Optimal Design Report
All-Terrain Wheelchair For Melody

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1 Optimal Design Project #1

1.1 Introduction

The purpose of this project is to design and develop a multi-purpose, all-terrain wheelchair for Melody Kettle. Melody is a 21 year-old girl who suffered a detrimental anoxic brain injury as a child. Melody’s brain injury was the result of a prolonged seizure. According to Melody’s parents, the seizure was likely caused by an immunization reaction. Before the seizure, Melody was a happy, healthy 18-month old little girl who was developmentally and intellectually on target for her age. This life-altering anoxic injury has left Melody severely disabled; both mentally and physically. She is completely dependent on others for 24-hour care. She receives nursing care 11 hours per day and relies on her immediate family members for the remainder of her daily care. She cannot do any of her activities of daily living. She can breathe on her own, though she has intermittent oxygen requirements and must have an oxygen tank available to her at all times. She cannot feed herself and has difficulty with the mechanical act of swallowing. Her swallowing is also affected by the copious amount of respiratory secretions that she produces. She requires frequent suctioning by her family and nursing staff. She has a surgical feeding tube to provide her nutritional support. Melody has minimal interaction with her family and environment. Melody cannot speak and has severely impaired vision. Melody will smile and utter some happy, though unintelligible, sounds when she is positively stimulated. Melody’s doctors believe she is clinically blind, though to her family, she does appear to react to certain visual stimuli. Either way, her vision is severely impaired. Melody has also endured multiple surgeries in the past. She undergone spinal instrumentation (with metal rods) and fusion that has left her with significantly limited range of motion in both her head and neck. Despite her severe disabilities, Melody does appear to have some voluntary control of her head. She is currently able to activate a head switch, in the temporal regions of both sides of her head that can turn on and off some mechanical devices that provide vibratory stimulation. Melody does have a wheelchair at present, however it is fraught with limitations. As such, Melody and her family are in desperate need of a new, modern wheelchair that is customized for Melody’s physical, emotional, medical and therapeutic needs. Because of her current wheelchair’s limited maneuverability when going off-road, Melody rarely goes outdoors. As Melody appears to thrive outdoors, she needs a wheelchair with off-road capabilities.

This chair will have the ability to traverse all types of terrain and will be easily operated by any of Melody’s caretakers. Melody is now 21-years-old and is not as easy to lift as she was in the past. Therefore, the new wheelchair needs to be a lighter-weight design than her present one. The wheelchair will be customized for Melody’s height, weight and physical limitations (i.e. past spinal surgery significantly limits Melody’s neck and head movement). It will also have additional customized components such as: vibration, visual stimulation and storage space for Melody’s medical necessities. The chair will provide happiness for Melody and a
sense of relief for Melody’s caretakers as it will be equipped with everything she may need in case of a medical emergency. While structure and function are of the utmost importance in this project, the true goal is to provide Melody and her family with a significantly improved quality of life.

The wheelchair will be designed so that it will be easily maneuvered off-road. The tires will be suitable for off-road use on all different types of terrain. The chair will incorporate a larger rear wheelbase with a single front wheel. The larger wheelbase will allow for more stability where the single front wheel will allow for greater maneuverability in all types of terrain. It must also be lightweight and easily maneuverable. To accomplish the design, we will be building a three-wheeled wheelchair with a lightweight frame. The frame is going to be built out of a lightweight material such as aluminum or steel. When constructing the frame, we will be using round tubing. This ensures that there will be no square corners in the design that Melody could injure herself on. Because the typical wheelchair wheel is very narrow for ease of pushing on hard surfaces, they will not be used. A narrow wheel is just not suitable for off-road use. To solve this issue, we will be using wider, knobbier tires. The rear tires will be. For ease of maneuverability, the front tire will smaller and narrower than the front. To ensure that the wheelchair glides across unstable terrain, we will be equipping the rear wheels with shocks.

