UNIVERSITY OF MANITOBA

MECH 4860
Design of Nihka Propellant Liner Trimming Tool
Final Design Report

Due: December 5th, 2011

Team # 14

Sponsoring Company:

MAGELLAN AEROSPACE

Project Advisor:
Q. Peng

Team Member

Zachary J. Wolff _______________

Reuben J. Hoogerdijk _______________

Yafang Li _______________

Nan Su _______________

Table of Contents

List of Figures

List of Tables

Abstract

Bristol Aerospace Ltd. manufactures a stage of the Black Brant sounding rocket known as the Nihka rocket motor. After casting propellant into the motor casing, a two stage trim process must occur whereby first the excess propellant is trimmed away, followed by the removal of insulation tab which protrudes above the remaining propellant. This process is currently done by hand, and operator error has resulted in significant damage to the nearly completed motor. To avoid such an occurrence in the future, Bristol has requested a tool be designed which can remove the element of operator skill from the process.

Research was conducted to obtain relevant information that may aid in developing solutions to the problem, as well as to determine if any patents pertaining to the issue exist. None were found. The information gathered was used by the design team through a concept development phase that resulted in the major geometry of the device being determined, as well as a framework for how the required motion of the device would be accomplished. Following approval by the client, this selected concept was developed further to ensure its technical viability, and to address factors such as safety, manufacturability, reparability, and cost. Detailed part drawings and manufacturing instructions are contained in the report.

The device will locate onto the rocket via a custom made interface plate that will bolt into pre-existing radial holes in the rocket. The use of three or more holes will guarantee the tool coincides with the rocket axes. Rotational motion is accomplished with a commercially available bearing. A tool holder can translate across the diameter above the propellant by sliding on radial bars which are fixed to the inner surface of the bearing. Two separate blades for the different cutting processes were designed which can move up and down relative to the rocket by means of a rack and pinion gear system contained in the tool holder. These three motions can be used together to ensure that the blades can cover all required surfaces for both the propellant and insulation liner. The entire assembly is fabricated from SAE 300 series stainless steel.

All necessary target specifications and constraints were adhered to in the solution of the problem. The final weight of the design is approximated at 60.7 pounds, and estimated budget, including machining costs, is \$7461.31. As this budget is significantly less than the

cost of repairing a single damaged motor, Team 14 recommends implementation of this device to the Nihka manufacturing process.

1. Problem Background & Statement

In order to appreciate how this project will aid the client to manufacture the Black Brant sounding rocket system, some background on the corporation and the program is included, beginning with the company, moving into the sounding rocket program, and finally with a description of the Nihka rocket motor, as well as the nature of the problem to which a solution is provided at the conclusion of this report.

1.1 Background of Bristol Aerospace Ltd.

Bristol Aerospace boasts a storied history of aviation excellence, experience and innovation that has been a backbone of the Winnipeg aerospace industry for nearly 80 years. The company was founded as the Macdonald Brothers Aircraft Company in 1930 to service a growing need for sea plane floats in the center of the continent. Over the years, its employees and facilities have actively participated in many of the great aeronautical achievements we still speak of today, serving both our country's military needs and the requirements of the civil aviation industry. Post World War II, Bristol won major service contracts for the RCAF, and took this opportunity to continue to expand its expertise and abilities into an impressive arsenal of in-house capabilities. By the 1960's, this company was a major player in repair and overhaul of jet engine afterburners (due to some major design innovations from the engineering team), as well as continuing to manufacture other aircraft components and branching out into diverse activities such as helicopter service contracts, nuclear reactor components, space operations, and military fabrication [1].

Around this time of increasing diversification, Bristol began to be involved with manufacturing solid propellant research rockets. In 1962, the company acquired a 3000 acre site, now known as the Rockwood facility, north of Winnipeg for these operations. These research rockets later became known as the Black Brant Sounding Rocket system, and all solid propellant rocket production is still carried out at this facility today [1].

1.2 Background of the Black Brant

Figure 1. Nihka rocket motor (in green box) [2]

The Black Brant Sounding Rocket system is a family of research rockets, and there are a number of configurations that can be achieved, which are tailored to the specific requirements of the experiment being carried out during the launch [2]. The system can range from a single stage rocket up to a four stage rocket if necessary. The configurations are as follows:

BB-5 (Single Stage)

BB-9 (2 Stage Rocket)

BB-10 (3 Stage Rocket; essentially the BB-9 plus the Nihka Rocket Motor)

BB-11 (3 Stage Rocket without the Nihka)

BB-12 (4 Stage Rocket; essentially the BB-11 plus the Nihka, (Figure 1) with the Nihka highlighted in the green box)

An in depth discussion of the Nihka rocket motor will be provided shortly to provide context to how it is involved in this project.

In the most powerful configuration (BB-12), this rocket can reach an altitude of about 1400 km (with a payload of 100 lbs), but doesn't achieve the velocity necessary to retain orbit. These rockets are used to transport experiments up into a zero gravity environment as the flight path can offer about 20 minutes of zero gravity environments. The Black Brant is still seen as a relatively inexpensive, effective means to carry out such experiments [1].

1.3 Background of the Nihka Rocket Motor

The Nihka Rocket Motor is the final stage of the Black Brant System. This rocket motor was designed to fire exo-atmospherically [2]. This motor was first manufactured in the 1980's and production continued until 1998. The Sounding Rocket Working Group noted "the Nihka capabilities are considered absolutely essential to the NASA Sounding Rocket Program" [3]. Another production run was carried out in the latter part of the 2000's, and to validate the production run, a static test was carried out on November 5, 2009 [2]. The ignition of this test is pictured in Fig. 2, and this picture also gives a better view of what the motor looks like when isolated from the remainder of the Black Brant [2].

Figure 2. Nihka static test, 5 Nov 2009 [2]

1.4 Overview of the Nihka's Construction and Components

A cutaway representation of the Nihka rocket is included to help the reader understand the main geometry of this component, as such an understanding will aid in visualizing the problem this project will address [2].

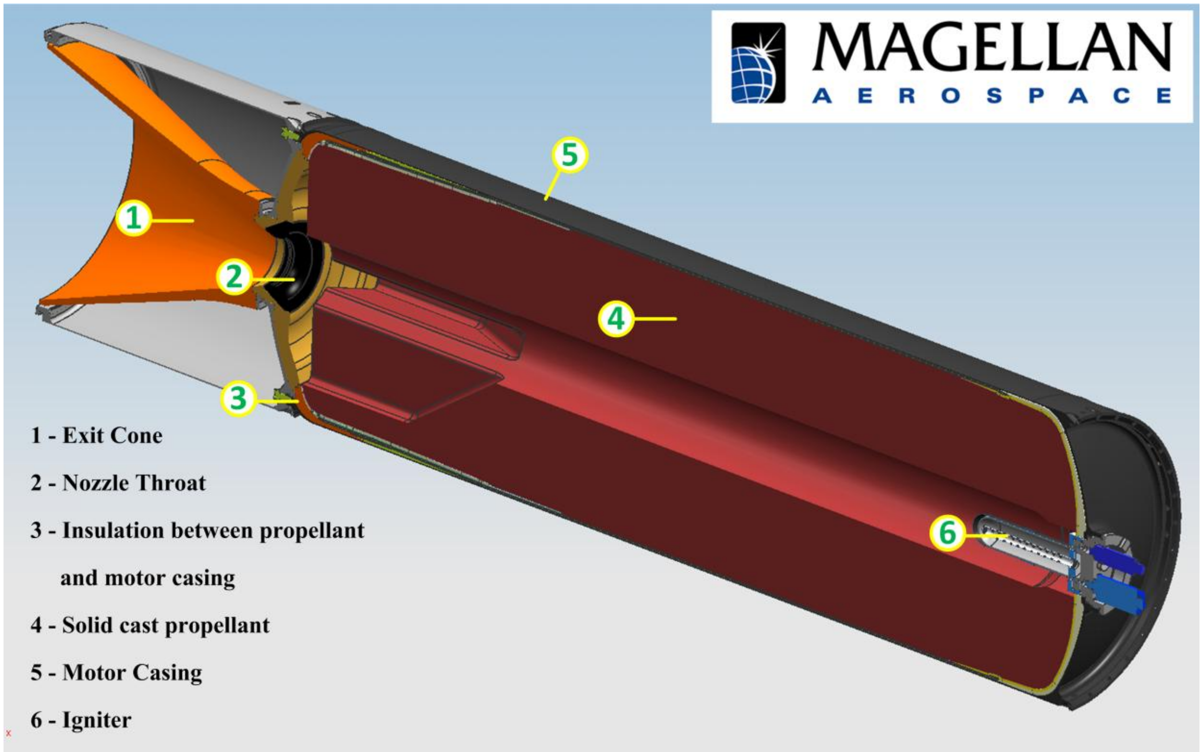


Figure 3. Nihka rocket motor [2]

The casing for this motor is constructed from low alloy carbon steel, grade 4335, which is a high strength steel with yield strengths tempered in the 180ksi range. Nominal thickness of the motor casing is between 0.07" to 0.075", and the minimum thickness is 0.069". The igniter, labelled 6 in Figure 3, can be seen to protrude into a cavity left in the propellant from a mandrel. The ignition reaction begins on the exposed surfaces and gains intensity very quickly. A squib fires a booster charge, which fires the main igniter charge, thereby pressurizing the chamber. The heat and gases exit through the graphite nozzle throat, labelled 2 in Figure 3, which is the highest erosion point on the rocket. This component is fabricated by milling a solid graphite block into net shape. The exit cone directs the forces produced from the reaction away from the rocket to produce thrust [2].

The main focus of the project concerns the insulation of the casing, which is labelled as 3 in Figure 3. During the burn, the environment within the motor casing can become quite severe. Temperatures reach as high as 3000 ℃, with pressures around 900- 1000 psi. Hydrochloric acids and aluminum slag will also be found in the motor at this time. To prevent these harsh conditions from causing burn-through in the casing during the 17 second burn period two part insulation is applied to the inner steel casing before the propellant is cast within it. First, silica phenolic fabric is pre-cured against the casing walls. Following this, a rubber like coating (Ethylene Propylene Diene Monomer, EPDM) is applied to seal the fabric and offer extra protection for the steel. A coating of primer is applied to the EPDM to promote adhesion of the solid propellant with the insulation [2].

1.5 Overview of the Casting

Prior to the actual casting of the propellant into the properly prepared motor casing, the propellant mixture is prepared and heated to a slightly elevated temperature. At the time of casting, the propellant is a viscous liquid. As it cools and solidifies the propellant bonds to the insulation and shrinks due to thermal expansion effects. To prevent damage to the propellant, the insulation needs freedom to pull away from steel, as it is pulled by the shrinking propellant. This leaves a gap exposed between the insulation and the steel around the aft lip of the rocket when viewed after cooling. However, as mentioned earlier it is very important to avoid getting any propellant between the insulation and the casing. In order to deal with this issue, the EPDM lining is extended slightly further than needed up the lip of the aft end of the casing. This extra EPDM effectively seals this point for the time being, and is cut off in a subsequent process. This tab is labeled in Fig. 4 [2].

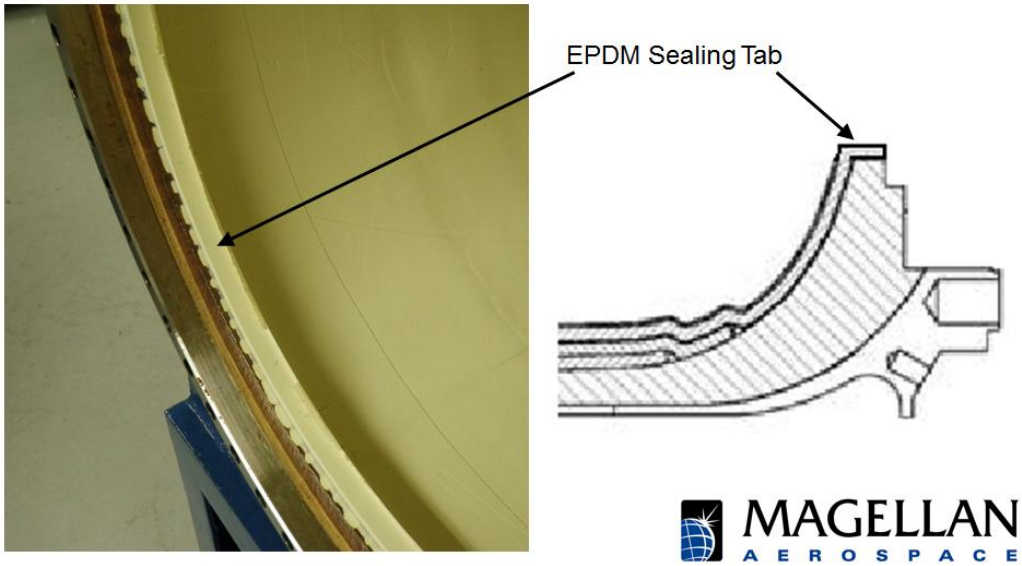


Figure 4. Nihka aft end (no propellant shown) [2]

During the casting process, a mandrel is located within the motor casing, and the propellant is cast around this mandrel. The shape of this mandrel is very sophisticated; the cavity left behind after removal of the mandrel has a surface area that affects the rate of the reaction (which is a function of surface area) at different points in the burn. The mandrel has a slight draft angle and is removed after the propellant has solidified. At this point in the process, a three step trim operation takes place to prepare the rocket for the mounting of the nozzle:

Step 1: The bulk excess of propellant that has flown around the mandrel and now protrudes beyond the aft end of the rocket is removed in Figure 45.

Step 2: The remaining propellant is faced using sandpaper to even out the surface.

Step 3: The EPDM sealing tab, mentioned previously, is manually cut with a knife, following the contour of the propellant [2].

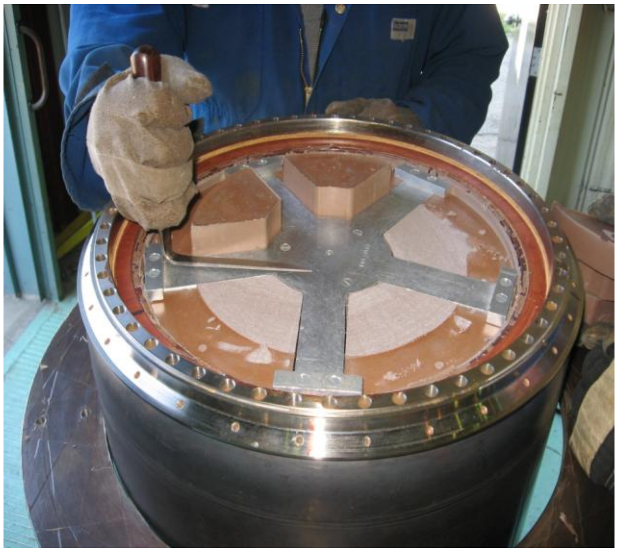


Figure 5. Nihka aft end - after casting [2]

1.6 Background of the Problem

A somewhat exhaustive overview of the rocket, its geometry, and the casting process was necessary in order to facilitate an understanding of where, specifically, the problem arises in this process. Step 3 of the trim process has been found to be highly operator dependent and poses risks for expensive and difficult rework at a late stage in the manufacturing process. The propellant has a consistency similar to a pencil eraser, while the EPDM is a much tougher material. This difference in material properties results in greatly different cutting forces required to trim the two materials, which makes the cutting procedure challenging. Because the EPDM tab is cut manually, with no tool to guide the operator or the blade, one incident has occurred where the tab was cut too deep, leaving some of the casing exposed. Inadequate operator training was found to be a contributing factor to this incident, so Bristol wishes to have a device which can reduce the operator skill factor from the process as much as possible. The following photo shows the lip of a motor damaged by over-trimming. The damaged area is boxed in red in Figure 6 [2].

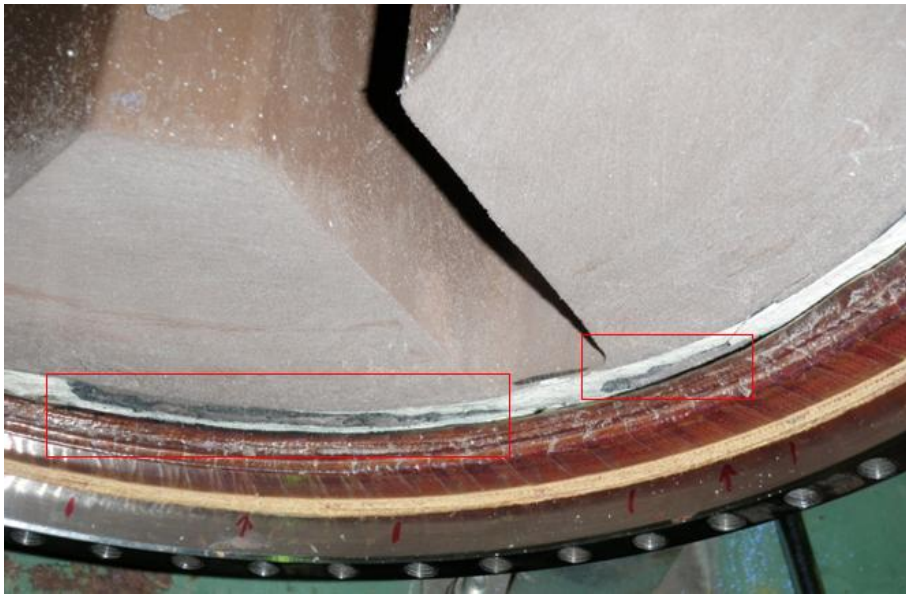


Figure 6. Nihka aft end - Over Trimming [2].

2. Project Objective

In order to have a metric by which to analyze the level of success Team 14 can realize in the completion of this project, we need to clearly define the objectives we wish to achieve. To that end, the successful completion of this design project will include the following [2]:

- A working design concept that Bristol may manufacture or have manufactured that is specifically designed to guide the cutting tool as it removes both the excess propellant and the EPDM tab, and conforms to the geometry of the current motor casing. Minor modification to dimensions, materials, or specific parts may be made by Bristol upon manufacturing the tool to accommodate available components or improve the interface between the rocket and the tool, as exact dimensions will not be provided to the design team for proprietary reasons.
- The main goal of this design is to reduce or eliminate the impact or possibility of operator error which occurs during the post casting trim operation on the Nihka Rocket Motor. Objectives such as reducing time or material waste are secondary to promoting quality and introducing repeatability into this stage of the manufacturing process.
- While all drawings and plans that are delivered will be reviewed and approved by a professional engineer prior to building the design, as much supplementary material as possible to aid in the description of the proposed design shall be delivered with the design report. This includes either drawings of the tool, a 3D CAD model, or both.
- All information required to manufacture the device, as well as any pertinent information regarding its intended usage, will be explored in as great a detail as possible and will be submitted in a formal engineering design report at the completion of the project, along with the aforementioned drawings.

2.1 Target Specification and Constraint Tables

Certain elements of the working environment for the tool designed in this report limit the possible solutions that may be presented as part of the design. Additionally, a number of geometrical and operational specifications have been specified to provide a framework that the device must satisfy. These target specifications are listed in

TABLE I SUMMARY OF TAGET SPECIFICATIONS, below.

TABLE I SUMMARY OF TAGET SPECIFICATIONS

Target Specifications		
Geometrical Specifications	1	Tool must mount on holes in a circular diameter pattern. This circular pattern has a diameter of approximately 15.5 inches.
	2	Tool must have an adjustable depth ranging from 0.1 inches to 0.5 inches.
	3	The tool must mount on the rocket which will be oriented horizontally.
	4	The tool must be light enough to ensure the rocket does not tip over upon installation. Weight will be limited at 60 pounds.
Environment for Tools to Operate	1	Tool will operate indoors, at room temperature with climate and moisture controlled.
	2	Environment must conform to explosive safety requirements.
Requirements for Operational Abilities of Device	1	Tool must be able to trim the propellant and the EPDM.
	2	Design must incorporate protection from over trimming EPDM tab.
	3	Device must be simple to use and not require extensive training.
	4	Tool must cut cleanly without tearing the material.

	5	Depth of cut must be precise and controllable.
	6	The tool must perform its operation accurately and allow for repeatability.
	7	Processing time should not significantly increase.
	8	Design must conform to explosive safety requirements.
Material Requirements	1	Material must be non-sparking.
	2	Cutting blade material must be able to cut through both propellant and EPDM.
Presentation Requirements	1	Pictures of design from 3D CAD software are preferred.
	2	Imperial units are required.

TABLE II contains a list of the design constraints and limitations.

