Auburn University's campus. The concrete lab has a ten ton crane that is well suited for the testing setup. The team used 18-wheeler tires that weighed 150 pounds each to simulate various user weights. When the weight was completely suspended, the falling distance is 23 feet. The TRIAD was loaded onto the rope and lifted to 23 feet. A quick release allowed the weights to rely on the TRIAD to descend down the fast rope. A picture of the setup can be seen in Figure 7. A table of testing results are shown in Table 4:

Table 4: Preliminary Test Results

Design Iteration	Testing Weight	Descent Rate (ft/s)
#1	150	18.75
#2	300	16.58
#3	300	6.96
#4	300	7.23
#4	450	8.72
#4	220	6.8

Corporation 13 used the General J.E. Livingston Obstacle Course with the permission of the Auburn ROTC program. The device and the gloves were tested in this setting. In Figure 8, the testing setup is shown for a team member testing the device. A climbing harness safety system was used to ensure injuries did not occur during testing. The user was suspended to the top of the frame using a pulley system and then allowed to freefall with the device controlling their descent speed.

During full scale testing, larger than necessary dampers were used to ensure safety causing descent rates to be slower than required. Table 5 shows the testing results of the TRIAD device in the human trials:

Table 5: Full Scale Test Results

Design Iteration	Testing Weight	Descent rate (ft/s)
#4 (200lb top damper, 100lb bottom)	240	3.4
#4 (200lb top damper, 100lb bottom)	180	1.34

To test the tactical gloves, Corporation 13 used thermal cameras to determine the areas most affected by heat on the glove. Figure 9 shows thermal images of preliminary glove testing after sliding down the fast rope. This dictated the placement of insulating pads.

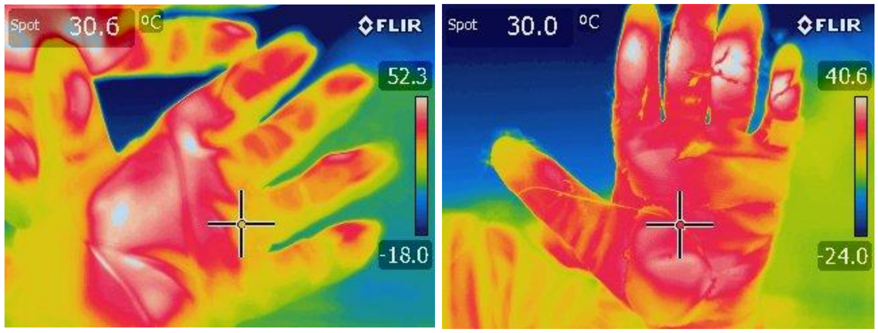


Figure 9: Thermal Images after Fast Roping

Hot plate tests were conducted to ensure the operating temperature of the construction was high enough for the fast rope application and to compare the designed gloves to Petzl rappelling gloves. Thermocouples were placed at the top of the palm and at the base of the thumb inside the glove. The glove was then placed on the 375°F hot plate for 10 seconds. The change in temperature was recorded for each glove and is shown below in Figure 10:

