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Design, analysis, and development of cost effective canine wheelchairs.

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DESIGN, ANALYSIS, AND DEVELOPMENT OF COST EFFECTIVE CANINE WHEELCHAIRS

By

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DESIGN, ANALYSIS, AND DEVELOPMENT OF COST EFFECTIVE CANINE WHEELCHAIRS

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ABSTRACT

Hind limb paralysis may occur in dogs for a variety of neurological or musculoskeletal reasons. For dogs with limited mobility their lack of ability to ambulate can have a great impact on their physical and mental health. Canine wheelchairs can provide these dogs with a mobility option. The purpose of this project was to design a cost effective, adjustable, and lightweight canine wheelchair for dogs with hind limb paralysis. To account for the diverse range of canine breed sizes, wheelchairs were categorized into three separate designs (small, medium, and large size wheelchairs). A quality function deployment (QFD) matrix was created to guide each design and to evaluate their performance. To assess the wheelchair designs, static strength, fatigue strength, and stability were analyzed.

The wheelchair frames were designed to be constructed from PVC piping. The von Mises stress for each wheelchair design was below the 7500 psi yield strength of PVC. Wheelchair fatigue life was determined to be 25200-39100, 895,000-$1x10^6$, and 1000-5110 cycles respectively for the small, medium and large wheelchair. Lateral tip angles were 42^o-61^o, 32^o-49^o and 30^o-45^o, respectively for the small, medium and large wheelchair. The wheelchairs cost between $148-$219, and took 4-5 hours to construct. The small, medium and large wheelchair weighed 3.25 lbs, 12.5 and 12.75, respectively.

Three wheelchair designs for dogs with hind limb paralysis were developed and prototypes were constructed that were cost effective, adjustable and had weights similar to commercially available canine wheelchairs. Compared with the minimum cost of a commercially available wheelchair ($220) the developed wheelchairs have the potential to be cost competitive.

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I. Introduction

Dogs with mobility impairments or paraplegia as a result of disease, age, or injury from an accident have limited options for inexpensive and flexible wheelchairs. As a result many animals go without any assistance and will never fully recover or are euthanized. Many of the wheelchairs currently on the market are custom-made for each individual dog, require extensive manufacturing, are not adjustable, and are expensive.

The goals of this project were to design, evaluate, and develop canine wheelchairs that are suitable for three size ranges of dogs and that are easily adjustable and produced at a low cost. The canine wheelchair designs were also to be evaluated using computer analyses that focus on performance features such as static strength, fatigue strength, and stability. These inexpensive wheelchairs are meant to give pet guardians an alternative to the existing relatively high cost, less adjustable wheelchairs for rehabilitation or geriatric care. The wheelchair dimensions will also be adjustable to changes in the animal's anatomical dimensions and progress made during its rehabilitation.

The specific aims of this project are:

1. Design three cost effective, adjustable, light weight canine wheelchairs for dogs of various size ranges with hind limb paralysis.
2. Perform static stress analysis, fatigue analysis, and lateral static stability analysis to determine design feasibility of each wheelchair design.
3. Construct prototypes of three canine wheelchair designs and assess their compliance with the established design goals.

II. Background

A. Conditions in Canines Requiring the Use of a Wheelchair

Paralysis of the hind limbs can be caused by any number of problems, most having to do with brain, vertebra, or nerve injury. Blunt trauma to the neck and spine from an accident and a ruptured intervetebral disc can be causes of paraplegia. A lack of calcium, phosphorous, and magnesium in the dog's diet can also lead to the animal becoming paraplegic (Bleby, 1986). When amputation is necessary, in many cases, dogs have been able to adapt with one or two amputated limbs, however if the dog has severe physical impairment, a wheelchair can be used to increase mobility.

A common condition in canine breeds that can lead to paresis or even paralysis is intervertebral disc disease (Toombs, 2003). This degenerative condition is caused when disc material has ruptured into the vertebral canal. Thoracolumbar lesions account for 84%-86% of intervertebral problems in canines. Dogs that are most at risk of developing these conditions are chondrodystrophic breeds such as dachshunds, Pekinegese, corgis, and beagles. Chondrodystrophic breeds are at their highest risk of developing an intervertebral disc condition between the age of 3 and 6 years, while in non-chondrodystrophic the ages for greatest risk of developing this condition are between 8 to 10 years. Good postoperative care for a dog that has developed intervertebral disc disease is to receive physical therapy as soon as possible to help maintain muscular growth and return normal function.

Degenerative myelopathy and acute polyradiculoneuritis are neurological disorders that can cause paralysis (Thomas, 2003; Inzana, 2003). Degenerative myelopathy is most commonly found in German Shepherds, but has been found in a few other large canine breeds (Barclay, 1994). This disease starts late in the dogs life (6 to 11 years), with demyelinization of spinal cord axons, eventually resulting in a weakening of the pelvic limbs. Over a period of six to 12 months the dog will begin to lose function of their hind limbs and in severe cases forelimb paralysis can occur.

Acute polyradiculoneuritis, or coonhound paralysis, causes inflammation of the peripheral nervous system (Inzana, 2003). Weakness and paralysis develop quickly (within 7 to 14 days of exposure). Though the canine may have quickly developed tetraparalysis, the tail movement and bladder function are usually kept intact.

A major problem in animals with any form of paralysis or extended periods of immobility is the possibility of forming decubital ulcers or pressure ulcers (Waldron, 2003). If the dog has paraplegia and a pressure sore is allowed to form, the ulcer may go unnoticed setting up the possibility of infection. Pressure ulcers may also form from the excessive use of a wheelchair (Bauer, 1992). The sores are a result of compression of the skin over a boney area (Waldron, 2003). For mild cases a pressure sore can be treated with topical creams, but more severe cases the sore must be treated by surgical means. Waldron suggested that to prevent ulcers from forming it is important that the patient is reposition on a regular basis, that a healthy diet is maintained, and that adequate bedding is provided especially for heavier animals. Also hydrotherapy can increase circulation. Cleaning the patient on a regular basis can help in the prevention of pressure ulcers.

In many cases of paraplegia, bladder control may not be present and periodic expression of the bladder is necessary to prevent any incidence of incontinence. Other problems can form post-paralysis including urinary tract infections and severe muscle atrophy (Thomas, 2003; Inzana, 2003). If proper care and rehabilitation are provided to avoid additional complications, then the dog can still live a healthy and happy life (Bleby, 1986).

B. Quality of Life Assessment for Individuals Using Wheelchairs

One of the goals of a wheelchair is to increase the quality of life of the user through increased mobility and independence. Jutai has developed a 26 question user-rated scale for grading assistive technologies on their quality of life impact called the Psychosocial Impact of Assistive Devices Scale or PIADS (2001). The ratings are on a -3 (negative impact) to +3 (positive impact) Likert scale with zero being a perceived neutral impact. Jutai reviewed a study where he used the PIADS on a sample size of 92 wheelchair users of varying conditions and types of wheelchairs. Much of the reports focus was on persons with amyotrophic lateral sclerosis (ALS), a degenerative motor neurone disease. Jutai discovered that people who were waiting to receive their wheelchair had rated the assistive technology as a PIADS value of zero or negative. This suggests that individuals had little expectation that the wheelchair would increase their quality of life or have any affect at all. After the first assessment each wheelchair user was evaluated two more times 3 months apart. During the next two assessments the PIADS scores had increased to an above zero value, meaning a more positive impact on their quality of life after actually receiving the wheelchair.

Bauer performed a study on pet owners' attitudes of home care for dogs with paraplegia (1992). The study paid for medical expenses for the animal and provided a K-9 Cart for participation in the 6 month study. The exact cause of each dogs' paraplegia were not discussed. Data was gathered from 30 different dogs, all weighing less than 15 kg, by sending questionnaires to the pet guardians for completion. The study found that 82% of participants strongly agreed that the wheelchair was beneficial in home care of their pet and 92% strongly agreed that they would recommend the wheelchairs to other owners of dogs with paraplegia. Only 26% felt that decubital ulcers (pressure sores) were a problem for their dogs. Most of the ulcers were a result of being in the wheelchair where the back of their feet would rub against the wheelchair or on the phalanges where the feet were dragging on the ground. The ulcers were managed by adjusting the wheelchair or protecting the areas where ulcers were forming with protective pads. The survey also concluded that 85% of the participants disagreed or strongly disagreed that the work related to caring for their pet lowered their own quality of life.

C. Canine Wheelchair Research to Date

Leighton developed a wheelchair design for small dogs that was lightweight, adjustable, and functional (1966). The wheelchair frame was constructed from aluminum rods that were bent to shape. Any surface that came into contact with the dog (i.e. the yoke) was covered by rubber tubing. Though the wheelchair was a functional design for dogs with permanent hind limb paralysis or amputation, the axle supporting the wheels prevented any movement of the hind limbs for dogs who might be recovering from surgery or need moderate relief of strain on the hind limbs.

Short discussed the importance of a canine wheelchair in recovering dogs with paraplegia (1968). Short does not include the cause of each patient's paraplegia in his discussion. The wheelchair was used for 2 hour periods three times a day providing the canine with 6 hours worth of exercise in the wheelchair every day. The study pointed out that important factors regarding the dog's mental and physical health should be constantly monitored: protecting any lesions and not allowing the patient to drag themselves or become soiled in feces or urine. The canine wheelchair along with antibiotics and hydrotherapy has been so successful in the patient's recovery that Short has abandoned other treatments requiring surgery.

D. Current State of Canine Wheelchairs

There are several canine wheelchairs currently available on the market. The web page handicappedpets.com is a website created specifically for the marketing of handicapped pet care devices (handicappedpets.com, 2008). Eddie's Wheels, K9 Carts, and Doggon Wheels are companies that produce canine wheelchairs that are commercially available for purchase. The only canine wheelchair with a patent is K9 Carts (Patent # 4,375,203). All three wheelchairs are made from an aluminum frame that is custom made for each individual patient. The most significant problem with these wheelchairs is their relative high cost and lack of adjustability. The lowest cost wheelchair is $220. It is a custom made wheelchair for dogs less than 15 lbs from Doggon Wheels. The most expensive wheelchairs range from $450 to $525 for dogs over 130 lbs.

E. Canine Breeds and Dimensions

To date there is little data on the average dimensions of specific breeds of canine. The only available data is on the weight and standard height at the withers (height at the dorsal aspect of the shoulders) as determined by the American Kennel Club (2008). These dimensions are standards that the AKC requires of show dogs and does not account for dogs that are larger or smaller than the designated show dog size. The size of dogs can range from 5 in to 9 in at the wither and 2 lbs for the Dachshund and Chihuahua, over 30 in at the withers and 150 lbs to 200 lbs for adult Irish Wolfhounds and Mastiffs

F. Low Cost Human Wheelchair Designs

Bosshard and Yeo developed a low cost design for a human wheelchair made mostly from off-the-shelf PVC pipe (1983). The wheelchair only weighed between 12 kg (26 lbs) without brakes and 13 kg (28 lbs) with brakes. The wheelchair cost, including parts and labor was $100 Australian (~ $ 190 U.S.; 2008) and could be assembled in 2 hours. Following an 18 month test period where the wheelchair was used in the field, the wheelchair design was modified to include PVC pipe that was fortified with resin and metal rod inserts.

Pettit and colleagues also developed an inexpensive light weight wheelchair using PVC piping(1992). The goals of the research were to determine the feasibility of PVC as a primary material for the construction of a wheelchair frame. The wheelchair was made from 1" diameter PVC piping and fittings. The end result was a wheelchair frame that cost only $30, weighed 10.5 kg (23 lbs) with wheels, and required little processing of the parts for the wheelchair. The wheelchair was evaluated on a double drum test machine (ISO 7176-8, 1999), and the wheelchair completed 100,000 cycles without a failure.

Authier, Pearlman, and colleagues developed a design for a sports wheelchair for low-income countries that cost under $125 without the wheels (2007). The frame was designed using steel tubing and was constructed in 30 hours using tools that could be found in low-income countries. The first design of the wheelchair failed at 125,000 cycles on a standard double drum fatigue test machine. In the redesign of the wheelchair, the hole inserts on the back brace were made longer and then completed 200,000 cycle on the double drum machine.

G. Human Wheelchair Testing Standards

There are several standards for testing human wheelchairs in both static and dynamic settings. One of these standards is the ISO 7176-8: Requirements and test methods for static, impact, and fatigue strengths (1998). These standards are used to test the soundness and durability of the wheelchair design. The static strength requirements (ISO 7176-8 Clause 8) states that components of the wheelchair must withstand forces applied directly without structural failure. The applied static loads take into account the varying weights the wheelchair will come into contact with in the environment. The lifecycle of a wheelchair is also important to determine. The two-drum fatigue test(ISO 7176-8 Clause 10) sets a standard number of cycles the wheelchair must complete without any structural failure due to fatigue. The two-drum test device consists of two cylinders with two raised slats on each drum out of phase by 180^{o} (FIGURE 1) to simulate the uneven terrains a wheelchair might experience over a five year period.

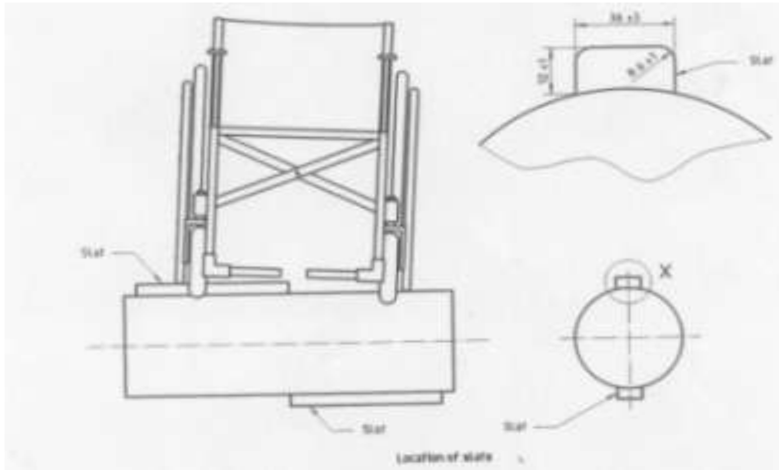


FIGURE 1 – Schematic of the Double Drum Machine with Dimensions.

The wheelchair must complete 200,000 cycles with the drums rotating at 1 m/s to meet the standard. A human wheelchair must also complete a kerb drop test (ISO 7176-8 Clause 10) in which the wheelchair is dropped from a height of 50 mm a total of 6,666 times without structural failure to meet the standard.

The standard for determining static wheelchair stability is ISO 7176-1: Determination of Static Stability (1999). The wheelchair is tested in three directions the angle at which the wheelchair becomes unstable or the angle at which one wheel loses contact with the ground. The test surface is made so that the wheelchair will not slide on the surface and the wheelchair must be restrained in a way that prevents slipping or any unwanted movement. The test platform should be set at a rate of 1 degree/sec and raised in such a way that does not affect the test results.

Cooper, Robertson, and colleagues performed life-cycle tests on 15 wheelchairs (six depot wheelchairs and nine rehab manual wheelchairs) (1996). Outcomes from this study evaluated the effects on wheelchair life-cycles that using a planar ANSI/RESNA test dummy versus using a HERL contoured test dummy representing the occupant, using pneumatic casters versus solid rubber casters, and a depot wheelchair versus a rehabilitation manual wheelchair. On average the wheelchairs using the ANSI/RESNA test dummy lasted longer than the wheelchairs using a HERL contoured dummy as an occupant. The rehabilitation manual wheelchairs lasted an average 13.2 times longer than the common depot wheelchair. Wheelchairs with the pneumatic caster wheels on average tripled the wheelchair life as compared to those with solid rubber casters.

Baldwin and Thacker recorded the output of three strain gauge rosettes mounted to wheelchairs on a double drum test machine to create a von Mises stress history (1995). The strain gauges were mounted on a powered and manual wheelchair with two on the front cross tube and one on the horizontal tube behind the right front caster wheel. The resulting von Mises stress history of the test showed that the peak stress was often twice the mean value. The stress history was then used to analyze computer models for fatigue using a strain-based fatigue analysis in a finite element (FEA) model. The von Mises stress histories developed from testing are useful guidelines for wheelchair designers concerned with the life-cycle of a given design.

II. Methodology

1. Design Three Cost Effective and Adjustable Wheelchairs for Canines With Hind Limb Paralysis.

A. <u>Quality Functional Deployment Matrix (QFD)</u>

A quality functional deployment chart (QFD) was used to aid in the design and assessment of each wheelchair design. The QFD format used for developing goals for the wheelchair designs These parameters include: maximum weight of animal, adjustability, weight of wheelchair, expected life, cost of material, and factor of safety. The QFD was also used to evaluate construction criteria such as: cost, time of construction/assembly, tools, weight, and strength. Figure 2 is a basic layout of the format used for each of the QFD's (Ullman, 2003).

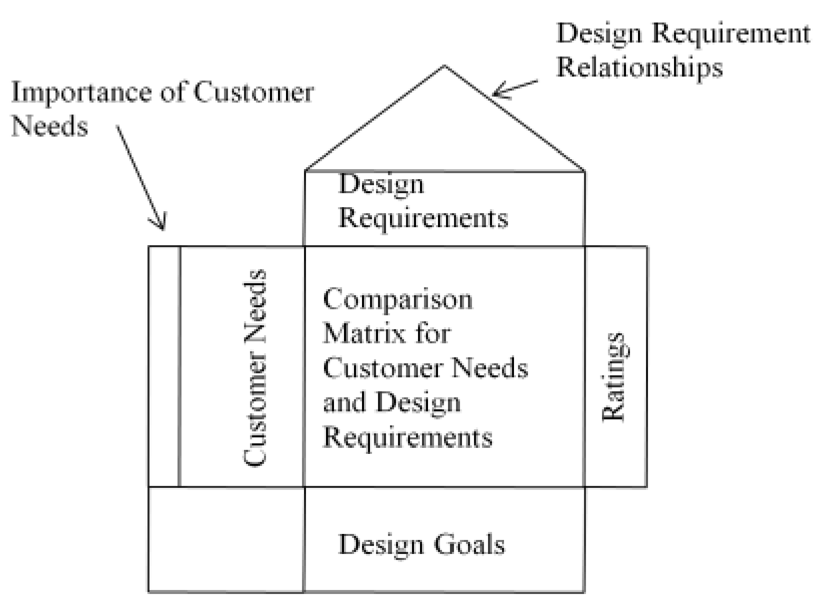


FIGURE 2 – Format for the QFDs.

The sections in Figure 2 labeled “Design Requirement Relationships” and the “Comparison Matrix…” relates the Design Requirements with other Design Requirement and the Design Requirements with the Customer Needs and rates them as either a strong relation, medium relation, weak relation, or no relation. For the Importance of Customer Needs category a Certified Canine Rehabilitation Practitioner and a owner with a dog having paraplegia rated each Customer Need on a 1 (least important) to 10 (most important) rating scale. The Ratings section of the QFD compares three wheelchairs that are commercially available and rates how each of product meets a Customer Need on a 1 (worse) to 5 (best) scale. The Design Goals determine “Delighted” (design meets targeted goals) and “Disgusted” (Design does not meet targeted goals) targets based on the Design Requirements for the project. The Design Goals developed for this project were determined by cross checking the Design Requirement values from other commercially available canine wheelchairs.

The wheelchair design was divided into three size categories to cover a range of dog sizes. Therefore three QFD’s were needed for each wheelchair design. The sizes of the small, medium and large wheelchairs were based on key anatomical dimensions of a range of canine breeds that fit into each category (TABLE 1).

TABLE 1

CANINE BREED HEIGHTS AND WEIGHTS (akc.org).

Breeds	Height at withers (in)	Weight (lbs)
Dachshund	8-9	16-32
Chihuahua	5-8	2-6
Labrador Retriever	22	55-70
Irish Wolfhound	30+	105
Mastiff	27+	150

TABLE 2

WHEELCHAIR SIZE, RANGE OF KEY ANATOMICAL PARAMETERS AND MAXIMUM CAPACITY

Wheelchair Size	Height at withers (in)	Hip to Shoulder Length (in)	Maximum Capacity (lbs)
Small	5-13	6-10	40
Medium	14-19	10-15	70
Large	20-27	15-20	100

The design goals for each wheelchair design are based on the sizes and the maximum capacities used to analyze each wheelchair design are in TABLE 2 and other design features from commercially available wheelchairs.

B. <u>Development of Potential Design Concepts</u>

The primary candidate material was PVC because of its availability, manufacturability, inexpensive cost, and its strength in low stress application. PVC is also a well studied material with material properties that are readily available. Brainstorming sessions took place to discuss key features a canine wheelchair must incorporate and how to achieve maximum adjustability at the lowest cost. Several sketches were developed on how to construct an adjustable wheelchair structure from PVC. Several features from each sketch were then used in the development of each wheelchair design. The medium wheelchair and large wheelchair would be the same except the length of the height leg would be longer for the large wheelchair.

The front and rear harness to frame interface was also developed in this stage. Plastic nylon buckles were determined to create an easy connection between frame and harness. The loading capacity of the available buckles were not provided by the manufacturer so several samples of buckles were tested to failure in an INSTRON 4500 tensile test machine. Each buckle was attached to testing grips by 7 inch lengths of nylon straps. FIGURE 3 shows the test setup and INSTRON machine used to test each buckle.

FIGURE 3 – Setup for Each Buckle Testing (Left) and the INSTRON 4500 (Right).

The test rate of each buckle was 1 in/min and each buckle was tested to failure or 200 lbs. The load at which each buckle failed was then recorded for comparison.

C. Create 3D Solid Models of Wheelchair Designs

Solid models of the three wheelchair designs were developed in SolidWorks™ 2006. The PVC pipe and fittings were measured and then modeled individually in SolidWorks™. Each pipe section was designed to a length that achieved the requirements developed in the QFD. The pipe sections and fittings were then modeled and assembled in SolidWorks™. The models were assembled using a series of mates that locked each part into their respective location. The material properties of PVC, the primary candidate material, were also integrated into the software for later analysis. Wheels, axles, and a solid ground were also modeled to create a realistic contact boundary condition between the wheels and ground for the analysis portion of this project. The adjustability of the wheelchairs and dimensions were checked against the QFD to assess any short comings in the design.

2. Conduct Static Strength, Fatigue Strength, and Stability Analyses of Wheelchair Designs.

A. Static Strength Analysis

The static strength analyses were performed using a linear finite element analysis (FEA) available within COSMOSWorks™. The sparse solver was use to analyze each wheelchair solid model using

$$Kd = r \tag{1}$$

where K is the stiffness matrix defined by the properties of the material, d is the deflection of the nodes, and r is the applied load (Cook, 2002). The sparse solver is best of the available for solving dissimilar materials such as plastic and steel. To mesh the solid model COSMOSWorks™ uses 10 node tetrahedral elements. The maximum weight capacities for each wheelchair size were distributed across the frame in the locations at which the pelvic harness is attached to the frame. The loads were applied in the form of a directly transferred remote load with a Factor of Safety of 2 (FOS=2). The direct connection in the remote load function transfers the load to the appropriate location as well as transfers the moment from the load. A flat platform was created to form a contact with the wheels that simulates the wheels resting on the ground. A coefficient of friction of 0.5 was used for each analysis, which is similar to that of a relatively slippery floor. The wheelchair is restrained in such a way that prevents the wheelchair from tipping forward or backwards. These restraints were placed on the front two supports on the front end of the wheelchair restricting movement in the horizontal and vertical directions. This prevents rigid body motion and simulates how the chest harness would actually attach to the frame. Figure 4 is a graphic of the medium wheelchair with boundary conditions. The green arrows represent the restraints and prevent movement in the direction in which they are pointing and the purple arrow is the applied load and is applied in the direction of the arrow.

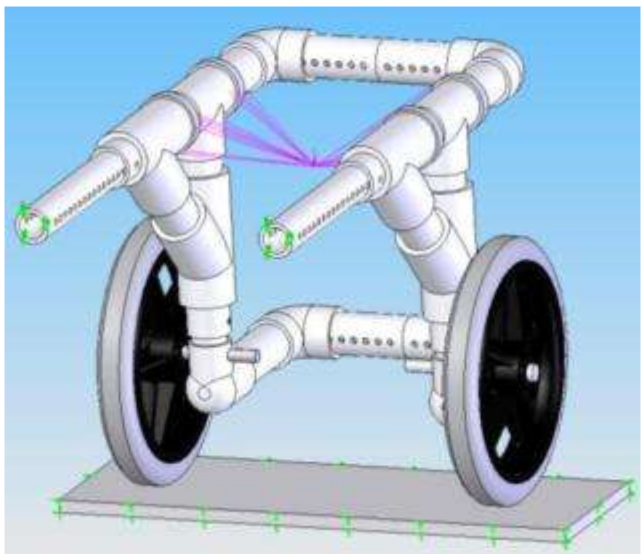


FIGURE 4 – Medium Wheelchair with Applied Boundary Conditions.

Each wheelchair was then meshed with an element size approximately 0.4 in. Areas of high stress concentrations (e.g. small holes) were automatically meshed with smaller elements to reduce the effects of errors from a course mesh in areas of high stress. The maximum von Mises stress was then determined and checked against the yield strength of each material to assure no plastic deformation occurred in the structure. The displacement of each wheelchair was also evaluated to assure that large displacements did not occur.

B. Fatigue Strength Analysis

The number of life-cycles to failure is important to predict for wheelchairs since they experience dynamic loading conditions and can fail at operating stresses much lower than yield strength (Juvinall, 2006). The life-cycles to failure of the wheelchair designs were determined using COSMOSWorks™ and was based on the von Mises stress values from the previous static strength analysis results. To meet the ISO 7176-8 Clause 10 fatigue strength standard, the wheelchair must complete 200,000 cycles (1998). COSMOSWorks™ uses the S-N Curve method to solve for the fatigue cycles to failure. For the purpose of this analysis a cycle will be the equivalent of one complete revolution of the double drum machine as defined in the ISO 7176-8 Clause 10 fatigue strength standard. To simplify the loading history, a loading was used where the maximum peak of the curve approaches 1.5 times the test weight and minimum peak approaches 0. The S-N curve used for PVC in this analysis is shown in Figure 5.

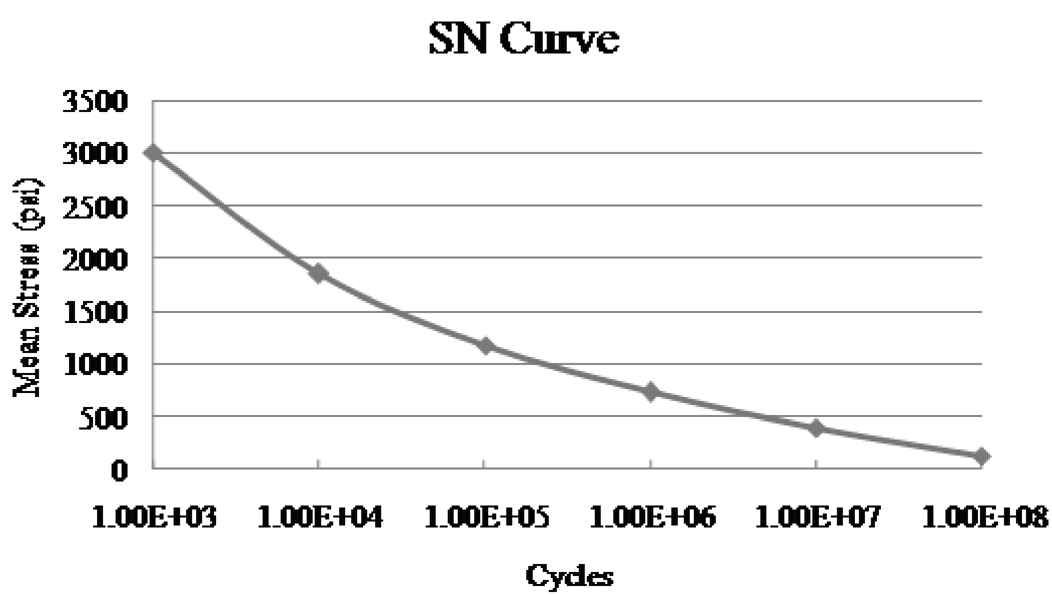


FIGURE 5 – S-N Curve for PVC (Jeffery, 2004).

The S-N curve provides the number of cycles the material will complete before failure for a given stress loading. The S-N curves for the other materials in the analysis were derived from the Elastic Modulus specific to that material in COSMOSWorks^{TM}. The wheelchair frame was the only structure of concern in the fatigue analysis, since the life-cycles of the axle and wheels are estimated to far exceed the frame. The life-cycle values were then compared with the values in the QFD to determine if the Design Goals specific to the life of the wheelchair were met.

C. Static Stability Analysis

The lateral stability angle of each wheelchair design is tested on the stability of the frame without an occupant. The stability analysis was performed in COSMOSMotion^{TM}. The analysis method was based on the ISO 7176-1 stability testing methods. To perform the analysis a solid model of a platform was developed consisting of two surfaces of the same dimensions. These two platform pieces were positioned so they were stacked vertically. The bottom half of the platform acts as a ground for the top platform to rotate around and the axis was formed by the edge on the bottom platform. The top half of the platform is then raised at a rate of 1 degree/sec from 0^o to 90^o. To determine the angle at which the wheelchair became unstable two graphs were developed. One plot described the angular displacement between the two platforms over time. The second graph displayed the angular displacement between the top platform and the wheel (the wheel that is furthest from the rotation axis) over time. The second graph will remain zero until the wheel loses contact with the top platform. When this happened the time was then cross checked with the angular displacement graph for the two platforms to determine angle of instability. This procedure was performed twice for each wheelchair design, once for the least stable configuration (maximum height and minimum width adjustments) and once for most stable configuration (minimum height and maximum width adjustments). These values were then recorded as a range from least stable to most stable configuration for each wheelchair. The two analysis setups for the least stable and most stable configurations of the medium wheelchair are displayed in Figure 6. The black dot, in the figures below, shows the pivot point of the platforms.

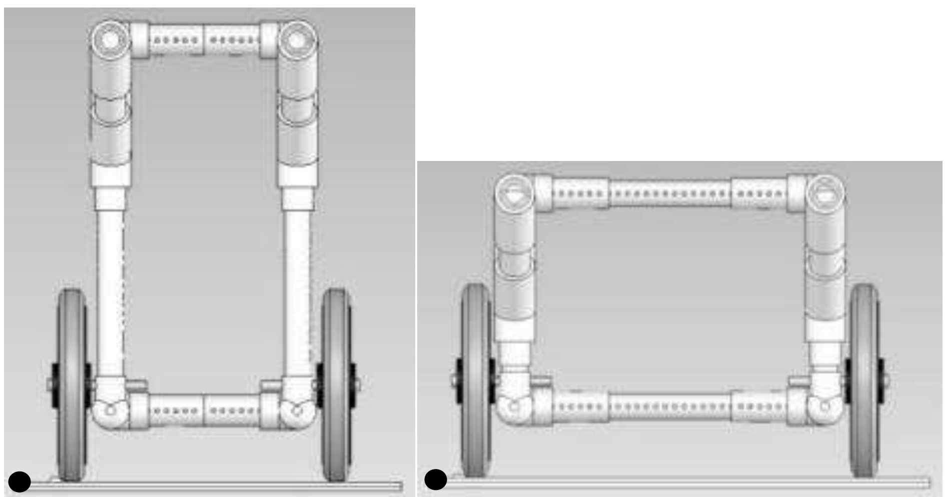


FIGURE 6 – Least Stable (Left) and Most Stable (Right) Configurations for the Medium Wheelchair.

The results were then compared with the QFD Design Goals to determine if met "Delighted" goal for tip angles.

The center of gravity (CG) for each wheelchair was evaluated and was determined using a suspension method. FIGURE 7 show where the CG was referenced from on the wheelchair.

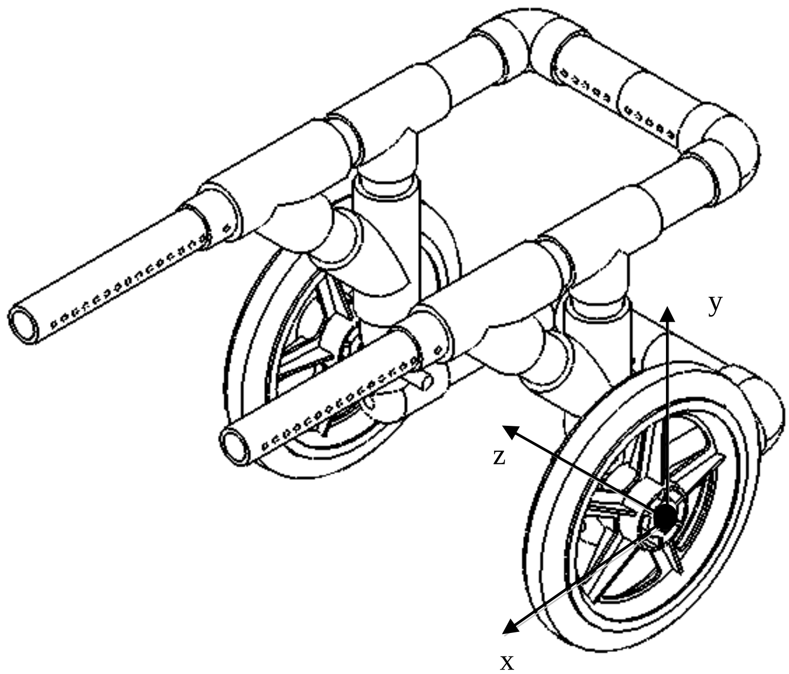


FIGURE 7 – Reference Origin for the Center of Gravity.

3. Construct Prototypes of Three Canine Wheelchair Designs and Assess Their Compliance with Established QFD Design Goals.

A. <u>Bill of Materials</u>

A bill of materials (BOM) was created for each wheelchair design to ease the process of purchasing and to assess costs. The BOM for each wheelchair design includes details of the information contained in TABLE 3. With the cost of each part accounted for, the total cost of the wheelchair can be assessed and divided into three categories: the cost of the wheelchair, the cost of the wheelchair without the harnesses, and the cost of the wheelchair frame. The cost of the wheelchair was then compared with the QFD Design Goals. Since there is limited data on the cost of labor and raw materials it takes to build the commercial canine wheelchairs the cost of wheelchair prototype (without labor) will be compared with the retail price of the commercial wheelchairs available on the market.

TABLE 3

BILL OF MATERIAL DETAILS

	Description
Reference #	Number assigned to each part in BOM to reference in design drawing.
Part Name	Descriptive name of each part given by manufacture/supplier.
Part Size	Size of the part (inches) include: pipe diameter, material width, etc…
Quantity	Number of each part required for wheelchair design.
Length	The length of each part (inches) used for the wheelchair.
Supplier	Where each part can be purchased.
Price	Cost of each part either in units of $/inches or $/part.
Shipping Cost	The cost to have the part shipped from supplier if not in retail.
Total Cost	The total cost for each part based on the quantity, price, and shipping.

B. Construction Jigs and Prototypes

The only design jig required for building the wheelchairs was a jig designed for drilling the half inch spaced holes in a straight line. Each part for the wheelchair was cut to size and drilled according to the solid models, labeled according to part length, and organized before assembling. The steps to assemble the wheelchair were then carefully documented so the wheelchair was built in a specific order to avoid any mistakes. Pictures were also taken for use in the Assembly Instruction Manual. The times to process each wheelchair component and to assemble the wheelchair were recorded and compared with the Design Goals from the QFD. With the prototypes built, other Design Goals were checked including: weight, the number of adjustment points, and the number of replaceable parts.

C. Assembly Instruction Manual

An assembly instruction manual was created to assist consumers in how to properly construct and assemble the canine wheelchair. The manual includes: assembly details for each wheelchair design and the construction jig to drill the holes in the PVC pipe. The assembly details are a pictorial guide on how to assemble the wheelchair. The harness connections are also explained in detail in the assembly instructions.

IV. Results

1. Design three cost effective wheelchairs for canines with hind limb paralysis.

A. Quality Functional Deployment Charts (QFD)

Figure 8 contains the QFD developed for the small size wheelchair. Customer needs, design requirements, and associated design goals from the QFD are displayed with greater detail in Tables 4 and 5. The QFD customer needs were developed as part of the first stages of the project to determine which characteristics are important in a canine wheelchair design. Table 4 contains the customer needs and user ratings of the importance of each of those needs.

TABLE 4

CUSTOMER NEEDS AND IMPORTANCE RATINGS

Customer Needs	Canine Guardian	Canine Rehab Specialist
Mobility	10	10
Allows dog to relieve themselves	10	8
Strength	10	10
Stability	10	10
Ease of donning and doffing wheelchair	6	10
Adjusts for female/male	10	6
Easy adjustments for comfort by owner	10	7
Adjusts to changes in anatomical dimensions	10	8
Easy to repair/maintain	10	9
No rusting/corrosion	10	9
Environmentally friendly material	10	8
Easy to clean	10	9
Prevents skin breaks/pressure sores	10	10
Adjustable for rehabilitation	10	10
Easy to manufacture	10	8
Weight	9	8
Cost of materials	10	8
Cost of manufacturing	10	10
Portability	10	9

Note: Scale: 1 (least important) and 10 (most important).

