DIY In-Home Anti-Gravity Harness

Final Proposal

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Khaled Alosaimi

Eileen Baker

Hasan Farman

A.J.Garcia

Noah Oliver

Team 10

Department of Mechanical Engineering
Northern Arizona University

Faculty Advisor: Dr. Kyle Winfree

Instructor: Dr. Sarah Oman

Disclaimer

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, is attempting to develop an in-home antigravity system that would enable these children to move effectively about a room, thereby increasing their social development. There are a number of anti-gravity systems on the market that were researched in order to better understand the engineering behind assistive mobility, concentrating on a Do-It-Yourself approach that would take parents less than a weekend to build. A series of designs were developed and winnowed to a final design which was tested by the group theoretically to determine feasibility. The team constructed an implementation schedule for the spring semester to guide the prototyping process in order to create the most effective final design.

Contents

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 are associated 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 were linked to greater social association.

Cerebral palsy (CP) is the most common motor disability in children, with every 1 in 323 child 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 experiences 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 seeks 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 seeks to be 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 will create 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 given verbatim as follows:

> Children with limited mobility often do not receive the much needed exposure to socialization to appropriately cognitively develop. Existing research shows that enabling young children with self-control of their own 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 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 will be 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 is an entirely new project there were no original systems the team will improve upon.

2 Requirements

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

2.1 Customer Requirements

After conferring with the client and the group, nine governing customer requirements with weights from 0-10 were produced and can be viewed in the table below.

Table 1. Customer Requirements and Weights

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

Among the top weighted sponsor requirements include safety, aesthetics, and comfort. The rationale for these requirements was derived 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 for our design will depend on parents of children putting trust into our harness system to not harm their kids in any way. This causes our safety weighting to be our most prioritized trait with a rating of a 10. Comfortability and aesthetics had been our next highest ratings of 9 and 8 respectively. The anti-gravity harness system will be used for time periods of up to four hours (T=<4). This forces comfort duration to be an important factor to test in our design. Lastly, aesthetics was an edition added by Dr. Winfree himself from his knowledge of current existing competition baby products. The team experienced delays in meeting the project's client due to schedule conflicts, so the first six customer requirements were developed and voted on by the team. After meeting the client, the requirements of cost, aesthetics, and workspace size were added to **Table 1** along with the assigned weights.

2.2 Engineering Requirements

From the customer requirements, as series of engineering requirements with targets and tolerances were developed in **Table 2**. Each customer requirement was paired 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 will enable the team to start prototyping and testing different designs for the anti-gravity system.

Table 2. Engineering Requirements

Customer Requirement	Correlating Engineering Requirement
Safety: Low choking/entanglement risk	• No Sharp Points • No Loose Ropes (Entanglement Risk) • Nontoxic Materials
Ease of Assembly: Avoid machining, complex parts	• No Pinch Points • Less than 20 parts • < 100 Screws and fasteners • Assembly spans two days • No Specialized Parts
Adjustability: Accommodate different sized children or growth	• Socket Sliders • Variety pack for weight bearing parts • Adjustable buckles
Durability: Materials pass various strength or fatigue tests	• Weight of System < 50 pounds
Size: Is unobtrusive and allows user to interact freely	• Fits in 12ftx12ftx12ft Volume Space • Weight of System < 50 pounds
Comfort: Refrain from using coarse/irritating materials	• Elastic Materials • No Pinch Points • No Sharp Points • Padding => .5 inch thick
Cost: Keep under target cost	• < 300 Dollars • No Specialized Parts
Workspace Size: Size above user	• Fits in 12ftx12ftx12ft Volume Space
Aesthetics: Contain multiple different colors	• Gloss Finish Paints (Non-toxic)

Once developed, the engineering requirements were added to the HOQ and correlations between these values and the customer requirements were ranked.

2.3 Testing Procedures

The testing procedures are a series of examinations performed on the final product to determine whether engineering requirements have been appropriately met.

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

2. The storage space and deployed size of the system will be measured with a tape measure provided by a member of the group. The storage space will be considered as passing the test if the measured values is less than 5’x5’x2.5’ with a foot tolerance in each direction. The deployed size must be able to fit in a $12ft^3$ space with a foot tolerance in each direction.
3. To ensure that the system can handle a 40lb child the team will place a group member’s dumbbells totaling 40lbs in the harness. This requirement will be considered a pass if the device can hold anywhere from 40-60lbs.
4. The standard of nontoxicity will be evaluated by comparing the list of materials in the system to standards set by the EPA. The EPA has lists of chemicals and manufacturing materials which are considered toxic, and the system will only pass this test if all materials are not found on this list. Additionally, if a toxic material is used it must be completely covered by a nontoxic material that cannot be removed by the user.
5. The padding on the harness will be measured with calipers obtained from a team member’s research lab. The padding will be considered sufficient if it is at least 0.5” thick.
6. No loose ropes due to entanglement risk will be evaluated by measuring any loose ends of rope-like materials with a tape measure procured from a team member’s house. The loose ends can be no longer than 3”, and if they are they must be secured with a zip tie or other constraint.
7. The total number of parts and screws/fasteners will be counted 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 will be tested to determine if when force is applied the system deforms more than 10% its original length. To accomplish this a force gauge will be taken from the physics building 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 will be 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 will be taken with a stopwatch to ensure it does not take a group member longer than two 8 hours days, with 24 hours as an absolute maximum.
11. To measure adjustable buckles and rope components the range of adjustability will be measured with a tape measure from a group member’s house. To satisfy this test all ‘adjustable’ materials must be able to scale at least one inch in both directions.
12. The criteria of no specialized parts will simply consist 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. The consideration of no sharp edges will be qualitatively determined by a team member wearing a soft glove while running it over the system. If the glove frays the system still has sharp edges that need to be smoothed.

