GuideCane-II:
Final Report

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SECTION #5

December 11, 2007

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ABSTRACT

The GuideCane-II is a mobility aid that will provide assistance and independence to visually impaired users by detecting obstacles and steering or braking accordingly. Current mobility aids have many limitations and require extensive training. Our goal is to design and develop a prototype of the GuideCane-II that actively steers and brakes in response to radio inputs. This model will demonstrate to users how it will feel to operate the final GuideCane-II and allow us to evaluate the performance of steering and braking subsystem. The final GuideCane-II will contain sensors and a computer to guide the user around obstacles while leading them in a given direction.

INTRODUCTION

Millions of blind and visually impaired individuals around the world have been restricted throughout their lives by the dangers of moving independently. Current solutions often require extensive training, are often unreliable, and provide no means of navigating beyond the users own interpretation. GuideCane-II, a "seeing-eye" robot, provides a remedy for these issues and offers improved mobility and independence to its users. Our project will be composed of a cane attached to a dual-wheeled base with steering and braking capabilities that respond to radio control input. Our goal is to design a prototype of the GuideCane-II that actively steers and brakes in response to radio inputs. We will attempt to build as much of this design as possible. This model will demonstrate to users what the final GuideCane-II model will feel like. The final GuideCane-II will contain sensors and a computer, allowing it to "see" at various levels in front and to the sides of the user and allows him or her to circumnavigate obstacles while simultaneously guiding them in a given direction.

Our project sponsor is the inventor of the original GuideCane, Professor Johann Borenstein. Before this can be realized, a radio-controlled prototype with the ability to steer and brake must be designed for testing and demonstrational purposes. Specifically, our design project will include the design and assembly of the body and chassis with emphasis on independently steered and braked wheels. Certain specifications including weight and size have been provided for us as seen in Chart 1 on page 5. The complete prototype must also be strong enough to withstand testing and demonstration. The body will be designed with the intention of housing all necessary hardware for a fully functional GuideCane-II though our prototype will not include the computer or sensors. Upon completion of our project the prototype will be human operated using remote control rather than the computer control that is intended for production. This prototype will be used to evaluate the performance of the steering and braking subsystem.

INFORMATION SEARCH

In order to prepare ourselves to move forward on our project, we conducted engineering and marketing research on comparable products that were either technologically or functionally similar to the GuideCane-II.

Engineering Research

Our engineering research consists of the consideration of products with similar components to those that could be used in our prototype. We focused our investigation on R/C model cars which similarly respond to radio control input, use servos to regulate their steering and braking, and contain parts of similar sizes to those we will use. R/C cars vary widely in their size and performance requirements so they offered us a wide range of variation. We visited a local hobby stop to speak with the enthusiasts and take a look at their models. Through our research, we determined that potential braking systems include cantilever, side-pull, center-pull, drum or disc brakes. Though all would likely provide adequate braking power to prevent the GuideCane-II user from putting themselves in danger or hitting an obstacle, disc brakes were the best option for our purposes because they could be used with a servo/remote control system without the use of a pneumatic system. The GuideCane-II will eventually incorporate Ackerman steering so we were limited to steering options of a 4-bar-linkage system or a solid axle system with one servo per wheel. The possibility of controlling each wheel entirely independently of the other and the larger range of motion afforded by the solid axle system made this the better choice. We used schematic information from TRAXXAS with advice from supplier employees who specialize in R/C cars. We have yet to determine which materials will be used for the frame and casing of the body, this will be resolved using the original GuideCane prototype as a model with reference texts with information on material properties.

As R/C cars are for recreational use and are not used for personal mobility, they do not provide a very accurate comparison with the GuideCane-II prototype. We completed marketing research to find our target customer base and what alternatives they have to the GuideCane-II. Traditionally, people with severe visual impairment may make use of guide dogs or long canes to allow them to move around independently. In the United States alone, there are approximately 10 million people with visual impairment, among them 1.3 million are legally blind. Among these, only 109,000 use long canes and 7,000 use guide dogs[1]. By comparison, the GuideCane-II would be significantly more expensive than a long cane, though it may be closer in cost to a guide dog. However, the GuideCane-II would not require the expensive training processes necessary with a long cane or a guide dog and as such, are more cost and time effective.

Market Research

An emerging market for electronic travel aids (ETAs) now exists with the advent of compact sensory technology, though no existing product has established itself as the market leader. ETAs vary in form from canes, walkers, glasses, headpieces and more. They each aim to provide their user with information regarding the landscape as they approach it using auditory signals, vibrations, or by diverting the user's path. Each method has pros and cons. Objects that provide their users with auditory or vibratory cues require constant assessment on the part of their user and must have extensive training processes before they can be used. Auditory signals have been proven effective in some cases, however, they require constant attention and may do harm by masking other auditory environmental cues. Some ETAs are heavy and large, forcing their users to take ramps or elevators where they may otherwise have been able to use stairs.

After establishing that we do have a concrete marketing group and proven engineering benchmarks, we further research must still be conducted before the product is market-ready. It may be useful to determine the proper braking levels so that the user is not stooped too slowly to avoid the obstacle or to quickly to keep balance.

CUSTOMER REQUIREMENTS AND ENGINEERING SPECIFICATIONS

With the creation of the GuideCane-II prototype, it is important to weigh design engineering specifications against the criteria that are important to the customers who will be using it.

Customer Needs

The customer of the GuideCane-II will be a blind person with several important needs.

Material/Geometrical Considerations The apparatus must have several material and geometrical considerations. The cane needs to be lightweight, so that the customer can move with it, carry it, and use it in tasks needed for everyday life. It must be durable and resistant to crack propagation, fracture, yielding, and collisions, as it will be subjected to dangerous environments. The GuideCane-II must be waterproof, as it will be used outside and must operate. It must be ergonomically made and comfortable to grip so that the customer can walk around safely with it and not injure his or her back. It must be portable – it should be able to fold or retract into a small, easy-to-carry device. The steering and braking systems will require supportive structure to hold the parts in place and connect them to the main body. This structure must be lightweight and strong, preferably easy to work with.

Movement of the Device (Braking and Steering) The GuideCane-II must also have design qualities that allow the user to move easily and safely. Since the prototype will roll on wheels in front of the customer, it needs to do so with ease, so that the friction forces of rolling and braking of the wheels on the ground surface are not too cumbersome for the customer to bear. There needs to be a tangible difference between walking with it safely and being abruptly stopped by the cautionary measures installed to prevent the blind person from danger. The GuideCane-II must be easy to steer as the user might tire from difficult pushing or pulling. When the GuideCane-II helps the blind person avoid obstacles and collisions, it must do so in the most comfortable way possible, not moving suddenly but smoothly transitioning between directions. The device should be able to either steer away from an obstacle to avoid it or brake to prevent the user from proceeding toward an "unavoidable" obstacle such as stairs.

Cost-effective Guide Cane Qualities The GuideCane-II needs to have several options that make it cost-efficient and more desirable than competitor's products. It should have a long-lasting power system to minimize the chance for the apparatus to stop working in a dangerous environment when it is not charged. The device must not be too noisy as it could annoy the user. The GuideCane-II must be aesthetically pleasing so no unwarranted attention is given to the blind customer. The GuideCane-II needs to be able to be purchased at a low cost, as it must replace other viable options for guidance (e.g., seeing eye dogs). The device must be durable so that its cost may be absorbed over a long usage period.

Engineering Specifications

The design team will create its products with parameters that are customized to the customers' needs.

Material/Geometrical Considerations The design team plans for the GuideCane-II to weigh less than 4 lbs so that it can be easily pushed, pulled, braked, and carried. A good material choice for the final product would perhaps be low density polyethylene (LDPE) as it has low density (ϱ = 0.92 g/cm^3). LDPE meets the durability requirement with its high resilience (SD55 hardness) and a reasonably high tensile strength for its environment (σ = 1700 psi or 11.7 MPa). LDPE is also flexible so it could be folded or retracted in some manner to reduce the space it takes up. LDPE is not adversely affected by water [2]. HDPE was not used as the added density is not needed to reinforce the housing since the housed components (wheel encoders, computer parts, etc.) are quite durable themselves. A soft foam plastic grip can be attached to an adjustable boom assembly (which could collapse into itself to give portability) to ensure that the customer has a comfortable-to-use product. The dimensions of the housing have been specified by our sponsor, with values of 8 cm x 11 cm x 28 cm (2464 cm^3). The material for the supportive structure for the braking and steering may be either aluminum or PVC, or a combination of both.

Movement of the Device (Braking and Steering) The design team plans to use independent steering for the wheel base of the GuideCane-II. A total of four servos, two on each side of the wheel, will control steering and cam brake systems. R/C car specialists use 75 in-oz. brakes to stop cars of comparable weight from traveling at speeds up to 70 mph. Two of these brake assemblies should be sufficient to provide adequate resistance and stop the momentum of the user. A full force analysis will be done in subsequent design reviews to determine the exact amount of torque needed to provide the brakes with enough resistance to stop the user. The wheels should be made out of 65-70 shore A urethane to ensure a high coefficient of friction value of 0.79 [3]. This will also increase the ability of the GuideCane-II to stop the user.

Cost-effective Guide Cane Qualities The design team is not responsible for the computer equipment or any of the sensors of the GuideCane-II; however, the design specifications to meet the customers' demands are shown below in Chart # to reduce power consumption and use of space by using a Hokuyo URG-04/LX Scanning Laser Rangefinder. The computer measures at 100 cm^2. A single Lithium-polymer (Li-Pol) battery can be used to power the apparatus continuously for 3 hours before need for recharging. Also, we will insulate the housing to reduce the level of noise created by the braking system so that it does not exceed 50 dB, or a level comparable to a quiet air conditioning unit. This could also act as added protection to the internal components of the device. The GuideCane-II will be made to be aesthetically pleasing as long as all other technical considerations are taken care of prior. The specifications for a light-weight device lead us to use minimal parts and this lends itself to better cost-effectiveness.

Specification Summary The design specifications called for in the GuideCane-II are summarized in Table 1 on page 6.

Table **1: Engineering Specifications of the GuideCane-II Prototype**

Dimensions (WxDxH)	8 cm x 11 cm x 28 cm = 2464 cm^3
Weight	< 4 lbs
Housing Material	LDPE (ϱ = 0.92 g/cm^3, σ = 1700 psi or 11.7 Mpa, SD 55 hardness)
Wheel Material	65-70 A Shore Urethane (μ_k = 0.79)
Braking torque	2 * 75 in-oz
Braking system	2 servos w/ cam brake for each wheel
Range	2 cm – 4m
Scan field	240 degrees
Scan time	100 ms
Power consumption	< 2.5 W (LiPol battery)
Steering system	2-servo, Ackerman steering

Benchmarking

We can also compare the advantages and disadvantages of existing travel aid alternatives to the GuideCane-II.

Long canes Canes are the standard today for blind people who want aid in navigating. This is because they are cheap to buy, easy to carry and portable. However, they have several disadvantages. They require over 100 hours of training to use [1], which can be expensive. Canes do not stop the user from entering dangerous environments; they only *detect* contact the dangers by the very limited means of contact. Also, they require constant scanning and focus by the user, preventing them from moving at a steady walking pace.

Seeing-eye Guide dogs Seeing-eye dogs provide many advantages to blind people who want to get around easily. They provide an active response toward obstacles; i.e., if a moving object obstructs the user's path, a seeing-eye dog will be able to maneuver around it. Guide dogs do not require the user to interpret any auditory signals – the mere tactile force of the dog stopping and starting will alert the user to obstacles and path changes. The dogs also provide reliable companionship for the user. However, they do have many disadvantages. Firstly, they require extensive training to use. Next, seeing-eye dogs are very expensive ($27,000) and need maintenance (food, clean-up, etc.). Thirdly, they can only travel in predefined, trained paths and have no means of indicating how the user should respond to any change in the environment.

ETA Long Cane Attachments ETA Long Cane Attachments are devices equipped with sensors that scan the path ahead and supplement the information their user gains from the cane. When they detect an obstacle or relevant path change, they create a vibration on the cane handle to alert the user. At this point the user must sweep the cane over the path ahead as with a typical long cane. These cane attachments are useful because they allow the user to walk at a faster rate than they would otherwise travel at because it eliminates the need for constant active scanning by the user. However, it adds cost, weight and training time to the long cane and does not work better than the cane for determining the exact obstacle location.

Auditory ETAs Auditory ETAs are devices that use sensors to locate obstacles or changes in ground conditions in the user's path and respond with auditory signals. The tone or frequency of the signal will indicate to the user how he or she should respond in order to continue safely. Two such devices include the Binaural Sonic Aid and the NavBelt. Auditory ETAs require extensive training periods to be effective and are considered somewhat dangerous because they mask external noises that may otherwise be cues to the user such as traffic sounds and human speech. Furthermore, as the figure below demonstrates, they can be very bulky.

Robotic ETAs Robotic ETAs are devices that couple electronic signals with mobility. These devices vary widely in design and function. The GuideCane-II falls in this category along with similar devices that are pushed in front of the user as well as walkers equipped with sensors.

QFD Diagram

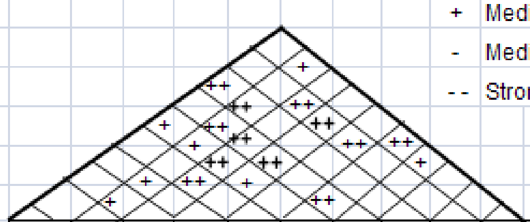
Taking into account customer needs, engineering specifications, and benchmarking of alternative travel aids, the following QFD diagram was created in Table 2 on page 8.

