SPORTS FOR NATHAN

FINAL REPORT

Prepared For: Nathan Cooper and Family

Prepared By:

Delaney Bales
Mechanical Engineering

Joseph Garrett
Mechanical Engineering

Chris Harter
Mechanical Engineering

Brenna Keane
Kinesiology

Mechanical Engineering Department
California Polytechnic State University
San Luis Obispo

Fall 2014 – Spring 2015
Senior Project

Statement of Disclaimer

Since this project is a result of a class assignment, it has been graded and accepted as fulfillment of the course requirements. Acceptance does not imply technical accuracy or reliability. Any use of information in this report is done at the risk of the user. These risks may include catastrophic failure of the device or infringement of patent or copyright laws. California Polytechnic State University at San Luis Obispo and its staff cannot be held liable for any use or misuse of the project.

Table of Contents

List of Tables

List of Figures

Abstract

Nathan Cooper is a local boy with spinal muscular atrophy. He enjoys playing games and being active. One assistive device that Nathan uses is his Standing Dani, a motorized mobile stander. Nathan enjoys playing golf and kickball, and prior to this project he had no way of playing golf and no safe way of playing kickball. The purpose of this project was to design and build a golf attachment for Nathan's Standing Dani that allows him to putt, and a kickball attachment that allows him to play kickball safely. First, the design team researched and defined the problem in terms of design specifications. Then, the team brainstormed a number of possible solutions. Decision matrices were used to narrow down the possible solutions to one best concept. Analysis and preliminary testing was then used to turn the top concept into a detailed design. Next, a prototype was constructed to put the design into action. Finally, the prototype was tested on a test frame and then with Nathan on the Standing Dani. The final golf putter attachment consists of a hockey blade that is used to putt the golf ball. The hockey blade is rigidly attached to the front of the Standing Dani with a shaft and brackets, and is driven to hit the ball by operating the Standing Dani like normal. The final kickball attachment consists of plastic guards that protect the Standing Dani from balls that may roll under it and tip it over. Both attachments work as intended and Nathan enjoys using them.

Chapter 1 - Introduction

The purpose of this project is to improve the lives of Nathan Stilts-Cooper and his family. Nathan is eight years old and was born with spinal muscular atrophy. The support from his family and assistive devices helps him be active at school, at home, and in his community. One of these devices, the Standing Dani, gives Nathan the power to drive around with a joystick while supported in a standing position. Nathan loves to play golf and kickball, but his physical condition and the limitations of his Standing Dani device made it difficult for him to play these sports as much as he would like to. The goal of our team was to design and build devices that adapt to his Standing Dani and allow Nathan to safely play his favorite sports.

With the creation of a device that allows him to play golf and kickball safely, Nathan is able to engage and enjoy playing these activities in ways that he currently cannot. Nathan formerly played golf using the casters of his Standing Dani to guide the ball into the hole. His grandfather enjoys golf and his younger brother is beginning to learn, so it was important to Nathan and his family that he can also participate. A device that attaches to the Standing Dani and allows Nathan to play golf more effectively was created. To play kickball, Nathan currently hits the ball with the frame of the Standing Dani by driving into it. On at least one occasion, the ball got stuck underneath the Standing Dani and threatened to tip him over. Since Nathan wants to keep playing kickball the same way, the interaction and functionality of his current method were not modified. However, safety features and improvements were made to allow Nathan to continue playing kickball without the risk of tipping over.

Both Nathan and his family's quality of life were improved with the creation of solutions that help him engage in activities that he enjoys. Golf and kickball are relatively simple sports that are easily accessible to most people. Formerly, Nathan did not have a well-suited method or device that allowed him to play golf and his participation in kickball was limited by safety concerns. Nathan deserves to participate in the activities that he enjoys and keep him active. Being able to play with Nathan and see their son living a healthy lifestyle brings great joy to Nathan's family. The implementation of attachable assistive devices is important to both Nathan and his family.

Management Plan

Since this was a very involved process with many different phases and processes, it was important that we divide the responsibilities to keep us each focused and efficient. We assigned some of the processes and sub processes to a particular member of the group. This does not necessarily mean that that member completed that process alone, but that he/she was responsible for knowing what needs to be accomplished by when and assigning and verifying tasks for that process. Joseph was in charge of communicating with the sponsor, drafting reports, engineering analysis, and ordering parts. Delaney was in charge of maintaining the budget, editing and formatting reports, 3-D modeling, and parts manufacturing. Chris was in charge of maintaining documents and records, writing weekly status reports, drafting reports, and building the prototype. Throughout the course of the project, we also relied on the sponsor's feedback and participation.

Funding

As a collaborative effort between Kinesiology and Mechanical Engineering students, our project provides the opportunity for an interdisciplinary learning experience. On November 14, 2014, our project received $2,000 from CPConnect, a program at Cal Poly that creates learning opportunities and supports multi-disciplinary collaboration for students through funding. These funds were available immediately until December 15, 2015. One of our responsibilities, as recipients of these funds, is to submit a comprehensive project report as well as an executive summary to the CPConnect committee by

December 15, 2015. This report is to ensure the donors that their contributions have made a significant impact toward interdisciplinary projects and the learning experience of Cal Poly students. Dr. Peter Schuster was our faculty advisor for the CPConnect funding.

Chapter 2 - Background

In order to find the best solution, it was important to understand the existing situation and all information related to this project. This included learning about Nathan's physical disability, the current state of Nathan's participation in sports, related devices that Nathan has used, and existing products that solve similar problems. In this section, background information is presented on these topics, as well as the benefits of standing and why none of the existing solutions fit Nathan's needs.

Spinal Muscular Atrophy

Spinal muscular atrophy (SMA) is a genetic disorder that limits voluntary muscle movement. It affects about 1 in every 8,000 people and can be distinguished into several types. [11] Nathan has Type II SMA. On a biological level, Type II SMA is a genetic mutation that weakens the motor neurons that carry signals from the brain to the muscles, causing muscular atrophy. Atrophy is a medical term that describes the shrinkage of muscles due to inactivity. [5] Individuals with Type II SMA can breathe, swallow, and sit unassisted, but need help to stand or walk. This disorder that affects Nathan is physically challenging, but does not affect his brain function or his intelligence. He, like any eight-year-old boy, would like to be able to engage in physical activities with his family and his friends. Nathan, like other individuals with SMA, has been overcoming his physical limitations with the help of a variety of devices and methods for his entire life.

Benefits of Standing

Mobile standing devices such as the Standing Dani allow individuals with physical limitations to spend time in an upright, standing position while maintaining mobility. Standing is associated with multiple physical and psychological health benefits. Physical health benefits include: improved blood circulation, improved bowel function, increased bone density, reduced muscular spasticity through posture change, and reduced pressure sores. Psychological health benefits include: increased independence, self-esteem, access, and well-being by allowing individuals to stand upright and communicate on the same level with peers. Using mobile standing devices can greatly impact an individual's life, overall improving their quality of life both physically and psychologically. [16]

Products that Nathan Has Used

There are many devices and methods that are used to overcome the challenges of SMA, including striders and the Standing Dani.

Standing Dani

The Standing Dani is a mobile stander for children with disabilities. It allows children who were not previously able to walk or stand on their own to move about autonomously and interact with others while supported in a standing position. Nathan's Standing Dani consists of a base frame, a vertical support, a battery, wheels, support straps and cushions, and a mounted joystick remote. A child stands on the footboard in a slightly forward position. Depending on the child's needs, the Standing Dani has adjustable straps, cushions and supports. A battery powers the rear wheel drive. The front wheels are on casters. The Standing Dani is steered with a joystick that controls the amount of power sent to each of the rear wheels. [1] By standing, children can strengthen the skeletal system, particularly the legs and leg joints, and improve certain bodily processes, including breathing and digestion. [6]

Figure 1. Nathan in his Standing Dani. [12]

The first Standing Dani was created in 1985 by Dan Davis, for his daughter, Danielle, who was born with cerebral palsy. Mechanical engineering professors at Kettering University assisted him with the initial design and fabrication. He formed a company, called DavisMade, Inc., that manufactured and sold the products for decades. While the company was still active, they regularly made design improvements and retrofitted Standing Danis. The company no longer exists or makes the product, however, so counting on the original designers to fix specific issues is not an option. [6]

Nathan's Standing Dani formerly did not have any special features that allow him to play golf properly. He used the front casters to guide a golf ball into the hole. This experience was not satisfying to a young boy full of energy such as Nathan. The existing method did not allow the ball to be hit very far and was not very accurate, which is why it was important to Nathan that a better alternative be developed.

Nathan also likes to play kickball with his family and classmates. Another person would roll the ball to him, and he would accelerate towards it on his Standing Dani. The force from his Standing Dani launches the ball back to the thrower. This is an activity that Nathan, his little brother, his parents, and his classmates all enjoy; however, he has not played kickball in a while out of precaution for his safety. On at least one occasion, the Standing Dani rolled up on top of the ball and almost tipped him over. Ever since, his family has been concerned for his safety while playing kickball, an activity that Nathan loves.

Nathan is not the only Standing Dani owner to have experienced this issue. In 2006, a child suffered from a concussion when a ball rolled up under a Standing Dani and tipped it over. Upon receiving a report of the incident, DavisMade, Inc. provided a wheel guard to prevent it from happening again. [9] Since the company is no longer in business, obtaining the same wheel guards for Nathan is not a viable option. If the Standing Dani were to tip over, Nathan could be seriously injured since the device is very heavy and he would not be able to control the fall. Safety was the main concern for kickball because Nathan would like to continue using his current method of accelerating the Standing Dani forward and using the frame to hit the ball.

At the beginning of this project, another desire for Nathan was to improve his support and comfort in the Standing Dani while leaning back. He currently has enough support while leaning forward, with his chin resting on a chin rest and his body being supported by a brace and vertical column. He is able to operate the Standing Dani with full functionality while leaning forward. However, the design of the Standing Dani does not allow him to lean back. He would be more comfortable if he had the option of leaning his head and body back during class or while standing still in the Dani for a long period of time. He would need a support for his upper back, neck, and head in order to lean back. Another concern is that his head could fall off the chin support when he is leaning forward and accelerating quickly, meaning a head and neck support could also improve the safety of the Standing Dani. During the process of brainstorming solutions for this problem, it was learned that George Leone in the Hangar machine shop had been working on a support for Nathan for several years and was almost done. So this part of the project was dropped in order to focus more effort on the golf and kickball attachments.

Strider

Several projects for Nathan have been worked on in the past by previous mechanical engineering senior project groups, including multiple striders. In 2010, a Strider was created to support Nathan in a standing position to allow physical exercise and better circulation. [8] The final product was strong in both safety and performance, but lacked practicality because it was heavy (60 pounds), it was not foldable, and the spring suspension system did not work as intended. Nathan was not able to propel himself forward in this design because it was too heavy and uncomfortable. The 2010 Strider senior project design is shown in Figure 2 and Figure 3.

Figure 2: Strider senior project from 2010, designed by Eric Johnson, Ricardo Garcia, and Alex Trask. [8]

Figure 3: Nathan using the 2010 Senior Project Strider. [8]

In 2011, another senior project group redesigned the Strider to improve weight, transportability, and comfort. [4] They created a blue-frame device featuring a harness that Nathan straps into and either walks himself or gets pushed by someone else, as seen in Figure 4 and Figure 5.

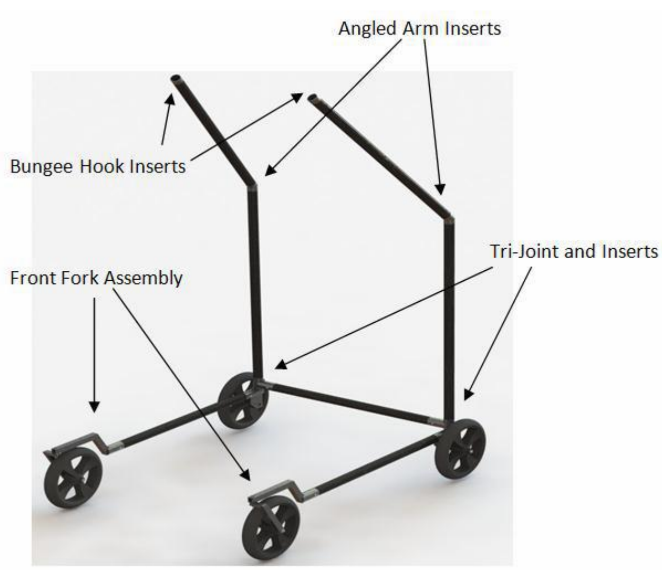


Figure 4: Strider senior project from 2011, redesigned by George Cummings, Brian Kreidle, Ricky Lee, and Clark Steen. [1]

Figure 5: Nathan using the 2011 Senior Project Strider [1]

This design took comfort, weight, and convenience into consideration. They designed a harness suspension for Nathan to ride comfortably while standing, swinging his legs freely, and resting. Previous solutions lacked sufficient shock absorbency, so the suspended harness also helped reduce the tiring effects of bumps and increase the comfort and ease of use for Nathan. In order to accommodate Nathan's parents and other third-party users, the design was made to be easily disassembled with quick-release connections. This feature, along with being lightweight, allowed Nathan's caretakers to easily transport and lift the device while travelling. The team for this project also placed a lot of importance on what they called the "Nathan Factor," which is the human factor that considers Nathan's user experience. The Nathan Factor guided the project to determine the best balance between design features. For example, the previous Strider design had too high of a safety factor that the made the device too heavy to be used autonomously by Nathan. This partially inhibited the main purpose of the design. The 2011 Strider design was able to balance function and safety. However, his family pointed out that this Strider design was still too big to fit in their car. The 2011 Strider is no longer in use since the Coopers were able to get a motor-controlled Standing Dani for Nathan.

Other Similar Products

Besides the products that Nathan has tried, there are other existing devices that could be relevant to the solution. There is not a single device that fully accomplished all of our goals, so we broke down the functions to find products or devices that were relevant to certain functions.

Golf

Paramobile

The first function that we found similar existing products is playing golf. The most common way of playing golf, even for those with limited mobility, is by using a golf club. There are a number of products that allow people with disabilities to use a standard golf club. One example of these products is the Paramobile. [13] The Paramobile allows people with limited use of their legs to move around a golf course, move into a standing position, and swing a club with their arms. This device though, as well as other similar devices, are not practical for an individual who does not have the arm strength to swing a golf club unassisted.

Figure 6: Paramobile in action. [13]

Universal Play Frame

The Universal Play Frame (UPF), an adaptive device created by Cal Poly engineering students, includes a function that allows users without the strength or dexterity to swing a club to play golf. The UPF is a device that allows people in wheelchairs to participate in various sports and activities. It is a frame that sits in front of the user and includes slots for mounting a number of attachments. One of these attachments is a golf attachment. The golf attachment has clamps that hold an actual golf club. The club is controlled by a wheel that the user turns to pull the club back to a desired position. A ratchet and pawls keep the club in place while the user is turning the wheel. When the user wants to release the club and allow it to hit the ball, he or she simply pulls the wheels out, releasing the club. The UPF golf attachment is designed to be used by someone in a wheelchair. Nathan wants to play in his Standing Dani, so in order to use the golf attachment, an entire new frame would need to be constructed. Also, Nathan would not be able to turn or pull the wheel hard enough to operate the golf attachment. While the design overall is not suitable for Nathan's needs, we did consider aspects of the UPF golf attachment design. [2]

Figure 7: Universal Play Frame VI with a wheelchair. [1]

Figure 8: Computer model of the Universal Play Frame golf attachment. [2]

A second device that assists in hitting a golf ball was designed by Michigan Tech students in 2008. This device is powered by a pneumatic cylinder and a linear spring. The system is controlled by a joystick and button. When the joystick is pulled back, the cylinder is pressurized, compressing the spring. When the button is pushed, the energy stored in the spring turns a set of gears which in turn swing the club. This system is easy to use, and with the right joystick and button could be adapted for Nathan to use. The problem with using this system, being housed in a standard golf bag, is that it is relatively large. This is impractical because in order to implement this system for Nathan, someone else would need to be with him to transport, set up, and position the device before each swing. [15]

Iron Byron

Golf ball and golf club manufacturers use different mechanical golf club swingers to test equipment. The most notable of these devices is the “Iron Byron” used by the United States Golf Association. All of these testing devices are much more expensive than our device needs to be. The “Iron Byron” cost $250,000 to build in 1963. Also, because they are meant to testing with and not playing with, they are rather large and not easily portable. [17]

Figure 9: "Iron Byron" golf club and ball tester. [17]

Kickball

In researching things that could make kickball safer, we focused on the safety more than the function. It was clearly communicated to us that what we are designing should make the existing function safer, but should not interfere with the way that he currently hits a ball. As such, things that could make his current method safer are potentially relevant, while new ways for him to propel a kickball are not relevant.

One way to stop the ball from rolling under Nathan's Standing Dani would be to add guards or bumpers. Some current devices that employ guards or bumpers include go-karts and bumper cars. The bumpers on these vehicles are mainly to keep the vehicles from being damaged when they collide with barriers or other vehicles, but a similar system of guards could also function to keep a ball from rolling under the Standing Dani. Adding some form of bumper to keep the ball from rolling under the Standing Dani is a concept that we seriously considered in our design.

Figure 10: Go-kart with a bumper. [7]

One very specific instance of a guard being used for safety on a Standing Dani is documented in an FDA adverse event report. After a child in a Standing Dani rolled up onto a ball and tipped over, the inventor of the Standing Dani provided and installed a "wheel guard". This device could potentially be very relevant to our project, but the event report does not contain and specific information about the guard and the company that created and produced Standing Dani and the guard is no longer in business.

Why Nathan Needed a New Product

No existing systems have harnessed the movement and power of an existing motored device to hit a golf ball. All other golf systems that can be operated by a person with a disability include a separate control system. There are a few non-golf systems, though, which behave similarly and do not require a separate set of controls. Some of these systems are the ones used in wheelchair soccer. Wheelchair soccer is a common activity in which wheelchairs with special guards are used to hit a ball and try to score goals. Bumpers to use for this sport vary in size, shape, and material and are readily available. [10] The similarities are obviously that a powered vehicle is used to propel a ball with some amount of precision. Some differences between this and our application are that the bumpers are used on a wheelchair instead of a Standing Dani and the bumpers are partially to protect against collisions with other wheelchairs, which is not part of our design. Also, the minimum ground clearance needed to hit a golf ball is much less than the minimum clearance to hit a soccer ball and soccer aim does not need to be as precise as golf aim.

For the kickball function, the only direct competitor is the wheel guard designed by the creators of the Standing Dani. The wheel guard is mentioned in the previous section, but is not a viable option because the company no longer exists and there are no specific details about the design. The wheelchair soccer bumper concept is also partially relevant to the kickball idea. This idea also uses the power created by the vehicle in motion to propel a ball, and the bumpers protect the vehicle and the user. One main difference is that it has been specifically requested that we leave the front area in the same configuration that allows Nathan to trap and control the ball in the area between the wheels, while the wheelchair soccer bumpers are convex and do not have an area in which to control a ball.

Golf is a very precise sport. The standard testing regime includes procedures for testing numerous components of all balls and clubs. [14] This collection of test procedures is not directly relevant to our testing process, but it does show that the precision of the system is extremely important. Because of this, we kept the controllability and user friendliness in mind during the design phase.

Chapter 3 - Objectives

Problem Statement

Nathan is a young boy who enjoys playing outside. He desires to play games and sports with his friends and family, but with his physical condition and the limitations of his Standing Dani device, he is unable to participate as much as he would like to. He also needs additional support for his head and back while in the Standing Dani. Nathan plays kickball with his friends and formerly it was not a safe operation for him because there had been previous issues where a ball had gotten stuck under his Standing Dani and almost resulted in him falling over in it. Nathan and his grandfather like to play golf together, but Nathan had no means of hitting a golf ball effectively.

- After the first stage of design, we were notified that George Leone and the machine shops had been working for several years on a support/seat design to enhance Nathan's comfort in the Standing Dani and that their device would soon be finished and implemented. As such, our goal changed to no longer include the head and back support.

Goals

The goal of our team was to design and build an apparatus that can increase Nathan's involvement and accessibility in playing outdoor activities. To address the problem detailed in the problem statement, our team set out to build potentially several contraptions that will allow Nathan to play golf and kickball more effectively than he is currently able to, as well as an attachment that will improve his comfort and stability while operating his Standing Dani. To address the safety concerns, one of our goals was to allow Nathan to still play kickball but to prevent him from rolling over a ball and tipping over. To allow him to participate in playing golf with his grandfather and others, we intended to build an attachment that will assist Nathan with hitting a ball, giving him confidence and allowing him to practice hitting the ball by himself.

Customer Requirements

Below is a list of the customer requirements laid out by our sponsor.

- Safe
- Small
- Light weight
- Low cost
- Hands-free operation
- Devices do not cause discomfort
- Visibility not compromised
- Easy to assemble
- Reliable
- Repeatedly hit a golf ball
- Kick a ball safely

Our team translated these requirements and any specifics given by Nathan's parents Amy and Bob into measurable engineering specifications to be met throughout the design and development phase of this project.

Quality Function Deployment (QFD)

With these customer requirements, our team applied the Quality Function Deployment (QFD) method and constructed a House of Quality. We produced engineering specifications to meet these requirements, as seen in the next section. Using the methods provided, which are based off of industry practices, we quantified customer requirements to help us understand the problem. The House of Quality, presented in Appendix A, compares the who, what, and how of each customer requirement, engineering specification, and verifiable testing method. The far left Customer Requirements column lists the customer's needs and requirements, such as "safe" and "small." The middle top column lists the measurable specifications, which are detailed in the next section, such as "less than 25 lbs." These specifications allowed us to quantify and measure how well the design satisfies the customer requirements. There are also columns to rank the importance of each requirement, since some are more crucial than others. For example, safety is our most important requirement since our design will be used by 8-year-old Nathan. In contrast, the effect of our design on the speed of the Standing Dani is less important because it does not fully inhibit any functionality or put anyone in danger.

Engineering Specifications

Though our project was seemingly very open-ended in approach and solution development, we were able to provide several specifications that could be tested or verified. Below is a table summary of our engineering specifications and the tests that can be used to verify them. Compliance describes how each design requirement will be verified, whether through analysis (A), testing (T), similarity to existing designs (S), and/or inspection (I). Risk is a measure of how critical each specification is to be met in order to properly address the goals and problem statement. The risk of each specification is judged as either high (H), medium (M), or low (L).

Table 1: Engineering Specifications

Spec #	Parameter	Requirements & Target	Tolerance	Risk	Compliance
1	Safety	Does not tip @ 5° incline	Max	L	T, A
2	Size	2'x2'x2'	Max	L	I
3	Weight	25 lbs	Max	M	T
4	Cost	$2000	Max	L	A
5	Hands-free use	Only use existing Standing Dani controls	Max	L	I
6	Assembly	10 steps or less	Max	M	T, I
7	Impact testing	Deformation does not inhibit ability to function	Max	L	A, T
8	Visibility	Putter face 6" in front of frame	Min	M	T, I
9	Accuracy/ Precision	Golf ball trajectory within 60° range 90% of time	±30° Min %	H	T, I
10	Safety ground clearance	2.5 in	+/- 1.5 in	M	T, I
11	In-use putter clearance	1.0 in	+/- .5 in	M	T,I

The following are detailed descriptions of each of the specification in Table 1:

1 – The Standing Dani must be able to operate at 5 degree incline with no tipping occurring when devices are attached.
2 – The prototype(s) must fit into Amy's mini-van for travel. Currently a considerate amount of space is provided.
3 – Due to combined weight of Nathan and Standing Dani (and its stability), 25 lbs inherently (depending on location of force line of action) is not a major concern, but the attachments cannot be too heavy for Nathan's family or friends to assemble/attach.
4 – Funds are limited to $2000, so we must budget accordingly.
5 – Hands-free operation is safer for Nathan because he does not the strength to manually operate another device in conjunction with the Standing Dani joystick. This requirement does not allow any input from Nathan besides the current controls for the Standing Dani.
6 – Since Nathan's family or friends (school, etc.) will be assembling and attaching devices to Standing Dani, they cannot take too long or be too difficult to assemble.
7 – The device will undergo a drop test to check for durability. FEA modeling along with design analysis and safety factors will be implemented prior to testing to ensure prototype does not fail during testing, yet attain reasonable results.
8 – Visibility for safety is not of great concern but for functional purposes, Nathan needs to be able to see the ball(s) that he is hitting/ impacting.
9 – Once struck, the golf ball must land within a 60° sweep angle, ± 30 degrees relative to centerline of impact. Multiple tests will be performed and the golf ball must land in this designated range at least 90% of the time.
10 – If the attachments are too low, they can get caught on the ground (especially if incline/decline is present), or a ball/object can get stuck underneath attachments if they are too high and cause the Standing Dani to tip over. This is a high priority for safety.
11 – If the putter face is too low, it can cause similar problems. If it is too high it will not contact a golf ball. Having the putter face at the correct height is important for device functionality.

Chapter 4 - Design Development

Idea Generation

The first step that was taken towards finding the best solution that satisfied the specifications was to generate ideas. First, we broke the solution down into three functions: golf, kickball, and comfort attachment. We used brain writing, brainstorming, and action verb categories as brainstorming techniques. During brain writing, we chose a function and each wrote as many ideas as possible in our notebooks for 2 or 3 minutes, then passed our notebooks to the next person to see what we wrote and continue writing for another few minutes. For brainstorming, we wrote a function on the whiteboard, such as "advance a kickball", timed ourselves to 15 minutes, and then wrote single ideas of how to move a kickball on sticky notes to paste on the board. The technique of action verb categories is similar to brainstorming, except we wrote a specific action verb, such as "swinging", and then used sticky notes to capture all ideas for things that swing. Altogether we came up with 200 ideas for each function, although many of the ideas were clearly not feasible.

- Although we brainstormed and narrowed down several ideas for the back and neck support, these were dropped when the project scope was modified. After generating the first set of Pugh matrices, we met with the Coopers and shared some of our concepts to get an idea of what works for Nathan. We learned that another group has been working on the back and neck support, so that has been dropped from our project scope. We also learned that the kickball attachment should only focus on the safety of preventing a ball from rolling underneath the Standing Dani frame, since Nathan enjoys using his front casters to hit the kickball and would like to keep the same functionality. It was also confirmed that a manually-controlled golf club would be too difficult for Nathan to enjoy, hence the hands-free operation requirement.

Figure 11: Function brainstorming technique using sticky notes and a whiteboard.

Idea Selection

We began the next phase of development by eliminating all of the ideas that were not feasible. This left us with 9 ideas for kickball and 12 ideas for golf. Pugh matrices were created for both kickball and golf, as seen in Appendix B in Table 9 and Table 10. The kickball concept was chosen after the Pugh matrix was created and after discussion with the Coopers. The Pugh matrix helped guide discussion that generated a new golf attachment idea and eliminated the weaker ones, resulting in the top 4 golf concepts. To evaluate these top 4 golf concepts, a weighted decision matrix was created (Appendix B, Table 12). A pairwise comparison matrix, in which criteria importance is judged against each other in order to determine weight factors, was also created and is shown in Table 11 in Appendix B.

Preliminary Design

At the end of fall 2014, we presented our preliminary design to the Coopers. The following information describes our preliminary design and the analysis we performed. After this preliminary design, our design was modified and refined and is discussed in the Final Design section.

Preliminary Design Discussion

Kickball Attachment

After visiting the Coopers and discussing the new direction for the kickball portion of the project, we brainstormed ideas that catered to these new requirements. Since the scope of possible solutions significantly narrowed, there was one main concept that clearly addressed the issue of safety without interfering with Nathan's current preferred method of playing kickball. The top concept was protective guards that would prevent balls from rolling under and getting stuck between the ground and his Dani, yet would have enough ground clearance for him to drive over small objects and slight inclines. The guards would be attached to the base frame of the Standing Dani and could be removed easily in case they interfere with anything. To allow Nathan the option of playing both golf and kickball at the same time, the guards were designed to not interfere with the golf attachment when both are attached to the Dani. One possible method to attach the guards is to use Velcro through holes drilled in the guard material and around the Standing Dani frame. Other solutions to this were considered after more testing and discussion with Nathan's family. We updated the Pugh matrix that was created before the requirements changed with four new ideas, as seen in Appendix B. To choose our final concept, we focused on these four ideas from the Pugh matrix:

- Rigid metal bars
- Rigid guard plates
- Flexible guard plates
- Mud flaps

The two rigid material ideas were ruled out because they may be too stiff to allow small objects like rocks to pass under them and cause the Standing Dani to get stuck and potentially tip over. The mud flap idea, such as the rubber flaps on the back of semi-truck tires, would allow for Nathan to drive over small objects and have ground clearance for rougher terrain, but they would not be stiff enough to prevent larger balls from getting stuck in the frame of the Standing Dani. Our final concept was to attach flexible, maybe plastic, guards to the Standing Dani to provide the needed safety features and still be practical for rolling over rocks and other terrain. We also considered the possibility of combining the rubber flaps and the plastic guards as a multifunctional guard that would stop larger balls, yet also be flexible enough to allow Nathan to drive over small ground objects as needed and handle variations in the ground structure. A sketch of our kickball attachment concept is shown below in Figure 12.

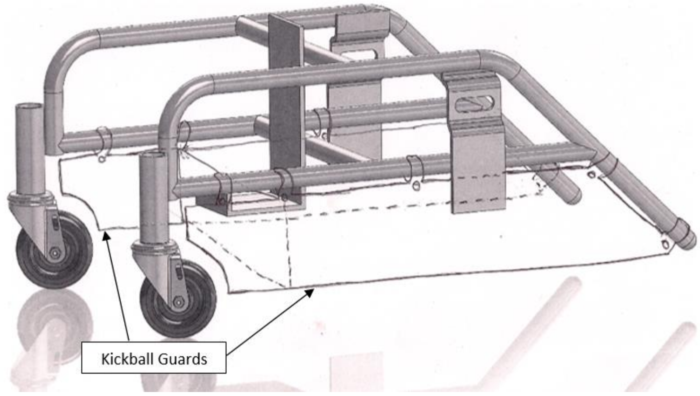


Figure 12: Kickball attachment concept.

The material and dimensions of the guards were not decided at this point in the design process beyond the fact that they would be made of some type of plastic or flexible composite material. In order to validate the usefulness of the guards, we will construct a test frame of the Standing Dani and test the guards. The test frame would allow us to gather data without needing Nathan and also to ensure his safety against untested products. No preliminary analysis for the guards was performed and was not considered needed at the time.

Golf Attachment

As a result of discussion from the Pugh matrix, a new idea was formed and the golf attachment was narrowed down to the top four concepts, which are described on the next page.

	Weight Factor	Wheels on Both Ends		Wheel Inside Hollow Putter		Ball Bearing Axle and Round Corner with Wheel		Fixed putter head with end shaft bearings and spring box with wheel		Scale 0-3
Safe	8	1	8	1	8	2	16	3	24	
Small	3	1	3	1	3	2	6	2	6	
Light weight	2	2	4	2	4	3	6	2	4	
Low Cost	1	3	3	3	3	2	2	1	1	
Easy to Operate	7	2	14	2	14	2	14	2	14	
Easy to Assemble	4	2	8	1	4	2	8	2	8	
Reliable	5	1	5	1	5	2	10	3	15	
Avoids Interference	6	1	6	1	6	2	12	2	12	
∑			51		47		74		84	

Figure 13. Decision matrix for golf attachment concept.

The top concepts were evaluated with a weighted decision matrix, shown in Figure 13 above. Higher priority was given to safety, ease of operation, and interference avoidance because these directly relate to Nathan's safety and abilities. Reliability was also important because the design needs to be robust enough to withstand a speedy 8-year-old, the possibility of impact, and various ground conditions. Cost, weight, and size of the attachment had lower weight factors because they are more flexible requirements. The final decision matrix showed two clear winning concepts that we discussed and decided to combine into one top concept.

Our top four concepts are listed below.

1. Wheels on Both Ends: A putter head rigidly attached to a shaft would be clamped to the Standing Dani frame. To support the weight and to handle ground terrain, wheels would be placed on each end of the putter.