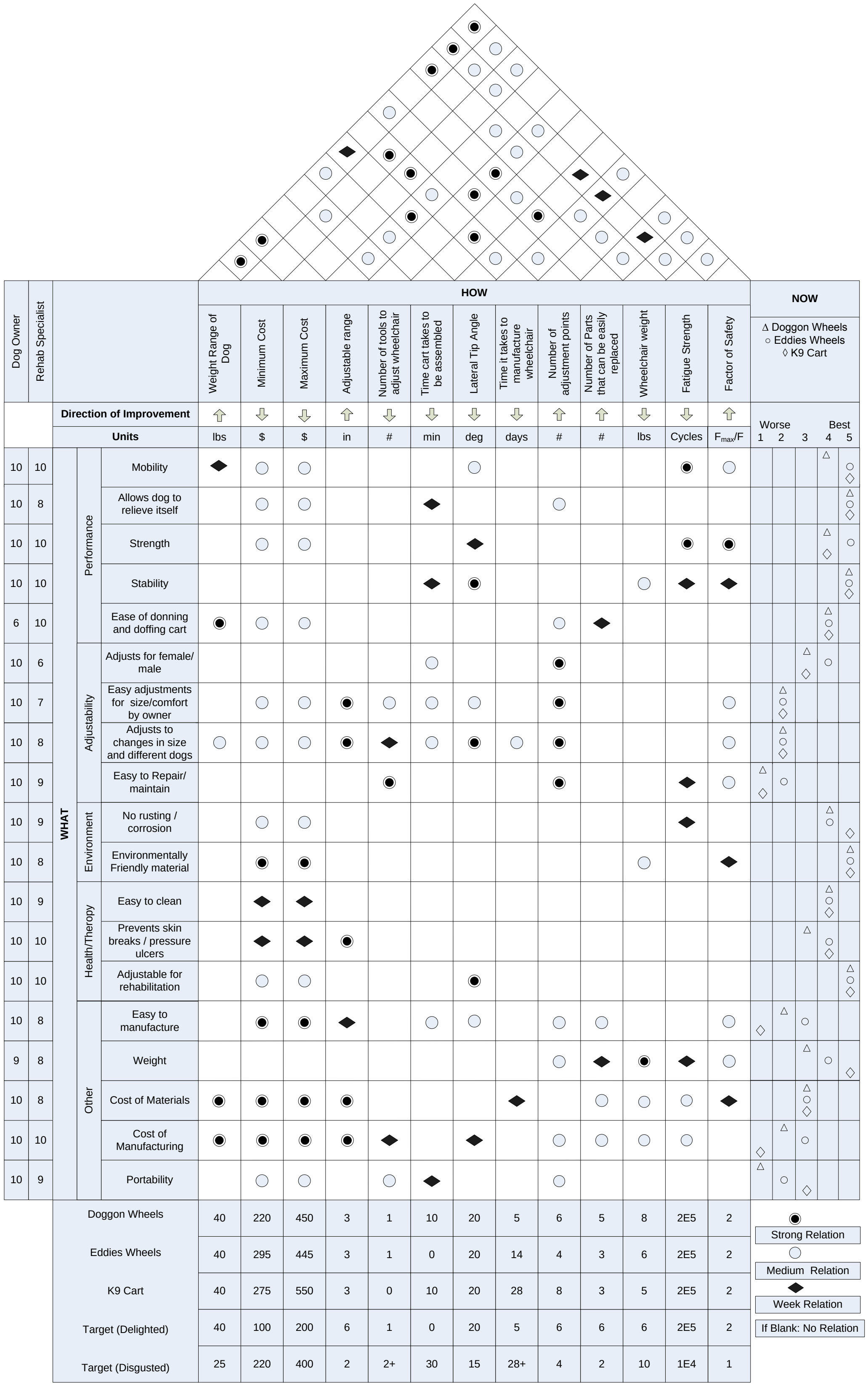


FIGURE 8 – QFD for the Small Wheelchair.

The design requirements and design goals were developed through research of human wheelchair standards and reviewing of commercially available wheelchairs. Table 5 contains the design requirements and design “Delighted” and “Disgusted” goals for each wheelchair design (i.e. small, medium, and large wheelchair). Once again the “Delighted” targets are the goals that the wheelchair is designed to either meet or exceed, and the “Disgusted” targets are the goals that require a change in the design to address any shortcomings. The QFDs’ design goals were determined through thorough examination of each of the manufacturers’ websites, handicappedpet.com, and other sources that contained valid information for this project (2008). There is little technical information published or available on the performance of canine wheelchairs. If the information wasn’t available (i.e. the life-cycles of each wheelchair), it was assumed based on another reference such as the ISO Standards (ISO 7176-8, 1999). Each of the wheelchair designs are assessed and evaluated in greater detail in the following sections. The time to process the wheelchair was developed based on the time it takes the commercially available canine wheelchair manufacturers to turnaround the order since specific information on their manufacturing process and times is limited. Appendix I contains the QFD’s for all three wheelchair designs.

TABLE 5

DESIGN REQUIREMENTS AND DESIGN GOALS

	Small Wheelchair		Medium Wheelchair		Large Wheelchair	
Design Requirements	Delighted	Disgusted	Delighted	Disgusted	Delighted	Disgusted
Weight Range of Dog (lbs)	40	20	70	50	100	70
Minimum Cost ($)	100	220	100	220	100	220
Maximum Cost ($)	200	400	200	400	200	400
Adjustable Range (in)	6	2	6	2	6	2
Number of tools for adjustments (#)	1	2	1	2	1	2
Time to assemble wheelchair (hr)	1	4	1	4	1	4
Time it take to process wheelchair (days)	5	28	5	28	5	28
Number of adjustment points (#)	6	4	6	4	6	4
Number of parts that can be easily replaced (#)	6	2	6	2	6	2
Wheelchair weight (lbs)	6	10	6	10	6	10
Fatigue Strength (cycles)	$2x10^5$	$1x10^4$	$2x10^5$	$1x10^4$	$2x10^5$	$1x10^4$
Lateral tip angle (deg)	20	15	20	15	20	15
Factor of Safety (F_{max}/F)	2	1	2	1	2	1

B. Development of Potential Design Concepts

The design of each wheelchair started with a few sketches that were developed during a brainstorming session. Figure 8 contains a sketch of a potential wheelchair design.

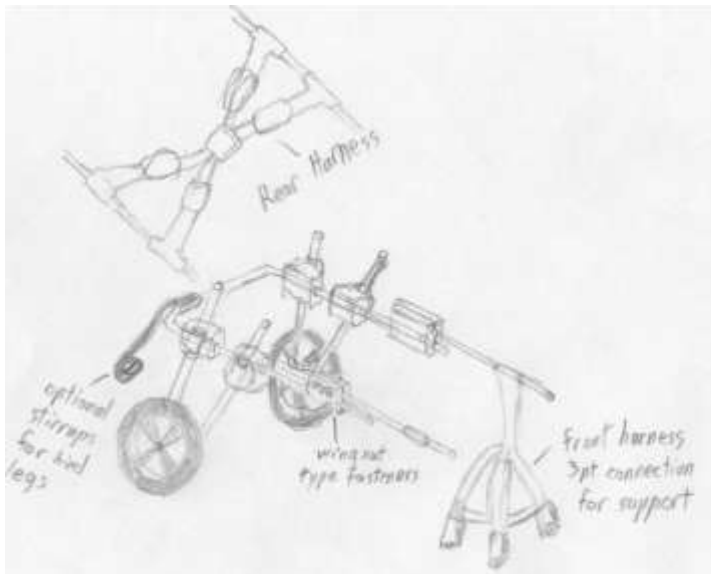


FIGURE 9. Potential Wheelchair Design Concept for a Canine Wheelchair.

Several ideas were used from the sketches that were developed such as using a telescoping pipe for adjustability and using blocks that allow for a cylinder to slide through a hole as in Figure 9.

PVC was chosen as the material for the frame because it’s inexpensive, readily available, and has durable material properties (Pettit, 1992). The standard 1 in PVC pipe will telescope in and out of 1-1/4 in PVC pipe with a clearance of 0.038 in between the two sizes pipes. This feature will allow for telescopic adjustability in the wheelchair design. PVC is also available in a wide range of shapes and sizes. This provides possibilities in the adaptability of the design. The material properties for PVC are as follows (matweb.com, 2008) (TABLE 6).

TABLE 6

MATERIAL PROPERTIES OF PVC

Property (units)	
Elastic Modulus (psi)	41000
Yield Strength (psi)	7500
Ultimate Strength (psi)	8000
Poisson's Ratio (in/in)	0.41
Density (lb_m/in^3)	0.051

Note: Obtained from matweb.com.

To connect the harness to the wheelchair plastic nylon buckles with a side release mechanism were chosen. Two types of plastic buckles were tested to evaluate load carrying capacity in an INSTRON 4500 tensile test machine because the information was not readily available from the manufacturer. The first buckle was a 1 in nylon buckle manufactured by ITW Nexus ($1.10), and the second buckle is a 1 in nylon buckle manufactured by Dritz with a reflector ($2.49). Figure 10 contains the results from the tensile tests of five Nexus plastic buckles presented as a load versus displacement plot. The red crosses on the graphs represent the point on the loading curve where the buckles failed.

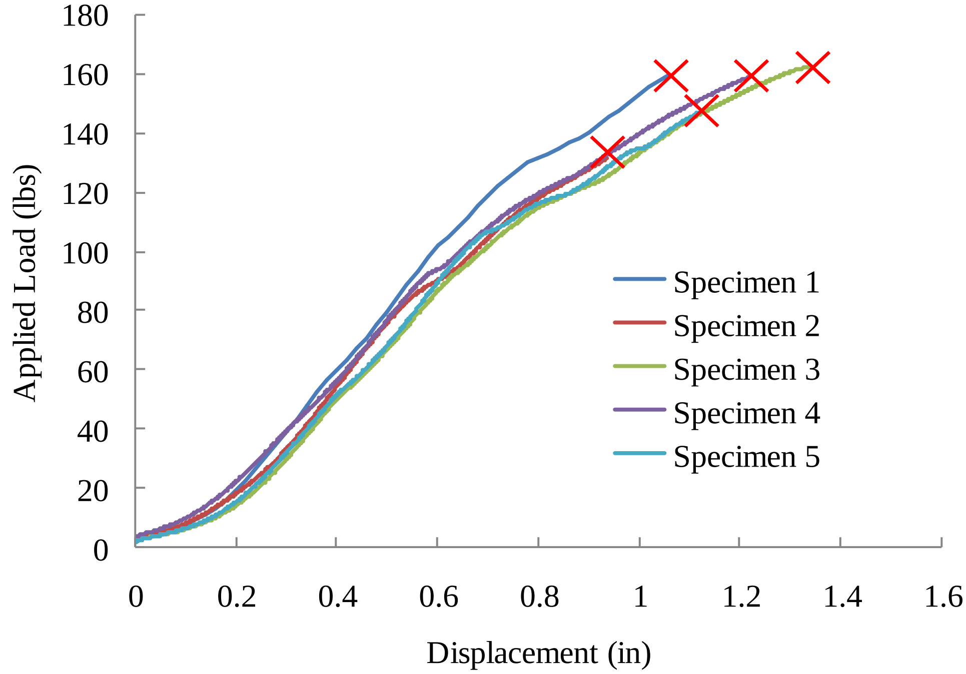


FIGURE 10 – Load Versus Displacement of the Nexus Plastic Buckle.

The average failure load of the Nexus buckles was 151 lbs. Figure 11 contains the test results from the tensile test of the Dritz plastic buckle.

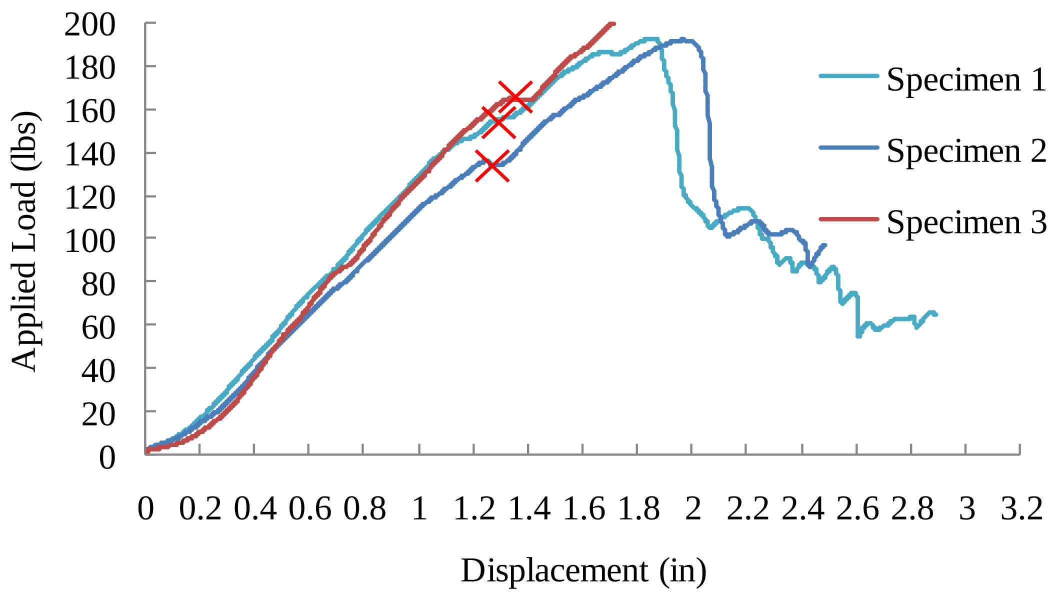


FIGURE 11– Load Versus Displacement of the Dritz Plastic Buckle.

The average failure load for the Dritz buckles was 148 lbs. The Nexus plastic buckles were chosen over the Dritz buckles for its strength and relatively inexpensive cost for the harness-to-frame interface.

C. Create 3D Solid Models of Wheelchair Designs

After dimensioning the PVC fittings and pipe diameters (inner and outer) each wheelchair design was created in SolidWorks™ as a solid model. Figures 12 through 15 are isometric views of the wheelchair solid models in their fully contracted and fully extended configurations.

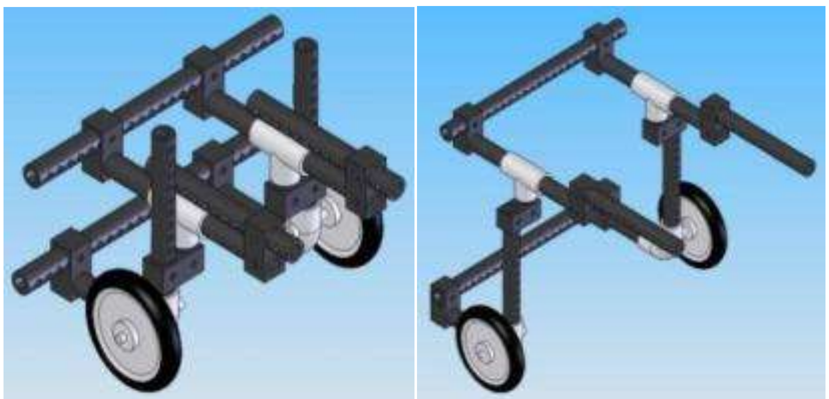


FIGURE 12 – Fully Contracted (Left) and Fully Extended (Right) Configurations of the Small Wheelchair Solid Model.

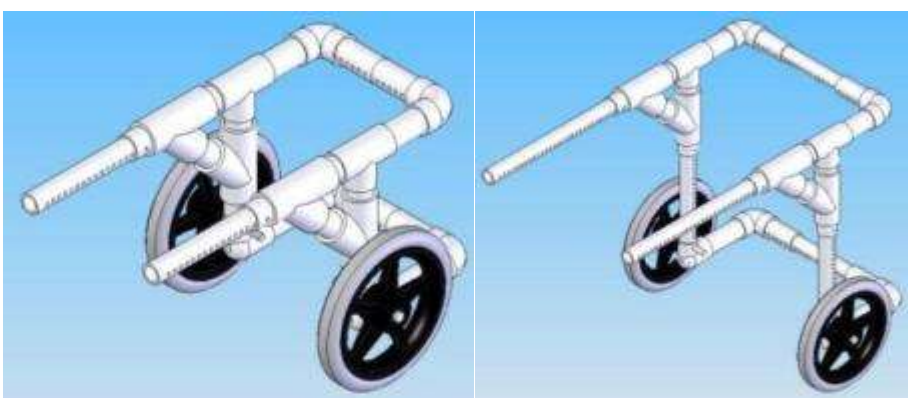


FIGURE 13– Fully Contracted (Left) and Fully Extended (Right) Configurations of the Medium Wheelchair Solid Model.

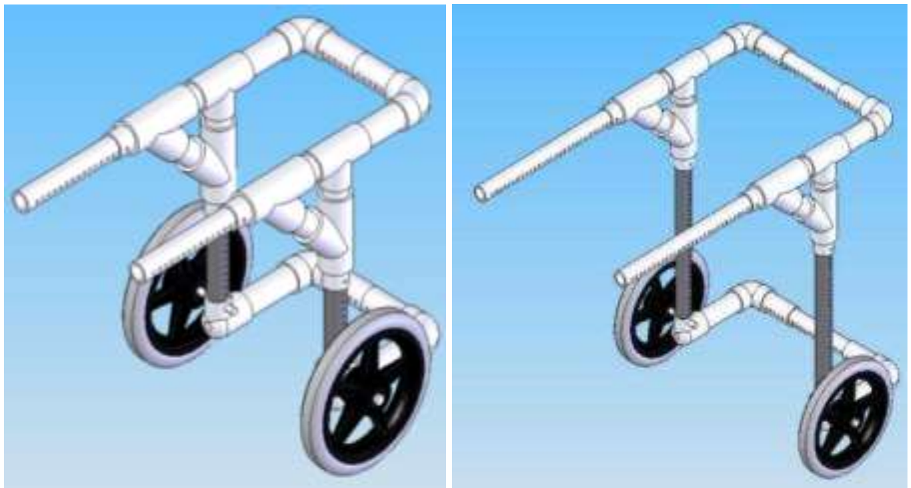


FIGURE 14 – Fully Contracted (Left) and Fully Extended (Right) Configurations of the Large Wheelchair Solid Model.

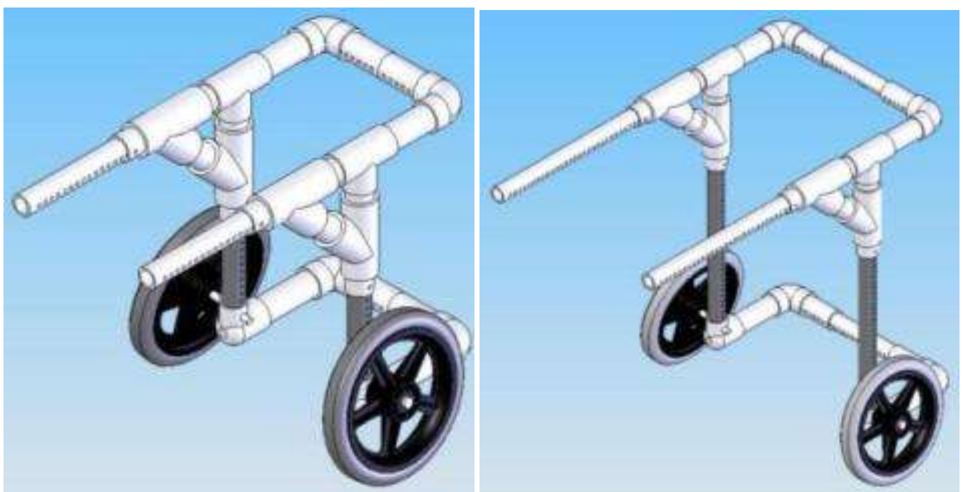


FIGURE 15 – Fully Contracted (Left) and Fully Extended (Right) Configurations of the Large Wheelchair Solid Model with an 8^{o} Wheel Camber.

The large wheelchair was also designed with an 8^{o} camber (FIGURE 15) on the wheels to determine whether the camber will increase the wheelchairs stability. The large wheelchair was the best candidate to determine the feasibility of the wheel camber because it was the least stable of the three wheelchair frames.

With the solid models created, the adjustability of the wheelchairs was determined within SolidWorks^{TM}. The height, width, and length measurements were taken from the dimensions shown in Figure 16.

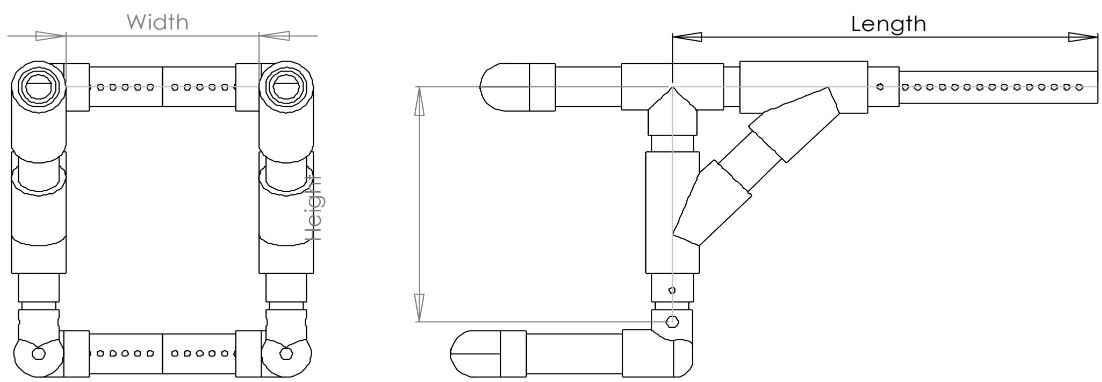


FIGURE 16 – Dimensions for Measuring the Adjustability of the Wheelchair.

Table 7 contains the values of the height, width, and length of each wheelchair in the contracted and extended configurations, as well as the adjustability for each dimension.

TABLE 7

MEASUREMENTS OF WHEELCHAIR DIMENSIONAL RANGE AND ADJUSTABILITY

Wheelchair	Measurement	Contracted (in)	Extended (in)	Adjustability (in)
Small	Height	3.66	8.66	5
	Width	3.91	7.91	4
	Length	5.50	10.5	5
Medium	Height	9.95	18.45	8.5
	Width	7.98	14.48	6.5
	Length	16.13	22.63	6.5
Large	Height	15.50	24.00	8.5
	Width	7.98	14.48	6.5
	Length	16.13	22.63	6.5

The design of each wheelchair has eight points where the wheelchair can be adjusted. Each design has two points of adjustability for the length, two points for the height, and four for the width. Since the wheelchair is not permanently joined together there are also six components of the wheelchair frames that can easily be replaced.

The properties of the tires and wheels were set to be Nylon 6/6 which as described by the COSMOSWorks™ library of materials and their associated properties. The steel axles were assigned properties of plain carbon steel from the COSMOSWorks™ material library.

2. Conduct Static Strength, Fatigue Strength, and Stability Analyses of each Wheelchair.

A. Static Strength Analysis

The three wheelchair designs were each analyzed in their fully contracted and fully extended configurations. Therefore two analyses were required for each design. Figure 17 -24 shows the von Mises stress distribution from the FEA for each wheelchair design in their fully contracted and fully extended configurationss.

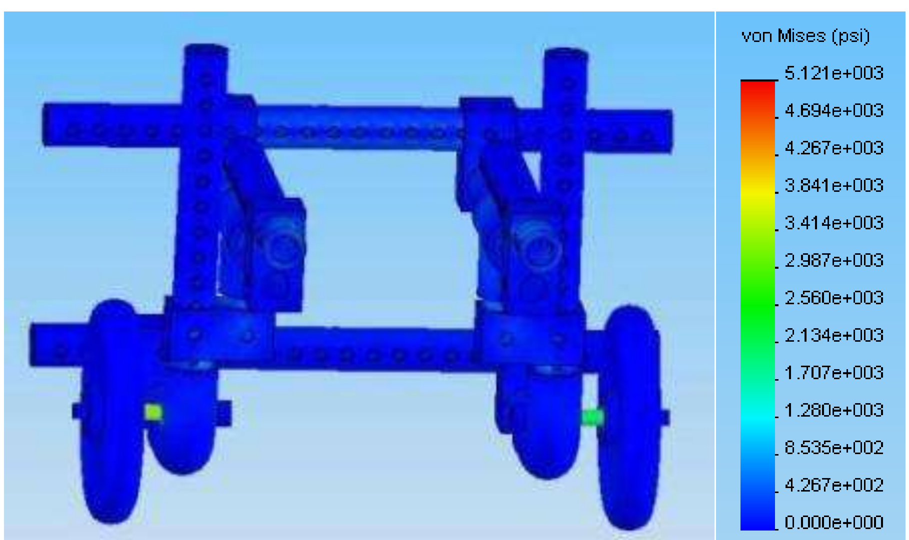


FIGURE 17 – Von Mises Stress Distribution of the Small Size Wheelchair in its Fully Contracted Configuration and Associated Stress Fringe Order.

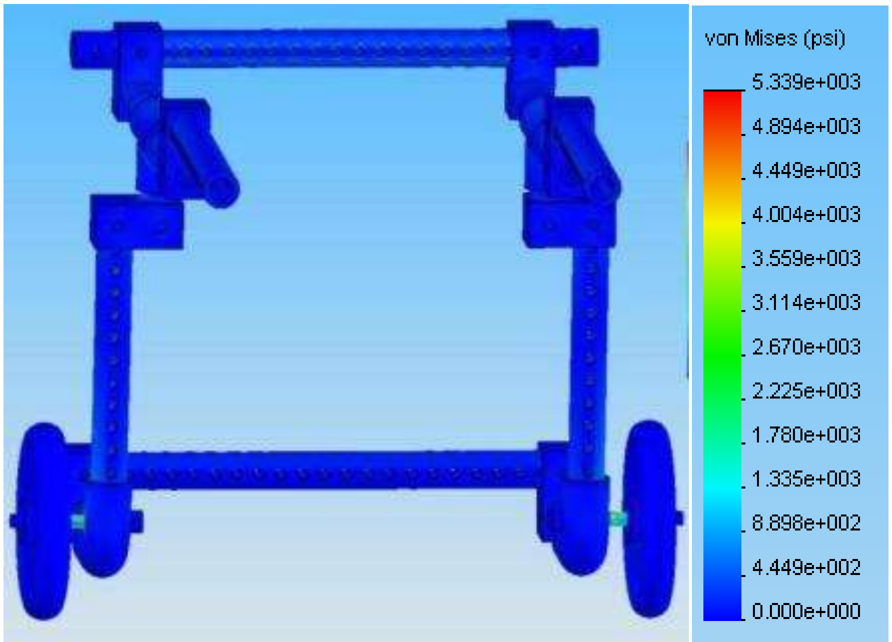


FIGURE 18 – Von Mises Stress Distribution of the Small Size Wheelchair in its Fully Extended Configuration and Associated Stress Fringe Order.

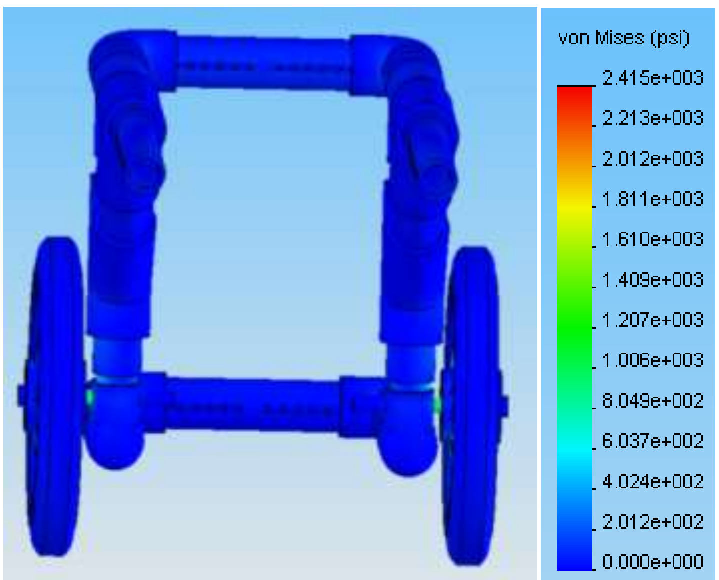


FIGURE 19 – Von Mises Stress Distribution of the Medium Size Wheelchair in its Fully Contracted Configuration and Associated Stress Fringe Order.

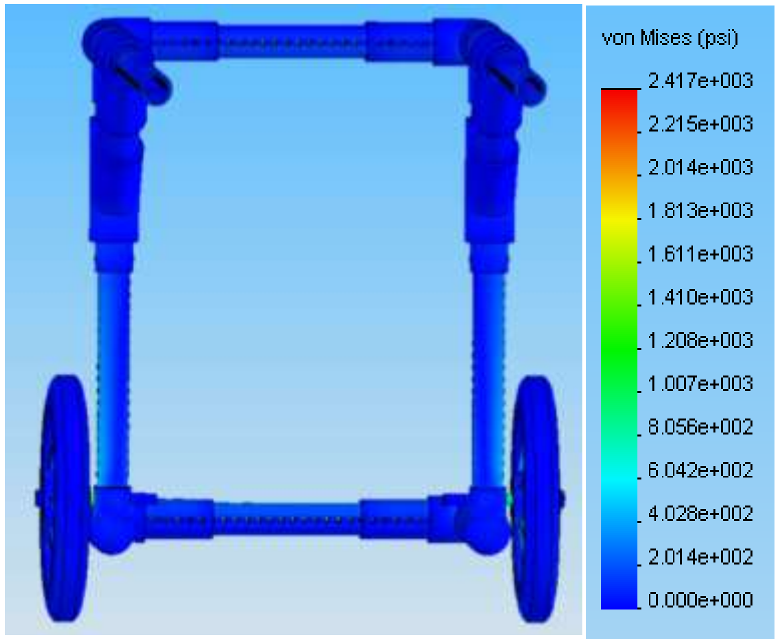


FIGURE 12 – Von Mises Stress Distribution of the Medium Size Wheelchair in its Fully Extended Configuration and Associated Stress Fringe Order.

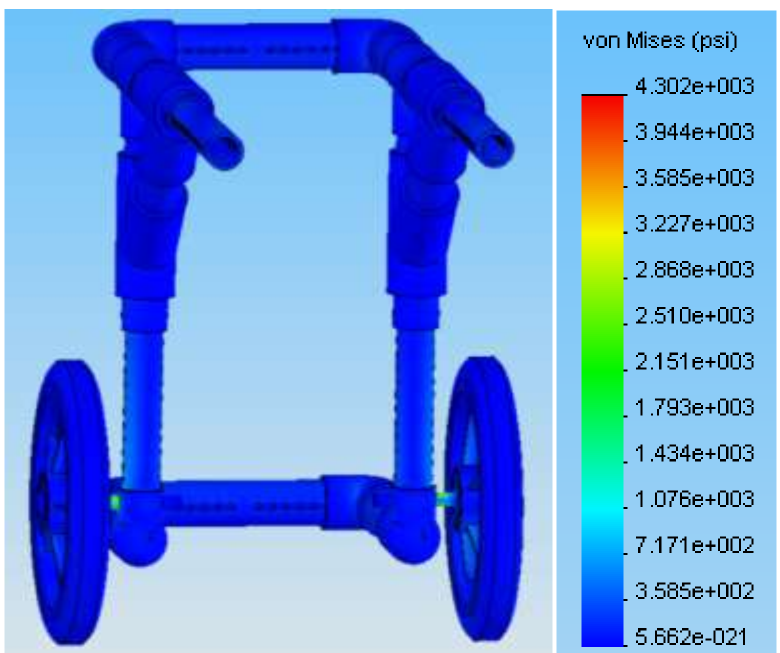


FIGURE 21 – Von Mises Stress Distribution of the Large Size Wheelchair in its Fully Contracted Configuration and Associated Stress Fringe Order.

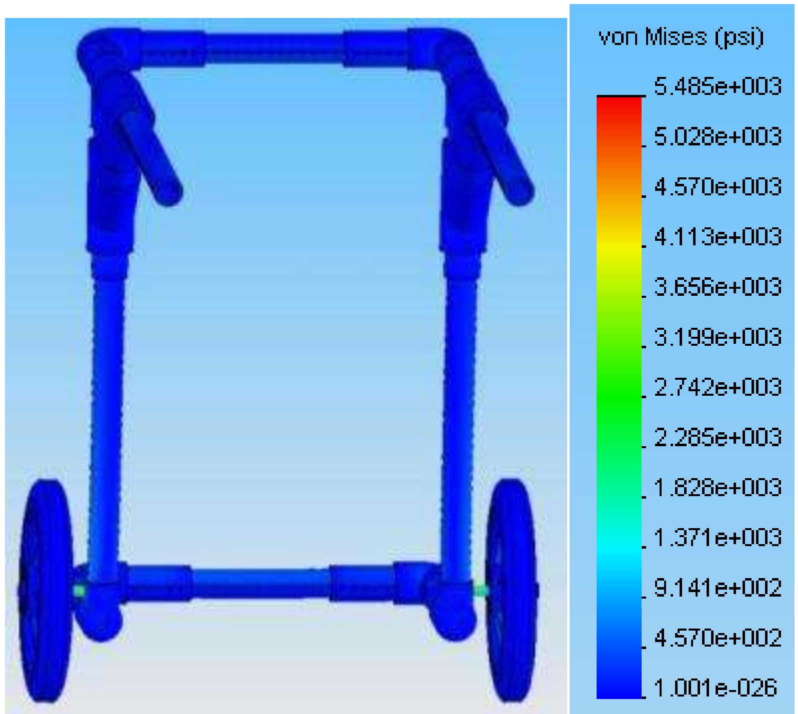


FIGURE 22 – Von Mises Stress Distribution of the Large Size Wheelchair in its Fully Extended Configuration and Associated Stress Fringe Order.

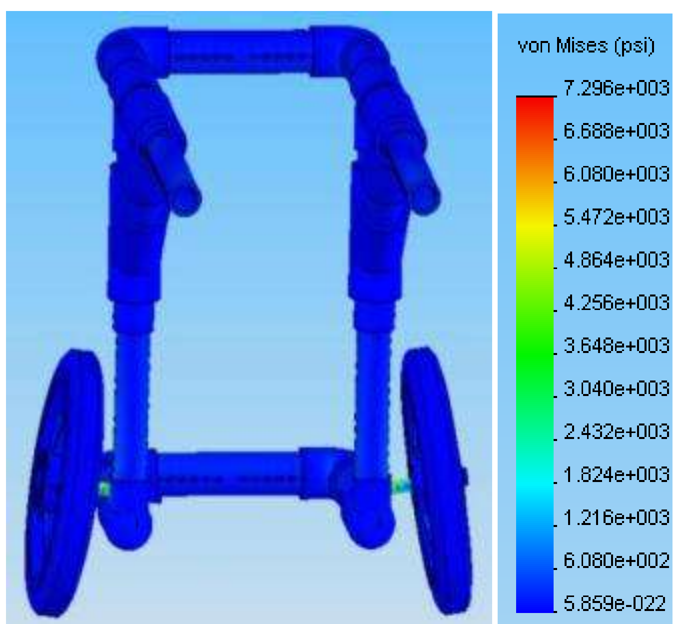


FIGURE 23 - Von Mises Stress Distribution of the Large Size Wheelchair in its Fully Contracted Configuration with an 8° Wheel Camber and Associated Stress Fringe Order.

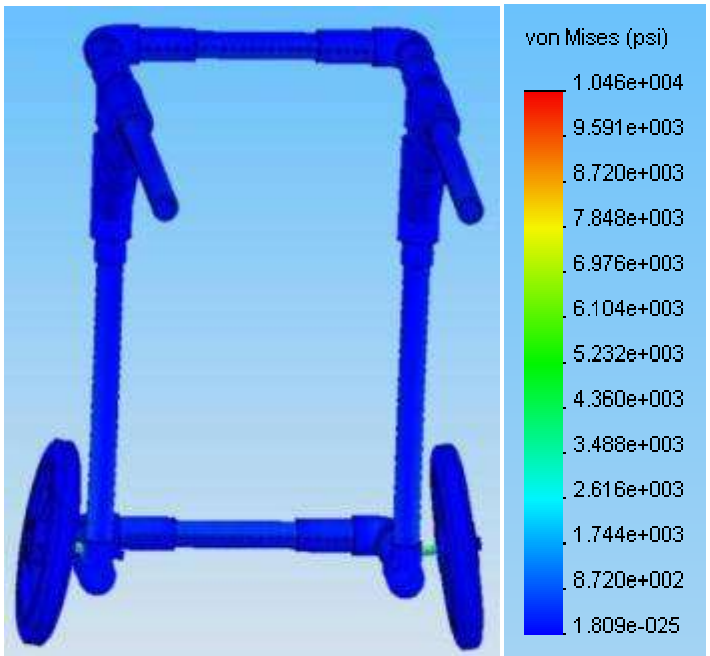


FIGURE 24 - Von Mises Stress Distribution of the Large Size Wheelchair in its Fully Extended Configuration with an 8° Wheel Camber and Associated Stress Fringe Order.

The largest stresses are placed on the axle of the wheelchair for each design. Figure 26 through 32 are close up views of the axle joint on the frame of each wheelchair.

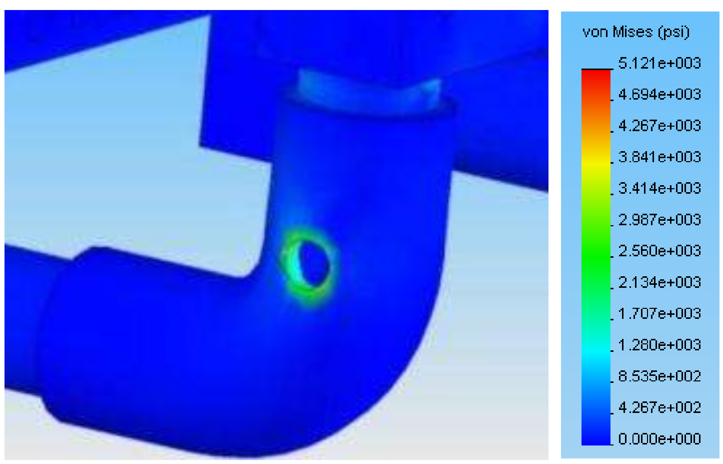


FIGURE 25 – Stresses on the Small Wheelchair Frame at the Axle Connection (Fully Contracted Configuration).

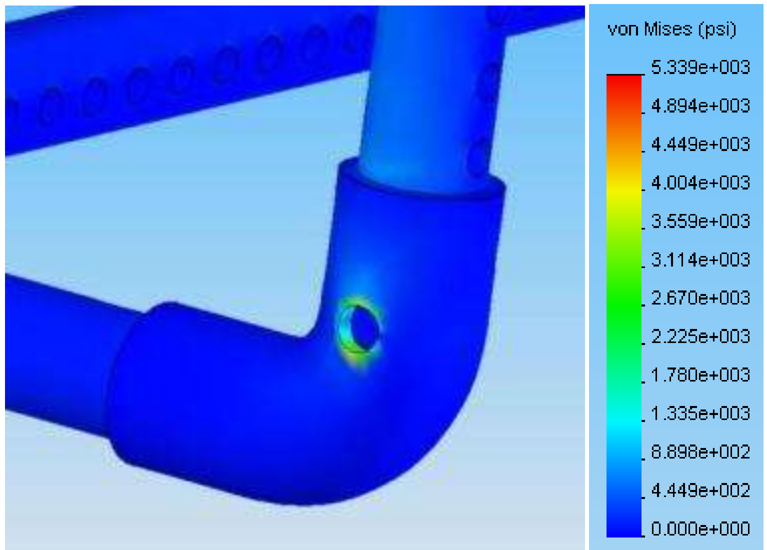


FIGURE 26 – Stresses on the Small Wheelchair Frame at the Axle Connection (Fully Extended Configuration).

