

# DIY In-Home Anti-Gravity Harness

## Final Report

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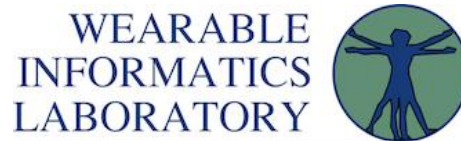
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## Disclaimer

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## Acknowledgements

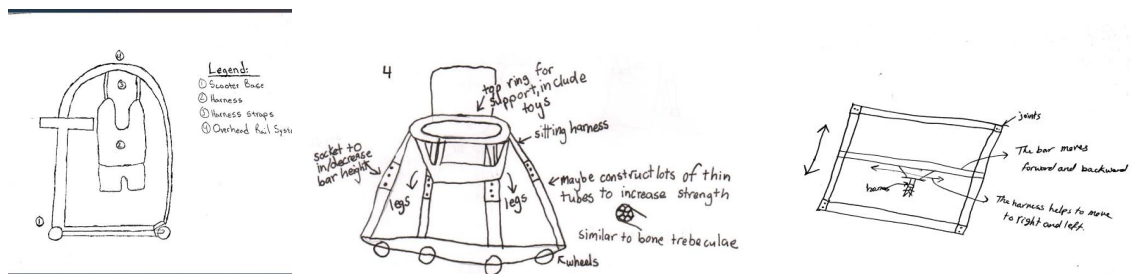
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## Executive Summary

In the United States, over 10 million children are living with cerebral palsy, which negatively affects their ability to move around and socialize. Until the age of 5, these children are immobile, relying on family members to pick them up and facilitate interactions, which can be difficult for parents limited by time and money. Dr. Kyle Winfree, the client for the project and faculty at Northern Arizona University, asked the team to develop a manual for an in-home antigravity system that would enable these children to move effectively about a room, thereby increasing their social development. The device had to be DIY so any parent could build it with no more than an ability to use basic tools.

The design process began during Fall 2016 with gathering customer requirements from the client and translating them to engineering requirements. Several similar projects created for rehabilitation were researched to determine the most important attributes of mobility devices. The top ideas generated from the requirements are included a scooter, baby walker, and Easy Up themed frame.



The final design selected at the end of the fall semester was that of the Easy Up frame, which was prototyped using wooden materials.

The team formulated a plan for manufacturing of the device, which began after winter break. The main point of concentration was the guide rails, which would support the weight of the user while only balanced on the Easy Up Frame. The team experienced significant difficulties with the wheels of the system, which were reengineered three times, and were even subject to design of engineering testing to determine the best way to make the device move. The final product was tested in accordance with procedures formulated during the fall semester of capstone, with only minor modifications to client needs.



The only significant change made to the client requirements was increasing the allowable storage size of the device to accommodate the middle bar. An additional point of concern for the team was the weight of the user, as the Easy Up is not constructed to hold loads greater than ~50lbs without failure. However, there was a worry that a vigorous 40lb child would still not be safe with the device, which was reflected in the operating instructions. The ultimate deliverable, the instruction manual, was completed to client specifications and made available to individuals interested in manufacturing their own system.

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## Background

### 1.1 Introduction

Children with disabilities, especially those with limited mobility, find difficulties later in life with socialization and cognitive development. A study found that additionally, children less able to interact with their environments have a connection with poor performance on cognitive activities and learning tasks [1]. The same study found that increasing the number of strides a day with disabled toddlers was linked to the greater social association.

Cerebral palsy (CP) is the most common motor disability in children, with every 1 in 323 children born with it [2]. It is a congenital disorder that affects the patient's posture, muscles, and movement. There are no cures for CP, and the associated treatments are often time and money intensive and can last for the entire lifetime of the child. Every case of CP is unique as each patient experience different physical impairments, including what limbs are affected and to what extent. Children with CP under the age of 5 are often totally restricted in mobility, depending on parents or siblings for all movement or interaction, which negatively affects their developmental outcomes in the future.

This project sought to formulate a solution to the limited mobility of disabled children by designing a Do-It-Yourself (DIY) anti-gravity balancing system. The sponsor, Dr. Kyle Winfree, is part of the Informatics and Computing division of NAU that aims to create wearable systems that aid everyday life. The project was DIY to assist parents of disabled children who may be limited by time, money, or training when it comes to improving the socialization of their kids. To fully complete the capstone project, the team created a device that reduces the body weight of disabled children, allowing them to interact with the world around them, without requiring an advanced degree in engineering or physical therapy for the parents.

### 1.2 Project Description

The project description from the client was as follows:

Children with limited mobility often do not receive the much-needed exposure to socialization to develop cognitively. Existing research shows that enabling young children with self-control of their environment can have meaningful impacts on the long-term outcomes given such impairments as cerebral palsy or muscular dystrophy. One place to start and increase mobility is in the home. Imagine you are a toddler, who isn't yet able to walk or crawl on your own, and you want to play with a toy on the other side of the room. How the heck is that going to happen if you cannot walk or crawl?

The goal of this project was to design and fabricate a Do-It-Yourself in-home gravity balancing harness system that parents of children with movement disabilities can build with limited resources.

### 1.3 Original System

As this was an entirely new project, there were no original systems that the team improved upon.

## 2 Requirements

The client provided the requirements and weighting that were integrated into a House of Quality to facilitate the design process.

## 2.1 Customer Requirements

Conferring with the client and the group resulted in nine governing customer requirements with weights from 0-10 as seen in the table below.

**Table 1.** Customer Requirements and Weights

Customer Requirement	Weight (x/10)
<b>Safety:</b> Low choking/entanglement risk	10
<b>Ease of Assembly:</b> Avoid machining, complex parts	7
<b>Adjustability:</b> Accommodate different sized children or growth	5
<b>Durability:</b> Materials pass various strength or fatigue tests	7
<b>Size:</b> Is unobtrusive and allows user to interact freely	6
<b>Comfort:</b> Refrain from using coarse/irritating materials	8
<b>Cost:</b> Keep under target cost	7
<b>Workspace Size:</b> Size user has available	6
<b>Aesthetics:</b> Contain multiple colors and child-friendly designs	9

Among the top weighted sponsor requirements were safety, aesthetics, and comfort. The rationale for these requirements resulted from the team's concern for creating a product that will positively change lives of children who have Muscular Dystrophy (MD) and various other mobility issues. Part of the success of the design depends on parents of children putting trust into this harness system. This caused the safety weighting to be the most prioritized trait with a rating of a 10. Comfortability and aesthetics were the next highest ratings of nine and eight respectively. The anti-gravity harness system may be used in chunks of time up to four hours, requiring a comfortable fit that does not chafe. Lastly, aesthetics was an addition added by Dr. Winfree from his knowledge of current baby themed products. The team experienced delays in meeting the project's client due to schedule conflicts, which led to the development of the first six customer requirements being voted on by the team. The addition of cost requirements, aesthetics, and workspace size to **Table 1** along with the assigned weights followed the meeting with the client.

## 2.2 Engineering Requirements

The engineering requirements with targets and tolerances are in **Table 2** and were formulated using the customer requirements. The process involved pairing each customer requirement with physical parameters that could be measured or calculated to ensure the customer requirements were met, taking the form of target values and acceptable tolerances. These measurable specifications enabled the team to start prototyping and testing different designs for the anti-gravity system.



**Table 2.** Engineering Requirements

<b>Customer Requirement</b>	<b>Correlating Engineering Requirement</b>
<b>Safety:</b> Low choking/entanglement risk	<ul style="list-style-type: none"><li>• No Sharp Points</li><li>• No Loose Ropes (Entanglement Risk)</li><li>• Nontoxic Materials</li></ul>
<b>Ease of Assembly:</b> Avoid machining, complex parts	<ul style="list-style-type: none"><li>• No Pinch Points</li><li>• Less than 20 parts</li><li>• &lt; 100 Screws and fasteners</li><li>• Assembly spans two days</li><li>• No Specialized Parts</li></ul>
<b>Adjustability:</b> Accommodate different sized children or growth	<ul style="list-style-type: none"><li>• Socket Sliders</li><li>• Variety pack for weight bearing parts</li><li>• Adjustable buckles</li></ul>
<b>Durability:</b> Materials pass various strength or fatigue tests	<ul style="list-style-type: none"><li>• Weight of System &lt; 50 pounds</li></ul>
<b>Size:</b> Is unobtrusive and allows user to interact freely	<ul style="list-style-type: none"><li>• Fits in 12ftx12ftx12ft Volume Space</li><li>• Weight of System &lt; 50 pounds</li></ul>
<b>Comfort:</b> Refrain from using coarse/irritating materials	<ul style="list-style-type: none"><li>• Elastic Materials</li><li>• No Pinch Points</li><li>• No Sharp Points</li><li>• Padding =&gt; .5 inch thick</li></ul>
<b>Cost:</b> Keep under target cost	<ul style="list-style-type: none"><li>• &lt; 300 Dollars</li><li>• No Specialized Parts</li></ul>
<b>Workspace Size:</b> Size above user	<ol style="list-style-type: none"><li>1. Fits in 12ftx12ftx12ft Volume Space</li></ol>
<b>Aesthetics:</b> Contain multiple different colors	<ul style="list-style-type: none"><li>• Gloss Finish Paints (Non-toxic)</li></ul>

The next step involved addition of the engineering requirements to the HOQ and correlations between these values as well as a ranking of the customer requirements.

## 2.3 Testing Procedures

Determining whether a final product meets engineering requirements required a series of testing procedures to be performed at the end of the year.

1. The parts for the entire system were weighed using a digital scale from a group member's house. A member of the team held the materials and stepped on the scale to record the total weight. Then the group member alone was weighed and subtracted from the total to ensure the system weight was ideally under 50lbs, but no more than 70lbs max.

