Optimal Design

Wheelchair for Abby Miller

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1. Optimal Design Project

1.1 Introduction

Abby Miller is a 17 year old girl from Clinton, Illinois that was born with Cerebral Palsy and is in desperate need of a more comfortable wheelchair. Cerebral Palsy is a condition characterized by disorders involving the nervous system and can affect functions such as movement and posture. Some symptoms include tight muscles, muscle weakness and an abnormal gait. It is caused by abnormal development or damage to the part of the brain responsible for control of muscle tone and motor activities. Abby’s condition limits her use of her hands and arms. She has the ability to stand but needs supportive assistance because she lacks the ability to balance herself. Abby also has very exaggerated tone throughout her body.

The purpose of this project is to provide Abby with a customized wheelchair that better suits her and her family’s needs. Abby’s parents would like a wheelchair that allows Abby to sit more comfortably, but also incorporates features they enjoy on Abby’s current wheelchair including a tilt-in-space option that allows her parents to lean her backwards to help get her in and out of the chair. The Miller’s would also like to have the option to interchange the tires to better handle the terrain and weather conditions, as the chair is intended for indoor and outdoor use.

For broader impact, the wheelchair’s design needs to accommodate a variety of clients with cerebral palsy. It must be constructed of a lightweight indoor/outdoor, all terrain wheel chair. It must have a head, neck, and leg restraints and a form of strap or seatbelt in order to keep the client safely in the seat. The chair must have the ability to tilt at varying angles to allow for easier exit and entry into the wheel chair. The chair cushions and safety constraints must be comfortable for the client to sit in for long periods of time and the tires must be indoor/outdoor tires that are non-marking, and will have the ability to be interchanged as desired. By incorporating all of these features, we can create a wheelchair that is specific to Abby’s needs, but can also be used by other patients with similar physical limitations.

1.2 Subunits

We intend to purchase an inexpensive Tilt-in-Space wheelchair in order to utilize a majority of the budget towards comfort and safety features. If a wheelchair cannot be purchased, we hope to obtain a donated wheelchair to re-utilize the parts.

1.2.1 Mechanical Design

1.2.1.1 Chassis and Tilt-in-Space

The frame of the wheelchair will be the chassis of a traditional, steel wheelchair that will be purchased. The frame will also incorporate a “Tilt-in-Space” apparatus that allows for the body of the chair to move independently from the frame. This feature enables the seat and backrest angles to remain fixed while tilting backwards. This is typically a desirable feature for people with complex seating needs with poor trunk and head control (www.assistireland.com).
1.2.1.2 Wheels

There will be two sets of non-pneumatic tires on Abby’s chair, the back wheels and the front wheels. The back wheels will only be able to go forward and backwards, with no option for steering. The front wheels will be like casters, they will be able to freely spin forward and backwards as well as to the left and the right for steering.

The back wheels will be composed of an aluminum frame with a solid tubeless tire compound. The tread on the rear tires will be aggressive to handle some slight to moderate terrain such as grass and small stones, as well as to supply adequate traction for wet and slippery surfaces like concrete and tile. The rear wheels will also be quite large, 22 inches by 1 3/8” which is the wheel size on Abby’s current chair. This large diameter will give the wheelchair more ground clearance as well as providing better stability. The Millers prefer that the tires be non-pneumatic, thus we have selected a urethane tire with street tread. The urethane tire will provide smoothness, but the tread will also provide traction for indoor and outdoor usage. This model is equipped with chrome handrails and 8 spokes.
The front wheels will be primarily responsible for steering. These wheels are much smaller than the back wheels, only 6” in diameter. The Millers prefer a larger back tire on Abby’s chair, thus a larger diameter front tire is needed to balance out the frame of the wheelchair and keep the chair level. We are currently looking into products made by the company, Frog Legs, which offers two types of tires, aluminum and a novel aerospace Lexon material tire.
The Lexon tire option has a three-spoked composite hub and is favorable because the aerospace composite material, Lexon, produces a more uniformly round hub than nylon. The Lexon polycarbonate material utilizes less water in the mixing process which prevents warping as the material cures (www.frogsleginc.com). This tire also provides impact resistance and has the ability to withstand up to 500 pounds of force. The Urethane tread is also a desirable feature because not only is it smooth, but it also does not absorb water which means that it is suitable for indoor and outdoor use because water will not be tracked inside after being outdoors.

