Main Reduction Gear Debris Identification and Removal Device

A Senior Project

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by

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Navy Project C

Final Project Report

Main Reduction Gear Debris Identification and Removal Device

Prepared For:

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Statement of Disclaimer

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List of Nomenclature

Cable Arm	One of the main subsystems, this refers to the flexible cable assembly that is fed through the Boom Arm and hangs into the gearbox. Attaches to the Cable Control Surface at one end and the Gripper at the other.
Actuation Cable	Steel cables that run along the length of the cable arm, and actuate the arm when pulled.
Gripper Actuation Cable	Steel cable run through the middle of the cable arm that actuates the Gripper
Cable Guide	Nylon rings attached to the cable arm that guide the Actuation Cables
Cable Control Surface	One of the main subsystems, this refers to the assembly that is fixed to one end of the cable arm and is house inside the boom arm. Used for controlling the many actuation cables of the cable arm.
Actuation Disk	A disk to which the Actuation Cables attach, which pulls the cable when rotated.
Control Knob	A small shaft attached to the Actuation Disk, giving operator mechanical advantage when rotating the disk.
Control Knob Cap	A small cap attached to the end of the Control Knob, allowing easy turning of the Control Knob.
Chassis	The main body of the Cable Control Surface, which holds the Actuation Disks
Boom Arm	One of the main subsystems, this refers to the rigid structure that supports the Cable Arm as it is extended out into the gearbox.
Bushing Mount	A small aluminum piece that hold the bushing and attaches to the Boom Arm segments.
Cable Holder	Similar to the Bushing Mount, this is a small aluminum piece that has a groove for guiding the cables that actuate the Boom Arm.
Gripper	One of the main subsystems, this refers to the claw-like mechanism that attaches to the end of the Cable Arm and actuates to grip debris found in the gearbox. Also holds the borescope, which provides lighting and video capability.
Cable Connector	A threaded piece that attaches the Cable Arm, allowing the Gripper to be screwed on and off.
Gripper Connector	A matching threaded piece attached that is part of the Gripper, allowing the Gripper to be screwed on and off.
Locknut	A locknut that is threaded onto the cable connector after the Gripper connector is threaded on, locking the Gripper to the Cable Arm.

Executive Summary

This report details the development of a tool to remove objects and debris from a large gearbox found on ships of the United States Navy, specifically to be used by NAVSEA. The tool is to be used in situations where an object or contaminant cannot easily be removed or found without completely disassembling the gearbox. This will be done using a boom arm, a cable, a gripper and a borescope. This combination will allow for a large amount of mobility and versatility when searching for the object or contaminant, which is necessary for use in different gearboxes. The process we followed to arrive at our final design can be found below. This includes background research, similar product comparison, concept generation and detailed design, followed by prototype construction and testing.

Chapter 1 – Introduction

Sponsor Background and Need

The NAVSEA Southwest Regional Maintenance Center in San Diego is responsible for the maintenance and modernization of the entire Pacific US Naval fleet, which consists of roughly 180 ships (COMPACFLT). These ships can contain some very large mechanical equipment, including massive gearboxes which transmit torque to ship propellers. During the preventative maintenance inspections of these gearboxes, various small debris (tools, rags, etc.) are occasionally dropped inside the gearbox, and may be hard to locate or outside the reach of maintenance workers. In some cases, large components of the gearbox must be removed to find and extract debris, costing the Navy substantial amounts of time and money. NAVSEA has requested that our team, with the assistance of faculty and navy advisors, design, build, and test a device capable of finding and extracting debris from these gearboxes with as little effort and disassembly as possible, and with no chance of further contamination. The device should be flexible enough to inspect a wide range of gearboxes from a wide variety of access points. This is to be accomplished by our team in about thirty weeks.

Problem Statement

When a foreign object or debris falls into the main reduction gearbox of Navy vessels, the item needs to be found before the gearbox can be considered fully repaired. The current solution, looking around with a fiberscope and eventually taking apart the gearbox till the object is found, is too expensive and time consuming. The customer, NAVSEA, needs a more effective, less costly, and more efficient way of finding and removing foreign objects and debris that have fallen into the gearbox.

Goals

With this problem statement in mind, our team has set the following goals for ourselves:

- Design multiple, feasible solutions to the problem.
- Provide NAVSEA with multiple options for our final design concept.
- Build and test the NAVSEA approved final concept design.
- Successfully pick up debris from inside of main reduction gearboxes without adding more debris or damaging the gears inside.

Engineering Specifications

Our specifications based on our interpretation of the problem from sponsor teleconferences and on the initial values provided by NAVSEA in the project description presentation. All other values were generated using the QFD method, which can be found in the Appendix I. The QFD method also facilitated determining which specifications would be high risk, or more difficult, to accomplish. The risk level was assessed not only by comparing the required or target value with current solutions or technologies, but also by using our research and past experience to determine the difficulty in meeting a given requirement.

Table 1 – Navy Project C Formal Engineering Requirements

Spec. #	Parameter Description	Requirement or Target	Tolerance	Risk	Compliance
1	Target Weight	50 lb.	Max.	M	A, T, S
2	Collapsed Size	2 cu. ft.	Max.	M	I, A
3	Extended Length*	10 ft.	Min.	L	I, T, S
4	Lighting/Recording Capability*	Yes	Min.	L	I, T
5	Light Intensity	2000 lux (at 5 ft.)	± 25 lux	L	I, T, S
7	Camera Resolution	1 MPx	Min.	L	S
8	Maximum Outer Diameter of Actuating Arm*	4 in	Max.	H	A, I, S
9	Number of Joints*	2	Min.	L	A, S
10	Average Range of Joints	90 deg	± 5 deg	L	A, T, S
11	Extractable Weight*	2 lb.	± 0.2 lb.	H	A, T
12	Exterior Hardness	125 (Rockwell)	Max.	L	I, T
13	Precision at Full Extension	0.1 in	Min.	M	I, T
14	Display Size	8 in (diagonal)	Max.	L	S
15	Detachable Gripping Mechanism*	Yes	Min.	M	I
16	Must be transportable down a ladder*	Yes	Min.	M	I,T,S

Explanation of Risk Designations:		**Explanation of Compliance Designations:**	
		A	Analysis
L	Low	I	Inspection
M	Medium	T	Test
H	High	S	Similarity to Existing Designs

Those specifications which include an asterisk were given to us explicitly by our sponsor, but most of the others are either based upon our interpretation of more ambiguous requirements which the sponsor mentioned or our own conception of the ideal final features. This list of requirements is only an initial proposal of our team's interpretation of the sponsor's need, and as such, these requirements may be subject to change in the future.

Discussion of Specifications

Our maximum weight of 50 lbs. was based upon sponsor suggestions that the device should be easy to transport. We assumed that a technician would be able to carry a 50 lb. device. The collapsed size requirement was developed through similar reasoning. Neither of these requirements is absolute.

The light intensity requirement is possibly an overestimation, but we believed that it would be better to have a brighter work area than a darker one, given the conditions of a gearbox and the small size of the some of the items we will be extracting.

Our camera resolution and display size requirements were based upon NAVSEA's request that operators should be able to detect a ring five feet away. The need to detect a ring five feet away is the more important requirement, but also the less defined one. In evaluating this requirement, we had to consider the size and color of the ring, as well as environmental factors, like the possibility that the ring is covered in grease. The precision at full extension requirement is also based on a vague but important requirement: that the device must be able to effectively pick up objects.

We decided to add a max hardness requirement to try to minimize the chance of damaging gears. It is more of a consideration than a requirement.

Chapter 2 – Background

Literature Review

Journal Articles

We were able to find two Journal articles that discussed a method of actuation which may prove to be applicable to our design. In both articles, different aspects of the use of Bowden cables as means of mechanical actuation was explained. Bowden cables are cables that are encased in an outer, flexible sheath, and are used to transmit mechanical force (Bowden). In the articles we found, Bowden cables were used to transmit power from a power source that was separated from the actuated joint, thus relieving the actuating mechanism of the weight of the power source, which was generally an electric motor (Veneman) (Letier). In our application, being able to move the weight away from the actuating member would be very helpful. Our actuating arm will need to be of considerable length, and having heavy power source attached to an extended arm will increase the power necessary to actuate the arm, as well as increase the structural support necessary to keep the arm stable.

Patents

Our team also found patents that described various aspects of Bowden cable adjustment and control. U.S. Patent 5,376,094 describes a method involving a pulley which could be used to amplify the operator's motion to increase the travel distance of a Bowden cable, thus magnifying the actuation of a given object connected to the end of the Bowden cable (Kline). Originally designed for medical purposes, the concept could be adapted for use in our project as a method for amplifying the operators' motion to actuate our extended armature.

Additionally, U.S. Patent 4,638,679 discusses a method for adjusting Bowden cables through the use of a linearly adjusted control knob, instead of the more standard practice of turning a knob radially to adjust the cables (Tannenlaufer). This device was designed for adjusting heating and ventilation flaps in automobiles, but could be utilized in our design as well. The gripping mechanism, for example, could be actuated by a linear control knob, such as the one described here.

Aside from Bowden cables, we also looking into other ideas that we could incorporate into our design. A method for gripping and picking up objects, using a grabber arm, can be seen in US Patent 4,547,121 (Nesmith). The patent describes a 4 fingered telescoping arm that uses a worm drive to extend outward. This allows the arm and fingers to self-lock. The self-locking component and the fingers from this device could be used in our project in order to produce an arm that will lock to prevent unwanted motion and keep any object we pick up to remain secure within the gripper or fingers.

We also found US Patent 4,954,042, which describes a double telescoping arm for robotic palletizers (Becicka). This telescoping action could be utilized in our project to allow us to reach the desired length required to remove debris. The patent mechanism consists of 3 members, an outer member, an intermediate member, and an inner member. An idler wheel, mounted to the intermediate member, simultaneously connects the outer member and inner member. This causes the intermediate member and inner member to extend at the same rate. Applying this to our design would allow easy control of the extension arm, but would have the downside of being quite heavy and of a cumbersome size.

Codes and Standards

NAVSEA has informed us that there are no specific codes or standards that our design needs to adhere to, instead we need to focus on ensuring that failure of the device will not result in debris being left behind in the gearbox.

Existing Products

Due to the rather specialized nature of our task, our team could not find any products available today which already meet all of our needs. However, we were able to look into a number of existing technologies which could either inspire or be incorporated into our design. It is hard to talk about some of these options without seeming to suggest a more limited range of design solutions than may be available, but that is the nature of investigating these products.

Vision and Lighting Systems

Our device will need a camera of some kind to search for debris which would not otherwise be visible to the operator. There are a wide variety of pre-existing products which would likely be useful for our project.

Flexible borescopes, or fiberscopes, are flexible fiber optic cables attached to eyepieces by which a user can inspect small objects or look around corners (Fiberscope). They can be quite thin and long and provide lighting but the eyepiece might be difficult to use while simultaneously operating a device.

Video borescopes are like Flexible borescopes but use miniature cameras instead of fiber optic cable (Borescope). Instead of an eyepiece, they feed a video signal to a display screen. They can be cheaper and higher resolution than fiberscopes and may still include a light. The camera can sometimes be aimed using a joystick. Although they are cheaper, they can still get quite expensive, and a high-end video borescope could cost $10K or more.

NAVSEA has an existing video borescope, the GE XLG3, on-site which they have volunteered for our design in the interest of reducing costs. It is only the 3 meter model, which is a slight limitation as NAVSEA requested a possible maximum length for our product of 15 feet (4.6 meters), but it is highly likely that we will still incorporate it, both for cost and complexity reasons. It includes a 6.4” display and, like many video borescopes, in-built lighting capabilities and an articulating head (XLG3).

Other types of cameras, such as webcams, could simply be attached to the end of our device and feed back to a laptop or other viewing screen. A 1.3 megapixel USB camera is available from digikey for approximately $400 which is only 65 x 86 x 37 mm in size, and larger cameras may be much cheaper

(243-1117-ND). Cameras also exist with electronically controlled pan and tilt servos, potentially giving our device much greater inspection ability (MotorsParkFlyer).

We believe that whatever option we choose for the camera system will likely come with its own incorporated light source. However, if we were to handle the lighting separately, we would require about 2000 lux of illumination (Illuminance).

Object Gripping/Pickup Methods and Mechanisms

Gripping mechanisms have been continually developed over the history of assembly line and robotic design. Non-electronic mechanism designs have slowly been replaced, but still exist and can be investigated. Hobby electronics shops may also include prefabbed mechanisms within a reasonable price range. A few of these options are investigated below.

The selection of grippers available in online hobby shops or other online catalogues is surprisingly sparse. The few available either come with industrial arms which are not suitable for us or require pneumatic supply. Some hand-operated grippers exist either as children's toys or as general purpose tools around the house, all of which rely upon the same basic design – the user pushes a plunger or trigger at one end and the force is transmitted through a cable or linkage to a simple gripper on the other side (Amazon.com). A vise is another type of gripper whose design could be useful both for the linear nature of its motion and its mechanical advantage. Ultimately, the choice of gripping mechanism will depend upon the object being picked up. The ideal shape and angle at which the fingers grip, for example, may vary based upon the object.

Some objects could be picked up by magnets, with a sticky pad, or by suction; a quick search reveals that electromagnets exist which are more than small, light, cheap, and powerful enough for our design. For example, a reasonably sized magnet was found weighing 1 lb., capable of holding 100 lbs., for just $30 (Amazon.com). Because our gripper is required to be detachable, the sticky pad and suction possibilities can be set aside and considered later, as a replacement gripper would be easy to make. Suction does not seem like it would be an easy or an effective solution, but were it required, it could be incorporated. It seems likely, however, that the greasy environment might become a concern, should a suction device be implemented.

Physical Articulation Methods

It is difficult to find an existing product available for controlling a 15 foot articulating arm. Smaller options may be available to be included for the final few feet of the arm, and either human or machine powered actuators will be needed to control joints. Because of the wide range of solutions we may consider, a very wide range of actuators may be considered, and so specific products will be used only as examples.

Hobby suppliers or other sources have built articulating arms in the past, and some of these are available for purchase, although they are typically smaller than we need. One example is the AL5D robotic arm kit from Lynxmotion (Lynxmotion). But it has only a 10.5" median range and may only lift 13 ounces, costs $350, and requires assembly. Thus it could only be used at the very end of our device and would not meet all of our requirements. It is hard to find any product which is more appropriate.

As far as individual actuators go, however, there are many options available. Electronics include motors with gearboxes, linear actuators, and numerous control and sensing technologies which could be useful. There are also pneumatic / hydraulic possibilities, but the systems needed to control these types of mechanisms are much more complex, which makes them somewhat less desirable. Finally, things like cables (Bowden or other), four bar mechanisms, human-operated screw mechanisms or gearboxes, springs, and other mechanisms either already exist as products or can be built easily using many pre-existing products.

Some additional feasibility analysis for electric motors may be found in Appendix III, under “Michael’s Analysis.” The large motor ultimately selected in that analysis costs 99 dollars and offers excessive torque and speed for our requirements at just 1.5 lbs. and a size (with gearbox) of 1.5 x 1.5 x 5 inches (Robot MarketPlace).

Modular Technologies

An interesting idea, considering the wide range of ways in which our final product may end up being used, would be to include some modular and adjustable options for the operator to decide how/whether to use before he begins. Variable length beams, with variable joint locations and angles, for example. One option which already exists for this purpose is to include 80/20 modular aluminum frames in the design (80/20® Inc.). There are likely other options available for this purpose which could be investigated further once we have a better understanding of our design.

Chapter 3 – Design Development

Concept Generation

In order to develop a wide range of ideas for our designs, we consulted a design textbook, Creative Design of Products and Systems by Saeed B. Niku, for various methods for idea generation. We used techniques such as brainstorming, a variation of the 6-3-5 method, a morphological attribute list, and a list of alternative actions. The results of these all the following techniques have been added in **Appendix II**.

Brainstorming

There were multiple brainstorming sessions that took place, utilizing different methods to allow us to generate new ideas. Our first and most basic session simply involved the team sitting together and sketching various ideas we had for different elements of the design. Future sessions involved timed sketching periods and throwing all our ideas in the middle of the group, to help us avoid judging our ideas too quickly and to allow us to gain inspiration from others' ideas.

6-3-5 Method

This method needed to be slightly modified to work for our team, with the original concept involving 6 participants sketching three solutions in 5 minutes. Since our project team only consists of three people, we only had 3 participants, but the rest of the technique worked well.

Morphological Attribute List

The Morphological Attribute List was perhaps one of the most successful methods we used to generate ideas. It was here that we first broke our designs down into separate components, and then listed as many ways as possible of achieving the function of each component. Many of the ideas for components we generated here went into our decision matrices.

List of Alternative Actions

Our final idea generation technique involved creating a list of verbs, and then attempting to repurpose the verbs in a way that could be used to solve our problem. This produced several amusing ideas, but some of the ideas we generated were feasible enough for further development.

Concept Selection

Once several ideas had been generated, we used decision matrices to determine which ideas were the most feasible to be pursued. Our design ideas were based more around components of the design that could be combined in multiple ways to reach a final design, so our decision matrices were of these individual components, rather than for complete designs. A sample of a decision matrix that we generated is shown below, while all the decision matrices are available in **Appendix IV**.

Table 2 - Gripper Style Decision Matrix

		Idea					
Factors	**Weighting**	Bike Clamp	Magnets	3 Finger (plunger)	Motor Actuated Clamp	Solenoid Actuated	Spring and Pin
Cost	0.05	1	2	1.5	-2	-1	0
Failure Risk	0.35	1	-2	1.5	2	1	-2
Weight	0.20	1	2	2	-2	0	1
Manufacture Difficulty	0.20	2	2	2	-2	0	-1
Ease of Use	0.10	1	2	1.5	1	-1	-2
Lifting Capability	0.10	1	0	-1	2	1.5	1.5
Sum of +		1.20	1.10	1.55	1.00	0.50	0.35
Sum of -		0.00	-0.70	-0.10	-0.90	-0.15	-1.10
Total		1.20	0.40	1.45	0.10	0.35	-0.75
Rank		2	3	1	5	4	6

After these decision matrices were generated and a ranking was found for each of the individual components, we collected the best ranking components from each matrix and combined them into three concepts for further development. It is important to note, however, that these combinations do not need to be final, and the individual components could easily be interchanged between concepts to form a different, possibly more functional concept for our final design.

Conceptual Designs

Preliminary Analysis

Due to the fact that these are all preliminary designs, our analyses are limited to simple feasibility calculations. The calculations for each concept vary based on the individual designs, but these calculations are available in **Appendix III**.

Concept 1 – Four-Bar Linkage

Figure 1 – Solid model depiction of Four-Bar Linkage concept

Concept Description

Our first design was the Four-Bar Linkage concept. This concept uses 3 sections of circular tube and 4 thin bars to create an arm that can extend using rotary motion. The 4 thin bars are connected in a way that allows the shaft with the gripper to extend but not rotate by itself. The rotary motion is translated via pulleys which are fully enclosed in the 3 circular tube sections. The existing fiberscope at NAVSEA will be fed through the tube sections and will be used for the lighting and recording capabilities.

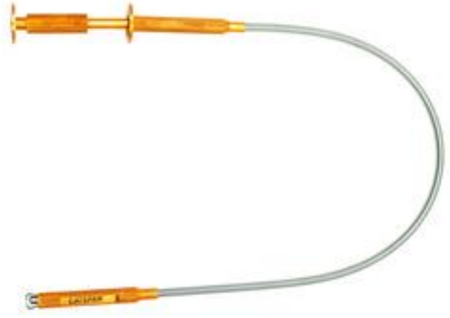

Figure 2 – Mayhew Tools pick up tool, Part # 45046

The gripper is based on the pickup tool above. The cable will be fed through the circular tubes with the handle placed at the start of the first tube. As you compress the button, the hooks extend outward from the sheath, allowing for an object to be grabbed. Releasing the button pulls the hooks back into the sheath, gripping the object and holding it securely in place. The cable controlling the gripper is flexible which is ideal for this situation given the necessary maneuverability.

Discussion of Specifications

The SolidWorks assembly of Concept 1 yielded a weight estimate of 20 to 25 lbs. using aluminum for all parts in the assembly. This concept was designed to collapse to a manageable size but still meet the stretch goal of 15 feet of extension into the gear box. The total length of the extension is limited by the length of the borescope currently in use by NAVSEA, which is 3 meters in length. The concept has two joints with approximately 120 degrees of rotation. The extractable weight of 2 lbs. would not be a problem for this concept. In addition, the gripper will use a screw joint to attach to the inside of the circular tube shafts. With all these specifications met, the total cost would be approximately $300 for the raw materials.

Concept 2 – Fishing Pole

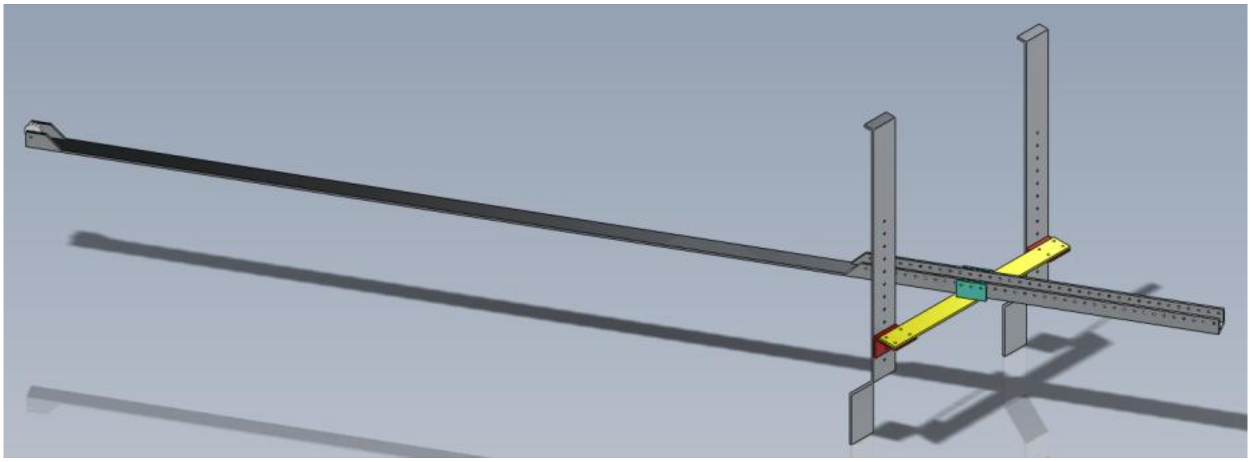

Figure 3 – Solid model depiction of Fishing Pole concept

Concept Description

Our second design was the Fishing Pole concept. This concept employs a single cantilever arm that extends out into the gearbox. At the end of this arm is a roller, over which a cable containing a borescope and a gripping element would be draped. This combination would allow for both horizontal and vertical actuation of the gripper element. In addition, the cable holding the gripper element would have Bowden cables within it, as shown in the figure to the right, which would allow further actuation of the gripper element. The arm assembly would be supported by the yellow support arm, which would be attached to the vertical crossbars by bolted brackets. The crossbars would hang from the hatch of the gearbox, and allow the arm assembly to be supported while in use.

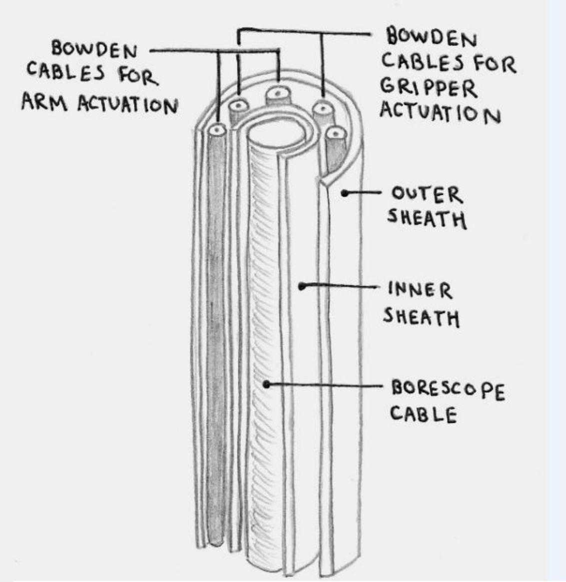

Figure 4 – Cable cross section

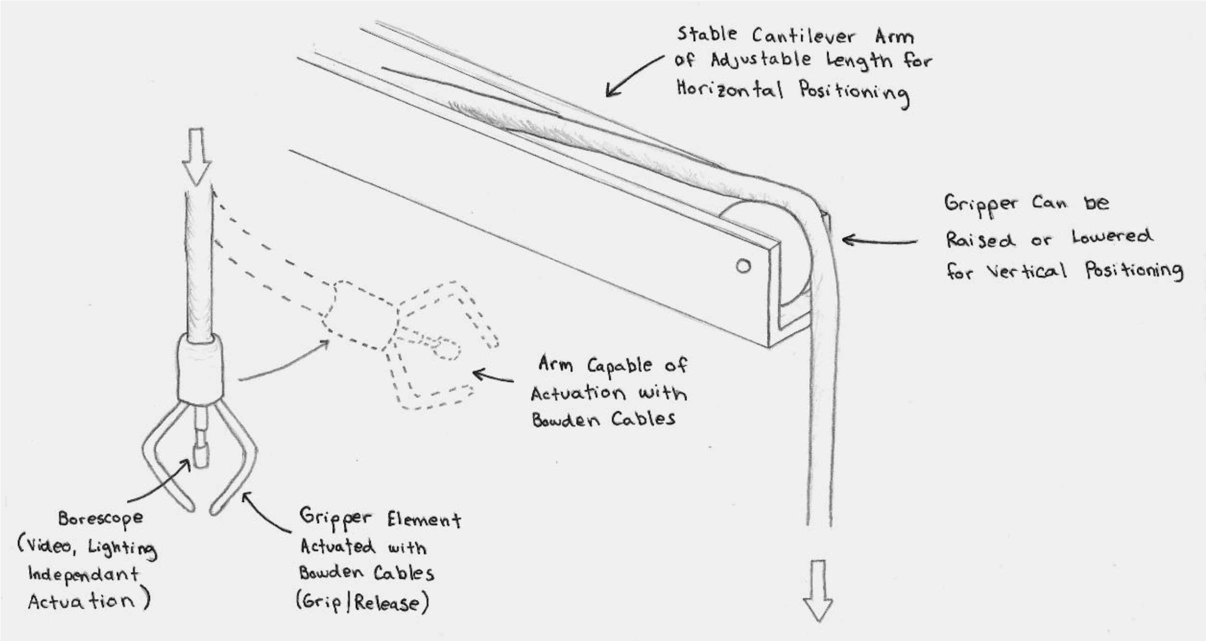

Figure 5 – Detail sketch of cable hanging over roller element and gripper at cables end with actuation.

The figure above shows the cable function in more detail. The cable will drape over a roller at the end of the cantilever arm, and extend down into the gearbox. The gripper element and the borescope would be at the end of the cable, allowing for lighting and video coverage to be available at the gripper while it was being used to capture debris.

Discussion of Specifications

After creating a solid model of the concept in SolidWorks, a weight estimate of about 16 lbs. was generated using aluminum as the material for the entire assembly. The concept is designed to be collapsible, to facilitate transportation. The total extended length of the device is limited by the length of the borescope, as it will be necessary to run the borescope through the entire length of the cable. The borescope will also provide the video and lighting capacity of the device, as well as the display. The extension will have two total joints: the first located at the roller, and the second in the cable, with up 90 degrees of actuation available in 4 directions. The device should easily be able to extract up to the maximum weight of 2 lbs. Finally, the gripping element of the concept will be detachable, so that multiple gripping styles can be used depending on the debris being removed.

Concept 3 – Electro-Mechanical

Concept Description

Our third concept chosen for analysis was a mechatronic arm attached to the operator by means of a tether, with an electromagnetic gripper. For the purposes of feasibility analysis, the simplest design which fit the requirements was chosen, consisting of three five foot long arm sections joined by two identical motorized joints, as shown below (magnet not shown.) Note the collapsible nature of the design for transportation, with collapsed dimensions of approximately 5 ft. x 1 ft. x 4 inches.

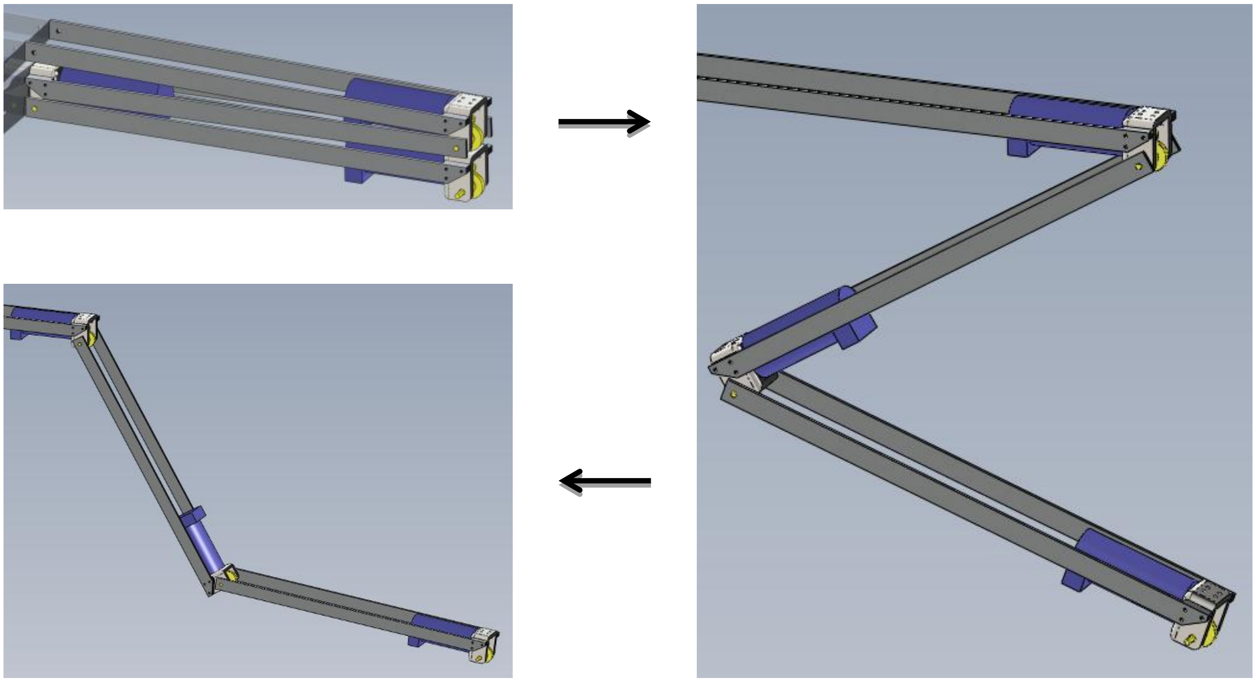

Figure 6 – Mechatronic Arm Actuation

Like the other two designs, due to the slow-moving and simple control required to operate this device, it was determined that no microcontroller would be required for this design – three-way switches would be used to control the motors, while worm gears would be used to provide speed reduction and prevent back driving of the motors. Fuses could be used to protect against motor stalling. As discussed in the background section, electromagnets were also found which were powerful, lightweight, and cost-effective for the gripper

Discussion of Specifications

Despite the aforementioned positive aspects, the mechatronic design was still the most expensive of the three designs. The total cost was estimated to be between $325- 500, due to the expense of the motors, gears, power supply, and other materials. These expensive components were also more likely to fail. This design also offered no advantages in terms of weight or size, and the slight advantage in versatility this design may have offered could almost certainly be achieved by purely mechanical mechanisms, although those mechanisms were not among our final three chosen.

Several possible alterations to the design were considered for future analysis, including modularity, motor relocation, "hybrid" designs which combined electromechanical and manual actuation, and designs featuring either linear actuation or rotation about the axis of the device's arm. However, these modifications would only increase the cost and complexity of the system, or in the case of "hybrid" designs, provide little benefit over purely mechanical solutions.

Design Review with Project Sponsor and Concept Modification

Once generated, our top three concepts were presented to our sponsor for review. Of the three concepts, the Mechatronic concept was deemed too complex for further development, given the relatively high chance of failure. Our sponsor suggested combining elements of the Four-Bar Linkage and Fishing Pole concepts to develop a design with more mobility to actuate around gears. This led us to our final design concept, which is shown below.

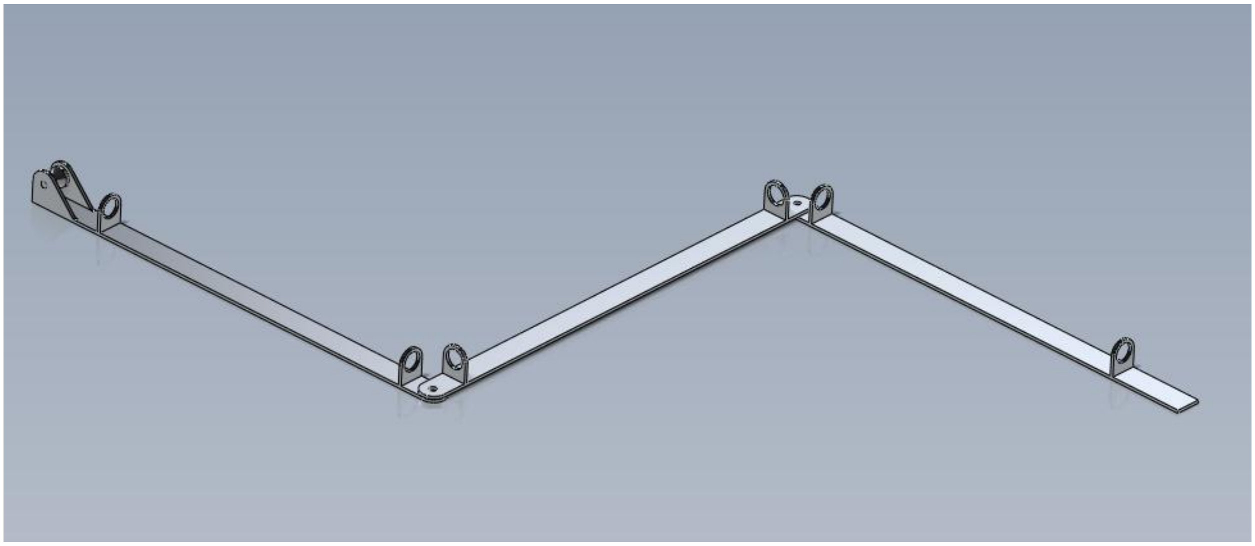

Figure 7 – Solid model of our final design concept, presented to our sponsor shortly after our design review.

This final design would incorporate a total of four points of actuation for maneuvering around the gears and searching for debris. The boom (depicted in the figure) has two independently actuating joints, with a roller at the end that the cable arm would hang over, providing the third pivot. Finally, the cable arm itself would actuate as described above in the fishing pole design concept, thus giving us a fourth degree of freedom. We presented this design to our sponsor, and it was approved for a more thorough design and analysis.

Proof of Concept Prototyping

To ensure that our cable arm concept was a feasible one, we built prototypes to prove the concept. We built a total of three prototypes to test the concept, and to learn about the variables that would need to be considered when constructing our final design. The first prototype was constructed out of vinyl tubing and actuated with three strands of 30 lb test fishing line guided by cardboard cable guides. The strands were fixed at the end of the prototype by simply tying the fishing line to the cardboard. Photos of the first prototype are shown below.

Figure 8 – From left to right: A) The un-actuated prototype with pre-set bend B) Prototype actuated against the pre-set bend curve C) Prototype actuated with the pre-set bend curve.

The most important thing we learned from this first prototype was that our concept was indeed feasible. Pulling on the actuation “cables” caused the desired actuation of the “cable arm”. But, we also learned that material selection was going to be a subject for further research. The pre-set curve that was inherent in the vinyl cable caused the cable to spiral when actuated in the direction of the pre-set, which is not a behavior we want in our final design.

Our second prototype was a modification of the first. We cut the first prototype into segments and added flexible joints between the segments by gluing short sections of latex rubber tubing into the vinyl tubing. We wanted to see if adding these flexible joints would allow us to counteract the pre-set curvature problem we encountered in the first prototype. The same fishing line actuation cable set up was used to actuate the second prototype. Photos of the second iteration are shown below.

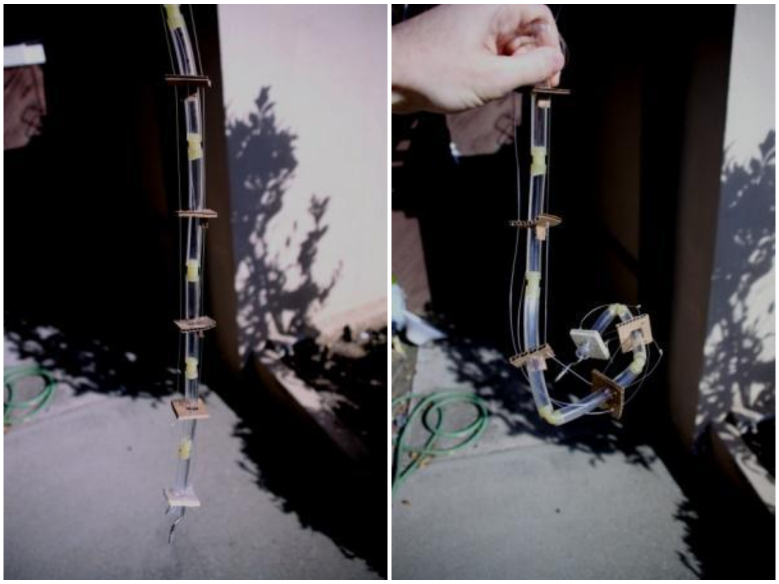

Figure 9 – From left to right: A) The un-actuated prototype with flexible joints B) Prototype actuated and presenting erratic bending behavior.

Unfortunately, the second prototype was not an improvement over the first. Instead of reducing the spiral behavior, the flexible joints caused the cable arm to fold up upon itself instead of actuating in a specific direction. It is conceivable that if the range of motion of the flexible joints was limited, then a more desirable bending profile could be achieved, but the complexity of the cable design, along with the possibility of failure, would increase drastically.

Our final prototype was also constructed out of vinyl tubing, but of a stiffer vinyl than the first two prototypes. We used four strands of galvanized steel wire rope to actuate our final prototype. The cables were fixed at the end with crimped cable end fittings, and guided through balsa wood cable guides.

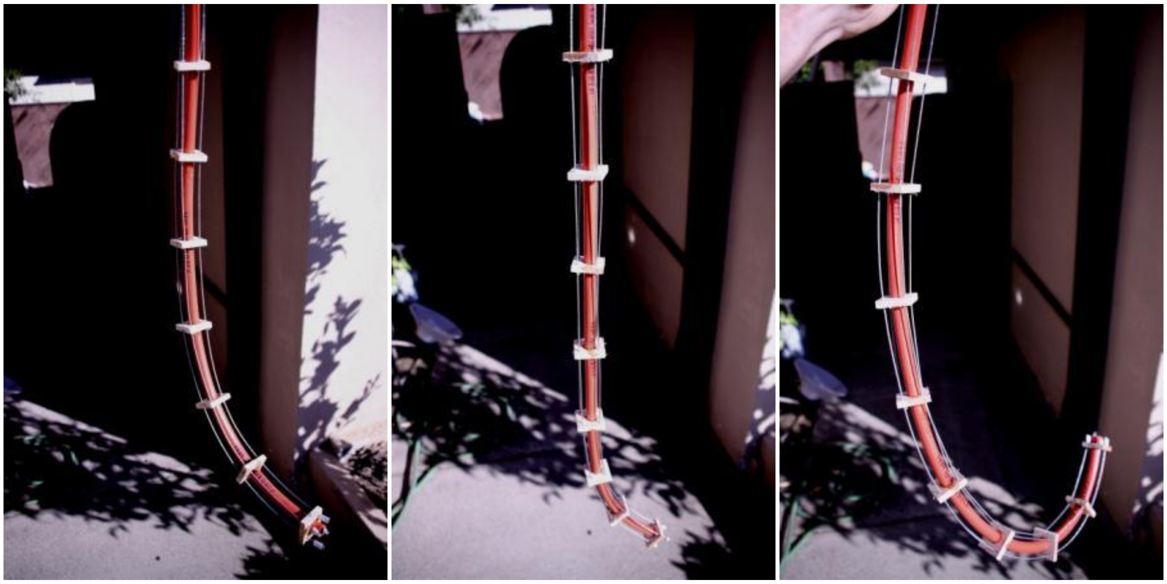

Figure 10 – From left to right: A) The un-actuated prototype with pre-set bend B) Prototype actuated against the pre-set bend curve C) Prototype actuated with the pre-set bend curve.

We found that the four cable configuration gave us much better control over the actuation of the cable arm. Aside from that, the behavior of the prototype was similar to that of the first, with unwanted spiral behavior occurring when we actuated the prototype in the direction of the pre-set. This led us to conclude that the material that we use for our final design must be resistant to developing this pre-set bend for our design to function properly. We were also able to roughly gauge the amount of force required to pull the cable to be around 10 lbs.

Chapter 4 – Final Design

Overview

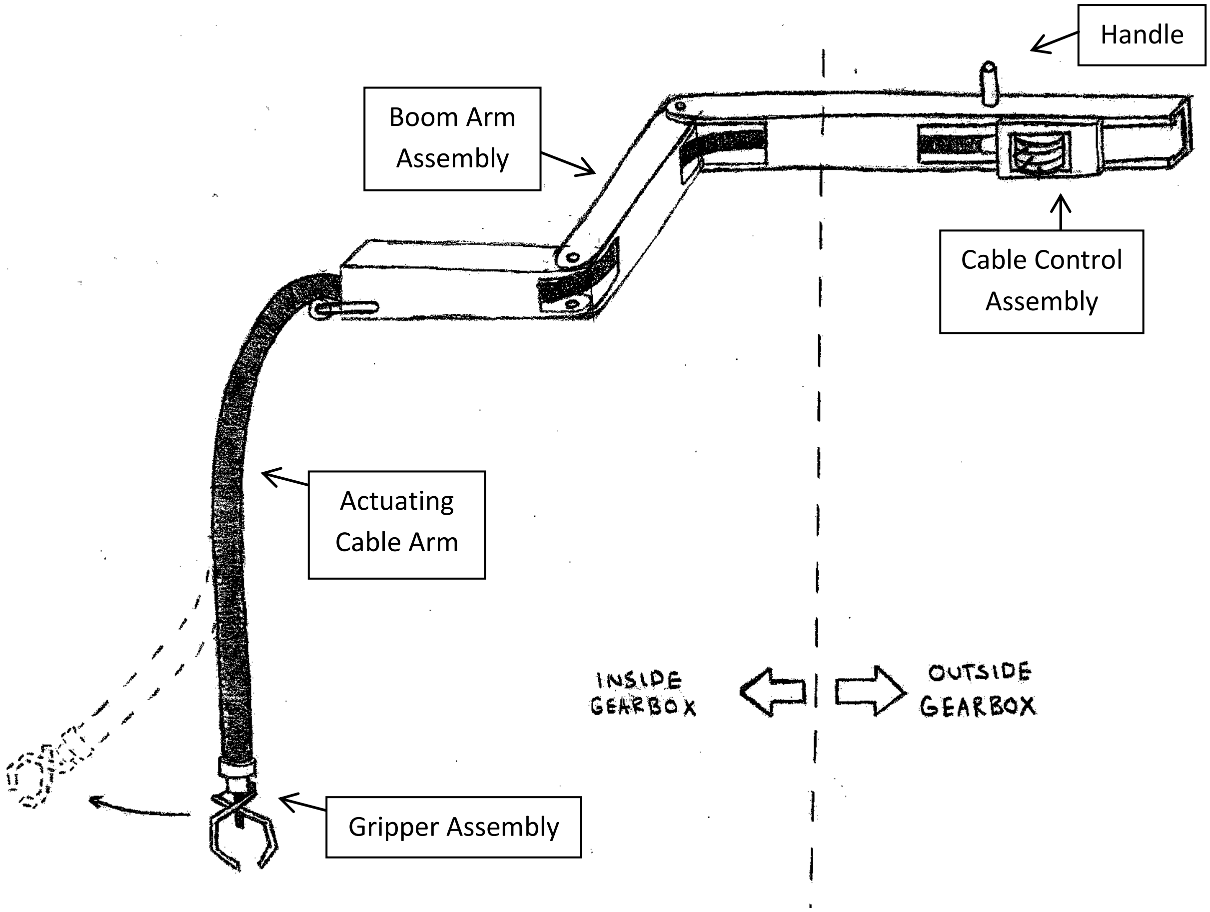

Figure 11 – Isometric assembly drawing of our Final Design.