TABLE II SUMMARY OF CONSTRAINTS & LIMITATIONS

Constraints & Limitations		
Explosive Safety Requirements	1	No electrical power to move either blades or device.
	2	No electrically powered lights.
	3	No metal to metal impact to prevent sparks.
	4	Materials used in design must be non-sparking .
Avoid Contamination of the Rocket Propellant	1	Ferric oxide (rust) is a component of propellant so steel blades may be used to cut the materials.
	2	No solvents can be used as they will contaminate the propellant.
	3	No coolants can be used as they will contaminate the propellant.
	4	No condensation can be occur as it will contaminate the propellant.
	5	No grease, so mechanical components should be selected that

		do not need lubrication.
Conform to Existing Geometry	1	Bolt pattern which will be used to locate tool is fixed with a 15.5 inch diameter.
	2	Weight should be under 60 pounds to allow for easy movement and setup.
	3	Design must be small enough to require one operator at a time.
Time	1	Design process must be completed in 3 months, which is dictated by the length of the Engineering Design course.
Cost	1	Approximate figure of $10,000 dollars given for a budget.

3. Final Design and Analysis

A lengthy concept development process was conducted to generate possible solutions to the problem statement given, while observing the specifications and constraints that accompany the project. Details of this process are included in Appendix D. The concepts were organized into table format, and following each round of idea generation the proposals were critiqued, and positive aspects combined to develop increasingly complete possible designs. At the completion of this stage of the design process, the team had selected the framework for a tool that could satisfy the design requirements. Sections 3.1- 3.3 will provide details of the completed design, as well as describe critical components, analysis, and cost and manufacturing considerations.

3.1 Features of Final Design

Prior to describing the operation and importance of individual components in the design, some overview is in order. Figure 7 pictures the assembled tool as it will locate on the aft lip of the rocket.

Figure 7. Overall of final design

The tool will mount on the rocket via a pattern of bolts holes that are arranged radially on the aft lip of the motor. These bolting locations are pre-existing, and will eventually be used to mount the exit cone to the completed motor. A tool to rocket interface plate will contain the same pattern of holes to accomplish locating the tool properly. Extending perpendicular upwards from this interface plate is a stainless steel ring, which can be seen in Figure 7. A pre-existing industrial bearing has been sourced which will be press fit into this outer ring. The bearing has a critical function in the design, as it allows the components mounted to the inner face to rotate freely. To help illustrate this range of motion, a series of captures from Animations 1 and 2 are included in Figure 8 and Figure 9 below.

Figure 8. Animation 1

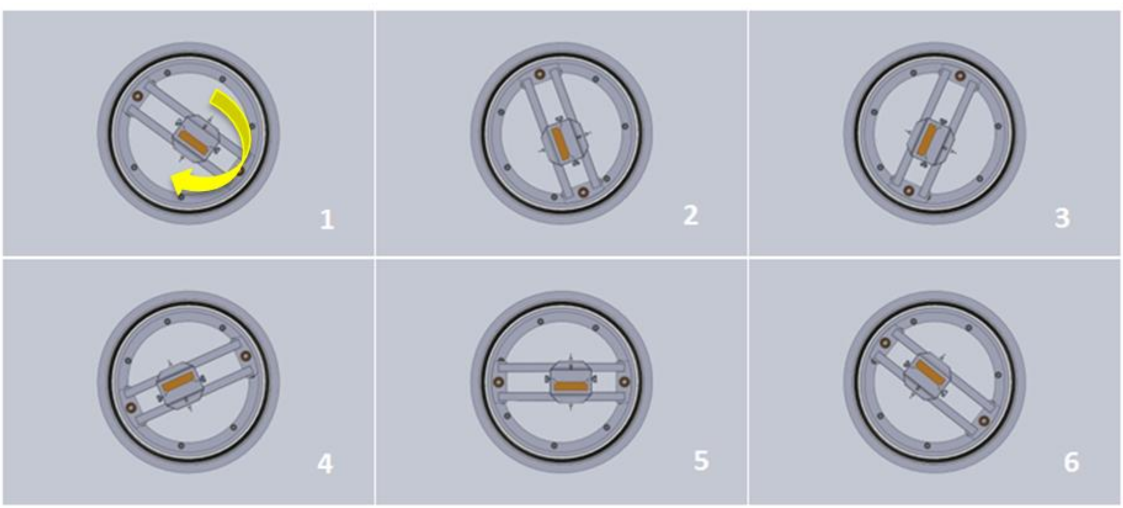


Figure 9. Animation 2

A second ring will be press fit inside to the bearing. Fig.11 shows two radial beams that extend directly across the diameter above the exposed rocket propellant. These beams are used to guide the tool holder to any radial position desired. A third animation is included to help illustrate this range of motion.

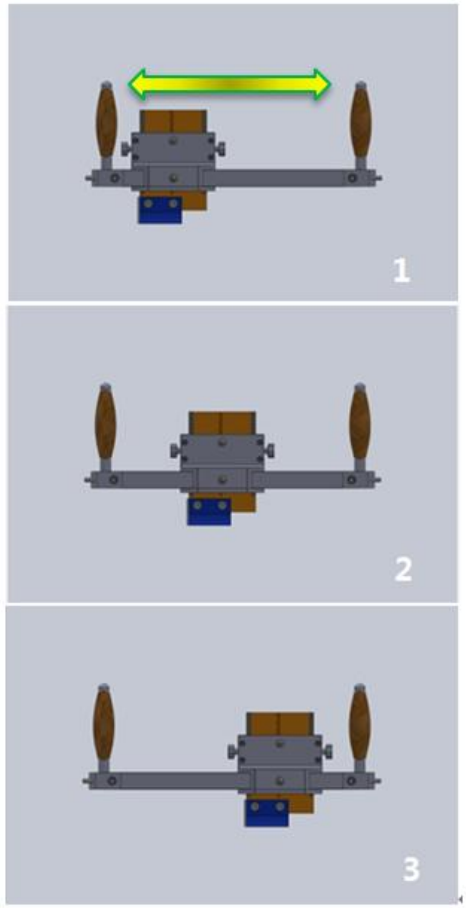


Figure 10. Animation 3

Between the motions demonstrated in Animations 1-3, the tool holder is able to cover every surface within a given vertical plane. The final motional ability of the device is the capacity of the tool holder to move up and down into the propellant cavity of the rocket. This is accomplished through a gearing system located within the tool holder. This motion is demonstrated in Animation 4 of Figure 11.

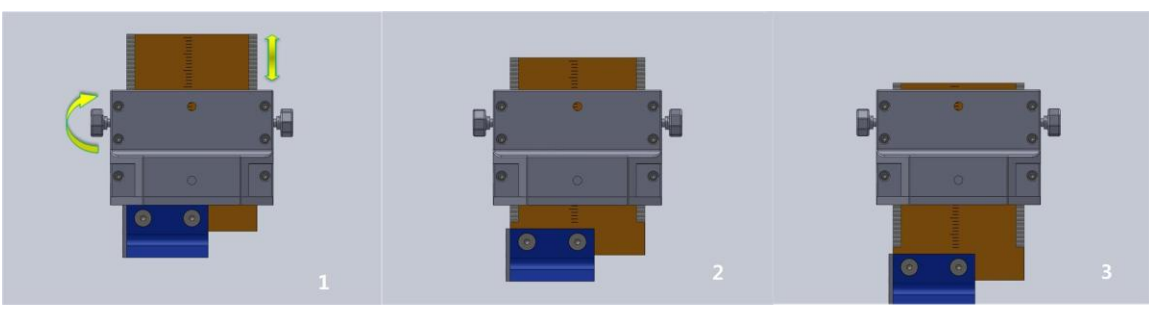


Figure 11. Animation 4

The operation of the device is simple. A blade, which has been custom designed to shave off layers of the propellant, is mounted at the base of a plate which moves in relation to the tool holder via a rack and pinion gear system. Two handles, which can be seen protruding upwards in Figure 12, are used to rotate the inner portion of the bearing 360 °at a fixed vertical distance. After this has been accomplished, the tool holder is incremented radially outwards from the center of the rocket diameter, sliding along the radial beams, and the 360 °rotation is repeated. This increment is repeated until the blade encounters the outer lip of the rocket and all of the required propellant in the vertical plane to which the tool holder is set has been removed. The tool holder is returned to the axial center of the rocket, and the rack and pinion gear system is used to move the blade downwards as desired. The preceding process is repeated until the propellant has been satisfactorily removed.

A second blade is required to perform the EPDM trim, which is the following stage of the post casting trim process. This second blade is much smaller, and a mount for it has been incorporated into a holder of the same geometry as the blade used for the propellant trim. Once the propellant has been trimmed to the correct depth, the propellant blade is removed from the blade mount by removing two bolts and the second blade mount is re-attached. The same motion of the tool can now be used to remove the tab by sliding the tool holder to the outer diameter until the protruding blade pierces the EPDM located on the rocket wall, and a single final rotation of the tool will slice off the base of the excess EPDM, completing the trim operation.

Some additional images are included to aid in understanding the overall geometry of the device before specific components will be discussed. In Fig. 12, on the following page, the orange block protruding from the top of the tool holder is the blade mount, which has the ability to move up and down via the gear system and has the propellant cutting blade fixed to its base.

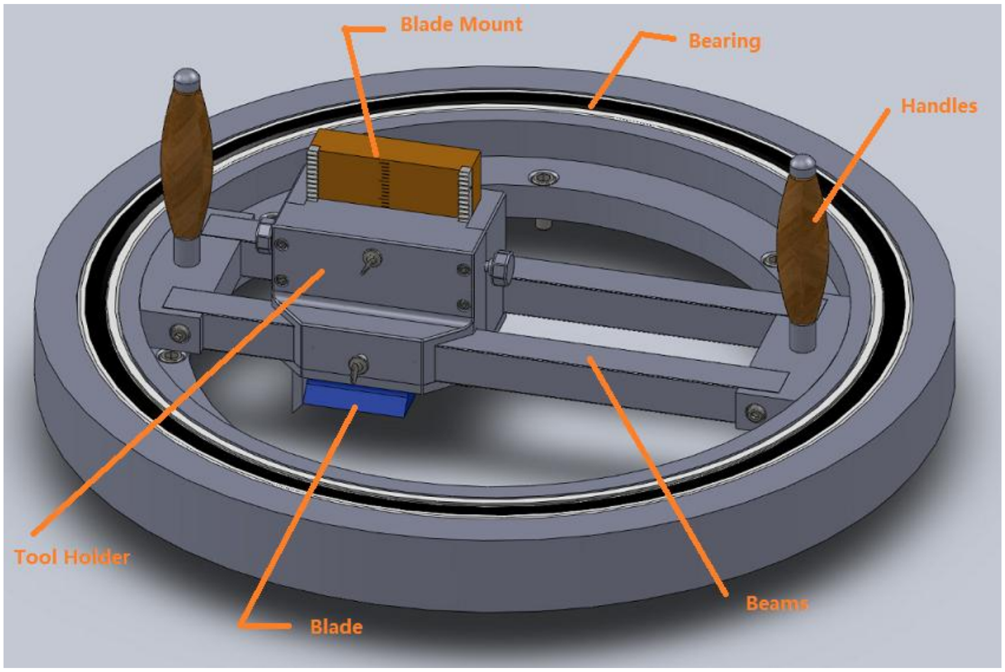


Figure 12. Main Part Names of Final Trimming Tool

A bottom isometric view of the assembly is shown in Fig. 13 to better illustrate the location of the cutting blade, as well as demonstrate the location of the radial bolt pattern which will fix the tool to the aft lip of the rocket.

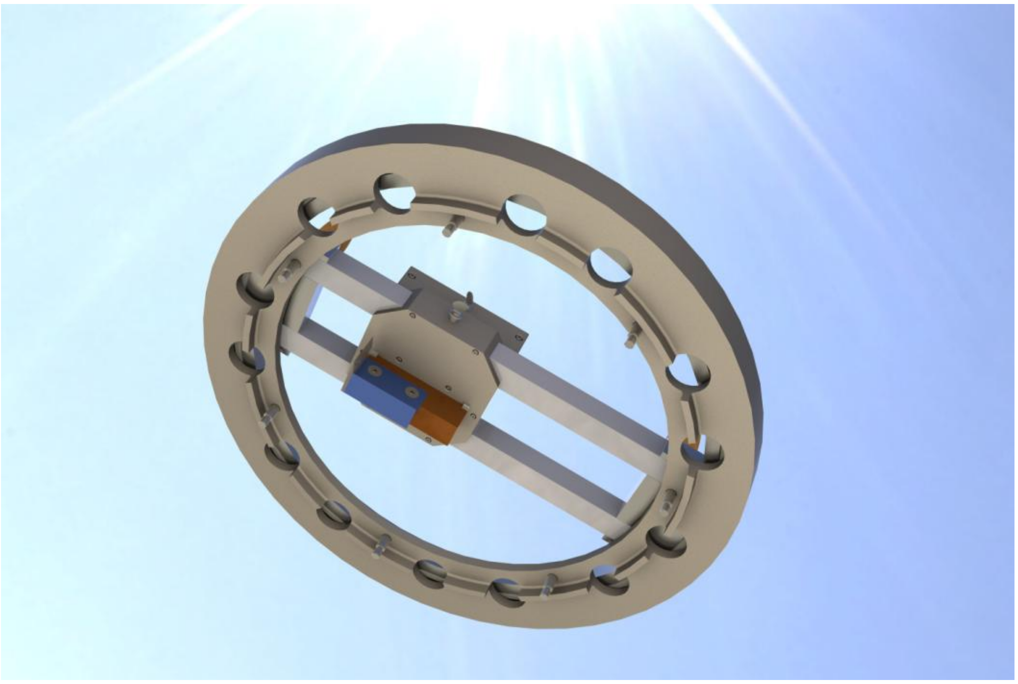


Figure 13. Bottom view of the assembly

3.1.1 Rocket to Tool Interface and Bearing

Three critical components in the function of the design are the bearing to rocket interface, the bearing itself, and the inner ring, pictured in Figure 14. The three components are labeled A, B and C respectively in Figure 14. Component B, the bearing, is essential as it accomplishes the most important motion of the entire assembly by allowing all components mounted to its inner surface the ability to rotate. A number of design proposals were considered to fabricate this as a custom component, but the decision was made to source an existing component to control manufacturing cost. This decision also ensures whatever device is selected to provide this critical motion has the benefit of previous field applications to verify its structural integrity. A sealed bearing was chosen to ensure debris from the cutting process would not collect between the two rotating rings, thereby reducing the service life of the component. Also, the bearing is 4 point contact in nature, which secures both the inner and outer rings of the bearing firmly, regardless of orientation, so that the tool has no danger of becoming mis-calibrated or rotating poorly when not in a vertical orientation, as it will be horizontal during service. Component A, the outer ring and bearing to rocket interface plate, secures the bearing (and therefore the entire inner assembly) in the correct orientation relative to the rocket, as well as allowing the assembly to bolt to the rocket via the radial holes on the aft lip as discussed earlier in this section. The inner ring provides a surface for the radial beams to mount the without risking damage to the bearing by necessitating either bolts locations or a weld. Any weld to the finely calibrated bearing risks distorting the heat affected ring, and detracting from the rotational ability, or ruining the bearing altogether. Both the inner and outer rings are secured to the bearing by a press fit. The compressive and tensile forces from these two opposing press fit rings will work together to reduce the tendency of the bearing to distort under the interference fit, which may have been a concern if only one press fit ring was used. The inner ring should be cooled and pressed into the bearing first, followed by elevating the outer ring temperature and carrying out the second press fit operation. A detailed set of manufacturing instructions for components A and C, as well as all other custom components specified in the design, is included in Appendix B.

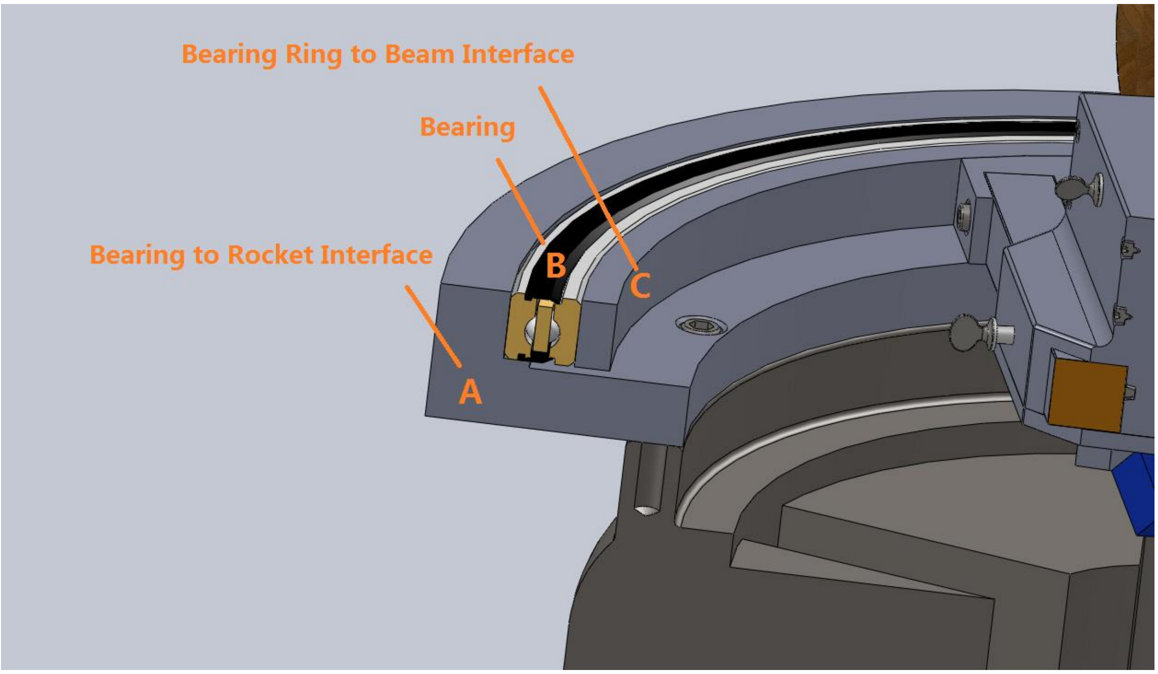


Figure 14. Rocket to tool interface and bearing

3.1.2 Bearing Ring to Beam Interface Device

A custom bracket has been designed that will mount to the inner ring (component C in Figure 14) to allow for secure attachment of the radial beams. Mounting the beams to this inner surface will allow the inner tool holder and assembly to spin with the bearing. Details on manufacturing and how to secure both the radial beams to the interface device, as well as the interface device to the inner ring, are included in Appendix B. Manual power is applied to rotate the tool through these components, as the two handles which will be turned by the operator extend vertically, again as in Figure 12. Two handles were chosen, rather than one, to allow for a smoother, more even application of force throughout the motion of the tool. The interface device, as mounted to the inner ring, is shown in Figure 15.

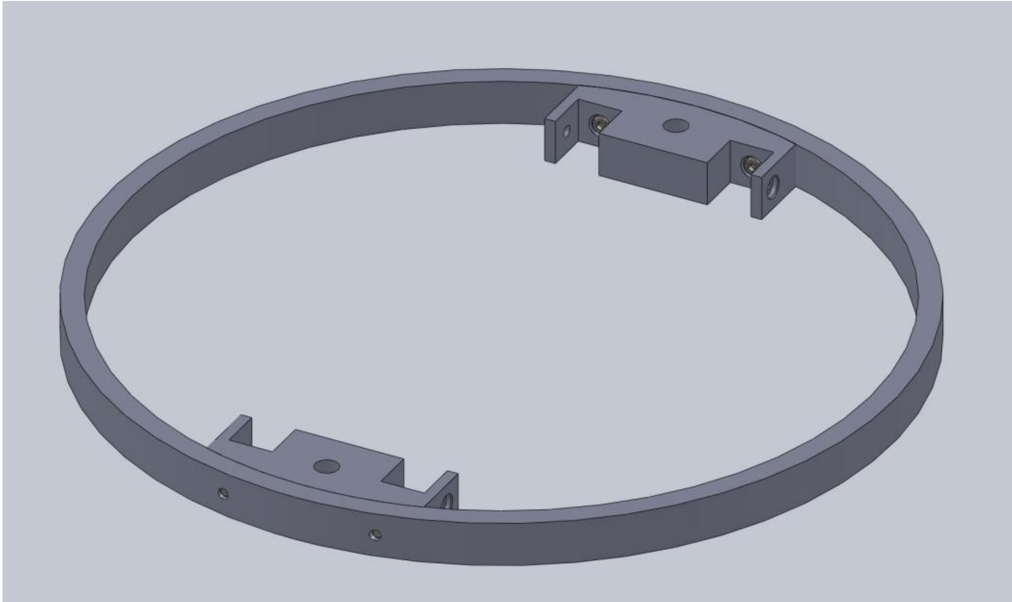


Figure 15. Interface device

3.1.3 Radial Beams and Tool Holder Assembly

The radial beams that span the diameter above the propellant cavity provide the dual function of supporting the tool holder, as well as allowing the tool holder to slide from side to side, thereby covering the required surface area as in animation 3. The inner assembly is demonstrated in Figure 16. A beam-in-bending analysis was performed to determine the deflection of these bars under a worst case scenario of the entire weight of an operator applied directly to the center of the beams. The full analysis can be found in Appendix A, with the result being 0.167mm deflection. This value is sufficiently small to be considered negligible, especially considering the unlikelihood of such a force being applied during operation. To prevent excessive friction from the tool holder sliding on the radial beams, as well as the possibility of metallic shavings falling into the propellant cavity to contaminate the propellant, the beams will be coated with Protocoat, which is a Teflon-like coating which is baked onto the beams with a resulting thickness of roughly 0.002”.

