May 2014

Development of Hand Control Interface for Manual Transmission Vehicles

John J. LaCamera
Worcester Polytechnic Institute

Leo Edward Torrente
Worcester Polytechnic Institute

Zachary Glenn Bornemann
Worcester Polytechnic Institute

Project Number: MQP-MQF 3121_

Development of Hand Control Interface for Manual Transmission Vehicles

A Major Qualifying Project

Submitted to the Faculty of the

WORCESTER POLYTECHNIC INSTITUTE

In Partial Fulfillment of the Requirements for the Degree of Bachelor of Science

in

Mechanical Engineering

by

Zachary Bornemann	John LaCamera	Leo Torrente
Mechanical Engineering	Mechanical Engineering	Mechanical Engineering

MIRAD Laboratory, May 1, 2014

Approved by:

Prof. Mustapha S. Fofana, Advisor

Director of MIRAD Laboratory, Mechanical Engineering Department

Abstract

The goal of the MQP was to design and build a minimally invasive hand control interface that can be used by paraplegics or double leg amputees to control manual transmission automobiles. This control interface can also be used by individuals who describe themselves as car enthusiasts and enjoy driving manual transmission vehicles. The primary components of the control interface are mechanical linkages and a steel cable system to actuate the brake and clutch pedals of an automobile. Some products exist that offer control of the gas, brake, and clutch to the user by the means of a hand interface such as the Guidosimplex 'Duck' Semi-Automatic Clutch and the Alfred Bekker Manual Hand Clutch, however these products are expensive, invasive, and take away from the full experience of driving a manual transmission of the car. The team conducted analysis of current assistive driving devices, calculated the dynamics of mechanical linkages and steel cables for the brake and clutch systems, and manufactured a prototype control interface. Compared to earlier control interfaces, the team was able to design and build a mechanical control interface with reduced components that offers a tactile response with a simple installation process.

Table of Contents

List of Figures

List of Tables

Acknowledgments

The Team would like to thank the following people for their help and support during the duration of our project.

- Professor Fofana for his guidance and supervision of this project in the MIRAD Laboratory.

- The Handiman team 2012-2013,Gregory DiLullo, Stephen Kocienski, and Daniel Zopatti, for giving us the resources to continue and improve upon their project.

- Barbara Furhman, WPI Purchasing Office, for her assistance in purchasing materials for the team’s project.

- Elm Park Auto for the time spent attempting to acquire a functioning manual transmission vehicle for testing purposes.

- Adriana Hera for her assistance in using ANSYS.

- Matthew DiPinto and Joseph Monasky for assisting with prototyping techniques.

Chapter 1: Introduction

This project was inspired by those who have a passion for driving, but who have lost function of their legs. It is recorded that there are approximately between 238,000 to 332,000 people in the United States that are currently living with a spinal cord injury (Brault, 2010). The reasons for the person's handicap can be attributed to many causes including motor vehicle crashes, sport injuries, military service, or acts of violence. Existing assisted driving devices are mostly targeted towards automatic cars and the devices that do exist for manual vehicles limit the driving experience for the user. These devices are very expensive and can more than $15,000. Living with a severe disability can be expensive, one of the team's goals is to keep the cost of these selected technologies to a minimum so there is no additional burden for the person with disabilities.

This project was conducted to enable paraplegics and double leg amputees to safely operate and control a manual transmission automobile. Existing available systems are not ideal for manual transmission automobiles because they require the use of both hands for operating the accelerator and brake, and thereby limiting the ability of operating the clutch. The purpose of examining existing assistive device technologies and the previous team's prototype is to gain a foundation of understanding of what is available on the consumer market. With this understanding the team evaluated existing technology's advantages and limitations in regards to safety, invasiveness, and intuitive use. The full-scale prototype was assembled and tested for functionality, ergonomics, and safety.

Chapter 2 describes the literature reviewed for this project. The team researched and reviewed currently available assisted driving devices as well as information concerning paraplegics and their disabilities. Zero leg-input designs currently exist for driving automatic cars, and there are manual transmission solutions, however they lead to a reduced driving experience. The team also evaluated the 2012-2013 Handi-man's prototype as a potential design. Chapter 3 contains the design process and fabrication that the team used to develop a solution. Preliminary design concepts were evaluated against design specifications to establish the optimal design. The Team decided that the optimal design for this interface was the use of mechanical linkages and steel cable system for the actuation of the brake and the clutch accordingly. After iteration of the design's components, a full scale prototype was fabricated on a model of a Toyota Corolla. The full scale prototype was created by using a steel frame and steering column, with the same dimensions as a Toyota Corolla. Most parts that were to be machined out of 6061 Aluminum were replaced with ¼" acrylic for ease of fabrication. Chapter 4 concludes the success of the team's interface and provides recommendations for further development of the device.

Chapter 2: Developing a Need and Analysis of Existing Devices

2.1 – Disabilities in the United States

As of the 2010 census 56.7 million people, or 18.7% of the US population has some sort of disability. This percentage has decreased from 21.8% of the population, with respect to population growth, since the report "*Americans with Disabilities: 2005*" was released. This definition of disability accounts with those who have communicative, physical, or mental disabilities (Brault, 2010). The report 2005 breaks up those with disabilities in two separate factions, those with non-severe disabilities and severe disabilities. Some examples of non-severe disabilities are dyslexia, Attention Deficit Hyperactivity Disorder (ADHD), and slight physical disabilities. Severe disabilities however are more substantial, i.e. person who needs assistance doing simple household tasks, autism for example, and those who cannot function without the use of a wheelchair, cane, crutches or walker. Those with severe disabilities make up 12.6% of the American population or 38.3 million people (Brault, 2010). Disabled people who live with limitations associated with lower body movement accounts for 30.6 million people and they are typically above the age of 15 years.In this category, 23.9 million people have difficulty walking a quarter of a mile. Since these individuals cannot walk with ease, they most often use some kind of assistive aid to help them in their efforts. 11.6 million people require the use of a cane, crutches or a walker to help them stay mobile. The number of people who are in constant need of a wheelchair is significantly lower at about 3.6 million people. 2 million of those in wheelchairs are above the age of 65.

The reason for people's disabilities varies from person to person. However according to a recent report by the University of Alabama at Birmingham, it is estimated that a range of 238,000 to 332,000 persons have been disabled due to a spinal cord injury (Spinal Cord Injury, 2013). These spinal cord injuries can result in either tetraplegia or paraplegia. Tetraplegia results in the partial or total function in all four limbs. Paraplegia results in the loss of only the lower limbs

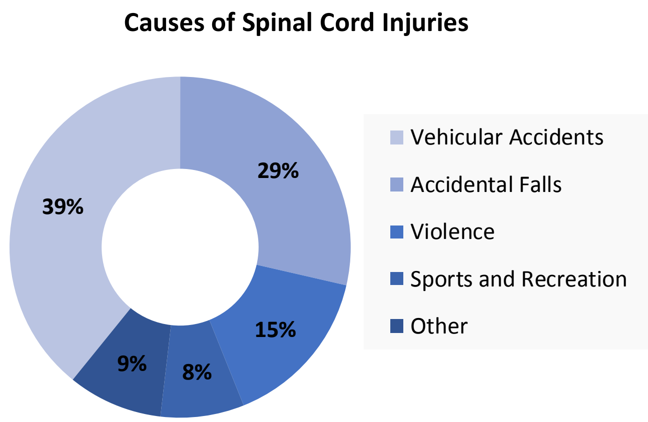

Figure 1 Causes of Spinal Cord Injuries (Brault, 2013)

As seen in Figure 1, there are many different ways in which one can receive a spinal cord injury. The most prevalent cause of injury is vehicle accidents and collisions, falling injuries, and violent encounters. Spinal cord injuries primarily are seen in young adults with the average age of 28.7 (*Spinal Cord Injury*, 2013). 80.7% of those with reported spinal cord injuries are male. Due to the debilitating nature of these injuries, it takes lots of time and money for these people to adjust to their injuries. The first year costs associated with becoming a tetraplegic can range from about $754,524 to over $1,044,197. Every year afterwards, the costs are between $111,237 and $181,328 (*Spinal Cord Injury*, 2013). These costs include things like insurance, medical fees, and assistive devices. For a paraplegic the costs are lower, however they are still steep. First year costs are on average $508,900 and each subsequent year costing the individual about $67,500 (*Spinal Cord Injury*, 2013).

Out of all of these different kinds of injuries, some people still choose that they would like to drive. Paraplegics are able to drive with the assistance of hand controlled systems. In a report released by the Department of Transportation in 1997, it was reported that approximately 211,000 persons choose to install some kind of adaptive equipment in their motor vehicle (*Estimating the Number*, 1997). At the time of this report they estimated that there were 382,907 vehicles to have some type of adaptive equipment to assist disabled persons.

2.2 Existing Designs

The current market for assistive driving devices covers a vast range of disabilities. There have been advances in driving aids for those who experience driving impairments such as deafness, partial blindness, arthritis, amputation and paralysis. The purpose of the project is not to start from scratch and "reinvent the wheel." The project seeks to evaluate the limitations and challenges of existing designs that share similar purposes and improve upon them while catering to the project's specific application. Hand operated mechanical devices developed to aid in driving automatic cars fall under three major types; push-rock, push-pull, and twist-push (Products: Hand Controls). The push-pull devices are the simplest of the three to operate. The devices consist of a lever that activates one pedal when it is pulled and another when pushed as seen in Figure 2-a. The push-rock system also consists of one lever, but this lever is connected to two pushrods. When the lever is rocked, it creates one input compressing the accelerator pedal, and when it is pushed downward it creates another input compressing the brake pedal, as seen in Figure 2-b. The orange arrow points to the lever the operator push and rocks. The push-twist system utilizes a twist throttle lever and a push to brake lever as seen in Figure 2-c.

Figure 2-a: Push-Pull System

Figure 2-b: Push-Rock System

Figure 2-c: Push-Twist System

Figure 2 Examples of Existing Devices for Gas and Brake Control

Devices developed for operating a manual transmission car without the use of the pedals must include three main input components: brake, gas, and clutch. There does not seem to be devices on the market that incorporate all three components in the same system. However, some developers have been successful with devices that focus on each component separately. Creating devices for each component separately allows them to market each device to drivers with various impairments. Although some of the existing designs have had success and given freedom back to their customers, they have limitations in their applications.

The force required to actuate the clutch varies immensely for all different types of automobiles. The clutch actuation can be "light" like the hydraulic driven in most modern cars, or "heavy" for vehicles such as trucks, race, sport, classic, and super cars. The existing hand operated clutch mechanisms are not always able to produce enough power to engage the clutch in some of the heavier vehicles or are not designed to operate mechanical clutch mechanisms at all. The two types of clutch actuation control in existing driving aids are manual and electronic assisted. The controls determine how the clutch is actuated once the hand input is engaged.

A common design for the manually actuated clutch incorporates a lever located on one side of the steering wheel. Alfred Bekker Co. is the leader in using this design with their *Right Hand Clutch Hand Control* product as seen with a blue arrow in Figure 3. The operation is simple; the driver pulls the lever towards himself to depress the clutch which locks into place and then changes gear with the same hand. The driver then slowly releases the lever to engage the gear (Right Hand Clutch Control). This device still requires the use of one leg, but it can be implemented with other assistive devices such as the ones discussed earlier for automatic cars.

Figure 3 Right Hand Clutch Control

The electronic actuated clutch has been gaining popularity over the manual for a one major reason it is simpler to operate and requires less input. Some of these designs require only the press of a button to engage the clutch. One such system is the *Syncro Drive Clutch* by eLap in Figure 4-a. This clutch system incorporates an infrared sensor on the gear knob that detects the operator's hand when starting to change gear. The system then actuates the clutch and completes the operation of the pedal. This system from eLap also monitors the rpm, braking, acceleration, and speed of the car to prevent the car from stalling while changing gears. Another successful electronically actuated clutch by eLap is the *Duck Clutch* shown in Figure 4-b. The *Duck Clutch* design is operated by depressing a lever that is located on the front of the gear knob, which performs complete operation of the clutch pedal. This design is intelligent similarly to the *Syncro Drive Clutch*, except it uses a “fly-by-wire” control. This is where the system finds the “bite point” of the clutch and hits it with a slight release of the lever.

Figure 4-a: elap Syncro Drive Clutch

Figure 4-b: eLap Duck Clutch

Figure 4 Commercially Available Electric Clutch Examples

All the systems discussed perform well and achieve their purpose as a single component of a system. These designs, however, have a shared limitation when the devices are implemented together to create one system. They impede on the driver’s ability to operate all the necessary components of the vehicle simultaneously. One component is always left out of the operation, whether it is gas and brake, steering, or shifting. We examined the user operation of several combinations of the existing devices. For example, the electronic *Duck Clutch* paired with the push-pull device to achieve zero-leg input, the driver must release the gas, engage the clutch and shift gears, and then apply the gas to accelerate. Throughout the operation, both of the driver’s hands are occupied with the throttle and the shifting knob, leaving the steering wheel unattended.

There are serious safety concerns with the operator not having full control of the steering wheel. One of the major considerations of this project is to ensure the automobile can be operated safely. The main safety concerns are emergency maneuvers, defensive driving, and panic operation of the vehicle. With the driver having about a quarter-second reaction time between making an observation and being able to react, it is clear that the driver must have the full ability to operate the manual transmission while maintaining one hand on the steering wheel at all times.

There are existing devices that have the throttle located on the steering wheel, which could be a step in the right direction for solving this limitation. One device like this is the *DARIOS* by KEMPF in Figure 5.

Figure 5 DARIOS by KEMPF

This device is a ring around the steering wheel that the operator presses to accelerate and pulls back on a lever next to the steering wheel to brake. *DARIOS* is an effective system that allows the driver to steer and accelerate with the same hand. However, this device requires the use of both hands on the steering wheel or operating the brake, making it effective only in an automatic car.

There is another major limitation with the existing designs that is very prevalent in our project. This limitation is the lack of customization to the operator's driving style. The driving style with a manual transmission vehicle varies from driver to driver. The electronic clutch systems can be customized, but the driver still lacks the ability to customize the remaining components of operation to their preferences. The driving style also varies depending on the type of driving being performed. The basic everyday drive does not require intense customization of the system, however, for those who enjoy pushing the limits of the vehicle it is required. A popular driving technique called heel-toeing is used for more intense driving such as racing. This technique requires the driver to use gas, brake, and the clutch simultaneously. A driver without a disability has the freedom to learn this technique and others while still being able to drive that same vehicle to work every day. The existing assistive driving devices do not enable the physically impaired with a passion for driving to experience this. There is a need for a system that can give the impaired driver back their freedom so they can once again experience the thrill of driving their own vehicle in their own style.

2.3 Actuation Systems

The team researched multiple types of systems beyond the electric system utilized by Handi-man 2012-2013 to actuate each pedal to select the optimal choice. These systems included hydraulic systems, pneumatic systems, and mechanical systems.

2.3.1 Hydraulic Systems

Hydraulic Systems use a reservoir of liquid, sometimes water-based but usually oil based, to increase energy from one side of a system to the other. Hydraulic systems are reliable because they do not need power to work. They will remain stable if there is a power failure, or more likely, if the vehicle is turned off. Because there are three pedals, the hydraulic system would require three separate tanks to hold liquids that take up space and can be heavy (*Noonan*).

2.3.2 Pneumatic System

Pneumatic systems function similarly to hydraulic systems, but rather than using a liquid, it relies on compressed air. They too remain stable when the car is turned off. Should there be a leak in the system, no toxins will be released. On the contrary, it can be difficult to set and control speed and precision of the pneumatic pistons because it functions with compressed air, which has no definite volume. The air pressure would have to be monitored constantly, which means more devices in place, meaning more cost. Also, similar to a hydraulic solution, there would need to be a large area for the tanks that hold the air (*Orwell*).

2.3.3 Mechanical System

Mechanical systems can be comprised of many components. This vast category encompasses many components such as gears, linkages, levers etc. Once designed and constructed using kinematic principles, the components and dimensions are unchanging, leading to minimal maintenance. A disadvantage of using mechanical systems is that in some cases they can be space consuming.

2.4 Pedal Actuation Forces

To create a hands only system, the team analyzed the data Handi-man 2012 collected through experimentation of the force necessary to actuate each pedal. The force relating to the accelerator pedal in relation to distance depressed can be seen in Figure 6 below

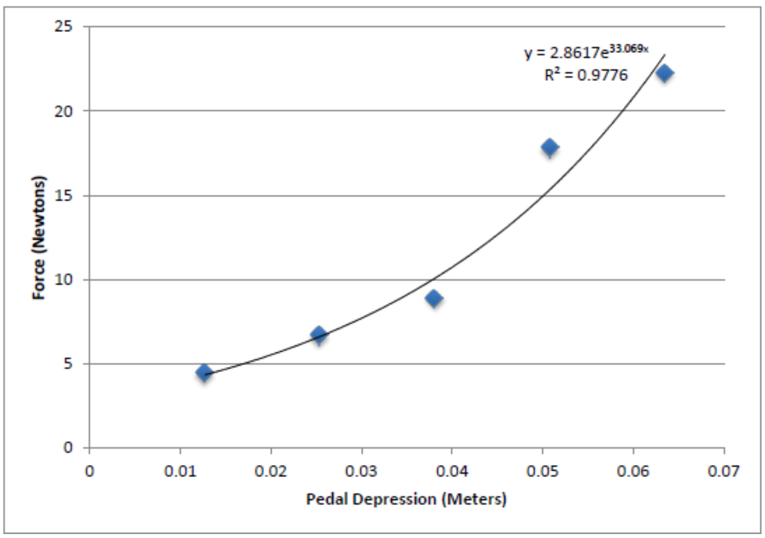

Figure 6 Force Required to Depress Accelerator (Handi-man 2012)

The maximum force needed to depress the accelerator pedal is 25N or 5.6 pound. The force behind depression of brake pedal against distance depressed may be seen in Figure 7 below.

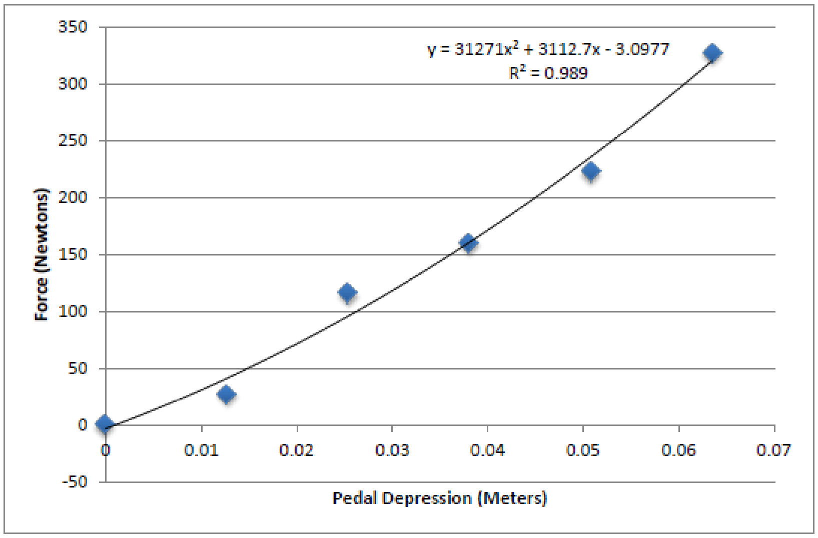

Figure 7 Force Required to Depress Brake (Handi-man 2012)

Traditional driving of a vehicle requires the driver to use 0-170N or about 38 pounds of force at most on average. The Highest point of depression is when braking "instantly" requiring 325N or 73 pounds of force.

An *Ergonomics* Journal describes research published by Taylor & Francis in 2000 about the ideal placement, resistance, and distance of the clutch pedal. The journal explains that the average resistance of clutch pedal actuation is between 20-30 pounds of force, and an actuation distance of 4-6 inches of travel. The team wanted to make this system as versatile as possible and the most common cars in America are compact or midsized cars, so 20 pounds of push force and a 4-inch travel was chosen as the criteria to meet.

2.5 Hand Capabilities

This system consists of a hand controlled interface, so the average hand grip strength needed to be evaluated. A table comparing different types of grips and average strength of each grip can be seen below in Table 1.

Table 1 Hand Grip Strength (Center, 2006)

Hand grip strength: (pounds) sitting elbows @ 90 degrees and forearm in neutral

Grip Type	Sex	Hand	Mean	SD
Power	Male	Dominant	137	
		Non-Dominant	129	
	Female	Dominant	81	
		Non-Dominant	75	
Pinch				
Thumb & index finger	Male	Not specified	19	
	Female	Not specified	15	
Thumb & little finger	Male	Not specified	6	
	Female	Not specified	4	
Thumb & middle finger	Male	Not specified	15	
	Female	Not specified	10	
Thumb & ring finger	Male	Not specified	10	
	Female	Not specified	7	
Thumb & index and middle finger	Male	Dominant	23	1.1
	Female	Dominant	16	0.8
Tip of Thumb and index finger	Male	Dominant	17	0.92
	Female	Dominant	11	0.58
Lateral Pinch or key grip	Male	Dominant	27	1.1
	Female	Dominant	20	1.1

The boundaries of this system are dependent on the type of pedal actuation system chosen and the hand controls behind it. For instance, a male's dominant power grip hand strength can have 137 pounds of force, while a female's dominant power grip hand strength is only 81 pounds. To make the system as universal as possible, the resistance should be fitted for female strength. If the design requires a force only males can produce, then that limits the targeted audience and excludes the female population.

2.6 Evaluation of Previous Design

Handi-man 2012-2013 recommended the use of linear servos to actuate each pedal as shown below in Figure 8.