2. Measuring the storage space and deployed size of the system involved using a tape measure provided by a member of the group. The storage space passed the test if the measured values were less than 5'x5'x2.5' with a foot tolerance in each direction. The deployed size could fit in a 12ft<sup>3</sup> space with a foot tolerance in each direction.
3. To ensure that the system could handle a 40lb child, the team placed a group member's dumbbells totaling 40lbs in the harness. This requirement will be a pass if the device can hold anywhere from 40-60lbs.
4. The standard of nontoxicity underwent an evaluation that compared the list of materials in the system to standards set by the EPA. The EPA has lists of chemicals and manufacturing materials considered toxic, and the system would pass this test if all materials are absent from the list. Additionally, if a toxic material applies in the process, it must be completely covered with a nontoxic material that cannot be removed by the user.
5. Calipers obtained from a team member's research lab measured the padding on the harness. The padding was sufficient if it is at least 0.5" thick.
6. No loose ropes due to entanglement risk underwent evaluation by measuring any loose ends of rope-like materials with a tape measure procured from the lab. The loose ends could be no longer than 3", and if they were, a zip tie or other constraint must secure them.
7. The total number of parts and screws/fasteners was counted by group members to ensure the parts number less than 20, and screws/fasteners are less than 100.
8. The ropes and other potentially elastic materials were tested to determine if when force was applied the system deforms more than 10% its original length. A force gauge taken from the physics building assisted in accomplishing this, and a force of 200N applied with the deformation measured with a ruler taken from the chemistry building.
9. The total cost of the product and tools as measured by totaling the receipts from purchasing all the materials. The product should be ideally under \$300 but no more than \$400, and the tools less than \$100 but no more than \$150.
10. The time taken to assemble the entire product was taken with a stopwatch to ensure it did not take a group member longer than two 8 hour days, with 24 hours as an absolute maximum.
11. A tape measure from a group member's house measured the range of adjustability in the case of adjustable buckles and rope components. All 'adjustable' materials had to scale at least one inch in both directions to satisfy this test.
12. The criteria of no specialized parts consisted of the team evaluating the parts to determine if any were produced at a machine shop and not readily available at a hardware or craft store.
13. No pinch points will be tested by inserting delicate fabric such as silk between two fastenings and seeing if the fabric tears upon applied force.
14. Determining the consideration of no sharp edges involved a qualitative approach by a team member running a soft scarf over the system. If the scarf frayed the system still had sharp edges that need smoothing.
15. The aesthetics of the design called for the team to use neutral colors so as not to make the system gender specific. Supporting documentation provided parents with options to make the system more aesthetically pleasing to their specific child.

The team formulated these testing procedures to provide a method of impartially determining the possibility of meeting the engineering requirements in the final design. Should the product fail any one of the testing procedures, a re-engineering of the system is required. These engineering requirements are crucial for the design to conform to customer requirements, which were related using design links.

## 2.4 Design Links

The design links between engineering requirements and real world needs are listed below:

1. The storage space for a harness can come from the closet and other unused space that the user can use to place the system when not in use. The team created a storage space limit of 5x5x2.5 ft. with a slight tolerance of  $\pm 1$  ft. By incorporating an EZ-up frame into the harness design, it allows the design to be folded into this space easily. When the design is not in use, the team can fit it in a 5x5x2.5 ft. volumes space.
2. The workspace size is volume space the user can have the independent maneuverability to travel while when using the anti-gravity harness. The EZ-up design maximizes this space with a frame having 10 ft.x10ft measurements when unfolded. This is within the 12x12x12 ft. Allowable workspace.
3. The harness system will meet the engineering requirement of no pinch points by using a harness that contains enough stiffness, so it does not allow material to fold on itself beyond certain degrees. To ensure sharp points do not exist in the design, the material of the harness will be soft enough to not snag to the user to cause discomfort. The team will compare the materials ordered for the project to lists of published lists of toxic materials, and substitute any materials that contain harmful toxins with materials that comply with these lists
4. The amount of security the harness will have will increase directly with some contact points the harness contains. The design will most likely contain three contact points to prevent tipping/falling off the user and still provide easy access to the harness
5. Supports which extend from the frame to the user can become a choking hazard to the user if they become loose. The design must contain zero loose ropes and keep the total amount of supports/ropes that extend to the user to a minimal amount ( $<5$ ) to prevent choking hazards to the user.
6. One of the main project goals for a DIY anti-gravity harness will include minimizing the number of time parents of a child with a disability and/or mobility issues to build our design. The group had accomplished this by limiting the number of parts and fasteners to 20 and 100 respectively. Numbers that exceed these amounts would increase assembly time and cost which are significant customer requirements.
7. Aesthetics in the design are crucial for the design to be successful. The colors picked in the design must be bright and vibrant to appeal to small children. Gloss finish paints will apply in painting the final design to ensure the fulfillment of this engineering requirement.
8. Deformation in the design can cause safety hazards for the user. The frame structure used in the gravity harness design is a product of aluminum alloys and steel. These materials are rigid enough to undergo cyclic loadings of 40 pounds and have axial deformations of under  $1 \times 10^{-2}$  inches. The requirement needed to achieve this includes having no elements which are elastic materials that experience high amounts of deformation.
9. Families with children who experience mobility issues and/or have Cerebral Palsy and Muscular Dystrophy is the community that would benefit from group's anti-gravity harness design. Keeping the final product cost to a minimal is vital to have middle-class families the ability to use our design. In response, the group established a limit of 300 dollars for the final price of the harness with a tolerance of 100 dollars. A number of tools needed for a DIY project must be minimal and widely accessible to customers. A tool budget created covered a limit of 100 dollars. This will allow the use of simple electric drills and screwdrivers when constructing the harness system.

10. Installing the design should take no longer than two full days, as the average working parent is short on time as well as monetary resources.
11. The use of adjustable buckles will allow the sizing of harness along with a growing child. This prevents having to buy an entirely new system when growth spurts happen.
12. 14. The harness design uses parts that can easily undergo fastening. The case is only possible when there are no machined parts for the assembly. Avoiding specialized parts to keeps the cost within the budget and allows most families the ability to put together the project with simple tools found at home.
13. The group's design will be under the weight requirement of 50 pounds. Tolerancing for this portion is +/- 20 pounds which will allow for heavier parts that provide more strength to the design but keep the overall weight from becoming a hazard.
14. The average weights of children between 1 and five should not exceed 40 pounds. Therefore, the system will be designed to support 40 pounds tolerance with an additional 20 pounds.
15. The comfort of the system depends on the padding that will apply in the harness. Half-inch thick padding will help the user to be more comfortable and freely to move around.
16. Using covers for the buckles assures that the user does not get hurt by catching skin between two pressure points.

The team used House of Quality to guide the design process after the engineering needs were related to the client requirements, along with explanations for the selected targets.

## 2.5 House of Quality

The House of Quality (HOQ), found in Appendix A, was organized to present the customer and engineering requirements, as well as the correlations between the two (**Figure 1**). The HOQ continues to provide an organized way to begin evaluating any potential designs and existing devices for adherence to the project guidelines. Research on existing devices proved easier with an idea of what characteristics an anti-gravity system needed most. The relative technical importance (RTI) of each quality was ranked using values of one through ten as assigned to specify how strongly an engineering requirement correlate to a customer requirement. Positive numbers denoted a positive relationship while negative numbers signify a negative relationship. The absolute technical importance (ATI) incorporated the relative technical importance and the weights assigned by the client to highlight the most important qualities of the future product. The first 10 engineering requirements ranked by RTI and ATI can be seen in **Table 3**.

**Table 3.** Top Engineering Requirements

<b>Requirement</b>	<b>RTI</b>	<b>ATI</b>
Device Weight	211	1
No Sharp Points	180	2
Harness Contact Points	168	3
No Pinch Points	150	4
Support 40lbs	135	5
Nontoxic Materials	124	6
No Specialty Parts	126	7
Harness Padding	120	8
No Loose Ropes	109	9
<100 Fasteners	93	10

Assigning targets and tolerances to each of the engineering requirements were a tool for the creation of testing procedures. The HOQ underwent a few minor rewordings after the week of final

design selection to conform to client expectations. The revised copy, as well as signed approval from all members and the client, is again accessible in the Appendix A (**Figure 1**).

## 2.6 Customer Need Changes

The only major change made to the customer needs was that of storage space. The original engineering requirement was that all items could fit in a 5'x5'x2.5' space. When performing the testing procedures from Section 2.3, the team realized that the middle bar could not be broken down and had to be stored as its original ~9.8ft size. The client was contacted to approve the change to the requirements, now a storage space that accommodates the entire pole, which can be seen in the updated HOQ in Appendix A (**Figure 1**).

## 3 Existing Designs

The rehabilitation industry contains some devices used to assist patients with walking in everyday life, and three of these were selected to help provide a baseline for the project.

### 3.1 Design research

The research of existing devices concentrated on journal articles and scientific publications specific to rehabilitation devices using anti-gravity technology.

The process started by finding a variety of different devices from their product pages and continuing the search on Google Scholar. The Google Scholar search produced articles from scientific journals on the various benefits of the systems. The measurement of the articles focused on normal joint angles and forces, metabolic testing with CO<sub>2</sub>, and surveys used to assess user satisfaction. Sorting the existing devices will then follow based on the benefits observed and if the system would be suitable for children with cerebral palsy to use under the age of five.

From these search results, the team selected three system designs that were appropriate to the project requirements.

### 3.2 System Level

Research focusing on the series of three existing rehabilitation devices (G-Trainer, ZeroG, and Kickstart) educated the team about existing anti-gravity systems.

#### 3.2.1 G-Trainer

The G-Trainer is a rehabilitation device that uses air pressure to unload weight from a patient's lower body and enables them to run on a treadmill with reduced impact forces (**Figure 2**). The G-Trainer sees use in military hospitals, universities, and on professional athletics teams to relearn proper gait and balance without fully loading an injured body part.



**Figure 2.** G-Trainer Anti-Gravity Treadmill [3]

The integrated treadmill system can support up to an 80 percent reduction in body weight without using a harness that can become uncomfortable or chafe patients [3]. Special shorts are worn to integrate with the airtight enclosure, using air pressure to adjust the amount of loading experienced by the legs. The system is as comfortable on the user as water training but allows the leg swing to mimic above ground locomotion, which contributes to less impairment of normal joint movements. Studies showed that a reduction of 20% body weight did not alter metabolic responses when using the treadmill, proving its ability to maintain fitness during rehabilitation [4].

