Final Design Report: Polymer Fatigue Characterization Test Method

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Statement of Disclaimer

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Executive Summary

Polylogix is a team dedicated to the design, build, and testing of a fatigue machine to simulate cyclic loading on a biomedical polymer. This project is sponsored by Endologix, Inc. to provide test data characterizing mechanical material properties of various formulations of polymer used in abdominal aortic aneurysm surgeries. With this project goal, the machine must be able to test the polymer at body conditions; these include a testing temperature of 37℃ and a cycling frequency ranging from 1 Hz to 10 Hz. This report proposes the following solution to this design challenge: an AC motor-driven mechanism utilizing a planetary gearbox and pulley system to reduce the speed of the motor to those necessary to achieve testing frequencies of 1 Hz, 2 Hz, 5 Hz, 8 Hz, and 10 Hz. From the drive mechanism, a shaft-mounted cam translates the rotational motion to linear motion through a cam follower. This cam follower carries a load cell and test specimen grip fixtures which clamp onto the specimen to apply cyclic loading. To vary the percent elongation applied to the test specimen, the cam has been designed to be interchangeable to accomplish a range of elongations: 10%, 20%, 30%, 40%, and 50%.

For this application, the standard dumbbell test specimen shape does not accurately represent the physiological behavior of the polymer. Therefore, we redesigned the shape to be a cylinder with a head to neck area ratio of 4.5:1 to induce failure in the neck section before failure at the grips. The grips clamp onto the specimen at ringed-grooves on both the top and bottom. This minimizes stress concentrations due to excessive clamping force. This shape was chosen based on a finite element analysis of several possible test specimen shapes.

Safety is critical to the operation of this machine, as there are moving parts, heating elements, and a motor requiring manual voltage control. We have mitigated safety concerns with this design by implementing a controls system that allows for easy operator and leave-alone regulation.

Chapter 1: Introduction

Project Background

Endologix and Polylogix are collaborating to develop a fatigue test machine and related test methods to analyze and assess stress-strain characterization of different polymer formulations of the Nellix EndoVascular Aneurysm Sealing (EVAS) System through conduction of tensile tests. If time permits, creep and stress relaxation tests will also be performed.

This project aims to achieve an understanding of long-term fatigue tests that comply with American Society for Testing and Materials (ASTM), International Organization for Standardization (ISO), and Food and Drug Administration (FDA) standards. Upon completion of the project, test method and fixture applications will aid in the development of a greater grasp of clinical test methods conditions. The final product(s) will be used in Endologix's laboratory site to further assess how the polymer's shape and mechanical properties vary with fatigue over time, assisting in design iterations of new polymer formulations.
The completion of this project will award Polylogix with hands-on experience in conducting a biomedical industry-related project, and will prepare team members for their post-graduate life.

Endologix, Inc. and Abdominal Aortic Aneurysms

Endologix, Inc. primarily focuses on the development and manufacturing of minimally invasive treatments of abdominal aortic aneurysms (AAAs). The abdominal aorta transports oxygenated blood from the heart to the lower portion of the body. Its health and ability to function properly is vital to survival. An aneurysm occurs when the walls of the aorta begin to weaken and balloon out as a result of bodily forces. If left untreated, an aneurysm will reach a critical state and rupture, causing internal bleeding and loss of blood pressure to the lower extremities. Aneurysms in the abdominal aorta have a 75% mortality rate, making them a leading cause of death in the United States [7]. Factors that increase the chances of developing an aneurysm include smoking, high blood pressure, genetics, biological sex, and age.

Abdominal Aortic Aneurysm Treatment Options

All treatment options available for AAA patients aim to prevent the aneurysm from bursting. Appropriate treatment selection is dependent on not only the size and location of the aneurysm, but of the patient's overall well-being. Small aneurysms may only need regular examinations to keep track of its size. Aneurysms that are large and/or progressively growing require immediate treatment to prevent rupture. Current treatments readily available for AAA are open surgical repair, endovascular aneurysm repair (EVAR), and endovascular aneurysm sealing (EVAS) [9].

Open surgical repair requires incisions in the patient's abdomen to access the aortic aneurysm. A graft, which is a tube of biocompatible material, is sutured in place of the ruptured area to act as a "new" blood vessel. Successfully sewing the graft is difficult; blood flow through the aorta must be stopped while the graft is being located and applied. Open surgical repair is invasive and is not suitable for all patients, for it is heavily dependent on the patient's general wellbeing. The

recovery period from the operation may be at least three months, with the risk of a patient not convalescing to full function [9].

EVAR is a minimally invasive alternative to open surgical repair. Traditionally, it requires a small cut in one groin and a small puncture in the for endovascular stent graft insertion via the femoral arteries. Once placed inside the aneurysm in the aorta, blood begins to flow through the stent graft rather than the aortic aneurysm. The stent graft is left in the aorta permanently. Percutaneous endovascular repair (PEVAR), another form of EVAR, involves a small puncture incision across the skin of each groin. Suture devices are delivered across the skin prior to stent graft insertion, which are fastened to close the puncture incisions after the aneurysm is repaired. EVAR and PEVAR have shorter recovery periods of 4 to 6 weeks than that of open surgical repair [7].

Endologix developed the AFX Endovascular AAA System, a product implemented by either EVAR or PEVAR operative procedures. AFX is a stent graft technology that mimics the general shape of an abdominal artery (Figure 1). The graft (white sheath) is composed of multiple layers of a polymer to provide strength and seal. The cobalt-chromium alloy stent lines the innermost layer of the graft for structural support. The AFX graft is compressed prior to insertion and delivered by a catheter through the incisions (EVAR) or punctures (PEVAR) of the groin. When the stent graft is positioned properly, the stent is allowed to expand. Its resulting form holds its place in the aorta, reinforcing the walls of the aneurysm. When the single catheter delivery system is withdrawn from the patient's body, blood flows through the AFX system [7].

Figure 1. AFX Stent graft [4].

EVAS is another minimally invasive alternative to open surgical repair. Similar to EVAR, EVAS involves a small incision in each groin to access the femoral arteries to prepare for endovascular stent graft insertion. Each stent graft has an attached bag placed inside the aneurysm. The bag is filled with a liquid, medical grade polymer that solidifies in the bag to conform to and fill the entire aneurysm sac volume, as well as secure the stent graft to allow blood flow to divert through the graft rather than the weakened aortic wall. The stent grafts and the polymer-filled bags are permanently left in the aorta [9]. A patient undergoes full recovery in 4 to 6 weeks [8].

Endologix's Nellix EVAS System is an innovative method of treatment for AAA. Nellix technology approaches treatment by effectively sealing the entire aneurysmal sac with employment of a stent and polymer-filled bag. This method adopts the stent graft from AFX and applies it to the aorta, but the polymer-filled bag securely locates the stent grafts more so than solely the AFX stent graft in the aorta alone in EVAR. The implant procedure is similar to that of AFX, with the exception of EVAS being applied with two delivery catheters. One Endobag and one stent graft are attached to each catheter. Once the stents are in the correct position and established for re-directed blood flow, the Endobags are inflated at a controlled rate and prefilled with saline to determine the appropriate volume of polymer to inject into the Endobag for a complete aneurysmal seal. The delivery system is extracted once the polymer within the Endobag has completely cured [3].

The advantages and disadvantages of open surgical repair, P/EVAR, and EVAS are briefly summarized below in Table 1 [8].

Table 1. Advantage and disadvantage comparison amongst AAA treatment options.

Treatment Options	Advantages	Disadvantages
Open Surgical Repair	• Standard treatment method • Valid surgical procedure • Provides long-term results • Follow-up patient examinations are not required	• Patient endures major abdominal surgery (cut through their abdominal) • Higher surgical complication rate than EVAR • Longer recovery period than P/EVAR and EVAS
Endovascular Aneurysm Sealing (EVAS) **Percutaneous/ Endovascular Aneurysm Repair (PEVAR/EVAR)**	• Minimally invasive surgical procedure • One incision in one groin, one puncture in the other (EVAR) • One puncture in each groin (PEVAR) • Shorter recovery period than open surgical repair • EVAS can treat a wide range of complex anatomies [11]	• Higher chance of an endoleak and/or aneurysm rupturing than open surgical repair due to stent structure shifting (P/EVAR) • Long-term follow-up patient examinations are required • May call for supplementary treatment options

Current case reports and commentaries conclude that the Nellix EVAS System is a practical method of managing ruptured aneurysms from assessments of small range outcomes in a small sample size of patients [3]. EVAS is capable of effectively treating endoleaks due to inadequate sealing (type Ia), but long-term results are necessary [12, 13].

Industry Standards and Regulations

To safely and accurately run tests on polymer test specimens, existing regulations and standards must be incorporated into the design. ASTM standards D412-06a, D2990-09, and F2900-11, and

ISO 37 apply directly to this project, while FDA standards "Global Unique Device Identification Database" and "Guidance for Industry and FDA Staff - Non-Clinical Engineering Tests and Recommended Labeling for Intravascular Stents and Associated Delivery Systems" are most relevant to final documentation of the built system. These standards and their relevance to this project are as follows:

- *ASTM D412-06a "Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension"*: Referenced dumbbell test specimen die standards in development of project specific specimen geometry
- *ASTM D2990-09 "Standard Test Methods for Tensile, Compressive, and Flexural Creep and Creep-Rupture of Plastics"*: Standardized tensile creep test methods for application in this project if time permits
- *ASTM F2900-11 "Standard Guide for Characterization of Hydrogels used in Regenerative Medicine"*: Recommendations for valid mechanical property evaluation
- *ISO 37 "Rubber, Vulcanized and Thermoplastic Determination of Tensile Stress-Strain Properties"*: Referenced mechanical tensile test methods as related to ASTM D412-06a
- *FDA "Global Unique Device Identification Database"*: Apply identification requirements to final, verified machine
- *FDA "Guidance for Industry and FDA Staff - Non-Clinical Engineering Tests and Recommended Labeling for Intravascular Stents and Associated Delivery Systems"*: Compare test methods developed herein with established stent testing methods and documentation

Current Fatigue Testing Equipment

Bose Corporation provides advanced mechanical testing machinery with their 3000 ElectroForce® (ELF) test instrument series. Their 3200 test instrument is used for applications that require low force and high frequency parameters. With a linear motor drive, this machine is ideal for tests that demand for a combination of maximized repeatability, high frequency, and high cycle count. The equipment can handle loads up to 450 N, which is more than sufficient for testing the EVAS polymer, where previous tests were done using much lower loads. Through various fixtures, this model can accommodate up to 16 samples. The instrument primarily focuses its controls on displacement and/or load. Monitoring multiple samples allows for the use of transducers for individual specimen data collection. Typically, the 3200 model is implemented for strength characterization tests for intravascular devices, including biomaterials and polymers [6, 16].

The ELF 3300-AT test instrument tests for axial and torsion. It retains the capabilities of the 3200 model, but for higher frequency and cycle counts. The ELF 3300-AT is applied for a broader range of tests, including strength characterization tests and in vitro simulation tension/compression for intravascular devices (endovascular stent grafts). In vitro simulated tension/compression testing provides empirical evidences regarding the structural integrity of the test specimen when subjected to mechanical tension/compression replicating in vivo (bodily) conditions. The samples undergo accelerated tests with saline at 37°C and relevant physiological conditions to collect data in less time than biological rates would allow [16, 17].

Bose's pulsatile radial fatigue/stent graft-tester (ELF 9100 series) verifies the fatigue life of various vascular prosthetics under simulated biological conditions similar to the human body. The machine mounts 4 to 12 samples between manifolds that contain linearly driven motorized pumps. The control system delivers radial strain to the samples under controlled temperatures. The stent-graft tester is implemented in in vitro durability testing for intravascular devices. Pulsatile durability testing involves mounting the samples (in a mock artery mold) to the stent-graft tester and subjecting them to cyclic pressure pulses. The specimens experience dynamic radial strains, as it would in the body, simulating the device's radial fatigue due to expansion/contraction of the surrounding vessel. These tests are accelerated for the same reasons as the accelerated in vitro tests [18, 19].

For the aforementioned Bose test instruments, strength characterization tests encompass the following, applicable to the project:

- Determination of circumferential/longitudinal tensile strength
  - A tubular sample is placed in two pins/jaws, stretched at a uniform rate until it yields/breaks.
- Local compression
  - A localized compressive force, perpendicular to the samples longitudinal axis, is exerted on the sample in increments until elastic response no longer occurs

The strength characterization tests are designed to optimize physiological geometries and scenarios for accurate and reliable data [20].

Design Requirement & Specification Development

The goals of this project are to design and build a fatigue testing mechanism that cycles the specimen between two positive deflections. With additional design iterations and optimization, apparatus users will be able to perform rate-dependent tests at biological and room temperatures. Machine operation will assist in analysis of tensile, creep, and stress relaxation tests by conducting stress-strain and destructive tensile tests. Furthermore, completion of an optimized polymer geometry using finite-element analysis (FEA) will be performed in order for accurate characterization of the polymer material and proper testing mechanism function.

A quality function deployment (QFD) decision matrix (Appendix A) was constructed to assist Polylogix understand the problem, quantify the customer requirements, and maintain focus on what needs to be designed based from the customers' needs and expectations. Figure 2, as shown below, qualitatively depicts the setup of the QFD.

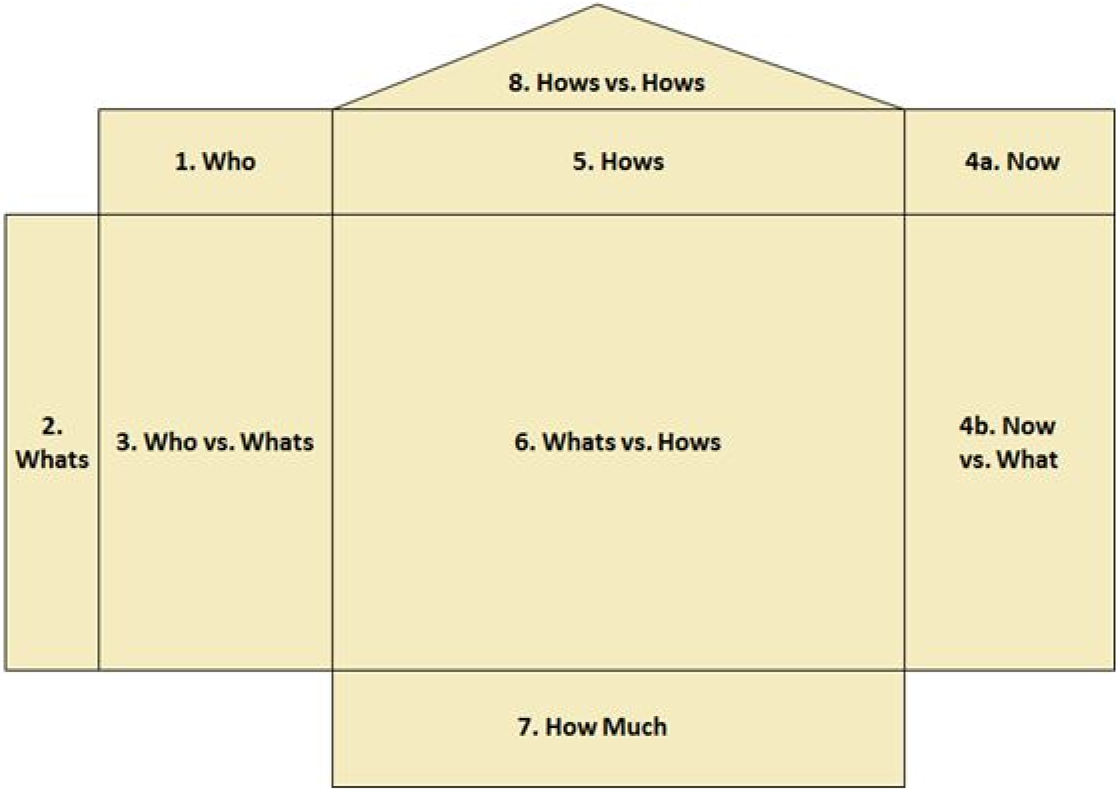


Figure 2. General "House of Quality" guideline for QFD [2].

QFD is a means of linking customer requirements to engineering specifications, and also establishes a quantifiable relationship between the two. Once specific customers are defined (who), customer requirements (whats) are listed in rows to the left of the diagram and engineering specifications (hows) in columns on top of the diagram. The importance of each requirement is evaluated (who vs hows) per customer on a "1" to "10" scale from least to most importance, respectively. The current status of the customers' satisfaction is discussed for the well performing products that are currently available (now and now vs. what). Symbols representing the strength of the relationship between a specific customer requirement and engineering specification are placed in the boxes where the rows and columns meet (whats vs. hows). Target values (how much) are added beneath the relationship space to further define the engineering specifications. The engineering specifications are then assessed for their correlation to one another (hows vs. hows).

The QFD of Figure 2 can be revised to better suit the project and its goals, seen below in Figure 3.

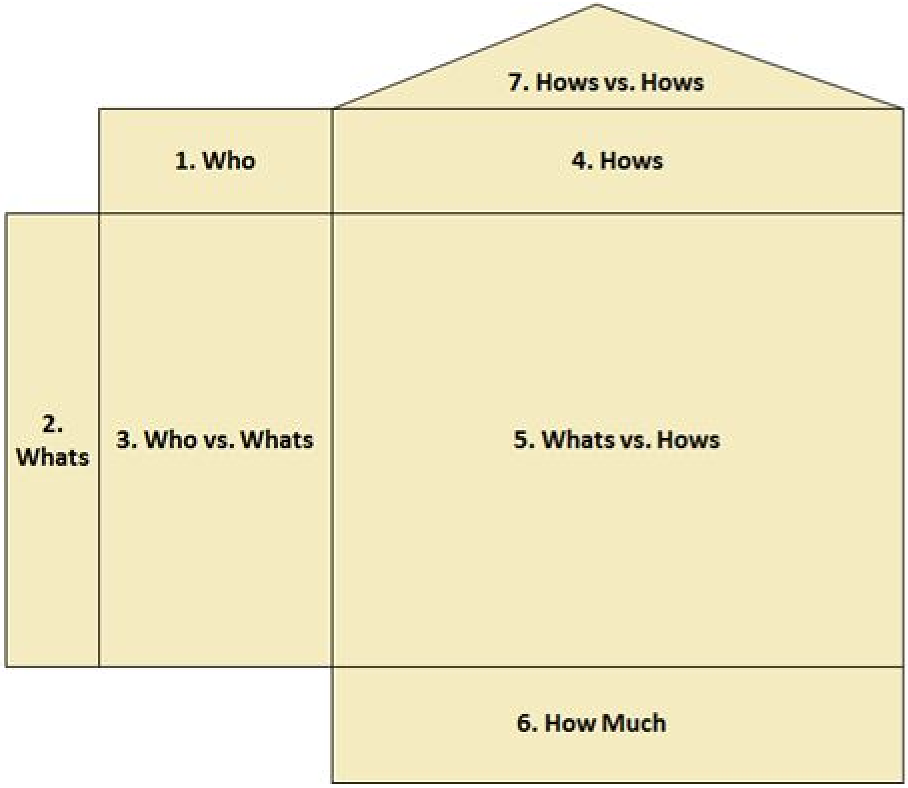


Figure 3. Revised "House of Quality" QFD Matrix.

The right-hand-most sections of the matrix ((now and now vs. what) are needed for projects that require product development. Seeing as this project involves designing a test method and machine for private, non-profit use, these sections were removed.

Taken from the QFD in Appendix A, Table 2 further defines the relevant engineering specifications. Anticipated tolerances, risks, and project section assignments are included in this table.

Table 2. Engineering specifications.

Spec #	Parameter Description	Requirement or Target (units)	Tolerance	Risk	Compliance*
1	Cost	$2500	± $500	M	A
2	Fatigue Maximum Displacement	18.0 mm	± 2.0 mm	L	A, T
3	Ability to Measure and Set Test Speed	1Hz - 10Hz (60 RPM - 600 RPM)	TBD	M	T
4	Temperature Controlled Environment	37°C (internal body) 23°C (room)	± 0.5°C	L	S, T
5	Saline Bath Required During Testing	7.4 pH	-0.4 pH	L	S, T
6	Multiple Samples at Once	5 (will begin testing with 1)	-4 samples	M	A
7	Uniform Test Piece	No visible irregularities	N/A	M	I
8	Storage Temperature	-30°C	+20°C	L	A, I
9	Test Cycles	TBD	TBD	L	A, T, I

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

Initially, the project specifications included the development of a standardized test method related to a mechanism capable of mechanically characterizing at least five samples of polymer for an average of 50 million cycles [9]. Preliminary research on polymer fatigue characteristic behavior leads to an understanding of the viscoelastic properties of polymers. Subject to fatigue analysis, and considering the time dependency of the mechanical properties, attempting to accelerate the 50 million cycle testing time frame would compromise the measured properties. Obtaining accurate test data requires testing of the polymer specimens to occur at a rate similar to the average heartbeat range (60 BPM [1]), resulting in an experimental period of

approximately 1.5 years. After further discussion with Endologix, the focus was shifted to general characterization of the polymer's properties and a reduced fatigue life test. We have since updated the test speed target to reflect the frequency we expect to see on the test specimen.

Team Management

This section will detail the team management, including team hierarchy and organization, responsibility allocation, and group dynamics.

Team Development

To begin the design process, the first major step in becoming a cohesive team required scheduling time for social development. This key step involved exchanging all forms of contact information, developing a team schedule, and team bonding. By establishing a strong social foundation, we build trust, hold each other accountable, and foster an openness between each other that would allow for better conceptualization, group functioning, and overall project outcomes. Team development also included communication with our industry and academic advisors. Within the first week of the design process we had meetings scheduled:

- Internally with Polylogix
- Externally with academic advisors (face-to-face meeting)
- Externally with Endologix advisors (telecommunication)

By setting up regular meeting times and work hours, we can effectively complete tasks and reach milestones. Close communication with advisors allows for time-efficient solution strategies when faced with unpredicted design roadblocks.

Individual Responsibilities

The four-member team aiming to complete this project has a diverse set of skills which allow for the even allocation of project responsibilities. Overseen by Dr. Davol — our acting Project Engineer — each team member will have authority over specific segments of the project, as well as an administrative role to enhance the team's performance, as depicted in Figure 4 below.

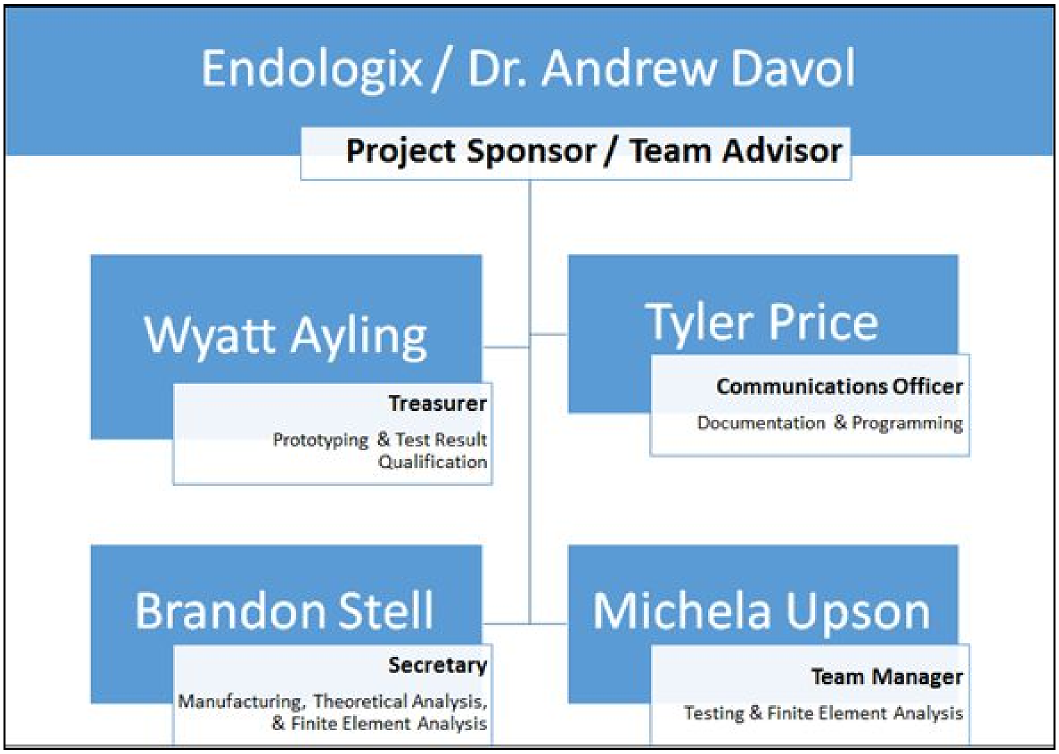


Figure 4. Polylogix hierarchy including individuals' administrative and lead positions.

Wyatt Ayling holds the administrative role of Treasurer. In this role, he is responsible for the project budget and regulates expenses accordingly. Expenses include travel, prototyping, tooling, off the shelf part, and raw material costs. All purchases require the Treasurer's approval such that the budget is not exceeded. Previous experience managing a year-long student project qualifies Wyatt for this position.

In addition to his administrative responsibilities, Wyatt will also be leading prototyping and test result qualification. As prototyping lead, he is responsible for leading the team in the generation of physical, low-cost models to represent various design concepts. This will include prototyping during the conceptual design phase as well as prototyping the machine towards the end of the build process. As lead of test result qualification, he will collect the data from testing, oversee its post-processing and organization into clear and concise documentation, compare the test results with theoretical values, and initiate test method adjustments as needed to produce more accurate data. The inclusion of this lead position ensures that the project goals are accounted for and achieved.

Tyler Price is the Communications officer with the primary goal of maintaining regular, clear communication with the Endologix sponsor team. This position includes managing the team email account, planning and scheduling conference calls, and generally being the primary point of contact for the sponsor team. Although Tyler oversees the team email account, and holds the primary responsibility of sending and replying to email communications, the other team members also have access to the account and may use it when necessary. This position ensures clear lines of communication and minimizes confusion regarding the exchange of information.

In addition to her officer position, Tyler will also be leading the documentation stages and programming requirements within the project. Concerning the various documentation, Tyler will initiate the creation of the Project Proposal, Preliminary Design Report, Final Design Report, and the Final Project Report. Following the document's creation, the required sections will be fairly partitioned and assigned within the team. As documentation lead, she will also follow up with each member to ensure timely completion of the reports, and will be the head editor of each document. Contrastingly, the programming lead will not partition up the programming requirements, and will instead be the core source of knowledge and skills for this part of the project. As a mechatronics concentration, she is most qualified for this position, but may call upon the other teammates for assistance when required.

Brandon Stell holds the administrative position of Secretary. As such, his responsibilities include managing the team Google Drive, preparing the weekly status reports, and recording official meeting minute—both during conference calls and advisor meetings. Regarding the team Google Drive, he will create a comprehensive method of organization for folders, documents, and project photos. The implementation of this position within our management structure ensures ease of access to important documents and adds traceability to our design process for simplification of future review.

In addition to these administrative responsibilities, Brandon also holds the lead positions of manufacturing, and theoretical analysis, and co-lead of the finite element analysis effort. The manufacturing lead position involves coordinating a machining schedule, reserving an appropriate workspace, and distributing part creation responsibilities to each team member. Brandon's internship experience involved significant shop time, qualifying him for this position. As theoretical analysis lead, he will oversee the distribution of hand calculations for the various design elements, ensure that each machine component has associated appropriate sizing and selection calculations, and will manage any related documentation. Finally, the responsibilities of co-leading the finite element analysis effort will be detailed in the next team member's related section.

Michela Upson is the team manager. This administrative position allows her to call additional team meetings, edit all email-based communication with Endologix or other external resources, and oversee the general performance of the team. She works with each team member to identify skillsets and assign the appropriate responsibilities and lead titles. Managing the team long-term requires a focus on the maintenance of a cohesive, open, and honest team environment to facilitate idea-sharing, and subsequently, to help team members navigate conflict without losing sight of the end-goal. Her past leadership experience as a club officer and freshman orientation leader qualify her for this position.

In addition, Michela will lead testing and co-lead the finite element analysis effort. As testing lead, she will oversee the creation of and adherence to testing procedures, secure an on-campus location where testing may occur without frequent interruption, acquire equipment required to safely run machine, create a testing schedule, and allocate test segments between the team members. Experience leading testing for previous long-term projects qualifies her for this position. Co-leading the finite element analysis effort with Brandon involves performing an

analysis of the maximum loading stress-state of a Nellix system, analysis of selected test specimen shape, and analysis of projected effect of complete number of life cycles on the final test specimen. Additional analysis cases may arise as the team progresses through the design process. Michela and Brandon are both currently enrolled in the introductory finite element analysis course, qualifying them for this shared responsibility.

Project Management

The Polylogix method of design development begins with a standard engineering design process model using design, build, test, and subsequent iteration as the foundation. From the design-build-test model, the method was broken down into smaller intermediate stages, having tasks and milestones within each stage. The general breakdown can be seen in Figure 5 below.

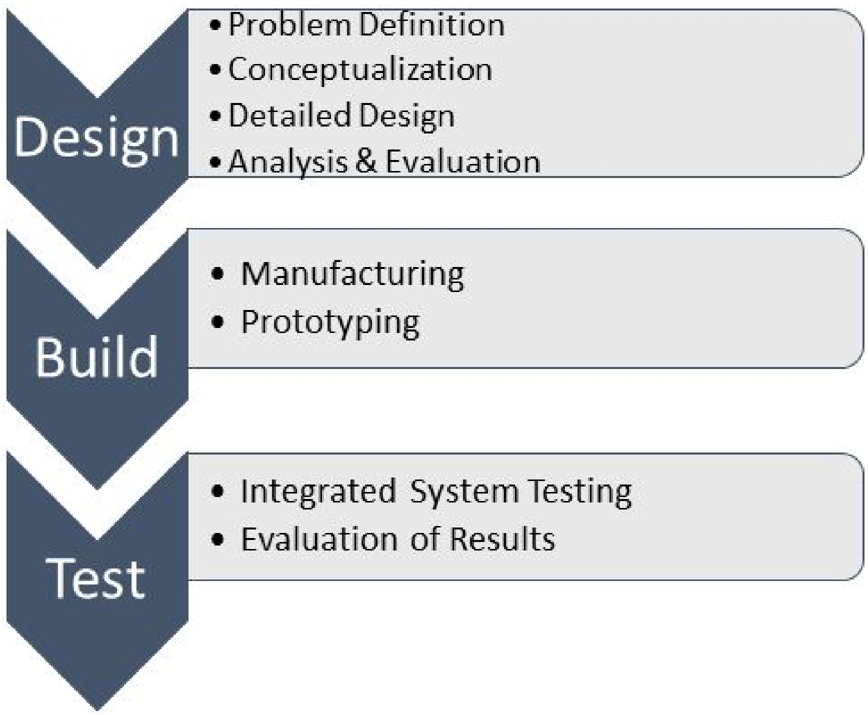


Figure 5. General design process model.

Project Scheduling

This section will include information regarding the design process Polylogix utilized, with respect to time-keeping and process management.

The next step in the project was to budget the time available to the team. An academic school year for our team is broken into three quarters, with each quarter focusing on a different phase of the design process: Winter quarter 2015 (design), Spring quarter 2016 (build), and Fall quarter 2016 (Finalize & Present). In order to accommodate the needs of a thorough design process in the time allotted to us, adjustments were made to the generalized phase approach stated above. Additionally, the school year runs through a summer break, requiring preparation for two academic project expositions (early June and mid-December of 2016). As a result, the build

phase of the design process began earlier, at the end of Fall quarter, and running through June. This change in pace would allow for more technical preparation for both expositions, as well as ensure proper iteration of our system in order to optimize the final design before the project turnover.

Included in Appendix A is a current Gantt chart, developed in accordance with our general design model, and consideration for the Cal Poly Senior Project requirements.

Table 3. Polylogix project tasks in order of date.

Task Name	Duration [days]	Start	Finish
Design	104 days	Mon 1/11/16	Thu 6/2/16
Advisor Meeting	101 days	Thu 1/14/16	Thu 6/2/16
Endologix Teleconference	101 days	Wed 1/13/16	Wed 6/1/16
Problem Statement	0 days	Thu 1/21/16	Thu 1/21/16
Project Proposal Report	1 day	Tue 2/2/16	Tue 2/2/16
QFD House of Quality	0 days	Thu 1/28/16	Thu 1/28/16
Concept Modeling	9 days	Thu 2/4/16	Tue 2/16/16
Pugh Matrices	0 days	Tue 2/16/16	Tue 2/16/16
Final Design Matrix	0 days	Thu 2/25/16	Thu 2/25/16
Preliminary Design Report	0 days	Mon 2/29/16	Mon 2/29/16
Preliminary Design Review	1 day	Thu 3/3/16	Thu 3/3/16
Design Analysis	36 days	Tue 3/1/16	Tue 4/19/16
Final Design Report	8 days	Tue 4/26/16	Thu 5/5/16
3rd Team Eval & Reflection	0 days	Tue 5/3/16	Tue 5/3/16
CDR with Endologix	1 day	Wed 5/11/16	Wed 5/11/16
CDR with Cal Poly	1 day	Thu 5/5/16	Thu 5/5/16
Build	28 days	Tue 4/26/16	Thu 11/30/16
All parts Ordered	120 days	Tue 4/26/16	Thu 11/24/16

Status Report	0 days	Thu 6/2/16	Thu 6/2/16
Project Update Memo	0 days	Fri 9/30/16	Fri 9/30/16
Prototype Construction	28 days	Tue 11/12/16	Thu 11/30/16
Exposition	20 days	Mon 9/27/16	Fri 12/13/16
Project Update Memo	0 days	Tue 9/27/16	Tue 9/27/16
Project Hardware Check	0 days	Tue 10/30/16	Tue 10/30/16
Winter Expo	0 days	Mon 12/1/16	Mon 12/1/16
Final Project Checklist	0 days	Fri 12/9/16	Fri 12/9/16
Final Project Report	0 days	Thu 12/12/16	Thu 12/12/16
Final Reflection	0 days	Tue 12/13/16	Tue 12/13/16
Final Sponsor Presentation	0 days	Fri 12/16/16	Fri 12/16/16

Table 3 details the tasks required by each design phase with respect to the time length and beginning/ending dates. The task items with a 1-day duration are project milestones, set by the Cal Poly Senior Project program. The Gantt chart in Appendix A includes the items in Table 14, as well as the dependency and progress of tasks. Along with the Gantt chart, a program evaluation and review technique (PERT) chart (Figure 6) has been developed to ensure that the resulting critical path of our tasks fits within our academic timespan.

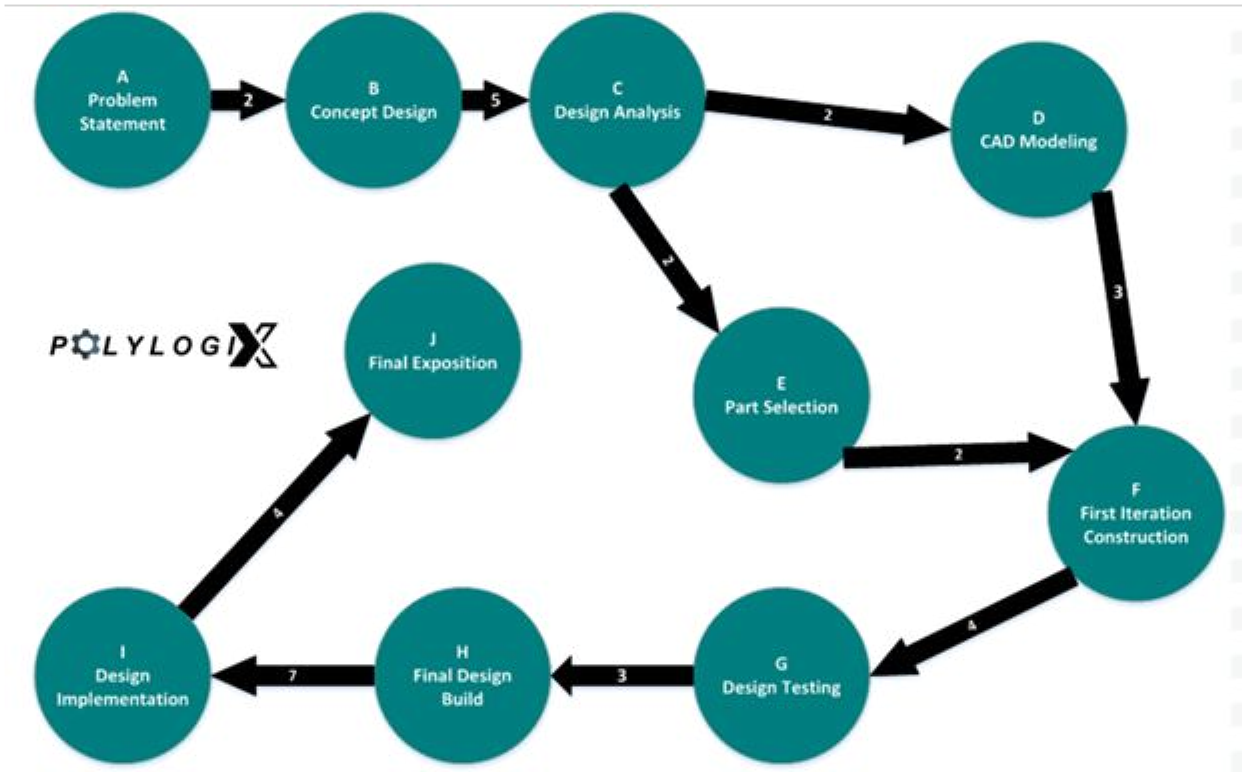


Figure 6. Polylogix PERT chart.

The circular elements of the PERT chart contain time-sensitive tasks. Arrows connecting tasks show the length of time needed for each task to be completed. From the path of tasks, the critical path for the entire design process is 30 weeks, which gives us the time to complete the engineering process before the end of the academic year.

Gantt Chart

The Gantt chart included in Appendix A displays information regarding the tasks, milestones, and project summaries, with their respective deadlines and durations. Starting with the columns on the far left end of the chart, we included the task name along with its duration and start/finish dates. The tasks that are bold include subtasks that are shown below it and indented. Duration times for each subtask and absorbed into the main task that it belongs to. The horizontal bar chart included on the right half of the Gantt chart uses a week-based timeline (included along top of chart) to display a visual representation of task duration and dependencies. Project milestones are one day in length and are shown as blue and black box markers with their respective deadline displayed next to it. The summary tasks of the Gantt charge change several dates, and include an engineering process that was utilized. Summary tasks are shown as blue (downward-facing) brackets. Included next to summary tasks is the Polylogix team's percent progress. As our team progressed into our final aspect of the design process, manufacturing and construction, we quickly learned that we lacked the amount of labor hours to manufacture all parts to meet originally established deadlines. This led to the prototype construction phase taking exceedingly longer than expected due to parts constantly being manufactured at a pace that allowed us to still maintain our academic progress and wellbeing. During final construction, parts were tested for

fits and short-run operation in order to ensure that the project had an eventual possibility of full testing and further iteration.

Chapter 2: Design Development

The design phase of the process encapsulates the refinement of the provided project requirements into a solid problem definition. Spanning three months, beginning in January the design phase required thorough background research dedicated to Endologix's current products and advancements as well as the current industry standards related to the project. An additional key aspect to the design phase was frequent communication with industry and academic advisors. Obtaining information about the project and narrowing any broad project requirements will lead to a more effective conceptualization process. This aspect of our design process involved studying Endologix's practices and systems due to our project being dependent on existing Endologix testing systems and standards. Once an acceptable amount of research was conducted, we began ideation or brainstorming before refining our generated ideas using decision matrices as a valuable aid. Matrices served as a major optimization step in the design process because they allowed for direct comparison of ideas with respect to our project requirements. In preparation for design reviews with industry and academic groups, CAD models were fully developed and justified. We will be producing three major reports during this design phase:

- Project proposal report (due February 2, 2016)
- Preliminary design report (due February 29, 2016)
- Final design report (due December 12, 2016)

The significant time gap between the preliminary design report and final design report was a result of an academic summer break, as well the time needed for design reviews and subsequent iterations. During the design phase and remainder of the project, regular team evaluations and reflections were held to ensure efficient and effective team function.

Ideation and Refinement

Design ideation focused on five primary subcomponent designs: test specimen shape, grip fixtures, rotational to linear motion, hydration, and temperature control. The Polylogix team prides itself on having the best environment for idea generation, referred to as "Blue Sky". Blue Sky takes advantage of the various ideation methods available. During the design phase of the project, Blue Sky conducted four main ideation sessions, utilizing methods such as brain mapping and group brainstorming. Several rounds of ideation were conducted so that no possible design solution was overlooked or disregarded.

Blue Sky generated several ideas for the system components and operation methods. The subsections below describe the top ideas for each subcomponent.

Once the ideas for each of the five components were consolidated, the next step was strict idea refinement based on the design requirements. The refinement process included two decision methods: Pugh and weighted decision matrices. The Pugh matrix was most appropriate for the subcomponent decisions because Pugh matrix uses a go-nogo requirement checking process. A

weighted decision matrix was reserved for the final system decision. With respect to the five primary subcomponent designs mentioned previously, Pugh matrices were implemented to refine ideas for hydration, and temperature control. Table 4 includes a Pugh matrix that we developed for the hydration method, comparing it to other ideas for that subcomponent, with respect to a set of criteria specific to that subcomponent and its requirements.

Table 4. Pugh matrix for the hydration method with "Submersion" as the datum.

	Tank		Tankless						
	Submersion	Sauna	Mist	Humidifier	Water gun	Testing Relocation	Waterfall Effect	Injected Liquid	Permeable Cage
Testing Temperature	DATUM	-	-	-	-	-	+	+	-
Distilled Water		+	S	+	S	-	S	S	-
100% Humidity		-	-	-	-	-	S	S	-
Realistic Testing Conditions		-	-	-	-	-	S	S	-
Safety		-	S	S	-	-	S	S	-
Sum of (-)		4	3	3	4	5	0	0	5
Sum of (+)		1	0	1	0	0	1	1	0
Sum of S		0	2	1	1	0	4	4	0

Pugh matrices, similar to the one included above, reduced the hydration method down to two top ideas, and the temperature control method down to one idea. This left the clamping mechanism, test specimen shape, and mechanical motion method left to be decided. Upon realizing the dependency of the clamping mechanism on the specific test specimen shape, Polylogix took the decision for the shape particularly serious, delving into outside resources.

Polylogix is currently using a finite element analysis (FEA) method to optimize the shape by reducing stress points. FEA in Abaqus will be completed in order to narrow down the options for test specimens. The primary goal of this analysis will be to maximize the stress difference between the neck and grip locations of the test piece. This will help ensure that fracture will have the highest probability of occurring within the test region, away from the applied gripping forces. Another goal of Abaqus analysis will be to find the best solution to minimize gripping forces on the test piece, while still preventing slipping. This analysis will not be completed in time for the preliminary design report. Results are expected by March 11, 2016.

With the test specimen shape being developed simultaneously, the final system decision matrix was created in order to integrate the top subcomponent ideas into a single cohesive fatigue test system design. Weighted decision matrices place numerical weights on each requirement and test the influence of the requirements' weight on the final decision. Before a decision could be made, we had to determine the numerical weights used through a decision matrix as well. The weighting matrix and final decision matrix are included in Appendix A. The decision matrix consists of our remaining ideas (rotational-to-linear and hydration method) along the far left column, as seen in Table 5, and the design criteria along the top.

Table 5. Final integrated system decision matrix.

Decision: Weighting	Temperature	Leave-Alone Safety	Operator Safety	Repeatability	Realistic Testing Conditions	Maintainability	Multiple Specimen Accommodation	Cost	Manufacturability	Total	**Rank**	**Weight**
Temperature	0	-1	-1	0	0	1	1	1	1	0	**5**	**3**
Leave-Alone Safety	1	0	-1	1	1	1	1	1	1	4	**2**	**6**
Operator Safety	1	1	0	1	1	1	1	1	1	6	**1**	**7**
Repeatability	0	-1	-1	0	0	1	1	1	-1	0	**5**	**3**
Realistic Testing Conditions	0	-1	-1	0	0	1	1	1	1	0	**5**	**3**
Maintainability	-1	-1	-1	-1	-1	0	1	-1	-1	-4	**6**	**2**
Multiple Specimen Accommodation	-1	-1	-1	-1	-1	-1	0	-1	-1	-6	**7**	**1**
Cost	1	1	1	1	1	-1	-1	0	0	3	**3**	**5**
Manufacturability	1	1	1	-1	1	-1	-1	0	0	1	**4**	**4**

Discussion of Preliminary Conceptual Designs

Overall System Design

The overall preliminary system can be seen in Figure 7. Water will be placed into the testing tank and the heating circulator will be set to the desired test temperature. Once the water is at a steady state, the testing specimen will be taken out of the freezer as a two part liquid solution and will be injected into a mold in order to set at the desired shape. The user will then quickly transfer the mold to the water bath. Pinching the lower grip will open the grip fixture and the bottom portion of the test piece can be easily secured. The follower will be placed in its lowest position and the upper clamp will be applied to fully secure the test specimen. When the motor is switched on the

cam will rotate, moving the follower. The follower hangs on top of the cam and moves up and down along the guide rods, which originate from the base of the testing platform. Control systems will be put in place in order to monitor the testing process. This is explained in much more detail in the Control System Design Section.

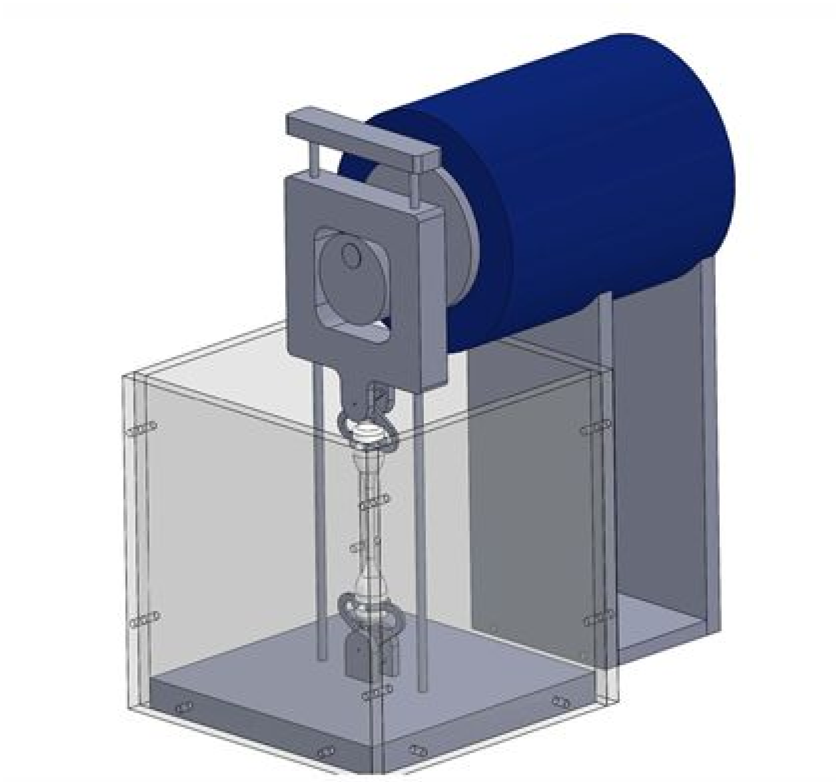


Figure 7. Preliminary System Design.

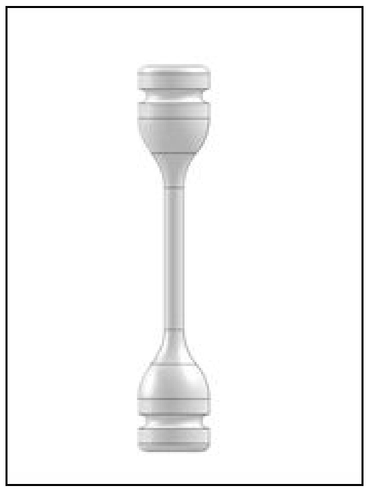
Test Specimen Shape

In the previous preliminary design report, the assumption was made that a ring-grooved test specimen was expected to yield the best results. At the time, little analysis had been completed to verify this claim. Following the approval of the design goals in the preliminary design report, finite element analysis was used to compare five possible test specimen shapes, including the ring-grooved test specimen, to verify our previous claim.

The material properties used in this analysis are for low density polyethylene. Although the material properties are not those of the polymer we will ultimately utilize as the test specimen, they allowed us to model the specimen as a ductile, elastic material--simplifying the analysis while still providing a baseline for valid specimen geometry comparison. The various test specimen geometries we compared included: the standard dumbbell shape, a slotted, rectangular cross-sectional area shape, a cylindrical shape with a pin-hole for the grip, a cylindrical shape with flat clamping areas at the grips, and the ring-grooved test specimen shape. All test specimen variations had similar grip area to neck area ratios, neck lengths, and followed the related ASTM D412-06a standards for dumbbell test specimen dies.

We conclude that the ideal test specimen shape is that of a cylindrical cross-section and a pin-hole for fixturing. It has the largest magnitude stress ratio, ensuring failure in the neck occurs before failure at the grip. However, we decided against pursuing this as our ultimate test specimen shape because loading and unloading the test specimen into the grip fixture will cause high stresses at the pin-holes and may cause the test specimen to fracture before fatigue testing begins. These high stresses would be caused by the friction forces resulting from forcing a pin through the hole, and could be eliminated by creating a larger hole. A larger pin-hole, however, would allow for slop in the alignment and inaccurate cycle frequencies being translated to the test specimen.

For these reasons, we have selected the second highest performing test specimen shape for our uses, the cylindrical, ring grooved specimen. Further refinement of this test specimen will be documented in the final design section within this report.



Figures 8. Cylindrical, grooved test specimen.

Grip Fixture

Clamping force and location needs to be consistent in order to get comparable results for each run. The circular jaws fit into the groove of the test specimen and are held in place with a spring, which is in tension. The spring will have the same displacement for each test piece, causing the gripping force to be consistent without the need for adjustment every run. Pinching the ends of the clamps together releases the test specimen. This is depicted in Figure 9.

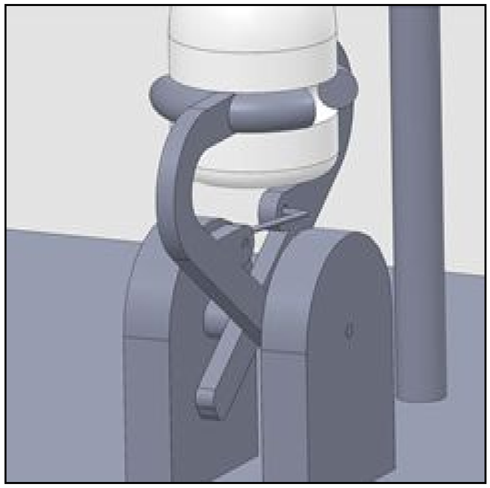


Figure 9. Spring clamping mechanism.

Rotational to Linear Motion

Rotational to linear motion is accomplished through a cam and follower system. The cam is mounted at the end of the output shaft of the motor. The geometry of the cam will define the fatigue maximum displacement, and will be designed to meet the requirement of specification two from Table 2 [14]. Hanging on the cam is the follower system, which moves along two vertical guide rods. The upper clamps of the test specimen are attached to the follower using a tab, seen extruding from the follower in Figure 10.

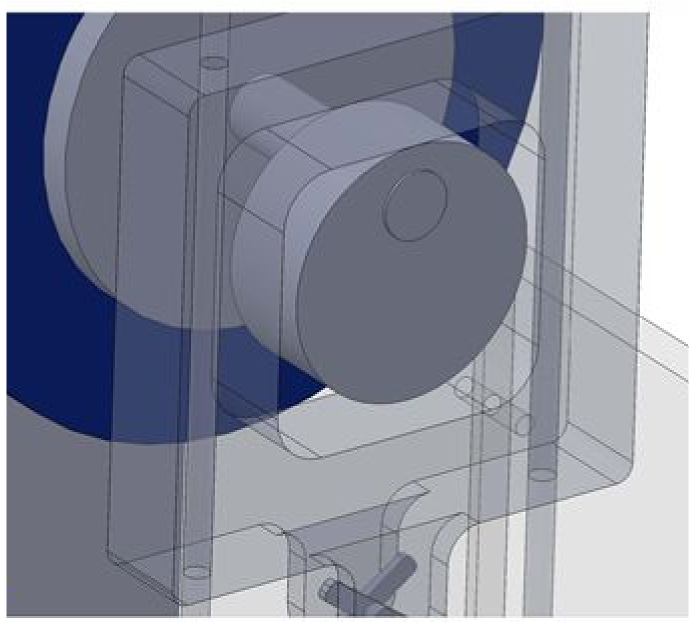


Figure 10. Cam and Follower.

Hydration Method

The best method in order to maintain hydration of the test specimen was determined to be a water bath. The water is retained by a Plexiglas casing surrounding the test platform. Portions of the guide rods, the entirety of the test piece, and the upper and lower clamps are submerged.

Temperature Control

Water temperature is controlled at the temperature specified in Table 2, using an off the shelf heater, usually used for fish tanks. These are proven systems, which will ensure that the test piece is kept in conditions similar to those seen in the body. Requirements for the temperature controller include maintaining a constant temperature of 37℃ with a resolution of ±0.5℃.

Controls System

The mechanical system illustrated in Figure 4 requires the development of a control system to ensure operator and runtime safety. This control system focuses on maintaining proper test conditions with regards to the test specimen, and controlling the power distributed to the motor.

Four sensors will be implemented in the final design, and will be applied as follows. A sensor will be placed within the submersion tank to record water height. If water levels fall below what is acceptable, then the testing will be terminated such that the tank may be checked for leaks, and the machine checked for any other anomalies affecting the tank water level. A second sensor will be a thermocouple placed near the test specimen to verify the temperature of the water. Although an aquarium heater will be implemented in order to maintain a water temperature of 37°C, using a sensor to verify this temperature nearer to the test specimen will validate the test condition's accuracy. The third sensor will be a proximity sensor to track the displacement of the test specimen fixture. If the cam follower becomes uncoupled from the cam, this may cause the test specimen fixture to compress the test specimen and invalidate the test. Finally, a sensor will be used to monitor the safety shield which will encompass the entire machine. If the safety shield is not closed, and the sensor engaged, then the machine will not run. In this way, the operator and bystanders will be kept safe while the machine is running. This safety shield will be designed to allow for ventilation, minimizing the effect of humidity on the system performance.

Chapter 4: Final Design

For the final machine design, the drive requirements were expanded to include, not solely a single frequency, but a range of cycle frequency possibilities from 1 Hz to 10 Hz. The major differences between the previously discussed preliminary design and the final design are directly related to this design requirement change.

Overall Description

Figure 11 shows an illustration of the final machine design, which includes both the mechanical system and the controls system.

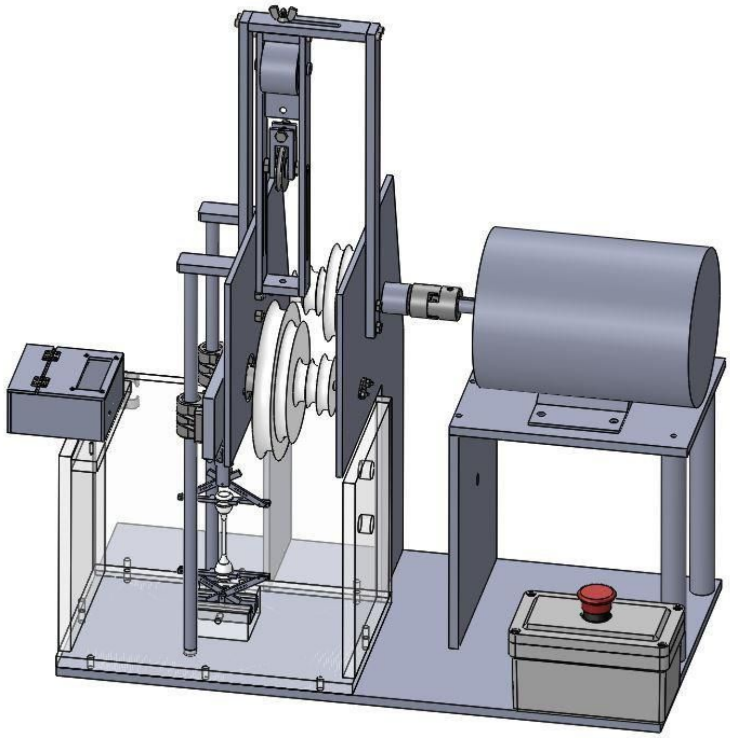


Figure 11. Final fatigue testing machine.

The overall system can be portioned into several subsystems: the existing system (as given by Endologix), the drive mechanism, the test specimen fixture, and the controls system. Essentially, the system takes the rotational motion of the motor, steps it down to the desired speed, translates the rotational motion into linear motion, and exerts a specific, known amount of strain on the test specimen. The actual frequency of the test specimen’s cycling, the number of cycles until failure, the temperature of the water, and the speed of the motor will all be monitored and/or controlled by the control system for safety purposes. Each system will be explained in-depth herein.

Existing System

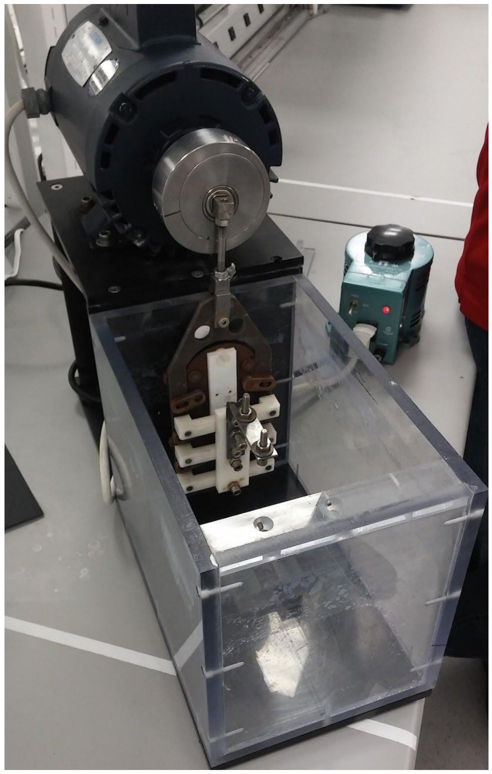


Figure 12. Previous fatigue testing mechanism.

To jumpstart the design process, Endologix provided us with the remains of an old project which attempted similar goals as described herein. These remains (pictured in Figure 12) included a Leeson AC motor mounted on a vibration isolation stand. Also on the stand was an unattached plexiglass tank with the base support of the old test fixture still glued to the floor of the tank chamber. The motor performance data is included below in Table 6. From this data, a motor performance chart was created (Table 6 and Figures 13 and 14).

Table 6. Motor performance data.

Load [%]	Current [Amps]	Power [kW]	Speed [RPM]	Torque [ft-lbs]	Efficiency [%]	Power Factor
0	4.6	0.148	1798	0	0	14
0.25	4.76	0.34	1786	0.75	56	31.1
0.5	5.17	0.542	1774	1.5	69.7	45.6
0.75	5.8	0.774	1762	2.25	72.8	58
1	6.42	0.993	1747	3	75	67.2
1.15	6.85	1.135	1737	3.45	75	72
1.25	7.56	1.271	1728	3.75	72.4	73.1
1.5	8.82	1.552	1708	4.5	70.3	76.5

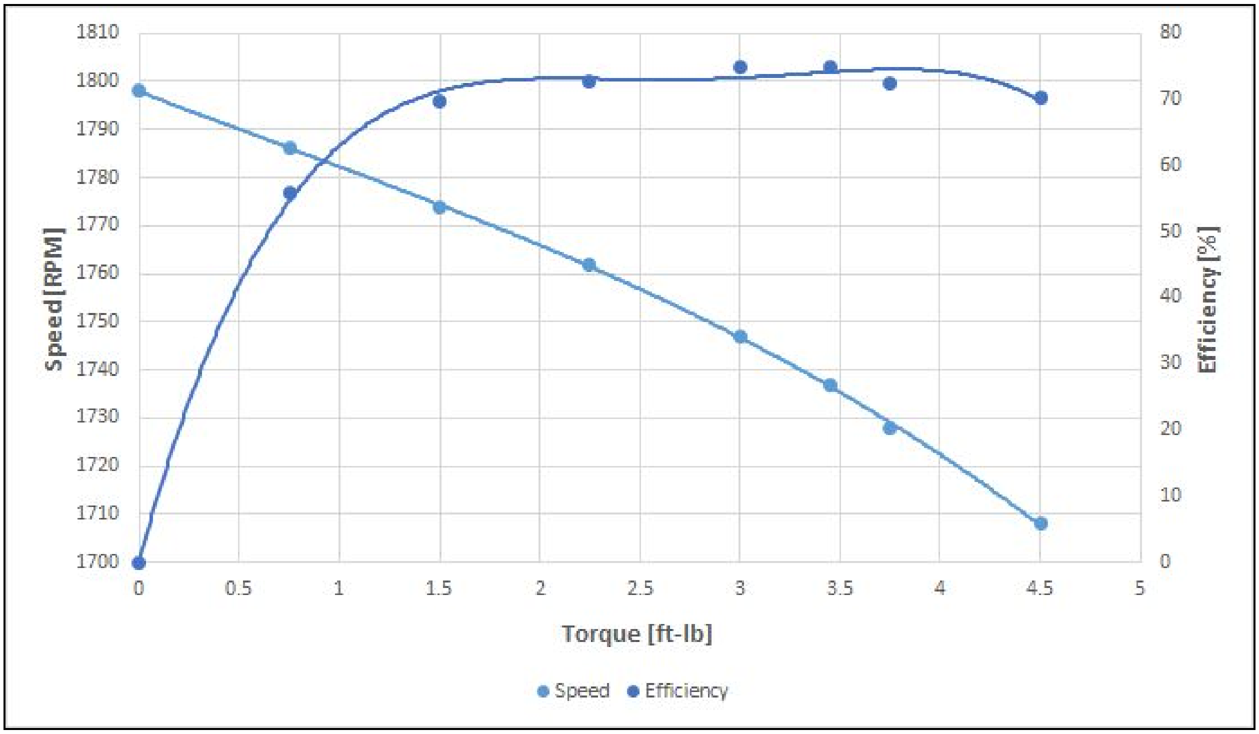


Figure 13. Motor performance curve including speed and efficiency as a function of motor torque.

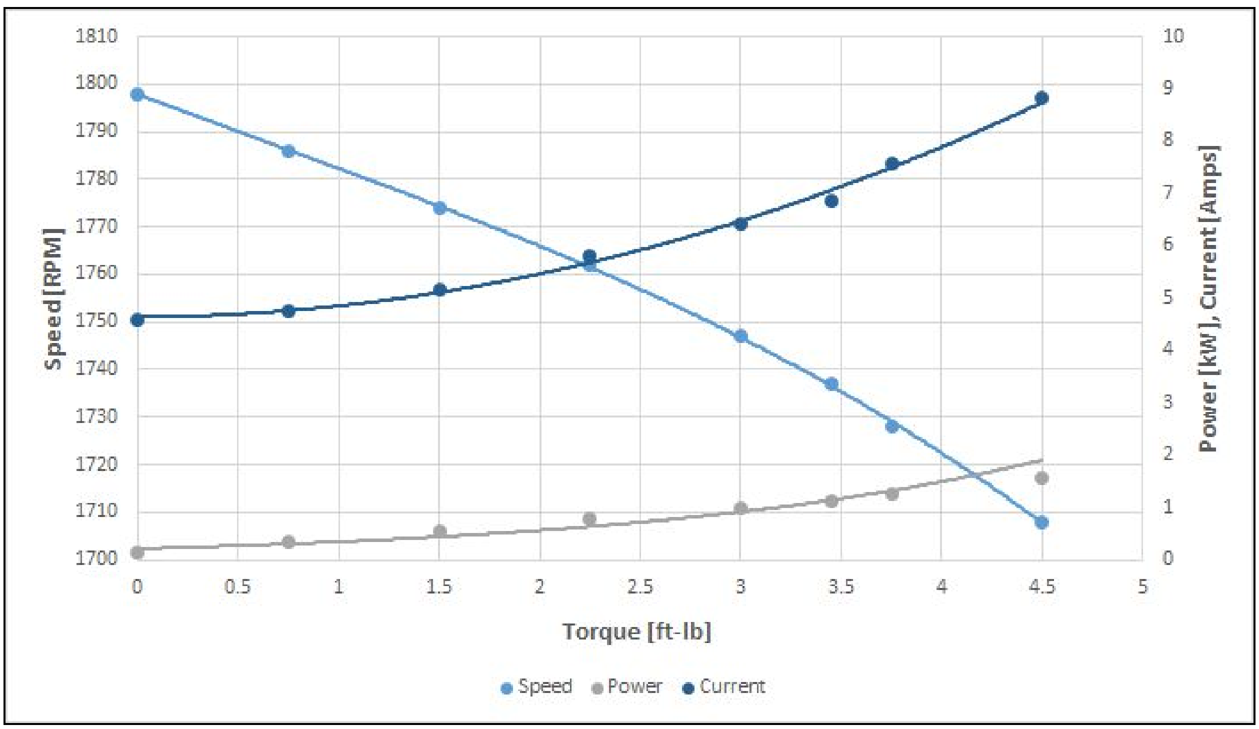


Figure 14. Motor performance curve of speed, power, and current as a function of torque.

The motor will be fed the appropriate voltage as to attain a steady-state speed of 1680 revolutions per minute (RPM) in order to attain the appropriate frequencies further into the drive mechanism. Using these existing systems to kick off our design established design limitations which both helped and hurt our creative design process. Time required in selecting a motor, material costs in the fabrication of the tank and the test stand, and vibration analysis were all saved by utilizing this existing system. However, being restricted to the existing Leeson motor created design challenges later in optimizing the drive mechanism for the frequencies required in the engineering specifications.

Drive Mechanism

At the heart of the design is the drive mechanism used to simulate cycling the polymer will experience throughout its life. This includes all components from the existing motor's output shaft to the cam used in the rotational-to-linear motion translation. To best explain the thought behind these design considerations, this breakdown will begin at the motor and move down the mechanism from there.

The nominal motor speed of 1680 RPM was selected as the motor data specification sheets included it within the given ranges, and it can best be stepped down to the frequencies required in the engineering specifications. The initial reduction necessary to attain speeds as low as 60 RPM (1 Hz) without obscenely large gear reductions is a 5.6:1, obtained using a planetary gearhead. With this reduction, a speed of 300 RPM may be obtained, which lends itself well to being stepped up to 600 RPM (10 Hz) or down to 60 RPM. In this way, we are able to satisfy the frequency range design challenge.

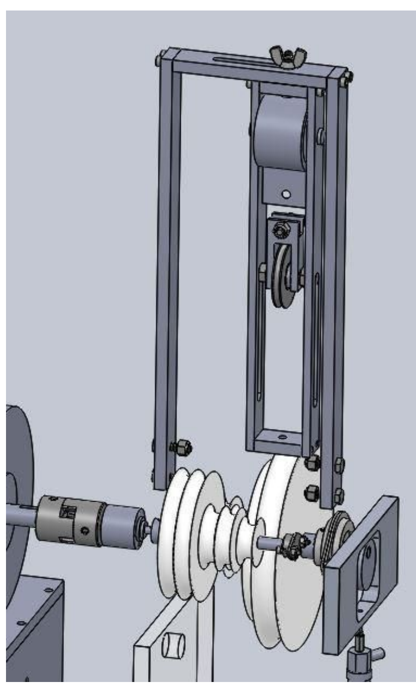


Figure 15. Planetary gear and pulley power transmission system.

Next in the drive system is the pulley power transmission system, as shown in Figure 16. Pulley were selected to achieve five different speed ratios: 5:1, 2.5:1, 1:1, 5:8, and 1:2. These five options satisfy the customer requirement of having speed variability as we include the frequency of blood pulsing through a resting body (60 RPM or 1 Hz), as well as higher frequencies to test the rate-dependency of the various polymer formulations. In order to restrict power transmission to a single pulley ratio at a time, only one round belt is utilized for all five pulley pairs. This is accomplished using a variable idler pulley mechanism. A center-to-center distance of 5in. was selected for the two main pulley shafts, and a belt length of 27in. was selected using Solidworks' belt simulation tool.

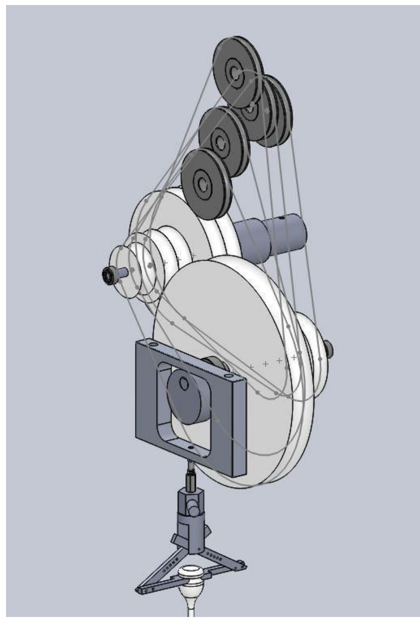


Figure 16. Drive pulley system location determination.

From these two defined values, the idler pulley (the smallest in diameter for a 3/16in. belt) was placed in the ideal locations for each pulley pair in order to visualize the variance in location necessary for its fixture. Adhering to design guidelines set up in Shigley's Mechanical Design textbook, the idler pulley sits such that the driving pulley is pulling the belt from the driven pulley and pushing it to the idler pulley. This necessitated the location of the idler pulley above the rest of the pulleys. To accommodate for the varying tensions in each pulley pair, the idler pulley is mounted on a fixture using a constant-force spring capable of exerting enough upwards force to maintain the necessary tensions. The single idler pulley is adjustable laterally so that it may line up with each pulley pair when a different output frequency is desired. The design challenge regarding the idler pulley centered around selecting a spring capable of achieving an extension range of 4in., necessary to provide adequate tension in the belt at each pulley combination. Upon selecting an adequate spring, height adjustments were necessary to accommodate the diameter of the spooled spring. Therefore, the idler pulley fixture subsystem brings the total height of the machine to approximately three feet tall. Since no limit was specified regarding the machine height, we assume this overdesign is acceptable for the purposes of this project.

At the end of the driven pulley shaft sits a cam. This cam is attached to the shaft with a set screw such that it may be easily replaced with cams of varying sizes. This will satisfy another engineering specification, that of varying percent strain induced on the test specimen. The cam sizes we will be using include the following percent strains: 10%, 20%, 30%, 40%, and 50%.

Test Specimen Fixture

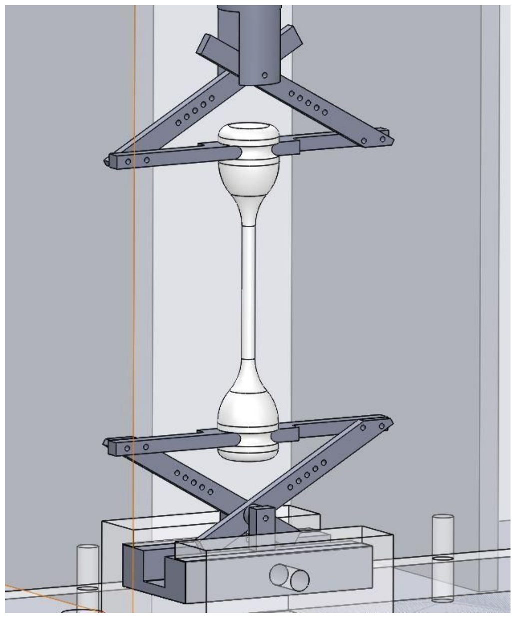


Figure 17. Test specimen fixture.

Up to now, all motion has been rotational, which will not translate well to inducing linear cyclic loads on the test specimen. In order to accomplish this, a cam follower has been designed to surround the cam and ride along linear bearings, translating the rotational motion to linear. In following sections, a contact stress analysis is included to validate this design.

Threaded into the base of the cam follower is a rod with both right- and left-hand threads. The purpose of this rod is to allow for linear adjustment in the height of the test specimen fixture. In case of an anomaly in the setup of the test specimen in the fixture, or in the molding of the specimen, this adjustment is useful such that the machine may still be used with adequate accuracy. The lower end of this threaded rod is threaded into a female-to-female threaded connector, which also has the top of the load cell threaded into it. The load cell in question is to be borrowed from the California Polytechnic State University, San Luis Obispo’s (Cal Poly) Mechanical Vibrations lab to save costs. Ultimately, when the machine is given to Endologix, this load cell will be returned to the lab and replaced by Endologix.

An adapter sits beneath the load cell and carries the scissor-like, spring-loaded grips. A spring in tension will maintain the grips’ hold on the test specimen at the ring-grooves, but can be forcibly extended in order to install or remove the test specimen. This grip mechanism is mirrored on the base of the test specimen such that both ends are inline and secured for the duration of the test. The test specimen fixture is partially submerged in distilled water heated to body temperature in

order to maintain 100% humidity on the test specimen. As a result, all materials used in the test specimen fixture are either stainless steel, aluminum, or plastic as to reduce rusting and inefficient motion.

Test Specimen Shape

To best simulate the polymer's in-use physiological condition, a cylindrical test specimen with ring indents for clamping will be used throughout the fatigue cycling and tensile destructive testing. Traditionally, test specimen of this manner are a flat, dogbone shape, unusable for this application. The polymer to be used for the test specimen is a hydrogel, with a slippery surface, and yet is extremely brittle. These properties make directly clamping a flat, dogbone polymer test specimen very difficult, and is the motivation for the new test specimen design.

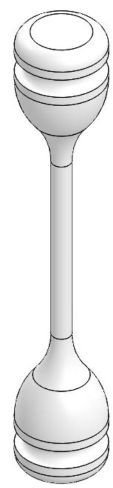


Figure 18. Test specimen shape.

The final test specimen design may be seen in the above Figure 18. Utilizing design standards for test specimen, this design incorporates an area ratio between the grip location and the neck of 4.5:1, which induces failure in the neck section of the test piece before failure occurs at the grip location. The test specimen grips are each designed to distribute a minimal clamping force along approximately a quarter of the circumference of the ring indents. In this way, we avoid high stress concentrations at the gripping points. Another method of reducing unwanted stress concentrations is the incorporation of a gradual transition from the larger cross-sectional area at the gripping section to the small cross-sectional area in the neck.

Previously, for the preliminary design (Chapter 3), a finite element analysis had been performed to select the most ideal test specimen shape. This analysis, however, utilized low density polyethylene as the material, which is not very similar to the polymer's material properties. Realizing this led to two additional finite element analyses; the first utilizing a linear, elastic material with a Young's modulus and Poisson's ratio equal to the average values of several test samples as listed in the Endologix Feasibility Report included in Appendix C, and the second utilizing a non-linear, hyperelastic material. This hyperelastic material was created using the second-order trendline equation shown in Figure 19 for the "Failed in Gauge Middle" results.

Strain values were selected, and the second-order equation used to iterate stresses for nine different strains. These were then adjusted such that a strain of 0.014 mm/mm became 0.00 mm/mm in order to optimize the curve for Abaqus. This adjustment was made on the recommendation of the Abaqus User's Manual, and can be seen in Table 7.

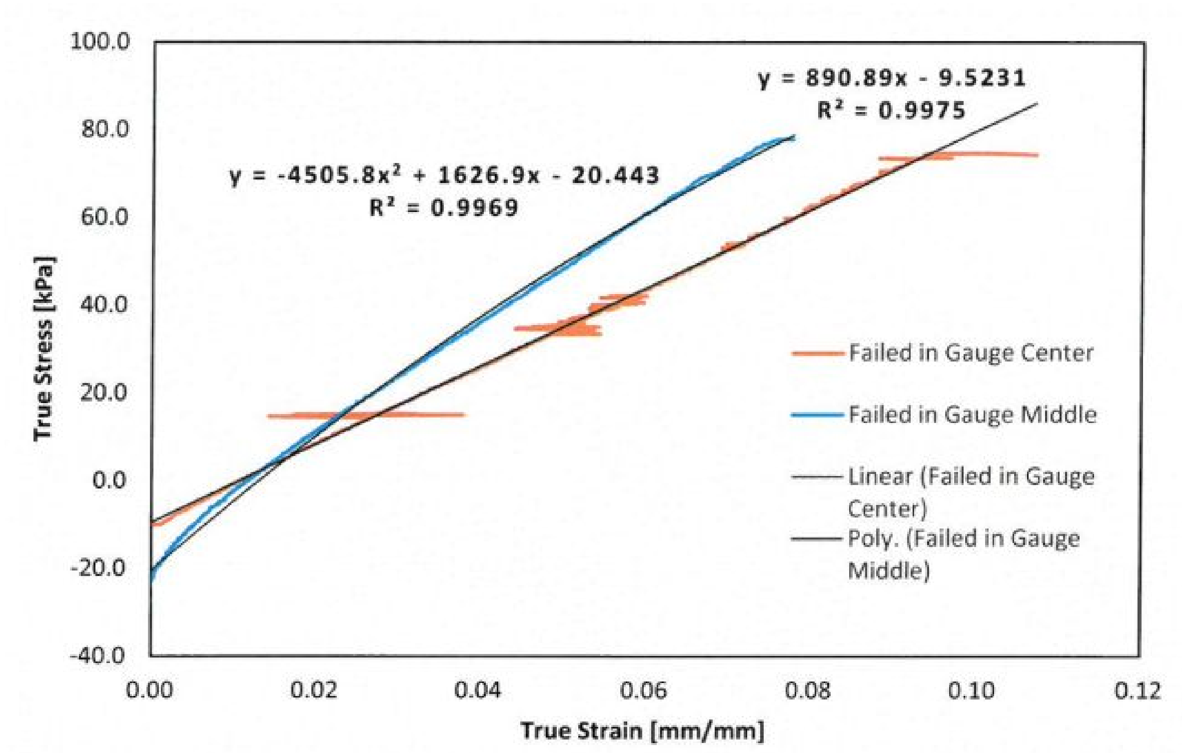


Figure 19. Stress-strain curve from Endologix provided material report.