Figure 8 Starting Pedal Actuation Stand Design

After research, the team realized that the use of servos was not viable because servos that are able to operate fast enough and with enough power to compress the brake/clutch pedals are not commercially available. The team wanted to attach the servos 5 inches down from the pivot point of the pedal lever arm to try and decrease the actuation time required. Based on the data from Table 2, the servo would have to compress the brake pedal with a 150-pound force and a speed of at least 6.3 inches per second.

Table 2 Speed and Force Requirements in Relation to Position on Pedal Arm

Position	Necessary Speed	Max Force: Gas Pedal	Max Force: Brake Pedal
cm	**cm/s**	**Newtons**	**Newtons**
2.5	3.2	222	3269
5.1	6.4	111	1635
7.6	9.5	74	1090
10.2	12.7	56	817
12.7	15.9	44	654
15.2	19.1	37	545
17.8	22.2	32	467
20.3	25.4	28	409
22.9	28.6	25	363
25.4	31.8	22	327
inches	**in/s**	**Pounds**	**Pounds**
1	1.3	50	735
2	2.5	25	368
3	3.8	17	245
4	5.0	13	184
5	6.3	10	147
6	7.5	8	123
7	8.8	7	105
8	10.0	6	92
9	11.3	6	82
10	12.5	5	74

Through research of companies such as progressive automations that sell servo motors, the best option available for purchase would take about 4.5 seconds to completely depress the clutch pedal. This would keep the driver out of full control of the vehicle for 4.5 seconds. For safety reasons, all three pedals must be actuated instantaneously. We contacted the manufacturing engineers at *Progressive Automations* and provided our specifications. According to the engineer we were in contact with, servos that have enough force to actuate a brake pedal or compress a clutch pedal fully do not have the speed fast enough to complete the task.

Chapter 3: Hand Control Interface for Manual Transmission Vehicles

3.1 Design Process

In Professor Robert Norton's Design of Machinery textbook, he defines the necessary steps of designing a solution. This takes engineers through the process starting at identifying the need for the product then onto development of specifications, and ultimately resulting in an end solution. Table 3 below shows Norton's steps in the 10 Step design process. Up until now, we have only discussed the first three steps of the design process. Chapter 3 outlines the remaining steps and describes the device.

Table 3 Outline of Norton's 10 step design Process

Design Process	
1	Identification of Need
2	Background Research
3	Goal Statement
4	Task Specifications
5	Synthesis
6	Analysis
7	Selection
8	Detailed Design
9	Prototyping and Testing
10	Production

3.2 Design Specifications

In order to create a device that will accomplish our goal, and benefit the end user, design specifications for the device were established. The specifications are listed in 3 sub-categories, overall design, controls, and implementation.

3.2.1 Overall Design

1. Minimal individual components for simple maintenance and troubleshooting
2. Intuitive use to ensure a licensed driver is able to learn the operation of a vehicle with the system within six months
3. Ergonomic to ensure comfortable operation of system for over two hours of continuous use
4. The brake pedal has an immediate response time
5. The gas and clutch pedals are actuated at the speed required by traditional driving standards
6. Allows for traditional vehicle operation (forward, reverse, and gear change)
7. Competitive market price to ensure affordability for target users

3.2.2 Controls

1. Allow for safe operation of the vehicle
2. Each pedal is operated independently of one another
3. One of the driver's hands can operate the steering wheel at all times
4. Provides the driver with vehicle control as close to the traditional manual driving experience as possible

5. Allows for recovery of vehicle control within one second in an emergency situation
6. Driver is able to use other features in the vehicle while operating system (i.e. stereo, turn signals)

3.2.3 Implementation

1. Able to be installed in the majority of compact vehicles
2. Installation of device requires minimal tooling.
3. Does not need a trained technician
4. Inexpensive installation

3.3 Preliminary Hand Control Designs

In Chapter 2, the limitations of combining existing assistive driving devices for a manual transmission vehicle were discussed. It was established that in order for the driver to maintain control of the vehicle, they must always have control of the steering wheel while using the hand controls. Combinations of various existing devices do not allow for consistent steering control while operating the vehicle. In order achieve this control for a manual transmission vehicle, the hand control placement is limited to the steering wheel and the shifting knob. These are the only necessary components for vehicle operation other than the pedals, establishing them as the crucial locations of hand placement. With this restraint, the team designed several possible hand interface systems and evaluated the proposed system from the 2012-2013 Handi-man Project.

3.3.1 Accelerator on Shifting Knob

One design the team developed that would achieve the proper control placement is shown in Figure 9 below.

This design consisted of placing the throttle and clutch controls on the shifting knob with the brake control situated on the steering wheel. This design would allow the operator to engage all three

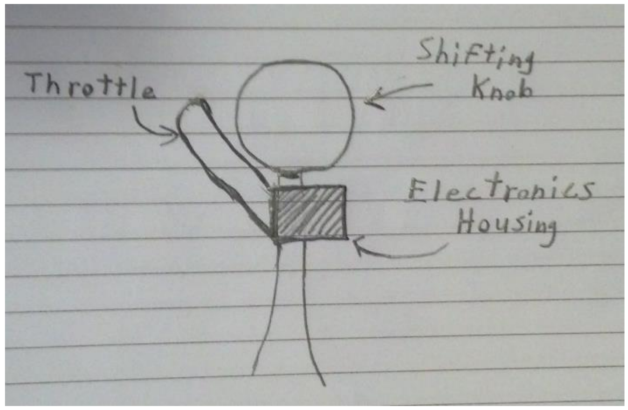

Figure 9 Accelerator and Shifting Lever on Shifting Knob Design

components if necessary while maintaining control of steering and shifting. The accelerator control would be engaged by the operator's right thumb in either a twisting or forward motion. The clutch would be engaged by pulling the control toward the operator's right palm using the fingers. The design for the brake control was a ring around the steering wheel that would be engaged by pulling the left fingers toward the left palm of the operator.

There were a few limitations of this design. When using this system the operator's right hand mobility was limited because they would need to keep their hand on the shifting knob when accelerating and shifting gears. While operating a manual vehicle with pedals, the right hand is only required to be on the shifting knob for shifting, making it available at other times for steering and engaging the necessary electronic components such as turn signals. With this design, the operator's ability to engage other components of the vehicle is limited with their right hand placed on the shifting knob for the majority of operation and their left hand effectively fixed on the wheel for steering and braking.

3.3.2 Brodie Knob

Another early design that the team developed incorporated the concept of an existing and widely used driving tool called the Brodie Knob, shown in Figure 10. Figure 11 is a picture of an ATV Throttle to show how it works. It was used to help inspire our design shown in Figure 12, where the brake and throttle controls were located on a platform attached to the steering wheel similar to that of the Brodie Knob.

Figure 10 Brodie Knob (Suicide and Brody Knobs)

Figure 11 ATV Throttle (ATV Throttle)

While both the accelerator and brake were on the steering wheel, the clutch control was installed and operated in essentially the same manner as the first preliminary design discussed. This design addressed the major limitation of hand movement. With the right hand only responsible for operating the clutch and shifting, it is available for engaging the necessary electronic components of the vehicle. The operator's left hand, however, would be responsible for steering and operating the brake and throttle, rendering it immovable from the knob to maintain control of the vehicle. The throttle of the design was similar to the thumb paddle throttle of most quad bikes, being operated by pressing the paddle forward.

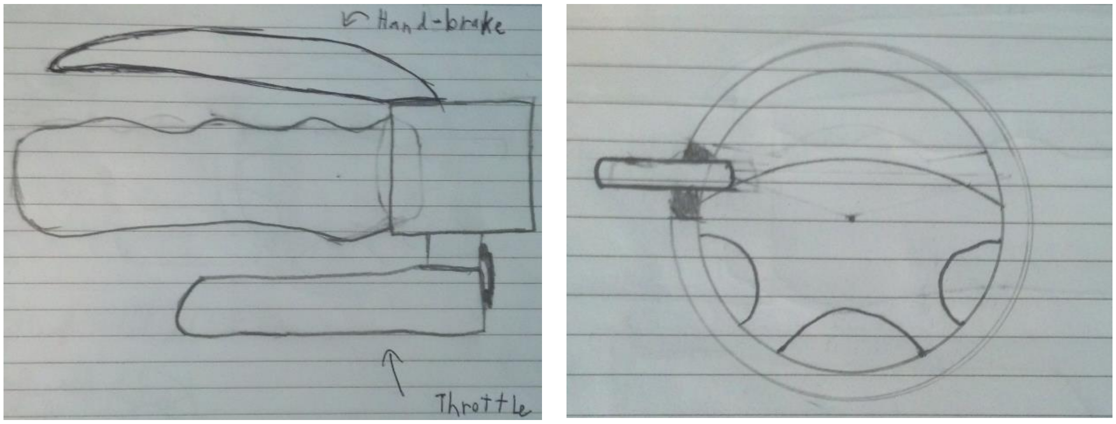

Figure 12 Potential Brodie Knob Inspired Throttle and Brake System

The brake control of this design followed close to the operation and design of a bicycle brake, and would engage by squeezing the handle towards the palm. This platform would be attached to the steering wheel at one point and would function like a Brody Knob, allowing for one hand steering control.

Safety and ease of operation are the main concerns with this design. We must consider driver error when developing these designs, and for the Brody Knob there is the distinct possibility of the driver losing control of the steering wheel. This could most likely occur if the operator's hand slips off the knob. In this situation, not only would the steering wheel be unattended, but also the brake and gas would be inaccessible until the driver regained control of the knob. This introduces serious safety concerns for both the driver and others near the vehicle. To counteract this potential risk, secondary controls would have to be placed in the car that would allow him to stop the vehicle, such as the brake ring, or a brake lever within arm's reach.

3.3.3 ATV Throttle

The third design incorporates the brake ring on the back of the steering wheel, the thumb paddle throttle, and the clutch lever on the shifting knob. The sketch of this design is shown below in Figure 13.

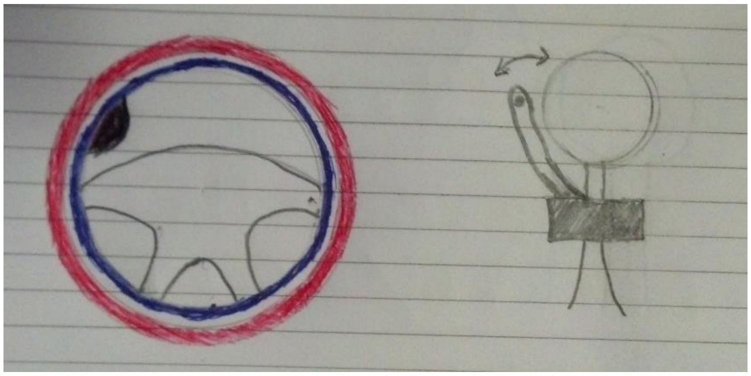

Figure 13 ATV Throttle on Steering Wheel with Lever Clutch

As shown above, the throttle paddle is black around the steering wheel shown in blue. The throttle pad is situated at one point on the steering wheel on the upper left side at its original position. To operate the throttle with this design the driver pressed the thumb paddle forward, away from the driver. The thumb paddle allowed for gradual acceleration much like that of the vehicle's gas pedal. The brake ring located on the back of the steering wheel, shown in red, was the same brake control design described earlier for the first preliminary design, engaging the brake gradually as the ring was squeezed towards the palm. The clutch hand control follows the same lever design on the shifting knob as the other preliminary designs.

The limitations of this design focus around the throttle hand control. Having the thumb paddle located at only one point on the steering wheel limits the driver's ability to access the gas with ease. Even if another paddle was placed on the steering wheel across from the existing one, they would still be difficult to engage at every position of the wheel's rotation. This challenge creates safety concerns for this throttle control. Another concern of the throttle paddle is the fatigue of the driver's thumb. It is possible that the driver's thumb would fatigue on longer drives but would not have an alternative way of engaging the throttle.

3.3.4 Double Ring

The team's final preliminary design was similar to the proposed design of the Handi-Man 2012-2013 project. This design consists of two rings on the front and back of the steering wheel and a clutch lever on the shifting knob. This design is shown in Figure 14 below.

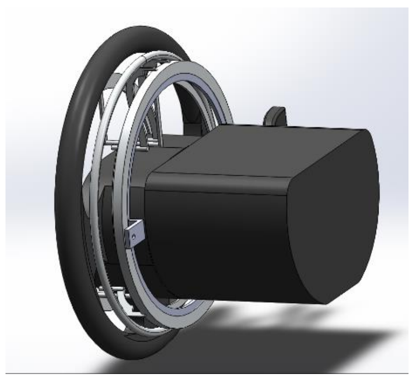

Figure 14 Double Ring Design

The ring on the back of the steering wheel engages the brake and is operated by squeezing the ring towards the driver. The front ring engages the gas and is operated by pressing the ring forward with the thumb or the palm. The clutch is engaged by pushing a lever on the shifting knob away from the driver and releasing.

There are fewer limitations to this design than the other designs discussed. The main concern is the amount of mechanisms located on the steering wheel. In an emergency situation the driver could potentially engage the wrong ring or squeeze the steering wheel and both rings all at once, rendering the vehicle out of control. Through training and practicing with the system, the driver could become comfortable with the double ring design and learn how to react in a potential panic situation. This process is similar to learning how to react safely in strenuous situations when learning to drive traditionally.

3.4 Our Selection Process

Taking all of these designs into consideration, the team evaluated each of their strengths and weaknesses against the design specifications in a design matrix shown in Table 4.

Table 4 Design Matrix

	Safety	Functionality	Ease of Use	Cost	Ease of Installation	Minimum Maintenance	
Weighting Factors							
Designs	100	95	80	80	50	40	Total
Shifting Knob	6/600	6/570	4/320	3/240	4/200	6/240	2170
Brodie Knob	4/400	4/380	2/160	2/160	5/250	5/200	1550
ATV Throttle	7/700	5/475	5/400	4/360	6/300	5/200	2435
Double Ring	9/900	8/760	10/800	6/480	7/350	7/380	3570

In this design matrix the design specifications of the project were categorized and weighted based on their importance in the final design. The preliminary hand control designs were rated for each design specification category on a scale of zero to ten, zero being a failure and ten being excellent. The rating scheme used in Table 4 above includes two values for each design to design specification comparison. The first number is the rating on the scale from zero to ten. The second number after the dash is the rating after being multiplied by the weighting factor for that design specification. For example, if a design received a rating of four for the Safety category its score would be represented as 4/400.

As shown in the table above, the team found that the double ring design would be the best option for moving forward for a few major reasons. The first is the ease of operation compared to the other designs. The controls on the steering wheel and the steering wheel itself allows for an easy recovery in an emergency situation. The fact that the rings are accessible from every point of rotation of the steering wheel proves that this system would be more reliable than the other designs. The second reason this design trumps the others is that the driver can operate the gas, brake, and steering wheel all at once using only one hand. This feature coincides with the driver's need to have the right hand free for operating the clutch and the electronic components of the vehicle.

3.5 Final Design of Hand Control Interface

3.5.1 Gas Control

Gas hand controls in the form of accelerator rings located on the front of the steering wheel are already available on the market and have become popular products. Their success and high functionality led our team to decide that for the design, analysis, and prototyping of the project the focus would lie on only the brake and clutch components. The team's design incorporated the recommendation that an accelerator ring be implemented with our system for optimal operation.

3.5.2 Brake Control

The brake control interface the team decided to pursue introduced a few challenges. The first challenge was to determine if the brake ring would rotate 360 degrees. With a freely rotating brake ring the driver's ability to engage the brake while turning the steering wheel is improved. Without the rotation in the brake ring the driver could have difficulty turning the steering wheel while attempting to engage the brake simultaneously. The freely rotating brake ring was an advantage that could help avoid potential dangerous and unsafe driving situations, making it an important feature to implement in the design.

In order to design the brake ring to allow full rotation, the team examined an existing and proven mechanism found on BMX bikes. The mechanism allows the hand brakes to operate while the handlebars rotate freely. Figure 15 below shows an example of this design.

Figure 15 BMX Bike Brake Mechanism

This design consists of a fixed ring that is set inside a freely rotating outer shell, both components are able to move together in a translational fashion. The shell is attached to the hand brakes through steel cables and the fixed ring is attached to the brakes through steel cables. When the operator engages the hand brake control, the shell is pulled upward bringing the inner ring with it and engaging the brake. The translational movement and rotational capabilities of the BMX brake mechanism correlate directly to the requirements of the brake hand control in our design.

Using the model of the BMX brake mechanism, the team designed the brake hand control shown in Figure 16 below.

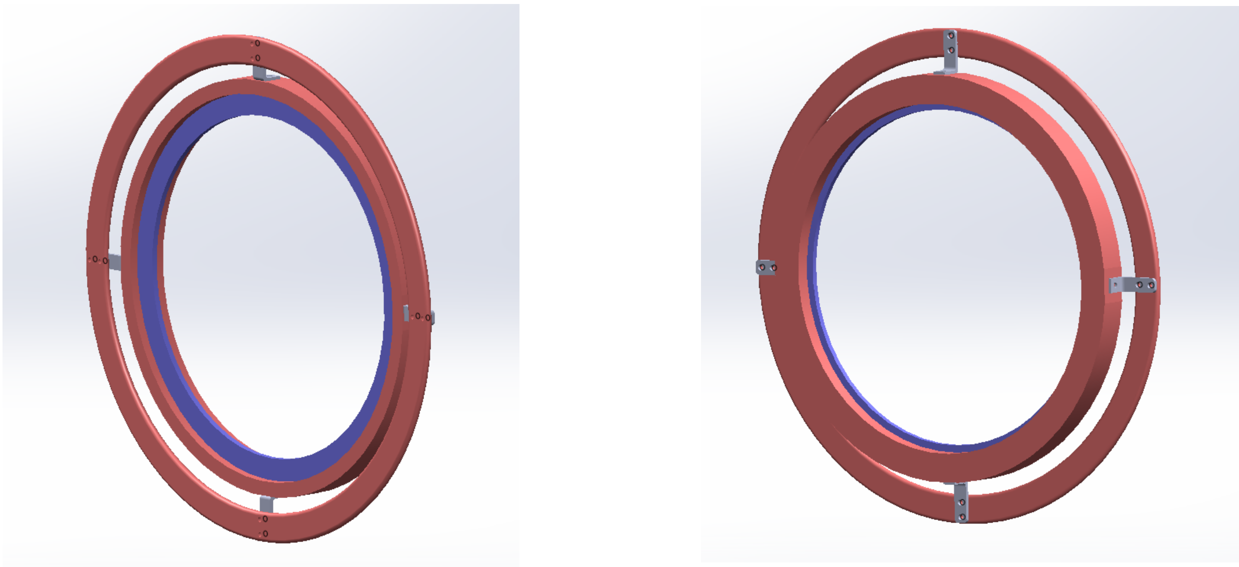

Figure 16 Brake Rings

In Figure 16 the fixed inner ring is shown in blue and the outer shell and brake ring are shown in red. To engage the brake the operator pulls the brake ring towards themselves which is fastened to the outer shell by four steel braces. Both the shell and inner ring move with the brake ring in a translational motion. During the operation of this control, the brake ring and shell maintain the ability to rotate 360 degrees around the fixed inner shell.

In order to minimize the weight of the system while maintaining strength and structural integrity, the components of the brake control are made of 6061 Aluminum. This material has been proven in the aerospace industry as relatively light compared to steel while maintaining a high yield strength. One part of the system that would require regular maintenance is the inner face of the shell that rotates around the inner ring. The specified area would have to be regularly lubricated to ensure that the two pieces of aluminum would not create enough friction to interfere with the functionality of the system.

Another challenge this particular control interface introduced was the centering and securing of the system behind the steering wheel. The design requirements of the supports were to allow translational movement and support the weight of the brake hand control. The team developed a double rail system that attaches the fixed inner ring directly to the top and bottom of the steering column as shown in Figure 17 below.

Figure 17 Double Rail System

Both of the slide rails in the design are modeled after desk drawer slides much like the ones shown in Figure 18.

Figure 18 Desk Drawer Rails for Sliding Rails

The base of the rails are secured directly to the steering column with two bolts to eliminate slippage or movement. The inner slide of the rails are attached to the inner fixed ring of the brake control by braces made from structural steel as shown in Figure 17. Although structural steel is a relatively heavy material, its strength is necessary to ensure the brake control system is entirely supported without fail. The rails would need to be checked before operation to ensure they are properly lubricated to reduce friction in the pull.

3.6 Clutch Hand Control

3.6.1 Hand Control Placement

As discussed earlier in the chapter, the design specifications called for a system that would offer a tactile response. The placement of the new clutch control in this design was placed on shifting knob, because the actuating of the clutch and shifting gears are an independent system used concurrently.

To achieve a tactile response, the team chose to use a bike brake cable, Bowden cable, to actuate the clutch. The Bowden cable, has a steel cable within a housing cable, If the housing cable is fixed, the steel cable inside can move transnationally, no matter the orientation. A picture of a bicycle brake cable may be seen in Figure 19 below.

Figure 19 Example of a Bowden Cable (Dave's Motors)

Starting from the clutch pedal, the cable is attached at the lowest point of the pedal and travels straight back and along the wall. The cable travels along the console, up and to the shifting lever as can be seen below in Figure 20.

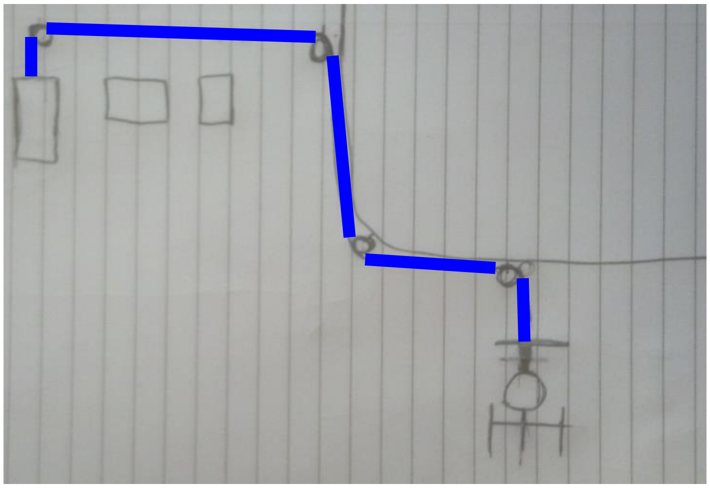

Figure 20 Travel Path of Clutch Cable

3.6.2 Clutch Specifications

As stated in Chapter 2, the system must be able to actuate a 20-pound force with a 4-inch actuation distance. The hand control can be seen below in Figure 21.

