Team 12

Memo

To: Mr. Edwin Anderson

From: ME 476c, Team 12 – Portable Laser Guidance System

cc: Jeb Duncan, Eddie Hoopingardner, Bryon Cole Middlebrook, Michael Orrill

Date: April 17, 2014

Re: Portable Laser Guidance System

The purpose of this memo is to provide information pertaining to the final design, prototype, and results of testing for the Portable Laser Guidance System.

The tripod and turret design with a joystick controller was chosen as the final design. A tripod mounted turret with a joystick controller design was chosen for numerous reasons with the primary concerns being safety and reliability. The tripod will hold the laser at a safe height above the average person's eye level. Power to the laser is limited to 20° above the horizon as an additional safety feature.

All of the parts for the prototype have been fabricated and assembled. The system is finished and operational.

Testing was carried out to acquire an estimate of battery life and reliability. The system was run at full power for four continuous hours with no notable loss of power or function. Use of the system during your presentations will not be continuous. Given this we estimate a minimum of eight hours battery life per charge. Significantly longer than the duration of any one presentation.

Portable Laser Guidance System

By
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Team 12

Final Report

Submitted towards partial fulfillment of the requirements for
Mechanical Engineering Design II – Spring 2014

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Nomenclature

a = Acceleration $[m/s^2]$
A = Area $[m^2]$
C_1 = tabulated value [22]
C_p = Specific Heat of Air $\left[\frac{kJ}{kgK}\right]$
D_0 = Outermost diameter [m]
dt = Change in time [sec]
dv = Change in velocity [m/s]
E = Modulus of elasticity [Pa]
F = Force [N]
h = Height $[m]$
h = Heat transfer coefficient $[W/m^2K]$
k = Thermal conductivity $[W/mK]$
k_{ins} = Thermal conductivity of insulation $[W/mK]$
k_{shell} = Thermal conductivity of Delrin $[W/mK]$
Nu_D = Nusselt Number
r_0 = Radius of cylinder $[m]$
r_1 = Inner radius of cylinder $[m]$
r_2 = Outer radius of cylinder $[m]$
r_3 = Outer radius delrin $[m]$
$R_{cond\ (cyl)}$ = Thermal resistance cylinder $[m^2K/W]$
R_{conv} = Thermal Resistance $[m^2K/W]$
Re = Reynolds Number
T_i = Initial Temperature [K]
T_O = Temperature of Interest [K]
T_∞ = Ambient Temperature [K]
V_f = Final velocity $[m/$s]
V_O = Initial Velocity $[m/$s]
ε = Strain [m/m, Dimensionless]
σ = Stress [Pa]
ρ = Density of Air $\left[\frac{kg}{m^3}\right]$
$\theta^* = \frac{(T_0 - T_\infty)}{(T_i - T_\infty)}$
δ_1 = tabulated value [22]

Abstract

Edwin Anderson, the Support Systems Analyst for the NAU Physics and Astronomy department, currently gives guided talks of the night sky using a 5 mW laser. This 5 mW laser is not power enough to effectively direct the attention of large groups of people because people not in Mr. Anderson's immediate vicinity cannot see the beam. A 20 mW laser would be powerful enough to direct large groups of people, but is too dangerous to be used as a handheld pointing device because of the risk of causing blindness. Mr. Anderson has requested that a device be designed that will use a 20 mW laser to point out stellar bodies while eliminating the possibility of shining the beam into someone's eyes.

The design must be capable of moving the laser across the sky at a minimum speed of 24° per second while maintaining a resolution of 0.5°. The design must not be longer than 48" in order to fit into the back of Mr. Anderson's vehicle. In addition, the design must weigh less than 100 lbs. Five general concepts were generated and analyzed to see which one would best meet the needs of Mr. Anderson.

The tripod and turret design with a joystick controller was chosen as the final design because of its simple design and relatively low cost. For this design, the laser would have an insulated case to ensure it stays within the lasers operating temperature range, even in cold winter conditions. In addition there would be a solenoid attached to the case to allow manual control of the laser power switch while using the joystick. A switch trigger will be installed to allow the device to function properly even if Mr. Anderson decides to use a different model laser with the power switch in a different location. To ensure the safety of everyone surrounding the device, electrical power to laser is removed if it were to drop below 20° from the horizontal.

Thermal analysis was conducted to make sure the laser would stay within operating temperatures during cold winter nights. This analysis was done at steady state to find the heat loss from the laser. Which was found to be 0.35 Watts. Transient analysis was conducted and showed that under extremely harsh conditions, it would take ~25 minutes for the laser to drop below operating temperatures beginning from room temperature. Because of the conservative approach taken in the analysis, it was concluded that the laser housing will be sufficient in maintaining proper operating temperatures.

The cost of all the components can be found in Table 4.1. A total cost of $1765.56 was spent to complete the design. Which is well below the allotted $3000.00 budget for this project.

1.0 Introduction

1.1 Project Summary

Mr. Edwin Anderson, the Support Systems Analyst for the NAU Physics department has requested a device to aid him in safely directing the attention of groups of people toward individual stars and constellations. He currently points out stellar bodies by hand with a 5 mW laser which is not powerful enough for people to see that are not in his immediate vicinity. He wants to use a 20 mW laser so that larger groups of people can see what he is pointing out, however it is too powerful to be operated by hand. If the beam were to make contact with someone's eye, instant blindness could occur.

1.2 Research

Several different types of technologies were explored as a possible solution to the client's problem. The different technologies researched focused around how Mr. Anderson will interface with the system to point out stars at will. Researched technologies included accelerometers and gyroscopes, motion tracking technology, tablet app software technology, and infrared detection technology.

Accelerometers were first researched due to their wide range of applications. These devices, wired and wireless, are useful in systems where impact force, vibrations, angle of tilt or inclination are needed. A Monnit wireless accelerometer is an example of a specific component considered and has dimensions of 1.77 x 1.04 x 0.785 inches, has a frequency of 900MHz and has a 250-300 feet non-line-of-sight range [1]. Both angle of tilt and acceleration forces are applicable to concept generation.

Motion detection technology has been used to capture real life motion for animated characters in movies and video games. This technology is applicable to this project by enabling the client to control an object motion manually, and translating that motion to another device that moves a laser. Xsens is a company that manufactures motion tracking devices and software. The system available from Xsens has features that include no line of sight occlusion, easy installation and calibration for software, real time preview of motion feedback, 17 motion trackers, and up to 500 feet wireless range [2].

Interactive applications for tablets was another technology researched as a possible solution to the client's need. The idea was to integrate the technology used for interactive constellation applications into a new software that enables a user to click on the constellation, satellite, or planet which would send a signal to a turret and redirect a laser to the corresponding location in the sky. Since the application tracks the sky in real-time, the software would be constantly updated with the correct location of the objects in the sky. Star walk is such an application, developed by Vito Technology, and specifically tracks 20,000+ objects in the night sky [3]. The app can locate constellations, stars, planets, and galaxies without needed an internet connection. This technology could be integrated with a new application for tablets that moves a laser pointer when a user taps on the object of interest.

Infrared Detection is an additional technology that may serve useful in creating a system for the client. Infrared can be used to track two LED emitters in space and translate the information into a line or vector. Johnny Lee, a graduate from Carnegie Mellon University, created a simple infrared tracking system from the Nintendo Wii controller and two LED emitters. The software created for this system converted the LED movement into digital code which moves an image on a TV screen giving the impression of a three dimensional environment for the user [4].

2.0 Problem Formulation

2.1 Identification of Need

Our client, Mr. Edwin Anderson the support systems analyst for the NAU Physics and Astronomy department, demonstrates the locations of various astrological points of interest with a 5mW laser pointer. Mr. Anderson is unable to give star gazing talks to large groups of people because the laser isn't powerful enough. More powerful lasers are too dangerous to be handheld due to the risk of eye damage. Mr Anderson would like a system built that would safely allow the use of a 20mW laser.

2.2 Project Goal

The goal of this project was to design and construct a system to safely focus the attention of an audience towards individual stars or constellations while observing the night sky.

2.3 Objectives

Our objective is to design and build a system that satisfies our client's requirements, while mitigating the risk of human harm to his audience. The system must be easily controlled with a resolution of at most ½°, the laser mounted at a height of no less than 6' 5". The entire system must fit into the cargo compartment of Mr. Anderson's car and weigh less than 100 lbs. the laser needs to have a movement speed of 24° per second, this speed was determined by considering a case in which the laser moves the maximum amount, generally 140°, in five seconds. This equates to an angular velocity of 24° per second or 0.4189 radians per second.

2.4 Operating Conditions

The design must be stable and comfortably operable in relevant weather conditions, i.e. typical Flagstaff winter night conditions. The laser will not operate if it becomes too cold. The main location of use will be the NAU observatory grounds, and other locations in and around Flagstaff such as Buffalo Park, Heritage Square and various elementary schools. A primary concern with various locations are differing minimum angles for the laser. For example, if the system was to be used near buildings, the system must not allow the laser to be shined into windows.

2.5 Constraints

The top priority of the project is to ensure that the laser will not come in contact with someone's eye, thus mitigating the risk of blindness. The laser must toggle on and off upon user command. The laser needs to be easily removable from the system. The overall project must remain within a budget of $3000.00 and must comply with all local, state, and federal regulations.

2.6 QFD

The section below presents and explains the quality function deployment (QFD) created for this project. Table 1.1 below depicts the QFD table.

Table 2.1 – Quality Function Deployment

Quality Function Deployment		Engineering Requirements					
		Insulation / Isolation	Weight	Cost	Height	Angle of Departure	Motor/Servo
Customer Requirements	Aesthetics			X			
	Stability				X		
	Controllablity			X			X
	Safety (no eye contact)				X	X	
	Inexpensive			X			X
	Long Lasting						X
	Operable in all temperatures	X					X
	Collapsible				X		
	Rapid Response						X
	One Person Mobility		X				
	High Resolution						X
	Units	R	kg	$	m	°	rad/sec
		10	W < 45.35	< 3000	1.9812	30	π rad in 5 sec
		Engineering Targets					

Definitions of each customer and engineering requirement are as follows:

Engineering Requirements

Insulation / Isolation – For operation of the laser, the temperature must be maintained at or above 40° Fahrenheit. To accomplish this temperature maintenance, the case in which the laser will be placed must be insulated. Insulation / Isolation pertains to the resistance associated with this insulation.

Weight – The client must be able to transport the device unaided by others. Thus, the weight of the system is of concern. The weight requirement is associated with the transportability of the system and is to not exceed 45.35 kg.

Cost – There exists a cost constraint on the project. The Cost requirement is associated with this cost and is to not exceed $3000.00.

Height – For safety, the device must be located above the average eye level of the individuals in the star talk. Thus, the Height requirement is not to be lower than 1.9812 meters from ground level.

Angle of Departure – To further ensure safe operation, limitation of the laser beam departure angle is necessary. This angle must be limited to 20° from the horizontal.

Motor / Servo – During star talks, the client frequently tracks fast moving objects across the night sky. To accomplish this task, a motor / servo speed of π radians in 5 seconds is necessary.

Customer Requirements

Aesthetics – The final device must be appealing to the eye so as not to distract from the star talks.

Stability – The customer requires the system to not easily topple in standard to extreme operating conditions, including temperatures at or above -5° Fahrenheit and winds up to 30mph.

Controllability – The client must be able to easily control the system and guide the laser beam to stellar objects in an efficient manner.

Safety – Safety is the primary concern and reason for this project, thus this requirement is the most important. The system must be error proofed to prevent the laser beam from inadvertently shining into observer's eyes.

Inexpensive – The overall system must not exceed the client's budget of $3000.00, thus the components must be relatively inexpensive to accomplish this requirement.

Long Lasting – This system is designed for long lasting use. The client has invested in this system and intends on using it long term for star talks.

Operable In All Temperatures – The system must be capable of operating in typical all season Flagstaff weather conditions.

Collapsible – The system must fit in the storage compartment of a typical vehicle. If the system is larger than the compartment of a vehicle, it needs to be collapsible.

Rapid Response - During star talks, the client frequently tracks fast moving objects across the night sky. The system must be response to the operator in a timely fashion to be capable of stellar object tracking. Twenty-four degrees per second has been determined as a sufficient speed.

One Person Mobility - The client must be able to transport the device unaided by others.

High Resolution - The client must be able to easily control the system and guide the laser beam to within ½° of stellar objects in an efficient manner.

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3.0 Proposed Design

3.1 Final Concept Selection

The tripod and turret design with a joystick controller was chosen as the final design shown in Figure 3.1 below. A tripod mounted turret with a joystick controller design was chosen for numerous reasons with the primary concerns being safety and reliability. The tripod will hold the laser at a safe height above the average person's eye level.

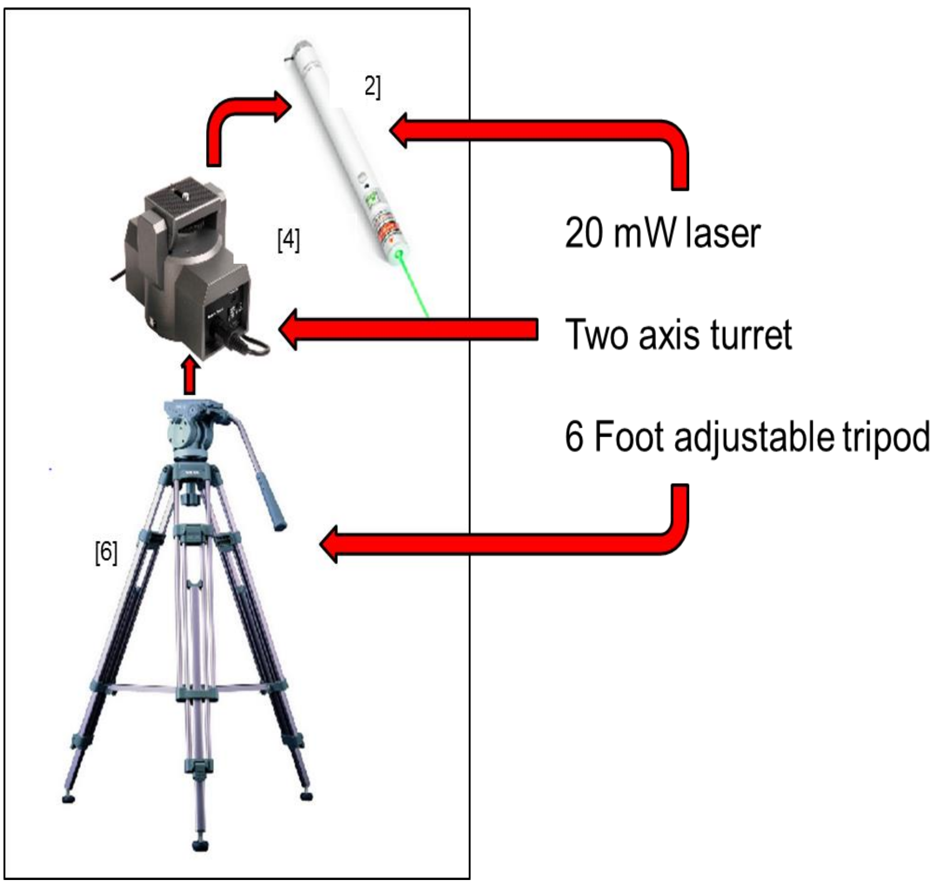


Figure 3.1 – Overall system design concept [10],[11]

The tripod will to hold the laser at a minimum height of 6'5''. The two-axis turret and tripod will be purchased. The turret control system may be modified. The turret will be used to physically aim the laser by moving in two spherical coordinate directions (i.e. theta and phi or a horizontal pan angle as well as a tilt angle).

The laser's enclosure will keep the laser within operating temperatures using insulation and will house the system responsible for toggling the laser on and off.