Chart 2: QFD of GuideCane-II

Quality Function Development (QFD)

Relationships

++	Strong Positive
+	Medium Positive
-	Medium Negative
- -	Strong Negative



(+) => more is better
(-) => less is better

	Weight*	Dimensions/Volume	Materials	Reaction time	Power consumption	Range and Scan field	Steering system	Braking torque	Geometry	Scan time	Noise levels	Benchmarks: *Long cane attachments*	*(Auditory) ETAs*	*Robotic-based Travel Aids*
Lightweight (4 lbs or less)	10	9	9	3				3	3			9	1	1
Comfortable grip	6		9						3			9		
Rolls easily	10	3	9	1			9	9	3					
Power lasts	8				9	3	3	9		9			9	9
Low cost	5	9	9					3	3	9		9	1	1
Aesthetics	1	9							9			3	1	3
Durability, Waterproofing	8		9									1	3	3
Ease of steering, giving direction	10	9		1	3		9	9	3	9				
Comfortable, sufficient braking syste	10			9	3	3	9	9		9				
Foldable, retractable, portable	8	9	9				9		9			9	1	1
Quiet for user	4							1			9	1	1	1
Measurement Unit		cm^3	N/A	s	W	m	N/A	in-oz	N/A	ms	dB			
Target Value		2464	N/A	N/A	<2.5	4	N/A	75*2	N/A	100	<50			
Importance Rating		**7**	**4**	**3**	**9**	**5**	**1**	**2**	**8**	**6**	**10**			
Total		336	423	140	132	54	366	391	204	297	36			
Normalized		0.14	0.18	0.06	0.06	0.02	0.15	0.16	0.09	0.12	0.02			

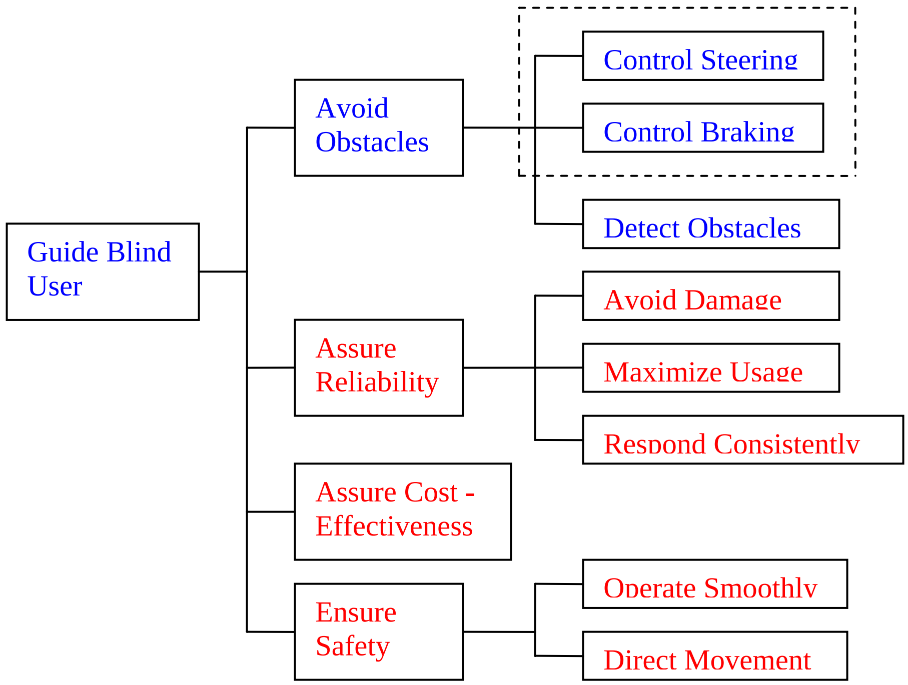
Key:
9 => Strong Relationship
3 => Medium Relationship
1 => Small Relationship
(blank) => Not Related

***Weights are figured on a scale of 1 to 10**
(ten being most important)

CONCEPT GENERATION

The FAST diagram shown in Figure 1 below demonstrates the functions of the GuideCane-II. In order for it to become a marketable product, all functions described below must be taken into account. However, for the limited scope of our project in developing the prototype, only the first two primary functions, "Control Steering" and "Control Braking" are relevant. The remaining functions have either been previously determined by our project sponsor or are yet to be considered.

Figure 1: FAST Diagram of GuideCane-II



The basic functions all derive from avoiding obstacles. This is the primary purpose that the GuideCane-II serves as human vision is the missing element for the blind user. Obstacle avoidance breaks down into steering, braking, and detection components. Illustrations of our various concept ideas are shown in Appendix C, the Morphological Chart.

The steering function allows for a number of different concept possibilities. We could choose to have one mechanism that controls both wheels via a four-bar-linkage system, or to have independent steering for each wheel with separate axes. The steering could be controlled by servo(s) or possibly an electrical or hydraulic device that responded to the radio input. The concept we have chosen to proceed with will include independent steering for each wheel, controlled by a servo/cam system. A radio input to the servo will cause a small rotational movement in the servo, which in turn pulls the cam and moves the wheel appropriately. This set-up allows for good range of motion for the GuideCane-II and will be easily applicable to Ackerman steering.

The braking function could also have one mechanism per wheel or one for both wheels calling for a dual or single-axis system, respectively. As previously states, options for braking systems include side-pull cantilever, center-pull cantilever, disc, or drum brake set-ups. These different designs are implemented differently using mechanical, pneumatic or hydraulic systems. The two caliper systems can only be applied using mechanical actuation. The disc and drum brake set-ups can use mechanical (via cam), pneumatic, or hydraulic systems. We have chosen to use disc brakes using a servo/cam system. Mechanical actuation is much simpler to design than hydraulic or pneumatic systems, and a servo can easily be used with radio application.

CONCEPT EVALUATION AND SELECTION

As illustrated by the morphological chart in Appendix C, there are 2 options that were conceptualized for the steering system and five options for the braking system of the Guide Cane-II, for total of 10 distinct combinations as design choices.

Braking Systems

For braking systems, the options are as follows: (1) side-pull cable; (2) center-pull cable; (3) cantilever cable; (4) drum brake; and (5) disc brake. Each of the braking systems are described and analyzed below.

1) **Side-Pull Cable** A side-pull cable braking system is composed of two arched arms of different sizes that intersect at a hinge above the wheel and hold the brake pad in place. When the cable is pulled, the arms come together and move toward the outmost portion of the rim, causing the wheel to stop through friction. However, this can lead to dislocation to one side of the wheel during braking, which results in the brake pad rubbing the rim even during periods of non-braking.

Figure 2: Side-Pull Cable on a Bicycle [9]

2) **Center-Pull Cable** This type of cable braking is very similar to the previous system, except that the arms are symmetrically sized and balanced. When the brake arms are activated, the tension on a straddle cable which is attached from the frame of the wheel to a pulley is equally dispersed to the arms. This prevents the brake from sliding to one side of the wheel rim, which cause the problems described above in side-pull cables.

Figure 3. Center-Pull Cable on a Bicycle [9]

3) **Cantilever Cable** Cantilever cables have one L-shaped arm on each side of the wheel that is connected to its own pivot, unlike center- or side-pull cables. However, cantilever cables, too, have a straddle cable attached from the frame of the wheel, which when the brake is activated, is pulled to make these arms displace linearly inward and rotate upward to push the brake pads into the wheel rims. These have the advantage of the having a short distance between the arm and the pivot point, which lowers the chance of arm flexure (which in turn lower the efficiency of the braking).

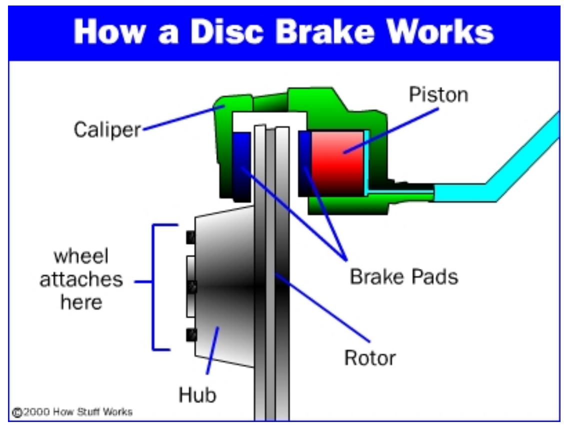
Figure 4: Cantilever-Pull Cable on a Bicycle [9]

4) **Drum Brake** Drum brakes consist of a piston, brake shoes, and springs in its basic form. When braking is initiated, the piston pushes the brake shoes against the braking surface (the inside surface of the drum), lodging them in place. Springs then pry the shoes from the drum and hold them in their starting position to repeat the cycle. Drum brakes are beneficial in that they only require a small piston and need little maintenance as long as nothing enters the drum. However, they require pneumatic or hydraulic actuation which is difficult to manufacture. They are heavier and do not provide as much braking torque as disc brakes.

Figure 5: Drum Brake with and without Drum [10]

5) Disc Brake Disc brakes work by pistons hydraulically or electro-mechanically pushing brake pads against a rotor. The friction force created between the brake pads and the disc lowers the disc's speed. Vents allow the heat of friction to be expelled from the system.

Figure 6: Disc Brake Diagram and Schematic [11]

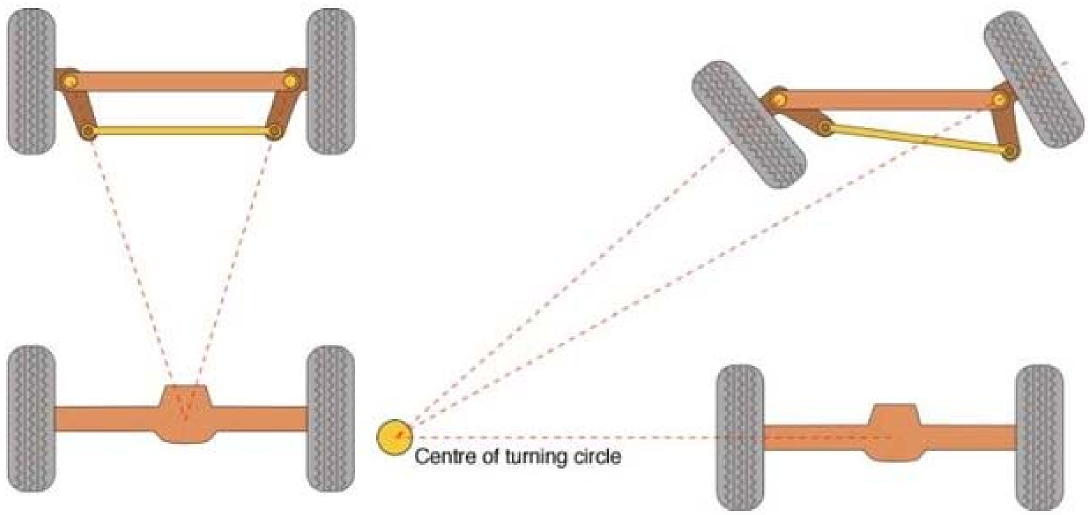


Steering

The steering choices are as follows: (1) a single servo to control a four-bar linkage which guides both wheels or (2) independent steering using dual servos

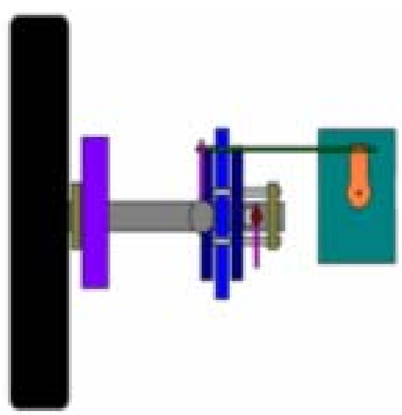
1) Four-Bar Linkage System This set-up includes 4 bars which interact to control the steering of both wheel when only one bar is moved. It follows the principles of Ackermann steering which is created when a vehicle's turning radius is part of the circumference of a pre-defined circle of turning, which is located on an imaginary line extended from the rear axle's axis. The wheels are then oriented to be at a 90 degree angle from the center of the turning circle, and will be at different angles (because they have turning circles of different radii). Since the wheels' angles are controlled the four-bar linkage (which will be controlled by a single servo), the range of motion is also somewhat constrained. This type of steering works for low-speed turning; but since it ignores some dynamic principles, it does not work as well for higher speeds.

Figure 7: Four-bar Linkage System [8]



2) Independent Steering A steering system utilizing dual servos has the wheel and brake on one side of the apparatus controlled by one servo, with another servo controlling the other side. This allows for one side to brake. Dual servos provide an unlimited range of wheel angles, and, thus, a greater range of motion. The wheels can also be moved inward to increase the effect of braking, whereas a conventional system of braking cannot accomplish this.

Figure 8: Independent Steering



Design Criteria

The criteria with which the design concepts were narrowed down to 5 choices were allocated according to the best compromise fit of customer requirements and engineering specifications explained in the previous two sections.

The brake should provide enough resistance to control the acceleration or deceleration of a human being pushing the device; however, it also must do so in a smooth, user-intuitive manner. It must not obstruct the GuideCane-II's ease of rolling, while maintaining quiet. The brakes need to be compact and lightweight to keep the weight and dimensional requirements set forth by our sponsor and customers. The brakes must be durable and have low maintenance needs.

The steering should provide the aforementioned ease of rolling, while giving the user the greatest range of motion possible. Like the brakes, it must be compact and lightweight, but durable enough to withstand high impact forces and abnormalities in terrain.

Concept A. Steering: Independent Control, Braking: Disc Brake

Merits Dual servos provide the greatest range of motion allowing it to move in any direction given a sufficient force applied by the user, because the wheels can move independently of each other. A dual servo design allows for there to be braking of only one wheel. Also, if one servo breaks, the device is not rendered useless like in a single-servo design and the user can still feel the braking torque from the other. Disc brakes are exposed to air, so they can dissipate heat more quickly, which translates into lower maintenance costs and longer cycling and lifetimes of wheels. Also, they are fairly waterproof in this state, so they throw off water and dry quickly. Disc brakes are lightweight and contain a lot less parts compared to drum brakes, which translates into low maintenance needs.

Limitations Disc brakes could experience warping due to the extended periods of time under the heat of friction where cooling is not allowed. This will soften the material of the brake, and change its shape, causing problems. Also, sharp or hard materials could come into contact with the disc and break it.

Concept B. Steering: Independent Control, Braking: Drum Brake

Merits Dual servos provide all of the advantages described above in Concept A. Drum brakes are relatively inexpensive. They also can be used in rear wheels to provide extra braking where heat dissipation is not such a problem (such as in automobiles). Drum brakes also provide protection against sharp or hard materials that could break the braking shoes. Without hydraulic systems aiding modern disk brakes, drum brakes require less pressure on the brake pedal.

Limitations The larger the force a human creates pushing the GuideCane-II, the weight of the drum brake must increase to allow for the dissipated heat to pass when it is stopped. Also, the braking shoes are inside the drum surface, which further reduces heat dissipation. Water and materials that enter the drum cannot leave due to the centrifugal force and reduces braking efficiency. Drum brakes also require many more moving parts than a disc brake, which translates to more maintenance. Drum brakes also do not provide as much torque. Fluid reservoirs for the hydraulic systems in the drum brake require a lot of space, as well.

Concept C. Steering: Four-Bar Linkage, Braking: Disc Brake

Merits Ackermann steering provides a dependable way to use one servo to control the wheels, which reduces cost compared to dual servos. The range of motion using this system would allow for the GuideCane-II to move around in many different situations and terrains. Disk brakes provide all of the advantages described above in Concept A.

Limitations Disk brakes provide all of the disadvantages described above in Concept A. The range of motion of the wheels is not as significant for Ackermann steering as it is in a dual servo mechanism. With Ackermann steering, the outer wheel will have a greater turning circle radius than the inner wheel. The inner wheel then has a higher slip angle than the outer, causing a dramatic increase the temperature of the tire with a lower load. This especially causes problems in cases of higher speed, lateral acceleration (which has a high chance of occurring in the uses of the GuideCane-II). [12] Ackermann steering also creates more weight and space to be taken up with the use of the four-bar linkage.

Concept D. Steering: Independent Control, Braking: Cantilever Cable

Merits Dual servos provide all of the advantages described above in Concept A. Angle of the arms in cantilever cable brakes can be adjusted to reduce flexure (and braking problems) as well as noise. Its symmetry causes a safer, more even distribution of braking force. Cantilever cable brakes are cheaper and more lightweight than drum or disk brakes, as well.

Limitations Cantilever cable brakes do not provide as much stopping torque as drum or disk brakes. This type of braking has no protection against the environment, and is not durable toward erosion They require relatively frequent maintenance checks. Also, the method in which the braking would be controlled is uncertain, as a servo could not as easily actuate a cable braking system.