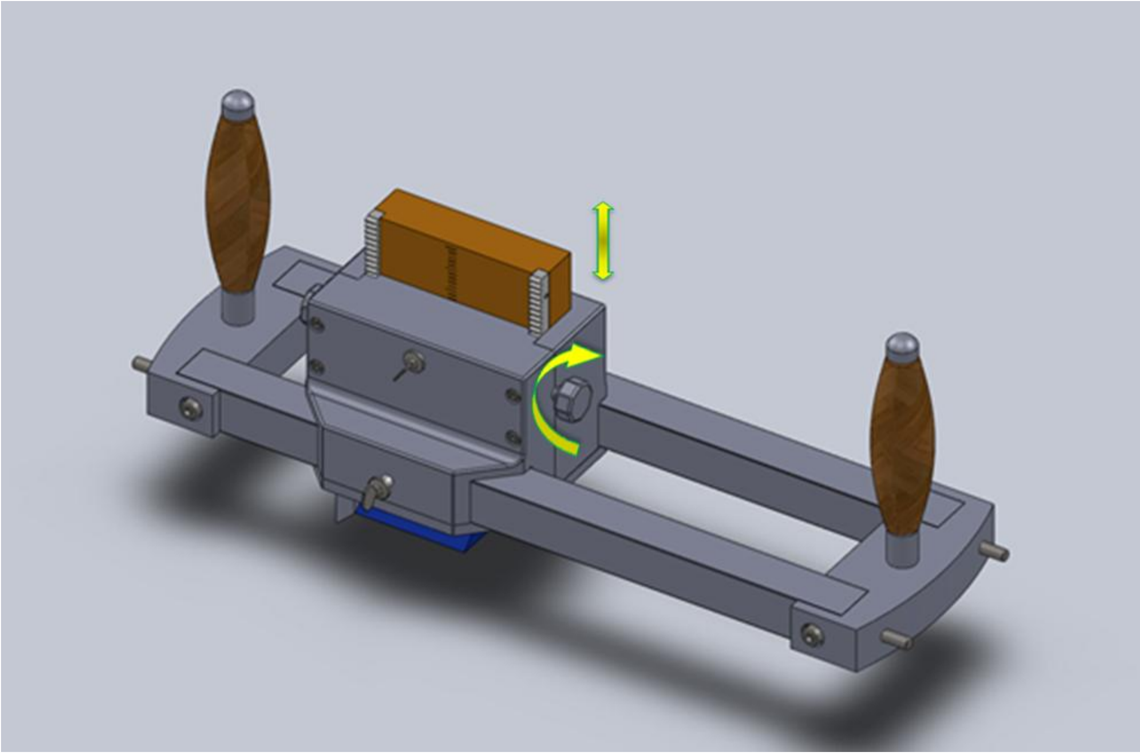


Figure 16. The inner assembly

A front view of the tool holder assembly is included before a detailed discussion of the components to aid with an understanding of the geometry, shown in Figure 17.

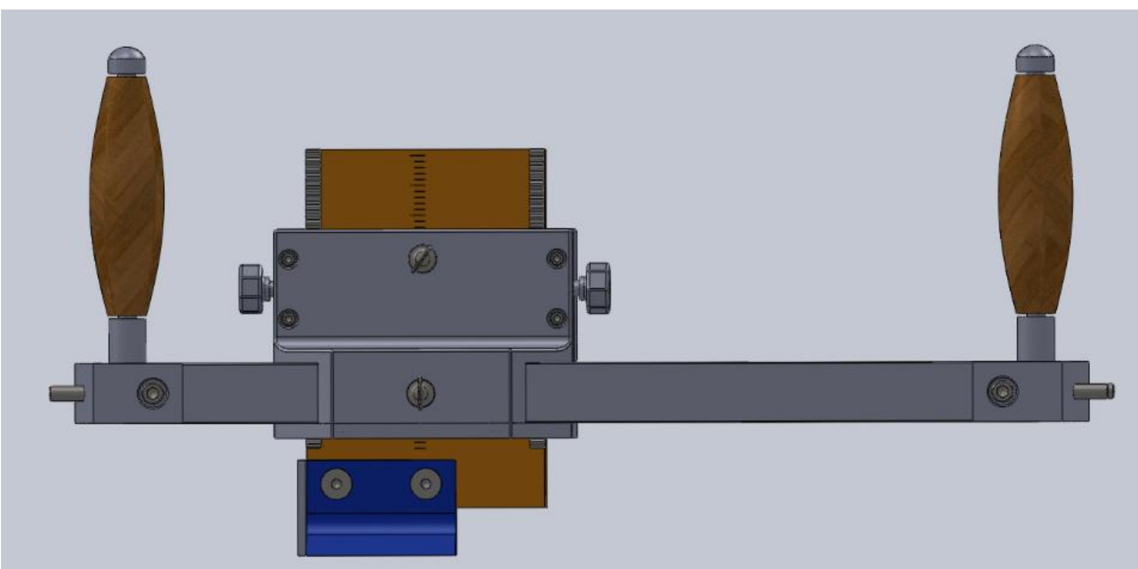


Figure 17. A front view of the tool holder assembly

The tool holder was initially designed as a single, rigid component which posed many problems for manufacturing purposes, as well as assembly and repair of the device.

Appendix B contains a discussion of the process of how the design was modified to promote ease of manufacturing to avoid spending an unnecessary amount of the manufacturing budget on fabricating one component. The result of the redesign was that the tool holder became three separate components that will be assembled around the previously installed radial bars via bolt locations. Unnecessary intricate geometry was removed to avoid requiring the use of expensive Computer Numerically Controlled (CNC) equipment. Figure 17 shows the relative size of the tool holder to the span of the radial beams, as well as demonstrating how the blade (pictured blue) will attach to the bottom of the blade mount. Figure 18 demonstrates some of the bolting locations that hold the upper front half to the upper rear half. Greater detail on how the assembly is divided is contained in Appendix B.

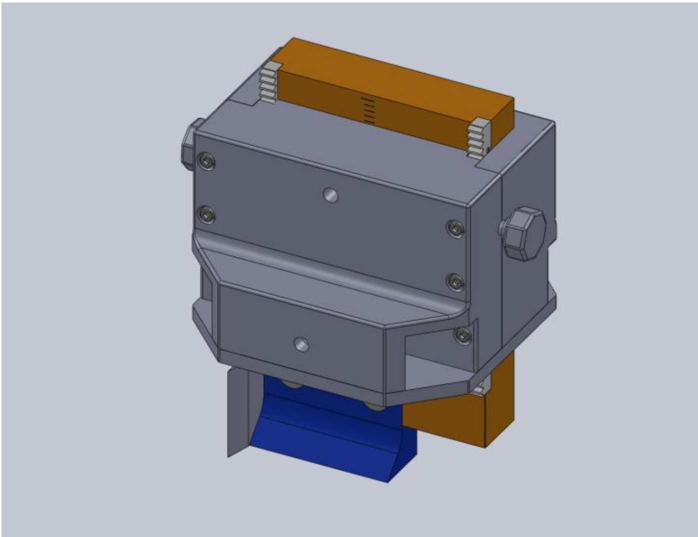


Figure 18. Tool Holder

Removing the front face of the assembly, as pictured in Figure 19, exposes the blade mount plate with the attached rack and pinion gear system. The two knobs located at the left and right of the rod supporting the pinion gears actuates the gear system to move the blade mount plate up or down. An Imperial scale will be attached to the front face of the blade mount to aid in calibration to further guard against overcutting of the propellant. The bolts that hold the front and back halves of the top portion of the assembly are left in the figure to provide reference as to the size of the cavity.

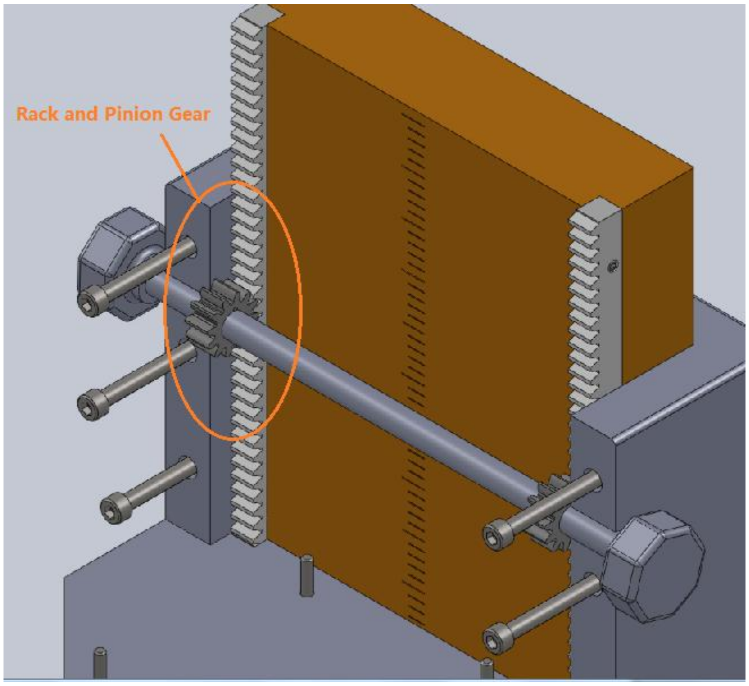


Figure 19. Section drawing of tool holder

The pinion gear will be fixed to the shaft via a small key, as shown in the orange circle in Figure 20. Snap rings could by applied to either side of the gear to ensure the pinions remain in the correct location relative to the rack during operation.

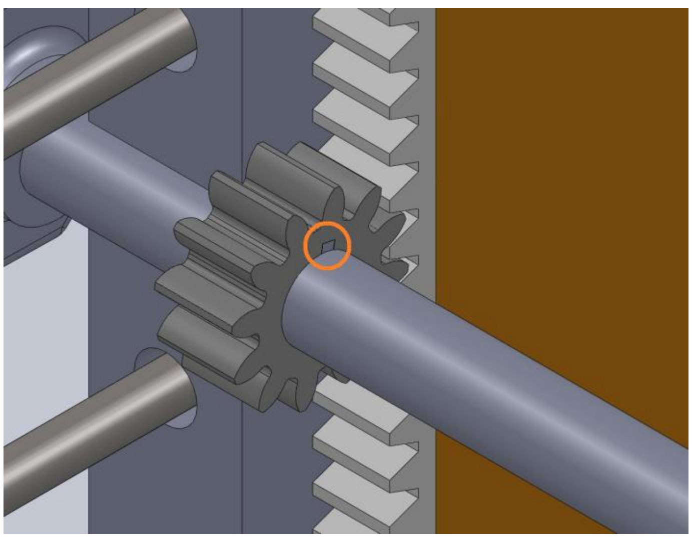


Figure 20. The pinion gear with key

After each time the tool holder is adjusted along the radial bars it is fixed into its orientation by a dull tipped screw which penetrates the tool holder cavity and is wedged against the radial bar beneath it. This ensures that the cutting force from the propellant does not simply deflect the blade. A similar lock is used on the blade mount itself, to ensure that gravity does not cause the blade to drift lower during operation, or for the cutting force to deflect the blade upwards in a similar manner. These locks are demonstrated in Figure 21 and Figure 22.

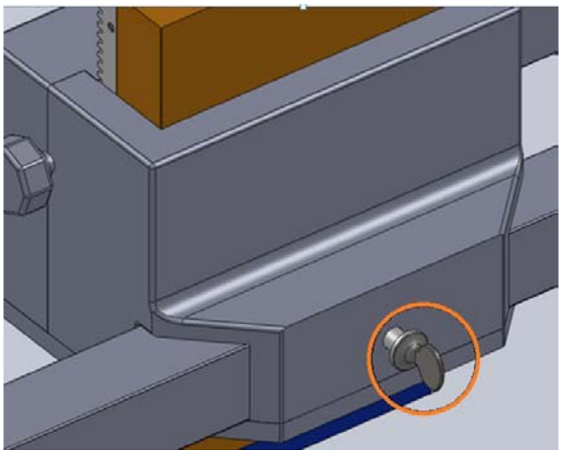


Figure 21. Horizontal Slider Lock

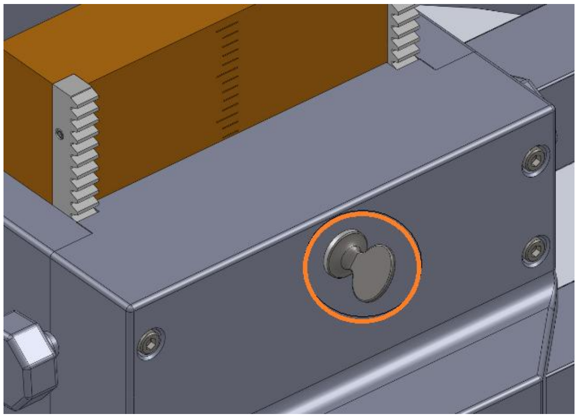


Figure 22. Vertical Blade Mount Lock

3.1.4 Blade Mount Assembly

The function of the blade mount assembly is to carry the propellant and EPDM cutting blades themselves. The blades will mount to the lower portion of the blade mount, and the components will move up and down relative to the tool holder as a rigid assembly by means of the gear system. Two bolts are used to fix the blades firmly to the mounting plate to fully constrain the relative motion. The rack of the purchased rack and pinion gear system will be fixed to the blade mount, as can be seen in Figure 13 and

Figure 17.

3.1.4.1 Propellant Blade

Due to the differing nature of the two types of material that must be cut during the trim process, a separate blade was designed to perform each process. A significant amount of time was devoted to blade research and concept generation as the concept development phase was carried out. Some indication of this is included in Appendix A. The result of these efforts was to select a convex style blade for the propellant, which is to be custom made. Rather than pursuing a blade more suited to slicing or cutting, the intent was to create a tool able to provide the scraping action required to peel off the tough, thick propellant, similar to a lathe tool. An exploded view of the blade is displayed in Figure 23.

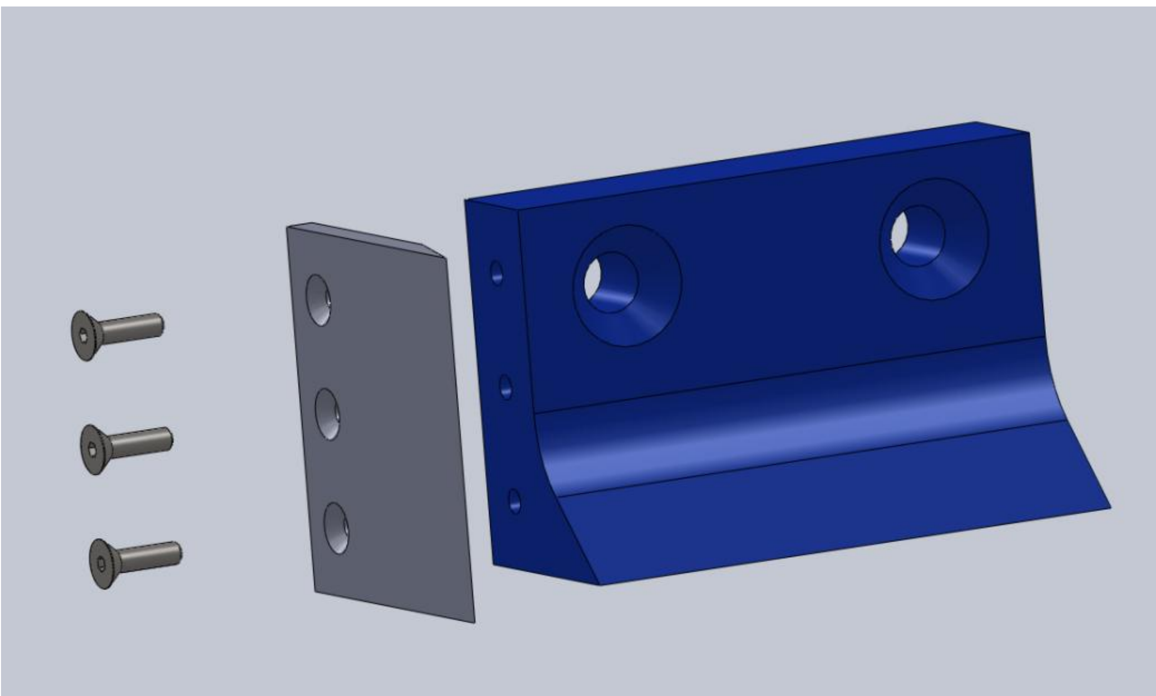


Figure 23. Exploded view of the blade

The main blade is shown in blue. The first concept for this style of blade included a convex style edge on the bottom, as pictured, as well as perpendicular to the bottom edge, in the same orientation as the silver alternate blade pictured in Figure 23. This idea was critiqued for its manufacturing difficulty, and an alternate way of creating this blade is now included as the detachable piece which is pictured. There are two main advantages to having a convex (protruding) blade rather than a more common concave blade. The main advantage deals with the properties of the propellant. Because of its tough, eraser-like consistency, and the requirement that the tool must cut the surface cleanly with no tearing of the material, this design will be more suited for peeling thin layers of the material off the body of the propellant, and the relief of the blade will guide the material along an exit path. The second advantage is that it increases the thickness of the blade, which adds to the stiffness of the cutting tool and removes any possibility of the blade deflecting under the cutting force. The tip of the blade will not be sharpened to a razor edge, but if the tool is found to dull undesirably after time the component can be easily removed from the blade mount and sharpened with a grinding wheel. The assembled cutting surface is depicted in Figure 24.

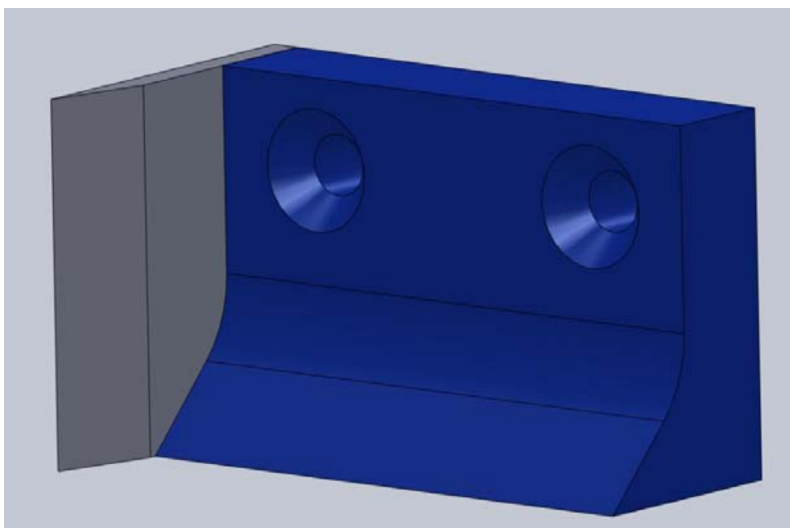


Figure 24. Assembled cutting surface

3.1.4.2 EPDM Blade

Similar to the propellant blade, many types and geometries of possible blades were considered to accomplish the EDPM trim process. The current process for cutting this material was encountering difficulties with positioning the blade properly, rather than having any troubles with the blade itself. Some risk was involved with any proposal to change the current cutting blade, due to the inability of the current tool to damage the silica phenolic layer of insulation that resides between the EPDM layer and the rocket motor casing. Because the silica phenolic is much harder than EPDM, no incidences have been reported where a thin carbon steel blade has been able to damage the insulation behind the EPDM due to excessive force. To take advantage of this, and avoid having to validate the effect of any new blades on the silica phenolic, the team proposed to use the same blade, and to design a holder for the blade of very similar geometry to the propellant blade itself. Some consideration was given to building the holding fixture into the propellant blade itself, and while this is a valid option, it was decided against to aid with the ease of changing the blades at the appropriate stage in the process, after the propellant trim was completed. The EPDM cutting blade cannot be in place during the propellant trim operation, so it was deemed easier for the operator to remove two bolts and change the entire blade at the base of the blade mount rather than try to install the EPDM blade to the bottom side of the propellant trim blade. Figure 25 illustrates how the blade (which is commercially known as an Exacto- Blade) is secured to the underside of the EPDM blade holder and how the blade protrudes from the blade holder during operation.

