Poly Spotlight Control

by

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Statement of Disclaimer

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Table of Contents

List of Figures

List of Tables

List of Nomenclature

CCAT = Cambria Center for the Arts Theatre
CPR = Counts Per Revolution, as on a digital rotary encoder
DMX = Digital Multiplex, a standard for digital communication networks
F = Force (lb)
GUI = Graphical User Interface
ϴ = Angular Position (rad or deg)
$\bar{I}_x$ = Mass Moment of Inertia, or MOI (slug-ft^2)
LED = Light Emitting Diode
m = Mass (slugs)
P = Electrical Power (Watts)
ω = Angular Velocity (rad/s)

Executive Summary

When this project began, The Cambria Center for the Arts Theater used a manually-operated spotlight. The sound created by the fans, along with the sheer size of the spotlight, required that it be housed in an attic room above the theater and shined through a closed window. This trapped a lot of heat in the room and involved some risk with climbing into and out of the attic room. This project sought to remedy those issues by mounting a pair of newer LED spotlights inside the theater. Doing this required a method for remotely controlling and actuating the angular position of each spotlight in two axes.

Over the course of one year, the Dynalux team researched, designed, and built a solution to CCAT's problem. The process by which they completed those steps is written in detail within this report. The first third of the year was spent in research and development. The team compared commercial and industry options to determine the best practices and designs. Many of the available options were too complicated or expensive and this reiterated that a cheaper and easier system was needed. At this point, Team Dynalux came up with a preliminary design that met all the design constraints.

The next third of the year was dedicated to detailed analysis and proving that the design would work as intended. This included looking at all aspects of the system from motor torque requirements to strength and material properties. At this stage, the design was presented to the sponsor and advisors to begin manufacturing.

The remainder of the project consisted of manufacturing, assembling, and testing. Some aspects had to be changed on-the-fly but the majority of the design remained the same throughout. Upon concluding machining and welding, the metal parts were finished and assembled with off-the-shelf components. When the mounts were complete, the electronics were added and tested in the overall system. Testing and manufacturing were time intensive but kept safety and reliability as the highest priority.

The contents of this report are intended to document the process by which the project was completed but also provide reference to the parts and techniques used to build the system. Also included are comprehensive drawings and instructions to make sure the system is running smoothly, and if needed, provide maintenance.

Introduction

Cambria Center for the Arts Theatre (CCAT) previously used a spotlight for their productions that was operated from inside an attic room. This unventilated room was a poor working environment due to the noise and heat the spotlight generated. These concerns, along with the poor accessibility of the room, prompted the organization to replace the setup with two new spotlights. The new lights use light-emitting diode (LED) bulbs to greatly reduce the noise and heat, allowing the spotlights to be mounted within the theatre room itself. The inclusion of a second spotlight, with the requirement that both lights be simultaneously controlled by a single operator, convinced CCAT to sponsor a senior project team from California Polytechnic State University, San Luis Obispo to build a custom mounting solution.

The following report outlines the steps team Dynalux took in order to research similar concepts, create and analyze a new design, build that design, test it, and ultimately install it in the theater.

Project Management

Each of the three members of team Dynalux maintained clear and open communication, met deadlines, and gave equal input to all parts of the project. While each member participated and contributed to all parts of the project, some main roles and positions were assigned:

Liaison (Oleg Frandle): This position managed communication with CCAT and with the advising professors, acting as the point of contact for the team. This involved writing and responding to emails from CCAT, and sending meeting agendas.

Secretary (Anthony Lombardi): This position was responsible for recording meetings and ensuring that all documentation and discussion pertaining to the project was saved and organized in an orderly fashion for later review.

Treasurer (Ryan O'Neill): This position tracked the usage of funds for the project to ensure accountability. This extended beyond the sponsor-stated budget for development of the project solution to also include travel and meal expenses, ensuring that these were fairly shared or reimbursed.

Hardware Analysis (Oleg Frandle): While this task was of critical importance to the success of the project and was ultimately shared across the team, one team member took the lead role to direct and coordinate efforts in ensuring all hardware designed or used in the project met material, safety, and other specified requirements.

Software Development (Anthony Lombardi): This task was also distributed across all members, but the lead team member was responsible for overseeing program style, architecture, and debugging to produce quality code.

Solid Modeling Lead (Ryan O'Neill): This position kept track of files and figures relating to solid models of the spotlight. This ensured that all components fit together aesthetically and without interference. Any and all changes to the overall design went through the solid modeling lead to make sure they were compatible with existing designs.

Background

A previous Cal Poly senior project designed and built a pair of swing-arm mounts for the static light sources used by the theatre. These arms can be swung back to lock flat against the side walls of the theatre for setup and maintenance, then swung back out into a locked perpendicular orientation for operation. These arms are firmly mounted, and in the end served as solid mounting points for this project. However, it was also initially proposed to mount the spotlights on poles located in the back corners of the seating. Both locations had positive and negative qualities that were considered during the design stage of this project.

Existing Products

Figure 1: Chauvet DJ Intimidator

There are a number of products on the market which at the time satisfied some, but not all, of the customer's wants and needs. For example, the Chauvet DJ Intimidator (see Figure 1) is a spotlight mount which is commonly used in stage lighting for concerts and nightclubs. It is not meant for following an actor on-stage; rather, it is used to move a colored spotlight around as ambient lighting and is often mounted on or near the stage. It is usually controlled by DMX via a computer alongside an array of other dynamic spotlight mounts. Because its intended uses are fundamentally different, it did not meet all of the specifications required by this design. It has excellent range of motion and speed capabilities, but cannot produce movements that are smooth or precise enough to follow an actor from a distance.

Another existing solution that was investigated was the GroundControl Followspot (see Figure 2). It is merely a control system, so it only covers that one function. Still, it met more of the customer's needs for that one function than any other current solution that the team investigated. It is a large physical beam supported on a gimbal with handles placed about two feet apart. This large lever arm allows for very precise control of the spotlight's position, and the mass of the beam helps the operator to move the light smoothly. It is very user-friendly and intuitive to control since the spotlight's angular position matches the angle of the beam on the controller. However, its price, size, and weight far exceeded the reasonable limits for this project. Each Followspot controller requires a footprint of at least 43 inches around and weighs 54 lbs. This is far too large and heavy for even one to be mounted in the control booth, let alone two for controlling both spotlights.

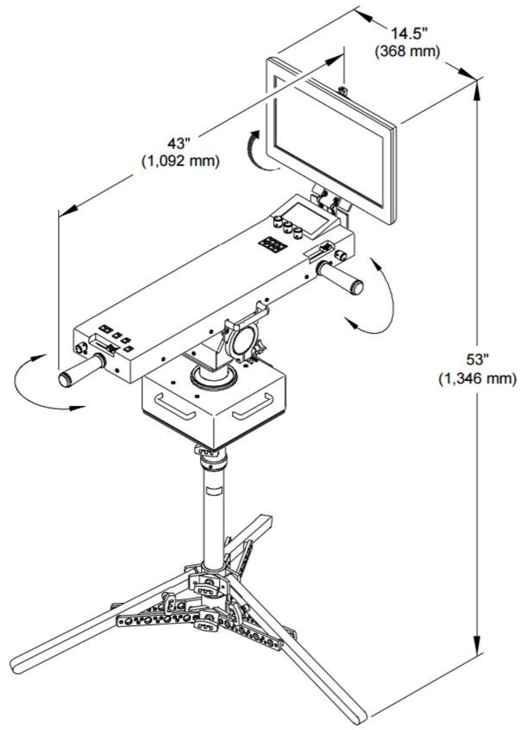


Figure 2: Diagram and basic dimensions of the GroundControl Followspot controller.

Another interesting feature of the GroundControl Followspot is its use of a camera on the spotlight which feeds into a large screen on the end of the controller's beam. This allows the operator to look at the stage through the light's point of view. The camera is able to operate with night vision, allowing the operator to move the spotlight even on a virtually black stage. This addressed a concern that neither CCAT nor the Dynalux team had previously considered. With the theater's previous setup, the operator always knew where the spotlight was aimed, regardless of visual cues, since he was manually controlling it with his hands. With a remotely-controlled spotlight, special consideration had to be taken so that the operator could locate and aim the spotlight even when it is turned off. This eventually sparked the idea of displaying a static image of the stage behind the user interface, allowing the operator to intuitively visualize angles from the spotlight's point of view.

The team also discovered a control solution called Spotrack during their research. This product is a computer-based system for controlling the position of multiple spotlights simultaneously. The computer interface features a live video feed from a camera, showing the entire stage and the locations of the actors. By clicking on different points of the stage, the operator can aim any number of remote spotlight beams at that point. Dragging the mouse cursor across the screen causes the spotlight beams to smoothly follow wherever the cursor goes on the stage. The complexity of this system lies in the computer software, which converts the cursor’s location on the 2D screen into a point on the stage in 3D space, and calculates the proper angles for each spotlight in real time. This also requires extensive calibration so that the software can build a 3D model to reference. Despite this behind-the-scenes complexity, Spotrack’s interface appears to be highly intuitive. It shows that while a computer-based system can introduce extra complexity, it can also make the operator’s job far easier. This also served as inspiration for this project’s user interface, allowing the operator to control both spotlights simultaneously from a single interactive display.

Design Requirements & Specifications

Based on input from the sponsor, team Dynalux identified the main constraints and specifications for the design. For each row there is a desired parameter, the target value, tolerance, risk, and compliance. The “Risk” column describes on a scale of High, Medium, or Low the importance and challenge of each parameter. The “Compliance” column then describes how each parameter was tested to ensure that it was met. These specifications were derived from a design tool called Quality Function Deployment (QFD), shown in Appendix 1. This involved producing a large table of qualitative requirements, which were then correlated to quantitative engineering specifications. The qualitative requirements were given weight based on the total number of involved parties to whom the requirement was important, and these weights were used when evaluating how adequately the existing commercial products met the requirements.

Table 1: Project Design Specifications.

Spec #	Parameter Description	Requirement Target	Tolerance	Risk	Compliance*
1	Cost	$2,000	Max	H	A
2	Sound	35 dB	Max	M	T
3	Range of Motion Vertical	90°	Min	L	I
4	R.O.M. Horizontal	90°	Min	L	I
5	Speed Onstage	1.8 rpm	Min	M	T, S
6	Static Stability	± 6in	Max	H	T, S, I

*Analysis (A), Test (T), Similarity to Existing Designs (S), Inspection (I)

Cost: As identified by the sponsor, cost was the primary specification that needed to be met. The overall budget for this project was to be under 2000 dollars (excluding the LED spotlights, which the theater purchased separately). This project involved developing and building two identical (but mirrored) spotlight mounts, as well as a control system, so the cost per spotlight mount was under 1000 dollars.

Sound: Given that the spotlights are mounted in a theater, atmosphere is an important characteristic. The sponsor identified sound as a priority, but the team categorized this as a medium risk; they did not expect it to be challenging to achieve less than 35 dB with the solution. Even so, sound testing was performed with a decibel meter on various iterations of the project to check whether further precautions (such as an external enclosure or vibration dampers on the motors) were necessary. In addition to continuous noise, the sponsor also noted that the team should also consider intermittency when designing and testing the spotlights. For example, a constant hum of 20 dB may go unnoticed, while a sudden spike of the same amplitude would draw more attention from the audience.

Range of Vertical Motion: With regards to vertical motion, the spotlight was required to point directly downwards and also straight forward, parallel with the floor. This made the total range of vertical motion 90°.

Range of Horizontal Motion: After walking through the theater and talking to CCAT staff, team Dynalux identified that the spotlight mounts would need approximately 90 degrees of motion spanning from parallel with the walls to perpendicular, facing toward the center of the room. This allows the spotlights to reach any point on or in front of the stage.

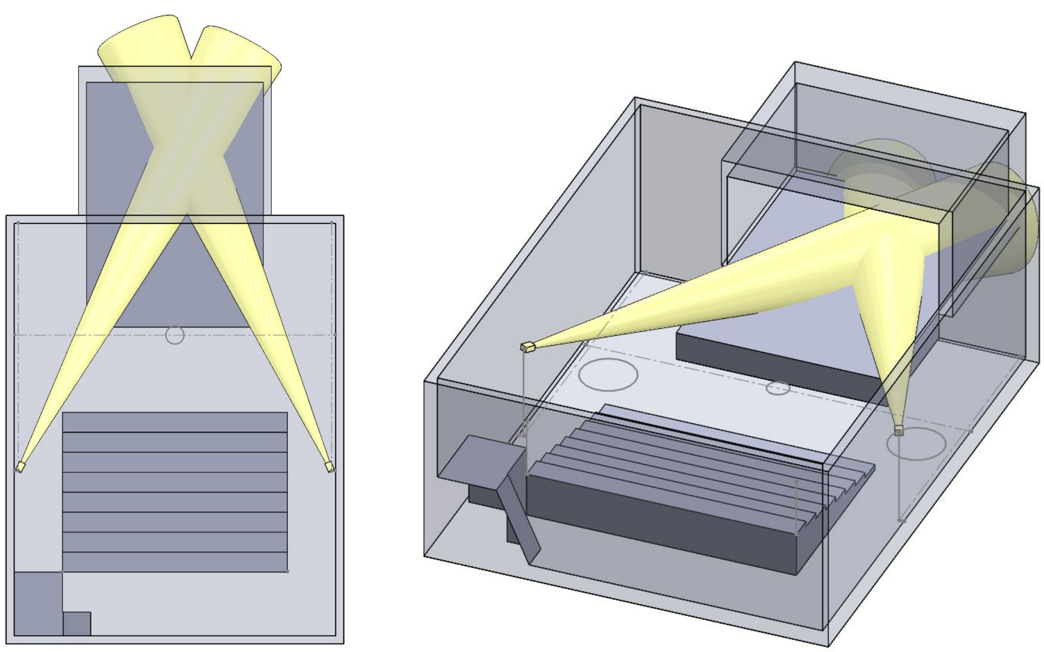


Figure 3: SolidWorks model of the theatre room.

The SolidWorks model in Fig. 3 depicts the spotlights in their final mounting locations and a general aim direction. This model was used to visualize and measure the angles and distances from the spotlights to various target points in the theatre.

Speed: The speed parameter can be broken down into two major categories: following speed and panning speed. Typical operation of the spotlight requires vertical and horizontal motion to keep up with an average human walking pace. In addition, there are times when an actor or actress jumps across the stage or moves faster than the spotlight or operator is able to keep up with. The operator may also need to quickly jump the beam to illuminate a different actor or portion of the stage. When this happens, the spotlight must cross the stage in roughly half a second with minimal overshoot and oscillation. The width of the stage is 22 feet, making the necessary minimum speed 44 feet per second.

Static Stability: Lastly, Dynalux identified static stability as a high risk specification. To clarify, this is defined as a lack of shakiness after the spotlights have moved to a new location or direction. During a show, if the spotlights are shaking or moving due to instability, it will be distracting to an audience and an inconvenience to the operator. Because every system is bound to have some amount of vibration, Dynalux decided to start with an allowable movement of ± 6in at the furthest point on stage in either the vertical or horizontal directions. At a distance of roughly 58 feet (the maximum distance that a point on stage could be from the spotlights), 6 inches on stage means the spotlight is shaking roughly half a degree in each direction.

Design Development

Conceptual Designs

Team Dynalux began visualizing the project in the form of quick and easy prototyping using Lego Mindstorms®. The team investigated different forms of transmission using gears and chains as can be seen in Appendix 1. This basic research led the way for further concepts and ideas later on.

A number of diverse solutions were created during the design process. The team developed several concepts besides purely electromechanical systems, even though all commercial solutions followed this pattern. For example, a hydraulic system with a direct hydraulic line between the controller and actuators was considered (Appendix 1 demonstrates one arrangement of this concept). Organizationally, the team broke the project into three main subsystems: "Mount" - how to attach a system to the existing theatre architecture; "Drive" - how to move the spotlight; and "Control" - how an operator would direct the spotlight's motion.

The mounting concepts were developed with a focus on mount stability and safety. A highly stable fixture would improve the spotlight's precision and make it easier to meet design specification #6, static stability. The focus on safety stems from the operational environment; the spotlights are directly above theatre personnel or audience members in a dark room. A mounting design that risks coming loose and dropping an expensive spotlight, thus damaging it and potentially causing injury to bystanders, was unacceptable. The original idea suggested from the sponsor was a mount atop a vertical pole behind the audience, but this proved to be less stable and safe when compared to the light boom mounting location. Appendices 2 illustrates two additional solutions considered for mounting a system.

While nearly all of the drive concepts under consideration used a simple gimbal with two orthogonal and independent axes, these concepts approached the problem of transferring motor power in a variety of ways (Appendix 1). All of the electromechanical designs focused on design requirements #3-5, the speed and range of motion, with particular concern for reducing a drive motor's speed to gain the necessary torque for rapid accelerations. In addition, the only non-mechanical designs that endured until final consideration were simple hydraulic systems that were either directly or electronically actuated (Appendix 1).

The controller concepts focused on simplicity of use, particularly on how to relate the motion of the spotlight from the input by an operator stationed on the far side of the room. Most of the proposed designs were electromechanical, with a microprocessor or computer acting as a middleman between the controller and whichever drive system was selected. However, the complexity of the middleman processor varied greatly among the concepts, and a simpler processor was considered a valuable trait in a design. Appendix 1 discusses one variant of a joystick-type solution. Addition ideas included a joystick, button pad similar to a keyboard, touchpad, mouse, or physical mock-up controller. All of these are included in the Pugh matrix below.

Concept Selection

Table 2 below is a Pugh Matrix, one method of comparing design concepts by scoring them relative to a datum, or reference solution. The leftmost solution under each of the three functions acts as the datum, which gets a score of zero. All other solutions received a score relative to this datum at the top of the Pugh matrix. A higher total score is better, and the highlighted concepts were the highest-scoring in their category. This was by no means an absolute determination of the best solution since a Pugh Matrix weighs every requirement equally; some requirements will be more important than others, and a design with a high score could fail a critical requirement but pass several easier ones. A zero (o) indicates that the proposed design was equally good at satisfying the requirement as the datum solution. A plus (+) indicates that it exceeded the datum's ability to satisfy this requirement, while a minus (-) indicates that the datum solution was better than the proposed design in regards to that requirement. A cross (X) indicates that a rating is unnecessary for that requirement.

After completing the Pugh matrix and getting a baseline rating system for all the concepts, the team discussed requirements that might trump others and ultimately decide which was best. For example, with the mount, a welded plate was much more stable and secure than any clamped option, pushing it ahead of the other options, even though getting a welder and losing portability of the spotlight were factors. When considering the drive aspect of the design, the geared solutions came out ahead in the Pugh matrix, but Dynalux viewed the sound requirement as more important when compared with similar transmission ability. Lastly, for the controller matrix, the button pad came out ahead from a technical perspective, but smooth motion and user friendliness would be severely impacted with that choice. Overall, after getting a general ranking from the Pugh matrices, the team had to consider which requirements might be more important for the overall design and choose the design accordingly.

Table 2: Pugh Matrix comparing various proposed designs for each of the three functions: mount, drive, and control.

Mount

#	Requirement	T-bracket c-clamps	Freestanding pole	T-bracket hose clamps	Vertical bar	Welded Pole	Horizontal Pole
	Total	0	-1	-1	-3	-1	-2
	Positives	0	3	3	2	4	3
	Neutrals	0	6	6	6	4	5
	Negatives	0	4	4	5	5	5
1	Appropriate speed capabilities	X	X	X	X	X	X
2	Precision	X	-	o	o	o	o
3	Smooth motion	X	X	X	X	X	X
4	Range of motion	X	-	o	+	o	+
5	Reliability	X	o	-	o	+	o
6	Safety	X	-	-	o	+	o
7	Stability	X	-	-	+	+	+
8	Dual control	X	X	X	X	X	X
9	Quiet	X	X	X	X	X	X
10	User friendliness	X	X	X	X	X	X
11	No interference	X	+	o	o	-	+
12	Under budget	X	o	+	-	-	-
13	Easy maintenance	X	+	+	-	-	-
14	Durability	X	o	-	o	+	o
15	Integration with current setup	X	X	X	X	X	X
16	Lightweight	X	o	o	-	o	-
17	Power consumption	X	X	X	X	X	X
18	Portability / ease of setup	X	+	+	-	-	-
19	Size	X	o	o	-	o	-
20	Ease of manufacture	X	o	o	o	-	o

Drive

#	Requirement	Direct drive gimbal	Belt gimbal	Spur gimbal	Worm gimbal	Rack & pinion gimbal	Chain gimbal	Hydraulic gimbal	Hydraulic ball	Kuka
	Total	0	1	3	3	2	1	-2	-3	-1
	Positives	0	4	5	5	5	4	5	5	5
	Neutrals	0	10	10	10	9	10	5	4	6
	Negatives	0	3	2	2	3	3	7	8	6
1	Appropriate speed capabilities	X	-	-	-	-	-	+	+	o
2	Precision	X	+	+	+	+	+	o	o	+
3	Smooth motion	X	+	+	+	+	+	+	+	o
4	Range of motion	X	o	o	o	o	o	-	-	+
5	Reliability	X	o	+	+	+	o	-	-	+
6	Safety	X	o	o	o	o	o	-	-	o
7	Stability	X	o	o	o	o	o	o	-	o
8	Dual control	X	X	X	X	X	X	X	X	X
9	Quiet	X	o	-	-	o	-	+	+	o
10	User friendliness	X	X	X	X	X	X	X	X	X
11	No interference	X	o	o	o	o	o	o	o	o
12	Under budget	X	o	o	o	o	o	-	-	-
13	Easy maintenance	X	-	o	o	o	-	-	-	-
14	Durability	X	-	o	o	o	o	o	o	+
15	Integration with current setup	X	o	o	o	o	o	-	-	-
16	Lightweight	X	+	+	+	+	+	+	+	-
17	Power consumption	X	+	+	+	+	+	+	+	-
18	Portability / ease of setup	X	X	X	X	X	X	X	X	X
19	Size	X	o	o	o	-	o	-	-	-
20	Ease of manufacture	X	o	o	o	-	o	o	o	+

Control

#	Requirement	Joystick	Button pad	Physical mockup	Mouse	Touchpad
	Total	0	1	-5	0	-4
	Positives	0	4	2	4	4
	Neutrals	0	7	5	6	2
	Negatives	0	3	7	4	8
1	Appropriate speed capabilities	X	X	X	X	X
2	Precision	X	-	+	+	-
3	Smooth motion	X	-	o	o	o
4	Range of motion	X	X	X	X	X
5	Reliability	X	+	-	o	-
6	Safety	X	X	X	X	X
7	Stability	X	X	X	X	X
8	Dual control	X	+	o	+	+
9	Quiet	X	o	o	o	+
10	User friendliness	X	-	+	-	+
11	No interference	X	X	X	X	X
12	Under budget	X	o	-	+	-
13	Easy maintenance	X	+	-	o	-
14	Durability	X	+	-	o	-
15	Integration with current setup	X	o	o	-	-
16	Lightweight	X	X	X	X	X
17	Power consumption	X	o	o	-	-
18	Portability / ease of setup	X	o	-	o	o
19	Size	X	o	-	-	-
20	Ease of manufacture	X	o	-	+	+

Preliminary Design

After consulting the Pugh matrices and taking into account the specifications and requirements, the team decided on the preliminary design shown in Figure 4 below. This design used the C-clamp and T-bracket method for mounting (original sketch in Appendix 1), a belt-driven two-axis gimbal with inner ring for the drive (Appendix 1), and a joystick as the controller.

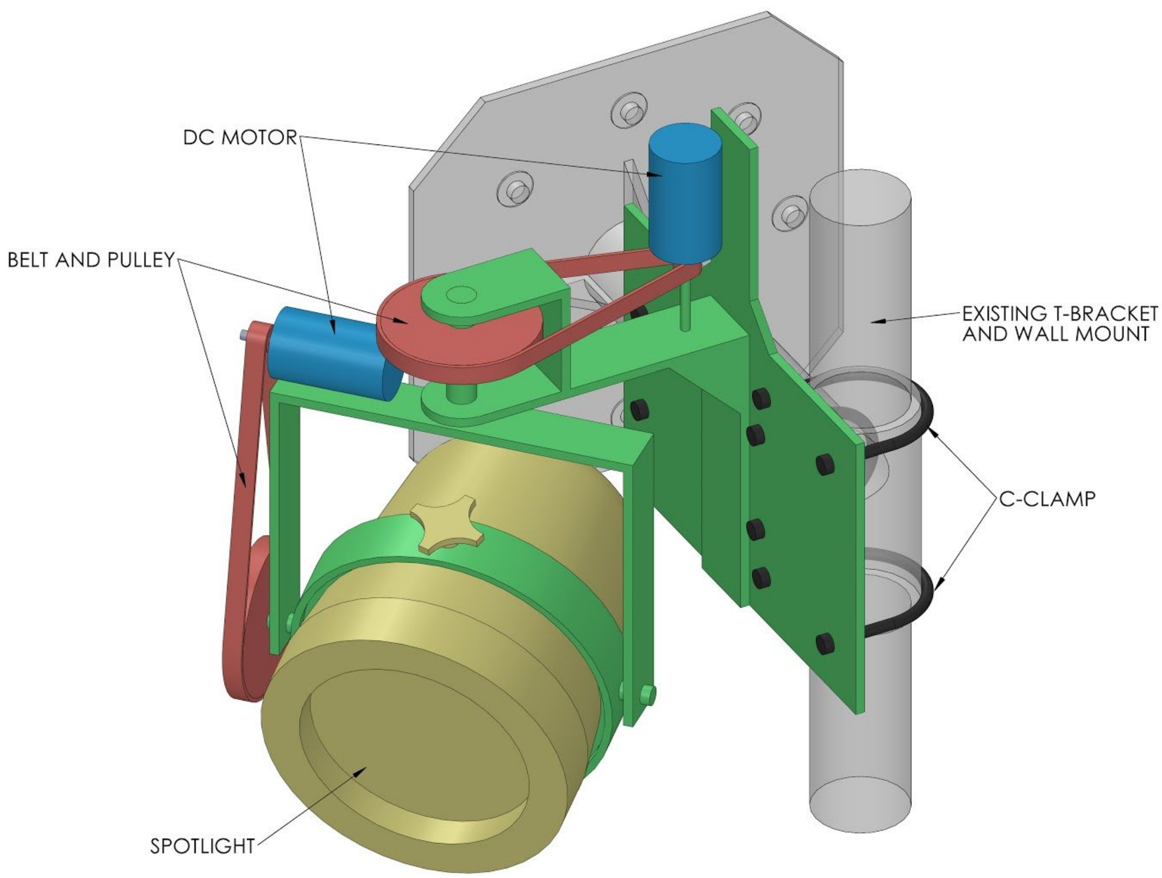


Figure 4: Solid model layout of the preliminary design.

In Fig. 4 above, translucent gray is part of the existing boom that was already installed in the theater. Green represents the mount and gimbal which the team planned to build and attach to the T-bracket. Blue and red represent the motors and belt/pulleys, respectively, which together control the angles of the gimbal. The yellow spotlight mounts into the green hoop of the gimbal.

The C-clamp mounting method involved a pair of semicircular metal rings, usually with a high-friction padding inside and bolted together on either side to form a ring that tightly grips cylindrical objects such as pipes. A threaded rod extends from one half of the rings perpendicular to the pipe. Three or four of these clamps would be affixed around the middle T-shaped hinge of the static lighting booms. A metal plate would be slid over the threaded rods and bolted down. This plate would then provide a solid and stable surface to which the rest of the system could be connected (Appendix 1).

For the drive and transmission part of the design, the team decided that using motors with belts on a two axis gimbal would be the best solution. The pulley-belt option aimed to minimize the size of the gimbal system by linking the motor to the pivot point by way of a synthetic-material drive belt. The relative sizes of the pulleys determined the ratio of speed and torque transmitted to the spotlight pivot point. Depending on the best operating conditions of the selected motor, the ratio could be selected to increase the torque (to improve acceleration but reduce speed), or increase the speed (to more easily meet the design specifications, but lose acceleration). The belt and pulley option has the advantages of being small and easily maintained, but the disadvantage that the belt needs to be inspected for wear and stretch occasionally. The hoop bracket which the light attached to allows the light to be easily removed and reattached in case of maintenance, without disassembling the mount. The vertical positioning of the bracket screws allows the light to be pivoted around its center of gravity without the additional complexity of accommodating the mounting screws at the pivot point, and ensures that the light will not risk coming unscrewed by the rotation of the mount during operation. This hoop bracket design assumed that the Chauvet Colorado 3 Solo spotlight would be used, although this was only one of several spotlights that the CCAT Theatre was considering to buy. However, due to the similarity in shape and size among theater-grade spotlights, it was assumed that this general design would work even if dimensions need to be adjusted at a later time. When a spotlight was eventually chosen, the only major change came in the shape of the spotlight's mounting bracket.

The joystick control method was initially chosen for a number of reasons: it was the original solution suggested by CCAT, it provided a simple interface that requires little electronic translation, and it was easily adaptable to whichever drive system was chosen - even the hydraulic possibilities. However, it did not come without problems. Most two-axis joysticks that would be feasible to build into a spotlight controller have a return-to-center property, where they require constant force to be displaced from a neutral position. This is not ideal, and several methods of dealing with this issue were evaluated by prototyping. Also, most joysticks used in this fashion were employed as speed controls rather than direct position controls, because otherwise the controlled system would follow the joystick and return to a central position when the joystick was released. Thus any solution that eliminated the return-to-center property could apply a joystick in a direct position-control system without issue.

Motor Sound Benchmarking

In order to get an idea of the noise created by a DC motor, the team measured sound levels while running a medium-sized DC brushed motor. The motor was connected to a 12V power source and the sound level was measured using a smartphone's microphone at a distance of 10 feet from the motor. The measured readings were 53 dB with the gearbox connected and 50 dB without the gearbox (just the motor). This far exceeded the 35 dB specification for this project. The test confirmed the team's hypothesis that running a smaller motor at high speeds was out of the question; instead, a higher-torque motor with lower operating speeds was deemed necessary.

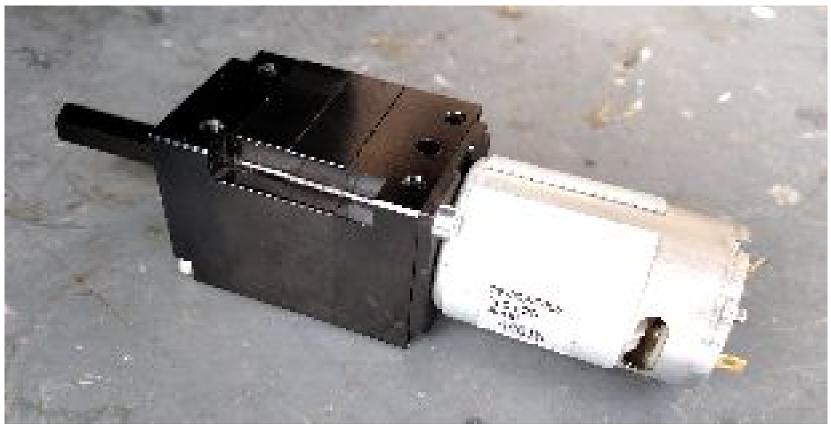


Figure 5: 12V DC motor with 100:1 Vex VersaPlanetary gearbox.

Final Design

Overall Layout

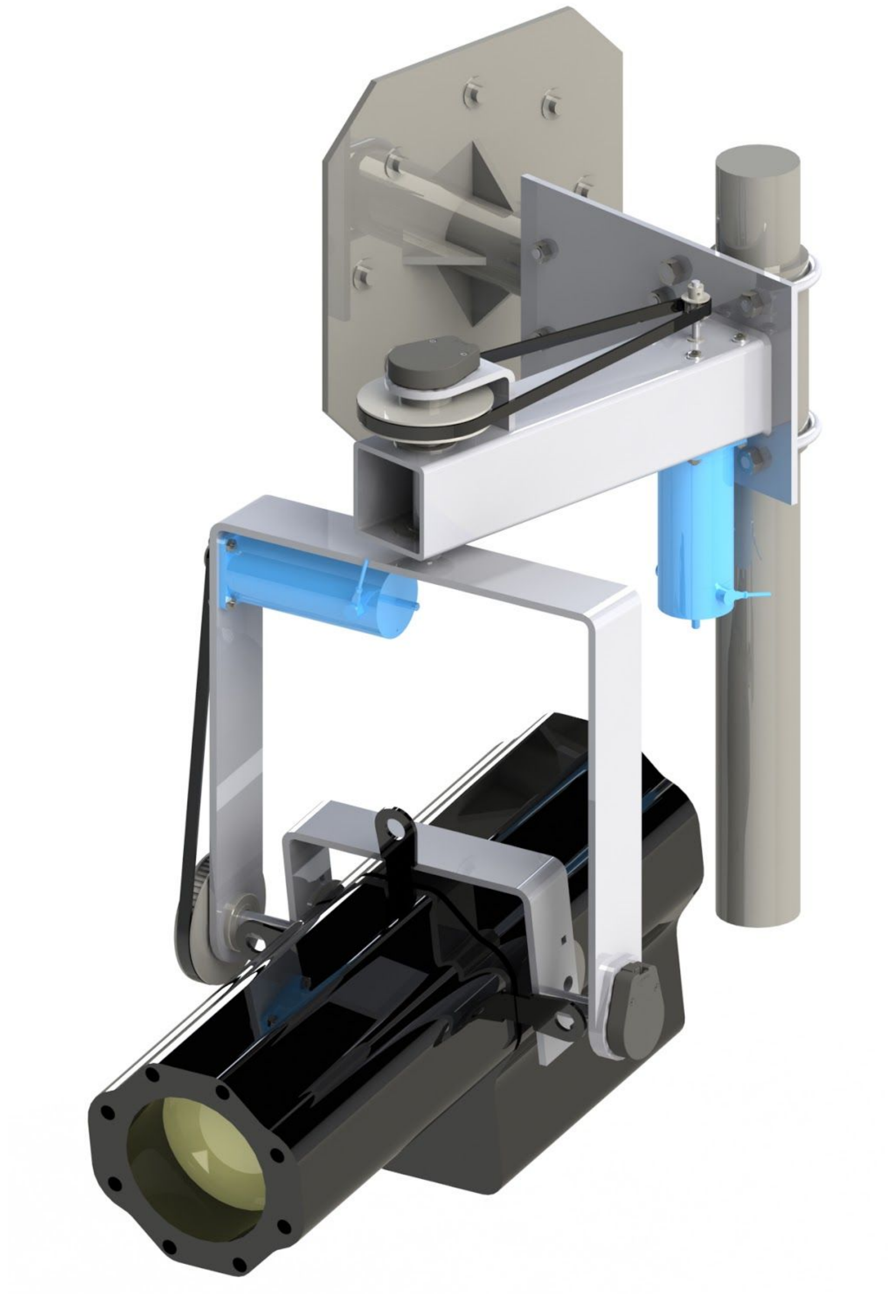


Figure 6: Final spotlight mount layout.

During the time between preliminary design review and the critical design review, the Cambria Center for the Arts Theatre decided on and purchased a spotlight: the ADJ Encore Profile 1000 Color. This spotlight is significantly longer and heavier than the Chauvet Colorado 3 Solo that the preliminary mount concept was designed for. However, the overall design remained essentially the same. The only component which needed to be completely re-designed was the bracket which the spotlight directly mounts to.

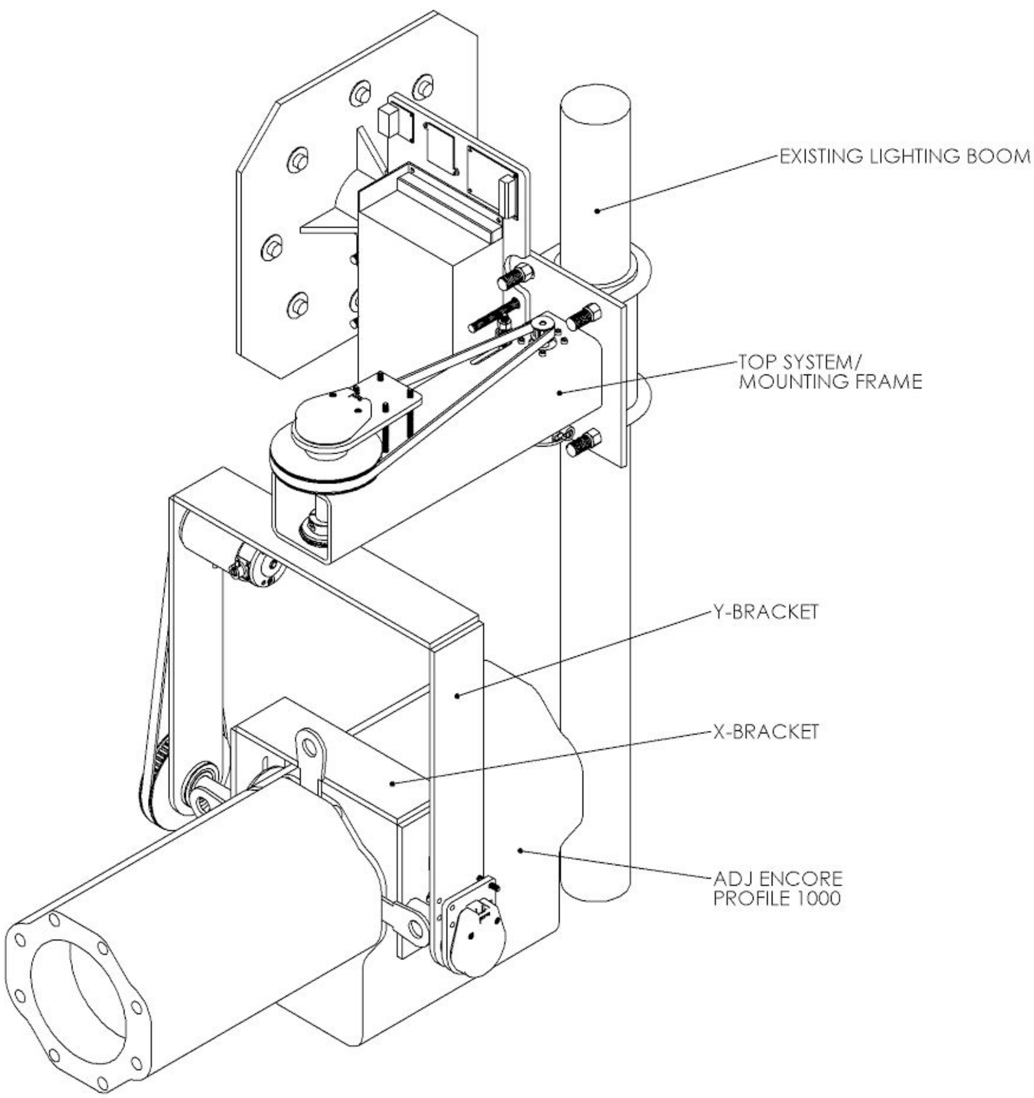


Figure 7: Top-level layout with labeled subassemblies.

For the purpose of clarity and understanding throughout the remainder of this document, specific nomenclature will be used based on the location of the part that is being referenced. The "Top System" will refer to any components attached to the plate and square tubing. The "Y-bracket" will refer to the larger U-shaped bracket which allows rotation about the vertical Y axis. The "X-bracket" will refer to the smaller U-shaped bracket which allows rotation about the secondary, horizontal X axis.

Mounting Frame

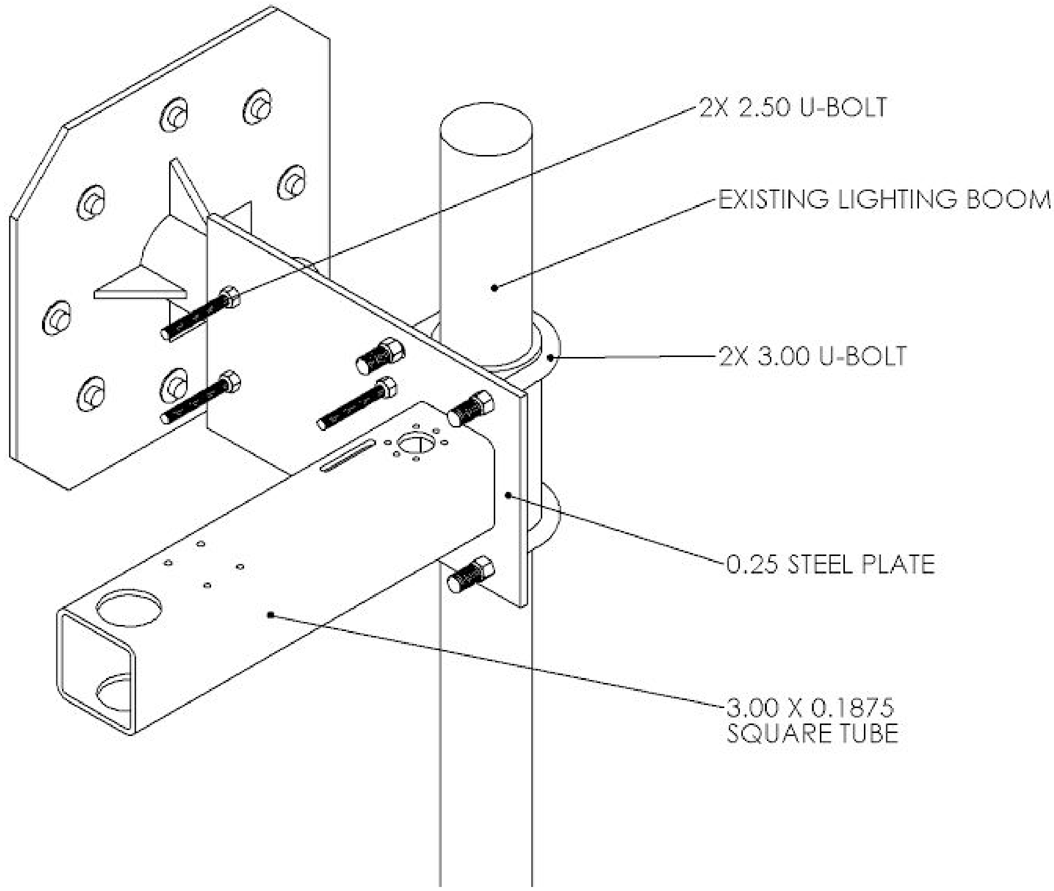


Figure 8: Mounting frame sub-assembly.