Concept E. Steering: Four-bar Linkage, Braking: Side-Pull Cable

Merits Ackermann steering provide all of the advantages described above in Concept A. Side-pull cable brakes are cheaper and more lightweight than drum or disk brakes.

Limitations Ackermann steering provide all of the disadvantages described above in Concept A. Side-pull cable brakes do not provide as much stopping torque as drum or disk brakes. This type of braking has no protection against the environment, and is not durable toward erosion They require relatively frequent maintenance checks. Also, its brake pad can be dislocated by its asymmetry and cause rubbing on the wheel rim during periods of non-braking. The method in which the braking would be controlled is uncertain, as a servo could not as easily actuate a cable braking system.

Pugh Chart

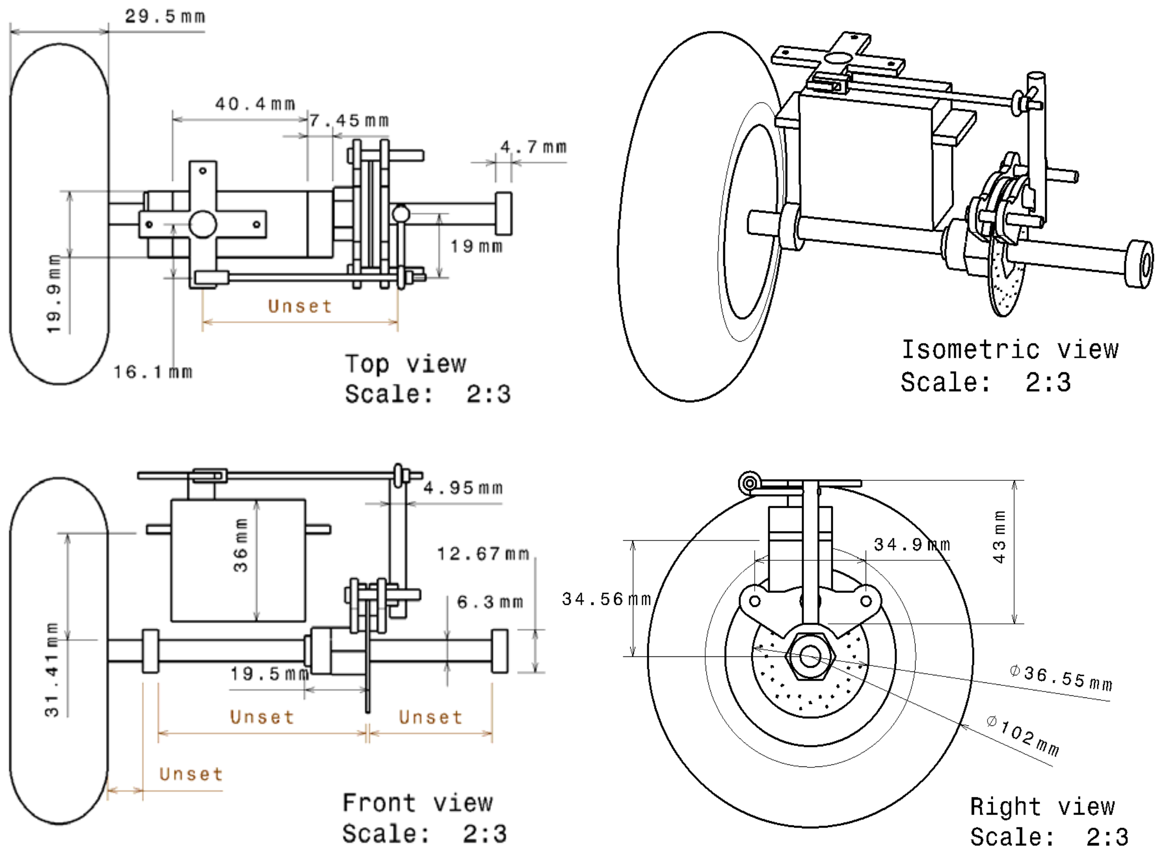
Using a Pugh Chart, these 5 design choices were narrowed to 1, taking into account the weight (importance) we determined in our QFD chart generally for the customer, as well as rankings our design team took into account for each conceptual individual design for these characteristics. These rankings are based on the merits and limitations for each concept alone as well as compared to its competing designs. Rankings range from 1 (a low-quality design with respect to this characteristic, or not-applicable) to 5 (a high quality design).

This Pugh Chart is shown on Appendix 4. The results of the Pugh Chart show that the design concept that will meet engineering specifications and customer requirements the best given the information acquired is Concept A, or an Independent Steering (Dual Servo) system with Disk braking.

SELECTED CONCEPTS

We have determined how the parts of the braking system will fit together. This can be seen in the CAD drawings in Figure 9. A scaled version is in Appendix E.

Figure 9: CAD Drawings of Braking System with Dimensions (not labeled scale)



This design is composed mostly of parts that were purchased at Rider's hobby shop. This design utilizes the disc brake system with a servo that pulls the cam arm to rotate the cam, which pushes the piston on the back of one of the brake pads. As the brake pads are pushed together they apply friction to the disc which stops the wheel from rotating. The servo will receive voltage from the battery pack as controlled by the radio receiver.

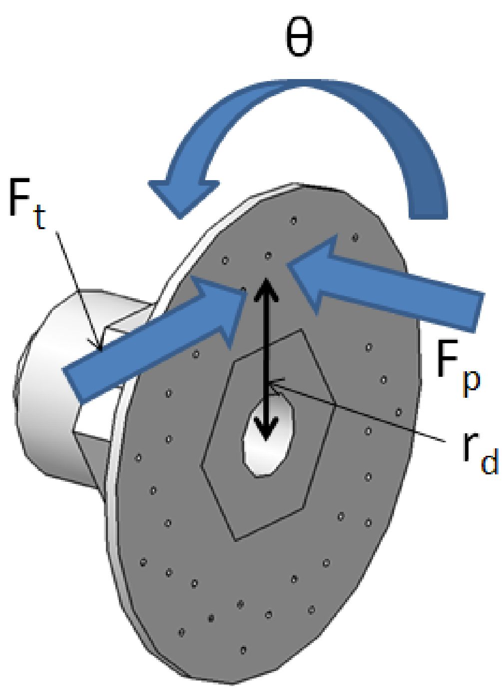
ENGINEERING ANALYSIS

The engineering analysis of this prototype will include theoretical and experimental evaluation of the braking system. Dimensions and tolerances were determined to optimize manufacturing time and the quality of the final assembly. These values are shown in the scaled final design image in Appendix H.

Quantitative Analysis – Braking

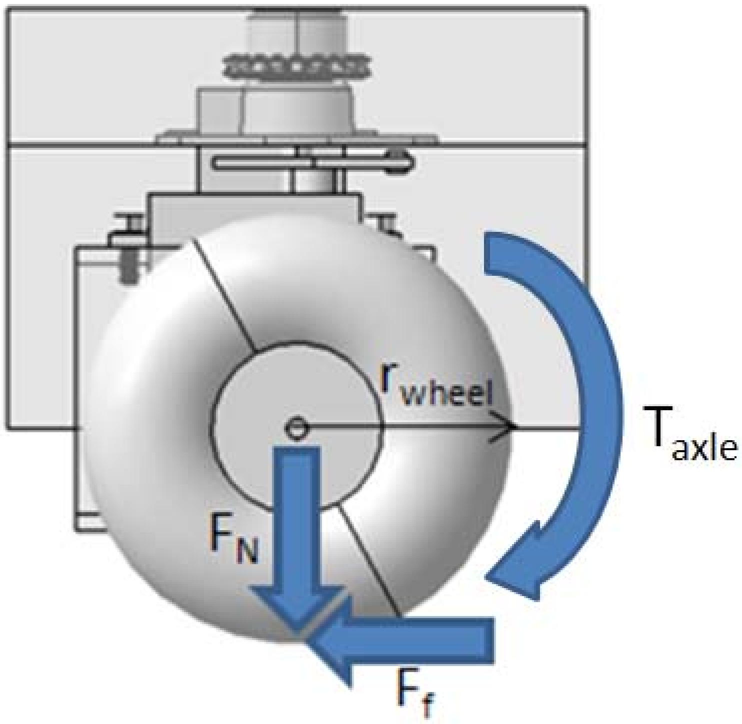
Theoretical Calculations Figure 10 below shows how a disk brake is applied using frictional force to stop the rotor of the wheel, where F_t is the tangential frictional braking force on the hex disc, F_p is the force of the piston pushing the brake pad onto the disc, and r_d is the radius of the hex disc. We are assuming that the brake pads are evenly distributing frictional force on both sides of the disc brake. This is only an approximation, since one of the pads is fixed in our concept design. Automotive brake pad's static coefficient of friction ranges from 0.15 to 0.65 [15], with race cars having μ_s = 0.54. We are conservatively estimating our brake pads to have an average coefficient of friction of 0.4.

Figure 10. Friction and Piston Forces applied to hex disc.



To find the force our braking servo must output, we can look at a frictional analysis of our wheel set-up, shown in Figure 11 on page 20.

Figure 11. Forces and torques applied to wheel's brake setup.



Frictional Analysis We know the relation of the force of friction to the normal force on the wheel:

$F_f = F_N * \mu$ (Equation 1)

Because the coefficient of friction is not known between the wheel and the ground surface, and those circumstances will vary widely with environment, we can assign a conservative friction coefficient, $\mu = 1.5$.

Thus, with a weight of 4 lbs, or 1.81 kg, the friction force, F_f, is:

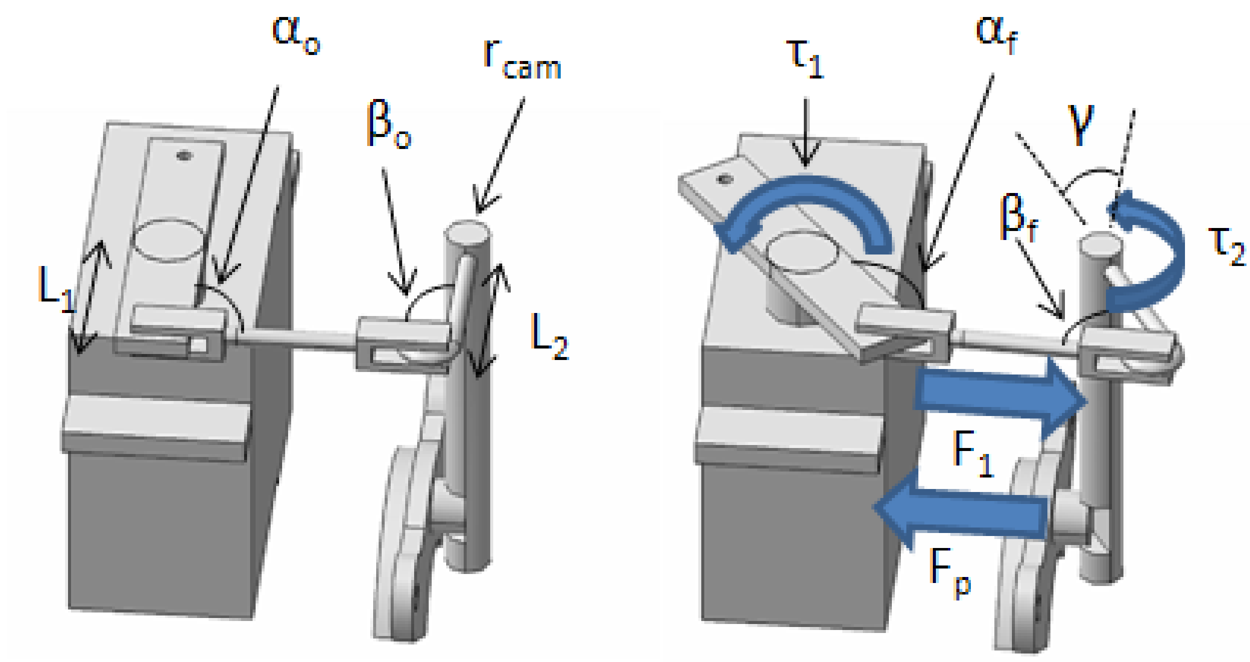
$F_f = (9.81 m/s^2)(1.81 kg)(1.5) = 26.6 N$

Torque is defined as:

$T_{axle} = F_f * r_{wheel} = (26.6N)(0.0413m) = 1.09N\text{-}m$ (Equation 2)

Arm lengths, cam geometry, and servo torque were chosen to exceed this torque value. Above this axle torque, the wheels begin to slide, which we refer to as the wheel lock condition.

Figure 12. Forces and torques applied to cam brake setup.



The list of parameters relevant to Figure 12 can be found below:

<u>Parameters of interest:</u>
T_1 = manufacturer prescribed servo torque
T_2 = cam torque
L_1 = servo horn length
L_2 = length of cam brake arm
α = angle between L_1 and F_1
β = angle between L_2 and F_1
γ = angle cam arm moves
r_{cam} = radius of cam
F_p = force of piston on brake pad
F_t = tangential braking force on disc
r_d = radius of hex braking disc
μ_s = friction coefficient between disc & pad

As the servo is actuated by the onboard computer's signal, the servo horn turns creating a torque on the cam as its angle changes. This angle change in the cam causes it to push on the brake pad, clamping down on the hex disc, which stops the axle. This results in the braking of the wheel.

We know the following braking kinematic equations, by using the angles α and β to relate the force on the linkage between the servo horn and cam, F_1, and the torque with which the cam turns. These are shown in Equations 3 and 4 below:

$$F_1 = T_1 \sin \alpha / L_1 \quad \text{(Equation 3)}$$

$$T_2 = F_1 L_2 \sin \beta \quad \text{(Equation 4)}$$

To simplify our analysis, we assume the piston's surface in contact with the cam to be flat. We also assume the diameter of the piston to be larger than the diameter of the cam and the contact between them to be frictionless. These assumptions deduce the motion of the cam to simple lever pushing against a flat piston surface. The resulting equation for the force of the piston, F_p, is shown below in Equation 5:

$$F_p = T_2 \cos \gamma / r_{cam} \quad \text{(Equation 5)}$$

The tangential braking force, F_t, slows the rotation of the hex disc; this also slows the rotation of the wheel, braking the device. This is a function of the coefficient of friction between the brake pad and the hex disc. This is shown in Equation 6 below:

$$F_t = F_p * \mu_s \quad \text{(Equation 6)}$$

The torque for braking the wheel is related by force cross arm length and is shown below in Equation 7:

$$T_{braking} = F_t r_d \quad \text{(Equation 7)}$$

The design condition with which we chose our servo braking torque values was based on this braking torque being equal to the torque of the axle turning. This is a design condition where the wheels are locked, and the tires begin to skid.

$$\text{Max } T_{braking} = T_{axle} \quad \text{(Equation 8)}$$

This condition was made given that there was the assumption of zero energy losses in the system (heat, etc.).

Further analysis reveals max $T_{braking}$ can achieve wheel lock causing tire slip at this level of conservative surface friction.

Qualitative Analysis – Braking

Design for Manufacturing and Assembly (DFMA) Analysis After completing a DFMA analysis considering the ease with which our design lends itself to large-scale manufacturing, we have identified five aspects of our design that make this process easier and more reliable.