The main goal of the developing company (Alter-G) is to create a more affordable product to make the G-Trainer a standard in rehabilitative care. There are additional plans to create a similar product for children, to target the population suffering from cerebral palsy or other disorders.

### 3.2.2 ZeroG

The ZeroG system is an over ground body-weight system that allows rehabilitation patients to practice daily behaviors while not carrying their entire body weight (**Figure 3**).



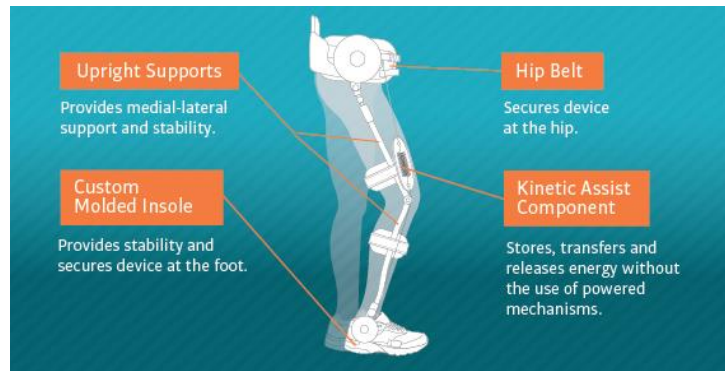
**Figure 3.** ZeroG Trolley System [5]

The entire system consists of a harness for the patient with support for the groin, hips, chest, and shoulders, a spreader bar to distribute weight, and a trolley connected to an adjustable ceiling track. The trolley tracking system supports the patient without holding them back and is accurate to less than 3 degrees, increasing its ability to prevent falls in the patient [5]. The setup is capable of supporting 400lbs statically and 200 lbs. when moving dynamically [6].

The ZeroG product is more appealing to conventional therapists and users because it allows for a variety of motions to be tested, including sit to stand, climbing stairs, and walking on a curving track. These options have more real life functionality than other rehabilitation setups that depend on lateral movement on a treadmill with only the ability to change speed or incline.

### 3.2.3 Kickstart

Kickstart is a hip-leg exoskeleton that uses tendon and spring technology to enable stroke survivors to learn to walk again. (**Figure 4**).



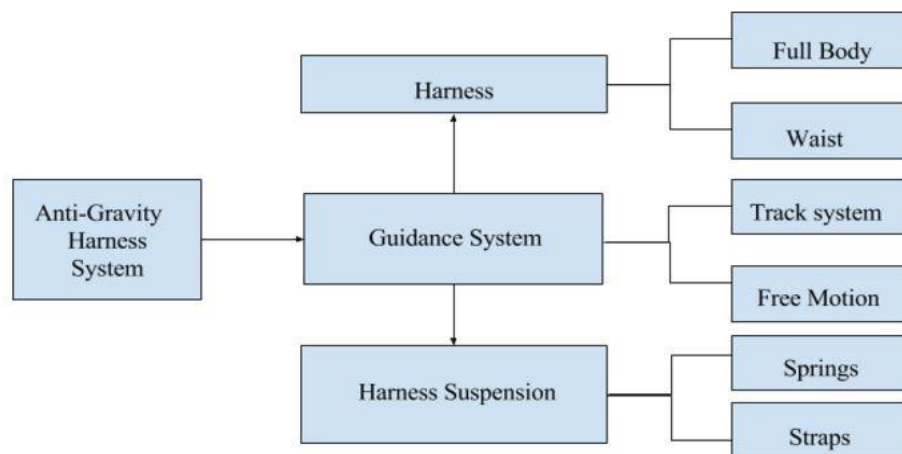
**Figure 4.** Kickstart Powered Assistance [7]

Cadence BioMedical, developer of Kickstart, market the technology as useful to those who have been paralyzed or cannot walk, even years after the incident that left them immobilized. The Exotendon is the core technology behind the device and allows energy to be stored and expended with each step the user takes [7]. The level of assistance can be set by the user or physical therapist to carefully guide the patient to walking on their own as much as possible. Many stroke survivors are afflicted with foot drop, which causes the foot to drag on the ground unless the patient dramatically adjusts their hip positioning with each step. Such a behavior leads to unequal strain on each side of the body, which Kickstart seeks to address by including a foot plate and external ankle joint to assist users with keeping their foot oriented properly. The combination of an external frame with powered assistance makes the Kickstart system extremely accessible for patients with limited mobility.

A restructuring of the system into subsystems followed for the three designs to enable the compartmentalization of the design tasks.

### 3.3 Subsystem Level

To complete the subsystem level designs, the team completed a functional decomposition of the entire project (**Figure 5**).



**Figure 5.** Functional Decomposition of System Level Design

The entire system was broken down into the following subsystems: Harness, Guidance System, and Harness Suspension.

The categorization of the harness was either a full body harness or a simple waist harness. A full body harness was similar to the support seen in the ZeroG system. This full body harness helps reduce the

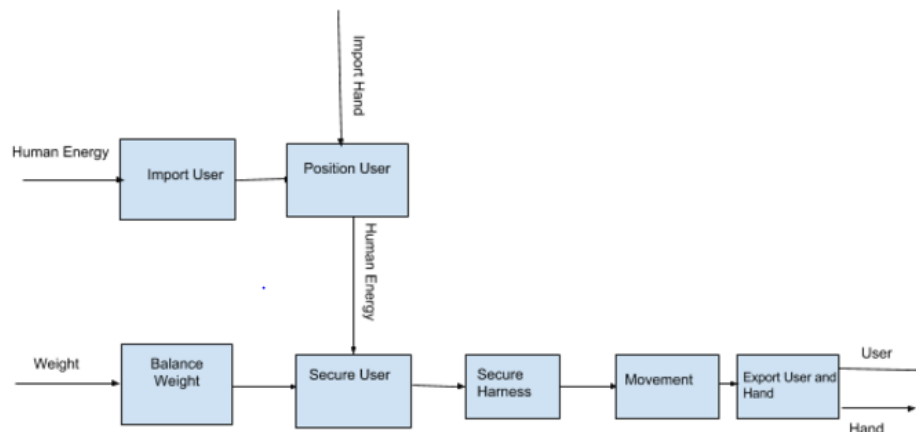


body weight of the user at the groin, hip, chest, and shoulder level to reduce the amount of pressure on a patient needing a high percentage of body weight support. The simple waist harness would benefit users if they can handle walking almost all their body weight but have troubles with weakness in the legs and can be supported by some outside system. The waist harness would provide the user with less coverage of the body which would be beneficial for some users with increased mobility while the full body harness would provide the necessary protection of the user needing extensive assistance.

The guidance system will be on a guided track system or free motion. The ceiling track system as seen in the ZeroG system will allow the user to follow the path in the direction involved in installing the track system. The free motion guidance system is more of a self-stabilizing harness in which the user is not set to walk on a specific path but can roam while wearing the harness. The way ceiling track benefits the user through increased security in being able to avoid falls that could arise in a free roam system. The upside to unrestricted motion is that the user is more easily able to interact with the environment in any way they please, potentially increasing cognitive development.

The suspension for the harness will be in springs or straps. Springs can provide a reduction in body weight from beneath the user while straps would provide that same reduction but from above the user. Straps provide same similar support but can be more assistive to the user by supporting them entirely.

The subsystem breakdown proved most beneficial to the design process because the different tasks can be divided up in a way that involved all team members' engineering knowledge. Additionally, a functional model of the system showing all energy flows clarified which steps will require input from the user (**Figure 6**).



**Figure 6.** Anti-Gravity Harness Functional Model

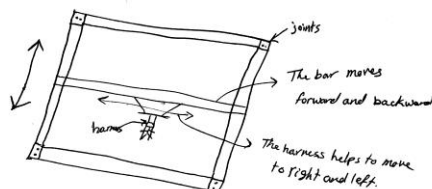
For the functional model of the design, the user has some inputs to the system at the starting phase including weight and hand movements. After this occurs, the user is positioned in the harness and will be balanced by outside straps, so they will not overturn over while in the system. The next stage was securing the user so they can be left to perform comfortable movements without upsetting the balance. For this step to be complete, the system must have another person's hands to secure the user properly within the system, as the children themselves are most likely incapable of performing this task. Upon the completion of all these steps, enabling the movement allows the user to use the system. Once movement comes to an end, exporting the user from the system will then follow with the help of another person.

## 4 Designs Considered

At first, the development of 20 designs used a mixture of a 5-3-5 and gallery concept design techniques. Then, 10 of these designs were under consideration as potential solutions to the problem of building an in-home anti-gravity device. The top four most representative designs are in the figure below

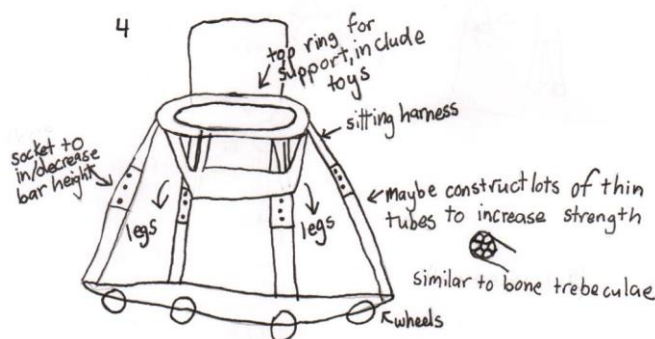


(**Figures 7-10**), with the remainder in the Appendix (**Figures 11-16**). Those in the Appendix are variations of the four designs in this section, either ceiling mounted or wheeled.