Table 7. Comparison of stresses within each type of polymer model.

Test Specimen Geometry		**Test Data**	**Forces Experienced**	**% Elongation**	**Elongation**	**Material**
Neck Length	*Neck Area*	*Max S22*	*Neck*			
m	m	Pa	N		[m]	
0.04	1.26E-05	6.09E+04	0.76	10	0.004	Nellix Polymer
		1.22E+05	1.53	20	0.008	
		1.83E+05	2.29	30	0.012	
		2.44E+05	3.06	40	0.016	
		3.04E+05	3.83	50	0.02	
		5.67E+04	0.71	5	0.002	True Nellix
		9.06E+04	1.14	10	0.004	
		9.85E+04	1.24	12.5	0.005	
				15	0.006	

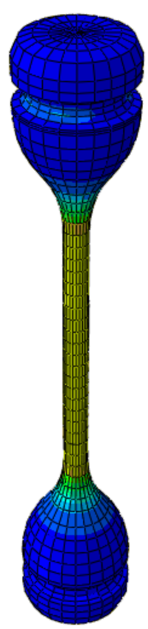


Figure 20. Non-linear hyperelastic model of polymer material.
Highlighted stresses are those along the vertical axis.

Results from the two material analyses may be seen in Table 7 and Figure 20. The purpose of these analyses is to estimate the forces experienced by the polymer in the neck section in order to properly size the load cell. The linear and non-linear materials did not return similar forces when subjected to similar percent elongations. The non-linear hyperelastic material experienced a much higher ratio of stress to strain than the linear elastic material, as seen by the forces experienced at 10% strain. Unfortunately, the hyperelastic model was unable to converge to a solution once a strain of 15% was applied, and the comparison had to be terminated. It is reasonable to expect, however, that if the model had been able to run at each sample point as the linear material, that the non-linear material would have experienced greater stresses--and forces--in the neck section of the test specimen. Due to the inability of the model to converge on a solution at the 15% strain loading condition, we are unable to anticipate the point at which the material fractures.

Controls System

The controls system of our fatigue testing machine provides proper maintenance of the test specimen test conditions, motor speed and cycles-to-failure verification, an effective method of measuring the forces the specimen experiences over the duration of a test run, and preventative measures for operator and stand-by safety.

As previously mentioned, the test specimen must be fully submerged in a bath maintained at 37℃. An electrical assembly of an Arduino Uno (arduino), type-K thermocouple amplifier, LCD display is interfaced with a type-K thermocouple with a temperature range of 32° to 900°F and an accuracy of ±0.75% (±0.28°C at testing temperature) to readout the temperature of the testing bath in real-time. The arduino is versatile and useful amongst various electromechanical applications. The type-K thermocouple allows for measuring the bath at the required testing temperatures. Because thermocouples are generally very sensitive, the thermocouple amplifier is necessary for reference junction compensation. This holds the reference terminal at a reference temperature of 0°C by adding the potential difference of the thermocouple voltage reading corresponding to the ambient temperature, ensuring an accurate measurement post-sensor calibration. The thermocouple subassembly will be sufficient for our application and provide accurate, precise, and reliable results for each test run. The thermocouple will be sitting in the bath, secured in its position by means of a cable clamp mounted to the side panel of the tank and a locator hole from the mounting panel located in front of the cam (Figure 21)

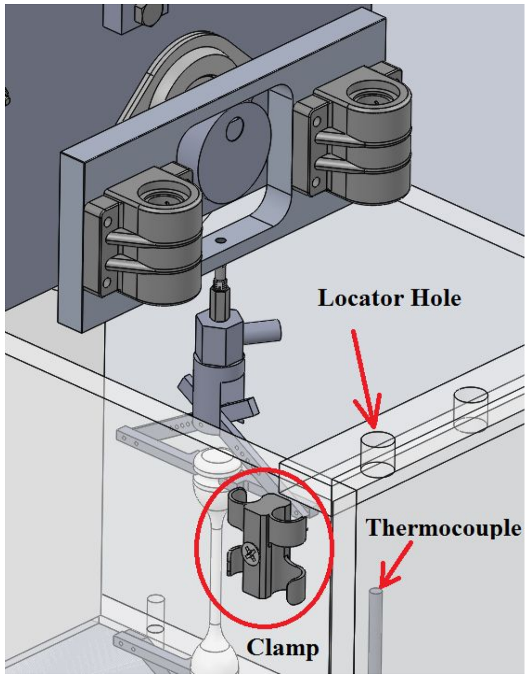


Figure 21. Thermocouple cable clamp and locator hole.

The speed of the motor and the cycles-to-failure counter are both monitored with an arduino-controlled optical tachometer. The tachometer subassembly (Figure 22, below), involves an acrylic-housed arduino, electrical circuit, LED bulb, and an infrared photodiode and LED (infrared photodiode sensor).

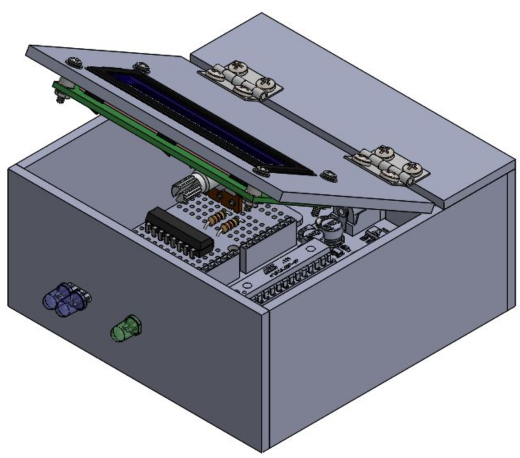


Figure 22. Tachometer subassembly.

When powered on, the LED bulb shines a bright light onto the cam, which bears a piece of highly reflective tape on its surface. The IR photodiode sensor receives the reflected light, and keeps track of the rate at which the sensor receives a signal due to the light reflected off of the reflective tape, which is then converted to an analog reading of the motor speed in RPM. The cycles-to-failure can be computed from the motor speed and the duration of the test run. The

hinged door at the top of the assembly provides for easy electrical maintenance and ventilation of the system throughout testing. The rear housing panel, as seen below in Figure 23 has port holes for powering the arduino.

Figure 23. Tachometer rear housing panel.

The provided load cell will be used to measure the cyclical axial forces and displacement that the test specimen is experiencing in real time with respect to time. The load cell has a measurement range of 44.48kN (10 lbf) in tension and compression, sufficiently encompassing the maximum force the test specimen will experience of about 1 lbf. Figure 24 shows the load cell location with respect to our entire assembly. The load cell will be mounted into the clamping jaws and the follower via screws.

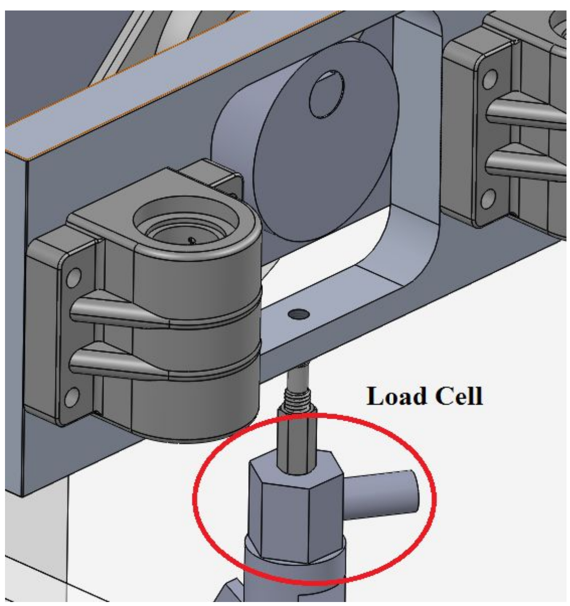


Figure 24. Load cell location.

The force-displacement-time data will be graphed and interfaced with the accompanying software and necessary equipment that Cal Poly's Mechanical Vibration's lab is currently using for their laboratory experiments. The obtained data will be compared to a MATLAB program that records the displacement of the test specimen from a video recording for accuracy.

Operator and stand-by/leave-alone safety requirements were accommodated by implementing a pull-to-reset emergency stop button and safety guard limit switches, respectively. For operator safety, the emergency stop will be connected in series with the motor's variable transformer outlet plug. The emergency stop button will be connected to a safety relay, both rated for more than the maximum amperage, horsepower, and voltage the motor will be running at a speed of 1740 RPM. When the button is pressed during operation, the emergency stop subassembly will power off the motor and thus stop the test. Limit switches mounted on the outer side panels of the tank will serve as contact limits for the safety guard that will cover the pulley and gearbox drive system. The motor will not power on until both the safety guard is completely secured, activating the limit switches, and the emergency stop button is reset by a pulling gesture.

Because of time constraints, the controls systems were not implemented to ensure that all the mechanical components of the final design were manufactured and assembled properly.

Material Selection

All material was selected to be water resistant and have a high strength and fatigue life to endure long periods of testing, resulting in the choice of using stainless steel, aluminum, and hydrophobic plastics. Specific material choices for each component can be found in the cost analysis section under the bills of materials.

Cost Analysis

This section details the cost of all system components, including part number and supplier. These prices do not include applied sales tax or shipping fees.

Table 8. Bill of materials for tachometer subassembly.

Subsystem	Part Description	Part No.	Qty.	Supplier	Cost
Tachometer					
→	Hinge	1603A2	2	McMaster-Carr	$ 2.86
→	Hinge Screws	92114A077	8	McMaster-Carr	$ 4.08
→	Housing	8560K257	1	McMaster-Carr	
→	Top Rear	-	-	-	-
→	Arduino Ports Side	-	-	-	-
→	Right Panel	-	-	-	-
→	Base	-	-	-	-
→	Left Panel	-	-	-	-
→	Door	-	-	-	-
→	Arduino Uno	485-2877	1	Mouser Electronics	$ 24.95
→	Arduino Mounting Screw	91772A106	4	McMaster-Carr	$ 3.98
→	Blue, 5mm LED	941-C503BBANCY0C0461	1	Mouser Electronics	$ 0.21
→	Infrared Photodiode	720-SFH203FA	1	Mouser Electronics	$ 0.65
→	Infrared LED	512-QED123	1	Mouser Electronics	$ 0.46
→	16 X 2 LCD Display	485-772	1	Mouser Electronics	$ 19.95
→	LCD Mounting Screw	90116A022	4	McMaster-Carr	$ 10.48
→	LCD Mounting Washer	90965A110	8	McMaster-Carr	$ 2.37
→	LCD Mounting Spacer	93657A202	4	McMaster-Carr	$ 3.84
→	LCD Mounting Nut	93935A305	4	McMaster-Carr	$ 3.04
→	10K Potentiometer	485-562	1	Mouser Electronics	$ 0.95
→	33kΩ Resistor	588-OK3335E-R52	1	Mouser Electronics	$ 0.12
→	270Ω Resistor	588-OD271JE	1	Mouser Electronics	$ 0.70
→	Breadboard	619-700-00012	1	Mouser Electronics	$ 3.99
→	SN74HC595 Shift Register	595-SN74HC595N	1	Mouser Electronics	$ 0.57
				Subtotal	$ 83.20
				Running Total	$ 83.20

Table 9. Bill of materials for thermocouple and safety assemblies.

Subsystem	Part Description	Part No.	Qty.	Supplier	Cost
Thermocouple					
→	Digital Temperature Controller	TR115SN	1	Aqualogic	$ 130.00
→	Arduino Uno	485-2877	1	Mouser Electronics	$ 24.95
→	Type K Thermocouple	3871K54	1	McMaster-Carr	$ 28.77
→	Thermocouple Cable Clamp	7429K45	1	McMaster-Carr	$ 5.38
→	Thermocouple Cable Clamp Screw	92485A640	1	McMaster-Carr	$ 7.71
→	16 X 2 LCD Display	485-772	1	Mouser Electronics	$ 19.95
→	Thermocouple Amplifier	485-269	1	Mouser Electronics	$ 14.95
				Subtotal	$ 231.71
				Running Total	$ 314.91
Safety					
→	Emergency Stop Button	A22E-M-01	1	Mouser Electronics	$ 29.95
→	Emergency Stop Enclosure	6916K310	1	McMaster-Carr	$ 50.30
→	Safety Relay	7456K78	1	McMaster-Carr	$ 76.37
→	Safety Guard Limit Switches	7510T120	2	McMaster-Carr	$ 11.38
				Subtotal	$ 168.00
				Running Total	$ 482.91

Table 10. Bill of materials for drive mechanism and raw material assemblies, including total cost.

Motor-Gearbox					
→	18-8 SST Flat-head socket cap screw 10-32, 3/4" long	92210A304	6	MMC	$8.81
→	18-8 SST Socket head screw 10-32 3/4"long	92196A272	18	MMC	$10.83
→	18-8 SST Socket head screw 5/16-18 3/4"long	92196A581	4	MMC	$6.75
→	18-8 SST Flat-head socket cap screw 3/8-16, 1" long	92210A624	4	MMC	$4.98
→	18-8 SST Extra-wide hex nuts 3/8-16	91849A625	4	MMC	$5.76
→	18-8 SST Washer for #10 Screw Size (thickness 0.025-0.040)	92141A011	16	MMC	$2.33
→	18-8 SST Narrow Hex Nut for 10-32 (ht. 1/8, wd. 3/8)	91841A195	10	MMC	$3.76
→	High-Efficiency Speed Reducer (5.6:1)	6481K75	1	McMaster-Carr	$272.66
→	18-8 SST Slotted Spring Pin	92373A461	1	McMaster-Carr	$6.01
→	High-Misalignment Flexible Shaft Coupling (7/8" Dia Shaft)	60635K91	1	McMaster-Carr	$40.34
→	High-Misalignment Flexible Shaft Coupling (3/4" Dia Shaft)	60635K92	1	McMaster-Carr	$40.34
→	Acetal Disk High-Misalignment Shaft Coupling	60635K99	1	McMaster-Carr	$30.53
→	Galvanized Steel Bracket, 4"Length Sides, No. 10 Size Screw Holes	1556A46	6	McMaster-Carr	$19.28
Raw Material/Other Fasteners					
→	Multipurpose 6061 Aluminum, 3/8" X 2" X 6"	8975K59	1	McMaster-Carr	$4.46
→	18-8 SST Socket head screw	92196A138	4	MMC	$1.70
→	18-8 SST Locknut	91831A122	4	MMC	$7.86
→	316 SS Hex Head Cap Screw 1/4"-20, 1" Long	93190A542	14	MMC	$5.82
→	316 SS Nylon-Insert Locknut 1/4"-20	90715A125	14	MMC	$7.50
→	316 SS Washer 1/4" Screw Size, OD 0.875", ID 0.266"	91525A119	12	MMC	$8.19
→	18-8 SST Thin Locknut (3/8"-24)	90101A245	1	MMC	$5.89
→	Chemical Resistant O-Ring Cord	1092T22	3	McMaster-Carr	$3.48
→	Multipurpose 6061 Aluminum [Mold Halves]	8975K239	1	McMaster-Carr	$24.95
→	Multipurpose 6061 Aluminum bar (1/8" X 2" X 3")	9057K113	1	McMaster-Carr	$45.48
→	Multipurpose 6061 Aluminum rod (OD 1-3/4" X 3")	1610T14	1	McMaster-Carr	$11.11
→	Multipurpose 6061 Aluminum bar (1/2" X 4" X 4")	9057K248	1	McMaster-Carr	$65.58
→	Multipurpose 6061 Aluminum bar (5/16" X 2" X 2")	8975K58	1	McMaster-Carr	$10.21
→	Multipurpose 6061 Aluminum rod (OD 7/8" X 24")	8974K12	1	McMaster-Carr	$11.97
→	Multipurpose 6061 Aluminum bar (1/4" X 3" X 3")	9057K175	1	McMaster-Carr	$42.24
→	Multipurpose 6061 Aluminum bar (1-1/4" X 2" X 3")	9057K413	1	McMaster-Carr	$86.53
→	Multipurpose 6061 Aluminum bar (5/8" X 12" X 3.0")	8975K224	1	McMaster-Carr	$15.62
→	Oversized Multipurpose 6061 Aluminum, (1/4" thick, 24"x24")	89155K26	1	McMaster-Carr	$160.85
→	Oversized Multipurpose 6061 Aluminum, (1/4" thick, 12"x24")	89155K115	1	McMaster-Carr	$82.03
→	Oversized Multipurpose 6061 Aluminum 3/8" x 18"x 18"	89155k28	1	McMaster-Carr	$128.86
→	Multipurpose 6061 Aluminum rod (1-3/4" Diameter, 1/2' Long)	8974K68	1	McMaster-Carr	$13.23
				Subsystem Cost	**$1,195.94**
				Total Cost	**$2,520.18**

Safety Considerations

With constantly rotating shafts, pulleys, belts, and a cyclic--albeit small--linear motion, critical safety concerns regard the motor, pinch points, and maintaining the safety of the operator. These are further identified in the following tables.

Identification of System Hazard(s)

The overall system poses several hazards, as seen below in Table 11, to the operators and/or any nearby persons. Table 12 goes into further detail on what the specific hazards are, what corrective/preventative actions will be taken, and when those actions will be completed.

Table 11. Senior project concept design hazard identification checklist [15].

Yes	No	Hazard Description
X		Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, squeezing, drawing, cutting, rolling, mixing, or similar action, including pinch points and shear points?
X		Can any part of the design undergo high accelerations/decelerations?
	X	Will the system have any large moving masses or large forces?
	X	Will the system produce a projectile?
X		Would it be possible for the system to fall under gravity creating injury?
	X	Will a user be exposed to overhanging weights as part of the design?
X		Will the system have any sharp edges?
X		Will any part of the electrical system(s) not be grounded?
	X	Will there be any large batteries or electrical voltage in the system above 40V either AC or DC?
X		Will there be any stored energy in the system such as batteries, flywheels, hanging weights, or pressurized fluids?
	X	Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
	X	Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
	X	Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
X		Can the system generate high levels of noise?
	X	Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
X		Is it possible for the system to be used in an unsafe manner?
	X	Will there be any other potential hazards not listed above? If yes, please include them.

Table 12. Hazard identification checklist descriptions and preventative actions [15].

Description of Hazard	Corrective Actions to be Taken	Planned Completion Date*	Actual Completion Date**
Repetitive Motion: - Rotating Shafts/Components - Vertical Motion (Displacement)	Design appropriate safety fixture(s)	04/26/2016	05/03/2016
Possibility of High Motor Acceleration and Deceleration	Implement a motor control system	04/26/2016	05/03/2016
Support Structure Failure via System Vibration	Vibration isolators and/or dampers	04/26/2016	05/03/2016
Sharp System Features (Edges/Corners)	Design with appropriate fillets and chamfers	04/26/2016	05/03/2016
Un-ground Electrical Systems	Grounded power strip with surge protection	04/26/2016	05/03/2016
Motor Power Voltage Above 40V AC	Implement a motor control system	04/26/2016	05/03/2016
Possible Spring as a Means of Stored Energy	Utilize safe design practices	04/26/2016	05/03/2016
High Motor Noise Level	Option to use earplugs when system is in-use	04/26/2016	05/03/2016
Operational Safety Hazards	Writing a safety operations manual	04/26/2016	05/03/2016

*Original due date.
**Updated due date (postponed one week after the original due date of 04/26/2016).

Analysis Results & Sustainability

This section will cover the design analysis topics that we deemed necessary for a confident physical model to be developed.

Test Specimen Finite Element Analysis

In order to optimize the test specimen shape for this application, a finite element analysis was performed on five different shape iterations, including the standard dumbbell test specimen shape. The final poster, which includes the finite element analysis results is included in Appendix C.

Speed Reduction

The following table was used to calculate the ideal speed reduction. A final motor speed of 1740 was selected to be used as it resulted in a 5.8:1 ratio to step down to 300 RPM. This speed can then be more easily stepped up or down to the other desired frequencies.

Table 13. Required speed reduction ratios at motor specification speeds.

Reduction Table					
Motor Speed	Reduced Speeds [Hz]				
	1	2	5	8	10
[RPM]	60	120	300	480	600
1800	30	15	6	3.75	3
1790	29.83	14.92	5.97	3.73	2.98
1780	29.67	14.83	5.93	3.71	2.97
1770	29.5	14.75	5.9	3.6875	2.95
1760	29.33	14.67	5.87	3.67	2.93
1750	29.17	14.58	5.83	3.65	2.92
1740	29	14.5	5.8	3.625	2.9
1730	28.83	14.42	5.77	3.60	2.88
1720	28.67	14.33	5.73	3.58	2.87
1710	28.5	14.25	5.7	3.5625	2.85
1700	28.33	14.17	5.67	3.54	2.83
Step to: [RPM]					
300	5	2.5	1	0.625	0.5

The “Step to” row from the table above, refers to the additional reduction required to step the speed either down or up from the 300 RPM initial planetary gear reduction. This calculation defined the pulley diameters used in the drive mechanism.

Surface Fatigue

Although several components of the final system design make contact during system operation, the cam and follower subcomponent pair required further considerations. The reason the cam-follower subsystem requires a contact surface stress analysis is due to the test specimen mechanical components' weights directed upon the surface of the cam itself. This analysis was necessary in order to assure that failure would not occur under the repetitive loading. By completing the analysis, Polylogix can construct a physical model of the proposed design with confidence knowing that surface failure will not occur within either of the subcomponents of this assembly. The analysis information is included in Appendix A. Polylogix prides itself on using materials that are most likely to withstand the loading that the design must withstand during operation. Therefore, stainless steel was selected for the application partially because of its strength and resilience under repeating loading. The results of the analysis confirm that the maximum possible force that could be applied to the cam-follower subassembly produces a maximum shear stress of roughly 7 psi. Material properties confirm that stainless steels' high ultimate stress values are nowhere near the value determined during analysis. The step forward toward a physical model can be completed with confidence.

Chapter 5: Product Realization

Manufacturing Process

The manufacturing phase stretched from the beginning of October 2016 to the beginning of December 2016. During this phase, over 35 parts were machined by members of this team. The prototyping period would involve integrating the fixture system, testing specimen, environment control, and data collection into a collective operating unit. Due to our system relying on a previous Endologix testing fixture, it was necessary to understand, re-design, and integrate this into our own testing system design.

Initial builds of the specimen mold were rapid prototyped with the 3D printing machines available on-campus. The shape endured several design iterations until a final design was reached.

The manufacturing plan was as follows: the cam and the motor output shaft were machined as a single piece. Bar stock was turned down in the lathe to the outer profile of the component. Soft jaws were made so the mill could grab the cam by the motor output shaft. The offset shape of the cam was then be CNC milled out. The follower was machined completely on the manual mill. Radii that cannot be included in the manual mill process were created by hand using a grinding wheel. The polymer test specimen was set in a mold. This mold needed to be precise and has many complicated features. The CNC Mill was used for the entirety of this piece. The plexiglass casing overall shape was created using the table saw. The manual mill was then be used to clean up the edges and drill the holes. The guide rods were ordered to a set precision ground diameter and length. The base of the testing platform was manually milled to size and chamfering was done by hand on the grinder. The clamps have a very complicated shape, which were difficult to hold during any type of machining, but we redesigned them to be manually milled. Table 15 depicts the manufacturing process undergone when building the final assembly.

Table 14. Final build manufacturing methods.

Component	Method
Cam	Manual Lathe/Manual Mill
Follower	Manual Mill/Grinder
Test Specimen Mold	Rapid Prototype (3D Printing)
Plexiglass Casing	Incomplete
Guide Rods	Purchased to Engineering Spec
Base	Manual Mill/Grinder
Grip Fixtures	Manual Mill/Grinder

For the cam, rather than using CNC milling, a manual mill was used with a rotary table attachment. This allowed the creation of the desired geometry, without having to wait for access to the on campus CNC machines.

The follower's outer profile, clearance holes, and predrill hole were machined in a vice on the manual mill. The left hand 10-32 thread was cut by hand by using a tapping kit. A removable teflon strip was added to the design in order to prevent wear between the aluminum cam and aluminum follower. The teflon strip was cut using shears and bolted to the follower using flat head screws. Holes in the teflon piece were made using a hand drill.

The first iteration of the test specimen mold (Figure 25) was rapid prototyped to begin getting samples of the newly design 3D test specimen shape. The printed mold halves had a very smooth surface finish due to the high resolution of the 3D printer. Although the mold produced test samples that did not have any surface discontinuities or ridges, these samples were missing the neck of the specimen. This resulted in another iteration of the the test specimen mold (Figure 26).

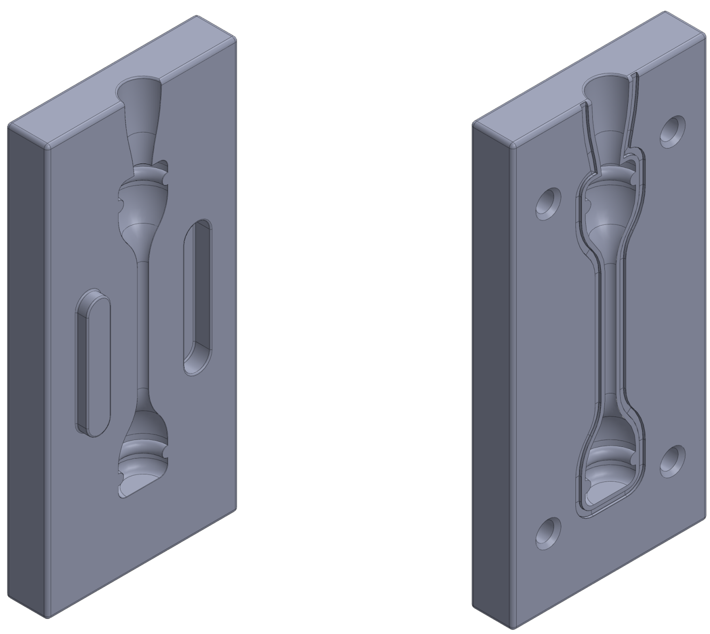


Figure 25. First iteration test specimen mold (left) and current test specimen mold design (right).

The new iteration is reduced 60% by volume to save material and money. Rather than CNC machined as originally planned, the mold halves were 3D printed. A groove around the specimen cavity is for o-ring cord stock, which is glued and cured in to catch the extra polymer that oozes out of the crack. The oval pin mates for alignment were replaced with holes for bolts for more precise alignment of the mold halves.

All plates were manufactured using the manual mill. In order to accommodate the larger plates, the vice had to be removed. Wood blocks were placed under the plates in order to allow for drilling of through holes and toe clamps were used to hold the plates in place. Once the plate was

in place and the datum was established, it was ensured that all features were machined in one sitting. This was done because breaking the established setup and refinding the datum could result in small movements of the datum, resulting in errors.

Initial plans for the grip included rapid prototyping of the complicated geometries. Grip design was changed in order to allow the components to be manufactured on the manual mill. Each grip consisted of two parts, which were held together by 0-80 screws. Assembly with such small screws proved to be difficult, but was overall a success. The radiused portion of the grip that fits into the groove of the test specimen was completed using a grinder, rather than the originally planned radiused cutting tool.

Future Manufacturing Recommendations

With this machine's sizing, many components were designed with ease of manufacturing in mind, however, the drive shafts were designed to fit the 10 pulleys used in the power transmission, and as a result, have a complex stepping design making assembly difficult. Tolerance stacking became a previously unforeseen challenge regarding the idler pulley subsystem. The idler pulley itself came a little over its expected dimensions, causing the belt hinge to not properly fit through the pulley holder. Many of the plates that were a part of the design were ordered as a combined single plate and later cut down to size in an effort to save money. This unexpectedly added a significant amount of time to the manufacturing process. For the future it would be better to order parts as close to the final design size as possible.

Chapter 6: Design Verification

Future Testing Plans Overview & Description

Design iteration will result in the creation of a working polymer tensile fatigue testing mechanism. A series of checks will be made through the conduction of tests in order to assure that the design satisfies the parameters originally established during the project proposal. These evaluations will call to question how well our test data was collected, and comparing it to Endologix and industry standards. We will utilize Endologix information and consult with industry advisors familiar with fatigue for life. The accuracy of our tests and the quality of our test data will be a primary concern. Testing (or test validation) was not able to be completed during the course of this project, but may be completed by Endologix if so desired. The final Operator's Manual may be found in Appendix G.

Test 1 - Test Specimen Neck Displacement

One of the primary parameters of the testing mechanism is to have the ability to cyclically strain the neck of the test specimen in increments of ten, from ten to fifty percent. This adjustable, fixed max displacement is accomplished through the use of several interchangeable cams. An area of concern of the design is a discrepancy between the displacements of the cam versus the displacement of the neck of the test specimen due to slop within the design. Extension of the neck of the test specimen will be tuned through the use of optical tracking. Two red dots will be placed on the ends of the area of interest and their movement will be captured with a GoPro. Matlab will be used to look for saturations in red and create bounding boxes around the dots. The centroid of each bounding box will be determined in terms of pixels and the pixel distance will be multiplied by the distance to pixel ratio in order to find the true extension of the specimen neck.

Test 2 - Frequency Calibration

Another parameter of the system is to be able to effectively maintain and adjust frequency of cyclic loading in stages ranging from 1 Hz to 10 Hz. An AC electric motor and a voltage controller were provided at the beginning of the project. The voltage controller was ineffective in implementing the small speed changes which are required for testing. A transmission was developed, which involved a planetary gear system and adjustable pulleys. This allowed for the motor to operate within optimum parameters, while still delivering the proper output to the cam shaft. Effectiveness of the transmission system will be confirmed through tachometer testing. The tachometer will send out a single beam of light, which will reflect off of the cam whenever it completes a cycle. The returning signal will be received by an infrared photodiode sensor and actual RPM will be displayed. The cam speed will be tested for each pulley setting and each voltage input setting in order to accurately create labels which will allow the user to set the speed to their desired speed with ease. The tachometer's accuracy and precision will be ideally verified by a commercial optical or analog tachometer, or by an encoder directly on the cam shaft.

Test 3 - Test Specimen Quality

The test specimen is another area of concern for the project, which will have to be addressed through testing. One important property that needs to be seen in the polymer test piece is uniformity. This depends heavily on the molding design, process, and handling of the polymer. An initial mold will be created using rapid prototyping. After becoming familiar with the polymer and the curing methods, the Polylogix team tried different polymer entry methods into the mold. For each iteration of the polymer molding the test specimens will be assessed visually and photos will be taken for further reference. As the only test attempted by this team within the allotted time, we present the following findings regarding Test 3 - Test Specimen Quality.

May 24th, 2016 Test Specimen Quality Test

Time Defrost Began: 8:15AM Ended: 9:37AM

(Defrosting involved removing cartridges from packaging and submerging in tap water)

Mold Clamp System: First iteration resin, hollow printed mold
Two C-Clamps
Mold not submerged during filling

Trial 1:

- Volume Used: 5 mL
- Variables: Injection Speed (Fast)
  Mold Angle (Vertical, injection holes open to ceiling)
- Results: Only ended up with top grip part and very base

Trial 2:

- Volume Used: 12 mL
- Variables: Injection Speed (Slow)
  Mold Angle (Vertical, injection holes open to ceiling)
- Results: Filled top and bottom grip portions, Neck length unfilled
  Observed polymer leak through sides

Trial 3:

- Volume Used: 10 mL
- Variables: Injection Speed (Fast)
  Mold Angle (20 degrees up from horizontal)
- Results: Filled neck section, but only half of grip sections

Figure 26. Test specimen from Trial 3 (5/24/2016).

November 31st, 2016 Test Specimen Quality Test

Mold Clamp System: Second iteration resin, solid, printed mold
Two C-Clamps
Mold not submerged during filling
Nozzle had coffee straw attachment

Trial 1:

Volume Used: 12 mL
Variables: Injection Speed (Slow)
Mold Angle (Vertical, injection holes open to ceiling)
Results: Ended up with completely filled test specimen

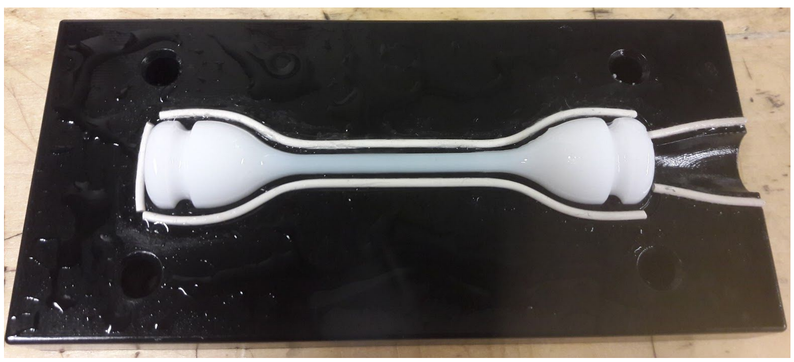


Figure 27. Test specimen from Trial 1 (11/31/2016).

Chapter 7: Conclusions and Recommendations

Project Conclusions

Twelve months is a long time to be working on a single project as students. One of the biggest challenges with senior project is maintaining moral, drive, and dedication throughout the entire year. As a team, we understand that industry projects regularly span years, so having this opportunity to become accustomed to long-term projects has been great preparation for our future careers.

As mentioned before in this report, the goal of this project is to accomplish one iteration of the design process (design, build, test) for this polymer fatigue characterization machine. At the end of this Fall quarter, this team will have accomplished almost a full iteration of the design process, and will conclude the project partially through the testing portion of the design process. The challenges preventing us from completing this testing process include complicated designs, unanticipated tolerance stacking, misjudging necessary machining time, and attempting to coordinate four conflicting schedules throughout Fall (testing) quarter. These mechanical system challenges were discussed in Chapter 5.

This team is composed of four work individuals involved with various campus clubs and projects, while also working, which makes schedule coordination extremely difficult. It is so important to meet as a whole team so ideas may be discussed openly, and individual challenges brought forth so new perspectives might take a crack at them. So, though it was a challenge, we made it a priority to all work together when we could, though meeting times were usually late in the evening. At these meetings, we worked on developing our technical writing and presentation skills, worked on stretching personal design capabilities and limitations, and helped each other gain clarity in the midst of difficult analysis.

Each member of this team has his or her own list of takeaways from this project, but those following are overarching learning themes we would like to share with the reader of this report. Upon completing this project, we wish to stress the importance of:

- Communicating challenges as they arise with project managers, since they do not experience the day-to-day efforts and struggles of the team.
- Maximizing the skills of each individual team member through project management and responsibility assignments to maintain member dedication and ensure quality results.
- Taking initiative, looking for unclaimed tasks and completing them.
- Pacing oneself to maintain motivation and health.
- Managing stressful situations and completing necessary tasks event when under extreme pressure.

Recommendations for Future Projects

This best advice this team can give to students, sponsors, and advisors embarking on senior project is to select a project objective and stick to it no matter what happens. Many of the design problems and time mismanagement issues which occurred during this project were due to a critical project objective change which occurred three weeks before the machine design deadline.

This amplified the pre-existing design challenges and took the project from very achievable to unmanageable with respect to the time we could dedicate to this project. Late design changes should be caused by safety improvements to the project--that is they should be deemed safety critical before being required. Maintaining respect for the initial project objectives is crucial for harmonizing expectations between the three aforementioned groups.

To maintain harmony within the working student group, open and effective communication is critical. If members are struggling with their tasks, then they must reach out to their teammates and alert them to the situation. Additionally, when tasks are successfully completed, or questions questions (even trivial ones) raised, the related student should share their results or questions with the other members. This way, all students stay accountable and understand the holistic progress of the project. Members who are disengaged from each other lose effectiveness as it causes a loss of overall focus, allows for tasks to be ignored and left incomplete, and the process of assembling each individual member's findings into a finalized project will be significantly more difficult. Once open and effective communication begins to breakdown within the team, progress slows. Throughout this project, Polylogix succeeded in establishing an environment of trust in which each member felt comfortable raising issues as they arose. However, this team is not perfect, and we encountered communication challenges, which is the basis for this recommendation.

The Cal Poly Mechanical Engineering Senior Project program is extremely effective and strengthens all students who begin their projects willing to compromise, collaborate, and apply textbook knowledge to real world challenges. Team members Wyatt, Tyler, Brandon, and Michela have each enjoyed working on the Polylogix team advised by Dr. Andrew Davol, and sponsored by Endologix. We look forward to applying our skills from this project to new problems as we transition into our professional engineering careers.

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Appendices

Appendix A: Preliminary Design Support Material

Weighted Decision Matrices

Table D-1. Weight Decision Matrix

Decision: Weighting	Temperature	Leave-AloneSafety	OperatorSafety	Repeatability	BodyConditions	Maintainability	Possibility of Multiple Specimen Accommodation	Cost	Manufacturability	Total	**Rank**	**Weight**
Temperature	0	-1	-1	0	0	1	1	1	1	0	**5**	**3**
Leave-Alone Safety	1	0	-1	1	1	1	1	1	1	4	**2**	**6**
Operator Safety	1	1	0	1	1	1	1	1	1	6	**1**	**7**
Repeatability	0	-1	-1	0	0	1	1	1	-1	0	**5**	**3**
Body Conditions	0	-1	-1	0	0	1	1	1	1	0	**5**	**3**
Maintainability	-1	-1	-1	-1	-1	0	1	-1	-1	-4	**6**	**2**
Possibility of Multiple Specimen Accomodation	-1	-1	-1	-1	-1	-1	0	-1	-1	-6	**7**	**1**
Cost	1	1	1	1	1	-1	-1	0	0	3	**3**	**5**
Manfacturability	1	1	1	-1	1	-1	-1	0	0	1	**4**	**4**

Table D-2. Overall system weighted decision matrix.

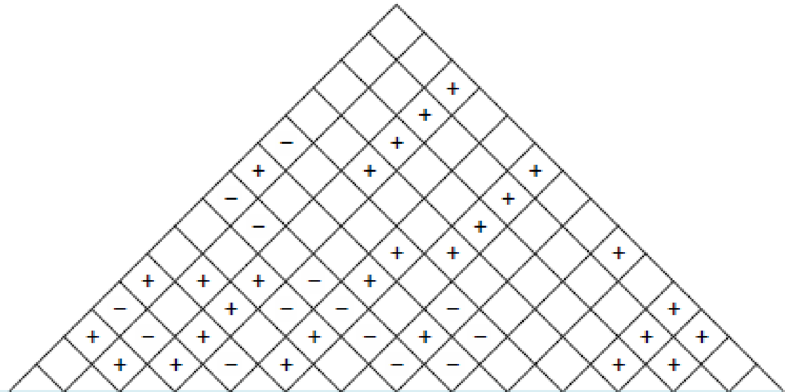
Decision: System	Temp [3]	Leave-Alone [6]	Operator [7]	Repeat [3]	Body [3]	Maintain [2]	Multiple [1]	Cost [5]	Manufact [4]	Total
Sub + pin-slide	0	0	0	0	0	0	0	0	0	0
Sub + cam	0	0	0	0	0	2	0	0	0	**2**
Sub + swash	3	-6	-7	-6	0	0	1	-5	-4	-24
Mist + pin-slide	-3	-6	7	-6	3	-2	0	-5	-4	-16
Mist + cam	-3	-6	7	-6	3	-2	0	-5	-4	-16
Mist + swash	-3	-6	7	-3	3	-2	1	-5	-4	-12

Appendix B: Quality Function Deployment

Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼



Row	Weight Chart	Relative Weight	Davol	Endologix	Other biomedical companies	Surgeons & Patients	Maximum Relationship	WHAT: Customer Requirements (explicit & implicit) / HOW: Engineering Specifications	1 Testing temperature	2 Polymer storage temperature	3 Industry standards	4 Five samples accomodated	5 Data collection equipment	6 Test cycles	7 Crack generation measurement	8 Cost	9 Cal Poly regulations	10 Modularity	11 Constant deflection during test	12 Internal forces	13 External forces	14 Solution salinity
								Direction of Improvement	◇	◇	◇	▲	◇	▲	▲	▼	◇	▲	◇	◇	◇	◇
1	|||||	11%	1	10	8	10	9	Biological-based boundary conditions	●	▽	○			●				▽	●	●	●	●
2	|||||	11%	1	10	8	10	9	Internal body testing conditions	●	▽	○			●				▽	●	●	●	●
3	|||||	11%	1	10	10	10	9	Standard conformity & quality control	▽	●	●	▽	●	○	●	▽	○	○	▽	▽	▽	○
4			4%	1	7	2	1	9	Test five polymer samples simultaneously				●	●	▽		○		▽				
5	|||	6%	1	9	7	1	9	Obtain stress, strain, cycle data	●	○	●	▽	●	●	▽	▽	▽	○	●	●	●	○
6			3%	1	3	2	1	9	Perform creep test	●	●	○	○	▽		●	○	▽	▽	●	●	●	▽
7			3%	1	3	2	1	9	Perform stress relaxation test	●	●	○	○	▽		○	○	▽	▽	●	●	●	▽
8	||	4%	1	9	2	1	9	Perform destructive tensile test	○	●	○	○	▽		●	●	▽	▽	●	●	●	▽
9	||||	9%	1	8	7	9	9	Design for infinite life	●	●	●	○	▽	●	●	●	▽	▽	●	●	●	▽
10			4%	1	8	1	1	9	Budget of $2-3K	○			●	○	○		●		▽				○
11	|||||||||	19%	10	10	10	3	9	Safe to operate	●	▽	●	●	▽	●	○	●	●					▽
12	|||	7%	1	8	8	3	9	Ergonomic	○		▽	▽	▽		○		▽	●				▽
13	|||	7%	1	9	1	8	9	Polymer storage conditions		●	○	▽		▽		▽	▽			▽	▽	○
								HOW MUCH: Target	T = 37 C	T = -30 C	ISO, ASTM, FDA	5 samples	Necessary equipment	TBD	Crack (s) observed	$2-3k	Cal Poly approved	Accomodates samples and maintenance	TBD	TBD	TBD	~0.9%

Contact Stress Analysis: Cam & Follower

Variables:					
R1	0.7875	in	cam radius		
R2	1E100000	in	flat face radius		
F	3.8688678	N	average load	17.20957702	lbf
L	0.5	in	length of contact		
Material Properties: Aluminum					
Poisson's Ratio (v)	0.33				
Modulus of Elasticity (E)	68.9	GPa	10000	ksi	kips/in^2
Modulus of Rigidity (G) / Shear Modulus	26	GPa	3770	ksi	

Follower Weight:	0.39438	kg

(yellow)	System Input Values
(orange)	Critical Values

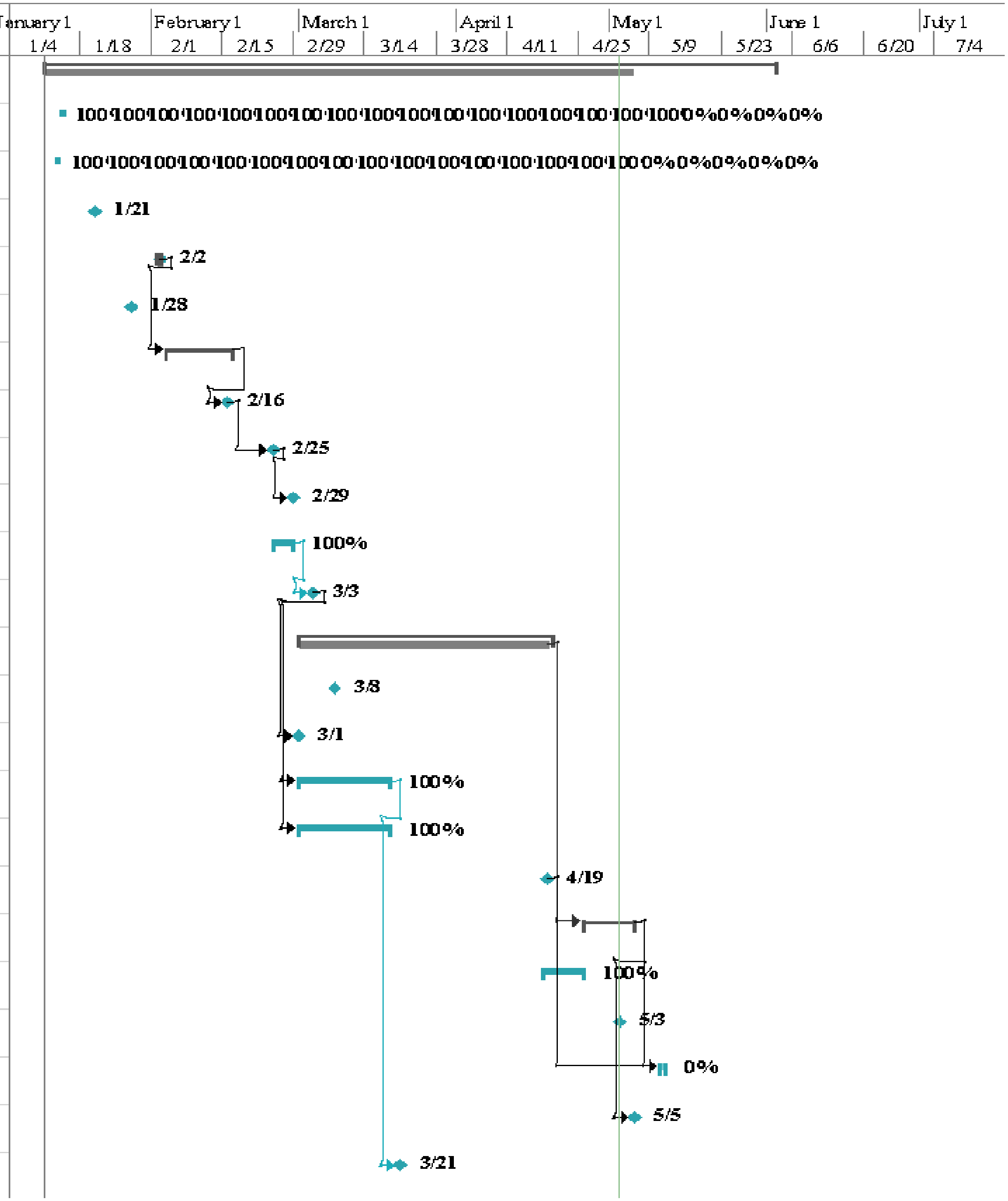
Analysis:		
b	0.944819929	in
p_max	23.19162979	psi

Principal Stresses:	
sigma_1,x	-7.437815999
sigma_2,y	-4.305363665

sigma_3,z	-18.2334727		z	0.7426284642	in
shear_max	**6.957488936**	**psi**			

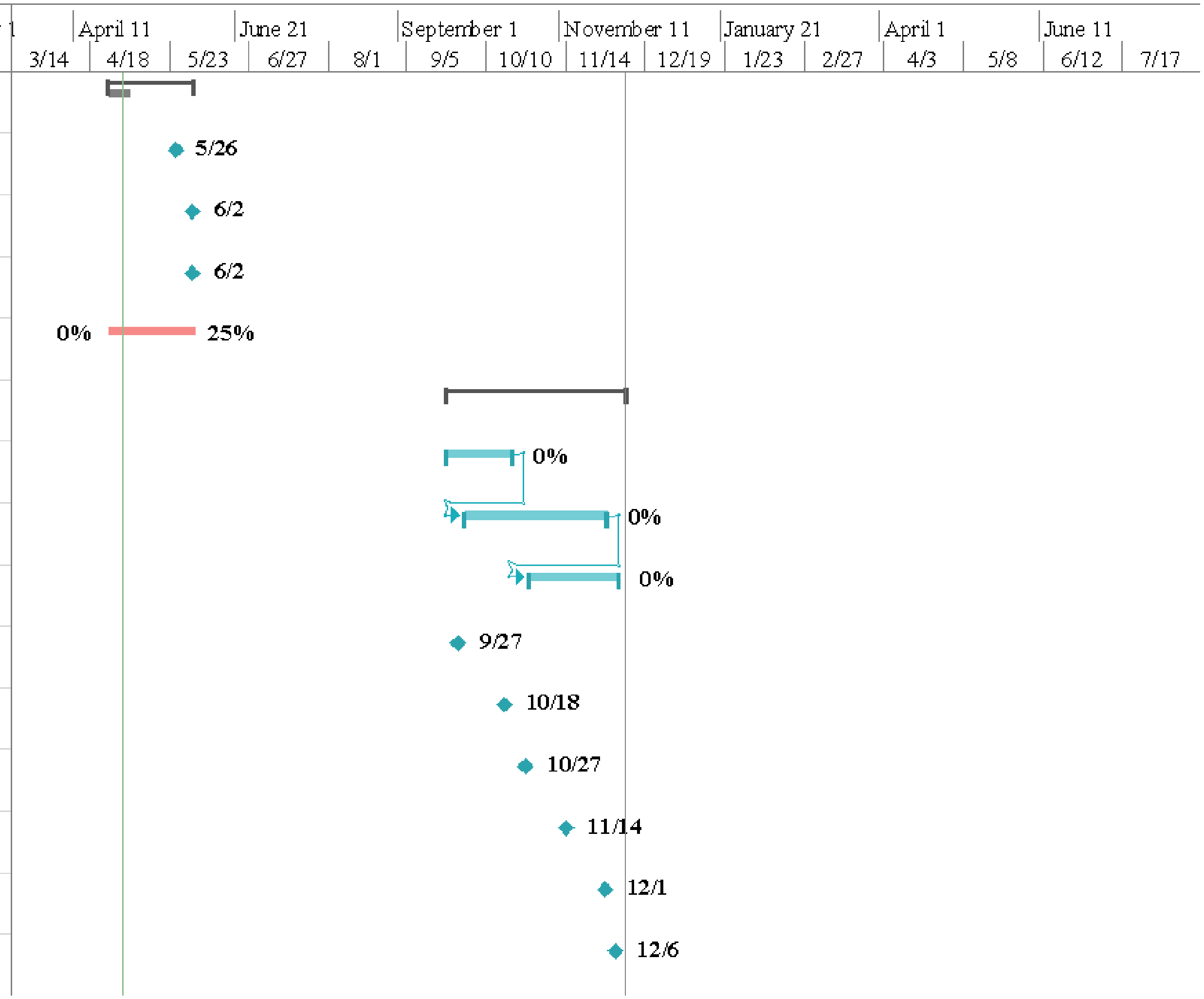
Polylogix Project Gantt Chart: Design

Task Name	Duration	Start	Finish
Design	**104 days**	**Mon 1/11/16**	**Thu 6/2/16**
Advisor Meeting	**101 days**	**Thu 1/14/16**	**Thu 6/2/16**
Endologix Teleconference	**101 days**	**Wed 1/13/16**	**Wed 6/1/16**
Problem Statement	0 days	Thu 1/21/16	Thu 1/21/16
Project Proposal Report	**1 day**	**Tue 2/2/16**	**Tue 2/2/16**
QFD House of Quality	0 days	Thu 1/28/16	Thu 1/28/16
Concept Modeling	**9 days**	**Thu 2/4/16**	**Tue 2/16/16**
Pugh Matrices	0 days	Tue 2/16/16	Tue 2/16/16
Final Design Matrix	0 days	Thu 2/25/16	Thu 2/25/16
Preliminary Design Report	**0 days**	**Mon 2/29/16**	**Mon 2/29/16**
Report development	3 days	Thu 2/25/16	Sun 2/28/16
Preliminary Design Review	1 day	Thu 3/3/16	Thu 3/3/16
Design Analysis	**36 days**	**Tue 3/1/16**	**Tue 4/19/16**
2nd Team Eval & Reflection	0 days	Tue 3/8/16	Tue 3/8/16
PDR with Endologix	0 days	Tue 3/1/16	Tue 3/1/16
Part Selection	14 days	Tue 3/1/16	Fri 3/18/16
CAD Modeling	14 days	Tue 3/1/16	Fri 3/18/16
Schedule CDR with Endologix	0 days	Tue 4/19/16	Tue 4/19/16
Final Design Report	**8 days**	**Tue 4/26/16**	**Thu 5/5/16**
Report Development	6 days	Mon 4/18/16	Mon 4/25/16
3rd Team Eval & Reflection	0 days	Tue 5/3/16	Tue 5/3/16
CDR with Endologix	1 day	Wed 5/11/16	Wed 5/11/16
CDR with Cal Poly	1 day	Thu 5/5/16	Thu 5/5/16
All Parts Ordered	0 days	Mon 3/21/16	Mon 3/21/16

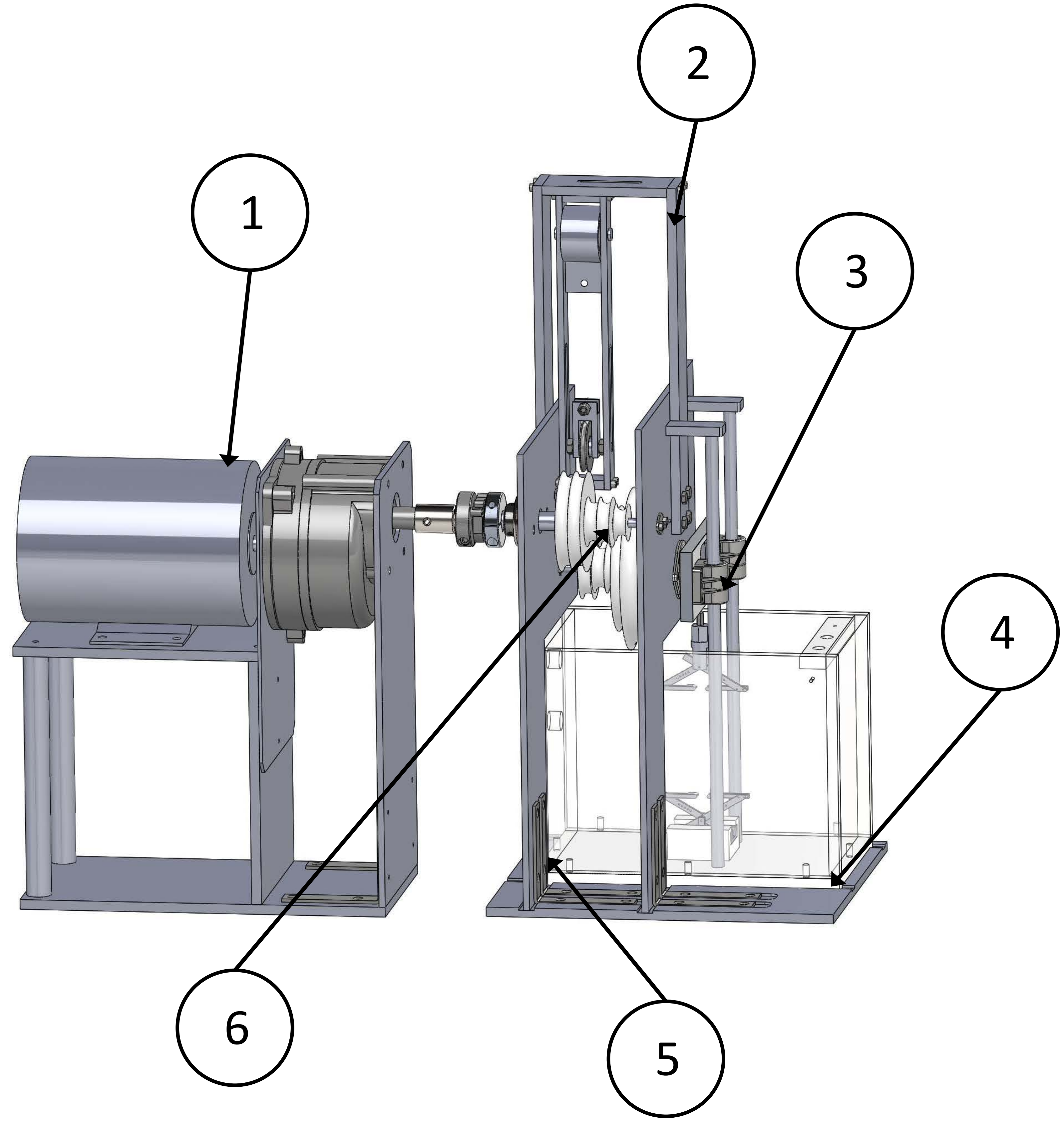


Polylogix Project Gantt Chart: Build & Test

Task Name	Duration	Start	Finish
Build	**28 days**	**Tue 4/26/16**	**Thu 6/2/16**
Spring Expo	0 days	Thu 5/26/16	Thu 5/26/16
4th Team Eval & Reflection	0 days	Thu 6/2/16	Thu 6/2/16
Status Report	0 days	Thu 6/2/16	Thu 6/2/16
Prototype Construction	28 days	Tue 4/26/16	Thu 6/2/16
Test	**57 days**	**Thu 9/22/16**	**Fri 12/9/16**
Prototype Testing	21 days	Thu 9/22/16	Thu 10/20/16
Final Design Build	45 days	Fri 9/30/16	Thu 12/1/16
Final Design Test	28 days	Fri 10/28/16	Tue 12/6/16
Project Update Memo	0 days	Tue 9/27/16	Tue 9/27/16
Project Hardware/Safety Demo	0 days	Tue 10/18/16	Tue 10/18/16
5th Team Eval & Reflection	0 days	Thu 10/27/16	Thu 10/27/16
Winter Expo	0 days	Mon 11/14/16	Mon 11/14/16
Final Project Report/ Exposition	0 days	Thu 12/1/16	Thu 12/1/16
6th Team Eval & Reflection	0 days	Tue 12/6/16	Tue 12/6/16

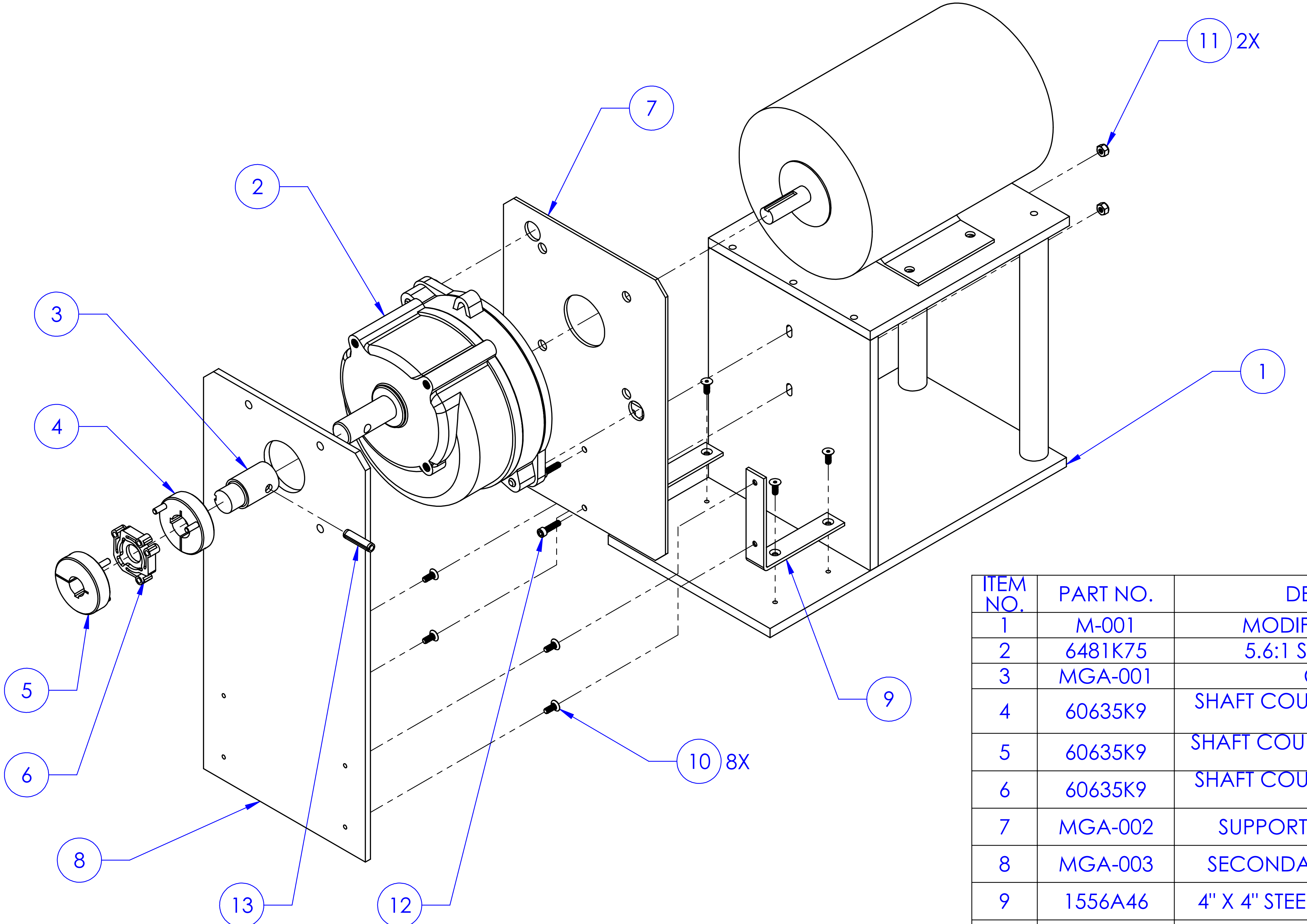


Appendix B: Drawing Packet



ITEM NO.	PART NO.	DESCRIPTION	QTY.
1	MGA-004	MOTOR GEARBOX ASSEMBLY	1
2	TS-007	TENSION PULLEY ASSEMBLY	1
3	FG-001	FOLLOWER GRIPS	1
4	TB-002	TANK BASE ASSEMBLY	1
5	1556A46 (MCMASTER -CARR)	4"x4" STEEL CORNER BRACKET	4
6	PS-001	PULLEY SYSTEM	1

ME 430 QTR 3	Title: POLYLOGIX OVERALL ASSEMBLY	Dwg: PLX-001	Drwn. By: BRANDON STELL
	Nxt Asb: N/A	Date: 12/11/16	Chkd. By: TYLER PRICE



NOTES:
UNLESS OTHERWISE SPECIFIED
1. ALL DIMENSIONS ARE IN INCHES.
2. REMOVE ALL BURRS AND BREAK ALL SHARP EDGES TO 0.015 MAXIMUM.
3. MATERIAL: ALUMINUM 6061
4. FINISH: AS MACHINED
5. TOLERANCES:
   - X.X ±.1
   - X.XX ±.01
   - X.XXX ±.005
   - X° ±2°

ITEM NO.	PART NO.	DESCRIPTION	MATERIAL	QTY.
1	M-001	MODIFIED BASE PLATE	GIVEN	1
2	6481K75	5.6:1 SPEED REDUCER	MCMASTER-CARR	1
3	MGA-001	COUPLER	ALUMINUM 6061	1
4	60635K9	SHAFT COUPLING HUB FOR 7/8" DIA.	MCMASTER-CARR	1
5	60635K9	SHAFT COUPLING DISC FOR 7/8" DIA.	MCMASTER-CARR	1
6	60635K9	SHAFT COUPLING HUB FOR 7/8" DIA.	MCMASTER-CARR	1
7	MGA-002	SUPPORT PLATE, GEARBOX	ALUMINUM 6061	1
8	MGA-003	SECONDARY SUPPORT PLATE	ALUMINUM 6061	1
9	1556A46	4" X 4" STEEL CORNER BRACKET	MCMASTER-CARR	2
10	90729A311	10-32 X 1/2" 100 DEG HEX FLAT HEAD SCREW	MCMASTER-CARR	8
11	91831A411	10-32 LOCKNUT	MCMASTER-CARR	2
12	92196A272	10-32 X 3/4" SHCS	MCMASTER-CARR	2
13	92373A461	SPRING PIN, 5/16" DIA. X 1/4" LG.	MCMASTER-CARR	1

POLYLOGIX ME 430 - QTR 3	Title: MOTOR GEARBOX ASSEMBLY	Dwg. #: MGA-004		Drwn. By: TYLER PRICE
	Nxt Asb: N/A	Date: 10/16/16	Scale: 1:2	Chkd. By: BRANDON STELL

NOTES:
UNLESS OTHERWISE SPECIFIED
1. ALL DIMENSIONS ARE IN INCHES.
2. REMOVE ALL BURRS AND BREAK ALL SHARP EDGES TO 0.015 MAXIMUM.
3. MATERIAL: 6061 ALUMINUM
4. FINISH: AS MACHINED
5. TOLERANCES:

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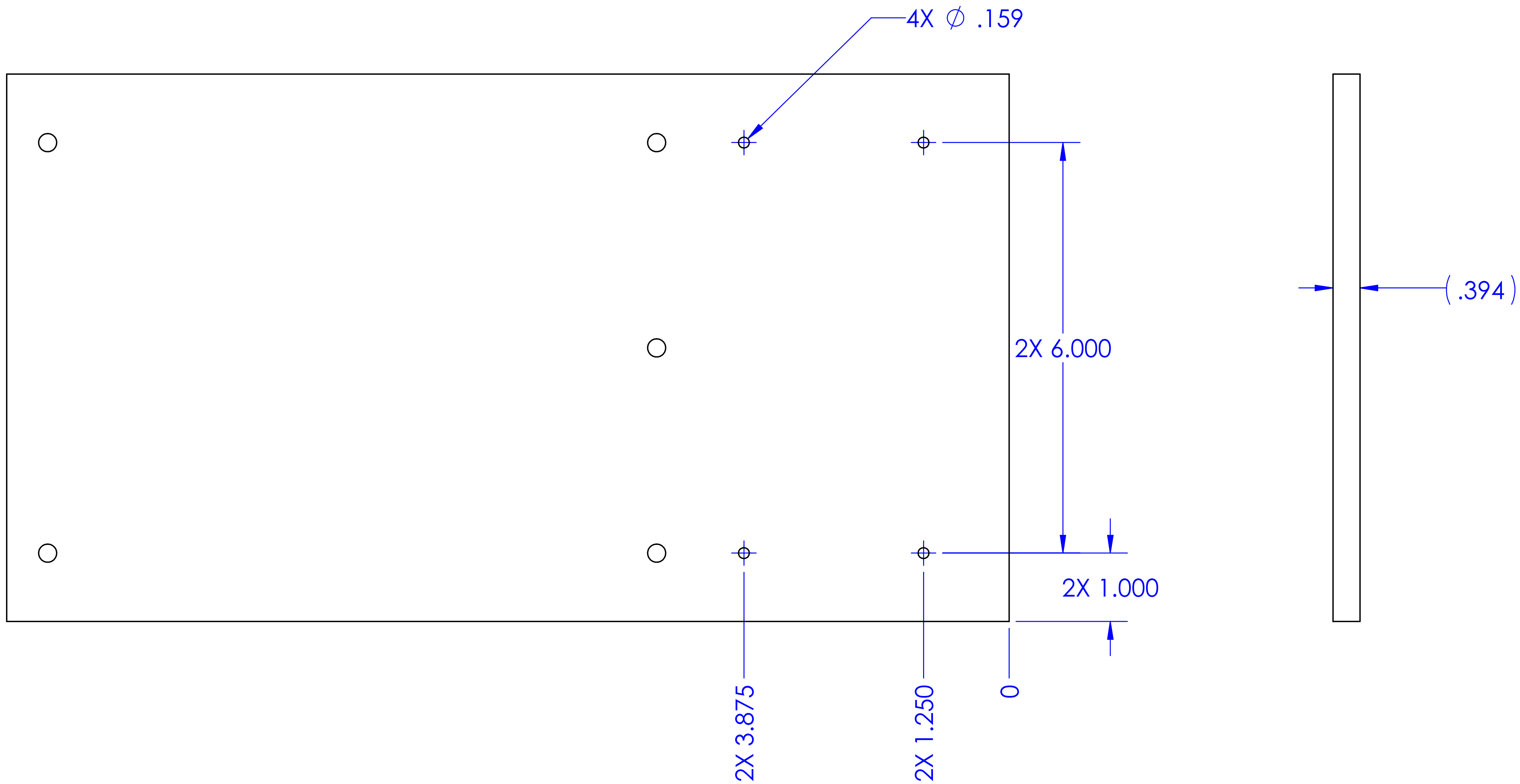
X.XX	±.01
X.XXX	±.005
X°	±2°



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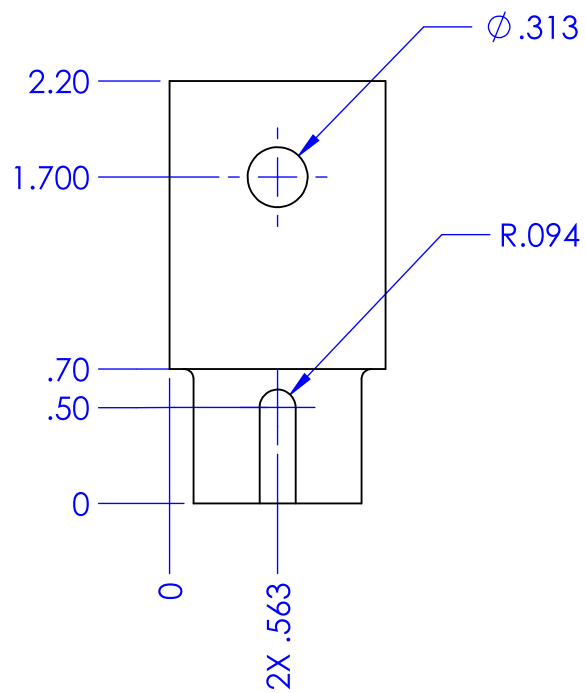

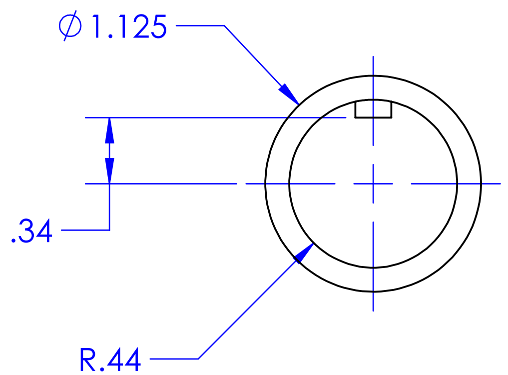

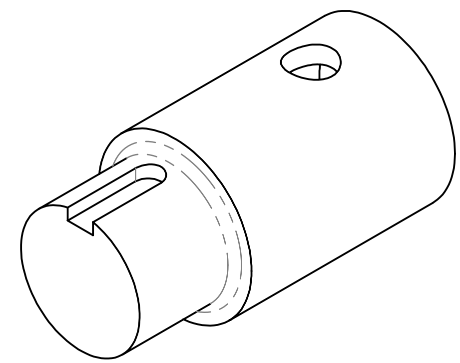

NOTES:
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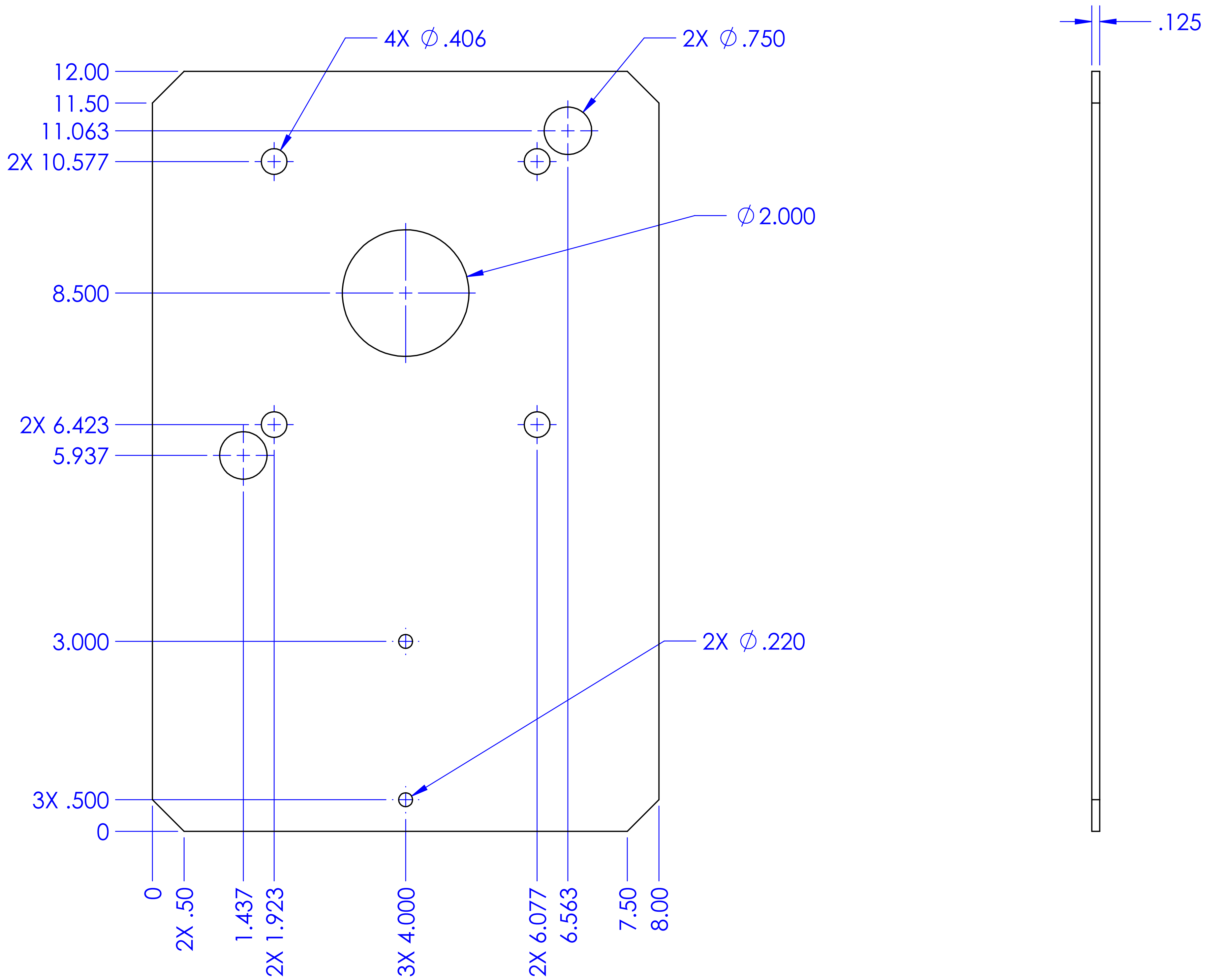
3. MATERIAL: 6061 ALUMINUM
4. FINISH: AS MACHINED
5. TOLERANCES:

X.X	±.1
X.XX	±.01
X.XXX	±.005
X°	±2°

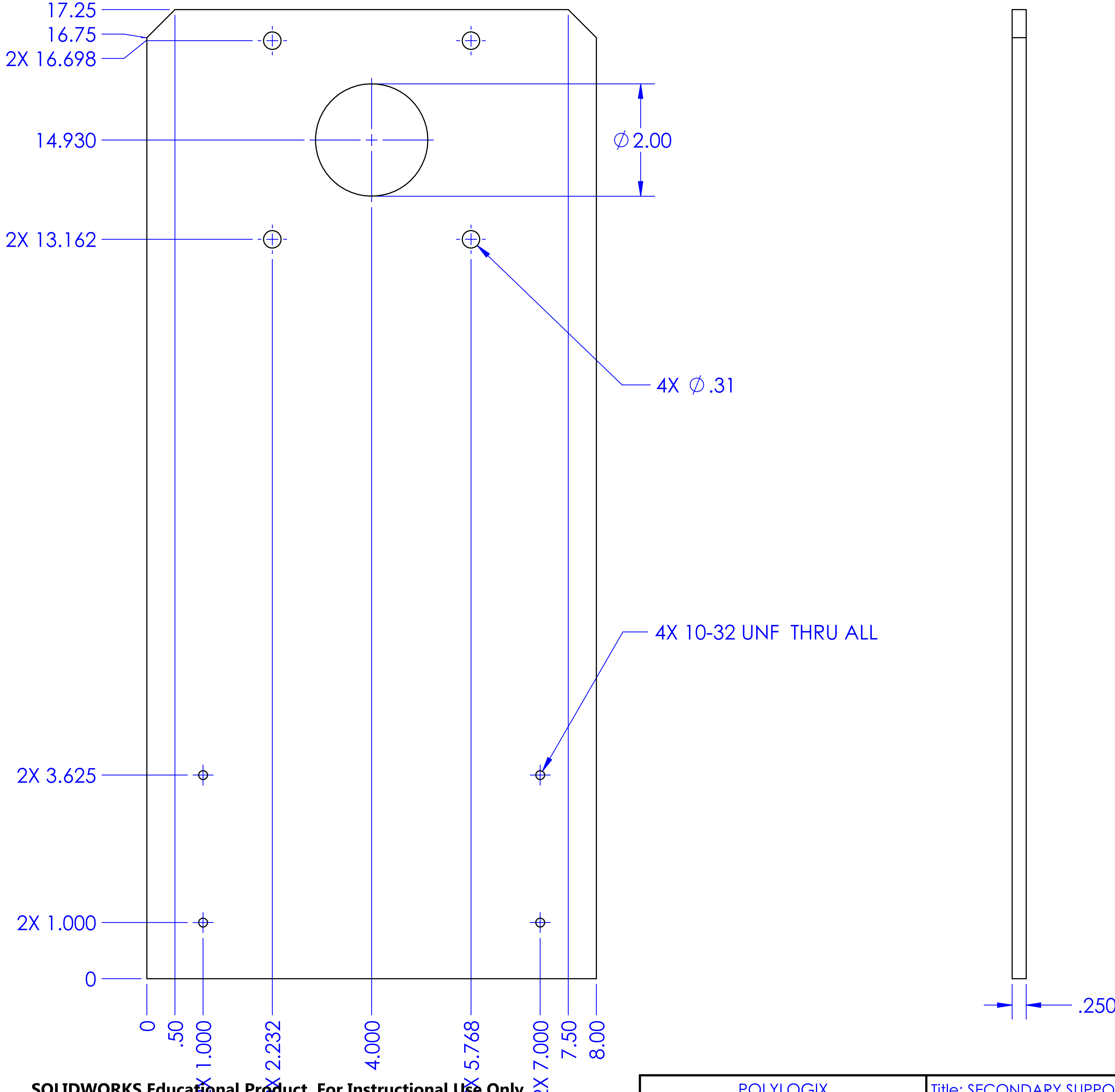
POLYLOGIX	Title: COUPLER, GEARBOX SIDE	Dwg. #: MGA-001		Drwn. By: TYLER PRICE
ME 430 - QTR 3	Nxt Asb: MOTOR GEARBOX ASSY	Date: 10/16/2016	Scale: 1:1	Chkd. By: BRANDON STELL



NOTES:
UNLESS OTHERWISE SPECIFIED
1. ALL DIMENSIONS ARE IN INCHES.
2. REMOVE ALL BURRS AND BREAK ALL SHARP EDGES TO 0.015 MAXIMUM.
3. MATERIAL: 6061 ALUMINUM
4. FINISH: AS MACHINED
5. TOLERANCES:

X.X	±.1
X.XX	±.01
X.XXX	±.005
X°	±2°

POLYLOGIX	Title: SUPPORT PLATE, GEARBOX	Dwg. #: MGA-002		Drwn. By: TYLER PRICE
ME 430 - QTR 3	Nxt Asb: MOTOR GEARBOX ASSY	Date: 10/16/16	Scale: 1:2	Chkd. By: BRANDON STELL



NOTES:
UNLESS OTHERWISE SPECIFIED
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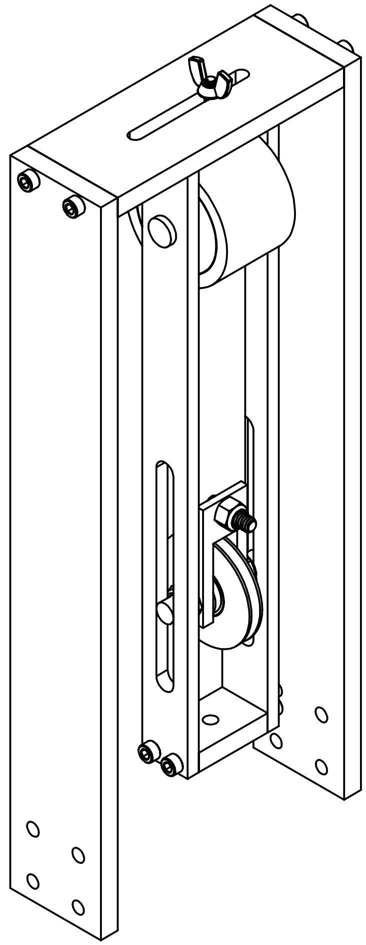
2. REMOVE ALL BURRS AND BREAK ALL SHARP EDGES TO 0.015 MAXIMUM.
3. MATERIAL: 6061 ALUMINUM
4. FINISH: AS MACHINED
5. TOLERANCES:

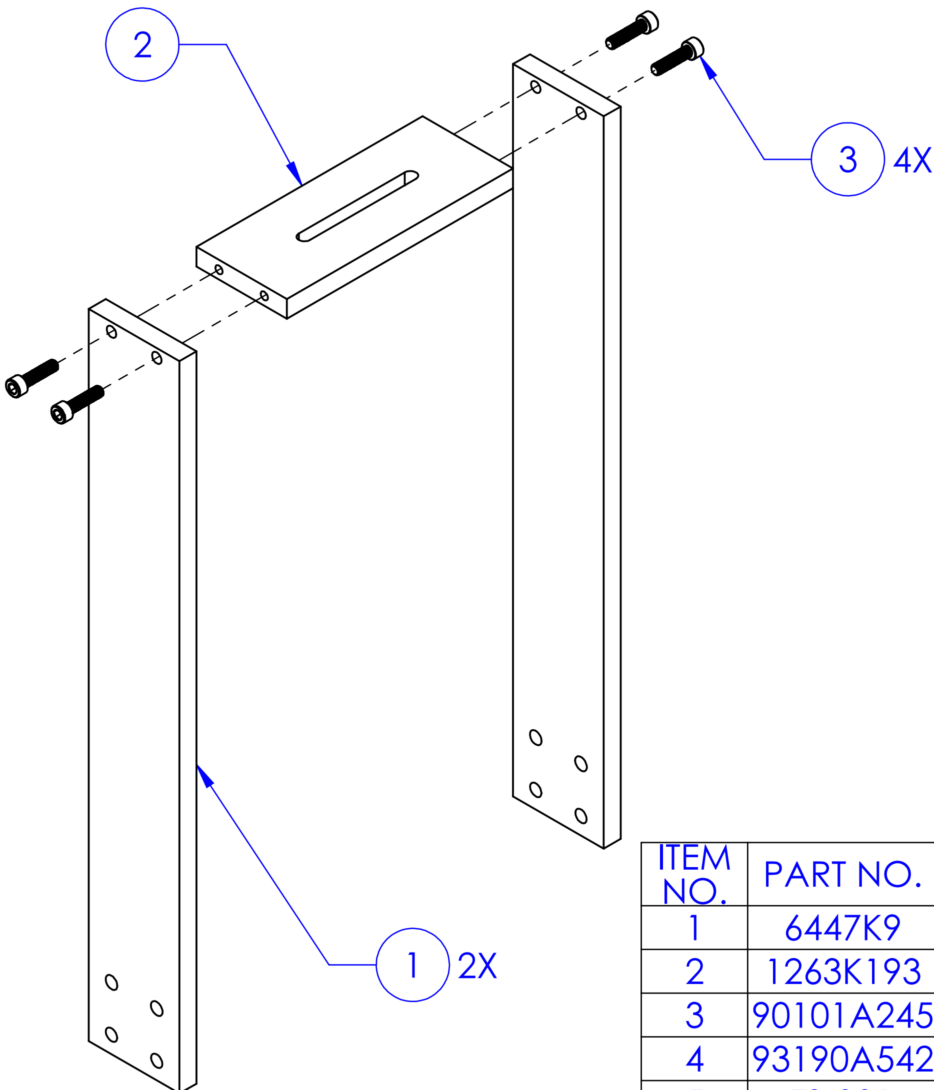
X.X	±.1
X.XX	±.01
X.XXX	±.005
X°	±2°

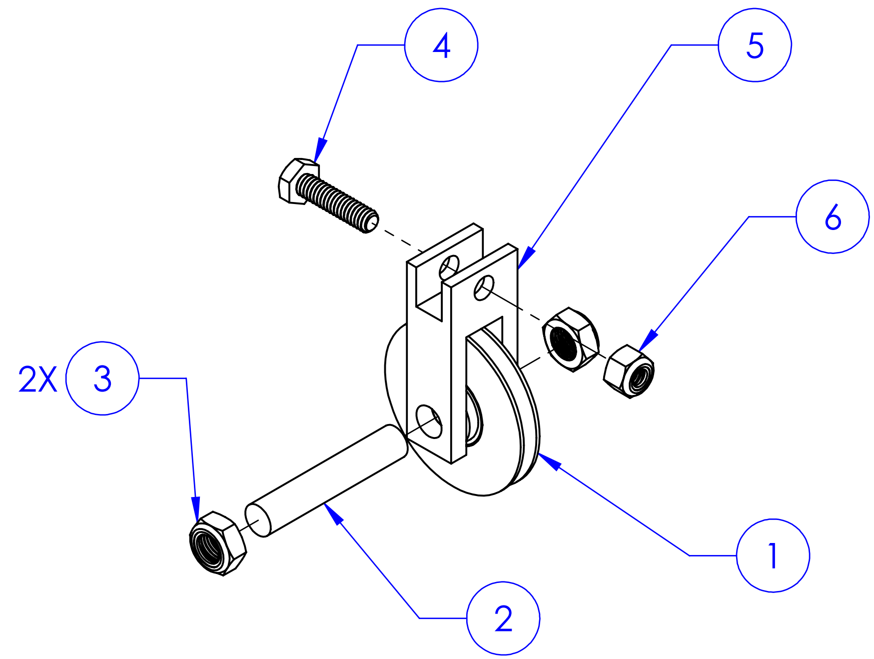
POLYLOGIX ME 430 - QTR 3	Title: SECONDARY SUPPORT PLATE	Dwg. #: MGA-003		Drwn. By: TYLER PRICE
	Nxt Asb: MOTOR GEARBOX ASSY	Date: 10/16/16	Scale: 1:2	Chkd. By: BRANDON STELL



POLYLOGIX	Title: TENSION PULLEY ASSY	Dwg. #: TS-007		Drwn. By: TYLER PRICE
ME 430 - QTR 3	Nxt Asb: N/A	Date: 10/16/2016	Scale: 1:3	Chkd. By: BRANDON STELL

ITEM NO.	PART NO.	DESCRIPTION	MATERIAL	QTY.
1	TS-005	OVERALL SUPPORT	ALUMINUM 6061	2
2	TS-004	LATERAL SLIDER	ALUMINUM 6061	1
3	92196A272	10-32 X 3/4" SHCS	MCMASTER-CARR	4

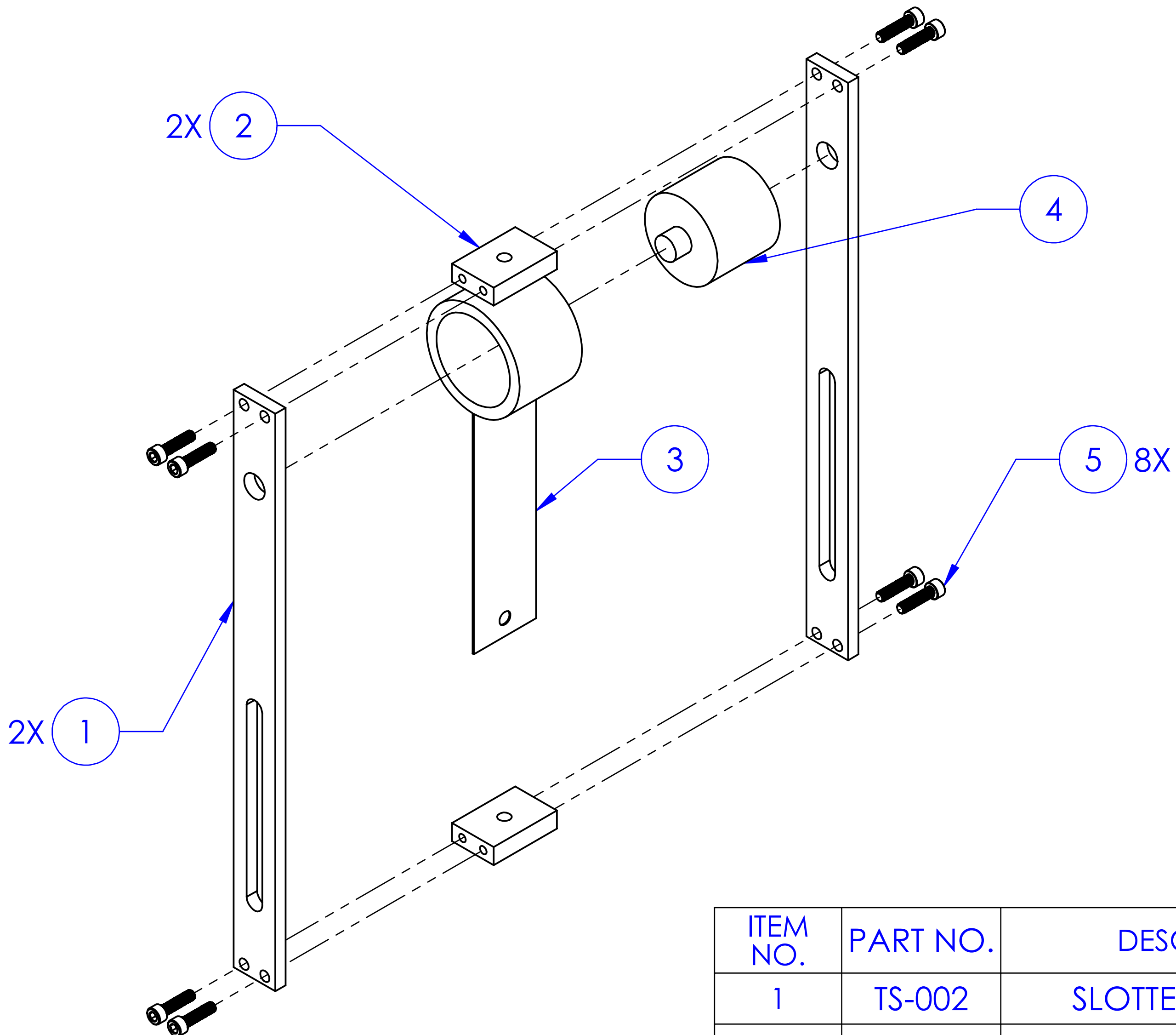




SCALE 1:2

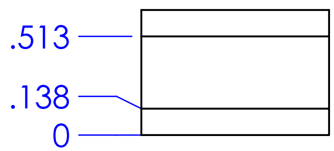
ITEM NO.	PART NO.	DESCRIPTION	MATERIAL	QTY.
1	6447K9	BRASS IDLER PULLEY	MCMASTER-CARR	1
2	1263K193	3/8" DIA. X 3" LG. ROTARY SHAFT	MCMASTER-CARR	1
3	90101A245	3/8"-24 THIN LOCKNUT	MCMASTER-CARR	2
4	93190A542	1/4"-20 X 1" HEX HEAD SCREW	MCMASTER-CARR	1
5	TS-001	PULLEY SPRING ATTACHER	ALUMINUM 6061	1
6	90715A125	1/4"-20 LOCKNUT	MCMASTER-CARR	1

POLYLOGIX ME 430 - QTR 3	Title: TENSION PULLEY ASSY	Dwg. #: TS-007	Drwn. By: TYLER PRICE
	Nxt Asb: N/A	Date: 10/16/2016 · Scale: 1:3	Chkd. By: BRANDON STELL



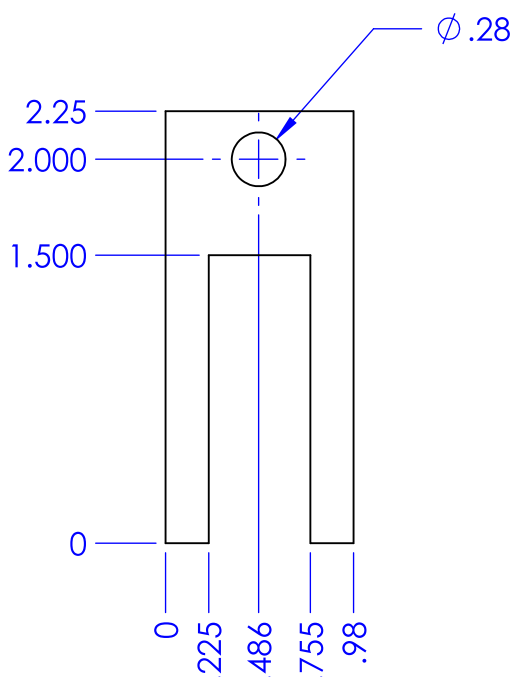
ITEM NO.	PART NO.	DESCRIPTION	MATERIAL	QTY.
1	TS-002	SLOTTED SUPPORT	ALUMINUM 6061	2
2	TS-003	TOP SUPPORT	ALUMINUM 6061	2
3	9293K130	CONSTANT FORCE SPRING	MCMASTER-CARR	1
4	TS-006	SPRING SHAFT	ALUMINUM 6061	1
5	92196A272	10-32 X 3/4" SHCS	MCMASTER-CARR	8

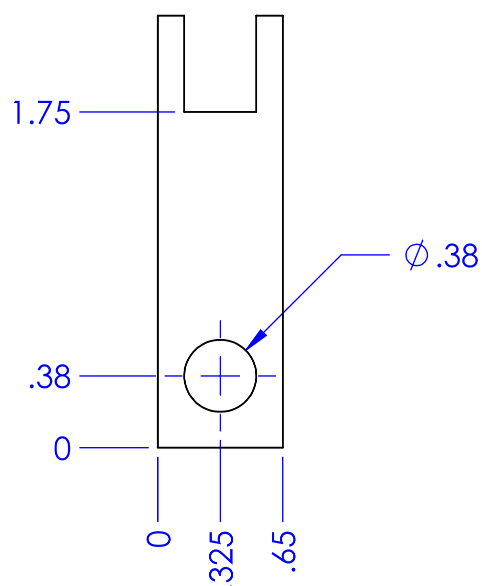
POLYLOGIX ME 430 - QTR 3	Title: TENSION PULLEY ASSY	Dwg. #: TS-007	Drwn. By: TYLER PRICE
	Nxt Asb: N/A	Date: 10/16/2016 Scale: 1:3	Chkd. By: BRANDON STELL

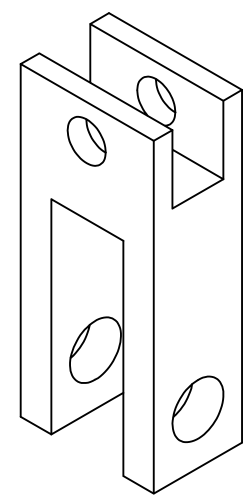


NOTES:
UNLESS OTHERWISE SPECIFIED
1. ALL DIMENSIONS ARE IN INCHES.
2. REMOVE ALL BURRS AND BREAK ALL SHARP EDGES TO 0.015 MAXIMUM.
3. MATERIAL: 6061 ALUMINUM
4. FINISH: AS MACHINED
5. TOLERANCES:

X.X	±.1
X.XX	±.01
X.XXX	±.005
X°	±2°



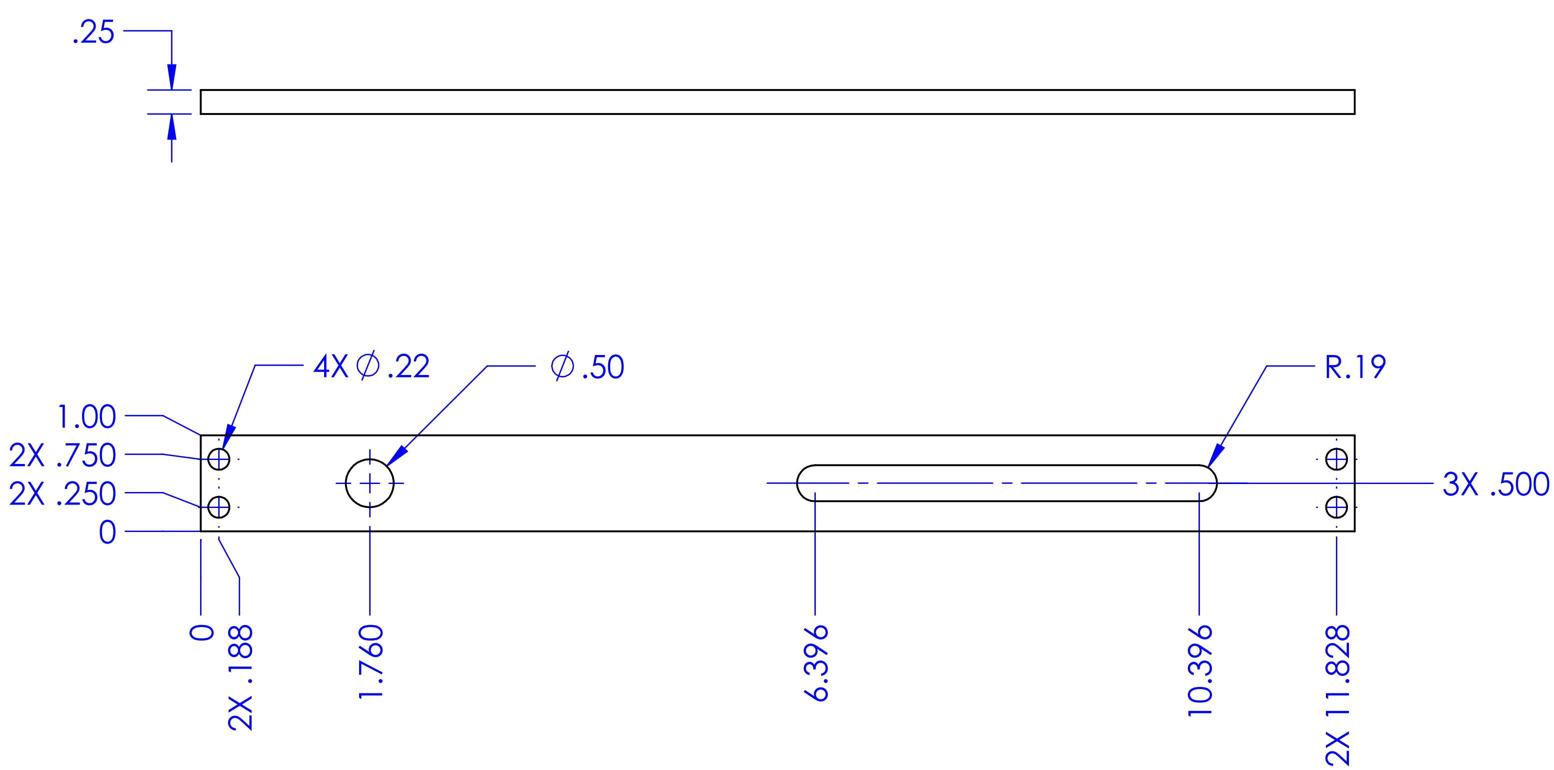




POLYLOGIX ME 430 - QTR 3	Title: PULLEY SPRING ATTACHER	Dwg. #: TS-001		Drwn. By: TYLER PRICE
	Nxt Asb: TENSION PULLEY	Date: 10/16/2016	Scale: 1:1	Chkd. By: BRANDON STELL

NOTES:
UNLESS OTHERWISE SPECIFIED
1. ALL DIMENSIONS ARE IN INCHES.
2. REMOVE ALL BURRS AND BREAK ALL SHARP EDGES TO 0.015 MAXIMUM.
3. MATERIAL: 6061 ALUMINUM
4. FINISH: AS MACHINED
5. TOLERANCES:

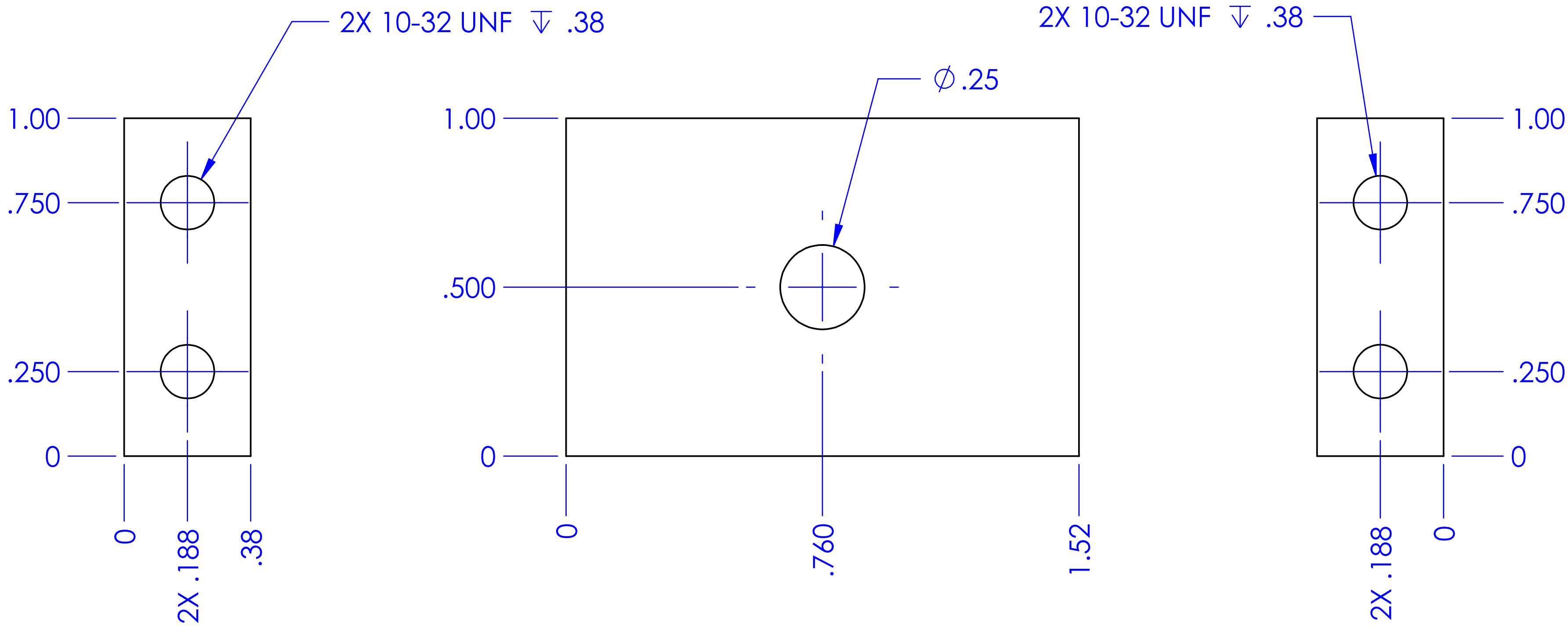
X.X	±.1
X.XX	±.01
X.XXX	±.005
X°	±2°



POLYLOGIX ME 430 - QTR 3	Title: SLOTTED SUPPORT	Dwg. #: TS-002	Drwn. By: TYLER PRICE
	Nxt Asb: TENSION PULLEY	Date: 10/16/2016 · Scale: 1:2	Chkd. By: BRANDON STELL

NOTES:
UNLESS OTHERWISE SPECIFIED
1. ALL DIMENSIONS ARE IN INCHES.
2. REMOVE ALL BURRS AND BREAK ALL SHARP EDGES TO 0.015 MAXIMUM.
3. MATERIAL: 6061 ALUMINUM
4. FINISH: AS MACHINED
5. TOLERANCES:

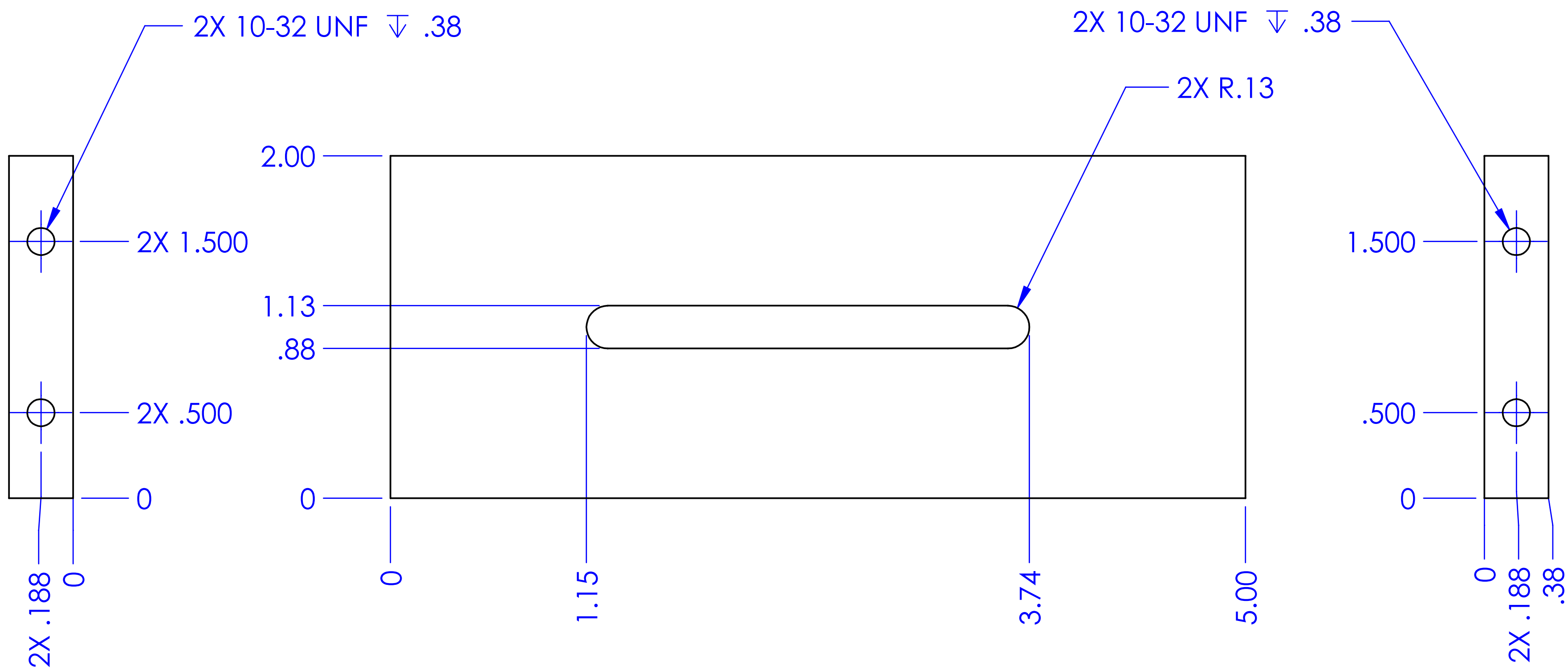
X.X	±.1
X.XX	±.01
X.XXX	±.005
X°	±2°



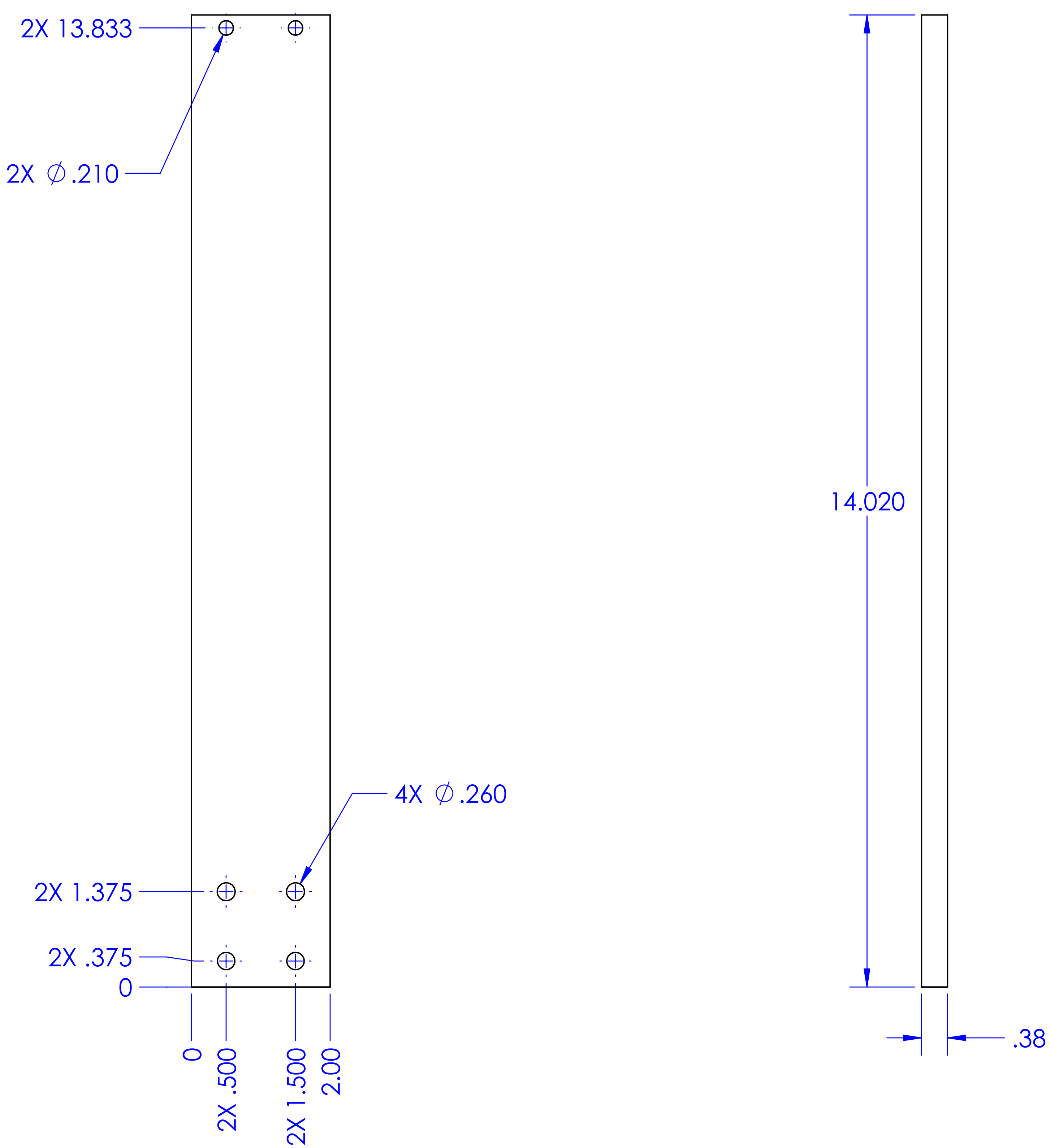
POLYLOGIX	Title: TOP SUPPORT	Dwg. #: TS-003	Drwn. By: TYLER PRICE
ME 430 - QTR 3	Nxt Asb: TENSION PULLEY	Date: 10/16/2016 / Scale: 2:1	Chkd. By: BRANDON STELL

NOTES:
UNLESS OTHERWISE SPECIFIED
1. ALL DIMENSIONS ARE IN INCHES.
2. REMOVE ALL BURRS AND BREAK ALL SHARP EDGES TO 0.015 MAXIMUM.
3. MATERIAL: 6061 ALUMINUM
4. FINISH: AS MACHINED
5. TOLERANCES:

X.X	±.1
X.XX	±.01
X.XXX	±.005
X°	±2°



POLYLOGIX	Title: LATERAL SLIDER	Dwg. #: TS-004	Drwn. By: TYLER PRICE
ME 430 - QTR 3	Nxt Asb: TENSION PULLEY	Date: 10/16/2016 Scale: 1:1	Chkd. By: BRANDON STELL



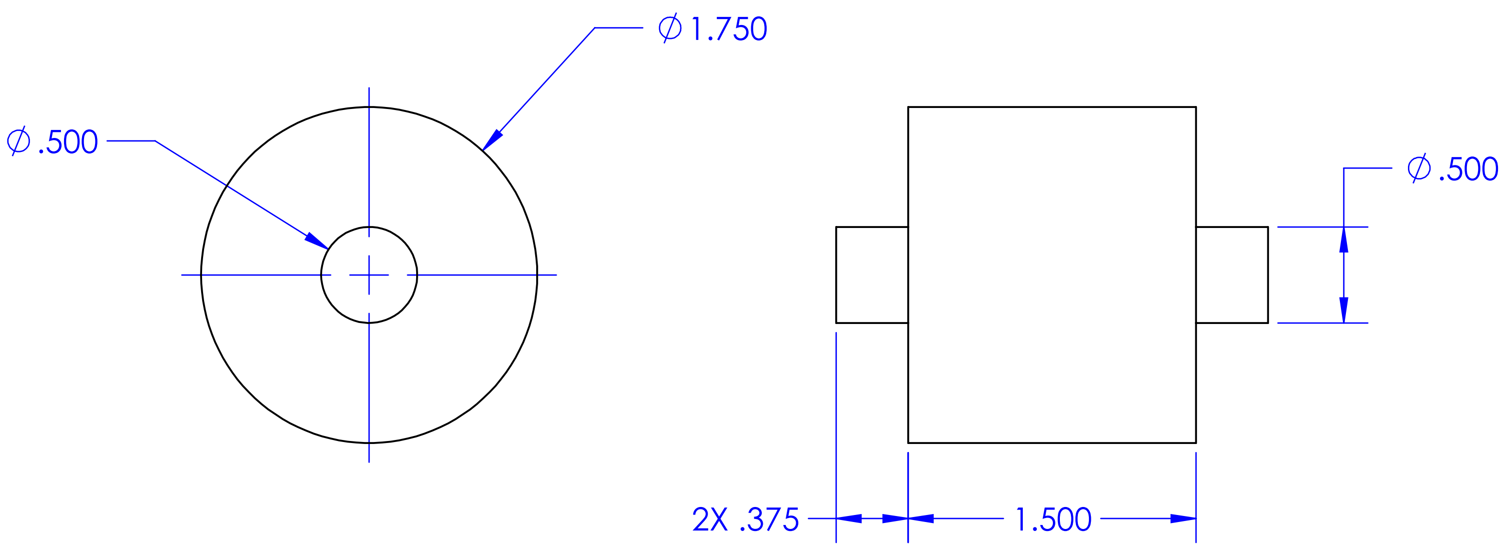
NOTES:
UNLESS OTHERWISE SPECIFIED
1. ALL DIMENSIONS ARE IN INCHES.
2. REMOVE ALL BURRS AND BREAK ALL SHARP EDGES TO 0.015 MAXIMUM.
3. MATERIAL: 6061 ALUMINUM
4. FINISH: AS MACHINED
5. TOLERANCES:

X.X	±.1
X.XX	±.01
X.XXX	±.005
X°	±2°

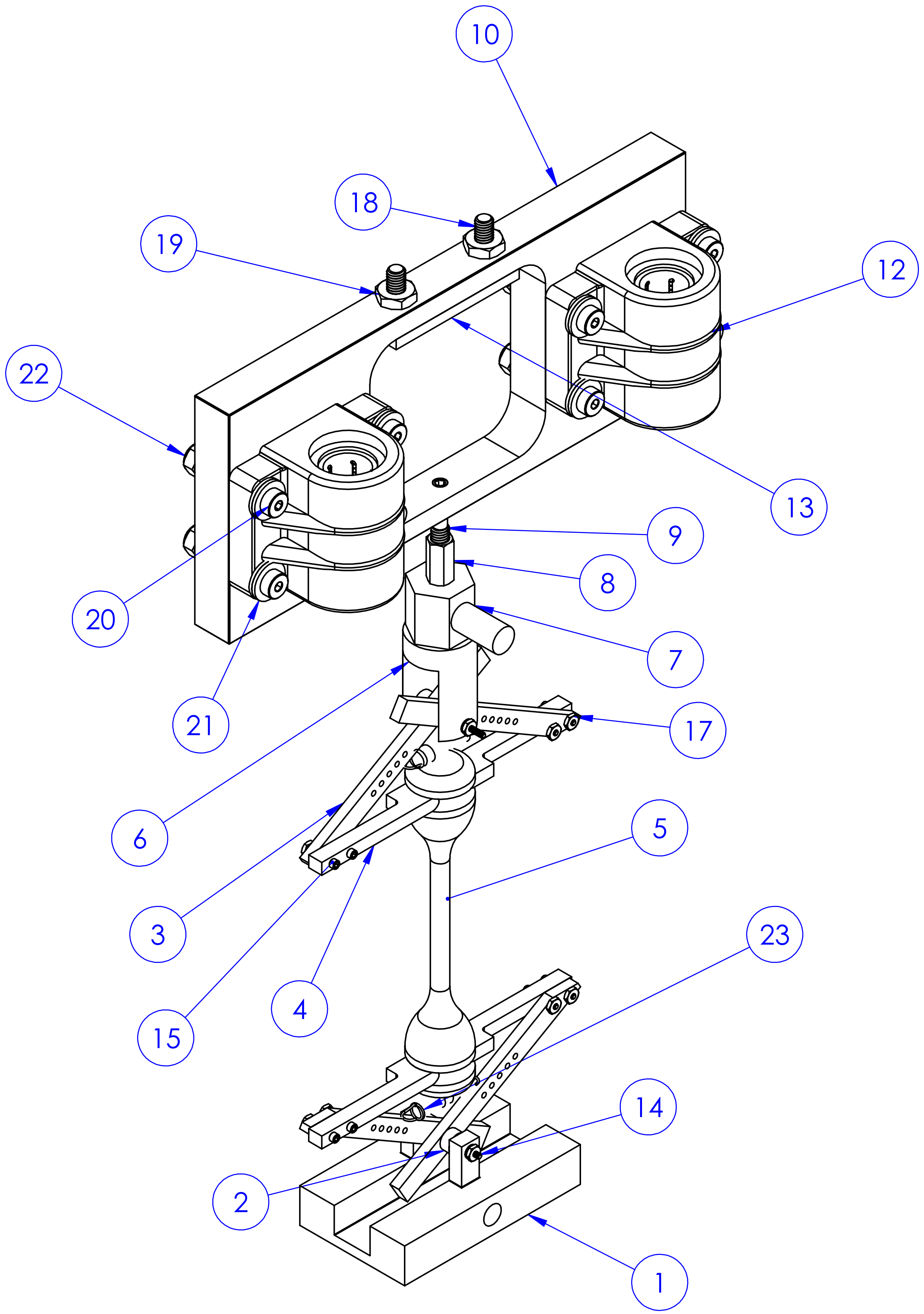
POLYLOGIX	Title: OVERALL SUPPORT	Dwg. #: TS-005		Drwn. By: TYLER PRICE
ME 430 - QTR 3	Nxt Asb: TENSION PULLEY	Date: 10/16/16	Scale: 1:2	Chkd. By: BRANDON STELL

NOTES:
UNLESS OTHERWISE SPECIFIED
1. ALL DIMENSIONS ARE IN INCHES.
2. REMOVE ALL BURRS AND BREAK ALL SHARP EDGES TO 0.015 MAXIMUM.
3. MATERIAL: 6061 ALUMINUM
4. FINISH: AS MACHINED
5. TOLERANCES:

X.X	±.1
X.XX	±.01
X.XXX	±.005
X°	±2°

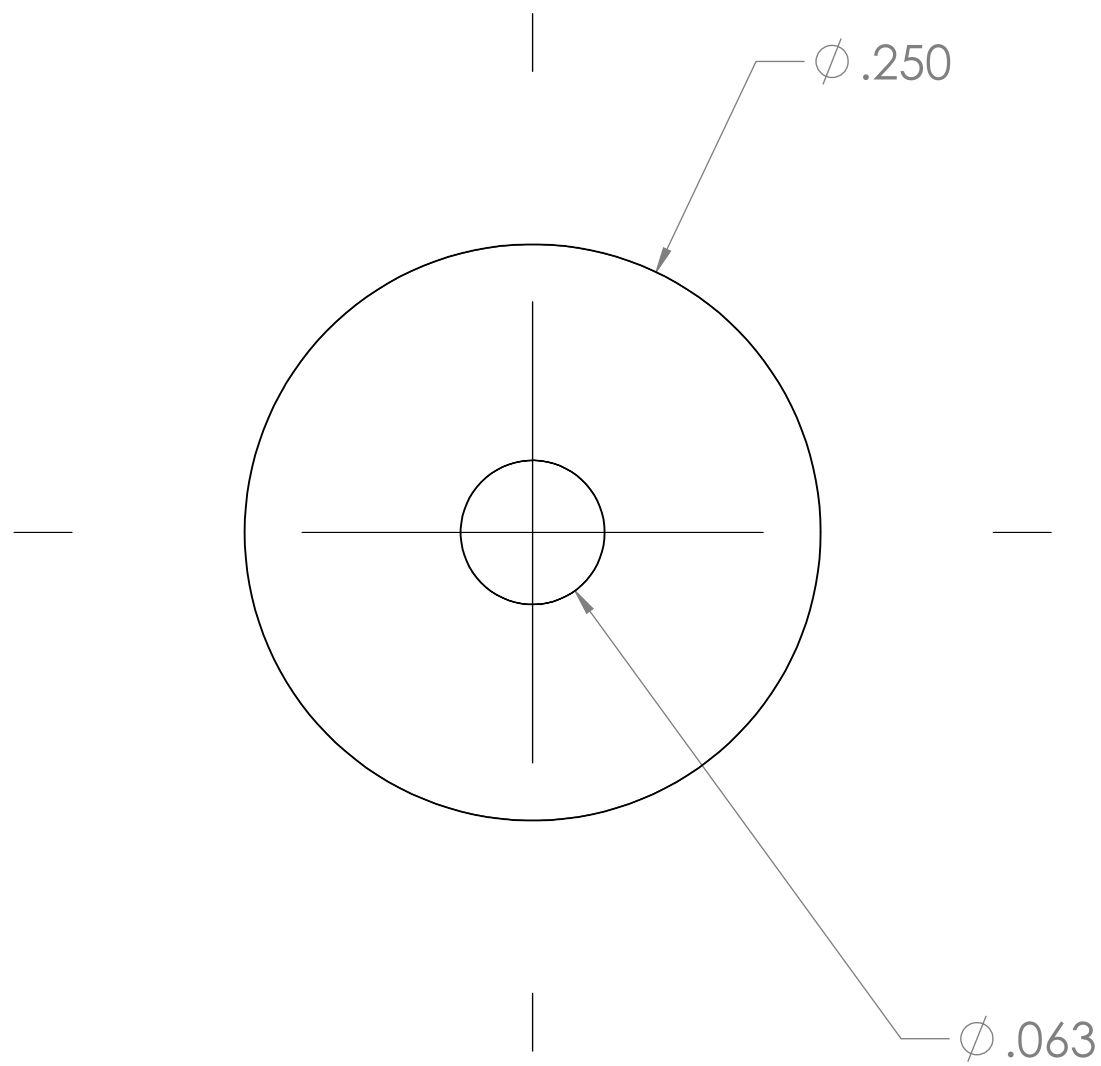


POLYLOGIX	Title: SPRING SHAFT	Dwg. #: TS-006	Drwn. By: TYLER PRICE
ME 430 - QTR 3	Nxt Asb: TENSION PULLEY	Date: 10/16/2016 Scale: 1:1	Chkd. By: BRANDON STELL



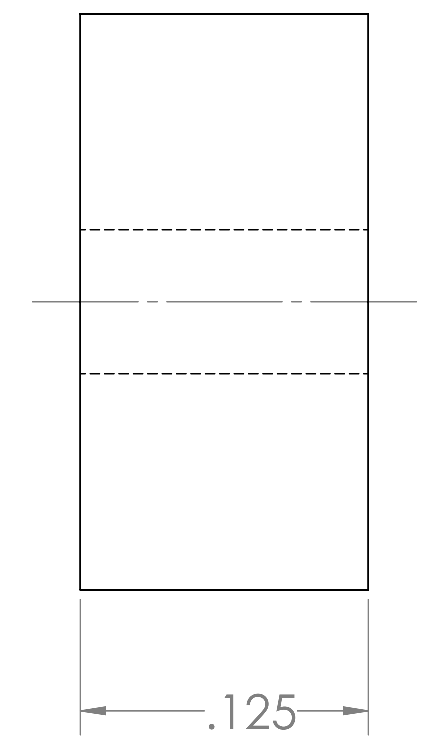
ITEM NO.	PART NUMBER	DESCRIPTION	MATERIAL	QTY.
1	FG-002	BASE SLIDER	6061-T6	1
2	FG-003	GRIP BUSHING	6061-T6	4
3	FG-004	GRIP ARM	6061-T6	4
4	FG-005	GRIP	6061-T6	4
5	FG-006	TEST SPECIMEN	-	1
6	FG-007	GRIP CLEVIS	6061-T6	1
7	FG-008	LOAD CELL	-	1
8	91115A151	-	MCMASTER-CARR	1
9	91442A260	-	MCMASTER-CARR	1
10	FG-009	FOLLOWER	6061-T6	1
11	FG-010	LOAD CELL MOUNT THREADED ROD	-	2
12	1052K11	-	MCMASTER-CARR	2
13	FG-011	TEFLON STRIP	TEFLON	1
14	92196A060	-	MCMASTER-CARR	2
15	92196A057	-	MCMASTER-CARR	8
16	90107A001	-	MCMASTER-CARR	2
17	91841A115	-	MCMASTER-CARR	10
18	92210A304	-	MCMASTER-CARR	2
19	91841A195	-	MCMASTER-CARR	2
20	94035A155	-	MCMASTER-CARR	8
21	92141A011	-	MCMASTER-CARR	16
22	91831A007	-	MCMASTER-CARR	8
23	9432K26	-	MCMASTER-CARR	2

POLYLOGIX ME 430 - QTR 3	Title: FOLLOWER GRIPS	Dwg. #: FG-001		Drwn. By: BRANDON STELL
	Nxt Asb: PLX-001	Date: 10/16/16	Scale: 2:3	Chkd. By: TYLER PRICE



NOTES:

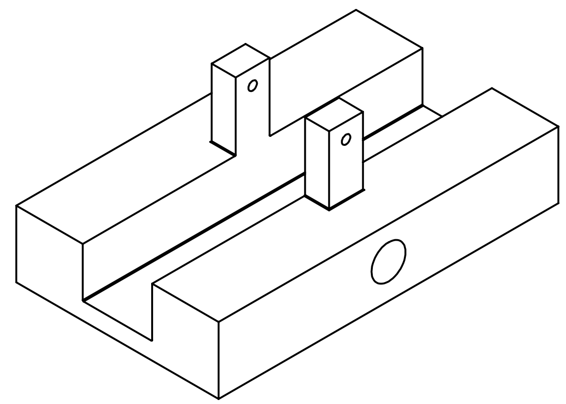
1. Unless otherwise specified, dimensions are in inches.
2. Material: 6061 Aluminum
3. Manufacturing Process: Lathe
4. Tolerances to ±0.001

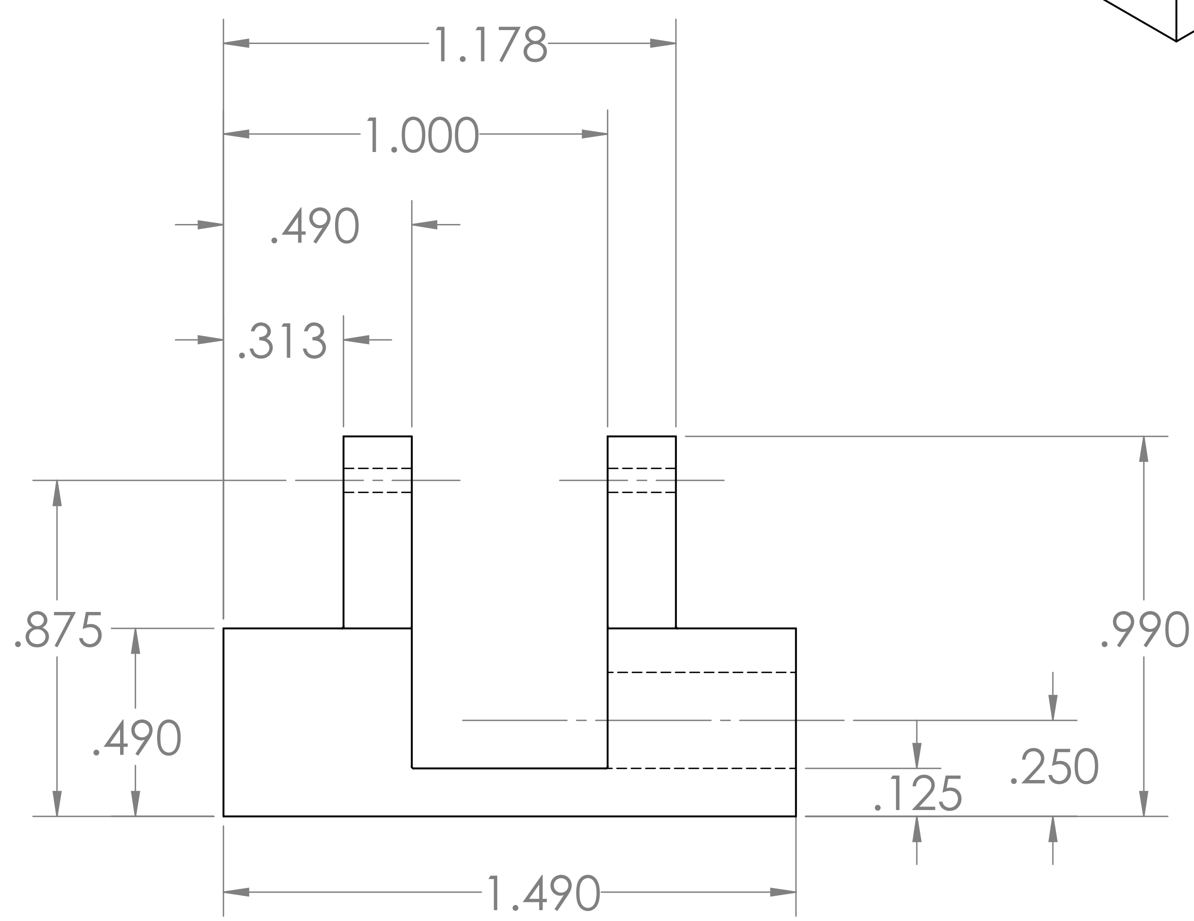


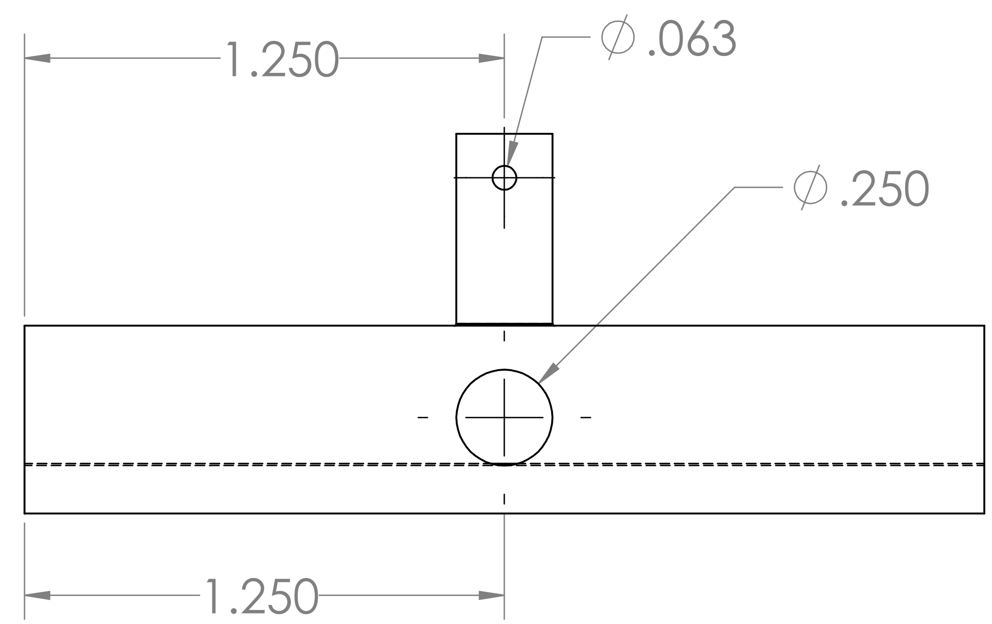
Cal Poly Mechanical Engineering	Lab Section: 04	Overall System	Title: CLAMP BUSHING		Drwn. By: BRANDON STELL
ME 429 - Spring 2016	Dwg. #: PLX-001	Nxt Asb: PLX-002	Date: 05/03/2016	Scale: 12:1	Chkd. By: TYLER PRICE

NOTES:

1. Unless otherwise specified, dimensions are in inches.
2. Material: 6061 Aluminum
3. Manufacturing Process: Mill
4. Tolerances to ±0.001



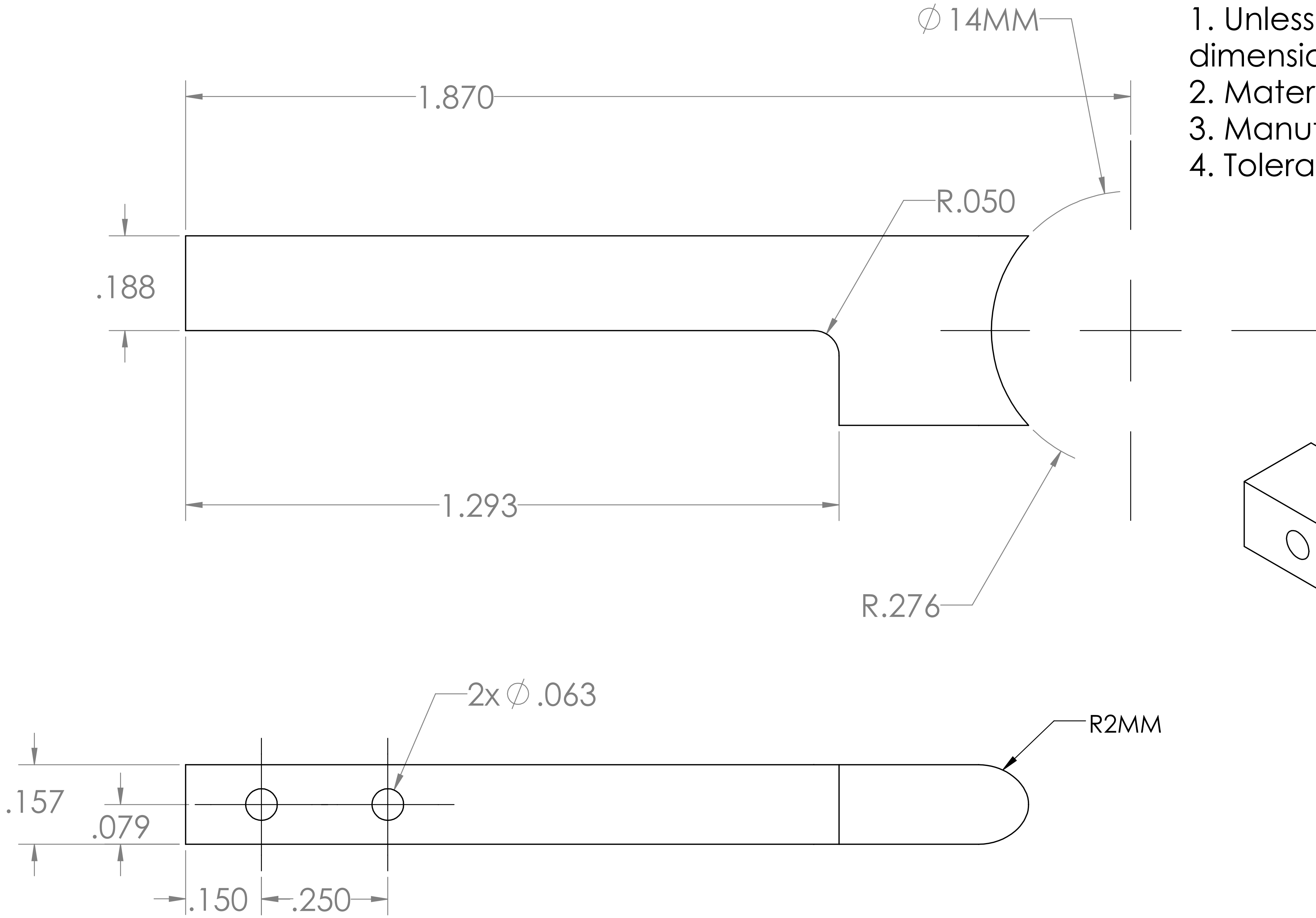


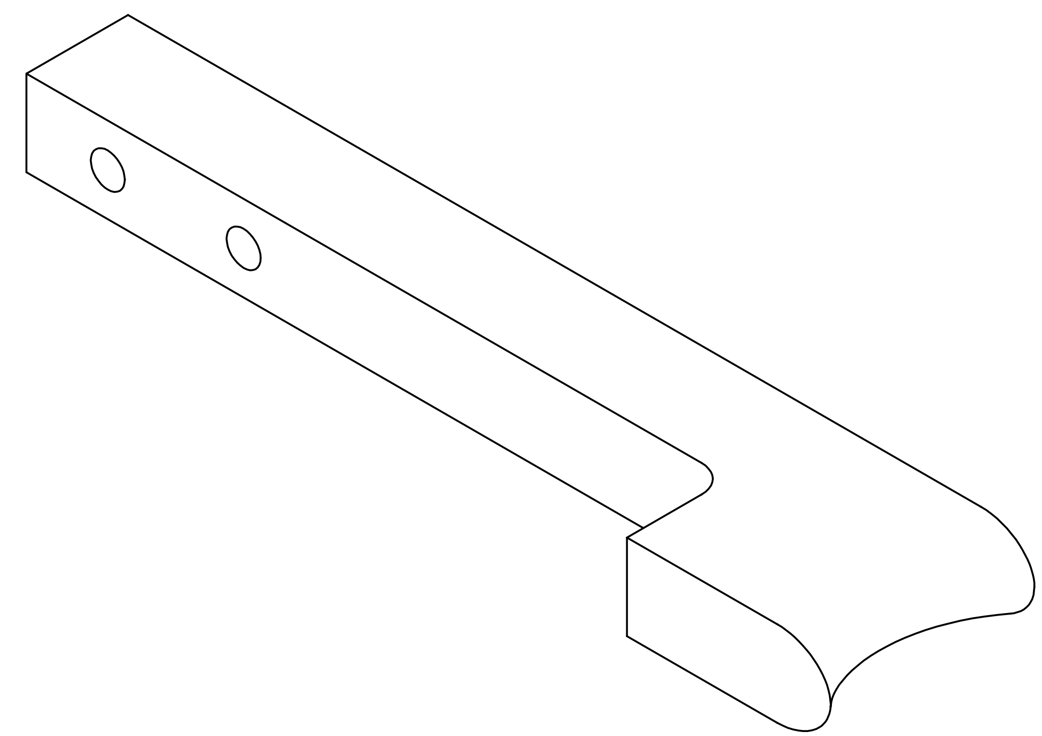


Cal Poly Mechanical Engineering ME 429 - Spring 2016	Lab Section: 04	Overall System	Title: BASE SLIDER		Drwn. By: BRANDON STELL
	Dwg. #: PLX-002	Nxt Asb: PLX-003	Date: 05/03/2016	Scale: 2:1	Chkd. By: TYLER PRICE

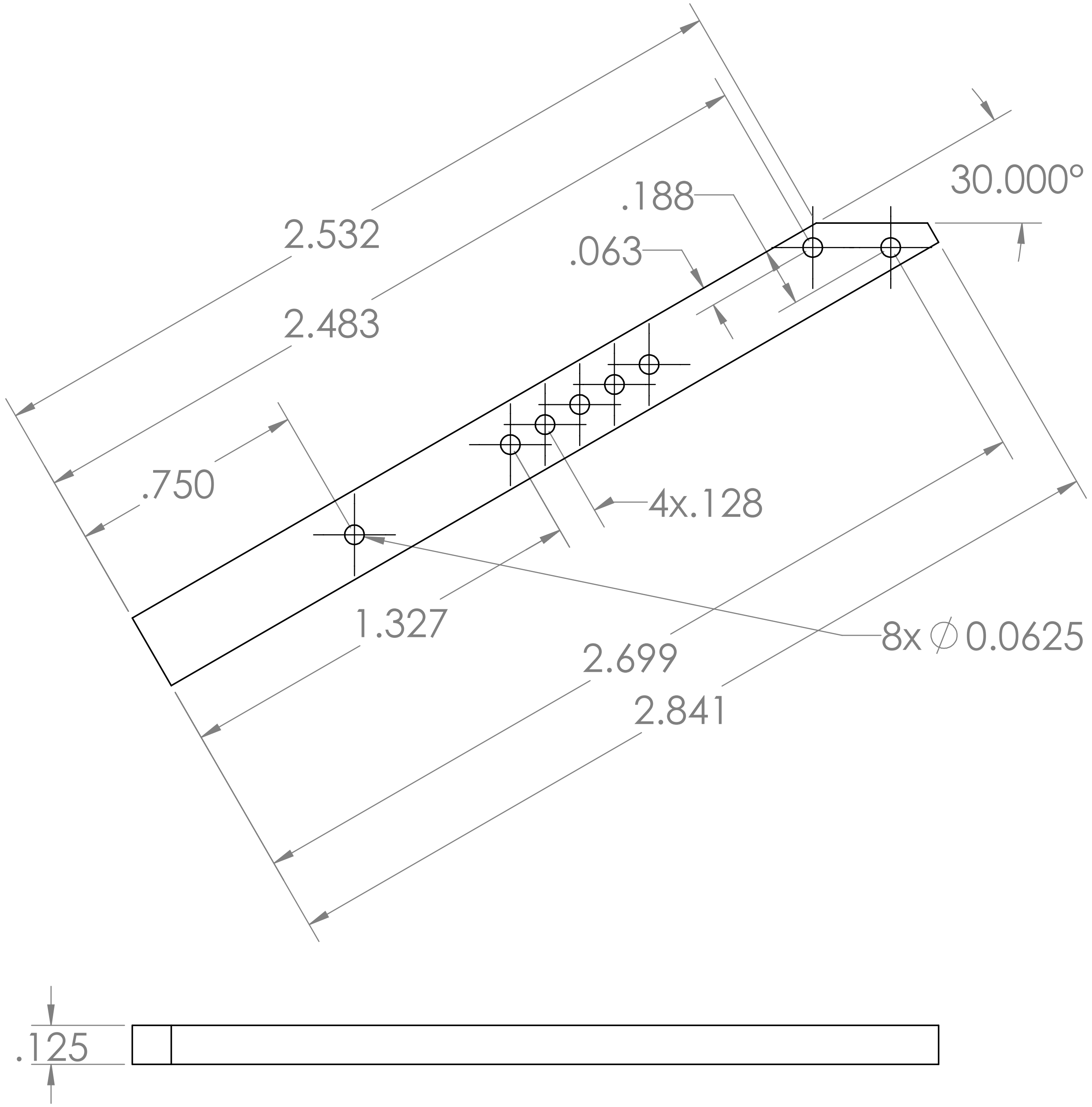
NOTES:

1. Unless otherwise specified, dimensions are in inches.
2. Material: 6061 Aluminum
3. Manufacturing Process: Mill
4. Tolerances to ±0.001





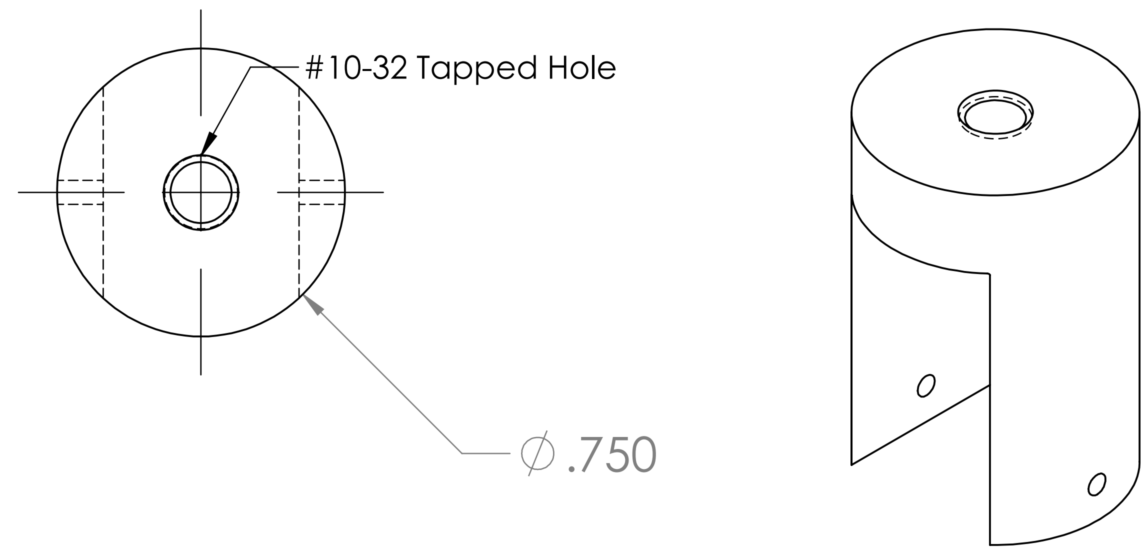
Cal Poly Mechanical Engineering	Lab Section: 04	Overall System	Title: CLAMP GRIP	Drwn. By: BRANDON STELL
ME 429 - Spring 2016	Dwg. #: PLX-003	Nxt Asb: PLX-004	Date: 05/03/2016 Scale: 4:1	Chkd. By: TYLER PRICE



NOTES:

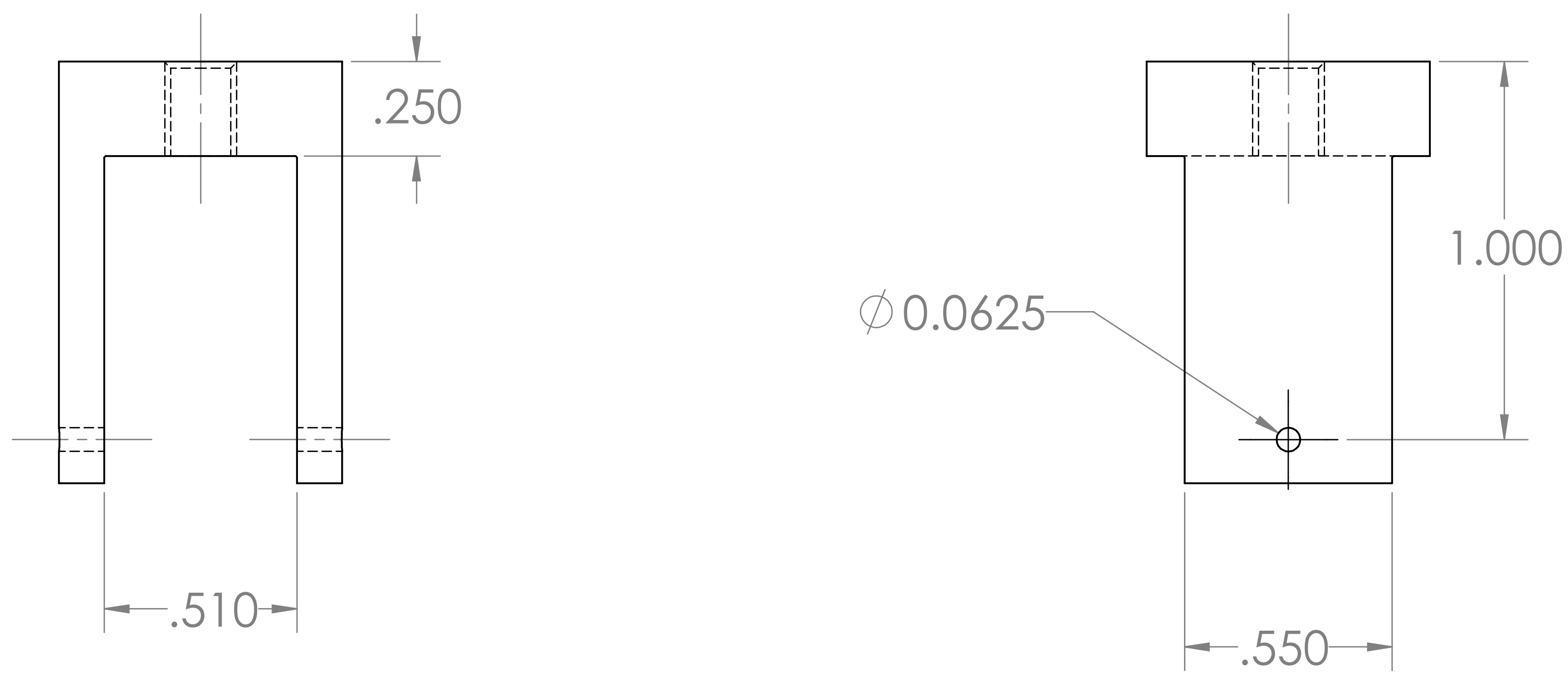
1. UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES.
2. MATERIAL: 6061 ALUMINUM
3. MANUFACTURING PROCESS: MILL
4. TOLERANCES TO ±0.001

Cal Poly Mechanical Engineering	Lab Section: 04	OVERALL SYSTEM	Title: CLAMP ARM		Drwn. By: BRANDON STELL
ME 429 - Spring 2016	Dwg. #: PLX-004	Nxt Asb: PLX-005	Date: 05/03/2016	Scale: 2:1	Chkd. By: TYLER PRICE



NOTES:

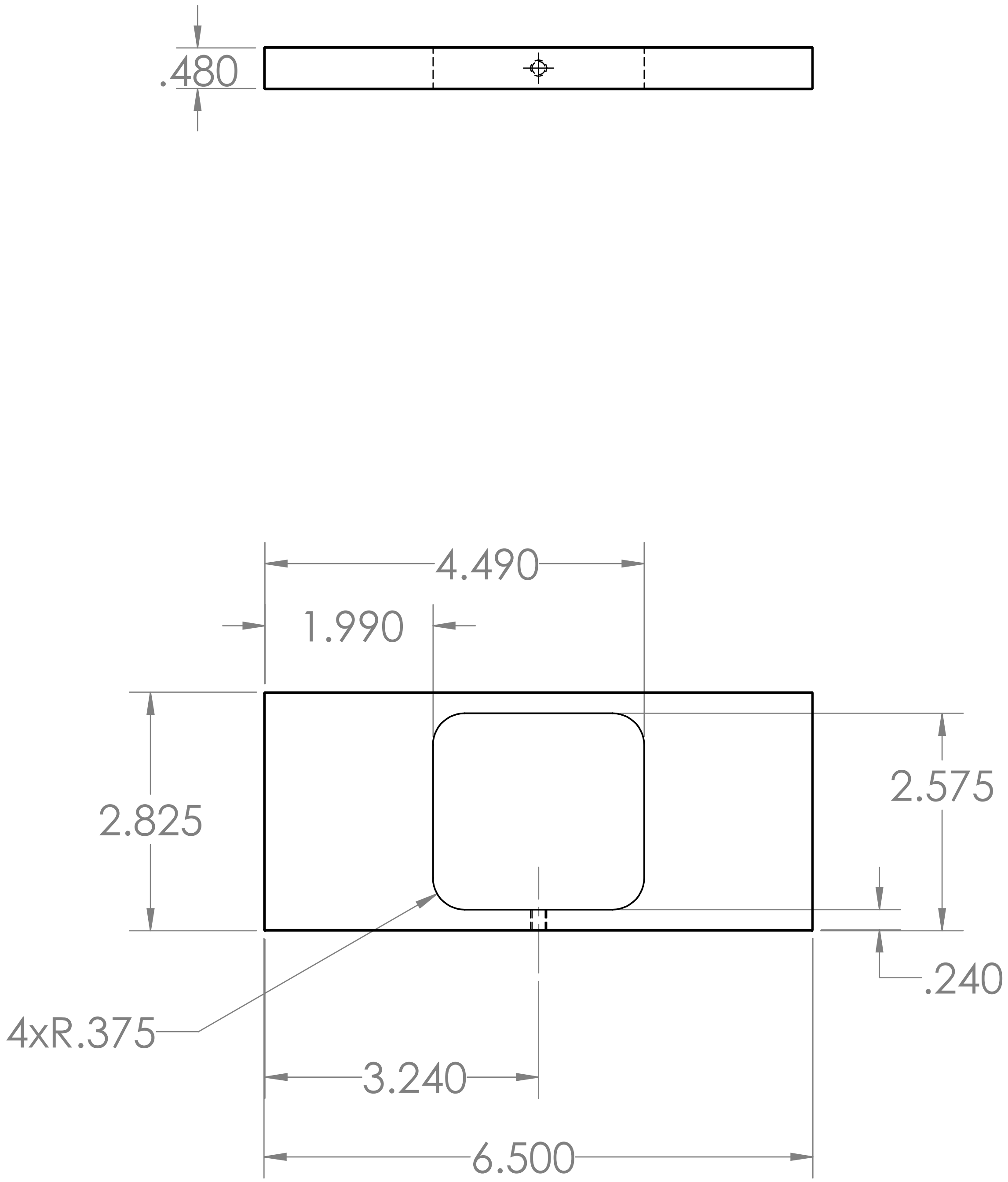
1. UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES.
2. MATERIAL: 6061 ALUMINUM
3. MANUFACTURING PROCESS: MILL
4. TOLERANCES TO ±0.001

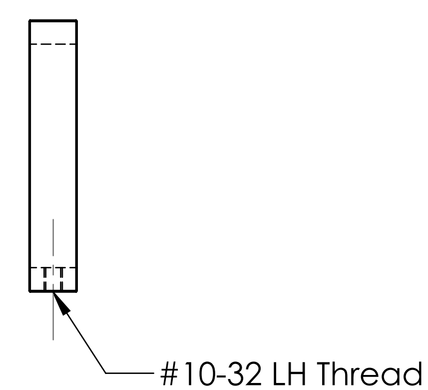


Cal Poly Mechanical Engineering ME 429 - Spring 2016	Lab Section: 04	OVERALL SYSTEM	Title: TOP CLAMP CLEVIS	Drwn. By: BRANDON STELL
	Dwg. #: PLX-005	Nxt Asb: PLX-006	Date: 05/03/2016 | Scale: 2:1	Chkd. By: TYLER PRICE

NOTES:

1. UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES.
2. MATERIAL: 6061 ALUMINUM
3. MANUFACTURING PROCESS: MILL
4. TOLERANCES TO ±0.001

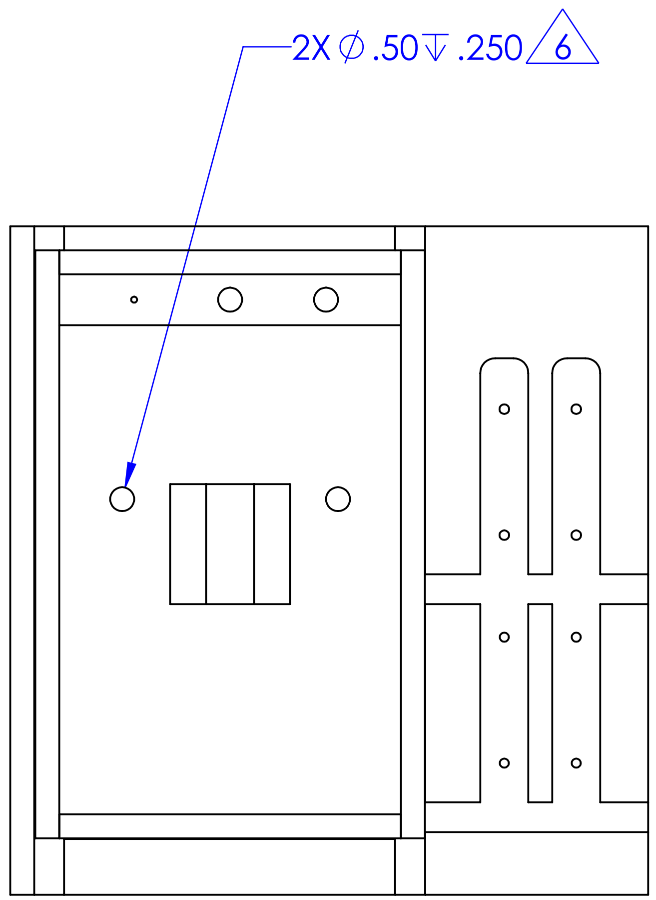


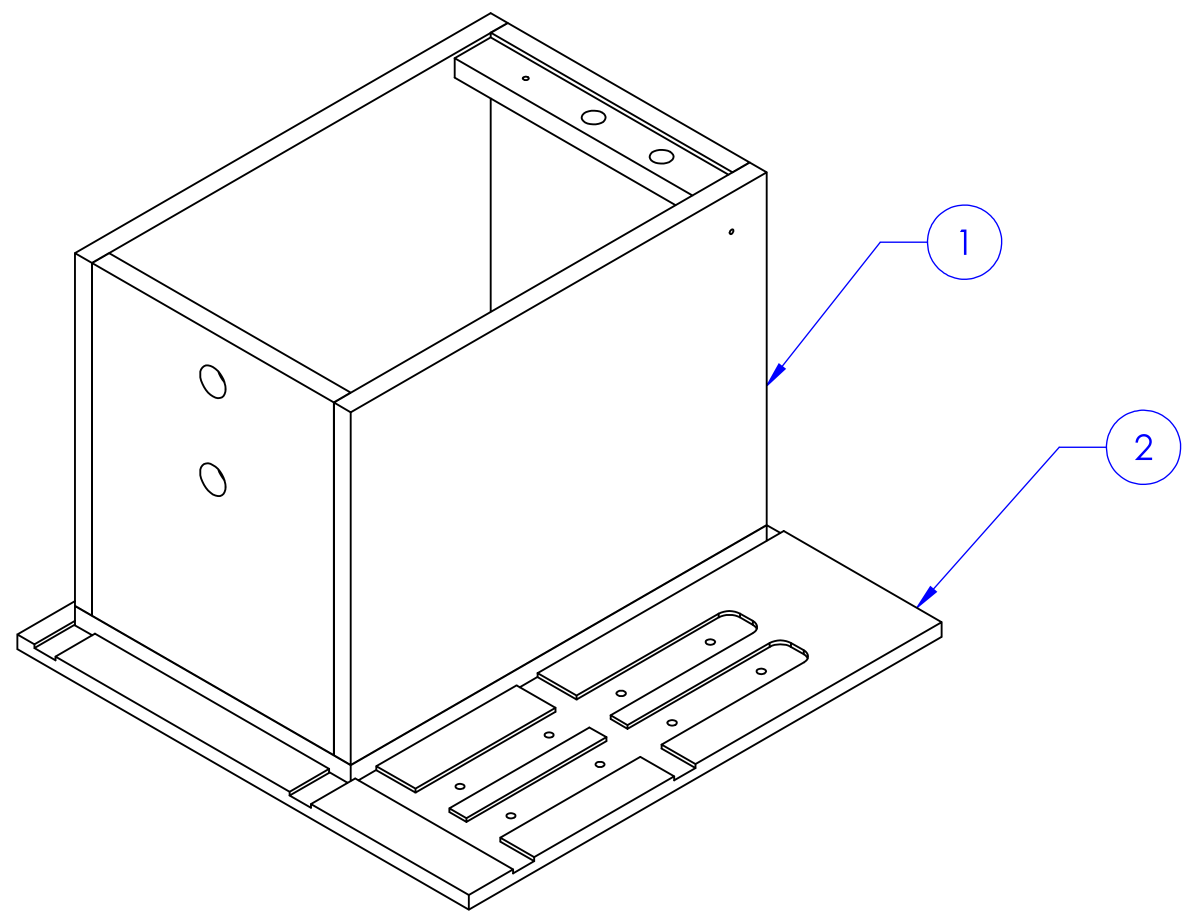


Cal Poly Mechanical Engineering	Lab Section: 04	OVERALL SYSTEM	Title: FOLLOWER	Drwn. By: BRANDON STELL
ME 429 - Spring 2016	Dwg. #: PLX-006	Nxt Asb: PLX-007	Date: 05/03/2016 Scale: 2:1	Chkd. By: TYLER PRICE

NOTES:
UNLESS OTHERWISE SPECIFIED
1. ALL DIMENSIONS ARE IN INCHES.
2. REMOVE ALL BURRS AND BREAK ALL SHARP EDGES TO 0.015 MAXIMUM.
3. MATERIAL: 6061 ALUMINUM
4. FINISH: AS MACHINED
5. TOLERANCES:
   X.X ±.1
   X.XX ±.01
   X.XXX ±.005
   X° ±2°

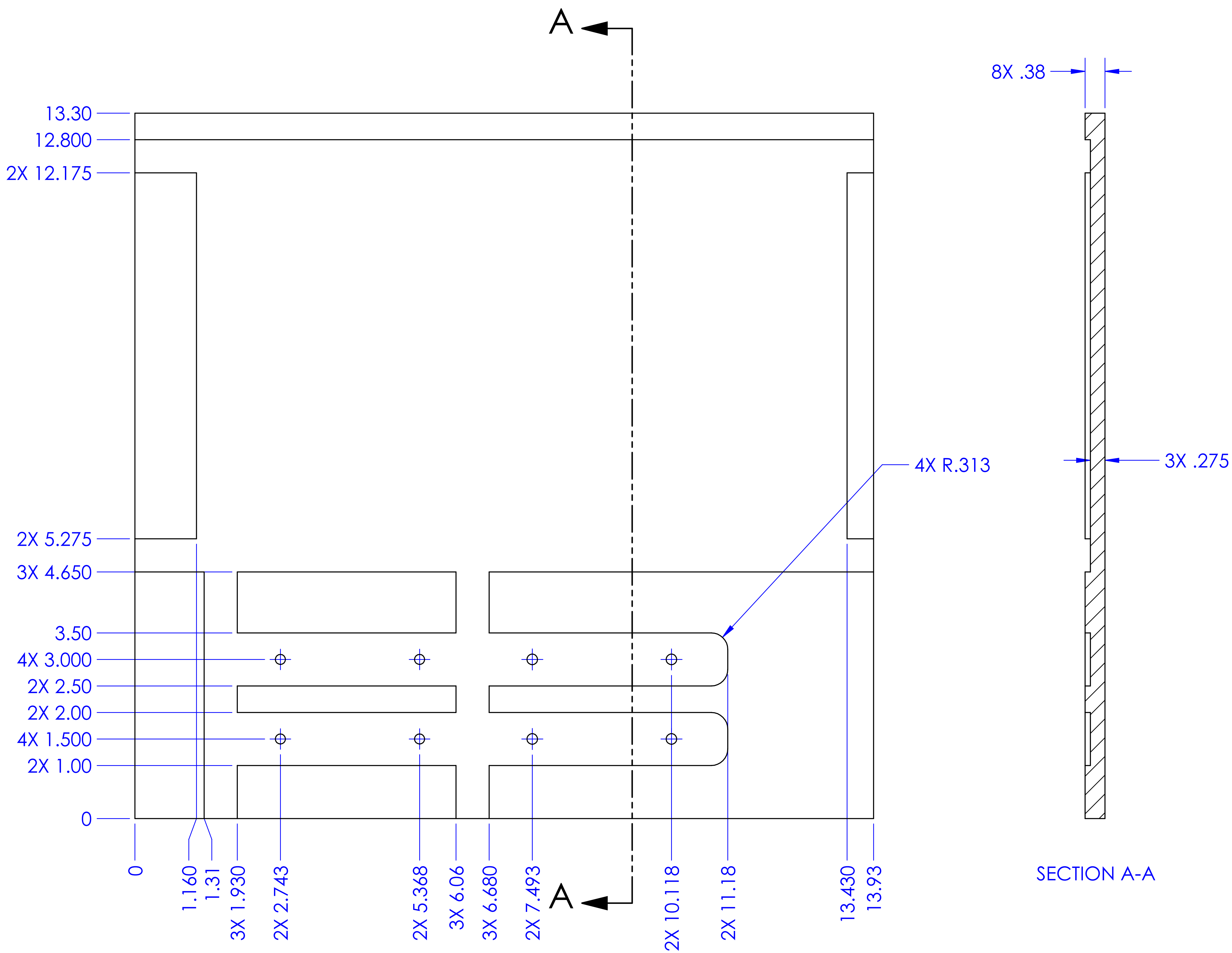
△6 FINAL ASSEMBLY DIMENSION.