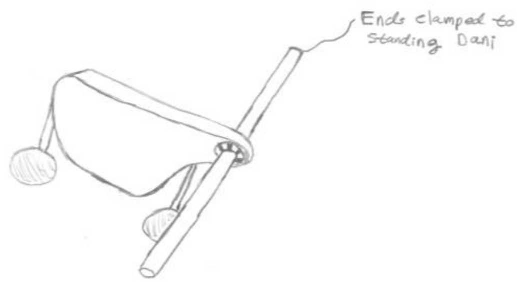


Figure 14: Concept with two wheels on putter and shaft clamped to Standing Dani.

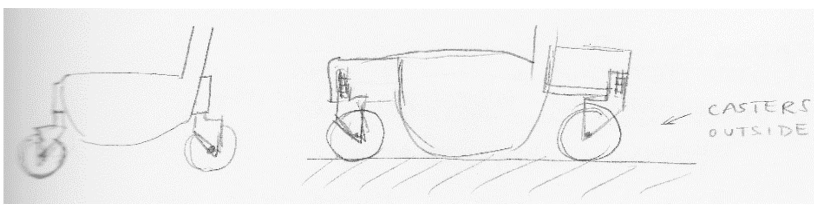


Figure 15: Putter with a wheel on each end.

2. Wheel inside Hollow Putter: The putter would take the shape of the larger rounded golf putters, but the bottom would be shelled out to create space for a wheel to be attached inside. The putter head would be attached rigidly to the shaft, which would rotate and be temporarily attached to the Standing Dani.

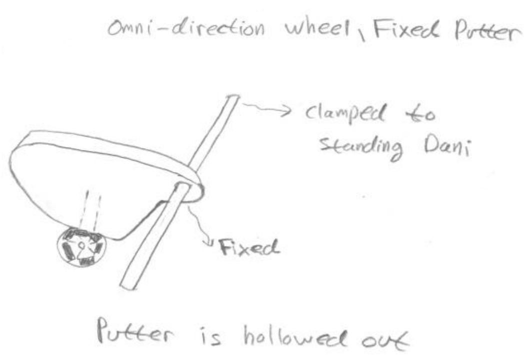


Figure 16: Concept with wheel inside hollow putter and shaft clamped to Standing Dani.

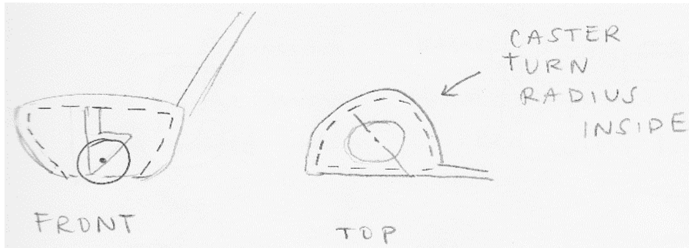


Figure 17: Hollow putter head with wheel inside.

3. Ball Bearing Axle and Round Corner with Wheel: The putter has a curved profile in the front so if it hits a sidewalk or obstacle, the putter will curve up and flip out of the way. The wheel helps the putter roll back and forth while Nathan drives the Dani, and also side to side when he puts the ball. In this concept, the shaft does not rotate. Instead, the putter connects to the shaft with a ball bearing to allow the putter head to rotate upwards during potential impact with a door or wall. This would help prevent breakage of the device and the Dani getting caught and tipping over.

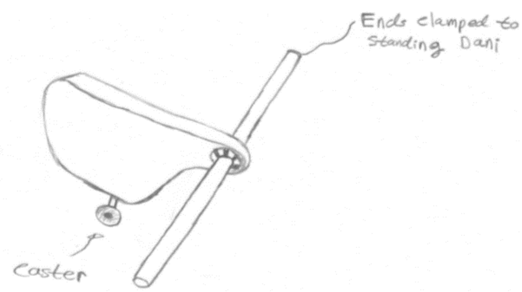


Figure 18: Ball bearing concept with curved putter geometry.

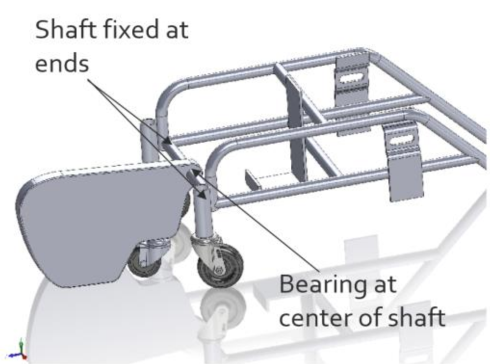


Figure 19: SolidWorks model of ball bearing concept.

4. Fixed Putter Head with End Shaft Bearings and Spring Box with Wheel: The putter has one wheel and is rigidly attached to the shaft. Each of the shaft ends have bearings and a shock-absorbing spring-damper system that is placed in a protective housing that will be attached to the Standing Dani but can be removed. The spring-damper box will be semi-permanently attached to the Dani, and the shaft and putter will be easily removable between the two boxes.

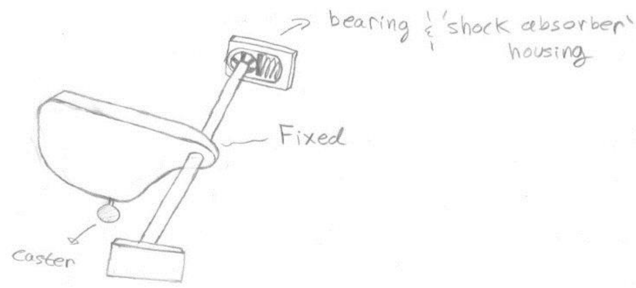


Figure 20: Concept with bearing and spring inside a housing at each end of shaft.

For the top four concepts, the term "wheels" is generic because we could not decide on the best kind of wheel and wanted to focus the comparison on the mechanism, not the type of wheel. We considered casters, omni-directional wheels, and spherical ball transfers. We planned to buy and test samples of these wheels to determine which one is the best option for Nathan.

Figure 21: Caster wheel from McMaster-Carr. [18]

Figure 22: Omni-directional wheel used on VEX robots. [20]

Figure 23: Ball transfer wheels. [19]

Concepts 3 and 4 were the top two designs from the weighted decision matrix. The first two concepts were not as safe or reliable, which were weighted heavily and counted against them. Ultimately, we decided to pursue Concept 4, the spring-damper box design, because it most effectively protects the device and Nathan against hard impacts and allows for a modular design that simplifies assembly and interchangeability.

Golf Attachment Preliminary Design

Our top concept was the spring-damper box that would have been semi-permanently attached to the Standing Dani base with a detachable putter and shaft. A model of this top preliminary design concept installed in a mock-up Standing Dani base frame is shown below in Figure 24.

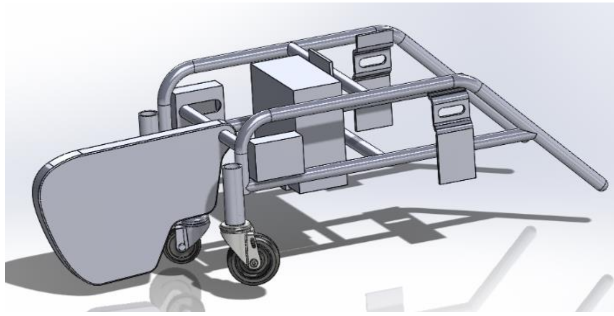


Figure 24: SolidWorks model of our top golf attachment concept.

How It Meets the Requirements

In this preliminary design, the putter and shaft would rotate together upon impact. Placing the bearings at the ends is more advantageous because they would be more stable. Since assembling shafts and bearings together is difficult, we would have only wanted to do that once. The bearings at the ends would have had small permanent stubs that the main axle would attach to, making assembly and disassembly a lot easier. This concept met the engineering specifications in the following ways:

1. Safety: The location of the center of gravity for the device would not cause a stability imbalance large enough to cause tipping before the Dani itself would already tip.
2. Size: The size would be much smaller than 2' x 2' x 2'.
3. Weight: Given the materials and dimensions most likely to be used, weight was not an issue.
4. Cost: Rough estimates of the cost for one of these prototypes were around $700.
5. Hands-free use: This design would not require Nathan to output any additional force along with his current Standing Dani controls.
6. Assembly: The assembly had less than 10 assembly steps.
7. Impact Testing: This would be verified with testing.
8. Visibility: We would design the putter to be visible 6" in front of the Standing Dani.
9. Accuracy/Precision: This would be verified with testing.
10. Safety ground clearance: The putter geometry would determine the ground clearance.
11. In-use putter clearance: The putter geometry and wheel diameter would determine the ground clearance.

- An additional design consideration was added to the project after the preliminary design. We were informed that a different Standing Dani base might be used in the future and that our design should work for both bases. The newer base adds functionality to the Standing Dani, but for the purposes of our project it operates identically to the existing base. The only difference to our project was that the bases have slightly different dimensions. The new base has smaller diameter tubing on the frame, and the width of the base is about one inch smaller than the existing base width. These dimensions affect the length of the shaft across the front of the Standing Dani and the size of the attachment mechanism of the golf and kickball attachments to the frame. These small dimensional changes do not affect the preliminary design in any way, but they will be considered in the final design when detailed dimensions are added to the design.

Preliminary Load Analysis

Preliminary load analysis was performed with our top concept. Two cases were considered as loading conditions for safety concerns: (1) impact between the putter and the ball during swinging, and (2) direct impact on the front of the putter head from potential collision with a curb, door, or wall. The detailed steps taken for the analysis can be found in Appendix C.1. For case (1), a safety factor of 3 was assumed, from which the max allowable force was found to be 147 lbs. For case (2), a safety factor of 4 was assumed, making the max allowable force to be 283 lbs. Both forces seem to be large enough that there is not a concern for yielding of the attachment, especially with safety factors of 3 and 4, respectively.

Components

Our preliminary design featured a spring-damper and bearing system enclosed in a box that would have been attached to the Dani frame. Due to potentially high axial loads, roller tapered bearings would have been desired. If it was determined that the thrust loads were not too large, then regular roller bearings or bushings would have been used. If bearings were to be used, we would have considered manufacturers such as SKF and Timken. The dampers, springs, and shock absorbers could have been purchased from McMaster-Carr. If dampers or shock absorbers were to be used, then the effective energy capacity would have been determined in order to properly select these components from the manufacturer. The shaft would have potentially been made of 6061 hollow aluminum tubes and purchased directly from McMaster-Carr. The material of the putter was still tentative, but aluminum and plastic were considered as the most feasible options. All remaining fasteners and hardware would have been purchased from hardware stores or online. Since most of these parts were fairly standard, we did not expect any lag time for ordering parts. Any machining would be performed by either members of our team or by a shop technician at Mustang 60 or the Hangar.

- After presenting our preliminary design to the class and to our sponsor, we received valuable suggestions and feedback to improve our design. First, many of the parts in this design would have had to be custom made. We were challenged to redesign our attachments to be mostly store-bought with as few manufacturing modifications as possible. This would improve the reproducibility and maintenance of our device in case a part broke or Nathan needed a new one. Also, other people with Standing Danis would be able to recreate our product without heavy customization costs. Second, the shape of the putter was very bulky and unattractive. Third, the bearings and spring-damper system seemed to be over-designed for this application. Nathan’s mother Amy assured us that Nathan is a reliable driver of his Standing Dani and there was little to no chance that he would run into something. We took all of these suggestions into consideration and redesigned our product to become the Final Design below.

Chapter 5 - Final Design

Our final design for both the golf attachment and the kickball guards is shown in green below in Figure 25, installed on a Standing Dani. In this section, we will describe the functions of our two main products, the analysis and calculations we performed to verify that our design is safe, the materials we chose for each component, how we planned to make each component, and how the final design assembles together.

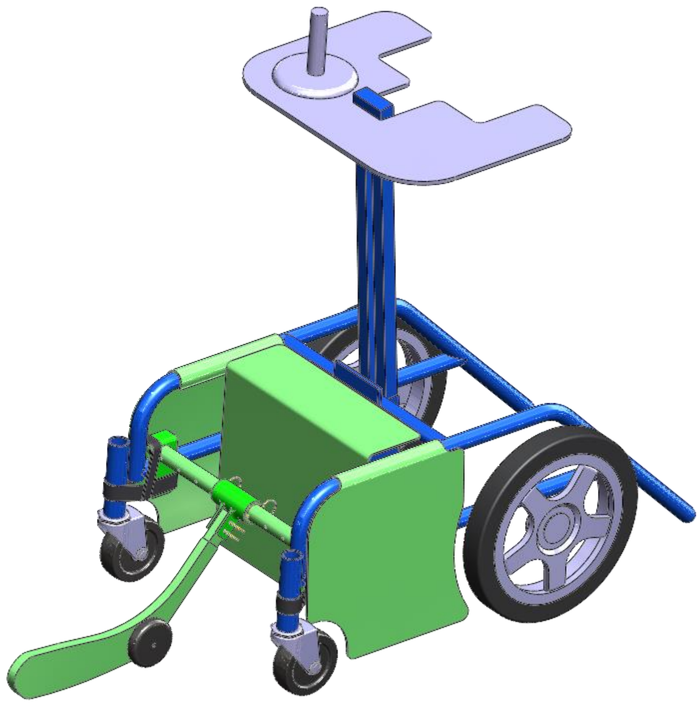


Figure 25. Final design for golf attachment and kickball guards is shown in green.

Functional Description

The final design consists of two products for Nathan: kickball guards and a golf attachment. Below, we describe how these products work. Further details regarding analysis and specific component selection and manufacturing can be found in the next sections.

Kickball Guards

The guards clip onto both sides of the Standing Dani frame and in front of the battery in order to close off any large gaps that balls could get stuck under. Nathan's family was concerned that balls would roll up and get stuck underneath the frame and possibly cause Nathan and the Standing Dani to tip over. The kickball guards, seen below in Figure 26, block off the vulnerable open spaces between the ground and the frame where balls could get stuck, specifically targeting the sides in front of the wheels and underneath the battery. The guards are formed to snap onto the top bar of the frame and can also be strapped onto the middle bar with Velcro straps. The guards are formed using tubes that are smaller than the existing Standing Dani tubes so that they fit tightly over the top bars while also fitting onto the smaller bars of the new Standing Dani base that may be used in the future. These attachment features make it very easy for someone such as Nathan's parents or his little brother to attach and detach the guards when Nathan wants to play.

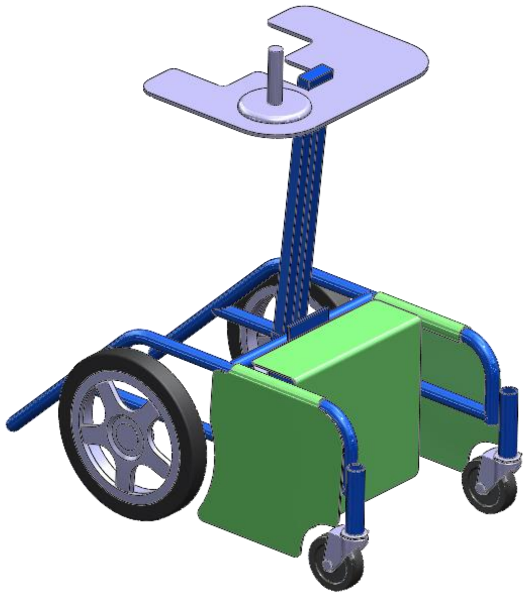


Figure 26. Kickball guards, in green, installed on a Standing Dani.

Golf Attachment

The golf attachment is essentially a hockey blade attached to a bar that is strapped onto the front of the Standing Dani, as displayed in Figure 27.

Figure 27. Golf attachment, shown in green, installed on a Standing Dani.

The golf putter is a junior-sized replacement hockey blade instead of an actual golf club or the hunk of metal that was our preliminary putter design. A golf club would have needed to be cut down to size and it would have been difficult to add a wheel. The replacement hockey blade already has a short stem and there are many different types that can be purchased from sporting goods stores. Since the hockey blade is made of either composites or wood, it is much easier to drill a hole and add wheels. The wheels attached to the putter allows for ground clearance to roll over rocks or uneven surfaces. Specifically, the wheel is an omni-directional wheel that moves both forward-and-back and side-to-side without the turning radius of a caster. The hockey blade putter is connected perpendicularly to the main shaft of our design with a metal T-joint. The T-joint has a plastic bushing inside that allows free rotation about the main shaft, which is static. The putter would need to rotate upwards when it rolls over bumps or to avoid high impact during a collision. The T-joint is held in place with pins on either side so that it cannot slide along the main shaft. To give the Nathan the option of adjustability, holes are drilled along the main shaft so that the putter can be relocated to whatever location is most convenient for him. The user would simply have to pull the pins out, slide the putter to the desired location, and put the pins back in.

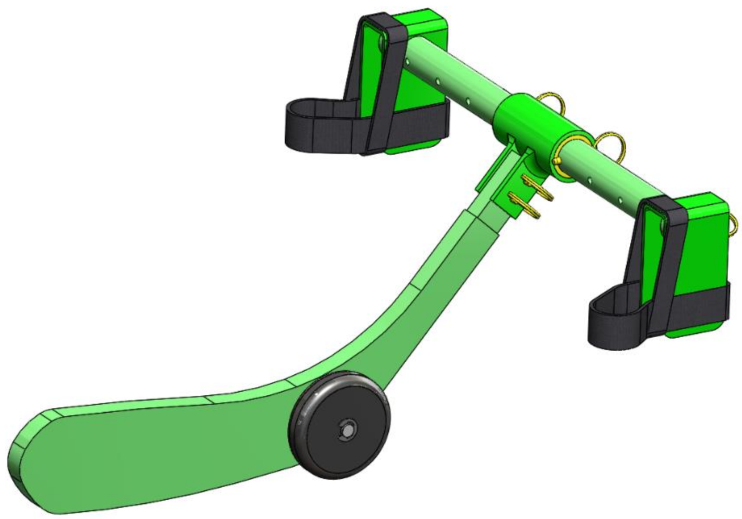


Figure 28. Full golf attachment with hockey blade, wheel, T-joint, plastic bushing, main shaft, pins, U-brackets, and Velcro straps.

The main shaft connects to the Standing Dani frame using U-brackets and Velcro straps. The ends of the main shaft are connected to two U-brackets: one welded and one pinned in place. The one end is welded for rigidity and to keep the two components together for assembly. The other end is pinned in place to allow removal of the U-bracket in case the T-joint needs to be replaced, but also keeps the shaft and U-bracket together for assembly. In addition, the pin that holds one U-bracket in place will be placed close enough to the end of the shaft so that the U-bracket can slide over an inch along the shaft. This allows the effective width of the attachment to change to match either base that could be used in the future. Keeping the whole golf attachment held together with welds and pins makes attaching the device to the Standing Dani very easy and simple. The whole attachment gets placed onto the Standing Dani as one piece, and is then strapped to the frame with Velcro straps. Two Velcro straps are riveted to each U-bracket and prevent the attachment from sliding back and forth and from rotating around the shaft. The device will need to be attached to the Dani by someone helping Nathan, such as his parents or his little brother. To play golf, Nathan will operate his Standing Dani as usual to rotate and hit a golf ball on the ground. He will likely have to practice playing golf with this new method in order to master aim and force of hitting the ball. According to the Kinesiology department, this will be a good challenge for him. The complete golf attachment by itself is shown in Figure 28 above.

Analysis

Engineering analysis was performed to determine kickball guard deflection from impact, stresses and deformations on the golf attachment from two different loading cases, and weld sizes. This analysis was simplified when the bearings and spring-damper system from the preliminary design was dropped. Before, we were concerned that Nathan might accidentally drive into a curb edge or door. After talking with Nathan's mom, this was no longer a concern because Nathan is a good driver and the spring-damper system would have been greatly overdesigned for this application. With these simplifications, we modified our concept and defined the components of our system for analysis and design verification.

Kickball Guards Analysis

The guards essentially act as a cantilever beam with a distributed load being applied from the kickball as it hits the guards. The guard rests tangent against the center of the bottom bar of the Dani frame, which was treated as the fixed end of the guard cantilever and is approximately 7.5 inches above the ground. The diameter of a size 4 ball is 8.25 inches. With a desired ground clearance of 1.5 inches for the guards, the ball's line of center of mass will impact at around 3.375 inches from the free end of the cantilever beam. Although the force is actually distributed across a small localized area on the beam, a concentrated point load was assumed as a pseudo safety factor (SF) and the effective cantilever length was increased from 3.375 to 4 inches during analysis. To find the force that the ball applied to the guard as a cantilever beam, Newton's Second Law was used in Impulse-Momentum form. The changes in velocity and the time increments in which they occurred in were chosen to be conservative for this analysis. The assumed change in velocity of the ball from impact was 35 mph while the smallest time step that was assumed for this change to occur was .05 seconds (or 50 milliseconds). The velocity change is high, but certainly probable, in the case of a stray soccer ball or a hard throw by a fellow student. Since the 50ms time interval is highly improbable, it is reasonable to conclude that the beam will not fail in real life under the latter conditions and assumptions. Testing will be performed to verify their design and durability; details can be found below in the Testing section of this report. A sheet of ABS plastic was purchased and will be tested to ensure its practicality as a material for the final kickball guards.

The results listed below in Table 2 were performed in MATLAB using *for*-loops to iterate through an array of assumed time intervals to calculate the force from the ball, then calculate the bending stress and tip deflection of the beam for each force in the array. The maximum force was found to be 31 lbs, which resulted in a maximum stress of 1984 psi and a tip deflection of 1.7 inches. By only reaching 64% of yield stress, S_y, the stress is not a big concern. The deflection seemed high so we performed a quick bend test to approximate the 1.7 inch deflection and saw that the material was flexible enough to handle the deflection and not crack or yield. Detailed calculations are shown in Appendix C.2.

Table 2. Results of calculations for guards under impact, assuming cantilever behavior.

Maximum Force (lbs)	Cantilever Length (inches)	Maximum Stress (psi)	Tip Deflection (in)	Percent of S_y Reached (%)
31	4	1984	1.7	64

Golf Attachment Analysis

The attached putting device is assumed to have two different loading conditions, as shown in Figure 29: Case One (C1) of putting, and Case Two (C2) of direct impact. Normal forces from the ground were neglected due to the fact that the T-joint is free to rotate about the shaft so if a large enough normal force from the ground occurred then the hockey stick would rotate upwards and then fall back down. As mentioned before, Nathan's parents did not have any concerns with Nathan's driving ability so normal forces from the ground are neglected. Although the direct impact loading case is similar to potential normal force loads, the potential forces that would occur for direct impact are larger and more concerning than the normal force loading from the ground. If the components can survive the direct impact loading case for both stress and deflection, then they are assumed to be able to withstand normal loading.

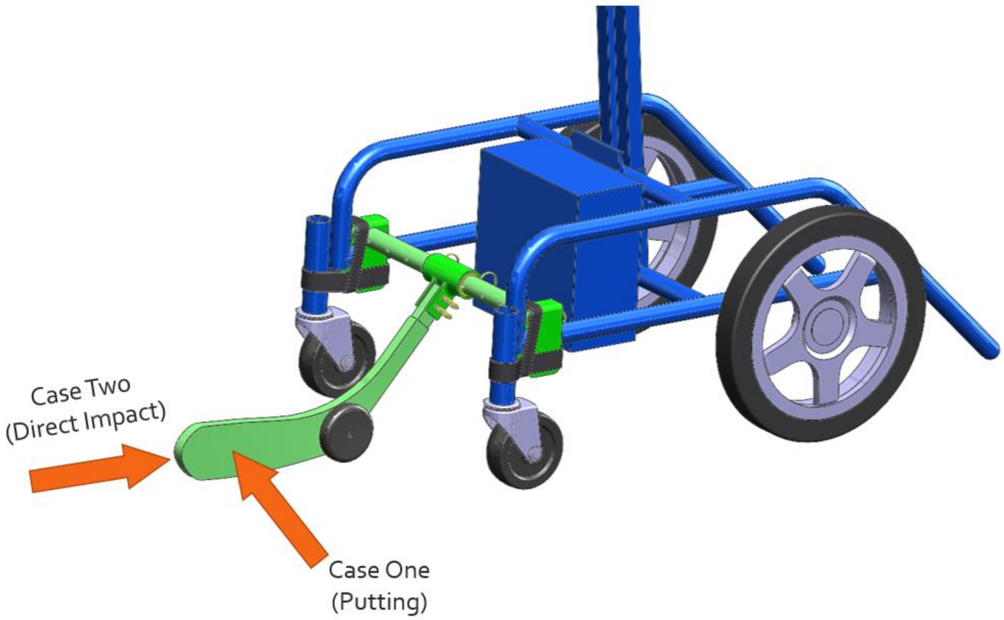


Figure 29. Two load cases for golf putter analysis.

For C1 loading (putting), the force from the golf ball is applied perpendicularly to the putter surface due to the changes in momentum of the golf ball as Nathan hits it. This will create a moment about the shaft as well as the welds that are holding the aluminum plates to the aluminum tube in the T-joint. In order to find the forces, Newton's Second Law was used again to estimate a range of forces exerted on the putter from the golf ball upon contact for a 70 ft/s change in velocity (approximately 50 mph) during a time interval of 5ms-20ms. The assumed change in velocity is very large relative to what will actually occur as Nathan hits the golf ball. As for the time interval, it is highly unlikely that the golf ball's momentum will change from rest to any speed in only 5 milliseconds, let alone a change of 50 mph. Nonetheless, we want to be very conservative with our design so it does not fail and, more importantly, for Nathan's safety. The largest force used for calculations was approximately 3 times the largest force found from the Impulse-Momentum analysis as another safety factor. For the shaft, principal stresses (bending and axial) and shaft deflections were calculated at each force in the force array. An *if*-statement was established in the *for*-loop in MATLAB to call out when a particular force in the array caused yielding, followed by the corresponding force and stress at that yielding point. The results of interest from MATLAB are given below. Complete analysis can be found in Appendix C.3.

Table 3. MATLAB results for C1 loading.

Maximum Force (lbs)	Maximum Principal Stress (psi)	Tip deflection (in)	Percent of S_y Reached (%)
120	1984	1.54	56.7

The welds on the T-joint have to be sized in order to handle the bending stress and transverse (direct) shear stress acted on them by the putting loads. In order to calculate the size of the weld, an adjusted "allowable shear" equation similar to the M.S.S.T (Max Shear Stress Theory) equation was used along with D.E.T (Distortion Energy Theory) to solve for the needed weld height along the thin plates that are welded to the T-joint tube. A safety factor of 1.67 was employed as suggested by Shigley's *Mechanical Engineering Design*. [22] The equation was re-arranged algebraically and solved for in MATLAB using a *for*-loop with the same force array as before with the shaft in C1 loading. The results are given below. Note that the adjusted equation was suggested per Y.C. Yong's mechanical engineering design notes. [24]

Table 4. Results of weld calculations for C1 loading.

Safety Factor (D.E.T)	Weld Height (inches)	Applied Load (lbs)	Maximum Putting Force (lb)	Corrected Safety Factor
1.67	.189	60	42	2.39

For the C2 loading case, the analysis includes shaft deflection, bending stress, and bearing stress that the shaft creates when pressed into the U-bracket. No impulse forces were calculated for the case of direct impact. A force range of 50-500 lbs was inputted into MATLAB and the corresponding stresses and deflections at the center were calculated using a *for*-loop. The force of 500 lbs was an arbitrary input. Analysis for the hockey blade was not considered since it does not fail for C1 loading and it is designed to play hockey, where the forces and cyclic loading involved are much greater than that of the occasional golf ball. Even if we ignored the fact that Nathan is a good driver, an impact force of 500 lbs would still be unlikely. It is important to note that the calculations were performed under quasi-static conditions where the impulse force was considered as a concentrated and static load. In real impact, the force is a function of time and peaks at a value that is sometimes higher than the critical load of a material, such as a baseball bat, but only occurs for milliseconds or fractions of milliseconds. So if a maximum impact force of 500 lbs did occur and was of any concern, the average force over the interval of impact would be the force to consider for failure and would be lower than that of the maximum. Hence, blade analysis was not considered, but will be analyzed if testing shows otherwise. The results for direct impact are given below. The complete analysis can be reviewed in Appendix C.4.

Table 5. MATLAB results for C2 loading.

Maximum Force (lb)	Maximum Bending Stress (psi)	Maximum Bearing Stress (psi)	Tip Deflection (in)	Percent of S_y Reached (%)
500	29800	1563	.032	85.1

Preliminary Testing

For the wheel selection, our design selection was based on preliminary testing rather than complete engineering analysis. The testing consisted of drilling a hole in the hockey stick blade and mounting an omniwheel on a shaft onto the blade. The omniwheel was chosen as the first wheel to test because it was the only option that mounted simply onto the hockey stick blade, and it was inexpensive to purchase and test. We originally purchased and tested a 2.75-inch diameter omniwheel. This wheel rolled well on hardwood flooring, smooth cement, industrial carpet, and artificial grass. It did not roll well on rough asphalt, shag carpet, and lawn-length grass. These results are adequate, because the surfaces that the wheel does not roll well on are also worthless for putting. The testing methodology and complete results are in Appendix D.

Figure 30. Preliminary testing of 2.75 inch diameter omniwheels.

While the wheel passed the rolling test, the diameter of the wheel was deemed to be too small. When mounting the wheel on the hockey blade, the shaft hole had to be drilled close to the bottom of the blade. This is not ideal because the stress concentrations grow larger the closer the hole gets to the edge of the blade. Also, the blade's ground clearance during testing was lower than desired. For these reasons, we chose a 4-inch diameter omniwheel for our final design. The larger wheel allows the blade to have a higher ground clearance, but is the same style so we assumed that it rolled at least as well as the smaller wheel.

Safety Considerations

The safety of Nathan and others around him is extremely important. It is vital that the completed project does not introduce any significant hazards to people or property. When operated correctly, this design will not be a safety concern. There are no large masses, sharp edges, fast accelerations, or hazardous substances introduces by this project. There are, however, certain elements of the design that Nathan and his family, and any other future users, should be aware of and cautious of. The first minor hazard is the potential pinch point between the U-brackets and the Standing Dani frame during assembly. The attachment itself is not heavy, but if the user leans on the device while their fingers are between the U-bracket and the Standing Dani, the user's fingers could be pinched and injured. Our design allows the user to set the device onto the Standing Dani by holding the main shaft, away from the ends, since the device stays together as one piece.

A second safety precaution is that Nathan should not play kickball while the golf attachment is in place. The point of adding the guards was to prevent a kickball from becoming wedged under the bars. The putter shaft attached introduces a new wedge point if installed while he plays kickball. The likelihood of a ball becoming wedged under the putter shaft is low and the chances of the Standing Dani tipping are also low. However, the potentially catastrophic consequences of tipping were motivation enough to add kickball guards, so avoiding the addition of new wedge points is important. Both devices can be attached to the Standing Dani at the same time, however the golf attachment shaft should not be installed while he plays kickball. He can play golf with the kickball guards in place.

The main source of potential hazard is in driving the Standing Dani. If the putter is swung and hits someone or something, that person or property could be injured or damaged. The power in this scenario, though, would be supplied from the Standing Dani. This form of misuse is more a hazard of the Standing Dani than a hazard introduced by our project. Nathan, an experienced Standing Dani operator, is a very low risk for this type of misuse. If someone else were to use this product, however, this hazard and all other hazards of operating the Standing Dani should be considered and appropriate steps should be taken to avoid them. All of these potential hazards are described in the Hazard Identification Checklist in Appendix E.

Component Details

In this section, the material selection, purchasing details, and fabrication processes are explained for each component of the final design. Assembly, testing, maintenance, and cost analysis are detailed in the next sections. The fabrication and assembly processes described here were the planned processes for the final product. The final actual fabrication and assembly processes are very similar, but the details of them and the few minor differences are described in the Product Realization section. Below is a table that summarizes each component, and following is a detailed description of each component. The SolidWorks drawings and specification sheets are found in Appendix F.1 for the golf attachment and in Appendix F.2 for the kickball guards.

Table 6. Summary table of components, material, purchasing details, and manufacturing processes.