15. The aesthetics of the design call for the team to use neutral colors so as not to make the system gender specific. Supporting documentation will provide 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 whether engineering requirements will be met in the final design. Should the product fail any one of the testing procedures, a reengineering 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 closet and other unused space that the user can use to place the system when not in use. A storage space limit if 5x5x2.5 ft. was created with a slight tolerance of +-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, it can be fit into a 5x5x2.5 ft. volumes space.

2. The workspace size is volume space the user can have 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 materials ordered for the project will be compared to lists of published lists of toxic materials and any materials that contain harmful toxins will be substituted with materials that comply with these lists

4. The amount of security the harness will have will increase directly with the amount of contact points the harness contains. The design will most likely contain three contact points to prevent tipping/falling of the user and still provide easy access into 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 includes minimizing the amount 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 amount 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. To ensure this engineering requirement is fulfilled, gloss finish paints will be used paint the final design.

8. Deformation in the design can cause safety hazards for the user. The frame structure used in the gravity harness design is made from aluminum alloys and steel. These materials are rigid enough to undergo cyclic loadings of 40 pounds and have axial deformations of under $1x10^{-2}$ inches. The requirement needed to achieve this includes having no members which are elastic materials that experience high amounts of deformation.

9. Families with children who experience mobility issues and/or are diagnosed with 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. The amount of tools needed for a DIY project must be minimal and widely accessible to customers. A tool budget was created and capped at a limit of 100 dollars. This still allows simple electric drills and screwdrivers to be able to be used when constructing the harness system.

10. Installing the design should take no longer than two full days since the average working parent is short on time as well as monetary resources. By limiting the parts for the design to less than 20 and fasteners to less than 100, the amount of time for parents to construct the harness will meet our requirement of two days or less.

12. The use of adjustable buckles allows the harness to be sized along with a growing child, this prevents having to buy an entirely new system when growth spurts happen. Buckles which slide along the length of the rope will be installed to set the harness at different heights. A set value for this requirement proved to be abstract so the team had decided to maximize this trait with a 'MAX' value inputted in the HOQ.

14. The harness design uses parts that can easily be fastened together. This is only possible when there are no machined parts for the assembly. The design meets this criterion since all materials will be ordered from retailer stores around the U.S.

15. 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. To ensure this requirement is met, the heaviest parts that cause the total weight to exceed our limit will be substituted with similar parts.

16. The average weights of children between 1 and 5 should not exceed 40 pounds. Therefore the system will be designed to support 40 pounds toleranced with an additional 20 pounds. The deformation of the metals used for the harness frame will be less than 10^{-2} inches proving the structure will be able to support 40 pounds.

17. The comfort of the system depends on the padding that will be used for the harness. ½-inch thick padding will be required to cover the surface of the harness. This will be met from ordering the correct specified padding with the required thickness to use on our design.

18. Using covers for the buckles assures that the user does not get hurt by catching skin between two pressure points. All buckles will be covered with fabric/padding to be completely hidden from view and not be exposed to the user. This satisfies the groups requirement of padding all buckles.

The team was better able to use the 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 the Appendix, was an organized way to present the customer and engineering requirements, as well as the correlations between the two (**Figure 1**). The HOQ will continue 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 were assigned to specify how strongly an engineering requirement was correlated to a customer requirement. Positive numbers denote 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.

Targets and tolerances were assigned to each of the engineering requirements as 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 can again be found in the Appendix (**Figure 1**).

3 Existing Designs

The rehabilitation industry contains a number of 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. These were measured in terms of normal joint angles and forces, metabolic testing with CO_2, and surveys used to assess user satisfaction. Existing devices were sorted through based on the benefits observed and if the system would be suitable for children with cerebral palsy to use under the age of 5.

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

3.2 System Level

A series of 3 existing rehabilitation devices (G-Trainer, ZeroG, and Kickstart) were researched in order to educate 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 as a way to relearn proper gait and balance without fully loading a injured body part.

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

The integrated treadmill system can support up to an 80 percent reduction in bodyweight without using 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 in order 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 learn to walk again. (**Figure 4**).

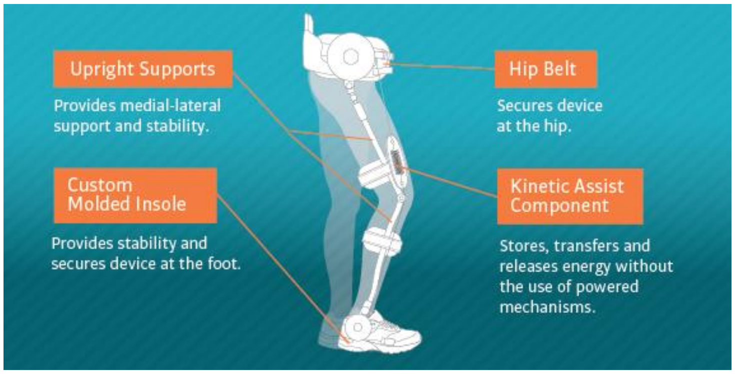

Figure 4. Kickstart Powered Assistance [7]

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. This 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.