First, we have chosen a cam shaft which actuates the brake via a piston which locks firmly into place. It would be clear to any manufacturer whether or not the cam shaft is in place because having the proper location and orientation of the cam shaft is very intuitive.

To avoid confusion and assembly costs, we have ensured that minimal parts are used. The more moving parts we have, the more room for error and physical variation there will be in the assembly. One example of this is that we changed our design to have a brake pad connected to a piston rather than two separate parts as we originally considered.

We had the option of using one axle connecting both wheels and of using one servo. Instead, we chose to use separate axles and servos for each wheel to maintain symmetry of design in addition to other design considerations. Having both sides follow an identical design plan reduces error and eliminates the need to offset the steering and braking systems as was the case in the original GuideCane prototype.

One design option that we could consider would be to reduce the number of threaded holes and add nuts to secure the bolts into place. Thus far we have chosen to thread multiple holes as a tradeoff for reducing the additional parts that would be required if nuts were used but further analysis may reveal that the time saved in manufacturing processes warrants the use of extra parts.

The next element of our design that is focused on manufacturability deals with the pieces of the subassembly. There are three surfaces of it and we had a number of options as to how to assemble them. We could use three separate pieces, two pieces with one of them bent, or one piece with two bends in it. We avoided the option of using three separate pieces because we wanted to reduce parts and we felt that the structure would be weaker and may need supportive pieces. We chose to use two pieces, one of which is an L bracket, at the bend there would not be a true right angle and the part will be more structurally sound. We had to have two separate pieces however because one required thicker aluminum and we did not wish to make the whole part that thick because of weight limitations.

Design for Environment (DFE) Analysis If this product ever becomes successful enough to warrant large-scale manufacturing, there are many elements that can be taken into consideration in the process to ensure environmental responsibility and sustainability practices.

Material selection is an important aspect of our environmental considerations. Currently the most prevalent material in our prototype is aluminum, by far. Aluminum is a recyclable material and users could recycle the aluminum parts after use. However, recycling often calls for separation of different materials and the GuideCane-II will have steel screws in the aluminum parts so they must be separated before recycling. If we could replace the steel with aluminum without compromising the strength and safety of the product it would be a worthwhile consideration. Also, when the full product is complete, it will contain computerized components and sensors which can be recycled but often require special facilities. This adds another element of difficulty to the recycling process; however, we do not have the option of using alternate materials in this case as computer parts do not exhibit great variability in materials.

The choice of battery used to the GuideCane-II has strong environmental implications. Common battery choices include lead-acid, Nickel-cadmium (NiCd), Nickel metal hydride (NiMH), Lithium-ion (Li-ion), and Lithium polymer (Li-Pol) varieties. [13] Lead-acid batteries are the most widely used type of battery but the lead they contain is highly toxic and they are heavy and large in size. NiCd cells require lower voltage and are lighter than lead-acid batteries, but cadmium is a "highly toxic" substance which requires stringent regulation and waste treatment. NiMH cells are a non-toxic alternative to NiCd batteries but are relatively high in cost and are less reliable. Li-Pol batteries are very efficient and have high energy density though they have a history of "thermal runaway," which causes them to overheat and possibly catch fire. However, technological advancements including electronic chips to prevent overheating. Lithium is a non-toxic chemical. Li-Pol batteries are the next generation of Li-ion cells, they are lighter and thinner and can assume a number of shapes but are also more costly. [14] Our current prototype contains a NiMH battery, chosen for its balance between cost, size and toxicity. In the future we may consider Li-Pol or Li-ion batteries as an alternative.

The parts that compose our product are quite small compared to many other manufactured objects. Their small size and simple shape indicate that they may possibly be formed from the scrap metal produced by other industrial processes. If we were able to partner with a company that created a steady supply of scrap metal of consistent size, it is very likely that we could help them by reducing their waste output and help ourselves by using low-cost materials. If this were the case we must consider the reliability of the materials and the consistency of their shape and size, because it would make for difficult manufacturing processes if we had to constantly adjust to changing sizes.

If our product were to reach large-scale production, the manufacturing facility will have many options for increasing environmental safety. It could operate on renewable energy such as on-site wind turbines and solar panels or on alternative fuels such as biofuels including ethanol.

Failure Mode and Effect Analysis (FMEA) To identify any possible failures and to prevent them, a FMEA was conducted, and it can be seen in Appendix F. From this we can see that by using better tolerance for our holes for screws and by choosing the material with the highest yield strength, fracture toughness, and resistance to crack propagation while maintaining a low weight (under 4 lbs), we can drastically reduce the likelihood of failure modes. No other actions need be taken to prevent failures.

Cost Analysis An analysis of the GuideCane-II prototype was also done. The bill of materials is shown in Appendix G. The total project cost includes all materials required for the prototype's housing, steering and braking systems.

Steering Analysis

Fitting In order to determine the overall size and dimensions of the braking subassembly, we needed to consider how each component fit in the complete GuideCane-II. To do this we needed to design the steering assembly because this is what connects the braking assembly to the GuideCane-II main body. The braking subassemblies are designed so that they can be integrated with any steering system that will be built later. We designed a steering system that maximized the remaining space that will be needed to house the computer, batteries, and other electronics.

Chain Driven Steering We chose independent control steering from our list of steering design concepts, as mentioned previously. More specifically we chose to use chain drive steering with a 1:1 ratio. With this ratio the torque on the steering shaft is the same as the torque output from the steering servo. The GuideCane-I had one servo (43 in-oz) to steer the entire single-axle subassembly with a linkage. This subassembly was much more massive than our braking subassemblies. Our design has a servo for each side;

therefore, we can choose smaller servos because each one is turning a less massive assembly. By using a chain drive we eliminated the lockout problem the GuideCane-I experienced. When the servo turned past 45 degrees the linkage system would pass threshold, and not be able to turn back. This was one of the major drawbacks of the GuideCane-I design.

FINAL DESIGN

Bill of Materials

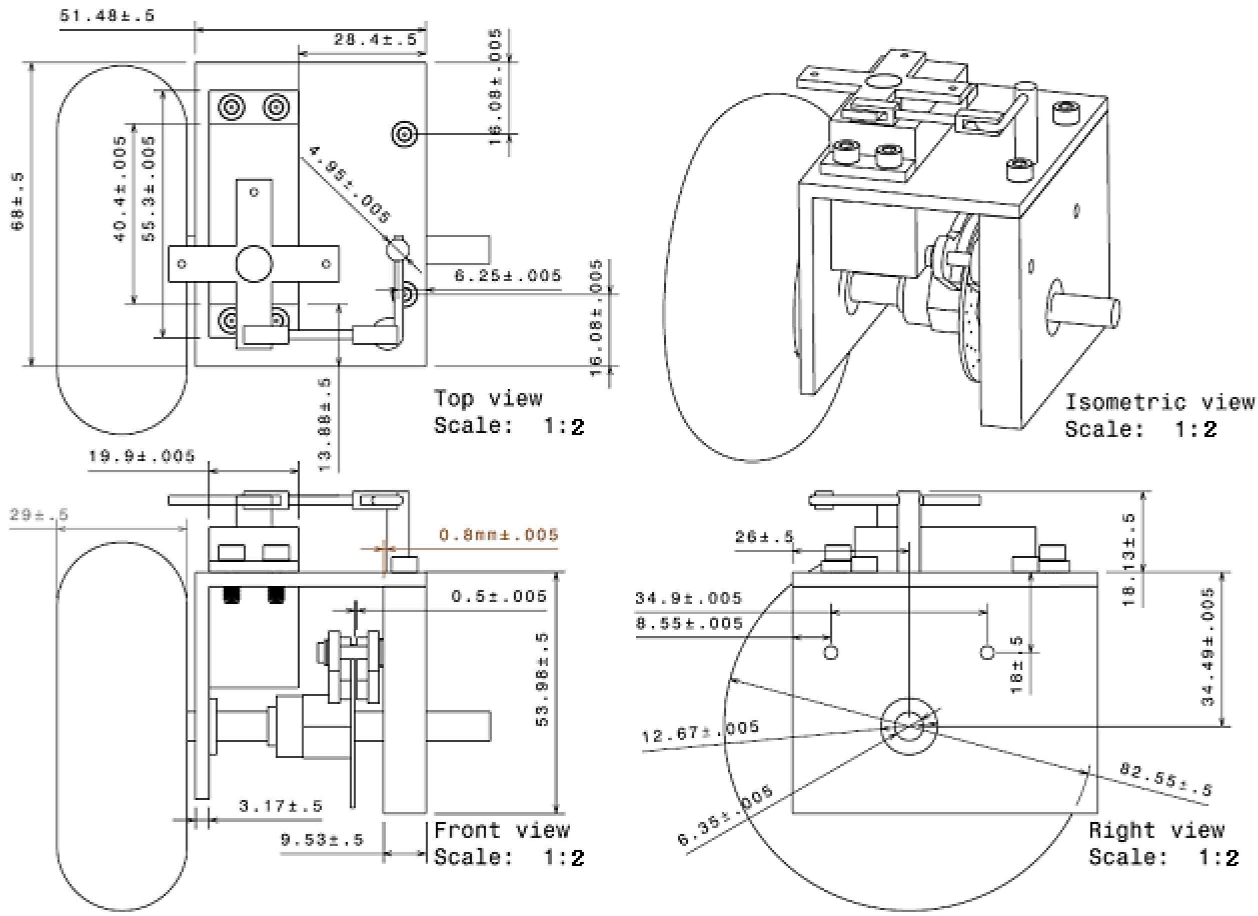
The full bill of materials can be found in Appendix G. We chose to use parts manufactured by R/C car manufacturers because our project is a similar application. Our goal is to minimize weight and cost while keeping the prototype strong enough to withstand normal wear and tear. The R/C parts such as the brake pads and cam shaft are engineered to be lightweight and designed to be strong enough for its purpose in the R/C car. These parts are relatively cheap considering their complexity, and parts that fit together come in kits that are cheaper than buying the parts separately. These parts are made from mostly aluminum and also steel.

We decided to use 6063 Aluminum for the sub-frame material. This material is lighter than steel with a high strength to weight ratio. Also since aluminum is relatively soft compared to steel, it is easier to machine. Aluminum is not able to be welded, but our design does not require welding so it is an adequate choice.

Design Specifications

Braking Assembly The sub-frame prototype design has been completed and is shown in Figure 14 on page 27. Tolerances have been determined based on the importance of threaded holes lining up and ease of accurate and precise manufacturing, etc. The most important tolerances are the cam location and hole size and the bearing size and bearing hole size. The bearings need to fit very closely in the sub-frame, therefore the tight tolerancing is required.

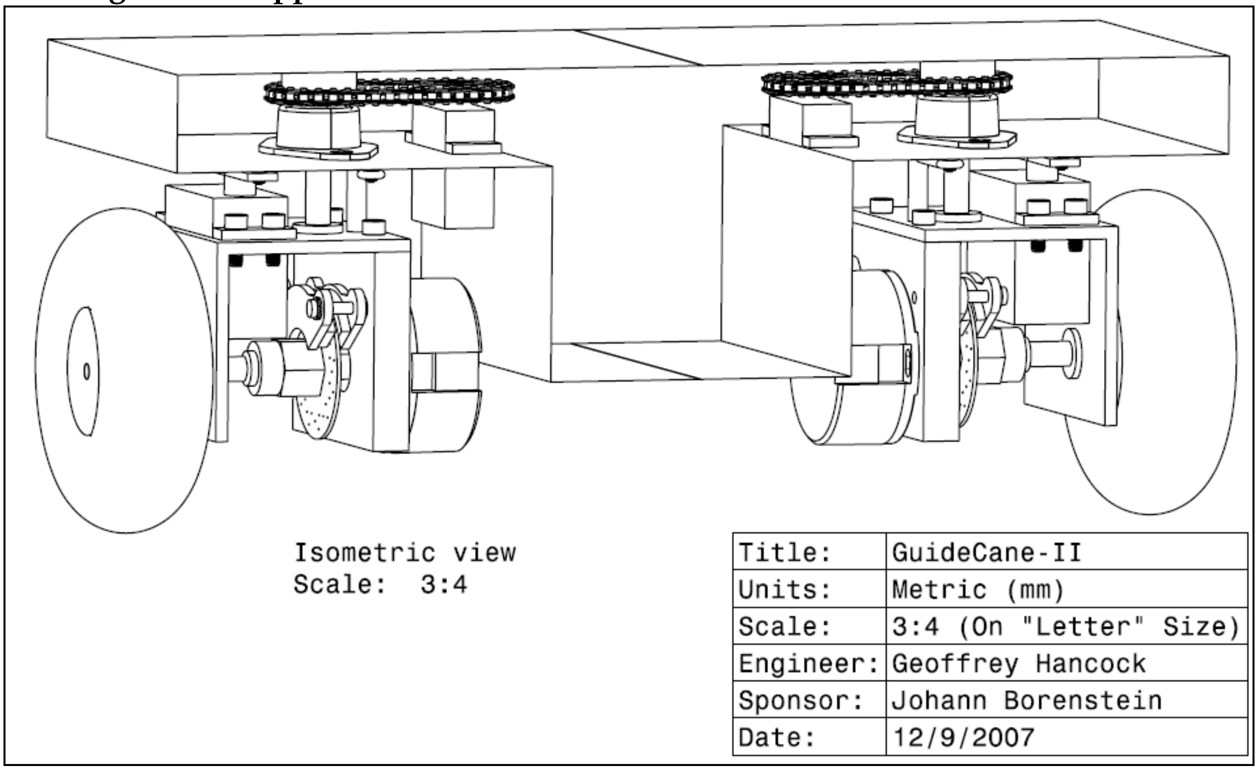
Figure 14. Braking subassembly design drawing with all dimensions in mm. For scaled drawing refer to Appendix H.



Engineering Change: Cam Link During testing of the braking system, we found that the cam link we had chosen was too weak. It was made of 2 plastic mini-clips connected with a steel threaded 2-56 rod. We upgraded this part to 2 steel pin joints connected with an unthreaded steel 2-56 rod. ECN is found in Appendix M.

Steering Assembly The chain drive steering system can be seen in Figure 15. We chose a steel chain with a pitch of 0.1475". The chain is driven by a servo horn mounted sprocket with 20 teeth. The chain drives a 20 tooth sprocket connected to the steering shaft. The steering shaft is mounted to the top of the braking subassembly. The positioning of the steering servo and steering shaft allows for the braking subassembly to turn 90 degrees in each direction without interference. The steering shaft is turns through a flange mounted bearing mounted on the main body of the GuideCane-II. The full drawing of our final design is found in Appendixes K and L.

Figure 15. Final design shows the integration of steering assembly. For scaled drawing refer to Appendixes K and L.

