Final Report

The ATPC-X42 All-Terrain Power Chair

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Abstract

The need for a more rugged power chair was expressed by the parents of Annalee Hughes after she tipped over her chair one day while operating it in her yard. Our group was tasked with the creation of a power chair which can function over the rocks and hills present in the Hughes' yard. The client, Annalee Hughes requires a power chair because she has Cerebral Palsy, and is unable to walk or sit upright for long period of time on her own, but wants to be able to explore outdoors and not be limited for where she goes by the functionality of her chair.

The construction of the power chair is being based off of a Quickie S626 power chair. The chair was created for use by children, but in order for Annalee to be able to grow with her new chair and not outgrow it after a year or two of use, the seat will be widened and a new back has been put on that allows for the chair to grow with her. The chair has also been modified to be able to handle rough terrain without the risk of tipping over on its side or backwards. This was accomplished by adding 4.5-inch wide go-kart wheels to the chair rather than the standard solid rubber wheels present on the rear of the chair. Go-kart wheels add stability, traction, and shock absorption to the chair, granting the client a smoother and safer ride. Larger wheels are also placed in the front casters of the chair which give it greater control when traveling over obstacles. Shock absorbing springs are also currently present on the chair, and translate bumps from the front casters to the rear.

Another large modification that has been added is the implementation of a tilt sensor that detects if the chair is operating at an angle where it is at risk of rolling or tipping. This sensor sounds an alarm if the angle reaches a dangerous level, and there are also the option for automatic adjustment of the chair angle. This is accomplished by letting a microcontroller receive the information from the tilt sensor and automatically adjust the actuator for the seat level. This second function will be optional, and can be activated or prevented by changing the chair mode on the joystick.
1. Introduction

1.1 Background

This project is aimed at designing and building an all-terrain power chair for Annalee Hughes, a ten year-old girl with cerebral palsy. Cerebral palsy is a neurological disease that is diagnosed in children, usually at birth, and permanently affects muscular movement [1]. Annalee cannot walk nor stand on her own power as a result of the disease, and she also has very poor upper body strength.

![Annalee Hughes, client, 10 years old.](image1.jpg)

Figure 1. Annalee Hughes, client, 10 years old.

She loves exploring the large, three-acre property on which her house is set, which includes a barn, small pond, and brush from which blueberries can be picked. However, the property is also very hilly and rocky, making it very difficult for her to travel around the yard in her current power chair. She has tipped over in her power chair while trying to access the yard, which shows the need for a new means of transport. She cannot get up on her own power if the current chair tips over. The all-terrain power chair with a low center of gravity will erase the danger associated with the traversing of the rugged backyard.
1.2 Purpose of the Project

The ultimate purpose of this project is to design an all-terrain power chair with a low center of gravity that allows Annalee to travel on her property without her or her family having to be concerned with her safety. Her current power chair, seen in the figure below, has proved to be unreliable as she tried getting to various parts of the large yard, and thus a new chair is necessary for her to enjoy the outdoors around her house.

As a very adventurous girl, she loves visiting the various parts of the yard, but she needs a safe means of getting there. Safety is the primary concern, and the chief difference between the power chair being built in this project versus the current power chair she uses is stability. The low center of gravity will prevent the chair from toppling over as she meanders around the
uneven, rocky terrain of her yard. Furthermore, the chair will have a tilt sensor, which will warn Annalee when she approaches a slope too steep for her to drive. Other typical safety constraints will also be in the chair’s design, such as a seat belt and harness to prevent her from slipping out of the chair and to help her maintain proper posture. The family also plans on getting a wheelchair accessible van in the near future, so the chair must remain compact enough to fit into the van with ease, so that they can take it to parks and go on trips without restricting what Annalee can see and do.

1.3 Previous Work Done by Others

1.3.1 Products

Previous designs and products have been prepared in an attempt to achieve goals similar to that of this project, which is to create a power chair capable of providing the operator safety when traveling on any terrain. One of these products is the X4-Extreme 4x4 All-Terrain Power Wheelchair from Vestil [8]. This product is intended to take the operator on any terrain, whether it is wet ground, dirt, or sand, reliably. The main difference between this product and a typical power chair is the size of the wheels, which are much larger than those of a normal power chair. It also features items such as a programmable joystick, different seating options, such as a recliner, adjustable footplates, various headrests, a power seat elevator, and other items. The base retail price of the chair is $16995, with some of the add-on items costing an additional fee.

Figure 4. Similar products on the market. From left to right: X4-Extreme, Tracabout, X8 Extreme
Another product which aims to serve the same goal as the project for Annalee Hughes is the Tracabout IRV 2000 [12]. This product is another joystick-controlled mobility device with various features such as power leg rests, a vertical seat elevator, and a recliner. However, instead of the large wheels that the X4-Extreme uses, it uses treads on its wheels. The retail price is $18498.

A third product designed with the same purpose as that of this project is the X8 Extreme 4WD electric wheelchair from Magic Mobility [13]. The device features a multi-positioning seat, charger, and a standard positioning belt. The base retail price is $14995.

1.3.2 Patent Search Results

A few patents were found for power chairs that were specifically tailored to handle rugged terrain, but there was a surprising lack of novelty in many of the ideas. One patent that stood out was the Mountain Wheelchair by HANDI TRAK, which was patented by Adolf Hammer in 2000 in the category of a small self-propelled vehicle for use by the disabled for all terrain transport. The system was designed for self-assisted access, and had rear motor driven treads that spanned the whole distance of the chair. The vehicle was powered by an internal combustion engine which drove hydraulic or electric motors to control movement. The Mountain Wheelchair was controlled by two armrest mounted joysticks as well as a steering wheel.

1.4 Map for the Rest of the Report

This report will continue by describing the design process of the power chair. Three alternative designs that were considered will be shown, and the design that was settled on will be expanded upon. The individual parts of the power chair will then be discussed, and how they have been modified or integrated will be described. The fabrication, assembly and testing of the chair will then be discussed. The constraints that must be considered during construction and after the project is complete will also be shown, and since safety is the primary concern of this project, a large section will be devoted to discussing the precautions taken. The impact of the project will also be discussed, as well as the knowledge that will be gained by the team during and after completion of the project.
The budget is an important aspect for efficient and careful design of any new product, so it will be discussed later in this report as well. Continuing with a focus on efficiency and timeliness with deliverables, the team is required to divide up labor and responsibilities, so the individual contributions will be acknowledged. The report will then be concluded so that the overall goals of the project can be seen clearly.

In order to allow for replication of this project in the future, references will be cited along with acknowledgements to anyone who had helped in the conceptual or mechanical building of this device. The project specifications will finally be shown in an appendix along with order forms for all of the parts needed by the group, drawings of newly designed parts, and stress analysis of certain components of the chair.
2. Project Design

2.1 Introduction

The proper designing of the ATPC-X42 All-Terrain Power Chair was imperative for the overall safety of the device. Since safety is the primary concern of the client, and subsequently the priority of this project, several items that affect the overall safety of the chair were considered. These included the center of gravity, wheel sizes, safety harness, and the tilt sensor. Furthermore, other items that needed to be considered included client comfort and needs, ease of operation, and cost effectiveness. In order to optimize the design, three alternative designs were first considered in depth. These designs were the first thoughts on how to tackle the creation of a chair that will meet all of the client’s needs. They included the part breakdowns of each subsystem and how they would be able to combine to make a functional device. Other items of interest were how practical, cost effective, and safe each design was. The rest of this section describes the three alternative designs, as well as the reason why the optimal design was chosen. The optimal design will then be described in detail, including each subunit and how it will operate. Then, the development of the prototype chair will be discussed, including specifications of the newly designed parts, how components were fabricated and assembled, and the testing of the power chair.

2.2 Alternative Designs

The three alternative designs that were heavily considered are described below in detail. A fourth design, which included tank treads instead of large wheels, was initially considered, but the idea was dropped after some thought. The treads would make the chair too wide, which would cause difficult storage and transport, and they would be expensive and difficult to repair. Thus, it would neither be practical nor cost effective. The general idea of the tank treads can be seen in Figure 5 below.
2.2.1 Design #1

Design 1 is a power wheelchair constructed from raw materials. The design is built around an aluminum chassis that will be machined to have a wide base and weight will be added to lower the center of gravity. The electrical systems will consist of a joystick and tilt sensor to control steering, braking, and issue a warning if the grade becomes too steep. The software to control the system will be written in C and operated via a microcontroller.

The major aspects of this design are the four off-road tires that will be used as well as the aluminum chassis, which will be custom made to pre-determined specifications. Since aluminum is a lighter metal, the addition of weight will help bring down the center of gravity, thus making
the chair much more stable. The chassis must be able to withstand external forces generated by the environment while in operation. Furthermore, it will house other components of the device, including the motors, microcontroller, gear box, tilt sensor and seat actuator. Thus, it is very important for the chassis to be extremely durable, as it is the main infrastructure of the all-terrain power chair.

The tires will also be large and wide enough to add to the stability of the chair. The rear two tires will be larger than the front two in order to maximize maneuverability and increase portability. Each of the rear two tires will be independently powered by separate motors, so the turning radius will be made tighter. The tires will be air-filled, as opposed to solid rubber, which will have a positive impact on the shock absorption.

The electrical components include the joystick controlling the power supply to the motors, the tilt sensor, and the seat actuator. When the joystick is left in the neutral position, power will not be sent to the motors, and the wheels will not move. However, when the joystick is pushed forward, backward, left, or right, the chair will move in the respective direction. The tilt sensor will involve an orientation sensor, and it will provide an alarm warning when the chair approaches grades that are too steep to safely traverse. The slope, as determined by the sensor, will also control the seat actuator. For example, when the chair is traveling downhill, the seat will actuate upward to keep the operator looking upright. All power will be supplied by two batteries, and a charge inverter will allow maximum operation time.

The software that will be used to control the joystick and tilt sensor are a microcontroller, which will be programmed in C. It will allow the chair to stop when the joystick is neutral, move forward when pressed forward, and so on. It will also set off the tilt sensor alarm when the orientation sensor recognizes a slope too steep.

2.2.2 Design #2

Design 2 involves purchasing a power chair and modifying the chassis, rather than machining a chassis from raw materials. If a pre-made chassis could be obtained, it would be much less laborious to simply modify it to the desired specifications, including a wider wheel base and a low center of gravity. It would also make the rest of the assembly easier because all of the other internal components, such as the motors and gearboxes, would already be in place.
However, the main drawback of this design is the cost of obtaining a power chair, which could be expensive.

Four off-road tires will be used, with the rear two tires being larger than the front two tires. Also, the two rear tires will be powered by individual motors, so that both tires do not need to be powered simultaneously when turning left or right. This will significantly decrease the turning radius and increase maneuverability. The size and width of the tires will also help decrease the center of gravity and increase the overall stability of the chair, making it safe to operate on rough terrain. Two small wheels will also be placed in the back of the chair to act as a further precaution against tipping. These will not be in contact with the ground normally, and will instead balance the chair if it does lean backwards.

The electrical components involved in this design are the two batteries sending power to the motors, which will be controlled by the joystick. When the joystick is left in the neutral position, no power will be sent to the motors, and when the joystick is pushed in a certain direction, the motors will follow respectively. Also, the tilt sensor will require power to properly activate the warning system if the chair approaches dangerously steep slopes. The grade determined by the tilt sensor will also control the seat actuator. The actuator will orient the seat such that the operator is always looking ahead and not up at the sky or into the ground when going up and down hilly terrain.

The software that will be used to control the joystick and tilt sensor are a microcontroller, which will be programmed in C. It will allow the chair to stop when the joystick is neutral, move forward when pressed forward, and so on. It will also set off the tilt sensor alarm when the orientation sensor recognizes a slope too steep.

2.2.3 Design #3

Design 3 involves a six-wheel power chair operating on mid-wheel drive. This is the way the client’s current chair is designed. Since it is a common power chair layout, a pre-existing chassis will be obtained and modified to increase the stability by allowing larger tires and a lower center of gravity. This design will provide increased front and back stability due to the orientation of the wheels; however, the suspension will have to be improved to better the left-right stability of the chair.
Figure 7. The alternative six-wheel design for the ATPC-X42 power chair.

This design places all six wheels under suspension so that each wheel will be able to maintain contact with the ground, even if the terrain is rough or uneven. It will involve a spring-shock absorption mechanism that will dampen impacts from the front and rear wheels. These springs lead to a third spring, which will further reduce the forces experienced by the operator from all wheels.

The electrical components involved in this design are the two batteries sending power to the motors, which will be controlled by the joystick. When the joystick is left in the neutral position, no power will be sent to the motors, and when the joystick is pushed in a certain direction, the motors will follow respectively. Also, the tilt sensor will require power to properly activate the warning system if the chair approaches dangerously steep slopes. The grade determined by the tilt sensor will also control the seat actuator. The actuator will orient the seat such that the operator is always looking ahead and not up at the sky or into the ground when going up and down hilly terrain.