The mounting frame includes the top-level components which bear the weight of the spotlight and connect it to the T-bracket of the existing lighting boom which is already mounted to the wall of the theater. Based on strength analysis performed by the senior project group that built it, this T-bracket can be treated as a rigid connection point - its load capacity surpasses any loads that the additional spotlight mount will exert on it. The sturdy connection to the wall right next to the spotlight's mounting point also ensures that it won't contribute to any vibration in the spotlight's beam. This gives it a significant vibration-resistant advantage over the vertical pole-mounted design that was originally proposed. The steel plate is attached to the T-bracket by 4 U-bolts. This entire frame is built from carbon steel, which was chosen for its superior strength-to-weight ratio and ease of welding.

X Shaft Layout

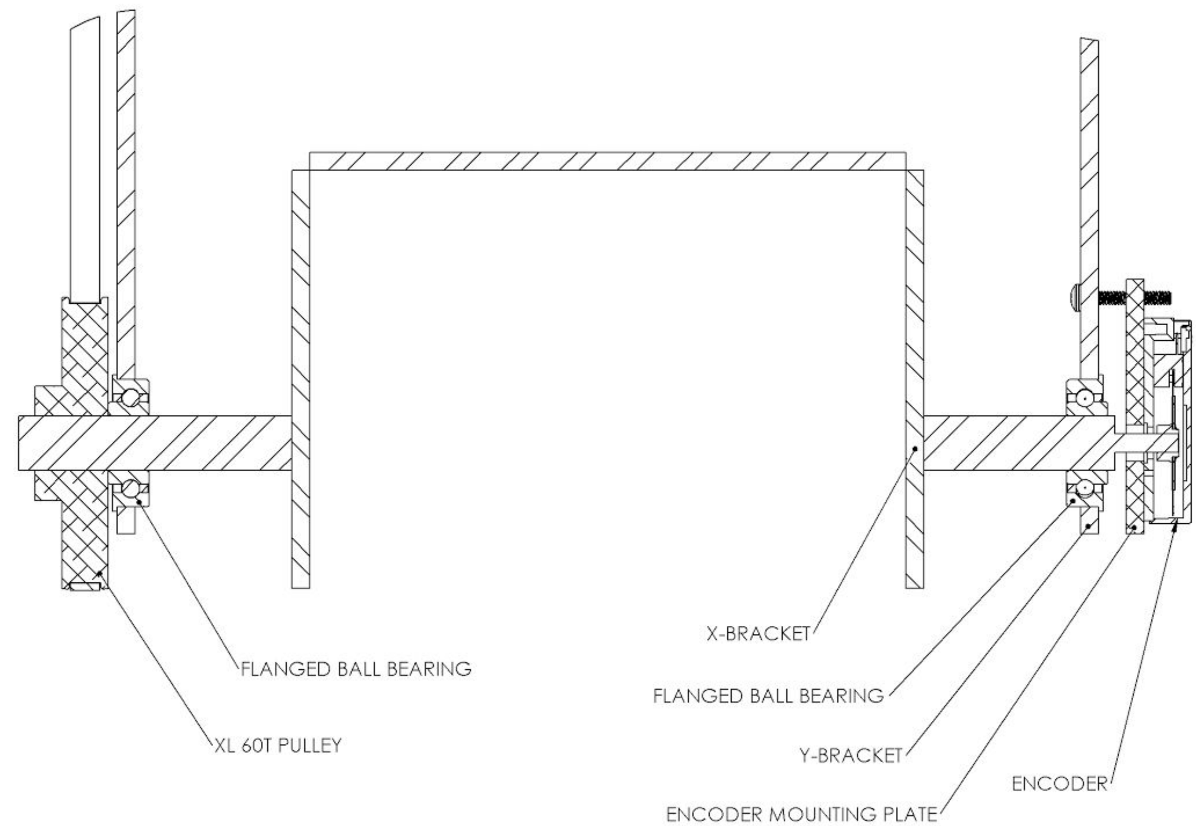


Figure 9: Layout of the X (tilt) bracket and shaft components.

The X-axis shaft uses a 3/4" shaft attached on either side of the mounting bracket. Each shaft then has a flanged ball bearing that is slid in with a press fit from the outside. One side has a large pulley attached to it while the other has an encoder on the end. The U shape of the spotlight mounting bracket fits over the spotlight and gets bolted down to it on one side to prevent the spotlight from rotating freely. Again, this was manufactured with carbon steel because of welding and rigidity requirements.

Y Shaft Layout

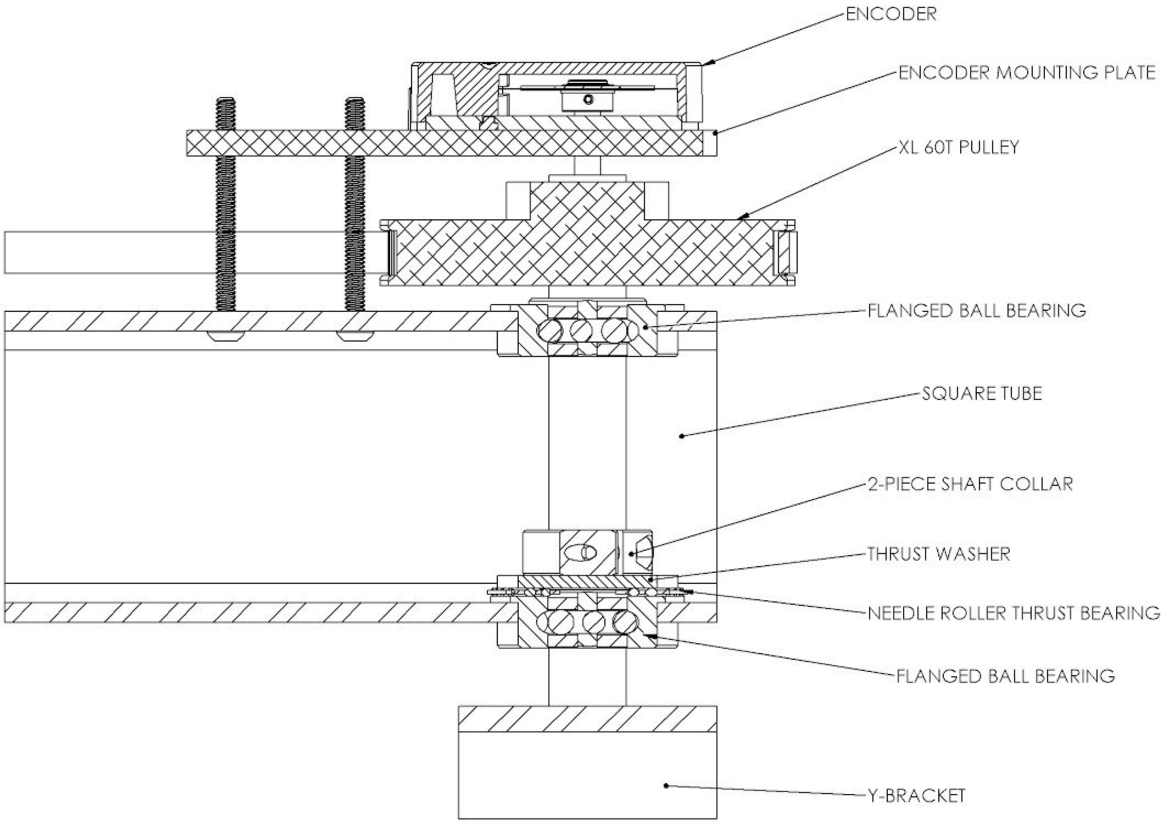


Figure 10: Layout of the Y (pan) shaft and shaft components.

The Y-axis shaft consists of a ¾” shaft that protrudes from the top of the Y bracket. It goes through the inner ring of two ball bearings, through a large pulley, and into an encoder. This shaft is secured into place using a two part clamping shaft collar which sits in a step above the upper bearing. This shaft collar rests on top of the ball bearing and holds the weight of the lower half of the system. Since this is a single point of failure, this part of the design is significantly over-designed. The shaft collar in a step ensures that material interference, rather than friction, prevents the shaft from slipping through the bearings. This Y-shaft spins freely with the spotlight assembly held below.

Control Software

The software for this project consists of two distinct components. The first is an operator program with a GUI (graphical user interface) that allows the spotlight operator to issue commands to the system. The second component is a drive program running on a microcontroller attached to the mount, translating the commands into motor movements with encoder feedback in a position control loop. The figure below illustrates this arrangement. The communication between the two processors running these programs is handled by a serial RS232 conversion chip. This standard protocol facilitates ease and reliability of connection over the long distances from the operator booth to the spotlights. Motor position feedback and regulation is handled locally by the drive program processor to reduce latency and improve stability, but the angular position of the spotlight is also sent back to the operator system to give the human operator visual feedback.

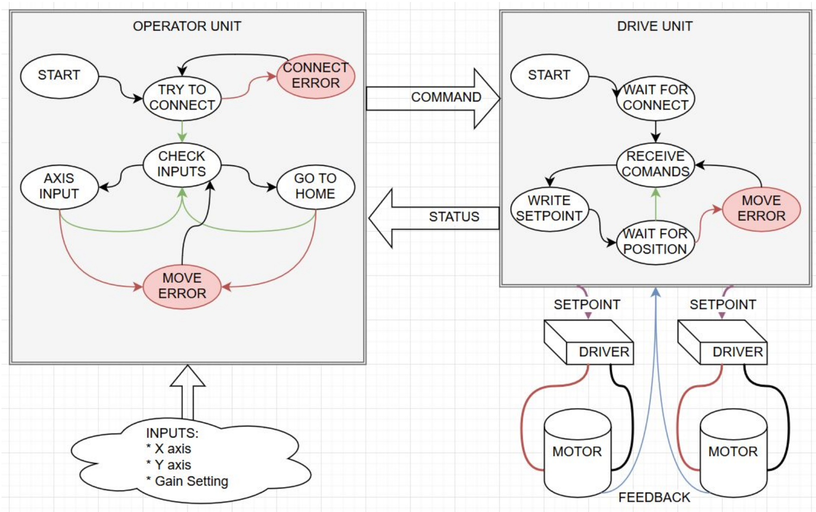


Figure 11: State flow logic diagrams for the operator and drive programs.

Analysis Results

Analysis was performed on all functions of the design. See Appendix 2 for details on each process and hand calculations.

An initial clearance analysis was performed in SolidWorks to check for interference between components - most importantly, the spotlight and the Y bracket. Once the spotlight was purchased, the team used empirical tests to find its center of gravity location and mass moment of inertia. The mass moment of inertia was calculated to be:

$MOI = 0.15\ slug\text{-}ft^2$

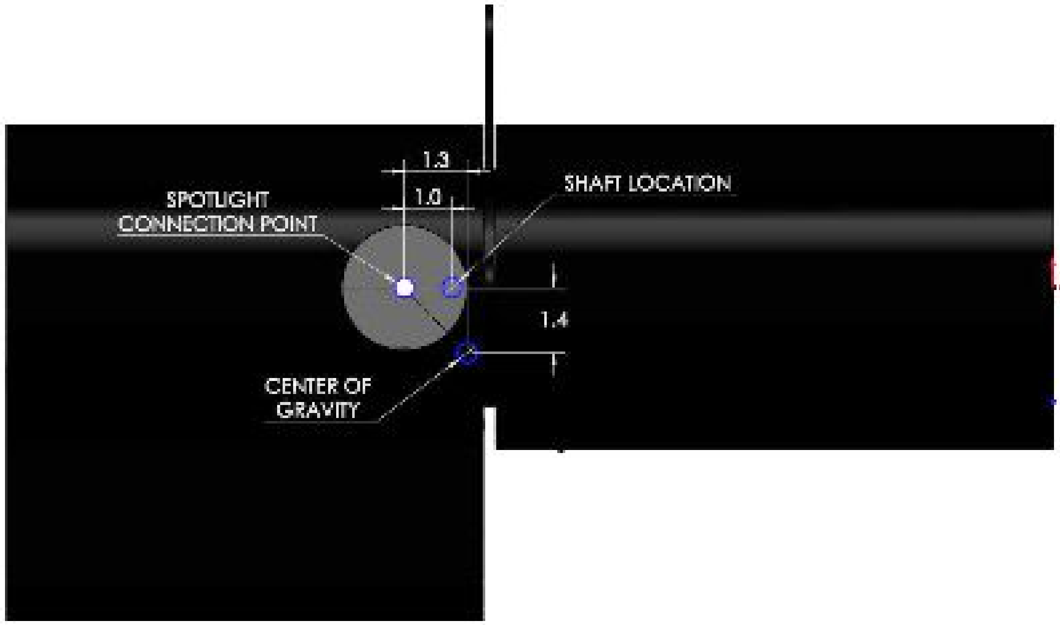


Figure 12: Experimentally-determined center of gravity (CG) location.

The motor torque and speed requirements were determined from a simulation run in MATLAB. Based on the estimated total moment of inertia of the system, the simulation was run iteratively using various torque values. In order to meet the speed requirements, a motor with the following spec is needed:

Peak Output Torque ≥ 0.8 N-m (113 oz-in).

The number of counts on the quadrature encoders was calculated in order to meet the positional accuracy requirements:

CPR ≥ 720 counts

Structural analysis on all load-bearing components was performed to check for stresses and deflections. All parts were modeled as simple beams and calculated by hand. Appendix 2 contains more information on loading cases and hand calculations, but Table 3 below contains results for the most critical points of deflection:

Table 3: Compiled list of critical deflections.

Component	Location of Deflection	Value	Unit
Back plate	Back Plate Outward Deflection	0.032219	in
Square Tube	Vertical deflection at end of beam	-0.00041	in
Y-bracket	Vertical deflection at end of cross-beam	0.01995	in

Y-bracket	Angular deflection along shaft (dynamic)	0.02	degrees
X-bracket	Angular deflection along shaft (dynamic)	0.02	degrees

Budget

The spotlight mounts built by the team are intended for long-term use in the theater, rather than acting as prototypes for large-scale manufacturing. Therefore, there is no cost breakdown for high-volume manufacturing; this budget accounts only for the two spotlight mounts and the control system that were built during the project. Below is a breakdown of the entire system's cost by category. For a complete breakdown of budget per part, see Appendix 3.

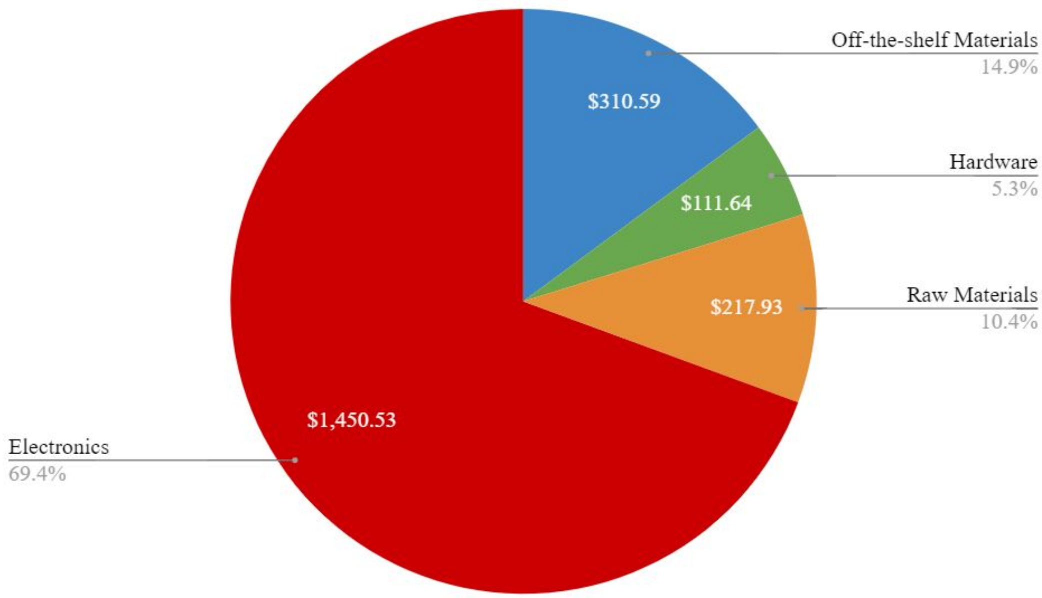


Figure 13: Budget breakdown based on categories of components.

The most costly materials were the electronic components - motors, encoders, and controllers. The prices listed for these components in the original budget were taken from the manufacturer's website directly while the team looked into obtaining discounts through personal contacts. Unfortunately, no such discounts were available.

Maintenance

The spotlights were designed to be removable for maintenance, cleaning, and repair. The U-bolts can all be unscrewed from the plate and the entire unit can be taken down. Further instructions can be found in the Operator's Manual. In addition, the separate parts of the mount were designed to be easily disassembled. For example, in an earlier iteration, the belts wrapped through part of the encoder mount, requiring the encoder to be disassembled and replaced in order to change the drive belt. In the final design, the belt was rerouted such that it can be removed without disassembling any other components. If the spotlight itself ever needs to be removed, the bolts in the spotlight mounting bracket can be loosened and disconnected from the spotlight. It will then drop out and can be replaced or serviced.

The Y-axis shaft is also designed to be removable in order to replace the bearings in the square tubing. If the clamping shaft collar is removed, the entire Y-arm assembly lowers out and the bearings can be replaced. Similarly, the spotlight mounting bracket can be removed from the Y-arm if the pulley, encoder, and bearings are removed from the outside.

Safety Considerations

A failure mode effects analysis (FMEA) was performed to determine what the primary safety concerns are during design and testing. The FMEA table is included in Appendix 1.

There were two primary effects that were identified after doing the analysis. Electrocution of the operator, while very unlikely, was the first one. This could result from the controller not being installed properly, safety precautions not being taken with the motor power source, or accidents occurring around the controller. The team decided that liquid spillage was the most likely cause of this effect.. Using a plastic case to enclose the system eliminates the risk of shock in the event of accidental spillage.

The second effect, and the more likely of the two, was a critical part of the spotlight mount breaking and causing the light to fall or more severely, fall and hurt someone. The spotlight mount is heavy, and if it were to fall, it could cause severe injury or even death. The precaution that the team identified to avoid this scenario was to find critical areas and simply over-design them. One of these critical points is the mounting hardware between the spotlight and the spotlight mounting bracket. In the factory setup for the spotlight, it features a central screw with an additional bolt to hold the light at the correct angle. In the proposed design, the team added three more bolts to clamp the light into the spotlight mounting bracket.. Another major critical point was the X-axis shafts attached to the spotlight mounting bracket. If one of these welds were to shear from excessive torque, that side would fall and most likely drop the spotlight. To avoid this, team Dynalux oversized these shafts to provide a large welding area, resulting in a large safety factor on dynamic loading cases.

Product Realization

Manufacturing Processes

Mounting Frame

The mounting frame is a combination of steel square tubing and a large flat plate. Construction of the back plate began by using a standard table saw to cut the rectangle to size 8”x12”. Using a flat edge of the plate, the team marked 8 holes where the U-bolts would protrude. It is critical that the holes were positioned correctly relative to each other because the U-bolts are set sizes. One of the challenges the team faced during this step was that the U-bolts were ordered after drilling the holes and they were wider than the holes. A quick squeeze in a vise corrected the issue.

The second component of the mounting frame is the square tube, a part that proved to be more challenging than intended. This part features two concentric 1.75” holes which hold the flanged bearings. After many suggestions as to how to drill these holes, the team settled with a fly cutter. They progressively stepped up the cutter until the desired diameter was achieved on one side of the tube. Using vise jaws as a datum, the square tube was flipped over and the process repeated to create the hole on the opposite side.

Figure 14: Using a fly cutter to widen the bearing holes.

After finishing the two concentric holes, the opposite side of the tube was milled to fit the motor mounting pattern and include a 0.25” slot for a tensioning bolt. These components were later installed once all manufacturing was completed. Lastly, the mill cut a large square hole beneath the motor template so that the motor could be inserted from below and mounted inside the square tube.

Once the steel plate and square tube were completed, they needed to be welded perpendicular to each other. The team added three long welds using a MIG welder on the top and both sides of the square tube. The bottom remained unwelded due to the square hole being close to the end of the tube. In order to make sure the tube and backplate weren’t rotated, the team used a square and tack welds to achieve the desired position. The team also welded an extra piece of square tubing to an extra plate, and used this for destructive testing ot the weld joint. Even with a sledgehammer, the team could not break or bend the joint at all (see Fig. 14).

This marked the end of manufacturing for the mounting frame. The team replicated the process for the other mount, ensuring that the two mounts mirrored each other (since they are placed on opposite sides of the theater).

Figure 15: Anthony performing destructive testing on a sample weld joint.

Y-Bracket

Manufacturing the Y-brackets proved to be more difficult, mainly due to the parallel and concentricity tolerances required between its plates. This required a number of machining processes on the 2.5 inch wide steel plates, as well as some welding. First, the steel plate was cut into rough lengths using an abrasive cutoff saw, as shown in Fig 17.

Figure 16: Oleg cutting the steel plates to length on the abrasive cutoff saw.

Once the plates were cut, they were milled to exact length according to the design. This not only ensured that the plates would be the same length on each side of the Y-bracket, making the bearing holes concentric, but it also created flat ends to ease the welding process.

Figure 17: Boring through the steel plates with a large drill bit.

The most difficult process on the Y-brackets was machining the holes in which the flanged ball bearings sit. These holes are 1.75” in diameter and require tight diametric tolerances (±0.5 thousands of an inch). The team began by stacking all four plates together on a mill and drilling holes through them all at the same time, beginning with small drill bits and slowly working up to larger diameters. The largest drill bit in Cal Poly’s Mustang ‘60 shop is 1.00” in diameter, leaving a lot of material to be removed. The holes were then widened to their final diameter of 1.75” using the same fly cutter as was used on the square tubing.

To check that the bearings would fit, the team inserted a flanged ball bearing into each of the holes. Many of the holes were still too much of an interference fit, so they were widened with a dremel and sandpaper wheel until the bearings could be pressed in using reasonable force.

Once the machining was completed, the welding process began. First, the ¾” shaft was attached to the cross-beam plate. Attaching the shaft first made it easier for the team to ensure perpendicularity with the plate. This was achieved by using two magnetic triangles to check for perpendicularity. The shaft was then super-glued onto the plate, allowing the triangles to be removed and the weld joint to be made. The weld was done in two 180° passes around each side of the shaft, ensuring the greatest amount of weld material possible. While the first welding pass may have warped the metal, it appeared by inspection that the shaft was sufficiently perpendicular to the plate.

The two arms were attached to the cross-beam using a right-angle welding vise. First, the outside fillet of each corner joint was welded. Then, the bracket was clamped to the table by the bottom of each arm, as seen in Fig. 16, with the inner distance precisely measured. This ensured that the gap between the two arms would remain accurate while the inner fillet joints were welded and cooled. Welding on both the outside and inside of these corners was an easy way to strengthen these safety-critical joints and give the design a high factor of safety.

Figure 18: Welding the corner joints on the Y-bracket.

X-Bracket

The manufacturing of the X-bracket was very similar to that of the Y-bracket. It began with cutting the 2.5” wide plates to length and milling them to exact size. Holes and slots were milled to create mounting points for the spotlight. Again, the ¾” shafts were welded to the side plates first since perpendicularity was the most critical tolerance. The plates were then welded at the corners using the same right-angle vise as before. This time, however, only the outsides of the corners were welded. The loads experienced at these joints are lower than those on the Y-bracket, so welding both sides of the joint was unnecessary.

Finish Coating

After manufacturing and welding all three steel parts, they needed to be finished to protect them from rust. Even though the spotlight mounts are located inside a building, Cambria’s close proximity to the beach meant that the steel would still be prone to rusting. The team began by using an angle grinder with an 80 grit flap disk to remove welding bumps, dirt, and carbon on the metal. This provided a smooth and clean surface for coating. There were several different finishes considered, ranging in price from black paint up to powder coating the metal parts. Ultimately, the group chose to use an off-the-shelf spray rubber coating because it was low cost, easy to apply, and had a matte black finish (see component list for coating material information). Roughly 4-5 light coats were applied to all areas of the metal.

Electronics

The first step in preparing the electronics was to install header pins and terminals, as most of the components were sold without these attached. Three 2-conductor screw terminals were installed side by side on the bottom face of the motor driver board's power supply and output pads, to ensure that the casing of the terminals did not interfere with the components on the top face of the board. Next to these, a 2-conductor lever action terminal was soldered into place on the underside of the logic level (5V) pads. This served to distinguish this connection from the higher-voltage motor ports while not requiring a second size of screwdriver when installing wires.

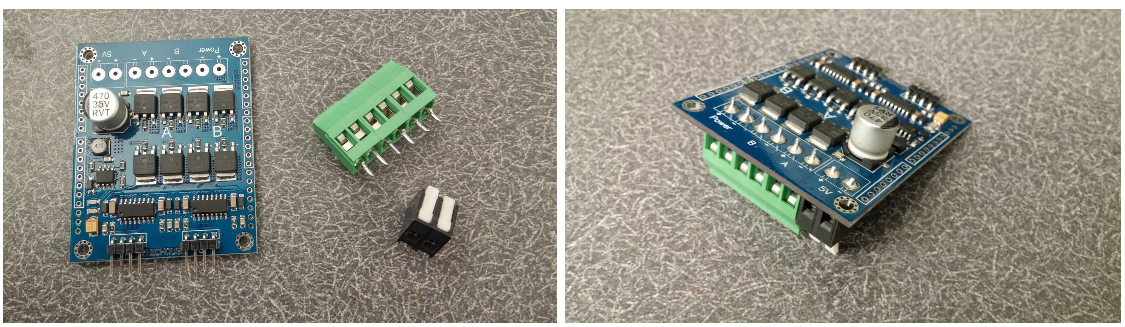


Figure 19: Motor driver board before and after soldering the four terminal blocks.

While some versions of the Pyboard microcontroller are sold with pre-installed header pins, the team selected a Pyboard Lite model that did not, due mostly to cost reasons. This also served to reduce confusion during the wiring stage, as there were fewer valid connection points for the wires to plug into. Different models of the Pyboard have different pinouts, so care was taken to ensure that the headers and connected wires would match the expected connections for a Pyboard Lite V1.0.

The wires used to connect the three controller components were mostly off the shelf 24 AWG, a standard in hobby electronics and breadboarding. One end was a female DuPont-style connection to attach to the exposed header pins on the motor driver and serial converter boards, while the other end was soldered to male header pins to plug into the sockets previously installed on the Pyboard. Male DuPont crimped pins would function just as well; the soldered header pins were used due to their availability, and the useful feature of being sold in adjustable rows to enforce pin arrangements. The long wires used to reach each encoder were braided together as five-conductor sets to keep them organized, simplify wire routing, and avoid potential problems near moving parts. Another option would be to use tape to bind the sets of five wire together, but the braid was chosen for its more appealing appearance. It is important to note that the encoder wires, as well as those of the serial converter board, were split into two sets where they connect to the Pyboard: power and ground were a two-pin connection, while the encoder signals were a separate three-pin connection and the serial transmit / receive lines were a two-pin connection.

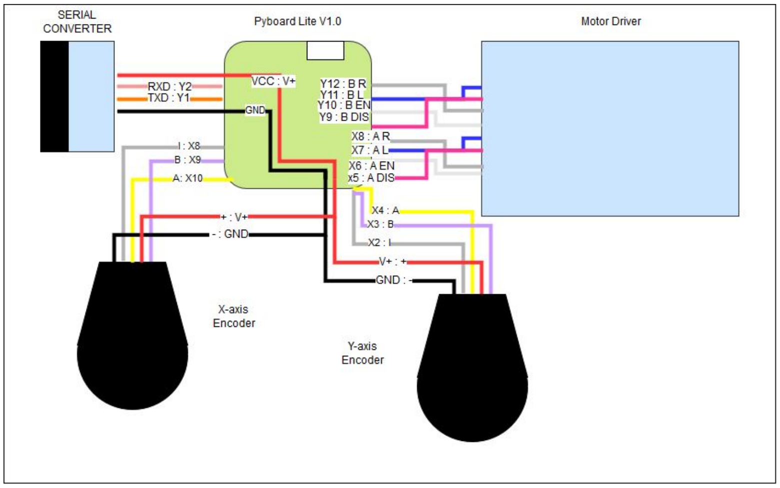


Figure 20: Wiring diagram for the controller. Power and motor connections for the driver are omitted.

The wires used for the motors required a different specification due to their higher operating voltage and potential for high current flow. 16 AWG silicone-insulated wire was used for these connections to ensure adequate ampacity rating and flexibility. For the motors, one end of the wire was a crimped automotive-style connector designed to slide over the tabs on the motors, while the other end was simply tinned to prevent fraying of the strands; this end was installed into the screw terminals on the motor driver, so no additional work was necessary. The wires linking the main power supply to the motor driver were also simply tinned on the driver end, and the supply end was crimped into a fork-style automotive connection.

The motor power supply was not sold with a power cable included, so it was necessary to assemble two AC cables. This was done by purchasing well-insulated three-conductor cable and an AC male plug from a local hardware store. Less than two inches of insulation were stripped off of each end, and then the internal wires were stripped roughly a quarter of an inch. One end of each conductor was installed into the AC male plug, and the other ends were crimped into fork-style automotive connectors for the terminals on the power supply.

Before the boards were installed, all the wires were connected. For the smaller wires, this was simply a matter of plugging both ends in to the correct places as per the wiring diagram in Appendix 5. The larger wires required a screwdriver, to ensure they were secured into the terminals on the driver and the power supply well.

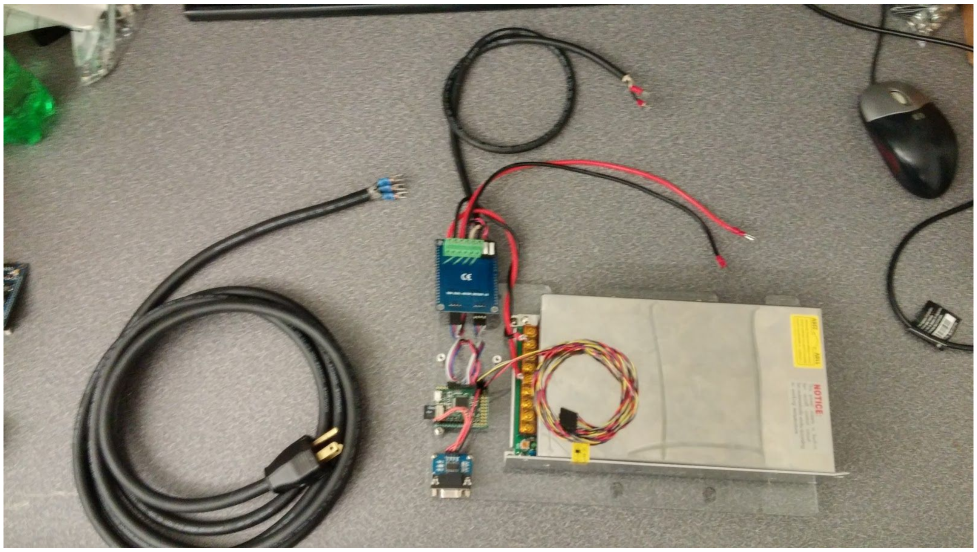


Figure 21: Partially-assembled controller board, showing some of the connections.

After the wires and boards were prepared, they were installed onto an acrylic plate using standoffs, screws, and washers. The power supply did not use standoffs; this maximized the amount of contact with the acrylic plate and reduced the stress from its weight. As one of the mounting holes on the motor driver was obstructed by the screw terminals, the driver only used three standoffs. This did not affect the stability of the board, especially as it is mounted in a static position.

Once all four major components were installed onto the acrylic board, it was ready for mounting. The holes in the acrylic board were laid out such that they would line up with the secondary U-bolts used on the mounting frame of the spotlight. It was installed there after the spotlight itself was installed and assembled. It is critical to note that the secondary U-bolts used two sets of lock nuts in their installation - one set pressed against the mounting frame to ensure that the U-bolts were tight against the lighting boom, and a second set that held the acrylic in place. Acrylic is not suited to the potential compressive load that the U-bolts could exert, so this double arrangement of lock nuts allowed the acrylic to be mounted securely while not experiencing any of the spotlight mount’s loading forces.

Once the controller board was secured to the mount, the encoder and motor wires needed to be connected. This was fairly simple for the Y axis motor due to its positioning in the square tube, but the X axis motor and encoder were more complex. The wires for these two components were routed through the square tube to emerge past the Y axis. Zip ties were used to secure the encoder wire to the Y bracket on its way down to the encoder, while the motor wire was short enough to not require any securing. Both of these cables needed a certain amount of slack near the Y axis bearings to prevent them from interfering with the expected rotation envelope of the mount.

Once all of the mount electronic components were installed and connected, the final steps were to route and secure the RS-232 serial cable from the Raspberry Pi controller to the serial board on the acrylic, and to power the system up. The Pyboard was supplied with power from its micro-USB port using an AC to micro-USB wall charger. Before the AC cable for the motor power supply was plugged in, the control system was given a final inspection to ensure that no wires had come loose during installation and that the motor power supply's input voltage switch was set to the "110" setting, and not to "220".

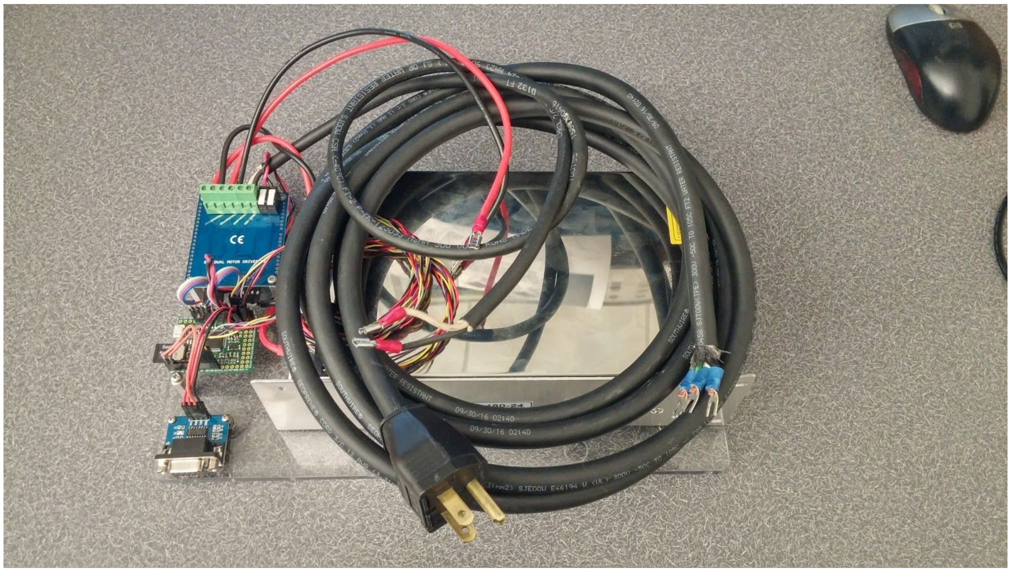


Figure 22: Fully-assembled board with all cable stacked for transportation.

Differences from Planned Design

After the welding was completed, a full assembly of one spotlight mount (including the spotlight) was performed to check that all the parts fit together properly. It was found that the X-bracket has an extra 0.25" of clearance between its two plates, most likely due to an erroneous measurement of the distance between the two side-plates on the spotlight itself. This was not ultimately a problem, since the plates were still close enough to support the spotlight's weight on both sides. However, this meant that the spotlight could only be clamped down (to prevent free rotation) on one side instead of both. By inspection of wiggling the mount, it was clear that clamping on only one side would be more than sufficient to prevent the spotlight from rotating freely.

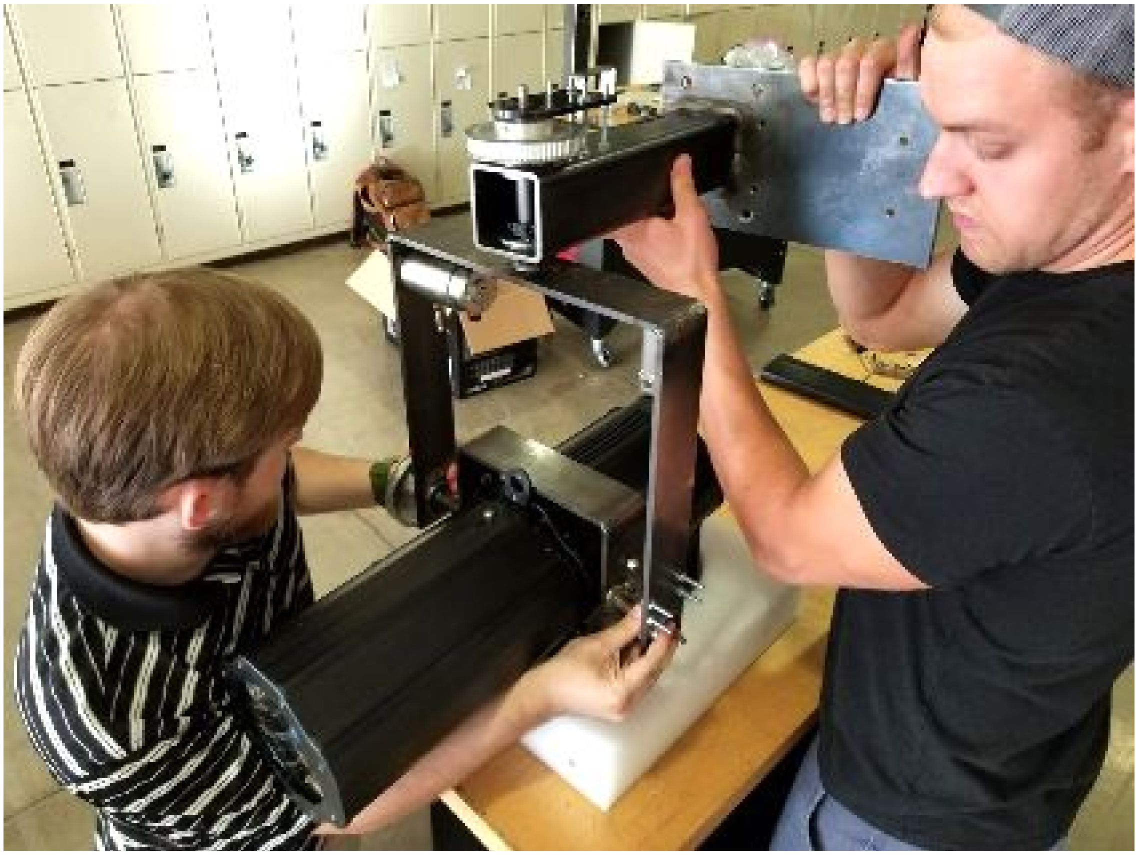


Figure 23: Preliminary assembly to check for fit between components.

It was also discovered upon initial assembly that all 4 belts were too long. The outer circumference was approximately 0.5” too long, or about 3 teeth of the timing belt. The slot which was intended for the idler pulley was not long enough to take up that much slack. This was disappointing, since a great deal of time was spent determining the exact length required for each belt. The team resolved this issue by purchasing 4 new belts of shorter lengths.

Future Recommendations

While it is not necessarily intended at the time of this project’s completion, it is possible that more spotlight mounts may be manufactured. In that case, the team has several recommendations:

1. Consider using CNC machines instead of a manual mill and lathe. All of the of the machining processes could have been performed on CNC machines with more speed and accuracy. For example, the holes in the rectangular plate for the U-bolt mounts, as well as the motor mounting holes in the square tube, could have been made with tighter diametral tolerances. Other processes would have been easier for a CNC machine to perform, particularly the 1.75” diameter holes for the bearing mounts. Instead of using the fly cutter, a CNC machine could have used an end mill with a smaller diameter and simply moved the tool in a circular pattern to achieve the same result.
2. Provide looser holes or slot in the acrylic encoder mounts. The laser-cut acrylic mounts did not allow any adjustment clearance for the encoder, which would allow its position to be more

accurately concentric with the steel shaft. To provide this adjustment clearance, many of the encoder mounting holes had to be manually drilled to a larger diameter.

3. Redesign the slots for the idler pulley. The current design only allows for about ½ of a tooth, or about 0.1" of the belt's slack, to be taken up.

Design Verification

Initial Motor Testing

As discussed previously in the section on motor torque, the motors specified in the final design were selected based on the results of simulations. Once a motor was chosen and purchased, an initial test was run to benchmark its torque and speed capabilities. A steel beam with a mass moment of inertia roughly ⅙ that of the combined spotlight and Y-bracket was attached to the motor. Because the pulley system uses a 1:6 ratio, this test simulated the same effective moment of inertia on the motor as in the final setup. While performing open-loop step responses, the motor rotated the steel beam at an acceptable rate of angular acceleration.

Figure 24: Temporary test setup during the coding and controller tuning phase of the project.

Specification Verification

After we built the spotlight mounts, we revisited our design specifications shown below in order to validate our design. Each parameter had a target, tolerance, and risk involved. Based on those factors, certain specifications became more or less important to meet. At the time of writing this report, some of the specifications were not possible to test because the system was still being tested and not yet installed in the theater.

Table 4: Reiteration of the project's technical specifications.

Spec #	Parameter Description	Requirement Target	Tolerance	Risk	Compliance*
1	Cost	$2,000	Max	H	A
2	Sound	35 dB	Max	M	T
3	Range of Motion Vertical	90°	Min	L	I
4	R.O.M. Horizontal	90°	Min	L	I
5	Speed Onstage	1.8 rpm	Min	M	T, S
6	Static Stability	± 6in	Max	H	T, S, I

In terms of cost, the project was very close to the total budget of $2,000. Dynalux came in at roughly $2,090 which was slightly over budget. This was mainly due to unforeseen shipping costs, price changes on components, and small changes in design that required extra hardware that wasn't accounted for in the initial budget.

After installing the motor, the team ran it at 100% power to check sound generated. The motor was quieter than 35 dB and the sound was barely noticeable in a room. However, because a lab setting doesn't have the same acoustic properties as the actual theater, team Dynalux will test for sound once the mounts are both installed in the theater.