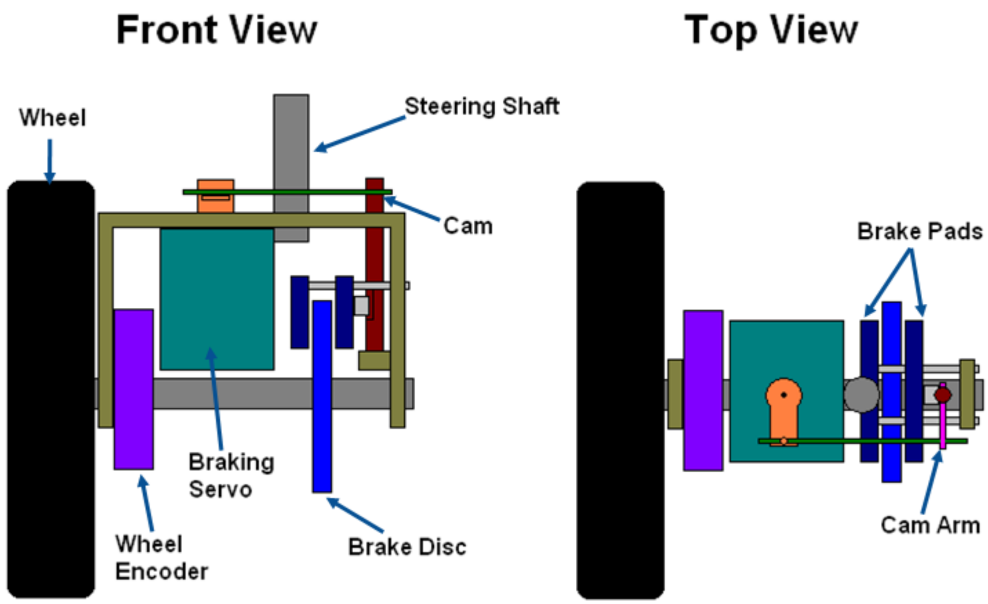


MANUFACTURING

We are limiting our manufacturing processes to include only a portion of what is required for a full GuideCane-II prototype. Because of this, we are considering only short-term development, not mass-production, although we are working to ensure that what we do develop will be complementary to the final model.

We built our prototype based on the design shown in Figure 16 on page 29.

Figure 16. Wheel Assembly that Includes Braking System.

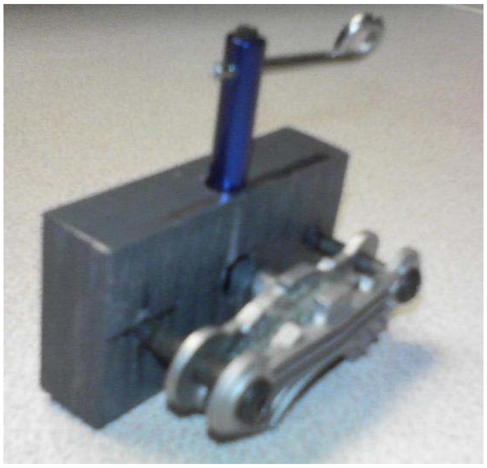


The braking system we have chosen is similar to that of a high performance RC truck [5]. This system uses a cam and disk style brakes. The servo rotates the cam which tightens one brake pad against the disk.

Preliminary

Before we began assembly on the prototype we manufactured portions of it with balsa wood, PVC and the brake assembly parts. The frame was build using “unset” dimensions. We will determine these dimensions using the steering radius and the amount of space needed for all components. We fabricated a mock-up of one the ends of the frame using PVC to help understand the critical dimensions and spacing show in Figure 17 on page 30.

Figure 17. Mock-up of the brakepad-cam assembly.



Based on this preliminary assembly, we have decided to create this frame from aluminum to keep the weight down. The frame will be bent in two ninety-degree corners to avoid additional screws and to eliminate the need for welding (which is not easily done using aluminum). This is especially important around the cam so that all the potential torque on the cam arm is utilized. We also need to determine how the steering shaft connects to the braking frame. Once this frame is fabricated we can proceed with fabrication of the steering system and main body frame.

Prototype Manufacturing

The prototype completed at this stage in development has symmetrical and fully functional braking subassemblies. These subassemblies have been temporarily fixed with a thin aluminum plate containing a PVC fixture for mounting the handle, receiver and battery. Each sub-frame was manufactured from two pieces of aluminum stock (2″x3/8″ and 2″x2″x1/8″ angle iron). The axle is made of ¼″ steel music wire. The sub-frame and axle act as a platform for all braking components purchased as listed in the bill of materials in appendix G.

Manufacturing Steps

The step by step process for assembling the prototype braking assembly is provided in Appendix I. It is composed of manufacturing stages including cutting, milling, filing, tapping, gluing, and drilling. Optimizing considerations were used to decrease manufacturing time. This includes minimizing the number of faces to be milled to four. The assembly stages follow these steps and largely include directions for combining parts and inserting screws. The exploded assembly can be seen in Appendix J.

The completed sub-frame is intended on being utilized for the final automated prototype, however to demonstrate our projects braking capabilities it was necessary to construct a temporary linkage. This linkage was built from a 2″ x 4″ x 3/8″ aluminum stock from which a 2″ x 1.5″ x 1″ PVC block is attached in the center. A 1″ hole was drilled at 60 degrees to fit the handle of a Swiffer floor scrubber. Two holes were drilled and tapped through the side of the block to be used for setscrews to fix the Swiffer handle. Two holes were drilled and tapped in the base of the sub-frames thick wall along with the bottom of the PVC block. Six holes total were drilled in the aluminum linkage plate and all pieces were attached with 6-32 3/8″ steel screws.

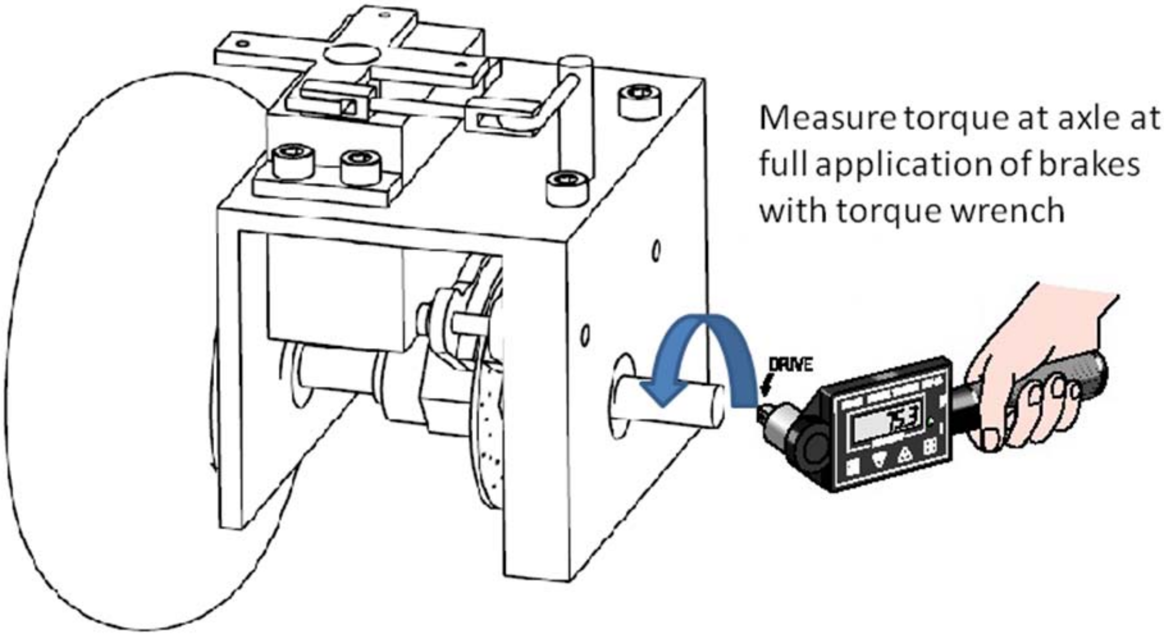
Mass Production Considerations
Our prototype is not intended for mass production at this stage in development. The material suppliers we used were based largely on convenience simply for the small quantities that we were ordering. If mass production was required purchasing directly from the manufacturers of our parts could drastically reduce material prices.

There are a number of parts that we chose to buy rather than engineer and manufacture in house. For our prototype it is more important to have the entire system working rather than spending time and energy in designing and building each individual component. In a mass production situations cost reduction by manufacturing more components in house may outweigh costs of engineering analysis.

TESTING

In order to validate our force and stopping distance predictions, the axle was physically tested. We used a digital torque wrench on the axle to measure the torque at the full application of the brakes. We took the torque value when the wheel started to move. Figure 18 on page 32 shows the first testing analysis on the brake sub-assembly.

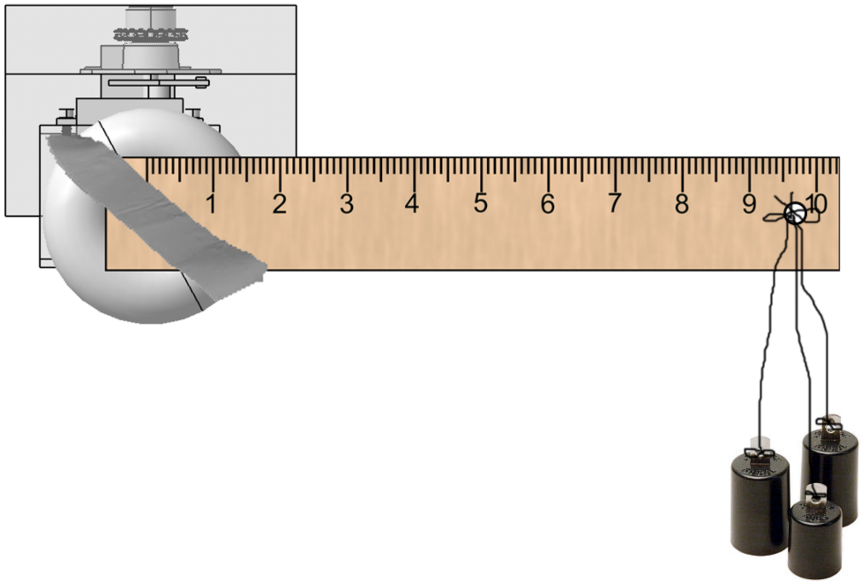
Figure 18. First experimental testing setup of brake



To measure the torque, we first acquired a torque wrench graduated to a maximum value of 24 in-oz. This was taped to the axle and the brakes were fully applied. A torque was then applied to the wheel until it started to move. This is the maximum torque the axle could provide. However, the scope of the torque wrench was exceeded and an alternate method of determining this axle torque was used.

Instead, we taped a lever arm onto the wheel and attached weights using the relation, F x r. This setup is shown in Figure 19 on page 33.

Figure 19: Second experimental testing setup of brake



Torque is measured by fixing arm to wheel face and adding weights at the end of the arm. We calculated torque since we knew that the braking torque is defined as the force of gravity cross the arm length:

$T_{braking}$ = Weight * Arm length (Equation 9)
$T_{braking} \approx (9.81m/s2)(0.2kg)(.2413m) = 0.473N\text{-}m$ (for one wheel)
Total $T_{braking} = 0.95N\text{-}m$

$T_{braking} = 0.95N\text{-}m \approx 1.09N\text{-}m$

Wheel lock is not desired condition so the torque value is acceptable and can be reduced for varying surface conditions.

Therefore, with a braking torque of 0.473N-m or 66.98 in-oz for each side, we chose our servos to have a prescribed manufacturer torque of 59 in-oz (the closest attainable value).

DISCUSSION FOR FUTURE IMPROVEMENT

While we feel that we have designed a very high quality prototype, some improvements could be made and the overall project itself it far from over.

Improvements could be made to the wheels-shaft connection. After excessive use the glue binding the wheels to the axle has weakened and allowed the wheel to move even when the brakes are fully applied. We worked hard to fit the design specifications given to us and all of the parts fit precisely where they were designed to go. However, we did not allocate much space beneath the braking sub-assembly frame whereas ideally there would be more clearance on the ground for rough terrain. Future projects may include the manufacture of the steering assembly, analysis of the sensor range and motion, computer programming, and wheel encoder considerations.

CONCLUSIONS

The million of blind and visually impaired individuals around the world are in need of a high quality mobility aid that will allow them to travel independently. Current solutions often require extensive training, are unreliable, and provide no means of navigating beyond the users own interpretation. Our work with the GuideCane-II prototype is an important step toward the development of a fully functional "seeing-eye" robot to guide its users. This solution is superior to market alternatives because it has the potential for numerous capabilities impossible with current methods and because the computer it contains will be more reliable than interpretation from a cane or guide dog.

We have designed a dual-wheeled base with steering and braking capabilities that respond to radio control input. The final GuideCane-II will contain sensors and a computer, allowing it to "see" at various levels in front and to the sides of the user and allows him or her to circumnavigate obstacles while guiding them in a given direction. We designed a independent steering system that will provide 180° rotation, this is over twice the rotation of the original GuideCane and will not be subject to locking in place as the original was. We have designed and built a dual-braking system with disc brakes that exerts 1.09 N-m of torque on each wheel. This quality of braking functionality allows user to be safe, which is the primary aim of the GuideCane-II. We are proud to be a part of this potentially life-changing technology and feel that our work has brought this product one step closer to aiding those who need it.

ACKNOWLEDGEMENTS

Adam Borrell
Professor Jwo Pan
Professor Johann Borenstein
Professor Bogdan Epureanu

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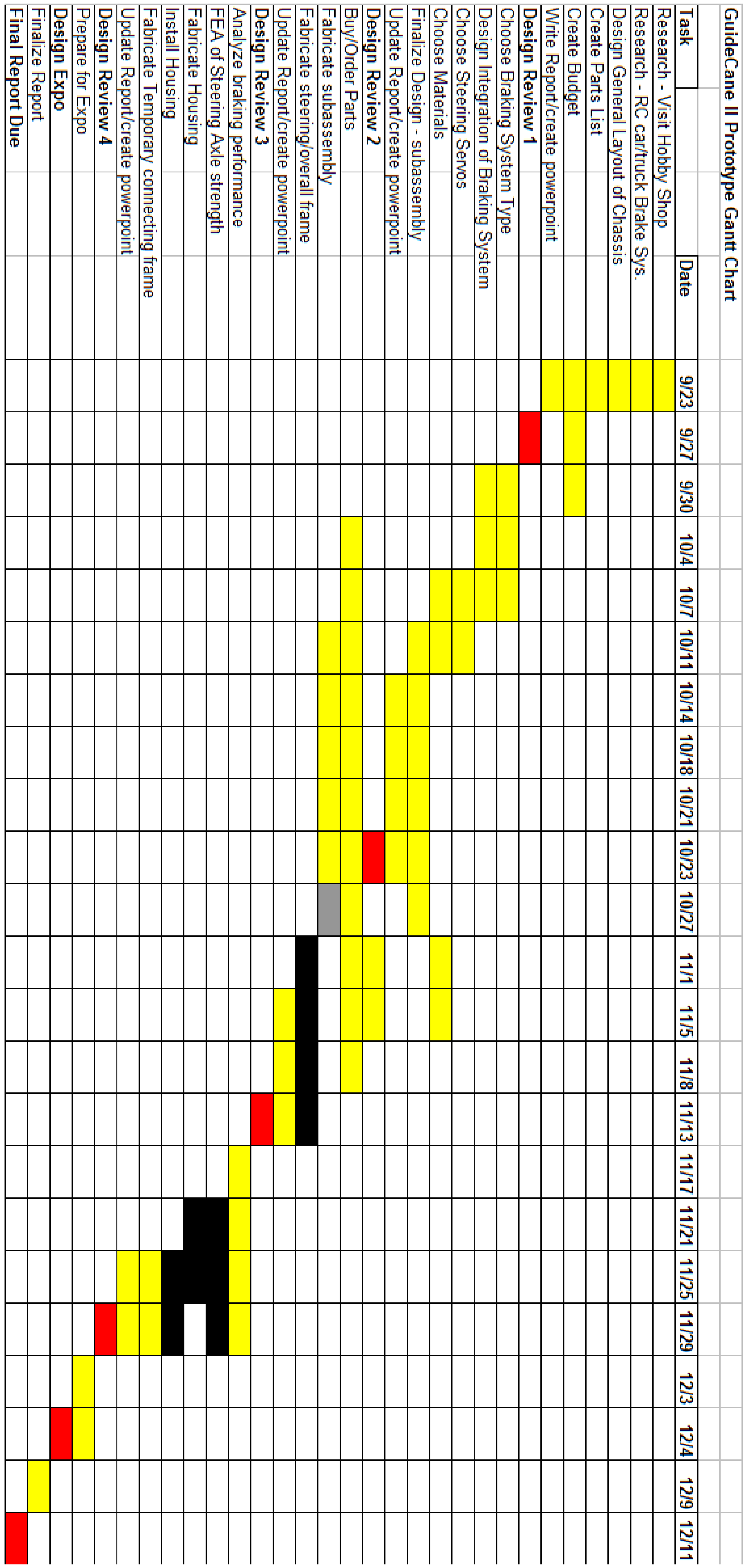
NOMENCLATURE

