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Design of a Bedside Walker-Cane Hybrid to Aid Senior Adults Avoid Falls during Night Walks

Jorge L. Gutierrez
The University of Texas Rio Grande Valley

DESIGN OF A BEDSIDE WALKER-CANE HYBRID

TO AID SENIOR ADULTS AVOID FALLS

DURING NIGHT WALKS

A Thesis

by

JORGE L. GUTIERREZ

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COMMITTEE MEMBERS

Dr. Noe Vargas Hernandez
Co-Chair of Committee

Dr. Alley Butler
Co-Chair of Committee

Dr. Miguel Gonzalez
Committee Member

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ABSTRACT

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The objective of this research and development work is to design a device to help senior adults prevent fall during night walks indoors. The problem of elders falling at a night setting was found to be caused by the multiple environmental and medical conditions. The target demographic was found to be seniors from age 65 and older. Several occupational therapists and two physical therapists were consulted to gain knowledge on elders' behavior, possible improvements on current existing devices, and feedback regarding the early prototype built. Several products and patents were researched with a lack of findings on similar products that perform the proposed functions. A walking aid device was successfully designed using a systematic design process. A bed anchor and locking mechanism were also designed for the walking aid device to be attachable to the bed. This gives the ability for the walking device to be always available when needed. A finite element analysis, failure modes effects analysis, working model simulations, and early prototype tests were made. The tests determined the possible failures, materials, stability, and demonstrated the interaction between user and device.

DEDICATION

I dedicate this thesis to all of my family. My parents, Miguel and Leticia, thank you for all of the support you have given me. Thank you for all of your teachings and sacrifice so that I could achieve all of my goals and education. Also as important, I thank Merari for all of the advice, love, support, and motivation you have given me all of the years we have known each other. I would also like to thank my brothers for being great role models and reminding me that to be the best, you have to always do your best work.

Thank you all for always getting the best out of me. I love you all.

Le dedico esta tesis a mi familia. A mis padres, Miguel y Leticia, gracias por todo el apoyo que me han dado. Gracias por todas sus enseñanzas y sacrificios para que pueda lograr todas mis metas y educación. Igual de importante, le agradezco a Merari por todos sus consejos, amor, apoyo, y motivación que me has dado todos estos años que nos hemos conocido. También quisiera agradecer mis hermanos por ser buenos modelos a seguir y recordarme que para ser el mejor, siempre tienes que hacer tu mejor trabajo.

Gracias a todos por siempre sacar lo mejor de mí. Los amo a todos.

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CHAPTER I

INTRODUCTION

Over the years, the use of mobility assistance devices has become more common and accessible to individuals. Devices such as canes, crutches, walkers, and wheelchairs are amongst the most commonly used among individuals with walking disabilities. Individuals that may use these devices are people, of any age, with any kind of disability caused by illnesses or problems with their limbs. More specifically, individuals of old age regularly starting at 65 years and older require more assistance when ambulating. This is due to an increased chance of falls caused by a higher probability of illnesses and body weakness.

When it comes to older people, it is more important to mitigate or prevent their falls altogether. A fall is more dangerous for a person of old age compared to younger people due to their skin and bone fragility, as well as their reduced reflexes to mitigate the fall themselves. When an older person falls, the best-case scenario is being unharmed, but a fractures in the hip, leg, or arm are a large possibility because of osteoporosis. The worst-case scenario is death by severe fractures or head trauma after an impact with an object or the ground. There are several consequences to a fall such as loss of independence, hospitalization, costs, death, as well as the impact to the victim’s family. For these reasons, it is of the upmost importance to prevent falls with the elderly.

There exists several types of canes and walkers on the market which give extra support, but many also have diverse functionalities among them. Some canes are collapsible and may even include a seat to rest. Walkers are the devices that give the most support and some also have additional features. A variation of the walker called rollator may include seats, wheels, carrying baskets or bags, etc. The goal of this project is to design an assistive walking device that gives more support compared to a cane. It is to be used for ambulation at night when there is less visibility and the risk of falls increases. As later seen in the patents section, there are numerous patents and products that prevent rolling out of bed while sleeping and help stand up the user from the bed. However, there are no existing products or patents that work as both a bed rail and a walking aid device or one that attaches to the bed.

1.1 Origin of the Problem

In the Fall of 2017 the author participated in a regional NSF I-Corps program sponsored by the NSF. The presented project in the program was also directed to a target audience of seniors. The program is based on performing several interviews to understand the problem more deeply. The I-Corps program aids scientists and researchers in academia understand entrepreneurial concepts focusing mainly on the customer discovery process. Through interviews to a variety of stakeholders (i.e. senior care experts, researchers, etc.), several questions were asked about the lifestyle of seniors in several types of situations. The main goal of the interviews was to understand how frequent and severe falls were, and if a device to help them get back up was of any utility. The biggest answer obtained from the interviews was not the speed of getting individuals back up, but the mitigation of the fall to prevent the injury or the fall itself. One of the questions asked to several interviewees was “Where do the seniors fall more often?”. The answer was eye-opening for the team as they answered, “inside the bathroom or getting out of bed." Falling in the bathroom can be easily imagined, but falling bedside wasn't an intuitive scenario. How can they fall and get injured more often being beside of their own soft bed? The most common answer given by interviewees was the lowering of blood pressure by quickly standing up or orthostatic hypotension. There were other causes to their falls given by the interviewees. Besides low blood pressure there is sleepiness from a recent night sleep or nap, being dizzy after taking medication, being overmedicated, stroke, signs of a new illness or new symptoms, weakness on the lower part of the body, being tripped by an object, partial blindness or blurry vision, etc. This customer discovery experience began the search for a solution to the out-of-bed-fall problem.

1.2 Objective

The objective of this thesis is to design and test a device that can help the user sit up on their bed and help them stand. After the person has safely stood up, the device aids the person to move within their home, to the bathroom or kitchen for example, during day or night and back to their bed. The device can be attached to the side of the bed and operate as a bed rail which can be detached and used as a walking aid device. This walking device is also capable of being used as a regular, but lighter walker for indoor activities any time of the day. The device is not intended to replace a walker but enhance the support given by a cane. The main steps of the design process used to develop the proposed device was inspired by the book Engineering Design: A Systematic Approach [1]. Other inspiration for the process includes the "wirk" element methodology by Thomas Jensen [2] for the functional decomposition. The ideas borrowed from this paper helped grasp a better understanding of functions, how to break down a function to its most basic components, and their importance during the conceptual stage. One final source of inspiration came from the Strategyzer course based on building a business model [3]. This course helped understand how to interview the product stakeholders and consider all their needs to avoid making a product that does not offer a real value to users.

CHAPTER II

REVIEW OF LITERATURE

The following chapter focuses on the review of previous research by various scientific articles and paper in an effort to provide basic knowledge on topics required to start the investigation. The chapter will focus on four main topics; causes of falls, consequences of falls on seniors, the target demographic, and an overview on the theory of the design process. These topics give a better understanding on what is currently known, the severity, and ramifications of falls in the elderly. Additionally, they provide the background knowledge necessary to understand the design process that was applied.

2.1 Causes of Falls

When it comes to causes of falls, there are multiple reasons for which a person can fall. Focusing only on seniors, they have several common causes of falls such as orthostatic hypotension, overmedication, use of sedatives, arm or leg strength impairments, limited range of motion, balance or gait issues and many others. The causes discussed in the following sections are the most relevant because they are problems this project tries to resolve.

Balance involves regulating the position and motion of the body's center of mass with respect to the stability limits defined by the base of support. To achieve static postural equilibrium, the center of mass must be positioned over the base of support. Loss of balance can result when the center of mass is displaced in relation to the base of support because of voluntary movement or an external perturbation. [4]

2.1.1 Orthostatic Hypotension

Orthostatic stress is a common daily challenge for humans when posture changes from lying to standing or during prolonged quiet standing. Note that this whole section on orthostatic hypotension was based on a review done by Fabrizio Ricci, et al. in 2015 [5] and a study done by Vishal Gupta and Lewis Lipsitz in 2007 [6]. Orthostatic hypotension (OH) is a cardiovascular disorder, with or without signs of underlying neurodegenerative disease. It frequently affects older people and patients who have neurodegenerative disease, diabetes, or hypertension. OH is diagnosed on the basis of an orthostatic challenge and implies a persistent systolic/diastolic blood pressure decrease of at least 20/10 mm Hg upon standing. Studies have revealed an increased prevalence of orthostatic hypotension with age. In community dwelling individuals greater than 65 years of age, its prevalence is approximately 20%; in those greater than 75 years of age it is as high as 30%. In frail elderly individuals living in nursing homes, the prevalence of orthostatic hypotension is even higher, up to 50% or more. Orthostatic hypotension also is associated with significant morbidity at older age. It has been linked to falls, fractures, transient ischemic attacks, [7] syncope, and myocardial infarction. In addition, elderly people with orthostatic hypotension are more likely to be physically frail and thus to have decreased functional capacity, a factor that is often overlooked during the evaluation of older patients.

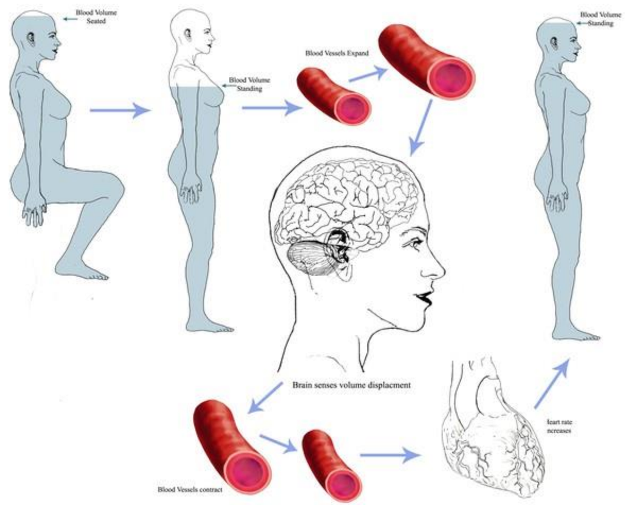


Figure 1: Orthostatic Hypotension [7]

2.1.1.1 Pathogenesis

In healthy people, approximately 500 to 1,000 milliliters of blood are transferred below the diaphragm upon assuming an erect posture. This leads to decreased venous return to the heart, reduced ventricular filling, and a transient decrease in cardiac output and blood pressure. Consequently, baroreceptors in the carotid arteries and aorta are activated, resulting in increased sympathetic outflow and decreased parasympathetic outflow from the central nervous system [6].

2.1.1.2 Treatments

2.1.1.2.1 Patient Education

Patient education is central to effective treatment of OH. It is crucial that patients understand the basics of postural physiology and mechanisms of orthostatic intolerance, as well as aggravating factors; learn how to avoid conditions that potentially trigger symptoms and syncope; and be instructed in how to prevent BP decreases using physical countermeasures [5].

2.1.1.2.2 Elastic Stockings and Abdominal Binding

When the symptoms of orthostatic intolerance are very pronounced (class III to IV) and patient education plus pharmacological treatment does not lead to substantial improvement, elastic stockings and abdominal binding may be helpful. Limb and abdomen compression improves orthostatic tolerance in up to 40% of symptomatic patients [5].

Figure 2: Elastic Stockings [8]

Figure 3: Abdominal Binding [9]

2.1.1.2.3 Pharmacological Treatment

Although nonpharmacological measures are effective, most patients with class III to IV orthostatic intolerance, experiencing severe, persistent, or very frequent symptoms, often immediately upon standing, require pharmacological treatment with antihypotensive drugs. Management of symptomatic OH consists of both nonpharmacological and pharmacological methods, but they are often unsatisfactory [5].

2.1.2 Sleepiness

When an individual awakens and gets out of bed after a deep sleep, they are most often not fully awake and conscious when they stand up. Being partially asleep and not fully awake limits the brain's capability to perceive the world around them. Their vision is not fully responsive, and their body is not at full strength. In the event that the senses are working properly, the mind is not at its full processing potential limiting the information processed by the brain and reducing the responsiveness of the individual. This increases the risk of environmental hazards as one could trip over or slip due to the impaired visual capabilities. The issue is then exponentially increased if the individual awakens at night when there is absence of light or very minimal localized light provided by lamps. Body strength is also a side effect of drowsiness as stated before. This can also be very dangerous as the person does not realize that they have a weak body until they try to get up or after taking their first steps. These factors are significantly dangerous for any young and healthy individual. Therefore, the threat is amplified on an older person with visual and body strength complications, which numerous seniors have. For this reason, it is important that the individual is fully conscious and mentally aware to perceive their surroundings properly and successfully analyze themselves without the confidence of being in control of their own bodies after awakening.

2.1.3 Falls While Using a Cane or Walker

Even though many seniors agree to need and use a cane or a walker, the use of one of those does not guarantee a safe walk. Both the cane and the walker help improve stability by giving the user a bigger center of gravity and widening their base of support to help release some weight from the affected limb. The cane helps in cases where, for example, the person has gait problems due to an injured or weak leg, early signs of joint problems, etc. However, a large portion of users experience difficulties, and the use of these devices is associated with increased risk of falling. Walking aid devices, in general, also can also harm the user by altering their posture into a forward-leaning posture or a lateral-leaning posture in case of canes. This problem arises after the person has used a device for some time with an improper height. [10] These improper postures can lead to further risk of falls. Besides altering the gait and posture, an improper cane height can lead to a higher risk of falling. An improper cane height changes the angle at which horizontal forces are applied to the device [4]. Horizontal forces are necessary for braking and propulsion. Due to an incorrectly adjusted cane, these horizontal forces are improperly shifted affecting the person's efforts to steady themselves after a loss of balance. This could be very important specially if the person places too much weight on the cane.

A study done by Liu and Eaves in 2011 [10] indicates that 36% of the cane users experienced at least one fall since using the cane and 28% experienced a fall at least once during a 12-month period. Factors such as incorrect cane height, forward-leaning posture, lateral-leaning posture, and incorrect hand to hold the cane were analyzed for significance. The incorrect cane height, lateral-leaning posture, and incorrect hand to hold the cane factors did not show any significance associated with the rate of falls. The significant factor in this study was the forward-leaning posture as 67% of cane users with forward-leaning posture experienced a fall.

It is believed that the body might adapt to the center of gravity when the person uses the cane and cause the person to alter their posture into these forward-leaning postures and lateral-leaning postures. The bad posturing caused by the body's adaptation can negate the positive benefits given by the increased base of support. These postures cause even more problems when the person does not use the cane. When the individual ambulates without a cane, they are more likely to fall forwards or laterally because the body is used to the center of gravity provided by the cane.

Some studies report that environmental obstacles are associated with falls when using a mobility aid device. It also appears that walker-related injuries can occur due to the contact of a walking aid device and environmental objects such as carpets and doorframes that would normally not be considered as obstacles. During a loss of balance, instinctual forms of balance recovery might include rapid postural reactions at the ankle, hip, trunk, and neck but sometimes this could fail. When these methods are insufficient to recover equilibrium, in cases such as relatively large postural perturbations or if the person does not have the sufficient strength due to weakness or impaired neuromotor control, the only solution is to change the base of support by stepping rapidly or reaching out to another stable object such as a dresser, wall, or handrail. These reactions are instinct based and there is evidence that a walking aid device might interfere with these actions. It has been observed that a walker or mobility aid device of the same type might impede the rapid lateral movement of the legs and hence disable the capacity to perform the compensatory stepping reaction during lateral loss of balance. A study done by Hamid Bateni et al. in 2004 [11] indicates that collisions between the swing foot and walker were frequent with an occurrence of more than 60% of stepping reactions. Although not as frequent as with walkers, canes also presented the same problem and led to a significant reduction in lateral step length. The study was performed on healthy young adults which indicate that the results might be of greater significance when concerning senior adults.

As a consequence of the weight and inertia of the arm and device, the act of lifting and advancing the aid creates reaction forces and moments at the shoulder that could potentially disturb the center of mass unless countered by preventive adjustments. When lifting a device, the arm movement is likely to be slower, and the reduced speed would tend to increase the stabilizing effect. However, the added weight and inertia of the device could amplify the destabilization. The degree on which his subject causes actual instability has not been investigated but still it is a possibility. It is also possible that the act of lifting the device could cause instability like when a person lifts a foot. This causes the center of mass to fall toward the unsupported side during walking [4].

2.1.4 Community Living Falls vs Institutional Falls

The living conditions for seniors living in community living centers, nursing homes, or independent are vastly different in terms of falls. The causes of falls between them vary from facility to facility. A study done by Laurence Z. Rubenstein and Dan Osterweil [12] analyzes the different causes of falls by reviewing multiple studies for comparison. The number of falls on community-living elderly compared to elderly in nursing homes is two times lower. This can be due to the more delicate nature of the elderly for the reason they have been institutionalized. The institution's more accurate monitoring and reporting nature also contributes to this comparison. Another point to observe is the difference between the likelihood of different cases and risks of falls. As seen in Table *1*, institutionalized seniors have higher probability of falling due to gait disorders, weakness, dizziness, and confusion. Comparing that to community-living seniors, they tend to have a higher probability of falling due to their environment.

Table 1: Causes of Falls in Nursing Homes Compared with Community-Living Populations [12]

Cause of Falls	Nursing Home (N = 4 studies 1076 falls)[25,41,65,75]	Community-Living (N = 7 studies 2312 falls)[9,13,20,44,48,61,71]
Gait/balance disorder, weakness	26% (20%–39%)†	13% (2%–29%)
Dizziness/vertigo	25% (0%–30%)	8% (0%–19%)
Environment-related	16% (6%–27%)	41% (23%–53%)
Confusion	10% (0%–14%)	2% (0%–7%)
Visual disorder	4% (0%–5%)	0.8% (0%–4%)
Postural hypotension	2% (0%–16%)	1% (0%–6%)
Drop attack	0.3% (0%–3%)	13% (0%–25%)
Syncope	0.2% (0%–3%)	0.4% (0%–3%)
Other specified causes‡	12% (10%–34%)	17% (2%–39%)
Unknown	4% (0%–34%)	6% (0%–16%)

In the nursing home, gait/balance and weakness takes up one fourth of the cases studied. A comparison between fallers and non-fallers showed that lower extremity weakness was a significant risk factor that increased the probability of falling by five times.

This leads to the conclusion that gait and balance disabilities are the most important causes in nursing homes. Dizziness is also a very big cause in nursing home falls as it also takes up one fourth of the total falls. It is often difficult to diagnose as it can show up as a side effect of other issues and vertigo is often the cause of gait disorder. Environmental hazards are more common causes in community-living falls as it takes up 40% of the total cases studied compared to the 16% in nursing homes. This in part makes sense because nursing homes have very crude bedrooms controlled by nurses and staff. They are carefully constructed with only the essential equipment in the room. Compared to a community-living room, the room is made to feel as a home-based room for the senior. Falls in nursing homes primarily have occurred during bed, chair, or wheelchair transfers. Falls also occurred when taking trips to or from the bathroom or nocturia. The environmental hazards involved in these kinds of falls are wet floors because of incontinence, poor lighting, bedrails, and improper bed height.

Orthostatic hypotension is more common for people with certain predisposing risk factors common in nursing homes such as autonomic dysfunction, hypovolemia, low cardiac output, parkinsonism, metabolic and endocrine disorders, and medications. Yet there are not many falls regarding orthostatic hypotension. This may be because it is often difficult to document after the fall or because most people that feel light headed quickly find a seat to rest.

Other important causes of falls in the nursing home are visual problems, acute illness, disorders of the central system, and drug side effects. Drugs frequently have side effects that result in impaired cognitive abilities, stability, and gait. These medications often include sedatives, antidepressants, psychotropic, and antihypertensive effects.

Even though there are differences among community-living and nursing homes the probability of the underlying causes of the falls are still the same. They can happen in both settings but with different likelihood.

2.2 Consequences of a Fall

Falls can have a variety of consequences ranging from no injury or minor injury, to serious injury or death. Apart from physical damage, there are several more consequences that can happen such as a decrease in confidence in the ability to ambulate safely and loss of independence for the senior and for the family members. There are many more outcomes to a fall, but this thesis only covers some of them.

2.2.1 Loss of Independence

Senior citizens are always going to want to be independent in their actions. They often reject the help of their family members, nurses, caregivers, etc. After a person falls their family members or caregivers, in case they are in a living center, place safety measures to ensure that another incident does not happen. During the interviews performed in the NSF I-corps program, the people interviewed stated that after a fall, family members usually sent the senior to an assisted living center or nursing home. They wanted them to have better care and supervision compared to living at home. In case the senior is not injured after the fall, family members typically place someone to constantly monitor them to prevent another fall. Equipment might also be placed in the room such as: bed rails, handle bars, fall mitigation mats, and other expensive equipment. Without considering the senior's necessities or believes of the matter. Most cases of falls do end with an imminent injury which may range from a minor lesion to a fracture. Depending on the type of injury, the senior person might be confined to use a walking cane, walker, or wheelchair. These pieces of equipment do provide some mobility for the person, but still takes away their freedom to walk or move freely. In a worst-case injury, the person might ultimately be confined to stay in bed due to a fractured hip, for example. Again, these options, depending on the type and gravity of the injury, have a range of time as short as a week or as long as an indefinite time.

2.2.2 Family Impact

When a senior falls and loses independence due to an injury, the family is affected as well. Some family members might have to be absent from their jobs to stay home and help their loved one recover from the fall. In some cases, family members could even take a leave of absence or quit their jobs to become full-time caregiver when the injury is severe. Also, to keep an eye on them and prevent another accident from happening. [13]

2.2.3 Cost

According to a study done in 2012, the total cost of a non-fatal fall related injury totaled $30.3 billion for the amount of 3.2 million medically treated non-fatal fall related injuries. Out of that $30.3 billion, 57% ($17.2 billion) was for hospitalization, 27% ($8.2 billion) was cost for emergency department (ED) visits, and 16% ($4.8 billion) was the cost for office based and outpatient visits. The average cost per fall is around $9,463 per fall with $29,562 being the average cost per fall for hospitalization, $4,673 the average cost per fall for ED visits, and $5,625 the average cost per fall for office based and outpatient visits. The total direct medical cost was $616.5 million with a sum of 24,190 fatal fall injuries. The average cost for a fatal fall is about $25,487 per fall. These numbers have been adjusted for inflation to 2015 dollars. The total costs from 2012 has since increased to $31.3 billion for fatal injuries and $637.5 million for non-fatal injuries with an average cost of medically treated falls of $9,780 on 2015. [14]

	Fatal		Nonfatal total		Hospitalizations		ED visits		Office based and outpatient visits	
	Av. cost per fall	Total cost[a]	Av. cost per fall	Total cost[b]	Av. cost per fall	Total cost[b]	Av. cost per fall	Total cost[b]	Av. cost per fall	Total cost[b]
Total	$26,340	$637.2	$9780	$31.3	$30,550	$17.8	$4829	$8.5	$5813	$5.0
Sex										
Men	$25,769	$282.2	$8462	$9.0	$29,407	$5.1	$3894	$2.1	$5317	$1.9
Women	$26,812	$355.0	$10,441	$22.2	$31,029	$12.8	$5252	$6.4	$6155	$3.1

Figure 4: Fatal and Nonfatal Cost Estimates Table for Unintentional Fall Injuries by Treatment Setting and Sex [14]

2.3 Target Demographic

The target user is based upon the subject's ability to stand, walk, and self-evaluate themselves on their capability of walking and awareness. The main target is senior people from the ages of 65 and older. The subject must have certain characteristics about their lifestyle. These characteristics include mobility well-being, walking independence, at most require a cane, sufficient strength to lift themselves up from a lying position to a sitting position with minimal to no help, and the ability to stand from a seated position with minimal to no help. The device can be useful for seniors with personal caregiving, living with a partner, or completely independent by living alone. This device would also serve the hospital and assisted living homes as well. Caregiving does not always operate at a 24-hour level. Even if the subject has someone at their disposal at that moment, the caregiver may not always be available or in the room the exact moment the senior needs assistance [12].specific criteria were chosen to identify the best user for the device. These characteristics include the ability to walk with minimal assistance, sufficient body strength, and the ability for the user to self-evaluate their walking capabilities at that moment. Following these characteristics, among others, the most suitable user for the proposed device can be identified.

2.4 Design Process

The previous sections focused on the understanding of the problem and the user. These next sections explain the steps of the design process that was used. It covers how to identify the problem, the product opportunity gap and its value, various design concepts, embodiment, validation, and several other subjects. In between the design sections, a discussion about a personal experience of the author during the NSF I-Corps program was also added to further discuss the practice of user research.

2.4.1 Problem Identification

The starting point to any solution should always start with problem identification. Identifying the problem further helps to create a better solution or modify existing products to better solve the problem. What is the problem? How big of a problem is it? How would a solution affect the victim of the problem? How does the problem affect their victims? These and much more are all questions that must be asked before creating a solution to fully understand the problem. In this section Set Factors, Product Opportunity Gap, and Value Opportunity Analysis are discussed and explained. These areas help the designer conceive a problem based on current influencing factors in our world or societies.

2.4.2 SET Factors

SET factors are the social, economic, and technological factors that together correspond to the gap that exists between available products and the new product to be developed.

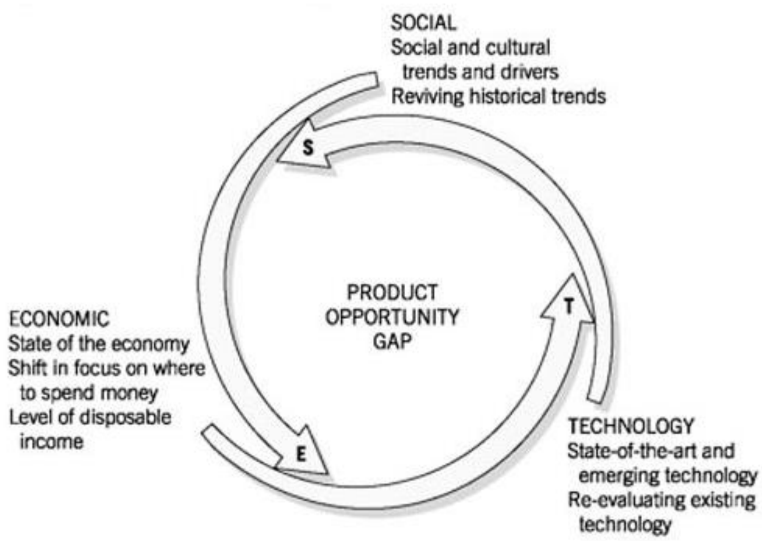


Figure 5: SET Factors and Product Opportunity Gap Illustraion [15]

Social factors focus on social interactions and cultural influences. Social factors include family and work patterns, health issues, use of computers and the internet, political environments, successful products in other fields, sports, entertainment, and any factor that involve social interactions [15].

Economic factors focus on the excess income that people perceive they have, or that they expect to have, to give them purchasing power. These factors are driven by the economic strength and forecast such as fuel costs, raw material costs, loan rates, stock market, etc. Product development is also influenced by understanding the target demographic, who is buying, from who are they buying it, who has the income to purchase. Economic factors are proportionally related to social factors. As social factors change, the peoples spending of their money also changes [15].

Technology factors focus on the direct and imagined results of new technologies as well as the acceptance of new technologies. These factors include incremental changes in the computing power, the electronics tendency of being reduced in physical size, new material and manufacturing advances, electrical and mechanical innovations, etc. [15].

2.4.3 Product Opportunity Gap

Once the SET factors have been stablished for a certain product idea, the hunt for an opportunity gap emerges. The opportunity gap is a hole in the product space dictated by the specific SET factors that the current products have not covered. This gap creates an opportunity for innovation that meets the conscious and unconscious expectations of customers and is perceived as useful, usable, and desirable. An example of this is Apple's iPod. The SET factors established had a gap where there existed no media player capable of storing media in the device itself without the need of an external device storage such as a CD or cassette tape. The device was also extremely portable and of high capacity storage. [15]

2.4.4 Value Opportunity Charts and Analysis

The value opportunity charts and analysis start by identifying the value opportunities of a product or idea after a potential solution to the product opportunity gap has been allegedly found. Value opportunities are the attributes that contribute to a product and reflect on the user's experience. For the user, the better the experience, the greater the value they find in the product and therefore find a greater satisfaction with the product. Some examples include emotion, ergonomics, aesthetics, impact, quality and so on. These attributes can be broken down into more specific attributes, for example, aesthetics can be broken down into visual, auditory, tactile, taste, olfactory and so forth. The value opportunities differentiate a product from the competition in the way that people's needs, wants, and desires influence the purchase and use of the product [15].

The Value Opportunity Chart consists in a better visualization of every element of value in a product by compiling the value opportunities into a chart. Besides containing all of the value opportunities, these opportunities can be ranked as Low, Medium, or High or a point scale system by a black line beside the value as shown in Figure 6. If the product did not meet any level of that attribute, no line is drawn. The profit impact (across the company), brand impact (on the company brand), and extendable at the bottom of the chart are not value opportunities. These attributes indicate the overall success of the product [15].

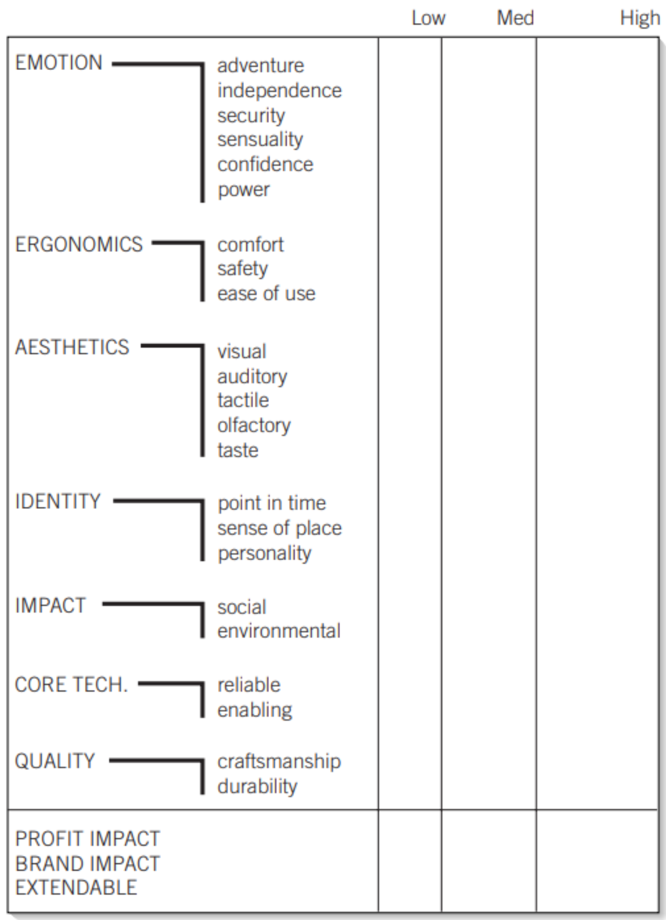


Figure 6: Value Opportunity Chart [15]

Once the value opportunity chart has been created, it can then be analyzed and compared to other existing products. A first analysis can be made to determine the low areas which the end user might consider important, elementary, or desired value opportunities. These areas can then be improved upon and make the product more appealing to the end user. Also, a comparison analysis can be made to compare experimental product to an existing product. This serves as a way of determining which value opportunities are higher or lower than the existing product which therefore makes it a better or worst product, respectively [15].

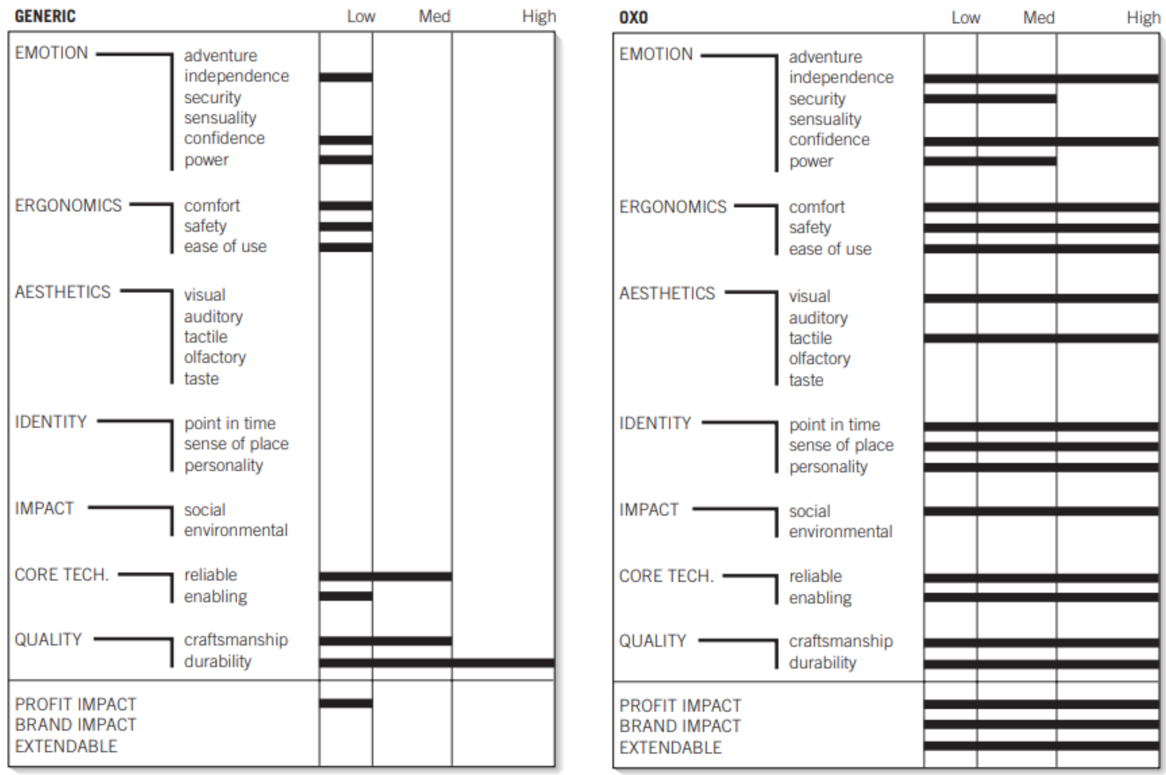


Figure 7: Value Opportunity Chart Example Between Two Products [15]

Maximizing the value opportunities is not enough to guarantee the product’s success with the consumer. The value opportunities must not be maximized to the eyes of the maker but the eyes of the user. The product fails if the maker only focuses on their perception of what the attribute’s level are. The attributes must be scored with the consumer’s perception of them in mind [15].

2.4.5 Problem Formulation

2.4.5.1 Background Research: Problem Research

Background research is the study of all topics and areas of interest that relate to the understanding of the end user and the problem. During a background research, the designer must study any potential topics that might not be suitable to investigate during the user research. The objective is to learn more about the environment the design is exposed to and any previous studies done to solve a similar, if not the same, problem being researched. The objective is not to look for an answer to the problem being explored, but to look at what has been studied that must be considered when designing the project such as statistics, articles, journals, etc.

2.4.5.2 User Research

User research is one of the most important, if not the most important, section during the design process. The user research serves to answer questions about the problem and ensure that the final product offers value to the user. For novel products as well as redesigned products, the ultimate objective is to perform a function that is valued by the user and the product stakeholders. To design a product that best fits the needs of the end user, first the problem needs to be fully understood. To start the user research, the designer must first make a stakeholder map in which it lists all of the people that influence or are connected in some way to the product (e.g., end user, insurance companies, investors, etc.).

The types of user research that can be carried out include both qualitative (e.g., ethnographic studies, scenarios, personas, focus groups, prototyping) and quantitative methods (e.g., surveys, eye tracking, controlled laboratory or field testing). The chosen tools and methodologies depend on the type of system being developed, the timeline and budget constraints, and the usage environment [16].

If the user research is not done correctly, the final product may not actually solve the user problem effectively. The user research is the best opportunity to understand the real problem. Even though the designer has identified an issue, it does not mean it is a problem for the user or an important problem. Once the designer starts interviewing the user about their problems, the user might answer exactly what the designer is expecting and validate their assumptions. On the other hand, the user might state the designer's assumed problem is not real or it is only a small issue from a bigger problem. Interviews or any other method chosen are the best way to understand the problem, the stakeholders, and the requirements a solution must have. The information gathered should serve to complete a list of needs and wants from the stakeholders and later a design specification.

2.4.5.3 Strategyzer Course and I-Corps

The Strategyzer course [3], even though it is focused on creating a business, contains tools that help engineers and designers alike understand the importance of listening to the stakeholders (i.e. voice of the customer) and finding the value in their solutions. Sometimes engineers observe a problem and engineer a solution that no one wants to buy because it has no value for the end user.

The Strategyzer course [3] also makes an emphasis on having a direct contact with the stakeholders and avoid designing in a "vacuum." This means urging the designer to "get out of the building" to perform interviews to as many stakeholders possible and avoid assuming that the designer is the user. The author had the opportunity to participate in the Southwest regional node NSF I-Corps program with a previous version of the design, a fall aid device. During the I-Corps program the Strategyzer lessons were applied. This was a valuable experience to learn how to conduct better stakeholder interviews. Instead of a lengthy questionnaire, it is better to define basic open-ended questions and engage in a conversation with the stakeholder. These questions should not be considered as questions but key points to cover during the conversation. One should not fixate on the specific problem definition but allow the stakeholder to explain their perspective. This allows them to reveal new and important aspects of the problem. If the problem being researched is as important as the interviewer thinks, they should mention it and if not, it may not even be a problem at all. If the stakeholder validates the initial designer's assumptions, the designer should dig deeper asking further questions without the stakeholder noticing the interviewer's interest in that specific problem. In case the stakeholder deviates from the main issue or subject, the interviewer should nudge them back into the subject. If the interviewer already has a solution idea to their problem, they also should not mention anything about it. This would pollute and bias the answers and mentality of the stakeholder. The interviewer is not interested in direct answers about the problem but on how the stakeholder manages the questions and how they talk and express their view point about the problem.