For range of motion, the spotlight is free to move in any direction necessary. The Y-bracket was designed to allow the spotlight to point directly down and almost directly upwards. This far exceeds the 90 degree requirement set forth by CCAT. In addition, the spotlight has almost 180 degrees of rotation side to side with boundaries at the wall and the light boom behind the light.

Due to not being fully installed, both speed onstage and static stability will be tested at a later date. In order to ensure that these specifications will be met, the team used a controller that has variable gains and can be adjusted as necessary.

Conclusions & Recommendations

The prior document explained in detail the final design of two spotlight mounts built by Team Dynalux for the Cambria Center for the Arts. The initial design remained relatively unchanged except for being adjusted for a different spotlight. In addition to everything before the preliminary design, this report focused on presenting the final design and addressing safety and manufacturing concerns relating to the project. The budget was also presented along with verification of the built design.

Bibliography

[1] "GroundControl Followspot System." *PRG Stage Lighting*. PRG- Production Research Group, n.d. Web. 02 Mar. 2017. <http://www.prg.com/technology/products/luminaires/groundcontrol-followspot-system>.

[2] "GroundControl Remote Followspot System User Manual." *PRG*. PRG- Production Resource Group, n.d. Web. 2 Mar. 2017. <http://www.prg.com/~/media/Files/US/PRG-Products/GroundControl-Followspot-System/Manuals/prg_GCFS_manual.pdf?la=en>.

[3] "Spotrack." *Spotrack*. Enterprise Ireland, n.d. Web. 02 Mar. 2017. <http://www.spotrack.com/index.html>.

Appendices

Appendix 1: Idea Generation & Preliminary Design
Appendix 2: Supporting Analysis
Appendix 3: Budget
Appendix 4: Data Sheets
Appendix 5: Detail Drawings

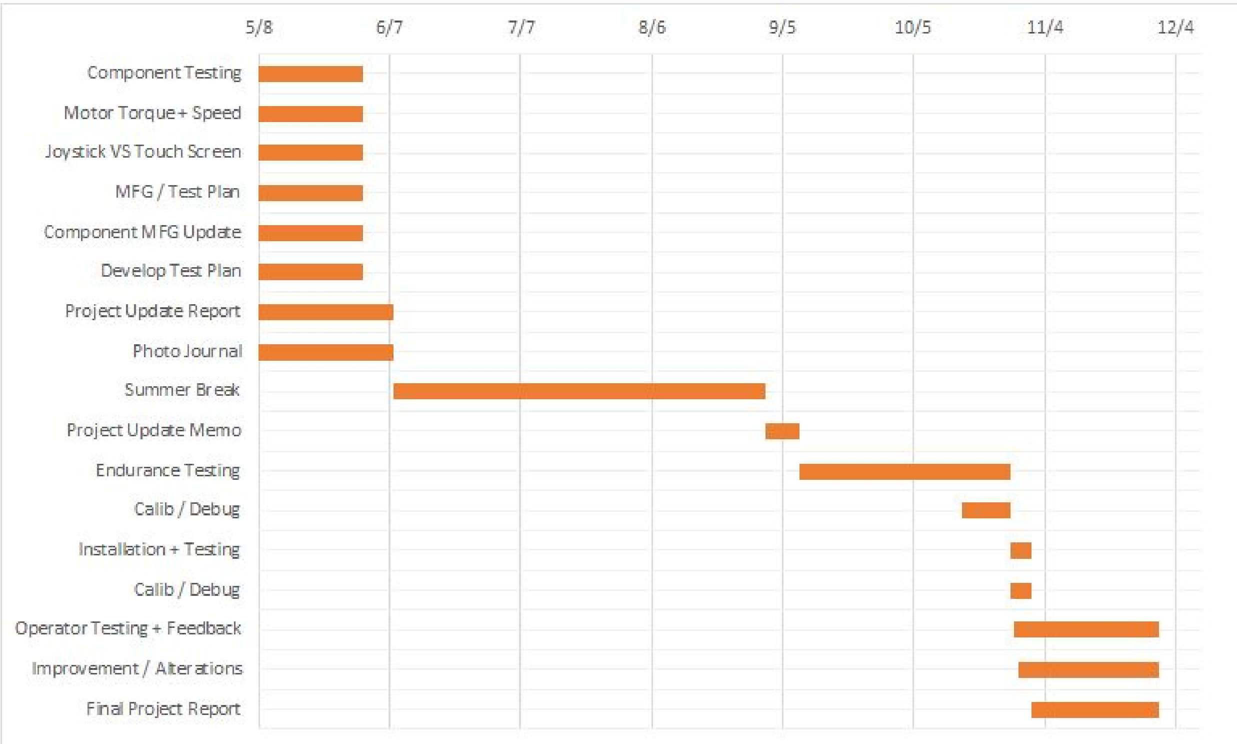
Appendix 1: Idea Generation & Preliminary Design

Quality Function Deployment

#	Relative Weight	Total	McFarland	Theater leadership	Actors	Audience	Director	Operator	Customer Requirements	A Decibels (<35 dB)	B Cost (< $2000)	C Peak power consumption (<500 Watts)	D Max speed onstage (>44ft/s)	E # Parts	F Weight	G Max temperature	H Pinch points	I Dimensions	J Min. angle increment (0.5°)	K Angle tolerance (>90°)	Our Solution (not decided)	GroundControl Followspot	Spotrack
1		6	1	1	1	1	1	1	Appropriate speed capabilities		1	2	3								0	2	1
2		6	1	1	1	1	1	1	Precision		2		1						3	3	0	9	2
3		6	1	1	1	1	1	1	Smooth motion										3		0	3	0
4		6	1	1	1	1	1	1	Range of motion												0	2	2
5		6	1	1	1	1	1	1	Reliability					2		2				2	0	2	1
6		6	1	1	1	1	1	1	Safe	1					2	3	3				0	2	2
7		4			1	1	1	1	Stability				2		2			1		3	0	2	0
8		4	1		1		1	1	Multi-function		2									2	0	0	3
9		3				1	1	1	Quiet	3		2									0	3	2
10		3	1				1	1	Easy to control / user friendly				1						2		0	3	0
11		3	1				1	1	Doesn't interfere with equipm.												0	1	0
12		2	1	1					Under budget		3			1	1						0	0	0
13		2		1				1	Easy to maintain					3	2	2	2	1			0	1	2
14		2		1				1	Durability				1			3					0	1	1
15		2	1					1	Integration with current setup									1			0	0	0
16		1						1	Lightweight		2	2			3			1			0	0	1
17		1		1					Low power consumption		1	3	2								0	1	1
18		1						1	Portable / easy to setup					2	3		2	3			0	0	0
19		1						1	Small									3			0	0	2
20		0							Easy to manufacture					3	1						0	0	0
									Technical Importance Rating	4	11	9	10	11	14	10	7	10	8	10			
									Relative Importance	4%	11%	9%	10%	11%	13%	10%	7%	10%	8%	10%			

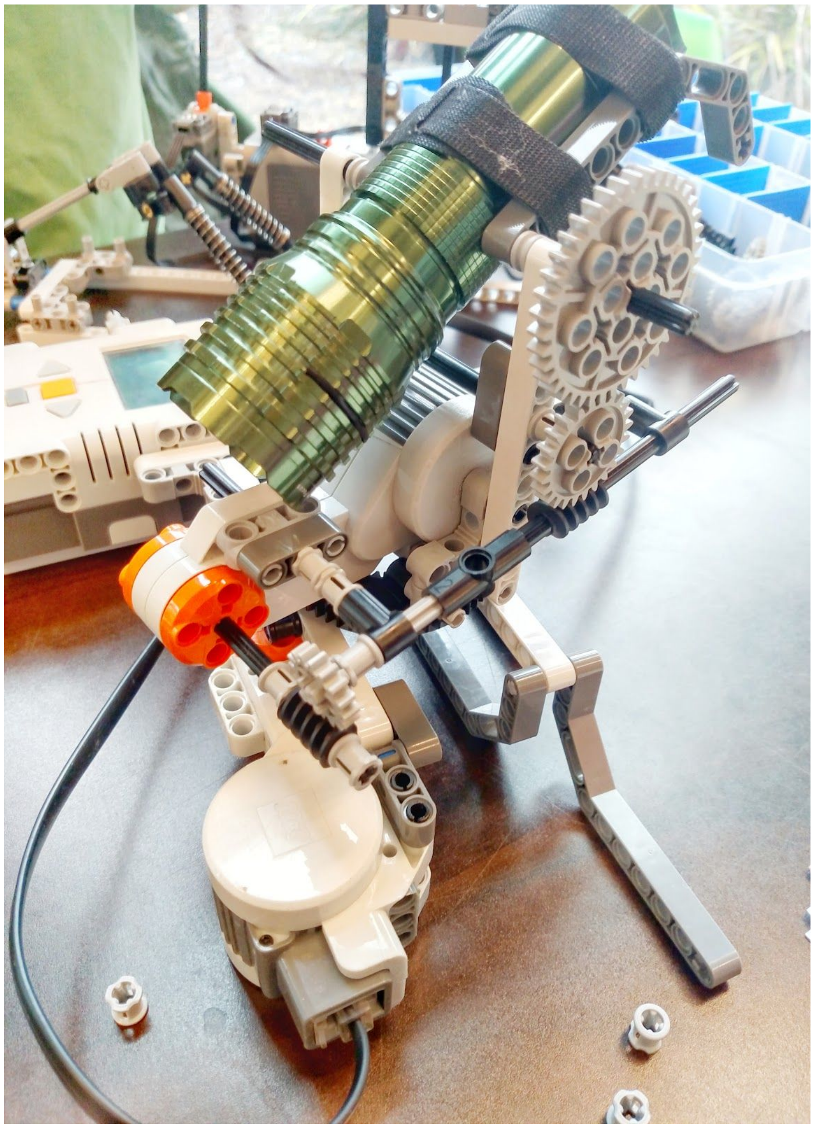
1.1 Quality Function Deployment (QFD) to compare the relative importance of each customer requirement and their correlation to each engineering specification.

Gantt Chart

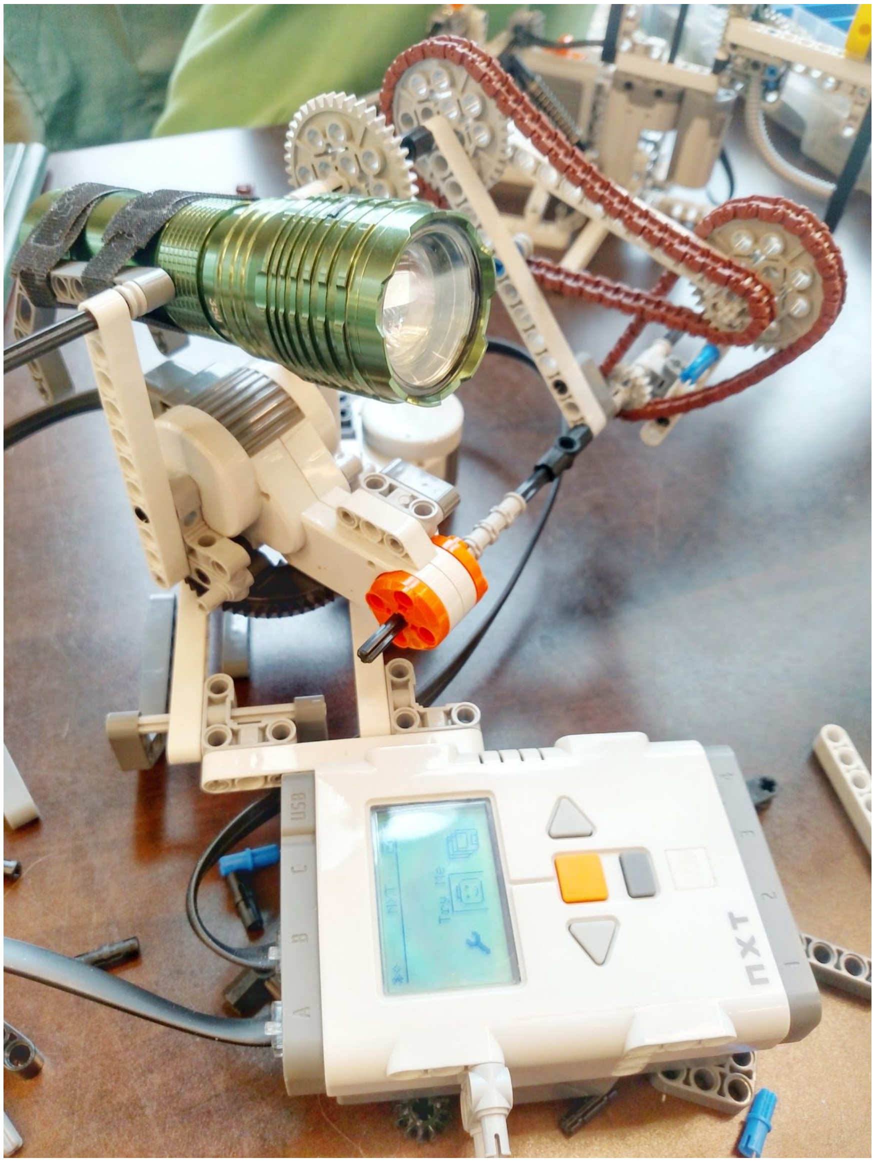


5/8
6/7
7/7
8/6
9/5
10/5
11/4
12/4
Component Testing
Motor Torque + Speed
Joystick VS Touch Screen
MFG / Test Plan
Component MFG Update
Develop Test Plan
Project Update Report
Photo Journal
Summer Break
Project Update Memo
Endurance Testing
Calib / Debug
Installation + Testing
Calib / Debug
Operator Testing + Feedback
Improvement / Alterations
Final Project Report

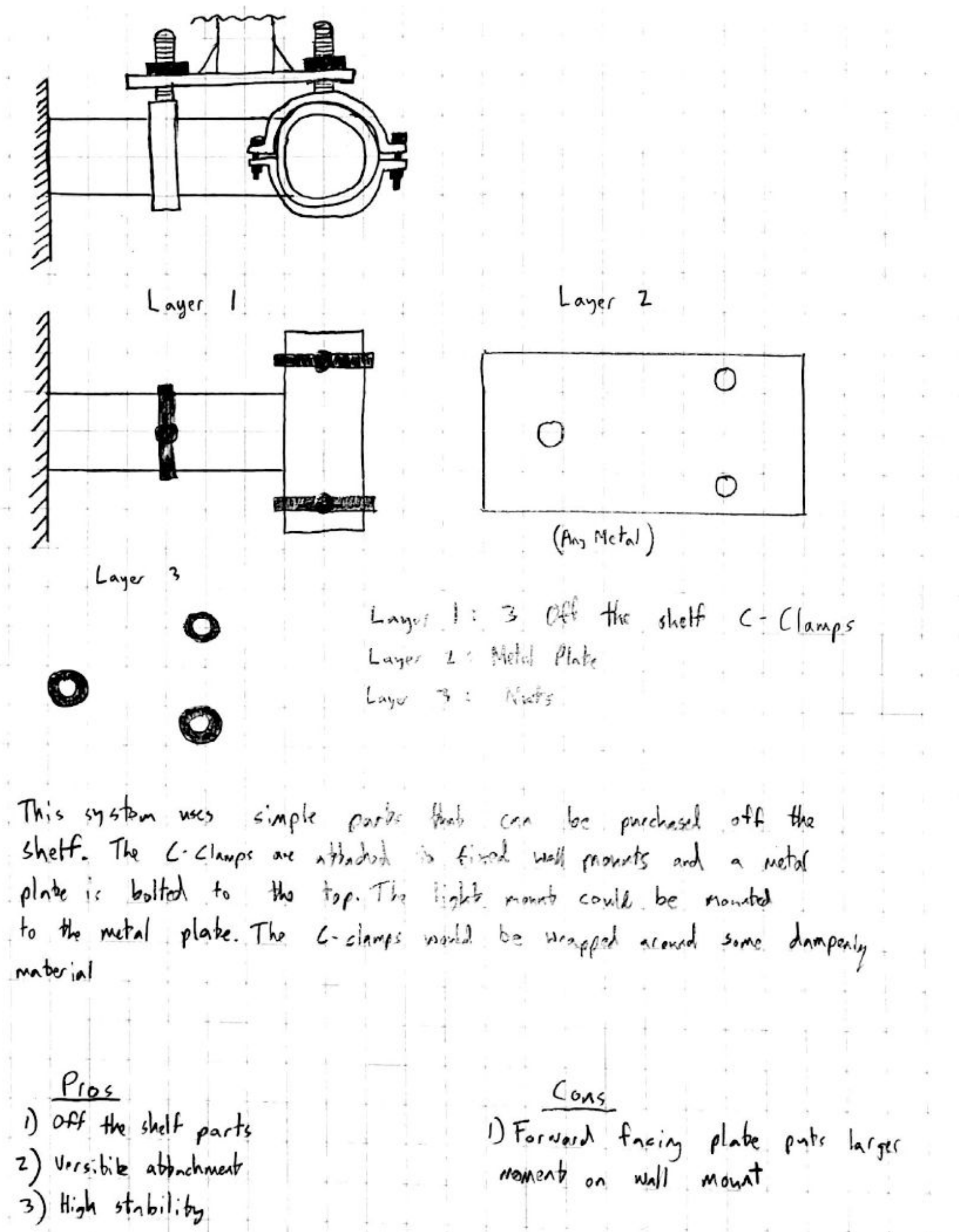
Concept Development and Design Sketches



2.1 Worm Gear Gimbal LEGO Prototype

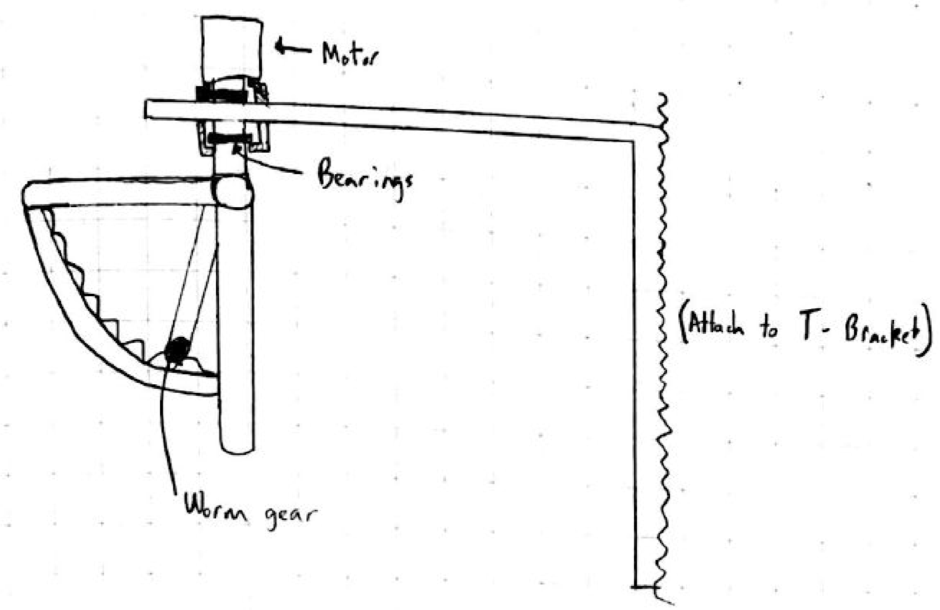


2.2 Double Chain Gimbal LEGO Prototype



2.3 T-Bracket Concept Drawing

Rack + Pinion (Angled)



This approach use a worm gear & angled rack in order to tilt the light downward. The motor can be direct driven or alternatively driven with a gear, belt, or any other transmission method.

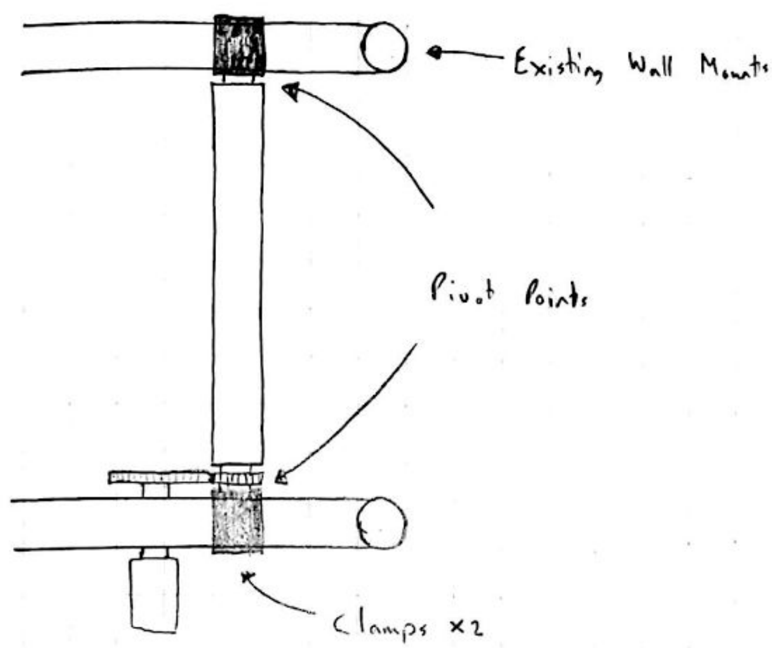
Pros

1) Lots of fine tuning for up & down directions

Cons

1) Complicated Solution
2) Lot of weight on top bearings
3) Only downward angles
4) Possibility for excess vibration
5) Side to side has less fine tuning.

2.4 Rack and Pinion Concept Drawing



This mount would use 2 wall mounts as opposed to just 1. It would be clamped or fastened to the existing wall mounts with a bar or pole between that rotates

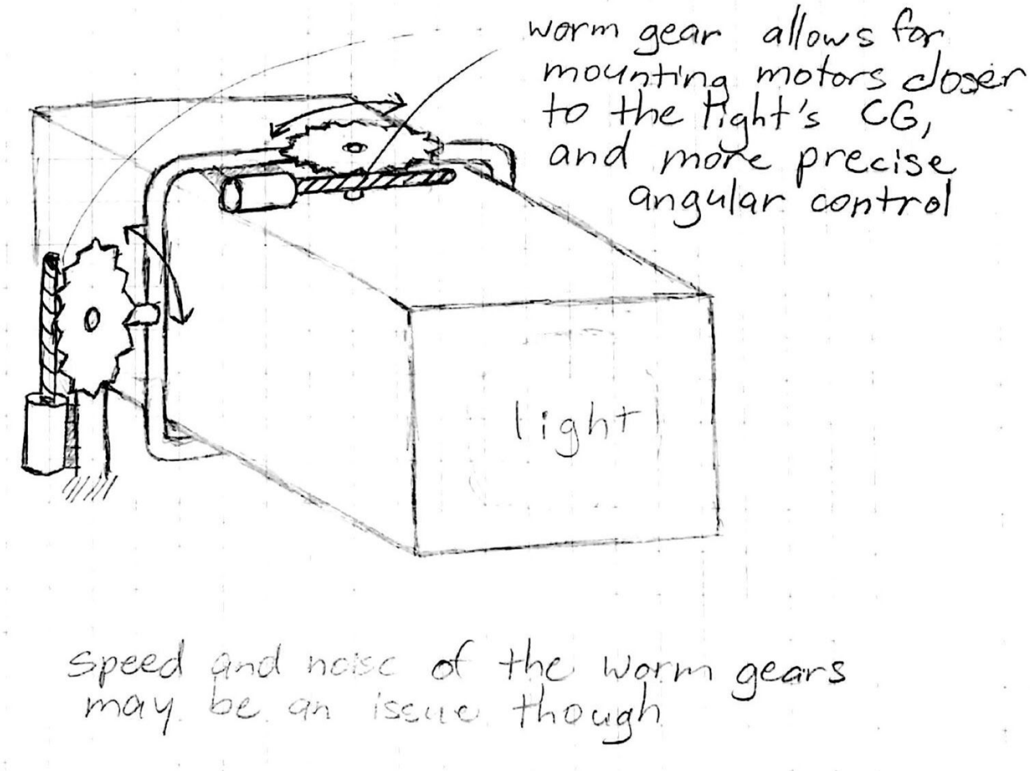
Pros

1) More support than using 1 wall mount
2) Y - Direction (Vertical) forces and very minimal torsion on the wall mounts

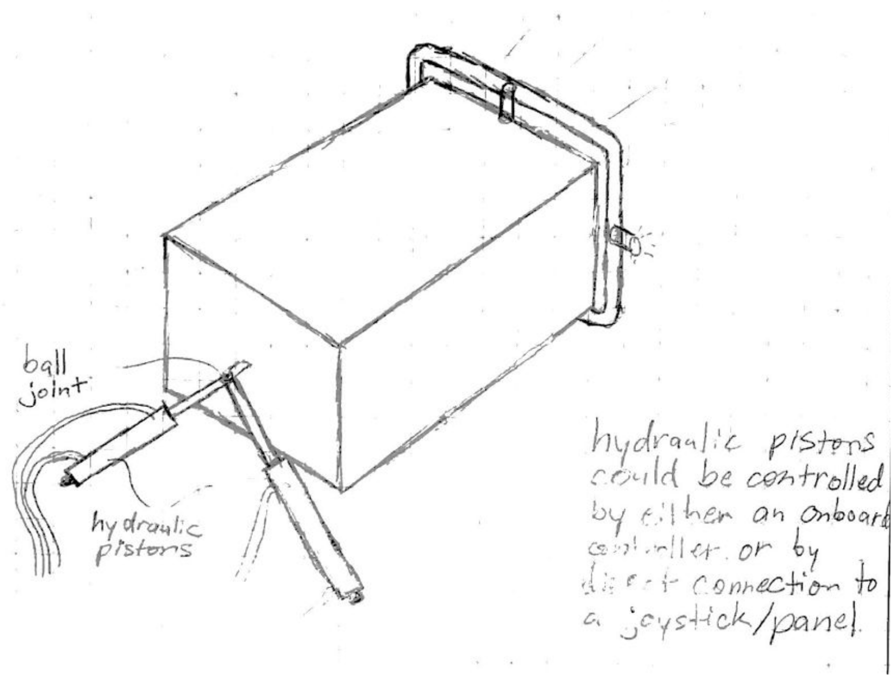
Cons

1) Large moment on gears due to swinging mount

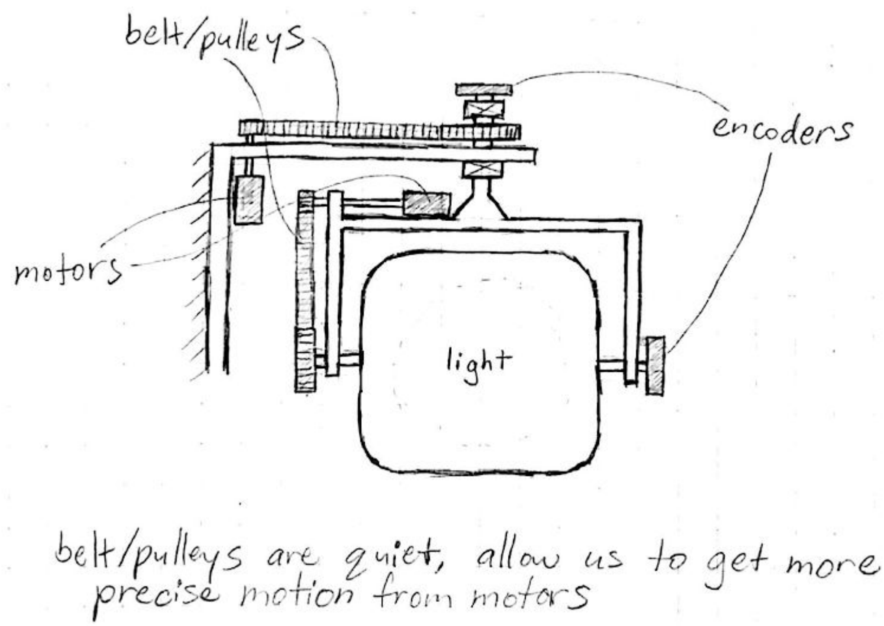
2.5 Vertical Pole Concept Drawing



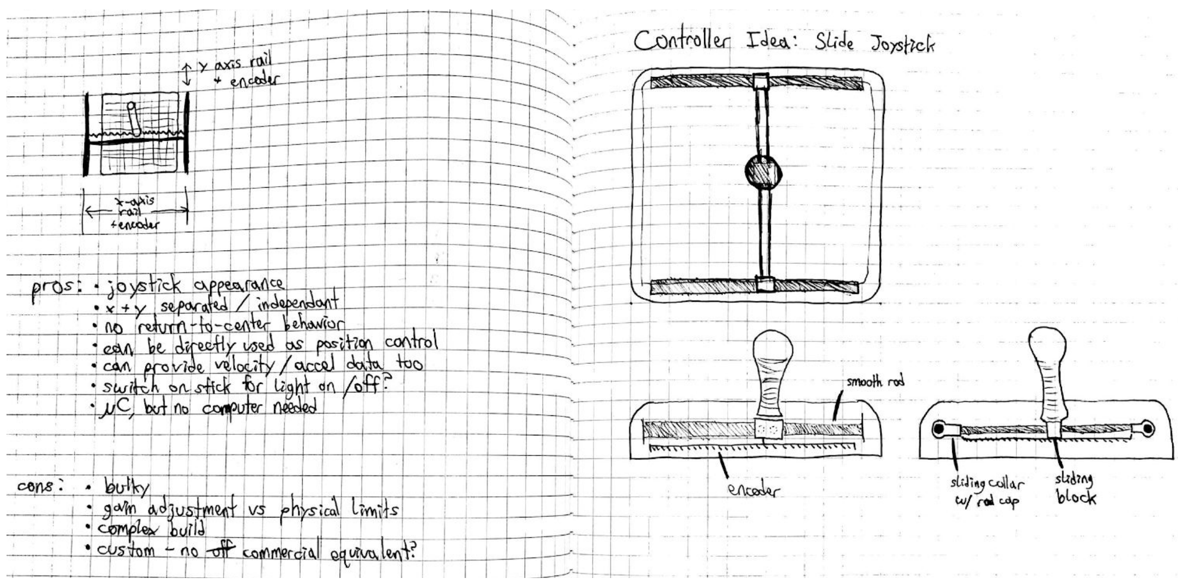
2.6 Worm Gear Gimbal Concept Drawing



2.7 Hydraulic Delta Gimbal Concept Drawing



2.8 Belt-Driven Gimbal Concept Drawing



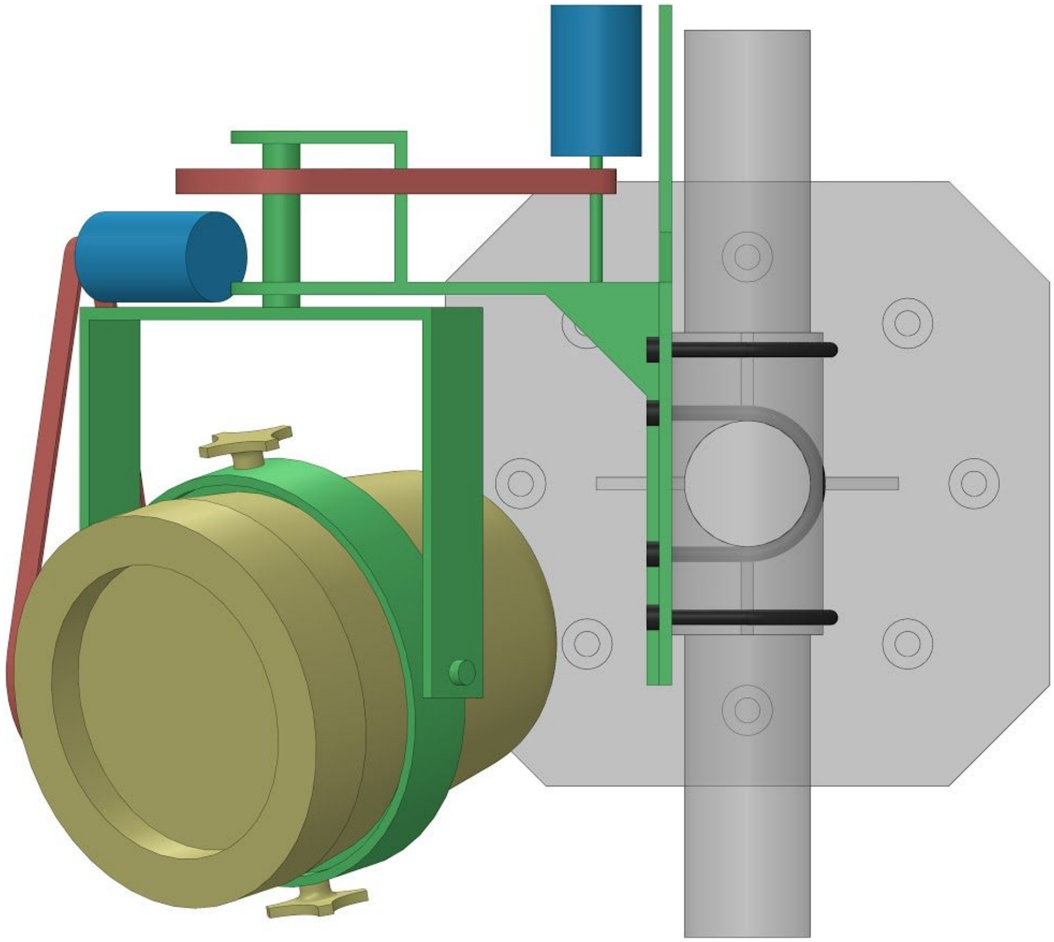
2.9 Two-Axis Slide Joystick Concept Drawing

Failure Mode Effects Analysis

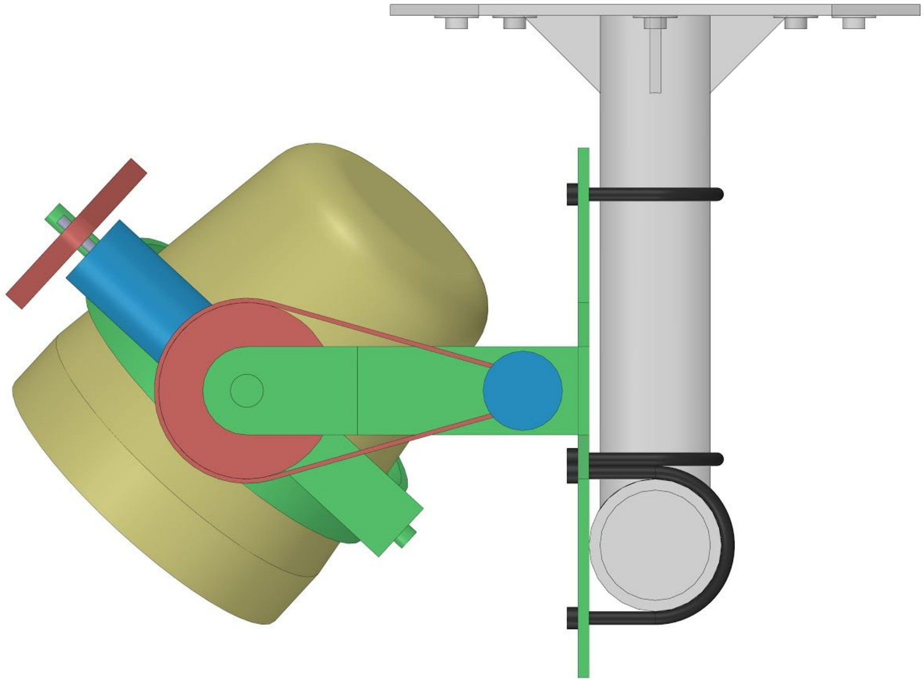
Function	Failure Mode	Effect	Severity	Cause	Occurrence	Criticality	Recommended Actions
Mount holds spotlight to wall	Mount connection (hardware) breaks	Entire mount falls off wall & hits someone	10	Earthquake / major wall vibration	2	20	Oversize mounting hardware
				Improper installation	5	50	Quality Installation Guide
				Incorrect replacement parts	4	40	Descriptive BOM
				Excessive loading conditions	6	60	Keep mount out of reach/Minimal grabbing points
				Stripped threads on C-clamps	4	40	Design mount so bolts are easy to access during installation
		Entire mount falls off wall & hits the ground	9	Earthquake / wall vibration	2	18	Oversize mounting hardware
				Improper installation	5	45	Quality Installation Guide
				Incorrect replacement parts	4	36	Descriptive BOM
				Excessive loading conditions	6	54	Keep mount out of reach/Minimal grabbing points
				Stripped threads on C-clamps	4	36	Design mount so bolts are easy to access during installation
		Spotlight shakes	7	Earthquake / major wall vibration	2	14	Oversize mounting hardware
				Improper installation	5	35	Quality Installation Guide
				Incorrect replacement parts	4	28	Descriptive BOM
				Excessive loading conditions	6	42	Keep mount out of reach/Minimal grabbing points
				Stripped threads on C-clamps	4	28	Design mount so bolts are easy to access during installation
		Spotlight does not point at stage	8	Earthquake / wall vibration	2	16	Oversize mounting hardware
				Improper installation	5	40	Quality Installation Guide
				Incorrect replacement parts	4	32	Descriptive BOM
				Excessive loading conditions	6	48	Keep mount out of reach/Minimal grabbing points
				Stripped threads on C-clamps	4	32	Design mount so bolts are easy to access during installation
		Interfere with the static light boom	6	Earthquake / wall vibration	2	12	Oversize mounting hardware
				Improper installation	5	30	Quality Installation Guide
				Incorrect replacement parts	4	24	Descriptive BOM
				Excessive loading conditions	6	36	Keep mount out of reach/Minimal grabbing points
				Stripped threads on C-clamps	4	24	Design mount so bolts are easy to access during installation
	Mount ring breaks	Spotlight falls out of mount	10	Excessive loading conditions	6	60	Keep mount out of reach/Minimal grabbing points
				Heavier Replacement Spotlight	2	20	Clearly specify weight limits of spotlight mount
		Spotlight does not point at stage	8	Excessive loading conditions	6	48	Keep mount out of reach/Minimal grabbing points
				Heavier Replacement Spotlight	2	16	Clearly specify weight limits of spotlight mount
		Spotlight becomes loose inside mount	7	Excessive loading conditions	6	48	Keep mount out of reach/Minimal grabbing points
				Heavier Replacement Spotlight	2	16	Clearly specify weight limits of spotlight mount
Mount allows spotlight to rotate	Rotational joint breaks	Excessive noise	7	More cycles than calculated life	3	24	Safety factor on fatigue (design for infinite life)
				Excessive loading conditions	6	48	Keep mount out of reach/Minimal grabbing points
				Excessive friction in bearings	5	40	Safety factor on bearings
		Shaky motion	7	More cycles than calculated life	3	24	Safety factor on fatigue (design for infinite life)
				Excessive loading conditions	6	48	Keep mount out of reach/Minimal grabbing points
				Excessive friction in bearings	5	40	Safety factor on bearings
		Fails to rotate spotlight	8	More cycles than calculated life	3	24	Safety factor on fatigue (design for infinite life)
				Excessive loading conditions	6	48	Keep mount out of reach/Minimal grabbing points
				Excessive friction in bearings	5	40	Safety factor on bearings
		Inaccurate positioning	7	More cycles than calculated life	3	24	Safety factor on fatigue (design for infinite life)
				Excessive loading conditions	6	48	Keep mount out of reach/Minimal grabbing points
				Excessive friction in bearings	5	40	Safety factor on bearings
	Power transmission wears down	Excessive noise	7	Mount interference	1	7	Leave clearance to account for deformation
				Belt stretches	6	42	Use proper belt tensioning
				Excessive friction in bearings	5	35	Safety factor on bearings
		Jerky motion	7	Mount interference	1	7	Leave clearance to account for deformation
				Belt stretches	6	42	Use proper belt tensioning
				Excessive friction in bearings	5	35	Safety factor on bearings
		Failure to rotate	8	Mount interference	1	8	Leave clearance to account for deformation
				Belt stretches	6	48	Use proper belt tensioning
				Excessive friction in bearings	5	40	Safety factor on bearings
		Inaccurate positioning	7	Mount interference	1	7	Leave clearance to account for deformation
				Belt stretches	6	42	Use proper belt tensioning
				Excessive friction in bearings	5	35	Safety factor on bearings
Drive rotates spotlight	Power transmission failure	Complete Loss of Motion	8	Belt is tensioned too tightly	3	24	Provide adequate instruction for tensioning belt
				Fatigue exceeds life	3	24	Safety factor on fatigue (design for infinite life)
				Excessive loading conditions	6	48	Keep mount out of reach/Minimal grabbing points

Function	Failure Mode	Effect	Severity	Cause	Occurrence	Criticality	Recommended Actions
Drive rotates spotlight	Power transmission failure	Complete Loss of Motion	8	Belt is tensioned too tightly	3	24	Provide adequate instruction for tensioning belt
				Fatigue exceeds life	3	24	Safety factor on fatigue (design for infinite life)
				Excessive loading conditions	6	48	Keep mount out of reach/Minimal grabbing points
	Motor wears down	Excessive noise	7	Belt is tensioned too tightly	3	21	Provide adequate instruction for tensioning belt
				Fatigue exceeds life	3	21	Safety factor on fatigue (design for infinite life)
				Excessive loading conditions	6	42	Keep mount out of reach/Minimal grabbing points
		Jerky motion	7	Belt is tensioned too tightly	3	21	Provide adequate instruction for tensioning belt
				Fatigue exceeds life	3	21	Safety factor on fatigue (design for infinite life)
				Excessive loading conditions	6	42	Keep mount out of reach/Minimal grabbing points
		Reduced range of motion	7	Belt is tensioned too tightly	3	21	Provide adequate instruction for tensioning belt
				Fatigue exceeds life	3	21	Safety factor on fatigue (design for infinite life)
				Excessive loading conditions	6	42	Keep mount out of reach/Minimal grabbing points
	Motor failure	Complete Loss of Motion	8	Belt is tensioned too tightly	3	24	Provide adequate instruction for tensioning belt
				Fatigue exceeds life	3	24	Safety factor on fatigue (design for infinite life)
				Excessive loading conditions	6	48	Keep mount out of reach/Minimal grabbing points
Controller controls spotlight position	Mechanical Failure	Doesn't Move/Stuck in Place	8	Debris in Controller	4	32	Add some sort of cover to the design
				Broken Part	3	24	Reinforce interior to prevent breakage
		Uncomfortable for Operator	7	Broken Handle	3	21	Make replacing handle simple and easy
				Non-ergonomic design	8	56	Make sure design is ergonomic
	Electrical malfunction	Electrocutes operator	10	Accidental Liquid Spillage	7	70	Add some sort of cover to the design
				Open Wires/ Components	4	40	Include maintenance manual
		Spotlight motion is lost	8	Accidental Liquid Spillage	7	56	Add some sort of cover to the design
				Open Wires/ Components	4	32	Include maintenance manual
		Spotlight motion is erratic	7	Accidental Liquid Spillage	7	49	Add some sort of cover to the design
				Open Wires/ Components	4	28	Include maintenance manual
		Loss of Connection to Spotlight	8	Accidental Liquid Spillage	7	56	Add some sort of cover to the design
				Open Wires/ Components	4	32	Include maintenance manual
	Software Malfunction	Spotlight motion is lost	8	Bugs in the Code	4	32	Debug
		Spotlight motion is erratic	7	Bugs in the Code	4	28	Debug
		Loss of connection to spotlight	8	Bugs in the Code	4	32	Debug