Our final design consists of three main subsystems: the cable system (consisting of the actuating cable arm and the cable control assembly), the boom arm assembly, and the gripper assembly, as shown in the diagram above. The operator stands outside the gearbox, looking towards the porthole, grips the handle, and rests his arm on the boom. The device rests on the edge of the port hole through which it enters the gearbox, and it may also be supported by additional existing fixtures on the gearbox exterior. The gripper assembly is a swap-able gripping device used to pick up objects inside the gearbox. It is operated by an actuation cable inside the cable arm. The cable arm actuates in four directions, controlled in a manner described in detail below. The Boom arm is a rigid assembly with two joints by which the cable system is maneuvered horizontally into the gearbox and around the gears. The control surface allows the operator to easily operate the cable system and the gripper assembly. A borescope which travels through the cable system and displays the gripper's viewpoint to the operator is included, but not shown, and will be fed out through the control surface and hung from fixtures on the gearbox by the operator.

Cable System

Actuating Cable Arm

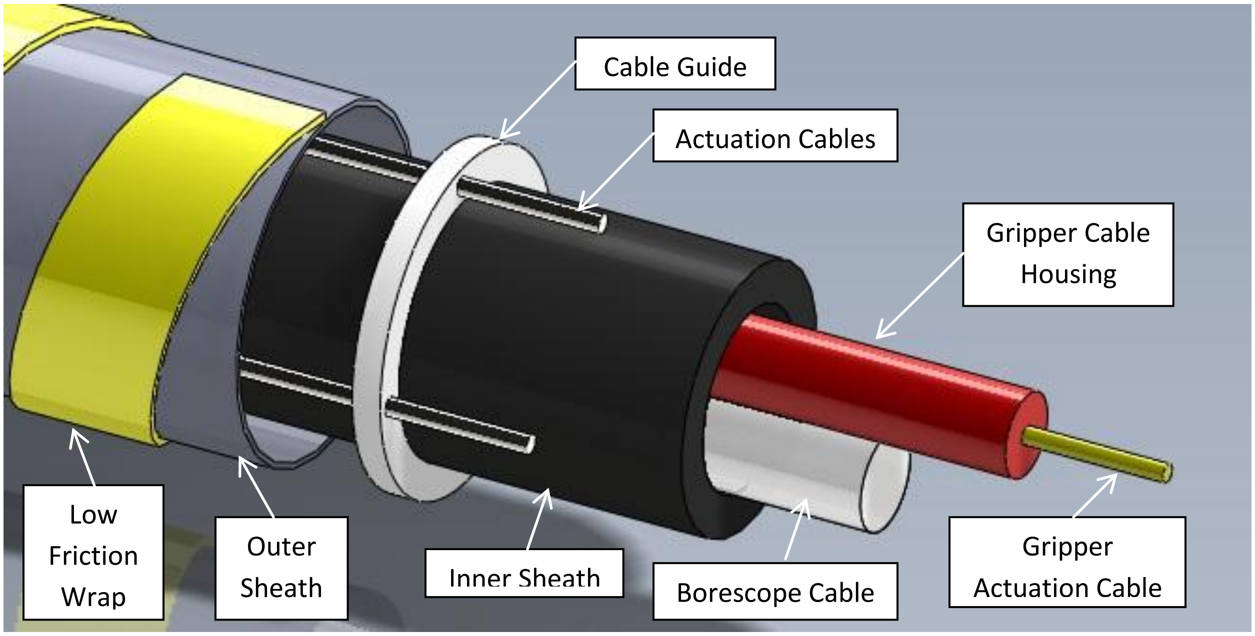

Figure 12 – Labeled assembly drawing of the cable arm.

The cable arm is perhaps the most unique aspect of our design. At its core are the borescope and the gripper actuation cable, both of which are contained within a heavy duty rubber hose, which is the inner sheath in the figure above. Attached with adhesive to the outside of this rubber hose are the actuation cable guides. The guides will run along the entire cable arm, and be located every 4 in along its length. These cable guides are nylon rings with four guide holes drilled 90 degrees from one another along the guide's circumference. It is through these guide holes that we will run the actuation cables, which are the 1.5mm thick steel wire rope cables (bicycle brake cables, standardized in metric units) used to cause the actuation motion of the cable arm, a movement that we proved feasible with our prototype testing described previously. At the end of the cable arm that hangs into the gearbox, these cables will be run through an aluminum piece that is fit onto the cable end that connects the gripping element, with a cable stop on the other side, fixing the cables at this length. At the other end, these cables will be fit via existing end attachments into slots machined into the actuation disks that will be used to adjust the length of the cables in the arm. This actuation cable design allows our cable arm to be actuated in four directions once it is lowered into the gearbox. Over this whole structure we will slide a plastic mesh sheath, which will serve as a safety net, preventing anything from falling into the gearbox in the event that something on the cable arm should break. We will wind PTFE bundling wrap over the mesh sheath in order to reduce the friction between the cable and the boom assembly.

The only part that will require manufacture for the cable arm will be the cable guides, which will be made out of nylon to decrease friction between the guides and the steel actuation cables. The inner sheath will be made of braided rubber hose, which we have observed to have a minimal pre-set bend and good flexibility, characteristics which we learned would be desirable from our prototype testing. Bicycle cables were used throughout for their minimal stretching, low friction, and wide availability. All parts, with the exception of the cable guides, will be purchased and assembled almost as they come, with some modification to the lengths of certain materials being necessary. An engineering drawing of the cable guide can be found in **Appendix VII**.

Cable Arm Control Assembly

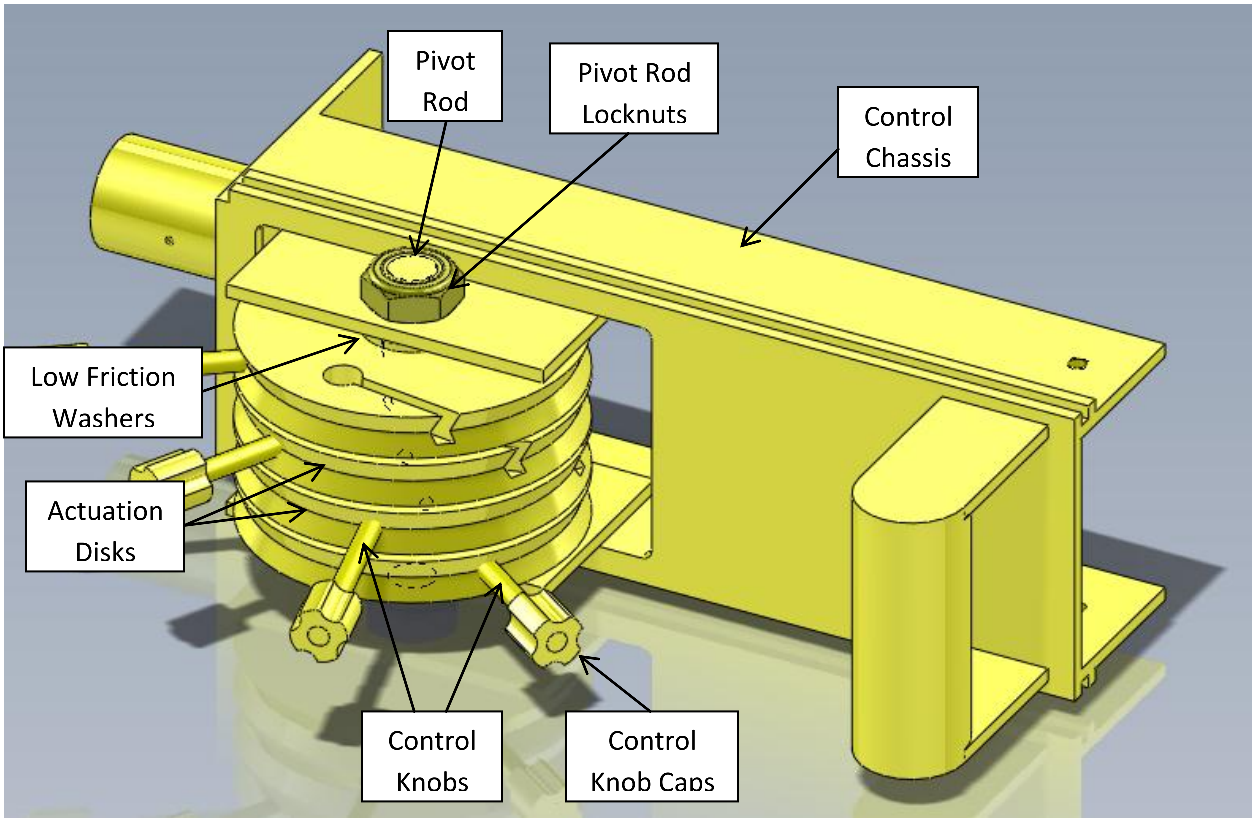

Figure 13 – Labeled assembly drawing of the cable arm control assembly.

The cable arm control assembly is where the cable arm is fixed in the boom assembly, and where the various actuation cables are controlled. The rubber hosing will feed into one end of the control assembly, where it will be fixed with an adhesive in the tube that extends from the front face. Small screws set through the aluminum tube will also serve to hold the cable in place. The actuation cables will be guided from the final cable guides at the cable arm's end through the front plate with cable housing, whereupon they will feed directly to the actuation disks and attached as previously described. The actuation disks are aluminum disks with a groove cut into the curved face to retain the cable on the disk. There is also a threaded hole drilled into this face, into which the control knobs will where they can be tightened into the center rod to fix the disk into a certain desired position. A small hole will be drilled through the disks flat face, 45 degrees from the threaded hole. A thin channel will then be machined from this hole to the edge of the disk. These two features will house the cable end attachment, which comes pre-attached to the bicycle cables we have chosen, and guide the cable from this attachment to the edge of the disk. The borescope and the gripper actuation cable will be fed out past the actuation disks, eventually connecting to the video screen and the gripper clamp lever, respectively. Located further away from the front plate of the control assembly is an aluminum handle, to which the gripper clamp lever will be attached. The gripper actuation cable will be fed out the back of the assembly and be wound around to this lever.

With only a few exceptions, the control surface will be made out of 6061 aluminum for ease of manufacture and light weight. The washers are polyethylene to reduce friction between the disks as they rotate relative to one another. The control knob caps will be rapid prototyped and press fit to the end of the control knobs, simplifying the manufacture of each piece.

The loads we are dealing with in the actuation of the cable are quite low, so we did not forsee any part failure. Regardless, failure analysis was performed on the most susceptible piece, the control knob, which corroborated our initial assumption. This analysis is can be found in **Appendix V**.

A complete set of engineering drawings detailing each piece can be found in **Appendix VII**

Boom Arm Assembly

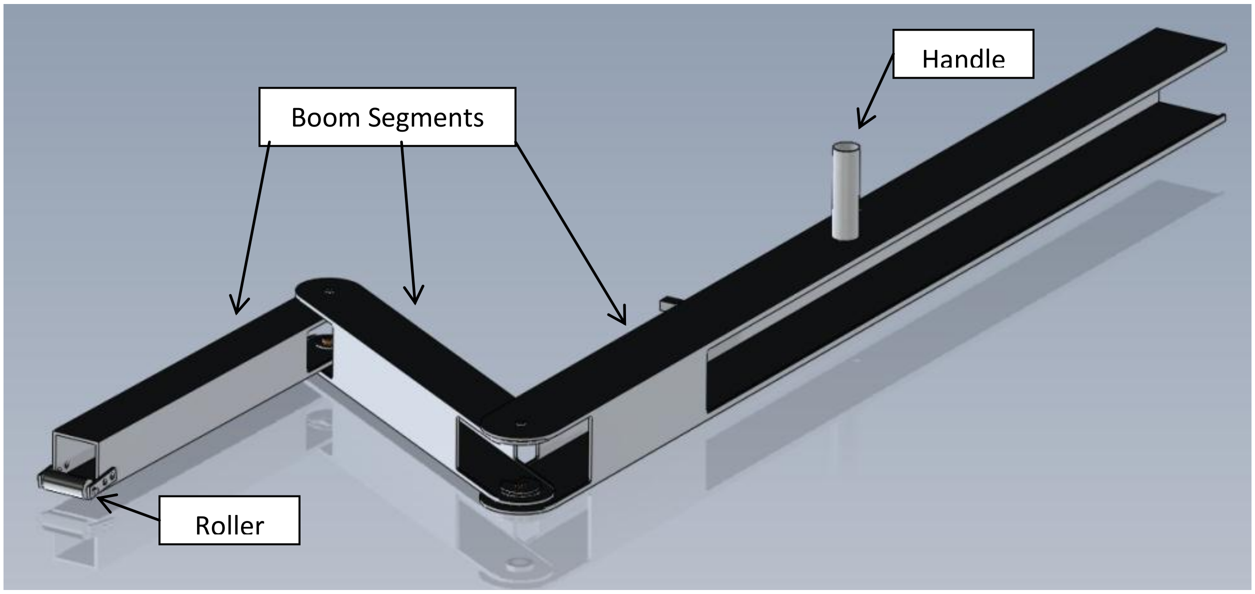

Figure 14 – Labeled assembly drawing of the boom arm assembly.

The boom arm assembly is designed for a mix of low weight, manufacturability, ease of use, and safety. The assembly is constructed from nested square aluminum tubing, with two cable-actuated joints providing maneuverability. The total length is seven feet, with roughly 3 feet designed to operate inside the gearbox, and the remainder being used for the motion of the control assembly and the grip of the operator. Some additional range will be provided by the actuation of the cable arm. There is a roller attached at the end of the boom to reduce friction and eliminate possible kinking of the cable arm. There is also a cable looped through a hole near the handle which will be looped around the operator's arm and/or body, preventing the device from falling into the gearbox.

Note that the square tubing is only available as Al-6063 while the other components are typically Al-6061, but this has been factored into the design. Research indicates that these alloys are easily welded together.

Both rotating joints are comprised of two independent bushings and shafts on the top and bottom side of the boom. These components are shown in Figure 15. These shafts cannot be joined through the middle of the boom because the cable arm will be in the way, and so will be supported on either side by nearly identical but independent assemblies. The central shaft (yellow) is pressed and welded into the outer (larger) boom segment, which is leaving the pictures above to the right. The shaft slides into a bushing, which is modeled in the image as bronze, although it's been replaced with a plastic one. That bushing is press fit into a "cable holder", shown as transparent. This is in turn pressed and welded into the inner (smaller) boom segment. The cable holder also secures a cable which will be pulled from either side to provide the remote actuation of the joint.

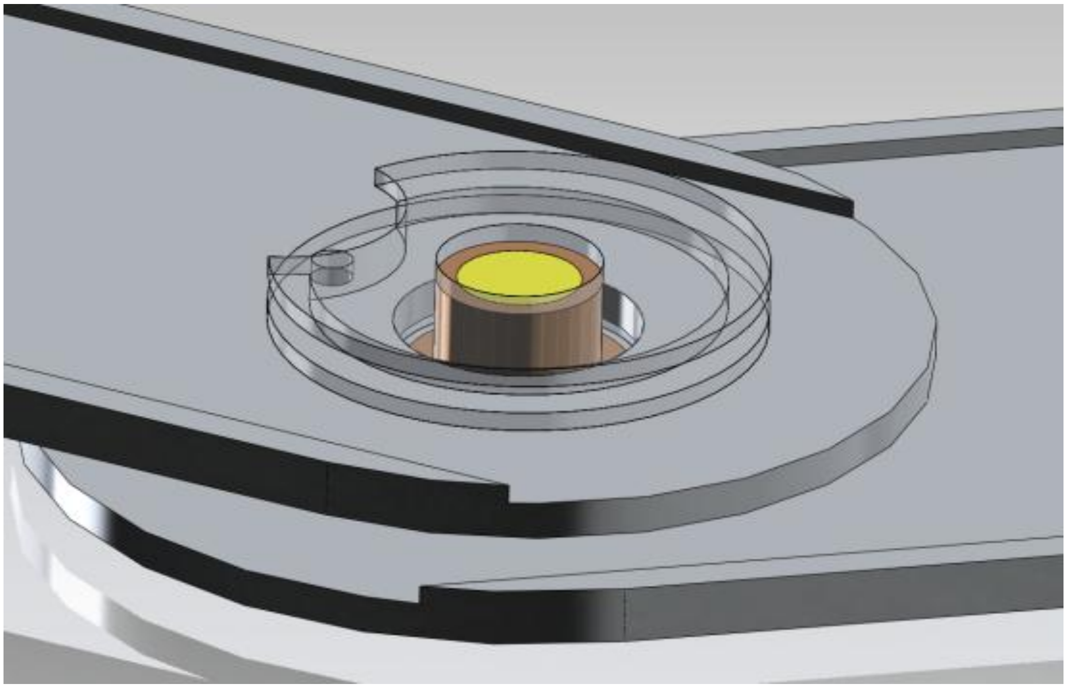

Figure 15 – Detail model of the boom arm pivot point.

One potential issue with this design is friction. The strong radial loads on the bushings lead to friction between them and the central shafts, which in turn requires large forces to be exerted on the cables to break static friction. Early (extremely excessive) estimates of this force were as high as 40 lbs., due in part to difficulty predicting the friction coefficient of bronze on aluminum. By replacing the bronze bushings with plastic ones, this estimate was reduced to a maximum of 15 lbs, and a more likely estimate between 4 and 8 lbs. This may be further reduced with lubrication if necessary, as seen in the bushing spec sheet in **Appendix VII**. This may mean that re-lubricating the joints will be required on occasion for maintenance. For all strength / failure analysis performed, this design was shown to be quite safe, even if calculations are based on significantly loading. Further details of these calculations can be found in **Appendix V**.

The cables used will be standard 5mm bike brake cables, similar to the one shown below, and will be routed around corners in a similar fashion. Ferrules, housing, cable, and weldable stops which make routing simple have been found.

Figure 16 – Descriptive image of a standard bike brake cableing setup

The cables will ultimately pass through two holes to the outside of the boom, where they will be locked/unlocked as seen below:

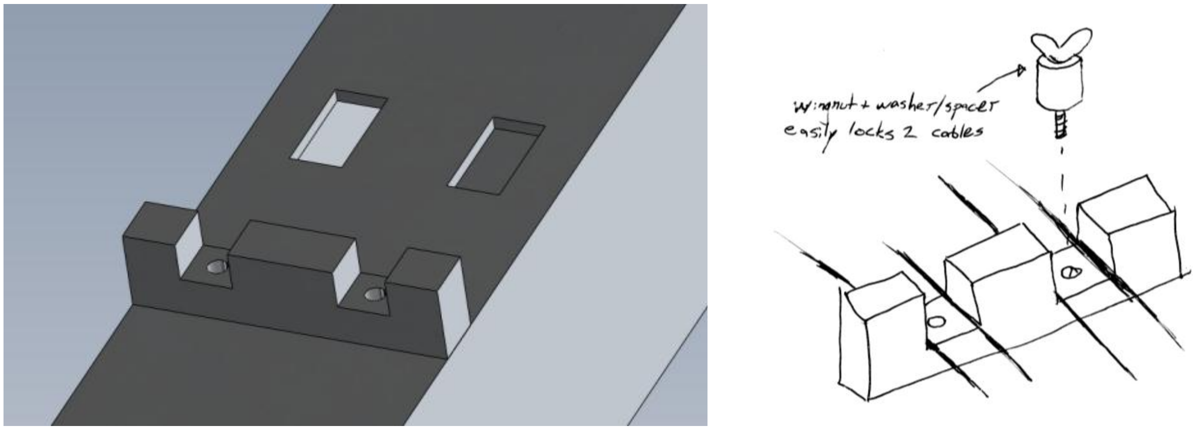

Figure 17 – Boom control cable locking mechanism.

The cables to be locked/unlocked as pairs are the clockwise/counterclockwise cables for a single joint, which always move together.

Due to the many welds involved in the final assembly, disassembling the boom for repairs will likely be impossible. All care will be taken, both in design and manufacturing, to ensure that no repair will be necessary. Even in the case of failure, the gearbox should not be damaged.

Gripper Assembly

The gripper assembly is based on the designs of bicycle brakes. The gripper has 2 rounded arms that come together to grab the desired object. The arms are attached to each other with a pin joint and a bushing. One of the arms is attached to a threaded cylinder that will provide the connection to the cable system. The arm will be welded in place onto the cylinder. Along with the cylinder being threaded, a lock nut will be screwed on to the assembly to keep the gripper attached to the cable system. This design will ensure the security of the gripper, which is the main concern of the entire project. A tandem bicycle brake cable will be used to actuate the arms of the gripper. This cable was chosen over push-pull cables and other cables due to its availability, its simplicity and the threaded ends that will simplify connection.

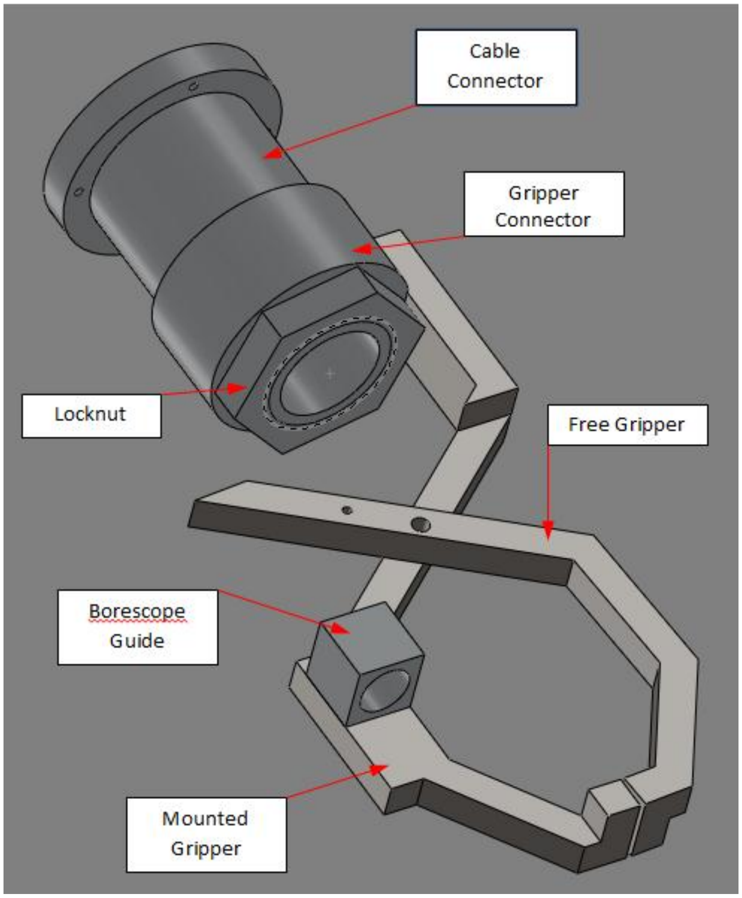

Figure 18 - Labeled assembly drawing of the boom arm assembly.

All parts to be manufactured on the gripper will be made with aluminum, specifically 6061. Aluminum was chosen given its relatively low price and lower density. This will help to keep the weight of the gripper from causing an undesirable moment in the boom arm. Aluminum is also readily available in the many types that will be needed, such as cylindrical tubing and flat half-inch plates. 6061 aluminum alloy can be welded, machined, and brazed. This is ideal given the processes required to produce the parts for the gripper and also allows for unforeseen complications to be easily remedied.

To ensure the gripper will not fail, analysis was done on all parts where failure could take place. In addition, static analysis was performed to ensure the gripper will have enough actuation force to successfully hold the object to be removed. These calculations can be found in **Appendix V**.

Maintenance for the gripper will consist of lubricating the pin joint before all operations. The actuation cable connection to the gripper will also have to be checked for wear before each operation. This will ensure that all parts will be secure and operational before the prototype is inserted into the gearbox. Repairs to the gripper will be performed as necessary. In the event that the grippers become bent or damaged, they can be removed and either hammered or forced back into a straight configuration. If the pin becomes damaged, a new pin can be inserted with the removal of the old pin. The connection of the gripper and cable can also be replaced with new parts in the event that they become damaged.

Cost Analysis

After assembling a bill of materials, we tracked down a prospective supplier for each material and estimated the total cost of our final prototype to be $513.93, which we believe to be a reasonable price for such a complex design. Our most expensive items tended to be our raw metals, with circular aluminum tubing for the gripper and square aluminum tubing for the boom arm being the most expensive items at $50.38 and $46.16 respectively. Where possible we tried to use the same materials for different sub-assemblies, such as the bicycle cabling and some circular aluminum tubing, but the specialized dimensions of some parts made this difficult for most of our materials. Cost was therefore a bit high, due to our necessity of purchasing more material than was needed, solely because the smallest sizes or lengths offered were greater than we required.

A complete cost analysis spreadsheet and bill of materials for the entire model can be found in **Appendix VII**.

Chapter 5 – Product Realization

Unfortunately, our project lost our sponsors funding in the final quarter. We were able to build a prototype due to a generous donation from the Mechanical Engineering department, but the costs had to be minimized and parts were order much later than originally planned. As a result, many of our parts were produced using the rapid-prototyper on campus, which gave us geometrically correct parts, but parts that were not as strong as the aluminum parts that we had designed. Ultimately, this affected the functionality of the final prototype.

Boom Arm

Rapid prototyping was not an option for the Boom Arm, as this was our main load carrying assembly. The Boom Arm was created from three square tubular pieces of aluminum. Each piece was cut to length with a vertical bandsaw, and the channels at each end were cut with milling operations. On the longest piece, plunging cuts on the mill were used to create the guide holes for the Boom Arm cable housing. Holes for the shafts and bushing mounts were also cut with the mill. The shafts themselves were cut from 3/8" rod then welded into place on the respective arm segments. The bushing mounts were cut from 1 ½" rod in a lathe operation, and the bushing were press fit into place. The bushings were then glued into place. Finally, handle was welded on.

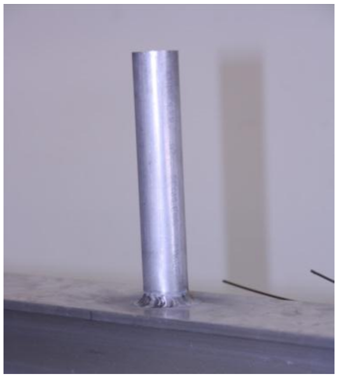

Figure 19 – Boom handle welded on.

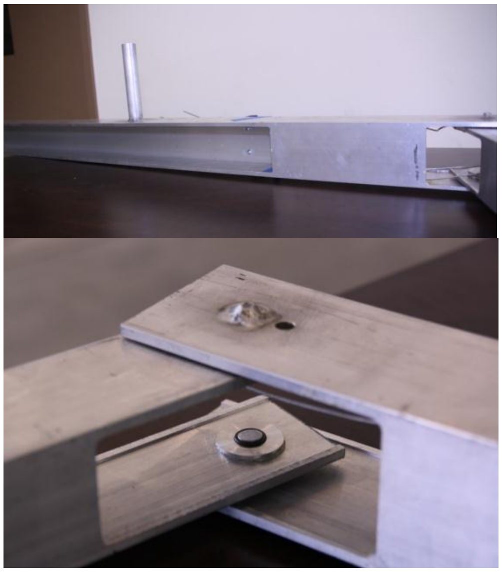

Figure 20 – Above: Long channel cut into boom to guide control surface. Below: End channels cut with mill-, bushing mounts cut with late operations.

Cable Arm

The Cable Arm was mostly assembled from purchased parts, with the exception of the cable guides. The cable guides were made from 1 ¼" nylon 6-6 rod stock. The center of the stock was drilled out in a milling operation, the guide holes for the cable were drilled out on a mill for precision placement, then each guide was cut from the stock with a bandsaw. The cable guides were attached to the inner sheath, which is rubber

Figure 21 – Construction of Cable arm: rubber hose, cable guides, cable spacers, and actuation cables.

hosing cut to length, by the use of epoxy. The actuation cables were run through these cable guides, starting at the Cable Control Surface and ending at the Gripper interface. To prevent pinching, short lengths of cable housing were placed between the cable guides to provide a radial buffer between the cable, the inner sheath, and the outer sheath, made of a nylon mesh stretched over the cable. The usb camera and the actuation cable for the Gripper were then fed through the inner sheath.

Cable Control Surface

The Cable Control Surface was almost entirely made from rapid-prototyped parts; the chassis, the actuation disks and the control knob cabs were rapid prototyped; the washers, the pivot rod, and the pivot rod locknuts were purchased; and the control knobs were cut from 1/8" rod stock, then ground smooth. The control knobs were glued into the actuation disks instead of being threaded through, because the rapid prototyped material cannot be threaded. The control knob caps were also glued onto the control knobs. The actuation cables were pressed into the actuation disks, then fed through the chassis to the cable arm.

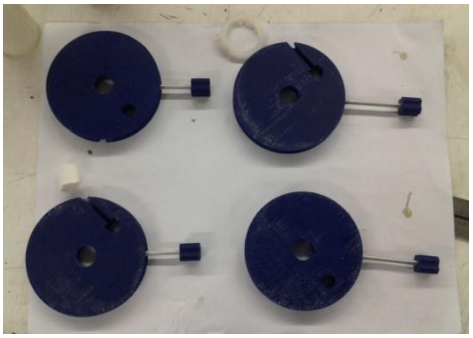

Figure 23 – Actuation disks with actuation knobs and knob cabs glued into place.

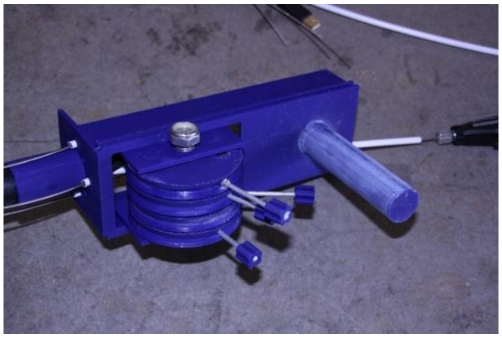

Figure 22 – Front view of assembled Cable Control Surface.

Gripper

The gripper was rapid prototyped. This was due to the funding restrictions and ease of manufacture. After considering the amount of time we had for assembly, the amount of time needed for manufacture and the differential in cost from aluminum and rapid prototyping, rapid prototyping was the clear winner. This caused some unforeseen problems as the gripper weighted much less than designed. We were counting on the weight from the Gripper to pull the Cable Arm straight down into the gear box, but the lighter Gripper left a slight bend in the cable arm, due to the "remembered" shape of the rubber hose.

The gripper was also redesigned with larger tolerances and larger arms after the first iteration failed. In addition, the mounting hole for the borescope was changed and elevated to allow for the installation of a webcam. The webcam was secured to the gripper using epoxy.

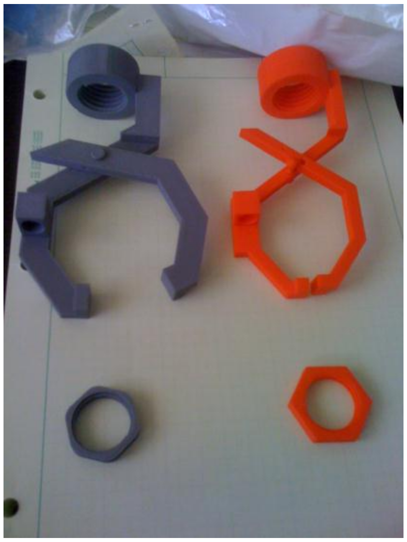

Figure 24 – Comparison of original gripper design (red) and redesigned gripper (gray).

Future Recommendations

Manufacturing the original design, without the rapid prototyped parts, would have been a much longer and more difficult process, which suggests that parts of our design would be worthy of redesign for manufacturability. The Cable Control Surface, for instance, would have required numerous accurate welds and some way to hold the aluminum plate in place for welding. This would have been a very difficult and frustrating process.

The Gripper could also be redesigned. The current design requires higher level manufacturing experience and difficult processes, such as internal and external threads. A gripper designed more for manufacturability would reduce the complexity of the subsystem. It may also increase the functionality of the gripping mechanism. Making the gripper out of aluminum would improve the durability and increase the weight of the gripper.

The Boom Arm, however, was quite easy to manufacture, although rather time consuming. The straight cuts and drilled holes were quite easy to place with a mill. Welding the shafts straight was the hardest exercise, but the weld strength is preferable to a simple press fit. The Cable Arm was also quite easy to construct, as it was mostly assembled from prefabricated parts.

Chapter 6 – Design Verification

Target Weight

Our target weight for the entire device is a maximum of 50 pounds. Based on the SolidWorks models of our prototype and weight specifications from McMaster-Carr, Home Depot and Art's Cyclery for the remaining parts, we felt that we would easily meet this requirement. After construction, we weighed the completed prototype using a bathroom scale. This was done by having a team member step onto the scale and recording their weight, then the same member step onto the scale while holding the prototype and recording this new weight. The difference between the two weights gave us the weight of our prototype, roughly 15 lbs. This was well below our maximum target.

Visual Checks

Some of our requirements are based on whether or not our prototype has a capability. These include number of joints, lighting, recording and gripper detachability. For these specifications we performed simple visual Go-No Go tests.

Figure 25 – Visual checks: detachable gripper, video and lighting capability.

Geometric Checks

The geometric requirements of our device were confirmed by measuring the specifications using the correct measuring tool. For the average range of joints, we adjusted the joints to their maximum angles and measured the displacement from the centerline. To measure the outer diameter we used calipers. To measure the collapsed size, we used a tape measure to measure the length, width and height of the collapse prototype. Then we calculated the storage volume using the three dimensions. To measure the maximum extended length, we fully extended the prototype and measured from the gripper tip to the control assembly on the widest beam in the arm, which was not included in the total length because it will be outside the gearbox during operation.

Other Measurements

The camera resolution and light intensity were found from online specifications of the bore scopes that NAVSEA currently has in their possession. Although our prototype used a webcam instead, those would be the values of the device if it were used by the Navy. The webcam met the basic requirements we'd set as well.

The hardness of the individual parts was to be tested using the hardness tester in the Hanger, but this was not completed due to time constraints. However, looking up the hardness values for Al 6063-T4 and the other alloys we used online, we found that we were well within our limit.

Boom Arm Actuation

To test the arm actuation, we intended to create a simple obstacle course that can be rearranged into different configurations and then maneuver the arm through the course. As we had some difficulties with the actuation of the arm joints using the auxiliary cables, this was not done, as the test was considered already failed. The joints only rotate about 45 degrees from the centerline, not 90 degrees, due to interference from the main cable.

Gripper Actuation and Lift Capacity

To test the gripper actuation and lift capacity, we planned to will place objects (i.e. ring, crescent wrench, eyeglasses, BIC pen, etc.) on the ground and try to pick up the object with the gripper using the actuation cable. This will verify the ability of the gripper to pick up a variety of objects. Due to the decision to rapid-prototype the gripper, which created a risk of gripper breakage, as well as a problem with cable retraction (which was later fixed), this was not done. We are still confident that with a metal gripper the prototype would be able to provide this functionality.

Cable Arm Actuation

To test the cable actuation, we hung the arm out from an elevated position (the second story railing in building 192) and lowered the cable to a desired distance. Then we manipulated the cable to ensure that we could produce a desirable cable actuation with relative ease. We found that the cable actuation was effective, but that due to the rapid-prototyping of the cable arm actuation discs, they began to crack well before we could test the maximum articulation. With proper aluminum discs, the cable should be able to provide a substantial actuation. Cable extension and retraction were also functional after a problem with the front roller was fixed.

Figure 26 – Alex holding the prototype during testing. Cable arm draped over the end of the boom was able to actuate properly.

Results

The system as a whole did not fulfill its primary objective, which was retrieving an object or debris from inside the gearbox. This failure was caused by the cable arm and roller interface. Due to sizing issues with the roller or the outer diameter of the cable arm, the cable arm became wedged at the end of the boom are due to its own weight and could not be retracted. Because the arm could not retrieve its own weight, we did not test whether or not it could retrieve any objects. It later occurred to us to fix this issue simply by mounting the roller in a different way, but it was too late to test again.

Another aspect that did not meet our requirements was the actuation of the boom arm. Due to the primitive materials we used because of funding issues, the bike cables became coated with residue from the epoxy and gorilla glue. When the cables were actuated, the epoxy and glue were moved into the cable guides, where they solidified and became jammed in the actuation mechanism. In addition, gorilla glue and epoxy were used to secure the actuation cables to the discs. This connection also failed at the second actuation point, the joint between the smallest and midsized arm sections. The combined stress of the cable tension on both sides of the disc repeatedly broke the cable free of its bonding. This could have been fixed with a more solid attachment, such as welding or a set screw, which was in the original design but removed due to manufacture time and cost.

A smaller failure was the maximum diameter. This failure was discussed with our sponsor, who approved of the increased diameter. They confirmed that the largest arm section would not have to pass through small gaps, like the other sections, and it would be acceptable to have a slightly larger diameter (4.2 inches versus 4.0 inches).

The webcam and gripper section were not tested with the system as a whole. The gripper worked and could be actuated and removed from the end of the cable arm as designed. The webcam also worked and provided the video and lighting capabilities that were listed in our design specifications. Because the other components that would position the camera and gripper had failed, we did not test them with the entire prototype but instead tested them individually. A full summary of all tests we performed and their results can be found on the next page in Table 3.

Table 3 – Summary of prototype testing and results with descriptions of reasons for failure.

Spec #	Parameter Description	Requirement Value	Actual Value	Passed Test	Failure Description
1	Total Weight	>50 lbs.	15 lbs.	Y	
2	Collapsed Size	2 cu. ft.	1.2 cu. ft.	Y	
3	Extended Length	< 10 feet	14 feet	Y	
4	Maximum Outer Diameter	4 in	4.2 in	N	Dimension approved by sponsor
5	Number of Joints	2	2	Y	
6	Average Range of Joints	90 deg.	45 deg.	N	Interference from cable and debris in cable housing
7	Extractable Weight	2 lbs.	0 lbs.	N	Design could not retrieve own weight
8	Gripping Mechanism	Must be detachable	Fully Detachable	Y	
9	Transportation	Carried up and down a ladder	Can be carried	Y	More difficult than expected
10	Recording/Lighting	Must have recording and lighting	Has recording and lighting	Y	

Chapter 7 – Conclusions and Recommendations

Overall, the prototype worked about as well as expected. The gripper and cable arm both worked as designed. Unfortunately, we could not test the precision of the cable actuation to the desired extent. The boom also lived up to its design. It proved to be even more lightweight that we originally thought. Additionally, it is very sturdy and keeps the cabling secure and well protected from outside interference or damage. The joints worked very well and actuated smoothly as well as solidly holding the individual sections together. Overall the prototype was easily transportable. The light weight and collapsibility made up for its overall awkward shape and size.

Along with the above successes, the prototype failed in a few aspects. First, the auxiliary cables that control the position of the boom could not be securely fixed to the boom joints. The cables also became contaminated with epoxy and glue, which caused them to get stuck in the cable guides. A combination of these failures and the overall complexity of the cable system prevented the boom arm from being actuated to the desired 90 degree range. Solving this failure would require a lot of analysis and redesigning the cable system with less complexity. Second, the roller was larger than designed. This caused the cable arm to become wedged in the end of the boom arm, which prevented the retrieval of the cable arm. This was due to a manufacturing error and could easily be solved by reducing the diameter of the roller or repositioning it slightly lower on the end of the boom. Finally, the boom joints have trouble rotating past 45 degrees without bending the cable arm too severely to operate. This would be difficult to fix, as it would require changing the design of the boom arm joints.

The entire overall operation and control scheme proved to be difficult to operate with one person and even frustrating with two people. All of this could be improved with a mechatronic system for controlling the actuation of the Boom Arm and possibly also the Cable Control Surface, but would require more analysis and further funding to succeed. A mechatronic system was avoided initially to prevent a failure from leaving debris in the gearbox, but it may be possible to locate most of the components outside of the gearbox, where they could also serve as a counterbalance for the portion of the arm that extends inside. The mechatronic system would allow for much more accurate control and remove the need for the cable control surface and auxiliary cable system. This could be added on to the existing system as part of another senior project with NAVSEA. Another possibility would be to modify the existing system with sturdier components, instead of rapid prototyped components, which may allow for more actuation of the cables and easier control of the system as a whole.

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Appendix I – Quality Function Deployment Table

	MRG Inspection Device			Engineering Requirements															Benchmarks						
		Operator	Design Review Team	Total Length	Resolution (Camera)	Lighting Intensity	Max. Outer Diameter	Gripping Capability	Number of Joints	Range of Joints	Extractable Weight	Device Weight	Device Size (Collapsed)	Gripper Detachability	Exterior Hardness	Precision at Full Extension	Display Size (Diagonal)	Resolution (Display)	Fiberscope/Borescope	Pincher Grabber	Magnet + Pole	Flashlight	Mechanic	Webcam	Pick and Place Robot
NAVSEA	Find debris																								
	See ring 5 feet away	30	28	-	5	4	-	-	-	-	-	-	-	-	-	-	3	5	5	-	-	5	4	1	-
	Video display	*	*	-	-	2	-	-	-	-	-	-	-	-	-	-	5	5	5	-	-	-	-	5	-
	Video recording	0	14	-	5	5	-	-	-	-	-	-	2	-	-	-	2	2	5	-	-	-	-	5	-
	Reach debris																								
	10-15 foot range	*	*	5	-	-	2	-	-	-	-	3	3	-	-	1	-	-	3	1	5	-	2	-	5
	Maneuver around obstacles	*	*	2	-	-	4	-	5	5	3	2	-	-	-	3	-	-	-	1	1	-	3	-	2
	Maneuver into gear crevices	25	14	3	-	-	5	2	5	5	-	-	-	5	-	5	-	-	-	-	-	-	3	-	2
	Remove debris																								
	8 inch crescent wrench	*	*	4	-	-	-	5	3	3	5	-	-	-	-	2	-	-	-	4	5	-	5	-	5
	Ring	*	*	3	-	-	-	5	4	3	1	-	-	-	-	5	-	-	-	5	1	-	5	-	5
	Glasses	*	*	3	-	-	-	5	4	3	2	-	-	-	-	4	-	-	-	5	1	-	5	-	5
	Rag	*	*	2	-	-	-	5	3	3	2	-	-	-	-	3	-	-	-	5	1	-	5	-	5
	Speed	9	2	3	-	-	-	-	3	3	4	5	-	-	-	5	-	-	3	5	5	5	2	5	5
	Transportability	21	7	5	-	-	3	-	4	4	-	5	5	3	-	-	-	-	5	5	2	5	5	5	-
	Not leave debris	*	*	-	-	-	-	-	-	-	-	-	-	5	3	5	-	-	5	5	5	5	1	5	5
	Don't damage gears	*	*	-	-	-	4	-	-	-	-	-	-	-	5	5	-	-	5	4	3	5	5	5	2
	Removable upon failure	*	*	3	-	-	4	-	5	5	-	4	-	3	-	-	-	-	5	5	1	5	2	5	1
	Grease resistant	15	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		5	5	5	5	2	5
	Low product cost	0	21	2	3	2	2	3	2	4	3	4	3	3	4	4	5	4	1	5	5	5	1	5	1
	Units			ft	MPx	lux	in	y/n	#	deg	lb	lb	ft^3	y/n	HBW	in	in	MPx							
	Targets			15	1	2k	4	y	high	high	2	50	3	y	low	0.1	8	1							
	Fiberscope/Borescope			15	2	?	0.5	n	1	90	-	3	0.5	-	?	8	-	-	Necessary Criterion						*
	Pincher Grabber			3	-	-	3	y	0	-	3	2	0.5	n	?	0.1	-	-	Strong Correlation						5
	Magnet + Pole			15	-	-	2	y	-	-	3	10	1.5	n	?	1	-	-	Medium Correlation						3
	Flashlight			-	-	?	2.5	n	-	-	-	5	0.3	-	?	-	-	-	Small Correlation						1
	Mechanic			6	-	-	4	y	3	180	20	200	12	n	?	0.01	-	-	No Correlation						-
	Webcam			-	3	-	2	n	-	-	-	1	0.1	-	?	-	-	-							
	Pick and Place Robot			15	-	-	6	y	3	180	100	500	20	n	?	0.001	-	-							

Appendix II – Concept Generation

Gordon's Concept Generation

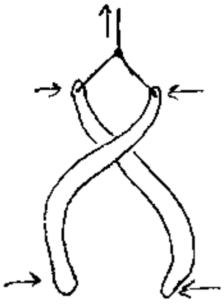
10/25/2011

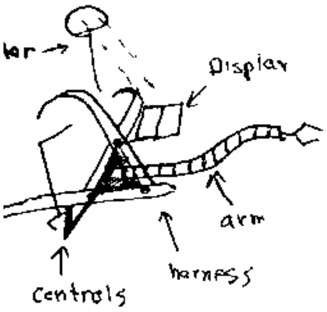
ncept Generation

ep 1: Brainstorming

Cables are guided through eyelets, and tension in the cables cause the structure to bend. Cables controlling the camera/gripper system can be run through the body.

