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Improved Walker Design

A Major Qualifying Project Report
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by

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Executive Summary

It is estimated that over 41,000 elderly people sustain injuries involving walkers each year. A person falls when their center of mass (COM) travels outside their base of support (BOS). When a person uses a walker, their BOS is the footprint of the walker defined by the four legs. Unfortunately, many people use walkers improperly by ambulating with their feet outside the BOS. This is a very unstable position that may cause a fall. The most severe falls are lateral falls, which can lead to hip fractures that may cause death. Therefore, there is a need to improve the current walkers to reduce lateral falls.

A means of controlling the location of the user's COM and temporarily increasing the BOS were developed as walker accessories. An IR rangefinder detects when the user is outside the BOS and activates a solenoid that engages the brakes. This requires the user to step back into the BOS to deactivate the brakes in order to continue using the walker. Four lateral leg extensions, each comprised of a connecting shaft, spring, and piston, are attached to detachable walker legs at a thirty degree angle to the vertical. In the event that the user begins to fall, this attachment will give them extra time to correct their fall by contacting the ground after the walker tips 5 degrees. The spring will then compress giving the user an extra 5 degrees. Thus, the lateral leg extensions give the user a total of 10 additional degrees to tip laterally before falling. Extensive background research was conducted to determine three stepping reactions elderly use to regain their balance. Pro-E's Manikin package was utilized to model users in these three stepping reactions in order to obtain their COM and mass moment of inertia. These properties were used in dynamic analysis to determine the dimensions of the lateral leg extension. To evaluate the effectiveness of the accessories, subjects conducted comparative testing and the data was analyzed. Eight students participated in the testing in which the prototype was compared to a standard two wheeled walker. The prototype reduced the occurrence of stepping outside the BOS by 95%. Overall, the volunteers were more comfortable with the prototype and found it easier to use.

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1.0 Introduction

From 1900 to 2009, the elderly population (persons 65 years old and older) in the United States increased from 3 million to 35 million. The elderly population is still increasing; by the year 2030, the population is predicted to rise to 80 million people (Hobbs, 2008) (Kaye, Kang, and LaPlante, 2000). Figure 1 shows the growth of the elderly population from 1900 to 2010 and the predicted growth through 2050.

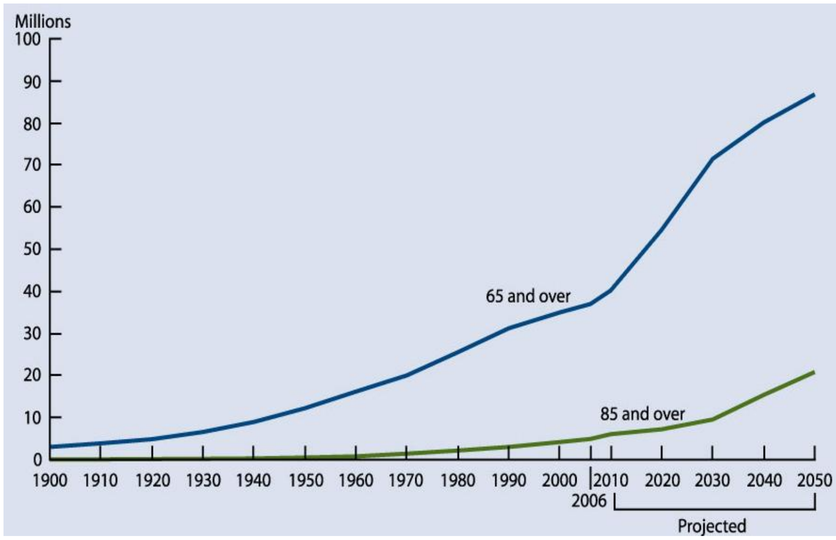


Figure 1: Size of Elderly Population by age group from 1900-2050 (projected from 2010-2050) (U.S. Census Bureau, 2006)

Although both the overall United States population and the elderly population are growing, the elderly population is growing more rapidly than the overall population. The percentage of the population that is elderly is expected increase so that by 2030 one out of every five people in the United States will be elderly (Figure 2).

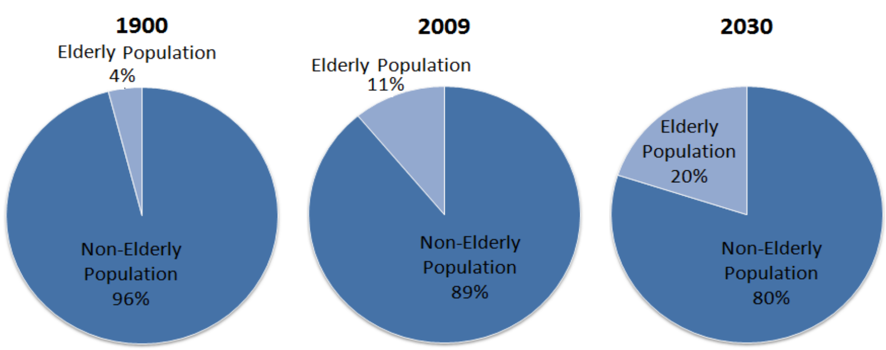


Figure 2: Percentage of population that was elderly in 1900 and 2009 and predicted for 2030.

As people age, their muscles degenerate and decrease in function. This results in an increase in falls, which are the primary cause of injury in elderly adults. The injuries that result from these falls can lead to a loss of motor function, independence, reduced quality of life, and even death. In 2006, elderly people falling caused 16,650 deaths and 1.84 million visits to the emergency room (Centers For Disease Control and Prevention, 2009). Falling is a very serious issue and with an increase in the elderly population there is a greater need for assistive devices to help them avoid falling.

Approximately 12% of elderly adults use an assistive device to reduce their risk of falling while still maintaining an active lifestyle. These devices include canes, walkers, crutches, wheelchairs, and scooters. Elderly people that suffer from overall weakness, have trouble bearing weight on their lower limbs, lack balance control, or have general incapacitating conditions typically use walkers (Bateni and Maki, 2005). Despite the use of assistive devices, elderly people still fall. The Center for Desease Control’s National Electronic Injury Surveillance System estimated that more than 41,000 elderly people sustain injuries involving walkers each year.

Out of the injuries that result from falling, a hip fracture is typically the most devastating. If an elderly person breaks their hip, they have a 20% chance of death and a 25% chance of being admitted to a hospital or nursing home for an extended period of time. A study of patients who sustained hip fractures determined that 76% of people who broke their hip did so by falling onto their side (Parkkari et al., 2009).

The goal of this Major Qualifying Project is to design, analyze, manufacture, and evaluate an improved walker to reduce lateral falls of the elderly when walking. The most basic cause of a fall is when the user’s center of mass moves outside their base of support and they are unable to correct it before they fall. The two strategies that are used to improve the standard walker to reduce falls are increasing the base of support, and controlling the user/walker system’s center of mass. Additionally, this device should be easy for the elderly to use and maintain the image of a current standard walker in order to minimize the negative stigma associated with using an assistive device.

2.0 Background

In order to develop an improved walker, one must understand the basics of walkers. This section will explain how walkers work, why they are prescribed, and the types of commercial walkers. These commercial walkers have limitations, and therefore improved devices were developed to improve upon said limitations; this section will discuss these patented devices.

2.1 The Purpose of a Walker

Walkers are used to increase the stability and balance of an individual while walking. The majority of people who use walkers are elderly because as a person's age increases, their muscle mass decreases. This phenomenon is referred to as sarcopenia (Spirdus, Francis, & MacRae, 2005). As the muscle mass decreases, the muscle strength is lost such that by the age of 60, muscle strength has already decreased by 20% and by age 80 by 40%. This drastic decline in muscle strength affects balance and stability. In both static and dynamic situations, an individual's stability is determined by the position and velocity of their center of mass relative to their base of support (BOS). A person's BOS is their feet. It is easier to control the center of mass (COM) in a static situation because in a dynamic situation, the BOS and COM are continuously changing. Therefore, to maintain balance in dynamic motion, the individual must have greater control over their muscles (Spirdus, Francis, & MacRae, 2005). The difficulty of this task increases with age because of sarcopenia. Walkers aim to increase elderly people's BOS while walking, which improves their balance and stability. The walker expands the BOS, which allows the user to keep their COM within the boundaries of the BOS over wider ranges of motion. The BOS of a walker is defined by the width and depth of its legs in contact with the ground, also referred to as the walker's footprint.

Throughout the report, the term “standard” walker will be used. This term refers to the type of walker depicted by Figure 3. The standard walker is made up of two identical side frames connected by a front frame. It consists of four legs with rubber stoppers at the ends and is typically made of aluminum tubing.

Figure 3: "Standard" Walker (Vienna Medical, 2006)

2.2 How to Use a Walker

To use a walker, the individual must begin inside the walker and push or lift their walker slightly ahead of them, keeping their toes even with the back legs of the walker (Figure 4 step 1, 2). When all the legs of the walker are on the ground, the user must step with the weaker leg into the walker (Figure 4 step 3, 4). The user repeats this procedure with the other leg and continues walking using this process. To maintain good posture while walking, the individual should always be close enough to the walker so with one step they can easily be inside of the walker. Unless specifically designed to, walkers should not be used to help individuals sit down or stand up.

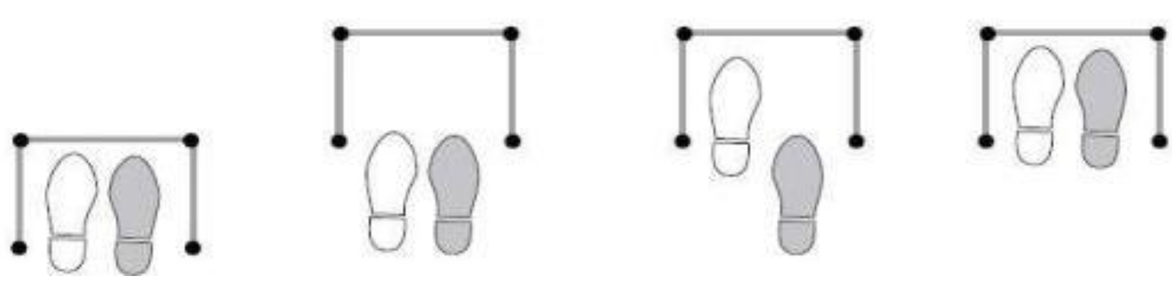


Figure 4: Correct Way to use a Walker (Steps 1-4 shown left to right) (Center, 2004)

2.3 Ergonomics of a Walker

To avoid injuries, the walker must be fitted properly to the user by having the correct height and type of grip. At the correct height, the top of the walker should be level with the user's wrists when they have their arms by their sides. This ensures that the user will be able to maintain proper posture when using the walker. The user should not bend over or hunch their shoulders during use. The individual should be standing upright and their forearms should be making a 30 degree angle with the walker when they are inside of the walker (Figure 5).

Figure 5: Maintaining a 30 degree angle (highlighted in red) between forearm and walker to ensure proper posture (Mayo Clinic, 2007)

Maintaining good posture with arms slightly bent takes stresses off of the user's back and upper extremity joints. Furthermore, walkers have a variety of grips ranging from only the aluminum bar to gel padded grips. Gel or foam grips are ideal because they accommodate various users' hand sizes. The preferred grip size of the item being used is proportional to the hand size of the individual using it (e.g. a person with large hands prefers using a device with a large handle). This suggests that an adaptive handle accommodating various hand sizes will reduce the force needed to operate the device for a greater number of people compared to a rigid handle (Karwowski & Marras, 1999).

2.4 Commercially Available Walkers

There are many different types of commercially available walkers. These devices can come without wheels, or with two to four wheels. Many of these products were designed to improve on the standard walker by making it easier to use. A summary and specifications the basic types of commercially available walkers is shown in Table 1.

Table 1: Type of Walkers (1800Wheelchair, 2009)

Type	Standard	2 Wheels	3 Wheels	4 Wheels
Image				
Height (in.)	30.4-37.4	32-39	34-38	34-38
Footprint (in.)	Depth: 16.5-18 Width: 21-23	Depth: 15-19.5 Width: 21-27	Depth: 23-28 Width: 21-27	Depth: 23-28.5 Width: 23-28
Weight Capacity (lb.)	250-300	250-300	250-300	250-300
Weight (lb.)	5-9	6-11	9-17	9-23
Cost	$49-99	$58-102	$85-122	$69-399

The standard walker is a simple frame device that the user holds in front of him or herself by using the hand grips on each side. They are typically made out of aluminum tubing. Some models of this walker are able to fold for easy storage and have adjustable heights and widths to accommodate many users. To prevent sliding, rubber stoppers are attached to the bottom of the legs of this walker to create friction between the walker and the surface. The primary function of this walker is to help stabilize users while walking. It increases the user's BOS by adding the walker's base to that provided by the user's feet. This model does not have any wheels, thus it can support users who have a lower level of mobility. A lower level of mobility includes users who have trouble taking a few steps on their own (1800Wheelchair, 2009). The disadvantage of this walker is that it has to be picked up for every step that the user takes, which can be tiring for the user (The Wheelchair Site, 2009). Using this walker requires the individual to exert 50% more energy than the walkers with wheels (Bateni and Maki, 2005).

The two-wheeled walker improves upon the standard walker by providing better maneuverability and requiring less effort to use. This walker is designed for people who are unsteady on four wheels and also have trouble lifting the standard walker. The two-wheeled walker has the same frame as a standard walker, but has two wheels attached at the bottom of the front legs. The wheels enable the walker to be pushed in front of the user instead of lifted forward. These wheels are typically standard wheels that do not swivel, but can be replaced by casters if desired.

Another common type of walker in the commercial market is the Rollator. This walker is designed for users that have a medium to high mobility level (The Wheelchair Site, 2009). It has wheels instead of rubber stoppers, located at the bottom of all the legs. Since the Rollators have wheels on each leg, they come equipped with a braking system. The mechanism used to activate the braking system (usually caliper hand brakes) is located directly underneath the hand grips. These brakes can be squeezed, similar to bike brakes, which force the Rollator to stop. The brakes also have a locking feature that can be utilized if the user wants the Rollator to remain stationary or when the user is seated on the Rollator, as some Rollators are equipped with a flip-down seat. The seat allows the user to rest in between periods of walking. Four-wheeled Rollators have more support and stability than 3-wheeled Rollators, which are designed more for tightly enclosed spaces. The Rollators are heavier and have a larger footprint than the standard and two-wheeled walkers. The wheel sizes can vary depending on how the person is using the Rollator. The wheels can either be small, allowing more maneuverability indoors or large for traveling over rougher terrain found outdoors (The Wheelchair Site, 2009). A Rollator is much more maneuverable than a standard walker or a 2-wheeled walker, however, they require more cognitive function and fine motor skills to apply the brakes in order to stop the walker or lock the brakes to keep the walker stationary.

2.5 Walker Accessories

In addition to being able to choose different types of walkers, users can also purchase walker accessories to improve their walker and adapt it to their needs. These attachments have a range of purposes from improving the maneuverability or ergonomics, to providing the user with storage or a place to sit. Both standard and two-wheeled walkers can be modified using replacement legs. These are attached in the same manner as the original legs, but can be longer to make the walker high enough to accommodate a tall user or have wheels attached (Figure 6). These wheels can be used to convert a standard walker into a two-wheeled walker or to adapt the two-wheeled walker for particular terrain.

Figure 6: Replacement Walker Legs and Wheels (Complete Medical Supplies, Inc., 2010)

One problem with current walkers is that they have trouble transitioning from surface to surface and sometimes the back legs of the two-wheeled walkers can catch on the ground. To make the walker move more smoothly and transition better from surface to surface, accessories can be put on the bottom of the walker legs. These accessories include things such as skis, tennis balls, or gliders (Figure 7) (Wright, 2009).

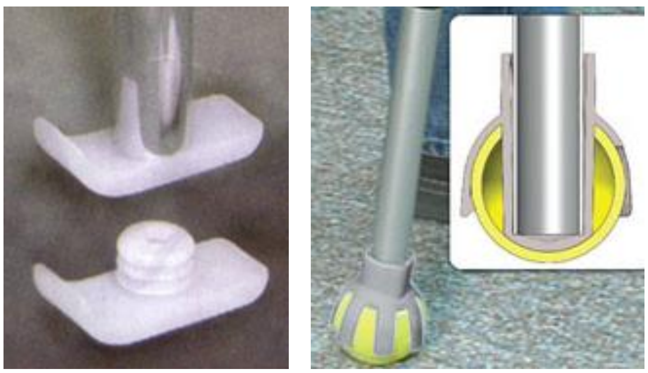


Figure 7: Surface Transition Accessories Left-Walker Gliders (Wright, 2009), Right-Tennis Balls (Sammons Preston, 2010)

2.6 Problems Resulting from Using a Walker

Although walkers are assistive devices used to improve an individual's quality of life by increasing their balance and stability, there are some disadvantages. Users of walkers typically have weak lower limbs and are prescribed walkers to compensate for their disability. However, the frequent use of the walkers can add stresses to upper extremity joints, which can lead to arthritis, tendonitis, and carpal tunnel syndrome. The loads the user applies to the walker depend upon the person's medical condition. Users with lower limb prostheses and spinal cord injuries apply 85% to 100% of their body weight to the walker, while persons with supranuclear palsy generate walker loads of approximately 30% of their body weight. By exerting a higher load on the walker, the forces on the upper extremities of the user increase resulting in a higher probability of developing other problems (Bateni and Maki, 2005).

Improper use or incorrect selection of a walker can also lead to injuries for users. If the person does not maintain good posture while using the walker, they will experience back and neck pain. Poor posture includes rounding of the shoulders and bending the neck forward, which results from neglecting to keep a 30 degree elbow flexion (Raton, 2008).

2.7 Balance and Falling

There are many different factors that can cause elderly people to fall and research has established that elderly people often fall for different reasons. Although the cause of the falls may vary significantly, the basic principle behind them is the same (Spirdus, Francis, & MacRae, 2005). As mentioned in the introduction, people fall when their COM moves outside their base. When this happens the reaction forces at their feet are unable to counteract the moment created by their weight and they begin to fall. It has been estimated that while standing still, elderly people are capable of maintaining their balance (i.e. keeping their COM over their base) when they are leaning forward or backwards up to 12 degrees and up to 16 degrees to either side (Spirdus, Francis, & MacRae, 2005). This angle is the angle between the vertical and the line created between the center point of person's feet and their center of mass.

There are three primary methods people employ to maintain their balance and stop falling. These techniques are flexing one's ankles, flexing one's hips, and stepping. Figure 8 illustrates the three balance strategies with ankle on the left, hip in the middle, and stepping on the right. The ankle strategy involves moving one's body around the ankle joint in order to retain balance. This strategy is typically used only when small adjustments are needed to maintain balance, because ankle muscles are not very strong, making it hard to generate a significant reactive force. The hip strategy consists of moving one's hip in the opposite direction of one's lower body thus moving one's COM back over the BOS. This technique can be used when someone is more off balance, because it can be done quickly and involves moving a large muscle group that is capable of counteracting most of the moment created by the offset of one's upper body. The final balance control strategy is stepping. This involves taking a step in order to realign one's base with their COM. It is commonly used when an individual's COM is moving, such as with walking, but is also employed when someone begins to lose their balance while standing still (Spirdus, Francis, & MacRae, 2005). Research has suggested that the stepping method is the preferred technique to recover balance. These three techniques are not exclusive, and are commonly used in combination to maintain balance, with the hip and stepping strategies most commonly used for correcting balance when walking (Spirdus, Francis, & MacRae, 2005).

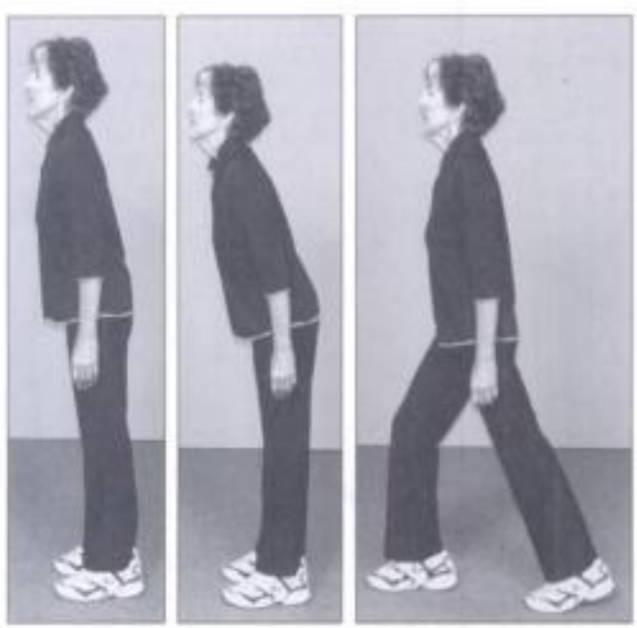


Figure 8: Picture of Woman Employing Balance Strategies (ankle on the left, hip in the middle, and stepping on the right) (Spirdus, Francis, & MacRae, 2005)

For elderly people, various health ailments can make these three methods of maintaining balance difficult. The ankle strategy requires appropriate ankle strength, range of motion in the ankle, as well as feeling in the foot in order to detect pressure. The hip method relies mainly on the strength and range of motion of one's hip muscles, which will determine the speed at which they can make adjustments with their hip. The stepping strategy depends in large part on the strength of one's lower limbs and their muscles' ability to react quickly. However, range of motion as well as the person's ability to quickly process what is happening also affect their ability to catch their balance by stepping (Spirdus, Francis, & MacRae, 2005).

One study determined there are differences in leg reactions used to recover from lateral instability between young adults (20-30 years old) and elderly (65-73 years old). The study concluded that when lateral perturbation was induced while the subjects were walking in place, 65% of the time the elderly took more than two reaction steps to regain balance, whereas this occurred only 8% of the time with the younger subjects. Since the elderly took more steps, collisions between their feet occurred in 55% of the trials versus only 8% in the young adult trials. This study proved it is more difficult for elderly to regain their balance from lateral instability and that their leg reactions may cause them to fall due to lack of coordination (Maki, 2000).

2.8 Causes of Falling When Using a Walker

Although the ultimate goal of using a walker is to prevent falling due to the user's lack of stability and balance, it is hard to measure how effective this assistive technology is. According to the *Journal of the American Geriatrics Society* (Stevens et al, 2009), 47,000 elderly users of walkers and canes go to the emergency room every year. Also, walker users are 7 times more likely to fall and injure themselves than cane users (Stevens et al, 2009). Despite the fact that there is a stronger correlation between a person using a walker and falling than a person using a cane and falling, one might expect this because the people who are prescribed to use walkers have more significant health issues and need more assistance than people who use canes. There are many factors that cause people to fall when using walkers: some are walker-related and some are not.

2.8.1 Non-Walker Related Causes

When using a walker, many elderly users experience falls due to causes other than the walker. These causes can be filtered into three problem categories: intrinsic factors, home, and improper use. Intrinsic factors account for 12.4% of walker related falls. These factors are specific to each patient and include type of medication, poor eyesight, weakness, and dizziness (Stevens et al, 2009). The patient's home may be cluttered or have changing surfaces (such as rug to wood floor) which would increase the user's probability of falling. Lastly, improper use puts the user at great risk of falling. If the user places the walker too far in front of them, they are more likely to become unstable and fall. Also, walkers are not made to aid in standing up or sitting down. If the user of the walker tries to use the walker for these activities, they are more likely to fall as well.

2.8.2 Walker Related Causes

One of the ways in which walkers can lead to falls is by inhibiting the user's natural balance reactions. In situations where the walker cannot provide enough support to stabilize the user they may rely on other methods to recover their balance such as reaching for a railing or taking a step. When a person who is using a walker tries to catch their balance by taking a lateral step, their foot and leg is likely to collide with a horizontal bar or leg of the walker. One study showed that 60% of the time someone using a walker took a lateral step in order to recover their balance their foot collided with the walker (Maki et al. 2008). Although they could not directly link these collisions with an inability to recover one's balance, this is most likely due to the fact that the study was conducted with healthy young adults whereas elderly people with mobility issues would be much less able to recover from a collision and not fall.

Studies of people subjected to perturbations while using a walker revealed that the three most common stepping reactions are the counter-lateral step (CLS), crossover step (COS), and side step (SS) (Bateni and Maki, 2005). Figure 9 shows the three stepping reactions for a person who is falling to the right. In the counter-lateral step the person's left foot steps to the left, which is the opposite direction in which they are falling. In the crossover step the person's left foot crosses over either in front of or behind their right foot in order to step to the right. In the side step the person's right foot steps to the right, which is the direction they are falling.

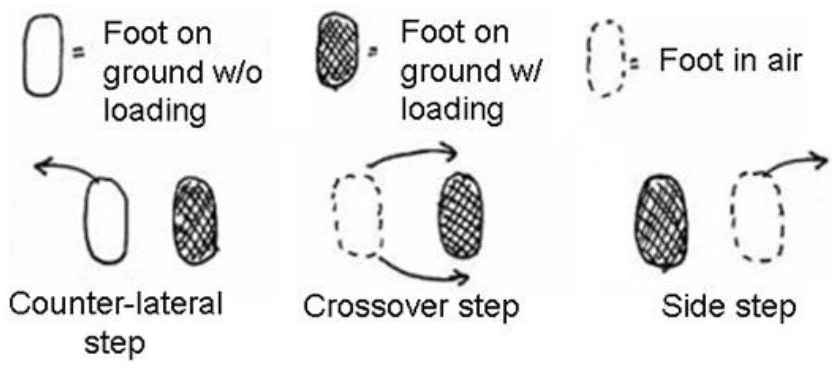


Figure 9: Diagrams of Three Stepping Reactions

In response to the findings about the number of foot and walker collisions while stepping laterally, researchers developed and tested two modified walker designs to decrease the number of collisions. The first of these designs removed the horizontal bars connecting the front and back walker posts and replaced it with a high arch. The second used the same arch bar design and moved the front and back posts further apart. Neither of the designs altered the width of the walker at all. Pictures of a standard walker (A), the high arch design (B), and the extended base design (C) are shown in Figure 10.

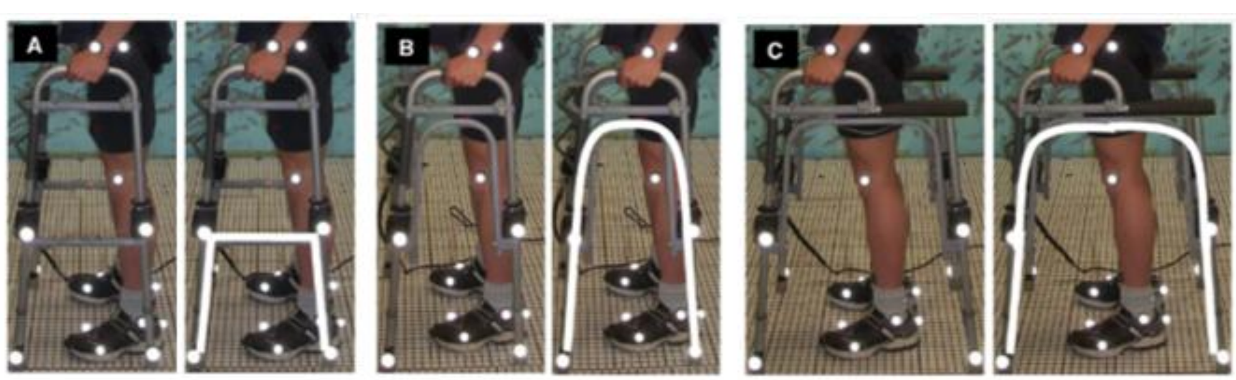


Figure 10: Picture of Normal and Modified Walkers Highlighting Horizontal Bars (Maki et al. 2008)

The high arch design reduced the collisions to 14% of the time and the extended walker resulted in collisions in only 5% of the trials (Maki et al. 2008). This proves that moving the horizontal bars higher up and the posts further away from the user's feet decreases the number of collisions between the users' feet and the walker.

One shortcoming of standard walkers is that they rely upon the user's upper body strength in order to stop the person's fall despite the fact that walker users are the elderly who have decreased muscle strength compared to the general public. As people age their muscle strength decreases. Research has shown that 65-78 year old men and women have 15.5-26.7% less muscle strength than their 45-54 year old counterparts (Frontera, Hughes, Lutz, & Evans, 1991). When someone tries to regain their balance while using a walker they must exert significant forces on the walker with their arms and hands. If they do not have the upper body strength to exert these forces, they will be unable to arrest their fall and hold themselves up.

If a walker is too bulky it can actually be the cause of someone falling. According to estimates of injury surveillance data 4.5% of falls with a walker between 2001 and 2006 were a result of walkers hitting or getting caught on an object. Furthermore, 60.9% of the falls with a walker occurred in the user's home (Stevens, Thomas, Teh, & Greenspan, 2009). People who use walkers must be able to maneuver them in tight spaces and around obstacles and objects one might find in a home. When considering one's ability to maneuver a walker it is also important to consider the condition of the person using the walker. Although a walker might be small enough to be easily be maneuvered into some location by a normal adult, it might be difficult for an elderly person who has impaired vision, impaired cognitive function, or decreased motor skills which are associated with old age (Spirdus, Francis, & MacRae, 2005).

If the COM of the user/walker system moves outside the user/walker BOS, the walker will tip over and be unable to prevent the user from falling. This can happen in a combination of two ways. In the static situation, the user leans too far out of the walker's footprint and when the COM of the system passes beyond the BOS, the system tips over and the user falls. The width of the walker and the mass of the walker determine the user/walker system's stability when the user is leaning laterally. However, if the person was leaning forward, the mass and depth of the walker would be of importance. If the mass, the width, or the depth of the walker were to be increased, it would increase the stability of the walker.

It is important to consider the dynamic situations that can lead to a fall as well as the dynamics of someone falling. If a person is in motion, their stability is dependent upon the velocity at which they are moving in addition to the location of their COM relative to their BOS. Whether or not someone who is in motion will fall is related to how much momentum they have; the faster someone is moving relative to their BOS, the more likely they are to fall (Hof, Gazendam, Sinke, 2005), (Pai, Patton, 1997). Research has shown that a slower gait speed is associated with an increase in lateral falls (Smeesters, Hayes, McMahon, 2001). This combined with the fact that walker users are not typically walking in the lateral direction indicate that the momentum involved in a lateral fall might not be as significant as in the case of a forward fall. However, it is still important to consider the momentum of the person in preventing a fall.

In order to keep from falling, the person in motion has two options. They can move their BOS so that it travels along with their COM. When someone runs they are moving their COM as well as their BOS (i.e. their feet). The other means of preventing someone from falling is for the person to stop moving before they travel beyond their BOS. This can be done by something imparting an impulse on the person.

Another way in which a walker can tip over is if there is significant horizontal force exerted on the walker. The factors that determine the stability of the walker in this situation include the coefficient of friction between the walker and the ground, because if there is very little friction, such as when the walker has wheels, the walker can slide or roll instead of tipping. Another factor that is important is the height of the walker (Deathe, Pardo, Winter, Hayes, & Russell-Smyth, 1996). The height is the radius that determines the magnitude of the moment created by the person, so if the walker is taller there will be a greater moment thus decreasing its stability. The mass of the walker and where its mass is distributed, which is typically determined by its shape, are also factors of the stability in this situation. If either the mass of the walker is increased or the distance from the COM to the leg that the walker wants to tip around is increased, the stability of the walker will increase. A free body diagram depicting this situation is shown in Figure 11.

Fp=Force exerted by unstable user
mg=weight of walker
Fn=Normal force on left legs
Fμ=Frictional force on left legs
w=width of walker
h=height of walker

Assumptions: The walker is about to tip so there are no normal forces exerted on the two rightmost legs and the weight of the walker can be simplified as a single force acting at the center of the walker

$$F_{xPerson} = F_{person} * \cos(\phi)$$

$$\sum M_A = h * F_{xperson} - \frac{w}{2} mg = 0$$

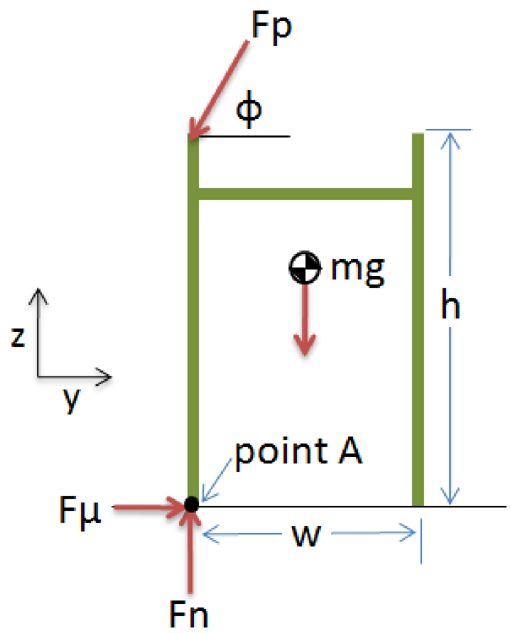


Figure 11: Two Dimensional Free Body Diagram of Walker Almost Tipping

2.9 Patents

Many patents exist that improve upon various aspects of the standard walker. In order to design a walker to reduce lateral falls it is important to explore patents that aim at increasing lateral stability. Some strategies to increase lateral stability include increasing the BOS, controlling the user/walker system's COM, and limiting user actions that could lead to a fall. These patents apply these strategies in an attempt to reduce falls or increase the stability of the user. Other factors that contribute to the success of a design are ease of use and ergonomics. Thus, patents that improve the human walker interface will be relevant to the design. Patents that address other factors such as manufacturability and ease of transporting the walker when it is not being used will also be discussed.

2.9.1 Method and Apparatus for Gait Measurement (Patent No. 5511571)

If the improved walker is going to actively prevent someone from falling, it will need a means of determining when the user is falling or becoming unstable. Patent number 5511571 addresses this need by providing a method and device that measure gait. Strain gauges, which can be used to determine loads, are installed on the assistive walking device. This system can be installed on a walker, cane, or crutches, but the preferred embodiment is a walker (Figure 12) with 24 strain gauges (14-37) mounted onto it.

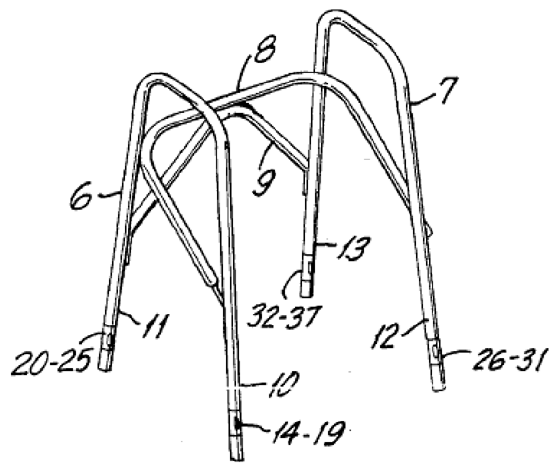


Figure 12: Patent No. 5511571

The strain gauges are mounted towards the bottom of each of the four posts as shown in Figure 13. They are positioned such that they can determine the axial, bending and torsional loads on the walker. This information is used to determine what percentage of the user's body weight is being supported by the walker, as well as their body position relative to the walker. This information would be applied to determine if a person is falling and could trigger or start in motion another system to prevent the user from falling.

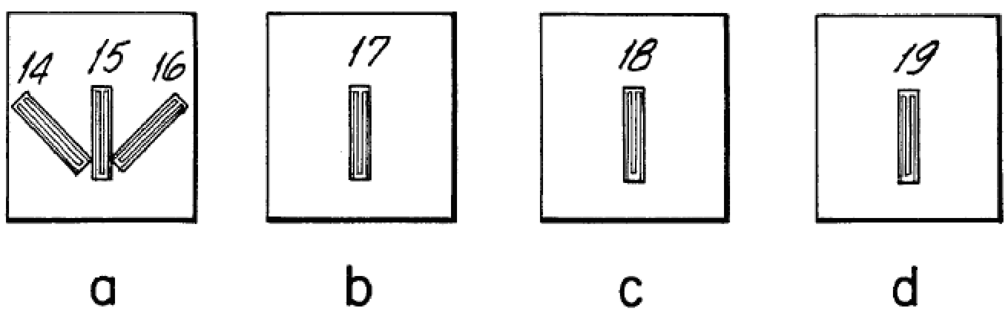


Figure 13: Placement of Strain Gauges on left rear Leg (a-front quadrant which faces patient as the walker is used, b-quadrant facing to user's left, c-quadrant facing away from user, d-quadrant facing to the user's right) (Patent No. 5511571)

2.9.2 Walker (Patent No. 4387891)

If a walker needs to be picked up each time the user takes a step it can be destabilizing as well as tiring. The objective of patent No. 4387891 (Figure 14) is to allow the user to advance forward without lifting the walker. The walker has two “spoked” wheels (2 and 4), connected by an axle (88) located at the bottom of the front two legs. The spokes are offset so that the device can only be advanced by the user shifting their weight from one side of the walker to the other. Figure 15 shows the left and right views of the walker frame. When one side of the walker is resting on two of the spokes of its wheel (2) the other side is resting on one spoke (4). When force is applied to the side that is only resting on one spoke, the wheel will move forward and rest on two spokes. Because the wheels are on the same axle (88) this motion moves the other wheel (2) onto one spoke. This process continues and the user is able to advance forward. This advancement process eliminates the need for the user to lift the walker between each step. This allows the walker to maintain surface contact with as many points as possible during use, which increases the user’s stability.

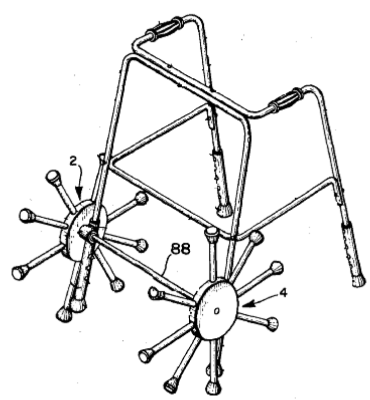


Figure 14: Patent No. 4387891

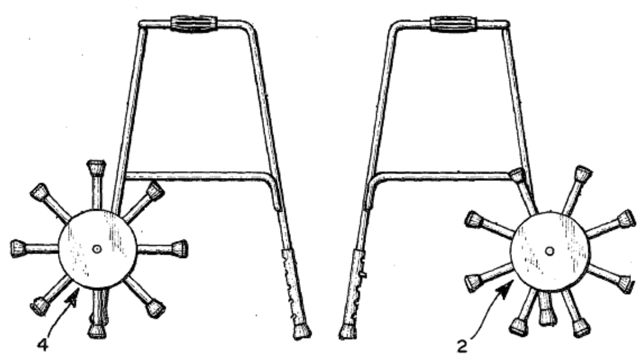


Figure 15: Side View of Patent No. 4387891 Highlighting Offset of Spokes on Wheels

2.9.3 Armrest Rolling Walker with Removable Utility Tray (Patent No. 7547027)

This patent, No. 7547027 (Figure 16), is a walker that includes armrests (40 and 22) and a cylindrical pistol grip (28). The design helps to keep the user within the BOS by providing armrests to keep the user behind the walker and following the path of movement. The armrests also distribute the load that the user puts on the walker. The walker is taller than the traditional walker so that the user can comfortably rest their arms on the armrests. This design is based on a conventional Rollator, which includes a seat (16), four wheels (11a and 11b), a braking system (42 and 48), and can collapse for storage. The user can engage the brakes by squeezing the brake handle (42) towards the grip (28). This design also includes a tray table (54) that can attach to the tops of the armrests (22) of the walker. The tray table fits on top of the armrests and does not change the how the walker is used, but it does force the user to stand back further, moving their center of mass outside the base of support provided by the walker. With the height modification and the armrests, this design distributes the load of the person over their hand and arm, reducing the strain on their wrists. This walker also incorporates a seat in case the individual becomes fatigued during use (Bohn, 2007). One drawback to this design is the position of the seat, which appears as though it might inhibit the motion of the user's feet, and is positioned such that the user has to turn around to use it.

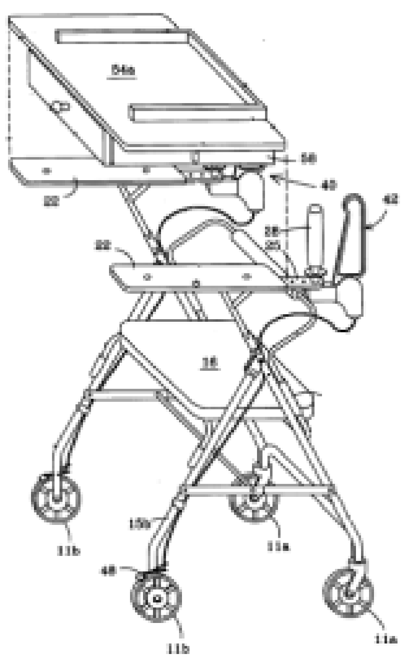


Figure 16: Patent No. 7547027

2.9.4 Walker (Patent No. 5040556)

Patent number 5040556 (Figure 17) aims to improve the standard walker by increasing stability, decreasing the required resources for use, and helping to decrease the user's momentum in the event of a fall (Raines, 1991).

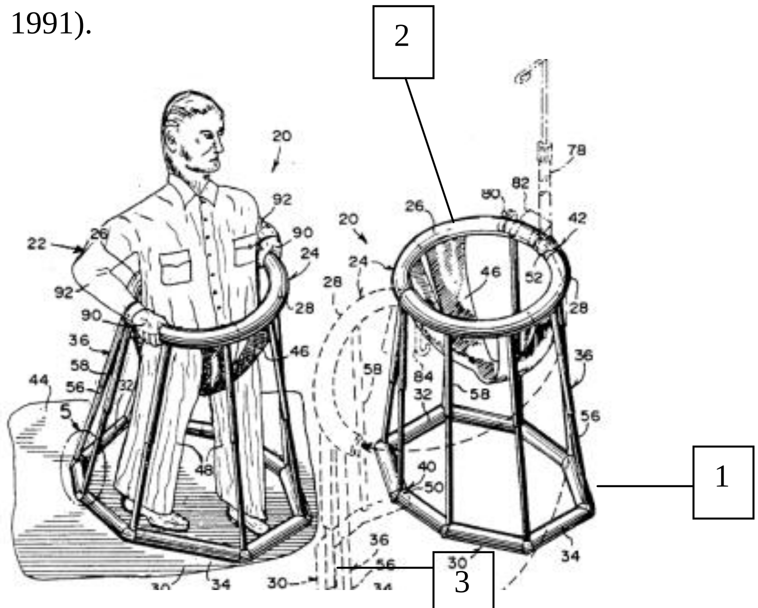


Figure 17: Patent No. 5040556

Unlike the current walker design, this design completely encloses the user. In order to allow the user to enter the device, the side of walker opens like a gate (3). The harness (2) can also detach from the frame (via a clip) to allow the user to enter and then can be clipped back to the device, thus securing the user. This design enhances stability through the passive means of increasing the BOS (1) and adding the harness (2). The harness controls the user's COM by ensuring it is always within the BOS, thus decreasing the user's chances of falling in any direction. The harness also catches the user if a fall does occur and will support them, while the user regains their balance. The device is also easy to use because it is omnidirectional and the individual is able to operate the walker by simply walking; pushing or lifting the walker is not required. The drawbacks of this design are its aesthetics and its footprint, or base. The design resembles a baby walker which would most likely make users very self-conscious, and unwilling to use the walker. Also, the footprint is very large, severely decreasing its maneuverability.

The way this patent achieves its improvements to the current walker design aligns with the team's project goals. This patent extends the BOS to increase stability, and adds a harness to control the user's COM, which ensures the individual, will never move out of the BOS. The patent does not require the user to lift or push the walker, thus limiting the user's actions as well. All of these features provide a more stable walker that decreases falls in any direction.

2.9.5 Walker (Patent No. 4770410)

Patent number 4770410 (Figure 18) is very similar to the previous patent.

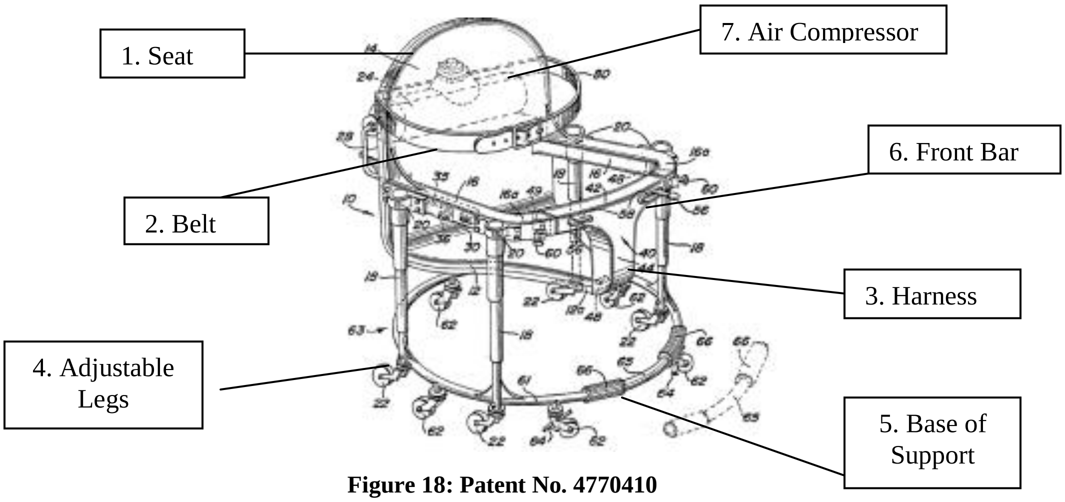


Figure 18: Patent No. 4770410

It aims at improving the traditional walker design by increasing stability, increasing safety, and incorporating an easily accessible seat (Brown, 1988). To use this device the individual stands behind the front bar (6) and is strapped to the seat (1) via the belt. The belt and harness work together to secure the user within the walker, therefore controlling the COM. Stability and safety are achieved through various features including the large BOS (5), the belt (2), and the harness (3). The large BOS prevents the walker from tipping and the belt ensures that the user stays within the BOS, which decreases their chances of falling while using the device. The belt and harness are able to support the user in the event of the fall, which will help the user regain stability and balance. Furthermore, this device has an easily accessible seat (1) that is behind the user. Current walker designs have seats that are positioned in front of the user, which require the individual to turn around in order to use the seat. Turning around can be a dangerous activity for the elderly and increases their chances of falling. This design minimizes this risk by eliminating the need for the user to turn around in order to use the seat. If the user desires to utilize the seat aspect of this design, they must adjust the length of the device's legs (4). The user can adjust the leg heights through controls on the arm that regulate the air pressure provided by the air compressor (7). The individual can then simply sit down, and does not have to turn around. Therefore, the adjustable legs allow the user to operate the device standing or sitting because their feet are always in contact with the ground allowing them to ambulate in either position. When seated, the user's COM is lower to the ground, which increases stability as well. One disadvantage of this patent's design is the large footprint. Even though a large BOS is advantageous for stability, it impedes maneuverability and makes transporting the device difficult.