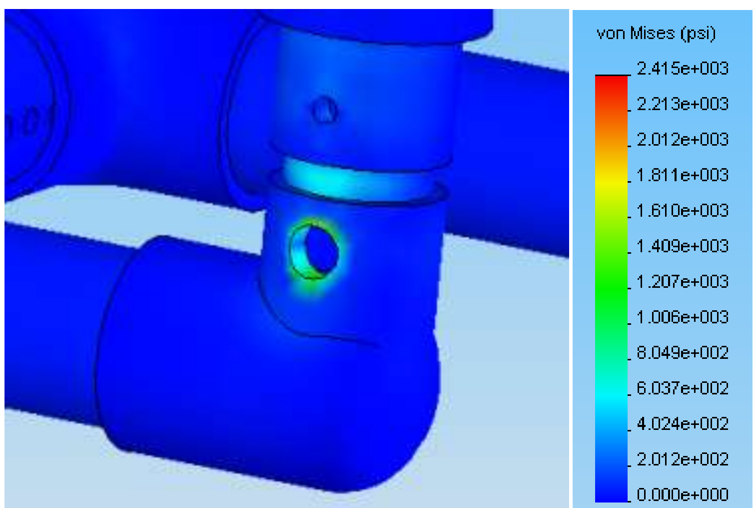


FIGURE 27 – Stresses on the Medium Wheelchair Frame at the Axle Connection (Fully Contracted Configuration).

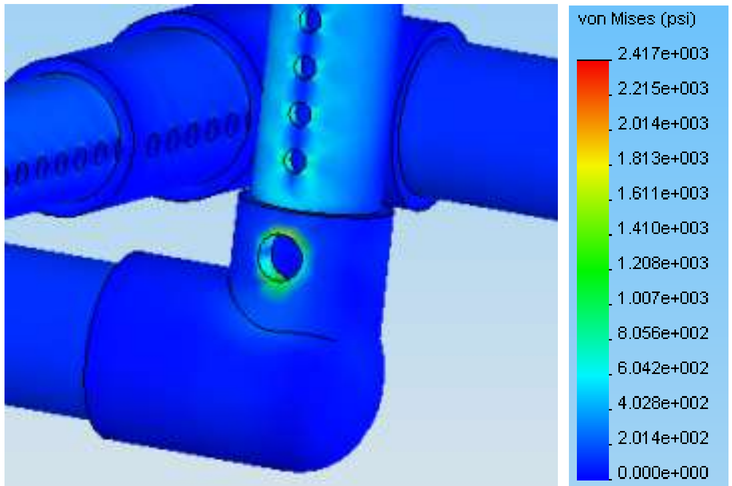


FIGURE 28 – Stresses on the Medium Wheelchair Frame at the Axle Connection (Fully Extended Configuration).

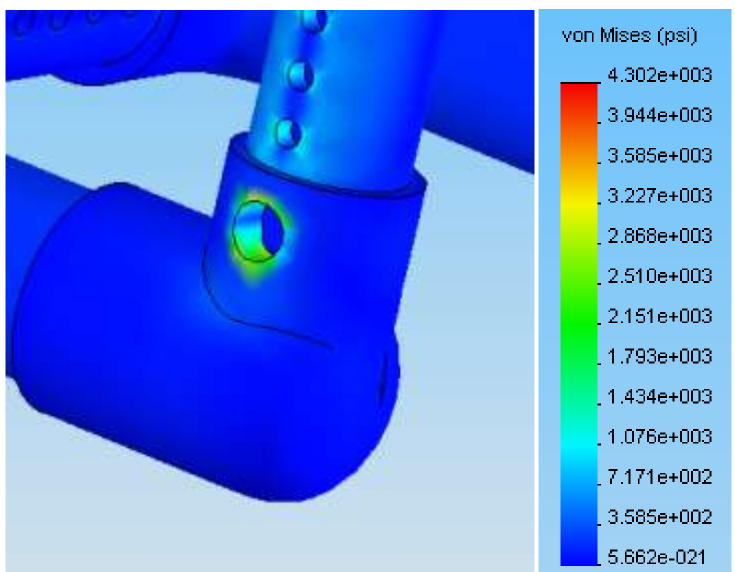


FIGURE 29 – Stresses on the Large Wheelchair Frame at the Axle Connection (Fully Contracted Configuration).

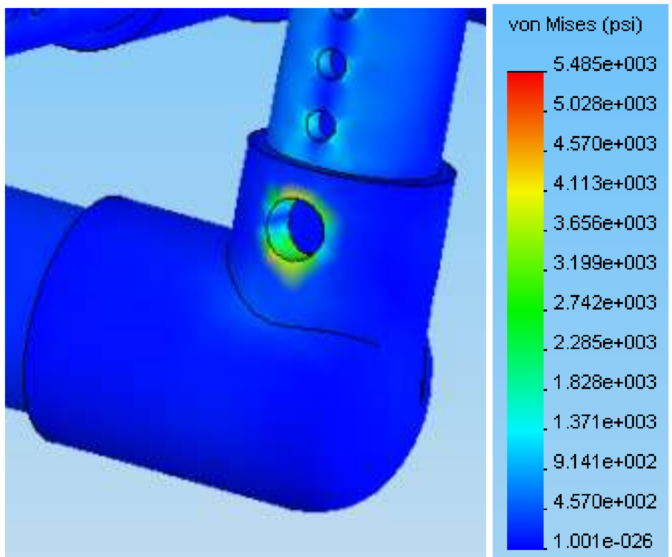


FIGURE 30 – Stresses on the Large Wheelchair Frame at the Axle Connection (Fully Extended Configuration).

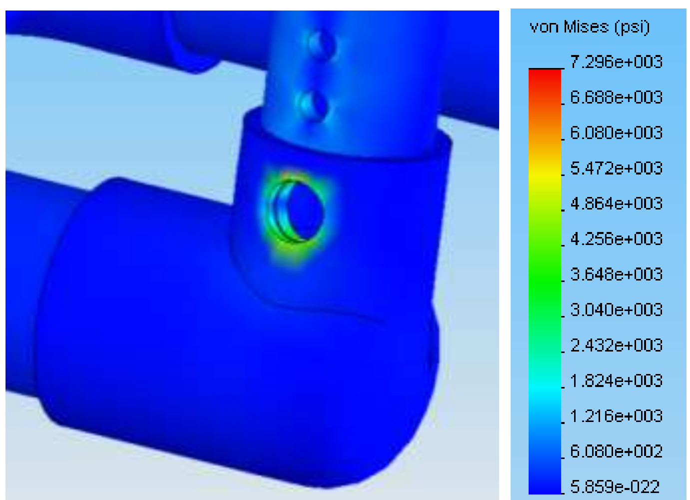


FIGURE 31 – Stresses on the Large Wheelchair Frame at the Axle Connection (Fully Contracted Configuration, 8^{o} Wheel Camber).

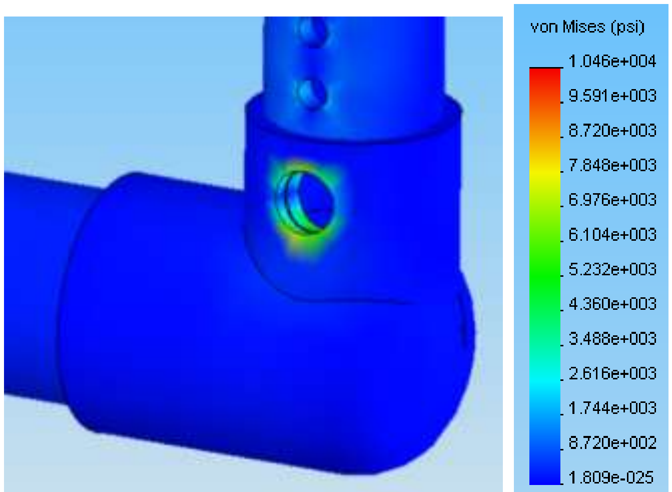


FIGURE 32 – Stresses on the Large Wheelchair Frame at the Axle Connection (Fully Extended Configuration, 8^o Wheel Camber).

Table 8 contains the maximum von Mises stress value experienced by each wheelchair design which occurred either on the outside or inside of the axle-to-frame interface. Each wheelchair experienced maximum stress values on the axle of the wheelchair.

TABLE 8

VON MISES STRESS RESULTS FROM FEA STATIC STRENGTH ANALYSIS

Wheelchair (configuration)	Max. von Mises Stress on Wheelchair (psi)	Max. von Mises Stress on Frame (psi)
Small (contracted)	5121	3770
Small (extended)	5339	4112
Medium (contracted)	2415	1866
Medium (extended)	2417	1991
Large (contracted)	4302	3144
Large (extended)	5485	4548
Large (contracted, 8^o wheel camber)	7296	5680
Large (extended, 8^o wheel camber)	10460	7234

Note: The yield strength of PVC used is 7500 psi. Stresses are based upon a maximum weight capacity with a FOS = 2.

The displacement of the wheelchair was also determined through the static strength analysis. Figures 33 through 40 provide displacement distributions for each wheelchair design and their associated fringe orders.

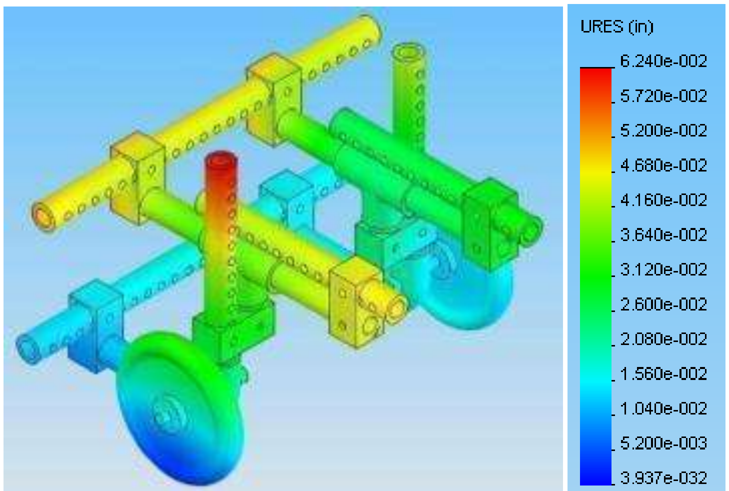


FIGURE 33 – Displacement Distributions for the Small Size Wheelchair in the Fully Contracted Configuration.

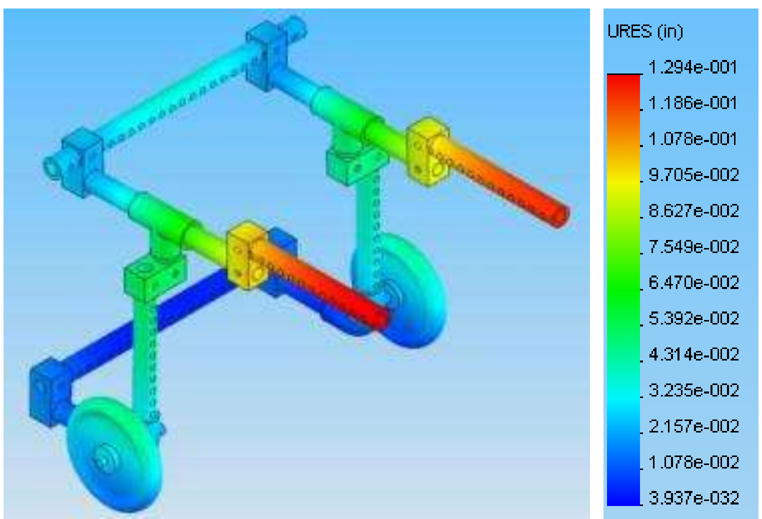


FIGURE 34 – Displacement Distribution for the Small Size Wheelchair in the Fully Extended Configuration.

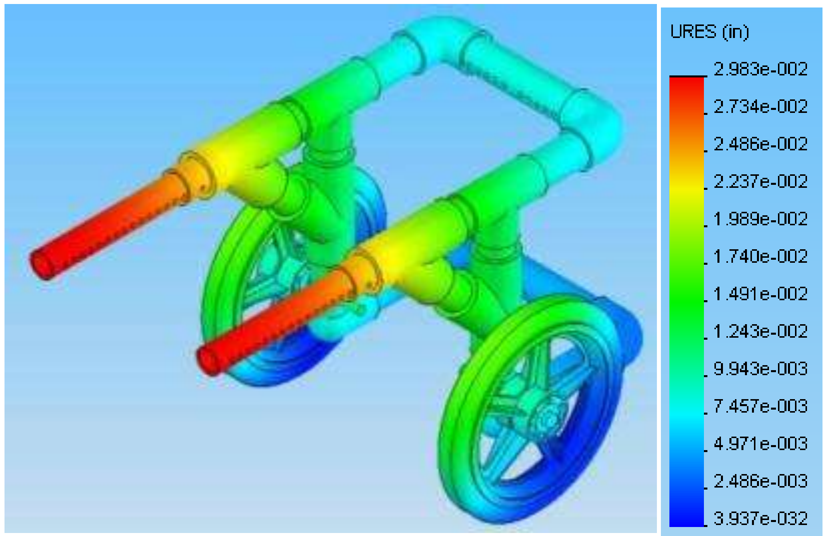


FIGURE 35 – Displacement Distribution for the Medium Size Wheelchair in the Fully Contracted Configuration.

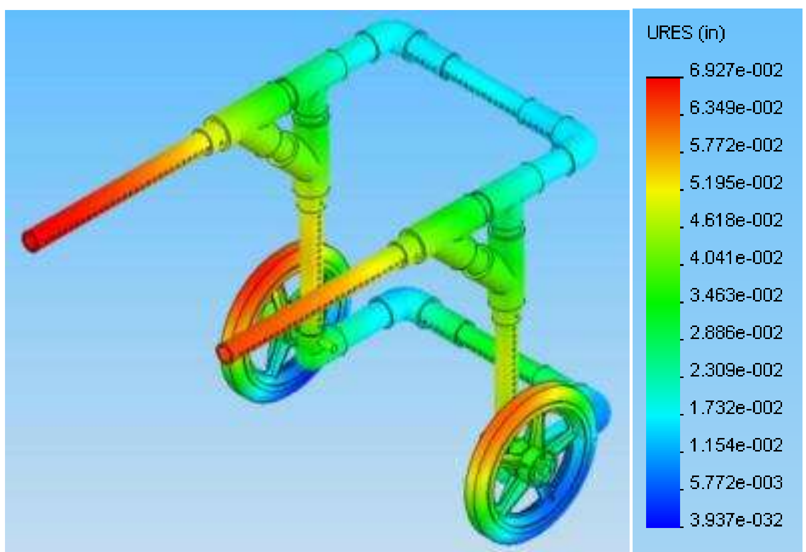


FIGURE 36 – Displacement Distribution for the Medium Size Wheelchair in the Fully Extended Configuration.

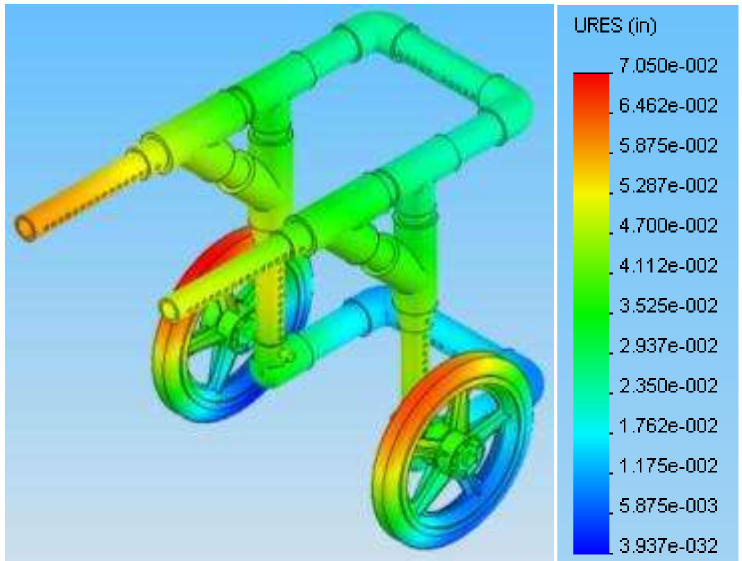


FIGURE 37 – Displacement Distribution for the Large Size Wheelchair in the Fully Contracted Configuration.

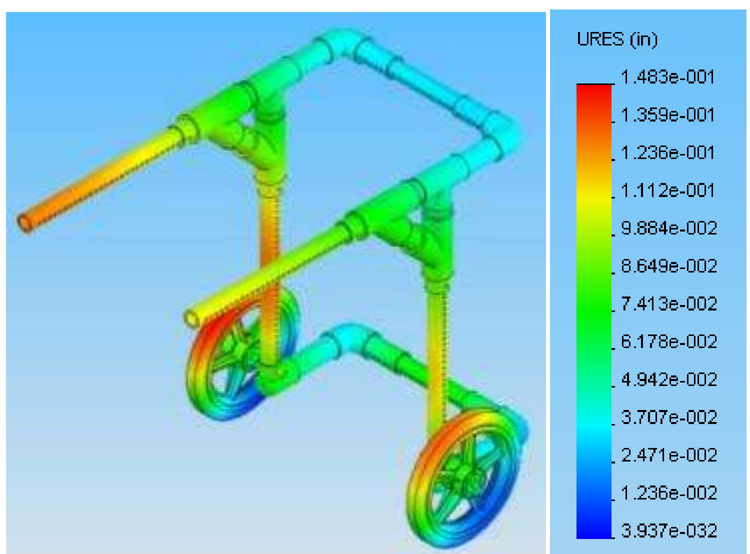


FIGURE 38 – Displacement Distribution for the Large Size Wheelchair in the Fully Extended Configuration.

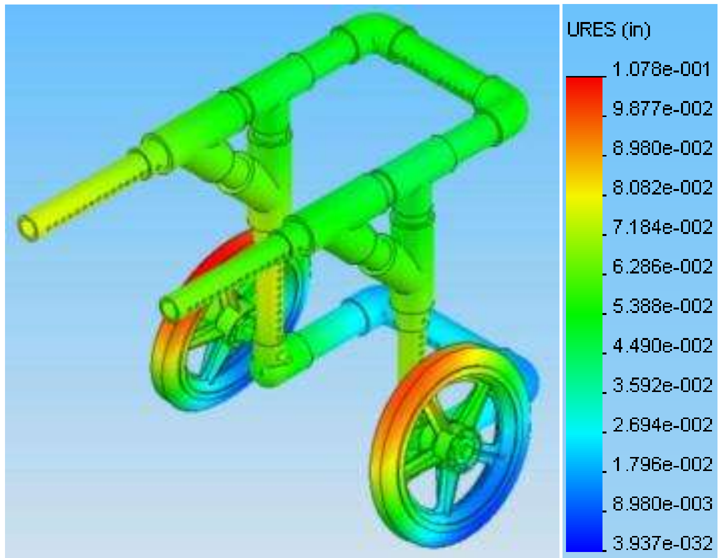


FIGURE 39 – Displacement Distribution for the Large Size Wheelchair in the Fully Extended Configuration (8^o Wheel Camber).

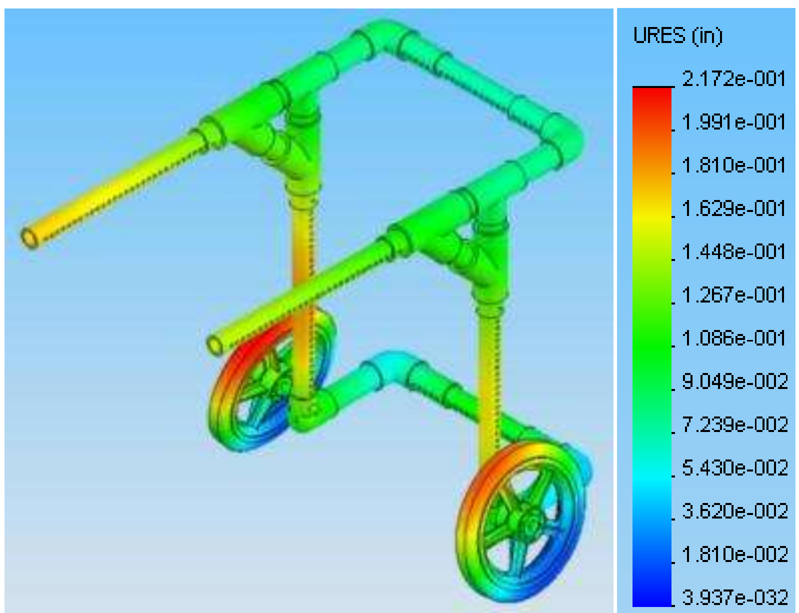


FIGURE 40 – Displacement Distribution for the Large Size Wheelchair in the Fully Extended Configuration (8^o Wheel Camber).

Table 9 contains the maximum displacement for each wheelchair configuration. The maximum displacements occurred at the front tips of the wheelchair and the top of the wheels.

TABLE 9

MAXIMUM DISPLACEMENT FOR EACH WHEELCHAIR

Wheelchair Size (configuration)	Max. Displacement (in)
Small (contracted)	0.06
Small (extended)	0.13
Medium (contracted)	0.03
Medium (extended)	0.07
Large (contracted)	0.07
Large (extended)	0.15
Large (contracted, 8^o wheel camber)	0.11
Large (extended, 8^o wheel camber)	0.22

B. <u>Fatigue Strength Analysis</u>

With the static strength analysis finished the results from the analyses were used to solve for the fatigue life-cycles of each wheelchair frame. Figures 41 - 48 display the fatigue life cycle plots for each wheelchair design. The wheels assembly has been removed to clearly show the areas of fatigue failure. Fatigue failure is most likely to occur in the area where the axle connects to the frame.

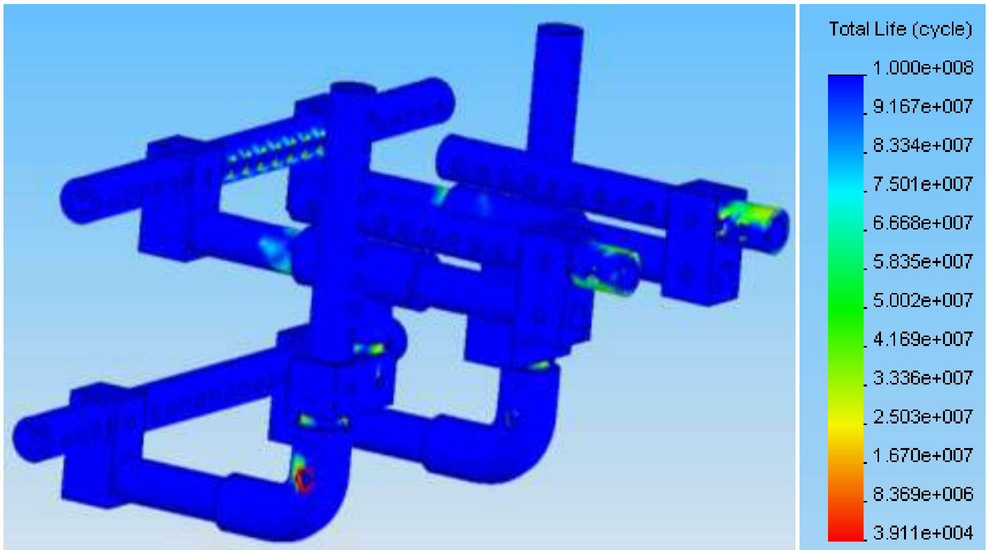


FIGURE 41 – Fatigue Life Plot for the Small Size Wheelchair (Fully Contracted Configuration).

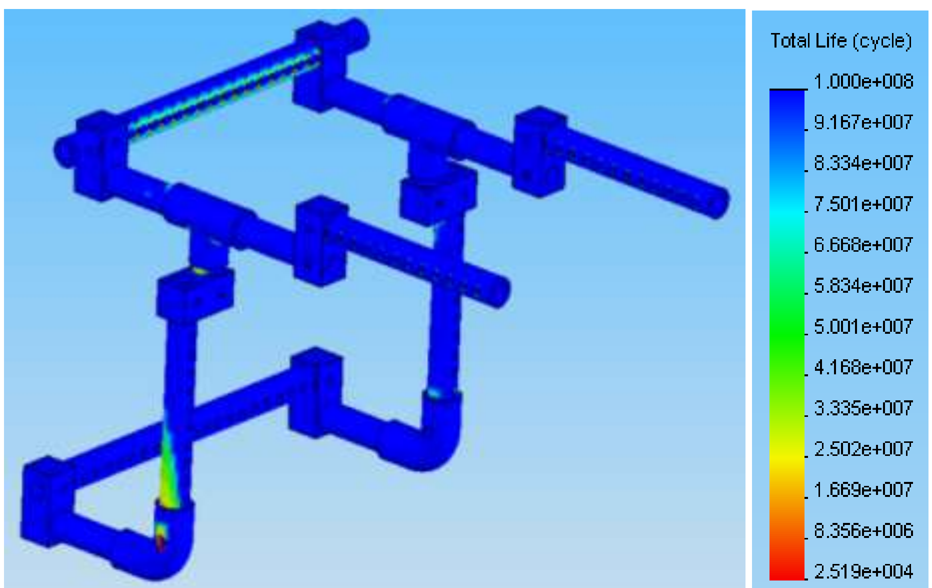


FIGURE 42 – Fatigue Life Plot for the Small Size Wheelchair (Fully Extended Configuration).

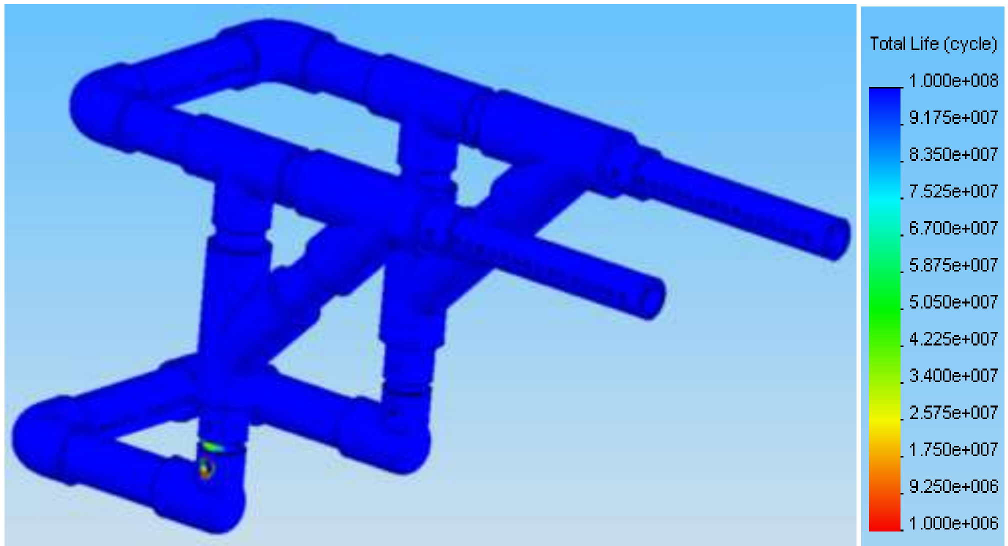


FIGURE 43 – Fatigue Life Plot for the Medium Size Wheelchair (Fully Contracted Configuration).

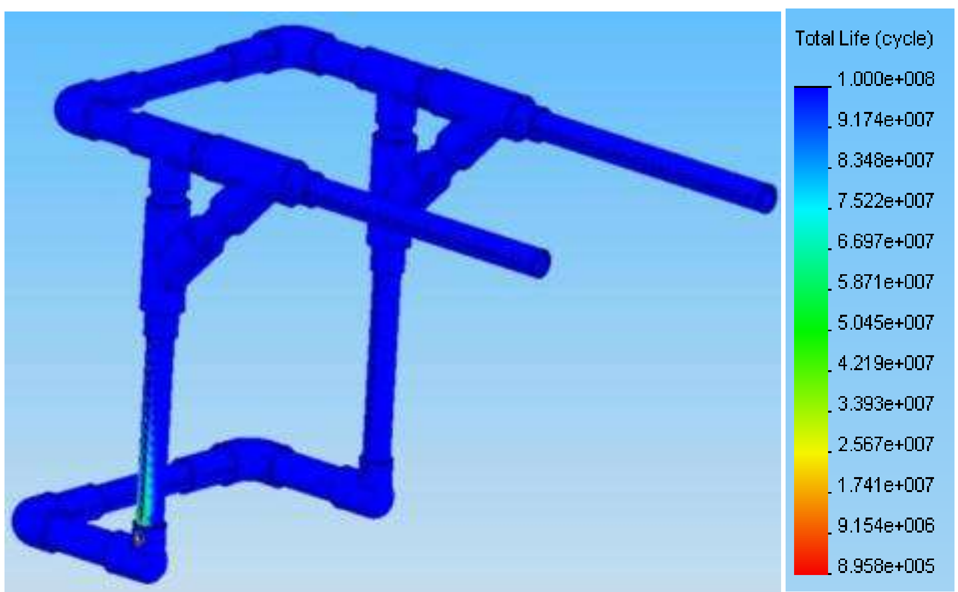


FIGURE 44 – Fatigue Life Plot for the Medium Size Wheelchair (Fully Extended Configuration).

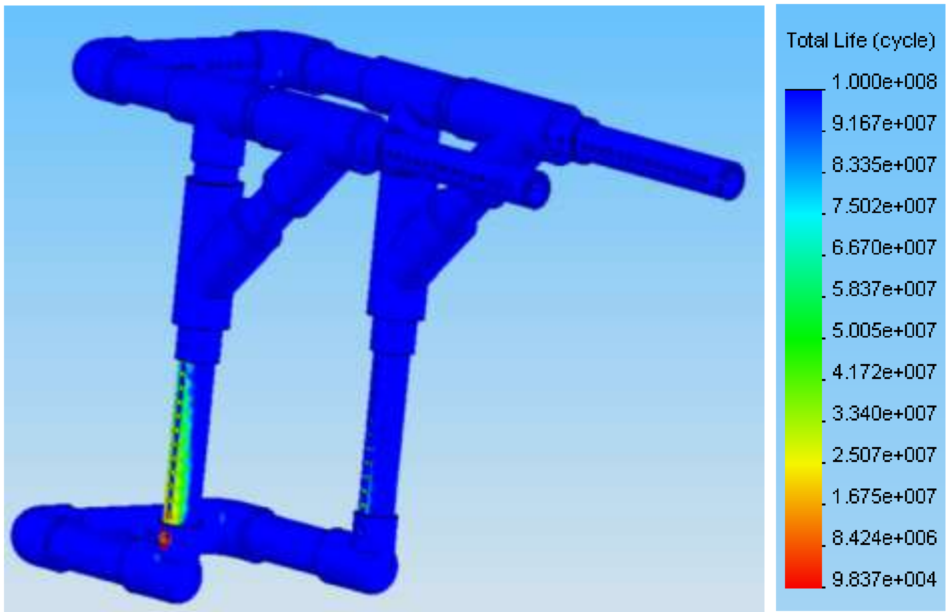


FIGURE 45 – Fatigue Life Plot for the Large Size Wheelchair (Fully Contracted Configuration).

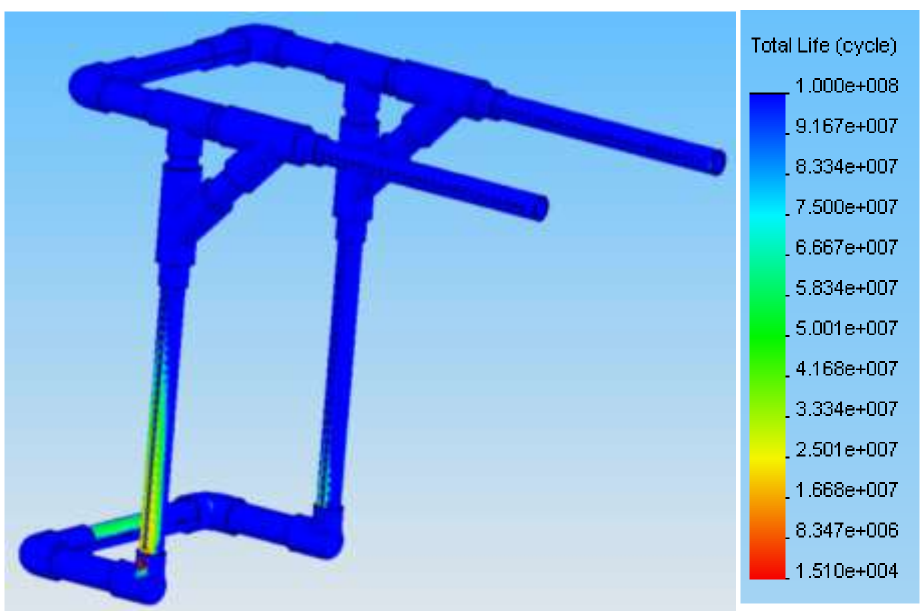


FIGURE 46 – Fatigue Life Plot for the Large Size Wheelchair (Fully Extended Configuration).

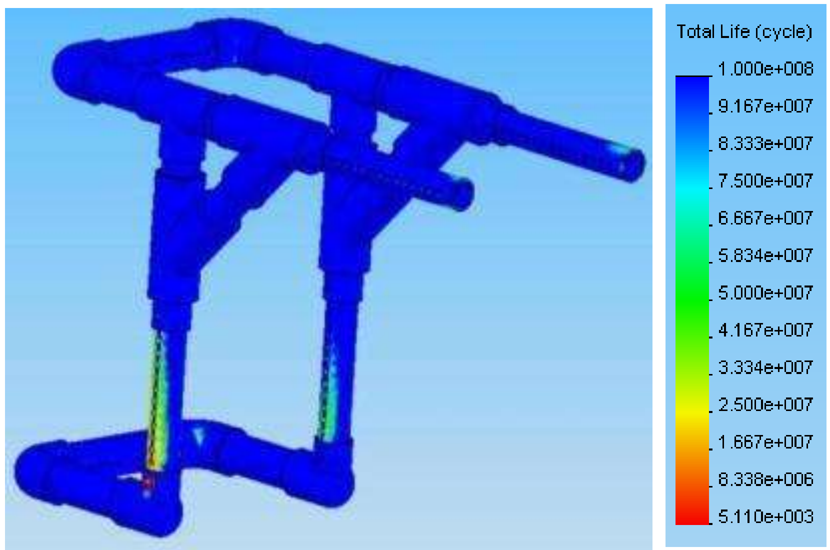


FIGURE 47 – Fatigue Life Plot for the Large Size Wheelchair (Fully Contracted Configuration, 8^o Wheel Camber).

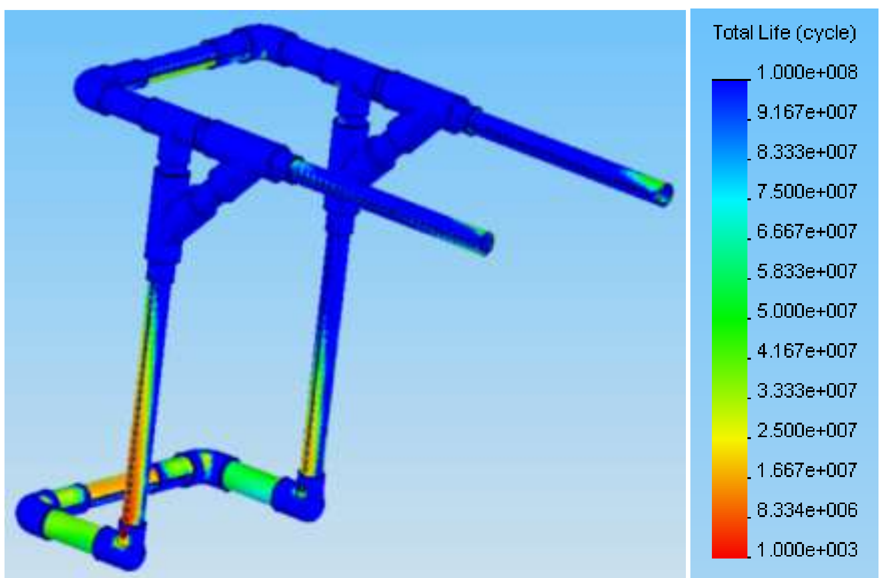


FIGURE 48 – Fatigue Life Plot for the Large Size Wheelchair (Fully Extended Configuration, 8^o Wheel Camber).

Figures 49 through 56 are a close up of the elbow fitting where the frame connects to the axle.

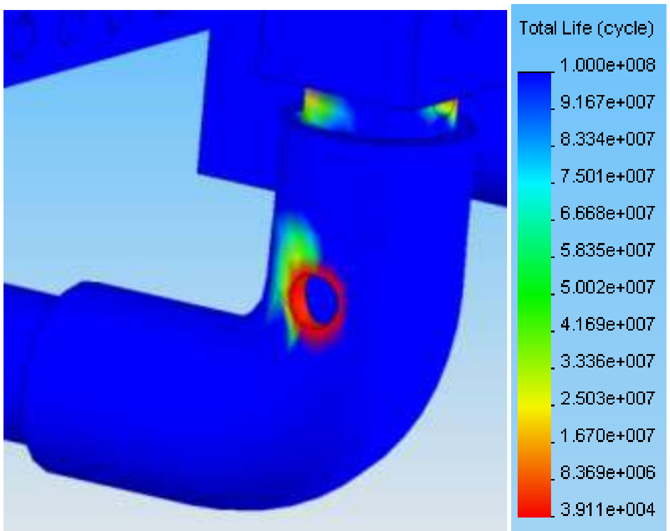


FIGURE 49 – Location of Fatigue Failure for the Small Size Wheelchair (Contracted Configuration).

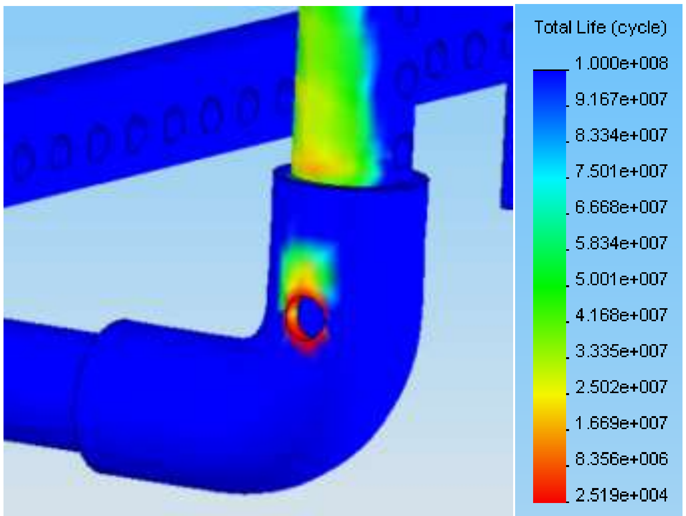


FIGURE 50 – Location of Fatigue Failure for the Small Size Wheelchair (Extended Configuration).