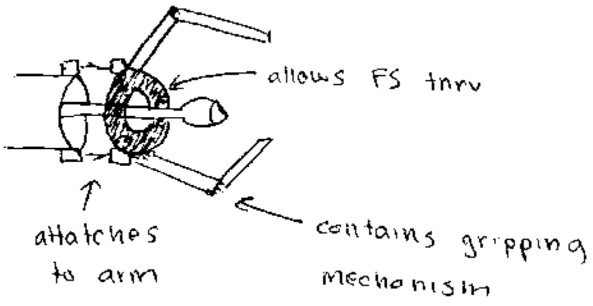
Gripping mechanism similar to bike brakes w/cabling mechanism.

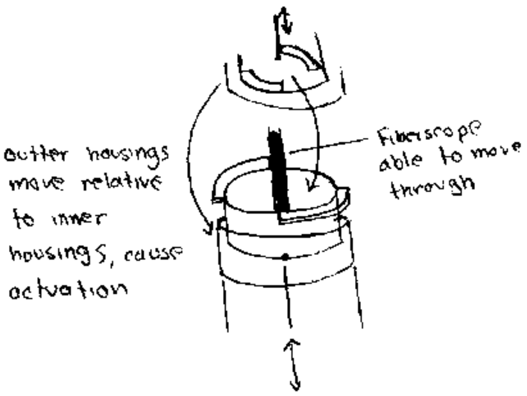




Harness/Belt system to carry display/controls/arm while in use for operator

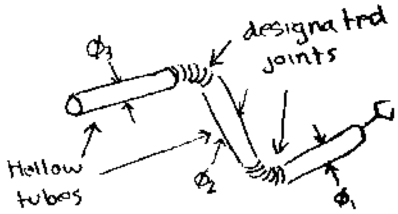
Grip attachment method hat fits over fiberscope, llowing free range of FS otion while allowing ultiple gripper attachments



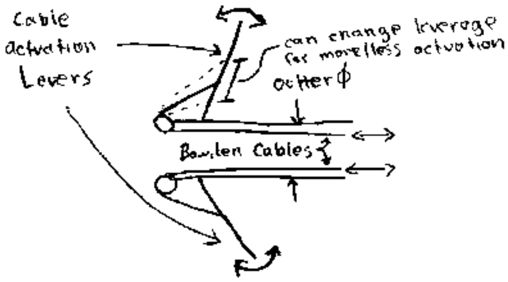


Method for attaching gripper mechanism that allows for a hollow area ~~between~~ through which fiberscope could be run.

Not infinitely variable, instead using hollow tubes to house cables that bend at given intervals.

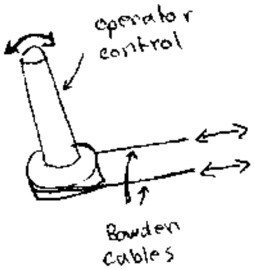


$\phi_3 > \phi_2 > \phi_1$

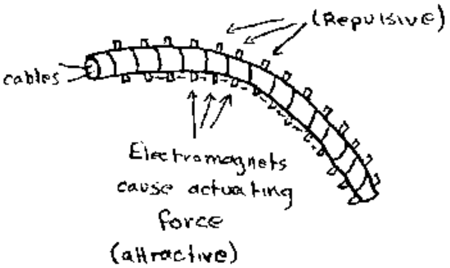


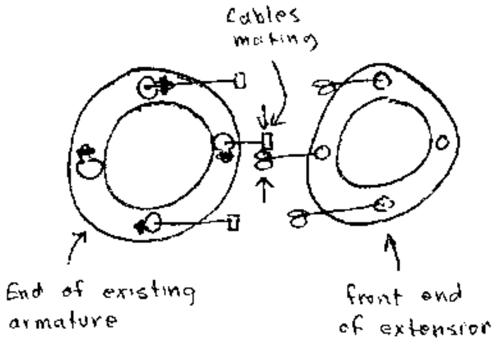
Method for controlling arm actvation with lever system.

Method for controlling arm actuation with control knob.



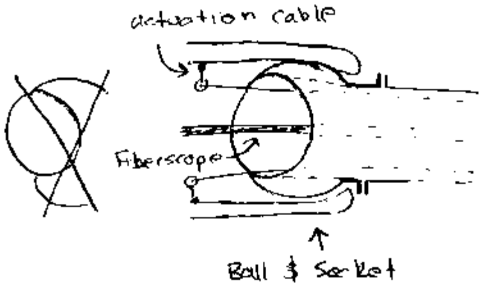
Actuating member due to electro magnets (repulsive and attractive)

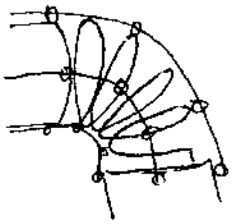




Method for adding attatchable arm extension & maintaining articulation

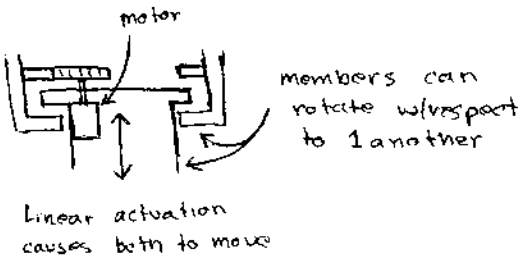
Hollow ball & socket Joint w/Bowden actuation.
(4 directional movement

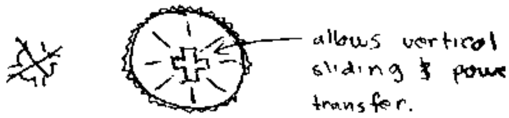


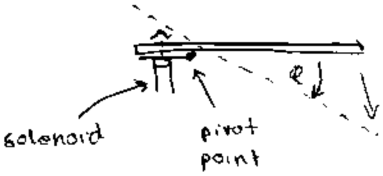


Spring type (accordian)
joint type w/Bowden actuation
(4 directional movement)

Method for allowing gripper rotation while still providing linear actuation.





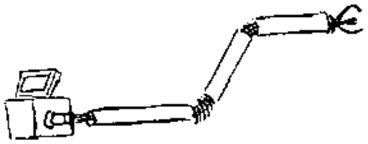


Method for gripper engagement w/ solenoid

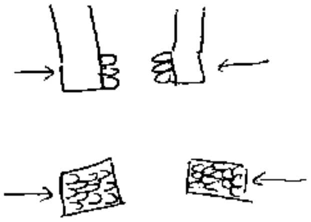
Concept Generation

6-3-5 Method

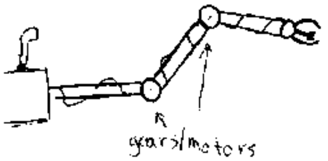
"Bowden Actuation"



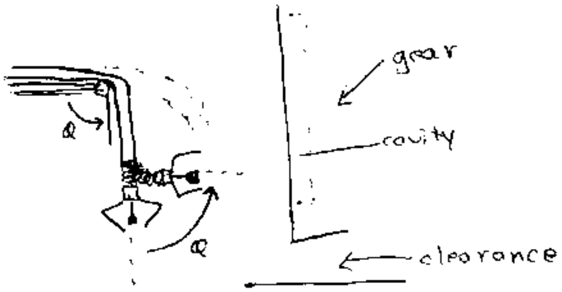
Gripping mechanism



"Gear/Motor Actuation"



"Fishing Pole"



11/3/2011 - Morphological Attribute List

Gripping style	Extension style	Power Transfer	Actuation Method	continuous/ non-continuous	control interface	camera
Bike brake clamp	Rigid. multi-joint (motor driven)	Bowden Cables	Bowden cables & flex joints	discrete sections	manual (lever system)	fiberscope
magnets	"infinitely variable" - no rigid section	Electric Motors	Motor/gear actuation	continuous/ fully flexible	Laptop integrated controls	separate camera
Pan style"	Rigid sections with flexible joints	Motors w/belts, cables	"fishing pole" (straight pole, w/ bowden act)	discrete sections w/ flexible joints	Joysticks (electrical, non-comp connected) - controls actuate motors @ joints - controls actuate motors controlling bowden cables	self-actuating
Nipple Style"	"fishing pole"	Levers				independant actuation
three finger (Plunger, other)		pulley systems				
Motor actuated clamp		pneumatics/ hydraulics				
solenoid actuated		solenoids				
Spring & Pin						

lighting	Joint methods	Mounting	Cabling Methods	outer surface/ containment	video display	Gripper (De)attachment
on fiberscope	accordian connection	Harness	thru-shaft	outer sheath	Laptop connection/ display	circular locking method
Separate lighting	hollow ball & socket	Counterweight	exterior routing	hollow arm segments	Onboard display	Magnetic
	Pin/shaft Joint	Bulkhead Mount	combo	Soft material	Existing fiberscope Display	Screw mechanism
						Bolt on attachment
						Clip on

List of Alternative Actions

change✓
Alternate
reverberate
expediate

swing✓
torn
burn
churn

wash
dry
rotate
invert

extend
divert✓
squeeze
sweep✓

plant
finish
clean
inspect

lift
suck
blow✓
spin✓

dodge
heat
recycle
reset

Change - change context of the problem: instead of removing the debris, move it somewhere where it can be more easily remove.
- change/interchange grippers, parts, etc.

Alternate -

Swing - swing end like a wrecking ball, w/magnets to grab sides, serve as p.o.c.

Sweep - two trays or tray & broom closing/sweeping an item up.

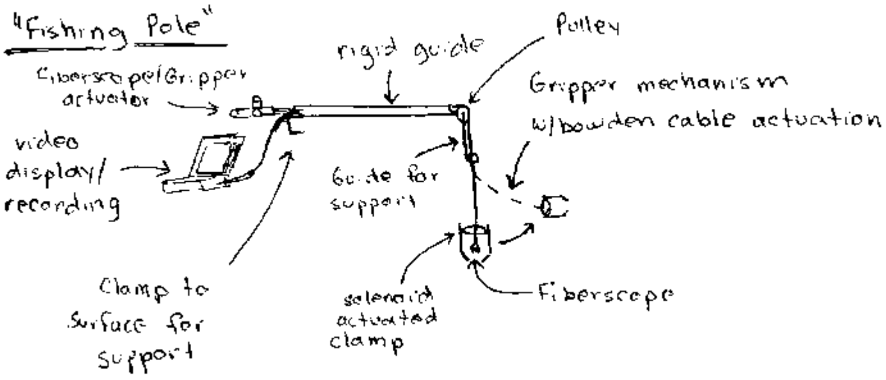
Spin - impeller/screw in a tube to lift out debri
- Bowden cable actuation for rotational elements

Blow - *See mike's sticky: displace oil

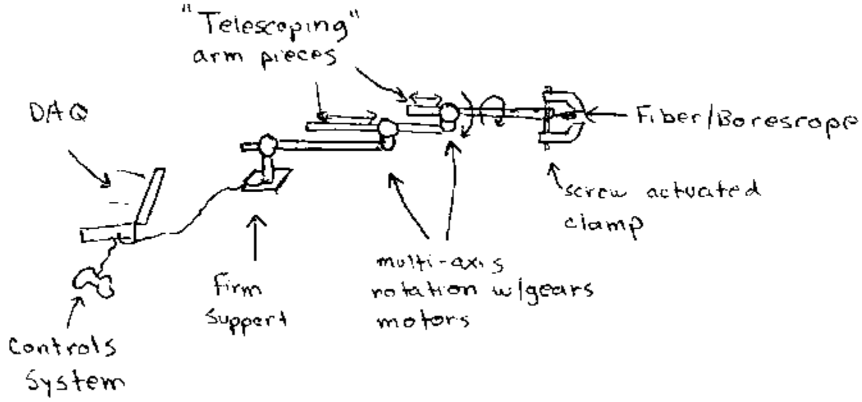
Divert - elements of rigid piping, or other, to ~~dife~~ divert flexible elements (cables) to turn a certain way. Adjustable, to control amount of bend.

11/7/2011 - Big 3 Concepts

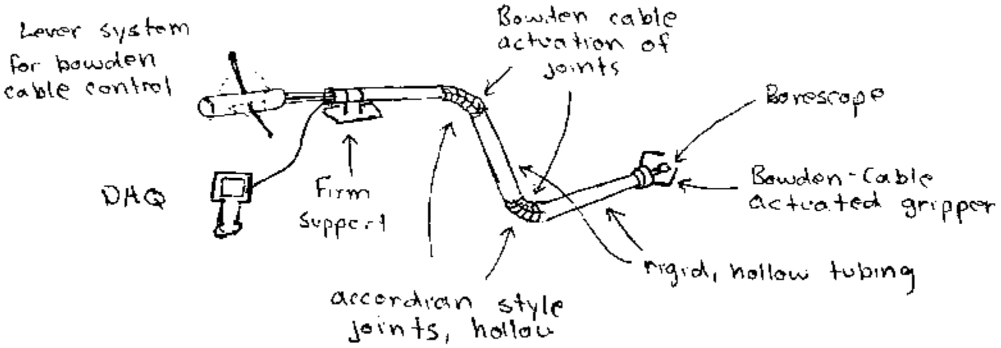
"Fishing Pole"



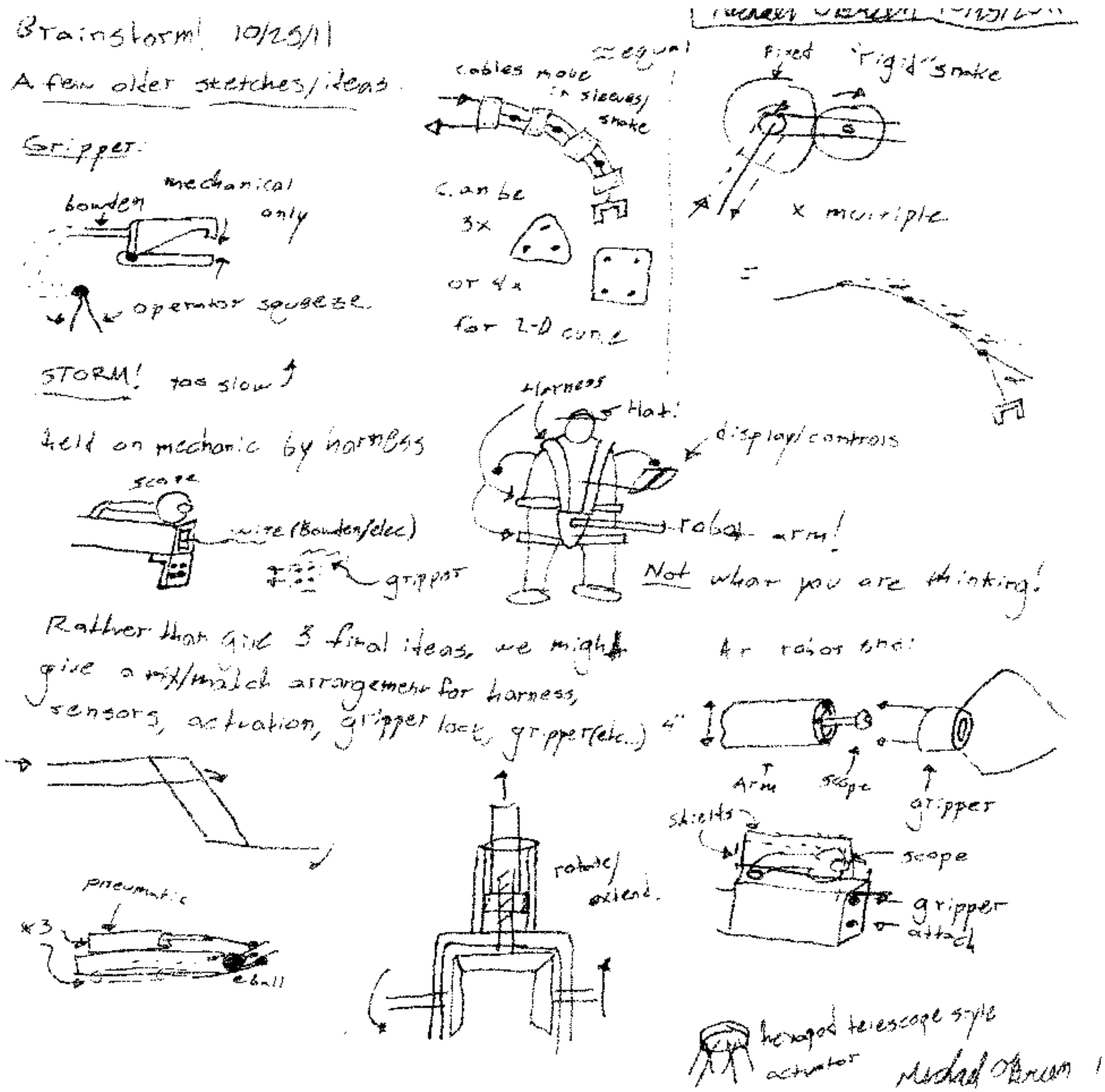
"Motors & Gears"



"Segmented Arm"



Michael's Concept Generation



Brainstorm! 10/25/11

A few older sketches/ideas.

Gripper:

STORM! too slow

Held on mechanic by harness

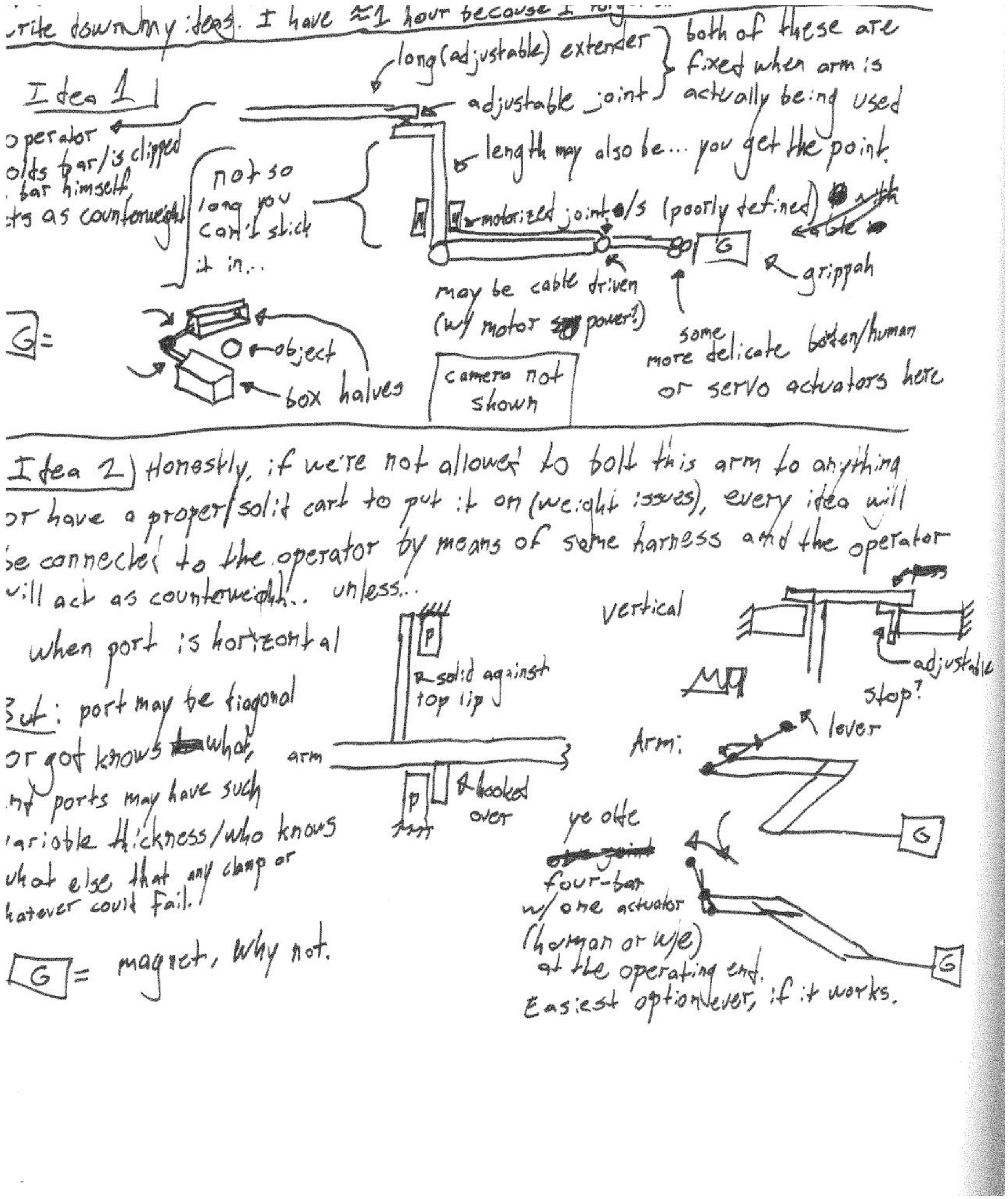
Not what you are thinking!

Rather than give 3 final ideas, we might give a mix/match arrangement for harness, sensors, actuation, gripper lock, gripper (etc...)

At robot end:

hexapod telescope style actuator

Michael O'Brien !



rite down my ideas. I have ≈1 hour because I

Idea 1)

operator
olds bar/is clipped
bar himself
ts as counterweight

not so
long you
can't stick
it in...

long (adjustable) extender
adjustable joint
both of these are fixed when arm is actually being used

length may also be... you get the point.

motorized joint/s (poorly defined) ~~with cable~~

may be cable driven
(w/ motor power?)

grippah

some
more delicate bowden/human
or servo actuators here

G =

object

box halves

camera not shown

Idea 2) Honestly, if we're not allowed to bolt this arm to anything or have a proper/solid cart to put it on (weight issues), every idea will e connected to the operator by means of some harness and the operator will act as counterweight.. unless..

when port is horizontal

But: port may be diagonal
or God knows what,
nd ports may have such
ariable thickness/who knows
hat else that any clamp or
hatever could fail.

G = magnet, why not.

p

solid against
top lip

arm

p

hooked
over

vertical

adjustable
stop?

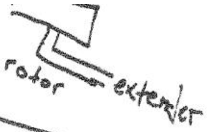
Arm:

lever

G

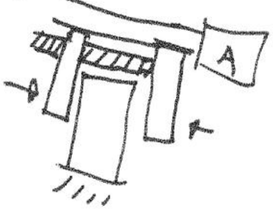
ye olde
four-bar
w/ one actuator
(human or w/e)
at the operating end.
Easiest option ever, if it works.

G



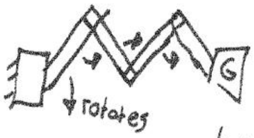
Idea 4 Attachment: ~~Operator~~

Screw clamp, operator tightened.

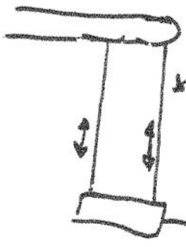


Arm: I honestly feel that all of the "best" ideas for the arm were integrated into the first idea, but…

extener top view:



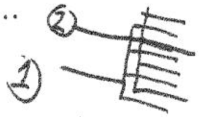
A =



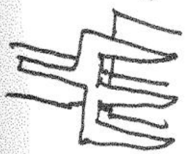
or just boxing glove style actually

G =

the closing grippers (which come in from the side) are like forks that mesh…



lord you know what forks are…



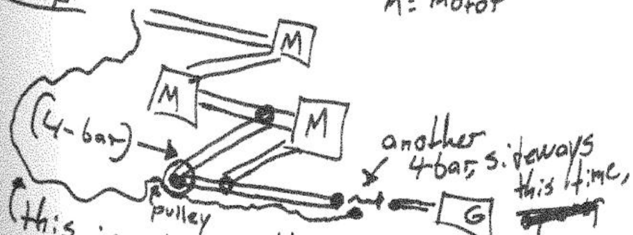
God I'm bad at drawing forks…

Idea 5 Just to use my 507 design as much as possible (I know Gordon will include the snake thing so I won't bother)

Attach: Operator harness

Arm ~~Grip~~:

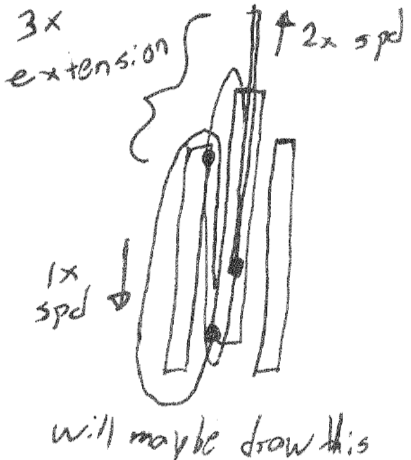
M = motor



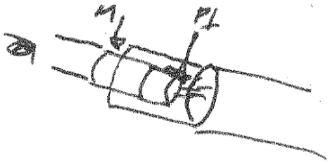
G = sticky glue ball.

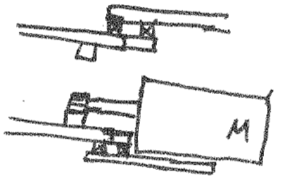
(this is a loose cable which goes around pulley. Operator yanks by hand to tighten cable (he may have a lot of slack) to operate last 4-bar

11

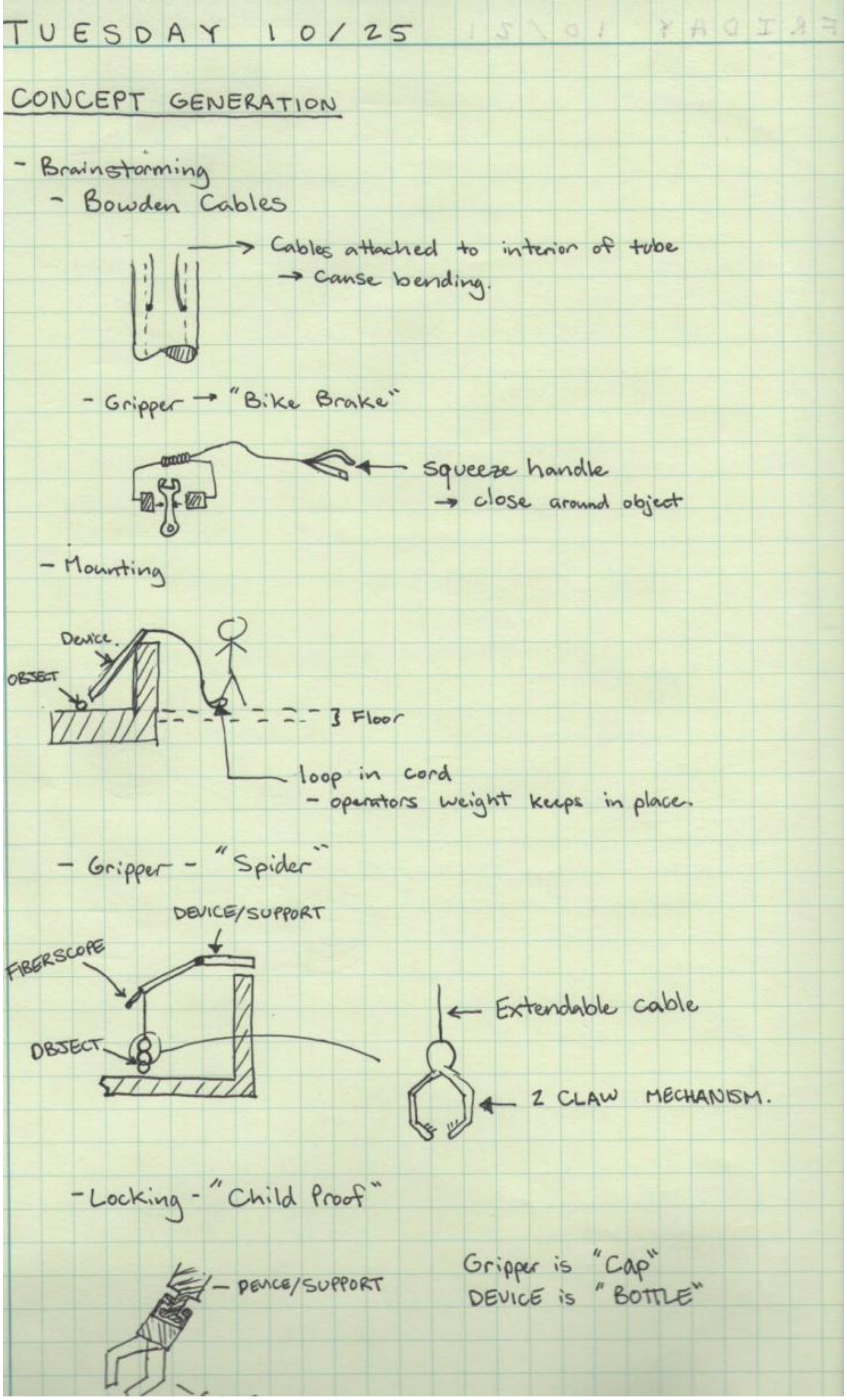


will maybe draw this
better later...





Alex's Concept Generation



TUESDAY 10/25

CONCEPT GENERATION

- Brainstorming
  - Bowden Cables

Cables attached to interior of tube
→ cause bending.

- Gripper → "Bike Brake"

squeeze handle
→ close around object

- Mounting

loop in cord
- operators weight keeps in place.

- Gripper - "Spider"

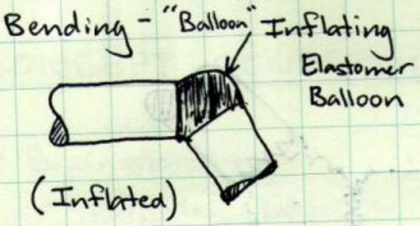
← Extendable cable

← 2 CLAW MECHANISM.

-Locking - "Child Proof"

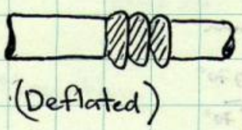
Gripper is "Cap"
DEVICE is "BOTTLE"

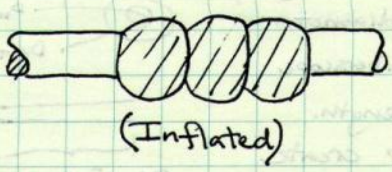
- Bending - "Balloon" Inflating



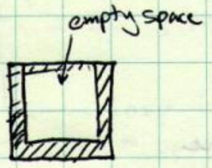
- Blood Pressure squeeze ball
  - → inflates at joint
  - → ~~feate~~ releases back to original position
  - → variable by psi
- Air suspension / Lift-kit.

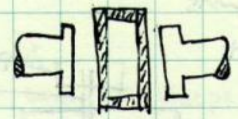
- LINEAR EXTENSION

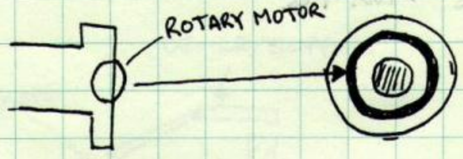




- CONNECTION "WWII SUB PIPE BRACING" (Burst Pipe + Periscope)



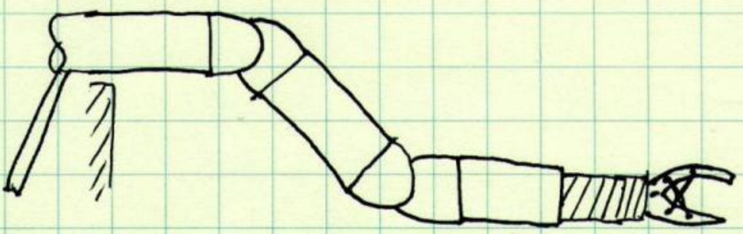




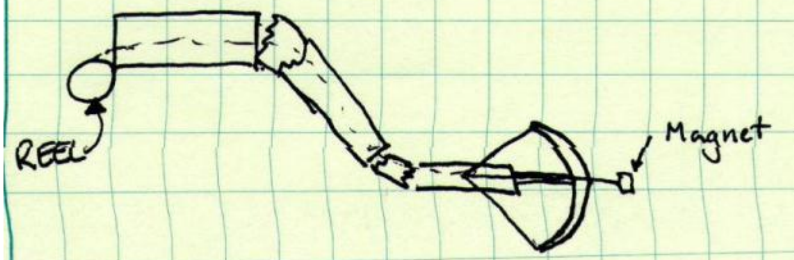
MOTOR ROTATES IN GROOVE OF CONNECTED "PIPE"

3-3-5 Method.

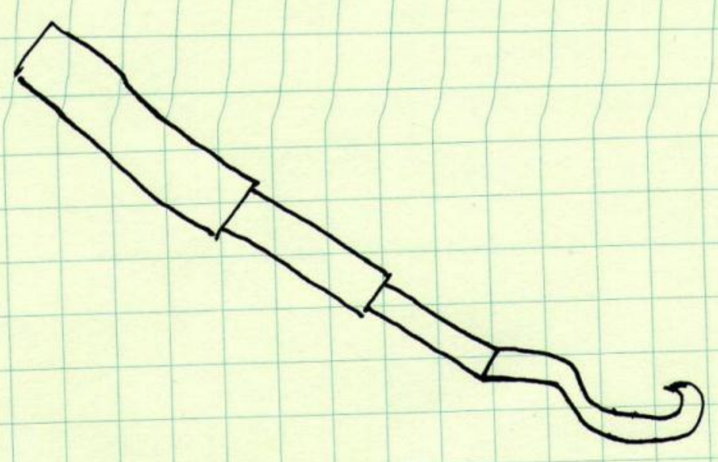
1)



2)



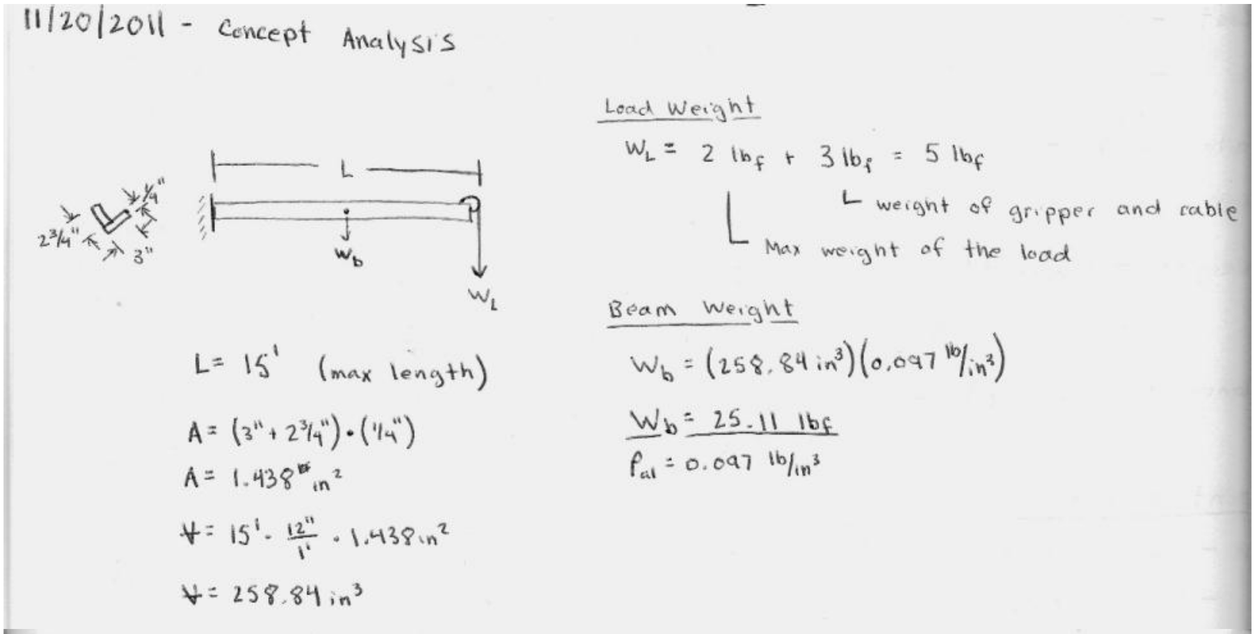
3)



→ Clip like Keychain/Necklace/Handcuffs.

Appendix III – Preliminary Analysis

Gordon's Analysis



11/20/2011 - Concept Analysis

$L = 15'$ (max length)

$A = (3" + 2\frac{3}{4}") \cdot (\frac{1}{4}")$

$A = 1.438\ in^2$

$\forall = 15' \cdot \frac{12"}{1'} \cdot 1.438\ in^2$

$\forall = 258.84\ in^3$

Load Weight

$W_L = 2\ lb_f + 3\ lb_f = 5\ lb_f$

└ weight of gripper and cable

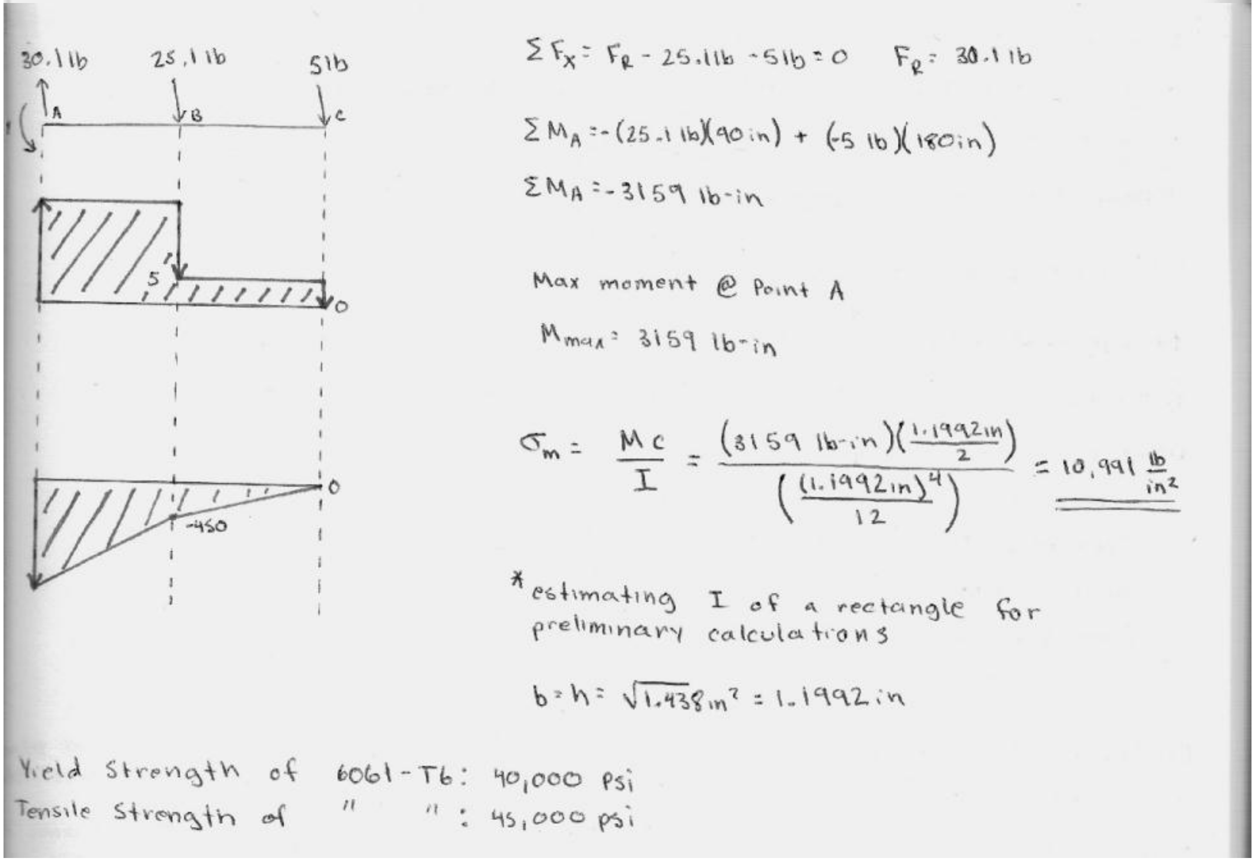
└ Max weight of the load

Beam Weight

$W_b = (258.84\ in^3)(0.097\ lb/in^3)$

$\underline{W_b = 25.11\ lbf}$

$\rho_{al} = 0.097\ lb/in^3$



$\Sigma F_x = F_R - 25.1 lb - 5 lb = 0 \quad F_R = 30.1\ lb$

$\Sigma M_A = -(25.1\ lb)(90\ in) + (-5\ lb)(180\ in)$

$\Sigma M_A = -3159\ lb\text{-}in$

Max moment @ Point A

$M_{max} = 3159\ lb\text{-}in$

$$\sigma_m = \frac{Mc}{I} = \frac{(3159\ lb\text{-}in)\left(\frac{1.1992 in}{2}\right)}{\left(\frac{(1.1992 in)^4}{12}\right)} = \underline{\underline{10,991\ \frac{lb}{in^2}}}$$

*estimating I of a rectangle for preliminary calculations

$b = h = \sqrt{1.438\ in^2} = 1.1992\ in$

Yield Strength of 6061-T6: 40,000 psi

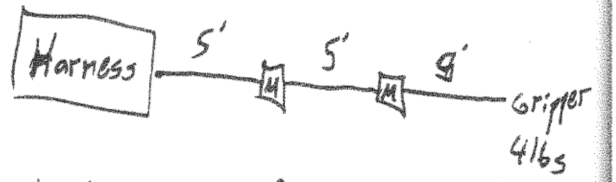
Tensile Strength of " " : 45,000 psi

Michael's Analysis

11/20/11

I need to design something. I will work from the magnet backwards, makes most sense because we have weights to calculate torques if we analyze this way. ~~Re~~ Rare earth mags ~4k "orsteads" (low estimate) 10k "Gauss". Wow, found calc online. A 50 lb force magnet is 1"x1"x1", 0.26 lbs. So for 2 lb force, we can assume ~~at~~ the magnet is negligible. Maybe if we go with electromag, that would be a bit more, but I found electromag w/ 200 lb. force which seems fairly small. Found 1.2 lb electromagnet w/ 70 lb pull. So magnets = nothing weight wise. (Bookmarked magnets to put in report if necessary.) Full weight magnet + mounting & bolt + wrench ≈ 4 lbs, including camera too.

We need 2 joints max so for now, just to see if design is at all feasible, lets do this:

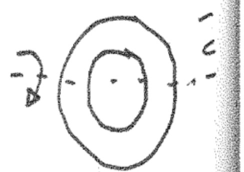


5 ft × 4 lbs = 20 ft lbs (joint 1)

+ wt. of arm × 2.5 ft.

Arm ~~needs~~ is tubular or rectangular, lets to hollow tube for now. Don't remember how to to this.. Finding book... ~~Just to~~

~~$\tau = \frac{Tc}{J}$~~ $\tau_{max} = \frac{2V}{A} = \sqrt{\cancel{30\ \text{ft lb}}} = \frac{2.4\ \text{lbs}}{}$ god I remember none of this



$\tau_{max} = \frac{Tr}{J} = \frac{Tr}{\frac{\pi}{32}(d_o^4 - d_i^4)}$ make it 1" OD, 1/16" thick...

$$= \frac{20\ \text{ft}\cdot\text{lb}\cdot 0.5''}{\frac{\pi}{32}\left(1''^4 - \left(1-\frac{1}{4}\right)^4\right)} = 246\ \frac{\text{ft}\cdot\text{lb}\cdot\text{in}}{\text{in}^4} \times \frac{12\ \text{in}}{\text{ft}} = 2954\ \text{psi}$$

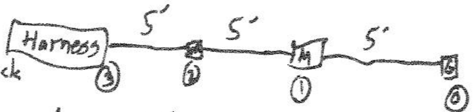
, we need material w/ $S_y > 2954$ I

something is wrong...