**Figure 7. Concept A**

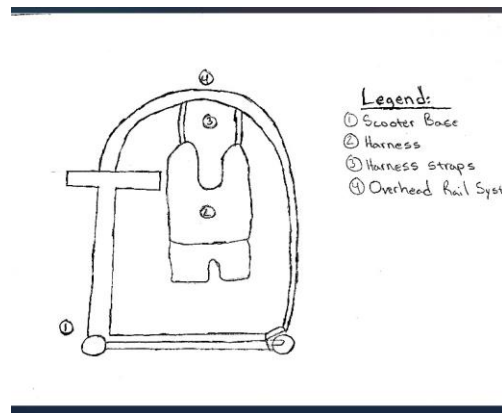
Concept A was a ceiling track system that allows the user full range of motion across the area the track covers (**Figure 7**). This system was not the simplest design regarding ease of assembly since the bar in the middle helps the child to move in all directions, requiring heavy modification from basic materials. The harness has two support guidewires on either side to distribute the weight evenly. Unfortunately, the design is for a single room so the child cannot go to another room, limiting the workspace size. The design has a high level of safety based on the secure fastening of the ceiling track. The cost for this design would not be expensive depending on the materials used and can be very durable. It might be difficult to adjust the design for use in other rooms, but adjusting the height for a growing child should prove easy by shortening the strap supports. The design is comfortable for the child with a padded harness that has weight bearing sections.



**Figure 8. Concept B**

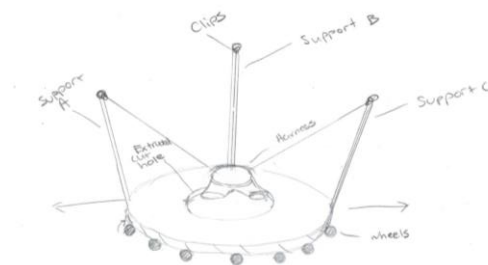
Concept B consisted of a high chair apparatus that employs a harness for the lower extremities rather than a chair suspended from an upper ring at the level of the child's chest (**Figure 8**). The whole device is under the guidance of wheels with opportunities for interactive toy placed along the top ring, increasing its aesthetic appeal to children. The device does well under the criteria of being easy to assemble, as most the device is similar to toys already in stores for children learning to walk. Additionally, the relative size of the system makes it very mobile, as well as increasing the range of the child from a single room, to an entire floor of the house if entryways are level. Unfortunately, this design is one of the least adjustable for growing children as there are multiple components that would need to be sized up to increase maneuverability. A way to mitigate this would be to create adjustable legs for the chair to raise it above its normal position. The device would have different safety risks than a ceiling

system, as the wheels would make it slightly easier to be tipped over, stranding or injuring the child. The durability would depend on the activity level of the child as well as the comfort. The cost would approximately be the same as a ceiling track system, especially since there should be less individual components going into it.



**Figure 9. Concept C**

This design was a scooter harness system that gives the user the ability to maneuver around the workspace without being limited to the workspace of a single room within a house (**Figure 9**). This design includes a harness connected to an overhead rod that would suspend the user from the ground while allowing the user to still touch the ground with the removal of the user's body weight on their legs. The approach allows the user to walk with less body weight weighing on them as they walk. The scooter sub-system of the design is to direct the user to the chosen way to pursue as well as give them additional balance while operating the system. This design gives the user more maneuverability than a track system because track system is free of binding elements that would be within one room of a house. This design is a smaller more mobile design compared to a track system and requires fewer parts to put together overall. The scooter design also has a great adjustability factor that gives the range of heights which allows a wide variety of users to use it no matter their overall size of the user.



**Figure 10. Concept D**

This wheeled system contained a circular base with an extruded circle cut in the middle (**Figure 10**). This hole leaves open space for the user to have contact with the ground and move around, increasing the available workspace size, though the size of the product is quite a bit larger than some of the other wheeled designs. The thought is to make the device free range motion, but the larger size makes fitting through doorways more difficult. The harness attaches to three rigid supports with elastic straps as

the suspension. The user can jump and move like bungee jump systems at amusement parks, which may work to enhance the aesthetic appeal to children. The buckles on the straps provide adjustability options for the user to accommodate different heights. This assembly can easily be stored in a closet and should be durable, if the construction uses strong materials. The safety might be variable depending on how fast the child moves or the range of motion of the legs, as the inner hole may need to undergo widening. But overall, the device has less of a chance to tip than the other wheeled devices.

With the development of several different styles of anti-gravity systems, the team moved on to evaluating the merits of each design. From this, a final product with the highest stats for each customer requirement was selected to begin construction.

## 5 Design Selected

The process of design selection took the top 10 designs down to the three most viable, and finally, the top idea which the team began prototyping.

### 5.1 Rationale for Design Selected

The first step in the design selection process used a Pugh Chart (**Table 4**) to rank the developed ideas against a Datum concept, as the ceiling track and harness system developed by students at the University of Delaware (**Figure 18**). The system uses a rectangular PVC system to distribute weight on the harness over a larger area before attaching to a ceiling track.



**Figure 18.** University of Delaware GoBabyGo [8]

The ranking system was qualitative, with a (+) meaning the concept was superior in that category to the datum, a (-) indicated the concept as worse, and an (S) meant the concept had the same expected performance for that criteria.

**Table 4.** Pugh Chart for Concept Selection

Concept	A	D	E	B	F	Datum	C	G	H	I	J
Criteria											
Safety	S	S	S	S	+		S	S	S	S	+
Easy to Assemble	+	-	-	+	-		-	S	-	S	-
Adjustable	-	+	S	-	-		S	+	-	S	+
Durable	+	S	S	S	S		+	S	+	S	S
Size	+	S	-	+	+		+	S	-	(depends)	+
Comfort	S	+	-	S	S		S	S	+	S	+
Cost	+	S	-	S	S		S	-	S	S	-
Workspace Size	+	+	S	+	+		+	+	+	S(depends)	-
Aesthetics	S	S	+	+	+		+	S	+	S	S
Sum +	5	3	1	4	4		4	2	4	0	4
Sum -	1	1	4	1	2		1	1	3	0	3
Sum S	3	5	4	4	3		4	6	2	9	2

Using the Pugh Chart designs A, B, C, and the Datum emerged as the top concepts. The selections were all wheeled because the team could see the potential of increased safety and maneuverability with a stable, grounded base through the exception of Datum.

These concepts underwent further evaluation using a decision matrix (**Table 5**), which quantitatively ranked each of the concepts using weighted criteria.

**Table 5.** Decision Matrix for Concept Selection

Weight		Concepts							
		A		B		C		Datum	
Criterion									
Safety	0.15	85	12.75	85	12.75	100	15	100	15
Easy to Assemble	0.11	65	7.15	90	9.9	70	7.7	75	8.25
Adjustable	0.08	85	6.8	60	4.8	90	7.2	100	8
Durable	0.11	70	7.7	70	7.7	70	7.7	70	7.7
Size	0.09	100	9	100	9	100	9	70	6.3
Comfort	0.12	80	9.6	80	9.6	90	10.8	90	10.8
Cost	0.14	100	14	86	12.04	85	11.9	85	11.9
Workspace Size	0.09	100	9	100	9	100	9	85	7.65
Aesthetics	0.11	90	9.9	100	11	100	11	80	8.8
<b>Totals</b>		85.9		85.79		89.3		84.4	
<b>Relative Rank</b>		2		3		1		4	

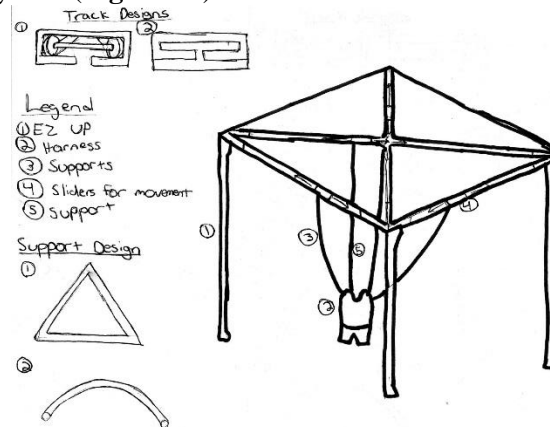
From the decision matrix, the team selected Concept B as a final design. The harness scooter performed best in the areas of safety, device size, workspace size, and aesthetics. The case is common for many of the wheeled devices, as the ability to go beyond the room of one house when building interactions with disabled children, ranked highly. The team saw lots of potentials to increase the aesthetic potential of the device, as scooters are already very popular with children. The harness system combined with wheels play a vital role since it allowed taking off weight from the children at the same

time as facilitating their movement and stability with the scooter frame. The areas needing the most improvement were ease of assembly and durability, as the design may necessitate slightly rarer parts to fit specifications.

After speaking with the client and watching videos of children with cerebral palsy walking, the team decided to change the final design to one like the datum. The jerky walking behavior of the user children exposed safety flaws in a wheeled system which could cause serious damage to the user and the device. A full description of the chosen final design can be found in the following section.

## 5.2 Design Description

The initial sketch of the final design hybridized an overhead track system with a pop-up tent frame to create a more flexible system (**Figure 19**).



**Figure 19.** Easy Up Track System

The final design involved a wheeled track attached to an Easy Up (pop up tent) frame directly above the user. The square Easy Up structure was going to be modified to place weight bearing members running diagonally through the square area. Installing sliders for member movement to the top frame allows the user to move around the area in which the Easy Up covers. Rope supports extend from each rolling slider to a harness system in which involves secure placement of the user. When the user through with the process and the design is not in use, the Easy Up frame folds easily from pushing on all four sides to compact the structure.