This patent is similar to the previously mentioned patent (5040556) because its improvements are met through goals that are similar to the team's project designs as well. This patent extends the BOS to increase stability, adds a harness to control the user's COM, and limits user's actions that would make the user/walker system unstable. All of these features provide a more stable walker that decreases falls in any direction.

2.9.6 Walker (Patent No. 5803103)

Patent No. 5803103 (Figure 19) makes several modifications to improve the user interface with the walker. There is one handlebar (11) with grips across the front of the walker instead of the typical two grips on either side of the user. The user can also place their arms on the armrests (10), which can adjust laterally (13). The design is aimed at improving the stability of the user by allowing the height of the frame to adjust (12) to the height of the user's elbows, which allows the user to support more weight with less effort. The four wheels of the walker have been modified. The front two wheels (4) are castors and the rear wheels (5) include a mechanism that provides resistance in the reverse direction. This feature improves the safety of the walker by allowing the user to decide how fast the wheels are allowed to turn.

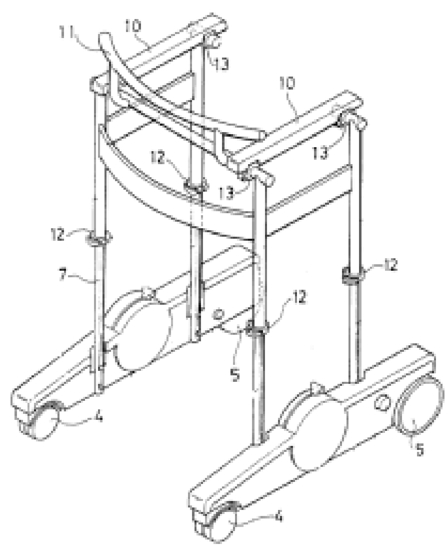


Figure 19: Walker (Patent No. 5803103)

Although all of these patents are aimed at improving some aspects of the standard walker, none of them resemble a standard walker. In order for a design to be successful the user must want to use the device. For this reason, one of the goals of this project is to improve the current walker design while maintaining the traditional appearance of a walker.

3.0 Product Specifications

Product specifications were developed to evaluate the performance of our device in improving the current walker. They were divided into three categories based on how important they are to the success of the design. These categories are critical, important, and desirable.

3.1 Critical Specifications

Walker must provide more assistance than the standard walker in stopping the user's fall, by either extending the Base of Support or controlling the user/walker system's center of mass

- Current walkers are designed to increase stability and balance as a means of preventing falls when walking. However, in the event of a fall, the standard walker does nothing to help the user stop their fall; instead the walker will tip over with them (Deathe, Pardo, Winter, & Hayes, 1996).

The walker frame must not have obstructions other than the walker's feet that are less than 1 ft. off the ground

- A study has shown that when a lateral stepping reaction is induced the user's leg collides with the walker 31% of the time. The study also proved that when the horizontal crossbars were redesigned to be higher off the ground, the user's leg collided with the walker only 14% of the time when the lateral stepping action was induced (Maki et al., 2008).

Vertical supports must be at least 18 in. apart laterally.

- In order for the consumer to use the walker it must not get in the way of the user's feet. The width of unstable elderly people's gait varies significantly and increases the less stable they are (Woolley, Czaja, & Drury, 1997). Therefore, the specification is based on the 95th percentile of the women's waist width (17.4 in.), which is larger than the men's (Goldsmith, 1976).

Must be no wider than 32 in.

- This is the ADA standard for doorways and will allow the user to travel through all handicapped accessible doorways (United States Department of Justice, 2002).

Must not have a depth greater than 26 in.

- This specification aims to ensure maneuverability by setting the maximum depth of the walker equal to the average depth of the largest commercially available walker, the Rollator.

Must be able to support 184 lb.

- This requirement ensures that the walker can support anyone that weights no more than a 50% percentile elderly male. Walkers are predominantly used by women and the standard commercially available walkers are made to fit the ergonomics of this demographic.

Must not require the user to lift more than 7 lb. when walking

- The average weight of a typical walker is 7 lbs (1800Wheelchair, 2009). There are negative effects of having a heavy walker. It can lead to instability, place increased strain on the user's upper body joints, and increase the energy needed to walk (Bateni and Maki, 2005). Thus, it was determined that the user should not be required to lift more than 7 pounds in order to minimize any negative effects of the walker.

Must be adjustable from 32.5" to 39.5" in height

- This specification ensures that the walker is adjustable to the same heights as the standard commercially available walkers.

3.2 Important Specifications

Must not make the user feel more self-conscious than if they were using a current walker

- If users are not willing to use the device because of a stigma associated with it, then the improvements of the design will not matter.

Must limit by design user actions that might cause the user/walker system to become unstable –such movements include using the walker in an over extended position so the user's feet are completely outside of the walker and having to manually activate the brakes

- Using the walker in an overextended position causes the user to be outside the BOS provided by the walker, and therefore increases their risk of falling. Also, requiring the user to activate the brakes places dependence on users who sometimes have difficulty activating the brakes due to poor motor skills and cognition.

Must be able to fit in an 18 x 22 x 31 in. space when being transported

- This specification enables the user to transport the device. The space is based on average dimensions of a walker (not collapsed) which can fit in most cars.

Must not cost more than $110

- The walker should not be too expensive because its users are elderly people, a large portion of which have low income and rely on social security. However, the added benefits of the design warrant a higher cost than the common walkers. The benchmarking showed prices averaging around $70 for no wheeled walkers, $101 for two wheeled walkers, and $107 for four wheeled walkers.

Must be able to use on all common indoor and outdoor surfaces (i.e. rugs, grass, pavement, and tile)

- This specification would enable the user to use the walker to help them move on most surfaces they would encounter.

Must be able to use on curb ramps with slopes less than or equal to 1:10 (Figure 20) and ramps with slopes (Figure 21) less than or equal to 1:12

- This is the ADA standard for curb ramps and ramps, which will enable the user to travel on all handicapped accessible areas. The maximum rise for ramps that incorporate the ramp ratio shall be 30 in. long (United States Department of Justice, 2002).

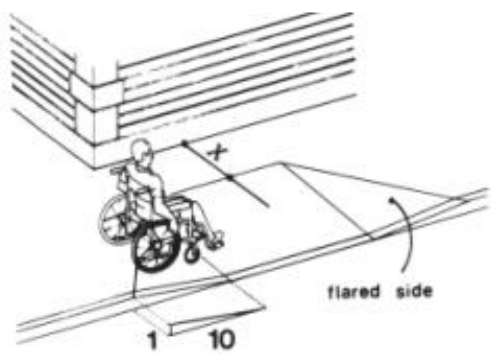
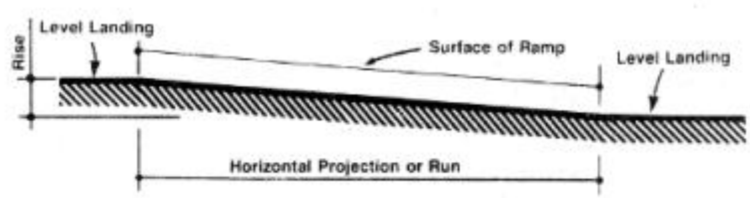


Figure 20: Sides of Curb ramps flared sides (United States Department of Justice, 2002)



	Maximum Rise		Maximum Horizontal Projection	
Slope	in	mm	ft	m
1:12 to < 1:16	30	760	30	9
1:16 to < 1:20	30	760	40	12

Figure 21: Components of a ramp run and sample ramp dimensions (United States Department of Justice, 2002)

Must not have any sharp edges

- This specification ensures that the user cannot be cut by the walker.

Must not have any pinch points

- This specification will help to ensure the safety of the user.

Must be able to withstand everyday use for 2-3 years

- This is the average use of walkers and in order for the device to be competitive with other devices it must be able to last that long.

3.3 Desirable Specifications

Must come assembled

- The people who need this device have limited motor function thus it must be easy for them to assemble.

Must have a minimum number of custom made parts

- This specification will help to ensure manufacturability.

Hardware for design should be minimized (i.e. using as few different fasteners, etc.) as necessary.

- This specification will help to ensure manufacturability.

4.0 Preliminary Designs

All of the designs that were developed aim at reducing falls by means of one or more of three fundamental strategies to reduce falls. The first of these strategies is to extend the Base of Support, so that the center of mass of the user/walker system will have to travel further to be outside of its base. The second method is to control the user's center of mass, so that it is less likely to move outside its Base of Support. The final method is to control the user's actions that may cause the walker to become unstable, leading to a fall.

4.1 *Foam Pad* Design

The goal of this walker is to increase stability and limit users' actions that may cause them to become unstable. This design (Figure 22) is consistent with the standard walker design because it also has identical side frames (1) that attach to the front frame (2). The design has two wheels (4) in the front and two rubber stoppers (5) in the back.

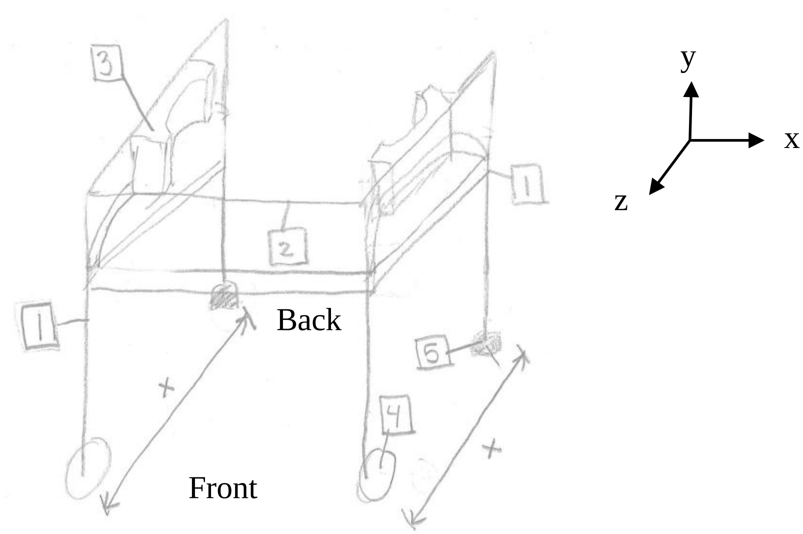


Figure 22: *Foam Pad* Design

Stability is increased through the passive means of expanding the Base of Support and using a guidance system to control the user's center of mass. The depth of the side frames is increased (distance x), along the z-axis, to help keep the user inside the Base of Support of the walker. Furthermore, foam padding (3) is added to the side frames and serves two purposes: limit user actions that may make the system unstable and control the user's center of mass. The user's actions are limited by the foam padding because it helps guide the user when they are ambulating with the walker. The foam padding is formed to a specific shape that helps keep the walker from moving too far away from the user. This increases the likelihood of the individual using the walker correctly, thus decreasing the probability of falling. The foam padding also controls the user's center of mass passively by indicating where the user is supposed to stand when using the walker. When the user enters the walker, the front of their thighs should be near the protruding part of the foam padding (Figure 23, Number 6) closest to the front of the walker. The user holds onto the grips (8) and pushes the walker in front of them, until their hamstrings are almost touching foam padding in the back (7). The padding provides visual cues to the user so that they know when they should push the walker or take a step.

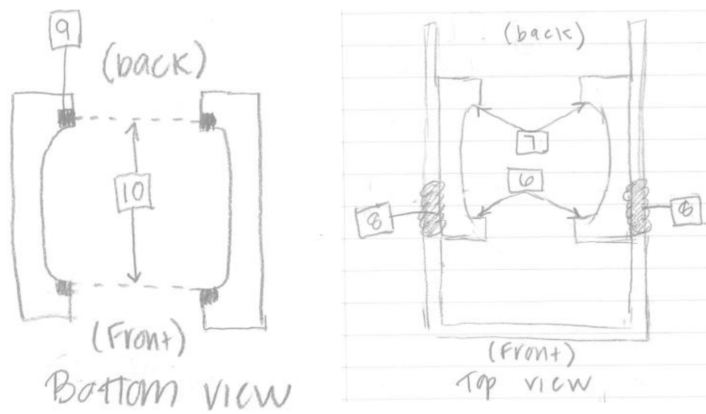


Figure 23: Top and Bottom Views of *Foam Pad* Design

Another aspect to this design is an active mechanism, which includes motion sensors and braking mechanism. This system would ensure that the user remained within the Base of Support when the device was moving. It would have two sensors mounted on the device (Figure 23, 9). They would be mounted on level with the grips and would run along the front and back protruding edges of the foam (6, 7). The sensors would detect if something was in between the back and front edges of the foam (10). The sensors act as switches, which would control a set of brakes that would be installed on the wheels of the walker. When the user's legs touch the back protruding edges of the foam (7), the brakes will be activated. The brakes will remain locked until the user's thighs trip the sensors on the front edge of the foam (6). This system would ensure that the consumer was not using the walker in an overextended position. Ensuring the user's center of mass is always within the Base of Support will decrease their chances of experiencing a lateral fall. The foam padding constrains the user's actions when utilizing the device, and therefore decreases the probability that the device will be improperly used and cause a fall.

4.2 *Counter-Weight Walker* Design

This design (Figure 24) uses a moving mass to increase the stability of a walker and actively arrest falls, by controlling the center of mass of the user/walker system. The mass (4) would be on a slider (5) that sits on the front of the walker out of the way of the users legs. It would most likely be installed directly under the front horizontal bar (1). As the user begins to fall the mass would move in the opposite direction in order to keep the center of mass of the user walker system within the Base of Support.

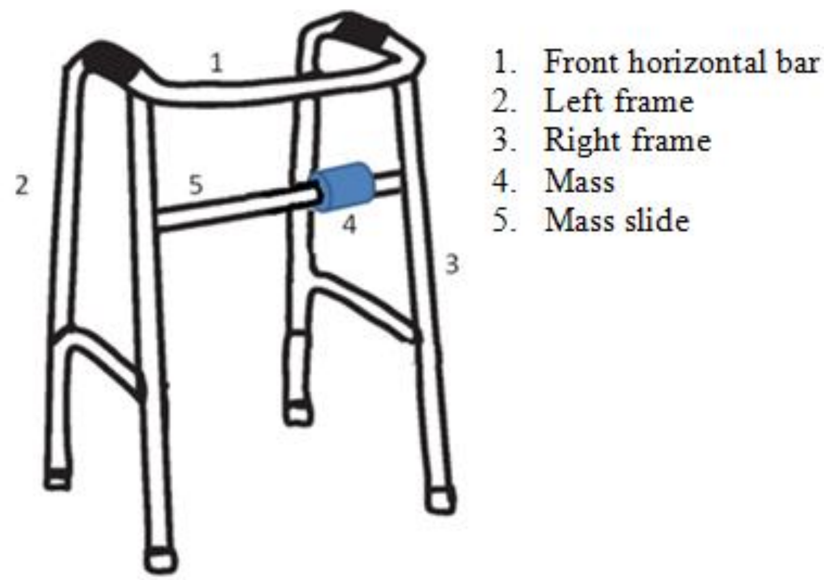


Figure 24: Isometric View of *Counterweight Walker* design

4.3 *Passive Kickstand* Design

The *Passive Kickstand* design attempts to arrest a lateral fall by increasing the Base of Support of the user/walker system when the walker begins to tip. This design could be incorporated into a standard or two wheeled walker, but it is discussed here as a modification to the standard walker. It involves four short bars that stem out from the four legs of the walker (Figure 25). If the walker begins to tip over, the short bars would hit the ground, stopping the walker from continuing to tip, and preventing the user from falling. The small bars would be angled downward and laterally away from the center of the walker as illustrated in the back view of Figure 25.

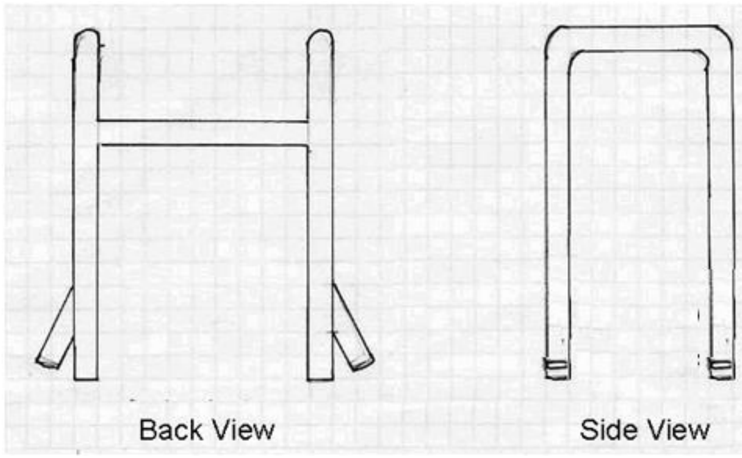


Figure 25: Front and Side Views of *Passive Kickstand* Walker Design

The advantage these legs would have over simply widening the current walker's base is that the amount by which they increase the Base of Support is greater than the width that the bars add to the walker. The short bars extend the Base of Support in the direction of the fall, but only when the fall is occurring. This is illustrated in Figure 26, which shows the width of the bar (x) and distance from the bottom of the leg to the bottom of the bar when the walker is in the tipped position (k). Because k is the hypotenuse of the z, y, k triangle, k is always larger than y. Thus, the Base of Support is extended by more than it would be by merely putting the posts y distance further apart. The length and angle of the bars are irrelevant how much stability is gained by the added bars. The added stability is based on the location of the bottom of the bar.

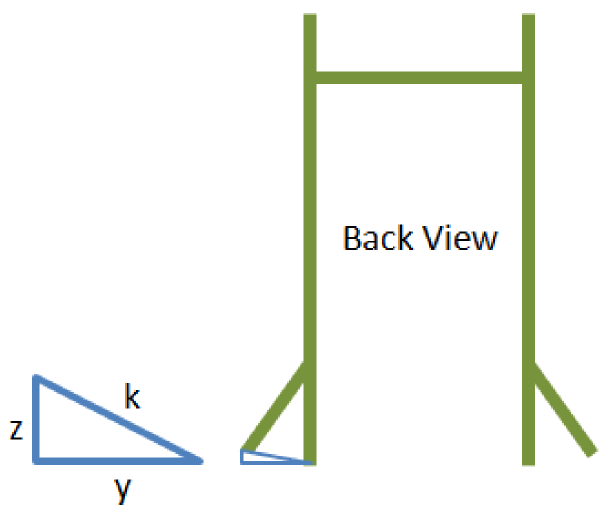


Figure 26: Back View Illustrating the Base Extension (k) is Larger than the Width the Bar Adds to the Walker(y)

4.4 *Active Kickstand* Design

This design was created to prevent lateral falls when using a walker through temporarily expanding the Base of Support (Figure 27a). When the walker becomes unbalanced the extra supports (Figure 27b) will swing out from the side of the device. A combination of push sensors and inclinometers would be used to sense when the system is about to tip over and trigger the spring loaded mechanism that would cause the legs to come out. This design could be applied to a standard or two-wheeled walker.

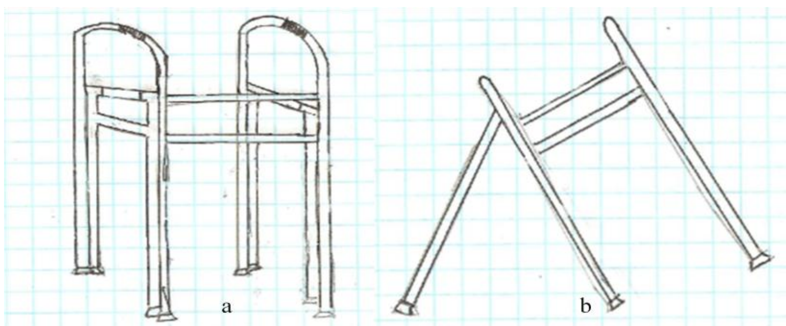


Figure 27: The four extra legs will remain in between the walker's side frames (a), until a lateral fall, when the legs will swing outward (b).

The bottom of each foot on the extra legs would have a rubber stopper that would provide friction to impede the user/walker system's lateral motion. The two extra legs would be stored against the side frame. Keeping the extra legs close to the original side frame provides the user nearly the same maneuverability as a standard or two-wheeled walker. When the extra legs are being deployed, a locking mechanism will stop the movement of the extra legs at the correct position. This locking mechanism could be a bar linkage, slider linkage, or another mechanism. One possible embodiment of this mechanism is a fourbar linkage (Figure 28a) that stops the motion of the legs by entering into a toggle position (Figure 28b).

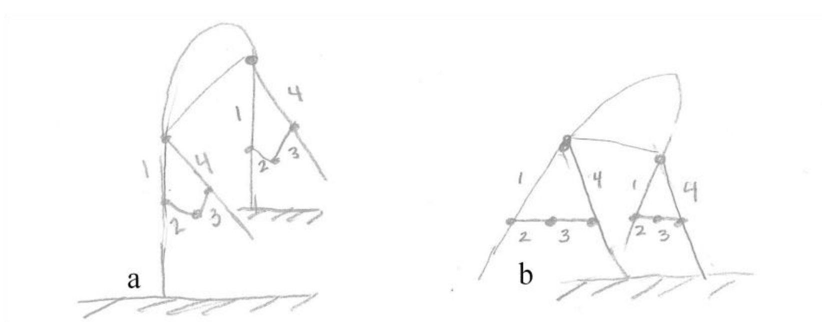


Figure 28: Fourbar linkage in the *Active Kickstand* Design (a) non-toggle position, b) toggled position)

The extra legs could be reset by the user maneuvering the locking position back in to its stored position or by an automated device.

This design increases the Base of Support of the walker actively and temporarily, so that the walker is more stable in situations where the user is falling, but is essentially as maneuverable as the standard walker during normal use. When the user is falling, this walker acts to arrest the user's lateral fall by stabilizing the walker and arresting the momentum of the user.

4.5 *Adult Baby Walker* Design

The *Adult Baby Walker* design improves upon the standard walker by increasing the stability, assisting in arresting the user's fall, and limits the user's actions that create the system to become unstable. Stability is increased through passive means including extending the Base of Support and incorporating a harness. The large Base of Support decreases the probability of the walker tipping over and injuring the user. The harness also increases stability by controlling the user's center of mass. The harness does not allow the user's center of mass to move outside the Base of Support, which decreases the chances that the user will fall in all directions. The harness also supports the user and assists the user when they are falling by decreasing their momentum so they are able to regain their balance. The *Adult Baby Walker* design is also omnidirectional, which makes this device more mobile and easier to user than the current walkers. The user's actions are also limited because in order to use this design, they must simply get into the device, secure themselves within the harness, and walk forward. The current walkers require the user to follow a process of lifting/pushing the walker in front of them, stepping into the device, and continuing this motion to move forward. Simplifying the required resources to operate the device and limiting the user's actions that may make the user/walker system become unstable, ensures proper use and decreases the chances of falling.

5.0 Analysis of Preliminary Designs

5.1 Analysis of Counter-Weight Design

The counter-weight design was analyzed to determine what magnitude of mass would be necessary to arrest a fall. A free body diagram of the situation was developed (Figure 29). The magnitude of the mass was solved for by balancing the moments created by the mass, walker, and person (Appendix A).

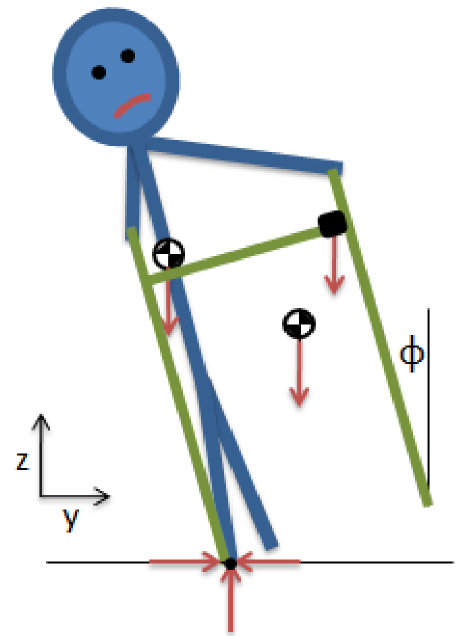


Figure 29: Schematic for Analyzing the Counter-weight Design

It was determined that the mass would need to weigh at least 30 lbs to stop the biggest user from falling. This weight would make it hard to maneuver the walker because even if the walker was on wheels, the user would have difficulty traveling on inclined surfaces and over a change of surfaces. It would also make transporting the device difficult because it is unlikely that the user could lift it into a car unassisted.

5.2 Analysis of Passive Kickstand Design

A static analysis was conducted to determine how far the kickstand would have to extend horizontally from the base in order to arrest the user's fall after they have fallen through a certain angle (Appendix B). To determine this, a free body diagram of the walker and the user was created (Figure 30).

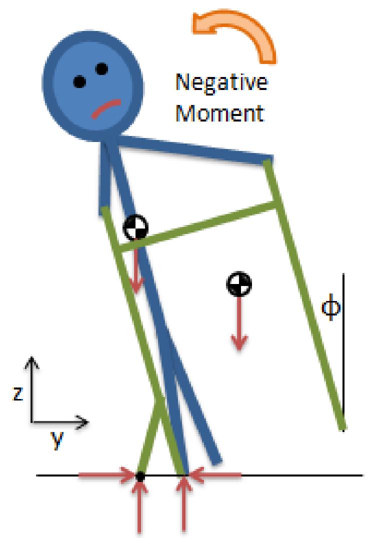


Figure 30: FBD of Person Falling With Walker

Using MathCAD, the moments created by the walker, person, and ground were calculated as a function of the kickstand's vertical height and horizontal displacement. The moments on the walker were plotted as a function of the horizontal distance of the mechanism (y), and the height of the mechanism was varied manually (Figure 31).

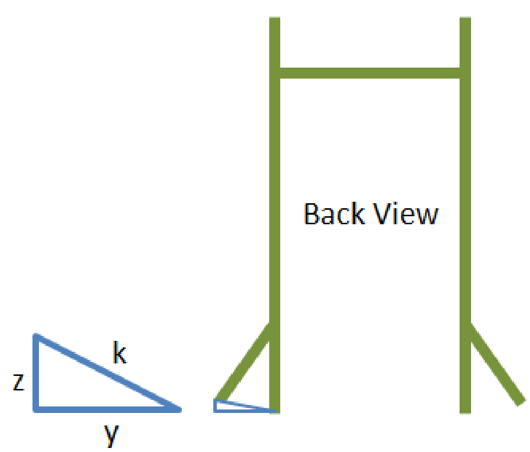


Figure 31: Back View of Walker and Label of Kickstand Dimensions

According to the coordinate system specified, the moment on the walker had to be zero or greater in order for the system to stop falling. The moment created by the kickstand increases as the horizontal distance the kickstand is from the base increased. This is illustrated in the plot of the moment of the system as a function of the outward distance of the kickstand in Figure 32. For this plot the height of the kickstand (z) was held constant at .25 inches.

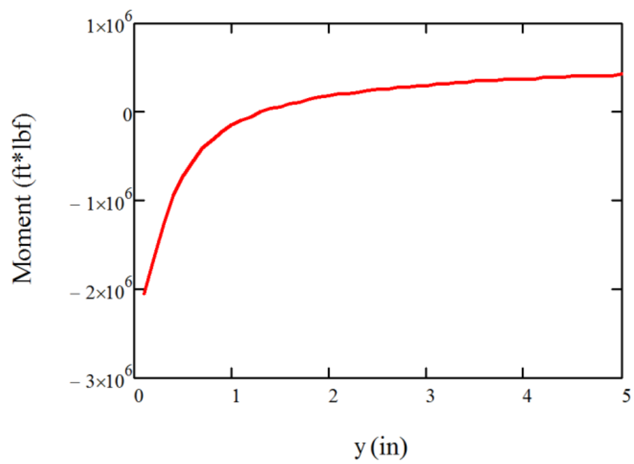


Figure 32: Moment of System as a Function of Horizontal Offset of Kickstand

The angle which the system falls through before the kickstand contacts the ground decreases as the horizontal offset distance of the kickstand is increased when the height of the kickstand is held constant. The behavior of this is illustrated in the plot of the angle as a function of the horizontal offset of the kickstand (Figure 33).

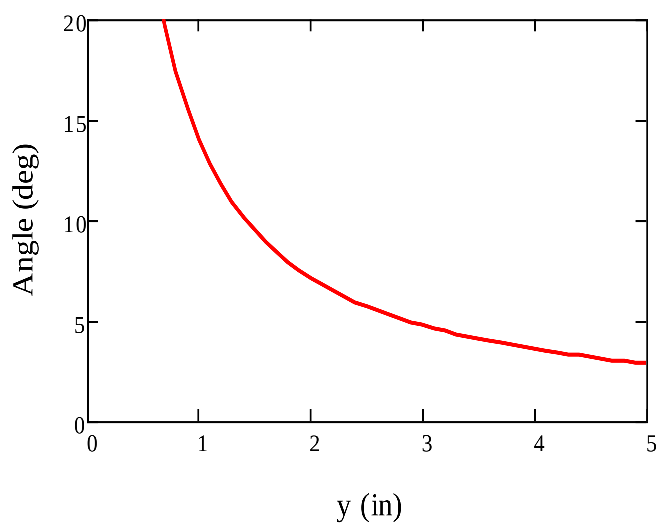


Figure 33: Angle of System from Vertical as a Function of Horizontal Offset of Kickstand

The moment and angle are also affected by the height the kickstand is off the ground before the walker begins to tip. The moment decreases and the angle of displacement increases as the vertical displacement (z) of the mechanism increases. This behavior is illustrated in the plot of the moment and angle of the system as a function of the horizontal offset plotted for several different vertical heights (Figure 34 and 35).

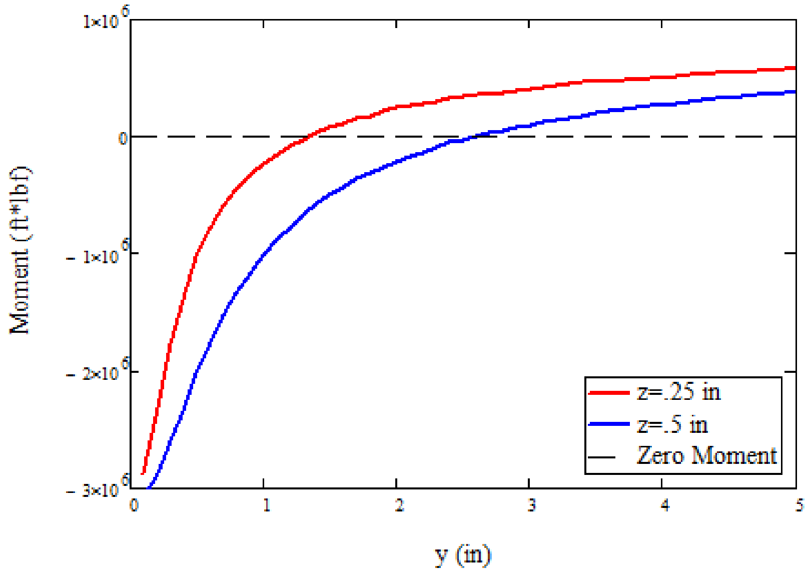


Figure 34: Moment on Walker vs. Horizontal Placement of Support

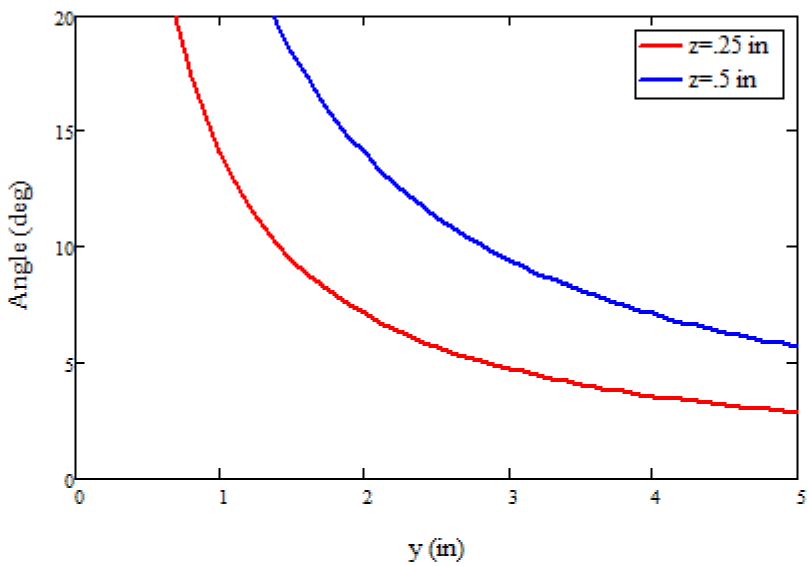


Figure 35: Angle of Displacement from Vertical of Walker vs. Horizontal Placement of Support

Thus, in order for the moment to be positive when the kickstand contacts the ground and for the person not to fall through a large angle before they are stopped, the height of the kickstand needed to be as small as possible. The initial vertical distance from the ground was set at no less than 0.25 in because having the kickstand too low could result in the user catching the kickstand on uneven ground. A passive kickstand would be capable of stopping a person from falling; assuming that they fall in the predicted manner, without extending the walker 5 inches horizontally, which means it would be within the width specifications. Through this analysis it was determined that a kickstand device would be plausible for stopping a user from falling.

5.3 Analysis of Active Kickstand Design

The inactive and active kickstand designs are based on the same principle of extending the base. Thus, the analysis just discussed also proves that an active kickstand would be capable of stopping a user's fall under the same assumptions of the static analysis.

Next, a dynamic analysis of the system was conducted. For this analysis, a rigid inverted pendulum model was used to calculate the motion of the system. The equation of motion for a rigid inverted pendulum is shown below. In order to calculate the motion of the system the moment of inertia (I), mass (m), and length to center of mass (l) needed to be determined. Also, the initial conditions velocity (ω) and displacement (θ) must be known.

$$I\frac{d^2\theta}{dt^2} = mlg\sin(\theta)$$

As discussed in the background section, studies of people subjected to perturbations while using a walker revealed that the there are three common ways people step when reacting to falling with a walker. These stepping reactions are the counter-lateral step (CLS), crossover step (COS), and side step (SS) (Bateni and Maki, 2005)

Using the Mannequin software for Pro/E, a 50th percentile male was moved into positions that represent the location of the person's body parts while carrying out these stepping reactions in response to falling (Figure 36). A 50th percentile male was used for these calculations as he represents the worst case scenario in that he is the tallest and heaviest of all walker users. Because walkers are used by the elderly, who lose height as they grow older and are predominantly elderly women, it was assumed that the 50th percentile male would be the largest person to reasonably use a standard walker. The pendulum was assumed to rotate around the person's right foot. This point was taken to be the origin for all of the calculations.

Figure 36: Pro-E Model Configured in the Process of Carrying out Stepping Reactions, from left to right: Counter-Lateral Step, Crossover Step, and Side Step.

The moment of inertia of the person in these three positions was determined using the mass properties function within Pro/E. The distance from the center of mass to the person's right foot was measured so that the moment of inertia around the person's right foot could be calculated. Also, the distance of the center of mass from the origin was calculated.

In order to determine the moment of inertia of the entire system, the moment of inertia of the walker also had to be calculated (Appendix C). To approximate the mass per unit length of the tubing, the mass of the walker was divided by the length of tubing. Using the walker dimensions, the mass and locations of the COM of the components of the walker were determined (Figure 37). The moment of inertia of each component was calculated and then the moment of inertia for each component around the x axis was calculated using the parallel axis theorem.

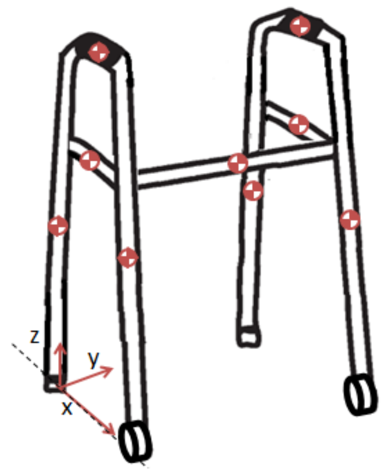


Figure 37: Image of Walker Depicting COM of Walker Components

The initial velocity for the counter stepping reaction was taken to be zero, because it is assumed that the person is flailing their left leg in order to move their COM away from the direction they are starting to fall, but not actually tipping their body. The two other stepping reactions were assumed to have an initial angular velocity of 5.901 deg/s. They were assumed to have a velocity because the person is actually moving their entire body towards the direction of the fall as the person steps. They were given the specific linear velocity of 3.937 in/s because this is consistent with perturbations experienced by people in trials for lateral falls (Maki, 2000). As the person begins to tip and fall their linear velocity is transformed into angular velocity which was calculated using the height of the person's center of mass. The various initial conditions for the three different systems are shown in table 2.

Table 2: Values and Initial Conditions for the Three Stepping Reactions

Stepping Reaction	Vertical Location of COM	Moment of Inertia Around Origin	Initial Angular Velocity	Initial Angular Displacement
CLS	41.90 [in]	$3.481*10^{5}$[in^{2}lb]	0 [deg/s]	0.5 [deg]
SS	38.30 [in]	$3.213*10^{5}$ [in^{2}lb]	5.901 [deg/s]	0 [deg]
COS	41.90 [in]	$3.210*10^{5}$ [in^{2}lb]	5.901 [deg/s]	0 [deg]

Having determined the values and initial conditions, the velocity and displacement were solved for using a differential equation solver in MathCAD (Appendix D). Plots of the displacement angle and angular velocity are shown below (Figure 38 and Figure 39).

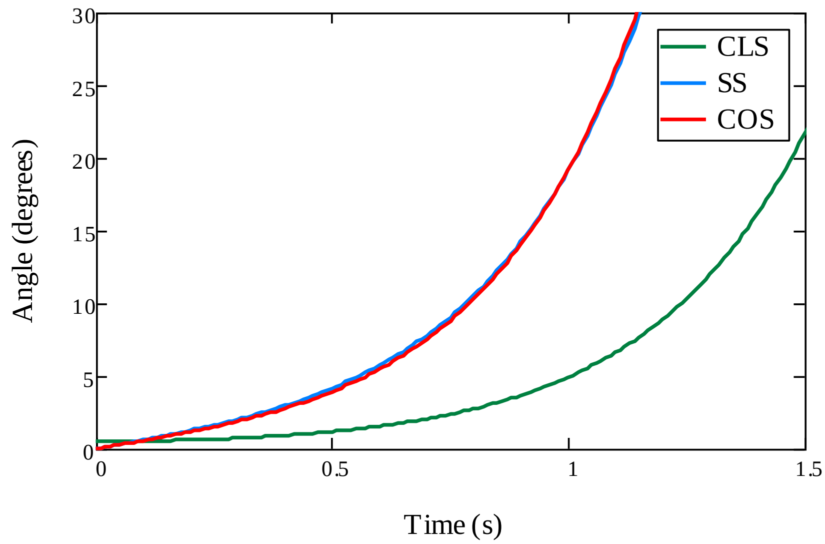


Figure 38: Plot of Displacement Angle vs. Time for the Three Stepping Reactions

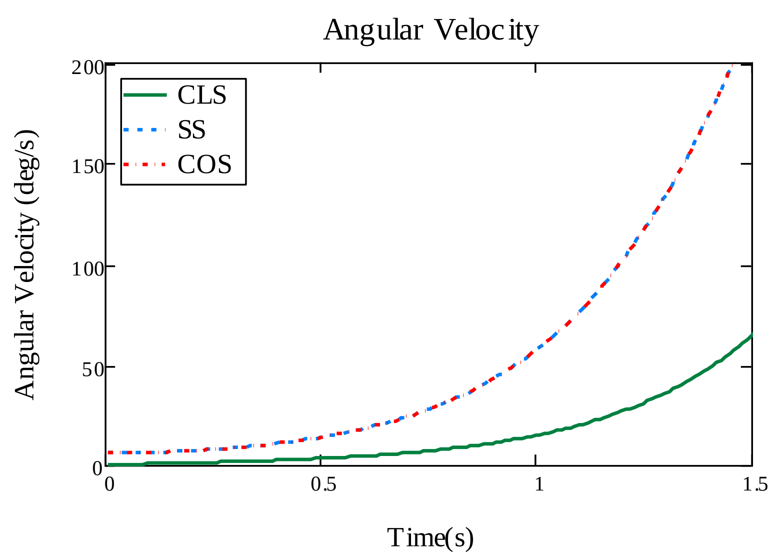


Figure 39: Plot of Angular Velocity vs. Time for the Three Stepping Reactions

After experimenting with larger values of θ, it was determined that having the device activate at 5 degrees and arrest the fall by 10 degrees would be adequate. Stopping the user's fall at a later point means that the horizontal displacement of the kickstand would need to be greater, so this minimizes the nuisance of the passive kickstand and the travel required by the active kickstand. It also prevents falls early before the user is traveling with significant speed and before it gets more difficult for them to return to an upright position.

Adhering to these parameters, the dynamic analysis predicted that an active kickstand device, if triggered when the walker tipped through 5 degrees and stopped the fall at 10 degrees, would have 0.558 seconds to react. The time necessary was calculated for all three reactions and the side step reaction had the smallest reaction time with 0.558 seconds. Although this might be plausible, it puts serious constraints on the methods used to move the kickstand, because of the limited time it would have to move to the appropriate position.

6.0 Design Selection

This section details how the final design was chosen. The first step was to evaluate the design specifications. These specifications were compared using a pairwise comparison chart. Afterwards, weights were given to each of these design specifications based on how important each were to the design overall. A rubric was created for each design specification with a scale from 1-5 with a score of 5 being optimal and 1 being poor. Using the rubrics each design was evaluated for each of the specifications and scored using the assigned weight for each specification.

6.1 Pairwise Comparison

Before the initial designs were analyzed, a pairwise comparison was constructed in order to determine how important each specification was relative to the others. The specifications in the first column are compared to each specification that is in the first row. A 1 in a cell signifies that the specification in the top row is more important than the specification in the first column. If the specification in the row is more important than the one in the column, than the matching cell has a zero in it. If the specifications have the same importance a 0.5 in put in the cell.

In evaluating the design specifications for this project, it was determined that the two most important specifications are stopping the fall and pinch points/sharp edges. Stopping the fall is a key design specification, because it relates directly to the overarching goal of the project. Without meeting this specification, a design cannot be successful. Pinch points/sharp edges are also a key specification because it relates directly to the safety of the user. The next most important design specification was stigma, because if people are not comfortable using the design, and thus do not use it, than all of the other benefits would be useless. Controlling user actions also scored high because a lot of falls occur because the user is not using the walker correctly. If the user actions were limited and controlled by the device somehow, the number of falls would decrease. The next most important design specification was weight/lifting, because the users of walkers do not have the strength and stamina to be moving around a heavy walker. These were the top four factors that received the highest scores in the decision matrix. The complete list of how the specifications ranked in respect to each other is shown in Table 3.

Table 3: Pairwise Comparison of Design Specifications

	Stop fall	Not obstruct	Foot-print	Strength	Weight/lifting	Adjust-ability	Pinch /Sharp	Stigma	Transport-ability	Life-span	Cost	Env.	User Actions	Score
Stop fall	--	1	1	1	1	1	.5	1	1	1	1	1	1	11.5
Not obstruct	0	--	.5	1	0	.5	0	0	1	1	1	1	0	6
Footprint	0	.5	--	1	0	1	0	0	1	1	1	1	0	6.5
Strength	0	0	0	--	0	0	0	0	1	1	1	1	0	4
Weight/lifting	0	1	1	1	--	1	0	0	1	1	1	1	0	8
Adjust-ability	0	.5	0	1	0	--	0	0	1	1	1	1	0	5.5
Pinch /Sharp	.5	1	1	1	1	1	--	1	1	1	1	1	1	11.5
Stigma	0	1	1	1	1	1	0	--	1	1	1	1	1	10
Transport-ability	0	0	0	0	0	0	0	0	--	1	0	0	0	1
Lifespan	0	0	0	0	0	0	0	0	0	--	0	0	0	0
Cost	0	0	0	0	0	0	0	0	1	1	--	.5	0	2.5
Environment	0	0	0	0	0	0	0	0	1	1	.5	--	0	2.5
User Actions	0	1	1	1	1	1	0	0	1	1	1	1	--	9

Once the specifications had been compared using the pairwise comparison they were assigned a weight from 1-50 (Table 4). These were assigned in order to differentiate the weighting values assigned for the specifications. It also allowed a greater reflection of how important the specifications were overall to the design, and not just relative to each other.