With these three level designs in mind, the system was decomposed in subsystems so design tasks could be compartmentalized.

3.3 Subsystem Level

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

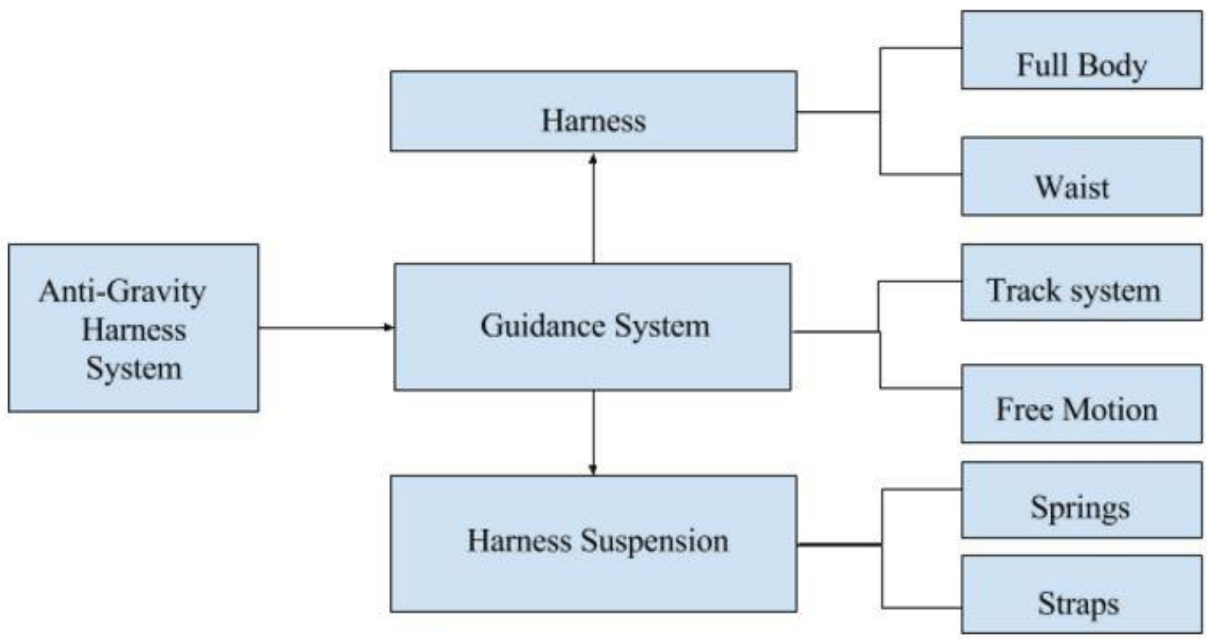

Figure 5. Functional Decomposition of System Level Design

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

The harness was categorized as being either a full body harness or a simple waist harness. A full body harness would be 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 in order 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 of 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 was broken down into a guided track system or free motion. The ceiling track system as seen in the ZeroG system allows the user to follow the path in the direction that the track system was installed. 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 has the ability to 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 was broken down into using 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 similar same support but can be more assistive to the user by supporting them entirely.

The subsystem breakdown should prove most beneficial to the design process because the different tasks can be divided up in a way that involves all team member's engineering knowledge. Additionally, a functional model for the system showing all energy flows clarifies which steps will leave the design at the mercy of the user (**Figure 6**).