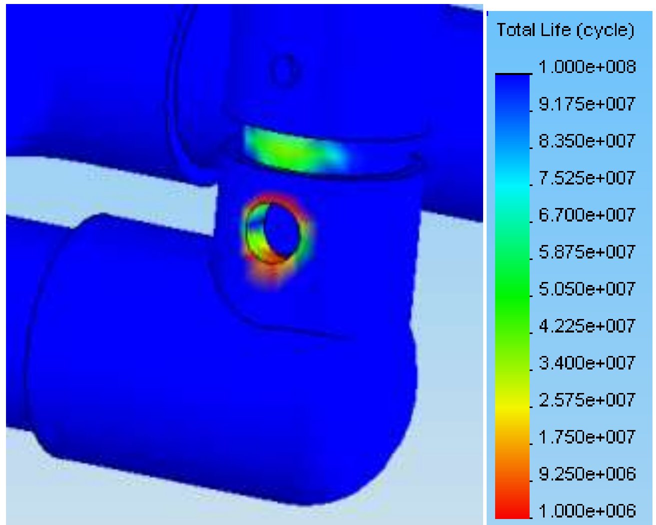


FIGURE 51 – Location of Fatigue Failure for the Medium Size Wheelchair (Contracted Configuration).

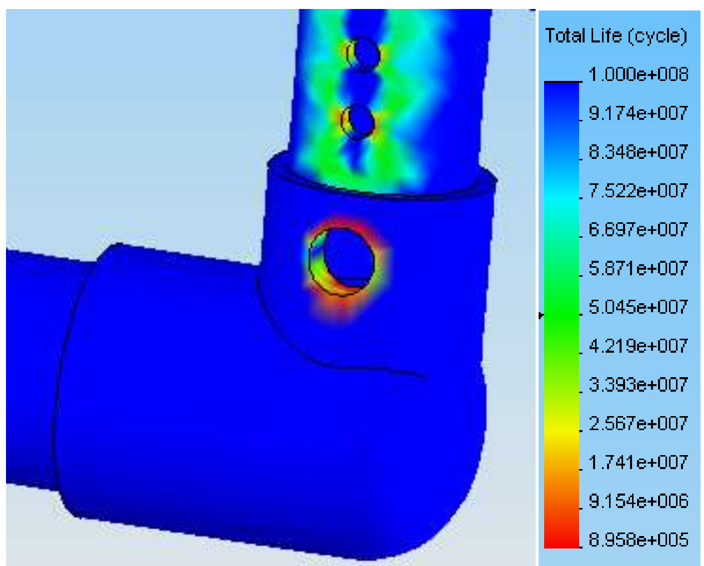


FIGURE 52 – Location of Fatigue Failure for the Medium Size Wheelchair (Extended Configuration).

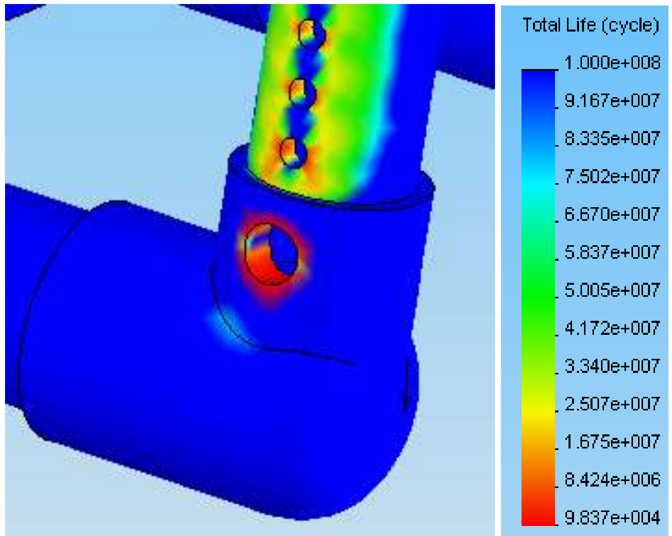


FIGURE 53 – Location of Fatigue Failure for the Large Size Wheelchair (Contracted Configuration).

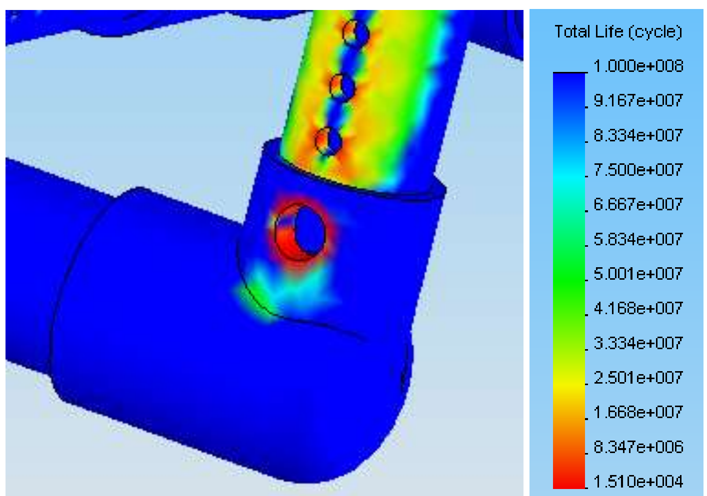


FIGURE 54 – Location of Fatigue Failure for the Large Size Wheelchair (Extended Configuration).

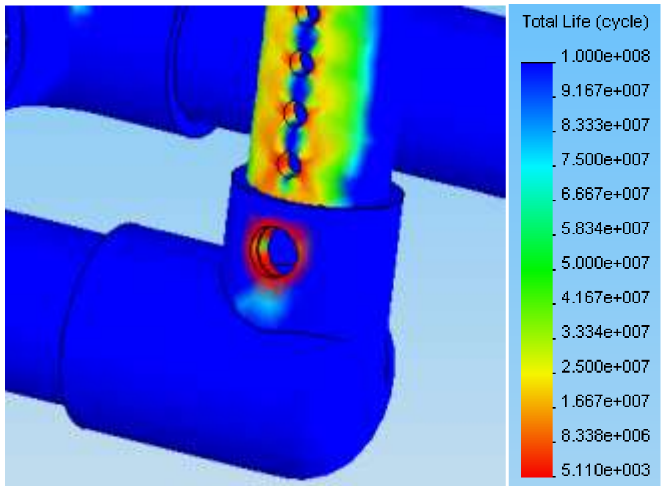


FIGURE 55 – Location of Fatigue Failure for the Large Size Wheelchair (Contracted Configuration, 8^{o} Wheel Camber).

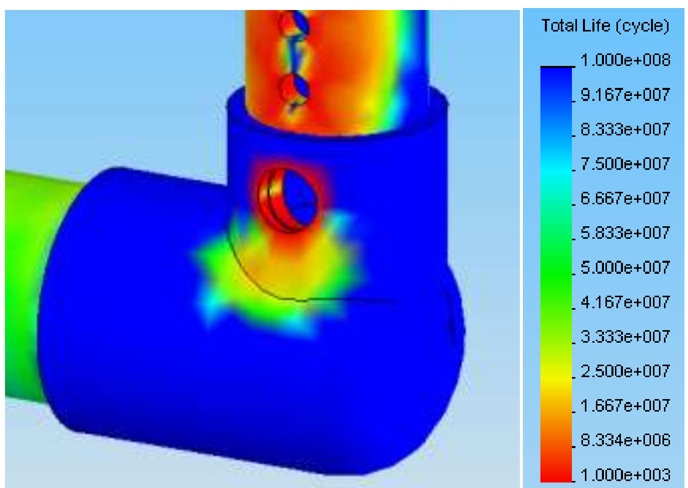


FIGURE 56 – Location of Fatigue Failure for the Large Size Wheelchair (Extended Configuration, 8^{o} Wheel Camber).

Table 10 contains the predicted fatigue life-cycle values of each wheelchair design for both fully contracted and extended Configurations.

TABLE 10

PREDICTED LIFE-CYCLES OF EACH WHEELCHAIR

Wheelchair (configuration)	Life-Cycles
Small (contracted)	$3.91x10^4$
Small (extended)	$2.52x10^4$
Medium (contracted)	$1.00x10^6$
Medium (extended)	$8.95x10^5$
Large (contracted)	$9.84x10^4$
Large (extended)	$1.51x10^4$
Large (contracted, 8^o Wheel Camber)	$5.11x10^3$
Large (extended, 8^o Wheel Camber)	$1.00x10^3$

C. Static Stability Analysis

The lateral static stability of each wheelchair was analyzed using COSMOSMotion™ by positioning the wheelchair on a rotating platform. Figure 57 shows the progression of the wheelchair as the platform rotated until the tip angle is reached.

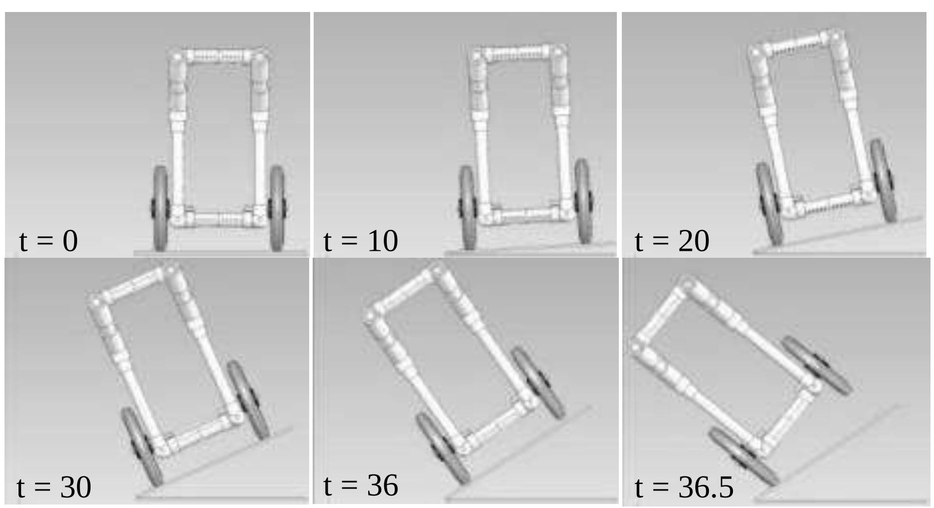


FIGURE 57 – Lateral Static Stability Analysis for the Medium Size Wheelchair in its Least Stable Configuration.

All wheelchair stability analyses are similar to that shown in Figure 57. Figure 58 shows the angle of the rotating platform over the 90 second rotation for the medium wheelchair in its least stable configuration.

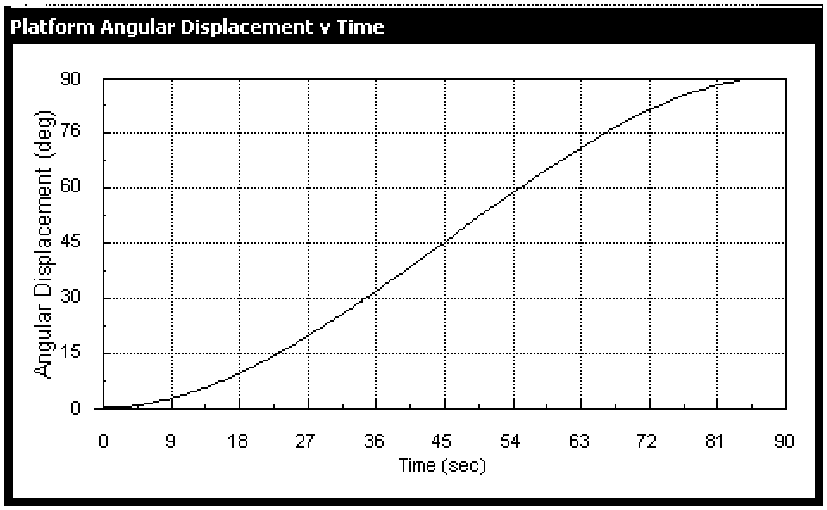


FIGURE 58 - Angular Displacement of the Rotating Platform Over Time.

Figure 59 through 66 are the graphs for the angular displacement between the wheel furthest from the axes of rotation and the tipping platform over the 90 second test period for both least and most stable configurations of each wheelchair design.

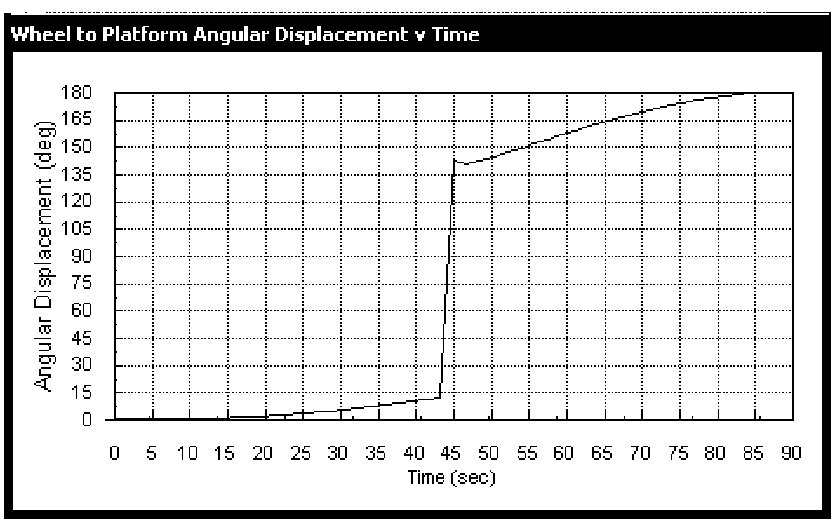


FIGURE 59 – Wheel to Platform Angular Displacement Over Time for the Small Size Wheelchair (Least Stable Configuration).

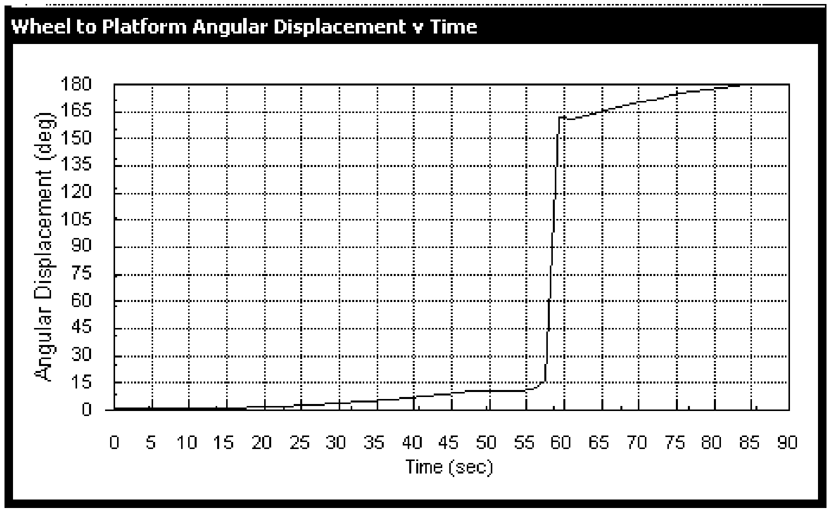


FIGURE 60 – Wheel to Platform Angular Displacement Over Time for the Small Size Wheelchair (Most Stable Configuration).

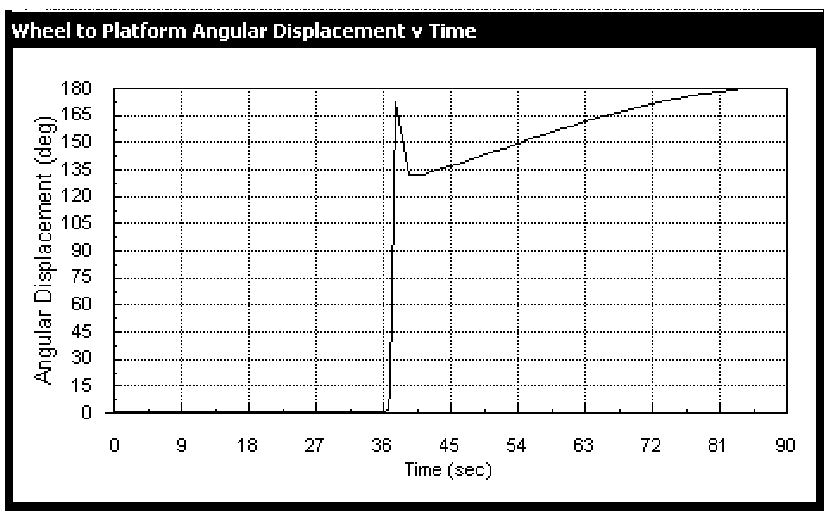


FIGURE 61 – Wheel to Platform Angular Displacement Over Time for the Medium Size Wheelchair (Least Stable Configuration).

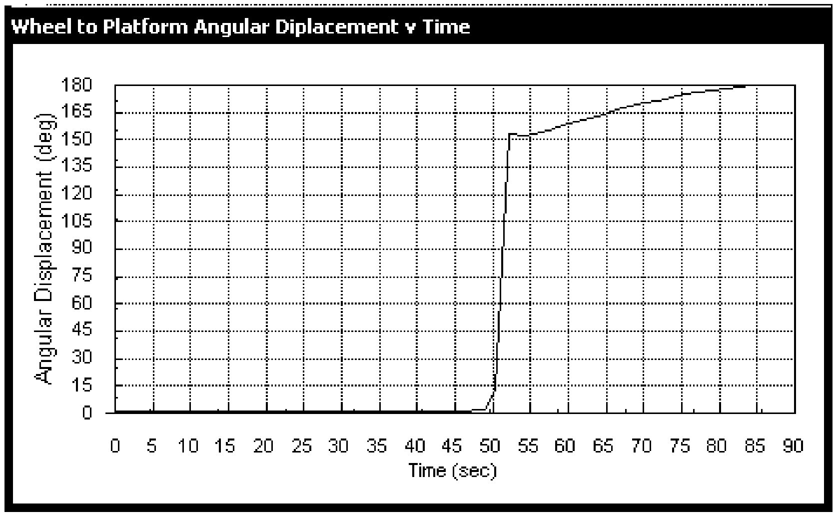


FIGURE 62 – Wheel to Platform Angular Displacement Over Time for the Medium Size Wheelchair (Most Stable Configuration).

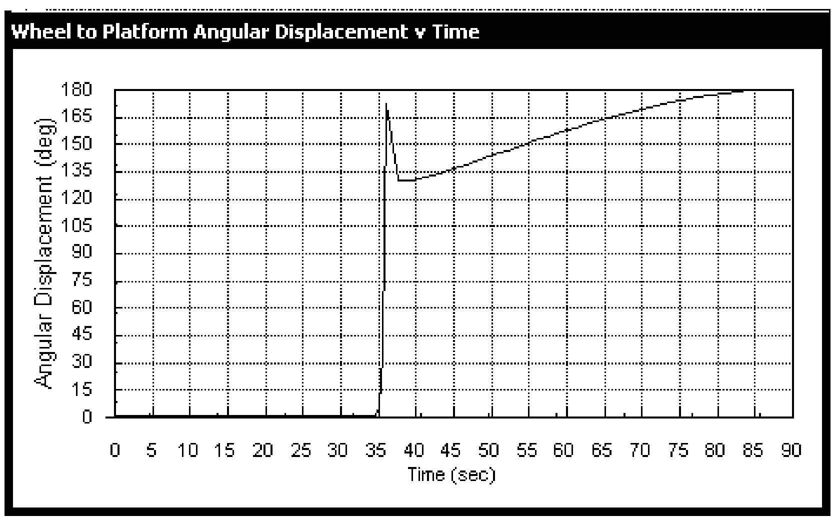


FIGURE 63 –Wheel to Platform Angular Displacement Over Time for the Large Size Wheelchair (Least Stable Configuration).

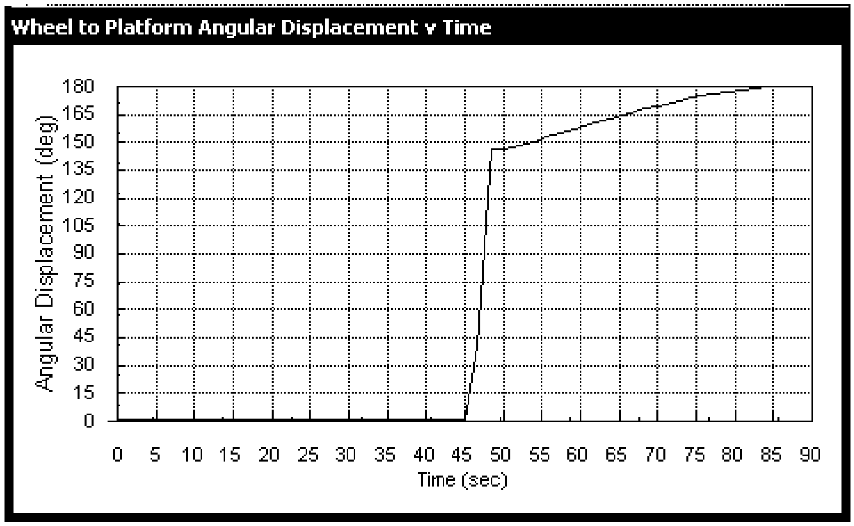


FIGURE 64 –Wheel to Platform Angular Displacement Over Time for the Large Size Wheelchair (Most Stable Configuration).

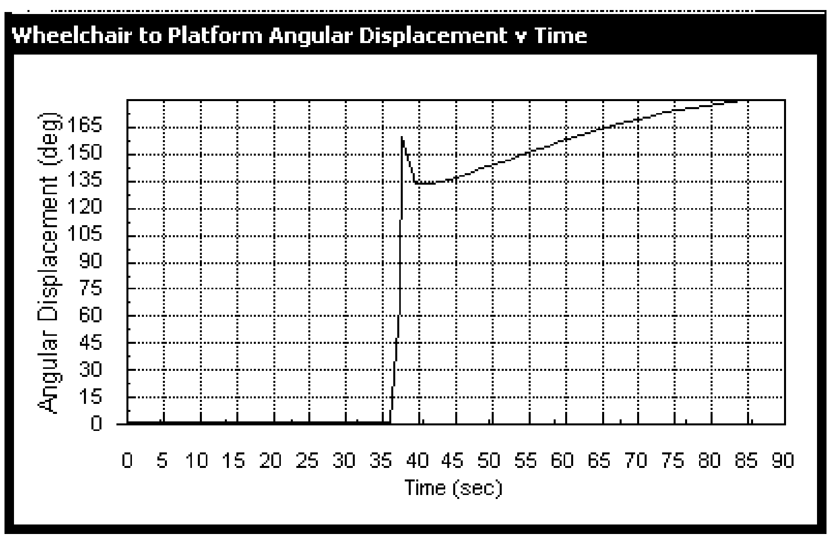


FIGURE 65 –Wheel to Platform Angular Displacement Over Time for the Large Size Wheelchair (Least Stable Configuration with 8° Wheel Camber).

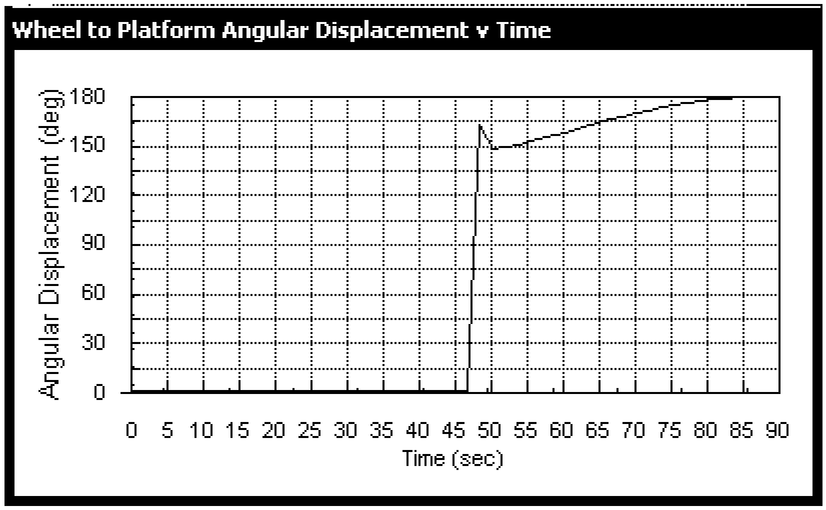


FIGURE 66 – Wheel to Platform Angular Displacement Over Time for the Large Size Wheelchair (Most Stable Configuration with 8° Wheel Camber).

The wheelchair is considered unstable when the angle between the wheel and the platform spikes as in Figure 58. The time at which the tipping occurs is then compared with the angular displacement of the platform in Figure 35 to determine the tipping angle. Table 11 contains the tip angle values (in degrees) for the six test setups.

TABLE 11

LATERAL TIP ANGLES FROM STATIC STABILITY ANALYSIS.

Wheelchair Size	Least Stable Angle (Degrees)	Most Stable Angle (Degrees)
Small	43	61
Medium	32	49
Large	30	45
Large (8° wheel camber)	32	48

The smallest wheelchair is the most stable of the three wheelchair designs. The least stable is the large wheelchair without the camber on the wheels

3. Construction of the prototypes for each of the wheelchair designs.

A. Bill of Materials (BOM)

The bill of material (BOM) was developed as the materials were purchased for building the prototypes. The cost of the wheelchair was evaluated three ways: total cost, total cost without harnesses, and total cost of frame. Table 12 contains the final cost of each wheelchair design.

TABLE 12

COST COMPARISON OF WHEELCHAIR DESIGNS

Wheelchair Size	Total Cost	Total Cost Without Harnesses	Total Cost of Frame
Small	$148.43	$88.43	$47.97
Medium	$218.26	$89.36	$51.09
Large	$219.13	$90.82	$52.22

The entire BOM with a breakdown of information for each part for each wheelchair is provided in the APPENDIX II. The commercial harnesses accounted for 40 to 60 percent of the total cost of the wheelchair

B. Consturction Jigs and Prototypes

Wheelchair construction was aided through the use of one design jig. The purpose of the jig was to drill the holes that allow for wheelchair adjustability. The construction jig centers a piece of PVC pipe under the bit on any regular drill press and slides along the base to allow consecutive holes to be drilled. Figure 67 contains the solid model of the design jig and the physical jig used for the prototyping.

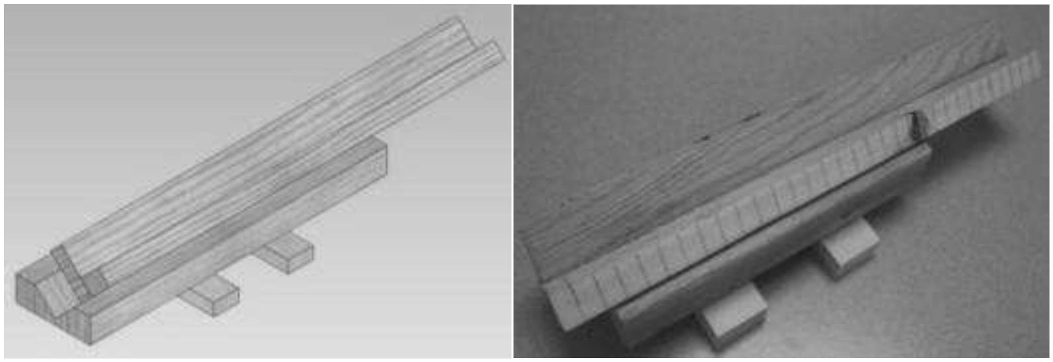


FIGURE 67 – Solid Model and Physical Jig used for Drilling Holes.

Detailed instructions for the construction and use of the construction jig are in the APPENDIX III.

Figure 68 is the prototype built for the small wheelchair design.

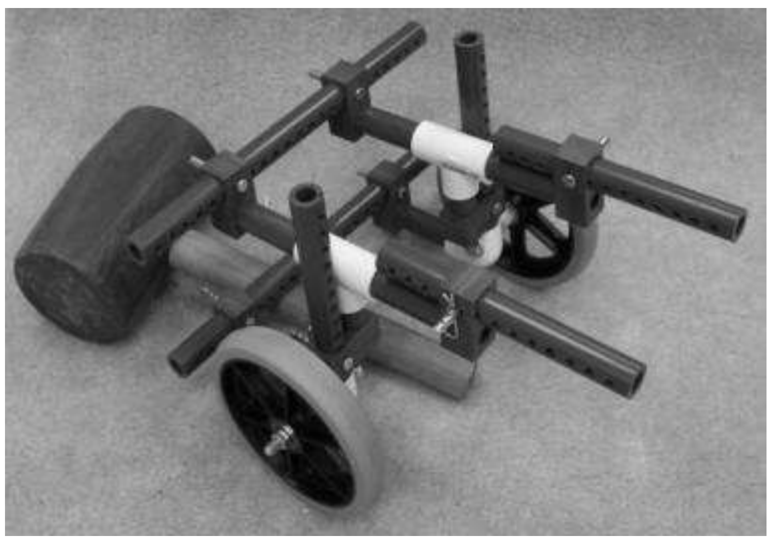


FIGURE 68 – Small Wheelchair Prototype.

Since the small wheelchair is designed for the smaller breeds of dogs, the small wheelchair prototype will utilize a 5/8 in plastic buckle to connect the harness to the frame. Figure 69 is the prototype built for the medium wheelchair design.

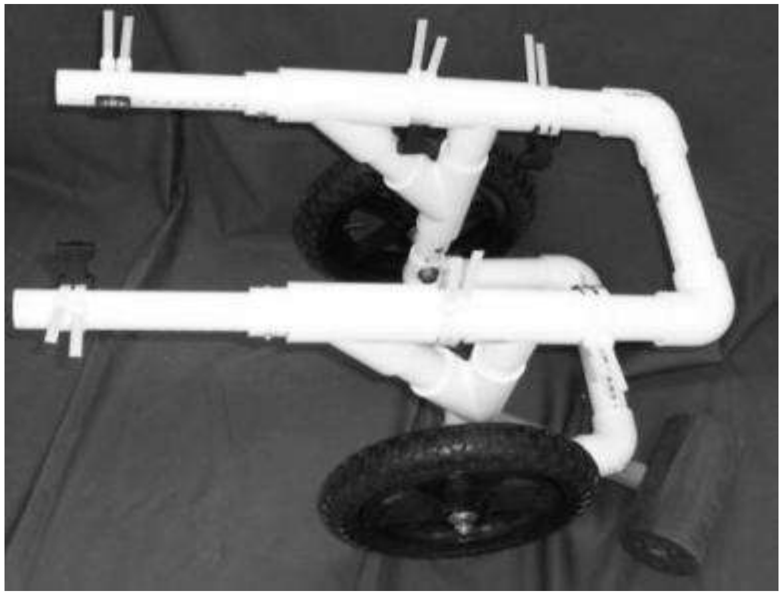


FIGURE 69 – Medium Wheelchair Prototype.

Figure 70 is the prototype built for the large wheelchair design.

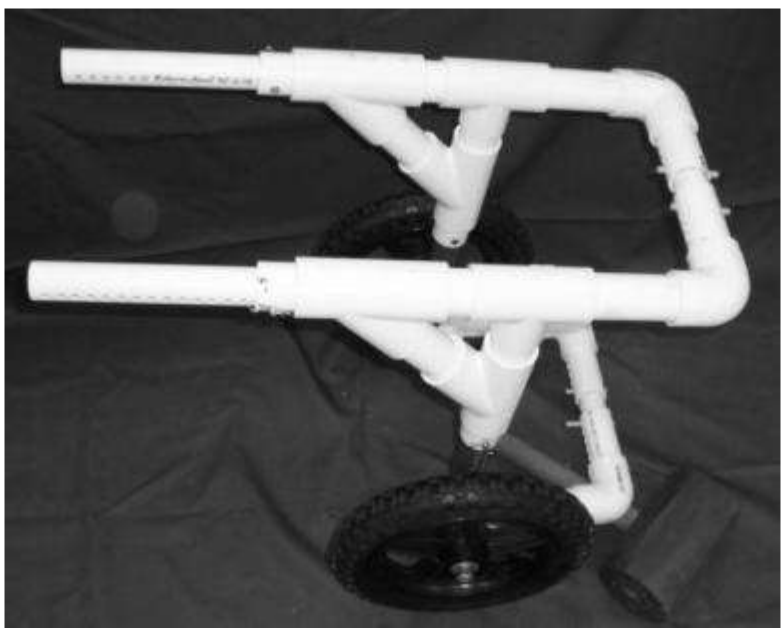


FIGURE 70 – Large Wheelchair Prototype.

Each wheelchair took an average of 4-5 hours to process and assemble. The majority of the time was spent processing each part for the wheelchair prototypes. The medium and large wheelchair took approximately the same time to construct because of the similarities in the design. Cutting and drilling the holes on the pipes required on average 3.5 hours, while the actual assembling of those parts only took 30 minutes. Table 13 contains the weight of each wheelchair including the wheels.

TABLE 13

WHEELCHAIR PROTOTYPE WEIGHT

Wheelchair Size	Weight (lbs)
Small	3.25
Medium	12.5
Large	12.75

The center of gravity was also determined for each prototype in its contracted and extended configurations (TABLE 14). The center of gravity of each wheelchair was found using a suspension method.

TABLE 14

CENTER OF GRAVITY FOR EACH WHEELCHAIR

Wheelchair Size (configuration)	CG_x (in)	CG_y (in)	CG_z (in)
Small (contracted)	0.375	3.00	5.25
Small (extended)	0.375	4.00	7.75
Medium (contracted)	0.375	4.50	8.5
Medium (extended)	0.25	8.00	11.25
Large (contracted)	0.07	6.02	8.5
Large (extended)	0.51	9.44	11.25
Large (contracted, 8^o wheel camber)	0.07	6.09	8.5
Large (extended, 8^o wheel camber)	0.51	9.52	11.25

Note: All dimensions relative to the axle hub.

C. Assembly Instruction Manual

The Assembly Instruction Manual details the process preparing parts and for assembling each wheelchair. The manual uses pictures taken while assembling the wheelchair to create a user friendly method for assembling the wheelchairs. The full manuals are attached in the APPENDIX III. The Assembly Instruction Manual also includes how to interface the wheelchair frame with the harnesses.

V. Discussion

A. QFD

TABLE 15

SUMMARY OF QFD DESIGN GOALS

	Small Wheelchair		Medium Wheelchair		Large Wheelchair	
Design Requirements	Contracted	Extended	Contracted	Extended	Contracted	Extended
Weight Range of Dog	P	P	P	P	P	P
Minimum Cost	P	P	N/A	N/A	N/A	N/A
Maximum Cost	N/A	N/A	F	F	F	F
Adjustable Range	P	P	P	P	P	P
Number of tools for adjustments	P	P	P	P	P	P
Time to assemble wheelchair	P	P	P	P	P	P
Time it take to process wheelchair	P	P	P	P	P	P
Number of adjustment points	P	P	P	P	P	P
Number of parts that can be easily replaced	P	P	P	P	P	P
Wheelchair weight	P	P	F	F	F	F
Fatigue Strength	F	F	P	P	F	F
Lateral tip angle	P	P	P	P	P	P
Factor of Safety	P	P	P	P	P	P

Table 15 is a summary of the QFD Design Goals of this project and whether the wheelchair design passed (P) or failed (F) the requirements. The performance of each with respect to the design goals are discussed in greater detail below.

B. Small Wheelchair Design

The small wheelchair design was developed to support the smallest range of canine breeds. Since the 1 in and 1-1/4 in PVC pipes were large compared with the size of the smaller breeds of canine, the decision was to use the smaller 1/2 in Schedule 80 PVC pipe for its increased wall thickness and rigidity. Half inch PVC pipe does not telescope with 3/4 in or 1/4 in PVC pipe, so a 1 in by 1 in square bar of PVC was used to join the frame together while giving the frame the flexibility for adjustments. The frame height with 6 in caster wheels is 6.66 in and can be adjusted to 11.66 in. To meet the requirements for adjustability, the height needed to be able to adjust over a range of 6 in. The design of the wheelchairs allows for a longer piece of pipe to be used for the vertical and horizontal members to increase the size the wheelchair can be adjusted to. The pipe length can easily be changed to 9 in, giving an adjustability range of 7 in which is above the “Delighted” target.

For the static strength analysis the small wheelchair, in both the fully contracted and extended configurations, the von Mises stress was below the yield strength of the PVC. The wheelchair in its contracted configuration had a maximum von Mises stress of 5121 psi on the axle assembly, but the frame only experienced 3770 psi which is well below the 7500 psi yield limit. The weight capacity of the small wheelchair is 40 lbs and with an applied Factor of Safety = 2 the applied load to the frame was 80 lbs in a static loading environment. The large portion smaller canines breeds that would use this size wheelchair are well below the 40 lb limit (Thomas 2003). Knowledge of wheelchair deformed is helpful to assure that there are no excessive displacements that could interfere with the occupant. The fully extended configuration displayed the largest displacement with the greatest occurring at the front of the wheelchair at the horizontal supports. For the small wheelchair, the maximum displacement was 0.13 in directed toward the center of the wheelchair. This value is for one side of the wheelchair only and needs to be doubled obtain the total inward deflection. This would result in a decrease in width of the wheelchair of approximately 0.25 in. To protect against wheelchair contact with the dog extra padding should be considered for protection where the frame connects to the front harness.

The fatigue analyses for the small wheelchair designs in both the fully contracted and extended configurations were below the “Delighted” target of 200,000 cycles, but above the “Disgusted” target of 10,000 cycles. The failure was predicted to form on the frame at the connection with the axle for every analysis. The use of pneumatic wheels have been experimentally determined to triple the number of cycles to failure, but the additional cost of a small pneumatic wheel could not be justified and the resulting cycles would still be below the “Delighted” target (Cooper, 1996). The small axle size (5/16 in diameter axle) is believed to be a contributing factor to the reduced life expectancy as predicted by the fatigue analysis. The use of an axle bushing or rubber grommet may help reduce the stresses. Increasing the axle size could also distribute the stresses better and increase the fatigue life-cycles.

The small wheelchair is the most stable of the three wheelchair designs. The tip angle for the small wheelchair in the least stable configuration (43^o) is double the "Delighted" target of 20^o. Since the lengths of PVC pipe that adjust for height are on the outside of the upper portion of the wheelchair frame, the wheel base distance is an addition 2-3 inches wider than the top of the frame. The larger wheel base and the lower center of gravity of the wheelchair allow this wheelchair to be more stable.