The software that will be used to control the joystick and tilt sensor are a microcontroller, which will be programmed in C. It will allow the chair to stop when the joystick is neutral, move forward when pressed forward, and so on. It will also set off the tilt sensor alarm when the orientation sensor recognizes a slope too steep.
2.3 Optimal Design

2.3.1 Objective

The objective of the optimal design is to create an all-terrain power chair with a low center of gravity that allows Annalee to travel on her property without her or her family having to be concerned with her safety. It must be safe enough for Annalee to operate without having to worry about tipping, and it must also be cost effective, durable, comfortable, and easy to operate. The device also has different features than her current chair.

The current chair is a six-wheel system with mid-wheel drive. It can be seen that the power is supplied to the middle two wheels, while the front and rear wheels are for front-back stability. The main problem with this is these wheels are not suited for rugged terrain. Thus, the ATPC-X42 instead features four, larger off-road tires, with the rear two being larger than the front two.

The new device uses the chassis of a Quickie S-626 power chair, which was acquired from NEAT Marketplace, a drive train that has two motors to individually power the rear wheels, a shock-absorbing suspension system, and an automated seat actuator. It also contains a joystick control system to mimic the current chair, a kill switch in case Annalee loses control of the chair, and a tilt sensor that will set off an alarm if she approaches dangerously steep slopes. The chair also has 2 main safety constraints, including a five-point harness and seat belt, as well as a seat that holds the body’s posture properly.

The design that will be explained in the following section has been chosen for multiple reasons. First, since a pre-made chassis was acquired, the time and cost of machining one from scratch is completely eliminated. Furthermore, the Quickie S-626 was in working order when purchased, which means it had working motors and a functional joystick and actuator. The large tire design will significantly increase the stability of the chair, as Annalee’s current chair tipped due to the inability of smaller wheels getting over hills, rocks, and bumps. The tilt sensor with alarm system will also increase the safety of device.

Overall, this design met the criteria necessary to continue moving forward with the fabrication of the ATPC-X42. It will be a safe, stable chair that will be easy for Annalee to operate because the joystick controller is similar to that of her current chair. It will be cost effective because many of the parts were already acquired as a part of the Quickie S-626 power chair, and a new seat will ensure comfort.
2.3.2 Subunits

The complete chair described above is made up of a number of smaller systems that come together to make everything work. Each of these subunits has to be designed so that it not only accomplishes its task, but also integrates into the complete system. The following section details the design of each of these subunits, and describes where they fit in the complete design. They can be broken down into three sections, mechanical, electrical and software. An overview of the Autodesk model of the full all-terrain power chair is shown in the figure below.

![The overall Autodesk model of the ATPC-X42.](image)

**Figure 8.** The overall Autodesk model of the ATPC-X42.

**Mechanical**

The mechanical components of the power chair encompass all of the parts that have a role in the structure and mobility of the device. These parts include the seat and seat back, seat mount, chassis, tires and hubs, casters, drive train, suspension, anti-tip wheels, footrest and seat actuator. The way in which each of these parts will play a role in the mechanics of the power chair is described below.

**Seat and Seat Back**

The seat of the power chair plays a vital role in keeping the proper positioning of the operator. Since Annalee is unable to maintain herself in the upright position, it is both an issue of safety and health for the seat to provide the proper posture for her when she is operating the
device. The seat also plays an important role in securing the operator via a harness and seat belt. These parts must work in unison to support Annalee without restricting or harming her as she drives the chair around her rugged yard.

The seat consists of a seat back and a cushion, and both have been acquired from NEAT Marketplace. The seat back is contoured to provide left-right positioning and prevent jostling as Annalee is operating the chair. These parts can be seen Figure 9, which displays each of the seat components put together below.

Figure 9. The seat assembly, including seat base and back.

The overall seat will be larger than the one on Annalee’s current chair, which she has been using for almost two years. The current seat sports a depth of 15 inches, width of 14 inches, and height of 19 inches, not including the headrest. As Annalee gets older, it is important for the seat to be able to fit her, and thus we will acquire parts that are larger than the old seat. The new seat has been measured to make sure it can be small enough for Annalee to use right away with the capacity to adapt to her growth.

Since the seat will be larger, a new seat base plate has been designed and fabricated for the seat to rest on the seat mount. The acquired Quickie S-626 power chair has a seat base plate of the dimensions 14” (w) x18.5” (l) x0.2” (d) and the plan is to widen the base by two inches, which will provide Annalee room to grow. Also, a new seat back mount was designed to
accommodate the new seat back. It required a mounting bracket for the five-point harness and seat belt, and it is modular to permit seat and constraint adjustments for when Annalee grows. The seat back also features an attachment for the headrest to be attached. The Autodesk model of the seat back is shown in the figure below.

![Figure 10. The Autodesk model of the seat back mount with headrest attached.](image)

**Seat Mount**

The seat mount is the portion of the chair on which the seat rests and is connected to the chassis. The seat mount is what must be able to withstand the direct weight of Annalee and the seat apparatus, and it is also what inclines and declines when the actuator is in operation.

![Figure 11. The Autodesk model of the seat mount assembly.](image)
The space between the inside faces of the two outside rails of the seat mount on the Quickie S-626 power chair was 13 inches. One of the key modifications that have been made to the chair was the addition of one-inch spacers in the seat mount that increase this width to 15 inches. This allows the implementation of the wider seat base plate, and therefore the larger seat. The spacer is made out of aluminum and is attached between the crossbars of the seat mount and the outside rails. The spacer can be seen in red in the figure below.

![Spacer Design](image.png)

**Figure 11.** The design of the spacer (in red) that widens the seat mount.

The side rails of the seat mount, which are seen in yellow in the picture above, also contain the dove tail tracks which hold the attachment points for the seat back to the rest of the chair and the armrests.

**Chassis**

The chassis provides the core foundation of the power chair, as it is the main structure to which all components are attached. From the casters, to the motor and battery cages, to the seat mount and armrests, everything stems from the chassis. Thus, it is imperative that the chassis be built strong enough to withstand all forces acting upon it, including impacts with bumps and rocks on the ground and the weight of the operator and other components.

The chassis that is being used in the design of the ATPC-X42 all-terrain power chair is that of the Quickie S-626. It is made of aluminum, and it has been modeled in Autodesk. It should be built strong enough, as it was manufactured and put into a product that was in operation, but it is still important to know for a fact that Annalee will be safe while operating the chair, and thus stress analysis as conducted in ANSYS via Autodesk Inventor has been completed and can be seen in the Appendix with all other stress analyses done.
**Tires and Hubs**

The tires will be one of the key differences between the client’s current power chair and the all-terrain power chair. Four larger tires have been used rather than maintaining the current six-wheel system. It is also important to note that these will be real tires that can gain traction on grass and dirt rather than rubber slabs that do not have good traction when operating off asphalt or flat ground. The tires are all tubeless tires with proper wheel rims. Two large, off-road tires in the rear are powered by two electric motors, and their size would account for increased stability and traction. These rear tires are 16 inches in diameter and 4.5 inches wide. Two smaller, off-road tires in the front are also being used, but they will be large enough to prevent the compromising of the chair stability. These front tires are 10.5 inches in diameter and 3.5 inches wide. They have been placed into custom-made front casters that extend from the chassis and will assist in changing direction and maintaining a certain direction.

The rear tires approximately the same diameter as her current chair however they are much wider than the cheap rubber tires that are on there currently. The tires will be wide to help with the left-right stability of the chair by maintaining more contact with the ground. The larger tires also help increase the variety of terrain that the chair can operate on. However, the new tires also required new wheel hubs to attach to the motors, and these hubs are able to fit the rear tires as well as withstand the torque generated by the turning motors. The wheel hub design can be seen in an unassembled-view below in Figure 13.

![Figure 13. Expanded view of the wheel hub design.](image-url)
Casters

The front casters that are currently on the Quickie S-626 are only 2 ¾ inches wide, and therefore are not wide enough for the front tires that are desired. Furthermore, front casters obtained from a discarded Torque SP, seen below, are three inches wide. Again, this width is not enough for the three-inch wide tires that plan to be implemented, since the tires need space to rotate. The front tires shown below are only 2.5-inches wide.

Figure 14. The widest casters currently available. New ones have been fabricated.

Thus, new casters have been made from scratch out of aluminum. The bolt that extends from the chair must be able to fit into the holes at the front of the chassis, and the casters themselves are 4.5-inches wide from inside face-to-inside face to accommodate the 3.5-inch wide tires, which also have a protrusion. Tires that would fit into the pre-made casters would make the chair more unstable due to their narrowness, since they would have to be less than three-inches wide. Instead, it was worth making new casters to hold wider tires that add to the safety of the power chair. The originally-proposed caster can be seen below in Figure 15.

Figure 15. The general design of the new front casters, which are 1.5-inches wider than those on the Torque SP.
Drive Train

The drive train will provide the device with a rear-wheel two-wheel drive mechanism. Two individual motors receive power from the batteries and each powers a rear wheel independently. This will allow the chair to have a tight turning radius, since it will be possible for the left wheel to be in motion while the right is stationary and vice versa. The motors will also deliver the torque that will get the device up and down the hills. The client states the current chair, which uses Sunrise Medical motors (part number 499152), does not have quite enough power to navigate the hills of the property. Thus the new motors used in the ATPC-X42 will provide more torque that will allow easier traversing of the hills. The current chair attains a maximum speed of 6 miles per hour, and the ATPC-X42 allows approximately the same speed. Two motors from a stronger power chair will be used to operate the chair. The motors with gearboxes are already attached in the Quickie S-626; they are two 4 pole motors capable of going 6 miles per hour. By keeping the center of gravity and motors towards the rear, it will increase the stability of the chair. In the motor assembly there is also a lever to engage and disengage each motor. The current chair has this feature and is required for proper wheelchairs. This allows the chair to be pushed by another person if it is required in the case of a break down or loss of power. Without this if the chair got stuck the wheels would lock and would have to be dragged or transported via another mechanism instead of rolling it elsewhere.

Suspension

The suspension of the device is essential for preventing imbalance and tipping during operation, which has happened with the client’s current power chair. Furthermore, since the device will be operated on rough, hilly, and rocky land, the suspension will play an important role in keeping the operator stabilized and comfortable. Annalee’s upper body strength is already very weak, and she will not be able to compensate for any extra forces from the terrain.

The Quickie S-626 is already equipped with two shock absorbers, as seen in the following figure. The purpose of these shock absorbers is to transmit forces experienced by the front tires to the larger rear tires. They are especially important for the front of the chair, which takes the majority of the impacts as the chair operates on rough terrain.
**Anti-tip Wheels**

As part of the safety precautions in place, there are anti-tip wheels in the back of the Quickie S-626 chair. The current chair simply has two wheels that are in constant contact with the ground at all times. The four wheel design of this chair offers a lower center of gravity than a conventional six wheel chair, but the risk of tipping backwards is slightly increased [2]. Due to this, in the back of the chair behind the rear wheels will be two smaller wheels that are on small axle. The axle is located slightly above the ground to prevent drag and if the chair tilts backwards too much the anti tip wheels will make sure that the chair does not flip backwards.

**Footrest**

The footrest is another important component of the ATPC-X42, as it functions in securing Annalee's feet out of the way of the front wheels as she operates the chair. An imperative part of the design is clearance from the casters, which it sits above and beyond. Otherwise, the rotating tires are potentially dangerous. The footrest has straps for Annalee's feet, and it can rotate out of the way so she can enter and exit the chair with ease. The design also features a modular system that can shorten and extend to fit Annalee as she grows. The overall design of the footrest involves one point of attachment onto the seat mount and a footplate that sits on another metal plate to aid in reducing the torque experienced. The footrest can be seen in Figure 17 below.
The seat actuator is a motor that elevates and lowers the orientation angle of the seat. The actuator receives a linear signal automatically from either the tilt sensor or manually from the actuator controller and translates that into a mechanical force up or down. When the chair is traveling down a hill, the motor of the actuator will provide torque at the hinge of the seat mount that connects it to the chassis. This will cause its angle with the ground to increase. The operator will then be looking parallel to the ground rather than into it, and it will prevent Annalee, who has a weak upper body, from falling forward out of the seat and into the harness. It will provide torque in the opposite direction when she is traveling uphill to prevent her from looking at the sky as well. The amount of elevation or depression will depend on the grade of the slope Annalee is traveling on, and it will be automated with respect to the tilt sensor.

Electrical

The electrical portions of the subunits come together to control and operate the mechanical portion of the whole project. The electronics portion provides the power to the chair in order to fulfill all day operations. The key parts of the electrical subunits are the batteries,
charger, killswitch, joystick, controller, and tilt sensor and automatic actuation circuit. The overall circuitry is shown in Figures 17 and 18.