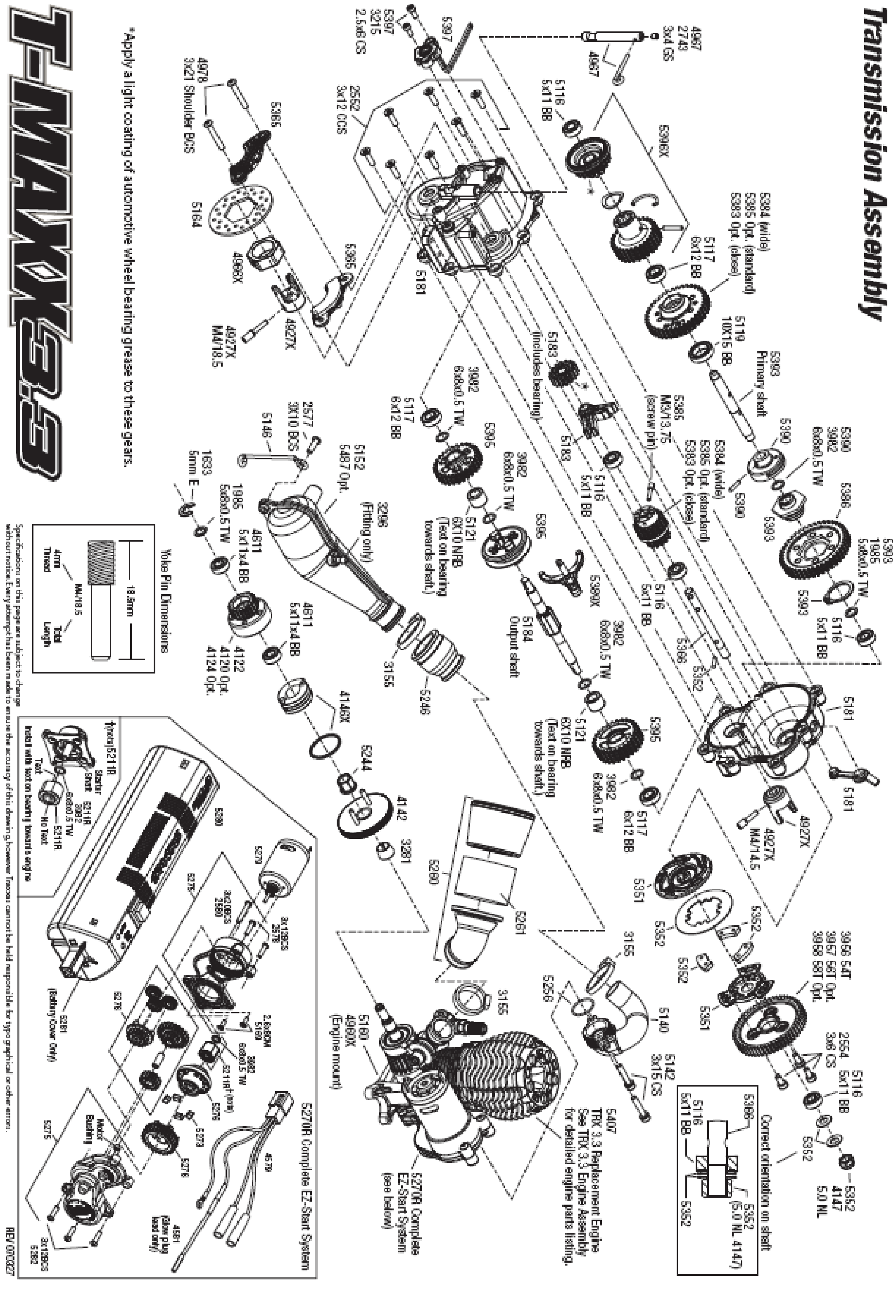
ETA- Electronic Travel Aid
Legally Blind- "Legal blindness is a level of visual impairment that has been defined by law to determine eligibility for benefits. It refers to central visual acuity of 20/200 or less in the better eye with the best possible correction, as measured on a Snellen Vision Chart, or a visual field of 20 degrees or less."
QFD- Quality Function Deployment
R/C- Radio Controlled

APPENDIX

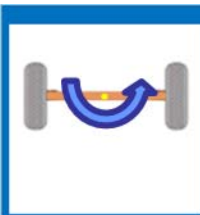
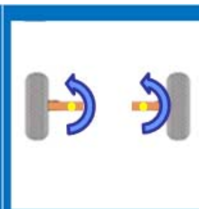
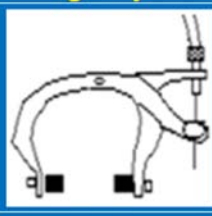
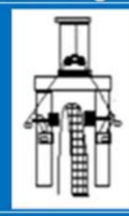
A. Gantt Chart



B. TRAXXAS Brake System



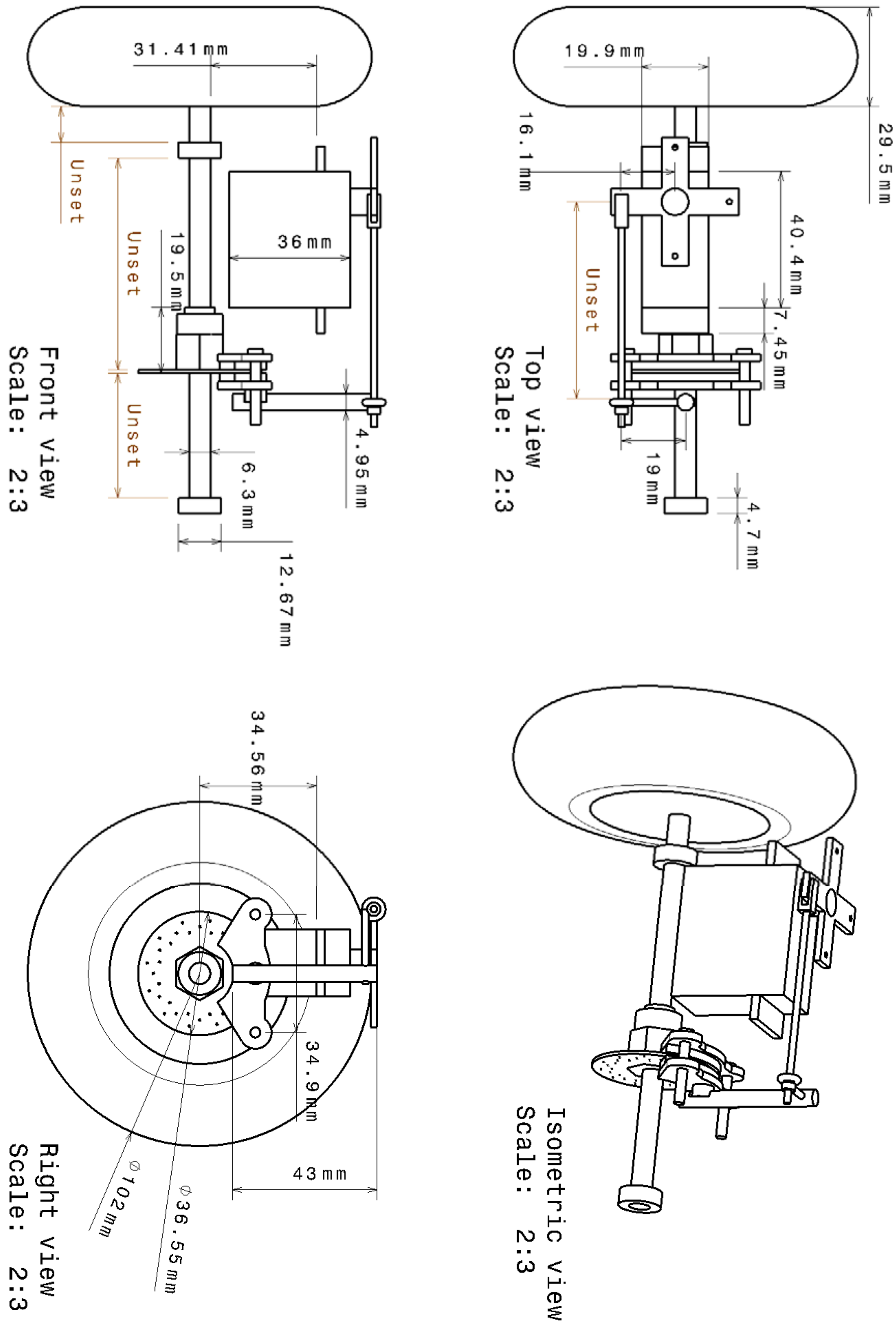
C. Morphological Chart

Steering Design Options					
	Four-bar linkage system	Single Axis Steering	Independent Steering		
Braking Design Options					
	Side-Pull Cable	Center-Pull Cable	Cantilever Cable	Pneumatic/ Hydraulic	Disc Brake

D. Pugh Chart

Pugh Chart											
		Concept A Dual Servo/Disc		Concept B Dual Servo/Drum		Concept C Ackermann/Disc		Concept D Dual Servo/Cantilever		Concept E Ackermann/Side-pull	
Characteristics	Weight	Ranking	Weighted Value	Ranking	Weighted Value	Ranking	Weighted Value	Ranking	Weighted Value	Ranking	Weighted Value
Lightweight	0.1389	5	0.6945	2	0.2778	4	0.5556	5	0.6945	5	0.6945
Comfortable Grip	0.0833	1	0.0833	1	0.0833	1	0.0833	1	0.0833	1	0.0833
Rolls easily	0.1389	5	0.6945	5	0.6945	3	0.4167	5	0.6945	3	0.4167
Power lasts	0.1111	1	0.1111	1	0.1111	1	0.1111	1	0.1111	1	0.1111
Aesthetics	0.0694		0		0		0		0		0
Durability, Waterproofing	0.1111	4	0.4444	4	0.4444	4	0.4444	4	0.4444	4	0.4444
Ease of steering	0.1389	5	0.6945	5	0.6945	3	0.4167	5	0.6945	3	0.4167
Comfortable, sufficient braking system	0.1389	5	0.6945	3	0.4167	5	0.6945	5	0.6945	3	0.4167
Foldable, retractable, portable	0.1111	3	0.3333	1	0.1111	3	0.3333	2	0.2222	1	0.1111
Quiet for user	0.0556	3	0.1668	3	0.1668	3	0.1668	4	0.2224	4	0.2224
		Total:	3.9169		3.0002		3.2224		3.8614		2.9169

E. Scale CAD Drawing of Braking System



F. FMEA Chart (Page 1)

Product Name: GuideCane-II	Development Team: 22													
System: Braking/ Steering/ Electronic							FMEA #1							
							11/13/2007							
Part # & Function	**Potential Failure Mode**	**Potential Effects of Failure**	**Severity**	**Potential Causes/Mechanisms of Failure**	**Occurrence**	**Current Design Controls/Tests**	**Detection**	**Recommended Action**	**RPN**	**New S**	**New O**	**New D**	**New RPN**
1. Music Wire (1/4" diameter) (Axle) Shaft with all rotating components attached	Fracture, Yield, Cracking	Inability to hold other components in place, absorb impact, or even allow apparatus to roll	9	Impact running into obstacles	7	Material strength tests	1	Use stronger material	63	6	3	1	18
	Misalignment, Deformation	friction/resistance, apparatus would wobble, and force, torque equilibrium	8	Terrain or impact causing axle to shift out of original position, or holes drilled too small/large	4	Holes can be drilled to correct size	3	Tolerance holes to right dimension	96	5	1	1	5
	Corrosion	performance negatively affected	4	Environment (exposure to temperature, humidity, chemicals)	1	Corrosion test	10	Use corrosion resistant material	40	1	1	3	3
2. Treaded wheels (3-1/4" diameter) (Wheel) Rolls to move the apparatus	Cracking	Wheel does not turn	9	Road conditions	4	Material strength tests	5	Use stronger material	180	6	1	3	18
	Wear, Loosening	Wheel wobbles, detaches, or breaks off	8	Friction, road conditions	4	Stopping distance test	3	Use rubber wheels	96	5	1	1	5
3. 1/4"x1/2"x3/16" Shielded Ball bearing (Bearing) Supports, guides, and reduces the friction of motion between fixed and moving machine parts.	Loose fitting	Ball bearing would not stay in place or reduce friction	4	Holes drilled too small/large	3	Holes can be drilled to correct size	10	Tolerance holes to right dimension	120	1	1	5	5
4. 2"x2"x1/8" Aluminum Angle Iron (Brake Housing) Serves as protective barrier around brakes/electronic/etc.	Fracture, Yield, Cracking	Parts inside not protected/ do not function/apparatus does not move	8	Impact running into obstacles	7	Material strength tests	1	Use stronger material	56	5	3	1	15
5. 2"x3/8" (x12") Aluminum Block (Brake Housing) Serves as protective barrier around brakes/electronic/etc.	Fracture, Yield, Cracking	Parts inside not protected/ do not function/apparatus does not move	8	Impact running into obstacles	7	Material strength tests	1	Use stronger material	56	5	3	1	15
6. 42mm Steel Brake Disc (Brake) Pushes Brake Pad against rotor to stop	expansion/shock/ relaxation, Erosion	Brakes do not fit, break, or even stop apparatus	10	Heat, removal of material caused by friction	9	Stopping distance test	3	Use heat resistant material	270	7	5	1	35
7. 1/4" Aluminum Hex Disc Mount (Brake) Hold Brake Disc in place	Fracture, Yield, Cracking	Brake disc would not be held in place and apparatus would not stop	10	Impact running into obstacles	7	Material strength tests	5	Use stronger material	350	7	3	3	63
8.Brake Pad (Brake) Pushed against rotor to stop	Misalignment, Wear, Thermal fatigue	Brake Pad would not provide adequate stopping force	10	adequate material properties, coefficient of friction, alignment to provide friction	7	Stopping distance test	2	Use heat resistant material	140	7	3	1	21
9. 6-32 3/4" steel screws (Housing) Connect aluminum frames together	Stripping, Loose fitting, Wear, Excessive Shear	Housing would not stay together, internal parts would be exposed to damage	7	Impact running into obstacles, holes drilled too small/large, excessive installation force	7	Holes can be drilled to correct size	3	Tolerance holes to right dimension	147	4	3	1	12
10. 6-32 3/8" steel screws (Electronics) Attach servo to housing	Stripping, Loose fitting, Wear, Excessive Shear	Housing would not stay together, internal parts would be exposed to damage	7	Impact running into obstacles, holes drilled too small/large, excessive installation force	7	Holes can be drilled to correct size	3	Tolerance holes to right dimension	147	4	3	1	12