0.5 lb

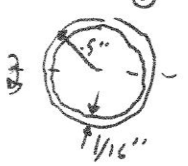
11/29/11) Analysis: Magnet + object weight ≈4 lb

4 lb × 5' = 20 ft lb. use Aluminum bar 1" OD 1/64" thick



$$\frac{Tr}{\frac{\pi}{64}(D_o^4 - D_i^4)} = \frac{(20\ ft \cdot lb)(.5\ in)}{\frac{\pi}{64}(2^4 - (\frac{7}{8})^4)\ in^4} \cdot \frac{12\ in}{1\ ft} = 5907\ psi.$$

S_y for 2024 Al is 11k untreated, 56k at T6. Good✓



This is honestly as neat/organized as my work gets✓

Motor ①: Need T = 20 ft·lb Try www. Teamdelta.com/ products/prod5.htm, Dewalt + transmission drill motor.

450 rpm @ 400 in-lb, $400\ in \cdot lb \times \frac{1\ ft}{12\ in} = 33\ ft \cdot lb$ well holy god.

Net weight ≈ (7.1 + 17.1) oz = 1.5 lbs, but that's with a <u>huge</u> speed. This <u>must</u> be an inaccurate spec, no way drill is that powerful. It is probably Free RPM + stall torque. But we can operate @ near stall torque for short periods + we don't need that agressive ~~gearing~~ speed. This won't fit in... we could probably make this fit 4" OD actually, just a drill motor. But w/ wires + support would cut it a little close

Solarbotics.com/products/gm8/specs has 76 in.oz → 0.39 ft.lb, gear up 50:1 is ~1 RPM nevermind. Nothing from this site is big enough.

www.robotmarketplace.com/products/0-BH631.htm → if geard down additional 30:1 @ 24 V, has ~ 61 ft·lb stall torque @ 12 rpm free speed. I wish they gave <u>real</u> motor curves but this is probably enough to tell that this would work + <u>but</u> it is being overpowered (24V vs. 12V) and has a slight chance of melting.

1.46" OD ✓ 7.4 oz + gearing + shaft ≈ 2 lbs we'll say ✓

There are also <u>super</u> high quality/light weight hobby aircraft motors I know about (expensive) which could probably work, but this is good for this analysis.

<u>⓪→① beam</u>

Forgot to calculate weight of ⓪→① beam → $A\rho = \pi(r_o^2 - r_i^2)L \cdot 0.094 \frac{lb}{in^3} = \underline{1\ lb}$

20 ft·lb + 1 lb · 2.5 ft = 22.5 ft·lb @ point ①, not significant

<u>Now analyzing beam ②→① gives</u> T = 4·10 + 1·7.5 + 2·5 + ?·2.5 = 57.5 lb·ft ~60 lb·ft

lets do 1.5" OD, 1/16" thick Al beam.

$$\frac{Tr}{\frac{\pi}{64}(D_o^4 - D_i^4)} = \frac{(60\ ft \cdot lb)(\frac{1.5}{2}\ in)}{\frac{\pi}{64}(1.5^4 - (1.5 - \frac{1}{8})^4)\ in^4} \times \frac{12\ ft}{1\ lb} = S_y = 7392\ psi < 11k\ psi$$

still good even for <u>untreated</u> 2024!

$weight = \frac{\pi}{4}(D_o^2 - D_i^2)L \times 0.094 \frac{lb}{in^3} =$ 1.66 lb ≈ 1.5 lb or lighter with proper design. I haven't used "real" safety factors but everything is bulky.

<u>**Motor ②**</u> T~62 lb

Found a better (?) motor. www.robotmarketplace.com/products/0-PDX256.html. 1.5"×1.5"×5" size, no extra gearing needed @ 12V, plenty of torque/speed. 2 or at most 2.5 lb when mounted, 1.2 lb unmounted. Looking at this, I feel confident that we can find powerful, reasonably-sized motors for anything we'd want for this project. $99 for this...

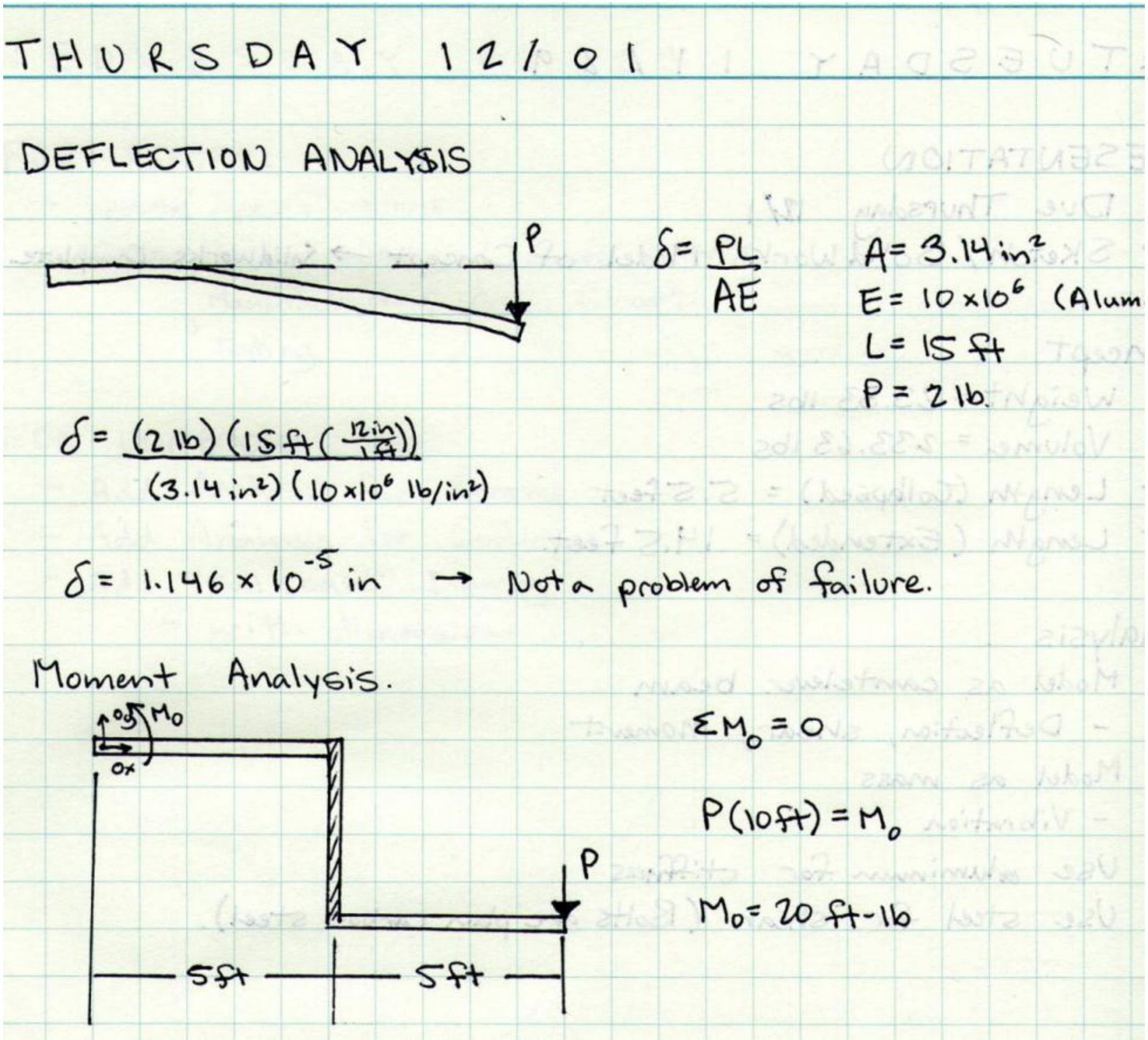
[illegible] to analyze "harness", it's... a harness...)

1/29/11

Analysis Discussion/Continuation: One thing I forgot was a power supply or batteries (ugh, no) to get 120 V, 60 Hz, 15-amp fuse (?) wall current down to 12 or 24 V D.C. power w/ stall amperage (we would have a secondary fuse) of failure max (if someone majorly screws up) 300 A but operational max of ~ 50 or less. If necessary, design could be modified to reduce ~~power to~~ this substantially by simply gearing the motors down more. But I need ~~my m~~ to ask my mechatronics professor to check my design anyway, and he could comment on this. It wouldn't add more than 20% to any of the values I calculated. I can't do it right now because class is starting + I will have mechatronics soon.

The cost and everything else does Not include the cost of the vision components. It assumes that we should use ~~poor~~ the Navy's ~~fibre~~ fiberscope, which is only 9 feet long so... it doesn't actually 100% match this design. We absolutely should do a CBA of using/not using the fiberscope. With a fiberscope, it has its own control scheme and in fact, if we went really ghetto, our motor controls could be no more than a few switches on a panel, cutting our cost ~~by~~ substantially → 550 to 325 becomes 350 to 220, which is pretty absurd

Alex's Analysis



THURSDAY 12/01

DEFLECTION ANALYSIS

$\delta = \frac{PL}{AE}$

$A = 3.14 \text{ in}^2$

$E = 10 \times 10^6$ (Alum

$L = 15$ ft

$P = 2$ lb.

$$\delta = \frac{(2\text{ lb})(15\text{ ft}(\frac{12\text{in}}{1\text{ft}}))}{(3.14\text{ in}^2)(10\times10^6\text{ lb/in}^2)}$$

$\delta = 1.146 \times 10^{-5}$ in → Not a problem of failure.

Moment Analysis.

$\Sigma M_o = 0$

$P(10\text{ft}) = M_o$

$M_o = 20$ ft-lb

Appendix IV – Decision Matrices

Table 4 – Gripper Style Decision Matrix

		Idea					
Factors	**Weighting**	Bike Clamp	Magnets	3 Finger (plunger)	Motor Actuated Clamp	Solenoid Actuated	Spring and Pin
Cost	0.05	1	2	1.5	-2	-1	0
Failure Risk	0.35	1	-2	1.5	2	1	-2
Weight	0.20	1	2	2	-2	0	1
Manufacture Difficulty	0.20	2	2	2	-2	0	-1
Ease of Use	0.10	1	2	1.5	1	-1	-2
Lifting Capability	0.10	1	0	-1	2	1.5	1.5
Sum of +		1.20	1.10	1.55	1.00	0.50	0.35
Sum of -		0.00	-0.70	-0.10	-0.90	-0.15	-1.10
Total		1.20	0.40	1.45	0.10	0.35	-0.75
Rank		2	3	1	5	4	6

Table 5 – Mounting Style Decision Matrix

		Idea			
Factors	**Weighting**	Clamp: to access hatch	Cross-bar over/under access hatch	Harness	Counterweight ("Foot harness")
Cost	0.10	-2	-1	1	2
Failure Risk	0.35	1	2	-1	-2
Weight	0.20	-2	-1	1	2
Manufacture Difficulty	0.20	-2	0	1	2
Ease of Use	0.15	0.5	1	1	2
Sum of +		0.43	0.85	0.65	1.30
Sum of -		-1.00	-0.30	-0.35	-0.70
Total		-0.58	0.55	0.30	0.60
Rank		4	2	3	1

Table 6 – Extension Style Decision Matrix

		Idea					
Factors	**Weighting**	Rigid, Multi Joint	Rigid, Hollow sections, flexible Joints	Fishing Pole	4 Bar Linkage	Boxing Glove	Zip-line "Sky Cam"
Cost	0.20	-2	-1	1.5	-1	-2	2
Failure Risk	0.25	0	-1	1	2	-0.5	-2
Weight	0.20	-2	-0.5	1.5	0	-2	2
Precision	0.10	2	0	1	0	-1	-1
Manufacture Difficulty	0.15	-1.5	-0.5	1	1.5	-2	2
Ease of Use	0.10	2	1	1	0.5	1	-2
Sum of +		0.40	0.10	1.20	0.78	0.10	1.10
Sum of -		-1.03	-0.63	0.00	-0.20	-1.33	-0.80
Total		-0.63	-0.53	1.20	0.58	-1.23	0.30
Rank		5	4	1	2	6	3

Table 7 – Joint Method Decision Matrix

		Idea				
Factors	**Weighting**	Motor/Gear Joints	Accordion Joint	Hollow Ball and Socket	Linear Actuators	Pulley
Cost	0.10	-2	1	-2	-2	2
Failure Risk	0.30	-1	-2	-2	-1	2
Weight	0.20	-2	2	-1	-2	1
Range of Motion	0.20	2	1	0.5	1	-1
Manufacture Difficulty	0.20	-2	1.5	-2	2	1.5
Sum of +		0.40	1.00	0.10	0.60	1.30
Sum of -		-1.30	-0.60	-1.40	-0.90	-0.20
Total		-0.90	0.40	-1.30	-0.30	1.10
Rank		4	2	5	3	1

Table 8 – Power Transfer Method Decision Matrix

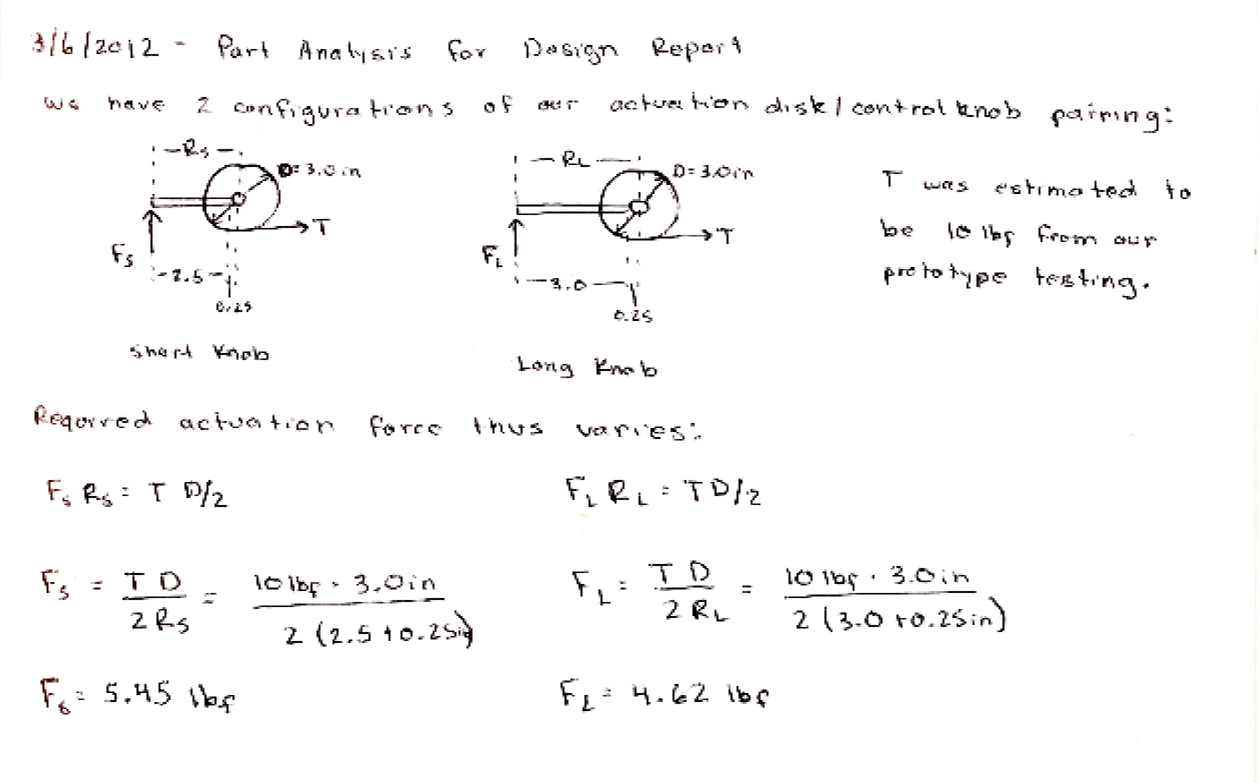
		Idea					
Factor	**Weighting**	Bowden Cable	Pulley Systems	Levers	Motors	Solenoids	Motors w/ belts, cables
Cost	0.1	0	0	0	-1	-1	-2
Failure Risk	0.25	0	-1	0	-1	-1	-2
Weight	0.2	0	-0.5	-1	-1	-1	-2
Speed	0.05	1	1	1	-1	1	-1
Precision	0.1	-1	-1	0	2	-2	2
Max. Torque	0.05	0	0.5	0.5	1.5	1	2
Manufacture Difficulty	0.15	0	1	0	-1	0	-2
Ease of Use	0.1	0	0	0	1	1	1
Sum of +		0.05	0.225	0.075	0.375	0.2	0.4
Sum of -		-0.1	-0.45	-0.2	-0.75	-0.75	-1.45
Total		-0.05	-0.225	-0.125	-0.375	-0.55	-1.05
Rank		1	3	2	4	5	6

Table 9 – Gripper Attachment Method Decision Matrix

		Idea			
Factor	**Weighting**	Circular Locking	Magnetic	Screw Mech.	Bolt on
Cost	0.1	-1	-1	1	2
Failure Risk	0.25	-1	-2	1	2
Weight	0.1	-1	-1	0	2
Weight (pick up)	0.15	1	-1	1	2
Power transfer	0.2	1	0	0	0
Manufacture Difficulty	0.2	-1	1	1	2
Sum of +		0.35	0.2	0.7	1.6
Sum of -		-0.65	-0.85	0	0
Total		-0.3	-0.65	0.7	1.6
Rank		3	4	2	1

Appendix V – Final Concept Analysis

Gordon's Analysis



3/6/2012 - Part Analysis for Design Report

We have 2 configurations of our actuation disk/control knob pairing:

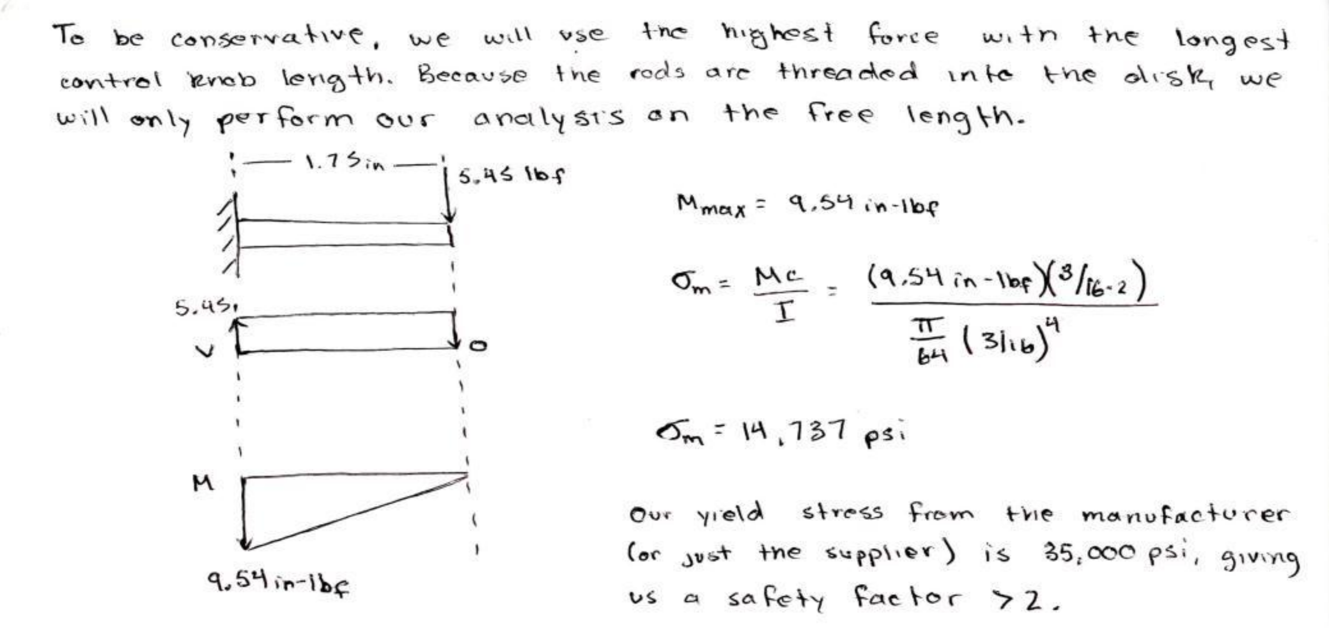
T was estimated to be 10 lbf from our prototype testing.

Required actuation force thus varies:

$$F_s R_s = T\, D/2 \qquad F_L R_L = T D/2$$

$$F_s = \frac{T D}{2 R_s} = \frac{10\,\text{lbf} \cdot 3.0\,\text{in}}{2\,(2.5 + 0.25\,\text{in})} \qquad F_L = \frac{T D}{2 R_L} = \frac{10\,\text{lbf} \cdot 3.0\,\text{in}}{2\,(3.0 + 0.25\,\text{in})}$$

$$F_s = 5.45\ \text{lbf} \qquad F_L = 4.62\ \text{lbf}$$



To be conservative, we will use the highest force with the longest control knob length. Because the rods are threaded into the disk, we will only perform our analysis on the free length.

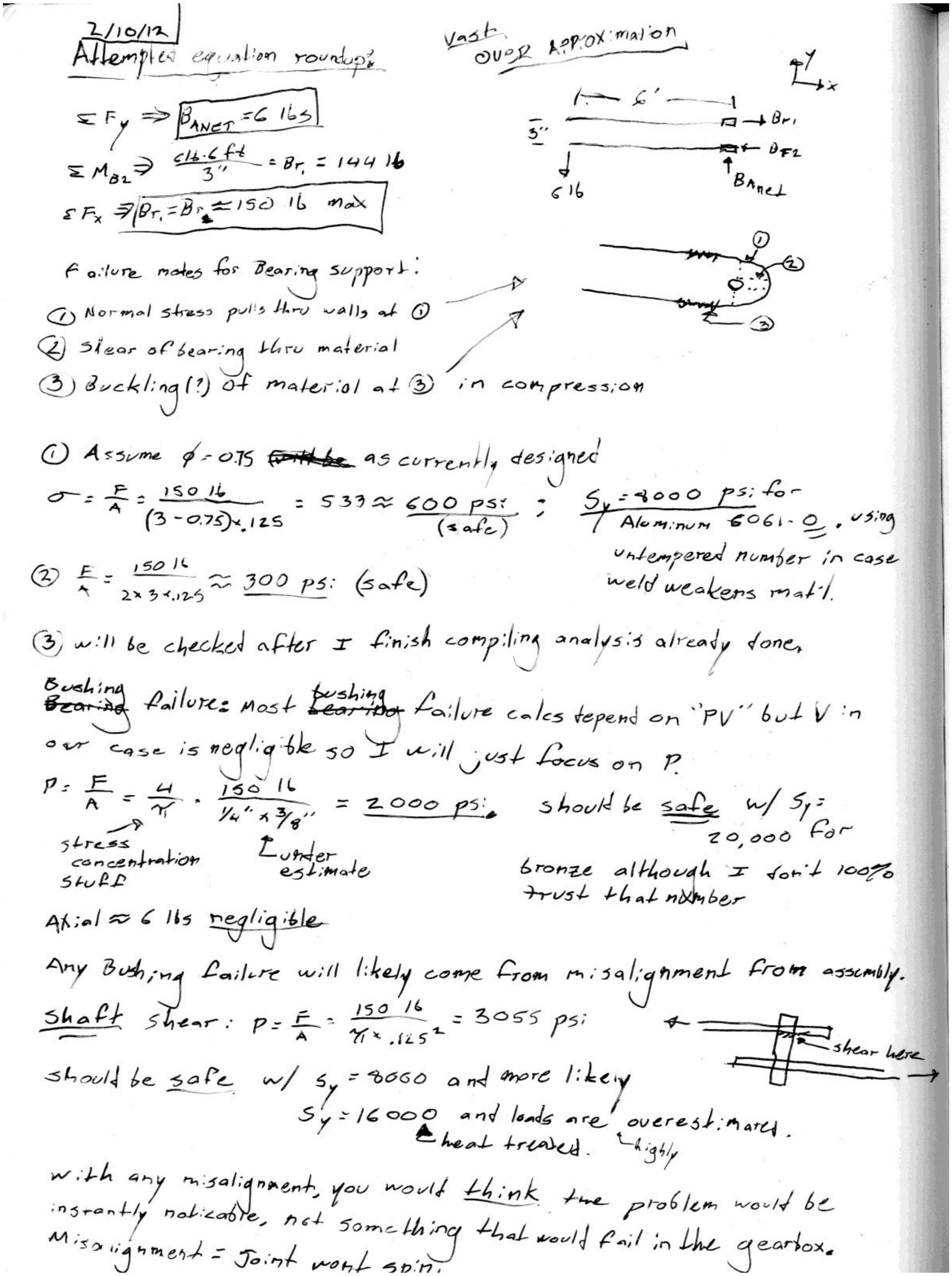
$$M_{max} = 9.54\ \text{in-lbf}$$

$$\sigma_m = \frac{Mc}{I} = \frac{(9.54\ \text{in-lbf})\left(\frac{3}{16 \cdot 2}\right)}{\frac{\pi}{64}\left(3/16\right)^4}$$

$$\sigma_m = 14,737\ \text{psi}$$

Our yield stress from the manufacturer (or just the supplier) is 35,000 psi, giving us a safety factor > 2.

Michael's Analysis



2/10/12

Attempted equation roundup

$\Sigma F_y \Rightarrow \boxed{B_{ANET} = 6\text{ lbs}}$

$\Sigma M_{B2} \Rightarrow \frac{6\text{lb} \cdot 6\text{ft}}{3''} = B_{r_1} = 144\text{ lb}$

$\Sigma F_x \Rightarrow \boxed{B_{r_1} = B_{r_2} \doteq 150\text{ lb max}}$

Failure modes for Bearing support:

① Normal stress pulls thru walls at ①

② Shear of bearing thru material

③ Buckling (?) of material at ③ in compression

① Assume $\phi = 0.75$ ~~will be~~ as currently designed

$\sigma = \frac{F}{A} = \frac{150\text{ lb}}{(3-0.75) \times .125} = 533 \approx \underline{600\text{ psi}}$ (safe) ; $\underline{S_y = 8000\text{ psi}}$ for Aluminum 6061-O, using untempered number in case weld weakens mat'l.

② $\frac{F}{A} = \frac{150\text{ lb}}{2 \times 3 \times .125} \approx \underline{300\text{ psi}}$ (safe)

③ will be checked after I finish compiling analysis already done.

Bushing ~~Bearing~~ failure: most bushing ~~bearing~~ failure calcs depend on "PV" but V in our case is negligible so I will just focus on P.

$P = \frac{F}{A} = \frac{4}{\pi} \cdot \frac{150\text{ lb}}{1/4'' \times 3/8''} = \underline{2000\text{ psi}}$ should be safe w/ $S_y = 20{,}000$ for bronze although I don't 100% trust that number

stress concentration stuff

under estimate

Axial ≈ 6 lbs negligible

Any Bushing failure will likely come from misalignment from assembly.

Shaft shear: $P = \frac{F}{A} = \frac{150\text{ lb}}{\pi \times .125^2} = 3055\text{ psi}$

should be safe w/ $S_y = 8060$ and more likely $S_y = 16000$ and loads are highly overestimated.

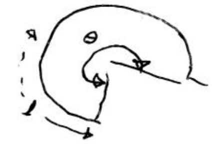
heat treated.

with any misalignment, you would think the problem would be instantly noticable, not something that would fail in the gearbox. Misalignment = Joint wont spin.

Lets see... the length of travel calcs check out, but the numbers are w/ Gordon. Length of travel for my cables:

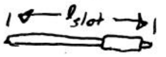
$\phi_{guite} = 1.5''$

$180° = \theta$, but use 270° or $\frac{3}{2}\pi$ rad just in case.



$l = \frac{3}{2}\pi\frac{\phi}{2} = \underline{3.53''}$ of travel for boom cables

If "sliders" are 1.5" long, thats 5" per slider slot.



Friction on ~~3k~~ boom cables: Coefficient of friction for Sintered Bronze → steel is 0.13. (lubricated) and Aluminum-Bronze vs. steel is 0.45 dry.

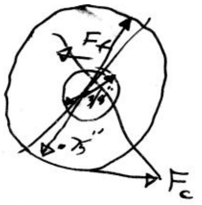
Static friction $F_f \le \mu F_n$ w/ $F_n \approx \cancel{150}\ 300$ lb

If $\mu = .45$, $F_f \approx \cancel{75}\ 150$ lb we will call this max for now.

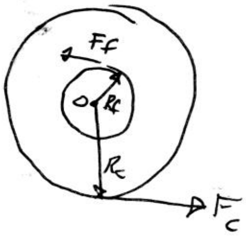
From sketch, $\Sigma M_o \Rightarrow F_f R_f = F_c R_c$:

$F_c = \frac{F_f R_f}{R_c} = \cancel{75}\ 150\text{ lb}\left(\frac{3/16}{.75}\right) = \cancel{18.75\text{ lb}}\ 37.5\text{ lb}$

we will consider the max tension on one cable to break static friction 37.5 lb for now. Note that this is a vast overestimate in ~~so many~~ several ways (coefficient of friction, force applied) but will serve as a max for now.

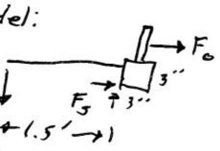


If we were to use ~~Alumino~~ Steel instead of aluminum, and lubricate bearing (can we?), we would have $F_f = 10$ lb and if we use an appropriate force on the bearing (not overestimated) that becomes ≈ 5 lb. Still not ideal for precise control though.
or even 2.5



Force on Operator

Simplified model:

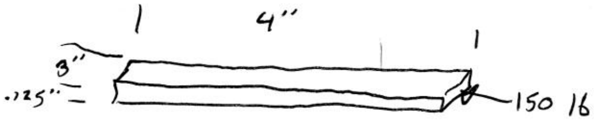


$\Sigma M_s = 0$: $1.5 \times 10 = \sim \frac{4.5}{12} \times F_o$

$F_o = \underline{\underline{40}}$ lb. Overestimate but still, our current control scheme must be rethought.

Finally, buckling calc:

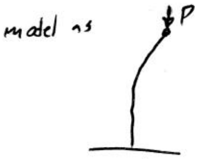
③ from p. 58



$$P_{cr} = \frac{C\pi^2 E I}{l^2}$$

$$I = \frac{1}{12} \cdot 3 \times .125^3 = .0004893 \text{ in}^4$$

model as



$$P_{cr} = \frac{1}{4} \cdot \pi^2 \cdot \frac{10\times10^6 \text{ psi} \times .0004893 \text{ in}^4}{(4 \text{ in})^2}$$

$= \underline{753 \text{ lb}} > 150$ lb so we are <u>safe</u> from buckling.

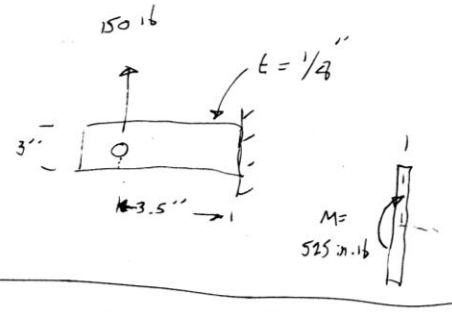
C = 1/4 as this is the worst case scenario and is... the loading is complex. This may or may not be the best model.

This is everything I'd like to calculate and <u>can</u> to some degree. (for the Boom) There may be things which I ~~can~~ haven't thought of (for the boom) or ings I dont know how to calculate. the only thing I can think of right ow is friction on the arm cable, which depends on a lot of things I don't ow, ~~p~~ such as coefficient of friction. There are also calcs I could do at are so blatantly safe/negligible that I'm not doing them, like friction n the front roiler.

$$\sigma = \frac{Mc}{I} \qquad I = \frac{1}{12} \cdot 3^3 \cdot 1/8 = .28125 \text{ in}^4$$

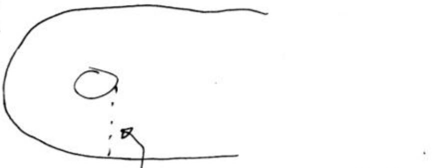
$$= \frac{525 \text{ in}\cdot\text{lb} \times 1.5 \text{ in}}{.28125 \text{ in}^4}$$

$= 2800$ psi ✓



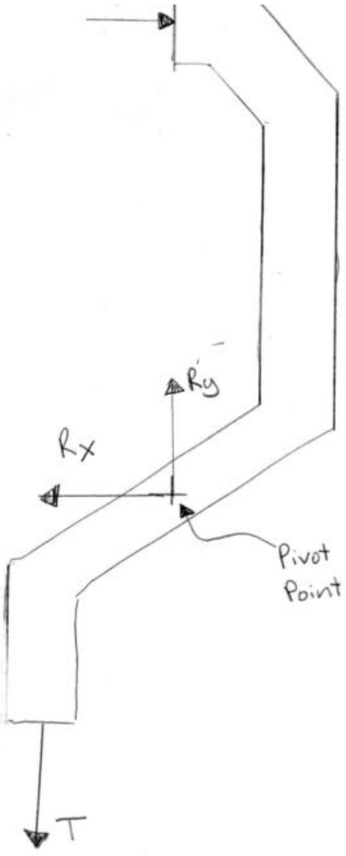
$$\tau = \frac{150 \text{ lb}}{1.5'' \times 1/8''} = 800 \text{ psi}$$ ✓

Both overestimated, both well below S_y = 8000 psi.



lets say it will shear here just to check it.. Dont think it will work Quite this way though

Alex's Analysis



$$\Sigma M_{PIVOT} = Fd_1 - Td_2 = 0$$

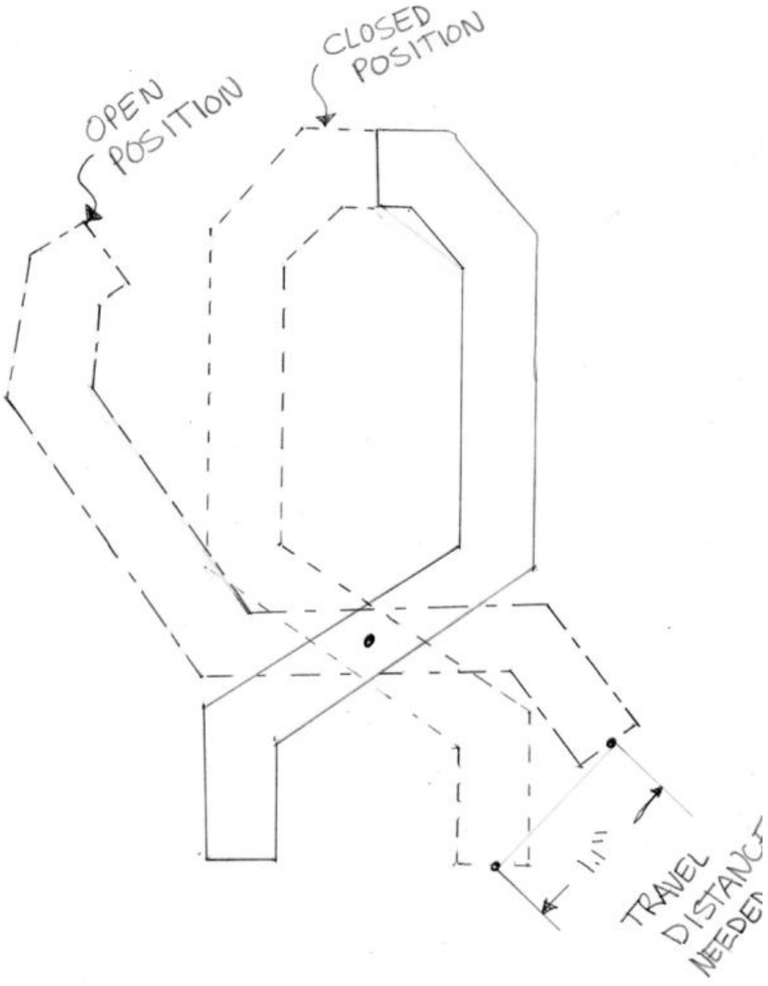
$$\boxed{F = \frac{Td_2}{d_1}}$$

$$\Sigma F_y = R_y - T = 0$$

$$\boxed{T = R_y}$$

$$\Sigma F_x = R_x - F_x = 0$$

$$\boxed{R_x = F_x}$$



Appendix VI – Manufacturer Specification Sheets

Borescope

GE
Measurement & Control Solutions

XLG3™ VideoProbe®

Inspection Technologies

Productivity Tool

Designed by GE's Inspection Technologies business and built on the Everest legacy, comes a revolutionary new video borescope – XLG3 VideoProbe system. The next imaging advancement from leader's in remote visual inspection (RVI) equipment.

A power tool for improving inspection productivity.

Features

- Extra-bright, high-resolution LCD screen and high-output illumination deliver sharp, clear images
- Dual-purpose shipping and operating case
- Lightweight remote control (optional)
- Powerful computing platform for data management and worldwide connectivity

QuickChange™ Probes

With its interchangeable QuickChange probes, the XLG3™ system quickly reconfigures probe diameter and length for maximum productivity. Probes come in 3.9 mm, 5.0 mm, 6.1 mm, 6.2 mm and 8.4 mm diameters and are built for increased durability with:

- Titanium camera head that is 8 times stronger than older designs
- Bending necks seams that are laser welded to strengthen critical joints
- 6.1 mm, 6.2 mm and 8.4 mm probes are built with a double tungsten braid insertion tube for added crush resistance

System

The base unit is a portable workstation for inspection data management, plus light source and storage reel for the probe. The unit features:

- 4.0GB internal CompactFlash® card
- 3 USB 2.0 ports
- 10/100 Ethernet port for PC with optional Internet connection
- Optional battery/UPS pack in one- or two-hour capacities
- User configurable NTSC/PAL video format selection
- Optional internal Wi-Fi card

Advanced Features, Improved Inspection

A: ***All-Way® articulation and high-output illumination*** *deliver sharp, clear images for critical decision making*

B: ***High-resolution wide VGA LCD screen*** *delivers incredibly sharp, bright images*

C: ***Shipping, storage and inspection case*** *protects XLG3™ VideoProbe® system from transport damage and doubles as an operations station*

D: ***Most system accessories*** *store in case lids or in extended case (C)*

E: ***Control buttons, multi-function joystick*** *provide full system control through the handset*

3D Phase Measurement Technology

The 3D Phase Measurement is a new approach to video borescope measurement in aerospace and rotating equipment applications. The new measurement technology enables inspectors to both view and measure a defect using a single tip optic, eliminating the extra steps required to back out, change the tip and then relocate the defect. In effect, 3D Phase Measurement provides accurate measurement "on-demand" while saving time and increasing overall inspection productivity. The XLG3 VideoProbe with 3D Phase Measurement is one of the most advanced and technically powerful visual inspection tools available.

The 3D Phase Measurement combined with the XLG3 creates a 3D surface scan of the viewing area and can measure all aspects of surface indications using a 3D scan. The probe creates a new type of measurement called Profile View, a cross section view of the surface, allowing inspectors to better visualize the shape and characteristics of an indication and make a well informed decision on the serviceability of the asset.

Owners of XLG3 systems can enhance their initial equipment investment as 3D Phase Measurement probes and optical tips can be used with existing equipment. Current owners can add Phase Measurement probes and tips to their existing equipment, or choose to purchase additional XLG3 systems with Phase Measurement components.

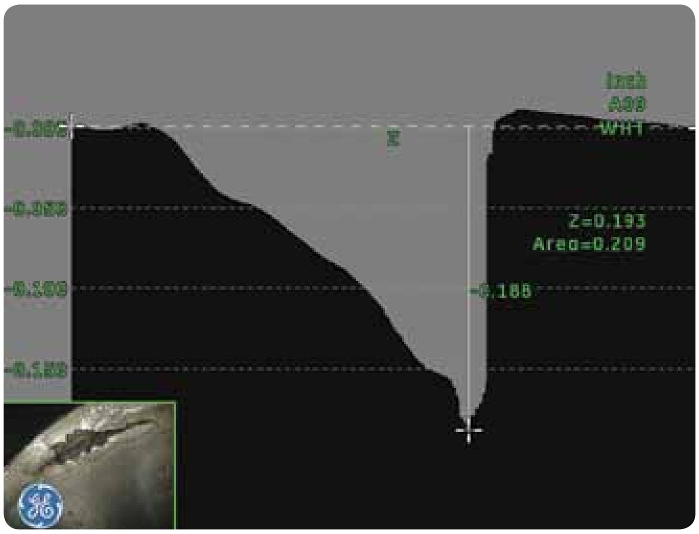
See a Demo

Ed Hubben, Senior Product Manager for the Inspection Technologies product line, demos 3D Phase Measurement technology.