2.4.5.4 Competitive Analysis

Before any project may be done successfully, it is important to understand the market and existing product available to the user. Preliminary research must be performed on the relevant areas of interest, primarily ensure the uniqueness of the proposed project. Once the project is ensured to be unique or an improvement on the existing products, research on all products and patents should be done as well. This also enlarges the creative mindset of the designer and provides new ideas and solutions outside of their usual creative box. It allows the designer to conceive a general understanding on previous research on areas such as geometry, materials, pricing, etc. Lastly, this analysis also helps, in the competitive sense, to determine the strengths and weaknesses of current products to better ensure the quality, superiority, and unique development of the new product or project as well.

2.4.5.5 Design Specification

The design specification is a tool used in design to enable the designer set goals, wishes, and demands on their product. This list includes the main characteristics and functions of the product as well as its limitations. The list is both a guide on designing the project as well as a judgment tool to determine how successful the design is compared to the requirements and specifications set. The requirements listed on the design specification are written by the designer in technical terms based on the wishes and wants set by the user or consumer. In other words, the user research is a basis of user demands, and it is the designer's job to translate these primary demands into a more technical list called the design specification. The designer also has input on the list based on their technical judgment, observations, and research. The requirements set by them may not be noticed by the consumer but may be necessary for a successful product. An example of this need could be safety precautions, standard sizes regulated by an organization, or extra features that the user may not know they want.

Main headings	Examples
Geometry	Size, height, breadth, length, diameter, space requirement, number, arrangement, connection, extension
Kinematics	Type of motion, direction of motion, velocity, acceleration
Forces	Direction of force, magnitude of force, frequency, weight, load, deformation, stiffness, elasticity, inertia forces, resonance
Energy	Output, efficiency, loss, friction, ventilation, state, pressure, temperature, heating, cooling, supply, storage, capacity, conversion.
Material	Flow and transport of materials. Physical and chemical properties of the initial and final product, auxiliary materials, prescribed materials (food regulations etc)
Signals	Inputs and outputs, form, display, control equipment.
Safety	Direct safety systems, operational and environmental safety.
Ergonomics	Man-machine relationship, type of operation, operating height, clarity of layout, sitting comfort, lighting, shape compatibility.
Production	Factory limitations, maximum possible dimensions, preferred production methods, means of production, achievable quality and tolerances, wastage.
Quality control	Possibilities of testing and measuring, application of special regulations and standards.
Assembly	Special regulations, installation, siting, foundations.
Transport	Limitations due to lifting gear, clearance, means of transport (height and weight), nature and conditions of despatch.
Operation	Quietness, wear, special uses, marketing area, destination (for example, sulphurous atmosphere, tropical conditions).
Maintenance	Servicing intervals (if any), inspection, exchange and repair, painting, cleaning.
Recycling	Reuse, reprocessing, waste disposal, storage
Costs	Maximum permissible manufacturing costs, cost of tooling, investment and depreciation.
Schedules	End date of development, project planning and control, delivery date

Figure 8: Checklist for Design Specification Requirements [1]

There may be limitless categories that the designer uses in their design specification list, but Figure 8 obtained from Engineering Design: A Systematic Approach [1] shows a list of some examples that are commonly used across projects. Note that not all of the categories listed should be used. All projects are unique and require customized categories that may not be included in Figure 8.

2.4.6 Concept Design

2.4.6.1 Functional Definition

Once the design specification has been created using the customer requirements, user research, and competitive analysis, the next step is to identify the overall function of the design to be created and its sub functions. Functions can be defined in general as activities, effects, goals and constraints and define the behavior of artefacts (tasks, activities, characteristics) [1]. In this part, it is important to define only the functions and not parts or components that realize functions, that comes later. This allows for freedom to search the design space and avoids committing to a specific solution. It is also important to create an organized list, diagram, or structure to prioritize these functions and sub functions by hierarchical order as well as interconnectivity between them. This functional decomposition can be created similar to the one specified in Engineering Design and Systematic Approach [1] where they use boxes and arrows to separate and connect functions. The overall function of the design is its primary objective, the main purpose, or the goal the device has to reach. Sub functions are not inferior to the overall function but serve to achieve it. They are divisions and a breakdown of the overall function. They can also have a hierarchy because not all are equally important. The combination of individual sub functions results in a function structure representing the overall function [1]. The main function is the most important sub function in the hierarchy. Functions are usually defined by statements consisting of a verb and a noun, for example “increase pressure,” “transfer torque” and “reduce speed.” They are derived for each task from the conversions of energy, material and signals.

It is useful to distinguish between main and auxiliary functions. While main functions are those sub functions that serve the overall function directly, auxiliary functions are those that contribute to it indirectly. They have a supportive or complementary character and are often determined by the nature of the solutions for the main functions. The overall function of a bicycle, for example, is to transport a person from one location to another. Its sub functions are the ability to stop at will (brakes), the user’s weight support and comfort (seat), the connection of all parts and elements (frame), the mechanism that transforms the rotational motion from the legs to translational motion on the wheels (pedal and chain system), and even a sound system to alert pedestrians to move (bell).

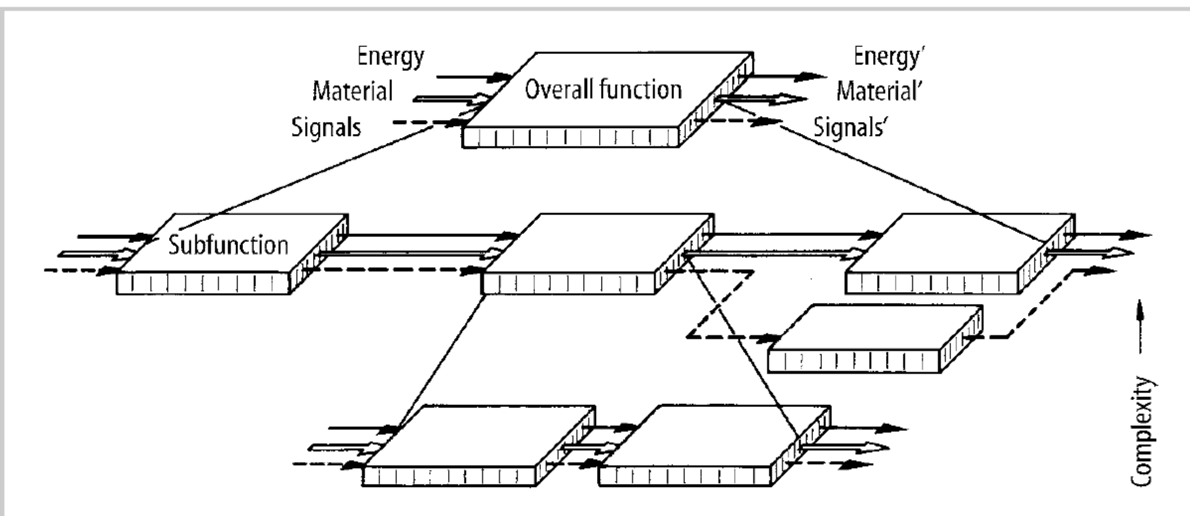


Figure 9: Overall Function Breakdown into Sub Functions [1]

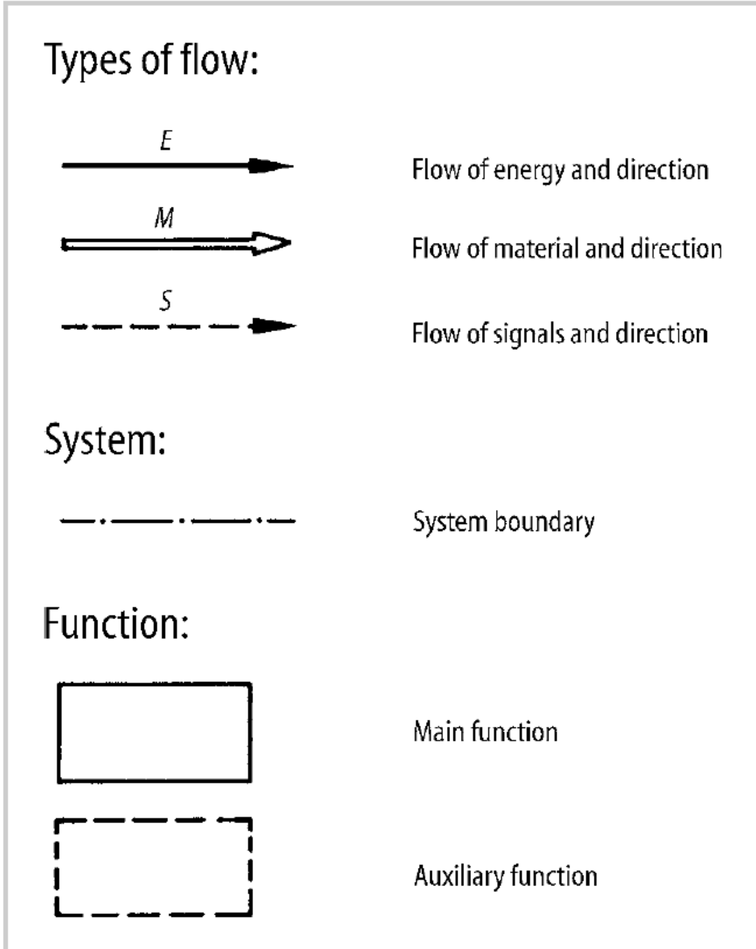


Figure 10: Symbols Used to Represent Sub Functions in a Function Structure [1]

Note that functions and features are two different concepts. A function is the ability that the design has to solve a problem or an action. A feature is a characteristic, attribute, or aspect the design has. Another way of differentiating them is that a function is a goal the design is trying to reach, and a feature is the means in which the function is reached. In the bicycle example, a function is the transportation from one location to another, and the feature is the size of its wheels.

2.4.6.2 Interactions and Constraints

After defining and decomposing the functions of the design, the designer determines the interactions the design haves with the outside world. There may be several ways to call these interactions such as disturbances or constraints. An interaction is any form of communication or disturbance experienced by the design that is not caused by it. All forces, torques, collisions, weather conditions, stresses, friction, etc. that does not come from the device to be designed is an input interaction. Following the example of the bicycle, the functions were determined to be transportation, braking, supporting the person's weight, etc. All of these are outputs that the bicycle provides the user. Interactions, on the other hand, are the weight of the person being applied to the frame or seat, the force that the person's feet applies to the pedals, the air drag that the bicycle and user experiences, the friction between the chain and the gear, etc. Again, it is everything that the bicycle is not providing but experiencing from outside the system. In some cases, when designing a component or components with different sub functions, one of the components may interact with another component. In this case, component 1 and component 2 may be considered sub-systems with component 1 taking "inputs" or "interactions" from component 2 or vice versa.

Just as with functions, interactions should have a hierarchy of importance and a sequence. Most of the interactions might just be complements to a function or of a problem the function is trying to solve. A function is a goal and an interaction is an opposition that needs to be overcome to achieve that goal. It is to be noted that functions solve interactions, but not all listed functions solve an interaction. Taking the case of two components interacting with each other, for example. The component 1 that the designer is trying to design has as an objective to solve sub function 1, not to solve the interaction that component 2 has on component 1. Again, all functions solve an interaction but not all interactions are solved by listed functions.

2.4.6.3 Functional Resolution

Once all of the functions and interactions have been defined, now is the time to explore potential solutions. It is important to solve both the functions and the interactions to avoid the system from failing or hindering the components from performing their functions correctly. Although there might be exceptions, interactions in general have a negative effect on the system if they are not solved. At this stage, the designer should brainstorm to explore the design space and find different potential solutions to solve individual functions or interactions. These solutions can be very basic or complex, as long as it solves the function or interaction. Earlier in the design, the solutions for the functions can remain abstract to allow for design freedom, for example, for the functions “power source” one solution is a battery, or a hand-crank generator, this approach allows for some freedom compared to committing to a Li-Ion Battery with part number xyz. These components should also be organized and even characterized by using a list, a table, a diagram, a morphological matrix, or any type of categorization method that gives the ability to look at all of the possibilities and later connect them or eliminate them. Note that in this stage the objective is not to design the whole system or device but to solve the sub functions individually and brainstorm possible solutions even if they are not feasible; that can be evaluated at a later stage. This is the time to be creative and think outside the box. Also, the components to be designed must be able to fulfill the function and withstand the interactions such as forces, stresses, friction, etc. as well.

This stage serves to define components that the designer is mostly certain that need to be at a specific place in the design. At the end of this stage, the design should be a shapeless fluff with possible solutions at a side and absolute solutions floating where they correspond in the design. This is similar to the steps on solving a jigsaw puzzle. When one starts, the first step is to place the corners of the puzzle in the correct place. It does not matter that the corners are not connected by the edges nor that the rest of the puzzle is not assembled. What matters is to have definite solutions which serve as a guideline for the rest of the process. Defining the design specification, functions, and interactions correctly allows the designer to generate these absolute components.

Going back to the bicycle example, trying to solve the ability to change direction may be to have a steering wheel, reins like with horses, handles, etc. Another sub function like "what does the user grab on to?" may result in similar solutions to the steering solutions and later on it may help eliminate possible solutions by combining both sub functions onto one component but at this stage the recommended thing to do is to keep their solutions and components separate. Having basic components can help during the next stages where several constraints can be solved using one component.

The determination of functions and interactions should be handled within a sweet spot. There should not be too little nor too many functions or interactions with respect of the product to be designed. There may be the case in which the designer has defined too many, and they hit a wall trying to solve an impossible puzzle. There may be so many pieces that it is impossible to connect them all. This is why a hierarchical system should be created for both functions and interactions. The same is true about having too little. If the functions or interactions are underdefined, there may not be enough puzzle pieces to connect. One way to handle this is to identify a hierarchy of function priorities (not to be confused with multiple levels of resolution as in sub, or sub-sub functions). For example sub-functions can be categorized into primary, secondary, etc. It is just like a word problem. If too much information is given, one would focus on irrelevant details that do not contribute to solving the primary problem. If too little information is given, it would be hard to relate the information and come up with a conclusion. The number of functions and interactions is not the issue but the right number of functions and interactions. An airplane, for example, may have hundreds of functions which are all important while a bicycle may have only ten important functions. The point is to not have unnecessary functions that disturb the functional resolution.

2.4.6.4 System Synthesis

At this point, the device does not have a definitive shape. It still exists as a semi-amorphous shape with some aspects defined and other aspects still undefined as the designer is still finding ways to fulfill the desired functions and constraints. The next steps in the design process aims to solidify this evolving concept into specific features, components, geometry, etc. Previously, each individual function was addressed by exploring the "design universe" for potential solutions. The next step is to select the most promising individual solutions and combine then into overall concept variants.

The selection procedure involves two steps, namely elimination and preference. First, all unsuitable solutions are eliminated. If too many possible solutions still remain, those that are clearly better than the rest must be given preference. It must be stressed that selection based on preference is only advisable when there are too many variants, otherwise a full evaluation is recommended. The designer first eliminates the most unlikely components from the list or table based on their logic and the results obtained from the calculated preliminary equations. The number of non-feasible solutions and components must be reduced early on. This ensures the reduction of potential combinations with unviable solutions. For a solution to survive, it must be evaluated against the following criterion:

- Criterion A: Be compatible with the overall task and with one another.
- Criterion B: Fulfil the demands of the requirements list.
- Criterion C: Be realizable in respect of performance, layout, etc.
- Criterion D: Be expected to be within permissible costs.

Once the morphological matrix has been reduced to fewer feasible individual solutions, combinations must be considered and evaluated against their compatibility. If components from two functions are not able to be combined, then they should not. These combinations (also known as concept variants) should then be analyzed in more detail by exploring further detailed drawings, CAD models, or more detailed equations that would determine their viability. The remaining concept variants must be gradually reduced through a simple selection process, using simple criterion, and further developing each concept variant as it moves to the next stage. For example, if there are 10 remaining combinations, a detailed drawing could be made to reduce that number to 5. After this, a CAD model can be drawn to further eliminate combinations and end up with 2. Finally, more detailed calculations, tests, or even a prototype can be built to narrow the designs to 1. In the end, there should only be one or few combinations that are subjected to further examination of its viability during the embodiment phase. The “American” approach of design would call for one final concept variant, while the “Japanese” approach may entertain more than one into the next design stage and delay the decision in case the final concept variants are close enough in their evaluation.

The method discussed is a derivation from the Systematic Combination method mentioned in the Systematic Approach book [1]. The book also talks about a more numbered, structured, and mathematical combination method, but this method was not used as it is too complex for the purposes of this project.

2.4.7 Embodiment

The embodiment stage or sometimes called the realization stage is exactly that, the realization or creation of the product. While most product design projects can follow similar steps and guidelines for problem identification, product opportunity gap, competitive analysis, etc., it is in the embodiment stage where products diverge depending on the specific areas involved. Some products require more structural analysis, others programming, controls, materials research, fluid dynamics, etc., in different levels. Every project is different and follows their own path. This stage is primarily the transformation of a concept into a real product. It evolves the concept by calculating, testing, modeling, prototyping, etc. to answer the questions of how to make this concept a real product. The embodiment stage tests the relationship and behavior between the functions, interactions, and components of the design. It ensures that every sub function necessary to achieve the overall function is achieved.

2.4.8 Prototype, Testing, and Validation

A prototype may be built according to the design specifications at any point in the design stage; it is recommended to prototype early and often. There exists many types of prototypes, but only an early prototype and a virtual prototype were made. The early prototype serves as a proof of concept in the early stages to test the design and its features. The prototype is never in its final form, it should evolve throughout the entire design process. One of the purposes of a physical model in the embodiment stage is the testing and validation of previous calculations. The calculations performed in the embodiment stage are always theoretical and in a perfect world. To determine the real variables, values, and behaviors of a design, it must be built in the real world and tested to determine its fidelity to the results obtained previously. A prototype does not necessarily need to be the construction of the whole device. It may be only an important or uncertain part of the model. If in doubt of the results obtained in the embodiment stage, it should be built to determine the real results. Apart from having a physical model, designers can also create and test virtual prototypes. These virtual prototypes serve as a way to test designs in scenarios that an underdeveloped prototype might not give insight, scenarios a finished prototype cannot be subjected to, or if no physical prototype was built. They are typically created using computer aided design (CAD). Evaluation of these prototypes can be performed using physics, structural, dynamics simulations, etc. These tests and more are important to validate the final design of the project. If a design fails in any test performed, the designers now know where, how, and why the design failed and can fix the problem.

CHAPTER III

PROBLEM IDENTIFICATION

The problem as it was discussed in the introduction was based on the fact that falls for seniors can be dangerous. Furthermore, it was found through the interviews discussed in section 1.1 that senior falls may concentrate when they are getting out of bed. Even though falls are a common problem for seniors, taking a walk to the bathroom right after waking up during the day or night, for example, highly increases the chances for falls.

By analyzing the situation, some questions and problems arise that give the opportunity for a device to solve them. When a person gets up from their bed, they often have trouble getting up due to lower body weakness from disabilities, weakness due to age, or insufficient strength due to the recent awakening. After the person gets up, a mayor risk of falling, as discussed before, is orthostatic hypotension or light headedness after standing up too quickly. This risk can be avoided if the person follows proper procedures such as doing every step from laying down to standing up very slowly to allow the blood to properly circulate and pressurize the body. Not being fully awake, in some sense, also contributes to this risk since a person may forget the correct way to stand up. This leads them to act by habit or instinct after awakening and stand up normally as if they were in their youth. Once the person has successfully stood erect, the risk factors increase dramatically as they start to walk away from a safe landing zone, the bed, to the riskier terrain of their home on which they can encounter obstacles and environmental hazards from which they can trip or slip, even if the only journey they make is from their bed to the bathroom and back. Note that these situations, which may also occur during the daytime, occur more often at night. As previously mentioned, waking up from a nap or deep sleep increases the potential for a fall because the person is not fully aware of their surroundings and their senses, perhaps already limited, and their mind may not be working to their full potential. Finally, many seniors use a walking aid device such as a walker or a cane which they often do not use for short trips to the bathroom or even inside their house altogether. This may be because they believe they do not need it, it is not close to them when they need it, it is too cumbersome to use a big device such as a walker for something simple such as going to the bathroom, or in the case they do use it, the device may not give the user the proper support they need as is the case of a cane.

What can be done to achieve a successful rise from the bed from a lying position to a sitting position and to a standing position? What can be done to prevent falls? In the case that the person falls, what can be done to mitigate the fall? What can be done to ensure that the person uses the device? What can be done to ensure that the device is readily available to the person when it is most needed? All these questions must be answered by the device to be designed.

3.1 Product Opportunity Gap

This situation opens an opportunity gap in which there is not a device to aid users be safe at night after they wake up. This gap is wide in the sense that there are problems with the person not being fully awake and not having the enough visibility and aid to successfully make a trip inside their home. Although there exists canes and walkers to help them walk, a cane might not provide enough support in case of the person tripping. The reflex reaction of a person when falling prioritizes feet repositioning and closing their hands as fast and tight as possible. These reflexes try to make the person avoid the fall by increasing their support with their feet or grasp a sturdy object. By using a cane, the person would not have the reflex to repositioning the cane to a better base of support. In the other hand, if a person trips, a walker would be of more support as it was said before, the reflex reaction of person prioritizes feet and hand grips. The reflex reaction of a person is to grip an object harder to better stabilize themselves. Because a walker has such a wide base of support, it does not need to be repositioned to assist the person during the fall. The problem with the walker is that it may not be immediately accessible when the person needs it. Additionally, after the person wakes up, the walker does not assist them to stand up nor be close for the person to immediately grab it and head to their destination.

3.2 Value Opportunity Analysis

A value opportunity analysis helps a designer evaluate and compare the device they are designing to what is available in the market. This analysis is typically done with a chart containing a list of value opportunities or attributes of different products or services in the market and the product to be designed. The chart serves as a visualization on how the new solution compares to existing ones. Because this comparison is done at an early stage in the design process, it is subjective in nature, and the value provided by the proposed design is a projection based on subjective appreciation and decisions informed at different levels of certainty. The Value Opportunity Analysis indicates the intention of the design. This analysis provides a visual representation of the strengths and weaknesses of existing products or services. From the chart, the designer can observe the areas of improvement on other devices and focus on improving them in their design to give it more value. Finally, it sets a starting point of the objectives the designer must achieve to improve upon current products and offer a value proposition to users. In this VOA there are 6 categories; base of support, size, ease of use, aesthetics, functions, and confidence. The base of support refers to how big the base is to provide more support for the user, larger is better. Size means how big the device is, smaller is better. Ease of use means how easy it is to use the device. Aesthetics refers to how good looking the device is to the user's perspective. The meaning of functions is how many functions can be performed with the device. And lastly, confidence is the measure of how secure the user feels they will not fall when using the device.

		1	2	3	4	5	Total
Base of Support	W						5
	PD						3
	C						1
Size	W						1
	PD						4
	C						5
Ease of Use	W						5
	PD						3
	C						4
Aesthetics	W						1
	PD						5
	C						5
Functions	W						3
	PD						4
	C						2
Confidence	W						5
	PD						4
	C						1

Sum	Walker (W)	20
	Proposed Device (PD)	23
	Cane (C)	18

Figure 11: Value Opportunity Analysis Chart

Figure 11 illustrates the value opportunity analysis chart for the proposed walking aid device compared to both walkers and canes. The attributes were ranked on a scale of 1 to 5 with 1 being worst and 5 being best. As it can be seen, both cane and walker have their strengths and weaknesses. The proposed walking aid device aims to be a mid-point between the two and provides better value in all areas. Even though it is a middle ground between the two, from the added points the proposed device provides more value to the user overall. The total equals 23 points compared to 20 points of the walker and 18 points of the cane. As previously stated, this analysis is subjective in nature and depends on the designer's view point, experience and background research. The points assigned were based on observations by the designer and interviews performed to occupational and physical therapists discussed in the following section. As an example, they considered that having a large base gives more support to the user but is too cumbersome to move and store. For this reason, walkers were given more points in base of support but less points in size. The opposite is true for canes, less size equals less support but more maneuverability. They can also be considered an objective the final design of this project should achieve.

3.3 Problem Formulation

3.3.1 User Research and Customer Requirements

User research involves gathering information from stakeholders to successfully understand a problem, generate criteria, and define objectives to design a product that gives the expected value to the end user. A stakeholder map, as explained before, is a list of all the people that influence or are connected in some way to the product (e.g., end user, insurance companies, investors, etc.). In this design, the user is at the center of the stakeholders map since this is a user-centered design as seen on Figure 12. The figure is arranged in a hierarchical manner where the most important stakeholder, the elderly, is placed in the center or bottom and the order of importance or involvement decreases as it gets farther from the center.

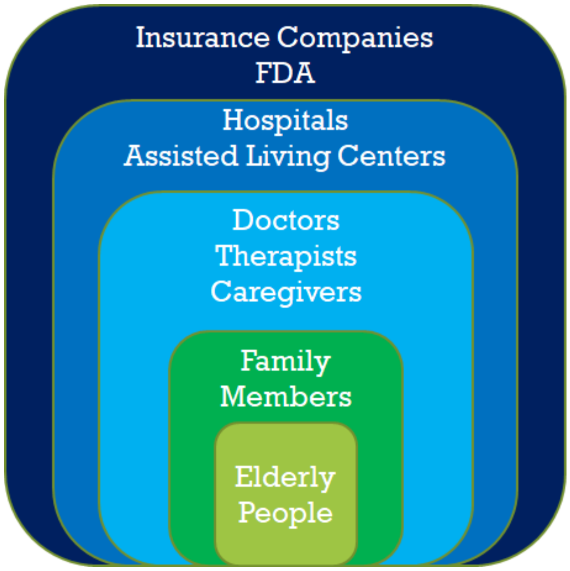


Figure 12: Visual Representation of Stakeholder Map

The stakeholders described in

Table *2* are typical of in an assistive or medical device. This table includes the stakeholders, important questions that could be asked to them, and the method to obtain the answers to these questions. Because of time constraints, the interviews were only performed to occupational and physical therapists to obtain a better understanding on how to solve the problem. In the future, further research could be done regarding insurance companies and FDA approval to further push this design to be a finalized product.

Table 2: Stakeholder Map

Stakeholder	Questions	Method of Information Gathering
Elderly People	How safe and comfortable do they feel using their assistance devices?	Surveys and Interviews
Family Members	What struggles do they have while dealing with senior family member? What is the daily routine of their senior family member?	Interviews
Doctors	What medical conditions can affect a senior person's balance?	Interviews
Hospitals	What are their methods and procedures for patient movement within the room?	Ethnographic Field Studies
Therapists	What are the current methods to prevent a fall? What devices currently assist the elderly to walk?	Focus Groups and Interviews
Caregivers	What can be done to give the elderly more independence when being taken care off by a caregiver?	Interviews
Assisted Living Centers	What are the living conditions and surroundings of a senior person within the facility?	Ethnographic Field Studies
Insurance Companies	What types of devices are covered by insurance and what are the requirements for a device to be covered by insurance?	Interviews
FDA	What safety criteria or requirements does a medical device have to comply to be approved by the FDA?	Interviews

To know exactly how the device should behave and what really matters to the end user, interviews were performed. Seniors are the main users of this device; they can provide the perspective from the end user while the occupational and physical therapists can provide rich perspectives of the physical mechanisms and reasons. Even though therapists are not the end user, they are the ones who prescribe and recommend devices to seniors and people who are disabled. They know how the devices operate and when a person with a certain condition has to use it. The interviews performed consisted of presenting the problem, concept, and solutions to them and notes regarding their observations were taken. The therapists were also questioned about the procedures and behaviors of a senior getting out of bed and walking to take note on where a device might be of assistance.

The first interview was performed during a faculty meeting which included the chair of the Department of Occupational Therapy and five more faculty members at the University of Texas Rio Grande Valley (UTRGV). Their views were very insightful and helped steer the project into the correct direction. When asked about the concept of the device, they were impressed at the idea of having a device that would attach to the bed and be available when the person needed to walk. An interesting point made was about the notion of having a separate device, apart from the patient’s cane, always to the side of the bed. They explained that therapists train seniors to take their assistance device everywhere including their bedside. Nevertheless, seniors almost never do what they are trained to do because of stubbornness or forgetfulness, assuming they had training from a therapist. There are countless seniors who are prescribed an assistance device by doctors but are not told how to use it. Family members may also buy it for their elder without knowing if that is the correct device to solve their issues.

Can a device be built for someone who needs a device in between a cane or a walker? People who use walkers are very different from people who use canes because their walking gates are very different. Those who use walkers need the device to walk safely without falling and they cannot walk without a walker. On the other hand, people who use canes only use them for little extra support for an alternating balance gate. For this reason, the device is targeted to people who do not need much more support than the use of a cane. Now that the target user was clarified, they added that if the proposed device is intended for cane users, the base does not need to be very large, just very stable.

They also explained that an important issue, if not the most important, is to get the person to stand up successfully. Once the senior has stood up, it is important that they have done so correctly with their knees locked. Otherwise, when they try to take their first step, they will have a false start and fall back down. That being said, a person who has been prescribed the use of a cane should be able to stand up by themselves without the need for assistance. If the senior does, in fact, need help from another person or device to stand up, then a walker would be prescribed because of its superior support instead of a cane. It was also mentioned that a device that only helps the senior to stand up would be of no use. If this was the case, after using the stand-up device, the person would have to let go of it and transition to the walking aid device. This transition is potentially dangerous because there is a moment where the senior is not supported by either device.

Other remarks mentioned were the ability for the device to make itself present, the effortless and simplistic nature of the anchoring mechanism, and the ability to provide illumination. The device should let the person know it is there. Seniors forget that they have equipment to help them walk. For example, the brain of a paralyzed person that had a stroke often is affected to the point that they forget they have half of their body, but they are at a point in their rehabilitation where they can use a cane to walk. Part of their rehabilitation is to make them aware and remember they have another side of their body. Because of this issue, some senior patients might need a reminder by the device to tell them it is there for them. Also, when the device hooks up to the bed, it must be a very simple mechanism because seniors sometimes do not have the cognitive capabilities to remember procedures. This problem is enhanced by their limited vision because of darkness or lack full awareness after waking up.

Lastly, another interview was conducted with a physical therapist [17] from the Doctors Hospital at Renaissance. After explaining the concept to the therapist, he stated that an important factor is the storage. The smaller and lighter the device, the better. The therapist mentioned that people may not like to use walkers because they are cumbersome and a nuisance to carry. Additionally, patients may not be trained well enough to use it or may not feel comfortable using it. The therapist also supported the theory that elders do not always use their walkers when they wake up at night because it is too much of a nuisance to wake up, open the walker, and go to the bathroom. When someone wakes up in the middle of the night, they want to go right away. If there was something that could be stored right next to them and could be more accessible, that would be of much help to them. Darkness is a problem because they might have other vision problems and adding darkness only affects them more while handling any device or finding it. A good remark made was that darkness is a problem for elders but too much light is also a problem. When an elder turn on a lamp or room light, it wakes them up more and after they have gone to bed, they cannot go back to sleep. It was also commented that elders should not always help themselves stand up using their chair or bed, as opposed to the comments made by the occupational therapists. Elders are recommended to use the most stable and supportive object they have in their vicinity which might be a chair, a wall, a rail on the wall, or their walking device, but in most cases, it would almost never be their walking device.

An extremely important statement made by the same therapist was that walking and standing are correlated. Coming to a standing position is a component of walking. One cannot walk without the ability to stand up. If a person has trouble standing up, they may need more help to walk than what a cane or a walker provides. He mentioned that therapists can easily tell what type of walking problems or the type of assistance the patient might need when walking just by observing them during the process of standing up. Regarding specifics about the design of the device, he mentioned that it would be better for the device to have a wide base for people with a wide stance.

Before interviewing the therapist, it was believed that the device would be held at approximately 8 in. away from the body. The therapist clarified this issue and stated that 4 in. would be better for support if the person happens to need it, for example while falling. The closer one is to the device, the easier it is for the arms and back muscles to support the person. The body has more strength in that position as opposed to holding an object far from the body. During last remarks he noted, on the braking mechanism, that the less input from the person, the better. Elders have significantly bad reaction times therefore anything that would be activated by the elder's input would not work.

Altogether, all the therapists were impressed by the concept and stated they have never seen or heard of something like the proposed design, and it would be of much help. From these remarks a design specification was made and is shown later in the document in a section with the same name.

3.4 Background Research

Background research studies topics and areas of interest that relate to the understanding of the end user and the problem. The objective is to learn more about the environment the design is exposed to. Background research includes topics that are important to the project but may not necessarily fit in the user research. This information is an addition to the user research that might aid during the design process.

3.4.1 Functional Limitations of Mobility Device Users

Before any design specifications or any design for that matter is done, the user and their capabilities must be understood. It is necessary to comprehend the limitations a person of 65 of age and older such as how much weight they can lift or how far they can walk. A study by Kaye, Kang, and LaPlante was done in 2000 [18] which provides an excellent source of information about users of mobility devices. In this study there was a section which discussed the limitations for these people. The survey conducted on 3.12 million people of 65 of age and older asked users if they had difficulty or were unable to perform tasks such as lifting 10 pounds, climbing stairs, walk a quarter of a mile, and stand for 20 min. The results are shown in Table 3 and only users of canes and walkers are shown.

Table 3: Functional Limitations of Cane and Walker Users [18]

	Total Number of Cane Users (3.2 million)	Total Number of Walker Users (1.42 million)
	Lifting 10 lbs. (1000s)	
Unable	633 (19.8%)	583 (41%)
Difficulty Only	821 (25.7%)	361 (25.4%)
	Climbing Stairs (1000s)	
Unable	565 (17.7%)	643 (45.3%)
Difficulty Only	1270 (39.7%)	506 (35.6%)
	Walking ¼ of a mile (1000s)	
Unable	1,121 (35%)	917 (64.6%)
Difficulty Only	1,183 (37%)	360 (25.3%)
	Standing 20 min (1000s)	
Unable	596 (18.6%)	566 (39.8%)
Difficulty Only	1205 (37.6%)	552 (38.8%)

It can be seen in the Table 3 there are greater percentages, almost double, of people that use walkers who are “Unable” to perform tasks compared to people who use canes, but all are similar in “Difficulty Only”. Cane users also have a greater percentage difference between “Difficulty Only” and “Unable” on climbing stairs and standing 20 min. On the other hand, there is a smaller difference between lifting 10 lbs. and walking one fourth of a mile, which have almost the same percentages. On the walker side, it can also be seen that the percentages for

“Unable” are greater than the percentages in cane users and surpasses the percentage of users with walkers that have “Difficulty Only” performing each task.

3.5 Products and Patents Review

3.5.1 Products

3.5.1.1 Canes

3.5.1.1.1 Purpose

Canes are used in general to give the user increased stability and balance. Users range from all ages as it can be used in accordance with any illness, disability, or weakness on one of the two legs or feet. To be able to use a cane, the person must be able to walk with both of their legs. It only aids in reducing a portion of the force placed on the damaged leg by a limited amount. Most have found that cane users rarely place more than 15% to 20% of body weight on the cane, but the cane loading likely depends on the nature of the disability [4]. When using a cane, it is important to know the correct side on which to hold it. Holding the cane on the side ipsilateral to the affected limb can actually increase the force on the affected hip joint, whereas holding it contralaterally reportedly reduces this hip force by up to 60%, compared with the joint loading that occurs in normal unassisted gait [4].

3.5.1.1.2 Types of Canes

Canes are a very basic type of mobility device. As opposed to a walker, canes are not as featured as walkers due to their main attributes which are its size, usage, and weight. There exist only two types of canes, basically, a standard cane and a quad cane each with their own benefits and drawbacks. The standard cane from Figure 13 is a long cylindrical tube with a handle at the top, usually of wood or aluminum, and a rubber tip at the bottom of the cane. This is the lightest and most popular cane type.

Figure 13: Standard Cane [19]

The second type of cane, as seen on Figure 14, is the quad cane. It is similar to the standard cane, by having a long cylindrical tube with a handle, but the base of the cane is comprised of four small feet arranged in a rectangular pattern with rubber tips. This quad base provides extra support for people who need to put more weight on the device. It also has the ability to stand on its own, and therefore, provides greater balance compared to the standard cane.

Figure 14: Quad Cane [20]

3.5.1.2 Walkers

3.5.1.2.1 Purpose

Walkers are used when a person needs more support than that given by a cane. A walker greatly enlarges the base of support (BOS) and eliminates the challenge of balancing solely on one leg as seen on Figure 15. The walker can be advanced during double-leg support, and the extended BOS it provides potentially allows either swing foot to be lifted and advanced while maintaining the center of mass (COM) in a stable position with respect to the BOS limits. A walker also aids stabilization by allowing large stabilizing hand-reaction forces and moments to be generated bilaterally.

