A Device that Enables the Elderly & People with Knee Injuries to Stay Active

Final Design Report

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SLDC Team 2

ME 175C Mechanical Engineering Design

Ben Morag, David Chon, Jesusxavier Diaz

Executive Summary

This report elaborates on the entire design for the hands free spring knee brace. The design begins with the Stanford Longevity design challenge. The challenge provides objectives and a field of operation. The focus of the project is on helping the elderly with knee problems in their everyday lives. The problem statement became: there is a need for a device that provides mobility to the elderly with weak knees, by helping them in their daily activities; such as getting in and out of a chair. After using the 3-6-5 method, analysis and a weighted decision matrix the next step is to move forward with the torsion spring knee brace design. There were various modeled iterations in Solidworks until the device became the ideal design. The goal is to lift 45% of the user's weight. Analysis is done to verify that it withstands the forces of motion and operates as desired. The design consists of a spring and spring locking mechanism within a housing unit, rods to connect to the housing unit, and straps that connect the mirrored rods together. The parts are machined in the Machine Lab in Bourns and 3D printed at Orbach Science Library. While Solidworks helps show that the design achieves the goals, the physical prototype shows that the process for machining is unrealistic. By welding the springs, the material properties lowers and causes a failure or fracture. This proves that the final design needs some modifications. Utilizing what is learned from building the physical prototype, recommendations are made for how to improve the design. The biggest recommendation is to design with the manufacturing process in mind.

Table of Contents

Table of Figures

Introduction

Staying active proves to have a huge impact in living a long and healthy life. As people age, maintaining healthy knees is of the utmost importance. Due to the accumulated use of the knees, injuries manifest themselves often. Such as fatigue on the joints, a loss of the range of motion, osteoporosis or even ligament tears. This leads to the lack of mobility to the injured and leads to deterioration of health overall. The elderly are especially prone to knee ailments as their knees have been utilized for almost an entire lifetime. Even the simple movements of average daily life proves burdensome for the elderly with knee problems. Thus there is a need for a device that allows the elderly with weak knees to maintain mobility. The focus of the design of this device is to help them get in and out of a chair. It will be a motivation to undertake this task in order to see all the benefits of a healthy life and to help those affected by knee ailments in our lives. This report will show how the team utilized the engineering design process to go from a design challenge into a physical prototype. This includes defining the problem statement, coming up with design solutions, analyzing these designs and ultimately building a physical prototype. Through unpredicted events, testing of the prototype halted and produced no experimented data. Conceptually, all goals were met and the prototype passed, even though it is unable to be tested.

Problem Statement

The Stanford Longevity Design Challenge is a yearly global challenge for students to motivate mobility in elders in order to optimize longevity. The designated goals for the elderly that use the device include the following: improve psychological functioning, reduce chronic disease, protect against heart disease, and depression, and happiness through financial security **[1]**. These goals assisted with addressing issues associated with aging, encouraging students to become more aware of aging issues, and providing designers with a path to change the world. In order to address the problem, the next step is to research the reasons why the elderly population become immobile.

Knee injuries are the most common sports injury for all ages. Many are either personally affected or know someone who is by this ailment. A knee injury can be anything from osteoporosis, which is common amongst the elderly, to a torn meniscus or ligament. All people are prone to knee injuries, but the elderly feel that burden more than most people due to the accumulated years their knees have been used in average daily activity. Also, since knee problems are already common enough amongst middle and younger aged individuals, the elderly are especially prone with their weakened and brittle bodies. There is a wide range of impact from a knee injury. This can be anything from the inability to support the person’s own weight or a slight loss in the range of motion of the knee. The goal for this problem is to help people with weakened knees live their average daily lives with comfort and ease. Although the audience for this problem statement targets the elderly, the device is not limited to just them. For this reason, the goal of this project is to be focused on the act of getting in and out of a chair. The problem statement is as follows:

"There is a need for an affordable device that provides mobility to the elderly with weak knees, by helping them support their body weight and providing a greater range of motion in their daily activities, which reduces the force on their knees."

The Stanford Longevity Design Challenge does not specify the dimensional constraints of the device, but only demands to make the device affordable to the public. Since there is no dimensional constraint, it is a very open ended problem, which makes the students create their own specifications and constraints. The constraints the team has created for the device is to lift around 45% of the user's weight. The device must also be compact in that it will not restrict the user from going about their everyday activity. Idealy, the device will also be small enough where the user wears it under their clothes. As for the dimensional constraint, the size of the device will vary from person to person as the height of the user has a direct correlation to the size of the device. Lastly, the device will be comfortable enough where the user does not feel any pain or soreness after using the device.

Design Solution

The selected design for the project is the knee brace with a spring and locking mechanism, shown in Figure 1. This device is designed to support the person while walking, be comfortable to wear on a daily basis, be adjustable for different sizes, and mainly assist the person get in and out of their seat. In order to understand this design better, the report will be broken down into parts to explain the function of each part of the device.

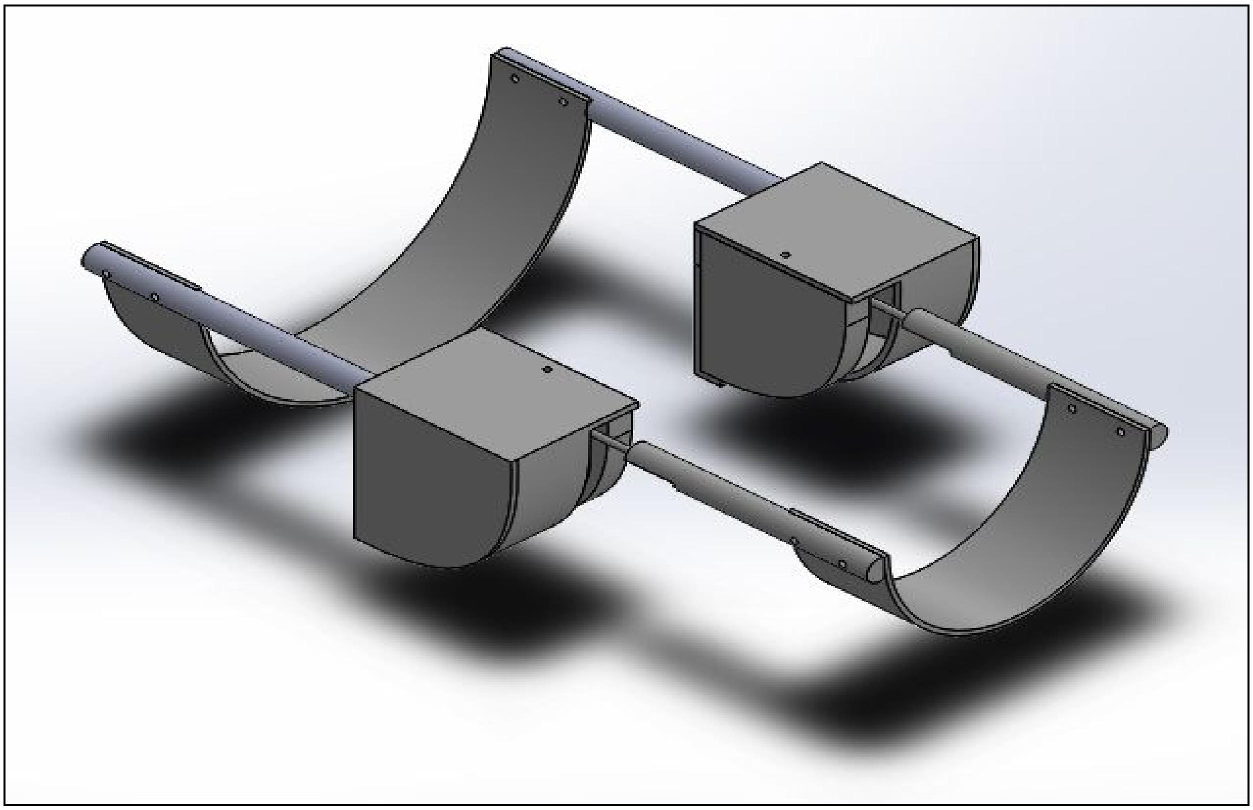

Figure 1. Prototype without padding or knee sleeve.

The first key feature of the mechanism is the knee sleeve. A knee sleeve is usually made of textile materials or plastic, which wraps around a person's knee to provide support and/or prevent injuries. Knee sleeves often come in different sizes and are easily adjustable. The knee sleeve functions in many different ways within the device, such as: providing support, making the device adjustable, and providing an internal casing for the mechanism to be attached; as seen in Figure 2. It prevents any irritation from the device directly touching the skin.