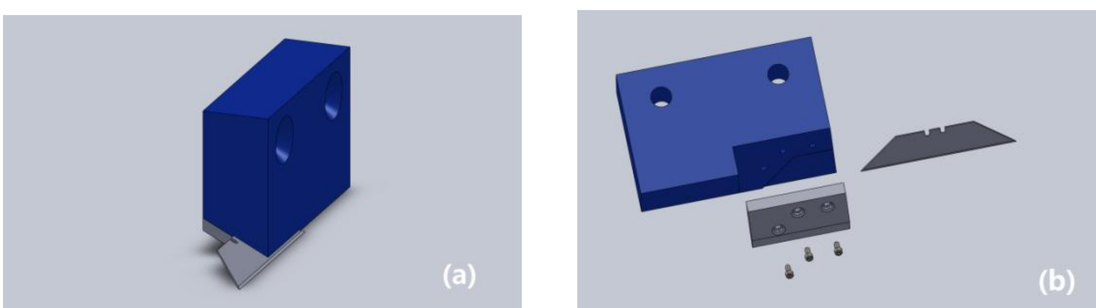


Figure 25. Exacto- Blade and blade holder a) Parts separated b) Parts combined

3.2 Operation of Final Design

Our final design uses five steps to successfully trim the propellant and the EPDM. The five steps with brief explanations are listed below.

Step 1: Locate and attach the device on the rocket motor.

As was described in Section 3.1, the rocket motor has a circular hole pattern on the aft lip of the rocket. The final design locates onto this hole pattern and fastens to the rocket using bolts.

Step 2: Trim the propellant material.

The final design uses a separate blade that is specifically designed for cutting through the propellant material. This step involves adjusting the location of the cutting tool holder and rotating the device to cut the propellant. Because the blade is only a few inches long, the location of the cutting tool on the track must be adjusted to ensure that all the propellant is trimmed.

Step 3: Change out the propellant cutting blade for the EPDM cutting blade.

Once the propellant has been trimmed the blade used for cutting the propellant is removed. The blade for trimming the EPDM attaches in a similar manner as the previous blade. After the EPDM cutting blade is attached the tool is ready for use.

Step 4: Trim the EPDM material.

Step 4 adjusts the location of the cutting tool so that the tool is located correctly. Once the tool is located correctly, trimming of the EPDM occurs by rotating the device.

Step 5: Remove the tool from the rocket

The final step is the removal of the trim tool from the rocket motor. This step involves removing the bolts that lock the final design in place and safely moving and storing the device. Following the removal of the tool, the device should be cleaned to ensure that it remains in good working order.

3.3 Cost Analysis

A bill of materials which specifies part numbers to be purchased as well as the amounts of raw materials can be found in Appendix C, which contains an in depth cost analysis for each component. Manufacturing processes for each component are described in Appendix B, and the estimated amount of machine and set up time has been summed to generate an estimate of the machine costs associated with manufacturing the trim tool. Results of the cost analysis can be found in TABLE III.

TABLE III SUMMARY OF COST

ITEM	COST
COMMERCIALLY AVAILABLE COMPONENTS	$3134.56
RAW MATERIAL	$2133.07
MANUFACTURE COSTS	$2195
TOTAL	$7462.63

4. Conclusions and Recommendation

The design that has been discussed throughout this report adequately satisfies the problem statement given to the design team at the outset of the project. Implementation of this design will significantly improve the accuracy of the propellant and EPDM trim processes as the possibility for human error is greatly minimized. This main objective is accomplished through introducing a guidance system which has the ability to move the cutting blade through arcs of increasing radius at any selected depth of cut, thereby covering all of the required surface area. The tool has been designed in such a way that this cutting plane may be incremented downwards in a controlled manner through the gear system until the propellant has been trimmed to the required depth, and the tool will not deflect under the cutting force to allow for accidental overcut. The desired range of vertical motion of 0.5’’ has been met and exceeded by avoiding a shim based design and incorporating a rack and pinion gear system. Additionally, the cutting blade has been designed to incorporate a firmly fixed blade of the same type that is currently used to remove the EPDM tab, and the rotational ability of the tool can be used to slice the tab off with a greatly reduced chance of an incorrect path of cut resulting in damage to the rocket motor. Training required to use this device will be minimal, and will reduce the amount of training required for an operator to perform the trim process as the dependency on operator skill has been similarly reduced.

Locating of the tool to ensure the motion of the device coincides exactly with the axes of the rocket has been made error proof by basing all geometry off of bolting the tool into an existing bolt pattern around the lip of the rocket. Since the existing bolt pattern is circular, it will be impossible to mis-locate the tool if a minimum of three separate bolts are in place. Six bolting locations are included in the design. The exact geometry of this bolt pattern was not made known to the design team for proprietary reasons. To account for this, the design team avoided attempting to mount the bearing directly onto the rocket lip and instead mounts the bearing to an outer ring that rests on a tool to rocket interface plate. The advantage of this plate is it provides the client freedom to manipulate the bolting locations specified for it to conform exactly to the existing rocket, without requiring the majority of the design’s dimensions and analysis to be recalculated. This provides a simple path to move the concept from a proposal to a manufacturable design. In spite of increasing the dimensions to allow for greater freedom of movement and greater ease of geometric manipulation for the client, the design has been created compact enough that a single operator may use the device with ease, and there is no danger of tipping the horizontally orientated rocket during tool installation. Estimated weight of the tool is 60 pounds.

Explosive safety requirements dictate the use of non-sparking materials in the design. Aluminum was considered for this reason, but at the specific request of the client material choice was switched to SAE 300 series stainless steel to provide a more robust device that can provide a long service life, withstanding the damage it may encounter during use in a factory setting. A single component, the inner ring, is to be fabricated from aluminum to reduce the weight of the device. Additionally, using a steel bearing over an aluminum bearing allows the inner and outer rings to be press fit without distorting the bearing or causing undue damage to the rollers during operation.

No external power is required to operate the tool. Electric power was neglected due to the expense associated with isolating the electricity adequately to meet the explosive safety requirements. Pneumatic power was considered, but ultimately not included to increase control, reduce complexity, and reduce expense. Control is increased because any pneumatic forward or downward motion has the potential to increment further than desired, detracting from the reliability of the design. Secondly, incorporating pneumatic power was considered to spin a circular blade, with the actual rotational and downward motion of the cutting blade accomplished via the same mechanisms specified to move the stationary blade used in this design. This was also rejected, since the greater power associated with this moving blade would be unsuitable for cutting the EPDM tab, as the blade would cut through the tab and score the silica phenolic layer that rests between the tab and the steel rocket casing. The relative hardness of the phenolic compared to the EPDM is utilized for this design to avoid having to design a lateral stop to prevent the blade from cutting through the EPDM into the phenolic, as the client has advised the design team that there is no danger of this method of overcut when using a simple stainless steel blade. Finally, due to the low volume of production that the tool will be involved in, any time savings accomplished by using an externally powered device rather than a manually powered device are negligible, and the added design complexity was deemed not worth the extra cost.

The use of a sealed bearing and a baked Teflon coating (Protocoat) on the radial beams eliminated any requirement for solvents or grease in the operation of the device. This satisfies the stipulation that no contaminants may encounter the propellant, as well as removing any requirement for a maintenance/ lubrication regime.

Careful consideration of manufacturing techniques throughout the entire design process has resulted in a cost to implement the design that is significantly under budget. Major contributions to this success include sourcing an existing bearing to provide the desired rotational ability for the tool, as preliminary estimates to fabricate such a custom component consumed an acceptable portion of the manufacturing budget. Upon completion of the initial design, components were revisited considering the principles of Design for Manufacturing, Design for Assembly, and Design for Repair. This resulted in major changes to the geometry of the tool holder, taking one complicated custom component and breaking it into three sections that are not only much easier to manufacture, but allow for much easier assembly of the device, as well as disassembly in the even that repairs are required. A detailed manufacturing consideration of each custom component is included in Appendix B to estimate machining costs, as well as forecast any manufacturing difficulties that may require redesign of the components of prevent the design from being implemented. The estimated machine time results from this appendix, as well as the costs for raw materials and sourced components, was summed to determine an estimated total manufacturing cost of $7462.63. This value puts the project under budget.

In summary, Team 14 has put forward a proposal that has been measured against each of the stated target specifications and found to either meet or exceed each of the criteria. All of the constraints that relate to the project have been similarly adhered to. The resulting tool concept has been thoroughly described and extensive detail is provided to allow for manufacturing in the form engineering drawings and CAD models. Team 14 recommends that the client, Bristol Aerospace, implement the described tool to aid in production of the Nihka rocket motor.

5. References

[1] Bristol Aerospace Ltd. (2008). *Bristol Aerospace - History* [Online]. Available: http://www.bristol.ca/History.html [September 25, 2011].

[2] L. Mayor and P. Marmillod (private communication), September 23, 2011.

[3] NASA Sounding Rocket Working Group (2003, June 26). *NASA Sounding Rocket Science* [Online]. Available: http://rscience.gsfc.nasa.gov/mt_03_jun_find.html [September 28, 2011].

[4] McMaster- Carr. (n.d.) *Thumb Screws.* [Online] Available: http://www.mcmaster.com/#catalog/117/3074/=f5jdv6. [November 20, 2011.]

[5] McMaster- Carr. (n.d.) *Socket Head Cap Screws*. [Online] Available: http://www.mcmaster.com/#catalog/117/3112/=f5jhna. [November 20, 2011.]

[6] McMaster-Carr. (n.d.) *Cup Point Set Screws.* [Online] Available: http://www.mcmaster.com/#catalog/117/3058/=f5jiyc. [November 20, 2011.]

[7] McMaster-Carr. (n.d.) *Socket Head Cap Screws.* [Online] Available: http://www.mcmaster.com/#catalog/117/3098/=f5jjo7 [November 20, 2011.]

[8] McMaster-Carr. (n.d.) *14-1/2 °& 20 °Pressure Angle Spur Gears.* [Online] Available: http://www.mcmaster.com/#catalog/117/1056/=f5jvmz. [November 20, 2011.]

[9] McMaster-Carr. (n.d.) *Handles.* [Online] Available: http://www.mcmaster.com/#catalog/117/2206/=f5jx57. [November 20, 2011.]

[10] McMaster-Carr. (n.d.) *Knobs.* [Online] Available: http://www.mcmaster.com/#catalog/117/2195/=f5jyg9. [November 20, 2011.]

[11] Kaydon infinite® bearing solutions. (n.d.) *Reali-Slim sealed bearings / JG series (double sealed) / Type X-four-point contact.* [Online] Available: http://www.kaydonbearings.com/RealiSlim_sealed_bearings_JG_typeX.htm. [November 20, 2011.]

[12] McMaster-Carr. (n.d.) *Stainless Steel.* [Online] Available: http://www.mcmaster.com/#89535k21/=f5k56h. [November 20, 2011.]

[13] McMaster-Carr. (n.d.) *Multipurpose Stainless Steel (Type 304).* [Online] Available: http://www.mcmaster.com/#catalog/117/3657/=f5k937. [November 20, 2011.]

Appendix A: Technical Analysis of Final Design

List of Figure

In order to ensure the tool does not cut the propellant deeper than desired during operation, the two radial beams that will be welded to the selected bearing must be analyzed to select dimensions that will prevent unacceptable amounts of deflection.

A worst case loading scenario will be defined as the entire weight of an operator (approximately 200 lbs) being applied to the tool as a point load at the center of the beam. The force will be considered as a point load split evenly between both beams. Boundary conditions will be taken as zero deflection and zero slope of each beam at the point where it is welded to the inner bearing.

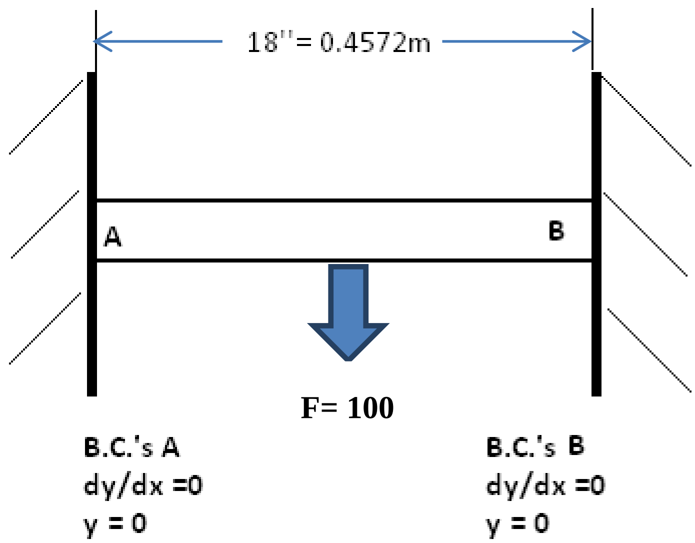


Figure A 1 Beam analysis

Deflection Analysis

$$+\uparrow \Sigma F_y = 0 = R_A + R_B - P$$

By symmetry, we can determine$R_A = R_B = \frac{P}{2}$, and that at the midpoint (x=L/2) $\frac{d_y}{d_x} = 0$.

Therefore, on $0 \leq X \leq \frac{L}{2}$ we can write $M = M_A + \frac{1}{2}Px = EI\frac{d^2y}{dx^2}$

Integrating once, we find

$$EI\frac{dy}{dx} = M_A x + \frac{1}{4}Px^2 + C_1$$

Applying boundary conditions at x=0 we determine $C_1 = 0$. this allows us to solve for $M_A$by applying the condition that the slope of the shaft is 0 at the midpoint. This gives $M_A = \frac{1}{8}PL$ and, using symmetry again, $M_B = -1/8$ PL.

Integrating again to determine the equation for deflection we have

$$EIy = \frac{M_A x^2}{2} + \frac{Px^3}{12} + C_2$$

And applying y=0 at x=0 we find C_2=0 which yields

$$y = \frac{1}{EI}(\frac{5PL^3}{192})$$

Constants for this scenario are E=193 Gpa (SAE SS 301), P = 450 N (100 lbf) and L = 0.4572 m (18'').

$$y = \frac{5.803E^{-12}}{I}$$

Where I is the moment of inertia, which for a rectangular cross section is

$$I = \frac{base \times height^3}{12}.$$

Since the bearing which the beams will mount to is pre-selected with a depth of 1'', we will examine this geometry to determine if the deflection is acceptable. Calculating the moment of inertia for a square beam at 1'' per side, and substituting the result into the deflection equation determined above, we find the maximum deflection of the beam to be 0.167 mm. Since it is unlikely this amount of force will be applied at the mid span of the tool as it will be orientated perpendicular to gravity, and even in this worst case the magnitude of the deflection is negligible, we find this to be acceptable and select a beam of 1'' per side.

Appendix B: Manufacturing Consideration

List of Figures

List of Tables

Ease of manufacturing of the components necessary for the tool was a primary consideration observed throughout the design process. Wherever possible, existing components were sourced to avoid the costs associated with fabricating custom pieces. The most striking example of this was the use of a commercially available bearing. The bearing selected to incorporate into the tool provides the necessary rotational ability at a fraction of the cost that would be required to fabricate such a device if it were a custom component. Taking advantage of such economies of scale that can be provided by a larger volume manufacturer not only assists the design team to stay within budget, but also provides a higher quality component as the sourced bearing will already have been field tested in previous applications. The same reasoning was used to select an existing rack and pinion gear system to move the blade mount up and down into the propellant cavity, as design of a custom gear system is similarly expensive and unnecessary.

In spite of these efforts, some unique components are necessary to accomplish the design function. These parts were first designed to provide the required abilities, and then refined to improve manufacturability. Manufacturing steps for the tool holder, which rides on the radial beams and allows the blade mount to move both vertically and horizontally, will be described in the following section.

B1. Tool Holder

The preliminary design for the tool holder shown in Fig.B1 posed many challenges for fabrication, and would have necessitated the use of CNC machinery.

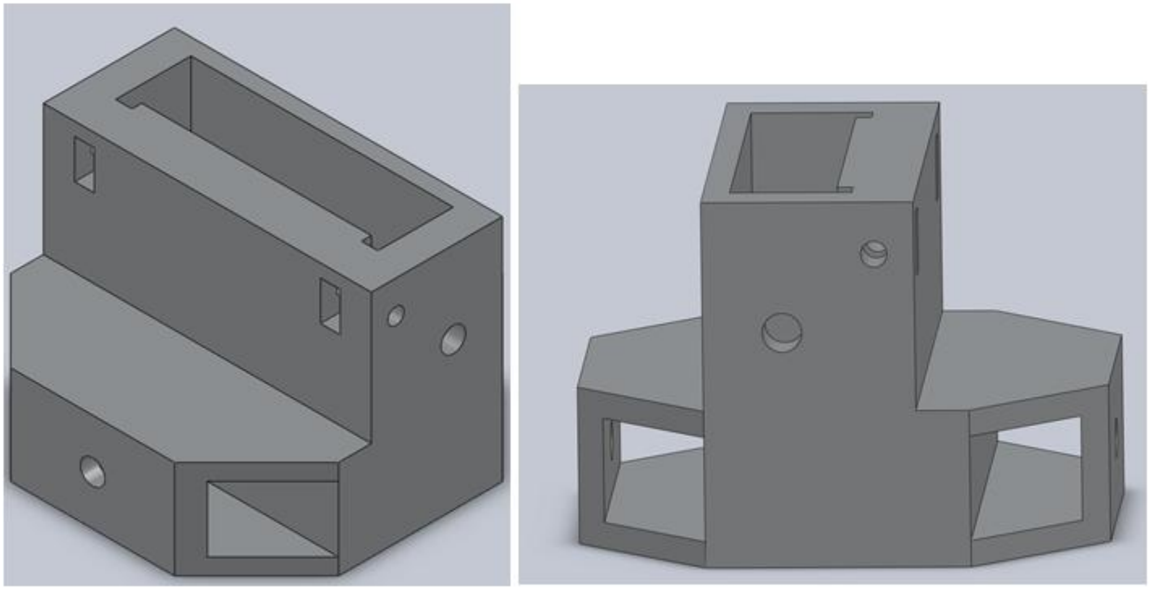


Figure B 1 Preliminary design for the tool holder

In addition to manufacturing difficulty, the rigid nature of the above design would have posed issues to mounting the device onto the radial bars, and made the entire part very difficult and time consuming to disassemble for repair. To address these issues, the design was altered such that the component is now made of several parts which will be assembled via fasteners around the radial bars after being milled to net shape. Additionally, the way that the device was split into separate components was determined considering order of milling operations, to ensure that the part could be adequately held to prevent tool chatter during the process. An exploded view of the modified tool holder is included below for visual comparison to the initial design, with each component labeled appropriately.