The total cost of the wheelchair is a major component of the design. The cost of the small wheelchair without any commercial harnesses is $88.43. This is below the "Delighted" target for the minimum cost which is specific to the small wheelchair. If the chest and pelvic harnesses were to be included into the cost, it would add $60 to the total cost ($148.43) which places the cost in between the "Delighted" target and "Disgusted" target. The PVC frame without any wheels is $47.97. The cost for an entire container of PVC glue was added to the cost of the frame even though ideally one container would last over the construction of several wheelchairs. The total cost of the wheelchair is still below the cost of the smallest wheelchair available commercially from Eddie's Wheels, Doggon Wheels, and K9 Karts which retail at a bottom price of $220 for a small wheelchair, but the retail cost of the commercial wheelchairs also includes the cost of labor. The cost evaluated for the small wheelchair is the cost for one prototype and does not include the cost of labor or tools. This means that the cost of the wheelchair is based on the retail value of each component, but if the wheelchair was to be manufactured the cost would be greatly reduced.

Constructing the prototype met the "Delighted" targets for processing time. The entire wheelchair was built within 5 hours and required only the use of a saw, used to cut the pipe, and a drill press, used to create the holes needed for adjustments and the axle. The cutting and drilling of the wheelchair took the longest amount of time to complete (4.5 hours). The frame can be assembled within 30 minutes which is the value set for the "Disgusted" target for the assembly time. Assembly time is partly driven by the quick setting PVC glue and needing to align certain parts before the glue is allowed to set. Also experience is a significant factor in the time it takes to build a wheelchair and as more wheelchairs are built the more the processing and assembly times will be reduced. The processing of the PVC was done with relative ease. To cut the PVC pipe a saw that will provide a straight cut is required. For the prototypes, a hand powered miter saw was used to cut the PVC pipe with little kerfing (thickness of the saw cut). To drill the holes a drill press was used to ensure the straightness of the holes. To drill the holes in the PVC a slow drill speed and feed rate produced the best results. With the faster drill speeds the drill bit tends to "grip" the plastic. The weight of the small wheelchair prototype was only 3.25 lbs. This is lighter than the "Delighted" target of 6 lbs in the QFD.

C. <u>Medium Wheelchair Design</u>

The medium wheelchair was the first wheelchair to be designed in this project. With the use of 1 in PVC pipe that can slide easily inside of 1-1/4 in PVC pipe the adjustability aspects of the wheelchair were met. The wheelchair height with 12.5 in pneumatic wheels measured 15.95 in and can be expand to a height of 24.45 in. This adjustability of 8.5 in exceeds the "Delighted" goal of 6 in for adjustability.

The medium wheelchair performed well in the static strength analysis for both fully contracted and extended configurations of the wheelchair. The maximum von Mises stress on the axle of the contracted medium wheelchair was 2415 psi while the maximum stress on the frame was only 1866 psi which is below the yield strength of 7500 psi. The static stress analysis for the medium wheelchair was based on the applied load of 140 lbs (70 lbs with a FOS = 2). The results for static stress analysis of the medium wheelchair in its extended configuration were similar to the contracted configuration though the stresses on the frame experienced increased stresses. The von Mises stress on the frame in the extended configuration was 1991 psi. The medium wheelchair in both configurations met the QFD's "Delighted" goals for strength requirements. The maximum displacement of the medium wheelchair frame was the smallest of the three wheelchair designs. The greatest deflection occurs on the front of the wheelchair at the horizontal supports which displaced towards the center of the wheelchair. The inward decrease in the width dimension was less than 0.125 in. Even though the displacement is relatively small, extra padding where the frame connects to the front harness should be considered to protect the occupant.

The medium wheelchair design also performed well in the fatigue analysis with the wheelchair in the extended configuration predicted to have a life-cycle to failure around 895,000 cycles. This is substantially higher than the "Delighted" goal of 200,000 cycles. With a high life-cycle, the medium wheelchair is a good candidate for a highly active dog.

The lateral tipping angle of the medium wheelchair (32^o) was larger than the "Delighted" target of 20^o for both the least stable and most stable configurations. The lateral tipping angle is based on the wheelchair without an occupant with harnesses attached.

The total cost of the medium wheelchair (including two harnesses) is $218.26. The total cost is $18 over the “Delighted” target of the QFD. Once again this is the cost of a single medium wheelchair prototype. If multiple wheelchairs were to be produced the cost of the wheelchair would be reduced due to volume discounts. If the two commercial harnesses are removed from the cost, the total is then reduced to $89.36. The commercial harnesses make up 60% of the total cost of the wheelchair. The cost could drastically be reduced if a design was also developed for a cost effective harness that easily interfaces with the wheelchair. The cost of the PVC frame itself, without wheels, is $51.09. Once again the entire cost of the PVC glue was added to the BOM, but one container would last for the construction of several wheelchairs.

Building the medium wheelchair was relatively easy and took little time. The processing of each part only required the use of a saw used in cutting lengths of pipe, a drill press, and the construction jig for drilling the holes. The total time to process and assemble the wheelchair was 4 hours. The majority of the time in constructing the medium wheelchair is in processing the PVC which was performed in 3.5 hours. With each part of the wheelchair processed, the wheelchair required 30 minutes to be assembled. The total time needed to process the material and assemble the wheelchair is below and at the “Disgusted” goals of the QFD respectively. With experience and improved technique, both the manufacturing time and assembly time will become shorter. The weight of the medium wheelchair is 12.5 lbs which is heavier than the “Disgusted” target of 10 lbs. To address this, a solid model was built without the 1-1/4 in 45^{o} wyes and extra bracing. This removed 2 lbs from the wheelchair weight, but this reduction does not drop the wheelchair into the below the “Disgusted” target range and it has yet to be determined how this affects the strength of the frame. An added benefit of removing the wyes is that they are the most expensive PVC component on the frame at $3.95 each plus shipping. If the wyes were removed the cost of the frame would drop by at least $16.

D. Large Wheelchair Design

The large wheelchair uses the same basic design as the medium wheelchair with only a few design changes. The vertical support that adjusts the height was increased from 10.5 in. to 16 in. in length. For that same support, the schedule 40 pipe was replaced with a schedule 80 pipe to make the frame more rigid and add additional strength.

The maximum von Mises stress on the axle of the wheelchair in the fully contracted configuration was 4302 psi and the stress on the frame was 3144 psi. The stresses on the axle of the wheelchair in its extended configuration were 5485 psi, but the axle is made of steel which has yield strength approximately equal to 30,000 psi. The maximum stress on the fully extended frame was 4548 psi. The stresses on the frame in both configurations were both under the 7500 psi yield strength of the PVC material. The load used for the large wheelchair was 200 lbs (100 lbs with a FOS =2). Since stresses of both configurations of the wheelchair were under the yield strength, the design met the "Delighted" target for the weight capacity with a factor of safety. The displacement on the wheelchair was largest near the top of the wheels. The camber of the wheels causes greater bending on the structure of the frame and increases the displacement. The displacement on the wheelchair frame was still relatively small, but extra padding should be used on the front, where the frame connects to the front harness, of the wheelchair to protect the wheelchair from coming into contact with the dog.

With the increased stresses due to the camber of the wheels the predicted fatigue life-cycles of the wheelchair were between the "Disgusted" and "Delighted" target values of 10,000 to 200,000 cycles. The contracted configuration of the large wheelchair had a fatigue life of 98,370 cycles and the extended configuration of the large wheelchair had a 15,100 cycle life. Even though the large wheelchair design with the camber and without the camber passed the static strength analysis both still failed the fatigue strength goals. Additional analysis is needed to evaluate the affects that bushings or rubber grommets have on the axle and frame stresses.

The results from the stability analysis showed that the angle for the wheelchair without the wheel camber in its least stable configuration was 30^{o} and 45^{o} for the wheelchair in its most stable configuration. The large wheelchair was also modeled with an 8^{o} wheel camber to evaluate the affects the sloped wheels have on the stability of the frame. Both the cambered wheels and non-camber wheels design met the "Delighted" goals for stability.

Table 16 compares the results of the strength, fatigue, and stability analyses for the large wheelchair with both and 8^{o} camber and without the camber.

TABLE 16

ANALYSIS RESULTS FOR THE LARGE WHEELCHAIR WITH AN 8^{o} WHEEL CAMBER AND WITHOUT THE CAMBERED WHEELS

Analysis Type (configuration)	With 8^{o} Camber	Without Camber
Max. Stress (contracted)	5680 psi	3144 psi
Max. Stress (extended)	7234 psi	4548 psi
Fatigue Life (contracted)	5110 cycles	98370 cycles
Fatigue Life (extended)	1000 cycles	15100 cycles
Lateral Tip Angle (least stable)	32^{o}	30^{o}
Lateral Tip Angle (most stable)	48^{o}	45^{o}

Table 16 shows that adding the camber to the large wheelchair frame has little benefit in terms of stability due to the insufficient increase in the wheel base dimension and very little change in the height of the center of gravity. The camber also increases the stresses on the wheelchair and substantially decreases the life expectancy of the wheelchair. Therefore it is recommended that any subsequent wheelchairs be built without the wheel camber or further testing be done to verify the analysis results.

The total cost of the large wheelchair was $219.13, which is $19 over the "Delighted" target for the maximum cost of the wheelchair, but below the "Disgusted" target. As with the medium wheelchair design, the harnesses made up 60% of the wheelchair cost. Without the harnesses, the cost of the wheelchair was $90.82. The cost of just the large wheelchair frame without wheels was $52.55. The reason that the medium wheelchair and large wheelchair were similar in cost is because the large wheelchair has the same parts the medium wheelchair has, except the vertical supports for the large wheelchair are longer, are a larger wall thickness, and are more expensive.

The construction for the large wheelchair is the exact same as the medium wheelchair except that the large wheelchair design requires the legs be cut longer. The drilling of the extra holes has little effect on the time it takes to construct the wheelchair. The entire time to process the frame components was 4 hours and the time to assemble the wheelchair was still 30 minutes. The processing time of 4 hours is at the "Disgusted" target goal from the QFD. This time will be reduced with greater experience with the construction of the prototypes and possible changes to streamline the process.

E. Limitations

Access to commercially available canine wheelchairs was a limitation in developing design goals for this project. Several wheelchairs and patients were observed throughout the project, but in many cases the wheelchairs were custom built for that dog or one of similar size. This led to several assumptions being made about the performance of the commercially available wheelchairs such as expected life and stability. The lack of technical studies, data, and knowledge on the performance of canine wheelchairs also led to assumptions or comparisons to human wheelchair studies for fatigue analysis.

Several limitations were associated with the computer analysis portion of this project. In the static strength study any clearance between the 1 in and 1-1/4 in PVC pipe was ignored. If these clearances were to be considered, contact elements would have to be used, increasing the complexity and time needed to run the analysis. The clearance in the pipes allows the pipe to deform a little even before a load is even applied. The other limitation in the static stress analysis is that COSMOSWorks™ has a maximum coefficient of friction of 0.5 for contact elements. The finite element model also assumed that contacting solids that were not assigned contact elements were bonded into one solid piece for the analysis. In reality the PVC will be bonded using glue that has its own separate properties.

Using the S-N method for determining the life-cycles is only a prediction. The history was based on a constant amplitude cycle where the load varied from 1.5 times the maximum weight capacity and zero. The simplistic loadings were due in part to the lack of knowledge of the loading profiles of a dog in a hind limb support wheelchair. The wheels for the medium and large wheelchair were modeled as solid core nylon tires.

While this made the static strength analysis quicker, pneumatic tires have been shown to increase the number of cycles to failure for wheelchairs (Cooper, 1997). The medium and large wheelchair prototypes built in this project used pneumatic tires.

The stability analyses were performed on each wheelchair without a model of the occupant. An occupant would change the stability of the wheelchair and require more advanced software to perform.

For the computer model the harnesses were modeled as boundary conditions. The rear pelvic harness was modeled as the applied load and the front chest harness was modeled as restraints on the forward end of the upper adjustable horizontal support members. In reality the harnesses are flexible and dynamic.

For the prototypes the commercial harnesses purchased required modification to interface the wheelchair frame. In many places the harnesses needed to be hand stitched. This increased the cost of the wheelchair and modifications on the chest harness were difficult.

F. Recommendations For Future Work

Several aspects of the design need to be investigated further. To investigate increasing the fatigue strength of the wheelchairs, axle bushings and rubber grommets should be evaluated to determine if they cause an improvement in the number of cycles completed. To reduce the weight of the medium and large wheelchair designs, the model built without the extra bracing and the wyes should be analyzed to determine the performance of the designs change.

The design and development of a non-commercial harness would greatly reduce the cost. The two harnesses currently being used have limited adjustability and a new design that is tailored to fit the canine wheelchairs would give the wheelchairs greater flexibility by allowing the harness to be designed around the wheelchair.

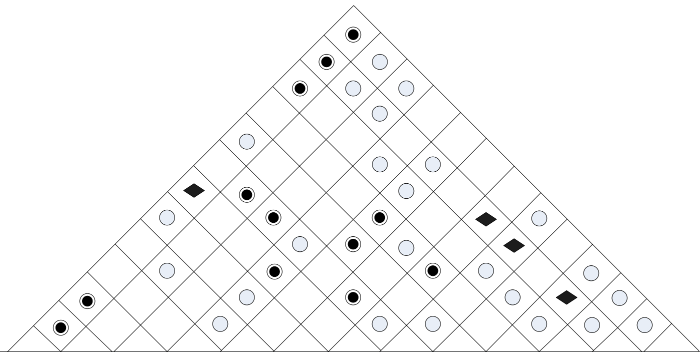
To reduce the cost of each wheelchair design, the possibility of moving to a manufacturing level or production should be considered. If the quantity of the parts purchased at one time is increased, certain companies will give a "bulk" discount. To do this, the marketability of the wheelchair needs to be assessed to determine if a capital venture into the market is feasible.

As a follow-up to this study, each prototype built will be experimentally tested to verify the analysis portion of this project. This includes a static strength test, a fatigue strength test using a single drum test machine, and a static stability test. After verification of the physical models, the wheelchair should then undergo field testing stage to determine the usability of each design. Currently, one of the large wheelchair prototypes built is being used by a Doberman Pincher that was hit by a vehicle resulting in hind limb paralysis. To properly secure the frame to the chest harness four plastic buckles were needed to balance out the dynamic upward and downward forces, and to stabilize the wheelchair during use. The dog guardian is monitoring the wheelchair use on a daily basis and files weekly reports on the wheelchairs usability.

VI. Summary

The goal of this project was to design a cost effective, adjustable, and light weight wheelchair that fits the needs of both the canine and guardian so both can have an improved quality of life. Three canine wheelchairs were designed that were cost effective and adjustable. Only the small wheelchair design met the weight requirement goal. Constructing the wheelchairs from PVC components allows for easy processing, availability, and maintenance. Using finite element analysis and stability analysis it was shown that all three designs are strong, stable structures, but two of the wheelchair designs failed to meet the fatigue life “Delighted” target of 200,000 cycles. It was also determined that the wheelchairs were stable in the lateral direction. Each wheelchair can be adjusted in 0.5 in. increments without the use of any tools and the frames can be adjusted 5in and up to 8.5 in. Future work will include further computer analysis of design changes to increase the life-cycles of each frame and to decrease the weight of the medium and large wheelchairs. Field testing of the wheelchair prototypes will also be needed to verify the design.

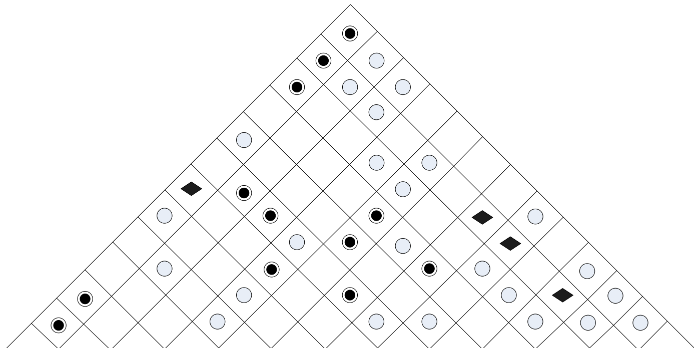
APPENDIX I



Dog Owner	Rehab Specialist	Category	WHAT	Weight Range of Dog	Minimum Cost	Maximum Cost	Adjustable range	Number of tools to adjust wheelchair	Time cart takes to be assembled	Lateral Tip Angle	Time it takes to process wheelchair	Number of adjustment points	Number of Parts that can be easily replaced	Wheelchair weight	Fatigue Strength	Factor of Safety	NOW 1 (Worse)	2	3	4	5 (Best)
			Direction of Improvement	⇧	⇩	⇩	⇧	⇩	⇩	⇩	⇩	⇧	⇧	⇩	⇩	⇧					
			Units	lbs	$	$	in	#	min	deg	hr	#	#	lbs	Cycles	F_{max}/F					
10	10	Performance	Mobility	◆	○	○				○					●	○				△	○ ◇
10	8	Performance	Allows dog to relieve itself		○	○			◆			○									△ ○ ◇
10	10	Performance	Strength		○	○				◆					●	●				△ ◇	○
10	10	Performance	Stability						◆	●				○	◆	◆					△ ○ ◇
6	10	Performance	Ease of donning and doffing cart	●	○	○						○	◆							△ ○ ◇	
10	6	Adjustability	Adjusts for female/ male						○			●							△ ◇	○	
10	7	Adjustability	Easy adjustments for size/comfort by owner		○	○	●	○	○	○		●				○		△ ○ ◇			
10	8	Adjustability	Adjusts to changes in size and different dogs	○	○	○	●	◆	○	●	○	●				○		△ ○ ◇			
10	9	Adjustability	Easy to Repair/ maintain					●			○	●			◆	○	△ ◇	○			
10	9	Environment	No rusting / corrosion		○	○									◆					△ ○	◇
10	8	Environment	Environmentally Friendly material		●	●					◆			○		◆					△ ○ ◇
10	9	Health/Theropy	Easy to clean		◆	◆														△ ○ ◇	
10	10	Health/Theropy	Prevents skin breaks / pressure ulcers		◆	◆	●												△	○ ◇	
10	10	Health/Theropy	Adjustable for rehabilitation		○	○				●											△ ○ ◇
10	8	Other	Easy to manufacture		●	●	◆		○	○	●	○	○			○	◇	△	○		
9	8	Other	Weight									○	◆	●	◆	○			△	○	◇
10	8	Other	Cost of Materials	●	●	●	●				◆		○	○	○	◆			△ ○ ◇		
10	10	Other	Cost of Manufacturing	●	●	●	●	◆		◆		○	○	○	○		◇	△	○		
10	9	Other	Portability		○	○		○	◆			○					△	○	◇		
			Doggon Wheels	40	220	450	3	1	10	20	*5 days	6	5	8	2E5	2					
			Eddies Wheels	40	295	445	3	1	0	20	*14 days	4	3	6	2E5	2					
			K9 Cart	40	275	550	3	0	10	20	*28 days	8	3	5	2E5	2					
			Target (Delighted)	40	100-	200-	6	1	0	20	1	6	6	6	2E5	2					
			Target (Disgusted)	25	220	400	2	2+	30	15	4	4	2	10	1E4	1					

NOW: Δ Doggon Wheels, ○ Eddies Wheels, ◊ K9 Cart

● Strong Relation
○ Medium Relation
◆ Week Relation
If Blank: No Relation
* Based on order turn around for companies

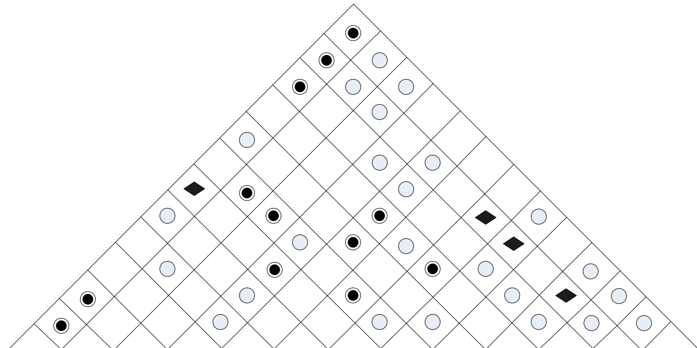


Dog Owner	Rehab Specialist	Category	WHAT	Weight Range of Dog	Minimum Cost	Maximum Cost	Adjustable range	Number of tools to adjust wheelchair	Time cart takes to be assembled	Lateral Tip Angle	Time it takes to process wheelchair	Number of adjustment points	Number of Parts that can be easily replaced	Wheelchair weight	Fatigue Strength	Factor of Safety	NOW 1 (Worse)	2	3	4	5 (Best)
			Direction of Improvement	⇧	⇩	⇩	⇧	⇩	⇩	⇩	⇩	⇧	⇧	⇩	⇩	⇧					
			Units	lbs	$	$	in	#	min	deg	hr	#	#	lbs	Cycles	F_{max}/F					
10	10	Performance	Mobility	◆	○	○				○					●	○				△	○ ◇
10	8	Performance	Allows dog to relieve itself		○	○			◆			○									△ ○ ◇
10	10	Performance	Strength		○	○				◆					●	●				△ ◇	○
10	10	Performance	Stability						◆	●				○	◆	◆					△ ○ ◇
6	10	Performance	Ease of donning and doffing cart	●	○	○						○	◆							△ ○ ◇	
10	6	Adjustability	Adjusts for female/ male						○			●							△ ◇	○	
10	7	Adjustability	Easy adjustments for size/comfort by owner		○	○	●	○	○	○		●				○		△ ○ ◇			
10	8	Adjustability	Adjusts to changes in size and different dogs	○	○	○	●	◆	○	●	○	●				○		△ ○ ◇			
10	9	Adjustability	Easy to Repair/ maintain					●			○	●			◆	○	△ ◇	○			
10	9	Environment	No rusting / corrosion		○	○									◆					△ ○	◇
10	8	Environment	Environmentally Friendly material		●	●					◆			○		◆					△ ○ ◇
10	9	Health/Theropy	Easy to clean		◆	◆														△ ○ ◇	
10	10	Health/Theropy	Prevents skin breaks / pressure ulcers		◆	◆	●												△	○ ◇	
10	10	Health/Theropy	Adjustable for rehabilitation		○	○				●											△ ○ ◇
10	8	Other	Easy to manufacture		●	●	◆		○	○	●	○	○			○	◇	△	○		
9	8	Other	Weight									○	◆	●	◆	○			△	○	◇
10	8	Other	Cost of Materials	●	●	●	●				◆		○	○	○	◆			△ ○ ◇		
10	10	Other	Cost of Manufacturing	●	●	●	●	◆		◆	○	○	○	○	○		◇	△	○		
10	9	Other	Portability		○	○		○	◆			○					△	○	◇		
			Doggon Wheels	70	220	450	3	1	10	20	*5 days	6	5	8	2E5	2					
			Eddies Wheels	70	295	445	3	1	0	20	*14 days	4	3	6	2E5	2					
			K9 Cart	70	275	550	3	0	10	20	*28 days	8	3	5	2E5	2					
			Target (Delighted)	70	100-	200-	6	1	0	20	1	6	6	6	2E5	2					
			Target (Disgusted)	50	220	400	2	2+	30	15	4	4	2	10	1E4	1					

HOW / WHAT

NOW: ∆ Doggon Wheels, ○ Eddies Wheels, ◊ K9 Cart

● Strong Relation
○ Medium Relation
◆ Week Relation
If Blank: No Relation
* Based on order turn around for companies



Dog Owner	Rehab Specialist	WHAT		Weight Range of Dog	Minimum Cost	Maximum Cost	Adjustable range	Number of tools to adjust wheelchair	Time cart takes to be assembled	Lateral Tip Angle	Time it takes to manufacture wheelchair	Number of adjustment points	Number of Parts that can be easily replaced	Wheelchair weight	Fatigue Strength	Factor of Safety	NOW 1 (Worse)	2	3	4	5 (Best)
			Direction of Improvement	⇧	⇩	⇩	⇧	⇩	⇩	⇩	⇩	⇧	⇧	⇩	⇩	⇧					
			Units	lbs	$	$	in	#	min	deg	days	#	#	lbs	Cycles	F_{max}/F					
10	10	Performance	Mobility	◆	○	○				○					●	○				△	○ ◇
10	8	Performance	Allows dog to relieve itself		○	○			◆			○									△ ○ ◇
10	10	Performance	Strength		○	○				◆					●	●				△ ◇	○
10	10	Performance	Stability						◆	●				○	◆	◆					△ ○ ◇
6	10	Performance	Ease of donning and doffing cart	●	○	○						○	◆							△ ○ ◇	
10	6	Adjustability	Adjusts for female/ male						○			●							△ ◇	○	
10	7	Adjustability	Easy adjustments for size/comfort by owner		○	○	●	○	○	○		●				○		△ ○ ◇			
10	8	Adjustability	Adjusts to changes in size and different dogs	○	○	○	●	◆	○	●	○	●				○		△ ○ ◇			
10	9	Adjustability	Easy to Repair/ maintain					●			○	●			◆	○	△ ◇	○			
10	9	Environment	No rusting / corrosion		○	○									◆					△ ○	◇
10	8	Environment	Environmentally Friendly material		●	●					◆			○		◆					△ ○ ◇
10	9	Health/Theropy	Easy to clean		◆	◆														△ ○ ◇	
10	10	Health/Theropy	Prevents skin breaks / pressure ulcers		◆	◆	●												△	○ ◇	
10	10	Health/Theropy	Adjustable for rehabilitation		○	○				●											△ ○ ◇
10	8	Other	Easy to manufacture		●	●	◆		○	○	●	○	○			○	◇	△	○		
9	8	Other	Weight									○	◆	●	◆	○			△	○	◇
10	8	Other	Cost of Materials	●	●	●	●				◆		○	○	○	◆			△ ○ ◇		
10	10	Other	Cost of Manufacturing	●	●	●	●	◆		◆	○	○	○	○	○		◇	△	○		
10	9	Other	Portability		○	○		○	◆			○					△	○	◇		

NOW: Δ Doggon Wheels, ○ Eddies Wheels, ◊ K9 Cart

	Weight Range of Dog	Minimum Cost	Maximum Cost	Adjustable range	Number of tools	Time assembled	Lateral Tip Angle	Time to manufacture	Number of adjustment points	Number of Parts replaced	Wheelchair weight	Fatigue Strength	Factor of Safety
Doggon Wheels	150+	220	450	3	1	10	20	*5 days	6	5	8	2E5	2
Eddies Wheels	150	295	445	3	1	0	20	*14 days	4	3	6	2E5	2
K9 Cart	126	275	550	3	0	10	20	*28 days	8	3	5	2E5	2
Target (Delighted)	140	100-	200-	6	1	0	20	1	6	6	6	2E5	2
Target (Disgusted)	70	220	400	2	2+	30	15	4	4	2	10	1E4	1

● Strong Relation
○ Medium Relation
◆ Week Relation
If Blank: No Relation
* Based on order turn around for companies

APPENDIX II

Ref #	Part	Quantity	Supplier	Manuf - Model - Notes	Price ($/in, $/part)	Shipping	Total Cost
1	12" Length of 1/2" dia. Sch 80 PVC	2	Grainger		$0.03		$ 0.74
2	7" Length of 1/2" dia. Sch 80 PVC	2	Grainger		$0.03		$ 0.41
3	2.5" Length of 1/2" dia. Sch 80 PVC	2	Grainger		$0.03		$ 0.15
4	4" Length of 1/2" dia. Sch 80 PVC	6	Grainger		$0.03		$ 0.71
7	1/2" 90^{o} elbow	2	Lowe's		$0.23		$ 0.46
8	1/2" T-joint	2	Lowe's		$0.68		$ 1.36
9	PVC bar Type 1 (1"x1")	8	McMaster Carr		$0.37	$5.00	$ 10.92
10	Pin Clip	8	Lowe's	Hillman-H# 881075	$0.23		$ 1.84
11	Clevis Pin (2" long, 1/4" dia.)	8	Lowe's	Hillman-#881095	$1.87		$ 14.96
12	Gorilla PVC Glue	1	Flexpvc.com	Gorilla Glue	$4.96		$ 4.96
13	Axle (3" long, 5/16" dia. Hex bolt)	2	Lowe's	Steel Grade 8	$0.29		$ 0.58
14	Cable Ties (18", 175lbs)	12	Lowe's	Gardner Bender or equivalent	$0.28		$ 3.36
15	5/8" Plastic Buckle	6	ITW Nexus	TSR75 Assembly (w/Latch 150-0075)	$1.10		$ 6.60
16	Nylon Spacers (1/2" long, 3/8" dia.)	2	Lowe's		$0.46		$ 0.92
17	5/8" Nylon Webbing	1	Strapworks.com	or equivalent webbing	$0.60		$ 0.60
18	5/16" SAE Washer	6	Lowe's		$0.29		$ 1.72
19	5/16" Steel Hex Nut	2	Lowe's		$0.07		$ 0.14
20	6" Caster Wheels	2	Skyway Wheels		$19.00		$ 38.00
						Total	$ 88.43
						Total (w/o harness)	$ 88.43
						Total (frame)	$ 47.97

Ref #	Part	Quantity	Supplier	Manuf - Model - Notes	Price ($/in, $/part)	Shipping	Total Cost
1	10.5" Length of 1" Sch 40 PVC	2	Lowe's		$0.02		$ 0.40
2	16" Length of 1" Sch 40 PVC	2	Lowe's		$0.02		$ 0.61
3	8.5" Length of 1" Sch 40 PVC	2	Lowe's		$0.02		$ 0.33
4	2.5" Length of 1-1/4" Sch 40 PVC	4	Lowe's		$0.03		$ 0.27
5	3.25" Length of 1-1/4" Sch 40 PVC	4	Lowe's		$0.03		$ 0.35
6	4.75" Length of 1-1/4" Sch 40 PVC	2	Lowe's		$0.03		$ 0.25
7	5.5" Length of 1-1/4" Sch 40 PVC	2	Lowe's		$0.03		$ 0.29
8	6.5" Length of 1-1/4" Sch 40 PVC	2	Lowe's		$0.03		$ 0.35
9	4.1" Length of 1-1/4" Sch 40 PVC	4	Lowe's		$0.03		$ 0.44
11	1-1/4" 90^o elbow	4	Lowe's		$0.69		$ 2.76
12	1" : 1-1/4" 90^o reduction elbow	2	Lowe's		$1.11		$ 2.22
13	1-1/4" 45^o wyes	4	Flexpvc.com		$3.95	$9.00	$ 24.80
14	1-1/4" T-joint	2	Lowe's		$1.22		$ 1.22
15	2" Long, 1/4" dia. Clevis Pin	8	Lowe's	Hillman-H# 881075	$1.87		$ 14.96
16	Pin Clip	8	Lowe's	Hillman-#881095	$0.23		$ 1.84
17	1" Plastic Buckle	10	ITW Nexus	WSR 25 Assembly (w/Latch 525-1100)	$1.10		$ 11.00
18	Gorilla PVC Glue	1	Flexpvc.com	Gorilla Glue	$4.96		$ 4.96
19	12.5" utility wheels	2	Northern Tools	#40148	$8.99	$7.99	$ 25.97
20	Axle (5" Long, 1/2" dia. Hex bolt)	2	Lowe's	Steel Grade 8	$1.82		$ 3.64
21	Cable Ties (18" long, 175 lbs)	18	Lowe's	Gardner Bender or equivalent	$0.28		$ 5.04
22	Nylon Spacers (3/4" long, 1/2" dia.)	2	Lowe's		$0.69		$ 1.38
23	1" Nylon Webbing	1	Strapworks.com	or equivalent webbing	$0.05		$ 1.20
24	Lg Rear Harness	1	handicappedpets.com	Walk About	$55.00	$8.05	$ 63.05
25	Lg Front Harness	1	For Dog Trainer	Dog Pulling Harness - H6	$39.90	$9.00	$ 48.90
26	1/2" dia. SAE Washer	6	Lowe's		$0.34		$ 2.04
27	1/2" dia. Steel Nut	2	Lowe's	Steel Grade 8	$0.14		$ 0.28
						Total	$ 218.26
						Total (w/o harness)	$ 89.36
						Total (frame)	$ 51.09

Ref #	Part	Quantity	Supplier	Manuf - Model - Notes	Price ($/in, $/part)	Shipping	Total Cost
1	16" Length of 1" Sch 80 PVC	2	Grainger		$0.06		$ 1.81
2	16" Length of 1" Sch 40 PVC	2	Lowe's		$0.02		$ 0.63
3	8.5" Length of 1" Sch 40 PVC	2	Lowe's		$0.02		$ 0.33
4	2.5" Length of 1-1/4" Sch 40 PVC	4	Lowe's		$0.03		$ 0.27
5	3.25" Length of 1-1/4" Sch 40 PVC	4	Lowe's		$0.03		$ 0.35
6	4.7" Length of 1-1/4" Sch 40 PVC	2	Lowe's		$0.03		$ 0.26
7	5.5" Length of 1-1/4" Sch 40 PVC	2	Lowe's		$0.03		$ 0.30
8	6.5" Length of 1-1/4" Sch 40 PVC	2	Lowe's		$0.03		$ 0.36
9	4.1" Length of 1-1/4" Sch 40 PVC	4	Lowe's		$0.03		$ 0.44
11	90^o elbow	4	Lowe's		$0.69		$ 2.76
12	90^o reduction elbow	2	Lowe's		$1.11		$ 2.22
13	45^o wyes	4	Flexpvc.com		$3.95	$9.00	$ 24.80
14	T-joint	2	Lowe's		$1.22		$ 1.22
15	2" Long, 1/4" dia. Clevis Pin	8	Lowe's	Hillman-H# 881075	$1.87		$ 14.96
16	Pin Clip	8	Lowe's	Hillman-#881095	$0.23		$ 1.84
17	1" Plastic Buckle	10	ITW Nexus	WSR 25 Assembly (w/Latch 525-1100)	$1.10		$ 11.00
18	Gorilla PVC Glue	1	Flexpvc.com	Gorilla Glue	$4.96		$ 4.96
19	12.5" utility wheels	2	Northern Tools	#40148	$8.99	$7.99	$ 25.97
20	Axle (5" Long, 1/2" dia. Hex bolt)	2	Lowe's	Steel Grade 8	$1.82		$ 3.64
21	Cable Ties	18	Lowe's	Gardner Bender or equivalent	$0.28		$ 5.04
22	Nylon Spacers (3/4" long, 1/2" dia.)	2	Lowe's		$0.69		$ 1.38
23	1" Nylon Webbing	1	Strapworks.com	or equivalent webbing	$0.60		$ 0.60
24	Lg Rear Harness	1	handicappedpets.com	Walk About	$55.00	$8.05	$ 63.05
25	Lg Front Harness	1	ForDogTrainer.com	Dog Pulling Harness - H6	$39.90	$9.00	$ 48.90
26	1/2" dia. SAE Washer	6	Lowe's		$0.34		$ 2.04
27	1/2" dia. Steel Nut	2	Lowe's	Steel Grade 8	$0.14		$ 0.28
						Total	$ 219.13
						Total (w/o harness)	$ 90.82
						Total (frame)	$ 52.55

APPENDIX III

<u>Sliding Hole Drilling Jig</u>

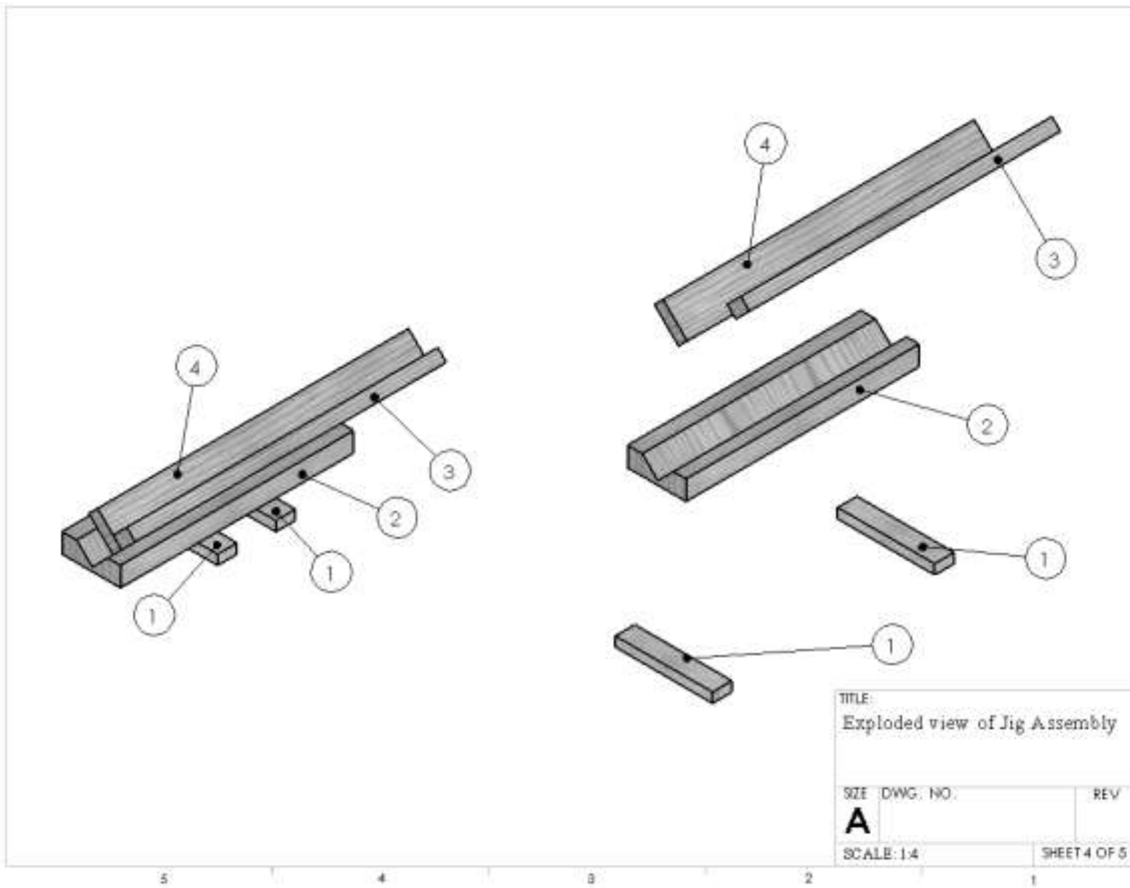


FIGURE 74 – Construction Jig (Left) and Exploded View (Right) of Jig.