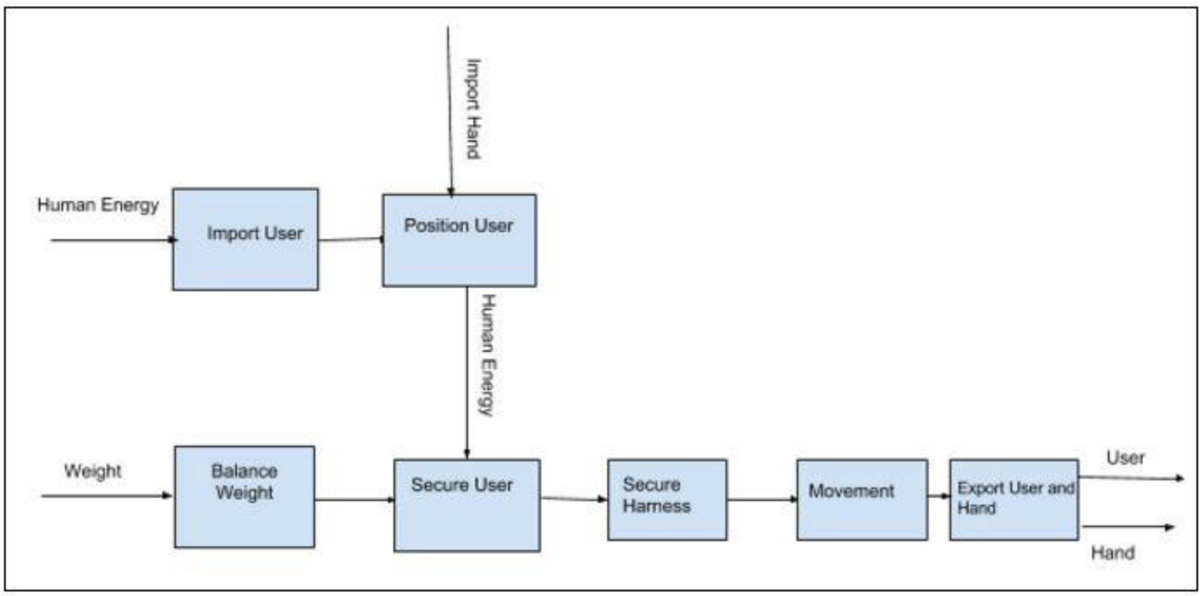

Figure 6. Anti-Gravity Harness Functional Model

For the functional model of the design, the user has a number of 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 is securing the user so they can be left to perform comfortable movements without upsetting the balance. For this step to be completed 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. Once all these steps are completed, movement is enabled for the user and they are able to use the system. Once movement has ended, the user can be exported from the system with the help of another person.

4 Designs Considered

At first, a total of 20 designs were developed using a mixture of a 5-3-5 and gallery concept design techniques. Then, 10 of these designs were seriously considered as potential solutions to the problem of building an in home anti-gravity device. The top four most representative designs can be found 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.

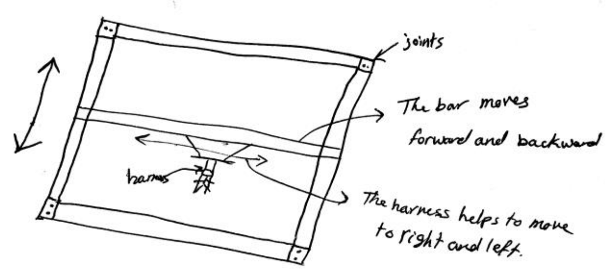

Figure 7. Concept A

Concept A is a ceiling track system that allows the user full range of motion across the area the track covers (**Figure 7**). This system is not the simplest design in terms of 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 high level of safety as long as the ceiling track is securely fastened. The cost for this design is not 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 several weight bearing sections.

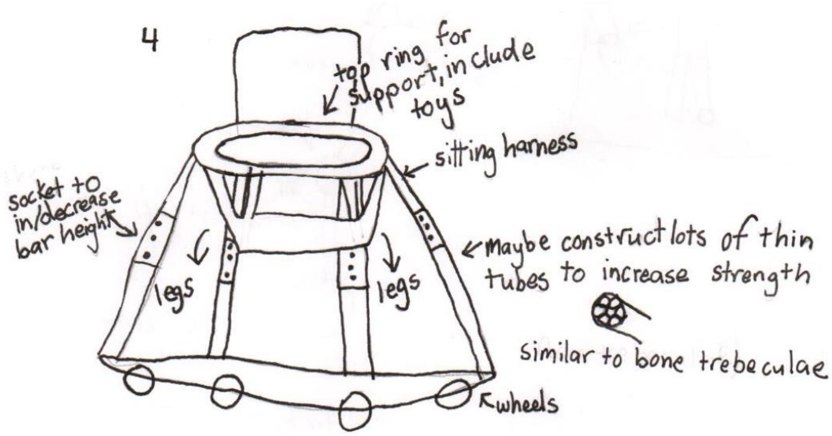

Figure 8. Concept B

Concept B consists of a high chair apparatus that employs a harness for the lower extremities rather than a chair, which is suspended from an upper ring at the level of the child's chest (**Figure 8**). The whole device is guided with wheels with opportunities for interactive toys to be place along the top ring, increasing its aesthetic appeal to children. The device does well under the criteria of being easy to assemble, as the majority of 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 as long as 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 so it would be raised. 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.

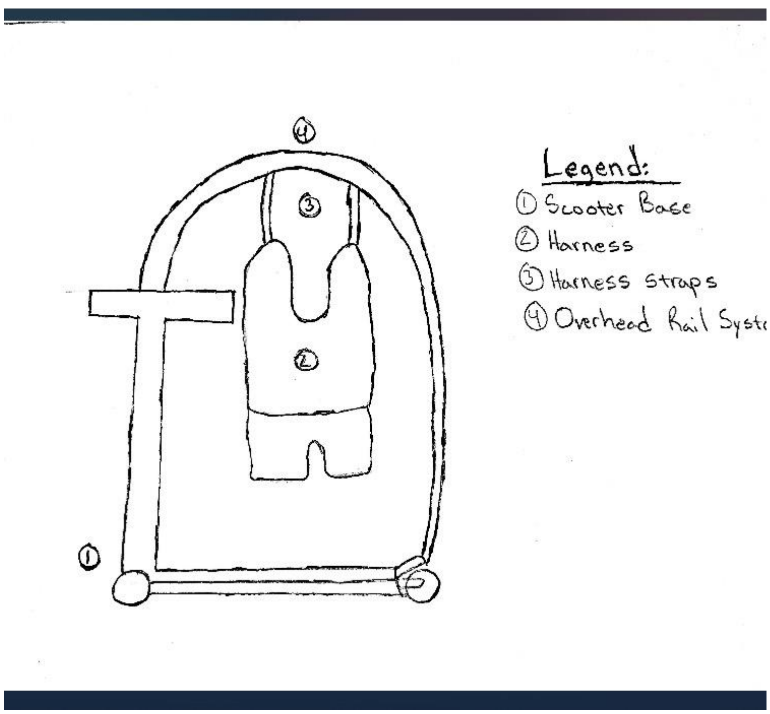

Figure 9. Concept C

This design is 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 that is connected to an overhead rod that would suspend the user from the ground while allowing the user to still touch the ground with removal of the user's body weight on their legs. This allows the user to walk with less body weight weighing on them as they walk. The scooter sub-system of the design is to aid the user in directing the user along the path they would like 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 it is not bound by a track system that would be within one room of a house. This design is a smaller more mobile design compared to a track system and requires less 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.