Table 4: Pairwise Comparison Results and Final Rankings of Design Specifications

Design Specification	Pairwise Comparison	Weight
Stop Fall	11.5	50
Pinch Points/Sharp Edges	11.5	N/A
Stigma	10	49
User Actions	9	44
Weight/Lifting	8	35
Footprint	6.5	33
Not Obstruct	6	30
Adjustability	5.5	20
Strength	4	15
Environment	2.5	13
Cost	2.5	6
Transportability	1	3
Lifespan	0	0

The most important design specification, stopping the fall, was given a value of 50. Even though pinch points/sharp edges was equally important, the team decided not to include this factor in the decision matrix because any design could be developed to not have pinch points. Lifespan was also not included in the decision matrix because it is the least important design specifications and would not help in differentiating the designs because they all have similar lifespans.

6.2 Rubrics

Each design was evaluated with each design specification and given a score between 1 and 5 with 1 being the worst and 5 being the best. A summary the rubric for each design specification is below. A complete listing of the rubrics can be found in Appendix E.

Stopping the Fall

Stopping the fall is the most important criterion for this device. The device is created to reduce lateral falls, and if the device cannot stop a fall, it is essentially a standard walker. There are two different ways that a fall with a walker can be stopped: by controlling the center of mass of the system or increasing the base of support. A score of 1 was given if the device could not stop falls better than a standard walker. The score was increased gradually by how well and how many times the device can stop the user from falling.

Vertical Load Strength

The walker needs to be able to support the load of the user while the device is being used. If the walker is not strong enough to support the user's load, the material will fail, and the device will be useless. The 50^{th} percentile elderly (over the age of 65) male has a weight of 185 lb. The walker must be able to support that load across the handles. The rubric classified a 5 as being able to support more than a 185 lb load, a 4 being able to support a 185 lb load, and then 3-1 incrementally supporting less weight.

Stigma

Stigma for the design is another important consideration. If people do not feel comfortable using the design, they will not use it. For the rubric, three aspects were considered: if it has a harness, if it does not resemble a walker, and if it is more bulky than the Rollator (the Rollator has the largest volume of any of the commercially available walking aids). The lowest score includes all three of these aspects and the highest score does not include any of these aspects. Any score in between has a combination of these three aspects.

Environment

The device must be able to be easily used in most environments so users have the ability to travel to most destinations. The most common surfaces that the walker would traverse would be hardwood, pavement, tile, rugs, grass, and brick. For the lowest score, the criterion was a very flat smooth surface with each point progressing slightly until the highest score, which stated that the walker can be used easily on all common indoor and outdoor surfaces and can be used on changing surfaces that are level or have a 1:10 slope.

Transportability

Transportability is necessary for this device because if the device cannot accompany the user to different locations, it will not be useful to many users. The factors in transportability are how much the device weighs, if it can fit into a trunk or backseat of a car, and whether the device can fold to decrease its volume. The lowest score includes that the device weighs more than 8 lb and cannot fit in the backseat of a car. This continues with each higher score providing easier transportability. The highest score is that the device weighs 8 lb or less and can be easily folded to a thickness of 4 in.

Weight

Weight is also a concern with a device such as this because the targeted users do not have unlimited strength. The device must be lightweight enough that users can move it easily to store or transport. The lowest score was that the device weighs more than or equal to 25 lb. As the score increases, the weight range decreases incrementally until the highest score states that the device weighs less than 7 lb.

User Actions that Lead to Falling

Using the walker while outside the base of support and requiring the user to activate the brakes, can lead to falls. The worst that this device could do is to not limit any user actions at all and the best that this device can achieve is to effectively limit both user actions that lead to falls. The middle score is if the device limits one user action.

Not Obstruct Lateral Stepping Reactions

In the event of a lateral fall, the user usually tries to recover by stepping laterally in some pattern. Unfortunately, a horizontal bar on the side frame of the standard walker impedes the user's motion and a fall ensues. The team decided that in order to improve upon the standard walker, the design would not include any horizontal obstructing members less than 1 ft off the ground. For the lowest score, the device would have horizontal bars 6" off the ground or less. The height of the horizontal members gradually increases until at the highest score the horizontal members are 1 ft or more off the ground.

Footprint

The footprint of the walker is of great concern because it is directly related to the maneuverability of the walker. To maintain the same maneuverability as the standard walker, the footprint cannot significantly exceed that of a standard walker. The values for the width and depth of the standard walker are 21 in and 17 in respectively. These dimensions received the highest score. The dimensions gradually increase for the lower scores. The width increases by 2 in and the depth increases by 3 in because it is a bigger concern if the width of the walker is too large.

Adjustability

To create a wide market for this walker, it needs to be adjustable to fit as many users as possible. The standard walker has a maximum height of 39.5 in and minimum height of 32.5 in. The maximum height was decreased a half an inch and the minimum height was increased a half an inch for each gradually lower score.

Cost

Standard walkers are inexpensive, but because of the electronics and sensors that will be needed to sense and stop a walker from falling, the prices were increased with the lowest score rating the design at $140 and the highest score rating the design at $100.

6.3 Decision Matrices

6.3.1 Initial Decision Matrix

The five designs that were evaluated in the decision matrix were the active kickstand, guiding design, baby walker, passive kickstand, and counter-weight design. The first decision matrix included all of the design specifications except pinch points/sharp edges and lifespan because of the reasons stated earlier. In this initial decision matrix, each of the five designs was awarded a 5 for strength, not obstruct, and environment. These designs will use the same material as and be structurally similar to the standard walker, thus they will have similar strength. For not obstruct, all five of these designs will not inhibit the user walking with the walker, will have vertical supports that are more than 26 in apart and will have horizontal supports that are more than 1 ft off the ground. For environment, these designs will have the same wheels as the standard two-wheeled walker and will be able to climb and descend slopes and traverse on indoor and outdoor surfaces. These scores were later not counted to allow the team to easily differentiate between the five designs. The complete results can be seen in Table 5.

The design that scored the highest was the guiding foam design. This design was followed closely by the passive kickstand, baby walker, and the active kickstand. The design that received the lowest score was the counter-weight design. Explanations for scores for each of these designs are as follows:

Table 5: First Decision Matrix

Design	Stop fall	Stigma	User Actions	Weight	Footprint	Not Obstruct	Adjustability	Strength	Cost	Env.	Trans.
	50	49	44	35	33	30	20	15	13	6	3
Foam/Guide	3	4	5	4	3	5	4	5	2	5	4
Active Kickstand	4	4	1	4	5	5	4	5	2	5	4
Passive Kickstand	4	4	1	5	4	5	4	5	5	5	4
Baby Walker	5	1	5	4	1	5	2	5	4	5	2
Counter-weight	2	5	1	1	5	5	4	5	4	5	1
Foam/Guide	150	196	220	140	99	0	80	0	26	0	12
Active Kickstand	200	196	44	140	165	0	80	0	26	0	12
Passive Kickstand	200	196	44	175	132	0	80	0	65	0	12
Baby Walker	250	49	220	140	33	0	40	0	52	0	6
Counter-weight	100	245	44	35	165	0	80	0	52	0	3

Guide/Foam Design

The guide/foam design received a 3 for the stop fall category because it does not actively stop a fall when a fall is happening. Rather it prevents falls from happening by controlling how the user interacts with the walker. If the user is using the walker correctly then the user will be less likely to fall. For the design specification of stigma, the guide foam design received a 4 because this design will still resemble a walker, does not have a harness but is as bulky as a Rollator because of the addition of sensors and an extension to the depth. This design received a 5 for limiting user actions because it corrects any misuse of using the walker and requires the user to use the walker properly. A 4 was given for weight for this design because it will not be much heavier than a standard as the only additional components will be the sensors and the foam. This design received a 3 for footprint because the depth will be expended past that of a standard walker. For adjustability, this walker received a 4 because this walker has a standard walker frame, but the sensors and wires may inhibit optimal adjustability. For cost, this design received a 2 because of the sensors needed to operate it. For transportability, this design received a 4 because this design will resemble a standard walker and can be folded to fit into a trunk or backseat of a car.

Active Kickstand Design

This design received a 4 for the stop fall specification because it effectively stops falls by increasing the base of support by deploying a kickstand in the event of the fall. For stigma this design received a 4 because even though the active kickstand remains in line with the vertical supports when not in use, sensors and space are required to activate the kickstand. To encase these objects, a storage box would be needed for cover. This design received a 1 in limiting user actions because it does not limit how the user uses it at all. It received a 4 for weight because the mechanism and sensors added would not increase the weight of the walker that much. This walker received a 5 for footprint because the active kickstand would not add to the footprint unless there was a fall. For adjustability, this walker received a 4 because this walker should adjust as much as a standard walker, but because of the addition of sensors and mechanisms, the adjustability might be curbed. For cost, this walker received a 2. This walker will be more expensive because of the addition of sensors and mechanisms. For transportability this walker received a 4 because it will still have the ability to fold and fit into a trunk or backseat of a car.

Passive Kickstand

The passive kickstand received a 4 in the stop fall category because it effectively stops a fall by extending the base. It also received a 4 in the stigma category because it does not have a harness, resembles a walker, but is bulkier than a Rollator because of the protruding kickstands. For user actions, this design received a 1 because it does not limit any user actions. For weight, however, this design received a 5 because the added passive kickstands do not add much material to the standard walker. For footprint, this design received a 4 because the kickstands add width to the standard walker. This design received a 4 for adjustability because it should be just as adjustable as a standard walker, but may not be because of the addition of passive kickstand mechanism. For cost, this design received a 5 because all that is necessary is the mechanism for the kickstand. For transportability, this design received a 4 because it will be able to fold to fit into a trunk or backseat of a car and will weigh 8 lbs or less.

Baby Walker

The baby walker design received a 5 for stopping a fall because it has the ability to stop a fall in any direction. Unfortunately, it received a 1 for stigma because it does not resemble a walker, is bulkier than a Rollator, and has a harness. This design will completely surround the user, so it will be much larger than a standard walker and will also have a harness so that the user will be completely supported while on their feet. It received a 5 for limiting user actions because the user will always walk inside the base of support, will inhibit walking continuously with a walker, and will operate the brakes automatically. This design received a 4 for weight because it will weigh between the ranges of 7 to 15 lbs. For footprint, this design received a 1 because it will be much larger than the standard walker's footprint because it completely surrounds the user. This design received a 2 for adjustability because this device surrounds the entire user and a custom width and depth will need to be provider based on the user's body type. For cost, this design received a 4 because it will cost more to manufacture because the base of support surrounds the user, but does not include any sensors. For transportability, this design received a 1 because it is too large to transport in the trunk or backseat of a car.

Counter-weight Design

For stopping the fall, this design received a 2 because it would inconsistently prevent falls by attempting to control the center of mass. For stigma, this design scored a 5 because it resembles a standard walker, is less bulky than a Rollator, and does not come equipped with a harness. This design received a 1 in limiting user actions because it does not attempt to limit any actions that could lead to a fall. For weight this design received a 1 because the counter-weight needed to stop a fall for a 95th percentile elderly man was 30 lbs. This makes the total weight of the design much more than the standard walker. This design received a 5 for footprint however because the counter-weight stays within the footprint of the standard walker. For adjustability, this design received a 4 because it should be able to adjust as much as a standard walker, but may not be able to because of the counter-weight mechanism. For cost, this design received a 2 because of the price of the sensors and devices necessary to move the weight at the correct time. For transportability this design received a 1 because this walker weighs so much that picking it up and putting it into a car would be almost impossible for the elderly.

The total scores from the first decision matrix are in Table 6. The top three designs were the guiding/foam design, the passive kickstand, and the active kickstand. These designs all ranked fairly close to each other as illustrated by the percentage difference in the total scores. The guide/foam design and the kickstands each have high scores in different categories: the guide/foam design scored the highest in limiting user actions and the kickstand designs scored the highest in stopping the fall. Due to the fact that the two kickstand designs and the foam design complimented each other so well, it two hybrid designs were pursued. Hybrid 1 combines the foam and active kickstand designs and hybrid 2 combines the foam and passive kickstand.

Table 6: Total Scores from First Decision Matrix and Percent Difference between Designs

Design	Total	% difference
guide/foam	923	
passive kickstand	904	2.059
active kickstand	863	4.54
Baby Walker	790	8.46
Counter-weight	724	8.35

6.3.2 Final Decision Matrix

In the final decision matrix the initial designs were compared along with the two new hybrid designs (Table 7)

Table 7: Final Design Matrix

Design	Stop fall	Stigma	User Actions	Weight	Footprint	Not Obstruct	Adjustability	Strength	Cost	Env.	Trans.	
	50	49	44	35	33	30	20	15	13	6	3	
Foam/Guide	3	4	5	4	3	5	4	5	2	5	4	
Active Kickstand	4	4	1	4	5	5	4	5	2	5	4	
Passive Kickstand	4	4	1	5	4	5	4	5	5	5	4	
Baby Walker	5	1	5	4	1	5	2	5	4	5	2	
Counter-weight	2	5	1	1	5	5	4	5	4	5	1	
Hybrid 1	4	3	5	3	2	5	4	5	1	5	3	
Hybrid 2	4	4	5	4	2	5	4	5	3	5	4	Total
Foam/Guide	150	196	220	140	99	0	80	0	26	0	12	923
Active Kickstand	200	196	44	140	165	0	80	0	26	0	12	863
Passive Kickstand	200	196	44	175	132	0	16	0	65	0	12	840
Baby Walker	250	49	220	140	33	0	40	0	52	0	6	790
Counter-weight	100	245	44	35	165	0	80	0	52	0	3	724
Hybrid 1	200	147	220	105	66	0	80	0	13	0	9	840
Hybrid 2	200	196	220	140	66	0	80	0	39	0	12	953

Hybrid 1

The hybrid between the active kickstand and the guide/foam design scored a 4 for stopping the fall because it can effectively stop the fall by deploying the kickstand. It scored a 3 for stigma because there will be added components to deploy the active kickstand and sensors for the guiding/foam portion of the walker. These objects will modify the appearance of the standard walker. For limiting user actions, this design received a 5 because of the guiding/foam portion of the design. This design effectively limits user actions that cause a fall. For weight, this design received a 3 because of the added sensors for the guiding aspect of the design and for the added mechanisms for the active kickstand. These components will make this walker heavier than a standard walker. For footprint this design received a 2 because of the guiding aspect. The guiding portion will add depth to the walker so that the user always stays within the base of support of the walker. This design received a 4 for adjustability because it should have the same adjustability as a standard walker, but because of the components of the design, the adjustability might not be the same as a standard walker. For cost, this design received a 1 because it would be the most expensive design because of the sensors needed for the guiding portion and for the active kickstand. For transportability, this design received a 3 because it might not be able to fold with all of the sensors and would only be able to fit in the trunk of a car.

Hybrid 2

This design received a 4 for stopping the fall because it will be able to stop a person's fall effectively by the passive kickstands. For stigma, this design received a 4 because it will resemble a walker and will not have a harness, but will probably more bulky than a Rollator because of the kickstands that permanently eject from the walker. For user actions, this hybrid received a 5 because it should be able to limit all user actions that could lead to a fall. For weight, this design received a 4 because the only added components to the standard walker would be the passive kickstands and the sensors for the guiding aspect of the design. For footprint, this design received a 2 because the depth will be increased due to the guiding aspect of the design and the width will be increased because of the addition of the passive kickstands. This design received a 4 for adjustability because it should be able to adjust like a standard walker, but it may not be able to with the addition of the sensors. This design received a 3 for cost because sensors will only be needed for the guiding portion of this design. For transportability, this design was given a 4 because it still would be able to fold and fit into a car's trunk or backseat.

The hybrid between the guiding foam design and the passive kickstand (Hybrid 2) scored the higher than the hybrid between the guiding foam and the active kickstand (Hybrid 1) and the five original designs. After analysis, the hybrid between the active kickstand and the guiding design did not prove feasible. The active kickstand must deploy within a certain time limit to stop a user from falling laterally. Between the small time interval and the weight of the person falling, the load that the kickstand needed to support the user was very high. With an object deploying at a very high speed might be dangerous for anyone to use. The kickstand could be deployed accidentally or it could deploy when other people were within striking distance. This idea was finally discarded due to safety issues.

The hybrid of the guiding foam design and the passive kickstand proved to be the best design. It could stop a user's fall and guide the user to use the walker correctly. Unfortunately, to stop a user's fall safely, the passive kickstands must remain deployed at all times and this decreases the maneuverability of the walker. The benefits, however, outweigh the disadvantages because this design proved to be the safest, least expensive, and most simple way to stop a person from falling laterally.

7.0 Design Description

The prototype consists of walker accessories including four lateral leg extensions, which temporarily increase the base of support and a braking system with foam guides to control the location of the user's center of mass. The following sections describe these components in detail.

7.1 Lateral Leg Extensions

The lateral leg extensions are the portion of the design that momentarily extends the base of support when the walker tips 5 degrees laterally. The function of these accessories is to give the user extra time to allow them to correct their fall in the event that the walker begins to tip. Each lateral leg extension is attached to each detachable walker leg (Figure 40). Dimensioned drawings of all of the parts are shown in Appendices F and G

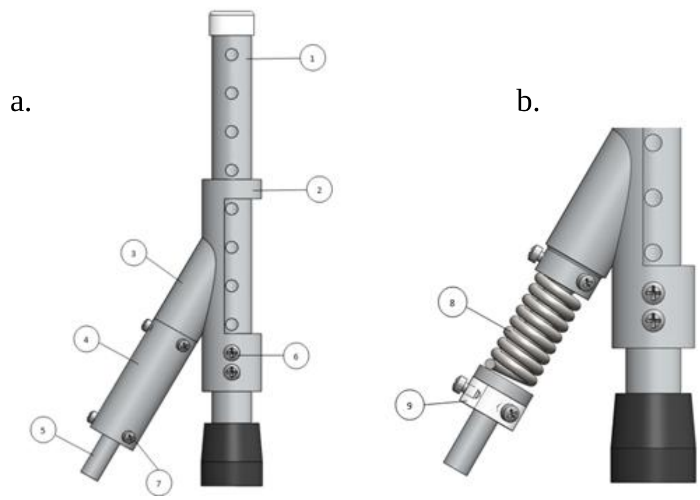


Figure 40: (a) Lateral Leg Extension Accessory (b) Internal components of Lateral Leg Extension Accessory

Each lateral leg extension is 6.79 inches in length and consists of a sleeve, connecting shaft, cover, piston, compression spring, a nylon bushing, and hardware. The sleeve (2) attaches to the detachable walker leg (1), which makes the lateral leg extensions a universal accessory because all standard walkers have detachable legs. The sleeve attaches to the removable walker leg using two ¼-20 screws (6) that are threaded through the sleeve. The sleeve was designed to leave space for the holes of the detachable walker leg to ensure the button could still fit through the holes, which allows the walker to be adjusted to meet various heights. This part is located 1.74 in. from the bottom of the walker leg and was designed with enough thickness (.25 in.) to ensure the connecting shaft could be welded to it. The connecting shaft (3) is designed so that a compression spring (8) can fit over the smaller diameter portion. The connecting shaft is also designed to fit around a 1.5 in. diameter of the sleeve and forms a 30 degree angle with the vertical walker leg. The compression spring compresses .27 in. and has a spring constant of 871 lbf/in. The bottom end of the spring is in contact with the piston (5). The piston is the portion of the leg extension that makes contact with the ground. When the walker is typically being used and not tipping over, the piston sits 0.25 inches above the ground. Furthermore, a nylon bushing (9) is located around the piston and acts as a linear bearing to reduce friction while the piston slides in and out. When the lateral leg extensions are not activated, the piston rests against the nylon bushing. The cover (4) contains the spring, piston, nylon bushing, and a section of the connecting shaft. This cover is connected to the connecting shaft and the nylon via six 10-24 screws (7).

These components work together and become activated when the walker is tilted through 5 degrees. As the walker tilts and the lateral leg extension makes contact with the ground, the spring compresses, absorbing some of the user's energy, and making the stop less jarring than it would be with a rigid device. An end cap (not shown) is placed at the end of the piston to create friction so that the kickstand device does not slide.

Since the two front legs of the walker have wheels attached to them, two 1/16 inch washers were placed in between the wheel and the sleeve (Figure 41). This washer allowed enough clearance between the wheel and the sleeve so that normal motion would not be affected by the addition of the lateral leg extensions.

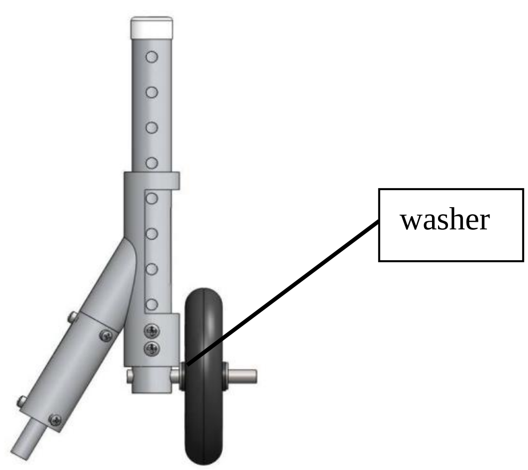


Figure 41: Assembly of Kickstand on Wheeled Leg

7.2 Foam and Brake System

The foam and brake system is the portion of the design which is aimed at controlling the location of the user's center of mass, thus preventing user actions that lead to a fall. This system consists of an IR rangefinder; VEX microcontroller, relay, two solenoids, batteries, and two caliper bike brakes. Furthermore, the system has foam padding to provide a reference point from the front of the walker to the furthest distance where the device can still be used properly.

7.2.1 Control System

The control system consists of several different components whose function is to keep the user within the walker's BOS. A schematic with the components is shown in Figure 42. The infrared sensor determines the location of the person and relays the information back to the controller which acts as the "brains" of the system. The VEX controller turns on the corresponding LED depending on the location of the person. Also, if the user is outside the acceptable range it sends a current to the relays. The relay then switches, thus completing the solenoid circuit and the solenoid activates the brakes. The technical specifications for each of the components can be found in Appendix H.

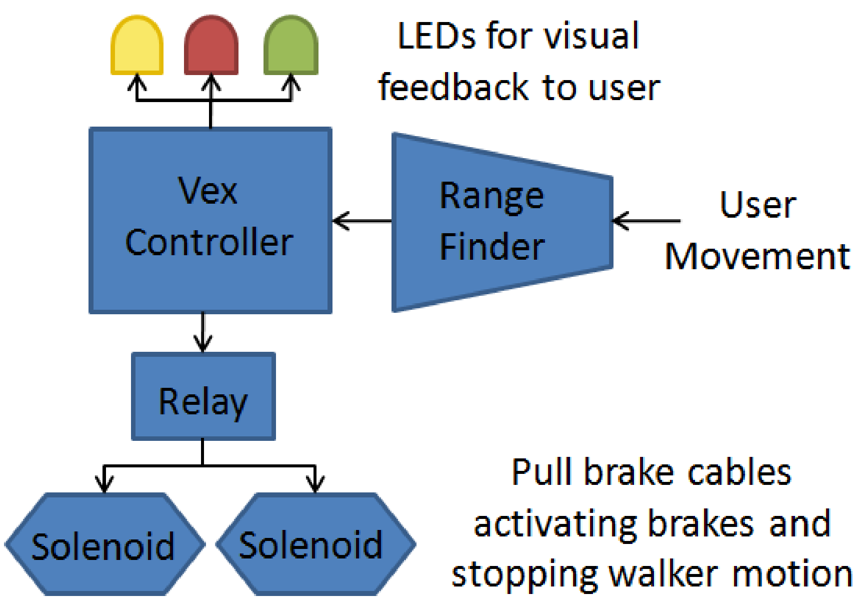


Figure 42: Controls Diagram

The control system is used to activate the brakes and turn on LEDs depending upon where the user is positioned (Figure 43). A majority of the time when the user is in the appropriate area inside the base of support the green LED will light up (the user is less than 13 in. from the front). As they approach the edge of the acceptable zone, a yellow LED lights up to warn them that they are about the leave the walker's base of support. When the user moves outside the base of support a red LED will light up and the brakes will engage (greater than 17 in. from the front). The user must then move inside the walker frame for the brakes to disengage.

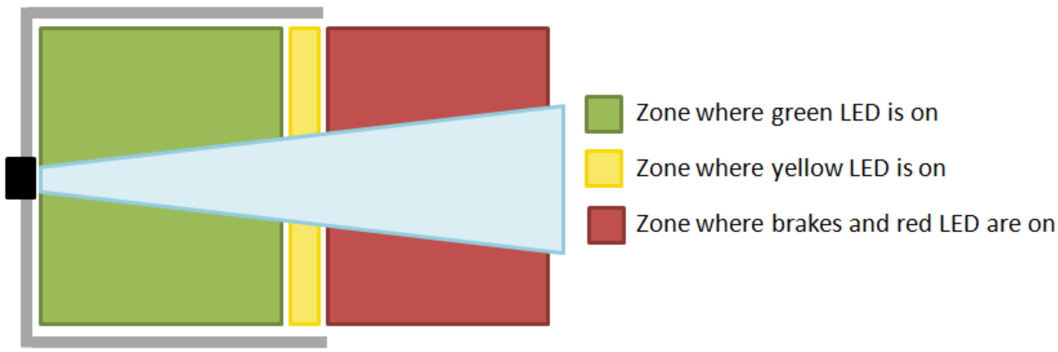


Figure 43: Schematic Looking Down at Walker that Depicts the Braking and LED Zones

The infrared sensor is attached to the front of the walker and faced toward the user as shown in Figure 45. The sensor has a range of 8 inches to 60 inches. It creates a voltage output which corresponds with the distance the object is from the front of the walker. This voltage output was calibrated to determine what voltage output corresponds with the distances that make up the edges of the three zones. The C code, that controller follows to carry out the functions described above, appears in Appendix I. The microcontroller is the "brain" of the control system (Figure 44). It interprets the information from the infrared sensor and sends current to the LEDs and relay when appropriate. The VEX Microcontroller is powered by a 7.2 V battery.

Figure 44: VEX Microcontroller (VEX Robotics, 2010)

The Spike relay is an electromagnetic switch that completes the circuit to activate the solenoid. Since each solenoid draws 24 volts, it requires a larger voltage than the VEX controller can provide. The Spike relay is the interface between the microcontroller and the solenoid circuit. The relay works as a magnetic switch. When the magnet is turned on by the current provided by the microcontroller, the switch is pulled completing the solenoid circuit. When the magnet is off, the current cannot flow to the solenoid because the switch is off (Figure 45).

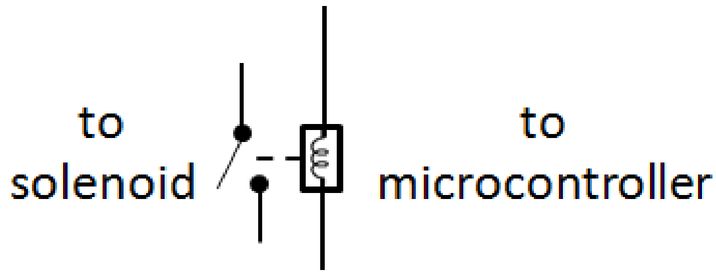


Figure 45: Relay Schematic

The solenoids are used to operate the brakes by pulling on a brake cable. The solenoid translates electrical current into linear motion. It does this through creating electromagnetic force generated by current traveling through a coil that is wrapped around the outside of the pin (Figure 46). This force magnetizes the pin and pulls it inside the coil. The linear motion of the pin will pull the brake cables and operate the brakes.

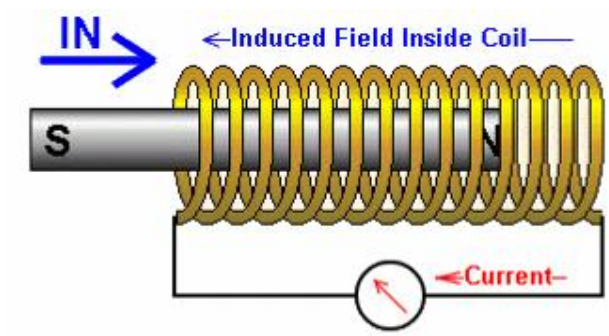


Figure 46: Solenoid Schematic (Society of Robots, 2010)

7.2.2 Brakes

The braking mechanism consists of a caliper bike brake activated by the solenoid (Figure 47). The solenoid pulls on the brake cable (1), which pulls the two lever arms (2) towards each other. The lever arms actuate around the pivot axis (3) moving the two brake pads (4) in towards each other. This causes the brake pads to come in contact with the walker wheel and apply a frictional force, which stops the walker.

Figure 47: Caliper Bike Brake Used in Design

7.2.3 Foam

Although the brakes will keep the user within the base of support while they are using the walker, the user might find the braking abrupt if it is unexpected. Also, the brakes are design to ensure the person uses the walker correctly. Ideally the person will grow to understand how a walker should be properly used, adjust their behavior accordingly, and eventually remove the foam. The foam provides visual cues and physical reminders to the users so that they understand when they should be moving the walker and stepping. The foam wraps part way around the back of the walker in an "L" shape so that if the person moves outside the base of support it touches the back of their legs reminding them to stay within the walker base as shown in Figure 48.

Figure 48: Side view of user with foam component

The foam assemblies attach to the walker's rear bars (Figure 49). The "L" portion extends backwards from the walker. The straight portion of the foam assembly extends forward to the walker's front vertical bars. At this location there is a magnet on the walker and on the foam assembly. These magnets hold the foam in place while the person is using the walker and allow them to open up the foam assembly in order to enter and exit the walker. The entire foam assembly is detachable to allow users that already have a walker to purchase only the foam and brakes, as opposed to buying a new walker.

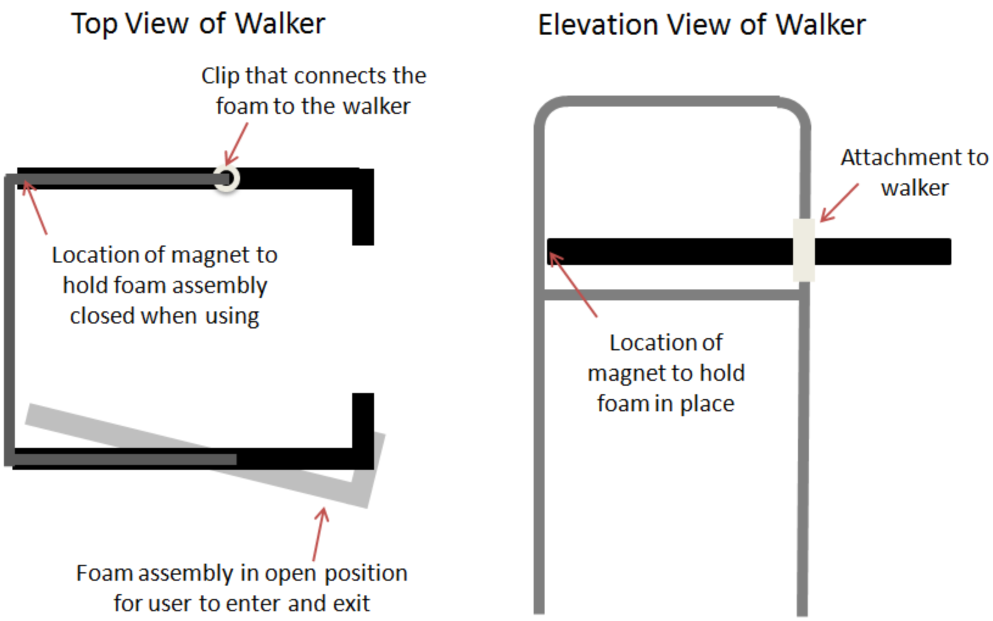


Figure 49: Top and Elevation Views of Walker and Foam (Note: the front of the walker is to the left in both pictures)

8.0 Final Design Analysis

8.1 Static Analysis and Dimensions of Lateral Leg Support

Once it was determined that the passive kickstand would be the final design, the specific dimensions of the kickstand were determined and analyzed (Appendix J). The minimum lateral leg support distance of 0.25 in. from the ground was maintained in order to minimize the likelihood of catching the kickstand on uneven ground. Using this condition, the same moment analysis discussed in the initial design analysis (Section 5) was conducted in order to determine what the horizontal offset of the kickstand (c) would need to be. The necessary offset is different when the kickstand begins to stop the fall at 5 degrees and when it has completely stopped the fall at 10 degrees because of the movement of the weight of the user and the walker. A simple picture of the front of the design and the kickstand as the walker is falling is shown in Figure 50. It was determined that the lateral leg support would need to extend outward 1.34 in. to stop a fall at 10 degrees and extend 2.86 in (c) in order to stop a fall at 5 degrees. The greater distance of 2.86 was taken to be the initial offset of the kickstand, so that it would contact the ground at 5 degrees.

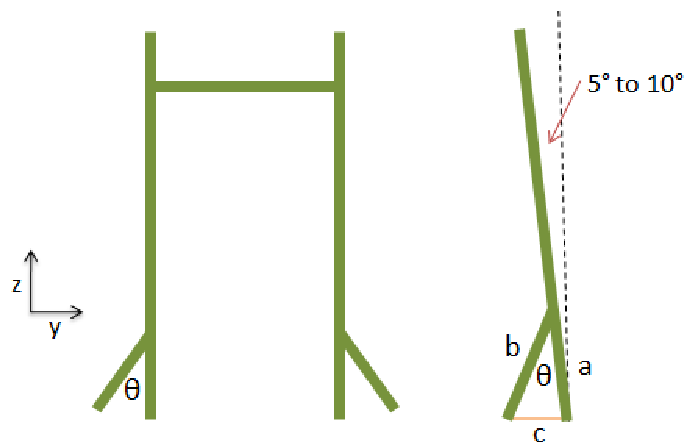


Figure 50: Drawing of Passive Kickstand and Legs of the Triangle Created by the Kickstand

An analysis of the friction force required between the kickstand and the ground was conducted. This was done to determine what friction coefficient was necessary to keep the kickstand from sliding outward when the person begins to fall. There needs to be enough friction between the ground and the walker so that the base of the kickstand stays stationary while the kickstand compresses. Figure 51 shows the free body diagram used to calculate the necessary coefficient of friction.

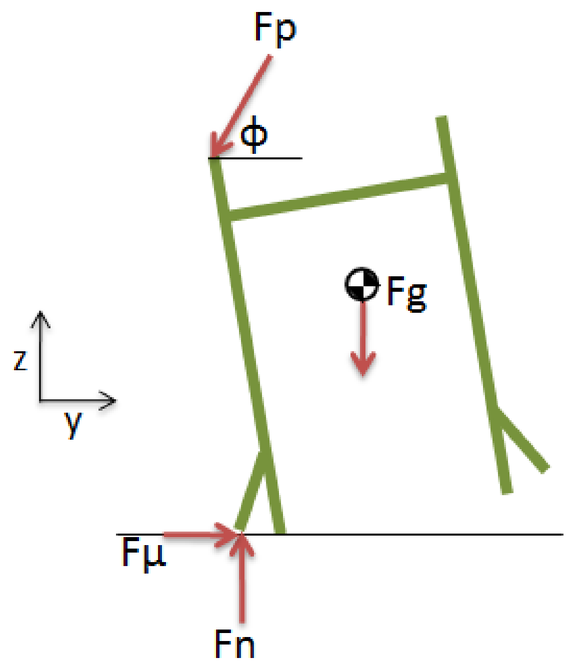
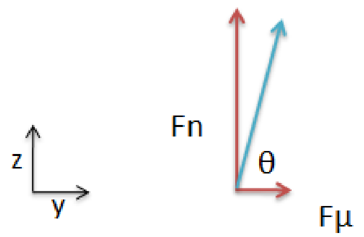


Figure 51: Friction Analysis Free Body Diagram (Fp is the force of the person, Fg is the center of gravity of the system, Fμ is the force of friction, and Fn is the normal force of the kickstand)

It was determined that a friction coefficient of 0.2 was necessary to keep the kickstand from sliding. Although the coefficient varies when rubber is against different surfaces, the lowest coefficient of friction for the surfaces the walker will be commonly used is 0.25 and occurs on wet asphalt. This value is higher than the necessary coefficient of 0.2. Thus, the walker will not slide when the user begins to fall. The full analysis is shown in Appendix K.

From the friction analysis, the angle of the force on the kickstand that results from the ground's frictional and normal forces was also determined. As shown in Figure 52 this force acts at a 79 degree angle from the horizontal. In order to reduce friction between the internal components of the kickstand as it compresses, it was determined that the angle of the kickstand should be as close to this angle as reasonably possible. If the kickstand was at a 79 degree angle it would be nearly 15in. long. In order to determine an angle that would compromise the need for the kickstand to align with the resultant force and the need for the kickstand to not be too long and heavy, the lengths were determined over a range of angles. These angles and lengths are shown in Table 8. An angle of 60 degrees which yields a length of 5.72 inches was chosen.



$$\theta = \tan^{-1}\left(\frac{F_n}{F_\mu}\right) = \tan^{-1}\left(\frac{1}{.2}\right) = 79°$$

Figure 52: Diagram and Calculation of Resultant Force

Table 8: Kickstand Lengths at Different Angles

Kickstand Angle from Horizontal	Kickstand Length
50	4.45 in
55	4.99 in
60	5.72 in
65	6.77 in
70	8.36 in
75	11.05 in
79	14.99 in

Using the angle and the outward length constraints, determined by the initial static analysis, the length of the kickstand when fully compressed was calculated. The kickstand at its normal position, when it is not in use, is the same length as when it first touches the ground at 5 degrees. This is the 5.72 inches. The length after the kickstand has compressed and the walker is at a 10 degree angle is 5.45 in. This was calculated using trigonometry and is shown in Table 9.

Table 9: Kickstand Length at 5 and 10 degrees

Kickstand length at 5°	5.72 in
Kickstand Length at 10°	5.45 in
Change in Length	0.27 in

8.2 Stress Analysis of the Lateral Leg Extension

Once the dimensions of the kickstand were determined, the stress was analyzed on planes A-A, B-B, and C-C (Figure 53). Plane A-A intersects the screws, cover, and nylon. Plane B-B intersects the screws, cover, and connecting shaft. Plane C-C intersects the bolts, sleeve, and detachable walker leg.

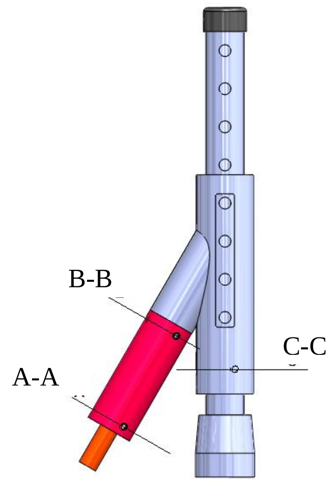


Figure 53: Stress Analysis Planes

8.2.1 Stress Analysis of Screws Connecting the Cover to the Nylon Bushing

The first plane, A-A, used for stress analysis is where the screws connect the cover of the lateral leg extension to the nylon bushing. There are three screws, which are located around the circumference of the cover and the connecting shaft. They are equally spaced with 120 degrees in between them. Stress analysis was performed on each of these three points. The free body diagram for this plane was determined by the static analysis above (Figure 54). The frictional force (Fµ) and the normal force (Fn) are 83 and 417 lbf, respectively.

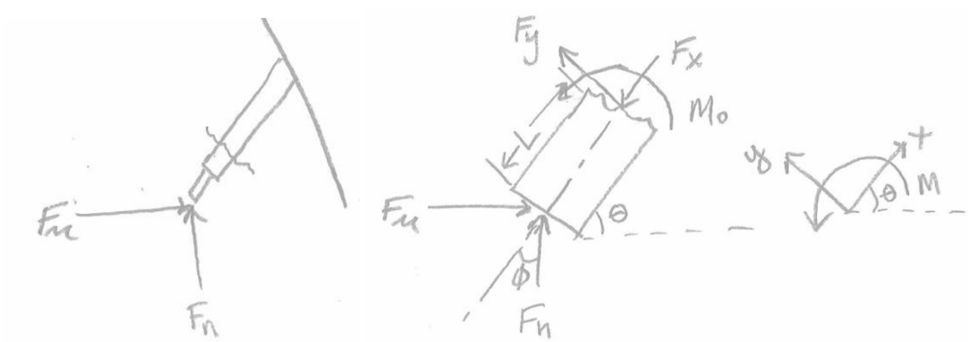


Figure 54: Free Body Diagram for Plane A-A

The length from the end of the lateral leg extension to plane A-A is 1.875 in. Theta (θ) is the angle between the lateral leg extension and the horizontal (ground). This angle is 65 degrees because the lateral leg extension is 60 degrees from the vertical plus 5 degrees that the walker must fall through so that the lateral leg extension touches the ground. With the cut at Plane A-A, there is a resulting force in the x direction and the y direction. These forces are the normal force (x-direction) and shear force (y-direction) with respect to the plane. A moment is also acting about Point O on this plane as well. The shear force (Fy), the normal force (Fx), and the moment were each solved for. These values are summarized in Table 10.

Table 10: Summary of Forces and Moment at Plane A-A

Shear Force (Fy)	Normal Force (Fx)	Moment (Mo)
268 lbf	575 lbf	339 lbf*in

To find the bending stress at each point on plane A-A, the cross sectional area was found. The cross sectional area is in the shape of a circle with an inner and outer diameter. The area was 1.031 in^2. To find the locations of the points, the distance from the x axis was found for each point on the plane (Figure 55).

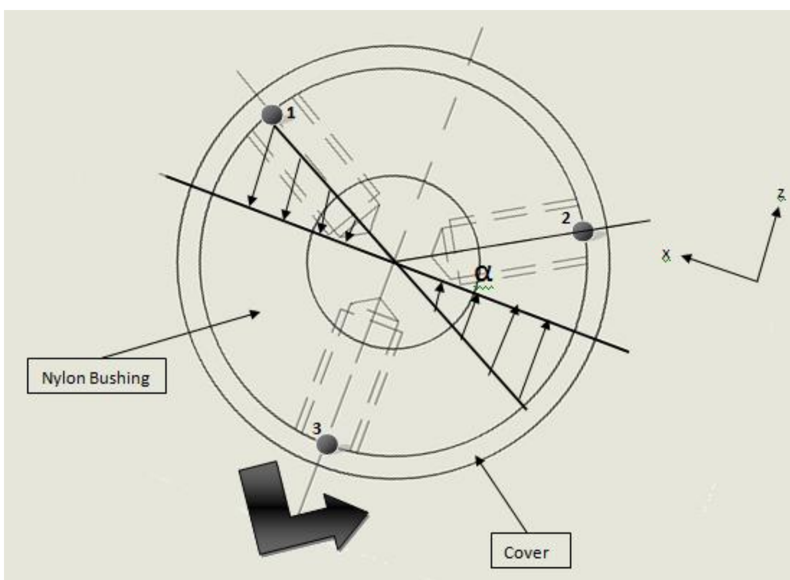


Figure 55: Cross Section of Plane A-A

The last point was located directly on the x axis, so the bending moment about this point is zero. The normal stress, and the shear stress were calculated using the forces found and the cross sectional area. The bending stress was found by calculating the moment, the area moment of inertia of a tube using the cross sectional area, and the distances from the neutral axis. Point 1 is in tension, therefore, the normal stress was subtracted from the bending stress and Point 2 is in compression, so the normal stress was added to the bending stress. The results are summarized in Table 11. For detailed calculations see Appendix L.

Table 11: Summary of Stresses Calculated on Plane A-A

Normal Stress	Shear Stress	Bending stress at Point 1	Bending Stress at Point 2	Bending Stress at Point 3
558 psi	260 psi	848 psi	$1.96*10^3$ psi	0 psi

8.2.3 Stress Analysis of Screws Connecting the Cover to the Connecting Shaft

The same free body diagram was used to analyze the stress in the screws where the cover connects the connecting shaft (Figure 56). There are three screws that are located 120 degrees from each other around the circumference of the cover and are located 3.79 in from the end of the kickstand.

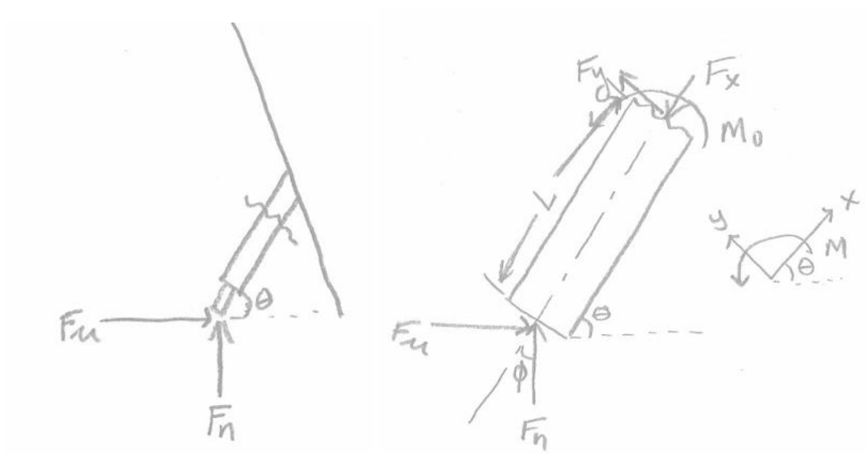


Figure 56: Free Body Diagram for Plane B-B

Most of the variables are the same as in the analysis done previously. The frictional force (Fμ) and normal force (Fn) are the same and the shear force (Fy) and normal force (Fx) to Plane B-B are the same. The moment around Point O is different, because of the change in the moment arm. To find the stress at this plane, the cross sectional area was found. This area was determined using the outer diameter of the cover as its diameter. The screws at this point are in the same position as in the previous analysis (Figure 57).