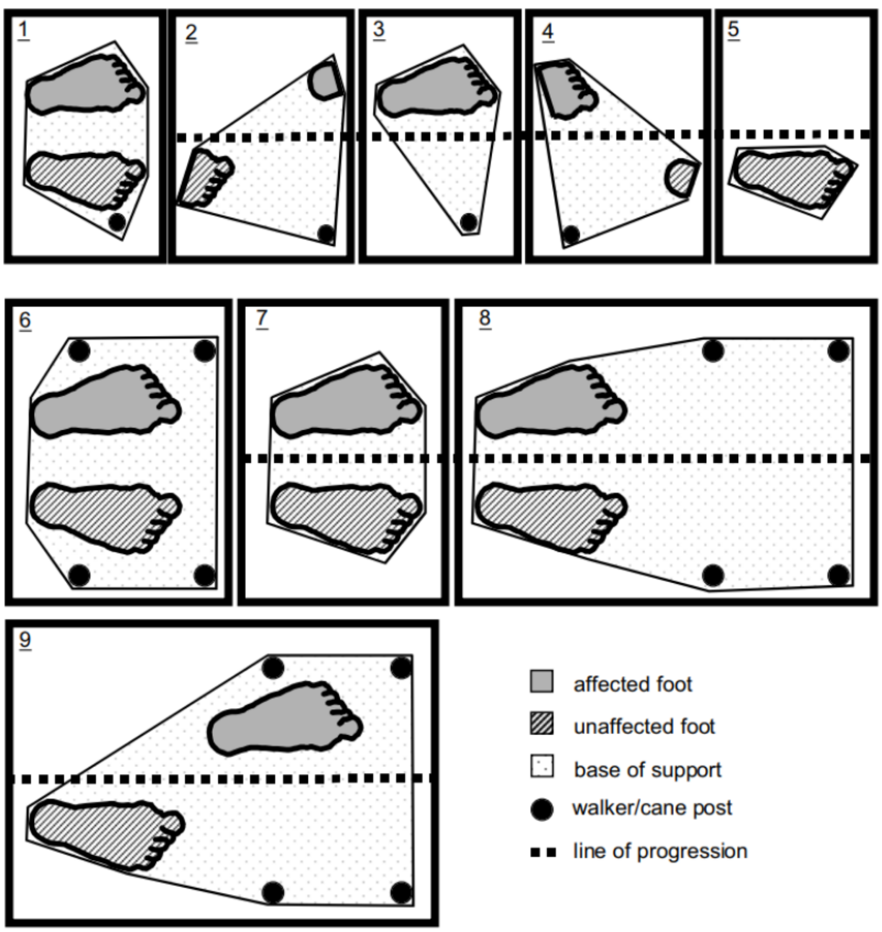


Figure 15: Walker and Cane Support [4]

Although relatively few studies have examined walker loading, the reported forces are generally much higher than with cane use. They range up to 85% of body weight in patients who used a lower-limb prosthesis and up to 100% of body weight in subjects with spinal cord injuries. In contrast, patients with progressive supranuclear palsy, for example, who required a walker for balance rather than for weight support, generated much lower average walker loads when ambulating (30% of body weight).

3.5.1.2.2 Types of Walkers

Like canes, there exists various types of walkers with different additaments and features but there are mainly three types of walkers. Each walker has its own advantages and disadvantages as well as each type being more suitable to people with specific problems. The standard four-legged walker is the first type of walker, as seen in Figure 16. It is the most commonly used. This walker has rubber tips as feet, and some can even fold for more compact storage. The walker's shape is comprised of three frames, one in front of the person and two on each side to surround the person. To use the walker the person must stand with their feet together and then lift the walker and place it in front of them a step ahead. The person then walks up to the walker one step at a time from each foot starting with their weak foot and repeat the process.

Figure 16: Standard Four-Legged Walker [21]

The second type of walker is the two-wheeled walker illustrated in Figure 17. This type of walker is very similar to the previous walker but differs in its legs because it has two fixed wheels on its front legs instead of rubber tips. The added wheels provide an enhanced level of mobility to the user compared to the standard walker, especially for ambulation outdoors. The use of this walker is also similar to the standard walker. From a standing position with both of the person’s feet together the walker is rolled, not lifted, a step length forward. Then the person walks up to the walker with their weak foot being their first step and then the healthy foot and repeats the process. This walker also allows for a more natural walking pattern as it does not have to be lifted to walk.

Figure 17: Two-Wheeled Walker [22]

The last type of walker is the wheeled walker or rollator. This walker might have either four wheels or three wheels instead of feet. They offer the greatest range of movement and the most mobility with many models offering swivel wheels and hand brakes. Rollators with larger wheels offer the most mobility. They also are often equipped with seats and baskets. This makes it ideal for very active users who travel long distances and need a short rest. This type of walker is mainly recommended for people with minor lower body weakness or minor balance problems. Because these types of walkers move very easily, it is not recommended for people who need a lot of support or to bear a lot of weight. The wheels are not fixed and can rotate in any direction. The way to use the rollator is even simpler than the other two walkers. The user must only walk in a normal way rolling the walker in front of them.

Figure 18: Four Wheeled Walker (Left) [23] and Three Wheeled Walker (Right) [24]

3.5.1.3 Hybrids

There exist two other types of walking aid devices that do not quite fit either category. These are devices that might be called hybrids or a device between a cane and a walker. The hemi walker or one-handed walker, from Figure 19, provides more support than a cane but is more lightweight than a standard walker. It is commonly made of aluminum and has four legs with a bar across the top at hip level. The hemi walker's feet have rubber tips and does not roll. The user must pick up the walker to move it in the desired direction. Unlike a standard walker, a hemi walker is designed for use at the side of your body, rather than in front. It is ideal for people that have one-side weakness as a result of a stroke or brain injury.

Figure 19: One-Handed Walker [25]

The second type of hybrid is the two-legged walkabout walker from Figure 20. This type of hybrid is made of aluminum and is comprised of two legs joined together by a handle bar in the middle. At the bottom of the legs, the walkabout has rubber tips for traction. The walker offers a wide variety of uses, as it is adjustable, such as a two-legged cane, a standard cane, and can be used on stairs. The walkabout can be used two handed in front or one handed at the side of the person. Like a cane or a walker, to use the walkabout the person must lift the device, place it a step forward in front of them, and then walk up to the walkabout with the weak leg being the first step.

Figure 20: Walkabout [26]

3.5.2 Patents

After a wide search, there were no patents that resemble or were similar in form or function to the one proposed. This section covers patents regarding devices that aid users stand up from a seated position and walking aid devices. It contains patents that have a similarity or perform a function like the developed walker.

3.5.2.1 Device for Assisting a Person to Sit or Stand

US5449013A 1993 [27]

This device aides the user with a disability to raise from a seat to a standing position as well as to sit down from a standing position. The device is also able to provide assistance when switching from a normal chair or bed to a wheelchair or walker. It is comprised of a mat attached to floor rails which are attached to hand grips and forearm supports.

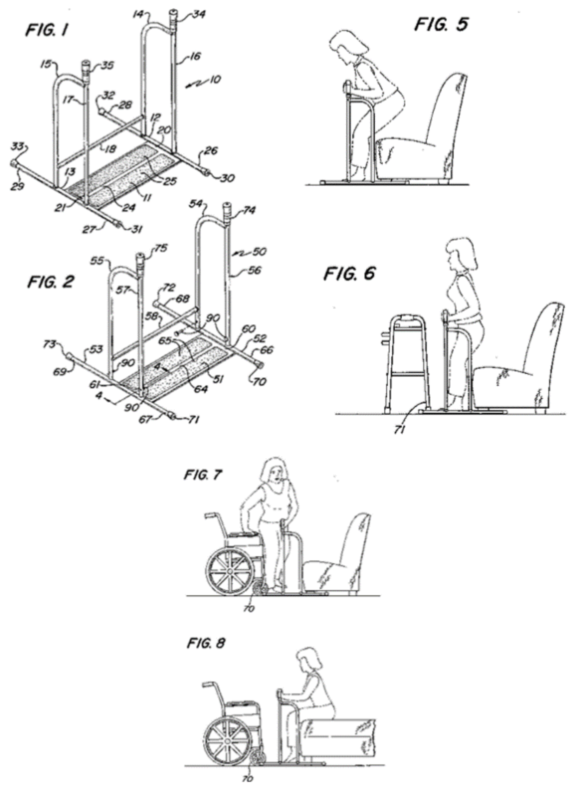


Figure 21: Device for assisting a person to sit or stand (US5449013A)

3.5.2.2 Device to Assist Person to Stand

US6244285B1 1996 [28]

This device allows the users to stand from a seated position. The device does not require a base mat as it has a base frame positioned beneath the bed or chair. Attached to the base are two vertical posts with hand grips extending about 30 in. (76.2 cm) above the floor and each having a free end and a fixed end.

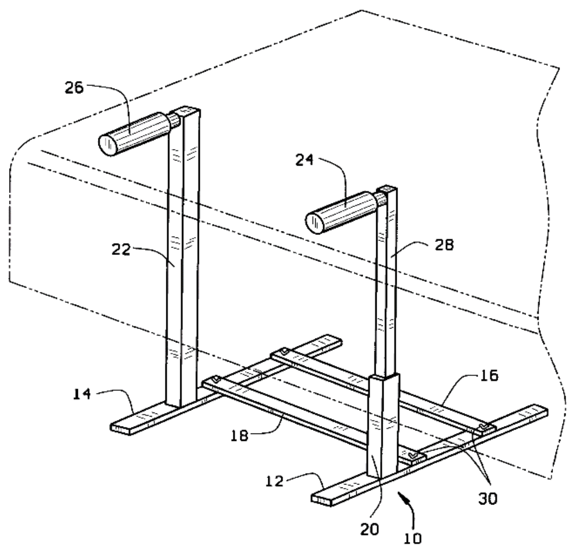


FIG. 1

Figure 22: Device to assist person to stand (US6244285B1)

3.5.2.3 Handle Apparatus

US5397169A 1992 [29]

This device comprises a pair of spaced handle arrangements, each comprising a handle portion and a support portion. The support portions are connected by adjustable rails and have lower sections which in use extend under a chair. Movable back stop members are adjustable along the lower sections. The apparatus is thus anchored relative to the chair and a user can lift himself from the chair using the grip sections of the handle portions. Furthermore, the handles on the apparatus can be lowered while anchored to the chair for comfortable seating.

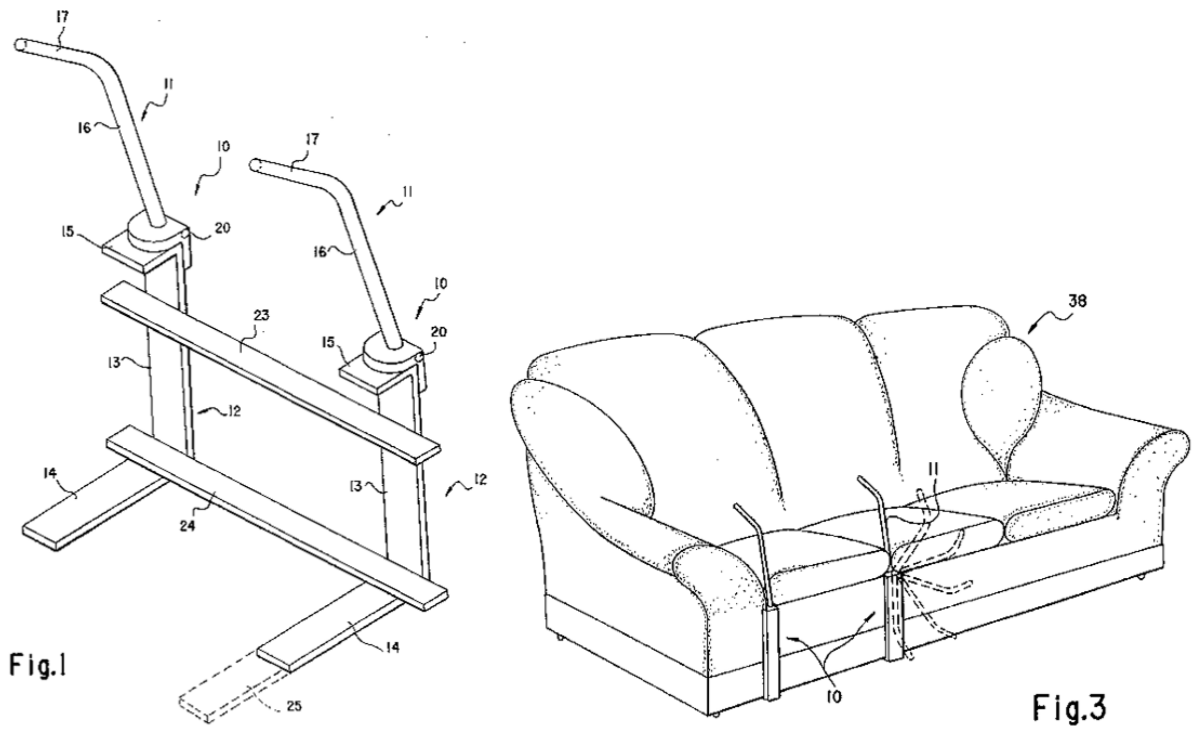


Figure 23: Handle apparatus (US5397169A)

3.5.2.4 Device for Assisting a Disabled Persons to Sit or Stand

US5509432A 1995 [30]

A device for assisting a disabled person to rise from a sitting to a standing position and for assisting a disabled person to sit from a standing position. The device includes a base mat to which are attached side support plates on which are mounted a plurality of horizontal floor rods and slotted vertical bars in which cross-handrails are inserted and adjustably mounted by means of tubes extended from the cross-handrails. In a preferred embodiment, the component parts of the device may be assembled and disassembled as needed. The device is arranged to be compatible for use with both wheelchairs and walkers. The user can easily use the device to transfer themselves from one location to another.

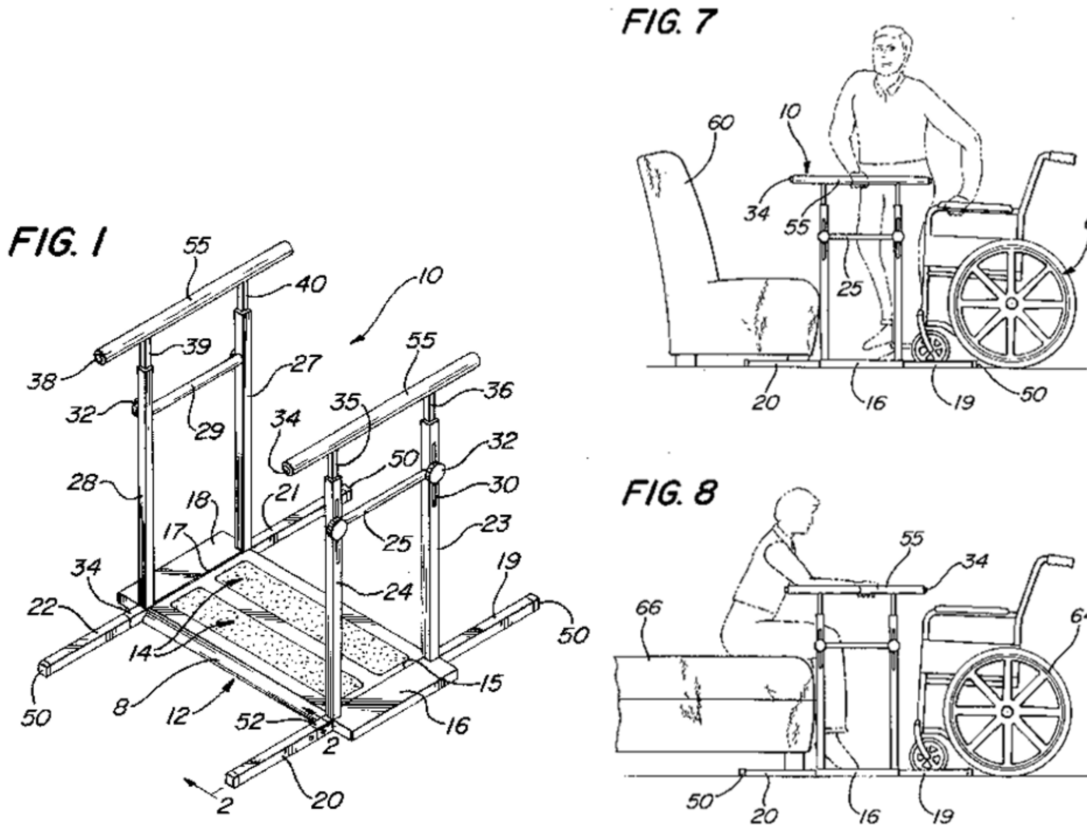


Figure 24: Device for assisting a disabled persons to sit or stand (US5509432A)

3.5.2.5 Walker

US4869279A 1986 [31]

An invalid walker comprising right and left side frame members in the form of an inverted Y-shape, each frame member containing a vertical leg, a side leg attached downwardly and rearwardly from the vertical leg and a horizontal brace connecting the vertical leg and side leg, a front horizontal member connecting the right and left side frame members, and handgrip support attached to the upper end of each vertical leg. Stair climbing convenience is provided by a forward extension of the horizontal brace and a restraint strap between the handgrip supports provides an optional safety feature. This patent is very similar to the objective design. It is smaller and more compact than a common walker but at the same time gives more support than a cane. Nonetheless, this is still not the correct form as it cannot be set beside a bed for ease of use and availability.

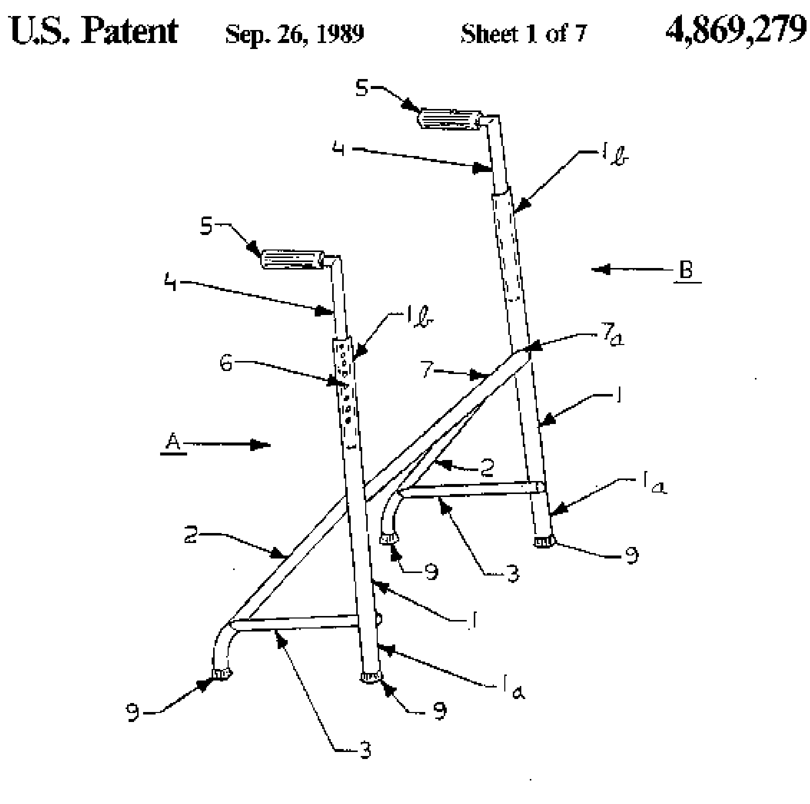


FIG. 1

Figure 25: Walker (US4869279A)

3.5.2.6 Bedside Cane Holder

US6311942B1 1993 [32]

A cane holder for holding upright a walking cane at the side of a bed has a generally planar frame to be inserted between a mattress and a box spring of a bed. A clamp on a side of the frame protrudes to one side of the bed. A walking cane held in the clamp provides a convenient hold for a person rising from the bed. The cane can then be released from the clamp for use as a walking aid away from the bed. A preferred walking cane has a foldable mid-height hand grip in addition to a top handle to provide two holds at different heights on the cane. This patent has a similarity to the proposed project in its way to hold the cane beside the bed for availability. It is always available to the user whenever they needed getting out of bed. However, a mayor disadvantage is the use of the cane as it may not provide the adequate support the person might need late at night.

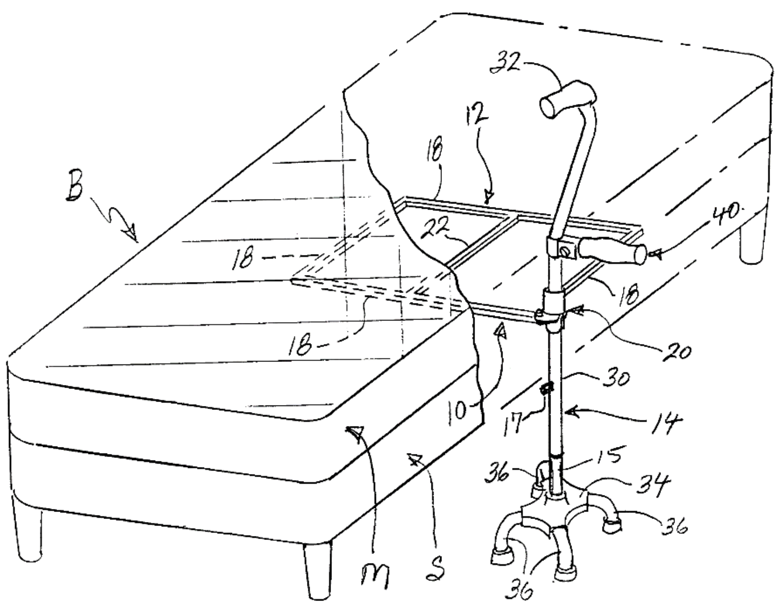


Figure 26: Bedside Cane Holder (US6311942B1)

3.5.2.7 Dual Stair Step Walker with Assist Bar

US5499645A 1995 [33]

An integral stair climber, lifter, bracer and walker includes a frame which has a pair of spaced apart upright struts or members. A cross piece extends between the upright members two-thirds of the distance up the upright members. A handle portion is attached to the upright members at the upper end thereof. The handle portion includes a pair of opposed, vertically disposed segments which are receivable on the upright members. A grip pair is located on top of each vertically disposed segment and includes two grips, one located posteriorly to a vertically disposed segment and another extending anteriorly to the vertically disposed segment. A transverse element extends between the two vertically disposed segments or struts. Each anteriorly located grip is connected between the transverse clement and the vertically disposed segment. A four-footed base is located on the lower end of each upright member and is orthogonal thereto. Each base includes a plate to which four feet are attached and which is fixed to the upright member. Each anteriorly located grip is tilted upwards at approximately a 45-degree angle and slightly inwards towards the transverse element at approximately a 25-degree angle.

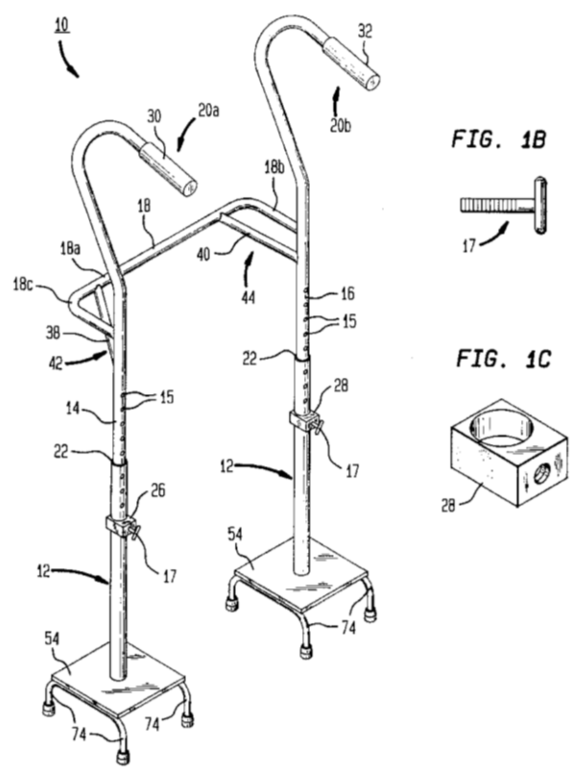


Figure 27: Dual stair step walker with assist bar (US5499645A)

3.5.2.8 Mobility Assistance Devices

US20120042918A1 2010 [34]

A mobility assistance device that employs a movable handle assembly and an extension support, both of which are movable between retracted and extended positions. The handle assembly is positioned when extended above a seating surface and provides leverage for a user to use his/her hands to assist in rising. The extendable support extends from a guide element along the floor beyond the center of gravity of the device and user to prevent tipping and to provide stability. When the extendable support and handle are disposed in the retracted position, the device is used like a typical cane, walker or rollator. This modular device may also be joined together with another similar device by a connecting rod to be used as a walker.

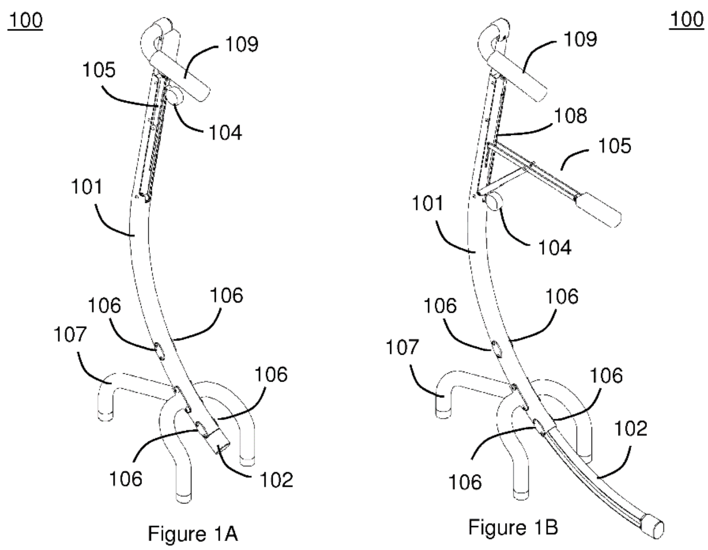


Figure 28: Mobility Assistance Device in Cane Form with Extendible Support

(US20120042918A1)

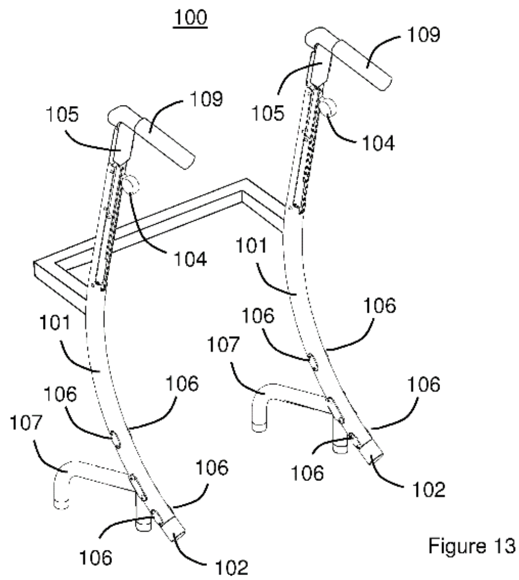


Figure 29: Mobility Assistance Device in Walker Form (US20120042918A1)

3.6 Design Specifications

The design specification is a tool used in design to enable the designer set goals, wishes, and demands on their product. This list includes the main characteristics and functions of the product as well as its limitations. The following are some design specifications that were found to be minimum requirements at the beginning of the device's design.

Size: The device is intended for indoor use; therefore, it should be compact enough to fit between doors and furniture. Doorways are designed to be a minimum of 2 ft. wide. The width of the device must not be greater than 2 ft, to allow the user to enter rooms with ease. The device must also be compact enough to be placed near a bed without interfering with the user's usual movements. The height of the device should also be adjustable depending on the user's height.

Weight: The device to be designed must be as light as possible. After a brief background research based on the weight of common walkers in the market, walkers can range from as little as 5 lbs. to 13 lbs. and the average weight of the walkers was found to be around 7 lbs. Rollators were found to be much heavier with the lightest one being 8 lbs. and the heaviest one to be 21 lbs. This device is estimated to be lighter than a normal walker because its design should be smaller in theory. Furthermore, this walker would not require the user to carry it because it has wheels and therefore weight is not an issue of concern. The weight discussion only concerns the walker portion of the proposed device and not the anchor, because the person only moves the walker. The anchor of the device will be attached to the bed at all times.

Material: The material used must be a light material to allow the whole walker to be light. The walker must also have a durable material as the user places a considerable amount of force on it. This material should not be easily bendable as a material failure would cause the whole device to fail and the user to fall.

Safety: Safety is the number one concern because any failure with the product may be fatal to the user. The device must be as safe as possible and in the case of failure, it should not cause more harm to the user.

Ergonomics and Human Factors: The device must be height-adjustable to comply with safety regulations and the user's height. The device must also be adjustable depending on the height of the bed and the clearance from the base of the bed to the floor for the device to be anchored successfully.

Assembly: Even though there are seniors who live with their family, not all seniors do. Some of them live with their partner or even live alone. Due to this fact, the device should require very minimal to no assembly at all. There may be some initial assembly or setup to integrate the anchor.

Operation: The device should be extremely easy to operate even for someone with limited eyesight. Because it is to be used at night by a semi-conscious elder, the act of attaching and detaching the walker must be intuitive in the simplest form. The device should have the ability to roll to avoid the user from carrying it to move forward.

Anchoring: The device includes an anchor to attach to the bed or base of the bed. This anchor serves as a holder for the walker. The anchoring mechanism must be very simplistic and easy to use because the person may use it in the dark, half asleep, and may have hindered eyesight,

Bed Rail: While the walker device is attached to the anchor, the whole device serves as a bed rail. On this setting, the device should give the user a boundary to avoid falling out of bed and provide support to help them sit down and stand up.

Base of Support: Because this device is targeted for people who use canes, it was advised that the base of support does not need to be very wide. The only important aspect of the base is to be very stable, but no exact measurements should be of concern.

Maintenance: The device should require very little maintenance. Elders may not be able to know when a device requires maintenance or may not be able to apply it.

Visibility: The walker should provide illumination for the user at a night setting. This illumination should serve as a guiding light during the night walks and also make the device present to the user. This lets the user be reminded that the device is beside them and ready to use.

Cost: Considering the costs of health products, this device should be as inexpensive as possible. It should not only be purchasable through insurance or health care but also by independent individuals.

CHAPTER IV

CONCEPT DESIGN

4.1 Concept Generation

4.1.1 Functional Definition

The overall function of the device is to provide the user with a stable support to successfully walk to their destination and back during the night. It should decrease the risk of falls by a considerable amount. The amount of support must be comparable or in between with the amount that a walker and a cane give the user. In the case of a slip, trip, or loose footing, the device should provide enough immediate support like a walker as opposed to a cane. The device should also be readily available to the user by being attachable and detachable to the bed of the user. The following are the specific functions the device achieves. The functions were numbered on a hierarchial order and not on a chronological order the device will be used. The arrows in Figure 30 indicate the relationship between the functions.

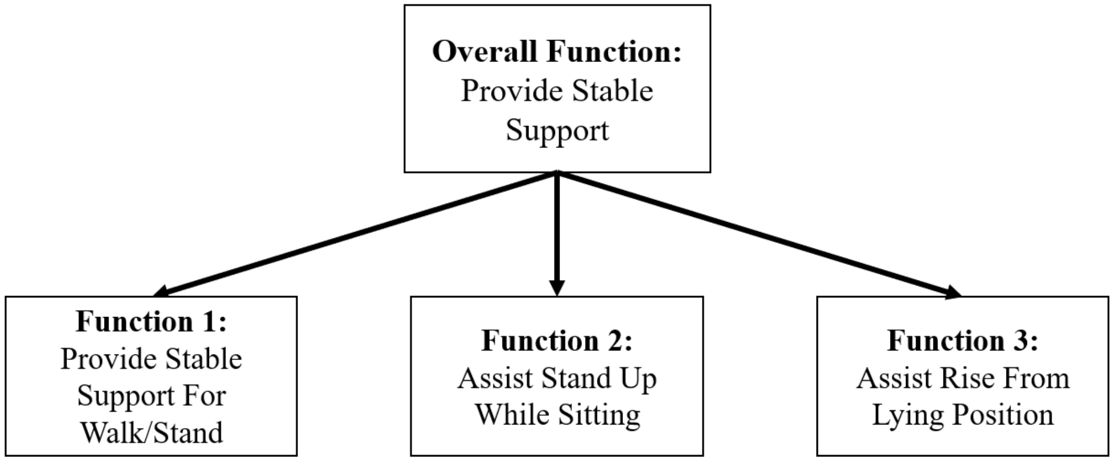


Figure 30: Overall Function Breakdown

- Function 1: Device provides a stable support for the user to grab and aid themselves to walk safer.
- Function 2: Only when attached to the bed, the device provides a stable support for the user when trying to stand up while sitting on the bed.
- Function 3: While attached to the bed, the device provides a stable support and aids the user when changing positions from lying down to sitting down on the bed.

The functions were divided into further sub functions in the next figures to extract and consider the most basic functions at work. These sub functions are part of a single diagram but are shown in different figures in order to appear at a legible size. Some sub functions may repeat but must be kept separate and considered. During the synthesis stage, these sub functions may merge into a single component.

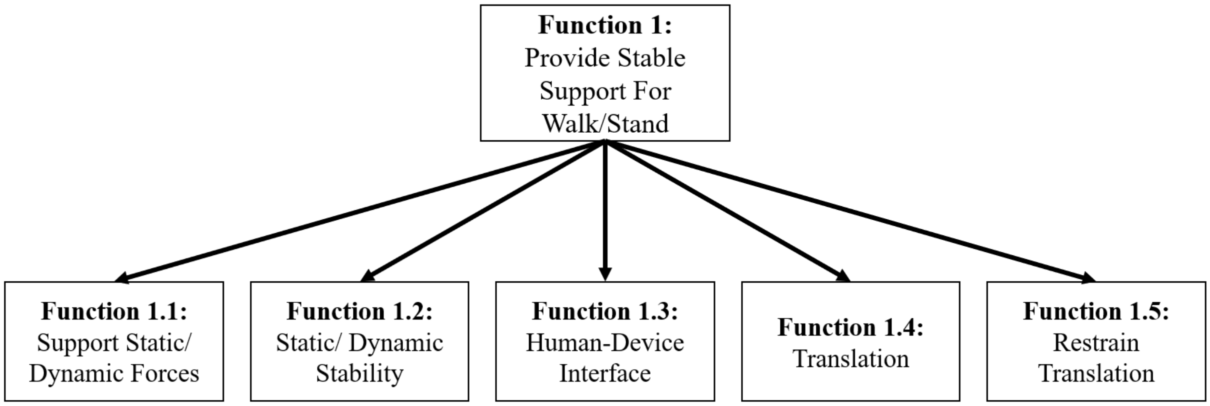


Figure 31: Function 1 Breakdown

- Function 1: Device provides a stable support for the user to grab and aid themselves to walk safer.
    - Function 1.1: The device resists the static and dynamic forces applied by the user to prevent the user from collapsing.
    - Function 1.2: The device has the integral structure and stability to prevent itself from failing.
    - Function 1.3: A suitable grip for the user to interface with the device. Ability to communicate with the user via ergonomics and human factors.
    - Function 1.4: The ability to translate without the device being lifted.
    - Function 1.5: An effective way to stop translation in case the person starts falling.

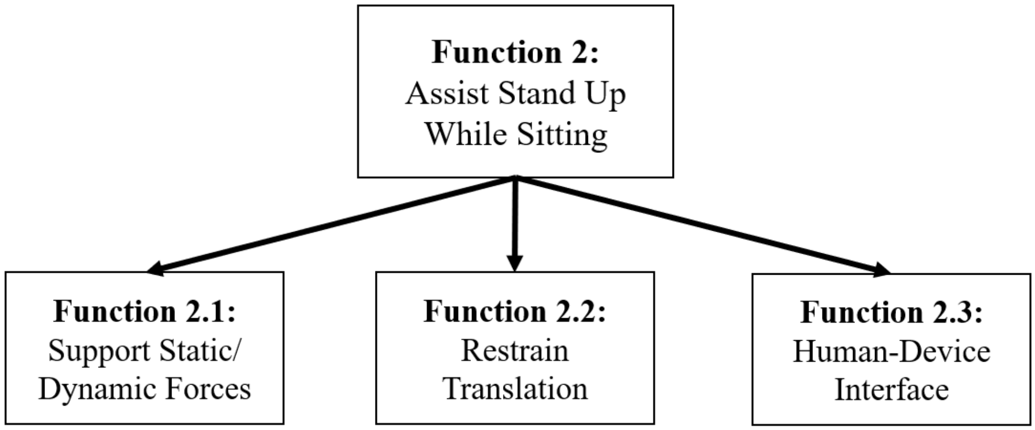


Figure 32: Function 2 Breakdown

- Function 2: Only when attached to the bed, the device provides a stable support for the user when trying to stand up while sitting on the bed.
  - Function 2.1: The device resists the static and dynamic forces applied by the user to prevent the user from collapsing.
  - Function 2.2: An effective way to prevent translation while the device is providing support.
  - Function 2.3: A suitable grip for the user to interface with the device. Ability to communicate with the user via ergonomics and human factors.

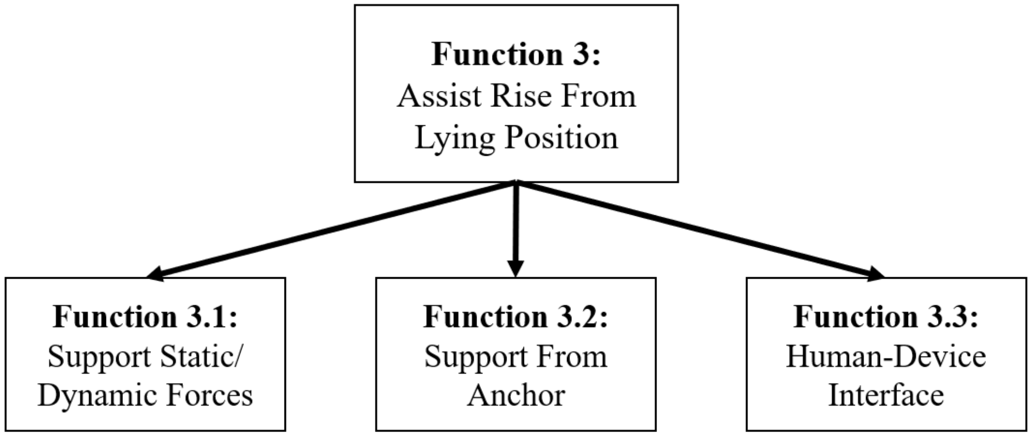


Figure 33: Function 4 Breakdown

- Function 3: While attached to the bed, the device provides a stable support and aids the user when changing positions from lying down to sitting down on the bed.
  - Function 3.1: The device resists the static and dynamic forces applied by the user to prevent the user from collapsing.
  - Function 3.2: The device receives some support and stability from the anchor it is attached to.
  - Function 3.3: A suitable grip for the user to interface with the device. Ability to communicate with the user via ergonomics and human factors.