Figure 21 Hand Clutch Control (Left: Relaxed) (Right: Actuated)

In the original design of the system, the lever was to be pulled toward the driver, this was changed because the housing of the clutch lever would slam in into the console in most vehicles. A push system also offers the driver more ease of use, by allowing the driver to use the whole are to compress the lever, while still using the dexterity of the hands to control the lever.

In order to obtain the required mechanical advantage with the system cable, the cable must be oriented downwards. By attaching the outer shell of the Bowden cable system to the shifting knob, it will allow tension to be maintained in the inner steel cable no matter the gear the shifting knob is in. This system does not impede the ability to drive the car traditionally so if it is a shared vehicle, the clutch may still be actuated with the left foot pushing on the pedal.

3.6.3 Spring Assistance

To make the system more versatile, the team suggests the use of a spring to help offset some of the force the user would have to input. While most people can input 20 pounds with their foot, if this force seems too difficult, a spring can be attached behind the clutch pedal to assist in actuation. The spring cannot be too strong or it will prematurely compress the pedal, but offset the 20-pound force.

3.7 Brake Pedal System

Because of the reliability of mechanical systems, we chose to create a system to actuate the brake pedal using mechanical linkages. Using 6061 Aluminum in our design would enable the device to be rigid and structurally stable and light enough that it would not bring a weight concern to the vehicle. The brake system has four parts that would need to be implemented into the vehicle, a rail system to guide a driver of the four bar linkage and that supports the weight of the hand controls, a stand which holds a bar to let the linkage system pivot, a mounting bracket attached to the pedal to actuate the brakes, and lastly the moving linkages.

3.7.1 Rail System

The rail system is comprised of two parts, the upper rail and the lower rail. Together they help to hold the weight and stabilize the hand controls. The lower rail's purpose, along with those previously mentioned, is to act as a driver for the four bar linkage. To minimize the weight and cost of additional linkages the team concluded that the use of the rail system to double as a stabilizer and as the driver would save space in the device.

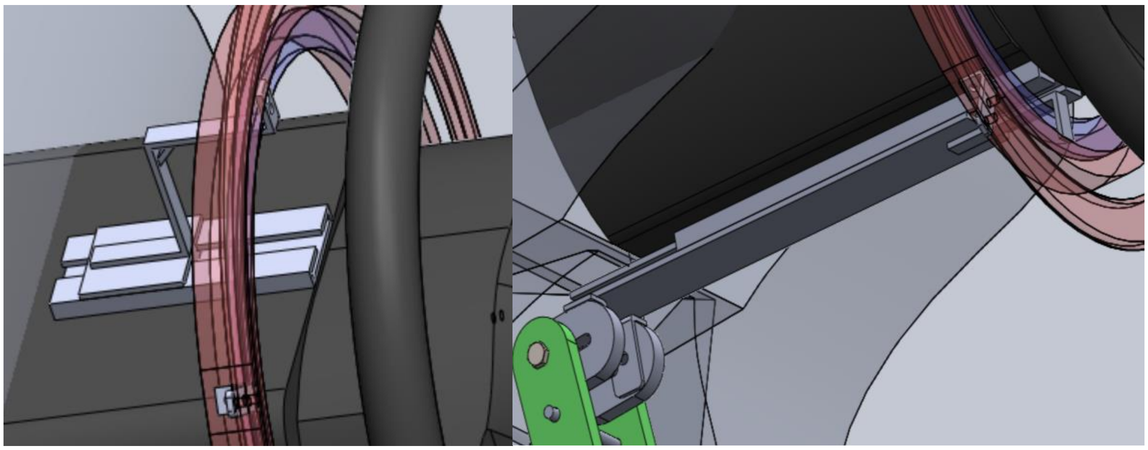

Figure 22 Top and Bottom Rails

As seen in Figure 22 above the rails are very different sizes, this is because of the purpose of each rail. The bottom rail's role is to act as a driver for the linkage system, by increasing the length of the rail to 10 inches it was possible to put the linkage system closer to the pedal instead of closer to the user's legs, minimizing the risk of injury. The top rail is only 4 inches, this is purely a size constraint. There is only around 5 inches of space on top of an average steering column.

3.7.2 Pivot bar

The purpose of this pivot bar, shown in Figure 23, is to act as a pivot for the linkage system. At this point in the linkage it will change the direction of the system from towards the user, to towards the brake pedal. Also, the majority of the systems weight will be held on this single bar.

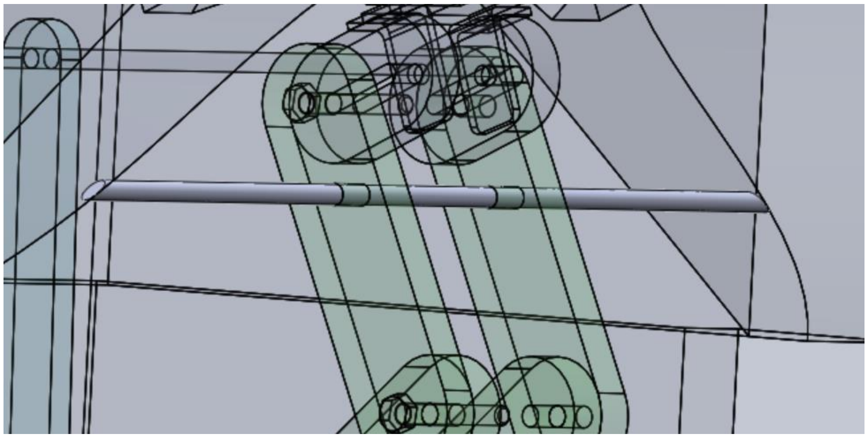

Figure 23 Pivot Bar

This bar can be implemented in the system either two ways, mounted directly into the side of the console and foot well, or onto a moveable stand that would then be mounted to the floor of the vehicle. For the purpose of simplicity, we chose to mount the pivot bar into the sides of the console and foot well. However as you can see in Section 3.8, the team chose to build the pivot bar on a stand for our prototype.

3.7.3 Pedal Bracket

To attach the linkage system to the pedal, we would need an easy way for the system to attach to a brake pedal. The team chose to make a simple mounting bracket that would attach to both sides of a brake pedal and then be bolted together. The team then thought of designs that would allow for the best grip on the brake pedal and to allow space for the linkages to move freely.

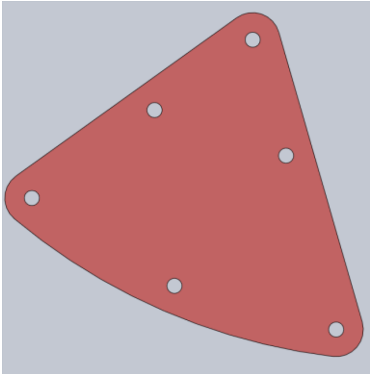

Figure 24 Brake Bracket I

The first design that was created had a great amount of surface area that would touch the pedal, and enough space at the top hole to allow for the linkage to rotate freely. However the team realized that over time, it was possible for the bracket to slip down and change the position of the linkage system. To overcome this problem an attachment for the pedal was created.

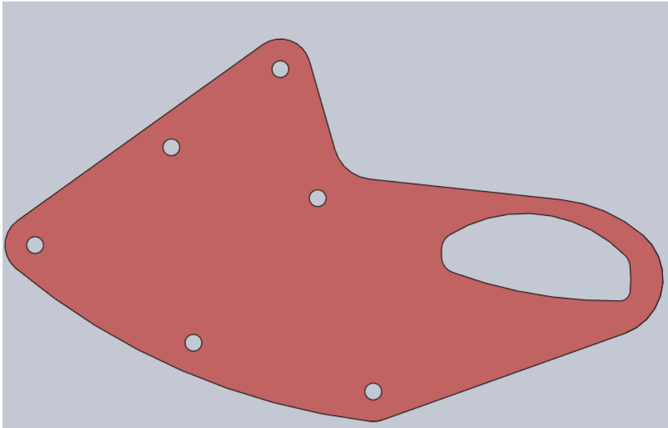

Figure 25 Brake Bracket II

The reasoning behind this design was that, the open hole would slip over the brake pedal and act as a shoe. It would not allow for the bracket to slip down and change the position of the linkages, however the bracket design became heavier. The team analyzed this design and iterated for a final time.

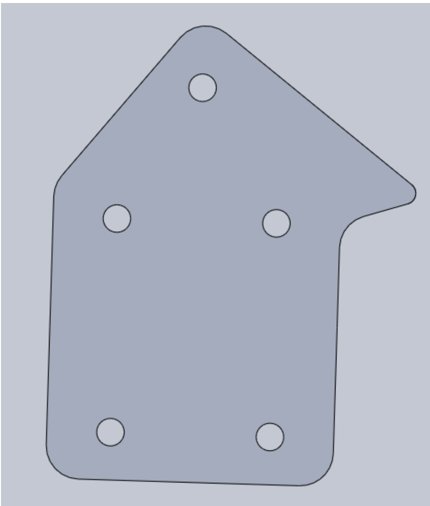

Figure 26 Brake Bracket III

The bracket shown above in Figure 26 is the final iteration of the bracket. It is a quarter of the size of the previous iteration, and still provides the same functionality. The team realized that in the last design, the bottom part of the shoe was not necessary. The only part that needed to touch the brake pedal to stop slippage is the top part, so in this design there is a hook that will keep the system stable against the pedal.

3.7.4 Linkage System

The brake actuation system relies on the linkages. The team decided that the device was to transform 2 inches of motion, towards the user by way of the hand control ring, to 4 inches of actuating force towards the brake pedal.

Initially the team's intentions were to place linkages attached to the hand control, down to the pivot linkage, then a final linkage driving the force into the pedal. However, after conducting testing and analysis on the system, we realized that in order to properly stabilize that system we would need a supports to hold the large linkage that is acting as a driver, which would make less room for the user.

The solution to overcome this design flaw was the implementation of the rail system as previously stated in section 3.7.1 however this rail presented a new problem. Because the pivot linkage makes a curve when actuated, the pure translational motion of the rail system would halt movement from happening because that one linkage needs to spin in order to work properly.

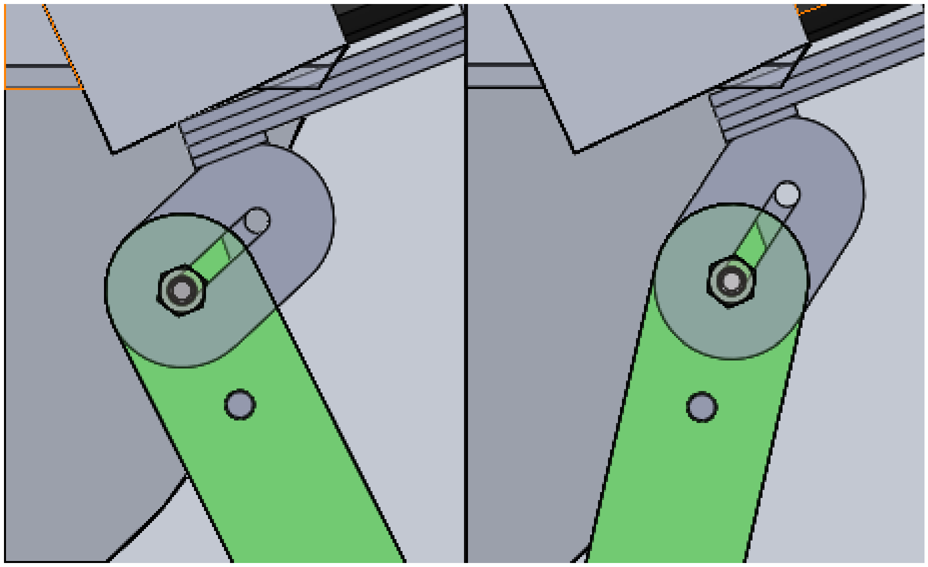

Figure 27 Slot Linkage

To overcome this problem the team implemented a small slotted linkage that would add a small inch of slack in the top of the system where it is mounted to the rail. This small bit of slack would make up for the angular distance in which the pivot needed to travel.

Now that the extra slot linkage exists, the relationship that existed between the pivot linkage that gave the 2:1 ratio of input and output distance, had to be changed. The team treated the slotted piece in full extension as a single linkage, so there had to be a ratio of 2:6 from one slot to the pivot point, to the opposite hole to enable the motion of 2 inches of the user, translated into 4 inches of output to the pedal.

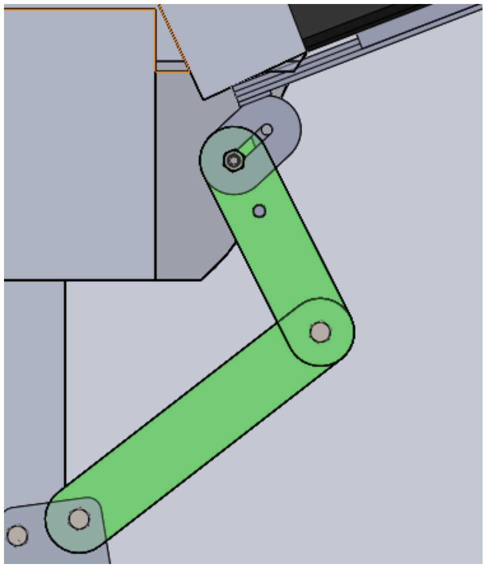

Figure 28 Linkage system

The components described previously all are added together with a final linkage to transform the angular distance of the bottom pivot linkage into translational motion by the bottom linkage which connects to the brake bracket. All together, the system is now functional.

3.7.5 Analysis of Brake Design

Further analysis of the final system design gave evidence that the components of the system could withstand the forces acting on them. To gather this data, the team conducted finite element analysis on two components of the brake hand control system, the ring braces and the outer brake shell. These two components were found to potentially have the highest stress concentrations of all the components in the system. Based on the force analysis of the brake pedal explained in Chapter 2, the team determined that the components would experience 50 Pounds of reactionary force overall in the direction of the driver. By applying this force to the components in the specified locations along with securing the appropriate locations as supports, the team conducted the necessary analysis.

For the analysis of the bracket, the 50 Pound force was applied to the top of the piece and the bottom portion was secured as a compression-only support. The resulting von-Mises stresses are shown in Figure 29 for the bracket.

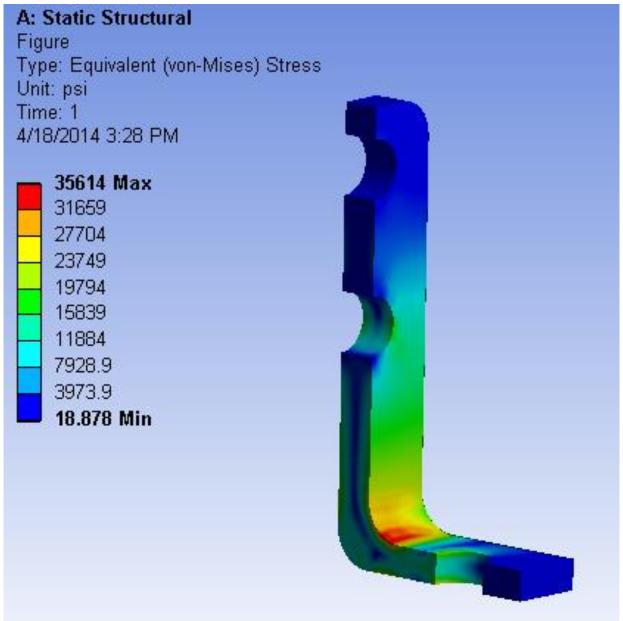

Figure 29 Finite Element Analysis of Bracket

As seen, the highest stress concentration on the bracket is the inside of the bend. The maximum stress the piece experiences at that location is 35614 psi. Structural steel, or A36 steel, has a minimum yield strength of 36000 psi or 250 Mpa (Engineeringtoolbox). The bracket would not fail under these conditions.

The analysis of the outer brake shell was conducted very similarly. The 50 Pounds of force was applied to the inner portion of the ring where it would make contact with the inner ring. Four supports were placed on the flattened portions of the outer face of the piece as compression-only supports. These supports represented the four brackets that are attached to the outer face of the shell. The finite element analysis of the resulting von-Mises stresses is shown in Figure # 29.

As seen above, the major stress concentrations on the shell were on the inner edge of where

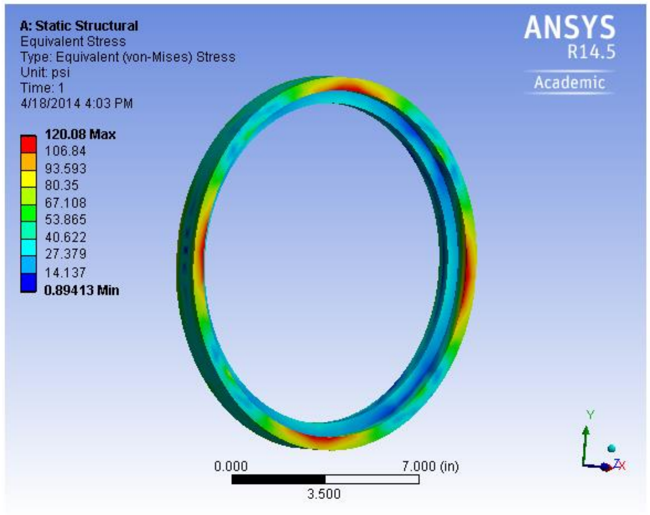

Figure 30 Finite Element Analysis of Brake Ring

the brackets are attached. The force from the inner ring is distributed evenly along the inner face of the shell, making the effects less significant on the shell. The maximum von-Mises stress found at these four locations was 120.08 psi. The shell is constructed of 6061 Aluminum with a yield strength of 40000 psi (ASM). With these specifications, the shell would withstand the forces acting on it with a significant safety factor.

3.8 Brake System Prototyping

To prove our proposed design of the hand controlled interface can be implemented into a system, the team wanted to install the system into a working manual car. However due to budgetary reasons we were unable to do so and instead decided to build a full scale proof of concept model of the device.. Because of our previous design goal of universal compatibility, we chose to build our prototype with the dimensions of a cabin of a Toyota Corolla. This vehicle is very popular in American, and by showing that this device can fit in a small car such as the Corolla, it shows that this system can be implemented in a wide variety of vehicles.

The first part that the team needed to build was “the car”. To find the proper sizes of steel to be cut for our car frame, the team created blueprints within Solidworks using our pre-existing model of the system. With the use of this model we were able to properly plan what size the prototype had to be in order to duplicate the dimensions of a Corolla.

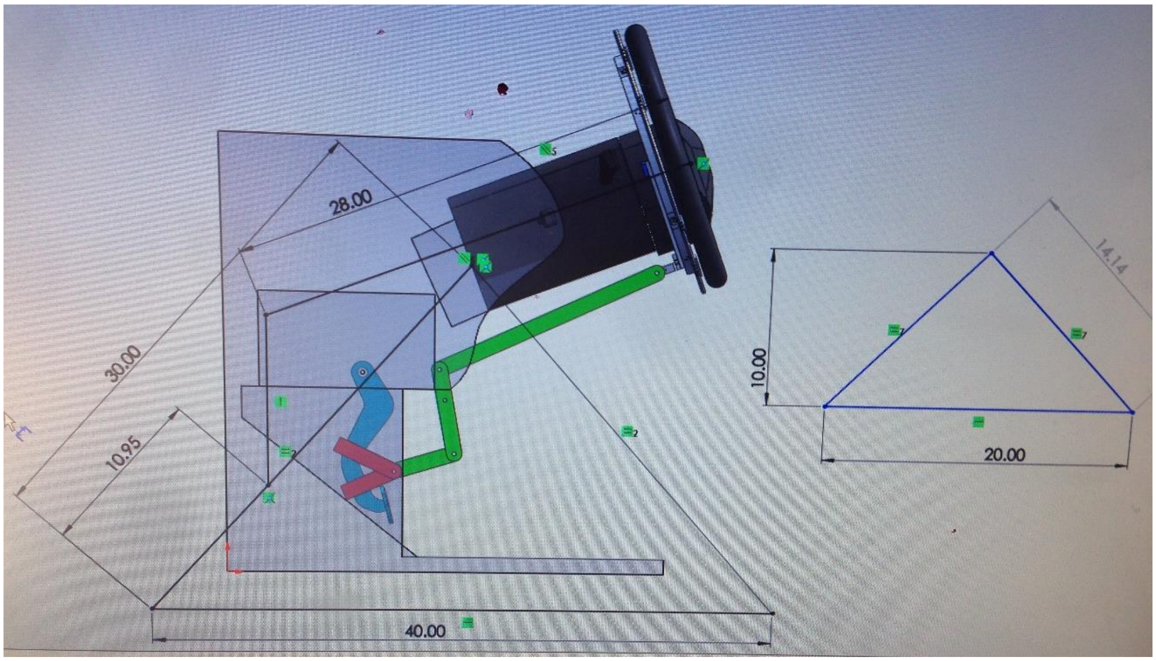

Figure 31 Prototype frame blueprint

With help from the team’s mutual friend and peer, Joseph Monasky, the team created a steel frame constructed using steel angle bars and welded them together to create a triangular structure that would act as our car. The team determined that it was necessary to keep the components of our prototype that was not a part of the assisted driving device stationary, so the team welded a steering column to the frame as seen in Figure 32.