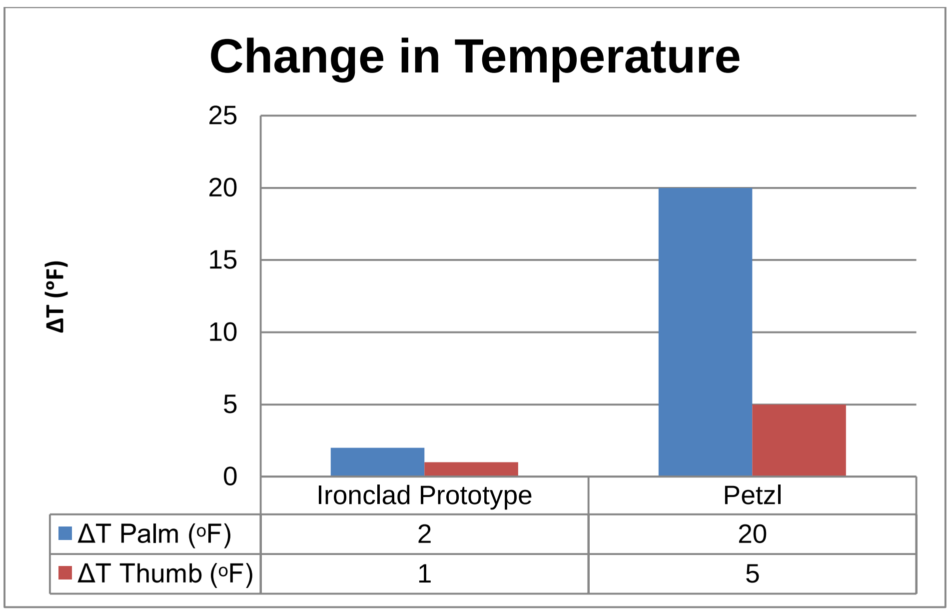


Figure 10: Hot Plate Test Results

Full scale testing was then conducted at the General J.E. Livingston Obstacle Course from 20 feet to gage abrasion and wear resistance as well as performance of the glove design alone. Thermocouples were placed again at the top of the palm and at the base of the thumb. Data from testing is found in Figure 11 below:

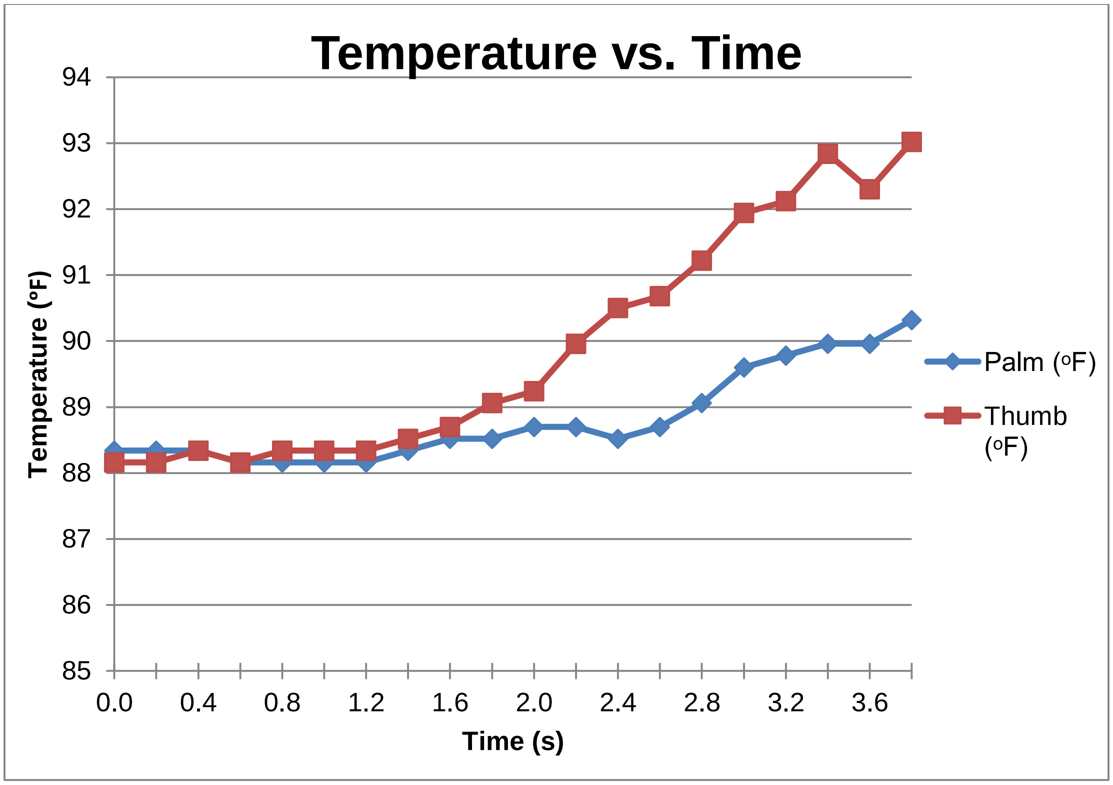


Figure 11: Temperature of Hand during Operation

Appendix C

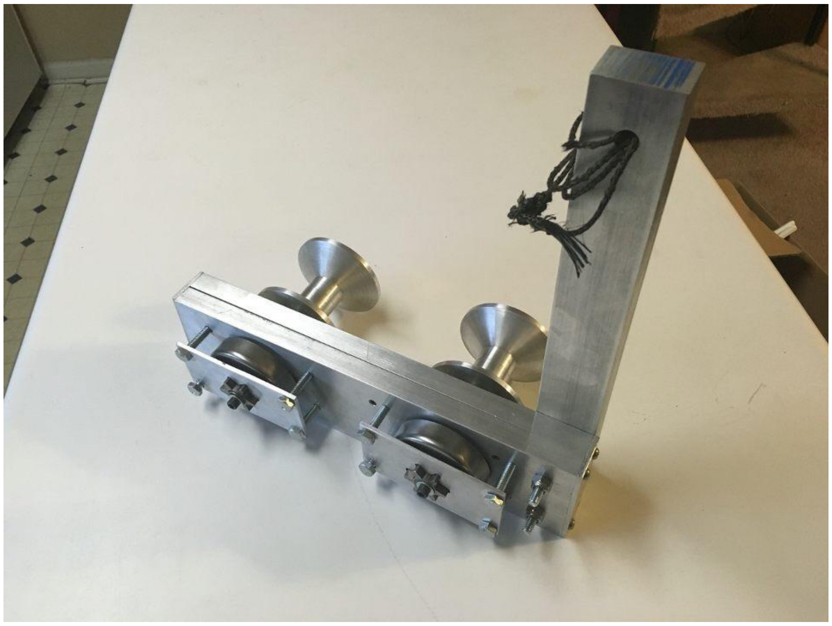


Figure 12: Original Two-Piece Frame and Square Handle

Appendix D: Additional Calculations

Overview of the Device:

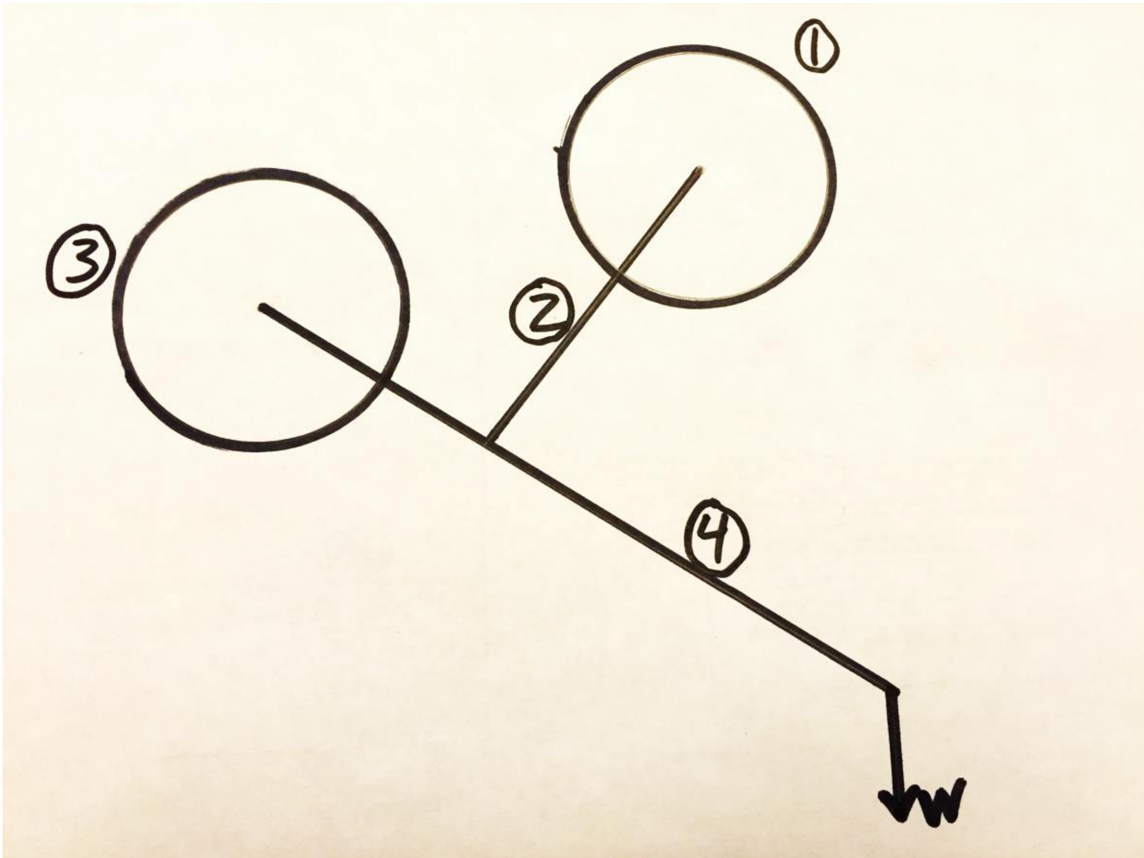
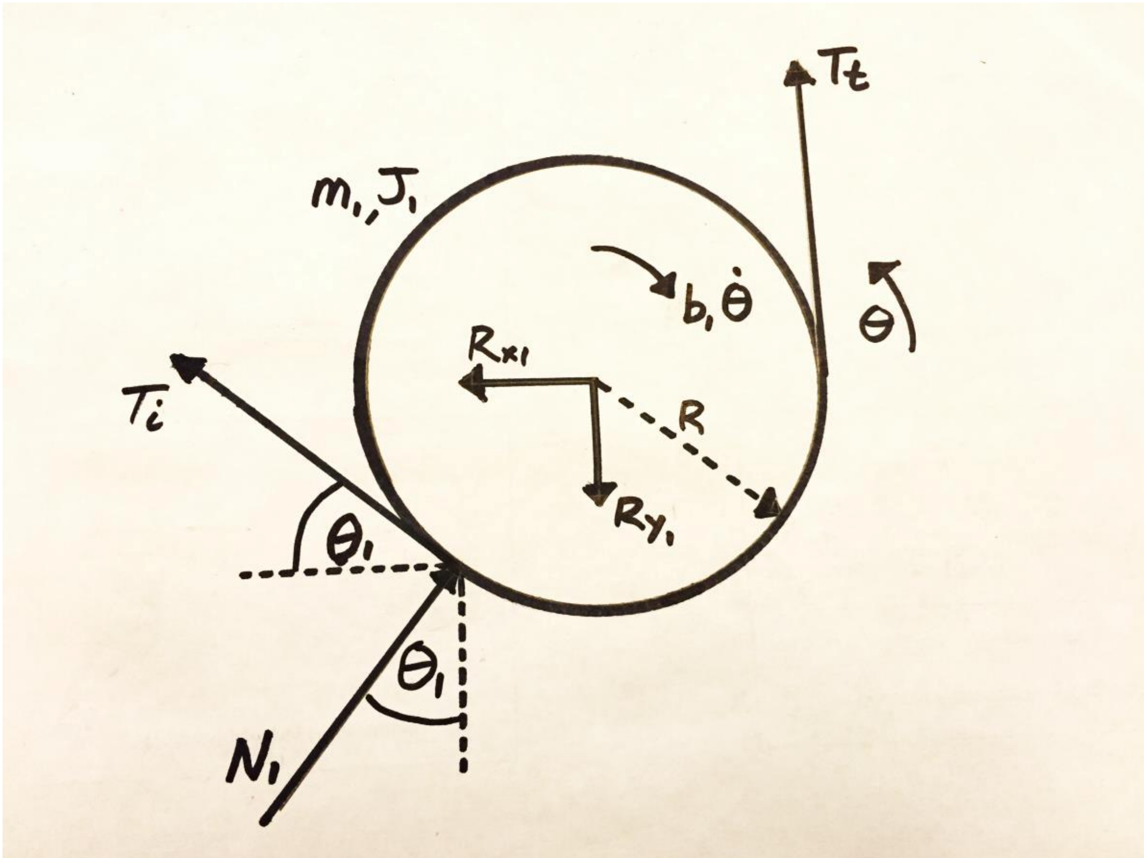