Component	Material	Purchased From	Part Identification	Quantity	Manufacturing Modifications
Main Shaft	6061 Aluminum	McMaster-Carr	9056K36	1	Cut, drilled, welded
Plastic Bushings	UHMW Plastic	McMaster-Carr	57785K45	2	Press-fit
T-Joint	6061 Aluminum Tube	McMaster-Carr	9056K38	1	Cut, welded
T-Joint	6061 Aluminum Plate	McMaster-Carr	89015K94	2	Cut, drilled, welded
Hockey Blade	Wood	Inline Warehouse	Easton Jr. Zetterburg	1	Holes drilled
Omniwheel	Plastic	AndyMark	AM-3080	2	None
Wheel Shaft	Stainless Steel	McMaster-Carr	2025K6	1	Cut
Retaining Rings	Stainless Steel	McMaster-Carr	98408A134	2	None
Pins	Stainless Steel	McMaster-Carr	98404A010	5	None
U-Bracket	6061 Aluminum	McMaster-Carr	89015K94	1	Cut, drilled, bent, welded
Velcro Straps	Velcro	McMaster-Carr	3955T66	6	Glued
Kickball Guards	ABS Plastic	TAP Plastics	2'x2'x1/8"	1	Heat-formed

Main Shaft

The shaft will be made of 6061 Aluminum with an outer diameter (OD) of 1" and 1/8" wall thickness. The stock part will be purchased online from McMaster-Carr. The part number we will purchase for a 2 foot length is 9056K36. We chose aluminum because the total metal cost was significantly cheaper than steel, it is strong enough for our purposes, it can be welded, it is easy to machine, and it is lightweight, allowing us to better meet our customer requirements. The shaft will be cut to length at 15.75" with a band saw and de-burred at the edges. A U-bracket will be welded to one end. A hole of 3/16" diameter will be drilled half an inch from the non-welded end to locate the pin that attaches the other U-bracket. Nine more holes of 3/16" diameter will be drilled into the shaft using a drill press with a spacing of slightly more than 1.5 inches apart to fit the T-joint. The number of these locating holes is subject to change depending on prototype testing results and any preferences from Nathan and his mom.

- When the final product was made, the pinhole for the U-bracket was drilled at two orientations. Details of this can be found in the Product Realization section.

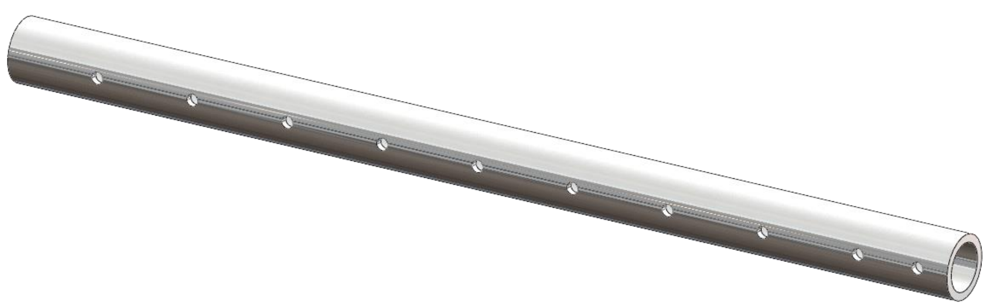


Figure 31. Main shaft.

Plastic Bushings

Instead of making our own bushings from PVC or plastics, we will be buying high quality bushings from McMaster. They will be made of Ultra High Molecular Weight Polyethylene (UHMWPE) and have an inner diameter (ID) of 1" to fit over the shaft and an OD of 1.25" to fit inside the T-joint. Since the plastic bushing is the interface between the static shaft and the rotating T-joint, it is important to have a low friction factor. We chose plastic because it is oil-based, so it will not need additional lubrication. We need a total length of 3 inches, but the stock part 57785K45 on McMaster is only sold in 1.5 inch lengths so we purchased two. They will be placed next to each other and the pins inserted into the main shaft will hold them and the T-joint in place. We already received this part and we have tested that it spins freely on the main shaft, which is exactly what we want. This bushing will need to be press-fit into the T-joint aluminum tube.

- When the bushings were press fit into the T-joint tube, they no longer easily fit over the main shaft and the inside diameter needed to be sanded down. Details of this can be found in the Product Realization section.

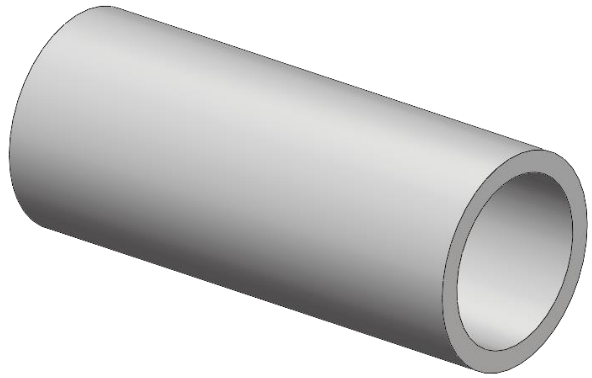


Figure 32. Plastic bushing.

T-Joint

Due to its ease of machinability and practicality for welding, 6061 aluminum will be used in order to construct the T-joint. The T-joint consists of an aluminum tube welded to two aluminum plates. The tube has dimensions of 1.5” OD and 1/8” wall thickness that will be cut to a 3” length using a band saw. The stock part number for the tube is 9056K38 on McMaster and was purchased at their shortest length of 1 foot long. The tube is sized to fit over the plastic bushings that slip onto the main shaft.

Two .16”-thick aluminum plates of 1.25” height and 1.5” length will be cut out from plate also purchased at McMaster (#89015K94). The purchased plate, sized at 12” by 12”, is large enough to create both the U-brackets and the T-joint plates from the same stock part. Spare T-joints could also be made for testing and replacement. We chose to make the part of the T-joint that goes on either side of the hockey stick to be plates, rather than square tubing, because we could better match the dimensions of the hockey blade, which is important so that the putter is secure. A .75” radius half circle will be cut into the plates to fit the curvature of the tube and improve the quality of the welds. In addition, two vertically related holes will be drilled in the center, .60” apart. These holes are where the hockey blade will be pinned. The dimension between the holes is important so that the holes are not too close to cause stress concentrations in the hockey stick. We designed this part to have two vertical holes to prevent secondary rotation about the hockey blade pin; we want the T-joint to rotate as a whole.

After machining the plates, the T-joint will be TIG welded together. To keep the plates parallel during welding, bolts will be fed through the holes with spacers such as nuts and washers between the two plates, and tightened with a nut on the other side of the plate. It is also important that the two plates are perpendicular to the tube. Since aluminum is not magnetic, we will not be able to use an angle magnet to ensure the perpendicular angle while it is being welded. Instead, we will tack a little epoxy to between the edges of the plate and the tube to hold the pieces in place while TIG welding.

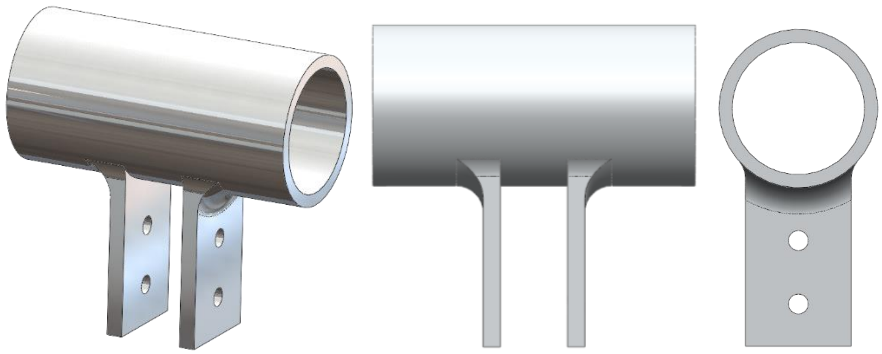


Figure 33. T-joint.

Hockey Blade

The hockey blade was bought from the Inline and Ice Warehouse in San Luis Obispo for only $3.00 each. The blades we purchased were Easton Jr. Zetterburg replacement hockey blades. We chose hockey blades as the golf putter because the shape closely resembled a golf club and are made of materials that are easier to modify. Hockey blades are generally made of either wood or composites, both of which are easier to cut and drill than metal golf clubs. A junior sized blade was chosen because it matched the ground clearance specification better than the regular sized blade. Even though this part is bought off the shelf, it requires a few holes for the pins and the wheel. Because of the weird shape of the hockey stick, an origin has to be identified. Towards the top of the replacement blade, there is a change in cross section where the part is normally fitted inside a hockey stick. This center of this line is referred to as the origin.

The hockey stick will need to be cut to 2.05” above the origin in order to allow proper clearance where the blade is pinned to the T-joint. Two 3/16” holes then will need to be drilled at the top of the blade shaft for the T-joint pins. Another 3/16” hole will be drilled near the heel of blade for the omniwheel shaft to be placed. Several of these blades will be bought to test for the optimal wheel location and ground clearance, as well as having spares for the Coopers in case the final prototype blade fails or is misplaced.

- When the final product was made, the top of the hockey blade did not quite fit into the T-joint. To solve this problem we sanded the blade down so that it fit and then glued a small piece of craft foam sheet to the top of it to ensure a tight fit, almost like a damper. Details of this can be found in the Product Realization section.

Figure 34. Hockey replacement blade with drilled holes.

Omniwheel

In order to have the blade not drag against the ground, two wheels will be purchased to be attached to either side of the putter. We chose not to use casters because they have a turn radius, they have to be mounted underneath the object where we have very little width, and they often have rolling backlash when it temporarily gets stuck rotating about the vertical axis. An omniwheel only needs a horizontal shaft and it allows rotation about two independent axes, causing there to be less rolling backlash than casters. The 4” diameter wheel will be purchased from AndyMark and a 3/8” stainless steel shaft and retaining rings from McMaster will also be bought to attach the wheel to the putter.[21] The steel shaft (part number 2025K6) already has retaining ring grooves cut into it so it will only need to be cut to size. Two retaining rings (part number 98408A134) will be placed on either side used to hold the wheels in place. [18]

- Because the omniwheels are $30 each, we began by buying only one wheel and testing the product with a single omniwheel. The device worked well with the single wheel so we did not purchase or use a second wheel.

Figure 35. AndyMark 4" diameter omniwheel with bearing. [21]

U-brackets

To attach the device to the Standing Dani, we will create U-brackets that go on either end of the main shaft and sit on top of the middle bar of the Dani frame. These U-brackets will be secured to the frame with Velcro straps. These Velcro straps will be glued to the U-bracket so that they do not get lost and the entire device stays together as one piece during assembly. As shown in Figure 37, one U-bracket will be welded to one end of the main shaft for rigidity. The other U-bracket needs to be removable in case the consumer wants to change out the T-joint or needs to replace something. To make the other U-bracket removable but also to keep it attached to the rest of the device, it will be pinned in place.

The U-bracket will be cut out of 6061 aluminum plate so that it can weld to the main shaft. This will be ordered as a 12” by 12” plate from McMaster, part number 89015K94. The flattened rectangle shape of the U-bracket will be cut out from the plate, the corners will be filleted to reduce sharp edges, and a 1” hole will be drilled on one side to fit the main shaft. The flat rectangle will then be bent into a three-sided U-shape with a finger brake machine at the Hangar Machine Shop on campus. According to several shop technicians, the bent shape dimensions of the U-bracket could be an issue in the finger brake because the tool might not be long enough to reach 3” deep to make the last bend. If we find that the machine cannot make the second bend, we will still bend half of it into an L-shape and then find a block of wood or steel that fits the 3” by 1” dimension and hammer the other side down into shape.

- We had problems manufacturing the U-brackets as planned. The best solution to the manufacturing problems was to use thinner aluminum plate and otherwise manufacture as planned. The aluminum we used can be ordered from McMaster as part number 89015K186. Details of the change can be found in the Product Realization section.

Figure 36. U-bracket.

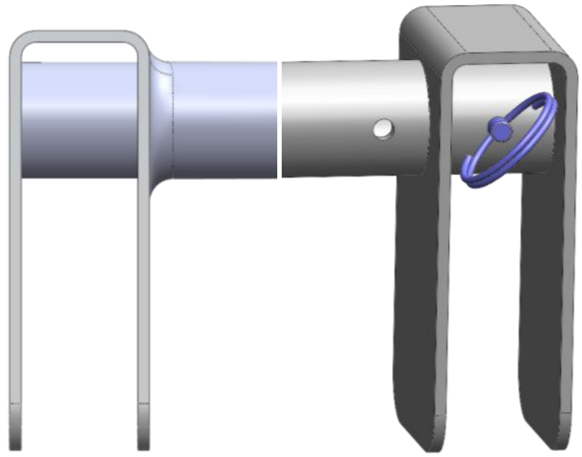


Figure 37. One U-bracket will be welded to the main shaft (left). The other U-bracket will be pinned onto the main shaft (right).

Velcro Straps

Four Velcro straps 1" wide will be purchased from McMaster to secure the U-brackets to the Standing Dani frame. The straps will need to be glued or riveted to the brackets so that they do not get lost or detach from the brackets, both in-use and out-of-use. We would use strong adhesive, such as a super glue, that could withstand the elements to attach the straps to the metal bracket. The Velcro straps we will be purchasing are weather-resistant polyester straps that resist water and UV light, in addition to meeting ASTM D6193 (standard practice stitches and seams) and MIL-F-21840 (military grade hook and line fasteners). Two Velcro straps are attached to each U-bracket, as shown in Figure 39. To install the device onto the Standing Dani, one strap will wrap horizontally around the caster, blue frame, and the U-bracket; the other strap will wrap vertically around the U-bracket and underneath the blue Dani frame. This should prevent the attachment from sliding back and forth across the frame as well as prevent rotation about the main shaft. Velcro straps will be strong enough to support the golf attachment as well as making it easier to assemble. [23]

Figure 38. Weatherproof Velcro strap from McMaster. [18]

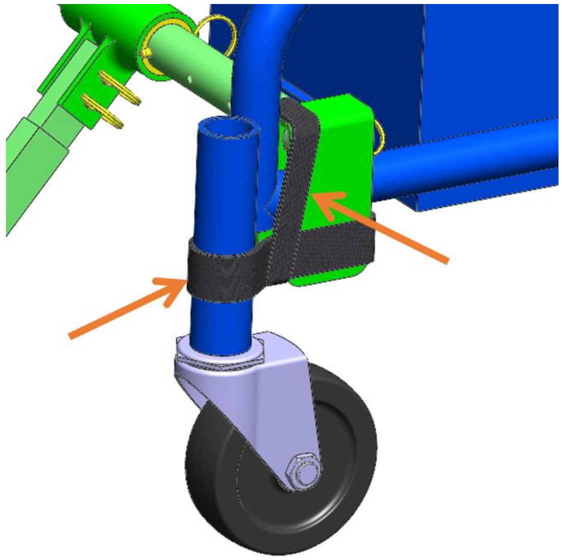


Figure 39. Velcro straps are used to install the golf attachment to the Standing Dani in both the horizontal and vertical directions, to prevent sliding and rotation of the attachment.

Velcro straps will also be glued to the inside of the side kickball guards in order to secure the guard to the middle bar of the Standing Dani frame and reduce its effective cantilever length. Tentatively, the front guard will be attached to the battery with adhesive Velcro strips. If we cannot use this method, then we will not use Velcro for the front kickball guard.

- For the final product, slits were cut in the plastic guards and the straps were fed through the slits instead of the being glued to the guards. Details of can be found in the Product Realization section.

Pins

A total of five 3/16" diameter stainless steel pins will be purchased from McMaster. Part 98404A010 has an effective length of 1", which would perfectly fit through the main shaft. Two pins will fasten the hockey blade to the T-joint, two pins will keep T-joint from sliding axially on the shaft during operation, and one will secure the U-bracket to the end of the main shaft. We chose these stainless steel pins because they are strong, inexpensive, and easy to connect and disconnect. The user simply needs to pull on the keychain to pull out the pin, or push it back in to secure something in place. We may need to order pins with a longer effective length to allow a small clearance, but they are inexpensive and McMaster ships quickly so this would not be an issue.

Figure 40. Quick-release pin.

Kickball Guards

The kickball guards will be made out of plastic and bought online from TAP Plastics. Currently, the plan is to purchase ABS plastics as they are reliable and are commonly used for a variety of applications. Then, we will test the guard on the test frame to see if another thickness or material needs to be selected. We have already purchased a 2' by 2' sheet of 1/8" thick plastic to make prototypes. There are three separate guards: the left side, the front, and the right side. The side guards will attach to the top bar of the Standing Dani by heat forming the top of the plastic sheet over a 1" diameter tube to create a circular arc that will clip onto the frame, as shown in Figure 41. We want the kickball guard to also attach to the lower bar of the Dani frame so the guard has another point of support and its effective cantilever length can be reduced. To attach to the lower bar, a Velcro strap will be glued to the inside of the guard to wrap around the frame.

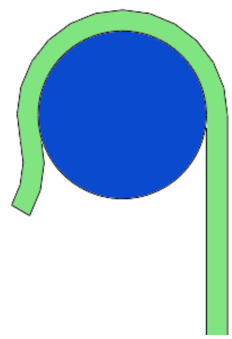


Figure 41. Kickball guards will be heat formed over a tube to create a circular clip. The green is the guard and the blue is the tube it attaches to.

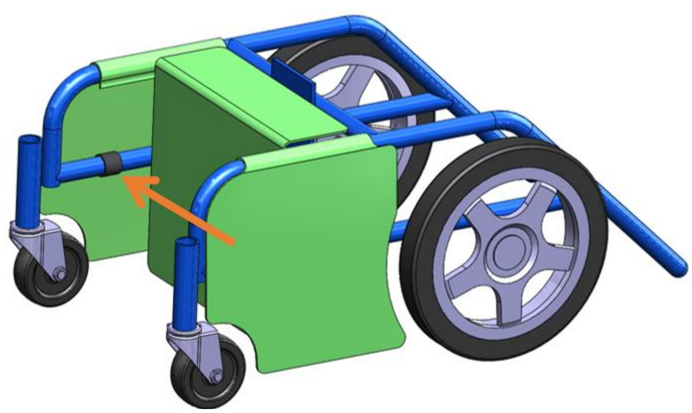


Figure 42. Kickball guards have a Velcro strap to secure to the middle bar of the Standing Dani.

Tentatively, the front kickball guard will stick to the battery with adhesive Velcro strips. Before we finalize this attachment method, we need to verify that we can permanently add adhesive Velcro strips to the battery of the Standing Dani. We will be reviewing this attachment method during our design review with the sponsor on February 9th. In case we cannot use Velcro to attach the front guard to the battery, we will change the design to clip onto the frame with the heat-forming method.

Shipping and Delivery

Most of our parts were ordered online and shipped to the Mustang 60 Machine Shop on campus. Many of our parts are purchased online from McMaster-Carr. In general, McMaster ships their orders with two-day shipping so these parts arrive quickly. TAP Plastics, where we purchased the plastic for the kickball guards, has standard shipping. When we ordered the first sheet, it only took about three days to arrive on campus because they are located in Stockton, CA. The website that sells the omniwheels, AndyMark, has vague shipping details on their website, but their standard shipping only takes about 1-2 weeks.

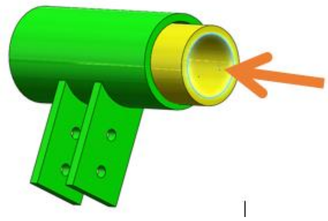
Some of our items were also purchased in San Luis Obispo. The hockey blade replacements were purchased at Inline and Ice Warehouse in SLO.

Ultimately, all of our stock components are easily attainable and do not require large waiting periods. We were able to get all of our parts within several weeks when we ordered them on the same day.

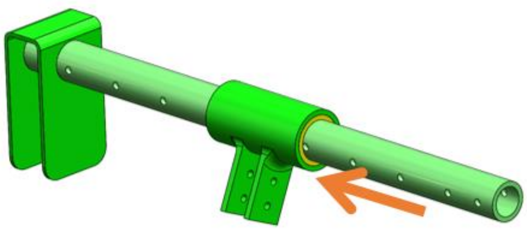
Assembly Instructions

After fabrication, the remaining parts can be assembled without any specialty equipment. To assemble the fabricated parts of the golf putter, follow the directions below:

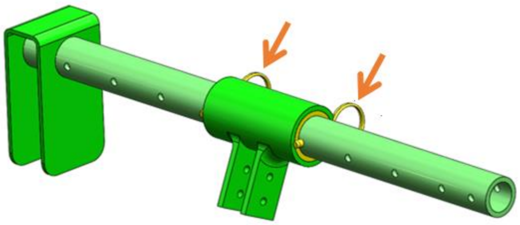
1. Press the plastic bushing sleeve into the aluminum t-joint.



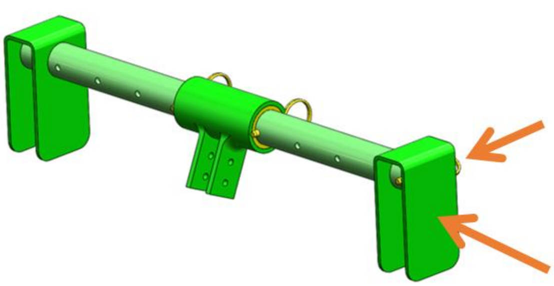
2. Slide the bushing and t-joint together onto the aluminum main shaft.



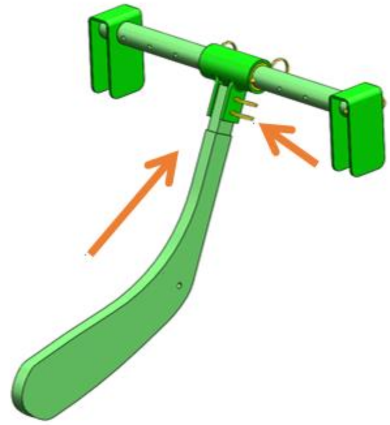
3. Align the T-joint on the shaft between two pinholes and place pins into holes.



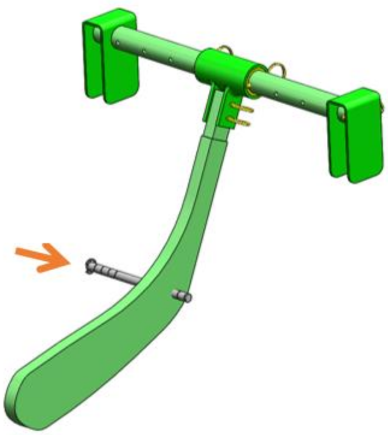
4. Place the other aluminum U-bracket onto the end of the main shaft and place a pin through the shaft inside the joint.



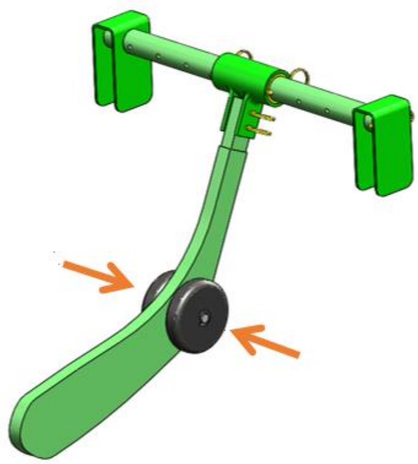
5. Align the holes in the top of the hockey blade shaft with the holes in the t-joint and place pins through both holes.



6. Place a retaining ring on one end of the shaft.

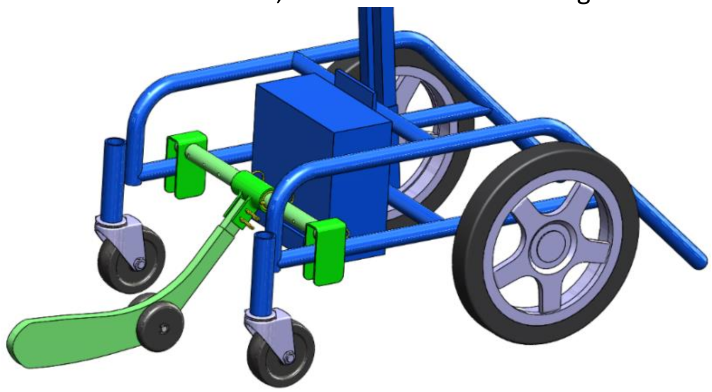


7. Slide the all items onto the shaft in the following order: one omniwheel, hockey blade, and the second omniwheel. Then place the retaining ring on the other end of the shaft.

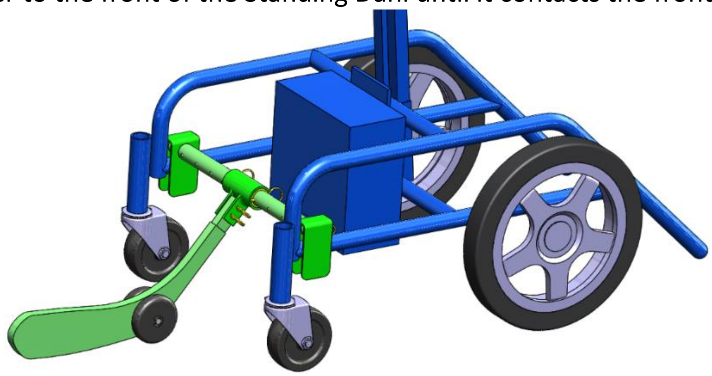


To attach the golf putter to the Standing Dani, follow these instructions:

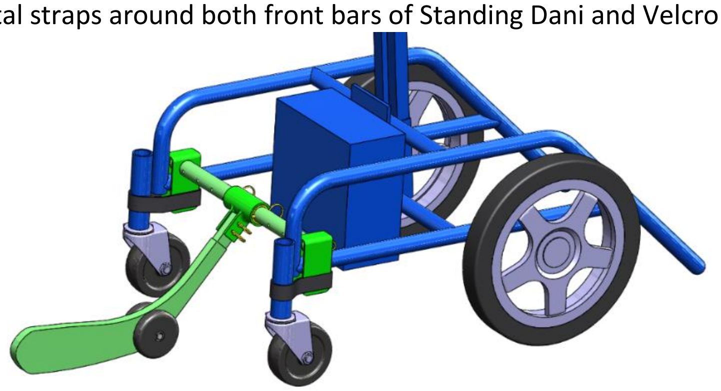
1. Place the U-brackets over the bottom, side bars on the Standing Dani.



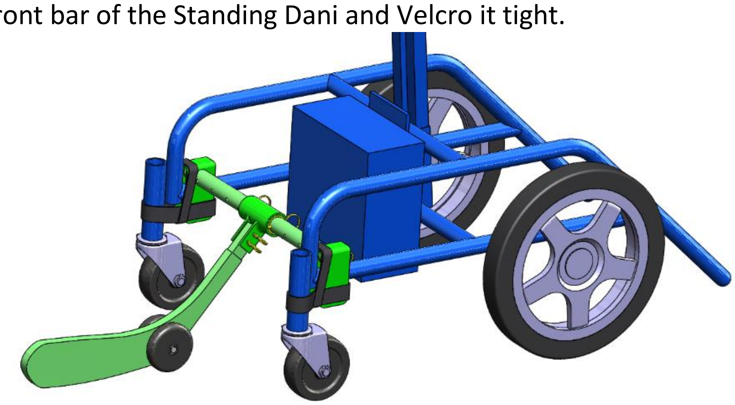
2. Slide the putter to the front of the Standing Dani until it contacts the front bars.



3. Wrap horizontal straps around both front bars of Standing Dani and Velcro it tight.

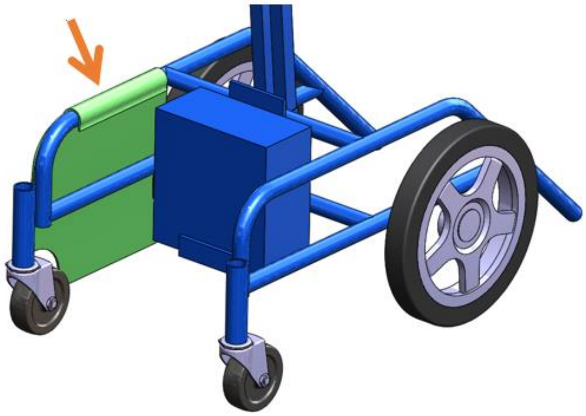


4. Wrap the vertical straps around both U-brackets, in front of the main shaft of the putter and behind the front bar of the Standing Dani and Velcro it tight.

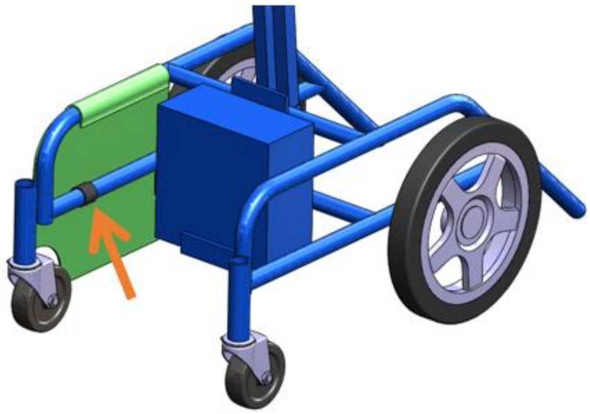


To attach the kickball guards to the Standing Dani, follow these instructions:

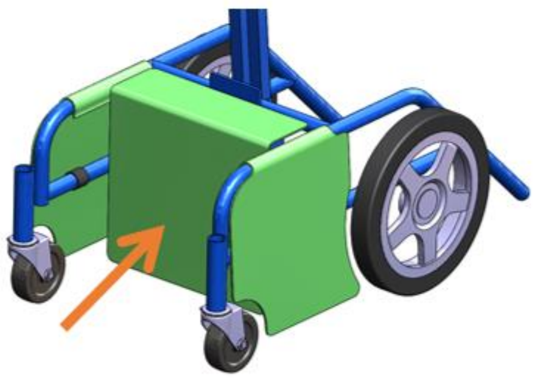
1. Snap one side-guard over the top bar on the side of the Standing Dani.



2. Wrap straps around the bottom bar and Velcro tight.



3. Repeat steps 1 and 2 with the other side-guard on the other side of the Standing Dani.
4. Place front-guard over battery, making sure that the slots are directly over the terminals.



5. Press down firmly on front-guard to secure Velcro.

Test Plan

This test plan includes details of the tests that we originally planned to do. Any changes from this plan and the detailed procedures are in the Testing section of this report.

To investigate the reliability and durability of our attachment design, we will test the finished prototype. To assist in this testing, we will build a replica of the Standing Dani base frame so we can test impact and functionality without having to schedule multiple visits to the Cooper's house or risk damaging the Standing Dani during testing.

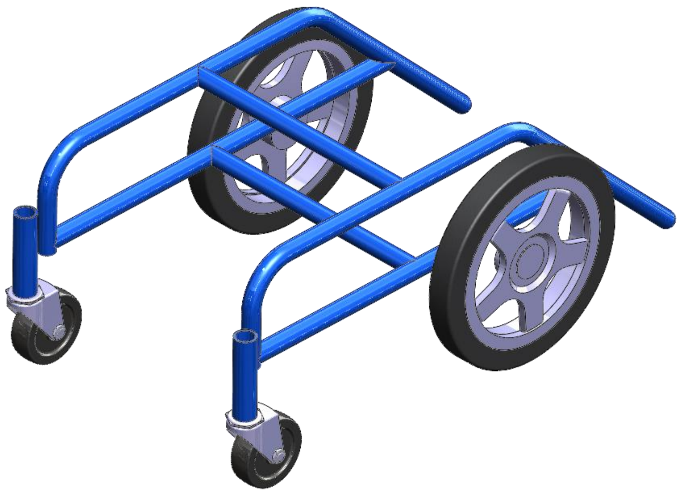


Figure 43. Model of the test frame.

The front of the test frame will have identical dimensions to the base of the Standing Dani, as shown above. It will have caster wheels in front, also identical in size to the Standing Dani. The back wheels will be lawn mower wheels with the same diameter of the Standing Dani's. The metal frame will be constructed by cutting, bending, and welding steel conduit. Because the steel conduit is galvanized, which is poisonous when welded, we will remove the galvanizing with a wire wheel or grinder before welding. Dimensions and parts necessary to build the test frame are outlined in Appendix F.3, and the costs to build the test frame are included in Appendix I. The following tests will be performed on the test frame:

1. Verify assembly method

   This test will be a simple verification that the assembly method outlined above does, in fact, work. If there are any problems with the assembly they will be noted and appropriate actions will be taken to fix them.

2. Verify dimensions

   This test will verify that the prototype fits on the test frame as it was designed to fit. It will also verify that the dimensional constraints from the

   Table 1 are met, namely (a) it is less than 2'x2'x2', (b) it is less than 25 lbs, (c) the guard ground clearance is 2.5"±1.5", and (d) the putter ground clearance is 1"±.5".