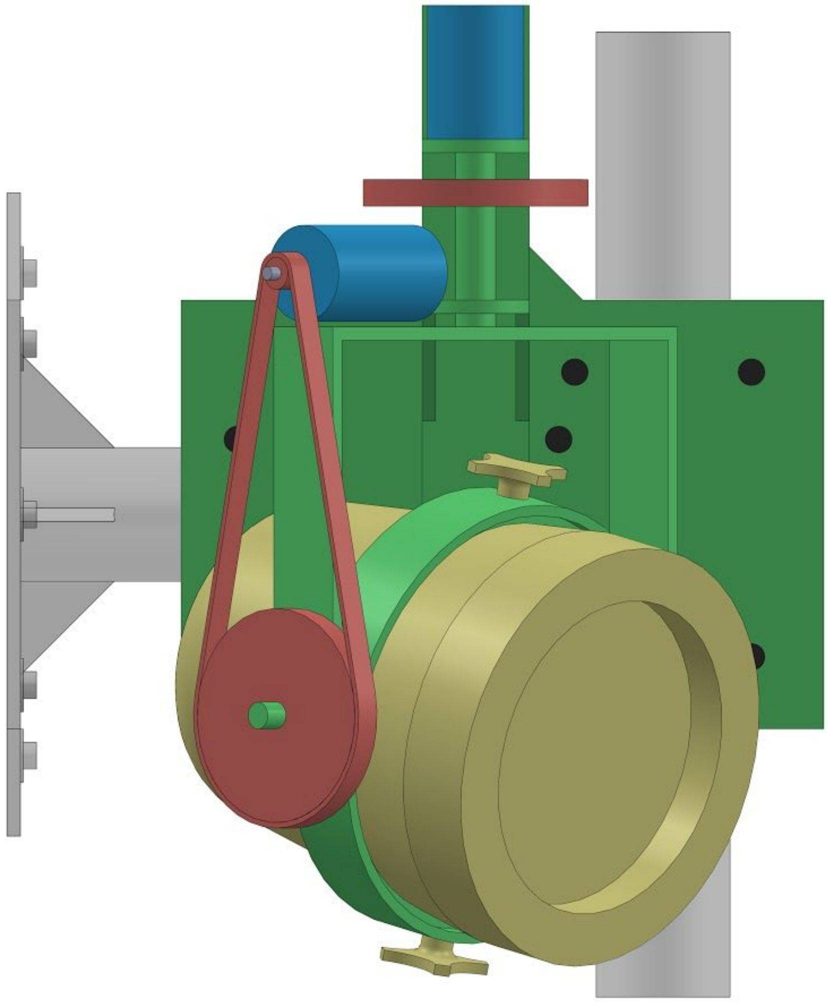
Preliminary Design - Layout Views



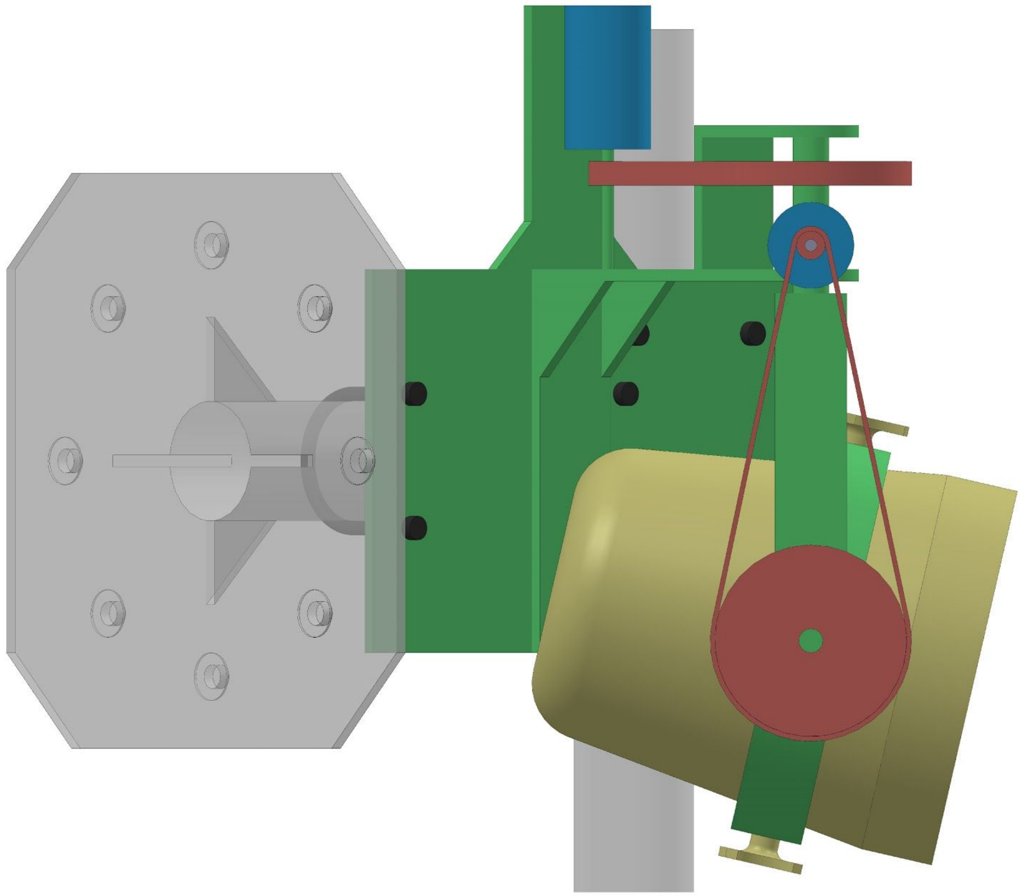
3.1 Side Layout View



3.2 Top Layout View



3.3 Front Layout View



3.4 Side view of gimbal showing the vertical belt apparatus.

Appendix 2: Supporting Analysis

Rotation Envelope Analysis

The most basic analysis of the system began with ensuring that the geometry of the mount allows for the specified range of motion (90 degrees in both axes) without interference. Accurate models of existing components, primarily the Encore Profile 1000 spotlight, were made in SolidWorks, along with each component that was purchased or fabricated by team Dynalux. The full SolidWorks assembly makes it easy to check for interference. Several critical geometries are pictured below.

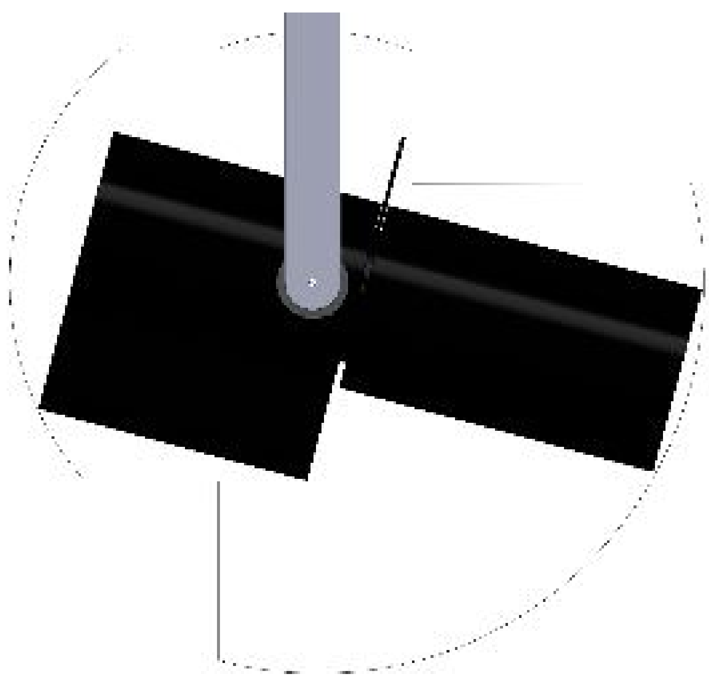


Figure 12: Rotational envelope of the spotlight.

First, the rotational envelope of the spotlight was drawn out to ensure that no other components interfered with that space. This was a driving factor for the length of the arms on the Y bracket which hang down on either side of the spotlight.

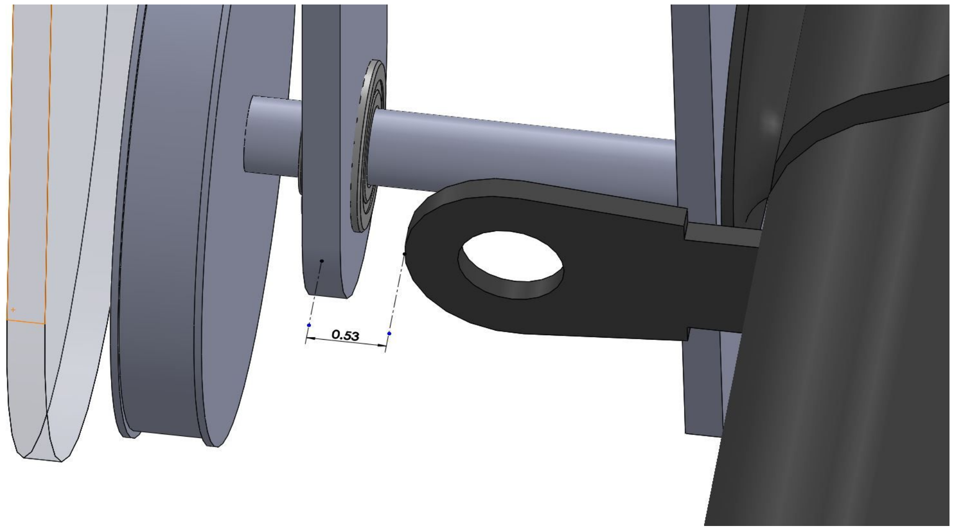


Figure 13: Clearance between the spotlight's shutter tab and bearing mount on the X shaft.

Another critical location which requires clearance is on the X shaft, allowing the spotlight to tilt up and down. Since the tabs can be manually pulled in and out to adjust the shutters inside the spotlight, they have potential for interfering with the vertical arms of the Y bracket where the bearing is mounted. The CAD model of the Encore Profile 1000 was created with the shutter tabs fully extended to be sure that there would be clearance with the tabs in any position.

Center of Gravity Analysis

The rotational X axis was designed to be located as close as possible to the spotlight's center of gravity, minimizing torque required from the motor while the spotlight is static. Static torque would require additional power to the motor and would create excess heat. ADJ does not provide data on the location of the center of gravity, so it had to be determined empirically. The simple test employed the fact that a rigid object will always hang such that its center of gravity is directly below the point of rotation.

The figure below depicts how the center of gravity was located. First (on the left), the clamp on the spotlight's hinge was loosened so that it could rotate about the bracket's hinge point. This shows that the center of gravity lies along the red line, about 45 degrees in front and down from the hinge point. Second (on the right), the bracket was clamped so that it was in line with the spotlight. This put the axis of rotation at the end of the bracket. This shows that the center of gravity is a little more than an inch below the hinge point.

Figure 14: Suspended test to determine the location of the spotlight's center of gravity.

After analyzing the images and measuring geometry using Photoshop and SolidWorks, it was determined that the center of gravity was located about 1.31 inches in front and 1.37 inches below the hinge point on the spotlight (as seen below). While this simple test was not very precise, it provided good confidence that the X axis shaft is located within an inch of the center of gravity. It is also worth noting that the bracket to which the spotlight connects goes above the light, bringing the combined CG of the bracket and spotlight even closer to the X axis.

Moment of Inertia Analysis

It was also necessary to find the spotlight's mass moment of inertia about its X axis in order to ensure that the motor has enough torque to accelerate the spotlight's angular position at an acceptable rate. Again, this spec is not provided by ADJ. However, the overall weight of the spotlight was given to be 21.94 lb according to the Encore Profile 1000's spec sheet. This was used to find an initial estimate of the spotlight's MOI, assuming that the spotlight is a homogeneous cylinder of diameter 8 inches and length 22 inches. The equation

$$\bar{I}_{x,\,cylinder} = \tfrac{1}{12} m \left(3r^2 + h^2\right)$$

resulted in a MOI estimate of 0.182 slug-ft^2. The hand calculations can be found in Appendix 7.

To find a more accurate moment of inertia, another empirical test was used. The spotlight was suspended just as last time, allowing it to swing about a point 6.5 inches behind the back plate (as seen below in Figure 15). The light was displaced by several inches, then allowed to swing back and forth. The period of each swing was recorded and averaged over a series of 3 tests. This period was used to calculate the moment of inertia about the point of rotation. Knowing the location of the center of gravity and using the parallel axis theorem, the team was able to find the MOI about the light's center of gravity. It was calculated to be 0.15 slug-ft^2, which is close to the initial estimate of 0.182 slug-ft^2. This discrepancy could be due to some amount of measurement error during the test, but is more likely a result of the uneven distribution of weight in the spotlight. The table of recorded swing times, as well as calculations to find the MOI, are also in Appendix 7.

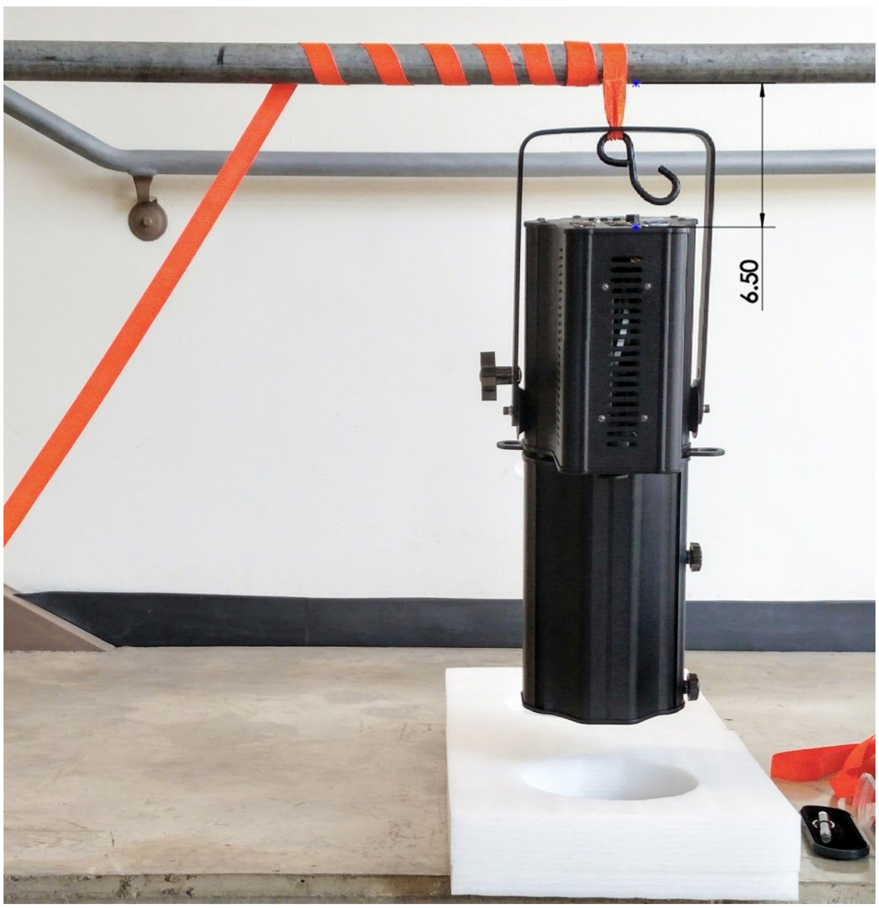


Figure 15: Suspended swinging test setup.

Motor Torque & Power Transmission Analysis

The required motor specifications were determined from the movement requirements. First, a velocity profile was constructed such that the motor would smoothly accelerate up at first, then down as the system approached the final position. This velocity path was integrated to confirm the system's angular position, and the derivative was used to find the acceleration. Using the inertia calculations from the previous section with this acceleration function, the required torque was found. Applying a pulley ratio to this torque and to the velocity function determined the required torque and speed output by the motor. Appendix 4 contains one iteration of these calculations. The selected motor was chosen for being the least-expensive motor in its category that exceeded these specifications.

In performing this analysis, it was discovered that increasing the transit time from the specified 0.5 seconds to 2 seconds drastically relaxed the motor specifications, with the required peak torque dropping by a factor of 4 and peak power dropping by a factor of 16. These reductions allow for the selection of a much smaller, and cheaper, motor than the original specification would allow, while still performing the 40-degree transit in a reasonable time. Discussion with the sponsor and CCAT personnel allowed the team to relax this specification and choose a smaller motor. Figure 14 below illustrates the magnitude of this change.

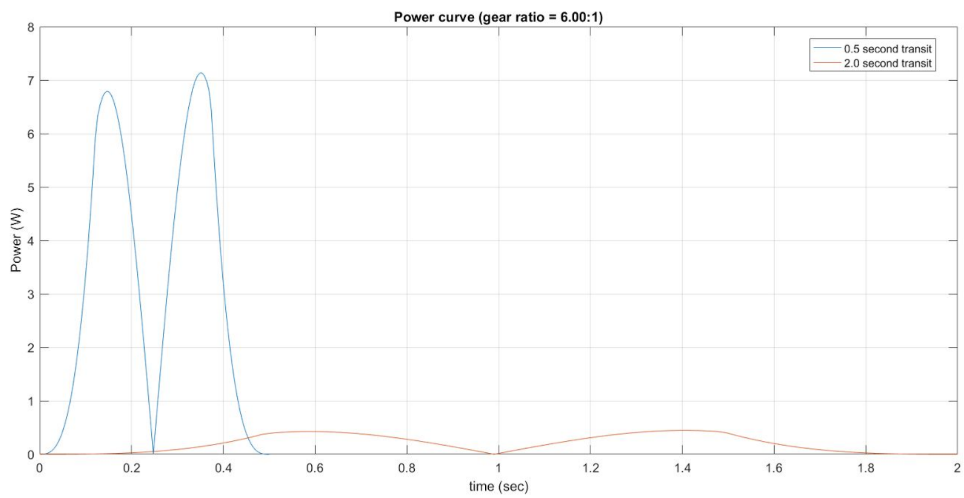


Figure 16: Power curves for a two-second and half-second transit time across a 40 degree turn.

The original specification arose from a requirement that the spotlight would be able to “jump” from one side of the stage to the other very quickly. However, the original system only had one spotlight, so quick jumps from one location to another were common. In the new system with two spotlights, these “jumps” can be performed by positioning each spotlight in its proper location, and simply turning one off and the other on.

Motor Torque & Power Hand Calculations

$\bar{\omega} = \frac{40^\circ}{0.5\text{ sec}} = 80^\circ/\text{sec}$ $\quad t_f = 0.5\text{ sec}$

$\omega = (At + B)(Ct + D)$

$t_1 = \frac{1}{4}(.5) = 0.125\text{ sec}$

$t_2 = \frac{2}{4}(.5) = 0.250\text{ sec}$

$t_3 = \frac{3}{4}(.5) = 0.375\text{ sec}$

$\omega|_0^{t_1}(0) = 0 \quad \therefore B = 0,\ D = 0$

$\omega|_0^{t_1}(t_1) = \bar{\omega} \quad \therefore A_1C_1 = \frac{\bar{\omega}}{t_1^2}$

$\omega|_0^{t_1} = \omega_1 = \left(\frac{\bar{\omega}}{t_1^2}\right)t^2$

$\omega|_{t_3}^{t_f} = \omega_3 = \left(\frac{\bar{\omega}}{t_1^2}\right)(t - t_f)^2 = \left(\frac{\bar{\omega}}{t_1^2}\right)(t^2 - 2t_f t + t_f^2)$

$\omega|_{t_1}^{t_3} = \omega_2 = AC(t - t_2)^2 + (AD + BC)(t - t_2) + BD$

$\omega_2(t_2) = \omega_p \quad \therefore BD = \omega_p$

$\omega_2(t_1) = \omega_2(t_3) = \bar{\omega}$

$AC(t_1 - t_2)^2 + (AD + BC)(t_1 - t_2) + \omega_p = AC(t_3 - t_2)^2 + (AD + BC)(t_3 - t_2) + \omega_p$

$(t_1 - t_2) = -(t_3 - t_2)$

$AD + BC = -(AD + BC)$

$AD = -BC$

$\omega_2 = AC(t - t_2)^2 + (0) + \omega_p$

$AC = \frac{\bar{\omega} - \omega_p}{(t_1 - t_2)^2}$

$\omega_p = 2\bar{\omega}$

$t_1 = \frac{1}{4}t_f$

$t_2 = \frac{2}{4}t_f$

$AC = -\frac{\bar{\omega}\cdot 16}{t_f^2}$

$\omega_2 = \frac{-16\bar{\omega}}{t_f^2}(t - t_2)^2 + 2\bar{\omega}$

$= \frac{-16\bar{\omega}}{t_f^2}\left(t^2 - t_f t + \frac{t_f^2}{4}\right) + 2\bar{\omega}$

$= \frac{16\bar{\omega}}{t_f^2}\left(-t^2 + t_f t - \frac{t_f^2}{4} + \frac{1}{8}t_f^2\right)$

$= \frac{16\bar{\omega}}{t_f^2}\left(-t^2 + t_f t - \frac{1}{8}t_f^2\right)$

$\omega_1 = \frac{16\bar{\omega}}{t_f^2}\cdot t^2$

$\omega_2 = \frac{16\bar{\omega}}{t_f^2}\cdot\left(-t^2 + t_f t - \frac{1}{8}t_f^2\right)$

$\omega_3 = \frac{16\bar{\omega}}{t_f^2}\cdot\left(t^2 - 2t_f t + t_f^2\right)$

$\alpha = \frac{d}{dt}\omega_1|_0^{t_1} + \frac{d}{dt}\omega_2|_{t_1}^{t_3} + \frac{d}{dt}\omega_3|_{t_3}^{t_f}$

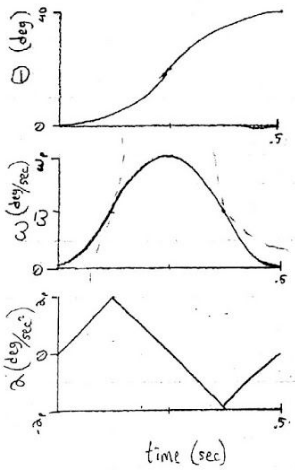
$\Theta = \int_0^{t_1}\omega_1\,dt + \int_{t_1}^{t_3}\omega_2\,dt + \int_{t_3}^{t_f}\omega_2\,dt$

$\Theta_0 = 0, \quad \Theta_f = 40^\circ$

$\alpha(t_1) = -\alpha(t_3) = \alpha_p$

Torque $M = I\alpha$

Power $P = \omega\cdot M$



4.1. Hand calculations performed to determine position, speed, and acceleration profiles for meeting the requirement of panning 40 degrees in 0.5 seconds.

4.2. MATLAB script to calculate and plot curves related to motor speed and torque.

```
clc;   % clear command window
close all; % close all figures
clearvars; % clear the workspace

%% Constants
mass_spot = 20;       % [lbm], mass of spotlight
I = 0.15;             % [slug-ft2], moment of inertia

r_p_spot  =  6;       % [in.], radius of spotlight-linked pulley
                      % note: this is just an inital guess to do sample calcs.
r_p_motor = 1;        % [in.], radius of motor-linked pulley (also a test value)

w_est = 1.39;         % estimated peak angular velocity value (in rad/sec)
t = linspace(0,0.5);  % [sec], the set of time values to solve over

%% Build the velocity profile
curve_a = 16*w_est/(t(end)^2) * ( t.^2);                          % start
curve_b = 16*w_est/(t(end)^2) * (-t.^2 + t(end)*t - (t(end))^2/8); % middle
curve_c = 16*w_est/(t(end)^2) * ( t.^2 - 2*t(end)*t + t(end)^2);   % end

% take the relevant part of each curve and combine to form the w profile
curve_sum = [curve_a(1:25), curve_b(26:75), curve_c(76:100)];

theta_sum = cumtrapz(t,curve_sum); % integration to develop angle profile

%% Acceleration and Torque calculations
% accel = dw/dt + w_0, and w_0 = 0.
dt = t(end)/100;            % linspace uses an array of 100 values, so this is the
delta.
dw = curve_sum(2:100) - curve_sum(1:99); % instant changes in velocity
alpha = [dw/dt,0];                       % dw/dt only gives 99 values, so we
concatenate.

% Torque = Inertia * alpha
M = I * alpha;                           % [ft-lbf]
M_peak = max(M);

% get peak required motor torque using pulley ratio, and convert to oz-in.
M_motor = (r_p_motor/r_p_spot) * (M * 12 * 16); % [oz-in]
M_motor_req = max(M_motor);

% get required motor speed, convert to rpm
w_motor = curve_sum * (r_p_spot/r_p_motor) * (60/(2*pi));

% Power calculation
P = abs( w_motor.*(M_motor/(12*16)) * 0.142 ); % [rpm * ft-lbf] = [W]
P_max = max(P);

disp(['Maximum Torque req.: ',num2str(max(M_motor/141.6)),' N-m']);
disp(['Power Rating: ',num2str(P_max),' W']);

%% plots
figure(1); % plot the whole of all three curves that went into curve_sum
plot(t, curve_a); hold on;
plot(t, curve_b); hold on;
plot(t, curve_c); hold on;
plot(t, zeros(1,100)); hold on; % show the lower bound
```

```
plot(t, w_est*ones(1,100));  % show the upper bound
title('Component Curves for Velocity');
legend('A', 'B', 'C', 'zero','w_m_a_x');

figure(2); % plot curve_sum (in degrees/sec), the angular velocity profile
plot(t, curve_sum*180/pi);
title('Angular Velocity');
ylabel('deg/sec');
xlabel('sec');

figure(3); % plot theta_sum (in degrees), the angular position profile
plot(t, theta_sum*180/pi);
title('Angular Position');
ylabel('degrees');
xlabel('sec');

figure(4); % plot of angular acceleration
plot(t, alpha*180/pi);
title('Angular Acceleration');
ylabel('degrees/second^2');
xlabel('sec');

figure(5); % plot of required torque, in N-m
plot(t, M*1.36); hold on;
plot(t, M*r_p_motor/r_p_spot*1.36);
title('Torque');
legend('Torque on Spotlight', 'Torque Required from Motor');
ylabel('N-m');
xlabel('sec');

figure(6); % plot of shaft flex
d_shaft = 1*2.54/100;
l_shaft = 4*2.54/100;
J_shaft = pi*d_shaft^4 /32;
th_shaft = (M*1.36)*(l_shaft)/( (79.3E9)*(J_shaft));
plot(t,th_shaft*180/pi);
title('Shaft twist');
ylabel('Twist (deg)');
xlabel('time (sec)');

figure(7); % plot of torque vs speed
plot(w_motor, M_motor/141.6);
title(sprintf('Torque vs Speed (gear ratio = %.2f:1)',r_p_spot/r_p_motor));
ylabel('Torque (N-m)');
xlabel('Speed (rpm)');

figure(8); % plot of power
plot(t, P);
title(sprintf('Power curve (gear ratio = %.2f:1)',r_p_spot/r_p_motor));
ylabel('Power (W)');
xlabel('time (sec)');

hold off;
```

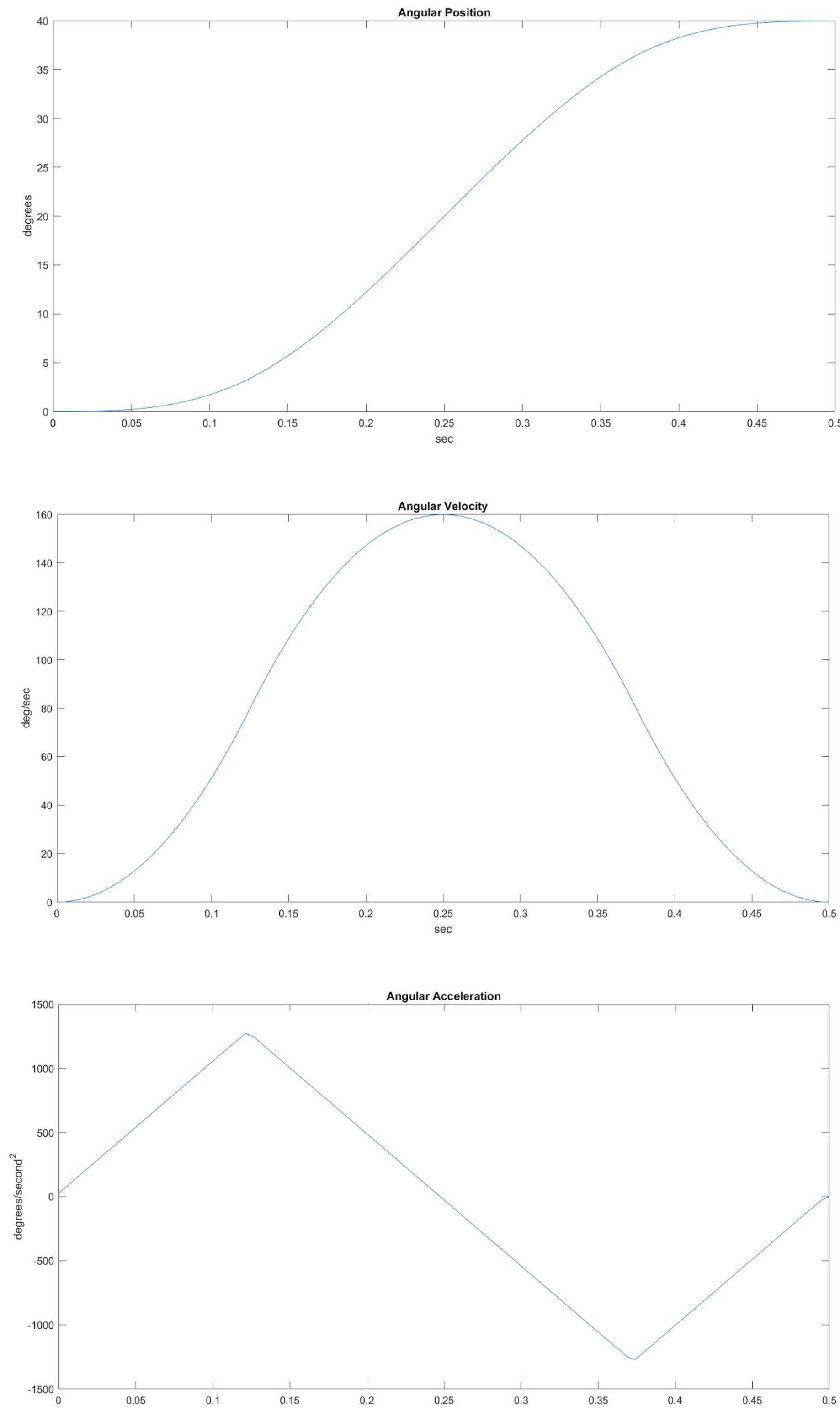


Figure 4.3. Position, velocity, and acceleration profiles calculated by MATLAB. The peak angular velocity required by the spotlight gimbal is 159.82 degrees per second using this profile set.

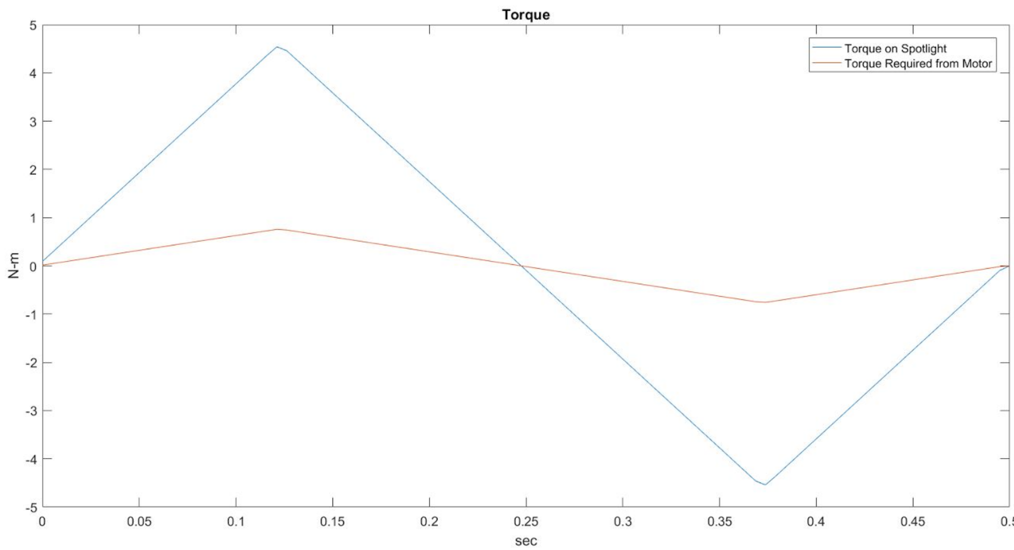


Figure 4.4. Torque requirements plotted by MATLAB, using a pulley reduction ratio of 6:1.

Encoder Precision Analysis

As discussed in the specifications section, the position of the spotlight must be known to at least ± 0.5 degrees. The encoder used on the spotlight for position control must be at least this accurate. As encoders are usually rated in counts per rotation (CPR), this leads to a minimum CPR of 720. Higher resolutions increase the accuracy and stability of the system, and it was found that certain brands of encoder do not increase cost too significantly with additional resolution. In addition, the system must be able to determine its position upon start-up without risking damage to itself by stalling the motors or colliding components. This means that an absolute encoder, in which the value of the encoder is unique for all angles, has a clear advantage. However, the team was able to use a relative encoder (where the signal only indicates changes in the angle after being powered on), by choosing one with an index signal. The position of this index signal acts in the same way as the zero reading on an absolute encoder, but with the caveat that the system would need to find it first on startup. This 'zeroing' process is easily done and is widely used in manufacturing systems, especially in additive processes such as 3D printing. With all this in mind, the team selected a US Digital relative encoder with 10,000 CPR and an index signal to produce a high degree of accuracy and stability while staying within the budget.

Mounting Frame Strength Analysis

The mounting frame includes all components which support the weight of the light and add stiffness to the system. The mounting frame must be safe (should not break or yield), hold the spotlight steadily (should not deflect), and maintain smooth rotation of the spotlight (should not yield relative to its other components, such that two bearings on the same axis become askew). In order to ensure this, the positional and angular deflections of critical components were calculated based on geometry defined in the final design model.

It should be noted that many of the dimensions were chosen because they corresponded to nominal sizes, fit with constrained parts, or were within the budget. Once general size was determined, team Dynalux used a spreadsheet to ensure all critical calculations were safe and then finalized the dimensions of each component. The hand calculations and spreadsheet results are all included in Appendix 7.

Back Plate: This component serves the purpose of supporting the square tube and connecting it to the existing light boom. It is a carbon steel plate fastened to the light boom using large U-bolts and nuts, and it has the following dimensions:

Table 5: Back Plate Data

Thickness	0.25	in
Width	12.00	in
Height	8.00	in
Weight	6.82	lbf
Outward Deflection	0.032219	in

The outward deflection results from a loading condition in which the ends of the plate are pinned. The spotlight hanging from the square tubing causes a moment in the middle of the steel plate. As a result, the top will deflect out and the bottom will deflect in. The outward deflection measures how much the top or bottom of the plate moves. This amount is very small and led the team to choose a standard 0.25 inch thick plate.

Square Tubing: As opposed to using a solid steel beam, square tubing was chosen as the primary support because it has a higher area moment of inertia (providing rigidity) and it makes installing bearings much easier. The base of the square tubing is welded to the back plate to provide a solid, permanent connection between the two.

Table 6: Square Tubing Data

Thickness	0.19	in
Width	3.00	in
Height	3.00	in
Length	14.00	in

Vertical Deflection	-0.00041	in

The deflection in the square tubing was calculated using the steel plate as a fixed surface and the spotlight weight as a point force. While this only models similar loading conditions, the cross-sectional geometry of the tubing was taken into account and the resulting deflection is minimal.

Y-Bracket: Due to the availability of tools in the Cal Poly machine shops, the team found it much easier to weld the Y-bracket into a U-shape instead of bending it from a single strip of steel. The dimensions of this strip are shown below:

Table 7: Y-Bracket Data

Thickness	0.25	in
Width	2.50	in
Side Arm Length	13.00	in
Top Length	13.50	in
Top Length End Deflection	0.01995	in
Side Arm Axial Stress	30.40	psi

Above are the results of loading conditions in which the shaft is welded to the Y-arm as a fixed point and the weight of the light hangs equally from both ends of the beam. This deflection, while not negligible, is small and the team decided to continue with these dimensions for manufacture. As with many of the components in this project, the Y-arm was built with carbon steel. When steel is in long thin beams, it tends to be fairly elastic when applied with transverse loads and much stronger when applied with longitudinal loads. As a result, the team focused more on transverse loads in order to minimize deflection that would cause the light to shake. The calculation for longitudinal stress is included above, but is 3 orders of magnitude smaller than the tensile strength of steel.

Bearing Strength & Life Analysis

Each spotlight requires 4 bearings that hold the load. When choosing bearings, there were a few characteristics that came into play. The first and most important for this project was load capacity. Because these components are critical, they need to be able to hold the entire weight of the spotlight. Second, but less critical, was bearing life. Compared to other bearing applications, the spotlights rotate much less, since they don’t turn in complete revolutions. Thus, the load capacity was the main consideration when choosing bearings.

Top System: This system was slightly more complicated to design because at least one bearing is required to support the thrust load from the spotlight and assembly weight. While many similar setups use one thrust bearing and one ball bearing, team Dynalux initially decided to choose two ball bearings because of the simplicity with assembly and ordering. Deep groove ball bearings have an inherent amount of axial load capacity along with their radial load capacity. The most conservative estimates on how much axial load a ball bearing can support is roughly 10%. This is well within the loading conditions predicted by the team, as can be seen below.

Table 8: Top System Bearing Loads

Load Capacity	1400	lbf
Axial Load Capacity	140	lbf
Spotlight Weight	19	lbf
Total Weight of Assembly	40	lbf

As can be seen from the table above, the axial load capacity is significantly higher than the total weight of the assembly. The load capacity of 1400 lbs is for one bearing, so even if it fails, the second bearing would still be able to support the load and keep it from crashing into the ground. However, after considering the event of an earthquake, which would result in spikes of higher loads, the team decided to add a thin thrust bearing in between the shaft collar and the ball bearing. This cheap needle-roller thrust bearing has a much higher axial load rating than the flanged ball bearings.

Bottom System: The bottom system was easier to model because all the load is in the radial direction. Because the bearings from the top system have a high enough rating to support the spotlight weight of 19 lbs, Team Dynalux decided to use two more of the flanged bearings for the bottom system. Keeping all four bearings identical will help with ordering and repair of the spotlight mounts in the future.

Shaft Sizing Analysis

On the spotlight mount, there are technically 5 shafts but for the purpose of analysis, only 4 will be considered because they have torque applied. The fifth shaft is merely used as an attachment point for an encoder. As with many other components, the shafts were sized according to available bar stock, and the angle of twist (rotational deflection) was calculated using those dimensions. If it was deemed too high, the shaft diameter was increased to the next standard size. The four shafts with basic dimensions and deflections are tabulated below.

Table 9: Top System Motor Shaft Data

Shaft Diameter	0.25	in
Shaft Length	4.00	in

Shaft Torque	3.54	lbf*in
Angle of Twist	0.18	degrees

Table 10: Top System Pulley Shaft Data

Shaft Diameter	0.75	in
Shaft Length	5.50	in
Shaft Torque	21.24	lbf*in
Angle of Twist	0.02	degrees
Axial Stress	86.01	psi

Table 11: Bottom System Motor Shaft Data

Shaft Diameter	0.25	in
Shaft Length	2.00	in
Shaft Torque	3.54	lbf*in
Angle of Twist	0.09	degrees

Table 12: Bottom System Pulley Shaft Data

Shaft Diameter	0.75	in
Shaft Length	3.00	in
Shaft Torque	36.01	lbf*in
Angle of Twist	0.02	degrees

All of these angles of twist are small enough to be ignored. If the angular deflections due to torsion were higher, then it would be important to look at the shear case as well. However, since the angular deflections are on such a small magnitude, it is assumed that the transverse deflections due to shear are even smaller.