Figure 1: The “top” roller

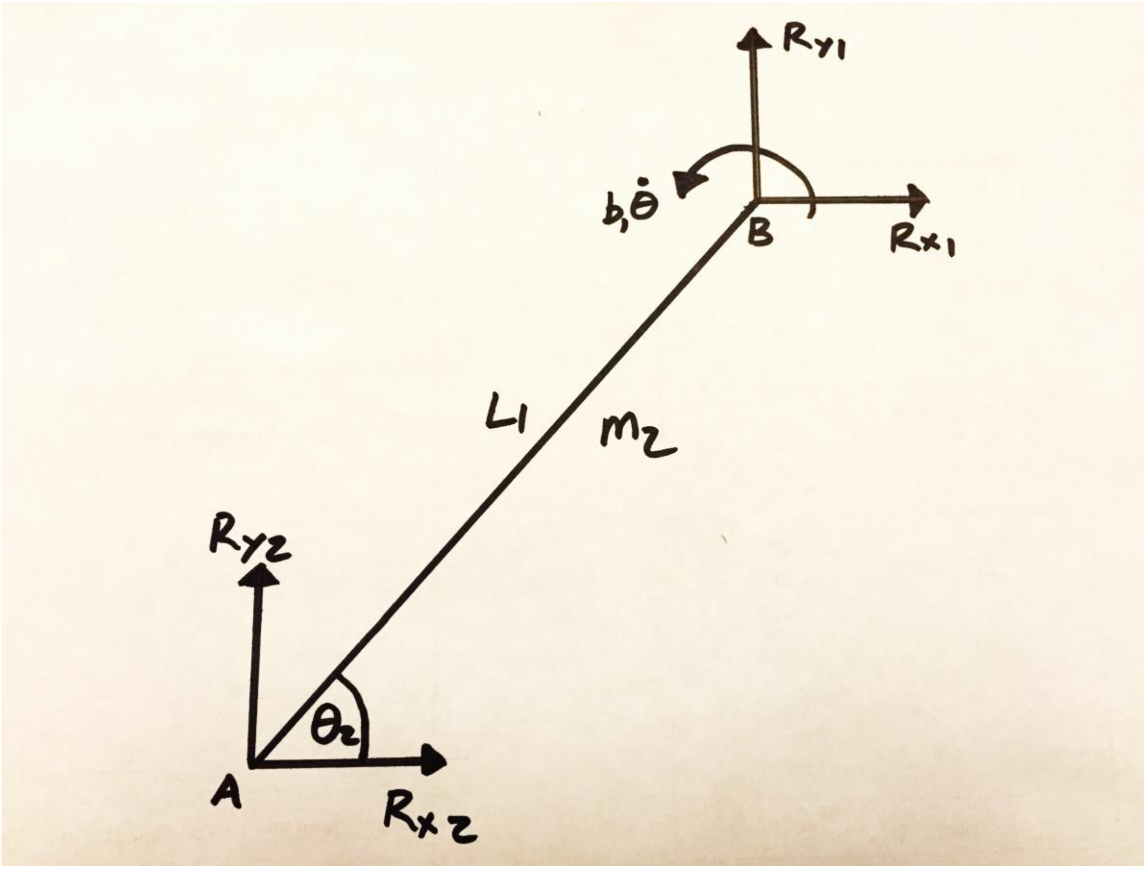


$$\Sigma M_{center} = J_1\ddot{\theta} = T_t * R - T_i * R - b_1\dot{\theta}$$
$$J_1\ddot{\theta} = 0 = -b_1\dot{\theta} + R * (T_t - T_i)$$
$$\frac{b_1}{R}\dot{\theta} = T_t - T_i$$

$$\Sigma F_y = m_1\ddot{y} = T_t + N_1 cos\theta_1 + T_i sin\theta_1 - R_{y1}$$
$$m_1\ddot{y} = 0 = T_t + N_1 cos\theta_1 + T_i sin\theta_1 - R_{y1}$$
$$R_{y1} = T_t + N_1 cos\theta_1 + T_i sin\theta_1$$

$$\Sigma F_x = m_1\ddot{x} = N_1 sin\theta_1 - T_i cos\theta_1 - R_{x1}$$
$$m_1\ddot{x} = 0 = N_1 sin\theta_1 - T_i cos\theta_1 - R_{x1}$$
$$R_{x1} = N_1 sin\theta_1 - T_i cos\theta_1$$