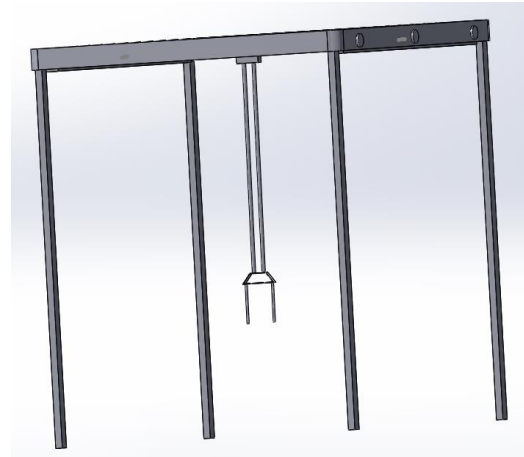
As the design is collapsible, it should easily fit in the specified 5'x5'x2.5' storage space and accommodate a 12'x12'x12' workspace. This design allowed increased adjustability regarding child size and growth, as a shortening of the height of the suspending ropes is possible for taller individuals. The durability of the materials used for this assembly should adequately support the 40-pound weight average of children between the ages of one and five, even when performing high energy activities. The harness system will provide at least three contact points which distribute the weight even further with a spreader bar attached above. The span of assembly for this design should not exceed two days, as the purchase of the main frame is possible at most sporting goods stores. Lastly, this design will have many aesthetic qualities integrated into its components with bright fabrics, stickers, and paints.

The team produced a Solidworks Rendering of the final design to show further how it will function as an assembly (**Figures 20 and 21**). After constructing each sub-system of the final design and assembling all pieces into a single unit, some constraint problems needed a solution from the top members. After the addition of mates between parts, the support ropes could not be placed properly to where they would allow the user to use the entire workspace of the system. The fix to this problem will involve cutting the number of rigid supports to two instead of four. Otherwise, the process may require a

new material. As the prototyping continues, the materials and shapes of the Solidworks model will undergo changes to reflect the work done.



**Figure 20.** Isometric Final Design View



**Figure 21.** Front Final Design View

After confirming the final design with the client, the team began the next steps in the construction of the DIY anti-gravity harness.

## 6 Proposed Design

With the selection of a final design, the team constructed an implementation time frame, bill of materials, and a detailed schedule for the spring 2017 semester.

### 6.1 Implementation Plan

The initial implementation of the final selected design began Nov-Dec 2016 and included:

- Subsystem design and theoretical testing with individual analyses
- Small scale prototyping using arts and crafts materials
- Larger scale prototyping to decide final size and look

During the winter break (Dec-Jan) the team ordered materials for construction of further prototypes during the spring semester.

From Jan-March 2017 the team planned to:

- Create an alpha prototype using the ordered materials
- Test prototype to ensure compliance with customer and engineering requirements
- Prototype should be advanced enough to be available for use

March-mid April (including earlier in March if time permits) the team will:

- Replace substandard materials where necessary
- Improve upon subsystems (such as how smoothly the track system runs, harness contact points and materials, etc.)

Mid-April to the end of the semester will be focused on:

- Constructing the final system for client, instructor, and department approval
- Compiling supporting documentation for parents to construct the system easily
- Prepare for final presentation

The next step for the team in the implementation plan above was to finish prototyping (proof of concept and industrial) and begin ordering parts for construction.

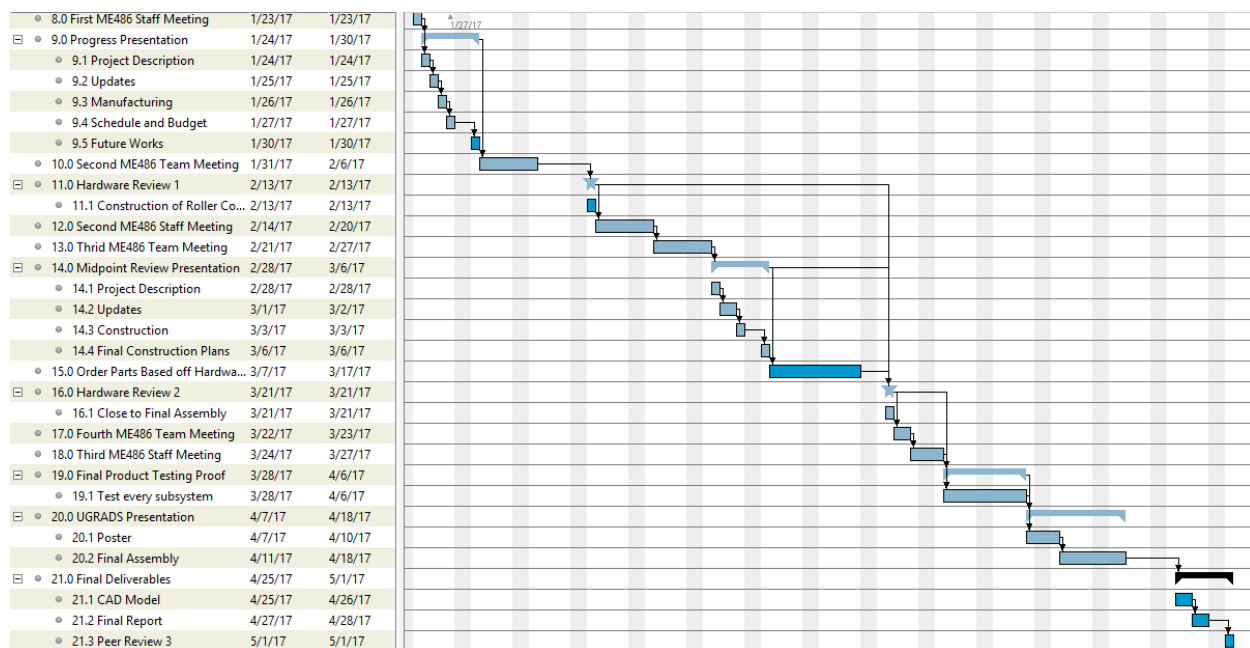
## 6.2 Bill of Materials

The bill of materials at the end of the fall semester contained the base items necessary for construction. The harness, ropes, and frame were selected as the best using load analysis for a jumping child, while the sliding components were selected due to their low friction coefficients. As the project is DIY, the availability of these materials was of utmost importance and are available at major retailers around the U.S.

The final design consists of the following parts: Jumper Harness, Nylon Rope, External Slider, Lifting Beam, Easy Up Pyramid Shade, Wrench, Hammer, Power drill, and Screwdriver. The final price for this design was \$587.45 at the end of the fall semester.

## 6.3 Spring Schedule

The updated team schedule included the spring semester deadlines and due dates for the completion of the senior capstone project (**Figure 22**).



**Figure 22.** Updated Gantt Chart with Tentative ME486 Schedule

The team was behind schedule for a week or two since there were adjustments to the final design after meeting with the client. After making the necessary changes the project is back on schedule and prototyping should proceed as planned for the remainder of the winter semester. All tentative deadlines for the spring 2017 semester were added to the Gantt chart and the team anticipates no problems sticking to his schedule. During the winter break the supplies were ordered for the construction of an alpha prototype during the first section of 2017.

## 7 Implementation

After the selection of the final design, the team built a ~60% complete product to stay on track with midpoint of the semester requirements. This included purchasing materials, assembly, testing, and plans for the remainder of the school year.



## 7.1 Design of Experiment

The design of experiment (DOE) was performed to maximize the ease of movement of the proposed final design.

After conferring with the client, the team decided to test variations of design that would increase the ability of the user to move large distances with the minimum amount of effort. The variables tested involved the middle bar of the design, including the wheels on the ends connecting to the track and the construction of the sliding bar than moves along the middle bar. The material of the wheels was changed (nylon vs. stainless steel) to see if different coefficients of friction make for a smoother motion. The second variable affected the sliding bar that currently consists of a PVC section where the team was interested to see if changing the length of the section (2ft vs 4ft) would distribute the weight differently. The last variable tested was the use of bearings to facilitate the movement of the PVC section or just using the current sliding bar without any changes.

To test these effects on the system, the Easy Up was assembled to the most recent configuration with the resident crash test dummy placed inside. Each possible combination of wheel material, presence of bearings, and length of PVC sliding bar was tested and assessed on total distance traveled, both forwards and laterally. The harness was moved to the “back” of the Easy Up and given a push by one group member forward. The distance traveled forwards was measured with a measuring tape and the harness was then moved laterally to the extreme side. The system was given another uniform push to the side by the same group member and the distance traveled to the side was measured. The two distances were added together for a total distance traveled, with a higher value being desired (**Figure 23**). The total process was repeated twice, with the order of tests randomized, to ensure precise results.

					m =	2	experiment levels		
<b>Ease of Movement</b>					n =	3	number of factors or design variables		
<b>Recorded: 3/2/2017</b>					Fraction =	1	fraction of full factorial experiment		
					N =	8	number of experimental combinations/trials		
					r =	2	number of replicants		
		wheel material	length	material					
	I	x3	x2	x1	y1	y2	ybar	SSE,i	
1	1	-1	-1	-1	63	77	70	98	
2	1	-1	-1	1	80	61	70.5	180.5	
3	1	-1	1	-1	74.5	79.5	77	12.5	
4	1	-1	1	1	51.5	54	52.75	3.125	
5	1	1	-1	-1	87	73	80	98	
6	1	1	-1	1	87	69	78	162	
7	1	1	1	-1	89.5	90.5	90	0.5	
8	1	1	1	1	75	71.5	73.25	6.125	
Effects		<b>12.75</b>	<b>-1.375</b>	<b>-10.625</b>					
β's	73.938	6.375	-0.6875	-5.3125					
SS		650.25	7.5625	451.5625		ybarbar	73.938	560.75 = SSe	
dof		1	1	1				70.094 = St*3 = MSe	
MS		650.25	7.5625	451.5625					
F		9.276861346	0.107891217	6.442264824				25.117 = 3*St	
Pr(F)		0.015922459	0.750990545	0.034810257					
						SSTrial	1594.7		

**Figure 23.** Design of Experiments

The results of the DOE showed that the variables of wheel material and the material of the sliding bar were the most impactful determinants of total distance traveled because the effects were farthest away from 0 (12.75 and -10.625 respectively). Specifically, the steel wheels and the PVC alone were favored for maximizing the distance traveled. The length of the PVC section did not seem to affect how far the



device could move. However, the effects were not statistically significant results as none of the results were bigger than three times the standard deviation of 8.33.