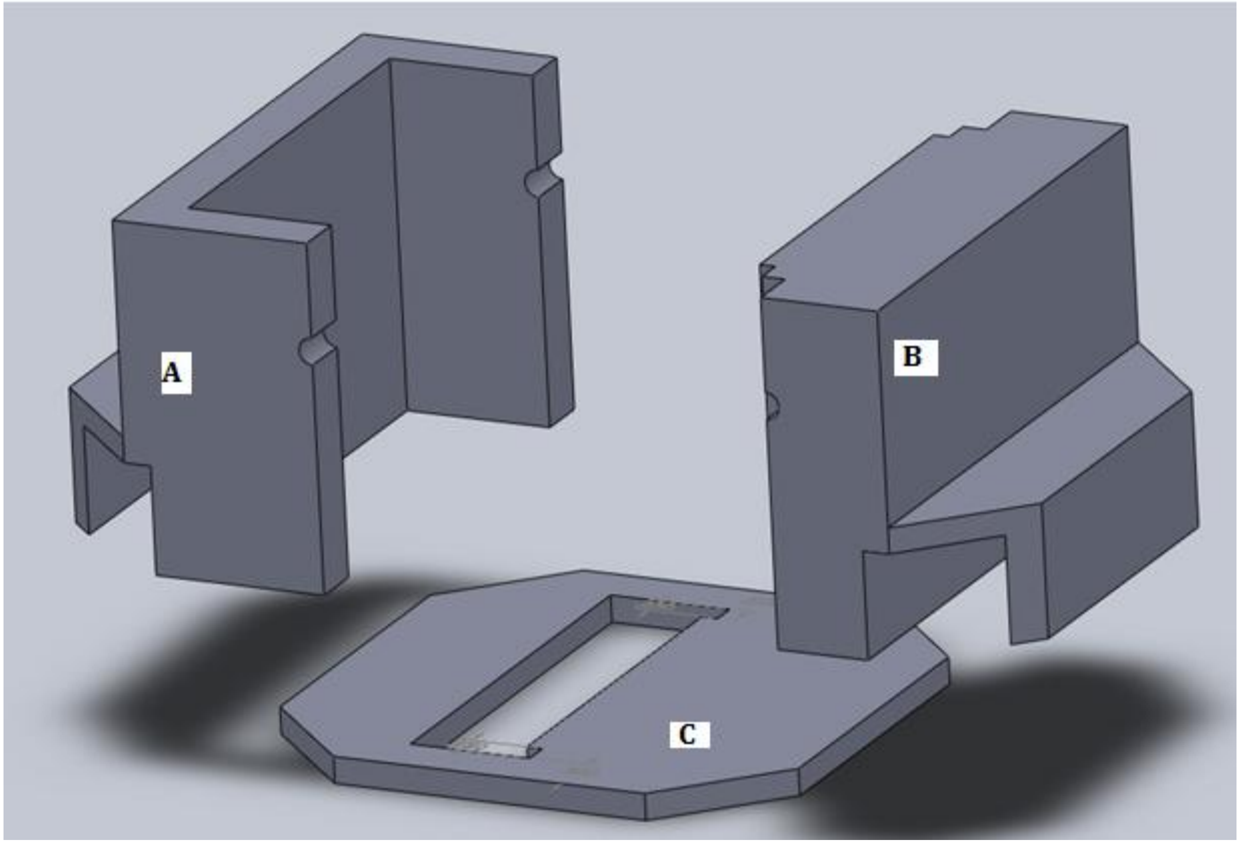


Figure B 2 Exploded view of final design for tool holder

Parts A and B will both be milled from Stainless Steel SAE 301 or 304. 300 series stainless steel has been requested by the client as it satisfies the facilities non sparking material requirements as well as providing a much longer service life than aluminum. 400 series are to be avoided due to sparking potential.

B1.1 Part A

There are three set ups necessary to create part A. Order of operations will be explained through each set up and estimates of machine time will be provided. Detailed drawings of the part will be included in a separate appendix of this report, so the purpose of this section is to indicate how the process will flow, rather than contain an exhaustive set of instructions including every dimension, etc.

- **Set Up 1**

A block of one of the above grades of stainless steel measuring a minimum 2.5'' x 5'' x 3.25'' will be loaded onto the bed of a manually controlled milling machine, with the 2.5'' direction perpendicular to the bed of the mill. If the stock exceeds the required dimensions, an end mill or similar will be used to face the blank to the required dimensions. Tolerances may be determined by the client at its discretion. With the part being held as indicated by the arrows in Fig.B3, an end mill will be used to create the two channels shown in the figure.

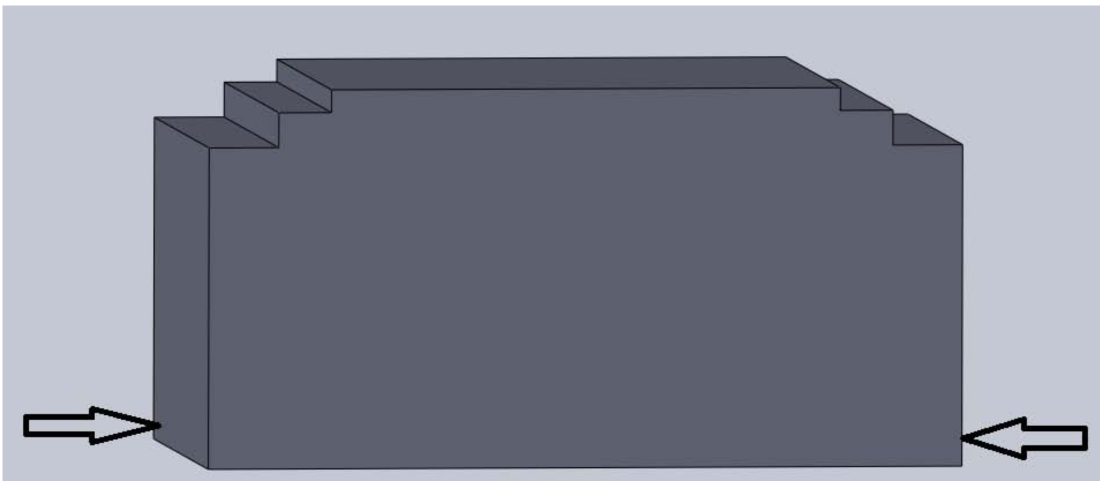


Figure B 3 Step 1 of set up 1 for part A in tool holder

Without releasing the part from the bed of the mill, the tool will be changed to a ¼'' ball nose end mill and the channel shown in Fig. B4 will be milled.

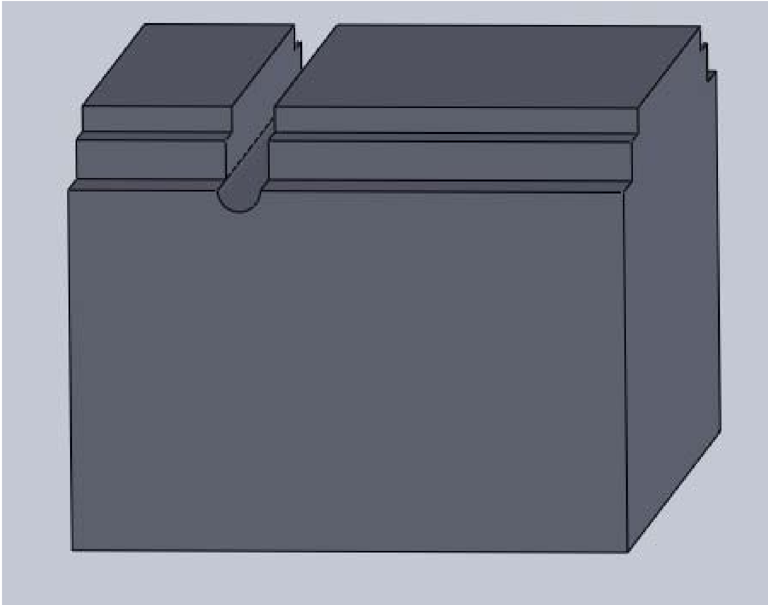


Figure B 4 Step 2 of set up 1 for part A in tool holder

- **Summary for Set Up 1**

TABLE B I SUMMARY FOR SET UP 1 OF PART A

Tool Changes	2
Set Up Time (Including Tool Changes)	25 min
Run Time	20 min
Total Time	**45 min**

- **Set Up 2**

The part must be removed and re-orientated to match that shown in Fig. B5. The purpose of this next set up will be to create the channel that the radial bar will sit in, and as such the channel is slightly oversized as compared to the bar to allow some freedom for movement. The inside radii are currently shown as being perfectly sharp. This detail is left to the client’s discretion during actual manufacturing, as it is purely a manufacturing consideration and is most affected by the specific tools available to millwright selected to perform the work. A small radius is always preferable to none from a stress perspective, but the strength of the material that has been selected is much greater than required for the application as is. A 1’’ end mill is recommended for this stage of production.

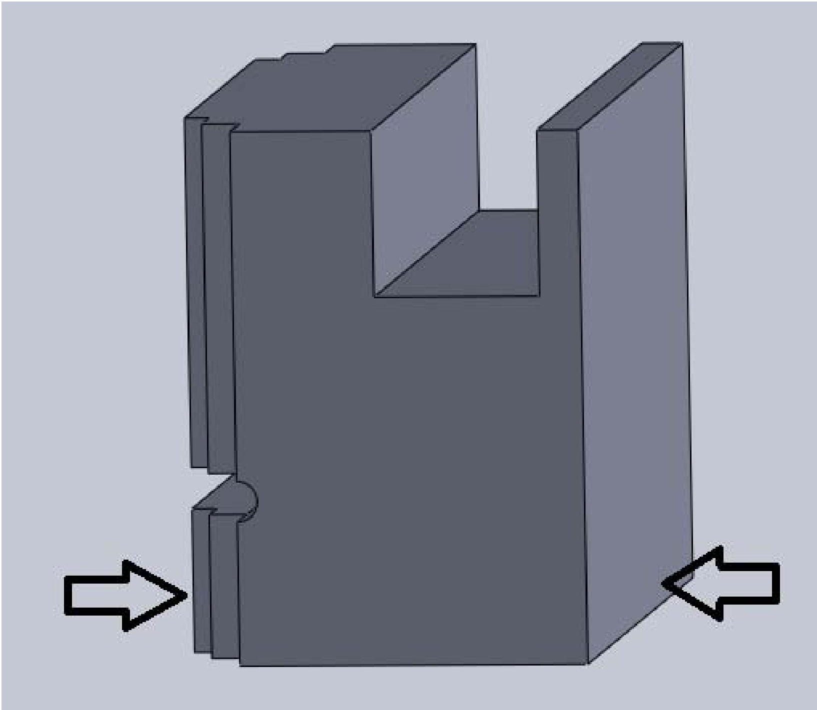


Figure B 5 Set up 2 for part A in tool holder

- **Summary for Set Up 2**

TABLE B II SUMMARY FOR SET UP 2 OF PART A IN TOOL HOLDER

Tool Changes	1
Set Up Time (Including Tool Changes)	15 min
Run Time	20 min
Total Time	**35 min**

- **Set Up 3**

One final set up will be required to complete the milling operations on this part. Again, the orientation is demonstrated in the accompanying figure (Fig.B6) and the presence and size of the fillet is at the client’s discretion. In this instance, a fillet is pictured as it will not interfere with any mating geometry but will require an additional tool change from an end mill to a ballnose end mill.

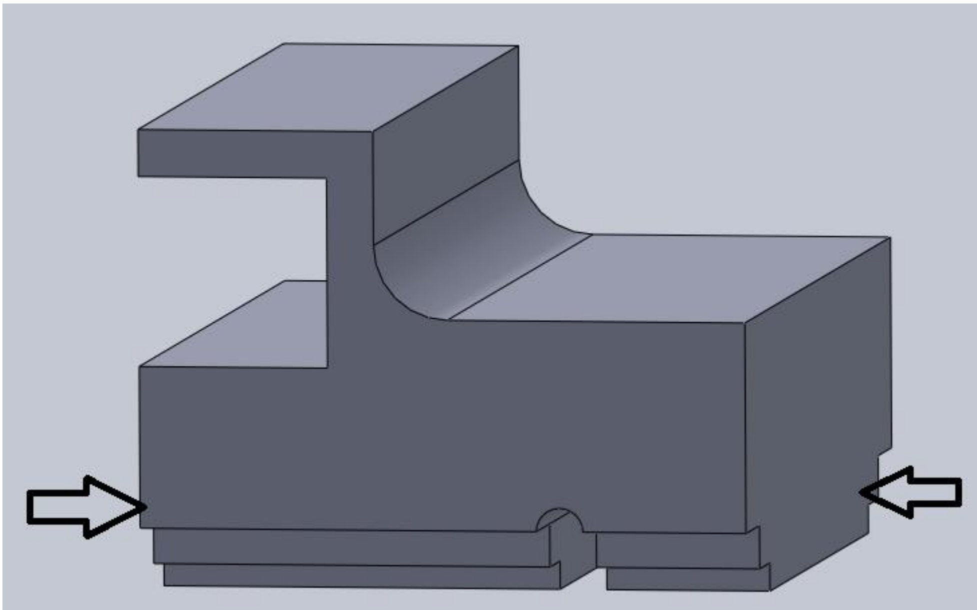


Figure B 6 Set up 3 for part A in tool holder

- **Summary for Set Up 3**

TABLE B III SUMMARY FOR SET UP 3 OF PART A IN TOOL HOLDER

Tool Changes	1
Set Up Time (Including Tool Changes)	25 min
Run Time	35 min
Total Time	50 min

B1.2 Part B

- **Set Up 1**

The second upper portion of the tool holder requires a blank of the same material for part A measuring 3.25’’ x 5.00’’ x 2.88’’. Due to the irregular depth (2.88’’) the first operation will require the stock to be faced to the correct dimension. Following this, the same ballnose end mill from setup 1 for part A will be used to mill a ¼'' diameter channel to match the dimensions in the included drawings. This channel, and its mirror in part A, will be used to insert the rod for the pinion gear later in the assembly process. Finally, an end mill will be used to remove the material to create a cavity for the blade mount. The result of this process, as well as the holding location, is shown in Fig. B7.

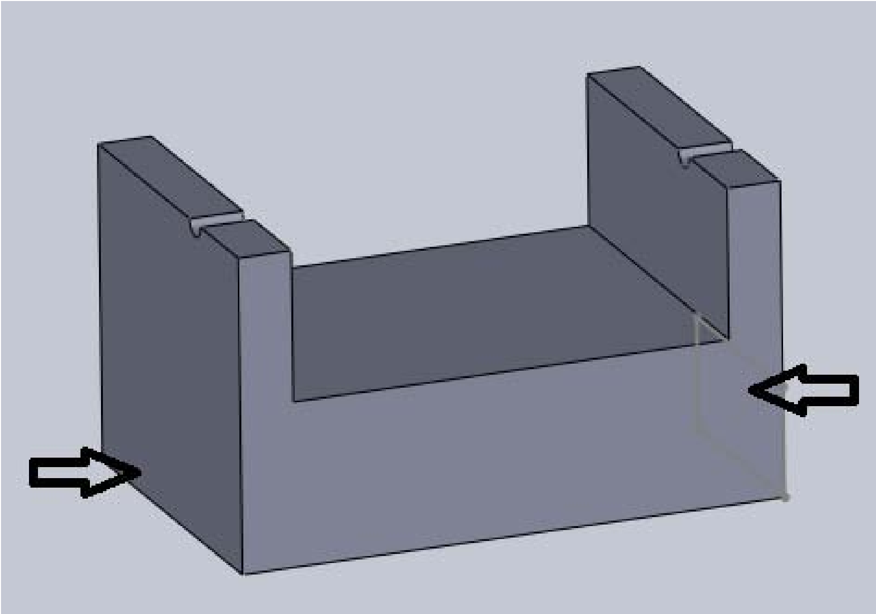


Figure B 7 Set up 1 for part B in tool holder

- **Summary for Set Up 1**

TABLE B IV SUMMARY FOR SET UP 1 OF PART B IN TOOL HOLDER

Tool Changes	3
Set Up Time (Including Tool Changes)	30 min
Run Time	40 min
Total Time	**70 min**

- **Set Up 2**

In the same manner as set up 2 for part A, the part will be re-orientated and the channel for the radial bar will be milled with an end mill. The same stipulations for optional radii apply. The orientation and result is again shown if Fig. B8.

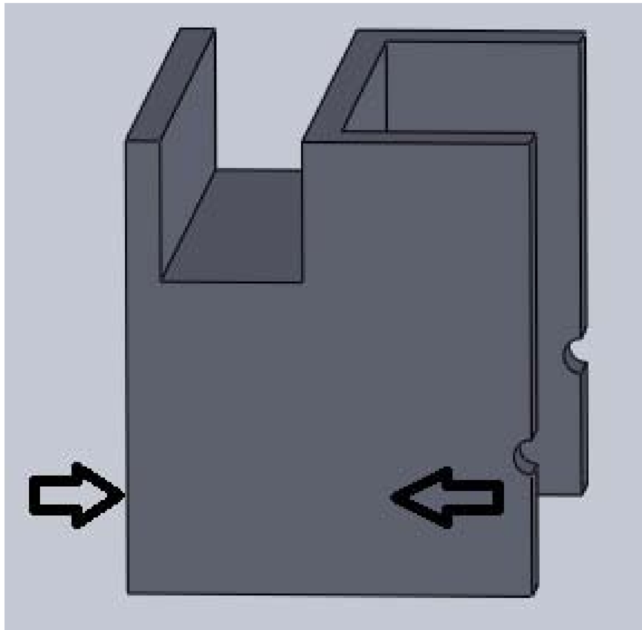


Figure B 8 Set up 2 for part B in tool holder

- **Summary for Set Up 2**

TABLE B V SUMMARY FOR SET UP 2 OF PART B IN TOOL HOLDER

Tool Changes	1
Set Up Time (Including Tool Changes)	15 min
Run Time	20 min
Total Time	35 min

- **Set Up 3**

Set up 3 will be nearly identical to that for part A, except an added complication will arise because it will now be necessary to hold the part on the outside faces of the hollow cavity created during set up 1. Since the force from the vice will be applied to

¼'' steel these faces will be strong enough to prevent excessive deflection while the part is being sufficiently held, but this set up requires more care than those previous.

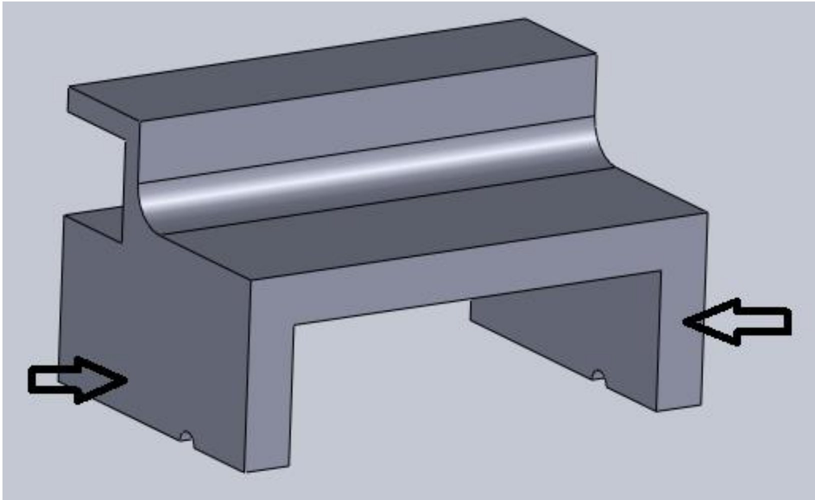


Figure B 9 Set up 3 for part B in tool holder

- **Summary for Set Up 3**

TABLE B VI SUMMARY FOR SET UP 3 OF PART B IN TOOL HOLDER

Tool Changes	1
Set Up Time (Including Tool Changes)	25 min
Run Time	35 min
Total Time	**50 min**

B1.3 Part C

The last piece of this assembly requires a 5.00'' x 5.00 '' piece of ¼'' thick stock of the same stainless steel used for the previous components. A bandsaw or vertical mill may be used to cut the piece to the proper rectangular footprint. One pocket will be required in the center of the piece to match the cavities created in the previous two pieces of the assembly. The best way to accomplish this would likely be to set this part up on the milling machine. This is the first feature where there will be a female corner parallel to the orientation of milling tool, and this will necessitate a fillet as there is not tool available to create a perfectly sharp corner. However, any fillet in these locations that decreases the size of the hole in the bottom face plate will interfere with the ability of the blade mount to move up and down. To avoid this problem, a 1/8’’ hole will be drilled in 6 locations as shown in Fig. B9 and specified in the part drawings. A smaller end mill than that used previously for parts A and B may now be used to remove the remaining material in the cavity.