The wheelchair must have the ability to stop instantaneously. In order to achieve this, a disc braking system will be used. The brake system will be mounted to each side of the axle and controlled by a hand lever located on one handle of the wheelchair. There will also be a hand break and a parking break system (a bar that rotates on the axle, so when stopped, the wheels can be locked into place) for additional stopping and locking measures. Melody’s chair will also need a customized seat that reclines backwards, allowing her Melody to be suctioned easily. This seat also allows for Melody to be repositioned easily. Repositioning is key to preventing pressure ulcerations from developing on Melody’s body. Melody’s chair will also be designed with both cushioned headrests and armrests. Since Melody does not have any functional control of her body, her head and extremities need to be protected by cushioning in case she involuntarily flails them around. To make sure her correct measurements are used, we will be using an older wheelchair of Melody’s that her family has given us. The older chair was built to Melody’s exact measurements (and they have not changed since this chair was used) we can use this as a model for the design. Her customized specifications will be built into the frame design of the new chair. Melody also needs to be able to go outside year round in any weather condition. Therefore, it is imperative that a retractable cover be mounted to the chair.

The wheelchair also needs to be extremely safe, and must not compromise Melody’s health, comfort, posture or range of motion. There must be space for oxygen and suction canisters because without these items, Melody could suffer from rapid respiratory distress. Melody is suctioned continuously due to her copious amount of respiratory secretions and must have suction available to her at all times. There must also be enough room for Melody’s “go bag.” This “go bag” is what Melody’s family refers to her emergency medical kit. It contains first aid supplies along with a list of contact telephone numbers, Melody’s past medical history and
current medication list. In the event that Melody needs to be transported to the hospital by someone other than her family member, medical staff can obtain all of her pertinent medical information from her “go bag.”

1.2 Subunits

Like any finished product, this all-terrain wheelchair will be the sum of its parts. This all-terrain wheelchair will be comprised of multiple smaller subunits. All of the subunits together will create the completed wheelchair. It is imperative that each subunit is designed not only to serve an individual function, but it must also integrate smoothly within the overall wheelchair design. This section describes each of the subunits individually, making mention as to where each subunit fits into the overall design.

1.2.1 Main Frame

The frame of the wheelchair will be built composed of 6061-T6 2x2-inch square tube stock aluminum that will be similar in construction to Fig. 1 below. This is a high-strength aluminum alloy that can be manipulated by welding. The aluminum can be welded very easily and unlike some metals, a welded area will be just as strong as un-welded aluminum after a few weeks have elapsed. The frame will be assembled and welded in the UConn machine shop almost immediately so that the welded areas of aluminum can recover and regain their maximum strength before Melody uses the wheelchair.

![Figure 1. Aluminum frame views](image)

1.2.2 Chair Frame

The Kettle family is donating one of Melody’s previously used wheelchairs, a Quickie GP, (Fig. 2) that was built exactly to her body’s specifications. This chair will be used as the chair frame for this project. It will attach to the main frame in the manner seen in Fig. 3 below. The wheelchair frame contains a positioning system within it that is comprised of a harness and safety belt. This system is designed to keep Melody within the center of the chair so that she may safely ride on different types of terrain. This positioning system is adjustable as Melody grows.
1.2.3 Wheels (Front and Back)

The wheels of this all-terrain wheelchair must be large, wide and have enough tread to traverse through all different types of terrain. We would like Melody’s chair to be able to travel through sand, dirt, snow and mud. Having wheels of differing size and composition will allow for most efficient all-terrain use. The two rear wheels (Fig. 4) will be approximately 24 to 29 inches in diameter and will be composed of material similar to that of a mountain bike. The front wheel (Fig. 5) will be approximately 10 to 14 inches in diameter and will be similar to those used on a stroller or trailer wheel. In order to effectively travel on different terrain, all of the wheels must be able to function at different air pressures.
1.2.4 Brakes

Melody’s anoxic brain injury does not allow her any functional use of her arms or legs. She does not have the ability to move or stop her wheelchair. As such, her parents and caregivers must have the ability to stop her all-terrain wheelchair instantaneously and at any given time. As such, the wheelchair will be equipped with a disc braking system. The brake system will be mounted to each side of the axle and controlled by a hand lever located on one handle of the wheelchair. There will also be a hand brake and a parking brake system (a bar that rotates on the axle, so when stopped, the wheels can be locked into place) for additional stopping and locking measures. The brake system used will be the Nashbar Mechanical Disc Brake Set, (Item # NB-MDB) below in Figure 6.