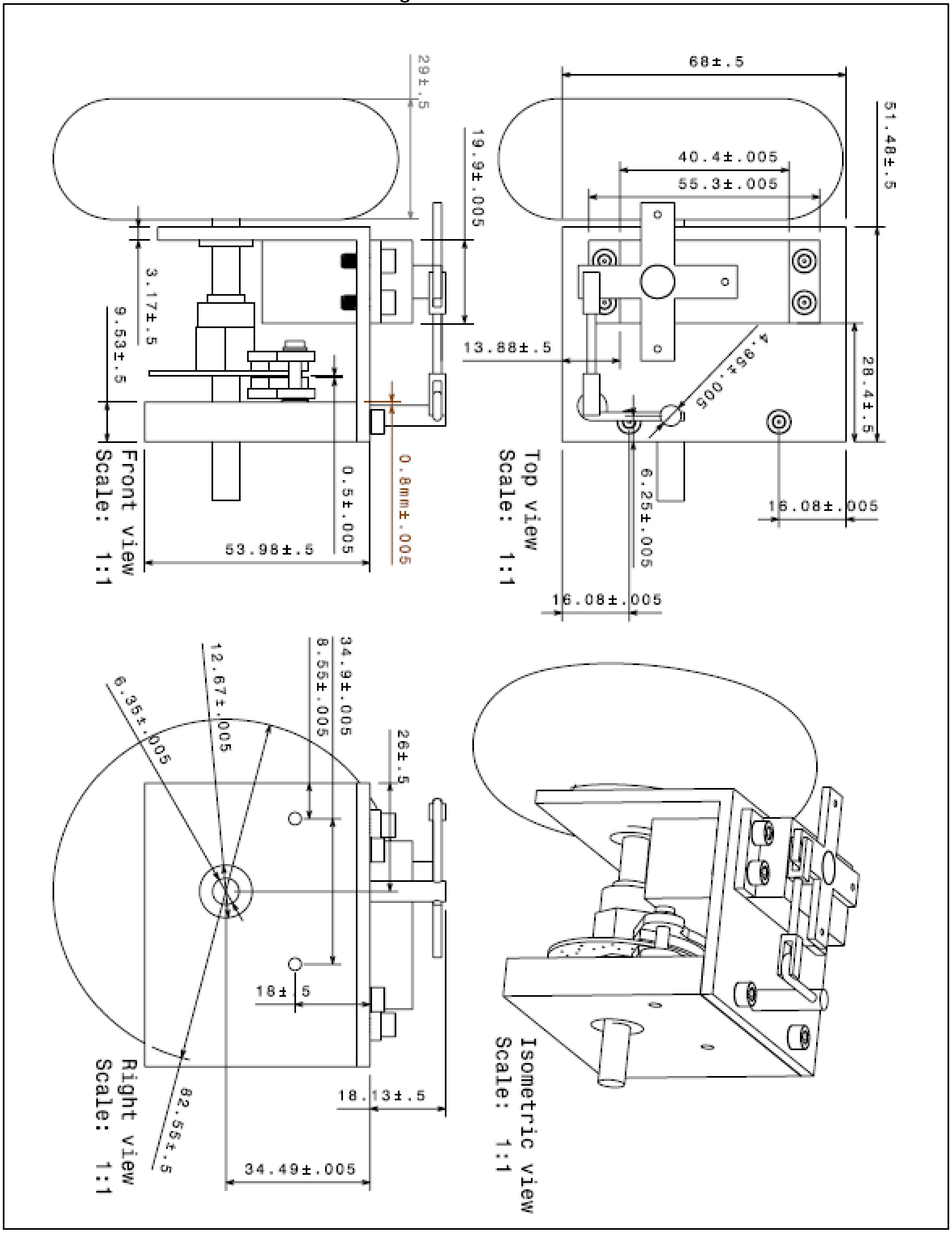
F. FMEA (Page 2)

11. Brake cam (Brake) Turns to apply brake force to rotor	Misalignment, Deformation	Cam would not have greatest range of turning, and braking torque would lessen	4	Holes drilled too deep, large, etc.	4	Holes can be drilled to correct size	3	Tolerance holes to right dimension	48	1	1	1	1
12. Cam lever (Brake) Pushes/rotates cam	Fracture, Yield, Cracking, Creep	Cam would break, not turn, and not actuate braking	10	Impact running into obstacles, applied forces over long periods of time	7	Material strength tests	1	Use stronger material	70	7	3	1	21
13. 3mm set screw (Brake) Attaches cam lever to cam	Stripping, Loose fitting, Wear, Excessive Shear	stay together, braking could not occur	10	Impact running into obstacles, holes drilled too small/large, excessive installation force	7	Holes can be drilled to correct size	3	Tolerance holes to right dimension	210	7	3	1	21
14. Set screw 21mm (Brake) Holds brake pads to aluminum housing	Stripping, Loose fitting, Wear, Excessive Shear	Brake disc would not be held in place and apparatus would not stop	5	Impact running into obstacles, holes drilled too small/large, excessive installation force	7	Holes can be drilled to correct size	3	Tolerance holes to right dimension	105	2	3	1	6
15. 2-56 threaded rod (Brake) Connects two mini-links	Fracture, Yield, Cracking, Creep, Stripping	Link would break so the cam would not turn, and not actuate braking	9	Impact running into obstacles, or this part gets pulled too hard during cam actuation	5	Material strength tests	3	Use stronger material	135	6	1	1	6
16. 2-56 mini-links (Brake) Connects servo to cam lever	Fracture, Yield, Cracking, Creep, Stripping	Link would break so the cam would not turn, and not actuate braking	9	Impact running into obstacles, or this part gets pulled too hard during cam actuation	5	Material strength tests	3	Use stronger material	135	6	1	1	6
17. Futaba servo (braking) (Brake) Turns cam lever, cam	Fracture, Surge, Electrical Short, Open Circuit	Wheels would not brak	9	Impact running into obstacles, inadequate or excessive power supply	6	None	5	None	270	6	2	3	36
18. Futaba servo (steering, sprocket-headed) (Steering) Turns wheels	Fracture, Surge, Electrical Short, Open Circuit	Wheels would not turn	9	Impact running into obstacles, inadequate or excessive power supply	6	None	5	None	270	6	2	3	36
19. Steering shaft (Steering) Connects sub frame to main body	Fracture, Yield, Cracking	Subassemblies would not be connected to main body, no steering would occur	10	Impact running into obstacles	7	Material strength tests	1	Use stronger material	70	7	3	1	21
20. Flange Mount Bearing (Steering) Allows steering shaft to turn in relation to main body	Loose fitting, Misalignment	Ball bearing would not stay in place or reduce friction	4	Holes drilled too small/large	2	Holes can be drilled to correct size	7	Tolerance holes to right dimension	56	1	1	5	5
21. Sprocket (Steering) Moves chain	Loose fitting, Misalignment	Uncontrolled or no steering	10	Impact running into obstacles, incorrect size/use of or breaking of chain	5	Rotation of sprocket with chain on	4	None	200	10	5	4	200
22. Chain (Steering) Moves subframe	Loose fitting, Misalignment	Uncontrolled or no steering	10	Impact running into obstacles, incorrect size/use of or breaking of sprocket	5	Rotation of sprocket with chain on	4	None	200	10	5	4	200
23. Casing (ethylene) Envelopes whole assembly	Fracture, Yield, Cracking	Parts inside do not function/apparatus does not move	6	Impact running into obstacles	7	Material strength tests	1	Use stronger material	42	3	3	1	9
24. Main body frame (aluminum) (Steering) Protects steering components	Fracture, Yield, Cracking	Parts inside do not function/apparatus does not move	6	Impact running into obstacles	7	Material strength tests	1	Use stronger material	42	3	3	1	9
25. Radio Control (RC) (Electronic) Controls braking/steering servos with pulse inputs	Fracture, Surge, Electrical Short, Open Circuit	Wheels would not brake, turn	10	Impact running into obstacles, inadequate or excessive power supply	5	None	1	None	50	10	5	10	500
26. Receiver, 3-channel (Electronic) Receives RC commands	Fracture, Surge, Electrical Short, Open Circuit	RC commands not received, no braking, turning	10	Impact running into obstacles, inadequate or excessive power supply	5	None	1	None	50	10	5	10	500
27. Rechargeable Batteries (AA or NiMH) (Electronic) Powers servos, etc.	Fracture, Corrosio	Power would run out, and servos would not work	10	Impact running into obstacles, environmental factors	5	None	10	None	500	10	5	10	500
28. Charger (Electronic) Charges batteries	Fracture, Surge, Electrical Short, Open Circuit	Batteries would not charge, and would run out of power earlier	6	Power used	10	None	10	None	600	6	10	6	360

G. Bill of Materials

#	Part Description	Purchased From	Mfg. Part #	amt.	Price (each)	Price (total)	Specs./Comments
00	**Subframe/Axle Assembly**						
01	1/4" Music wire (2 Axles)	Rider's Hobby		1	$5.00	$5.00	
02	3-1/4" Treaded Lightweight wheels (2)	Rider's Hobby (DU-BRO)	DUB325T	1	$6.59	$6.59	
03	1/4"x1/2"x3/16" Shielded Bearing (2)	Rider's Hobby	R188-zz	2	$7.99	$15.98	
04	2"x2"x1/8" Aluminum Angle Iron	Alro Metals Plus		2	$1.00	$2.00	scrap
05	2"x3/8"(x12") Aluminum Block	Alro Metals Plus		1	$7.00	$7.00	
06	6-32 3/4" steel screws (4)	Rider's Hobby		1	$0.99	$0.99	aluminum frame connectors
07	6-32 3/8" steel screws (4)	Rider's Hobby		2	$0.99	$1.98	servo mounting screws
10	**Brake Assembly**						
11	42mm Steel brake disc	Rider's Hobby (Traxxas)	5164	2	$2.50	$5.00	
12	1/4" Aluminum Hex Disc Mount	Rider's Hobby (Traxxas)	4966	2	$4.75	$9.50	
13	Traxxas Brake Pad Set Revo	Tower Hobbies (Traxxas)	5365	2	$7.19	$14.38	
14	Traxxas Button Head Machine Screw 3x21mm Revo (6)	Tower Hobbies (Traxxas)	4978	1	$2.39	$2.39	partially threaded
15	Brake cam (blue)/ cam lever/ 3mm set screw	Rider's Hobby (Traxxas)	4967	2	$6.25	$12.50	
16	2-56 aluminum threaded rod	Rider's Hobby		1	$0.79	$0.79	
17	Nylon Mini-link (2-56)	Rider's Hobby (DU-BRO)	228	2	$0.99	$1.98	
18	Futaba Servo	Rider's Hobby	s3003	2	$12.99	$25.98	
	Subframe Total					$112.06	
20	**Steering Assembly/Main Body**						
21	Servo (Sprocket-head)			2	$28.00	$56.00	high torque
22	Shaft						not determined yet
23	Flange Mount Bearing						not determined yet
24	Sprocket						not determined yet
25	Chain						not determined yet
26	aluminum	Alro Metals Plus					not determined yet
27	Casing (ethylene)						not determined yet
40	**Electronics**						not determined yet
41	Radio Control			1	$100.00	$100.00	
42	receiver, 3 channel			1	$30.00	$30.00	
43	Batteries AA recharg.			1	$15.00	$15.00	
44	Batteries NiMH			0	$30.00	$0.00	
45	battery holder			1		$0.00	
46	charger			1	$19.00	$19.00	
	TOTAL COST					**$332.06**	

H. Final CAD Model with Dimensioning and Tolerances



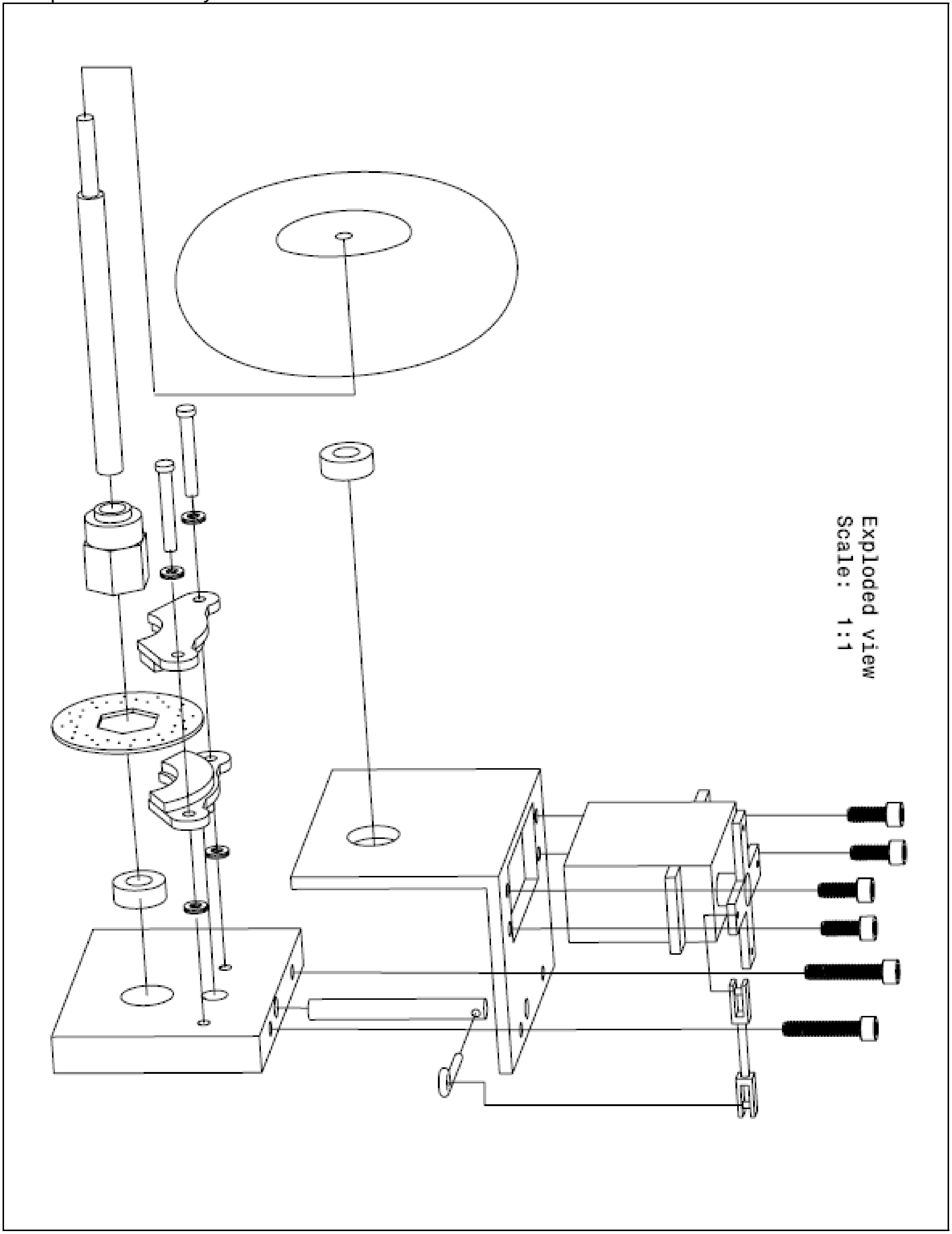
I. Step-by-Step Manufacturing Plan (page 1)