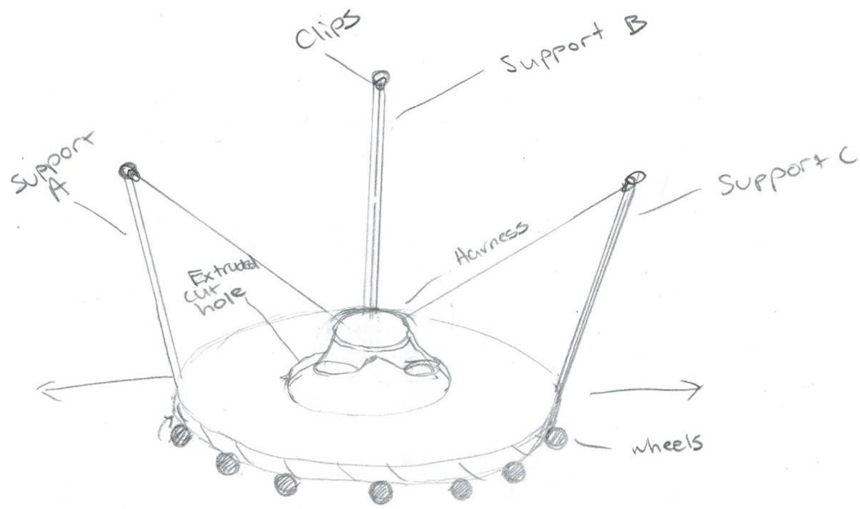

Figure 10. Concept D

This wheeled system contains 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 has the ability to jump and move similar to 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, as long as 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 be widened. 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 was able to move on to evaluating the merits of each design. From this a final product should be chosen with the highest stats for each customer requirement.

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 would begin prototyping.

5.1 Rationale for Design Selected

The first step in the design selection process was using a Pugh Chart (**Table 3**) to rank the developed ideas against a Datum concept, which was 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 larger area before attaching to a ceiling track.

Figure 18. University of Delaware GoBabyGo [8]

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

Table 3. 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	-	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 were selected as the top concepts. With the exception of the Datum, the selections were all wheeled because the team could see the potential of increased safety and maneuverability with a stable grounded base.

These concepts were further evaluated with a decision matrix (**Table 4**), which quantitatively ranked each of the concepts using weighted criteria.

Table 4. Decision Matrix for Concept Selection

		Concepts							
Weight		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
Totals			85.9		85.79		89.3		84.4
Relative Rank			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. This was common for many of the wheeled devices, as the ability to go beyond the room of one house when building interactions with disabled children was ranked highly. The team saw lots of potential to increase the aesthetic potential of the device, as scooters are already very popular with children. The harness system combined with wheels was most important since it allowed weight to be taken from the children at the same time as facilitating their movement and stability with the scooter frame. The areas needing the most improvement are 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 similar to 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 is given next.

5.2 Design Description

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

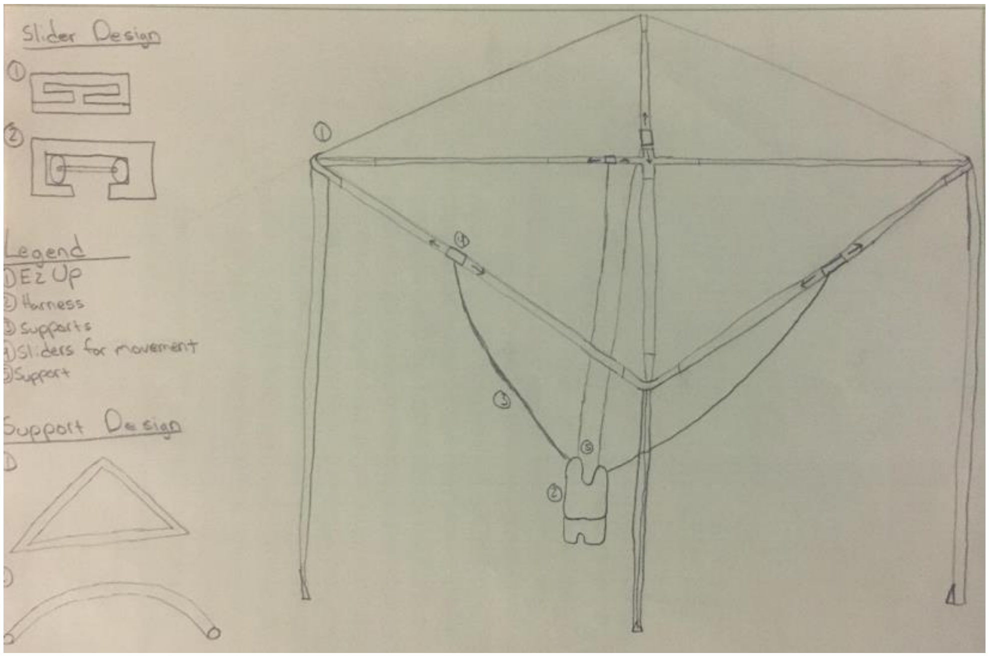

Figure 19. EZ-up track system

The final design involves a wheeled track attached to an EZ-up (pop up tent) frame directly above the user. The square EZ-up structure will be modified to place weight bearing members running diagonally through the square area. Sliders for member movement will be installed to the top frame allowing the user to move around the area in which the EZ-up covers. Rope supports will extend from each rolling slider to a harness system in which the user is securely placed into. When the user is done and the design is not in use, the EZ-up frame folds easily from pushing in all four sides to compact the structure.