Figure 32 Prototype frame

With the structural integrity of the steel welds, the team was confident that our device could be attached to this without the risk of device being insecure. In addition to the frame and steering column, the device needed to be attach to a brake pedal and clutch pedal. For these pedals the team made a mounting bracket for a steel rod to slide through to simulate the brake pedal and clutch pivot points. It was important that this rod was removable because of installation and transportation purposes.

After “the car” was built, the team focused on building the device. The first part that was constructed was the shell ring for the brake system. In the proposed design the team suggests that this part is machined out of 6061 Aluminum alloy, however because of machining restraints the team chose to create this part with layered acrylic. Using acrylic made the prototyping much easier and lighter which helps in the transportation of the team’s model. Attached to the shell ring is another ring which is what user grabs when using the system to actuate the brake pedal. This ring was also constructed out of acrylic for the same reasons as previously mentioned. The two rings were then fastened together using steel brackets.

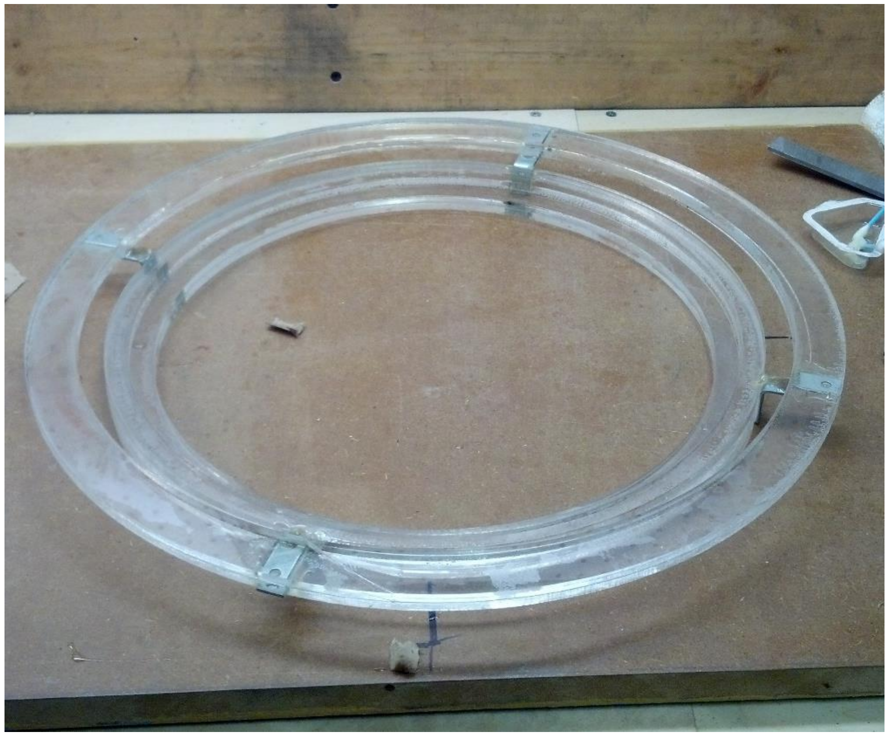

Figure 33 Brake ring Prototype

The next part to be constructed for our model was the rail system that acts as a support for the brake ring, and as a means of actuation for the brake linkage system. For the prototype the team chose to modify a rail system that is commercially accessible, drawer slides. The slides which the prototype were to use, needed to work upside down and right-side up so the team chose to use ball bearing drawer slides. This enabled the team to modify the existing product to create a 4-inch mounting rail on top to support the brake ring, and then a 10-inch mounting rail on the bottom to support some weight of the brake ring and also drive the brake actuation linkage system.

Figure 34 Ball Bearing Drawer Slides

Connected to the slides was the linkage for actuating the brake system. As described in section 3.7.4, the linkage system works by creating a four bar linkage that transforms 2 inches of motion from grabbing the brake control, into 4 inches of motion in the opposite direction triggering the brake pedal. Because our prototype model differed from our Solidworks model slightly, the team had to recalculate the linkage sizes so that they would move in the way that they were intended to. Our linkages were constructed using 1/4” acrylic, layered together to create ½” thick pieces for additional structural integrity.

Figure 35 Prototype Linkages

After all the components were constructed, they had to be assembled to the prototype's frame. The only modification that had to occur was a location for the mounting rails to be held. The team drilled into the steering column and tapped holes in the steel so that the drawer rails could be screwed into them without sliding. After that construction on every other component was attached with ease, showing how easily the prototype could be installed into a vehicle. To support the weight of the linkages and the system we created a stand to hold the pivot bar in which the four bar linkage would rotate around. In the final product the pivot bar can either be mounted this way or into the side console and foot well, however in our prototype we had no walls, so the team chose to mount the pivot bar on top of a moveable stand.

Figure 36 Picture of stand

3.9 Clutch System Prototyping

The housing for the prototype was made from aluminum 6061, the same material stated for the final market product. The part was modeled in Solidworks, input into Esprit for tooling, and cut using a mini-mill. It is important to have tool dimensions set appropriately because the part is not symmetrical. The finished component can be seen below in Figure 37.

Figure 37 Prototype of Lever Clutch Housing

The Esprit files may be viewed in Appendix B. For future manufacturing, it may be a wise decision to drill a hole in the middle of the part where the arrow is pointing. While machining the prototype, the part had to be strapped down and rotated multiple times. If there was a whole drilled in the center of the piece, Operation 1 could have been run without stopping. This would decrease production time and make this an easier part to manufacture.

For manufacturing purposes the lever arm was laser cut and layered from acrylic. Acrylic is an inexpensive material for prototyping and offers structural stability for proof of concept. The real model will be made from aluminum to ensure strength for infinite cycles.

Ball bearings were used with an aluminum rod through the housing to hold the lever to the handle. The steel cable attaches to the bottom of the lever with the outer shell attached to the shifting lever to establish the independent system and allow the positioning of the lever to be negligible. The cable travels along the steel frame and is connected behind the pedal. The completed clutch system may be seen in Figure 38 below

Figure 38 Prototype Clutch Lever

The Clutch cable travels along the steel frame and attaches to the base of the pedal. When the lever is pushed forward, it pulls the steel cable. The cable may be seen in Figure 39 below.

Figure 39 Clutch Pedal Prototype

The inner steel cable is pointed at by a blue arrow. This is the part of the cable that moves. The black outing tubing is fixed which allows the inner cable to actuate, as discussed in Chapter 3.7. A close up of how the steel cable was fastened to the pedal may be seen in Figure 40 below.

Figure 40 Attaching the Clutch Cable to the Clutch Pedal

3.10 Prototype Results

The teams fully constructed prototype shows the motion that it was intended to. The device turned 2 inches of motion into 4 inches of motion towards the brake, as well as making a one-to-one ratio of the clutch system with a steel brake system.

Figure 41 Final Prototype

Chapter 4: Conclusions and Recommendations

The final goal of this project was designing a device that will allow paraplegics and double leg amputees the opportunity to safely operate a manual transmission vehicle. In order to accomplish this task, the team evaluated existing devices to learn how market devices function. Next, the team continued the work done by the previous MQP group to solve the existing problem. The team created a design for a device that successfully actuates the brake and clutch systems using a mechanical system independently from each other. Lastly the team constructed a fully functioning prototype that exhibits that it is possible to implement this system into a compact car.

The team's final design consisted of two systems, the brake and the clutch system. The brake is actuated by compressing a ring that sits behind the steering wheel. That ring is connected to a sliding rail system that acts as a driver for a four bar linkage system that results in the actuation of the brake pedal. The clutch system is comprised of a housing that sits on the shifting knob with a lever attached. The lever is connected to a steel cable that is secured and attached to the back of the clutch pedal. By pushing on the lever, the steel cable is pulled and therefore actuating the clutch.

The team believes that there are three main conclusions that can be drawn from our work on this project, universal compatibility, cost effectiveness, and a more satisfactory driving experience. The team developed a device that was universally installable in many vehicles. With slight modification to the linkage system, this device could potentially work in any vehicle. Some existing market devices can potentially cost upwards of $10,000. This device is capable of being manufactured and installed for under $1000, giving it a significant advantage. With this mechanical system, the device gives the full experience of driving, directly to the user. The device enables the user to actuate the complete range of motion of the pedals that allows a tactile response by way of the hand controls0. Providing the user the experience of driving a manual transmission car to its fullest potential.

There are a few areas in which this project can be further improved upon in the future. Enclosures for each moving part is essential to improve upon safety; linkage system, steering wheel ring, and clutch lever. In addition, instead of mounting the slide rails directly to the steering column, the system could include a custom steering column cover. This cover would incorporate the rail system and replace the cover the vehicle comes with. This would allow for much easier installation and allow for more universal compatibility while safely covering the moving parts. Finally, before the product could be marketed it requires further testing and evaluation installed in a manual transmission vehicle.

References

Accessible Honda Element. (n.d.) Retrieved October 4, 2013, from Aeromobility: http://www.aeromobility.com/accessible.html

Adapt Your Vehicle with Mobility Products. (n.d.) Retrieved September 23, 2013, from GM Mobility: http://www.gmmobility.com/adapt-your-vehicle/

Ait-Oufroukh, N.; Messaoudene, K.; Mammar, S. "Dynamic model of steer-by-wire system for driver handwheel feedback", *Networking, Sensing and Control (ICNSC), 2013 10th IEEE International Conference on* Innovative Brake Handwheel Concept for Paraplegic Drivers http://ieeexplore.ieee.org/xpl/abstractCitations.jsp?arnumber=5466182&tag=1

Aluminum 6061, (n.d.) Retrieved March 14, 2014 from ASM Aerospace Specification Metals Inc: http://asm.matweb.com/search/SpecificMaterial.asp?bassnum=MA6061t6

ATV Throttle, (n.d.) Retreived March 3rd 2014, from Daves Cycle : http://www.davescycle1.com/catalog/56bc_1_1742_1.JPG

Automobile Adaptive Equipment. (n.d.) Retrieved on September 24, 2013, from United States Department of Veterans Affairs. http://www.prosthetics.va.gov/AAE.as

Bowden Cable (n.d.) Retrieved March 3rd 2014, from Daves motors : http://www.davesmotors.com/fg-10451-01-bowden-cable-for-rear-disc-brake-f1.html (bike brake picture)

Center, T. E. (2006, 10 24). *Human Strength Data Tables*. Retrieved April 1, 2013, from The Ergonomics Center of North Carolina: http://www.theergonomicscenter.com/graphics/Workstation%20Design/Strength.pdf

Clutch Systems Vehicle Adaption.(n.d). Retrieved October 4, 2013 from eLap Company: http://www.elap.co.uk/motoring/vehicle-adaptations/clutch-systems.

Das, B., & Forde, M. (1999). Isometric Push-up and Pull-down Strengths of Paraplegics in the Workspace: 1 Strength Measurement Profiles. Journal of Occupational Rehabilitation, 9(4), 277-289.

The Digital Accelerator Ring and the Main Hand Brake. (n.d.). Retrieved October 3, 2013, from KEMPF Inc.: http://www.kempf-usa.com/indexNew.html

DiLullo, D., Kocienski, S., Zopatti, D. (April 25, 2013). Development of Zero-Leg Input Manual Transmission Driving Interface. retrieved August 28, 2013, from WPI MQP: http://www.wpi.edu/Pubs/E-project/Available/E-project-042413-122016/unrestricted/Assistance_Driving_Device_Project_Report.pdf

Fischer, H. (2013). U.S. Military Casualty Statistics: Operation. Congressional Research Service.

Getting a Wheelchair into a Car. (n.d.). Retrieved from Research Institute for Consumer Affairs:http://www.rica.org.uk/content/getting-wheelchair-ca

Giuffre, Frank P. (1930). U.S. Patent No. 1833458. Washington DC: U.S. Patent and Trademark Office.

Hand Controls, Electronic Driving Systems and other Driving Aids. (n.d.). Retrieved October 3, 2013, from MobilityWorks Adaptive Vehicles: http://www.mobilityworks.com/mechanical-hand-controls.php

Kuhn, Robert (2001). U.S. Patent No. 20020104705. Washington DC: U.S. Patent and Trademark Office.

Linear Actuators : Quality.(n.d.) Retrieved October 5th, 2013, from Progressive Automations: http://www.progressiveautomations.com/search.aspx

Mammar, S., Oufriukh, N. A., & Messaoudene, K. (2010). Innovative Brake Handwheel Concept for Paraplegic Drivers. IEEE Transactions on Vehicular Technology, 3272-3285

Mechanical Hand Controls Vehicle Adaption.(n.d). Retrieved October 4, 2013 from eLap Company: http://www.elap.co.uk/motoring/vehicle-adaptations/mechanical-hand-controls/.

Messaoudene, Kamel; Oufroukh, Naima Ait; Mammar, Said. Driving assistance for paraplegic people "brake on handwheel coupled to the steering-by-wire system" Intelligent Autonomous Vehicles, Volume # 6 | Part# 1: http://www.ifac-papersonline.net/Detailed/43124.html

Modulus of Elasticity, (n.d.) Retrieved March 24, 2014 from Engineering Toolbox, http://www.engineeringtoolbox.com/young-modulus-d_417.html

Noonan,J,. Hydraulic Systems in Action, Retrieved October 6th, 2013, from Ferret: http://www.ferret.com.au/articles/in-focus/Hydraulic-Systems-in-Action-What-Are-the-Advantages-and-Disadvantages-n2509559

Norton, R. L. (1992). Design of machinery: an introduction to the synthesis and analysis of mechanisms and machines. New York: McGraw-Hill.

Odyssey G3 Gyro Brake Setup, (n.d.) Retreived fr March 3rd 2014, from Broadribb Cycles : http://www.discountcyclesdirect.co.uk/images/odyssey_g3_gyro_detangler_setup.jpg

Orthotec Vehicle Adaptions. (n.d.) Retrieved September 24, 2013, from Orthotec: http://www.orthotec.ch/en/pub/otc/vehicle_adaptation.htm

Orwell,M,. Advantages and Disadvantages of Pneumatic Systems, Retrieved October 6th, 2013 from eHow:http://www.ehow.com/facts_7594256_advantages-disadvantages-pneumatic-systems.html

Prasad, R., Hunter, J., & Hanley, J. (2006). Driving Experiences of Disabled Drivers. Clinical Rehabilitation, 445-450.

Prevalence and Most Common Causes of Disability Among Adults --- United States, 2005. (n.d.). Retrieved October 4,2013 , from Center for Disease Control and Prevention: http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5816a2.htm

Products: Hand Controls. (n.d.). Retrieved September 14, 2013, from Mobility Products and Design: http://www.mobilityproductsdesign.com/products.asp

Right Hand Clutch Control. (n.d.). Retrieved October 2, 2013, from Alfred Bekker API: http://www.alfredbekker.co.uk/hand-controls/right-hand-clutch/.

Rotating Seats Vehicle Adaption.(n.d). Retrieved October 4, 2013 from eLap Company: http://www.elap.co.uk/motoring/vehicle-adaptations/rotating-seats/.

Spinal Cord Injury Facts and Statistics. (n.d.). Retrieved October 4, 2013, from SCI-INFO-PAGES: Quadriplegic, Paraplegic & Caregiver Resources: http://www.sci-info-pages.com/facts.html

Suicide and Brody Knobs, (n.d.) Retrieved March 3rd 2014, from American Shifter Company:http://www.americanshifter.com/catalog/Suicide-and-Brody-Knobs

X. Wang , J. P. Verriest , B. Lebreton-Gadegbeku , Y. Tessier & J. Trasbot (2000) Experimental investigation and biomechanical analysis of lower limb movements for clutch pedal operation, Ergonomics, DOI: 10.1080/001401300421833 http://www.tandfonline.com/doi/pdf/10.1080/001401300421833

Wells-Engberg Product Catalog. (n.d.). Retrieved October 1, 2013, from Wells-Engberg: http://www.wells-engberg.com/products.html

Appendix A: Engineering Drawings

Table 5-A Bill of Materials

Bill of Materials		
Part No.	**Description**	**Material**
HM14-01	Bottom Rail	6061 Aluminum
HM14-02	Bottom Slide Insert	6061 Aluminum
HM14-03	Toyota Corolla Cabin	n/a
HM14-04	Slot Linkage	6061 Aluminum
HM14-05	Pivot Rail	6061 Aluminum
HM14-06	Driver Linkage	6061 Aluminum
HM14-07	Brake Bracket	6061 Aluminum
HM14-08	Pivot Linkage	6061 Aluminum
HM14-09	Top Rail	6061 Aluminum
HM14-10	Top Slide Insert	6061 Aluminum
HM14-11	Fixed Ring	6061 Aluminum
HM14-12	Brake Ring Brace	Structural Steel
HM14-13	Brake Ring	6061 Aluminum
HM14-14	Brake Shell	6061 Aluminum
HM14-15	Top Brace	Structural Steel
HM14-16	Bottom Brace	Structural Steel
HM14-17	Lever Case	6061 Aluminum
HM14-18	Lever Case Back	6061 Aluminum
HM14-19	Lever	6061 Aluminum