The other option is composed of a 6061 T-6 Aluminum which can handled up to 500 pounds of force and is very lightweight. The aluminum hub is a nice option because it comes in a variety of colors which would allow us to incorporate Abby’s favorite color, purple, into the design. These wheels are also coated with a Urethane tread like the Lexon tires.

There are also two options for the thickness of the tread, soft roll and court. The soft roll tires are intended for typical usage and have a thicker tread. The court model sports a thinner tread which is advantageous for sport activities. For Abby’s wheelchair we plan to implement the soft roll treads.

1.2.1.3 Armrests

The arm rests on Abby’s chair will be raised to a position more fit for her body height and will have the option of adjustable height. The arm rests will also have a tilting ability so that they can be moved out of the way when not in use. This will also allow the Millers to more easily help Abby in and out of her chair. The current length of her armrests is not long enough for her to rest her arms on, thus the length of the armrests will be adjusted from desk length to full length, nearly 14”. The armrests will be composed of a gel with a soft material lining for comfort and support.

![Figure 4. Wheelchair Armrests](image)

1.2.1.4 Seat

The design features a seat composed of a double layer of foam padding, a softer layer for comfort two to three inches thick and a dense layer underneath for added support. The dense layer’s
purpose is to prevent Abby from pushing through the seat chair. The dense foam will act as a barrier between Abby and the metal frame of the wheelchair, so if she does happen to push through, the dense foam will prevent her body from hitting the metal supports. In addition to the implementation of the foam, the seat cushion will be slightly wedged so that the thickest section of the seat is positioned under her knees. This is an essential component of the design because it will aid in preventing Abby from slipping out of her chair, and pushing down with her feet.

Figure 5. Front View of Seat Cushions and Head Rest

The figure above illustrates the seat along with the adjustable head rest. The seat will have supports on either side. This will help Abby keep seated straight and provide more comfort for her body if she leans to the side. The padding on either side of the chair will replace the supports she currently has on her chair, which are essentially pieces of covered metal located level with her armpits. The supports she has on her chair now are very uncomfortable. An extra support will be placed on her left side that will utilize more padding and provide more support for her left side. The foam will be purchased in the form of a mattress pad and placed on an existing stainless steel seat frame. The material to cover the foam will be a waterproof, cleanable material that will have the ability to be removed and washed if desired. The headrest will be composed of the same foam and covered with the same material as the seat.
1.2.1.5 Safety Belts

Many wheelchairs for people with disabilities include harnesses, which provide safety and support for the patients using them. Abby is affected by cerebral palsy that has drastically inhibited her ability to sit straight and control her motor functions. For this reason many safety belts and straps will be incorporated into our wheel chair design to help secure Abby and provide a safe chair for her to spend her time in.

The first main harness will be a butterfly strap harness (X-Strap) padded harness which will help to keep Abby’s body straight and against the back of the seat. An X-Strap harness accommodates for women much better than H-strap harnesses due to the location of the buckles. The harness will resemble that of a car seat for a baby or a backpack and will be similar to the straps that are on Abby’s current wheelchair. The strap will wrap around her shoulders and have two clips on either side. This will provide the support that Abby requires to stay sitting upright in her seat. The straps will work to keep Abby’s shoulders square and prevent her from leaning forward, which sometimes leads to her slipping out of the seat.
The second strap will be a seatbelt that will work to keep Abby’s hips against the rear of the seat. She is constantly sliding out of her current wheel chair and with this modification to her new chair we will prevent her from sliding forward. The seatbelt will be adjustable to accommodate for Abby’s growth and will be mounted to the actual wheelchair frame to help keep her safe. With this combination of safety harnesses and straps Abby will be safe and comfortable in her new chair. The issues that she has now with her current chair will be obsolete with the new safety harnesses and features.

1.2.1.6 Handlebars

The handle bars of the wheelchair will be similar to those of a typical traditional wheelchairs handles. The handles will be equipped with better material to allow for better gripping of the wheelchair.

1.2.1.7 Foot Rest

Abby’s current chair utilizes two separate footrests for each foot. The problem with this design is that Abby’s feet fall into the space between each footrest, which is very uncomfortable. The design of her new wheelchair will address this problem by incorporating a uniform footrest that both feet will be able to rest on. The footrest will be composed of stainless steel which is very durable.
The footrest will also have a thin piece of metal perpendicular to the footrest to prevent Abby’s feet from falling behind the footrest. This will provide support for her heels. The black piece in Figure X will be a stretchy, comfortable fabric, to provide support to her lower legs. This is called a leg rest panel. This feature will have the ability to removed and exchanged if desired by attaching by means of a fastener such as a zipper, Velcro or buttons.