The team found it surprising that the PVC alone moved better than with bearings, but attributed it to faulty connection points between the PVC and the bearings that was dragging along the middle bar. In a test after the DOE the team found that the harness assembly attached to the bearings alone could travel the entire length of the middle bar with ease. The focus of the next week will be to securely attach the PVC to the bearings so that the device has the benefits of weight distribution and low friction movement.

The steel wheels will continue to be used in the device, though the team would like to find a way to make them quieter, like the nylon ones. As the length of the PVC did not seem to make a difference the device will continue to employ the 2ft section, as it allows the user more freedom of lateral movement.

By exploring ease of movement options using a DOE, the team could determine which variables were contributors to later prototype success. Further testing with bearings should dictate whether the DOE results were due to incorrect coupling between sections or a real disadvantage to utilizing bearings.

## 7.2 Manufacturing

The team placed an emphasis on manufacturing the frame of the project as well as the areas requiring moving parts.

The Easy Up frame was modified from its original configuration by removing the top tent-like frame which supports the canopy. This left only the side walls, which were the supports for the guide rails. The guide rails were made of two sections of guide rails that were assembled from two sections of L-shaped slotted angles (**Figure 24**).



**Figure 24.** Guide Rail Construction

As the length of the sections was only four feet, the group put together three segments to span the length of the Easy Up. The guide rails were placed directly on the Easy Up and secured to the frame using nylon rope or zip ties to keep the rails from bowing inwards during use (**Figure 25**).



**Figure 25.** Guide Rails Attached to the Frame

The middle bar was the next subsystem of assembly, and proved the most difficult to work through. The bar itself was a steel pole used in chain link fences, and was trimmed to appropriate lengths

using a handsaw. The difficult manufacturing was in the construction of the wheeled system, which went through several iterations, including one with garage door wheels and rubber stoppers (**Figure 26**).



**Figure 26.** Garage Door Wheeled System

This assembly would cause the wheels to become misaligned when loaded, as seen in the image. Additionally, only having one wheel on each side made it impossible for the system to move smoothly unless force was applied directly in the center of the middle bar. To address these problems, the team worked to develop an original wheeled system that could be adapted to the L-Shaped guide rails.

The first step was construction of a PVC attachment that could be used to attach two wheels to each side of the middle bar (**Figure 27**).



**Figure 27.** PVC Attachment

Two training wheels typically seen on children's bikes were bolted to the two ends of the PVC, using several washers to keep the wheels from rubbing against the PVC and stopping motion. This process was repeated on the opposite side to complete the middle bar (**Figure 28**).



**Figure 28.** Complete Middle Bar Assembly

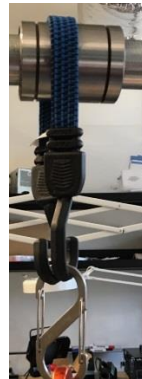
The harness system assembly proved to be the easiest system to assemble, as supporting the weight of a child had less moving parts. This assembly consisted of a jumping harness purchased from Target attached to a 2ft section of PVC, which had a tow strap connection to a rock climbing swivel (**Figure 29**).



**Figure 29.** Harness Assembly

The only changes from the original design resulted from an overengineered spreader bar used to move industrial cargo being switched to PVC and adding an adjustable tow strap buckle.

The connection from the harness assembly to the middle bar was constructed by attaching a bungee cord to the adjustable swivel and threading it over a linear ball bearing sitting on the middle bar (**Figure 30**).



**Figure 30.** Connection to the Middle Bar

With this addition, the user should be able to move smoothly side to side as well as across the Easy Up. The final design completely assembled can be seen in **Figure 31**.



**Figure 31.** Final Design

For detailed construction information, the instruction manual for the device can be found on the team capstone website [14].

### 7.2.2 Resources

Since the client specified that the final product should be affordable, the team made a separate account summary for what the user would expect to pay with the parts so far. At this moment, a user should spend \$387.92 on the materials for the device and ~\$50 for the tools, depending on what is currently owned by the user. A detailed breakdown of specific materials, costs, and sources can be found in the BOM (**Table 6 and 7, Appendix B**).

### 7.2.3 Implementation Schedule

A detailed implementation plan can be found in Appendix D (**Table 8**). The project was behind schedule for a few weeks due to the difficulties experienced in manufacturing the middle bar. But once completed, the team had no problem completing the remaining semester deliverables on time or even ahead of schedule.

## 8 Testing

The testing of the final product proceeded per the procedures laid out in Section 2.3.

1. The first test was total device weight, which was done through displacement. One member of the team stood on a scale and held all the parts of the system. Once the weight of the member was subtracted from the total, the device weighed a total of 57.2lbs, which passed the requirement of being 70lbs or less.
2. The next test was to determine the dimensions of in use and storage condition of the final product. Using a tape measure, the system measured 9.8ft in each direction for the in-use condition. This satisfied the condition of being less than 12ft in each direction specified by the client. The storage space was measured, and all subsystems of the design were able to fit within 5'x5'x2.5' except for the middle bar. This was addressed by obtaining permission from the client to redefine the storage space to 10'x5'x2.5', which was satisfied.
3. The test for durability required the device to be loaded with 40lbs to make sure that the system could support a child while using the system. The system was loaded with 40lbs of dumbbells without collapse, but there were some concerns about vigorous movement from the child that could make the system unsafe. The system technically passed the test, but the team addressed the weight concerns by adding safety warnings to the instruction manual.
4. Next all materials within the system were cross checked against the EPA list of toxic materials to verify that all materials being used would create a safe environment for the child. All materials used were confirmed to be nontoxic and safe for the child to be around with proper use, and a detailed list of materials and toxicities can be found in Appendix E (**Table 9**).
5. The comfort of the device was tested through measurement of the padding in the harness with calipers. The padding measured 1.468" which was greater than the .5" minimum established.
6. The next testing procedure was to verify that no loose ropes were present within the system. The biggest issue was the tow strap having excess rope which the child could

gain access to. To prevent this the excess strap was rolled up and tied together so that the strap could be adjusted without the problem of having a loose strap.

7. The parts and fasteners of the system were counted to ensure there were less than 100 so the system would still be simple to construct. The total number of fasteners and parts of the system was 66 which satisfied the testing condition.
8. All support straps and ropes were tested to make sure that they did not deform to more than 10% of the original length when pulled on with a set force. This was done by using a force gauge to find the required maximum force where the deformation would occur. The nylon rope, harness, and tow strap were tested and confirmed to deform less than 10% of their original length when loaded.
9. The overall cost of the entire system was calculated to make sure that the system was below \$400 for parts and tools under \$150. The in-depth bill of materials from Appendix B completed this testing procedure (**Tables 6 and 7**).
10. The setup time was tested by timing two group members assembling each section of the system from scratch. The total time came out to be roughly one hour. The team realized that this time was for individuals with an intimate knowledge of the system, but even with significant padding for new users, the time would still not exceed a weekend of work.
11. To make sure that the device would be able to adjust properly to different heights to support a full range of kids the team tested the adjustability of all locations that needed it. The main location this test was used for was the tow strap which allowed the harness to sit lower to the ground or can be higher depending on the size of the child.
12. The team used no specialized parts, as every item could be immediately purchased online or at local stores.
13. Pinch points in the system were found by running a silk scarf over the system and seeing if the scarf tore when force was applied. The one potential pinch point found was on the buckle of the tow strap, which was covered by cutting the toe of a sock off and threading it through the strap.
14. The same silk scarf used in pinch point testing was used to locate sharp edges on the device. The team found sharp edges on the legs of the Easy Up, which were then covered with pool noodle sections. The team included warnings in the instruction manual to ensure that the sharp edges normally out of reach of the child during use would be stored appropriately when not in use.
15. The aesthetics of the system were addressed by providing customization information at the end of the instruction manual. This included being able to paint the product, adding decals, and hanging streamers from the system to make it more appealing to children. The builder was encouraged to use these examples to spark their own creativity.

## 9 Conclusions

### 9.1 Contributions to Project Success

The team successfully completed two semesters of engineering capstone as the final product developed was acceptable to both the client and class advisor.

The team was formed to create an antigravity harness for Dr. Winfree to increase the mobility of children suffering from diseases like cerebral palsy and muscular dystrophy. The ultimate deliverable, an easy to follow DIY manual, was finished at the end of the semester and completely outlined the steps

needed to create the device. The team kept in good contact with the client, though sometimes experienced difficulties scheduling meetings due to busy spots in the semester, such as before UGrads. All deliverables required by the client were met, and the only late deliverable for the class was the second hardware review, which was delayed by difficulties with middle bar design.

The ground rules for meetings within the team were followed, even beyond what was stated in the Team Charter, as the team often met 2-3 times a week during manufacturing of the device. There were more agendas this semester, which seemed to help the team stay on track with weekly and long term goals. Each member stuck to their role in the group, the secretary and website manager were required to complete weekly assignments, and did so with little prompting on the part of the group. There were no major disagreements within the group, and the need for voting only arose rarely. The communication between members did suffer more during the spring semester versus fall, as the tasks increased in complexity. While no one pulled a disappearing act, there were points in the semester where tasks were delayed to the point where they interfered with other members' abilities to do their jobs. As long as everyone asked for clarification when there were issues, there was enough time to do several drafts of deliverables such as reports and presentations.

The cost aspect of the project was very positive as the team could stay under budget for both aspects of the project: capstone and final product. Overall the product was high quality, especially after the purchase of an Easy Up frame made from steel, as the old aluminum frame was unstable during use. The middle bar being completely built from scratch was required as no existing system worked for the team's specific needs, and the resulting PVC system was very sturdy after application of adhesive.

There were problems with time management that were mentioned earlier, and these contributed to delays in manufacturing. Some tasks would be assigned and then put off until the days before it was due, making it difficult to have quality work. During manufacturing, it was always the same people doing the work, and it would have improved efficiency if systems could be divided up without constant supervision. But as the manufacturing involved parts integrating with one another, it might have been more difficult to do building separately without interfering with some other moving part.