3. Impact testing for guards

Strain gauges will be attached to the kickball guards, and the guards will be subjected to loading by throwing balls at the guards similar. The strain will be measured and the maximum stress and force will be calculated. The maximum force calculated from the impacts will then be applied statically to the guards and the maximum deflection will be measured.

4. Impact testing for putter

   The putter will be placed on the test frame and then rammed into a hard surface at different angles. This test will be judged on a pass/fail basis, with any broken or deformed components resulting in a failed test.

5. Rolling test over various surfaces

   The test frame, with putter attached, will be rolled over various surfaces. These surfaces will include short-cut grass, artificial grass putting surface, concrete, asphalt, carpet, and hardwood. The test frame and attachment will be moved in a figure eight pattern on each surface to ensure that the omniwheel travels in all directions during the test. This test will be judged as pass/fail based on if the omniwheel rolls well on the surface or not. The test frame should roll well on all tested surfaces, but if it does not the golf attachment will be rolled by hand on the surfaces that the test frame does not work on.

6. Rough check of putting performance

   The putter attachment will be used to putt golf balls by moving the test frame. The balls will be putted from distances ranging from 3 to 12 feet from the target. The angular distance that the ball lands from the target will be measured.

After using the test frame to perform some tests, these tests will be performed with the Standing Dani:

1. Verify assembly method

   The assembly verification test will be repeated on the existing Standing Dani base.

2. Verify dimensions

   The putter and guard clearance measurements will be rechecked on the Standing Dani base.

3. Verify visibility

   Nathan will operate the Standing Dani with the putter attached, and he will say whether or not he can comfortably see the ball and enough of the putter to operate it. We will also check that no part of the attachment interferes with Nathan's ability to operate the Standing Dani.

4. Test putting performance

   The putting performance test will be repeated with Nathan on the Standing Dani.

Other testing options were considered at the counsel of the Coopers and Dr. Schuster, and the details of the actual tests performed can be found in the Testing section of this report.

Maintenance and Repair

No active maintenance is required to keep the putter or guard working correctly. Though both can be used outdoors and are water resistant, neither should be left in the sun or standing water for extended, unnecessary lengths of time. They should also not be exposed to extreme heat, though they can withstand temperatures up to and exceeding temperatures that humans can handle. The Velcro straps are specified to be able to withstand water and UV light, however too much exposure will eventually start to deteriorate the product and could cause a hazard. If they need to be replaced, the Velcro straps are very inexpensive and easy to find online or at a local hardware store.

The design of the putter and guard are both removable and can be disassembled to provide service if a part or parts fail. All of the parts that are not custom made can be simply replaced. All information needed to reorder purchased parts can be found in Appendix G. The hockey stick blade can be removed by removing the pins from the T-joint. The omniwheel can be removed by removing the shaft from the wheel. The T-joint can be removed by removing the pin from inside the U-bracket, sliding the U-bracket off of the end, removing the locator pins from the main shaft, and sliding the T-joint and plastic bushing off of the main shaft.

One of the biggest challenges for our final design was to make it out of as many off-the-shelf parts as possible. This saves money and time for custom machining in case something breaks or needs a replacement. Since our whole design is made from stock parts that can be ordered online and slightly modified, it will be very easy to maintain and repair our final product. We also hope to create several replacement parts with the extra material leftover, so the Coopers will have backups already made.

Cost Analysis

Since all of the parts needed for our prototype have been selected, we can calculate the total cost of the prototype. All of the parts needed and their respective costs are summarized in Table 7 below. Sales taxes and shipping and handling costs vary, so the listed prices do not include tax or shipping costs.

Table 7. Summary of Prototype Costs

Part	Purchased From	Part Number	Quantity	Price Per Unit	Total Cost
6061 Aluminum Tube 1” OD, 24” long	McMaster-Carr	9056K36	1	$13.86	$13.86
UHMW Plastic Bushings 1.25” OD, 1.5” long	McMaster-Carr	57785K45	2	$8.84	$17.68
6061 Aluminum Tube 1.5” OD, 12” long	McMaster-Carr	9056K38	1	$11.94	$11.94
6061 Aluminum Plate .16” Thick, 12” x 12”	McMaster-Carr	89015K94	1	$34.13	$34.13
Wheel Shaft	McMaster-Carr	2025K6	1	$12.44	$12.44
Retaining Rings (10-pk)	McMaster-Carr	98408A134	1	$4.45	$4.45
Quick Release Pins	McMaster-Carr	98404A010	5	$1.85	$9.25
Weatherproof Velcro Straps	McMaster-Carr	3955T66	4	$2.10	$8.40
4” Diameter Omniwheel	AndyMark	AM-3080	1	$29.00	$29.00
Hockey Blade	Inline Warehouse	Easton Jr. Zetterburg	1	$3.00	$3.00
Epoxy Putty	Home Depot	-	1	$5.97	$5.97
Craft Foam and Glue	Michaels	-	1	$2.98	$2.98
Putter Total					$153.10
Kickball Guards	TAP Plastics	ABS 18”x18”x1/8"	3	$12.20	$36.60
Weatherproof Velcro Straps	McMaster-Carr	3955T66	2	$2.10	$4.20
Guards Total					$40.80
Parts Total					$193.90

The cost breakdown shows that the most expensive item is the pair of omniwheels. We originally tested 2.75” omniwheels that cost only $3.00 each, but for reasons outlined in the preliminary testing section the 2.75” wheels are not adequate. The parts from McMaster-Carr could probably be found cheaper elsewhere, but since the total cost is low, we will use McMaster-Carr for convenience and reliability.

Our total project budget is $2,000. The cost to purchase the parts of one prototype is only $205, so it should not be difficult at all to keep our total project cost well under budget. In addition to the cost of materials to manufacture the prototype, there are costs associated with testing and design development. Beside prototype material costs, the other main cost will be for testing. The costs of the materials to build the test frame will be $75. Other testing costs could arise if parts are damaged and need to be repurchased. Other miscellaneous costs include $20 spent making simple concept models and another $20 spent testing the 2.75” omniwheels. All expenses up to this point in the project are listed in the budget sheet in Appendix I.

Chapter 6 - Product Fabrication

Manufacturing of Golf Attachment

The golf attachment was manufactured by the senior project team at the Mechanical Engineering shops the Hangar and Mustang '60.

Main Shaft

The main shaft was made from a single 2 foot long aluminum tube. The tube was ordered from McMaster Carr (part number 9056K36) and has 1" outer diameter and 1/8" wall thickness.

1. The tube was cut to a length of 15.75" with a vertical band saw.
2. 3/16" through holes were drilled at the designed intervals along the length of the shaft using a mill. This process can be seen in Figure 44, and the resulting shaft can be seen in Figure 45.

Figure 44. Chris and Joseph drilling the 3/16" holes along the shaft.

Figure 45. Main shaft with holes drilled along it and pins in two of the holes.

After the holes were drilled, one of the U-brackets was welded to one end of the shaft. This step is listed in the U-brackets section.

3. All cut and drilled surfaces were deburred with a deburrer.
4. The shaft was spray painted blue. The final shaft can be seen in Figure 46.

Figure 46. Finished main shaft.

The hole on the end of the shaft was redrilled after the U-bracket was welded on so that the pinned U-bracket could match the orientation of the welded one. The original and redrilled holes are shown in Figure 47. This redrilling was only necessary because the u-bracket was welded in the wrong orientation and is not part of the planned manufacturing process.

Figure 47. The main shaft showing the original holes and the redrilled holes.

T-Joint

The t-joint was made from a total of four parts purchased from McMaster: two plastic bushings (part number 57785K45), one aluminum tube (part number 9056K38), and one aluminum plate (part number 89015K94). The tube came with a 1.5" outer diameter, 1/8" wall thickness, and 1-foot length. The plate was 1'x1' and had a thickness of .16".

1. The tube was cut to a length of 3" with the vertical band saw. The resulting tube is shown in Figure 48.

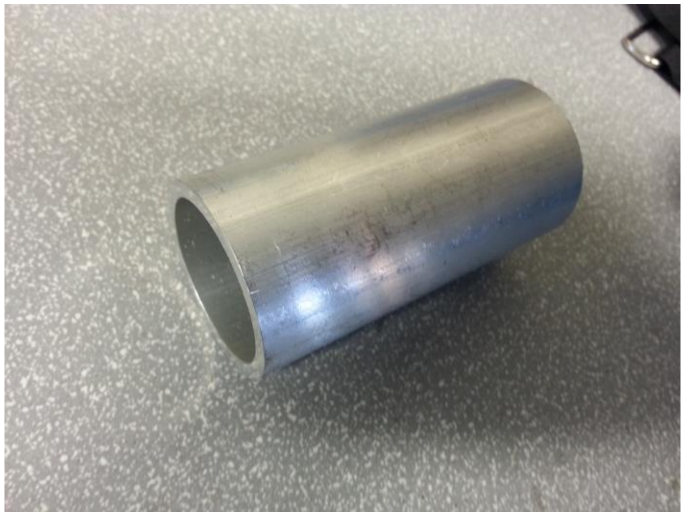


Figure 48. T-joint tube after being cut to length.

2. The plate was cut into two 1.5"x1" rectangular shapes, also with the vertical band saw.
3. One of the 1" sides on each rectangle were notched with a .5" radius notch centered on the side of the rectangle. The notches were made on a mill.
4. The two plates were welded onto the tube to form the t-joint. Trent Hellmann, a student technician, did the welding.
5. Two 3/16" through holes were drilled in the parallel rectangular plates using a drill press. The welded and drilled t-joint plates can be seen in Figure 49.

Figure 49. T-joint with plates welded on and drilled.

6. The bushings were press-fit into the tubing of the t-joint with a plastic mallet.
7. The inside of the plastic bushings were sanded down with a circular sander until the t-joint and bushings fit over the main shaft.
8. The corners of the plates were rounded with a bench grinder.
9. The t-joint was spray painted blue. The final t-joint including bushings is shown in Figure 50.

Figure 50. Completed T-joint.

U-Brackets

The U-brackets were from one piece of .06” sheet aluminum.

1. The aluminum was cut with the sheet metal shear into two 2”x7” rectangular shapes.
2. The sheet metal break was then used to bend two ninety-degree bends in each U-bracket.
3. A 1” hole through was drilled on one side of each U-bracket with a drill press.
4. One of the U-brackets was welded onto the end of the main shaft, with the shaft placed through the drilled hole in the U-bracket and welded around the shaft. Brett Johnson, a shop technician, did the welding. Figure 51 shows the weld.

Figure 51. U-bracket welded onto the main shaft.

5. The U-brackets were spray painted blue.
6. The Velcro straps were riveted onto the U-brackets, and the rivets were filed down on the inside of the U-bracket. A completed U-bracket can be seen in Figure 52.

Figure 52. Completed U-bracket.

The U-bracket plate thickness is different than originally designed. The original design was for the U-brackets to be made out of .16" thick plate because that size needed to be purchased for the t-joints and the smallest area was enough to make both the T-joint and U-brackets. The sheet metal break at the Hangar, however, requires a maximum plate thickness of .10". We attempted to heat and bend the thicker plate, but it was difficult to control the bend radius and location and the plate snapped while bending. The snapped plate is shown in Figure 53. We purchased the .09" thick aluminum plate so that we could attempt again with the sheet metal machines, but this plate snapped when bent past about 45-degrees in the sheet metal break. Someone else working in the shop at the time had scrap sheet aluminum that was .06" thick, so we tried it to see if it would snap or not. Since it did not snap, and there was enough to create both U-brackets, we used this free scrap aluminum to make the U-brackets on the final prototype. If more u-brackets needed to be made, more sheet aluminum could be purchased from McMaster (part #89015K186).

Figure 53. The .16" plate after snapping while being bent.

Omniwheel Shaft

The omniwheel shaft was made from a stainless steel shaft purchased from McMaster (part # 2025K6). The shaft has a diameter of 3/8", a length of 6", and grooves for retaining rings. The grooves are .039" wide and .036" deep.

1. The shaft was cut to a total length of 3" on a lathe.
2. A new groove with a depth of .036" and width of .039" was added to the shaft with the lathe. The new groove was made 2.72" from an existing groove on the shaft.
3. The shaft was press fit into the omniwheel bearing with a hydraulic press.
4. One retaining ring was snapped onto the shaft next to the wheel. The shaft in the wheel with the ring can be seen in Figure 54.

Figure 54. Wheel shaft with retaining ring after being press fit into bearing.

After shaft was pressed into the bearing, the shaft was bound to the hockey blade. This step is included in the putter section below.

5. The other retaining ring was snapped onto the end of the shaft that was put through the putter. This end of the shaft and the groove that was added to the shaft can be seen in Figure 55.

Figure 55. The end of the shaft that was passed through the blade.

Putter

The putter was made from an Easton Jr. Zetterberg replacement hockey blade. The hockey blade prior to fabrication is shown in Figure 56.

Figure 56. Hockey blade before manufacturing process.

1. The top of the blade was sanded down slightly to fit into the t-joint.

2. The 3/16” through holes for the t-joint connection were drilled with a drill press. These holes were drilled after the t-joint was drilled, and the t-joint was used to ensure correct alignment.
3. A 1/2” hole for the omniwheel shaft was drilled with a drill press.
4. The hockey blade was spray painted black.
5. A 1/2” washer was glued to either side of the putter to ensure a flat surface on both sides.
6. The shaft was bound to the blade with epoxy putty. The 1/2” hole was drilled larger than the 3/8” shaft to allow for space for the epoxy to be added.
7. A small piece of foam was glued to the top of the hockey blade to obtain a tight fit between the t-joint and the top of the hockey blade. The foam and pin holes on the top of the putter can be seen in Figure 57. Figure 58 shows the completed putter with omniwheel and shaft attached.

Figure 57. The top of the putter attachment with the two pin holes and the added foam for a tight fit.

Figure 58. Completed putter with wheel attached.

Manufacturing of Kickball Guards

The kickball guards were made from sheets of ABS plastic that were ordered from TAP Plastics and were made in the Mustang ’60 machine shop.

Side Guards

1. The unique shape was cut out on the laser cutter in Mustang ’60 Machine Shop. The laser cutter was the best option to get a replicable shape for both guards. Extra material was left around the heat-forming area so that we would have something to grab onto as we formed the plastic. The guards after cutting are shown in Figure 59.

Figure 59. A kickball guard after being laser cut.

2. A heat gun and welding gloves were used to melt the plastic and form the shape over a piece of conduit. The conduit was secured in a vise. The plastic was bent over the conduit to create a lip shape shown in Figure 60.

Figure 60. The lip shape that was heat-formed over conduit.

3. The excess material was cut off with a Dremel and a file to create a nice handle to easily clip on and off.

4. Slots for Velcro straps were cut out with drill and a file. The straps were fed through the slots and wrap around the lower horizontal bar on the Standing Dani. The slots are shown in Figure 61. The completed side guards are in Figure 62.

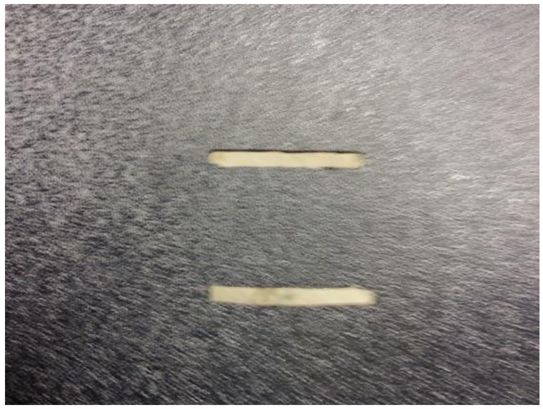


Figure 61. The slots in the kickball guards.

Figure 62. The completed side kickball guards.

Chapter 7 - Design Verification

To ensure the functionality of the project, multiple tests were performed; most of them being qualitative tests. The biggest concern with the implemented design is its operational safety when Nathan is using the golf-attachment or kickball guards. To help determine the effectiveness of the designs, and their safety implications for Nathan, several tests were proposed in the CDR in the beginning of ME 429. The complete DVP&R can be seen in Appendix K.

Design Verification Plan and Report

Table 8. DVP&R tests and descriptions.

Item No	Specification	Test Description	Acceptance Criteria	Test Performed
1	A.1	Test rig sufficiently rolls along ground	Maneuverable along flat surface	Yes
2	A.2	Test rig supports attachment	Attachment fits to both test rig and SD	Yes
3	A.3	Test rig has same dimensions and physical constraints as Standing Dani	Measurements are the same as SD	Yes
4	A.4	Golf putter ground clearance for different ball sizes	1.0 inch clearance	Yes
5	A.5.1	Golf impact testing of safety design considerations (shaft rotation and velcro straps)	Does not lose function or break after 100 lbs impact	No (N/A)
6	A.5.2	Repeated impact testing for deformation of putter and shaft	Does not lose function or break after 100 lbs impact	No (N/A)
7	A.5.3	Impact testing for bearing/bushing performance	Does not lose function or break after 100 lbs impact	N/A
8	A.6.1	Kickball guard ground clearance	2.5 inch clearance	Yes
9	A.6.2	Impact testing of kickball material	Does not lose function or break after 50 lbs impact	No
10	A.7	Assembly steps	10 steps or less	Yes
11	B.1	Ball trajectory testing in Standing Dani	45 degree range of accuracy for 95% of the time	Yes
12	B.2	Interference with normal functions	Nothing interfering	Yes
15	B.3	Balance on 5 degree incline with all attachments	SD does not lean or tip over	Yes
16	B.4	Nathan's visibility	Nathan can see putter and ball while operating	Yes
17	C.1	Attachment size	Smaller than 2'x2'x2'	Yes
18	C.2	Attachment weight	Less than 25 lbs	Yes

Testing Results and Justifications

A.1: The test rig was tested on several surfaces, including; grass, putting green turf, asphalt, concrete and carpet. Though the operational condition for the golf-attachment is designed for the putting green surface in Nathan's back yard, the test frame was still able to sufficiently roll around on the other surfaces.

Figure 63. Test frame replica of Nathan's Standing Dani.

A.2-A.3: The golf-attachment fit well on the test frame and adequately matched the dimensions and constraints of the actual Standing Dani.

A.4: The putting clearance for the golf-attachment ended up being less than a 1.0 inch clearance, but performed really well in Nathan's backyard and easily rolled over/through small rocks and debris that was on the putting green surface during testing. The hockey blade still had sufficient clearance over the ground and smoothly struck a golf ball when Nathan was testing the attachment. The hockey blade/wheel assembly can be seen below in Figure 64.

Figure 64. Omni wheel and hockey blade assembly.

A.5.1-A.5.2: Though these tests were not performed for the specific value of 100 lb_f, qualitative impact testing was performed as to appropriately match, though unlikely, the worst-case scenarios given the parameters of Nathan's driving, his backyard, the golf-attachment and the S.D. The S.D can only achieve approximately 5-7 mph and Nathan, according to his mother Amy, is an excellent driver, so the worst-case is extremely unlikely but some qualitative data or observation was desired. In order to test the potential case for impact, the putter-attachment was fixed onto the test frame and crashed into a cement curb at speeds estimated near those that the S.D would experience if Nathan (no matter how unlikely it would be) crashed into a wall or a curb.

A.5.3: This test was not performed as it was deemed unneeded once construction and assembly was performed.

A.6.1: The kickball guards ended up having a smaller clearance than 2.5 inches from the ground but were not too close such that Nathan would get stuck driving over small objects. Additionally, since the guards are relatively compliant, they would be able to sufficiently flex outwards if he needs to roll up on a small curb or non-flat surface in their backyard. The guards will be able to provide good protection against small to medium sized soccer balls that could get stuck between the lower frame rail and the back driver wheels.

Figure 65. Kickball guards on Standing Dani.

A.6.2: The biggest concern for the guards is the cantilever behavior that could occur if a soccer ball hit the bottom of the guard and flexed the plastic. The kickball guards were tested by rolling balls into it while they were attached on the test frame, but it was deemed unnecessary to attach strain gages onto the guards and test them using a linear actuator in series with a load cell. Reasons for this include the following: (1) since the force is distributed over an area, rather than a point load, and assuming the balls being thrown at Nathan are not rigid or really stiff, like a baseball, then there is little concern that the guards would fail due to excess stress or tip deflection, and (2) since the pressure from the ball would be concentrated conveniently over an area in line with the bottom rail, such that the guards would be under a compressive normal stress load, a cantilever effect and bending stress would unlikely occur.

A.7: To attach the golf putter to the Standing Dani, someone would only need to place the device on the side rails and then tighten the Velcro straps around the frame. Provided that the hockey blade is already attached to the golf-attachment, the current assembly method has fewer than ten steps. Each step is easy and friendly enough that Nathan's little brother could attach them himself in a few years when he is 6 or 7 years old.

B.1: This test was not performed and subsequently deemed unnecessary since the accuracy of the putted ball is not a function of the device, but of Nathan's ability to maneuver the Standing Dani. The accuracy depends on the learning curve with the device and how much practice Nathan will get playing golf in his backyard. The low learning curve was confirmed when Nathan first tested the golf attachment and was able to comfortably maneuver with the device and made a hole-in-one on his first try, and many more successful putts thereafter.

B.2: Neither the golf attachment nor the protective kickball guards interfered with the normal function of the Standing Dani when Nathan was in it.

B.3: The slope of the Cooper's backyard varies slightly and Nathan was able to easily roll across the entire backyard with both attachments. The grade of their backyard was not officially measured to match the 5 degree incline specification, however the weights and footprint of the devices are so negligible compared to the Standing Dani and Nathan, that the center of gravity was not shifted enough, if at all, to cause an imbalance. Additionally, most of the weight of the blade is supported by the omniwheel, which is less than a foot out in front of the casters.

B.4: Nathan can clearly see the golf attachment because it sits right in front and below him while he is in a comfortable position. This was confirmed by operational testing and asking Nathan himself if the alignment needed to be adjusted, to which he said no.

Figure 66. Nathan just after he completed a putt in their backyard mini golf turf.

C.1: The overall size of the golf-attachment is significantly smaller than 2'x2'x2' and will be of no concern if the Cooper family decides to take the attachments with them in their vehicle. The golf attachment is largest when it is assembled, at about 16" by 8", however the hockey blade and T-joint can be removed from the main shaft to make two smaller devices that easily fit inside a medium- to large-sized bag.

C.2: All of the attachments combined, including the guards, weigh just less than 2 lbs 13 oz, which is much less than the specified 25 lbs limit.

Chapter 8 - Conclusions and Recommendations

As the project comes to an end, the team reports on the Senior Project Expo, future manufacturing recommendations, and concluding thoughts.

Senior Project Expo

On May 29, 2015, we presented our project at the Engineering Senior Project Expo. The display included a poster, seen below in Figure 67, and a running video of Nathan playing golf with the new attachment for the first time in his backyard. A miniature putting green was also purchased so Nathan could play golf at the expo. Nathan, Amy, and their family visited the expo so Nathan could demonstrate his new golf attachment. Several reporters at local news outlets, including Mustang News, interviewed Nathan, his mom, and the project teammates at the expo.

Figure 67. Sports for Nathan Senior Expo poster.

Figure 68. Nathan being interviewed by Mustang News at the Senior Project Expo.

Future Manufacturing Recommendations

This product is very unlikely to be manufactured on a large scale. Because they will only be made on a small scale, the manufacturing methods should be very similar to the final methods that we used. We did try some things that did not work the first time, but replicating what worked for our final product would be the best option for future manufacturing. It is also important to know that there are many different models or Standing Danis, so if this product is going to be made for a different Standing Dani, the width and bar diameters should be checked.

Conclusion

In the beginning of the school year, the Sports for Nathan senior project team was asked by Nathan's mother, Amy, to create devices that would allow Nathan to play golf and kickball safely. They wanted a device that allows Nathan to play golf more proficiently than his current method of using the Standing Dani casters, as well as an easy-to-attach device that protects Nathan from tipping over if a ball got stuck under the Standing Dani frame. The team underwent design, build, and test phases in order to meet these overall goals. In the design phase, several brainstorming sessions were conducted and concepts were compared with one another using customer requirement constraints and decision matrices. After a project proposal and preliminary design, detailed CAD modeling and analysis was performed and a final design was made. Construction of the final design began at the end of winter and was finished near the end of the spring quarter. The golf attachment and kickball guards were tested at Cal Poly on a replica test frame, as well as testing with Nathan on the Standing Dani in the backyard of their house. The golf attachment fit Nathan's Standing Dani well and moved smoothly over different surfaces in their backyard. Additionally, the device was easy for Nathan to see and maneuver a small golf ball with, and was able to hit a hole-in-one on his first try! The kickball guards fit securely onto the Standing Dani frame and have an adequate clearance from the ground to allow Nathan to drive over small debris, yet still be able to protect him from getting stuck or tipping over. The goals that were set forth from the beginning of the academic year were not only met, but a young boy and his family were made happy and will be able to share many wonderful memories in the future.

References

[1] Bazant, Justin, Cullen Crackel, and Anthony Franceschi. “Universal Play Frame VI.” Digital Commons @ Cal Poly. Cal Poly, San Luis Obispo, Dec. 2010. Web. 25 Nov. 2014 <http://digitalcommons.calpoly.edu/mesp/44>.

[2] Cortese, Kimberly, Noelle Le Blanc, and Kevin Stewart. "Universal Play Frame Golf II." Cal Poly, San Luis Obispo, 2009. Print.

[3] Cummings, George, Brian Kreidle, Ricky Lee, and Clark Steen. "Strider." Digital Commons @ Cal Poly. Cal Poly, San Luis Obispo, 1 Dec. 2011. Web. 15 Oct. 2014. <http://digitalcommons.calpoly.edu/mesp/132>.

[4] "DavisMade, Inc. 510(k) Submission: Power Standing Dani." Food and Drug Administration. Department of Health and Human Services, 6 July 2009. Web. 15 Oct. 2014. <http://www.accessdata.fda.gov/cdrh_docs/pdf9/K090256.pdf>.

[5] "Facts About Spinal Muscular Atrophy." Muscular Dystrophy Association, 1 Dec. 2009. Web. 15 Oct. 2014. <http://mda.org/sites/default/files/publications/Facts_SMA_P-181.pdf>.

[6] Hibbard, Dawn. "Getting Kids on Their Feet." Kettering University, 2 Dec. 2005. Web. 15 Oct. 2014. <http://www.kettering.edu/news/getting-kids-their-feet>.

[7] "Go Kart with Safety Bumper (SX-G1101-1A)." *Yongkang Fourstar Co., Ltd.* Web. <http://chfourstar.en.made-in-china.com/productimage/noaQPZKOhMrR-2f1j00HZEtwgVPgTcm/China-Va-Kart-con-Safety-Bumper-SX-G1101-1A-.html>.

[8] Johnson, Eric, Ricardo Garcia, and Alex Trask. "Strider." Digital Commons @ Cal Poly. Cal Poly, San Luis Obispo, 1 June 2010. Web. 15 Oct. 2014.

[9] "MAUDE Adverse Event Report: DAVISMADE, INC. STANDINGDANIWHEELSTAND WITH EFIX POWER ADD-ON STANDING DANI WHEELSTAND." U.S. Food and Drug Administration. 30 Sept. 2014. Web. 15 Oct. 2014. <http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfMAUDE/ detail.cfm?mdrfoi__id=1036565>.

[10] "Soccer Guards." PowerSoccerShop.com. Web. 26 Nov. 2014. <http://www.powersoccershop.com/soccerguards.aspx>.

[11] "Spinal Muscular Atrophy." Genetics Home Reference. U.S. National Library of Medicine, 9 Oct. 2014. Web. 15 Oct. 2014. <http://ghr.nlm.nih.gov/condition/spinal-muscular-atrophy>.

[12] *Sports for Nathan.* Cal Poly ME 428 PolyLearn, Fall 2014 Sponsor Presentation Files, PDF.

[13] Stand Up and Play Foundation. Web. 26 Nov. 2014. <http://standupandplayfoundation.org/>.

[14] "Test Protocols For Equipment." USGA. Web. 26 Nov. 2014. <http://www.usga.org/equipment/testing/protocols/test-protocols-for-equipment/>.

[15] "Undergraduate Expo 2008." (2008): 24. Michigan Tech. Web. 25 Nov. 2014. <http://www.expo.mtu.edu/2008/2008Expo/Undergrad_Exposition_08.pdf>.

[16] Warner, MP. "Standing Tall: The Benefits Of Standing Devices." Exceptional Parent 37.3 (2007): 56-57. CINAHL Plus with Full Text. Web. 18 Nov. 2014

[17] Wilson, Paul, and Ken Steven. "Become A Swing Machine." Golf Tips. Web. 26 Nov. 2014. <http://www.golftipsmag.com/instruction/faults-and-fixes/lessons/become-a-swing-machine.html#.VG7ENIcwxEM>.

[18] McMaster-Carr. Web. 20 Nov. 2014. <http://www.mcmaster.com/>.

[19] "Spring Loaded Ball Transfer Units." Ball Transfer Systems, LLC. Web. 20 Nov. 2014. <http://balltransfer.com/spring-loaded-caster.html>.

[20] "VEX 2.75" Omni Directional Wheel - Double Roller (2-pack)." Robot Mesh. Web. 20 Nov. 2014. <http://www.robotmesh.com/vex-robotics/wheels/vex-2-75-omni-wheel>.

[21] "4-inch DuraOmni Wheel W/ 3/8" Bearings (am-3080)." AndyMark. Http://www.andymark.com/product-p/am-3080.htm. Web. 20 Jan. 2015.

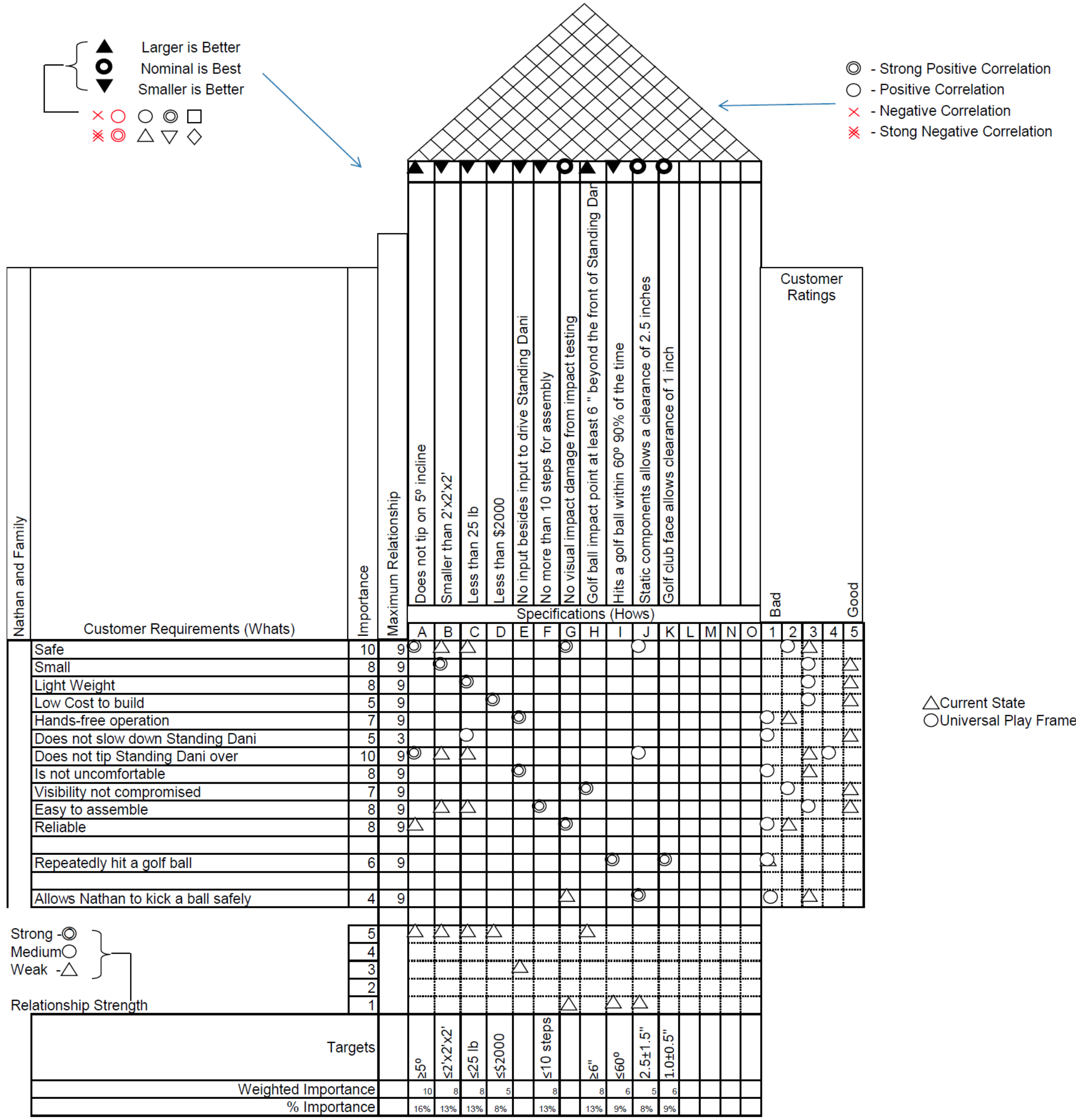
[22] Budynas, Richard G., and J. Keith Nisbett. Shigley's Mechanical Engineering Design. 9th ed. New York: McGraw-Hill, 2011. Print.