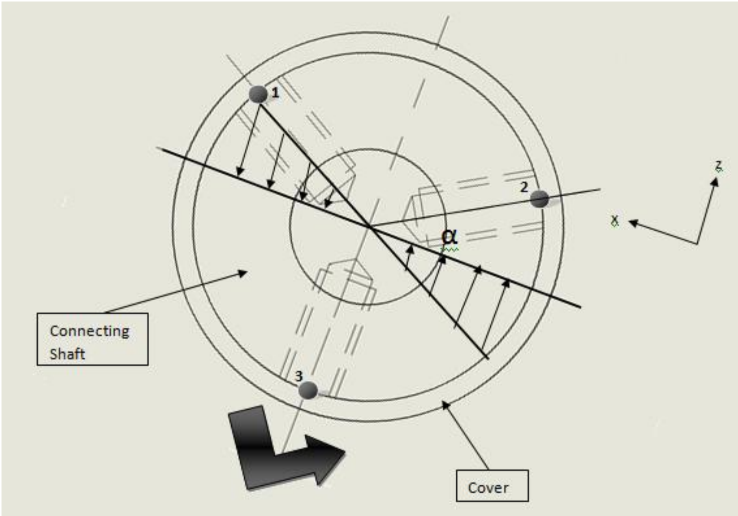


Figure 57: Cross Section View of Plane B-B

The normal and shear stress were calculated at Plane B-B using the cross sectional area and the normal and shear forces. The bending stresses were calculated at each of the three points. At Point 3 the bending stress was zero because of its location on the neutral axis. A summary of these results can be seen in Table 12.

Table 12: Summary of Stresses Calculated on Plane B-B

Normal Stress	Shear Stress	Bending stress at Point 1	Bending Stress at Point 2	Bending Stress at Point 3
527 psi	246 psi	679 psi	$1.73*10^3$ psi	0 psi

8.2.4 Stress Analysis Where the Sleeve Connects to the Walker Leg

The other area where hardware is located is at Plane C-C. There are two screws that connect the sleeve to the walker leg. A plane is cut at the location of one of these screws because the stresses should be almost the same at each screw (Figure 58).

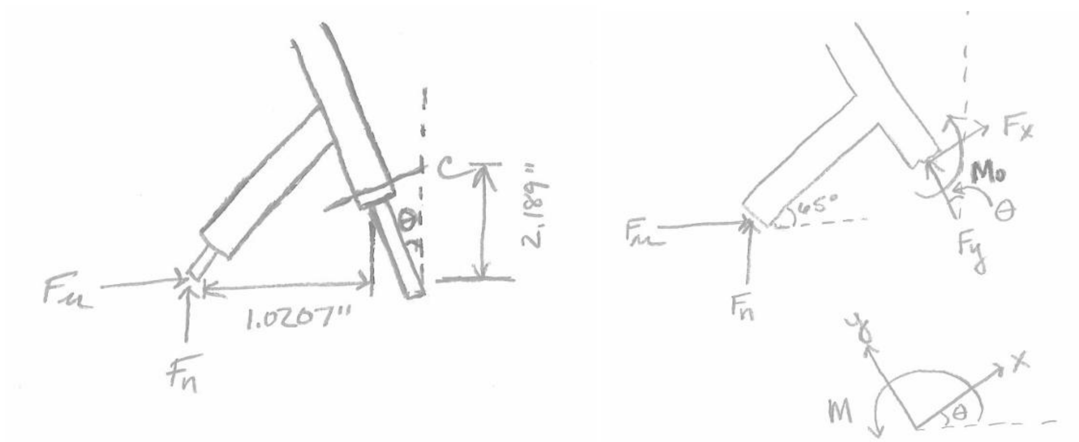


Figure 58: Free Body Diagram of the Stress Analysis at Plane C-C

First, the normal force (Fy), shear force (Fx), and the bending moment at Point O were calculated (Table 13).

Table 13: Forces Acting on Plane C-C

Normal Force	Shear Force	Bending Moment
-84.4 lbf	-105 lbf	-168 lbf*in

Once these forces are known, the normal stress, shear stress, and bending stress could be found at the point of the screw. The cross sectional area for this plane cut is in the shape of a tube. The outer diameter is the outer diameter of the sleeve and the inner diameter is the inner diameter of the walker leg. The area for this plane cut is 1.46 in^2. The normal stress, shear stress, and bending stress are located in Table 14. Since the screw is located on the neutral axis (c=0), the bending stress is zero.

Table 14: Summary of Results of Stress Analysis

Normal Stress	Shear Stress	Bending Stress
-57.8 psi	-71.7 psi	0 psi

8.2.5 Stress Analysis of the Screws within the Lateral Leg Extension

The compressive and shear stresses exerted on the screws were calculated and summarized in Table 15. These stresses are acting on each screw; however the screws are stainless steel. The shear modulus and compression strength of stainless steel are higher than these stresses, 11,200,000 psi and 24, 656 psi, respectively (Engineering Toolbox, 2010; AZo Materials, 2010). Therefore, the screws will be able to support the forces acting on them.

Table 15: Compressive and Shear Stresses Exerted on the Screws

Stress	Sleeve and Detachable Leg (psi)	Cover, Nylon, Connecting Shaft (psi)
Shear	4,207	5,798
Compressive	13,220	5,366

8.3 Dynamic Analysis of Kickstand

Dynamic analysis of the final design was conducted in order to determine what magnitude of energy would need to be converted into potential energy within the springs in order to stop the user from continuing to fall (Appendix M). This analysis was similar to the analysis conducted on the active kickstand design within the preliminary analysis section (Section 5). The work done by the walker is equal to the kinetic energy of the system as it falls through 5 degrees and the change in potential energy from 5 to 10 degrees. Using the velocity obtained from the earlier analysis, the kinetic energy of the person after he or she has fallen through 5 degrees was determined. The change in potential energy was calculated using the person's mass and the distance to his or her center of mass. The change in energy from the point when the kickstand activates until the person has stopped falling and the walker has tipped 10 degrees is equal to the work done by the kickstand. The work necessary for the three different falling scenarios is shown in Table 16.

Table 16: Work and Force Required by Device for Three Falling Scenarios

Scenario	Work
Counter-Lateral Step	10.1 ft-lbs
Side Step	9.22 ft-lbs
Crossover Step	10.5 ft-lbs

The work done by the spring was used to determine what springs would be suited for the design. Two commercially available springs were found that both compress 0.3 inches at maximum load and will absorb a majority of the necessary work so that the person is jarred as little as possible during the fall. The spring constants of these two springs, which were provided by the manufacturer, and the work done by each spring, as calculated using the spring constant and displacement, are shown in Table 17.

Table 17: Work Done by the Springs

Spring Constant	Work
1160 lbf/in	9.00 ft-lbs
871 lbf/in	6.79 ft-lbs

8.4 Dimensions and Location of Foam

The dimensions of the foam assembly were calculated using the dimensions of the walker and the anthropometric data of the users. The distance from the edge of the walker to the inside of the "L" shape of the foam (length) needed to be small enough so that it touched the user's leg just before they move outside the walker's base of support (Figure 59). The foam also needed to be wide enough so that it touches even slim users. The size of the foam assembly was determined using the anthropometrics of the smallest user, a 5th percentile elderly female; so that the foam would be close enough to keep all of the users inside the base of support.

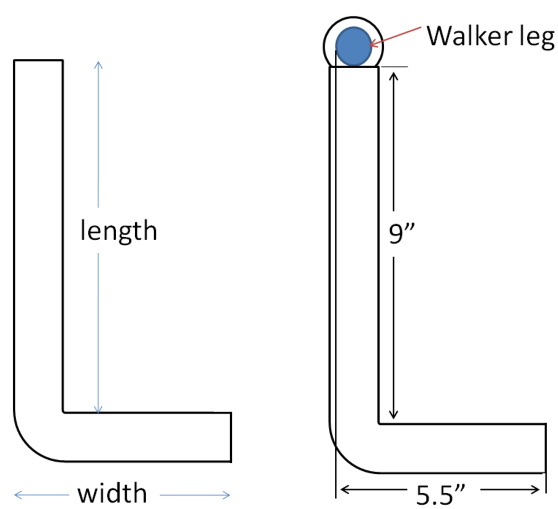


Figure 59: Foam "L" Dimensions

The length the user’s foot was the main factor in determining the length of the foam, because it is essentially the distance from where the user's front foot is to the back of their leg as shown in Figure 60. A fifth percentile female foot was used because this is the smallest user and the short distance and would ensure that all of the users stay inside the base of support. The person's width and the width of the walker were the main factors in determining the width of the foam. The foam extends about ¾ of an inch beyond the distance between the walker and the person. The Drillis and Contini model was used to compute body segment sizes based on user height (Winter, 1990). The final length of the foam was 9 inches and the width was 5.5 inches (Appendix N).

Figure 60: Person and Foam

Anthropometric data and body segment lengths were used to determine the specification for the location of the foam on the walker. Fifth and fiftieth percentile elderly men and women were considered for this specification. The length of the users’ thighs was calculated based on body-length segments, 0.248 times the height and 0.245 times the height, for women and men, respectively (Reinhold, 1986). These values were added to the lower leg body segment and foot segment to determine the distance of the foam from the ground (Figure 12). It was determined that the foam should be placed 11½ inches from the top of the walker (O). As shown by the graph in Figure 61, this specification falls within the range for each percentile and is indicated by the purple circle (Reinhold, 1986).

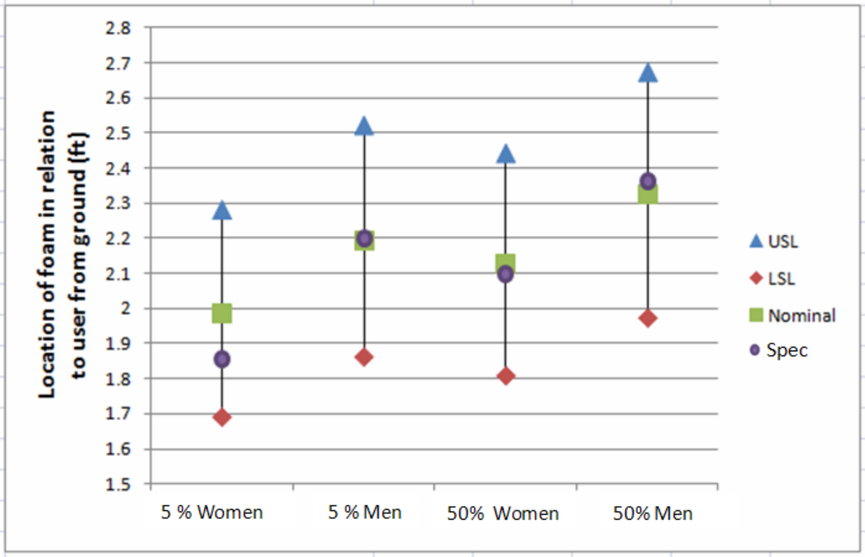


Figure 61: Specification for Foam Location Graph (Triangle is upper specification limit, Diamond is lower specification limit, Square is Nominal, and Purple is the Specification)

8.5 Friction Analysis

Friction tests between the walker wheels and the surfaces used in testing were conducted. Frictional force is based on the coefficient of friction between the two surfaces and the normal force between the surfaces. Thus, a weight of 38 lb consisting of a wooden board and weights was positioned across the top of the walker to simulate the downward force the user exerts on the walker (Figure 62). The magnitude of the weight was determined by using 25% of the weight of a 50th percentile elderly female. A study of force exerted on walkers determined that the average user exerts 25% of their weight on the walker (Bateni and Maki, 2005). A 50th percentile elderly female was used as the basis because walkers are typically used by elderly females.

Figure 62: Walker with 38lbf of weight to simulate users' force

The friction was determined by looping a string through the spokes in the wheel at a set radius. This string was attached to a force gauge and the string was pulled until the wheel began to slip on the surface as shown in Figure 63.

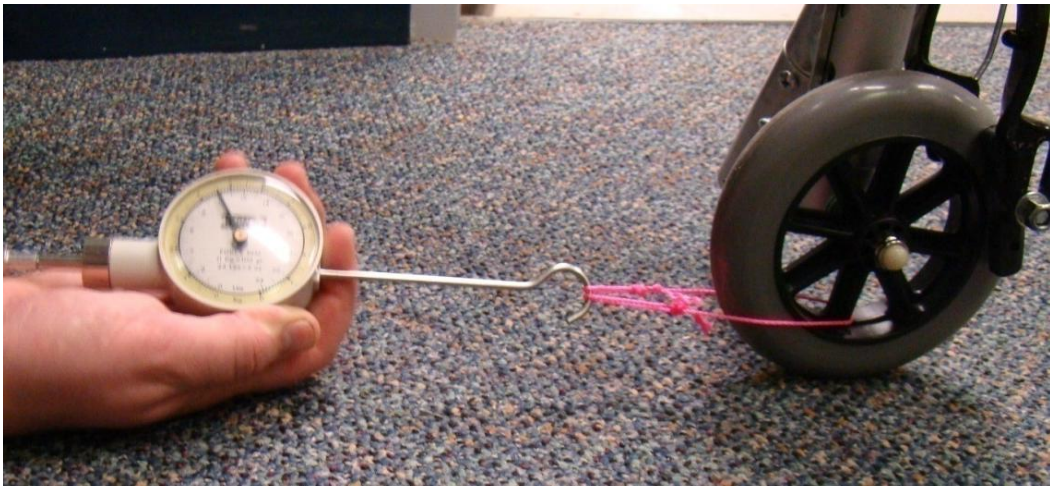


Figure 63: Friction Test Setup

The free body diagram of the wheel is shown in Figure 64. The weight and the frictional ground forces balance in the y direction. The bearing reaction force, force exerted by the gauge and the ground reaction force balance in the x direction.

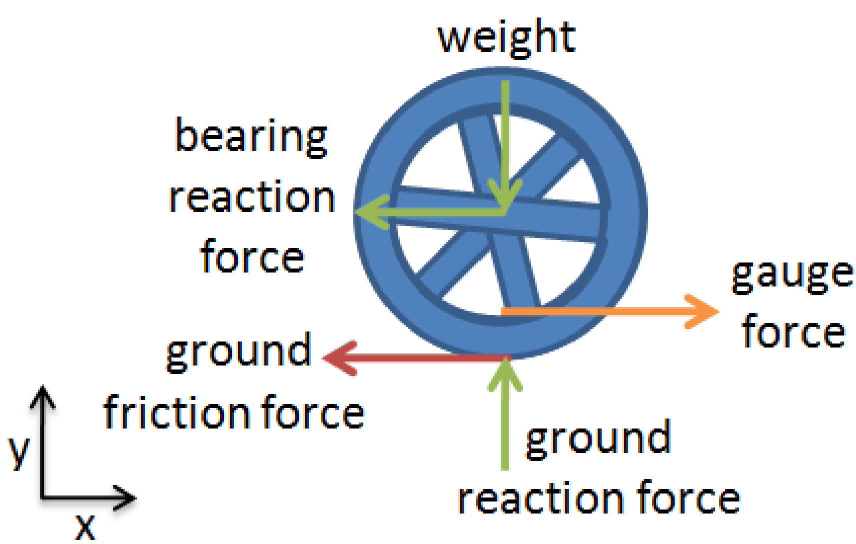


Figure 64: FBD of Wheel during Surface Friction Test

The ground frictional force was calculated using the reading from the force gauge. This was done by summing the moments as shown in Figure 65. The moments were summed around the axis of the wheel (A). The radius of the wheel (r_2) and the force gauge (r_1) were measured and used in the following equation to calculate the frictional force through balancing the moments on the wheel.

$$\sum M_A = F_g r_1 - F_\mu r_2 = 0$$

$$F_\mu = \frac{F_g r_1}{r_2}$$

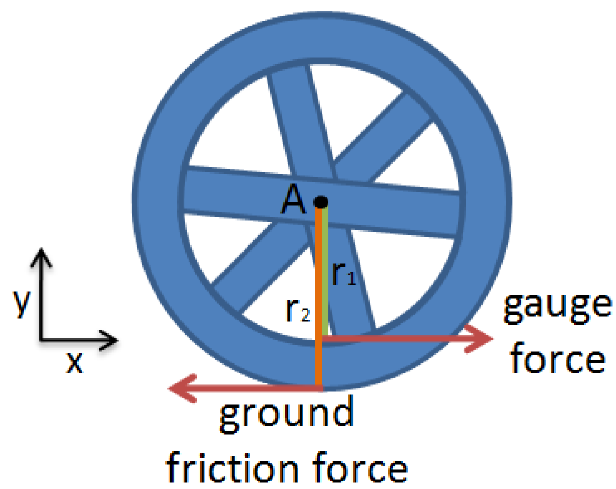


Figure 65: Forces that Generate Moments During Surface Friction Test and Equations

The results of the ground friction analysis are shown in Table 18. The table shows the gauge reading for each test, the calculated frictional force for each of the surfaces, as well as the moment that is generated by each of the frictional forces. Concrete exerted the greatest frictional force (11 lbf) and tile generated the smallest force (5.9 lbf).

Table 18: Surface Friction Test Results

Surface	Gauge Reading (lbf)	Frictional Force (lbf)	Resulting Moment (lbf*in)
Carpet	14	8.3	20
Tile	10	5.9	14
Concrete	19	11	27
Brick	13	7.7	19

The frictional force from the brakes was determined in a manner very similar to the surface procedure. The brakes were activated and a string was attached to the spokes of the wheel at a set radius. The string was attached to a force gauge that was pulled until the wheels began to slip. This was done while the walker was held in the air so there was no ground frictional force on the wheel at the time. The free body diagram of the wheel during the test is shown in Figure 66. The brake and gauge forces are balanced by the bearing reaction forces.

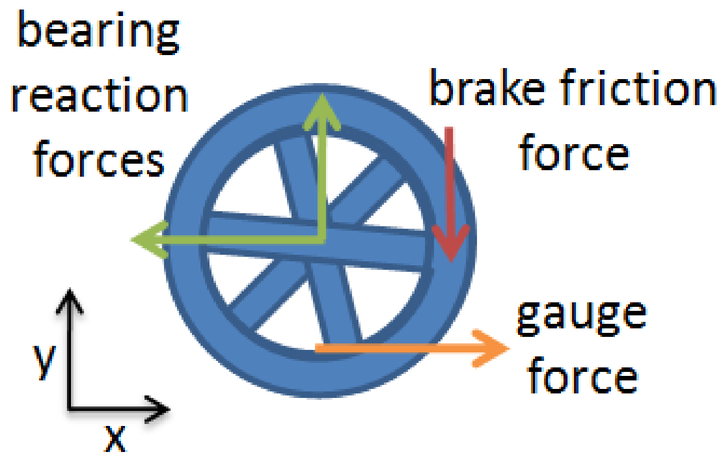


Figure 66: FBD of Wheel During Brake Friction Test

The ground frictional force was calculated using the reading from the force gauge. This was done by summing the moments as shown in Figure 67. The moments were summed around the axis of the wheel (A). The radius brakes (r_2) and the force gauge (r_1) were measured and used in the following equation to calculate the frictional force through balancing the moments on the wheel.

$$\sum M_A = F_g r_1 - F_b r_2 = 0$$

$$F_b = \frac{F_g r_1}{r_2}$$

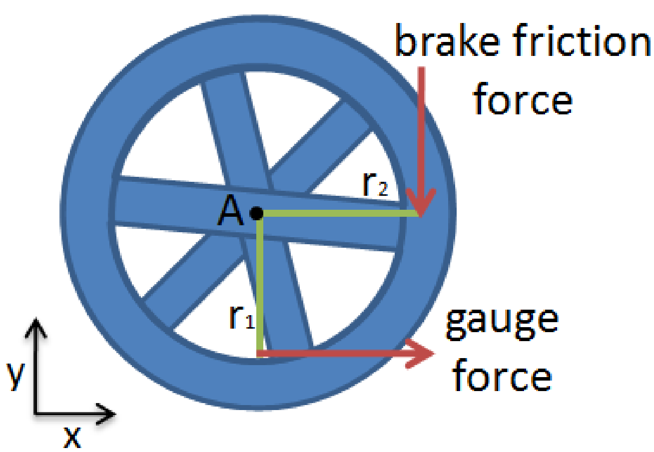


Figure 67: Forces that Generate Moments During Brake Friction Test and Equations

The results of the brake friction analysis are shown in Table 19. The table shows the gauge reading for the test, the calculated frictional force of the brakes, as well as the moment that is generated by each of the frictional forces.

Table 19: Brake Friction Test Results

	Gauge Reading (lbf)	Frictional Force (lbf)	Resulting Moment (lbf*in)
Brakes	12	8.6	17

The moments generated by the friction forces of each surface and the brakes are shown in Table 20. The moment generated by the brake is smaller than that generated by each of the surfaces except for tile. Thus, the walker will only skid on tile. Although the brake is not strong enough to make the walker skid on the other surfaces, the braking moment is within 15% of both the carpet and brick moments and within 37% of the concrete moment. This should providing significant braking to warn the user to step back inside the walker's BOS.

Table 20: Moments Generated by Each Frictional Force

Surface	Resulting Moment (lbf*in)
Tile	14
Brakes	17
Brick	19
Carpet	20
Concrete	27

8.6 Circuit Analysis

The entire electrical circuit consists of nine components: VEX microcontroller, infrared (IR) range finder, three LEDs, two power sources, a relay, and a solenoid (Figure 68).

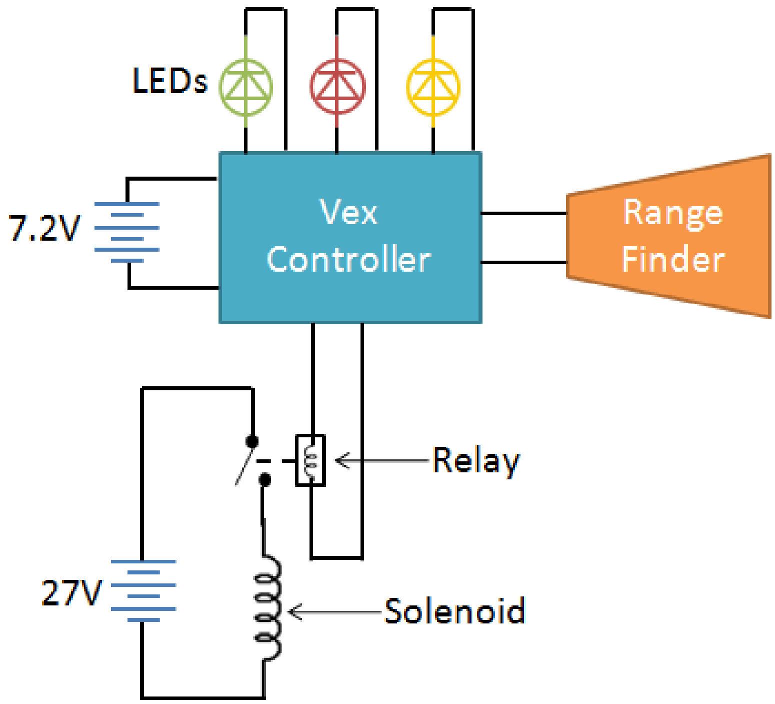


Figure 68: Control Circuit Schematic

This circuit can be broken down into three parts, which include a sensor, a switch, and an actuator that are based on the function of the components involved. The sensing part of the circuit is composed of the VEX microcontroller, the IR range finder, and a power source. The IR range finder senses the distance from the front of the walker to the user and sends this signal to the VEX microcontroller. The VEX microcontroller requires 7.2V (nominal) to operate, thus a 7.2 V power source is used. The components involved in the sensing portion of the circuit were determined based on functionality. There were two different choices to sense the distance from the front of the walker to the person, an IR range finder or an ultrasound range finder. The IR range finder was chosen because the ultrasound range finder senses objects by bouncing a sound wave off the object, which then returns to the sensor. However, the ultrasound range finder requires a flat surface to bounce the wave off of. This device needs to sense humans, which are not flat objects, thus an IR range finder was chosen. The sensor emits infrared light through its lens to the object. The sensor determines the angle of the returned light on a linear CCD array and uses this angle to conclude the distance from the sensor to the object (Figure 69).

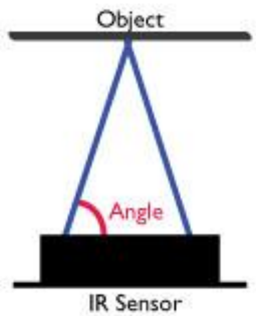


Figure 69: IR range finder schematic

A voltage is output by the IR range finder and sent to the VEX microcontroller. However, this signal is non-linear, and is in millivolts. The millivolt output at certain distances was determined experimentally for the two key distances, when the user crosses into the warning area and when the user exits the base of support. This was done by placing a piece of paper 13 inches and 17 inches away from the range finder and recording the voltage output.

The next part of the circuit is the switch, which connects the sensing portion to the actuating portion. For this function, a relay was used as a switch. Based on the specifications of the VEX microcontroller, which outputs 5V and 1mA of current, a relay that had these same specifications was chosen. When current travels through the relay, the switch inside the relay will close and allow current to flow through to the solenoid, which is the actuator (Figure 70).

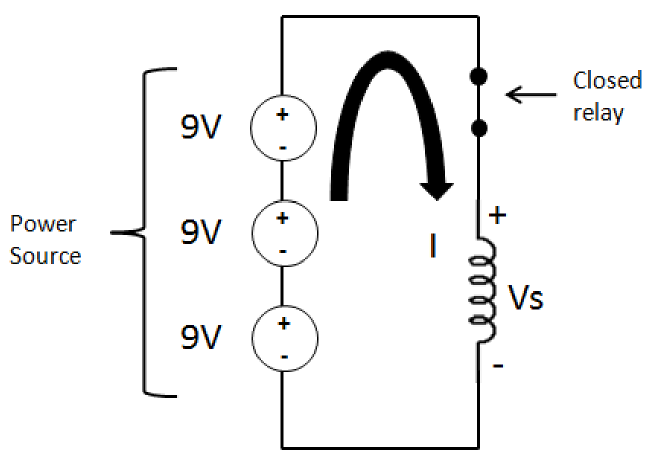


Figure 70: Actuator Circuit Diagram

A solenoid is being used to actuate the brakes, which will cause the walker to stop its forward motion. The type of solenoid required was based on four requirements which were determined from the brake analysis. First, the solenoid needs to be able to pull the brake cable 0.5 inches in order for the brakes to close on the wheel. Second, the solenoid has to be able to generate 2 lbs of force (or more) to close the brakes. Third, the pin of the solenoid must have a means for attaching the brake cable. Lastly, due to the orientation of the solenoid relative to the brake cable, a pull solenoid is needed. Therefore, a pull solenoid with a 1 inch stroke, 4 lbs holding force, and a hole through the pin was chosen. This pull solenoid requires 24V to fire. Therefore, three 9V batteries are used in series to power the solenoid. When batteries are placed in series, the voltages are added together and the amperage remains the same. Alkaline batteries were used, which have a capacity of 625 mA*hr. The resistance of the solenoid is 90 ohms; therefore the system requires 4 mA to run. The prototype can run continuously for a little over an hour.

9.0 Manufacturing the Final Design

All of the parts were manufactured using the machines in the Washburn Shops. The manufacturing process took a few weeks to complete. During the process, there were a few redesigns, which prolonged the manufacturing, but everything was completed correctly.

9.1 Lateral Leg Extension

Each lateral leg extension was constructed from six parts, five of which needed to be machined. The connecting shaft is the most unusual part and had to be machined using a five axis machine. It was machined from a 1.25 diameter aluminum rod. The first operation for machining this part was that the stock was faced and then the three different descending outer diameters for this part as expressed in the detail drawing (Figure 71) of the connecting shaft were turned using the lathe and then the part is cut to a specific length. The largest diameter is 1.25 in, the next diameter is 1.115 in, and the final diameter is 0.438 in (1, 2, 3 Figure 71). From each step down, the part will be filleted so that it is smooth. The second operation will be to achieve the scallop (4). The scallop is designed so that it can be welded around the sleeve. The sleeve has an outer diameter of 1.625 in. The connecting shaft was held in a fixture where it was rotated 60 degrees and held, so that the angle between the connecting shaft and the sleeve will be 30 degrees. With the part held at this angle the mill can move downwards to cut the scallop at that specific angle. Then the part was then put in a 4 axis machine so that it can be rotated around its axis so that the holes on the 1.115 in diameter can be drilled and tapped evenly spaced 120 degrees from each other (5). The final part is displayed in Figure 72.

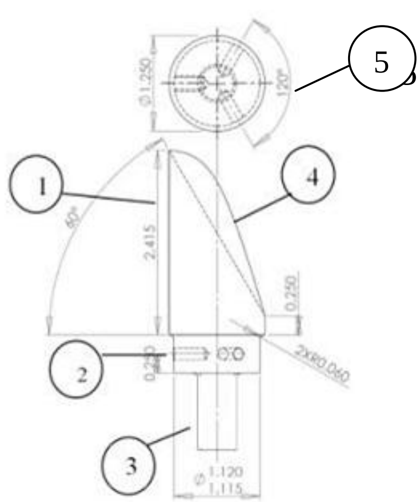


Figure 71: The Top and Front Views of the Drawing of the Connecting Shaft

Figure 72: Final Connecting Shaft

The sleeve is made from aluminum tubing with a 1.5 in outer diameter and a 1 in inner diameter. The first operation in machining the sleeve was to cut it to a specific length on the lathe (1 Figure 73) and the ends were squared. The length of the sleeve is 5.5 in, but the sleeve was cut ¾ in longer so that it could be mounted in the four-axis machine, and was then cut off later. From here, the open pocket was milled (2). This open pocket is necessary so that the user can access the pins that adjust the leg height of the walker. The cut is located 1.5 in from the bottom of the sleeve and 0.5 in from the top. A total of four holes were also indexed and then drilled and tapped (3). The first hole is 0.5 in from the bottom and the second hole is 1 in from the bottom. Two 10-24 screws will be placed in these holes to hold the sleeve to the walker leg. The sleeve was then returned to the lathe where it was cut to its final length, removing the extra ¾ in. The sleeve and the connecting shaft were then welded together where the cut of the connecting shaft is as seen in Figure 30. The final part can be seen in Figure 74.

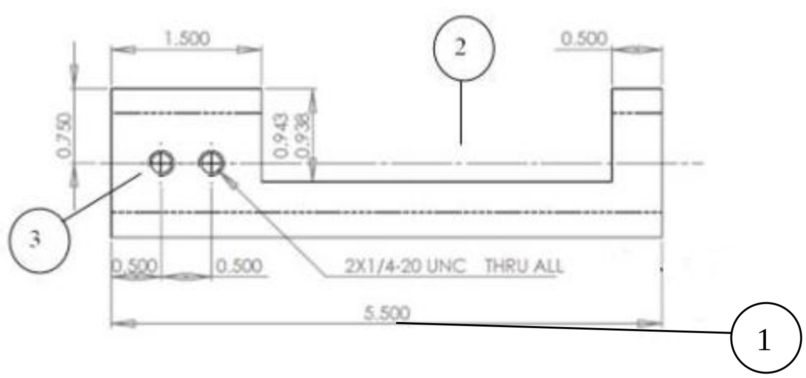


Figure 73: Front View of Sleeve Drawing

Figure 74: Final Sleeve

The piston was the simplest part to machine and was created from solid aluminum rod. This part was created with one operation on a lathe. The part was faced and then turned to the correct outer diameter. There were two outer diameters to this part (1, 2 Figure 75). The first diameter was 1.12 in and the second diameter was 0.5 in. Then this part was cut to length. The 1.12 in diameter section has a length of 0.25 in and the second diameter section has a length of 1.625 in. The final part is displayed in Figure 76.

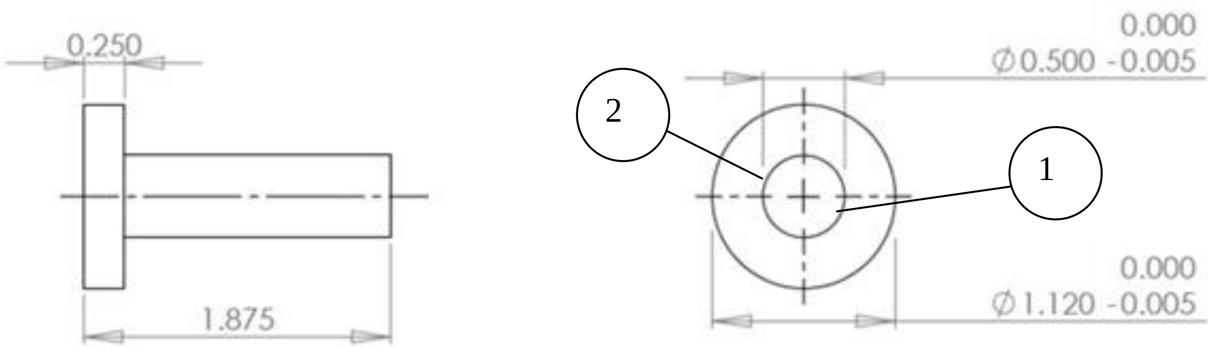


Figure 75: Drawing for the Piston

Figure 76: Final Piston

The fourth part that was created was the cover. This part was made from aluminum tubing with an outer diameter of 1.25 in. and an inner diameter of 1.12 in. (1 Figure 77) and it was machined using two operations. It was cut to length (2) using the lathe and then moved to the four-axis machine where three radial holes were drilled into the tubing at each end. The holes were spaced 120 degrees apart at each end of the cover (3) 0.25 in from either end. The final part is displayed in Figure 78.

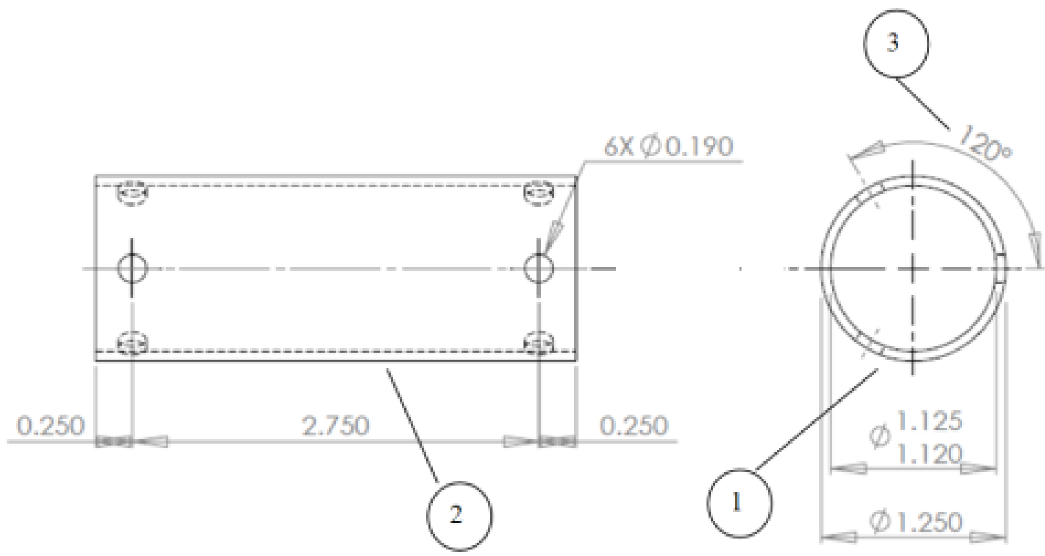


Figure 77: Drawing of Cover

Figure 78: Final Sleeve

The last part that was machined was the nylon bushing (Figure 79). This part proved to be deceivingly complicated to make. The nylon stock was first turned using a lathe to create the inner and outer diameters (1). Then a custom fixture was needed to hold the bushing in place in the four axis machine so that the radial holes could be drilled evenly 120 degrees apart. The holes were then tapped by hand (2) because the softness of the nylon made it unnecessary to be tapped by machine. The final part is displayed in Figure 80.

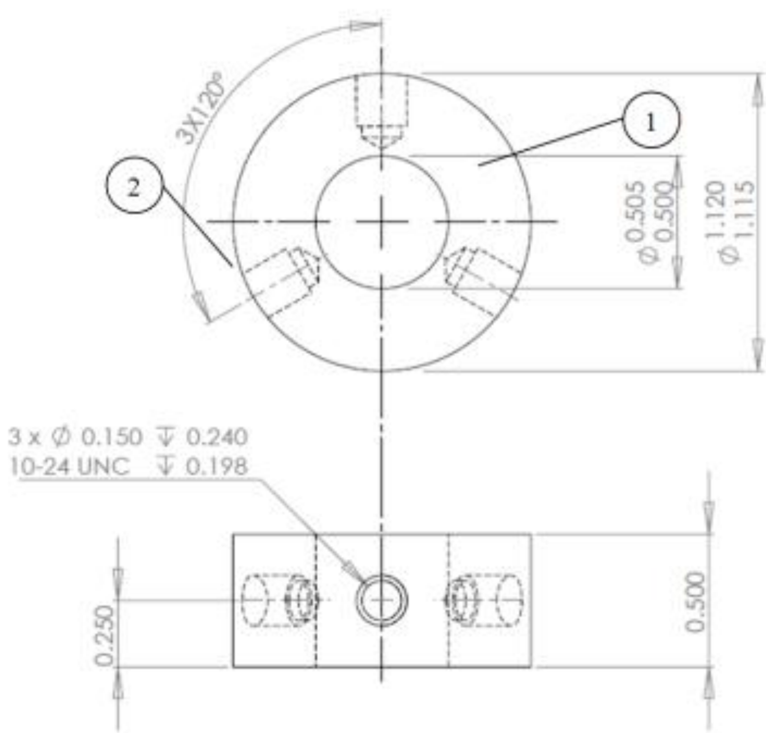


Figure 79: Drawing for the Nylon Bushing

Figure 80: Final Nylon Bushing

A custom fixture was needed to hold the bushing in place in the four axis machine so that the radial holes could be drilled (Figure 81). This fixture was created using an existing fixture (1) in the machine shop and a part that was custom made (2).

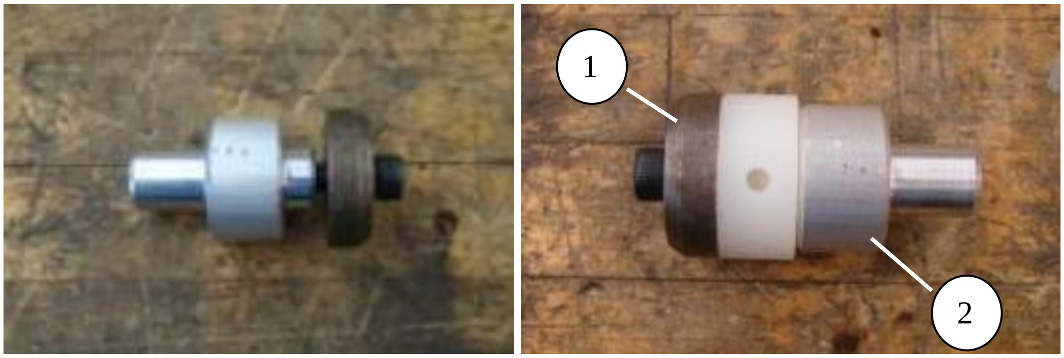


Figure 81: Fixture for Nylon Bushing

Since there is a lateral leg extender on each leg of the walker, there had to be four copies of each of the parts. The connecting shaft was welded to the sleeve using gas metal arc welding. First the connecting shaft was held in place using 90 degree brackets and tack welded into position to ensure it would stay in the correct location while it was being fully welded on. Welding the aluminum proved to be fairly difficult because of the change in thickness of the connecting shaft scallop. As the welding got to the tip of the shaft, less heat and time was needed to bond the two pieces. Fortunately, each connecting shaft and sleeve was successfully welded together and functions as designed. The final welded parts are displayed in Figure 82.

Figure 82: Welded Parts

All of the parts were assembled, including the purchased springs. The sleeves were then attached to each of the walker legs Figure 83.

Figure 83: Final Kickstand Assembly

9.2 Foam

The foam assembly consists of PVC piping that is surrounded by foam insulation that provides cushion for the user. The foam assembly has three main components, the "L" shaped section that keeps the user within the base of support, the modified cross which connects the foam assembly to the walker, and the closing mechanism, which keeps the foam assembly in position (Figure 84).

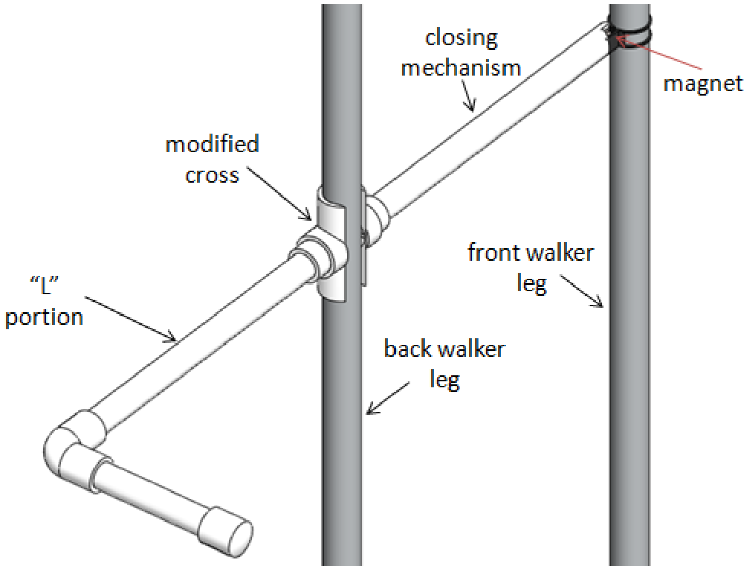


Figure 84: Isometric View of Foam Assembly (outer foam not shown)

The “L” portion of the foam assembly consists of PVC pipes and fittings that are encased in foam to protect the user (Figure 85). The piping is 0.5 in. diameter PVC piping. There is a 90° elbow which creates the bend and the end of the pipe is covered in an end cap so that there aren’t any sharp edges exposed to the user. The whole pipe assembly is surrounded by pipe insulation that is 3/8 inches thick (not shown).

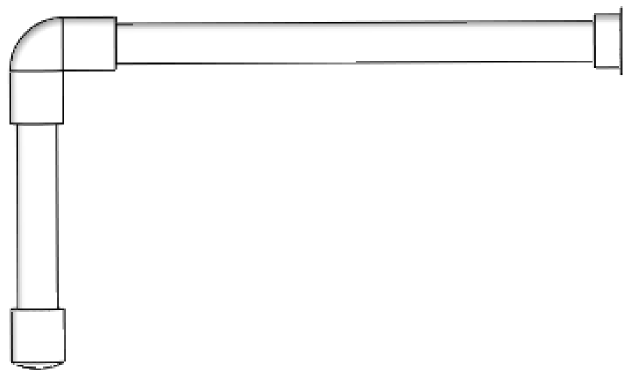


Figure 85: Top View of Components in “L” Portion of Foam Assembly with Foam Removed

The foam assembly is connected to the walker by using modified PVC crosses. The PVC cross has four fittings with an inside diameter of 1 in. (Figure 86). This allows the fitting to fit over the 1 in. tubing that makes up the walker. A 7/8 in. cut was made in the cross so that it could be snapped onto the rear leg of the walker.

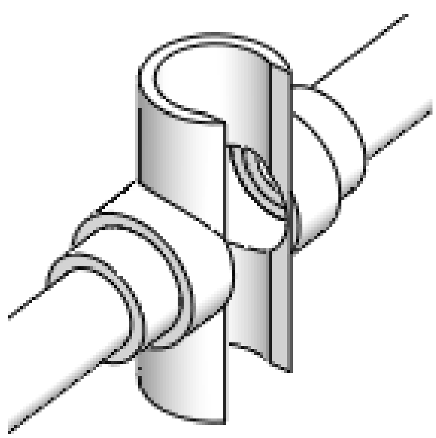


Figure 86: Isometric View of Modified PVC Cross

Two holes were made in the cross on the side that faces the user when they are standing behind the walker. They were drilled and tapped to for ¼ -20 bolts. These two holes house bolts, which tighten the fitting to the walker and keep the foam assembly from sliding up and down

(Figure 87). They are nylon instead of metal so that they will not mar the aluminum tubing of the walker. The two ends of the cross that connect to the foam assembly have PVC collars in them to adjust the inside diameter from 1 in. down to the diameter suitable for the 0.5 in PVC pipes.

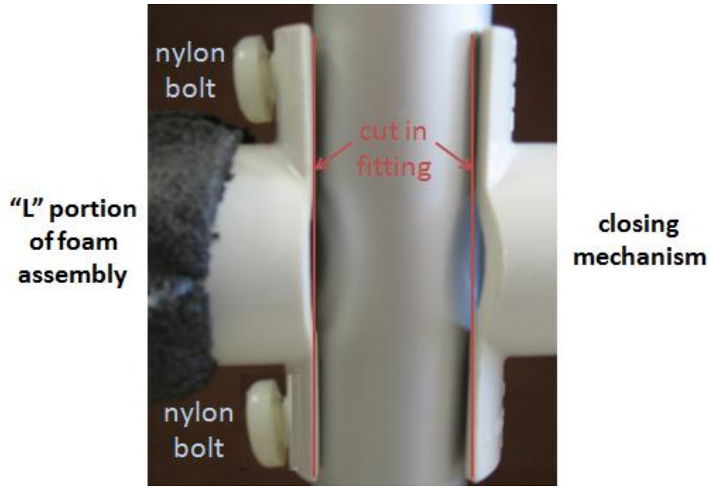


Figure 87: Side View of Cross Connector

The closing mechanism portion of the design consists of 0.5 in. PVC piping that is between the back leg of the walker, where it attaches to the cross connector, and the front leg (Figure 88). There is a 0.5 inch diameter magnet attached to the end of the PVC pipe. There is also a magnet attached to the front walker leg using a clip. These two magnets are attracted to each other and when they are within 0.25 inches of each other they pull the foam assembly into place and secure it there while the person is using the walker. The force required to separate the two magnets once they are up against each other was measured. It takes 2 pounds of force, which is enough force so that through normal use the foam will stay in place. However, they are weak enough so that they can be pulled apart by a person swinging the PVC pipe towards the middle of the walker.