The final design for the Celestial Identification System has been built and is functional. The final product will be delivered to our client by the end of April, 2014. The following tables describe the systems capabilities and specifications

Table 3.1 – Turret Specifications

Physical		Electrical	
Dimensions (WxHxD)	10" x 14" x 4"	Power Supply	110-230 VAC to 12 DC 1000 MA
Weight	4.5 lbs.	Connector	5.5 X 2.1 center Pos.
Cable Length	12 Feet	Charging Time	~ 8 Hours
Mounting	Upright or Inverted	Run Time	~ 4 Hours
Mounting Plate	3" x 3" with 3/8" hole	View Distance	1000 meters
Controls		**Capabilities**	
2 Axis Thumbstick P/T	30/30 degrees	Slowest Speed	1 rev in 10 minutes
Ramp	none	Max Speed	4 RPM @ 12 V
Linear	none	Pan Revolution	360° +
Logarithmic	fixed	Tilt Revolution	360° +
Speed Limit	0 to 100%	Capacity	18 pounds

Table3.2 – Tripod Specifications

Overall Specifications	
Max height	78" (1.98 m)
Min height	31" (0.7874 m)
Folded length	34" (0.8636 m)
Center post adjustment	15" (0.381 m)
Weight	9 lb (4.08 kg)
Max Tripod load	25 lb (11.34 kg)

3.2 Structural Analysis

For the tripod and turret design, structural analysis consisted of developing a model that describes the event of dropping the devise from a height of six feet onto solid ground. The system must be able to withstand an impact with the ground sustaining minimal permanent deformation to the enclosure and no damage to internal electrical components. The results for this model are shown below.

3.2.1 Structural Results

Structural analysis was conducted for the outer casing of the handheld design using two different materials. The two options were 6061-O Aluminum and Delrin 100. The purpose of the structural analysis was to estimate the impact force the handheld unit would sustain if dropped from six feet (1.83m) and calculate whether or not the outer casing would undergo plastic deformation. First, the velocity that the unit hits the ground at from six feet was calculated using the kinematic equation, Equation 1, listed below.

$$V_f^{\,2} = V_O^{\,2} + 2 * a * h \tag{1}$$

Where:

V_f = Final velocity [m/s]

V_O = Initial Velocity $[m/s]$
a = Acceleration $[m/s^2]$
h = Height $[m]$

The calculation for the velocity just before impact when dropped from 6 feet is listed below.

$$V_f^{\,2} = (0)^2 + 2 * \left(9.81\frac{m}{s}\right) * 1.83m$$

$$V_f = 5.99\frac{m}{s} \approx 6\frac{m}{s}$$

In order to calculate the force that is exerted at impact, the acceleration the unit undergoes during impact must be calculated. The equation for acceleration is listed below.

$$a = \frac{dv}{dt} \tag{2}$$

Where:
a = Acceleration $[m/s^2]$
dv = Change in velocity [m/s]
dt = Change in time [sec]

This calculation is only an estimation of the actual acceleration the unit would undergo. Therefore, it is assumed that the time is takes for the unit to go from 6 m/s to 0 m/s is 0.1 seconds. This is a rough estimate that was generated by dropping similar weighted objects from 6 feet on a hard concrete surface and estimating the time it took for the object to bounce.

$$a = \frac{(6-0)\,{}^{m}/_{s}}{(0-0.1)s} = 60\,{}^{m}/_{s^2}$$

Once the acceleration the unit undergoes during impact was calculated, the force was calculated using Newton's 2^{nd} law of motion.

$$F = ma \tag{3}$$

Where:
F = Force [N]
m = Mass of object [kg]
a = Acceleration $[m/s^2]$

To make this calculation the mass of each option, Aluminum and Delrin, had to first be calculated. The volume of the outer case was calculated by modeling the case in SolidWorks and looking up the volume under the "material properties". Volume calculated and weight of each option is listed in Table 3.1 below.

Table 3.3 – Casing material properties

	Aluminum (6061-O)	Delrin (100)
Volume [cm^3]	117.6	117.6
Density [g/cm^3]	2.70	1.41
Weight [g]	317.4	165.7

In addition to these weights, each design option shares all other components. A list of the components and their respective weights is listed in Table 3.2 below.

Table 3.4 – Mass of components

Component	Mass [g]
Polystyrene (Expanded)	4.7
Gyro / Accelerometer	4.0
Proximity Detector	5.0
Heating Element	12.0
Batteries (2 x AAA)	23.0
Laser Pointer	26.0
Total	**74.7**

The weights were then totaled and forces calculated.

Aluminum case: $$F = (0.3921\ kg) * \left(60\ {}^{m}/_{s^2}\right) \approx 23.5\ N$$

Delrin case: $$F = (0.2404\ kg) * \left(60\ {}^{m}/_{s^2}\right) \approx 14.4\ N$$

For the Aluminum, any stress that exceeds .02% of the yield strength will cause plastic deformation. Using the known properties of Aluminum 6061-O, this stress was calculated using the relationship below.

$$\sigma = E\varepsilon \tag{4}$$

Where:

σ = Stress [Pa]
E = Modulus of elasticity [Pa]
ε = Strain [m/m, Dimensionless]

The modulus of elasticity for Aluminum is 68.9 GPa. Using this, the minimum stress to cause plastic deformation was calculated.

$$\sigma = (68.9\ GPa)(.0002) = 13.8\ MPa$$

For Delrin 100, the modulus of elasticity is not listed in any sources. The modulus of elasticity was estimated by analyzing the stress-strain curve of Delrin at room temperature (23°C) as seen in Figure 3.1 below.

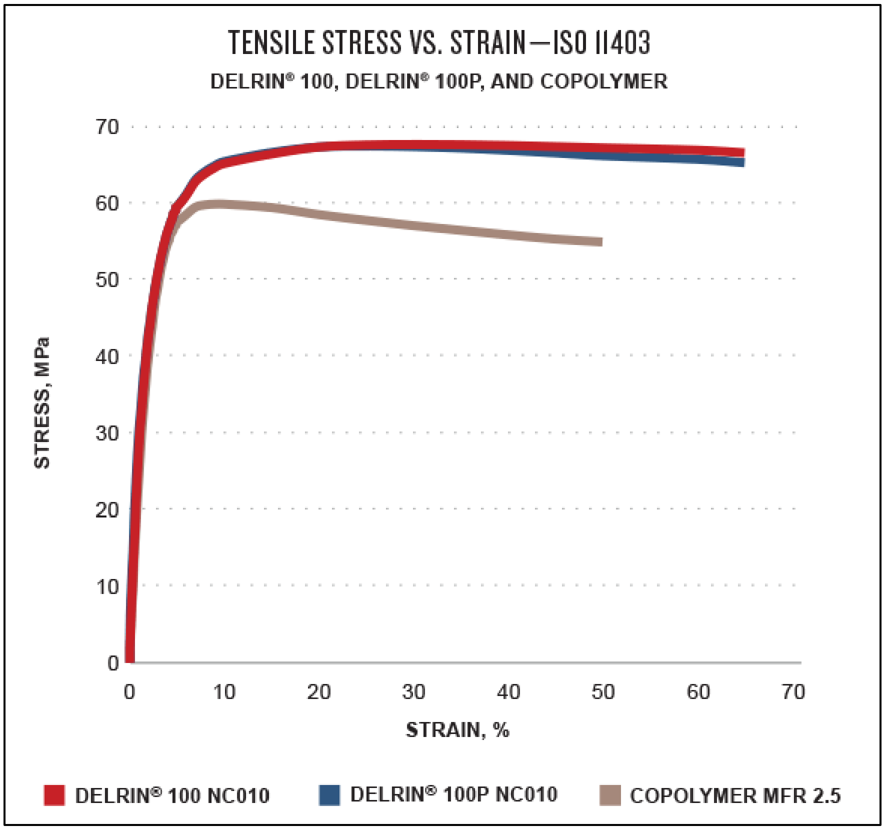


Figure 3.2 – Stress-Strain Curve Delrin 100 [21]

Listed below is the calculation for the modulus of elasticity.

$$E = \frac{(60\ MPa)}{(.03\ \frac{mm}{mm})} = 2\ GPa$$

The modulus of elasticity for Delrin was estimated to be 2 GPa. Using this information, the stress necessary to cause plastic deformation was calculated.

$$\sigma = (2\ GPa)(.0002) = 0.4\ MPa$$

Finally the actual stress the unit will undergo if dropped from six feet (1.83m) can be estimated. The way this is calculated is to calculate what area will undergo the stress when the unit is dropped and see if this is realistic. This area is calculated using the relationship to stress.

$$\sigma = \frac{F}{A} \tag{5}$$

Where:

σ = Stress [MPa]
F = Force [N]
A = Area [m^2]

The area necessary to undergo stress is calculated for each Aluminum and Delrin. The force and stress used in the calculation were calculated above.

Aluminum: $$13.8\ MPa = \frac{(23.5\ N)}{A}$$

$$A = 0.017\ cm^2$$

Delrin: $$0.4\ MPa = \frac{14.4\ N}{A}$$

$$A = 0.36\ cm^2$$

These calculated areas represent the maximum area that the force from the impact can be spread across. If the same force is exerted on a smaller area, there will be plastic deformation. The area for the aluminum is significantly smaller than the area for the Delrin. Simply, the aluminum case is much stronger and less likely to plastically deform if dropped. If either unit is dropped and lands either on along the length of the unit or on the top of the unit, there will be no plastic deformation. However, there is a possibility of plastic deformation if the unit is dropped and lands on one of the corners along the top or bottom for both the aluminum and the Delrin. The conservativeness of these calculations needs to be taken into consideration to make any decisions about which material should be used.

A time of 0.1 seconds was assumed for the calculation of acceleration. This was assumed by dropping the unit on hard concrete. It is known that Mr. Anderson often conducts his guided talks in the forest or on grassy fields. This makes the calculation of 0.1 seconds for the unit to come to complete stop very conservative.

It also must be taken into consideration the type of stress the unit would undergo if it were dropped. All calculations were based on the tensile strength of Delrin and Aluminum. However, the yield strength of Delrin is almost double in compression than it is for tension; 60MPa in tension vs. 125MPa in compression. This can be seen in Figure 3.2 below.

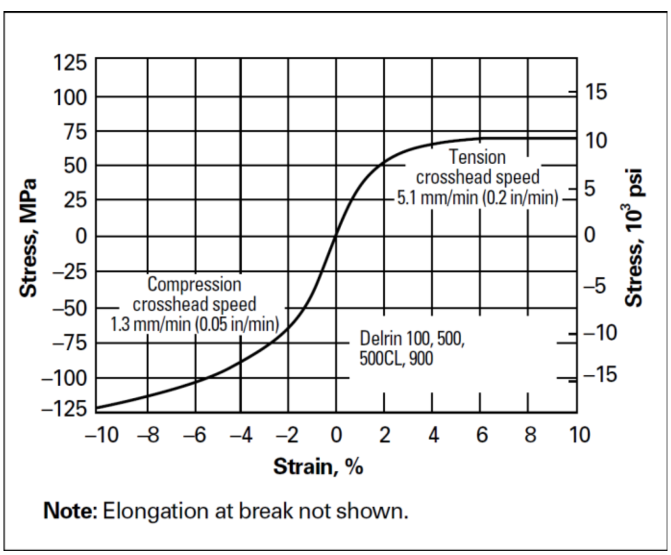


Figure 3.3 - Delrin Compressive and Tensile Stress Curve [19]

In conclusion, all estimates for the amount of stress needed to plastically deform the hand held unit when dropped from six feet are extremely conservative. This makes both the Aluminum and Delrin relatively equal candidates to be used in the final design. There is one material property that makes Delrin a much better choice than Aluminum and that is the thermal conductivity.

One of the main concerns with the hand held unit is keeping it above a certain temperature so the unit operates even in harsh winter environments. The thermal conductivity of Aluminum is significantly higher than Delrins; 237 vs 0.3 W/m*K. Since both materials are structurally sufficient for this design, but the ability for Delrin to act as an insulator is much better than Aluminum's, Delrin will be used as the casing for the final design.

3.3 Thermal Analysis

The laser must remain within operating temperatures at all times. For this reason thermal analysis was done for the tripod and turret design. This design incorporates insulation to maintain the desired temperature of the laser during operation. The important quantity is the heat loss through the housing under predicted worst case conditions.

3.3.1 Thermal Results

The tripod and turret design involves surrounding a laser with an outer shell of insulating material. The laser housing is been assumed to be equivalent in geometry for the design; the subsequent thermal analysis is considered at the worst case scenario (i.e. system exposed to cold air and wind conditions). The geometry has been simplified to a cylinder with a length equal or slightly longer than the length of the laser and variable radii for the insulation and outer shell. An Excel spreadsheet was created that determines total heat flow through our system while being able to change material type, geometry dimensions, and temperatures for operating conditions. The team chose Delrin to be the outer shell material and Polystyrene foam for insulation because they have relatively low thermal conductivities compared to other materials. Delrin was found to have a thermal conductivity of 0.3 $\left[\frac{W}{mK}\right]$ [15]. Polystyrene was found to have a thermal conductivity of 0.026 $\left[\frac{W}{mK}\right]$ [16]. The dimensions presented are an estimate of the needed thickness of our laser housing and can be altered if needed during construction. The laser operating temperature was determined using an average of the laser's specified operating temperature. The ambient temperature was assumed based on lowest temperatures seen in Flagstaff in which would be comfortable for a night sky presentation. Tables 3.3-3.5 show the chosen material properties and other variables described above.

Table 3.5 – Laser Housing Materials

Housing Material	**K (W/(m*K))**
LD PolyE	0.30
HD PolyE	0.48
PolyProp	0.20
Delrin	0.30
Insulation Material @270K	**K (W/(m*K))**
Polystyrene extruded	0.026
Blanket mineral fiber	0.040

Table 3.6 - Temperatures

Temp outside	**Deg F**	**Deg C**	**Kelvin**	**Appx Temp (K)**
	-5	-20.56	252.44	260.00
Temp laser functional	**Deg F**	**Deg C**	**Kelvin**	**Appx Temp (K)**
	32	0.00	273.00	280.00

Table 3.7 – Variable Dimensions for Laser Housing

K (insulation)	0.02600
K (housing)	0.30000
Length (in)	6.00000
r inner (in)	1.00000
r inner (in) insul	0.25000
r outer (in)	1.50000
r inner [m]	0.02540
r inner insul [m]	0.00635
r outer [m]	0.03810
Length [m]	0.15240

In order to calculate the convection from the outer shell surface to the ambient air, a heat transfer coefficient was determined. This coefficient was calculated using equation 7.54 from the textbook "Fundamentals of Heat and Mass Transfer", see Equation 6 below [21].

$$\overline{Nu_D} = 0.3 + \frac{0.62 Re_D^{\frac{1}{2}} Pr^{\frac{1}{3}}}{\left[1+\left(\frac{0.4}{Pr}\right)^{\frac{2}{3}}\right]^{\frac{1}{4}}} \left[1 + \left(\frac{Re_D}{282{,}000}\right)^{\frac{5}{8}}\right]^{\frac{4}{5}} \tag{6}$$

Where:

$Nu_D = \ Nusselt\ Number = 182.77$

$Re = Reynolds\ Number = \ 7.73 \times 10^4 \ \left(based\ on\ 30\ \frac{mi}{hr}\right)$

$\mathrm{Pr} = \ Pradtl\ Number = \ .7205$

Once the average heat transfer coefficient was calculated, the equivalent resistances were calculated and used to determine the heat transferred from the system. Equations 7 and 8 were used to determine resistances from the surface of the laser to the ambient air.

$$R_{conv} = \frac{1}{hA} \tag{7}$$

Where:

$R_{conv} =$ Thermal resistance $[m^2K/W]$

$h =$ Heat transfer coefficient $[W/m^2K]$

$A =$ Surface area $[m^2]$

$$R_{cond\ (cyl)} = \frac{ln\frac{r_2}{r_1}}{2Lk\pi} \tag{8}$$

Where:

$R_{cond\ (cyl)}$ = Thermal resistance for a cylinder $[m^2K/W]$
r_2 = Outer radius of cylinder $[m]$
r_1 = Inner radius of cylinder $[m]$

The total heat transfer in our system was found using Equation 9 below.

$$q = \frac{T_i - T_\infty}{\frac{1}{L\pi}\left[\frac{1}{hD_0} + \frac{ln\frac{r_2}{r_1}}{2k_{ins}} + \frac{ln\frac{r_3}{r_2}}{2k_{shell}}\right]} \tag{9}$$

Where:

T_i= Initial Temperature [K]
T_∞= Ambient Temperature [K]
r_3= Outer radius delrin [m]
k_{ins}= Thermal conductivity of insulation $[\frac{W}{m^2}]$
k_{shell}= Thermal conductivity of Delrin $[\frac{W}{m^2}]$
D_0= Outermost diameter

Table 3.6 shows calculated heat transfer coefficients and total heat transfer for wind speeds ranging from 0 to 50 miles per hour.