As the design is collapsible, it will easily fit in the specified 5’x5’x2.5’ storage space and accommodate a 12’x12’x12’ work space. This design allows increased adjustability in terms of child size and growth, as the height of the suspending ropes can be shortened 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 distributes the weight even further with a spreader bar attached above. The span of assembly for this design should not exceed two days, as the main frame can be purchased at most sporting goods stores. Lastly, this design can 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 further show 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, there were some constraint problems that needed to be addressed with 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 was cutting the number of rigid supports to two instead of four, otherwise a new material would need to be found. As the prototyping continues, the materials and shapes of the Solidworks model will change in order to best reflect the work being done.

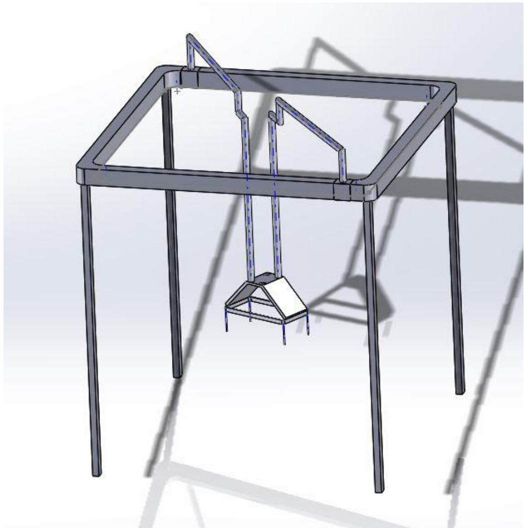

Figure 20. Isometric Final Design View **Figure 21.** Front Final Design View

After confirming the final design with the client, the team plans to begin the next steps in the construction of the DIY antigravity 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 will begin ordering materials for construction of further prototypes during the spring semester.

From Jan-March 2017 the team plans 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 is to finish prototyping (proof of concept and industrial) and begin ordering parts for construction, which can be found in the Bill of Materials.

6.2 Bill of Materials

The bill of materials shows the components of the final design determined by individual analytical analyses (**Table 5**). 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 is available at major retailers around the U.S.

Table 5. Bill of Materials

Component	Image	Cost	Seller
Jumper Harness		$13.88	Walmart.com [9]
Nylon		$16.2	HomeDepot.com [10]
External slider		$87	Photoscs.wordpress.com [11]
Lifting Beam		$183.24	Uscargocontrol.com [12]
Ez-up pyramid Shade		$219	Ezup4less.com [13]

Wrench		$7.89	Target.com [14]
Hammer		$9.07	Zoro.com [15]
Power drill		$24.88	Walmart.com [16]
Screwdriver		$26.29	Toolnut.com [17]

The final design consists of the following parts: Jumper Harness, Nylon Rope, External Slider, Lifting Beam, Ez-up Pyramid Shade, Wrench, Hammer, Power drill, and Screwdriver. The final price for this design is $587.45