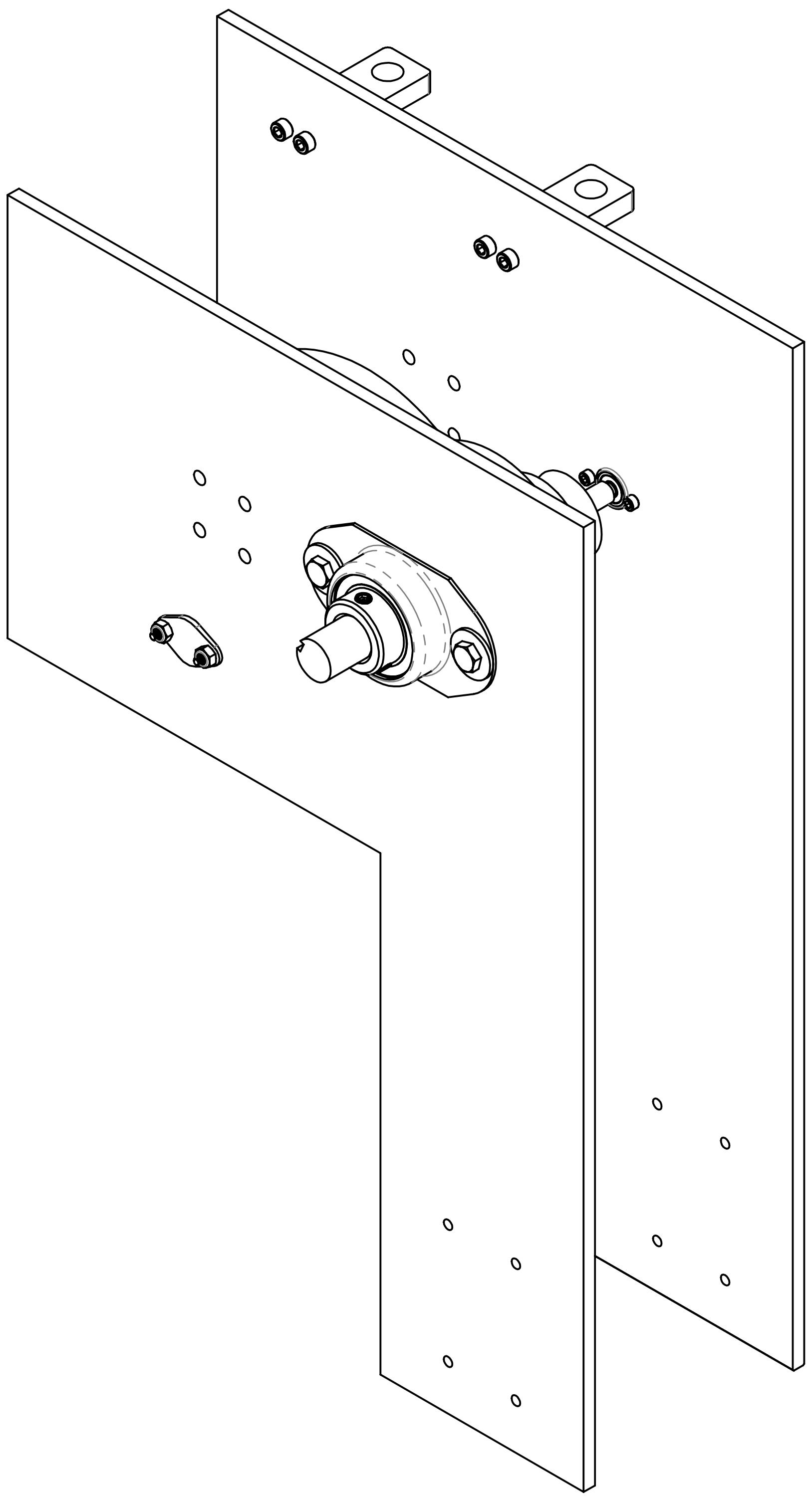
ITEM NO.	PART NO.	DESCRIPTION	MATERIAL	QTY.
1	GIVEN	TANK	SUPPLIED	1
2	TB-001	TANK BASE MOUNT	ALUMINUM 6061	1

POLYLOGIX ME 430 - QTR 3	Title: TANK BASE ASSY	Dwg. #: TB-002		Drwn. By: TYLER PRICE
	Nxt Asb: TANK BASE	Date: 10/16/16	Scale: 1:4	Chkd. By: BRANDON STELL



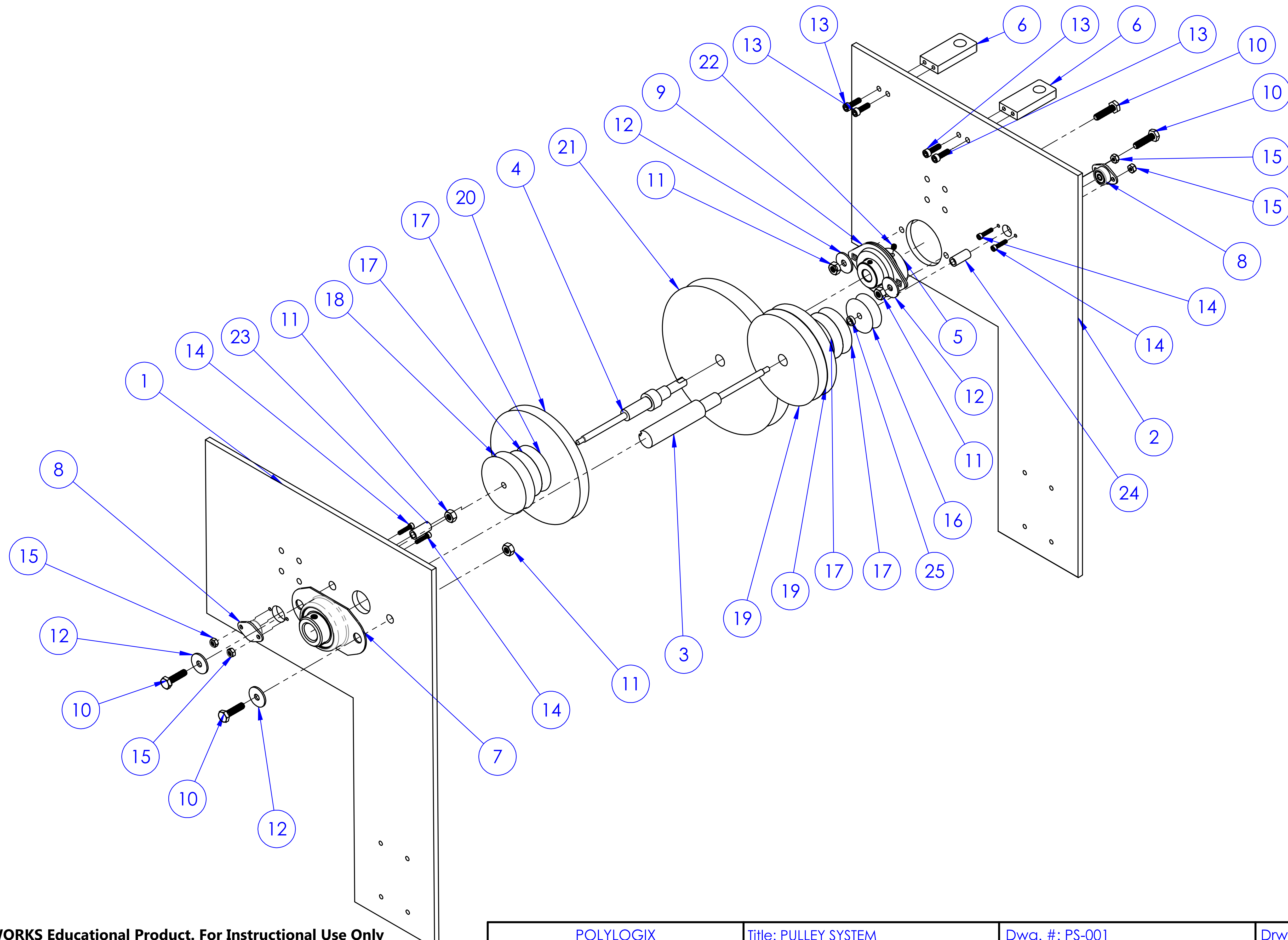
NOTES:
UNLESS OTHERWISE SPECIFIED
1. ALL DIMENSIONS ARE IN INCHES.
2. REMOVE ALL BURRS AND BREAK ALL SHARP EDGES TO 0.015 MAXIMUM.
3. MATERIAL: 6061 ALUMINUM
4. FINISH: AS MACHINED
5. TOLERANCES:
   - X.X $\pm$.1
   - X.XX $\pm$.01
   - X.XXX $\pm$.005
   - X° $\pm$2°

POLYLOGIX ME 430 - QTR 3	Title: TANK BASE PLATE	Dwg. #: TB-001		Drwn. By: TYLER PRICE
	Nxt Asb: TANK BASE	Date: 10/16/16	Scale: 1:2	Chkd. By: BRANDON STELL



ITEM NO.	PART NO.	DESCRIPTION	MATERIAL	QTY.
1	PS-002	MOTOR SIDE PLATE	6061-T6 (MCMASTER-CARR)	1
2	PS-003	TANK SIDE PLATE	6061-T6 (MCMASTER-CARR)	1
3	PS-004	MOTOR SHAFT	6061-T6 (MCMASTER-CARR)	1
4	PS-005	CAM SHAFT	6061-T6 (MCMASTER-CARR)	1
5	PS-006	CAM	6061-T6 (MCMASTER-CARR)	1
6	PS-007	ROD END CAP	6061-T6 (MCMASTER-CARR)	2
7	PS-008	MOTOR SIDE, MOTOR SHAFT BEARING	MCMASTER-CARR (7208K540)	1
8	PS-009	LIGHT DUTY BALL BEARINGS	MCMASTER-CARR (4575N320)	2
9	PS-010	TANK SIDE, CAM SHAFT BEARING	MCMASTER-CARR (5913K71)	1
10	PS-011	1/4"-20, 1" LONG, 316SS HEX HEAD SCREW	MCMASTER-CARR (93190A542)	4
11	PS-012	1/4"-20, GRADE 8, STEEL HEX NUT	MCMASTER-CARR (90499A029)	4
12	PS-013	1/4" SCREW SIZE, 316SS WASHER	MCMASTER-CARR (91525A119)	4
13	PS-014	10-32, 5/8" LONG, 18-8SS SOCKET HEAD SCREW	MCMASTER-CARR (92196A271)	4
14	PS-015	6-40, 5/8" LONG, 18-8SS SOCKET HEAD SCREW	MCMASTER-CARR (92196A138)	4
15	PS-016	6-40, 18-8SS NYLON INSERT LOCKNUT	MCMASTER-CARR (91831A122)	4
16	PS-017	POLY HI SOLIDUR, 1/4" BORE, 1.5" OD ROUND BELT PULLEY	MSC INDUSTRIAL SUPPLY CO. (35414267)	1
17	PS-018	POLY HI SOLIDUR, 1/4" BORE, 2" OD ROUND BELT PULLEY	MSC INDUSTRIAL SUPPLY CO. (35414275)	4
18	PS-019	POLY HI SOLIDUR, 1/4" BORE, 2.5" OD ROUND BELT PULLEY	MSC INDUSTRIAL SUPPLY CO. (35414283)	1
19	PS-020	POLY HI SOLIDUR, 1/2" BORE, 4" OD ROUND BELT PULLEY	MSC INDUSTRIAL SUPPLY CO. (35414317)	2
20	PS-021	POLY HI SOLIDUR, 1/2" BORE, 5" OD ROUND BELT PULLEY	MSC INDUSTRIAL SUPPLY CO. (35414333)	1
21	PS-022	POLY HI SOLIDUR, 1/2" BORE, 7.5" OD ROUND BELT PULLEY	MSC INDUSTRIAL SUPPLY CO. (35576297)	1
22	PS-023	10-32, 3/16" LONG, 18-8SS CUP POINT SET SCREW	MCMASTER-CARR (92311A424)	1
23	PS-024	PULLEY SPACER 0.25" ID, 0.375" OD, 0.86" LENGTH	6061-T6 (MCMASTER-CARR)	1
24	PS-025	PULLEY SPACER 0.25" ID, 0.375" OD, 0.83" LENGTH	6061-T6 (MCMASTER-CARR)	1
25	PS-026	PULLEY SPACER 0.25" ID, 0.375" OD, 0.125" LENGTH	6061-T6 (MCMASTER-CARR)	1

POLYLOGIX ME 430 - QTR 3	Title: PULLEY SYSTEM	Dwg. #: PS-001		Drwn. By: BRANDON STELL	SHEET: 1 of 2
	Nxt Asb: PLX-001	Date: 12/10/16	Scale: 1:3	Chkd. By: TYLER PRICE	



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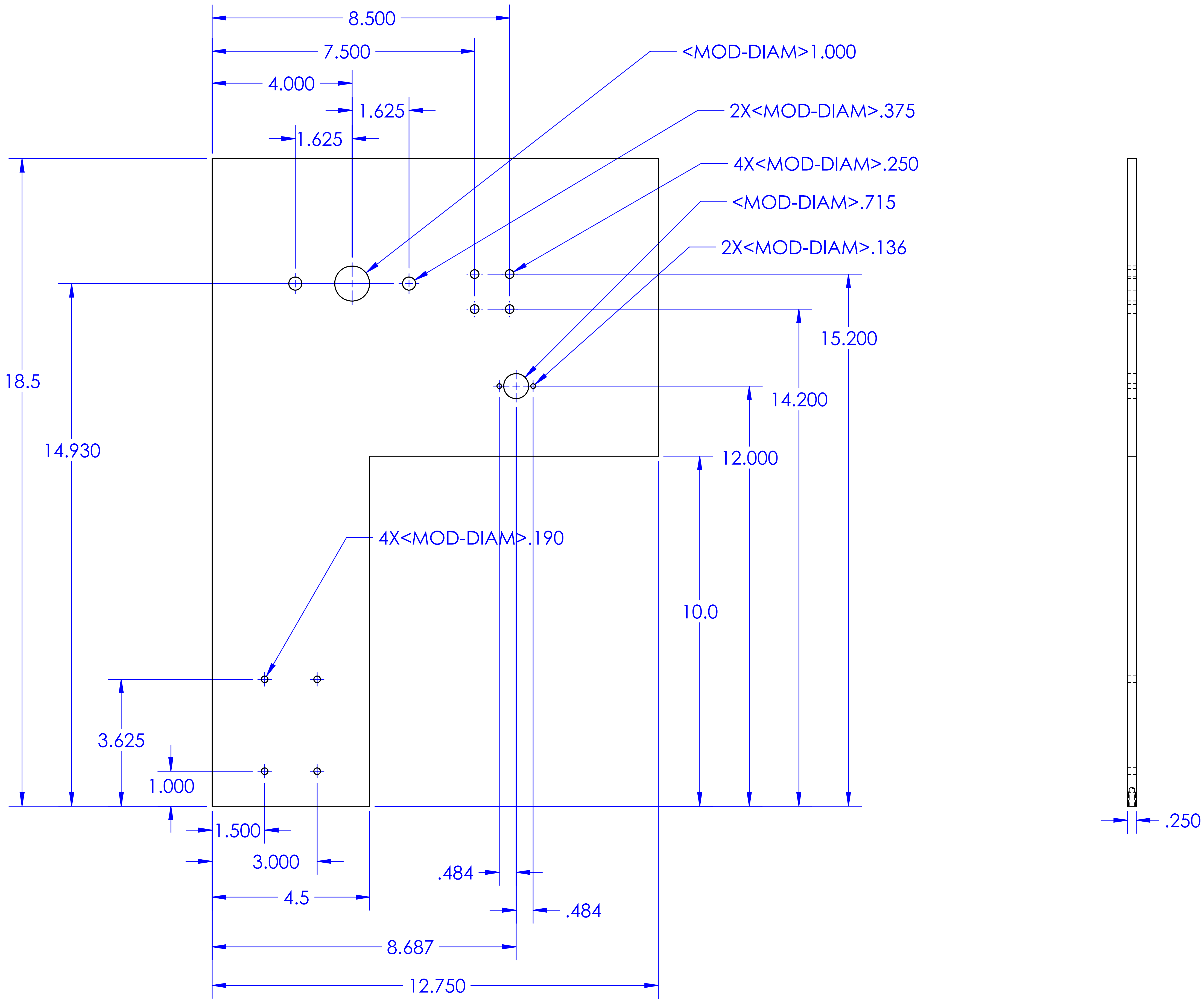
POLYLOGIX ME 430 - QTR 3	Title: PULLEY SYSTEM	Dwg. #: PS-001	Drwn. By: BRANDON STELL	SHEET: 2 of 2
	Nxt Asb: PLX-001	Date: 12/10/16 Scale: 1:3	Chkd. By: TYLER PRICE	



NOTES:
UNLESS OTHERWISE SPECIFIED
1. ALL DIMENSIONS ARE IN INCHES.
2. REMOVE ALL BURRS AND BREAK ALL SHARP EDGES TO 0.015 MAXIMUM.
3. MATERIAL: 6061 ALUMINUM
4. FINISH: AS MACHINED
5. TOLERANCES:
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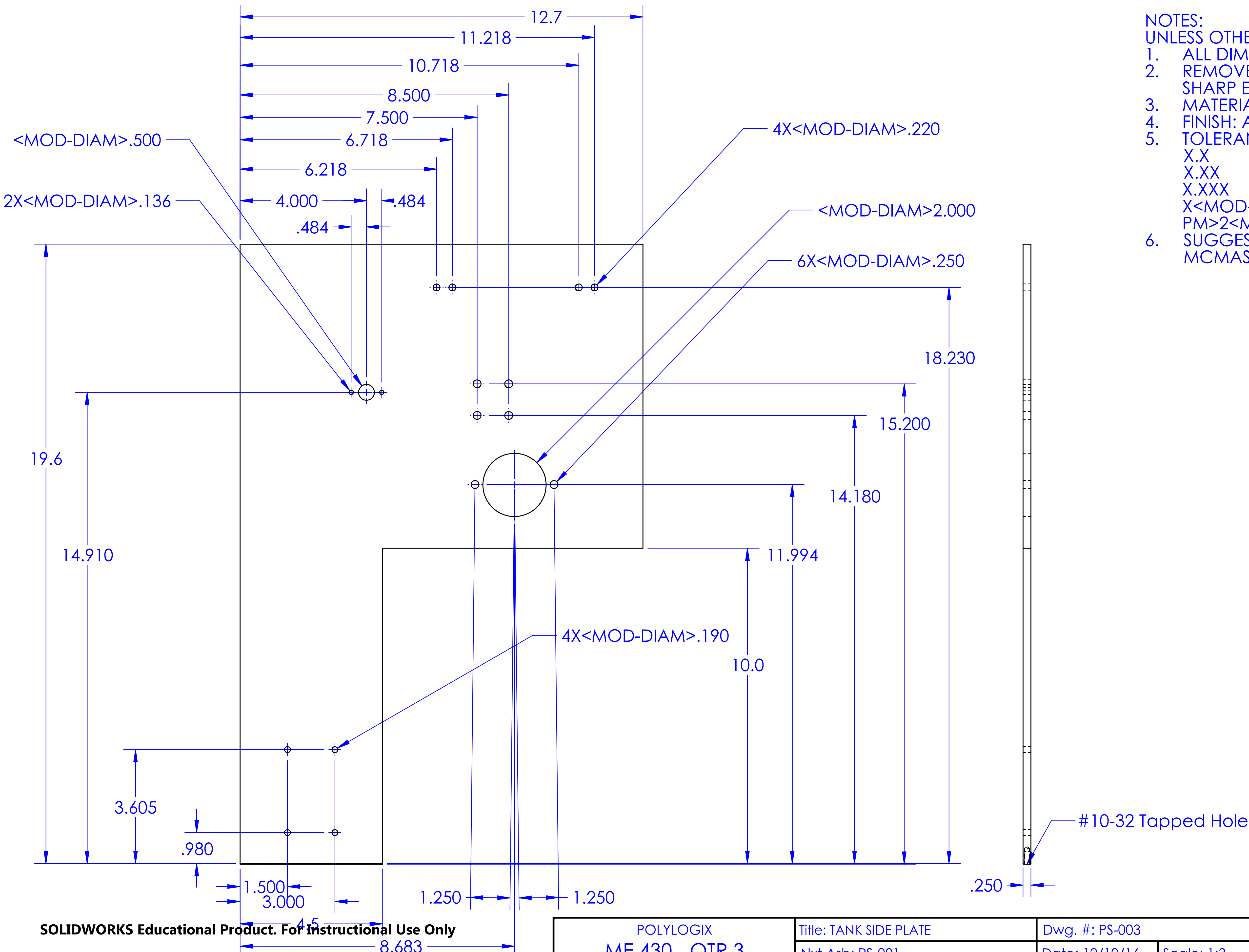
   X.XX <MOD-PM>.01
   X.XXX <MOD-PM>.005
   X<MOD-DEG> <MOD-PM>2<MOD-DEG>
6. SUGGESTED SOURCE OF SUPPLY: MCMASTER-CARR

POLYLOGIX	Title: MOTOR SIDE PLATE	Dwg. #: PS-002		Drwn. By: BRANDON STELL
ME 430 - QTR 3	Nxt Asb: PS-001	Date: 12/10/16	Scale: 1:3	Chkd. By: TYLER PRICE



NOTES:
UNLESS OTHERWISE SPECIFIED
1. ALL DIMENSIONS ARE IN INCHES.
2. REMOVE ALL BURRS AND BREAK ALL SHARP EDGES TO 0.015 MAXIMUM.
3. MATERIAL: 6061 ALUMINUM
4. FINISH: AS MACHINED
5. TOLERANCES:
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   X.XX <MOD-PM>.01
   X.XXX <MOD-PM>.005
   X<MOD-DEG> <MOD-PM>2<MOD-DEG>
6. SUGGESTED SOURCE OF SUPPLY: MCMASTER-CARR

POLYLOGIX ME 430 - QTR 3	Title: TANK SIDE PLATE	Dwg. #: PS-003	Drwn. By: BRANDON STELL
	Nxt Asb: PS-001	Date: 12/10/16 / Scale: 1:3	Chkd. By: TYLER PRICE

NOTES:
UNLESS OTHERWISE SPECIFIED
1. ALL DIMENSIONS ARE IN INCHES.
2. REMOVE ALL BURRS AND BREAK ALL SHARP EDGES TO 0.015 MAXIMUM.
3. MATERIAL: 6061 ALUMINUM
4. FINISH: AS MACHINED
5. TOLERANCES:
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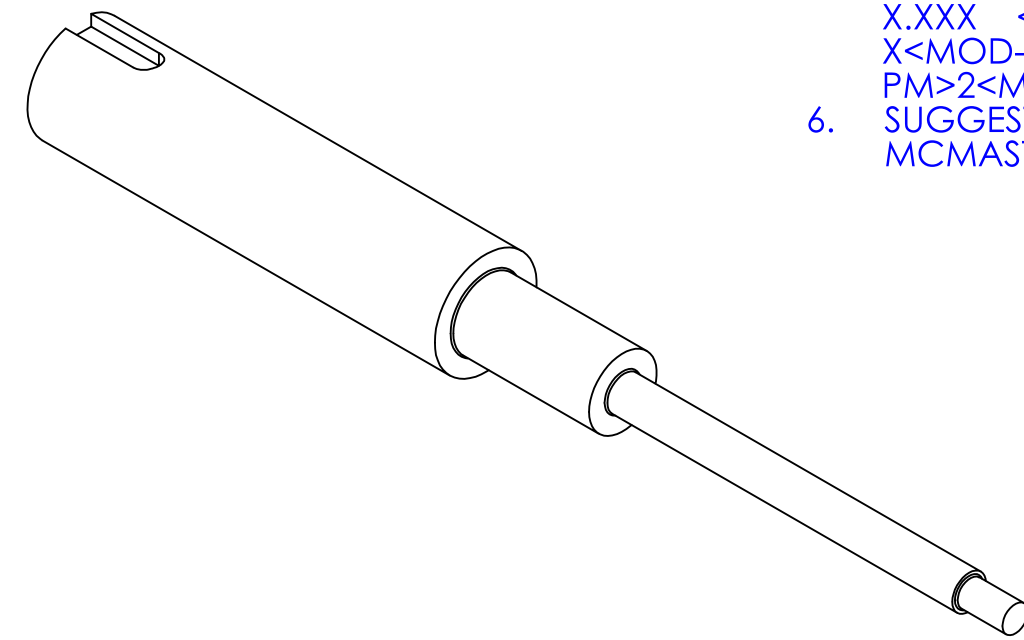
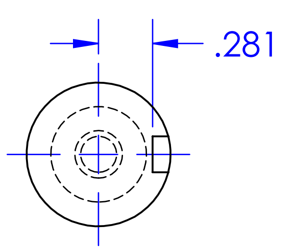
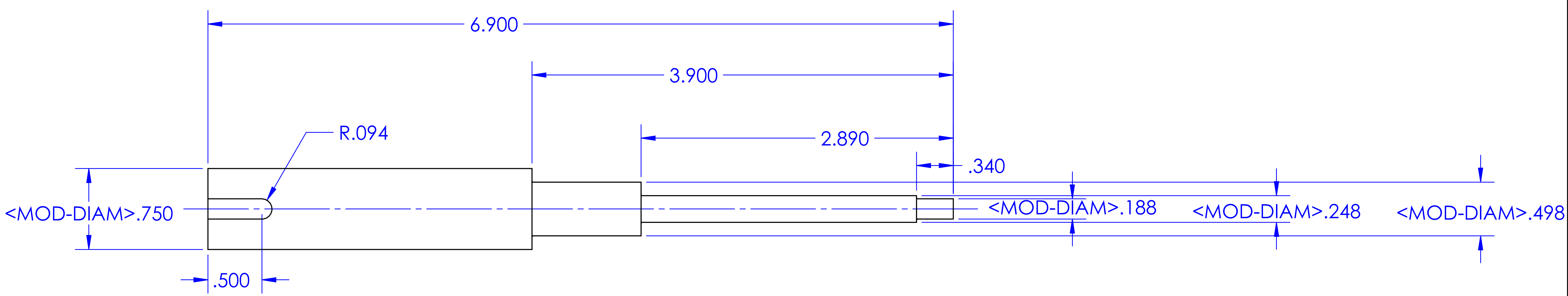
   X.XX <MOD-PM>.01
   X.XXX <MOD-PM>.005
   X<MOD-DEG> <MOD-PM>2<MOD-DEG>
6. SUGGESTED SOURCE OF SUPPLY: MCMASTER-CARR







SOLIDWORKS Educational Product. For Instructional Use Only

POLYLOGIX	Title: MOTOR SHAFT	Dwg. #: PS-004		Drwn. By:BRANDON STELL
ME 430 - QTR 3	Nxt Asb: PS-001	Date: 12/10/16	Scale: 1:1	Chkd. By: TYLER PRICE

NOTES:
UNLESS OTHERWISE SPECIFIED
1. ALL DIMENSIONS ARE IN INCHES.
2. REMOVE ALL BURRS AND BREAK ALL SHARP EDGES TO 0.015 MAXIMUM.
3. MATERIAL: 6061 ALUMINUM
4. FINISH: AS MACHINED
5. TOLERANCES:
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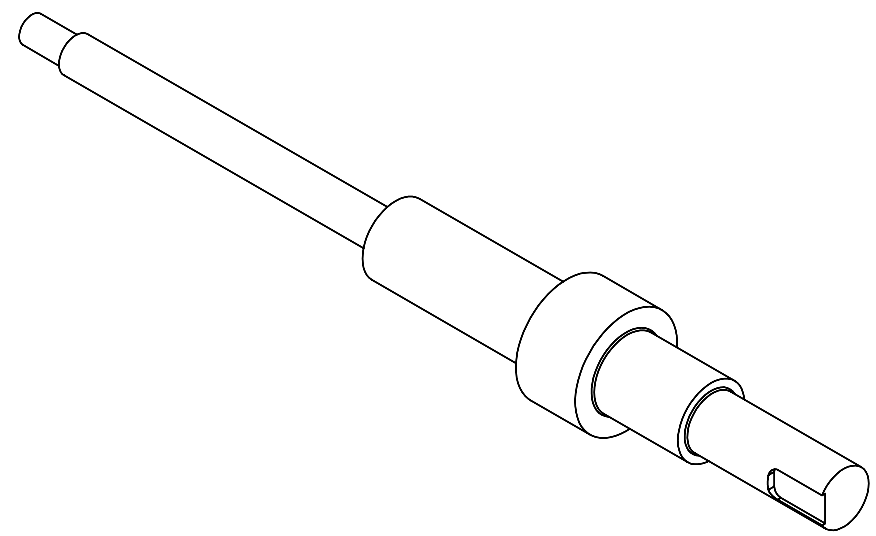
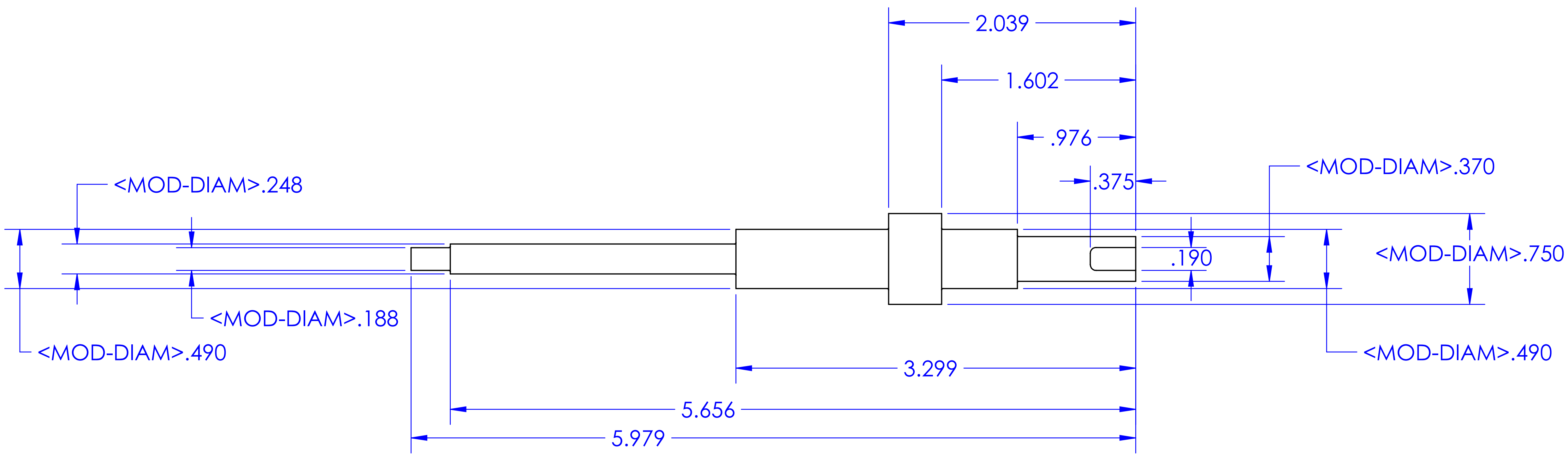
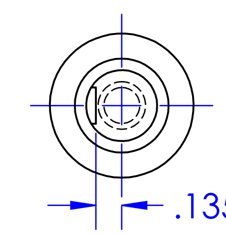
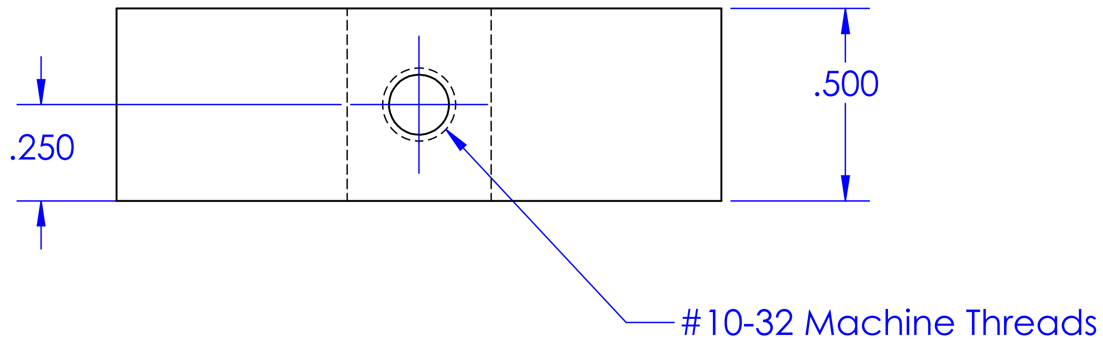


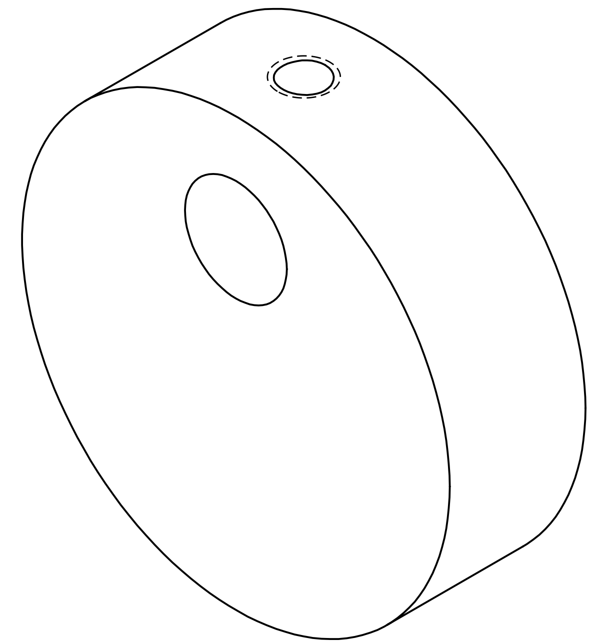




SOLIDWORKS Educational Product. For Instructional Use Only

POLYLOGIX ME 430 - QTR 3	Title: CAM SHAFT	Dwg. #: PS-005		Drwn. By: BRANDON STELL
	Nxt Asb: PS-001	Date: 12/10/16	Scale: 1:1	Chkd. By: TYLER PRICE





NOTES:
UNLESS OTHERWISE SPECIFIED
1. ALL DIMENSIONS ARE IN INCHES.
2. REMOVE ALL BURRS AND BREAK ALL SHARP EDGES TO 0.015 MAXIMUM.
3. MATERIAL: 6061 ALUMINUM
4. FINISH: AS MACHINED
5. TOLERANCES:
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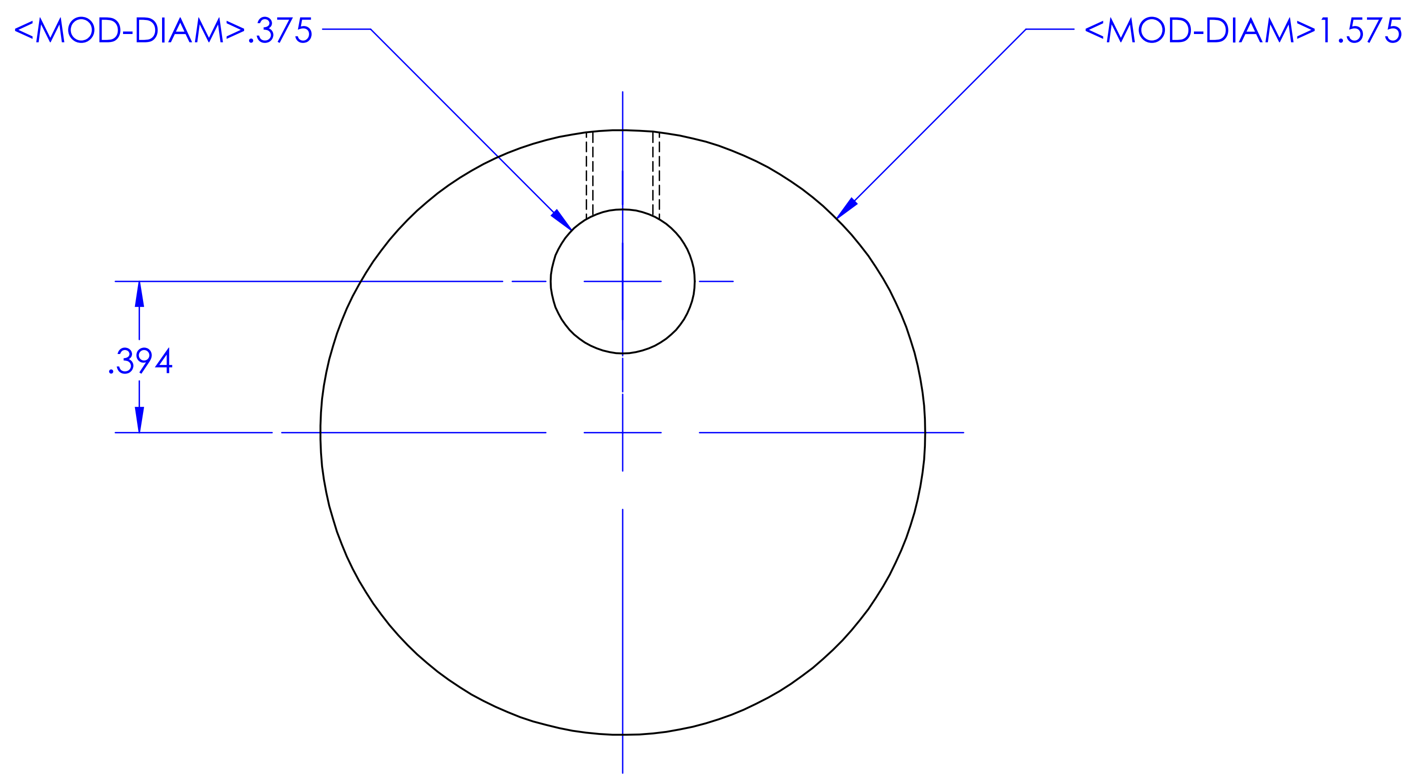
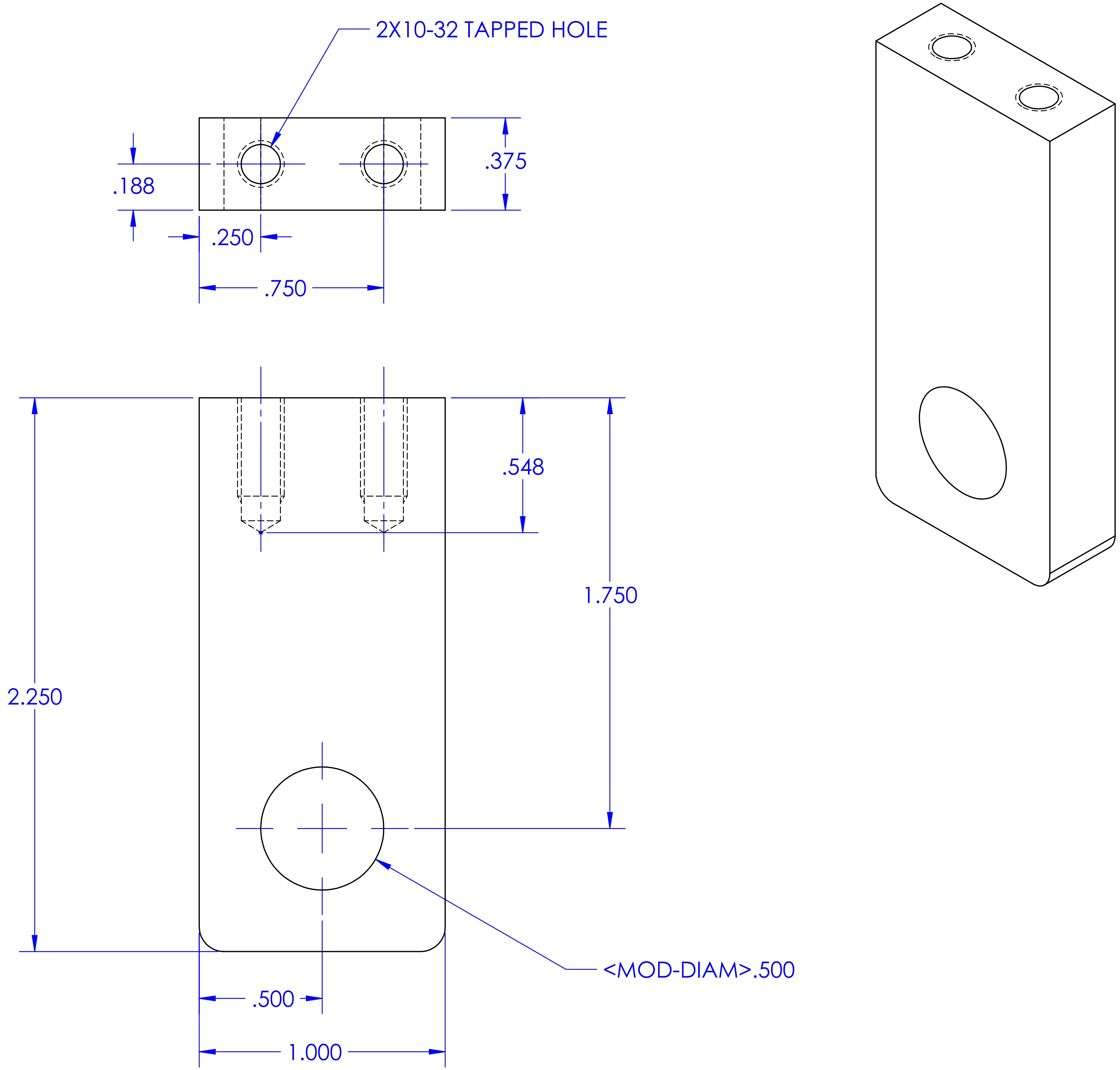
   X.XX <MOD-PM>.01
   X.XXX <MOD-PM>.005
   X<MOD-DEG> <MOD-PM>2<MOD-DEG>
6. SUGGESTED SOURCE OF SUPPLY: MCMASTER-CARR



POLYLOGIX ME 430 - QTR 3	Title: CAM	Dwg. #: PS-006	Drwn. By: BRANDON STELL
	Nxt Asb: PS-001	Date: 12/10/16	Scale: 2:1	Chkd. By: TYLER PRICE



NOTES:
UNLESS OTHERWISE SPECIFIED
1. ALL DIMENSIONS ARE IN INCHES.
2. REMOVE ALL BURRS AND BREAK ALL SHARP EDGES TO 0.015 MAXIMUM.
3. MATERIAL: 6061 ALUMINUM
4. FINISH: AS MACHINED
5. TOLERANCES:
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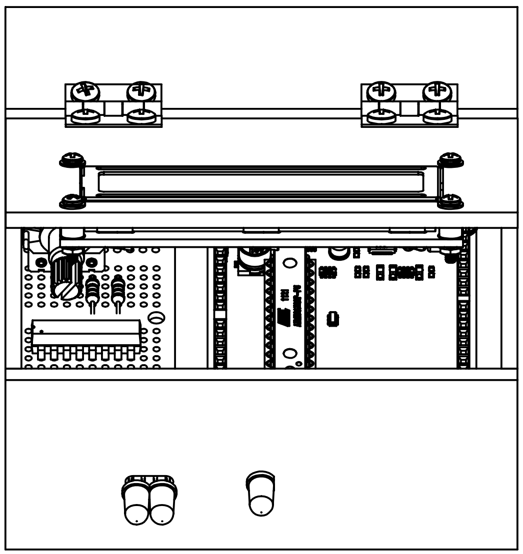
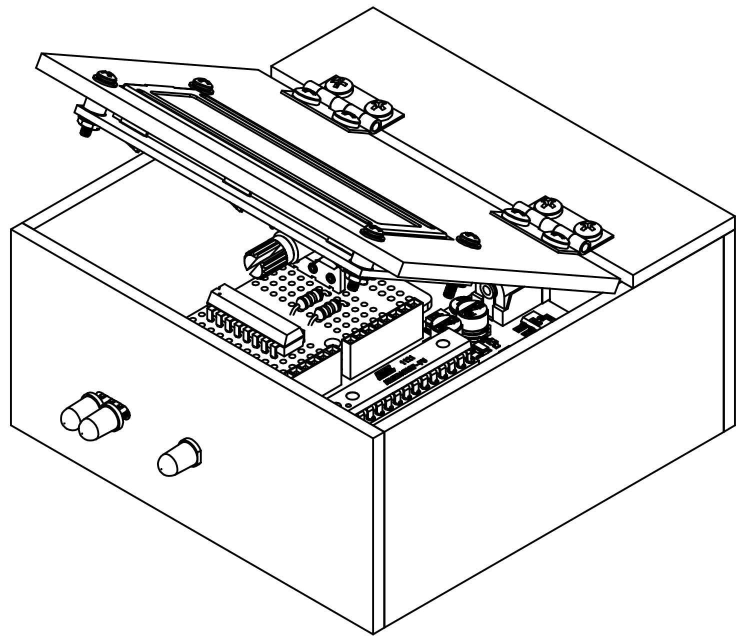
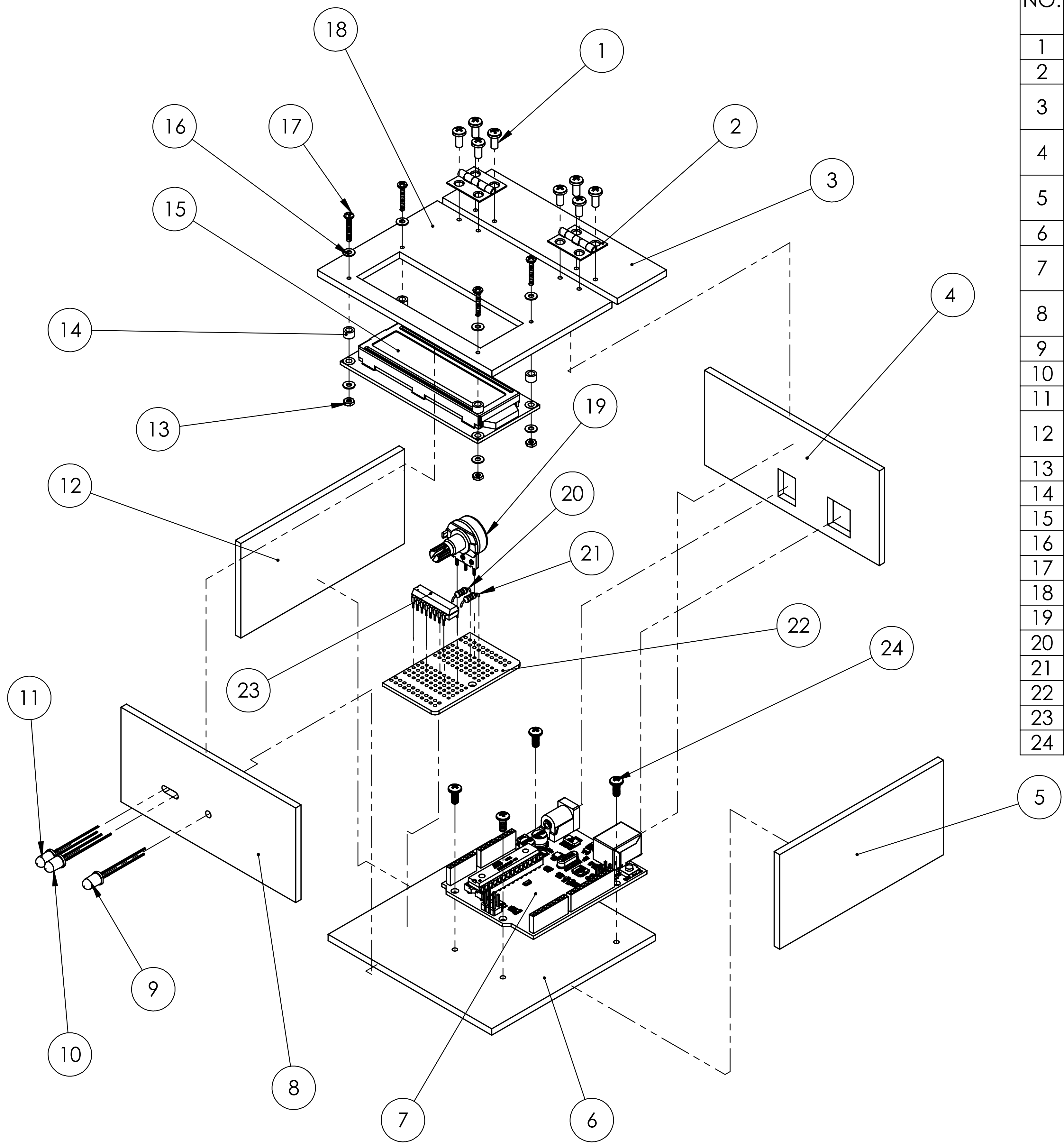
   X.XX <MOD-PM>.01
   X.XXX <MOD-PM>.005
   X<MOD-DEG> <MOD-PM>2<MOD-DEG>
6. SUGGESTED SOURCE OF SUPPLY: MCMASTER-CARR

POLYLOGIX	Title: ROD END CAP	Dwg. #: PS-007		Drwn. By: BRANDON STELL
ME 430 - QTR 3	Nxt Asb: PS-001	Date: 12/10/16	Scale: 2:1	Chkd. By: TYLER PRICE



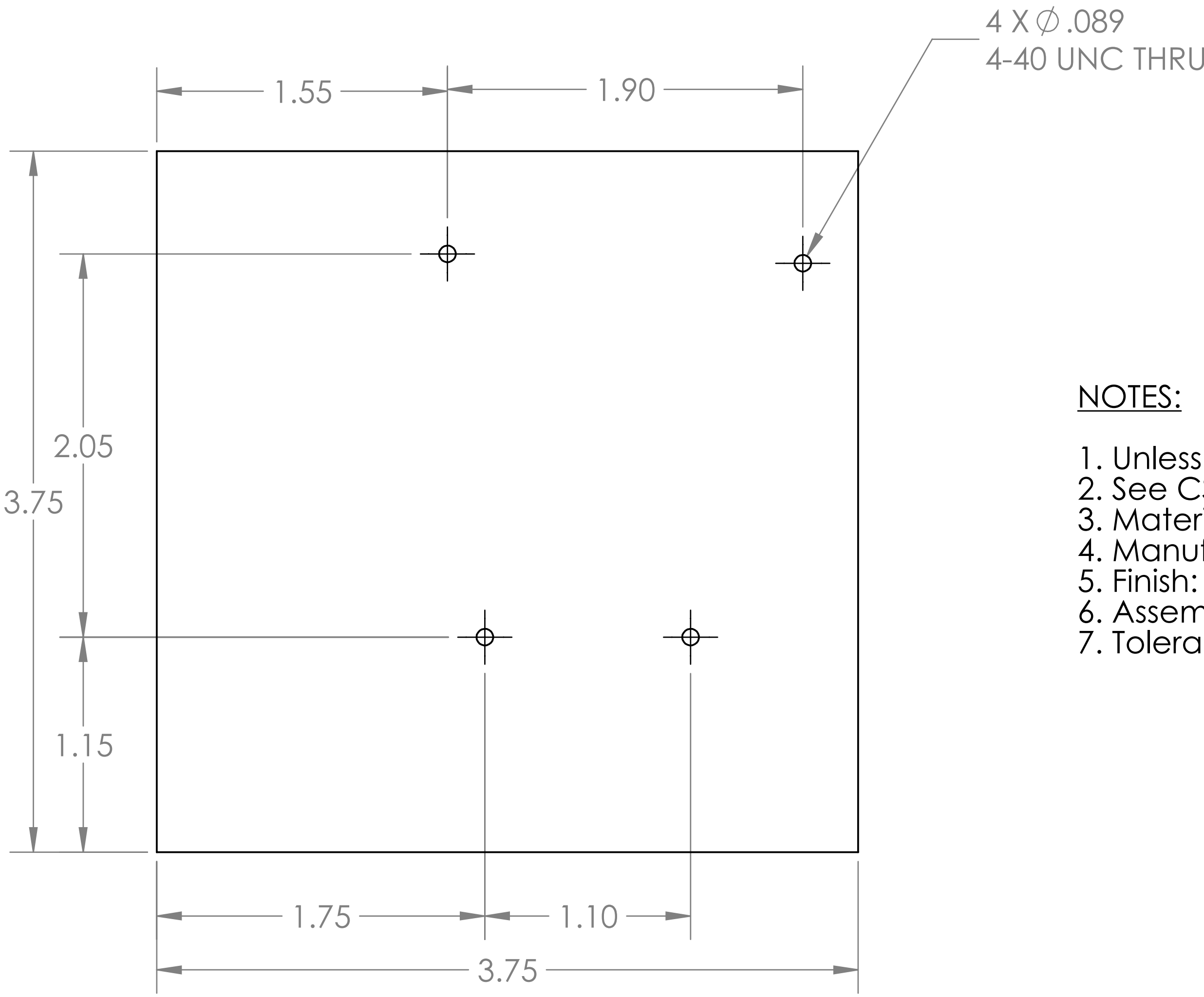


Cal Poly Mechanical Engineering	Lab Section: 04	Controls System	Title: Tachometer		Drwn. By: TYLER PRICE
ME 429 - Spring 2016	Dwg. #: CS-T-001	Nxt Asb: CS-T-002	Date: 05/01/2016	Scale: 2:3	Chkd. By: BRANDON STELL



NO.	PART DESCRIPTION (DRAWING NUMBER)	PART NO.	QTY.	SUPPLIER
1	HINGE SCREWS	92114A077	8	McMASTER-CARR
2	HINGE	1603A2	2	McMASTER-CARR
3	HOUSING, TOP REAR (CS-T-003E)	8560K257	1	McMASTER-CARR
4	HOUSING, ARDUINO PORTS SIDE (CS-T-003B)	8560K257	1	McMASTER-CARR
5	HOUSING, RIGHT PANEL (CS-T-003C)	8560K257	1	McMASTER-CARR
6	HOUSING, BASE (CS-T-003)	8560K257	1	McMASTER-CARR
7	ARDUINO UNO	485-2877	1	MOUSER ELECTRONICS
8	HOUSING, FRONT PANEL (CS-T-003D)	8560K257	1	McMASTER-CARR
9	BLUE 5mm LED	941-C503BBANCY0C0461	1	MOUSER ELECTRONICS
10	INFRADRED PHOTODIODE	720-SFH203FA	1	MOUSER ELECTRONICS
11	INFRARED LED	512-QED123	1	MOUSER ELECTRONICS
12	HOUSING, LEFT PANEL (CS-T-003C)	8560K257	1	McMASTER-CARR
13	LCD MOUNTING NUT	93935A305	4	McMASTER-CARR
14	LCD MOUNTING SPACER	93657A202	4	McMASTER-CARR
15	16 X 2 LCD DISPLAY	485-772	1	MOUSER ELECTRONICS
16	LCD MOUNTING WASHER	90965A110	8	McMASTER-CARR
17	LCD MOUTNING SCREW	90116A022	4	McMASTER-CARR
18	HOUSING, DOOR (CS-T-003F)	8560K257	1	McMASTER-CARR
19	10K POTENTIOMETER	485-562	1	MOUSER ELECTRONICS
20	33kΩ RESISTOR	588-OK3335E-R52	1	MOUSER ELECTRONICS
21	270Ω RESISTOR	588-OD27JE	1	MOUSER ELECTRONICS
22	BREADBOARD	619-700-00012	1	MOUSER ELECTRONICS
23	SN74HC595 SHIFT REGISTER	595-SN74HC595N	1	MOUSER ELECTRONICS
24	ARDUINO MOUNTING SCREW	91772A106	4	McMASTER-CARR

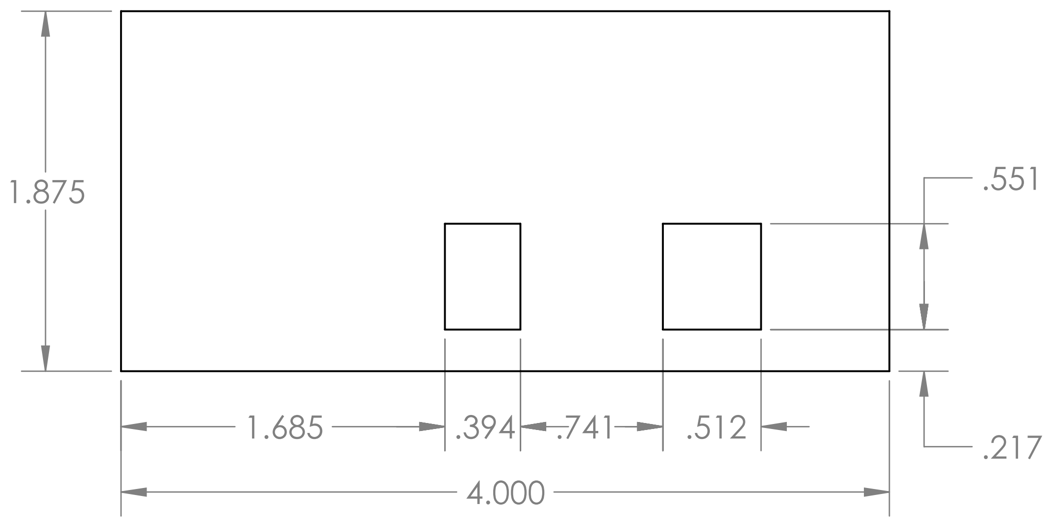
Cal Poly Mechanical Engineering	Lab Section:04	Controls System	Title: Tachometer (Exploded View)		Drwn. By:TYLER PRICE
ME 429 - Spring 2016	Dwg. #: CS-T-002	Nxt Asb:CS-T-003	Date: 05/02/2016	Scale: 1:2	Chkd. By: BRANDON STELL



NOTES:

1. Unless specified, dimensions are in inches.
2. See CS-T-002 for part number and supplier.
3. Material: Acrylic Sheet, 1/8" thick.
4. Manufacturing Process: Laser Cut.
5. Finish: As machined.
6. Assembly: General purpose super-glue.
7. Tolerances to ±0.001in.

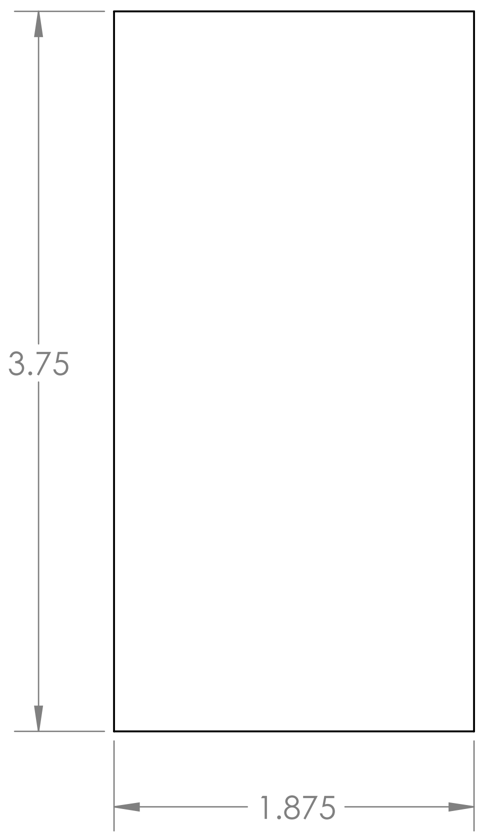
Cal Poly Mechanical Engineering ME 429 - Spring 2016	Lab Section: 04	Controls System	Title: Housing. Base		Drwn. By: TYLER PRICE
	Dwg. #: CS-T-003	Nxt Asb: CS-T-003B	Date: 05/03/2016	Scale: 1:1	Chkd. By: MICHELA UPSON



NOTES:

1. Unless specified, dimensions are in inches.
2. See CS-T-002 for part number and supplier.
3. Material: Acrylic Sheet, 1/8" thick.
4. Manufacturing Process: Laser Cut.
5. Finish: As machined.
6. Assembly: General purpose super-glue.
7. Tolerances to ±0.001in.

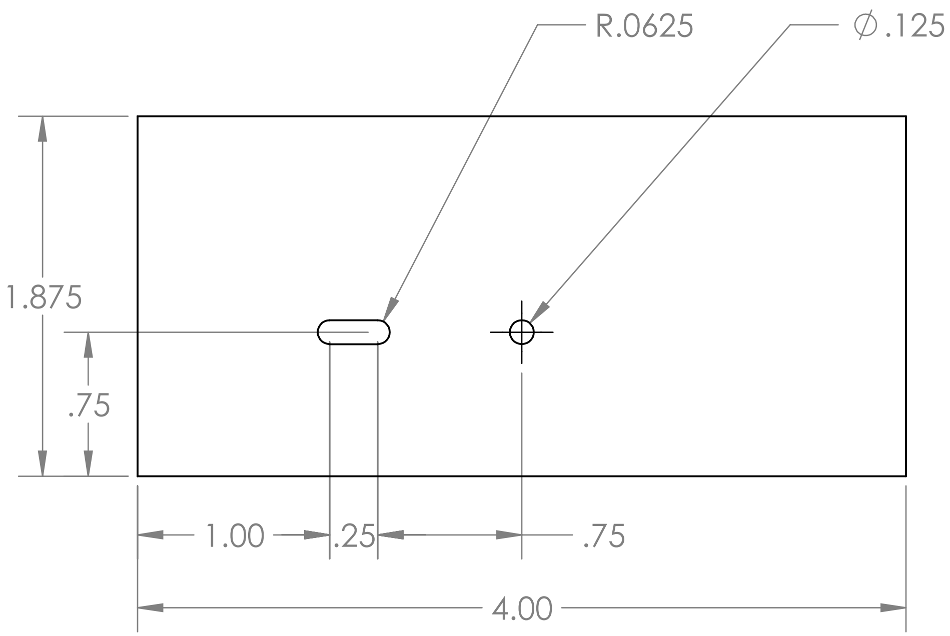
Cal Poly Mechanical Engineering	Lab Section: 04	Controls System	Title: Housing, Arduino Ports Side		Drwn. By: TYLER PRICE
ME 429 - Spring 2016	Dwg. #: CS-T-003B	Nxt Asb:CS-T-003C	Date: 05/03/2016	Scale: 1:1	Chkd. By: MICHELA UPSON



NOTES:

1. Unless specified, dimensions are in inches.
2. See CS-T-002 for part number and supplier.
3. Material: Acrylic Sheet, 1/8" thick.
4. Manufacturing Process: Laser Cut.
5. Finish: As machined.
6. Assembly: General purpose super-glue.
7. Tolerances to ±0.001in.

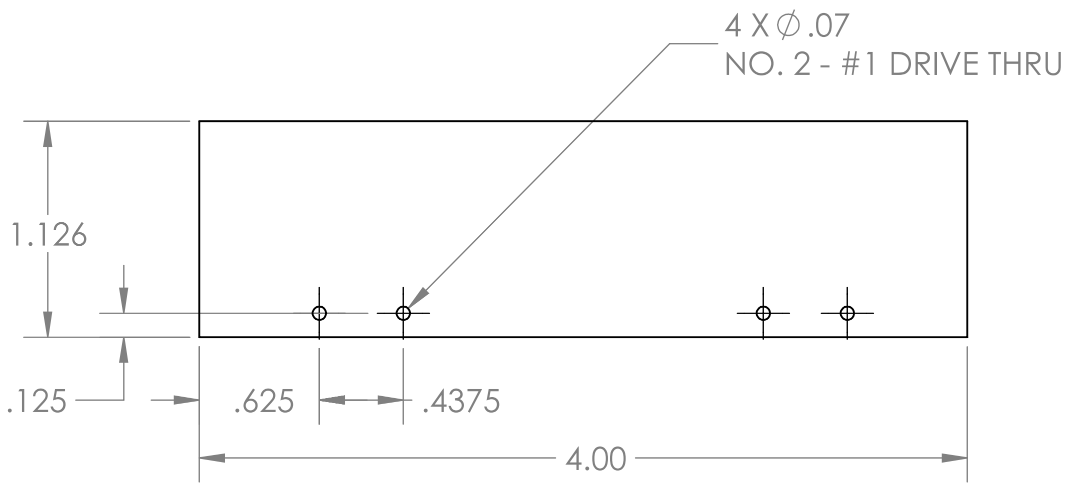
Cal Poly Mechanical Engineering	Lab Section: 04	Controls System	Title: Housing, Left and Right Panel		Drwn. By: TYLER PRICE
ME 429 - Spring 2016	Dwg. #: CS-T-003C	Nxt Asb:CS-T-003D	Date: 05/03/2016	Scale: 1:1	Chkd. By: BRANDON STELL



NOTES:

1. Unless specified, dimensions are in inches.
2. See CS-T-002 for part number and supplier.
3. Material: Acrylic Sheet, 1/8" thick.
4. Manufacturing Process: Laser Cut.
5. Finish: As machined.
6. Assembly: General purpose super-glue.
7. Tolerances to ±0.001in.