Table 3.8 - Calculated h in cross flow

U air (mph)	U air (m/s)	Re	h bar	Nusselt	Q total
0	0.00	0.00E+00	0.09	0.30	0.06
5	2.24	1.29E+04	19.49	62.14	0.34
10	4.47	2.58E+04	29.02	92.54	0.34
15	6.71	3.86E+04	37.02	118.02	0.35
20	8.94	5.15E+04	44.23	141.01	0.35
25	11.18	6.44E+04	50.95	162.43	0.35
30	13.41	7.73E+04	57.33	182.77	0.35
35	15.65	9.02E+04	63.45	202.29	0.35
40	17.88	1.03E+05	69.37	221.17	0.35
45	20.12	1.16E+05	75.13	239.53	0.35
50	22.35	1.29E+05	80.75	257.46	0.35

The total heat transfer was determined to be 0.35 Watts when using a wind velocity of 30 mph, a heat transfer coefficient of 57.33$\left[\frac{W}{m^2K}\right]$, and the parameters from Tables 3.2-3.4. Therefore, a heating element will be selected that can produce at least 0.35 Watts.

In order to validate our theoretical calculations, ANSYS was used to plot our temperature distribution for the conditions described above. Figure 3.3 below, shows the resulting temperature distribution.

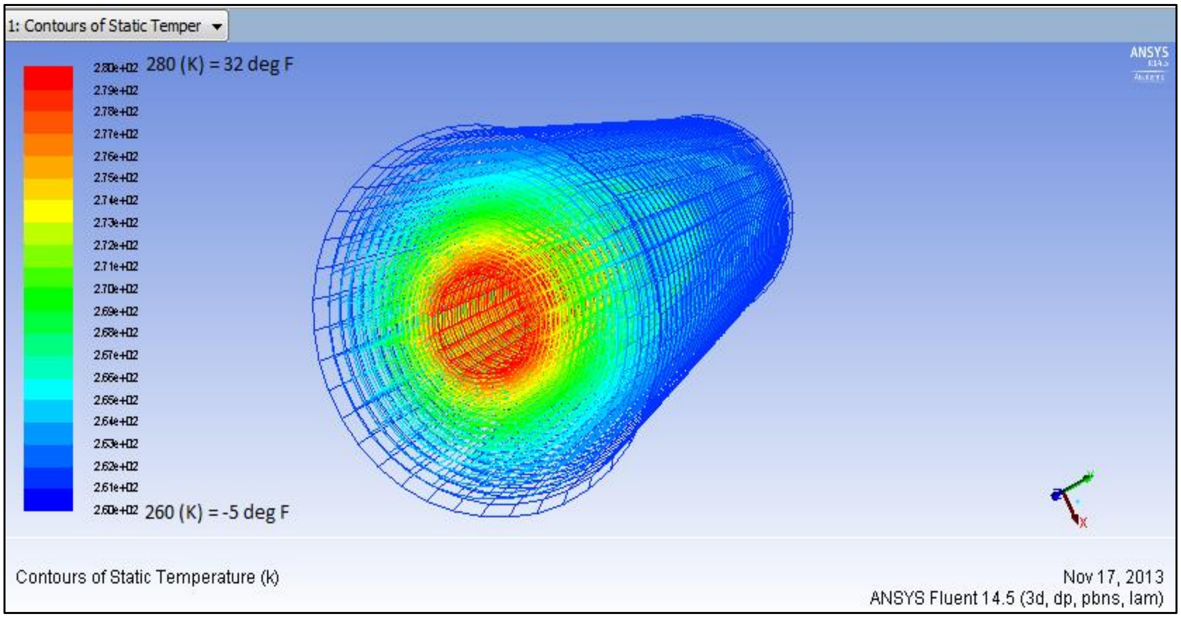


Figure 3.4 – Temperature Distribution

The temperature distribution shows the inner surface temperature of the laser at 280K, the appropriate operating temperature, and the ambient temperature at 260K. As seen in the figure, the insulated section retains more heat than the Delrin outer shell. This observation was expected due to the difference in equivalent thermal resistance between the outer shell and the insulation.

Equations 10 and 11 were used for the transient analysis.

$$F_o = \frac{\frac{k}{\rho C_p} * t}{r_0} \tag{10}$$

Where:

$k = Thermal\ conductivity\ of\ air \left[\frac{W}{mK}\right]$
$\rho = Density\ of\ air \left[\frac{kg}{m^3}\right]$
$C_p = Specific\ heat\ of\ air \left[\frac{kJ}{kgK}\right]$
$r_0 = Radius\ of\ cylinder\ [m]$

$$\theta^* = C_1 * exp(-\delta^2 F_o) * cos(\delta_1 x^*) \tag{11}$$

Where:

$\theta^* = \frac{(T_0 - T_\infty)}{(T_i - T_\infty)}$
C_1 = 1.1539
δ_1 = 1.0873

Transient conduction analysis was conducted to determine how long it takes for the laser temperature to drop below operating temperature. The average operating range for 20mW lasers in 32-95°F. Assuming the initial temperature of the laser is 70°F and the ambient temperature is worst case at -5°F, the laser will reach 32°F in 24.64 minutes. This is how long it takes for the temperature to reach the low end of the operating range. Additionally, when assuming the initial temperature of the laser is 70°F and the ambient temperature is worst case at -5°F, the laser will reach 50°F in 12.68 minutes. Additionally, when assuming the initial temperature of the laser is 70°F and the ambient temperature is 20°F (not worst case), the laser will reach 50°F in 16.16 minutes. The insulation alone is sufficient in our design only if the outside temperature is above the minimum operating temperature. Given the conservative nature of the above analysis, there is no need for a small heating element because the delrin laser housing has a low thermal conductivity and will insulate the laser and prevent heat loss in the system.

3.4 Material Selection

The housing containing the laser will be constructed of Delrin. A stock piece of Delrin will be machined to the specifications in the engineering drawings provided in Appendix B. The Northern Arizona University (NAU) machine shop will machine the case and the cap of the housing. The solenoid cover will be rapid prototyped in the NAU rapid prototyping lab from ABS.

The inner tube is the compartment where the laser will be placed will be constructed from $\frac{1}{2}$ inch electrical conduit. This compartment is designed such that a variety of laser models can be placed inside. This material is very inexpensive, strong, and easily machined. The inner tube will also contain pivot tabs, and a groove for the switch trigger, explained below.

The switch trigger will be made out of PVC and is a component necessary to accommodate several laser models. Not all laser are designed with the power switch in the same location. Thus it is necessary to design an actuator capable of operating switches in various locations. The switch trigger distributes the solenoid actuation over a longer functional distance. The switch trigger pivots in the switch trigger groove via the pivot point tab pin welded to the inner tube. When the solenoid is inactive, the switch trigger will be elevated such that the power switch for the laser is not depressed. When the solenoid is actuated, the switch trigger will depress the power switch, turning on the laser.

The solenoid is not a weather resistant device. To ensure that the solenoid will remain operational in outdoor conditions, a cover must be designed and constructed. The cover is made out of FDM rapid prototyping material, usually ABS or polycarbonate. This material will sufficiently remove the solenoid from the exposure to the elements.

To cap the internal components and support for the inner tube on the upper end, a Delrin cap was designed and built. The cap is press fit into the laser housing and seals the enclosure from the elements.

4.0 Prototype Fabrication

4.1 Fabrication Stages

This section details the all parts that were fabricated for the project, how they were made, and any problems encountered during the process.

4.1.1 Slip Rings

After all of the main components were received, one major issue surfaced. The chord that provided power to the tilt motor of the camera turret ran from the bottom bracket, across the pan axis of rotation to the motor. This caused the chord to bind up when the pan was rotated more than 360°. This was unacceptable and significant modification to the turret was designed. We wanted to design and build slip ring electrical contacts to transfer power across the pan rotation axis. This would allow for continuous power to the tilt motor with unlimited rotation of the pan axis. We needed to pass power across the axis for three circuits, both the pan and tilt motors and the solenoid.

The original design of the slip ring contacts used six copper rings press fit into a PVC base. Because of the placement of the slip ring, space was limited, so we were advised to use common ground for each of the three circuits reducing the copper rings to four. The copper rings were milled using hand coded CNC milling on the Tormach. The PVC base was milled using hand coded CNC milling on the Pro Light 1000. Speaker wire was soldered to the rings and they were pressed into the PVC base using fast setting JB weld as an adhesive. After the adhesive had cured the assembled slip rings were sanded down to ensure smooth contact with the carbon brushes, discussed later. During the sanding of the slip ring the outer most copper ring broke. It was sanded down all the way through its thickness. The reason for this was, there was not enough relief holes for the JB weld to flow out of the slots when the rings were pressed in, causing them to not press all the way into the base.

We then had to order more copper and fabricate the slip rings again. On the second iteration of the slip rings, the dimensions of rings were reduced because the original design interfered with the drive gear for the pan rotation by approximately 1/32 of an inch. After the second iteration of the slip ring was completed, it was installed and delivered power through the contacts. It was at this point we realized that having a common ground for the three circuits did not allow for the reversal of power to each circuit individually. Which is how electric motors turn both ways. The reversibility of the motors is an essential function for our design. Therefore, we then ordered a six wire slip ring online, fabricated a small plate on which to mount it, and fastened it into the mounting bracket of the turret. The original turret axis bolt was ¼” in diameter and incapable of allowing for a bore hole to allow the new slip ring wires to pass. To correct the wiring issue, a larger ½” bolt was bored with a ¼”through hole. All of the components which the contact the axis of rotation were then bored to ½” to accommodate the new axis bolt. The secondary design took two days and about $40 to make. The non-functional copper slip rings are seen in Figure 4.1, below with the block holding the carbon brushes. The slip ring setup that was implemented is shown in Figure 4.2. The picture on the left shows how the wires come through the turret mounting bolt. The picture on the right shows the bracket the slip rings are mounted to and how the bracket sits into the turret.

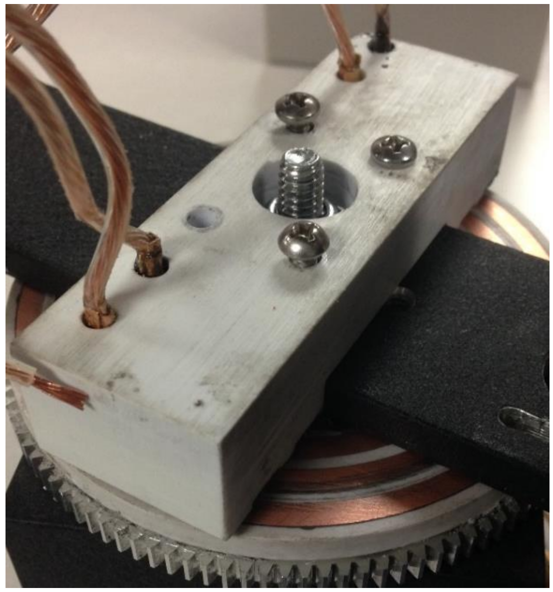


Figure 4.1 – Four contact slip rings with contact block installed on turret

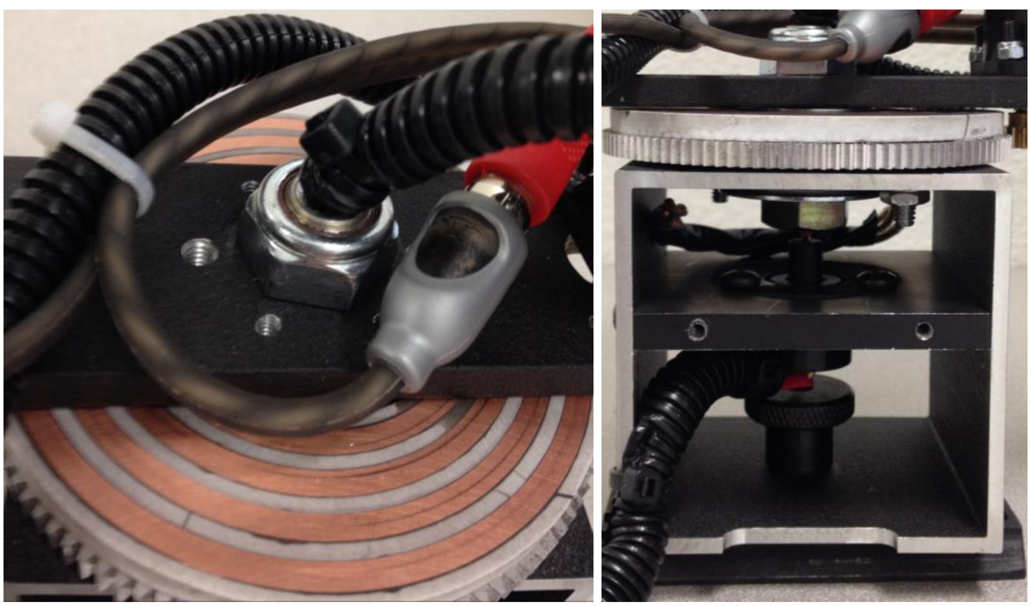


Figure 4.2 – Final slip ring setup

The first iteration of the slip rings yielded another obstacle in the manufacturing process. After the contacts were JB Welded in the contact base plate and had fully cured. The JB Weld had to be filed coplanar to the bottom of the contact base plate. During the filing process, the file slipped and caught one of the carbon brushes and broke it off of the spring plate to which it was mounted, see Figure 4.2 below. The contact was unrepairable and had to be milled out and JB Welded again. The replacement contact was then allowed to cure and filed.

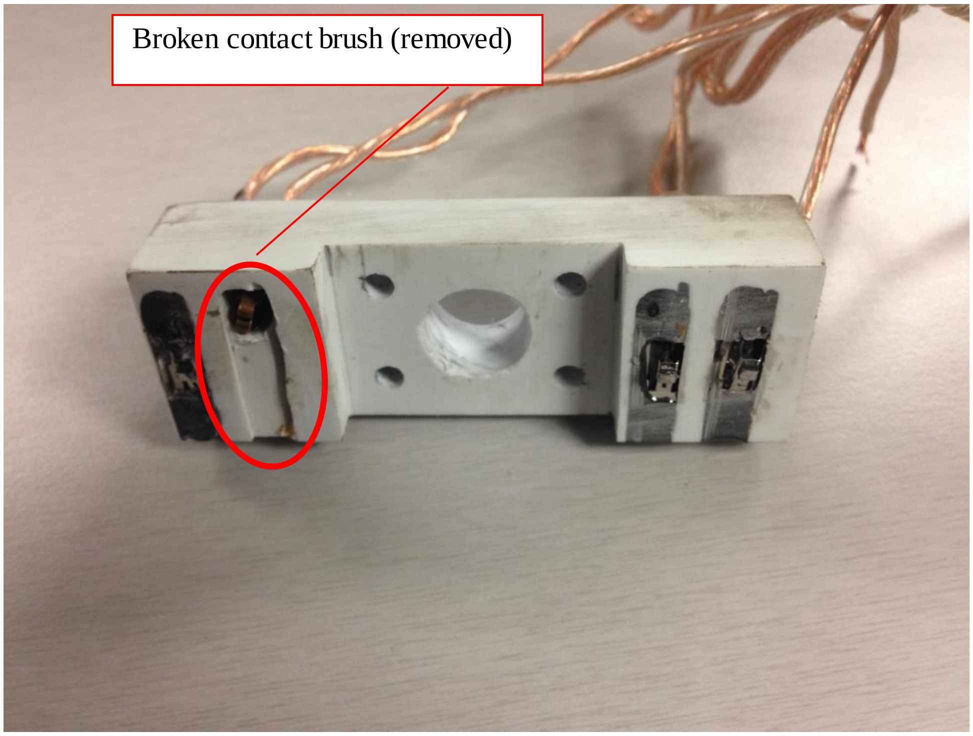


Figure 4.2 - Contact block with broken contact removed and prepped for replacement contact

The second major modification to the turret was to limit the range of the laser to 20° above the horizon. To accomplish this we fabricated a second set of slip rings for which the copper rings only span 140°, seen in Figure 4.3 below. These slip rings were mounted on the tilt motor gear. The design effectively limits the power to the laser to above 20° above the horizon. Similar to the full slip rings, a block for holding the carbon brushes was machined using a manual mill. The carbon brushes are held in place using fast setting JB weld in a PVC base plate. The PVC base plate was machined using a ProLight CNC mill. Similar to the four contact slip ring, upon insertion of the copper contacts, the contact surface was sanded to a fine finish for the carbon brushes to contact smoothly. The manufacture of the limiting slip rings yielded no negative results and no complications. Upon installation on the turret, the contacts functioned properly.