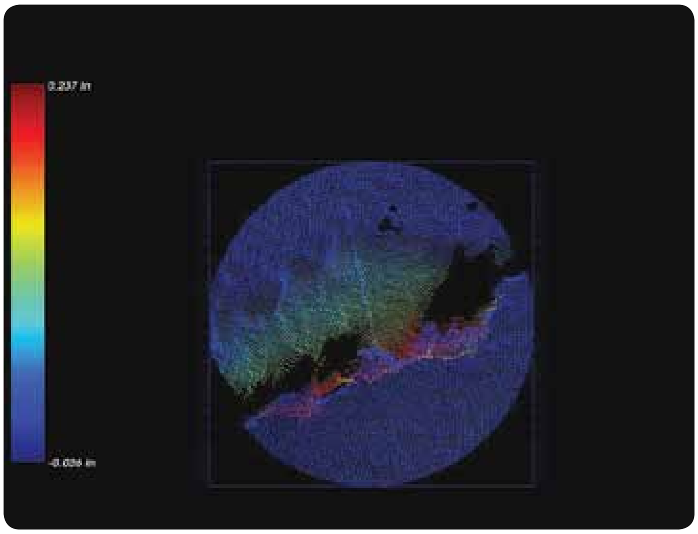
To watch, snap a photo of the icon or go to
http://www.youtube.com/watch?v=5eShovbZIys

Get the free mobile app at
http://gettag.mobi

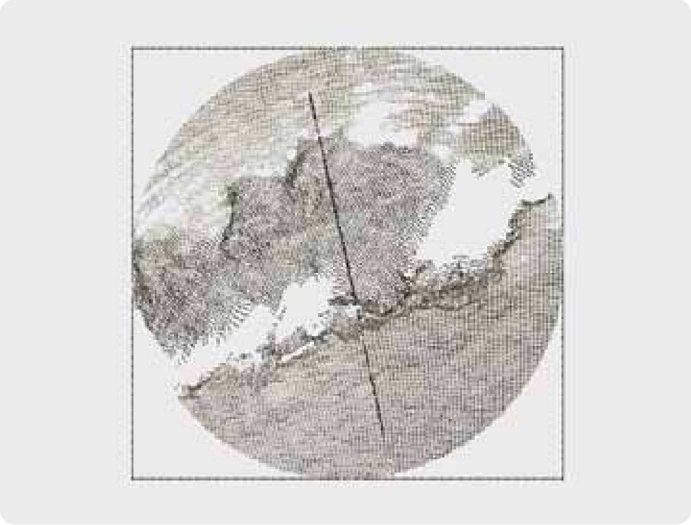
Depth Profile



Profile View

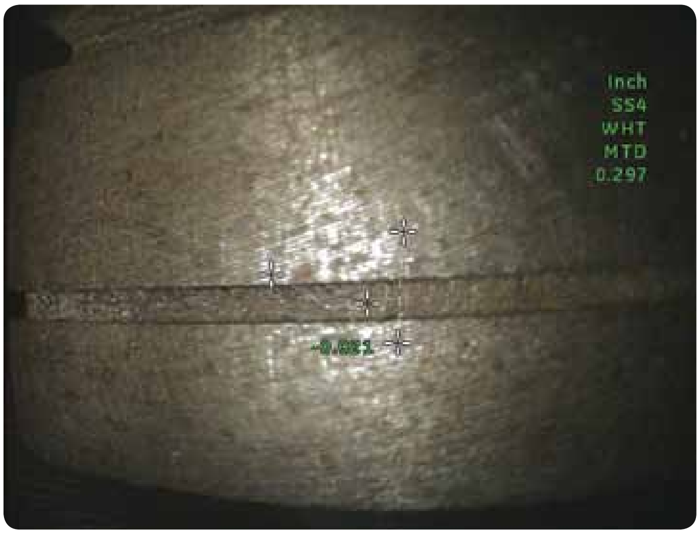


Point Cloud with Color Depth Map of Tear in Turbine Blade



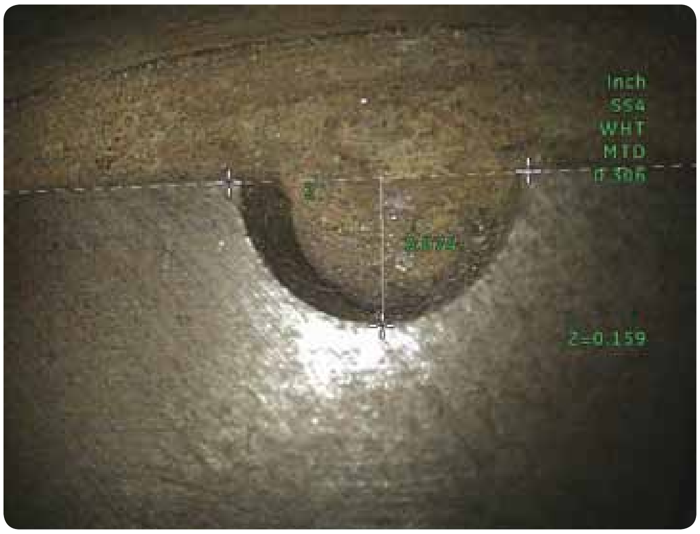
Point Cloud of Tear in Turbine Blade

Area Measurement

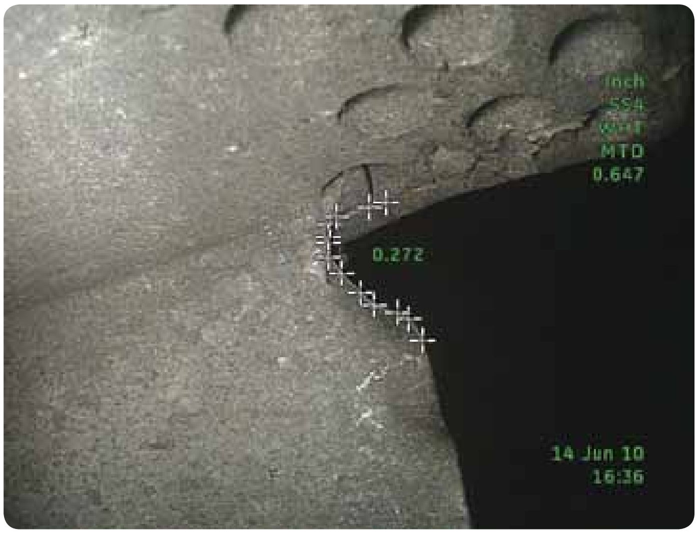


Depth Measurement

Length Measurement



Point-to-line Measurement



Multi-segment length Measurement

Turbine Blade Tip Clearance

Technical Specifications

System

Case Dimensions:	
Standard:	54.6 x 49.5 x 32.0 cm (21.5 x 19.5 x 12.6 in)
Tall:	54.6 x 60.9 x 32.0 cm (21.5 x 24 x 12.6 in)
Weight:	
In Case:	21.8 kg (48 lb)
Without Case:	10.9 kg (24 lb)

QuickChange™ Probes

6.1 mm (0.242 in), 5.0 mm (0.197 in) and 8.4 mm (0.331 in) Diameter Probes

Image Sensor:	1/6" Color SUPER HAD CCD®
Pixel Count:	440,000 pixels
Temperature Sensor:	Integrated Temperature Warning System
Camera Housing:	Titanium
Articulation:	360° All-Way®
Tip Optics:	Double threaded attachment

3.9 mm (0.154 in) and 6.2 mm (0.244 in) Diameter Probes

Image Sensor:	1/10" Color, SUPER HAD CCD
Pixel Count:	290,000 pixels
Camera Housing:	Titanium
Articulation:	360° All-Way
Tip Optics:	Double threaded attachment

Handset

Dimensions:	39 x 18 x 13 cm (15.4 x 7.1 x 5.1 in)
Weight:	1.81 kg (3.98 lb)
Construction:	Polycarbonate housing with integrated elastomer bumpers
LCD:	16.3 cm (6.4 in) diagonal, 16 x 9 aspect ratio, 800 x 480 pixels, wide VGA
LCD Brightness:	380 nits (cd/m2)
Power Tube:	2.4 m (8 ft) long
User Controls:	Joystick and complete button function set
Microphone:	Built-in microphone for audio annotation located at the top center of the handset

Base Unit

Dimensions:	44 x 22 x 35 cm (17.3 x 8.7 x 13.8 in)
Weight:	7.21 kg (15.90 lb)
Construction:	Aluminum chassis with polyurethane bumpers
System CPU:	Intel Pentium® M
Video Processors:	Multiple digital signal processors
Brightness Control:	Automatic and variable, adjustable auto gain and exposure
System Memory:	Internal CompactFlash® card, 2.7GB (standard)
Lamp Type:	75W High Intensity Discharge (HID)
Lamp Output:	4300 Lumens
Lamp Life:	1000 hour median
Keyboard Input:	USB keyboard with built-in trackball
Video Outputs:	Switchable NTSC/PAL S-Video, Standard 15-pin PC video connector
Video Input:	Auto detecting NTSC/PAL S-Video
USB:	Three external USB 2.0 ports
Ethernet:	Integrated 10/100 Ethernet port
CompactFlash:	One CompactFlash card (Type II) slot
AC Input:	AC Nominal input: 100 to 240 V, 50 to 60 Hz; 115 V, 400 Hz; 275 W max
AC Output:	100 W max; IEC320-2-2 Type F connector
AC Fuse:	6.3A, 250V, fast acting
DC Input:	11 to 15 VDC; nominal 12 VDC; 150 W max
DC Fuse:	20A, 600 VDC, fast acting
Audio Output Connectors:	Built-in front panel speaker, 3.5 mm stereo line level out, 2V RMS max, 3.5 mm stereo headphone
Audio Input Connector:	3.5 mm microphone

Operating Environment

System Operating Temp:	-4° to 115°F (-20° to 46°C) LCD requires warm-up period below 32°F (0°C)
Tip Operating Temp:	-13° to 176°F (-25° to 80°C) Reduced articulation below 32°F (0°C)
Storage Temperature:	-13° to 140°F (-25° to 60°C)
Relative Humidity:	95% max, non condensing
Waterproof:	Insertion tubes are watertight to 1 bar (14.5 psig, 10.2 m [33.5 ft] of H_2O)
Hazardous Environments:	Not rated for use in hazardous environments

Software

Operating System:	Multitasking with desktop software options
User Interface:	Drop-down menu driven operation, joystick, and keypad
File Manager:	File and folder creation, naming, copying and deleting
Measurements:	3D Phase, StereoProbe®, ShadowProbe® & Comparison
MDI Software (optional):	Provides user defined guided inspection Creates DICONDE compatible inspection files Creates MS Word™ compatible inspection reports
Audio Data:	PC compatible, 15 second files (WAV or MP3 format). PCM audio with MPEG2 video recordings
Image Controls:	Adjustable brightness, 1/10,000 sec to 12 sec exposure. Left/Right invert for side-view tip correction. Freeze frame, live/still Inverse+ enhancement, side-by-side split screen
Digital Zoom:	1X to 3X – Continuous and 5-level stepped
User Available Memory:	2.7GB internal, user-supplied external
Annotation:	Text and arrow overlays and custom logos
Articulation Controls:	360° All-Way® steering, Steer-and-Stay™, Home
Lamp Control:	On/Off, menu-controlled
Software Updates:	Field upgradeable via removable media
Temperature Warning:	Integrated camera and base unit temperature warning systems
DVD writing:	DVD+R, DVD-R, still images, audio clips, MPEG2 video and PCM audio real-time recording

Languages

Chinese, Czech, English, French, Japanese, Spanish, Russian, German, Italian, Portuguese, Swedish, or factory supplied custom language.

Tip Articulation

Length	Straight Tube
2.0 m, 3.0 m, and 4.5 m	Up/Down – 140° min, Left/Right – 140° min
6.0 m	Up/Down – 130° min, Left/Right – 130° min
8.0 m	Up/Down – 120° min, Left/Right – 120° min
9.6 m	Up/Down – 110° min, Left/Right – 110° min

Note: *Typical articulation exceeds minimum specifications*

Measurement (Supported Features)

Feature	3D Phase	ShadowProbe®	StereoProbe®	Comparison
Length/Distance	■	■	■	■
Depth	■	■	■	
Point-to-Line	■	■	■	■
Non-perpendicular Length	■	■	■	
Area	■	■	■	■
Multi-Segment Length	■	■	■	■
Circle Gauge	■	■		■
Blade Tip Clearance	■			
Profile View	■			
3x Zoom Windows	■	■	■	■
5 Measurements/ Image	■	■	■	■

Technical Specifications

Tip Optics

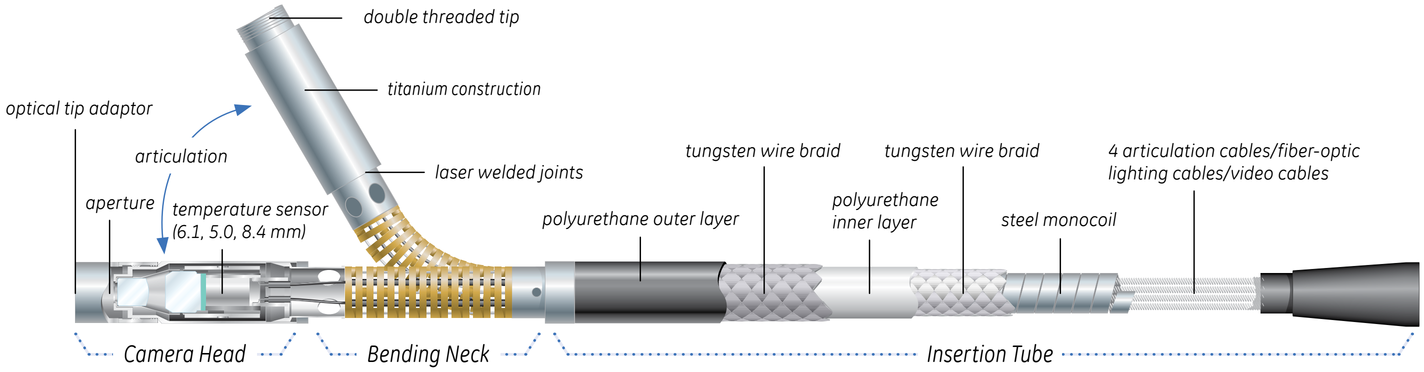
Tip View (DOV)	Tip Color	Field of View (FOV)*	Depth of Field (DOF)	3.9 mm Optical Tip Part #	5.0 mm Optical Tip Part #	6.1 mm Optical Tip Part #	6.2 mm Optical Tip Part #	8.4 mm Optical Tip Part #
Standard Tips								
FORWARD	NONE ☒	80°	6–80 mm (0.24–3.15 in)	PXT480FG				
FORWARD	ORANGE ●	90°	3-40 mm (0.12-1.57 in)	PXT490FN				
FORWARD	NONE ☒	50°	50 mm (1.97 in)–infinity		PXT550FF	XLG3T6150FF		
FORWARD	WHITE ○	50°	12–200 mm (0.47–7.87 in)		PXT550FG	XLG3T6150FG		
FORWARD	ORANGE ●	80°	3-20 mm (0.12-0.79 in)		PXT580FN	XLG3T6180FN		
FORWARD	YELLOW ●	90°	20 mm (0.79 in)-infinity			XLG3T6190FF		
FORWARD	BLACK ●	120°	5–120 mm (0.20–4.72 in)			XLG3T61120FG		
FORWARD	BLACK ●	100°	5–120 mm (0.20–4.72 in)		PXT5100FG			
FORWARD OBLIQUE	PURPLE ●	50°	12–80 mm (0.47–3.15 in)			XLG3T6150FB		
FORWARD	NONE ☒	40°	100 mm (3.94 in.)–infinity				PXT6240FF	
FORWARD	YELLOW ●	120°	25 mm (0.98 in.)–infinity				PXT62120FF	
FORWARD	BLACK ●	120°	4–190 mm (0.16–7.48 in.)				PXT62120FN	
FORWARD	BLUE ●	120°	5–200 mm (0.20–7.87 in)				XLG3T84120FN	
FORWARD	NONE ☒	40°	250 mm (9.84 in)–infinity					XLG3T8440FF**
FORWARD	WHITE ○	40°	80 - 500 mm (3.15 - 19.68 in)					XLG3T8440FG
FORWARD	YELLOW ●	80°	25–500 mm (0.98–19.68 in)					XLG3T8480FG
SIDE	BROWN ●	80°	4–80 mm (0.16–3.15 in)	PXT480SG				
SIDE	RED ●	90°	2-16 mm (0.08-0.63 in)	PXT490SN				
SIDE	BROWN ●	50°	45 mm (1.77 in.)–infinity			XLG3T6150SF		
SIDE	GREEN ●	50°	9–160 mm (0.35–6.30 in)		PXT550SG	XLG3T6150SG		
SIDE	BLUE ●	120°	4–100 mm (0.16–3.94 in)			XLG3T61120SG		
SIDE	BLUE ●	100°	4–100 mm (0.16–3.94 in)		PXT5100SG			
SIDE	RED ●	80°	1–20 mm (0.04–0.79 in)		PXT580SN	XLG3T6180SN		
SIDE	GREEN ●	80°	18 mm (0.71 in) – infinity				PXT6280SF	
SIDE	BLUE ●	80°	5 mm (0.20 in) – infinity				PXT62120SN	
SIDE	BROWN ●	40°	250 mm (9.84 in)–infinity					XLG3T8440SF**
SIDE	GREEN ●	80°	25–500 mm (0.98–19.68 in)					XLG3T8480SG
SIDE	BLUE ●	120°	4–200 mm (0.16–7.87 in)					XLG3T84120SN
ShadowProbe® Measurement Tips								
FORWARD	WHITE ○	50°	12–30 mm (0.47–1.18 in)			XLG3TM6150FG		
SIDE	BLUE ●	50°	7–24 mm (0.28–0.94 in)			XLG3TM6150SG		
StereoProbe® Measurement Tips								
FORWARD	BLACK ●	50°/50°	5–45 mm (0.20–1.77 in)	PXTM45050FG				
FORWARD	BLACK ●	60°/60°	4–80 mm (0.16–3.15 in)		PXTM56060FG	XLG3TM616060FG	PXTM626060FG	
FORWARD	BLACK ●	60°/60°	4–50 mm (0.16–1.97 in)					XLG3TM846060FG
SIDE	BLUE ●	50°/50°	4–45 mm (0.16–1.77 in)	PXTM45050SG				
SIDE	BLUE ●	45°/45°	2–50 mm (0.08–1.97 in.)		PXTM54545SG			
SIDE	BLUE ●	50°/50°	2–50 mm (0.08–1.97 in)			XLG3TM615050SG		
SIDE	BLUE ●	60°/60°	4–80 mm (0.16–3.15 in)				PXTM626060SG	
SIDE	BLUE ●	60°/60°	4–50 mm (0.16–1.97 in)					XLG3TM846060SG
3D Phase Measurement Tips								
FORWARD	BLACK ●	105°	8–250 mm (0.31–9.84 in)			XL4TM61105FG		
SIDE	BLUE ●	105°	7–250 mm (0.27–9.84 in)			XL4TM61105SG		

*FOV is specified diagonally.

**Indicates tips with maximum brightness.

Technical Specifications

Insertion Tube



Note: *Illustration is not drawn to scale.*

CAMERA DIAMETER	INSERTION TUBE WORKING LENGTH					
3.9 mm (0.154 in)	2.0 m (6.6 ft)	3.0 m (9.8 ft)				
5.0 mm (0.197 in)	2.0 m (6.6 ft)	3.0 m (9.8 ft)	4.5 m (14.8 ft)			
6.1 mm (0.242 in)	2.0 m (6.6 ft)	3.0 m (9.8 ft)	4.5 m (14.8 ft)	6.0 m (19.7 ft)	8.0 m (26.2 ft)	
6.2 mm (0.244 in)		3.2 m (10.5 ft)				
8.4 mm (0.331 in.)	2.0 m (6.6 ft)	3.0 m (9.8 ft)	4.5 m (14.8 ft)	6.0 m (19.7 ft)	8.0 m (26.2 ft)	9.6 m (31.5 ft)

ISO 9001
REGISTERED COMPANY

www.ge-mcs.com

Bushings

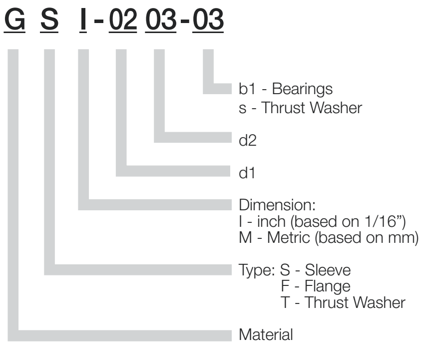
iglide® Plain Bearings
G300 - Technical Data

Product Range

- Standard Styles:
  Sleeve, Flange and Thrust Washer
- Custom shapes and sizes available
- Inner diameters:
  Inch sizes from 1/8 - 3 in.
  Metric sizes from 1.5 - 150 mm

Part Number Structure

Part Number Structure



Permissible Surface Speeds

	Continuous fpm	Short Term fpm
Rotating	196	393
Oscillating	137	275
Linear	787	1043

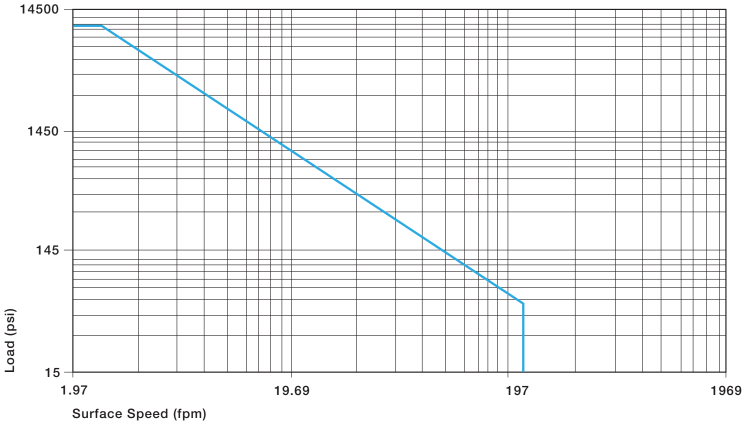
Usage Guidelines

- When you need an economical all-around performance bearing
- For above average loads
- For low to average running speeds
- When the bearing needs to run on different shaft materials
- For oscillating and rotating movements

- When mechanical reaming of the wall surface is necessary
  ➤ **iglide® M250**
- When the highest wear resistance is necessary
  ➤ **iglide® L280**
- If temperatures are constantly greater than +266°F
  ➤ **iglide® T500, F, Z**

Material Data

General Properties	Unit	iglide® G300	Testing Method
Density	g/cm^3	1.45	
Color		dark gray	
Max. moisture absorption at 73°F / 50% r.h.	% weight	0.7	DIN 53495
Max. moisture absorption	% weight	4.0	
Coefficient of friction, dynamic against steel	μ	0.08 - 0.15	
p x v-value, max. (dry)	psi x fpm	12,000	
Mechanical Properties			
Modulus of elasticity	psi	1,131,000	DIN 53457
Tensile strength at 68°F	psi	30,450	DIN 53452
Compressive strength	psi	11,310	
Max. static surface pressure (68°F)	psi	11,600	
Shore D-hardness		81	DIN 53505
Physical and Thermal Properties			
Max. long-term application temperature	°F	266	
Max. short-term application temperature	°F	428	
Min. application temperature	°F	-40	
Thermal conductivity	(W/m x K)	0.24	ASTM C 177
Coefficient of thermal expansion (at 73°F)	(K^{-1} x 10^{-5})	9	DIN 53752
Electrical Properties			
Specific volume resistance	Ωcm	> 10^{13}	DIN IEC 93
Surface resistance	Ω	> 10^{11}	DIN 53482



Graph 6.1: Permissible p x v - values for iglide® G300 running dry against a steel shaft, at 68°F

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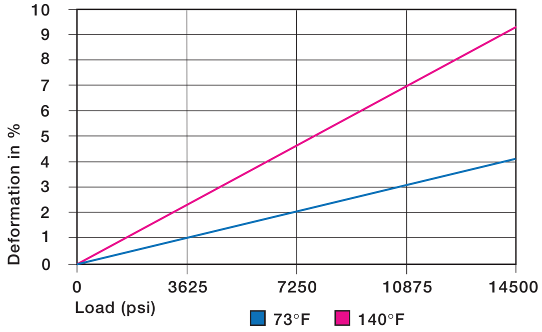
Compressive Strength

Picture 6.2 shows the elastic deformation of iglide® G300 during radial loading. At the maximum permissible load of 11,600 psi, the deformation is less than 5%. The plastic deformation is minimal up to a pressure of approximately 14,500 psi. However, it is also a result of the cycle time.

➤ Compressive Strength, Page 1.3



Graph 6.2: Deformation under load and temperature

Permissible Surface Speeds

iglide® G300 has been developed for low to medium surface speeds. The maximum values shown in Table 6.2 can only be achieved at low pressure loads. At the given speeds, friction can cause a temperature increase to maximum permissible levels. In practice, though, this temperature level is rarely reached, due to varying application conditions.

➤ Surface speed, Page 1.5
➤ p x v Value, Page 1.6

	Continuous fpm	Short Term fpm
Rotating	196	393
Oscillating	137	275
Linear	787	1043

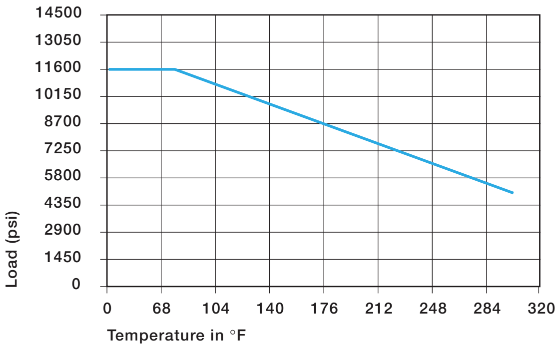
Table 6.2: Maximum running speed

Temperatures

Application temperatures affect the properties of plain bearings greatly. The short-term maximum temperature is 428°F, this allows the use of iglide® G300 plain bearings in heat treating applications in which the bearings are not subjected to additional loading.

With increasing temperatures, the compressive strength of iglide® G300 plain bearings decreases. The graph 6.3 shows this inverse relationship. However, at the long-term maximum temperature of 266°F, the permissible surface pressure is still above 5,800 psi. The ambient temperatures that are prevalent in applications also has an effect on the bearing wear. With increasing temperatures, the wear increases and this effect is notable starting at the temperature of 248°F.

➤ Application Temperatures, Page 1.7



Graph 6.3: Recommended maximum permissible static surface pressure of iglide® G300 as a result of temperature

iglide® G300	Application Temperature
Minimum	- 40 °F
Max. long-term	+ 266 °F
Max. short-term	+ 428 °F

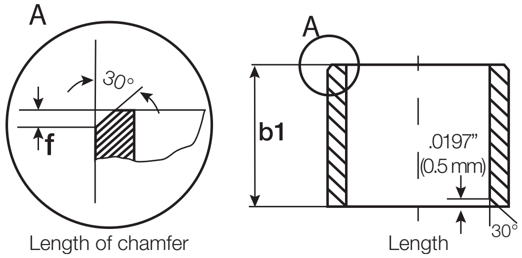
Table 6.3: Temperature limits for iglide® G300

iglide® Plain Bearings
G300 - Technical Data

Installation Tolerances

iglide® G300 plain bearings are oversized before being pressfit. After proper installation into a recommended housing bore, the inner diameter adjusts to meet our specified tolerances. Please adhere to the catalog specifications for housing bore and recommended shaft sizes. This will help to ensure optimal performance of iglide® plain bearings.

➤ See Tolerance Table, Page 1.14
➤ Testing Methods, Page 1.15



Length of chamfer

Length

For Inch Size Bearings

Length Tolerance (b1) Length (inches)	Tolerance (h13) (inches)	Length of Chamfer (f) Based on d1
0.1181 to 0.2362	-0.0000 /-0.0071	f = .012 → d_1 .040" - .236"
0.2362 to 0.3937	-0.0000 /-0.0087	f = .019 → d_1 > .236" - .472"
0.3937 to 0.7086	-0.0000 /-0.0106	f = .031 → d_1 > .472" - 1.18"
0.7086 to 1.1811	-0.0000 /-0.0130	f = .047 → d_1 > 1.18"
1.1811 to 1.9685	-0.0000 /-0.0154	
1.9685 to 3.1496	-0.0000 /-0.0181	

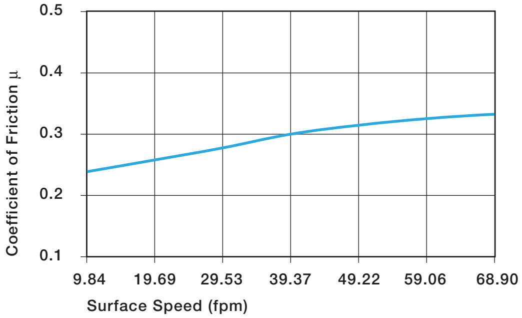
For Metric Size Bearings

Length Tolerance (b1) Length (mm)	Tolerance (h13) (µm)	Length of Chamfer (f) Based on d1
1 to 3	-0 /-140	f = 0.3 → d_1 1 - 6 mm
> 3 to 6	-0 /-180	f = 0.5 → d_1 > 6 - 12 mm
> 6 to 10	-0 /-220	f = 0.8 → d_1 > 12 - 30 mm
>10 to 18	-0 /-270	f = 1.2 → d_1 > 30 mm
>18 to 30	-0 /-330	
>30 to 50	-0 /-390	
>50 to 80	-0 /-460	

Friction and Wear

Similar to wear resistance, the coefficient of friction µ also changes with the load. The coefficient of friction decreases with increasing loads, whereas an increase in surface speed causes an increase of the coefficient of friction. This relationship explains the excellent results of iglide® G300 plain bearings for high loads and low speeds (See Graph 6.4 and 6.5).
The friction and wear are also dependent, to a large degree, on the shaft partner. Shafts that are too smooth, increase both the coefficient of friction and the wear of the bearing. For iglide® G300, a ground surface with an average roughness Ra= 32 rms is recommended (See Graph 6.6).

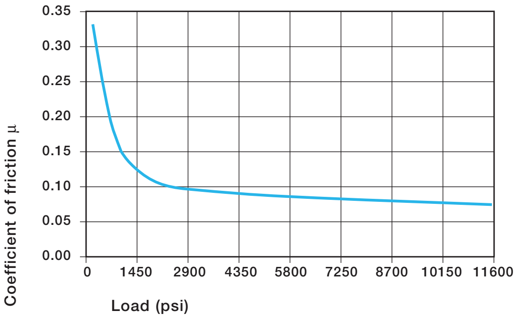
➤ Coefficients of friction and surfaces, Page 1.8
➤ Wear Resistance, Page 1.9



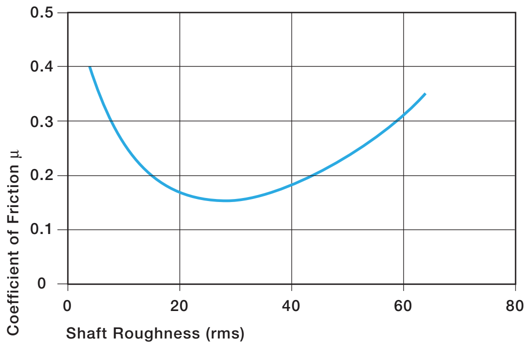
Graph 6.4: Coefficient of friction of iglide® G300 as a result of the running speed; p = 108 psi

iglide® G300	Coefficient of Friction
Dry	0.08 - 0.15
Grease	0.09
Oil	0.04
Water	0.04

Table 6.4: Coefficient of friction for iglide® G300 against steel (Shaft finish = 40 rms, 50 HRC)



Graph 6.5: Coefficient of friction of iglide® G300 as a result of the load



Graph 6.6: Coefficient of friction as result of the shaft surface (Shaft - Cold Rolled Steel)

iglide® Plain Bearings
G300 - Technical Data

Shaft Materials

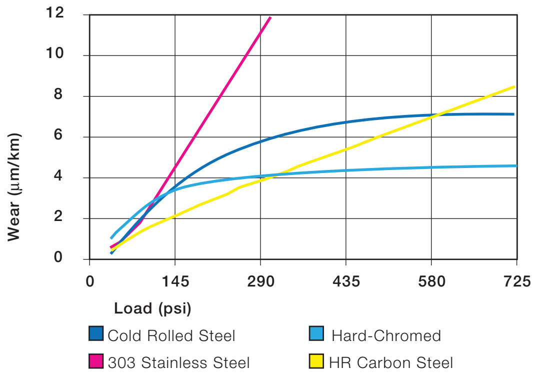
Graph 6.7 and 6.8 show results of testing different shaft materials with plain bearings made of iglide® G300.
In Graph 6.7 it is observed that iglide® G300 can be combined with various shaft materials. The simple shaft materials of free-cutting steel and HR Carbon Steel have proven best at low loads. This helps to design cost-effective systems, since both iglide® G300 and the sliding partner are economically priced.

It is important to note that with increasing loads, the recommended hardness of the shaft increases. The "soft" shafts tend to wear more easily and thus increase the wear of the overall system. If the loads exceed 290 psi, it is important to recognize that the wear rate (the slope of the curves) clearly decreases with the hard shaft materials.

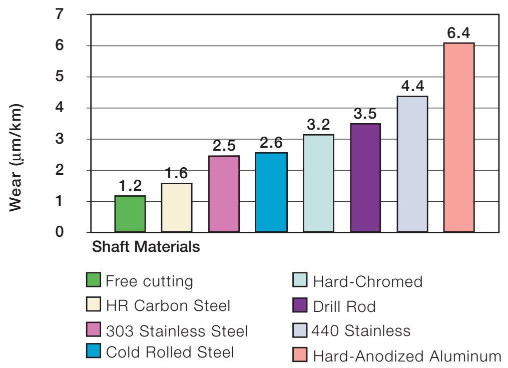
The comparison of rotational movements to oscillating movements shows that iglide® G300 can provide advantages in oscillating movements. The wear of the bearing is smaller for equivalent conditions. The higher the load, the larger the difference. This means that iglide® G300 can be used for oscillating movements that are well above the given maximum load of 11,600 psi. For these loads, the use of hardened shafts is recommended.

In addition to the shaft materials presented here, many others have been tested. If the shaft material you plan on using is not contained in the test results presented here, please contact us.

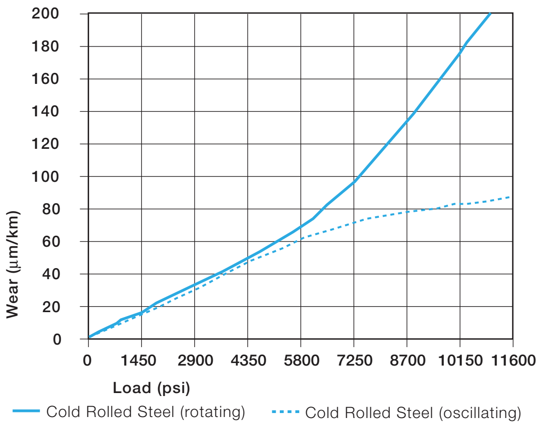
➤ Shaft Materials, Page 1.11



Graph 6.8: Wear with different shaft materials in rotational operation, as a result of the load



Graph 6.7: Wear of iglide® G300, rotating with different shaft materials, load p = 108 psi, v = 98 fpm



Graph 6.9: Wear for pivoting and rotating applications with shaft material Cold Rolled Steel 1018, as a result of the load

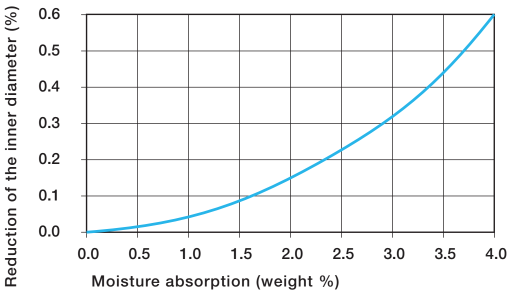
Chemical & Moisture Resistance

iglide® G300 plain bearings have strong resistance to chemicals. They are also resistant to most lubricants.
iglide® G300 plain bearings are not affected by most weak organic and inorganic acids.
The moisture absorption of iglide® G300 plain bearings is approximately 1% in the standard atmosphere. The saturation limit submerged in water is 4%. This must be taken into account for these types of applications.
➤ Chemicals Table, Page 1.16

Medium	Resistance
Alcohol	+ to 0
Hydrocarbon	+
Greases, oils without additives	+
Fuels	+
Weak acids	0 to –
Strong acids	–
Weak alkaline	+
Strong alkaline	0

+ resistant, 0 conditionally resistant, – not resistant

Table 6.5: Chemical resistance of iglide® G300
All data given concerns the chemical resistance at room temperature (68°F). For a complete list, see page 1.16



Graph 6.10: Effect of moisture absorption on iglide® G300 plain bearings

iglide® Plain Bearings G300 - Technical Data

Radiation Resistance

Plain bearings made from iglide® G300 are resistant to radiation up to an intensity of 3 x 10^2 Gy.

UV Resistance

iglide® G300 plain bearings are permanently resistant to UV-radiation.

Vacuum

iglide® G300 plain bearings outgas in a vacuum. Use in a vacuum environment is only possible for dehumidified bearings.

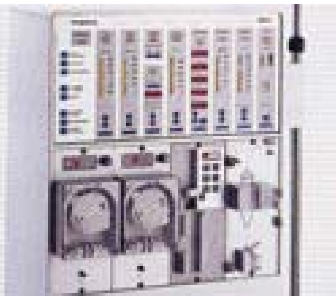
Electrical Properties

iglide® G300 plain bearings are electrically insulating.

iglide® G300	
Specific volume resistance	> 10^{13} Ωcm
Surface resistance	> 10^{11} Ω

Table 6.6: Electrical properties of iglide® G300

Application Examples



Reliable under high load, wear-resistant during continuous rotational use

Tested at a load of 4046 lbs for 10,000 cycles, resulted in no measurable wear

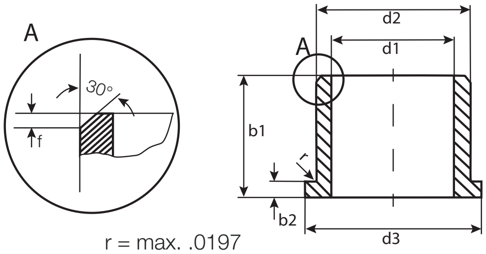
The pneumatic rotational drive unit in steam lines at temperatures up to 275°F

Vibrations, dirt, and temperatures up to 266°F characterize the area surrounding the engine

Conveyor chains: Through edge loading, short-term surface pressures of over 7,250 psi can occur

iglide® G300 plain bearings have proven themselves in control levers and pedals of farm tractors and construction vehicles

iglide® Plain Bearings
G300 - Flange Bearing, Inch



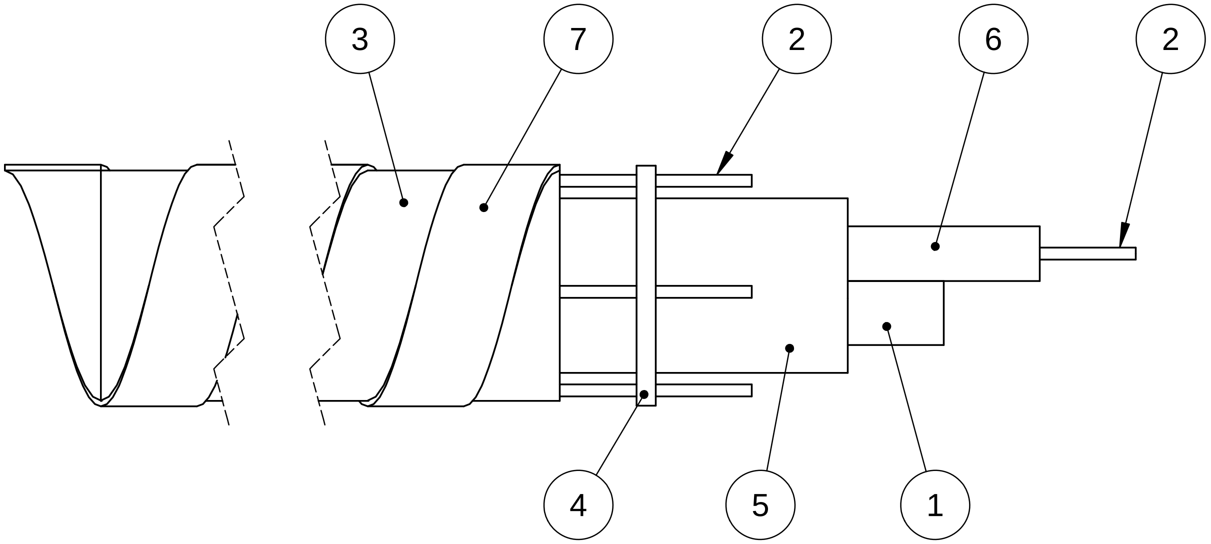
r = max. .0197

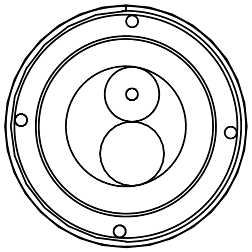
For tolerance values please refer to page 6.4

Part Number	d1	d2	b1	d3	b2	I.D. After Pressfit		Housing Bore		Shaft Size	
					-.0055	Max.	Min.	Max.	Min.	Max.	Min.
GFI-0203-02	1/8	3/16	1/8	.312	.032	.1269	.1251	.1878	.1873	.1243	.1236
GFI-0203-03	1/8	3/16	3/16	.312	.032	.1269	.1251	.1878	.1873	.1243	.1236
GFI-0203-04	1/8	3/16	1/4	.312	.032	.1269	.1251	.1878	.1873	.1243	.1236
GFI-0203-06	1/8	3/16	3/8	.312	.032	.1269	.1251	.1878	.1873	.1243	.1236
GFI-0304-04	3/16	1/4	1/4	.375	.032	.1892	.1873	.2503	.2497	.1865	.1858
GFI-0304-06	3/16	1/4	3/8	.375	.032	.1892	.1873	.2503	.2497	.1865	.1858
GFI-0304-08	3/16	1/4	1/2	.375	.032	.1892	.1873	.2503	.2497	.1865	.1858
GFI-0405-2.4	1/4	5/16	5/32	.500	.032	.2521	.2498	.3128	.3122	.2490	.2481
GFI-0405-04	1/4	5/16	1/4	.500	.032	.2521	.2498	.3128	.3122	.2490	.2481
GFI-0405-05	1/4	5/16	5/16	.500	.032	.2521	.2498	.3128	.3122	.2490	.2481
GFI-0405-06	1/4	5/16	3/8	.500	.032	.2521	.2498	.3128	.3122	.2490	.2481
GFI-0405-08	1/4	5/16	1/2	.500	.032	.2521	.2498	.3128	.3122	.2490	.2481
GFI-0405-12	1/4	5/16	3/4	.500	.032	.2521	.2498	.3128	.3122	.2490	.2481
GFI-0506-03	5/16	3/8	3/16	.562	.032	.3148	.3125	.3753	.3747	.3115	.3106
GFI-0506-04	5/16	3/8	1/4	.562	.032	.3148	.3125	.3753	.3747	.3115	.3106
GFI-0506-06	5/16	3/8	3/8	.562	.032	.3148	.3125	.3753	.3747	.3115	.3106
GFI-0506-08	5/16	3/8	1/2	.562	.032	.3148	.3125	.3753	.3747	.3115	.3106
GFI-0506-12	5/16	3/8	3/4	.562	.032	.3148	.3125	.3753	.3747	.3115	.3106
GFI-0607-04	3/8	15/32	1/4	.687	.046	.3773	.3750	.4691	.4684	.3740	.3731
GFI-0607-05	3/8	15/32	5/16	.687	.046	.3773	.3750	.4691	.4684	.3740	.3731
GFI-0607-06	3/8	15/32	3/8	.687	.046	.3773	.3750	.4691	.4684	.3740	.3731
GFI-0607-08	3/8	15/32	1/2	.687	.046	.3773	.3750	.4691	.4684	.3740	.3731
GFI-0607-12	3/8	15/32	3/4	.687	.046	.3773	.3750	.4691	.4684	.3740	.3731
GFI-0607-14	3/8	15/32	7/8	.687	.046	.3773	.3750	.4691	.4684	.3740	.3731
GFI-0708-04	7/16	17/32	1/4	.750	.046	.4406	.4379	.5316	.5309	.4365	.4355
GFI-0708-08	7/16	17/32	1/2	.750	.046	.4406	.4379	.5316	.5309	.4365	.4355
GFI-0809-02	1/2	19/32	1/8	.875	.046	.5030	.5003	.5941	.5934	.4990	.4980
GFI-0809-04	1/2	19/32	1/4	.875	.046	.5030	.5003	.5941	.5934	.4990	.4980
GFI-0809-05	1/2	19/32	5/16	.875	.046	.5030	.5003	.5941	.5934	.4990	.4980
GFI-0809-06	1/2	19/32	3/8	.875	.046	.5030	.5003	.5941	.5934	.4990	.4980
GFI-0809-08	1/2	19/32	1/2	.875	.046	.5030	.5003	.5941	.5934	.4990	.4980
GFI-0809-12	1/2	19/32	3/4	.875	.046	.5030	.5003	.5941	.5934	.4990	.4980
GFI-0809-16	1/2	19/32	1	.875	.046	.5030	.5003	.5941	.5934	.4990	.4980
GFI-1011-06	5/8	23/32	3/8	.937	.046	.6280	.6253	.7192	.7184	.6240	.6230
GFI-1011-08	5/8	23/32	1/2	.937	.046	.6280	.6253	.7192	.7184	.6240	.6230
GFI-1011-12	5/8	23/32	3/4	.937	.046	.6280	.6253	.7192	.7184	.6240	.6230
GFI-1011-14	5/8	23/32	7/8	.937	.046	.6280	.6253	.7192	.7184	.6240	.6230
GFI-1011-16	5/8	23/32	1	.937	.046	.6280	.6253	.7192	.7184	.6240	.6230
GFI-1011-24	5/8	23/32	1 1/2	.937	.046	.6280	.6253	.7192	.7184	.6240	.6230
GFI-1214-02	3/4	7/8	1/8	1.125	.062	.7541	.7508	.8755	.8747	.7491	.7479
GFI-1214-06	3/4	7/8	3/8	1.125	.062	.7541	.7508	.8755	.8747	.7491	.7479

Appendix VII – Engineering Drawings

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	-	Borescope	1
2	-	AcutationCable	5
3	-	Mesh Sheath	1
4	111-1	CableGuide	27
5	-	RubberHose	1
6	-	GripActSheath	1
7	-	BundlingWrap	1





The Muckrakers

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
2 DECIMAL ± 0.05
ANGULAR: MACH± 0.1deg
BEND ± 1.0 deg

MATERIAL
ALUMINUM - AL 6061

FINISH
AS MACHINED

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Gordon Cline	02/27/2012
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS: ASSEMBLY FOR
DIAGRAMATIC PURPOSES ONLY

TITLE:

Cable Arm Assy

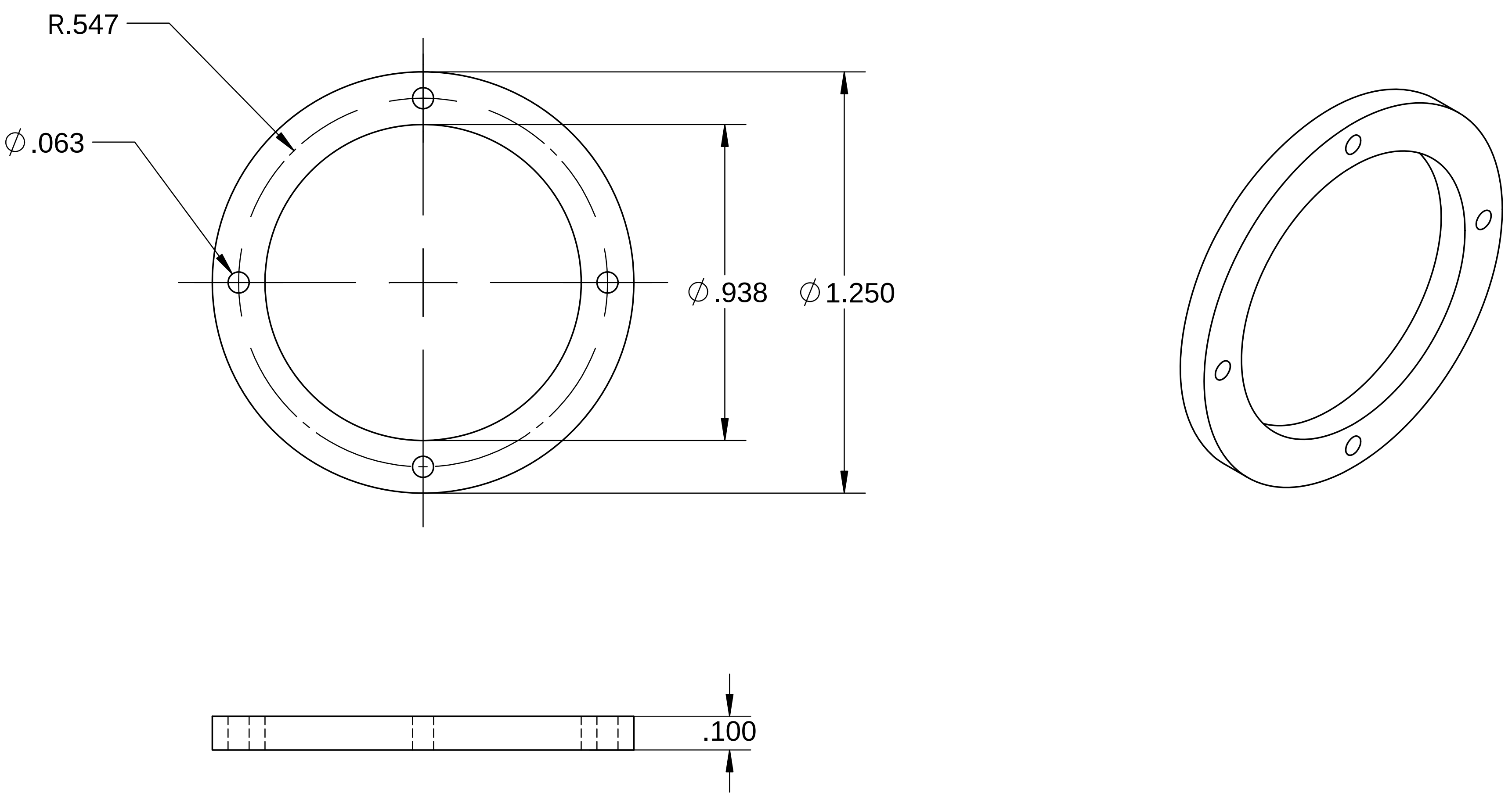
SIZE
A

DWG. NO.
111-0

REV

SCALE: 1:1
WEIGHT:
SHEET 1 OF 1

4 3 2 1



The Muckrakers

NEXT ASSY	USED ON
111-0	Cable Arm Assy
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
2 DECIMAL ± 0.05
ANGULAR: MACH± 0.1deg
BEND ± 1.0 deg
MATERIAL
NYLON 6/6
FINISH
AS MACHINED
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Gordon Cline	02/27/2012
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

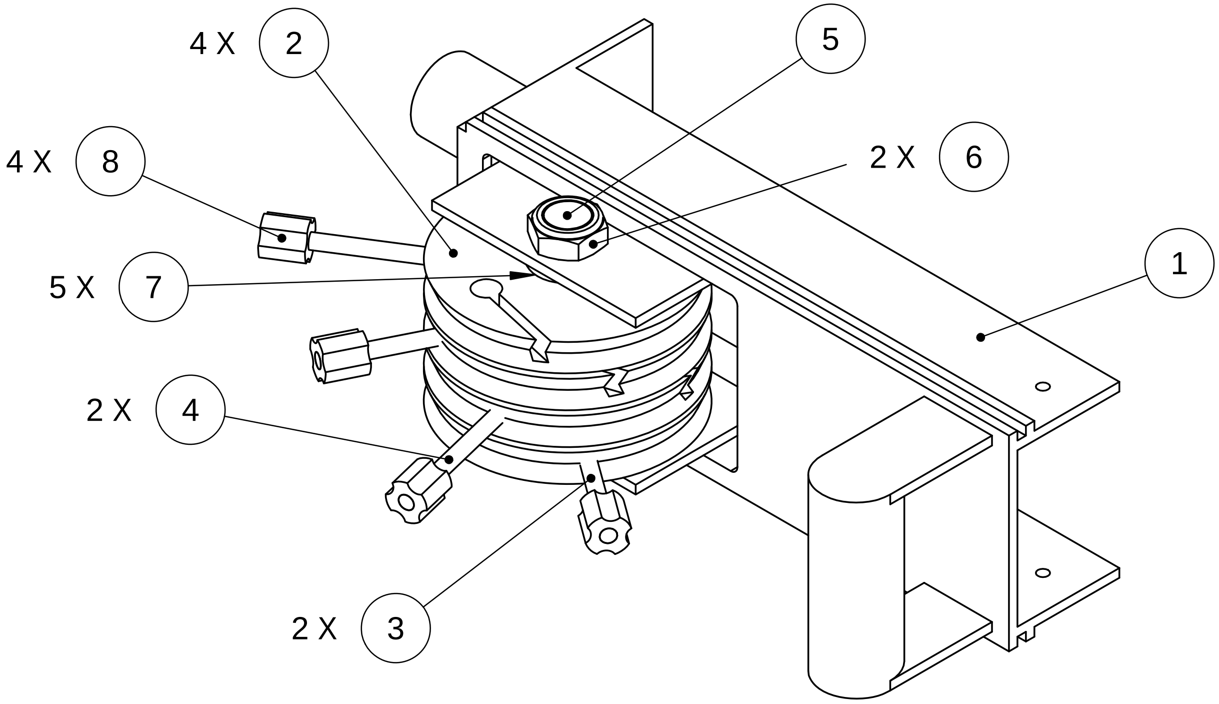
COMMENTS:

TITLE:

Cable Guide

SIZE
A
DWG. NO.
111-1
REV
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	121-1	End Chassis	1
2	121-2	Actuation Disk	4
3	121-3	Knob - Short	2
4	121-4	Knob - Long	2
5	121-5	Vert Rod	1
6	121-6	Rod Locknut	2
7	121-7	Washer	5
8	121-8	Knob Cap	4



The Muckrakers

	NAME	DATE
DRAWN	Gordon Cline	02/27/2012
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
2 DECIMAL ± 0.05
ANGULAR: MACH± 0.1deg
BEND ± 1.0 deg

MATERIAL

FINISH
AS MACHINED

DO NOT SCALE DRAWING

NEXT ASSY	USED ON
100-0	Prototype Assembly
APPLICATION	

TITLE:

Control Assy

SIZE A

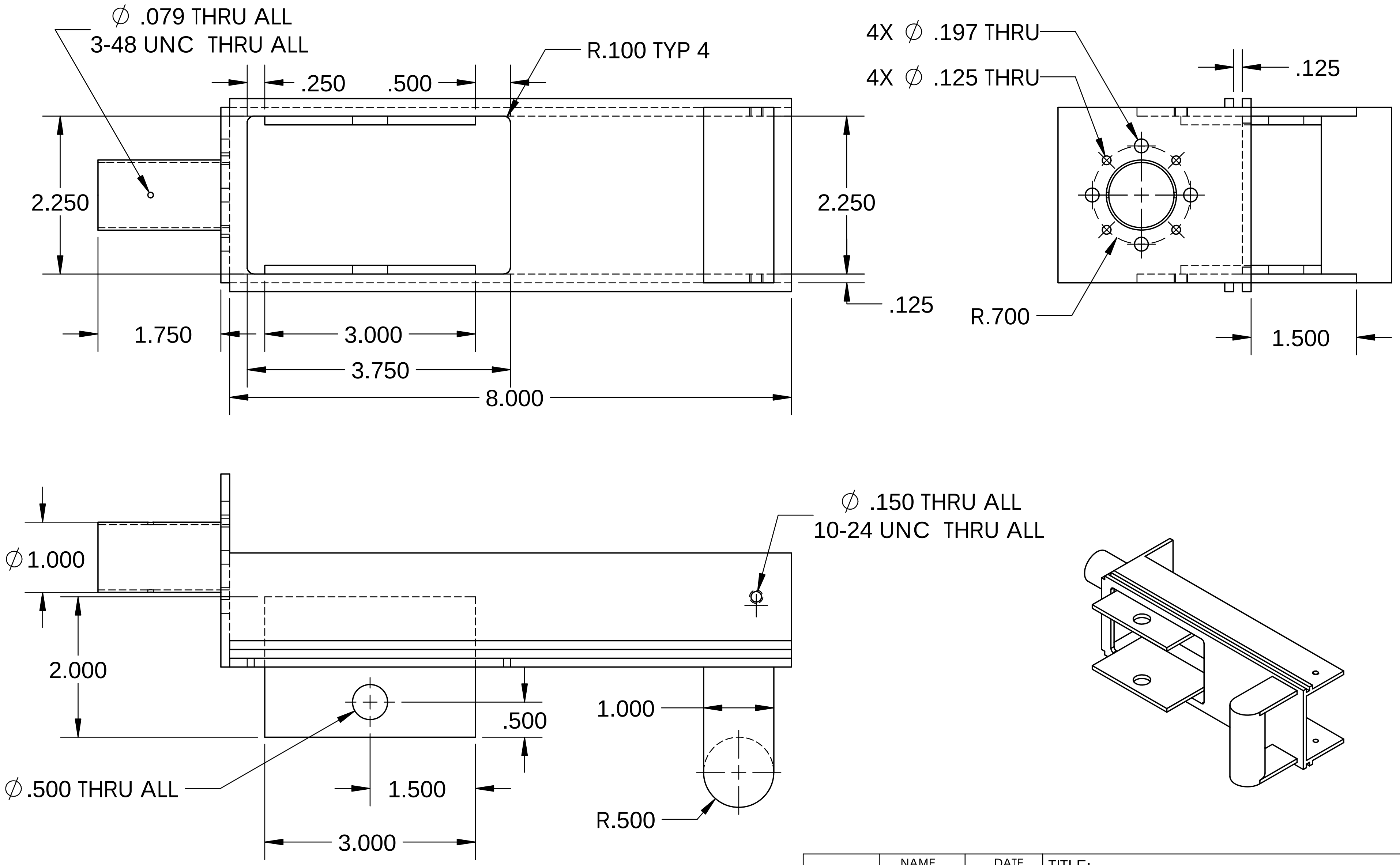
DWG. NO. 121-0

REV

SCALE: 1:2

WEIGHT:

SHEET 1 OF 1



	NAME	DATE
DRAWN	Gordon Cline	02/27/2012
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS: ALL PLATE THICKNESSES ARE 1/4" UNLESS OTHERWISE SPECIFIED

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
2 DECIMAL ± 0.05
ANGULAR: MACH± 0.1deg
BEND ± 1.0 deg

MATERIAL
ALUMINUM - AL 6061

FINISH
AS MACHINED

DO NOT SCALE DRAWING

NEXT ASSY	USED ON
121-0	Cable Control Assy
100-0	Prototype Assembly
APPLICATION	

The Muckrakers

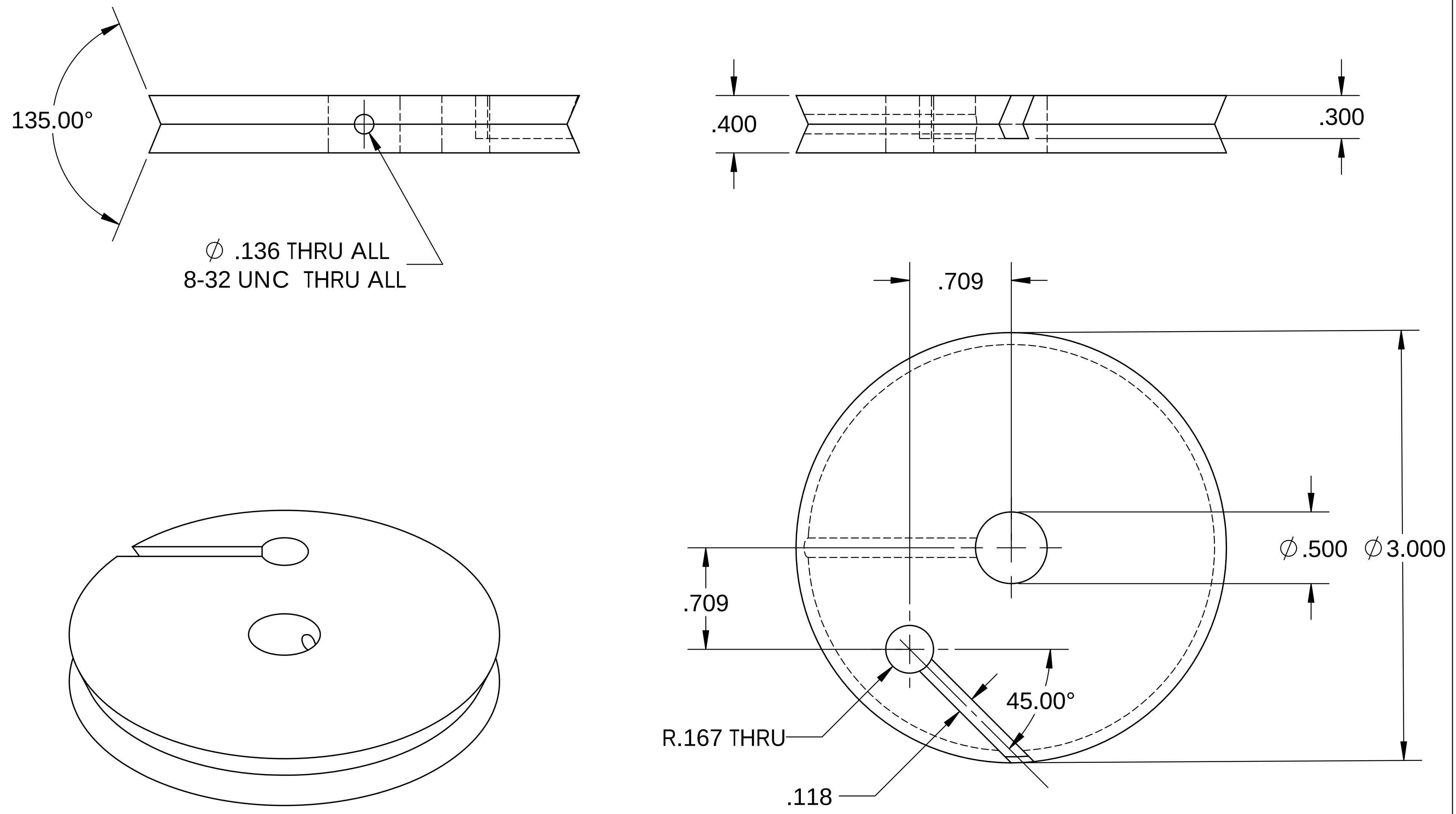
TITLE:

Chassis

SIZE	DWG. NO.	REV
A	121-1	

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



The Muckrakers

NEXT ASSY	USED ON
121-0	Cable Control Assy
100-0	Prototype Assembly
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES

TOLERANCES:
2 DECIMAL ± 0.05
ANGULAR: MACH± 0.1deg
BEND ± 1.0 deg

MATERIAL
ALUMINUM - AL 6061

FINISH
AS MACHINED

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Gordon Cline	02/28/2012
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

Actuation Disk

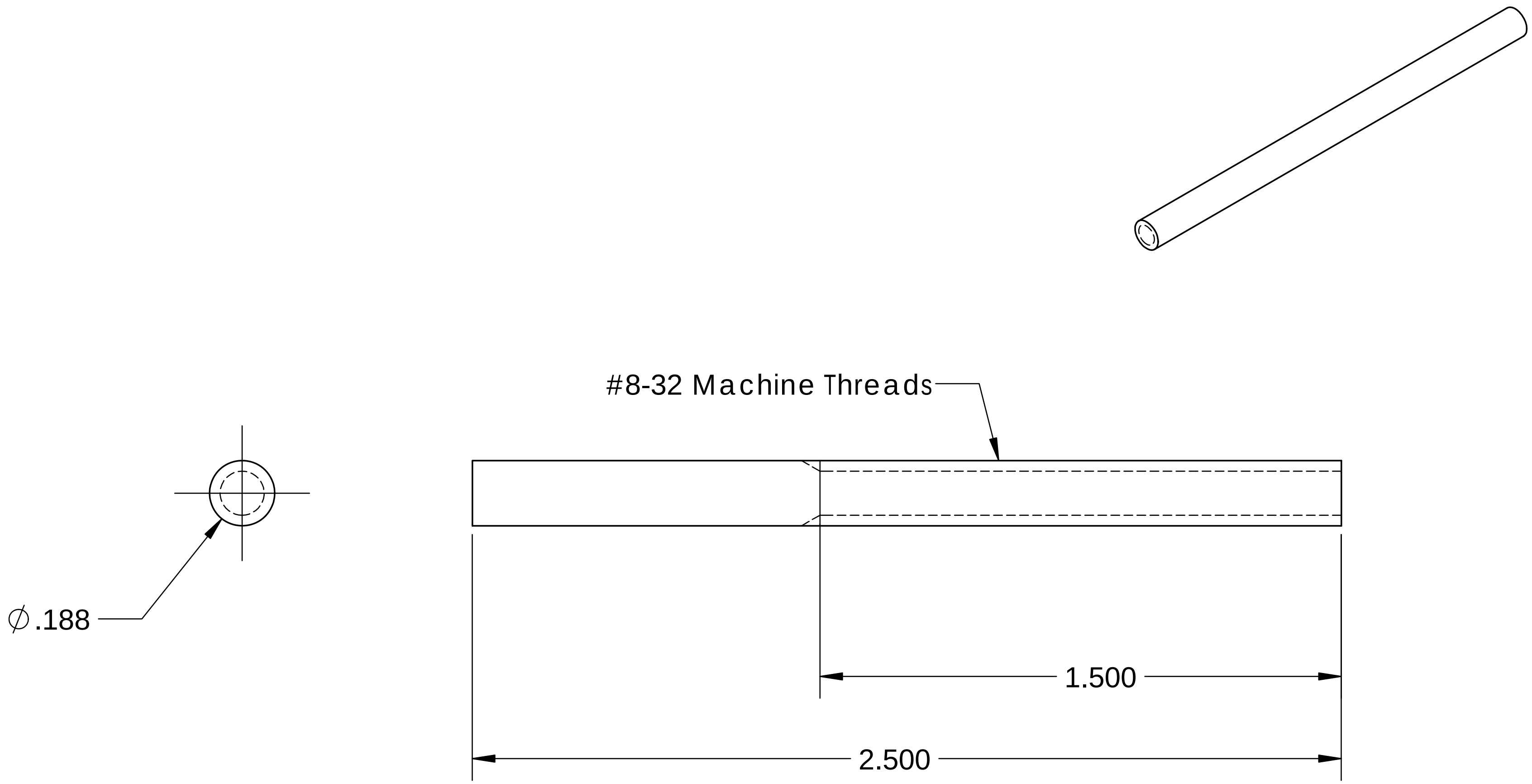
SIZE
A

DWG. NO.
121-2

REV

SCALE: 1:1
WEIGHT:
SHEET 1 OF 1

5 4 3 2 1



NEXT ASSY	USED ON
121-0	Cable Control Assy
100-0	Prototype Assembly
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
2 DECIMAL ± 0.05
ANGULAR: MACH± 0.1deg
BEND ± 1.0 deg

MATERIAL
ALUMINUM - AL 6061

FINISH
AS MACHINED

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Gordon Cline	02/27/2012
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

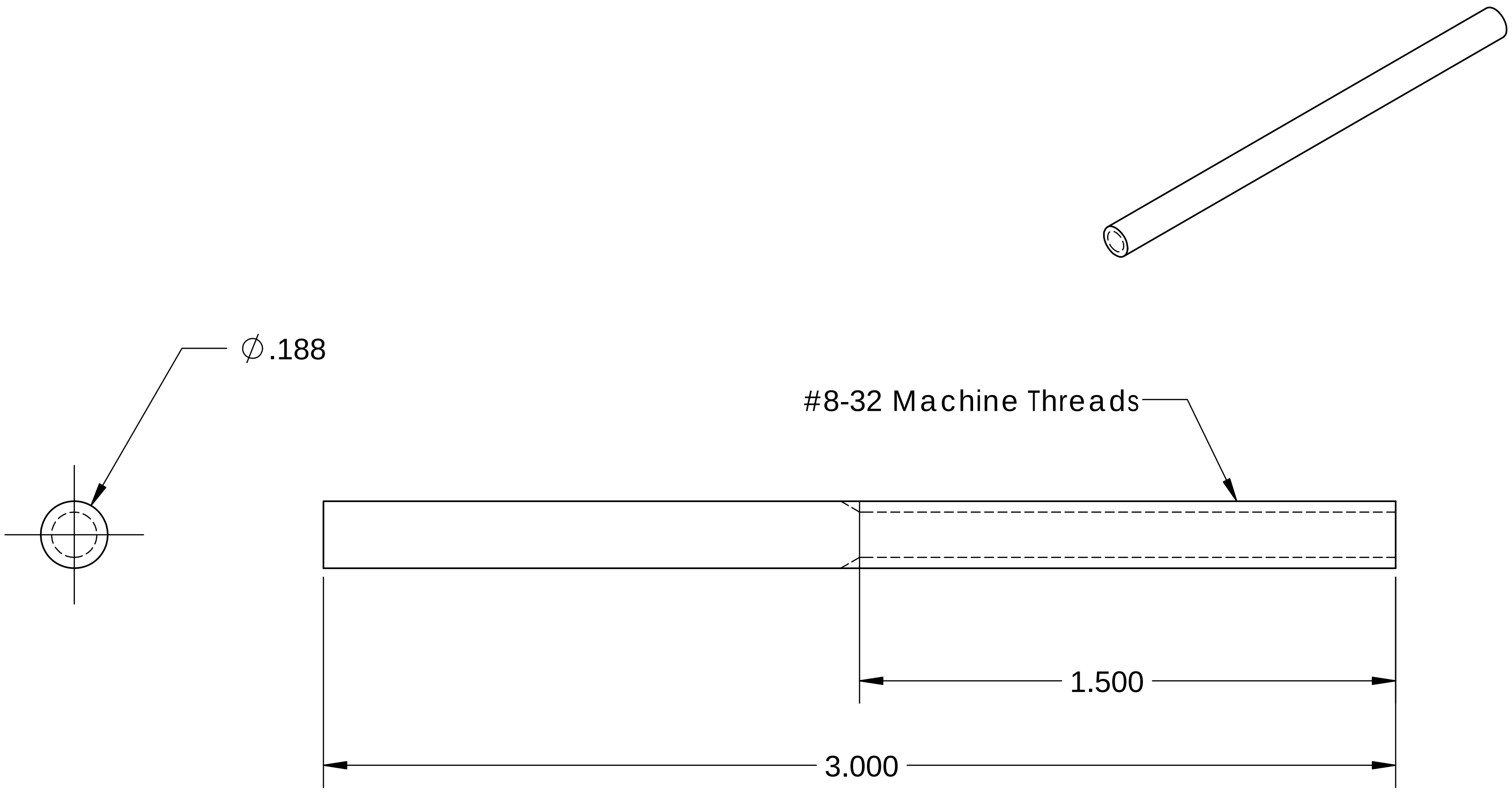
Knob - Short

SIZE	DWG. NO.	REV
A	121-3	

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

The Muckrakers

4 3 2 1



NEXT ASSY	USED ON
121-0	Cable Control Assy
100-0	Prototype Assembly
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
2 DECIMAL ± 0.05
ANGULAR: MACH± 0.1deg
BEND ± 1.0 deg
MATERIAL ALUMINUM - AL 6061
FINISH AS MACHINED
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Gordon Cline	02/27/2012
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

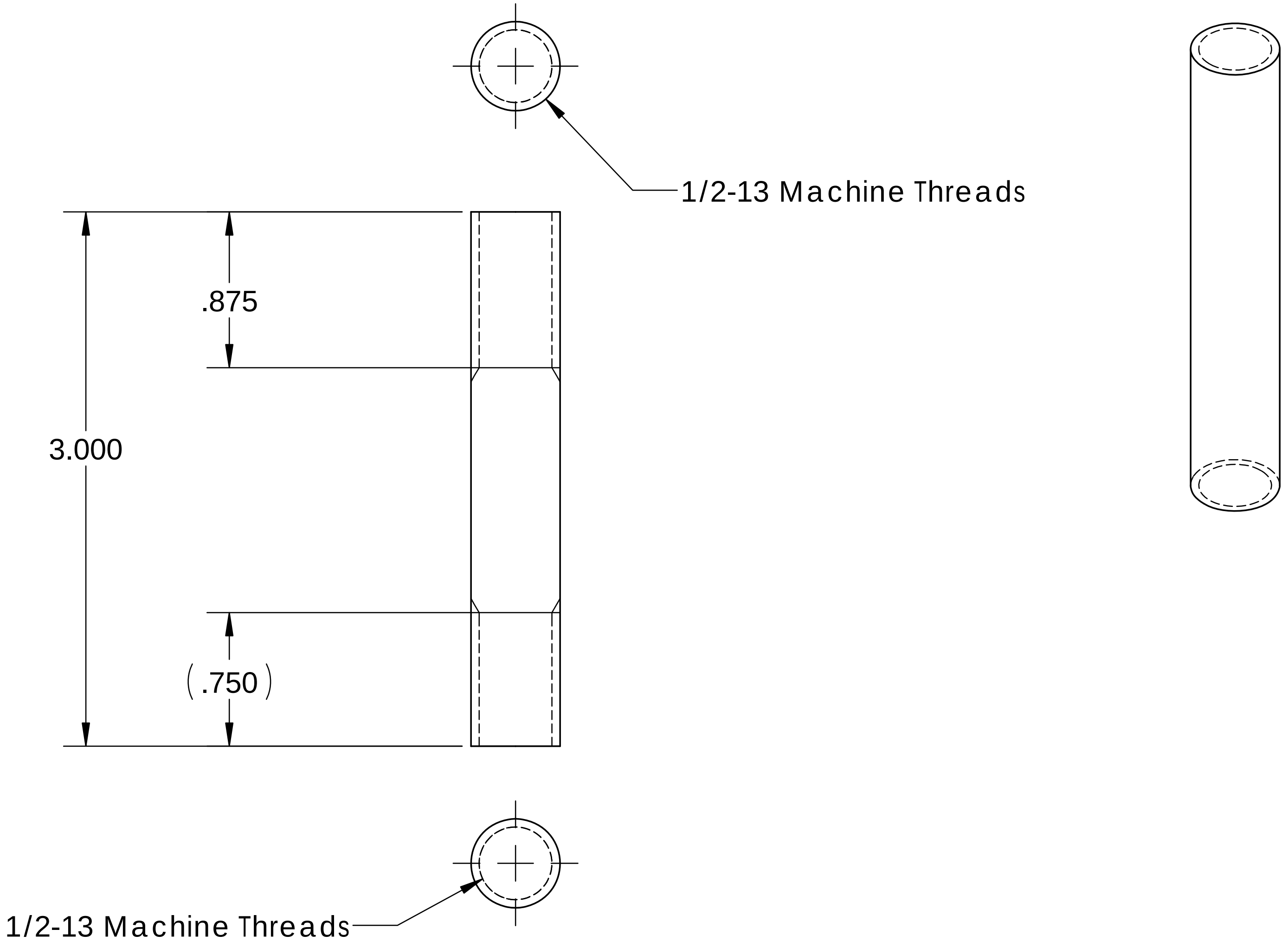
TITLE:

Knob - Long

SIZE **A**
DWG. NO. 121-4
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1

The Muckrakers

4 3 2 1



The
Muckrakers

NEXT ASSY	USED ON
121-0	Cable Control Assy
100-0	Prototype Assembly
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES

TOLERANCES:
2 DECIMAL ± 0.05
ANGULAR: MACH± 0.1deg
BEND ± 1.0 deg

MATERIAL
STAINLESS STEEL 18-8

FINISH
AS MACHINED

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Gordon Cline	02/27/2012
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

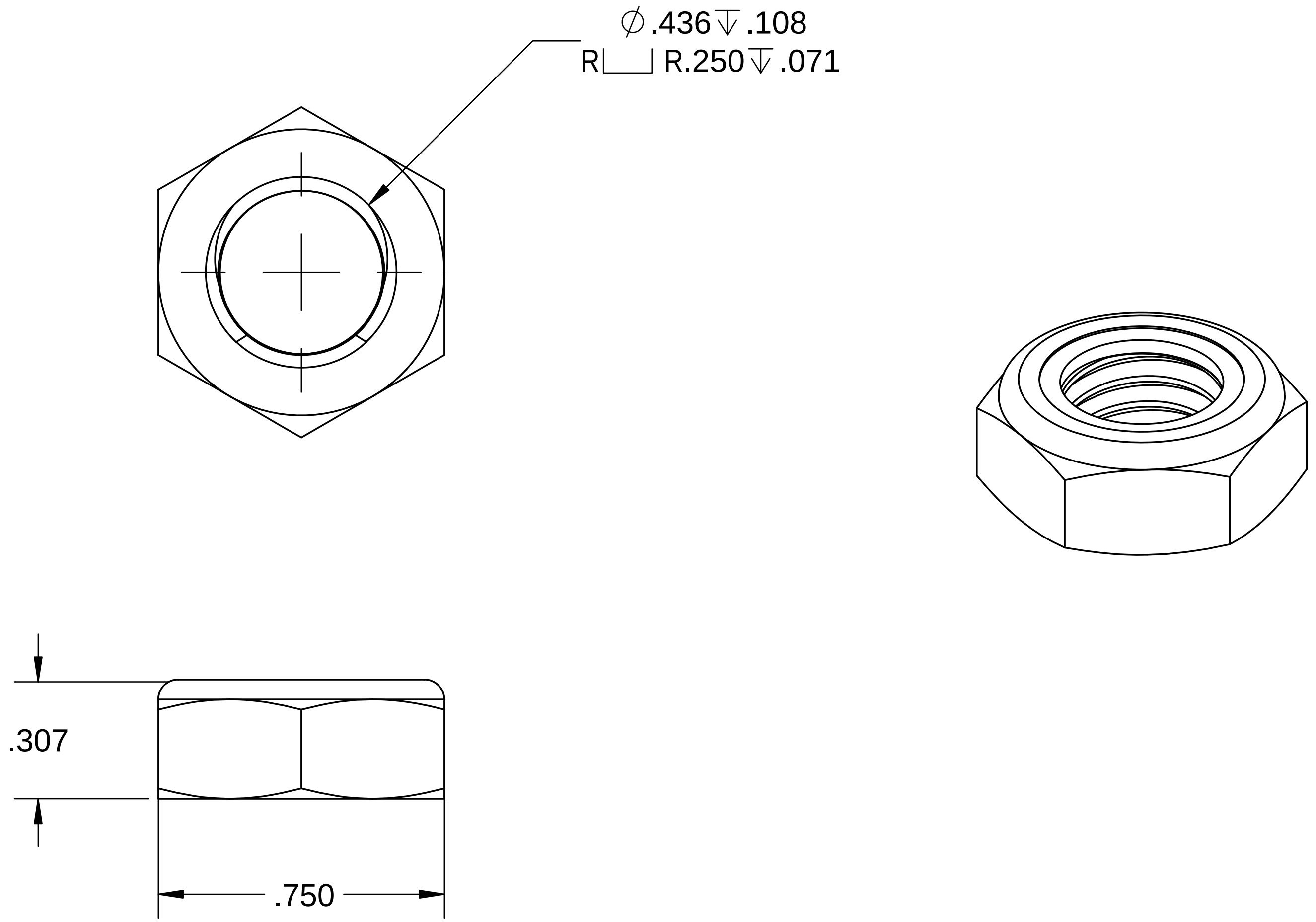
TITLE:

Center Pivot Rod

SIZE	DWG. NO.	REV
A	121-5	

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



The Muckrakers

NEXT ASSY	USED ON
121-0	Cable Control Assy
100-0	Prototype Assembly
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES

TOLERANCES:
2 DECIMAL ± 0.05
ANGULAR: MACH± 0.1deg
BEND ± 1.0 deg

MATERIAL 18-8 STAINLESS STEEL

FINISH AS MACHINED

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Gordon Cline	02/27/2012
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

Rod Locknut

SIZE A

DWG. NO. 121-6

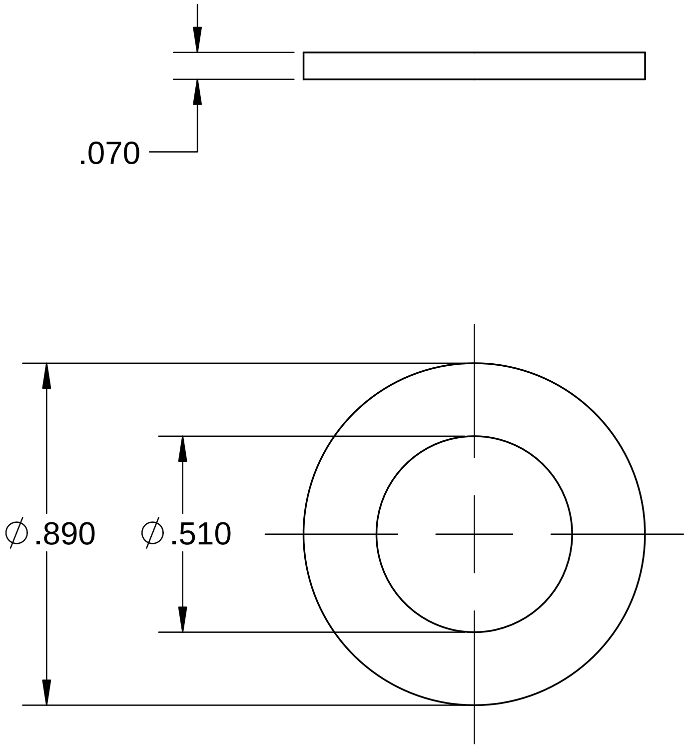
REV

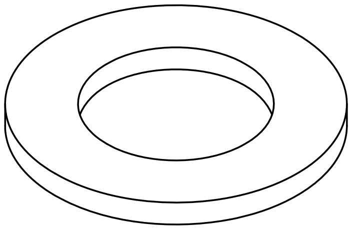
SCALE: 1:1

WEIGHT:

SHEET 1 OF 1

5 4 3 2 1





The Muckrakers

NEXT ASSY	USED ON
121-0	Cable Control Assy
100-0	Prototype Assembly
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
2 DECIMAL ± 0.05
ANGULAR: MACH± 0.1deg
BEND ± 1.0 deg
MATERIAL POLYETHYLENE
FINISH AS MACHINED
DO NOT SCALE DRAWING

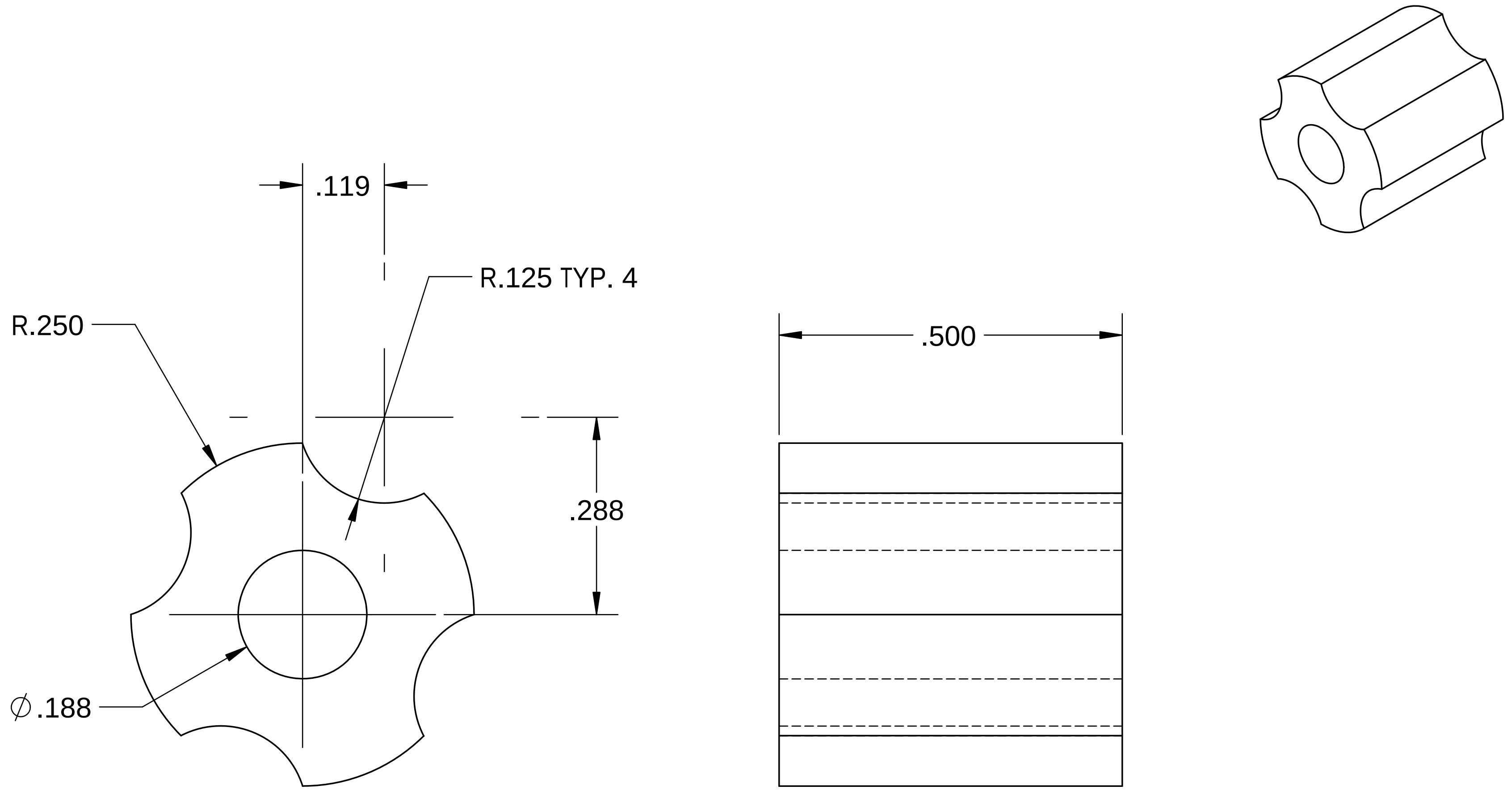
	NAME	DATE
DRAWN	Gordon Cline	02/27/2012
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

Washer

SIZE A
DWG. NO. 121-7
REV
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1



	NAME	DATE
DRAWN	Gordon Cline	02/27/2012
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
2 DECIMAL ± 0.05
ANGULAR: MACH± 0.1deg
BEND ± 1.0 deg

MATERIAL
ELASTOMER

FINISH
AS MACHINED

DO NOT SCALE DRAWING

NEXT ASSY	USED ON
121-0	Cable Control Assy
100-0	Prototype Assembly
APPLICATION	

TITLE:

Knob Cap

SIZE **A**

DWG. NO. 121-8

REV

SCALE: 4:1

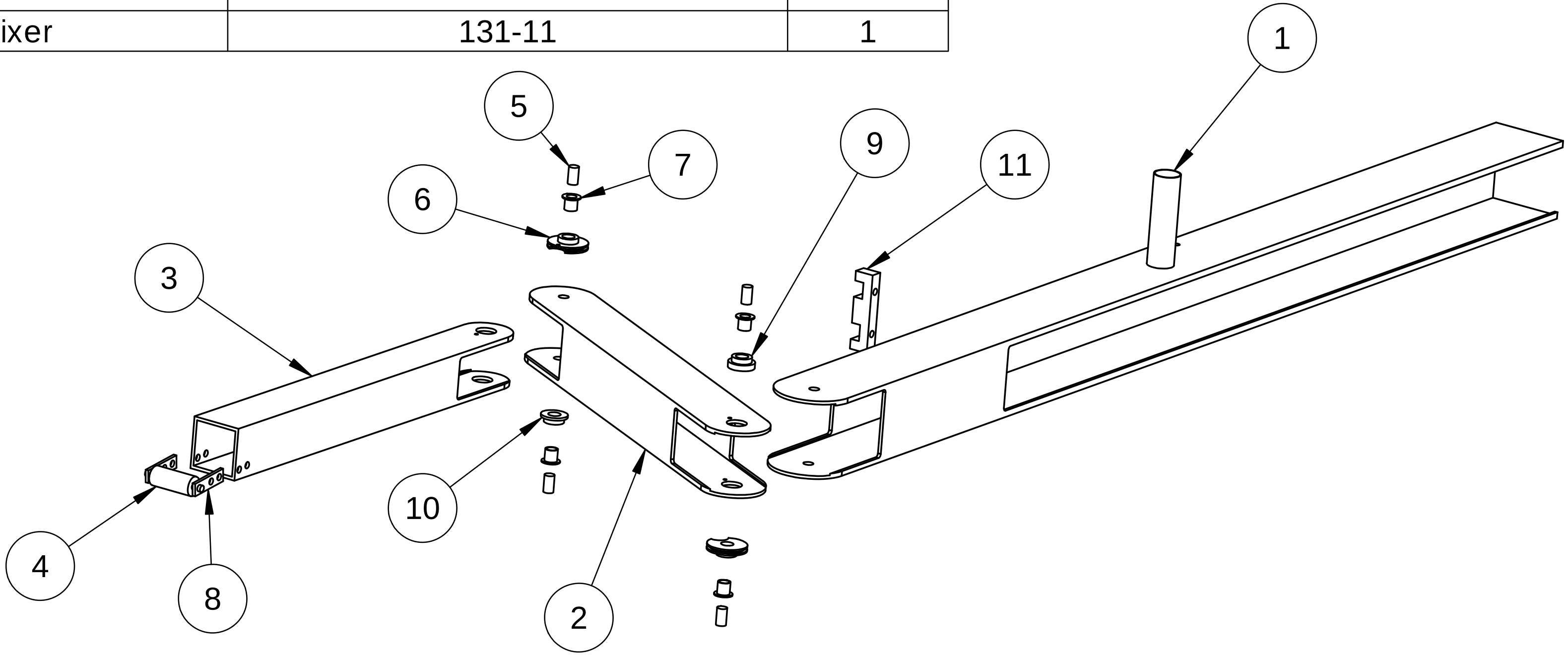
WEIGHT:

SHEET 1 OF 1

4 3 2 1

The Muckrakers

ITEM NO.	NAME	PART NO.	QTY.
1	Big Arm	131-1	1
2	Medium Arm	131-2	1
3	Small Arm	131-3	1
4	Roller	131-8	1
5	Pin	131-7	4
6	Cable Holder	131-4	2
7	Bushing	131-6	4
8	Roller Holder	131-9	2
9	Bushing Holder	131-10	1
10	Bushing Holder 2	131-5	1
11	Cable Fixer	131-11	1



The Muckrakers

NEXT ASSY	USED ON
1000	Prototype Assembly
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
2 DECIMAL ± 0.05
ANGULAR: MACH± 0.1deg
BEND ± 1.0 deg
MATERIAL
ALUMINUM - AL 6061
FINISH
AS MACHINED
DO NOT SCALE DRAWING

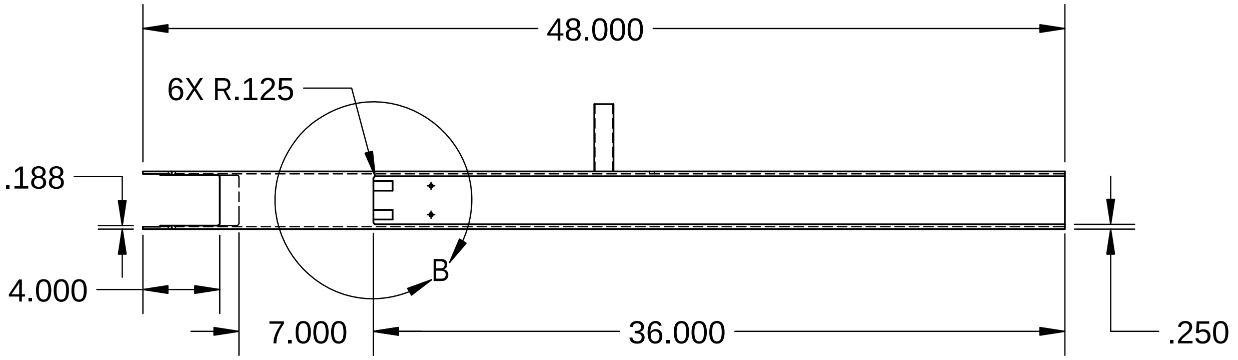
	NAME	DATE
DRAWN	M. O'Brien	02/27/2012
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