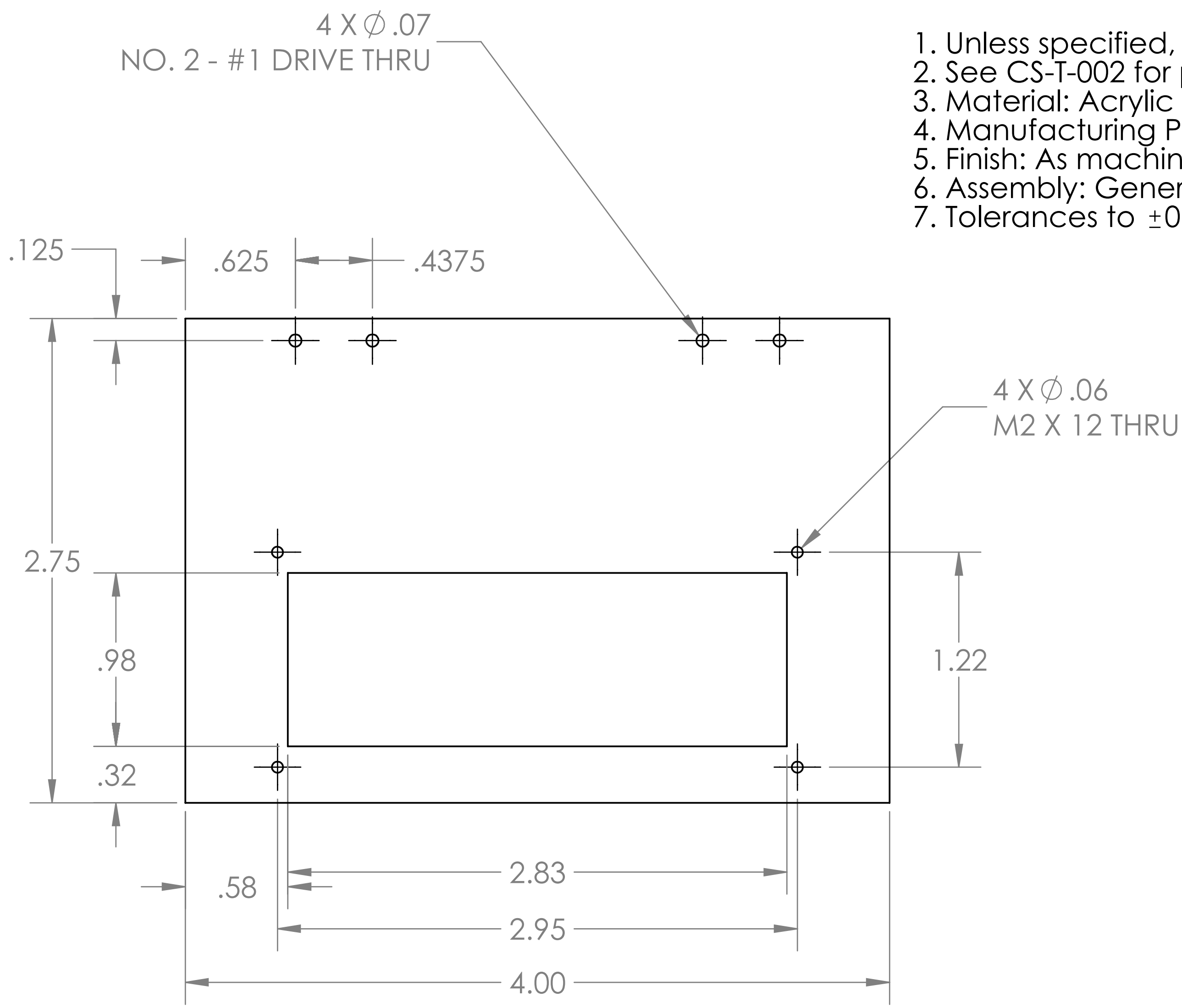
Cal Poly Mechanical Engineering	Lab Section: 04	Controls System	Title: Housing, Front Panel		Drwn. By: TYLER PRICE
ME 429 - Spring 2016	Dwg. #: CS-T-003D	Nxt Asb: CS-T-003E	Date: 05/03/2016	Scale: 1:1	Chkd. By: BRANDON STELL



NOTES:

1. Unless specified, dimensions are in inches.
2. See CS-T-002 for part number and supplier.
3. Material: Acrylic Sheet, 1/8" thick.
4. Manufacturing Process: Laser Cut.
5. Finish: As machined.
6. Assembly: General purpose super-glue.
7. Tolerances to ±0.001in.

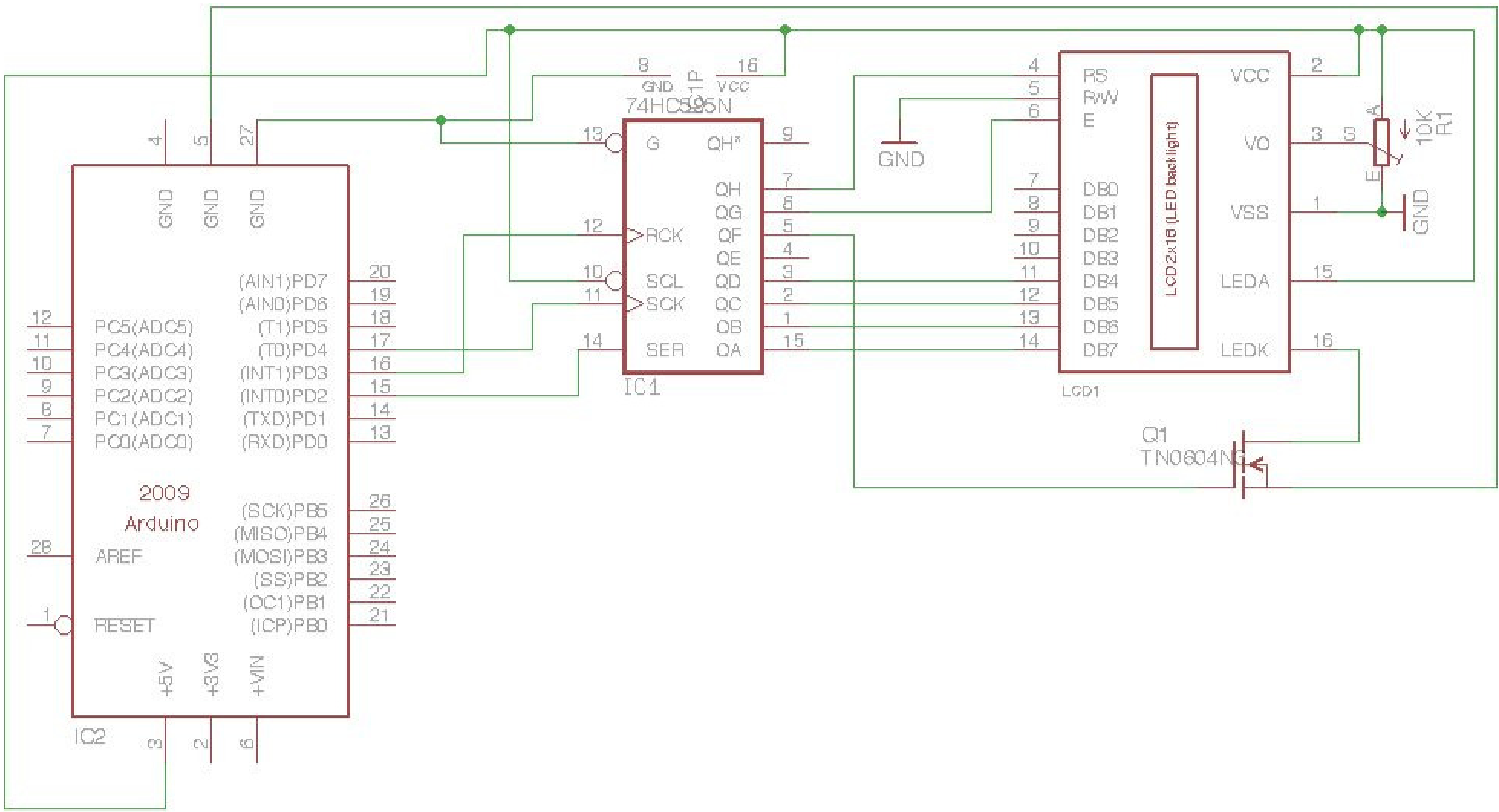
Cal Poly Mechanical Engineering	Lab Section: 04	Controls System	Title: Housing, Top Rear		Drwn. By: TYLER PRICE
ME 429 - Spring 2016	Dwg. #: CS-T-003E	Nxt Asb: CS-T-003F	Date: 05/03/2016	Scale: 1:1	Chkd. By: BRANDON STELL



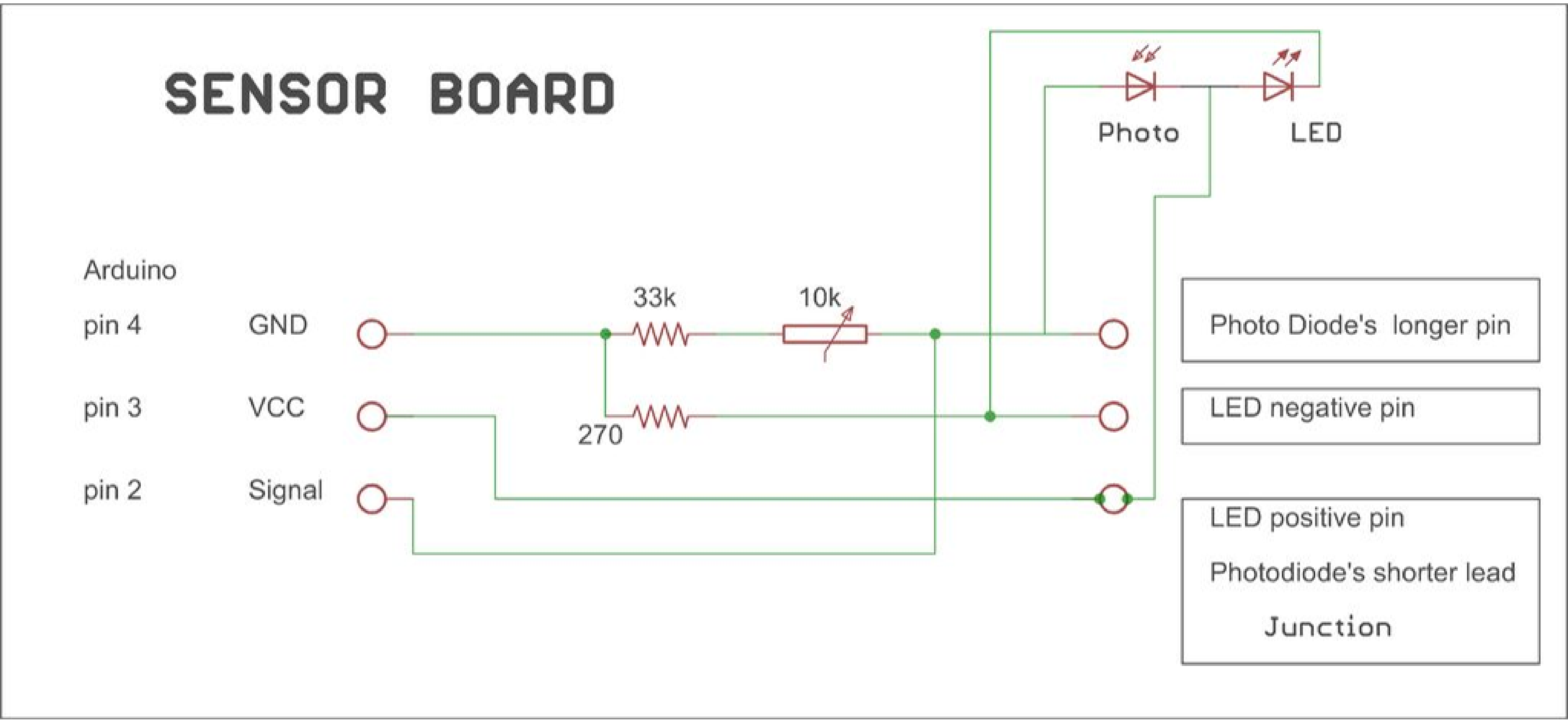
NOTES:

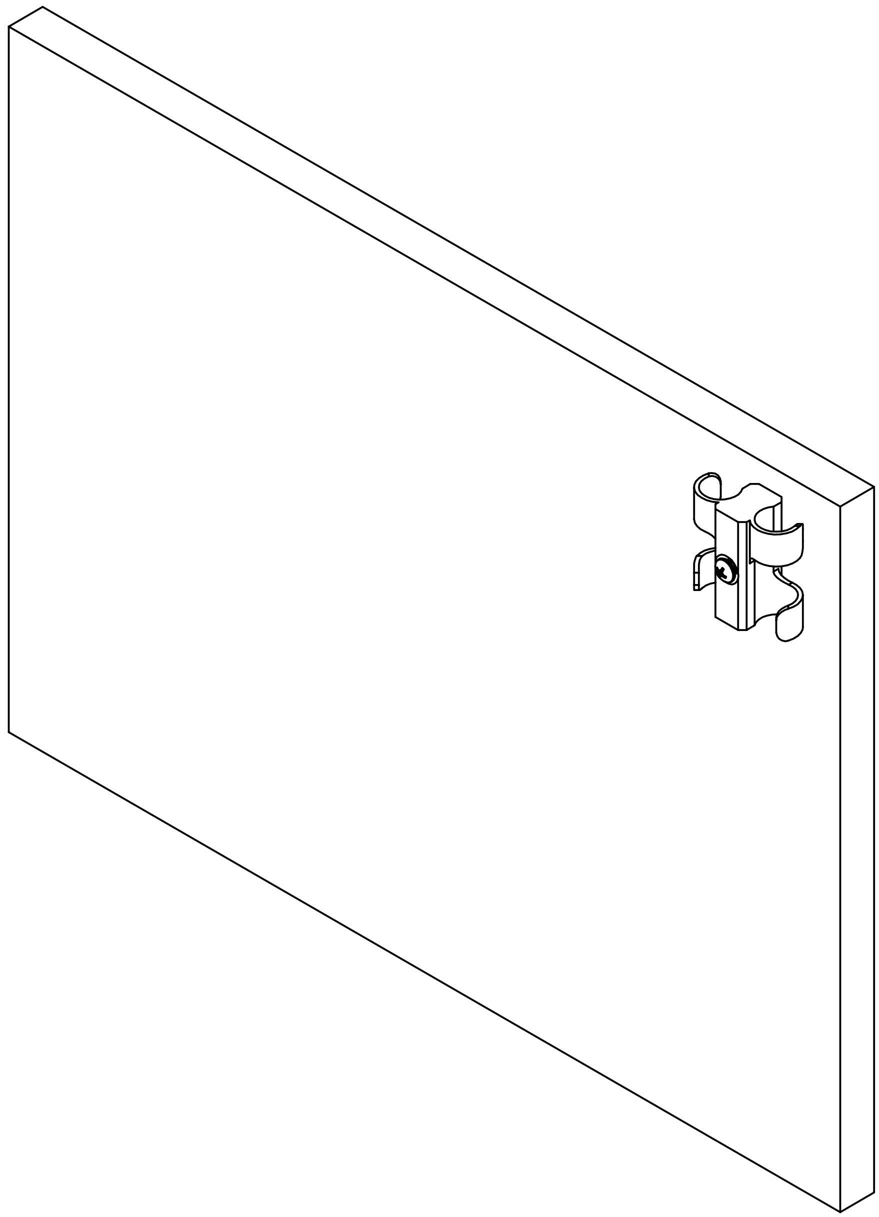
1. Unless specified, dimensions are in inches.
2. See CS-T-002 for part number and supplier.
3. Material: Acrylic Sheet, 1/8" thick.
4. Manufacturing Process: Laser Cut.
5. Finish: As machined.
6. Assembly: General purpose super-glue.
7. Tolerances to ±0.001in.

Cal Poly Mechanical Engineering	Lab Section:04	Controls System	Title:Housing, Door		Drwn. By: TYLER PRICE
ME 429 - Spring 2016	Dwg. #:CS-T-003F	Nxt Asb: N/A	Date:05/03/2016	Scale: 1:1	Chkd. By: BRANDON STELL



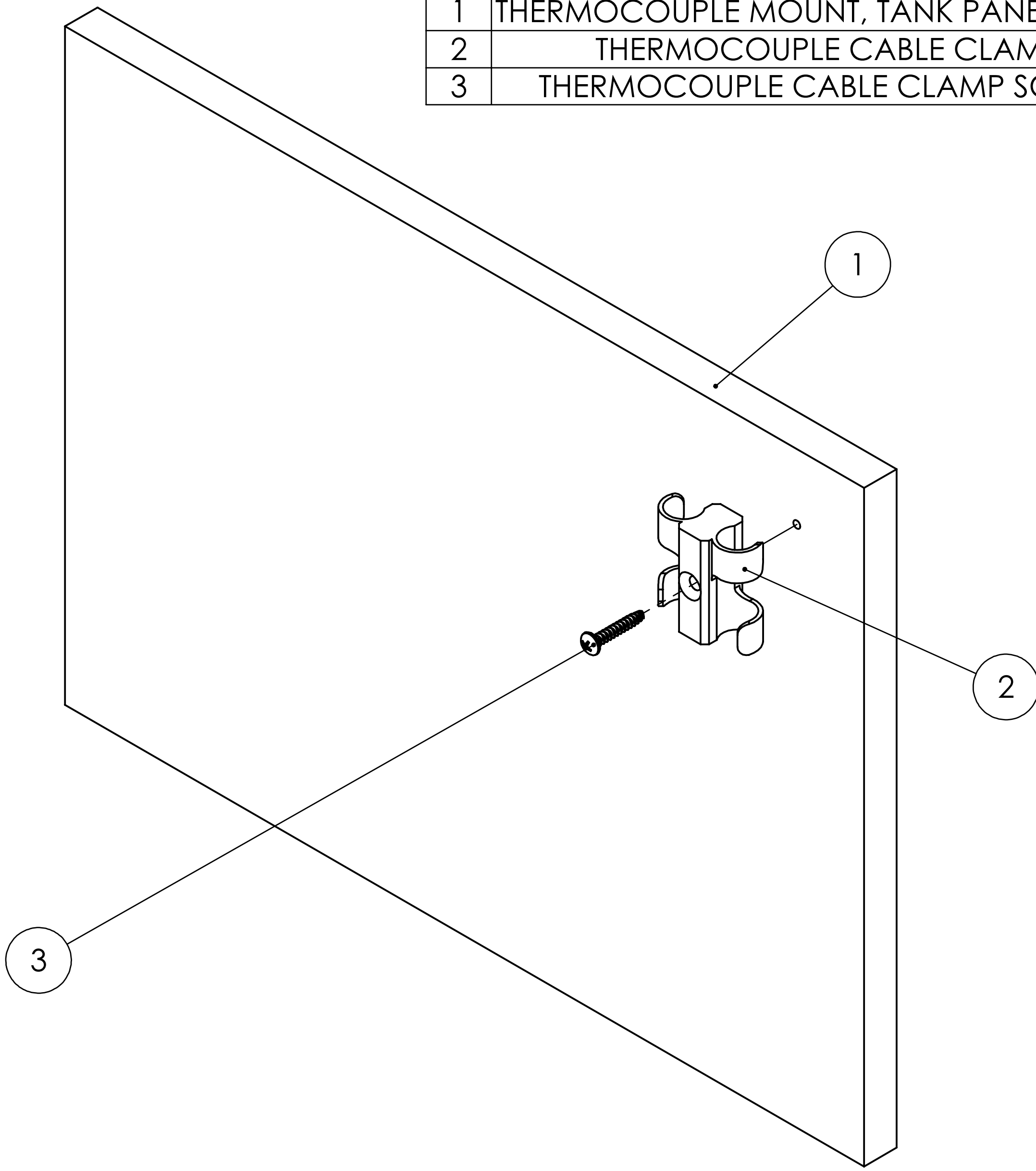
74HC595N
IC1
G
QH*
QH
QG
QF
QE
QD
QC
QB
QA
RCK
SCL
SCK
SER
GND
VCC
LCD1
RS
R/W
E
DB0
DB1
DB2
DB3
DB4
DB5
DB6
DB7
VCC
VO
VSS
LEDA
LEDK
LCD2x16 (LED backlight)
GND
10K
R1
Q1
TN0604N3
2009
Arduino
IC2
PC5(ADC5)
PC4(ADC4)
PC3(ADC3)
PC2(ADC2)
PC1(ADC1)
PC0(ADC0)
AREF
RESET
(AIN1)PD7
(AIN0)PD6
(T1)PD5
(T0)PD4
(INT1)PD3
(INT0)PD2
(TXD)PD1
(RXD)PD0
(SCK)PB5
(MISO)PB4
(MOSI)PB3
(SS)PB2
(OC1)PB1
(ICP)PB0
+5V
+3V3
+VIN


SENSOR BOARD
Photo
LED
Arduino
pin 4
GND
pin 3
VCC
pin 2
Signal
33k
10k
270
Photo Diode's longer pin
LED negative pin
LED positive pin
Photodiode's shorter lead
Junction

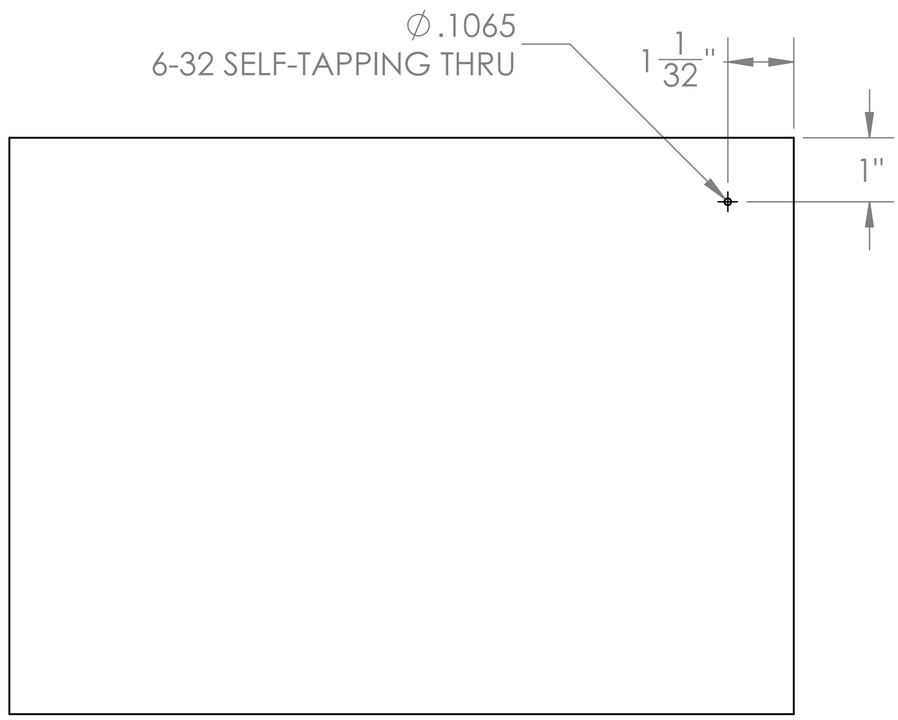


Cal Poly Mechanical Engineering	Lab Section: 04	Thermocouple	Title: Thermocouple Assembly	Drwn. By: TYLER PRICE
ME 429 - Spring 2016	Dwg. #: T-001	Nxt Asb: T-002	Date: 05/03/2016 Scale: 1:2	Chkd. By: BRANDON STELL

NO.	PART DESCRIPTION (DRAWING NO.)	PART NO.	QTY.	SUPPLIER
1	THERMOCOUPLE MOUNT, TANK PANEL (T-003)	N/A	1	ENDOLOGIX, INC.
2	THERMOCOUPLE CABLE CLAMP	7429K450	1	McMASTER-CARR
3	THERMOCOUPLE CABLE CLAMP SCREW	92485A640	1	McMASTER-CARR



Cal Poly Mechanical Engineering ME 429 - Spring 2016	Lab Section: 04	Thermocouple	Title: Thermocouple Assembly, Exploded View	Drwn. By: TYLER PRICE
	Dwg. #: T-002	Nxt Asb: T-003	Date: 05/03/2016 · Scale: 1:2	Chkd. By: BRANDON STELL



NOTES:

1. Unless specified, dimensions are in inches.
2. Drawing for manufacturing the dimensioned hole.
4. Manufacturing Process: Hand-Drill.
5. Finish: As machined.
6. Assembly: For thermocouple assembly mount.
7. Tolerances to ±0.001in.

Cal Poly Mechanical Engineering	Lab Section: 04	Thermocouple	Title: Thermocouple Mount, Tank Panel		Drwn. By: TYLER PRICE
ME 429 - Spring 2016	Dwg. #: T-003	Nxt Asb: N/A	Date: 05/03/2016	Scale: 1:3	Chkd. By: BRANDON STELL

Appendix C: Vendor Information

Vendor Information

Aqualogic

9558 Camino Ruiz

San Diego, CA 92126

Aqualogicinc.com | (858) 292-4773

McMaster-Carr Supply Company

P.O. Box 54960

Los Angeles, CA 90054-0960

www.mcmaster.com | (562) 692-5911

Mouser Electronics

1000 North Main Street

Mansfield, TX 76063

www.mouser.com | (800) 346-6873

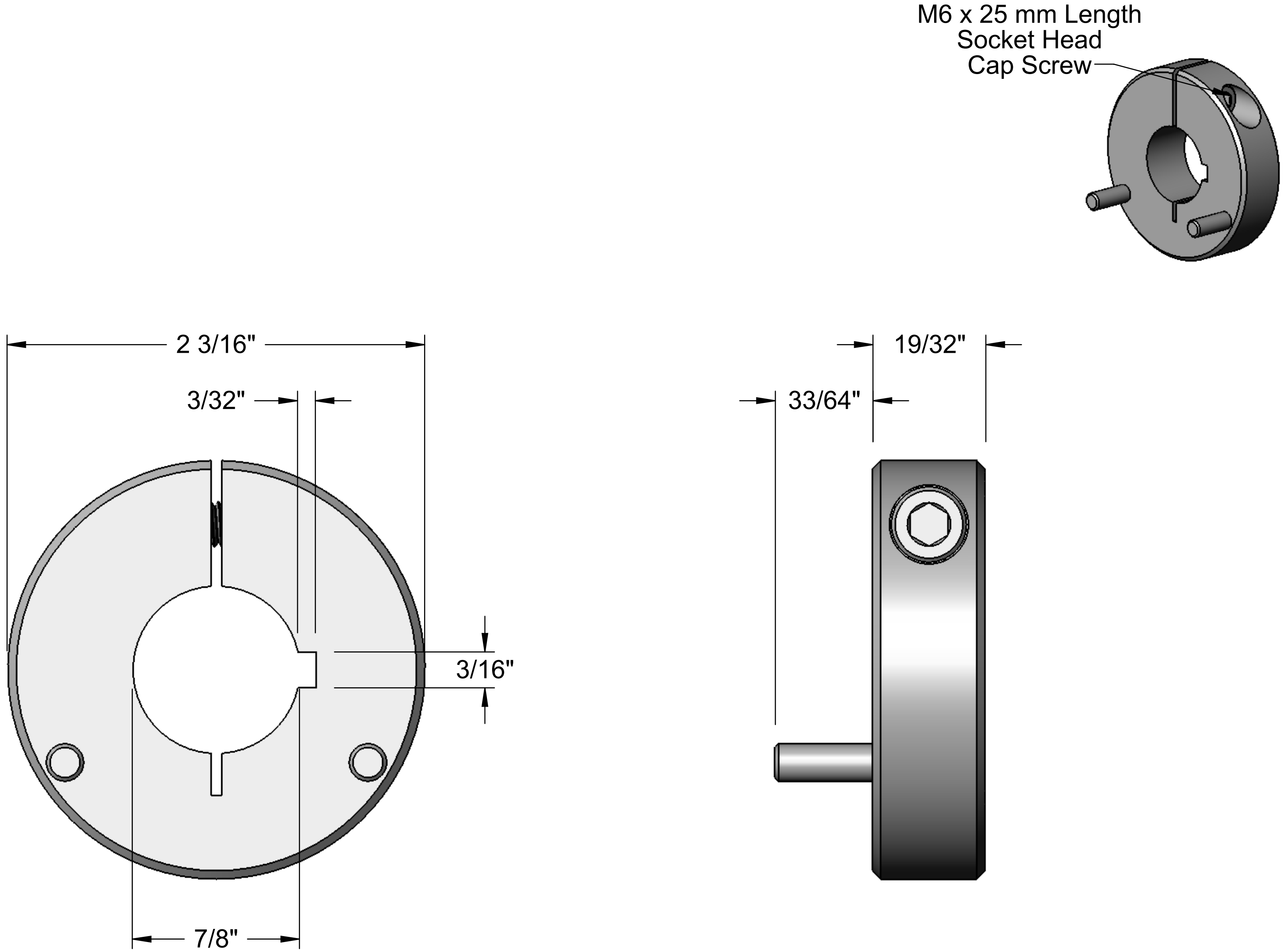
MSC Industrial Supply

75 Maxess Road

Melville, NY 11747

www.mscdirect.com | (800) 645-7270

Appendix D: Vendor Drawings and Data Sheets



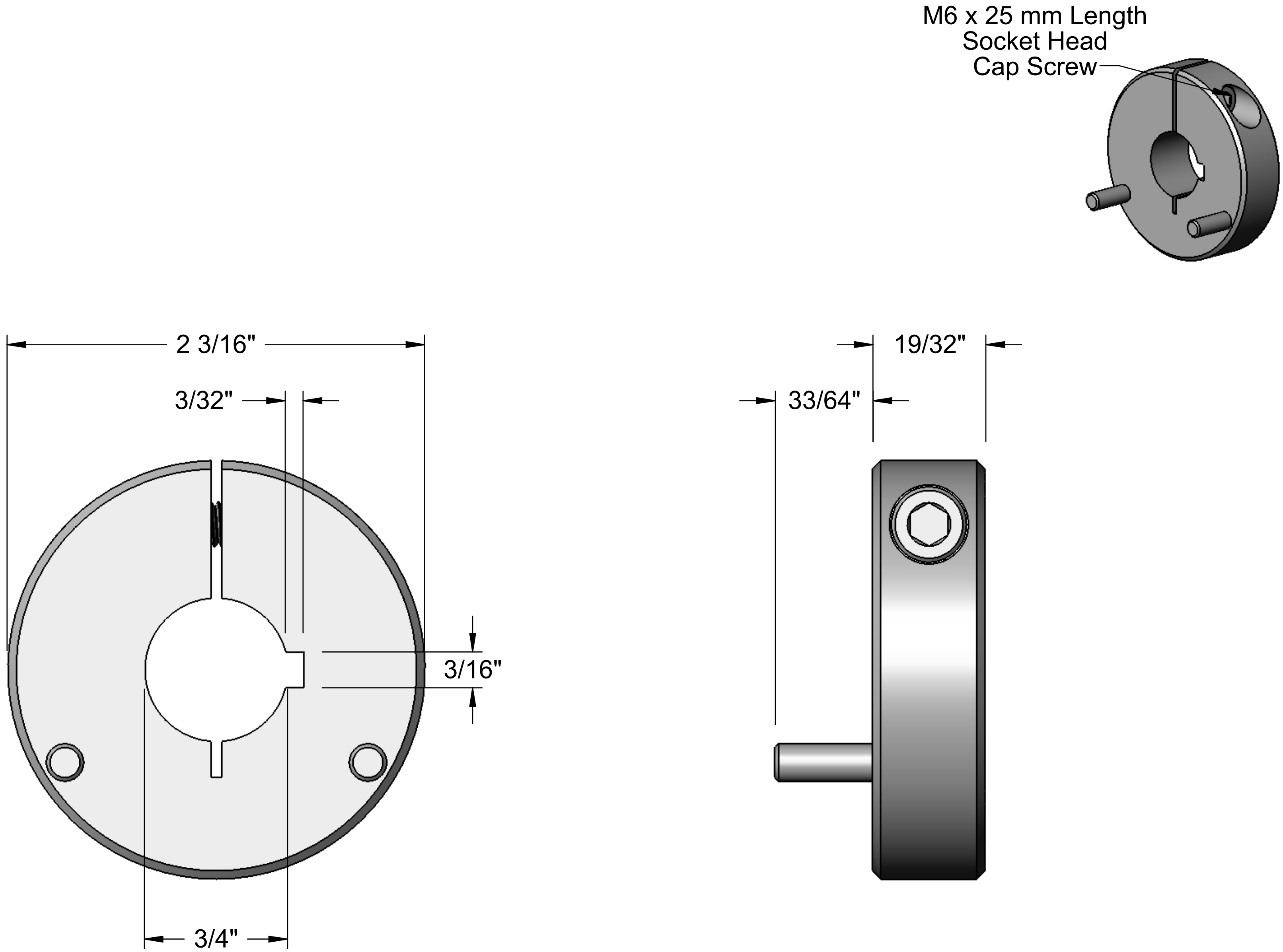
Complete Coupling (Two Hubs and One Disc) Overall Length 1 3/4"

McMASTER-CARR® CAD

PART NUMBER 60635K9

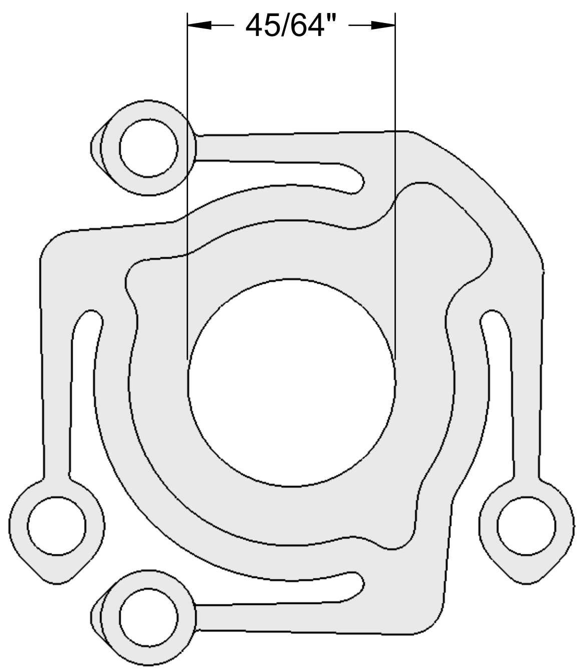
http://www.mcmaster.com

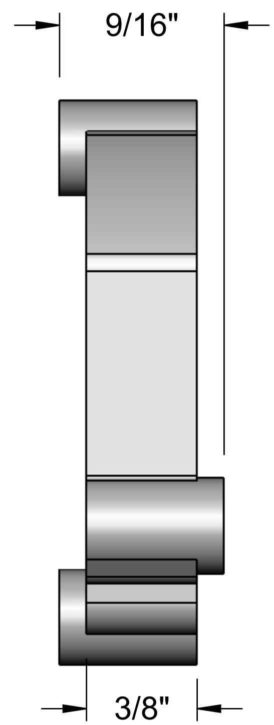
Coupling Hub for High-Misalignment Replaceable-Center Flexible Shaft Coupling

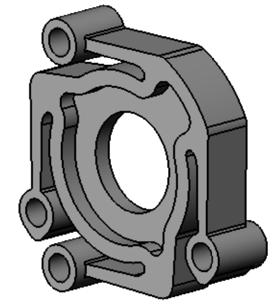


Complete Coupling (Two Hubs and One Disc) Overall Length 1 3/4"

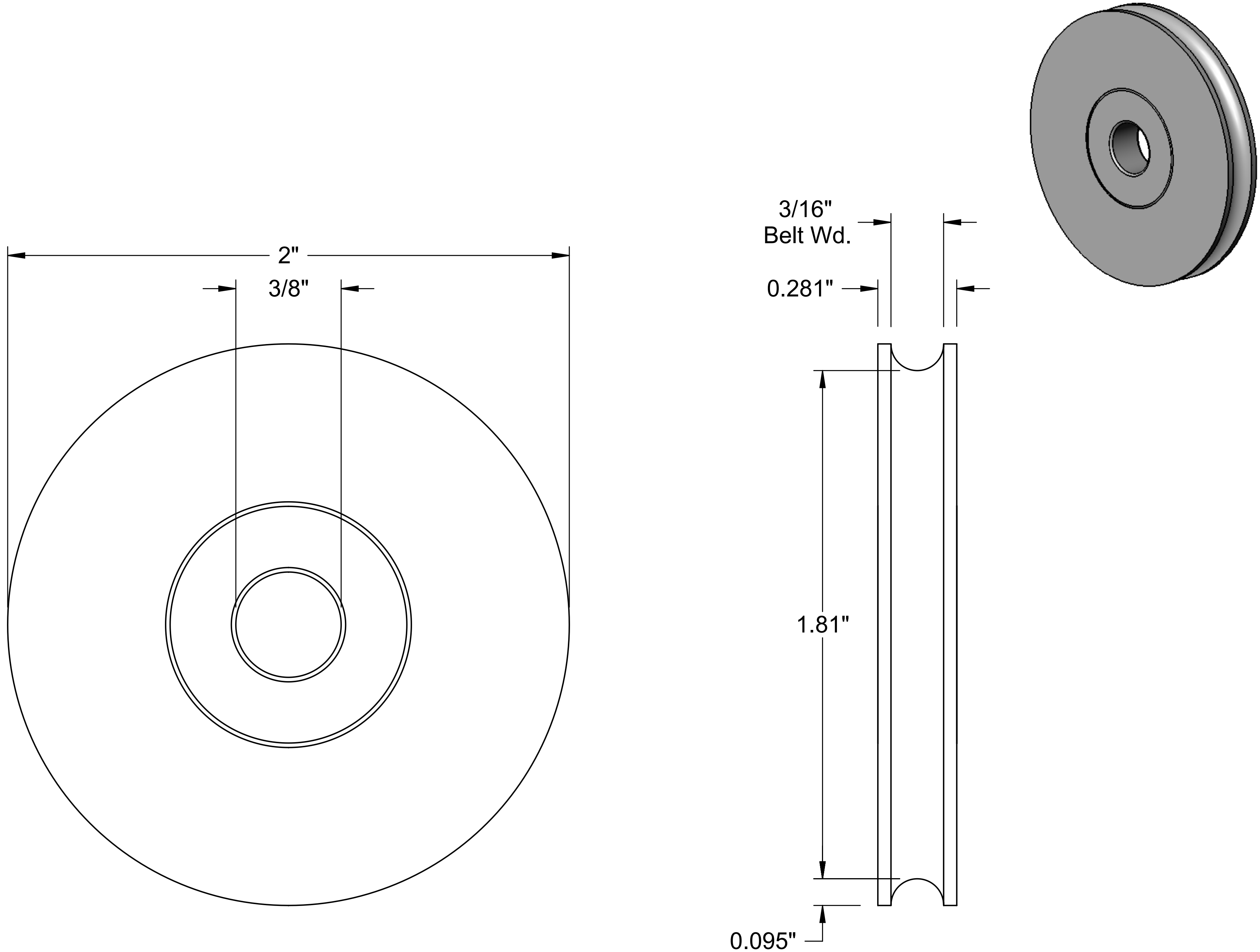
McMASTER-CARR® CAD	PART NUMBER	60635K9
http://www.mcmaster.com © 2013 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Coupling Hub for High-Misalignment Replaceable-Center Flexible Shaft Coupling	







McMASTER-CARR® CAD	PART NUMBER 60635K99
http://www.mcmaster.com © 2016 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Disc for High-Misalignment Replaceable-Center Flexible Shaft Coupling



McMASTER-CARR® CAD

PART NUMBER 6447K9

http://www.mcmaster.com

Round-Belt Idler Pulley

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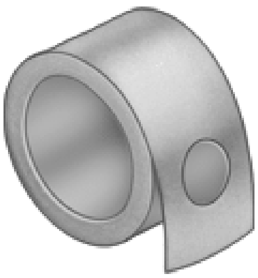
(562) 692-5911
(562) 695-2323 (fax)
la.sales@mcmaster.com
Text 75930

Stainless Steel Constant-Force Spring

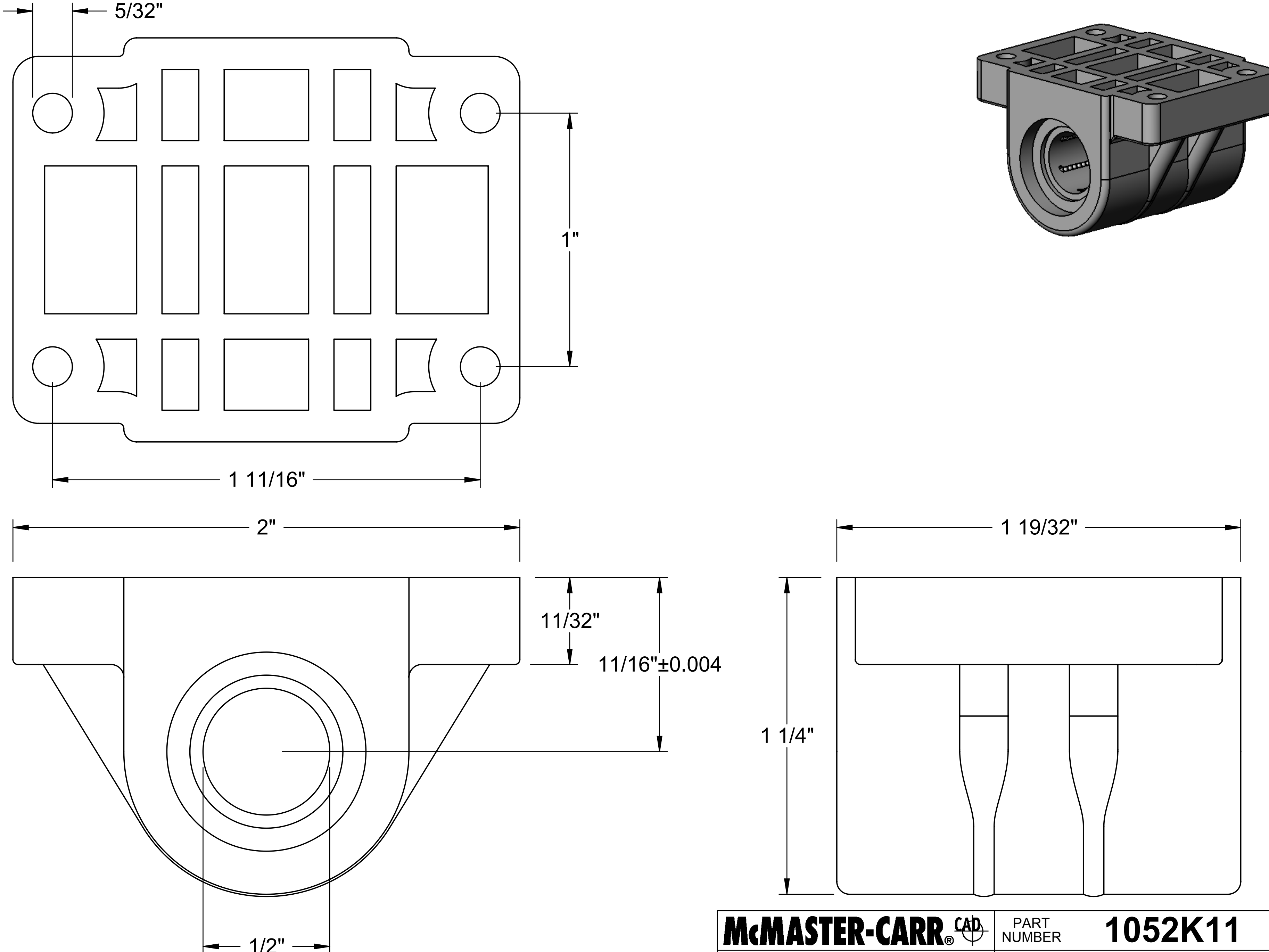
4000 Cycle Life, .025" Thick, 52.0" Long, 1.5" Wide

In stock
$18.58 Each
9293K13



Thickness	0.025"
Extended Length	52"
Width	1.500"
Wound	
ID	1.77"
OD	2.23"
End Hole Diameter	0.265"
Load	24.80 lbs.
Additional Specifications	4,000-Cycle Life Free end has two side-by-side holes at the tip of the spring.
RoHS	Compliant

Typically used as retractors in tape measures and cable reels, these springs are wound into a tight coil to provide uniform force throughout extension and retraction. They can be wrapped around a shaft, spool, or rod; allow for 1 1/2 extra coils on the shaft at full extension to hold the spring in place. All of these springs are made of Type 301 stainless steel. The free end has one hole for attaching a load to the spring, unless noted. Wound ID, wound OD, and load tolerances are ±10%.



McMASTER-CARR® CAD

PART NUMBER **1052K11**

http://www.mcmaster.com

Corrosion-Resistant Pillow-Block Linear Ball Bearing

Poly Hi Solidur - 1/4 Inch Bore, 1-1/2 Inch Outside Diameter, Finished Bore Round Belt Pulley
1/2 Inch Wide

Mfr Part #: PUHG1015 MSC Part #: 35414267 Write the first review

Zoom

Price: $11.96 ea.

Qty: 1

Register today and receive up to 25% off your first order!

Item Notes

$11.96

Add to Cart

In Stock

See more Finished Bore V-Belt Sheaves ►

Specs

Bore Diameter (Inch)	1/4
Type	Round Belt Pulley
Width (Inch)	1/2
Outside Diameter (Decimal Inch)	1.5000

POLY HI SOLIDUR
A MENASHA SUBSIDIARY

Brand:	Poly Hi Solidur
MSC Part #:	35414267
Mfr Part #:	PUHG1015
Big Book Page #:	**3755**

View the Safety Data Sheet (SDS).

Customers Also Viewed

Poly Hi Solidur
MSC #: 35414283

1/4 Inch Bore, 2-1/2 Inch Outside Diameter, Finished Bore

Price: $17.19 ea.

Poly Hi Solidur
MSC #: 35576370

1/4 Inch Bore, 4-1/2 Inch Outside Diameter, Finished Bore

Price: $59.75 ea.

Poly Hi Solidur
MSC #: 35414275

1/4 Inch Bore, 2 Inch Outside Diameter, Finished Bore Round

Price: $14.37 ea.

Poly Hi Solidur
MSC #: 35414333

1/2 Inch Bore, 5 Inch Outside Diameter, Finished Bore Round

Price: $42.92 ea.

Poly Hi Solidur - 1/4 Inch Bore, 2 Inch Outside Diameter, Finished Bore Round Belt Pulley

1/2 Inch Wide

Mfr Part #: PUHG1020 **MSC Part #: 35414275** Write the first review

Zoom

Price: $14.37 ea.

Qty: 1

Register today and receive up to 25% off your first order!

Item Notes

$14.37

Add to Cart

In Stock

See more Finished Bore V-Belt Sheaves ►

Specs

Bore Diameter (Inch)	1/4
Type	Round Belt Pulley
Width (Inch)	1/2
Outside Diameter (Decimal Inch)	2.0000

POLY HI SOLIDUR A MENASHA SUBSIDIARY

Brand:	Poly Hi Solidur
MSC Part #:	35414275
Mfr Part #:	PUHG1020
Big Book Page #:	**3755**

View the Safety Data Sheet (SDS).

Customers Also Viewed

Poly Hi Solidur
MSC #: 35414341
1/4 Inch Bore, 2 Inch Outside Diameter, Finished Bore Round
Price: $14.20 ea.

Browning
MSC #: 00756387
5/8 Inch Bore, 1-5/32 Long, 4-1/4 Inch Outside Diameter,
Price: $47.04 ea.

Poly Hi Solidur
MSC #: 35414317
1/2 Inch Bore, 4 Inch Outside Diameter, Finished Bore Round
Price: $31.05 ea.

Poly Hi Solidur
MSC #: 35414333
1/2 Inch Bore, 5 Inch Outside Diameter, Finished Bore Round
Price: $42.92 ea.

Poly Hi Solidur - 1/4 Inch Bore, 2-1/2 Inch Outside Diameter, Finished Bore Round Belt Pulley
1/2 Inch Wide

Mfr Part #: PUHG1025 **MSC Part #: 35414283** Write the first review

Price: $17.19 ea.

Qty: 1

Register today and receive up to 25% off your first order!

Item Notes

$17.19

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In Stock

See more Finished Bore V-Belt Sheaves ►

Metalworking Mania - Save Up to **35%** on orders over **$249**. ENTER CODE: MW249H CLICK TO APPLY ►✓ PROMO APPLIED

Specs

Bore Diameter (Inch)	1/4
Type	Round Belt Pulley
Width (Inch)	1/2
Outside Diameter (Decimal Inch)	2.5000

POLY HI SOLIDUR
A MENASHA SUBSIDIARY

Brand:	Poly Hi Solidur
MSC Part #:	35414283
Mfr Part #:	PUHG1025
Big Book Page #:	**3755**

View the Safety Data Sheet (SDS).

Customers Also Viewed

Poly Hi Solidur
MSC #: 35414309

1/2 Inch Bore, 3-1/2 Inch Outside Diameter, Finished Bore

Price: $25.84 ea.

Poly Hi Solidur
MSC #: 35414317

1/2 Inch Bore, 4 Inch Outside Diameter, Finished Bore Round

Price: $31.05 ea.

Poly Hi Solidur
MSC #: 35414333

1/2 Inch Bore, 5 Inch Outside Diameter, Finished Bore Round

Price: $42.92 ea.

Poly Hi Solidur
MSC #: 35413756

1/4 Inch Bore, 2.55 Inch Outside Diameter, Finished Bore

Price: $14.96 ea.

Poly Hi Solidur - 1/2 Inch Bore, 4 Inch Outside Diameter, Finished Bore Round Belt Pulley

1/2 Inch Wide

Mfr Part #: PUHG1040 **MSC Part #: 35414317** Write the first review

Zoom

Price: $31.05 ea.

Qty: 1

Register today and receive up to 25% off your first order!

Item Notes

$31.05

Add to Cart

In Stock

See more Finished Bore V-Belt Sheaves ►

Specs

Bore Diameter (Inch)	1/2
Type	Round Belt Pulley
Width (Inch)	1/2
Outside Diameter (Decimal Inch)	4.0000

POLY HI SOLIDUR
A MENASHA SUBSIDIARY

Brand:	Poly Hi Solidur
MSC Part #:	35414317
Mfr Part #:	PUHG1040
Big Book Page #:	**3755**

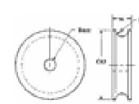
View the Safety Data Sheet (SDS).

Customers Also Viewed

Poly Hi Solidur
MSC #: 35414333
1/2 Inch Bore, 5 Inch Outside Diameter, Finished Bore Round
Price: $42.92 ea.

Poly Hi Solidur
MSC #: 35576248
1/2 Inch Bore, 5 Inch Outside Diameter, Finished Bore Round
Price: $36.53 ea.

Poly Hi Solidur
MSC #: 35576339
1/4 Inch Bore, 3 Inch Outside Diameter, Finished Bore Flat
Price: $39.09 ea.



Poly Hi Solidur
MSC #: 35576289
1/2 Inch Bore, 7 Inch Outside Diameter, Finished Bore Round
Price: $64.11 ea.

Poly Hi Solidur - 1/2 Inch Bore, 5 Inch Outside Diameter, Finished Bore Round Belt Pulley

1/2 Inch Wide

Mfr Part #: PUHG1050 **MSC Part #: 35414333** Write the first review

Zoom

Price:	$42.92 ea.
Qty:	1

Register today and receive up to 25% off your first order!

Item Notes

$42.92

Add to Cart

In Stock

See more Finished Bore V-Belt Sheaves ▶

Specs

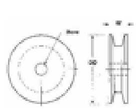
Bore Diameter (Inch)	1/2
Type	Round Belt Pulley
Width (Inch)	1/2
Outside Diameter (Decimal Inch)	5.0000

POLY HI SOLIDUR
A MENASHA SUBSIDIARY

Brand:	Poly Hi Solidur
MSC Part #:	35414333
Mfr Part #:	PUHG1050
Big Book Page #:	**3755**

View the Safety Data Sheet (SDS).

Customers Also Viewed



Poly Hi Solidur
MSC #: 35413897
1/2 Inch Bore, 5.05 Inch Outside Diameter, Finished Bore
Price: $41.36 ea.

Poly Hi Solidur
MSC #: 35414317
1/2 Inch Bore, 4 Inch Outside Diameter, Finished Bore Round
Price: $31.05 ea.

Poly Hi Solidur
MSC #: 35414283
1/4 Inch Bore, 2-1/2 Inch Outside Diameter, Finished Bore
Price: $17.19 ea.

Poly Hi Solidur
MSC #: 35414275
1/4 Inch Bore, 2 Inch Outside Diameter, Finished Bore Round
Price: $14.37 ea.

Poly Hi Solidur - 1/2 Inch Bore, 7-1/2 Inch Outside Diameter, Finished Bore Round Belt Pulley
3/4 Inch Wide

Mfr Part #: PUHJ1075 **MSC Part #: 35576297** Write the first review

Zoom


Price:	$68.62 ea.
Qty:	1

Register today and receive up to 25% off your first order!

Item Notes

$68.62

Add to Cart

In Stock

See more Finished Bore V-Belt Sheaves ▶

Specs

Bore Diameter (Inch)	1/2
Type	Round Belt Pulley
Width (Inch)	3/4
Outside Diameter (Decimal Inch)	7.5000

POLY HI SOLIDUR
A MENASHA SUBSIDIARY

Brand:	Poly Hi Solidur
MSC Part #:	35576297
Mfr Part #:	PUHJ1075
Big Book Page #:	**3755**

View the Safety Data Sheet (SDS).

McMASTER-CARR. OVER 555,000 PRODUCTS
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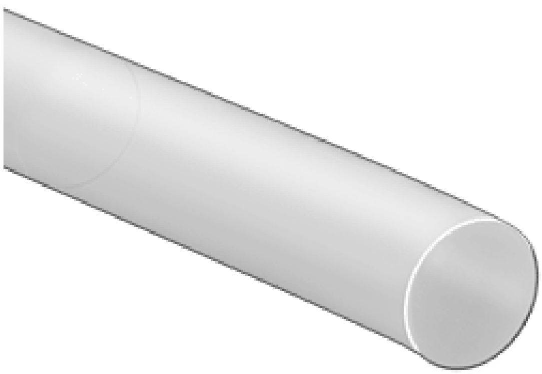
la.sales@mcmaster.com
Text 75930

Solid-Core Round Belting
3/16" OD

$0.91 per ft.
59725K731

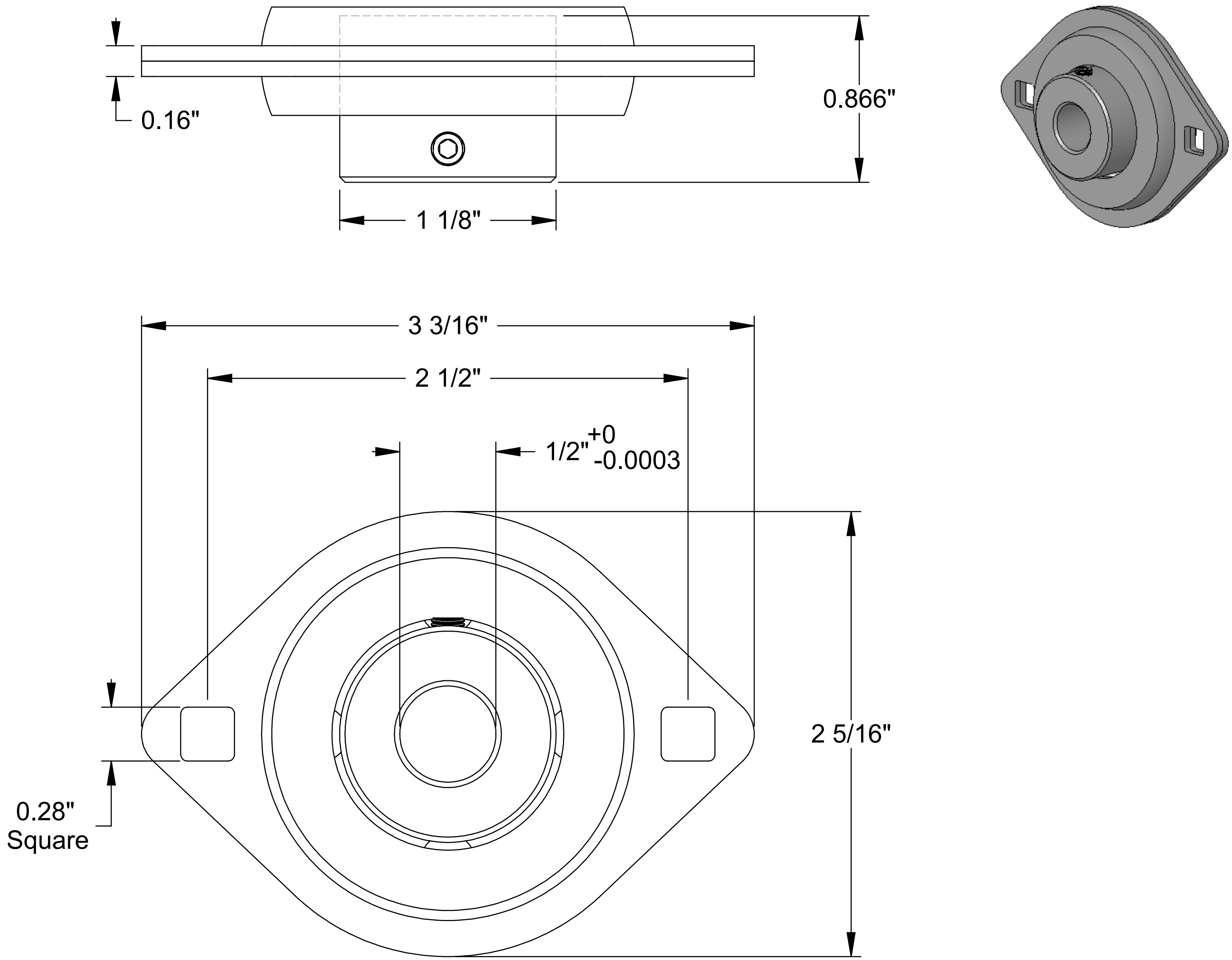


OD	3/16"
Minimum Pulley Diameter	1 1/2"
Core Construction	Solid
Surface Texture	Smooth
Color	Clear, Orange
Material	Urethane

Run this chemical- and abrasion-resistant urethane belting in light duty conveying and power-transmission applications. Inch sizes are made from FDA-listed material for use with food and beverage.

Belting with a smooth surface is easy to clean.

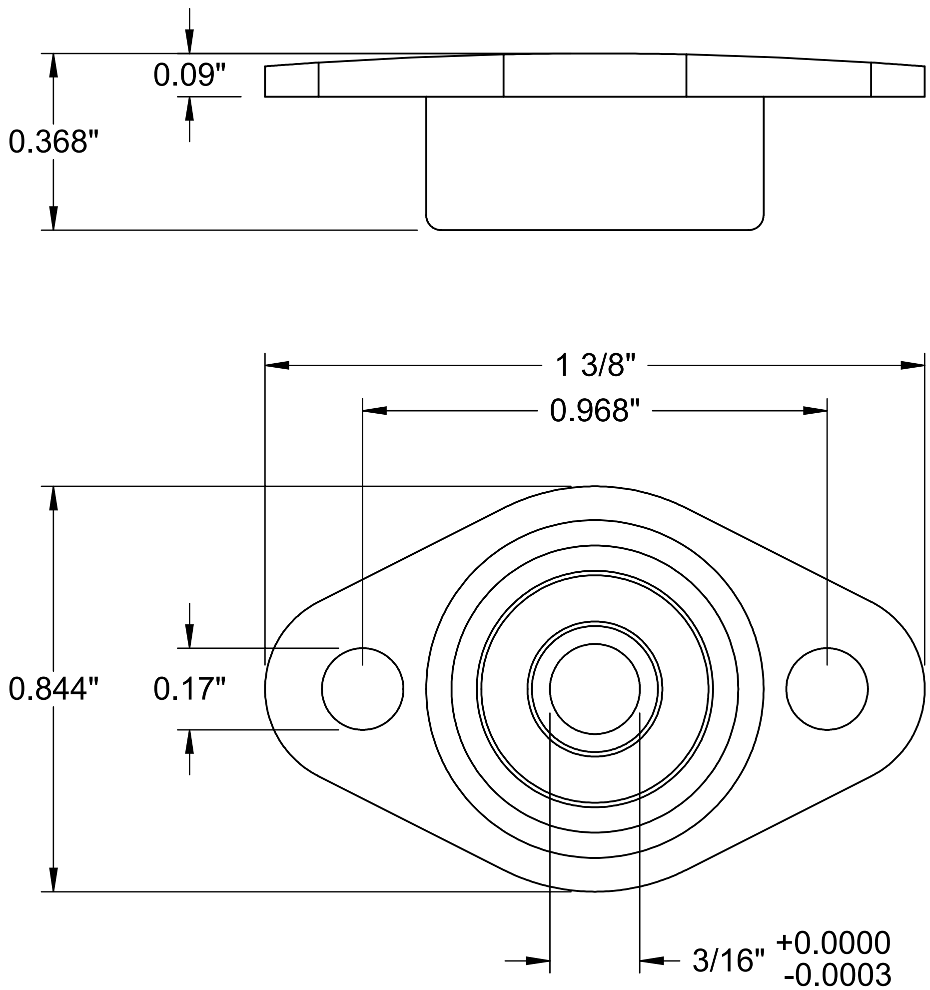
Solid-Core Belting—Choose this belting for stronger connections than quick-connect hollow-core belting. Join the ends of this belting with solid-core round belting connectors or use a welding kit.

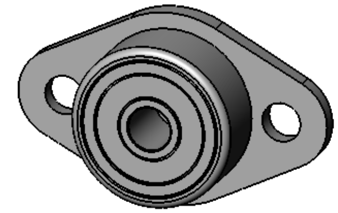


McMASTER-CARR® CAD

PART NUMBER **5913K71**

Stamped-Steel
Flange-Mounted Ball Bearing



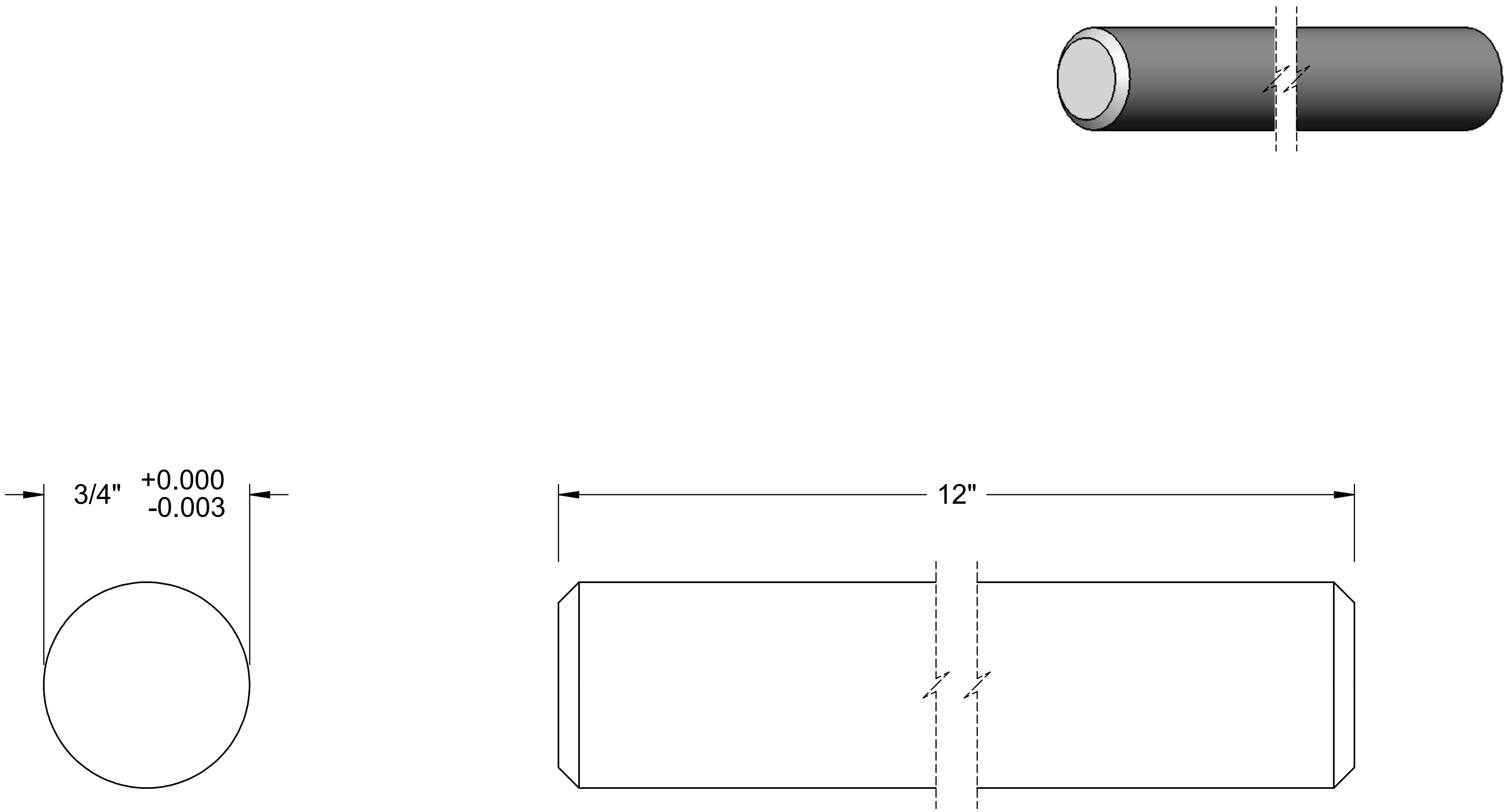


McMASTER-CARR® CAD

PART NUMBER 4575N32

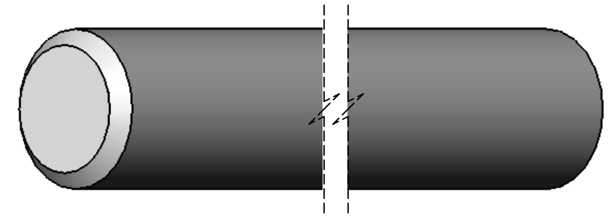
http://www.mcmaster.com

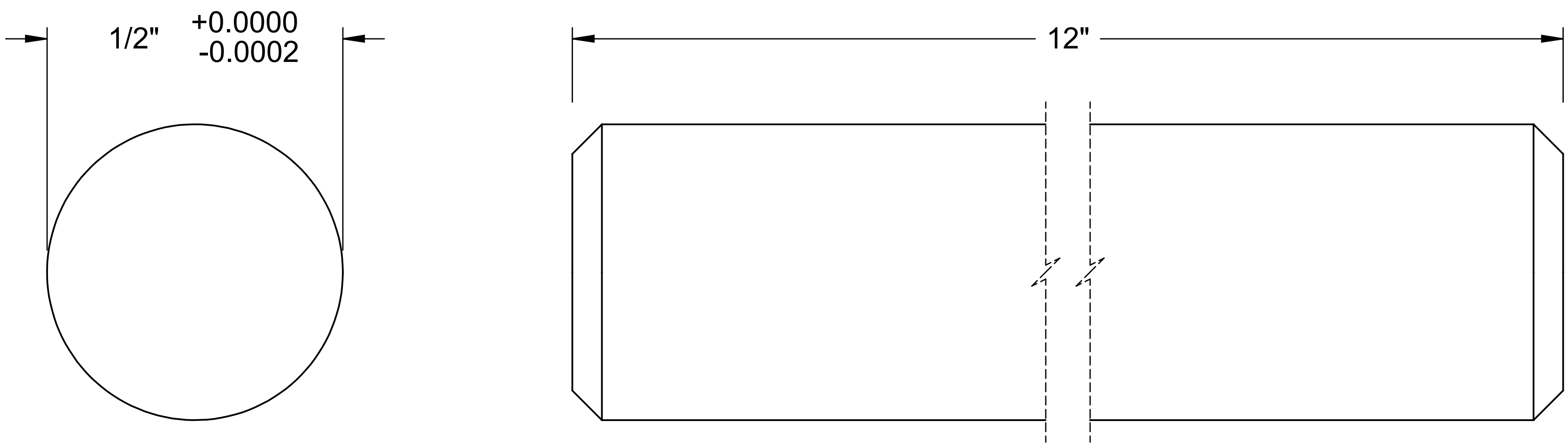
Miniature Flange-Mounted Shielded Stainless Steel Ball Bearing



Straightness Tolerance is 0.012" per Foot

McMASTER-CARR® CAD	PART NUMBER	1346K31
http://www.mcmaster.com © 2012 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Drive Shaft	





Straightness Tolerance is 0.0048" per Foot

McMASTER-CARR® CAD	PART NUMBER	8364T5
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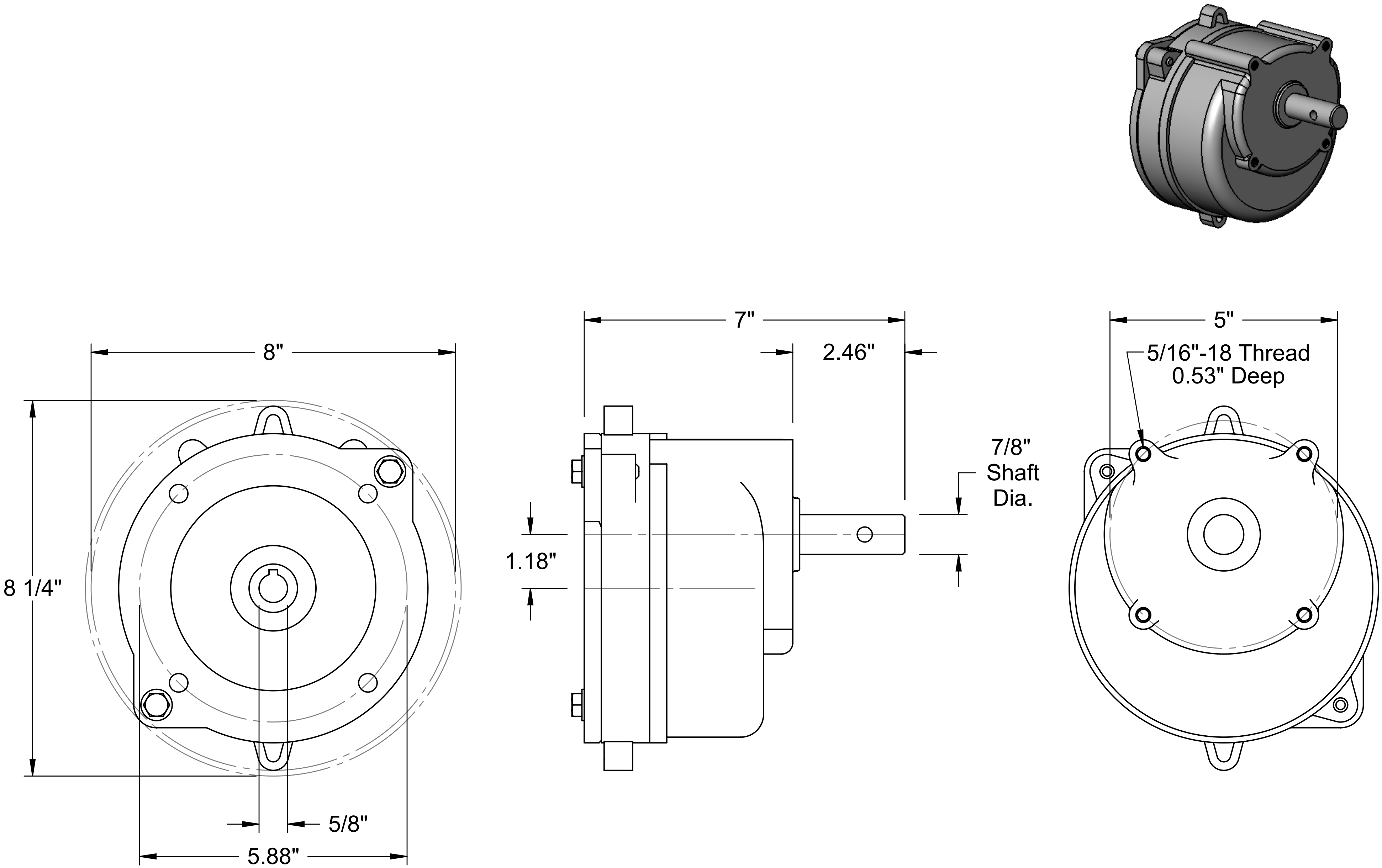

McMASTER-CARR® CAD

PART NUMBER **6481K75**

http://www.mcmaster.com

High-Efficiency
Speed Reducer

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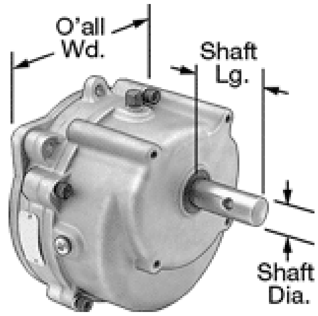
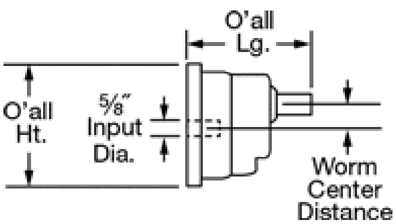
(562) 695-2323 (fax)
la.sales@mcmaster.com
Text 75930

High-Efficiency Speed Reducer

5.6:1 Ratio, 315 Output rpm, 290 in.-lbs. Torque

In stock
$272.66 Each
6481K75

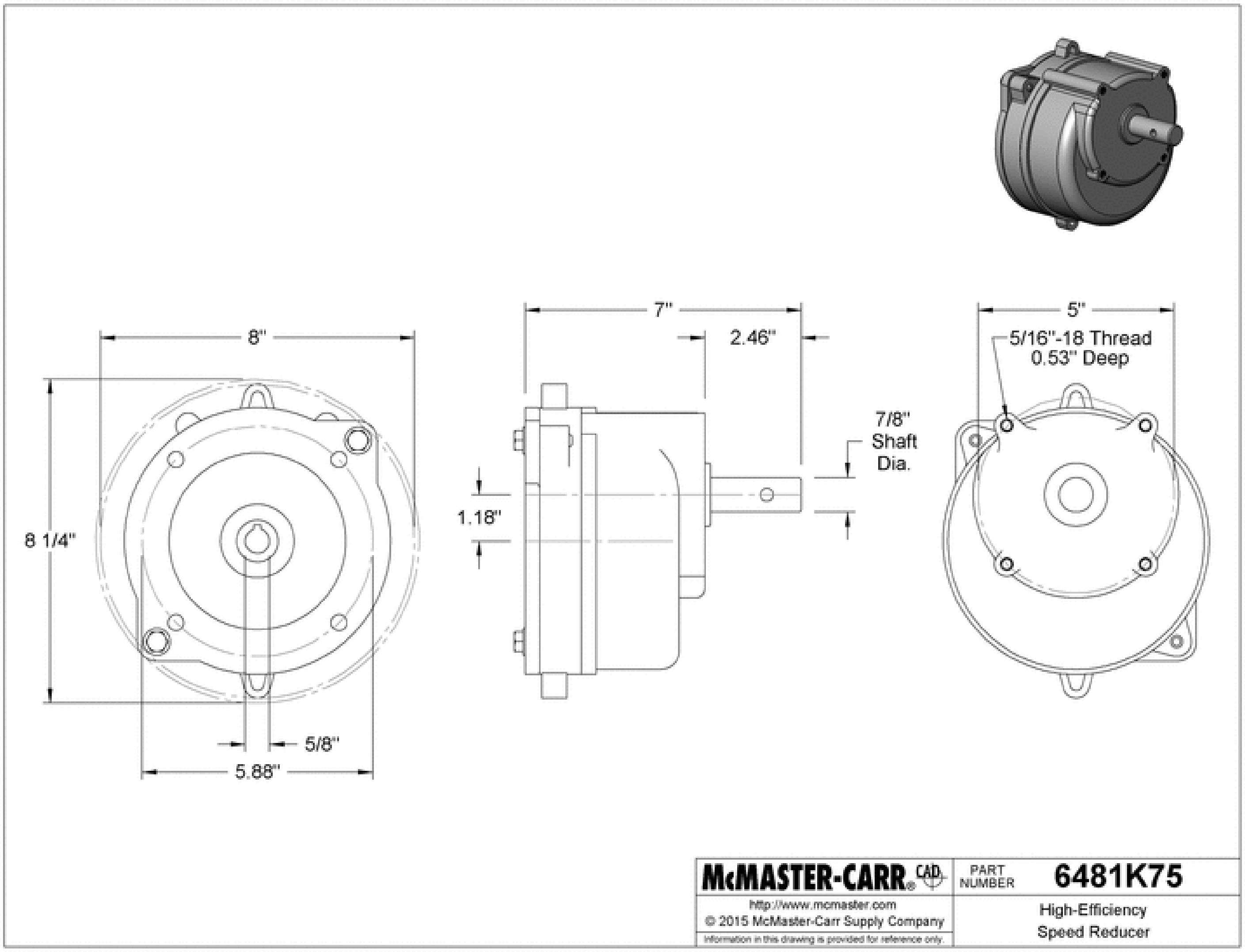




Shaft Orientation	Parallel
For Motor Frame	NEMA 56C
Mounting Orientation	Any angle with the vent plug above the shaft
Speed Ratio	5.6:1
Output	
rpm @ 1,750 Input rpm	315
Torque	290 in.-lbs.
Worm Center Distance	1.18"
Maximum Input	
hp	1.48
rpm	1,750
Overall	
Length	7"
Width	8"
Height	8 1/4"
Output Shaft	
Diameter	7/8"
Length	2.46"
Type	Solid with thru hole
Rotation	Same as Input Rotation
Material	Steel
Input Shaft Fits Diameter	5/8"
Rotation	Clockwise or Counterclockwise
Efficiency	98%
Lubrication Requirement	Required

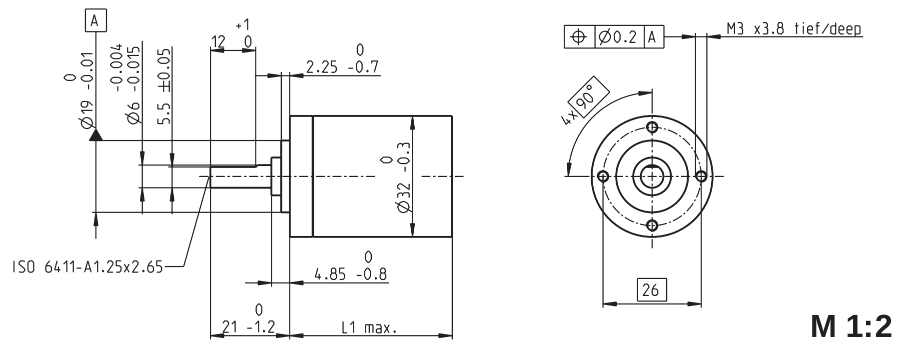
Gear	
Type	Spur
Material	Steel
Bearing Type	Ball
Housing Material	Aluminum
Overhung Load Capacity	246 lbs.
Related Product	1 qt. Lubricant

Designed to minimize torque loss between your motor and drive shaft, these speed reducers have spur gears that make them more efficient than our other speed reducers. Use these with a NEMA 56C motor to transmit motion parallel to the motor shaft while reducing speed and increasing torque.