The team found great success using online document and slide sharing applications, as the busy schedule necessitated working off site frequently. The Gantt Chart was not as useful for keeping the group on track, and by the end of the semester the team was relying on the project manager to have recorded the important due dates. Perhaps a different scheduling software could have been used which was more user friendly, thereby removing some of the stress involved in recording deadlines. The design of experiments was probably the most useful test performed during the semester, and it would have been good to extend the tests to other areas of the device performance aside from smooth movement. The bearings used for smooth lateral movement on the middle bar would not have been considered if the DOE had not been performed.

The biggest problems encountered by the team were all related to manufacturing. Due to the specific function of the device and constraints to make it DIY, there were several ideas that had to be discarded for not being feasible. Many of the hardware store options were just slightly different sized than needed, or more sophisticated options would put the budget out of reach of the average family. Creating smooth motion with a from scratch system was incredibly complicated, especially with a skeleton frame with which loads could be distributed.

While the final product was delivered on schedule to the client, there were several areas that could have improved.

## 9.2 Opportunities for Improvement

Despite an overall success of the capstone project for Team 10 in creating a final harness device as the project goal had stated, the group reflected on areas of improvement in aspects of organizational actions and in the design process.



The team experienced difficulties in contacting the client (Dr. Winfree) throughout the semester. This led to weeks of no contact with the client and in turn caused the group to fall behind in making the final CAD model and assembly of the design as displayed in the Gantt chart in **Figure 22**. This stemmed from schedule conflicts with groupmate's having class and the availability of the client. To avoid this issue, the client contact should reach out to the client at least a week in advance to schedule a meeting time. This would help ensure regular meetings with the client are fulfilled and allow the group to show progress and gain feedback on ideas more often.

Currently, the attachment method used to connect the harness to the middle bar was slightly unstable as it is not fixed into place on the linear bearing. The current attachment method uses straps which rest the harness onto the bearing but when in use can slide off the moving bearing. This caused the user to not be able to move within x-direction plane as the design intends to support. With more time, the group will be able to develop a solution to this problem.

The group was not able to meet all the original created engineering requirements and had to change the requirement stating the final design must fit into a folded space of 5x5x2.5 cubic feet. The design of the middle support bar did not meet this requirement as it was not foldable and an adjustment was needed to be made to accommodate the length of this piece. Some possible ways the group could have designed the middle bar to meet this requirement could have been to cut the fencing pole into two pieces which could be connected by PVC fittings and taken apart when the system is not in use.

Many technical lessons were learned from the completion of this project. Through the completion of the CAD model, the group learned how to model real-world designs and how to incorporate tolerancing of parts into CAD modeling. Setting tolerances for all parts of the system in the CAD model helped the group anticipate possible conflicts with interacting parts. This included anticipating buying a PVC fitting with a 2 ½ inch fitting to a 2-inch-thick pole. Using research to find manufacturing tolerances (+-.02 inch) and inputting them into a CAD model, one can physically see if a part with a maximum value tolerance would still fit another piece with a minimum tolerance even if the dimension given to the group are not necessarily correct. Using tolerances was also done to the wheels to see if dimensions chosen would be a problem for these parts.

The team overall gained experience in designing for a specific purpose of allowing children with muscular dystrophy, cerebral palsy, and other mobility issues to still develop crucial social skills when between the ages of two and five. This included designing around the idea of using parts which would classify the device as a Do-It-Yourself device (DIY) which greatly improved the team's design decision skills.

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## Appendix A

The House of Quality was updated the week of 11/14 and approved by all team members and the client (Figure 1).

Customer Requirement	Weight	Engineering Requirement	Fits in 10" x 12" x 2" Volume Space (Storage Space)	Fits in 12" x 12" x 2" Volume Space (Work Space)	No Pinch Points	No Sharp Points	Non-toxic Materials	Learned has at least three contact points	No Loose Ropes (Entanglement Risk)	> 20 parts	100 Screws and fasteners	Non-elastic materials	Class Finish Points (Non-elastic)	300 Dollars	100 Dollar Tool Budget	Assembly spans two days	Assembly pack for weight bearing parts	Adjustable buckles	Range of Adjustability	No Specialized Parts	Weight of System < 50 pounds	Support 40 pound child	Padding => 5 inch thick
1. Safety	10				7	10	10	8	10				1	1							8		
2. Easy to Assemble	7		-2							9	9				-2	10					6		
3. Adjustability	5							-1	-3			1.5					7	7	6				
4. Durability	7							4			1.5			5								7	6
5. Size	6		6	7															4		10	-1	
6. Comfort	8				10	10		7	3		4											-1	8
7. Cost	7						-3							7	7		3	3		8			
8. Workspace Size	6		7	5																			
9. Aesthetics	9						5	1					10								9		-1
Absolute Technical Importance (ATI)			70	72	160	180	124	168	109	83	83	29	80	4	35	70	56	26	24	128	211	135	120
Relative Technical Importance (RTI)			12	13	4	2	6	3	9	15	10	18	11	22	18	14	17	20	21	7	1	5	8
Target(s), with Tolerance(s)			Max, +1	Min, +1	0	0	0	Max, -1	0.15, +5	70	+5	Max	Max	250, +100	+50	+1	+5	Max	+1	0.30, +20	30, +20	0.75, +1	Max
Testing Procedure (TPs)			2	2	13	14	4	8	7	7	8	15	8	9	9	10	11	11	11	12	1	3	5
Design Link (DLs)			1	2	3	3	3	4	5	6	6	8	7	9	9	10	11	12	13	14	15	16	17

Approval (print name, sign, and date):

Team member 1: Hasan Farman

Team member 2: Khaled Alasami

Team member 3: Noah Oliver

Team member 4: A.J. Gray

Team member 5: Saleh Bakr

Team member 6: Aliya

Client Approval: [Signature]

April 19, 2017

Figure 1. Updated HOQ

## Appendix B

**Table 6.** Part Bill of Materials

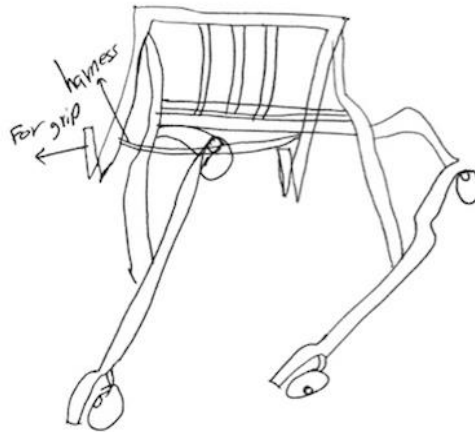
Part Name	Qty	Cost
Jumper Harness	1	16.00
Nylon Rope (12in)	4	6.00
Ez-up	1	175.00
Zinc Plated Punch	1	57.00
PVC	1	2.00
Tow Strap	1	10.00
Swivel	1	25.00
Bearings	1	31.00
Galvanized Steel Chain-Link Pole	1	12.00
T-Shaped PVC	2	3.00
Wheels	4	24.00
Screws and bolts	12	4.00
Strap Ties	12	21.00
Washers	16	1.92
<b>Total</b>	<b>61</b>	<b>\$387.92</b>

**Table 7.** Tools Budget

Component	Image	Cost	Seller
Wrench		\$8	Target
Power drill		\$25	Walmart
Hand Saw		\$10	Home Depot
Screwdriver		\$16	Toolnut.com

## Appendix C

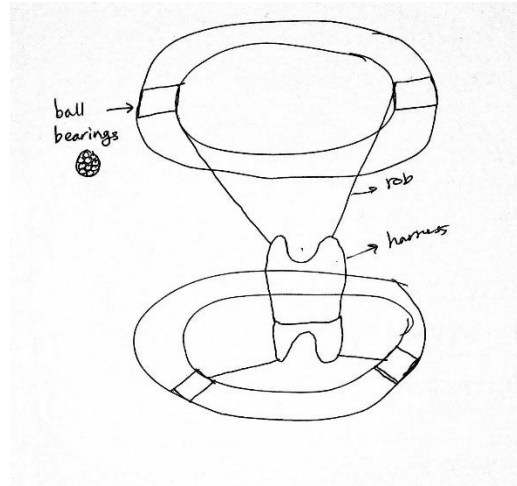
The following designs are a continuation of section 4, and all figures are variations of those seen above.



**Figure 11.** Concept E

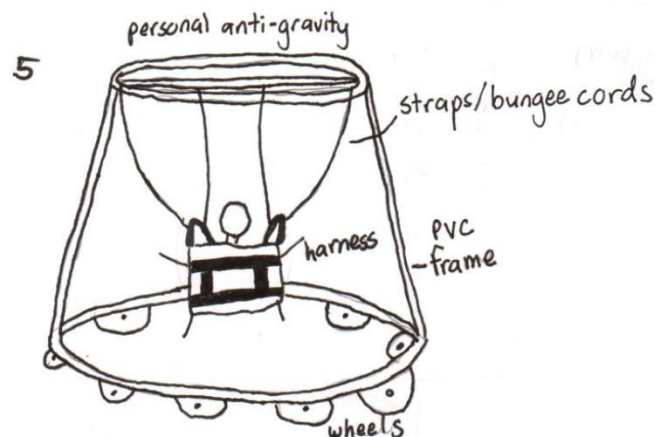
The first concept was an adapted walker such as those used by the elderly, with adjustments to make it more child-friendly (**Figure 11**). There is a seat harness that holds the user in place and gains its support from the straps attaching to the frame. The ability to move effortlessly is the most important need supplied by this product, as it maximizes the workspace while limiting the size of the product. This is a comfortable support system, as an increased number of straps distribute the weight evenly. As a wheeled system concept 1 has a high degree of safety, with wheels that can be locked to limit movement of the

child if the parent deems it necessary. It has even tabs for adjusting to the required arm size, whether the child wants to push with legs and want additional stability or to free the arms to interact with the world. The cost and durability of this design are dependent on the quality of materials used, with cheaper versions potentially including PVC pipe and wheelchair wheels. The aesthetics of the system is high, as the number of surfaces the child can touch is high, and each could have colorful objects or images.