4.1.2 Functional Resolution

4.1.2.1 First Calculations

Preliminary calculations are needed in order to have an informed idea generation process. These calculations did not dictate the exact form of the design but gave some insight as to the range of forces and other factors the component would be subjected to. Some creative ideas were considered during the brainstorming to allow flow of creativity and possibly a work around as to adapting that idea to make it work on the design.

The first calculations performed answers what the appropriate length of the device is to avoid being tipped over by the person applying too much weight on it. The calculations were done with only the frame of the device leaving out the wheels. The weight of the device was not considered in these calculations. When evaluating calculations, the forces were considered positive if they were down for the y direction and right for the x direction. The moment was considered positive in the clockwise direction. To obtain the appropriate length of the device, the force applied in the x direction (F_x) and the height of the device are needed. But first, the magnitude of the force and angle are needed. According to a review article by Hamid Bateni and Brian E. Maki [4], a person typically places about 15-20% of their body weight on a standard cane. Therefore, it was assumed, in the following calculations, that a person places 40% of their body weight onto the device. The two main variables considered were the person’s height and their weight. These variables influence the height of the device and the angle of the force the person exerts on the handles. To know the angle of the force, simple trigonometry can be used. By considering a right triangle between the distance from the device and the length of the arm from the shoulder to the wrist, it is easy to obtain the angle.

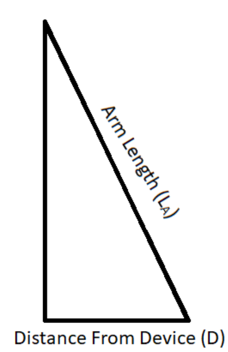


Figure 34: Triangle Formed Between the Device and the Elder

The length of the arm from the shoulder to the wrist is calculated by the anthropometric data and body segment length by height percentage [35] which is 0.33 percent of the person's height or

$$L_A = 0.33 * H \tag{1}$$

The appropriate height for a device is wrist height as discussed in section 2.1.3 Falls While Using a Cane or Walker. Therefore, the equation is the following:

$$H_D = 0.483 * H \tag{2}$$

Taking in consideration the distance recommended by the physical therapist [17] of 4 in. between the device and the person, it is easy to calculate the minimum distance for a forward base of support. The simplified equation from the trigonometric calculations is

$$\theta_F = 90^{\circ} - \sin^{-1}\left(\frac{12.12}{H}\right) \tag{3}$$

with θ_F meaning the angle of the force along the person's arm and using base units of degrees and inches. Using this angle, the magnitude of the force the person is applying can be calculated. To do this, the weight of the person is needed. The amount of force applied by their body weight was considered to be the force in the y direction or

$$F_y = 0.40 * W \tag{4}$$

The magnitude of the force was obtained using the equation

$$0.40 * W = F * \sin(\theta_F) \tag{5}$$

and used to obtain the force in the x direction with the equation

$$F_x = F * \cos(\theta_F). \tag{6}$$

The final step is to do a moment calculation to determine the length at which the device does not tip over (D_B). Using the forces obtained and the height of the device, the sum of moments equation comes out as

$$\sum M = F_x * H_D - F_y * D_B = 0 \quad (7)$$

and can be simplified to

$$D_B = 0.483 * H * \cot\left(90 - \sin^{-1}\left(\frac{12.12}{H}\right)\right) \quad (8)$$

Based on the anthropometric data from Anthropometric Reference Data for Children and Adults: United States, 2011–2014 by the CDC [36], the 5th percentile of weight for women between the ages of 60 and over is 96.9 lbs. and a height of 56.9 in. In men, the 95th percentile of weight between the ages of 60 and over is 279.2 lbs. and a height of 7 in. Only the 5th percentile of women and the 95th percentile of men, regarding height and weight, were taken because women are usually shorter and lighter than men and men are usually taller and heavier than women. By applying the formulas in excel, it can be seen from Figure 35 and Figure 36 the variable that changes the length of the base is the height of the person while changing the weight of the person does nothing to the moment of the device. For Figure 35, the height was set constant to 55 in. while changing the weight on a range of 80 lbs. to 190 lbs. For Figure 36, the weight was set constant to 80 lbs. while changing the height on a range of 55 in. to 77 in. [36]. Even though the chosen weights do not precisely fit the documented weights, precision was not required because they were only chosen for illustrative purposes.

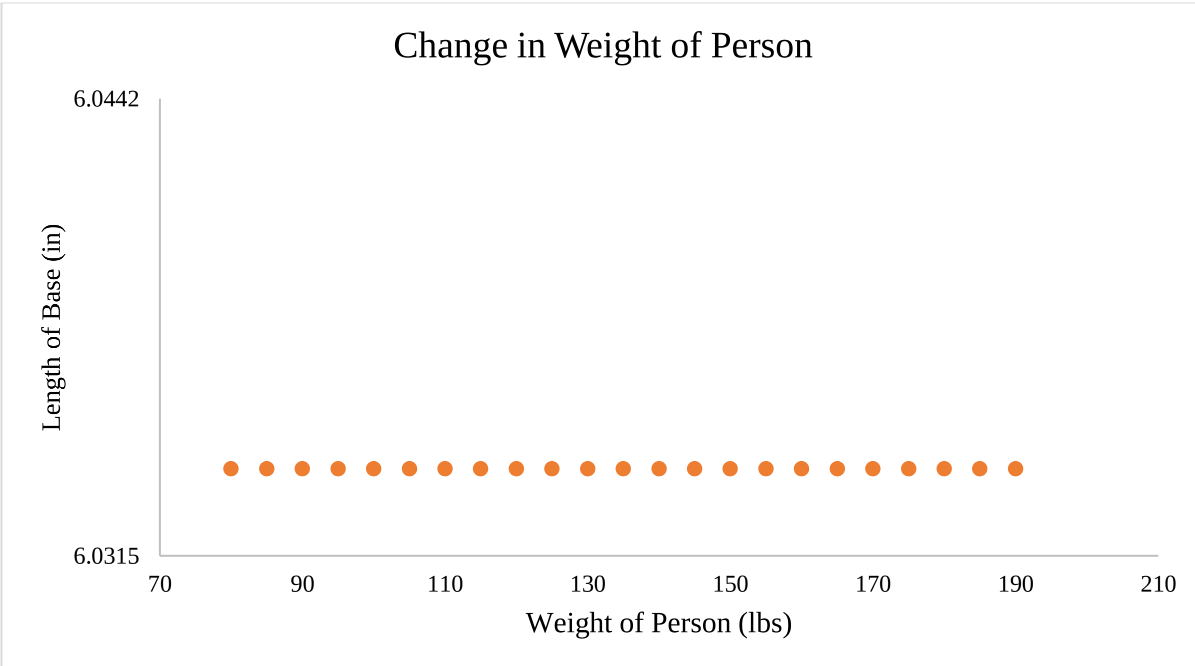


Figure 35: Change in Length of the Base in Relation to Weight

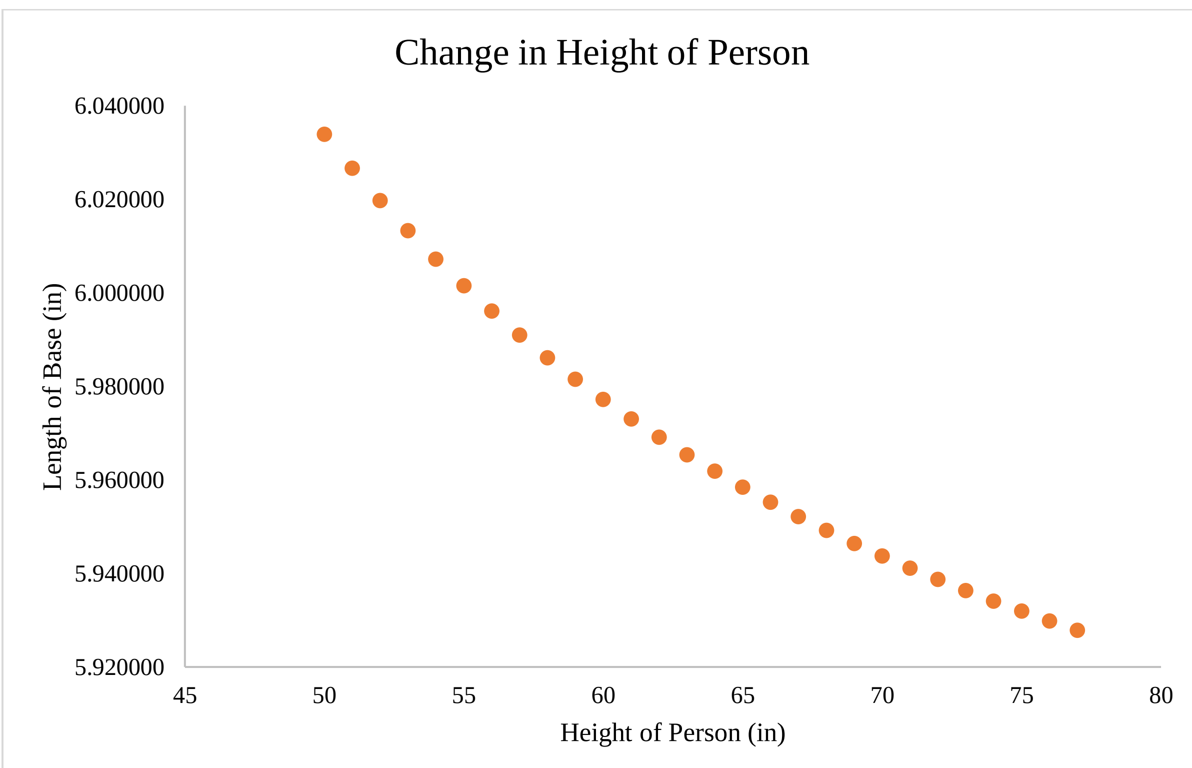


Figure 36: Change in Length of the Base in Relation to Height

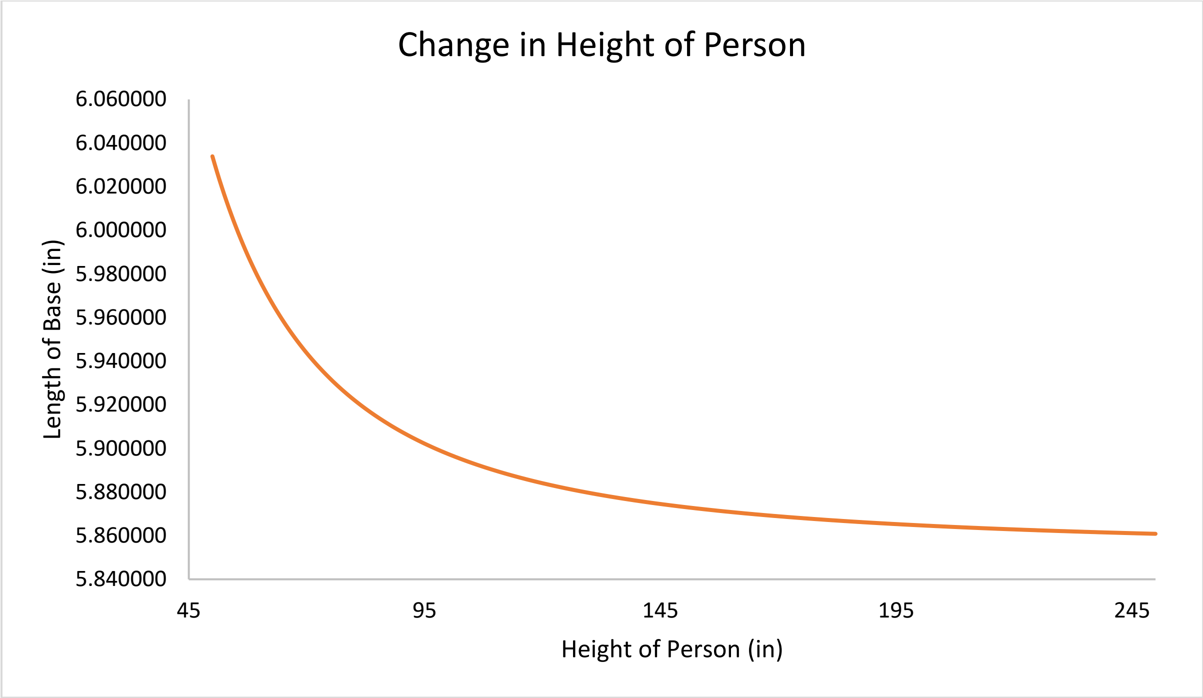


Figure 37: Length of the Base Convergence in Relation to Height

It is important to note that even though the height of the person increases, the length of the base in front of the legs converges to approximately 5.854 in. as the height of the person increases as seen on the exagerated plot in Figure 37. The length of the feet, however, increases the shorter the person is. Putting a limit at 50 in., the length of the feet must be more than 6.03 in. (Figure 36). The worst case scenario was also calculated with the person weighing 190 lbs. and a height of 50 in., but this did not change the result by much with the length of the base being 6.04 in. Therefore the device to be designed must have a base of support of no less than 6.04 in. in length from the body of the person and forward.

4.1.2.2 Morphological Matrix

The morphological matrix shown below in Figure 38 illustrates all the possible components considered for the design of the device. Some ideas are very specific while others are more abstract ideas. The table is sectioned by the functions described in section 4.1.1

Functional Definition. For each function, several ideas were provided for components that might solve it. Inspiration for these ideas came from existing product such as walkers, tanks, household products, etc. Some solutions came from researched patents, others came from personal creativity, and lastly some ideas were suggested by therapists during the interviews. The objective of this table is to explore the design space and for this, it is necessary to search ideas that are feasible, challenge and explore the limits of what this device can do. For this reason, some ideas are not viable but serve to explore creatively without judging prematurely.

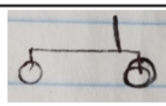
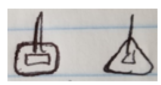
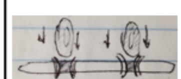
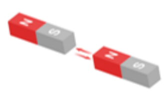
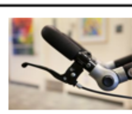
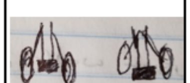
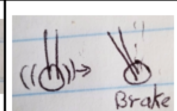
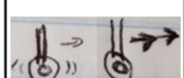
Stable Support	 **1.1 Forearm Support**	 **1.2 Curved Frame**	 **1.3 Trend Walker**	 **1.4 Standard Walker**	 **1.5 Frame with 4 Feet**	 **1.6 A-Frame**
Device Translation	 **2.1 Standard Wheels**	 **2.2 Continuous Track**	 **2.3 Non-Round Wheels**			
Device Anchor	 **3.1 Frame Between Bed**	 **3.2 Anchor on Base of Bed**				
Anchor Lock	 **4.1 Slide and Lock**	 **4.2 Slide and Lock From Top**	 **4.3 Magnetism**	 **4.4 Clamp**	 **4.5 Pin and Hole**	 **4.6 Hook**
Prevent Translation	 **5.1 Handle Brakes**	 **5.2 Pedal Brakes**	 **5.3 Weight Activated Brakes**	 **5.4 Angle Brakes**	 **5.5 Acceleration Brakes**	
Prevent Device Rotation	 **6.1 A-Frame**	 **6.2 Trend Walker**	 **6.3 Standard Walker**	 **6.4 Anti-Tip Bars**		

Figure 38: Morphological Matrix Filled with Solutions for Each Function

After creating the morphological matrix, it was acknowledged that most ideas proposed a challenge and were harder to conceive than others. It is very complicated to design an all mechanical device with simple mechanisms and is extremely simple to use without much input from the user. For example, designing a stable support that needed to be simple to initiate and operate, minimal in size, stable, and strong enough to support a person. This component was a challenge as there are only so many structures that comply with those tasks. Another challenging function to generate ideas was the braking mechanism that would stop the device from leaving the person's grasp without almost any input from the user, or conscious input at least. The only function that was relatively easy was providing translation to the device. This is because for translation there are very few options to consider and can be achieved very easily with a variety of wheels or casters.

4.1.3 System Synthesis

Now that ideas have been generated for each of the individual functions, the next step would be to eliminate the least feasible and choose the best ideas for further examination. For the function of providing stable support, the objective is to have a simple, yet stable frame that supports a certain percentage of the user's body weight similar to the one placed on a cane. Other ideas considered, not included in the morphological matrix, were the collapsing of an ordinary walker as shown in Figure 39 and two frame variations shown in Figure 40. These ideas were eliminated because it would be too complicated for an elder to assemble and too bulky, even collapsed, to have beside a bed. The frame at the left of Figure 40 would also not have worked based on the placement of the handles. If a person were to place any amount of weight on the handles, the device would immediately tip over.

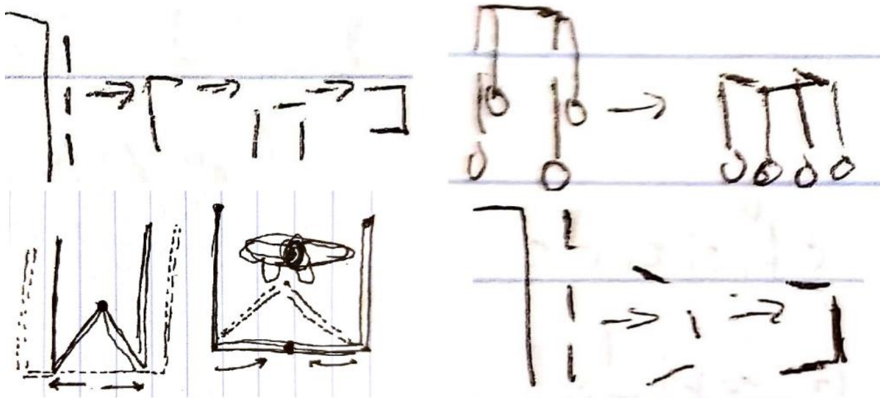


Figure 39: Walker Frame Collapse to Attach to Bed

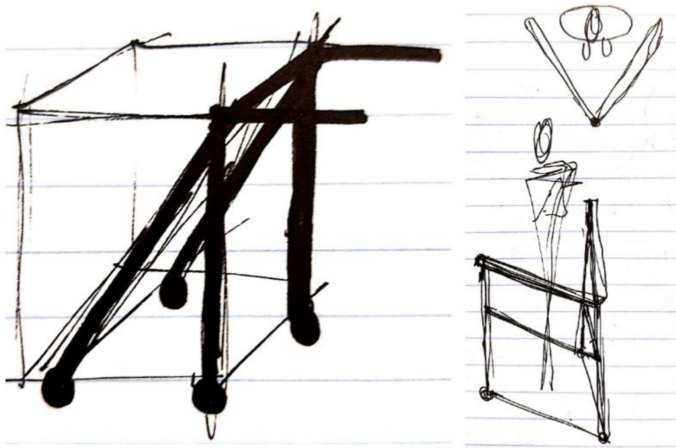


Figure 40: Discarded Frame Designs

The best idea was a trend style walker, marked 1.3 in Figure 38. This style of walker has an ample base of support. It is also compact enough to be placed beside a bed without the need to be collapsed or parts sticking in or out of the bed. The long legs that would provide the support for the person would be hidden inside the bed. This would make it compact enough to even fit it between a bed and a nightstand.

For the function of device translation, the ideas were very simple. A continuous track, marked 2.2 in Figure 38, was considered for better movement on rough terrain but considering the device would only be used inside the house, it was thought to be unnecessary. Idea 2.3 was a wheel that would limit the speed of the person while giving the support of a flat surface. It was also discarded as the wheels would desynchronize on turns. The chosen one was ordinary casters.

The anchor frame is the structure containing the locking mechanism and provider of support while the device is locked to it. For this function there were two ideas. One would be a frame that is inserted between the mattress and the base of the bed (3.1) and the second is a way to anchor the device to the feet of the bed (3.2). The first idea (3.1) was chosen as it has been proven to work for in-home use bed rails. The frame should be sturdy enough from the weight applied by the mattress. Idea 3.2 was discarded because there is too much variation on the placement of the feet of the bed and their height.

It is estimated that around 40% of the user's weight (or around 30 to 100 pounds) is placed on the device while it is anchored to the bed. These forces are considered to be in a horizontal direction. Considering all of the choices on how to lock the device, magnetism (4.3) was the first one to be eliminated because it can only support a small amount of weight. Even with strong earth magnets, if any level of force is applied to the device, the magnets would not have enough force to hold the device together with the anchor. Although it may be the simplest to use, it is not the best solution. Electromagnets are also not a practical option because electronics would make the device more expensive. Option 4.1 would be the best fit to lock the device because it would not require too much coordination to lock or unlock compared to the rest of the ideas. It also provides a secure and strong lock to allow the user to support themselves from the device without it unlocking.

The brakes are an important function to solve and there are many solutions available. Solutions 5.1 and 5.2 were automatically eliminated because the user does not have the coordination and reflexes to activate these types of braking mechanisms in time during a fall. As stated by the physical therapist [17]: “Elder’s reflexes are so bad that they notice they are falling once they are already on the floor.” Solution 5.5 would also not be feasible because everyone walks at a different pace and the brakes would not know when to activate. Solution 5.4 would be a clever way of stopping the device from moving when it tilts, but there does not seem to be a similar idea on the market. It would be worth considering in future work, but the objective of this project is not to design every single component in the system. Therefore, the best solution would be weight activated brakes (5.3) calibrated in correlation with the weight of the person, so it knows when too much weight is a signal for braking.

Lastly, to prevent the device from sliding away from the bottom and tilting, several solutions were provided in which 6.1 to 6.3 only referred to the base of support of the frame. The wider the base, the harder it would be to tilt. Because solution 1.3 was chosen for the basic shape of the frame, it coincides with solution 6.2. This does not ensure that the frame does not tilt, but it would depend on the final shape and design. If the problem persists even on the final design of the frame, the last solution (6.4) may be implemented and adapted to fit the final design.

In general, it would be best to not eliminate all options and have only one solution for each function but to have several solutions, so it is possible to obtain several combinations. In this case, only one solution for each function survived because there were not too many ideas to choose from. Other designs may have ten or more ideas for each function, but this design had a small amount of components and, therefore, few solutions. Also, one of the reasons why there were few ideas was because calculations were performed before the morphological matrix, in addition to discussions with different types of therapist which influenced the idea generation and selection.

CHAPTER V

EMBODIMENT

Up to this stage of the process, the problem has been defined and analyzed, all of the functions of the device have been broken down and defined, and a solution has been chosen for every function. In this chapter, all the solutions were analyzed, developed to best solve the functions, and fitted together correctly into a complete device. Although there are plenty of questions that need to be answered for this project to become a final product ready for market, this study only focuses on the most important questions regarding the functionality and reliability of the device.

Table 4: Questions for Each Function Solution

Support Frame	1. How stable will the frame of the device be? 2. How much weight can the frame withstand? 3. What dimensions should the frame be?
Movement and Braking	4. What would be the best size of the casters? 5. At what weight will the braking system be activated?
Anchor and Lock Mechanism	6. What are the dimensions of the anchor? 7. How will the slide lock mechanism work? 8. How strong will the lock be?
Materials	9. What material for the frame and anchor would have enough structural strength to withstand the applied forces and still be light and inexpensive?
Failure Mode and Effect Analysis	10. How can the device fail? 11. What would be the consequences if a component fails? 12. What can be done to prevent a failure?
Ergonomics and Human Factors	13. What are the best dimensions for the device? 14. How does the device make itself present? 15. How does the device help with the user's visibility?

5.1 Support Frame

The frame is the first on the list for analysis. To determine the stability and weight capacity of the frame, first the final shape and dimensions must be established. The first idea pitched in the morphological matrix is like a baby's trend walker as seen on Figure 41. Although the structure for the frame is based on a baby's trend walker, the only important part is the base because the seat for the baby is too large and unnecessary for the target audience.

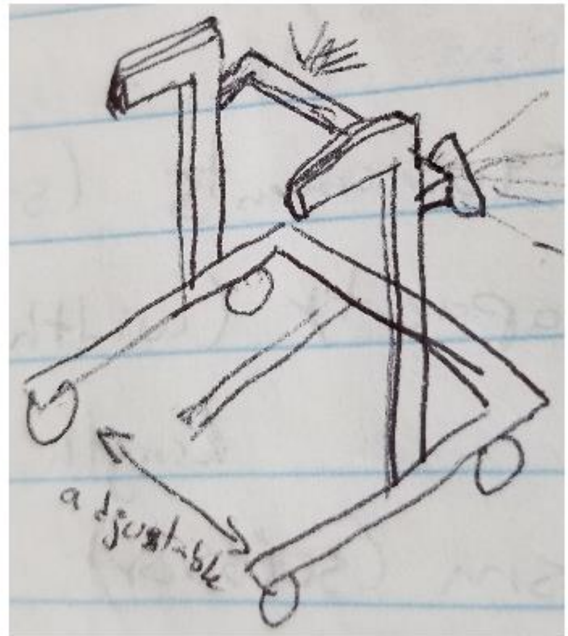


Figure 41: Baby Trend Walker [37] Compared to Proposed Frame Design

The goal of this project is to have a device that has a smaller form factor than the walker. Several improvements can be made to the original drawing to make it more compact. One modification would remove the side handles and keep only the front handle bar. This is because having side handles would extend into the bed space. Instead of removing them, one might argue that it would be best to make them rotate. This wrongly assumes that the user would have to be conscious enough and remember to perform this task in the middle of the night. Another goal is to have the device as close to the bed as possible with no moving parts or collapsible components. One previously established dimension was the length of the feet. The minimum length was found to be 6.04 in. To increase the safety of the device, it was decided that the length of the feet would be extended 1.5 times or a total of 9 in. The purpose of this design is to have the feet tuck beneath the bed. This way there is nothing sticking in or out of the bed and being a potential trip hazard. All of these considered, three designs were made in Solidworks with the same shape but slightly varied. The device would be made with a round tube as a handle, but these models were squared for modeling ease and rapid observations.

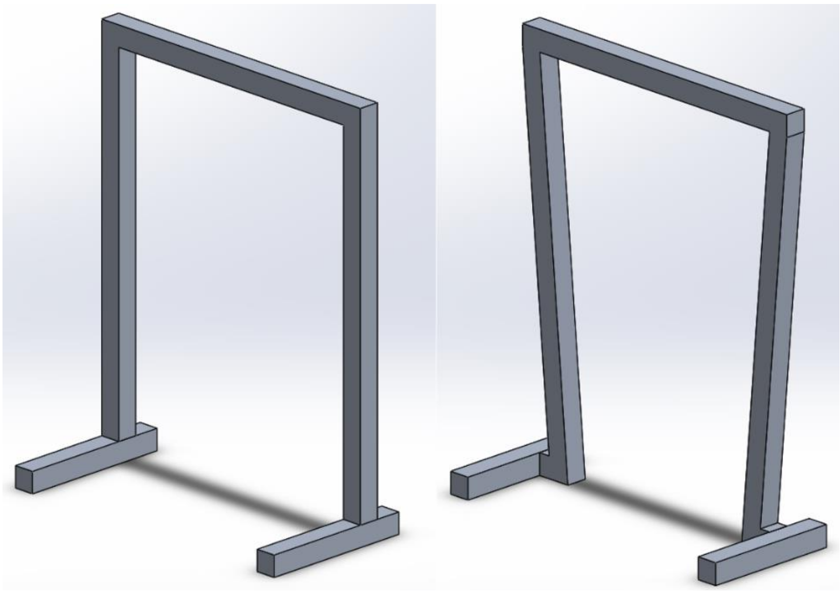


Figure 42: Basic Shape of Frame (Left) and Legs Converging Inward (Right)

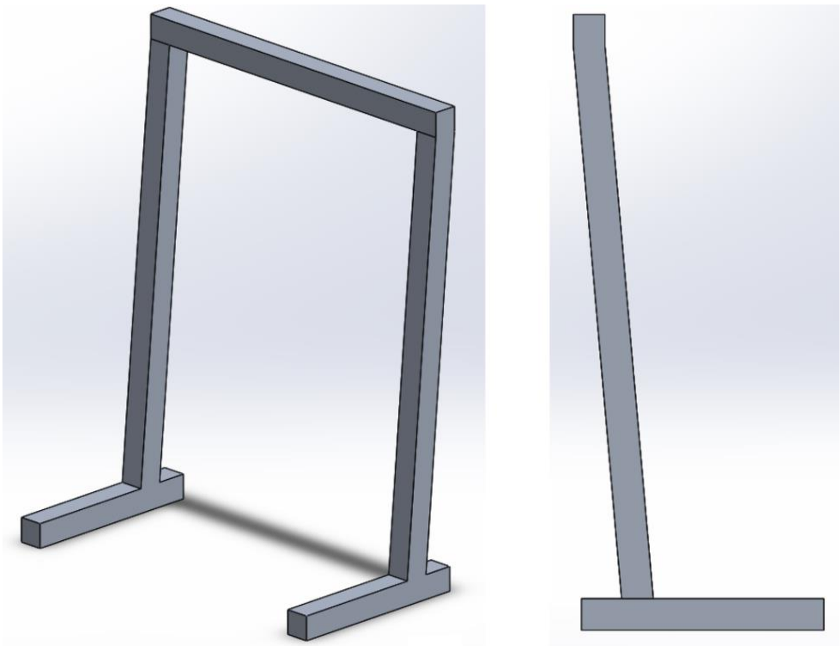


Figure 43: Frame with Tilted at a Backward Angle and its Side View

With these designs, the correct way to use the frame would be to stand in front of it on the side of the short part of the foot and have the long part of the foot in front of the person. If the person were to stand on the opposite side, the device might tip over. The torque from the horizontal forces and the 2 in. foot would overcome the torque from the person's weight. The idea for the first variation in Figure 42 (right) was to better distribute the force applied by the person throughout the device by redirecting some of that force in a horizontal component. This arrangement would relieve some stress from the front handle bar onto the feet of the device. The second variation shown in Figure 43 is aimed at having more torque by increasing the perpendicular distance from the force applied vertically. Even though there are three variants, it can be recognized that a basic design structure has been established.

From the previously stated goals, the frame with a backward angle from Figure 43 can be eliminated. This is because if the frame is set beside a bed as close as possible, there would still be a gap between the frame and the bed. This does not comply with the goal of having the device as close to the bed and as compact as possible. If the user were to have a nightstand, there would be a considerable amount of space in between the bed and the nightstand. Also, the vertical force applied on the handle would fall directly on top of the short side of the feet creating a moment that would make it more likely to tip over backwards (the short side of the feet).

To further study the frame, an early prototype was made using the basic design on the left of Figure 44. The exact dimensions are explained in section 5.7 Ergonomics and Human Factors. The prototype was made using PVC tubes and the feet were made of wood. It was developed to have a more tactile experience for experimentation and testing concerning stability and reliability rather than basing it all on theoretical calculations in a perfect world. The prototype appeared to be very strong and sturdy. The legs bent slightly when too much force was applied (around 120 lbs.) but nothing too concerning. The bending was caused by imperfections in the creation of the prototype and the materials used. PVC is a relatively flexible material compared to others. Regarding tilt, the device never felt like it would tilt forwards or backwards during use. It was surprisingly stable for the amount of weight applied to test its limits.

Figure 44: Prototype of Basic Frame

This prototype was demonstrated to the same occupational therapists and physical therapists previously interviewed for the User Research and Customer Requirements. One remark made by them was about the width of the device which was 1.5 ft. They pointed out that this width was good for thin people but would be uncomfortable for wider people or someone with a wider stance. They would end up kicking the legs instead of walking through them. Given this conversation, the design on the right of Figure 42 was also discarded because the legs converge inward and, therefore, the user would more likely kick the legs of the device while walking. It would not have mattered how wide the device was made, the legs would always be obstructing the middle section and would always be kicked. Because the feet of the device are very short on one side, there is a small possibility for the device to slip from under and tip over onto the person. This is very unlikely because the device is meant to be used very close to the body and the arms cannot apply a force in the direction towards the person. Even if the person would apply the necessary force in the incorrect direction, the device handle would still collide with the body and prevent it from rotating. A potential solution to this issue may be to implement a smaller version of the anti-tip bars mentioned in the morphological matrix.

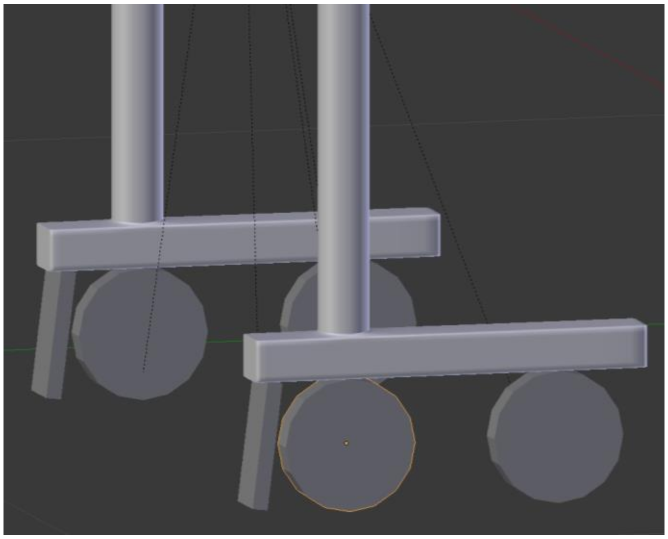


Figure 45: Potential Anti-tip Bars Implementation

Regarding the prototype, all the therapists were very positive about it and convinced that the design was very stable. They agreed this project would in fact provide more assistance to cane users as they do sometimes need extra support and assistance. At the same time, they confirmed that elders often leave their assistance devices somewhere else and this device would help with that issue. Also, they expressed the uniqueness in the solution as they have not seen anything similar in the market that would provide the user the required stability from a device compact enough that it can be stored in between the bed and the nightstand.

5.2 Materials

To determine the material that was used throughout the device, calculations of solid mechanics need to be completed. These calculations give an estimate on the stresses the device experiences when in use. The worst-case scenario was calculated assuming that the heaviest user would weight 200 lbs. Even though it has been shown that a person applies 15%-20% of their body weight on canes [4], 40% was used for these calculations to further push the worst-case scenario. To determine the stresses, the device was separated into three components, the handle, the legs, and the feet. The two stresses needed are the bending stress and transverse shear stress. These equations require the maximum bending moment, the first and second moment of inertia, and the maximum shear force. The handle was calculated first with the assumption that both ends are pinned. The geometry of the handle is a cylindrical hollow tube with a thickness of 0.01 in., a diameter of 1.57 in., and a length of 24 in. A free body diagram was done to determine the reaction forces as illustrated in Figure 46 with equilibrium equations for the moments and the forces in y. The forces in the y direction are positive going up and the moments are positive in a clockwise direction.

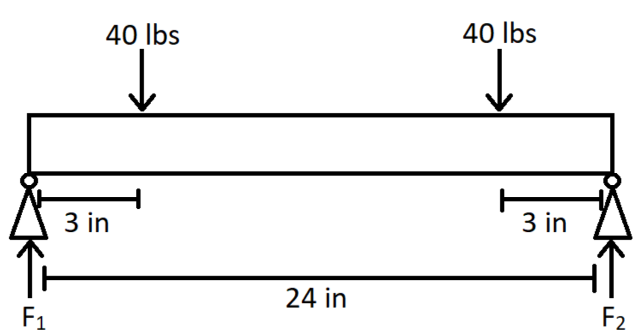


Figure 46: Free Body Diagram of Handle

$$\sum F_y = F_1 + F_2 - 40 \text{ lbs} - 40 \text{ lbs} = 0 \tag{9}$$

$$\sum M_o = 40 \text{ lbs} * (3 \text{ in}) + 40 \text{ lbs} * (21 \text{ in}) - F_2 * (24 \text{ in}) = 0 \tag{10}$$

The force applied on the handle was divided into two concentrated loads, one for each hand. From equations (9) and (10) the resulting reactions forces are $F_1 = F_2 = 40$ lbs. The next step was to draw the shear force and bending moment diagrams.