![Circuitry in battery box](image)

**Figure 17.** Circuitry in battery box

![Circuitry interfacing the controller](image)

**Figure 18.** Circuitry interfacing the controller

**Controller**

The controller, also known as the power module is the main command center for the power chair which will control the motors via power distribution. The controller being used is the Penny and Giles Pilot+. This controller as seen in Figure 18 interfaces with everything else in the circuit. They are 80 amp speed controllers which come standard with most power chairs. The module simply connects the batteries, both motors, joystick and actuator controller to its interface. Without the controller, commanding the motors would be much more difficult.
**Batteries**

The batteries are the most important part of the electrical subunits. Without proper batteries the wheelchair will not operate properly and may shutdown abruptly. A Deep Cycle battery is required to operate the motors and actuators in the wheelchair. With the use of deep cycle batteries it allows for up to 80% discharge before the batteries need to be charged again. This is essential for all day use and traversing the different terrains that the wheel chair will be used on. The batteries that will be used will be PowerSonic [3]. They are a sealed Gel Cell which provides quality and ease of maintenance. One battery has 75Ahrs and 12V. 75Ah represents the amount of current that can be delivered. This is a high amount compared to other chairs however this is what is necessary to get all day heavy usage. Two will be used in series in order to provide enough energy for the system to operate.

**Charger**

Because the system is electrically operated there needs to be a charging unit in order to recharge the batteries. A multi stage charger is necessary for this task. The function of the multi-stage charger is to charge as fast as possible without overcharging. The charger senses the battery’s state-of-charge and tapers the current as it approaches 100% charged. This maintains the battery at a full state without boiling away the water in the electrolyte [4]. We will be using a Lester Electrical 24 Volt Dual Mode Automatic Battery Charger. This charger is a standard used wheel chair battery charger and can successfully charge our large batteries. It delivers 8A of current maximum, and also has indicators that tell the user the charging level. There are indicators that tell the user when the batteries are less than 80%, greater than 80% and when they are fully charged. If there is some error in the charging the unit will also display a fault indicating that there is a wrong connection and should be fixed.

**Kill Switch**

A kill switch has been implemented for the increased safety of the all-terrain power chair. This will be in the form of a button that will cut off the power from the battery to the motor. This is also the normal on/off switch for the power chair. When set in the off position, the battery will not drain, and the motors cannot operate. This switch will be located on the joystick for ease and safety.
**Joystick**

The joystick is to be used as the controlling mechanism. The power supply to the motors will be controlled by the joystick. When the joystick is set to the neutral position there will be no power sent to the motor, and the wheels will be in stationary position. Whereas, when the joystick is pushed forward, backward, left, or right, the chair will follow the respective direction. In addition to this the joystick will be used to control the speed of the power chair. The joystick is made from the resistors that provide the input to the pulse width modulator (PWM) circuits [7]. Pulse width modulation controls the motor speed by driving the motor speed with short pulses. These pulses vary in duration to change the speed of the motor therefore, the longer the pulses, the faster the motor turns, and vice versa. The joystick has been obtained from a Quickie S-626. The joystick has a speed control to determine the maximum speed during use as well. The chair can be set to a slow crawl up to its maximum speed of about 7mph. As said before the joystick will also have the on/off kill switch for the motors. When inactivated there will be no power to the motors and therefore no movement. The joystick also houses the charging/programming port. When the chair needs to charged the connection will be made through this port when the chair is turned off. Reprogramming of the chair’s power module will also be done via this port.

**Actuator Control stick**

The actuator switch is a simple pull with two throws. When the switch is flipped one way two pins are activated and that sends the signal to the actuator to move in a specific direction. The opposite happens when the switch is turned in the opposite direction.

**Automatic Actuation Circuit and Tilt Sensor**

Due to the simplicity of the actuator switch the automatic actuation circuit can easily bypass the switch and control the chair through the use of a microcontroller. The automatic actuation circuit (AAC) will make sure the user is level at all times through the use of the seats actuator. The AAC uses an accelerometer, ADXL335, to control the tilt of the seat. By attaching the accelerometer to the chassis the accelerometer can able to tell when the chair is going down a hill. The seat accommodates for the tilt in the chair by actuating the seat upward so that user is not looking downward. This will maintain the Annalee in an upright position and will prevent her from falling forward in the chair.
The microcontroller performs analog to digital conversion on the voltage read from the accelerometer. Knowing the voltage from the accelerometer will then be translated into a distance using the proper conversion. Then by knowing the rate of actuation the actuator can be turned on for the correct amount of time to auto adjust back to level. Because the actuator works by connecting the pull to the right throw in the switch, two transistors were used like a switch to control the actuator. The pull is attached to the collector of each transistor. Each throw will then be attached to each emitter of the transistor. Finally the base is connected to two pins on the PIC.

When the seat needs to go down, then the “down” transistor will be turned on and when the “up” transistor is turned on the seat will move up. By creating a manual switch that will flip between the automatic control and manual control it prevents dual control of the actuator at the same time which can be harmful to the electrical system. Figure 19 shows what the AAC looks like. The circuit is powered with a 3 Volt button cell battery as this is enough power for the microcontroller and within the operating voltage of the accelerometer. The circuit is encased and easily accessible in case the battery needs to be changed. In addition to auto adjustment, at a certain angle an LED with buzzer will sound to indicate that the user is approaching a hill that is too steep and should be avoided.

![Diagram of the AAC circuit]

**Figure 19.** Automatic Actuation Circuit
Software

**Power Module**

Reprogramming of the power module was necessary in order to fine tweak the chair to perform up to specifications. By adding weight and changing the dimensions of the original chair, the response will be changed, therefore adjustments will be necessary. The Penny and Giles Qtronix Programmer was used to adjust the settings. Some of the main options that were important to adjust were the acceleration, deceleration, maximum and minimum speeds, and turn correction. The old chair was very jerky on acceleration and deceleration, so those settings were turned down along with the maximum speed to allow for better control.

**Automatic Actuation Microcontroller**

The microcontroller has been programmed to successfully control the actuator. The accelerometer was be connected to the A/D pin on the PIC so that the voltage that is given from the accelerometer can be converted and used in the program. The program can then determine if the chair is tilted or not. Using the acceleration information the program will then translate the acceleration into tilt. By knowing the tilt angle the actuator can be turned in the right direction in order to compensate for the tilt and make the seat level. The program will constantly be operating thus recognizing at all times what the tilt is. Therefore when the user switches over to auto adjustment the actuation can occur to auto adjust and make the seat level.

2.4 Prototype

This section of the report will cover the methods by which each of the individual mechanical features were designed and the reasons behind why they are the way they are. Then the way each of the mechanical parts was fabricated will be described. Finally the way subunits were tested will be explained as will painting of the chair, assembly, and complete full-unit testing. The overall view of the final chair can be seen in Figure 21 below.
2.4.1 Design of Components

Certain individual components were designed for this device in order to operate the way in which the specifications indicate. They were also designed in this way in order for them to properly fit together without any interference with other parts. Design of these parts was conducted in Autodesk Inventor 2009.

**Casters**

The casters were designed to not only hold the wider front wheels, which are 3.5-inches wide, but also operate the same way as the previous casters that were attached to the Quickie S-626. Thus, they are attached by the same bolt to the chassis being used and have the same angle of descent, which is 18 degrees. The casters are also designed to ensure clearance with the footrest while allowing full 360-degree rotation of the tires. Half-inch thick aluminum was the material chosen because aluminum is cheaper and easier to work with than steel, but it must be able to withstand the forces from ground impacts and the weight of the chair.

**Footrest**

The footrest design is based on the fact that Annalee requested a mechanism by which she could enter and exit the chair easily. In her current chair’s setup, the footrest is in the way
and she must be aided in climbing over them. Thus, rather than having a footrest attach from the middle of the seat and extend downward, the footrest is attached to the right side of the seat mount, and has a locking hinge mechanism. The hinge can be disengaged and the footrest can be swung out of the way to the side, allowing a clear pathway. The footplate also rotates upon the bar it is attached to. New holes were drilled to enhance the modularity of the footrest, as it can now be extended and shortened to suit Annalee's growth. The general footrest design can be seen in the Autodesk model below.

![Figure 22. General design of the footrest as created in Autodesk Inventor 2009.](image)

**Motor Extension**

The motor mounts needed to be extended due to interference with the rotation of the front casters. The motors were too far up, and when the front tires spun around, there was contact, and thus the motors needed to be moved further to the rear of the chair. This was done by welding a complementary piece of steel onto the currently existing motor mount that will act as a continuation of the mount. Holes were drilled in the same exact locations as on the motor itself for the points of security to continue to align properly. The idea behind this design can be seen in Figure 23, shown below.
Seat Attachments

The seat is attached to the back mount at two points to prevent rotation as Annalee presses her back against the back of the seat cushion. The hooks that came with the new seat were used to secure the top half of the seat by drilling holes in them and screwing them into dove tails that reside in tracks in the back mount. The second point of seat attachment uses the bars that extend from the lower part of the seat. A piece of metal sits on the face of the back mount where it can be screwed into a dove tail, and another piece of metal extends to the bar, where it is secured around it with a complementary semi-circle-shaped piece of metal. The Autodesk model of the second seat attachment is shown in Figure 24.
Figure 24. Second point of seat attachment using the bar from the seat.

Back Mount

The back mount used is the back mount of the Quickie S626, but since the base of the chair was widened by two inches, the back mount also needed to be two inches wider. Thus, the design involved cutting the cross bar in half and welding in a two-inch piece of aluminum cylindrical stock. This allows the back mount to be the proper width to be secured to the seat mount, and it also makes it wide enough to accommodate the larger seat. Furthermore, aluminum was used because the back mount is more for structural integrity than load-bearing. There is no axial loading on it, and nothing is attached to it that would cause any other forces. It just must be able to hold up as Annalee leans back in the seat.

Seat Plate

A larger seat plate is necessary to account for the larger seat mount and seat because the chair should be able to fit Annalee even after she grows. The plan for the larger seat plate was to order a larger piece of aluminum, cut it down to the desired size that would fit on the seat mount, and then drill holes in it that align with holes on the side rails of the seat mount. Aluminum that is thick enough was used because the plate is load-bearing; Annalee’s weight will be directed straight down into the seat plate via the seat cushion. Thus, it was necessary to prevent the plate from breaking while Annalee is operating the chair. The new seat plate with modified holes can be seen in the Autodesk drawing below.
Figure 25. Dimensioned seat plate drawing with modified holes.

**Headrest Attachment**

The design of the headrest attachment involved fitting the end of the headrest acquired from NEAT Marketplace. Since the headrest itself can be moved horizontally and vertically by loosening the collars on the part, the headrest attachment itself did not require modularity. A piece of aluminum has a through-hole that fits the bottom of the headrest and a smaller bore for a pin located on the collar of the headrest. This way, the headrest can lock in place and not come undone during operation. It is screwed into the back of the seat with four, long threaded screws that help divide the torque provided by the headrest and attachment itself. The overall design can be seen in the picture below.
One-inch Spacers

The purpose of the four one-inch spacers is to widen the seat mount to enable the implementation of the wider seat and seat cushion. The original Quickie S626 was a kid-sized power chair, and thus it needed to be enlarged to account for Annalee's growth. They are the same size as the attachment points of the crossbars holding the seat mount together and the holes align with the previously existing holes. One-inch longer screws are then used to hold the spacers in place as they screw into dove tails in the side rail tracks. The design showing how the spacers will be implemented can be seen again in Figure 27.
Wheel Hubs

New wheel hubs were designed in order to attach the motors to the new, larger rear wheels, which did not come with a point of attachment. Thus, custom hubs were designed that would fit the inner rim of the wheel as well as the axle of the motor. The general design used cylindrical pieces of steel that had a hollow shaft down the middle with a key-way complementary to that on the motor axle. Drilled holes line up with each of the holes in the rim for lug nuts to be attached to bolts, thereby connecting the wheel to the hub. A counter bore in the hub allows a nut to secure the motor axle in place by using the half-inch of threading on the end of the axle. Steel was used for the hub itself because it is in a load-bearing situation and must be able to take the forces from the ground and rotating axle. The Autodesk model of the complete wheel hub design can be seen in Figure 28 below. The green structure is the steel hub, and the blue object is the motor.

![Figure 28. Final design of the wheel hub.](image)

Joystick Hinge

The joystick hinge is designed to rotate the joystick outward to eliminate the obstruction it causes as Annalee enters and exits the seat. The original design involved using a cylindrical hinge that fit inside the bar upon which the joystick sat. However, there was too much give and the hinge would not be strong enough to support the weight of the joystick, despite pins locking the hinge to the bar. Instead, the rod was cut into two pieces, and two holes were drilled in the
rear piece and one in the front piece. The bars were connected by aluminum slats with holes drilled to align with the holes in the bar. The bars are separated just enough so that the front end of the bar can rotate to the right, out of the way of the chair entry pathway. This new design is much stronger, and can be seen below in Figure 29.

Figure 29. Autodesk model of the joystick hinge mechanism.

2.4.2 Part Fabrication

The components necessary for the building of the ATPC-X42 all-terrain power chair were fabricated in the University of Connecticut Machine Shop, located on the first floor of the Castleman Building. This section describes the methods used in the physical creation of these parts.