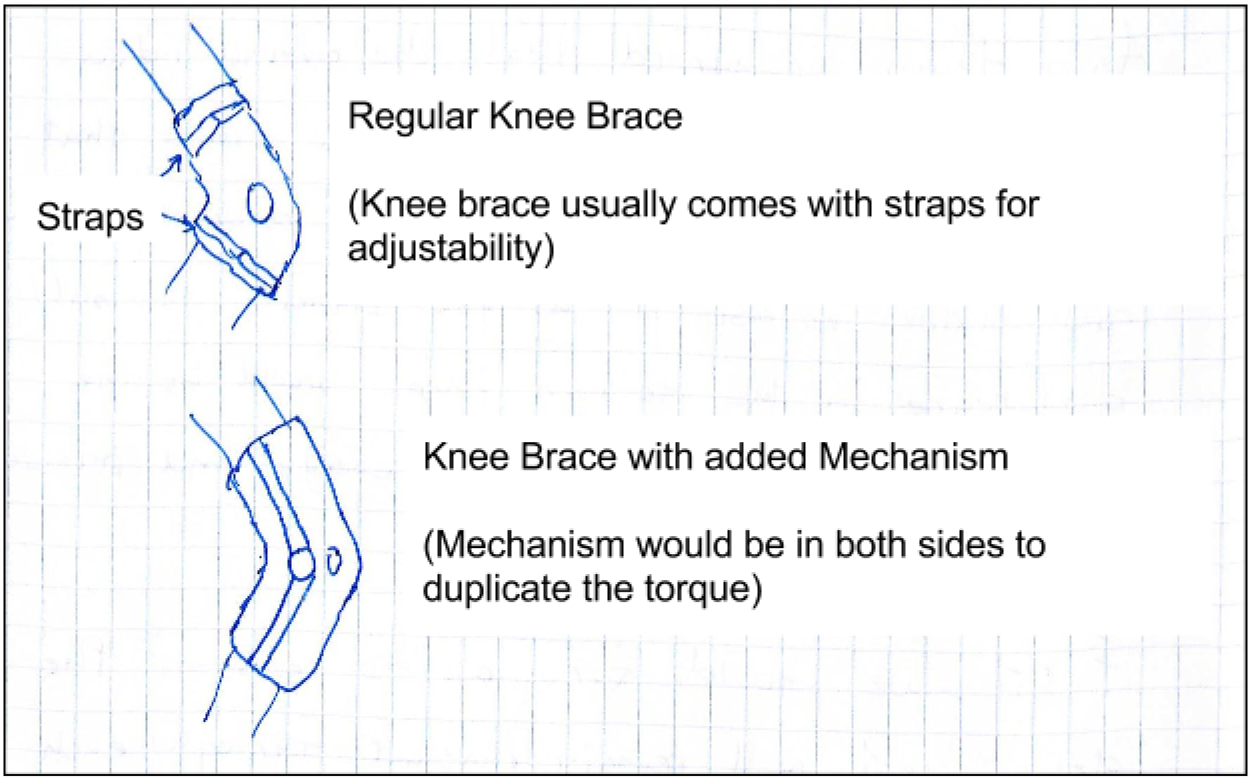

Figure 2. Comparison of Regular Knee Brace and Knee Brace with added Mechanism

The second key feature of the mechanism is the knee brace mechanism. The mechanism is made of two, five to ten inch long aluminum rods connected by a torsion spring and aluminum sheet metal on each end; as seen in Figure 3. The torsion spring will be in 180 degrees when in the resting position. Upon acting external torsion or compression on the spring, it will rotate to a 90 degree angle or less; depending of the range of motion of each user. This will convert the weight of the person into potential energy, storing it on the spring. Each knee brace will have a set of springs and rods on each side, making it a total of two springs per leg. The main function of the knee brace mechanism is to provide the stored potential energy that will lift the user from the rest.

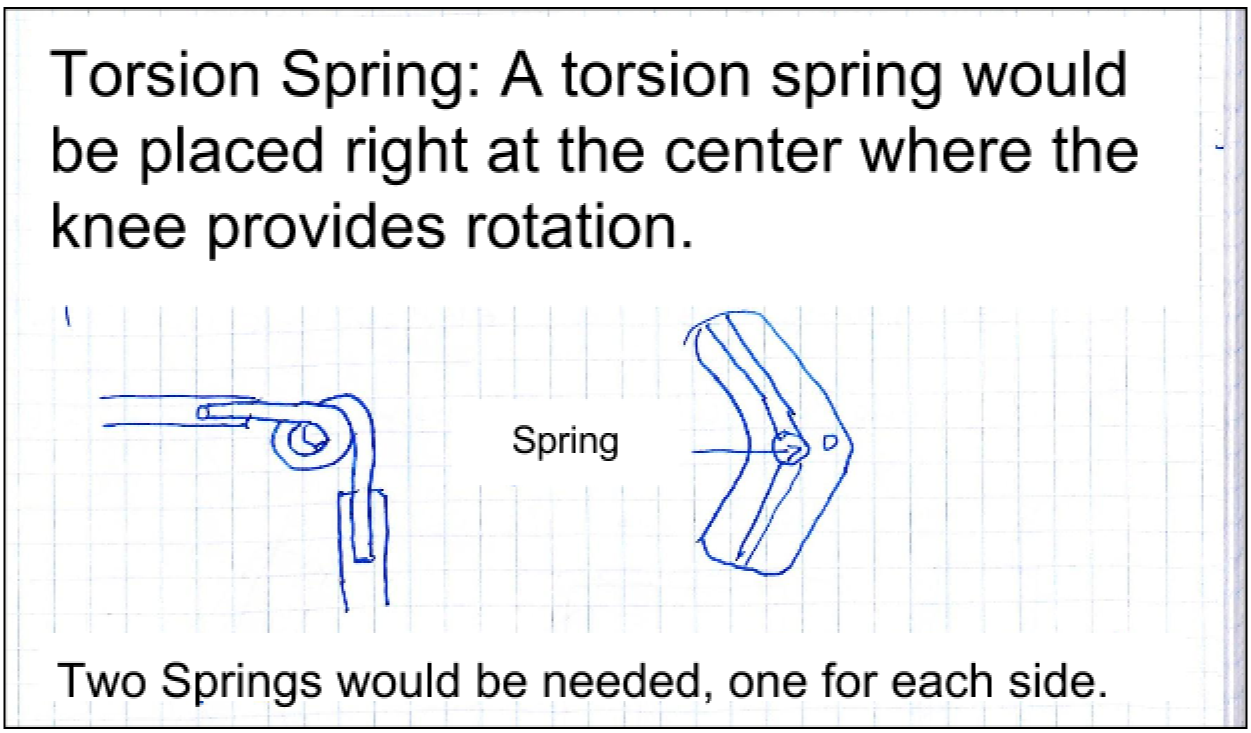

Figure 3. The torsion spring would be place right next to the knee on both the left and right side.

The last key feature of the mechanism is the lock and release system. In order for the device to be efficient, the device will be able to store the potential energy for as long as the person is seated and to be able to release it on demand, when the person stands up. The design includes a mechanism that will lock in place as soon as the spring reaches the intended compressed state. The mechanism will only lock the spring, but not the lower rods that guide it; this allows the user to move their legs freely while sitting down and stores the energy within the spring. A cylindrical guide, perpendicular to the leg, will be attached near the end of the spring, seen in Figure 4. As the spring compresses, the guide travels along the inner compression path until it reaches the locked position. At this point, the user will be allowed free control of their leg while still storing energy. When the user chooses to stand up, they will need to compress the spring further than the locking point in order to reach the end of the compression path; thus allowing it to travel into the extension path, returning all the way into the resting position where it started. At the end of the extension path, there will be a spring loaded gate which opens when the spring travels to the resting state and closes right after, forcing the guide to go through the compression cycle. As stated before, this mechanism is customizable in that the locking angle can be altered for people with a limited range of motion.

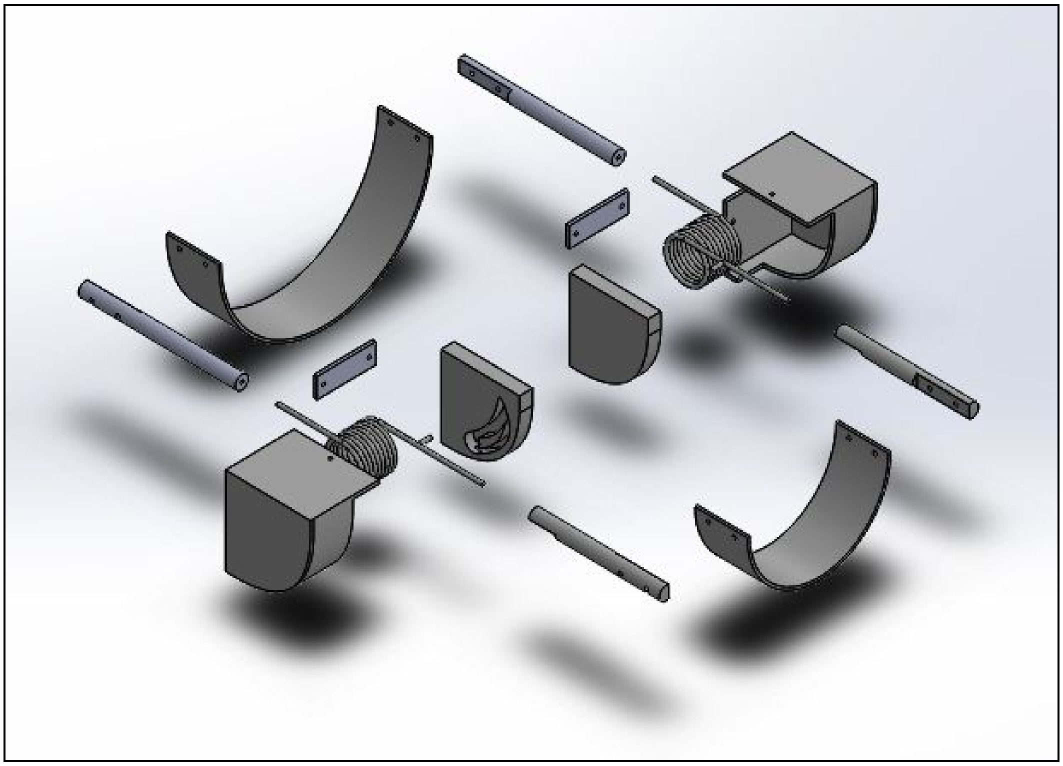

Figure 4. 3-Dimensional representation of the most up to date model.

There is a certain difficulty in replicating a knee sleeve in a 3-Dimensional model, therefore the 3-Dimensional representation is of the knee brace mechanism, seen in Figure 1. Below are representations for the locking mechanism. In Figure 5, the CnC'd plate has the track for the locking mechanism. As the user sits down the spring follower moves down the track on the inner left side until it slides into the locked position. Then by compressing it slightly more, which is caused by leaning forward when standing up, the spring is released from its locking mechanism. This releases the stored potential energy and while the spring guide follows the track on the outside, the user is able to stand up. The virtual prototype representation of the follower and track within a clear housing unit can be seen in Figure 6.