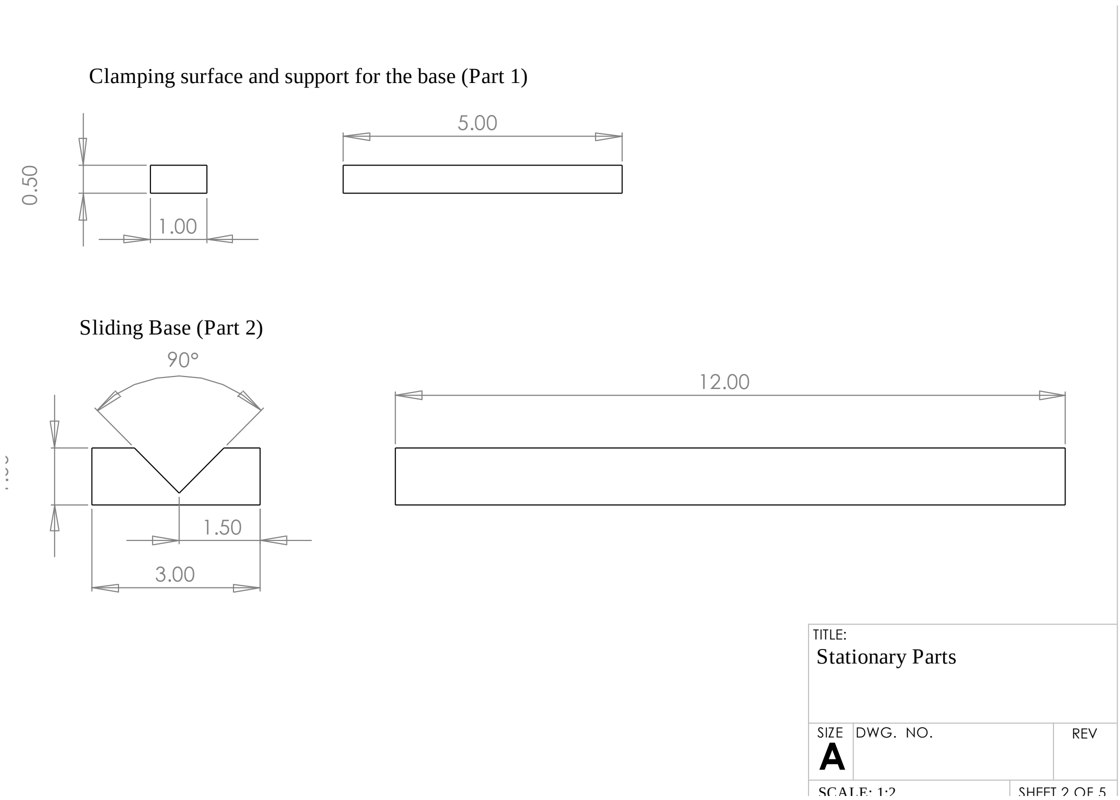


FIGURE 75 – Stationary Components of Construction Jig.

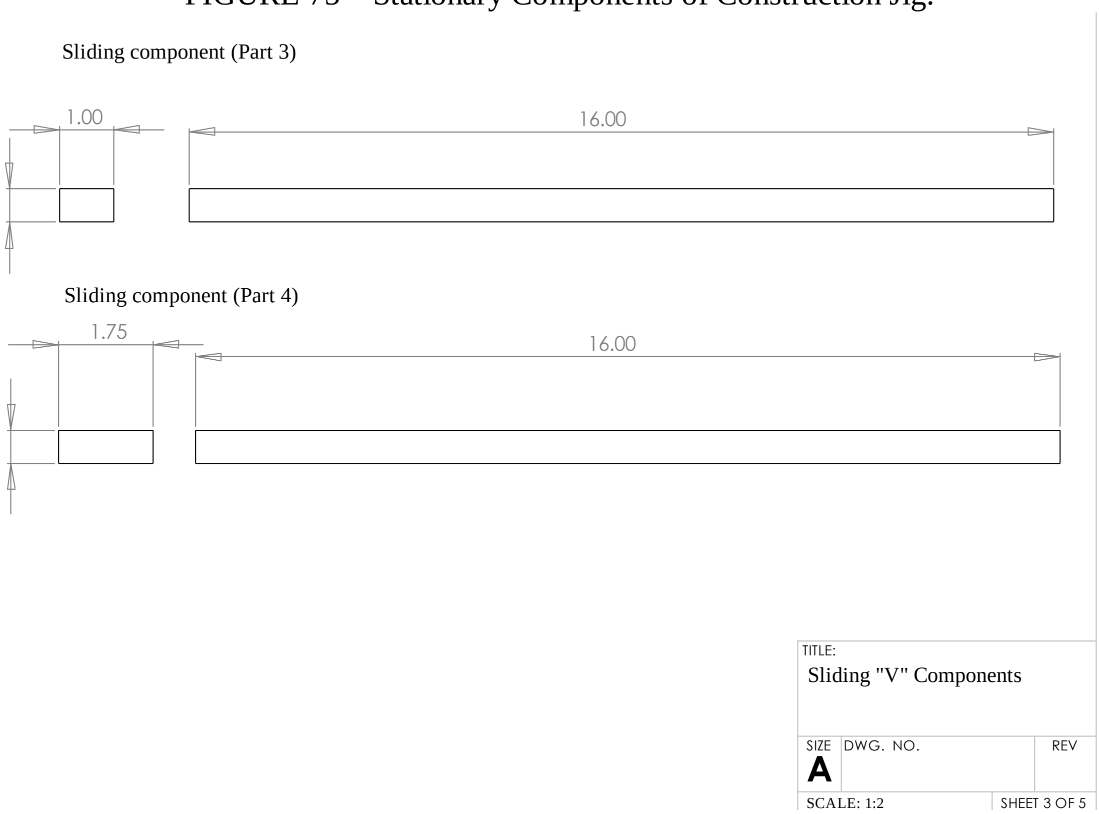


FIGURE 76 – Sliding Components of Construction Jig.

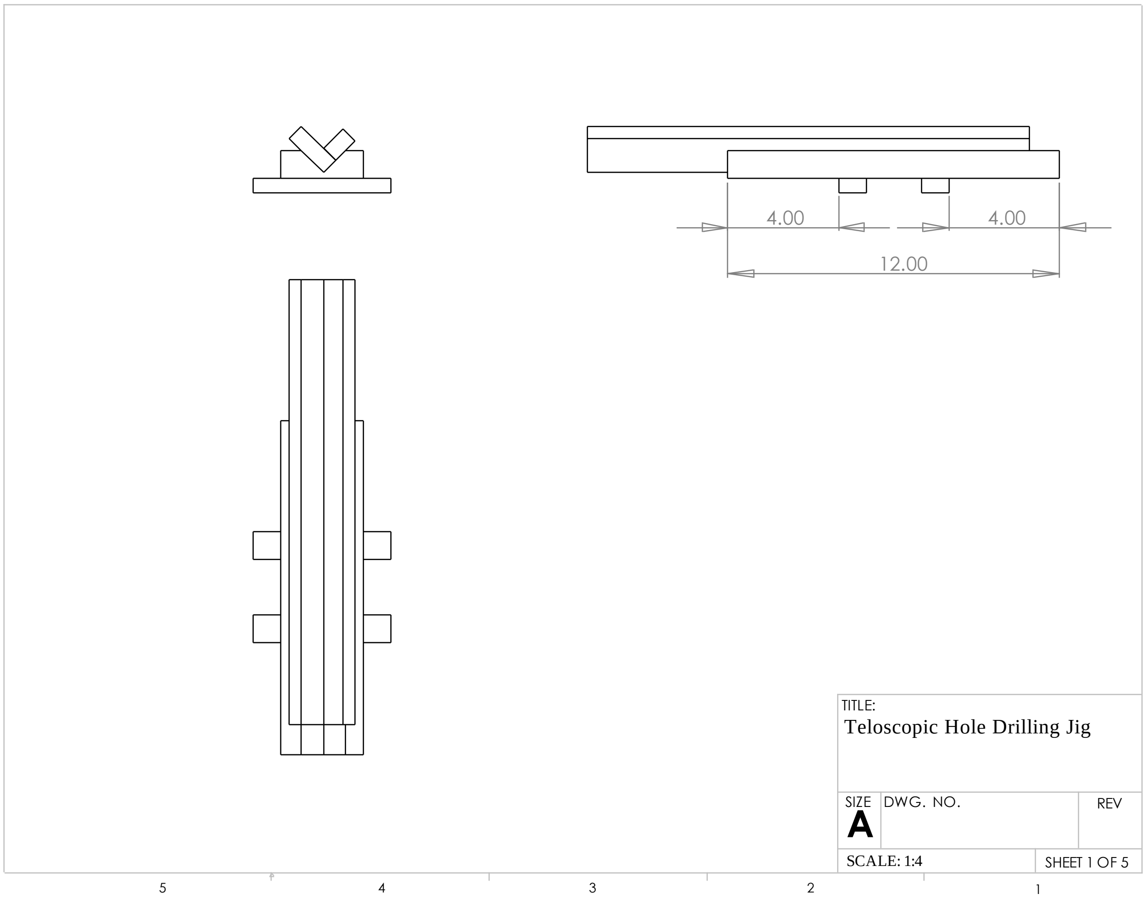


FIGURE 77 – Construction Jig and Location of 1 in x1/2 in Clamping Surfaces.

Tools used for assembly:

- Table saw
- Measuring tape
- Wood glue

Assembly Instructions:

Step 1: Cut wood to size for Parts 1, 2, 3, and 4 as shown in Figures 75 and 76.

Step 2: Glue Part 4 and 3 together as shown in Figure 74. Clamp together until the glue has set.

Step 3: Glue both Parts 1 to Part 2 in the location shown in Figure 77. Clamp the pieces together until the glue has set.

Step 4: Once the glue has hardened set the "V" slider, built in Step 2, into the groove of the structure built in Step 3.

Proper Use:

Step 1: With the measure tape mark a line every 1/2 in on the edge as shown in Figure 78. There should be a total of 31 lines.

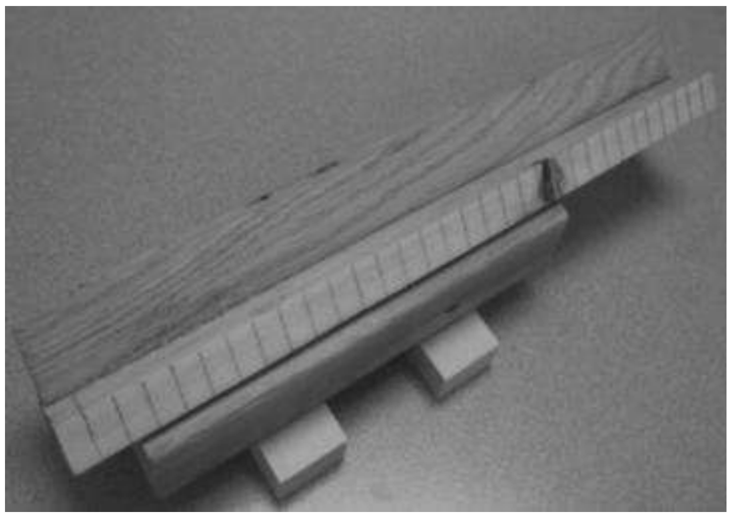


FIGURE 78 – Half Inch Markings Along the Edge of the Slider.

Step 2: Place the jig on the drill press table and use the drill bit to center the groove on the slider to center the jig and clamp to the table.

FIGURE 79 – Centering the Construction Jig on the Drill Press.

Step 3: With the jig secured to the drill press, place the PVC pipe in the jig and make sure that one end of the PVC pipe lines up with one end of the slider on the jig. Using a marker, place a line across the face of the PVC pipe and the slider of the jig. This mark will make sure the holes are drilled along a straight line. If the marked line is ever misalign, realign and begin drilling again. This alignment should be checked frequently.

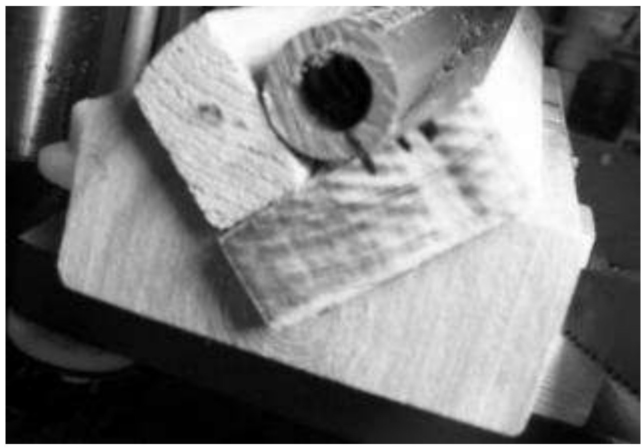


FIGURE 80 – Alignment of the PVC Pipe with the Jig.

Step 4: Line the slider with the drill bit until it is half way over the end of the PVC pipe. Make a mark on the stationary base where the beginning of the slider is located with a pensile. This "zeros" the jig and to drill the first hole just move the slider over until the first 1/2 in mark on the slider aligns with the zero mark on the base. Make sure to secure the PVC pipe while drilling the holes to prevent slips and misalignment.

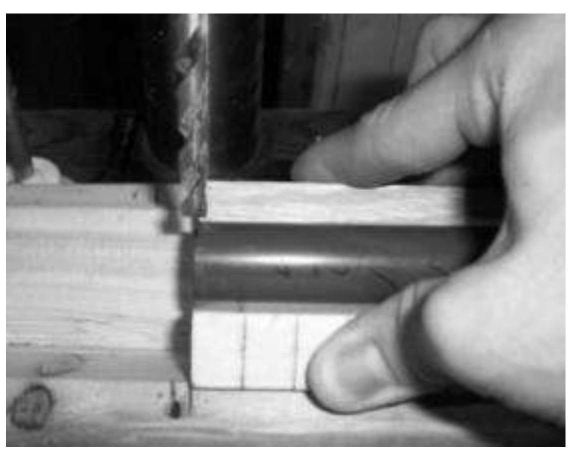


FIGURE 81 – Marking the "Zero" Line on the Base.

FIGURE 82 – Drilling the Holes with the Construction Jig.

APPENDIX IV

Small Canine Wheelchair Frame Assembly Instructions

The following small sized wheelchair frame is suitable for dogs weighing 40 lbs and under with a wither height of 5-13 in and a hip to shoulder length of 6-10 in.

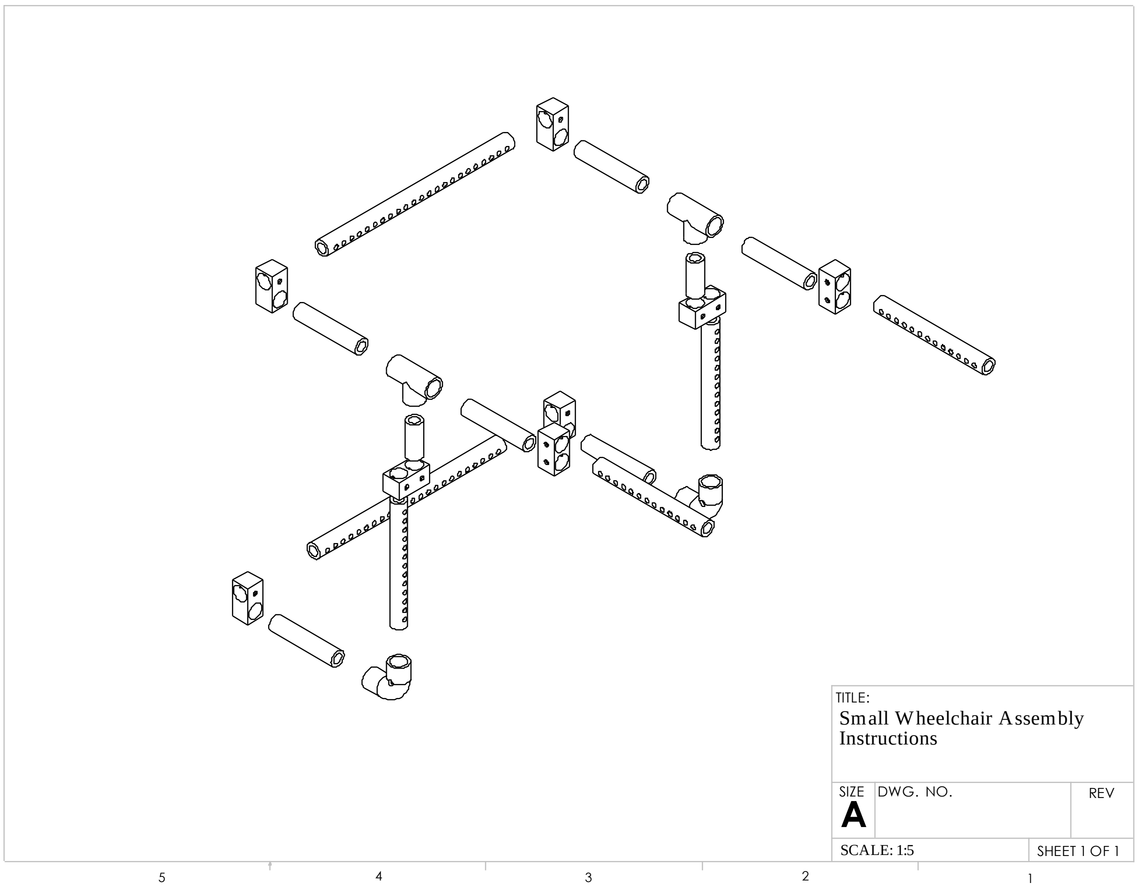


FIGURE 83 – Small Wheelchair Assembly.

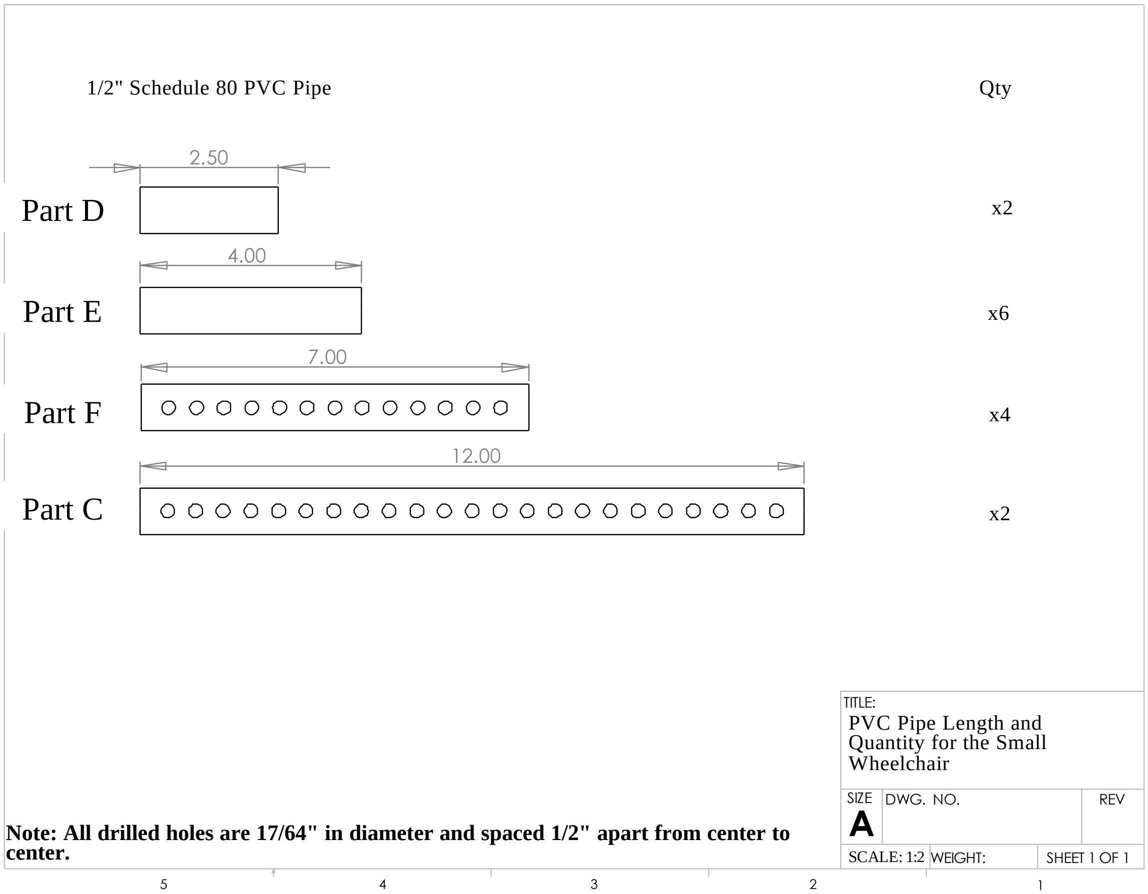


FIGURE 84 – PVC Pipe Length and Quantity Needed for Construction of the Frame (Units in Inches).

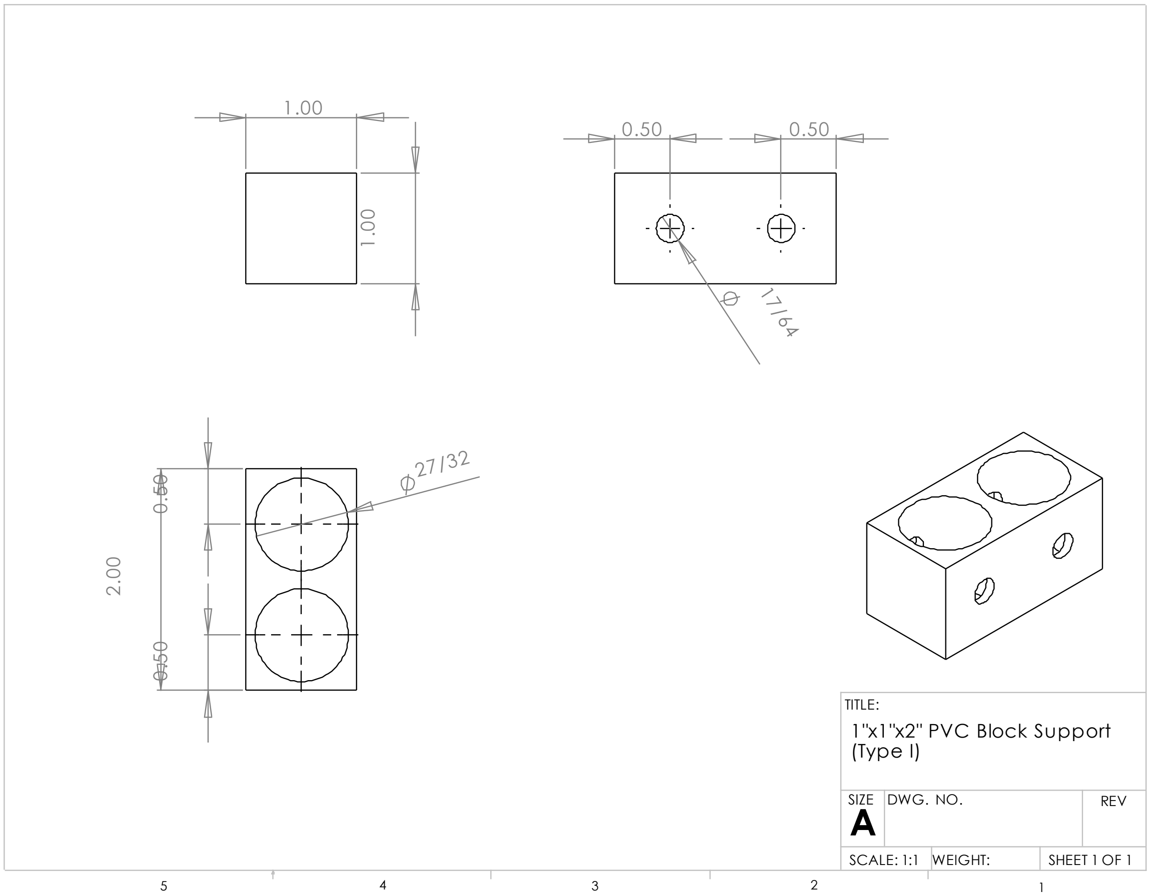


FIGURE 85 – Dimensions of the PVC Square Sliding Block Type 1 (Units in Inches).

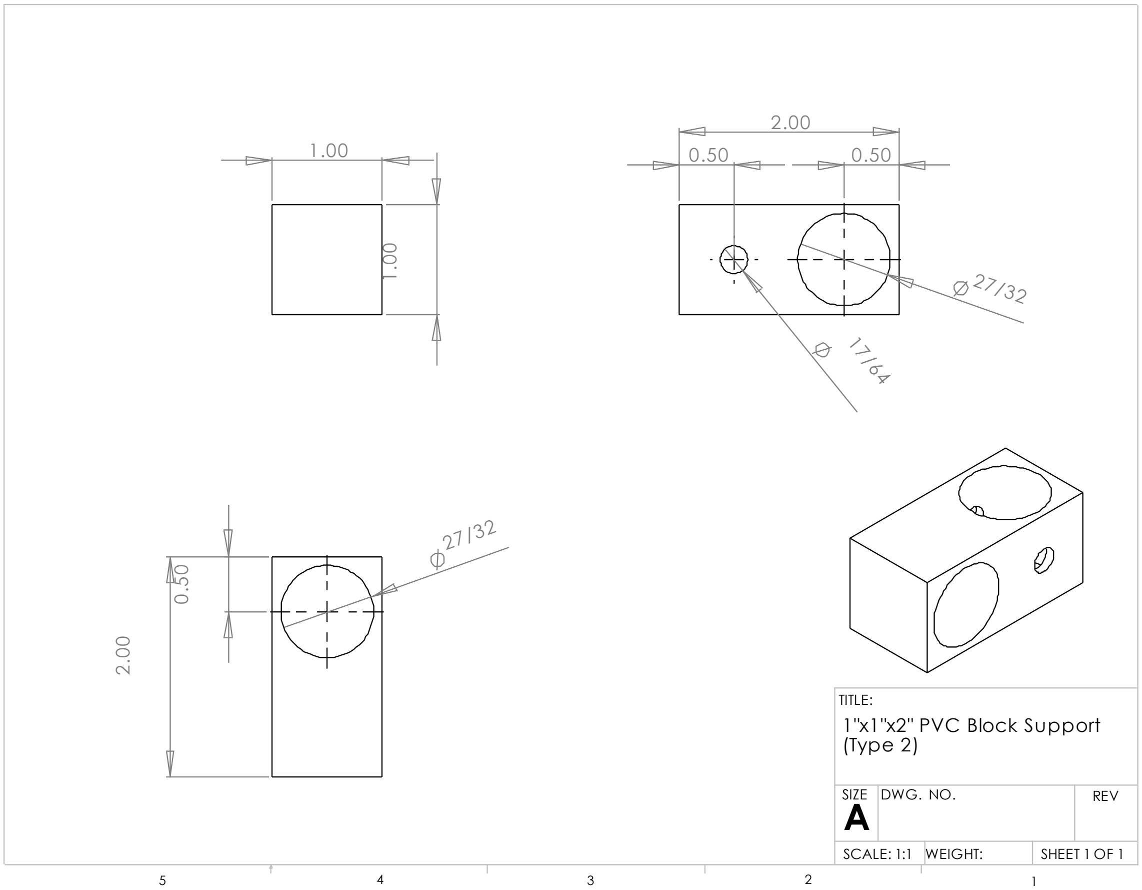


FIGURE 86 – Dimensions of the PVC Square Sliding Block Type 2 (Units in Inches).

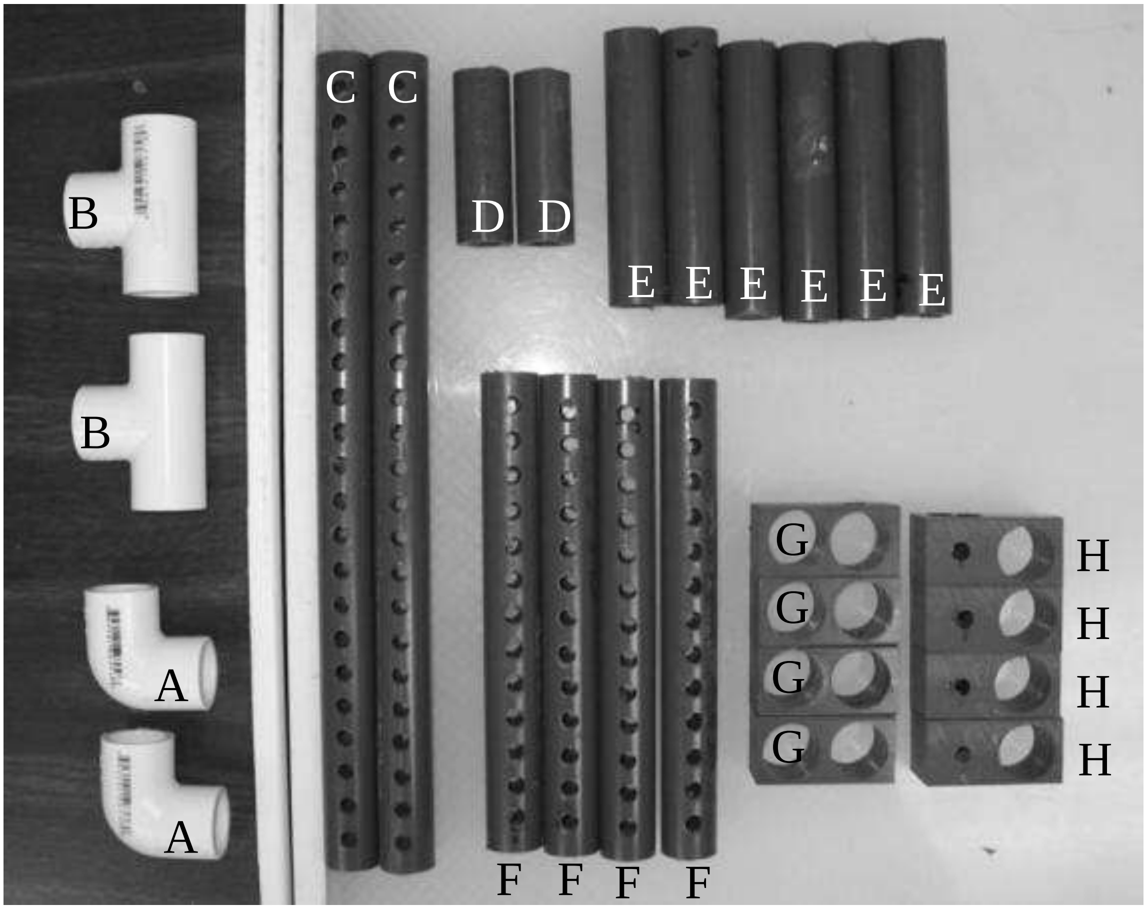


FIGURE 87 – PVC Pipe and Fitting Components Needed for Assembling the Small Wheelchair Frame.

TABLE 20

PART LIST FOR THE SMALL WHEELCHAIR ASSEMBLY

Part Label	Part Name	Quantity
A	1/2” PVC Elbow	2
B	1/2” PVC Tee Fitting	2
C	12” Schedule 80 PVC 1/2” Pipe	2
D	2.5” Schedule 80 PVC 1/2” Pipe	2
E	4” Schedule 80 PVC 1/2” Pipe	6
F	7” Schedule 80 PVC 1/2” Pipe	4
G	1”x1” PVC Sliding Block Type 1	4
H	1”x1” PVC Sliding Block Type 2	4
I	1/4” x 2” Clevis Pin & Clips	8

Tools and Supplies for Assembly

- Gorilla^{TM} PVC Glue (Non-toxic and no primer required)
- Mallet or hammer
- Miter saw or hand saw
- 5/16 in, 17/64 in, 27/32 in drill bits and drill press
- Adjustable wrench

NOTE: Even though the Gorilla PVC Glue has a slower setting time than other PVC Glues it will still set in under 1 minute. In all cases, liberally coat the inner circumference of the PVC fitting of each joint, with the PVC Glue, to ensure a secure fit. Read instructions carefully before starting to assemble the frame.

Step 1: Cut each PVC pipe to length as shown in Figure 87 and using the sliding construction jig drill out the telescoping holes in the pattern as shown in Figure ?.

<u>Side Portions of Small Wheelchair Assembly</u>

Step 2: Coat the inner surface of the middle opening of part B with PVC glue and insert Part D into the opening. Use the mallet to properly seat the connection.

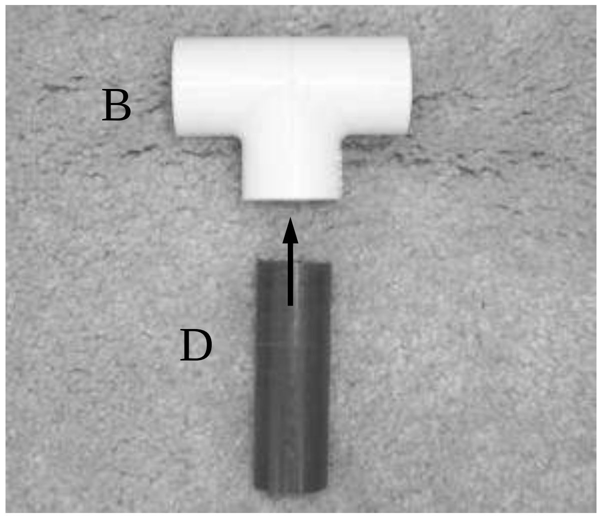


FIGURE 88 – Beginning Assembly for the Small Wheelchair (Step 2).

Step 3: Coat the inner surface of one end of Part B with PVC glue and insert Part E into the opening. Use the mallet to properly seat the connection.

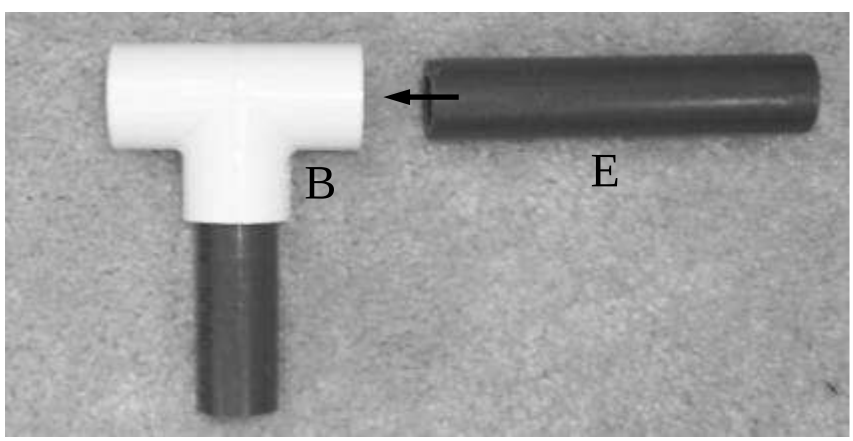


FIGURE 89 – Assembly of the Small wheelchair (Step 3).

Step 4: Coat the inner surface of the opposite opening of Part B with PVC glue and insert Part E into that opening. Use the mallet to seat the connection.

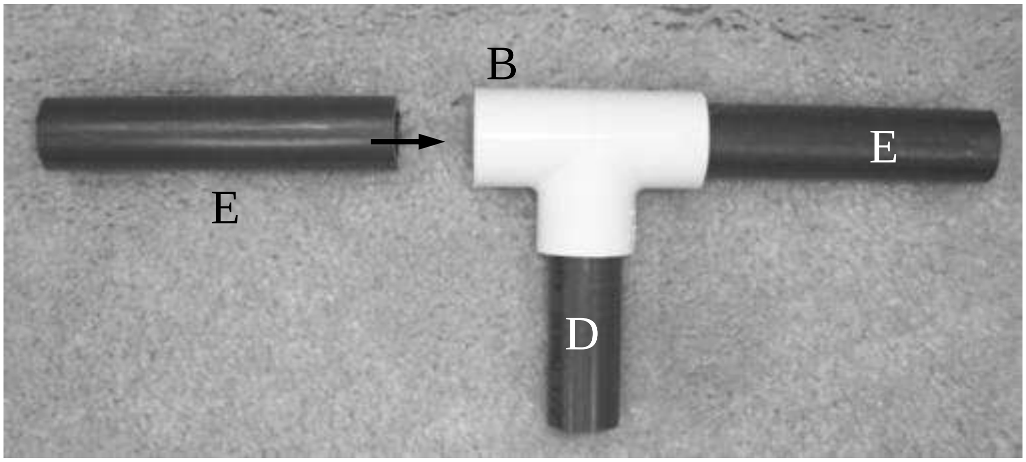


FIGURE 90 – Assembly of the Small Wheelchair (Step 4).

Step 5: Coat the inner surface of the larger hole of Part G, that does not have the 17/64 in hole passing through it, with PVC glue and slide over the end of Part E from the previous step until the end of the pipe is flush with the far surface of Part G. Be sure to keep the block perpendicular to Part E when seating on the pipe.

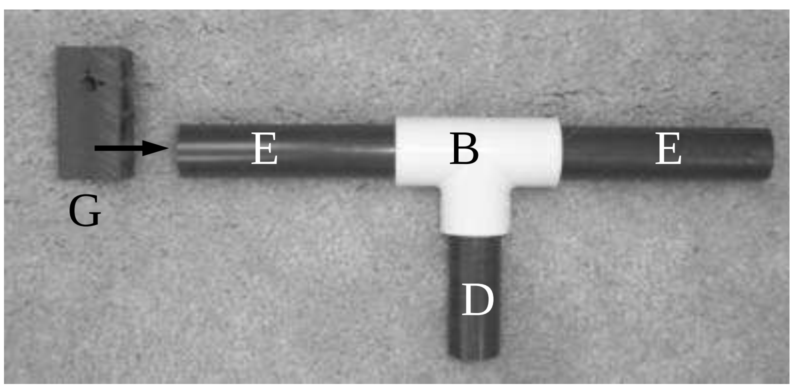


FIGURE 91 – Assembly of the Small Wheelchair (Step 5).

Step 6: Coat the inner surface of one of the larger holes in another Part G with PVC glue and slide it over the end of Part D of the structure as shown in Figure 92. Assure that the end of Part D is flush with the lower side of Part G.

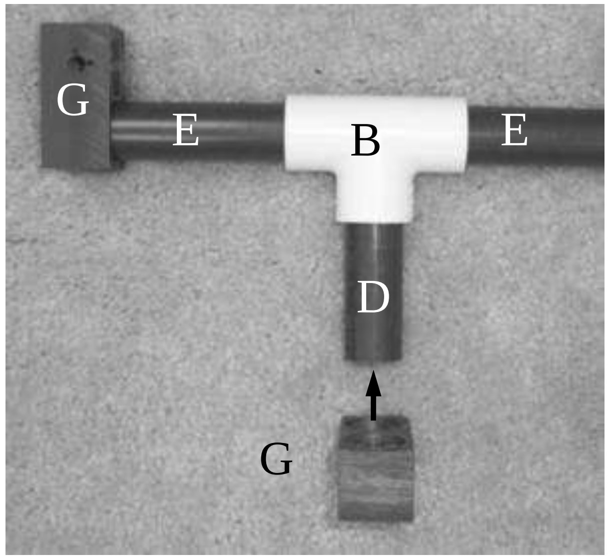


FIGURE 92 – Assembly of the Small Wheelchair (Step 6).