Footrest

The footrest was constructed by combining the mount currently present on the chair with a new shaft and plate. The mount was bored out at the bottom to a 9/16" hole 4" into the pipe to allow space for the new shaft. Three holes were drilled along the sides of the shaft at 7/32" spaced 1" apart to provide locking points for the shaft and allow the length to be adjusted and were countersunk. The top part of the bar needed to be extended so that the footrest would not interfere with the larger casters, so a 1" piece of 3/4" aluminum round bar was welded into the top piece, and a 1" piece of flat aluminum stock was bent and welded into the bottom mounting location. The footplate was created from a 13.25"x8.25" piece of 0.35" thick plastic. Eight holes
for restraints were drilled into the plate to allow for the restraints to be attached. The holes were begun 0.75" from the edge, and were spaced 4" apart. The upper holes were drilled 3.25" up from the back of the plate, and the closer holes were 0.75" from the back. The plate was mounted onto a single footrest plate underneath which attached to the footrest shaft. Four holes were drilled into this footrest at the same dimensions as the footplate so that bolts could go all the way through and attach. The final fabricated footrest can be seen in Figure 30 below.

![Figure 30. Completed footrest after full assembly.](image)

**Joystick Hinge**

A new bar was used to attach the joystick to the armrest of the chair. A 0.75" aluminum round bar was used and was cut to a length of 15." 4" was cut off the pipe to allow for a swing arm. Two pieces of 1/8" thick aluminum were cut to 0.5"X 2.5" in order to brace the rotating bar. One hole was drilled through the four inch bar 0.5" in using a 1/4" bit. Two holes were drilled through the back bar 3/4" in and 1.5" in using the same bit. Holes were drilled through each piece of aluminum as well in order to line up with the holes in the bar, and to allow space for the arm to rotate. These holes were drilled with the same spacing, but the distance between the single hole on the far bar and the first hole on the rear bar was made to be 1.5" apart to allow space for the bar to rotate. The plates were secured to the bar using 1.5" thick 1/4X20 bolts with
each piece separated by washers and bolted on at the end. The fully completed joystick hinge is shown in the figure below.

**Figure 31.** Joystick hinge as attached to the chair.

Motor Mount Extension

The motor mount was extended to accommodate the new location of the motors. A piece of 3/8” thick steel was cut into a 4”x3.5” piece and bent for the extension. A 2”x1” notch was cut off of the plate in the corner to fit against the existing mounting area. The plate was then bent next to the cut area to form the lip that is on the existing mount used to cradle the motor with little vibration. The mount was then adjusted by cutting off the inner tang from the original mount. This allows for correct placement of the plate and better contact. The plate and mount were then welded together. This allowed for an extension of 2” which was the necessary distance required for clearance of the motors. The mount then required the holes to be moved 2” toward the rear to line up with the motor. The mount was put in a vice on the end mill, and aligned. The 5 holes that are used to secure the motors were then drilled 2” back using a 1/4” drill bit. After drilling the new holes the motors were able to be moved backwards in the mount clearing any constraints issues.

Two Points of Seat Attachment

The first seat attachment was formed by modifying the existing U bracket on the new seat back. The tracks that the bracket slid in the back of the chair needed to be extended inwards, to allow them to fit bars 16” apart. This was done by filing away at the tracks until they were elongated 3/8” each. The bracket was then drilled through the middle of the U with a 1/4” bit, as
well as through the entire bar. A 1.5” bolt could then be slid through and secured into a 1/4X 28 dovetail present on the back of the mounting bar. The first seat attachment is shown in Figure 32.

![Figure 32. First point of seat attachment](image)

The second seat mount was constructed from two separate pieces of aluminum. A 3/8" thick 2"X1" piece of aluminum was used to attach to the seat back and a 1.5"X1” piece of 1/8" thick aluminum was used to attach to the mounting bar. These two pieces were welded together in an L shape. To attach the bracket to the mounting bar, a 1/4" hole was drilled in the thinner piece of aluminum so a 1/4X28 bolt could screw into another dovetail on the bar. The thicker piece of aluminum needed to wrap around a round bar jutting out of the seat back, so a clamp was constructed. This was done by tapping two 8X32 holes in the top of the bar 0.2” from one edge, and 0.875” in to the second hole. The holes were centered by drilling them 0.1875" in to the 3/8" thick bar. Then, an 11/32" hole was drilled through the middle of the bar 0.5” from the top edge, and cutting across the 11/32” hole so that it could be clamped down on the bar. The second seat attachment can be seen in the picture below.
Figure 3. Second point of seat attachment.

Back Mount

The back mount crossbar needed to be extended 2" in length to accommodate the wider seat base, and this was done by cutting the bar in half, and welding in a 2" piece of 1" aluminum round bar. This increased the length from 14" to 16." The newly assembled back mount is shown in Figure 34 below.

Figure 34. Back mount before chair painting; weld is clearly seen around new stock.
Headrest Attachment

The headrest was mounted to the seat back by attaching a block of aluminum to the back of the seat. A 3"(l)X2"(w)X2"(d) block of aluminum was used as the mount. A 57/64" hole was drilled with the center of the hole 3/4" into the 3 inch long piece of the mount. A second 1/4" hole was drilled offset from the large hole to secure the headrest by the pin in place. On the 2"X2" side of the block opposite where the headrest slots were drilled, 4 1/4"x28 holes were tapped into the block 1/2" in from each side. 1/4" holes were also drilled through the back of the chair, and 1.5" 1/4x28 flathead bolts secured the mount into the chair.

Wheel Hubs

The wheel hubs were formed from two pieces of 5" steel round bar initially cut to 2.75" long. The hub was cut down in a lathe, with the axle mount cut 2 1/8" into the bar down to a 2"
diameter. The plate to attach to the tire was cut down to 3/8" thickness, but was left at a 5" diameter. Once the shape was formed, a 9/16" bit drilled through the center of the hub to form the axle shaft. This shaft had to be bored out further to a thickness of 0.585" to properly fit the shaft. Once bored out, a 1 1/4" drill bit drilled through the outer face down to 1." The taper caused by the bit was bored out down to 1.25" to form a flat base, and the shaft was widened to 1.375." Once work on the lathe was completed, four holes to mount the wheels were drilled through the 5" diameter plate 2" out from the center. A 29/64" bit was used to allow a small amount of extra space for 1 1/2" long 7/16" bolts secured by lug nuts. The bolts were welded into place into the hub. Finally, a key slot was broached through the center of the axle mount. A 3/16" broach was used, and the key for the motor was milled down slightly to allow it to fit into the slot since its initial width was 0.2" and it needed to be milled down. The wheel hubs are shown in Figure 36.

![Figure 36](image.jpg)

**Figure 36.** The wheel hubs as connected to the motor and rear wheel.

**Casters**

The casters were made from aluminum; the major change made from the previous casters was increasing it in size. This is because the tires used were bigger in size, given that a wider
tire was used for better traction and load bearing. The caster length and width had to be adjusted to accommodate the tire. As a result the current casters were made to be 4.5in wider and the fork length was 8 in. The axle was made from a 5/6” size bolt which was used to attach the caster and the wheel. The bolt screws into one side of the caster which was threaded in order to lock it in place. The casters are shown below.

![Figure 37. The casters with front wheels attached.](image)

**Seat Base Plate**

The seat base plate was made of aluminum. It was essential to have the proper dimension since the seat of the power chair plays a fundamental role in keeping the appropriate position of the operator. The dimensions used were 16.75”(w)x18”(l)x0.25”(d) and the plate was specially ordered to these specifications. Twelve 1/4" holes were drilled 0.375” away from the edges of the plate to be able to attach it to the seat cross bar and shift the plate forward or backward on the bars if necessary. The seat base plate can be seen in the figure below.
One-inch spacers

The spacers were used to make the seat wider so 4 spacers were milled out of aluminum to a final size of 2.4”(w)X1.373”(l)X1(d). Two 9/32” holes were drilled through the spacer so that the side rails could be mounted an inch wider on each side. The spacers allow bolts through them which screw into dove tails that reside within the side rails. Overall, these spacers widen the seat from 14 inches to 16 inches, allowing Annalee room to grow with the chair, rather than the chair becoming unusable after a short amount of time.

Circuitry

The circuit for the auto actuation uses two ADXL335 accelerometers. The accelerometers have a linear relationship between the tilt and the voltage output, thus it was an ideal choice for tracking the tilt of the chassis and the chair. One sensor was attached to the chair and was contained within the actuation control box, while the other sensor was placed on the chassis in a small box.

The voltages are compared with the use of a microcontroller, the PIC16F874. It is able to perform analog to digital conversion on the voltage output and then compare the voltages to
control the actuation. The current actuator uses a single pull with two throw switch to actuate thus splicing the wire to control the actuation was done. This was accomplished with the use of two relays. When the seat needed to go down the seat would go down, the pin on the PIC meant for down actuation would go to high thus connecting the throw to the common in the existing actuation switch. When the seat needed to go up the pin for up would be set to high opening the relay and connecting the up throw with the common in the switch. There is also a buzzer in the circuit that goes off when the chair reaches a hill that is too steep. This indicates that the user should not go down the hill and should probably use another means around or use extreme caution. There are also two switches in the circuit which control power to the circuit which allows for hill detection but does not assist in the actuation. The second switch is used to turn on the auto actuation. If this switch is on, the user will always be level. If the user does not wish to have actuation he/she can turn it off and therefore only hear the buzzer when the user approaches a hill that is too steep and if the user wishes for no assistance at all, total power can be turned off to the circuit, with the first switch. The actuation control box is shown below in Figure 39.

![Figure 39](image-url) Control box for the manual and automatic actuation.
Programming

The auto-actuation is programmed using a microcontroller. The microcontroller was programmed to convert the analog signal to digital from the accelerometer. The accelerometer is connected to the A/D pin on the PIC so that the voltage that is given from the accelerometer can be converted and used in the program. The accelerometer is used to translate the acceleration into tilt. Once the tilt angle is known the actuator can be turned in the right direction in order to compensate for the tilt and make the seat level. The program will constantly be operating accordingly recognizing at all times what the given tilt is. In such a way when the user switches over from manual to auto adjustment the actuation can occur to auto adjust and make the seat level.

In programming the microcontroller 0 degrees was used as a level and given a value of 307 which is approximately 1.5 volt. The approximation 307 was found by using the following calculation \((1.5V \times 1024)/5V\) which gave the level value to be 307 or 0 degrees as defined above where, Since the return value for 10 bit is between 0-1024, thus the maximum value was taken and 5V is the power supply. Basically the auto-actuation works if the angle value is greater than 308 the seat will lift up to level the operator and if the angle value is less than 306 the seat will go down to level the operator. However, if the angle value is less than 295 which is approximately the 10 degrees the buzzer will go off and notify the user that he/she is approaching a hill that is too steep and needs to be avoided.

2.4.3 Chair Assembly and Testing

Assembly Modifications

Further modifications to the chair were made necessary once the parts were pieced back together and it was seen that there would be parts interfering in space. The larger front casters caused most of these problems, and it necessitated the extension of the footrest outward, the moving back of the motors, and grinding down of the crossbar in the front of the chair which the actuator rests on. The footrest was extended outward 1 inch as described in section 2.4.2 in order to prevent interference as the casters rotated. The motors needed to be moved back due to the same reason, as described in section 2.4.2. The cross bar needed to be ground down on the edge because the caster would get stuck on it as it rotated around because of the increased width of it.
**Painting Procedure**

Parts in need of painting were sanded down with a hand sander and then touched up with sandpaper to remove the existing paint. The chassis, footrest mount, seat support bars, and casters were primed with Rustoleum white primer and then painted with Rustoleum metallic blue paint.

The footplate, seat plate, headrest attachment, and crossbar for the seat back were all primed and painted with Rustoleum black matte paint.

**Individual Part Testing**

To test the parts of the chair, the main QTRONIX controller was used in conjunction with the joystick, motors, batteries, and actuation controller. The main controller only operates when all subunits are connected including the actuation controller. The system was tested outside of assembly to see if they were working properly. When the system was not working after coming back from break it was realized that it was damaged and that it would need to replaced. After replacing the controller the electrical system worked again. The system needed to be tested again when the new steel hubs were created and this was done in the same way by connecting the motors, batteries, and actuation controller to the controller. The motors were successful in spinning at an acceptable speed and did not show any deflection in the tire during spinning. The actuator was also tested various times with the switch that came with it and was confirmed to work from the beginning. During the testing of the auto actuation circuit the cord that connected to the actuation controller broke and this caused the actuation switch to not work. However, once replaced, the actuator worked again.

**Full Unit Testing**

After the entire chair was designed, modified, and built, the entire system was tested. The chair operated with too much speed and acceleration when first operated, which would have been unsafe for Annalee. The chair's controller settings were changed and tested to find the optimal settings for operation. The settings were set with the use of the Qtronix programmer. It is a stand alone device that plugs into the joystick and provides a GUI for the user to adjust the controllers settings. The maximum speed and acceleration was the first thing to change. The settings were originally at 100% and this lead to unsafe driving. We changed the settings to 50% speed and
15% acceleration which provided the proper conditions for all terrain driving. In addition the turn settings were also changed so that the chair did not swing fast left and right. The turn and acceleration for turn was set to 20%. The actuation was also tested during the testing procedures along with the auto actuation setup. The chair was tilted up and down with a jack, to ensure that the chair was actuating to make sure the chair was always flat. However the wires connected to the switch controlling the voltage supplies crossed and therefore damaged the sensors. Two new sensors have been ordered and have been replaced. They will be soldered back into the circuit and tested. The wires have been heat-shrunk at the switch to ensure that the wires do not cross again.