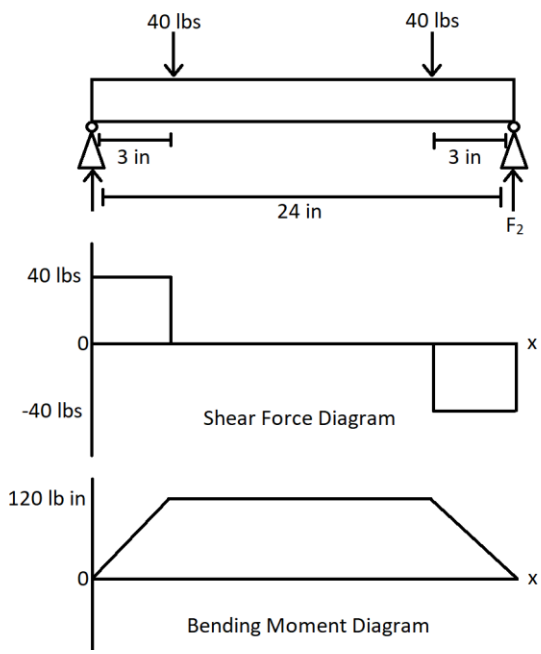


Figure 47: Shear Force and Bending Moment Diagrams

From the shear force diagram and the bending moment diagram, the maximum shear force (V_{max}) was found to be 40 lbs. and the maximum bending moment (M_{max}) was 120 lbs. in. The next values to obtain are the first and second moments of inertia (Q and I respectively).

$$Q = \sum y * A = \frac{2 * (r_o^3 - r_i^3)}{3} \tag{11}$$

$$I_x = \pi * \frac{D_o^4 - D_i^4}{64} \tag{12}$$

The formula of first moment of inertia (11) is for a hollow semicircle above the centroid (c) which is 0.785 in. while the formula for the second moment of inertia (12) given that the cross-sectional area is a hollow circle. The variable r means the radius of the circle and D the diameter of the circle with o being the denomination for outside and i for inside. These equations result in the first moment of inertia equal to $Q = 0.1082 \text{ in}^3$ and the second moment of inertia equal to $I_x = 0.1253 \text{ in}^4$ with the dimensions given at the beginning of the section. Once the individual variables were solved, the bending stress and transverse shear were calculated. Equation (13) was used to calculate the bending moment and equation (14) was used to calculate the transverse shear.

$$\sigma_{max} = \frac{Mc}{I} \tag{13}$$

$$\tau = \frac{V_{Max}Q}{It} \tag{14}$$

The results of these equations turned to be $\sigma_{max} = 751.80$ psi and $\tau = 22$ psi for the handle.

The next piece calculated was the legs of the device. Because the legs are a simple beam with a concentrated load applied to them, only the normal stress was calculated. The geometry of the legs is a 1.57 in. square tubes with a thickness of 0.1 in.

$$\sigma = \frac{P}{A} \tag{15}$$

The load applied was again 40 lbs. with an area of 0.588 in^2 and resulted in a normal stress of $\sigma = 68.03$ psi.

Lastly the foot of the device was calculated. The calculations for this part are very similar to the handle calculations with the exception that this too is a 1.57 in. square tube with a thickness of 0.1 in. It was also assumed that the legs were pinned at its ends.

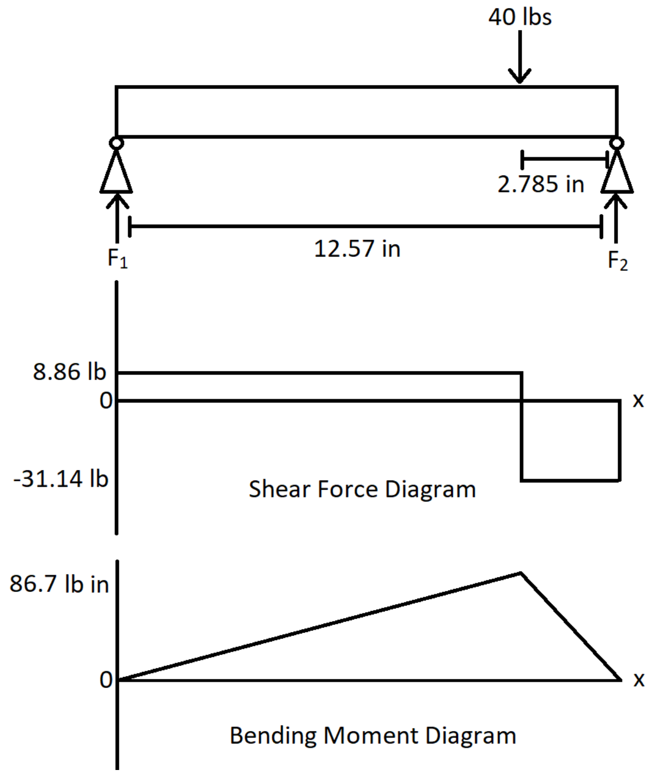


Figure 48: Free Body, Shear Force, and Bending Moment Diagrams

From these diagrams and the equations below, the absolute maximum shear force resulted in $V_{max} = 31.14$ lbs and the absolute maximum bending moment was $M_{max} = 86.70$ lb in.

$$\sum F_y = F_1 + F_2 - 40 \text{ lbs} = 0 \tag{16}$$

$$\sum M_o = 40 \text{ lbs} * (9.785 \text{ in}) - F_2 * (12.57 \text{ in}) = 0 \tag{17}$$

The final variables to calculate were the first and second moments of inertia. These formulas are based on a hollow square. Because the geometry of the foot is a hollow square, b and h are the base and height of the outside square and b_i and h_i are the base and height of the inside square.

$$Q = \sum y * A \tag{18}$$

$$I_x = \frac{bh^3}{12} - \frac{b_i h_i^3}{12} \tag{19}$$

The end result for the first moment of inertia (18) is $Q = 0.1623\ in^3$. The result for the second moment of inertia (19) is $I_x = 0.2127\ in^4$. As previously done with the handle, the last calculation to make are the bending stress and transverse shear stress using the same equations (13) and (14). Once the stresses were calculated, the results came out as $\sigma_{max} = 319.98$ psi for the bending stress and $\tau = 15.13$ psi for the transverse shear stress.

All of the stresses have now been calculated and can be compared to choose a material. To select the best material for the device, the yield strength of the material had to be larger than the stresses obtained considering a safety factor of at least 2. To recap, the bending stress for the handle was $\sigma_{max} = 751.80$ psi and for the foot was $\sigma_{max} = 319.98$ psi. The transverse shear stress for the handle was $\tau = 22$ psi and the foot was $\tau = 15.13$ psi. The normal stress for the legs was $\sigma = 68.03$ psi. The maximum stress out of all is the handle bending stress. By choosing a factor of safety of 2, the material's yield stress must be equal or greater than 1,503.6 psi. Because the device is subjected to very little forces, almost any material can be chosen. For the rest of the analyses the material to be used throughout the device was 6061 aluminum. 6061 aluminum was chosen because it has a yield strength of just shy of 8000 psi which gives a safety factor of 10.5. This material is also one of the most commonly used general-purpose aluminum alloys. Aluminum is a very light metal and strong enough to withstand the discussed stresses.

5.3 Movement and Braking

From the morphological matrix, it was determined that the use of ordinary casters is the simplest form of translation. The size of the casters was determined to be 2 in. in diameter. The size was determined by considering the height of a low-profile bed base which is 5 in. from the ground. The casters used in the prototype from Figure 44 are shown in Figure 49.

Figure 49: Rigid Caster (Left) [38] Swivel Caster (Right) [39]

These casters have a total height of 2.56 in. which only leaves a total height of 2.44 in. for the foot of the device. The use of bigger casters would give better mobility in floors with Saxony style carpets or large strand carpets. The choice of smaller casters was finalized but bigger casters could also work with some beds as high-profile bases are as high as 9 in. leaving 6 in. for the use of casters. When building the prototype, there were three possible configurations; two rigid wheels at the back (below the legs) with two swivels at the front, four rigid wheels, or four swivel wheels. The first option (two and two) was chosen because four rigid wheels would not give the ability to turn and four swivel wheels would give the user too much mobility in both horizontal degrees of freedom. This can be a problem when the person is pushed or tripped on a lateral direction.

The chosen braking system for the device was the weight activated brakes. The purpose of these brakes, essentially, is to stop the device from translating if the user is in the process of falling and needs the support of a stable object. The best location for these brakes is in the back casters of the device. The way weight activated brakes or compression brakes work is the caster has freedom to move and roll but once a weight limit has been exceeded, the caster does not move. This is done by a simple mechanism involving a spring. The spring holds the weight and once it is compressed, a metal plate applies pressure on the wheel which prevents it from moving. The way the person would activate the brakes in a falling situation is when a person starts falling forward, they would grab on to the device and apply more of their weight on it. This would be by instinct trying to move the device closer to themselves, so they can grab on to it better or by the nature of the fall which pushes them toward the device. By this method, the user would have no conscious input on the brakes freeing them from their awful reaction times. These types of brakes have been researched but unfortunately there are no casters similar to the ones in Figure 49. Compression brakes are commonly found in office chairs and heavy duty or industrial carts as seen on Figure 50.

Figure 50: Office Chair (Left) [40] and Heavy Duty (Right) [41] Compression Brake Casters

The mechanism does exist and can be made small enough to fit the dimensions of the casters needed as seen in the office chair casters, but they simply have not been commercialized. The only issue that requires further research is the correct weight capacity for activation because every user applies a different percentage of their body weight onto the device. This point is of concern because a person applying 40% of their weight could accidentally activate the brakes calibrated for a person of the same weight that only applies 20% on the device.

5.4 Anchor and Lock Mechanism

The anchor frame is the simplest component in the system because it has already been established by other products. It does not need to be redesigned in comparison to the current products in the market with the exception of incorporating the locking mechanism to its ends and removal of the handle. The frame used was based on the bed rail in Figure 51.

Figure 51: Bed Rail Frame [42]

This frame is adjustable for different bed heights and widths. It also has bands of rubber that serve as anti-slip grips which allow the frame to remain in place even when pulled outward. In the case where the frame does slip, a strap can be tied at the end of the frame to the base of the bed for added stability and firmness as seen on Figure 52. The dimensions of the cross section of the frame is a rectangle with a height of 1.07 in. and a width of 2.07 in. The height of the rectangle is smaller to make it more comfortable for the person on top of the bed. If the frame is too thick, the frame could be felt when the person is lying on the mattress, but it depends on the type of mattress. The designed frame had a length of 32 in., but this is adjustable to fit any size of bed. These issues can be further analyzed as future work. For example, the anchor frame's thinness, other methods for securing it to the bed, and how to better prevent displacement.

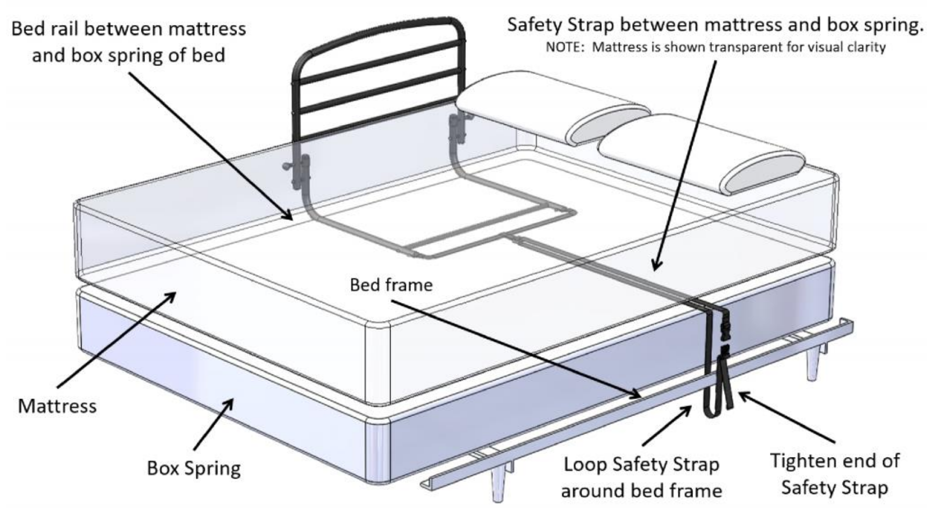


Figure 52: Safety Strap for Bedrail [43]

The locking mechanism that was designed started as a basic chain lock used to lock house or hotel doors. The chain lock consists of a knob with two circular pieces of metal with a small separation between them. This knob is then inserted through a circular hole that elongates. The key to the lock is that the edges of the elongated hole fit in the small space separating the two circular pieces of the knob. This way, the knob cannot exit in any other direction except by sliding along the edge of the elongated hole until it reaches the circular hole. This simple chain door lock mechanism was modified for the project to make it stronger and more secure to prevent accidental unlocking.

Figure 53: Chain Door Lock [44]

The first redesign made was the aperture of the lock. On a normal chain lock, the person must insert the knob into the circular hole and slide it laterally to lock. This was changed because a senior person operating the device at night would not have the coordination nor the vision required to precisely insert a knob in a hole. Instead, the circular hole was removed and one of the edges of the rectangle was opened up. This will allow the user to only insert the knob through one side of the lock. The aperture of the edge was also widened and then starts to narrow as shown on Figure 54. This wider opening allows the user to easily insert the knob without the need for aiming or lifting the device. The wide opening guides the knob to the right place.

Figure 54: Anchor Lock with Wide Opening

This lock works the same way as the original chain lock. The tip of the knob has a bigger size compared to the rest of the body. The elongated hole has an edge that grabs onto the knob to prevent it from exiting. The current anchor lock has the ability to prevent the knob from exiting outward but not laterally along the elongated hole. If a person accidentally pushed or pulled the locked device laterally, it would still slide away. To solve this issue, a small groove was made at the end of the elongated hole where the knob sits. This groove prevents the knob from moving in any direction except upwards. There is a lock for each leg of the device, and the groove on the second one was placed at the top. Having the groove at the top of the second lock ensures two things; the anchor is able to be used in both the right and the left side of the bed and to unlock the device from only one lock. The ability to unlock the device by lifting only one side was purposefully designed because it takes much less coordination this way rather than lifting both sides at the same time and pulling. The user would only pull up the side which is closest to them once they are sitting down on the middle of the bed.

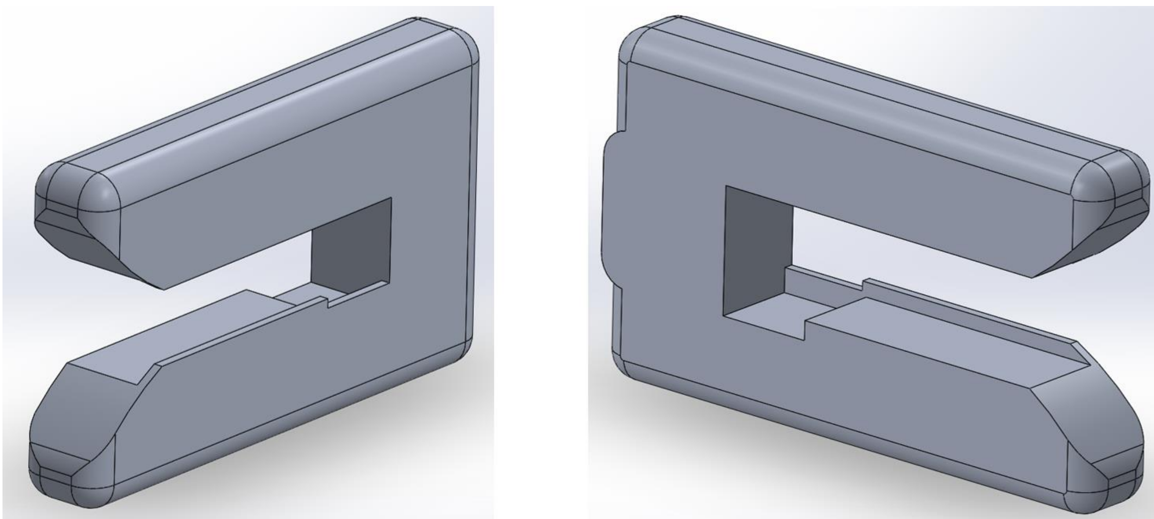


Figure 55: Front and Back View of Lock with Groove

Figure 55 was thought to be the final design of the lock until it was observed that the device was not truly secured. Once the knob falls into the groove, the top part of the knob does not have contact with the top edge of the lock. To solve this, the groove was made deeper in a lateral direction shown in Figure 57. It was also observed that the lock with the opening facing outside, is always the one that locks the device from moving laterally, regardless of the orientation of the anchor. Therefore, the lock with the opening facing inside should not have a locking groove but a groove with a rounded edge. The rounded edge allows the leg to be at the same level of the other leg once locked and also gives the ability to easily slide out of the groove. Taking these observations in consideration, the lock was modified as shown in Figure 56 and

Figure 57. Figure 57 shows both locks with the left having a squared edge for locking purposes and the right a rounded edge for unlocking ease.

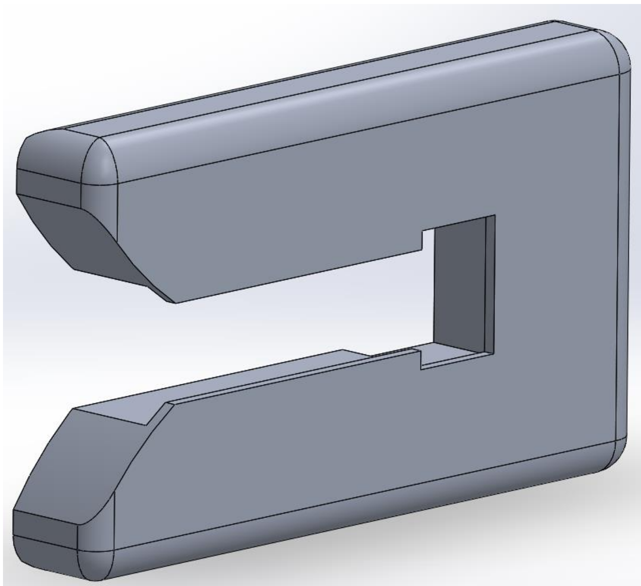


Figure 56: Anchor Lock Front View

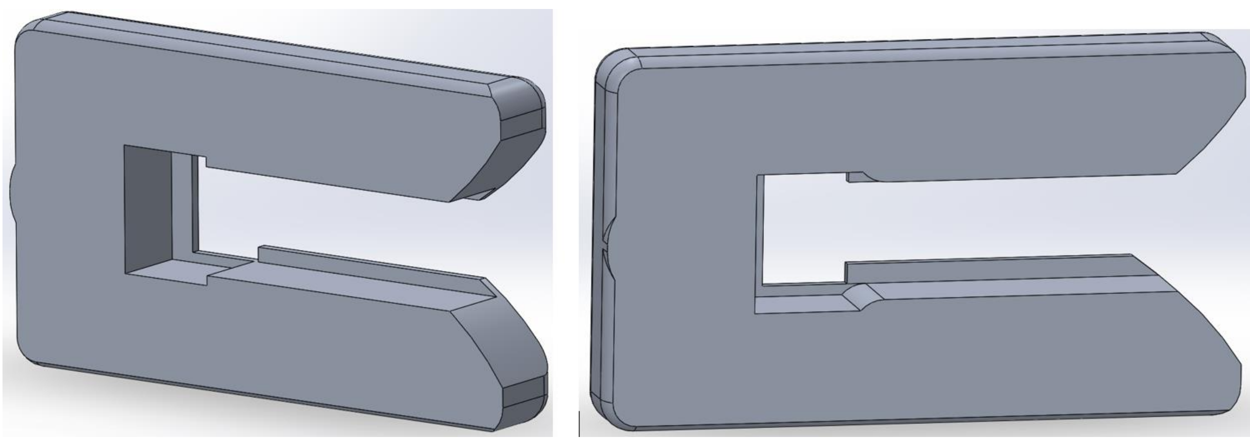


Figure 57: Opening Facing Outside (Left) and Opening Facing Inside (Right) Back View

As explained before, the process of locking the device consists in the user sliding the device laterally until the knob falls into the groove as shown in Figure 58. To unlock the device, the user would only lift one leg of the device to free it from the groove and pull out. All of the sharp corners and edges outside the lock were rounded off to avoid accidental injuries when walking beside the bed.

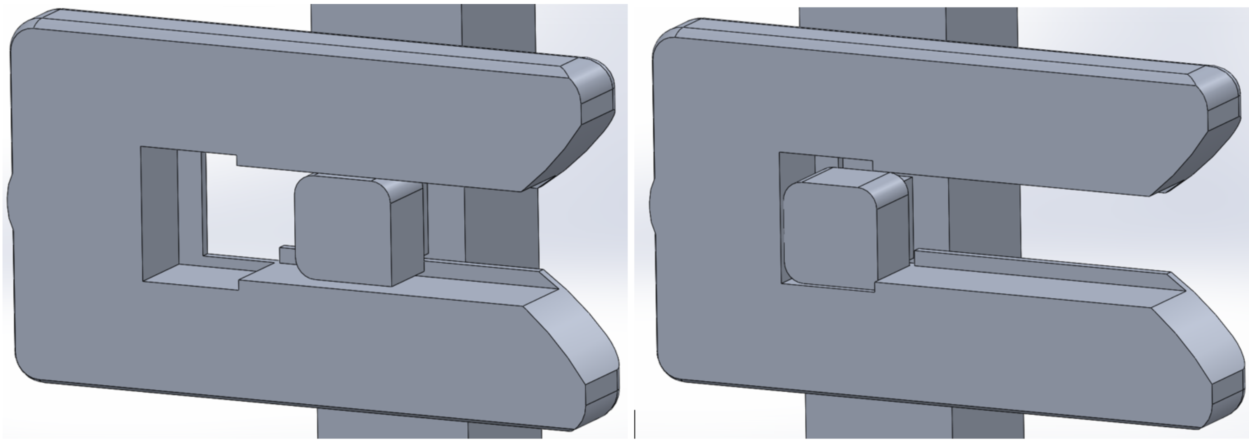


Figure 58: Process of Locking the Device

The knob of the device was placed a couple of inches below the center of the device's legs and consists of a 1 in. cube attached to a smaller cube of 0.8 in. The knob also has rounded edges for assistance during locking and unlocking with the exception of one edge. This edge was left sharp to avoid sliding off the groove and have a more secure lock.

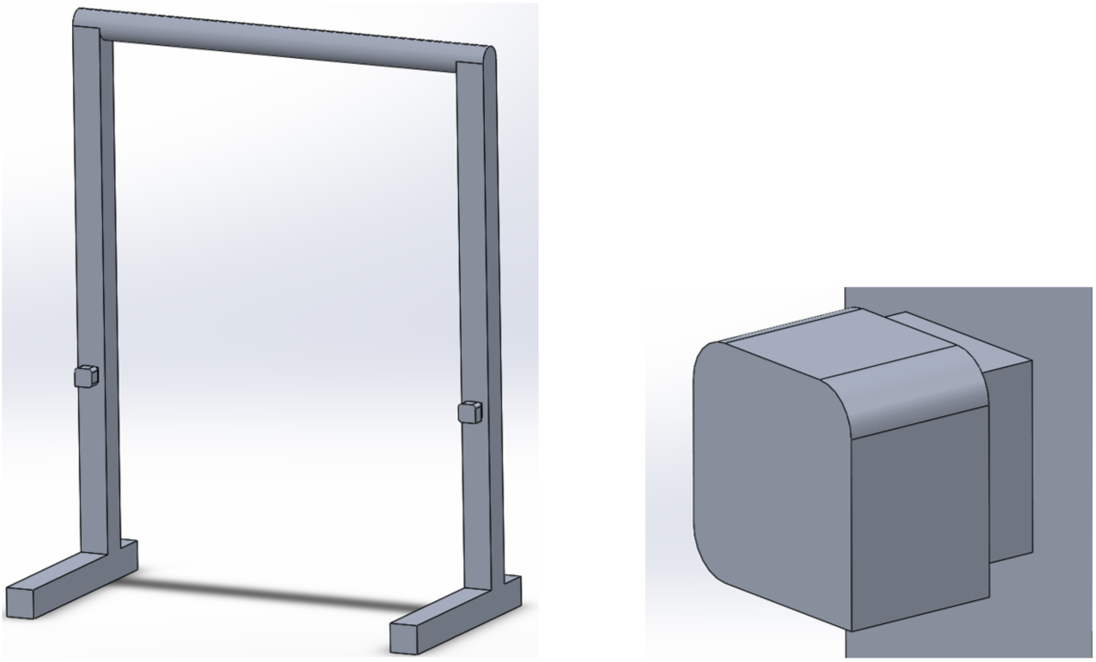


Figure 59: Knobs Placement on Device (Left) and Knob Close-Up (Right)

With the design of the locks finalized, both of the locks were attached to the frame of the anchor. The final shape of the entire frame is shown in Figure 60.

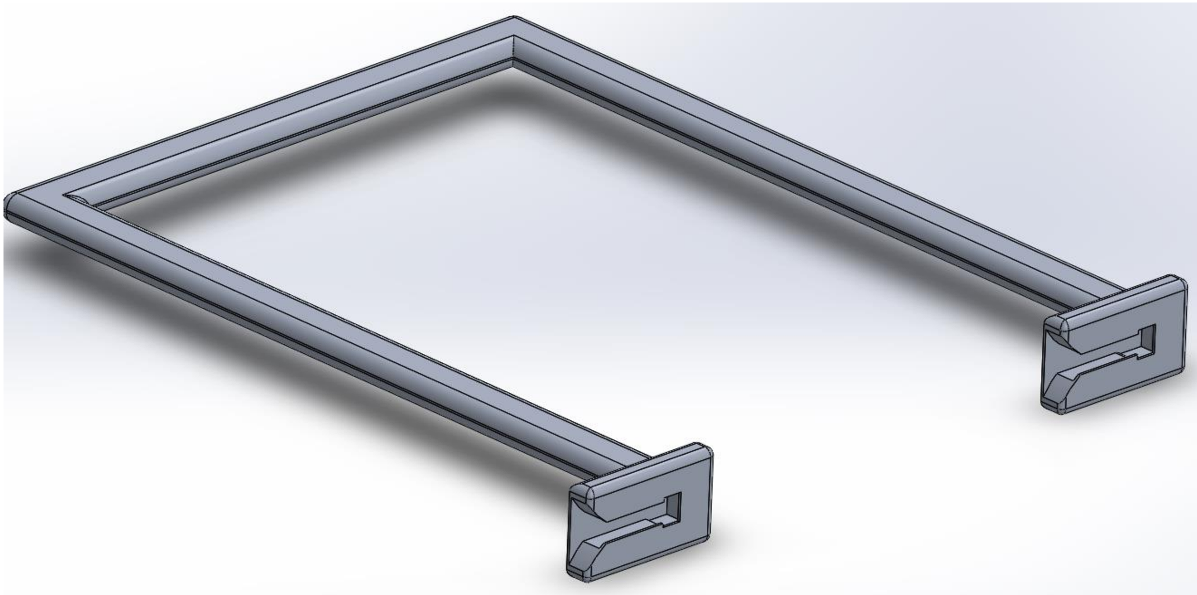


Figure 60: Anchor Frame with Locks

5.5 Finite Element Analysis

Finite element analysis (FEA) is a computerized method for predicting how a product reacts to real-world forces, vibration, heat, fluid flow, and other physical effects. FEA shows whether a product breaks, wears out, or work the way it was designed. It is called analysis, but in the product development process, it is used to predict what is going to happen when the product is used [45]. Now that both the frame and the anchor have been fully designed and a material has been chosen, a FEA can be performed. All the analyses were done using the Solidworks simulation software. Two main variables were reported in all analyses: stress and safety factor. Safety factor is a ratio between the failure stress and allowable stress $\mathrm{FS} = \frac{\sigma_{\mathrm{Fail}}}{\sigma_{\mathrm{Allow}}}$. From this value it can be concluded how much more stress can the part be subjected to until it fails.

5.5.1 Walking Aid Device Frame

The first analysis was done to the entire frame of the walking aid device. The bottom surfaces of the feet were set to have a roller support and the handle was subjected to a total of 80 lbs. or two loads of 40 lbs. each, one for each hand, placed 3 in. from the edge and estimating the length of the hand to be 3 in. These loads were chosen considering the worst-case scenario of a person weighing 200 lbs. and placing 40% of their body weight which is more than the average 15%-20% as explained in the materials section. The frame of the device was assumed to be made out of a single piece using hollow 1.57 in. x 1.57 in. square tubing with a thickness of 0.1 in. The handle bar is a hollow cylinder with a diameter of 1.57 in. and a thickness of 0.1 in. The diameter of the handle bar was based on the diameter of the PVC pipe used for the prototype, but further research indicated this diameter is ideal for an ergonomic handle.

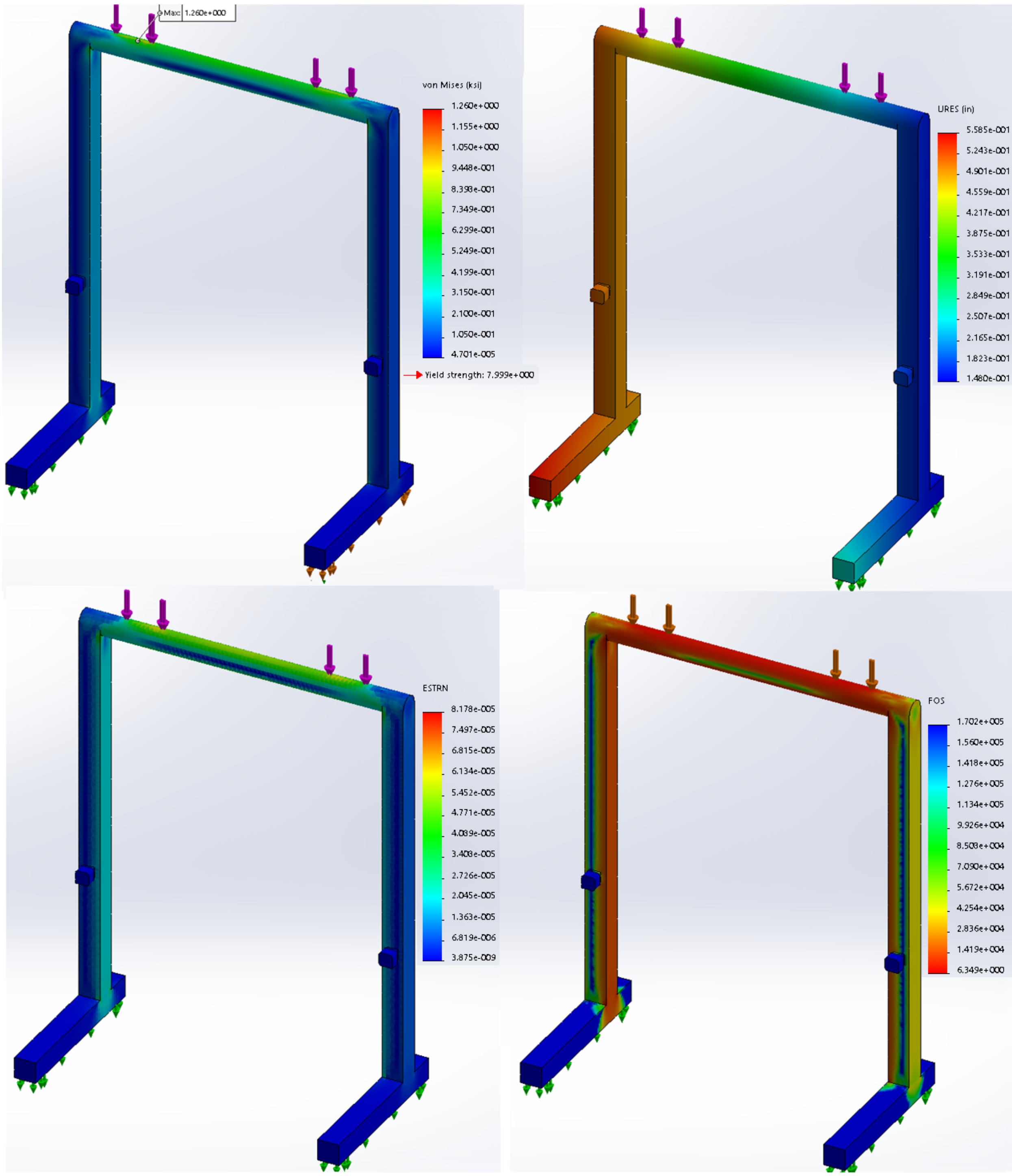


Figure 61: Finite Element Analysis of Frame

The results obtained are shown in Figure 61 which illustrates the maximum Von Mises stresses to be 1.26 ksi. These stresses are concentrated at the loads' location. The minimum stress is 4.701 x 10^{-5} ksi which can be observed throughout the feet. These stresses are not very big compared to the yield stress of the chosen material, 6061 aluminum, which has a yield stress of 7.999 ksi. For the device to fail, it would have to withstand a force of 507 lbs. in total or 254 lbs. in each hand. This result was estimated by interpolation $\mathrm{F_{Fail}} = \frac{1.26\ \mathrm{ksi} * 80\ \mathrm{lbs}}{7.999\ \mathrm{ksi}} = 507.3$ lbs and confirmed by the software. The maximum displacement is shown to be 0.5586 in. caused by the legs moving away from each other and the maximum strain was 8.178 x 10^{-5} which is almost non-existent. Lastly, the factor of safety was also obtained. The maximum value was changed manually to a limit of 300. This allows a better illustration of the different values throughout the body of the device. The maximum is shown to be at the feet with a value of 300 or more and the minimum is located at the handle with a safety factor of 6.35. The safety factor of 6.35 confirms the previous calculation of the maximum force until failure.

Later, in the ergonomics and human factors section, the benefits of a curved handle compared to a straight one are discussed. This change slightly increases the maximum stress and distributes the forces along the legs because the forces now have a perpendicular distance to the legs and create a moment which in turn created bending on the legs. The maximum stress is located at the intersection between the legs and feet with a value of 1.811 ksi. The factor of safety was also reduced from 6.35 to 4.42. The maximum still remains at the tips of the feet with 300 or more.

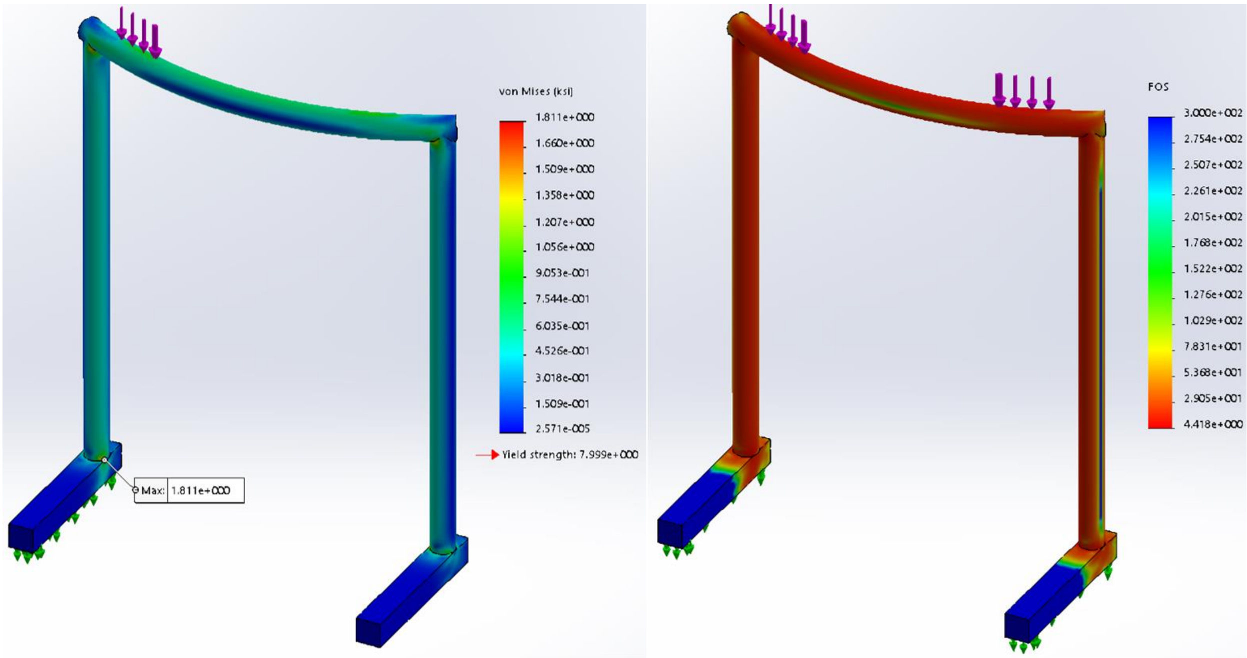


Figure 62: FEA on Device with Curved Handle

5.5.2 Anchor Frame, Knob, and Lock

After the walking device analyses, the whole assembly was analyzed. The anchor frame and locks were not analyzed individually because they are not directly used by the user. Instead, the walking device was attached to the anchor using the locks and forces were applied in different directions to simulate the real world. The anchor frame was constrained from displacing vertically and sliding outside the bed. The second constraint was applied by assuming the user attached a strap from the anchor to the frame of the bed. The images for these analyses are shown in the Appendix. Images for displacement and strain were not included because their values where so small ($x10^{-2}$ and $x10^{-5}$ respectively) they were not considered relevant.

The first analysis performed consisted on the application of a force from the inside of the bed to the outside. This force simulated the person pulling or pushing the device away from the bed. Two forces of 40 lbs. each were applied to the handle where it meets each leg. In this scenario, the user would weight 200 lbs. and apply 40% of their body weight onto the handle or 20% on each hand.

At the start of the analysis, it was observed that the knob would always fail due to stresses being bigger than the yield stress of 6061 aluminum. Several variations on the size of the knob and dimensions on the opening of the lock were attempted to minimize the bending experienced by the knob, but ultimately failed. The issue was solved by changing the material of the knob from 6061 aluminum to AISI 1020 steel. This material has a yield strength of 51 ksi compared to the 8 ksi of the aluminum.