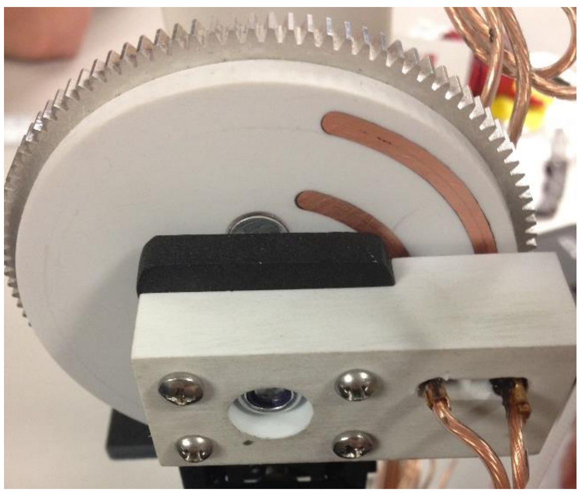


Figure 4.3 – 140° slip ring installed on the tilt components of the turret

4.1.2 Laser Housing

The laser housing was constructed from Delrin and machined on a manual lathe by the NAU machine shop staff. The manufacture of the laser housing yielded no unexpected problems and was completed to our specifications. A solenoid cover seen in Figure 4.4 was rapid prototyped for the purpose of protecting the solenoid from exposure.

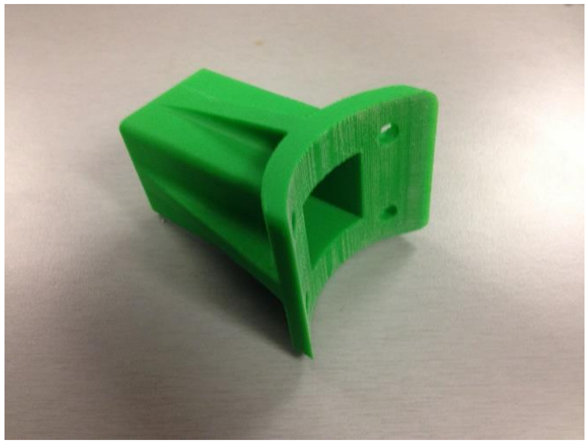


Figure 4.5 – Solenoid cover

4.1.3 Laser Housing Cap

The laser housing cap was also constructed from Delrin and machined on a manual lathe by the NAU machine shop staff. The manufacture of the laser housing cap also yielded no unexpected problems and was completed to our specifications.

4.1.4 Inner Laser Housing

The inner laser housing was constructed from ½" electrical conduit and 1/8" sheet metal. The tabs which hold the switch trigger were cut from the 1/8" sheet metal using a Dremel portable router. These tabs were then welded to the electrical conduit by the NAU machine shop staff. A pivot hole for the switch trigger was drilled through the two tabs after the tabs were welded and ground smooth. To align the inner laser housing with the outer laser housing, a dowel pin slot was machined on the side of the conduit. This slot was machined with a manual mill and indexed with a mill jig to be normal to the welded tabs. This slot allows a dowel pin in the laser housing cap to slide in snuggly and holds the assembly to the proper indexing. The welded assembly was then readied for the inner laser housing bushing to be JB Welded to it with some light sanding. The triangular bushing, seen in Figure 4.6 secured around the inner laser housing, was cut using hand coded CNC milling on the ProLight 1000. The part was completed with little unforeseeable issues.

Figure 4.6 – Laser Housing and Solenoid

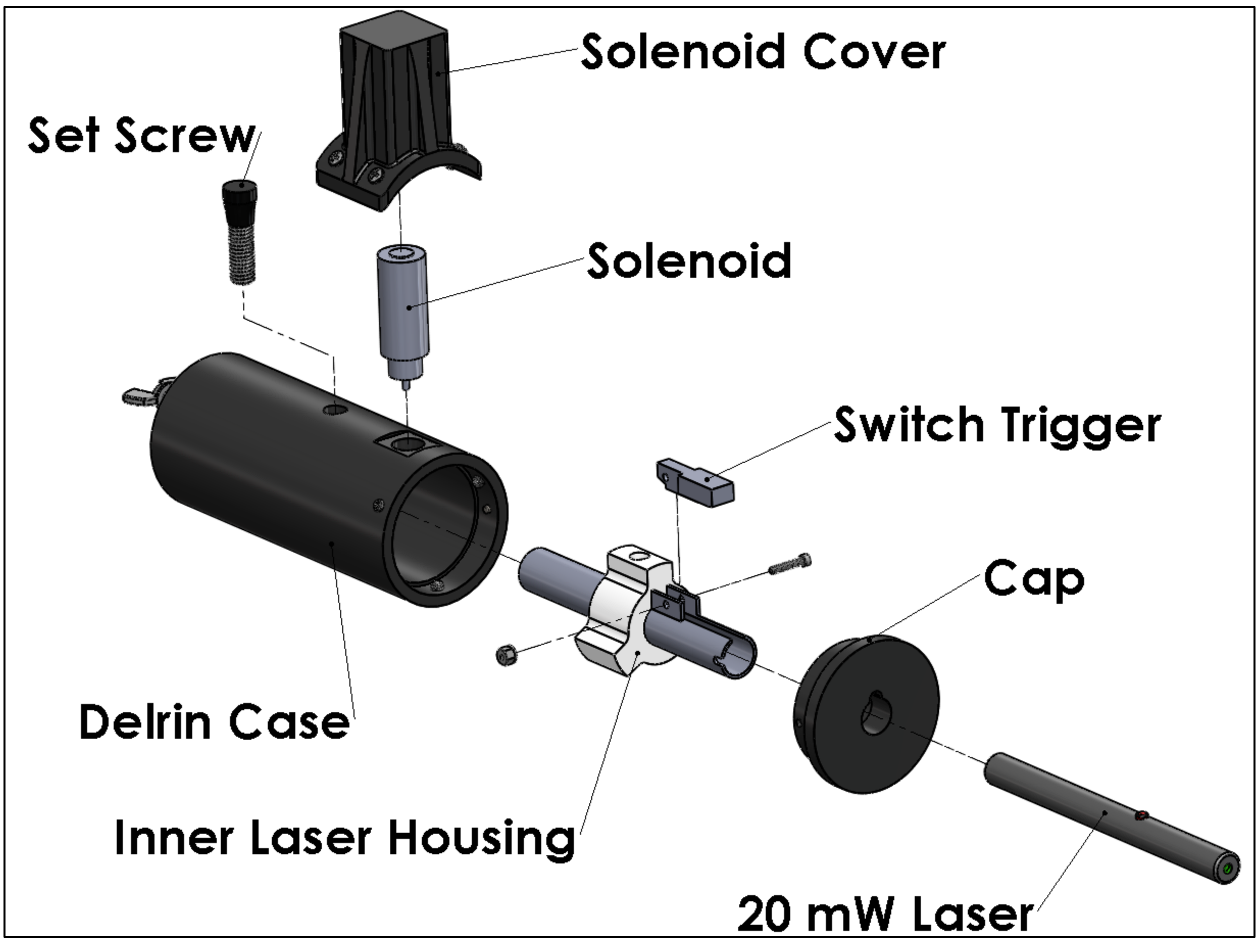


Figure 4.7 – Housing exploded view

4.1.5 Power Supply

The power supply houses the battery and is composed of four seven components. The main component is a used 30 caliber ammunition can that was modified to accommodate the battery, mounting components and the voltage indicator. The main challenge for this item was to find an inexpensive box suitable for housing the battery and all of the other components. Once the ammunition can was located, the remaining manufacturing progressed in a timely fashion. Some of the other components of the power supply are detailed in the following paragraphs.

The original top carry handle was removed in order to install the dowel pin assembly. The dowel pin assembly is composed of a mounting trough made from 1" square tubing. The square mounting trough was constructed using a hand held grinder with a cut off disc. No CAD model or drawing exists for this item due to it being made from scraps found in the NAU machine shop scrap bin and designed as necessity dictated. The second item in the dowel pin assembly is a closet ball latch. The ball latch enables the dowel pin to remain in either the upright position as seen in Figure 4.7 below, or in a reclined position for transportation. The final component in the dowel pin assembly is the dowel pin. It is constructed from ¾" X 1" Aluminum stock and was polished for the final assembly.

Figure 4.8 – Power supply

The power supply also contains battery clamping brackets inside the ammunition can to prevent the battery from moving.

4.1.6 Tripod

The tripod was unaltered except for a mounting bolt hole for the power supply. This mounting hole is located near the bottom of the main vertical tube of tripod. No complications were encountered by drilling the mounting hole.

4.1.7 Other Components

Figure 4.8 shows the joystick controller. An auxiliary button for the laser's power switch was custom ordered from the manufacturer of the turret system. Figure 4.9 shows the turret assembly case with all contents. It securely stores the turret, laser housing, laser, joystick, and wiring. Figure 4.10 shows the overall finished system completely assembled

Figure 4.9 – Joystick controller

Figure 4.10 – Turret assembly case

Figure 4.11 – Overall system assembly

5.0 Testing and Results

5.1 Testing Procedure and Environment

The testing for the system was relatively straightforward. The duration of battery life needed to determine as well as overall reliability. Both parameters were tested simultaneously by running the system with the joystick held at 45° which ran the system around in off axis circles, for four hours. Throughout the duration of the test there was no observable loss of power and the laser shut off and on as it crossed the 20° threshold each time.

5.2 Objectives and Constraints Satisfied

Table 5.2 below lists our constraints and objectives for the project and how they were met. Many of the constraints are not quantifiable. Quantitative values are given where applicable.

Table 5.2 – List of Constraints and Objectives and their satisfaction

Constraint		**Our system**
Beam - eye contact	-	Satisfied
Laser toggles on/off	-	Satisfied
Laser removable	-	Satisfied
Budget	$ 3,000.00	$ 1,765.52
Resolution	1/2°	< 1/2°
Elevation	6' 5"	8" (max)
Dimensions	-	Satisfied
Weight	100 lbs	38 lbs
Tracking speed	24°/sec	36°/sec

6.0 Cost Analysis

6.1 Bill of Materials

This section pertains to the itemization and declaration of component, assembly, and testing costs for the final design concept. All costs incurred are listed in Table 6.2 below, with descriptions of all major components in the following paragraphs.

Table 6.1 – Cost Analysis with Grand Total

Materials and Supplies		
Description	**Supplier**	**Cost [$]**
Conduit / Misc. connectors	Habitat for Humanity	5
Speaker wire RCA 4 output	Amazon	8.66
Power Wheels Charger 12V	Amazon	19.5
#6 Bolts	HomeCo	1.95
T104 Tap	Napa	6.9
7/64 Drill Bit		
GM terminal	Napa	11.96
JB Weld		
RCA 2 output	eBay	12
Socket head cap screws	Copper State	2.84
Bolts and Nuts	HomeCo	1.56
Bolts and Nuts	HomeCo	2.49
Contacts	RCBoyz.com	13.39
GM terminal	Napa	15.78
JB Weld		
Contacts	eBay	12.7
Speaker wire RCA 2 output	Amazon	31.4
Speaker wire RCA 2 output	Amazon	
Speaker wire RCA 4 output	Amazon	11.28

Contacts	Amazon	6.82
Contacts	Amazon	6.82
Electrical Terminals	Napa	5.73
Zip Ties		
Misc. Bolts and Nuts	HomeCo	8.14
Misc. Bolts and Nuts	HomeCo	1.56
Butt Connectors	Napa	3.57
Misc. Hardware	HomeCo	21.22
Plugs / Bushings	HomeCo	9.3
Ammunition Can	Horizon International	10
Wire Loom	Napa	19.85
Misc. Terminals		
Rivets		
Bosch Carry Case	Copper State	65.06
PVC	Amazon	20.3
Misc. Electrical	RadioShack	14.05
Misc. Hardware	HomeCo	5.6
Misc. Hardware	HomeCo	8.03
.0787 4 flute end mill	Quality Tool	10.4
.0787 4 flute end mill	Quality Tool	9.43
Contacts	Amazon	16.47
Slip Rings	Amazon	30.9
Wire loom	Napa	10.49
Electrical Tape		
Copper	McMaster Carr	61.23
O-rings	HomeCo Lumber	1.77
Shrink fittings	Radio Shack	27.06
RCA Jack		
Speaker Wire		
Springs	McMaster Carr	12.47
Turret	Camera Turret	861
Tripod	Amazon	163
Delrin stock	McMaster	43.46
Aluminum stock		
1/4" studs		
Rubber insulation		
Copper stock	McMaster	35.26
Solenoid	Galco	31.7
Volt Meter	Amazon	20.04
Power Wheels Battery	Amazon	67.38
Total		**1765.52**

Davis and Sanford 78" Tripod – This item is the tripod on which all other components will be mounted. It will be modified such that it will only function at the maximum height of 78 inches to ensure a safe elevation for laser operation.

RCA Cable – The operation of the solenoid to depress the power switch on the laser pointer will be via two RCA ports on the side of the turret. The RCA cable will connect the RCA ports on the turret to the solenoid connector pins.

.0589" sheet metal – Safety dictates that the laser pointer beam be directed away from potentially dangerous directions. To ensure that this always occurs, a laser beam shield will be constructed from the sheet metal to prevent the laser from dropping below the desired elevation.

PT5 Camera Turret – The Camera turret is the device that will move the laser to the desired position. This is a single purchased component which will undergo minimal modification during assembly.

Auxiliary Power Button – Power must be supplied to the solenoid to operate the power switch on the laser pointer. This is the button, located on the joystick, which will accomplish the switch signal. This component will be installed by the camera turret manufacture as per the design request.

Delrin Rod Stock 1' – The case and cap which will house the laser pointer will be constructed of Delrin. These parts must be machined from a larger bulk stock, which is represented in the table and is one foot long from the supplier.

½" Electrical Conduit 5' – Within the Delrin case will reside a tube constructed from electrical conduit. The bulk material which the part will be manufactured will be five feet in length.

Aluminum Stock 1 1/4" X 1' X 3/4" – In order for the solenoid to depress the power switch on the laser pointer, an intermediate beam must transition the linear motion to a semicircular motion. This semicircular motion will come from a part machined from the aluminum listed in the table.

M1.4 X .3 - T5 Drive Screw – The solenoid cover must be fastened to the Delrin case. These screws will provide ample fastening strength.

Blind Rivet 3/16" – The laser beam shield consist of two parts, a base plate and a tubular shield. The shield will provide laser beam blockage while the base plate supports the shield. The blind rivets will be used to fasten the shield to the base plate.

Heater – For cold weather conditions, a heater will be installed in the inner tube where the laser pointer will mount.

RCA Cable to Quick Connector – In order to connect the RCA cables to the solenoid, some adaptors will be required. These quick connectors are the adaptors.

Solenoid – The solenoid will actuate when a button is depressed on the joystick controller. While the button is depressed, the solenoid will apply force to the switch trigger thus depressing the power button on the laser.

Solenoid Cover – To keep the solenoid clean and dry, a cover is necessary. This cover will be 3-D printed in the NAU fabrication lab from a G code which the group will develop.