Figure 2: The bar holding the top roller

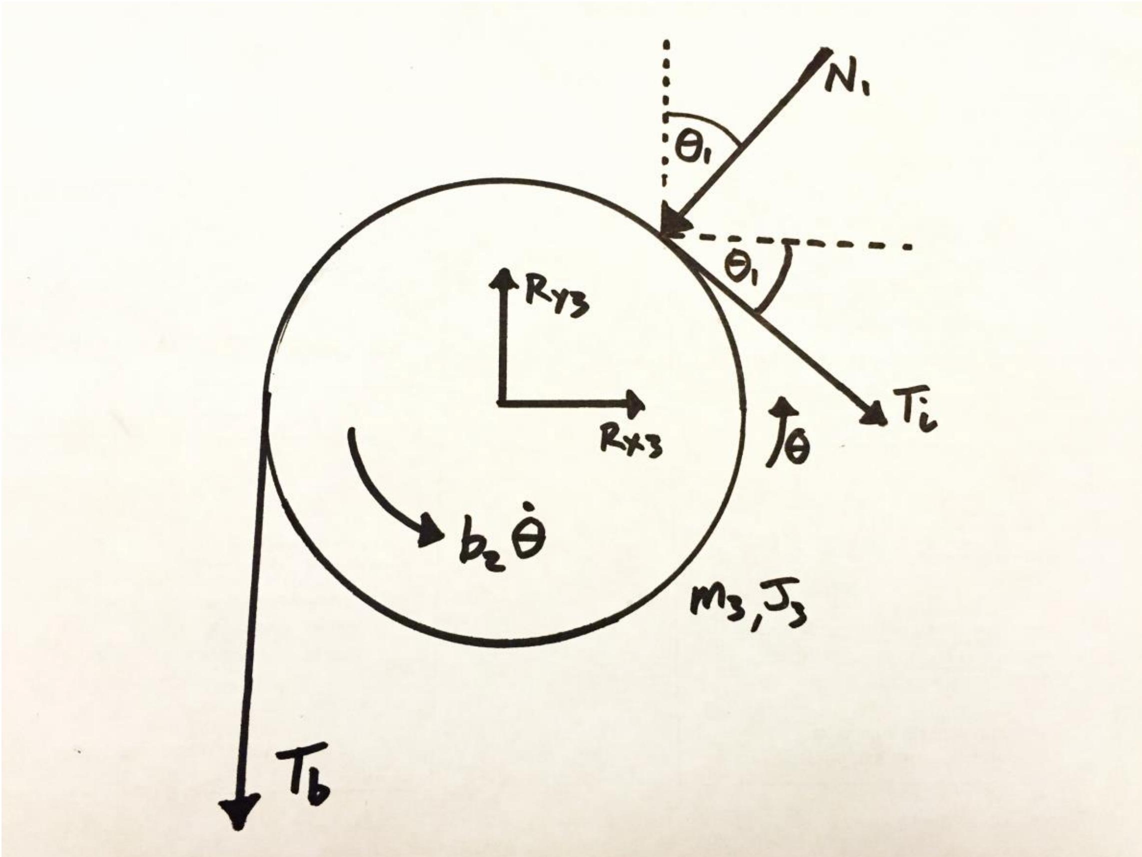


$$\Sigma F_y = m_2\ddot{y}_2 = R_{y1} + R_{y2}$$
$$m_2\ddot{y}_2 = 0 = R_{y1} + R_{y2}$$
$$R_{y1} = -R_{y2}$$

$$\Sigma F_x = m_2\ddot{x}_2 = R_{x1} + R_{x2}$$
$$m_2\ddot{x}_2 = 0 = R_{x1} + R_{x2}$$
$$R_{x1} = -R_{x2}$$

$$\Sigma M_A = J_2\ddot{\theta}_2 = b_1\dot{\theta} + R_{y1}L_1 cos\theta_2 - R_{x1}L_1 sin\theta_1$$
$$J_2\ddot{\theta}_2 = 0 = b_1\dot{\theta} + R_{y1}L_1 cos\theta_2 - R_{x1}L_1 sin\theta_1$$
$$R_{x1}L_1 sin\theta_1 = b_1\dot{\theta} + R_{y1}L_1 cos\theta_2$$