[23] McMaster-Carr. Web. 20 Nov. 2014. <http://www.mcmaster.com/>.

[24] Yong, Y.C. ME 329 Notes. 2013. Print.

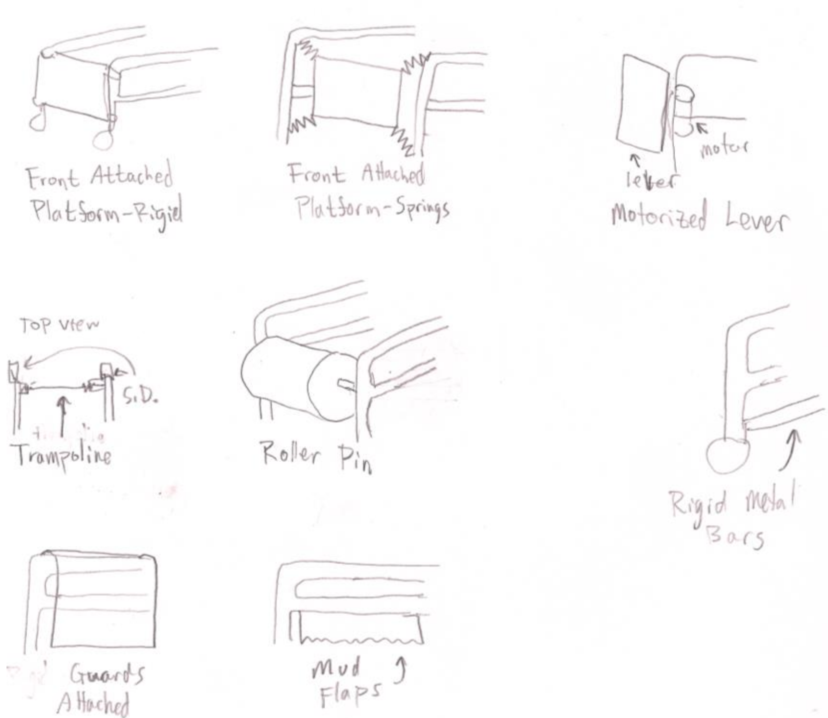
Appendices

Appendix A – Quality Function Diagram



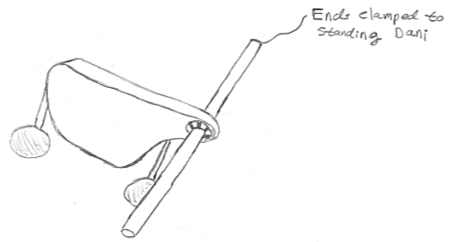
Appendix B – Pugh and Decision Matrices

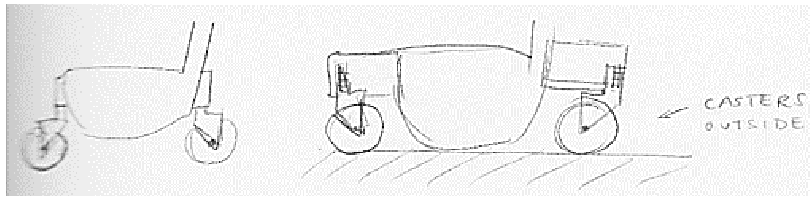
Table 9. Pugh matrix for kickball attachment.

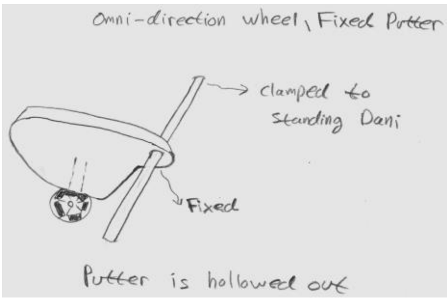


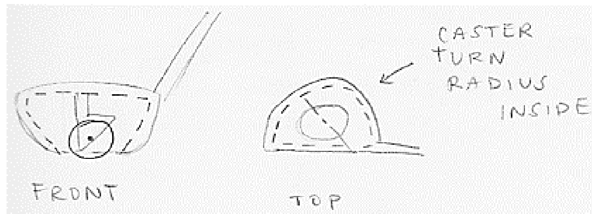
Criteria	Front attached platform- Rigid	Front attached platform- with springs	Motorized levers	Trampoline	Roller pin	Rigid Metal bars	Rigid guards attached	Flexible guards attached	Mud flaps
Size	D	S	+	S	S	+	+	+	+
Safe		+	+	+	+	-	S	+	-
Weight	A	S	-	S	S	+	+	+	+
Cost		-	-	-	S	-	-	-	+
Reliable	T	+	-	+	+	S	S	-	-
Assembly ease		S	-	S	S	+	S	S	S
User interaction	U	S	-	S	S	S	S	S	S
Σ+		2	2	2	2	2	2	3	3
Σ-	M	1	5	1	0	1	1	2	2
ΣS		4	0	4	5	4	4	2	2

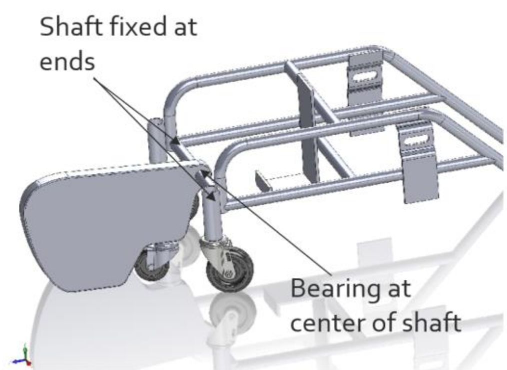
Table 10. First round Pugh matrix for golf attachment.

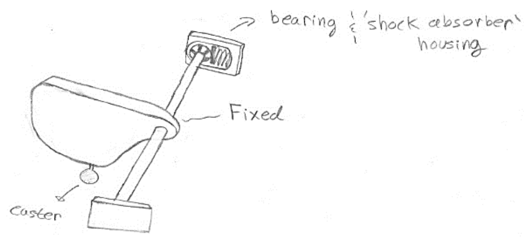


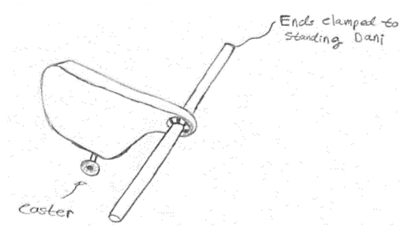












Function: Golf putting attachment to Standing Dani

Concept: / Criteria:	Spring and Round Corner	Motor Rotate	Casters between 2 Faces	Ball Transfer Wheels along Bottom	Casters on Putter with Ball Bumpers	Casters on Both Ends	Caster Inside Hollow Putter	Omni-direction Wheel Inside Hollow Putter	Two Spring Lift with Casters	Ball Bearing Axle and Round Corner	Pin Connect Spring with Casters	Static Board (Datum)
Safe	-	S	S	+	+	+	+	+	-	+	-	D
Small	-	-	-	+	-	-	-	+	-	+	-	
Light weight	S	-	-	S	-	-	-	S	-	S	-	A
Low Cost	S	-	-	-	-	-	-	-	-	S	-	
Easy to Operate	S	-	S	S	S	S	S	S	S	S	S	T
Easy to Assemble	S	-	S	S	S	S	S	S	-	S	-	
Reliable	+	-	+	S	S	+	+	+	-	+	S	U
Control Aim	S	S	S	S	+	S	S	S	S	S	S	
Avoids Interference	+	+	S	S	S	S	S	S	+	+	+	M
∑+	2	1	1	2	2	2	2	3	1	4	1	0
∑-	2	6	3	1	3	3	3	1	6	0	5	0
∑S	5	2	5	6	4	4	4	5	2	5	3	9

Table 11: Pairwise comparison matrix to determine criteria weight factors.

	Safe	Small	Light Weight	Low Cost	Easy to Operate	Easy to Assemble	Reliable	Avoids Interference	Score	Score +1
Safe		1	1	1	1	1	1	1	7	8
Small	0		1	1	0	0	0	0	2	3
Light Weight	0	0		1	0	0	0	0	1	2
Low Cost	0	0	0		0	0	0	0	0	1
Easy to Operate	0	1	1	1		1	1	1	6	7
Easy to Assemble	0	1	1	1	0		0	0	3	4
Reliable	0	1	1	1	0	1		0	4	5
Avoids Interference	0	1	1	1	0	1	1		5	6

Ranking:	Weight Factor:
Safe	8
Easy to Operate	7
Avoids Interference	6
Reliable	5
Easy to Assemble	4
Small	3
Light Weight	2
Low Cost	1

Table 12: Golf attachment weighted decision matrix.

	Weight Factor	Wheels on Both Ends		Wheel Inside Hollow Putter		Ball Bearing Axle and Round Corner with Wheel		Fixed putter head with end shaft bearings and spring box with wheel		Scale 0-3
Safe	8	1	8	1	8	2	16	3	24	
Small	3	1	3	1	3	2	6	2	6	
Light weight	2	2	4	2	4	3	6	2	4	
Low Cost	1	3	3	3	3	2	2	1	1	
Easy to Operate	7	2	14	2	14	2	14	2	14	
Easy to Assemble	4	2	8	1	4	2	8	2	8	
Reliable	5	1	5	1	5	2	10	3	15	
Avoids Interference	6	1	6	1	6	2	12	2	12	
∑			51		47		74		84	

Appendix C – Analysis

Appendix C.1 – Preliminary Load Analysis

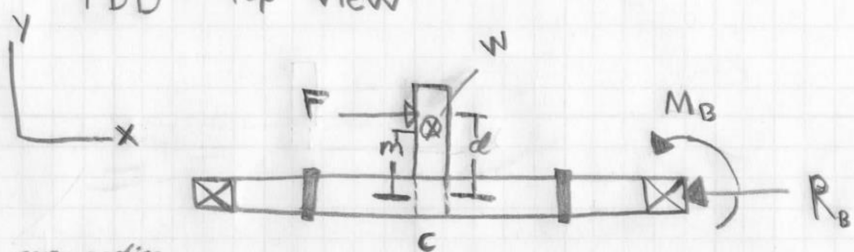
Design Analysis:

Beam with circular & hollow cross section-under bending and axial loads. Bearings will be @ ends of beam along with springs.

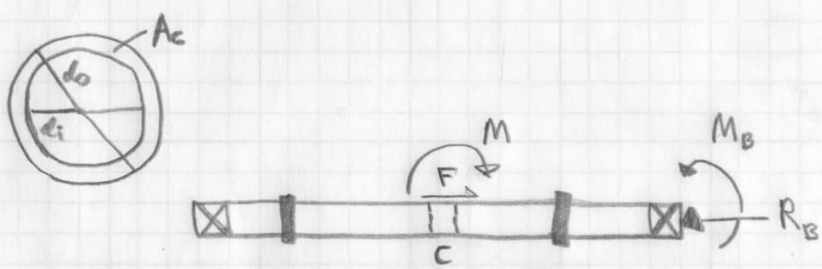
Loading:

Case I: Nathan is putting

FBD Top view



cross section



Assume: - Axial load is equally shared amongst two bolts/pins. $\Rightarrow F_B = \frac{F}{2} = \frac{R_B}{2}$

- Putter head and beam are considered one piece; therefore shear stress from surface traction will be ignored

- Moment arm 'd' goes from point contact of force to axis of beam.

Assume (cont.)

- Aluminum to be used
- m is moment arm distance for putter weight
- stress concentrations will be ignored
- weight of beam will be ignored
- W assumed to be 5 lbs

Stress calculations @ C

$$\sigma_a = \frac{F}{A_c}$$

$$\sigma_b = \frac{My}{I}, \quad M = Fd$$

- τ_{tor} from weight will be assumed negligible due to normal reaction support from wheel

$$\sigma = \pm\sigma_a \pm \sigma_b$$

$$\sigma_{1,2} = \frac{\sigma}{2} \pm \sqrt{\frac{\sigma^2}{4} + \tau^2} = \sigma$$ (τ^2 neg)

$$n = \frac{S_y}{\sigma_1}$$

allowed force from desired safety factor

- choose $n = 3$ ⇒

$$\sigma_1 = \frac{S_y}{n}$$ ⇒ (take magnitude of stress - compressive) ⇒

$$\left(\frac{F}{A_c} + \frac{Fdd_o}{2I}\right)\left(\frac{1}{2}\right) + \left(\left(\frac{F}{A_c} + \frac{Fdd_o}{2I}\right)^2\left(\frac{1}{4}\right)\right)^{1/2} = \frac{S_y}{n}$$

$$2\left(\frac{2A_c + dd_o}{4A_c^2 I}\right)F = \frac{S_y}{n}$$

$\Rightarrow$

$$F = \frac{S_y (4 A_c^2 I)}{2n(2A_c + d d_o)}$$

$$I = \frac{\pi}{64}(d_o^4 - d_i^4) \quad , \quad A_c = \frac{\pi}{4}(d_o^2 - d_i^2) \Rightarrow$$

$$F = \frac{4 S_y \left(\frac{\pi}{4}(d_o^2 - d_i^2)\right)^2 \frac{\pi}{64}(d_o^4 - d_i^4)}{2n\left(2\left(\frac{\pi}{4}(d_o^2 - d_i^2)\right)\right) + d d_o}$$

Values

$S_y = 35{,}000\ psi$ (Al 6061, McMaster Carr)

$n = 3$

Assumed

↓

$d_o = 1.25\ in$

$d_i = 1\ in$ $\Rightarrow$

$$F = \frac{4\left(35{,}000\frac{lb_f}{in^2}\right)\left(\frac{\pi}{4}(1.25in^2 - 1in^2)\right)^2 \frac{\pi}{64}(1.25in^4 - 1in^4)}{2(3)\left(\left(2\left(\frac{\pi}{4}(1.25in^2 - 1in^2)\right)\right) + (1.25in)(1in)\right)} \quad \frac{\left(\frac{lb_f}{in^2}\right)(in^4)}{in^2}$$

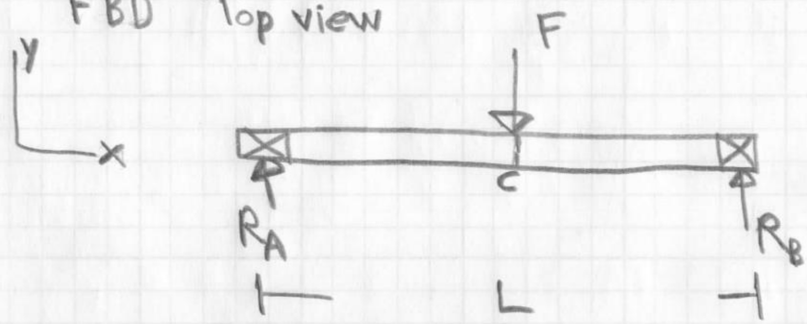
$$\boxed{F_{max} = 147.3\ lb_f}$$

The force to put will be substantially less than Fmax allowable.

CASE II:

Safety concern – with device attatched, Nathan drives into curb / wall / door. causing potential high impact loading

FBD Top view



Stress @ C

only σ_b is present

$$\sigma_b = \frac{My}{I} = \frac{FLd_o}{4(2)I}$$

assume $n = 4$ ⇒

$$\sigma_b = \frac{S_y}{n} \Rightarrow$$

$$\frac{FLd_o}{8I} = \frac{S_y}{4} \Rightarrow$$

$$F = \frac{2S_yI}{Ld_o} = \frac{2S_y\frac{\pi}{64}(d_o^4 - d_i^4)}{Ld_o}$$

$L = 14 \text{ in} \Rightarrow$

$$F = \frac{2(35{,}000 \frac{lb_f}{in^2})(1.25^4 in - 1^4 in)(\frac{\pi}{64})}{14 in (1.25 in)} \quad \frac{\frac{lb_f}{in^2}(in^4)}{in^2}$$

$F_{max} = 283.0 \; lb_f$

It seems unlikely that the impact force will exceed Fmax; and the S.F is 4.

Component Selection:

Tube/beam

6061 Aluminum tubes from McMaster Carr

Springs

Stainless steel compression springs from McMaster Carr

- Selection will be done process layed out in Shigley's 9th ed. ch 10.

Bearings

Due to axial load from putting, tapered roller bearings will need to be selected.
selection process to be from shigley's 9th ed. ch 11.
Timken or SKF will be used as manufacturer

Appendix C.2 – Kickball Guard Calculations

```
clc, clear, format compact

m=.031;  % mass of soccer ball [slugs]
dV=50;   % change in velocity of soccer ball after impact [ft/s] => ~ 35mph
dt=.050:.005:.1; % "delta t" [s] : created time interval for impulse to occur.
Fi=(m*dV)./(dt); % Newtons second law to find force on guards [lb]

L=[6 4 2.5]; % Effective Cantilever lengths of guards upon impact of ball
b=24;   % width of guard [in]
h=.125; % thickness of guard [in]
I=(b*h^3)/12; % Second Area Moment of Inertia of guards [in^4]
c=h/2; % distance to extreme fiber for bending stress [in]
F=Fi;  % renaming force for convienance during for loop
n=length(F);
Sy=3500;   % Yield stress of UHMWPE
E=110000; % Young's Modulus of Ultra High Molecular Weight Polyethylene (UHMWPE)

for j = 1:3
    for i=1:n
        M(i)=F(i)*L(j);      % Bending moment
        C=(L(j)^3)/(3*E*I); % multiplier constant
        y(j,i)= F(i)*C;      % deflection: iterrating through force and cantilever lengths
        sigma(j,i)=(M(i)*c)/I;     % Bending stress
        Sigma(j)=max(sigma(j,:)); % Getting max stress for each cantilever length
        Delta(j)=max(y(j,:));      % Getting max deflections for each cantilever length
        if sigma(i)>Sy
            disp ('yielding occurs')
    % If stress exceeds Sy, then print out the corresponding force & stress
            F(i)
            sigma(i)
        end
    end
end

disp('max "impulse" force (lb)')
F_m=max(Fi)
disp('max stresses (psi)')
Sigma
disp('max deflections (in)')
Delta
```

```
max "impulse" force (lb)
F_m =
    31
max stresses (psi)
Sigma =
        2976        1984        1240
max deflections (in)
Delta =
    5.1945    1.5391    0.3758
```

Appendix C.3 – Putting Calculations

```
clc, clear, format compact

m=.003; % mass of golf ball [slugs]
V=70;   % final velocity of golf ball after impact [ft/s] => ~ 50mph. Assumed Vi=0
dt=.005:.0005:.02; % "delta t": created time interval for impulse to occur.
L=16;   % length of shaft [in]
do=1;   % outer diameter of shaft  [in]
di=.75; % innner diameter of shaft [in]
d=16;   % moment arm length: from end of putter (worse case) to the center of the shaft [in]
Fi=(m*V)./(dt);    % Newtons second law to find force on putter [lb]
F=40:5:120;  % Force inputs for putting loading [lb]. max force above is 42 lb

Ac=(pi/4)*((do)^2-(di)^2);  % Cross sectional area of shaft [in^2]
I=(pi/64)*((do)^4-(di)^4);  % Second Area Moment of Inertia of shaft  [in^4]
Sy=35000;    % Yield strength of 6061 Aluminum shaft from McMaster Carr. [Psi]
E=10000000;  % Young's Modulus of Aluminum [Psi]

% For loop calculating principal stress
n=length(F);
for i=1:n
    % principal stress on shaft; bending and axial components
    sigma(i)=((1/Ac)+((d*do)/(2*I)))*F(i);
        if sigma(i)> Sy
         disp('Yielding occurs  ')
% If stress exceeds Sy, then print out the corresponding force & stress
        F(i)
        sigma(i)
    end
    C=(d*(L^2))/((E*I)*(72*(sqrt(3)))); % multiplier constant
    delta(i)=(F(i))*C;
end

disp('max "impulse" force (lb)')
F_m=max(Fi)
disp('max stress (psi)')
Sigma=max(sigma)
disp('max deflection (in)')
Delta=max(delta)
```

```
max "impulse" force (lb)
F_m =
    42
max stress (psi)
Sigma =
   2.8958e+04
max deflection (in)
Delta =
    0.0117
```

Appendix C.4 – Direct Impact Calculations

```
clc, clear, format compact

L=16;   % length of shaft [in]
do=1;   % outer diameter of shaft  [in]
di=.75; % innner diameter of shaft [in]
t=.16;  % thickness of aluminum plate [in]
F=[50:25:500]; % Force inputs for direct impact loading [lb]

I=(pi/64)*((do)^4-(di)^4);  % Second Area Moment of Inertia of shaft  [in^4]
Sy=35000;    % Yield strength of 6061 Aluminum shaft from McMaster Carr. [Psi]
E=10000000;  % Young's Modulus of Aluminum [Psi]

% For loop calculating stresses and deflections
n=length(F);
for i=1:n
    sigma(i)=((L*do)/(8*I))*F(i);  % bending stress
    bearing_stress(i)=((F(i))/2)/(do*t);  %bearing stress
    % If stresses exceeds Sy, then print out the corresponding force & stress
    if bearing_stress(i) > Sy
        disp('Yielding occurs ')
        F_bearing_failure= (F(i))
        failure_bearing_stress=sigma(i)
    end

    if sigma(i)> Sy
        disp('Yielding occurs  ')
        F_failure= (F(i))
        failure_stress=sigma(i)
    end
    C=(L^3)/(192*E*I);   % multiplier constant
    delta(i)=(F(i))*C;
end

disp('max bearing stress (psi)')
Bearing_Stress=max(bearing_stress)
disp('max stress (psi)')
Sigma=max(sigma)
disp('max deflection (in)')
Delta=max(delta)
```

```
max bearing stress (psi)
Bearing_Stress =
   1.5625e+03
max stress (psi)
Sigma =
   2.9801e+04
max deflection (in)
Delta =
    0.0318
```

Appendix C.5 – Weld Calculations

```
clc
clear
format compact

D=14;    % moment arm length [in]
d=.675; % inner distance between T-join Aluminum plates [in]
b=1.5;  % length T-join plates [in]

N= 1.67 ;   % safety factor as given by Shigley's and determined from D.E.T
F=40:5:120; % Force inputs for putting loading [lb]
Sy=18000;   % Yield stress of tig welding wire- ER4043

n=length(F);
for i=1:n

    h(i)= (((N^2)/((.577^2)*(Sy^2)))*(((1.414^2)*(F(i).^2)*(D^2))/((b^2)*(d^2)) + (F(i).^2)/(
1.414^2)*(b^2))))^.5;

end

f_h=F(h<=.2);    % Considering only forces that produce welds below .2 inches
f_m=max(f_h);    % Finding the max force of the above partitioned force array
disp(' Design weld size (in) ')
h_design=h(F==f_m)  % getting the weld size of the max partitioned force from above
h_m=max(h)/16;  % how many "sixteenths of an inch" the weld size is- for comparison
```

```
 Design weld size (in)
h_design =
    0.1887
```

Published with MATLAB® R2014a

Appendix D – Preliminary Wheel Testing

Testing Procedure

Mounting wheels:

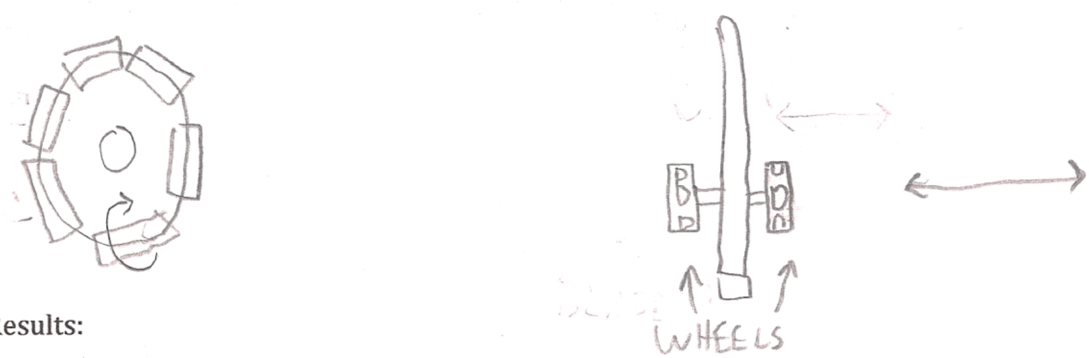
1. Drill ¼” hole near bottom and back of blade.
   - Locate hole 8” from front of blade and ½” from bottom of blade.
2. Slide 6 mm hardened steel shaft through drilled hole.
3. Slide 2” diameter omni wheels onto either side of blade.
4. Wrap ½” thick duct tape 4 times around shaft on either side of each wheel.

Testing wheels:

1. Hold end of shaft in hands so that both wheels rest on ground and bottom of shaft is parallel to the ground with ¼”-½” ground clearance.
2. Move shaft in primary rolling direction and secondary rolling direction on each test surface.
3. For each test, allow weight of blade to rest on wheels but do not apply any more force to wheels.

Primary Rolling:

Secondary Rolling:



Test Results:

	Hardwood	Smooth Cement	Rough Asphalt	Industrial Carpet	Shag Carpet	Artificial Grass	Lawn-length Grass
Primary Rolling	PASS	PASS	PASS	PASS	PASS	PASS	FAIL
Secondary Rolling	PASS	PASS	FAIL	PASS	FAIL	PASS	FAIL

Appendix E – Hazard Identification Checklist

ME428/429/430 Senior Design Project 2014-2015

SENIOR PROJECT CRITICAL DESIGN HAZARD IDENTIFICATION CHECKLIST

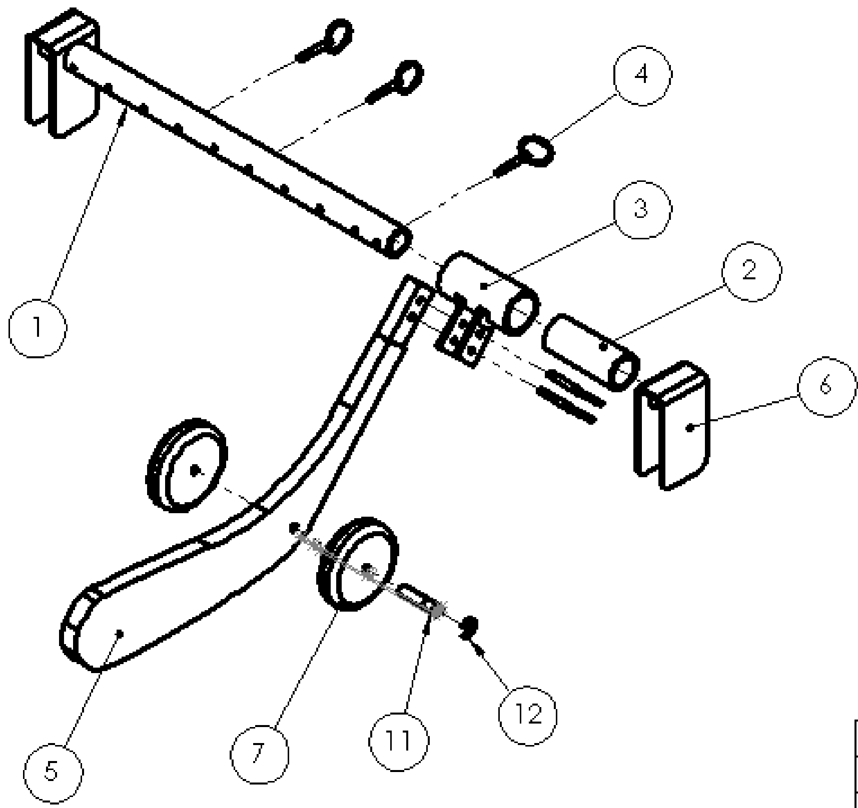
Team: Eight Blue Dogs Advisor: Peter Schuster

Y	N	
☒	☐	Do any parts of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points adequately guarded?
☐	☒	Does any part of the design undergo high accelerations/decelerations that are exposed to the user?
☐	☒	Does the system have any large moving masses or large forces that can contact the user?
☒	☐	Does the system produce a projectile?
☐	☒	Can the system to fall under gravity creating injury?
☐	☒	Is the user exposed to overhanging weights as part of the design?
☐	☒	Does the system have any sharp edges exposed?
☐	☒	Are there any ungrounded electrical systems in the design?
☐	☒	Are there any large capacity batteries or is there electrical voltage in the system above 40 V either AC or DC?
☐	☒	Is there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids when the system is either on or off?
☐	☒	Are there any explosive or flammable liquids, gases, dust, or fuel in the system?
☐	☒	Is the user of the design required to exert any abnormal effort and/or assume a an abnormal physical posture during the use of the design?
☐	☒	Are there any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
☐	☒	Will the system generate high levels of noise?
☒	☐	Will the product be subjected to extreme environmental conditions such as fog, humidity, cold, high temperatures ,etc. that could create an unsafe condition?
x2 on back ☒	☐	Is it easy to use the system unsafely?
☐	☒	Are there any other potential hazards not listed above? If yes, please explain on the back of this checklist.

For any "Y" responses, add a complete description on the reverse side. DO NOT fill in the corrective actions or dates until you meet with the mechanical and electrical technicians.