The next issue to arise was on the legs, on the surrounding area of the knob where it is attached. The analysis demonstrated that the leg would also fail as seen on Figure A- 1. The point, illustrated in the image, shows a stress level of 7.482 ksi and a factor of safety of 1.068 meaning 80 lbs. was the most it could take. To solve the problem, a small plate of 1 in. x 2 in. x 0.2 in. was added to increase the thickness of this area. Figure A- 2 demonstrates the effectiveness of this plate, considering that the stress was reduced to approximately 4 ksi with a factor of safety of 1.422. The weakest point could now endure up to 113 lbs. applied to the device, which is an increase by 41%. The maximum stresses on the knob are 7.84 ksi which leaves a safety factor of 9 in the weakest areas and a maximum of 20 or more. The safety factor was limited to a maximum of 20 to have a better illustration on different areas of the model. Figure A- 3 shows maximum stresses on the lock were around 2.7 ksi and a minimum factor of safety of 3. Lastly, Figure A- 4 illustrates a full view of how the stresses and safety factors distributed through the device and anchor.

The second analysis consisted on applying a force on one side of the walker. The chosen side was the one positioned at the middle of the bed simulating how a person would grab the rail when trying to sit up from a lying position. The same 80 lbs. was applied but only one force instead of dividing it into two forces. As seen on Figure A- 5, there are very small stresses throughout the device. The maximum stresses at the top of the device were approximately 2 ksi. The safety factor of this analysis was maxed out at 4 to have a better illustration at the distribution. Figure A- 6 shows the stresses of the knob had a maximum of 6.8 ksi and a safety factor of more than 4. Lastly, the lock had the largest stress of the analysis with 7 ksi and the smallest factor of safety of 1.15, as seen on Figure A- 7, at one securing edge.

The third and final analysis was made by applying a force from the outside of the bed to the inside. This simulated a person pushing or pulling it in the direction of the bed. Similar to the first analysis, there were two forces of 40 lbs. each applied to the legs at the point where they meet with the handle. Again the first image, Figure A- 8, shows both the walker and anchor and how stresses distributed among them. Most of the stress is concentrated around the knob area on the front and back with 2.6 ksi with a safety factor from 2.5 to 20 or more. The middle and corners of the anchor experienced 2 ksi of stress and a safety factor from 8 to 10. Figure A- 9 now shows the knob with both extremes. The tip of the knob had practically no stress while the neck experienced the maximum stress of the device with a value of 7.835 ksi. The safety factor was again set as a maximum at 20. The plate added had the least safety factor of only 1.42. The neck of the knob had between 8 and 9 in the corners, but 20 or more at the middle sections. Finally, Figure A- 10 shows the lock experienced some stresses inside with some areas ranging from 2.5 to 3 ksi and the securing edge around 2 ksi. Most of the lock does not have any significant stress. The safety factor of the most affected area is approximately 3, but most of the surrounding area increased to 6 and 7.

5.6 Failure Modes Effects Analysis

Failure modes and effects analysis (FMEA) is a step-by-step approach for identifying all possible failures in a design, a manufacturing or assembly process, or a product or service. Failures are prioritized according to how serious their consequences are, how frequently they occur and how easily they can be detected. The purpose of the FMEA is to take actions to eliminate or reduce failures, starting with the highest-priority ones. Failure modes and effects analysis also documents current knowledge and actions about the risks of failures, for use in continuous improvement. FMEA is used during design to prevent failures. Later it is used for control, before and during ongoing operation of the process. Ideally, FMEA begins during the earliest conceptual stages of design and continues throughout the life of the product or service [46]. There are three quantifiable categories in a FMEA; Severity (S), Probability of Occurrence (O), and Detectability (D). The rating for each one is ranged from 1 to 10 but with different meaning. For Severity a 1 is no effect at all and a 10 is hazardous, for Occurrence a 1 is almost never happens and a 10 is almost certain it happens, and for Detectability a 1 is almost certain it is detected and a 10 is almost impossible to detect. The purpose of these ratings is to have a Critical characteristic and a Risk Priority Number or RPN. Critical characteristics are obtained by multiplying the Severity and Probability of Occurrence (S*O). They are measurements or indicators that reflect safety or compliance with government regulations and need special controls. RPN is obtained by multiplying all three categories (S*O*D) to analyze the risk associated with potential problems identified during the FMEA.

Table 5: Failure Mode and Effects Analysis on Walking Aid Device

Function	Potential Failure Mode	Potential Effects of Failure	S	Potential Cause of Failure	O	Prevention	Detection	D	RPN	CRIT	Action Results					
											Action Taken	S	O	D	RPN	CRIT
Support from frame	Device fails to provide support	User falls during walk	10	Device is bent	1	6061 aluminum FS of 6	None	10	100	10	None	10	1	10	100	10
				Device breakage	1	6061 aluminum FS of 6	None	10	100	10	None	10	1	10	100	10
				Joint failure	2	Joints are are bolted	None	10	200	20	Reinforce by welding	10	1	10	100	10
				User uses device backwards	5	Contoured handles	Contoured handles	2	100	50	None	10	5	2	100	50
		Device is inoperable	8	Device is bent	1	6061 aluminum FS of 6	None	10	80	8	None	8	1	10	80	8
				Device breakage	1	6061 aluminum FS of 6	None	10	80	8	None	8	1	10	80	8
				Joint failure	2	Joints are are bolted	None	10	160	16	Reinforce by welding	8	1	10	80	8
Attachment to bed	Device is not attached	Device cannot be used as bedrail	6	Knob breakage	2	AISI 1020 Steel with reinforced attachment FS 1.5	None	10	120	12	None	6	2	10	120	12
				User unsuccessful locking	7	None	None	10	420	42	Audible noise when successfully locked	6	5	4	120	30
				Lock breakage	1	6061 aluminum FS <20	None	10	60	6	None	6	1	10	60	6
				Anchor frame not fixed	3	Anti-slip grips and strap	None	10	180	18	None	6	3	10	180	18
Device Displacement	Device cannot move	Device is inoperable	7	Caster detachment	1	Casters screwed to frame	None	10	70	7	None	7	1	10	70	7
				Jammed caster	2	None	None	10	140	14	Sealed Casters	7	1	10	70	7
				Stuck on Carpet	5	None	Device won't move	1	35	35	None	7	5	1	35	35
Pre-fall Support	Device does not prevent fall	User Falls	8	Brakes don't work	2	None	None	10	160	16	None	8	2	10	160	16
				Brakes not calibrated for person's weight	4	None	Device prescribed by professional	3	96	32	None	8	4	3	96	32
				Device tips over	7	None	None	10	560	56	Wider Base	8	4	10	320	32

Table 5 illustrates the FMEA performed on different functions of the entire device. These functions include: the ability for the frame to provide support to the user, the ability to attach to the bed, the ability for the device to translate while the user is operating it, and the ability to prevent or mitigate a fall. From these functions, several potential causes of failures were explored. Only one cause of failure was selected for having the highest RPN for each effect of failure mode; Joint failure occurred twice, User unsuccessful locking, Jammed caster, and Device tip over. Joint failure is the possibility for a breakage at the connection between two components. It can be seen in the table its RPN is 200 if the user is operating the device and 160 if it is not in use. Both causes assume the device is bolted together, but the RPN could be reduced to 100 and 80, respectively, if the joints are welded together. The next potential failure is if the user did not lock the device correctly to the anchor. This failure has an RPN of 420 because the device does not currently have a prevention or detection method. A simple solution to this problem is to implement a type of auditory feedback. This allows the user to know when the device has been locked correctly. If this solution is applied, the RPN would be reduced to 120. A Jammed caster is the next failure in the list. It refers to the possibility of the caster becoming jammed because of dirt, hair, or any obstruction constraining the caster to rotate. This failure had the lowest RPN of the entire FMEA, but the highest in the function with 140. At the moment, there is no way to prevent or detect this issue from happening, but a possible solution is to seal the rotating mechanism to prevent debris from entering. Lastly, the highest cause of failure with an RPN of 560 is the possibility of the device tipping over during the user's process of falling. This failure is hard to prevent because the device can never know in what direction the user falls. The proposed solution is to make the device with a wider base. This reduces the RPN to 320, which is still high. The only issue with making the device wider would be its effects on mobility around the house. A second solution is to implement the anti-tip bars illustrated in Figure 45. Because the device is not a finalized product, it is hard to predict the behavior between it, the user, and its surroundings. Further prototype testing is needed to have a more accurate FMEA.

5.7 Ergonomics and Human Factors

5.7.1 Dimensions

The height of the device needs to be adjusted for two reasons, the height of the user and the height of the bed. The correct height of the device depends on the height of the user. The appropriate height for a cane or walker is the distance from the floor to the line of the wrist on a person. This point is usually 0.483 * H, where H is the height of the person [35]. There must also be a second adjustable section on the device. This section of the device allows it to be at the correct height for it to be anchored to the bed. Every bed base has different clearance from the floor, but the standard for a high-profile base is around 9 in. in height, whereas a low-profile base is between 5 and 5.5 in. [47]. The adjustment of the device can be achieved by spring-loaded push buttons (Figure 63) located above and below the anchor locking knob.

Figure 63: Spring-Loaded Push Button Mechanism for Height Adjustability [48]

After researching the correct distance between each hole for the spring-loaded push button mechanism, no information regarding this topic was found. Based on existing medical devices, such as crutches or canes, it was observed that the holes are positioned 1 in. from each other. Therefore, the proposed walking aid device uses the same approach.

Figure 64: Crutch Spring-Loaded Push Button System [49]

In addition to the push button adjustment, a locking ring (Figure 65) was also added. By implementing this locking mechanism, it will ensure that the device is secure and stiff by avoiding the wobble caused by the lack of a tight fit from the push button mechanism. After the height has been set using the push buttons, the user would screw the locking ring as tight as possible.

Figure 65: Screwable Locking Ring [50]

The width of the prototype shown in Figure 44 was based on the minimum size of a door which is around 2 feet. The prototype had a width of 1.5 feet to fit through the smallest doors with no problem. This prototype was later shown to occupational and physical therapists for general thoughts and criticism. Regarding the dimensions of the device, they noticed that for a thin person, the width is correct, but it would not be appropriate for people of bigger size or wide stance. Thin people can easily fit their feet in between the legs of the device, but people with a wider stance would end up kicking the feet of the device with each step. It was explained to them the reasoning for the chosen width of 1.5 feet, but the physical therapist [17] mentioned that it was a tradeoff: it could be kept small to fit through doors and not be used by people of wider stance, or not fit through every door but used by anyone. In the end, he recommended to make the device wider even if it meant that the user would have to turn the device slightly to pass it through a door first and then themselves. He explained that even though it is not recommended for a patient to let go of their device, in this particular case and for this particular audience, the user could grab on to the door frame for a small moment in case they need that minor support. It was also mentioned that widening the device would allow the user to have a better grip on it. With a smaller device, the user is prone to hold the device right at the ends of the handle. This would result in the fingers being placed right at the corner of the handle and touching the legs of the device. Taking these comments into consideration, the width of the device was increased to 2 feet for a more comfortable walking experience for the user.

5.7.2 Handle

The correct operation of the device is based on the user knowing which side is correct to use essentially by instinct and without their vision. If the device is held backwards, the user risks a potential fall as the device could tilt forward with the smallest of forces. To solve this issue, it was decided to add two rubber hand grips with finger grooves like the ones in Figure 66 [51].

Figure 66: Hand Grips with Finger Grooves [52]

The finger contours would signal to the person they are holding the device the wrong way. If the user were to grab the device backwards, they would have immediate tactile feedback signaling them to turn the device for a more comfortable grip. The grips also allow the person to know where to correctly grab the handle bar; if the person grabs the handle from the middle, it would not give them the appropriate support if they need it. The more parallel the arms are to each other, the better position the arm muscles would be to give the most strength.

The therapists also pointed out that having a straight bar as a handle would not be very comfortable to grab. Because side handles cannot be added to the design, the handle could be at least slightly curved to better conform to the natural wrist position. This curve does not have to be very prominent, but can be very subtle to conform better to the natural positions of the wrist. The neutral position of the forearm is dictated by the rotation of the wrist. The best position of the wrist for a comfortable position in the forearm is at 90 degrees as seen in Figure 67 [53] [54].

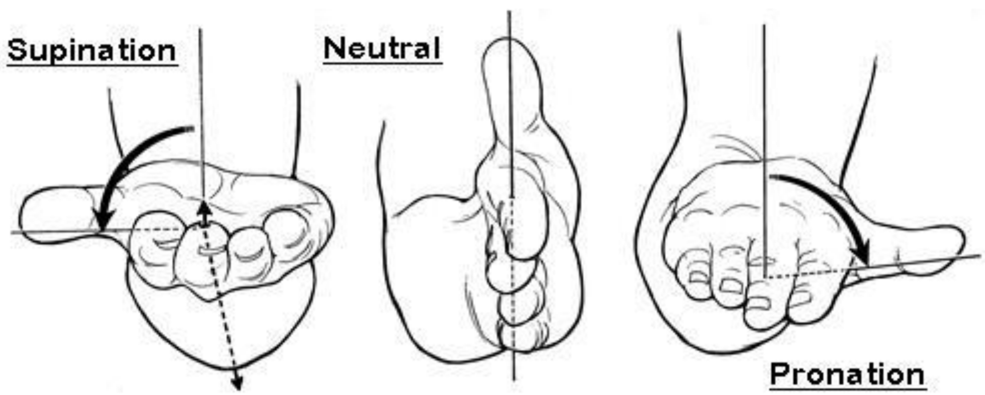


Figure 67: Types of Wrist Rotation [54]

The handle was given a curvature with a radius of 24 in. and an angle of 60 degrees measured from the center of the circle to the edges of the circle segment. The handle was curved as much as possible without it extending into the bed. Depending on the location of the hands, the wrist will have approximately 15 to 20 degrees of tilt from pronation. Figure 62 and Figure 68 illustrate the curvature of the handle.

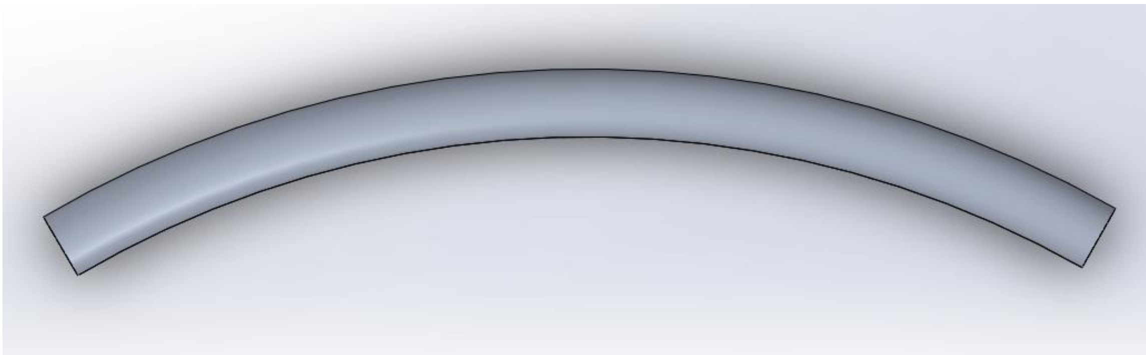


Figure 68: Top View of Curved Handle

Even though the curvature does not achieve a neutral wrist position, it does relieve strain on the forearm and wrist for a more comfortable grip. The handle is to be grabbed using a power grip. With a power grip the fingers are bunched firmly around an object and overlapped by the thumb. In this situation, the forearm muscles have shortened half-way through their available range of contraction, and they are at their most efficient because of the mechanics of the line of pull. There should be a large area of contact, with no spots of local high pressure to prevent strength of grip being inhibited by discomfort. To achieve a power grip, the best diameter for the handle is 1.18 to 1.57 in. and length of the contoured hand grip is 4 to 6 in. [51].

5.7.3 Visual and Auditory Feedback

The device also includes a strip of LED lights in the front of the handle to make the path visible for the user. This light is dim enough to not blind the user or wake them up but bright enough to receive a good view of the path in front of the person. The color of the light is also of concern as it has been stated that blue light specifically can significantly impact sleep [55] [56]. A yellowish-reddish color can be used to prevent further awakening of the user which would help them go back to sleep. An extra blinking LED indicator can be placed at the top of the device to allow the person to see it at night and remember that the device is there to help. This blinking LED only turns on when the device is anchored. Once the device is unhooked from the anchor, the LED strip would turn on and light the way. Another use for LEDs is in the anchor. Once the person has unhooked the device, a blinking LED placed on the anchor locks should turn on to show the person where the lock is. This assists the person once they are going back to bed and want to hook the device at night. Without any feedback from the device or anchor, the user would struggle to find and lock the device once they return from their trip. By placing LEDs on the anchor locks, the user would be able to find the anchor regardless of room lighting. An additional function to the groove on the lock was to have a tactile feedback once the knob has fallen into the groove. This effect can be enhanced by adding auditory feedback when the device has been locked to assure the user that the locking was successful.

5.8 Value Opportunity Analysis Revision

At the beginning of the design process, a value opportunity analysis was performed comparing a standard walker, a cane, and a projection on the device that was designed. The values given to this projection were based purely on an ideal design for the project. Now that the design has been finalized and tested, a revision can be made to the VOA to compare the products and the new device based on observations. These observations are still subjective based on the author's opinion, but backed with the observations made on the prototype and the final design.

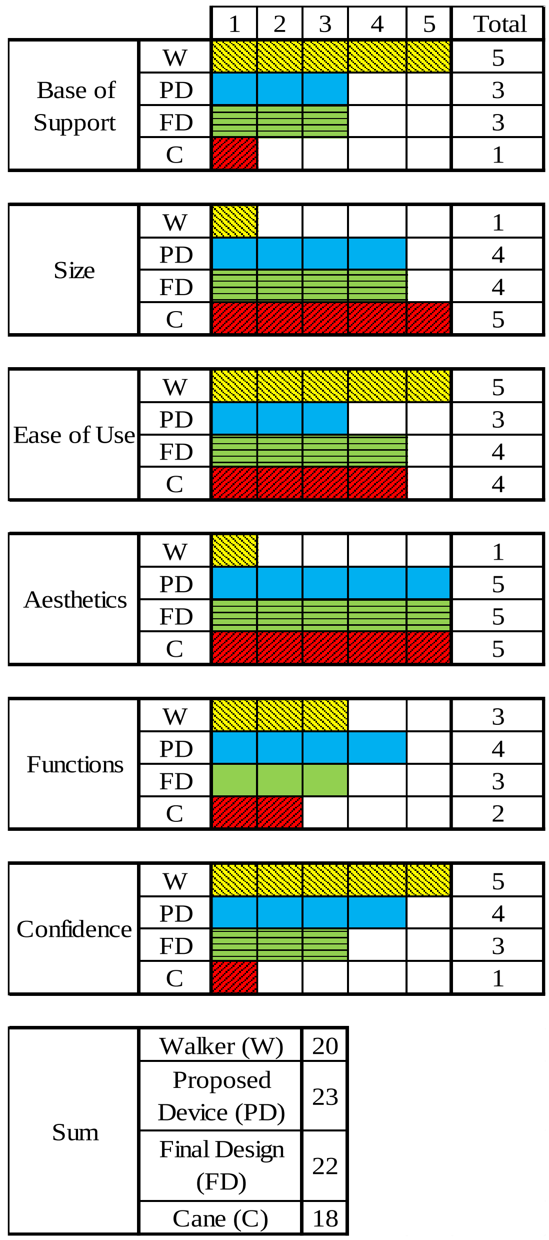


Figure 69: Revised Value Opportunity Analysis Chart

Figure 69 is a revised value opportunity analysis chart which illustrates the differences between the proposed device at the beginning of the design process and the final designed device. The first change was on the Ease of Use. This was increased by one point because the locking mechanism was successfully designed to be very simple to use while at the same time very secure. The Functions value was decreased by one point in comparison with the proposed model because during the early stages of design. It was believed the device would also assist the user to change from a sitting position to a standing position. This feature was eliminated in response to the interviews performed to the therapists. Lastly, Confidence was also brought down one point considering the FMEA performed and observing the consequences of several element failures. Even though solutions were proposed to solve the causes of failure, tipping over the device maintained a high value after the solution was implemented. The device is only one point down in the Total compared to the proposed device at the beginning of the design process. It also remains a better product than a cane or a walker based on the author's appreciation.

CHAPTER VI

TESTING AND VALIDATION

6.1 Working Model 2D

Working Model 2D is an engineering simulation software. Virtual mechanical components, such as springs, ropes, and motors are combined with objects in a 2D working space. After the software is run, the program simulates the interaction of the model's parts and can also graph the movement and force on any element in the project. It is useful for basic physics simulations and a powerful dynamic geometric analytical tool [57]. Although the early physical prototype was useful to visualize and understand the limitations of the design, a more detailed analysis is needed to study the interaction between the user and the device. For this reason, Working Model 2D was chosen to test a visual prototype. This software was used to simulate and validate the braking system and its stability as well as previously calculated results and the early prototype tests. All of the simulation videos can be accessed in https://faculty.utrgv.edu/noe.vargas/walker-videos/.

Five scenarios were chosen for this study. The best distance from the body to hold the device, the relationship between the person’s body weight and failure (tilt) of the device, the effectiveness of a braking system implemented in the casters, the behavior of the device when the person trips, and the interaction between the device and person when they faint or collapse while stationary. These scenarios were chosen to determine the different interactions between the device and the user. They were also chosen to validate previous assumptions and calculations made in the document. The overall question these simulations were expected to answer is; how much support does it provide and how stable is the device when subjected to different situations. These scenarios may not encompass all possible situations and failures, but they are a start to determine the stability of the device.

6.1.1 Simulation Setup

To perform the simulation, the device was drawn using the measurements found in previous sections and with the corresponding height of the human figure. The human figure was obtained from simulations provided by the software developer [58]. The figure had anatomically correct movement constraints employed by ropes and separators in the arm, leg, and head. In addition, the figure was also provided with further constraints to allow more accurate movement of the leg. Springs, actuators, and a second leg were also added to simulate the figure making half of a step forward, as seen on Figure 70.

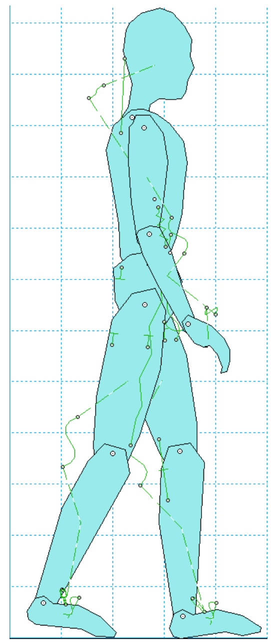


Figure 70: Human Figure with Constraints

The walking gait of the simulation started from the Pushoff phase and ended in the Midswing phase, as seen on Figure 71. At the end of the Midswing, the human figure is standing solely on one foot. The torso of the figure was sometimes given forward velocity from 1-4 feet per second (fps) as specified in the simulation. Only half a step was simulated because it is quite difficult to simulate a walking gait controlling every muscle in the body. This is a physics-based simulation, not an animation.

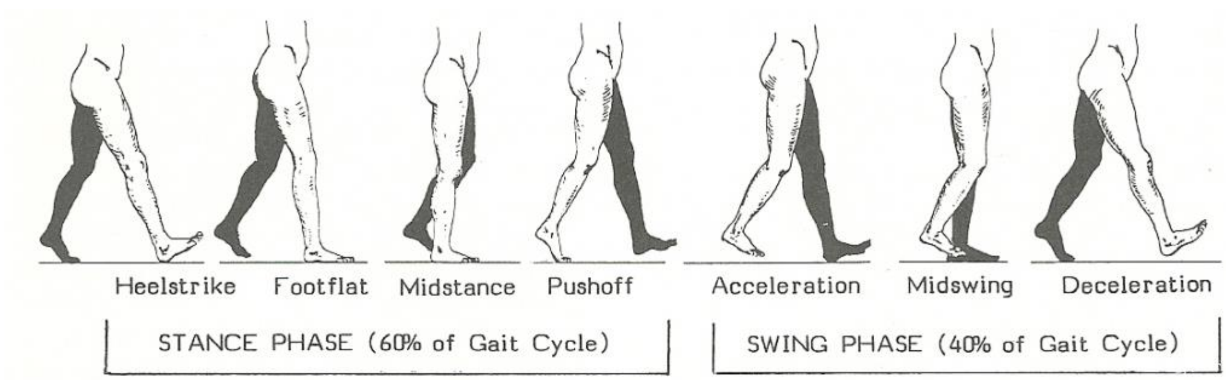


Figure 71: Walking Gait Cycle [59]

Every body part was given appropriate weight in relationship with the total weight of 120 lbs. of the human [35]. The hand of the model was attached to the handle of the device via a pin. All the device except for the handle was set to prevent collisions with the body of the human.

6.1.2 Best Distance Simulation

The first experiment performed was to determine the appropriate distance of the device from the body. This test revealed how the device reacts to the human when being held at the recommended distance as well as further away from the body. The starting distance was 4 in., as recommended by the physical therapist [17], and in each simulation the distance was increased by 1 in. until the device failed. An actuator was placed on the right foot to simulate walking. The torso of the human was also given an initial velocity of 2 fps to keep up with the motion of the legs. The simulation was divided into three sections as seen in the images below. It can also be seen that in the second and third sections of the images, the human figure is placing most of its body weight directly on the device. The simulations of 4 in. to 6 in., from Figure 72, Figure 73, and Figure 74, demonstrate the device did not tilt at those distances, but rather maintained complete contact with the ground.

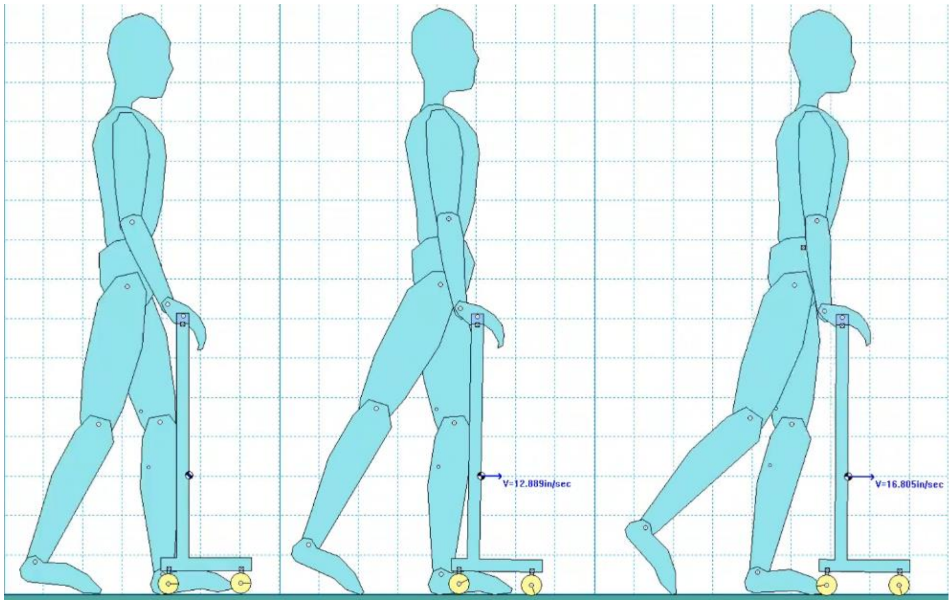


Figure 72: Figure Holding Walker at 4 in.

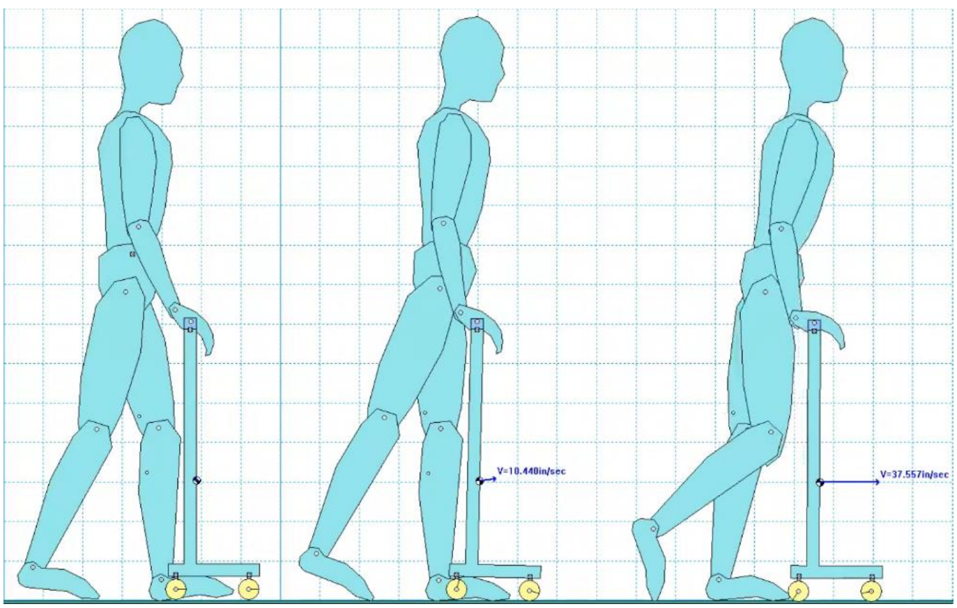


Figure 73: Figure Holding Walker at 5 in.

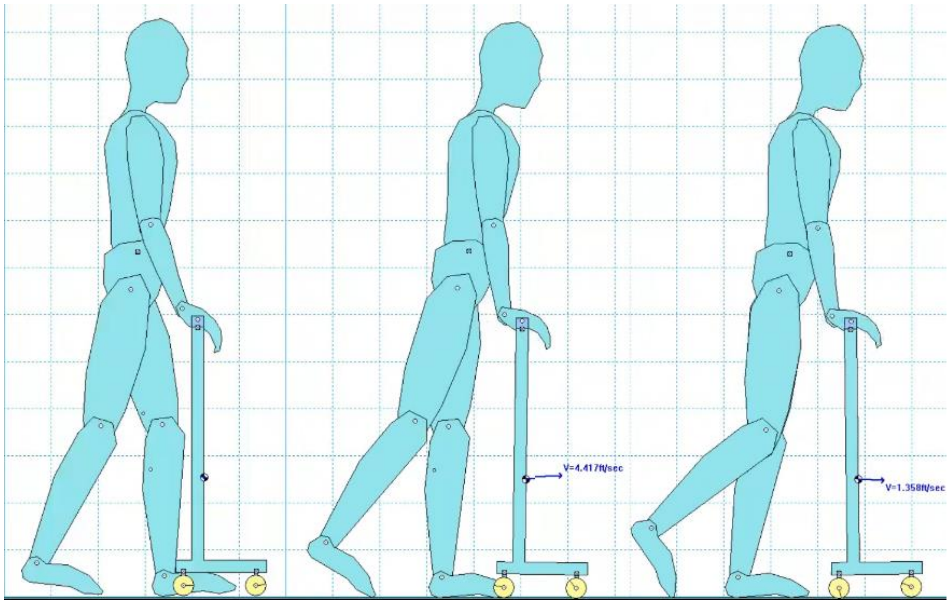


Figure 74: Figure Holding Walker at 6 in.

On the other hand, holding the device at 7 in. and 8 in., Figure 75 and Figure 76, illustrate how the device could fail if held too far away from the body. In both images, the device starts to tip over in the second section and worsens in the third. This is caused by the weight of the person not being placed directly on top of the device, but rather at a slight angle creating a moment. In case the device is being held from 4 to 6 in. away from the body and the device starts to tip over towards the user, the handle of the device would simply bump into the legs of the person and prevent it from tipping over. This was not demonstrated by the simulation but proved by the prototype.

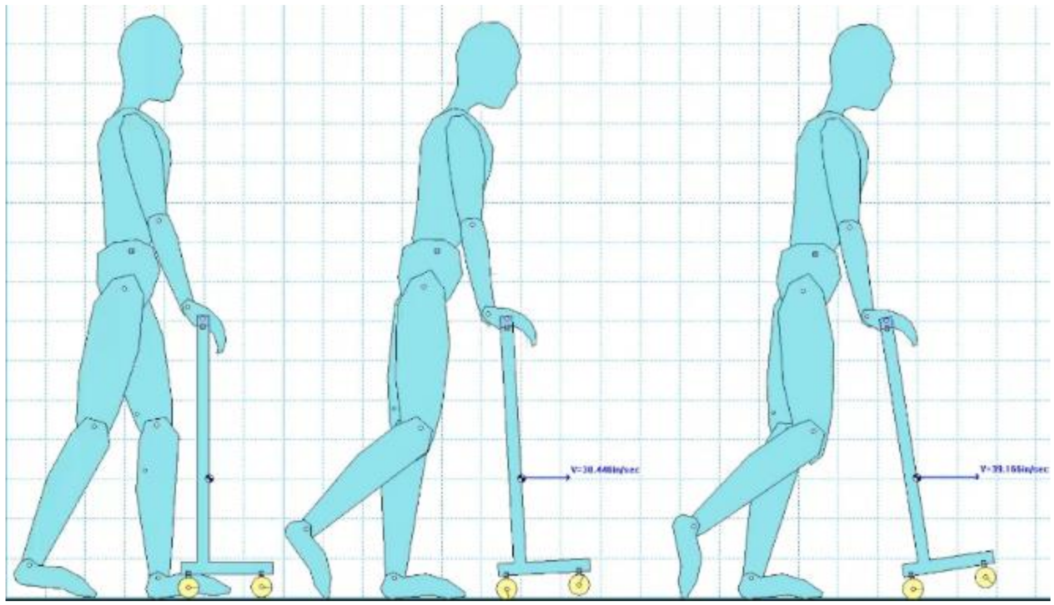


Figure 75: Figure Holding Walker at 7 in.

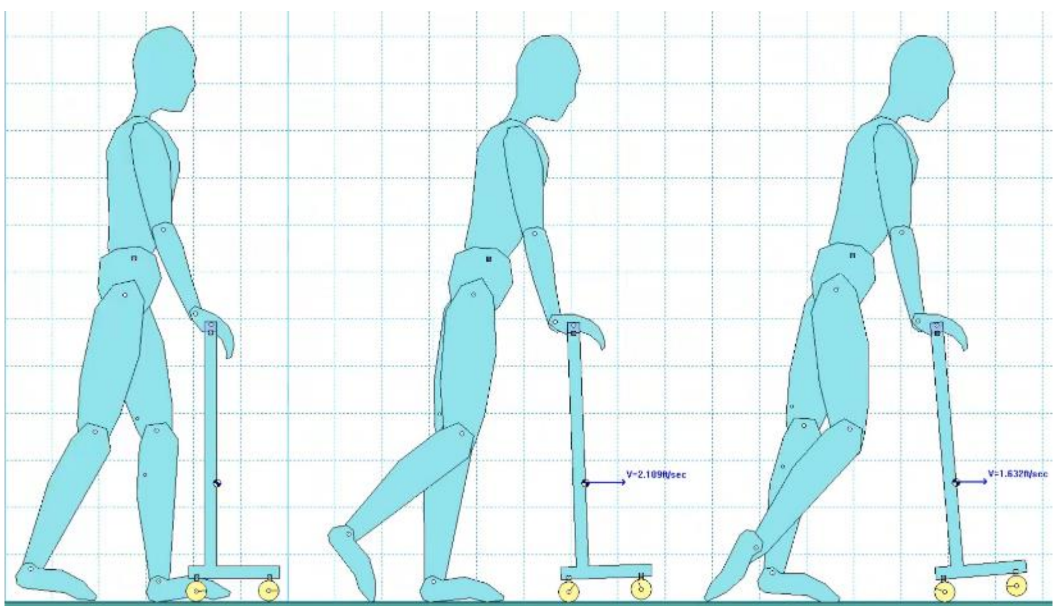


Figure 76: Figure Holding Walker at 8 in.

6.1.3 Body Weight Test Simulation

The second test consisted in examining the importance of the different human weights on the device. The three tested body weights were: 97 lbs., 133 lbs., and 233 lbs. Again, the right leg had an actuator and spring to simulate the walking motion. The torso was given an initial velocity of 1 foot per second for the simulations of 97 lbs. and 133 lbs., but 2 fps for the 233 lbs. simulation. The device was held at 4 in. The simulations' results were remarkably identical to each other. There was no change in the angle of the device or in the human's walking gait as seen on Figure 77, Figure 78, and Figure 79. An undocumented simulation went as far as making the human weight 500 lbs. and only failed when increased to 520 lbs. The slight variations between each simulation came from the estimated change in force values in the foot actuator and not the weight of the person itself. This result is expected because at the beginning of section 4.1.2 Functional Resolution it was determined the only important human variable in relationship to the device was their height. Therefore, if only the stability of the device is concerned and not the structural integrity, there is practically no weight limit for the device.