The frame support of the footrest will be composed of a stainless steel and will be adjusted to between a 75° and 85° angle. Slightly angling the footrest will be more comfortable than a 90° angle because Abby’s legs will be slightly elevated and encouraged to rest on the leg rest panel. This will also prevent Abby from pushing down on the footrest with her feet, which she frequently does to try to stand up.
1.2.1.8 Miscellaneous Features

The final design will have several additional features that will be customized for the client. Abby has indicated that she would love her favorite color, purple, to be incorporated into the design. This will be done by powder coating the metal components which will allow us to color the chassis a shade of purple. In addition, some of the wheel options we have investigated have options for colored hubs. Other hints of purple may also be incorporated into the head rest, seat cushions and arm rests.

A small basket for personal belongings will also be incorporated into the Abby’s wheelchair. It will have the ability to be removed if desired so that when the chair is being moved down a staircase, the basket will not be in the way. This feature is important because it will allow Abby to store personal belongings wherever she goes.

Cup holders will also be designed to attach to the chassis of the wheelchair so that Abby has somewhere to put her drinks. This feature may also be incorporated into the handlebar design so that Scott and Julie, Abby’s parents, can have a place to put their drinks while pushing Abby. This feature will also have the ability to be adjusted and removed as desired. A tray for activities and eating may also be designed in a similar fashion.
1.2.2 Electrical Design

1.2.2.1 Adjustable Seat Comfort

Abby has considerable weakness in her trunk which causes her to lean to her left side. Her current seat is very uncomfortable for her because it does not provide enough support for her back and side. To make the seat more comfortable for Abby and to make it adjustable for the family the incorporation of various inflatable bladders will be added. The bladders can be inflated or deflated as needed to position Abby correctly in her seat, which will maximize comfort and correct posture. Similar to a Sleep Number Bed, two inflatable bladders will be placed on the seat base and three in the back portion of the seat.

The bladders on the seat base will be positioned parallel to one another running the length of the seat. This will allow the Miller’s to adjust and balance Abby to sit correctly. For the back of the seat
one bladder will be positioned as a lumbar support and the other two will be placed parallel to one another, perpendicular to the lumbar support. This will allow the family to inflate and deflate the bladders to accommodate the fact that Abby leans severely to her left and build up the right side to support her back better. Since this feature allows the seat to be fully customizable the options for comfort and support are endless.

2. Realistic Constraints

When designing any medical device, there are many variables that may affect the design or outcome of the project. One of the largest constraints for the project is Abby’s medical condition, cerebral palsy. The purpose of creating a new wheelchair for Abby is to cater to her specific limitations and address each issue in order to develop a more comfortable and functional design. Her physical limitations reduce the flexibility of the design and require certain devices such as head and neck supports, seatbelts and braces.

An economic constraint of the project is the allotted budget because the amount of money has not yet been designated. Since this wheelchair is going to be a one off build and not mass produced, the components used do not have to be mass produced and at a really low cost, all though that would be nice. High quality parts are going to be used and they are going to be put together in a custom configuration the suit the client’s needs. Also since Abby is only 17 years old, the wheelchair needs to be economical in the future as well. When maintenance is needed on the wheelchair, the parts should be easily obtainable and affordable.

This wheelchair must be able to withstand the elements of nature and abuse. The materials used must not rust and get weak over time, which would allow for the chassis to lose integrity. Also the paint or the coating on the chassis must be chip resistant to further protect the materials uses, probably steel. The seat cover must also be water resistant to prevent soaking of the padding. This will allow for an easy cleanup and a comfortable dry surface.

A manufacturability constraint of the project is that there currently a wheelchair that suits the Miller’s needs does not currently exist. Furthermore, we will not have the ability to mass produce the wheelchair that we build for Abby, thus chair will only be built one time for one client. In addition, at age 17, Abby may still undergo growth and development, thus, sustainability of the chair is a constraint because it is being designed for her current body type. As she becomes older, she may outgrow some of the features of the device.