Figure 3: The “bottom” roller

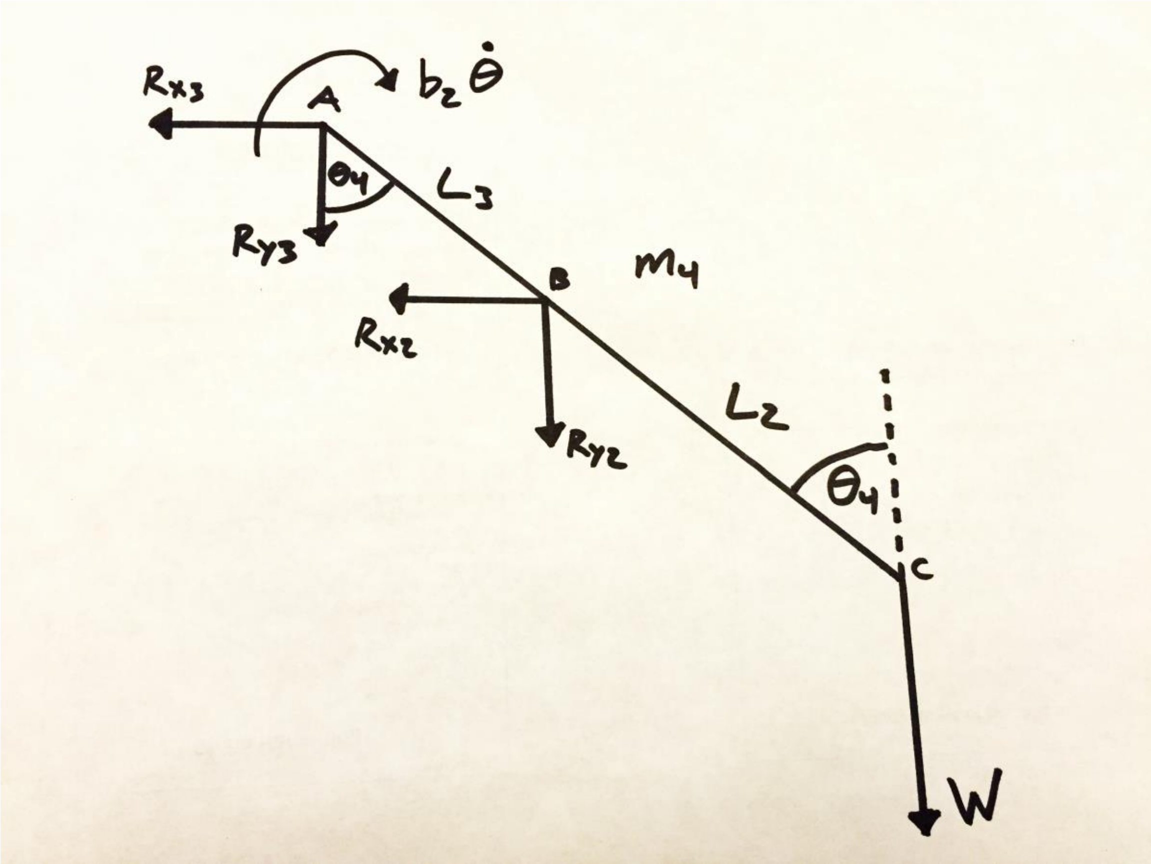


$$\Sigma M_{center} = J_3\ddot{\theta} = T_i * R - T_b * R - b_2\dot{\theta}$$
$$J_3\ddot{\theta} = 0 = -b_2\dot{\theta} + R * (T_i - T_b)$$
$$\frac{b_2}{R}\dot{\theta} = T_i - T_b$$

$$\Sigma F_y = m_3\ddot{y} = -N_1 cos\theta_1 - T_i sin\theta_1 - T_b + R_{y3}$$
$$m_3\ddot{y} = 0 = -N_1 cos\theta_1 - T_i sin\theta_1 - T_b + R_{y3}$$
$$R_{y3} = -N_1 cos\theta_1 - T_i sin\theta_1 - T_b$$

$$\Sigma F_x = m_3\ddot{x} = R_{x3} + T_i cos\theta_1 - N_1 sin\theta_1$$
$$m_3\ddot{x} = 0 = R_{x3} + T_i cos\theta_1 - N_1 sin\theta_1$$
$$R_{x3} = N_1 sin\theta_1 - T_i cos\theta_1$$