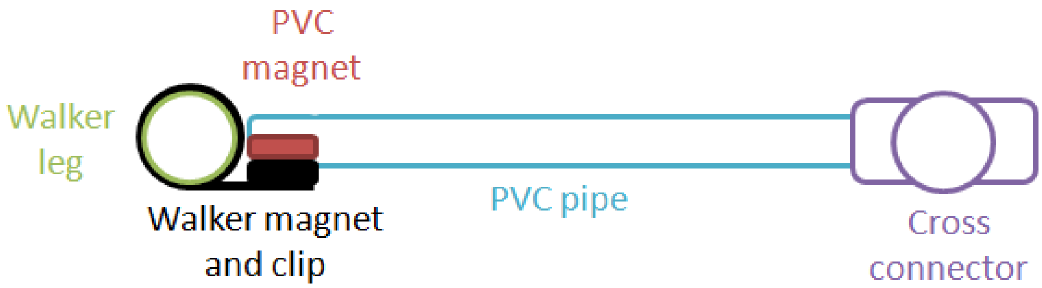


Figure 88: Top View of Closing Mechanism

9.3 Brakes

The brakes are mounted on top of the wheel using a pipe clip that slips over the sleeve. A bolt connects the clip and the brake (Figure 89). The clip is not a permanent mounting and is attached to the sleeve of the lateral leg extension.

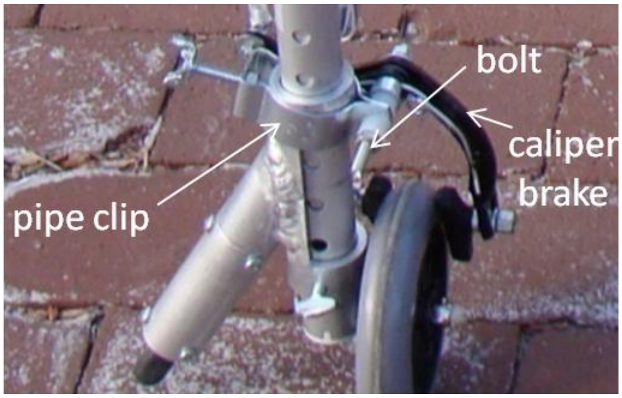


Figure 89: Caliper Brakes Used in Design

The brake housing box contains the end of the brake cable as well as the solenoid as shown in Figure 90. The box is attached to the leg of the walker via a plastic clip. The solenoid is mounted onto the bottom of the housing box and the brake travel runs up through the bottom of the box and connects with a lever. The lever pivots around a bolt that goes through both sides of the housing box.

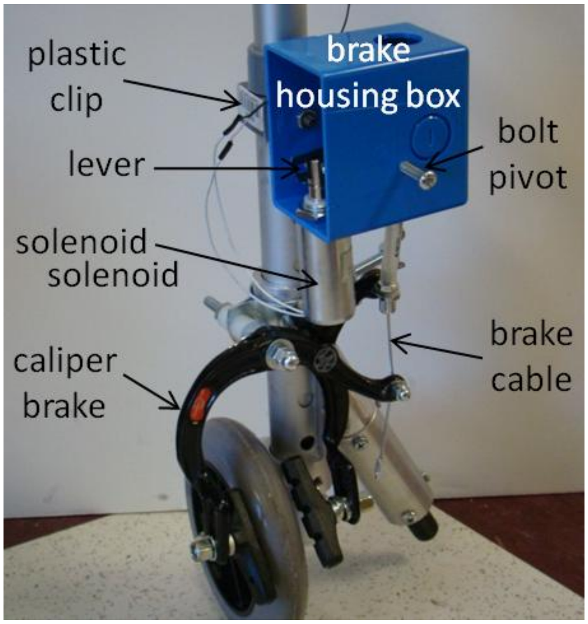


Figure 90: Inside of the Conduit Box

A schematic of the solenoid, lever, and brake cable is shown in Figure 91. The solenoid pulls down on one end of the lever, which pivots around a bolt, lifting the end of the brake cable. This pulls on the cable activating the brakes. The lever provides mechanical advantage to help pull the brake cable. The radius between the solenoid and the pivot is twice as large as the radius between the brake and the pivot, so the force exerted on the cable is twice as large as the output of the solenoid.

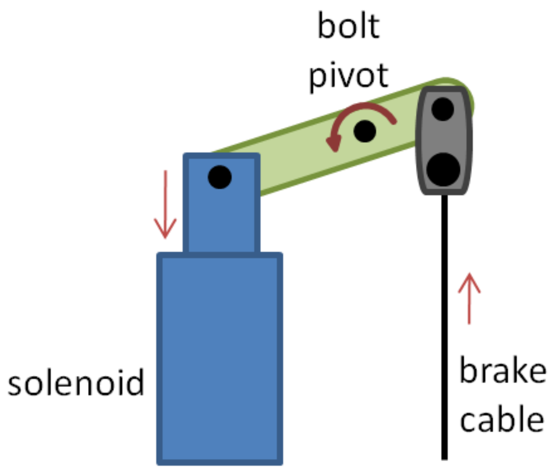


Figure 91: Schematic of Lever System

9.4 Controls

In order to contain the electronics and minimize stigma, most of the electronics are housed in a project box (Figure 92). The project box contains the two power sources and the relay. The VEX microcontroller is positioned with screws on the outside of the box and faces the user. The three LEDs are fixed to the top of the box so that they can be easily seen by the user. The IR range finder is positioned above the project box on the top crossbar of the walker directly in front of the user. Two screws are used to hold the box together and two rubber pipe clips connect the box to the walker leg. The two conduit boxes are positioned in each of the side frames of the walker so they do not interfere with the ambulatory function of the walker.

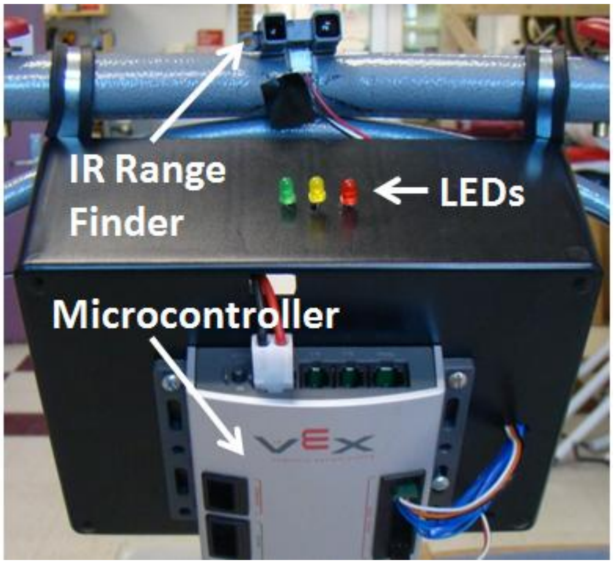


Figure 92: Front cross bar with VEX microcontroller, LEDs, and IR range finder

9.0 Testing and Results

This testing plan outlines the various procedures followed to test the final design. The control for most tests was the commercially available two-wheeled walker depicted in Figure 93. The results follow each testing plan.

Figure 93: Commercially available two-wheeled walker used for control in testing (Medical Center Respiratory , 2005)

9.1 Subject Testing and Results

The following test was completed by eight able-bodied college aged persons (2 males, 6 females). None of these individuals had ever used a walker, and none were privy to any information about the prototype or the goals of this MQP. Subjects were tested one at a time, at previously arranged times so they were not able to view how another test subject completed the test. This procedure was to reduce the introduction of preconceived notions about how to operate a walker. Before testing, the test subjects were instructed to follow a path using the walker (Figure 94). This was done so that they became accustomed to using the walker and was done for both walkers. Walkers were given to users in a random order.

Figure 94: A member of the group demonstrates walking along the testing path and remaining inside the base of support of the walker.

The path began in the Rehab Lab in Higgins Lab 129. Upon exiting the lab, the test subject was instructed to turn left and continue straight and take a right turn at the end of the hall. The subject continued to ambulate with the walker past the bathrooms and took another right at the end of the hall. Then, they took their last right turn at the end of the hall and returned back to the Rehab Lab. Once this path was completed with one walker, the testing of that walker began. This path was also repeated with the other walker before testing. The first test was the Limiting User Actions Testing and was followed by the Comparative Testing.

9.1.1 Limiting User Actions Testing

Currently, the control walker does not limit user actions that can lead to falls. As previously mentioned, the prototype is specifically trying to limit the user action of moving outside the BOS

(Figure 95). In order to determine if the foam and sensors effectively limit this user action compared to a standard two-wheeled walker, eight able-bodied individuals tested the prototype and the commercially available walker. After the subject completed the path and was comfortable using the walker, the first test was conducted. The user was instructed to ambulate with the walker down a 20 ft hallway. An observer counted the number of times the user was outside the BOS (i.e. their toes were behind the back posts of the walker for the control). If the brakes on the prototype were activated, this was counted as being outside the BOS.

Figure 95: The woman in the picture is outside the BOS because her toes are behind the back two posts of the walker

9.1.2 Limiting User Actions Results

The prototype scored higher than the standard walker in the limiting user actions tests. The graph in Figure 96 demonstrates that the subjects walked outside the BOS over 20 times more often using the commercial walker (control) than they did using the prototype.

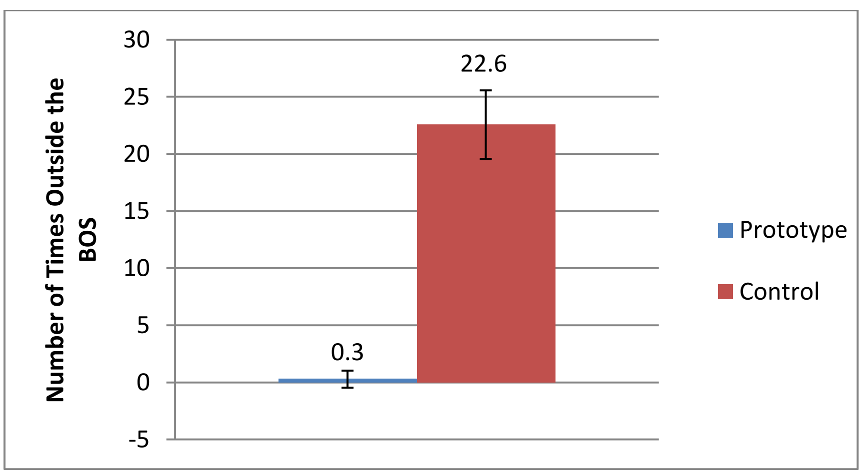


Figure 96: Limiting User Actions Testing Averages

This graph shows the mean values (represented by the numbers above the bars) after Chauvenet's Criterion was used to eliminate outliers. The standard deviations for the prototype and control are represented by the error bars and were .756 and 2.992, respectively.

9.1.3 Comparative Testing

The prototype must be able to perform under the same conditions as the current two-wheeled walker. Thus, it must be able to be used on all common surfaces and must be stable on ramps including curb ramps. Furthermore, the prototype must not make the user feel more self-conscious than if they were using a current two-wheeled walker. Each test subject ranked the prototype and the control using a scale from one to five for eight different categories (one being the worst and five being the best). These categories include ease of use, comfort level when using, and any additional comments the subjects may have. Before ranking the devices, the test subjects were asked to perform three tasks.

1. Use the walker on curb ramp with slopes less than or equal to 1:10 and ramps with slopes less than or equal to 1:12 (Figure 97)

a.

b.

Figure 97: (a) A group member demonstrates using the walker on a ramp. (b) Example of a curb ramp

2. Use the walker on indoor surfaces (distance over 20 ft): linoleum, carpet, tile and a change of surfaces (tile to carpet)

3. Use the walker on outdoor surfaces (distance over 20 ft.): pavement, brick, and a change of surfaces (brick to pavement) (Figure 98)

Figure 98: A group member demonstrates using the walker on the brick surface.

Based on these tasks, the subjects then ranked the devices using Table 21.

1=Poor 2=Fair 3=Well 4=Very Well 5= Excellent

Table 21: Comparative Testing Evaluation Form

Categories	Prototype Walker	Commercial Walker
Ease of use over curb ramp		
Ease of use over ramp		
Ease of use over tile surface		
Ease of use over carpet surface		
Ease of use in change of surface (tile to carpet)		
Ease of use over pavement		
Ease of use over brick		
Comfort level when using in public		
Totals		
Additional Comments:		

9.1.4 Comparative Results

The graph in Figure 45 shows that the prototype scored higher than the control in all of the comparative tests. The overall means and standard deviations for the prototype and commercial comparative testing are summarized in Table 22 below.

Table 22: Comparative Testing Results

Comparative Testing Results				
Type of Test	Prototype		Control	
	Mean	Standard Deviation	Mean	Standard Deviation
Comfort level in public	3.5	1.690	2.9	1.356
Ease of use over ramps	4.4	0.535	3.1	1.126
Ease of use over curb ramp	3.9	1.126	2.6	0.535
Ease of use over change in surfaces	4.4	0.535	3.1	0.991
Ease of use over tile	5.0	0.000	3.4	0.535
Ease of use over carpet	4.5	0.535	3.8	0.707
Ease of use over pavement	4.5	0.535	3.4	0.787
Ease of use over brick	4.6	0.535	3.3	0.488

After Chauvenet's Criterion was used to eliminate outliers from the data, the graph in Figure 99 below was developed to compare the mean values for each of the eight comparative tests.

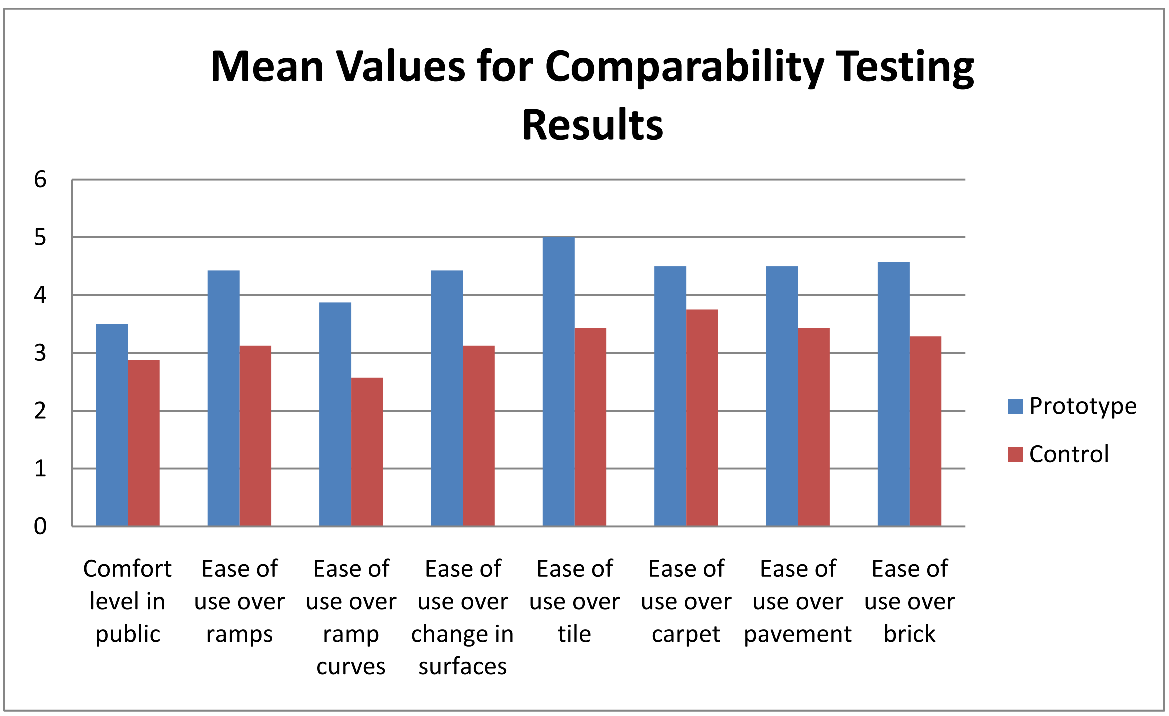
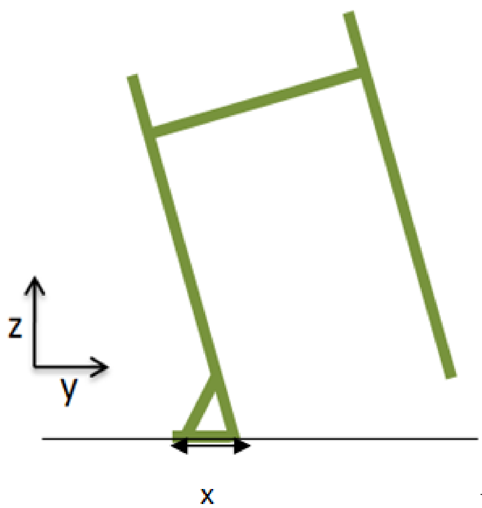


Figure 99: Mean Values for All of the Comparative Tests

A 1-5 numeric scale was used for the questionnaire and the prototype scored higher than the commercial walker in every category. This demonstrates that the current technology has been improved. The questionnaires filled out by the subjects at the end of testing are located in Appendix P.

9.2 Stability Testing and Results

The commercial walker does not offer any support when the walker is tipping. To increase stability, the prototype extends the BOS when the walker tips through an angle of five degrees. To determine how effective the prototype is at extending the BOS, the length of the horizontal leg was measured (Dimension x, Figure 100a). The total footprint (including the lateral leg extensions) of the prototype were compared to the control's BOS (Dimensions w and d, Figure 100b). For this test, the walker with the larger BOS was the walker that offered more stability because the larger the BOS, the more stable the walker is.



a.

b.

Figure 100: a) Additional Length Provided by Lateral Leg Extension b) Walker Displaying Foot Print Measurement

The standard width of this walker is 25.5 inches (Drive Medical Design and Manufacturing, 2009). The lateral leg extensions add 3.5 inches from the edge of each walker leg, which extends the footprint of the walker (Figure 101). With a larger footprint, the walker is more stable than a standard walker. The drawback is the walker has a larger width, which makes it more bulky to ambulate through doors and other narrow places.

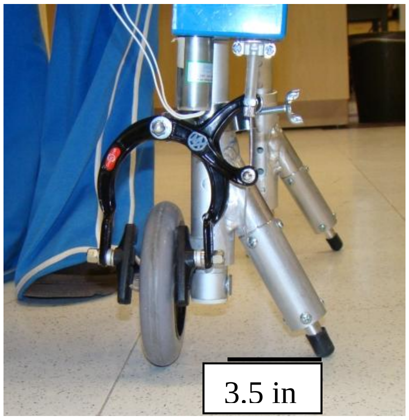


Figure 101: The Additional Width from the Lateral Leg Extensions

9.3 Dimensional Testing and Results

The dimensional specifications were tested by measuring the device. These were all pass or fail tests. The dimensions of the walker are very important because the maneuverability of the walker must be maintained. If the walker is too bulky, the user might find the prototype walker more difficult to use rather than helpful. The dimensions of the prototype are 24.75 in. x 29 in. (d x w) (Figure 102). The height was not affected by the accessories so it has the same range of heights as a standard walker, from 32 to 39 inches.

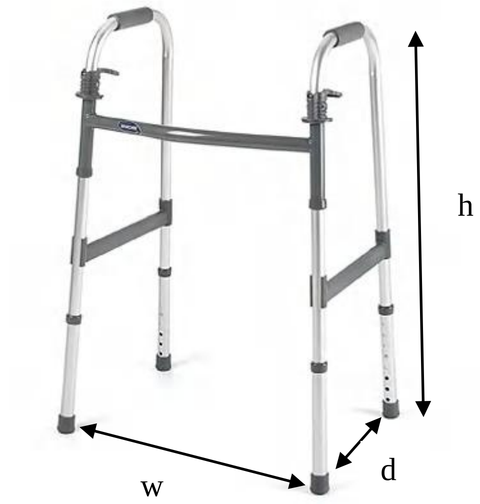


Figure 102: Maximum width, depth, and height dimensions of device

9.3.1 Width, Depth, and Height Testing and Results

The device must be at least 18 in apart and no wider than 32 in. (Dimension w, Figure 102). In order for the consumer to use the device, the walker must not get in the way of the user's feet while the user is ambulating. The width of unstable elderly people's gait varies significantly, thus using the women's (95%) waist width of 17.4 in. will ensure an optimal number of users can fit into the device. Furthermore, the width must not exceed 32 in. to ensure the device can travel through all handicap accessible doorways. The depth of the device must not exceed 26 in., which is the depth of the largest walker, the Rollator (Dimension d, Figure 102). The device must be able to adjust from 32.5 in. in height to 39.5 in. in height, which is the height range of most commercial walkers (Dimension h, Figure 102).

The width and depth of the device is 29 in. and 24.75 in. respectively (Figure 103). The height was not affected by the design and remained the same as a standard walker, with a range of 32.5 in. to 39.5 in.

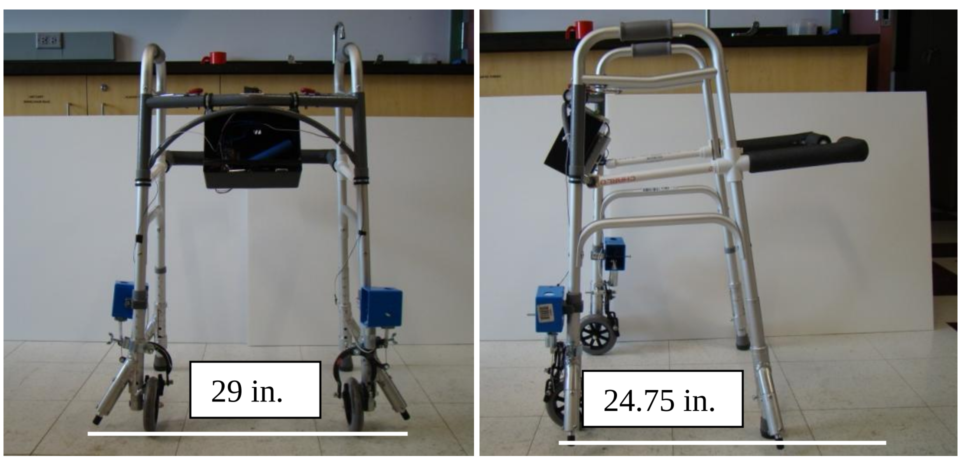


Figure 103: Dimensions of Prototype

9.4 Weight Testing and Results

The weight of the device must be less than 7 lb. To test the weight of the device, a string was tied around the handles of the walker and a force gauge lifted the walker into the air. The reading was then recorded. The walker is specified to be less than 7 lbs because the average weight of a standard two-wheeled walker is 7 lbs. In weighing the final prototype, the weight was 17 lbs. This is 10 lbs heavier than the specified weight because of the brakes, solenoids, and batteries. In starting with a standard walker, the weight was already approximately 7 lbs, but to make it safer, these objects were added. Another factor that was mentioned in Section

11.1 is that the locations in which the weight was added created a lower center of mass for the walker. The lower center of mass creates a much more stable feeling for the user

9.5 Transportability Testing and Results

The device must be able to fit in an 18 x 22 x 31 in^3 space when being transported. First, the dimensions of the walker were measured when the walker was deployed for use and when it was folded for storage. The dimensions stated in the above section were the fully deployed dimensions. The prototype did not fold as well as a standard walker can fold because when the foam guides are released from the magnets, they interfere with each other because they are on the same level. The walker can only be folded to a dimension of 17 in. x 29.5 in. x 32.5 in. with the foam intact. The first step in folding the walker is to release the right foam arm from the magnet. Then, push the red button on the crossbar to fold the right walker frame in, while allowing the foam arm to move through the left frame. Then push the red button to fold the left frame in (Figure 104).

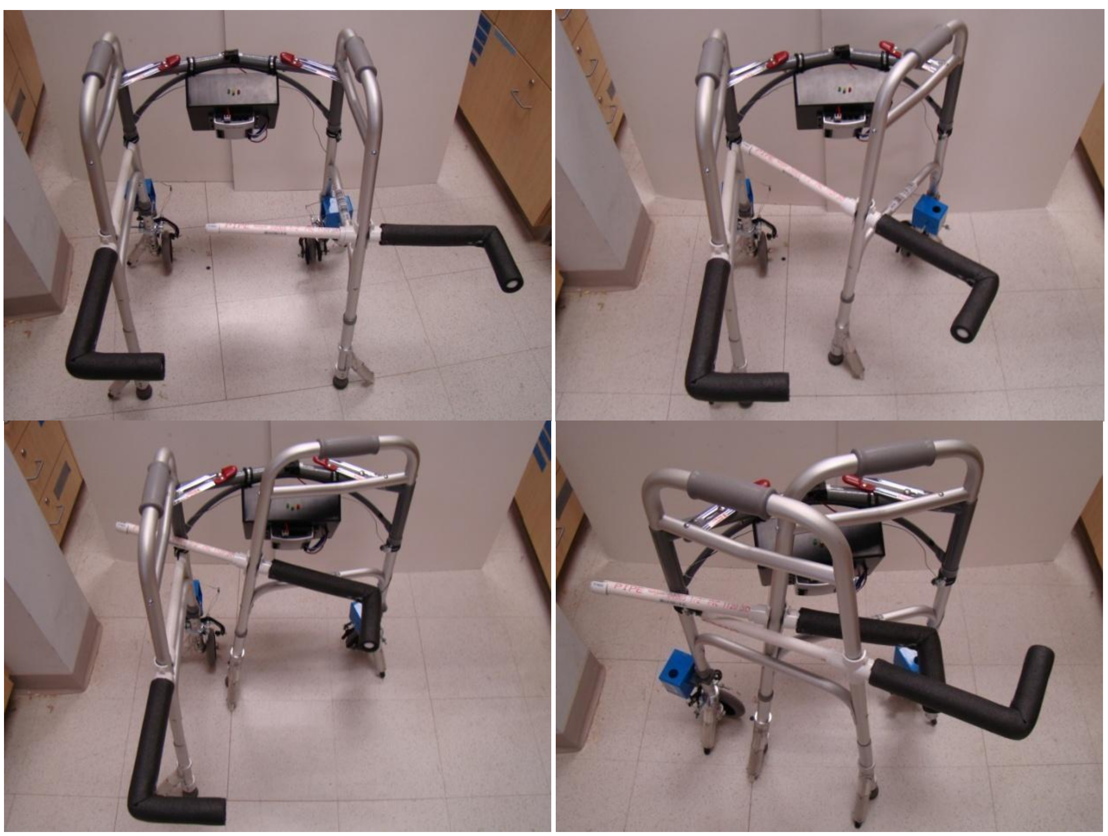


Figure 104: The Four Steps to Fold the Walker

The walker can be folded to slightly smaller dimensions without the foam at 14 in. x 25 in. x 32.5 in. (Figure 105).

Figure 105: The Prototype Folded Without the Foam

9.6 Obstruction Testing and Results

The sides of the walker's frame must not have any obstructions other than the walker's feet that are less than 1 ft off the ground so that the user is not inhibited in their stepping reactions during a fall (Figure 106). Nothing should be inside the area between the two side walker legs and if there is something there, its lowest position should be greater than 1 ft. above the floor to ensure that it does not impede the user.

Figure 106: If there is something between the two legs its lowest position (H) should be greater than 1 ft. So that it does not impede the user from ambulating with the walker

On the prototype, one of the blue solenoid housing boxes does sit in between the right side walker legs (Figure 107b). It is eight inches off the ground, and has a cross sectional area of six square inches. Unfortunately, the blue solenoid housing box can obstruct the user's lateral stepping reaction. Figure 107a shows the solenoid housing box outside the BOS where it will not interfere with the user's lateral stepping reactions.

a. 

b. 

Figure 107: The blue solenoid housing box obstructs the user's lateral stepping reactions in the right frame of the walker. a) Left Frame a) Right Frame

10.0 Data Analysis and Discussion

The following sections discuss the results of subject and dimensional testing. The prototype, on average, scored higher than the commercial walker (control). Also, the prototype met all of the requirements for the dimensional testing. Even though prototype weighed more than the control, this proved to be advantageous because it lowered the COM making the prototype more stable than the control. However, the electronic box and foam made it difficult for the prototype to fold as well as the control. The foam can be removed for storage purposes but the commercial walker does fold better than the prototype. The housing for the solenoids also poses a problem and may get in the way of the user's stepping reaction. Therefore, the housing of the solenoids should be moved to at least one foot above the ground.

Although one of the design specifications for the prototype was to be able to support a weight of 184 lbs, this was not tested. The prototype consists of a commercial standard walker with added accessories, and the commercial walker already met this requirement. The accessories did not alter the structural integrity of the walker, thus this specification was not tested.

10.1 Subject Testing Data Analysis and Discussion

The commercially available standard two-wheeled walker was used as a control for subject testing, which included the comparative and limiting user actions tests. Eight subjects were tested, six females and two males. The majority of test subjects were women because they are the predominate users of walkers. For liability reasons, walker users were unable to be tested. College students were used for all testing; therefore the results are strictly for functionality purposes and are not statistically significant.

10.1.1 Limiting User Actions Data Analysis and Discussion

The means and standard deviations for the limiting user actions tests are summarized in Table 14 below.

Table 23: Limiting User Actions Test Mean and Standard Deviation before Chauvenet's Criterion

Number of Times Outside the BOS		
	Prototype	Control
Average	0.9	21
Standard Deviation	1.808	5.237

The standard deviations are high, indicating the data varies far from the mean. To ensure accurate results, Chauvenet's Criterion for Rejecting Data was used to identify and eliminate outliers. Chauvenet's Criterion uses the number of samples (n) and the equation below to determine the ratio (c) between the deviation and the standard deviation of the distribution.

$$c = .9969 + .4040 * LN(n)$$

For the limiting user actions tests, eight subjects were used, thus n is equal to eight. Therefore, c was determined to be 1.837. This number was then multiplied by the standard deviations, for the prototype and control, to determine the critical deviation, 3.320 and 9.620, respectively. If the critical deviation is less than any data point minus the mean, then that data point can be discarded. Figures 108 and 109 are graphs of the resulting means for the limiting user actions tests, before and after utilizing Chauvenet's Criterion for data rejection.

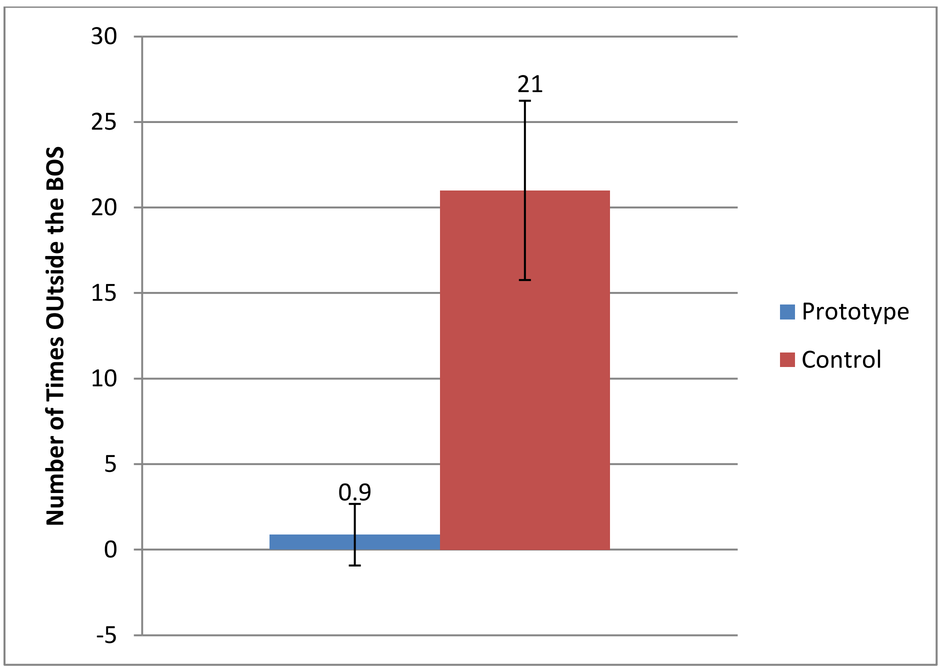


Figure 108: Graph of Results for Limiting User Actions Tests before Chauvenet's Criterion

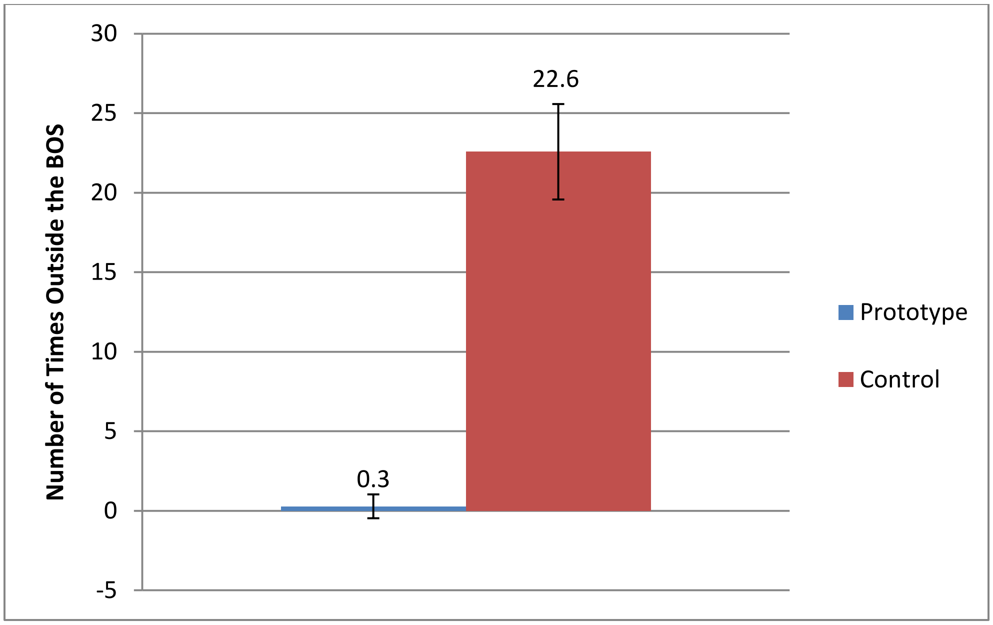


Figure 109: Graph of Results for Limiting User Actions Tests after Chauvenet's Criterion

The graphs demonstrate that eliminating the outliers decreased the standard deviations (indicated by the error bars) and made the difference between the means greater. The standard deviations decreased from .9 to .3 and 21 to 22.6 for the number of times outside the BOS for the prototype and control, respectively.

A z-distribution was used to determine the range in which 95% of the data would fall within for the limiting user actions tests for both the prototype and control. Since the standard normal distribution curve is symmetrical about zero, half of 95% (47.5%) was used to establish the z-value. Using a z-value table and the area under the curve (0.475), the z-value was determined to be 1.96 (Thomas Beckwith, 2007). The upper specification limit and lower specification limit for the number of times outside the BOS for the prototype and control were determined using the equation and the parameters in Table 24.

$$z = \frac{x \pm \mu}{\sigma}$$

Table 24: Parameters for Determining Range that fits 95% of the Data

Parameters	Variable	Prototype Value	Control Value
z-value	z	1.96	1.96
Mean	μ	0.29	22.57
Standard Deviation	σ	0.76	2.99
LSL	(-x)	-1.196	16.707
USL	(+x)	1.767	28.436

The range for the prototype is much smaller than the controls. This indicates that it is more likely for a user to use a commercial walker improperly as opposed to the prototype. The graph in Figure 110 shows that all of the data collected from the limiting user acts tests falls within the upper range (USL) and lower range (LSL) calculated from the z-distribution. The graph only shows 7 pairs of data points because one pair was eliminated using Chauvenet's Criterion.

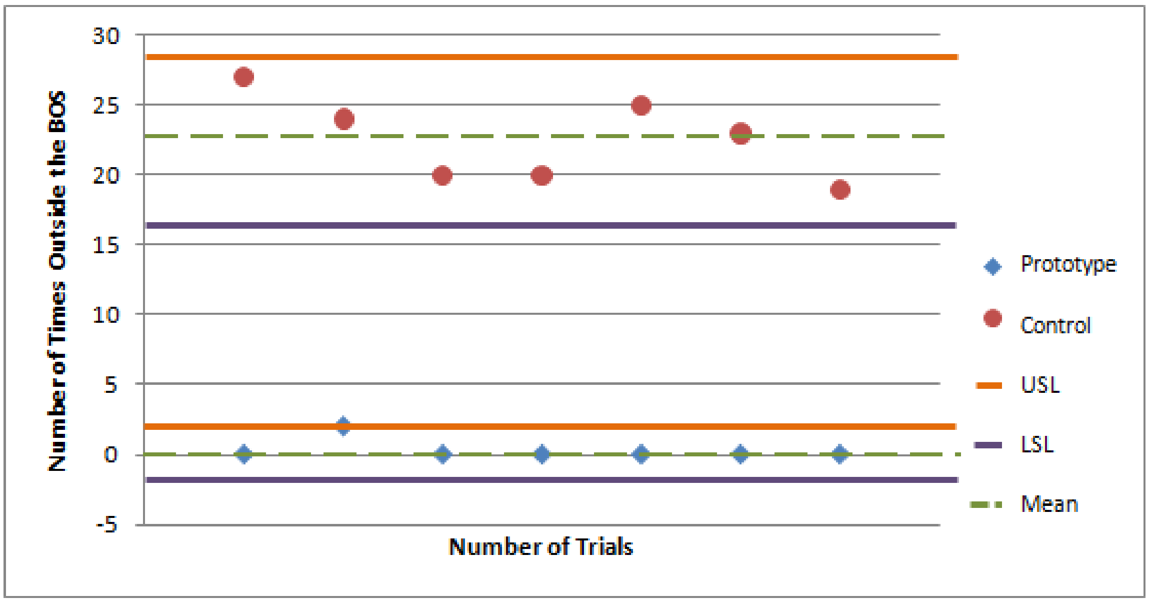


Figure 110: Graph displaying range in which 95% of data for Limiting User Action Testing

Since the least significant digit from the measurements was 1, the upper range and lower range were rounded to the nearest ones place. As demonstrated by the graph, subjects using the control were outside the BOS more frequently than the prototype, and the data varied much more for the control than the prototype. This proves the prototype was successful in limiting the user actions and keeping the user inside the BOS.

10.1.2 Comparative Testing Data Analysis and Discussion

The means and standard deviations for the comparative tests are summarized in Table 25.

Table 25: Comparative Tests Means and Standard Deviations before Chauvenet's Criterion

Before Chauvenet's Criterion				
Type of Test	Prototype		Control	
	Mean	Standard Deviation	Mean	Standard Deviation
Comfort level in public	3.5	1.690	2.9	1.356
Ease of use over ramps	4.3	0.707	3.1	1.126
Ease of use over curb ramp	3.9	1.126	2.4	0.744
Ease of use over change in surfaces	4.1	0.991	3.1	0.991
Ease of use over tile	4.8	0.707	3.6	0.744
Ease of use over carpet	4.5	0.535	3.8	0.707
Ease of use over pavement	4.5	0.535	3.1	1.126
Ease of use over brick	4.4	0.744	3.5	0.756

The standard deviations are high, indicating the data varies far from the mean. To ensure accurate results, Chauvenet's Criterion for Rejecting Data was used to identify and eliminate outliers. Since the same number of test subjects was used as before, eight, the corresponding ration between the deviation and the standard deviation of the distribution was determined to be 1.837. This number was then multiplied by the standard deviations, for the prototype and control, to determine the critical deviations. If the critical deviation is less than any data point minus the mean, then that data point can be discarded. Figures 111 and 112 are graphs of the resulting means, before and after utilizing Chauvenet's Criterion for data rejection.

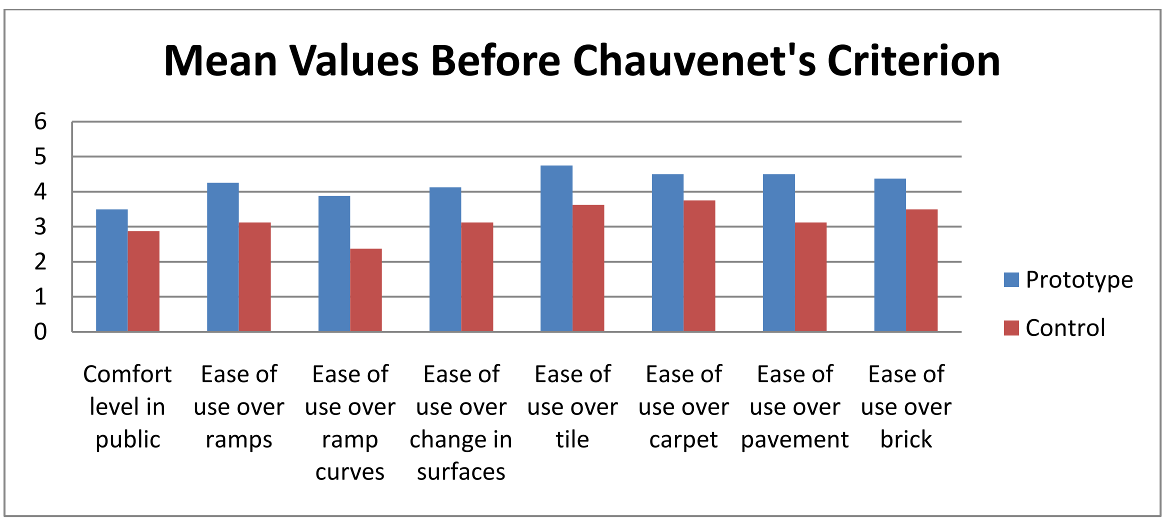


Figure 111: Graph of Results for Comparative Tests before Chauvenet's Criterion

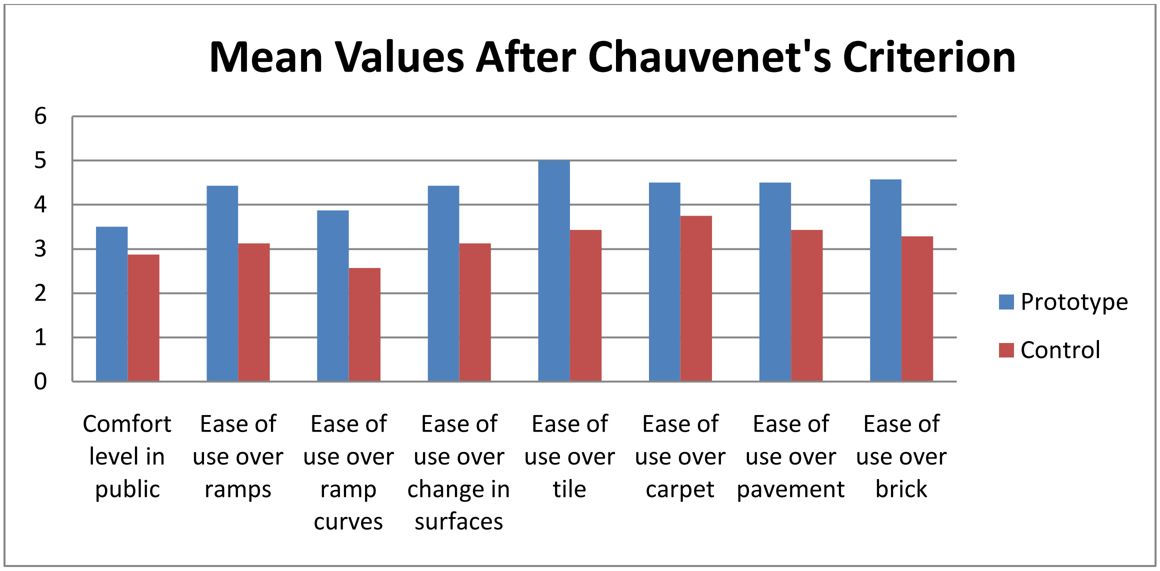


Figure 112: Graph of Results for Comparative Tests after Chauvenet's Criterion

By conducting the data elimination ensured that the error in the surveys would decrease because any answers that were farther greater than the critical distribution were discarded, meaning if the difference between a data point and the mean were greater than the critical distribution, the point was eliminated. Table 26 summarizes the means and standard deviations after utilizing Chauvenet's Criterion.

Table 26: Comparative Tests Means and Standard Deviations after Chauvenet's Criterion

After Chauvenet's Criterion				
Type of Test	Prototype		Control	
	Mean	Standard Deviation	Mean	Standard Deviation
Comfort level in public	3.5	1.690	2.9	1.356
Ease of use over ramps	4.4	0.535	3.1	1.126
Ease of use over curb ramp	3.9	1.126	2.6	0.535
Ease of use over change in surfaces	4.4	0.535	3.1	0.991
Ease of use over tile	5.0	0.000	3.4	0.535
Ease of use over carpet	4.5	0.535	3.8	0.707
Ease of use over pavement	4.5	0.535	3.4	0.787
Ease of use over brick	4.6	0.535	3.3	0.488

Table 26 when, compared to Table 25, demonstrates that eliminating the outliers decreased the standard deviations (some also remained the same if data could not be eliminated). The prototype still proved to be superior to the commercial walker in all of the categories for comparative testing. Therefore, the product specification of ensuring the prototype preformed as well as the commercial walker was met.

During testing, it was observed that the males disliked the foam. One male subject wrote he did not like the foam because he felt trapped. The males were the only test subjects to score the commercial walker as more comfortable to use in public than the prototype. None of the female test subjects scored the commercial walker over the prototype for comfort in public (two of the subjects scored them as a tie). In fact, the females said the prototype felt safer because it was more bottom heavy, making it more stable than the commercial walker. These responses demonstrate women would more likely be the majority users of the device because it feels safer, even though it is bulkier. The males did not seem to care as much as to which felt safer, but to which device was most inconspicuous (comment are located in Appendix P).

12.0 Summary

An improved walker design that limits the possibility of a user falling laterally was successfully constructed. The walker design was developed based on extensive background research and mathematical modeling of a users fall. The walker design employs two basic methods for limiting the likelihood of the user suffering a lateral fall. It temporarily extends the base of support in the event that the walker begins to tip laterally and controls the system's center of mass in order to keep the user inside the base of support as much as possible. The improvements were embodied as universal attachments that can be installed on any standard walker. The walker design was manufactured and tested which confirmed that it was functional and successful in employing the two strategies in preventing the user from falling.