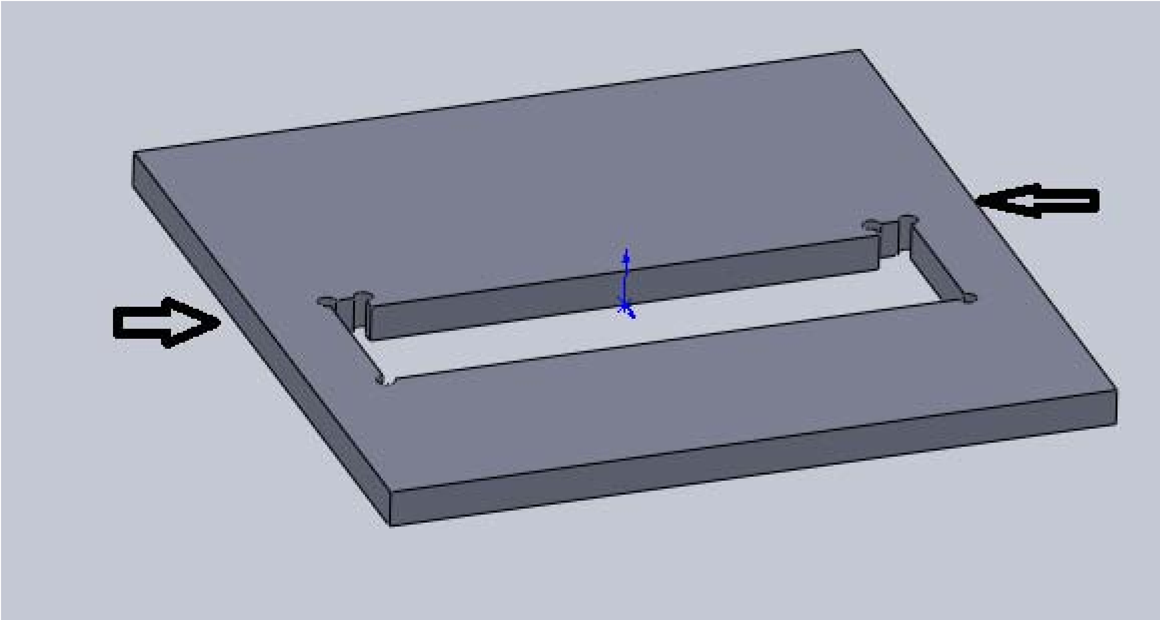


Figure B 10 Part C in tool holder

- **Summary for Part C**

TABLE B VII SUMMARY OF PART C IN TOOL HOLDER

Tool Changes	3 (including bandsaw)
Set Up Time (Including Tool Changes)	25 min
Run Time	35 min
Total Time	**60 min**

At this point all of the individual components for the tool holder have been fabricated. The assembly will be held together with 1/8’’ diameter stainless steel bolts. Ferry cap screws are recommended to allow for counter sinking. As the locations of these holes will need to be pre drilled and tapped, the assembly should be clamped securely into its final configuration and the holes drilled while the part is held together as one piece, to ensure the bolt holes line up perfectly between the separate parts. This may be accomplished with a center punch and drilled manually or with a drill press, again at the millwright's or engineer's discretion. Bolt hole locations are demonstrated in Fig. B10 and B11.

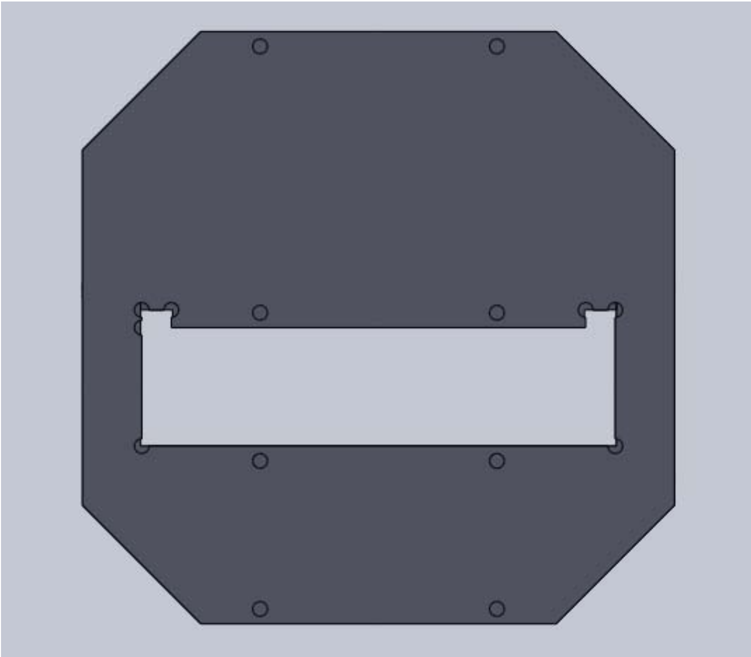


Figure B 11 Hole locations on the bottom plate in tool holder

8 locations are shown where the bottom plate will bolt to the top halves of the assembly.

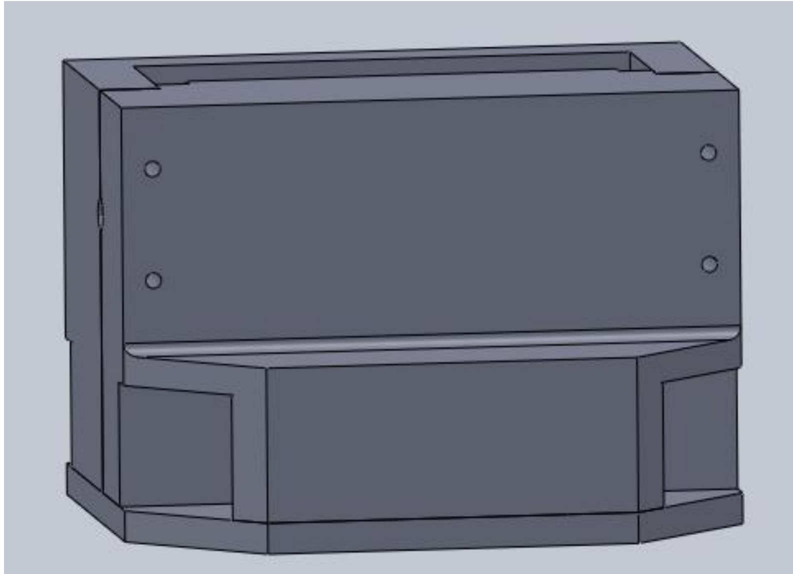


Figure B 12 Bolt locations in tool holder

4 additional bolt locations are shown to fix the top two halves of the assembly together. The chamfers shown in the preceding two images may be accomplished by using a bandsaw once the assembly has been bolted together, since the geometry will match more accurately if the assembly is cut as one part. Tolerances on these chamfers are loose, as they serve only to prevent any interference from the tool holder encountering the outside bearing during use. Estimated time for drilling bolt locations and chamfer is 60 minutes.

- **Summary**

The preceding discussion has shown how a single part with complicated geometry has been broken into three components, and how all of the features necessary for these components may be accomplished with common, manually controlled equipment without requiring the expensive of CNC machinery or NC programming time. Summing the estimated machine time for each of the operations, the total time required to manufacture this assembly is **405 minutes**, or 6.75 hours.

B2 Blade Mount

The blade mount is created from very simple geometry. Manufacturing will consist simply of using a bandsaw to cut the stock into the proper rectangular dimensions, and drilling and tapping bolt holes as required to mount the propellant cutting blade to the bottom portion, as well as for the set screws to mount the rack of the gear system, following instructions as provided by the gear manufacturer. Edges of the resulting blade mount plate should be filed after being cut to avoid burrs and sharp edges that may damage the inside face of the tool holder during operation of the gear system.

B3 Radial Beams

The preceding appendix on beam analysis has shown we require square beams of 1’’ per side. As discussed in the body of the report, the beams will be treated with protocoat, which will be estimated at a thickness of 0.002’’. The dimensional control on stock steel, when delivered, is not sufficient to meet the needs of this project, but the dimensions as ordered are a minimum and usually given as -0’’/+0.01’’. This means the beams will measure at least 1’’ per side and likely slightly more. Upon delivery of the material, the millwright should determine the exact dimensions of the stock, and mill two of the perpendicular faces (likely requiring only one pass of the tool) to create a beam which measures 0.998’’ per side. This will allow some clearance for the application of the protocoat, and still fit within the cavities created for the beams in the tool holder assembly. Estimated time for this process, for both beams, is **30 minutes** (not including the application of the protocoat).

B4 Bearing Ring to Beam Interface Device

The second most complicated custom component, next to the tool holder, will be the joint which allows the radial beams to mount to the ring press fit inside the bearing. The bearing has a 18’’ inner diameter, and a ½’’ thick stainless steel ring will be press fit inside of this bearing. The inner surface of this ring, with a diameter of 17’’, will be the surface which these interfaces will mount to. Manufacturing steps are given as follows:

- **Set Up 1**

The blank for this part will require a 1’’ thick piece of the same stainless steel which measures 1.375’’ x 5.000’’. This will require being custom cut, and can be accomplished using a bandsaw, if care is taken in marking the dimension. This could also be done using a face mill. After these dimensions have been created, an arc of 17'' diameter must be either cut with a bandsaw or milled onto one of the 5.000'' faces. Again, if this is done using a bandsaw the arc must be carefully scribed onto the surface prior to the cutting operation. If CNC equipment is available, this radius of curvature could be more accurately cut onto the part. The resulting geometry is shown in Fig B12.

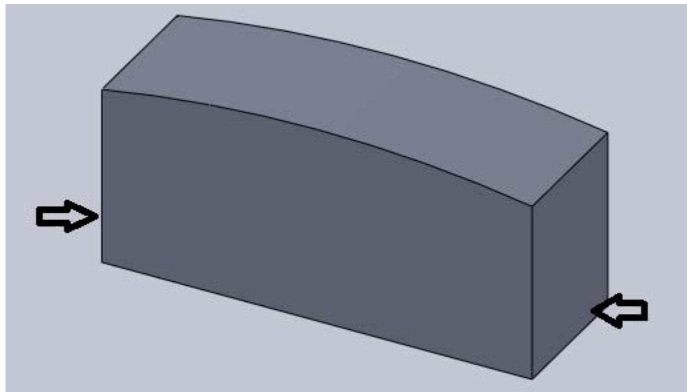


Figure B 13 Set up 1 for the bearing ring to beam interface device

Two of these components will be required. Because of the difficulty associated with properly scribing the required arc, estimated time to create both of the above blanks is **120 minutes**.

- **Set Up 2**

The pockets for the radial beams will next be milled by orientating the part as shown in Figure B13 and using an end mill to remove the indicated material. The beams will be held in these pockets by threaded fasteners, so the dimensions of the cut out holes will match the outer dimensions of the radial beams. Since there will be a 0.002'' coating baked on the beams at the time of installation, some clearance must be left between the beams and the mounting pockets to ensure room for a proper fit.

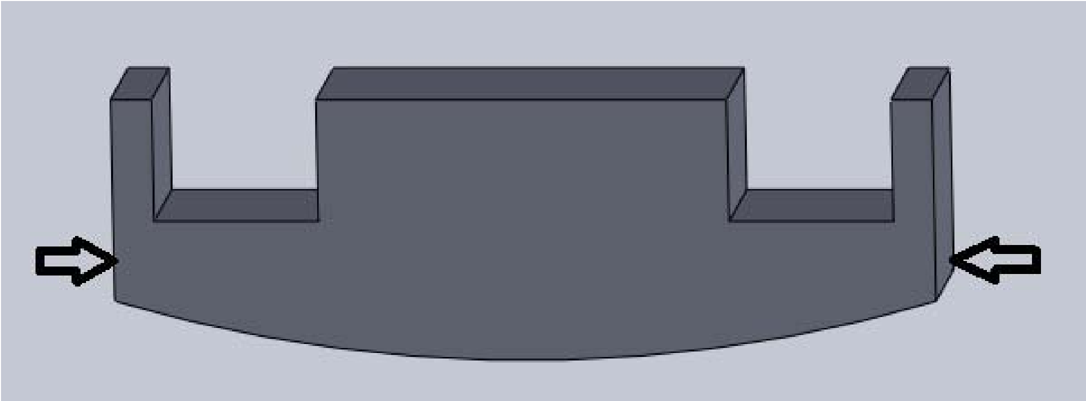


Figure B 14 Set up 2 for the bearing ring to beam interface device

In the same set up, through holes will be drilled and countersunk into the faces of the part shown in Figure B14. These holes will be used to mount the interface component to the ring which will fit inside of the bearing.

Figure B 15 Holes location for set up 2 for the bearing ring to beam interface device

- **Summary for Set Up 2**

TABLE B VIII SUMMARY FOR SET UP 2 OF BEARING INTERFACE DEVICE

Tool Changes	2
Set Up Time (Including Tool Changes)	20 min X 2 = 40 min
Run Time	30 min X 2 = 60 min
Total Time	**50 min X 2 = 100 min**

B5 Bearing Interface Ring

The fastest, most effective means to fabricate this component is to use a large bed lathe. This machinery is not always available, but the client (Bristol) routinely turns material up to 22’’ in the manufacture of the Black Brant rocket so this large dimension poses no problems for in house capabilities. The inner bearing interface ring is the only custom component that is to be made from aluminum, purely for weight reduction purposes. 6061 T6 Aluminum will be sufficient for this component. Stock for this component must be a minimum 18.25’’ diameter, to allow for proper rounding off of the part while it is being turned, and must have enough excess beyond the 1’’ thickness required for the part itself. Manufacturing steps are as follows:

1) Set stock up on lathe, and round off outside face to 18” diameter.
2) Leaving a 0.5” thick wall around the outside face, remove material in inner 17” diameter, to a minimum depth of 1”.
3) Part off resulting ring from material being held in chuck.

Prior to pressing the ring into the bearing, the ring should be placed in a freezer to use thermal expansion to shrink the ring to aid with installation into the bearing. After cooling, the ring will be press fit inside the bearing. The through holes in the beam to ring interface component will be used as guides to drill the holes a further 0.25’’ into the ring, and the resulting holes will be tapped to match the thread of the selected 0.25’’ diameter bolts selected to attach the interface device to the ring. Estimated time to fabricate the ring is **60 minutes**, with one set up on a large bed manual lathe.

B6 Bearing

As mentioned earlier, the bearing will be purchased as an existing component. The manufacturer has been selected and is specified in the bill of materials.

B7 Bearing to Rocket Interface

The final component that must be fabricated for the trim tool is the bearing to rocket interface. Depending on the discretion of the client, and the availability of material stock that satisfies the required geometry, this may be made as either two separate pieces that are welded together around the base or a single part that is milled or turned from a solid block of steel. It is recommended that the part is made on a large bed vertical mill, either manual or CNC, as this allows all of the geometry to be created with one set up, including the weight reduction holes, as well as avoiding the complexity of joining the two components together later with a weld. Recommended order of processes is to remove the inner diameter of material, mill out the ledge for the bearing to sit on, drill the lightening holes, and then cut out the outer diameter of the ring to remove the part. The outside diameter of this interface ring is fixed at 22''. A circular hole pattern can be drilled during this set up to allow the tool to locate onto the rocket cone in pre-existing holes, which will later be used to mount the exit cone. The interface ring is pictured in Fig. B16.

If the procedure is followed as recommended, estimated time for this step of fabrication is **240 minutes**. This lengthy time is mostly due to the large amount of steel being removed, which will require a low feed rate.

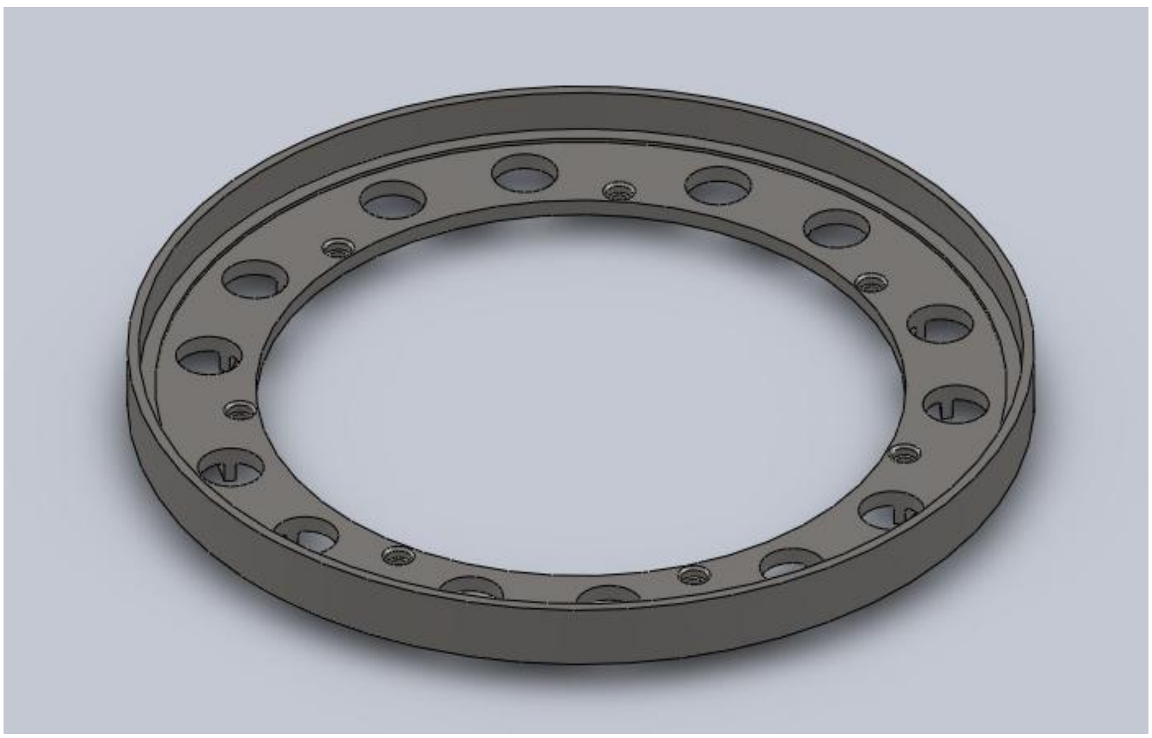


Figure B 16 Interface ring

Prior to press fitting the bearing assembly into the now manufactured outer ring, it is recommended that the outer ring be placed in an oven to expand the ring, aiding in the press operation.

B8 Total machine time

In order to provide an estimate of manufacturing costs for the device in total, the machine time, including set up, is summed from the estimates made throughout the previous discussion for both run time and set up time. The result is **955 minutes**, or **nearly 16 hours**.

TABLE B IX TOTAL MACHINE TIME

Parts Name		Manufacturing Time [min]
Tool Holder	Part A	130
	Part B	155
	Part C	60
	Drilling	60
Radial Beams		30
Bearing Ring to Beam Interface Device		220
Bearing Interface Ring		60
Bearing to Rocket Interface		240
TOTAL		955

This does not include the time for applying the Teflon coating to the radial bars, heating and cooling the rings before press fitting, or the press fitting operation itself as these will be done at the client's facility, and not contracted through a machine shop.

Appendix C: Details of Cost Analysis

List of Tables

TABLE C I COST OF SCREWS [4] [5] [6] [7]

Part #	Name	Description	Quantity	Serial #	$/ Package	Cost
1	0.25x0.51, Thumb Screw, Type A, Flat Point-N		2	91744A538	6.48/5	2.6
2	0.25x1.5, Thumb Screw, Type A, Flat Point-N		1	91744A548	9.3/5	1.86
3	SSFLATSKT 0.099-48x0.5-HX-N	Socket Set Screw Flat Point_AI	6	92313A109	10/50*	1.2
4	SCHCSCREW 0.099-48x0.375x0.375-HX-N	Socket Countersunk Head Cap Screw_AI	3	90585A202	3.36/10	1.1
5	SCHCSCREW 0.25-20x0.75x0.75-HX-N	Socket Countersunk Head Cap Screw_AI	2	90585A230	4.31/10	0.87
5	HX-SHCS 0.099-48x0.5x0.5-N	Socket Head Cap Screw_AI	8	92185A110	7.27/50	1.17
6	HX-SHCS 0.138-32x1.75x0.75-N	Socket Head Cap Screw_AI	6	92185A161	5.54/10	3.33
9	HX-SHCS 0.375-16x1x1-N	Socket Head Cap Screw_AI	7	92185A199	5.01/25	1.41
10	HX-SHCS 0.25-28x1x1-N	Socket Head Cap Screw_AI	4	92185A564	7.79/10	3.12
11	HX-SHCS 0.25-20x0.5x0.5-N	Socket Head Cap Screw_AI	4	92185A558	6.7/10	2.68
Total Cost for Screws					$19.34	

TABLE C II COST OF THE COMMERCIAL PARTS [8] [9] [10] [11]

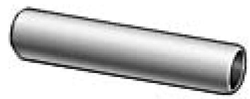
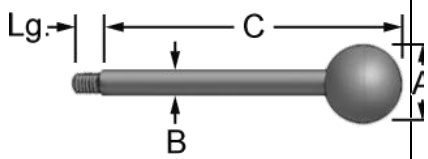
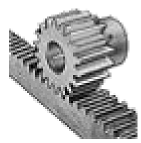
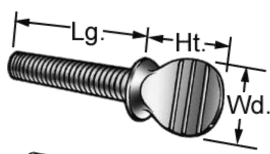
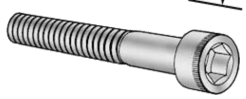
Part #	Part Name	Part Drawing For Raw Material	Quantity	Reference	Cost
1	Handles	 	2	4559T211 6303K68	74.34
2	Gears		2	6832K61	35.76
3	Bearing		1	Kaydon® JG180XP0	Estimated 3000
4	Screws	 	43	SEE TABLE D1	19.34
5	Knobs		2	6479K17	5.12
Total Cost Of The Parts Off The Shelf					3134.56

TABLE C III COST OF THE RAW MATERIAL [12] [13]

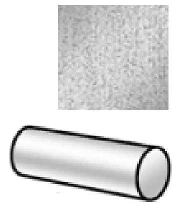
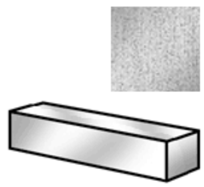
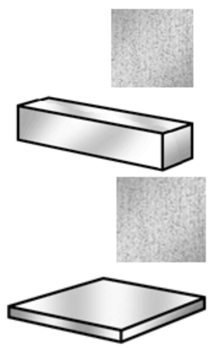
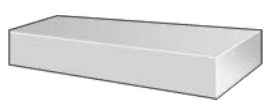
Part #	Part Name	Part Drawing For Raw Material	Quantity	Reference	$
6	Gear Shaft		1	R414	3.24
7	Beams		2	89415K33	78.61
8	Tool Holder		1	1251T74 1251T43 1251T45	626.08
9	Blades		1	Stanley Inc.. 11-911A	13.95
10	Bearing Ring to Beam Interface Devices		2	8992K854	47.7
11	Bearing Interface Ring		1	4529T83	1363.49
12	Bearing to Rocket Interface		1		
Total Cost Of The Raw Material					2133.07

TABLE C IV MANUFACTURING COST

Manufacture Processes	Rate [$/Hour]	Hours	$
Parts Manufacturing	120	16	1920
Coating	N/A	N/A	275
Total Cost of Manufacturing			2195

Total Cost = Commercial Parts Cost + Raw Material Cost + Manufacturing Cost

= $3134.56 + $2133.07 + $2195 = $7462.63

Appendix D: Selection Criteria and Concept Analysis

List of Figures

List of Tables

For this project our team used a multistep process to select a working final concept to present to our client. Our team brainstormed possible solutions for several days which led to preliminary concepts. Next, selection criteria were set forth based on the clients technical requirements, limitations, and constraints. An analysis was performed on each of the concepts based on these criteria using a screening matrix and a scoring matrix.