Deflection and Stress Hand Calculations

	A	B	C	D	E	F
1	Components					
2	Top System, Top Bearing			Side System, Top Bearing		
3	Bore Diameter	0.75	in	Bore Diameter	0.75	in
4	Outer Diameter	1.75	in	Outer Diameter	1.75	in
5	Max Rated Load	1400.00	lbs	Max Rated Load	1400.00	lbs
6	Max System Load		lbs	Max System Load		lb
7	Top System, Bottom Bearing			Side System, Bottom Bearing		
8	Bore Diameter	0.75	in	Bore Diameter	0.75	in
9	Outer Diameter	1.75	in	Outer Diameter	1.75	in
10	Top System, Motor Pulley			Side System, Motor Pulley		
11	Bore Diameter	0.25	in	Bore Diameter	0.25	in
12	Outer Diameter	0.86	in	Outer Diameter	0.86	in
13	Top System, Shaft Pulley			Side System, Shaft Pulley		
14	Bore Diameter	0.75	in	Bore Diameter	0.75	in
15	Outer Diameter	4.02	in	Outer Diameter	4.02	in
16	Top System, Belt (Timing Belt)			Side System, Belt (Timing Belt)		
17	Center-to-Center	11.38	in	Center-to-Center	11.50	in
18	θd	2.73	rad	θd	2.73	rad
19	θD	3.56	rad	θD	3.55	rad
20	Pitch	0.20	in	Pitch	0.20	in
21	Length	30.84	in	Length	31.08	in
22	Tensioning Force	NA	lbs	Tensioning Force	NA	lbs
23	Top System, Motor			Side System, Motor		
24	Shaft Diameter	0.25	in	Shaft Diameter	0.25	in
25	Power		W	Power		W
26	Shaft Torque	3.54	lbf*in	Shaft Torque	3.54	lbf*in
27	Shaft Length	4.00	in	Shaft Length	2.00	in
28	Shaft Angle of Twist	0.18	degrees	Shaft Angle of Twist	0.09	degrees
29	Torque	0.40	Nm	Torque	0.40	Nm
30	Max Speed		rpm	Max Speed		rpm
31	Top System, Pulley Shaft			Side System, Pulley Shafts		
32	Shaft Diameter	0.75	in	Shaft Diameter	0.75	in
33	Shaft Torque	21.24	lbf*in	Shaft Torque	36.01	lbf*in
34	Shaft Length	5.50	in	Shaft Length	3.00	in
35	Shaft Angle of Twist	0.02	degrees	Shaft Angle of Twist	0.02	degrees
36	Iz	0.02	in^4	Iz	0.02	in^4
37	Stress	86.01	psi	Vertical Deflection	0.00	in
38						
39	Calculations					
40	Top System, Belt Calculations			Side System, Belt Calculations		
41	Max C2C Distance	14.62	in	Max C2C Distance	14.62	in
42	Min C2C Distance	4.02	in	Min C2C Distance	4.02	in
43						

	G	H	I
1	Mount Dimensions		
2	Back Plate		
3	Thickness	0.25	in
4	Width	12.00	in
5	Height	8.00	in
6	Weight	6.82	lbf
7	I	0.0052	in^4
8	Deflection Outward	0.032219	in
9	Hole Diameter (12mm)	0.38	in
10	Extended Beam from Backplate (Square Beam)		
11	Thickness	0.19	in
12	Width	3.00	in
13	Height	3.00	in
14	Length	14.00	in
15	2nd M of Inertia, I about Z	2.80	in^4
16	Deflection	0.00284133	in
17	Y-Arm Dimension		
18	Thickness	0.25	in
19	Width	2.50	in
20	Side Arm Length	13.00	in
21	Top Length	13.50	in
22	Total Length	39.50	in
23	I	0.003255	in^4
24	Deflection	0.01995	in
25	Stress	30.40	psi
26	Hole Diameter		in
27	Spotlight Attached Bracket		
28	Thickness	0.25	in
29	Width	2.00	in
30	Side Arm Length	6.00	in
31	Top Length	8.70	in
32	Total Length	20.70	in
33	Deflection		in
34	Hole Diameter		in

	J	K	L
1	Light Dimensions		
2	Spotlight		
3	Weight	19.00	lbf
4	Length	21.94	in
5	Height	10.39	in
6	Width	7.43	in

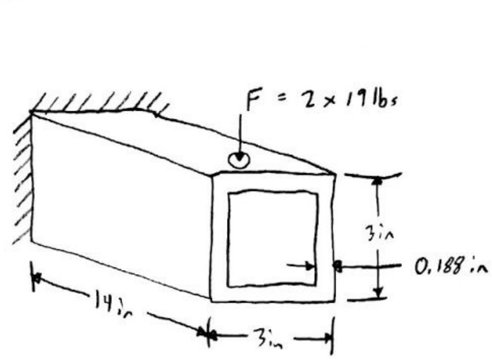
	M	N	O
1	Material Properties		
2	Steel		
3	E	30000000.00	psi
4	Density, p	0.28	lbm/in^3
5	G	11500000.00	psi

Square Tubing Deflection Calculation

$I_z = \frac{wh^3}{12}$

$y = -\frac{F\ell^3}{3EI}$

$E = 30\,MPsi$



$I = I_{OO} - I_{IO}$

$I = \frac{(3)(3)^3}{12} - \frac{(3-.188)(3-.188)^3}{12}$

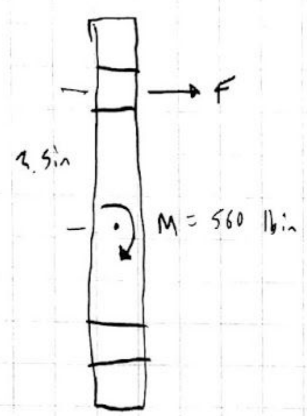
$I = 2.799\ in^4$

$y = \frac{-F\ell^3}{3EI}$

$= \frac{-(2\times19\,lbs)(14^3)}{3(30\times10^6\,psi)(2.799\,in^4)}$

$y = 0.00284\ in$

U-Bolt Stress



$F = M/d$

$F = 560\ lb\cdot in / 2.5\ in$

$F = 224\ lb$

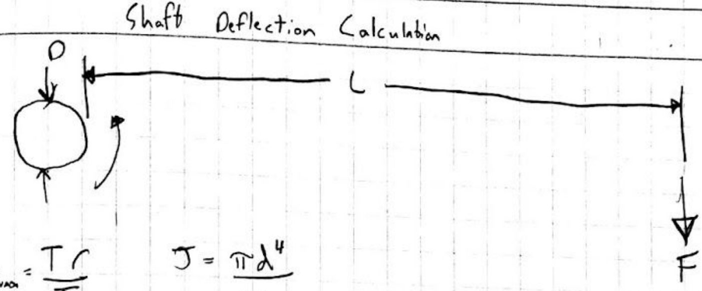
$A = (3/16)^2 \pi \cdot 2$

$A = 0.2209\ in^2$

$\sigma = F/A = 224\,lb / 0.2209\ in^2$

$\sigma = 1014\ lb/in^2$

Shaft Deflection Calculation



$$\tau_{max} = \frac{Tr}{J} \qquad J = \frac{\pi d^4}{32}$$

$$\tau_{max} = \frac{(F \cdot L)\left(\frac{D}{2}\right) 32}{\pi D^4}$$

$$\tau_{max} = \frac{F L D 16}{\pi D^4}$$

$$\tau_{max} = \frac{16 F L}{\pi D^3}$$

$$\tau_{max} \; \frac{16(25)(20'')}{\pi (1)^3}$$

$$\tau_{max} = 2546.47 \text{ lb/in}^2$$

$$\theta = \frac{T l}{G J} = \qquad J = \frac{\pi d^4}{32}$$

$$G = 11.5 \text{ Mpsi}$$

$$\theta = \frac{F(L) l \, 32}{G \pi d^4}$$

$$\theta = \frac{32 F(L) l}{G \pi d^4}$$

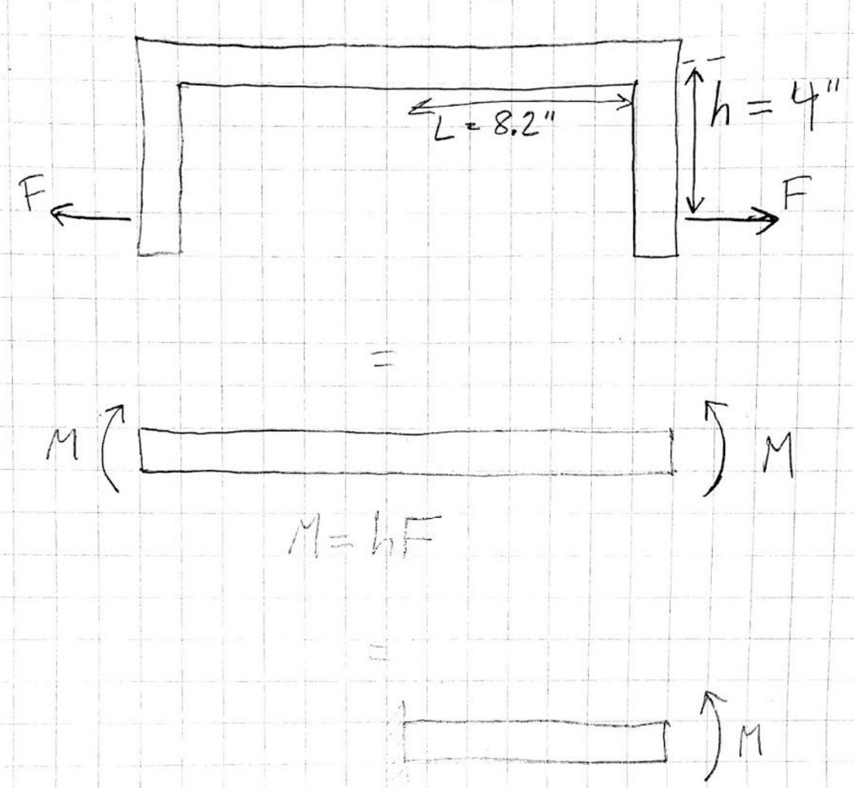
$$\theta = \frac{32 (454.1 \text{ Nm}) \left(4 \text{in} \left(\frac{2.54 \text{ cm}}{1 \text{n}}\right)\left(\frac{1 \text{ m}}{100 \text{cm}}\right)\right)}{\pi (79.3 \times 10^9 \text{ N/m}^2)(0.0254 \text{ m})} \quad (0.1016 \text{ m})$$

$$\theta = \frac{32 (25 \text{lb})(22 \text{in})(6 \text{in})(\text{in}^2)}{(11.5 \times 10^6 \text{lb})(d^4)}$$

$$\theta = 0.14 \left(\frac{360^\circ}{2\pi \text{ rad}}\right)$$

Mounting Bracket Stiffness

Assume an axial force of 10 lb.



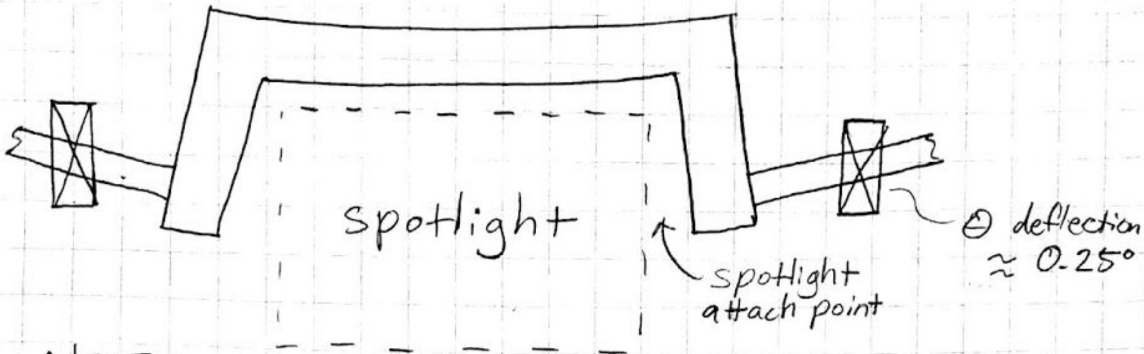
$$y' = \frac{ML}{EI}$$

$E_{steel} = 29\ Msi$

$I = \frac{1}{12} bh^3 = \frac{1}{12}(2\ in)(.25\ in)^3 = 0.002604\ in^4$

$$y' = \frac{(4\ in \cdot 10\ lb)(8.2\ in)}{(29 \times 10^6\ \frac{lb}{in^2})(.002604\ in^4)}$$

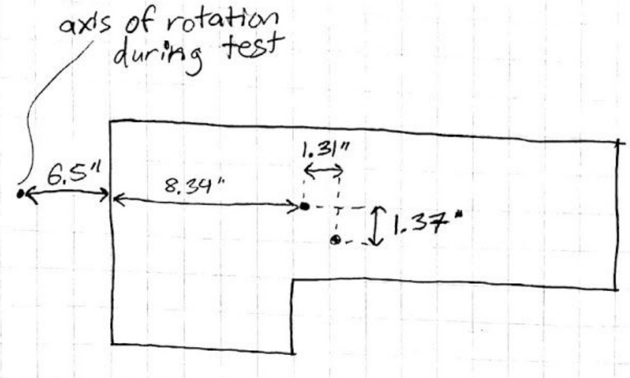
$y' = 0.00434\ \frac{in}{in}$



NOTE: This assumes that there is no light in the mount, which would add stiffness at the connection point and greatly reduce the angular deflection.

Also, the 10 lb axial force is arbitrarily assumed, as in a situation where the mount is lying on its side. During normal operation there will be no axial loading.

MOI$_x$ Test Results + Calcs



Location of CG was found graphically using the "string method" from Vibes (ME 318), but using a camera and SolidWorks to pinpoint the location.

Location is not accurate enough to be used for placing a shaft in line with the CG. It is only a rough estimate for finding the MOI about the CG.

$$I = \frac{mgr_{cg}}{4\pi^2 f_n^2} - mr_{cg}^2$$ (parallel axis theorem)

$mg = 19$ lb (adj.com specs)
$g = 32.2\ \frac{ft}{s^2}$
$r_{cg} = \sqrt{(8.34 - 1.31 + 6.5)^2 + 1.37^2} = 16.2$ in $= 1.35$ ft
$f_n = \frac{1}{T_{avg}}$ $\left(f_n = \frac{cycles}{sec}\right)$
$T_{avg} = 1.372\ \frac{sec}{swing}$ (found empirically – test results recorded in Anthony's logbook)

$$I = \frac{(19\ \frac{slug \cdot ft}{s^2})(1.35\ ft)}{4\pi^2 (\frac{1}{1.372}\ \frac{1}{sec})^2} - \left(\frac{19\ \frac{slug \cdot ft}{s^2}}{32.2\ \frac{ft}{s^2}}\right)(1.35\ ft)^2$$

$$I = 0.15\ slug \cdot ft^2$$

Torque estimation based on Anthony's required α estimation.

$$T = \bar{I}\alpha$$

$$\bar{I} = 0.15 \text{ slug}\cdot\text{ft}^2$$

$$\text{desired } \alpha = \overset{300}{\cancel{28}} \frac{\text{deg}}{\text{s}^2} = \overset{2}{\cancel{0.38}} \frac{\text{rad}}{\text{s}^2}$$

$$T = (.15 \text{ slug}\cdot\text{ft}^2)(\overset{2}{\cancel{0.38}} \frac{\text{rad}}{\text{s}^2})$$

$$T = \underset{0.3}{\cancel{0.057}} \text{ lb}\cdot\text{ft} = \underset{58}{\cancel{10.94}} \text{ oz}\cdot\text{in}$$ ~~? seems too low~~

Estimate $\bar{I}$, assuming the light is a homogeneous cylinder.

$$\bar{I}_{cylinder} = \frac{1}{12} m(3r^2 + h^2)$$

$$= \frac{1}{12}\left(\frac{19}{32.2} \text{ slug}\right)\left[3\left(\frac{4}{12} \text{ ft}\right)^2 + \left(\frac{23}{12} \text{ ft}\right)^2\right]$$

$$= 0.182 \text{ slug}\cdot\text{ft}^2 \qquad 0.182 \approx 0.15 \ \checkmark$$

Appendix 3: Budget

Item	Description	Quantity	*Cost (per)*	Cost	Store
XL 6:1 timing pulleys (pair)	XL 60T (19mm bore), 10T (6.35 mm bore), spare belt	4	*25.99*	*103.96*	eBay
XL timing pulley (148 tooth)	A 6R 3-148037	2	*9.17*	*18.34*	SDP-SI
XL timing pulley (151 tooth)	A 6R 3-151037	2	*9.30*	*18.60*	SDP-SI
0.75 flanged bearing	6384K369	8	*15.33*	*122.64*	McMaster-Carr
1.25 thrust bearing	5909K38	2	*3.23*	*6.46*	McMaster-Carr
9/16" 2-piece shaft collar	1L700	2	*6.30*	*12.60*	Amazon
Touch Screen Case	B01HV97F64	1	*27.99*	*27.99*	Amazon
Subtotal				***310.59***	
2.5" 5/16-18 U-bolt	42035	4	*4.13*	*16.52*	Fastenal
3" 1/2-13 U-bolt	41930	4	*8.19*	*32.76*	Fastenal
.25" ID x .5" OD x .625" spacer	92510A766	4	*1.60*	*6.40*	McMaster-Carr
.25" x .75" carriage bolt	93180A210	8	*6.31*	*6.31*	McMaster-Carr
.25" x 1.5" carriage bolt	93180A230	4	*9.19*	*9.19*	McMaster-Carr
#6-32 x 7/16 screw	Motor mounts	24	-		Home Depot
#10-24 x 1.25 screw	X encoder standoff	8	-		Home Depot
#10-24 x 2.25/2.50 screw	Y encoder standoff	8	-		Home Depot
#10-24 locknuts	Encoder standoffs	48	-	*56.98*	Home Depot
.75 ID x 2.00 OD washer	Thrust bearing top	2	-		Home Depot
1/4 locknuts	Spotlight Clamp, Idlers	16	-		Home Depot
1/4 ID x 3/4 OD washers	Spotlight Clamp	4	-		Home Depot
Subtotal				***111.64***	
3" x 0.1875" steel square tube		28"	*50.55*	*50.55*	Online Metals

0.75" steel round		25"	*17.48*	*17.48*	Online Metals
2.5" steel strip		60"	*40.46*	*80.92*	Online Metals
0.25" steel plate		2X 12" x 8"	*43.99*	*43.99*	Online Metals
0.22" acrylic	Electronics Plate	18" x 24"	*24.99*	*24.99*	Home Depot
Subtotal				***217.93***	
Motor	Pittman DC054B-3	4	*184.80*	*739.20*	Haydon Kerk
Encoder	E6-10000-250-IE-S-D-D-B	4	*79.91*	*319.64*	US Digital
USB RS-232 peripheral		2	*5.99*	*11.98*	Amazon
RS232 - Serial converter		2	*5.16*	*10.32*	NY Platform
RS-232 cable, 25'		3	*18.99*	*18.99*	Amazon
Dual-Channel motor driver		2	*25.90*	*51.80*	Elechouse
MicroPython Pyboard controller	Pyboard Lite V1.0	2	*24.84*	*49.68*	MicroPython Store
24V 20A motor power supply		2	*49.99*	*99.98*	Amazon
5V 2.5A uUSB power supply		3	*7.99*	*23.97*	Amazon
uSD card	8 GB class 4	3	*6.99*	*20.97*	Amazon
Raspberry Pi 2B		1	*35.00*	*35.00*	Amazon
Raspberry Pi Touch Screen		1	*69.00*	*69.00*	Amazon
Subtotal				***1,450.53***	
Total				***2,090.69***	

Appendix 4: Data Sheets

McMASTER-CARR®

Aluminum Unthreaded Spacer

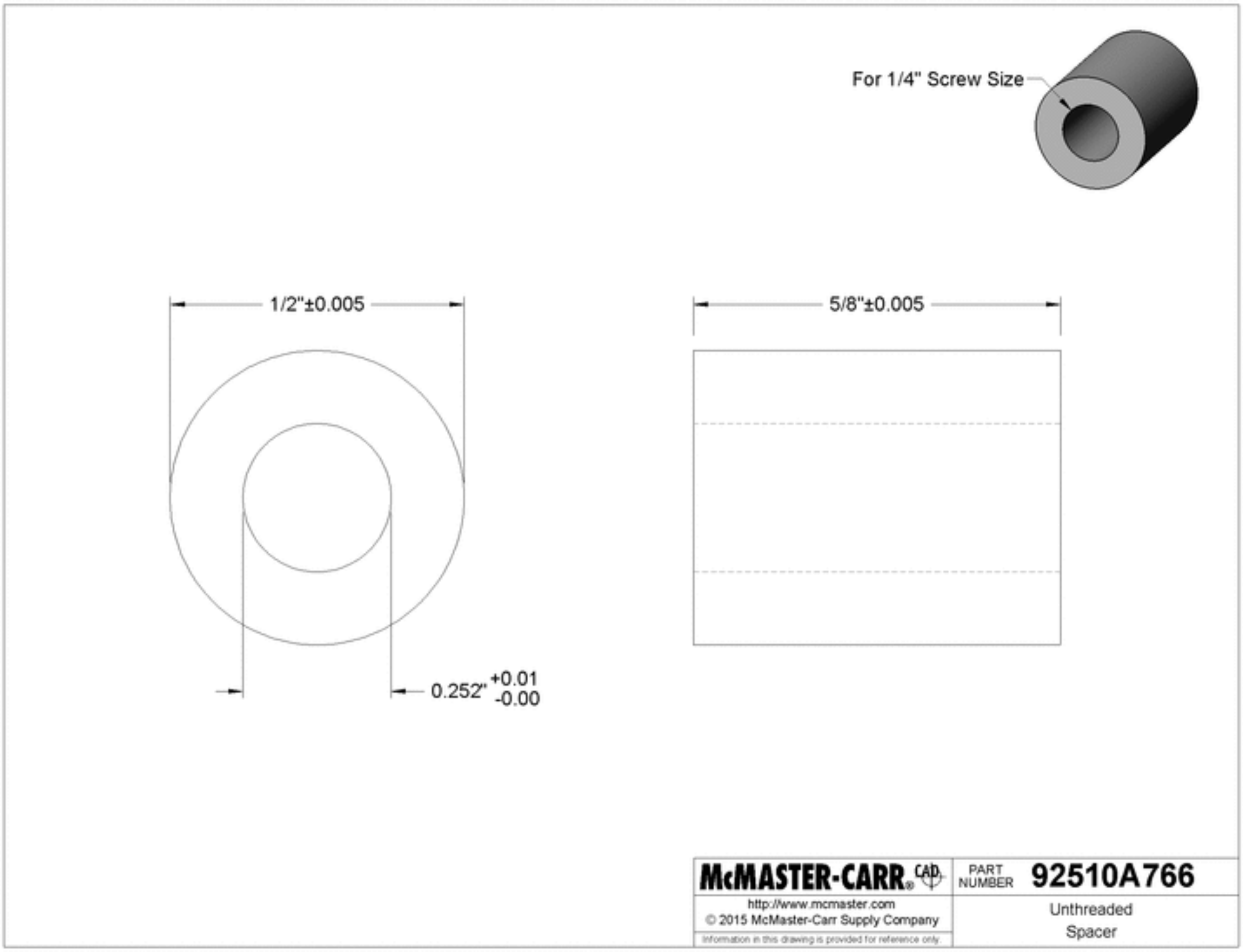
1/2" OD, 5/8" Long, for 1/4" Screw Size

In stock
1-9 Each $1.60
10 or more $1.35
92510A766

OD	1/2"
OD Tolerance	-0.005" to 0.005"
Length	5/8"
For Screw Size	1/4"
ID	0.252"
ID Tolerance	0" to 0.01"
Length Tolerance	-0.005" to 0.005"
Shape	Round
Tensile Strength	45,000 psi
Hardness	Rockwell B50
Material	2011 Aluminum
RoHS	Not Compliant

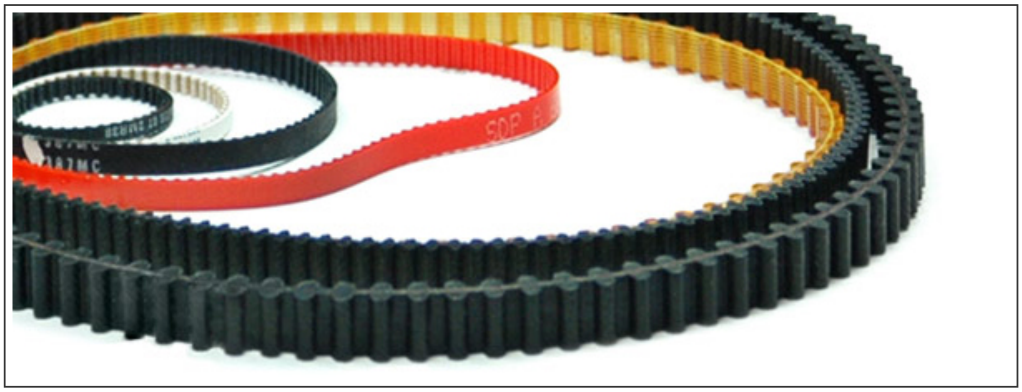
These spacers are also known as clearance spacers.

Aluminum and black-anodized aluminum are lightweight and have mild corrosion resistance.



The information in this 3-D model is provided for reference only.

Stock Drive Products/Sterling Instrument > Belts & Cables > Timing Belts (inch)



Access CAD

View Catalog Page

A 6R 3-148037

.200" (XL) Pitch, 148 Teeth, 3/8" Wide Single Sided Neoprene Belt with Fiberglass Cords

Qty Range	1 – 24	25 – 99	100 – 249	250 – 499	500+
Price/Unit	$9.17	$6.45	$5.04	$4.63	Request For Quote

Availability: 9 in Stock.

Sell Unit: Each

Quantity: 1 Add to Cart

Product Specifications

(Dimensions shown are for reference only, please refer to our catalog page for precise technical data.)

Belt Type	Single Sided
Pitch	.200" (XL)
Material	Neoprene

No. Of Grooves	148
Tension Member	Fiberglass
Belt Width	0.3750 Inch
Pitch Length	29.60 Inch

Related Products

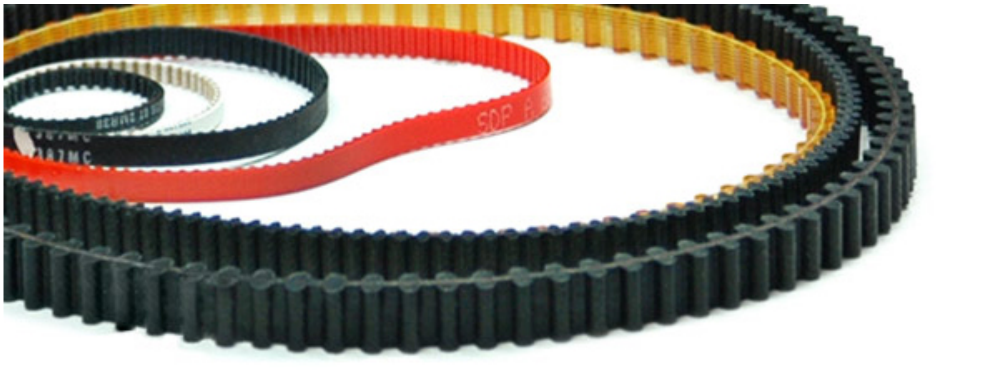
Metal Timing Pulleys

View Products

Pencil Type Tensi

View Produ

Stock Drive Products/Sterling Instrument > Belts & Cables > Timing Belts (inch)



View Catalog Page

A 6R 3-151037

.200" (XL) Pitch, 151 Teeth, 3/8" Wide Single Sided Neoprene Belt with Fiberglass Cords

Qty Range	1 – 24	25 – 99	100 – 249	250 – 499	500+
Price/Unit	$9.30	$6.54	$5.13	$4.70	Request For Quote

Availability: 71 in Stock.

Sell Unit: Each

Quantity: 1 Add to Cart

Product Specifications

(Dimensions shown are for reference only, please refer to our catalog page for precise technical data.)

Belt Type	Single Sided
Pitch	.200" (XL)
Material	Neoprene
No. Of Grooves	151
Tension Member	Fiberglass

Belt Width	0.3750 Inch
Pitch Length	30.20 Inch

Related Products

Metal Timing Pulleys

View Products

Pencil Type Tensi

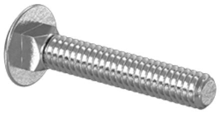
View Produ

McMASTER-CARR®

316 Stainless Steel Square-Neck Carriage Bolt

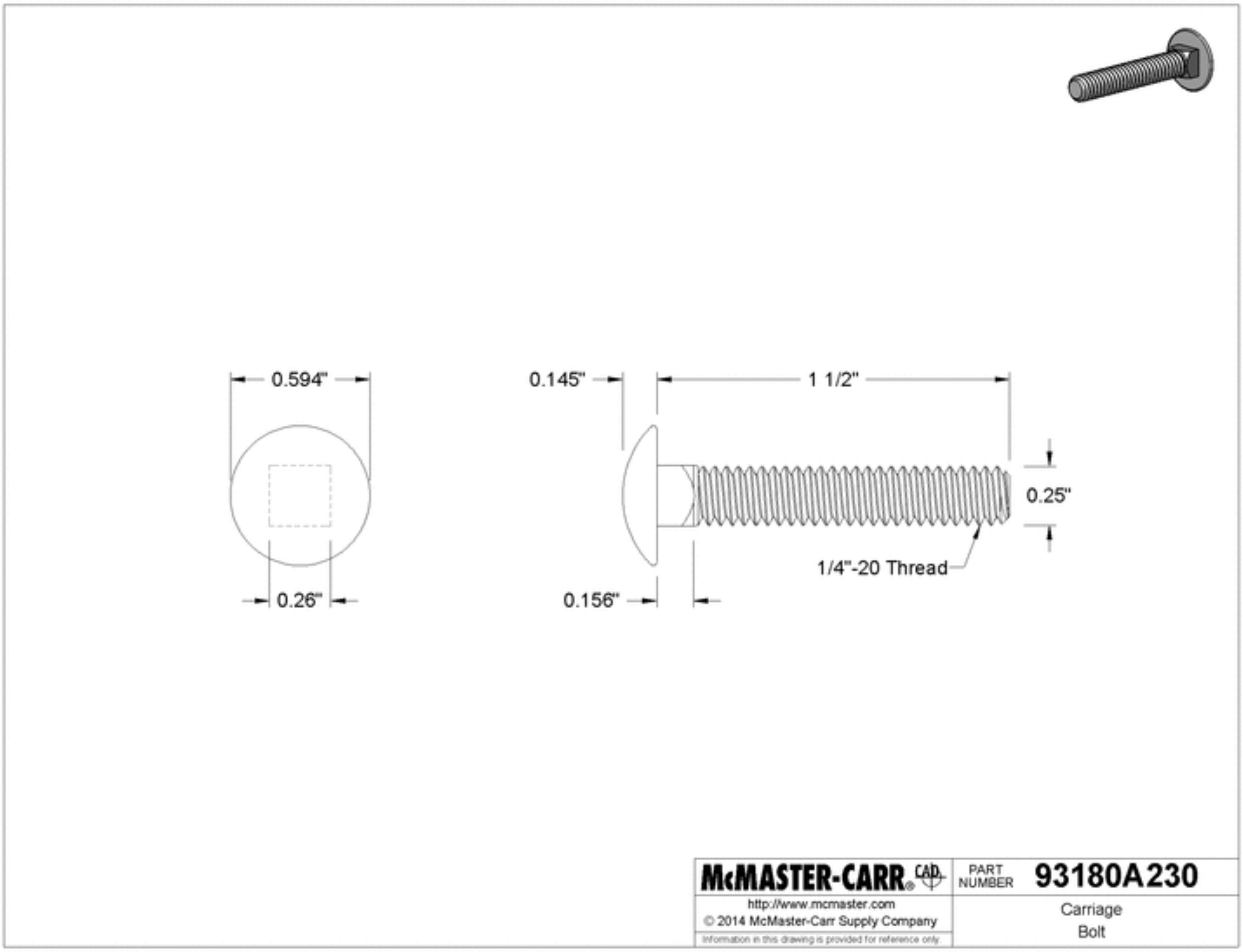
Super-Corrosion-Resistant, 1/4"-20 Thread Size, 1-1/2" Long

In stock
$9.19 per pack of 10
93180A230



Thread Size	1/4"-20
Length	1 1/2"
Threading	Fully Threaded
Head Diameter	0.594"
Head Height	0.145"
Neck Width	0.26"
Neck Length	0.16"
Material	316 Stainless Steel
Hardness	Rockwell B55
Tensile Strength	70,000 psi
Screw Size Decimal Equivalent	0.250"
Thread Type	UNC
Thread Spacing	Coarse
Thread Fit	Class 2A
Thread Direction	Right Hand
Head Type	Rounded
Rounded Head Profile	Wide
Rounded Head Style	Carriage
Neck Type	Square
Specifications Met	ANSI B18.5
System of Measurement	Inch
RoHS	Compliant

More corrosion resistant than 18-8 stainless steel bolts, these bolts have excellent resistance to chemicals and salt water and are a good choice for ACQ-treated (arsenic-free) lumber. They may be mildly magnetic. A square neck keeps them from turning when tightening a nut. A smooth, rounded head provides a finished look. Length is measured from under the head.



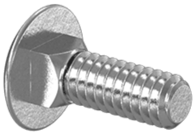
The information in this 3-D model is provided for reference only.

McMASTER-CARR®

316 Stainless Steel Square-Neck Carriage Bolt

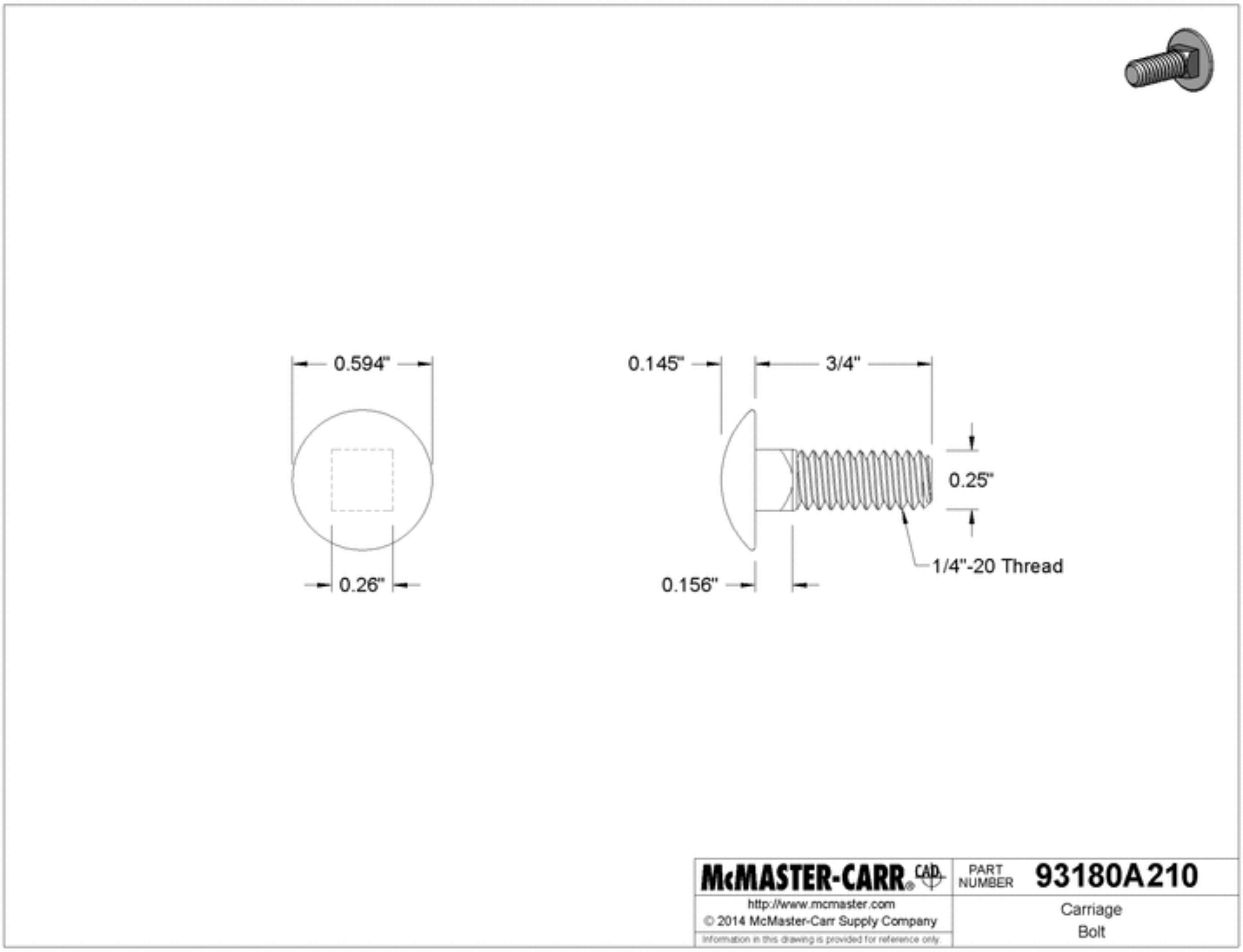
Super-Corrosion-Resistant, 1/4"-20 Thread Size, 3/4" Long

In stock
$6.31 per pack of 10
93180A210



Thread Size	1/4"-20
Length	3/4"
Threading	Fully Threaded
Head Diameter	0.594"
Head Height	0.145"
Neck Width	0.26"
Neck Length	0.16"
Material	316 Stainless Steel
Hardness	Rockwell B55
Tensile Strength	70,000 psi
Screw Size Decimal Equivalent	0.250"
Thread Type	UNC
Thread Spacing	Coarse
Thread Fit	Class 2A
Thread Direction	Right Hand
Head Type	Rounded
Rounded Head Profile	Wide
Rounded Head Style	Carriage
Neck Type	Square
Specifications Met	ANSI B18.5
System of Measurement	Inch
RoHS	Compliant

More corrosion resistant than 18-8 stainless steel bolts, these bolts have excellent resistance to chemicals and salt water and are a good choice for ACQ-treated (arsenic-free) lumber. They may be mildly magnetic. A square neck keeps them from turning when tightening a nut. A smooth, rounded head provides a finished look. Length is measured from under the head.



The information in this 3-D model is provided for reference only.

RoHS COMPLIANT

Description

The E6 Series rotary encoder has a molded polycarbonate which utilizes either a 5-pin or 10-pin latching connector. This optical incremental encoder is designed to easily mount to and dismount from an existing shaft to provide digital feedback information.

The E6 Series is easy to add to existing applications and only consists of five main components; base, cover, hubdisk, optical encoder module and internal differential line driver (differential version only).

The single-ended output version (**S**-option) is typically used with cables of 10 feet or less. For longer cable lengths, the differential output version (**D**-option) is recommended.

The base and cover are both constructed of a rugged 20% glass filled polycarbonate. Attachment of the base to a surface may be accomplished by utilizing one of several machine screw bolt circle options. Positioning of the base to the centerline of a shaft is ensured by use of a centering tool (sold separately). The cover is securely attached to the base with two 4-40 flat head screws to provide a resilient package protecting the internal components.

The internal components consist of a mylar disk mounted to a precision machined aluminum hub and an encoder module. The module consists of a highly collimated solid state light source and monolithic phased array sensor, which together provide a system extremely tolerant to mechanical misalignments.

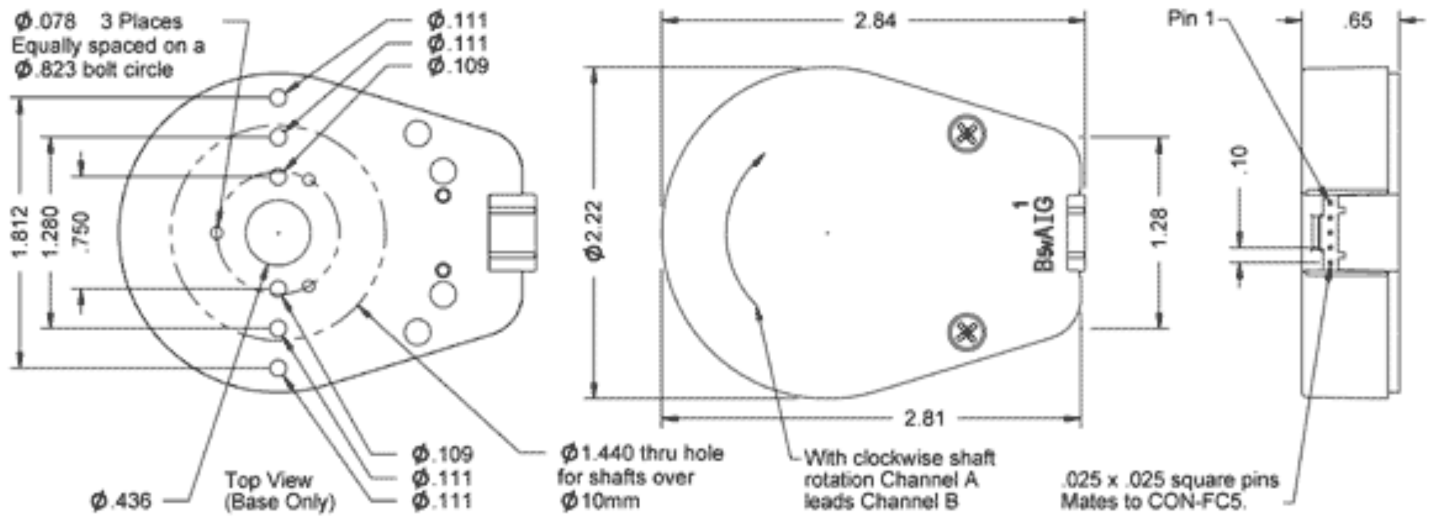
A secure connection to the E6 Series encoder is made through a 5-pin (single-ended versions) or 10-pin (differential versions) latching connector (sold separately). The mating connectors are available from US Digital with several cable options and lengths.