The improved walker temporarily extends the base of support in order to reduce lateral falls. It does this through the four lateral leg extensions. These extensions are made of solid and hollow round aluminum that connects to the walker, a spring, an aluminum piston that moves as the spring compresses, and a nylon bushing that contains the piston. These extensions extend 2.25 inches outward from the walker and the outermost tip sits .25 inches off of the ground. When the walker tips five degrees the lateral leg extensions touch the ground. The spring then compresses until the walker tips through five additional degrees (ten degrees total).

The temporary extension of the base of support helps the user from falling laterally in several ways. It provides the user with more time to employ stepping reactions and other means of regaining their balance before the he or she falls to the ground. Also, the lateral leg extensions were sized so that the user can push off of the handles of the walker as it begins to tip and they will be able to keep the user from continuing to fall. With the standard walker, as soon as the walker begins to tip it will continue to fall as there is nothing to stop it.

The lateral leg extensions could not be dynamically tested by someone falling due to the potential for the person to injure themselves. However, the walker was tipped to determine how much the lateral leg extensions extend the base of support. It was determined that they temporarily extend the BOS by 3.5 inches on either side in the event that the walker is tipped laterally.

The improved walker also reduces the chances of the user falling by reducing improper use. A common cause of falls is people using the walker while they are outside its base of support. The guidance system controls the systems center of mass keeping it within the base of support. The electrical brake system warns the user when they are about the leave the base of support and makes it difficult to move the walker if they move outside the BOS. This encourages the user to step back within the BOS before continuing the use the walker. The foam system is a nearly entirely mechanical device that controls the system's center of mass through physical contact.

The electrical system controls the user's center of mass through providing visual feedback to the user and activating brakes if he or she moves outside the BOS. An infrared range finder senses the location of the user and outputs a voltage to the vex microcontroller. A green, yellow, or red LED lights up depending on whether the user is inside the BOS, about to exit the BOS, and outside the BOS. If the user is outside the BOS the microcontroller sends a current to a relay which activates two solenoids. The solenoids pull on a brake cable which activates the caliper bike brakes mounted on the walker wheels. Through testing it was determined that the frictional force provided by the brakes was sufficient enough to induce skidding on tile and provided significant stopping on carpet, concrete, and brick.

The foam system provides additional feedback to the user through providing physical contact when they are about to move outside the BOS. The foam assemblies stick out from the back of the walker and around the user in an "L" shape. They are close enough to the walker that they contact the back of the user's leg just before they exit the BOS of the walker. They are held in place by magnets, which provide enough force to keep the foam assemblies in place during normal use, but a small enough force so that the assemblies can be opened to allow the user to enter the walker.

The ability of the foam and electrical systems to ability to control the user's center of mass was tested during the subject tests. Subjects walked down a hallway using a standard walker and the improved walker and the number of times they moved outside the base of support was recorded. It was determined that on average the users stepped outside the base of support 22.6 times (standard deviation of 2.99) with the standard walker and only .3 times (standard deviation of .756) with the prototype. This shows that the incidences of misuse via stepping outside the base of support was significantly reduced by the new walker design and that the systems successfully control the user's center of mass.

All of the improvements to the walker were constructed as attachments than can be purchased separately and easily mounted onto any standard walker. The lateral leg extensions are mounted to a detachable walker leg, which can be added or removed to the walker using its spring-loaded push button. The brakes and housing are also mounted to the detachable walker legs. The foam components quickly snap onto the frame of the walker. Finally, the electrical components are contained within a project box which has two mounts that are screwed around the cross bar of the walker. Besides reducing costs by not requiring the user to buy an additional walker, the attachments allow the consumer to purchase only the systems that they desire; it also helps to maintain the image of a standard walker, which reduces stigma.

Along with providing improvements to reduce lateral falls, the improved walker is not exceptionally large or cumbersome. During normal use when the walker is not tipped it is 29 inches wide. This is 4.5 inches wider than the standard walker, but well within the required specification that the walker be no wider than 32 inches. The improved walker's depth is also greater than the standard walker. The prototype is 24.75 inches long, which is 6.75 inches longer than the standard walker. The height and adjustability of the height of the standard walker were not affected by the accessories. One specification that was not met by the prototype was the ability to fold into an 18 x 22 x 31 in^3 space for transportation. Because of the excessively large electronics housing the walker was only able to be folded into a 17 in. x 29.5 in. x 32.5 in. space with the foam intact and a 14 in. x 25 in. x 32.5 in. space with the foam removed. Although these were not the specific dimensions set forth by the specifications, it does show that the walker is capable of folding into a space 901 cubic inches smaller than 12276 cubic inches required by the specified dimensions.

According to comparative studies conducted with volunteers, it is better received in terms of normal use and functionality than the standard walker. After using the standard and improved walkers over a series of surfaces and situations test subjects compared several factors about the two walkers. The users were more comfortable using the improved walker over all of the tested surfaces which included brick, tile, carpet, and pavement. They also felt more comfortable using the improved walker design over ramps and change of surfaces. Results showed that the users were more comfortable using the improved walker in public than the standard walker. Throughout the process steps were taken to minimize the weight of the improved walker. However, the final design had a weight of 17 lbs which is 10 lbs heavier than the standard walker. Through the comments on the test subjects questionnaires it was determined that the users liked the additional weight because it made the walker feel more stable and lowered the system's center of mass.

Overall, the improved walker design was a success. It temporarily extends the BOS in the event of a fall and controls the system's center of mass so that he or she stays within the system's BOS. It does this through accessories that can be easily added to a standard walker. The design was well received by the test subjects and functions better than the standard walker in all of the categories tested.

13.0 Recommendations

Although the prototype showed a proof of concept and accomplishment of the objectives of the design, there are areas in which it can be improved. There are several aspects of the design that can be streamlined in order to reduce the bulkiness of the accessories and minimize the walker's stigma. There are also improvements that can be made to simplify the manufacturing process and thus reduce the cost for the end user.

The electronics housing could be made smaller because it is larger than necessary to hold the components inside of it. It also inhibits the folding of the walker as the legs hit the housing when they are trying to fold. If the size of the box was reduced it would allow the walker to fold and be stowed in smaller locations. If the size of the box was reduced, the walker could be folded down an additional three inches so that is was within the 18 x 22 x 31 in^3 specification.

Another recommendation is to decrease the number of custom made parts in the lateral leg extension attachment (kickstand). Currently, the kickstand attachment consists of five custom made parts. In order to reduce costs to the final customer the number of custom made parts should be reduced. Another improvement that could be made to the kickstand would be to make the connecting shaft and cover one piece. The spring constant of the springs could also be reduced. The spring constant was calculated for a 50^{th} percentile elderly male, as it is the upper spectrum of the users in terms of size and weight. However, most walker users are smaller females. If one of these small female users began to tip while using the improved walker they would be jerked to a stop when the lateral leg extension contacted the ground because the spring is too stiff for their size and weight. Thus, it is recommended that there be two different lateral leg extensions which have springs with different spring constants one for smaller uses and one for larger users. This allows the consumer to easily buy the attachment that suits their size and weight.

The brake housing box could be improved to reduce its size and move it out of the way of the user. The size of the housing box which holds the solenoid and lever arm was predominantly determined by what was commercially available. However, it is larger than necessary and could be made smaller. Because of the shape of the two brakes purchased for the prototype and the fact that they were identical, they could not be mounted as mirror images of each other. They were mounted in the same manner and then the entire wheel attachment was spun 180 degrees so that both walker wheels were on the inside of the walker. This is illustrated in Figure 113. This mounting meant that one housing box was located inside the side walker frame, thus reducing the room for the user to employ a lateral stepping reaction. This could be easily corrected by purchasing brakes that were mirror images of each other or brakes that could be mounted forwards or backwards.

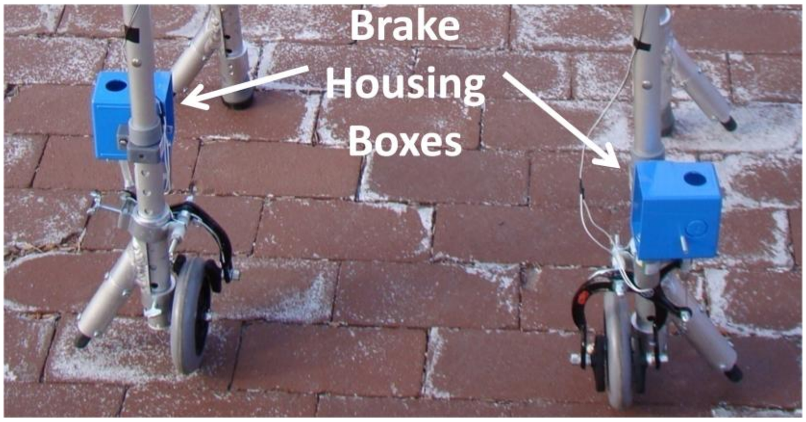


Figure 113: The Brake Setup and Solenoid Housing

Another issue with the bike brakes is that, in order to get the brakes to apply the necessary force, the spring back had to be reduced, which in turn caused the brake pads to remain in contact with the wheel. The lever also had to be constructed to provide additional mechanical advantage. To ensure that the brakes spring back and do not inhibit the wheel and that they apply significant breaking force when they are activated it is recommended that a stronger solenoid be used in the design.

The foam components could be improved by making two different attachments based on the user. The foam worked well at keeping all users in the walker, however for the taller users it appeared as though it significantly restricted the length of their stride. The length of the foam attachments are based on the anthropometric data of a fifth percentile elderly female. Thus, it would be useful to have two different length attachments: one that was suitable for a certain shorter height range and one that was suitable for a taller height range.

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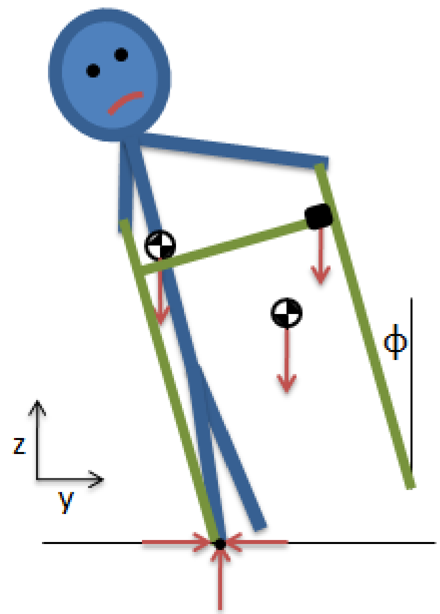
Appendix A: Weight Design Analysis

angle	$\phi := 14 \cdot deg$
mass of person	$m_p := 245 \cdot lb$
mass of walker	$m_w := 6.5 \cdot lb$
COM in x of walker	$C_w := 10.5 \cdot in$
height of person	$h_p := 6 \cdot ft$
width of walker	$w := 22 \cdot in$
COM in y of person	$C_p := .56 \cdot h_p = 40.32 \cdot in$
Unknown weight	m =?



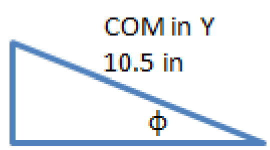
Origin is where the person's foot and walker meet the ground and is denoted by a small black dot

$$d_{cl} := \left(\frac{.191}{2}\right) \cdot h_p = 6.876 in$$

Moment caused by walker

$$y_w := C_w \cdot \cos(\phi) = 10.188 \, in$$

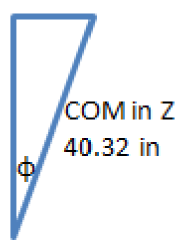
$$M_w := m_w \cdot g \cdot y_w = 2.557 \times 10^4 \cdot lb \cdot \frac{in^2}{s^2}$$



Moment caused by person

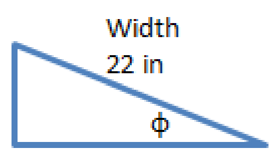
$$y_p := -C_p \cdot \sin(\phi) + d_{cl} = -2.878 \, in$$

$$M_p := m_p \cdot g \cdot y_p = -2.723 \times 10^5 \cdot lb \cdot \frac{in^2}{s^2}$$



Location of weight

$$x_m := w \cdot \cos(\phi) = 21.347 \cdot in$$



Magnitude of weight

$$M_{total} = M_w + M_p + m \cdot x_m \cdot g = 0$$

$$M := \frac{-M_w - M_p}{x_m \cdot g} = 29.933 lb$$

Appendix B: Active and Passive Kickstand Static Calculations

mass of person $m_p := 184 \cdot lb$

load on walker $L_w := .3m_p = 55.2 \cdot lb$

load supported by person $L_p := .85 \cdot m_p = 156.4 \, lb$

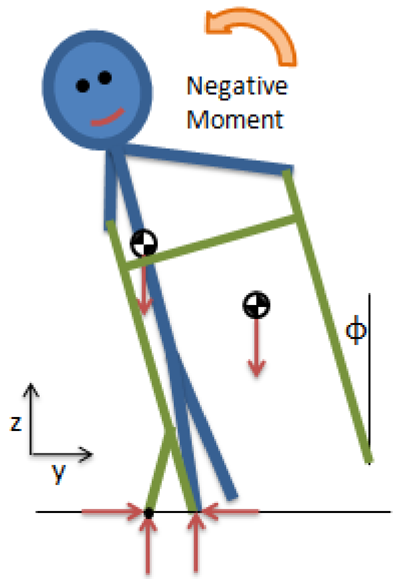
mass of walker $m_w := 6.5 \cdot lb$

COM in x of walker $C_w := 10.5 \cdot in$

height of person $h_p := 6 \cdot ft$

width of walker $w := 22 \cdot in$

COM in y of person $C_p := .56 \cdot h_p = 40.32 \, in$



$z := .25 in$

$y := 0in, .1 \cdot in .. 5 \cdot in$

The load on the walker comes from walker loading studies conducted by Maki

$$\phi(y) := \operatorname{atan}\left(\frac{z}{y}\right)$$

$$k(y) := \sqrt{z^2 + y^2}$$

$$d_{cl} := \left(\frac{.191}{2}\right) \cdot h_p = 6.876 in$$

Origin is where kickstand meets the ground and is denoted by a small black dot

Moment caused by gravity on walker

$$y_w(y) := \left(C_w \cdot \cos(\phi(y)) + k(y)\right)$$

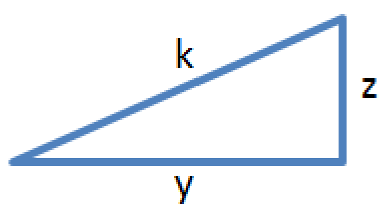
$$M_w(y) := m_w \cdot g \cdot y_w(y)$$

Horizontal components of the forces of the floor acting on the person and walker are neglected because they go through the origin and do not result in any moments

Moment caused by gravity on person

$$y_p(y) := -C_p \cdot \sin(\phi(y)) + k(y) + d_{cl}$$

$$M_p(y) := m_p \cdot g \cdot y_p(y)$$



Moment caused by force on person's feet

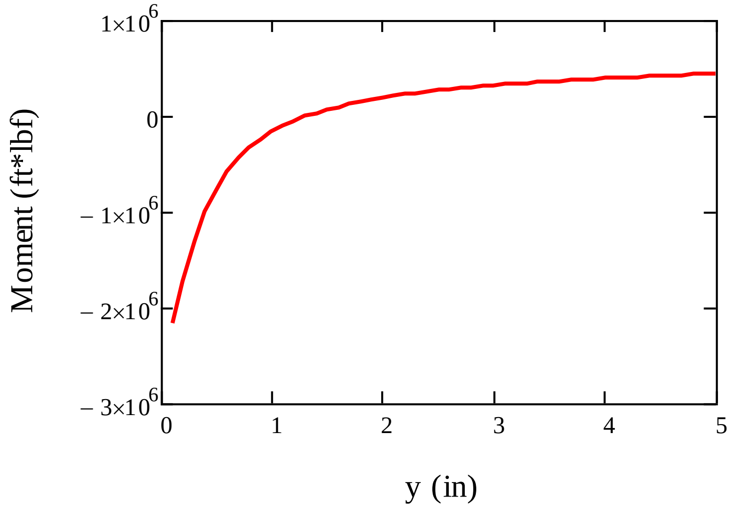
$$y_f(y) := k(y)$$

$$M_f(y) := -L_p \cdot g \cdot y_f(y)$$

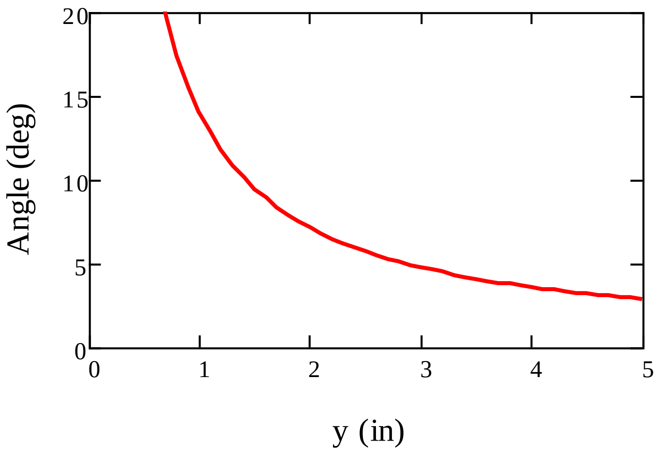
Total Moment

$$M_{total}(y) := M_w(y) + M_p(y) + M_f(y)$$

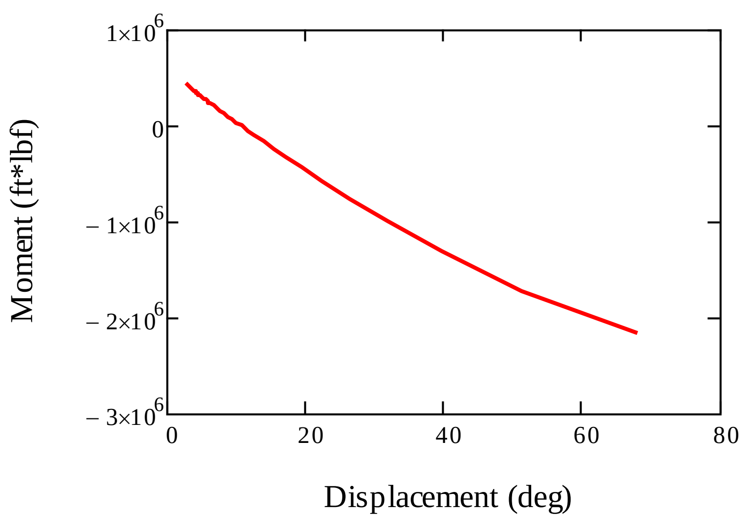
In order for the person to stop falling the total moment of the system needs to be positive.



Moment (ft*lbf)
1×10^6
0
− 1×10^6
− 2×10^6
− 3×10^6
0
1
2
3
4
5
y (in)



Angle (deg)
20
15
10
5
0
0
1
2
3
4
5
y (in)



Moment (ft*lbf)
1×10^6
0
− 1×10^6
− 2×10^6
− 3×10^6
0
20
40
60
80
Displacement (deg)

Guess

$$y := 2 \cdot in$$

Given

$$0 = M_w(y) + M_p(y) + M_f(y)$$

$$y_o := \text{Find}(y) \qquad y_o = 1.322 \cdot in$$

$$\phi_o := \text{atan}\left(\frac{z}{y_o}\right) = 10.706 \deg$$

$$y_5 := \frac{z}{\tan(5 \cdot \deg)} = 2.858 in$$

In order to touch the ground and arrest the fall at 10 degrees the kickstand needs to sit 1.322 inches horizontally from the walker leg. In order to touch the ground and arrest the users fall before they fall through 5 degrees the device must be at least 2.858 inches from the walker leg

Appendix C: Calculation of System's Moment of Inertia

total mass $M := 6.5\,lb$

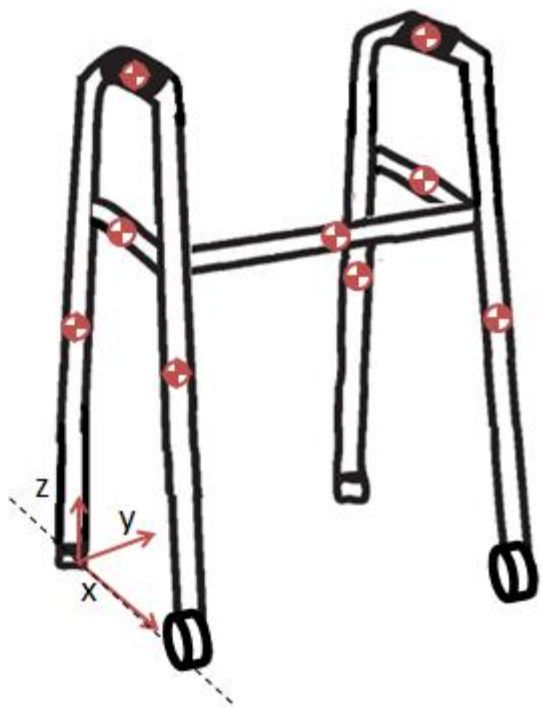
height $h := 37\cdot in$

width $w := 22\cdot in$

depth $d := 18\cdot in$

offset $h_1 := 5\cdot in$

tube diameter $t := 1\cdot in$



Leg length

$$L_l := h = 37\cdot in$$

Handle/side support Lengths

$$L_h := d - 2\cdot t = 16\cdot in$$

Front support length

$$L_f := w - 2\cdot t = 20\cdot in$$

total length of tubing

$$L := L_l\cdot 4 + L_h\cdot 4 + L_f = 232\cdot in$$

mass per length

$$\mu := \frac{M}{L} = 0.028\frac{lb}{in}$$

Note: it was assumed that the difference in mass of the handles, feet, and wheels were negligible thus a mass density for length of tubing was used to calculate the mass of the various sections of the walker

Mass of leg

$$M_l := L_l\cdot\mu = 1.037\,lb$$

Mass of handle/side support

$$M_h := L_h\cdot\mu = 0.448\,lb$$

Mass of front support

$$M_f := L_f\cdot\mu = 0.56\,lb$$

x component of COM

$$\frac{\left(M_l\cdot 2 + M_f\right)\cdot(d - t) + \left(M_h\cdot 4\right)\cdot\left(\frac{d}{2} - \frac{t}{2}\right)}{M} = 9.233\,in$$

y component of COM

$$\frac{\left[\left(2\cdot M_l + 2\cdot M_h\right)\cdot(w - t) + M_f\cdot\left(\frac{w}{2} - \frac{t}{2}\right)\right]}{M} = 10.5\,in$$

z component of COM

$$\frac{\left[2\cdot M_h\cdot\left(h-\frac{t}{2}\right)\right]+\left(2\cdot M_h+M_f\right)\cdot\left(h-h_1-\frac{t}{2}\right)+\left(4M_l\cdot\frac{h}{2}\right)}{M}=23.897\,in$$

Moment of inertia of near legs

$$I_{ln}:=\frac{M_l\cdot L_l^2}{12}+M_l\cdot\left(\frac{h}{2}\right)^2=473.052\,lb\cdot in^2$$

Moment of inertia of far legs

$$I_{lf}:=\frac{M_l\cdot L_l^2}{12}+M_l\cdot\left[\left(\frac{h}{2}\right)^2+(w-t)^2\right]=930.21\,lb\cdot in^2$$

Moment of inertia of front support

$$I_f:=\frac{M_f\cdot L_f^2}{12}+M_f\cdot\left[(w-t)^2+\left(h-h_1-\frac{t}{2}\right)^2\right]=821.792\,lb\cdot in^2$$

Moment of inertia of near handle

$$I_{nh}:=M_h\cdot\left(\frac{t}{2}\right)^2+M_f\cdot\left(h-\frac{t}{2}\right)^2=746.631\,lb\cdot in^2$$

Moment of inertia of far handle

$$I_{fh}:=M_h\cdot\left(\frac{t}{2}\right)^2+M_f\cdot\left[(w-t)^2+\left(h-\frac{t}{2}\right)^2\right]=993.744\,lb\cdot in^2$$

Moment of inertia of near support

$$I_{ns}:=M_h\cdot\left(\frac{t}{2}\right)^2+M_f\cdot\left(h-h_1-\frac{t}{2}\right)^2=556.114\,lb\cdot in^2$$

Moment of inertia of far support

$$I_{fs}:=M_h\cdot\left(\frac{t}{2}\right)^2+M_f\cdot\left[(w-t)^2+\left(h-h_1-\frac{t}{2}\right)^2\right]=803.226\,lb\cdot in^2$$

Moment of Inertia of walker

$$I_{walker}:=2\cdot I_{ln}+2\cdot I_{lf}+I_f+I_{nh}+I_{fh}+I_{ns}+I_{fs}=6.728\times10^3\cdot lb\cdot in^2$$

Mass of person $m_p := 185 \cdot lb$

height of person $h_p := 5.7 \cdot ft$

moment of inertia for situation 1

moment of inertia around COM

$$I_{pc1} := 1.466 kg \cdot m^2 = 5.01 \times 10^3 \cdot in^2 \cdot lb$$

moment of inertia around rotational axis

distance from COM to axis

$$d_1 := 1.08299 m = 42.637 \cdot in$$

vertical distance

$$h_{c1} := 1.0642 \cdot m = 41.898 \, in$$

$$I_{p1} := I_{pc1} + d_1^2 \cdot m_p = 3.413 \times 10^5 \cdot in^2 \cdot lb$$

moment of inertia for situation 2

moment of inertia around COM

$$I_{pc2} := 1.383 kg \cdot m^2 = 4.726 \times 10^3 \cdot in^2 \cdot lb$$

moment of inertia around rotational axis

distance from COM to axis

$$d_2 := 1.03945 m = 40.923 \, in$$

vertical distance

$$h_{c2} := .56 \cdot h_p = 38.304 \, in$$

$$I_{p2} := I_{pc2} + d_2^2 \cdot m_p = 3.145 \times 10^5 \cdot in^2 \cdot lb$$

moment of inertia for situation 3

moment of inertia around COM

$$I_{pc3} := 1.3141\,kg\cdot m^2 = 4.491\times 10^3\cdot in^2\cdot lb$$

moment of inertia around rotational axis

distance from COM to axis

$$d_3 := 1.140\,m = 44.882\cdot in$$

vertical distance

$$h_{c3} := 1.0642\,m = 41.898\,in$$

$$I_{p3} := I_{pc3} + d_2^{\,2}\cdot m_p = 3.143\times 10^5\cdot in^2\cdot lb$$

Total Moment of Inertia for 3 Scenarios

$$I_{t1} := I_{walker} + I_{p1} = 3.481\times 10^5\cdot in^2\cdot lb$$

$$I_{t2} := I_{walker} + I_{p2} = 3.213\times 10^5\cdot in^2\cdot lb$$

$$I_{t3} := I_{walker} + I_{p3} = 3.21\times 10^5\cdot in^2\cdot lb$$

Appendix D: Dynamic Analysis of Active Kickstand

mass of person $m_p := 184 \cdot lb$

load on walker $L_w := .3 m_p = 55.2 \cdot lb$

load supported by person $L_p := .85 m_p = 156.4 lb$

mass of walker $m_w := 6.5 \cdot lb$

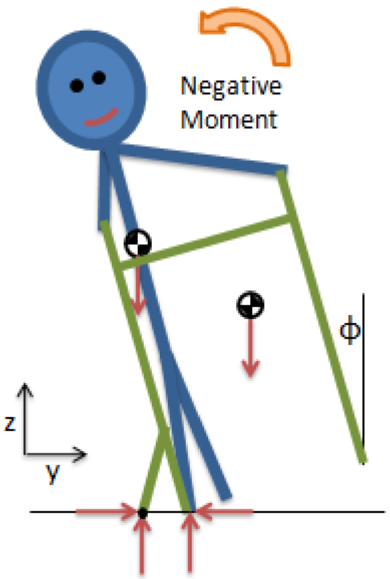
COM in x of walker $C_w := 10.5 \cdot in$

height of person $h_p := 5.7 \cdot ft$

width of walker $w := 22 \cdot in$

COM in y of person $C_p := .56 \cdot h_p = 38.304 in$

Mass of system $m_s := m_w + m_p = 190.5 lb$



The moments of inertia and centers of mass calculated earlier for each of the falling situations were applied to a differential equation solver in order to determine the displacement, velocity, and acceleration of the system for each of the situations.

Counter-Lateral Step

$z_{cm1} := 41.898 in$

$I_1 := 3.481 \cdot 10^5 \cdot in^2 \cdot lb$

$Te := 8$

$Nt := 1000$

Given

$$\frac{d^2}{d\tau^2}(x(\tau)) + \frac{s^2 \cdot m_s \cdot z_{cm1} \cdot -g}{I_1} \cdot \sin(x(\tau)) = 0$$

$x(0) = .5 deg \qquad x'(0) = 0$

$\theta_1 := Odesolve(\tau, Te)$

Side Step

$z_{cm2} := 38.304 \cdot in$

$I_2 := 3.213 \cdot 10^5 \cdot in^2 \cdot lb$

$V_{02} := .1 \cdot \frac{m}{s}$

$\omega_{02} := \frac{V_{02} \cdot s}{z_{cm2}} = 0.103$

$Te := 8$

$Nt := 1000$

Given

$$\frac{d^2}{d\tau^2}(\theta(\tau)) + \frac{s^2 \cdot m_s \cdot z_{cm2} \cdot -g}{I_2} \sin(\theta(\tau)) = 0$$

$\theta(0) = 0 \cdot deg \qquad \theta'(0) = \omega_{02}$

$\theta_2 := \text{Odesolve}(\tau, Te)$

Cross-over Step

$z_{cm3} := 41.898 \cdot in$

$I_3 := 3.21 \cdot 10^5 \cdot in^2 \cdot lb$

$V_{03} := .1 \cdot \frac{m}{s}$

$\omega_{03} := \frac{V_{03} \cdot s}{z_{cm3}} = 0.094$

$Te := 8$

$Nt := 1000$

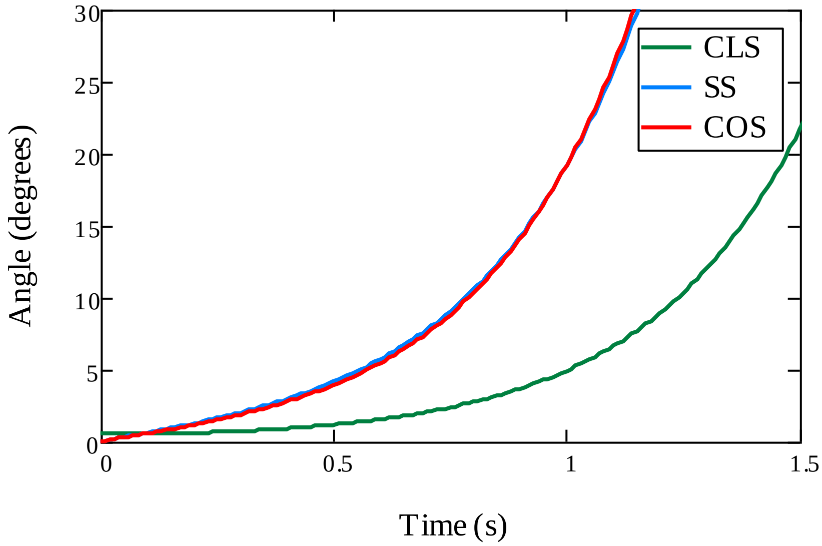
Given

$$\frac{d^2}{d\tau^2}(\theta(\tau)) + \frac{s^2 \cdot m_s \cdot z_{cm3} \cdot -g}{I_3} \cdot \sin(\theta(\tau)) = 0$$

$\theta(0) = 0 \cdot deg \qquad \theta'(0) = \omega_{03}$

$\theta_3 := \text{Odesolve}(\tau, Te)$

$n := 0, 0.01 .. T\epsilon$



Time When Person Falls through 10 degrees CLS

Guess

$\tau_1 := 1$

Given

$\theta_1(\tau_1) = 5 \cdot deg$

$\tau_{s1} := \mathrm{Find}(\tau_1) = 1.006$

Time When Person Falls through 10 degrees SS

Guess

$\tau_2 := 1$

Given

$\theta_2(\tau_2) = 5 \cdot deg$

$\tau_{s2} := \mathrm{Find}(\tau_2) = 0.558$

Time When Person Falls through 10 degrees COS

Guess

$\tau_3 := 1$

Given

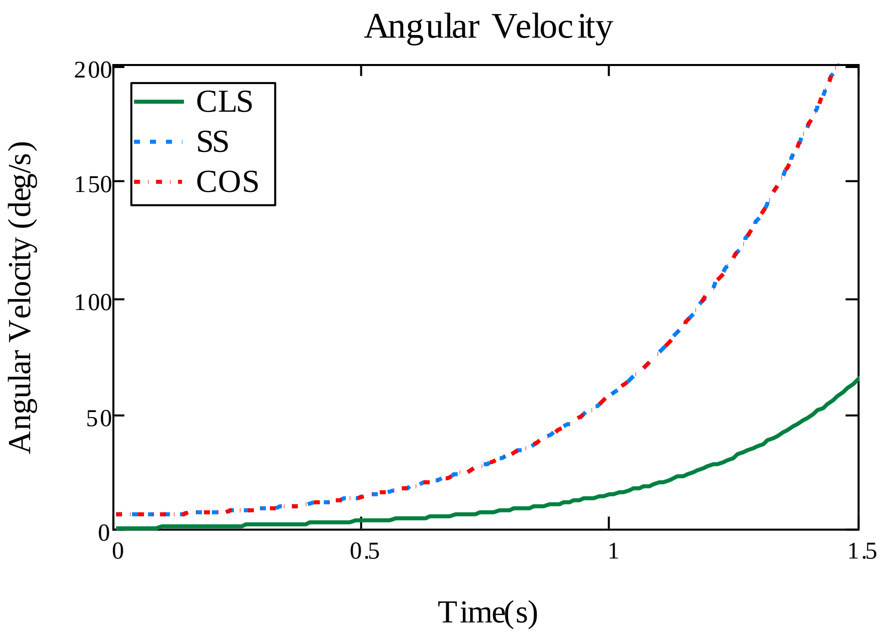
$\theta_3(\tau_3) = 5 \cdot deg$

$\tau_{s3} := \mathrm{Find}(\tau_3) = 0.574$

$$\omega_1(n) := \frac{d}{dn}\theta_1(n)$$

$$\omega_2(n) := \frac{d}{dn}\theta_2(n)$$

$$\omega_3(n) := \frac{d}{dn}\theta_2(n)$$



Angular Velocity When Person Falls through 10 degrees CLS

$$\omega_{s1} := \frac{\omega_1(\tau_{s1})}{s} = 0.258\frac{1}{s}$$

Angular Velocity When Person Falls through 10 degrees SS

$$\omega_{s2} := \frac{\omega_2(\tau_{s2})}{s} = 0.278\frac{1}{s}$$

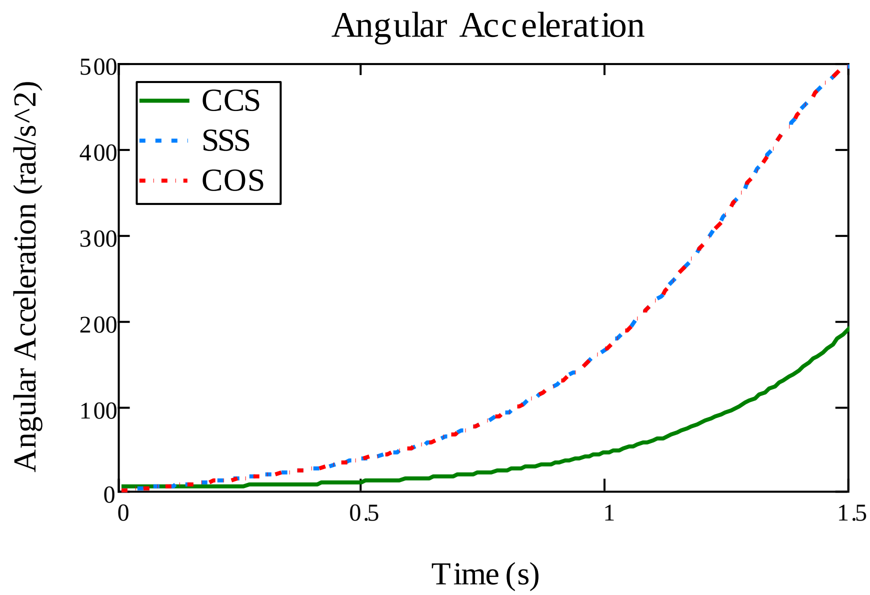
Angular Velocity When Person Falls through 10 degrees COS

$$\omega_{s3} := \frac{\omega_3(\tau_{s3})}{s} = 0.291\frac{1}{s}$$

$$\alpha_1(n) := \frac{d}{dn}\omega_1(n)$$

$$\alpha_2(n) := \frac{d}{dn}\omega_2(n)$$

$$\alpha_3(n) := \frac{d}{dn}\omega_3(n)$$



Appendix E: Decision Matrix Rubric

Stop fall

1. Does not stop falls any better than standard walker
2. Inconsistently prevents falls by attempting to control center of mass or increase base of support
3. Regularly prevents falls by attempting to control center of mass or increase base of support
4. Effectively stops falls through either increasing the base of support or controlling the center of mass
5. Stops falls by increasing base of support and controlling center of mass

Vertical Load Strength

1. The walker can support a 255 lb vertical load
2. The walker can support a 165 lb vertical load
3. The walker can support a 175 lb vertical load
4. The walker can support a 185 lb vertical load
5. The walker can support more than a 185 lb vertical load

Stigma

1. The design has a harness, does not resemble a walker, and is more bulky than a Rollator.
2. The design does not have a harness, but does not resembles a walker and is more bulky than a Rollator
3. The design resembles a walker, does not have a harness, but is more bulky than a Rollator
4. The design resembles a walker, does not have a harness, but is as bulky as a Rollator.
5. The design resembles a walker, is less bulky than a Rollator, and does not have a harness.

Environment

1. The walker can only be used on flat very smooth surfaces (i.e. hardwood, pavement, and tile)
2. The walker can be used on smooth surfaces (i.e. hardwood, pavement, and tile) that are flat or have a 1:10 slope
3. The walker can travel over most indoor and outdoor surfaces (i.e. rugs, hardwood, pavement, and tile)and sloped surfaces up to a 1:10 slope, but not easily
4. The walker can easily travel over most indoor and outdoor surfaces (i.e. rugs, hardwood, pavement, and tile) and sloped surfaces up to a 1:10 slope

5. The walker can be easily used on all common indoor and outdoor surfaces (i.e. rugs, grass, hardwood, brick, pavement, and tile) and can be used on changing surfaces that are level or have a 1:10 slope

Transportability

1. Weighs more than 8 lbs or cannot fit in the back seat of a car
2. Cannot fold but it weighs 8 lbs or less and can fit in the back seat of most vehicles
3. Cannot fold, but it weighs 8 lbs or less and can fit in the trunk of most vehicles
4. Weighs 8 lbs or less, folds to fit in trunk or backseat, but requires considerable effort (considerable strength, pushing buttons, etc.)
5. Weighs 8 lbs or less and can be easily folded to a thickness of 4 inches

Weight

1. Weighs more than or equal to 25 lbs
2. Weighs more than or equal to 20 lbs and less than 25 lbs
3. Weighs more than or equal to 15 lbs and less than 20 lbs
4. Weighs more than or equal to 7 lbs and less than 15 lbs
5. Weighs less than 7 lbs

User actions that lead to falls: Moving outside the base of support, and needing to operate the brakes

1. Does not limit user actions any more than standard walker
2.
3. Effectively limits one user action that lead to falls
4.
5. Effectively limits both user actions that lead to falls.

Not obstruct lateral stepping reactions

1. Horizontal supports are 6in or less off the ground
2. Horizontal supports are 8 in. or less off the ground
3. Horizontal supports are 10 in. or less off the ground
4. Horizontal supports are less than 1 ft. off the ground
5. Horizontal supports are 1 ft. or more off the ground

Footprint

1. Frame is wider than 29 in, and has a depth greater than 29 in

2. Frame is no wider than 27 in, and does not have a depth greater than 26 in
3. Frame is no wider than 25 in, and does not have a depth greater than 23 in
4. Frame is no wider than 23 in, and does not have a depth greater than 20 in
5. Frame is no wider than 21 in and does not have a depth greater than 17 in

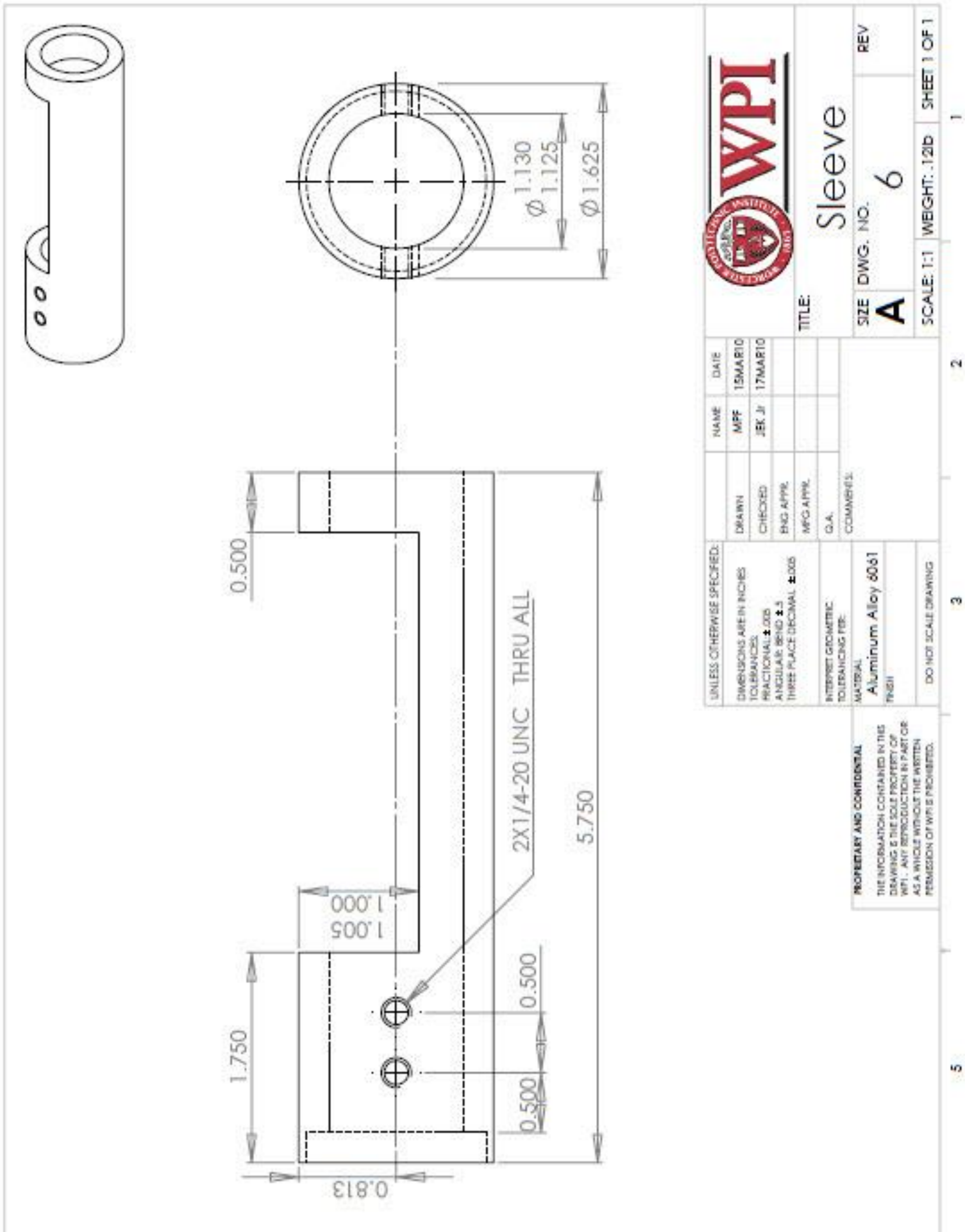
Adjustability

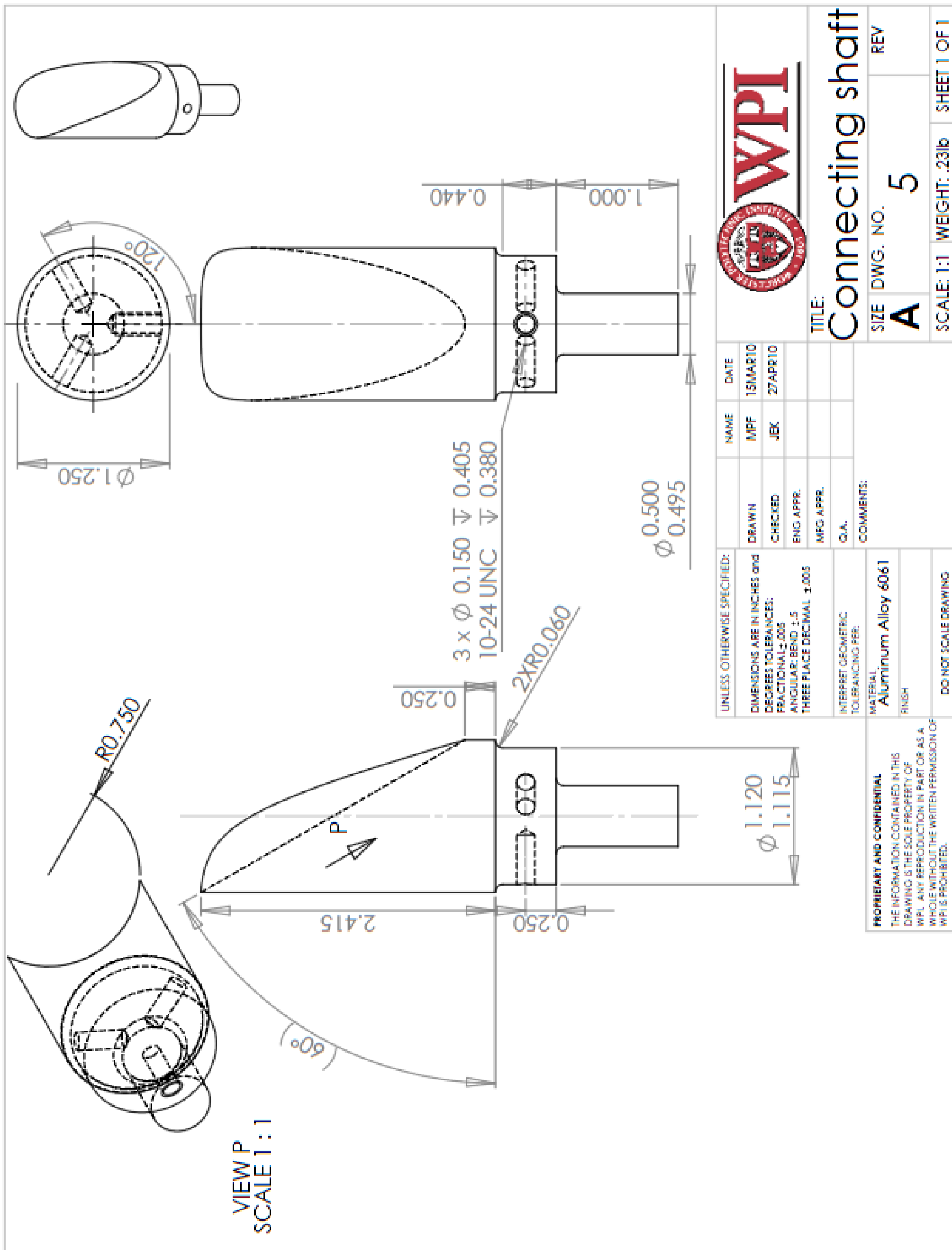
1. Does not adjust in height
2. Maximum height of 38 in and a minimum height of 34 in.
3. Maximum height of 38.5 in and a minimum height of 33.5 in.
4. Maximum height of 39 in and a minimum height of 33 in.
5. Maximum height of 39.5 in and a minimum height of 32.5 in.