The screening matrix was used to focus our team on the better concepts. This was accomplished by checking the designs to see if they complied with technical requirements, limitations, and constraints. If a design fulfilled a criteria then it was given score of 1. If a design failed to comply with a certain criteria it was given a score of -1. In the event that the criteria did not apply to the design or the design did not directly fulfill the criteria then a 0 was given. Once all the preliminary full designs had been scored using these numbers the scores were added up. The five designs with the most positive scores were selected for further development

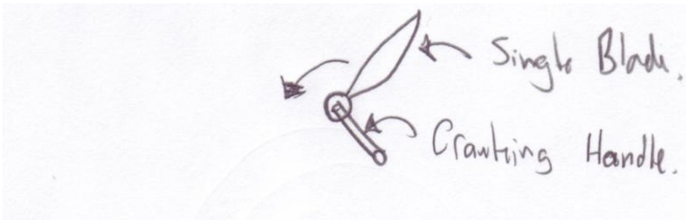
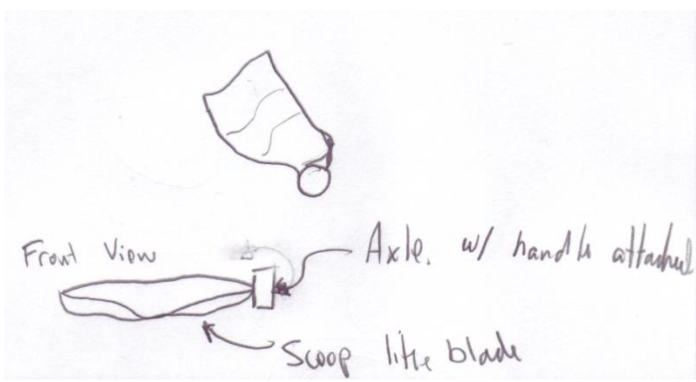
The scoring matrix was used to select a final concept. This was accomplished by scoring the designs based on how well they complied to the criteria. A score of 0 was given for lack of compliance and a score of 5 was given for complete compliance. Once all the refined full concepts were scored the numbers were added up and the design with the highest score was selected as the concept to be finalized and presented.

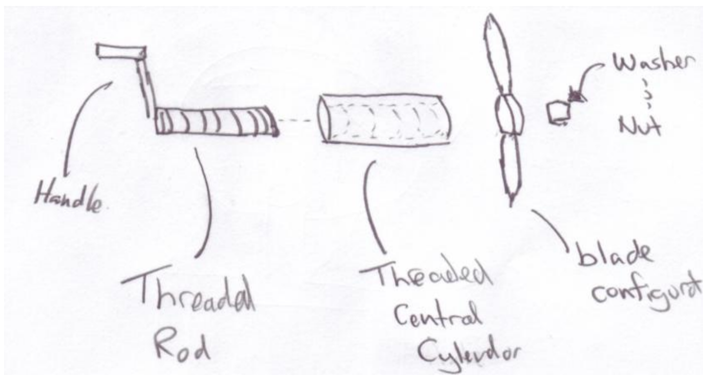
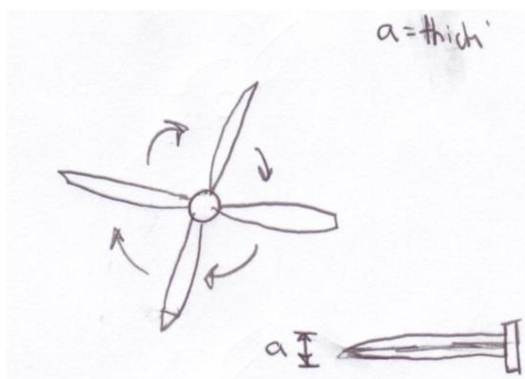
Lastly our team has taken this concept that was selected, analyzed it, and come up with some improvements based on the feedback received from our client. This section will explain this process in further detail. Also, included are tables showing pictures and descriptions of the preliminary ideas, preliminary full concepts, and refined full concepts.

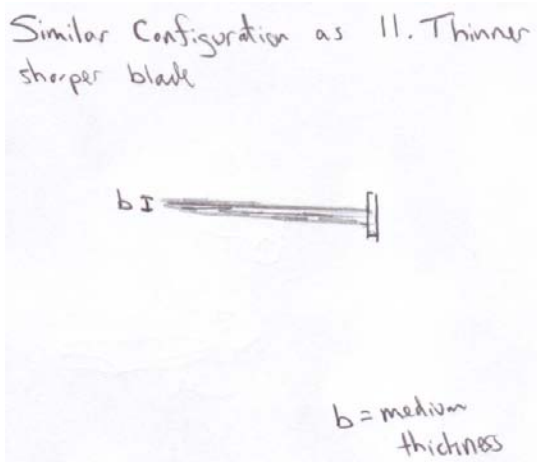
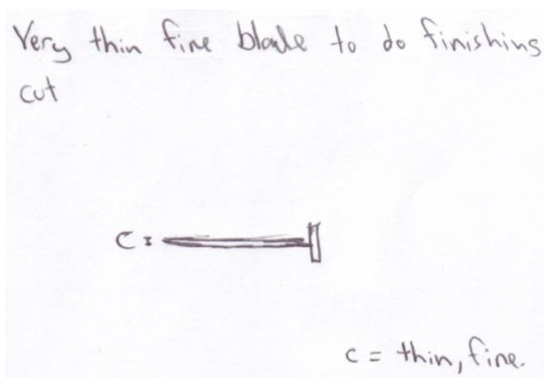
D1 Preliminary Ideas and Concepts

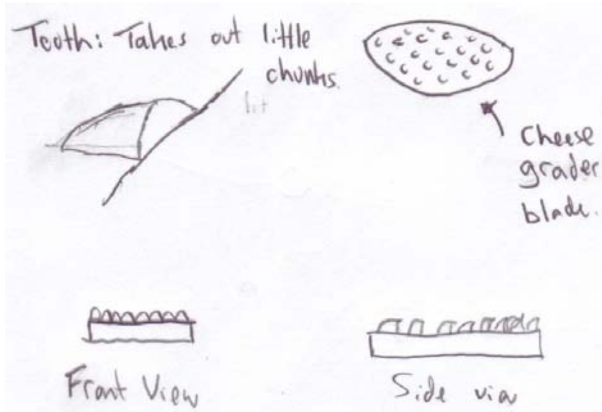
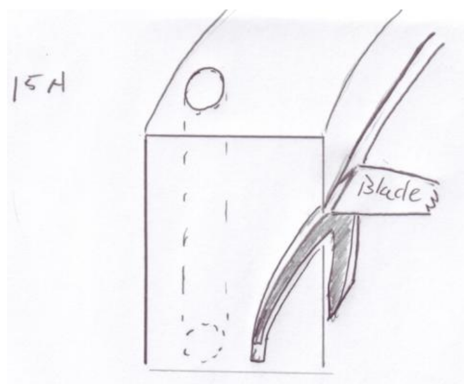
Our team used a process with several steps to select our final design. The first steps of this process were to brainstorm and come up with some basic ideas of components for our design. This was done over several meetings. These ideas are shown below in TABLE D I. Brief descriptions and a sketch of the general idea have been given for each of the ideas shown in the table below.

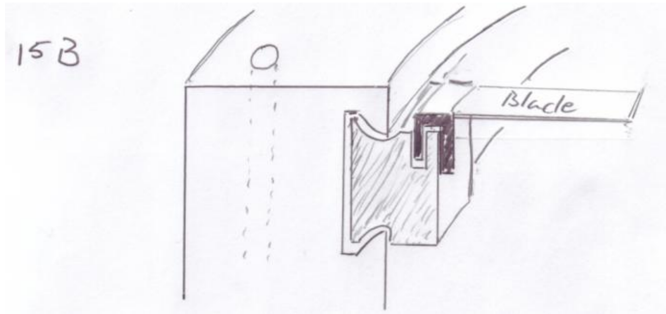
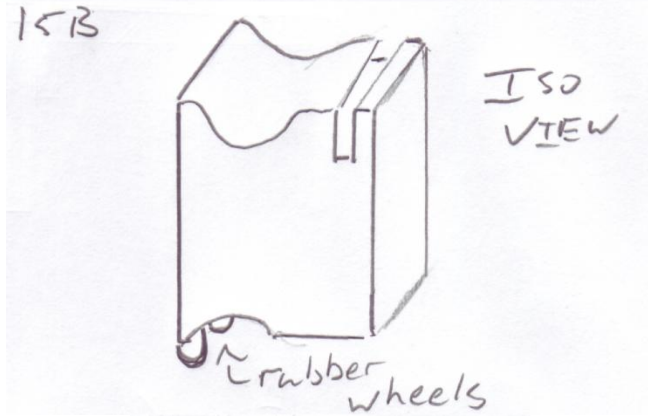
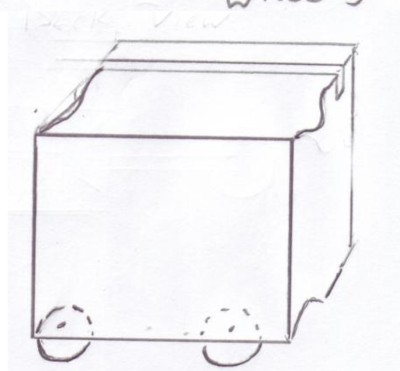
TABLE D I PRELIMINARY IDEAS AND CONCEPTS

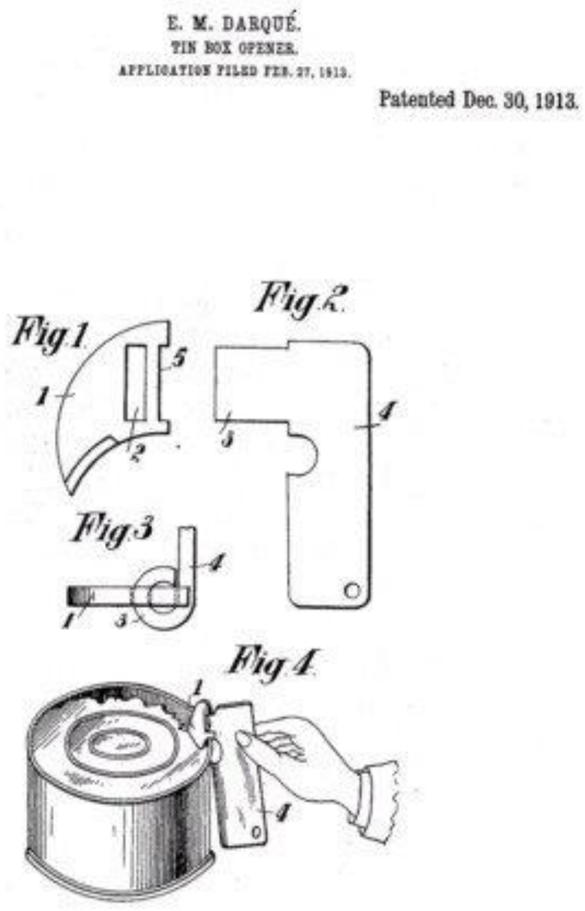
1	Blade Concept 1	1 Single Curved rotating around central axle(Thin Cutting Blades Like a Sword)
	 	
2	Blade Concept 2	2 Curved Blades rotating around central axle (Thin cutting blades like a sword)
		
3	Blade Concept 3	1 Scoop/Blade rotating around central axle (Long flat blade with some curvature)
	 	

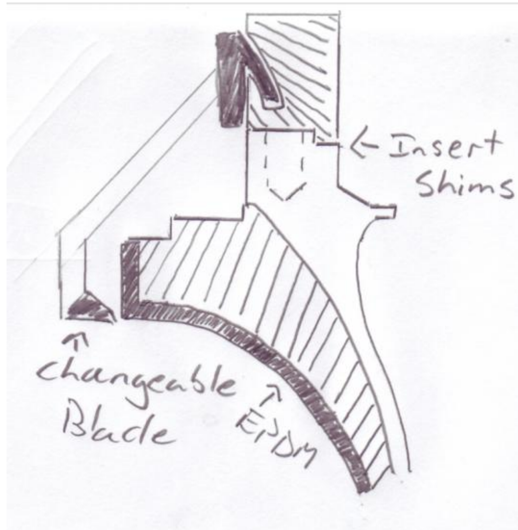
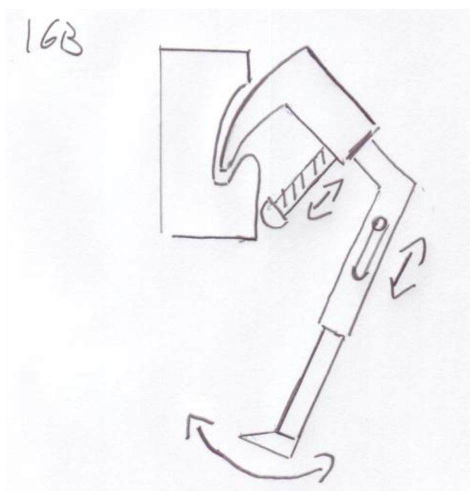
4	Center Axle	A very finely threaded hole into which a very finely threaded rod turns. A handle is attached to one end and a blade attached to the other. Blades will attach to the rod using a bolt/nut configuration allowing for easy changing of the blades. Or the blades and rod can be 1 piece. The fine threads allow for the cutting depth to be controlled.
		
5	Rough Cutting Blade attachment	3 or 4 knives attached to a central ring that do the rough cut of the propellant
		
6	Medium Cutting Blade Attachment	3 or 4 knives with a sharper edge that perform a second cut before the finishing cut is done

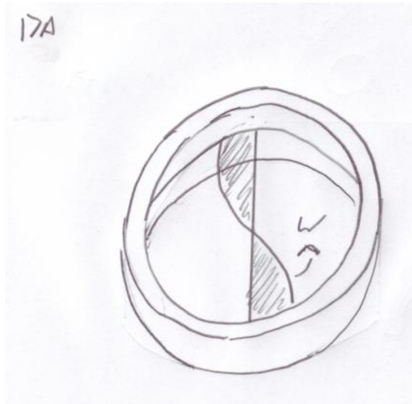
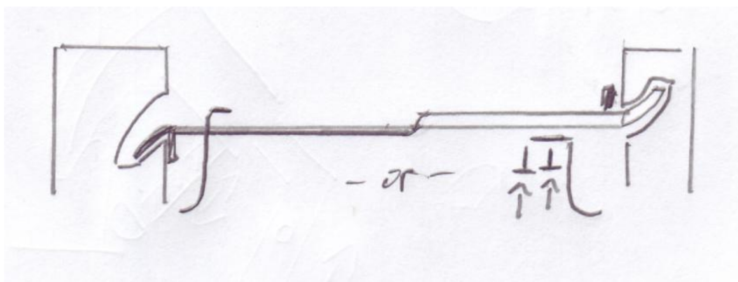
<table>
<tr><td></td><td colspan="2">
</td></tr>
<tr><td>7</td><td>Finishing Cutting Blade Attachment</td><td>3 or 4 very fine cutting blades that do a finishing cut to make everything nice and flat.</td></tr>
<tr><td></td><td colspan="2">
</td></tr>
<tr><td>8</td><td>Cheese Grater Style Removal of Propellant</td><td>A cheese grater style of blade turns around a central axle removing propellant material. This would be a rough cut as it would make a mess of the surface but remove lots of material.</td></tr>
</table>

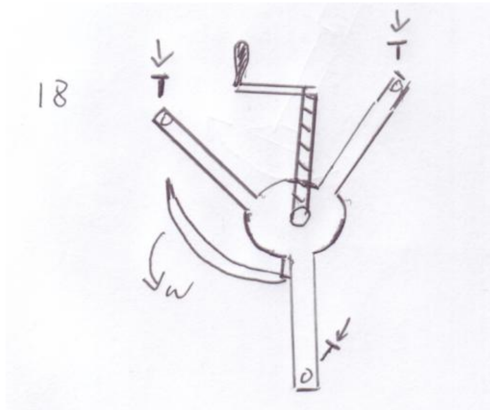
		
9 A	Gravity Lock Track	Track consists of diagonal slant milled into ring which is to fit around aft lip of rocket. Slant extends only downward into ring, so tool change would involve simply clipping arm of tool holder into ring and downward force applied while cutting would hold assembly into track.
		
9 B	Permanent 'runner' Fitted into Track	To reduce need for lubrication, sturdier/ more permanent fixture could protrude from track, with easy clip on/ clip off features incorporated into this assembly rather than the track itself. Possible to fit this runner with (spring loaded?) wheels along bottom to increase smoothness of use.

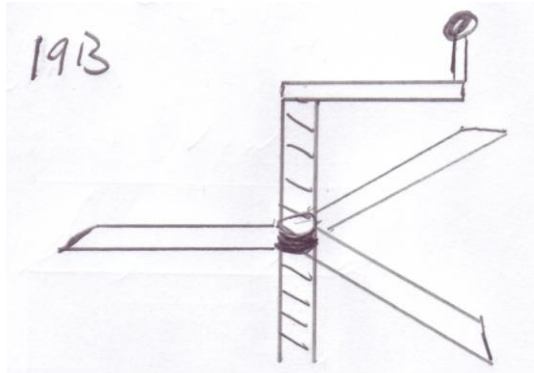
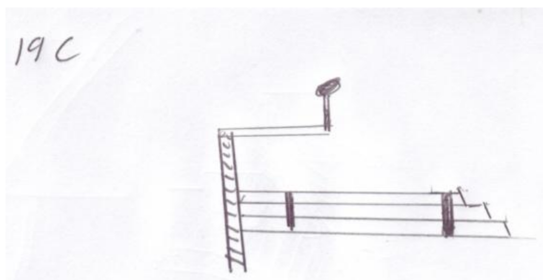
		  
9 C	Geared track	Track could incorporate some gear system which may move radially when actuated to propel whatever tool is fitted/ protruding from it.
9 D	Can Opener Style	Can opener style device (hand held) with proper hook to reach tab clips into track, and pulls itself around track as actuating mechanism turned by hand.