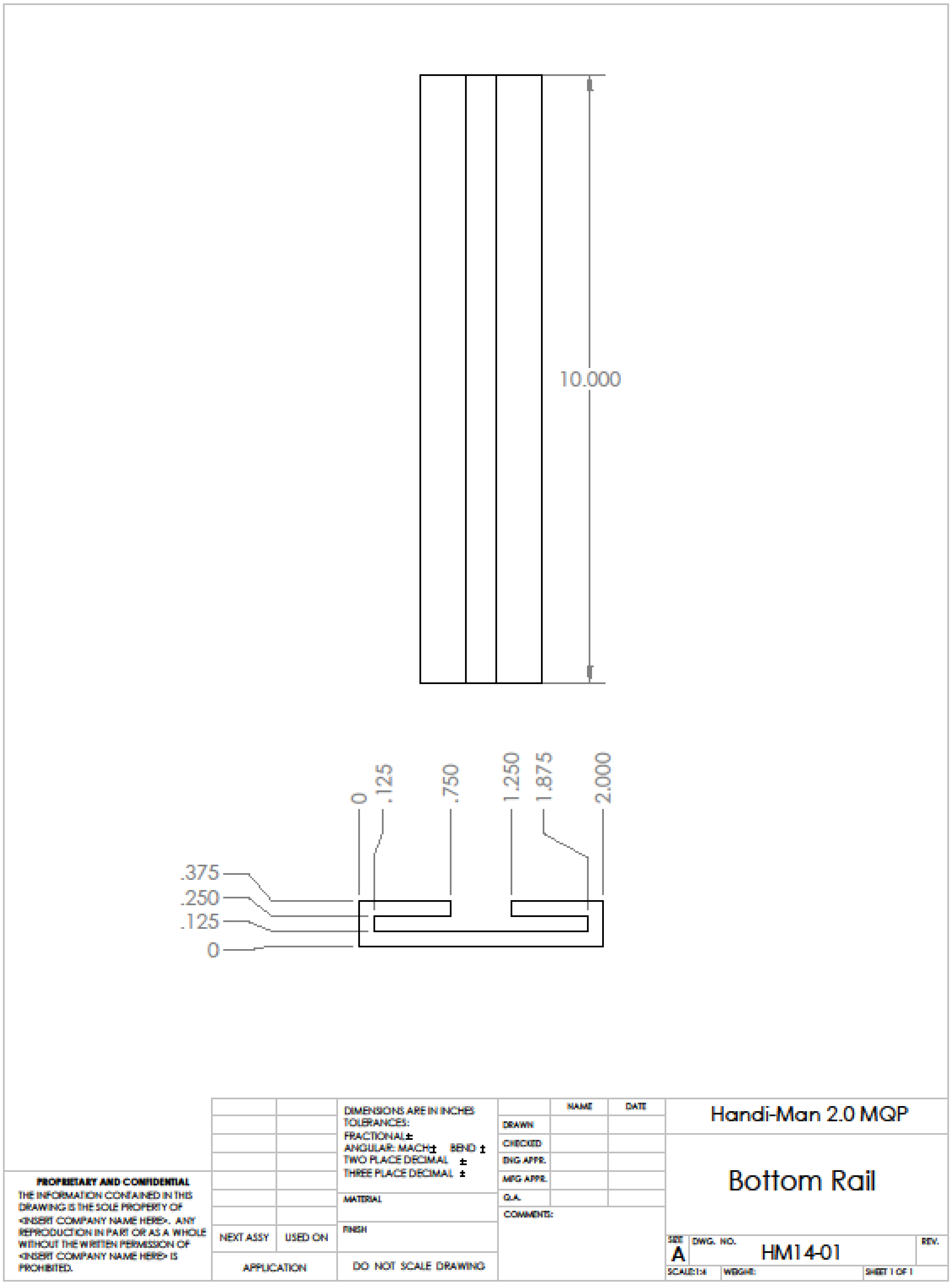

Figure 42-A: Bottom Rail

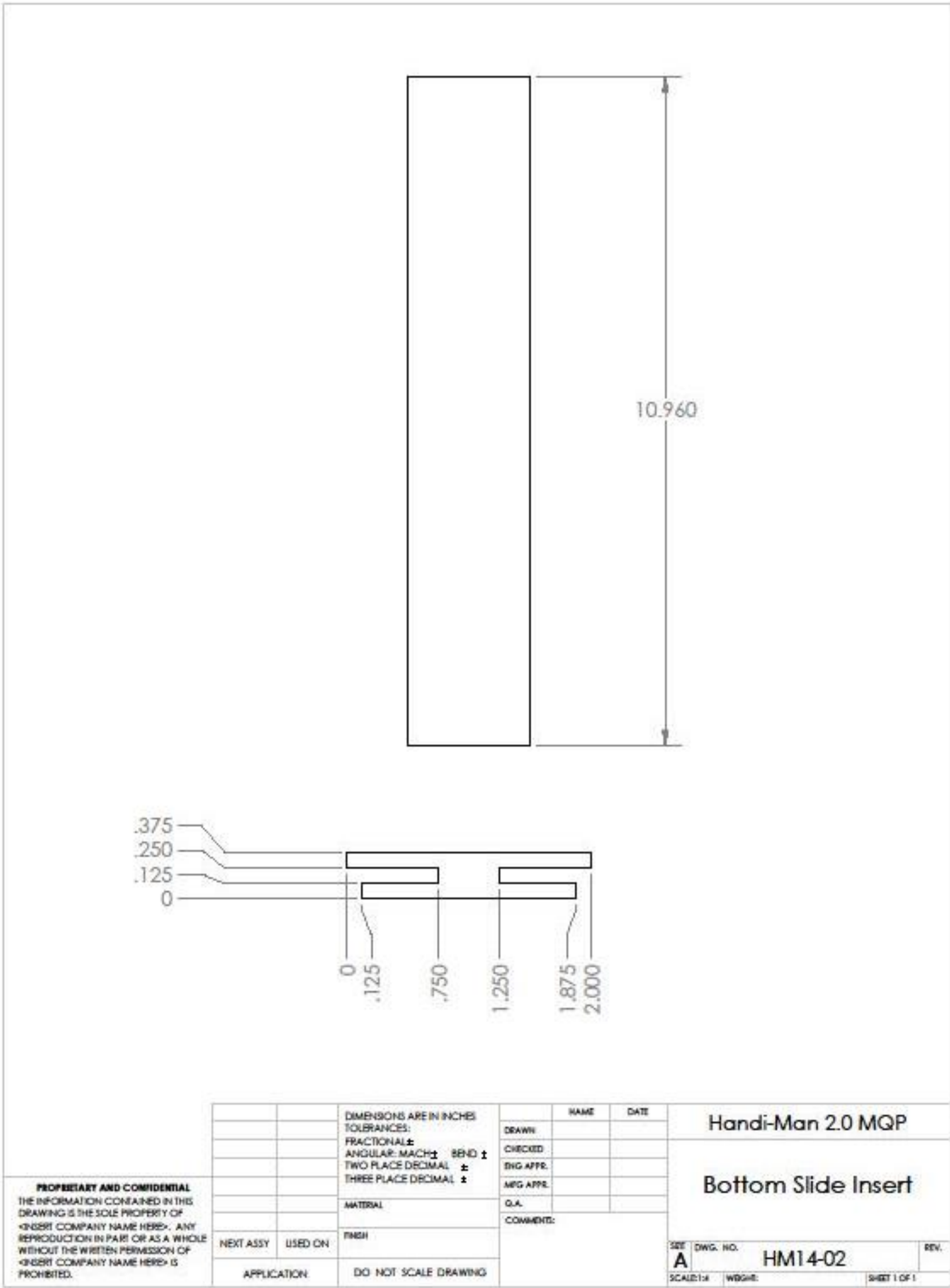

Figure 43-A: Bottom Slide Insert

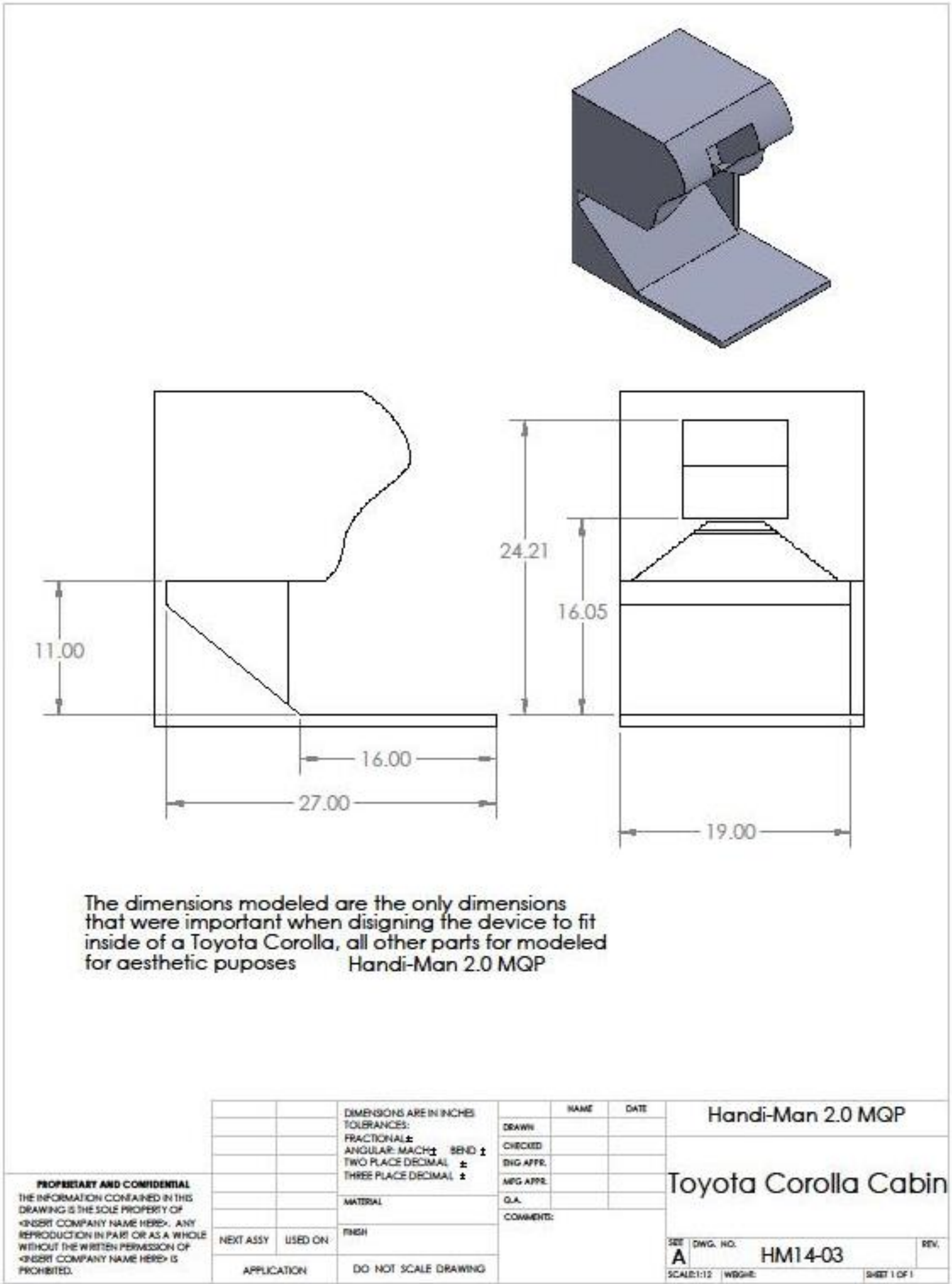

Figure 44-A: Toyota Corolla Cabin

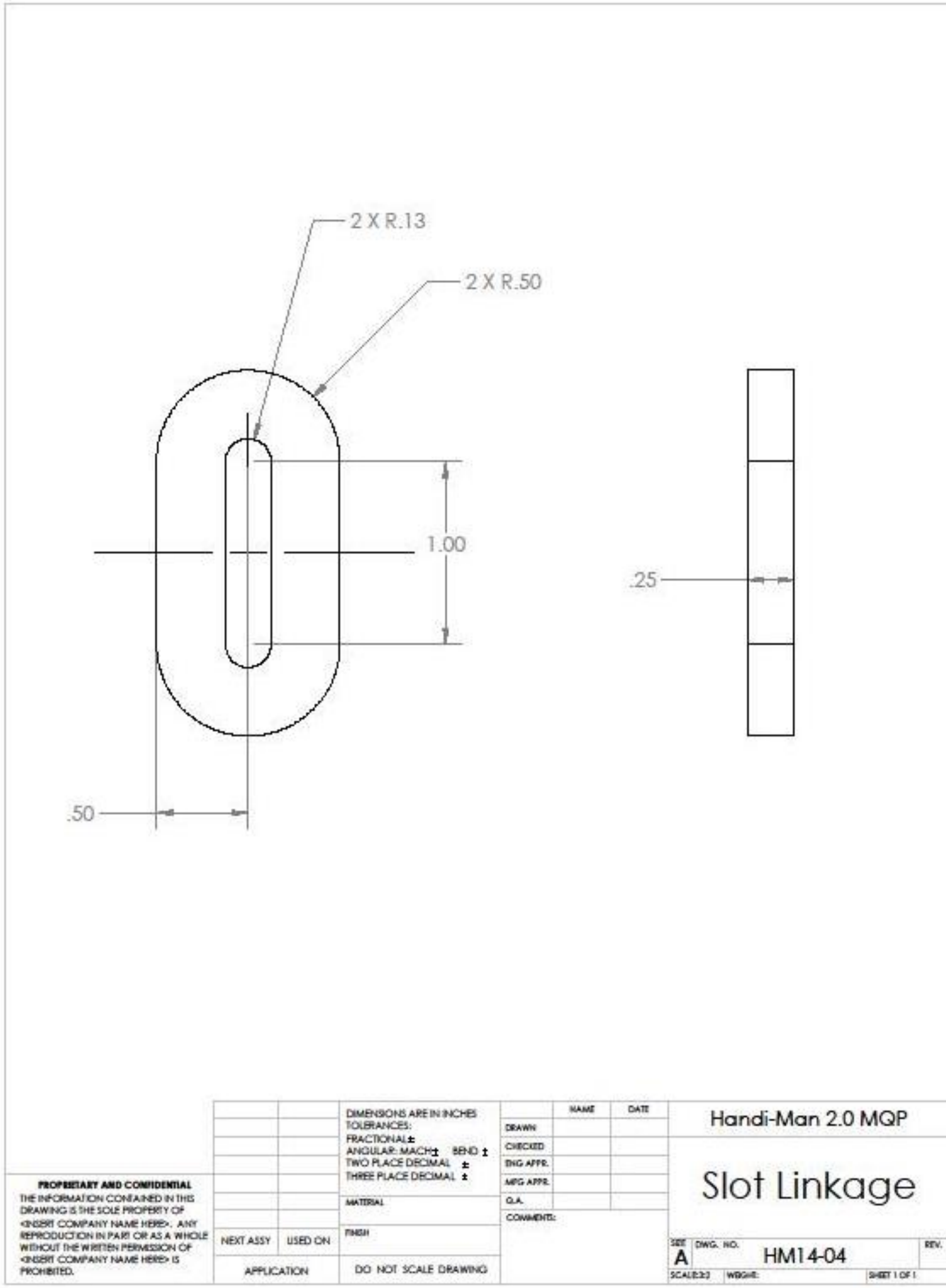

Figure 45-A: Slot Linkage

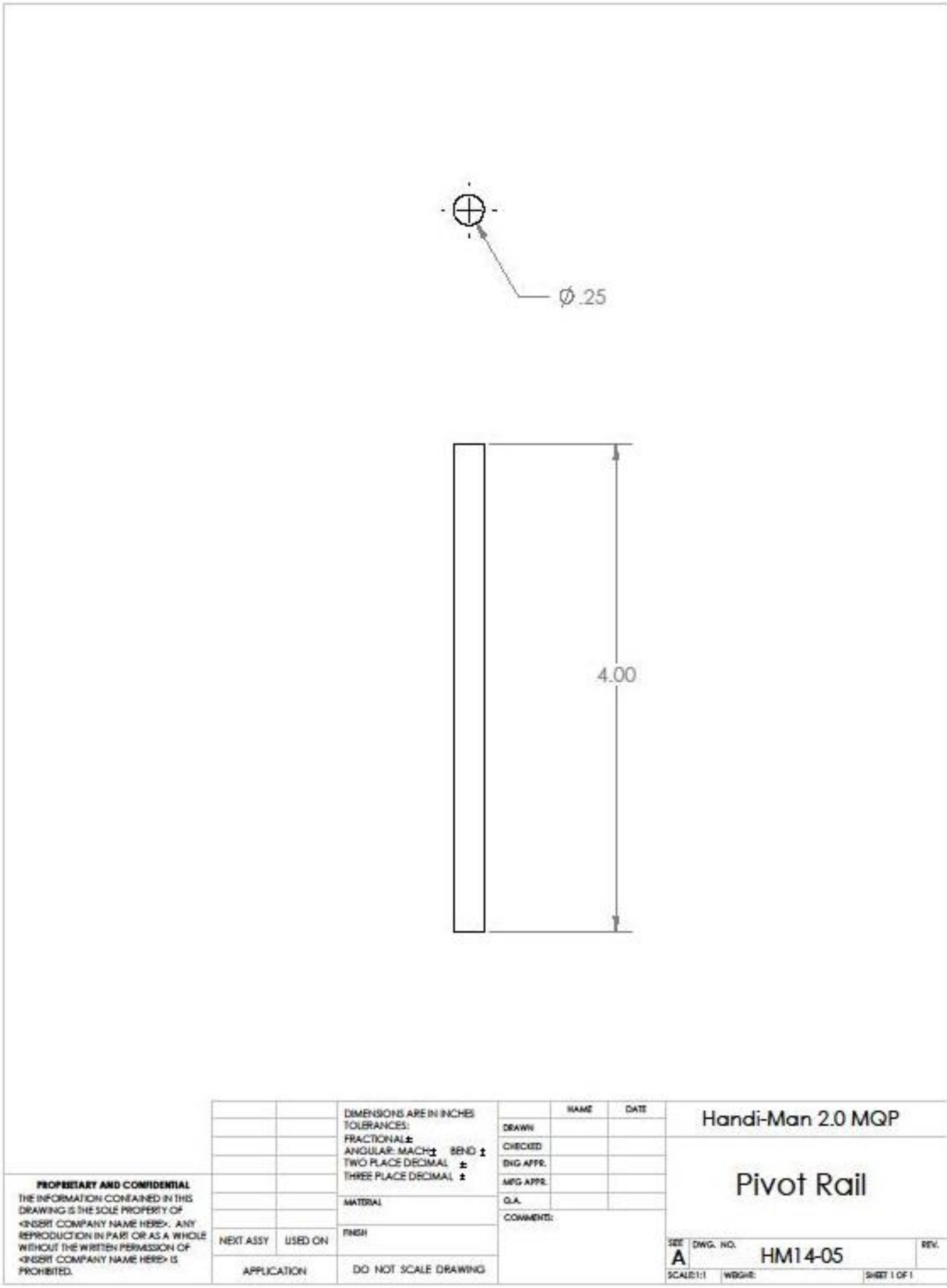

Figure 46-A: Pivot Rail

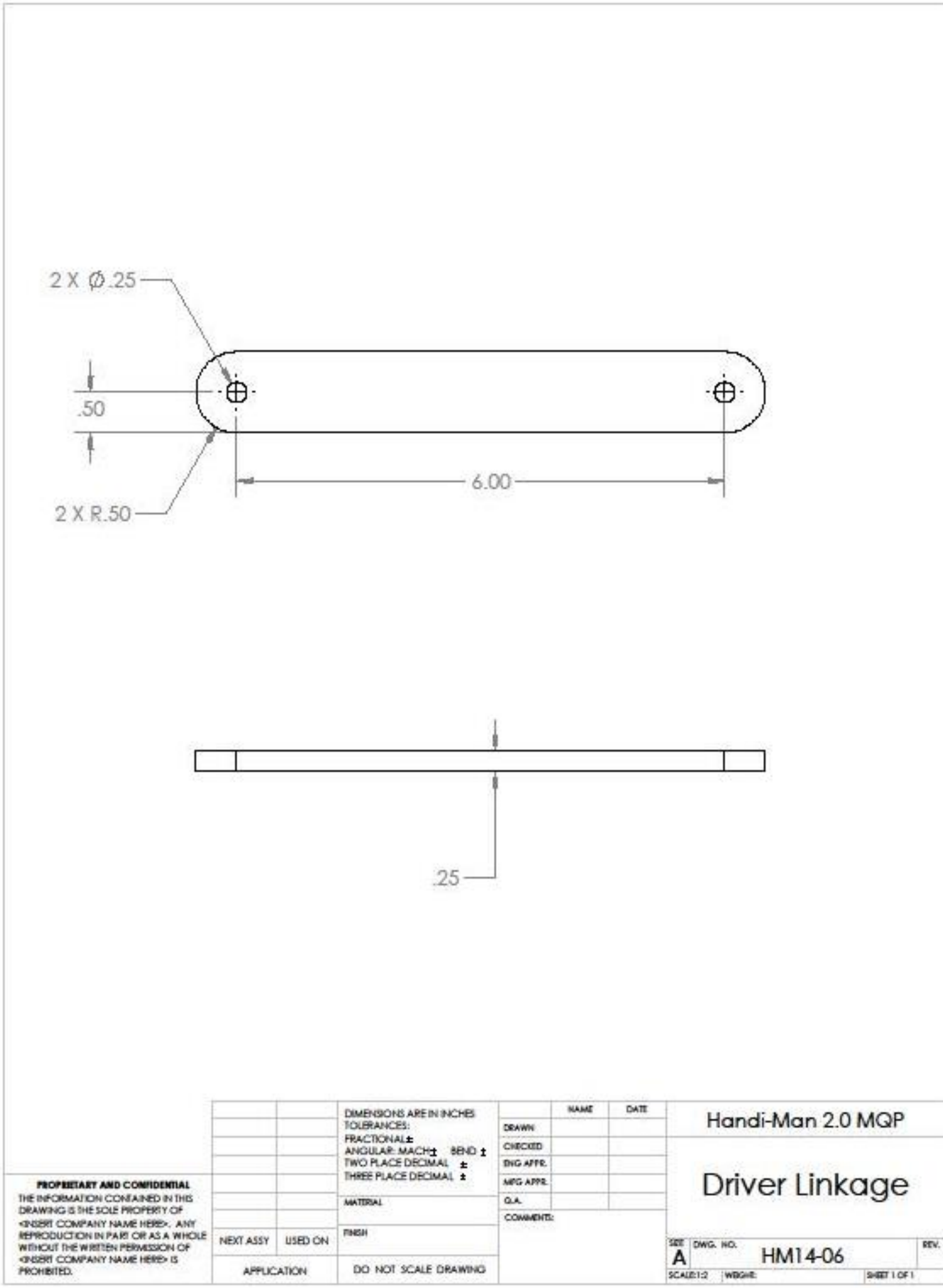

Figure 47-A: Driver Linkage

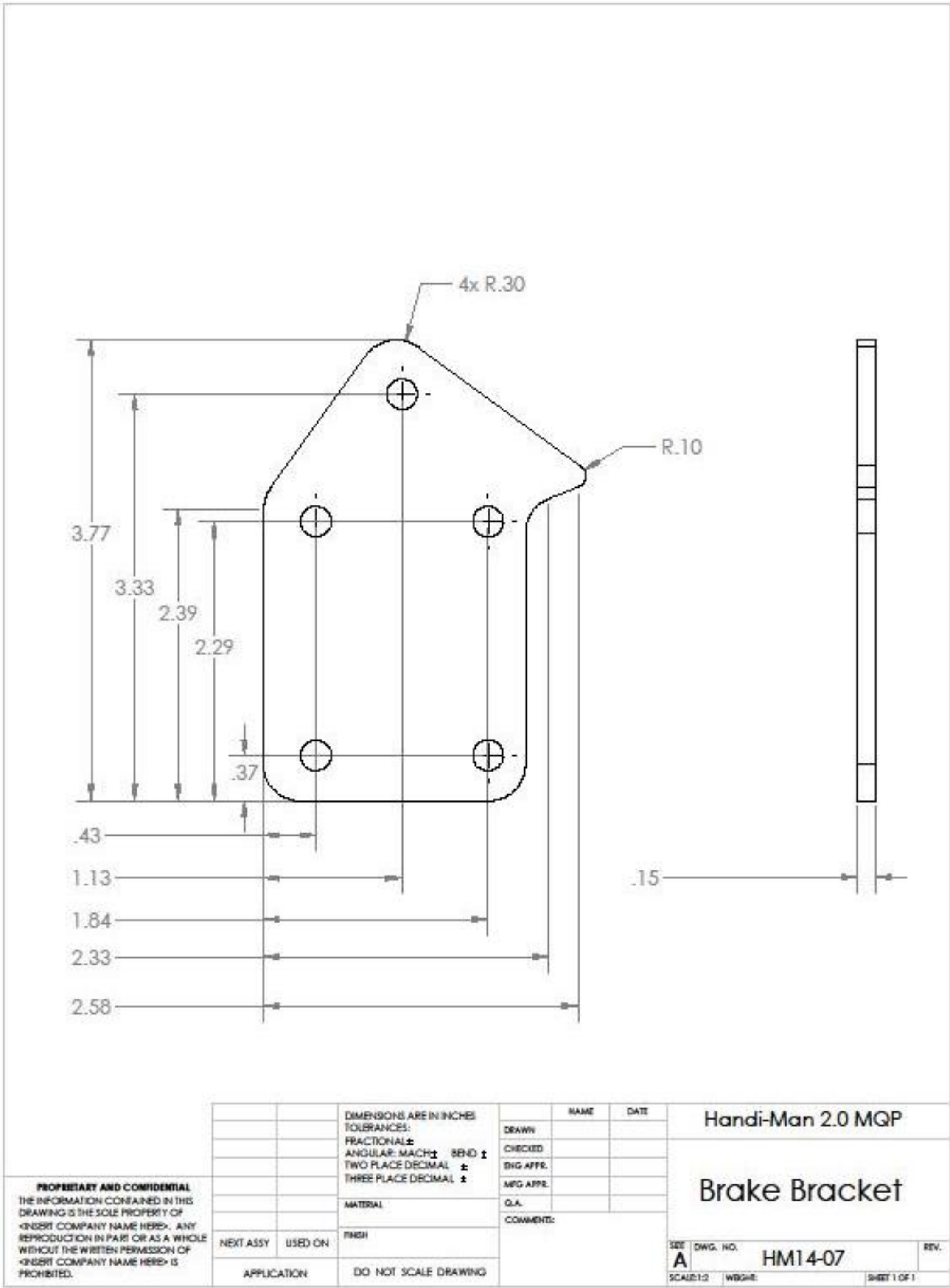

Figure 48-A: Brake Bracket

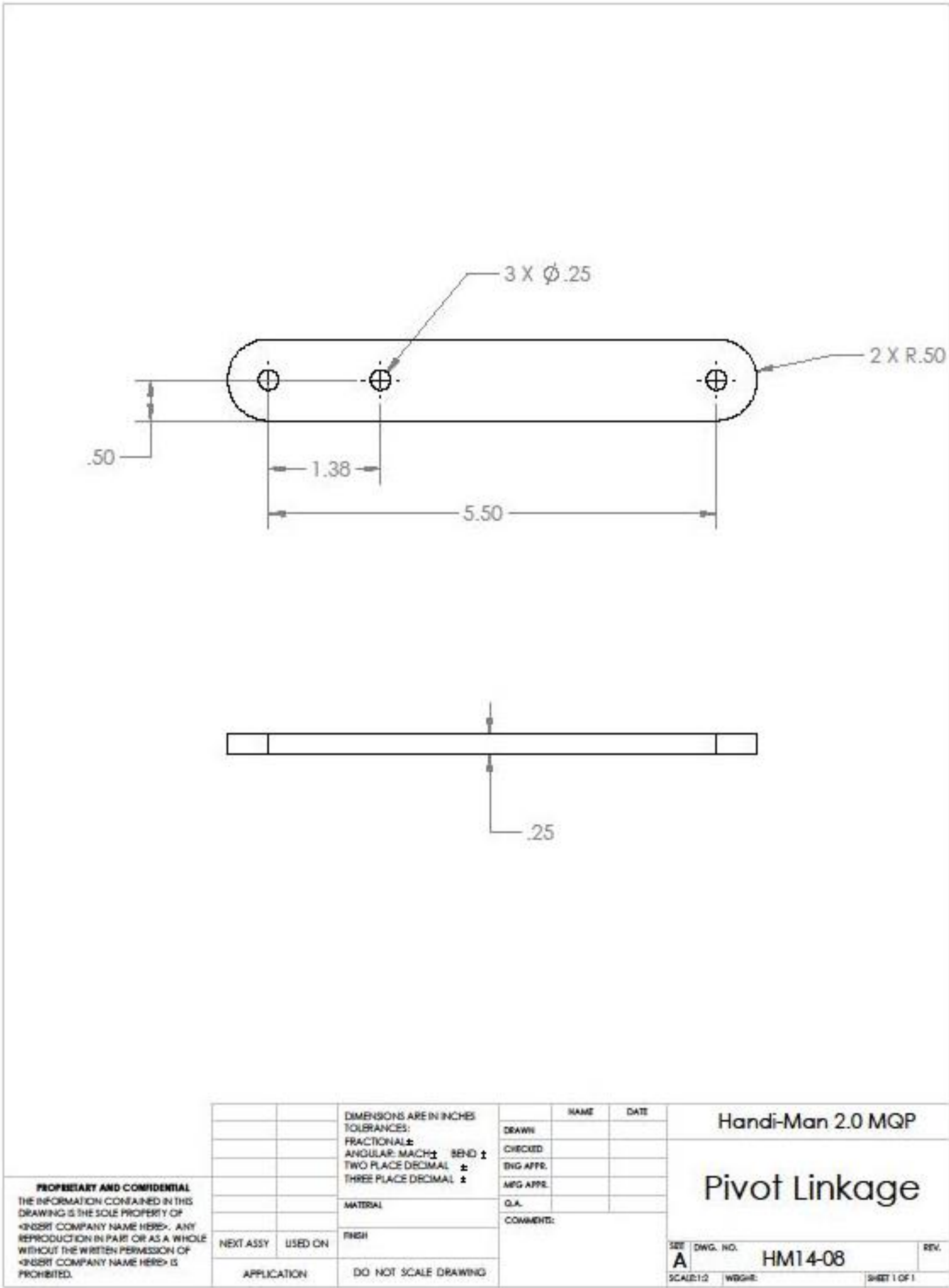