Prototype Manufacturing Plan										
								Time (hours)		
Op. #	Part	Face	Operation	Machine	Tool	Fixture	Parameters	Set-up	Run	Total
Cut										
1	Angle Iron	-	Cut	Vertical Saw	Saw Blade	-	2"x2"x1/8" and 2.7"	0.1	0.1	0.2
2	Thick Wall	-	Cut	Vertical Saw	Saw Blade	-	2"x3/8" and 2.7"	0.1	0.1	0.2
Mill										
3	Thick Wall	A	Drill Hole 1 and 2	Mill	Drill bit	Vice	#36 x 1.0" deep	0.1	0.1	0.2
4	Thick Wall	A	Drill Hole 3	Mill	Drill bit	Vice	#10 x 0.98"deep	0.1	0.1	0.2
5	Thick Wall	B	Drill Holes 4 and 5	Mill	Drill bit	Vice	#39 through	0.1	0.1	0.2
6	Thick Wall	B	Drill Hole 6	Mill	Drill bit	Vice	1/4" x 0.13" deep	0.1	0.1	0.2
7	Thick Wall	B	Center Drill Hole 7	Mill	Center Drill	Vice	-	0.1	0.1	0.2
8	Thick Wall	B	Drill Hole 7	Mill	Drill bit	Vice	.484" through	0.1	0.1	0.2
9	Thick Wall	B	Ream Hole 7	Mill	Reamer	Vice	1/2" through	0.1	0.1	0.2
10	Angle Iron	C	Drill Hole 8 and 9	Mill	Drill bit	Vice	#28 through	0.1	0.1	0.2
11	Angle Iron	C	Drill Hole 10	Mill	Drill bit	Vice	13/64" through	0.1	0.1	0.2
12	Angle Iron	C	Drill Holes 11, 12, 13, and 14	Mill	Drill bit	Vice	# 36 through	0.1	0.1	0.2
13	Angle Iron	C	Mill Servo Hole	Mill	End Mill	Vice	1/4" through	0.1	0.2	0.3
14	Angle Iron	D	Center Drill Hole 15	Mill	Center Drill	Vice	-	0.1	0.1	0.2
15	Angle Iron	D	Drill Hole 15	Mill	Drill bit	Vice	.484" through	0.1	0.1	0.2
16	Angle Iron	D	Ream Hole 15	Mill	Reamer	Vice	1/2" through	0.1	0.1	0.2
File										
17	All	-	File all cut edges	Hand	File	-	-	0	0.2	0.2
Turn										
18	Axle	-	Turn large	Lathe	Turning	-	0.25"	0.1	0.1	0.2

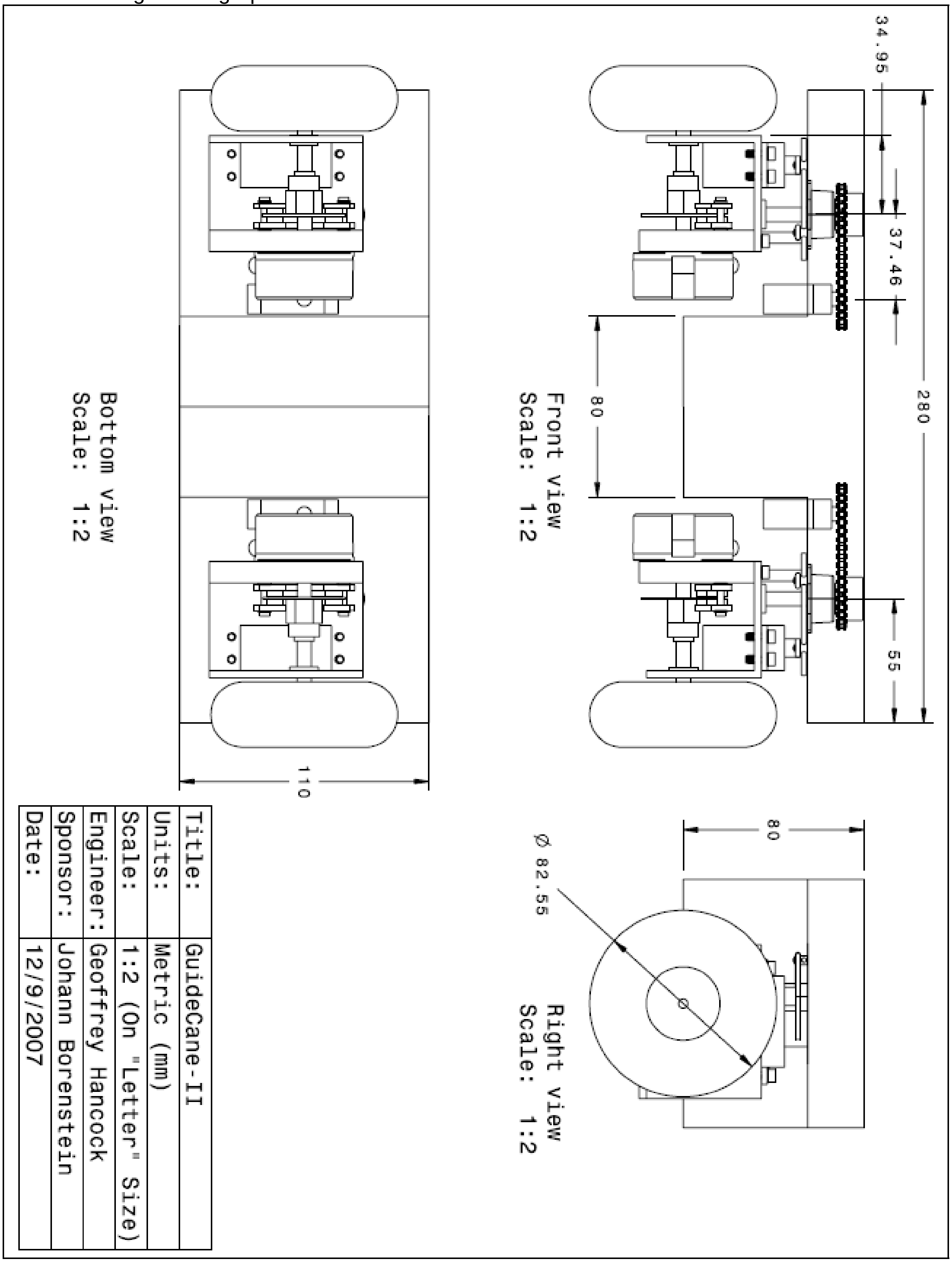
			diameter							
19	Axle	-	Turn small diameter	Lathe	Turning	-	0.158"	0.1	0.3	0.4
20	Axle	-	Cut to length	Lathe	Cutting	-	4.0"	0.1	0.1	0.2
					Tap					
21	Thick Wall	A	Tap Holes 1 and 2	Hand	Tap	Vice	6x32	0.1	0.1	0.2
22	Angle Iron	C	Tap Holes 11, 12, 13, and 14	Hand	Tap	Vice	6x32	0	0.2	0.2
23	Thick Wall	B	Tap holes 4 and 5	Hand	Tap	Vice	3x21(mm)	0.1	0.1	0.2
					Glue					
24	Thick Wall and Angle Iron	B, D	Glue bearings in hole 7 and 15	Hand	-	-	-	0	0.1	0.1
					Assemble					
25	Thick Wall	A	Apply lubricant to hole 6	Hand	-	-	-	0	0.1	0.1
26	Cam and Thick Wall	A	Slide Cam in hole 6	Hand	-	-	Face flat edge towards face C	0	0.1	0.1
27	2 3x21(mm) screws, 2 springs, inner and outer brake pad	B	Slide screw through outer pad, and inner pad	Hand	-	-	Leave 0.1" gap	0.1	0.1	0.2
28	4 6-32x3/8" screws, Servo, Angle Iron	C	Attach servo	Hand	-	-	Hand tight	0	0.1	0.1
29	2 6-32x3/4" screws, Angle Iron, and Thick Wall	C	Attach Angle Iron to Thick Wall	Hand	-	-	Hand tight	0	0.1	0.1
30	Cam Arm	-	Position cam with set screw	Hand	-	-	Hand tight	0	0.1	0.1

31	Brake Link	-	Attach brake link to servo horn and cam arm	Hand	-	-	-	0	0.1	0.1
32	Wheel and Axle	-	Attach wheel to axel	Hand	-	-	Press Fit	0	0.1	0.1
33	Hex mount and Disc	-	Slide disc over hex mount	Hand	-	-	Press Fit	0	0.1	0.1
34	Axle, hex mount	-	Slide axle through outer bearing, then with disc between brake pads slide axle through hex mount, and then through inner bearing	Hand	-	-	-	0	0.1	0.1
									Totals	
								2.2	3.9	6.1

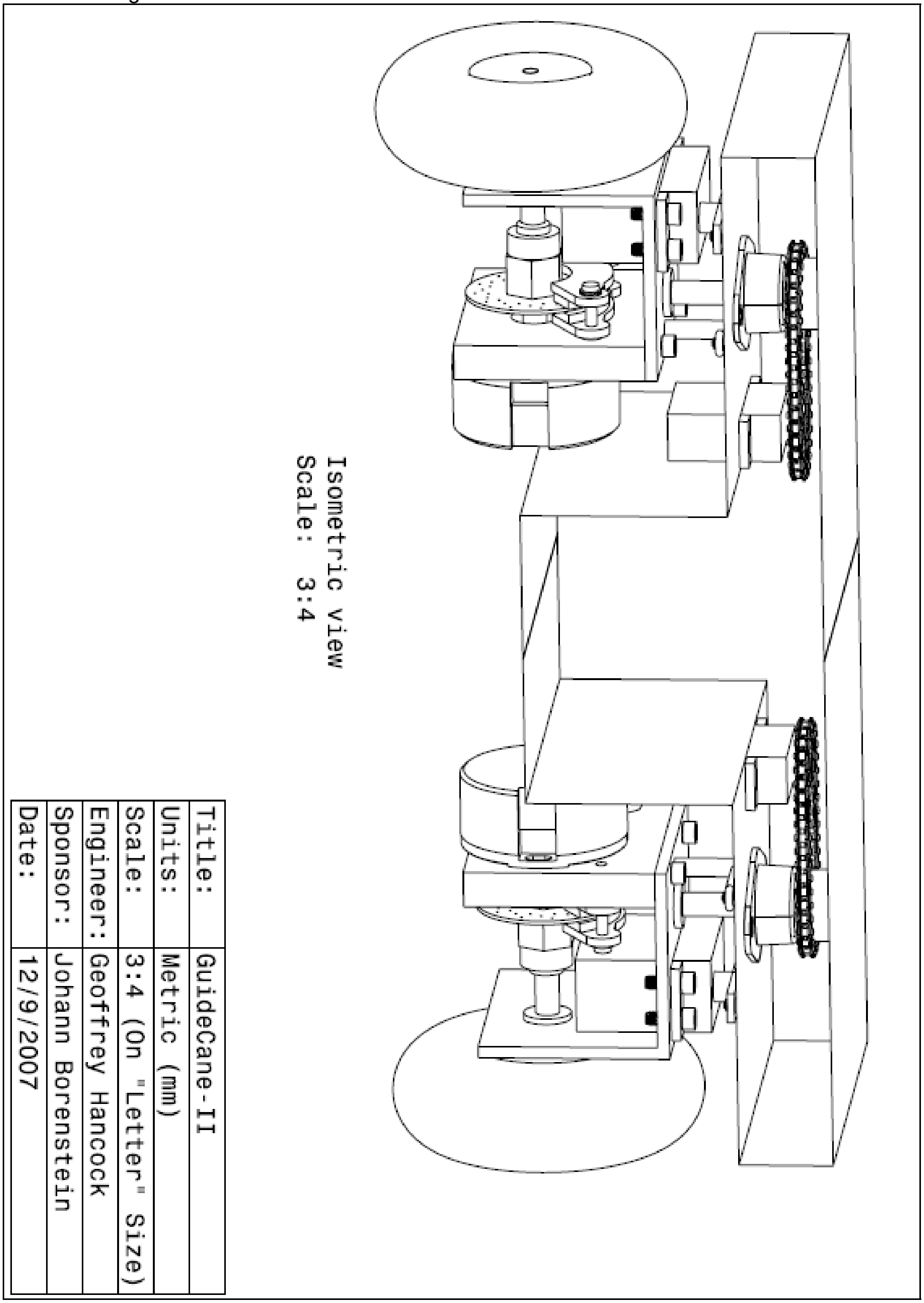
J. Exploded Assembly



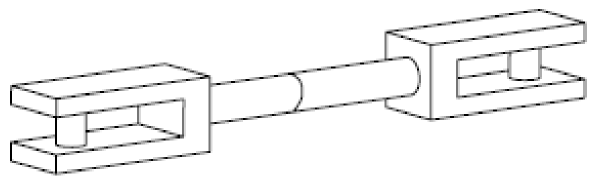
K. Final Design Orthographic Views



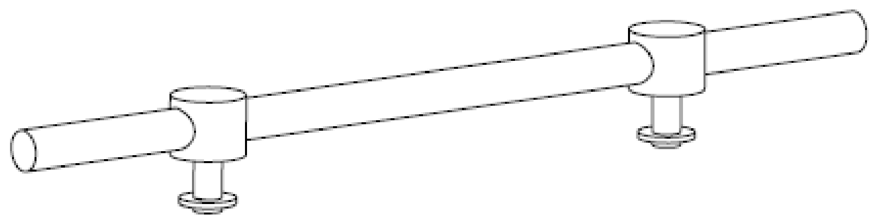
L. Final Design Isometric View



M. Engineering Change Notice



Old: Two plastic miniclips connected with 2-56 threaded rod



New: Two steel pin joints connected with 2-56 unthreaded rod, length constrained with set screws.

Isometric view
Scale: 3:1

Note: Torque output from servo was too large for the plastic parts. We upgraded the plastic miniclips to steel pin joints.

Title:	GuideCane-II ECN
Part:	Cam Link
Scale:	3:1 (On "Letter" Size)
Engineer:	Geoffrey Hancock
Sponsor:	Johann Borenstein
Date:	12/9/2007