6.3 Spring Schedule

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

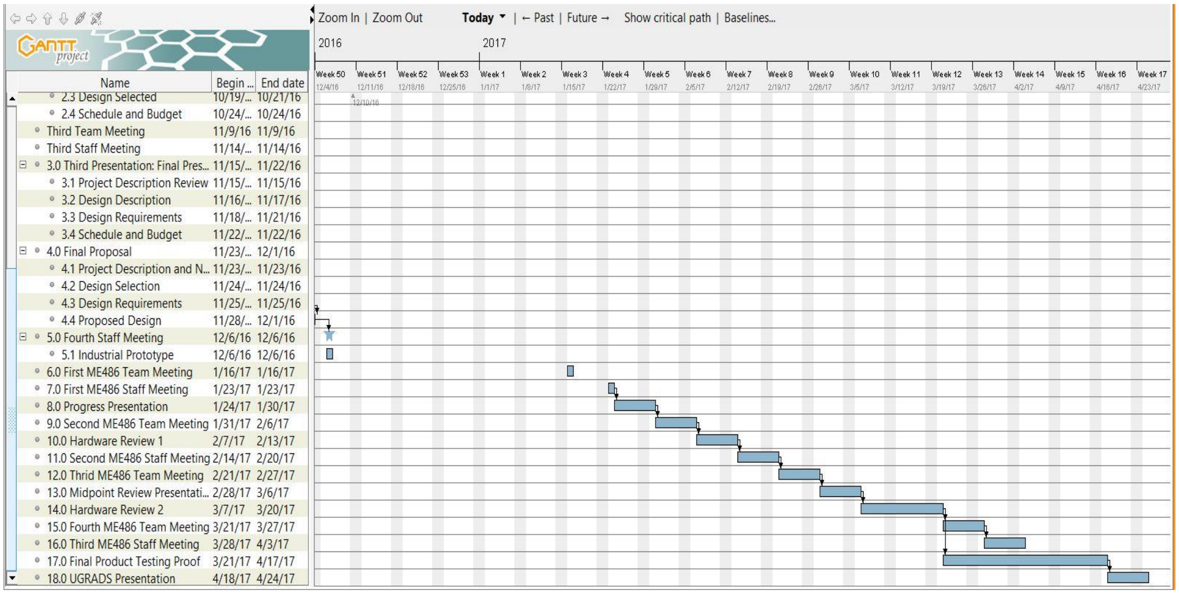

Figure 22. Updated Gantt Chart with Tentative ME486 Schedule

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 should be ordered for the construction of an alpha prototype during the first section of 2017.

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Appendix

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

House of Quality (HoQ)

Customer Requirement	Weight	Engineering Requirement	Fits in 5ftx5ftx2.5ft Volume Space (Storage Space)	Fits in 12ftx12ftx12ft Volume Space (Work Size)	No Pinch Points	No Sharp Points	Nontoxic Materials	Harness has at least three contact points	No Loose Ropes (Entanglement Risk)	< 20 parts	< 100 Screws and fasteners	Non-elastic materials	Gloss Finish Paints (Non-toxic)	< 300 Dollars	< 100 Dollar Tool Budget	Assembly spans two days	Variety 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	Pad/cover buckles
1. Safety	10				7	10	10	8	10				-1	-1				-3	-3		8	10	3	3
2. Easy to Assemble	7		-2							9	9				-2	10				10	5			
3. Adjustability	5							-1	-3		6	5					7	7	6					
4. Durability	7							4				-4		-5								7	5	
5. Size	6		8	7															4		10	-1		
6. Comfort	8				10	10		7	3			4										-1	8	4
7.Cost	7						-3							7	7		3	3		8				
8.Workspace Size	6		7	5																	6			
9.Aesthetics	9						5	1					10										-1	
Absolute Technical Importance (ATI)			76	72	150	180	124	168	109	63	93	29	80	4	35	70	56	26	24	126	211	135	120	62
Relative Technical Importance (RTI)			12	13	4	2	6	3	9	15	10	19	11	22	18	14	17	20	21	7	1	5	8	16
Target(s), with Tolerance(s)			Max, +1	Min, +-1	0	0	0	Max, -1	0	15,+-5	70, +-5	Max	Max	250,'+100	+- 50	2, +-1	5, +-5	Max	>1	0	30,+- 20	30, +-2	0.75, +- 1	Max
Testing Procedure (TP#)																								
Design Link (DL#)																								

Approval (print name, sign, and date):

Team member 1: Armando Garcia 11/22/16

Team member 2: Hasan Farman

Team member 3: Noah Oliver Noah Oliver

Team member 4: khaled alosaimi

Team member 5: Eileen Baker Eileen Baker

Team member 6:

Client Approval:

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

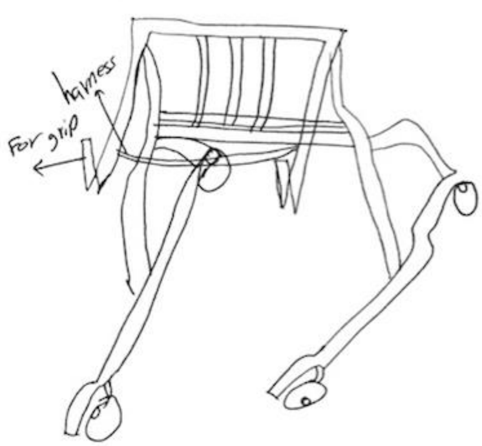

Figure 11. Concept E

The first concept is 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 for this design is 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 be covered with colorful objects or images.

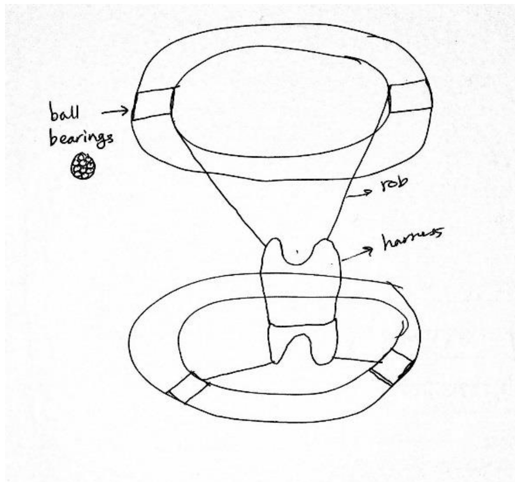

Figure 12. Concept F

Concept F is 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 ease of assembly as long as the circle shape is pre-formed. The motion of the system is guided, 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 in terms of the child vomiting if they manage to build up enough speed turning in circles.