Figure 49-A: Pivot Linkage

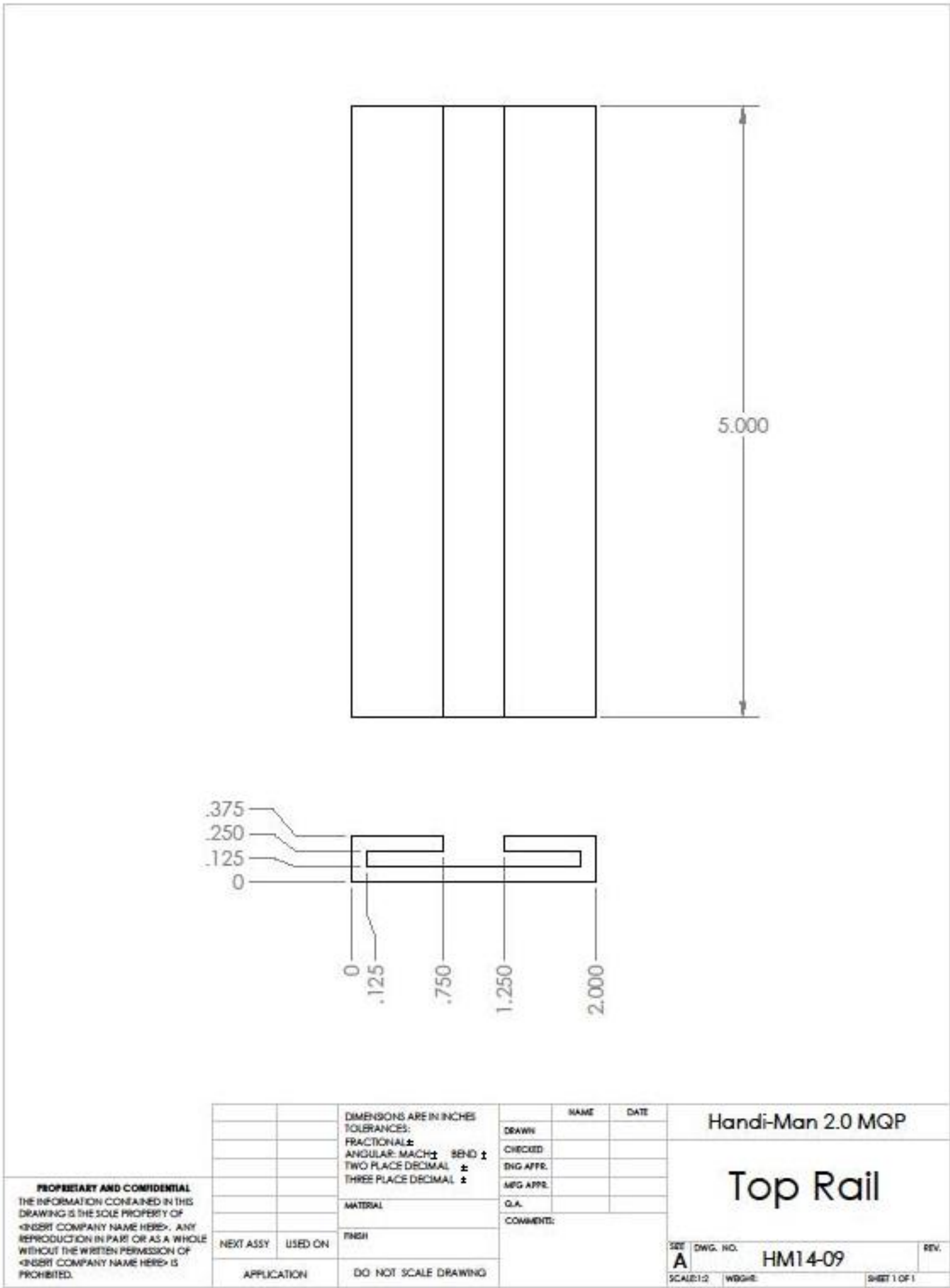

Figure 50-A: Top Rail

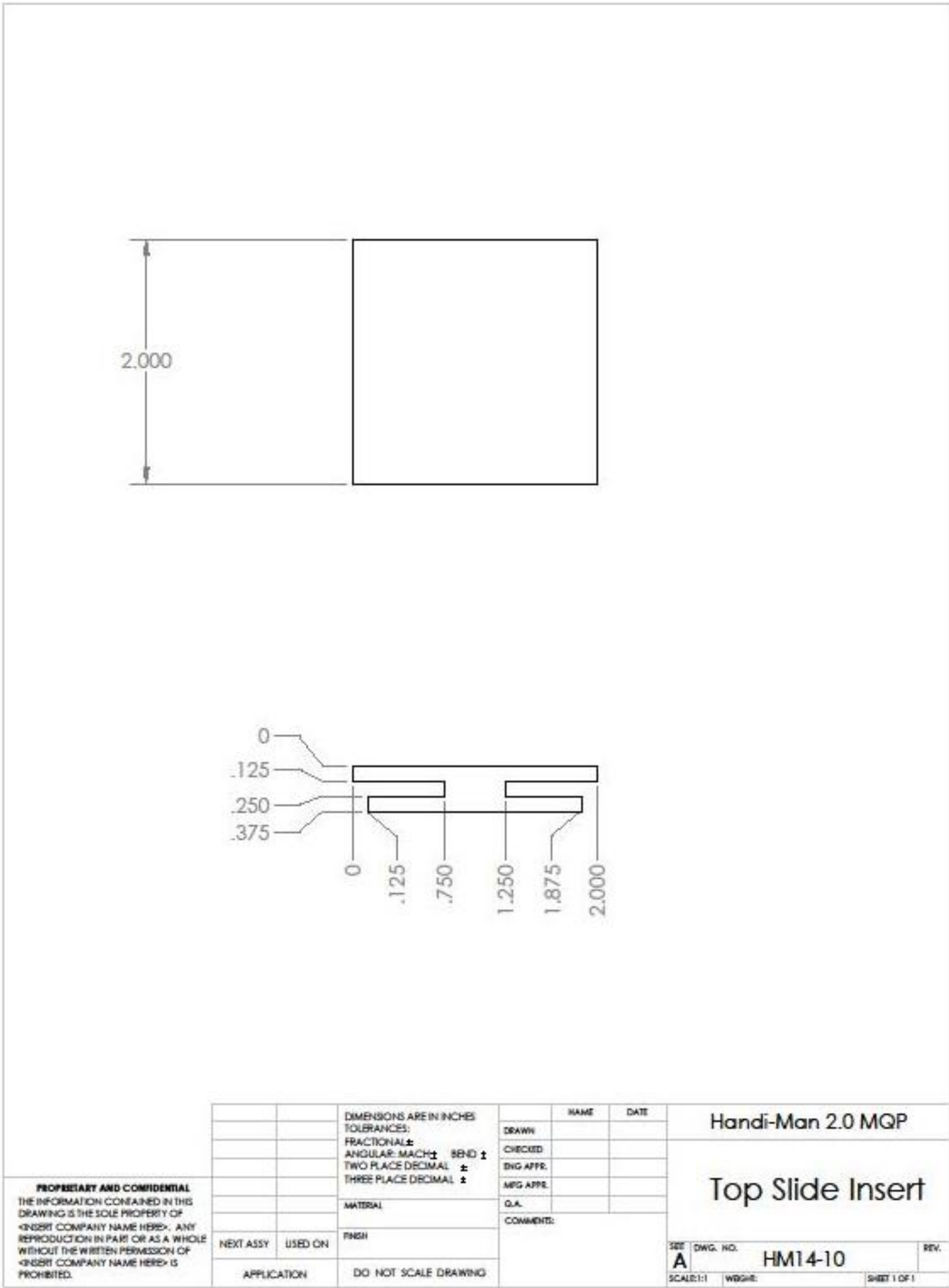

Figure 51-A: Top Slide Insert

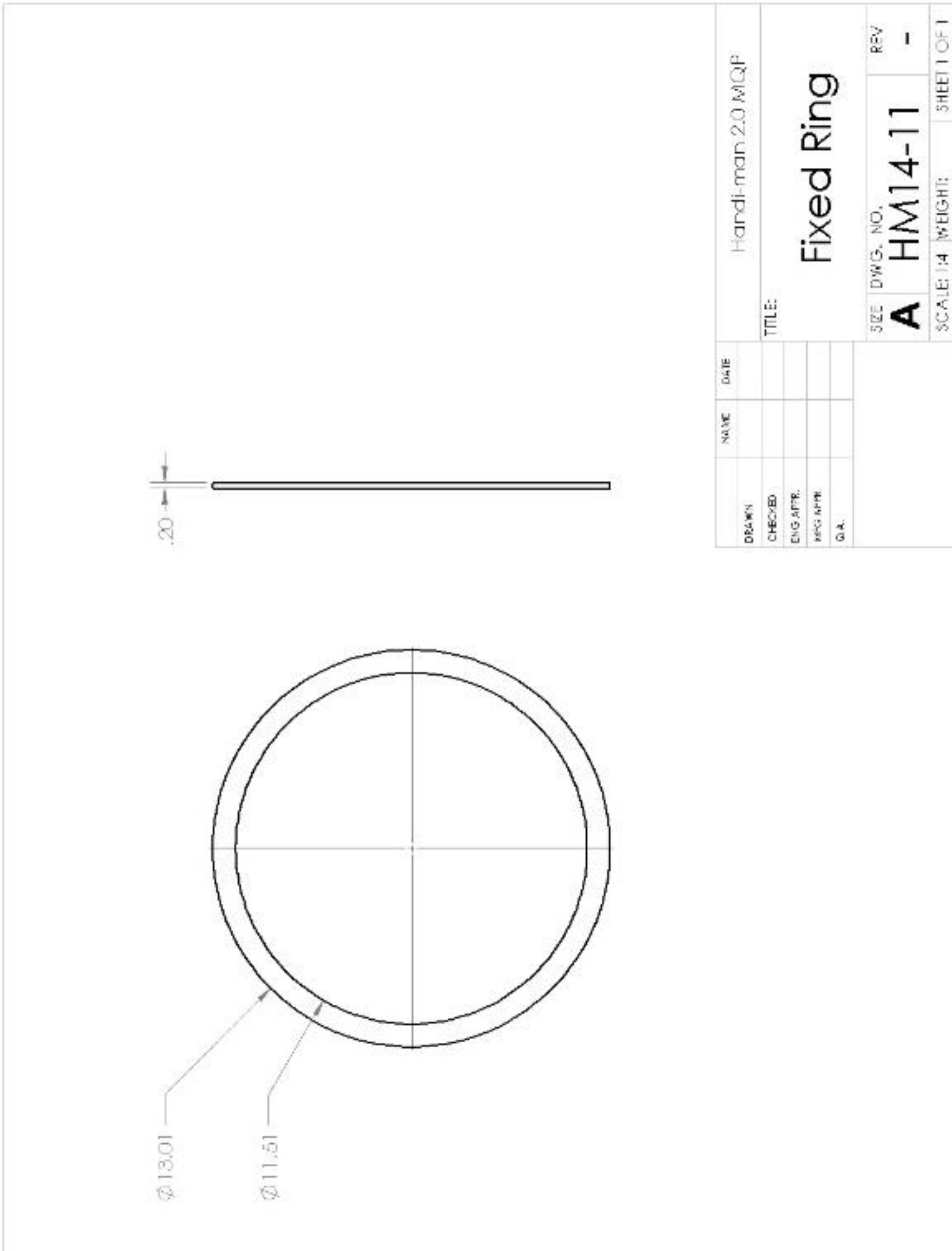

Figure 52-A: Fixed Ring

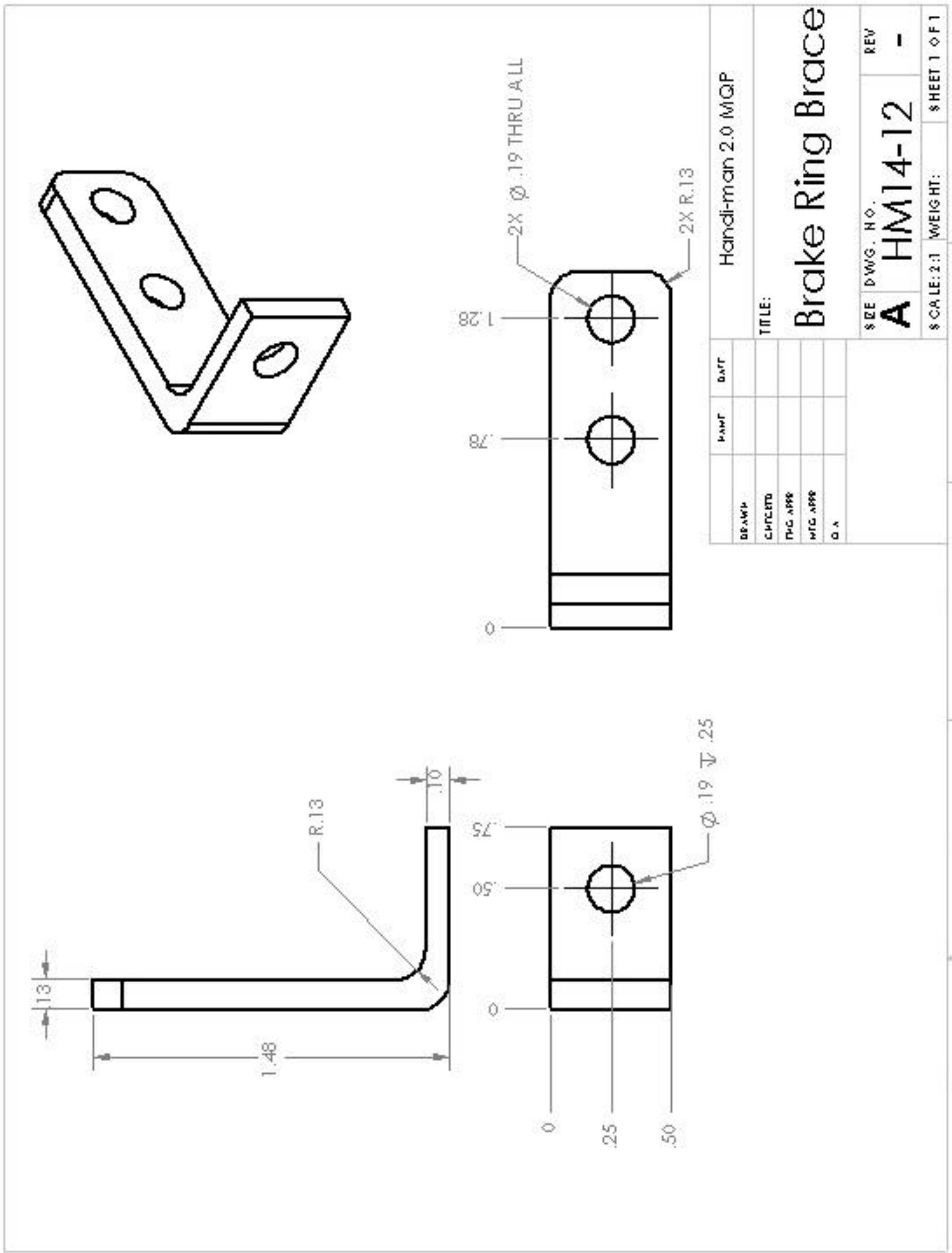

Figure 53-A: Brake Ring Brace

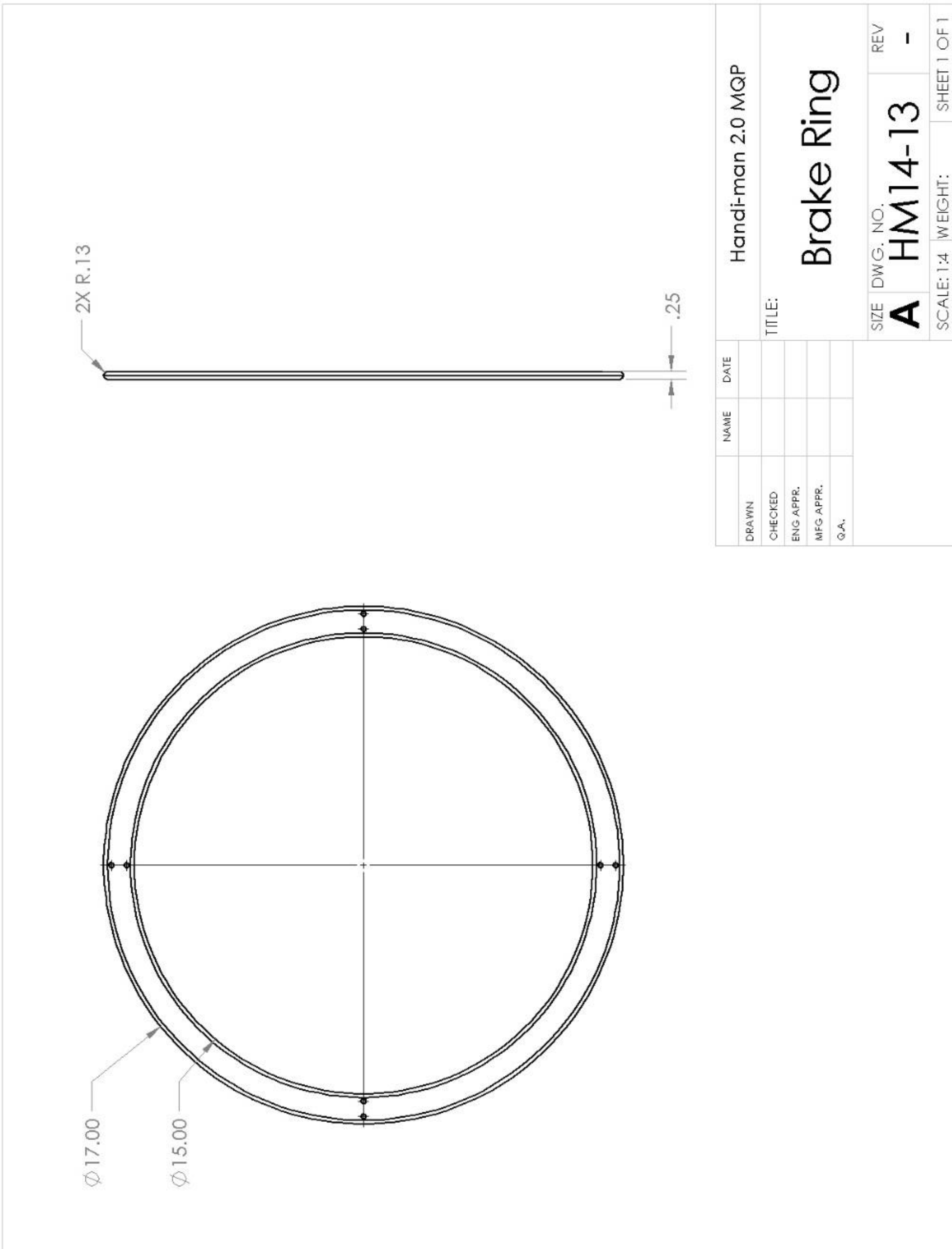

Figure 54-A: Brake Ring

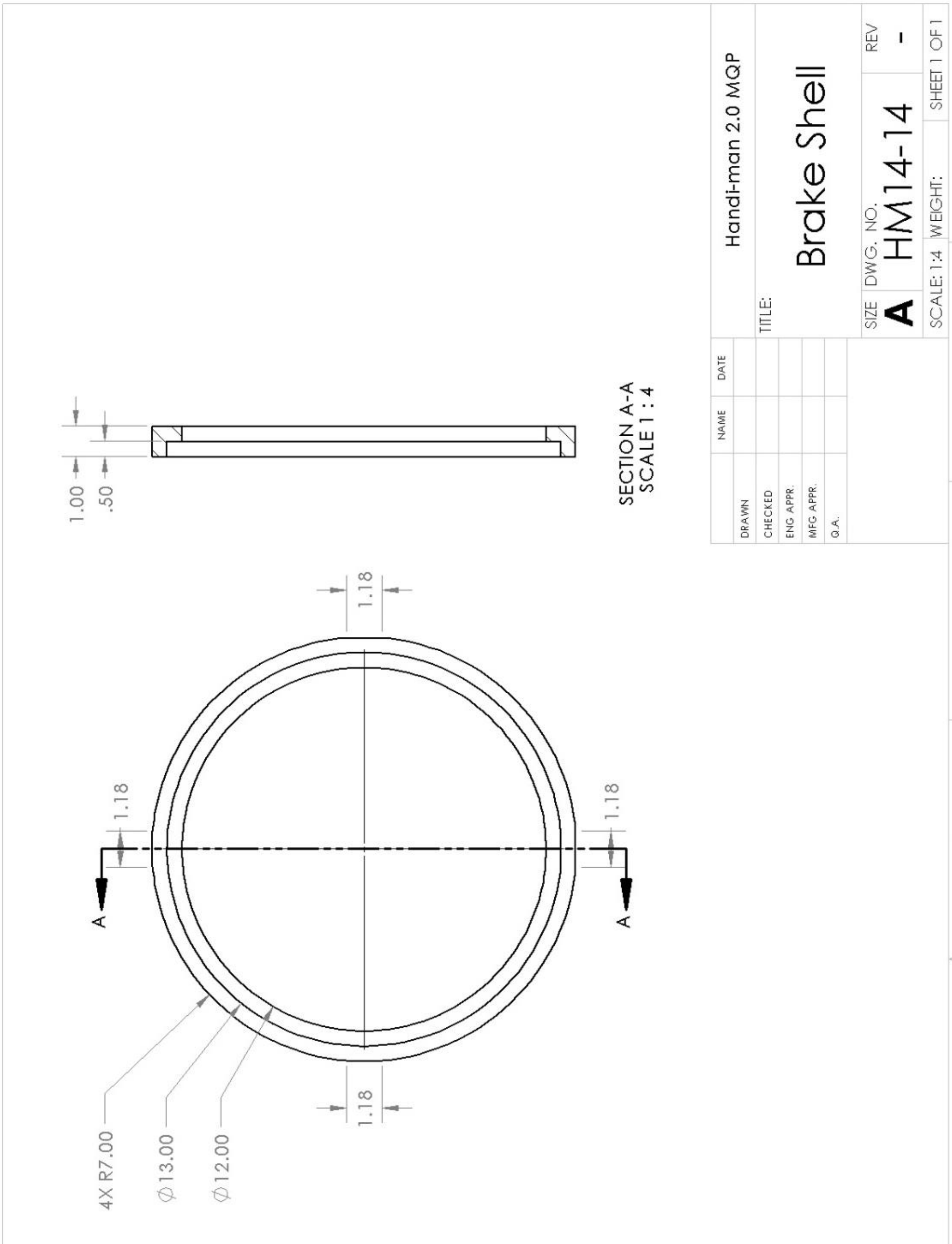

Figure 55-A: Brake Shell

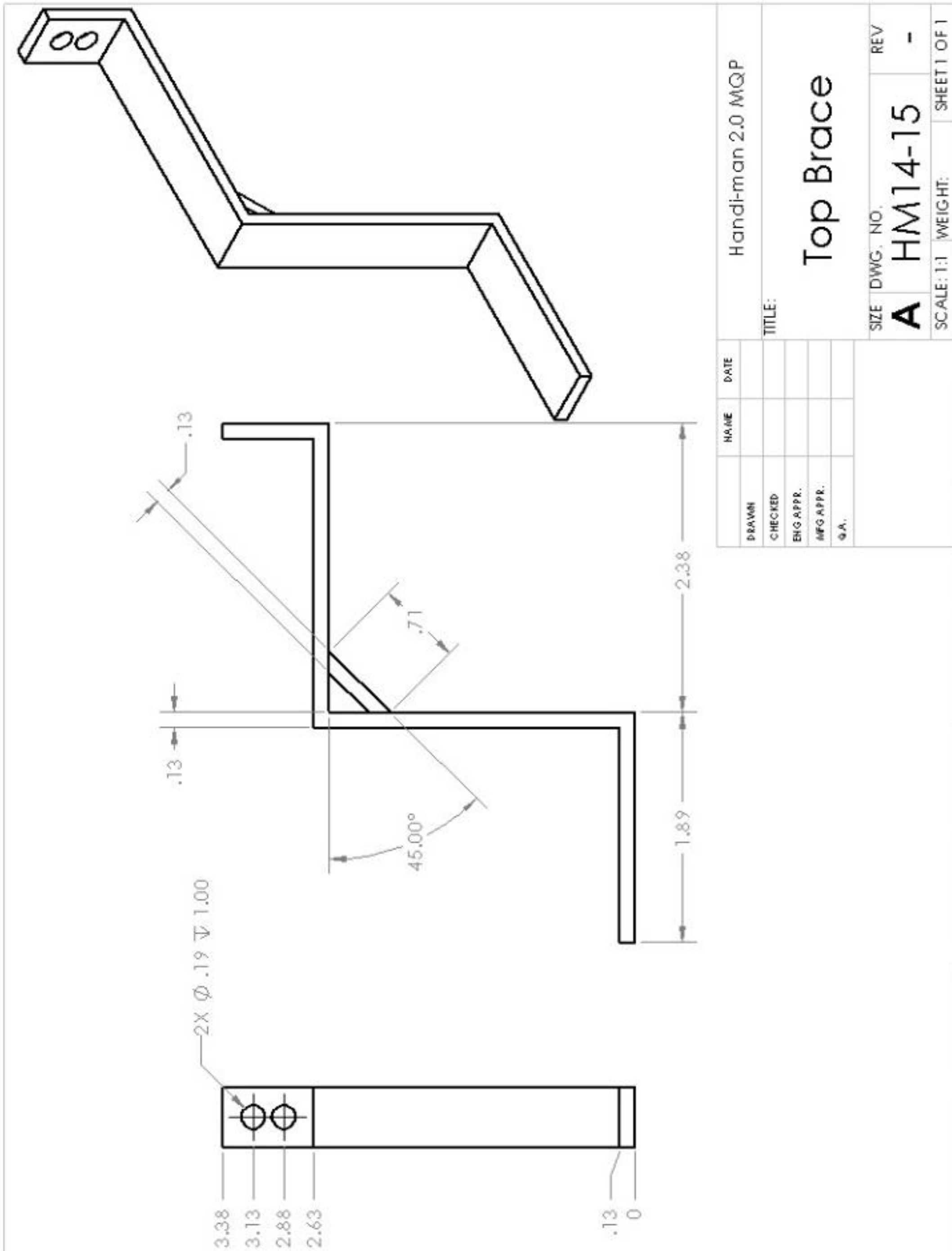

Figure 56-A: Top Brace