Cost

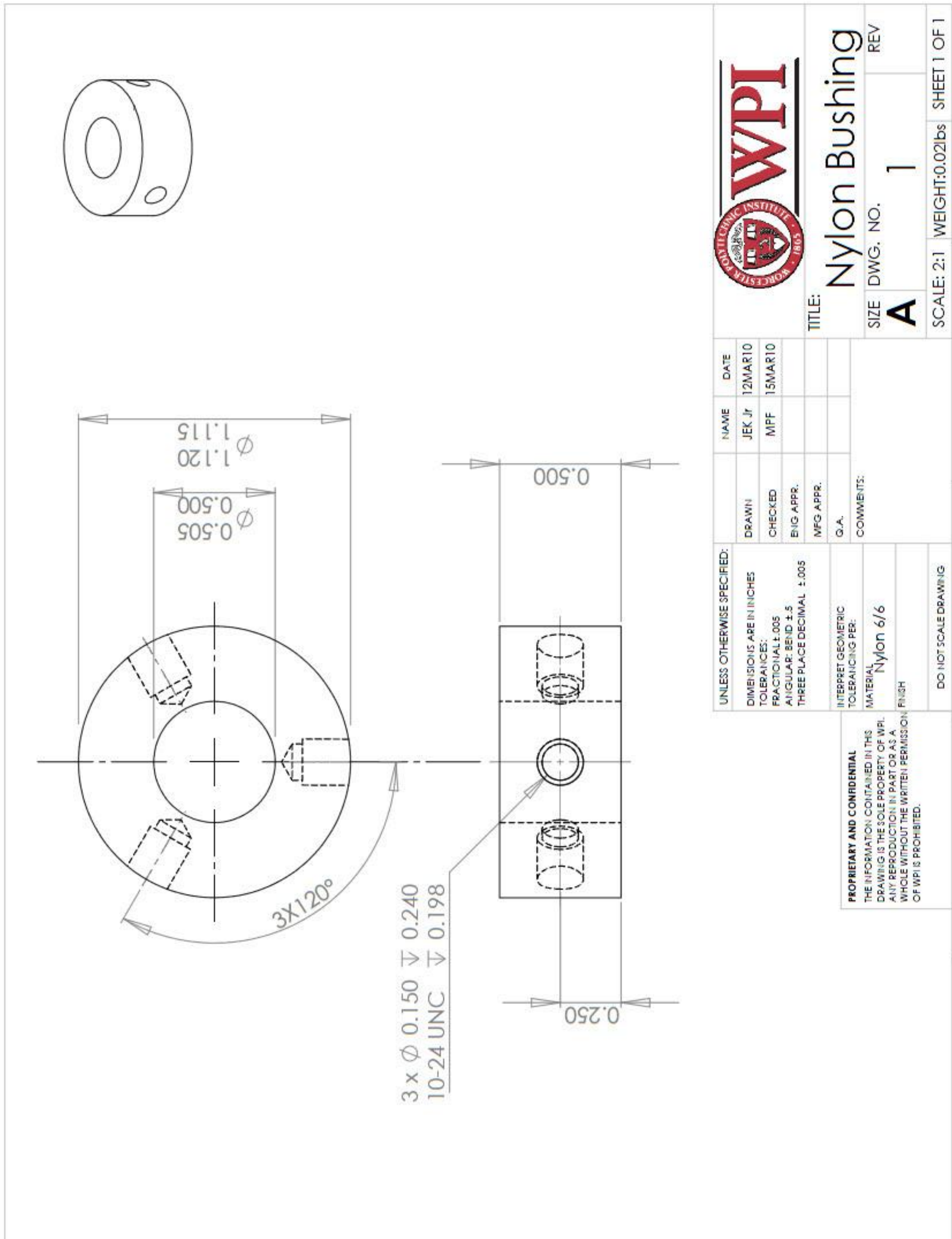
1. Costs less than $140
2. Costs less than $130
3. Costs less than $120
4. Costs less than $110
5. Costs less than $100

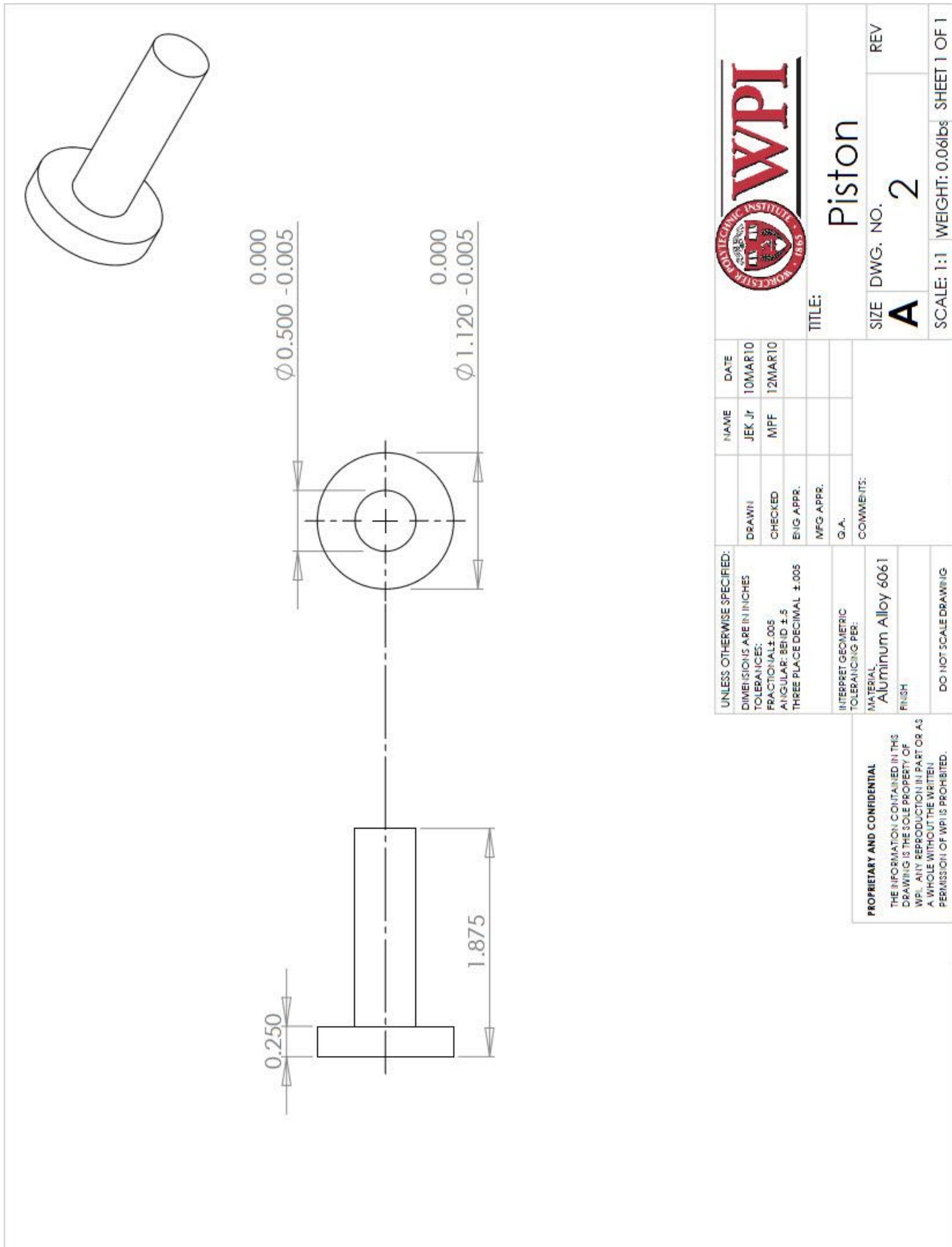
Appendix F: Lateral Leg Extension Component Drawings





Connecting shaft
TITLE:
SIZE A
DWG. NO. 5
REV
SCALE: 1:1
WEIGHT: .23lb
SHEET 1 OF 1
WPI
NAME DATE
DRAWN MPF 15MAR10
CHECKED JBK 27APR10
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES and DEGREES TOLERANCES:
FRACTIONAL ±.005
ANGULAR: BEND ±.5
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL Aluminum Alloy 6061
FINISH
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF WPI. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF WPI IS PROHIBITED.
VIEW P
SCALE 1 : 1
R0.750
60°
2.415
0.250
0.250
2XR0.060
Ø 1.120
1.115
3 x Ø 0.150 ↧ 0.405
10-24 UNC ↧ 0.380
Ø 0.500
0.495
Ø 1.250
120°
0.440
1.000
P
1
2
3
4
5


Ø 1.115
1.120
Ø 0.500
0.505
0.500
0.250
3X120°
3 x Ø 0.150 ⊽ 0.240
10-24 UNC ⊽ 0.198
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± .005
ANGULAR: BEND ± .5
THREE PLACE DECIMAL ± .005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Nylon 6/6
FINISH
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF WPI. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF WPI IS PROHIBITED.
NAME
DATE
DRAWN
JEK Jr
12MAR10
CHECKED
MPF
15MAR10
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
WPI
WORCESTER POLYTECHNIC INSTITUTE 1865
TITLE:
Nylon Bushing
SIZE
A
DWG. NO.
1
REV
SCALE: 2:1
WEIGHT:0.02lbs
SHEET 1 OF 1
1
2
3
4
5


0.000
Ø0.500 -0.005
0.000
Ø1.120 -0.005
1.875
0.250
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±.005
ANGULAR: BEND ±.5
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Aluminum Alloy 6061
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
JEK Jr
10MAR10
CHECKED
MPF
12MAR10
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
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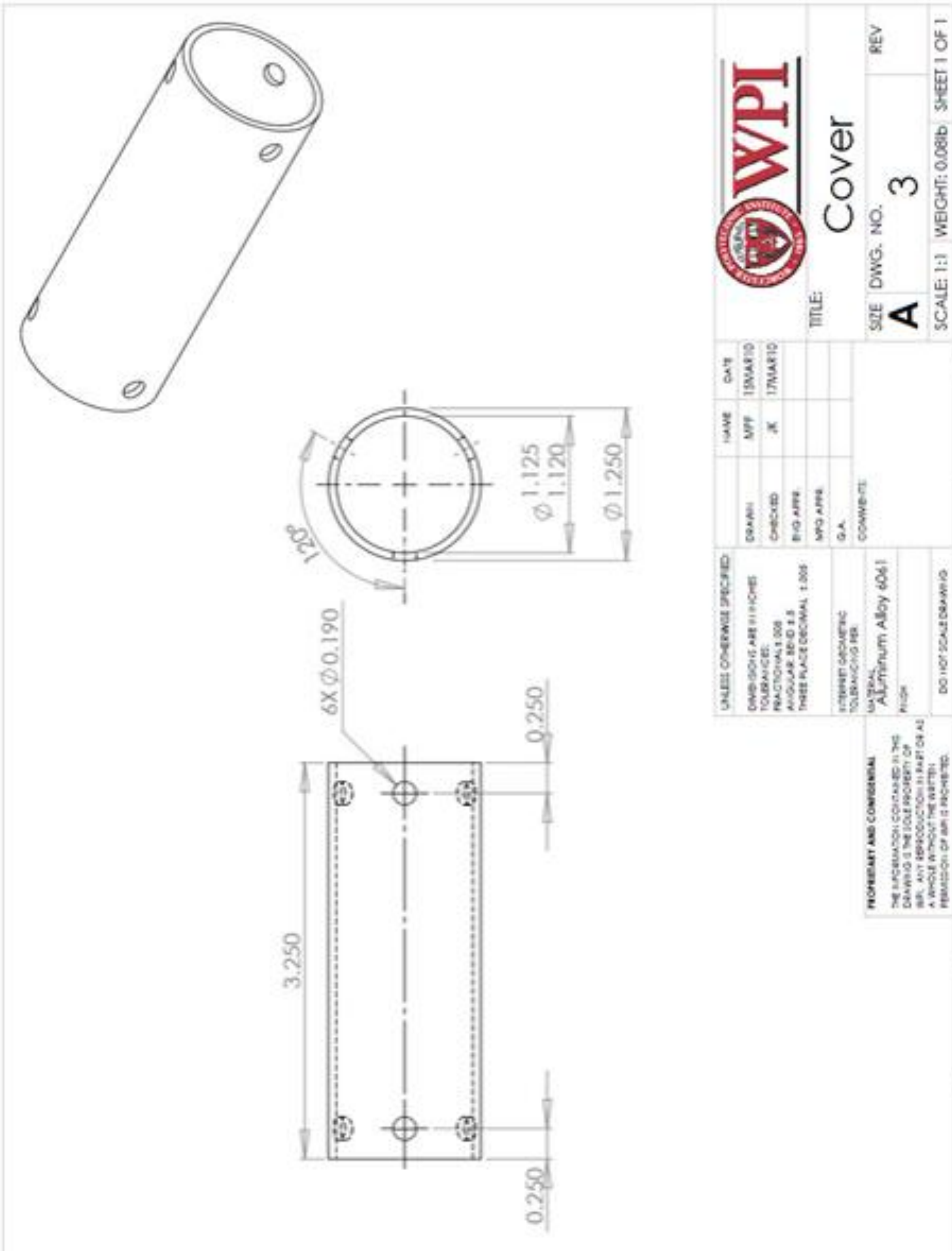
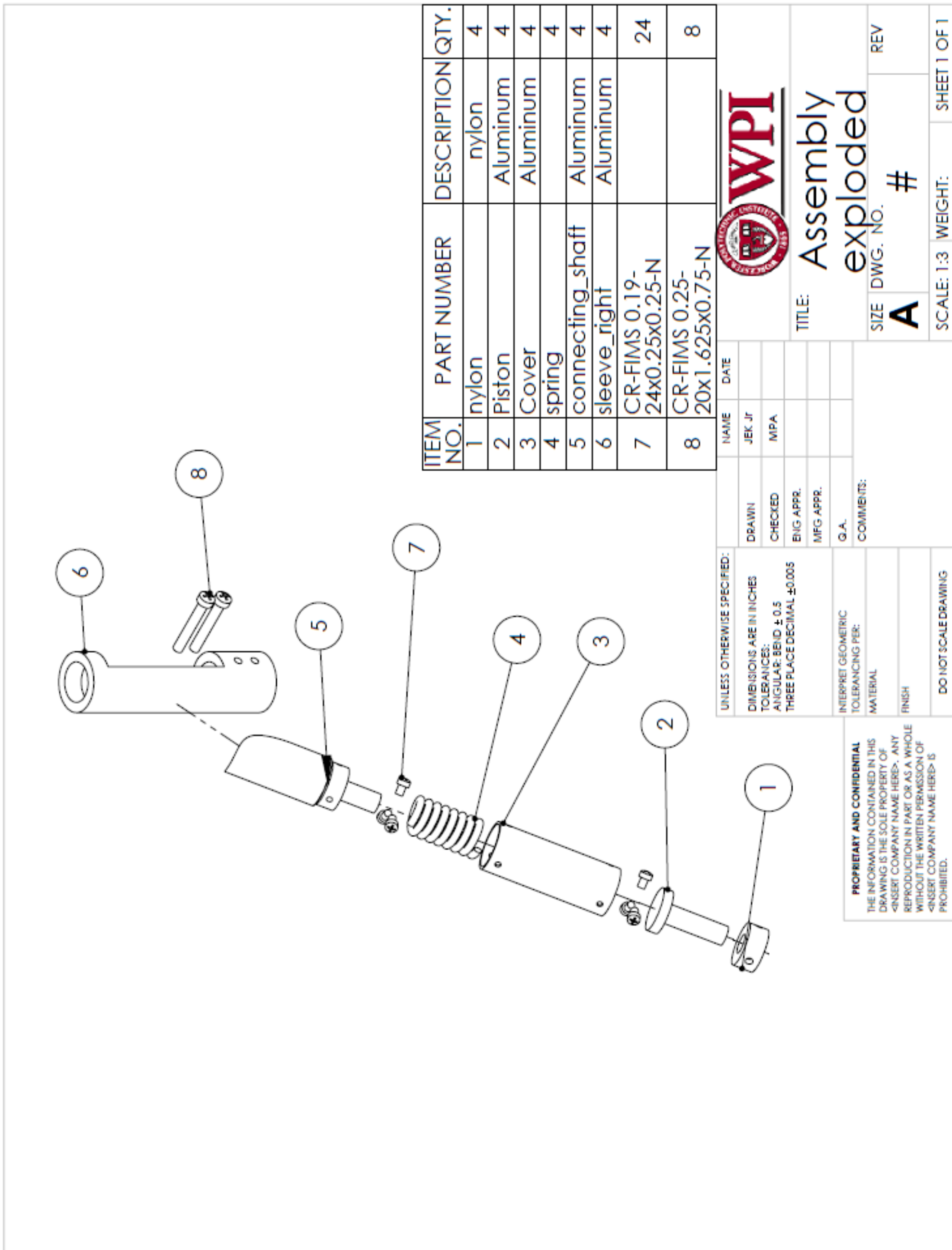
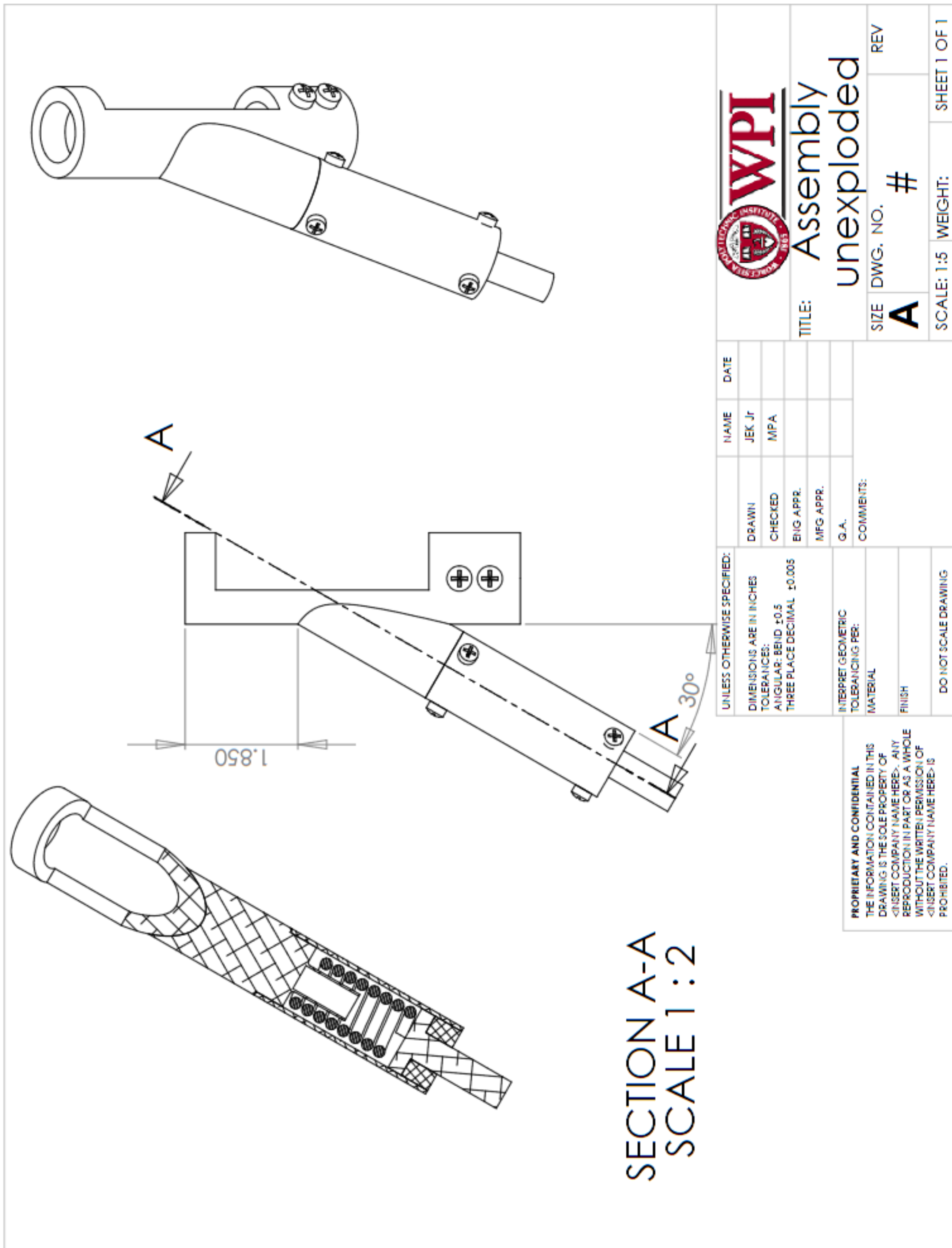
WPI
WORCESTER POLYTECHNIC INSTITUTE 1865
TITLE:
Piston
SIZE
A
DWG. NO.
2
REV
SCALE: 1:1
WEIGHT: 0.06lbs
SHEET 1 OF 1


3.250
0.250
0.250
6X Ø0.190
120°
Ø 1.125 1.120
Ø1.250
UNLESS OTHERWISE SPECIFIED:
DRAWN MPF 15MAR10
CHECKED JK 17MAR10
Aluminum Alloy 6061
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
WPI
TITLE:
Cover
SIZE A
DWG. NO. 3
REV
SCALE: 1:1
WEIGHT: 0.08lb
SHEET 1 OF 1

Appendix G: Lateral Leg Extension Assembly Drawings




SECTION A-A
SCALE 1 : 2
1.850
30°
A
A
TITLE:
Assembly
unexploded
SIZE
A
DWG. NO.
#
REV
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1
DRAWN
JEK Jr
CHECKED
MPA
DO NOT SCALE DRAWING

Appendix H: Electrical Components Technical Specification Sheets

Technical Specifications: VEX Microcontroller

Kit Contents	(1) VEX Microcontroller (5) Jumpers
Downloads & Docs	Inventors Guide - Logic Documentation Downloads
Battery In	Voltage: 7.2 volts nominal, 5 to 12 volts min/max. Type: Six AA batteries or 7.2V Robot Battery Current:62 mA for Controller & Receiver plus Motors & Servos
I/O Ports	**(8) Motor Outputs** Usage: For VEX motors or servos Type: Hobby standard PWM Refresh: Every 18.5 ms **(16) Digital I/O, Analog In** Digital In: 50 KHz input frequency. Analog In: 10-bit resolution. 10 µs access time. I/O Schematic: Schematic **(6) Interrupt I/O** Usage: Measuring Input changes via software interrupt **(1) Tx/Rx Port** Type:TTL Serial Speed:115Kb Label:TX and RX **(1) Serial Port** Usage: Used for reprogramming and debugging. Speed:115Kb **(2) Rx 1 & Rx2** Usage: Connects to (2) 75MHz receivers.
Microcontroller	Microchip PICmicro PIC18F8520 Speed:10 MIPS (Million Instructions Per Second) RAM:1800 bytes + 1024 bytes EE2 Flash:32K program space
Programming	easyC ROBOTC Microchip MPLAB IDE
Size	4.5in W x 3.9in L x 1.1in H
Weight	VEX Microcontroller.278 lbs (126 grams) Actual weight one item (no packaging)

Technical Specifications: VEX 7.2 Volt Robot Battery

Kit Contents	(1) 7.2V Battery with VEX standard connector
Compatibility	Use with any VEX Microcontroller (V0.5, Cortex M3, or VEXpro ARM9). Charge with the VEX Fast Battery Charger
Output Voltage	7.2V Nominal
Capacity	2000 mAh
Weight	7.2V Battery0.7 lbs (317 grams) Actual weight of one item (no packaging)

Technical Specifications: VEX Fast Battery Charger

Kit Contents	(1) Battery Charger (1) AC/DC Adapter
Compatibility	9.6V Transmitter Battery 7.2V Robot Battery
Input Voltage	120V @ 60Hz / Output 16V @ 850mA
Usage Notes	Charge time 1.4 to 2 hours. Charge current is 700mA for 9.6V batteries, 1000mA for 7.2V batteries. Protection from Over-current, Short circuit, and Reverse polarity

Technical Specifications: Spike H-Bridge Relay

Kit Contents	(1) Spike Relay H-Bridge Module
Downloads & Docs	Users Guide Size and Installation Info
Battery In	Operating Voltage:6V to 16V Power Connector:1/4" blade connectors
Outputs	Maximum Current:20A continuous Surge Current:100A for < 2 second Output Connector:1/4" blade connectors
Specification	Signal Connector: Uses a standard non-shrouded 3-wire cable. Control Signal:Hi: 3V min @ 4mA; Lo: open or ground. Max Switching: 20 operations per second no load, 6 operation per minute for rated life at rated load. Operate Time:5 ms typical Initial Release Time:2 ms typical Mechanical Life:10 million operations Electrical Life:100K operations at 20A, 14VDC, 1mH
Weight	0.12 lbs

Appendix I: Vex Microcontroller Code

```
#include <BuiltIns.h>

#define INNERRANGE 369
#define OUTRANGE 306

void main(void){
      int dist = 0;
      while(0==0){
            Wait(100);
            dist=GetAnalogInput(1);
            //printf("Distance: %d \n\r",dist);
            if(dist>INNERRANGE){
                  SetDigitalOutput(13,1);
                  SetDigitalOutput(14,0);
                  SetDigitalOutput(15,0);
                  SetDigitalOutput(16,1);
                  printf("Green \n");
            }
            if((dist<INNERRANGE)&&(dist>OUTRANGE)){
                  SetDigitalOutput(13,0);
                  SetDigitalOutput(14,1);
                  SetDigitalOutput(15,0);
                  SetDigitalOutput(16,1);
                  printf("Yellow \n");
                  }
            if(dist<OUTRANGE){
                  SetDigitalOutput(13,0);
                  SetDigitalOutput(14,0);
                  SetDigitalOutput(15,1);
                  SetDigitalOutput(16,0);
                  printf("Red \n");
                  }
      }
```

The IR range finder senses distances and outputs voltages. Therefore, the define lines, inner and out range, refer to the voltage output readings for distances 13 in. and 17 in., respectively. The inner range of 369 mV is when the yellow LED turns on and the out range of voltages greater than 306 mV is when the red LED turns on. The green LED is on whenever the distance is less than 13 in. (greater than 369 mV). The three "if" statements are where these commands are defined. Lastly, the lines following the "if" statements determine which controls the VEX Microcontroller turns on for each situation. Each control is attached to one of the Microcontroller's ports as shown below in Figure x. The green LED is in port 13, the yellow LED is in port 14, the red LED is in port 15, and the relay connects to port 16. A 1 is placed next to the port to denote when that control is turned on and a 0 is placed next to the port when that is to be turned off.

Appendix J: Determination of Change in Kickstand Length

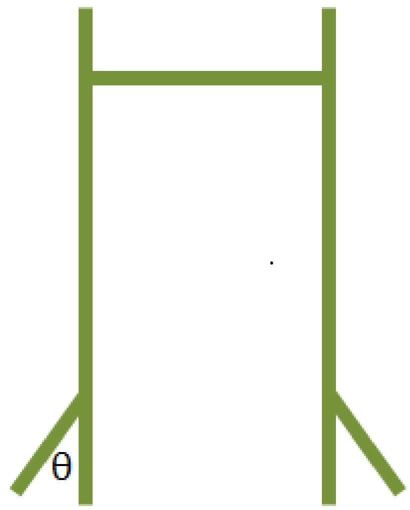
$$y_5 := \frac{z}{\tan(5 \cdot deg)} = 2.858in$$

$$b_{50} := \frac{y_5}{\cos(50 \cdot deg)} = 4.446in$$

$$b_{60} := \frac{y_5}{\cos(60 \cdot deg)} = 5.715in$$

$$b_{70} := \frac{y_5}{\cos(70 \cdot deg)} = 8.355in$$

$$b_{80} := \frac{y_5}{\cos(80 \cdot deg)} = 16.456in$$



Angle of kickstand to walker $\theta := 30 \cdot deg$

Bottom left angle Θ

$$c_5 := k(y_5) = 2.868\,in$$

$$z_1 := \frac{y_5}{\tan(\theta)} = 4.949in$$

$$z_{total} := z_1 + z = 5.199\,in$$

Determination of Compression of leg as the user falls from 5 to 10 degrees from horizontal

$$b_5 := \sqrt{z_{total}^{\ 2} + c_5^{\ 2} - 2 \cdot z_{total} \cdot c_5 \cdot \cos(90 \cdot deg - 5 \cdot deg)} = 5.715in$$

$$\Theta := 180 \cdot deg - \theta - (90 \cdot deg - 10 \cdot deg) = 70 \cdot deg$$

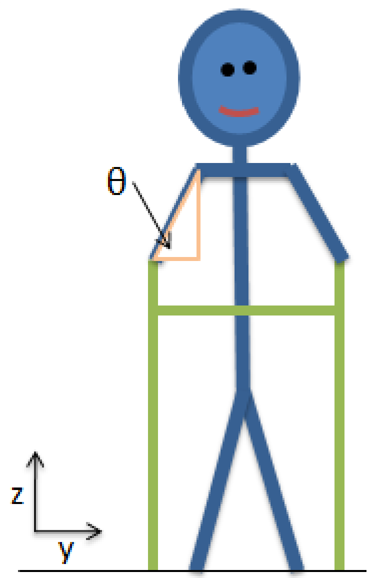
$$b_{10} := \frac{z_{total} \cdot \sin(90 \cdot deg - 10 \cdot deg)}{\sin(\Theta)} = 5.449in$$

Compression

$$\Delta := b_5 - b_{10} = 0.266\,in$$

Appendix K: Determination of Coefficient of Friction Necessary for the Walker to not Slide:

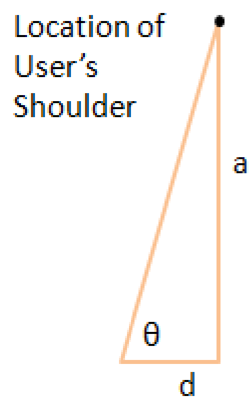
The worst case scenario will be used to determine the maximum necessary coefficient of friction. Anthropometric data for a 50th percentile male, which is the largest user of the product, was used.



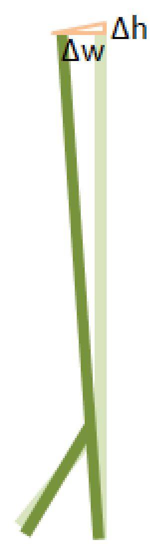
weight of person	$m_p := 185 \cdot lb$
height of person	$h_p := 5.7 \cdot ft = 68.4 \cdot in$
load on walker	$F_p := .3 m_p \cdot g = 55.5 \cdot lbf$
mass of walker	$m_w := 6.5 \cdot lb$
width of walker	$w_w := 22 \cdot in$

The correct fit for a walker is if the handles are at the same height person's wrists when they have their hands down at their sides. Ho the walker height adjusts in 1 inch increments.

Ideal height of walker	$h_{wi} := .485 \cdot h_p = 33.2 \cdot in$
actual height of walker	$h_w := 33 \cdot in$

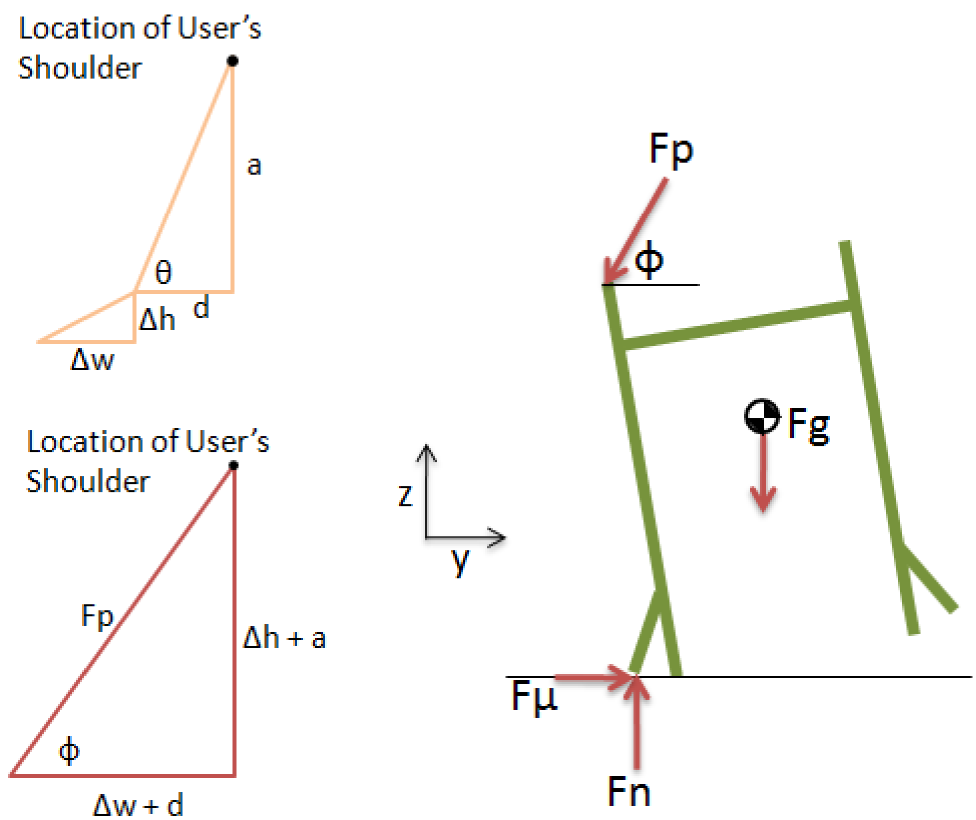


shoulder height	$h_s := .818 \cdot h_p = 56 \cdot in$
length from shoulder to walker	$a := h_s - h_w = 23 \cdot in$
shoulder width	$w_s := .259 \cdot h_p = 17.7 \cdot in$
horizontal distance from shoulder to walker	$d := \dfrac{w_w - w_s}{2} = 2.1 \cdot in$
angle between horizontal and arm	$\theta := \operatorname{atan}\left(\dfrac{a}{d}\right) = 85 \cdot deg$



vertical change in location of walker handle	$\Delta h := h_w \cdot (1 - \cos(5 \cdot deg)) = 0.1 \cdot in$
horizontal change in location of walker handle	$\Delta w := h_w \cdot \sin(5 \cdot deg) = 2.9 \cdot in$

As far as sliding is concerned the worst case occurs when the person begins to lose their balance, and pushes on the walker without actually beginning to fall with the walker. In this case the horizontal component of the user's force is maximized while the vertical (normal) force is minimized. For this reason the location of the person's shoulder is not considered to move, but the change in location of the walker due to tipping is considered.



angle of force exerted by user on walker $\phi := \mathrm{atan}\left(\frac{\Delta h + a}{\Delta w + d}\right) = 78 \cdot \mathrm{deg}$

Only one left leg is shown and only one normal and one frictional force are solved for because the frictional force is independent of the surface area, so it makes no difference in these calculations if the walker is tipping onto one or two kickstands. Also, because whether or not the walker is going to slide is dependent upon the summation of the forces in the y direction and no moments need to be considered, the fact that the total normal force and total frictional force would be divided between the left walker leg and the left kickstand is ignored.

Solving for Normal force by balancing forces in z direction

$$\Sigma F_z = F_n - F_p \cdot \sin(\phi) - m_w \cdot g = 0$$

$$F_n := F_p \cdot \sin(\phi) + m_w \cdot g = 60.7 \cdot \mathrm{lbf}$$

Solving for Frictional force by balancing forces in y direction

$$\Sigma F_y = F_\mu - F_p \cdot \cos(\phi) = 0$$

$$F_\mu := F_p \cdot \cos(\phi) = 11.8 \cdot \text{lbf}$$

Minimum value of frictional coefficient capable of stopping walker from sliding

$$F_\mu = \mu \cdot F_n$$

$$\mu := \frac{F_\mu}{F_n} = 0.2$$

Coefficient of frictions for rubber on different surfaces varies, but the lowest coefficient, which occurs when rubber rubs against wet asphalt, is .25. This is greater than the .2 that is necessary to prevent the walker from sliding away from the user. Thus the walker will try to tip compressing the kickstand.

Appendix L: Stress Analysis of Lateral Leg Extension

Stress Analysis of Screws connecting the Cover to the Nylon Bushing

Coefficient of friction between rubber and wood	$\mu := .2$
Coefficient of friction between nylon and aluminum	$\mu_1 := .3$
length of shaft component of piston	$L_p := 1.625\,in$
Thickness of nylon bushing	$L_n := .5 \cdot in$

Figure 1: Nylon Bushing

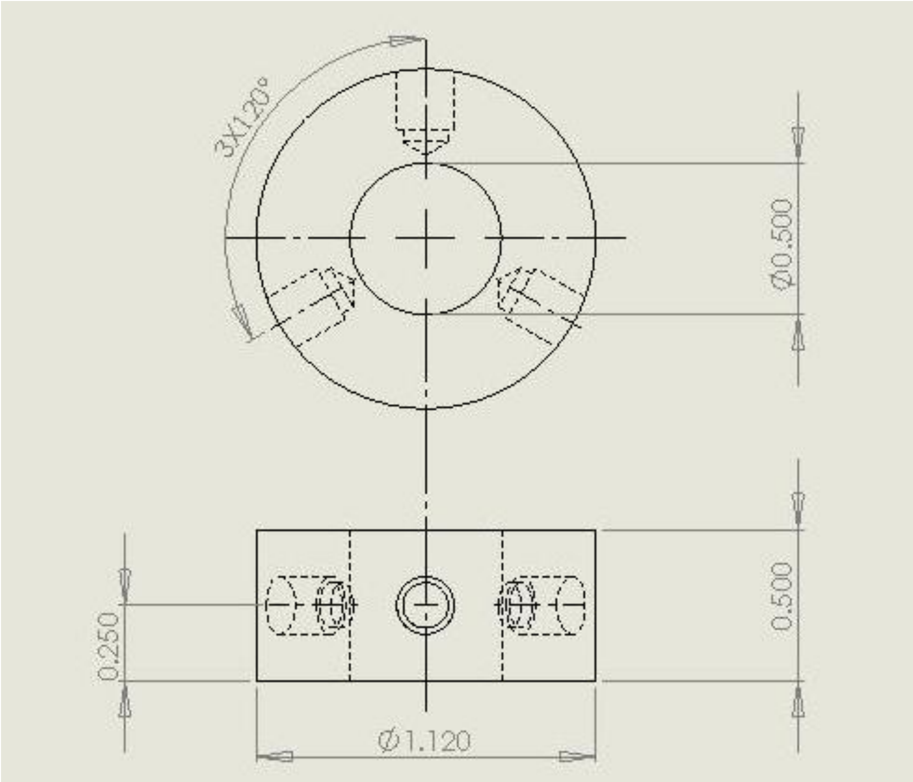
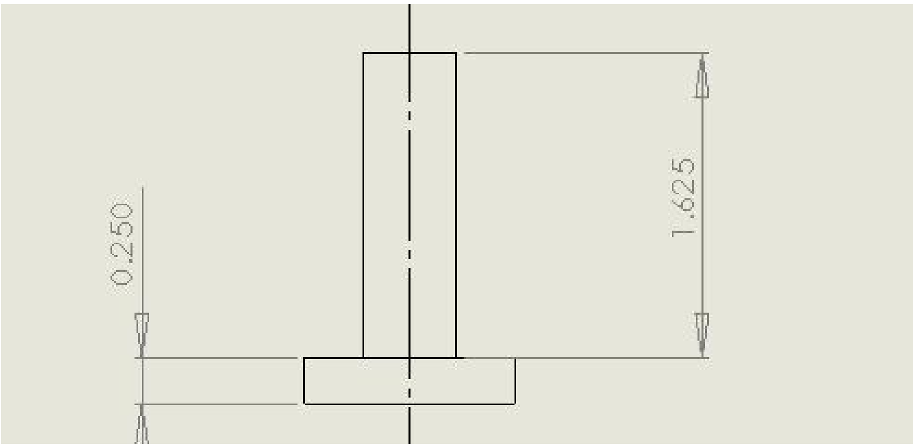
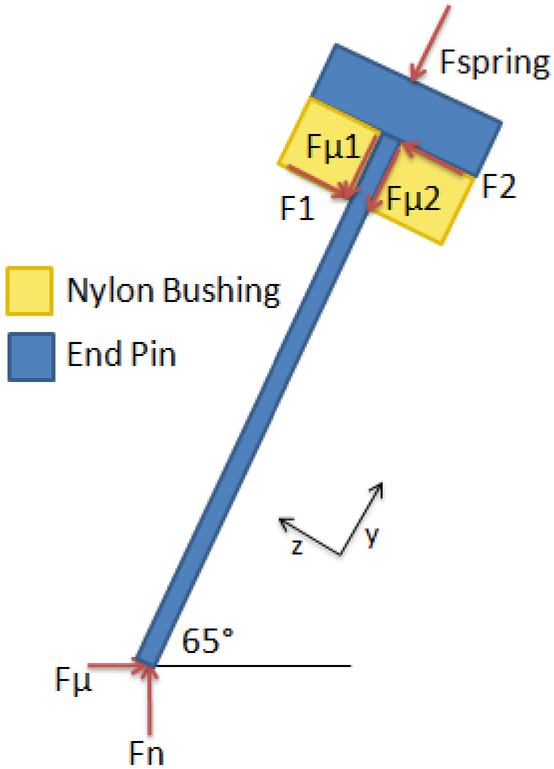


Figure 2: Piston



Free Body Diagram of Piston



From the dynamic analysis of the three different falling scenarios we know that the force exerted by the lateral leg extension on the user is 413 lbf along the axis of the kickstand. Thus the ground normal and frictional forces add up to 413 lbf and the force of the spring and the frictional forces from the nylon are equal to 413.

$$F_s + F_{\mu 1} + F_{\mu 2} = 413 \text{lbf}$$

$$F_n \cdot \sin(65 \cdot \text{deg}) + F_\mu \cdot \cos(65 \cdot \text{deg}) = 413 \cdot \text{lbf}$$

Sum of forces in z equals zero

$$\Sigma F_z = F_n \cdot \sin(65 \cdot \text{deg}) + F_\mu \cdot \cos(65 \cdot \text{deg}) - F_s - F_{\mu 1} - F_{\mu 2} = 0$$

Sum of forces y equals zero

$$\Sigma F_y = F_n \cdot \cos(65 \cdot \text{deg}) - F_\mu \cdot \sin(65 \cdot \text{deg}) + F_2 - F_1 = 0$$

Moment around point where pin touches ground equals zero

$$\Sigma M_G = F_2 \cdot L_p - F_1 \cdot (L_p - L_n) = 0$$

Frictional forces

$$F_{\mu} = F_N \cdot \mu$$

$$F_{\mu 1} = F_1 \cdot \mu_1$$

$$F_{\mu 2} = F_2 \cdot \mu_1$$

Solving system of equations for the variables

Guess

$$F_N := 100 \cdot lbf$$

Given

$$F_N \cdot \sin(65 \cdot deg) + F_N \cdot \mu \cdot \cos(65 \cdot deg) = 413 \cdot lbf$$

$$F_n := Find(F_N)$$

$$F_n = 417 \cdot lbf$$

$$f_1 = f_2 \cdot \frac{L_p}{L_p - L_n}$$

$$F_{\mu} := F_n \cdot \mu = 83 \cdot lbf$$

Guess

$$f_2 := 100 \cdot lbf$$

Given

$$F_n \cdot \cos(65 \cdot deg) - F_{\mu} \cdot \sin(65 \cdot deg) + f_2 - \frac{f_2 \cdot L_p}{L_p - L_n} = 0$$

$$F_2 := Find(f_2)$$

$$F_2 = 226 \cdot lbf$$

$$F_1 := F_2 \cdot \frac{L_p}{L_p - L_n} = 327 \cdot lbf$$

$$F_{\mu 1} := F_1 \cdot \mu_1 = 98 \cdot lbf$$

$$F_{\mu 2} := F_2 \cdot \mu_1 = 68 \cdot lbf$$

$$F_{\mu 12} := F_{\mu 1} + F_{\mu 2} = 166 \cdot lbf$$

Forces Acting on Plane A-A:

Stress analysis was performed at the three points where the screws connect the cover to the nylon. The screws are positioned 120 deg from each other on the circumference of the nylon (Figure 1). Also, the screws are located 0.25 inches from the distal end of the nylon (Figure 1). The surface cut was taken by Plane A-A (Figure 3) which intersects these three points. Figure 4 is the free body diagram of the lateral leg extension touching the ground (this is when the lateral leg extension is loaded because the person has fallen through the five degrees). Theta is the angle of the kickstand to the horizontal and L is the distance from the end of the piston to Plane A-A. A cut was taken at A-A, resulting in a force acting on Plane A-A in the x direction (normal force), a force acting on Plane A-A in the y direction (shear force), and a Moment about point O on Plane A-A acting in the positive (counter clockwise) direction.