Contingencies – This row is an additional cost which incorporates imposed costs that are unforeseen due to components not in the group's possession at the time of this report.

6.2 Total Cost of Production

The total cost of production is $1765.52 indicated at the bottom of the mill of materials. Since all fabrication was done in house by NAU shop staff or team members we did not add manufacturing or man power costs.

7.0 Conclusion

7.1 Problem description

Our client, Mr. Anderson, has requested a system that will use a 20 mW laser to aid him in pointing out stellar bodies during presentations of the night sky while eliminating the possibility of laser beam contact with anyone's eye. He currently uses a 5 mW laser which does not produce a powerful enough beam for people that are outside of his immediate vicinity to see clearly. A system is to be designed and constructed to focus the attention of large groups of people to stellar bodies while eliminating the possibility of shining the beam into someone's eye. Main design considerations are the usability and responsiveness of the system as well as the required operating temperature of the laser because it operates poorly when cold. The designed system must also fit into the cargo compartment of Mr. Anderson's Subaru Outback when fully collapsed, and weigh less than 100 lbs.

7.2 Concept generation/selection

Several concepts were generated as potential solutions to the client's problem. A handheld system using a system of gyroscopes and proximity sensors to detect when the laser is pointed below a preset critical angle or held below a certain height. This design would preserve the intuitive control of having the laser in your hand. Four other concepts were presented which all have the same overall design, a tripod camera mount and a 2-axix rotational video camera turret to direct the laser. These remaining concepts differ in the way the user will control the laser's position. Concept two would use a tablet computer with a star mapping application in which the user could touch stars on the screen or enter coordinates and the laser would move to the selected location. Concept three uses the six-axis motion detection technology of a smartphone and an accompanying application to translate the motion of the smartphone directly to the laser. Concept four would utilize the infrared motion detection technology found in modern gaming console controllers such as Nintendo's Wii and Sony's PS3 to translate the motion of the users arm to the laser. Concept five uses a wired joystick to control the laser.

After discussing the concepts with Dr. Venkatraman of the Electrical Engineering Department here at NAU to determine the feasibility of each concept given the team's electrical and computational knowledge, concepts one and five were chosen for analysis.

7.3 Engineering analysis

Many of the components for our design are purchased off the shelf and are to be used well below the maximum recommended loadings. For this reason the analysis for our design reduced to the housing for the laser, which the group will be designing and fabricating for this project. A mathematical model was developed for the event of the devise being dropped from a height of six feet onto solid ground. The housing will need to be designed to withstand this sort of event with little to no permanent deformation and no damage to the internal laser or electronics. By using Delrin 100 as the material for the outer case not only will the handheld unit be capable of withstanding numerous impacts, it will contribute to insulating the laser to maintain sufficient operating temperatures.

The tripod design was going to be analyzed for the event of being toppled over by the strong winds. However, our team reasoned that if there were strong enough sustained winds to knock the tripod over, an audience would not be comfortable sitting and watching a presentation. Thus our system would not be in use in these conditions and thus this portion of the analysis was omitted.

Thermal analysis was conducted on the laser housing for both concepts. The objective was to find the amount of heat leaving the system under worst case conditions which were determined to be a temperature of -20 °C or -5 °F and a wind speed of 13.4 m/s or 30 mph. Once this quantity of heat loss was determined an electrical heating element could be selected and installed to maintain the operating temperature of the laser. The resulting total heat transfer through our system was determined to be 0.35 Watts at worst case environmental conditions. With this information, a heating element was deemed unnecessary for the design.

7.4 Cost analysis

The costs incurred by the system design do not include labor costs, machine costs, or processing costs. This is because individuals in the group or NAU shop staff performed all machining and rapid prototype work, thus the labor cost is neglected. All manufacturing of components were completed in house, meaning at the NAU machine shop. The total system cost is $1765.52, well below the allotted $3000.00 budget, and fulfills all design requirements.

7.5 Conclusion

To conclude, the designed system meets or exceeds all objectives, constraints and requirements. Our Client, Mr. Edwin Anderson is happy with the system and its controllability. The system will be delivered to him following the UGRADS event on April 25th, 2014.

REFERENCES

Research:

[1] "Accelerometer - Tilt900 MHz - Commercial (Coin Cell)." *Wireless-Sensors*. N.p., n.d. Web. 09 Dec. 2013. <http://www.monnit.com/Products/Wireless-Sensors/Commercial-Coin-Cell/900-MHz/Wireless-Accelerometer-Tilt-Sensors>.

[2] "New Products: MVN Awinda / MVN BIOMECH Awinda." *Xsens : 3D Motion Tracking*. N.p., n.d. Web. 09 Dec. 2013. <http://www.xsens.com/>.

[3] "Star Walk - Interactive Astronomy Guide." *Star Walk - Interactive Astronomy Guide*. N.p., n.d. Web. 09 Dec. 2013. <http://vitotechnology.com/star-walk.html>.

[4] Lee, Johnny C. "Johnny Chung Lee Projects Wii." *Johnny Chung Lee*. N.p., n.d. Web. 09 Dec. 2013. <http://www.johnnylee.net/projects/wii/>.

Images:

[5] lordwhimsey, . "People pointing vector." *VectorStock.com*. N.p.. Web. 9 Dec 2013. <http://www.vectorstock.com/royalty-free-vector/people-pointing-vector-6316>.

[6] "Picture of the Day." *www.Mikesjournal.com*. N.p.. Web. 9 Dec 2013. <http://www.mikesjournal.com/July 2010/iPad Eclipse Star Walk App.htm>.

[7] "Nintendo Wii Remote Jackets Free Sample | Gadgets & Apps - Sample.net." Nintendo Wii Remote Jackets Free Sample | Gadgets & Apps - Sample.net. N.p., n.d. Web. 10 Dec. 2013. <http://www.sample.net/prod/gadgets-apps/nintendo-wii-remote-jackets-free-sample-453.html>.

[8] "Playstation Move Controller - Black (PS3)." : Amazon.co.uk: PC & Video Games. N.p., n.d. Web. 10 Dec. 2013. <http://www.amazon.co.uk/Playstation-Move-Controller-Black-PS3/dp/B003R7KV16>.

[9] *www.picstopin.com*. N.d. Photograph. n.p. Web. 11 Dec 2013. <https://www.google.com/search?q=joystick&source=lnms&tbm=isch&sa=X&ei=eyepUtOFKYOSyAGmwoGoBA&sqi=2&ved=0CAcQ_AUoAQ&biw=1920&bih=995

Components:

[10] "CAMERA TURRET TECHNOLOGIES, INC.." *PT5 Motorized Pan and Tilt System*. N.p.. Web. 9 Dec 2013. <http://cameraturret.com/pt5.htm>.

[11] "Davis &Sanford ProVista F12." *http://www.tiffen.com/*. Tiffen Company. Web. 9 Dec 2013. <http://www.tiffen.com/userimages/D&S Product Sheets/D&S_ProVistaF12_ss.pdf>.

[12] "Solenoids 53648-81." *http://www.deltrol-controls.com/*. Deltrol Controls. Web. 9 Dec 2013. <http://www.deltrol-controls.com/products/solenoids/c-frame-solenoids/c-4/53648-81>.

[13] "Miniature Heating Elements from Minco." *http://www.mod-tronic.com/*. N.p.. Web. 9 Dec 2013. <http://www.mod-tronic.com/Minco_Miniature_Heating_Elements.html>.

[14] "http://precisionsensors.meas-spec.com/." *PTC Thermistor Design Form*. Measurement Specialties. Web. 9 Dec 2013. <http://precisionsensors.meas-spec.com/custom/configptcheater.asp?thm=srh&v=50&s=50&p=Rect 0.472(L) x 0.236(W)&r=10>.

[15] "CITY OF FLAGSTAFF SERVICE AT A HIGHER ELEVATION." *http://www.flagstaff.az.gov/*. Flagstaff City Hall, 01 June 2013. Web. 9 Dec 2013. <http://www.flagstaff.az.gov/index.aspx?NID=53>.

Material Properties:

[16] "Delrin Design Information." *Dupont the Miracles of Science*. du Pont de Nemours and Company. Web. 12 Nov 2013.

[17] "Thermal Conductivity of Some Common Materials and Gases." *Thermal Conductivity of Some Common Materials and Gases*. N.p., n.d. Web. 17 Nov. 2013. <http://www.engineeringtoolbox.com/thermal-conductivity-d_429.html>.

[18] "Aluminum 6061-O." *http://amet-me.mnsu.edu/*. N.p.. Web. 9 Dec 2013. <http://amet-me.mnsu.edu/userfilesshared/DATA_ACQUISITION/mts/MET324/10-7-2011/MaterialData_9389-Al06061-2-fromMatWeb_com.pdf>.

[19] "DELRIN® acetal homopolymer." *http://www.ensinger-inc.com/*. N.p.. Web. 9 Dec 2013. <http://www.ensinger-inc.com/products.cfm?page=product&product=delrinandreg; acetal homopolymer>.

[20] "Delrin, acetal resin." . Dupont. Web. 9 Dec 2013. <http://plastics.dupont.com/plastics/pdflit/americas/delrin/230323c.pdf>.

[21] "Delrin® 100 Series." *http://www.dupont.com/*. N.p., n.d. Web. 9 Dec 2013. <http://www.dupont.com/products-and-services/plastics-polymers-resins/thermoplastics/Articles/delrin-100-series.html>.

Analytical Tools:

[22] Incropera, Frank P. *Fundamentals of Heat and Mass Transfer*. New York [etc.: John Wiley & Sons, 2006. Print.

[23] R.C. Hibbeler, "Kinetics of a Particle: Force and Acceleration," in *Dynamics,* 12th ed. Upper Saddle River, New Jersey, Pearson Prentice Hall, 2010, ch. 13