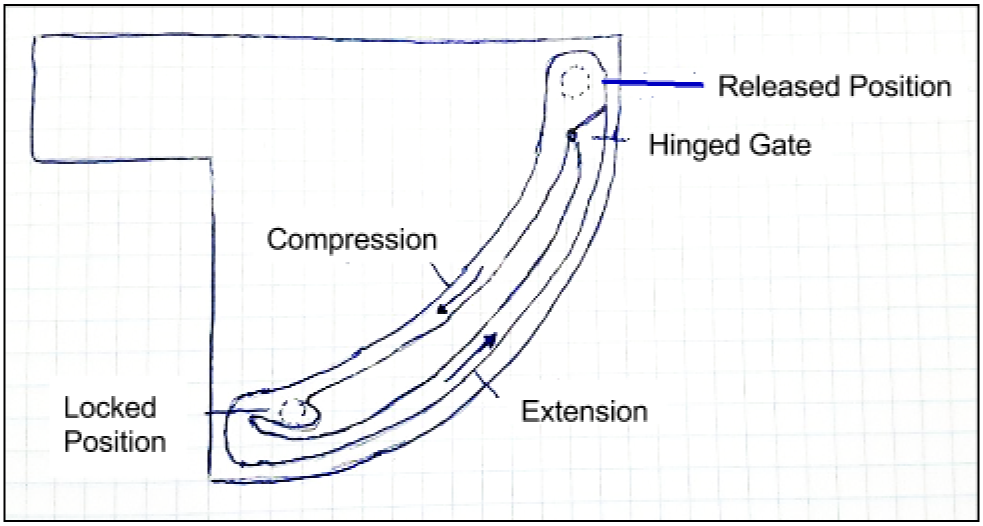

Figure 5. Lock and release system, bar attached to the spring is represented by a dotted line

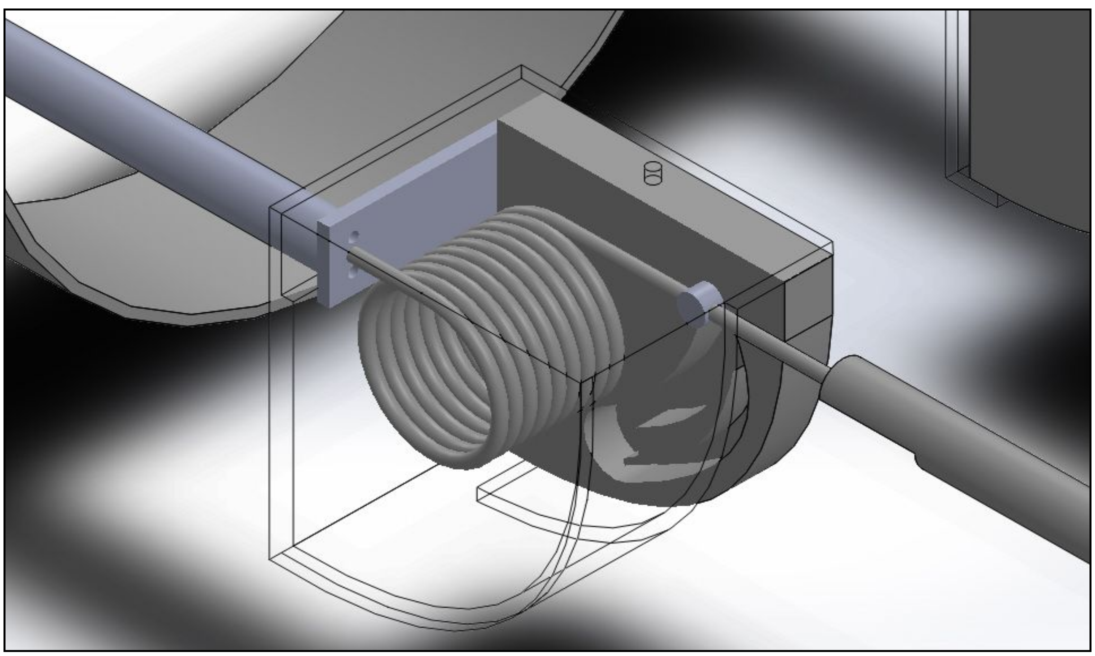

Figure 6. Solidworks model of locking mechanism

Modeling and Analysis

The knee brace mechanism is designed to utilize torsion springs to store potential energy provided by the user and minimize the shock onto the knees when the user gets in and out of their seat. A secondary function of the knee brace mechanism is to support the user while they are walking by providing a small spring loaded momentum during the heel strike stage of walking. The spring constant needed to help the user get out of a chair is found by calculating the torque the knee needs to produce. This torque is also calculated by modeling the device as a torsion spring-mass system and analyzing it with the provided specifications of the user such as: height, weight, the angle of the upper body makes with the thigh, and the angle the calf makes with the thigh. The actual values differ based on the user's weight and height, therefore the modeling and analysis is calculated with an average weight and height in mind.

Due to the relationship between height and age, the range for the target audience, the elderly, must be determined. Assuming the age for senior status starts at 55 years old, due to senior discounts starting at 55 years old, and people live up to 95 years old, the age range for the elderly is assumed to be (55-95) years old. This age range is used to figure out the height range of 50% of the population for both women and men using Figure 7 and Figure 8, which is estimated to be around (68-63.8) - (66.8-62) and (73.5-69.4) - (72-67.5) inches respectively.

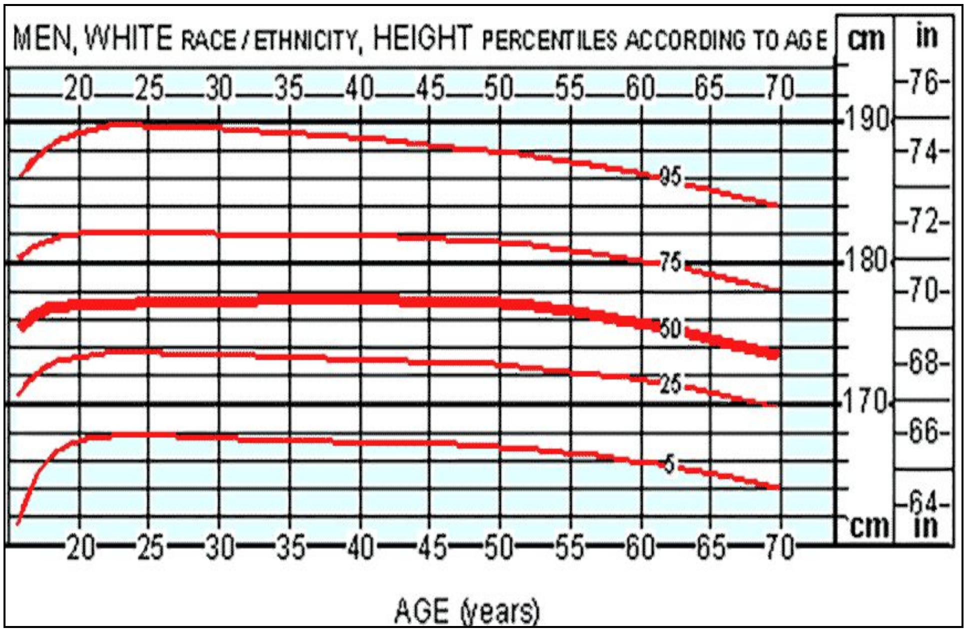

Figure 7. Height to Age Relationship for Men with Varying Confidence Levels **[4]**

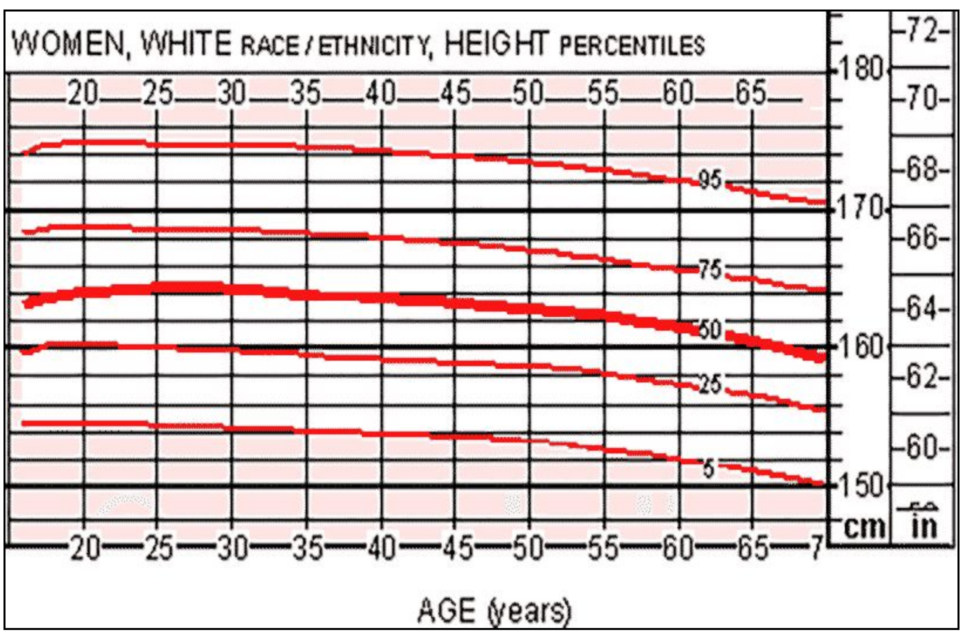

Figure 8. Height to Age Relationship for Women with Varying Confidence Levels **[5]**

There is another correlation between the height of the person and their weight. This is used to estimate the weight range of the customer, which is later used to calculate which spring to use in the prototype. Assuming the customer is in the healthy regime, the minimum and maximum range for women and men are [105-165] and [125-185] pounds respectively. When looking at both sexes as a single group, the weight range that the device must support is between [105-185] pounds.