Step 7: Slide Part F through the hole not occupied by Part D in Part G from Step 6 and use a clevis pin to hold it in place.

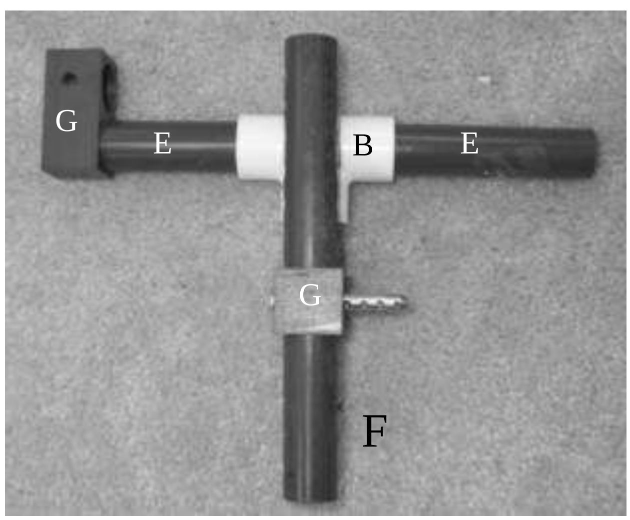


FIGURE 93 – Assembly of the Small Wheelchair (Step 7).

Step 8: Coat the inner surface of one of the openings of Part A with PVC glue and join it to the end of Part F as shown in Figure 94. Use the mallet to secure the connection.

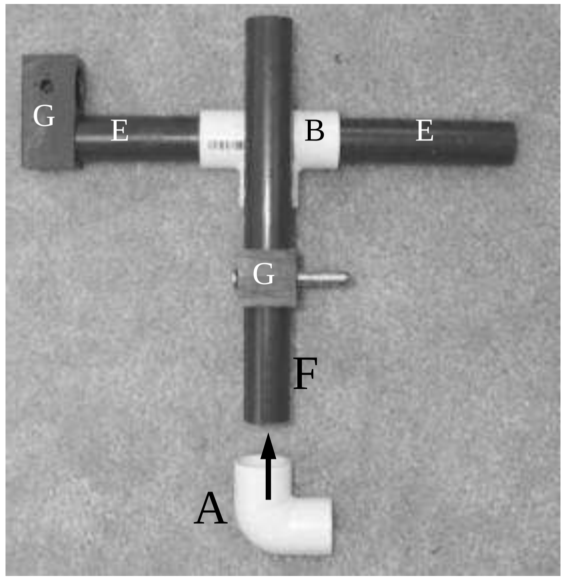


FIGURE 94 – Assembly of the Small Wheelchair (Step 8).

Step 9: Coat the inner surface of the other opening of Part A and insert Part E into this opening. Use the mallet to secure the connection. Rotate Part A around Part F to assure that Part E, inserted into Part A is parallel with Part E inserted into Part B.

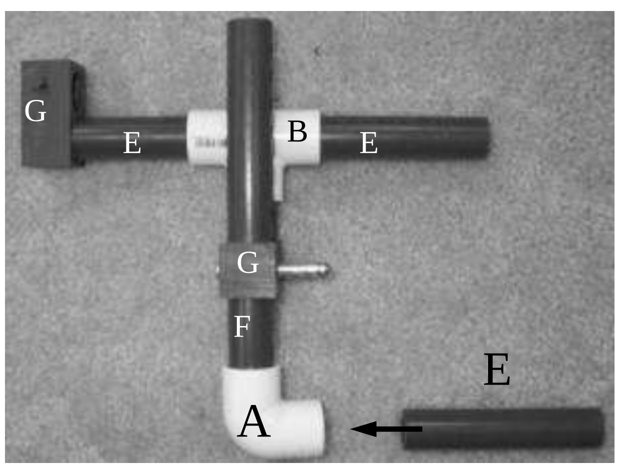


FIGURE 95 – Assembly of the Small Wheelchair (Step 9).

Repeat Steps 2-9 to construct the opposite side of the frame. There should be two assemblies that are mirror images of each other as shown in Figure 96.

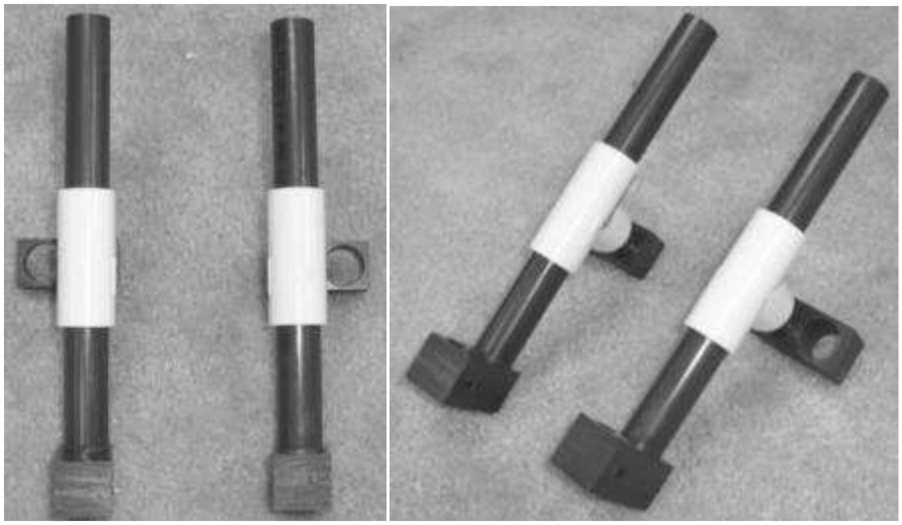


FIGURE 96 – Two Side Portions of the Small Wheelchair Frame without Part F Attached.

Step 10: Mark the hole half an inch from the top of Part A for the holes were the axle connect to the frame.

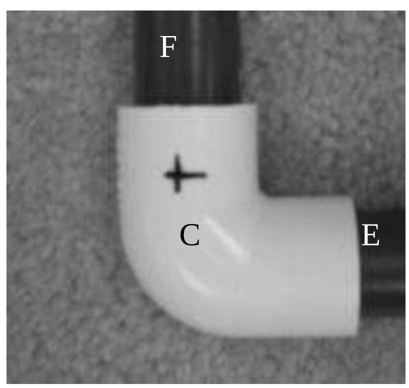


FIGURE 97 – Assembly of the Small Wheelchair (Step 10).

Step 11: Use the 5/16 in drill bit to drill the hole for the axle.

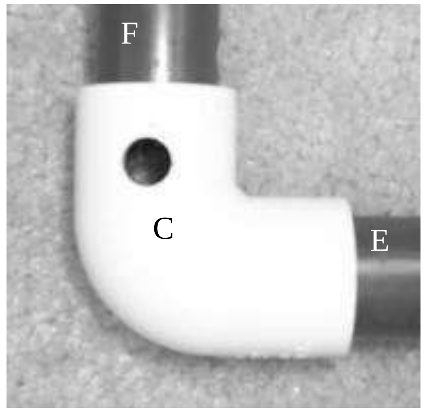


FIGURE 98 – Assembly of the Small Wheelchair (Step 11).

Step 12: Slide two Part H components onto Part C using the clevis pins to hold them together. Be sure to separate the blocks an equal distance apart from the ends on the 12 in length of pipe. This can be done by counting the holes. This rear support allows the frame to adjust for the width of the occupant.

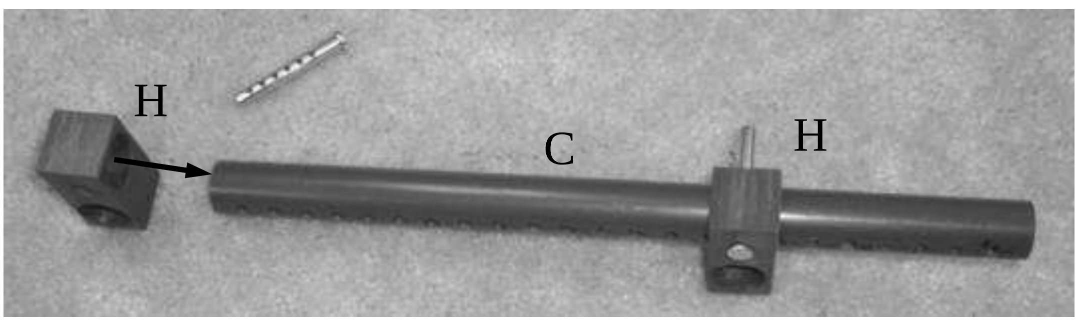


FIGURE 99 – Step 12 (Lower and Upper Rear Support Structure).

Repeat Step 12 for the upper rear support structure except place the blocks (Part H) 2 holes closer to the center of Part C. This accounts for the 2 in offset from the bottom portion of the wheelchair to the top.

Step 13: Coat the inner surface of the remaining holes in both Part H's that are joined to Part C with PVC glue and insert one of the finished side frame structures from Steps 2-9 into the hole. Repeat this procedure for the other remaining hole in Part H on the other side. Be sure to orient the two side frame structures as shown in Figure 100.

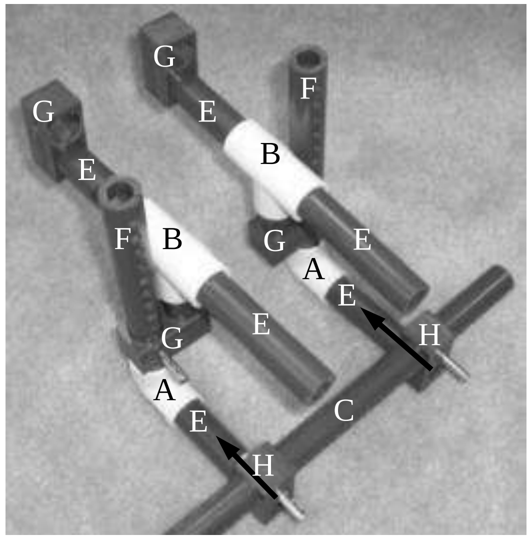


FIGURE 100 – Step 13, Correct Orientation of the Wheelchair. Assure Parallel Side Frame Structures.

Step 14: Coat the inner surface of the remaining holes in both Part H's already joined with Part C. with PVC glue and insert it over Part E for the side frame of the wheelchair as shown in Figure 101.

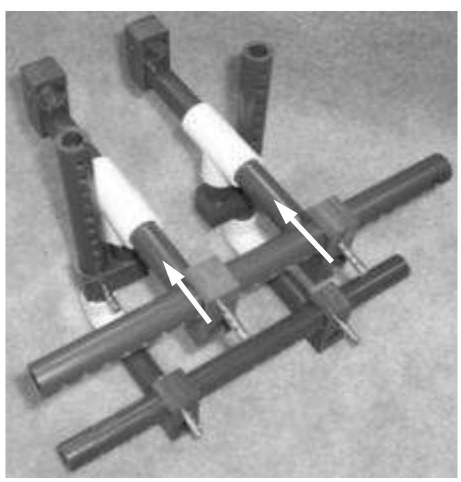


FIGURE 101 – Assembly of the Small Wheelchair (Step 14).

Step 15: With both upper and lower rear support structures attached to the frame rotate the frame until the two vertical legs are pointing straight upward and parallel.

Step 16: Finally, insert Part F into the remaining holes in Part G and use the clevis pins to secure their position. Repeat for the opposite side.

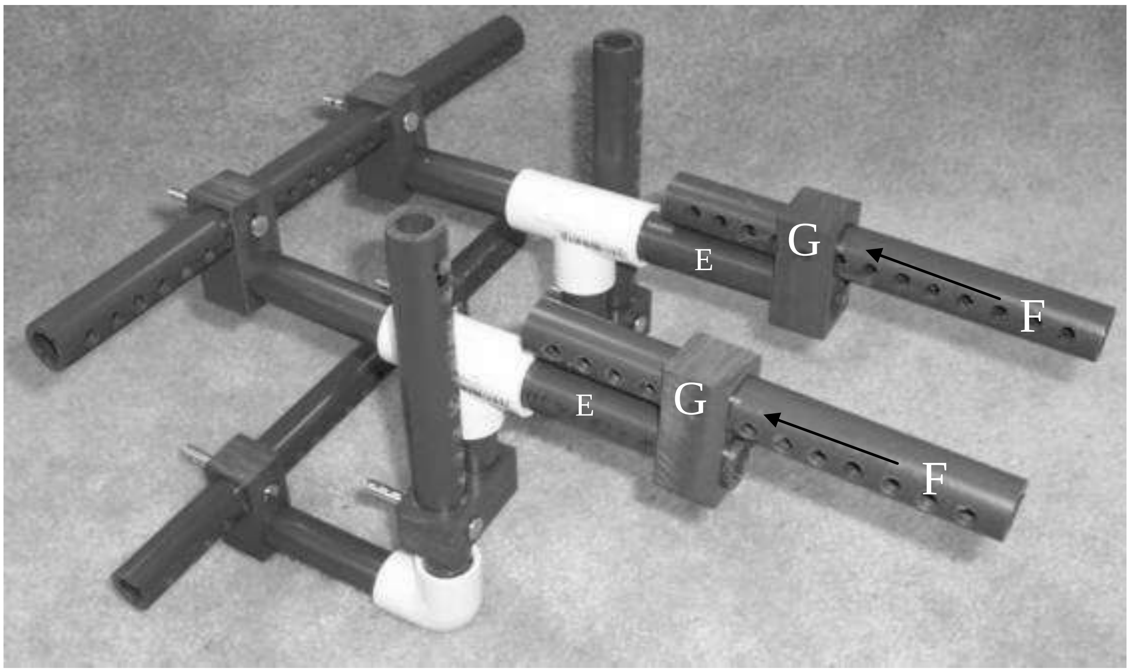


FIGURE 102 – Assembly of the Small Wheelchair (Step 16).

Wheel Assembly and Attachment

TABLE 21

LIST OF PARTS FOR BOTH LEFT AND RIGHT WHEEL ASSEMBLIES

Reference	Part	Quantity
A	5/16 in x 3.5 in Axle	2
B	Nylon Washer	2
C	SAE Washer	6
D	Bolt Nut	2
E	6 in Wheels	2

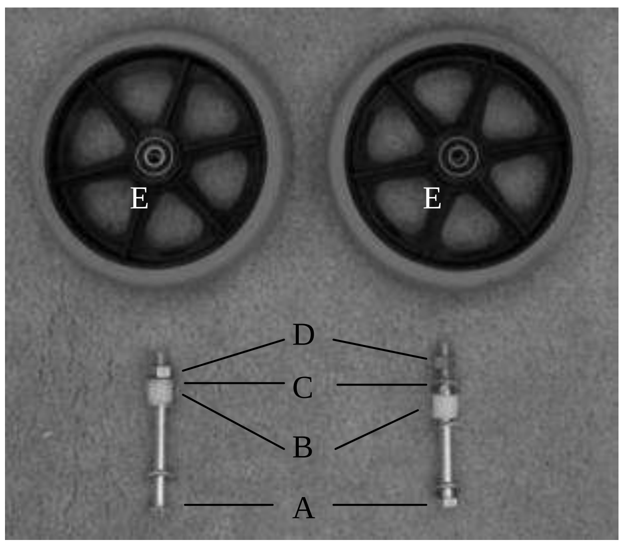


FIGURE 103 – Parts for Wheel and Axle Assembly.

Step 1. One wheel axle assembly includes: 1 – 3.5 in steel bolt (axle), 3 – 5/16 in SAE steel washers, 1 – 3/4 in x 0.562 in x 1/2 in nylon spacer, 1 – 5/16 in bolt nut, and 6 in wheels.

Step 2. Place washer on axle. Insert into 1/2 in diameter hole through Part C so that the head of the axle is located on the inside of the frame structure. Place another washer onto the axle adjacent to the outer side of Part C, followed by the nylon spacer and another washer. The wheel should then be placed on the axle followed by the nut. Use the adjustable wrench to tighten the nut onto the axle. Repeat these steps for the other wheel.

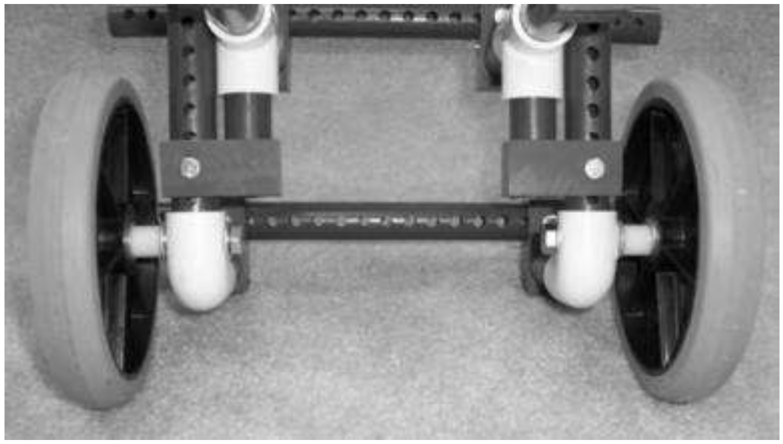


FIGURE 104 – Wheels Assembled and Attached to Wheelchair Frame.

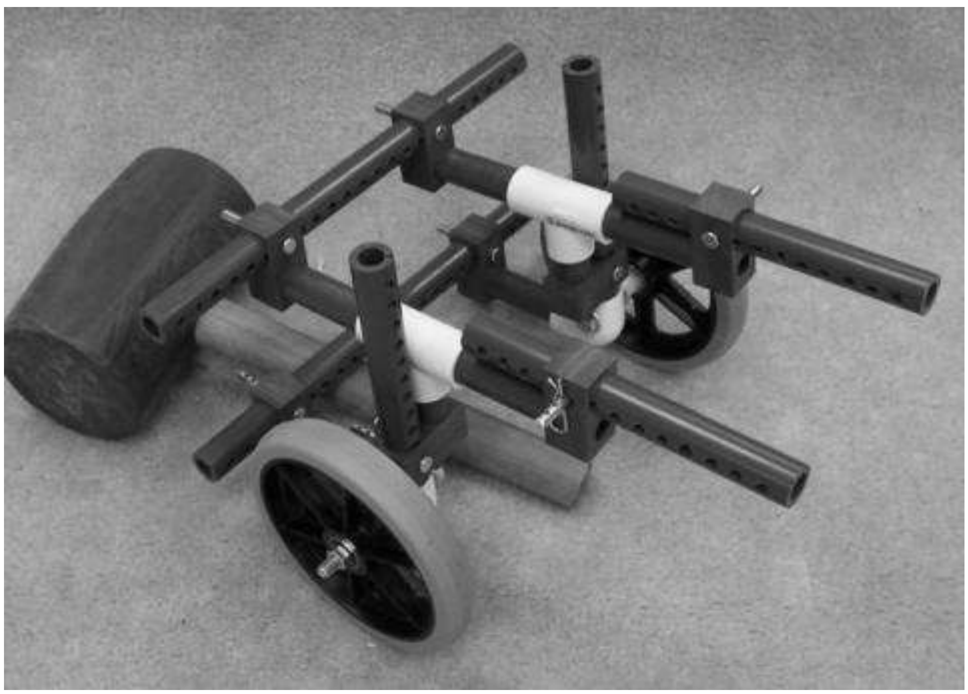


FIGURE 105 – Final Small Wheelchair Assembly.

APPENDIX V

Medium and Large Wheelchair Assembly Instructions

The following medium sized wheelchair is suitable for dogs weighing under 70 lbs with a wither height of 14-19 in and a hip to shoulder length of 12-20 in.

The following large wheelchair is suitable for dogs weighing 100 lbs and below with a wither height of 20-27 in and hip to shoulder length of 12-20 in.

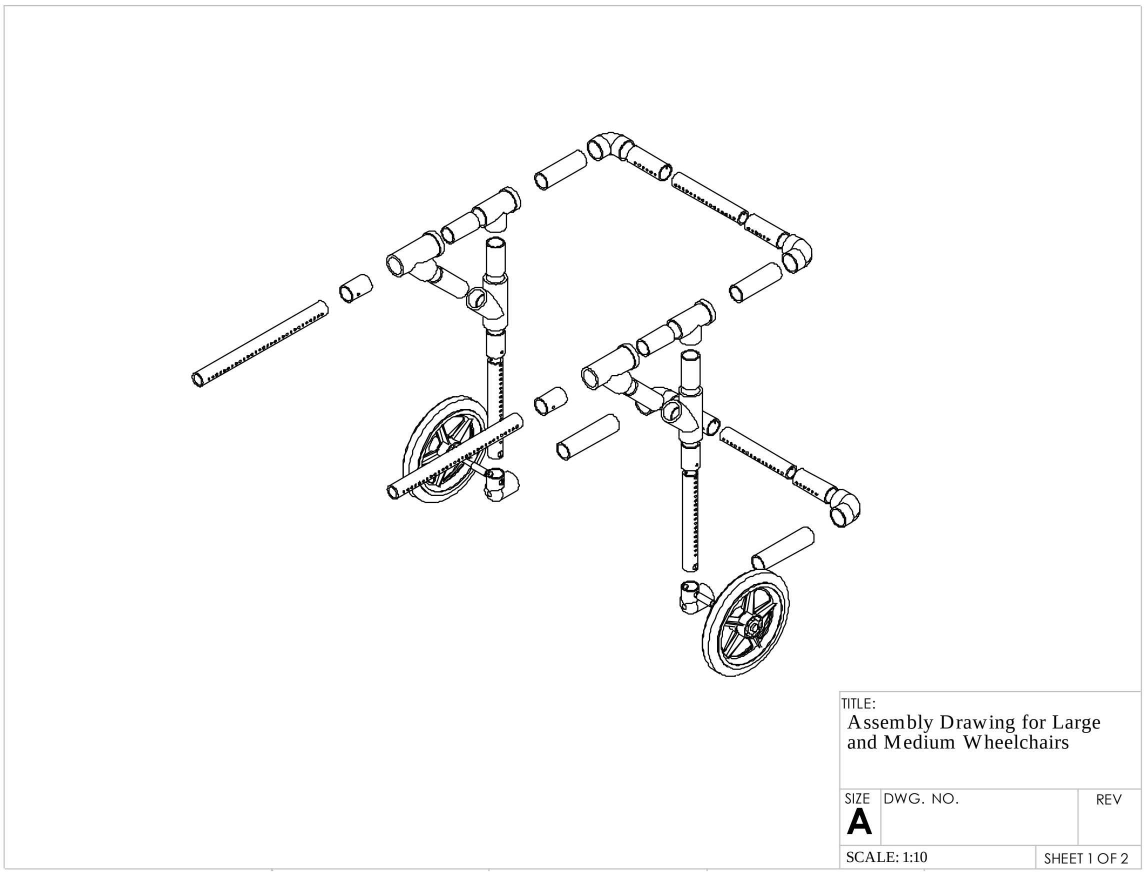


FIGURE 106 – Exploded View of the Medium Wheelchair Assembly.

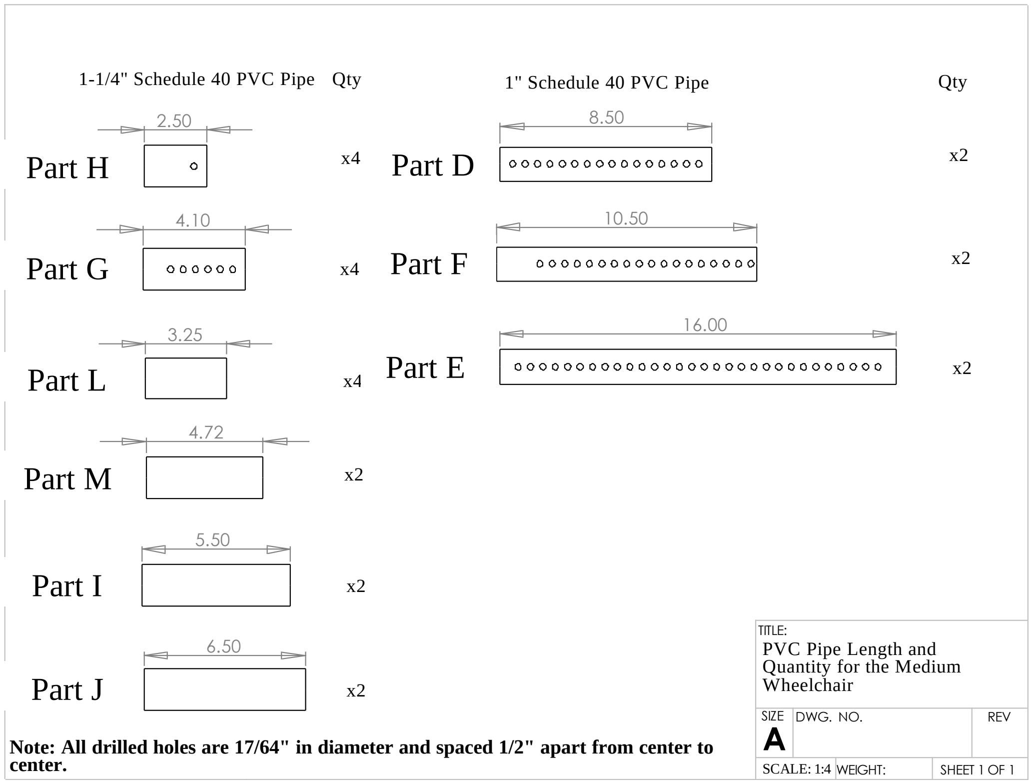


FIGURE 107 – PVC Pipe *Length and Quantity for the Medium Wheelchair.

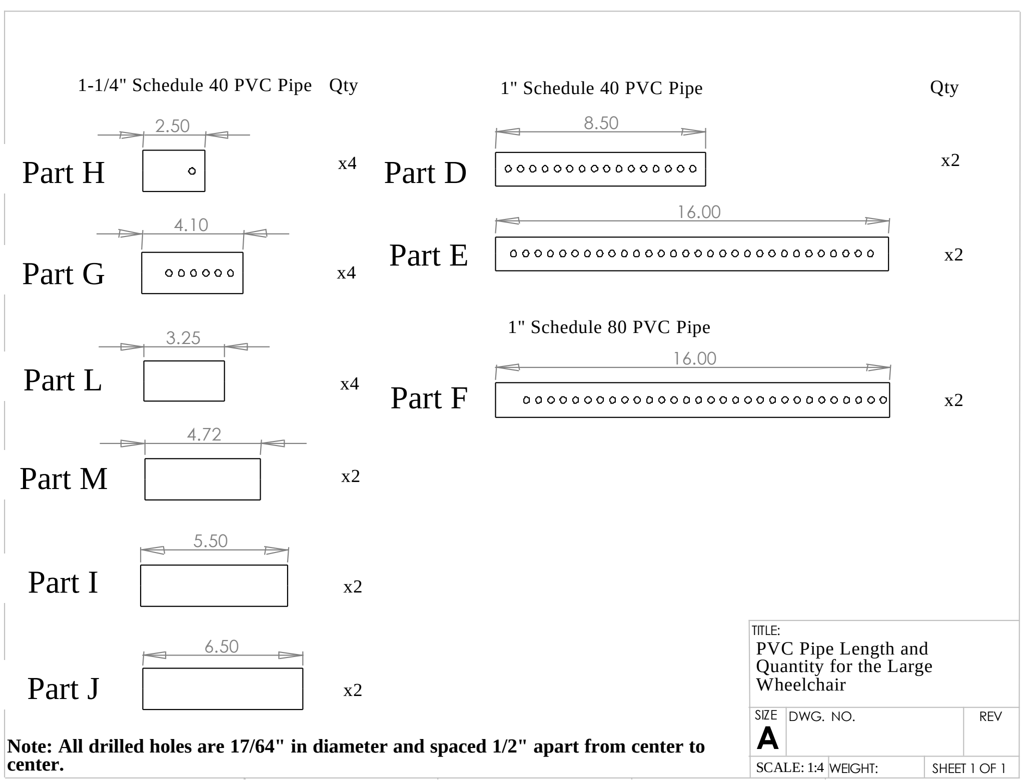


FIGURE 108 – PVC Pipe *Length and Quantity for the Large Wheelchair.

*Note: The holes are started at 1/2 in from the right hand side as shown in Figure 107 & 108.

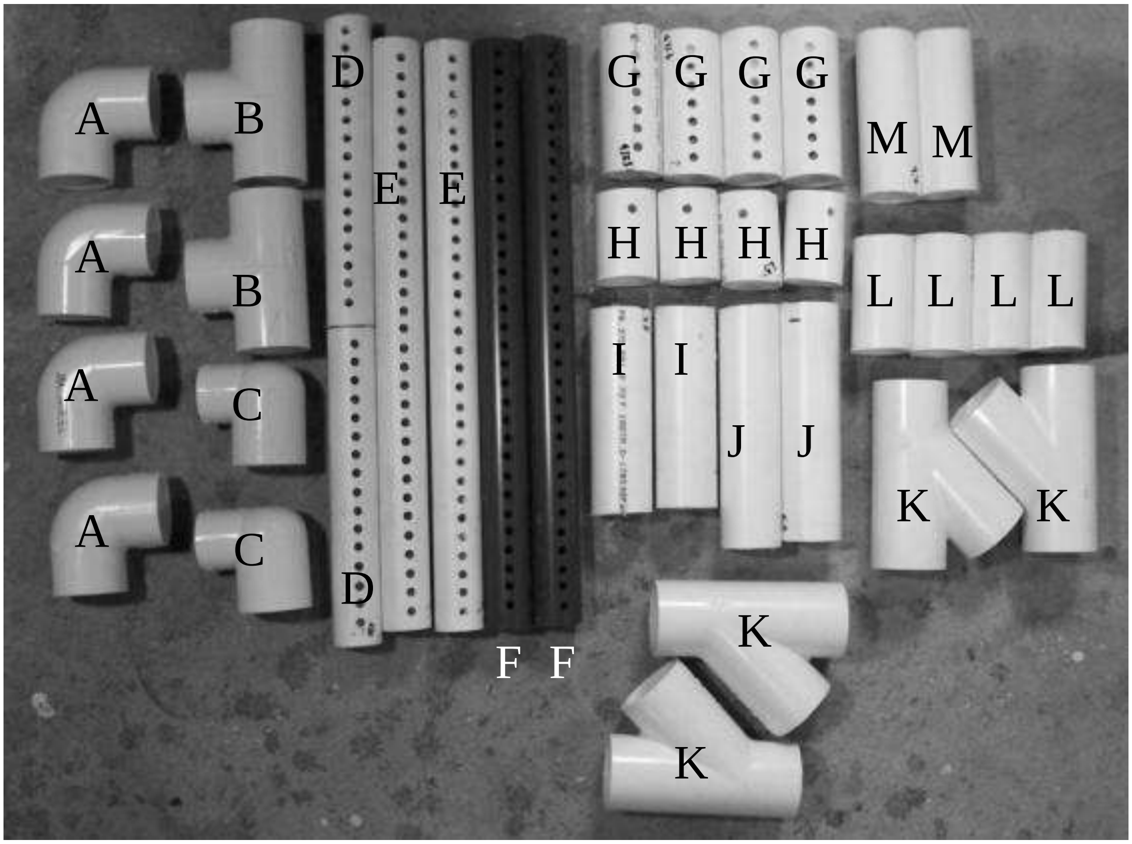


FIGURE 109 – PVC Parts Needed to Assemble the Large Wheelchair Frame.

TABLE 22

PARTS LIST FOR ASSEMBLING MEDIUM/LARGE WHEELCHAIR FRAME AND WHEELS

Part Label	Part Name	Quantity
A	1-1/4” PVC Elbow	4
B	1-1/4” PVC Tee Fitting	2
C	1-1/4” to 1” PVC Reduction Elbow	2
D	8.5” Schedule 40 PVC Pipe	2
E	16” Schedule 40 PVC Pipe	2
F*	16” Schedule 80 PVC Pipe (large wheelchair)	2
F*	10.5” Schedule 40 PVC Pipe	2

	(medium wheelchair)	
G	4.1" Schedule 40 PVC Pipe	4
H	2.5" Schedule 40 PVC Pipe	4
I	5.5" Schedule 40 PVC Pipe	2
J	6.5" Schedule 40 PVC Pipe	2
K	1-1/4" PVC Wyes	4
L	3.25" Schedule 40 PVC Pipe	4
M	4.7" Schedule 40 PVC Pipe	2
N	1/4" x 2" Clevis Pin & Clips	8
O	5" x 1/2" bolt for axle	2
P	3/4" x 1/2" Nylon Spacer	2
Q	1/2" SAE Washers	6
R	12.5" Pneumatic Wheels	2

*Note: The only difference in the large wheelchair design and the medium wheelchair design is the length and the use of Schedule 80 PVC for Part F. The large wheelchair use the 16 in section of pipe whereas the medium wheelchair uses the 10.5 in section of pipe.

<u>Tools and Supplies for Assembly</u>

- Gorilla PVC Glue™ (Non-toxic and no primer required)
- Mallet or hammer
- 1/2 in and 17/64 in drill bits and drill press
- Adjustable wrench
- Wire Tie Tensioner

NOTE: Even though the Gorilla PVC Glue has slower setting time than other PVC Glues it will still set in under 1 minute. In all cases, liberally apply a thick strip of PVC glue on the inner circumference of the PVC fitting on each joint. Read instructions carefully before starting to assemble the frame.

Step 1: Cut and drill the holes (where necessary) for each piece of pipe as shown in Figure 108 (Figure 107 for the medium wheelchair frame). Refer to the construction jig manual for the process of drilling the holes in the PVC pipe.

Wheelchair Side Frame

Step 2. Coat the inner surface of the middle opening of Part B with PVC glue and insert Part L into Part B. Gently tap Part L with a mallet until it is completely seated.

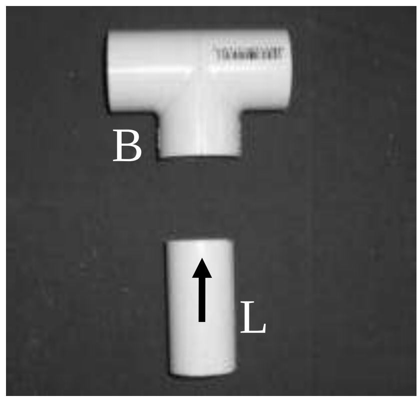


FIGURE 110 – Beginning Assembly for the Medium/Large Wheelchair (Step 2).

Step 3. Coat the inner surface of one of the end openings of Part B with PVC glue and insert Part L into this opening. Use the mallet to properly seat the connection.

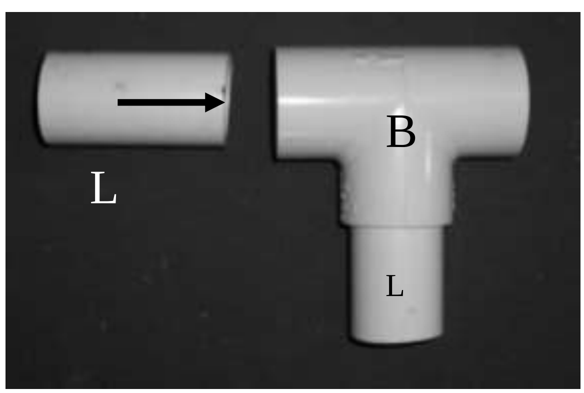


FIGURE 111 – Assembly of the Medium/Large Wheelchair (Step 3).

Step 4. Coat the inner surface of the angled opening of Part K with PVC glue and insert Part M into that socket. Use the mallet to properly seat the connection.

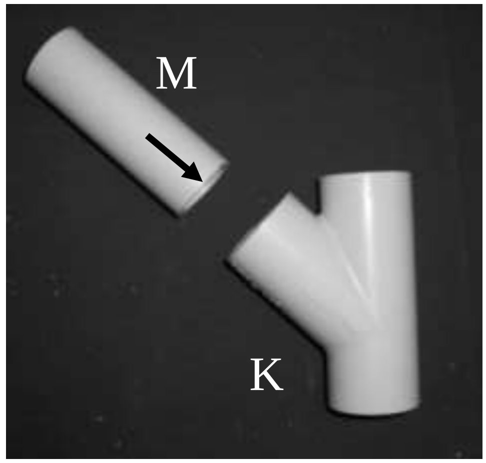


FIGURE 112 – Assembly of the Medium/Large Wheelchair (Step 4).

Step 5. Coat the inner surface of the three openings on the two Part K fittings shown by arrows in Figure 113 with PVC glue. Carefully align the openings and pipes to slide into each other at the same time. Use the mallet to properly seat each connection at an even rate by hitting each end two to three times then rotating the assembly to hammer the other fitting into place in the same manner.

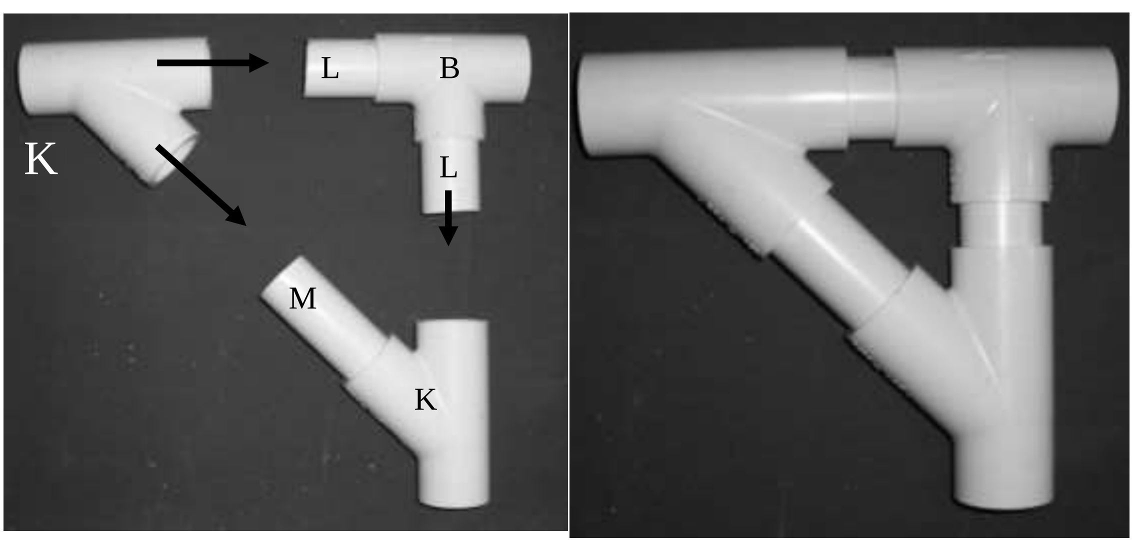


FIGURE 113 – Step 5 (Left) and Finished Structure (Right).