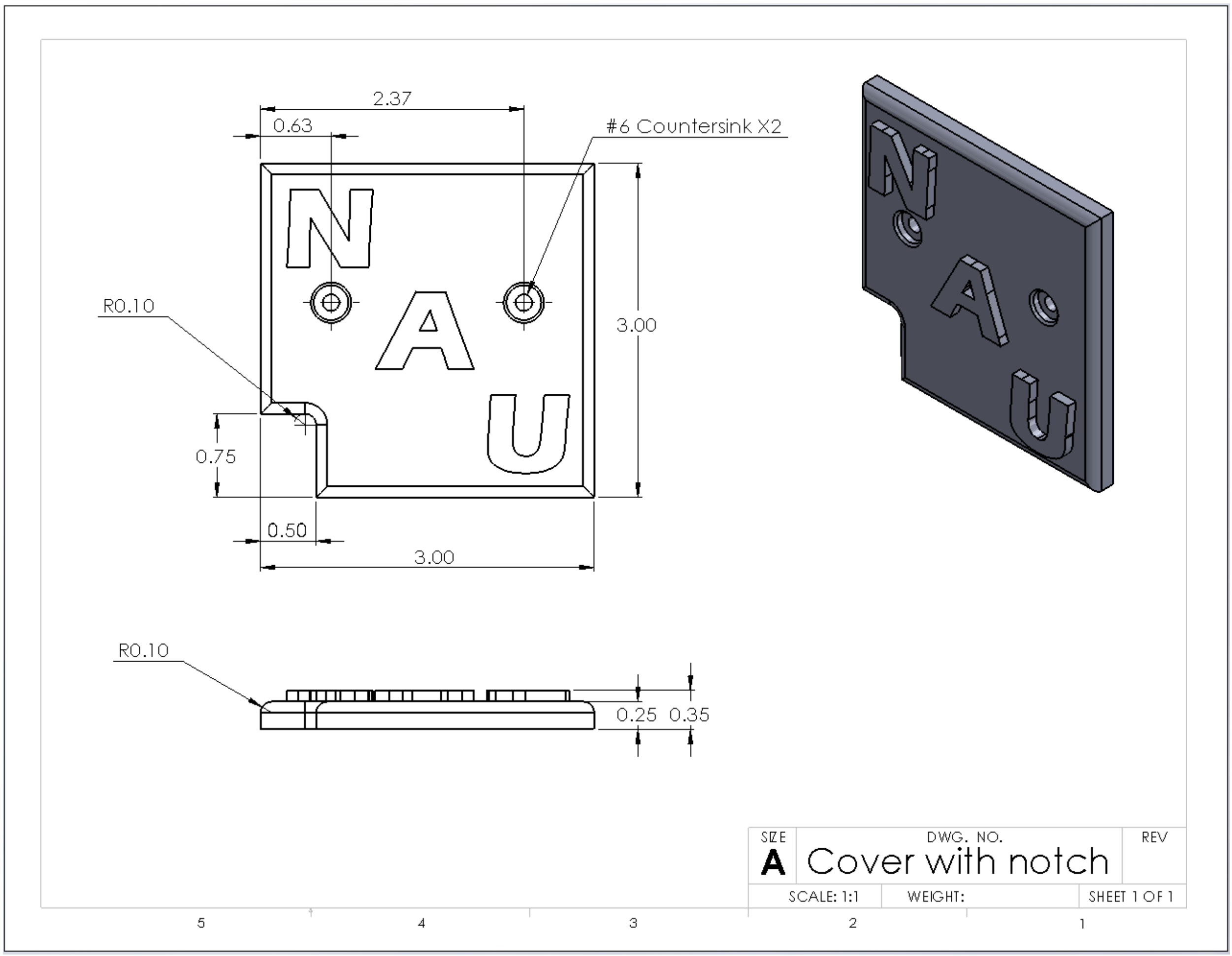
APPENDICIES

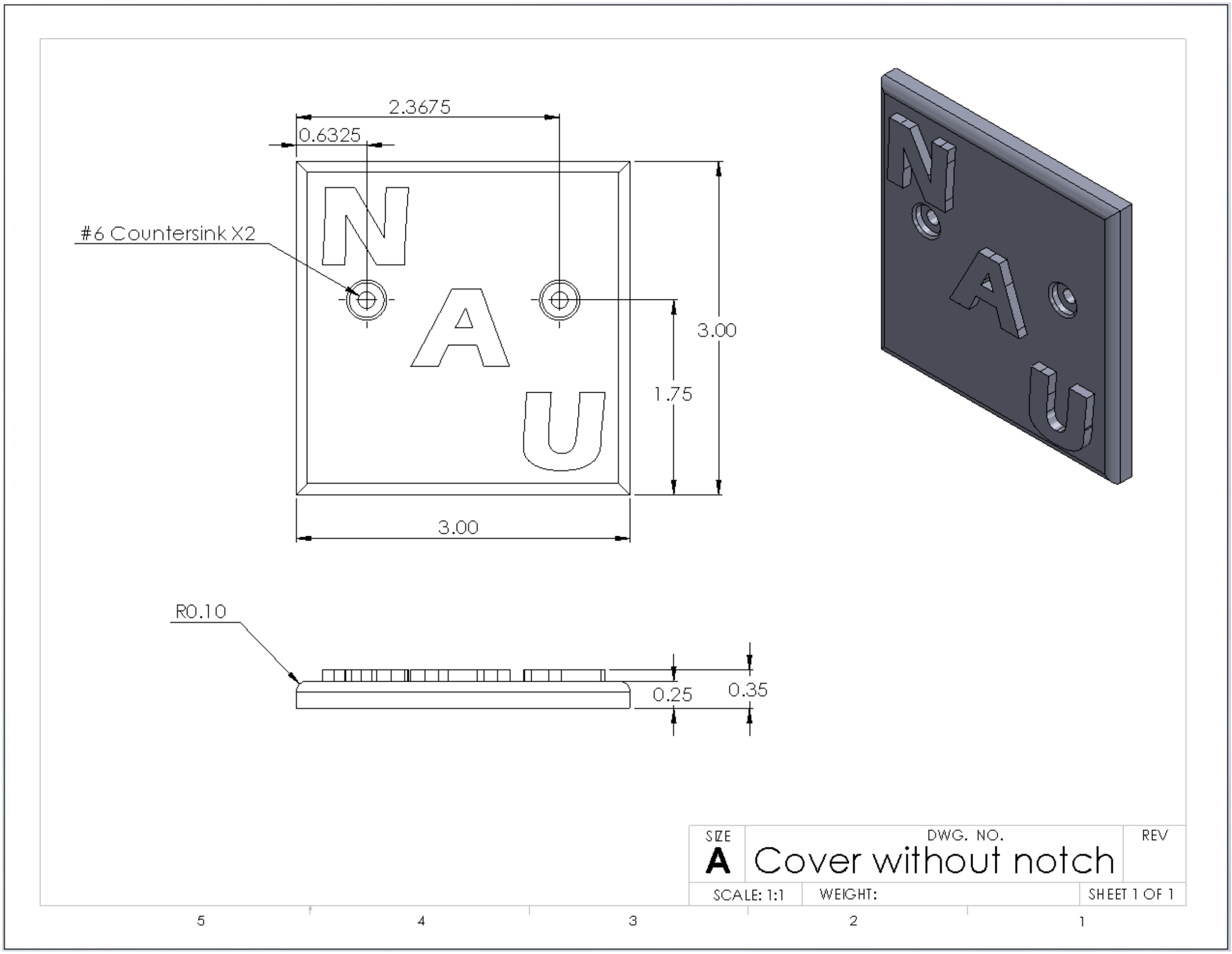
Appendix A: Acknowledgments

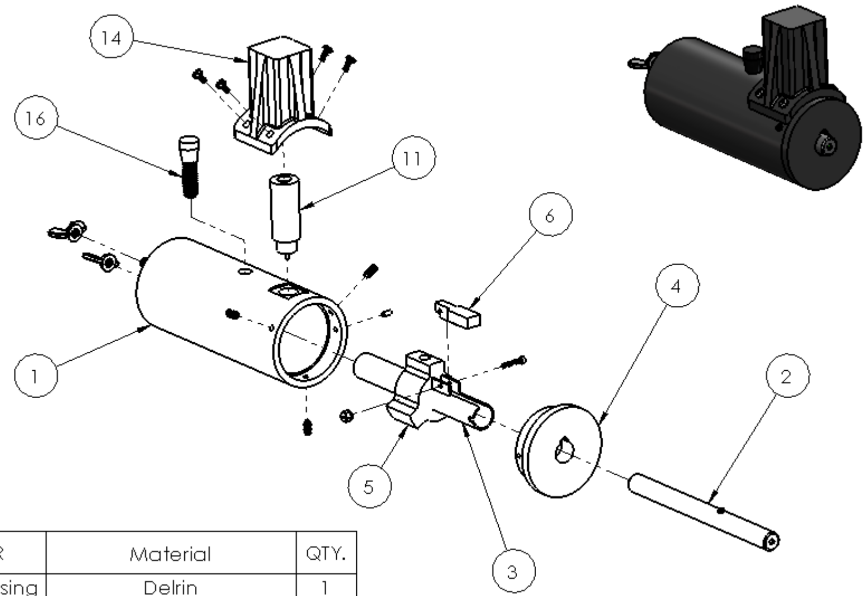
We would like to extend thanks to several individuals in no particular order: Mr. Edwin Anderson for requesting and funding the project. Dr. Srinivas Kosaraju for his advisement and support throughout the duration of the project. The NAU shop staff for their patience and help in fabrication of the parts of our system.

Appendix B: Engineering Drawings

All of the drawings for the fabricated parts are shown in the section below in case any components need to be remade or the system is to be duplicated at some point in the future.




2.3675
0.6325
#6 Countersink X2
3.00
1.75
3.00
R0.10
0.25
0.35
SIZE
A
DWG. NO.
Cover without notch
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1

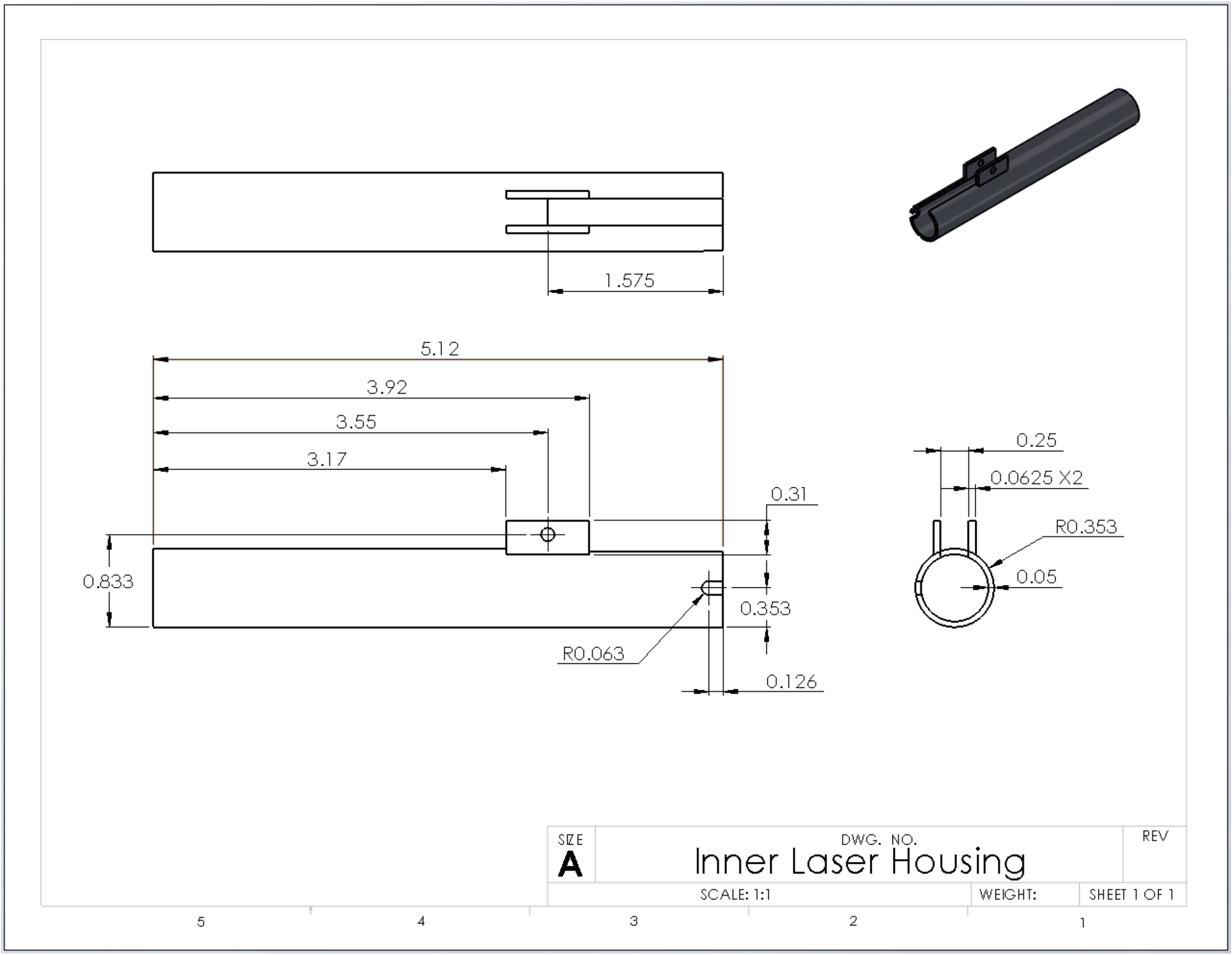


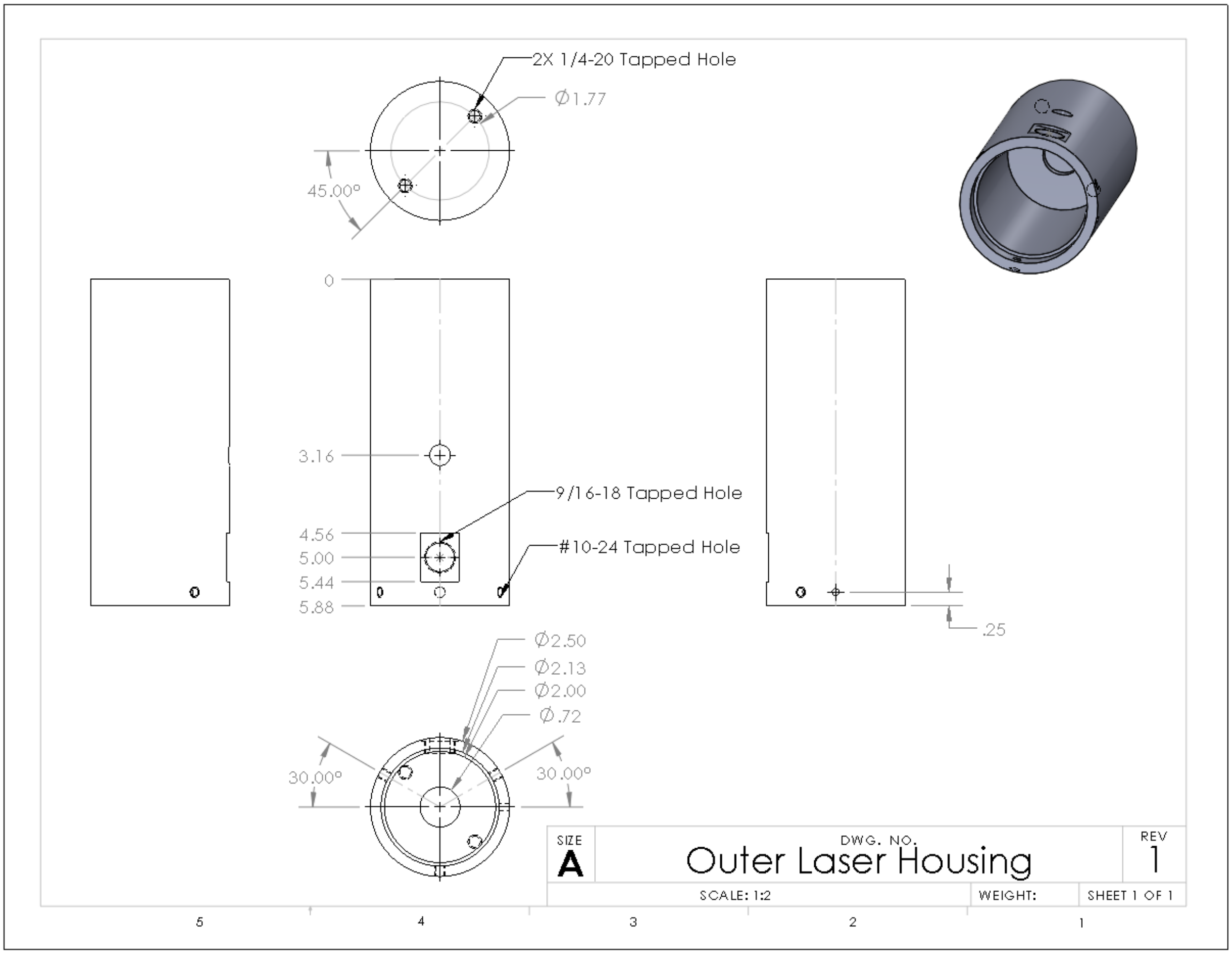
ITEM NO.	PART NUMBER	Material	QTY.
1	Outer Laser Housing	Delrin	1
2	Laser Pointer	N/A	1
3	Inner Laser Housing	1/2" Electrical Conduit	1
4	Cap	Delrin	1
5	Inner Housing Bushing	PVC	1
6	Switch Trigger	PVC	1
11	Solenoid	N/A	1
14	Solenoid Cover	ABS	1
16	Laser Set Screw	N/A	1

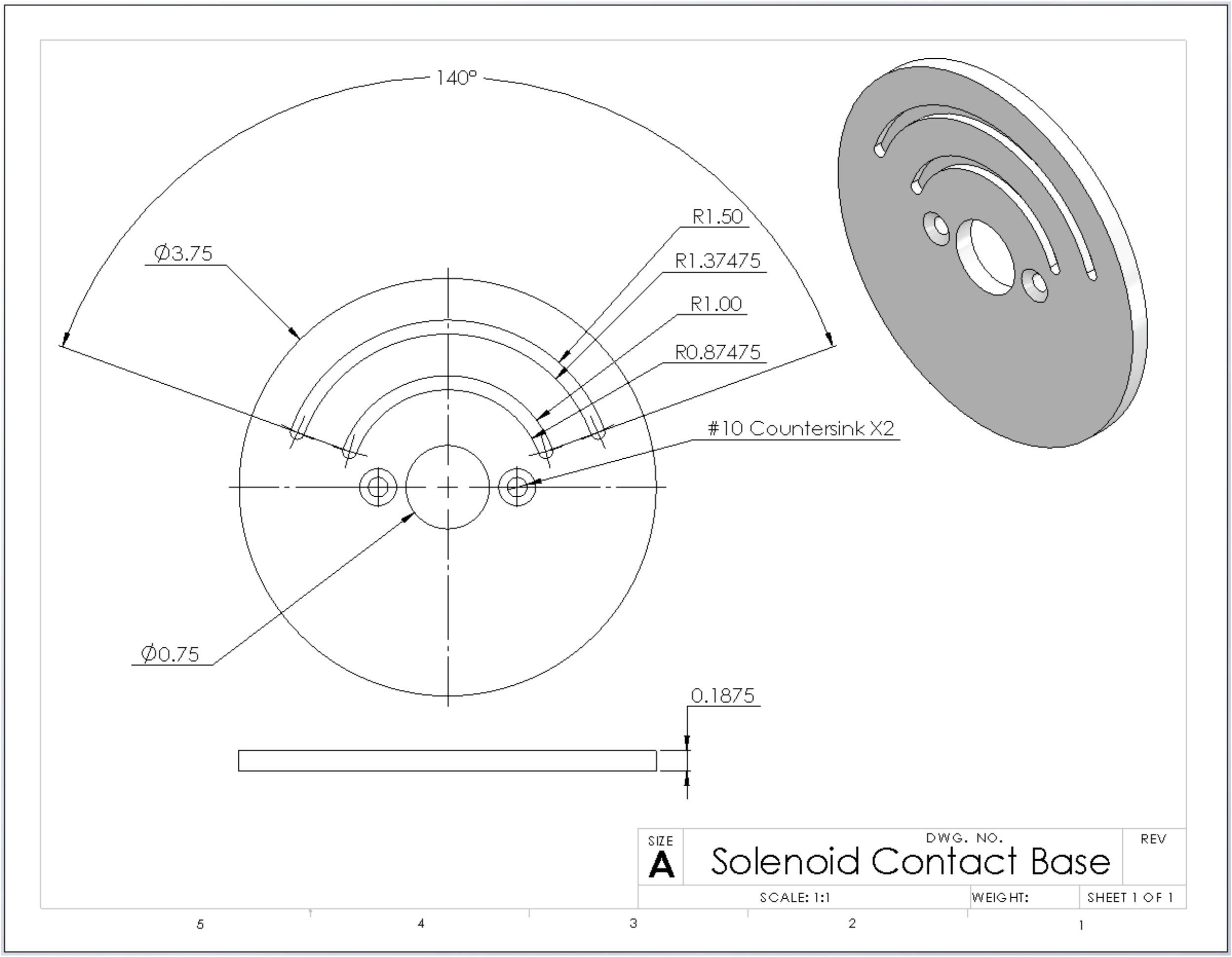
SIZE A TITLE: Laser Housing Assembly REV