Description of Hazard	Corrective Actions to be Taken	Planned Completion Date	Actual Completion Date
When attaching golf attachment to Standing Dani, hands/fingers could be pinched between U-brackets & Standing Dani	Make it clear in the report and presentation to Nathan and family that hands/fingers should be clear of bracket when placing it on the S.D.	5/29/15	
The system produces a golf ball projectile, but on the ground & at low speeds	Not a hazard	N/A	
The system will be used and stored outdoors, and could be subject to heat, cold, water, & sunlight	Verify that plastic chosen does not break down in sunlight and communicate that it should not be left in the sun unnecessarily.	4/21/15	
Nathan could drive into something with the putter attachment.	Ensure through testing that the velcro fails before any other components. Reduce surface area of velcro as necessary	4/21/15	
Nathan could play kickball with putter shaft in place, creating new tipping hazard	Make it clear in the report and presentation to Nathan & family that bar is to be removed when done golfing/before kickball	5/29/15	

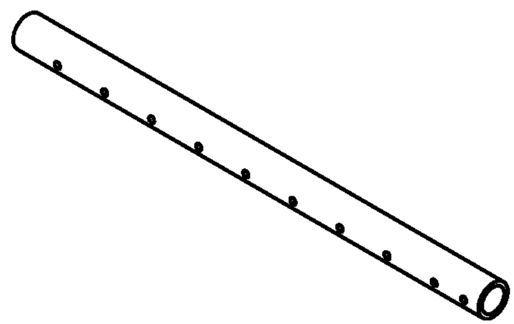
Appendix F – Solid Models and Part Drawings



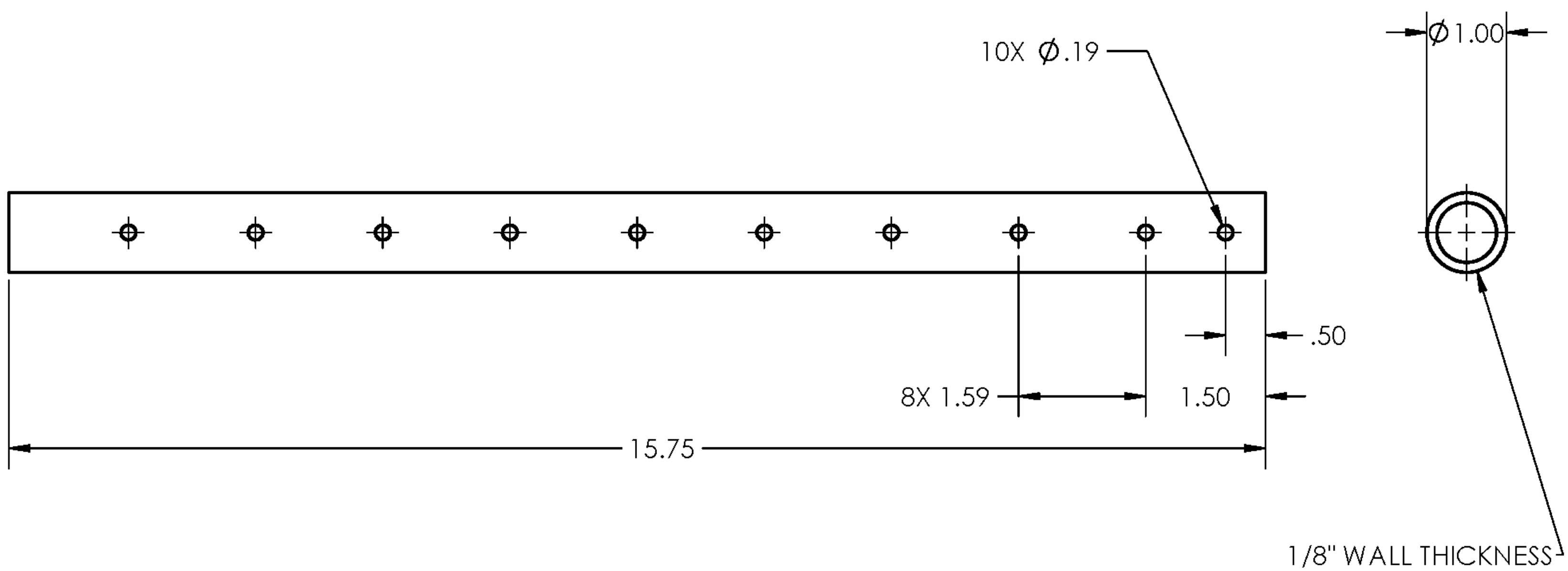
ITEM NO.	PART NUMBER	QTY.
12	98408A134	1
11	2025K6	1
10	Velcro Up Down	2
7	wheel	2
6	Ubracket	2
5	Hockey Stick	1
4	98404A010	5
3	Tjoint	1
2	Plastic Tube	1
1	Putter Shaft	1

Cal Poly Mechanical Engineering	Lab Section: 1	8 BLUE DOGS	Title: GOLF ATTACHMENT BOM		Drwn. By: DB. CH. JG
ME 429 - SPRING 2014	Dwg. #:	Nxt Asb:	Date: 2/5/15	Scale:	Chkd. By:

Appendix F.1 – Putting Attachment Detailed Drawings

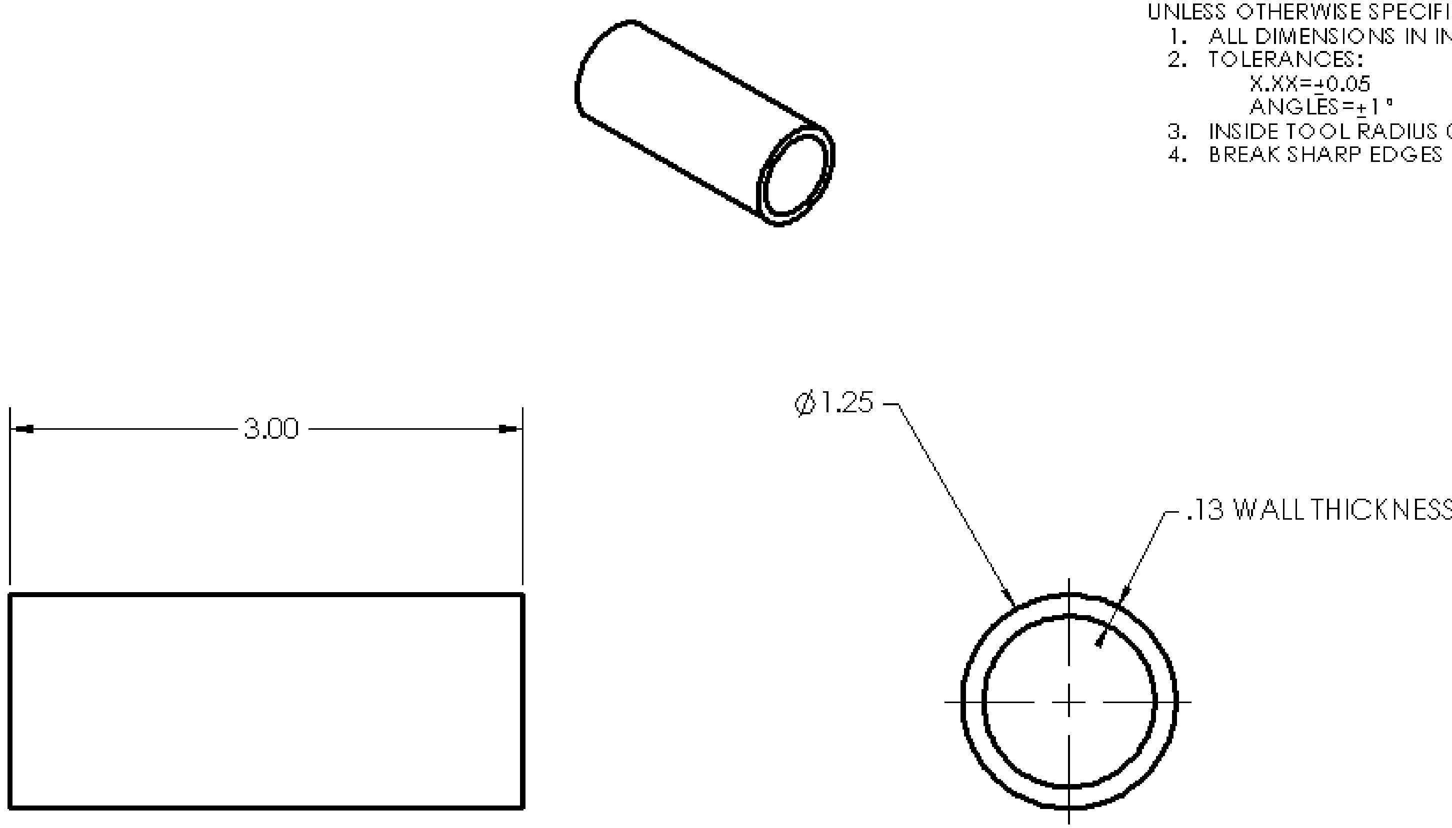


NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
   X.XX= ±0.05
   ANGLES= ±1°
3. INSIDE TOOL RADIUS 0.5 MAX.
4. BREAK SHARP EDGES 0.5 MAX.

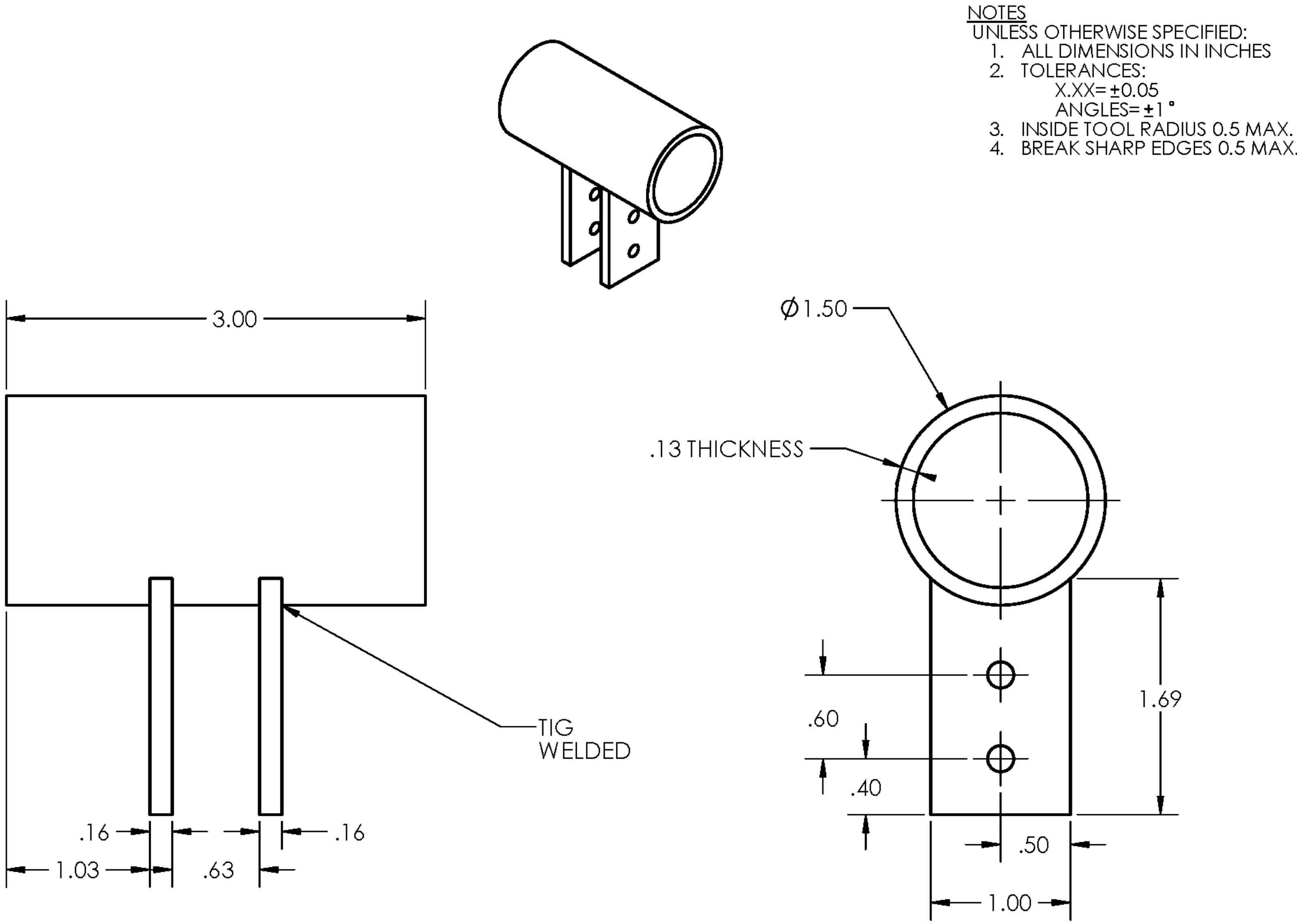


Cal Poly Mechanical Engineering ME 429 - SPRING 2014	Lab Section: 1	8 BLUE DOGS	Title: MAIN SHAFT		Drwn. By: DB, CH, JG
	Dwg. #: 9056K36	Nxt Asb:	Date: 2/5/15	Scale: 1=1	Chkd. By:

NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
   X.XX=±0.05
   ANGLES=±1°
3. INSIDE TOOL RADIUS 0.5 MAX.
4. BREAK SHARP EDGES 0.5 MAX.

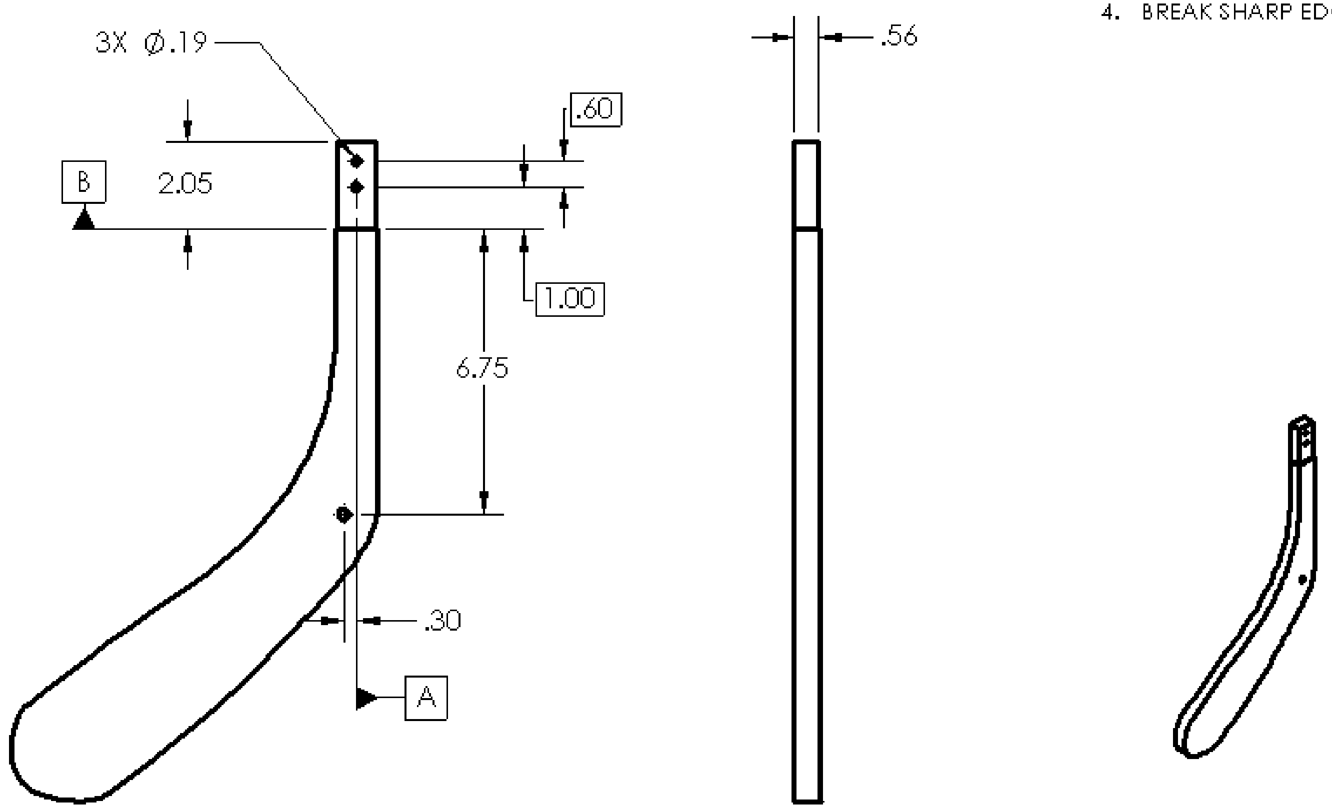


Cal Poly Mechanical Engineering ME 429 - SPRING 2014	Lab Section: 1	8 BLUE DOGS	Title: PLASTIC BUSHING	Drwn. By: DB. CH. JG
	Dwg. #:	Nxt Asb:	Date: 2/5/15 · Scale: 1=1	Chkd. By:



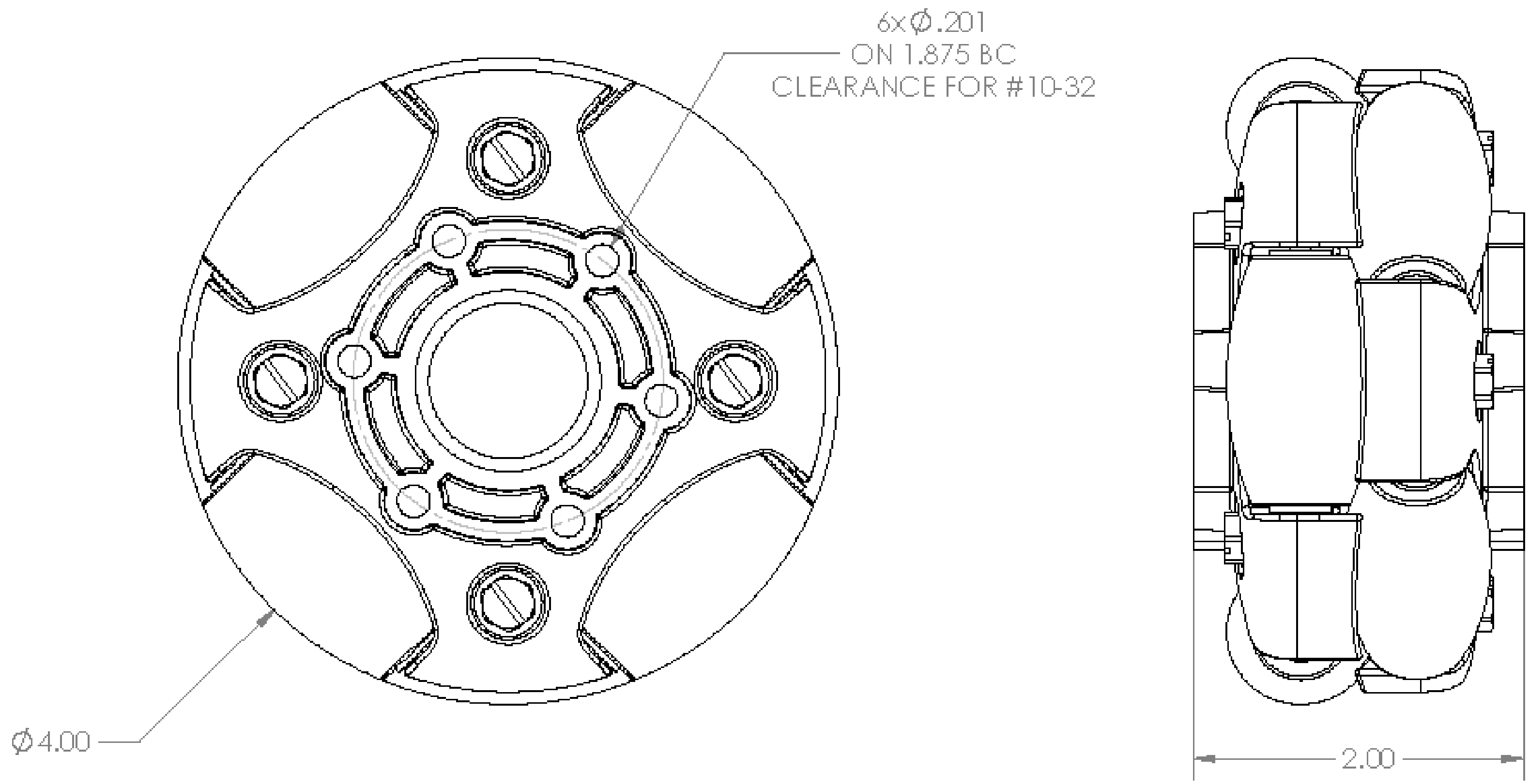
Cal Poly Mechanical Engineering	Lab Section: 1	8 BLUE DOGS	Title: T-JOINT		Drwn. By: DB, CH, JG
ME 429 - SPRING 2014	Dwg. #:	Nxt Asb:	Date: 2/5/15	Scale: 1=1	Chkd. By:

NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
   X.XX=±0.05
   ANGLES=±1°
3. INSIDE TOOL RADIUS 0.5 MAX.
4. BREAK SHARP EDGES 0.5 MAX.



Cal Poly Mechanical Engineering	Lab Section: 1	8 BLUE DOGS	Title: HOCKEY STICK		Drwn. By: DB, CH, JG
ME 429 - SPRING 2014	Dwg. #:	Nxt Asb:	Date: 2/5/15	Scale: 1=1	Chkd. By:

Rev	Discription of Changes
1	Original Print
0.5	Bolt circle hole diameter updated.



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL± ANGULAR: MACH± BEND ±° TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.005	DRAWN	NL	1/30/15
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

AndyMark

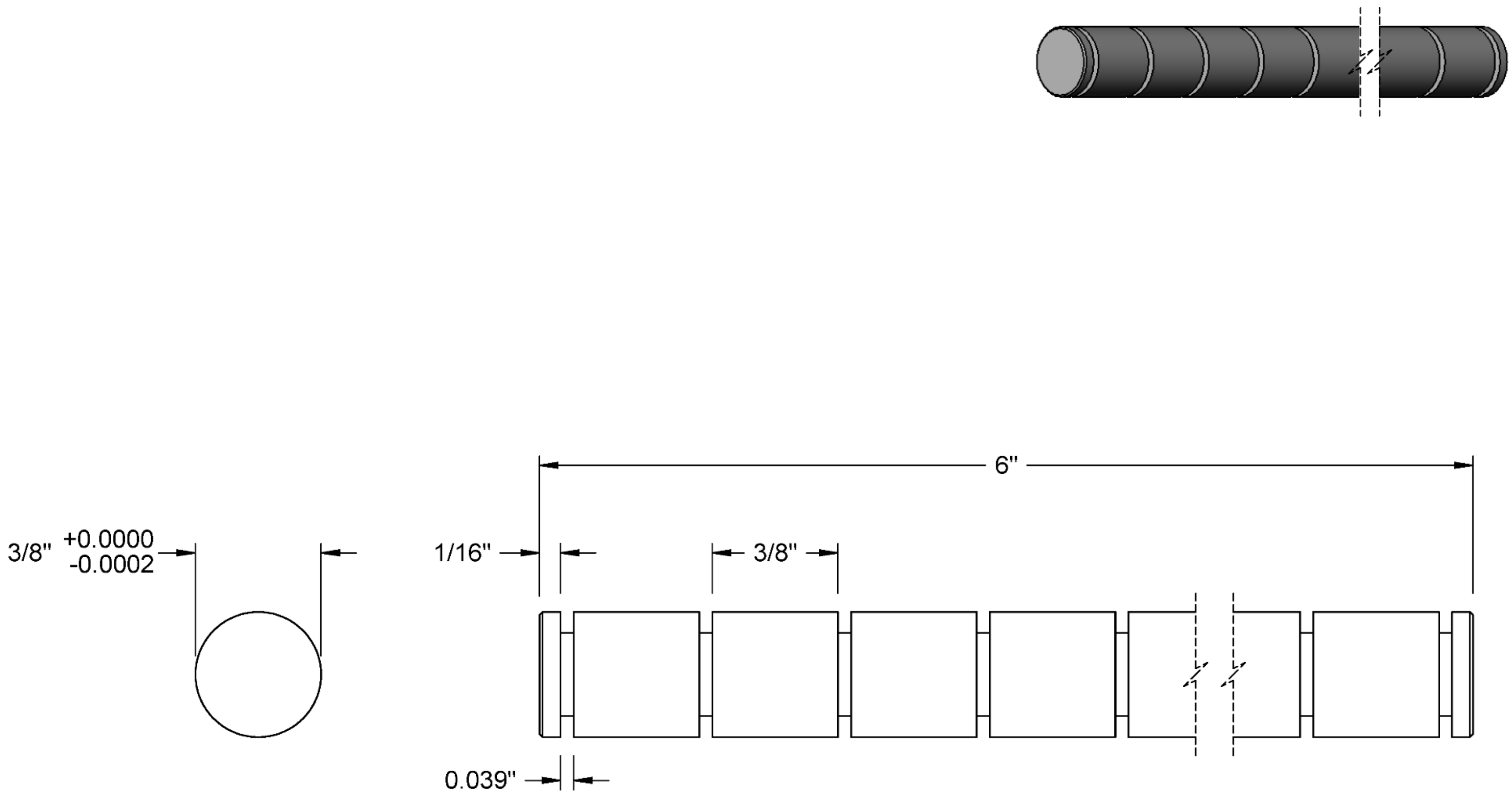
TITLE:

4" DuraOmni Layout Print

SIZE	DWG. NO.	REV
A	am-3030	0.5

SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1



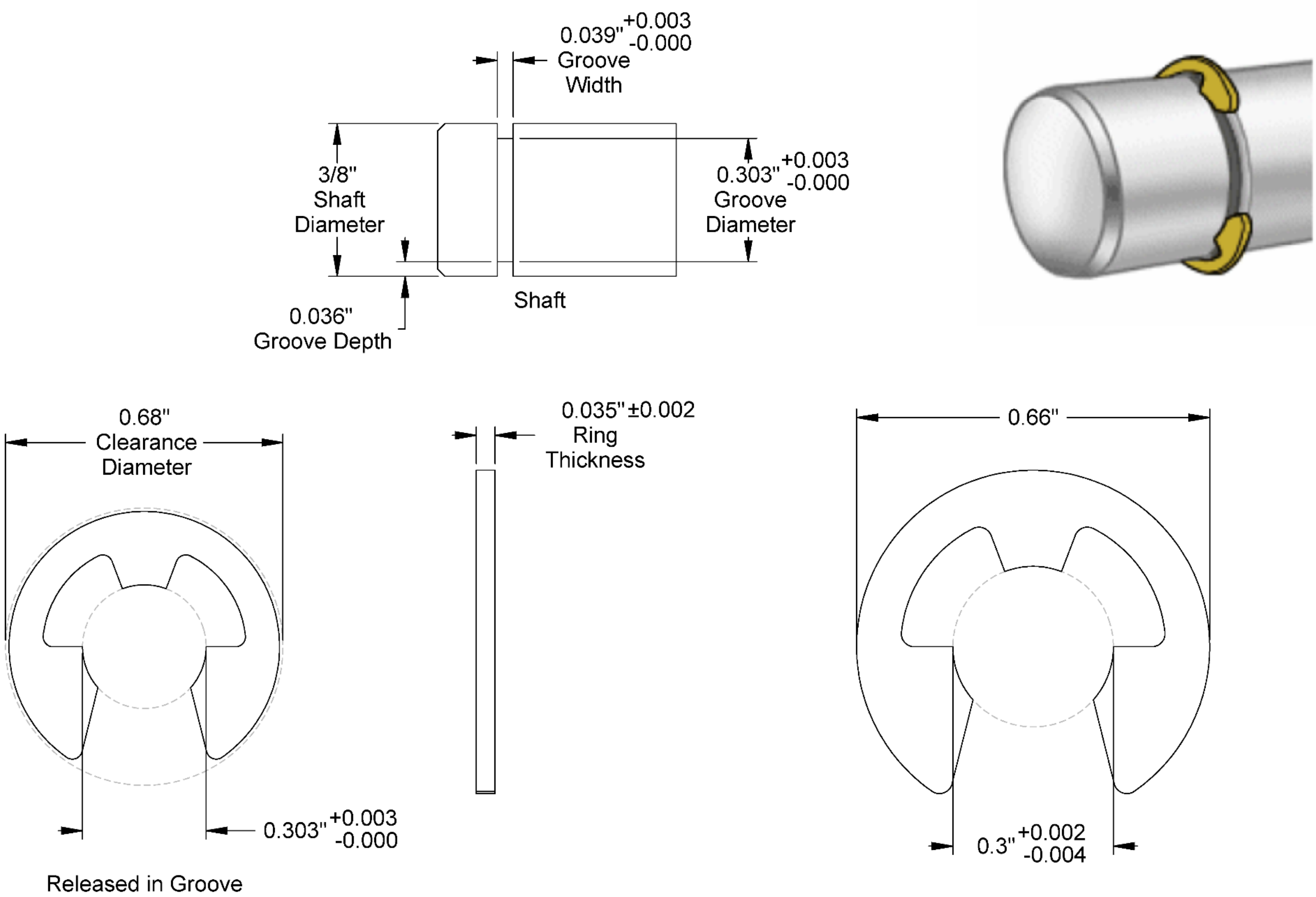
Straightness Tolerance is 0.0008" per Inch

McMASTER-CARR® CAD

PART NUMBER **2025K6**

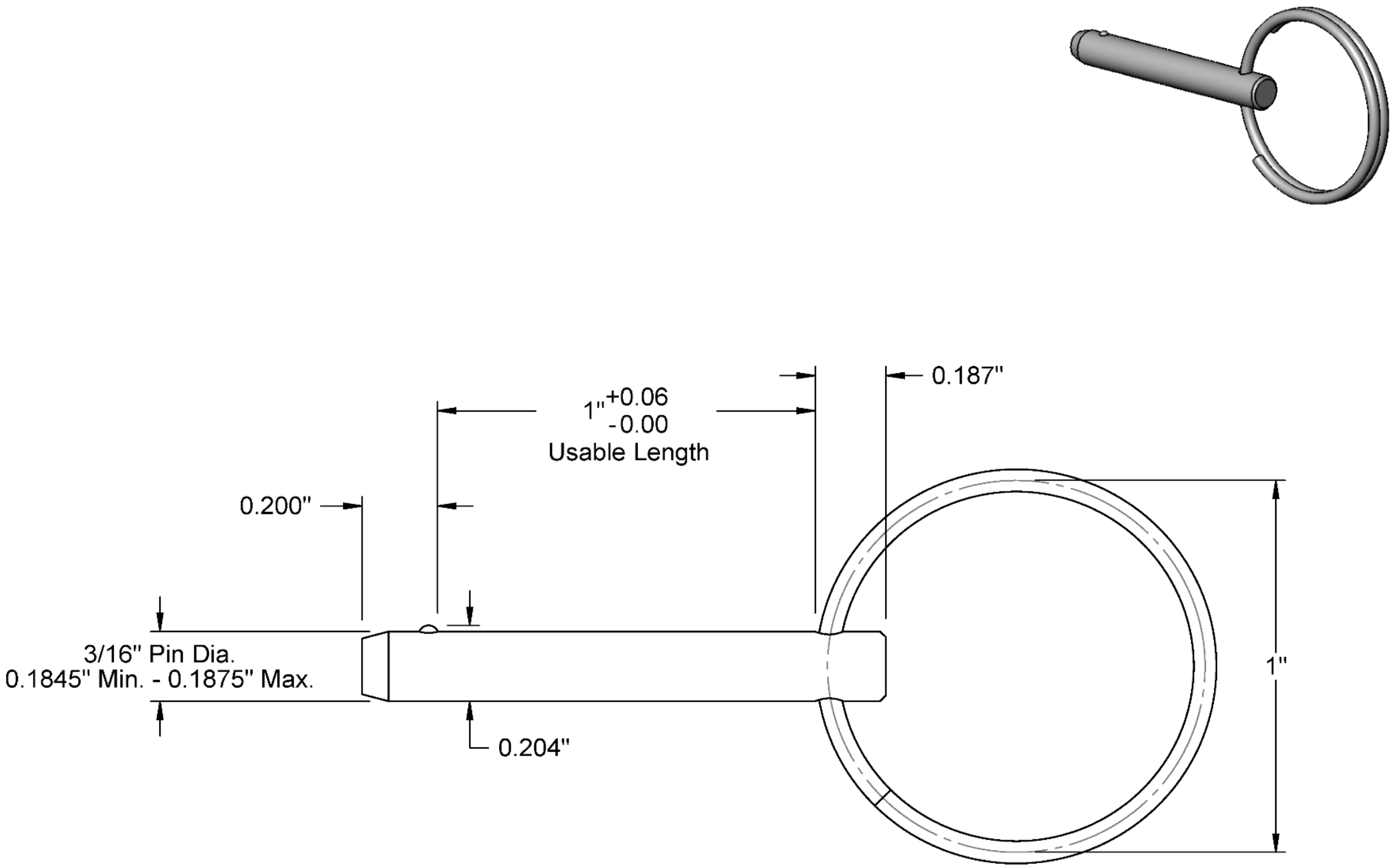
http://www.mcmaster.com

Shaft with Retaining Ring Grooves



Note: Clearance diameter is the diameter of a housing that can pass freely over the ring.