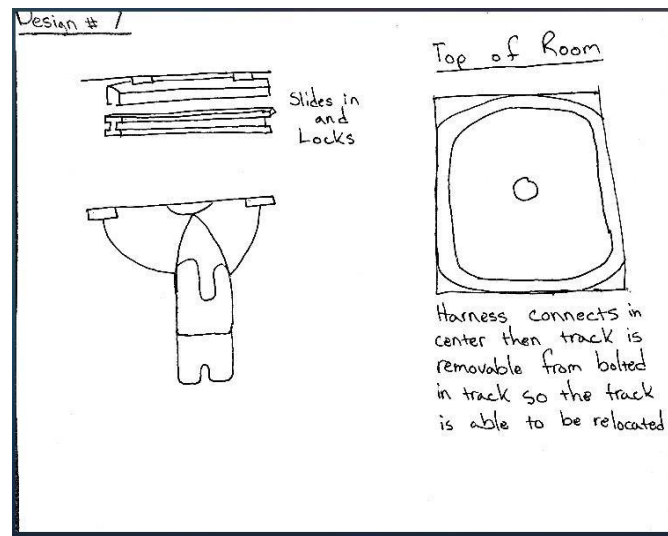
**Figure 12.** Concept F

Concept F was a ceiling track system that allows the child to go everywhere in the room, and potentially gain momentum going in circles (**Figure 12**). The harness has four guidewires that help to make the weight distributed, potentially increasing the comfort and safety of this system over other options. The design has parts less than 20 parts, as the circular track should contribute to the easing of assembly if the circle shape is pre-formed. The motion of the system involves control, as the frame limits the workspace of the child, even though the size of the product is on the smaller size. The aesthetics are up to the builder and child, though the appeal of being able to move at higher speeds may appeal to some users. The safety could also be a little questionable regarding the child vomiting if they manage to build up enough speed turning in circles.



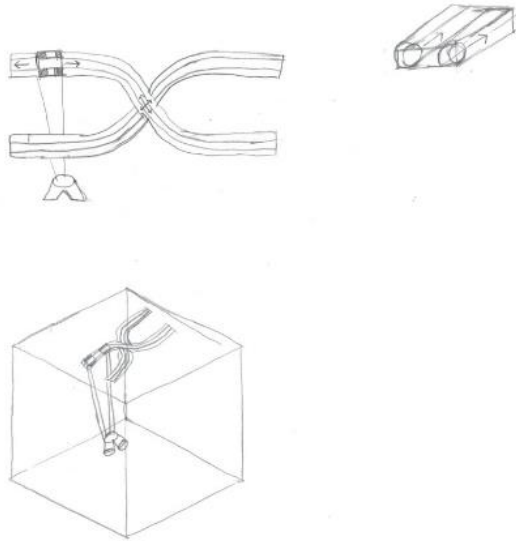
**Figure 13.** Concept H

Concept H was a variation of a ceiling track system, without being limited to a single room (**Figure 13**). The frame supports a harness on the child with straps while preserving a free motion guidance system with the wheels on the bottom. This concept has the same safety as a ceiling track system but only if designed appropriately, which would affect the ease of assembly. The adjustability of the device would also be difficult but is possible to accomplish by creating an initially taller frame and different lengths of straps. The workspace size of the child would be increased to any room of the house if the device fit through the door, but would probably be a little less durable due to bumping into objects. The comfort and aesthetics of the design are entirely reliant on the options of padding and paint as chosen by the parent of the child. The cost would hopefully be close to that of a ceiling track system, but such a hybrid system would most likely require a few prototypes before being completely safe.



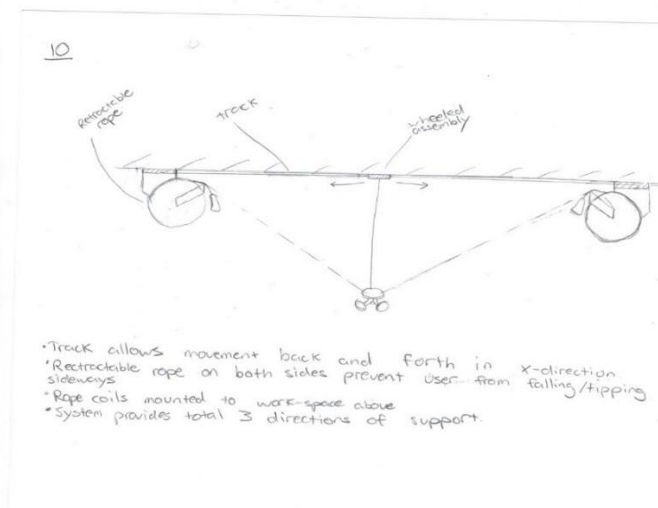
**Figure 14.** Concept I

This design was a variation of a ceiling track system in which the ceiling track can be removed from the bolted down railing system and moved to another track system to another room within a house which can maximize the workspace for the user by not limiting them to one room (**Figure 14**). The way this system would work would be a harness would be attached to sliders on a track system that would allow the user to maneuver the room the system is set up in a while in the harness to reduce body weight experienced on the user's legs. This design adds more workspace possibility for the user which can be beneficial since the user can utilize the system in different settings instead of being limited to a one room track system. This design involves adjustability at all corners of the track system and can in some cases be more durable than a mobile design because it does not have the chance of being crashed into a wall by a user. This design also has a higher safety rating than a mobile design since it is a track system and is not being moved around constantly like a mobile design.



**Figure 15.** Concept J

This track design was mounted in the ceiling space in a room and provides four outer-extreme points of destination the user can travel (**Figure 15**). A bearing assembly with wheels allows movement along the track. The harness subsystem is secured with two supporting straps to prevent the child from tipping over. The track design is extremely durable, and the harness is easily adjustable for different sized children. The system assembly has limited mobility and will be difficult to move into other rooms. The design does not have the ability to be stored separate from its location of use, increasing its size while not maximizing all available workspace. The aesthetics and safety of this product are similar to other ceiling mounted systems, with all aspects being safe, though potentially a bit restrictive. The system will be as comfortable based on the design of the harness, with increased padding and weight support being a top priority.



**Figure 16.** Concept M

This design used a combination of ceiling tracks, retractable pulleys, and a looser harness system to adapt the ceiling mounted designs seen so far (**Figure 16**). The user can move along two ways in the x-direction. The user has support from two directions with supports extending from the retractable rope

feeds, thereby increasing the safety and support in those directions. The track system uses small bearings that glide along the length of the track giving the user mobility. Tension forces in the rope can be adjusted/calibrated to keep the user balanced in equilibrium to prevent tipping, but an additional rope in the back may need to be added to prevent the child from flipping. The cost of this design would be higher than all previous designs discussed as the retractable rope feeds would be difficult to design. The complexity of assembly will cause a high risk of malfunction with inexperienced builders and may prove to be too challenging for a DIY project.

## Appendix D

**Table 8.** Implementation Tasks

Implementation Task	Details
Hardware Review 1	<ul style="list-style-type: none"> <li>Completed a prototype full scale model of the system as whole and the track system that the team hopes to use in the final design.</li> <li>This design gave the team an idea of how the track system should work in the final design and what needs to be changed to make the final design more efficient.</li> </ul>
Order Parts based off Hardware Review 1	<ul style="list-style-type: none"> <li>After the completion of Hardware review various parts were ordered from Home Depot and bearing production company to complete the DOE.</li> <li>Gather the necessary data to make the implementations during the alpha and beta prototype phase.</li> <li>Consider buying a new track system and new EZ UP that will be more rigid and supportive.</li> </ul>
DOE (Design of Experiments)	<ul style="list-style-type: none"> <li>This implementation task is needed to test different variables on different subsystems within the system.</li> <li>The variables that will be changed will be the wheel diameter and material, the length of the slider and material choice, and a bearing for the slider compared to without.</li> </ul>
Hardware Review 2	<ul style="list-style-type: none"> <li>Made changes based on Hardware Review 1 and DOE results to the system.</li> <li>These changes are the more significant ones since both Hardware reviews have been completed as well as the DOE. <ul style="list-style-type: none"> <li>This version of the system will be the Beta Prototype.</li> </ul> </li> </ul>
Beta Prototype	<ul style="list-style-type: none"> <li>Once the DOE is completed for the system the components that were tested will be adjusted to better suit the needs of the project.</li> <li>The system will be rebuilt with the changes and tested for durability, stability, and safety.</li> <li>Following the testing procedures that will be done the modifications that are necessary to fulfill each of the tests will be completed to prepare the system for the alpha prototype phase.</li> </ul>
Alpha Prototype/Final	<ul style="list-style-type: none"> <li>This prototype will include all the correct subsystems that will be involved in the final design.</li> </ul>

Testing Phase	<ul style="list-style-type: none"> <li>Once this prototype is completed the team will make the last adjustments to the overall system to prepare for the final design and UGRADS presentation.</li> </ul>
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## Appendix E

**Table 9.** Material Safety

Material	Analysis
Steel	<ul style="list-style-type: none"> <li>Chemical: Dust/fumes cause allergic skin reactions and cancer from inhalation. Inhaling dust can also cause respiratory damage.</li> <li>Solution: Steel in frame of EZ-up, fasteners, and track will generate no dust/fumes from use.</li> </ul>
Paints	<ul style="list-style-type: none"> <li>Chemical: Paints with lead are hazardous in case of skin contact, eye contact, ingestion, and inhalation</li> <li>Solution: Aesthetic paints must be water base (60-65%) lead-free paints to avoid contact with user from touching and breathing in paint fumes.</li> </ul>
Polyester	<ul style="list-style-type: none"> <li>Chemical: Dust from material may be considered as a nuisance dust.</li> <li>Solution: Polyester materials in use with system such as buckles, PVC fittings, and wheels will not generate enough friction to create dust from Polyesters.</li> </ul>
Polypropylene	<ul style="list-style-type: none"> <li>Chemical: No exposure risk to humans when used for designated purpose. (Temperatures do not exceed 700 degrees Fahrenheit)</li> <li>Solution: Quick-release/harness straps use variations of this material</li> </ul>