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

Planetary Gearhead GP 32 A ∅32 mm, 0.75–4.5 Nm



M 1:2

Technical Data

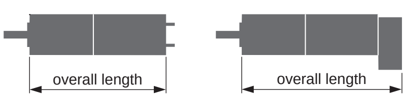
Planetary Gearhead	straight teeth
Output shaft	stainless steel
Shaft diameter as option	8 mm
Bearing at output	ball bearing
Radial play, 5 mm from flange	max. 0.14 mm
Axial play	max. 0.4 mm
Max. axial load (dynamic)	120 N
Max. force for press fits	120 N
Direction of rotation, drive to output	=
Max. continuous input speed	6000 rpm
Recommended temperature range	-40…+100°C
Number of stages	1 2 3 4 5
Max. radial load, 10 mm from flange	90 N 140 N 200 N 220 N 220 N

Option: Low-noise version

Stock program
Standard program
Special program (on request)

Part Numbers

			166155	166158	166163	166164	166169	166174	166179	166184	166187	166192	166197	166202
Gearhead Data														
1	Reduction		3.7 : 1	14 : 1	33 : 1	51 : 1	111 : 1	246 : 1	492 : 1	762 : 1	1181 : 1	1972 : 1	2829 : 1	4380 : 1
2	Absolute reduction		26/7	676/49	529/16	17576/343	13824/125	421824/1715	86112/175	19044/25	10123776/8575	8626176/4375	495144/175	109503/25
3	Max. motor shaft diameter	mm	6	6	3	6	4	4	3	3	4	4	3	3
	Part Numbers		166156	166159		166165	166170	166175	166180	166185	166188	166193	166198	166203
1	Reduction		4.8 : 1	18 : 1		66 : 1	123 : 1	295 : 1	531 : 1	913 : 1	1414 : 1	2189 : 1	3052 : 1	5247 : 1
2	Absolute reduction		24/5	624/35		16224/245	6877/56	101062/343	331776/625	36501/40	2425488/1715	536406/245	1907712/625	839523/160
3	Max. motor shaft diameter	mm	4	4		4	3	3	4	3	3	3	3	3
	Part Numbers		166157	166160		166166	166171	166176	166181	166186	166189	166194	166199	166204
1	Reduction		5.8 : 1	21 : 1		79 : 1	132 : 1	318 : 1	589 : 1	1093 : 1	1526 : 1	2362 : 1	3389 : 1	6285 : 1
2	Absolute reduction		23/4	299/14		3887/49	3312/25	389376/1225	20631/35	279841/256	9345024/6125	2066688/875	474513/140	6436343/1024
3	Max. motor shaft diameter	mm	3	3		3	3	4	3	3	4	3	3	3
	Part Numbers			166161		166167	166172	166177	166182		166190	166195	166200	
1	Reduction			23 : 1		86 : 1	159 : 1	411 : 1	636 : 1		1694 : 1	2548 : 1	3656 : 1	
2	Absolute reduction			576/25		14976/175	1587/10	359424/875	79488/125		1162213/686	7962624/3125	457056/125	
3	Max. motor shaft diameter	mm		4		4	3	4	3		3	4	3	
	Part Numbers			166162		166168	166173	166178	166183		166191	166196	166201	
1	Reduction			28 : 1		103 : 1	190 : 1	456 : 1	706 : 1		1828 : 1	2623 : 1	4060 : 1	
2	Absolute reduction			138/5		3588/35	12167/64	89401/196	158171/224		2238912/1225	2056223/784	3637933/896	
3	Max. motor shaft diameter	mm		3		3	3	3	3		3	3	3	
4	Number of stages		1	2	2	3	3	4	4	4	5	5	5	5
5	Max. continuous torque	Nm	0.75	2.25	2.25	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50
6	Max. intermittent torque at gear output	Nm	1.1	3.4	3.4	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
7	Max. efficiency	%	80	75	75	70	70	60	60	60	50	50	50	50
8	Weight	g	118	162	162	194	194	226	226	226	258	258	258	258
9	Average backlash no load	°	0.7	0.8	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
10	Mass inertia	gcm²	1.5	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
11	Gearhead length L1	mm	26.5	36.4	36.4	43.1	43.1	49.8	49.8	49.8	56.5	56.5	56.5	56.5

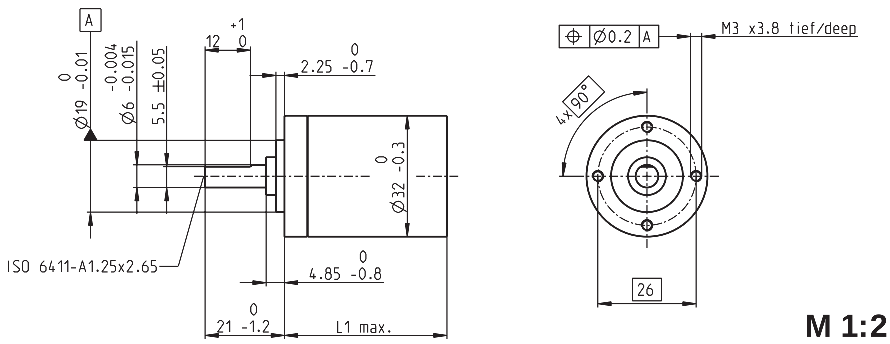


maxon Modular System

+ Motor	Page	+ Sensor/Brake	Page	Overall length [mm] = Motor length + gearhead length + (sensor/brake) + assembly parts											
RE 25	135/137			81.1	91.0	91.0	97.7	97.7	104.4	104.4	104.4	111.1	111.1	111.1	111.1
RE 25	135/137	MR	355	92.1	102.0	102.0	108.7	108.7	115.4	115.4	115.4	122.1	122.1	122.1	122.1
RE 25	135/137	Enc 22	361	95.2	105.1	105.1	111.8	111.8	118.5	118.5	118.5	125.2	125.2	125.2	125.2
RE 25	135/137	HED_ 5540	362/364	101.9	111.8	111.8	118.5	118.5	125.2	125.2	125.2	131.9	131.9	131.9	131.9
RE 25	135/137	DCT 22	373	103.4	113.3	113.3	120.0	120.0	126.7	126.7	126.7	133.4	133.4	133.4	133.4
RE 25, 20 W	136			69.6	79.5	79.5	86.2	86.2	92.9	92.9	92.9	99.6	99.6	99.6	99.6
RE 25, 20 W	136	MR	355	80.6	90.5	90.5	97.2	97.2	103.9	103.9	103.9	110.6	110.6	110.6	110.6
RE 25, 20 W	136	HED_ 5540	363/366	90.4	100.3	100.3	107.0	107.0	113.7	113.7	113.7	120.4	120.4	120.4	120.4
RE 25, 20 W	136	DCT22	373	91.9	101.8	101.8	108.5	108.5	115.2	115.2	115.2	121.9	121.9	121.9	121.9
RE 25, 20 W	136	AB 28	408	103.7	113.6	113.6	120.3	120.3	127.0	127.0	127.0	133.7	133.7	133.7	133.7
RE 25, 20 W	136	HED_ 5540/AB 28	363/408	120.9	130.8	130.8	137.5	137.5	144.2	144.2	144.2	150.9	150.9	150.9	150.9
RE 25, 20 W	137	AB 28	408	115.2	125.1	125.1	131.8	131.8	138.5	138.5	138.5	145.2	145.2	145.2	145.2
RE 25, 20 W	137	HED_ 5540/AB 28	362/408	132.4	142.3	142.3	149.0	149.0	155.7	155.7	155.7	162.4	162.4	162.4	162.4
A-max 26	161-168			71.3	81.2	81.2	87.9	87.9	94.6	94.6	94.6	101.3	101.3	101.3	101.3
A-max 26	162-168	MEnc 13	372	78.4	88.3	88.3	95.0	95.0	101.7	101.7	101.7	108.4	108.4	108.4	108.4
A-max 26	162-168	MR	355	80.1	90.0	90.0	96.7	96.7	103.4	103.4	103.4	110.1	110.1	110.1	110.1
A-max 26	162-168	Enc 22	361	85.7	95.6	95.6	102.3	102.3	109.0	109.0	109.0	115.7	115.7	115.7	115.7
A-max 26	162-168	HED_ 5540	363/365	89.7	99.6	99.6	106.3	106.3	113.0	113.0	113.0	119.7	119.7	119.7	119.7
RE-max 29	183-186			71.3	81.2	81.2	87.9	87.9	94.6	94.6	94.6	101.3	101.3	101.3	101.3
RE-max 29	184/186	MR	355	80.1	90.0	90.0	96.7	96.7	103.4	103.4	103.4	110.1	110.1	110.1	110.1

April 2015 edition / subject to change

Planetary Gearhead GP 32 A ∅32 mm, 0.75–4.5 Nm



M 1:2

maxon gear

Technical Data

Planetary Gearhead	straight teeth
Output shaft	stainless steel
Shaft diameter as option	8 mm
Bearing at output	ball bearing
Radial play, 5 mm from flange	max. 0.14 mm
Axial play	max. 0.4 mm
Max. axial load (dynamic)	120 N
Max. force for press fits	120 N
Direction of rotation, drive to output	=
Max. continuous input speed	6000 rpm
Recommended temperature range	-40…+100°C
Number of stages	1 2 3 4 5
Max. radial load, 10 mm from flange	90 N 140 N 200 N 220 N 220 N

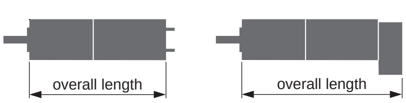
Option: Low-noise version

Stock program
Standard program
Special program (on request)

Part Numbers

			166155	166158	166163	166164	166169	166174	166179	166184	166187	166192	166197	166202
Gearhead Data														
1	Reduction		3.7 : 1	14 : 1	33 : 1	51 : 1	111 : 1	246 : 1	492 : 1	762 : 1	1181 : 1	1972 : 1	2829 : 1	4380 : 1
2	Absolute reduction		26/7	676/49	529/16	17576/343	13824/125	421824/1715	86112/175	19044/25	10123776/8575	8626176/4375	495144/175	109503/25
3	Max. motor shaft diameter	mm	6	6	3	6	4	4	3	3	4	4	3	3
	Part Numbers		166156	166159		166165	166170	166175	166180	166185	166188	166193	166198	166203
1	Reduction		4.8 : 1	18 : 1		66 : 1	123 : 1	295 : 1	531 : 1	913 : 1	1414 : 1	2189 : 1	3052 : 1	5247 : 1
2	Absolute reduction		24/5	624/35		16224/245	6877/56	101062/343	331776/625	36501/40	2425488/1715	536406/245	1907712/625	839523/160
3	Max. motor shaft diameter	mm	4	4		4	3	3	4	3	3	3	3	3
	Part Numbers		166157	166160		166166	166171	166176	166181	166186	166189	166194	166199	166204
1	Reduction		5.8 : 1	21 : 1		79 : 1	132 : 1	318 : 1	589 : 1	1093 : 1	1526 : 1	2362 : 1	3389 : 1	6285 : 1
2	Absolute reduction		23/4	299/14		3887/49	3312/25	38976/1225	20631/35	279841/256	9345024/6125	2066688/875	474513/140	6436343/1024
3	Max. motor shaft diameter	mm	3	3		3	3	4	3	3	4	3	3	3
	Part Numbers			166161		166167	166172	166177	166182		166190	166195	166200	
1	Reduction			23 : 1		86 : 1	159 : 1	411 : 1	636 : 1		1694 : 1	2548 : 1	3656 : 1	
2	Absolute reduction			576/25		14976/175	1587/10	359424/875	79488/125		1162213/686	7962624/3125	457056/125	
3	Max. motor shaft diameter	mm		4		4	3	4	3		3	4	3	
	Part Numbers			166162		166168	166173	166178	166183		166191	166196	166201	
1	Reduction			28 : 1		103 : 1	190 : 1	456 : 1	706 : 1		1828 : 1	2623 : 1	4060 : 1	
2	Absolute reduction			138/5		3588/35	12167/64	89401/196	158171/224		2238912/1225	2056223/784	3637933/896	
3	Max. motor shaft diameter	mm		3		3	3	3	3		3	3	3	
4	Number of stages		1	2	2	3	3	4	4	4	5	5	5	5
5	Max. continuous torque	Nm	0.75	2.25	2.25	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50
6	Max. intermittent torque at gear output	Nm	1.1	3.4	3.4	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
7	Max. efficiency	%	80	75	75	70	70	60	60	60	50	50	50	50
8	Weight	g	118	162	162	194	194	226	226	226	258	258	258	258
9	Average backlash no load	°	0.7	0.8	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
10	Mass inertia	gcm²	1.5	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
11	Gearhead length L1*	mm	26.5	36.4	36.4	43.1	43.1	49.8	49.8	49.8	56.5	56.5	56.5	56.5

*for EC 32 flat L1 is + 2.0 mm



maxon Modular System

+ Motor	Page	+ Sensor/Brake	Page	Overall length [mm] = Motor length + gearhead length + (sensor/brake) + assembly parts											
RE 30, 15 W	138			94.6	104.5	104.5	111.2	111.2	117.9	117.9	117.9	124.6	124.6	124.6	124.6
RE 30, 15 W	138	MR	356	106.0	115.9	115.9	122.6	122.6	129.3	129.3	129.3	136.0	136.0	136.0	136.0
RE 30, 15 W	138	HED_ 5540	362/364	115.4	125.3	125.3	132.0	132.0	138.7	138.7	138.7	145.4	145.4	145.4	145.4
RE 30, 60 W	139			94.6	104.5	104.5	111.2	111.2	117.9	117.9	117.9	124.6	124.6	124.6	124.6
RE 30, 60 W	139	MR	356	106.0	115.9	115.9	122.6	122.6	129.3	129.3	129.3	136.0	136.0	136.0	136.0
RE 30, 60 W	139	HED_ 5540	362/364	115.4	125.3	125.3	132.0	132.0	138.7	138.7	138.7	145.4	145.4	145.4	145.4
RE 35, 90 W	140			97.6	107.5	107.5	114.2	114.2	120.9	120.9	120.9	127.6	127.6	127.6	127.6
RE 35, 90 W	140	MR	356	109.0	118.9	118.9	125.6	125.6	132.3	132.3	132.3	139.0	139.0	139.0	139.0
RE 35, 90 W	140	HED_ 5540	362/364	118.3	128.2	128.2	134.9	134.9	141.6	141.6	141.6	148.3	148.3	148.3	148.3
RE 35, 90 W	140	DCT 22	373	115.7	125.6	125.6	132.3	132.3	139.0	139.0	139.0	145.7	145.7	145.7	145.7
RE 35, 90 W	140	AB 28	408	133.7	143.6	143.6	150.3	150.3	157.0	157.0	157.0	163.7	163.7	163.7	163.7
RE 35, 90 W	140	HEDS 5540/AB 28	362/408	150.9	160.8	160.8	167.5	167.5	174.2	174.2	174.2	180.9	180.9	180.9	180.9
A-max 32	169/171			89.5	99.4	99.4	106.1	106.1	112.8	112.8	112.8	119.5	119.5	119.5	119.5
A-max 32	170/172			88.1	98.0	98.0	104.7	104.7	111.4	111.4	111.4	118.1	118.1	118.1	118.1
A-max 32	170/172	MR	356	99.3	109.2	109.2	115.9	115.9	122.6	122.6	122.6	129.3	129.3	129.3	129.3
A-max 32	170/172	HED_ 5540	363/365	108.9	118.8	118.8	125.5	125.5	132.2	132.2	132.2	138.9	138.9	138.9	138.9
EC 32, 80 W	214			86.6	96.5	96.5	103.2	103.2	109.9	109.9	109.9	116.6	116.6	116.6	116.6
EC 32, 80 W	214	HED_ 5540	363/366	105.0	114.9	114.9	121.6	121.6	128.3	128.3	128.3	135.0	135.0	135.0	135.0
EC 32, 80 W	214	Res 26	374	106.7	116.6	116.6	123.3	123.3	130.0	130.0	130.0	136.7	136.7	136.7	136.7
EC 32 flat, 15 W	258			44.5	54.4	54.4	61.1	61.1	67.8	67.8	67.8	74.5	74.5	74.5	74.5
EC 32 flat, IE, IP 00	259			54.6	64.5	64.5	71.2	71.2	77.9	77.9	77.9	84.6	84.6	84.6	84.6
EC 32 flat, IE, IP 40	259			56.3	66.2	66.2	72.9	72.9	79.6	79.6	79.6	86.3	86.3	86.3	86.3

Aqua Logic Digital Temperature Controller

Read 39 reviews Write A Review

Item #: Please make a selection

Style: Please select...

Size: Please select...

Quantity: 1

From $130.00 + Add to Cart

60 DAY RETURNS ASK THE EXPERTS

Product Description Customer Reviews Accessories & Similar Items

Aqua Logic Digital Temperature Controller Information
Product Manuals & Documentation

Aqua Logic Single Stage Digital Controller - heater OR chiller up to 1/2hp

LCD Electronic Temperature Controller - This device is operable from a distance of up to 400 feet and has a superior accuracy for pinpoint temperature control of -30 °F to 220 °F. This digital display is easy to read and a pushbutton control allows you to choose selectable heating and cooling modes. It is not easy to find all these features in such an inexpensive monitor. A keypad lockout provides tamperproof protection. EEPROM memory retains control settings during power outage. This is an OEM product for some of the largest industrial chiller & heater manufacturers. Outperforms other thermostats which cost substantially more. Input power requirements 115 volts. Can control heater or chiller of up to 1/2HP or approx. 1,000 watts!

Specifications

Dimensions: 6.52" x 2.7" x 2.48". Made in the USA.

- Temperature differential range of 1 °F to 30 °F
- +/- 1° F Differential (i.e. can be set to turn on heat at 79 and off at 80; or turn chiller (or cooling fan) on at 85 and off at 65, etc.)
- Easy programming of setpoints, differential and heating/cooling mode using 3 front-mounted buttons. Select F or C scales at the push of a button.
- Pre-wired with power cord & remote sensor on 8-foot cable. Can be extended up to 400 feet using standard 22 gauge sensor wire (not included)
- LCD readout of sensor temperature, control settings, relay status and onboard diagnostics.
- Watertight Titanium Encapsulated Thermistor.

Product Manuals & Documentation

Aqua Logic Digital Temperature Controller - Single Stage
Owner's Manual available for download in Adobe PDF file format

Manufacturer Info

Aqua Logic Aquarium Supplies
Aqua Logic was founded in 1989 to meet the demand for quality products in the live seafood and aquaculture industries. Among the products that

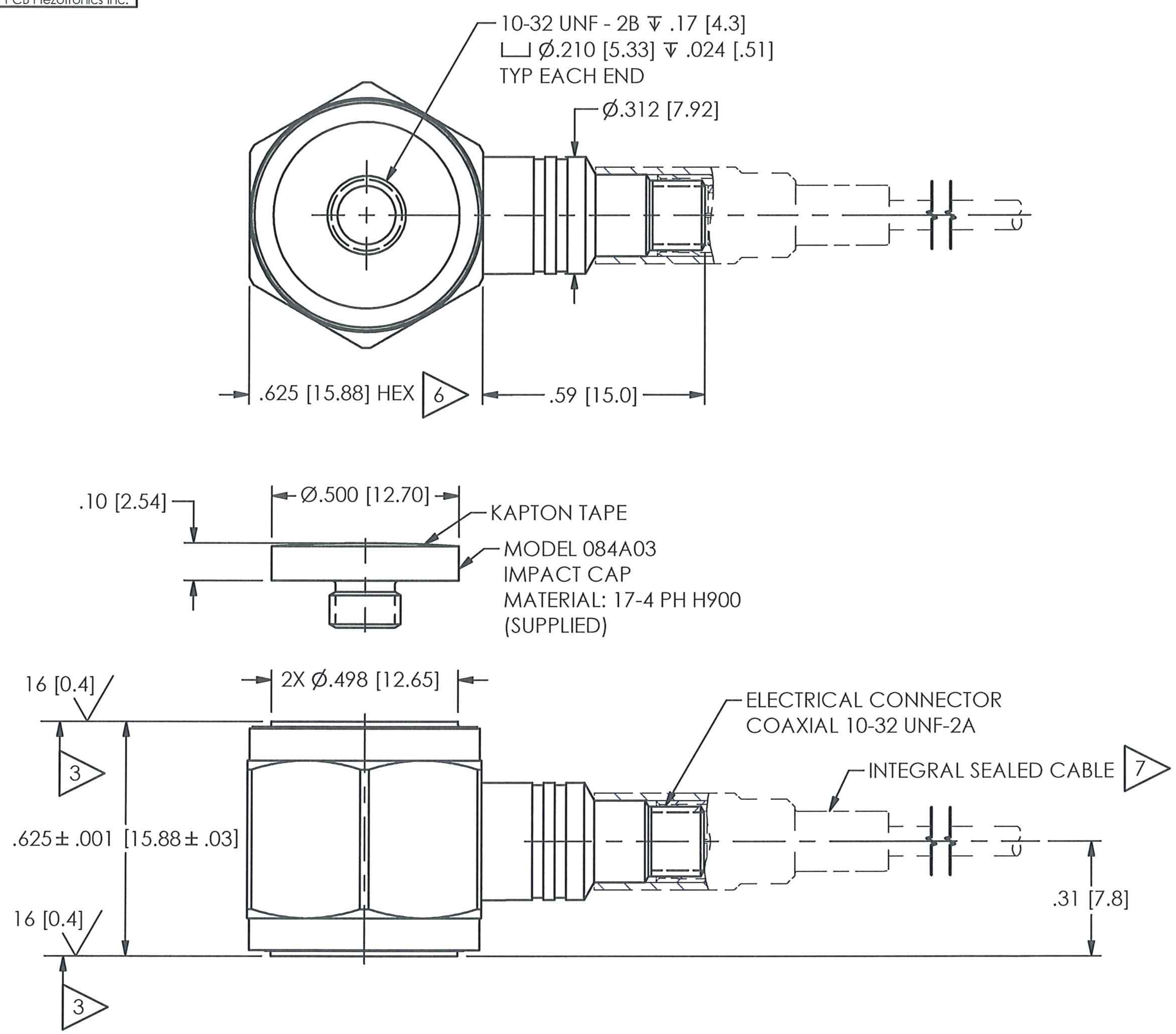
Aqua Logic has developed are titanium water chillers, heat pumps, heat exchangers, filters, display and holding tanks. Over the years, the company has expanded the art of aquatic filtration and temperature control to meet the needs of a variety of applications including public aquariums, zoos, theme parks and resorts, research labs and hydroponics facilities worldwide. Knowledge of materials and process are the cornerstone of its state-of-the-art manufacturing facility where all Aqua Logic's products are carefully designed and built by fabricating with titanium, stainless steel, aluminum, fiberglass, plastics and wood.

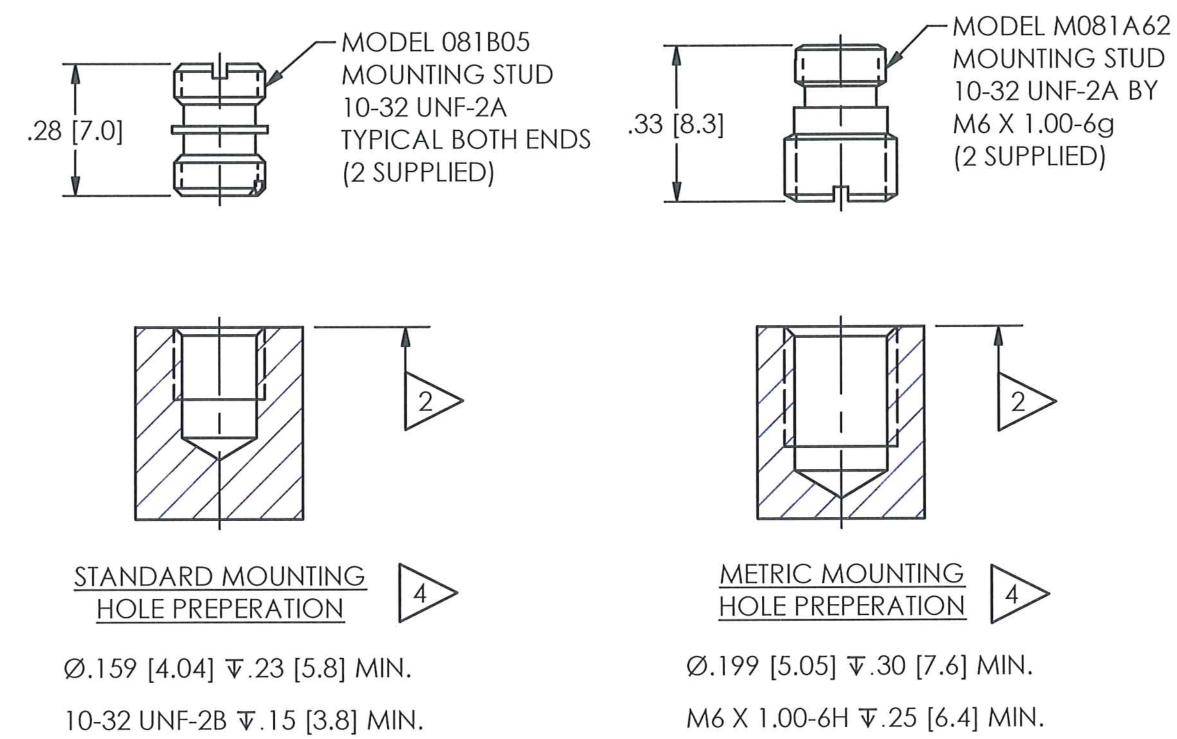
Warranty

Manufacturer`s Waranty: 1 year from date of purchase.

8561

REVISIONS		
REV	DESCRIPTION	DIN
E	ADDED NOTE 7	39128





7. ADD CABLE FOR WATER RESISTANT OPTION.

6. MOUNTING TORQUE ON .625[15.88] HEX, 16-20 IN-LBS [181-226 Ncm].

5.) COMPRESSIVE FORCE ON CELL YIELDS POSITIVE OUTPUT VOLTAGE.

4. DRILL PERPENDICULAR TO MOUNTING SURFACE TO WITHIN ±1°.

3. THESE SURFACES GROUND FLAT AND PARALLEL TO WITHIN .001[0.03] TIR.

2. MOUNTING SURFACE TO BE FLAT TO WITHIN .001[0.03] TIR WITH A MIN 125 [3.2] √

1.) CASE MATERIAL-STAINLESS STEEL.

UNLESS OTHERWISE SPECIFIED TOLERANCES ARE:	
DIMENSIONS IN INCHES	DIMENSIONS IN MILLIMETERS [IN BRACKETS]
DECIMALS XX ±.01, XXX ±.005	DECIMALS X ± 0.3, XX ± 0.13
ANGLES ± 2 DEGREES	ANGLES ± 2 DEGREES
FILLETS AND RADII .003 - .005	FILLETS AND RADII 0.07 - 0.13

DRAWN		CHECKED		ENGINEER	
JDM	6/5/12	ECB	6/12	JDK	6/5/12

TITLE: INSTALLATION DRAWING GENERAL PURPOSE ICP® FORCE SENSOR

PCB PIEZOTRONICS
3425 WALDEN AVE. DEPEW, NY 14043
(716) 684-0001 E-MAIL: sales@pcb.com

CODE IDENT. NO. 52681 | DWG. NO. 8561

SCALE: 2.5X | SHEET 1 OF 1

Model Number 208C01	ICP® FORCE SENSOR	Revision: K ECN #: 45224

Performance	ENGLISH	SI	
Sensitivity(± 15 %)	500 mV/lb	112,410 mV/kN	
Measurement Range(Compression)	10 lb	0.04448 kN	
Measurement Range(Tension)	10 lb	0.04448 kN	
Maximum Static Force(Compression)	60 lb	0.27 kN	
Maximum Static Force(Tension)	60 lb	0.27 kN	
Broadband Resolution(1 to 10,000 Hz)	0.0001 lb-rms	0.00045 N-rms	[2]
Low Frequency Response(-5 %)	0.01 Hz	0.01 Hz	[3]
Upper Frequency Limit	36,000 Hz	36,000 Hz	[4]
Non-Linearity	≤ 1 % FS	≤ 1 % FS	[5]
Environmental			
Temperature Range	-65 to +250 °F	-54 to +121 °C	
Temperature Coefficient of Sensitivity	≤ 0.05 %/°F	≤ 0.09 %/°C	
Electrical			
Discharge Time Constant(at room temp)	≥ 50 sec	≥ 50 sec	
Excitation Voltage	18 to 30 VDC	18 to 30 VDC	
Constant Current Excitation	2 to 20 mA	2 to 20 mA	
Output Impedance	≤ 100 Ohm	≤ 100 Ohm	
Output Bias Voltage	8 to 12 VDC	8 to 12 VDC	[1]
Spectral Noise(1 Hz)	0.0000126 lb/√Hz	0.0000562 N/√Hz	[2]
Spectral Noise(10 Hz)	0.0000042 lb/√Hz	0.0000189 N/√Hz	[2]
Spectral Noise(100 Hz)	0.0000015 lb/√Hz	0.0000067 N/√Hz	[2]
Spectral Noise(1000 Hz)	0.0000005 lb/√Hz	0.0000023 N/√Hz	[2]
Output Polarity(Compression)	Positive	Positive	
Physical			
Stiffness	6 lb/µin	1.05 kN/µm	[2]
Size (Hex x Height x Sensing Surface)	0.625 in x 0.625 in x 0.500 in	15.88 mm x 15.88 mm x 12.7 mm	
Weight	0.80 oz	22.7 gm	
Housing Material	Stainless Steel	Stainless Steel	
Sealing	Hermetic	Hermetic	
Electrical Connector	10-32 Coaxial Jack	10-32 Coaxial Jack	
Electrical Connection Position	Side	Side	
Mounting Thread	10-32 Female	10-32 Female	

CE [6]

All specifications are at room temperature unless otherwise specified.
In the interest of constant product improvement, we reserve the right to change specifications without notice.

OPTIONAL VERSIONS

Optional versions have identical specifications and accessories as listed for the standard model except where noted below. More than one option may be used.

N - Negative Output Polarity

Output Polarity(Compression)	Negative	Negative

W - Water Resistant Cable

NOTES:

[1]Sensor contains protected electronics which may cause long 'turn-on" times.
[2]Typical.
[3]Calculated from discharge time constant.
[4]Estimated using rigid body dynamics calculations.
[5]Zero-based, least-squares, straight line method.
[6]See PCB Declaration of Conformance PS023 for details.

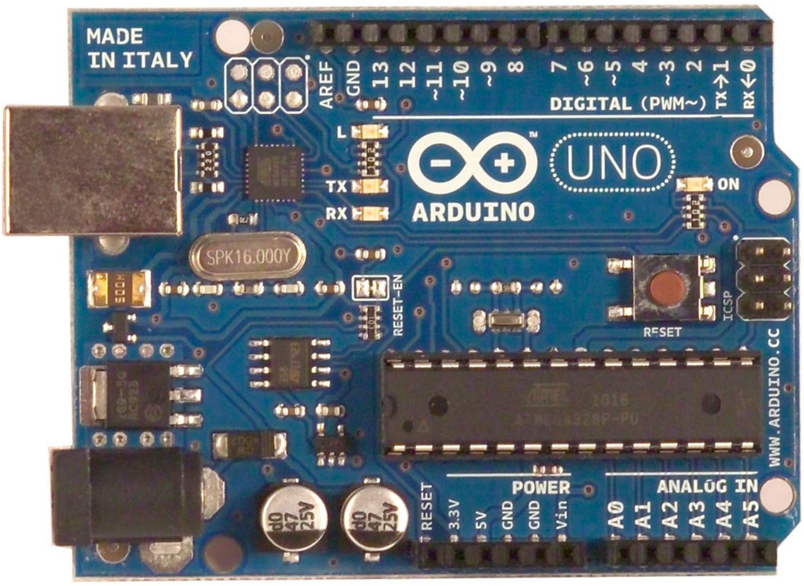
SUPPLIED ACCESSORIES:

Model 080A81 Thread Locker (1)
Model 081B05 Mounting Stud (10-32 to 10-32) (2)
Model 084A03 Impact Cap (1)
Model M081A62 Mounting stud, 10-32 to M6 x 1, BeCu with shoulder (2)

Entered: LK	Engineer: MJK	Sales: KWW	Approved: APB	Spec Number:
Date: 3/29/2016	Date: 3/29/2016	Date: 3/29/2016	Date: 3/29/2016	8625

PCB PIEZOTRONICS
3425 Walden Avenue, Depew, NY 14043
Phone: 716-684-0001
Fax: 716-684-0987
E-Mail: info@pcb.com

Arduino UNO



Product Overview

The Arduino Uno is a microcontroller board based on the ATmega328 (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. The Uno differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega8U2 programmed as a USB-to-serial converter.

"Uno" means one in Italian and is named to mark the upcoming release of Arduino 1.0. The Uno and version 1.0 will be the reference versions of Arduno, moving forward. The Uno is the latest in a series of USB Arduino boards, and the reference model for the Arduino platform; for a comparison with previous versions, see the index of Arduino boards.

Index

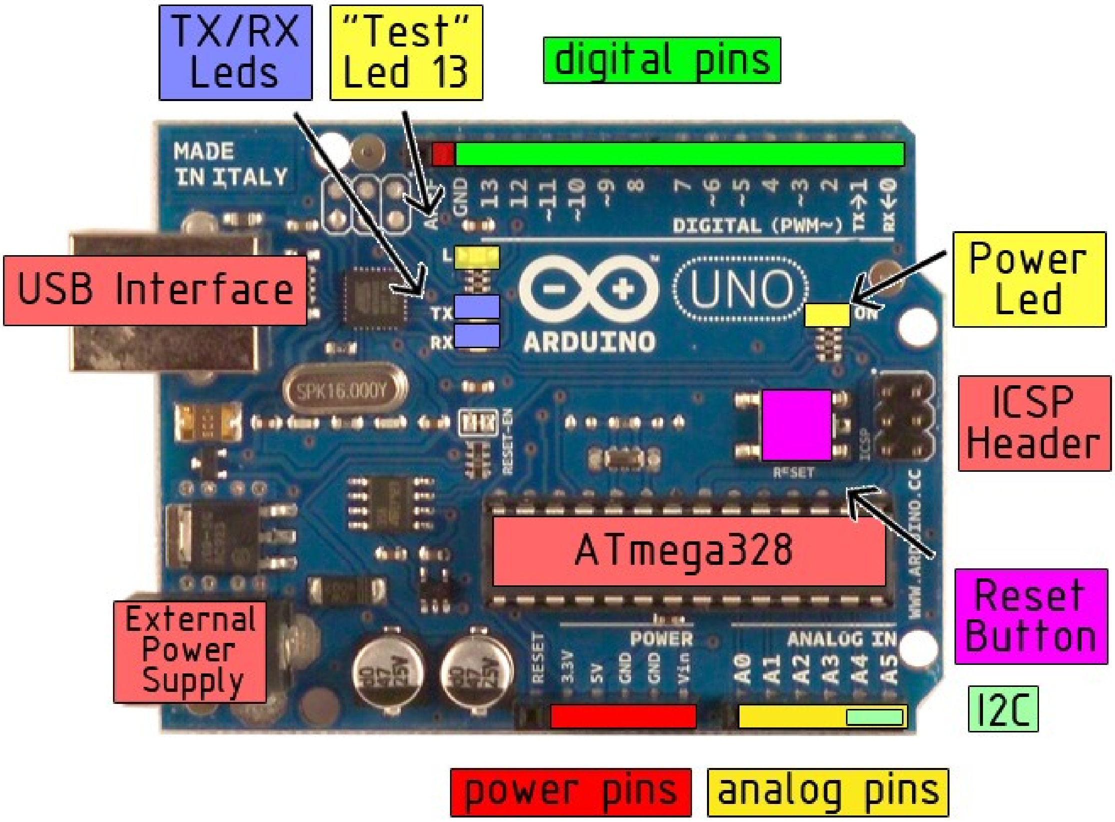
Technical Specification

EAGLE files: arduino-duemilanove-uno-design.zip Schematic: arduino-uno-schematic.pdf

Summary

Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB of which 0.5 KB used by bootloader
SRAM	2 KB
EEPROM	1 KB
Clock Speed	16 MHz

the board



Power

The Arduino Uno can be powered via the USB connection or with an external power supply. The power source is selected automatically.

External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Leads from a battery can be inserted in the Gnd and Vin pin headers of the POWER connector.

The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may be unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.

The power pins are as follows:

- **VIN.** The input voltage to the Arduino board when it's using an external power source (as opposed to 5 volts from the USB connection or other regulated power source). You can supply voltage through this pin, or, if supplying voltage via the power jack, access it through this pin.
- **5V.** The regulated power supply used to power the microcontroller and other components on the board. This can come either from VIN via an on-board regulator, or be supplied by USB or another regulated 5V supply.
- **3V3.** A 3.3 volt supply generated by the on-board regulator. Maximum current draw is 50 mA.
- **GND.** Ground pins.

Memory

The Atmega328 has 32 KB of flash memory for storing code (of which 0,5 KB is used for the bootloader); It has also 2 KB of SRAM and 1 KB of EEPROM (which can be read and written with the EEPROM library).

Input and Output

Each of the 14 digital pins on the Uno can be used as an input or output, using pinMode(), digitalWrite(), and digitalRead() functions. They operate at 5 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (disconnected by default) of 20-50 kOhms. In addition, some pins have specialized functions:

- **Serial: 0 (RX) and 1 (TX).** Used to receive (RX) and transmit (TX) TTL serial data. TThese pins are connected to the corresponding pins of the ATmega8U2 USB-to-TTL Serial chip .
- **External Interrupts: 2 and 3.** These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. See the attachInterrupt() function for details.
- **PWM: 3, 5, 6, 9, 10, and 11.** Provide 8-bit PWM output with the analogWrite() function.
- **SPI: 10 (SS), 11 (MOSI), 12 (MISO), 13 (SCK).** These pins support SPI communication, which, although provided by the underlying hardware, is not currently included in the Arduino language.

- **LED: 13.** There is a built-in LED connected to digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off.

The Uno has 6 analog inputs, each of which provide 10 bits of resolution (i.e. 1024 different values). By default they measure from ground to 5 volts, though is it possible to change the upper end of their range using the AREF pin and the analogReference() function. Additionally, some pins have specialized functionality:

- **I^2C: 4 (SDA) and 5 (SCL).** Support I^2C (TWI) communication using the Wire library.

There are a couple of other pins on the board:

- **AREF.** Reference voltage for the analog inputs. Used with analogReference().
- **Reset.** Bring this line LOW to reset the microcontroller. Typically used to add a reset button to shields which block the one on the board.

See also the mapping between Arduino pins and Atmega328 ports.

Communication

The Arduino Uno has a number of facilities for communicating with a computer, another Arduino, or other microcontrollers. The ATmega328 provides UART TTL (5V) serial communication, which is available on digital pins 0 (RX) and 1 (TX). An ATmega8U2 on the board channels this serial communication over USB and appears as a virtual com port to software on the computer. The '8U2 firmware uses the standard USB COM drivers, and no external driver is needed. However, on Windows, an *.inf file is required..

The Arduino software includes a serial monitor which allows simple textual data to be sent to and from the Arduino board. The RX and TX LEDs on the board will flash when data is being transmitted via the USB-to-serial chip and USB connection to the computer (but not for serial communication on pins 0 and 1).

A SoftwareSerial library allows for serial communication on any of the Uno's digital pins.

The ATmega328 also support I2C (TWI) and SPI communication. The Arduino software includes a Wire library to simplify use of the I2C bus; see the documentation for details. To use the SPI communication, please see the ATmega328 datasheet.

Programming

The Arduino Uno can be programmed with the Arduino software (download). Select "Arduino Uno w/ ATmega328" from the **Tools > Board** menu (according to the microcontroller on your board). For details, see the reference and tutorials.

The ATmega328 on the Arduino Uno comes preburned with a bootloader that allows you to upload new code to it without the use of an external hardware programmer. It communicates using the original STK500 protocol (reference, C header files).

You can also bypass the bootloader and program the microcontroller through the ICSP (In-Circuit Serial Programming) header; see these instructions for details.

The ATmega8U2 firmware source code is available . The ATmega8U2 is loaded with a DFU bootloader, which can be activated by connecting the solder jumper on the back of the board (near the map of Italy) and then resetting the 8U2. You can then use Atmel's FLIP software (Windows) or the DFU programmer (Mac OS X and Linux) to load a new firmware. Or you can use the ISP header with an external programmer (overwriting the DFU bootloader).

Automatic (Software) Reset

Rather than requiring a physical press of the reset button before an upload, the Arduino Uno is designed in a way that allows it to be reset by software running on a connected computer. One of the hardware flow control lines (DTR) of the ATmega8U2 is connected to the reset line of the ATmega328 via a 100 nanofarad capacitor. When this line is asserted (taken low), the reset line drops long enough to reset the chip. The Arduino software uses this capability to allow you to upload code by simply pressing the upload button in the Arduino environment. This means that the bootloader can have a shorter timeout, as the lowering of DTR can be well-coordinated with the start of the upload.

This setup has other implications. When the Uno is connected to either a computer running Mac OS X or Linux, it resets each time a connection is made to it from software (via USB). For the following half-second or so, the bootloader is running on the Uno. While it is programmed to ignore malformed data (i.e. anything besides an upload of new code), it will intercept the first few bytes of data sent to the board after a connection is opened. If a sketch running on the board receives one-time configuration or other data when it first starts, make sure that the software with which it communicates waits a second after opening the connection and before sending this data.

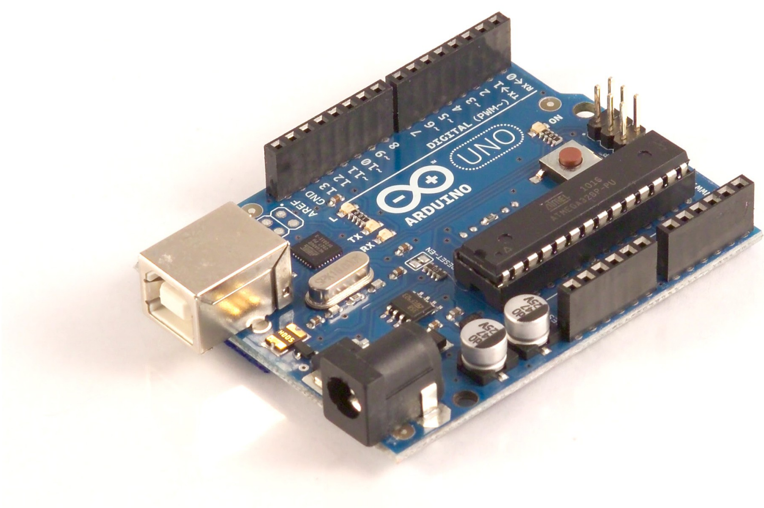
The Uno contains a trace that can be cut to disable the auto-reset. The pads on either side of the trace can be soldered together to re-enable it. It's labeled "RESET-EN". You may also be able to disable the auto-reset by connecting a 110 ohm resistor from 5V to the reset line; see this forum thread for details.

USB Overcurrent Protection

The Arduino Uno has a resettable polyfuse that protects your computer's USB ports from shorts and overcurrent. Although most computers provide their own internal protection, the fuse provides an extra layer of protection. If more than 500 mA is applied to the USB port, the fuse will automatically break the connection until the short or overload is removed.

Physical Characteristics

The maximum length and width of the Uno PCB are 2.7 and 2.1 inches respectively, with the USB connector and power jack extending beyond the former dimension. Three screw holes allow the board to be attached to a surface or case. Note that the distance between digital pins 7 and 8 is 160 mil (0.16"), not an even multiple of the 100 mil spacing of the other pins.



How to use Arduino

Arduino can sense the environment by receiving input from a variety of sensors and can affect its surroundings by controlling lights, motors, and other actuators. The microcontroller on the board is programmed using the Arduino programming language (based on Wiring) and the Arduino development environment (based on Processing). Arduino projects can be stand-alone or they can communicate with software on running on a computer (e.g. Flash, Processing, MaxMSP).

Arduino is a cross-platoform program. You'll have to follow different instructions for your personal OS. Check on the Arduino site for the latest instructions. *http://arduino.cc/en/Guide/HomePage*

Linux Install

Windows Install

Mac Install

Once you have downloaded/unzipped the arduino IDE, you can Plug the Arduino to your PC via USB cable.

Blink led

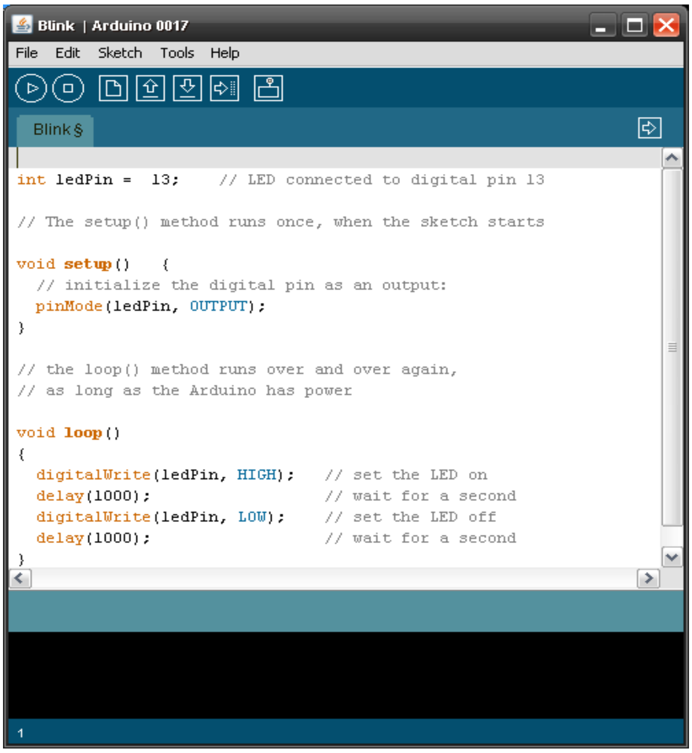
Now you're actually ready to "burn" your first program on the arduino board. To select "blink led", the physical translation of the well known programming "hello world", select

File>Sketchbook>
Arduino-0017>Examples>
Digital>Blink

Once you have your skecth you'll see something very close to the screenshot on the right.

In **Tools>Board** select

Now you have to go to
Tools>SerialPort
and select the right serial port, the one arduino is attached to.



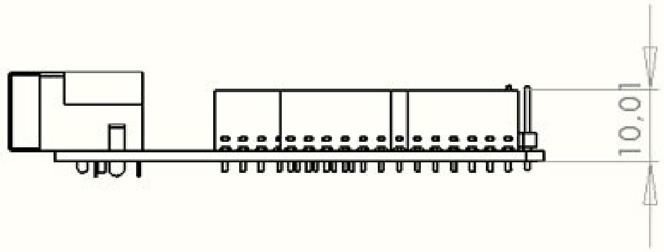
Done compiling.

Press Compile button
(to check for errors)

Upload

TX RX Flashing

Blinking Led!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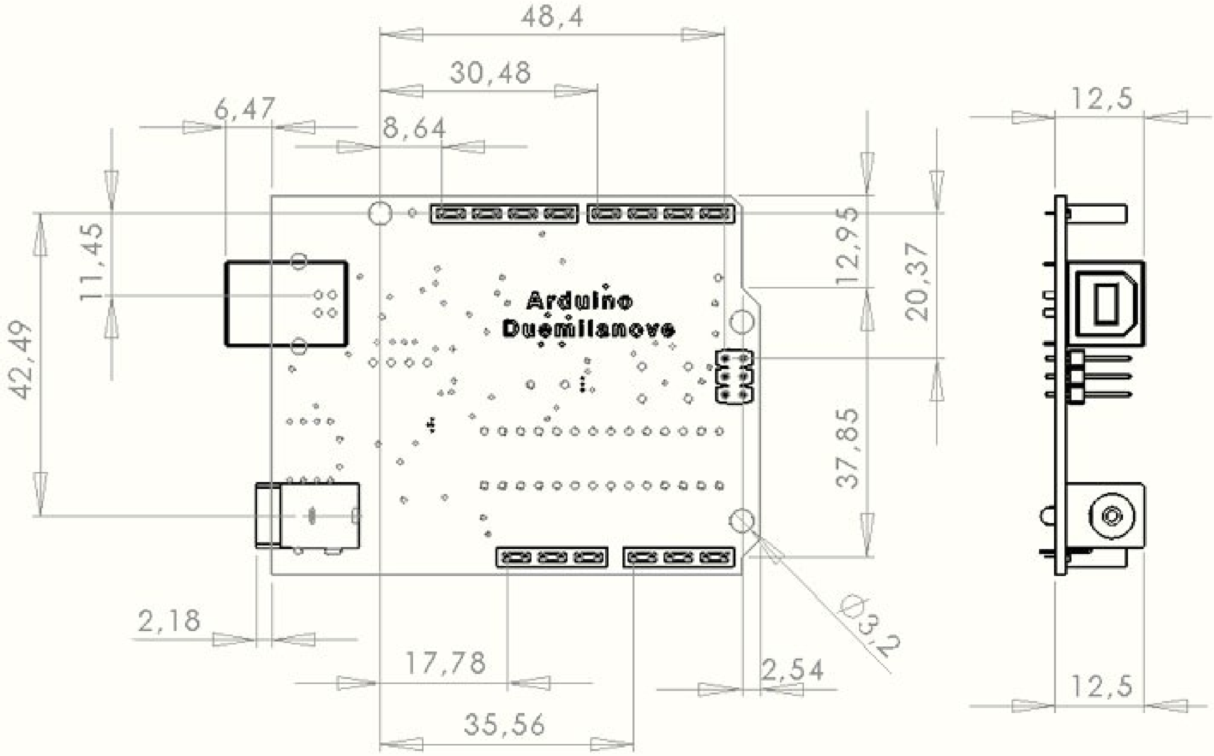
48,4
30,48
6,47
8,64
11,45
42,49
12,95
20,37
37,85
Arduino
Duemilanove
2,18
17,78
35,56
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Ø3,2
12,5
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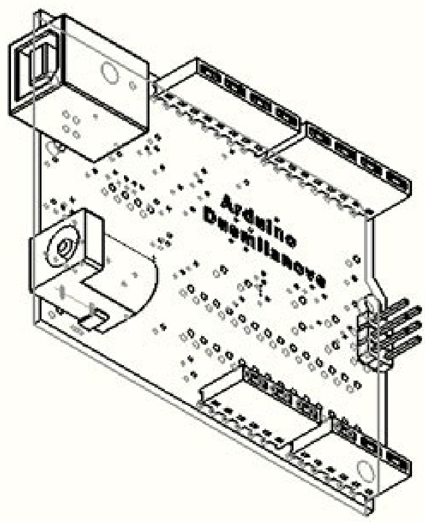
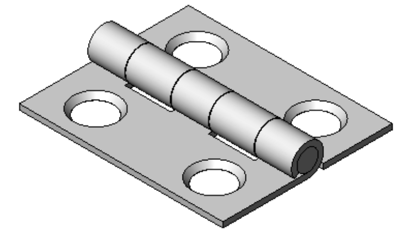
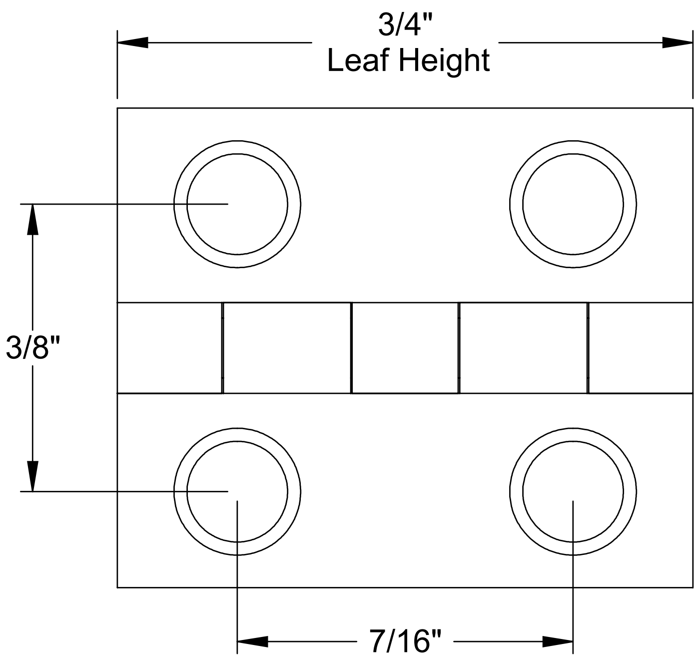
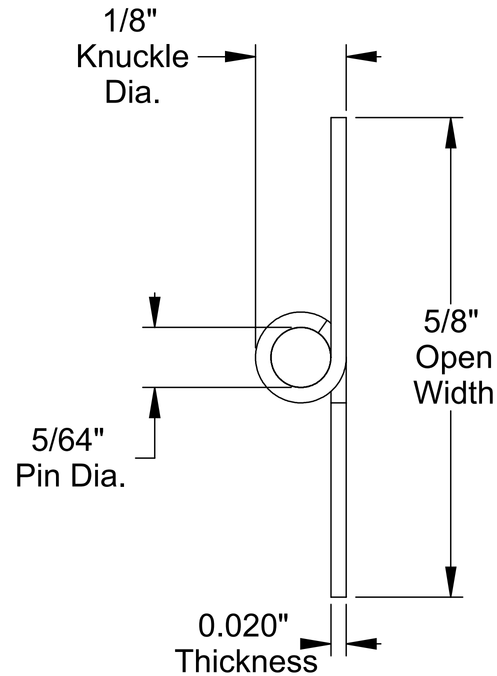

Arduino
Duemilanove







Hinge uses #2 screws.

McMASTER-CARR® CAD	PART NUMBER	1603A2
http://www.mcmaster.com © 2013 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Surface-Mount Hinge	

FAIRCHILD SEMICONDUCTOR®

August 2008

QED121, QED122, QED123
Plastic Infrared Light Emitting Diode

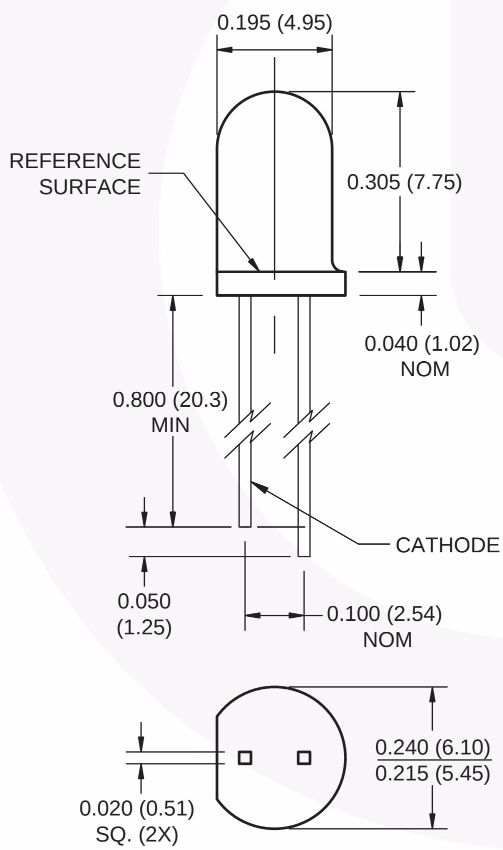
Features

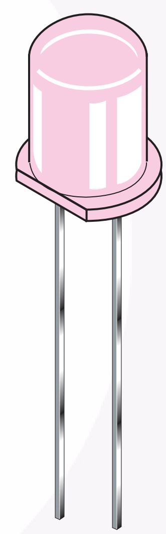
- λ = 880nm
- Chip material = AlGaAs
- Package type: T-1 3/4 (5mm lens diameter)
- Matched photosensor: QSD122/QSD123/QSD124
- Narrow emission angle, 16°
- High output power
- Package material and color: clear, peach tinted, plastic

Description

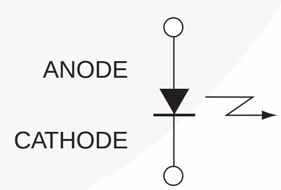
The QED121, QED122 and QED123 are 880nm AlGaAs LEDs encapsulated in a clear peach tinted, plastic T-1 3/4 package.

Package Dimensions





Schematic



Notes:

1. Dimensions of all drawings are in inches (mm).
2. Tolerance is ±0.010 (0.25) on all non-nominal dimensions unless otherwise specified.

Absolute Maximum Ratings (T_A = 25°C unless otherwise specified)

Stresses exceeding the absolute maximum ratings may damage the device. The device may not function or be operable above the recommended operating conditions and stressing the parts to these levels is not recommended. In addition, extended exposure to stresses above the recommended operating conditions may affect device reliability. The absolute maximum ratings are stress ratings only.

Symbol	Parameter	Rating	Units
T_{OPR}	Operating Temperature	-40 to +100	°C
T_{STG}	Storage Temperature	-40 to +100	°C
T_{SOL-I}	Soldering Temperature (Iron)(2)(3)(4)	240 for 5 sec	°C
T_{SOL-F}	Soldering Temperature (Flow)(2)(3)	260 for 10 sec	°C
I_F	Continuous Forward Current	100	mA
V_R	Reverse Voltage	5	V
P_D	Power Dissipation(1)	200	mW

Notes:

1. Derate power dissipation linearly 2.67mW/°C above 25°C.
2. RMA flux is recommended.
3. Methanol or isopropyl alcohols are recommended as cleaning agents.
4. Soldering iron 1/16" (1.6mm) minimum from housing.

Electrical / Optical Characteristics (T_A = 25°C)

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Units
λ_{PE}	Peak Emission Wavelength	I_F = 20mA		890		nm
TC_λ	Temperature Coefficient			0.2		nm / °C
$2\Theta^1/2$	Emission Angle	I_F = 100mA		16		°
V_F	Forward Voltage	I_F = 100mA, tp = 20ms			1.7	V
TC_{VF}	Temperature Coefficient			-6		mV / °C
I_R	Reverse Current	V_R = 5V			10	µA
I_E	Radiant Intensity QED121	I_F = 100mA, tp = 20ms	16		40	mW/sr
I_E	Radiant Intensity QED122	I_F = 100mA, tp = 20ms	32		100	mW/sr
I_E	Radiant Intensity QED123	I_F = 100mA, tp = 20ms	50	70		mW/sr
TC_{IE}	Temperature Coefficient			-0.3		% / °C
t_r	Rise Time	I_F = 100mA		900		ns
t_f	Fall Time			800		ns
C_j	Junction Capacitance	V_R = 0V		11		pF

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Green FPS™
Green FPS™ e-Series™
GTO™
IntelliMAX™
ISOPLANAR™
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2. A critical component in any component of a life support, device, or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

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PRODUCT STATUS DEFINITIONS

Definition of Terms

Datasheet Identification	Product Status	Definition
Advance Information	Formative / In Design	Datasheet contains the design specifications for product development. Specifications may change in any manner without notice.
Preliminary	First Production	Datasheet contains preliminary data; supplementary data will be published at a later date. Fairchild Semiconductor reserves the right to make changes at any time without notice to improve design.
No Identification Needed	Full Production	Datasheet contains final specifications. Fairchild Semiconductor reserves the right to make changes at any time without notice to improve the design.
Obsolete	Not In Production	Datasheet contains specifications on a product that is discontinued by Fairchild Semiconductor. The datasheet is for reference information only.

Rev. I36

Silicon PIN Photodiode
Silizium-PIN-Fotodiode
Version 1.1

SFH 203, SFH 203 FA

SFH 203

SFH 203 FA

Features:
- Wavelength range (S10%) 400 nm to 1100 nm (SFH 203) and 750 nm to 1100 nm (SFH 203FA)
- Short switching time (typ. 5 ns)
- 5 mm LED plastic package

Besondere Merkmale:
- Wellenlängenbereich (S10%) 400 nm bis 1100 nm (SFH203) und 750 nm bis 1100 nm (SFH203FA)
- Kurze Schaltzeit (typ. 5 ns)
- 5 mm-Plastikbauform im LED-Gehäuse

Applications
- Industrial electronics
- For control and drive circuits
- High speed photointerrupters

Anwendungen
- Industrieelektronik
- Messen / Steuern / Regeln
- Schnelle Lichtschranken

Ordering Information
Bestellinformation

Type: **Typ:**	**Photocurrent** **Fotostrom** **V_R = 5 V, Std. Light A, E_V = 1000 lx (SFH 203)** **V_R = 5 V, λ = 870 nm, E_e = 1 mW/cm^2 (SFH 203 FA)** **I_P [µA]**	**Ordering Code** **Bestellnummer**
SFH 203	80 (≥ 50)	Q62702P0955
SFH 203 FA	50 (≥ 30)	Q62702P0956

Maximum Ratings (T_A = 25 °C)
Grenzwerte

Parameter Bezeichnung	Symbol Symbol	Values Werte		Unit Einheit
		SFH 203	SFH 203 FA	
Operating and storage temperature range Betriebs- und Lagertemperatur	T_{op}; T_{stg}	-40 ... 100		°C
Reverse voltage Sperrspannung	V_R	20		V
Reverse voltage Sperrspannung (t < 2 min)	V_R	50		V
Total power dissipation Verlustleistung	P_{tot}	150		mW

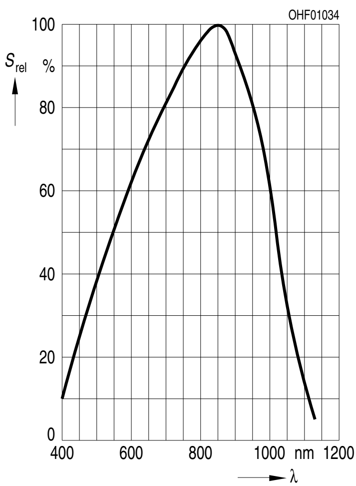
Characteristics (T_A = 25 °C)
Kennwerte

Parameter Bezeichnung	Symbol Symbol	Values Werte		Unit Einheit
		SFH 203	SFH 203 FA	
Photocurrent Fotostrom (E_v = 1000 lx, Std. Light A, V_R = 5 V)	I_P	80 (≥ 50)		µA
Photocurrent Fotostrom (V_R = 5 V, λ = 870 nm, E_e = 1 mW/cm^2)	I_P		50 (≥ 30)	µA
Wavelength of max. sensitivity Wellenlänge der max. Fotoempfindlichkeit	$\lambda_{S\,max}$	850	900	nm
Spectral range of sensitivity Spektraler Bereich der Fotoempfindlichkeit	$\lambda_{10\%}$	400 ... 1100	750 ... 1100	nm
Radiant sensitive area Bestrahlungsempfindliche Fläche	A	1.00		mm^2
Dimensions of radiant sensitive area Abmessung der bestrahlungsempfindlichen Fläche	L x W	1 x 1		mm x mm
Half angle Halbwinkel	φ	± 20		°

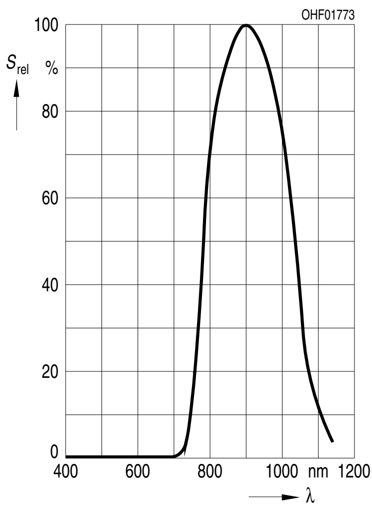
Parameter Bezeichnung	Symbol Symbol	Values Werte		Unit Einheit
		SFH 203	SFH 203 FA	
Dark current Dunkelstrom (V_R = 20 V)	I_R	1 (≤ 5)		nA
Spectral sensitivity of the chip Spektrale Fotoempfindlichkeit des Chips (λ = 850 nm)	$S_{\lambda\ typ}$	0.62		A / W
Quantum yield of the chip Quantenausbeute des Chips (λ = 850 nm)	η	0.90		Electrons /Photon
Open-circuit voltage Leerlaufspannung (E_v = 1000 lx, Std. Light A)	V_O	420 (≥ 350)		mV
Open-circuit voltage Leerlaufspannung (E_e = 0.5 mW/cm^2, λ = 870 nm)	V_O		370 (≥ 300)	mV
Short-circuit current Kurzschlussstrom (E_v = 1000 lx, Std. Light A)	I_{SC}	80		µA
Short-circuit current Kurzschlussstrom (E_e = 0.5 mW/cm^2, λ = 870 nm)	I_{SC}		25	µA
Rise and fall time Anstiegs- und Abfallzeit (V_R = 20 V, R_L = 50 Ω, λ = 850 nm)	t_r, t_f	0.005		µs
Forward voltage Durchlassspannung (I_F = 100 mA, E = 0)	V_F	1.3		V
Capacitance Kapazität (V_R = 0 V, f = 1 MHz, E = 0)	C_0	11		pF
Temperature coefficient of V_O Temperaturkoeffizient von V_O	TC_V	-2.6		mV / K
Temperature coefficient of I_{SC} Temperaturkoeffizient von I_{SC} (Std. Light A)	TC_I	0.18		% / K

Parameter Bezeichnung	Symbol Symbol	Values Werte		Unit Einheit
		SFH 203	SFH 203 FA	
Temperature coefficient of I_{SC} Temperaturkoeffizient von I_{SC} (λ = 870 nm)	TC_I		0.1	% / K
Noise equivalent power Rauschäquivalente Strahlungsleistung (V_R = 20 V, λ = 850 nm)	NEP	0.029		pW / $Hz^{½}$
Detection limit Nachweisgrenze	D^*	3.5e12		cm x $Hz^{½}$ / W

Relative Spectral Sensitivity
Relative spektrale Empfindlichkeit
SFH 203 $S_{rel} = f(\lambda)$

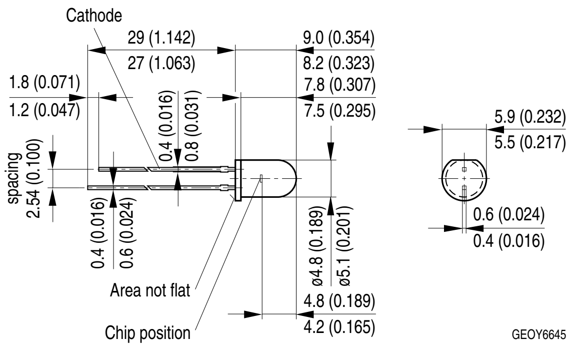


Relative Spectral Sensitivity
Relative spektrale Empfindlichkeit
SFH 203 FA $S_{rel} = f(\lambda)$



OSRAM
Opto Semiconductors

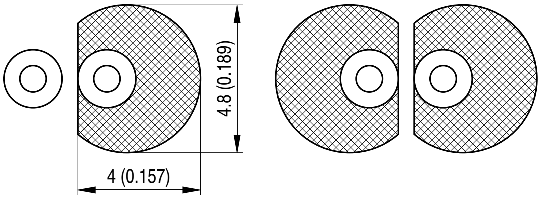
Package Outline
Maßzeichnung



Dimensions in mm (inch). / Maße in mm (inch).

Package	5mm Radial (T 1 ¾), Epoxy
Gehäuse	5mm Radial (T 1 ¾), Harz

Recommended Solder Pad
Empfohlenes Lötpaddesign
TTW Soldering / Wellenlöten (TTW)



Dimensions in mm (inch). / Maße in mm (inch).

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Attention please!
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Terms of delivery and rights to change design reserved.
Due to technical requirements components may contain dangerous substances.
For information on the types in question please contact our Sales Organization.
If printed or downloaded, please find the latest version in the Internet.

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Please use the recycling operators known to you. We can also help you – get in touch with your nearest sales office.
By agreement we will take packing material back, if it is sorted. You must bear the costs of transport. For packing material that is returned to us unsorted or which we are not obliged to accept, we shall have to invoice you for any costs incurred.

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Critical components* may only be used in life-support devices** or systems with the express written approval of OSRAM OS.

*) A critical component is a component used in a life-support device or system whose failure can reasonably be expected to cause the failure of that life-support device or system, or to affect its safety or the effectiveness of that device or system.
**) Life support devices or systems are intended (a) to be implanted in the human body, or (b) to support and/or maintain and sustain human life. If they fail, it is reasonable to assume that the health and the life of the user may be endangered.

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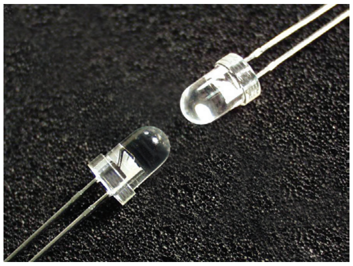
CLD-CT1094.004

Cree® 5-mm Blue and Green Round LED C503B-BAS/BAN/GAS/GAN C503B-BCS/BCN/GCS/GCN



PRODUCT DESCRIPTION

Round LEDs offer superior light output for excellent readability in sunlight and dependable performance. They provide extremely stable light output over long periods of time.

These lamps are made with an advanced optical-grade epoxy offering superior high-temperature and high-moisture-resistance performance in outdoor signal and sign applications.

FEATURES

- Size (mm): 5
- Color and Typical Dominant Wavelength:
  Blue (470nm)
  Green(527nm)
- Luminous Intensity (mcd)
  C503B-BAS/BAN:
  (4180-23500)
  C503B-BCS/BCN:
  (2130-12000)
  C503B-GAS/GAN:
  (16800-90500)
  C503B-GCS/GCN:
  (5860-32900)
- Viewing angle:
  C503B-BAS/BAN/GAS/GAN:
  15 degree
  C503B-BCS/BCN/GCS/GCN:
  30 degree
- Lead - Free
- RoHS Compliant

APPLICATIONS

- Electronic Signs & Signals (ESS)
- Motorway Signs
- Variable Message Sign (VMS)
- Advertising signs
- Petrol Signs
- Amusement

Cree, Inc.
4600 Silicon Drive
Durham, NC 27703
USA Tel: +1.919.313.5300

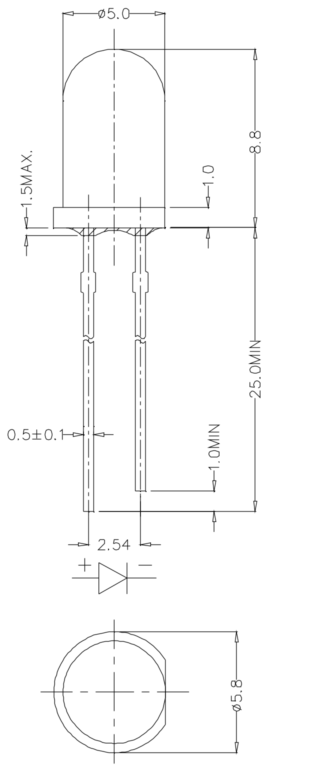
MECHANICAL DIMENSIONS

All dimensions are in mm. Tolerance is ±0.25 mm unless otherwise noted.

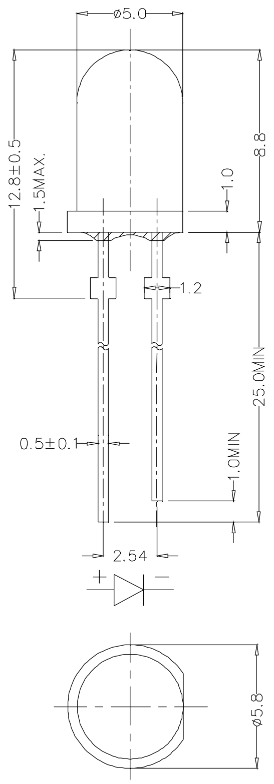
An epoxy meniscus may extend about 1.5 mm down the leads.

Burr around bottom of epoxy may be 0.5 mm max.

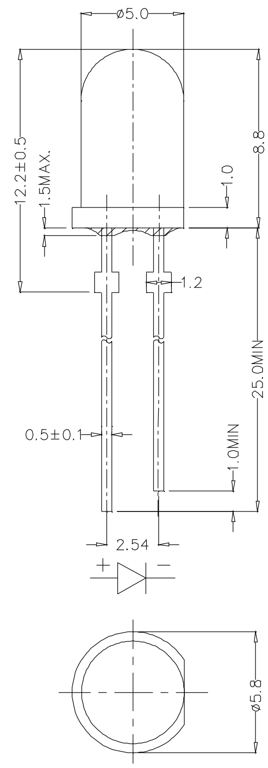
C503B-BAN/GAN/BCN/GCN:



C503B-BAS/GAS:



C503B-BCS/GCS:



NOTES

RoHS Compliance

The levels of environmentally sensitive, persistent biologically toxic (PBT), persistent organic pollutants (POP), or otherwise restricted materials in this product are below the maximum concentration values (also referred to as the threshold limits) permitted for such substances, or are used in an exempted application, in accordance with EU Directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS), as amended through April 21, 2006.

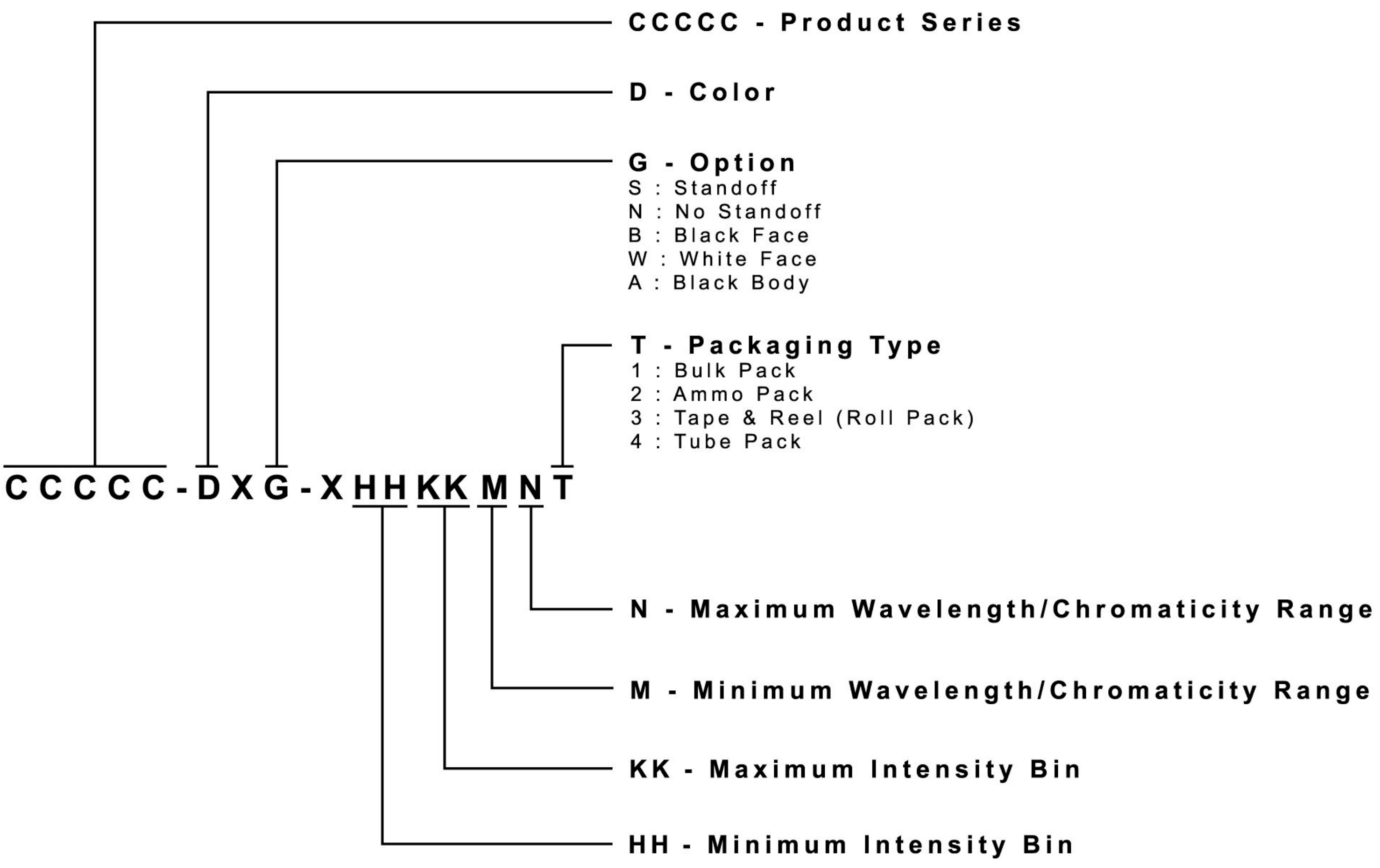
Vision Advisory Claim

Users should be cautioned not to stare at the light of this LED product. The bright light can damage the eye.