The chair was operated on the grass and dirt-covered hill in front of the Castleman Building in the University of Connecticut Student Union quad, and it worked well with the test-subject (Alex of Team 2) harnessed in and wearing the seat belt. However, an issue was the maximum speed on the rougher terrain. The chair drove slightly above a walking pace (approximately 5 miles per hour), and thus it was re-programmed to have a higher maximum speed to meet specifications. The new maximum speed is about 8 miles per hour. It should not be too fast otherwise it will be dangerous for Annalee to operate it on hills.
3. Realistic Constraints

When building a product it is important to consider what factors can limit the production and usability of the item. Once these issues are recognized, methods to keep them under control must be created so that the product can operate as well as possible with the given limitations.

3.1 Health and Safety

Since this project was created because of the failure of her previous chair, the ability to keep the client upright over rough terrain is the foremost constraint of the chair. The chair should also support Annalee in a proper way and allow her to control the device comfortably. This device also aims to increase the client's quality of life while in the chair by improving her ability to get in and out of her chair unassisted. In addition to the safety of client, the safety of the workers is also very important. When modifying the base of the chair, a metal cutter will be needed to push the rear wheels further back on the chassis, which will have to be done with care. Also, wiring up the system will take caution when working near the deep cycle batteries. The client’s and the workers’ health and safety must come first and foremost while designing this device.

3.2 Sustainability

Sustainability constraints are another issue in designing this device. Since the client is a ten year old girl, she is continuing to grow, and a chair which can’t grow with her would be a waste of time and money. To counteract this, the seat will be replaceable so that a larger one may be installed at a later date. The motors will also be strong enough to transport her if her weight increases. The chair’s design overall will consist of as many easily acquired parts as possible so that in the event of a part’s failure, it can be easily found and replaced. The ability to recharge the batteries will also increase the sustainability of the project, since deep cycle batteries can last a long time if they are cared for properly. Lastly, since the chair will be operated outdoors, it must be as able as possible prevent dirt, mud, water, and rust from getting into the circuitry and interior which would reduce the chair’s lifespan.

3.3 Environmental

The actual environmental factors are key constraints to think about. The device should be applicable in extreme working temperature whether it is hot or cold. The device should also
be gentle on its operating surface since this will often be the client's yard, but also could be a park or field. In order to eliminate pollution the device will run off an electric motor rather than a gas motor.

3.4 Social

One social constraint is to make sure Annalee can enjoy outdoors activities, rather than creating a device that confines her as her current power chair does. Letting her explore the outdoors and be able to reach new areas would help to decrease the social gaps caused by her palsy. Another social constraint is to make the device as quiet as possible so to not disturb the surrounding rural neighborhood while it is in use.

3.5 Economic

Economic constraints are very important in designing the device. Power chairs which are on the market and have the title “all terrain” cost upwards of $16000[8]. Since this is a project sponsored by the National Science Foundation, a budget that high is impossible. Thankfully, access to used power chair components has been obtained, and most of the chair will be able to be acquired for free or for cost. Knowing the budget will still help to finally determine what materials can be purchased to modify the power chair from its current condition into one which can handle the outdoors. Since the budget cannot be exceeded, it will set the limitation on what can be used to improve the design.

3.6 Manufacturing

Manufacturing constraints will come into play when modifying the chassis. Accessibility to the internal components should as easy as possible even though the frame will be extended and reinforced. The drive wheels will also be moved back on the chassis, so a factor of safety must be considered to make sure that they are mounted properly and securely. The chair will weigh approximately 300 pounds, and will carry a passenger who currently weights 56lbs but will continue to grow. Assuming that the client will not grow past 200 pounds, this means the chair should be able to withstand over three times that weight (1500lbs) without failure. It is also important to make this product as reproducible as possible, which means the manufacturing should be well-recorded and easy to replicate.
3.7 Political and Ethical

The last major constraints are political and ethical. The manufacturing of a product that might be physically and/or mentally destructive for clients and workers is a key political constraint. Also, designing the device without considering safety and health of the client, workers and/or the public is a major ethical constraint.

3.8 Engineering Standards

The standards of power chair production will also be maintained throughout this project to keep it as similar to the client’s current chair as possible. Normal top speed for a power chair is 6.5 miles per hour which will be kept the same. The joystick control will also be kept so that there will be a pre-existing familiarity with the methods of operation. When reinforcing the frame, welds will be done through stick-welding or TIG welding to standard for aluminum [9].
4. Safety Issues

In designing this device safety is a major concern when the device is both active and not. The main safety issues arise from the mechanical components of the all-terrain power chair, since the purpose of designing this device is so that the rough and uneven terrain that comprises the client’s yard can be easily and safely accessed. Therefore, for the purpose of increasing the stability of the chair, the chassis will be well-modified in order to accommodate larger, wider wheels. With more ground contact governed by wider wheels, the left-right stability of the chair will be significantly increased. Furthermore, the chassis will be also be widened for the same purpose, and it will be reinforced to lower the chair's center of gravity.

The suspension also adds to the overall safety of the chair due to Annalee’s poor upper body strength. As she operates the device on the uneven, rocky property, the suspension must be able to absorb the forces generated by the ground on the chair. If this is not accomplished, the ride will be very rocky, and will be harmful to Annalee, as she will not be able to secure herself in the seat. Rather, the ride will be uncomfortable and her posture will not be secured.

It is also extremely important for the chassis to be built strong enough in order for it to bear the weight of the seat and the operator, as well as any external forces. If it is not properly tested to ensure quality, then it is possible for the chassis to break at any moment, whether during operation or not. If the chassis were to break during operation, the client would be in extreme danger. Thus, it is imperative the chassis is built properly and tested so it will definitely never break. The same issue applies to the seat, which must be secured together since each separate piece is modular. The wheels must also be secured, because if a wheel came off during operation, it would also pose a great threat to the operator’s safety.

The electrical component wire which carries the current will be protected so that it does not cause be any environmental hazard. Therefore all used and unused wires should be secured and electrically isolated from each other and any other possible connection. In order to be safe from chemical hazard the battery should be well sealed. The motor will be covered using heat insulator so that the heat coming from the motor will not be a fire hazard for the user during or after operating the device. The soldering used to connect wires also needs to be secure and protected, if a wire becomes loose or crossed during operation, it could cause for a short or malfunction of the power chair which would result in a lack of control or shut down. This would
leave the client stranded in the chair outside, which could become dangerous if there weren’t other people around or if the weather was poor.
5. Impact of Engineering Solutions

The goal of this project is to create a power chair which can bring our client outdoors without the worry of tipping the chair for a cost much lower than the current market standard. Since the project is to be created for only one client, its impact globally will be negligible. If, however, it was to be marketed and sold, it could have a profound impact economically, environmentally, socially, and globally. This chair will cost much less to produce than current power chairs [8] marketed for use outside on rough terrain. If mass-produced, there would stand to be a large market for a power chair with a low cost which can bring people who have disabilities closer to a normal standard of living.

The environmental impact of a marketed all terrain power chair could have both positive and negative effects. On the positive side, it would bring a new demographic of people to nature and the outdoors, which could increase the concern for wildlife preservation, national parks conservation, air quality control, and other environmental issues due to the new group of people being exposed to these issues directly. A negative impact would be due to the increased presence of power chairs in parks and other places. Increased travel by treads would cause wear on lawns, creating an eyesore. The power chair itself could also cause an eyesore to other people, but in order to make it more aesthetically pleasing, it would have to be redesigned which would increase the cost.

Another side effect of marketing low-cost all terrain power chairs would be increased exposure to society for its users. People would begin to see users where they never have before, on hiking trails, in hilly fields, and at parks. This would increase a person with disabilities’ exposure to the outside world, and would decrease the stigma that is present in society that people with disabilities are different in a negative way.

The global impact of an all terrain power chair would be the most difficult to imagine, but would function to increase awareness of cerebral palsy as well as other disabilities. It would also increase the ability for the disabled to travel, boosting tourism. This would all come back in the end to improve the quality of life for disabled people worldwide.
6. Life-Long Learning

Many new skills were learned in order to design and construct this project which will be carried with the group beyond college. The first thing learned in this project was about cerebral palsy. It was important to find out that a person with cerebral palsy often has full mental function, such as in Annalee’s case. The disability associated with cerebral palsy is a lack of muscular control, which creates the need for a power chair in the first place.

This project has also helped build teamwork and social skills. Since it is a group project, the work needed to be divided efficiently and quickly to meet deadlines. Communication with the client requires respect and intelligent interviewing to find out what the client desires and what they dislike about their current situation.

Learning the components of a normal power chair was essential to the project. The electric motor needed a gearbox to connect to the wheels, and proper gear ratios were required to receive enough torque. The amount of horsepower and rpm provided by the motor was also an important factor to consider when considering which motor to use.

The programming required to control the steering and actuator required the most learning for this project. They were controlled by a microcontroller programmed in C, which meant understanding of the underlying commands was needed, and the tilt sensor needed to be programmed to provide automated control to adjust the seat position.

In order to draft the design for the power chair, accurate 3D drawings needed to be created. Autodesk Inventor is a CAD program that allows for 3D modeling and simulation of mechanical components, and is a professional grade utility used in the work environment. Knowledge of how to operate this program will be very useful for projects requiring R&D.

Lastly, in order to modify the chassis, the machine shop needed to be used. This took knowledge of welding and metal cutting as well as the material properties of the metal used. Precise measurements, cuts, and welds needed to be applied in order to maintain the measure of safety required for a medical device and prevent an unsuspected failure during use.
7. Budget

7.1 Itemized Budget Breakdown

The budget for the construction of the all terrain power chair was initially set at $1300. The breakdown of previous and expected expenditures is listed below in Table 1. At a total cost of $1084.97, the ATPC-X42 was built for $215.03 under budget.

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quickie S626 Power Chair</td>
<td>$100</td>
</tr>
<tr>
<td>2 Power Sonic 12V Rechargeable Batteries</td>
<td>$150 ea.</td>
</tr>
<tr>
<td>Accessories (Seat, charger, footplate, harness)</td>
<td>$50</td>
</tr>
<tr>
<td>Circuit Elements (Accelerometer, PIC, crystal)</td>
<td>$38.15</td>
</tr>
<tr>
<td>Circuit Elements (Accelerometer #2, header)</td>
<td>$3186</td>
</tr>
<tr>
<td>Metal Stock (rectangular bar and plate)</td>
<td>$99.23</td>
</tr>
<tr>
<td>Front and Rear Tires and Wheels</td>
<td>$140.67</td>
</tr>
<tr>
<td>New Accelerometers</td>
<td>$64.19</td>
</tr>
<tr>
<td>Machine Shop Parts and Labor</td>
<td>$175</td>
</tr>
<tr>
<td>Seat cushion</td>
<td>$45</td>
</tr>
<tr>
<td>Side Restraints</td>
<td>$10</td>
</tr>
<tr>
<td>Miscellaneous Supplies (screws, nuts, bolts, paint, grease)</td>
<td>$20.87</td>
</tr>
<tr>
<td>Invisible Hinge for Joystick Rotation Prototype</td>
<td>$10</td>
</tr>
<tr>
<td><strong>Free Items</strong></td>
<td></td>
</tr>
<tr>
<td>Armrests</td>
<td></td>
</tr>
<tr>
<td>Actuator</td>
<td></td>
</tr>
<tr>
<td>Joystick</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$1084.97</strong></td>
</tr>
<tr>
<td><strong>Total Allotted</strong></td>
<td><strong>$1300</strong></td>
</tr>
</tbody>
</table>

Table 1: Itemized Budget
8. Team Members Contributions to the Project

8.1 Niaz Khan (Bioinstrumentation)

Niaz has been focusing on the electrical components of the design, mainly on the construction and integration of the tilt sensor. Niaz was able to get the circuit installed and working for the automatic actuation of the chair. He also was able to help Selome in writing the code necessary for the actuation circuit in C. Niaz also provided help in mechanical fabrication. He was able to fabricate the wider casters for the larger tires that were purchased and also designed and fabricated a mount extension for the motors due to a constraint issue that came up. He was also been responsible for contacting Don Hoerman at the NEAT Marketplace in Hartford, CT, who has been an invaluable asset for acquiring the parts for the chair, visiting NEAT multiple times during the progress of the project. He also used the programmer to establish proper controller settings for the chair.

8.2 Selome Mandefro (Bioinformatics)

Selome was the main software designer for the project, she wrote the code for the seat auto-actuation using embedded C programming language with the help of Niaz. She also took part in the fabrication process of the seat base plate, casters, caster spacer, extending the seat back crossbar and motor mount. Selome was responsible for ordering the tires and wheels as well. In addition to that she was responsible for purchasing the seat cushion. Finally she took part in cleaning and painting and helping to assemble the wheelchair.