![Figure 6. Nashbar Mechanical Disc Brake Set](image)

1.2.5 Shocks

This all-terrain wheelchair is being designed so that it effectively travels through all different types of terrain. However, it must travel the terrain smoothly and comfortably without causing any distress to Melody when she rides. Therefore, the wheelchair will be equipped with shocks. The force the wheelchair experiences as it goes over rough terrain must be damped. Shocks, or large springs in this case, function as dampening devices. These springs must resist the mass of the wheelchair plus the force of additional shock from uneven terrain. The springs will provide Melody with an underdamped response from rough terrain. As a result, Melody’s body will not feel the impact of any uneven or difficult terrain. Without shocks, Melody would experience an overdamped suspension response to bumps or rough terrain and she would be unnecessarily jostled. The goal is to provide Melody with a smooth ride no matter that type of ground she travels. An example of a type of shock that will be used in the chair design is seen below in Figure 7.

![Figure 7. Spring shock](image)
1.2.6 Seat

Melody's wheelchair seat must be customized and cushioned so that it provides Melody with maximum support. Her existing seat on the old wheelchair will be used and modified by adding cushions to the specifications of her current custom seat. The chair will have the ability to recline backwards so that Melody can be orally or nasally suctioned whenever her secretions accumulate. While it is ideal to keep Melody centered within the chair, Melody must be able to be repositioned easily as repositioning is key to preventing pressure ulcerations from developing on Melody's body.

1.2.7 Safety Harness

Most wheelchairs designed for individuals with disabilities are equipped with safety harnesses that provide stability, security and support for the disabled individual. Melody's anoxic brain injury inhibits her ability to sit up straight and control her motor functions. Therefore, Melody must be safely secured within her chair at all times and safety straps will be incorporated into our wheelchair design. The safety harness will be a butterfly strap padded harness (Healthwares Flexible Chest Harness seen below in Fig. 8), which will help to keep Melody's body straight against the back of the seat. The Healthwares Flexible Chest Harness can be worn on all individuals, though it is particularly suited for women (as compared to a traditional H-strap harness) due to the location of the buckles. The harness will wrap around Melody's shoulders and clip together on either side. The harness closely resembles those used as baby carriers or backpacks.

![Healthwares Flexible Chest Harness](image)

Figure 8. Healthwares Flexible Chest Harness

1.2.8 Miscellaneous Features

The wheelchair must have space for oxygen and suction canisters because without these items, Melody could suffer from rapid respiratory distress. This design for an oxygen cylinder holder will use the design of the Ferno used for stretchers seen in Fig. 9. The rectangular base will have a built in clamp to fasten it to a tube in the center of the metal frame and two circular rings dimensioned to fit and slide the oxygen tank into. It will also have extra room to hold her suction
canister and emergency medical kit or “go bag” if needed. This “go bag” is what Melody’s family refers to her emergency medical kit.

Figure 9. Ferno oxygen cylinder holder

The chair will also be designed with an attached vibrating element that will be run off a motor. It will be activated by Melody’s head switches. A retractable cover/awning will be incorporated that will clip onto the frame of Melody’s wheelchair and come over the top of her wheelchair. It will be made to be detachable and of lightweight material, similar to that used for lawn chairs.

2 Realistic Constraints

The biggest constraint we are faced with in the design of this wheelchair is Melody’s medical condition itself. The purpose of this project is to provide Melody with an all-terrain wheelchair that will improve Melody’s quality of life. However, Melody’s medical condition and all of its complications must not be compromised in any way.