Figure 4: The handle



$$\Sigma F_y = m_4\ddot{y} = -R_{y2} - R_{y3} - W$$
$$m_4\ddot{y} = 0 = -R_{y2} - R_{y3} - W$$
$$W = -R_{y2} - R_{y3}$$

$$\Sigma F_x = m_4\ddot{x} = -R_{x3} - R_{x2}$$
$$m_4\ddot{x} = 0 = -R_{x3} - R_{x2}$$
$$R_{x3} = -R_{x2}$$

$$\Sigma M_B = J_4\ddot{\theta}_4 = R_{y3}L_3 sin\theta_4 + R_{x3}L_3 cos\theta_4 - WL_2 sin\theta_4 - b_2\dot{\theta}$$
$$J_4\ddot{\theta}_4 = 0 = R_{y3}L_3 sin\theta_4 + R_{x3}L_3 cos\theta_4 - WL_2 sin\theta_4 - b_2\dot{\theta}$$
$$WL_2 sin\theta_4 = R_{y3}L_3 sin\theta_4 + R_{x3}L_3 cos\theta_4 - b_2\dot{\theta}$$

Summary:

$$\frac{b_1}{R}\dot{\theta} = T_t - T_i$$
$$R_{y1} = T_t + N_1 cos\theta_1 + T_i sin\theta_1$$
$$R_{x1} = N_1 sin\theta_1 - T_i cos\theta_1$$
$$R_{y1} = -R_{y2}$$
$$R_{x1} = -R_{x2}$$
$$R_{x1}L_1 sin\theta_1 = b_1\dot{\theta} + R_{y1}L_1 cos\theta_2$$
$$\frac{b_2}{R}\dot{\theta} = T_i - T_b$$
$$R_{y3} = -N_1 cos\theta_1 - T_i sin\theta_1 - T_b$$
$$R_{x3} = N_1 sin\theta_1 - T_i cos\theta_1$$
$$W = -R_{y2} - R_{y3}$$
$$R_{x3} = -R_{x2}$$
$$WL_2 sin\theta_4 = R_{y3}L_3 sin\theta_4 + R_{x3}L_3 cos\theta_4 - b_2\dot{\theta}$$

12 equations and 12 unknowns, which can be condensed down into a single, simple equation:

$$b\dot{\theta} = \frac{W_{user}R}{2}$$

Where $b\dot{\theta}$ is the damping torque required by an ACE Controls Damper.

Weight of User (lbs)	Damping Torque Required (in-lbs)
150	56.25
200	75
250	93.75
300	112.5
350	131.25
400	150
450	168.75

Of course a factor of safety is needed, but this table gives the minimum needed damper to help control the descent speed of an operator. This table was used to size the dampers used in testing, and an average descent speed of 6-9 feet/second was achieved.

Overview of the gloves:

$$m = mass = 113.4\,kg = 250\,lb$$
$$g = 9.81\frac{m}{s^2}$$
$$v = velocity = 3.45\frac{m}{s} = 11.3\frac{ft}{s}$$
$$h = 27.43\,m = 90\,ft$$

$$Total\ Energy\ Absorbed = PE - KE_{bottom} = mgh - \frac{1}{2}mv^2$$
$$= 113 * \left(9.81 * 27.43 - \frac{1}{2} * 3.45^2\right) = 29{,}840\,J$$

$$q = \frac{Total\ Energy}{time} = \frac{29840}{7.95} = 3.75\,kW$$

$$q = \frac{kA(T_{rope} - T_{hand})}{L}$$
$$A = Constant$$
$$T_{rope} = Constant$$
$$q = Constant => q" = Constant$$
$$T_{hand} = T_{rope} - \frac{q"L}{k}$$