8.3 Alex Mann (Biochemical)

Alex was responsible for most of the fabrication involved in the construction of the chair. He built the footrest, the seat spacers, drilled the seat plate, made the headrest mount, built the joystick hinge, made the wheel hubs, and created the mounts to attach the seat back to the frame. He was also responsible for the design of these parts, though often with help from Vikram. Alex also sanded the parts before they were painted, and put the chair back together when it was completed. He was the main tester for the chair as well, and helped to program it for optimal settings using the Quickie programmer.

8.4 Vikram Shenoy (Biomaterials)

Vikram has worked primarily on the design of the ATPC-X42, and he has also worked on part fabrication, painting, and chair assembly. He has modeled the chair in CAD using Autodesk Inventor 2009, and has modeled modifications that will be done to the chair as well. The new
parts he created in Autodesk included the footrest, casters, one-inch spacers, seat plate, motor mount extensions, wheel hubs, headrest attachment, seat attachments, and joystick hinge. Vikram has also performed stress analyses on certain chair components. After helping fabricate the joystick hinge, footrest, back mount, and wheel hubs, he painted the casters, footrest, chassis, and seat mount.
9. Conclusion

The ATPC-X42 all-terrain power chair will provide Annalee Hughes with a safer means to access her back yard, which has many hills and rocks. By creating a power chair that allows her to travel on any terrain, whether it be hills, rocks, or uneven pavement, she will be able to enjoy the outdoors and various features of her property. She needs a way to access the family's barn and pond, but her current power chair is too unstable for her to safely reach those places. She has already tipped over in the current chair, further expressing the need for the all-terrain power chair.

The new chair will implement standard safety features such as a five point safety harness and side constraints as well as a tilt sensor. The harness and constraints will keep her stable and help maintain her posture in the seat. The tilt sensor will provide an audible warning when the device approaches slopes that are too steep for safe operation or is on uneven ground where it is at risk of tipping on its side. It will also be able to automatically adjust the seat level so that Annalee remains upright and is not forced to lean forward or backwards in her chair due to the grade of the hill.

Thus, an all-terrain power chair with all of these features must be built for Annalee in order to ensure her safety as she enjoys the outdoors. It would provide her with an opportunity to explore her large yard by herself, as her condition limits her from doing so already. Nobody should have to feel constrained, and the all-terrain power chair will allow Annalee to feel adventurous and independent.
10. References


11. Acknowledgements

We would like to give special thanks to the following people for their help in the design of this project:

Dr. John Enderle – UConn BME
James Paolino – UConn BME
Dave Kaputa – UConn BME
Don Hoerman – NEAT Marketplace
Kerrie Wenzler – UConn BME
Jen Desrosiers – UConn BME
Annalee Hughes, Susan Lucek, John Hughes
Mary Ann Tuttle
Rick Way
Serge, Pete and Rich – UConn Machine Shop
12. Appendix

12.1 Specifications

Physical:

Type of Material: aluminum chassis
aluminum and steel seat mount
rubber tires
plastic and foam seat cushions

Mechanical:

Size: 36” x 28” x 45” (L x W x H)
Weight: TBD
Speed: 8 mph
Power: TBD
Turning Radius: rotate in place

Electrical:

Maximum Input Voltage: 24V (2 12V batteries)
Maximum Input Current: 8A
Maximum Output Voltage: TBD
Maximum Output Current: TBD

Environmental:

Storage Temperature: -4ºF to 140ºF
Operating Temperature: 0ºF to 140ºF
Operating Environment: indoors/outdoors, any terrain

Software:

User Interfaces: joystick, kill switch
Hardware Interfaces: tilt/slope meter
Features: direction control, warning when approaching steep slopes, seat automatically actuates with respect to slope
Safety:

Constraints: five-point harness, 45º seat belt,

Other: tilt meter with alarm, auto-actuation of seat

Maintenance:

Battery recharging
Battery replacement
Cleaning
Greasing of motors
12.2 Stress Analysis Pictures

Chassis – 50 lb shear

Chassis – 100 lb shear
Chassis – 200 lb load

Chassis – 100 lb load
Footplate – 2 x 50 lb load

Seat Base Plate – 100 lb load
Front Casters – 100 lb load

Front Casters – 100 lb shear
12.3 Component Data Sheets and Specifications
Aluminum 6061-T6 Data Sheet

Subcategory: 6000 Series Aluminum Alloy; Aluminum Alloy; Metal; Nonferrous Metal

Close Analogs:

Composition Notes:
Aluminum content reported is calculated as remainder. Composition information provided by the Aluminum Association and is not for design.

<table>
<thead>
<tr>
<th>Component</th>
<th>Wt. %</th>
<th>Component</th>
<th>Wt. %</th>
<th>Component</th>
<th>Wt. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>95.8 - 98.6</td>
<td>Mg</td>
<td>0.8 - 1.2</td>
<td>Si</td>
<td>0.4 - 0.8</td>
</tr>
<tr>
<td>Cr</td>
<td>0.04 - 0.35</td>
<td>Mn</td>
<td>Max 0.15</td>
<td>Ti</td>
<td>Max 0.15</td>
</tr>
<tr>
<td>Cu</td>
<td>0.15 - 0.4</td>
<td>Other, each</td>
<td>Max 0.05</td>
<td>Zn</td>
<td>Max 0.25</td>
</tr>
<tr>
<td>Fe</td>
<td>Max 0.7</td>
<td>Other, total</td>
<td>Max 0.15</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Material Notes:
Information provided by Alcoa, Starrett and the references. General 6061 characteristics and uses: Excellent joining characteristics, good acceptance of applied coatings. Combines relatively high strength, good workability, and high resistance to corrosion; widely available. The T8 and T9 tempers offer better chipping characteristics over the T6 temper.

Applications: Aircraft fittings, camera lens mounts, couplings, marines fittings and hardware, electrical fittings and connectors, decorative or misc. hardware, hinge pins, magneto parts, brake pistons, hydraulic pistons, appliance fittings, valves and valve parts; bike frames.

Data points with the AA note have been provided by the Aluminum Association, Inc. and are NOT FOR DESIGN.

Physical Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Metric</th>
<th>English</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>2.7 g/cc</td>
<td>0.0975 lb/in³</td>
<td>AA; Typical</td>
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</table>

Mechanical Properties

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<th>Property</th>
<th>Metric</th>
<th>English</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness, Brinell</td>
<td>95</td>
<td>95</td>
<td>AA; Typical; 500 g load; 10 mm ball</td>
</tr>
<tr>
<td>Hardness, Knoop</td>
<td>120</td>
<td>120</td>
<td>Converted from Brinell Hardness Value</td>
</tr>
<tr>
<td>Hardness, Rockwell A</td>
<td>40</td>
<td>40</td>
<td>Converted from Brinell Hardness Value</td>
</tr>
<tr>
<td>Hardness, Rockwell B</td>
<td>60</td>
<td>60</td>
<td>Converted from Brinell Hardness Value</td>
</tr>
<tr>
<td>Hardness, Vickers</td>
<td>107</td>
<td>107</td>
<td>Converted from Brinell Hardness Value</td>
</tr>
<tr>
<td>Ultimate Tensile Strength</td>
<td>310 MPa</td>
<td>45000 psi</td>
<td>AA; Typical</td>
</tr>
<tr>
<td>Tensile Yield Strength</td>
<td>276 MPa</td>
<td>40000 psi</td>
<td>AA; Typical</td>
</tr>
<tr>
<td>Elongation at Break</td>
<td>12 %</td>
<td>12 %</td>
<td>AA; Typical; 1/16 in. (1.6 mm) Thickness</td>
</tr>
<tr>
<td>PROPERTY</td>
<td>VALUE</td>
<td>UNITS</td>
<td>NOTES</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Elongation at Break</td>
<td>17 %</td>
<td>17 %</td>
<td>AA; Typical; 1/2 in. (12.7 mm) Diameter</td>
</tr>
<tr>
<td>Modulus of Elasticity</td>
<td>68.9 GPa</td>
<td>10000 ksi</td>
<td>AA; Typical; Average of tension and compression. Compression modulus is about 2% greater than tensile modulus.</td>
</tr>
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<td>Notched Tensile Strength</td>
<td>324 MPa</td>
<td>47000 psi</td>
<td>2.5 cm width x 0.16 cm thick side-notched specimen, $K_t = 17$.</td>
</tr>
<tr>
<td>Ultimate Bearing Strength</td>
<td>607 MPa</td>
<td>88000 psi</td>
<td>Edge distance/pin diameter = 2.0</td>
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<tr>
<td>Bearing Yield Strength</td>
<td>386 MPa</td>
<td>56000 psi</td>
<td>Edge distance/pin diameter = 2.0</td>
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<td>Poisson's Ratio</td>
<td>0.33</td>
<td>0.33</td>
<td>Estimated from trends in similar Al alloys.</td>
</tr>
<tr>
<td>Fatigue Strength</td>
<td>96.5 MPa</td>
<td>14000 psi</td>
<td>AA; 500,000,000 cycles completely reversed stress; RR Moore machine/specimen</td>
</tr>
<tr>
<td>Fracture Toughness</td>
<td>29 MPa-m$^{1/2}$</td>
<td>26.4 ksi-in$^{1/2}$</td>
<td>$K_{IC}$; TL orientation.</td>
</tr>
<tr>
<td>Machinability</td>
<td>50 %</td>
<td>50 %</td>
<td>0-100 Scale of Aluminum Alloys</td>
</tr>
<tr>
<td>Shear Modulus</td>
<td>26 GPa</td>
<td>3770 ksi</td>
<td>Estimated from similar Al alloys.</td>
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<tr>
<td>Shear Strength</td>
<td>207 MPa</td>
<td>30000 psi</td>
<td>AA; Typical</td>
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**Electrical Properties**
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<tr>
<th>Property</th>
<th>Value</th>
<th>Units</th>
<th>Notes</th>
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</thead>
<tbody>
<tr>
<td>Electrical Resistivity</td>
<td>3.99e-006 ohm-cm</td>
<td>3.99e-006 ohm-cm</td>
<td>AA; Typical at 68°F</td>
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**Thermal Properties**
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<th>Property</th>
<th>Value</th>
<th>Units</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTE, linear 68°F</td>
<td>23.6 µm/m-°C</td>
<td>13.1 µin/in-°F</td>
<td>AA; Typical; Average over 68-212°F range.</td>
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<tr>
<td>CTE, linear 250°C</td>
<td>25.2 µm/m-°C</td>
<td>14 µin/in-°F</td>
<td>Estimated from trends in similar Al alloys. 20-300°C.</td>
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<tr>
<td>Specific Heat Capacity</td>
<td>0.896 J/g-°C</td>
<td>0.214 BTU/lb-°F</td>
<td></td>
</tr>
<tr>
<td>Thermal Conductivity</td>
<td>167 W/m-K</td>
<td>1160 BTU-in/hr-ft²-°F</td>
<td>AA; Typical at 77°F</td>
</tr>
<tr>
<td>Melting Point</td>
<td>582 - 652 °C</td>
<td>1080 - 1205 °F</td>
<td>AA; Typical range based on typical composition for wrought products 1/4 inch thickness or greater; Eutectic melting can be completely eliminated by homogenization.</td>
</tr>
<tr>
<td>Solidus</td>
<td>582 °C</td>
<td>1080 °F</td>
<td>AA; Typical</td>
</tr>
<tr>
<td>Liquidus</td>
<td>652 °C</td>
<td>1205 °F</td>
<td>AA; Typical</td>
</tr>
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</table>

**Processing Properties**
<table>
<thead>
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<tr>
<td>Solution Temperature</td>
<td>529 °C</td>
<td>985 °F</td>
<td></td>
</tr>
<tr>
<td>Aging Temperature</td>
<td>160 °C</td>
<td>320 °F</td>
<td>Rolled or drawn products; hold at temperature for 18 hr</td>
</tr>
<tr>
<td>Aging Temperature</td>
<td>177 °C</td>
<td>350 °F</td>
<td>Extrusions or forgings; hold at temperature for 8 hr</td>
</tr>
</tbody>
</table>

Steel Data Sheet

Stainless Steel Grade 316 / 1.4401

Stainless steel types 1.4401 and 1.4404 are also known as grades 316 and 316L respectively. Grade 316 is an austenitic grade second only to 304 in commercial importance.

316 stainless steel contains an addition of molybdenum that gives it improved corrosion resistance. This is particularly apparent for pitting and crevice corrosion in chloride environments.

316L, the low carbon version of 316 stainless steel, is immune to grain boundary carbide precipitation (sensitisation). This makes it suited to use in heavy gauge (over about 6mm) welded components.

For elevated temperature applications the high carbon variant, 316H stainless steel and the stabilised grade 316Ti stainless steel should be employed.

The austenitic structure of 316 stainless steel gives excellent toughness, even at cryogenic temperatures.

Property data given in this document is typical for flat rolled products covered by ASTM A240/A240M. ASTM, EN or other standards may cover products sold by Aalco. It is reasonable to expect specifications in these standards to be similar but not necessarily identical to those given in this datasheet.