KIT NUMBER SYSTEM

All dimensions in mm.Cree LED lamps are tested and sorted into performance bins. A bin is specified by ranges of color, forward voltage, and brightness. Sorted LEDs are packaged for shipping in various convenient options. Please refer to the “Cree LED Lamp Packaging Standard” document for more information about shipping and packaging options.

Cree LEDs are sold by order codes in combinations of bins called kits. Order codes are configured in the following manner:

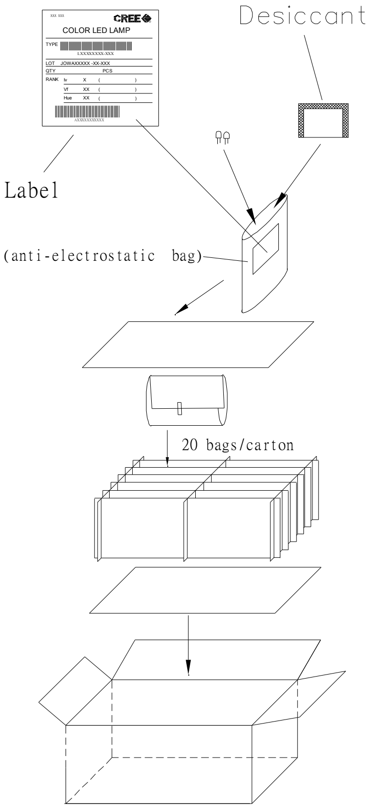


PACKAGING

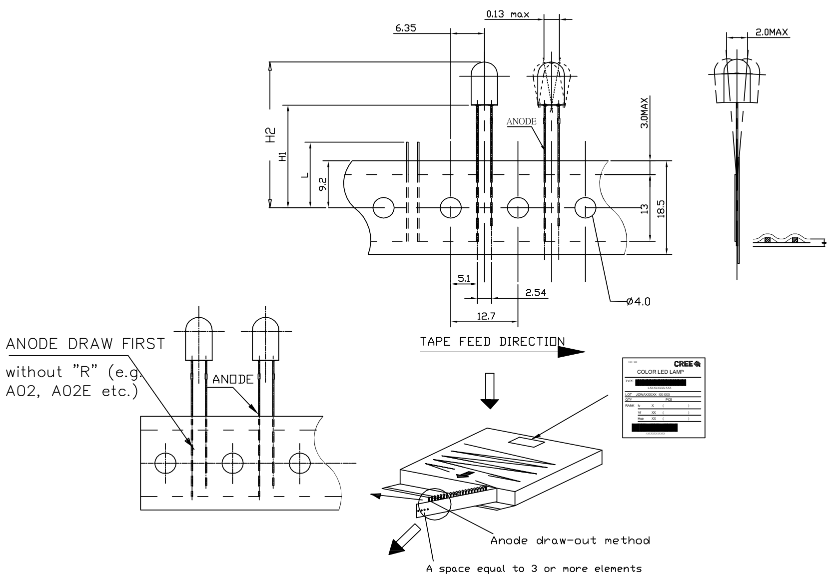
Features:

- The LEDs are packed in cardboard boxes after packaging in normal or anti-electrostatic bags.
- Cardboard boxes will be used to protect the LEDs from mechanical shock during transportation.
- The boxes are not water resistant, and they must be kept away from water and moisture.
- The Bulk Pack types of packaging.
- Max 500 pcs per bulk and Max 2500 pcs per ammo.

Bulk Pack Packaging Type:



Ammo Pack Packaging Type:



Model P160
16mm Rotary Potentiometer
Conductive Plastic Element
100,000 Cycle Life
Metal shaft / Bushing
Multi – Ganged available
RoHS Compliant

MODEL STYLES

Side Adjust , Solder Lugs	P160KNP
Side Adjust , PC pins	P160KN
Side Adjust , PC Pins, Long pins	P160KN2
Rear Adjust, PC pins	P160KNPD

ELECTRICAL[1]

Resistance Range, Ohms	500-1M
Standard Resistance Tolerance	± 20%
Residual Resistance	20 ohms max.
Power rating Input Voltage, maximum	200 Vac max.
Power Rated, Watts	0.2W- B taper, 0.1W-others
Dielectric Strength	500Vac, I minute
Insulation Resistance, Minimum	100M ohms at 250Vdc
Sliding Noise	100mV max.
Actual Electrical Travel, Nominal	260°

MECHANICAL

Total Mechanical Travel	300°± 10°
Static Stop Strength	90 oz-in
Rotational Torque	0.5 to 1.25 oz-in

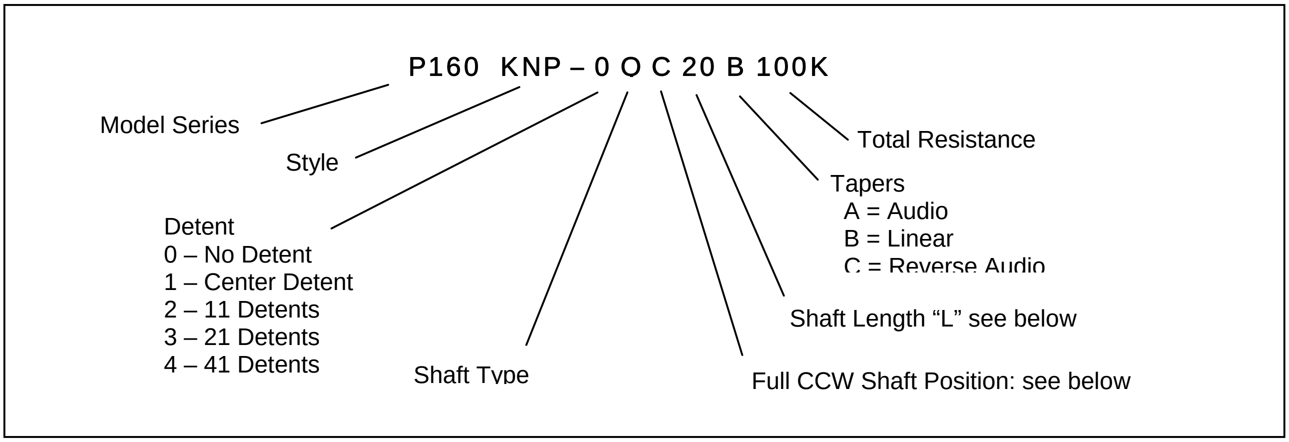
ENVIRONMENTAL

Operating Temperature Range	-20°C to +70°C
Rotational Life	100,000 cycles

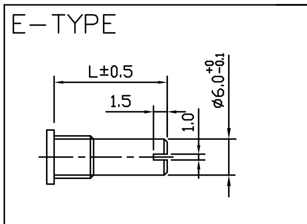
[1] *Specifications subject to change without notice.*

Model P160

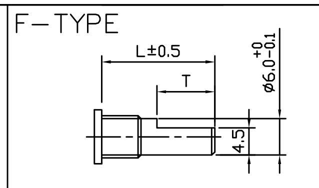
ORDERING INFORMATION[2]



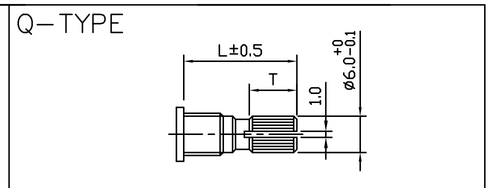
Shaft Types



L	10	15	20	25	30	35	40



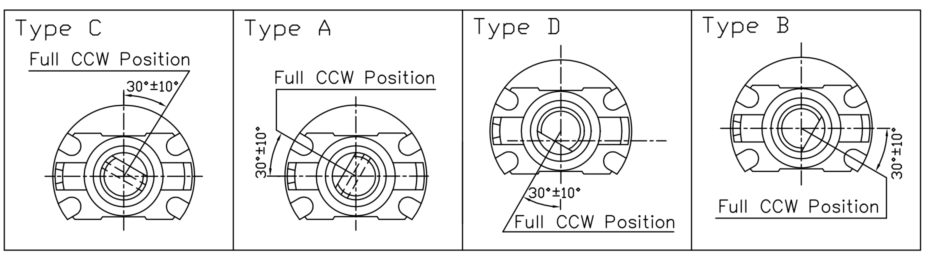
L	15	18	20	25	30	35
T	7	10	12	12	12	12



L	10	12	13	14	15	17	20	25	30	35	45
T	2.5	4.5	4	5	6	8	10	12	12	12	12

Shaft Position (F-Type Shaft)

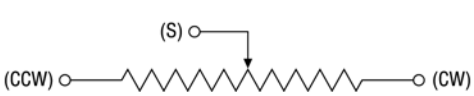
Dashed lines on Type "C" and Type "A" shows position of adjustment slot for E-Type and Q-Type shafts



STANDARD RESISTANCE VALUES, OHMS

500	1K	2K	5K	10K	20K	50K	100K	200K	500K	1MEG

CIRCUIT DIAGRAM

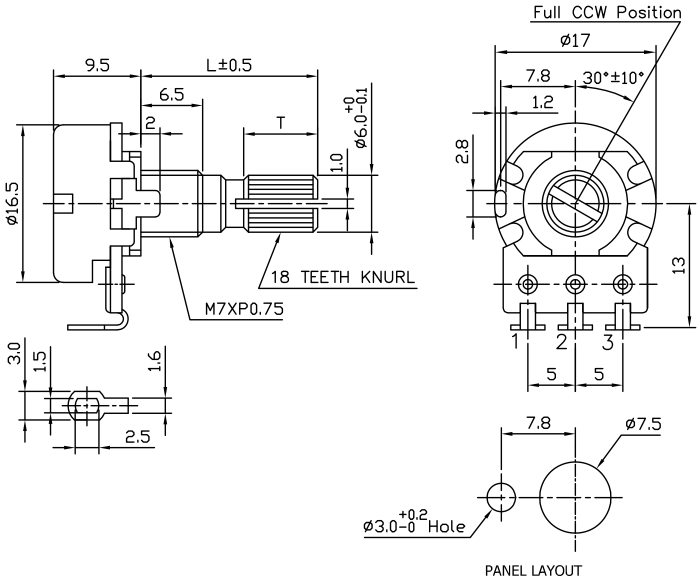


TT electronics BI technologies

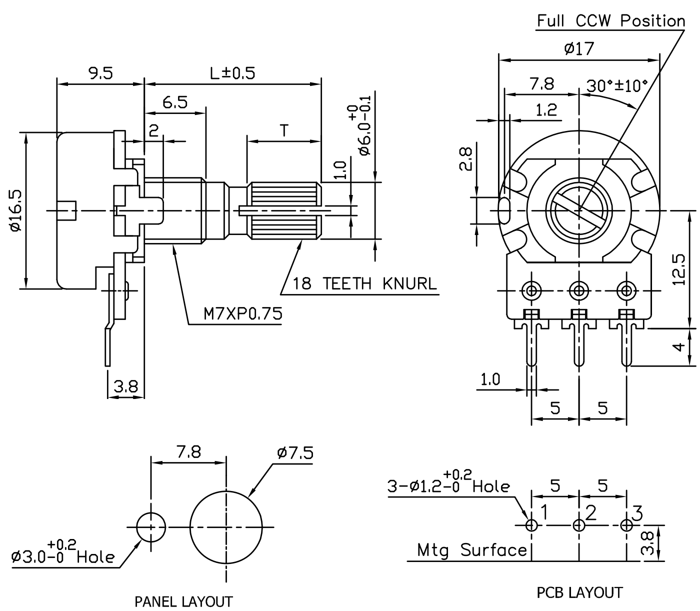
Model P160

OUTLINE DRAWING

Model P160KNP (Side Adjust , Solder Lugs)



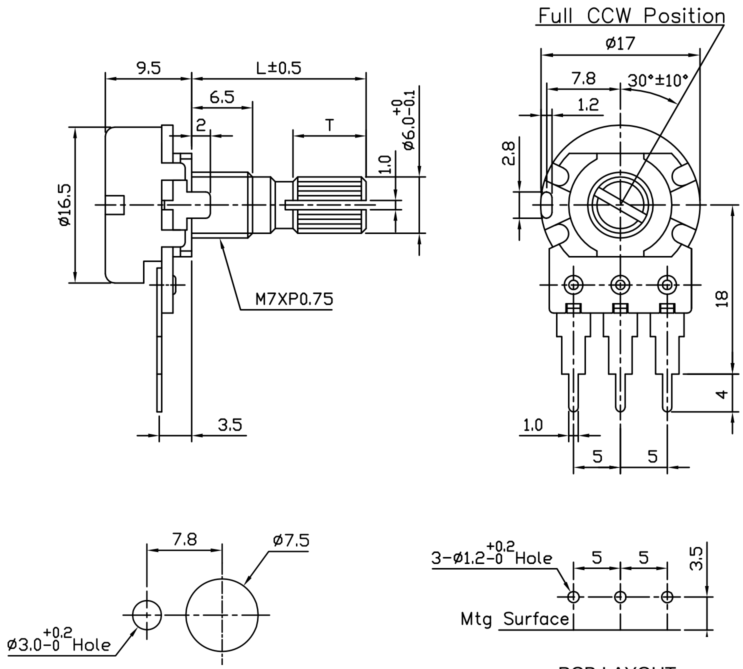
Model P160KN (Side Adjust , PC pins)



[2] *Contact our customer service for custom designs and features.*

Model P160

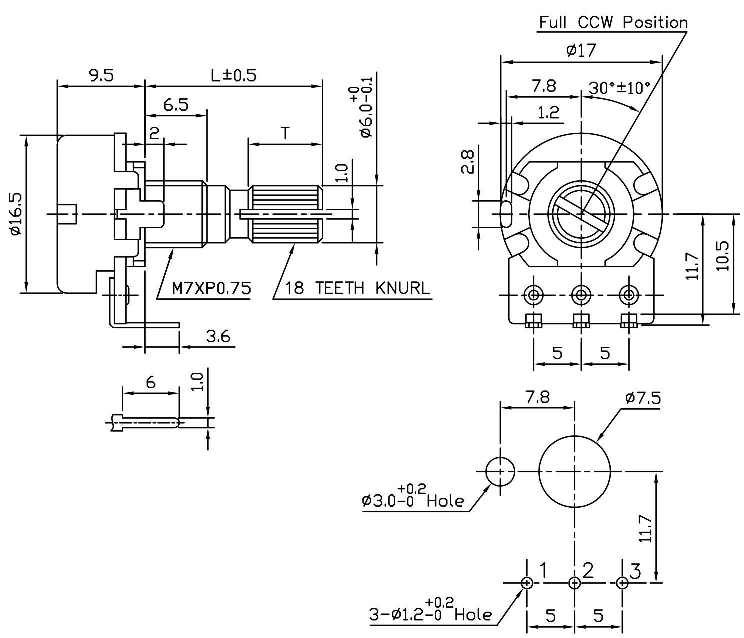
Model P160KN2 (Side Adjust , PC Pins, Long pins)



PANEL LAYOUT

PCB LAYOUT

Model P160KNPD (Rear Adjust , PC Pins)



PCB LAYOUT

Little Rebel®

Carbon Film Resistors, 5% Tolerance
Available in E24 Ohmic values

Little Rebels are one of Ohmite's more economical lines of low wattage resistors. Constructed of a pure carbon film deposited on a high-grade ceramic body, these units offer better stability performance than comparable carbon composition resistors.
Little Rebels are designed for electrical and electronic applications that demand small sizes and small power ratings plus high performance and reliability.

FEATURES

- High stability, low noise level, long life.
- Ideal for applications requiring a steady low power drop.
- Available in Resistor Cabinet Assortments.
- 24 Values per decade.

SERIES SPECIFICATIONS

Series	Wattage	Ohms	Max. Working Voltage
OJ	0.125	1.0- 1M	200
OK	0.250	1.0-10M	250
OL	0.500	1.0-10M	350
OM	1.00	1.0-10M	500
ON	2.00	1.0-10M	500

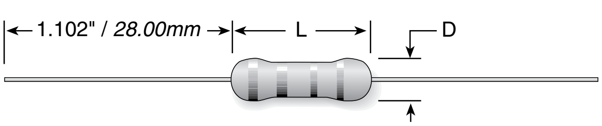
*Available in Cabinet Assortments

CHARACTERISTICS

Core	High-grade ceramic.
Terminals	Solder-coated copper lead.
Derating	Linearly from 100% @ +70°C to 0% @ 155°C.
Tolerance	±5%.
Temperature Coefficient	1Ω to 10: ±350 ppm/°C 11Ω to 91K: -450 ppm/°C 100K to 1M: -700 ppm/°C 1.1M to 10M: -800 to 1500 ppm/°C
Maximum Overload Voltage	OJ: 400 Volts OK: 500 Volts OL: 700 Volts OM: 1000 Volts ON: 1000 Volts
Quantity per reel	OJ: 5000 OK: 5000 OL: 4000 OM: 2500 ON: 1000

DIMENSIONS

(iin./mm)



Series	Wattage	Max. Length	Max. Diam.	Lead ga.
OJ	0.125	0.138 / 3.5	0.073 / 1.85	24
OK	0.250	0.268 / 6.8	0.099 / 2.5	22
OL	0.500	0.355 / 9.0	0.118 / 3.0	22
OM	1.00	0.473 /12.0	0.197 / 5.0	20
ON	2.00	0.630 / 16.0	0.217 / 5.5	20

(continued)

Little Rebel®

Carbon Film Resistors, 5% Tolerance
Available in E24 Ohmic values

ORDERING INFORMATION

Standard part numbers for standard resistance values

Ohmic value	Part No. Prefix ➤ Suffix ▼	OJ— 0.125	OK— 0.25	OL— 0.50	OM— 1.0	ON— 2.0
1	—10G5	✔	✔	✔	✔	✔
1.1	—11G5	✔	✔	✔	✔	✔
1.2	—12G5	✔	✔	✔	✔	✔
1.3	—13G5	✔	✔	✔	✔	✔
1.5	—15G5	✔	✔	✔	✔	✔
1.6	—16G5	✔	✔	✔	✔	✔
1.8	—18G5	✔	✔	✔	✔	✔
2.0	—20G5	✔	✔	✔	✔	✔
2.2	—22G5	✔	✔	✔	✔	✔
2.4	—24G5	✔	✔	✔	✔	✔
2.7	—27G5	✔	✔	✔	✔	✔
3.0	—30G5	✔	✔	✔	✔	✔
3.3	—33G5	✔	✔	✔	✔	✔
3.6	—36G5	✔	✔	✔	✔	✔
3.9	—39G5	✔	✔	✔	✔	✔
4.3	—43G5	✔	✔	✔	✔	✔
4.7	—47G5	✔	✔	✔	✔	✔
5.1	—51G5	✔	✔	✔	✔	✔
5.6	—56G5	✔	✔	✔	✔	✔
6.2	—62G5	✔	✔	✔	✔	✔
6.8	—68G5	✔	✔	✔	✔	✔
7.5	—75G5	✔	✔	✔	✔	✔
8.2	—82G5	✔	✔	✔	✔	✔
9.1	—91G5	✔	✔	✔	✔	✔
10	—1005	✔	✔	✔	✔	✔
11	—1105	✔	✔	✔	✔	✔
12	—1205	✔	✔	✔	✔	✔
13	—1305	✔	✔	✔	✔	✔
15	—1505	✔	✔	✔	✔	✔
16	—1605	✔	✔	✔	✔	✔
18	—1805	✔	✔	✔	✔	✔
20	—2005	✔	✔	✔	✔	✔
22	—2205	✔	✔	✔	✔	✔
24	—2405	✔	✔	✔	✔	✔
27	—2705	✔	✔	✔	✔	✔
30	—3005	✔	✔	✔	✔	✔
33	—3305	✔	✔	✔	✔	✔
36	—3605	✔	✔	✔	✔	✔
39	—3905	✔	✔	✔	✔	✔
43	—4305	✔	✔	✔	✔	✔
47	—4705	✔	✔	✔	✔	✔
51	—5105	✔	✔	✔	✔	✔
56	—5605	✔	✔	✔	✔	✔

Ohmic value	Part No. Prefix ➤ Suffix ▼	OJ— 0.125	OK— 0.25	OL— 0.50	OM— 1.0	ON— 2.0
62	—6205	✔	✔	✔	✔	✔
68	—6805	✔	✔	✔	✔	✔
75	—7505	✔	✔	✔	✔	✔
82	—8205	✔	✔	✔	✔	✔
91	—9105	✔	✔	✔	✔	✔
100	—1015	✔	✔	✔	✔	✔
110	—1115	✔	✔	✔	✔	✔
120	—1215	✔	✔	✔	✔	✔
130	—1315	✔	✔	✔	✔	✔
150	—1515	✔	✔	✔	✔	✔
160	—1615	✔	✔	✔	✔	✔
180	—1815	✔	✔	✔	✔	✔
200	—2015	✔	✔	✔	✔	✔
220	—2215	✔	✔	✔	✔	✔
240	—2415	✔	✔	✔	✔	✔
270	—2715	✔	✔	✔	✔	✔
330	—3315	✔	✔	✔	✔	✔
350	—3515	✔	✔	✔	✔	✔
360	—3615	✔	✔	✔	✔	✔
390	—3915	✔	✔	✔	✔	✔
430	—4315	✔	✔	✔	✔	✔
470	—4715	✔	✔	✔	✔	✔
510	—5115	✔	✔	✔	✔	✔
560	—5615	✔	✔	✔	✔	✔
620	—6215	✔	✔	✔	✔	✔
680	—6815	✔	✔	✔	✔	✔
750	—7515	✔	✔	✔	✔	✔
820	—8215	✔	✔	✔	✔	✔
910	—9115	✔	✔	✔	✔	✔
1,000	—1025	✔	✔	✔	✔	✔
1,100	—1125	✔	✔	✔	✔	✔
1,200	—1225	✔	✔	✔	✔	✔
1,300	—1325	✔	✔	✔	✔	✔
1,500	—1525	✔	✔	✔	✔	✔
1,600	—1625	✔	✔	✔	✔	✔
1,800	—1825	✔	✔	✔	✔	✔
2,000	—2025	✔	✔	✔	✔	✔
2,200	—2225	✔	✔	✔	✔	✔
2,400	—2425	✔	✔	✔	✔	✔
2,700	—2725	✔	✔	✔	✔	✔
3,000	—3025	✔	✔	✔	✔	✔
3,300	—3325	✔	✔	✔	✔	✔
3,600	—3625	✔	✔	✔	✔	✔

Ohmic value	Part No. Prefix ➤ Suffix ▼	OJ— 0.125	OK— 0.25	OL— 0.50	OM— 1.0	ON— 2.0
3,900	—3925	✔	✔	✔	✔	✔
4,300	—4325	✔	✔	✔	✔	✔
4,700	—4725	✔	✔	✔	✔	✔
5,100	—5125	✔	✔	✔	✔	✔
5,600	—5625	✔	✔	✔	✔	✔
6,200	—6225	✔	✔	✔	✔	✔
6,800	—6825	✔	✔	✔	✔	✔
7,500	—7525	✔	✔	✔	✔	✔
8,200	—8225	✔	✔	✔	✔	✔
9,100	—9125	✔	✔	✔	✔	✔
10,000	—1035	✔	✔	✔	✔	✔
11,000	—1135	✔	✔	✔	✔	✔
12,000	—1235	✔	✔	✔	✔	✔
13,000	—1335	✔	✔	✔	✔	✔
15,000	—1535	✔	✔	✔	✔	✔
16,000	—1635	✔	✔	✔	✔	✔
18,000	—1835	✔	✔	✔	✔	✔
20,000	—2035	✔	✔	✔	✔	✔
22,000	—2235	✔	✔	✔	✔	✔
24,000	—2435	✔	✔	✔	✔	✔
27,000	—2735	✔	✔	✔	✔	✔
30,000	—3035	✔	✔	✔	✔	✔
33,000	—3335	✔	✔	✔	✔	✔
36,000	—3635	✔	✔	✔	✔	✔
39,000	—3935	✔	✔	✔	✔	✔
43,000	—4335	✔	✔	✔	✔	✔
47,000	—4735	✔	✔	✔	✔	✔
51,000	—5135	✔	✔	✔	✔	✔
56,000	—5635	✔	✔	✔	✔	✔
62,000	—6235	✔	✔	✔	✔	✔
68,000	—6835	✔	✔	✔	✔	✔
75,000	—7535	✔	✔	✔	✔	✔
82,000	—8235	✔	✔	✔	✔	✔
91,000	—9135	✔	✔	✔	✔	✔
100,000	—1045	✔	✔	✔	✔	✔
110,000	—1145	✔	✔	✔	✔	✔
120,000	—1245	✔	✔	✔	✔	✔
130,000	—1345	✔	✔	✔	✔	✔
150,000	—1545	✔	✔	✔	✔	✔
160,000	—1645	✔	✔	✔	✔	✔
180,000	—1845	✔	✔	✔	✔	✔
200,000	—2045	✔	✔	✔	✔	✔
220,000	—2245	✔	✔	✔	✔	✔

Ohmic value	Part No. Prefix ➤ Suffix ▼	OJ— 0.125	OK— 0.25	OL— 0.50	OM— 1.0	ON— 2.0
240,000	—2445	✔	✔	✔	✔	✔
270,000	—2745	✔	✔	✔	✔	✔
300,000	—3045	✔	✔	✔	✔	✔
330,000	—3345	✔	✔	✔	✔	✔
360,000	—3645	✔	✔	✔	✔	✔
390,000	—3945	✔	✔	✔	✔	✔
430,000	—4345	✔	✔	✔	✔	✔
470,000	—4745	✔	✔	✔	✔	✔
510,000	—5145	✔	✔	✔	✔	✔
560,000	—5645	✔	✔	✔	✔	✔
620,000	—6245	✔	✔	✔	✔	✔
680,000	—6845	✔	✔	✔	✔	✔
750,000	—7545	✔	✔	✔	✔	✔
820,000	—8245	✔	✔	✔	✔	✔
910,000	—9145	✔	✔	✔	✔	✔
1 MEG	—1055	✔	✔	✔	✔	✔
1.1 MEG	—1155		✔	✔	✔	✔
1.2 MEG	—1255		✔	✔	✔	✔
1.3 MEG	—1355		✔	✔	✔	✔
1.5 MEG	—1555		✔	✔	✔	✔
1.6 MEG	—1655		✔	✔	✔	✔
1.8 MEG	—1855		✔	✔	✔	✔
2.0 MEG	—2055		✔	✔	✔	✔
2.2 MEG	—2255		✔	✔	✔	✔
2.4 MEG	—2455		✔	✔	✔	✔
2.7 MEG	—2755		✔	✔	✔	✔
3.0 MEG	—3055		✔	✔	✔	✔
3.3 MEG	—3355		✔	✔	✔	✔
3.6 MEG	—3655		✔	✔	✔	✔
3.9 MEG	—3955		✔	✔	✔	✔
4.3 MEG	—4355		✔	✔	✔	✔
4.7 MEG	—4755		✔	✔	✔	✔
5.1 MEG	—5155		✔	✔	✔	✔
5.6 MEG	—5655		✔	✔	✔	✔
6.2 MEG	—6255		✔	✔	✔	✔
6.8 MEG	—6855		✔	✔	✔	✔
7.5 MEG	—7555		✔	✔	✔	✔
8.2 MEG	—8255		✔	✔	✔	✔
9.1 MEG	—9155		✔	✔	✔	✔
10 MEG	—1065		✔	✔	✔	✔

O J 1 0 3 5 E - R 5 2

Tolerance
5 = 5% (Std.)
1 = 10%

RoHS Compliant

Series
Selected from Specification Chart

Ohms
3 Digit IEC Code
("G" as 3rd digit = 0.1)
11G=1.1Ω
101=100Ω
102=1000Ω
103=10,000Ω
104=100,000Ω
105=1 MΩ
106=10 MΩ

Packaging Code
R52 = Tape & Reel 52mm
(**except ON:** R58 = Tape & Reel 58mm)
A52(26) = Ammo Pac 52mm (26mm)

OD/OF/OA Series

Little Demon® Carbon Composition Molded OD/OF Series (5% Tol.) OA Series (10%)

Discontinuance Notice: OA series is not recommended for new designs. The OA series will no longer be available for new orders after 8-30-14. After this date existing stock will be sold until depleted.

FEATURES

- Molded insulation for high dielectric strength
- Rugged construction
- High surge capabilities
- Comparable to “Mil” RC07, RC20, and RC32 types
- OD/OF Series available in E24 values
- OA Series available in E12 values

Ohmite’s Little Demons are small, reliable carbon composition resistors with exceptional strength. They are made tough by a molding process that combines the terminals, insulation and resistive element into an integrated unit. Along with their small size, Little Demons perform with low noise, dissipate heat rapidly and offer high temperature stability.

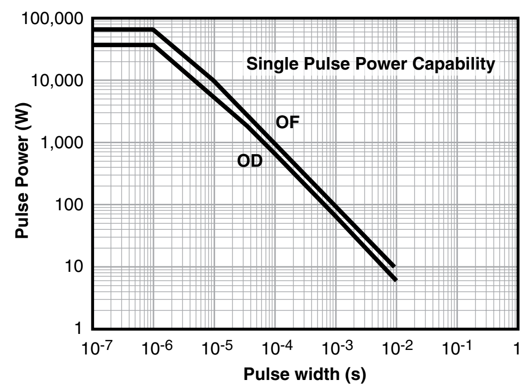
Color codes are readable even after prolonged use thanks to a very durable coating that resists abrasions and chipping normally associated with automatic insertion equipment.

SERIES SPECIFICATIONS

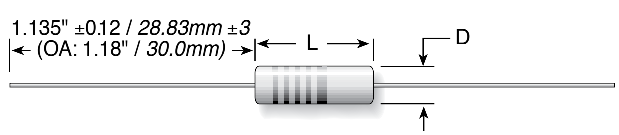
Series	Wattage	Ohms	Tolerance	Max. Voltage	Dielectric VAC
OD	0.25	2.2-5.6M	±5%	250	500
OF	0.50	2.2-20M	±5%	350	700
OA	1.00	2.2-1M	±10%	500	1000

CHARACTERISTICS

Terminals	Solder-coated copper terminal.
Body	Molded Phenolic
Tolerance	±5% (OD/OF); ±10% (OA)
Derating	Linearly from 100% @ +70°C to 0% @ 130°C



DIMENSIONS



Series	Length max.	Diam. max.	Lead Dia.
OD	0.276 / 7.0	0.098 / 2.5	0.024/0.60
OF	0.406 /10.3	0.150 / 3.8	0.028/0.70
OA	0.591 /15.0	0.236 / 6.0	0.035/0.92

(continued)

OD/OF/OA Series

Little Demon® Carbon Composition Molded OD/OF Series (5% Tol.) OA Series (10%)

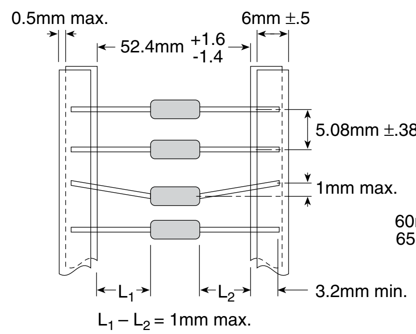
PACKAGING

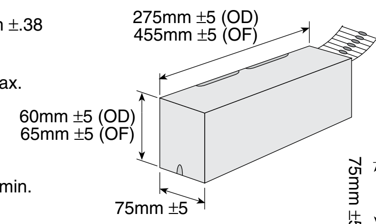
All resistors are packaged in sealed poly bags with desiccant to maintain a consistent humidity during storage. If parts are removed from the protective plastic bag they should be used as soon as possible or resealed in the plastic bag.

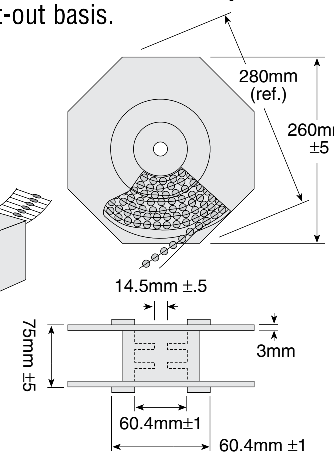
Storage: Ohmite recommends storing carbon composition resistors in a controlled environment at a temperature of 5° to 35°C and relative humidity of less than 60%. Inventory should always be used on a first-in-first-out basis.

Tape/Reel	OD	OF
Qty./reel	5000	3000
Reel size (mm)	260	260
Qty./carton	40,000	24,000
Gross carton wt. (kg)	12	13
Carton size (m^3)	0.04	0.04

Ammo Box	OD	OF
Tape width (mm)	52	52
Qty./box	2000	2000
Qty./carton	30,000	30,000
Gross carton wt. (kg)	10	16
Carton size (m3)	0.03	0.05







RESISTOR USE GUIDELINES

Carbon composition resistors are manufactured by extruding a blend of carbon and organic binders inside a phenolic outer body. The extrusion is cut to length, leads inserted, cured, and marked to form a finished resistor. The carbon and binder mixture is adjusted to produce different resistance values. The resistors are sorted for 5%, 10%, and 20% tolerance values.

Carbon composition resistors are able to withstand larger short-term pulses and higher voltages than film resistors and are virtually impervious to ESD events (Electro-static discharge). Carbon composition resistors are also sensitive to moisture and, therefore, storage recommendations should be adhered to. Generally, any moisture absorbed during storage will be "baked out" during the soldering operation. If the product is stored properly the resistance shift during the soldering operation will be minimal, less than 2% or 3%.

Carbon composition resistors are highly hygroscopic and changes in resistance value can occur if too much moisture is absorbed. For this reason, it is recommended not to use water or water-soluble solvents to clean these components. Alcohol or hydrocarbon solvents are recommended for rinsing.

BAKE PROCEDURE

A. Heat Treatment

110°C ±10°C
15 hours

B. Frequency of heat treatment

1 time only

C. Solder heat test after treatment

Type	Solder Temp.	Dip Time	Evaluation
OD	300°C	3 sec	within ±3%
OF	350°C	3 sec	within ±3%

*Depth of Immersion: 3mm from the resistor body

D. Cautions

Solderability: may be affected due to oxidization of lead wire

Resistance value: some units may not completely recover to original value.

Soldering heat: some treated product may have substantial resistance change during soldering operation. It is recommended that parts be tested to evaluate soldering heat effects.

ORDERING INFORMATION

- OD/OF Series available in E24 values
- OA Series available in E12 values

O D 6 8 3 J E -TR

- **RoHS compliant**: E
- **Tape & reel** *optional*: -TR
- **Series**: OD, OF, OA
- **Ohms**: 68G = 6.8; 680 = 68; 681 = 680; 682 = 6,800; 683 = 68,000; 684 = 680,000
- **Tolerance**: OD, OF: J = 5%; OA: K = 10%

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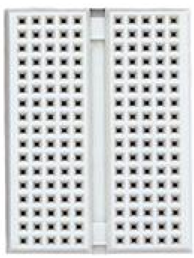

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See Product Specifications

Mouser Part #:	619-700-00012
Manufacturer Part #:	700-00012
Manufacturer:	Parallax
Description:	PCBs & Breadboards Repluggable Breadboa rd

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Page 2,372, PDF Catalog Page

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RoHS:	RoHS Details
Brand:	Parallax
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Type:	Solderless
Description/Function:	Breadboard Solderless
Unit Weight:	0.512000 oz

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	GS-400	PCBs & Breadboards	393	QuickView
	TW-E40-1020	PCBs & Breadboards	369	QuickView
	2N3904BU	Bipolar Transistors - BJT	38,880	QuickView
	WK-3	Jumper Wires	241	QuickView
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Texas Instruments

SN54HC595, SN74HC595

SCLS041I – DECEMBER 1982 – REVISED SEPTEMBER 2015

SNx4HC595 8-Bit Shift Registers With 3-State Output Registers

1 Features

- 8-Bit Serial-In, Parallel-Out Shift
- Wide Operating Voltage Range of 2 V to 6 V
- High-Current 3-State Outputs Can Drive Up to 15 LSTTL Loads
- Low Power Consumption: 80-μA (Maximum) I_{CC}
- t_{pd} = 13 ns (Typical)
- ±6-mA Output Drive at 5 V
- Low Input Current: 1 μA (Maximum)
- Shift Register Has Direct Clear
- On Products Compliant to MIL-PRF-38535, All Parameters Are Tested Unless Otherwise Noted. On All Other Products, Production Processing Does Not Necessarily Include Testing of All Parameters.

2 Applications

- Network Switches
- Power Infrastructure
- LED Displays
- Servers

3 Description

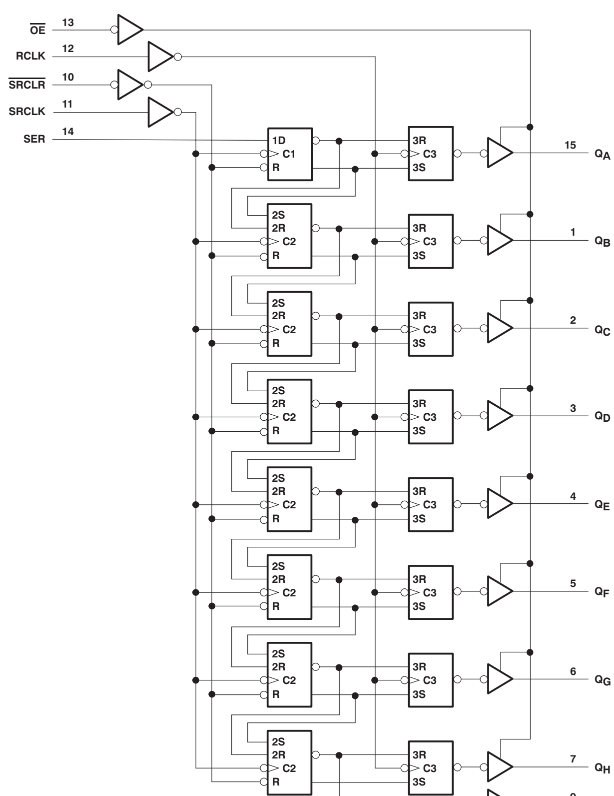
The SNx4HC595 devices contain an 8-bit, serial-in, parallel-out shift register that feeds an 8-bit D-type storage register. The storage register has parallel 3-state outputs. Separate clocks are provided for both the shift and storage register. The shift register has a direct overriding clear ($\overline{SRCLR}$) input, serial (SER) input, and serial outputs for cascading. When the output-enable ($\overline{OE}$) input is high, the outputs are in the high-impedance state.

Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
SN54HC595	LCCC (20)	8.89 mm x 8.89 mm
	CDIP (16)	21.34 mm x 6.92 mm
SN74HC595	PDIP (16)	19.31 mm × 6.35 mm
	SOIC (16)	9.90 mm x 3.90 mm
	SOIC (16)	10.30 mm x 7.50 mm
	SSOP (16)	6.20 mm x 5.30 mm
	TSSOP (16)	5.00 mm x 4.40 mm

(1) For all available packages, see the orderable addendum at the end of the data sheet.

Logic Diagram (Positive Logic)



Pin numbers shown are for the D, DB, DW, J, N, NS, PW, and W packages.

Table of Contents

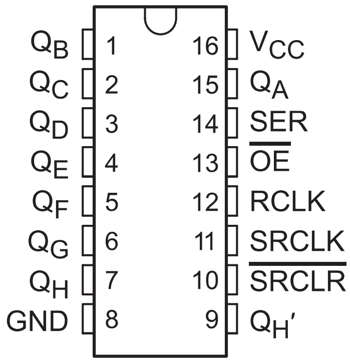
4 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

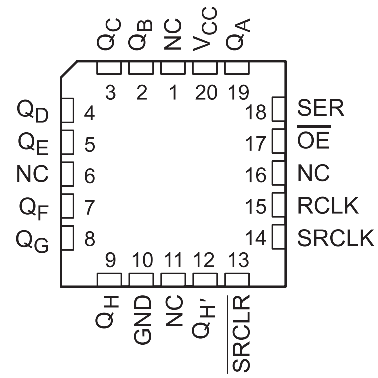
Changes from Revision H (November 2009) to Revision I	Page
• Added *Applications* section, *Device Information* table, *Pin Configuration and Functions* section, *ESD Ratings* table, *Thermal Information* table, *Feature Description* section, *Device Functional Modes*, *Application and Implementation* section, *Power Supply Recommendations* section, *Layout* section, *Device and Documentation Support* section, and *Mechanical, Packaging, and Orderable Information* section	1
• Deleted *Ordering Information* table.	1
• Added Military Disclaimer to *Features* list.	1

6 Pin Configuration and Functions

D, N, NS, J, DB, or PW Package
16-Pin SOIC, PDIP, SO, CDIP, SSOP, or TSSOP
Top View



FK Package
20-Pin LCCC
Top View



Pin Functions

PIN			I/O	DESCRIPTION
NAME	SOIC, PDIP, SO, CDIP, SSOP, or TSSOP	LCCC		
GND	8	10	—	Ground Pin
$\overline{OE}$	13	17	I	Output Enable
Q_A	15	19	O	Q_A Output
Q_B	1	2	O	Q_B Output
Q_C	2	3	O	Q_C Output
Q_D	3	4	O	Q_D Output
Q_E	4	5	O	Q_E Output
Q_F	5	7	O	Q_F Output
Q_G	6	8	O	Q_G Output
Q_H	7	9	O	Q_H Output
$Q_{H'}$	9	12	O	$Q_{H'}$ Output
RCLK	12	14	I	RCLK Input
SER	14	18	I	SER Input
SRCLK	11	14	I	SRCLK Input
$\overline{SRCLR}$	10	13	I	$\overline{SRCLR}$ Input
NC	—	1	—	No Connection
		16		
		11		
		16		
V_{CC}	—	20	—	Power Pin

7 Specifications

7.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)[1]

			MIN	MAX	UNIT
V_{CC}	Supply voltage		–0.5	7	V
I_{IK}	Input clamp current[2]	$V_I < 0$ or $V_I > V_{CC}$		±20	mA
I_{OK}	Output clamp current [2]	$V_O < 0$ or $V_O > V_{CC}$		±20	mA
I_O	Continuous output current	$V_O = 0$ to V_{CC}		±35	mA
	Continuous current through V_{CC} or GND			±70	mA
T_J	Junction temperature			150	°C
T_{stg}	Storage temperature		–65	150	°C

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions* is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) The input and output voltage ratings may be exceeded if the input and output current ratings are observed.

7.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human body model (HBM), per ANSI/ESDA/JEDEC JS-001, all pins[1]	2000	V
		Charged-device model (CDM), per JEDEC specification JESD22-C101, all pins[2]	1000	

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

7.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)[1]

			SN54HC595			SN74HC595			UNIT
			MIN	NOM	MAX	MIN	NOM	MAX	
V_{CC}	Supply voltage		2	5	6	2	5	6	V
V_{IH}	High-level input voltage	V_{CC} = 2 V	1.5			1.5			V
		V_{CC} = 4.5 V	3.15			3.15			
		V_{CC} = 6 V	4.2			4.2			
V_{IL}	Low-level input voltage	V_{CC} = 2 V			0.5			0.5	V
		V_{CC} = 4.5 V			1.35			1.35	
		V_{CC} = 6 V			1.8			1.8	
V_I	Input voltage		0		V_{CC}	0		V_{CC}	V
V_O	Output voltage		0		V_{CC}	0		V_{CC}	V
Δt/Δv	Input transition rise or fall time[2]	V_{CC} = 2 V			1000			1000	ns
		V_{CC} = 4.5 V			500			500	
		V_{CC} = 6 V			400			400	
T_A	Operating free-air temperature		–55		125	–40		85	°C

(1) All unused inputs of the device must be held at V_{CC} or GND to ensure proper device operation. See the TI application report, *Implications of Slow or Floating CMOS Inputs*, SCBA004.
(2) If this device is used in the threshold region (from V_{IL}max = 0.5 V to V_{IH} min = 1.5 V), there is a potential to go into the wrong state from induced grounding, causing double clocking. Operating with the inputs at t_t = 1000 ns and V_{CC} = 2 V does not damage the device; however, functionally, the CLK inputs are not ensured while in the shift, count, or toggle operating modes.

7.4 Thermal Information

THERMAL METRIC(1)		SN74AHCT595						UNIT
		D (SOIC)	DB (SSOP)	DW (SOIC)	N (PDIP)	NS (SO)	PW (TSSOP)	
		16 PINS	16 PINS	16 PINS	16 PINS	16 PINS	16 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	73	82	57	67	64	108	°C/W

(1) For more information about traditional and new thermal metrics, see the *Semiconductor and IC Package Thermal Metrics* application report, SPRA953.

7.5 Electrical Characteristics

over recommended operating free-air temperature range (unless otherwise noted)

PARAMETER	TEST CONDITIONS		V_{CC}	T_A = 25°C MIN	TYP	MAX	SN54HC595 MIN	MAX	SN74HC595 MIN	MAX	UNIT
V_{OH}	$V_I = V_{IH}$ or V_{IL}	I_{OH} = –20 µA	2 V	1.9	1.998		1.9		1.9		V
			4.5 V	4.4	4.499		4.4		4.4		
			6 V	5.9	5.999		5.9		5.9		
		$Q_{H'}$, I_{OH} = –4 mA	4.5 V	3.98	4.3		3.7		3.84		
		$Q_A – Q_H$, I_{OH} = –6 mA		3.98	4.3		3.7		3.84		
		$Q_{H'}$, I_{OH} = −5.2 mA	6 V	5.48	5.8		5.2		5.34		
		$Q_A – Q_H$, I_{OH} = –7.8 mA		5.48	5.8		5.2		5.34		
V_{OL}	$V_I = V_{IH}$ or V_{IL}	I_{OL} = 20 µA	2 V		0.002	0.1		0.1		0.1	V
			4.5 V		0.001	0.1		0.1		0.1	
			6 V		0.001	0.1		0.1		0.1	
		$Q_{H'}$, I_{OL} = 4 mA	4.5 V		0.17	0.26		0.4		0.33	
		$Q_A – Q_H$, I_{OL} = 6 mA			0.17	0.26		0.4		0.33	
		$Q_{H'}$, I_{OL} = 5.2 mA	6 V		0.15	0.26		0.4		0.33	
		$Q_A – Q_H$, I_{OL} = 7.8 mA			0.15	0.26		0.4		0.33	
I_I	$V_I = V_{CC}$ or 0		6 V		±0.1	±100		±1000		±1000	nA
I_{OZ}	$V_O = V_{CC}$ or 0, $Q_A – Q_H$		6 V		±0.01	±0.5		±10		±5	µA
I_{CC}	$V_I = V_{CC}$ or 0, I_O = 0		6 V			8		160		80	µA
C_i			2 V to 6 V		3	10		10		10	pF

7.6 Timing Requirements

over operating free-air temperature range (unless otherwise noted)

			V_{CC}	T_A = 25°C		SN54HC595		SN74HC595		UNIT
				MIN	MAX	MIN	MAX	MIN	MAX	
f_{clock}	Clock frequency		2 V		6		4.2		5	MHz
			4.5 V		31		21		25	
			6 V		36		25		29	
t_w	Pulse duration	SRCLK or RCLK high or low	2 V	80		120		100		ns
			4.5 V	16		24		20		
			6 V	14		20		17		
		$\overline{\text{SRCLR}}$ low	2 V	80		120		100		
			4.5 V	16		24		20		
			6 V	14		20		17		
t_{su}	Set-up time	SER before SRCLK↑	2 V	100		150		125		ns
			4.5 V	20		30		25		
			6 V	17		25		21		
		SRCLK↑ before RCLK↑ (1)	2 V	75		113		94		
			4.5 V	15		23		19		
			6 V	13		19		16		
		$\overline{\text{SRCLR}}$ low before RCLK↑	2 V	50		75		65		
			4.5 V	10		15		13		
			6 V	9		13		11		
		$\overline{\text{SRCLR}}$ high (inactive) before SRCLK↑	2 V	50		75		60		
			4.5 V	10		15		12		
			6 V	9		13		11		
t_h	Hold time, SER after SRCLK↑		2 V	0		0		0		ns
			4.5 V	0		0		0		
			6 V	0		0		0		

(1) This set-up time allows the storage register to receive stable data from the shift register. The clocks can be tied together, in which case the shift register is one clock pulse ahead of the storage register.

7.7 Switching Characteristics

Over recommended operating free-air temperature range.

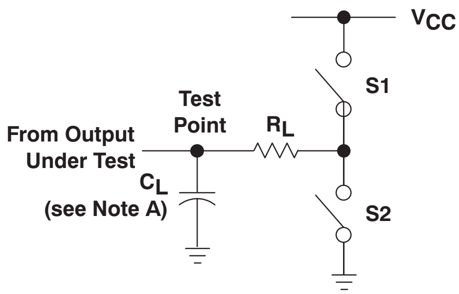
PARAMETER	FROM (INPUT)	TO (OUTPUT)	LOAD CAPACITANCE	V_{CC}	T_A = 25°C			SN54HC595		SN74HC595		UNIT
					MIN	TYP	MAX	MIN	MAX	MIN	MAX	
f_{max}			50 pF	2 V	6	26		4.2		5		MHz
				4.5 V	31	38		21		25		
				6 V	36	42		25		29		
t_{pd}	SRCLK	$Q_{H'}$	50 pF	2 V		50	160		240		200	ns
				4.5 V		17	32		48		40	
				6 V		14	27		41		34	
	RCLK	$Q_A – Q_H$	50 pF	2 V		50	150		225		187	
				4.5 V		17	30		45		37	
				6 V		14	26		38		32	
t_{PHL}	$\overline{SRCLR}$	$Q_{H'}$	50 pF	2 V		51	175		261		219	ns
				4.5 V		18	35		52		44	
				6 V		15	30		44		37	
t_{en}	$\overline{OE}$	$Q_A – Q_H$	50 pF	2 V		40	150		255		187	ns
				4.5 V		15	30		45		37	
				6 V		13	26		38		32	
t_{dis}	$\overline{OE}$	$Q_A – Q_H$	50 pF	2 V		42	200		300		250	ns
				4.5 V		23	40		60		50	
				6 V		20	34		51		43	
t_t		$Q_A – Q_H$	50 pF	2 V		28	60		90		75	ns
				4.5 V		8	12		18		15	
				6 V		6	10		15		13	
		$Q_{H'}$	50 pF	2 V		28	75		110		95	
				4.5 V		8	15		22		19	
				6 V		6	13		19		16	
t_{pd}	RCLK	$Q_A – Q_H$	150 pf	2 V		60	200		300		250	ns
				4.5 V		22	40		60		50	
				6 V		19	34		51		43	
t_{en}	$\overline{OE}$	$Q_A – Q_H$	150 pf	2 V		70	200		298		250	ns
				4.5 V		23	40		60		50	
				6 V		19	34		51		43	
t_t		$Q_A – Q_H$	150 pf	2 V		45	210		315		265	ns
				4.5 V		17	42		63		53	
				6 V		13	36		53		45	

7.8 Operating Characteristics

T_A = 25°C

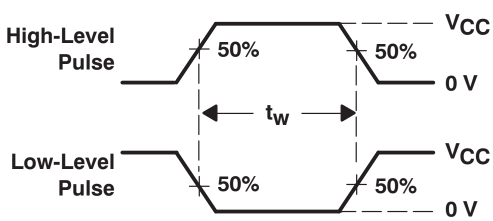
PARAMETER		TEST CONDITIONS	TYP	UNIT
C_{pd}	Power dissipation capacitance	No load	400	pF

8 Parameter Measurement Information

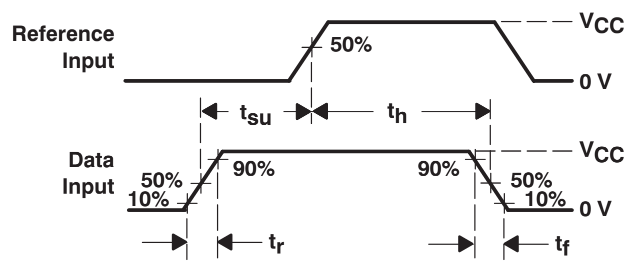


LOAD CIRCUIT

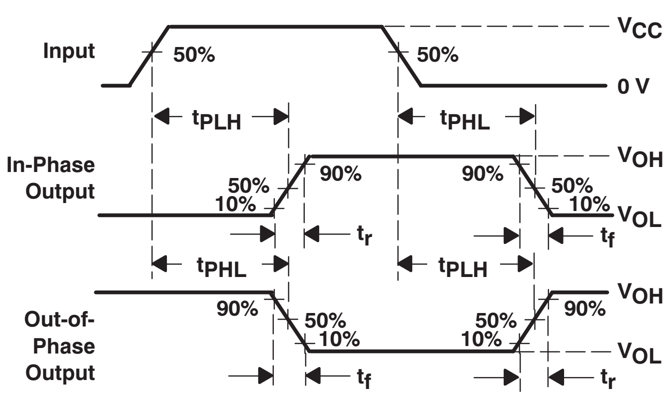
PARAMETER		RL	CL	S1	S2
t_{en}	t_{PZH}	1 kΩ	50 pF or 150 pF	Open	Closed
	t_{PZL}			Closed	Open
t_{dis}	t_{PHZ}	1 kΩ	50 pF	Open	Closed
	t_{PLZ}			Closed	Open
t_{pd} or t_t			50 pF or 150 pF	Open	Open



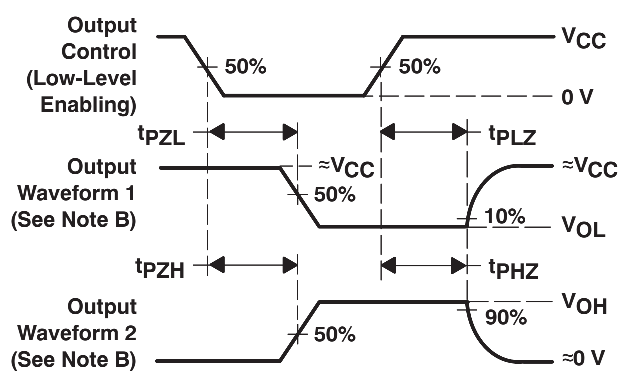
VOLTAGE WAVEFORMS
PULSE DURATIONS



VOLTAGE WAVEFORMS
SETUP AND HOLD AND INPUT RISE AND FALL TIMES



VOLTAGE WAVEFORMS
PROPAGATION DELAY AND OUTPUT TRANSITION TIMES



VOLTAGE WAVEFORMS
ENABLE AND DISABLE TIMES FOR 3-STATE OUTPUTS

NOTES:
- A. C_L includes probe and test-fixture capacitance.
- B. Waveform 1 is for an output with internal conditions such that the output is low, except when disabled by the output control. Waveform 2 is for an output with internal conditions such that the output is high, except when disabled by the output control.
- C. Phase relationships between waveforms were chosen arbitrarily. All input pulses are supplied by generators having the following characteristics: PRR ≤ 1 MHz, Z_O = 50 Ω, t_r = 6 ns, t_f = 6 ns.
- D. For clock inputs, f_{max} is measured when the input duty cycle is 50%.
- E. The outputs are measured one at a time, with one input transition per measurement.
- F. t_{PLZ} and t_{PHZ} are the same as t_{dis}.
- G. t_{PZL} and t_{PZH} are the same as t_{en}.
- H. t_{PLH} and t_{PHL} are the same as t_{pd}.

Figure 3. Load Circuit and Voltage Waveforms

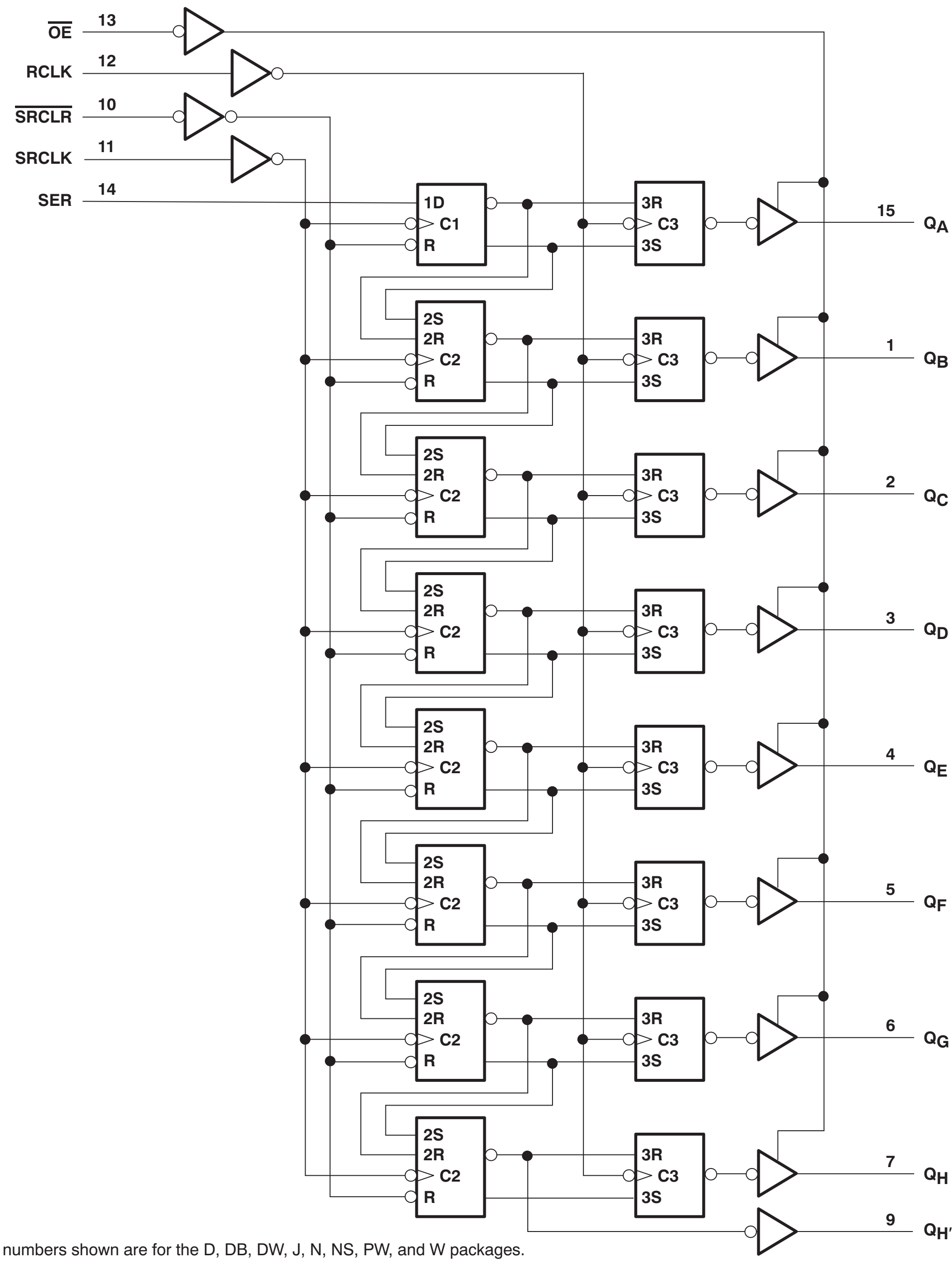
9 Detailed Description

9.1 Overview

The SNx4HC595 is part of the HC family of logic devices intended for CMOS applications. The SNx4HC595 is an 8-bit shift register that feeds an 8-bit D-type storage register.

Both the shift register clock (SRCLK) and storage register clock (RCLK) are positive-edge triggered. If both clocks are connected together, the shift register always is one clock pulse ahead of the storage register.

9.2 Functional Block Diagram



Pin numbers shown are for the D, DB, DW, J, N, NS, PW, and W packages.

Figure 4. Logic Diagram (Positive Logic)

9.3 Feature Description

The SNx4HC595 devices are 8-bit Serial-In, Parallel-Out Shift Registers. They have a wide operating current of 2 V to 6 V, and the high-current 3-state outputs can drive up to 15 LSTTL Loads. The devices have a low power consumption of 80-μA (Maximum) I_{CC}. Additionally, the devices have a low input current of 1 μA (Maximum) and a ±6-mA Output Drive at 5 V.

9.4 Device Functional Modes

Table 1 lists the functional modes of the SNx4HC595 devices.

Table 1. Function Table

INPUTS					FUNCTION
SER	SRCLK	$\overline{SRCLR}$	RCLK	$\overline{OE}$	
X	X	X	X	H	Outputs Q_A – Q_H are disabled.
X	X	X	X	L	Outputs Q_A – Q_H are enabled.
X	X	L	X	X	Shift register is cleared.
L	↑	H	X	X	First stage of the shift register goes low. Other stages store the data of previous stage, respectively.
H	↑	H	X	X	First stage of the shift register goes high. Other stages store the data of previous stage, respectively.
X	X	X	↑	X	Shift-register data is stored in the storage register.

10 Application and Implementation

10.1 Application Information

The SNx4HC595 is a low-drive CMOS device that can be used for a multitude of bus interface type applications where output ringing is a concern. The low drive and slow edge rates will minimize overshoot and undershoot on the outputs.

10.2 Typical Application

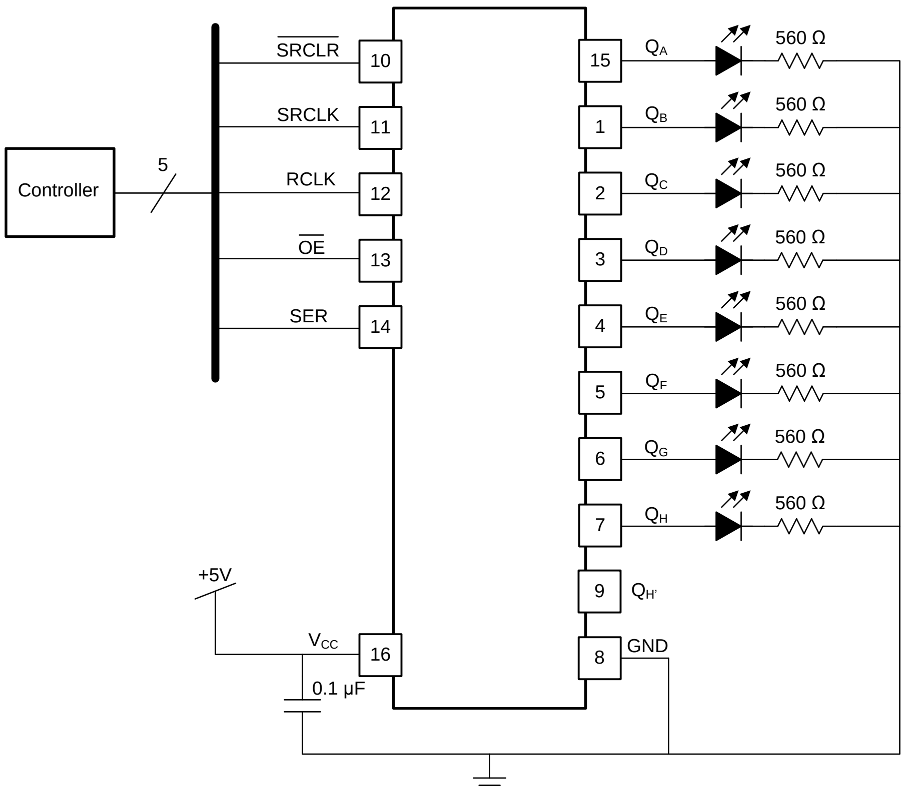


Figure 5. Typical Application Schematic

10.2.1 Design Requirements

This device uses CMOS technology and has balanced output drive. Take care to avoid bus contention because it can drive currents that would exceed maximum limits. The high drive will also create fast edges into light loads so routing and load conditions should be considered to prevent ringing.

10.2.2 Detailed Design Procedure

- Recommended input conditions
  - Specified high and low levels. See (V_{IH} and V_{IL}) in the *Recommended Operating Conditions* table.
  - Specified high and low levels. See (V_{IH} and V_{IL}) in the *Recommended Operating Conditions* table.
  - Inputs are overvoltage tolerant allowing them to go as high as 5.5 V at any valid V_{CC}
- Recommend output conditions
  - Load currents should not exceed 35 mA per output and 70 mA total for the part
  - Outputs should not be pulled above V_{CC}

11 Power Supply Recommendations

The power supply can be any voltage between the minimum and maximum supply voltage rating located in the *Recommended Operating Conditions* table.

Each V_{CC} pin should have a good bypass capacitor to prevent power disturbance. For devices with a single supply, 0.1 μf is recommended; if there are multiple V_{CC} pins, then 0.01 μf or 0.022 μf is recommended for each power pin. It is acceptable to parallel multiple bypass caps to reject different frequencies of noise. A 0.1 μf and a 1 μf are commonly used in parallel. The bypass capacitor should be installed as close to the power pin as possible for best results.

12 Layout

12.1 Layout Guidelines

When using multiple-bit logic devices, inputs should never float.

In many cases, functions or parts of functions of digital logic devices are unused, for example, when only two inputs of a triple-input AND gate are used or only 3 of the 4 buffer gates are used. Such input pins should not be left unconnected because the undefined voltages at the outside connections result in undefined operational states. Figure 7 specifies the rules that must be observed under all circumstances. All unused inputs of digital logic devices must be connected to a high or low bias to prevent them from floating. The logic level that should be applied to any particular unused input depends on the function of the device. Generally they will be tied to GND or V_{CC}, whichever makes more sense or is more convenient. It is generally acceptable to float outputs, unless the part is a transceiver. If the transceiver has an output enable pin, it will disable the output section of the part when asserted. This will not disable the input section of the I/Os, so they cannot float when disabled.

12.2 Layout Example

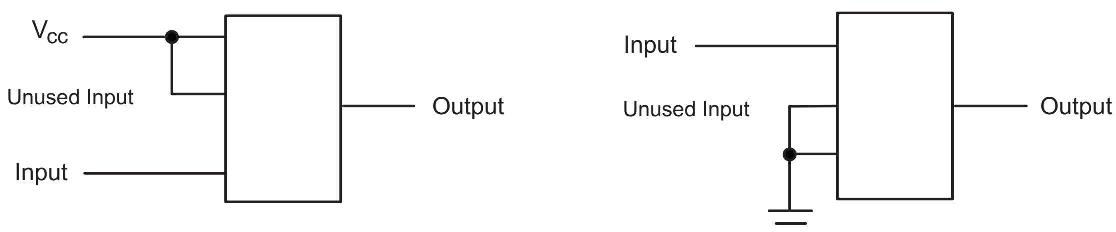


Figure 7. Layout Diagram

13 Device and Documentation Support

13.1 Documentation Support

13.1.1 Related Documentation

For related documentation, see the following:

Implications of Slow or Floating CMOS Inputs, SCBA004

13.2 Related Links

The table below lists quick access links. Categories include technical documents, support and community resources, tools and software, and quick access to sample or buy.

Table 2. Related Links

PARTS	PRODUCT FOLDER	SAMPLE & BUY	TECHNICAL DOCUMENTS	TOOLS & SOFTWARE	SUPPORT & COMMUNITY
SN54HC595	Click here	Click here	Click here	Click here	Click here
SN74HC595	Click here	Click here	Click here	Click here	Click here

13.3 Community Resources

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of Use.

TI E2E™ Online Community ***TI's Engineer-to-Engineer (E2E) Community.*** Created to foster collaboration among engineers. At e2e.ti.com, you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

Design Support ***TI's Design Support*** Quickly find helpful E2E forums along with design support tools and contact information for technical support.

13.4 Trademarks

E2E is a trademark of Texas Instruments.
All other trademarks are the property of their respective owners.

13.5 Electrostatic Discharge Caution

These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

13.6 Glossary

SLYZ022 — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

14 Mechanical, Packaging, and Orderable Information

The following pages include mechanical packaging and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser based versions of this data sheet, refer to the left hand navigation.

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
5962-86816012A	ACTIVE	LCCC	FK	20	1	TBD	POST-PLATE	N / A for Pkg Type	-55 to 125	5962-86816012A SNJ54HC595FK	Samples
5962-8681601EA	ACTIVE	CDIP	J	16	1	TBD	A42	N / A for Pkg Type	-55 to 125	5962-8681601EA SNJ54HC595J	Samples
5962-8681601VEA	ACTIVE	CDIP	J	16	1	TBD	A42	N / A for Pkg Type	-55 to 125	5962-8681601VEA SNV54HC595J	Samples
5962-8681601VFA	ACTIVE	CFP	W	16	1	TBD	A42	N / A for Pkg Type	-55 to 125	5962-8681601VFA SNV54HC595W	Samples
SN54HC595J	ACTIVE	CDIP	J	16	1	TBD	A42	N / A for Pkg Type	-55 to 125	SN54HC595J	Samples
SN74HC595D	ACTIVE	SOIC	D	16	40	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	HC595	Samples
SN74HC595DBR	ACTIVE	SSOP	DB	16	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	HC595	Samples
SN74HC595DBRE4	ACTIVE	SSOP	DB	16	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	HC595	Samples
SN74HC595DBRG4	ACTIVE	SSOP	DB	16	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	HC595	Samples
SN74HC595DE4	ACTIVE	SOIC	D	16	40	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	HC595	Samples
SN74HC595DG4	ACTIVE	SOIC	D	16	40	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	HC595	Samples
SN74HC595DR	ACTIVE	SOIC	D	16	2500	Green (RoHS & no Sb/Br)	CU NIPDAU | CU SN	Level-1-260C-UNLIM	-40 to 85	HC595	Samples
SN74HC595DRE4	ACTIVE	SOIC	D	16	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	HC595	Samples
SN74HC595DRG3	ACTIVE	SOIC	D	16	2500	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 85	HC595	Samples
SN74HC595DRG4	ACTIVE	SOIC	D	16	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	HC595	Samples

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
SN74HC595DT	ACTIVE	SOIC	D	16	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	HC595	Samples
SN74HC595DTE4	ACTIVE	SOIC	D	16	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	HC595	Samples
SN74HC595DW	ACTIVE	SOIC	DW	16	40	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	HC595	Samples
SN74HC595DWG4	ACTIVE	SOIC	DW	16	40	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	HC595	Samples
SN74HC595DWR	ACTIVE	SOIC	DW	16	2000	Green (RoHS & no Sb/Br)	CU NIPDAU | CU SN	Level-1-260C-UNLIM	-40 to 85	HC595	Samples
SN74HC595DWRE4	ACTIVE	SOIC	DW	16	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	HC595	Samples
SN74HC595DWRG4	ACTIVE	SOIC	DW	16	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	HC595	Samples
SN74HC595N	ACTIVE	PDIP	N	16	25	Pb-Free (RoHS)	CU NIPDAU | CU SN	N / A for Pkg Type	-40 to 85	SN74HC595N	Samples
SN74HC595NE4	ACTIVE	PDIP	N	16	25	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	-40 to 85	SN74HC595N	Samples
SN74HC595NSR	ACTIVE	SO	NS	16	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	HC595	Samples
SN74HC595PW	ACTIVE	TSSOP	PW	16	90	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	HC595	Samples
SN74HC595PWG4	ACTIVE	TSSOP	PW	16	90	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	HC595	Samples
SN74HC595PWR	ACTIVE	TSSOP	PW	16	2000	Green (RoHS & no Sb/Br)	CU NIPDAU | CU SN	Level-1-260C-UNLIM	-40 to 85	HC595	Samples
SN74HC595PWRE4	ACTIVE	TSSOP	PW	16	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	HC595	Samples
SN74HC595PWRG4	ACTIVE	TSSOP	PW	16	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	HC595	Samples
SNJ54HC595FK	ACTIVE	LCCC	FK	20	1	TBD	POST-PLATE	N / A for Pkg Type	-55 to 125	5962-86816012A SNJ54HC 595FK	Samples
SNJ54HC595J	ACTIVE	CDIP	J	16	1	TBD	A42	N / A for Pkg Type	-55 to 125	5962-8681601EA SNJ54HC595J	Samples

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
SNJ54HC595W	OBSOLETE			16		TBD	Call TI	Call TI	-55 to 125		

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

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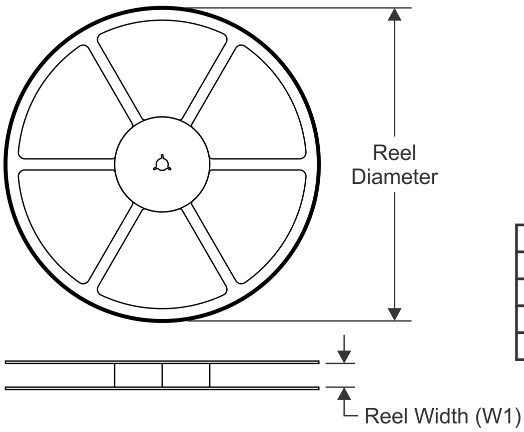
In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

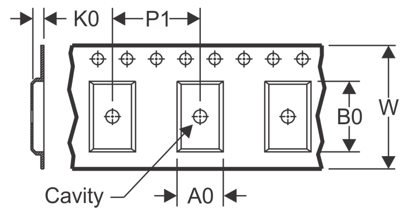
OTHER QUALIFIED VERSIONS OF SN54HC595, SN54HC595-SP, SN74HC595 :

TAPE AND REEL INFORMATION

REEL DIMENSIONS

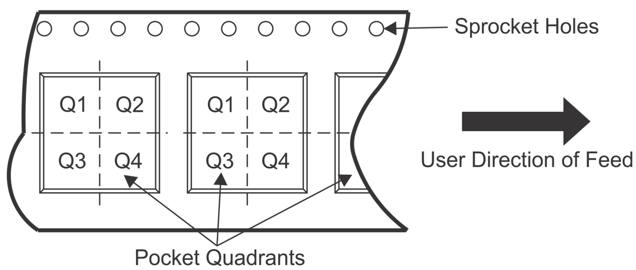


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

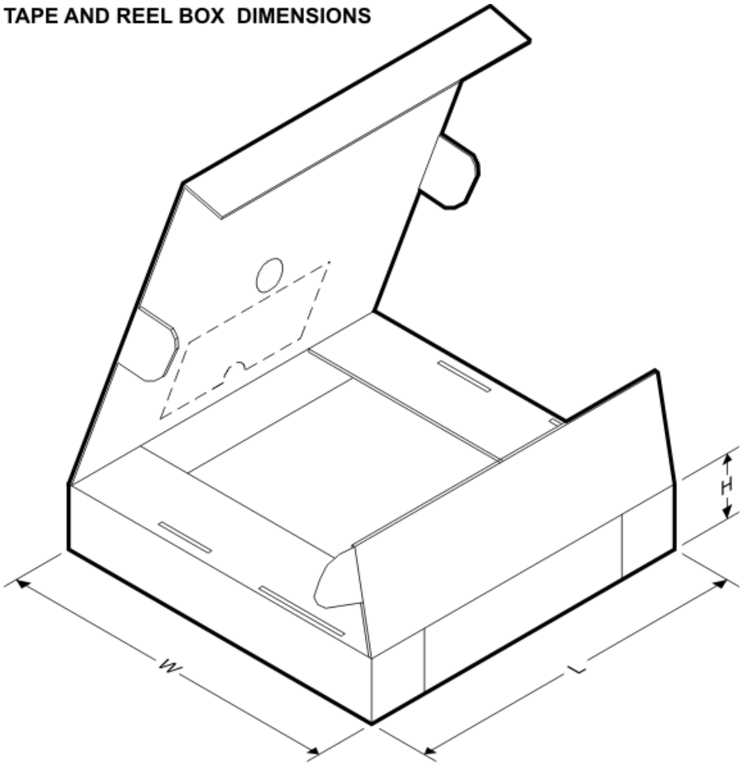
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
SN74HC595DBR	SSOP	DB	16	2000	330.0	16.4	8.2	6.6	2.5	12.0	16.0	Q1
SN74HC595DR	SOIC	D	16	2500	330.0	16.8	6.5	10.3	2.1	8.0	16.0	Q1
SN74HC595DRG3	SOIC	D	16	2500	330.0	16.8	6.5	10.3	2.1	8.0	16.0	Q1
SN74HC595DRG4	SOIC	D	16	2500	330.0	16.4	6.5	10.3	2.1	8.0	16.0	Q1
SN74HC595DRG4	SOIC	D	16	2500	330.0	16.4	6.5	10.3	2.1	8.0	16.0	Q1
SN74HC595DWR	SOIC	DW	16	2000	330.0	16.4	10.75	10.7	2.7	12.0	16.0	Q1
SN74HC595DWRG4	SOIC	DW	16	2000	330.0	16.4	10.75	10.7	2.7	12.0	16.0	Q1
SN74HC595PWR	TSSOP	PW	16	2000	330.0	12.4	6.9	5.6	1.6	8.0	12.0	Q1

TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
SN74HC595DBR	SSOP	DB	16	2000	367.0	367.0	38.0
SN74HC595DR	SOIC	D	16	2500	364.0	364.0	27.0
SN74HC595DRG3	SOIC	D	16	2500	364.0	364.0	27.0
SN74HC595DRG4	SOIC	D	16	2500	367.0	367.0	38.0
SN74HC595DRG4	SOIC	D	16	2500	333.2	345.9	28.6
SN74HC595DWR	SOIC	DW	16	2000	367.0	367.0	38.0
SN74HC595DWRG4	SOIC	DW	16	2000	367.0	367.0	38.0
SN74HC595PWR	TSSOP	PW	16	2000	367.0	367.0	35.0

MAX31855

Cold-Junction Compensated Thermocouple-to-Digital Converter

General Description

The MAX31855 performs cold-junction compensation and digitizes the signal from a K-, J-, N-, T-, S-, R-, or E-type thermocouple. The data is output in a signed 14-bit, SPI-compatible, read-only format. This converter resolves temperatures to 0.25°C, allows readings as high as +1800°C and as low as -270°C, and exhibits thermocouple accuracy of ±2°C for temperatures ranging from -200°C to +700°C for K-type thermocouples. For full range accuracies and other thermocouple types, see the *Thermal Characteristics* specifications.