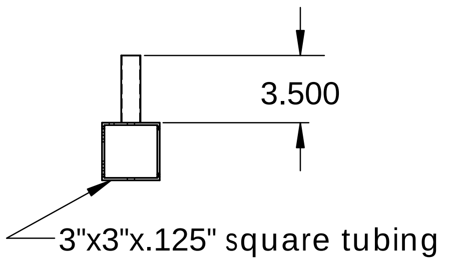
TITLE:

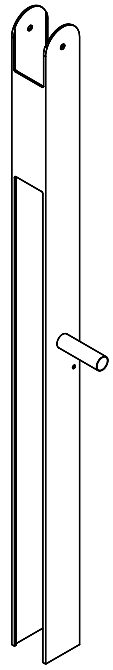
BOOM ASSEMBLY

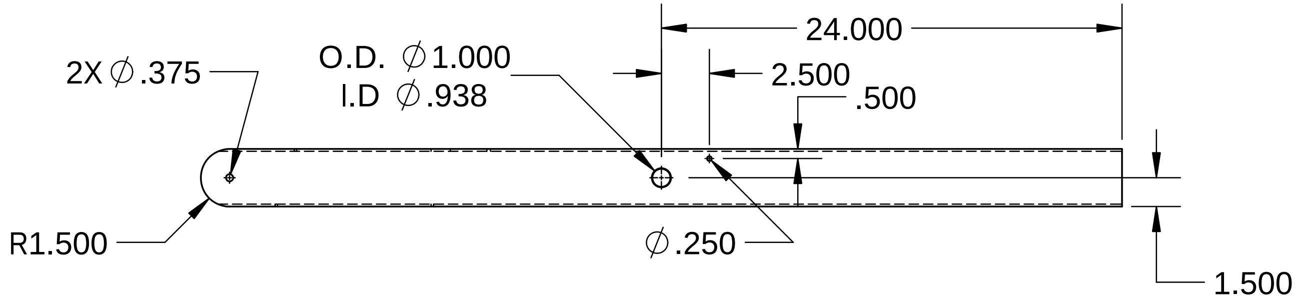
SIZE **A**
DWG. NO. 1310
REV
SCALE: 1:7
WEIGHT:
SHEET 1 OF 1

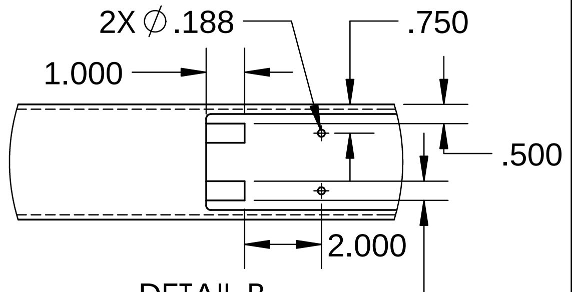
4 3 2 1











DETAIL B
SCALE 1 : 5

Dimensions symmetrical where not given

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES	
TOLERANCES: 2 DECIMAL ± 0.05 ANGULAR: MACH± 0.1deg BEND ± 1.0 deg	
MATERIAL	ALUMINUM - AL 6063
FINISH	AS MACHINED
DO NOT SCALE DRAWING	

NEXT ASSY	USED ON
1310	Boom Assembly
1000	Prototype Assembly
APPLICATION	

	NAME	DATE
DRAWN	M. O'Brien	02/27/2012
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

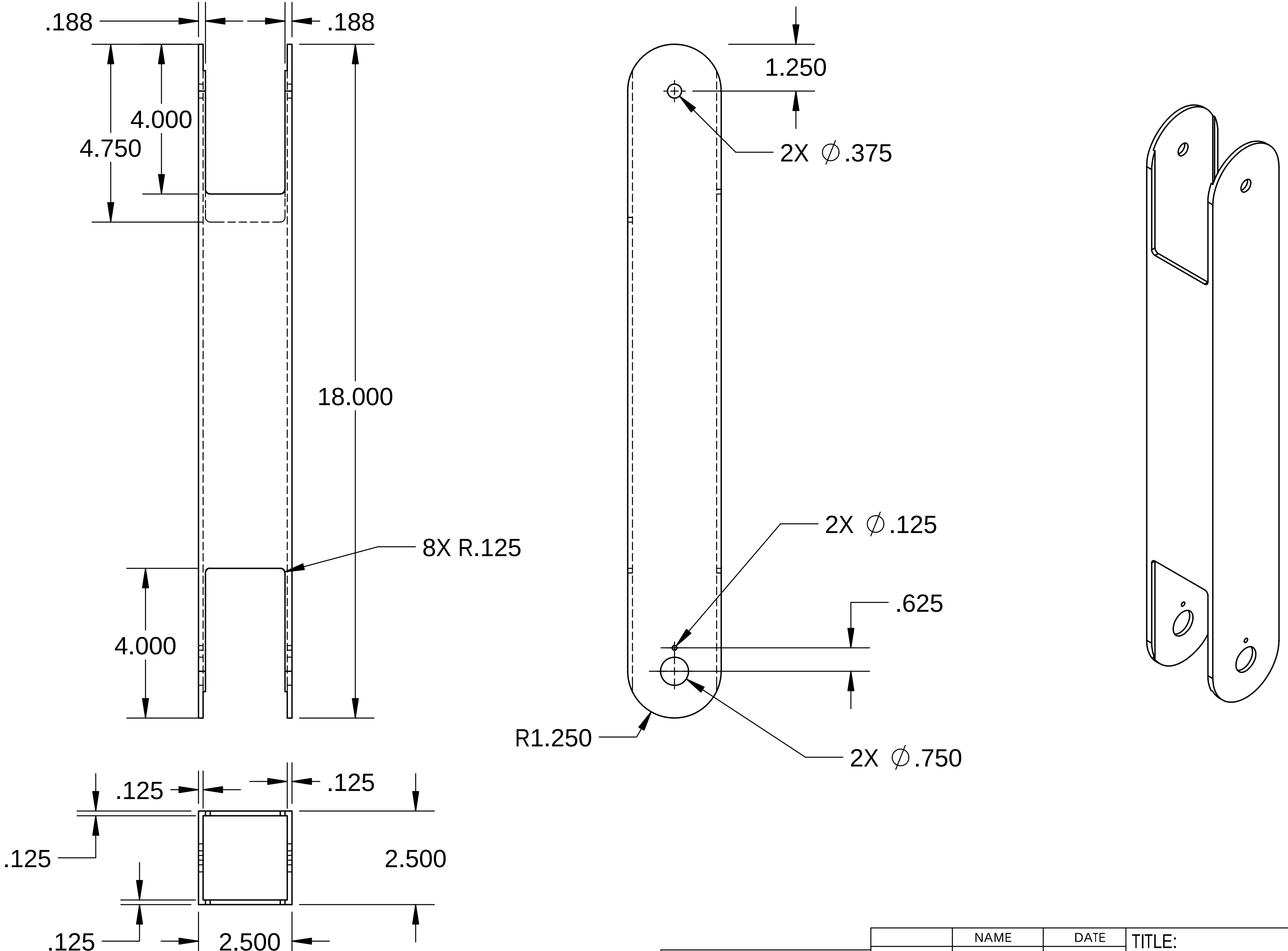
TITLE:

BIG ARM

SIZE	DWG. NO.	REV
A	131-1	
SCALE: 1:10	WEIGHT:	SHEET 1 OF 1

4 3 2 1

The Muckrakers



			NAME	DATE
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES		DRAWN	M. O'Brien	02/27/2012
		CHECKED		
NEXT ASSY	USED ON	TOLERANCES: 2 DECIMAL ± 0.05 ANGULAR: MACH± 0.1deg BEND ± 1.0 deg	ENG APPR.	
			MFG APPR.	
1310	Boom Assembly	MATERIAL ALUMINUM - AL 6063	Q.A.	
1000	Prototype Assembly	FINISH AS MACHINED	COMMENTS:	
APPLICATION		SCALE: 1:4		

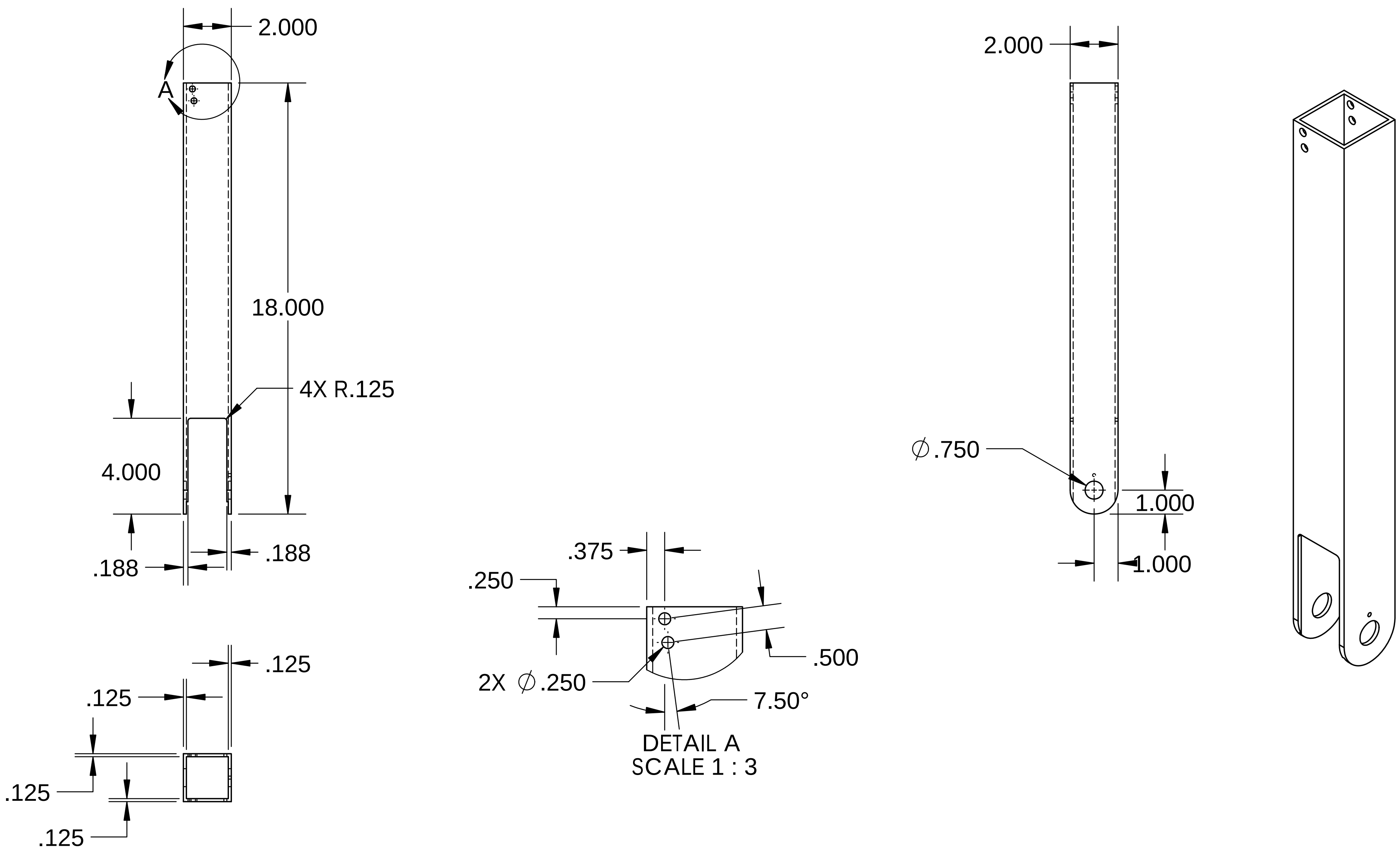
TITLE:

MEDIUM ARM

SIZE	DWG. NO.	REV
A	131-2	
SCALE: 1:4	WEIGHT:	SHEET 1 OF 1

4 3 2 1

The Muckrakers



	NAME	DATE
DRAWN	M. O'Brien	02/27/2012
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
2 DECIMAL ± 0.05
ANGULAR: MACH± 0.1deg
BEND ± 1.0 deg
MATERIAL
ALUMINUM - AL 6063
FINISH
AS MACHINED
DO NOT SCALE DRAWING

NEXT ASSY	USED ON
1310	Boom Assembly
1000	Prototype Assembly
APPLICATION	

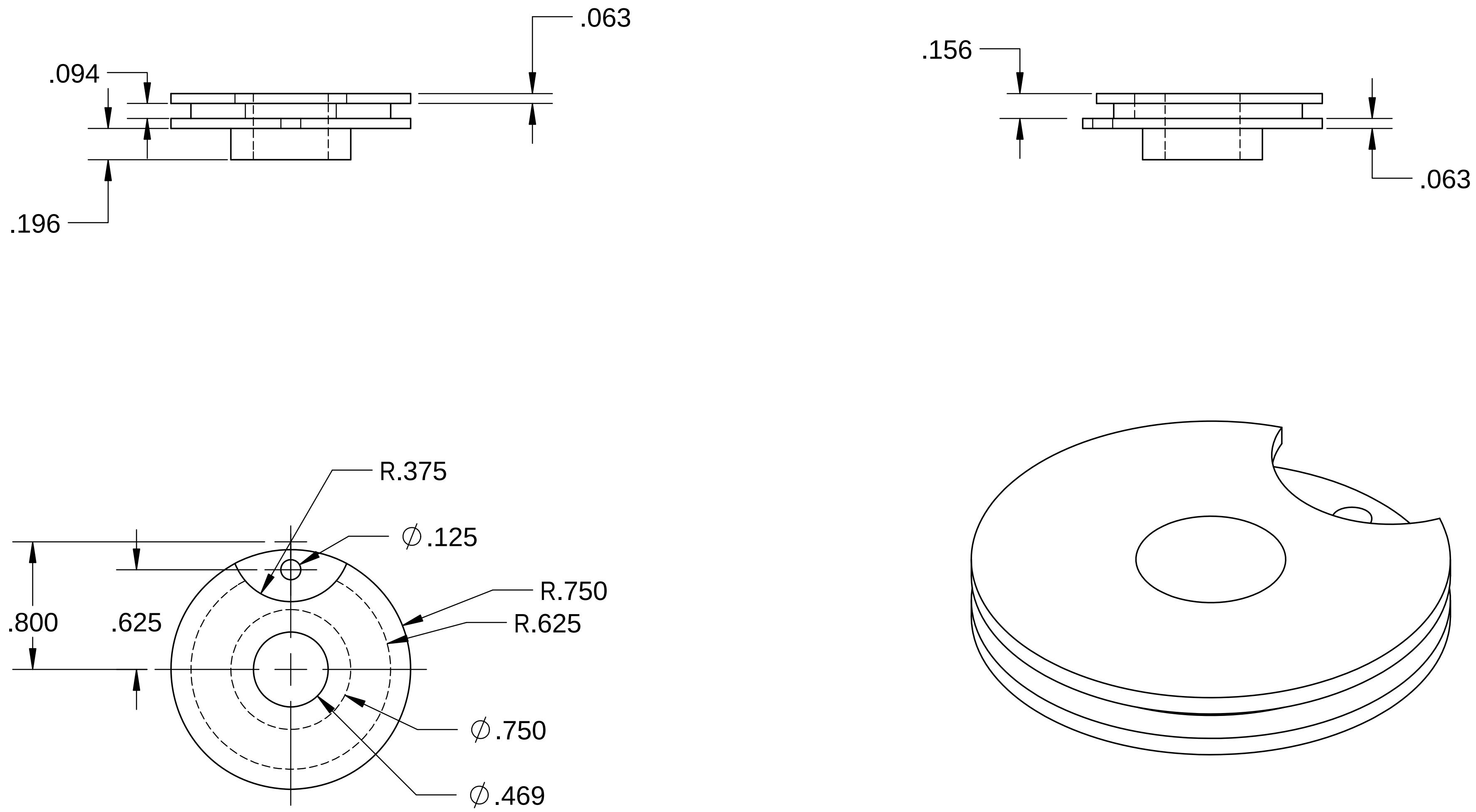
TITLE:

SMALL ARM

SIZE
A
DWG. NO.
131-3
REV
SCALE: 1:6
WEIGHT:
SHEET 1 OF 1

The
Muckrakers

4 3 2 1



	NAME	DATE
DRAWN	M. O'Brien	02/27/2012
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
2 DECIMAL ± 0.05
ANGULAR: MACH± 0.1deg
BEND ± 1.0 deg

MATERIAL
ALUMINUM - AL 6061

FINISH
AS MACHINED

DO NOT SCALE DRAWING

NEXT ASSY	USED ON
1310	Boom Assembly
1000	Prototype Assembly
APPLICATION	

TITLE:

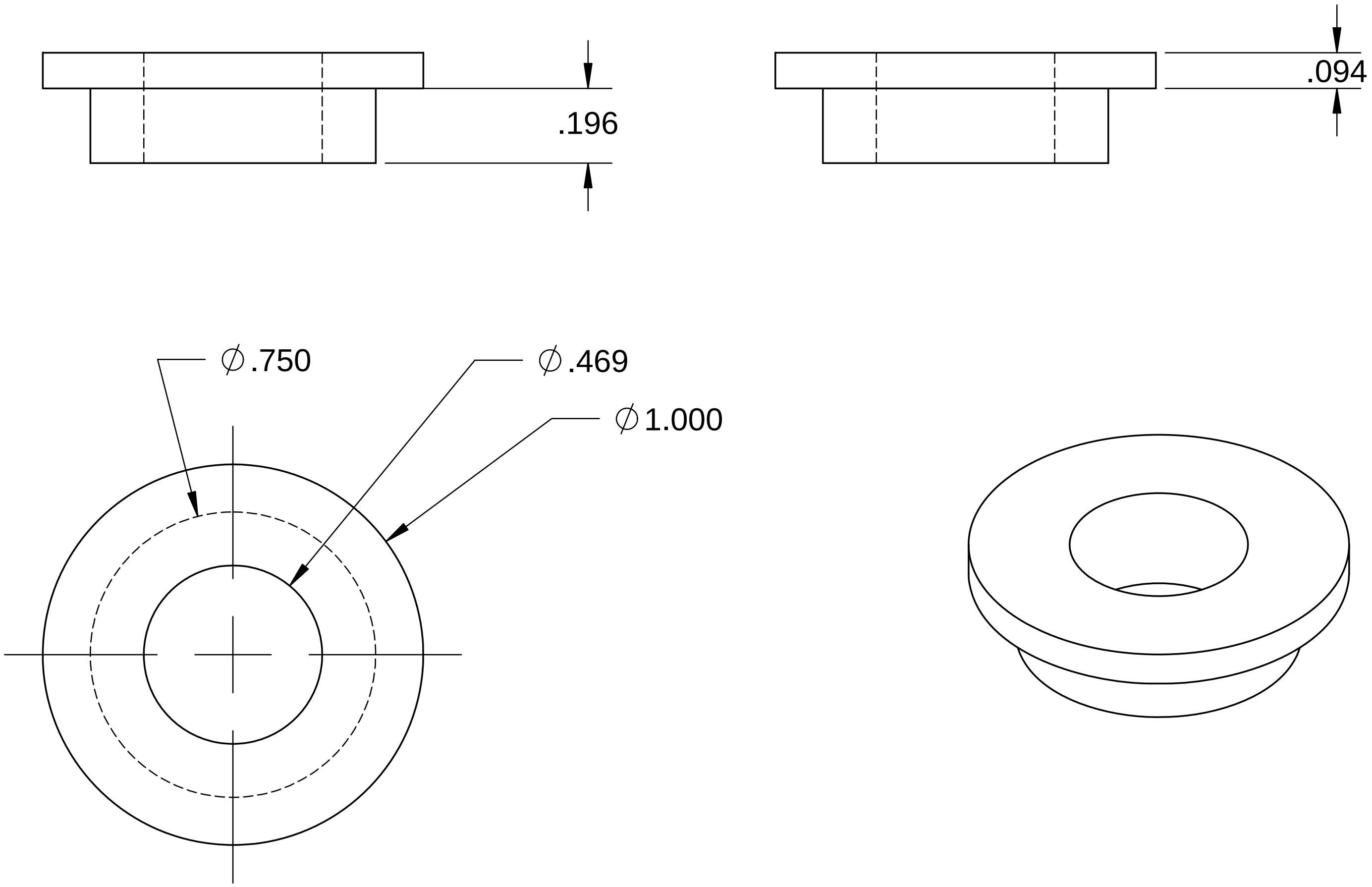
CABLE HOLDER

SIZE A
DWG. NO. 131-4
REV

SCALE: 1:1
WEIGHT:
SHEET 1 OF 1

4 3 2 1

The Muckrakers



	NAME	DATE
DRAWN	M. O'Brien	02/27/2012
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

BUSHING MOUNT 2

SIZE A

DWG. NO. 131-5

REV

SCALE: 2:1

WEIGHT:

SHEET 1 OF 1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
2 DECIMAL ± 0.05
ANGULAR: MACH± 0.1deg
BEND ± 1.0 deg

MATERIAL
ALUMINUM - AL 6061

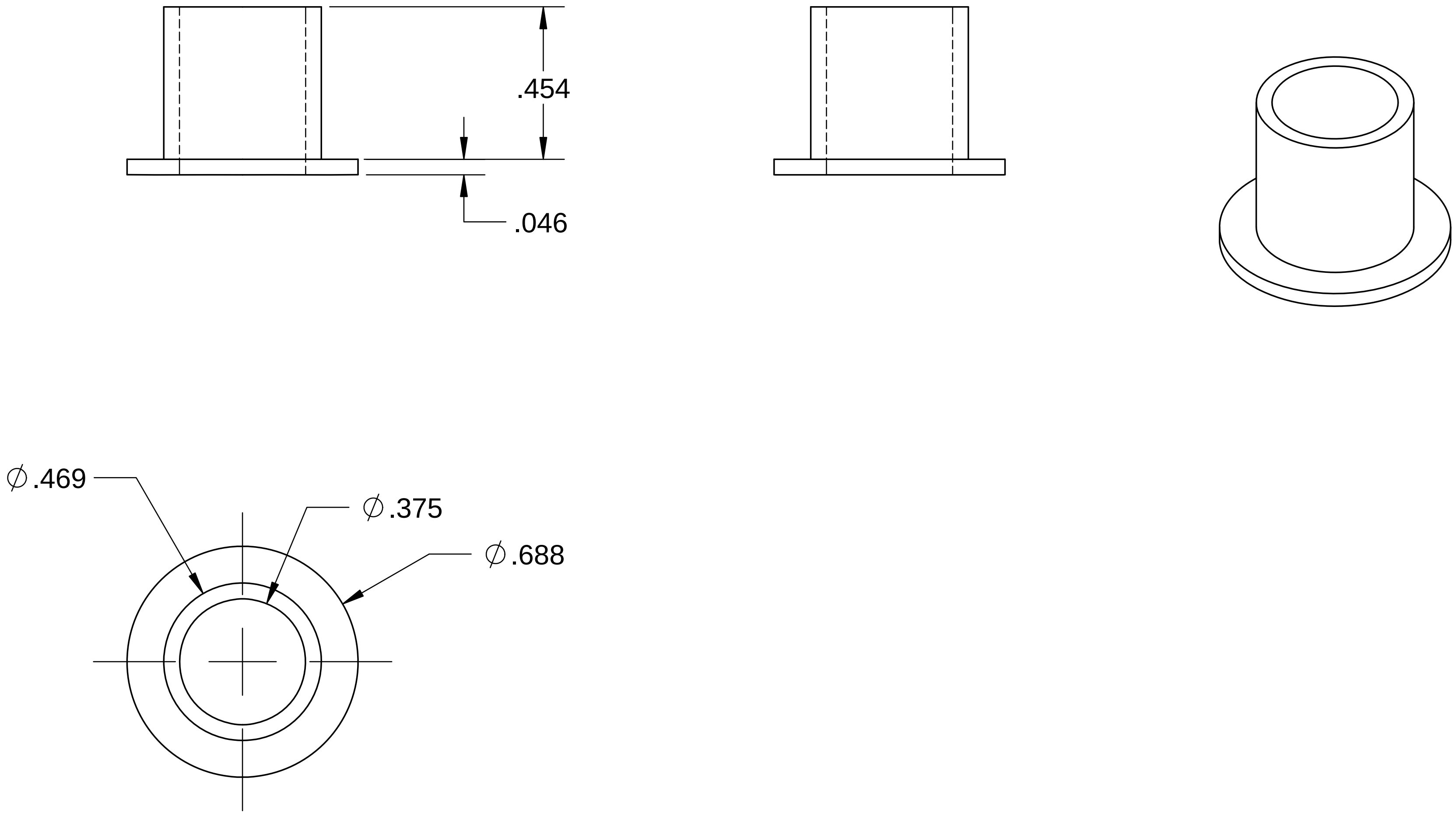
FINISH
AS MACHINED

DO NOT SCALE DRAWING

NEXT ASSY	USED ON
1310	Boom Assembly
1000	Prototype Assembly
APPLICATION	

The Muckrakers

4 3 2 1



NEXT ASSY	USED ON
1310	Boom Assembly
1000	Prototype Assembly
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
2 DECIMAL ± 0.05
ANGULAR: MACH± 0.1deg
BEND ± 1.0 deg
MATERIAL Plastic (IGUS G)
FINISH AS MACHINED
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	M. O'Brien	02/27/2012
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

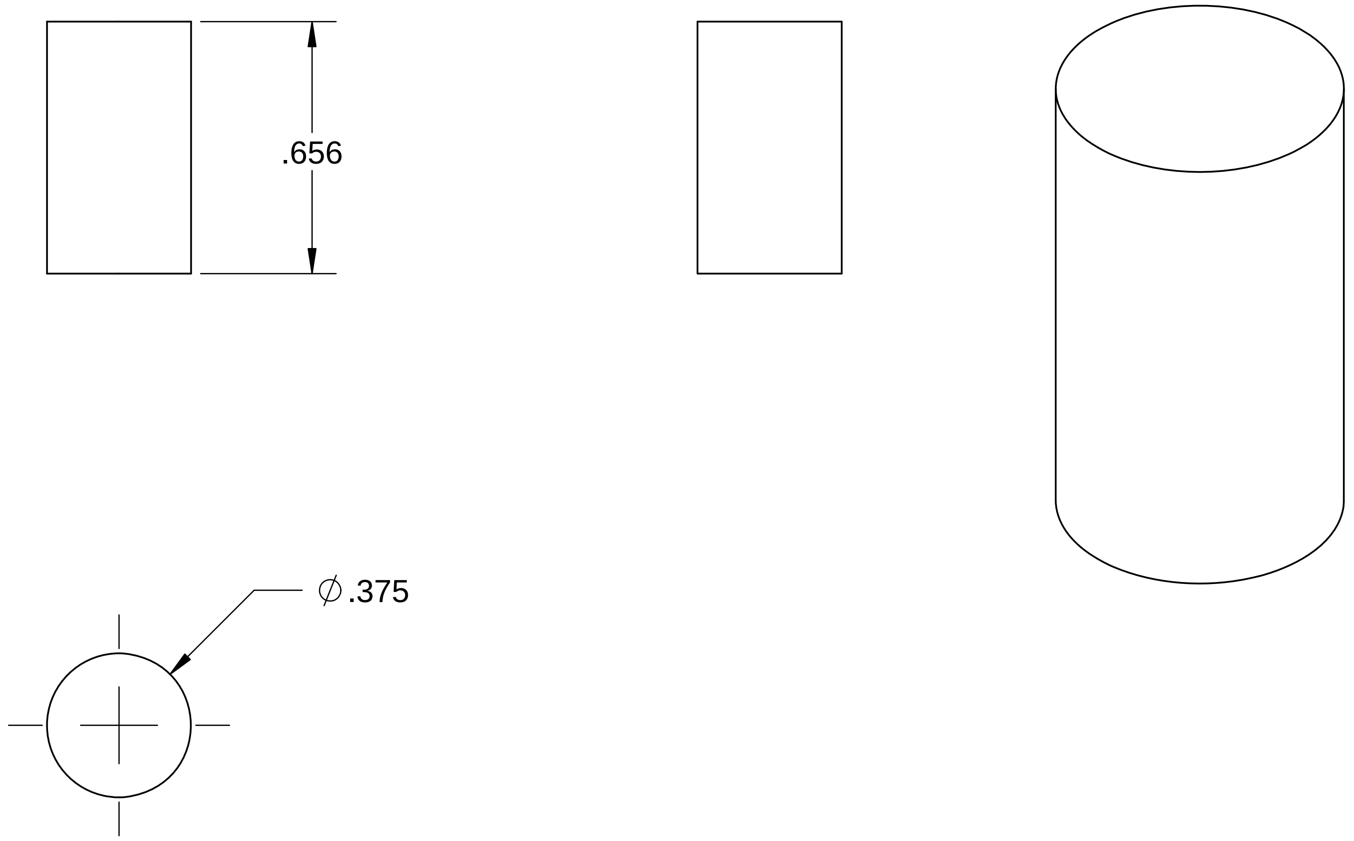
TITLE:

BUSHING

SIZE A
DWG. NO. 131-6
REV
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1

The Muckrakers

4 3 2 1



NEXT ASSY	USED ON
1310	Boom Assembly
1000	Prototype Assembly
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
2 DECIMAL ± 0.05
ANGULAR: MACH± 0.1deg
BEND ± 1.0 deg
MATERIAL ALUMINUM - AL 6061
FINISH AS MACHINED
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	M. O'Brien	02/27/2012
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

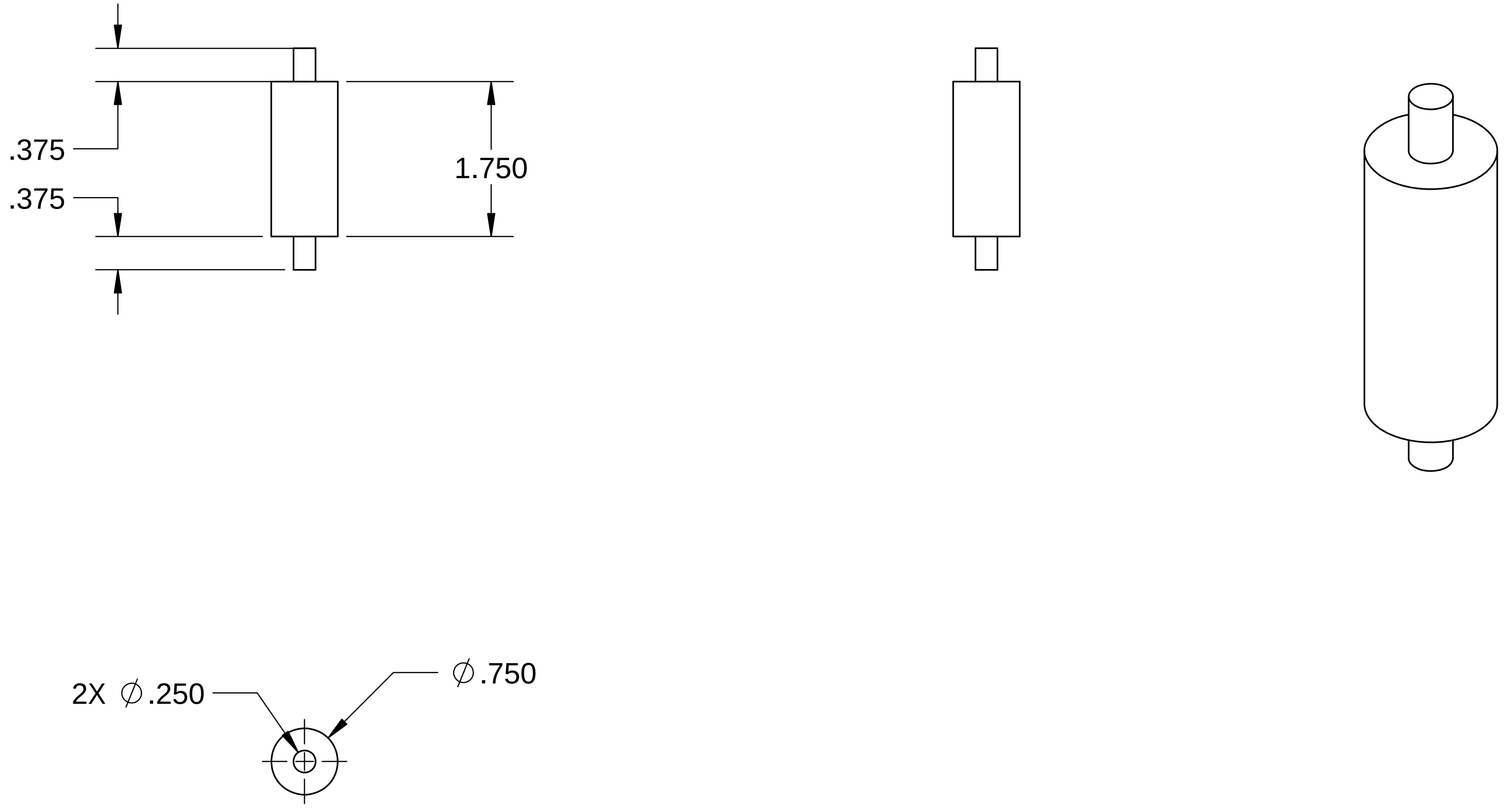
COMMENTS:

TITLE:

BOOM SHAFT

SIZE **A**
DWG. NO. 131-7
REV
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1

4 3 2 1



	NAME	DATE
DRAWN	M. O'Brien	02/27/2012
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
2 DECIMAL ± 0.05
ANGULAR: MACH± 0.1deg
BEND ± 1.0 deg

MATERIAL
NYLON

FINISH
AS MACHINED

DO NOT SCALE DRAWING

NEXT ASSY	USED ON
1310	Boom Assembly
1000	Prototype Assembly
APPLICATION	

TITLE:

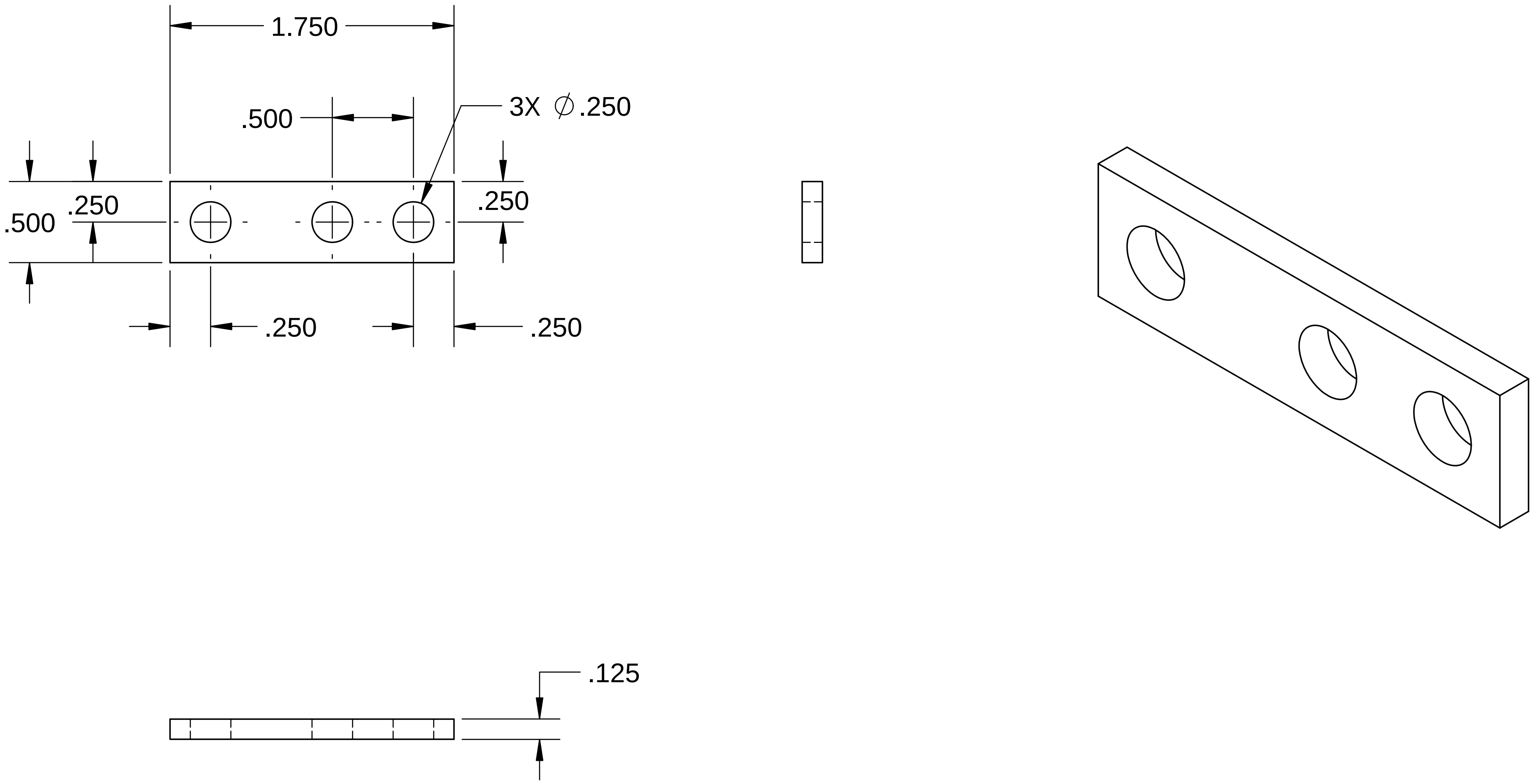
ROLLER

SIZE	DWG. NO.	REV
A	131-8	

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

The Muckrakers

4 3 2 1



	NAME	DATE
DRAWN	M. O'Brien	02/27/2012
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
2 DECIMAL ± 0.05
ANGULAR: MACH± 0.1deg
BEND ± 1.0 deg

MATERIAL
ALUMINUM - AL 6061

FINISH
AS MACHINED

DO NOT SCALE DRAWING

NEXT ASSY	USED ON
1310	Boom Assembly
1000	Prototype Assembly
APPLICATION	

TITLE:

ROLLER HOLDER

SIZE
A

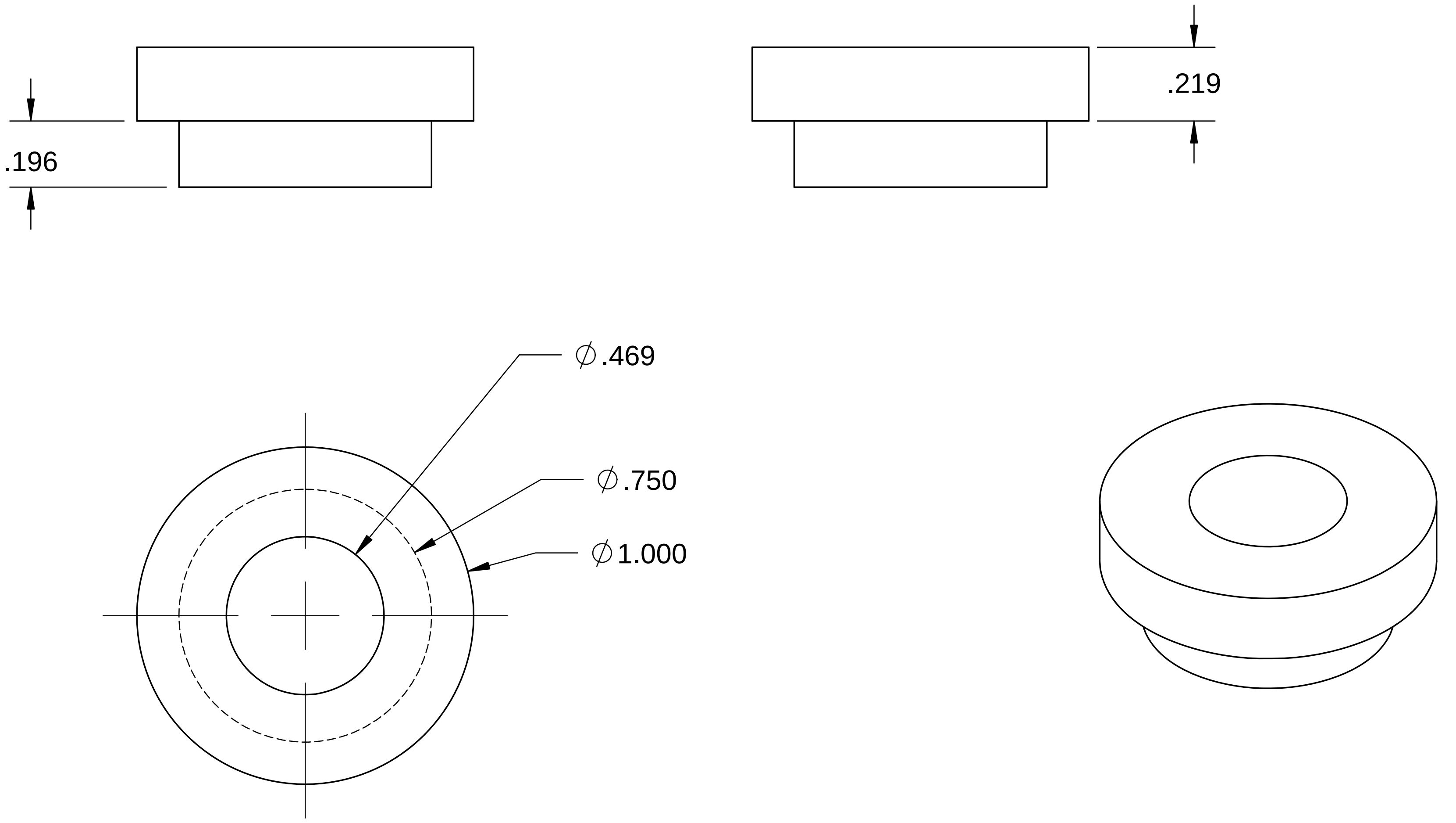
DWG. NO.
131-9

REV

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

The Muckrakers

4 3 2 1



NEXT ASSY	USED ON
1310	Boom Assembly
1000	Prototype Assembly
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
2 DECIMAL ± 0.05
ANGULAR: MACH± 0.1deg
BEND ± 1.0 deg
MATERIAL ALUMINUM - AL 6061
FINISH AS MACHINED
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	M. O'Brien	02/27/2012
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