Features

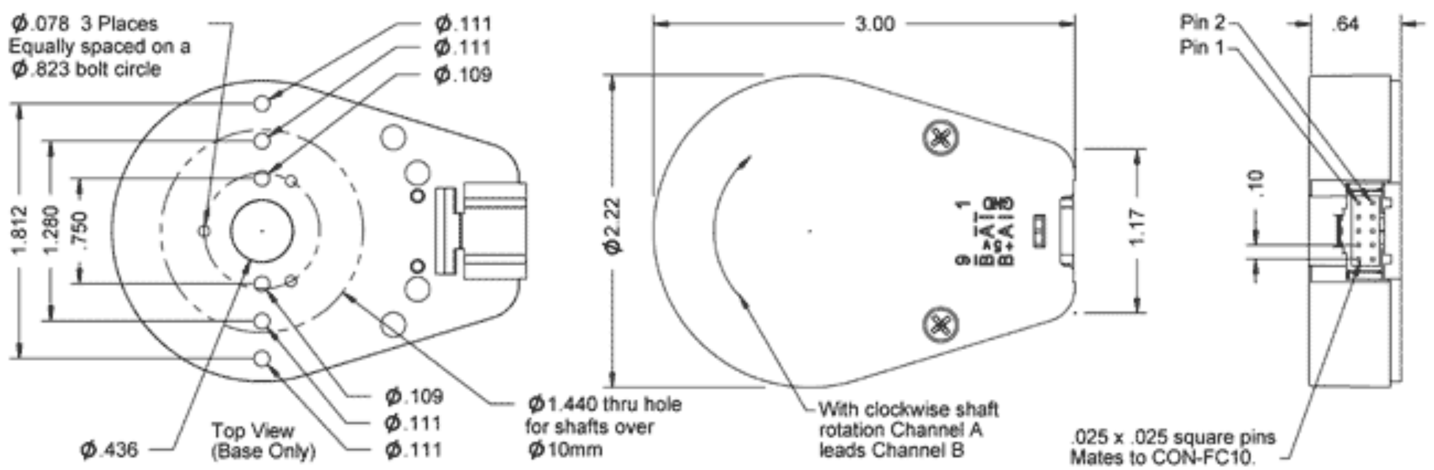
- Quick, simple assembly and disassembly
- Rugged screw-together housing
- Positive latching connector
- Accepts .010" axial shaft play
- 64 - 10000 CPR
- 2 channel quadrature TTL squarewave outputs
- Optional index (3rd channel)
- Fits shaft diameters from 2mm to 1"

RoHS COMPLIANT

Single-Ended



Differential



Environmental

Parameter	Value	Units
Operating Temperature (CPR < 3600)	-40 to 100	C
Operating Temperature (CPR ≥ 3600)	-25 to 100	C
Vibration (5Hz to 2kHz)	20	G
Electrostatic Discharge, IEC 61000-4-2	± 4	kV

Mechanical

Parameter	Dimension	Units
Max. Shaft Axial Play	±0.010	in.
Max. Shaft Eccentricity Plus Radial Play (1)	0.004	in.
Max. Acceleration	250000	rad/sec²
Max. RPM (2) **(CPR ≤ 2500)** e.x. CPR=2500, max. rpm=7200 e.x. CPR=100, max. rpm=60000	minimum value of ((18 x 10^6) / CPR) and (60000)	rpm
Max. RPM (2)**(CPR > 2500 and ≤ 5000)** e.x. CPR=4096, max. rpm=5273	(21.6 x 10^6) / CPR	rpm
Max. RPM (2)**(CPR > 5000)** e.x. CPR=10000, max. rpm=4320	(43.2 x 10^6) / CPR	rpm
Typical Product Weight Single-Ended (**S**-option) Differential (**D**-option, **L**-option)	 1.55 1.83	oz.
Codewheel Moment of Inertia	8.9 x 10^-5 for bore < 12mm 4.0 x 10^-4 for bore ≥ 12 mm	oz-in-s²
Hub Set Screw	#3-48 or #4-48	
Hex Wrench Size	0.050	in.
Encoder Base Plate Thickness	0.135	in.
3 Mounting Screw Size	#0-80	
2 Mounting Screw Size	#2-56 or #4-40	
3 Screw Bolt Circle Diameter (3)	0.823 ± 0.005	in.
2 Screw Bolt Circle Diameter	0.750 ± 0.005	in.
Required Shaft Length (4) With E-option (3) With H-option	0.445 to 0.570 0.445 to 0.750 > 0.445	in.
Index Alignment to Hub Set Screw	180 Typical	mechanical degrees

Torque Specifications

Parameter	Torque
Hub Set Screw to Shaft	2-3 in-lbs
Cover (4-40 screws through cover into base)	2-4 in-lbs
Base to Mounting Surface	4-6 in-lbs
Base to Mounting Adapter Plate	4-6 in-lbs
Adapter Plate to Mounting Surface	4-6 in-lbs

RoHS COMPLIANT

Parameter	Torque
Module to Base	3.5-4 in-lbs

Phase Relationship

Single-Ended (S) / Differential (D) Option:

A leads B for clockwise shaft rotation, and B leads A for counterclockwise rotation as viewed from the cover/label side of the encoder.

Avago/Agilent compatible pin-out (A, L) Option:

B leads A for clockwise shaft rotation, and A leads B for counterclockwise rotation as viewed from the cover/label side of the encoder.

Single-ended Electrical

- Specifications apply over entire operating temperature range.
- Typical values are specified at Vcc = 5.0Vdc and 25 ° C.
- For complete details, see the EM1 andEM2 product pages.

Parameter	Min.	Typ.	Max.	Units	Conditions
Supply Voltage	4.5	5.0	5.5	V	
Supply Current		27	33	mA	CPR < 1000, no load
		54	62	mA	CPR ≥ 1000 and < 3600, no load
		72	85	mA	CPR ≥ 3600, no load
Low-level Output			0.5	V	I_{OL} = 8mA max., CPR < 3600
			0.5	mA	I_{OL} = 5mA max., CPR ≥ 3600
		0.05		mA	no load, CPR < 3600
		0.25		mA	no load, CPR ≥ 3600
High-level Output	2.0			V	I_{OH} = -8mA max., CPR < 3600
	2.0			V	I_{OH} = -5mA max., CPR ≥ 3600
		4.8		V	no load, CPR < 3600
		3.5		V	no load, CPR ≥ 3600
Output Current Per Channel	-8		8	mA	CPR < 3600
	-5		5	mA	CPR ≥ 3600
Output Rise Time		110		nS	CPR < 3600
		50		nS	CPR ≥ 3600
Output Fall Time		35		nS	CPR < 3600
		50		nS	CPR ≥ 3600

Differential Electrical

- Specifications apply over entire operating temperature range.
- Typical values are specified at Vcc = 5.0Vdc and 25 ° C.
- For complete details, see the EM1 and EM2 product pages.

Parameter	Min.	Typ.	Max.	Units	Conditions
Supply Voltage	4.5	5.0	5.5	V	
Supply Current		29	36	mA	CPR < 1000, no load
		56	65	mA	CPR ≥ 1000 and < 3600, no load
		74	88	mA	CPR ≥ 3600, no load
Low-level Output		0.2	0.4	V	I_{OL} = 20mA max.
High-level Output	2.4	3.4		V	I_{OH} = -20mA max.
Differential Output Rise/Fall Time			15	nS	

Pin-outs

5-pin Single-ended (1)		10-pin Differential, Standard (2)		10-pin Differential (L-option) (2)		10-pin Single-ended (A-option) (2)	
Pin	Description	Pin	Description	Pin	Description	Pin	Description
1	Ground	1	Ground	1	No connection	1	A channel
2	Index	2	Ground	2	+5VDC power	2	+5VDC power
3	A channel	3	Index-	3	Ground	3	Ground
4	+5VDC power	4	Index+	4	No connection	4	No connection
5	B channel	5	A- channel	5	A- channel	5	No connection
		6	A+ channel	6	A+ channel	6	Ground
		7	+5VDC power	7	B- channel	7	+5VDC power
		8	+5VDC power	8	B+ channel	8	B+ channel
		9	B- channel	9	Index-	9	+5VDC power
		10	B+ channel	10	Index+	10	Index

(1) 5-pin single ended mating connector isCON-FC5.
(2) 10-pin differential mating connector is CON-FC10.

Options

Index

Provides a single pulse per revolution.

3-option

3-option makes all five of these hole diameters .125".

View option:

- Single-ended Version

- Differential Version

E-option

The **E**-option provides a cylindrical extention to the cover allowing for longer shafts of up to .750".

Please note: Only available for shaft diameters <.472".

View option:

- Single-ended Version

- Differential Version

H-option

The **H**-option adds a hole to the cover for the shaft to pass through.

- Shafts 2mm to 10mm, a .438" diameter hole is supplied.
- Shafts 12mm to 1", a 1.047" diameter hole is supplied.

View option:

- Single-ended Version

- Differential Version

L-option

Provides Avago / Agilent / HP differential compatible pin-out. See direct replacement information above.

M-option

This adapter plate is for mounting to a 3" diameter bolt circle.

View option:

- Single-ended / Differential Versions

T-option

When mounting holes are not applicable, a pre-applied transfer adhesive mounting option is available.

Instructions: The T-option includes transfer adhesive with a peel-off backing on the encoder base. First, peel the paper backing from the transfer adhesive. Next, align the centering tool with the center hole on the non-adhesive side of the encoder base. Slide the base (adhesive side down) with the centering tool over the motor shaft and press firmly to form a solid bond between the encoder base and mounting surface. Remove the centering tool and continue with the standard assembly. You are required to use the centering tool with the T-option to ensure proper placement.

View option:

- Single-ended Version

- Differential Version

Accessories

1. Centering Tool

The centering tool is only included with the **-3** packaging option. It has to be ordered separately for other packaging options.

Part #: CTOOL - (Shaft Diameter)
Description: This reusable tool provides a simple method for accurately centering the **E6** base onto the shaft. It is recommended for the following situations:

- When using mounting screws smaller than #4-40.
- When the position of the mounting holes is in question.
- When using the 3-hole mounting pattern.
- When using the **T**-option transfer adhesive.

Instructions: When mounting encoder base, slide centering tool down shaft until it slips into centering hole of encoder base. Tighten mounting screws, then remove centering tool.

2. Hex Tool

Depending on the order packaging option, either a hex driver or hex wrench is included.

Part #: HEXD-050
Description: Hex driver, .050" flat-to-flat for #3-48 or #4-48 set screws. Only included with **-B** or **-1** packaging options.

Part #: HEXW-050
Description: Hex wrench, .050" flat-to-flat for #3-48 or #4-48 set screws. Only included with **-2** or **-3** packaging options.

3. Spacer Tool

A spacer tool is included for all packaging options.

Part #: SPACER-E6S
Description: For shaft sizes < 0.472"

Part #: SPACER-E6L
Description: For shaft sizes 12mm to 1"

4. Screws

Screws for base mounting must be purchased separately. Screws for mounting the housing to the base are included.

Part #: SCREW-080-250-PH
Description: Pan Head, Philips #0-80 UNF x 1/4"
Quantity Required for Mounting: 3 per encoder

Part #: SCREW-256-250-PH
Description: Pan Head, Philips #2-56 UNC x 1/4"
Quantity Required for Mounting: 2 per encoder

Part #: SCREW-440-250-PH
Description: Pan Head, Philips #4-40 UNC x 1/4"
Quantity Required for Mounting: 2 per encoder

Avago Direct Replacement

Avago Direct Replacement:

US Digital's **E6** encoder may now be used as a direct replacement for the following Avago encoders:

HEDL-6500, **HEDL-6505**, **HEDL-6540**, **HEDL-6545**.
HEDM-6500, **HEDM-6505**, **HEDM-6540**, **HEDM-6545**.
HEDS-6500

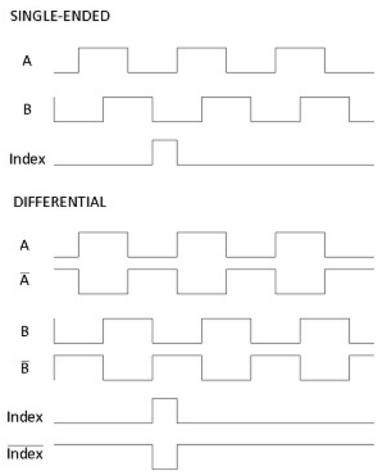
, **HEDS-6505**, **HEDS-6540**, **HEDS-6545**.

Notes:

- In order for the **E6** to be fully compatible, CA-3921-2FT* must also be ordered separately.

*Custom cable lengths are available (standard length is 2ft).

Output Waveforms



Assembly Instructions

E6 Assembly Instructions - http://usdigital.com/assets/general/E6_Assembly_Instructions.pdf

Ordering Information

E6 - [ ] - [ ] - [ ] - [ ] - [ ] - [ ] - [ ]

RoHS COMPLIANT

CPR	Bore	Index	Output	Cover	Base	Packaging
64 =	079 = *2mm*	NE = *No Index*	S = *Single-ended*	D = *Default*	D = *Default*	B = *Encoder components packaged in bulk. One spacer tool and one hex wrench for orders up to 9 units, for orders of 10...*
100 =	118 = *3mm*	IE = *Index*	D = *Differential*	E = *Cover Extension*	3 = *0.125" diam. for five base mounting holes*	1 = *Encoders Individually packaged. One spacer tool and one hex wrench for orders up to 9 units, for orders of 10 units...*
200 =	125 = *1/8"*		L = *Avago Compatible Differential*	H = *Hole in Cover*	M = *Adds 4-hole mounting adapter plate.*	2 = *Encoders packaged individually with one spacer tool and one hex wrench per encoder.*
400 =	156 = *5/32"*		A = *Avago Compatible 10-pin Single-ended*		T = *Adds transfer adhesive to base*	3 = *Encoders packaged individually with one spacer tool, one hex wrench, and one centering tool per encoder.*
500 =	157 = *4mm*					
512 =	188 = *3/16"*					
1000 =	197 = *5mm*					
1024 =	236 = *6mm*					
1800 =	250 = *1/4"*					
2000 =	313 = *5/16"*					
2048 =	315 = *8mm*					
2500 =	375 = *3/8"*					
3600	394 = *10mm*					
4000	472 = *12mm*					
4096	500 = *1/2"*					
5000	551 = *14mm*					
7200	625 = *5/8"*					
8000	750 = *3/4"*					
8192	787 = *20mm*					
10000	875 = *7/8"*					
	984 = *25mm*					
	1000 = *1"*					

RoHS COMPLIANT

Notes

- Cables and connectors are not included and must be ordered separately.
- US Digital warrants its products against defects in materials and workmanship for two years. See complete warranty for details.

US DIGITAL
1400 NE 136th Avenue
Vancouver, Washington 98684, USA
info@usdigital.com
www.usdigital.com
Local: 360.260.2468
Toll-free: 800.736.0194

McMASTER-CARR®

Ball Bearing

Flanged, for 3/4" Shaft Diameter, 1-3/4" OD

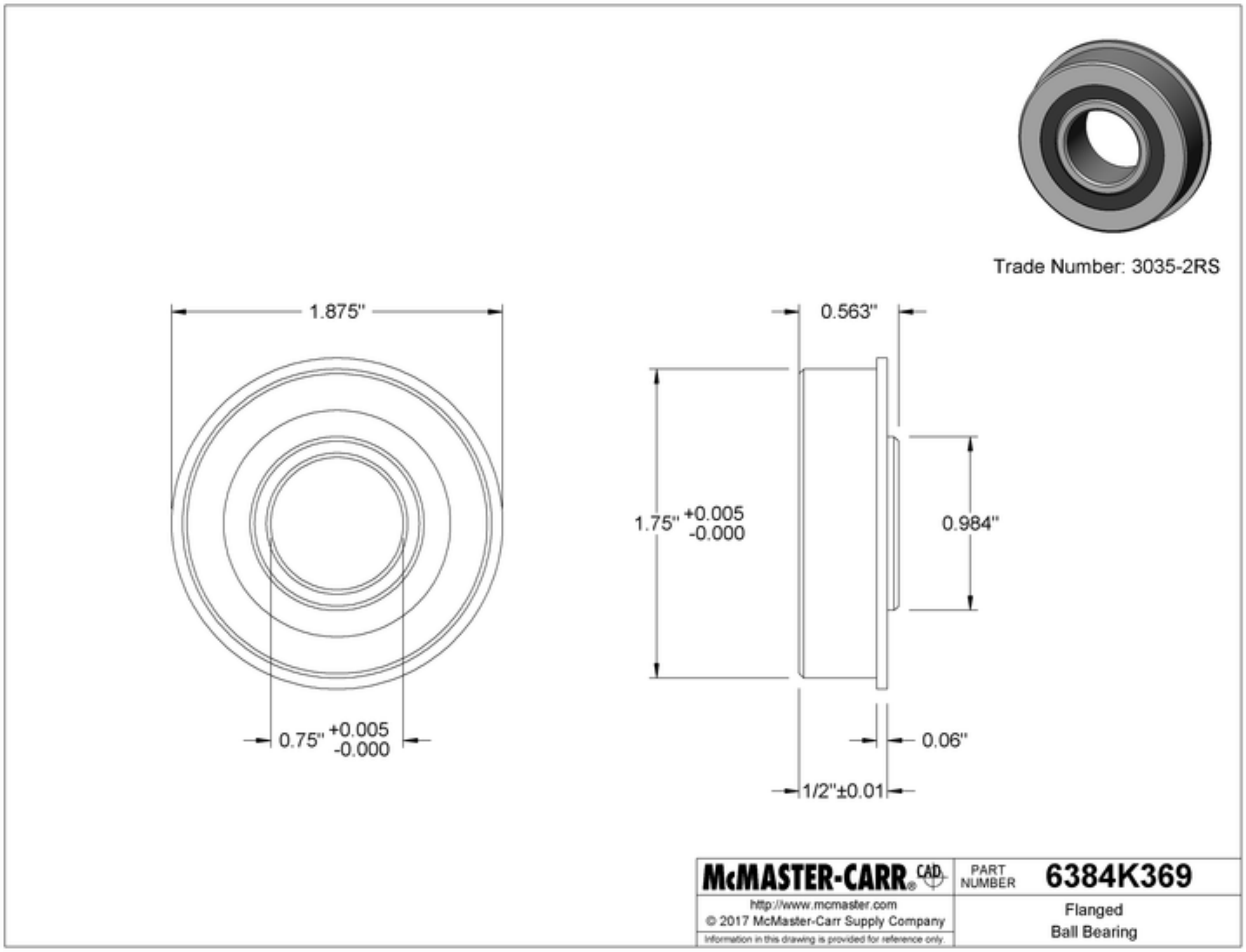
In stock
$15.33 Each
6384K369

Bearing Type	Ball
For Load Direction	Radial
Construction	Single Row
Seal Type	Sealed
Inner Ring Type	Extended
Ball Bearing Type	Flanged
Trade No.	3035-2RS
For Shaft Type	Round
For Shaft Diameter	3/4"
ID	0.75"
ID Tolerance	0" to 0.005"
For Housing ID	1 3/4"
OD	1.75"
OD Tolerance	0" to 0.005"
Width	1/2"
Width Tolerance	-0.01" to 0.01"
Flange	
OD	1.875"
Thickness	0.06"
Inner Ring	
OD	0.984"
Width	0.563"
Ring Material	Steel
Ball Material	Steel
Cage Material	Nylon Plastic
Seal Material	Buna-N Rubber
Radial Load Capacity, lbs.	
Dynamic	1,300
Static	1,000
Maximum Speed	3,000 rpm
Lubrication	Lubricated
Lubricant	Grease
Shaft Mount Type	Press Fit
Temperature Range	-20° to 250° F
ABEC Rating	Not Rated
Radial Clearance	0.001" to 0.005"
RoHS	Compliant

The flange ensures proper positioning inside a tube or housing.

Sealed bearings block out dust and other contaminants better than open and shielded bearings, but retain the most heat.

Bearings with extended inner ring provide additional shaft support.



The information in this 3-D model is provided for reference only.

HOT ROLLED MILD STEEL PLATE A36

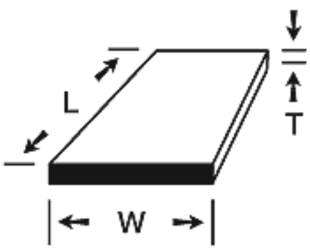
Part #: 9610

0.25" A36 Hot Rolled Steel Sheet/plate is made of low carbon steel that is commonly found in most industries. A36 offers good weldability, machinability, and can be heat treated to harden its surface.

Unlike cold rolled steel, Hot Rolled Steel has a rougher surface and with galvanization, it can resist corrosion well.

View our "Guide to Mild Steel" for available grades, shapes and additional information.

Material Meets These Standard(s): ASTM A-36



Available Sizes

Create a Custom Size

Technical Information

DIMENSIONS

Weight/Square Foot: 10.19 pounds

Dimension Name	Value
Thickness	0.25"

View Other Sizes

Weight/Square Foot
10.19 pounds

Material Specifications

This material meets the following specs: **ASTM A-36**

Chemistry Information: A36 Mild Steel

Element	Percentage
C	0.26
Cu	0.2
Fe	99
Mn	0.75
P	0.04 max
S	0.05 max

Please note that this data is to be used ONLY FOR REFERENCE, NOT FOR DESIGN, and by using it, you agree that any decisions you make regarding materials for your project are at your own discretion.

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SanDisk

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- Seamless speed and performance with microSD/SDHC compatible device
- Class 4 Speed performance rating (based on SD 2.0 Specification)
- Tested under the most extreme conditions
- Ships in Certified Frustration-Free Packaging

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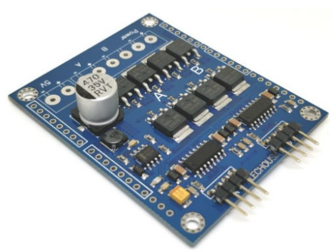

50A Dual-Channel motor drive module-Arduino Compatible

$25.90

Units in Stock: 1835
Date Added: Friday 22 June, 2012

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Product Description:

Introduction

This motor driver works with single channel max 20A working current capacity. This module performs far better than MC33886 or L298 motor driver, especially in terms of motor speed control and power efficiency.

This driver has a brake function, which can quickly stop the motor. And the operation is very easy.The driver module contains a full-bridge driver chip and MOSFET with as low as 0.003 Ohm internal resistance. The full-bridge driver IC minimizes the switching loss of MOSFET and improves power efficiency.

This driver module can work under the PWM duty cycle of 0% -98%.

Parameter

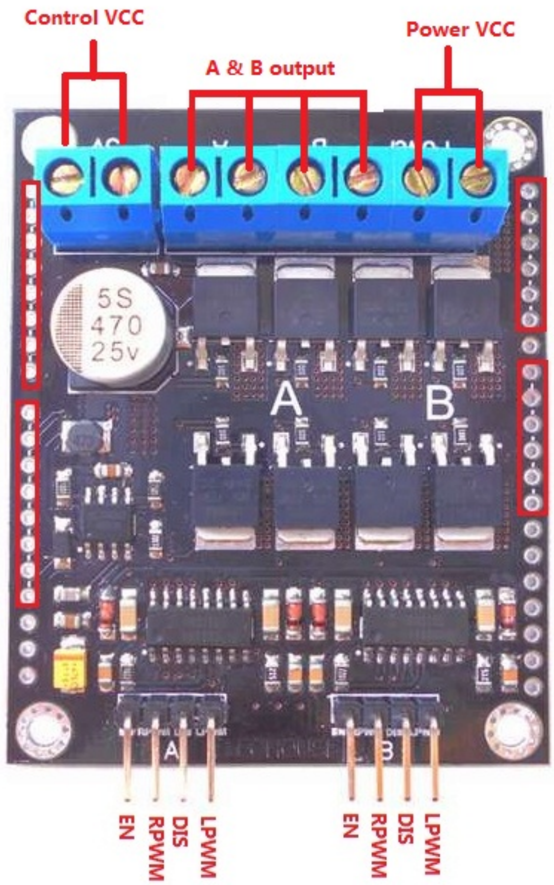
- Peak current (Load): 150A
- Recommend max working current(Load): 20A
- Power VCC (Load): 0V~30V
- Recommend power VCC (load) : 12V ~ 26V
- Controlling VCC: 4V~12V
- Controlling TTL Voltage; 2.5V ~ 12V

Note:

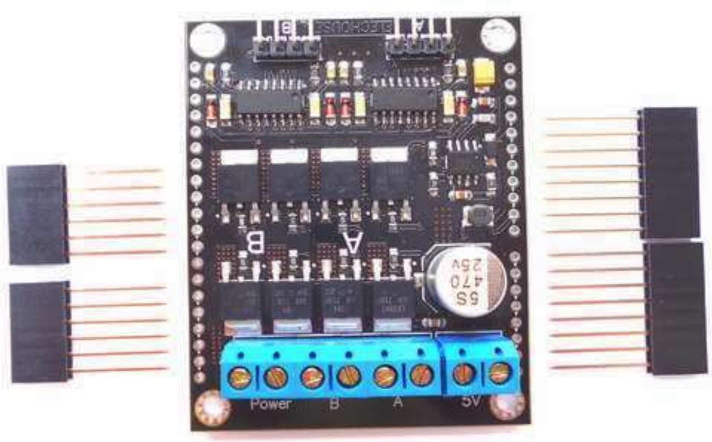
1. Controlling TTL voltage means the High voltage of the control pins (EN, LPWM, RPWM, DIS).
2. The stable max working current is 20A while load VCC is between 12V~30V. The current is restricted by heat dissipation. Current, we don't add any heat radiator on the board.So if the current is over 20A, the heat may melt the sldering tin and cause problems. If you want it working stable at higher current, you should add radiator.
3. Power VCC is recommended to be higher than 12V if your load is large-current devices. While over 12V, the MOSFET is working fully and its power consumption is small. So the heat will be less. If your load current is not large and just several Amperes, the power VCC can be as low as 3V.

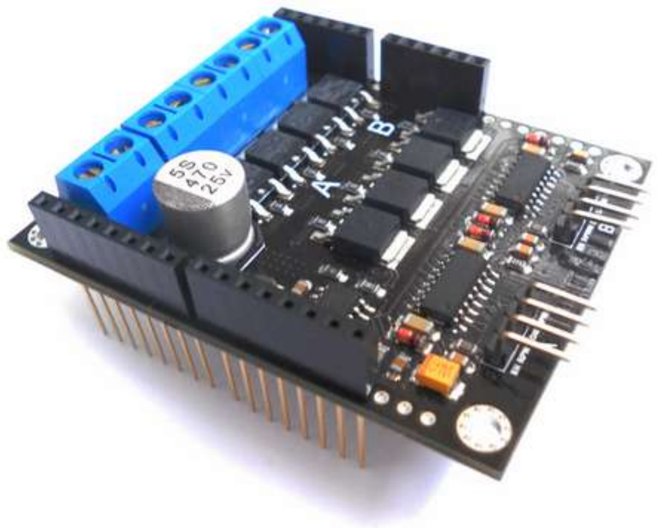
Interface

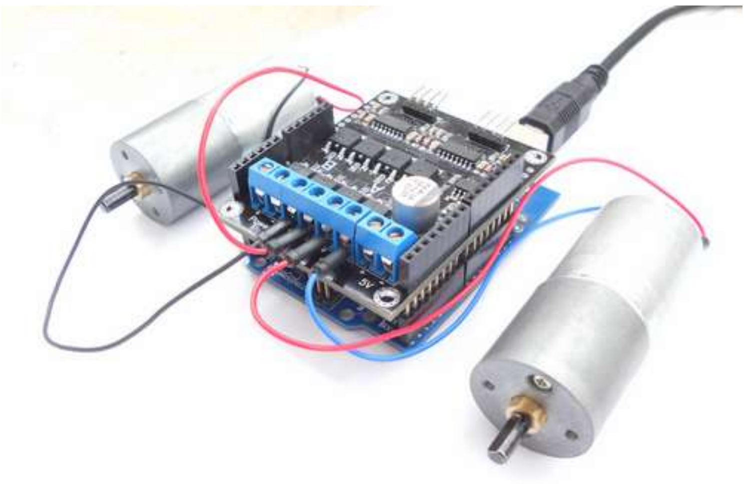
We are trying to let this driver be compatible with Arduino and non-Arduino users. We leave holes on the PCB and so mount long-pin felmale hearders to plug in Arduino. If you are non-Arduino user, leave the holes alone.



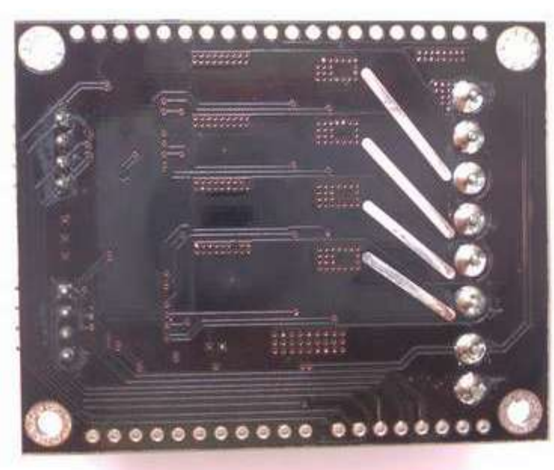
Pins above in the red box are for Arduino. They are for Arduino.







To improve performance while with large current load. you could add soldering tin on the routs shown below.



Dimension

- PCB Size: 52.3mm x 63.9mm
- Mount Hole: 44.4mm x 57.0mm, 3mm Diameter
- High: 12.4mm (without long-pin headers) or 27.4mm (with long-pin headers)

Control

Basically the control is very easy.

- Rotate forward: EN = HIGH, RPWM = PWM, LPWM = HIGH, DIS = vacant
- Rotate reverse: EN = HIGH, RPWM = HIGH, LPWM = PWM, DIS = vacant

- Stop and brake: EN = HIGH, RPWM = HIGH, LPWM = HIGH, DIS = vacant
- Stop but not brake: EN = 0, RPWM = HIGH, LPWM = HIGH, DIS = vacant
- Prohibit : EN = X, RPWM = X, LPWM = X, DIS = HIGH

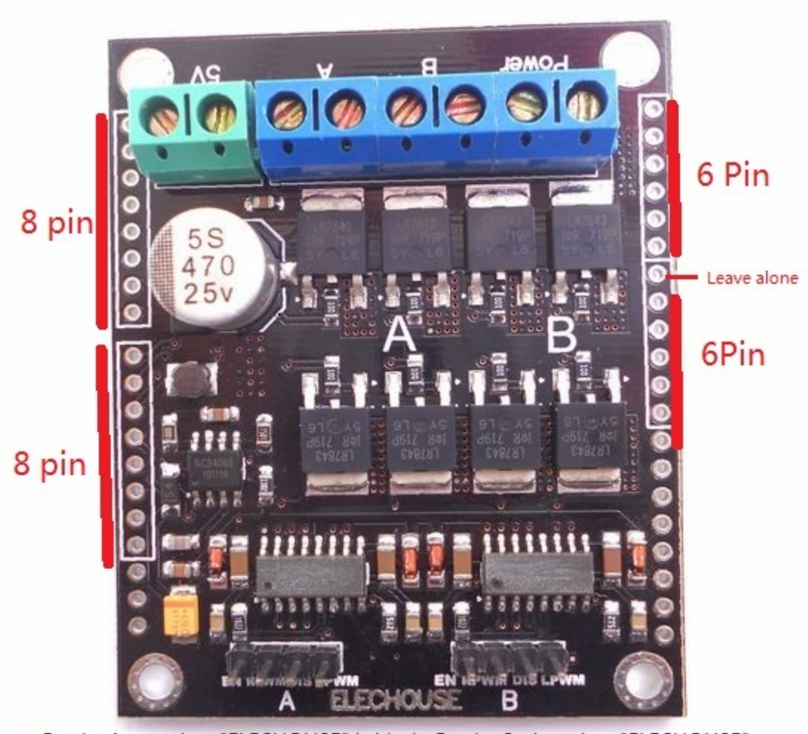
For Arduin users:

Channel	Driver Module	Arduino Pin (V1)	Arduino Pin (V2)
A	EN	2	2
	RPWM	3	3
	DIS	4	4
	LPWM	5	11
B	EN	8	8
	RPWM	9	9
	DIS	7	7
	LPWM	6	10

Please note:

1. Smaller PWM duty will get higher speed.
2. PWM frequency should be 1Khz ~ 60Khz. Smaller frequency could get it work but not in perfect performace.It may increase the module's response time, but very slight in nanosecond level.We are not able to sense it. Default frequency of Arduino PWM is 0.5Khz. In our test, the default frequency could get it work very well. But remember, for better performance, the recommended frequency is 1Khz ~ 60Khz. In our library, we set the pwm frequency over 1Khz.

Note
Current we updated this module to V2. If you version is the 2nd version, be careful while you solder the long-header pins.



On the 1st version, "ELECHOUSE" is black. On the 2nd version, "ELECHOUSE" is silver

The software is also modified for version 2. You could find corresponding comments on the change in the library.

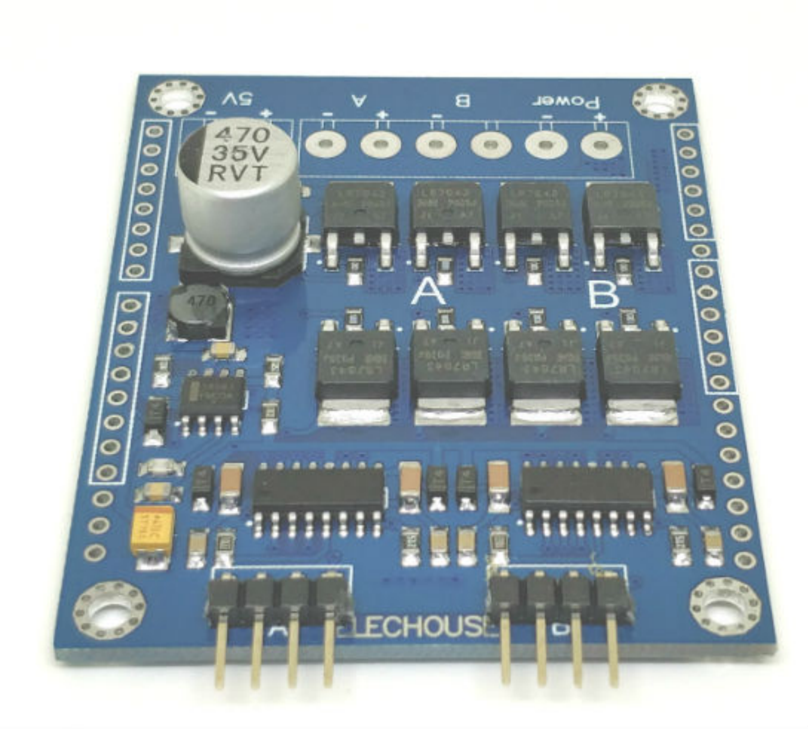
Document

Library for Arduino

Product list

- 50A motor drive module x1

Note: as the blue header could not bear more than 10A current, now all the new boards have no blue header mounted.



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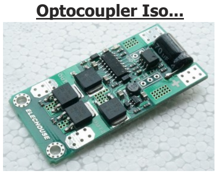

Details

Wrobot L298N Motor Driver Board V1.0

Details

USB/TF MP3 Play and Recording Mini Modul...

Details

10p 1.27mm socket and connector with wir...

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1.8KM NRF24L01+ Module, PA+LNA, w/ Anten...

Details

nRF24LU1 nRF24L01 Kits, wireless downloa...

Details

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Brush DC Motor
Product Number 14203S009-SP
$184.80

Motor Series	DC054B Series Brushed DC Motor (Originally 14000)
Price (USD)	$184.80
Frame Size (Mounting Face) (in)	2.125
Motor Frame Size (in)	2.125
Gear Frame Size (in)	n/a
Overall Body Length (in)	3.703
Supply Voltage (V)	24
Continuous Output Torque (oz-in)	21
Output Speed @ Cont. Torque (RPM)	2950
Current @ Cont. Torque (A)	2.8
Continuous Output Power (W)	46
No Load Current (A)	0.24
No Load Output Speed (RPM)	3390
Peak Current (A)	17
Peak Output Torque (oz-in)	160
Motor Constant (oz-in/√W)	7.88
Motor Torque Constant (oz-in/A)	9.26
Motor Voltage Constant (V/krpm)	6.85
Terminal Resistance (Ohms)	1.38
Inductance (mH)	2.3
Coulomb Friction Torque (oz-in)	1.6
Viscous Damping Factor (oz-in/krpm)	0.18
Electrical Time Constant (ms)	1.6
Mechanical Time Constant (ms)	6.8
Thermal Time Constant (min)	26
Thermal Resistance (ºC/Watt)	8.1
Maximum Winding Temperature (ºC)	155
Rotor Inertia (oz-in-s2)	0.003
Output Bearing	Ball
Gear Series	n/a
Gear Ratio (xx.x:1)	n/a
Gear Type	n/a
Gear Efficiency	n/a
Gear Maximum Torque (oz-in)	n/a
Encoder Series	n/a
Encoder Resolution (CPR)	n/a
Encoder Output Channels	n/a
Weight (Mass) (oz)	31
Voltage Note	n/a

Torque Warning	n/a

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Specifications for this item

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EAN	0712324538069
Item Weight	3.0 pounds
Model Number	4330943486
Part Number	S480
UNSPSC Code	39121011
UPC	712324538069
Wattage	480.0 watts

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d ASUS Tinker Board

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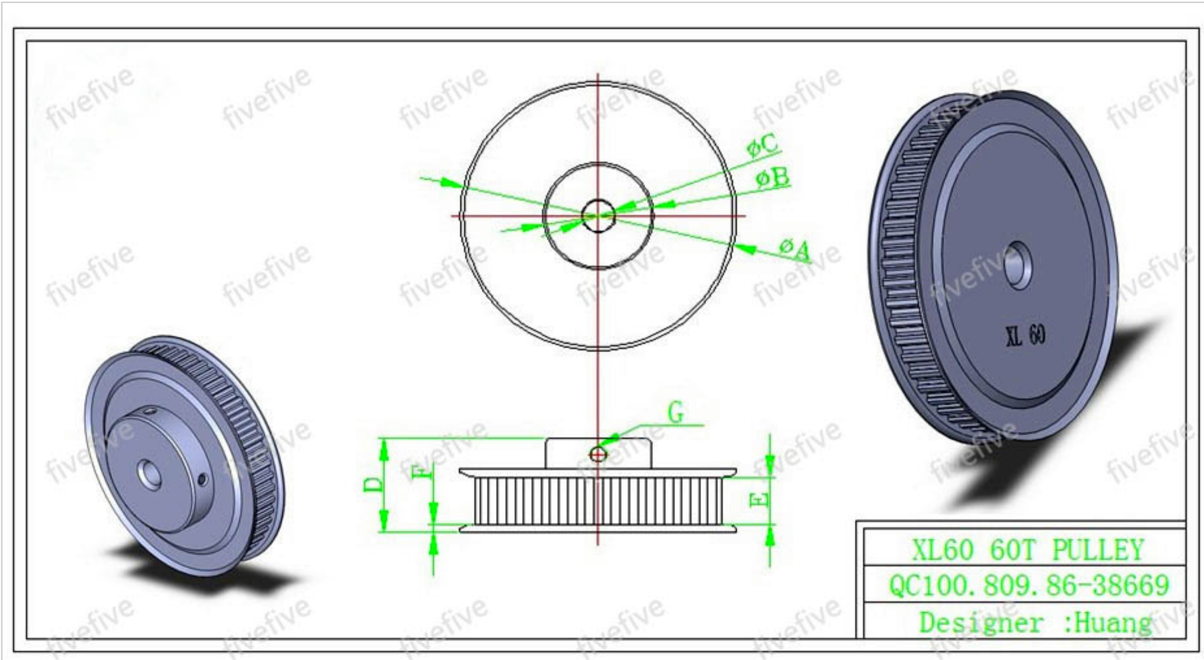
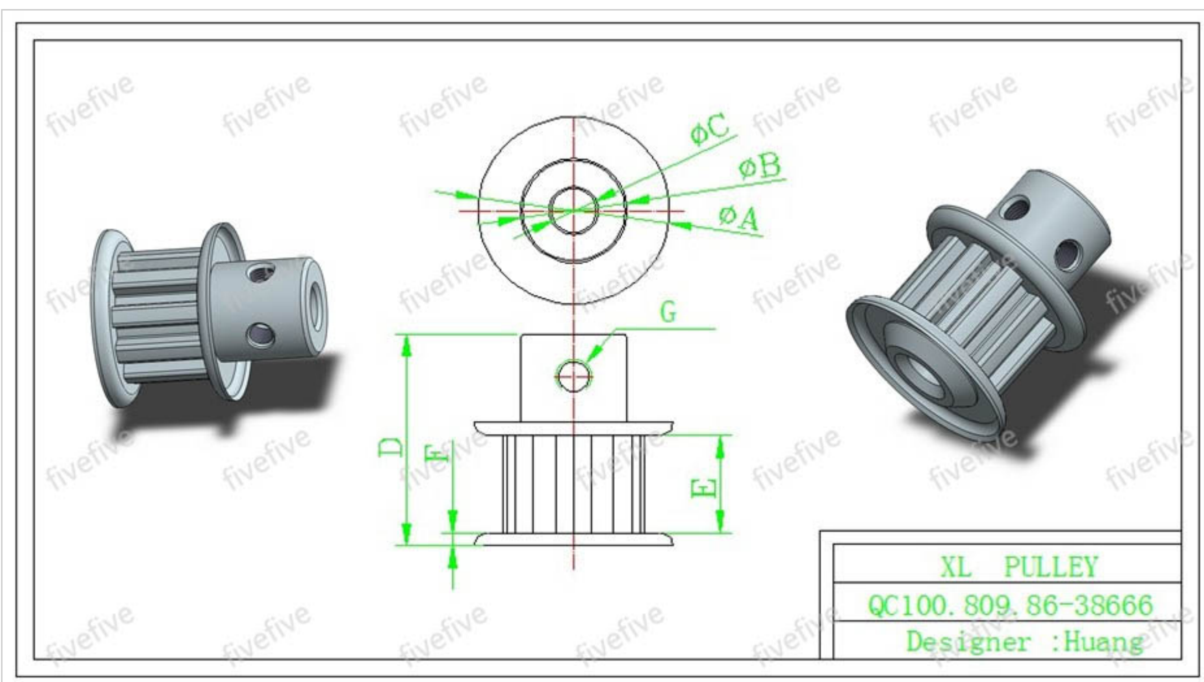


A=102mm B=40mm C=you can choose D=25mm E=11mm F=2.5mm G=M5

Blueprint of XL 10T:



A=21.5mm B=12mm C=you can choose D=23.5mm E=11mm F=1.8mm G=M4

PRODUCT DESCRIPTION

Features:

Widely used in machine tools, textile, printing, food packaging, wire and cable, instrumentation, petrochemical, tobacco, telecommunications and other industries in the new mechanical belt drive.

The wheelbase you can choose:

106.7mm	**194mm**
115mm	**207mm**
131mm	**212mm**
144mm	**225mm**
152mm	**230mm**
173mm	**238mm**
181mm	**251mm**

We will send you a belt according to the wheelbase you choose, you can leave a message or a note to tell us the wheelbase you choose when buying. If no message and note, we will send the106.7mm wheelbase one.