A social constraint of the project is the physical distance between the design team and the client. There is no way that the client and the team can meet to discuss the design concepts. The only means of communication can occur through Skype, email or telephone. Since this wheelchair is going to made for a 17 year old girl, it needs to fit all her needs and at the same time it needs to be trendy and fit in with all of the social trends that are in style. Abbey wants this chair to be purple, so the frame is going to get a purple powder coat, which will protect the frame and keep it looking good.

There are no ethical or political issues that will affect the design of Abby’s wheel chair.
3. Safety Issues

One of the most important aspects in the design of this project is to address the need for safety features. Due to Abby's physical limitations, there are high risks for injury, thus there are many components of the design that address her needs for extra support and restraints for specific parts of her body.

Abby has very weak trunk strength which causes her to lean to the side. It is essential that the harnesses incorporated into the design have the ability to keep Abby safely seated in her wheelchair without confining her too much. Abby has similar weakness in her neck, so it is important to ensure that her neck will be properly supported to prevent injuries and neck strain. This will be addressed by adding extra padding on each side of the headrest and expanding the dimensions of the headrest on a traditional wheelchair.

In addition to Abby’s needs for physical safety features, it is important that the wheelchair itself have some additional safety features. One major safety issue of wheelchairs is the possibility that the wheelchair will tip backwards when being guided down the stairs. An anti-tip bar will be incorporated to prevent the wheelchair from tipping backwards when Abby is sitting in it. This feature will be removable to allow the Millers to move the wheelchair up and down stairs. The anti-tip bar would prevent the Millers from being able to tilt the wheelchair backwards in order to move her safely, thus it is essential that this feature is removable. In addition, as found on most wheelchairs, brakes will be incorporated for the larger tires to prevent unwanted movement when Abby desires to remain stationary.

4. Impact of Engineering Solutions

The design of this wheelchair is an improvement on designs that are currently on the market because it is a more comfortable alternative and is much cheaper. Current tilt in space wheelchairs on the market can be very expensive and also must be highly customized in order to be accommodating for the person using them. Karman Healthcare makes a portable folding tilt in space wheelchair for $1,699 and Quickie’s version runs for $2,825.00. Unfortunately, these prices only envelop the base cost of the wheelchair without any customization or comfort upgrades. Our wheelchair is being designed for a much lower cost with more high quality materials and thus has high economic impact.

Although this design will only directly impact the life of one person, the overall design will benefit the global field of engineering because it combines the features of wheelchairs available in commercial products with features that clients with disabilities need and want. In addition, the wheelchair design impacts engineering solutions in an environmental context because our design is based off of utilizing parts from a donated wheelchair. The wheelchair will not be manufactured from raw materials but materials already existing will be reused and utilized.

This wheelchair has several societal impacts because it is more affordable, useful, and comfortable. By designing a product with a specific client in mind, the client will be more satisfied which benefits society. Designing this wheelchair for a specific cliental benefits society directly because it provides a less expensive yet more useful product for their specific needs.
5. Life-Long Learning

The design of this project has been and will continue to be a huge learning experience. We have had to do sufficient amounts of research on the disease Cerebral Palsy. Specifically, we have learned about the causes, effects and symptoms of Cerebral Palsy, and the limitations specific to our client, Abby Miller. We have also looked into other diseases that cause muscle weakness in order to broaden our design for other clients.

We have also learned a lot regarding the general construction of traditional wheelchairs currently on the market. Wheelchairs that are currently on the market are typically mass produced and are not tailored to a client’s specific needs. This makes it difficult for clients to find a wheelchair that not only meets all of their needs but does so for an affordable price. We have found that even though there are a lot of different options available, that these options are often very expensive and not designed to meet specific needs. It is unfortunate that there are not a lot of companies out there that provide inexpensive alternatives to customizable features because people are in wheelchairs for many different reasons. A person with severe cerebral palsy has very different needs than a person with spina bifida.

In addition to the information we have learned due to research, we have also learned a considerable amount about the business aspects of engineering and the dynamics of the company-client relationship. Since our clients are located in Illinois, we have had to use other means of communication besides meeting in person. This has taught us that the key to the success of our project will be communicating frequently with our client about their wants, needs and concerns. We want to make the client feel as comfortable as possible and encourage frequent suggestions.

Overall, this entire design process has been a huge learning experience and we anticipate learning much more over the course of the next eight months about wheelchairs, cerebral palsy, and the business aspects of engineering projects.

6. References

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