Applications

Initially developed for use in paper mills 316 stainless steel is now typically used in:

- Food processing equipment
- Brewery equipment
- Chemical and petrochemical equipment
- Laboratory benches & equipment
- Coastal architectural paneling
- Coastal balustrading
- Boat fittings
- Chemical transportation containers
- Heat exchangers
- Mining screens
- Nuts and bolts
- Springs
- Medical implants

Typical Chemical Composition

<table>
<thead>
<tr>
<th>Grade</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
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<tbody>
<tr>
<td>316</td>
<td>0.06max</td>
<td>0.3max</td>
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<td>0.03</td>
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<tr>
<td>316L</td>
<td>0.02</td>
<td>2.0</td>
<td>0.75</td>
<td>0.045</td>
<td>0.03</td>
</tr>
<tr>
<td>316H</td>
<td>0.02</td>
<td>2.0</td>
<td>0.75</td>
<td>0.045</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Typical Mechanical Properties

<table>
<thead>
<tr>
<th>Grade</th>
<th>Tensile Strength (MPa)</th>
<th>Compression Strength (MPa)</th>
<th>Proof Stress 0.2% (MPa)</th>
<th>Elongation A5 (%)</th>
<th>Hardness Rockwell B</th>
</tr>
</thead>
<tbody>
<tr>
<td>316</td>
<td>515</td>
<td>170</td>
<td>205</td>
<td>40</td>
<td>95</td>
</tr>
<tr>
<td>316L</td>
<td>485</td>
<td>170</td>
<td>170</td>
<td>40</td>
<td>95</td>
</tr>
<tr>
<td>316H</td>
<td>515</td>
<td>170</td>
<td>205</td>
<td>40</td>
<td>95</td>
</tr>
</tbody>
</table>

Typical Physical Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>8.00 g/cm³</td>
</tr>
<tr>
<td>Melting Point</td>
<td>1375–1400°C</td>
</tr>
<tr>
<td>Modulus of Elasticity</td>
<td>193 GPa</td>
</tr>
<tr>
<td>Electrical Resistivity</td>
<td>0.074×10⁻⁸ Ω·m</td>
</tr>
<tr>
<td>Thermal Conductivity</td>
<td>16.3 W/m.K at 100°C</td>
</tr>
<tr>
<td>Thermal Expansion</td>
<td>15.9×10⁻⁶ /K at 100°C</td>
</tr>
</tbody>
</table>
Alloy Designations

Stainless steel 316 also corresponds to the following standard designations and specifications:

<table>
<thead>
<tr>
<th>Euronorm</th>
<th>UNS</th>
<th>BS</th>
<th>En</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4401</td>
<td>S31600</td>
<td>316S31</td>
<td>58H</td>
<td>316</td>
</tr>
<tr>
<td>1.4404</td>
<td>S31603</td>
<td>316S11</td>
<td>-</td>
<td>316L</td>
</tr>
<tr>
<td></td>
<td>S31609</td>
<td>316S51</td>
<td>-</td>
<td>316H</td>
</tr>
<tr>
<td>1.4571</td>
<td>-</td>
<td>320S31</td>
<td>-</td>
<td>316Ti</td>
</tr>
</tbody>
</table>

Corrosion Resistance

Grade 316 has excellent corrosion resistance when exposed to a range of corrosive environments and media. It is usually regarded as “marine grade” stainless steel but is not resistant to warm sea water. Warm chloride environments can cause pitting and crevice corrosion. Grade 316 is also subject to stress corrosion cracking above around 60°C.

Heat Resistance

316 has good resistance to oxidation in intermittent service to 870°C and in continuous service to 925°C. However, continuous use at 425-860°C is not recommended if corrosion resistance in water is required. In this instance 316L is recommended due to its resistance to carbide precipitation.

Where high strength is required at temperatures above 500°C, grade 316H is recommended.

Fabrication

Fabrication of all stainless steels should be done only with tools dedicated to stainless steel materials. Tooling and work surfaces must be thoroughly cleaned before use. These precautions are necessary to avoid cross contamination of stainless steel by easily corroded metals that may discolour the surface of the fabricated product.

Cold Working

Grade 316 is readily brake or roll formed into a variety of parts. It is also suited to stamping, heading and drawing but post work annealing is recommended to relieve internal stresses.

Cold working will increase both strength and hardiness of 316 stainless steel.

Hot Working

All common hot working processes can be performed on 316 stainless steel. Hot working should be avoided below 927°C. The ideal temperature range for hot working is 1149-1260°C. Post-work annealing is recommended to ensure optimum corrosion resistance.

Heat Treatment

316 stainless steel cannot be hardened by heat treatment.

Solution treatment or annealing can be done by rapid cooling after heating to 1010-1120°C.

Machinability

316 stainless steel has good machinability. Machining can be enhanced using the following rules:

- Cutting edges must be kept sharp. Dull edges cause excess work hardening.
- Cuts should be light but deep enough to prevent work hardening by riding on the surface of the material.
- Chip breakers should be employed to assist in ensuring swarf remains clear of the work.
- Low thermal conductivity of austenitic alloys results in heat concentrating at the cutting edges. This means coolants and lubricants are necessary and must be used in large quantities.
### SPECIFICATIONS

$T_x = 25^\circ C$, $V_\text{IL} = 3$ V, $C_x = C_y = C_z = 0.1$ $\mu$F, acceleration = 0 g, unless otherwise noted. All minimum and maximum specifications are guaranteed. Typical specifications are not guaranteed.

#### Table 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>SENSOR INPUT</td>
<td>Each axis</td>
<td>±3</td>
<td>±3.6</td>
<td></td>
<td>g</td>
</tr>
<tr>
<td>Measurement Range</td>
<td></td>
<td>±0.3</td>
<td></td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>Nonlinearity</td>
<td>% of full scale</td>
<td>±1</td>
<td></td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>Package Alignment Error</td>
<td></td>
<td>±0.1</td>
<td></td>
<td></td>
<td>Degrees</td>
</tr>
<tr>
<td>Interaxis Alignment Error</td>
<td></td>
<td>±1</td>
<td></td>
<td></td>
<td>Degrees</td>
</tr>
<tr>
<td>Cross Axis Sensitivity$^1$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>SENSITIVITY (RATIO-METRIC)$^2$</td>
<td>Each axis</td>
<td>270</td>
<td>300</td>
<td>330</td>
<td>mV/g</td>
</tr>
<tr>
<td>Sensitivity at $X_{\text{IN}}, Y_{\text{IN}}, Z_{\text{IN}}$</td>
<td>$V_\text{IL} = 3$ V</td>
<td></td>
<td></td>
<td></td>
<td>%/°C</td>
</tr>
<tr>
<td>Sensitivity Change Due to Temperature$^3$</td>
<td>$V_\text{IL} = 3$ V</td>
<td>±0.015</td>
<td></td>
<td></td>
<td>%/°C</td>
</tr>
<tr>
<td>ZERO g BIAS LEVEL (RATIO-METRIC)</td>
<td>Each axis</td>
<td>1.2</td>
<td>1.5</td>
<td>1.8</td>
<td>V</td>
</tr>
<tr>
<td>0 g Voltage at $X_{\text{OUT}}, Y_{\text{OUT}}, Z_{\text{OUT}}$</td>
<td>$V_\text{IL} = 3$ V</td>
<td></td>
<td></td>
<td></td>
<td>mg/°C</td>
</tr>
<tr>
<td>0 g Offset vs. Temperature</td>
<td></td>
<td>±1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOISE PERFORMANCE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Noise Density $X_{\text{IN}}$</td>
<td>280</td>
<td></td>
<td></td>
<td></td>
<td>μg/Hz m/s</td>
</tr>
<tr>
<td>Noise Density $Y_{\text{IN}}$</td>
<td>350</td>
<td></td>
<td></td>
<td></td>
<td>μg/Hz m/s</td>
</tr>
<tr>
<td>FREQUENCY RESPONSE$^4$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bandwidth $X_{\text{OUT}}, Y_{\text{OUT}}$</td>
<td>No external filter</td>
<td>1600</td>
<td></td>
<td></td>
<td>Hz</td>
</tr>
<tr>
<td>Bandwidth $Z_{\text{OUT}}$</td>
<td>No external filter</td>
<td>550</td>
<td></td>
<td></td>
<td>Hz</td>
</tr>
<tr>
<td>$R_{\text{OUT}}$ Tolerance</td>
<td></td>
<td>52 ± 15%</td>
<td></td>
<td></td>
<td>kHz</td>
</tr>
<tr>
<td>Sensor Resonant Frequency</td>
<td></td>
<td>5.5</td>
<td></td>
<td></td>
<td>kHz</td>
</tr>
<tr>
<td>SELF TEST$^5$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Logic Input Low</td>
<td></td>
<td>+0.6</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>Logic Input High</td>
<td></td>
<td>+2.4</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>ST Actuation Current</td>
<td></td>
<td>+60</td>
<td></td>
<td></td>
<td>μA</td>
</tr>
<tr>
<td>Output Change at $X_{\text{OUT}}$</td>
<td>Self test 0 to 1</td>
<td>−150</td>
<td></td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>Output Change at $Y_{\text{OUT}}$</td>
<td>Self test 0 to 1</td>
<td>+150</td>
<td></td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>Output Change at $Z_{\text{OUT}}$</td>
<td>Self test 0 to 1</td>
<td>−60</td>
<td></td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>OUTPUT AMPLIFIER</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output Swing Low</td>
<td>No load</td>
<td>0.1</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>Output Swing High</td>
<td>No load</td>
<td>2.8</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>POWER SUPPLY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating Voltage Range</td>
<td>$V_\text{IL} = 3$ V</td>
<td>1.8</td>
<td>3.6</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>Supply Current</td>
<td>$V_\text{IL} = 3$ V</td>
<td>320</td>
<td></td>
<td></td>
<td>μA</td>
</tr>
<tr>
<td>Turn-On Time$^7$</td>
<td>No external filter</td>
<td>1</td>
<td></td>
<td></td>
<td>ms</td>
</tr>
<tr>
<td>TEMPERATURE</td>
<td></td>
<td>−25</td>
<td></td>
<td>+70</td>
<td>°C</td>
</tr>
</tbody>
</table>

$^1$ Defined as coupling between any two axes.

$^2$ Defined as the output change from ambient-to-maximum temperature or ambient-to-minimum temperature.

$^3$ Actual frequency response controlled by user-supplied external filter capacitors ($C_x$, $C_y$, $C_z$).

$^4$ Bandwidth with external capacitors = 1/2 x $n$ x 33.3 kΩ x $C_x$. For $C_x = 0.003$ μF, bandwidth = 1.6 kHz. For $C_x = 0.01$ μF, bandwidth = 0.5 Hz.

$^5$ Self-test response changes cubically with $V_\text{IL}$.

$^7$ Turn-on time is dependent on $C_x$, $C_y$, $C_z$ and is approximately 160 x $C_x$ or $C_y$ or $C_z + 1$ ms, where $C_x$, $C_y$, $C_z$ are in μF.
### ADXL330

#### Absolute Maximum Ratings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration (Any Axis, Unpowered)</td>
<td>10,000 g</td>
</tr>
<tr>
<td>Acceleration (Any Axis, Powered)</td>
<td>10,000 g</td>
</tr>
<tr>
<td>$V_{DD}$</td>
<td>$-0.3 \text{ V to } +7.0 \text{ V}$</td>
</tr>
<tr>
<td>All Other Pins</td>
<td>(COM - 0.3 V) to (V$+$ + 0.3 V)</td>
</tr>
<tr>
<td>Output Short-Circuit Duration (Any Pin to Common)</td>
<td>Indefinite</td>
</tr>
<tr>
<td>Temperature Range (Powered)</td>
<td>$-55^\circ \text{C to } +125^\circ \text{C}$</td>
</tr>
<tr>
<td>Temperature Range (Storage)</td>
<td>$-65^\circ \text{C to } +150^\circ \text{C}$</td>
</tr>
</tbody>
</table>

Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

#### Table 3. Recommended Soldering Profile

<table>
<thead>
<tr>
<th>Profile Feature</th>
<th>Sn63/Pb37</th>
<th>Pb-Free</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Ramp Rate ($T_i$ to $T_f$)</td>
<td>3°C/s max</td>
<td>3°C/s max</td>
</tr>
<tr>
<td>Preheat</td>
<td>100°C</td>
<td>150°C</td>
</tr>
<tr>
<td>Minimum Temperature ($T_{\text{MIN}}$)</td>
<td>150°C</td>
<td>200°C</td>
</tr>
<tr>
<td>Maximum Temperature ($T_{\text{MAX}}$)</td>
<td>60 s to 120 s</td>
<td>60 s to 180 s</td>
</tr>
<tr>
<td>Time ($T_{\text{MIN}}$ to $T_{\text{MAX}}$)</td>
<td>$T_i$</td>
<td>$T_i$</td>
</tr>
<tr>
<td>$T_{\text{MAX}}$ to $T_i$</td>
<td>3°C/s max</td>
<td>3°C/s max</td>
</tr>
<tr>
<td>Ramp-Up Rate</td>
<td>183°C</td>
<td>217°C</td>
</tr>
<tr>
<td>Time Maintained Above Liquidus ($T_i$)</td>
<td>60 s to 150 s</td>
<td>60 s to 150 s</td>
</tr>
<tr>
<td>Liquidus Temperature ($T_i$)</td>
<td>240°C + 0°C to -5°C</td>
<td>260°C + 0°C to -5°C</td>
</tr>
<tr>
<td>Time within 5°C of Actual Peak Temperature ($t_f$)</td>
<td>10 s to 30 s</td>
<td>20 s to 40 s</td>
</tr>
<tr>
<td>Ramp-Down Rate</td>
<td>6°C/s max</td>
<td>6°C/s max</td>
</tr>
<tr>
<td>Time 25°C to Peak Temperature</td>
<td>6 minutes max</td>
<td>8 minutes max</td>
</tr>
</tbody>
</table>