Specification of timing pulley:

•Tooth pitch: 5.08mm

•Flange: double

•Tooth width: 11mm

Specification of timing belt:

•Belt Section: XL

•Whether standard parts: standard parts

•Pitch: 5.08mm

•Belt Width: 10mm

Package Included:

1* XL 60 tooth pulleys.

1* XL 10 tooth pulleys.

1* XL loop timing belt.

4* setscrews

1* Allen key.

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- **High Quality goods.** Every item is processed quality testing before we put them into stock.
- **Varies shipping methods.** we offer varies shipping methods, you can choose the one that suits. Every parcel is shipped with tracking number.
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- **Wholesale price.** We can offer you special price for a large quantity, send us an offer or a message.
- **Customized service.** We can customize some non-standard parts if you offer the blueprint. Contact us for this service.

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Combine shipping. We charge only one delivery freight if you buy more goods.

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sensing capable of detecting 10 fingers.

- Only two connections from the Pi to the display are necessary; power from GPIO (or USB) connection to the DSI port. The adapter board handles power, signal conversion, and touch input conversion.
- Kit Contents: 7" Touchscreen Display Adapter Board DSI Ribbon Cable 4 x Stand-offs and Screws 4 x Jumper Wires

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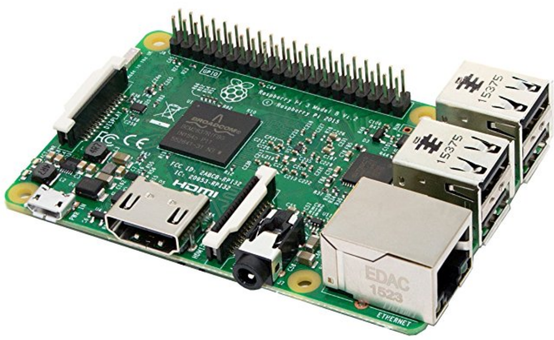

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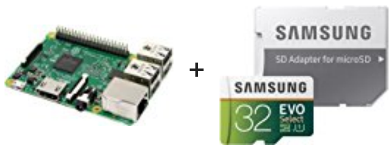

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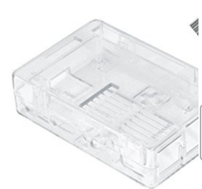

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Product description

Built on the latest Broadcom 2837 ARMv8 64 bit processor the Raspberry Pi 3 Model B is faster and more powerful than its predecessors. It has improved power management to support more powerful external USB devices and now comes with built-in wireless and Bluetooth connectivity. To take full advantage of the improved power management on the Raspberry Pi 3 and provide support for even more powerful devices on the USB ports, a 2.5A adapter is required. Technical Specifications: - Broadcom BCM2837 64bit ARMv8 QUAD Core 64bit Processor powered Single Board Computer running at 1.2GHz - 1GB RAM - BCM43143 WiFi on board - Bluetooth Low Energy (BLE) on board - 40pin extended GPIO - 4 x USB2 ports - 4 pole Stereo output and Composite video port - Full size HDMI - CSI camera port for connecting the Raspberry Pi camera - DSI display port for connecting the Raspberry Pi touch screen display - MicroSD port for loading your operating system and storing data - Upgraded switched Micro USB power source (now supports up to 2.5 Amps) This product is made under license in both China and the U.K. Please see the product packaging.

Product information

Technical Details

Collapse all

Summary

Screen Size	60 inches
Processor	1.2 GHz
RAM	1 GB
Wireless Type	802.11bgn
Number of USB 2.0 Ports	4

Other Technical Details

Brand Name	Raspberry Pi
Series	RASPBERRYPI3-MODB-1GB
Item model number	RASPBERRYPI3-MODB-1GB
Hardware Platform	Raspberry pi
Operating System	Linux
Item Weight	1.6 ounces
Product Dimensions	4.8 x 3 x 1.3 inches
Item Dimensions L x W x H	4.8 x 2.99 x 1.34 inches
Color	Raspberry PI 3
Processor Brand	Broadcom
Processor Count	4
Voltage	5 volts

Additional Information

ASIN	B01CD5VC92
Customer Reviews	1,939 customer reviews 4.7 out of 5 stars
Best Sellers Rank	#1 in Computers & Accessories > Computer Components > Motherboards
Shipping Weight	2.1 ounces (View shipping rates and policies)
Domestic Shipping	Currently, item can be shipped only within the U.S. and to APO/FPO addresses. For APO/FPO shipments, please check with the manufacturer regarding warranty and support issues.
International Shipping	This item is not eligible for international shipping. Learn More
Date First Available	February 28, 2016

Warranty & Support

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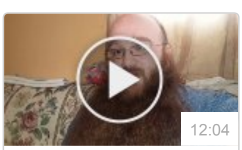

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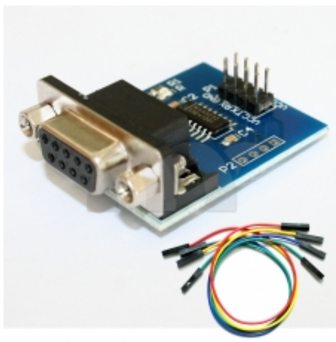

Product Code: MAX3232 RS232 to TTL
Reward Points: 0
Availability: In Stock

Price: $5.16

Qty: 1 Add to Cart - OR - Add to Wish List
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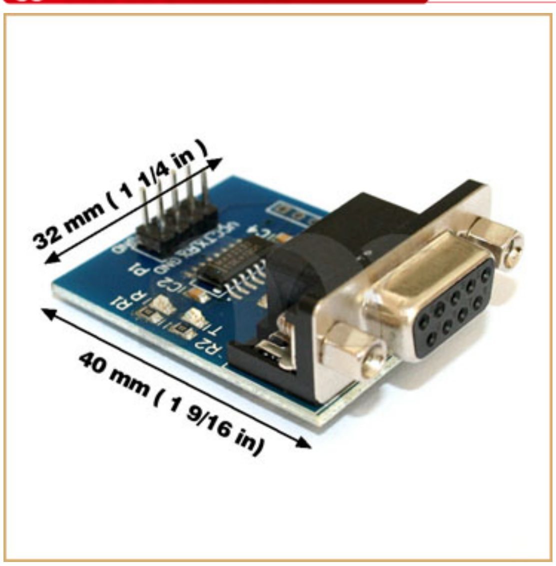
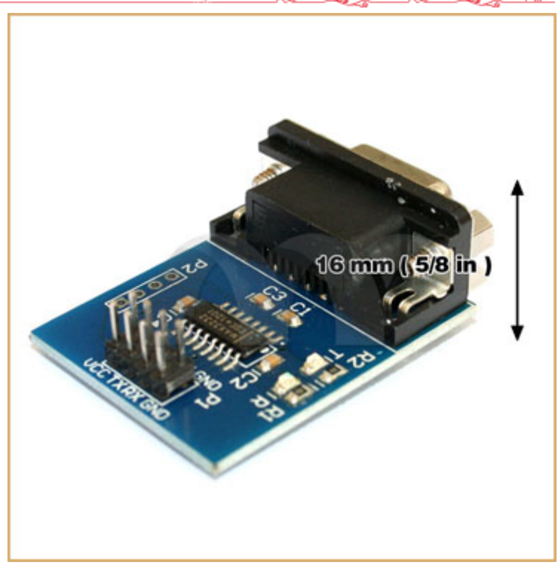
Description **Reviews (0)**

Serial Module RS232 to TTL With DuPont Line

- This module can be used to serial port of microcontroller module expand DVD / router / hard drive and other equipment to upgrade, the module is tested by STM32 development board 3.3V voltage 115200 baud rate before delivery.

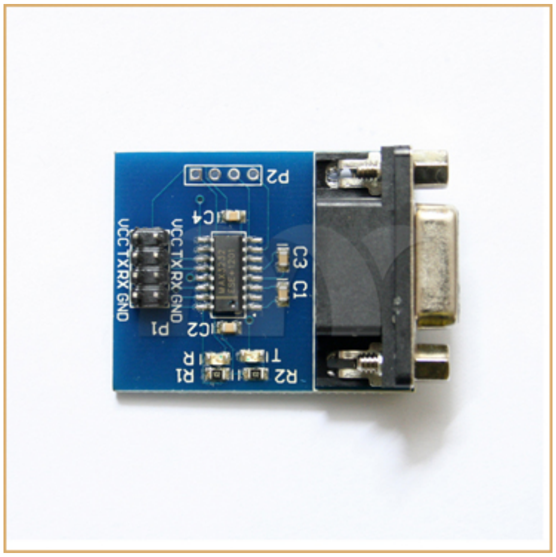
SIZE INFORMATION





PRODUCT FUNCTION

- Chip: MAX3232 (Made in China)
- Voltage: 3.3V/5V

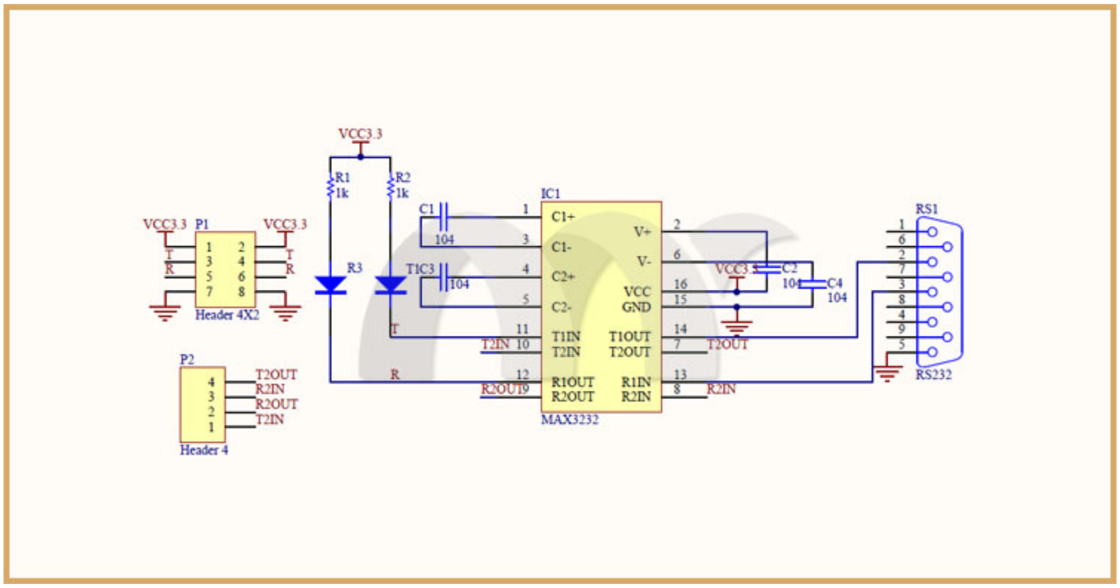


APPEARANCE DISPLAY

PACKAGE INCLUDES

- Serial Module x1
- DuPont Line x4

RULES OF SAFETY



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Ruland

Ruland SP-9-F Two-Piece Clamping Shaft Collar, Black Oxide Steel, .563" Bore, 1 1/4" OD, 7/16" Width (Pack of 2)

Be the first to review this item

Price: $43.14 ($21.57 / Shaft Collar) + $3.89 shipping

In stock.

Arrives before Christmas.

Get it as soon as Dec. 12 - 15 when you choose **Standard** at checkout.
Ships from and sold by DataAlchemy.

New (2) from $14.30 & FREE shipping on orders over $25.00. Details

Specifications for this item

Part Number	SP-9-F	EAN	06345290219
UPC	634529021	Item Diameter	1 1/4 inches
Measurement System	English	Material	Steel
Bore Diameter	0.563 inch	Number of Items	2
Brand Name	Ruland	Width	7/16 inches

See more product details

Share

Qty: 1

$43.14 + $3.89 shipping
In stock. Sold by **DataAlchemy**

Add to Cart

Turn on 1-Click ordering for this browser

Ship to:
Charles Frandle- San Luis Obis - 93405

Add to List

Other Sellers on Amazon

$14.30 ($7.15 / Item) Add to Cart
& **FREE Shipping** on eligible orders. Details
Sold by: Amazon.com

New (2) from $14.30 & FREE shipping on orders over $25.00. Details

Have one to sell? Sell on Amazon

Customers also shopped for

Page 1 of 4

HOT ROLLED MILD STEEL SQUARE TUBE A500

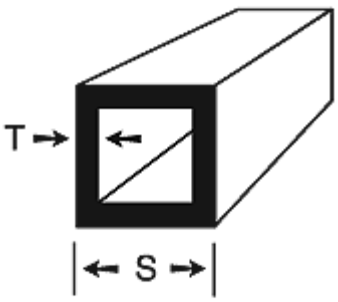
Part #: 10362

3" OD x 0.1875" Wall A500/A513 Hot Rolled Mild Steel Square Tubes are made of cold formed and seamlessly welded hot rolled steel.

A500 offers high weldability and is used frequently in structural applications in bridges and buildings as well as in both the automotive and appliance industry. A500 and A513 are comparable in composition and strong content.

View our "Guide to Mild Steel" for available grades, shapes and additional information.

Material Meets These Standard(s): ASTM A500



Available Sizes

DIMENSIONS

Weight/Lineal Foot: 7.1706 pounds

Dimension Name	Value
Height	3"
Wall	0.1875"
Internal Height	2.625

View Other Sizes

Create a Custom Size | Technical Information

Weight/Lineal Foot
7.1706 pounds
Material Specifications
This material meets the following specs: **ASTM A500**

Please note that this data is to be used ONLY FOR REFERENCE, NOT FOR DESIGN, and by using it, you agree that any decisions you make regarding materials for your project are at your own discretion.

COLD FINISH ALLOY STEEL ROUND 4130 NORMALIZED

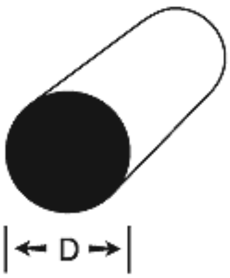
Part #: 7366

0.75" 4130 Cold Finish Alloy Steel Round Bar/Rods offer good weldability without compromising steel abrasion and impact resistance. It is commonly used in structural applications, including gears, fasteners, and some aircraft exterior.

4130 Steel has good machinability, good weldability, and can be heat treated.

View our "Guide to Alloy Steel" for available grades, shapes and additional information.

Mill Test Reports are available on this item and can be selected during the checkout process.



Material Meets These Standard(s): AMS 6370, AMS-S 6758

Available Sizes

Create a Custom Size

Technical Information

DIMENSIONS

Weight/Lineal Foot: 1.5 pounds

Dimension Name	Value
Diameter	0.75"

View Other Sizes

Weight/Lineal Foot

1.5 pounds

Tolerances

Dimension Name	Plus	Minus
Diameter	**0"**	**0.004"**

Material Specifications

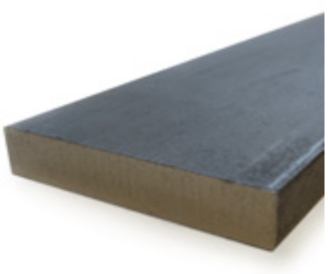
This material meets the following specs:
AMS 6370

This material meets the following specs:
AMS-S 6758

Chemistry Information: 4130 Alloy Steel

Element	Percentage
C	0.28 - 0.33
Cr	0.8 - 1.1
Fe	97.3 - 98.22
Mn	0.4 - 0.6
Mo	0.15 - 0.25
P	0.035 max
S	0.04 max
Si	0.15 - 0.35

Please note that this data is to be used ONLY FOR REFERENCE, NOT FOR DESIGN, and by using it, you agree that any decisions you make regarding materials for your project are at your own discretion.



COLD FINISH MILD STEEL RECTANGLE 1018

Part #: 7471

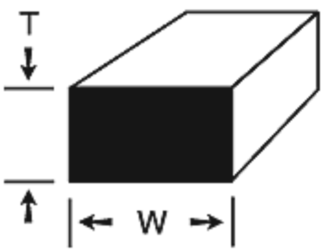
0.25" x 2.5" 1018 Carbon Steel is the most common grade of carbon steel. Flat Bar Cold Finish is commonly in a wide variety of applications including structural and manufacturing.

It has high strength and good ductility but offers poor corrosion resistance. 1018 is machinable, weldable and is heat treatable.

View our "Guide to Mild Steel" for available grades, shapes and additional information.

Mill Test Reports are available on this item and can be selected during the checkout process.

Material Meets These Standard(s): ASTM 108



Available Sizes

Create a Custom Size

Technical Information

DIMENSIONS Weight/Lineal Foot: 2.1525 pounds

Dimension Name	Value
Thickness	0.25"
Width	2.5"

View Other Sizes

Weight/Lineal Foot

2.1525 pounds

Tolerances

Dimension Name	**Plus**	**Minus**
Thickness	**0"**	**0.003"**
Width	**0"**	**0.005"**

Material Specifications

This material meets the following specs:
ASTM 108

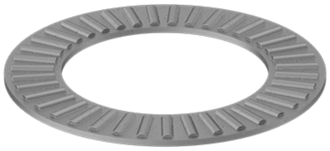
Chemistry Information: 1018 Mild Steel

Element	**Percentage**
C	0.14 - 0.2
Fe	98.81 - 99.26
Mn	0.6 - 0.9
P	0.04 max
S	0.05 max

Please note that this data is to be used ONLY FOR REFERENCE, NOT FOR DESIGN, and by using it, you agree that any decisions you make regarding materials for your project are at your own discretion.

Thrust Needle-Roller Bearing
for 1-1/4" Shaft Diameter, 1-15/16" OD

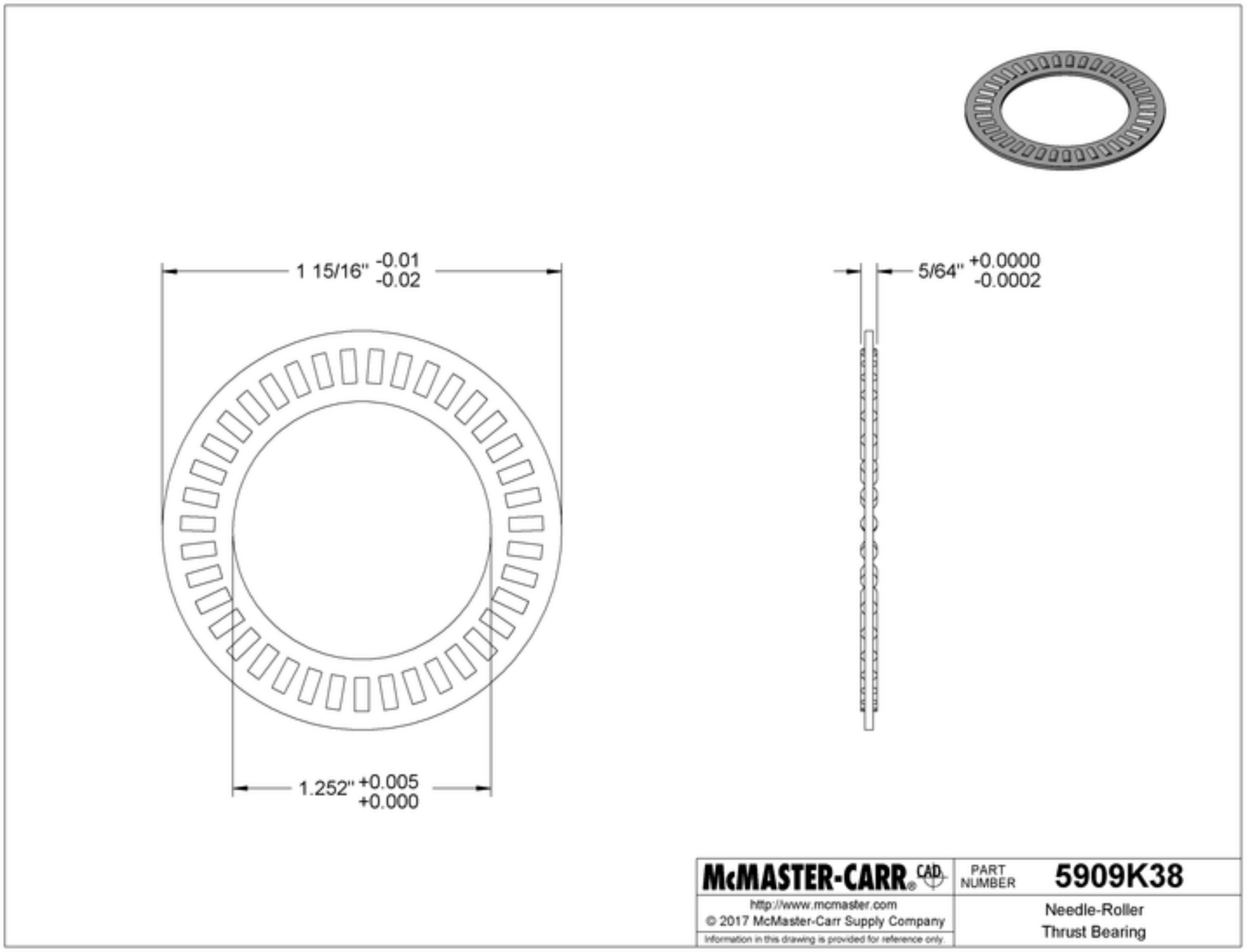
In stock
$3.23 Each
5909K38



System of Measurement	Inch
Bearing Type	Roller
Roller Bearing Type	Needle
For Load Direction	Thrust
Seal Type	Open
For Shaft Type	Round
For Shaft Diameter	1 1/4"
ID	1.252"
ID Tolerance	0" to 0.005"
OD	1 15/16"
OD Tolerance	-0.02" to -0.01"
Thickness	5/64"
Thickness Tolerance	-0.0002" to 0"
Roller Material	Steel
Cage Material	Steel
Thrust Load Capacity, lbs.	
Dynamic	4,500
Static	20,500
Maximum Speed	6,000 rpm
Lubrication	Required
For Shaft Surface Smoothness (Ra)	16 microns
Temperature Range	0° to 240° F
RoHS	Not Compliant
Related Products	0.032" Thick Washers
	0.126" Thick Washers

Thinner rollers allow these bearings to fit in tighter spaces than tapered-roller thrust bearings. Because of the large contact area between the rollers and washers (not included), these bearings are great for medium to heavy duty, low-friction jobs. For use on hardened and ground surfaces.

Washers allow you to use the bearing on unhardened and unground surfaces.



The information in this 3-D model is provided for reference only.

FASTENAL

Home > Fasteners > Bolts > U-Bolts

Compliance

CAD Drawings

Product Standards

3D

2D Left Side View

2D Front View

2D Sales Drawing

1/2"-13 x 2-1/2" Pipe Size Hot Dip Galvanized Round Bend U-Bolt w/ 2 Nuts

Fastenal Part No. (SKU)	41930
UNSPSC	31161616
Manufacturer	Fastenal Approved Vendor

This is a Standard Catalog Item

Wholesale: $8.60 / Each

QTY 1 ADD

Product Attributes

U-Bolt Plate Number	6
Pipe Size	2-1/2"
Thread Length	1-5/8"
Thread Size	13
Diameter-Thread Size	1/2"-13
Inside Length	4-1/2"
Style	Round Bend with 2 Nuts
Finish	Hot Dipped Galvanized
Diameter	1/2"
Material	Steel
Type	U-Bolt
System of Measurement	Imperial (Inch)
Inside Width	3"
Product Weight	0.59
UOM	Each
Catalog Page	BBV11, Page 01-33

Notes

A U-Bolt is a U shaped bolt with two threaded arms protruding from a curved base. There are many uses for a U-bolt such as attaching pipes to machines. Whereas a square shaped U-Bolt is mainly used for lumber applications. Galvanized plating protects the bolt from corrosion; typically used in outdoor application

Sign In to view Inventory Location(s)

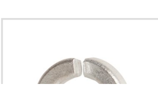
Bin Stock

Vending

Supply Chain

Availability	A Available
Direct Ship	Ships Tue, Dec 5

Related Items (1)



SKU: 33634
7/8" Zinc Finish Medium Split Lock Washer

Home > Fasteners > Bolts > U-Bolts

Compliance

No Records Found

CAD Drawings

Product Standards

Fastenal Product Standard

5/16"-18 x 2" Pipe Size Zinc Plated Round Bend U-Bolt

Fastenal Part No. (SKU)	42035
UNSPSC	31161616
Manufacturer	Fastenal Approved Vendor

This is a Standard Catalog Item

Wholesale: $4.13 / Each

QTY 1 ADD

Product Attributes

U-Bolt Plate Number	4
Pipe Size	2"
Thread Length	3"
Thread Size	18
Diameter-Thread Size	5/16"-18

Inside Length	5-5/8"
Style	Round Bend
Finish	Zinc
Diameter	5/16"
Material	Steel
Type	U-Bolt
System of Measurement	Imperial (Inch)
Inside Width	2-1/2"
Product Weight	0.215
UOM	Each
Catalog Page	BBV11, Page 01-33

Notes

A U-Bolt is a U shaped bolt with two threaded arms protruding from a curved base. There are many uses for a U-bolt such as attaching pipes to machines. Whereas a square shaped U-Bolt is mainly used for lumber applications. Zinc plating, retards the corrosion rate in a normal atmosphere.

Sign In to view Inventory Location(s)

Bin Stock

Vending

Supply Chain

Availability	A Available
Direct Ship	Ships Tue, Dec 5

Related Items (4)

1

SKU: 1136304
5/16"-18 Zinc Finish Grade 5 Finished Hex Nut

Manufacturer
Fastenal Approved Vendor

Wholesale: $8.61 / Pkg of 100
Unit Price: $0.0861 / Each

A Available

E6 Single-Ended Assembly Instructions

Please Note: These instructions apply to the E6 single-ended version *only*.

Step 1:

Base Mounting

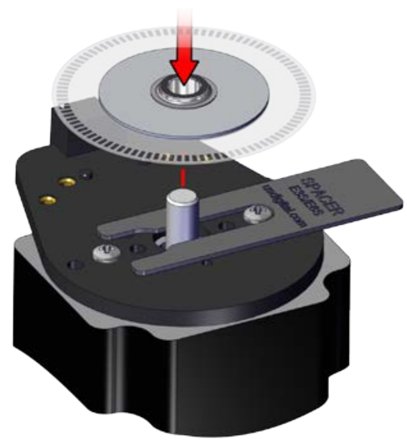
Place encoder base onto mounting surface. Slip the centering tool over shaft and into center hole of base. Hold pressure on centering tool to align base and tighten mounting screws. Remove centering tool.

Transfer Adhesive: Peel off paper backing, place centering tool into center hole of base, slip centering tool onto shaft and slide base and centering tool down onto mounting surface as one piece. Press to form a good bond, then slip centering tool off shaft and continue with standard mounting instructions.

Step 2:

Hubdisk and Spacer Alignment

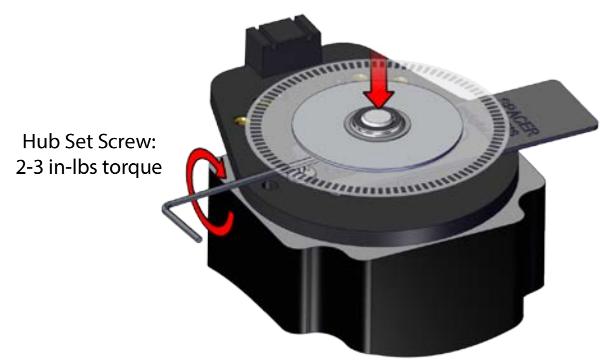
Lay spacer tool flat on the base so that it straddles the shaft. Orient hubdisk so that the set screw is between the disk and encoder base. Slip hubdisk assembly onto shaft and slide down until it bottoms out against spacer tool.



Step 3:

Hubdisk Installation

Tighten set screw with hex wrench provided while pressing down on hub to ensure contact with spacer tool. Remove hex wrench and spacer tool.



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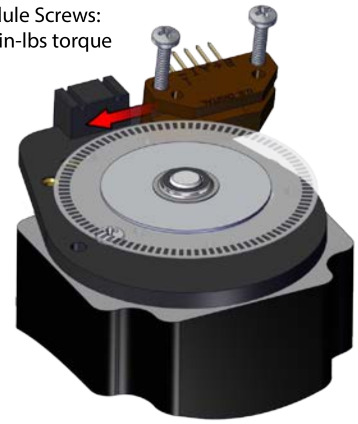
E6 Single-Ended Assembly Instructions

Step 4:

Module Installation

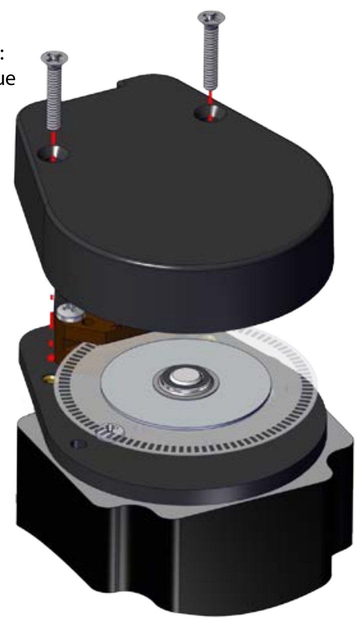
Slide optical module into position until the two alignment pins slip into holes of module (thick side of module towards bottom). Secure with 4-40 x 1/2" pan head screws (supplied).



Step 5:

Cover Installation

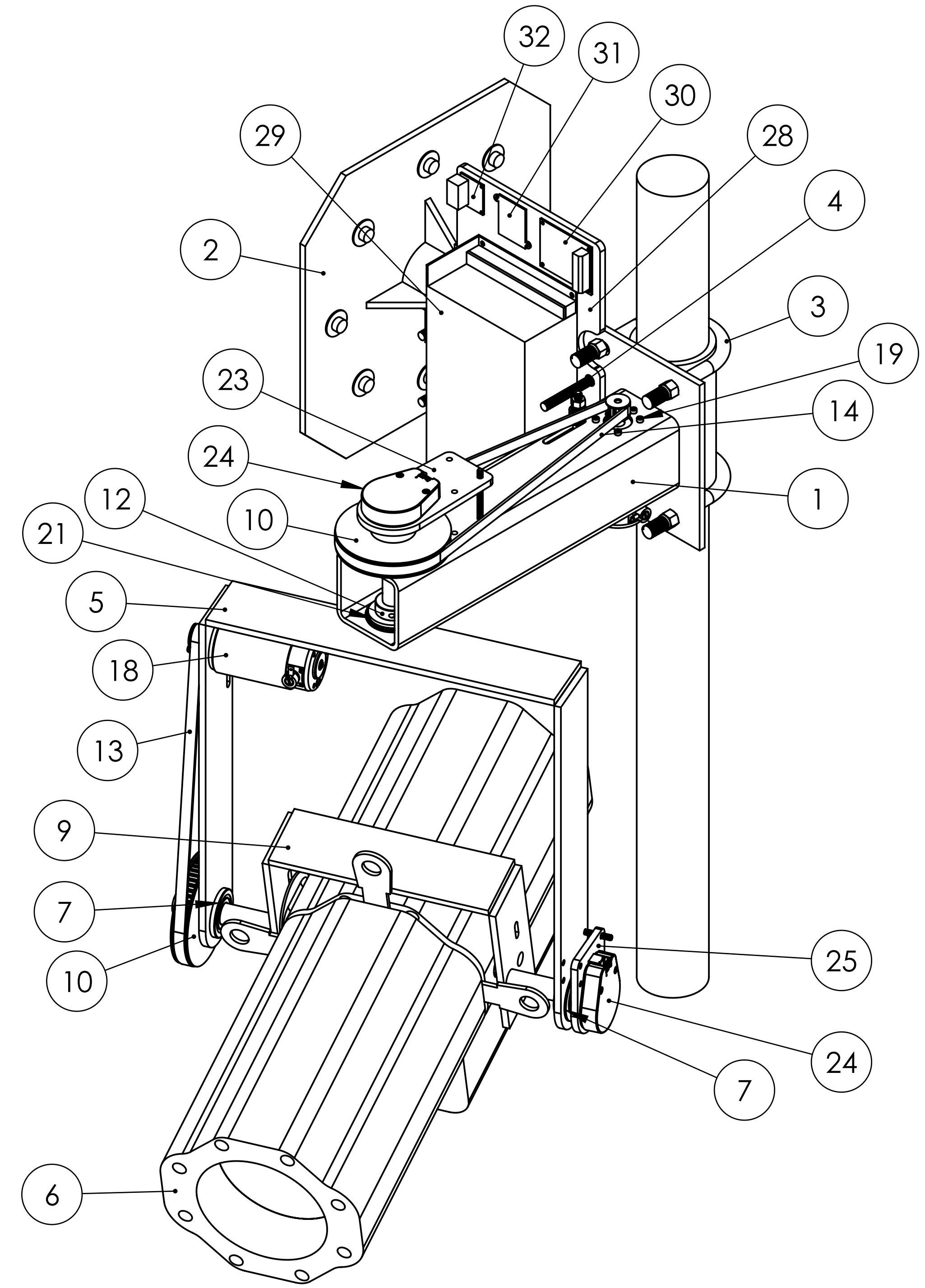
Place cover over assembly and secure with two 4-40 x 5/8" flat head screws (supplied).



Appendix 5: Detail Drawings

The following pages include an assembly drawing with a Bill of Materials, plus detail drawings for any manufactured parts. Note that the BOM does not include a complete list of all hardware; for tabulated hardware components, please see the Budget in Appendix 3.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Top System	Top System	1
2	Tbracket	Existing T-Bracket	1
3	Fastenal 41930 U-Bolt 3.00	Large U-Bolt	2
4	Fastenal 42035 U-Bolt 2.50	Small U-Bolt	2
5	Ybracket	Y Bracket	1
6	ADJ Encore Profile 1000	ADJ Encore Profile 1000 Spotlight	1
7	6384K369	Flanged Ball Bearing	4
8	97135A230	Nylon Locknut	4
9	Xbracket	X Bracket	1
10	57105K32	XL 60T Pulley	2
11	57105K32	XL 10T Pulley	2
12	SP-9-F Shaft Collar	Two-piece Clamping Shaft Collar	1
13	Xbelt	31" XL Timing Belt	1
14	Ybelt	30" XL Timing Belt	1
15	90185A546	Square Neck Carriage Bolt	2
16	95036A012	1/4-20 Hex Nut	2
17	60355K503	1/4" ID Idler Bearing	4
18	Pittman DC054B-3	Pittman Brushed DC Motor	2
19	91251A148	Motor Mounting Screw	12
20	97135A220	Nylon Locknut	4
21	7814K32	Multipurpose Thrust Washer	1
22	5909K38	Needle-Roller Thrust Bearing	1
23	Top Encoder Mount	Top Encoder Mount	1
24	E6-X-250-X-S-D-D-X	10000 CPR Digital Quad Encoder	2
25	X Encoder Plate	X Encoder Plate	1
26	92949A825	Button-head Socket Cap Screw	1
27	90272A249	Phillips-head Machine Screw	1
28	Electronics Plate	Electronics Plate	1
29	Power Supply	PSU	1
30	Motor Driver	Motor Driver	1
31	PyBoard	Pyboard	1
32	Serial Port	Serial Port Module	1



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APPLICATION

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DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: Plain Carbon Steel

FINISH: Paint Matte Black

DO NOT SCALE DRAWING

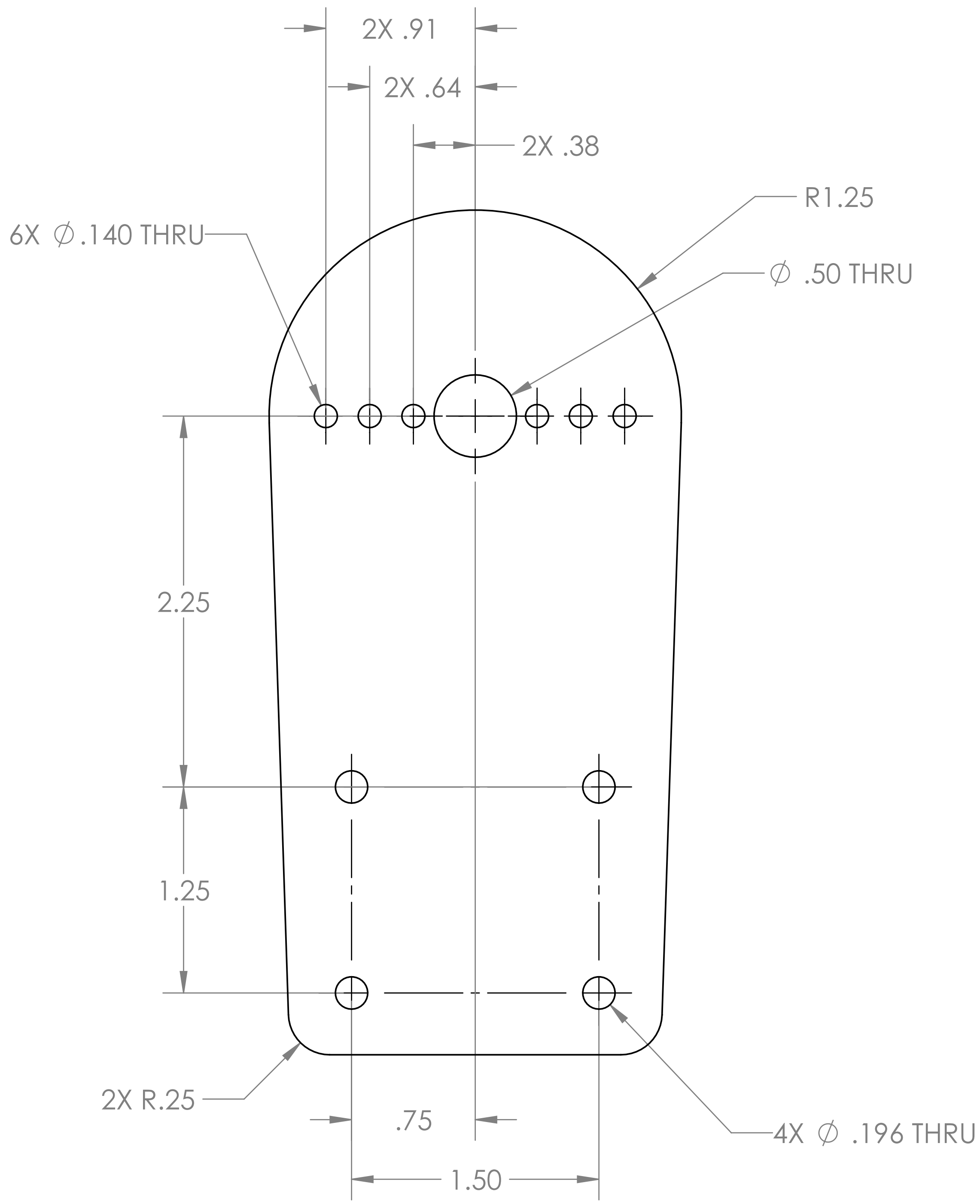
	NAME	DATE
DRAWN	R. O'NEILL	10/2/2017
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

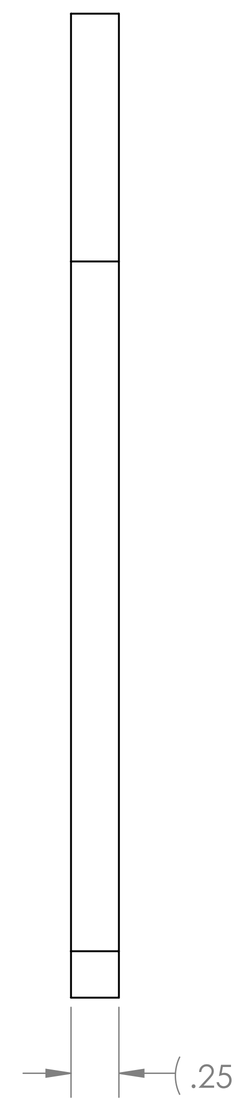
COMMENTS:

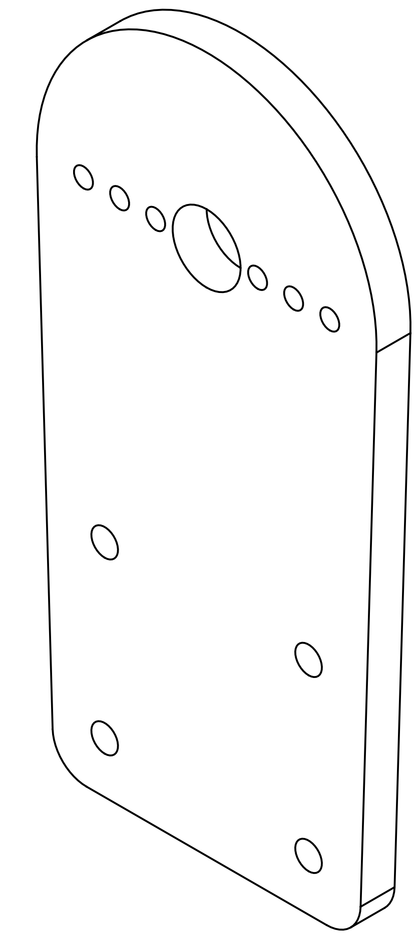
TITLE: ASSEMBLY

SIZE B | DWG. NO. 00000000 | REV

SCALE: 1:6 | WEIGHT: | SHEET 1 OF 1







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APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Acrylic (Medium-high impact)