2.1 Engineering Standards

This all-terrain wheelchair will be designed to meet industrial wheelchair development standards. It will be composed of high quality material and will be best suited for all of Melody’s medical conditions. It will maintain function similar to that of most wheelchairs and almost identical to all-terrain wheelchairs. All members of the design team will undergo machine shop training (including safety training) so that the wheelchair can be optimally fabricated. We will ensure optimal craftsmanship while all parts are made and when the wheelchair is assembled.

2.2 Economic

Wheelchairs are expensive and customized wheelchairs for disabled individuals are even more costly. The average cost of a wheelchair is close to $7,000 (disabled-world.com) though, wheelchairs in general can cost anywhere between $3,000 and $30,000 (disabled-world.com). Not surprisingly, economic constraints are a major concern for this project. We suspect that the majority of the costs for
this project will be related to the special needs of Melody’s medical conditions. The materials that comprise the wheelchair (tires, frame, seat, brakes, etc) are expensive to obtain and customize. We do have a set budget for the project, though we are concerned as to how we can meet all of Melody’s needs while we stick to the budget. As such, we are going to seek donations from many different companies so that we can create the highest quality all-terrain wheelchair that will meet all of Melody’s healthcare demands.

2.3 Environmental

Manual wheelchairs have minimal impact on the environment. It is imperative that Melody’s wheelchair does not destroy any of the types of terrain it is designed to travel through. The tires will be similar to mountain bike tires that are readily used without any damage to the environment. We also plan on using materials (aluminum frame, tires, etc) that will not damage or negatively impact the environment. We are concerned that extreme environmental conditions, like rain, sleet and snow, could potentially damage the wheelchair over time. Therefore, we will recommend that the chair be stored indoors. We certainly expect the wheelchair to operate in all types of weather conditions and it will be designed to do so. However, extensive exposure to harsh elements could damage the strongest of materials. Therefore, we will recommend that the wheelchair be stored indoors when not in use.

2.4 Sustainability

It is imperative that this wheelchair be sustainable for a long time. Melody’s family has limited resources available to them and must make use of the materials they have. They simply do not have the financial ability to buy Melody a new wheelchair whenever they wish. This wheelchair will be designed so that it can be used for many years with minimal maintenance. It will also be able to be adjusted for Melody’s changing body as she grows. Since all materials wear and tear over time, we will make sure the wheelchair parts can be easily replaced if necessary. We want to do whatever is necessary to limit costs and maintenance of the wheelchair for the Kettle family. We will recommend that the chair be cleaned regularly (to remove dirt etc) to prevent corrosion and damage to the wheelchair.

2.5 Manufacturability

We suspect that this wheelchair, with all of its customized specifications, will be somewhat difficult and expensive to create. However, after building this wheelchair for Melody, we hope to be able to learn a great deal as to how manufacture future wheelchairs at less cost. We can order products in bulk to cut down on costs and we can use any and all donated materials to further decrease prices. Additionally, we can select material that is durable and easily manufactured.

2.7 Safety
Melody's all-terrain wheelchair must be functional and extremely safe. Her wheelchair will be equipped with a safety harness that will provide Melody with stability, security and support. It will help to keep Melody's body straight against the back of the seat since she is unable to control her own motor function. The wheelchair will also be designed with a wide base so that it will not tip and fall over easily. Additionally, the wheelchair is being designed with a disc braking system that allows for instantaneous stopping at any time.

2.8 Social

Socially, we are unable to meet with Melody and the rest of the Kettle family on a regular basis because of the relatively large geographic distance between their home and the University of Connecticut. We would like to spend as much time with Melody as possible and make sure the chair is perfectly customized in each step of the design process. Unfortunately, because of the distance, we must communicate with the Kettle family on the phone or through email. Though, we will still make as many visits to Kettle home as possible.

Additionally, Melody seems to thrive when she is outdoors. She is socially more interactive when she is in her backyard or enjoying other outdoor areas. Having an all-terrain wheelchair that allows her to thoroughly experience nature and the elements will most certainly improve her quality of life and will bring joy to her family members.