Weight lbs	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180	185	190	195	200	205	210	215
Kgs	45.5	47.7	50.0	52.3	54.5	56.8	59.1	61.4	63.6	65.9	68.2	70.5	72.7	75.0	77.3	79.5	81.8	84.1	86.4	88.6	90.9	93.2	95.5	97.7
Height in/cm		Underweight					Healthy					Overweight					Obese				Extremely Obese			
5'00" - 152.4	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
5'01" - 154.9	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	36	37	38	39	40
5'02" - 157.4	18	19	20	21	22	22	23	24	25	26	27	28	29	30	31	32	33	33	34	35	36	37	38	39
5'03" - 160.0	17	18	19	20	21	22	23	24	24	25	26	27	28	29	30	31	32	32	33	34	35	36	37	38
5'04" - 162.5	17	18	18	19	20	21	22	23	24	24	25	26	27	28	29	30	31	31	32	33	34	35	36	37
5'05" - 165.1	16	17	18	19	20	20	21	22	23	24	25	25	26	27	28	29	30	30	31	32	33	34	35	35
5'06" - 167.6	16	17	17	18	19	20	21	21	22	23	24	25	25	26	27	28	29	29	30	31	32	33	34	34
5'07" - 170.1	15	16	17	18	18	19	20	21	22	22	23	24	25	25	26	27	28	29	29	30	31	32	33	33
5'08" - 172.7	15	16	16	17	18	19	19	20	21	22	22	23	24	25	25	26	27	28	28	29	30	31	32	32
5'09" - 175.2	14	15	16	17	17	18	19	20	20	21	22	22	23	24	25	25	26	27	28	28	29	30	31	31
5'10" - 177.8	14	15	15	16	17	18	18	19	20	20	21	22	22	23	24	25	25	26	27	28	28	29	30	30
5'11" - 180.3	14	14	15	16	16	17	18	18	19	20	21	31	22	23	23	24	25	25	26	27	27	28	29	30
6'00" - 182.8	13	14	14	15	16	17	17	18	19	19	20	21	21	22	23	23	24	25	25	26	27	27	28	29
6'01" - 185.4	13	13	14	15	15	16	17	17	18	19	19	20	21	21	22	23	23	24	25	25	26	27	27	28
6'02" - 187.9	12	13	14	14	15	16	16	17	18	18	19	19	20	21	21	22	23	23	24	25	25	26	27	27
6'03" - 190.5	12	13	13	14	15	15	16	16	17	18	18	19	20	20	21	21	22	23	23	24	25	25	26	26
6'04" - 193.0	12	12	13	14	14	15	15	16	17	17	18	18	19	20	20	21	22	22	23	23	24	25	25	26

Figure 9. Height to Weight Ratio Covering Different Weight Status **[6]**

Since the user is not lifting their total body weight, body ratio assumptions were made to calculate how much the knee has to lift. Assuming that the thigh is 2/3 of the weight of the leg, the amount the knee must lift is calculated. The head weight is 0.034*m_h. This means that the weight range the knee must lift is (0.034+0.56+2*0.048+2*0.155*(2/3))m_h = 0.8967*m_h = [94.15-165.8833] lbs or [42.7057-75.2434] kg.

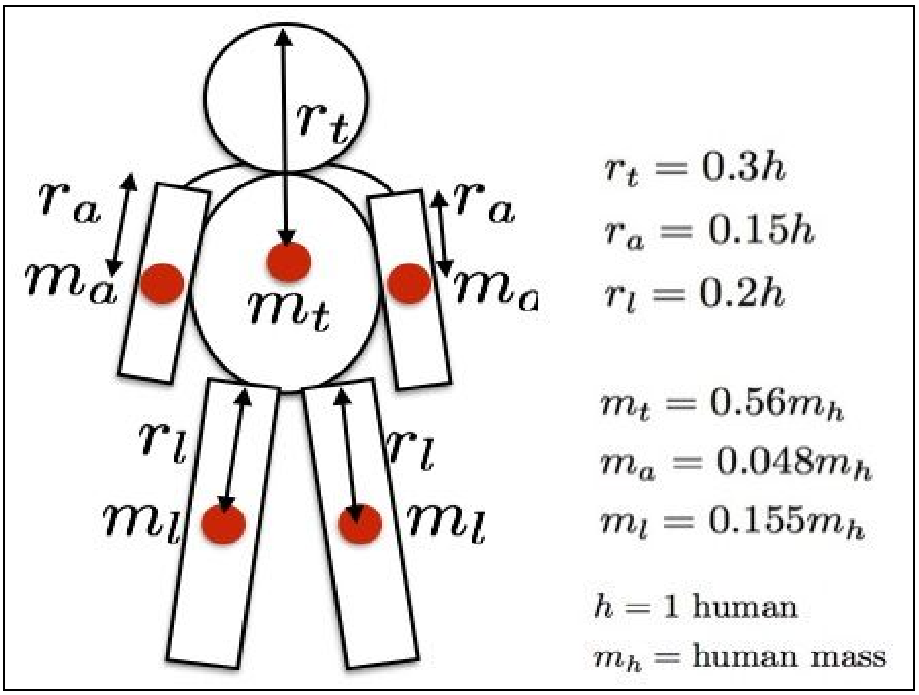

Figure 10. Center of Gravity Locations and Ratios

In theory, designing the device to lift all the weight of the user produces problems for multiple reasons. First, the force that lifts the person leads to a sudden push, which causes the user to fall forward. Without a damper system, the sudden release of energy flings either the upper body or lower legs. Secondly, the device alters the user's legs to weaken over time, which is counter productive of the device. The device is meant to help reduce strain on the knees while helping build stronger legs. Lastly, if the device lifts all of the user's weight, there must be an equal amount of weight to compress the spring. Therefore, the spring does not start to compress unless there is a minimum weight of the user's body, meaning it is impossible to use a spring that lifts all of the user's weight. Upon looking at the possible problems the device confronts, it is in the best interest to make the device lift 50% of the remaining weight, which is around 45% of the user's total weight. This results in the device needing to lift theoretically [47-83] lbs.

Due to the amount of variables within the system, torque is a function of height, weight, the angle of the upper body makes with the thigh (θ), and the angle the calf makes with the thigh (φ). The importance of a variable is found by varying one variable and keeping the rest at a known set value, which is conducted for the four variables. As seen in Figure 11, the angle (φ) does not produce as much torque as the other variables. The difference in maximum and minimum values are around 12 N•m when the difference for other variables are above 50 N•m.

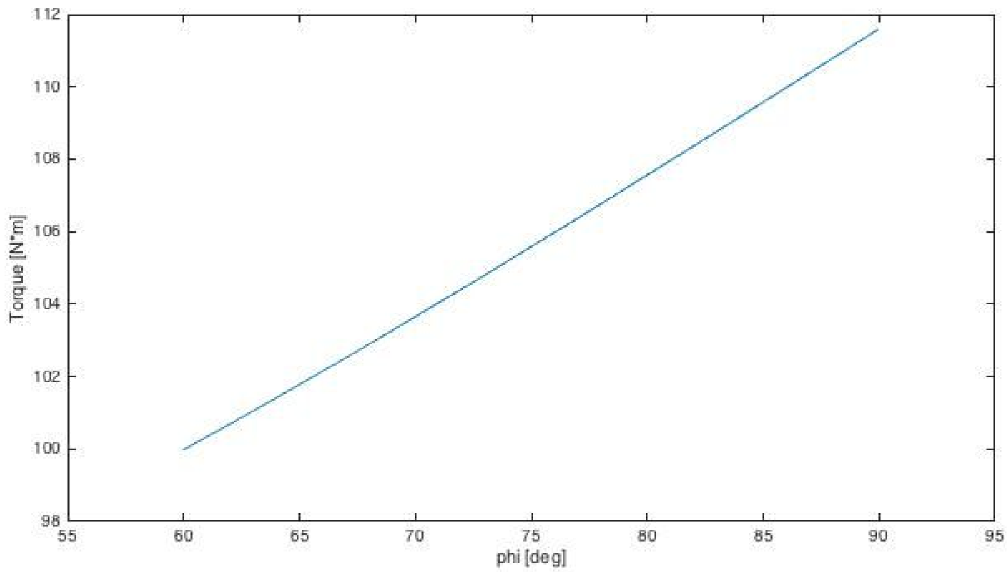

Figure 11. Torque vs Phi with Constant Variables (θ=60°,Weight=145 lb, Height=67.75 in)

During the initial stages of standing up, people tend to lean forward to balance their body. As seen in the time lapse of a person standing up, in Figure 12, the center of gravity remains aligned with the center of the thigh. In order to calculate the torque needed by the spring, it is safe to assume that the distance from the spring to the center of gravity is the same distance from the knee to the center of the thigh.

Figure 12. Time Lapse of a Person Standing Up **[3]**

According to the National Center for Health Statistics **[3]**, the average length of an adult thigh is 42 centimeters. The distance to the center of the thigh results in 21 centimeters or 8.3 inches. Using the formula for torque,

$$\tau = r \times F \tag{1}$$

the total torque needed to produce lift is [390-690] in-lbs. Since the design is using a total of four springs, the torque required by each spring is theoretically [97.5-172.5] in-lbs.

Approach to Solution

During the concept generation period of the design process, the objective is to generate as many concepts as possible. Each team member, of which there are only three, is responsible for contributing as many good concepts. The 6-3-5 method is incorporated in the brainstorming process and seeing that there are only three people, the 3-3-5 method is used. The team of three people has three minutes to produce five concepts, which are passed around two more times to build upon the generated concepts. The design criteria that are determined, after discussing together, are the following: Adjustability, Comfort, Convenience, Durability, Effectiveness, Range of Motion, Support, Simplicity and Weight Support. After isolating the top three design concepts, they are assessed against one another on these eight criterias.

Idea 1: Spring Loaded Seat

The idea for this device is a spring loaded seat, which easily folds up and carried around. It is built with a spring inside that charges up as the user sits down on it. As the user sits down, the spring converts the initial potential energy and later uses it as kinetic energy. Also, the spring acts as a damper for the motion of sitting down, reducing the burden of the movement on the user's knees. The seat is connected by a rod to the knee of the occupant and helps prevent the knee from moving in the wrong direction or blowing out as the user sits down and stands up. Also, the device is optionally connected to the user's walker so that the user relies on the walker's assistance to stand before and after they sit. To operate the spring, the user puts their hands on their walker and presses the operating button installed on the walker. After the user stands up and is using the walker for assistance, the device is collapsed and attached to the walker for mobility.

The side view of the concept can be seen in Figure 13. The thick black lines represent the walker, the striped lines represent the seat cushion. As the user sits down, the spring compresses and the cushion locks into the case, creating an elevated seat. The arm connecting to the walker helps ensure that the user will avoid falling. It will be a complete seat, or a seat split down the middle into two separate spring seats, that way it fits any person of size, and easily attaches to the walker.