Step 6. Coat the inner surface of the remaining opening on the horizontally oriented Part K with PVC glue and insert one of the Part H pipes into the opening, making sure to align the holes horizontally at the midpoint as shown in Figure 114. Use the mallet to properly seat the connection.

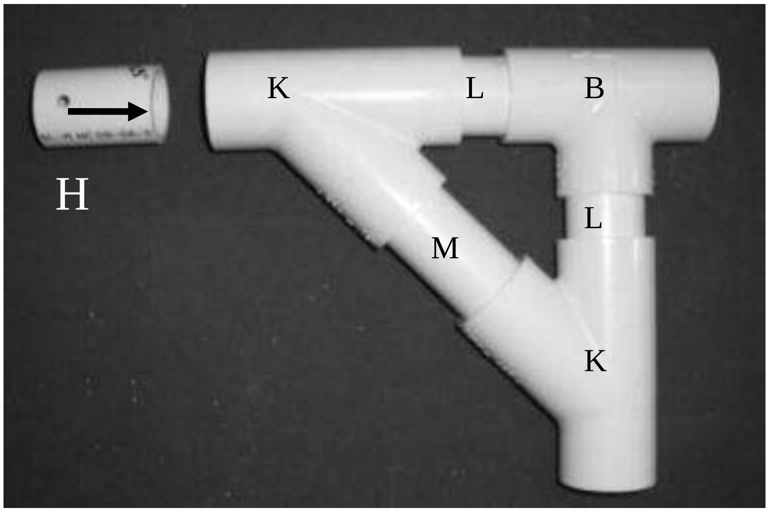


FIGURE 114 – Assembly of the Medium/Large Wheelchair (Step 6).

Step 7. Coat the inner surface of the remaining opening on the Part B with PVC glue and insert one of Part I into the opening. Use the mallet to properly seat the connection.

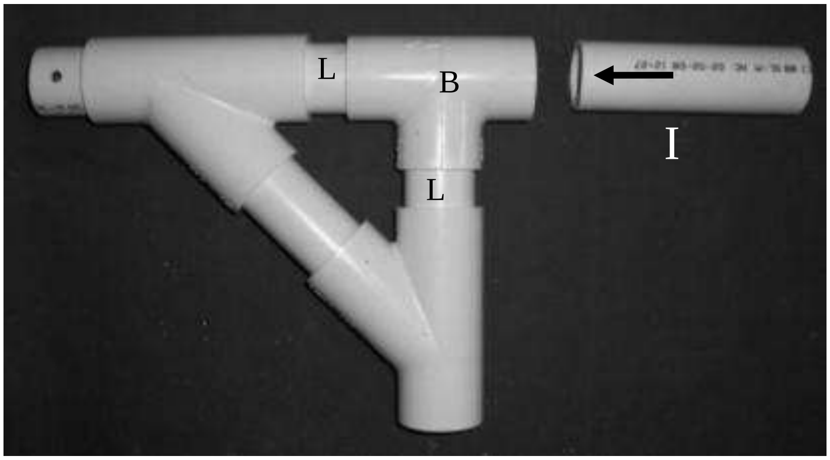


FIGURE 115 – Assembly of the Medium/Large Wheelchair (Step 7).

Step 8. Coat the inner surface of the remaining opening of the vertically oriented Part K with PVC glue and insert one of the Part H pipe into the opening, making sure to align the holes at the midpoint as shown in Figure 116. Use the mallet to seat the connection.

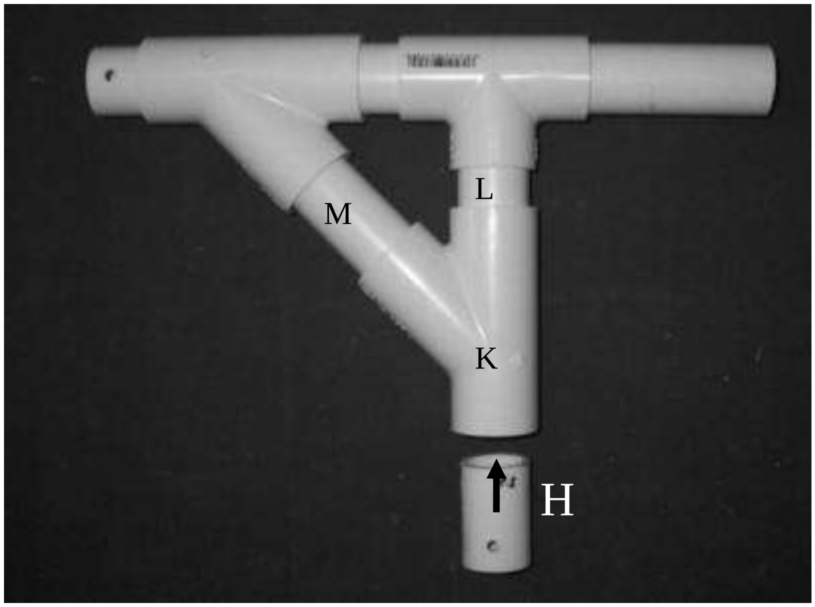


FIGURE 116 – Assembly of the Medium/Large Wheelchair (Step 8).

Repeat Steps 2-8 to create the opposite side of the wheelchair frame.

Upper and Lower Rear Wheelchair Frame

Step 9. Coat the inner surface of the opening of Part A with PVC glue and insert Part G into this opening. Align the holes horizontally at the midpoint of the pipe. Use a mallet to seat the connection.

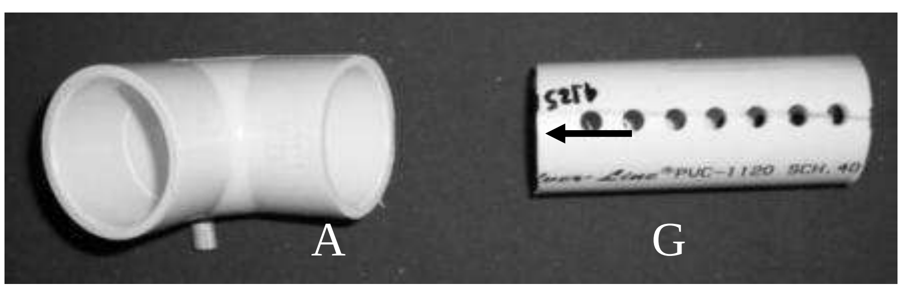


FIGURE 117 – Assembly of the Medium/Large Wheelchair (Step 9).

Step 10. Use clevis pins (or dowel rods if clevis pins are unavailable) to align the holes of the two Part G pipes with the Part D as shown in Figure 118.

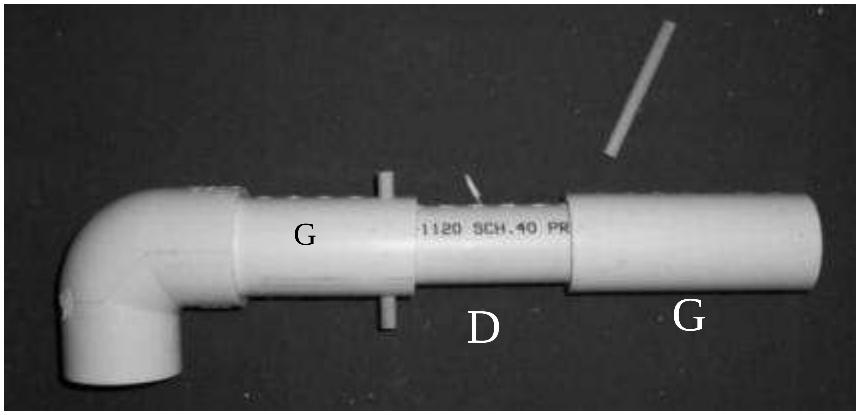


FIGURE 118 – Assembly of the Medium/Large Wheelchair (Step 10).

Step 11. Coat the inner surface of the openning on another Part A with PVC Glue and insert onto the Part G, attached in the last step, being careful to keep the Parts A, G, and D oriented in the same horizontal plane as shown in Figure 119. This is best accomplished by laying all components on a flat horizontal surface. Use the mallet to seat the connection

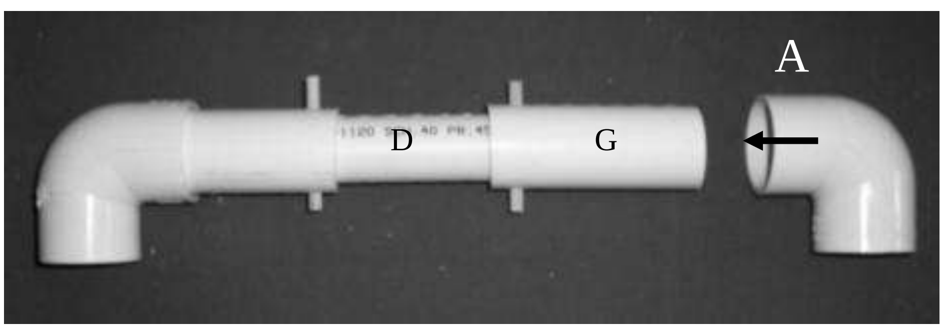


FIGURE 119 – Assembly of the Medium/Large Wheelchair (Step 11).

Repeat Steps 9-11 to create the lower rear wheelchair frame.

Joining the Side Frame to the Rear Frame of the Wheelchair

Step 12. Use a clevis pin or dowel rod to align the holes in the lower opening Part H with the side frame structure created in Step 8 as shown in Figure 120.

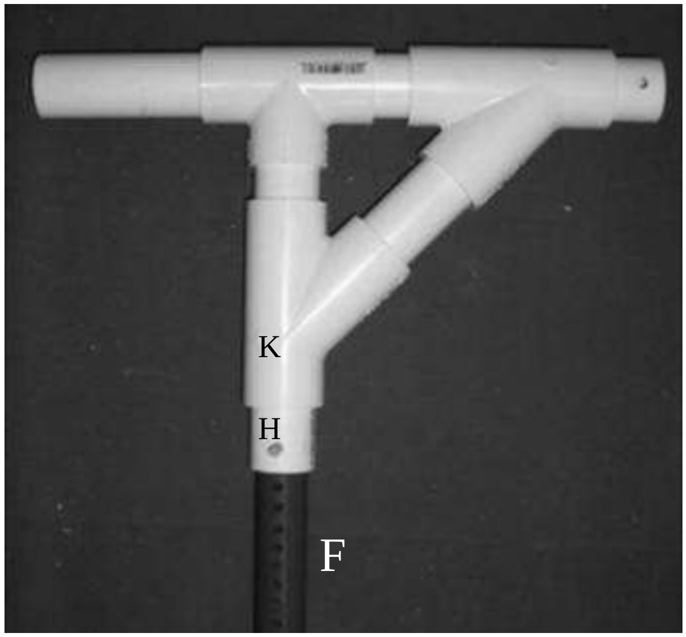


FIGURE 120 – Assembly of the Medium/Large Wheelchair (Step 12).

Step 13. Coat the inner surface of the 1 in opening of Part C with PVC Glue and insert it onto the free end of Part F. Use the mallet to seat the connection while carefully making sure that Part C is in plane with the rest of the structure.

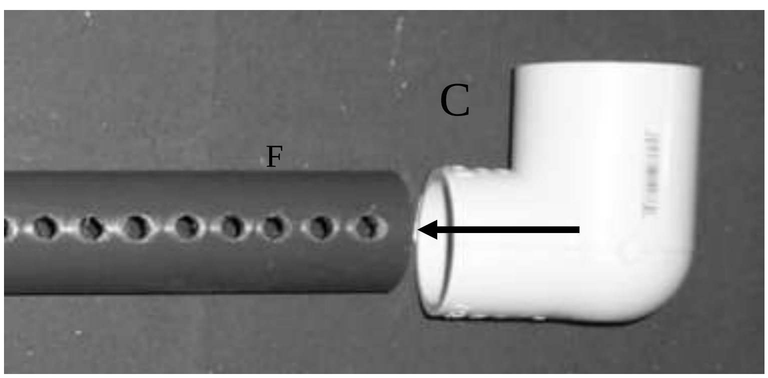


FIGURE 121 – Assembly of the Medium/Large Wheelchair (Step 13).

Step 14. Mark a point 0.5 in from the intersection and mid-plane (FIGURE 122) of the Part F and Part C (1 in opening side) connection to drill a 1/2 in hole for the axle (FIGURE 123). Drill the 1/2 in diameter hole through both walls of Part F and C assuring that the hole is perpendicular to the surface of Part C.

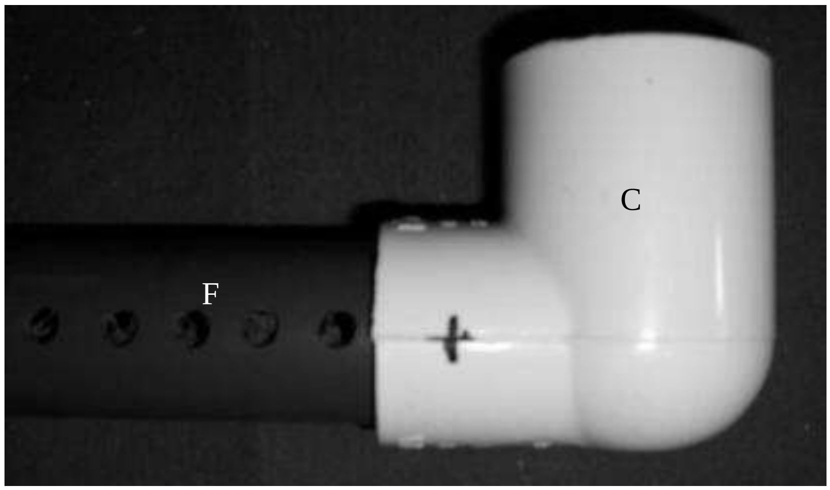


FIGURE 122 – Step 14, Marking the Hole to be Drilled.

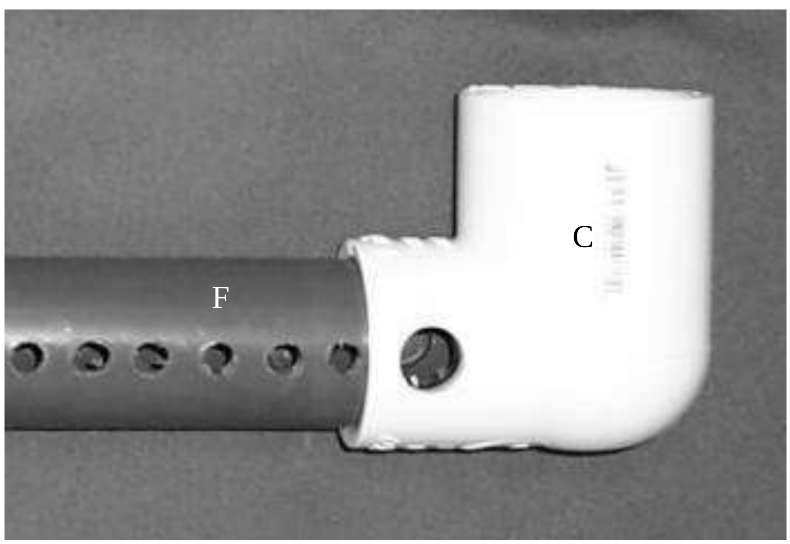


FIGURE 123 – Step 14, 1/2 in Drilled Axle Hole.

Step 15. Coat the 1-1/4 in socket of Part C with PVC Glue and insert Part J into the socket. Use the mallet to seat the connection.

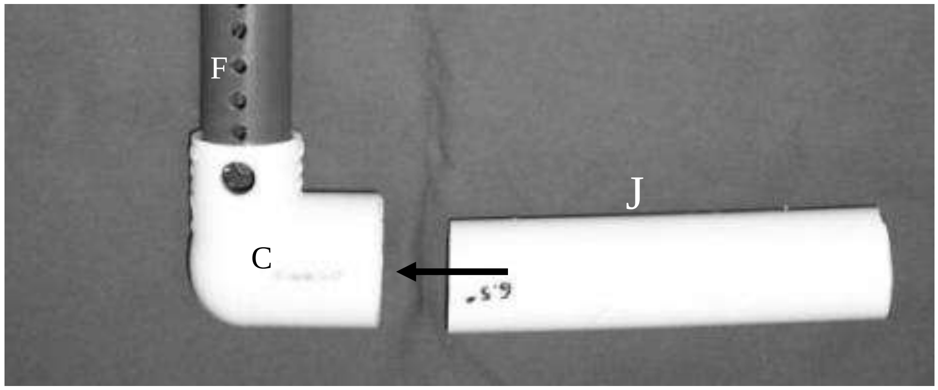


FIGURE 124 – Assembly of the Medium/Large Wheelchair (Step 15).

Repeat Steps 12-15 for the other side of the frame.

Step 16. Remove the dowel/clevis pin and remove Part F from the side wheelchair frame in Part H. Coat the inner surface of the opening of Part A on one end of the lower rear frame structure (created in Steps 9-11) and insert the other end from Part J (attached to the structure created in Steps 12-15) into the opening. Keep the dowels/clevis pins in the lower rear frame structure (Part G and E) for alignment. Use the mallet to seat the connection.

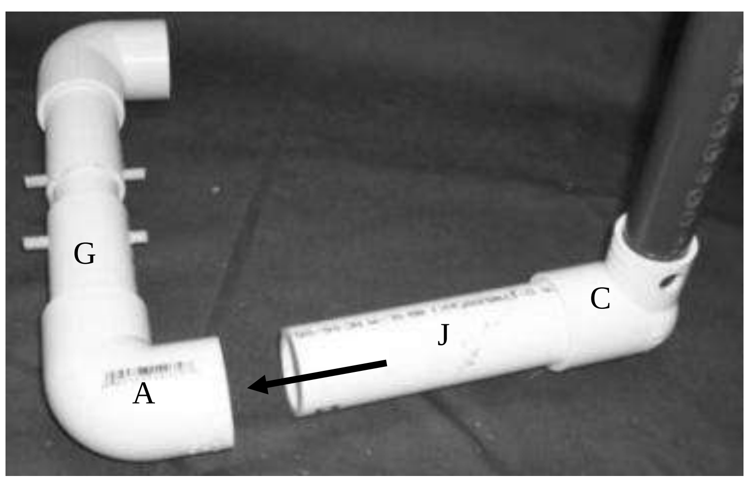


FIGURE 125 – Assembly of the Medium/Large Wheelchair (Step 16).

Step 17. Repeat Step 15 for the opposite side (FIGURE 126).

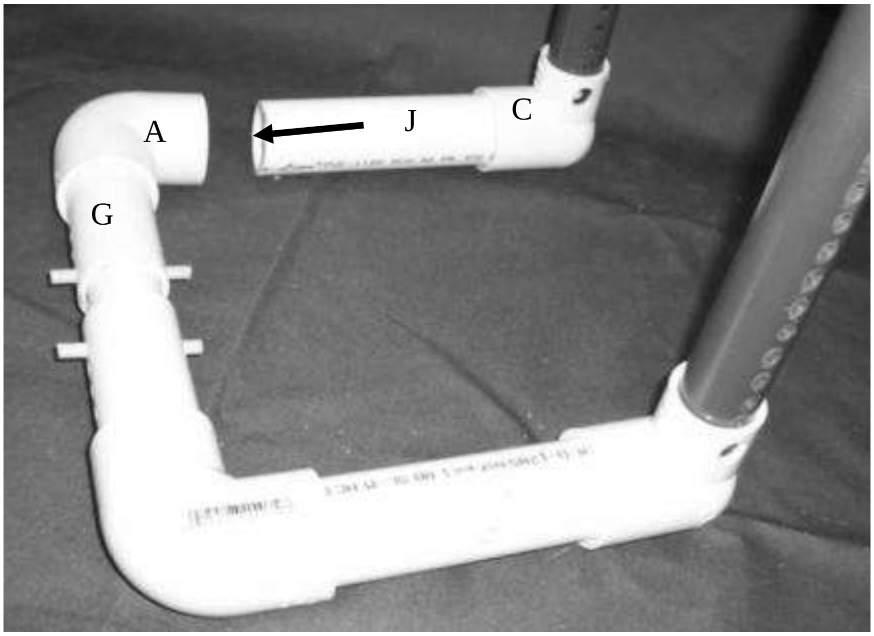


FIGURE 126 – Assembly of the Medium/Large Wheelchair (Step 17).

Step 18. Check the alignment of the vertical legs (Parts F) to assure they are both parallel to each other and vertical. If not, correct before the glue sets.


FIGURE 127 – Assembly of the Medium/Large Wheelchair (Step 18).

Step 19. Using the 1/4 in clevis pins or dowel/clevis pins through holes aligned between Parts F and H, attach the structures created in Steps 2-8 to the lower portion (created in Steps 9-11).

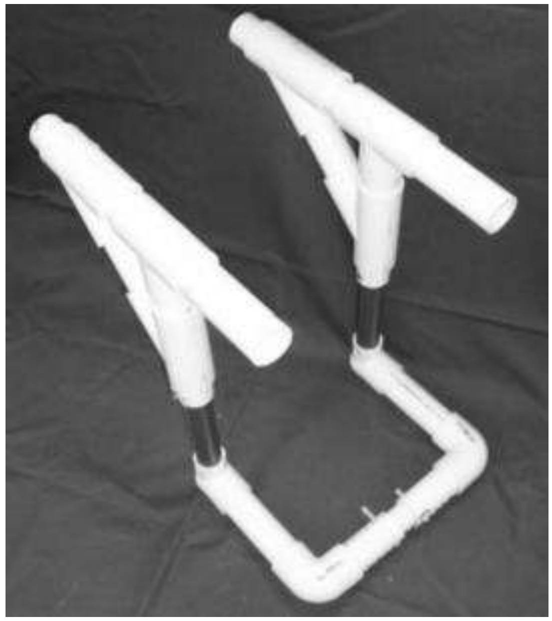


FIGURE 128 – Assembly of the Medium/Large Wheelchair (Step 19).

Step 20. Coat the inner surface of both ends of the upper rear wheelchair frame (Part I) with PVC glue and insert it onto both Part I's of the side frames as shown in Figure 129. Once again, take care to keep the alignment of the frame intact. Use the mallet to seat the connections.

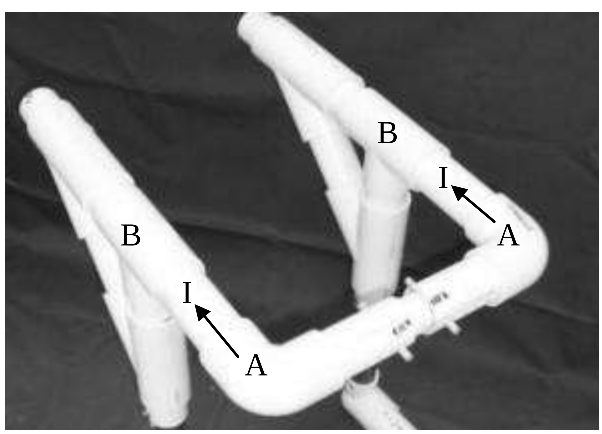


FIGURE 129 – Assembly of the Medium/Large Wheelchair (Step 20).

Figures 130 – 131

FIGURE 130 – Side View of Completed Wheelchair Frame.

FIGURE 131 – Front View of Completed Wheelchair Frame.

Wheel Assembly and Attachment

Step 1. One wheel axle assembly includes: 1 – 5 in steel bolt (axle), 3 – 1/2 in SAE steel washers, 1 – 3/4 in x 1/2 in nylon spacer, 1 – 1/2 in bolt nut, and 12.5 in pneumatic wheels (Parts O-R, TABLE 22).

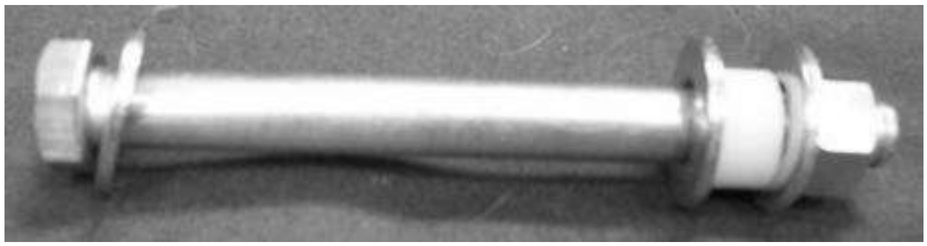


FIGURE 132 - Axle Assembly for Attaching the Wheels.

Step 2. Place washer on axle. Insert into 1/2 in diameter hole through Part C so that the head of the axle is located on the inside of the frame structure. Place another washer onto the axle adjacent to the outer side of Part C, followed by the nylon spacer and another washer. The wheel should then be placed on the axle followed by the nut. Use the adjustable wrench to tighten the nut onto the axle. Repeat these steps for the other wheel.

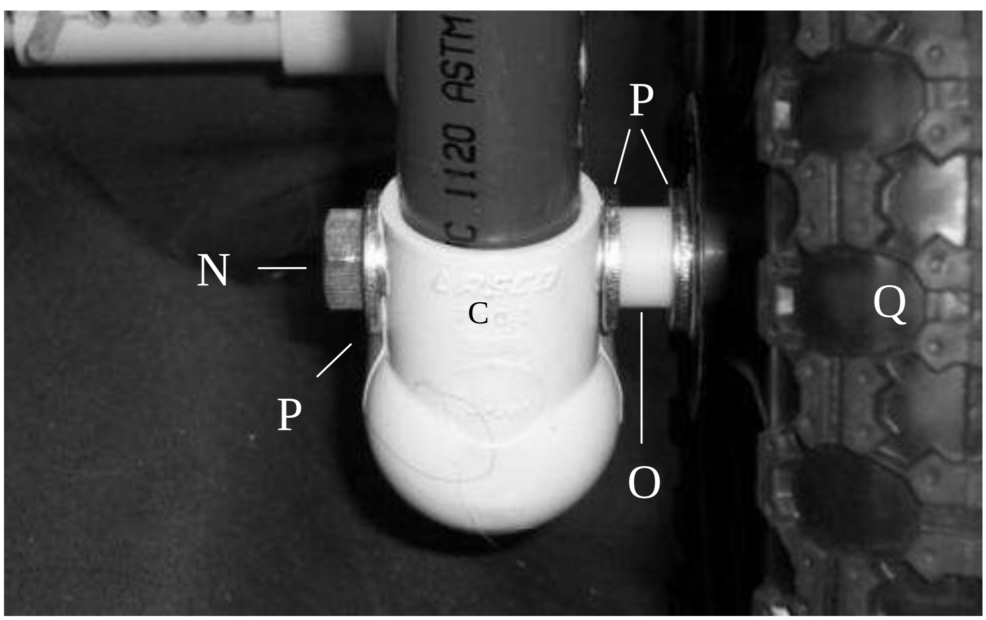


FIGURE 133 - Order of the Axle/Wheel Assembly.

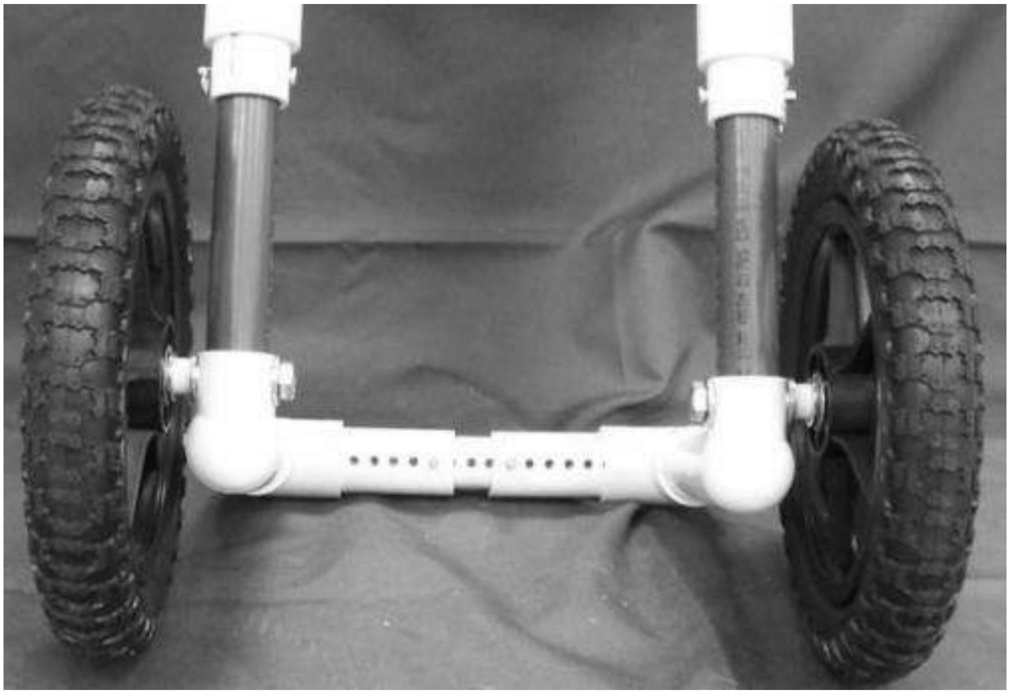


FIGURE 134 – Picture of the Lower Portion of the Wheelchair with Both Wheels Attached to the Frame.

Final Wheelchair Frame Assembly

Step 1. Finally, both Parts E can be inserted into Parts H of the side frame and connected with the clevis.

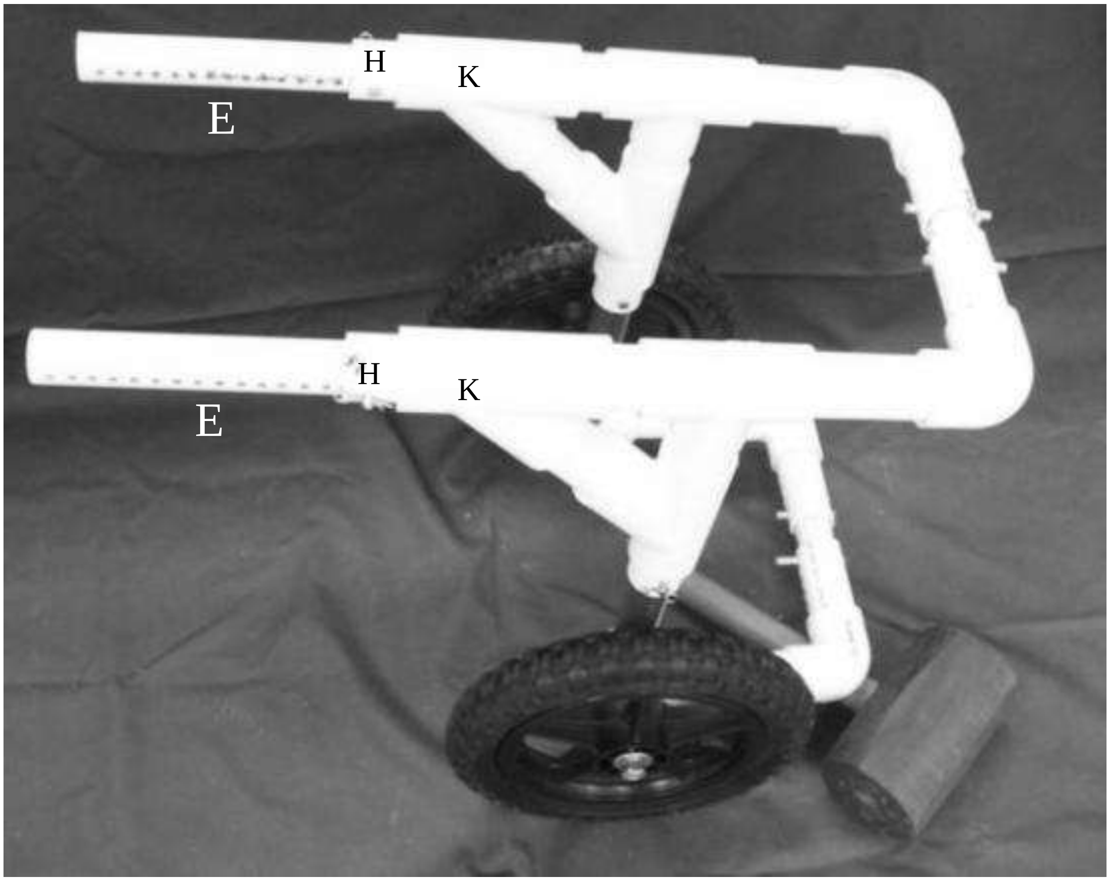


FIGURE 135 – Final Canine Wheelchair Frame Assembly with 12.5 in Wheels.

APPENDIX VI

Harness to Frame Interface

TABLE 23

LIST OF PARTS FOR THE HARNESS CONNECTION

Part	Quantity
Cable Ties (120 lb capacity)	16
Plastic Side Snap Buckles	8
Front Chest Harness	1
Rear Pelvic Harness	1

Rear Pelvic Harness:

Attach the buckles to the frame with two cable ties to minimize the twisting of the buckles and to restrain their ability to slide on the PVC. Figure 136 shows the four buckles used to attach to the rear harness to the frame. Notice the two buckles are positioned between the horizontal 1-1/4 in wyes fitting and the 1-1/4 in tee fitting. The other two are located directly behind the 1-1/4 in tee fitting of the wheelchair. The distance between the buckles on one side of the wheelchair frame is approximately 4-5 in. Use the cable ties to attach the female half of the buckles to the wheelchair frame.

FIGURE 136 – Location of the Buckles for the Rear Harness.

The pelvic harness is sewn in such a way that the supports webbing can be leveled out with the buckles attached to the frame. Figure 137 is the rear pelvic harness laid out displaying the underside of the harness. The areas on the harness in Figure 137 that are circled are where the stitching ends.

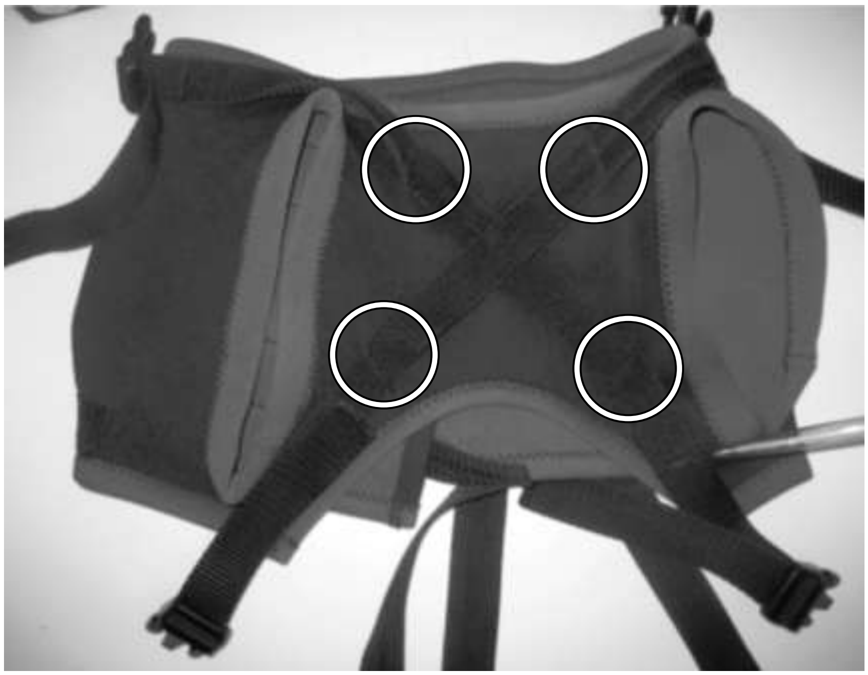


FIGURE 137 – Underside of the Pelvic Harness.

Figure 138 shows how the harness and the dog should be positioned into the wheelchair.

FIGURE 138 – Top View of the Pelvic Harness Attached to the Wheelchair Frame.

Front Chest Harness:

To balance the dynamic forces placed on the front end of the wheelchair 4 plastic buckles should be used. Figure 139 illustrates how the buckles should be oriented to balance the front end of the wheelchair. One buckle should be oriented to balance the upward forces and one buckle should be oriented to balance the downward forces.

FIGURE 139 – Orientation of the Buckles for the Chest Harness

The male end of the buckles should be attached to the harness. To do this, a section of nylon webbing is looped around the male half of the buckle and sewn into the harness at the appropriate location and orientation. The harnesses should be test fitted on the dog to make sure the buckles are in a location that allows them to easily connect to the frame and the majority of the dog's weight is positioned directly over the wheels and vertical support members of the frame. Once the buckles are oriented in the correct direction the cable ties can be tightened down and the excess trimmed off. Figure 140 shows the chest harness attached to the wheelchair frame.

FIGURE 140 – Top View of the Chest Harness Attached to the Front of the Wheelchair.

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EDUCATION

Master of Engineering, Mechanical Engineering, August 2007 – Expected date: December 2008
University of Louisville

Graduate Student Thesis Research: Thesis revolves around the design and development of a cost effective canine wheelchair for animal rehabilitation. Extensive use of CAD and FEA software such as Solidworks and Cosmosworks have been needed to determine the feasibility of wheelchair designs before a prototype is made. Other aspects of this project include technical writing, material research, and prototype development.
GPA: 4.00

Bachelor of Science in Mechanical Engineering, August 2003 - August 2007
University of Louisville
GPA: 3.45

EXPERIENCE

General Electric Consumer & Industrial, Louisville, KY
Internal Quality Engineer Co-op, 3rd rotation, May 2006 – August 2006

Worked with internal and external suppliers of dishwasher parts to ensure the quality of each unit was up to company standards. Worked in teams to solve large scale problems in production. Developed ability to use root cause analysis to troubleshoot production problems. Worked extensively in Microsoft Excel to develop project reports and track defective parts. Routinely measured part dimensions to determine if parts were within specifications of the draft drawings.

General Electric Consumer & Industrial, Louisville, KY
Sourced Quality Engineer Co-op, 2nd rotation, August 2005 – December 2005

Work included extensive work with suppliers of GE cooking products and field technicians to collect information on defective units and fix the problem quickly. Created a quick system of contacting and receiving technician's emails using Mail Merger and Excel. Also was involved in a Co-op Lean manufacturing project competition that placed first for developing a technique for identifying and catching a defective part on the line without any additional equipment.

SKILLS

- CAD programs: Auto CAD 2004, SolidWorks 2006, SolidEdge V19
- FEA programs: ANSYS 11, visualNastran 4D, COSMOSWorks 2006
- Microsoft Office: Excel, Word, PowerPoint, Visio, Project
- Program Languages: MATLAB
- Basic training in Six Sigma and Lean manufacturing practices from General Electric C&I

VOLUNTEER WORK / AWARDS / HOBBIES

- Volunteer projectionist at The Grand Theatre in Frankfort, KY
- Received Eagle Scout Award in 2000
- Woodworking: woodturning, box making, and furniture making
- John B. Dressman Freshman Design Award 2004