3 Safety Issues

Melody's safety is the number one concern in the design of this all-terrain wheelchair. All of the mechanical components of the wheelchair that are being built by our design team must be properly crafted. They will be properly tested within the design lab, by students and eventually by Melody, to ensure the wheelchair meets all of the recommended safety standards.

3.1 Mechanical

The mechanical components of the wheelchair must be extremely safe so that Melody's health and well-being are never compromised. The wheelchair must be stable to withstand all types of terrain (uneven, rocky, wet, etc). A solid chassis and larger (mountain bike-like) wheels will be used to provide maximum stability. The chassis must be a solid so that it can support Melody's weight. If not properly built and tested, the chassis could break at any time; causing Melody potential grief and injury. The wheels must be durable and have the ability to withstand all types of terrain and weather. All of the subunits of the wheelchair must be properly mounted or attached to the final project so that nothing will falter or fall off during use. For example, if one of the wheels fell off while in use, the wheelchair could become exceedingly unstable and fall over. An unforeseen fall could be detrimental to Melody and we would never want to see this happen. This wheelchair is designed
so that Melody is stabilized when in use. The safety harness will keep Melody in almost a 90 degree position (straight to the back of the seat) at all times. The seat back will be well-cushioned so that Melody's skin is not abraded or invaded.

4 Impact of Engineering Solutions

We suspect there are thousands of people like Melody who are completely dependent on their caregivers and require wheelchairs for their everyday lives. There is a huge market for customized, all-terrain wheelchairs. If we can design and create this wheelchair for Melody, we can design it for anyone. The key to successful future use is in determining how to most cost-effectively create customized all-terrain wheelchairs. Once we create Melody's wheelchair, we will know what materials to use and how to make the most of our budgetary constraints. We hope be able to manufacture future wheelchairs at a significantly reduced cost. This wheelchair has the potential to positively impact the lives of so many disabled individuals. Traditional manual wheelchairs are really only made for the indoors. We have the ability to introduce disabled individuals to a whole new world through an all-terrain wheelchair. We will give them the ability to go outdoors. Disabled individuals with more function than Melody might be able to go outdoors on their own, further increasing their autonomy and improving their quality of life.

5 Life-Long Learning

The design team has learned so much not only from Melody but also from the entire production process. Most of us were not familiar with anoxic brain injuries and had no idea what impact it could have on a person and family. We have gained an incredible appreciation for the selfless work that Mr. and Mrs. Kettle do on a daily basis in caring for their daughter. We have also realized just how fortunate we are to be able to go to school and pursue our dreams. Melody’s family would probably give anything to have the same opportunities for Melody. We have also learned many mechanical skills that will help us in all of our future careers. This project has been an incredible learning experience to all of the members of our group.

5.1 Social

When we began this project, we were individuals who were selected to work together on a project. We developed strong social skills to effectively communicate with Melody’s family. We needed to establish a strong rapport with the Kettle family so they would know we had the best intentions when creating an all-terrain wheelchair for their daughter. We divided tasks to make the most of our time, though we always kept in constant communication so that we were always on the same page. We had to be organized, detail-oriented and efficient so that we could develop the best product possible for Melody. This project was successful because of our teamwork and because off the inspiration we derived from Melody and the entire Kettle family.
5.2 Educational

Melody suffers from the complications of an anoxic brain injury. As most group members were unfamiliar with this condition, we researched the condition and became much more educated on anoxia and its complications. We also educated ourselves on how to effectively adhere to budgetary constraints within a project. We learned how to interact with family members, company owners (when asking for donations) and team members.

5.3 Mechanical

Since the wheelchair had to be created from multiple different parts, it was imperative that the team members used how to effectively use different tools and power equipment. Additionally, some members will learn how to weld and cut various metal types. It is important for the group to learn how to use different tools and power equipment. Building the all-terrain wheelchair significantly improved the overall mechanical skills of all group members.

5.4 Software

In order to successfully complete the design and development of Melody’s all-terrain wheelchair, all group members had to become more familiar with some engineering computer programming. For the chair’s initial design, it was essential to learn Solidworks, a CAD program that allows for 3-D modeling and simulation of mechanical components.

6 References