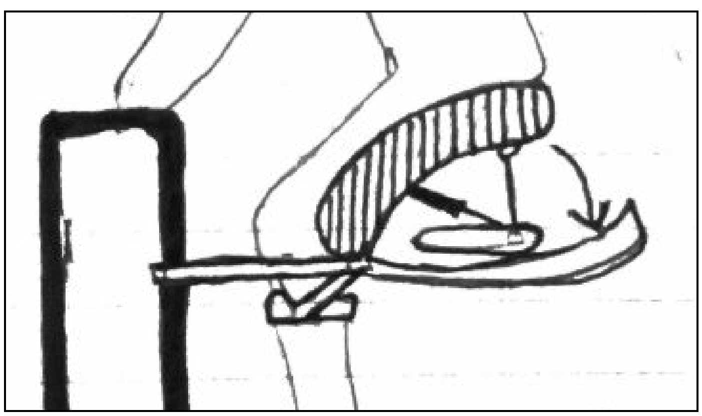

Figure 13. Side view of spring loaded seat design

Idea 2: Knee Brace with Levers/Spring Mechanism

The idea for this device is to incorporate a lifting mechanism into what is commonly known as a knee sleeve. This device has the adjustability and comfort of a regular knee sleeve, but a mechanism with a torsion spring is attached to store potential energy as the person sits down, as seen in Figure 5 and 6. The spring locks so the energy is saved for future use, which is when the person stands. The concept behind this idea is to use metal bars attached to the legs through the knee brace as levers. These levers will be connected to the spring and as the person sits down, the torsion spring compresses and stores the potential energy. Upon reaching its maximum bending point the mechanism locks, so that the person moves their legs freely without worrying about the force pushing back. Once the person wants to stand up, the user simply puts their legs down and unlocks the system so the spring releases its potential energy into kinetic energy.

Idea 3: Full Thigh Support

The goal for this device is to help get the initial upward motion out of the chair. As people attempt to get out of the chair, the upper body leans forward to actuate the motion. When this happens, the center of gravity shifts from above the buttocks to the thigh. Most of the force or pressure is on the ball of the foot as the body lifts up the body into a standing position. This device helps imitate that motion so that the user will experience less stress on the knees.

There are two pads on the thighs that are connected to rods on both legs. These rods located below the thighs are connected to rods that run along the calves. Then the rods along the calves are connected to cushioned shoe insoles that are put into the user's shoes or walk around as a stand alone. The main component in this device is a spring and damper system fit under the knee that supports the sitting down motion along with helping stand up without any need of other external devices or people. Once the user wants to stand up, the weight will be sensed by the shoe inserts and actuate the spring section of the device. While standing straight, the device is still sensing the weight of the user and commanding the spring to be fully extended which helps support the body.

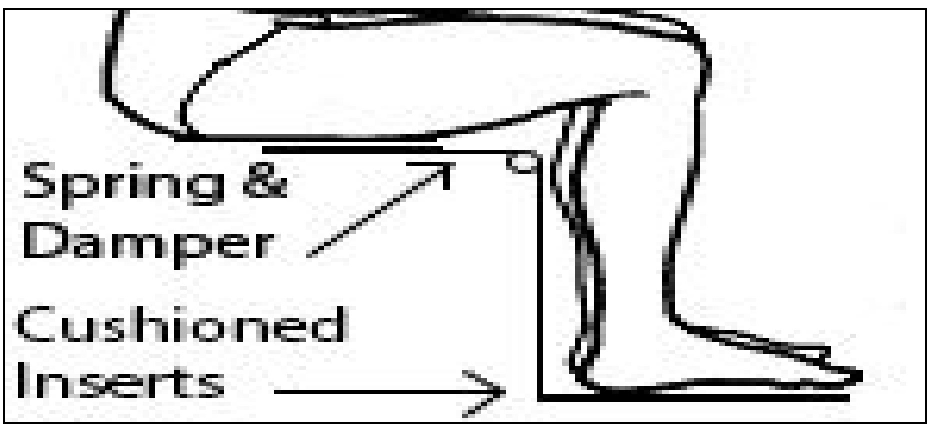

Figure 13. Side View of Full Thigh Support

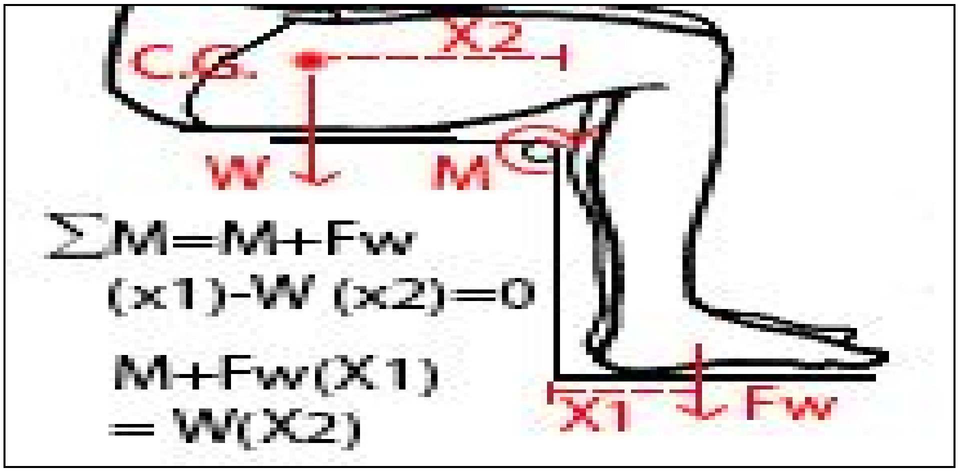

Figure 14. Mathematical Concept on Helping Stand and Sit Motion

In order to decide which design is best, the weighted decision matrix is used in choosing the best design. To help decide which design to proceed with, the concepts are compared based on the characteristics and rated from 1 through 3. The design with the highest score proceeds to be the final design.

Characteristic	Weight	Spring Loaded Seat	Knee Brace with Torsion Spring	Full Thigh Support	Comments
Adjustability	**2**	3	3	3	All designs are fairly adjustable.
Comfort	**3**	2	2	1	First design includes a seat cushion.
Convenience	**3**	1	2	2	The first design requires the user to carry the device.
Durability	**2**	3	2	2	The second design is exposed and vulnerable.
Effectiveness	**3**	2	2	3	The first design requires a walker to be effective.

Range of Motion	**2**	2	3	2	The first design doesn't provide the full range of motion
Simplicity	**1**	2	3	1	The second design was the simplest
Support	**2**	1	2	3	First design doesn't provide support.
Total Raw Score		16	19	17	
Weighted Score		35	41	39	

Table 1. Weighted Decision Matrix for the top 3 designs.

From the weighted decision matrix, it is clear that each design has their own strengths and weaknesses. The first design seems like a hassle to carry around and it relies on a walker or some other source of support to remain stable, therefore it seems cumbersome. The third design, even though similar to the second design, seems really uncomfortable, which is really unappealing to most people. However, the second design seems to fit the perfect middle ground between a regular knee brace, which only gives support and a robotic knee which does all the work. Not only does it provide a wide range of motion of the knees, it also supports the user's body weight due to the use of torsion springs.

The reason a weighted decision matrix is used as the main object of the selection process is due to its ease of use and understanding. Someone who has no idea of what the designs are can easily see the matrix and understand the selection process without having any other knowledge. Now that the final design is decided, the model has to be designed in Solidworks and the design has to work towards a better final rendering.

Design Evaluation

During the design process, the goal is to have the following features incorporated: hands free, self powered, a lock and release system, a spring loaded knee support, and a customizable brace that will fit a variety of knee sizes and ranges of motion **[1]**. The chosen design contains all of the desired features. It does not require any electronics or manual operation to function, thus fulfilling the desire to be hands free. In order to use the device, the user sits down when they want to redistribute the load, and leans forward slightly before standing up to utilize the stored energy of the spring when standing. With the ability to switch spring constants, by using different spring sizes, and the ability to elongate the length of the connecting bands, the device is highly customizable. While the design goals are met, it is critical to ensure that the device functions as designed. A physical prototype is developed in order to test the results against the virtual prototype.

By modeling the design in Solidworks, it is possible to analyze how the device reacts to various forces. Through different simulations, it is possible to understand how the device handles the stress across the design. The device operated as desired with respect to displacement. As seen in Figure 16, when the force is applied to the calf connection band, it moves downwards compressing the spring while the remainder of the device remains intact. The conducted analysis also suggests that the compression of the spring is well below the ultimate tensile strength of the spring that is used in the prototype. The lower threshold for ultimate tensile strength of the spring that is used is $2.31*10^5$ Pounds per square inch **[2]**. Had the physical prototype not broken, there would be many trials done to test the range of motion, percentage of the weight the springs took on and the comfort of the device. It will ideally redistribute the weight to the calfs and thighs. While the generated Solidworks models suggested everything about the design is fine, the physical prototype stated otherwise.