FINISH
Paint Matte Black

DO NOT SCALE DRAWING

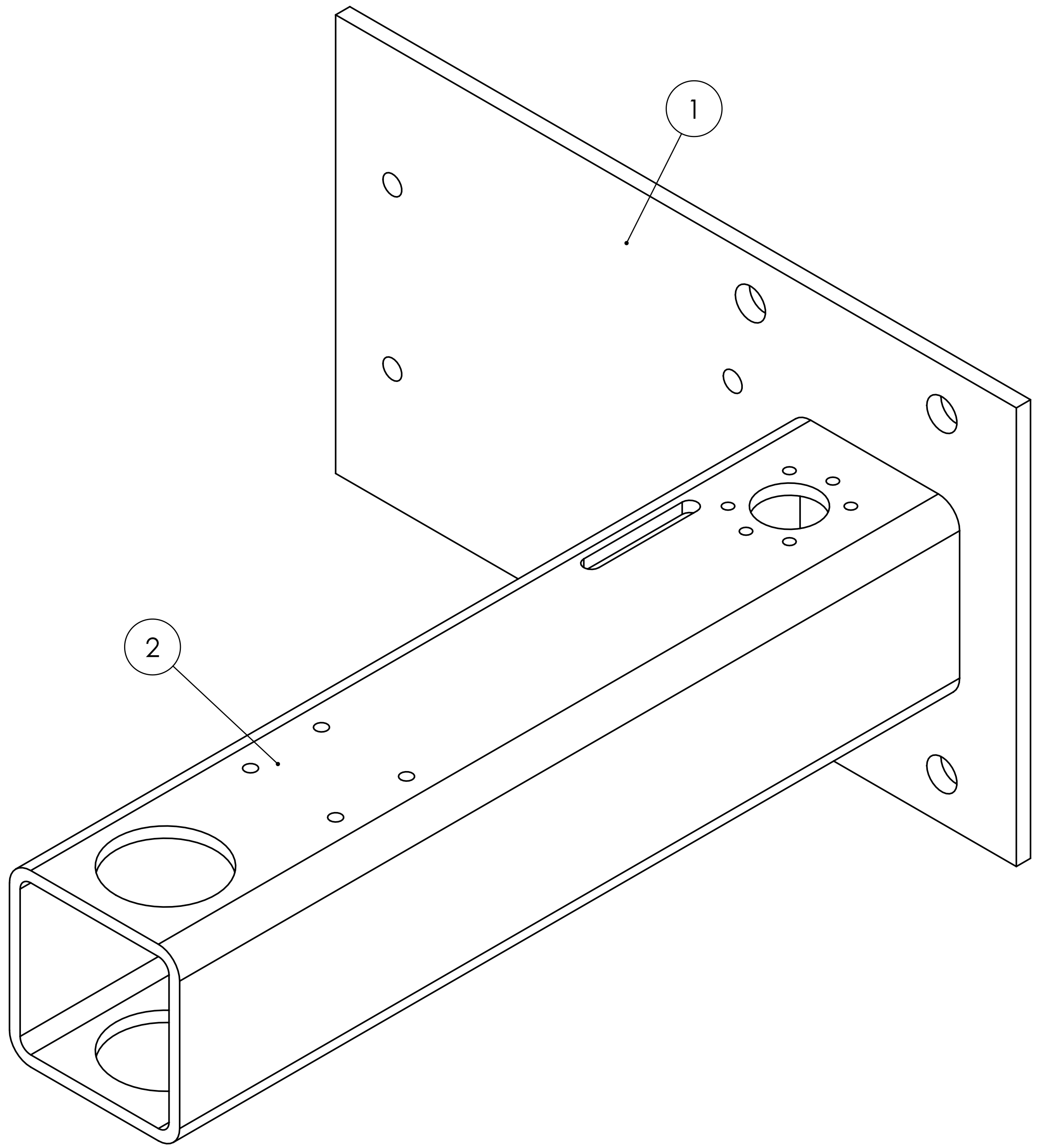
	NAME	DATE
DRAWN	R. O'NEILL	10/2/2017
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

TITLE:

Top Encoder Mount

SIZE **B** DWG. NO. 00000005 REV

SCALE: 1:1 WEIGHT: SHEET 1 OF 1



ITEM NO.	QTY.	DESCRIPTION	LENGTH
1	1	PLATE, 0.25 THICK	
2	1	TUBE, 3 SQUARE X 0.1875 WALL	13.75

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Plain Carbon Steel

FINISH
Paint Matte Black

DO NOT SCALE DRAWING

NEXT ASSY | USED ON
APPLICATION

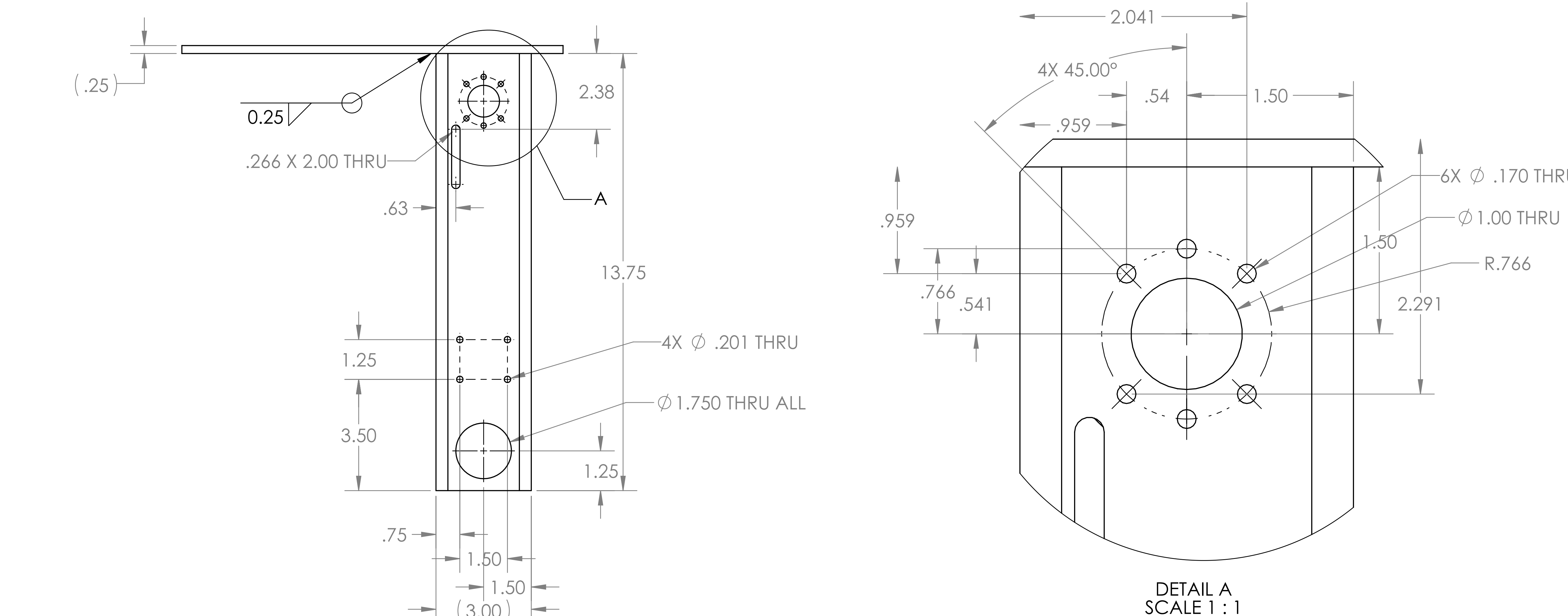
	NAME	DATE
DRAWN	R. O'NEILL	10/2/2017
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

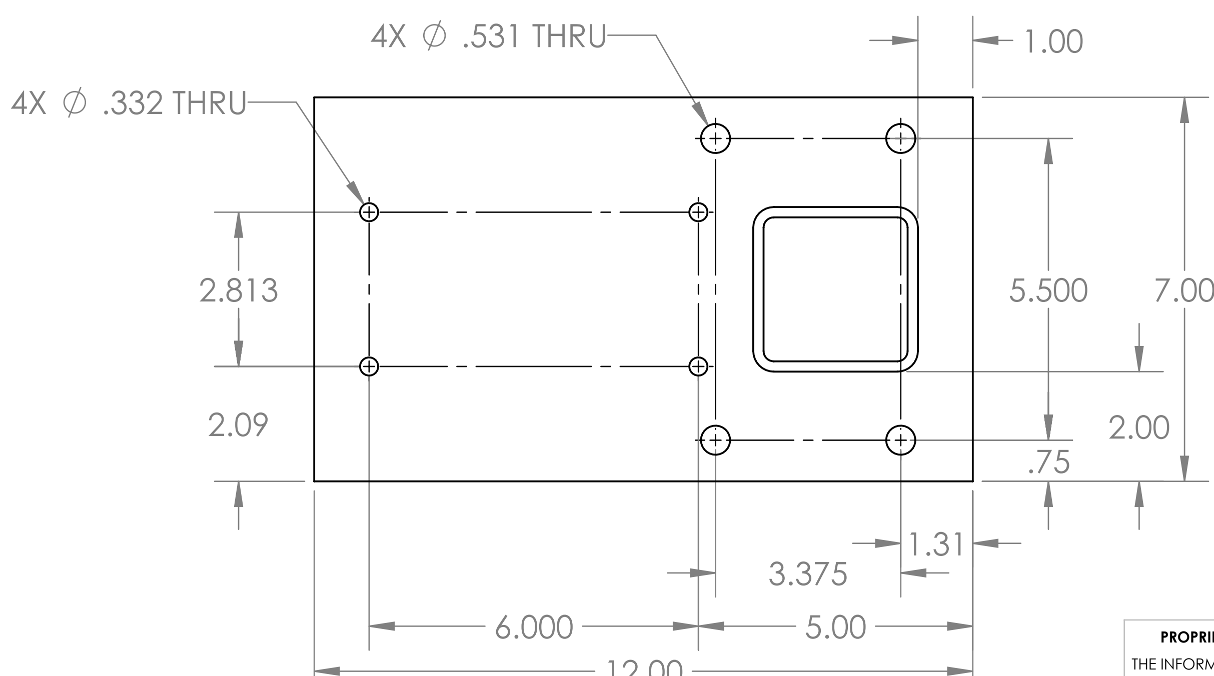
COMMENTS:

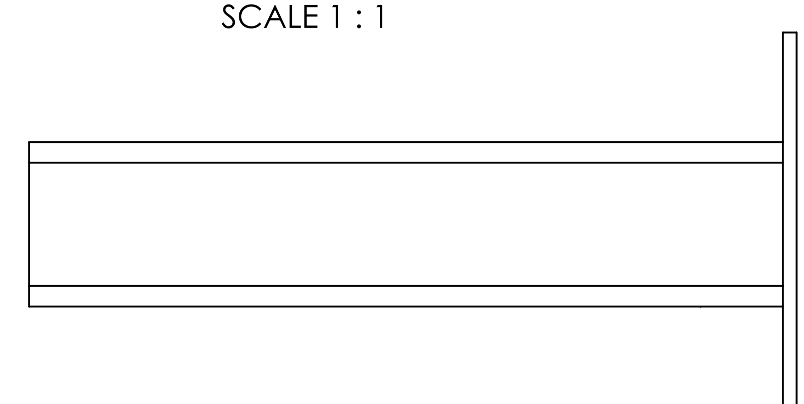
TITLE:
Top System

SIZE B | DWG. NO. 00000001 | REV

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 2







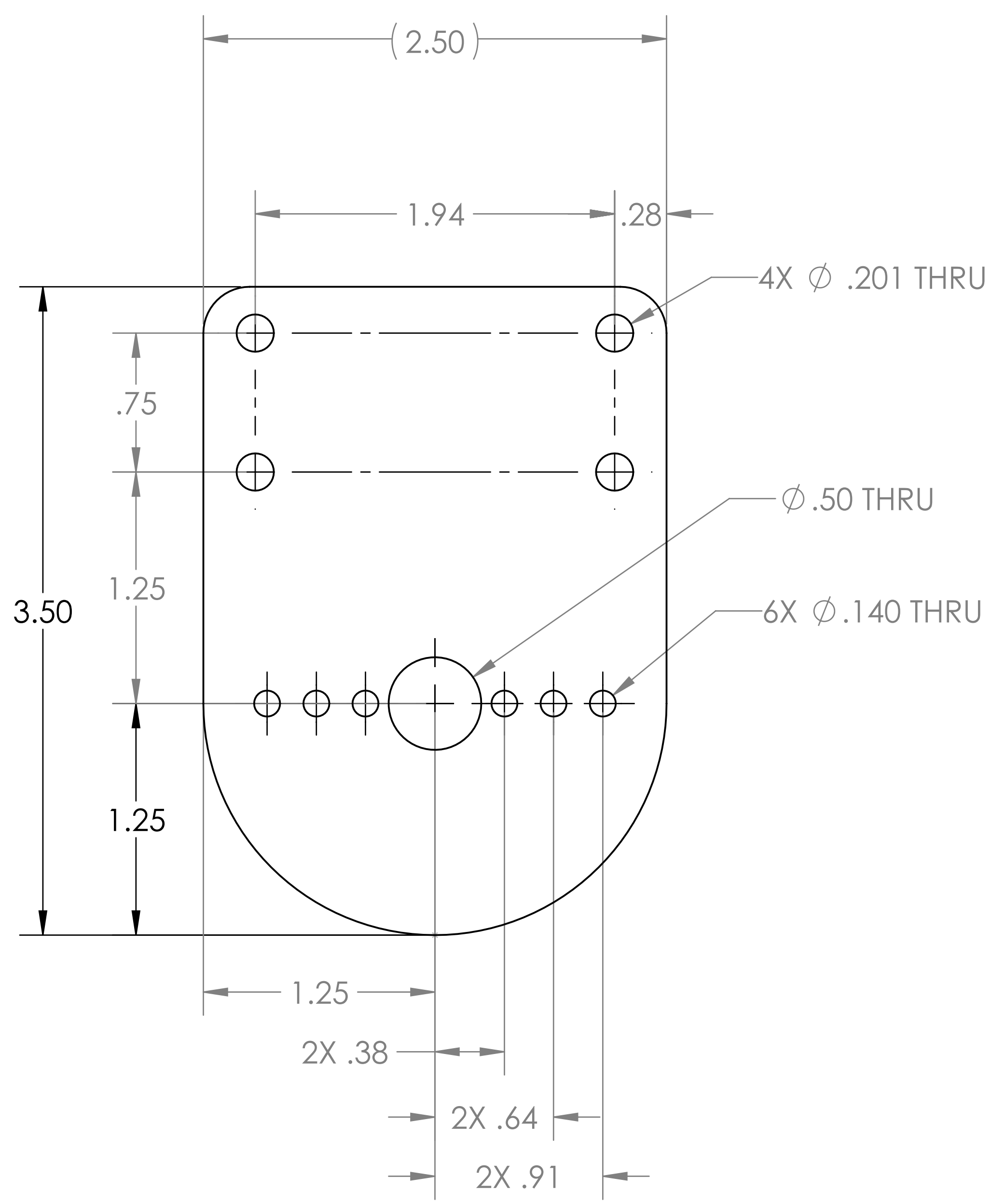
		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	R. O'NEILL	10/2/2017
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL Plain Carbon Steel	COMMENTS:		
NEXT ASSY	USED ON	FINISH Paint Matte Black			
APPLICATION		DO NOT SCALE DRAWING			

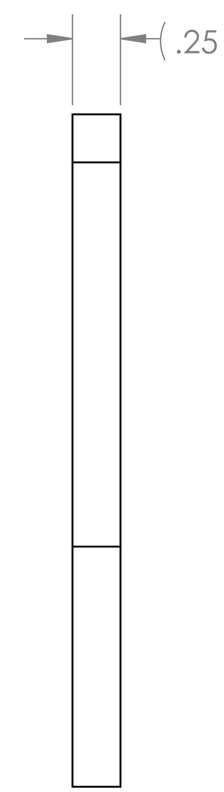
TITLE:

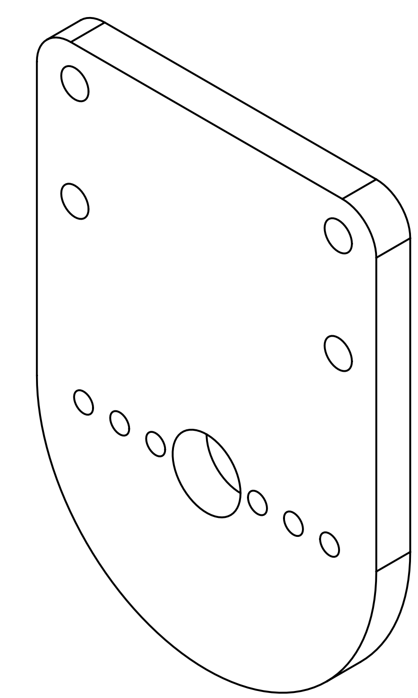
Top System

SIZE B | DWG. NO. 00000001 | REV

SCALE: 1:3.5 WEIGHT: SHEET 2 OF 2







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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Acrylic (Medium-high impact)

FINISH
Paint Matte Black

DO NOT SCALE DRAWING

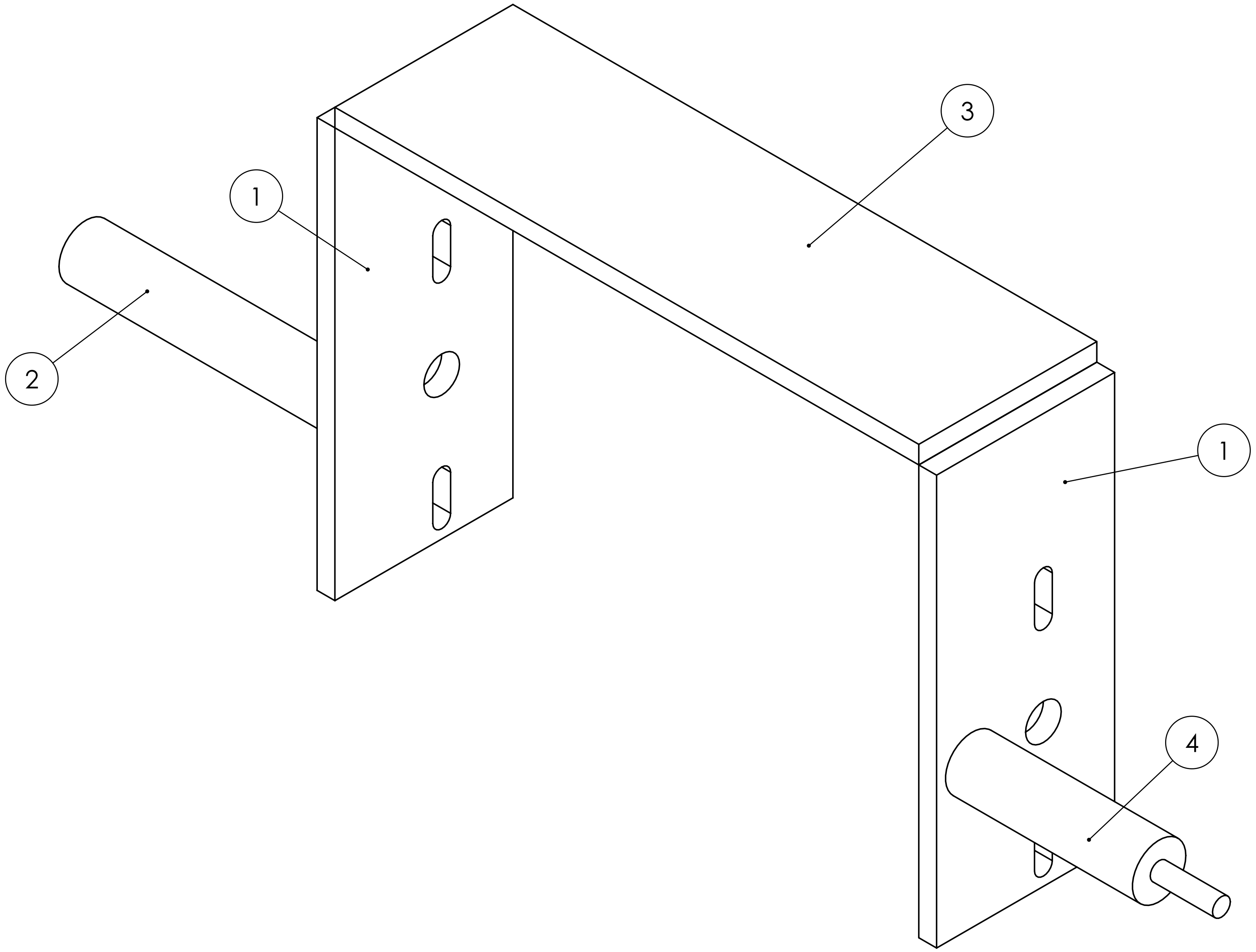
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
X Encoder Plate

SIZE **B** DWG. NO. 00000004 REV

SCALE: 1:1 WEIGHT: SHEET 1 OF 1



ITEM NO.	QTY.	DESCRIPTION	LENGTH
1	2	2.50 STRIP, 0.25 THICK	
2	1	0.75 BAR	
3	1	2.50 STRIP, 0.25 THICK	
4	1	0.75 BAR	

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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Plain Carbon Steel

FINISH
Paint Matte Black

DO NOT SCALE DRAWING

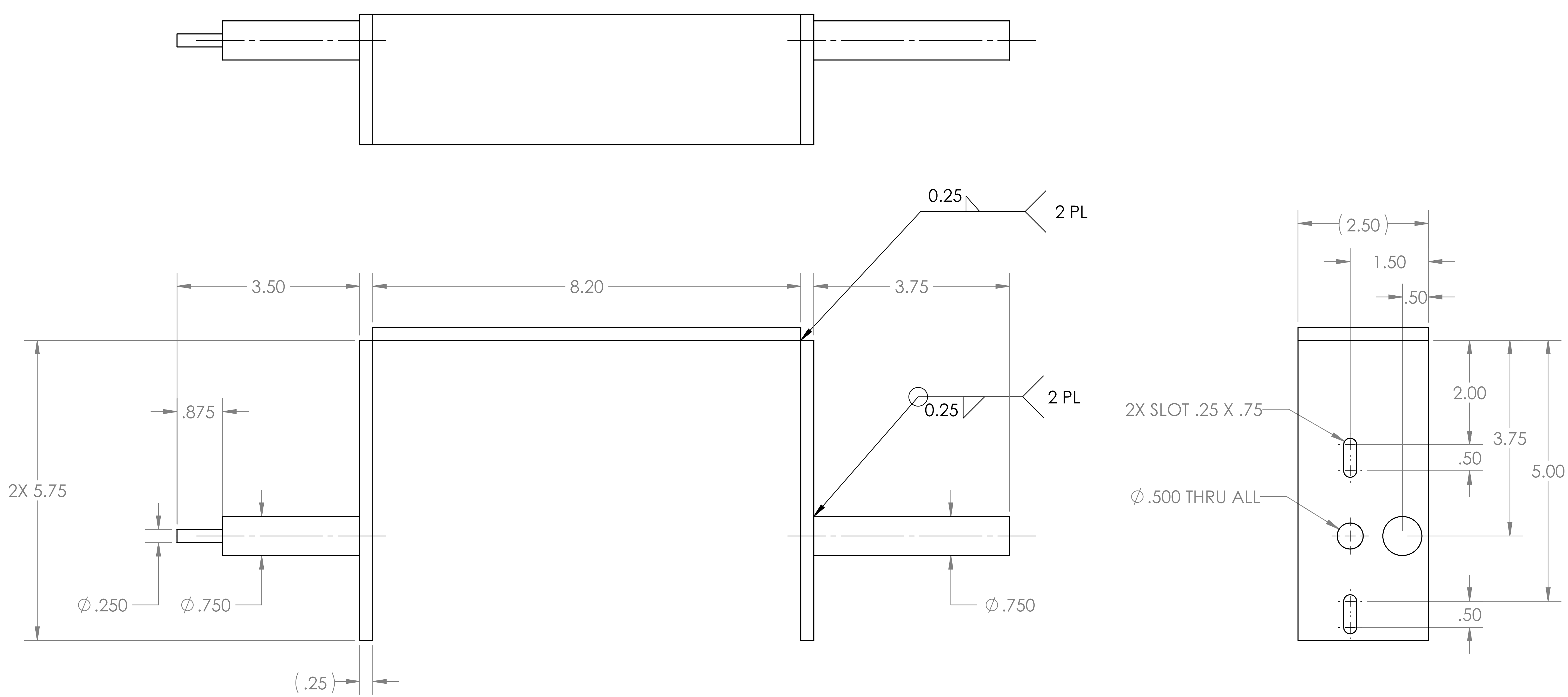
	NAME	DATE
DRAWN	R. O'NEILL	10/2/2017
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
X Bracket

SIZE **B** DWG. NO. 00000003 REV

SCALE: 2:3 WEIGHT: SHEET 1 OF 2



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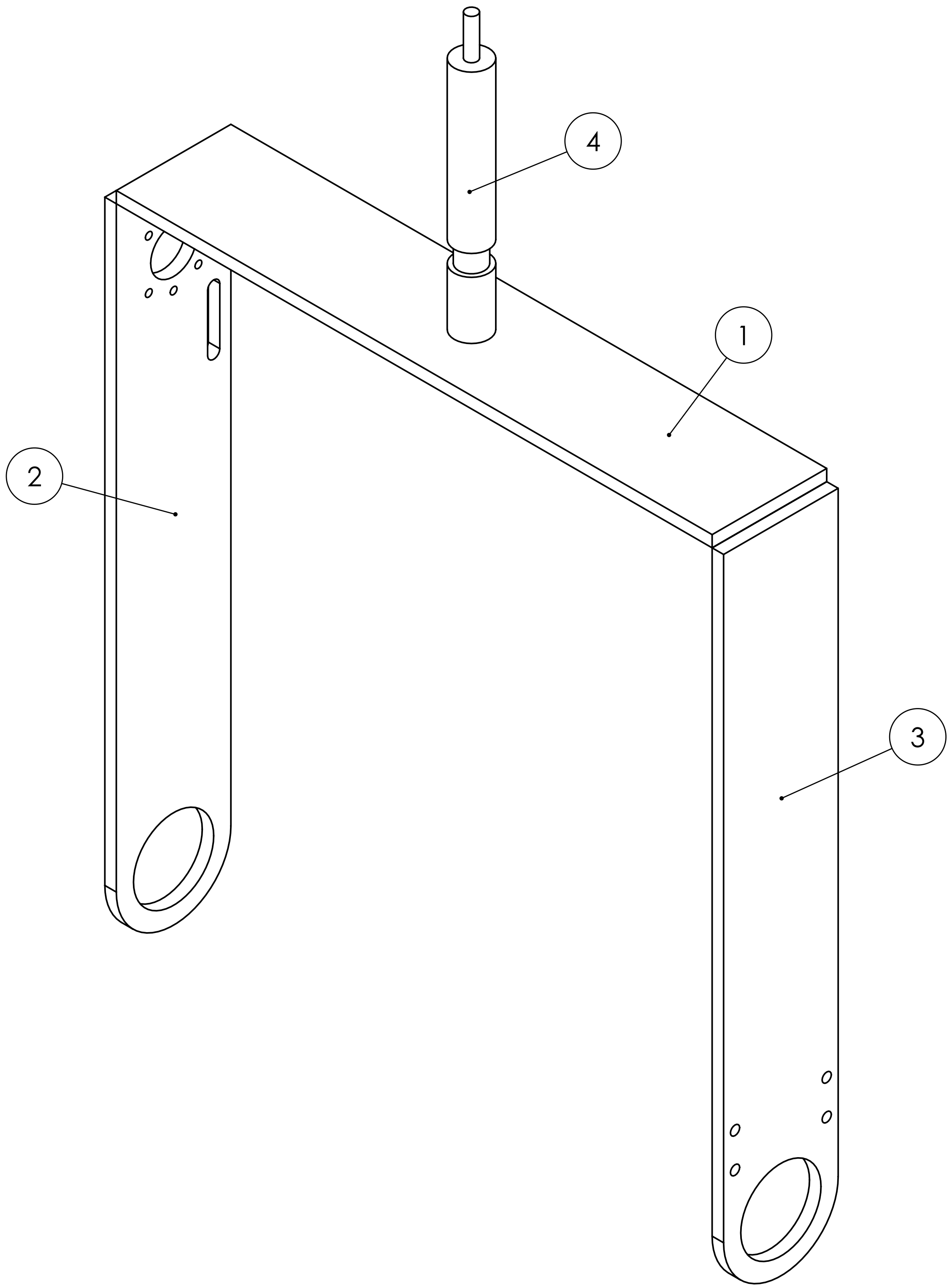
NEXT ASSY	USED ON	UNLESS OTHERWISE SPECIFIED:		NAME / DATE
APPLICATION		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	R. O'NEILL 10/2/2017
		INTERPRET GEOMETRIC TOLERANCING PER:	CHECKED	
		MATERIAL Plain Carbon Steel	ENG APPR.	
		FINISH Paint Matte Black	MFG APPR.	
		DO NOT SCALE DRAWING	Q.A.	
			COMMENTS:	

TITLE:

X Bracket

SIZE	DWG. NO.	REV
B	00000003	
SCALE: 1:2	WEIGHT:	SHEET 2 OF 2



ITEM NO.	QTY.	DESCRIPTION	LENGTH
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2	1	2.50 STRIP, 0.25 THICK	
3	1	2.50 STRIP, 0.25 THICK	
4	1	0.75 BAR	

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Plain Carbon Steel

FINISH
Paint Matte Black

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	R. O'NEILL	10/2/2017
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

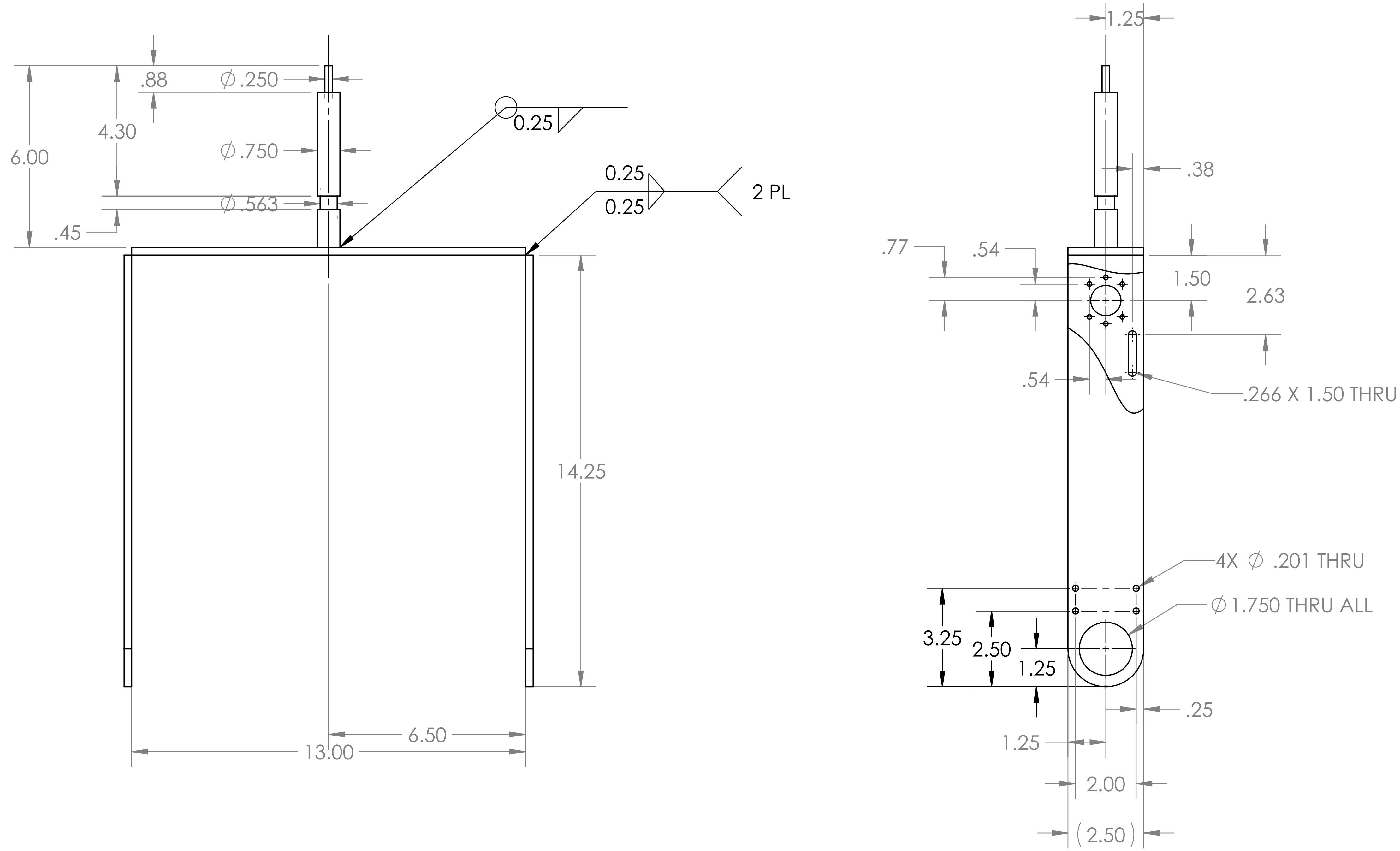
COMMENTS:

TITLE:

Y Bracket

SIZE **B** DWG. NO. 00000002 REV

SCALE: 2:5 WEIGHT: SHEET 1 OF 2



PROPRIETARY AND CONFIDENTIAL

NEXT ASSY | USED ON

APPLICATION

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Plain Carbon Steel

FINISH
Paint Matte Black

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	R. O'NEILL	10/2/2017
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

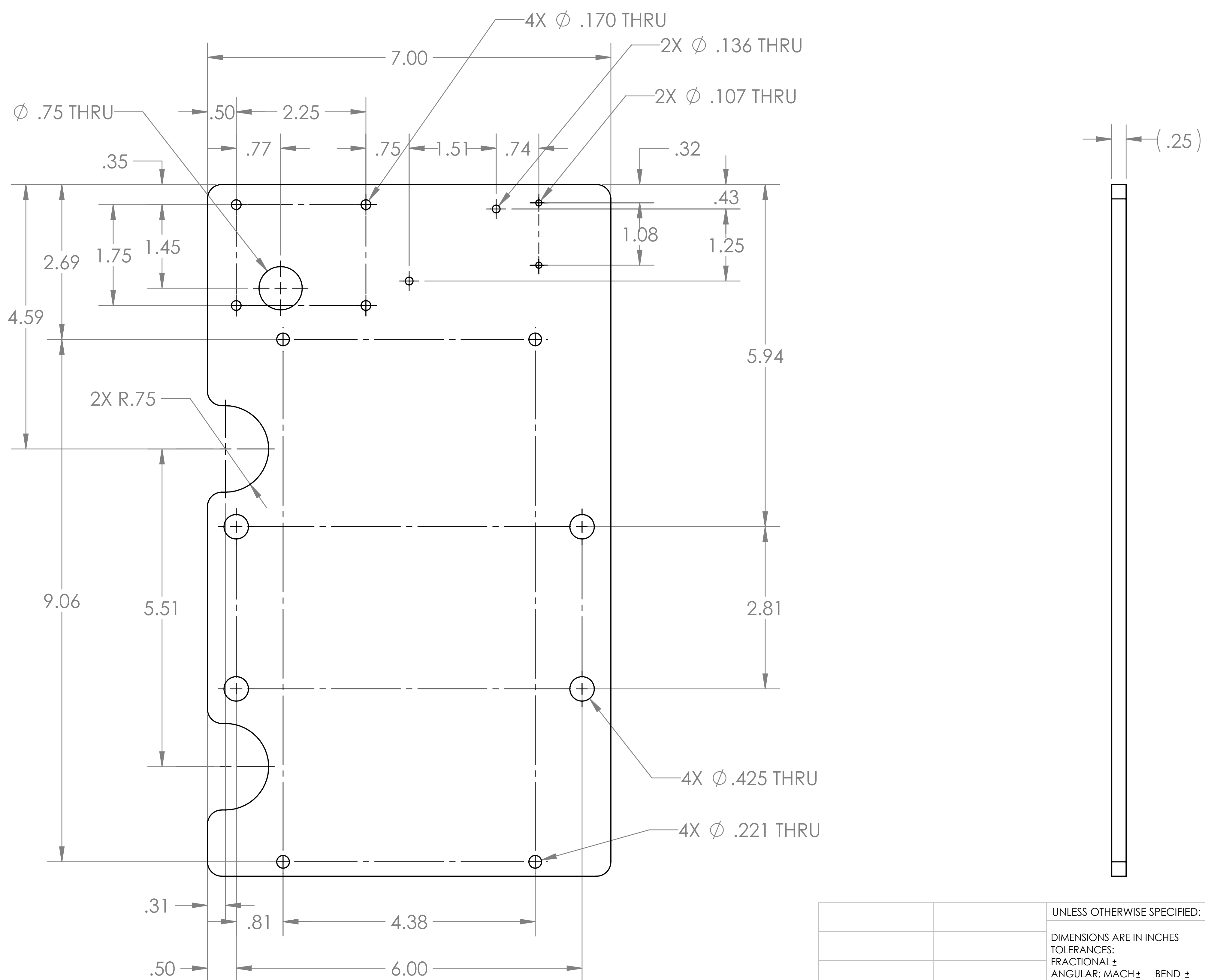
COMMENTS:

TITLE:

Y Bracket

SIZE **B** | DWG. NO. 00000002 | REV

SCALE: 1:4 | WEIGHT: | SHEET 2 OF 2



NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	R. O'NEILL	10/2/2017
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

TITLE:
ELECTRONICS PLATE

SIZE	DWG. NO.	REV
B	00000006	

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

Appendix 6: Operator's Manual

Introduction

The following appendix contains all information needed to properly maintain, assembly, and use the spotlight mount system. It should be noted that this system is complex, heavy, and potentially dangerous. Any information contained below will help to minimize risk of personal injury or system malfunction but by no means eliminates all potential sources of danger. When handling, operating, or being near the spotlight mounts, general precaution should be taken to avoid personal injury and injury to those around you.

If at any time the system isn't operating as intended, power should be immediately disconnected and all aspects of the mount be inspected for potential issues.

Maintenance

Team Dynalux recommends that each mount be inspected on a monthly basis. During such an inspection, an operator should disconnect power to the system, climb up to the spotlight mount, and complete the following itemized list.

1. Begin by check all four U-bolts and nuts to ensure that they are secure, holding the mount in the correct position, and corrosion free. If any bolts appear to be failing they should immediately be replaced.
2. Check the belt tensions and adjust the belt tension bolts on the top and side of the mount if necessary. In addition, visually make sure the belts aren't slipping or broken.
3. Spin both axes by hand to ensure they rotate smoothly and with minimal resistance.
4. Check motor mounting screws to make sure both motors remain securely attached to the mount.
5. Inspect the X-bracket attachment points to the spotlight and make sure connections are secure and corrosion free. Should they be loose or rusted, replace as soon as possible.
6. Check all electrical connections and ensure there are no loose wires.
7. Provide a general cleaning to remove any foreign material or dust from the spotlight mount. When clean, check for corrosion of the metal and generally inspect all metal parts.

Assembly Instructions

Due to the spotlight's large size and weight, it is best assembled in parts. The first step is to insert the belt tensioning carriage bolt through the large square hole in the tube and into the slot, and use a wrench to tighten a lock nut on it. Then, attach the vertical motor to the mounting frame through the square hole using four screws. Next, the small pulley is positioned on the motor shaft and held in place using a set screw. After that, four long bolts are inserted into the top of the square tube and protrude outward. These will hold the acrylic encoder plate and encoder. Use four nuts to secure the bolts and 8 more to position and secure the encoder plate. The encoder plate is best left off until the Y-bracket is inserted into the square tube later in the process.

Once all the smaller components are installed on the mounting frame, it is time to lift the mounting frame up to the light boom and secure it firmly using 4 U-bolts. It is critical that all the nuts are tight because the mounting frame provides a base for the remainder of the mount and light. At this point, insert two flanged bearings into the 1.75” holes in the square tube from above the holes so that the flange prevents them from falling out. The mounting frame is now ready to accept the Y-bracket.

Adding smaller components to the Y-bracket can be done before or after it is lifted into the square tube. In addition, the X-bracket can also be assembled and attached to the Y-bracket and both parts lifted up together. **Due to weight concerns, it is recommended that the Y-bracket and X-bracket be the only two parts lifted together. When the entire mount is assembled, it is very heavy, has a large moment, and can be very difficult to maneuver even with multiple people.**

The Y-bracket components are similar to the square tube. Start by attaching the horizontal motor to the inside of the bracket using four screws to secure the motor. Next, add four bolts for the encoder plate such that they protrude away from the bracket, and fasten them the same way you did for the screws in the square tube. After securing the encoder bolts, slide 2 more flanged bearings into the large holes on the sides from the outside. Lastly, put another belt tensioning carriage bolt into the slot on the motor side of the bracket so that it points outward.

Once the Y-bracket is complete, begin the X-bracket by inserting four short carriage bolts into the slots on the sides facing outwards. Use lock nuts to hold them in place, but they do not need to be tight as they will later be tightened to secure the spotlight.

When both the Y and X brackets have been completed, slip the X-bracket into the Y-bracket starting with one X-shaft, pushing it all the way through. Once the other side clears the Y-bracket, recenter the shafts so that both brackets line up with each other. Keep in mind that this step can be completed on a table or in the air. While doing this on a table is sometimes easier, it does increase the amount of weight that will need to be lifted at one given time. In addition, the bearings may need to be removed from the Y-bracket before the X-bracket will fit. They can be reinserted once the X-bracket is in the correct location. Once the brackets are in place, slide the large pulley onto the X-shaft on the side without a step in the shaft, and secure with two set screws.

Lift the whole assembly up into the square tube and slide the Y-shaft through both bearings until it extends above the tube. As this is done, add the thrust bearing and washer to the Y-shaft so that they rest inside of the square tube, on top of the lower bearing. While holding the assembly in place, put both halves of the shaft collar around the step in the Y-shaft and secure the shaft collar halves together with screws. When it is firmly attached, slowly lower the Y and X brackets down until the square tube is supporting the load of the brackets. Keep holding the system until you are certain all parts are securely fastened and nothing will fall.

When all three metal parts are attached and hanging, additional components can be added. Begin with belts and adjust tensioner bolts to provide tension. Lift the spotlight into position in front of the X-bracket at the same height and then slide the round disks on the light between the carriage bolts on both sides of the mount. Insert the mount attachment screws into the center holes of the X-bracket, and then tighten down all four carriage bolts until they are firmly secured to the disks on both sides of the spotlight. Inspect all connections to make sure they are secure and the spotlight does not rotate independently of the X-bracket. Finish by putting the encoder plates onto the encoder bolts, and ensure they are centered around the shafts and flat by adjusting the plate lock nuts. The encoders are the most sensitive and fragile components, so time and care should be taken when installing them. Instructions for assembling the US Digital E6 single-ended encoders used in this project can be found on US Digital's website and in the datasheets included with this report.

Lastly, attach wires to the motors and adjust their length and position so they don't impede with free movement of the spotlight. Motor A is the horizontal X-axis motor, and Motor B is the vertical Y-axis motor.