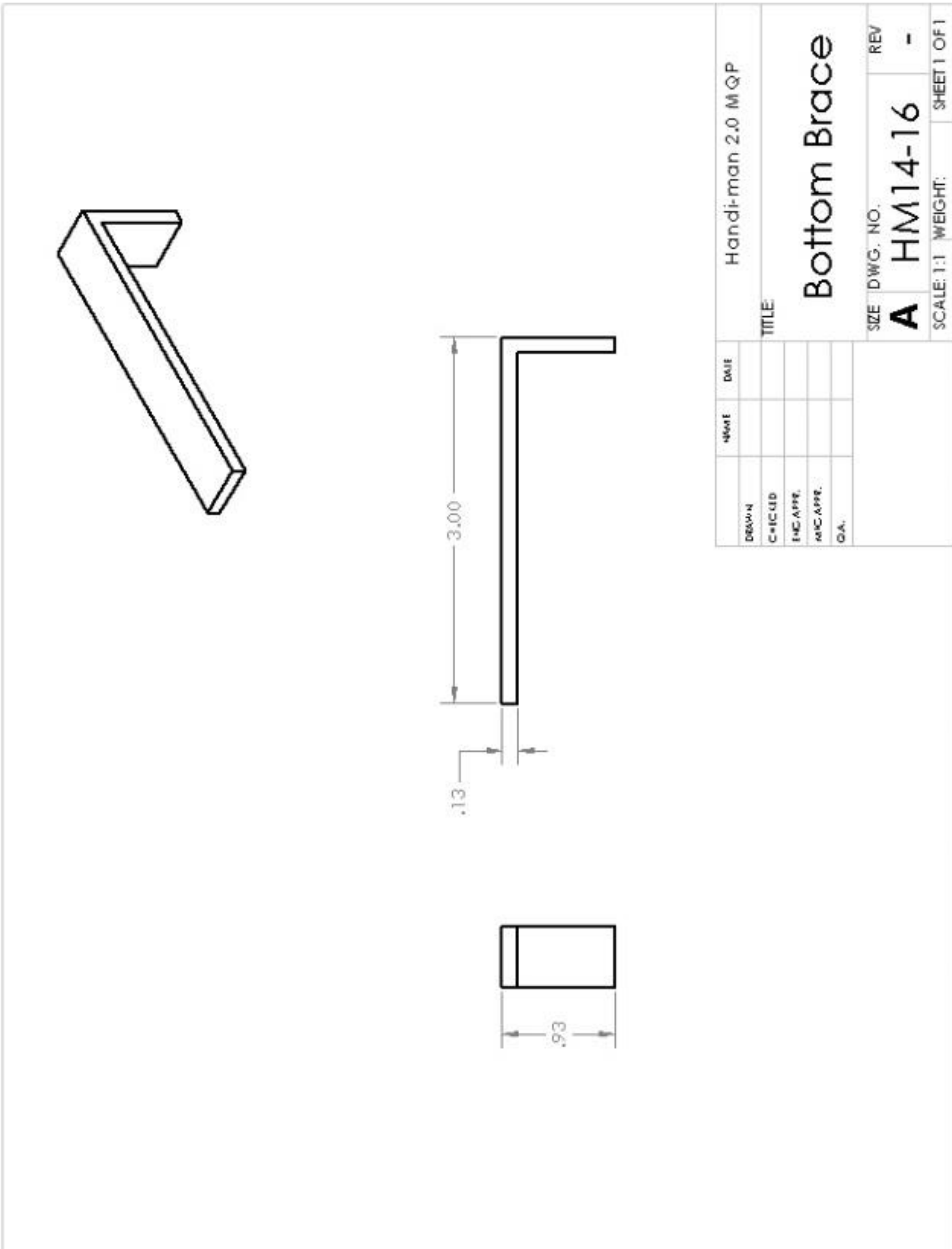

Figure 57-A: Bottom Brace

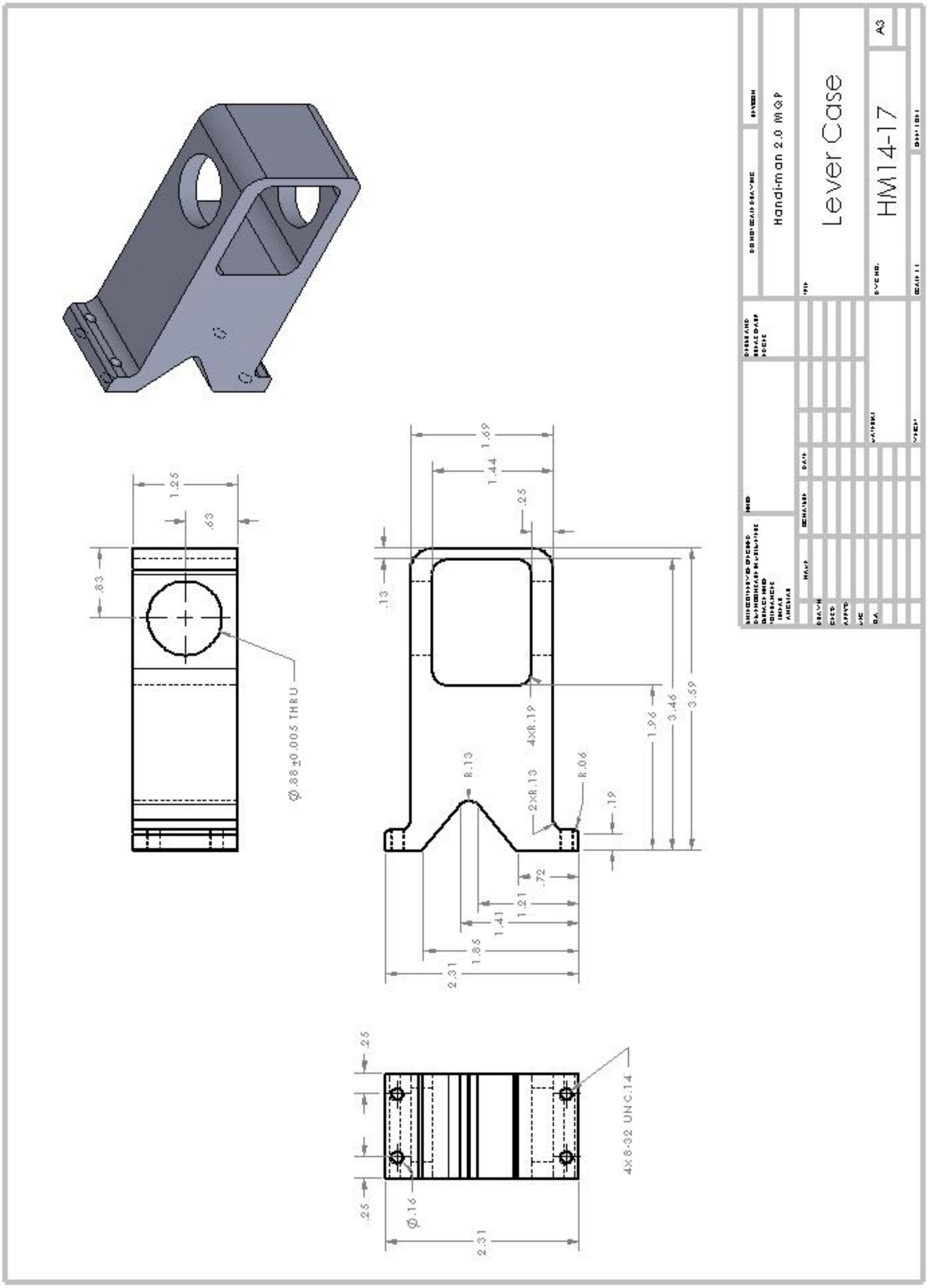

Figure 58-A: Lever Case

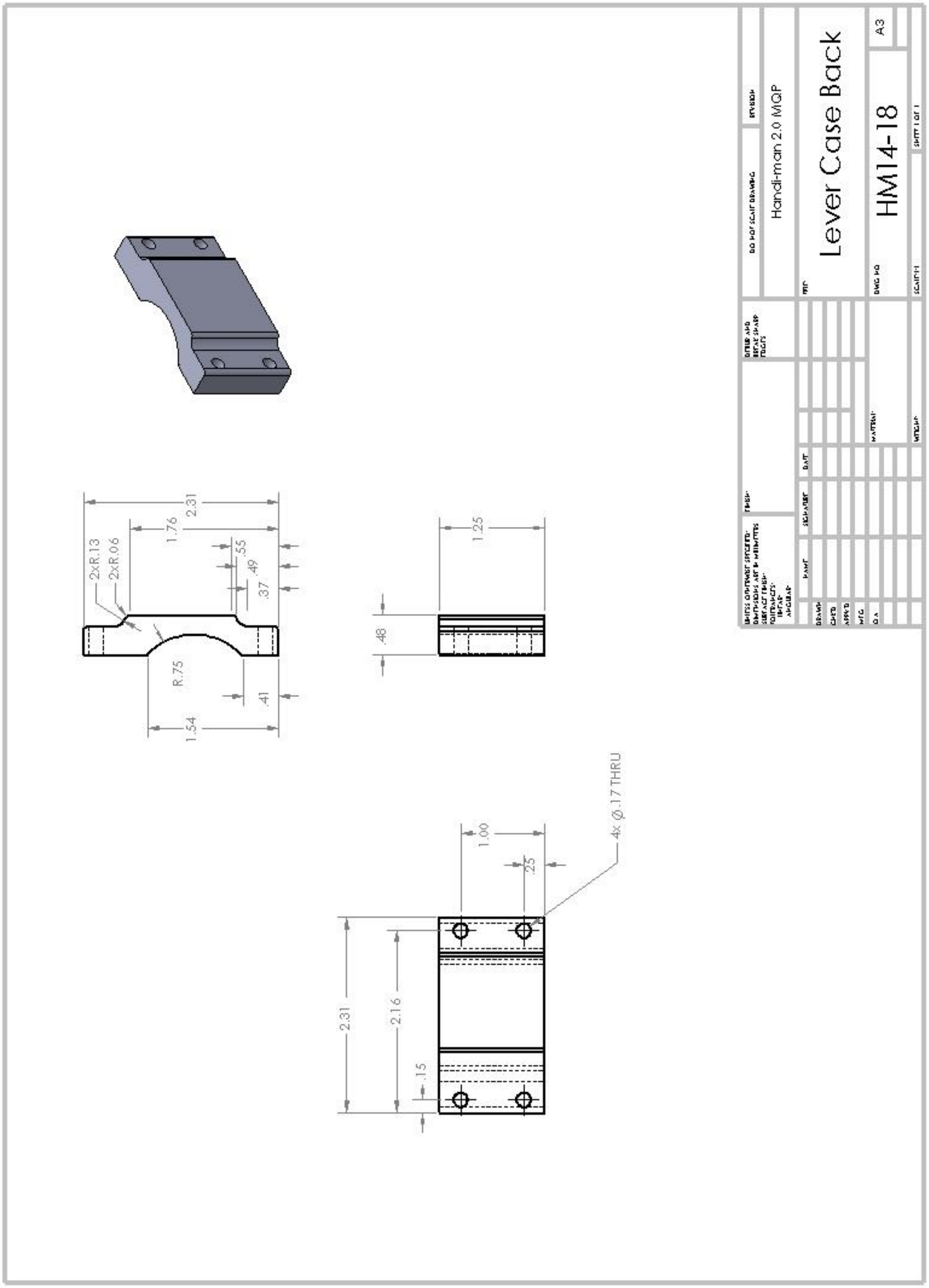

Figure 59-A: Lever Case Back

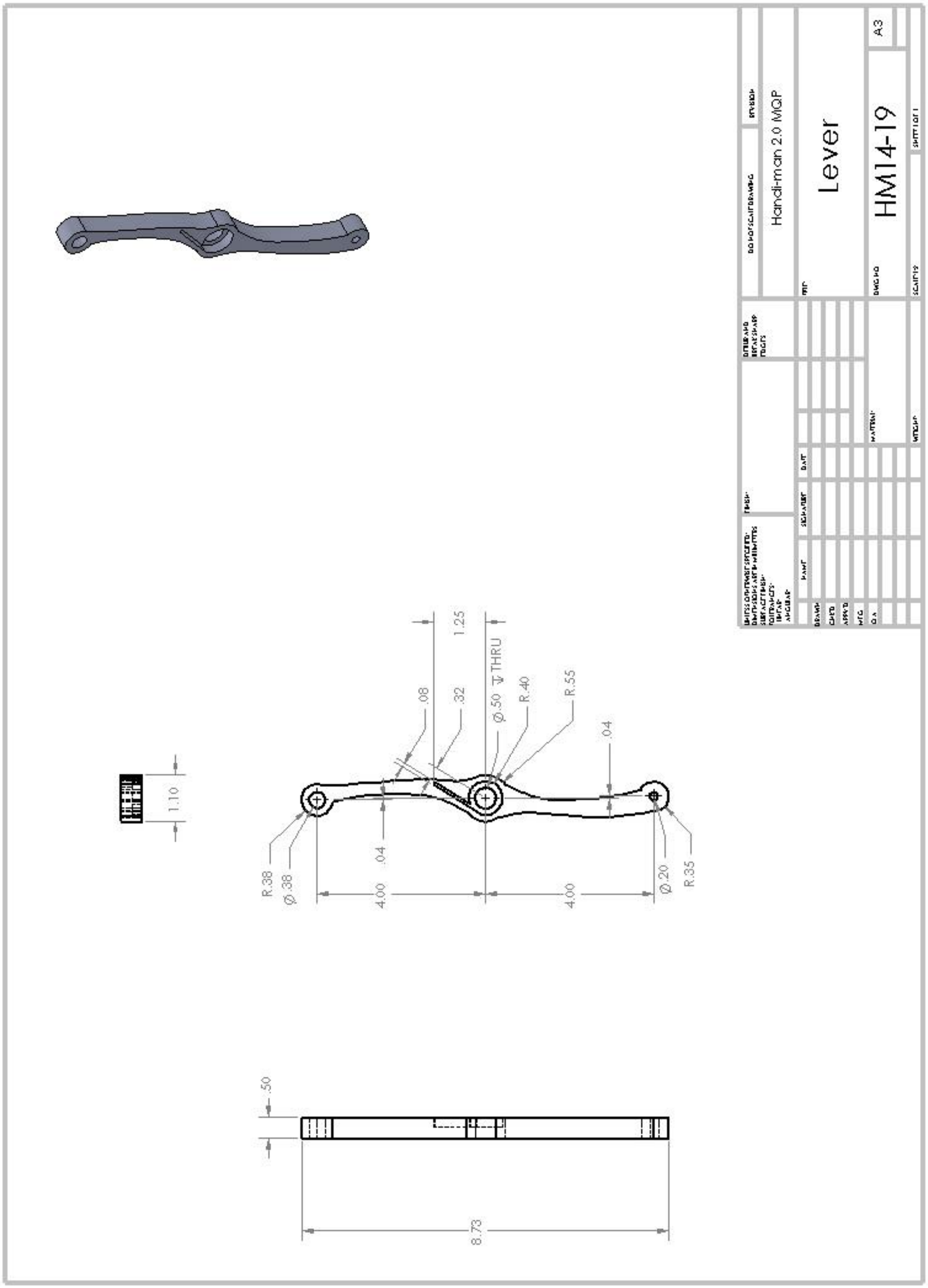

Figure 60-A: Lever

Appendix B: Machining Tool Paths

Table 6-B: Machine Bits Required

		Id	No.	Dia./Rad.	Length Comp
Head: 1 item(s)					
S...			0	0	0
Unassigned: 6 item(s)					
		1/2 EM	1	0.5	1
		3/8 EM	2	0.375	2
		1/4 EM	3	0.25	3
		.136 DR	4	0.136	4
		3/8 DM	5	0.375	5
		1/2 DR	6	0.5	6