Applications

Industrial

Appliances

HVAC

Automotive

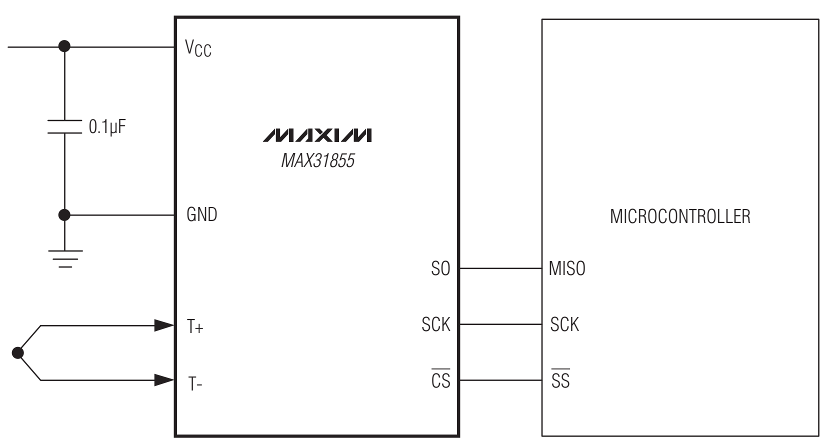
Features

- ♦ Cold-Junction Compensation
- ♦ 14-Bit, 0.25°C Resolution
- ♦ Versions Available for K-, J-, N-, T-, S-, R-, and E-Type Thermocouples (see Table 1)
- ♦ Simple SPI-Compatible Interface (Read-Only)
- ♦ Detects Thermocouple Shorts to GND or V_{CC}
- ♦ Detects Open Thermocouple

***Ordering Information** appears at end of data sheet.*

*For related parts and recommended products to use with this part, refer to: **www.maxim-ic.com/MAX31855.related***

Typical Application Circuit



ABSOLUTE MAXIMUM RATINGS

Supply Voltage Range (V_{CC} to GND)..................-0.3V to +4.0V
All Other Pins... -0.3V to (V_{CC} + 0.3V)
Continuous Power Dissipation (T_A = +70°C)
SO (derate 5.9mW/°C above +70°C).......................470.6mW
ESD Protection (All Pins, Human Body Model)..................±2kV
Operating Temperature Range........................-40°C to +125°C
Junction Temperature ....+150°C
Storage Temperature Range ....-65°C to +150°C
Lead Temperature (soldering, 10s) ....+300°C
Soldering Temperature (reflow) ....+260°C

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

PACKAGE THERMAL CHARACTERISTICS (Note 1)

SO
Junction-to-Ambient Thermal Resistance (θ_{JA}) ....170°C/W
Junction-to-Case Thermal Resistance (θ_{JC})..............40°C/W

Note 1: Package thermal resistances were obtained using the method described in JEDEC specification JESD51-7, using a four-layer board. For detailed information on package thermal considerations, refer to **www.maxim-ic.com/thermal-tutorial**.

RECOMMENDED OPERATING CONDITIONS

(T_A = -40°C to +125°C, unless otherwise noted.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Power-Supply Voltage	V_{CC}	(Note 2)	3.0	3.3	3.6	V
Input Logic 0	V_{IL}		-0.3		+0.8	V
Input Logic 1	V_{IH}		2.1		V_{CC} + 0.3	V

DC ELECTRICAL CHARACTERISTICS

(3.0V ≤ V_{CC} ≤ 3.6V, T_A = -40°C to +125°C, unless otherwise noted.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Power-Supply Current	I_{CC}			900	1500	µA
Thermocouple Input Bias Current		T_A = -40°C to +125°C, 100mV across the thermocouple inputs	-100		+100	nA
Power-Supply Rejection				-0.3		°C/V
Power-On Reset Voltage Threshold	V_{POR}	(Note 3)		2	2.5	V
Power-On Reset Voltage Hysteresis				0.2		V
Output High Voltage	V_{OH}	I_{OUT} = -1.6mA	V_{CC} - 0.4			V
Output Low Voltage	V_{OL}	I_{OUT} = 1.6mA			0.4	V

THERMAL CHARACTERISTICS

($3.0V \le V_{CC} \le 3.6V$, T_A = -40°C to +125°C, unless otherwise noted.) (Note 4)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
MAX31855K Thermocouple Temperature Gain and Offset Error (41.276µV/°C nominal sensitivity) (Note 4)		$T_{THERMOCOUPLE}$ = -200°C to +700°C, T_A = -20°C to +85°C (Note 3)	-2		+2	°C
		$T_{THERMOCOUPLE}$ = +700°C to +1350°C, T_A = -20°C to +85°C (Note 3)	-4		+4	
		$T_{THERMOCOUPLE}$ = -270°C to +1372°C, T_A = -40°C to +125°C (Note 3)	-6		+6	
MAX31855J Thermocouple Temperature Gain and Offset Error (57.953µV/°C nominal sensitivity) (Note 4)		$T_{THERMOCOUPLE}$ = -210°C to +750°C, T_A = -20°C to +85°C (Note 3)	-2		+2	°C
		$T_{THERMOCOUPLE}$ = -210°C to +1200°C, T_A = -40°C to +125°C (Note 3)	-4		+4	
MAX31855N Thermocouple Temperature Gain and Offset Error (36.256µV/°C nominal sensitivity) (Note 4)		$T_{THERMOCOUPLE}$ = -200°C to +700°C, T_A = -20°C to +85°C (Note 3)	-2		+2	°C
		$T_{THERMOCOUPLE}$ = +700°C to +1300°C, T_A = -20°C to +85°C (Note 3)	-4		+4	
		$T_{THERMOCOUPLE}$ = -270°C to +1300°C, T_A = -40°C to +125°C (Note 3)	-6		+6	
MAX31855T Thermocouple Temperature Gain and Offset Error (52.18µV/°C nominal sensitivity) (Note 4)		$T_{THERMOCOUPLE}$ = -270°C to +400°C, T_A = -20°C to +85°C (Note 3)	-2		+2	°C
		$T_{THERMOCOUPLE}$ = -270°C to +400°C, T_A = -40°C to +125°C (Note 3)	-4		+4	
MAX31855E Thermocouple Temperature Gain and Offset Error (76.373µV/°C nominal sensitivity) (Note 4)		$T_{THERMOCOUPLE}$ = -200°C to +700°C, T_A = -20°C to +85°C (Note 3)	-2		+2	°C
		$T_{THERMOCOUPLE}$ = +700°C to +1000°C, T_A = -20°C to +85°C (Note 3)	-3		+3	
		$T_{THERMOCOUPLE}$ = -270°C to +1000°C, T_A = -40°C to +125°C (Note 3)	-5		+5	
MAX31855R Thermocouple Temperature Gain and Offset Error (10.506µV/°C nominal sensitivity) (Note 4)		$T_{THERMOCOUPLE}$ = -50°C to +700°C, T_A = -20°C to +85°C (Note 3)	-2		+2	°C
		$T_{THERMOCOUPLE}$ = +700°C to +1768°C, T_A = -20°C to +85°C (Note 3)	-4		+4	
		$T_{THERMOCOUPLE}$ = -50°C to +1768°C, T_A = -40°C to +125°C (Note 3)	-6		+6	
MAX31855S Thermocouple Temperature Gain and Offset Error (9.587µV/°C nominal sensitivity) (Note 4)		$T_{THERMOCOUPLE}$ = -50°C to +700°C, T_A = -20°C to +85°C (Note 3)	-2		+2	°C
		$T_{THERMOCOUPLE}$ = +700°C to +1768°C, T_A = -20°C to +85°C (Note 3)	-4		+4	
		$T_{THERMOCOUPLE}$ = -50°C to +1768°C, T_A = -40°C to +125°C (Note 3)	-6		+6	

THERMAL CHARACTERISTICS (continued)

(3.0V ≤ V_{CC} ≤ 3.6V, T_A = -40°C to +125°C, unless otherwise noted.) (Note 4)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Thermocouple Temperature Data Resolution				0.25		°C
Internal Cold-Junction Temperature Error		T_A = -20°C to +85°C (Note 3)	-2		+2	°C
		T_A = -40°C to +125°C (Note 3)	-3		+3	
Cold-Junction Temperature Data Resolution		T_A = -40°C to +125°C		0.0625		°C
Temperature Conversion Time (Thermocouple, Cold Junction, Fault Detection)	t_{CONV}	(Note 5)		70	100	ms
Thermocouple Conversion Power-Up Time	t_{CONV_PU}	(Note 6)	200			ms

SERIAL-INTERFACE TIMING CHARACTERISTICS

(See Figure 1 and Figure 2.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Input Leakage Current	I_{LEAK}	(Note 7)	-1		+1	µA
Input Capacitance	C_{IN}			8		pF
Serial-Clock Frequency	f_{SCL}				5	MHz
SCK Pulse-High Width	t_{CH}		100			ns
SCK Pulse-Low Width	t_{CL}		100			ns
SCK Rise and Fall Time					200	ns
$\overline{CS}$ Fall to SCK Rise	t_{CSS}		100			ns
SCK to $\overline{CS}$ Hold			100			ns
$\overline{CS}$ Fall to Output Enable	t_{DV}				100	ns
$\overline{CS}$ Rise to Output Disable	t_{TR}				40	ns
SCK Fall to Output Data Valid	t_{DO}				40	ns
$\overline{CS}$ Inactive Time		(Note 3)	200			ns

Note 2: All voltages are referenced to GND. Currents entering the IC are specified positive, and currents exiting the IC are negative.

Note 3: Guaranteed by design; not production tested.

Note 4: Not including cold-junction temperature error or thermocouple nonlinearity.

Note 5: Specification is 100% tested at T_A = +25°C. Specification limits over temperature (T_A = T_{MIN} to T_{MAX}) are guaranteed by design and characterization; not production tested.

Note 6: Because the thermocouple temperature conversions begin at V_{POR}, depending on V_{CC} slew rates, the first thermocouple temperature conversion may not produce an accurate result. Therefore, the t_{CONV_PU} specification is required after V_{CC} is greater than V_{CCMIN} to guarantee a valid thermocouple temperature conversion result.

Note 7: For all pins except T+ and T- (see the Thermocouple Input Bias Current parameter in the *DC Electrical Characteristics* table).

Detailed Description

The MAX31855 is a sophisticated thermocouple-to-digital converter with a built-in 14-bit analog-to-digital converter (ADC). The device also contains cold-junction compensation sensing and correction, a digital controller, an SPI-compatible interface, and associated control logic. The device is designed to work in conjunction with an external microcontroller (µC) in thermostatic, process-control, or monitoring applications. The device is available in several versions, each optimized and trimmed for a specific thermocouple type (K, J, N, T, S, R, or E.). The thermocouple type is indicated in the suffix of the part number (e.g., MAX31855K). See the *Ordering Information* table for all options.

Temperature Conversion

The device includes signal-conditioning hardware to convert the thermocouple's signal into a voltage compatible with the input channels of the ADC. The T+ and T- inputs connect to internal circuitry that reduces the introduction of noise errors from the thermocouple wires.

Before converting the thermoelectric voltages into equivalent temperature values, it is necessary to compensate for the difference between the thermocouple cold-junction side (device ambient temperature) and a 0°C virtual reference. For a K-type thermocouple, the voltage changes by about 41µV/°C, which approximates the thermocouple characteristic with the following linear equation:

$$V_{OUT} = (41.276\mu V/°C) \times (T_R - T_{AMB})$$

where V_{OUT} is the thermocouple output voltage (µV), T_R is the temperature of the remote thermocouple junction (°C), and T_{AMB} is the temperature of the device (°C).

Other thermocouple types use a similar straight-line approximation but with different gain terms. Note that the MAX31855 assumes a linear relationship between temperature and voltage. Because all thermocouples exhibit some level of nonlinearity, apply appropriate correction to the device's output data.

Cold-Junction Compensation

The function of the thermocouple is to sense a difference in temperature between two ends of the thermocouple wires. The thermocouple's "hot" junction can be read across the operating temperature range (Table 1). The reference junction, or "cold" end (which should be at

Table 1. Thermocouple Wire Connections and Nominal Sensitivities

TYPE	T- WIRE	T+ WIRE	TEMP RANGE (°C)	SENSITIVITY (µV/°C)	COLD-JUNCTION SENSITIVITY (µV/°C) (0°C TO +70°C)
K	Alumel	Chromel	-270 to +1372	41.276 (0°C to +1000°C)	40.73
J	Constantan	Iron	-210 to +1200	57.953 (0°C to +750°C)	52.136
N	Nisil	Nicrosil	-270 to + 1300	36.256 (0°C to +1000°C)	27.171
S	Platinum	Platinum/Rhodium	+50 to +1768	9.587 (0°C to +1000°C)	6.181
T	Constantan	Copper	-270 to +400	52.18 (0°C to +400°C)	41.56
E	Constantan	Chromel	-270 to +1000	76.373 (0°C to +1000°C)	44.123
R	Platinum	Platinum/Rhodium	-50 to +1768	10.506 (0°C to +1000°C)	6.158

the same temperature as the board on which the device is mounted) can range from -55°C to +125°C. While the temperature at the cold end fluctuates, the device continues to accurately sense the temperature difference at the opposite end.

The device senses and corrects for the changes in the reference junction temperature with cold-junction compensation. It does this by first measuring its internal die temperature, which should be held at the same temperature as the reference junction. It then measures the voltage from the thermocouple's output at the reference junction and converts this to the noncompensated thermocouple temperature value. This value is then added to the device's die temperature to calculate the thermocouple's "hot junction" temperature. Note that the "hot junction" temperature can be lower than the cold junction (or reference junction) temperature.

Optimal performance from the device is achieved when the thermocouple cold junction and the device are at the same temperature. Avoid placing heat-generating devices or components near the MAX31855 because this could produce cold-junction-related errors.

Conversion Functions

During the conversion time, t_{CONV}, three functions are performed: the temperature conversion of the internal cold-junction temperature, the temperature conversion of the external thermocouple, and the detection of thermocouple faults.

When executing the temperature conversion for the internal cold-junction compensation circuit, the connection to signal from the external thermocouple is opened (switch S4) and the connection to the cold-junction compensation circuit is closed (switch S5). The internal T- reference to ground is still maintained (switch S3 is closed) and the connections to the fault-detection circuit are open (switches S1 and S2).

When executing the temperature conversion of the external thermocouple, the connections to the internal fault-detection circuit are opened (switches S1 and S2 in the *Block Diagram*) and the switch connecting the cold-junction compensation circuit is opened (switch S5). The internal ground reference connection (switch S3) and the connection to the ADC (switch S4) are closed. This allows the ADC to process the voltage detected across the T+ and T- terminals.

During fault detection, the connections from the external thermocouple and cold-junction compensation circuit to the ADC are opened (switches S4 and S5). The internal ground reference on T- is also opened (switch S3). The connections to the internal fault-detection circuit are closed (switch S1 and S2). The fault-detection circuit tests for shorted connections to V_{CC} or GND on the T+ and T- inputs, as well as looking for an open thermocouple condition. Bits D0, D1, and D2 of the output data are normally low. Bit D2 goes high to indicate a thermocouple short to V_{CC}, bit D1 goes high to indicate a thermocouple short to GND, and bit D0 goes high to indicate a thermocouple open circuit. If any of these conditions exists, bit D16 of the SO output data, which is normally low, also goes high to indicate that a fault has occurred.

Serial Interface

The *Typical Application Circuit* shows the device interfaced with a microcontroller. In this example, the device processes the reading from the thermocouple and transmits the data through a serial interface. Drive $\overline{CS}$ low and apply a clock signal at SCK to read the results at SO. Conversions are always being performed in the background. The fault and temperature data are only be updated when $\overline{CS}$ is high.

Drive $\overline{CS}$ low to output the first bit on the SO pin. A complete serial-interface read of the cold-junction compensated thermocouple temperature requires 14 clock cycles. Thirty-two clock cycles are required to read both the thermocouple and reference junction temperatures (Table 2 and Table 3.) The first bit, D31, is the thermocouple temperature sign bit, and is presented to the SO pin within t_{DV} of the falling edge of $\overline{CS}$. Bits D[30:18] contain the converted temperature in the order of MSB to LSB, and are presented to the SO pin within t_{D0} of the falling edge of SCK. Bit D16 is normally low and goes high when the thermocouple input is open or shorted to GND or V_{CC}. The reference junction temperature data begins with D15. $\overline{CS}$ can be taken high at any point while clocking out conversion data. If T+ and T- are unconnected, the thermocouple temperature sign bit (D31) is 0, and the remainder of the thermocouple temperature value (D[30:18]) is 1.

Figure 1 and Figure 2 show the serial-interface timing and order. Table 2 and Table 3 show the SO output bit weights and functions.

Table 2. Memory Map—Bit Weights and Functions

	14-BIT THERMOCOUPLE TEMPERATURE DATA				RES	FAULT BIT	12-BIT INTERNAL TEMPERATURE DATA				RES	SCV BIT	SCG BIT	OC BIT
BIT	D31	D30	…	D18	D17	D16	D15	D14	…	D4	D3	D2	D1	D0
VALUE	Sign	MSB 2^{10} (1024°C)	…	LSB 2^{-2} (0.25°C)	Reserved	1 = Fault	Sign	MSB 2^6 (64°C)	…	LSB 2^{-4} (0.0625°C)	Reserved	1 = Short to V_{CC}	1 = Short to GND	1 = Open Circuit

Table 3. Memory Map—Descriptions

BIT	NAME	DESCRIPTION
D[31:18]	14-Bit Thermocouple Temperature Data	These bits contain the signed 14-bit thermocouple temperature value. See Table 4.
D17	Reserved	This bit always reads 0.
D16	Fault	This bit reads at 1 when any of the SCV, SCG, or OC faults are active. Default value is 0.
D[15:4]	12-Bit Internal Temperature Data	These bits contain the signed 12-bit value of the reference junction temperature. See Table 5.
D3	Reserved	This bit always reads 0.
D2	SCV Fault	This bit is a 1 when the thermocouple is short-circuited to V_{CC}. Default value is 0.
D1	SCG Fault	This bit is a 1 when the thermocouple is short-circuited to GND. Default value is 0.
D0	OC Fault	This bit is a 1 when the thermocouple is open (no connections). Default value is 0.

Table 4. Thermocouple Temperature Data Format

TEMPERATURE (°C)	DIGITAL OUTPUT (D[31:18])
+1600.00	0110 0100 0000 00
+1000.00	0011 1110 1000 00
+100.75	0000 0110 0100 11
+25.00	0000 0001 1001 00
0.00	0000 0000 0000 00
-0.25	1111 1111 1111 11
-1.00	1111 1111 1111 00
-250.00	1111 0000 0110 00

Note: *The practical temperature ranges vary with the thermocouple type.*

Table 5. Reference Junction Temperature Data Format

TEMPERATURE (°C)	DIGITAL OUTPUT (D[15:4])
+127.0000	0111 1111 0000
+100.5625	0110 0100 1001
+25.0000	0001 1001 0000
0.0000	0000 0000 0000
-0.0625	1111 1111 1111
-1.0000	1111 1111 0000
-20.0000	1110 1100 0000
-55.0000	1100 1001 0000

Applications Information

Noise Considerations

Because of the small signal levels involved, thermocouple temperature measurement is susceptible to power-supply coupled noise. The effects of power-supply noise can be minimized by placing a 0.1µF ceramic bypass capacitor close to the V_{CC} pin of the device and to GND.

The input amplifier is a low-noise amplifier designed to enable high-precision input sensing. Keep the thermocouple and connecting wires away from electrical noise sources. It is strongly recommended to add a 10nF ceramic surface-mount differential capacitor, placed across the T+ and T- pins, in order to filter noise on the thermocouple lines.

Thermal Considerations

Self-heating degrades the device's temperature measurement accuracy in some applications. The magnitude of the temperature errors depends on the thermal conductivity of the device package, the mounting technique, and the effects of airflow. Use a large ground plane to improve the device's temperature measurement accuracy.

The thermocouple system's accuracy can also be improved by following these precautions:

- Use the largest wire possible that does not shunt heat away from the measurement area.
- If a small wire is required, use it only in the region of the measurement, and use extension wire for the region with no temperature gradient.
- Avoid mechanical stress and vibration, which could strain the wires.
- When using long thermocouple wires, use a twisted pair extension wire.
- Avoid steep temperature gradients.
- Try to use the thermocouple wire well within its temperature rating.
- Use the proper sheathing material in hostile environments to protect the thermocouple wire.
- Use extension wire only at low temperatures and only in regions of small gradients.
- Keep an event log and a continuous record of thermocouple resistance.

Ordering Information

PART	THERMOCOUPLE TYPE	MEASURED TEMP RANGE	PIN-PACKAGE
MAX31855KASA+	K	-200°C to +1350°C	8 SO
MAX31855KASA+T	K	-200°C to +1350°C	8 SO
MAX31855JASA+	J	-40°C to +750°C	8 SO
MAX31855JASA+T	J	-40°C to +750°C	8 SO
MAX31855NASA+	N	-200°C to + 1300°C	8 SO
MAX31855NASA+T	N	-200°C to + 1300°C	8 SO
MAX31855SASA+	S	+50°C to +1600°C	8 SO
MAX31855SASA+T	S	+50°C to +1600°C	8 SO
MAX31855TASA+	T	-250°C to +400°C	8 SO
MAX31855TASA+T	T	-250°C to +400°C	8 SO
MAX31855EASA+	E	-40°C to +900°C	8 SO
MAX31855EASA+T	E	-40°C to +900°C	8 SO
MAX31855RASA+	R	-50°C to +1770°C	8 SO
MAX31855RASA+T	R	-50°C to +1770°C	8 SO

Note: *All devices are specified over the -40°C to +125°C operating temperature range.*
+Denotes a lead(Pb)-free/RoHS-compliant package.
T = Tape and reel.

Package Information

For the latest package outline information and land patterns (footprints), go to **www.maxim-ic.com/packages**. Note that a "+", "#", or "-" in the package code indicates RoHS status only. Package drawings may show a different suffix character, but the drawing pertains to the package regardless of RoHS status.

PACKAGE TYPE	PACKAGE CODE	OUTLINE NO.	LAND PATTERN NO.
8 SO	S8+4	21-0041	90-0096

Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
0	3/11	Initial release	—
1	11/11	Corrected ESD protection value; added "S" and "R" type specifications	1, 2, 3, 8, 12
2	2/12	Corrected the thermocouple temperature conditions in the *Thermal Characteristics* table and Table 1; added clarification to the *Serial Interface* section to help users better understand how to communicate with the device; added a recommendation to add a 10nF differential capacitor to the T+/T- pins in the *Noise Considerations* section	3, 8, 9, 11

McMASTER-CARR. OVER 555,000 PRODUCTS
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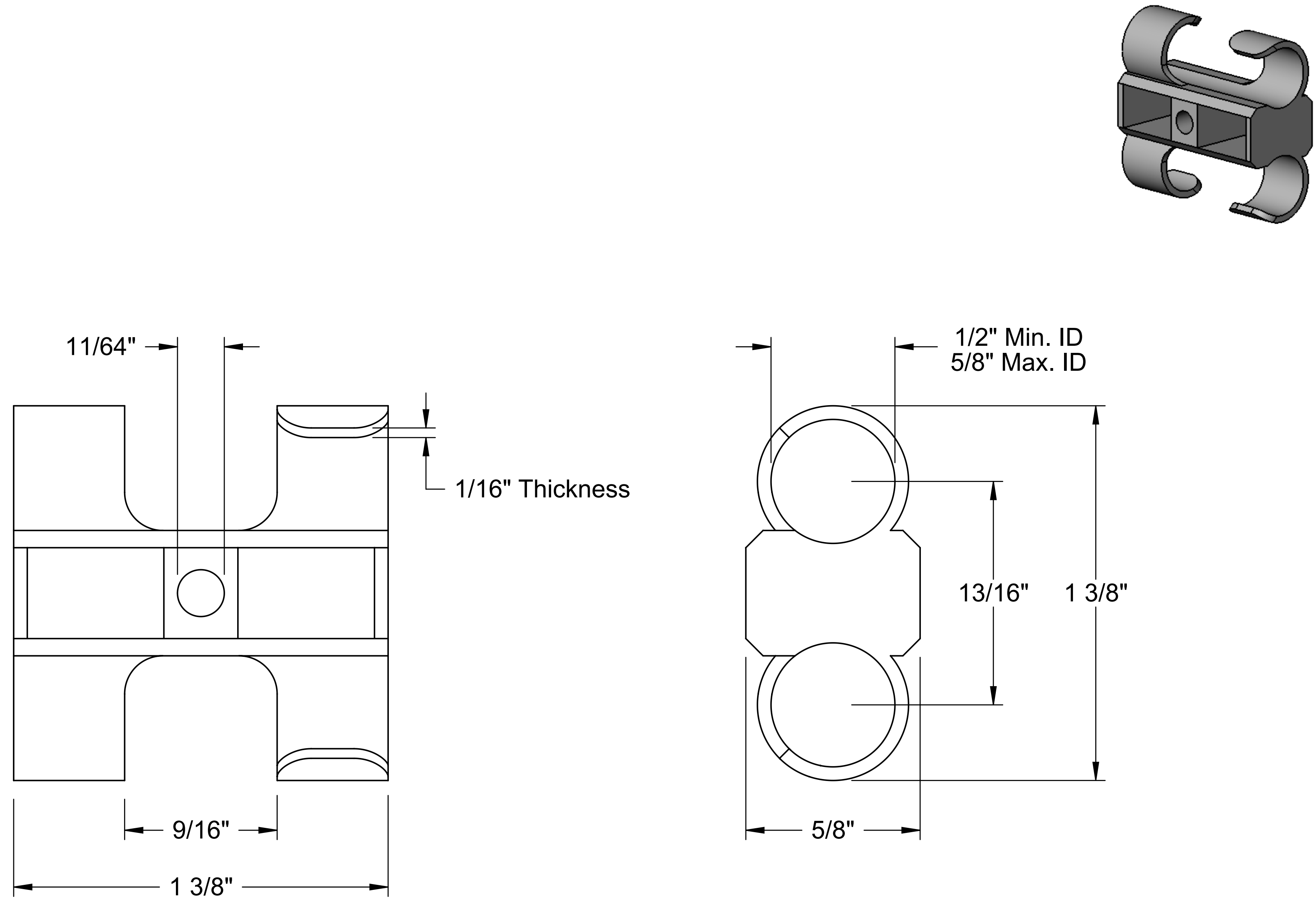
Text 75930

Thermocouple Probe for Liquids and Gases

Type K, 32 Degree to 900 Degree F, 6" Length x 3/16" Diameter Probe

In stock
$28.77 Each
3871K54

Type	K
Temperature Range	32° to 900° F
Probe	
Length	6"
Diameter	3/16"
Accuracy	±0.75%
Response Time	Not Rated
Cable Length	4 ft.
For Use With	Liquids, Gases
Connection Type	Wire Leads
Sensor Type	Grounded
Cable Material	Fiberglass
Probe Material	Stainless Steel
Maximum Cable Temperature	900° F
Wire	
Lead Length	1 3/4"
Gauge	20



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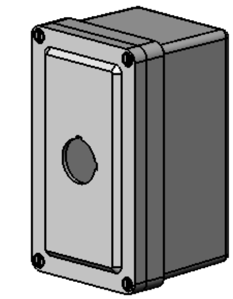
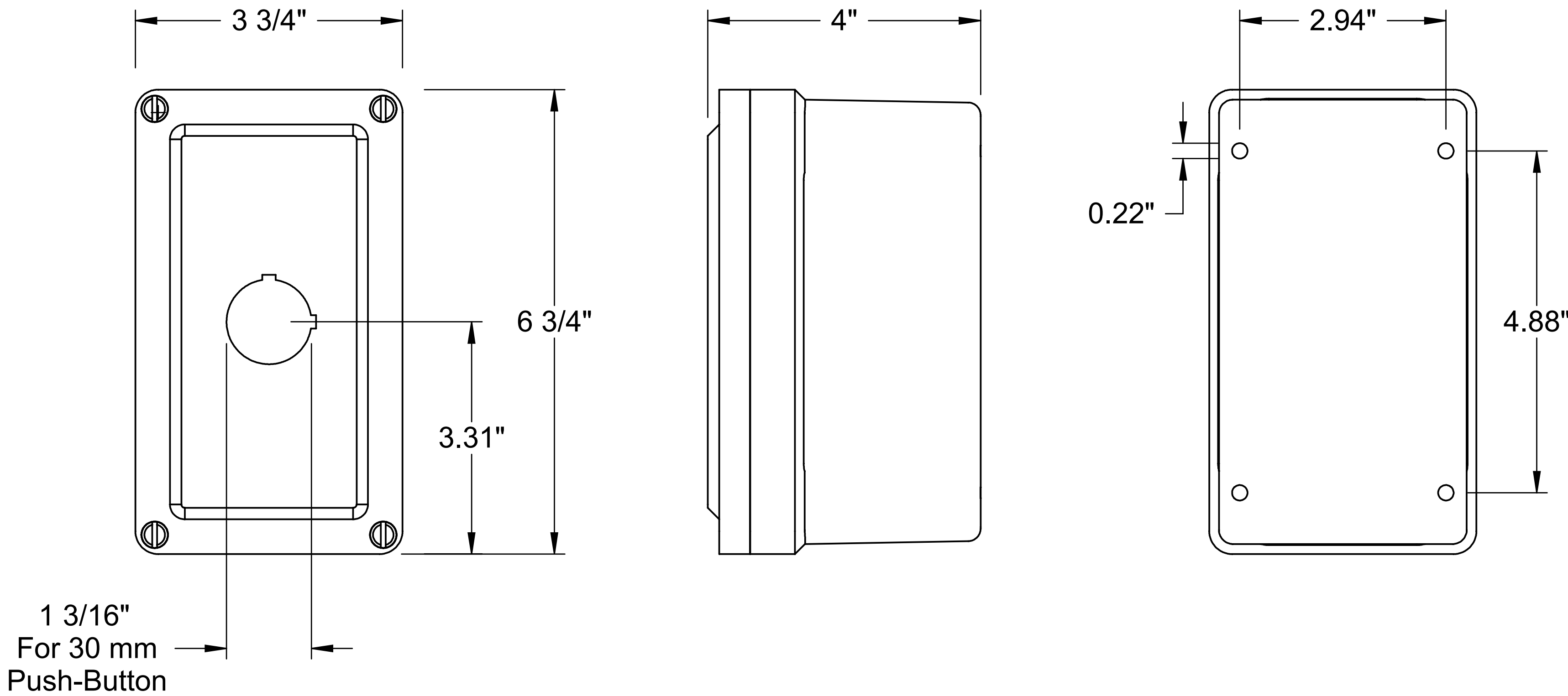
PART NUMBER 7429K45

http://www.mcmaster.com

Snap-In Plastic Clamp





Approximate Internal Dimensions: Ht. 6", Wd. 3 1/8", Dp. 3 5/8"

McMASTER-CARR® CAD	PART NUMBER 6916K31
http://www.mcmaster.com © 2014 McMaster-Carr Supply Company	Push-Button Enclosure
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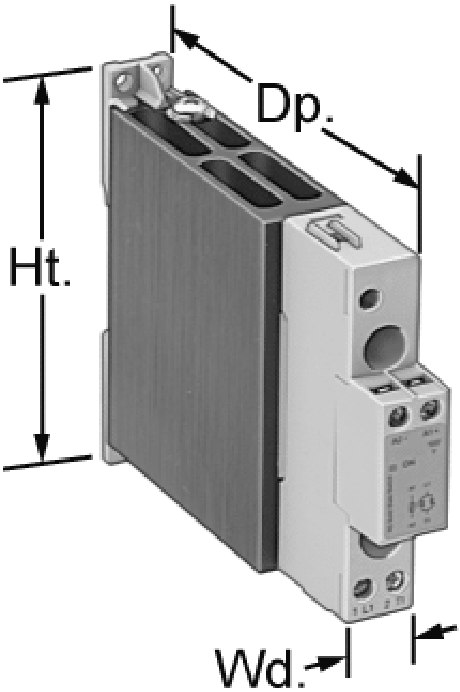
Long-Life Medium-Amp Relay

with Heatsink, SPST-NO, 20-275VAC/24-190VDC, 30 Amps@230VAC

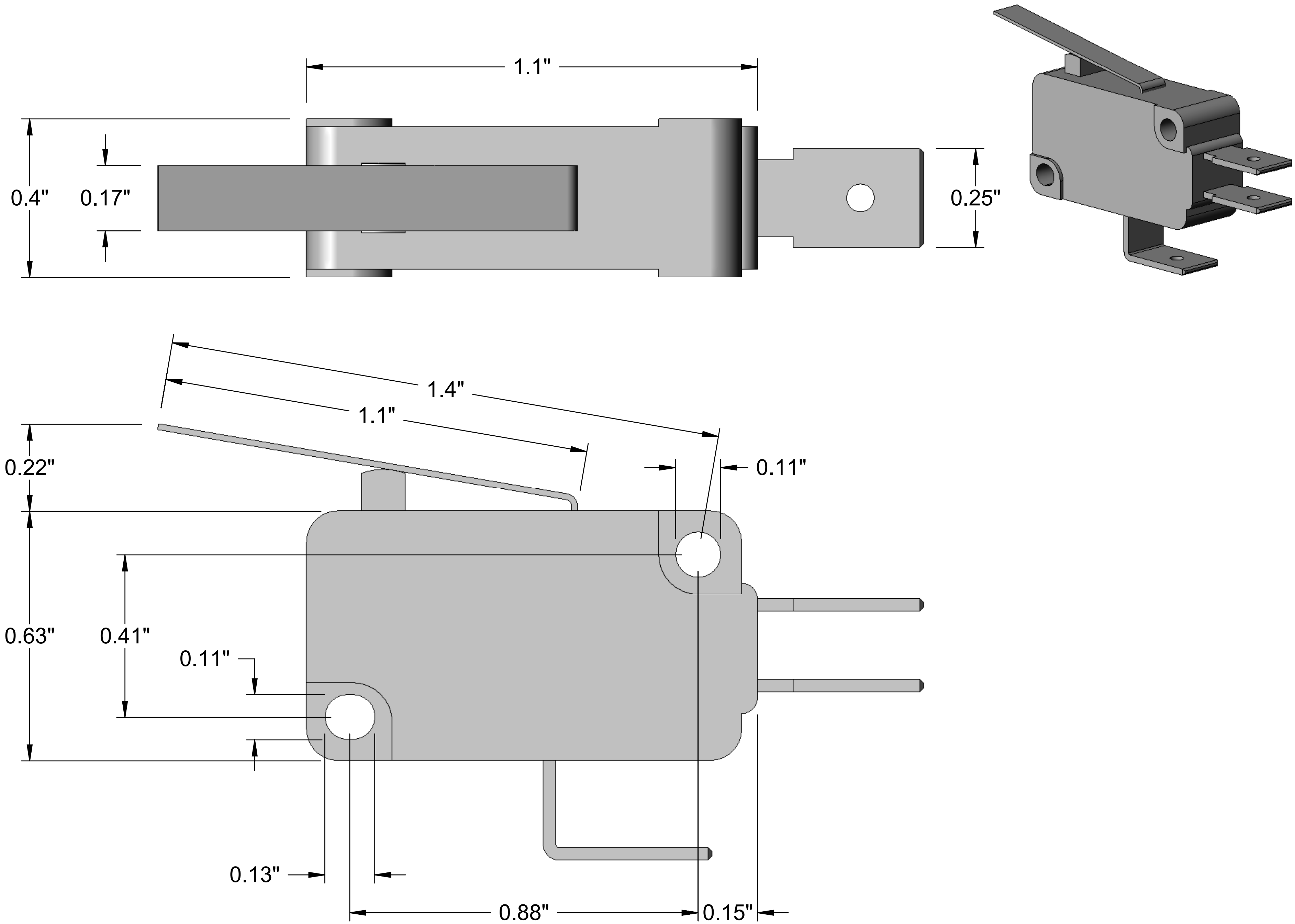
In stock
$76.37 Each
7456K78



Control Voltage	20-275 AC/24-190 DC
Amp Rating	30 @ 230V AC
Additional Specifications	Switch One Circuit On (SPST-NO)

A heat sink attached to these relays provides optimal convection cooling. Also known as solid state relays, they have no moving parts for silent operation and long service life. Relays have screw terminal connections and a built-in safeguard that protects against high starting current. Mount to 35 mm DIN rail. Contacts spring back (momentary) when power is removed. UL and C-UL listed.

One-circuit relays are 4.2" Ht. × 5.4" Dp. The 30-amp relays are 0.9" wide.



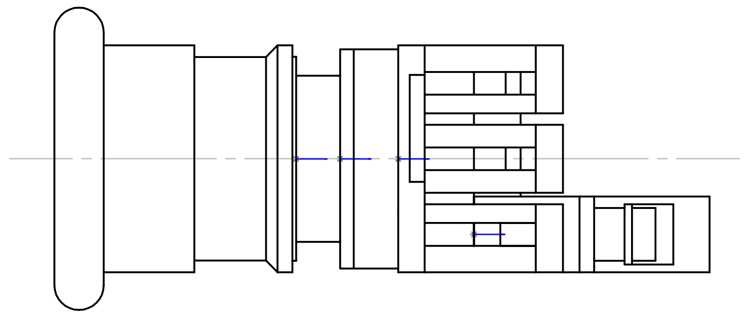
McMASTER-CARR® CAD

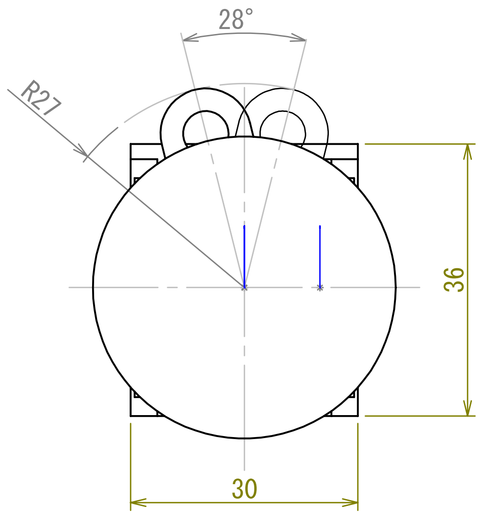
PART NUMBER **7510T12**

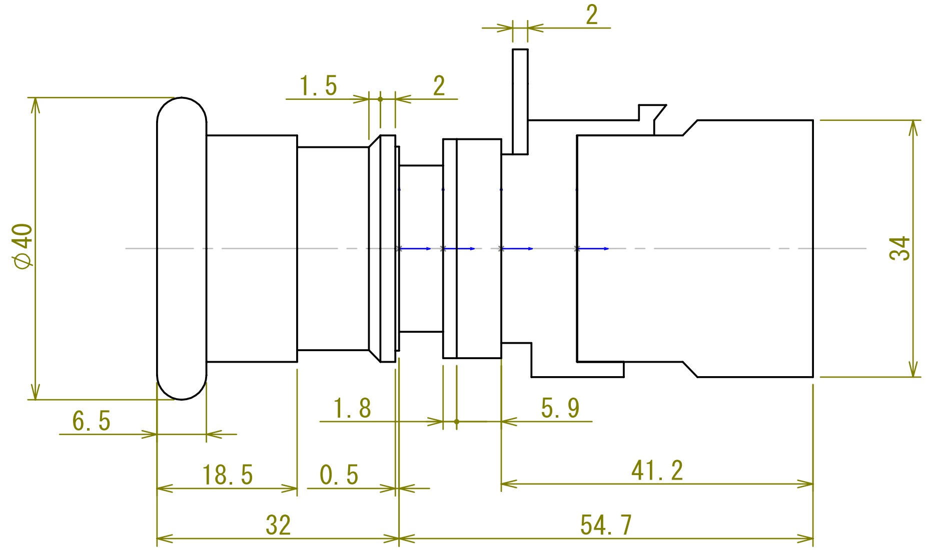
http://www.mcmaster.com

Rigid Lever
Minature Snap-Acting Switch

Emergency Stop Button
Supplier: Mouser Electronics (P/N: 653-A22E-M-01)
Manufacturer:Omron Automation and Safety (P/N: A22E-M-01)







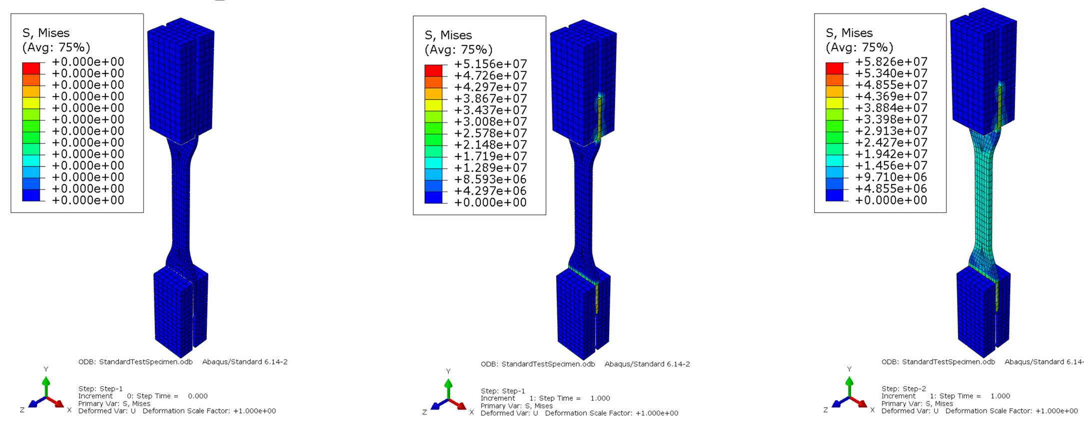
Appendix E: Detailed Supporting Analysis

Test Specimen Optimization

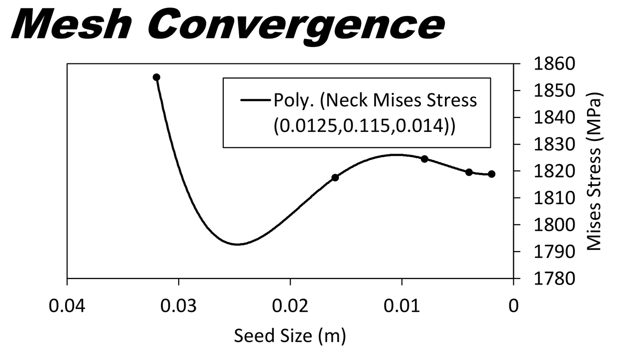
Presented by Brandon Stell and Michela Upson

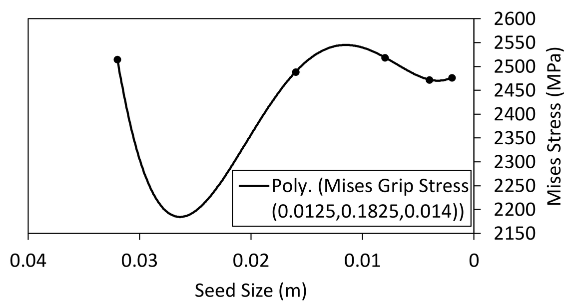
Standard Test Specimen:

Model



Mesh Convergence





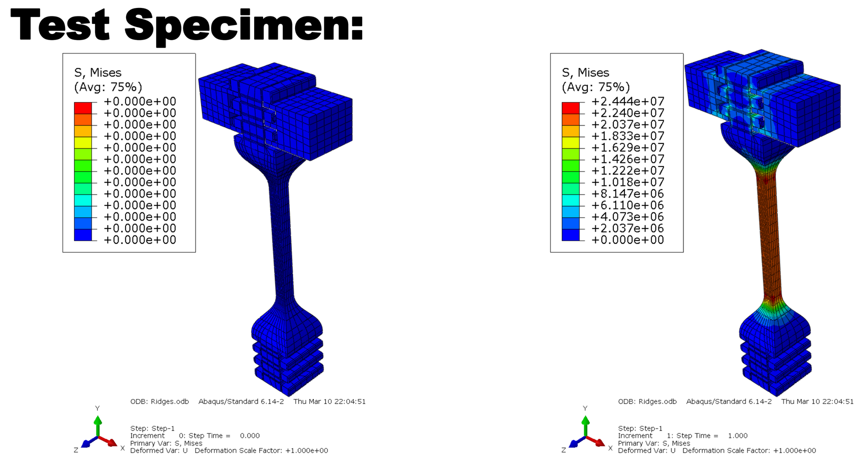
Model Characteristics

Mesh Type	Sweep Medial Axis (Specimen) / Structured (Clamp)
Element Type	Solid Quadratic Quadrilateral
Seed Size	0.004 meters
# DOF	29931
Average Aspect Ratio (Mesh Quality)	1.14

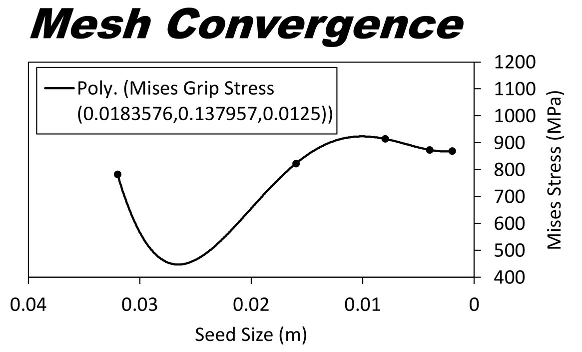
- **Initial Time Step – ENCASTRE applied to the right lower clamp, DOF freedom limited for the left lower clamp for all directions except in the Z, tie constraint between clamps and test piece**
- **Time Step 1 – Displacement of 0.0003 meters in –Z applied to each left clamp**
- **Time Step 2 – Displacement of 0.0059 meters in +Y applied to the upper clamps to pull the test piece**

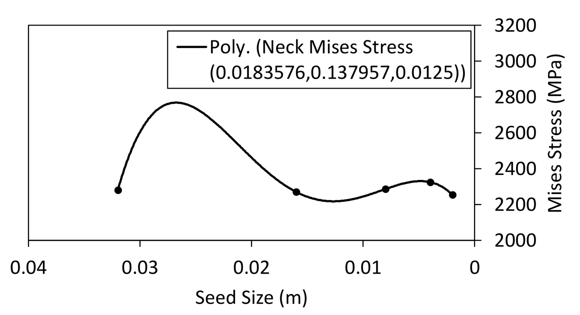
Slotted Test Specimen:

Model



Mesh Convergence





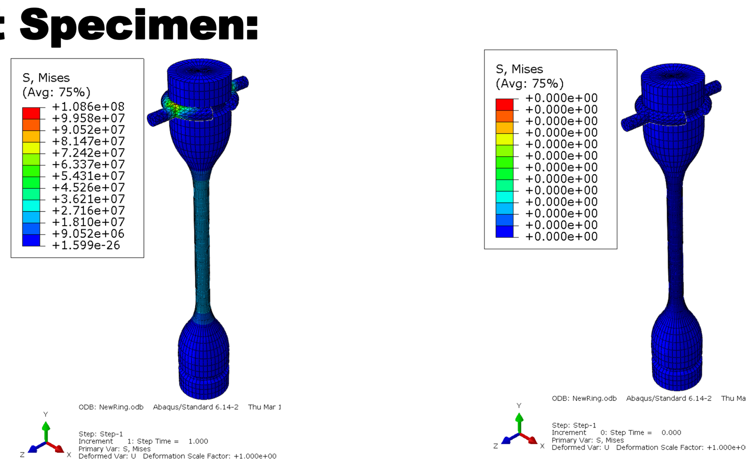
Model Characteristics

Mesh Type	Sweep Medial Axis & Advancing Front (Specimen) / Structured (Clamp)
Element Type	Solid Quadratic Quadrilateral
Seed Size	0.004 meters
# DOF	52623
Average Aspect Ratio (Mesh Quality)	1.66

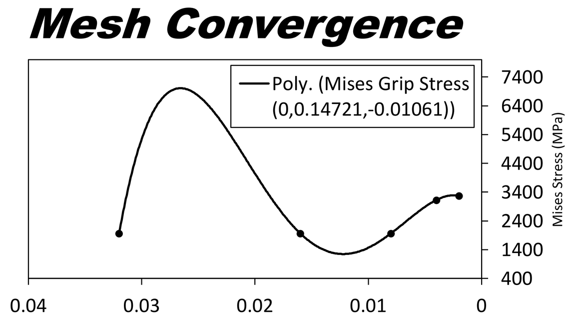
- **Initial Time Step – ENCASTRE applied to base of the element, tie constraint between top of fins of clamp and bottom of fins of test specimen**
- **Time Step 1 – Displacement of 0.0059 meters in +Y applied to each clamp**

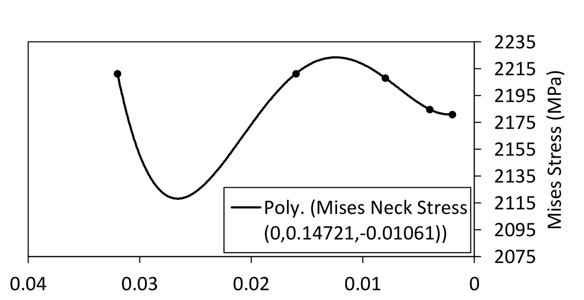
Ringed Test Specimen:

Model



Mesh Convergence





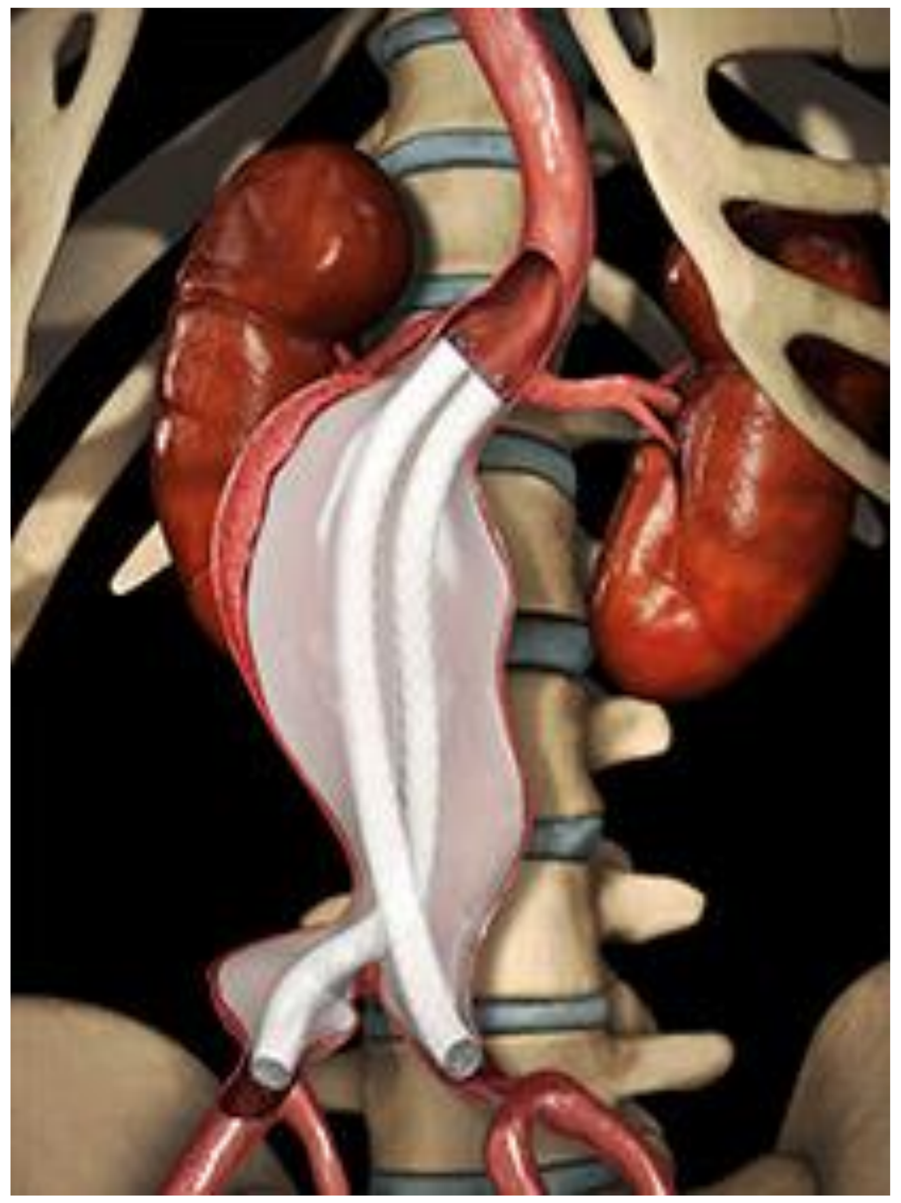
Model Characteristics

Mesh Type	Sweep Medial Axis (Specimen) / Free (Clamp)
Element Type	Solid Quadratic Quadrilateral (Specimen) / Solid Quadratic Tetrahedral (Clamp)
Seed Size	0.004 meters
# DOF	82053
Average Aspect Ratio (Mesh Quality)	1.73

- **Initial Time Step – ENCASTRE applied to lower notch, tie constraint created between clamps and the upper surface of the upper notch**
- **Time Step 1 – Displacement of 0.0059 meters in +Y applied to each upper clamp**

Introduction:

The purpose of this finite element analysis is to select an ideal test specimen shape for use in the polymer fatigue machine senior project for Endologix. This selection process involves comparing resulting stresses in five test specimen, with varying geometry and loading points, as a result of tensile loading. All test specimen results will be evaluated regarding the following: appearance of unusually high stress concentrations near the applied loading condition, test specimen breaking in the thin neck area as opposed to near the applied loading condition, a reasonable displacement before break, accurate FEA conditions which are true to those applied in real world testing, and an achievable and realistic loading condition.



Background:

Endologix, a biomedical company, has developed NELLIX, an endovascular aneurysm sealing system to be used with abdominal aortic aneurysms. This sealing system involves inserting stents into the abdominal aorta via the femoral arteries to provide alternate blood channels and relieve pressure from the weakened aorta. A bag surrounding the stents is filled with saline solution to fill up the enlarged aorta, and once it has filled the space, is then replaced with a polymer. Polylogix has been tasked with designing a fatigue machine to characterize material properties of newly developed polymers. Ultimately, we will use the ideal test specimen, identified herein, in a cyclic fatigue test we run on our machine.

Material Properties:

Test Specimen

Material	Density (g/cm^3)	Tensile Modulus (MPa)	Tensile Strength (MPa)	Yield Strength (MPa)	Elongation at Break (%)
Polyethylene (low density)	0.917	300	7	64.8	60

Clamps

Material	Density (g/cm^3)	Tensile Modulus (GPa)	Tensile Strength (MPa)	Yield Strength (MPa)	Elongation at Break (%)
Aluminum	2.7	68.9	230	130	22

Relevant ASTM Standards for Fatigue Test Specimen:

Table (below). Dimensions of standard dumbbell dies as defined in ASTM D412-06a.

Dimension	Units	Tolerance	Die A	Die B	Die C	Die D
A	mm	±1	25	25	25	16
B	mm	max	40	40	40	30
C	mm	min	140	140	115	100
D	mm	±6B	32	32	32	32
D-E	mm	±1	13	13	13	13
F	mm	±2	38	38	19	19
G	mm	±1	14	14	14	14
H	mm	±2	25	25	25	16
L	mm	±2	59	59	33	33
W	mm	±0.05, –0.00	12	6	6	3
Z	mm	±1	13	13	13	13

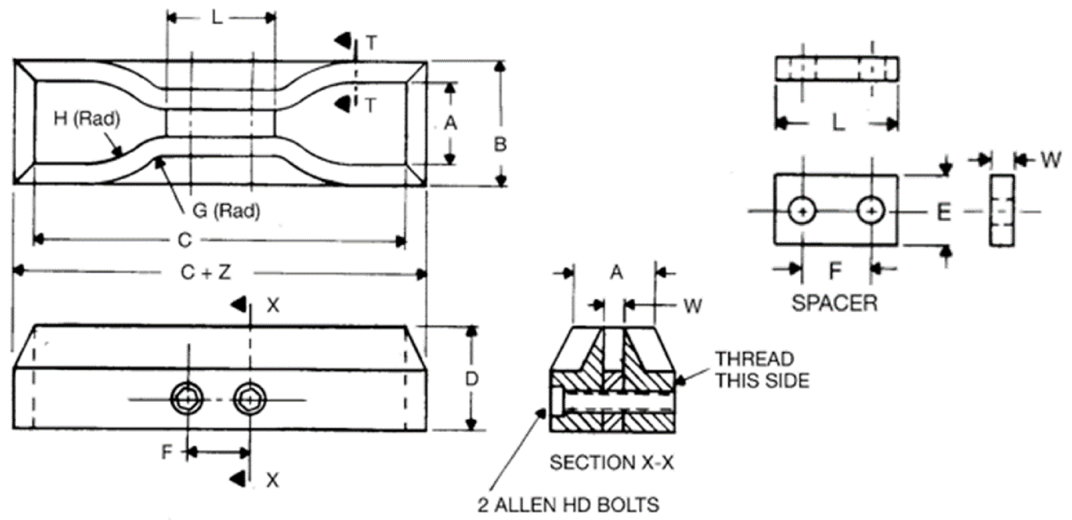


Figure (above). Standard dumbbell die referenced dimensions as in ASTM D412-06a.

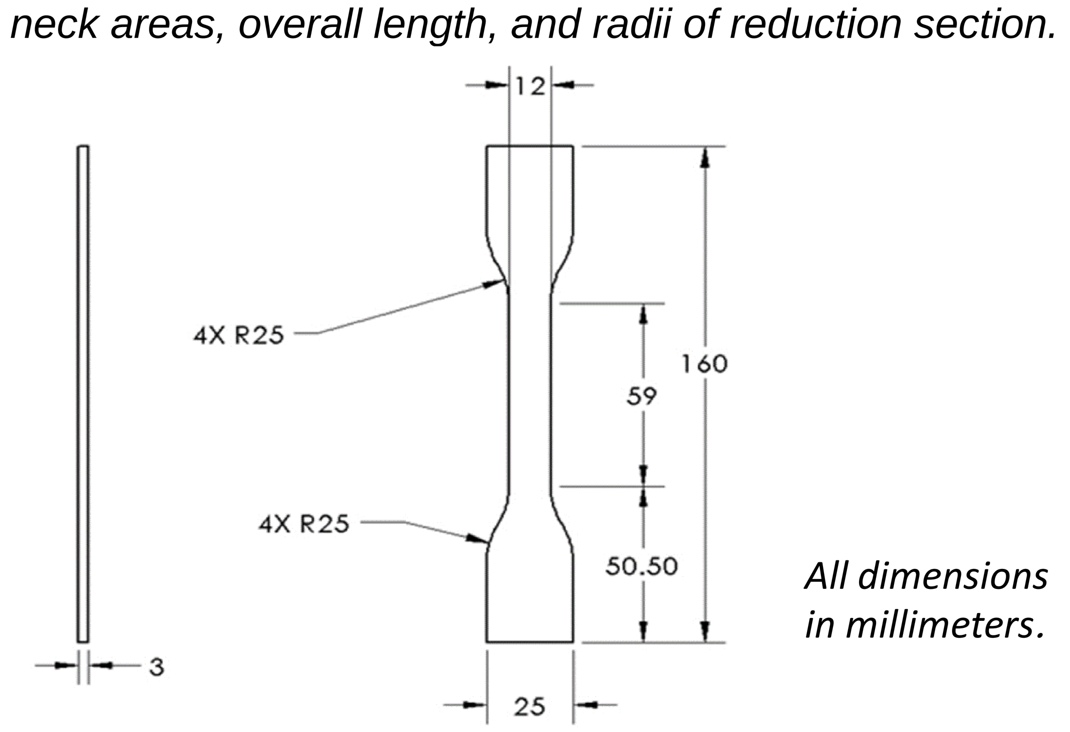
Hand Calculations:

Axial stress of the isolated neck section of the test specimen.

$L = 59\ mm$ $A = 36\ mm^2$ $E = 300\ MPa$ $d = 5.9\ mm$	$[k]\{d\} = \{f\}$ $k = \frac{AE}{L}$ $k = 183051\ N/m$ $f = 1080\ N$ $\sigma = \frac{F}{A}$ $\sigma = \frac{1080\ N}{36\ mm^2}$ $\sigma = 30\ MPa$

Abaqus Test Specimen Reference Geometry:

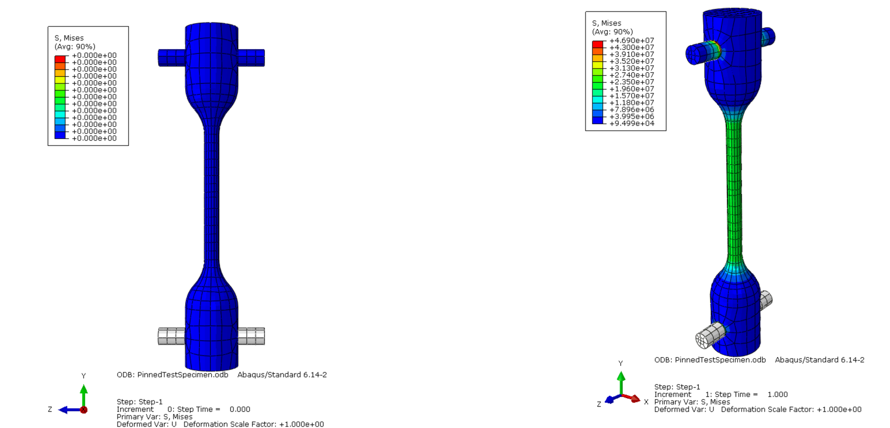
All test specimen variations maintained identical test section neck length, neck areas, overall length, and radii of reduction section.

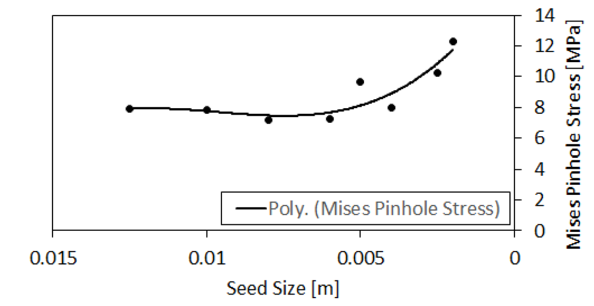


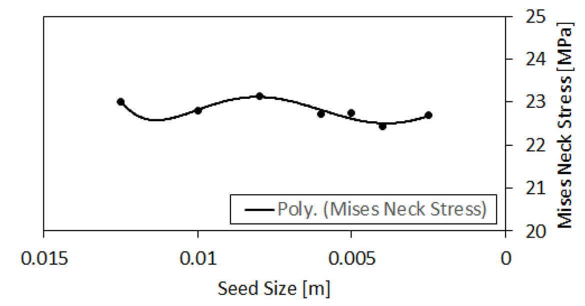
All dimensions in millimeters.

Pinned Test Specimen:

Model







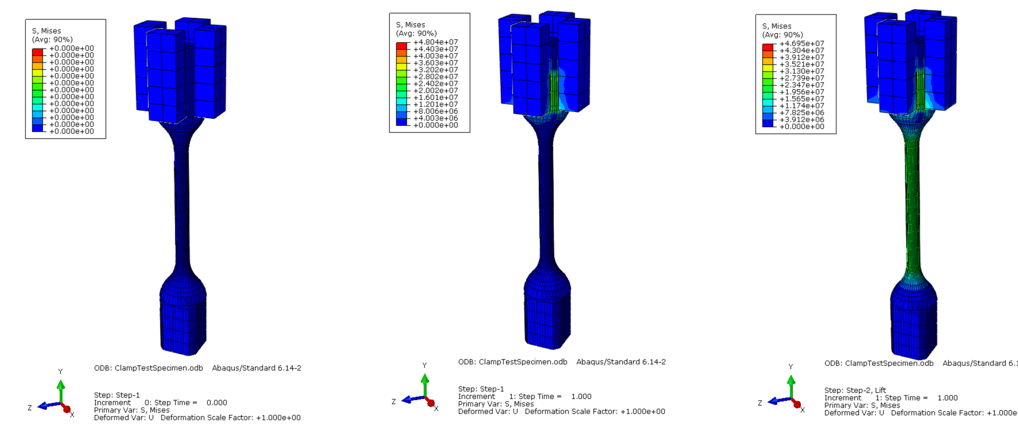
Model Characteristics

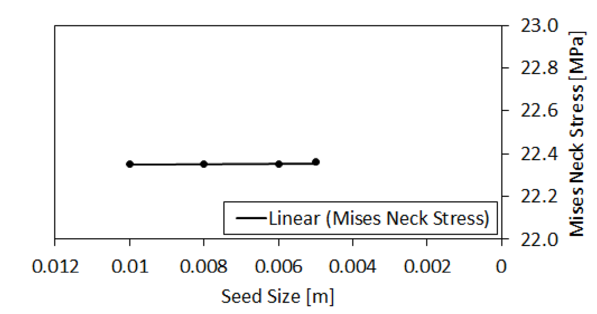
Mesh Type	Sweep Medial Axis (Specimen) / Sweep Medial Axis (Pin)
Element Type	Solid Quadratic Quadrilateral
Seed Size	0.004
# DOF	22539
Average Aspect Ratio (Mesh Quality)	3.24

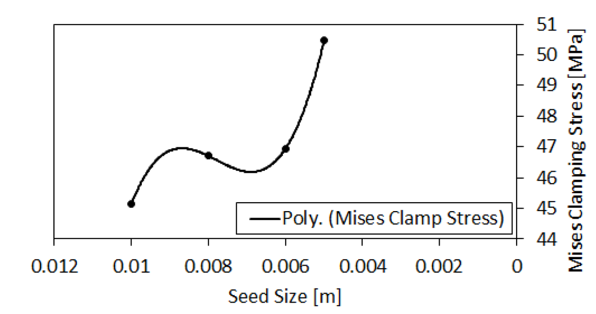
- **Initial Time Step – ENCASTRE applied to rigid body lower pin, tie constraint between surface of bottom of pin and contacting side of hole**
- **Time Step 1 – Displacement of 0.0059 meters in +Y applied to extruding ends of upper pin, tie constraint between upper surface of pin and contacting side of hole**

Clamped Test Specimen:

Model







Model Characteristics

Mesh Type	Sweep Medial Axis & Structured (Specimen) / Structured (Clamps)
Element Type	Solid Quadratic Quadrilateral
Seed Size	0.008
# DOF	57093
Average Aspect Ratio (Mesh Quality)	11.99

- **Initial Time Step – ENCASTRE applied to lower clamp faces of specimen, tie constraint created between clamps and the upper specimen clamp faces**
- **Time Step 1 – Displacement of 0.00015 meters in both X and Z directions to contacting face of each clamp in the direction towards the +Y axis**
- **Time Step 2 – Displacement of 0.0059 meters in +Y applied to top face of each upper clamp**

Results:

Test Specimen	Mises Max Neck Stress (MPa)	Mises Max Handle Stress (MPa)	Neck to Handle Mises Stress Ratio
Standard	17.52	21.43	1.22
Slotted	24.44	11.75	2.08
Ringed	22.03	12.47	1.77
Pinned	22.75	8.02	2.84
Clamped	22.35	17.70	1.26

Conclusion:

From the above results table, we can conclude that our ideal specimen is the pinned, followed by the slotted and then the ringed. The pinned specimen has the largest magnitude stress ratio, ensuring failure in the neck length portion of the specimen before failure in the grip portion. In the future we hope to establish a dynamic model to simulate a destructive tensile test. Also, we hope to include nonlinear material properties for the currently used polymer.

Appendix F: Project Gantt Charts

Table 1a. Polylogix Actual Project Schedule

Task Name	Duration	Start	Finish
Team Development	**7 days**	**Mon 1/11/16**	**Tue 1/19/16**
Advisor Meetings: Fall	**41 days**	**Wed 10/12/16**	**Wed 12/7/16**
Endologix Teleconferences: Fall	**51 days**	**Wed 9/28/16**	**Wed 12/7/16**
Endologix Teleconferences: Winter, Spring	**96 days**	**Wed 1/13/16**	**Wed 5/25/16**
Advisor Meetings: Winter, Spring	**101 days**	**Thu 1/14/16**	**Thu 6/2/16**
Design	**104 days**	**Mon 1/11/16**	**Thu 6/2/16**
Problem Statement	0 days	Thu 1/21/16	Thu 1/21/16
Project Proposal Report	**1 day**	**Tue 2/2/16**	**Tue 2/2/16**
QFD House of Quality	0 days	Thu 1/28/16	Thu 1/28/16
Concept Modeling	**9 days**	**Thu 2/4/16**	**Tue 2/16/16**
Pugh Matrices	0 days	Tue 2/16/16	Tue 2/16/16
Final Design Matrix	0 days	Thu 2/25/16	Thu 2/25/16
Preliminary Design Report	**0 days**	**Mon 2/29/16**	**Mon 2/29/16**
Preliminary Design Review	1 day	Thu 3/3/16	Thu 3/3/16
Design Analysis	**36 days**	**Tue 3/1/16**	**Tue 4/19/16**
Final Design Report	**8 days**	**Tue 4/26/16**	**Thu 5/5/16**
3rd Team Eval & Reflection	0 days	Tue 5/3/16	Tue 5/3/16
CDR with Endologix	1 day	Wed 5/11/16	Wed 5/11/16
CDR with Cal Poly	1 day	Thu 5/5/16	Thu 5/5/16
Build	**157 days**	**Tue 4/26/16**	**Wed 11/30/16**
All Parts Ordered	153 days	Tue 4/26/16	Thu 11/24/16
Status Report	0 days	Thu 6/2/16	Thu 6/2/16
Prototype Construction	14 days	Sat 11/12/16	Wed 11/30/16
Polish & Produce	**59 days**	**Tue 9/27/16**	**Fri 12/16/16**
Project Update Memo	0 days	Tue 9/27/16	Tue 9/27/16
Hardware/Safety Review	0 days	Sun 10/30/16	Sun 10/30/16
Winter Expo	0 days	Thu 12/1/16	Thu 12/1/16
Final Checklist	0 days	Fri 12/9/16	Fri 12/9/16
Final Project Report	0 days	Mon 12/12/16	Mon 12/12/16
Final Team Evaluation/Reflection	0 days	Tue 12/13/16	Tue 12/13/16
Final Sponsor Presentation	0 days	Fri 12/16/16	Fri 12/16/16

Table 1b. Original Polylogix Project Schedule

Task Name	Duration	Start	Finish
Team Development	7 days	Mon 1/11/16	Tue 1/19/16
Design	82 days	Mon 1/11/16	Tue 5/3/16
Advisor Meeting	46 days	Thu 1/14/16	Thu 3/17/16
Endologix Teleconference	46 days	Wed 1/13/16	Wed 3/16/16
Problem Statement	1 day	Thu 1/21/16	Thu 1/21/16
Project Proposal Report	1 day	Tue 2/2/16	Tue 2/2/16
QFD House of Quality	1 day	Thu 1/28/16	Thu 1/28/16
Concept Modeling	9 days	Thu 2/4/16	Tue 2/16/16
Pugh Matrices	1 day	Tue 2/16/16	Tue 2/16/16
Final Design Matrix	1 day	Thu 2/25/16	Thu 2/25/16
Preliminary Design Report	1 day	Mon 2/29/16	Mon 2/29/16
Preliminary Design Review	1 day	Thu 3/3/16	Thu 3/3/16
Design Analysis	36 days	Tue 3/1/16	Tue 4/19/16
Final Design Report	1 day	Tue 4/26/16	Tue 4/26/16
→Report Development	6 days	Mon 4/18/16	Mon 4/25/16
3rd Team Eval & Reflection	1 day	Tue 5/3/16	Tue 5/3/16
CDR with Endologix	1 day	Tue 4/26/16	Tue 4/26/16
CDR with Cal Poly	1 day	Tue 4/26/16	Tue 4/26/16
All Parts Ordered	1 day	Mon 3/21/16	Mon 3/21/16
Build	28 days	Tue 4/26/16	Thu 6/2/16
Spring Expo	1 day	Thu 5/26/16	Thu 5/26/16
4th Team Eval & Reflection	1 day	Thu 6/2/16	Thu 6/2/16
Status Report	1 day	Thu 6/2/16	Thu 6/2/16
Prototype Construction	28 days	Tue 4/26/16	Thu 6/2/16
Test	57 days	Thu 9/22/16	Fri 12/9/16
Prototype Testing	21 days	Thu 9/22/16	Thu 10/20/16
Final Design Build	45 days	Fri 9/30/16	Thu 12/1/16
Final Design Test	28 days	Fri 10/28/16	Tue 12/6/16
Project Update Memo	1 day	Tue 9/27/16	Tue 9/27/16
Project Hardware/Safety Demo	1 day	Tue 10/18/16	Tue 10/18/16
5th Team Eval & Reflection	1 day	Thu 10/27/16	Thu 10/27/16
Winter Expo	1 day	Mon 11/14/16	Mon 11/14/16
Final Project Report/ Exposition	1 day	Thu 12/1/16	Thu 12/1/16
6th Team Eval & Reflection	1 day	Tue 12/6/16	Tue 12/6/16

Appendix G: Operator's Manual

Polymer Fatigue Characterization Machine: Operator's Manual

Safety Warning: When handling electrical plug for LEESON motor, exercise caution and use rubber gloves as it is missing its ground prong (broke off during assembling). Always wear safety glasses when assembling and operating this equipment. Keep wiring dry and away from water tank. Do not ingest polymer test specimen material. Keep machine out of reach of children.

Materials:

- Assembled machine as per Appendix C detailed and assembly drawings
- Saline solution or filtered water for tank
- Polymer cartridges to be used for test specimen
- Access to one 60 Hz, 120 V outlet
- Test specimen mold halves
- Vice grips or similar clamping mechanism
- Polymer injection gun with mixing nozzle
- Thin coffee straw/stirrer

Figure 1. Polymer injection gun (left) and test specimen mold halves (right).

Test Specimen Creation

1. Line up mold halves by aligning through holes and polymer injection holes.
2. Clamp aligned halves together using vice grips allowing access to injection holes.
3. Attach coffee straw/stirrer to mixing nozzle of polymer injection gun, and load gun with polymer cartridges.

4. Gently insert end of straw/stirrer into the mold cavity until it almost touches the bottom of the mold. Slowly inject polymer into the mold while drawing out the straw/stirrer.
5. When mold cavity seems almost filled, tap mold to allow bubbles to loosen and rise, then add additional polymer solution as necessary.
6. Allow mold to sit for 5 minutes to allow polymer to set.
7. Carefully unclamp mold and separate halves. Immediately move polymer test specimen into tank of water.

Figure 2. Assembled polymer fatigue characterization machine.

Machine Operation

1. Ensure machine is assembled as per assembly drawings in Appendix C including off-the-shelf parts from Appendix D.
2. Fill tank approximately 2/3 full with saline solution or filtered water. Ensure that entire test specimen will remain submerged.
3. While wearing safety goggles and gloves, plug motor power cord into voltage regulator. Then plug voltage regulator into emergency stop button, and plug the emergency stop button power cord into 120 V outlet.
4. Slide pulley belt across desired pulley combination and tighten idler pulley mount in line with two shaft pulleys so belt runs in single plane. Ensure belt is being held in tension by spring.
5. Slowly increase the voltage regulator dial from 0% to 93% to achieve a motor running speed of 1680 RPM.
6. Leave machine running in clear area for desired length of time. Record cycle count to failure using tachometer.