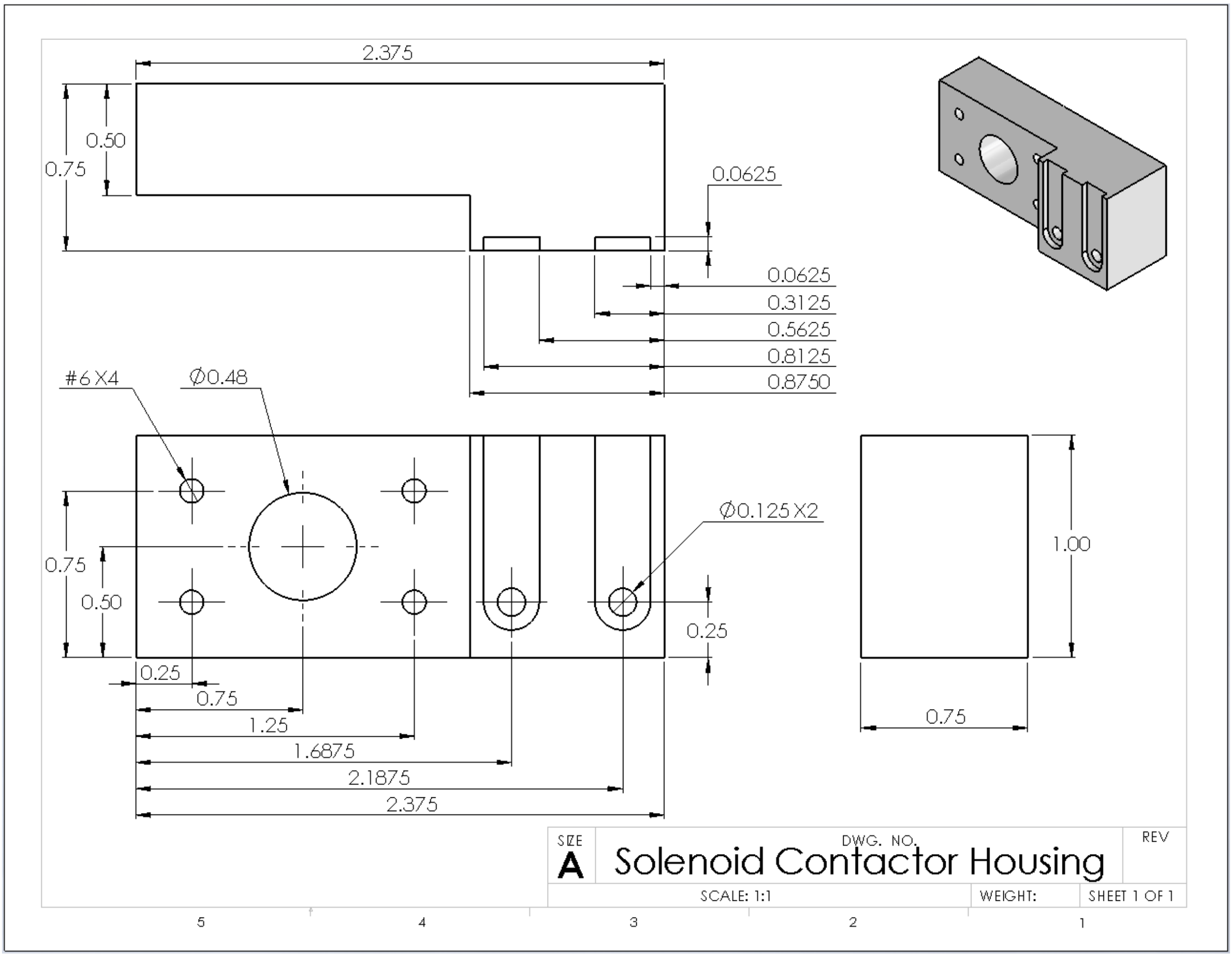
SCALE: 1:4 SHEET 1 OF 1

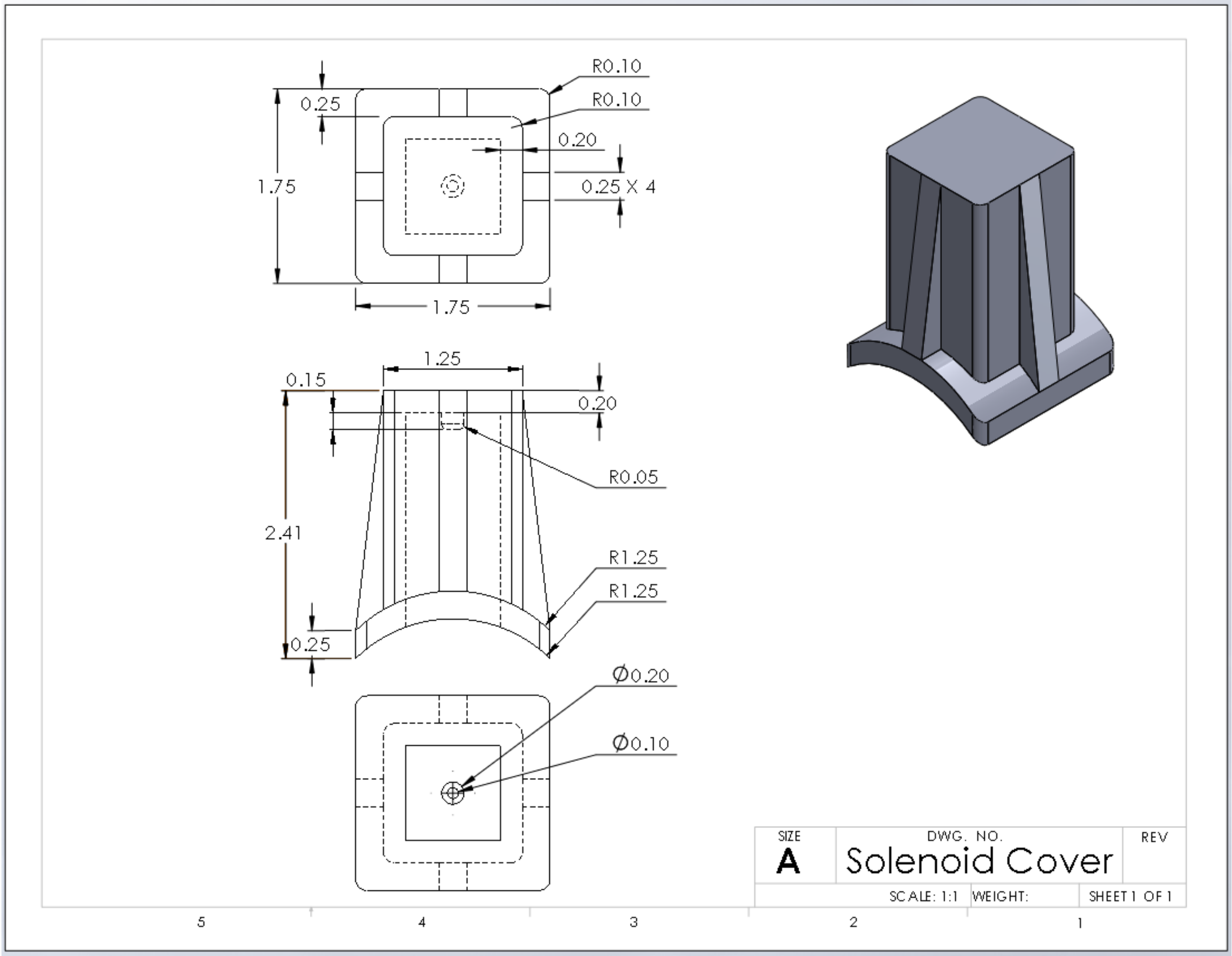
5 4 3 2 1

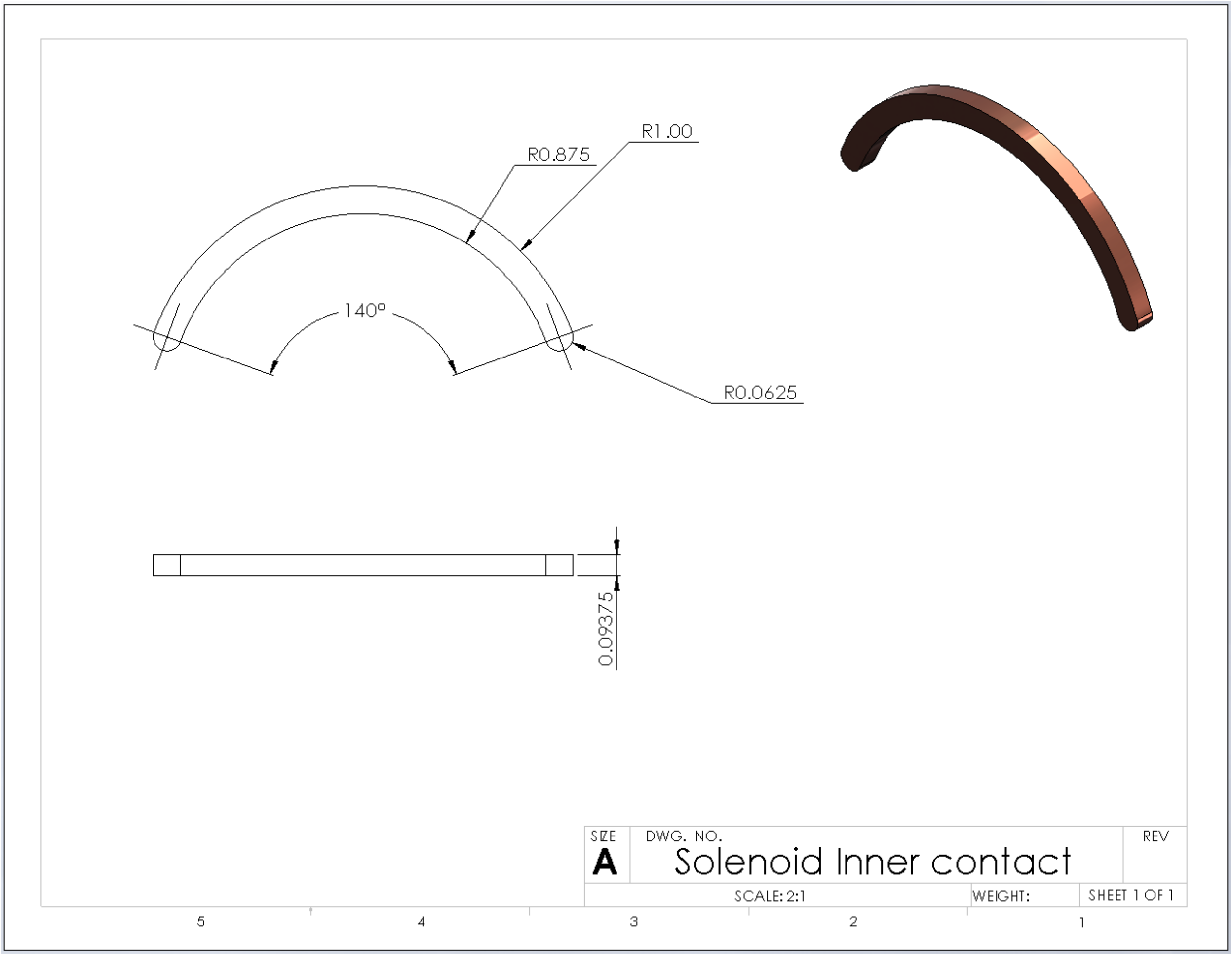

1.575
5.12
3.92
3.55
3.17
0.31
0.833
0.353
R0.063
0.126
0.25
0.0625 X2
R0.353
0.05
SIZE
A
DWG. NO.
Inner Laser Housing
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1

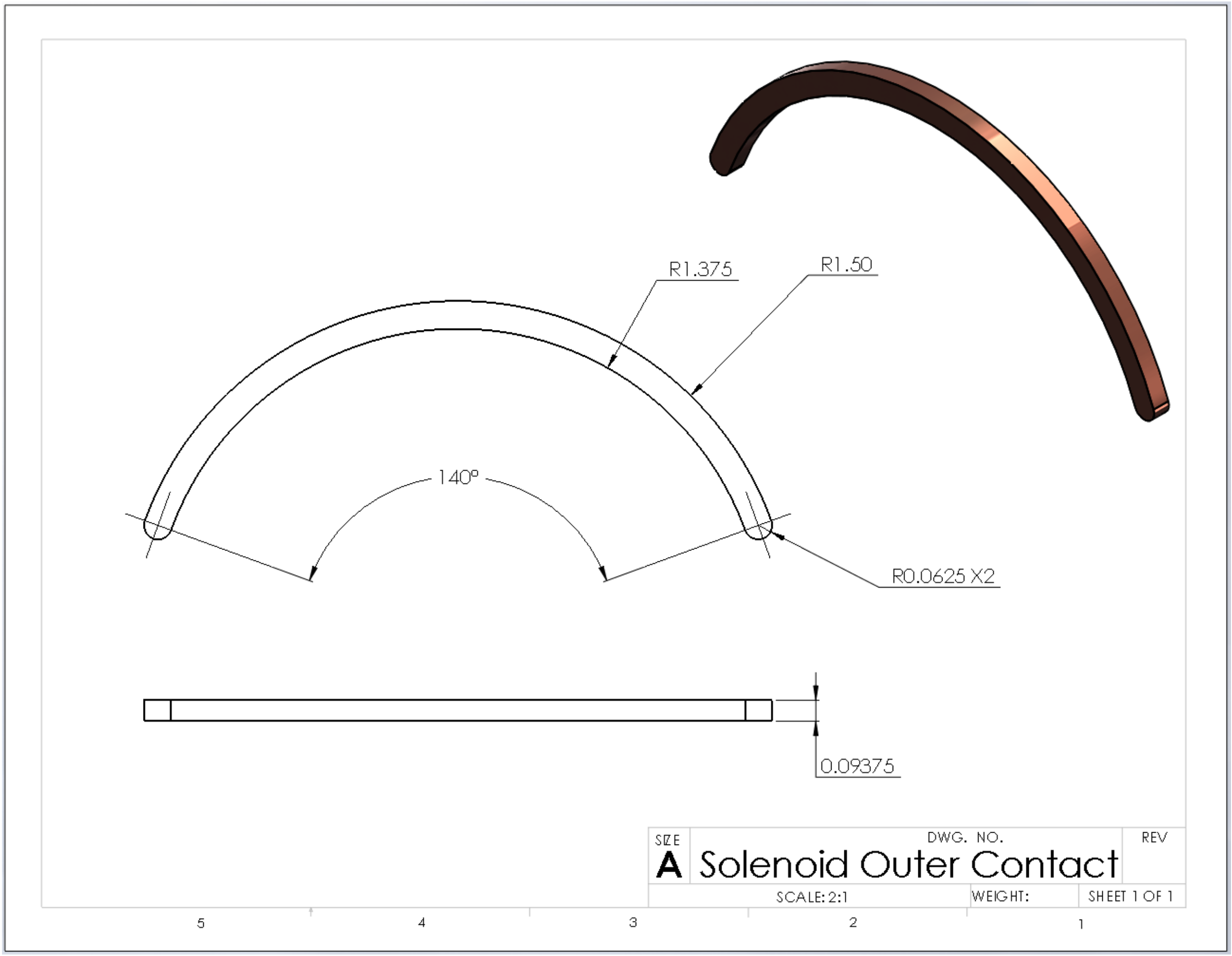

2X 1/4-20 Tapped Hole
Ø1.77
45.00°
0
3.16
9/16-18 Tapped Hole
4.56
5.00
5.44
5.88
#10-24 Tapped Hole
.25
Ø2.50
Ø2.13
Ø2.00
Ø.72
30.00°
30.00°
SIZE
A
DWG. NO.
Outer Laser Housing
REV
1
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1