#### ESD Caution

ESD (electrostatic discharge) sensitive device. Electrostatic charges as high as 4000 V readily accumulate on the human body and test equipment and can discharge without detection. Although this product features proprietary ESD protection circuitry, permanent damage may occur on devices subjected to high energy electrostatic discharges. Therefore, proper ESD precautions are recommended to avoid performance degradation or loss of functionality.
PIN CONFIGURATION AND FUNCTION DESCRIPTIONS

Figure 3. Pin Configuration

Table 4. Pin Function Descriptions

<table>
<thead>
<tr>
<th>Pin No.</th>
<th>Mnemonic</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NC</td>
<td>No Connect</td>
</tr>
<tr>
<td>2</td>
<td>ST</td>
<td>Self Test</td>
</tr>
<tr>
<td>3</td>
<td>COM</td>
<td>Common</td>
</tr>
<tr>
<td>4</td>
<td>NC</td>
<td>No Connect</td>
</tr>
<tr>
<td>5</td>
<td>COM</td>
<td>Common</td>
</tr>
<tr>
<td>6</td>
<td>COM</td>
<td>Common</td>
</tr>
<tr>
<td>7</td>
<td>COM</td>
<td>Common</td>
</tr>
<tr>
<td>8</td>
<td>ZOUT</td>
<td>Z Channel Output</td>
</tr>
<tr>
<td>9</td>
<td>NC</td>
<td>No Connect</td>
</tr>
<tr>
<td>10</td>
<td>YOUT</td>
<td>Y Channel Output</td>
</tr>
<tr>
<td>11</td>
<td>NC</td>
<td>No Connect</td>
</tr>
<tr>
<td>12</td>
<td>XOUT</td>
<td>X Channel Output</td>
</tr>
<tr>
<td>13</td>
<td>NC</td>
<td>No Connect</td>
</tr>
<tr>
<td>14</td>
<td>Vdd</td>
<td>Supply Voltage (1.8 V to 3.6 V)</td>
</tr>
<tr>
<td>15</td>
<td>Vss</td>
<td>Supply Voltage (1.8 V to 3.6 V)</td>
</tr>
<tr>
<td>16</td>
<td>NC</td>
<td>No Connect</td>
</tr>
</tbody>
</table>
PIC16F874 Microcontroller Data Sheet

PIC16F87X
28/40-Pin 8-Bit CMOS FLASH Microcontrollers

Devices Included in this Data Sheet:
- PIC16F873
- PIC16F876
- PIC16F874
- PIC16F877

Microcontroller Core Features:
- High-performance RISC CPU
- Only 35 single word instructions to learn
- All single cycle instructions except for program branches which are two cycles
- Operating speed: DC - 20 MHz clock input
DC - 200 ns instruction cycle
- Up to 6K x 14 words of FLASH Program memory
Up to 395 x 8 bytes of Data Memory (RAM)
Up to 208 x 8 bytes of EEPROM Data Memory
- Pinout compatible to the PIC16C73B/74B/73/77
- Interrupt capability (up to 14 sources)
- Eight level deep hardware stack
- Direct, indirect and relative addressing modes
- Power-on Reset (POR)
- Power-up Timer (PWRT) and Oscillator Start-up Timer (OST)
- Watchdog Timer (WDT) with its own on-chip RC oscillator for reliable operation
- Programmable code protection
- Power saving SLEEP mode
- Selectable oscillator options
- Low power, high speed CMOS FLASH/EEPROM technology
- Fully static design
- In-Circuit Serial Programming™ (ICSP) via two pins
- Single 5V In-Circuit Serial Programming capability
- In-Circuit Debugging via two pins
- Processor read/write access to program memory
- Wide operating voltage range: 2.0V to 5.5V
- High Sink/Source current: 25 mA
- Commercial, Industrial and Extended temperature ranges
- Low-power consumption:
  - 0.2 µA typical @ 3V, 4 MHz
  - 20 µA typical @ 5V, 32 kHz
  - < 1 µA typical standby current

Peripheral Features:
- Timer0: 8-bit timer/clock with 8-bit prescaler
  - Timer1: 16-bit timer/clock with prescaler,
    can be configured during SLEEP via external crystal/clock
- Timer2: 8-bit timer/clock with 8-bit period register, prescaler and postscaler
- Two Capture, Compare, PWM modules
  - Capture is 16-bit, max. resolution is 12.5 ns
  - Compare is 16-bit, max. resolution is 200 ns
  - PWM max. resolution is 10-bit
- 10-bit multi-channel Analog-to-Digital converter
- Synchronous Serial Port (SSP) with SPI™ (Master mode) and I²C (Master/Slave)
- Universal Synchronous/Asynchronous Receiver Transmitter (USART/GCI) with 8-bit address detection
- Parallel Slave Port (PSP); 8-bits wide, with
  external RD, WR and CS controls (PD4-4 pin only)
- Brown-out detection circuitry for
  Brown-out Reset (BOR)
### PIC16F87X

#### Key Features

<table>
<thead>
<tr>
<th>Feature</th>
<th>PIC16F873</th>
<th>PIC16F874</th>
<th>PIC16F876</th>
<th>PIC16F877</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Frequency</td>
<td>DC - 20 MHz</td>
<td>DC - 20 MHz</td>
<td>DC - 20 MHz</td>
<td>DC - 20 MHz</td>
</tr>
<tr>
<td>Resets (and Delays)</td>
<td>POR, BOR (PWRT, OST)</td>
<td>POR, BOR (PWRT, OST)</td>
<td>POR, BOR (PWRT, OST)</td>
<td>POR, BOR (PWRT, OST)</td>
</tr>
<tr>
<td>Flash Program Memory (14-bit words)</td>
<td>4K</td>
<td>4K</td>
<td>8K</td>
<td>8K</td>
</tr>
<tr>
<td>Data Memory (bytes)</td>
<td>102</td>
<td>102</td>
<td>368</td>
<td>368</td>
</tr>
<tr>
<td>EEPROM Data Memory</td>
<td>128</td>
<td>128</td>
<td>256</td>
<td>256</td>
</tr>
<tr>
<td>Interrupts</td>
<td>13</td>
<td>14</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>Timers</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Capture/Compare/FWM Modules</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Serial Communications</td>
<td>MSSP, USART</td>
<td>MSSP, USART</td>
<td>MSSP, USART</td>
<td>MSSP, USART</td>
</tr>
<tr>
<td>Parallel Communications</td>
<td>PSP</td>
<td>---</td>
<td>PSP</td>
<td>---</td>
</tr>
<tr>
<td>10-bit Analog-to-Digital Module</td>
<td>5 input channels</td>
<td>8 input channels</td>
<td>5 input channels</td>
<td>8 input channels</td>
</tr>
<tr>
<td>Instruction Set</td>
<td>35 instructions</td>
<td>35 instructions</td>
<td>35 instructions</td>
<td>35 instructions</td>
</tr>
</tbody>
</table>
PowerSonic Batteries Data Sheet

Features

- Absorbent Glass Mat (AGM) technology for superior performance
- Valve regulated, spill proof construction allows safe operation in any position
- Power/volume ratio yielding unrivaled energy density
- Rugged impact resistant ABS case and cover (UL94-HB)
- Integrated ABS carrying handles for ease of movement
- U.L. recognized under file number MH 20845

Performance Specifications

<table>
<thead>
<tr>
<th>Performance Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Voltage</td>
<td>12 volts (6 cells)</td>
</tr>
<tr>
<td>Nominal Capacity</td>
<td>75.0 AH</td>
</tr>
<tr>
<td>20-hr. (3.75A to 10.50 volts)</td>
<td>75.0 AH</td>
</tr>
<tr>
<td>10-hr. (7.2A to 10.50 volts)</td>
<td>72.0 AH</td>
</tr>
<tr>
<td>5-hr. (13.8A to 10.20 volts)</td>
<td>88.0 AH</td>
</tr>
<tr>
<td>1-hr. (47A to 9.00 volts)</td>
<td>47.0 AH</td>
</tr>
<tr>
<td>15-min. (180A to 9.00 volts)</td>
<td>40.0 AH</td>
</tr>
<tr>
<td>Approximate Weight</td>
<td>50.60 lbs. (22.95 kg)</td>
</tr>
<tr>
<td>Energy Density (20-hr. rate)</td>
<td>1.83 Wh/In3 (99.81 Wh/l)</td>
</tr>
<tr>
<td>Specific Energy (20-hr. rate)</td>
<td>17.79 Wh/lb (39.21 Wh/kg)</td>
</tr>
<tr>
<td>Internal Resistance (approx.)</td>
<td>6 milliомs</td>
</tr>
<tr>
<td>Max Discharge Current (7 Min.)</td>
<td>225.0 amperes</td>
</tr>
<tr>
<td>Max Short-Duration Discharge Current (10 Sec.)</td>
<td>560.0 amperes</td>
</tr>
<tr>
<td>Shelf Life (% of nominal capacity at 88°F (20°C))</td>
<td>97%</td>
</tr>
<tr>
<td>1 Month</td>
<td>97%</td>
</tr>
<tr>
<td>3 Months</td>
<td>91%</td>
</tr>
<tr>
<td>6 Months</td>
<td>83%</td>
</tr>
<tr>
<td>Operating Temperature Range</td>
<td></td>
</tr>
<tr>
<td>Charge.</td>
<td>-4°F to 122°F (50°C)</td>
</tr>
<tr>
<td>Discharge</td>
<td>-40°F to 140°F (80°C)</td>
</tr>
<tr>
<td>Case</td>
<td>ABS Plastic</td>
</tr>
<tr>
<td>Power-Sonic Chargers</td>
<td>PSC-1210000A-C</td>
</tr>
</tbody>
</table>

To ensure safe and efficient operation always refer to the latest edition of our Technical Manual, as published on our website. All data subject to change without notice.
**Constant Power Discharge Ratings**

<table>
<thead>
<tr>
<th>MODEL</th>
<th>FINAL VOLTAGE</th>
<th>WATTS PER CELL @ 25°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5 MIN</td>
<td>10 MIN</td>
</tr>
<tr>
<td>PS-12750</td>
<td>1.75</td>
<td>480</td>
</tr>
<tr>
<td></td>
<td>1.70</td>
<td>509</td>
</tr>
<tr>
<td></td>
<td>1.67</td>
<td>518</td>
</tr>
</tbody>
</table>

**Discharge Time vs. Discharge Current**

**Discharge Characteristics**

**Charging**

Cycle Applications: Limit initial current to 2.25A. Charge until battery voltage (under charge) reaches 14.4 to 14.7 volts at 86°F (30°C), hold at 14.4 to 14.7 volts until current drops to under 750mA. Battery is fully charged under these conditions, and charger should be disconnected or switched to "Float" voltage.

"Float" or "Stand-By" Service: Hold battery across constant voltage source of 13.5 to 13.8 volts continuously. When held at this voltage, the battery will seek its own current level and maintain itself in a fully charged condition.

Notes: Due to the self-discharge characteristics of this type of battery, it is imperative that they be charged within 6 months of storage, otherwise permanent loss of capacity might occur as a result of sulfation.

**Chargers**

PowerSonic offers a wide range of chargers suitable for batteries up to 100AH. Please refer to the Charger Selection Guide in our specification sheets for H-Series Switch Mode Chargers and "Transformer Type A and F Series". Please contact our Technical department for advice if you have difficulty in locating suitable models.

**Shelf Life & Storage**

**Further Information**

Please refer to our website www.power-sonic.com for a complete range of useful downloads, such as product catalogs, material safety data sheets (MSDS), ISO certification, etc.

**Contact Information**

<table>
<thead>
<tr>
<th>DOMESTIC SALES</th>
<th>CUSTOMER SERVICE</th>
<th>TECHNICAL SUPPORT</th>
<th>INTERNATIONAL SALES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tel: +1-818-661-2020</td>
<td>Tel: +1-818-661-2030</td>
<td>Tel: +1-850-364-5001</td>
<td>Tel: +1-850-364-5001</td>
</tr>
<tr>
<td><a href="mailto:national-sales@power-sonic.com">national-sales@power-sonic.com</a></td>
<td><a href="mailto:customer-service@power-sonic.com">customer-service@power-sonic.com</a></td>
<td><a href="mailto:support@power-sonic.com">support@power-sonic.com</a></td>
<td><a href="mailto:battery@power-sonic.com">battery@power-sonic.com</a></td>
</tr>
</tbody>
</table>

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