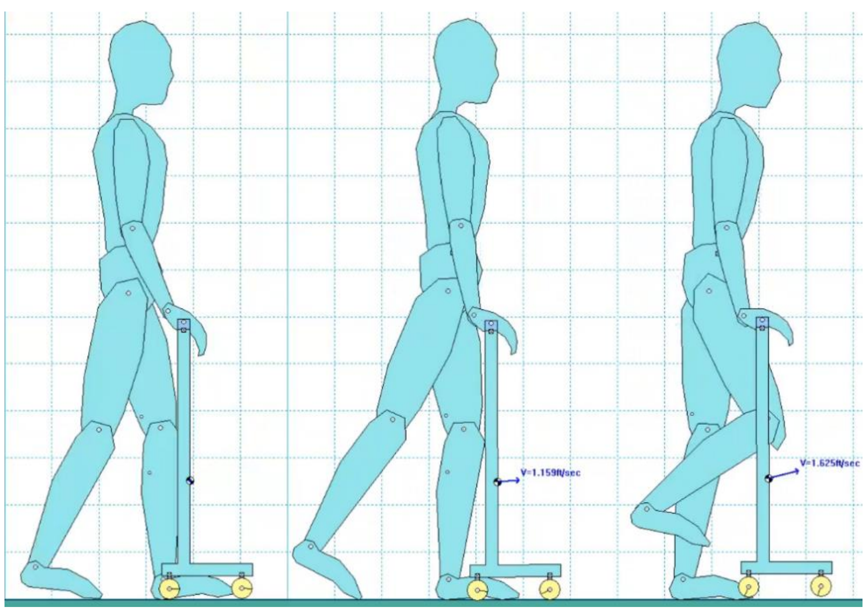


Figure 77: 97 lbs. Body Weight at 1 fps

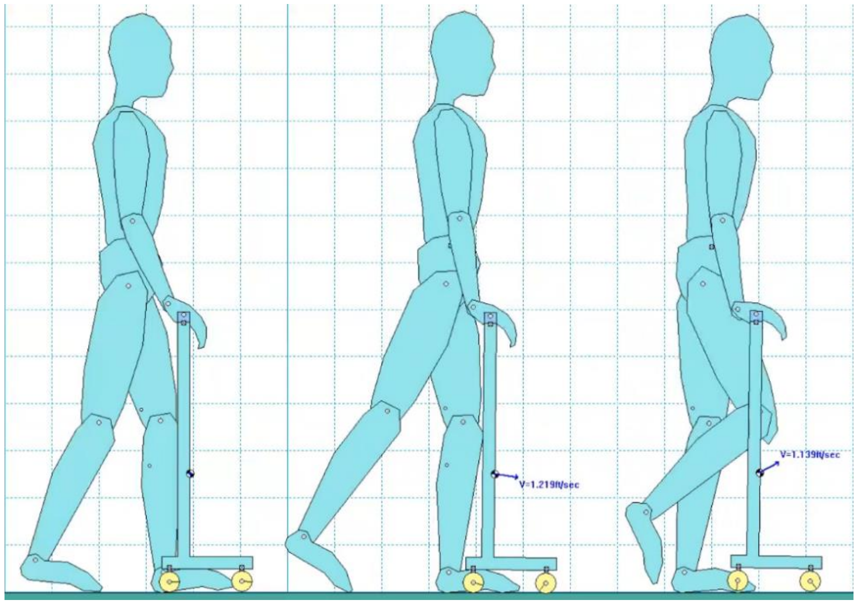


Figure 78: 133 lbs. Body Weight at 1 fps

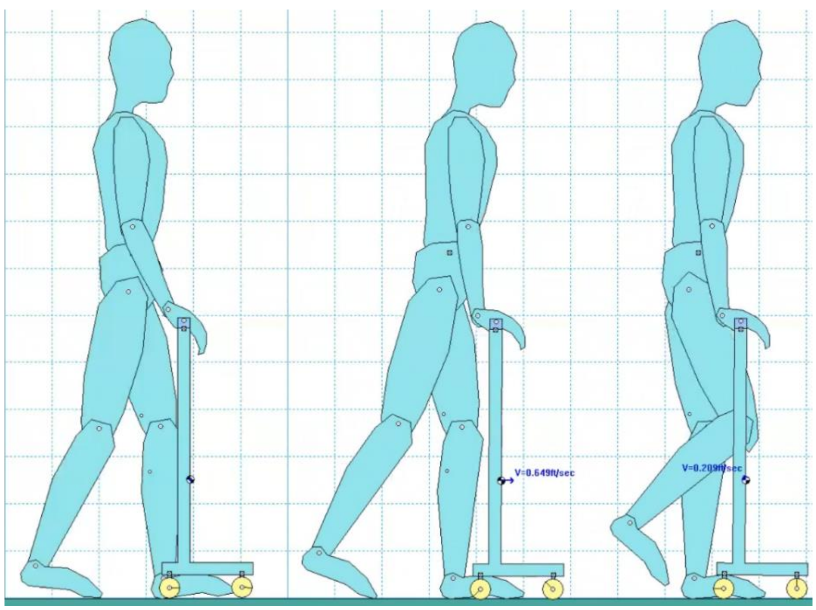


Figure 79: 266 lbs. Body Weight at 2 fps

6.1.4 Brake System Simulation

The third test performed determined the usefulness and effectiveness of a braking system implemented as described in section 5.3 Movement and Braking. The system consists of specialized casters placed on the back of the device that stops rolling completely when too much weight is applied. This aids the user when they trip forward and is in need for a stable support. The braking system prevents the device from rolling away.

For this test, the human did not have actuators and springs to simulate walking but rather to help the figure stand. The only motion provided was on the torso simulating a difference in velocity between the upper section and lower section of the body. This difference in velocity replicates a person tripping or slipping. Several simulations were made comparing a device with no brakes (Figure 80, Figure 81, and Figure 82) and another with activated brakes (Figure 83, Figure 84, and Figure 85). For both, three different torso velocities were tested ranging from 2-4 fps. The brakes were simulated by removing the pin from the back casters and replacing it with a fixed pin.

Figure 80 and Figure 82 illustrate how the absence of brakes cause the device to tilt towards the user and then fall to the ground. A possible cause for the tilting is because the device experiences a sudden rapid force. This creates rapid front and back rocking by the user which leads to the device's tilt. A second cause is the user's response to the fall. The user may tilt the device while trying to pull it towards them. The opposite may also be true as the user may push it away from them because of the stumbling. For this reason, it is recommended to hold the device close to the body. The absence of brakes does not signify the device is guaranteed to fail when a person trips. Figure 81 proves this circumstance where the human moving at a velocity of 3 fps did not cause the device to tip over. The simulations shown in Figure 80 and Figure 82 are just examples of the possibility of device tilt and how it could be solved by adding brakes.

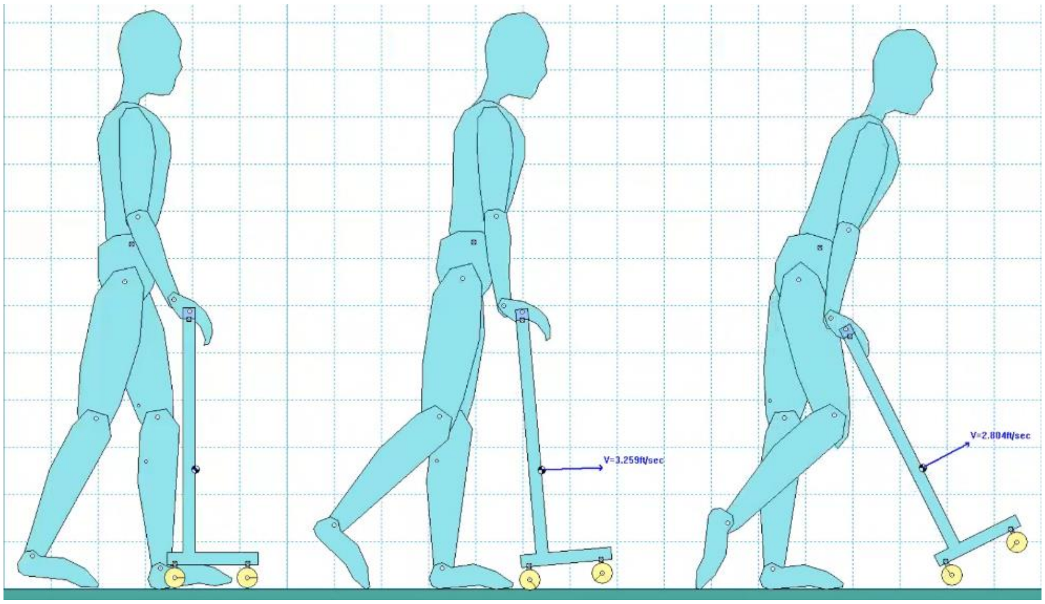


Figure 80: Velocity of 2 fps without Brakes

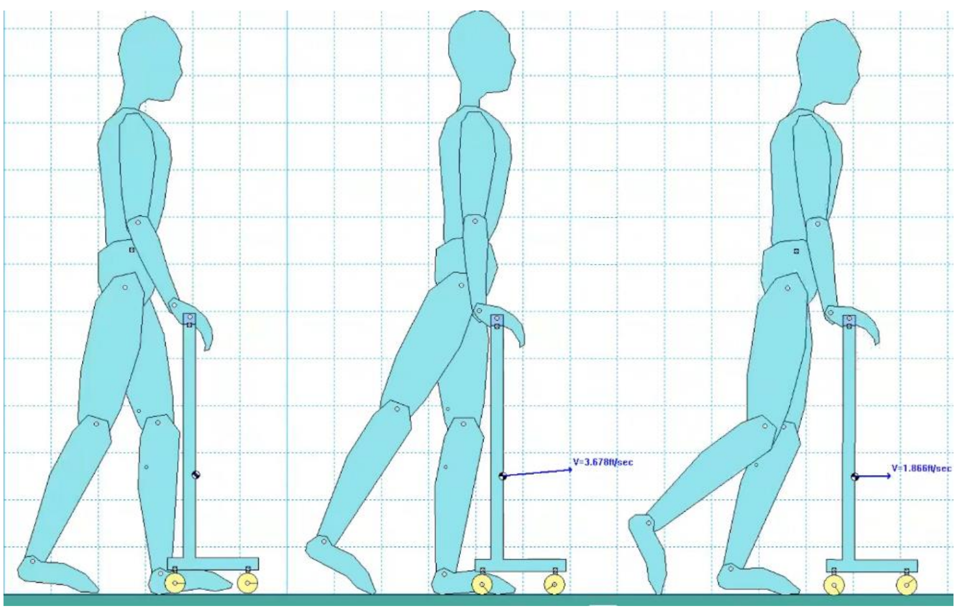


Figure 81: Velocity of 3 fps without Brakes

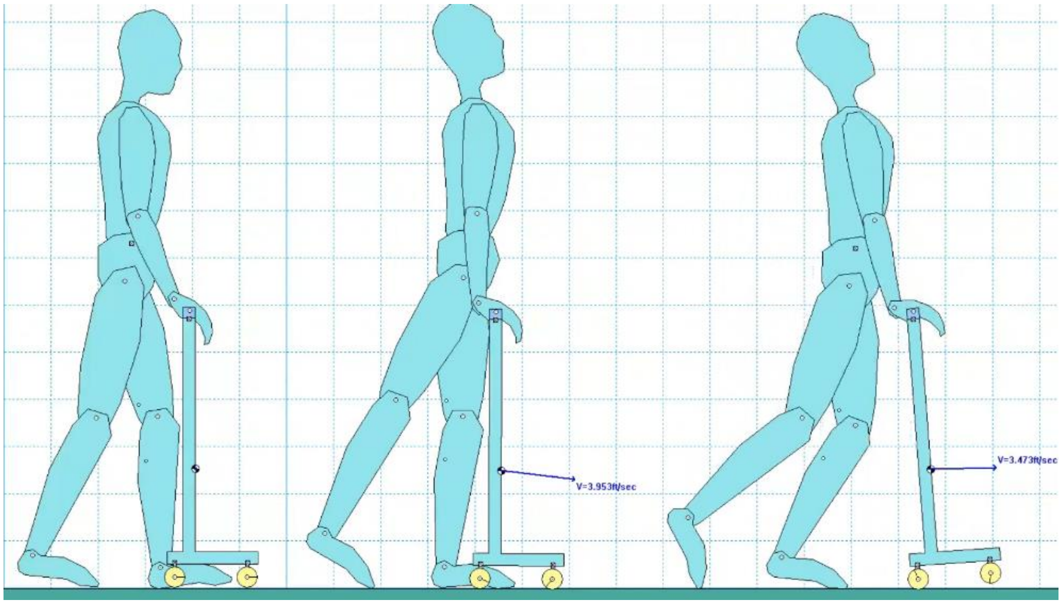


Figure 82: Velocity of 4 fps without Brakes

On the other hand, Figure 83, Figure 84, and Figure 85 demonstrate how the presence of brakes actually aids the prevention of the fall by providing support to the person. The brakes were so effective that the human would stay standing on one foot for a couple of seconds before falling backwards. Figure 85 shows how the device remains firm and correctly positioned even after the person falls over it. This simulation is continued in the next section. The lack of rotation on the back casters prevents the three possible problems discussed. While it does not prevent rocking, it prevents the sliding of the back casters while the front ones are in the air. Although, this is also dependent on the friction between the casters and the ground. The brakes prevent further displacement of the device, and therefore, it cannot be pushed away by the user.

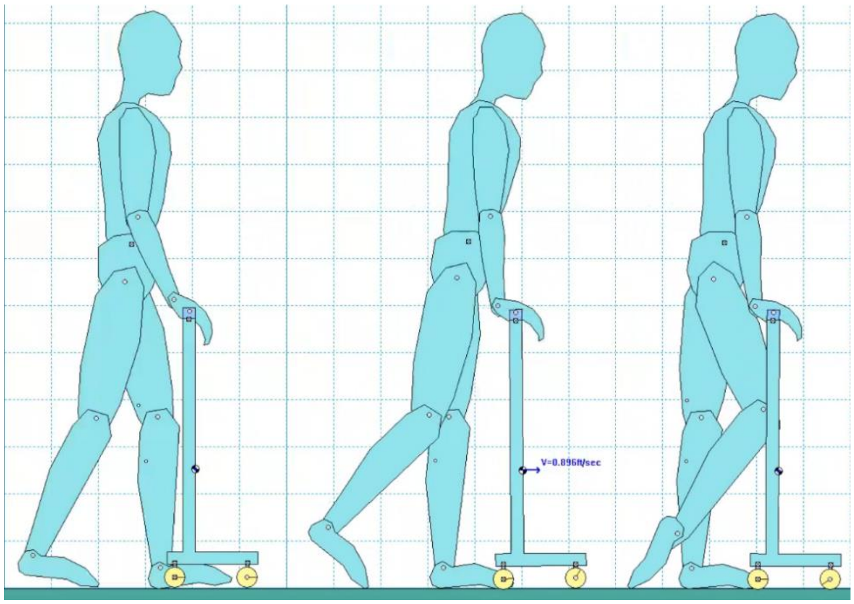


Figure 83: Velocity of 2 fps with Brakes

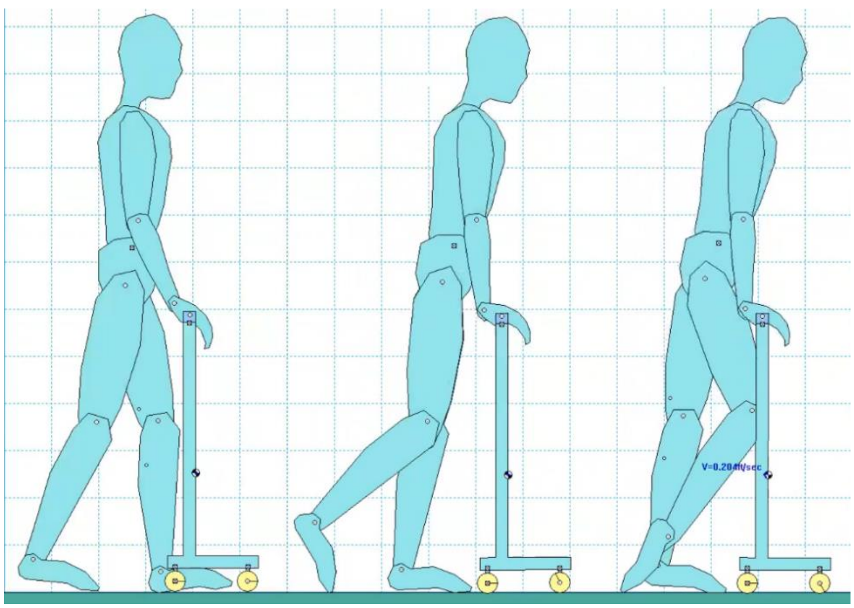


Figure 84: Velocity of 3 fps with Brakes

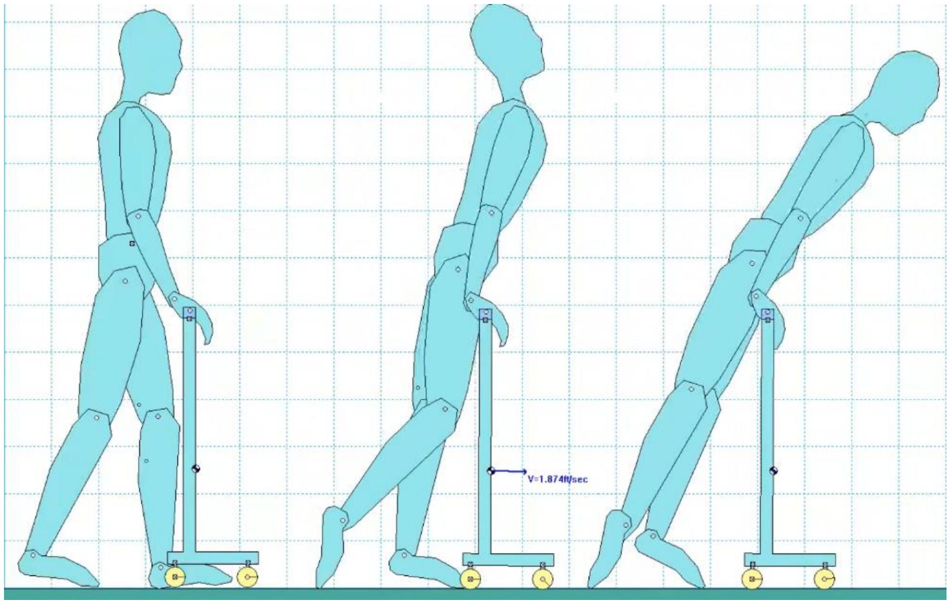


Figure 85: Velocity of 4 fps with Brakes

6.1.5 Device Stability

The previously examined tests were the focus for the simulations, but during the testing, some observations were made. During early simulation tests and the brakes simulation of Figure 85, the human figure fell over the device. This was an unexpected but welcomed result because it demonstrated the stability of the device. Figure 86 is the continuation of the simulation with the activated brakes and a torso velocity of 4 fps. The simulation shows how the human starts to lean on the device, putting their entire body on top of it, and then falling over. During the entire simulation, the device did not tilt or rotate at all. It also remained stationary as the braked back casters prevented the device’s movement. During the fall, the human’s body remained stiff straight because the hand was permanently pinned to the device.

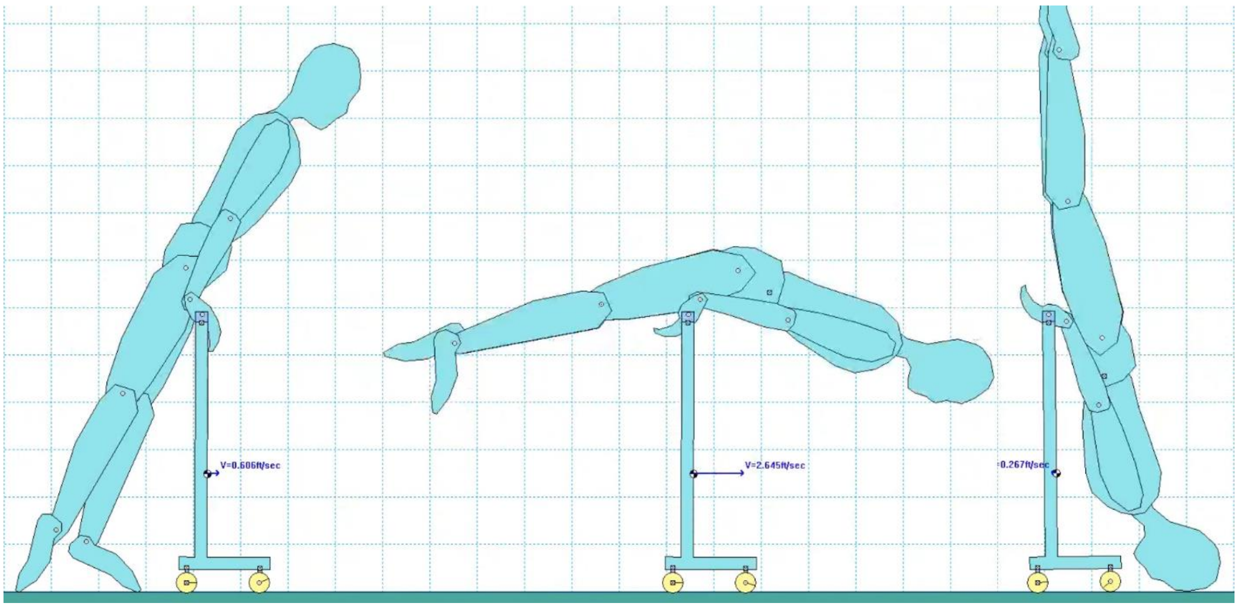


Figure 86: Human Falling Over Device with Hand Pinned

To illustrate a more realistic fall, the hand was freed of the pin 1.5 seconds after the simulation started, or when the human started to lean on the device. Figure 87 shows a more realistic body movement where half of the body hangs on the handle of the device. Regardless of the modification, the device remained sturdy until the human fell over it and pushed it backwards with its legs. These simulations demonstrate and reinforce the effectiveness of the device to provide support to the user without the worry of it rotating forwards. This situation is possible but improbable because if the user trips, they would be conscious enough to prevent themselves from falling over the device. It should only happen if the user faints while walking at a high speed.

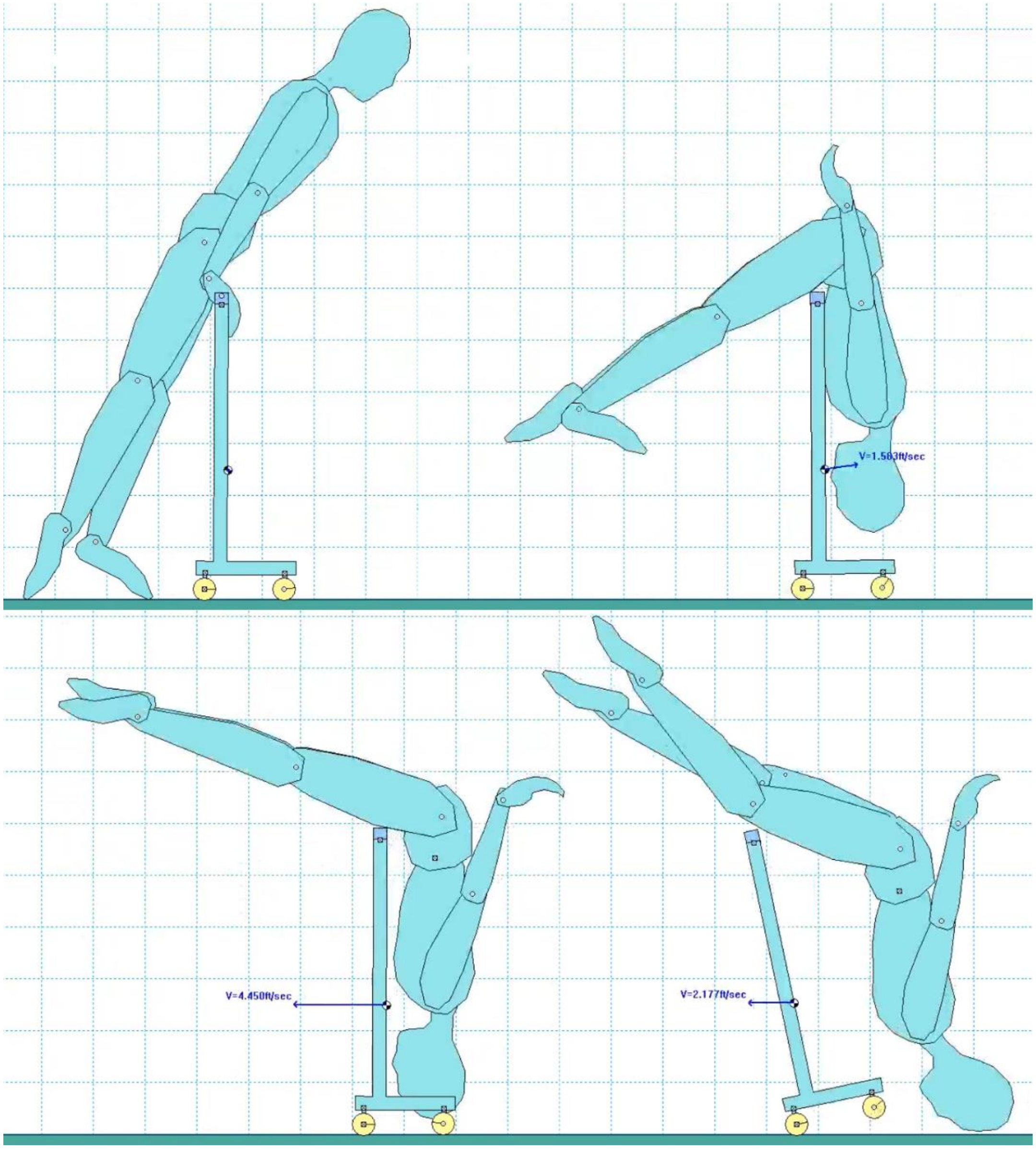


Figure 87: Human Falling Over Device with Hand Unpinned After 1.5 Seconds

6.1.6 User Collapse

Lastly, a final test was made to determine the interaction between the device and the user if they were to suddenly collapse or faint. The result of this simulation was not expected to give any feedback on device failure. There are only so many problems a single device can solve. The main concern, regarding falling with the device, was the possibility of striking the device while falling and to examine how harmful would the device be in that situation. Several simulations were made by changing variables to vary the outcomes. The torso velocity was set to 0 fps, 3 fps, and 3.5 fps. Even though torso velocity was applied, the human figure did not walk similarly to previous simulations because no forces in the feet and leg actuators or springs were applied. The second variable was the back-caster brakes which were only activated or deactivated. The first simulations consisted in the human holding the device throughout the entire simulation. This led to it striking its head with the handle while falling, as seen on Figure 88. This type of simulation was inaccurate because when a person faints, they lose strength throughout their entire body and, therefore, release the device.

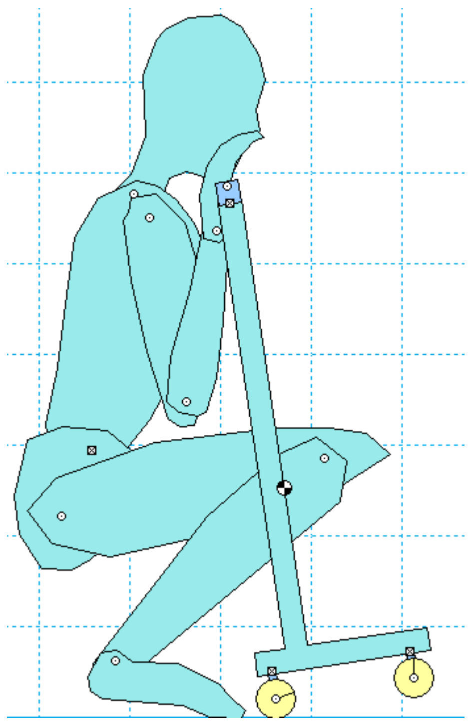


Figure 88: Head Strike While Hand is Permanently Pinned to Device

This was changed by setting a timer on how long the human would hold the device. The hand was switched to hold the device between 0.2 and 0.3 seconds.

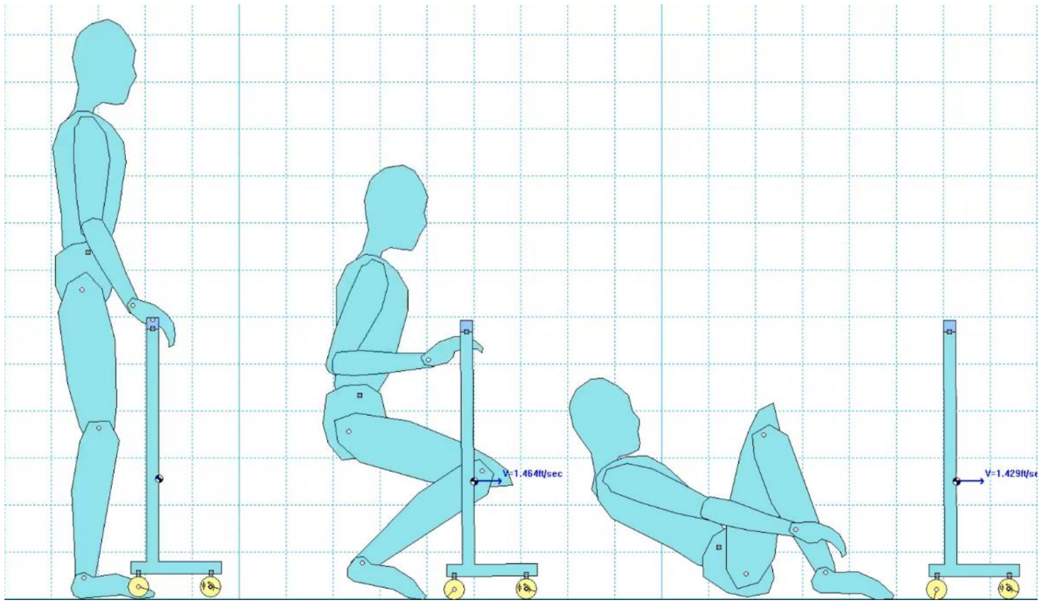


Figure 89: Human Fall with 0 Torso Velocity

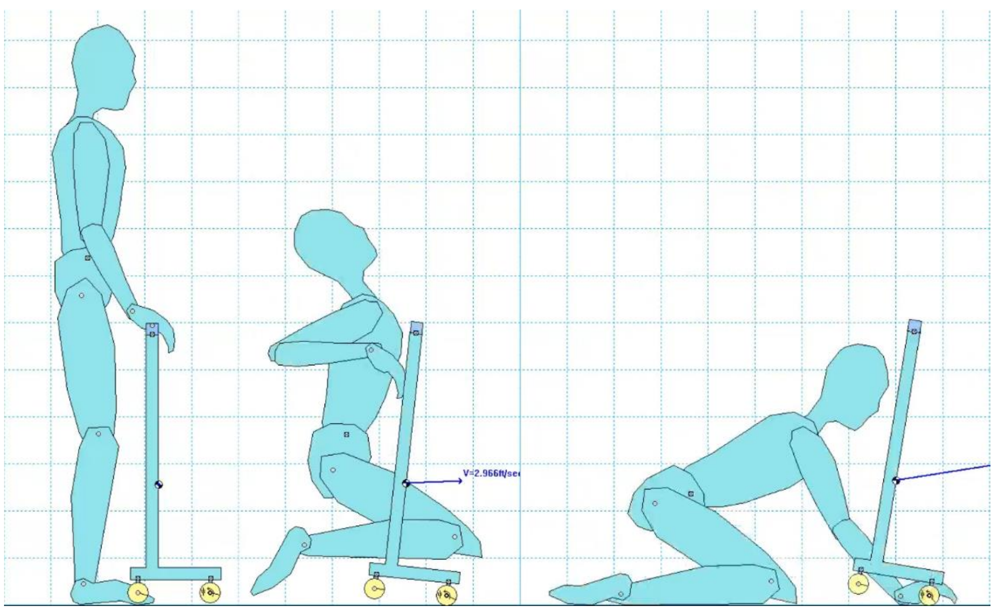


Figure 90: Human Fall with 3 or 3.5 fps Torso Velocity

The results were unexpectedly similar to each other. Even though there were twelve simulations performed, all results varied between two types of falls illustrated in Figure 89 and Figure 90. The first type of fall (Figure 89) only occurred when the human had 0 torso velocity.

It consisted in the human falling downward and onto their backs. The second type of fall (Figure 90) occurred when the human had any velocity. It consisted in the human falling downward to its knees and remained in that position for the rest of the simulation. The change in time holding the device or state of the brakes had no effect on the fall, aside from how far the device was pushed away by the human's hands or chest. Overall, there was never any direct impact between the device and the human in the simulations. Even though the tests demonstrated no harmful contact with the human in these scenarios, these tests are only simplified 2D representations of the interactions between the device and the user. These simplified simulations provide useful insight into the user-product interaction in basic scenarios. Future analyses should increase the model validity by increasing the quantity and complexity of variables involved as well as physical prototype testing under controlled conditions to avoid harming potential users. As previously mentioned, all simulation videos can be accessed in https://faculty.utrgv.edu/noe.vargas/walker-videos/.

6.2 Prototype

As previously stated in section 5.1 Support Frame, an early prototype was built to gain important insights. This prototype was only made to study its stability and support. It is by no means a final prototype because several components are missing like the braking system and anchor. The prototype was made using PVC tubes and wooden feet. The feet had fixed casters at the back and swivel casters at the front.

Figure 91: Prototype of Basic Frame

The prototype was tested by the author in similar scenarios to the Working Model simulations. It was tested by walking normally, using only one foot or hopping, and walking with a forward leaning posture. The author is a healthy 25-year-old 120 lbs. male at the time of testing. During these tests, the device aided the author during the different walking methods. It provided sufficient support even when walking on one foot. The prototype was also tested by applying as much weight on the device as possible while being stationary or walking. To test the weight limit, the author placed his entire body on top of the device while stationary. The legs had a minimal forward bend of less than 1 in. when too much force was applied, but remained stationary. This is because the device was not glued together, the holes in the wood were not perfectly made, and PVC is relatively flexible compared to 6061 aluminum. The device was also used from 4 in. to 10 in. away from the body. The author agrees with the recommendation of the Working Model simulation and the physical therapist [17]. The device is most stable when used at a distance of 4 to 6 in. When the device was used further away, the author had less control of the device and its support. It is safer to have the device as close as possible to the body for the device to provide the support needed. If a slip or stumble were to occur, the arms should be as straight and vertical as possible to utilize the device’s support. Also, if the device were to tilt backwards but is close to the body, it would collide with the body to prevent it from slipping away. On a final note, the device would never rotate forwards nor backwards during walking tests. It did not matter how much weight was placed on the device. It remained stable throughout all tests.

As stated in section 5.1 Support Frame, the prototype was shown to occupational and physical therapists. All the therapists had very positive comments about the device and were convinced the design was very stable. They agreed this project would in fact provide more assistance to cane users as they do sometimes need extra support and assistance at night. The main remark was to increase the width of the device from 1.5 to 2 ft to be more comfortable for walking and hand positioning.

Further testing is required to completely realize the device. A prototype of the anchor and lock mechanism is also desired to test their rigidness when combined with the walking aid device. Nevertheless, this early prototype provided important insight to the design process.

6.3 Final Concept Design

The following figures illustrate the final design conceptualized by the author. All of the design functions mentioned throughout the thesis and the design specifications can be seen throughout the illustrations. The only feature that could not be illustrated was the breaking system.

Figure 92: Illustration of Finalized Design

Figure 93: Walking Aid Device Frame

Figure 93 illustrates the finalized design for the walking aid device alone. Most of the components in the final design were based on the proposed design specifications in section 3.6. The device has a width of 2 ft, as proposed by the therapists, so it can be used by a wider audience at the expense of mobility through doors. After performing several structural tests, it was decided to make the device from 6061 aluminum. This material is widely used in medical devices because it is light and strong. The handle of the device is curved to reduce strain and increase comfort in the forearms and wrists. Contoured hand grips were also added for better device-to-user communication. It allows the user to know if the device is facing the right direction as well as communicating the best hand placement. As proposed by the therapists and design specifications, an LED light was included to illuminate the user's path while walking and it also reminds the device is present. The device has the ability to change its height depending on the user. It contains a push button mechanism as well as a screwable locking ring to tighten both ends, as shown in Figure 93.

Figure 94: Walking Device Compact Feature

It can be seen in Figure 94 the device was designed to be so slim that it can even fit in between the bed and the drawer. The length of the feet is only 9 in. long extended from the minimum length of 6 in. Being placed in this location does not hinder the functionality of the device. The user would simply need to unlock the device to remove it from the tight space. To operate the device, the user would unlock it from the anchor by pulling it towards them. This figure also shows the functionality of the short feet. Apart from making the device slim, they are short to avoid being a trip hazard. As explained before, the handle of the device is curved but Figure 94 shows this curvature is small and does not intrude the bed space.

Figure 95: Anchor Locks Placed on Bed

Figure 95 shows how the anchor and its locks would be placed almost flush with the bed. The locks should always be with the opening facing towards the foot of the bed. They contain a channel where the knobs of the walking device can slide in and be locked. The entrance of the locks is curved to allow easy entry and not struggle finding the channel's hole. The curves guide the knobs into the right place. The anchor is also made out of 6061 aluminum. This material is needed because it will be subjected to considerable amounts of forces when the walking device is anchored and used to stand up. By making the locks out of 6061 aluminum and the knobs from AISI 1020 steel, the device can make a distinct sound once the device has been locked. This sound is produced when the knob hits the bottom part of the lock.

Figure 96: Walking Aid Device Anchored to the Bed

This last figure, Figure 96, illustrates the device when it is locked to the bed. Being anchored to the bed, the device also behaves as a bed rail. In this mode, the device can provide support to the user when changing positions in bed. To lock the device the user would walk to the bed and slide it to the right. The device's knobs slide along the lock and fall into a grove that locks the device in every direction. To unlock, the device needs to be lifted only on the left side (closest to the middle of the bed) and pulled towards the middle of the bed.

CHAPTER VII

CONCLUSION AND FUTURE WORK

The problem of elders falling at a night setting was found to be an important problem caused by various medical and environmental conditions. The target demographic was also found to be seniors from age 65 and older. Several occupational therapists and two physical therapists were consulted to gain knowledge on elders' behavior, possible improvements on current existing devices, and feedback regarding the early prototype built. Several products and patents were researched with a lack of findings on similar devices that perform the proposed functions.