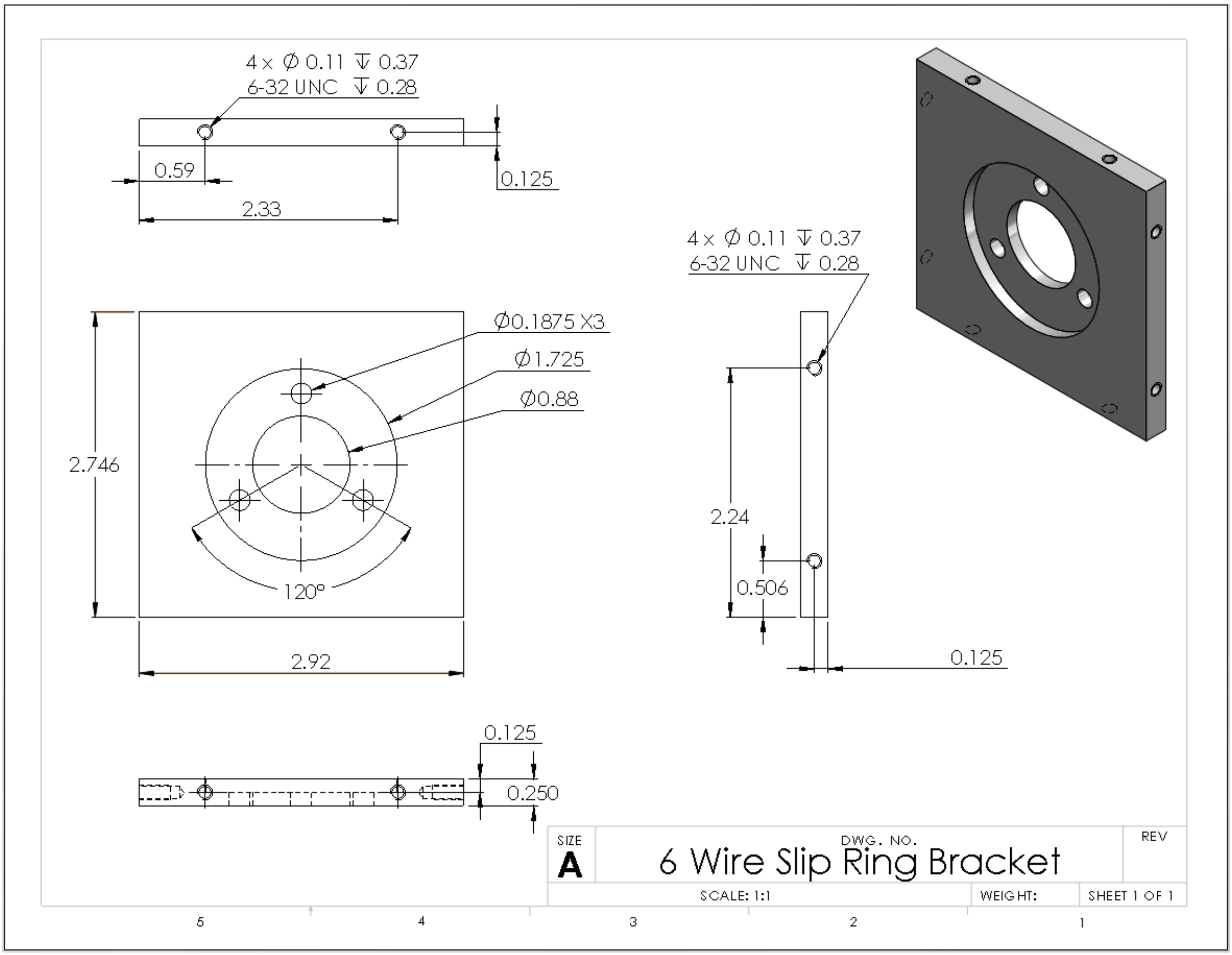

140°
Ø3.75
R1.50
R1.37475
R1.00
R0.87475
#10 Countersink X2
Ø0.75
0.1875
SIZE
A
DWG. NO.
Solenoid Contact Base
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1


2.375
0.50
0.75
0.0625
0.0625
0.3125
0.5625
0.8125
0.8750
#6 X4
Ø0.48
Ø0.125 X2
1.00
0.75
0.50
0.25
0.25
0.75
1.25
1.6875
2.1875
2.375
0.75
SIZE
A
DWG. NO.
Solenoid Contactor Housing
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1

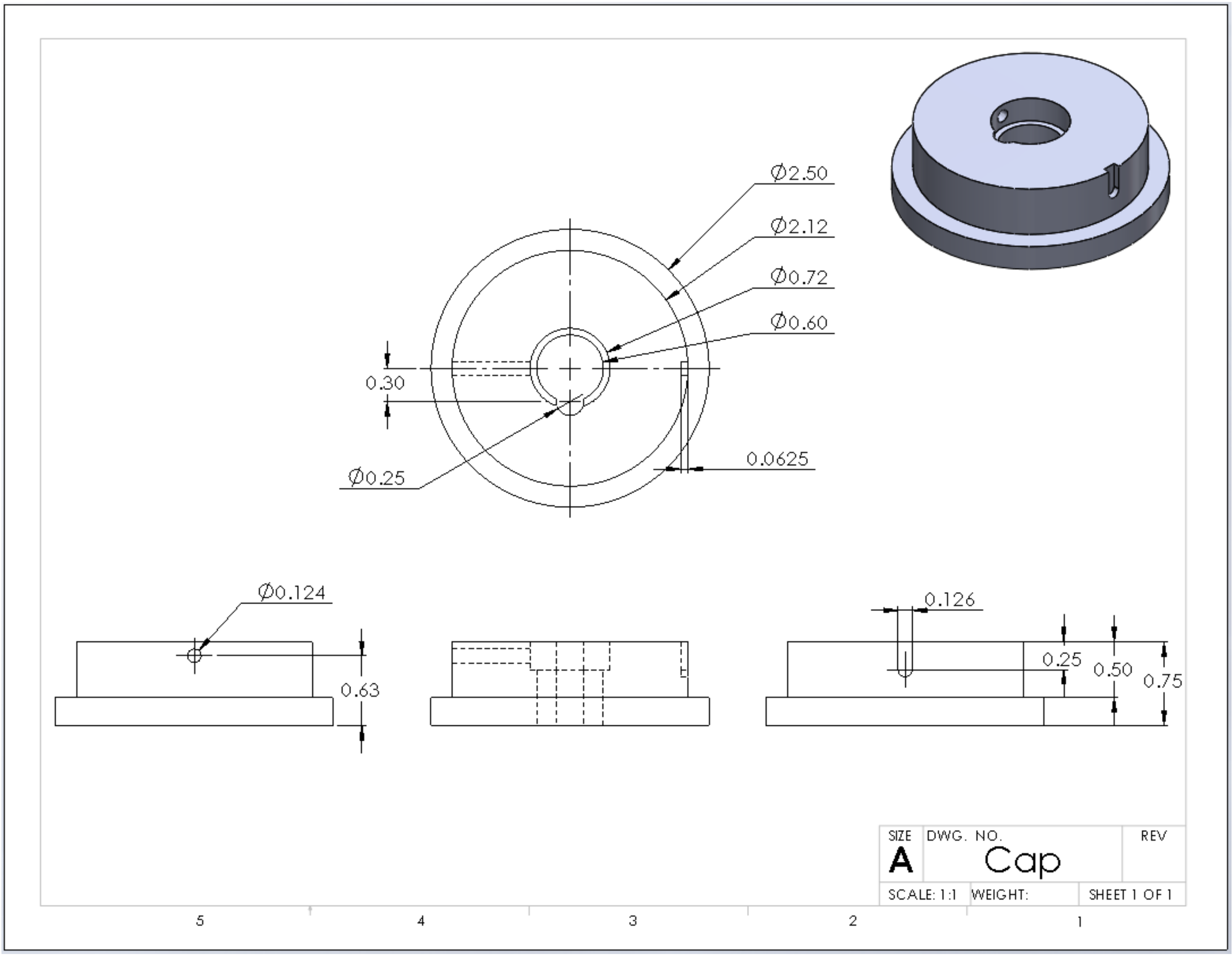

R0.10
R0.10
0.25
0.20
1.75
0.25 X 4
1.75
1.25
0.15
0.20
R0.05
2.41
R1.25
R1.25
0.25
Ø0.20
Ø0.10
SIZE
A
DWG. NO.
Solenoid Cover
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1

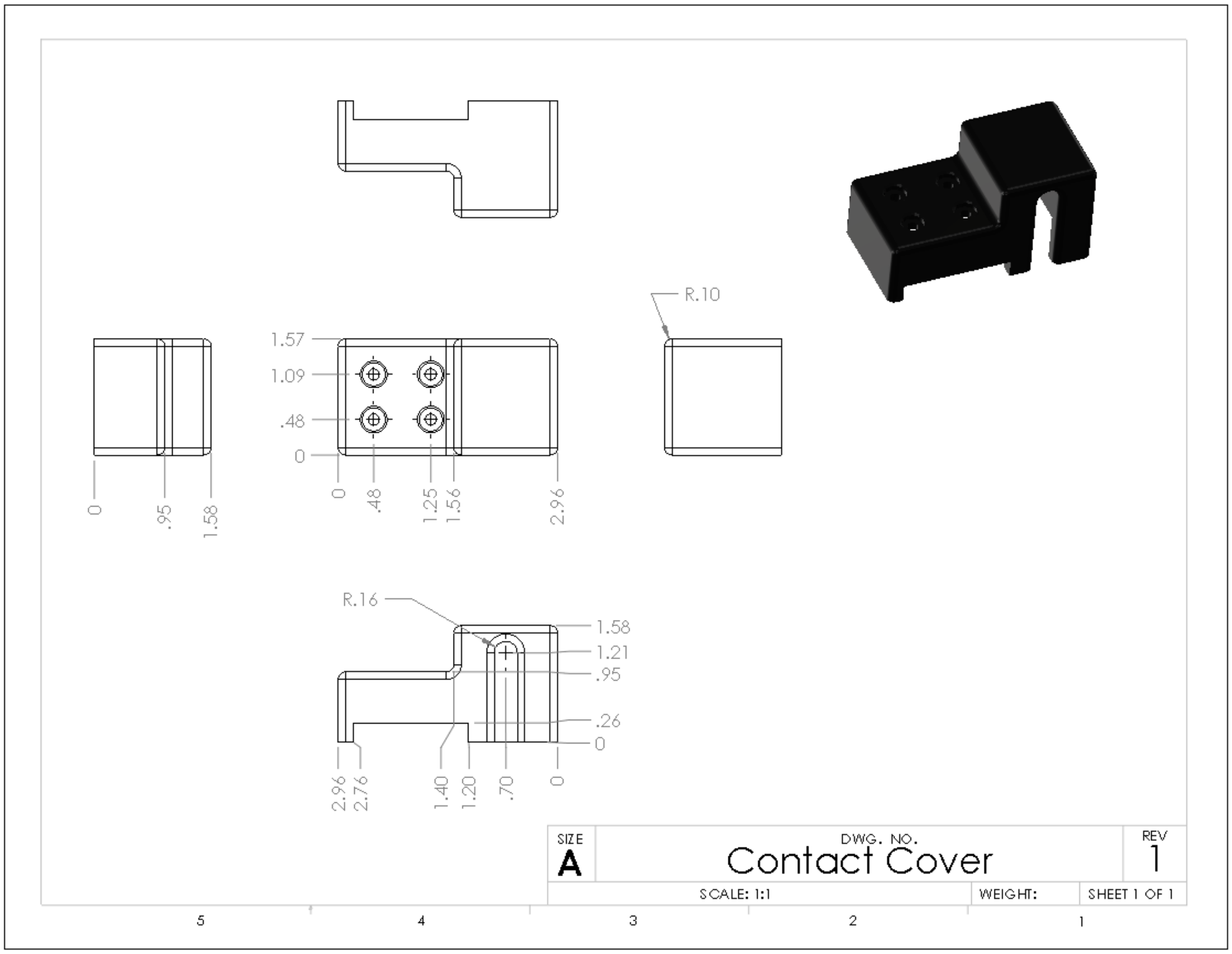

R1.00
R0.875
140°
R0.0625
0.09375
SIZE
A
DWG. NO.
Solenoid Inner contact
REV
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1

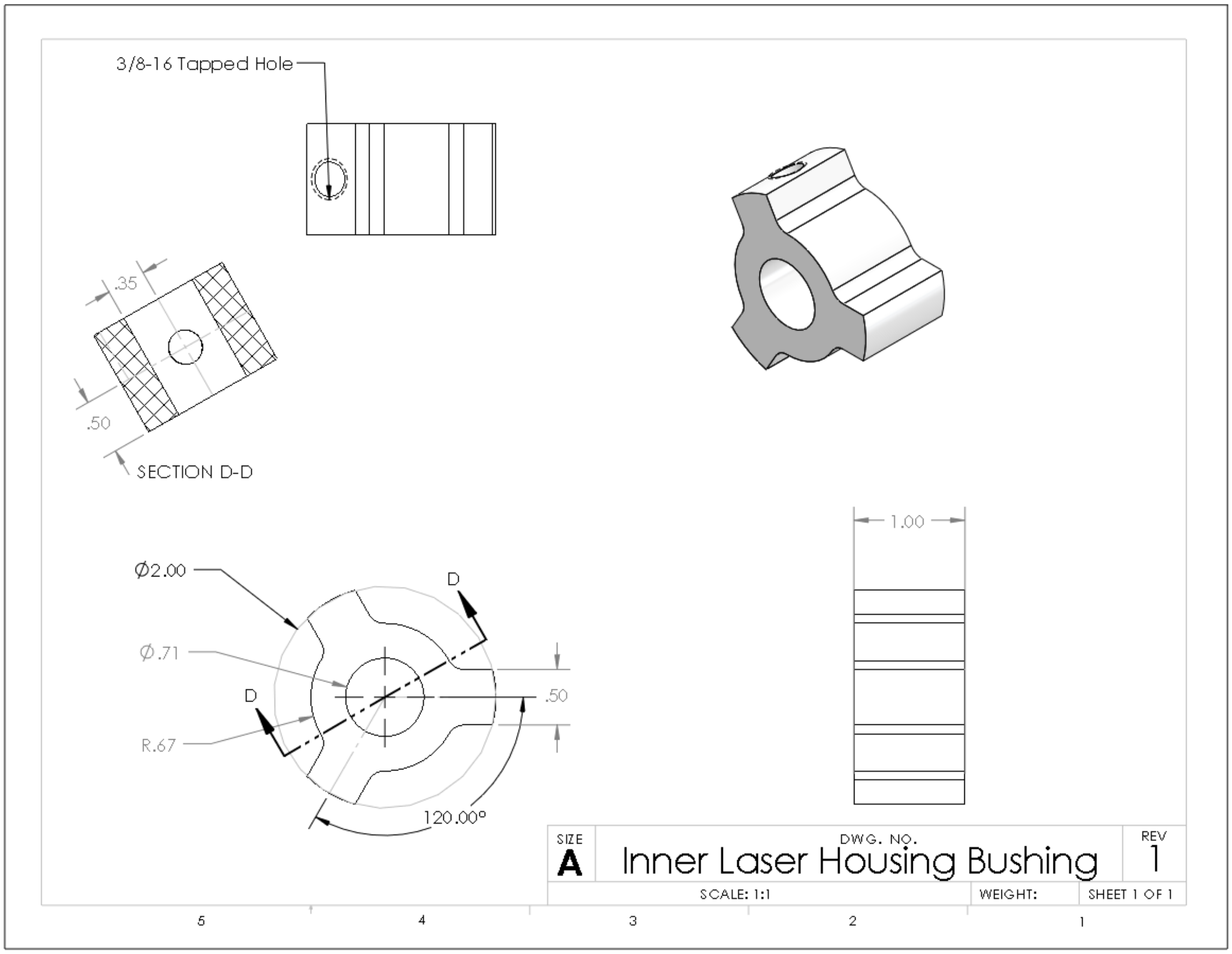

R1.375
R1.50
140°
R0.0625 X2
0.09375
SIZE
A
DWG. NO.
Solenoid Outer Contact
REV
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1



4 x Ø 0.11 ↧ 0.37
6-32 UNC ↧ 0.28
0.59
2.33
0.125
Ø0.1875 X3
Ø1.725
Ø0.88
2.746
120°
2.92
4 x Ø 0.11 ↧ 0.37
6-32 UNC ↧ 0.28
2.24
0.506
0.125
0.125
0.250
SIZE
A
DWG. NO.
6 Wire Slip Ring Bracket
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1


Ø2.50
Ø2.12
Ø0.72
Ø0.60
0.30
Ø0.25
0.0625
Ø0.124
0.63
0.126
0.25
0.50
0.75
SIZE
A
DWG. NO.
Cap
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1


R.10
1.57
1.09
.48
0
0
.95
1.58
0
.48
1.25
1.56
2.96
R.16
1.58
1.21
.95
.26
0
2.96
2.76
1.40
1.20
.70
0
SIZE
A
DWG. NO.
Contact Cover
REV
1
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1


3/8-16 Tapped Hole
.35
.50
SECTION D-D
1.00
Ø2.00
D
Ø.71
.50
D
R.67
120.00°
SIZE
A
DWG. NO.
Inner Laser Housing Bushing
REV
1
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1