McMASTER-CARR® CAD	PART NUMBER 98408A134
http://www.mcmaster.com © 2011 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Stainless Steel Side-Mount External Retaining Ring

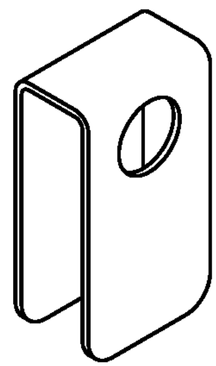


McMASTER-CARR® CAD

PART NUMBER **98404A010**

http://www.mcmaster.com

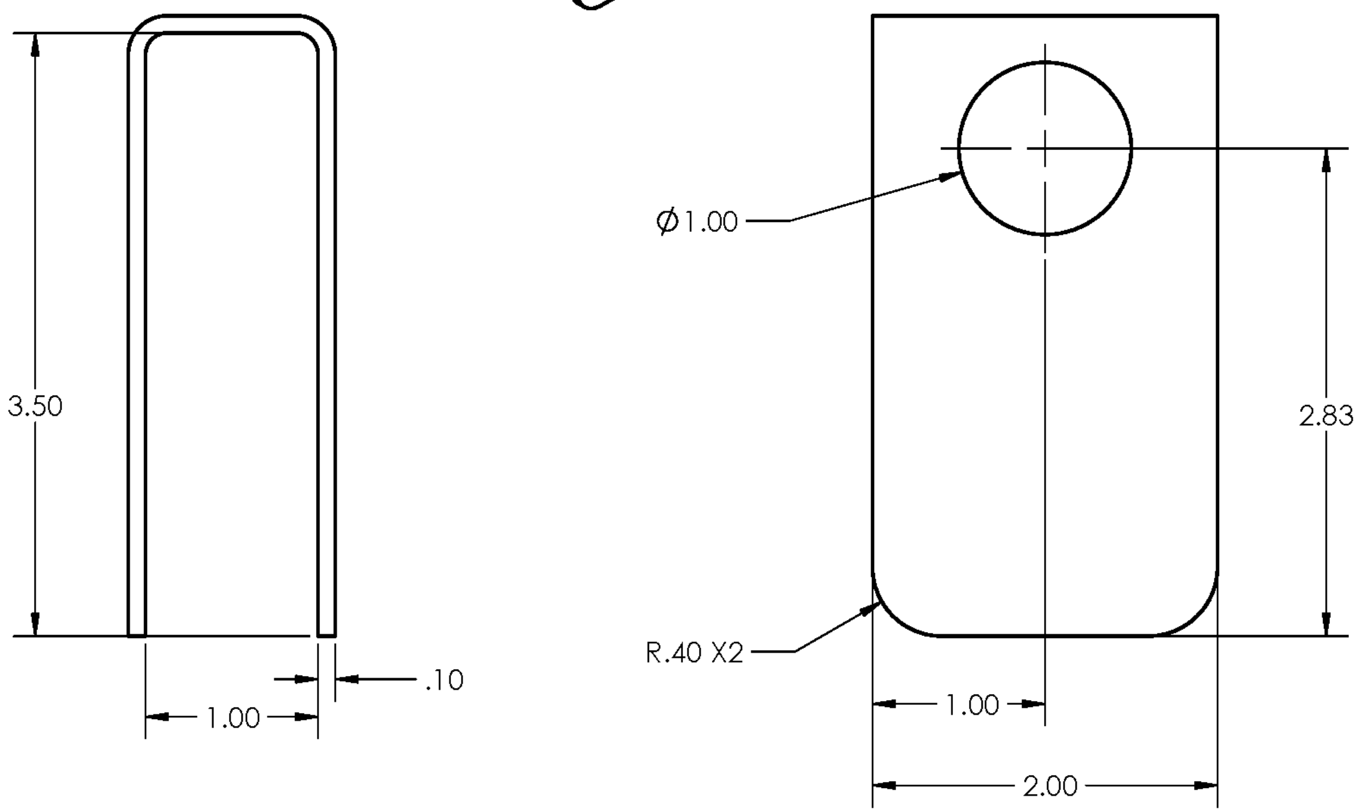
18-8 Stainless Steel
Quick-Release Pin



NOTES

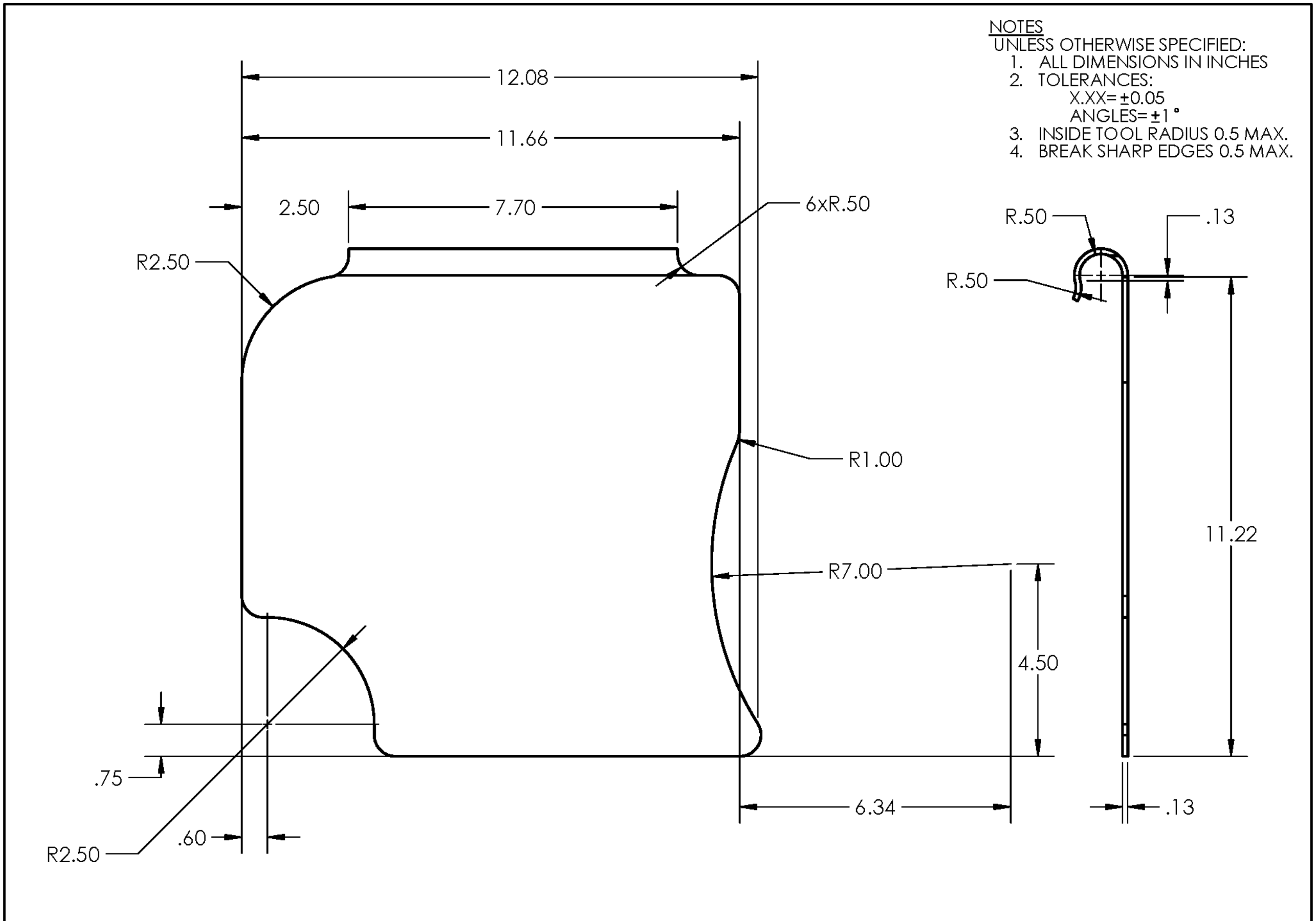
UNLESS OTHERWISE SPECIFIED:

1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
   X.XX= ±0.05
   ANGLES= ±1 °
3. INSIDE TOOL RADIUS 0.5 MAX.
4. BREAK SHARP EDGES 0.5 MAX.



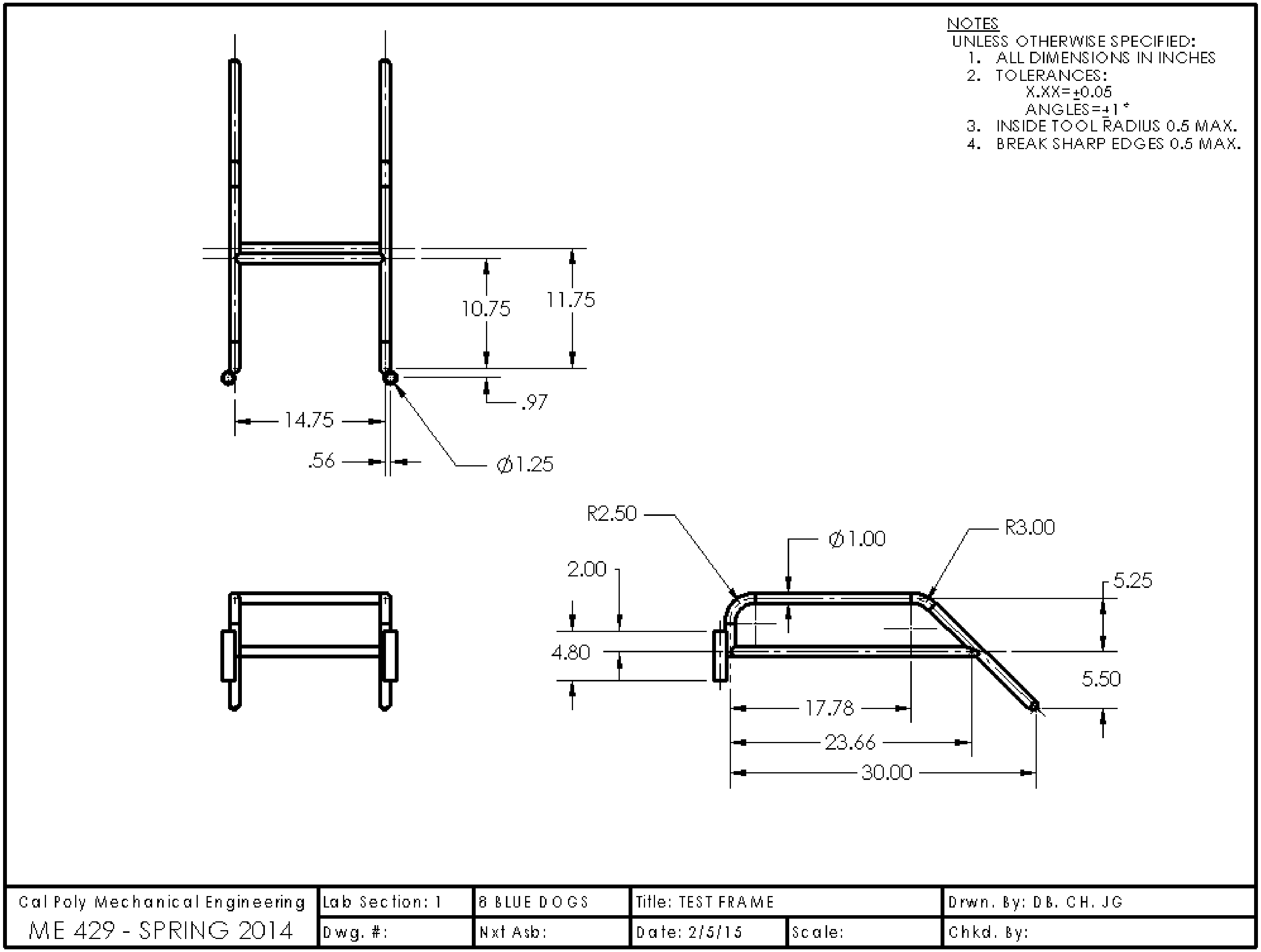
Cal Poly Mechanical Engineering ME 429 - SPRING 2014	Lab Section: 1	8 BLUE DOGS	Title: U-BRACKET		Drwn. By: DB, CH, JG
	Dwg. #:	Nxt Asb:	Date: 2/5/15	Scale: 1=1	Chkd. By:

Appendix F.2 – Kickball Guards Detailed Drawings



Cal Poly Mechanical Engineering	Lab Section: 1	8 BLUE DOGS	Title: KICKBALL SIDE GUARDS		Drwn. By: DB, CH, JG
ME 429 - SPRING 2014	Dwg. #:	Nxt Asb:	Date: 2/5/15	Scale: 1=1	Chkd. By:

Appendix F.3 – Test Frame Detailed Drawing



Appendix G – Purchased Items Literature

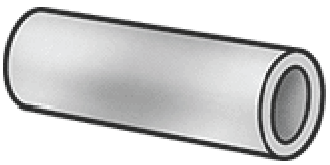
MCMASTER-CARR® OVER 555,000 PRODUCTS

(562) 692-5911
(562) 695-2323 (fax)
la.sales@mcmaster.com
Text 75930

Multipurpose 6061 Aluminum Tube

9056K36

1" OD, .125" Wall Thickness



OD	1"
ID	3/4"
Length	1/2 ft., 1 ft., 2 ft., 3 ft., 6 ft.
Yield Strength	35,000 psi
Hardness	Soft (95 Brinell)
Temper	Heat Treated (T6511, unless noted)
Additional Specifications	Round Tubes—Unpolished 0.125" Wall Thick. (±0.020") Meet ASTM B241, unless noted Temper is T6. Meet ASTM B210.

The most widely used aluminum, Alloy 6061 is a popular choice for vehicle parts and pipe fittings. It has better corrosion resistance and weldability than Alloys 2024 and 7075, but it's not as strong. It is nonmagnetic, heat treatable, and resists stress cracking. Temperature range is -320° to 300° F.

View detailed performance properties and composition for aluminum.

Yield strength is approximate and may vary based on size and shape.

OD tolerance for 1" to 6 1/2" dia. tubes is ±0.035". Straightness tolerance for 3/8" to 6 1/2" dia. tubes is 0.020" per foot. Length tolerance for 1/2-ft. lengths is ±1/2". Length tolerance for 1-ft. to 6-ft. lengths is ±1".

McMASTER-CARR® OVER 555,000 PRODUCTS
(562) 692-5911
(562) 695-2323 (fax)
la.sales@mcmaster.com
Text 75930

UHMW Bearing

Sleeve, for 1" Shaft Diameter, 1-1/4" OD, 1-1/2" Length

In stock
$8.84 Each
57785K45

For Shaft Diameter	1"
OD	1 1/4"
Length	1 1/2"
For Shaft Diameter Tolerance	+0.006" to +0.020"
OD Tolerance	+0.004" to +0.008"
Length Tolerance	-0.005" to +0.005"
Material	UHMW
Temperature Range	-200° to 180° F
P Maximum	1,000
V Maximum	100
PV Maximum	2,000

UHMW—Ultra-high molecular weight (UHMW) polyethylene is USDA approved and FDA compliant. It withstands wet, corrosive environments.

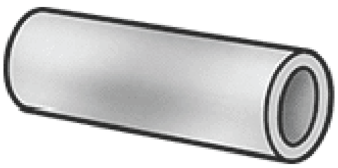
McMASTER-CARR® OVER 555,000 PRODUCTS

(562) 692-5911
(562) 695-2323 (fax)
la.sales@mcmaster.com
Text 75930

Multipurpose 6061 Aluminum Tube

9056K38

1-1/2" OD, .125" Wall Thickness



OD	1 1/2"
ID	1 1/4"
Length	1/2 ft., 1 ft., 2 ft., 3 ft., 6 ft.
Yield Strength	35,000 psi
Hardness	Soft (95 Brinell)
Temper	Heat Treated (T6511, unless noted)
Additional Specifications	Round Tubes—Unpolished 0.125" Wall Thick. (±0.020") Meet ASTM B241, unless noted Temper is T6. Meet ASTM B210.

The most widely used aluminum, Alloy 6061 is a popular choice for vehicle parts and pipe fittings. It has better corrosion resistance and weldability than Alloys 2024 and 7075, but it's not as strong. It is nonmagnetic, heat treatable, and resists stress cracking. Temperature range is -320° to 300° F.

View detailed performance properties and composition for aluminum.

Yield strength is approximate and may vary based on size and shape.

OD tolerance for 1" to 6 1/2" dia. tubes is ±0.035". Straightness tolerance for 3/8" to 6 1/2" dia. tubes is 0.020" per foot. Length tolerance for 1/2-ft. lengths is ±1/2". Length tolerance for 1-ft. to 6-ft. lengths is ±1".

PRODUCTS
Deals of the Day
New Products
FIRST
Gearbox / Transmission
Wheels
Drive Chassis Bases
Extrusion and Structure
Electrical Components
Gears
Bearings
Hubs
Motors
Hardware
Tools
Sprockets and Chain
Pneumatics
Browse ALL Products
Custom Builds
Discontinued
Education
Calendar / Events
Contact Us

Home > Wheels > Omni Wheels >

4" DuraOmni Wheel w/ 3/8" Bearings (am-3080)

Price: $29.00

Stock Status: In Stock

Qty

Larger Photo

Like Share 0

Description **Files & Documents**

Product Overview:
4" DuraOmni Wheel with 3/8" id bearings

This new Heavy Duty (HD) omni wheel is a vast improvement over our older 4" omni wheels and other wheels on the market. The body has been totally redesigned wi
in mind. The design intent is to provide a smooth roll along with the ability to handle impacts very well.

The body is made from black polycarbonate, while the rollers are each molded with a nylon core and TPU tread. These rollers spin smoothly on a captured 1/8" x 1.87

Specifications:

- Diameter: 4 inches
- Width Across Middle: 2.0 inches
- Bore: 0.375 inch
- Bolt Pattern: 6 holes on a 1.875 inch bolt circle
- Body Material: Black polycarbonate
- Load Capacity: 120 pounds (rollers don't spin past this point)
- Weight: 0.72 pounds
- Number of Rollers: 8
- Roller Material, Outside: Gray TPU rubber
- Roller Durometer: 77A
- Roller Material, Inside: white nylon
- Roller Bearing Material: nylon spinning on steel
- Roller Axle: 1/8" diameter steel dowel pin
- Roller Length: 1.62 inches
- Roller Diameter: 0.9 inch
- Assembled and Repairable by installing or removing 10-24 screws

Included Hardware:

- One - Interior polycarbonate body piece
- Two - Outer polycarbonate body pieces
- Eight - Gray Rollers
- Eight - 1.875x1/8 Steel Dowel Pins
- Eight - #10-24 x 0.50" Hex Head Screws, thread-forming

Usage:
With Axle and Hub:

- If you wish to drive one of these wheels with an axle and hub, then no bearings are needed. Use am-3047 instead.

With Sprocket:

- To drive this wheel with a sprocket, the sprocket needs to be attached to the side of the wheel with screws. This setup will work nicely spinning over a 3/8" diam

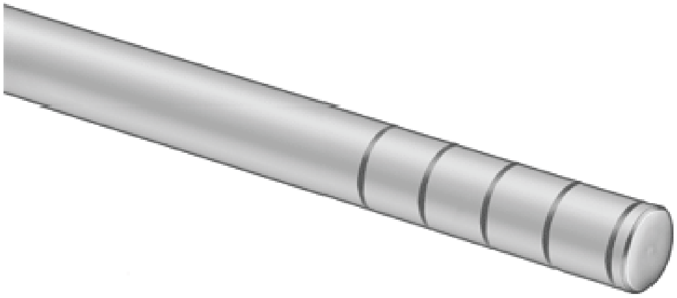
http://www.andymark.com/

McMASTER-CARR® OVER 555,000 PRODUCTS
(562) 692-5911
(562) 695-2323 (fax)
la.sales@mcmaster.com
Text 75930

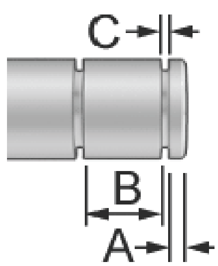
303 Stainless Steel Shaft with Retaining Ring Grooves

3/8" OD, 6" Overall Length

In stock
$12.44 Each
2025K6



Material	Type 303 Stainless Steel
Diameter	3/8"
Diameter Tolerance	-0.0002" to 0"
(A)	1/16"
(B)	3/8"
Groove Width (C)	0.039"
Overall Length	6"
Straightness Tolerance	0.0008" per inch



Multiple grooves (four or five on one end; two on the other) allow mounting flexibility, positioning bearings in a fixed spot, and using these shafts as an axle. All are Type 303 stainless steel and have good corrosion resistance. Hardness is Rockwell B83. Straightness tolerance is 0.0008" per inch. Ends are beveled. (Retaining rings are not included.)

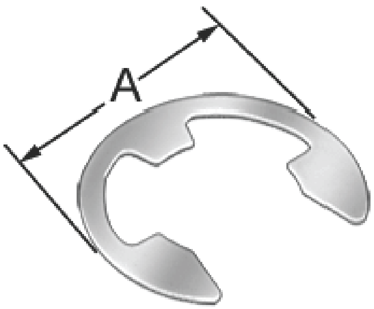
http://www.mcmaster.com/

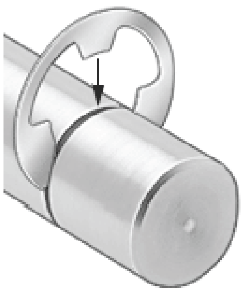
McMASTER-CARR® OVER 555,000 PRODUCTS
(562) 692-5911
(562) 695-2323 (fax)
la.sales@mcmaster.com
Text 75930

Side-Mount External Retaining Ring (E-Style)

Stainless Steel, for 3/8" Shaft Diameter

In stock
$4.45 per pack of 10
98408A134





For Shaft Diameter	3/8"
Fits Groove	
Diameter	0.303"
Width	0.039"
Ring Size	
(A)	0.66"
Thickness	0.035"
Additional Specifications	Stainless Steel
RoHS	Compliant

Snap rings into the groove from the side of the shaft. Their three prongs make contact with the shaft and provide a wider shoulder than other external retaining rings for a larger retaining surface. They are magnetic.

Stainless steel rings are made of Type 15-7 or 17-7 PH stainless steel. Minimum Rockwell hardness is C44.

http://www.mcmaster.com/

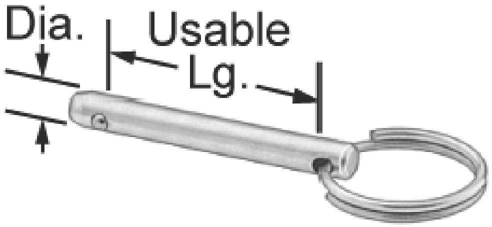
McMASTER-CARR® OVER 555,000 PRODUCTS

(562) 692-5911
(562) 695-2323 (fax)
la.sales@mcmaster.com
Text 75930

18-8 Stainless Steel Quick-Release Pin

3/16" Diameter, 1" Usable Length

In stock
$1.85 Each
98404A010



Usable Length	1"
Additional Specifications	18-8 Stainless Steel without Lanyard 3/16" Dia.—Breaks at 2,700 lbs.
RoHS	Compliant

Also known as faspins, these pins have a ring grip. The ball springs inward during installation and pops out to lock the pin in place. The ball and spring are Type 316 stainless steel. The pin diameter equals the hole size. Shaft diameter tolerance is -0.003". Shafts have a minimum Rockwell hardness of B85, except aluminum have a minimum Rockwell hardness of B56. Breaking strength is measured as single shear, which is the force required to break a pin into two pieces.

18-8 stainless steel pins are more corrosion resistant than zinc-plated pins and may be mildly magnetic.

http://www.mcmaster.com/

McMASTER-CARR® OVER 555,000 PRODUCTS

(562) 692-5911
(562) 695-2323 (fax)
la.sales@mcmaster.com
Text 75930

Multipurpose 6061 Aluminum

Sheet, .160" Thick, 12" x 12"

In stock
$34.13 Each
89015K94

Material Certification	Sheets
Thickness	0.160"
Thickness Tolerance	±0.009"
Yield Strength	35,000 psi
Hardness	Soft (95 Brinell)
Temper	Heat Treated (T6)
Additional Specifications	Sheets—Unpolished 12" × 12" Meet ASTM B209
RoHS	Compliant

The most widely used aluminum, Alloy 6061 is a popular choice for vehicle parts and pipe fittings. It has better corrosion resistance and weldability than Alloys 2024 and 7075, but it's not as strong. It is nonmagnetic, heat treatable, and resists stress cracking. Temperature range is -320° to 300° F.

View detailed performance properties and composition for aluminum.

Yield strength is approximate and may vary based on size and shape.

Sheets meet AMS 4027. Width tolerance is ±1/16". Length tolerance is ±1/8".

http://www.mcmaster.com/

McMASTER-CARR. OVER 555,000 PRODUCTS
(562) 692-5911
(562) 695-2323 (fax)
la.sales@mcmaster.com
Text 75930

Hook and Loop Cable Tie with Buckle

Weather Resistant, 12" Long, 2-3/4" Bundle Diameter, 1" Wide

In stock
$2.10 Each
3955T66

Overall Length	12"
Additional Specifications	Straps 1" Wide Weather-Resistant Black Polyester

Use straps again and again without any loss in gripping strength. Straps have a nickel-plated steel ring unless otherwise stated.

Weather-resistant black polyester straps resist water and UV light; they meet ASTM D6193 and MIL-F-21840.

Warning! Never use for lifting applications.

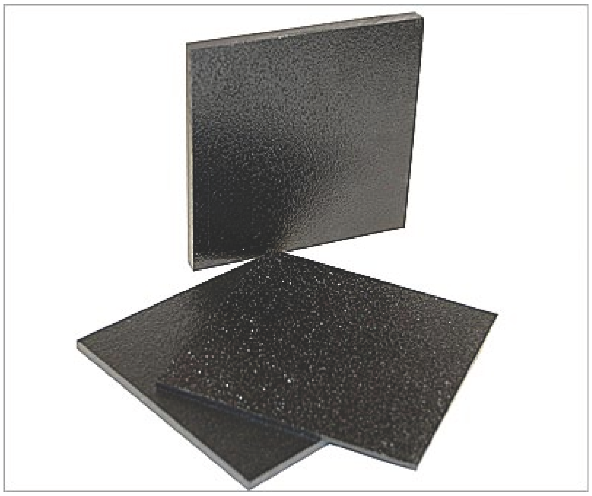
Track my Order | My Account | Cart | Contact Us

TAP Plastics

PRODUCT INFORMATION | PRODUCT APPLICATIONS | ABOUT TAP PLASTICS | STORE LOCATIONS

Cut-to-Size Plastic > ABS Sheets

- New Arrivals
- Cut-To-Size
- Fiberglass
- Plastics
- Window Films
- Mold Making Materials
- Repair Products
- Signage
- Supplies & Tools



ABS Sheets

Sheet size, colors, thickness and products available on our website are just a fraction of what's available at 20 TAP Plastics store locations.

Cut to size orders can take one to two business days to process.

ABS sheet has high-impact strength with a textured hair-cell finish on one side. Great for appliance covers, crisper trays, instrument panels. ABS has high impact strength and is ideal for making prototypes. It can be sawed, routed, glued and heat formed.

ABS Sheets

ENTER YOUR SPECIFICATIONS FOR THIS PRODUCT

Color	Black	
Buy 1/8" x 4" x 4" Sample	☐	
Thickness	1/8 (.118)	INCHES
Width *(1" min, 48" max)*	Whole Number 24 AND 0/16	INCHES
Length *(1" min, 96" max)*	Whole Number 24 AND 0/16	INCHES
Quantity	1	SHEETS
Edge Polishing	NOT AVAILABLE FOR THIS ITEM	
Radius Corners ? *($5 / pc | 4 corners)*	RADIUS None	INCHES

Calculate

YOUR RESULTS

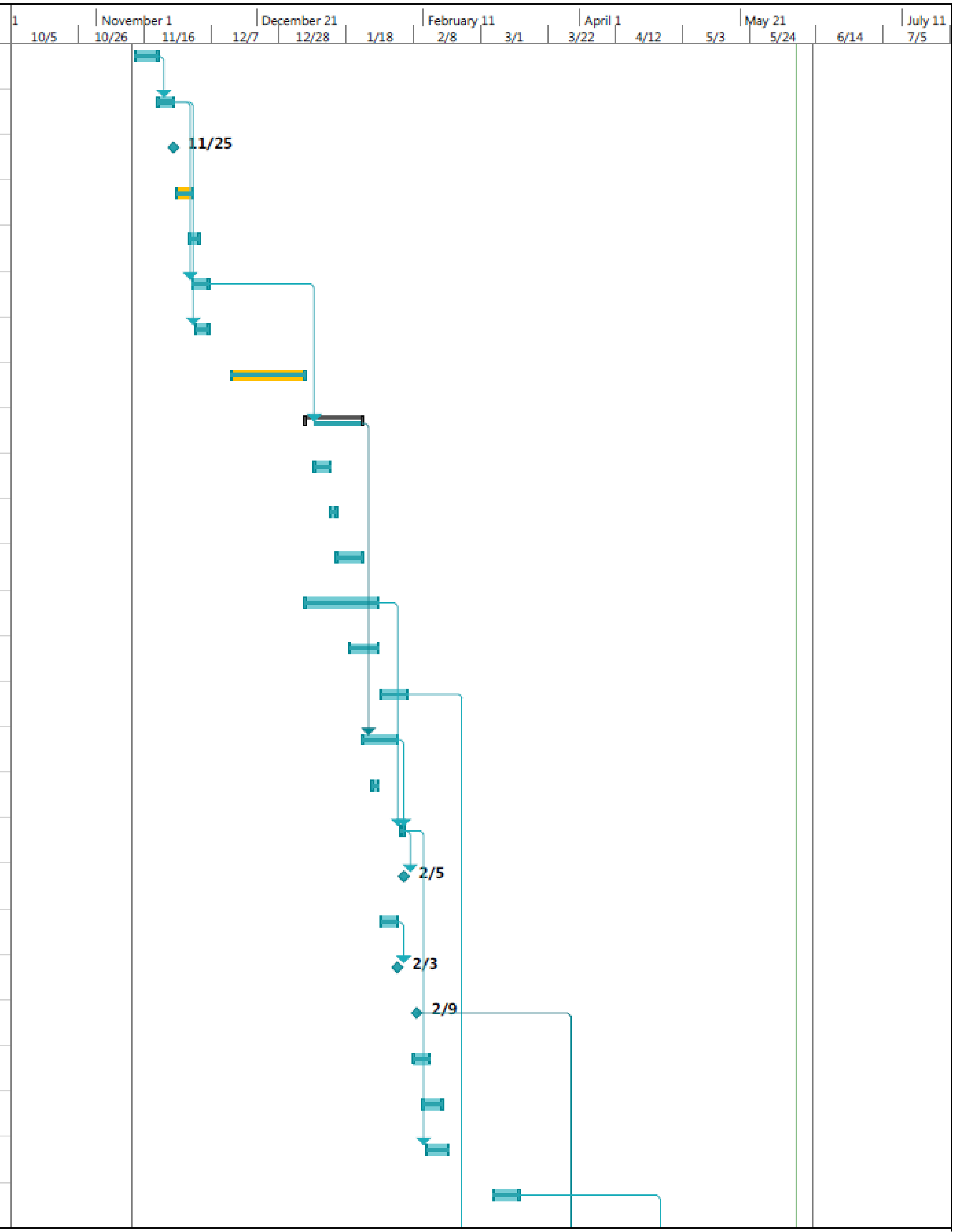
Color	Black
Size	1/8 (.118)" Thick, 24" Wide, 24" Long
Quantity	1
Cost	$16.60

Add to cart »