The device was successfully designed following the systematic design process from Pahl and Beitz [1]. This includes the decomposition of the device's functions and resolution to generate ideas and find potential combinations to further examine using the morphological matrix approach. Ideas for every component were generated aided by preliminary equations calculated before the idea generation process. The designs for the walking aid device, anchor, and locking mechanism were created and optimized to fulfill their functions. The walking aid device was effectively designed based on the proposed design specifications. It was designed with a small base of 2 ft which provides sufficient support, easy operation, and no assembly required as recommended by the therapists. The function of all other components was discussed to explain how they work in relation to the completed device. A finite element analysis was performed on the support frame alone and also attached to the anchor frame to determine its yield strength and failure points. 6061 aluminum alloy was chosen as the best material based on solid mechanics calculations. This material is lightweight but strong as proposed in the design specifications. The frame alone successfully withstood the forces applied with a minimum factor of safety of 6.35. The material for the knobs was changed to AISI 1020 steel to better withstand the forces applied when the device is used as a bed rail. The lowest factor of safety among all tests performed on the anchor was found to be 1.15 located in the locking mechanism.

Casters with a weight activated breaking mechanism were found to be the best choice for displacement and pre-fall prevention, although physical testing was not performed. A failure analysis was also performed to determine possible causes of failure and their negative effects on the user. Several potential solutions were found to reduce the risk of occurrence. However, the device tipping over because of the user falling was found to be still high after the solution was implemented. An ergonomics and human factors research were performed to determine the best dimensions for the product, sensory feedback (visual and tactile), and machine to user communication to further enhance the user's experience with the device based on the design specifications.

Simulations using Working Model 2D software were made to test the dynamics, interactions, and functionality between the device and the user. It was found that the best distance to hold the device is between 4 to 6 in. The weight of a person is not a concerning issue related to the stability of the device. The braking system was found to be effective in preventing falls caused by stumbling or tripping of the user. Based on the simulations, the device was found to be stable enough that it will not rotate forwards even if the person falls on top and over it. The device was also determined to not prevent or mitigate falls in any way if the user collapses or faints, but neither did it hurt the user during the fall. Lastly, the basic prototype built early in the design process was tested by the author. A variety of walking styles were imitated by the author to test the device. The tests yielded positive results as the prototype proved to be stable and provided the required support even when the entire body weight was applied to it. To finalize, the objective was met and a walking aid device was successfully designed with minor setbacks.

Future Work

Further testing is needed to validate and approve the entire device. Several tests on the walking device such as the weight limits for breakage or failure to provide support and a simulation of a person falling may be performed in the future. There were important components to the device that could not be handled in real life such as the weight activated braking system, anchor, and the locking mechanism. These prototypes are important to test the stability and rigidness of the device in bed rail mode. Physical testing of the weight activated braking system is needed to reinforce and validate the results obtained in the working model simulations. Human testing and user comparisons between this device and other walking aid devices are also needed. The appropriate regulations from the FDA need to be researched on a medical device of this category in order to be reachable by consumers.

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APPENDIX

APPENDIX

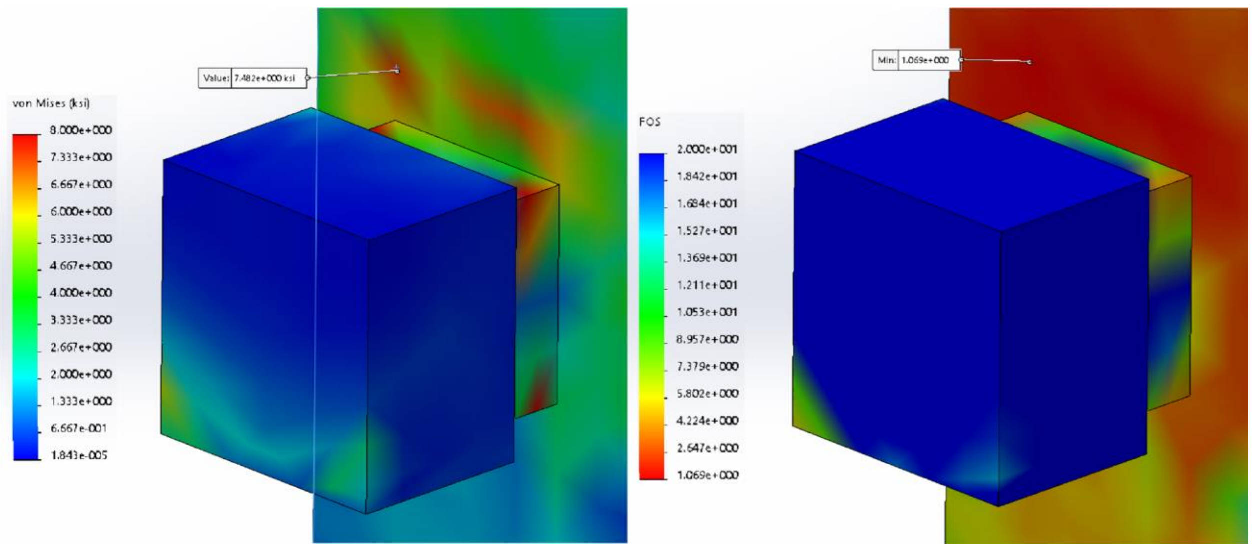

Figure A- 1: FEA on Knob without Plate; Stress Analysis (Left) and Factor of Safety (Right)

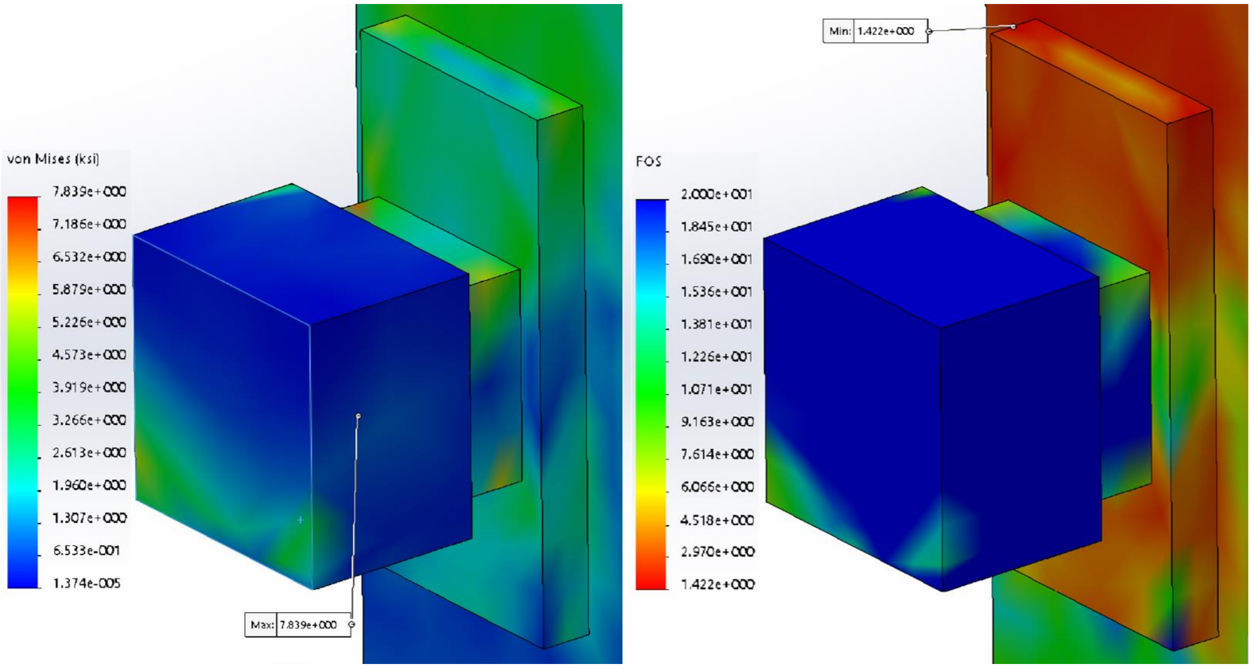

Figure A- 2: FEA on Knob with Plate; Stress Analysis (Left) and Factor of Safety (Right) (First Analysis)

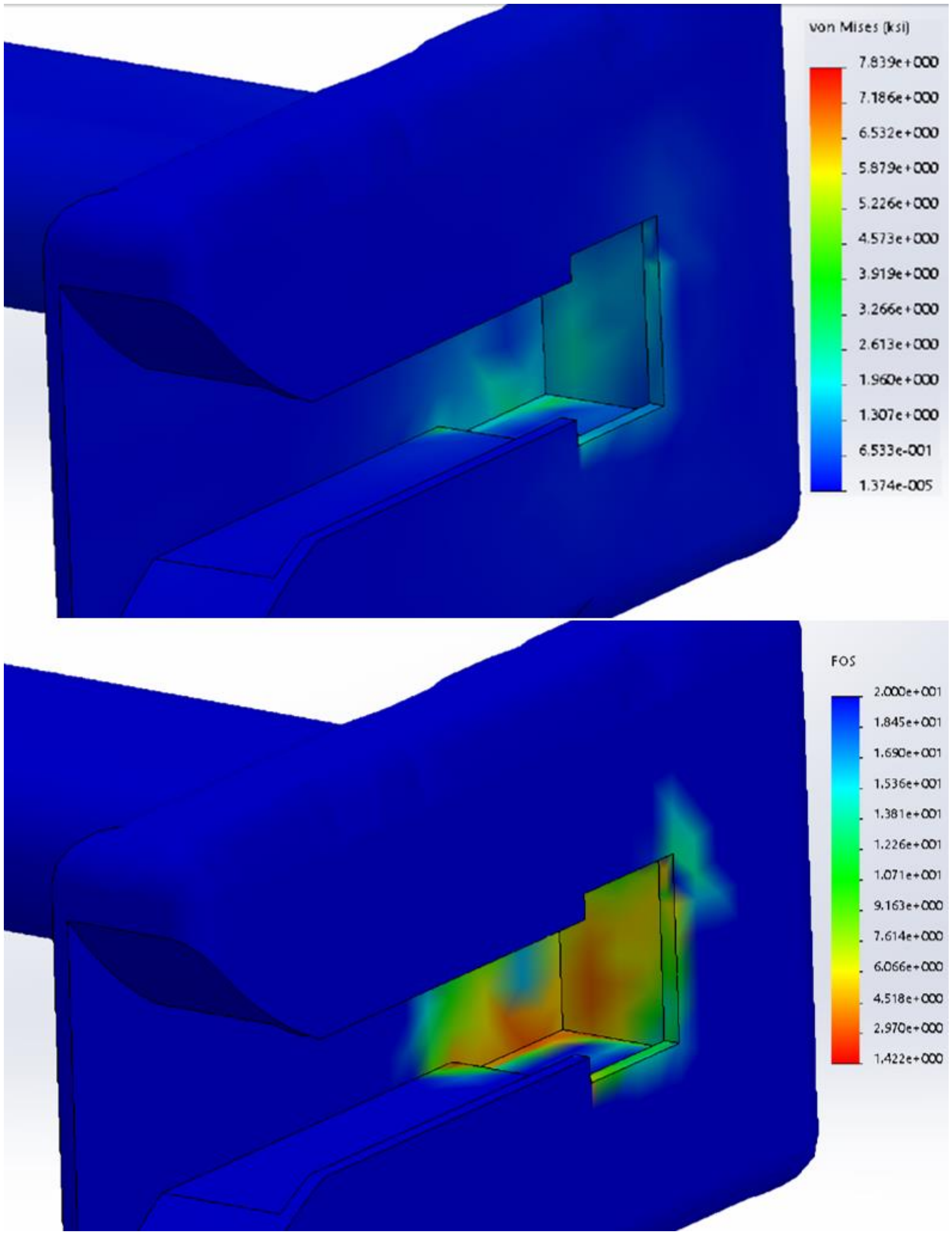

Figure A- 3: FEA on Lock; Stresses Analysis (Top) and Factor of Safety (Bottom) (First Analysis)

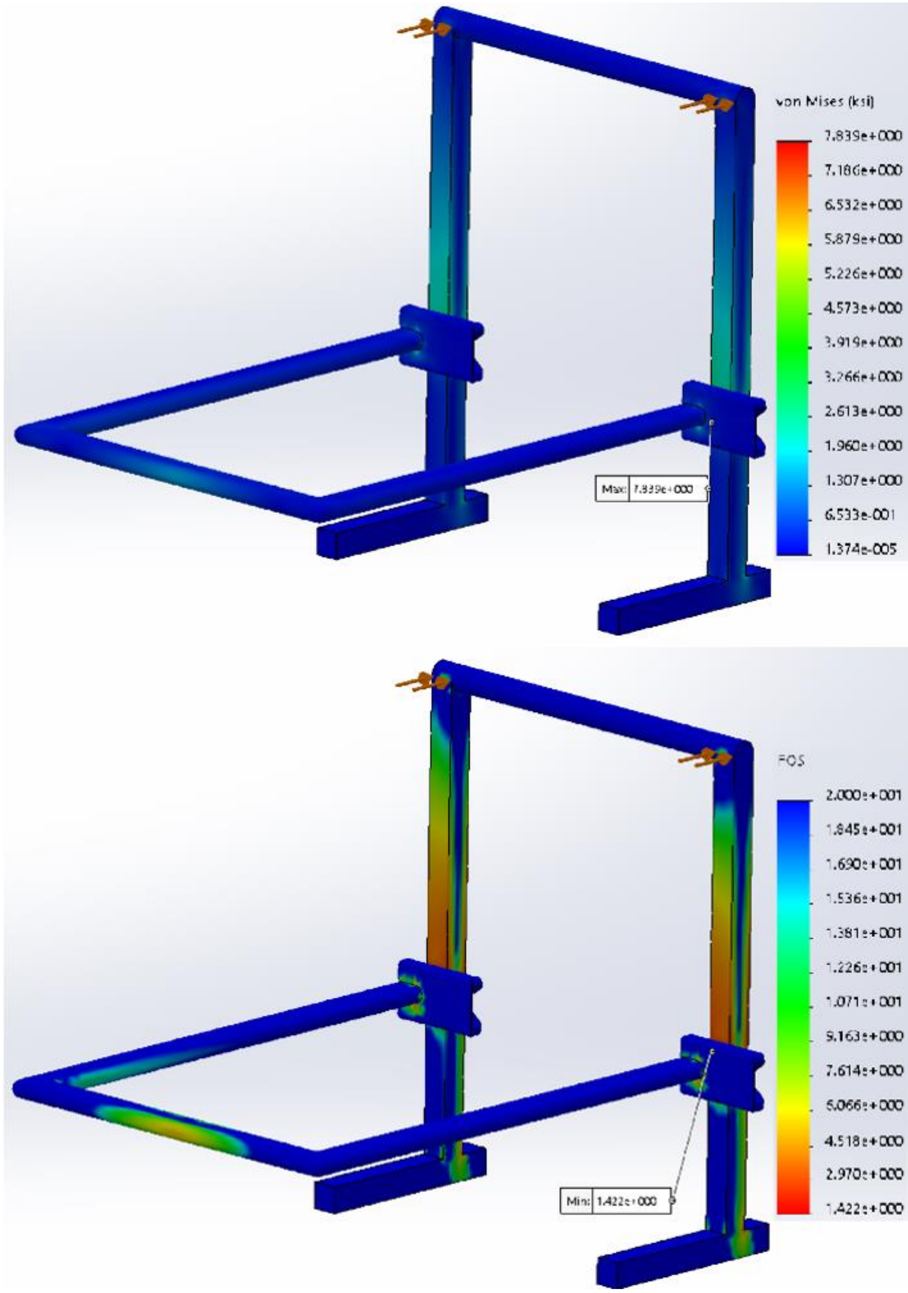

Figure A- 4: FEA Full View of Devices; Stresses Analysis (Top) and Factor of Safety (Bottom)

(First Analysis)

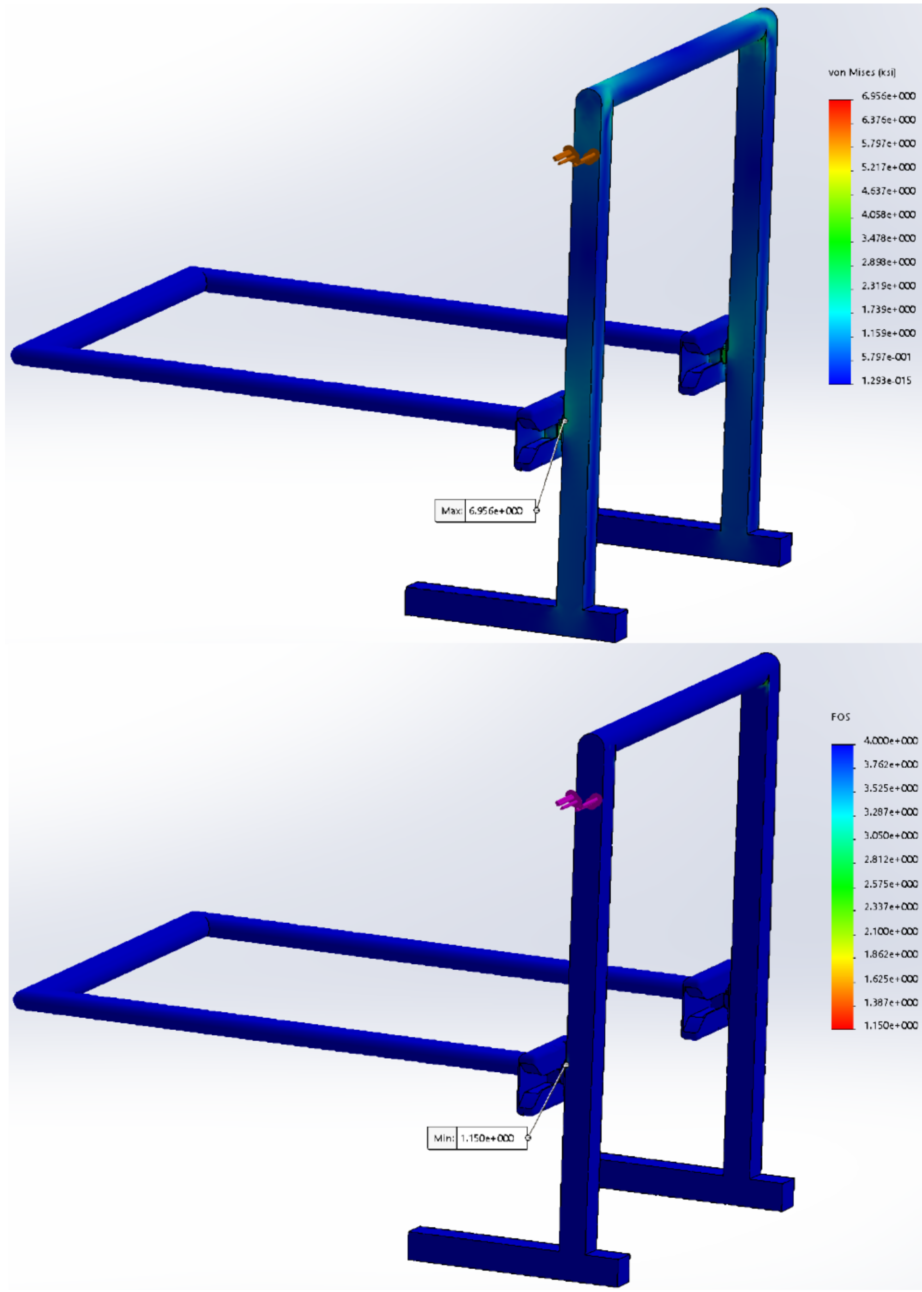

Figure A- 5: FEA Full View of Devices; Stresses Analysis (Top) and Factor of Safety (Bottom)

(Second Analysis)

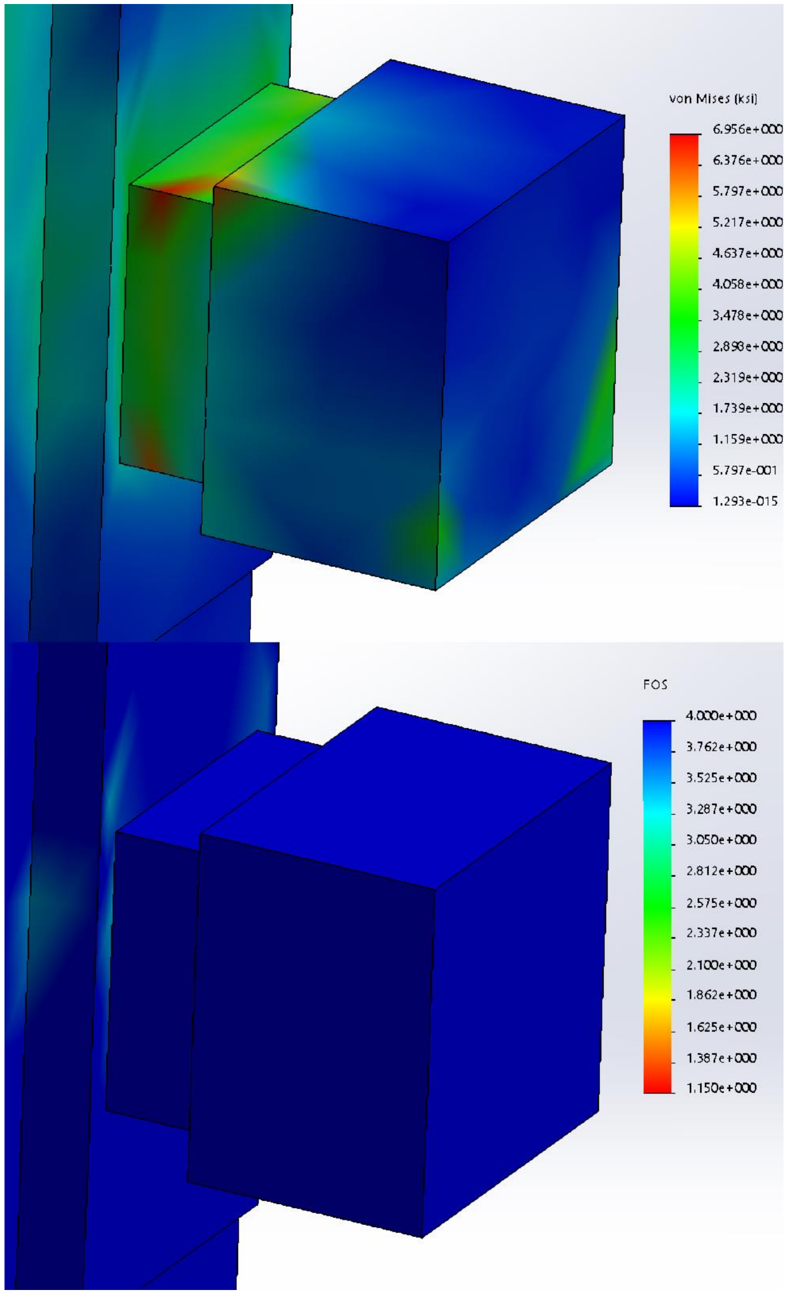

Figure A- 6: FEA Knob; Stress Analysis (Left) and Factor of Safety (Right) (Second Analysis)

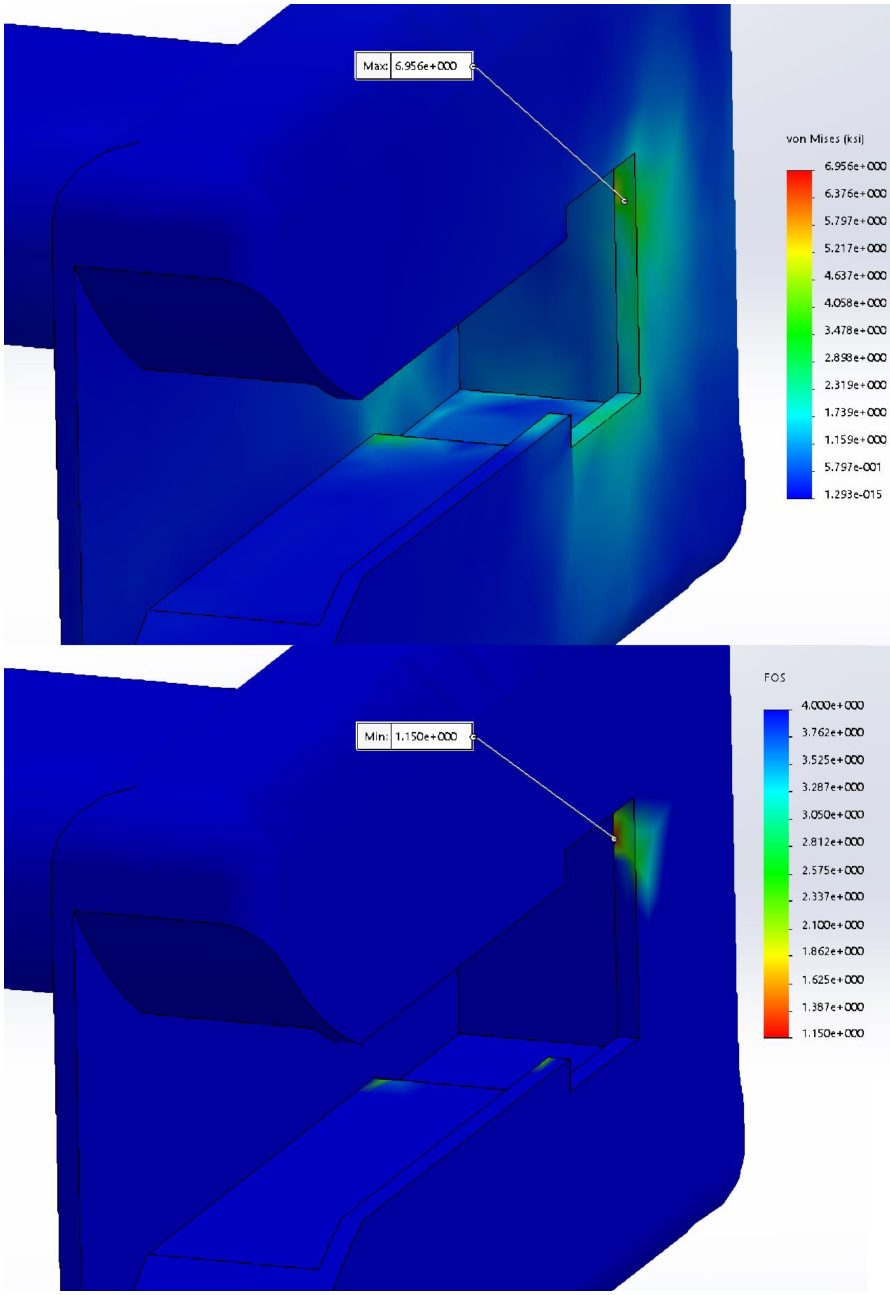

Figure A- 7: FEA on Lock; Stresses Analysis (Top) and Factor of Safety (Bottom) (Second Analysis)

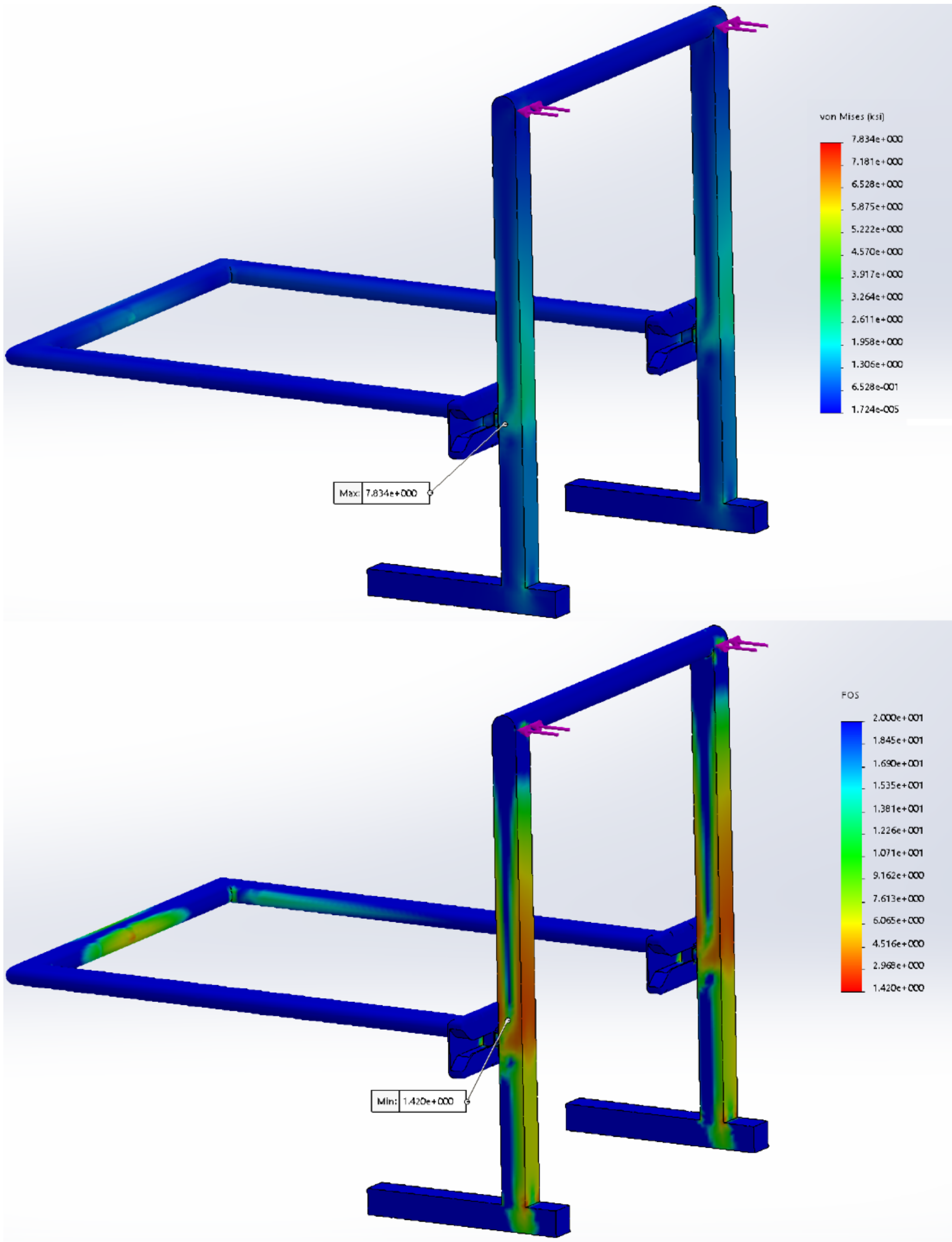

Figure A- 8: FEA Full View of Devices; Stresses Analysis (Top) and Factor of Safety (Bottom)

(Third Analysis)

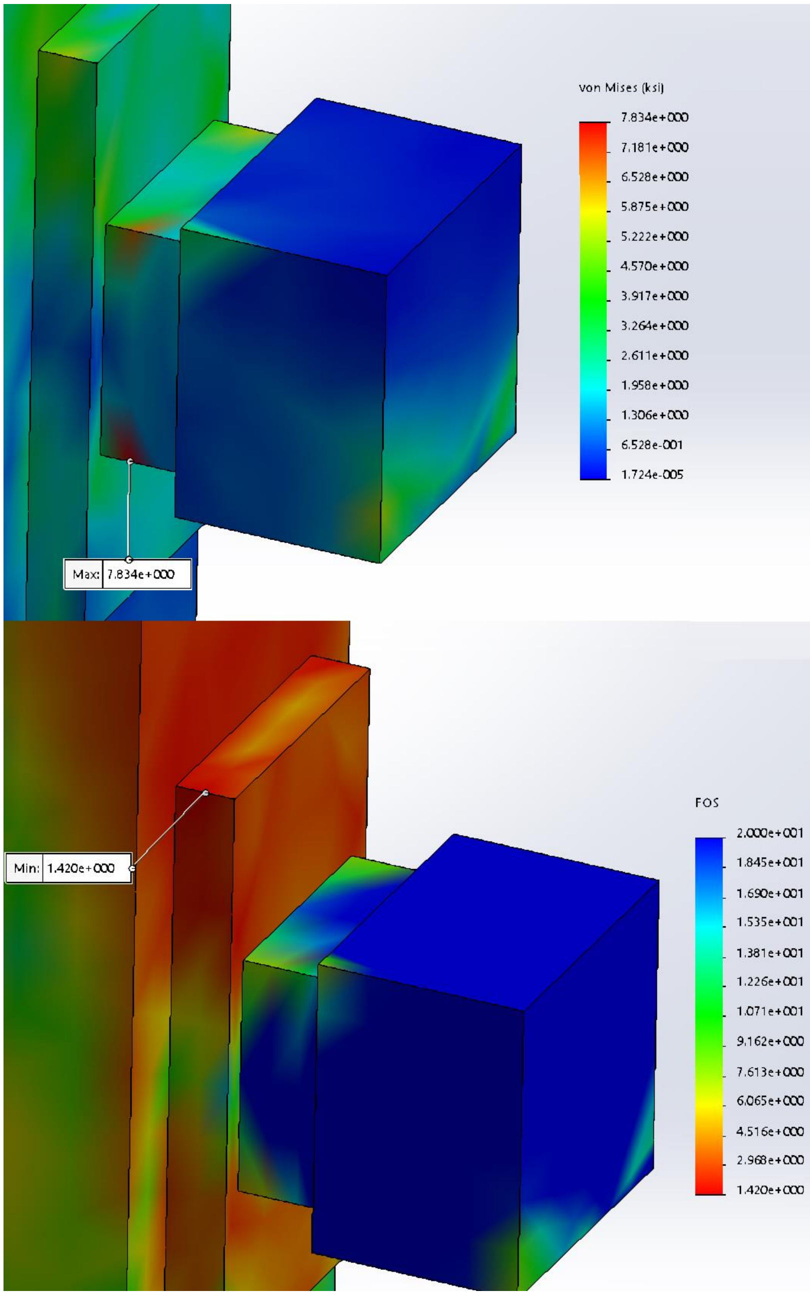

Figure A- 9: FEA Knob; Stress Analysis (Left) and Factor of Safety (Right) (Third Analysis)

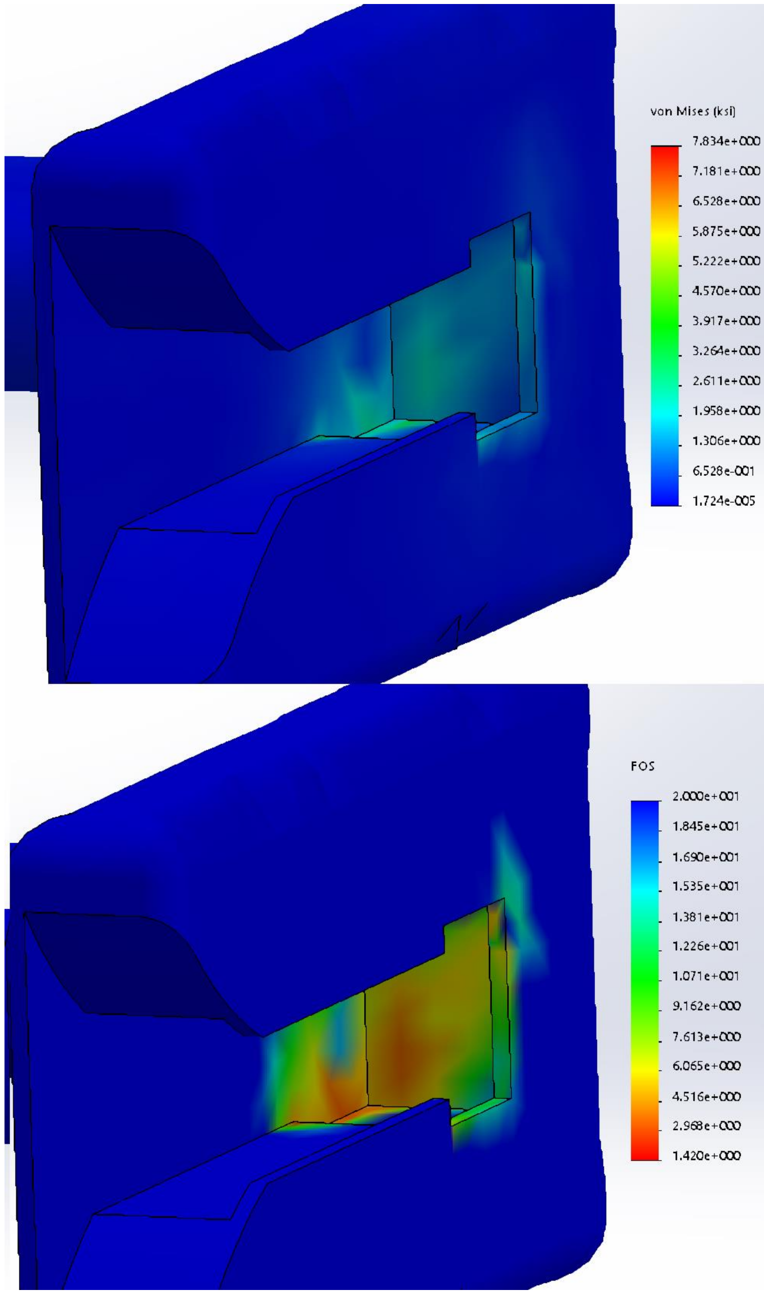

Figure A- 10: FEA on Lock; Stresses Analysis (Top) and Factor of Safety (Bottom) (Third Analysis)

BIOGRAPHICAL SKETCH

Jorge Luis Gutierrez was born in Reynosa, Tamaulipas on July 7, 1993. He attended Instituto Internacional de Estudios Superiores high school and graduated in the Spring of 2011. Afterwards, he attended the University of Texas Rio Grande Valley, where he graduated with a Bachelor of Science in Mechanical Engineering and a Minor in Electrical Engineering in the Fall of 2016. He chose to continue his studies at the University of Texas Rio Grande Valley and obtained his Master of Science in Manufacturing Engineering in May 2019. Jorge may be reached by email at jorge_g93@hotmail.com.