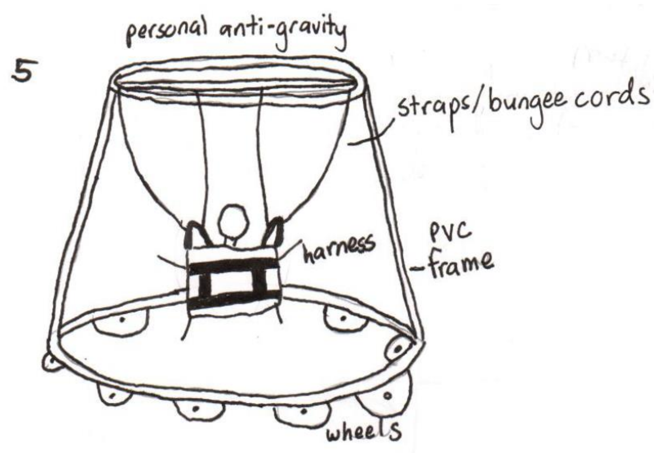

Figure 13. Concept H

Concept H is 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 could be accomplished 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 as long as 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 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.

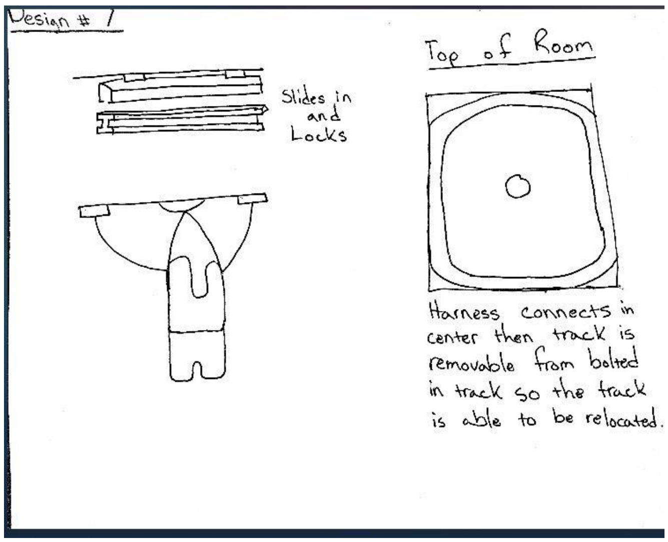

Figure 14. Concept I

This design is a variation of a ceiling track system in which the ceiling track is able to 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 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.

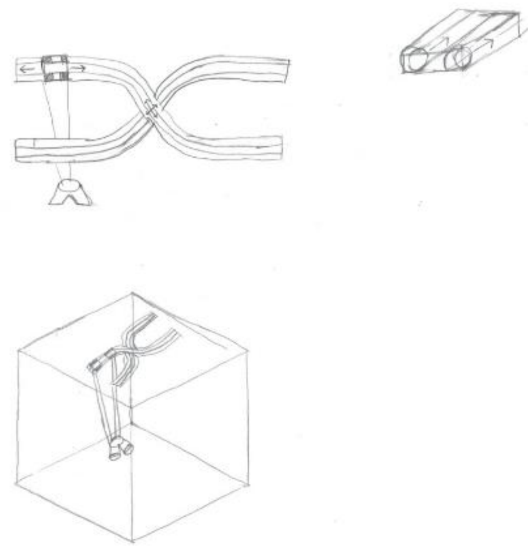

Figure 15. Concept J

This track design is mounted on 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 harness can easily be adjusted 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 is similar to other ceiling mounted systems, with all aspects being fairly safe, though potentially a bit restrictive. The system will be as comfortable as the harness is designed for, with increased padding and weight support being top priority.

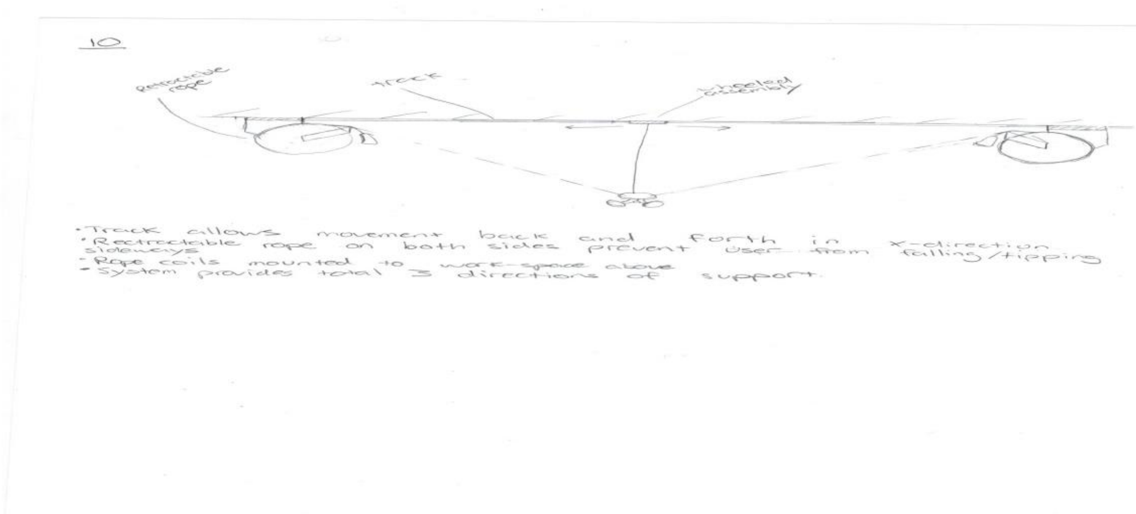

Figure 16. Concept M

This design uses 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 is supported 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 high risk of malfunction with inexperienced builders and may prove to be too challenging for a DIY project.