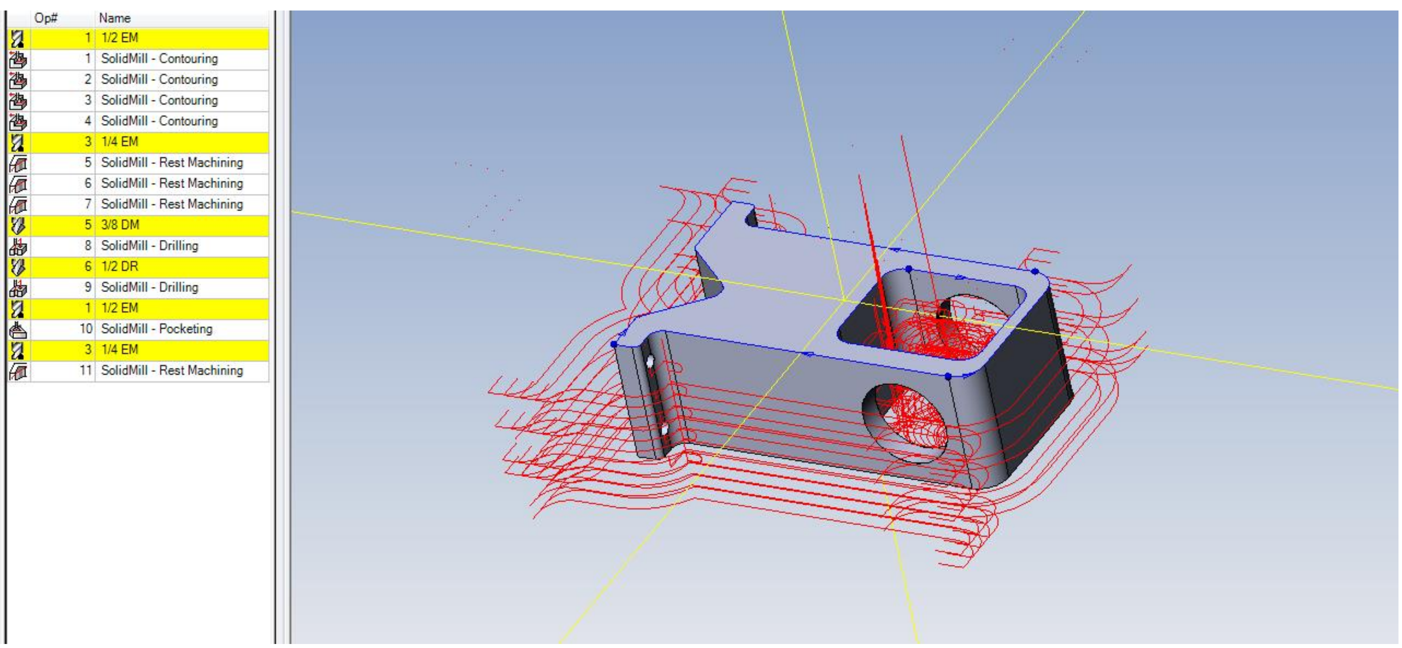

Figure 61-B: Lever Case Operation 1

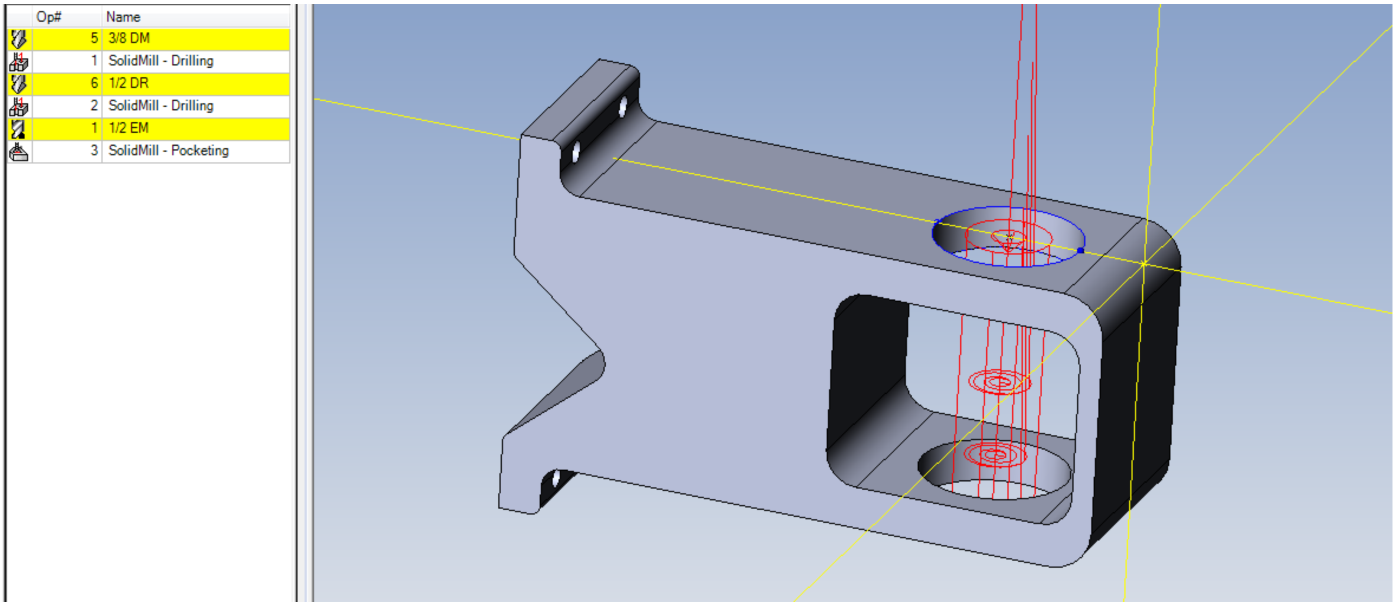

Figure 62-B: Lever Case Operation 2

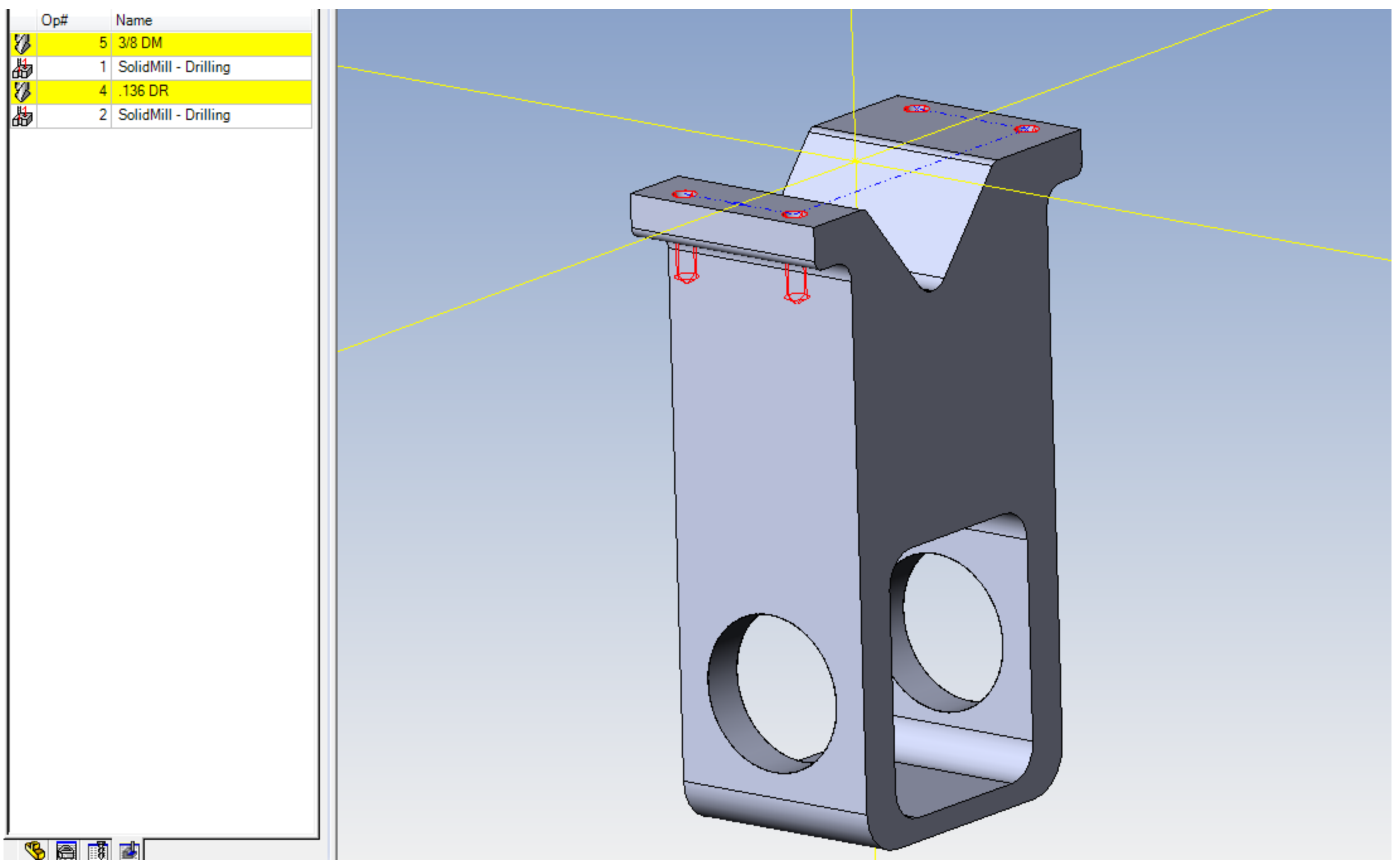

Figure 63-B: Lever Case Operation 3

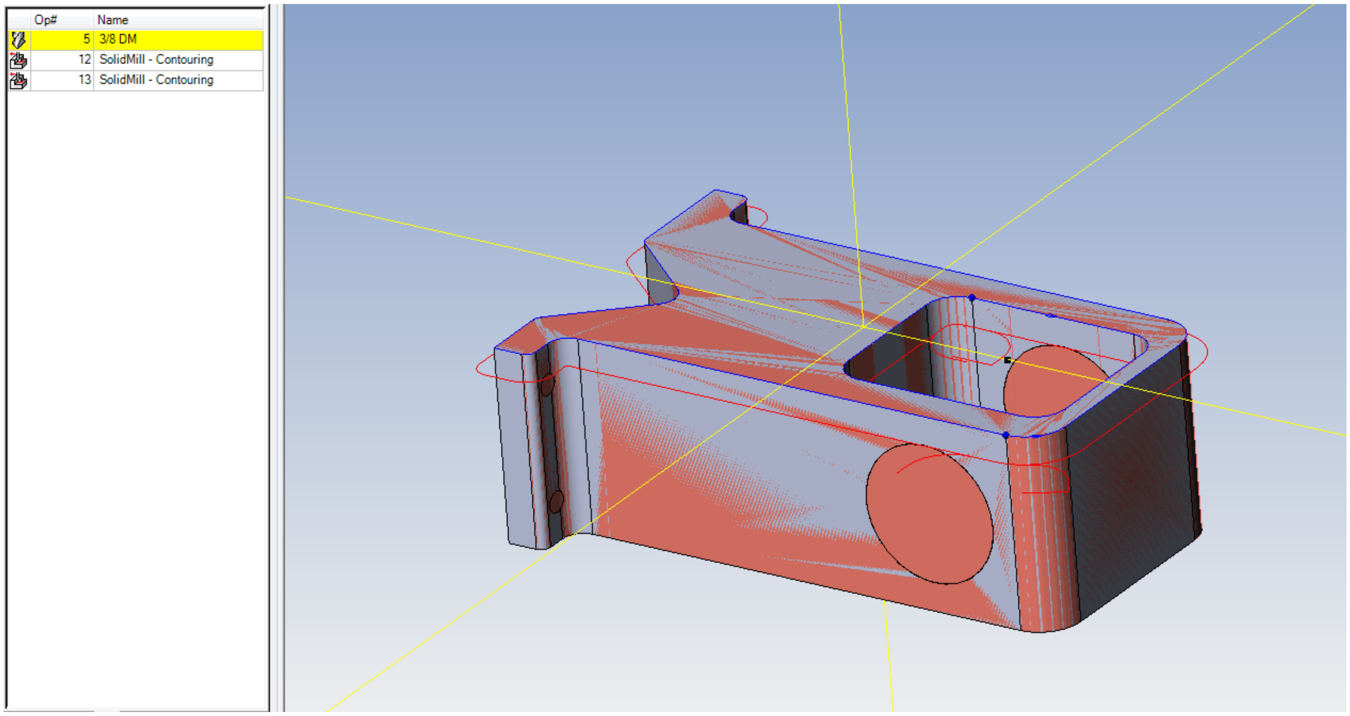

Figure 64-B: Lever Case Operation 4

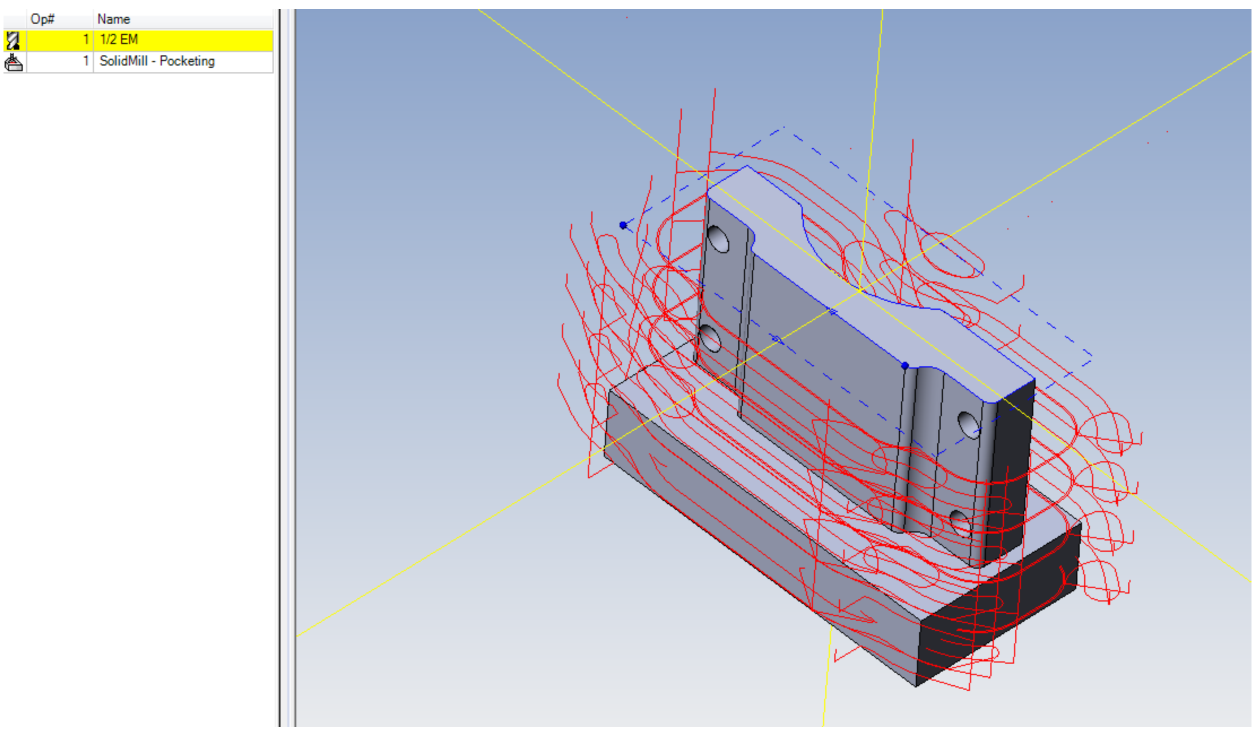

Figure 65-B: Lever Case Back Operation 1

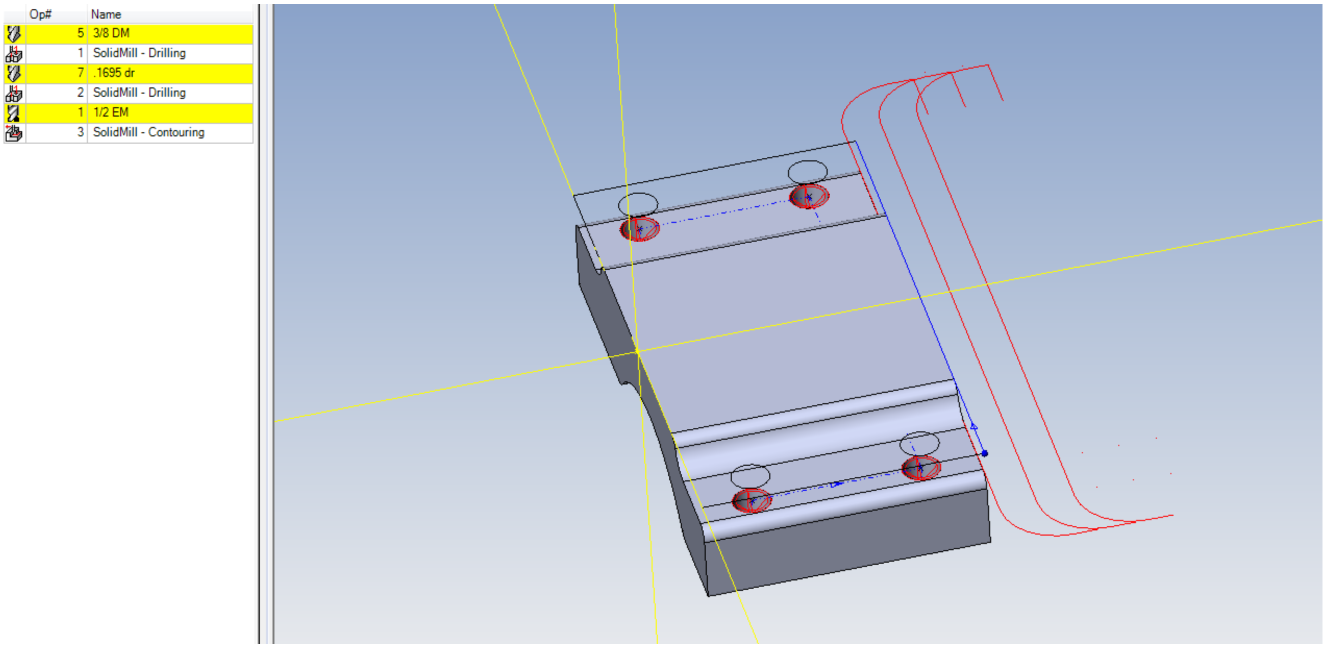

Figure 66-B: Lever Case Back Operation 2

Figure 67-B: Finished Machined Lever Case