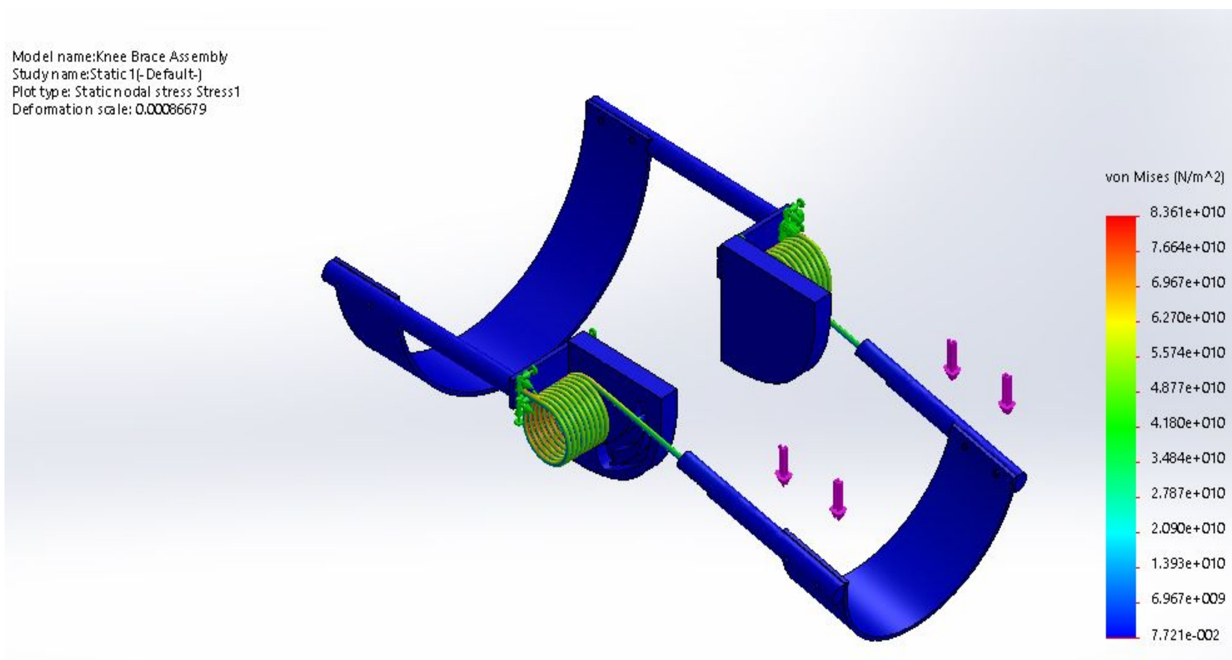

Figure 15: Stress Analysis of the prototype generated on Solidworks

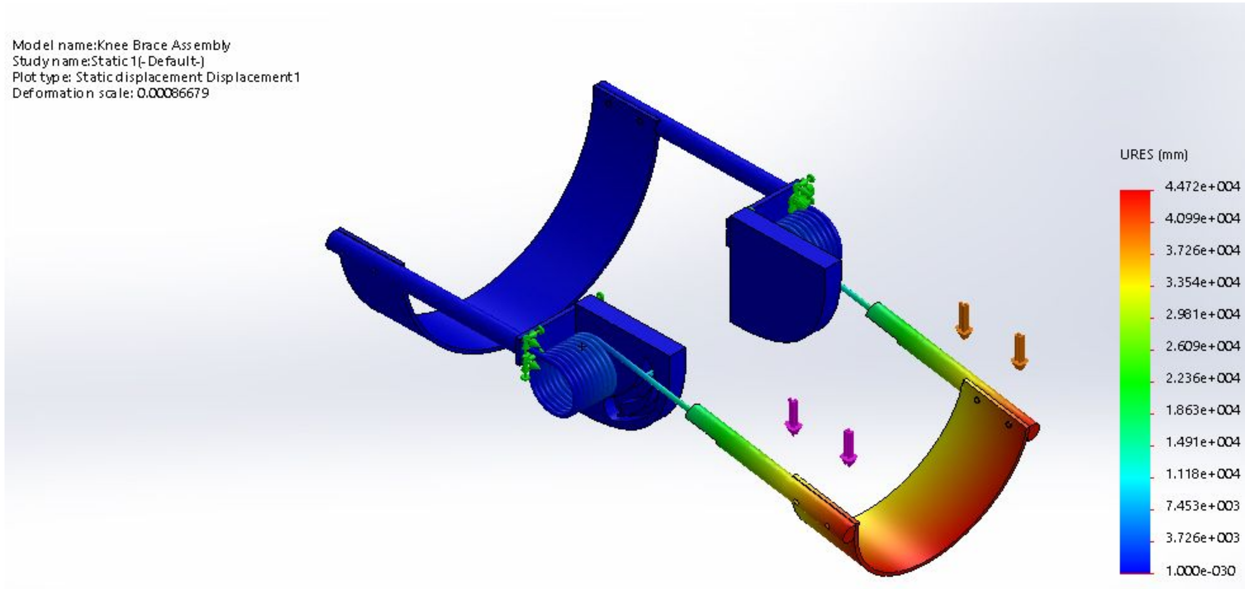

Figure 16: Force analysis of the prototype generated on Solidworks

When building the physical prototype, there are many flaws in the design that the virtual prototype did not display. In the design the plan is to cut the ends of the springs and weld them back on as following members, which are perpendicular to the rest of the spring. The guides will travel through the track of the locking mechanism and lock the spring in place. The generated virtual prototype assumes perfect material properties throughout the whole process. When the guide is welded to the spring it is firm, yet brittle. Once the prototype testing started, the spring fractured into two pieces due to the welding. This displays that the intended design is not practical. Due to the welding of the guide onto the spring, the material property changed and reduced the material strength. For the intended design to work, the locking mechanism must be designed in a different fashion. However, this is not the only issue with the physical prototype.

When the welding problem emerged, it is crucial to check if the concept of the design works without the locking mechanism. Once the concept of the design is valid, it is fundamental to move onto the padding system. However, due to the device having nothing to grab onto, it is difficult staying in place. Rather than staying centralized around the knee, the device will slide below it. It is very problematic to constantly adjust the device and thus violates the design goals for support and hands free operation. Another issue with the prototype is the bulkiness of the design. With the 3D printed housing units, the design produces a large block on both sides of the knee. In theory this will cause discomfort to those with hypersensitive knees even if the padding and support is implemented into the prototype.

Conclusion and Recommendations

The intended prototype design achieved all the goals that were created. The device reduces the load on the knees by carrying some of the load through the spring resistance. It also does this without the need for manual operation. However, the prototype is problematic as it encountered a spring failure. It is a shame that the failure did not happen earlier, which it will allow time to make progress with the design with updated prototypes. The engineering design process is a long development with many ups and downs. The knowledge of the design failure has been used to improve the design. Regardless, for the scope of the project, and the timeline available, the overall design is a success in creating a device which solves the problem statement.

To improve this design, the device should be made out of lighter and sturdier materials, such as carbon fiber. While aluminum is a great material for a prototype, it is not ideal to use for an actual device. A better choice is something that is lighter while not comprising on strength. There is also a lack of comprehensive understanding of the machining process and its limitations when designing the prototype. With hands on experience in the machine shop, there is a clear understanding on some of the impacts and limitations of various machining techniques. If additional time is provided, there are many things that can be incorporated into the design. For instance, welding anything to a spring material is not advised.

It is also possible to reduce the bulkiness and sheer size of the spring mechanism by utilizing a simpler and more compact approach. Furthermore, the locking mechanism can be located on a different part of the design. The current design puts too much stress on the machined spring.

It is essential that the device be padded and comfortable for the user. The main goal for the device is supposed to provide support, not pain. This should be done by using thick padding on the bottom plate of the spring mechanism housing unit and a soft fabric covering everywhere where the brace will contact the user's skin. Thick spandex similar to that used to make compression shorts is the best, as it is firm yet comfortable. The support will also help keep the mechanism attached to the leg and in proper operating position. This is a problem with the current design, which due to the spring failure did not get reinforced with padding and support. If more time is provided, the device can become something truly wonderful.

It is clear during the presentation that the need for a simple, affordable device, such as the one that is created, is legitimate. Numerous individuals spoke to the team about how they are interested in this product, when and if it is complete. However, to get the design finished, it will not only require all of the additional improvements listed above, but it will also require research on the impacts of the design. The most important continuation of this project will be longitudinal studies to understand how the design will affect the knee health and mobility of the user.

The team enjoyed working on this problem and learning more about the process behind engineering design. Even though the device did not work entirely in the end, the progress that has been made over the past 20 weeks is still valuable. Through the process we learned how to use the mill and lathe, and take a project from a problem statement to a physical prototype. We also have a newfound respect for all the work that goes into making a fully developed design. This is an experience we aim to build off of during our careers as mechanical engineers.