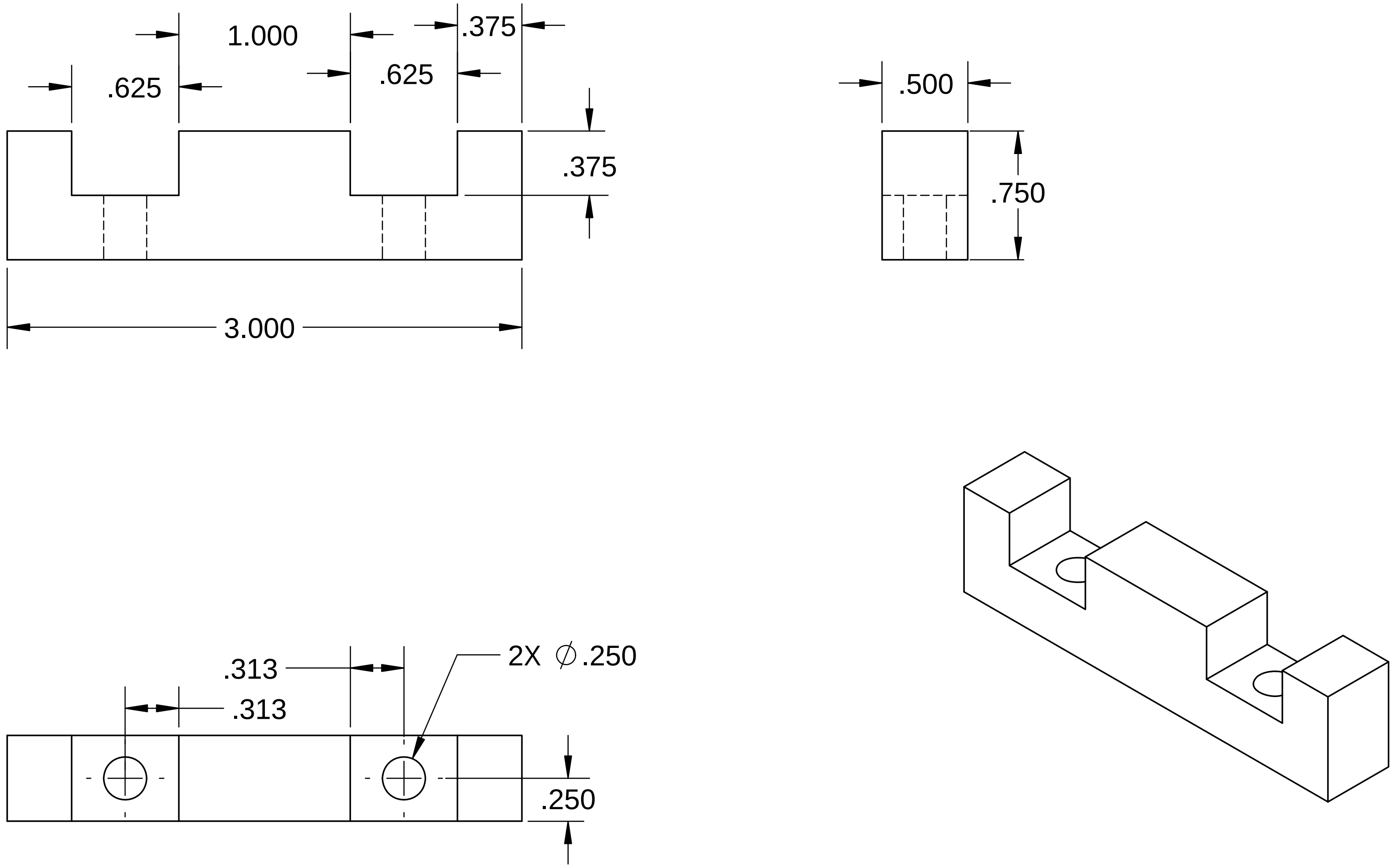
BUSHING MOUNT

SIZE **A**
DWG. NO. 131-10
REV

SCALE: 2:1 WEIGHT: SHEET 1 OF 1

The Muckrakers

4 3 2 1



NEXT ASSY	USED ON
1310	Boom Assembly
1000	Prototype Assembly
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
2 DECIMAL ± 0.05
ANGULAR: MACH± 0.1deg
BEND ± 1.0 deg
MATERIAL ALUMINUM - AL 6061
FINISH AS MACHINED
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	M. O'Brien	02/27/2012
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

CABLE FIXER

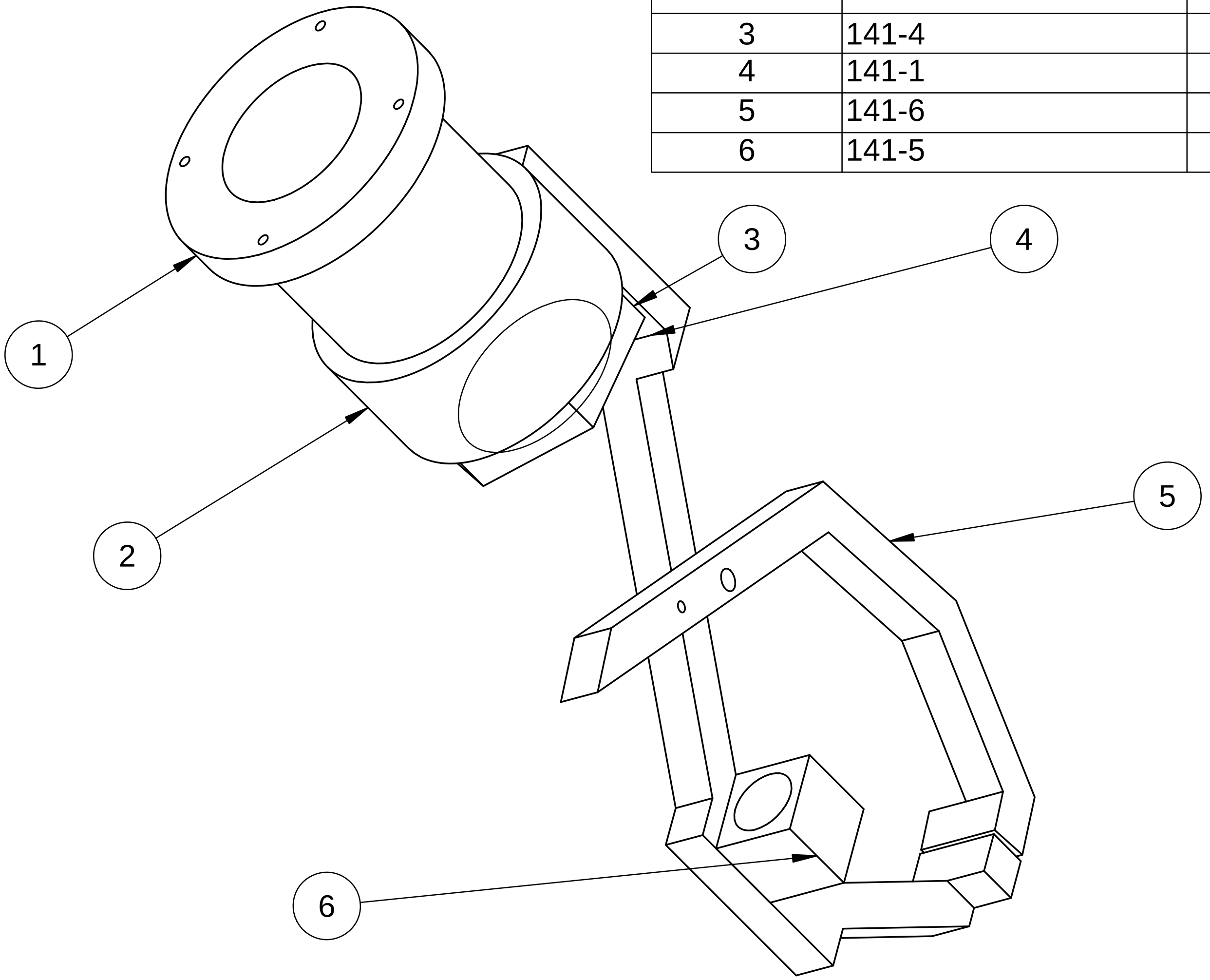
SIZE A
DWG. NO. 131-11
REV

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

4 3 2 1

The Muckrakers

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	141-2	Cable Connector	1
2	141-3	Gripper Connector	1
3	141-4	Locknut	1
4	141-1	Mounted Gripper	1
5	141-6	Free Gripper	1
6	141-5	Borescope Guide	1



NEXT ASSY	USED ON
1000	Prototype Assembly
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
2 DECIMAL ± 0.05
ANGULAR: MACH± 0.1deg
BEND ± 1.0 deg
MATERIAL
ALUMINUM - AL 6061
FINISH
AS MACHINED
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Alex Tittiger	02/26/2012
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

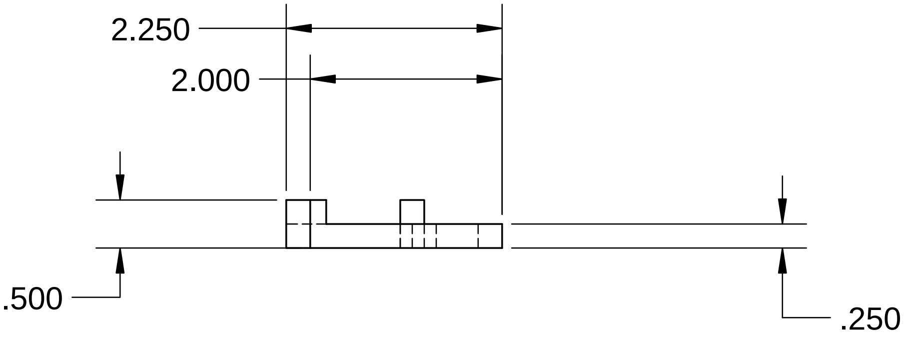
TITLE:

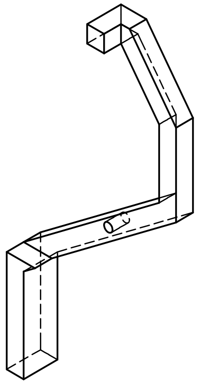
Gripper Assembly

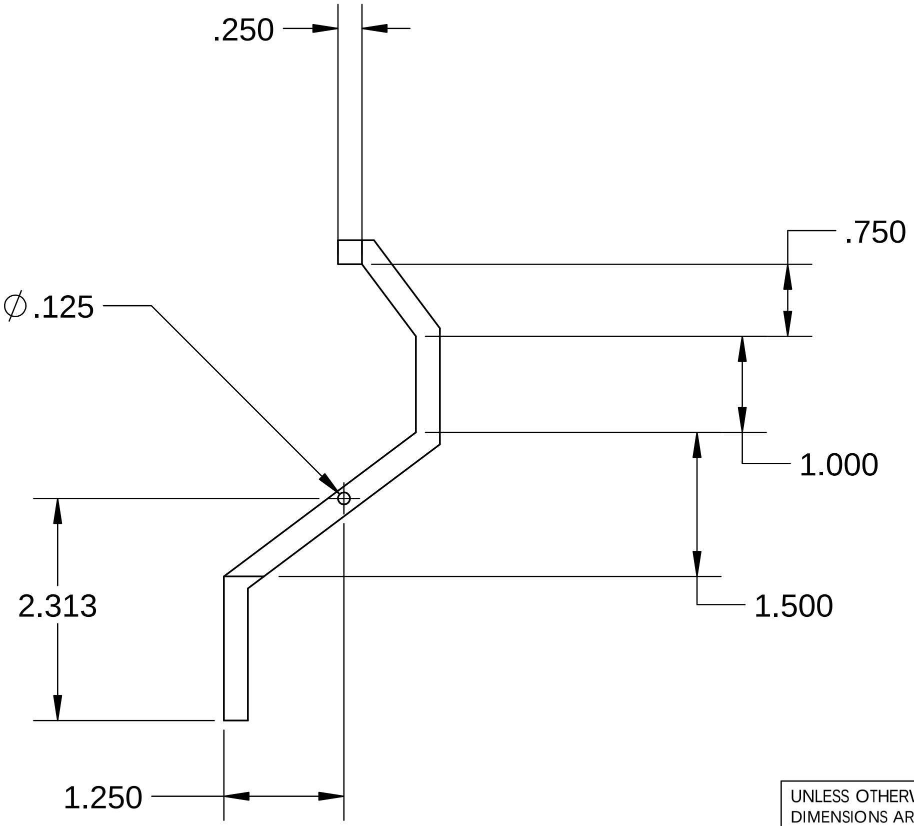
SIZE **A**
DWG. NO. 1410
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1

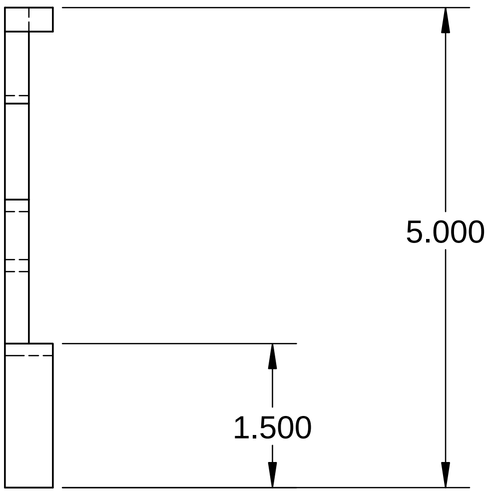
The Muckrakers

4 3 2 1









	NAME	DATE
DRAWN	Alex Tittiger	02/26/2012
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
2 DECIMAL ± 0.05
ANGULAR: MACH± 0.1deg
BEND ± 1.0 deg

MATERIAL
ALUMINUM - AL 6061

FINISH
AS MACHINED

DO NOT SCALE DRAWING

NEXT ASSY	USED ON
1410	Gripper Assembly
1000	Prototype Assembly
APPLICATION	

TITLE:

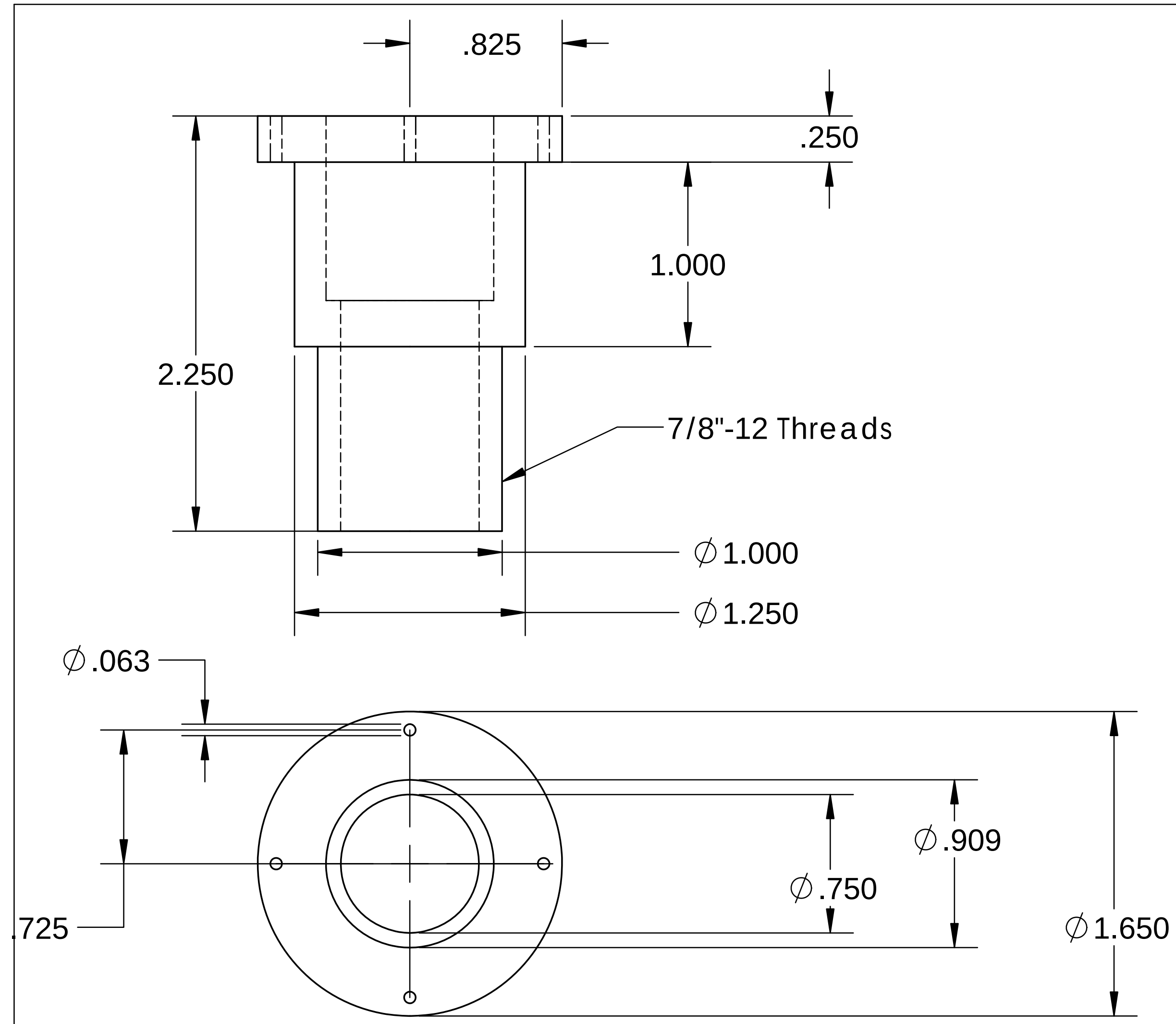
Mounted Gripper

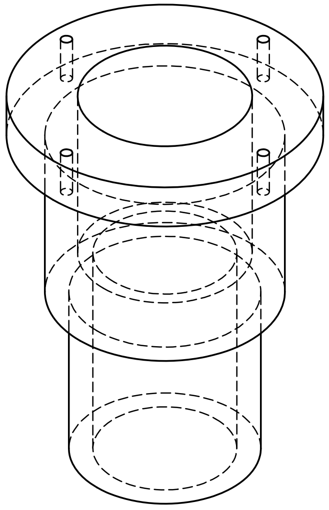
SIZE A
DWG. NO. 141-1
REV

SCALE: 1:2 WEIGHT: 0.22 lb SHEET 1 OF 1

The Muckrakers

4 3 2 1





	NAME	DATE
DRAWN	Alex Tittiger	02/26/2012
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
2 DECIMAL ± 0.05
ANGULAR: MACH± 0.1deg
BEND ± 1.0 deg

MATERIAL
ALUMINUM - AL 6061

FINISH
AS MACHINED

DO NOT SCALE DRAWING

NEXT ASSY	USED ON
1410	Gripper Assembly
1000	Prototype Assembly
APPLICATION	

TITLE:

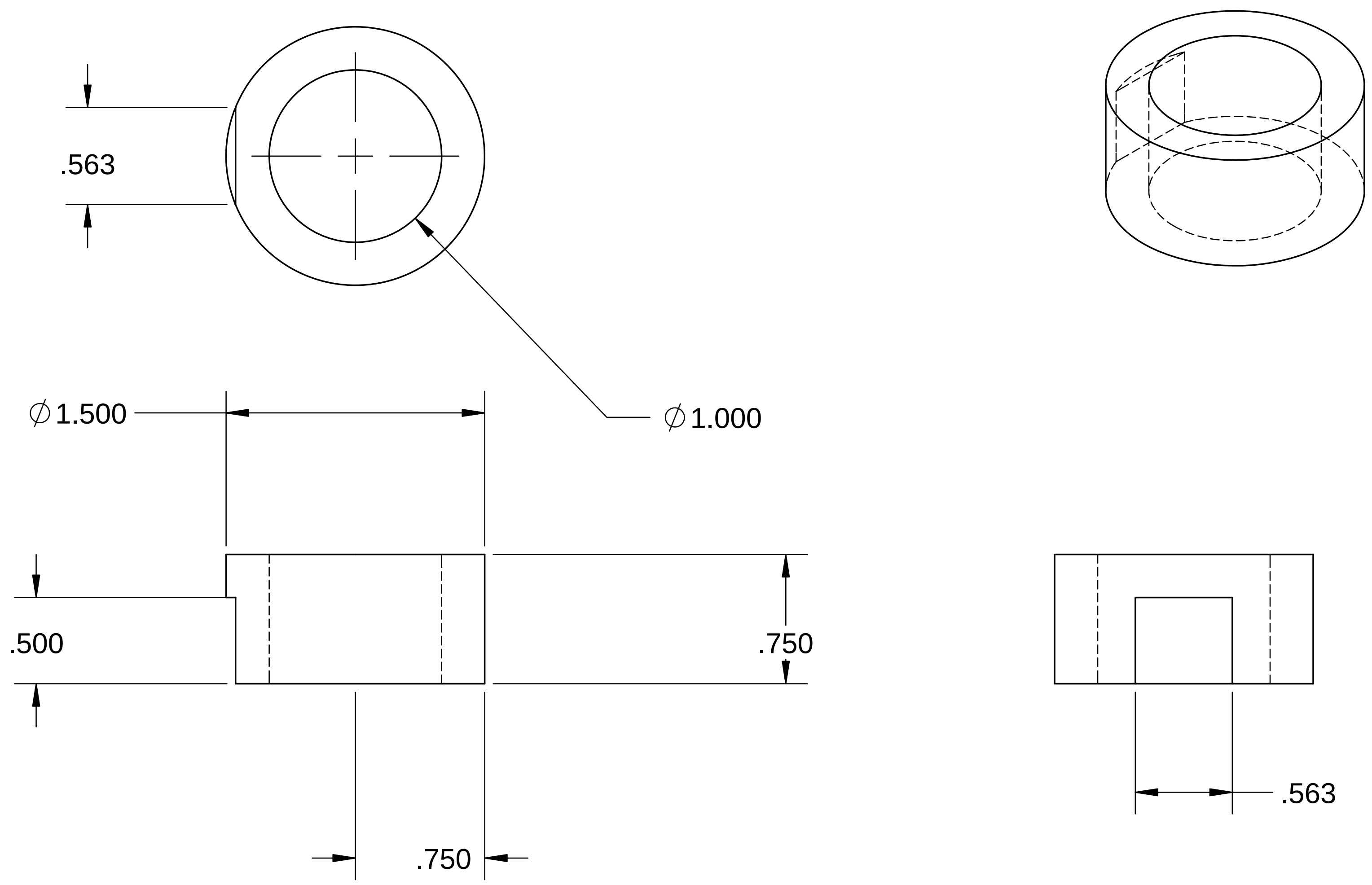
Cable Connector

SIZE A
DWG. NO. 141-2
REV

SCALE: 1:1
WEIGHT: 0.09 lb
SHEET 1 OF 1

The Muckrakers

4 3 2 1



	NAME	DATE
DRAWN	Alex Tittiger	02/26/2012
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

Gripper Connector

SIZE A

DWG. NO. 141-3

REV

SCALE: 1:1

WEIGHT: 0.07 lb

SHEET 1 OF 1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
2 DECIMAL ± 0.05
ANGULAR: MACH± 0.1deg
BEND ± 1.0 deg

MATERIAL
ALUMINUM - AL 6061

FINISH
AS MACHINED

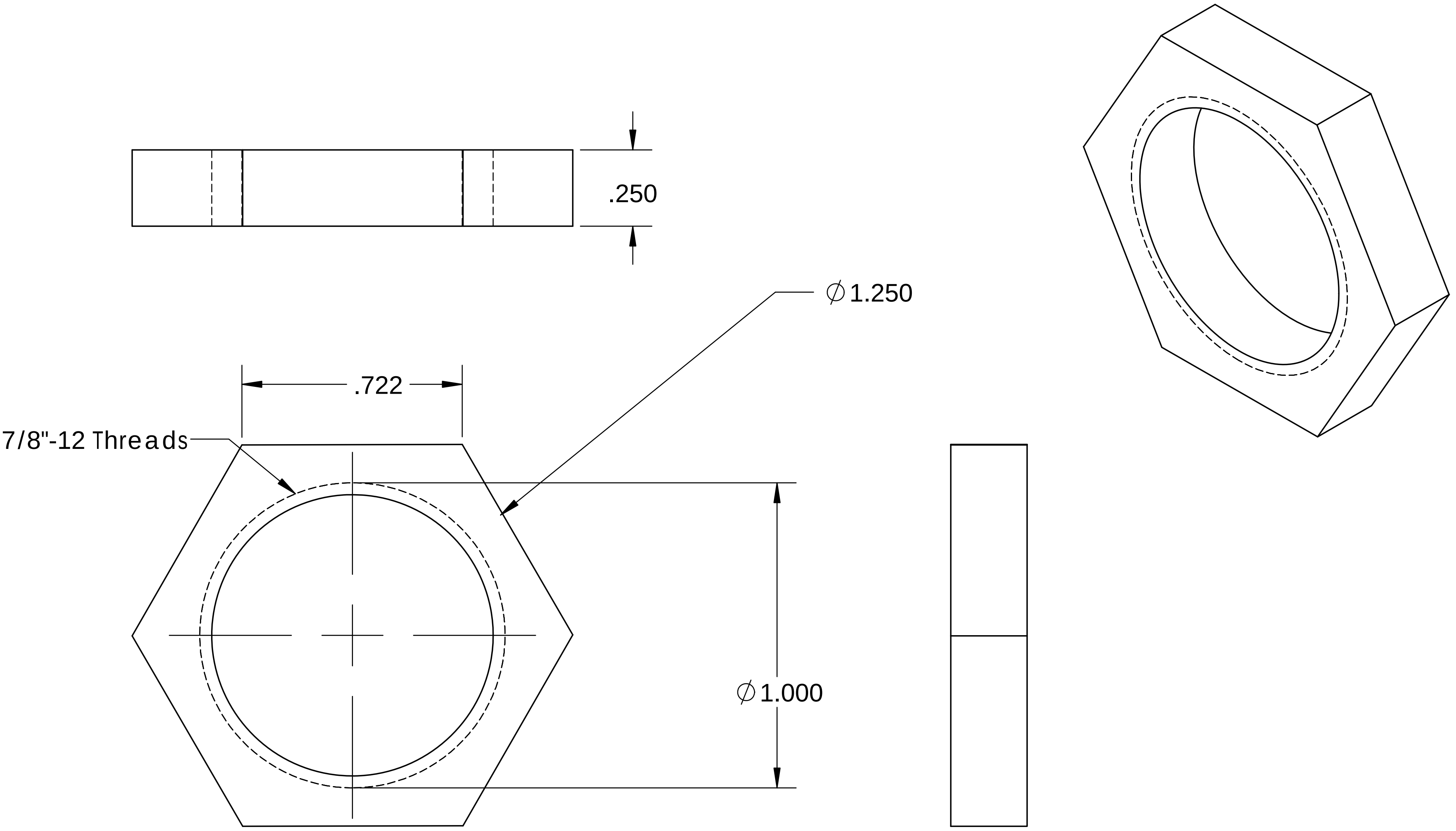
DO NOT SCALE DRAWING

NEXT ASSY	USED ON
1410	Gripper Assembly
1000	Prototype Assembly

APPLICATION

The Muckrakers

5 4 3 2 1



	NAME	DATE
DRAWN	Alex Tittiger	02/26/2012
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
2 DECIMAL ± 0.05
ANGULAR: MACH± 0.1deg
BEND ± 1.0 deg

MATERIAL
ALUMINUM - AL 6061

FINISH
AS MACHINED

DO NOT SCALE DRAWING

NEXT ASSY	USED ON
1410	Gripper Assembly
1000	Prototype Assembly
APPLICATION	

TITLE:

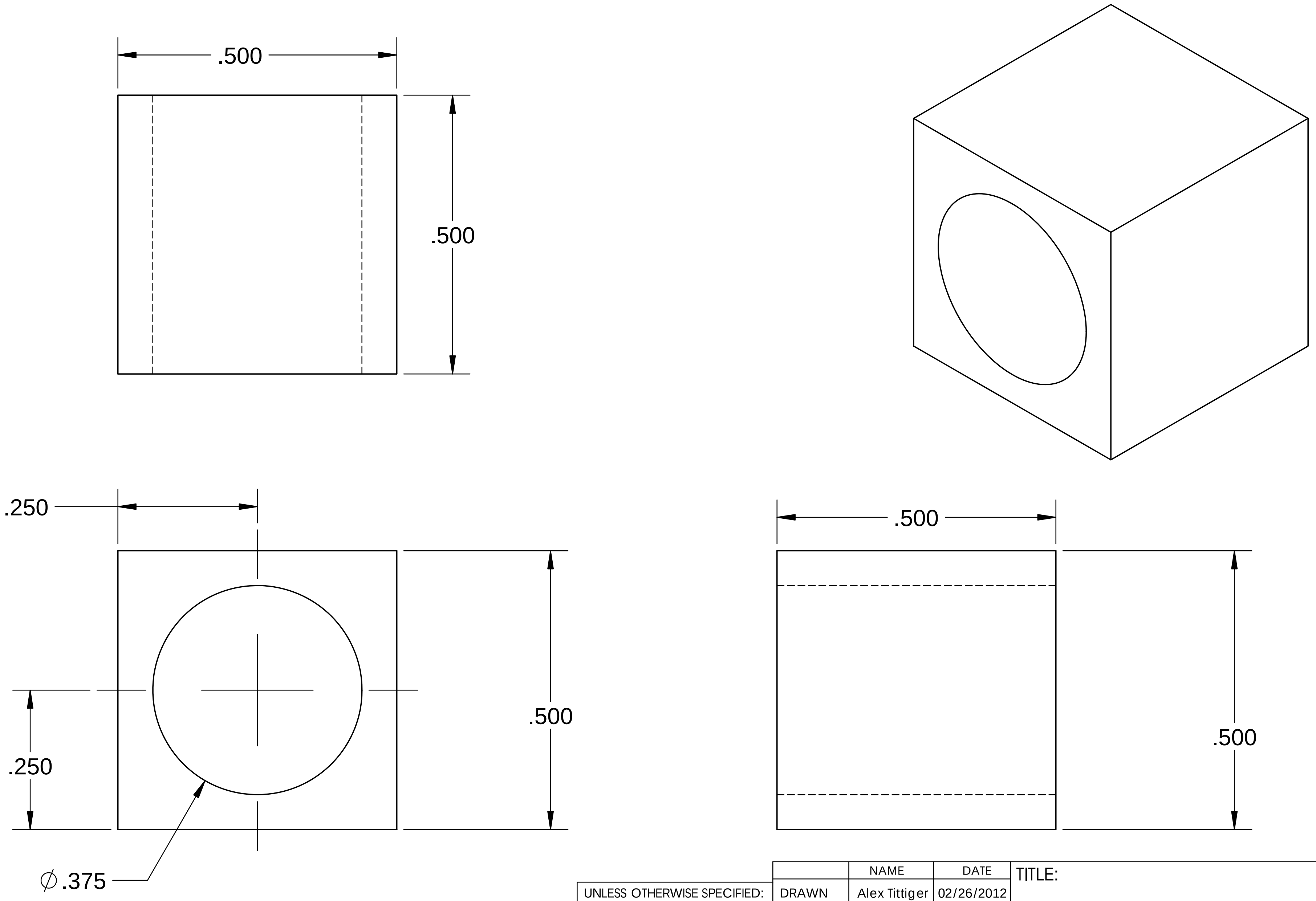
Locknut

SIZE A DWG. NO. 141-4 REV

SCALE: 2:1 WEIGHT: 0.01 lb SHEET 1 OF 1

The Muckrakers

4 3 2 1



	NAME	DATE
DRAWN	Alex Tittiger	02/26/2012
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

Borescope Guide

SIZE	DWG. NO.	REV
A	141-5	

SCALE: 4:1 WEIGHT: 0.01 lb SHEET 1 OF 1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES

TOLERANCES:
2 DECIMAL ± 0.05
ANGULAR: MACH± 0.1deg
BEND ± 1.0 deg

MATERIAL
ALUMINUM - AL 6061

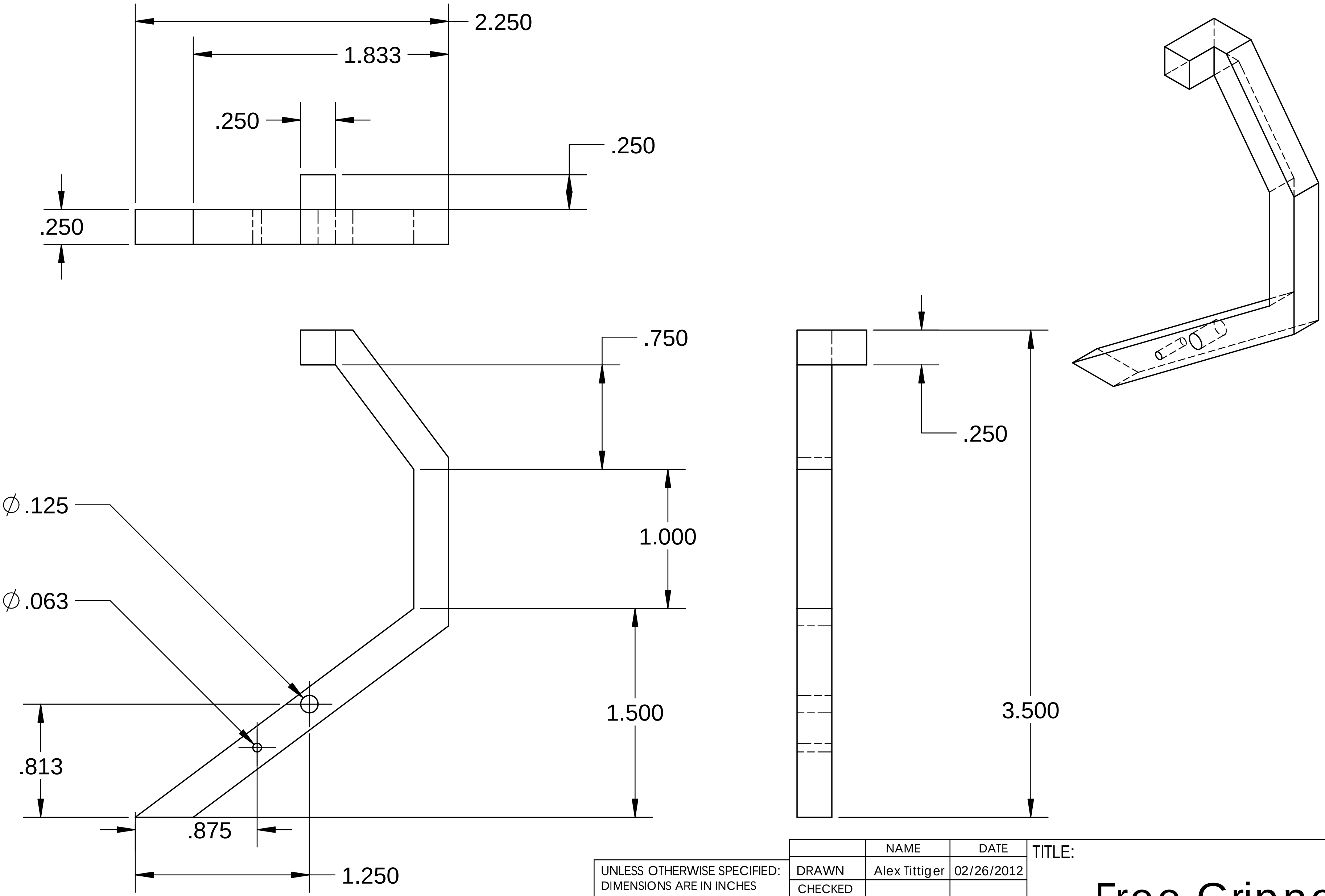
FINISH
AS MACHINED

DO NOT SCALE DRAWING

NEXT ASSY	USED ON
141-0	Gripper Assembly
100-0	Prototype Assembly
APPLICATION	

The Muckrakers

4 3 2 1



NEXT ASSY	USED ON	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: 2 DECIMAL ± 0.05 ANGULAR: MACH± 0.1deg BEND ± 1.0 deg
1410	Gripper Assembly	MATERIAL ALUMINUM - AL 6061
1000	Prototype Assembly	FINISH AS MACHINED
APPLICATION		DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Alex Tittiger	02/26/2012
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

TITLE:

Free Gripper

SIZE **A** DWG. NO. 141-6 REV

SCALE: 1:1 WEIGHT: 0.22 lb SHEET 1 OF 1

The Muckrakers

4 3 2 1

Appendix VIII – Cost Analysis Spreadsheet

Sub Assembly	Part	Material	Dimensions/Description			Qty	Unit Price	Total Price
Boom Arm								
	Cable/Bearing Holders	6061 Aluminum Rod	1.5 in OD	2 in L +		1	12.78	12.78
	Bushing	Plastic	3/8 ID	3/8 in L		1	1.35	1.35
	Bushing	Plastic	3/8 ID	1/2 in L		3	1.45	4.35
	Shafts	6061 Aluminum Rod	3/8 in OD	3 in L +		1	11.85	11.85
	Large Boom Arm	6061 Aluminum Tubing	1/8 in t	3 x 3 in	4 ft L	1	46.16	46.16
	Medium Boom Arm	6061 Aluminum Tubing	1/8 in t	2.5 x 2.5 in	2 ft L	1	20.10	20.10
	Small Boom Arm	6061 Aluminum Tubing	1/8 in t	2 x 2 in	2 ft L	1	14.72	14.72
	Cable Housing + Ferrules	Various	5 mm	25 ft		1	18.00	18.00
	Cable Stops	Aluminum	N/A			12	0.97	11.64
	Threaded rods	Steel	1/4"	1"		2	1.02	2.04
	Wing Nuts	Cast Zinc Alloy Steel	1/4"	1" wing spread		2	2.22	4.44
	Washer Pack	Zinc plated Steel	1/4" ID	5/8" OD		1	2.46	2.46
Cable Arm								
	Gripper Cable Disconnect	Quick Disconnect	N/A			1	12.95	12.95
	Gripper Cable Housing	SRAM Brake housing	5 mm D	30 m L		1	36.99	36.99
	Inner Sheath	Rubber Hose	5/8 in ID	0.91 in OD	50 ft	1	28.97	28.97
	Actuation Cable	Wire Rope	1/16 in D	50 ft		1	7.50	7.50
	Cable Guide	Nylon 6/6 Rod	1-1/4 in D	1 ft		1	5.19	5.19
	Outer Sheath	Mesh Sleeving	1 1/4 in D	10 ft		1	9.69	9.69
	Friction Reducing Sheath	PTFE Bundling Wrap	1/4 in D	10 ft		1	23.70	23.70
	Test Camera	Web Cam	N/A			1	4.80	4.80
	USB Extension Cable	USB Extension Cable	9.8 ft L			1	5.99	5.99
Cable Control Assembly								
	Control Assy Housing	6061 Aluminum Plate	1/8 in t	3 in w	36 in L	1	14.57	14.57
	Actuation Disks	6061 Aluminum Rod	3 in D	3 in L		1	16.23	16.23
	Control Rod	6061 Aluminum Rod	1/8 in D	12 in L		1	2.11	2.11
	Pivot Rod	18-8 Stainless Steel Stud	1/2 in D	3.0 in L	threaded 1/2-13	1	2.86	2.86
	Pivot Rod Nuts	Nylon-Insert Thin Hex Locknuts	1/2 in D	10 ct	threaded 1/2-13	1	8.75	8.75
	Control Surface Lock Screw	Spade Head Thumb Screw	10-24	1/2 in L		1	5.94	5.94
	Actuation Cable Adjuster	Travel Agent	N/A			1	19.76	19.76
	Gripper Clamp	Shimano Acera BL-M421 Levers	N/A			1	8.96	8.96
	Actuation Disk Washers	UHMW Polyethylene Washers	0.51 in ID	0.89 in OD	10 ct.	1	6.25	6.25
Gripper Assembly								
	Arms	6061 Aluminum Plate	1/2 in th	6 in x 3 ft		1	26.37	26.37
	Cylinder	6061 Aluminum Tubing	1 in OD	3 ft L		1	50.38	50.38
	Lock Nut	Nylon Insert Steel Hex Locknut	3/4 in ID	10 Thread		2	1.29	2.58
Multi-Assembly Materials								
	Actuation Cable	Slick Stainless Brake Wire, Road	1.5 mm D	3500 mm L		6	6.89	41.34
	Cable Input Tube/Grip Tube	6061 Aluminum Tubing	1 in OD	0.902 in ID	36 in L	1	22.16	22.16
Total								513.93

Found At
Mcmaster 8974K181 http://igus.com/iPro/iPro_02_0001_0000_USen.htm?ArtNr=G http://igus.com/iPro/iPro_02_0001_0000_USen.htm?ArtNr=G Mcmaster 8974K32 www.metalsdepot.com www.metalsdepot.com www.metalsdepot.com http://www.rei.com/product/737535/novara-brake-cable- http://www.cycle-frames.com/bicycle-frame-tubing/NOVA- http://www.mcmaster.com/#98750A011 http://www.mcmaster.com/#99862A110 http://www.homedepot.com/Tools-Hardware-Hardware-
http://www.amazon.com/Ritchey-Quick-Disconnect-Brake- http://www.amazon.com/Sram-Brake-Housing-5mm- http://www.homedepot.com/buy/outdoors/garden- http://www.mcmaster.com/#3498T61 http://www.mcmaster.com/#8538K24 http://www.mcmaster.com/#9284K416 http://www.mcmaster.com/#7432K713 http://www.amazon.com/Webcam-Camera-Vision-Meeting- http://www.amazon.com/AmazonBasics-Male-Female-
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http://www.mcmaster.com/#8975K442 http://www.mcmaster.com/#89965K392 http://www.mcmaster.com/#97135A290
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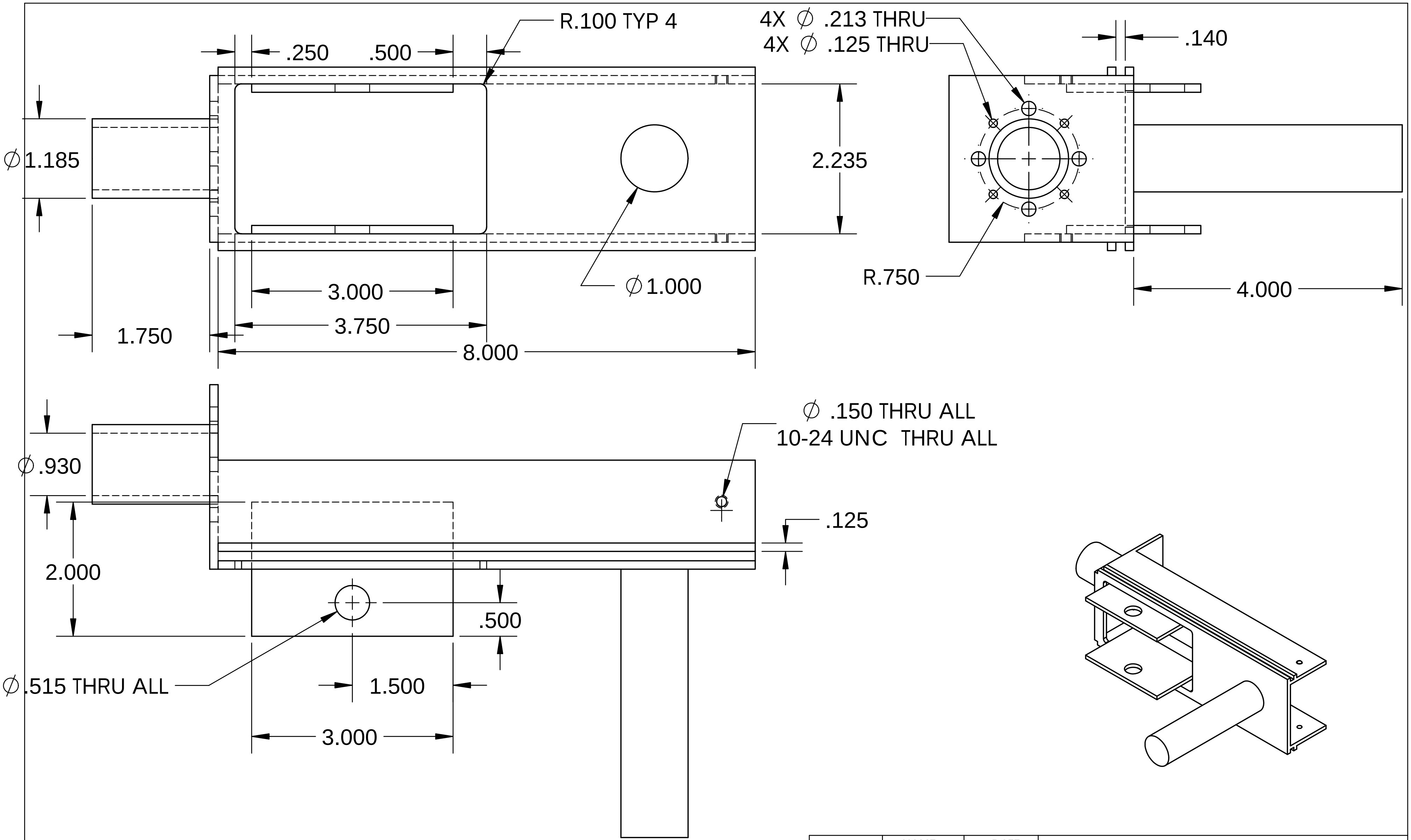
Appendix IX – Modified Part Drawings



	NAME	DATE
DRAWN	Gordon Cline	05/07/2012
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS: ALL PLATE THICKNESSES ARE 1/4" UNLESS OTHERWISE SPECIFIED

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
2 DECIMAL ± 0.05
ANGULAR: MACH± 0.1deg
BEND ± 1.0 deg

MATERIAL
ALUMINUM - AL 6061

FINISH
AS MACHINED

DO NOT SCALE DRAWING

NEXT ASSY	USED ON
121-0	Cable Control Assy
100-0	Prototype Assembly
APPLICATION	

TITLE:

Modified Chassis

SIZE A
DWG. NO. 121-1
REV

SCALE: 1:2
WEIGHT:
SHEET 1 OF 1

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4 3 2 1