$\theta := 65\cdot deg$ $\quad L := L_p + \frac{L_n}{2} = 1.875\,in$

$\phi := 25\cdot deg$

The sum of Fx= 0

$$F_x := F_n \cdot \cos(\phi) + \frac{F_\mu}{\cos(\theta)}$$

$$F_x = 575.026\,lbf$$

The sum of Fy=0

$$F_y := F_n \cdot \sin(\phi) + \frac{F_\mu}{\sin(\theta)}$$

$$F_y = 268.139\,lbf$$

Moment Calculation about Point O on Plane A-A:

$$M_o := F_n \cdot \cos(\phi) \cdot L - \frac{F_\mu}{\cos(\theta)} \cdot L$$

$$M_o = 338.46\,in \cdot lbf$$

The moment is acting in the counter clockwise direction, which was chosen to be positive. Therefore, point 1 is in tension and point 2 is in compression.

Area of the Cross Section:

To find the normal, shear, and bending stress at points 1, 2, and 3, (Figure 3), the cross sectional area of this section of the kickstand was found (A). The outer radius (ro), inner radius (ri), outer diameter (do), and the inner diameter (di) of the cross section were also found.

$r_o := \frac{1.25 in}{2}$ $\quad d_o := 1.25 \cdot in$ $\quad r_{nylon} := .56 \cdot in$

$r_i := \frac{.5 in}{2}$ $\quad d_i := .5 \cdot in$

$A := \pi \cdot r_o^2 - \pi \cdot r_i^2 = 1.031 in^2$

Location of Points 1, 2, 3:

The distance from the three points to the x-axis was found for each point on Plane A. c1, c2, and c3 are the distances from the x axis for points 1, 2, and 3 respectively. c3 is zero because it is located on the z axis.

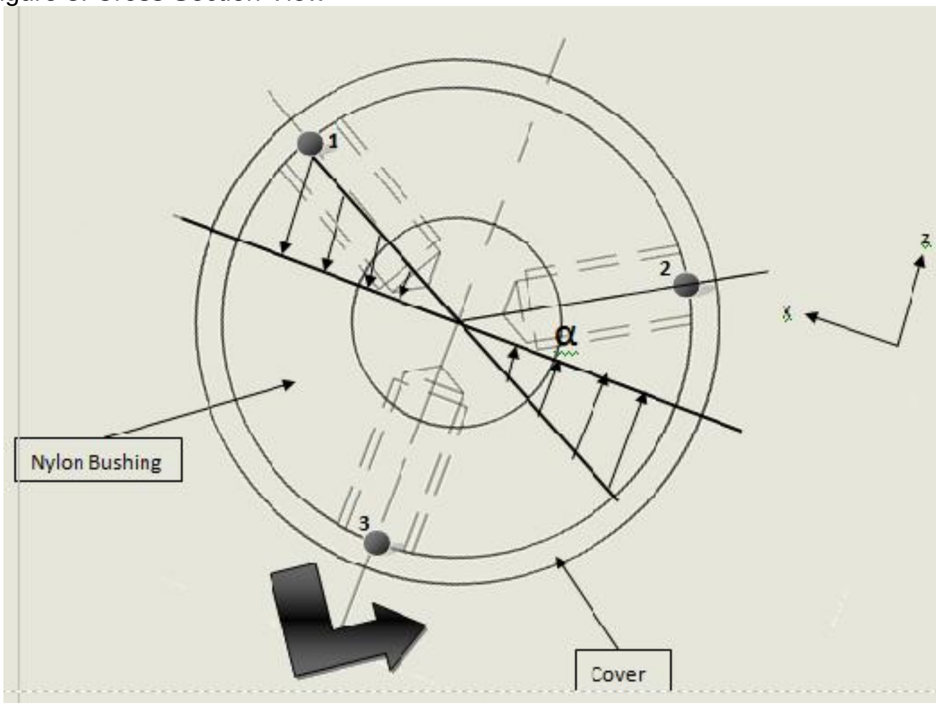
$c_1 := .56 \cdot in \cos(30 \cdot deg)$ $\quad c_1 = 0.485 in$

$c_2 := .56 \cdot in \cos(30 \cdot deg)$ $\quad c_2 = 0.485 in$

$c_3 := 0$ $\quad c_3 = 0 \cdot in$

The cover and nylon cross section was assumed to be a tube because of the inner and outer diameters; therefore the area moment of inertia was calculated for a tube.

Figure 3: Cross Section View



Area Moment of Inertia:

$$I := \frac{\pi\left(d_o^{\,4} - d_i^{\,4}\right)}{64} = 0.117\text{in}^4$$

This is the area moment of inertia for this cross section.

Stress Analysis:

$$\sigma_n := \frac{F_x}{A} = 557.825\text{psi}$$

σ_n is the normal stress acting on Plane A-A

τ_s is the shear stress acting on Plane A-A

$$\tau_s := \frac{F_y}{A} = 260.118\text{psi}$$

$$\sigma_1 := \frac{M_o \cdot c_1}{I} = 1.406\times 10^3 \cdot \text{psi}$$

The bending stresses only occur at points 2 and 3 because 1 is on the neutral axis

σ1 is in tension, so the normal stress is subtracted

$$\sigma_{b1} := \sigma_1 - \sigma_n = 847.829\text{psi}$$

$$\sigma_2 := \frac{M_o \cdot c_2}{I} = 1.406\times 10^3 \cdot \text{psi}$$

$$\sigma_{b2} := \sigma_2 + \sigma_n = 1.963\times 10^3 \cdot \text{psi}$$

σ2 is in compression, so the normal stress is added

$$\sigma_3 := \frac{M_o \cdot c_3}{I} = 0 \cdot \text{psi}$$

Stress Analysis of Screws Connecting the Cover to the Connecting Shaft

$F_n := 400 \cdot lbf$

This is the normal force acting on the lateral leg extension

$F_\mu := 120 \cdot lbf$

This is the friction force acting on the lateral leg extension

Stress analysis was performed at the three points where the screws connect the cover to the connecting shaft. The screws are positioned 120 deg from each other. Also, the screws are located 0.25 inches from the proximal end of the cover. The surface cut was taken by Plane B-B (Figure 1) which intersects these three points. Figure 2 is the free body diagram of the passive BOS extender touching the ground (this is when the passive base of support extender is loaded because the person has fallen through the five degrees). Theta is the angle of the kickstand to the horizontal and L is the distance from the end of the piston to Plane B-B. A cut was taken at B-B, resulting in a force acting on Plane B-B in the x direction (normal force), a force acting on Plane B-B in the y direction (shear force), and a Moment about Point P on Plane B-B acting in the positive (counter clockwise) direction.

Forces acting on Plane B-B:

$L := 3.79 in$

$F_y := 301.5 lbf \qquad \phi := 25 \cdot deg$

$F_x := 646.4 lbf \qquad \theta := 65 \cdot deg$

Moment about Point P:

The moment at Point P is Mp.

$$M_p := F_n \cdot \cos(\phi) \cdot L - \frac{F_\mu}{\cos(\theta)} \cdot L$$

$$M_p = 297.814 lbf \cdot in$$

The moment is acting in the counter clockwise direction, which was chosen to be positive. Therefore, point 1 is in tension and point 2 is in compression.

Area of the Cross Section:

To find the normal, shear, and bending stress at points 1, 2, and 3, (Figure 3), the cross sectional area of this section of the kickstand (A) was found using the outer diameter of the cover, 1.25 in.

$D := 1.25 in$

$$A := \frac{\pi \cdot D^2}{4} = 1.227 in^2$$

Distance of points 1, 2, and 3 to the x-axis:

The distance from the three points to the x-axis was found for each point on Plane A-A. c1, c2, and c3 are the distances from the x axis for points 1, 2, and 3 respectively. c3 is zero because it is located on the z axis.

$c_1 := .56\cos(30\cdot deg)\cdot in \qquad c_1 = 0.485\,in$

$c_2 := .56\cdot\cos(30\cdot deg)\cdot in \qquad c_2 = 0.485\,in$

$c_3 := 0$

Stress Analysis:

$\sigma_n := \frac{F_x}{A} \qquad \sigma_n = 526.734psi$

σ_n is the normal stress acting on Plane B-B

$\tau_s := \frac{F_y}{A} \qquad \tau_s = 245.684psi$

τ_s is the shear stress acting on Plane B-B

To find the bending moment at the different points where the screws are located, the area moment of inertia is calculated using the equation for a solid cylinder.

$$r := \frac{1.25in}{2} = 0.625in$$

$$I := \frac{\pi\cdot r^4}{4}$$

$$I = 0.12in^4$$

$$\sigma_1 := \frac{M_p\cdot c_1}{I}$$

$$\sigma_1 = 1.205\times 10^3\cdot psi$$

$$\sigma_2 := \frac{M_p \cdot c_2}{I}$$

$$\sigma_2 = 1.205\times 10^3 \cdot psi$$

$$\sigma_3 := \frac{M_p \cdot c_3}{I}$$

$$\sigma_3 = 0$$

The bending stresses only occur at points 1 and 2 because 3 is on the neutral axis.

$\sigma_{b1} := \sigma_1 - \sigma_n = 678.452psi$ σ1 is in tension, so the normal stress is subtracted

$\sigma_{b2} := \sigma_2 + \sigma_n = 1.732\times 10^3 \cdot psi$ σ2 is in compression, so the normal stress is add

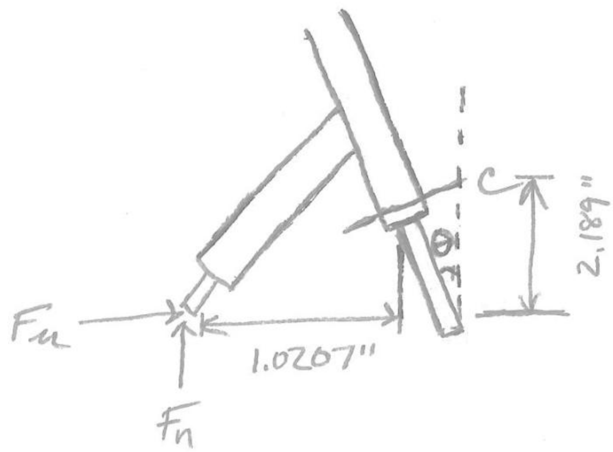
Stress Analysis of Plane C-C where the Sleeve Is Connected to the Walker

This is the stress analysis of the sleeve where it is bolted to the leg of the walker (Figure 1). Fμ is the frictional force on the kickstand and Fn is the normal force on the kickstand. Theta is 5 degrees because this is the angle that the walker is falling through.

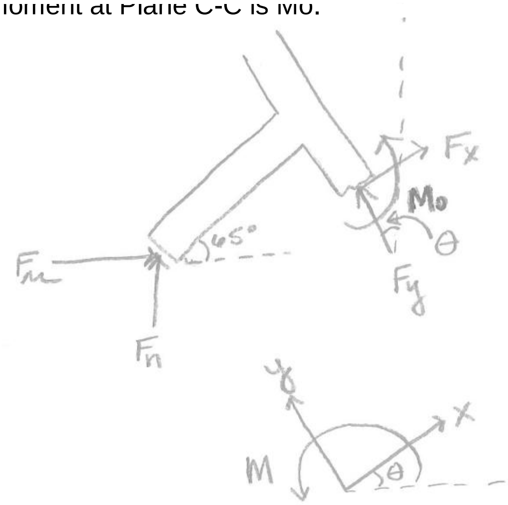
$F_{\mu} := 111.708\,lbf$

$F_n := 74.914\,lbf$

$\theta := 5 \cdot deg$



The free body diagram for this situation is Fig the shear force acting at Plane C-C. The bending moment at Plane C-C is Mo.



$F_y := -\cos(\theta) \cdot F_n - \sin(\theta) \cdot F_{\mu}$

$F_y = -84.365\,lbf$

$F_x := F_n \cdot \sin(\theta) - F_{\mu} \cdot \cos(\theta)$

$F_x = -104.754\,lbf$

$M_o := F_n \cdot (1.0207 \cdot in) - F_{\mu} \cdot 2.18897 \cdot in$

$M_o = -168.061\,lbf \cdot in$

To find the normal, shear and bending stresses, the cross sectional area (A) was calculated using the diameter (D) and radius (r) (Figure 3).

$D_o := 1.5 \cdot in \qquad D_i := .625 \cdot in$

$$A := \frac{\pi \cdot \left(D_o^{\,2} - D_i^{\,2}\right)}{4} = 1.46\,in^2$$

$$\sigma_n := \frac{F_y}{A} = -57.777\,psi$$ The normal stress

The shear stress $$\tau_s := \frac{F_x}{A} = -71.732\,psi$$

To calculate the bending stress, the area moment of inertia (I) was calculated. Since the screw is along the neutral axis, c equals zero. This causes the bending stress at Point 1 to be zero.

$$I := \frac{\pi \cdot \left(D_o^{\,4} - D_i^{\,4}\right)}{64}$$

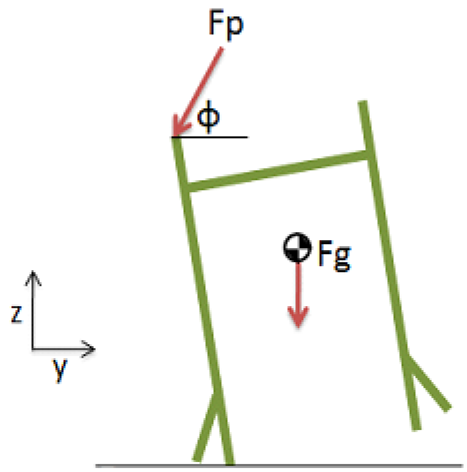
$$I = 0.241\,in^4$$

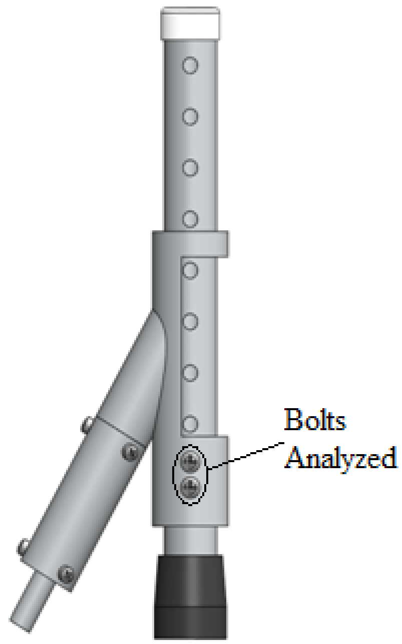
$$c := 0$$

$$\sigma_1 := \frac{M_o \cdot c}{I} = 0$$

Stress Analysis-Sleeve screws

The shear and compressive stresses, on the bolts fastening the sleeve to the detachable walker leg, were determined by considering the total force acting on the walker when it is tipped 5 degrees laterally. The variables used in the these calculations are defined below. The free body diagram below was used in the calculations.





$d := .25$ in

$F_p := 413$ lbf

$F_v := F_p \cdot \sin(25 \cdot deg) = 174.541$ lbf

The verticle force acting on the bolts is 174.5 lbf. Since there are two bolts, this force was divided by two

$F := \frac{F_p}{2} = 206.5$ lbf

Shear Stress

The shear stress was determined by dividing the force acting on each bolt by the cross sectional area of each bolt. The bolts used were 1/4-20 in.

$$A := \pi \cdot \left(\frac{d}{2}\right)^2 = 0.049 \qquad \text{in^2}$$

$$\tau_s := \frac{F}{A} = 4.207 \times 10^3 \qquad \text{psi}$$

Compressive Stress

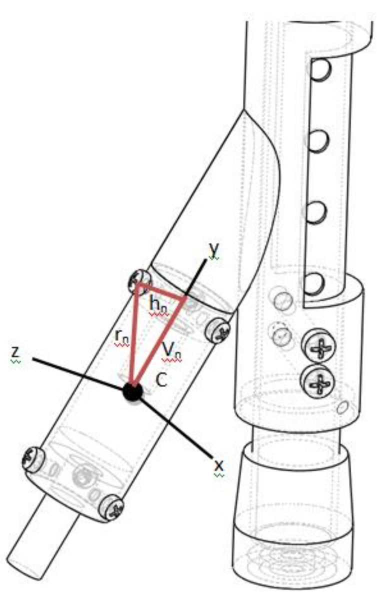
The compressive stress was determined by dividing the force acting on each bolt by the diameter of the bolts multiplied by the thickness of the detachable walker leg

$$t := \frac{1}{16} = 0.063 \qquad \text{in}$$

$$\sigma_c := \frac{F}{d \cdot t} = 1.322 \times 10^4 \qquad \text{psi}$$

Stress Analysis- Cover Screws

This analysis involved finding the centroid of the cover and determining the distance from the screws to the centroid (hn and vn). The figure below displays the variables used in the analysis. C represents the centroid of the cylinder and Cx and Cy are the locations of the centroid in the x and y directions.



Cover, nylon, connecting shaft screw analysis

To compute the shear and compressive stresses of the screws fastening the cover to the connecting shaft and nylon bushing, the total force acting when the walker is tipped 5 degrees. The vertical and horizontal distance from holes to centroid were first determined in order to calculate the centroid of the cover (centroid of a cylinder). For this analysis, the cut was taken at the top of the cover

$v_n := 1.625 - .25 = 1.375$ in

$h_n := .625$ in

$c_x := \frac{1.25}{2} = 0.625$ in

$c_y := \frac{3.25}{2} = 1.625$ in

$F := 413$ lbf — Total force acting on walker

$R := 1.625$ in — Distance from the centroid to the force

$F_{nv} := \frac{F}{6} = 68.833$ lbf — Fnv equals F/# of screws

$r_n := 1.51$ in — Distance from the centroid to the center of the screw

$$F_{nm} := \frac{F \cdot R \cdot r_n}{r_n^{\,2} \cdot 6} = 74.076 \quad \text{lbf}$$

Force in x direction

$$F_x := \frac{F_{nm} \cdot v_n}{\sqrt{h_n^{\,2} + v_n^{\,2}}} = 67.436 \quad \text{lbf}$$

Force in y direction

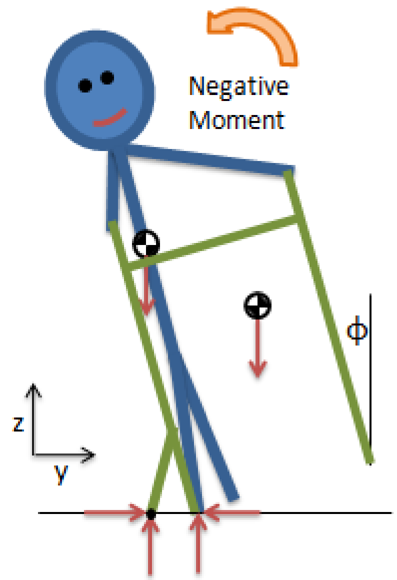
$$F_y := \frac{F_{nv} + \left(F_{nm} \cdot h_n\right)}{\sqrt{h_n^{\,2} + v_n^{\,2}}} = 76.226 \quad \text{lbf}$$

$F_y := \frac{F_{nv} + (F_{nm} \cdot h_n)}{\sqrt{h_n^2 + v_n^2}} = 76.226$	lbf	Force in y direction
$F_t := \sqrt{F_x^2 + F_y^2} = 101.774$	lbf	Magnitude of force
$d := .1459$	in	Diameter of 10-24 screws
$A := \pi \cdot \left(\frac{.1495}{2}\right)^2 = 0.018$	in^2	Cross sectional area of screw

---

$\tau_t := \frac{F_t}{A} = 5.798 \times 10^3$	psi	Shear stress on each screw
$t := .13$	in	Thickness of cover
$\sigma_c := \frac{F_t}{(d \cdot t)} = 5.366 \times 10^3$	psi	Compressive stress on each screw

Appendix M: Dynamic Analysis of Kickstand



Calculation of static forces on device

$$\Sigma F_y = -F_p - F_w + F_N + F_d$$

Vertical Force From Ground onto Support

$$F_{dy} := g\cdot\left(m_p + m_p - L_p\right) = 211.6\,\mathrm{lbf}$$

Counter-Lateral Step

$$z_{cm1} := 41.898\,\mathrm{in}$$

$$I_1 := 3.481\cdot 10^5\cdot\mathrm{in}^2\cdot\mathrm{lb}$$

$$Te := 8$$

$$Nt := 1000$$

Given

$$\frac{d^2}{d\tau^2}(x(\tau)) + \frac{s^2\cdot m_s\cdot z_{cm1}\cdot -g}{I_1}\cdot\sin(x(\tau)) = 0$$

$$x(0) = .5\cdot\deg \qquad x'(0) = 0$$

$$\theta_1 := \mathrm{Odesolve}(\tau, Te)$$

Side Step

$$z_{cm2} := 38.304\,\mathrm{in}$$

$$I_2 := 3.213\cdot 10^5\cdot\mathrm{in}^2\cdot\mathrm{lb}$$

$$V_{02} := .1\cdot\frac{m}{s}$$

$$\omega_{02} := \frac{V_{02}\cdot s}{z_{cm2}} = 0.103$$

$$Te := 8$$

$$Nt := 1000$$

Given

$$\frac{d^2}{d\tau^2}(\theta(\tau)) + \frac{s^2\cdot m_s\cdot z_{cm2}\cdot -g}{I_2}\sin(\theta(\tau)) = 0$$

$$\theta(0) = 0\cdot\deg \qquad \theta'(0) = \omega_{02}$$

$$\theta_2 := \mathrm{Odesolve}(\tau, Te)$$

For each of the stepping reactions, the vertical location of the center of mass (Zcm) and the moment of inertia around the center of mass (I) were previously calculated using the Mannequin model. Using the parallel access theorem the moment of inertia around the origin was calculated for each of the reactions. A small initial velocity was given to the user and the differential equation for an inverted pendulum was solved for to determine the user's location, velocity, and acceleration as functions of time for each reaction.

Cross-over Step

$z_{cm3} := 41.898\,in$

$I_3 := 3.21\cdot 10^5\cdot in^2\cdot lb$

$V_{03} := .1\cdot\frac{m}{s}$

$\omega_{03} := \frac{V_{03}\cdot s}{z_{cm3}} = 0.094$

$Te := 8$

$Nt := 1000$

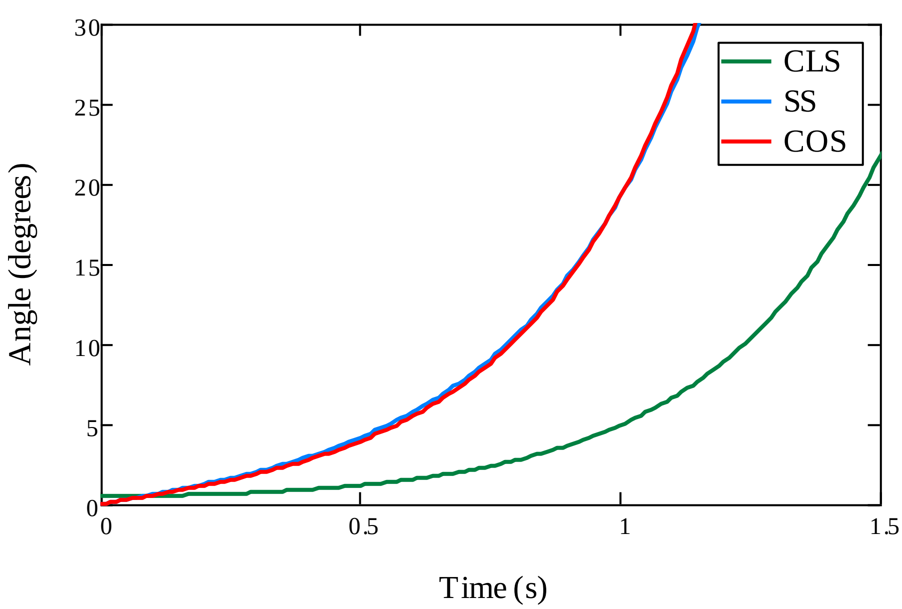
Given

$$\frac{d^2}{d\tau^2}(\theta(\tau)) + \frac{s^2\cdot m_s\cdot z_{cm3}\cdot g}{I_3}\cdot\sin(\theta(\tau)) = 0$$

$\theta(0) = 0\cdot deg \qquad \theta'(0) = \omega_{03}$

$\theta_3 := Odesolve(\tau, Te)$

$n := 0, 0.01 .. Te$



Time When Person Falls through 10 degrees

Guess

$$\tau_1 := 1$$

Given

$$\theta_1(\tau_1) = 5 \cdot deg$$

$$\tau_{s1} := Find(\tau_1) = 1.006$$

Time When Person Falls through 10 degrees

Guess $\tau_2 := 1$

Given

$$\theta_2(\tau_2) = 5 \cdot deg$$

$$\tau_{s2} := Find(\tau_2) = 0.558$$

Time When Person Falls through 10 degrees

Guess $\tau_3 := 1$

Given

$$\theta_3(\tau_3) = 5 \cdot deg$$

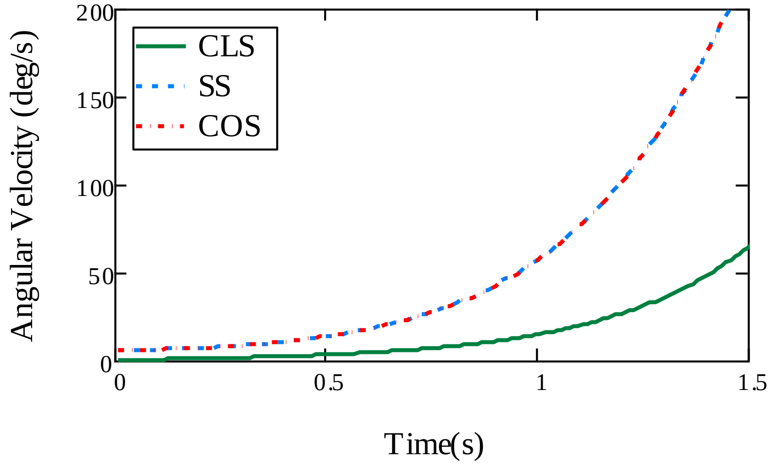
$$\tau_{s3} := Find(\tau_3) = 0.574$$

$$\omega_1(n) := \frac{d}{dn}\theta_1(n)$$

$$\omega_2(n) := \frac{d}{dn}\theta_2(n)$$

$$\omega_3(n) := \frac{d}{dn}\theta_2(n)$$

Angular Velocity



$$\omega_{s1} := \frac{\omega_1(\tau_{s1})}{s} = 0.258\frac{1}{s}$$

$$\omega_{s2} := \frac{\omega_2(\tau_{s2})}{s} = 0.278\frac{1}{s}$$

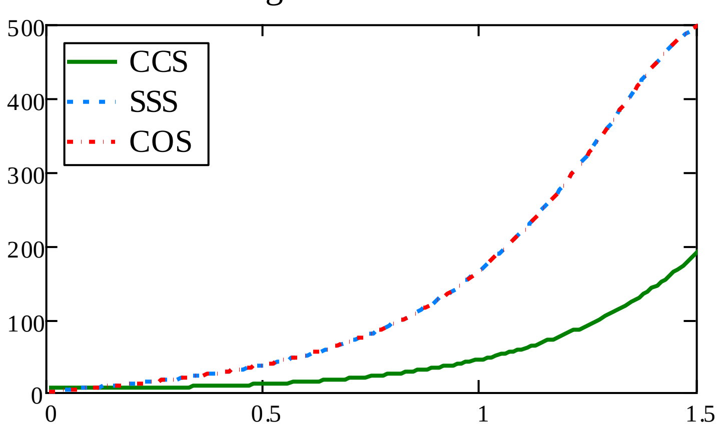
$$\omega_{s3} := \frac{\omega_3(\tau_{s3})}{s} = 0.291\frac{1}{s}$$

$$\alpha_1(n) := \frac{d}{dn}\omega_1(n)$$

$$\alpha_2(n) := \frac{d}{dn}\omega_2(n)$$

$$\alpha_3(n) := \frac{d}{dn}\omega_3(n)$$

Angular Acceleration



Counter Step

rotational kinetic energy

$$K_{r1} := \frac{1}{2} \cdot I_1 \cdot \omega_{s1}^{\ 2} = 3.397 W \cdot s$$

change in potential energy

$$U_1 := m_s \cdot g \cdot z_{cm1} \cdot (1 - \cos(5 \cdot deg)) = 3.432 J$$

work done by device

$$U_\delta := m_s \cdot g \cdot z_{cm1} \cdot (\cos(5 \cdot deg) - \cos(10 \cdot deg)) = 10.269 J$$

$$W_1 := K_{r1} + U_\delta = 13.666 J$$

Force applied by device

$$\delta := \Delta$$

$$F_1 := \frac{W_1}{\delta} = 454.639 lbf$$

Side Stepping

rotational kinetic energy

$$K_{r2} := \frac{1}{2} \cdot I_2 \cdot \omega_{s2}^{\ 2} = 3.634 J$$

change in potential energy

$$U_2 := m_s \cdot g \cdot z_{cm2} \cdot (1 - \cos(10 \cdot deg)) = 12.525 J$$

work done by device

$$W_2 := K_{r2} + U_\delta = 13.903 J$$

Force applied by device

$$F_2 := \frac{W_2}{\delta} = 462.511 lbf$$

Crossover Step

rotational kinetic energy

$$K_{r3} := \frac{1}{2} \cdot I_3 \cdot \omega_{s3}^{\ 2} = 3.968J$$

change in potential energy

$$U_2 := m_s \cdot g \cdot z_{cm1} \cdot (1 - \cos(10 \cdot deg)) = 13.7J$$

work done by device

$$W_3 := K_{r3} + U_\delta = 14.237J$$

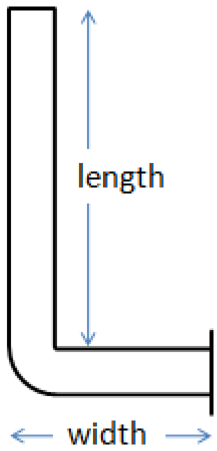
$$K := 1160 \frac{lbf}{in}$$

$$K_1 := 872 \cdot \frac{lbf}{in}$$

$$E_{spring} := 2 \left(\int_0^{.305 \cdot in} K \cdot x \, dx \right) = 12.192J$$

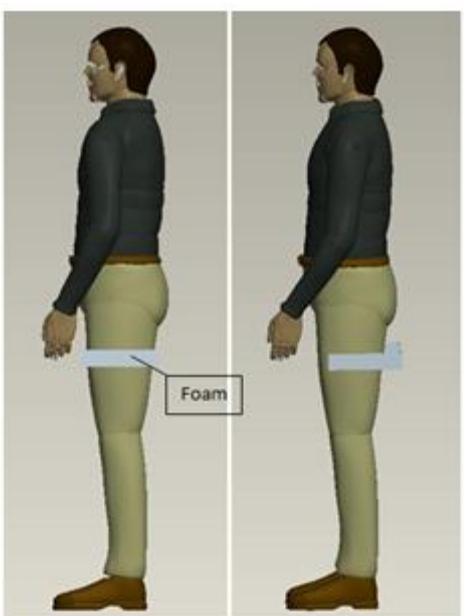
$$E_{spring1} := 2 \left(\int_0^{.305 \cdot in} K_1 \cdot x \, dx \right) = 9.165J$$

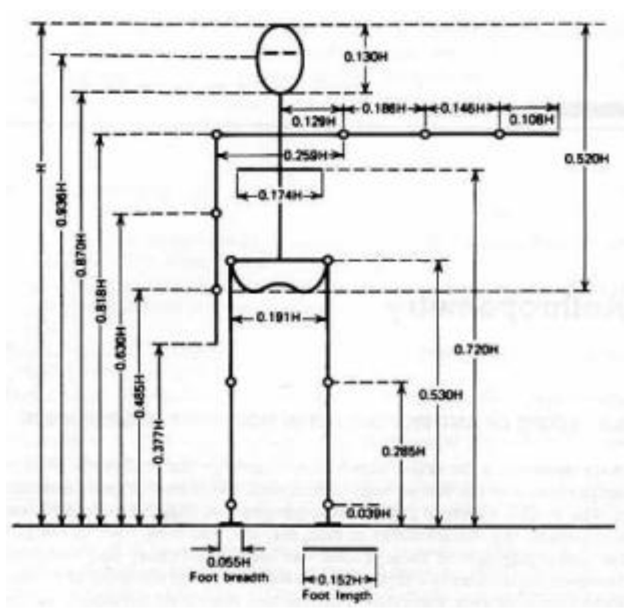
Appendix N: Determination of Dimensions and Location of Foam



The dimensions of the foam assembly were determined based off of the dimensions of the walker and the anthropometric data of the users. The length of the "L" shape of the foam needs to be small enough so that it touches the user's leg just before they move outside the walker's base of support. The foam also needs to be wide enough so that it touches even slim users. The size of the foam assembly was calculated using the anthropometrics of the smallest user a 5% female, so that the foam would be close enough to keep all of the users inside the walker.

The person's foot length was the main determining factor in the length of the foam, because it is essentially the distance from the front of the user's foot to the back of their leg as shown in the picture below. The device ensures that as the user is pushing the walker forward before they take their next step, they cannot push the walker forward far enough to be outside the base of support without their legs making contact with the foam. The Drillis and Contini model was used to compute body segment sizes based on user height.





height of person $h := 4.9\,ft$

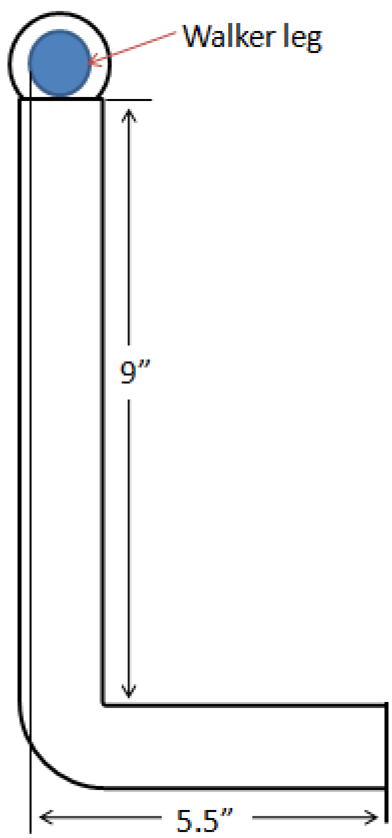
foot length as percentage of height $f := .152$

length of user's foot $l_f := h \cdot f = 9\,in$

The person's width and the width of the walker were the main factors in determining the width of the foam. Again the smallest user was the basis for this calculation and the Drillis and Contini model was used.

height of person	$h := 4.9ft$
foot length as percentage of height	$w := .191$
length of user's foot	$w_p := h \cdot w = 11in$
width of walker	$w_w := 21in$
distance from outside of walker to user	$d := \dfrac{w_w - w_p}{2} = 4.9in$

This number was rounded up to 5.5 inches to make sure that it went behind the user and did not just graze them as they moved past it.



Appendix O: Determination of Specification for Foam Location from Top of Walker

The specification of the foam location was determined to be 11½ inches from top of the walker. This specification was based on the top of the walker so the foam would be in the same location on the walker regardless of the changes in height of the walker. The function of the foam is to touch the users' hamstrings, which is a large area so a range was first established. The length of the hamstring was calculated for each percentile using 0.248 multiplied by the height of the women and 0.245 multiplied by the height of the men (Reinhold, 1986). These values are indicated by Lh in the chart below.

Table 27: Summary of Foam Specification Calculations

(ft)	Women (5%)	Men (5%)	Women (50%)	Men (50%)
Hp	4.77	5.38	5.11	5.70
Hw	2.83	3.17	3.08	3.33
Lh	1.18	1.32	1.27	1.40
Hf	1.98	2.19	2.13	2.32
Hf USL	2.28	2.52	2.44	2.67
Hf LSL	1.69	1.86	1.81	1.97
Wf (in)	10.20	11.70	11.50	12.12
Height of foam from ground	1.87	2.20	2.12	2.37

Ideally, the foam would be located in the middle of the hamstring so Lh was divided by two; the value is Hf in the chart. Hf was then divided by two in order to establish an upper specification limit and a lower specification limit. Half of Hf was added to Hf and half of Hf was subtracted from Hf, to determine the upper specification and the lower specification, respectively. A range for where the foam could come in contact with the user was then established, shown in Figure 49.

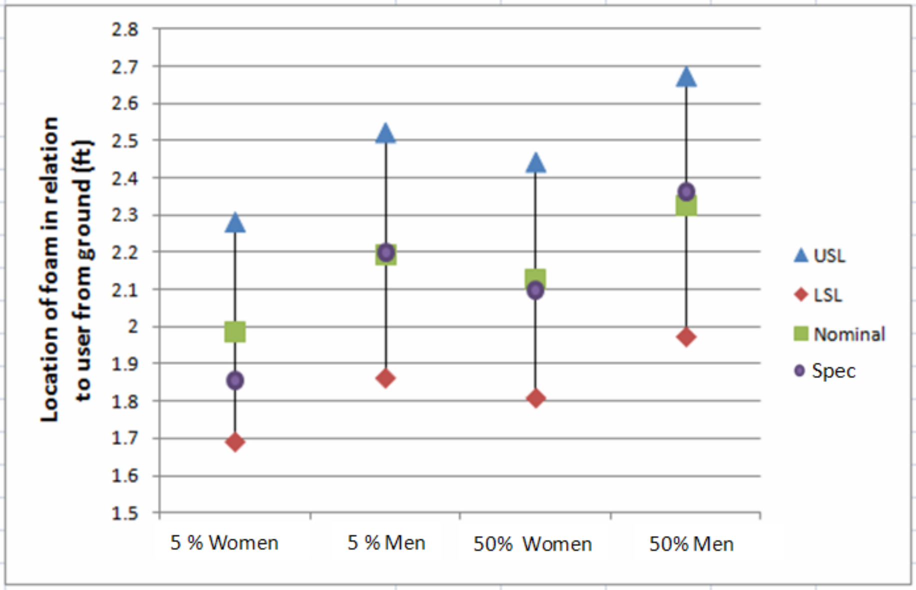


Figure 114: Location of Foam in Relation to User from Ground

Using the body length segments for the wrist, hamstring, lower leg, and foot, the distance from the ground to the user's wrist was determined. This value established the height of the walker needed for each user because the top of the walker should be level with the user's wrists when fitted properly (Hw). Since the specification is based on the distance from the top of the walker, the distance from the ground to the foam (Hf) was subtracted from the height of the walker (Hw). This distance (Wf) determined the position of the foam on the walker relative to top of the walker. The specification was based on these distances. Averaging the two middle percentile groups, 50th percentile women and 5th percentile male, a specification of 11½ inches from the top of the walker was settled. To ensure this specification fell within the expected range, shown in the figure above, the distance from the ground to the position of the foam was determined to be 20.4 inches for the walker on its lowest setting (full height of the walker is 32 inches). By adding the required number of holes to achieve the proper height for each percentile, the position of the foam could be found for each user's height. The value was plotted in the figure above, which is indicated by the purple circle and is shown in the chart of Figure 49.

Appendix P: Completed Questionnaires from Test Subjects

The questionnaires that were filled out by a male test subject are denoted by an "M" under the height and weight.

①

4x6=24
3x5=15
39
9+12=21

1=Poor **2=Fair** **3=Well** **4=Very Well** **5= Excellent**

Categories	Prototype Walker	Commercial Walker
Ease of use over ramp curve	4	2
Ease of use over ramp	4	2
Ease of use over tile surface	5	3
Ease of use over carpet surface	4	3
Ease of use over ~~hardwood~~ lin. surface	4	2
Ease of use in change of surface (~~hardwood~~ tile to carpet)	5	3
Ease of use over pavement	4	1
Ease of use over brick	5	3
~~Ease of use over grass~~		
~~Ease of use over change of surface (brick to grass)~~		
Comfort level when using in public	4	2
Totals	39	21
Additional Comments: Much easier to use than commercial walker. The back legs did not get caught on pavement or other surfaces		

Height 5'7" Weight 135 lbs

2

1=Poor   2=Fair   3=Well   4=Very Well   5= Excellent

Categories	Prototype Walker	Commercial Walker
Ease of use over ramp curve	3	2
Ease of use over ramp	4	4
Ease of use over tile surface	5	3
Ease of use over carpet surface	5	4
~~Ease of use over hardwood surface~~	/	/
Ease of use in change of surface (~~hardwood~~ tile to carpet)	4	4
Ease of use over pavement	4	3
Ease of use over brick	5	4
~~Ease of use over grass~~	/	/
~~Ease of use over change of surface (brick to grass)~~	/	/
Comfort level when using in public	3	4
Totals	15 +12 +6 33	20 +8 28
Additional Comments: Prototype walker was much smoother in nearly all tests. It felt more stable and safe. Its just a tad bulky which is why the score of 3 for comfort level.		

Height 6'4 Weight 220lbs

M

3

1=Poor 2=Fair 3=Well 4=Very Well 5= Excellent

Categories	Prototype Walker	Commercial Walker
Ease of use over ramp curve	2	1
Ease of use over ramp	4	2
Ease of use over tile surface	3	3
Ease of use over carpet surface	~~4~~ 5	~~3~~ 4
Ease of use in change of surface (tile to carpet)	2	2
Ease of use over pavement	4	3
Ease of use over brick	4	3
Comfort level when using in public	1	2
Totals	25	20

Additional Comments:
I Did not like the thing in back of my legs. I felt trapped.
I thought the prototype was easier to use.

Height 5' 9.5 Weight 175

M

4

1=Poor 2=Fair 3=Well 4=Very Well 5= Excellent

Categories	Prototype Walker	Commercial Walker
Ease of use over ramp curve	5	3
Ease of use over ramp	5	5
Ease of use over tile surface	5	3
Ease of use over carpet surface	5	~~5~~ 4
Ease of use in change of surface (tile to carpet)	5	4
Ease of use over pavement	5	5
Ease of use over brick	5	4
Comfort level when using in public	4	2
Totals	39	30

Additional Comments:

I liked how the prototype seemed more stable. Especially how the handels didn't rattle.

Height 5'8" Weight 140

5

1=Poor 2=Fair 3=Well 4=Very Well 5= Excellent

Categories	Prototype Walker	Commercial Walker
Ease of use over ramp curve	5	3
Ease of use over ramp	5	4
Ease of use over tile surface	5	4
Ease of use over carpet surface	4	3
Ease of use in change of surface (tile to carpet)	4	2
Ease of use over pavement	5	3
Ease of use over brick	4	3
Comfort level when using in public	5	4
Totals	37	26
Additional Comments: prototype walker was much easier to use and much more comfortable. easily adapted to different surfaces compared to the commercial walker.		

Height 5'3" Weight 135

6

1=Poor 2=Fair 3=Well 4=Very Well 5= Excellent

Categories	Prototype Walker	Commercial Walker
Ease of use over ramp curve	3	2
Ease of use over ramp	3	2
Ease of use over tile surface	5	4
Ease of use over carpet surface	4	4
Ease of use in change of surface (tile to carpet)	4	4
Ease of use over pavement	4	4
Ease of use over brick	5	5
Comfort level when using in public	1	1
Totals	29	26
Additional Comments:		

Height 5'9" Weight 165

7

1=Poor 2=Fair 3=Well 4=Very Well 5= Excellent

Categories	Prototype Walker	Commercial Walker
Ease of use over ramp curve	5	3
Ease of use over ramp	5	3
Ease of use over tile surface	5	4
Ease of use over carpet surface	4	3
Ease of use in change of surface (tile to carpet)	4	2
Ease of use over pavement	5	3
Ease of use over brick	4	3
Comfort level when using in public	5	3
Totals	37	24

Additional Comments:

It was nice how the commercial was lighter but the prototype was ~~had~~ much ~~better~~ smoother had better maneuverability.

Height 6'0 Weight 180

8

1=Poor 2=Fair 3=Well 4=Very Well 5= Excellent

Categories	Prototype Walker	Commercial Walker
Ease of use over ramp curve	4	3
Ease of use over ramp	4	3
Ease of use over tile surface	5	5
Ease of use over carpet surface	5	5
Ease of use in change of surface (tile to carpet)	5	4
Ease of use over pavement	4	3
Ease of use over brick	4	3
Comfort level when using in public	5	5
Totals	36	31

Additional Comments:

Wheels felt smoother on ground w/ prototype.
Couldn't go ~~to~~ backwards with either if you wanted to.

Height 5'5" Weight 145