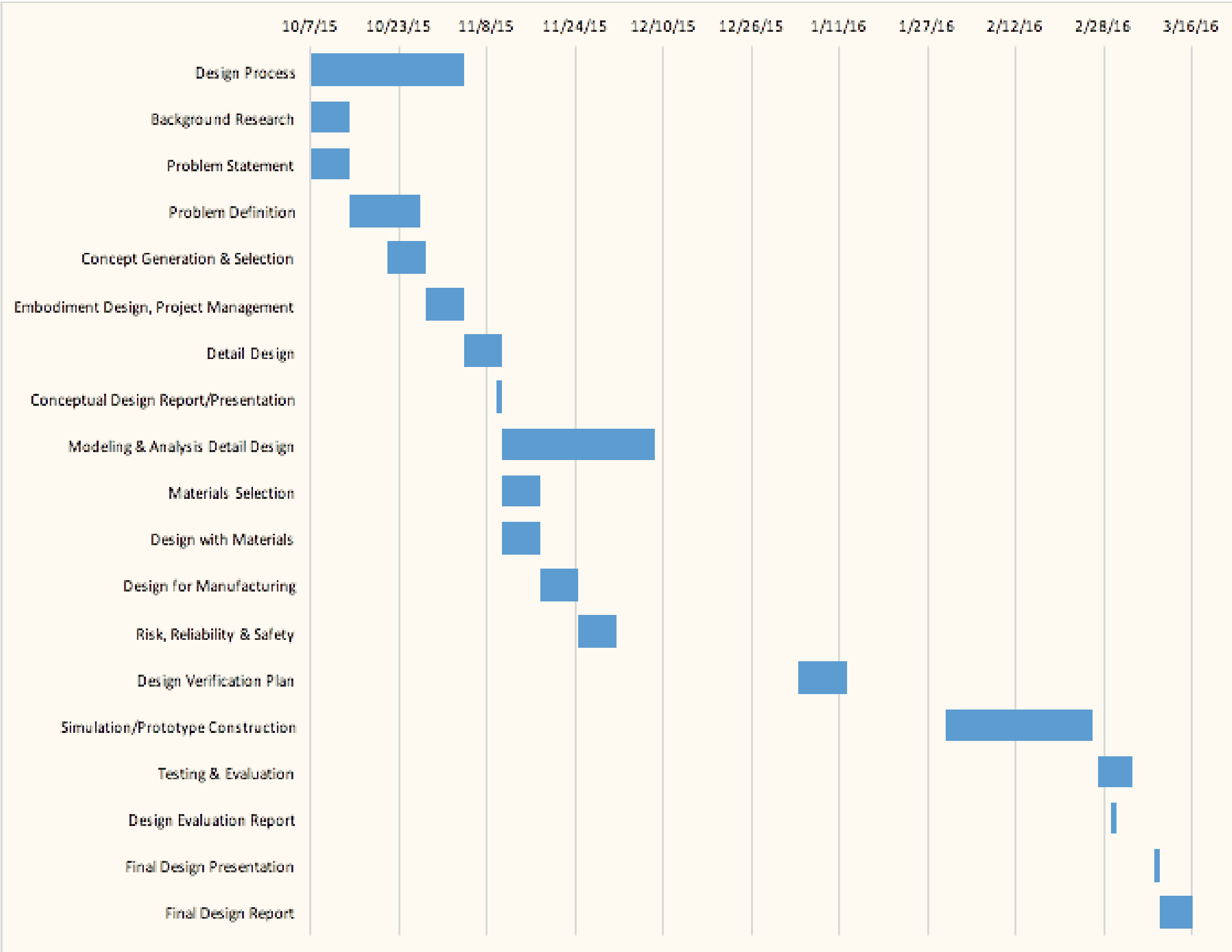

Figure 17: Gantt chart showing the progress of the project

References

1. "Stanford Center On Longevity Design Challenge", *Stanford Center on Longevity Design Challenge 2015-2016.* n.p., n.d. Web 5 October 2015. <http://longevity3.stanford.edu/designchallenge2015-16/>
2. N.p., *Matweb: Material Property Data*, Matweb, n.d. Web. 2 February. 2016. <http://www.matweb.com/search/datasheet.aspx?matguid=4bcaab41d4eb43b3824d9de31c2c6849&ckck=1>
3. Margaret A. McDowell, M.P.H., R.D.; Cheryl D. Fryar, M.S.P.H.; Rosemarie Hirsch, M.D.; and Cynthia L. Ogden, Ph.D., *Active Data: From Vital and Health Statistics*, DHHS Publications, 7 July. 2005. Web. 2 February. 2016. <http://www.cdc.gov/nchs/data/ad/ad361.pdf>
4. Steven Halls, MD, *halls.md.* Steven Halls, n.d. Web. 18 November. 2015. <http://halls.md/average-height-men-height-weight/>
5. Steven Halls, MD, *halls.md.* Steven Halls, n.d. Web. 18 November. 2015. <http://halls.md/average-height-women-height-weight/>
6. n.p., *Diet Health Club*, Mac Millan Interactive Communications, 16 January. 2014. Web. 18 November. 2015. <http://www.diethealthclub.com/do-you-know-if-you-are-fat-for-your-height.html>

Appendix

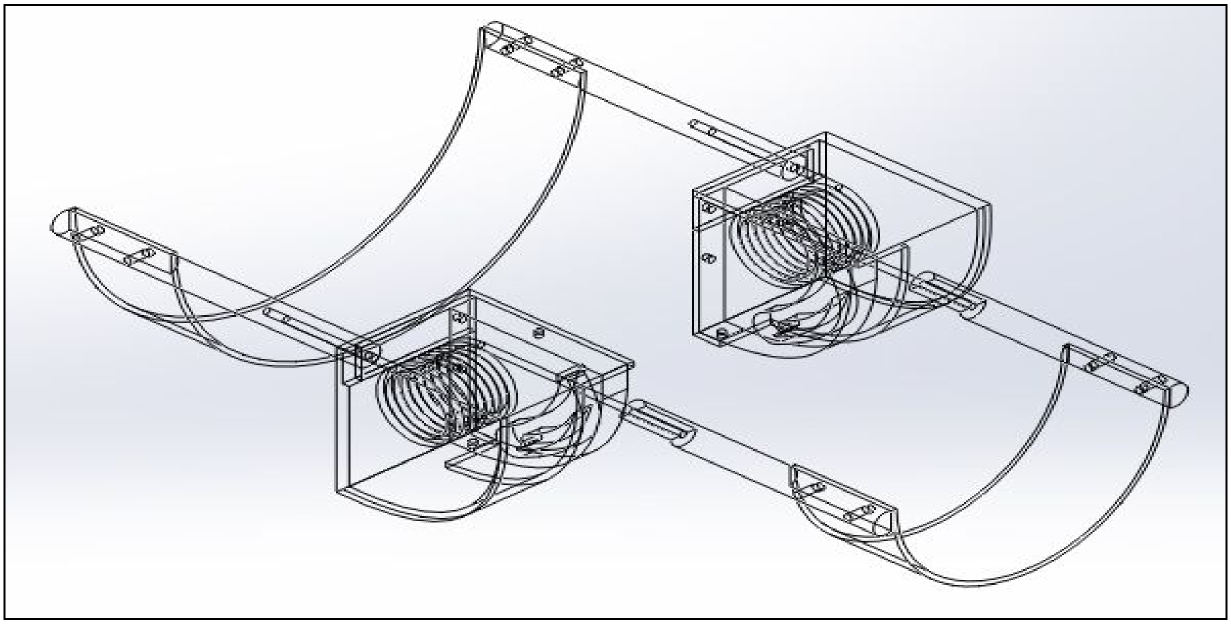

Figure 18: Transparent version of the prototype

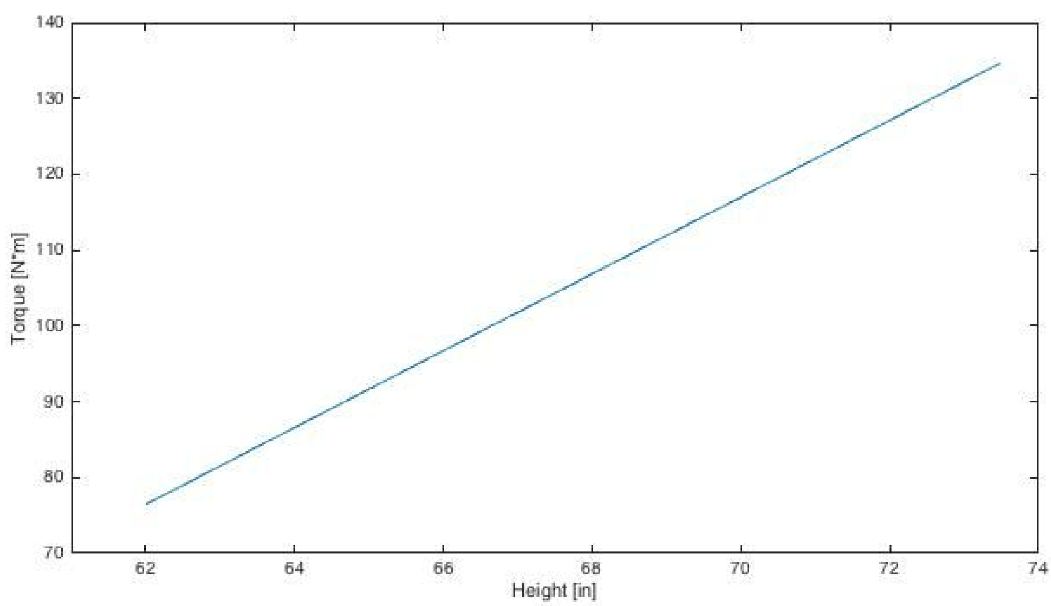

Figure 19. Torque vs Height with Constant Variables (θ=60°, φ=75°, Weight=145 lbs)

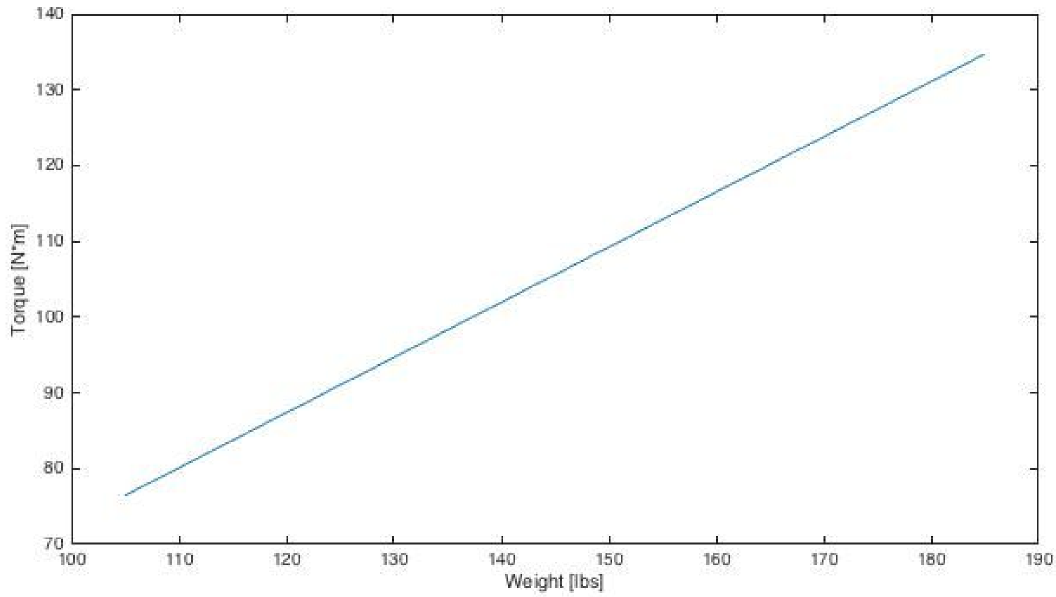

Figure 20. Torque vs Weight with Constant Variables (θ=60°, φ=75°, Height=67.75 in)