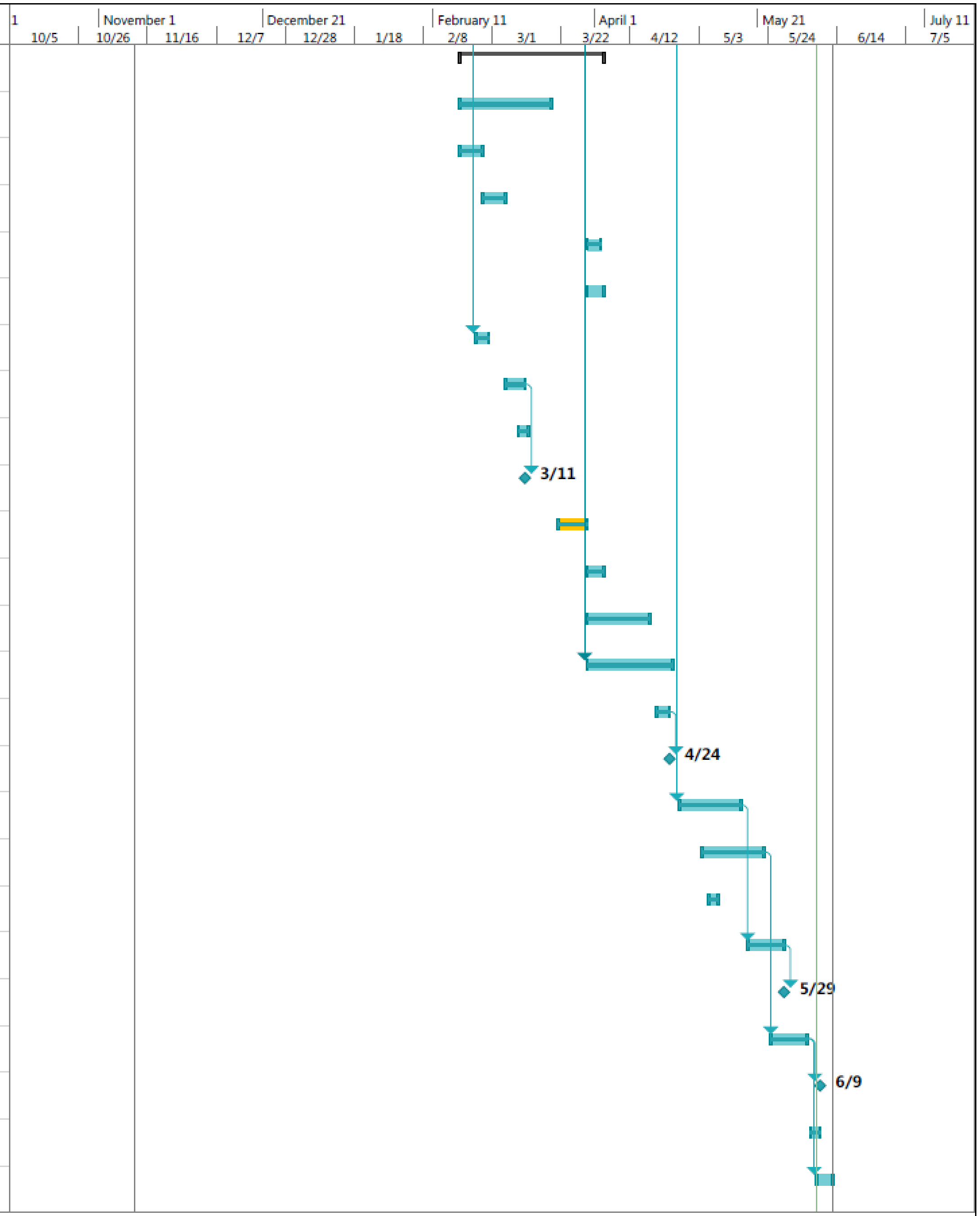
http://www.tapplastics.com/

Appendix H – Gantt Chart

ID		Task Mode	Task Name	Duratio	Start	Finish	Predecessors
1			PDR Draft	5 days	Thu 11/13/14	Wed 11/19/14	
2			PDR Edit/Complete	3 days	Thu 11/20/14	Mon 11/24/14	1
3			PDR Due	0 days	Tue 11/25/14	Tue 11/25/14	
4			Thanksgiving Break	4 days	Wed 11/26/14	Sun 11/30/14	
5			Team Evaluation/Reflection	3 days	Sun 11/30/14	Tue 12/2/14	
6			Analysis Plan	5 days	Mon 12/1/14	Fri 12/5/14	2
7			FDR First Draft (from PDR)	4 days	Tue 12/2/14	Fri 12/5/14	2
8			Winter Break	17 day	Sat 12/13/14	Sun 1/4/15	
9			**Analysis**	**14 day**	**Mon 1/5/15**	**Thu 1/22/15**	**6**
10			Shaft Calculations	3 days	Thu 1/8/15	Mon 1/12/15	
11			Weight of system components	2 days	Tue 1/13/15	Wed 1/14/15	
12			Weld Calculations	6 days	Thu 1/15/15	Thu 1/22/15	
13			CAD Models	17 day	Mon 1/5/15	Tue 1/27/15	
14			Test Wheels by Hand	7 days	Mon 1/19/15	Tue 1/27/15	
15			Order Parts	6 days	Thu 1/29/15	Thu 2/5/15	
16			FDR Full Rough Draft	7 days	Fri 1/23/15	Mon 2/2/15	9
17			Schedule CDR w/Sponsor	2 days	Mon 1/26/15	Tue 1/27/15	
18			FDR Edit/Complete	1 day	Wed 2/4/15	Wed 2/4/15	16,13
19			FDR Due	0 days	Thu 2/5/15	Thu 2/5/15	18
20			Prepare CDR Presentation	3 days	Thu 1/29/15	Mon 2/2/15	
21			CDR Presentation	0 days	Tue 2/3/15	Tue 2/3/15	20
22			CDR with Sponsor	0 days	Mon 2/9/15	Mon 2/9/15	
23			Team Evaluation/Reflection	5 days	Sun 2/8/15	Thu 2/12/15	
24			Ethics Memo	4 days	Wed 2/11/15	Mon 2/16/15	
25			First Draft of Final Report (from FDR)	5 days	Thu 2/12/15	Wed 2/18/15	18
26			Testing Plan	6 days	Thu 3/5/15	Thu 3/12/15	



ID		Task Mode	Task Name	Duratio	Start	Finish	Predecessors
27			**Build Prototype**	**32 day**	**Thu 2/19/15**	**Fri 4/3/15**	
28	✓		Make T-Joint	20 day	Thu 2/19/15	Wed 3/18/15	
29	✓		Make Shaft	5 days	Thu 2/19/15	Wed 2/25/15	
30	✓		Cut/Drill rest of parts	5 days	Thu 2/26/15	Wed 3/4/15	
31	✓		Make U-brackets	4 days	Mon 3/30/15	Thu 4/2/15	
32			Assemble parts	5 days	Mon 3/30/15	Fri 4/3/15	
33	✓		Add Parts Info to Final Report	4 days	Tue 2/24/15	Fri 2/27/15	15
34	✓		Manufacturing/Testing Presentation	4 days	Thu 3/5/15	Tue 3/10/15	
35	✓		Team Evaluation/Reflection	3 days	Mon 3/9/15	Wed 3/11/15	
36	✓		Manufacturing/Testing Presentation Due	0 days	Wed 3/11/15	Wed 3/11/15	34
37	✓		Spring Break	7 days	Sat 3/21/15	Sun 3/29/15	
38	✓		Project Update Memo	5 days	Mon 3/30/15	Fri 4/3/15	
39	✓		Add to Contruction to Final Report	15 days	Mon 3/30/15	Fri 4/17/15	
40	✓		Build Test Rig	20 day	Mon 3/30/15	Fri 4/24/15	22
41	✓		Hardware/Safety Demo Prep	4 days	Mon 4/20/15	Thu 4/23/15	
42	✓		Hardware/Safety Demo	0 days	Fri 4/24/15	Fri 4/24/15	41
43	✓		Testing	15 day	Mon 4/27/15	Fri 5/15/15	26
44	✓		Add Testing to Final Report	15 days	Mon 5/4/15	Fri 5/22/15	
45	✓		Team Evaluation/Reflection	3 days	Wed 5/6/15	Fri 5/8/15	
46	✓		Prepare for Expo	9 days	Mon 5/18/15	Thu 5/28/15	43
47	✓		Senior Project Expo	0 days	Fri 5/29/15	Fri 5/29/15	46
48	✓		Edit/Complete Final Report	9 days	Mon 5/25/15	Thu 6/4/15	44
49			Final Report Due	0 days	Tue 6/9/15	Tue 6/9/15	48
50	✓		Team Evaluation/Reflection	2 days	Sat 6/6/15	Mon 6/8/15	
51			Final Checklist	5 days	Mon 6/8/15	Fri 6/12/15	48



Appendix I – Budget Sheet

TOTAL BUDGET:	**$2,000.00**					
TOTAL SPENT:	**$729.84**					
TOTAL REMAINING:	**$1,270.16**					
Operating Expenses	$1,580.00	79%				
Spent	$729.84					
Remaining	$850.16					
Supplies & Materials	$1,540.00	Date	How Much	Where	What	Who
Spent	$729.84	10/26/2014	$10.78	Michaels	Concept model supplies, brads, foam board	Joseph
Remaining	$810.16	11/9/2014	$3.18	Home Depot	Concept model supplies, wooden dowel	Joseph
		1/15/2015	$9.18	Amazon	2X 2.75" omniwheels	Delaney
		1/15/2015	$27.66	TAP Plastics	ABS Plastic Sheet 1/8", 2'x2', black	Delaney
		1/15/2015	$14.28	McMaster	Omniwheel shaft 6mm, length 200mm	Delaney
		1/21/2015	$9.72	Inline Warehouse	3 Eaton Jr. Zetterburg replacement hockey blade	Joseph
		1/27/2015	$107.26	McMaster	Plate, tube, plastic sleeve, pins for prototype	Delaney
		2/13/2015	$25.92	Inline Warehouse	8 hockey blades	Joseph
		2/24/2015	$37.97	AndyMark	4" omniwheel	Delaney
		2/24/2015	$70.45	McMaster	Casters, sockets, tubes, retaining rings, shaft	Delaney
		2/24/2015	$13.87	Home Depot	Conduit	Chris
		2/27/2015	$53.69	McMaster	0.09" Aluminum plate, 12"x12"	Delaney
		3/31/2015	$90.69	Home Depot	1" Pipe Bender	Joseph
		4/13/2015	21.76	McMaster	Velcro straps	Delaney
		4/13/2015	$37.42	Home Depot	1/2" Pipe Bender	Joseph
		4/20/2015	$18.28	TAP Plastics	16"x18" ABS Plastic for side guard	Delaney
		4/21/2015	$17.25	Home Depot	Conduit, Wire brush	Chris
		5/14/2015	$58.86	Home Depot	Wheels, U-bolts, Wheel Bolts, Bolts, Nuts, Wash	Chris
		5/14/2015	$9.39	Home Depot	U-bolts & Wheel Bolts	Chris
		5/19/2015	$8.60	Home Depot	Paint	Chris
		5/19/2015	$6.45	Home Depot	Epoxy Putty	Chris
		5/20/2015	$38.24	Amazon	Putting Green for expo	Delaney
		5/25/2015	$2.41	Michaels	Foam for damper	Delaney
		5/28/2015	$7.53	Home Depot	File	Chris
		5/28/2015	$7.47	University Bookstore	Poster foam core	Delaney
		6/6/2015	$21.53	TAP Plastics	18"x18" ABS Plastic for front guards	Delaney
		Sum:	$729.84			

Appendix J – User Manual

This user's manual includes instructions for product use and important safety information. Read this section entirely including all safety warnings and cautions before using the product.

<u>Important</u>:	This product is meant for use on a Standing Dani motorized prone stander. Before using this product, the user should be familiar with the operation and safety risks of

Using the Golf Putter

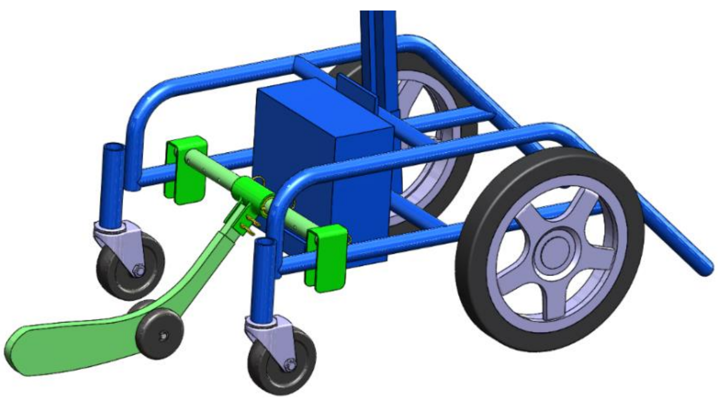
<u>Warning</u>:	**Do not play kickball while the golf putter is attached**. Both attachments can fit onto the Standing Dani simultaneously, but since the kickball guards are designed to prevent a ball from rolling under a bar and the golf putter adds a bar to the front, the golf putter must be removed before the guards

The following instructions include everything you need to know to use your new golf putter attachment.

Attaching the Golf Putter

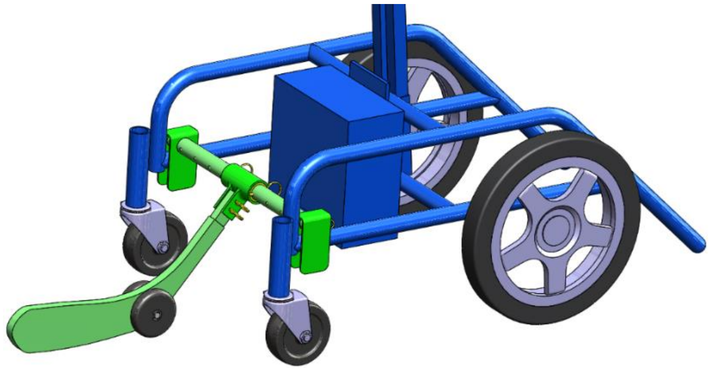
Follow these directions to attach the golf putter to the Standing Dani:

1. Grasp the main shaft of the golf putter and place the U-brackets over the bottom, sidebars on the Standing Dani.

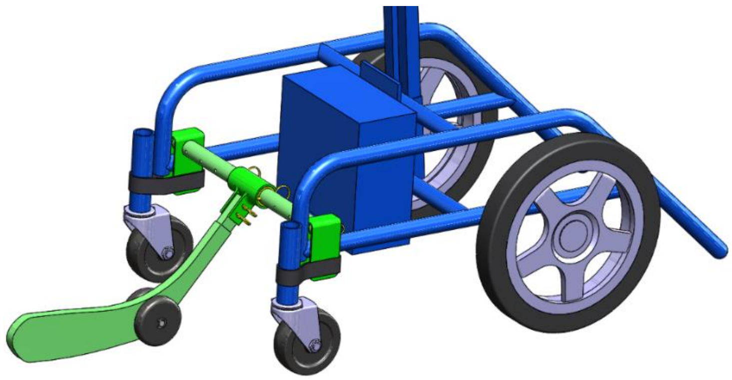


<u>Caution</u>:	Placing the U-brackets over the bars on the Standing Dani and sliding the putter forward may create pinch points. To avoid pinching, hold the golf attachment by the main shaft and check that nothing is obstructing the U-brackets from fully resting on the sidebars and from sliding completely forward to contact the front

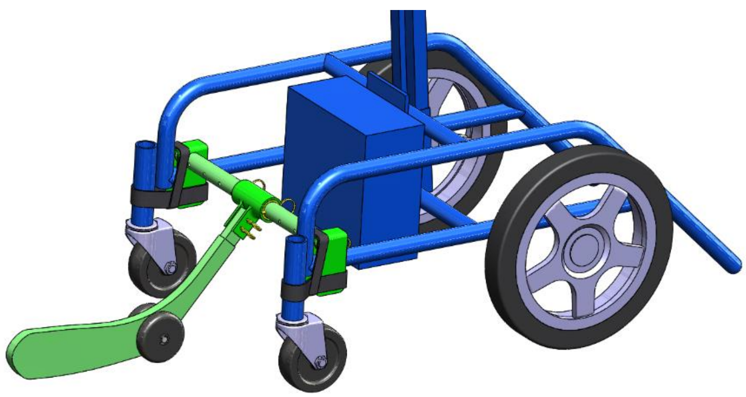
2. Slide the putter to the front of the Standing Dani until it contacts the front bars.



3. Wrap horizontal straps around both front bars of Standing Dani and Velcro it tight.



4. Wrap the vertical straps around both U-brackets, in front of the main shaft of the putter and behind the front bar of the Standing Dani and Velcro it tight.



Putting with the Golf Putter

After the golf putter is attached to the Standing Dani, simply move the putter by driving the Standing Dani. Move the putter into a golf ball, hitting the ball at the desired speed and angle to try and sink the putt.

<u>Caution</u>:	The Standing Dani is a heavy motorized device. The user should be familiar with all safety concerns of driving the Staning Dani before use. Misuse of the Standing Dani could injure people or damage property, including the putter.

Using the Kickball Guards

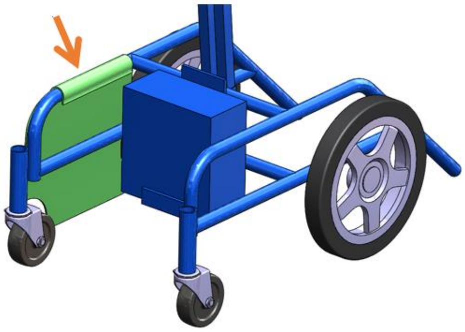
Warning:	**Do not play kickball while the golf putter is attached**. Both attachments can fit onto the Standing Dani simultaneously, but since the kickball guards are designed to prevent a ball from rolling under a bar and the golf putter adds a bar to the front, the golf putter must be removed before the guards

The following instructions include everything you need to know to use your kickball guards

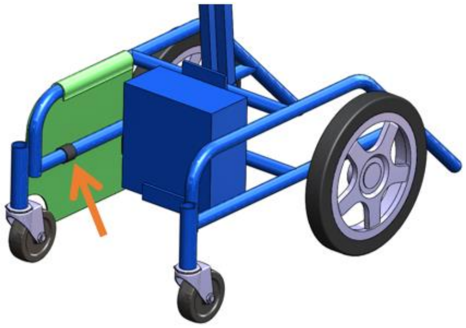
Attaching the Kickball Guards

Follow these instructions to attach the kickball guards to the Standing Dani:

1. Snap one side-guard over the top bar on the side of the Standing Dani.



2. Wrap straps around the bottom bar and Velcro tight.

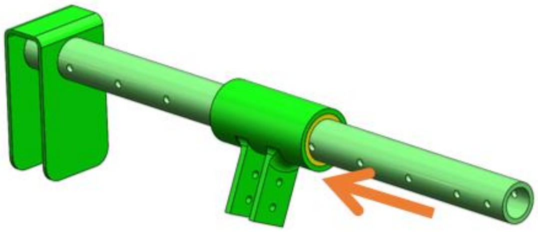


3. Repeat steps 1 and 2 with the other side-guard on the other side of the Standing Dani.

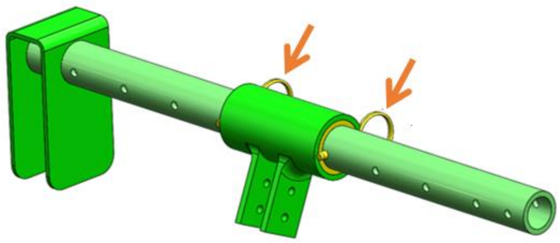
Assembling the Putter

The following assembly instructions were used to assemble the fabricated pieces of the golf putter attachment. The putter does not need to be reassembled in between uses, but all or part of the assembly process will be used to remove parts for adjustment, repair, or replacement.

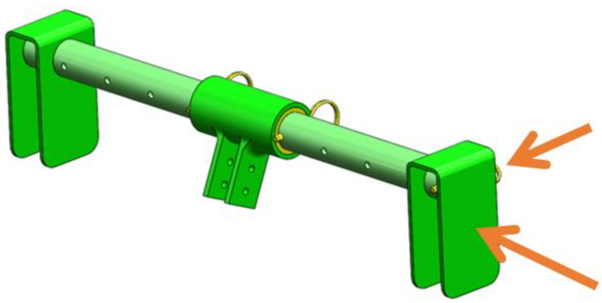
1. Slide the bushing and t-joint together onto the aluminum main shaft.



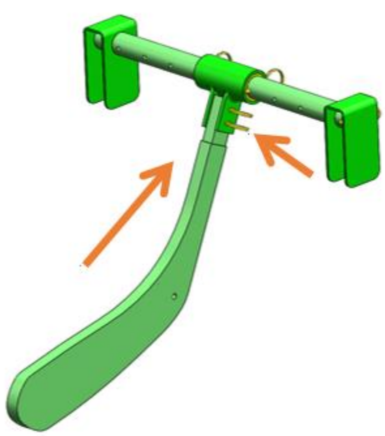
2. Align the T-joint on the shaft between two pinholes and place pins into holes.



3. Place the other aluminum U-bracket onto the end of the main shaft and place a pin through the shaft inside the joint.



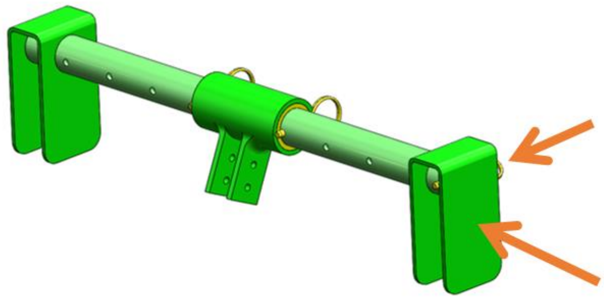
4. Align the holes in the top of the hockey blade shaft with the holes in the t-joint and place pins through both holes.



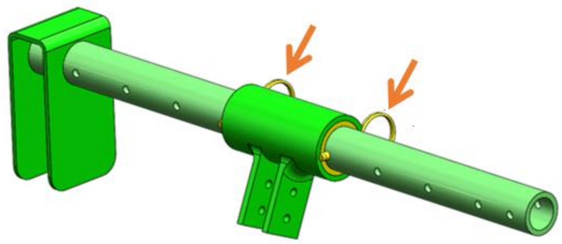
Adjusting the Putter Location

The following instructions will show you how to adjust the location of the putter on the main shaft:

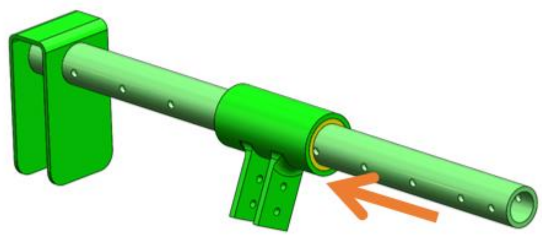
1. Remove the pin from inside the U-bracket and slide the U-bracket off the shaft.



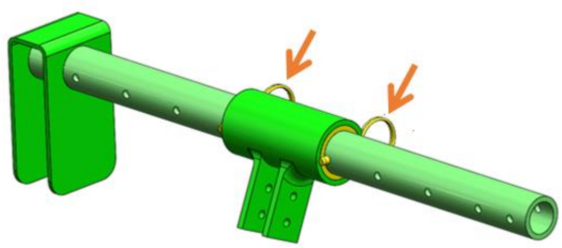
2. Remove the pins from the main shaft.



3. Slide the T-Joint to the desired location between two pinholes.



4. Insert the pins directly on either side of the T-joint.



Maintenance

No active maintenance is required to keep the putter or guard working correctly. Though both can be used outdoors and are water resistant, neither should be left in the sun or standing water for extended, unnecessary lengths of time. They should also not be exposed to extreme heat, though they can withstand temperatures up to and exceeding temperatures that humans can handle.

Replacing or Repairing Parts

To replace or repair a part, simply remove the part by disassembling the putter. It may be helpful to review the assembly process above before removing the necessary parts to retrieve the desired part. To make a replacement part, follow the process in the Product Realization section of this report. Some spare hockey blades are included with the product, and these can be used to simply replace the original blade if it is broken or lost.

Appendix K – Design Verification Plan and Report

Design Verification Plan and Report (DVP&R)													
Report Date: 6/8/1	Sponsor: Nathan Cooper & Family, CPConnect			Component: Golf & Kickball Attachment				Project: Sports for Nathan			Reporting Engineer: Joseph Garrett		
TEST PLAN										TEST REPORT			
						SAMPLES TESTED		TIMING		TEST RESULTS			
Item No	Specification	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	Quantity	Type	Start date	Finish date	Test Result	Quantity Pass	Quantity Fail	NOTES
1	A.1	Test rig sufficiently rolls along ground	Maneuverable along flat surface	CH	CV	1	Test Rig	5/23/2015	5/11/2015	Pass	-	-	Requires wheels on test frame
2	A.2	Test rig supports attachment	Attachment fits to both test rig and SD	CH	CV	1	Test Rig	5/4/2015	5/10/2015	Pass	-	-	-
3	A.3	Test rig has same dimensions and physical constraints as Standing Dani	Measurements are the same as SD	DB	CV	1	Test Rig	5/4/2015	5/10/2015	Pass	±.75"	-	-
4	A.4	Golf putter ground clearance for different ball sizes	1.0 inch clearance	DB	CV	1	Test Rig	5/4/2015	5/10/2015	Pass	.5"	-	-
5	A.5.1	Golf impact testing of safety design considerations (shaft rotation and velcro straps)	Does not lose function or break after 100 lbs impact	JG	DV	1	Test Rig	5/11/2015	5/17/2015	N/A	-	-	Requires wheels on test frame
6	A.5.2	Repeated impact testing for deformation of putter and shaft	Does not lose function or break after 100 lbs impact	JG	DV	2	Test Rig	5/11/2015	5/17/2015	N/A	-	-	Requires wheels on test frame
7	A.5.3	Impact testing for bearing/bushing performance	Does not lose function or break after 100 lbs impact	JG	DV	1	Test Rig	5/11/2015	5/17/2015	N/A	-	-	Requires wheels on test frame
8	A.6.1	Kickball guard ground clearance	2.5 inch clearance	DB	CV	1	Test Rig	5/11/2015	5/11/2015	Pass	2"	-	Requires wheels on test frame
9	A.6.2	Impact testing of kickball material	Does not lose function or break after 50 lbs impact	JG	DV	2	Test Rig	5/4/2015	5/10/2015	N/A	-	-	-
10	A.7	Assembly steps	10 steps or less	DB	PV	1	Test Rig	5/4/2015	5/10/2015	Pass	5 steps	-	-
11	B.1	Ball trajectory testing in Standing Dani	45 degree range of accuracy for 95% of the time	CH	PV	10	Standing Dani	5/18/2015	5/20/2015	Pass	User Accuracy	-	Requires meeting with Nathan
12	B.2	Interference with normal functions	Nothing interfering	CH	CV	1	Standing Dani	5/18/2015	5/20/2015	Pass	-	-	Requires meeting with Nathan
15	B.3	Balance on 5 degree incline with all attachments	SD does not lean or tip over	CH	PV	1	Standing Dani	5/18/2015	5/20/2015	Pass	-	-	Requires meeting with Nathan
16	B.4	Nathan's visibility	Nathan can see putter and ball while operating	CH	CV	1	Standing Dani	5/18/2015	5/20/2015	Pass	-	-	Requires meeting with Nathan
17	C.1	Attachment size	Smaller than 2'x2'x2'	DB	CV	1	Attachment	5/4/2015	5/10/2015	Pass	-	-	-
18	C.2	Attachment weight	Less than 25 lbs	DB	CV	1	Attachment	5/4/2015	5/10/2015	Pass	2 lb 12.9 oz	-	-

Appendix L – Potential Design Failure Modes and Effects Analysis

Potential
Failure Mode and Effect Analysis

___ System
Subsystem
___ Component

(Design FMEA)

Design Responsibility: Eight Blue Dogs

Model Year(s)/Vehicle(s): Standing Dani golf/kickball attachment

Key Date:

Prepared By: Chris Harter

Core Team: Eight Blue Dogs (Joseph Garrett, Delaney Bales, Chris Harter)

FMEA Date (Orig.) 12/2/15

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occur	Crit	Recommended Action(s)	Responsibility & Target Completion Date	Action Results			
									Actions Taken	Sev	Occur	Crit
"Putter" must propel golf ball from at least 6 inches in front of Standing Dani to within 30° of target without dragging on the ground	Putter does not propel ball	Difficult to hit ball	8	Putter clearance is too high	4	32	Test putter clearance on test rig	DB 4/19/15				
			8	Putter face contact area too small	5	40	Test contact area with Nathan to ensure that it is large enough	DB 4/19/15				
	Putter drags on ground	Difficult to hit ball	8	Putter clearance is too high	4	32	Test putter clearance on test rig	DB 4/19/15				
			8	Putter face contact area too small	5	40	Test contact area with Nathan to ensure that it is large enough	DB 4/19/15				
		Putter damages putting surface	7	Wheels do not roll	9	63	Test and select wheels that roll reliably	CH 1/29/15				
			7	Putter clearance is too low	5	35	Test putter clearance on test rig	DB 4/19/15				
			7	Wheels come off of putter	3	21	Calculate forces on wheels and ensure attachment is strong enough	JG 1/23/15				
	Putter does not hit ball within 30° of target	Cannot reliably aim the ball	8	Putter face contact area too small	5	40	Test contact area with Nathan to ensure that it is large enough	DB 4/19/15				
			8	Putter face not stiff enough	2	16	Calculate neccesary stiffness and select appropriate material	JG 1/23/15				
			8	Shaft not stiff enough	1	8	Calculate neccesary stiffness and select appropriate material	JG 1/23/15				
			8	Wheels do not roll smoothly	9	72	Test wheels and select ones that roll smoothly	CH 1/29/15				
	Putter hits ball less than 6 inches from Standing Dani	Cannot see the ball	6	Putter is too short	3	18	Design putter length to be at least 6 inches past Standing Dani	All 1/29/15				

			6	Shaft not stiff enough	1	6	Calculate neccesary stiffness and select appropriate material	JG 1/23/15				
			6	Shaft mounted too far back	1	6	Design the mounting position in an easy to reproduce location	All 1/29/15				
"Putter" must absorb energy from direct collision but remain able to transfer energy to ball	Putter does not absorb energy from large collisions	Putter breaks from impact	8	Spring not stiff enough	7	56	Calculate neccesary stiffness and select appropriate spring	JG 1/23/15				
			8	Spring too stiff	7	56	Calculate neccesary stiffness and select appropriate spring	JG 1/23/15				
			8	Putter not thick enough	1	8	Calculate neccesary thickness	JG 1/23/15				
		Shaft breaks or bends from impact	8	Shaft not stiff enough	1	8	Calculate neccesary stiffness and select appropriate material	JG 1/23/15				
			8	Shaft is not strong enough	1	8	Calculate neccesary thickness	JG 1/23/15				
		Nathan/Standing Dani is impacted	10	Spring not stiff enough	7	70	Calculate neccesary stiffness and select appropriate spring	JG 1/23/15				
			10	Spring too stiff	7	70	Calculate neccesary stiffness and select appropriate spring	JG 1/23/15				
			10	Bushing binds	3	30	Calculate forces on bushing and range of motion required and select appropriate bushing	JG 1/23/15				
	Putter absorbs energy from impact with ball instead of propelling ball	Difficult to hit ball	8	Putter clearance is too high	4	32	Test putter clearance on test rig	DB 4/19/15				
			8	Putter face contact area too small	5	40	Test contact area with Nathan to ensure that it is large enough	DB 4/19/15				
		Cannot reliably aim the ball	8	Putter face contact area too small	5	40	Test contact area with Nathan to ensure that it is large enough	DB 4/19/15				
			8	Putter face not stiff enough	2	16	Calculate neccesary stiffness and select appropriate material	JG 1/23/15				
"Guard" must prevent ball from rolling under the Standing Dani but must not touch the ground or prevent Nathan from controlling it with his caster wheels	Guard allows kickball to roll under it	Standing Dani tips over	10	Guard clearance too high	4	40	Test guard clearance on test rig	DB 4/19/15				
			10	Guard not stiff enough	4	40	Calculate neccesary stiffness	JG 1/23/15				
			10	Guard not strong enough (breaks)	5	50	Calculate neccesary strength	JG 1/23/15				

		Guard pops the kickball	3	Guard Clearance too high	4	12	Test guard clearance on test rig	DB 4/19/15				
			3	Guard too stiff	2	6	Calculate neccesary stiffness	JG 1/23/15				
			3	Guard not strong enough (breaks)	4	12	Calculate neccesary strength	JG 1/23/15				
	Guard drags on the ground	Guard damages driving surface	7	Guard clearance too low	4	28	Test guard clearance on test rig	DB 4/19/15				
			7	Guard not mounted securely	4	28	Calculate forces on guard and mount appropriately	JG 1/23/15				
			7	Guard not strong enough (breaks)	4	28	Calculate neccesary strength	JG 1/23/15				
		Driving the Standing Dani is impossible	9	Guard clearance too low	4	36	Test guard clearance on test rig	DB 4/19/15				
	Guard does not allow Nathan to control the kick ball with the caster wheels	Nathan cannot hit ball the way he would like	4	Middle guard mounted too close to the front	2	8	Test guard clearance on test rig	DB 4/19/15				
"Putter" must attach/detach easily and in less than ten steps	Putter takes more than ten steps to attach/detach	Attachment/detachment too long	5	Instructions not clear	3	15	Have the instructions reviewed by Nathan's family and other outside sources	CH 5/29/15				
	Putter does not attach/detach	Putter is stuck on the Standing Dani	8	Shaft not stiff enough (deforms)	1	8	Calculate neccesary stiffness and select appropriate material	JG 1/23/15				
			8	Pins stuck in pin holes	3	24	Select proper sized pin/holes	JG 1/23/15				
		Putter will not attach to Standing Dani	8	Shaft diameter too large	1	8	Ensure that ordered parts are correctly sized	CH 3/11/15				
			8	Collar too small	3	24	Ensure that ordered parts are correctly sized	CH 3/11/15				
			8	Pins do not fit in pin holes	3	24	Select proper sized pin/holes	JG 1/23/15				