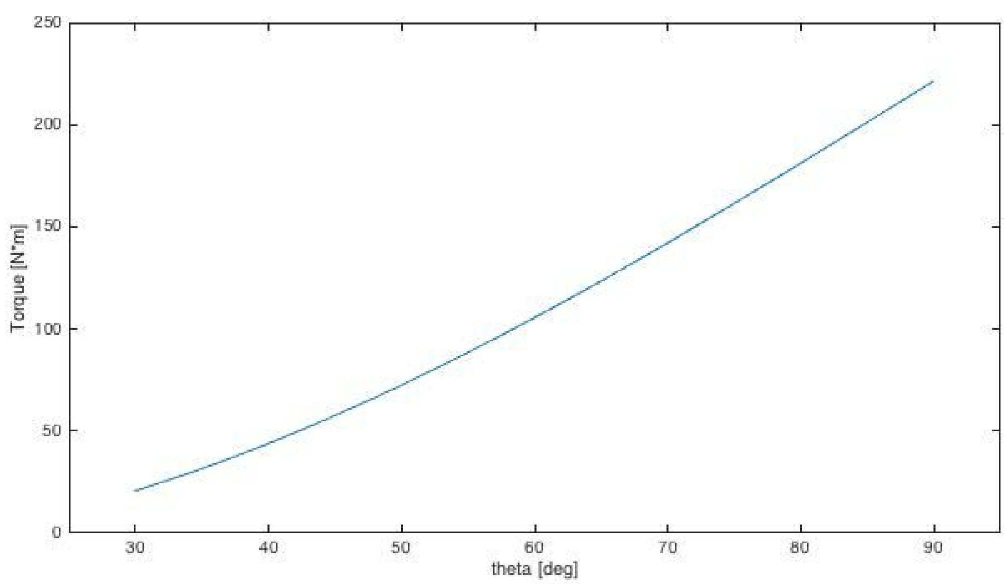

Figure 21. Torque vs Theta with Constant Variables (φ=75°, Weight=145 lbs, Height=67.75 in)

Matlab Code:

```
clear all

close all

clc


%%Finding Input Values

%Finding Weight and Height

prompt1 = 'What is Weight of Person?[lbs]';

W = input(prompt1)*0.453592*9.81;  %[N]

Fb = (0.034 + 0.56 + 0.048*2) * W;

Ft = (0.155*2*2/3) * W;

Ff = (0.155*2*1/3) * W;

prompt2 = 'What is the Height of Person?[in]';

H = input(prompt2)*0.0254;  %[m]

x1 = 0.55 * H * 0.55;

x2 = 0.5 * 0.45 * H * 2/3;

x3 = 0.5 * 0.45 * H;


%Looking at Angles

prompt3 = 'What is Leaning Angle?';
```

```
theta = input(prompt3);

prompt4 = 'What is Leg Bending Angle?';

phi = input(prompt4);


%%Calculation

M = Fb*(x2-x1*cosd(theta))+Ft*(2/3*x2)-Ff*(x3*cosd(phi))


%%Plots

%Theta

figure

H = 67.75*0.0254;        %[m]

x1 = 0.55 * H * 0.55;

x2 = 0.55 * 0.45 * H;

x3 = 0.45 * 0.45 * H;

W = 145*0.453592*9.81;    %[N]

Fb = (0.034 + 0.56 + 0.048*2) * W;

Ft = (0.155*2*2/3) * W;

Ff = (0.155*2*1/3) * W;

phi = 75;

theta = linspace(30,90);

M1 = Fb*(x2-x1*cosd(theta))+Ft*(2/3*x2)-Ff*(x3*cosd(phi));

plot(theta,M1)
```

```
xlabel('theta [deg]');
ylabel('Torque [N*m]');
xlim([25,95]);


%phi
figure;
H = 67.75*0.0254;        %[m]
x1 = 0.55 * H * 0.55;
x2 = 0.55 * 0.45 * H;
x3 = 0.45 * 0.45 * H;
W = 145*0.453592*9.81;    %[N]
Fb = (0.034 + 0.56 + 0.048*2) * W;
Ft = (0.155*2*2/3) * W;
Ff = (0.155*2*1/3) * W;
theta = 60;
phi = linspace(60,90);
M2 = Fb*(x2-x1*cosd(theta))+Ft*(2/3*x2)-Ff*(x3*cosd(phi));
plot(phi,M2)
xlabel('phi [deg]');
ylabel('Torque [N*m]');
xlim([55,95]);
```

```
%Weight
figure;
H = 67.75*0.0254;       %[m]
x1 = 0.55 * H * 0.55;
x2 = 0.55 * 0.45 * H;
x3 = 0.45 * 0.45 * H;
theta = 60;
phi = 75;
W1 = linspace(105,185);
W2 = linspace(105*0.453592*9.81,185*0.453592*9.81);
Fb = (0.034 + 0.56 + 0.048*2) * W2;
Ft = (0.155*2*2/3) * W2;
Ff = (0.155*2*1/3) * W2;
M3 = Fb*(x2-x1*cosd(theta))+Ft*(2/3*x2)-Ff*(x3*cosd(phi));
plot(W1,M3)
xlabel('Weight [lbs]');
ylabel('Torque [N*m]');


%Height
figure;
W = 145*0.453592*9.81;    %[N]
Fb = (0.034 + 0.56 + 0.048*2) * W;
```

```
Ft = (0.155*2*2/3) * W;

Ff = (0.155*2*1/3) * W;

theta = 60;

phi = 75;

H1 = linspace(62,73.5);

H2 = linspace(62*0.0254,73.5*0.0254);

x1 = 0.55 * H2 * 0.55;

x2 = 0.55 * 0.45 * H2;

x3 = 0.45 * 0.45 * H2;

M4 = Fb*(x2-x1*cosd(theta))+Ft*(2/3*x2)-Ff*(x3*cosd(phi));

plot(H1,M3)

xlabel('Height [in]');

ylabel('Torque [N*m]');

xlim([61,74]);
```

Code 1. Matlab code used to calculate the torque using the 4 different variables: weight, height, phi and theta.

INDUSTRIAL METAL SUPPLY CO. — INVOICE

8300 SAN FERNANDO RD, SUN VALLEY, CA 91352 | 2481 ALTON PARKWAY, IRVINE, CA 92606 | 7550 RONSON ROAD, SAN DIEGO, CA 92111 | 301 MAIN ST, RIVERSIDE, CA 92501 | 5150 S 48TH ST, PHOENIX, AZ 85040 | 3757 E COLUMBIA ST, TUCSON, AZ 85714

Page 1

PLEASE REMIT ALL PAYMENTS TO: 8300 SAN FERNANDO BLVD. SUN VALLEY, CA 91352

For questions related to this invoice please call 951-300-9900

INVOICE DATE 02-10-16
INVOICE NO. 0961430
SHIPPER NO. 0961430

CUSTOMER NO. RRT

BILL TO: RRT, 301 MAIN ST, RIVERSIDE, CA 92501

E

SHIP TO: JESUS DIAZ DE LA PENA, 301 MAIN ST, RIVERSIDE, CA 92501

ORDERED BY: 951-300-9900

SHIP DATE	SALES REP	CUSTOMER PURCHASE ORDER #	ORDER DATE	SHIP VIA	TERMS
02-10	VONNIE KENT		02-10-16	RETAIL WILL CAL	COD

QTY ORDERED.	QTY SHIPPED.	QTY B/O	PART # / DESCRIPTION	NO. PIECES	UNIT MEAS.	UNIT PRICE	EXTENDED PRICE
2	2	0	61PREBAR 6061 BAR PRE-CUT 6061 ALUMINUM BAR PRE-CUT	2	LB	3.2900	6.58
1	1	0	52PRESHT 5052 ALUM SHT/PLT PRE-CUT ALUM 5052 SHT/PLT PRE-CUT	1	LB	2.1900	2.19
			Payment Received 02-10-16 MC		$8.52		

Win a $150 IMS gift card!
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Your feedback counts!

CUT METAL: WHEN FURNISHED CORRECTLY, CANNOT BE RETURNED FOR CREDIT.
CLAIMS, All claims for defective material are waived unless made in writing within ten days from the date of shipment. Our liability is limited to replacing the material or refunding invoice value of the material sold. All claims for storage must be made within five days after receipt of shipment.

Customer Copy

TERMS:
ALL TERMS ON THIS INVOICE ARE SUBJECT TO THOSE TERMS & CONDITIONS OF THE SALE NOTED ON THE BACK OF THE ABOVE REFERENCED SHIPPER.

SUB TOTAL	8.77
05 EDUCATION DI	0.88-
SALES TAX	0.63
FREIGHT	0.00
TOTAL	8.52

Appendix 1: Listing of raw materials bought from IMS.

McMASTER-CARR.

Receipt

562-692-5911
562-695-2323 (fax)
la.sales@mcmaster.com

Purchase Order	**0210JDIAZ**
Paid	**$20.22**
Invoice	**49664732**
Invoice Date	**2/10/16**

Billed to

ATTENTION: JESUS DIAZ DE LA PENA
JESUSXAVIER DIAZ
1701 MENDOTA ST.
CHULA VISTA CA 91913

Shipped to

Jesusxavier Diaz
1701 Mendota St.
Chula Vista CA 91913

Information About Your Payment

Credit Card	MasterCard Ending- 1057
Date	2/11/16
Name on Card	Jesus Diaz De La Pena
Your Account	99882000

Jesusxavier Diaz placed this order.

Line		Product	Ordered	Shipped	Balance	Price	Total
1	9271K127	Music Wire Torsion Spring, 180 Degree Angle, 1.189" Spring OD, .135" Wire, Left-Hand, Packs of 1	1 Pack	1	0	6.89 Per Pack	6.89
2	9271K126	Music Wire Torsion Spring, 180 Degree Angle, 1.189" Spring OD, .135" Wire, Right-Hand, Packs of 1	1 Pack	1	0	6.89 Per Pack	6.89

Merchandise	13.78
Sales Tax	1.10
Shipping	5.34
Total	$20.22
Payment Received 2/11/16	(20.22)
Balance Due	$0.00

Packing List	Shipped	Weight	Carrier	Tracking
6932239-01	2/10/16	1 lb.	UPS Ground	1Z92930103603999920

Federal ID 36-1456720 McMaster-Carr Supply Company Page 1 of 1

Appendix 2: Listing of springs bought from McMaster.

Signatures

Ben Morag

David Chon

Jesusxavier Diaz