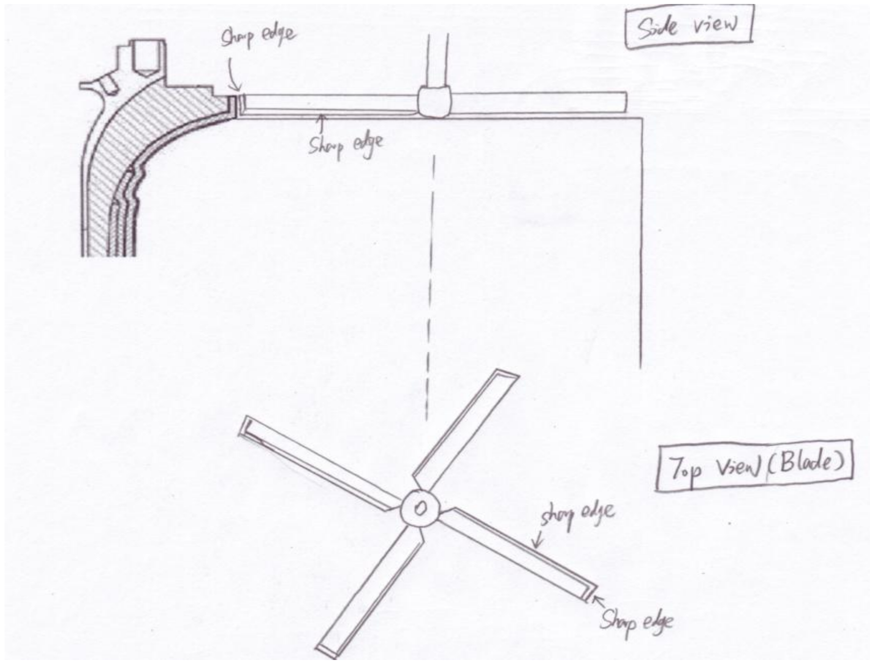
		
10 A	Drop Down Bracket, Precision Geometry	Single piece (Al?) machined to attach into track located as previously discussed around lip of rocket. Geometry would be fixed to position bladed exactly as needed, and if vertical adjustments were necessary shims could be used between the rocket lip and the track itself.

		
10 B	Adjustable stop	One 'arm' of tool mount clips into track, the other extends downwards and acts as a brace to control angle that tool approaches EPDM at. Bracing arm would be adjustable to increase/decrease angle tool makes with aft lip, thereby altering angle of tool extending down into cavity.
		
11 A	Lawn Mower Style	Also mounts into same track. One blade, with two cutting edges (switches axial center) spans diameter of cavity and faces propellant upon rotation.

		
11 B	Lawn Mower B	Blades themselves could have a mount which is used to clip on a second blade, fish hook style, that extends downward into cavity for EPDM trim
		
11 C	Two track lawn mower concept	Lawn mower concept could be combined with concepts in 15 by having a second track cut above first one in aluminum cylinder that is to fit onto aft lip.
12	Downward Spiral Corkscrew	Three arm brace, tailored to fit in between gaps left in propellant after mandrel is removed, bolts onto track, which fits around aft lip. Threaded rod in center has blade attached, fine thread allows for depth control as assembly is screwed in and downward.

		
13 A	Apple Sauce Maker	One large (wide), leaf shaped blade with some relief in profile used to slice into propellant and then guide material away. Shape of blade could be tailored to best meet requirements of situation.
		
13 B	Evenly spaced blades about axle	3 blades spaced evenly about center axle. Cutting tip orientation could be altered so each progressive blade cut slightly deeper, with a slightly finer blade to increase quality of cut.

		
13 C	Mach 3 Style co-located blades	Same idea as above, except all blades would be essentially stacked on top of one another. This would decrease the balance of the contraption, but would allow for some bracing across blades to decrease drooping and maintain a level cut.
		
14	Cavity located Mandrel Mount	Have a mounting fixture of identical shape to mandrel (or at least exterior portion of it) that fits back into cavity in propellant. Threaded rod protrudes upwards out of the cavity that cutting blades can be screwed onto, and downwards until desired depth of cut is achieved.
15	Turbine blade cutter	Same kind of frame as vertical mill. Cutting depth is controlled by the moveable blade mounting fixture. Multiple cutting steps. From rough cut to final cut. Simple design, no gear involved.

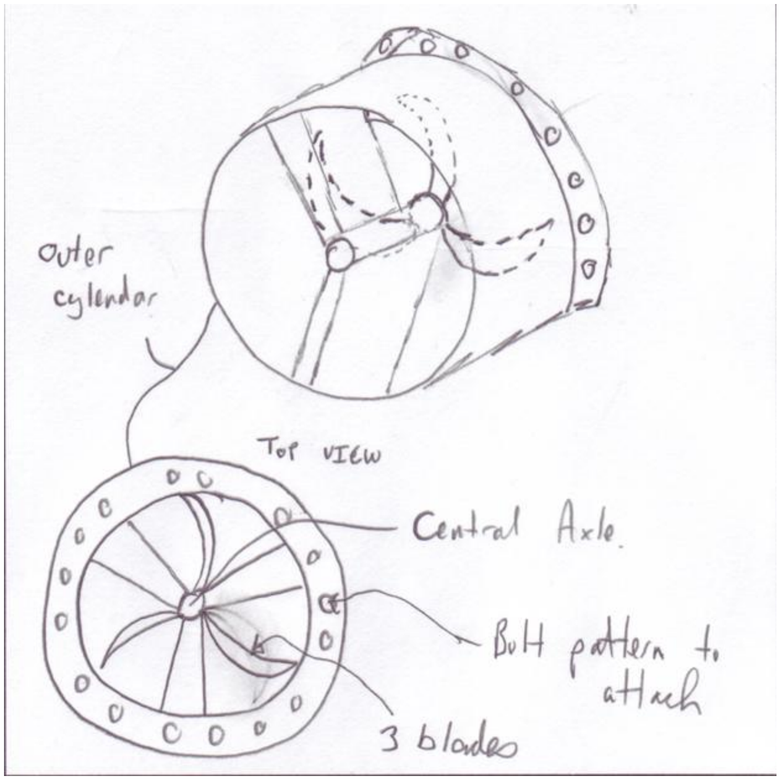
	 Frame design same as “Vertical Milling Machine Style”. Except the change the mill cutter to turbine blade.

D2 Preliminary Full Concepts

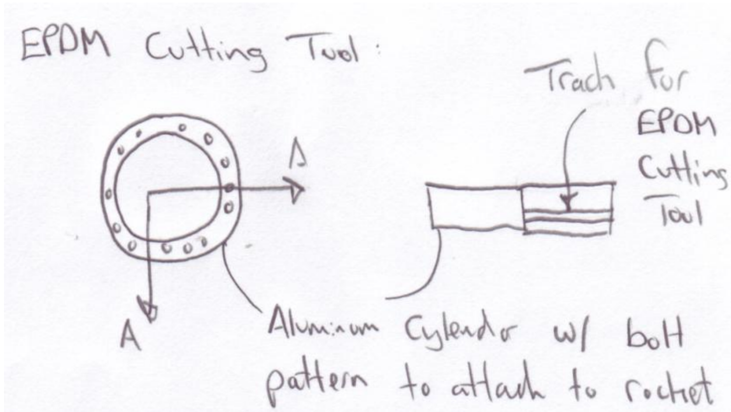
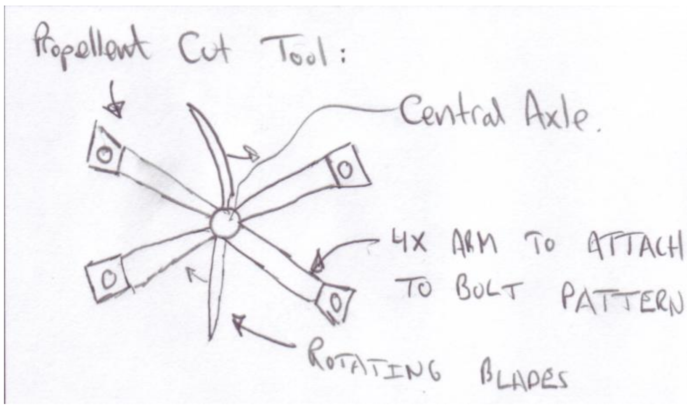
After brainstorming a large number of small ideas and concepts our team started piecing these together to make full designs. TABLE D II, below, gives a brief description of each design and shows a sketch of the concept.

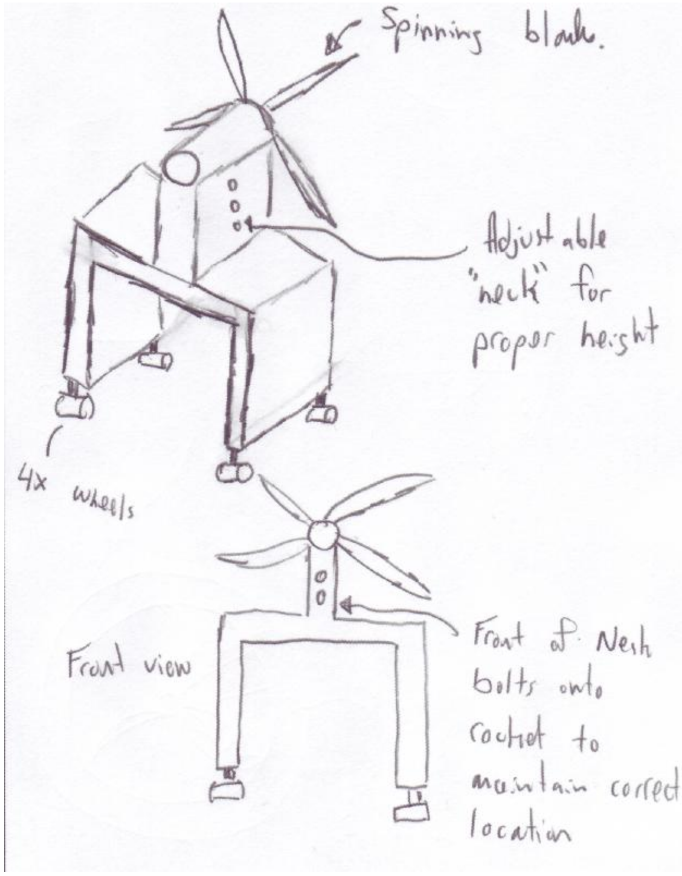
TABLE D II PRELIMINARY FULL CONCEPTS

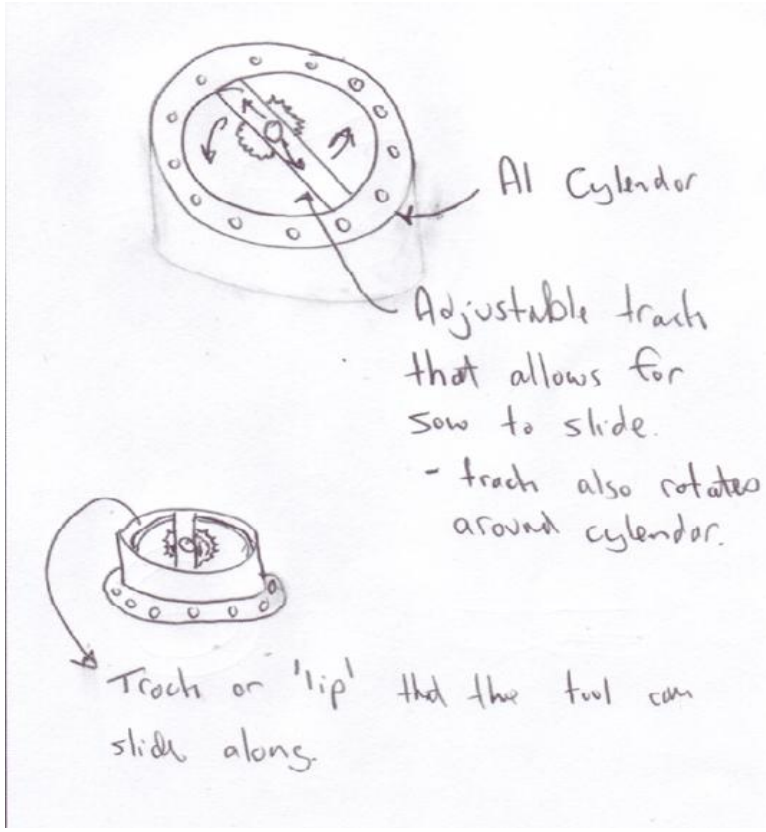
1	Turbine Style	An outer cylinder with a centrally located axle about which blades spin around to cut. Could have different blades for a rough cut, medium cut, and a finer cut. Could be hand powered. Track at the closest side to the rocket motor for trimming of the EPDM tab.



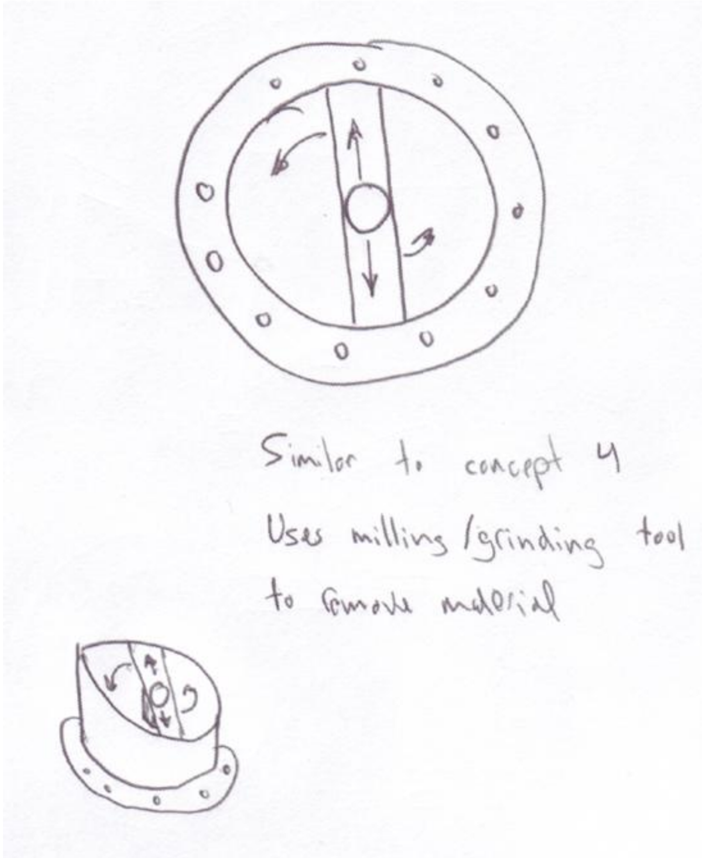
2	Turbine Style With Material Removed	Centrally located axle is attached to the hole pattern by 4 arms. Blades spin around the axle. Same options for blades, and cuts as (1). This would cut the propellent. To cut the EPDM use some sort of a bolt on aluminum cylinder with a track to a specilized blade around to cut the EPDM properly.

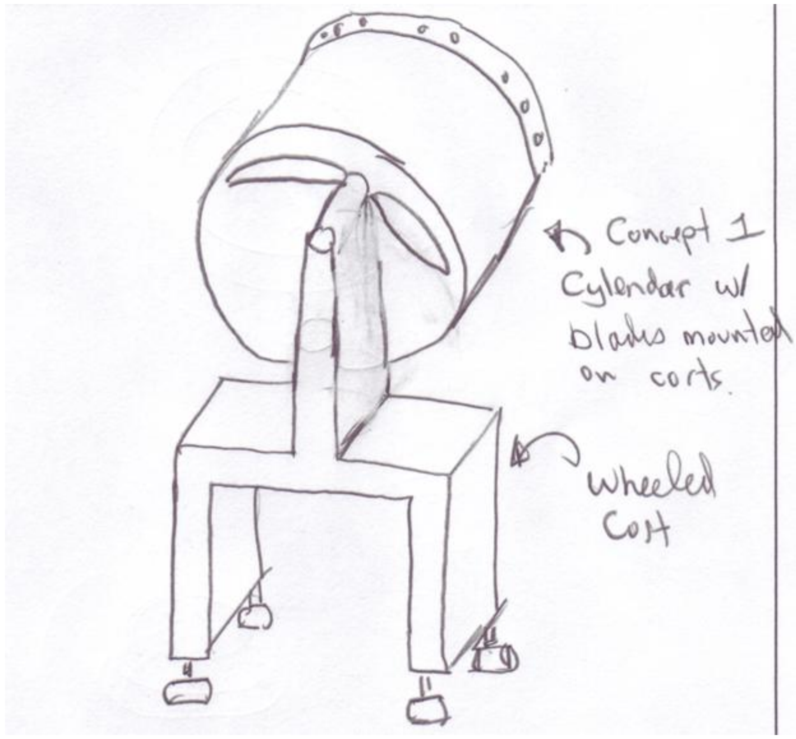
	 	
3	Fan Style	Wheeled cart with fan like axle and blades on it. Aluminum cart with wheels. On the cart is an adjustable 'neck' on top of which is the axle and blades. The 'neck' can move up and down in order to bolt the tool to the bolt pattern. The fan part of this design would have an axle with blades attached to it. The neck would bolt to the rocket bolt pattern in order to locate the center axle. Would need a separate aluminum track thing like in (2) to cut the EPDM

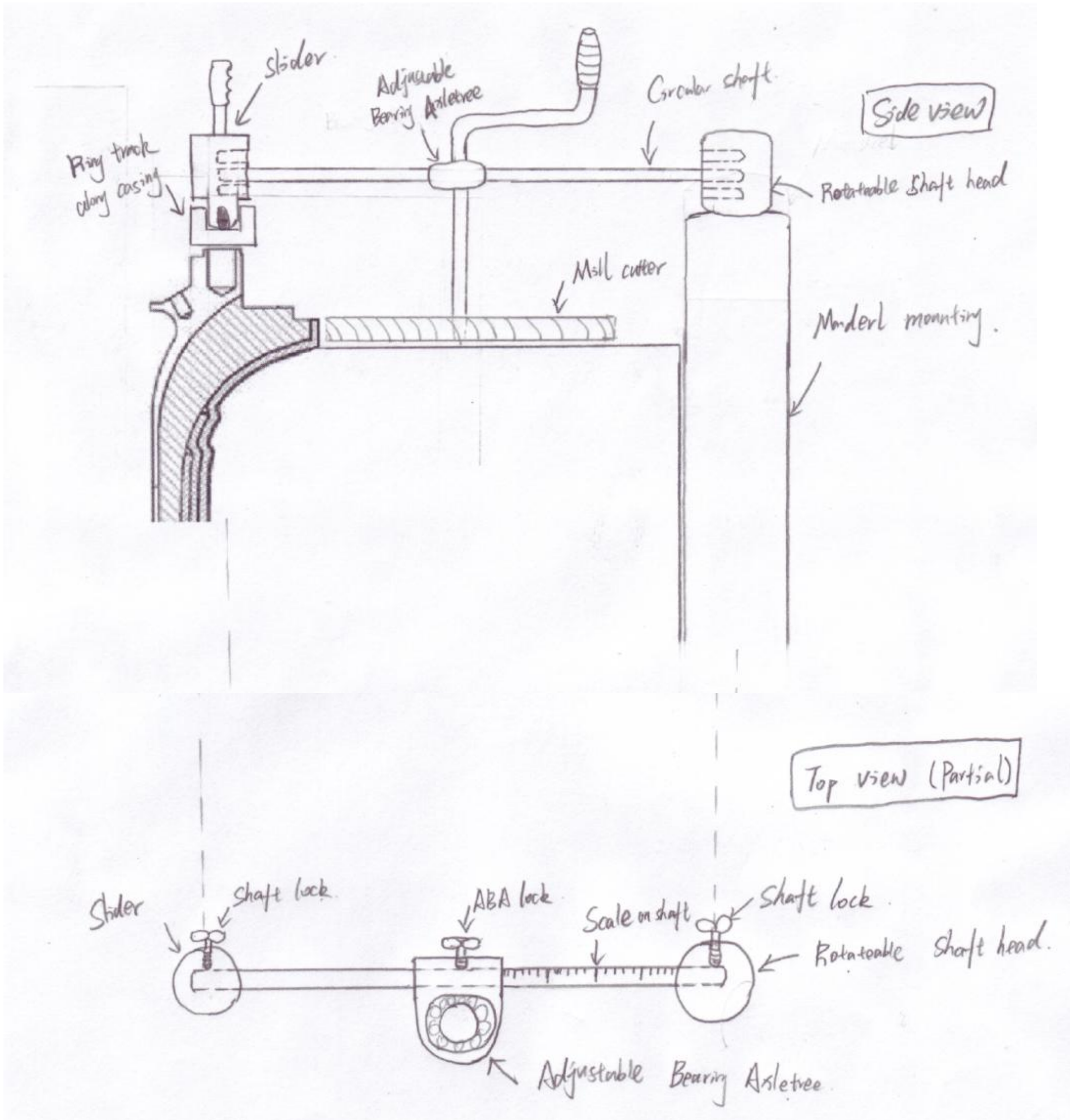
		
4	Vertical Cutting Tool	A rotating cutting tool (Circular Saw Blade) with varying circular track. A circular bolt on aluminum cylinder would be anchored to the bolt pattern. There would be some sort of a guide track to attach the small rotating saw. The saw would be moved around the track manually to cut the propellent. This design could have a built in track in order to cut the EPDM

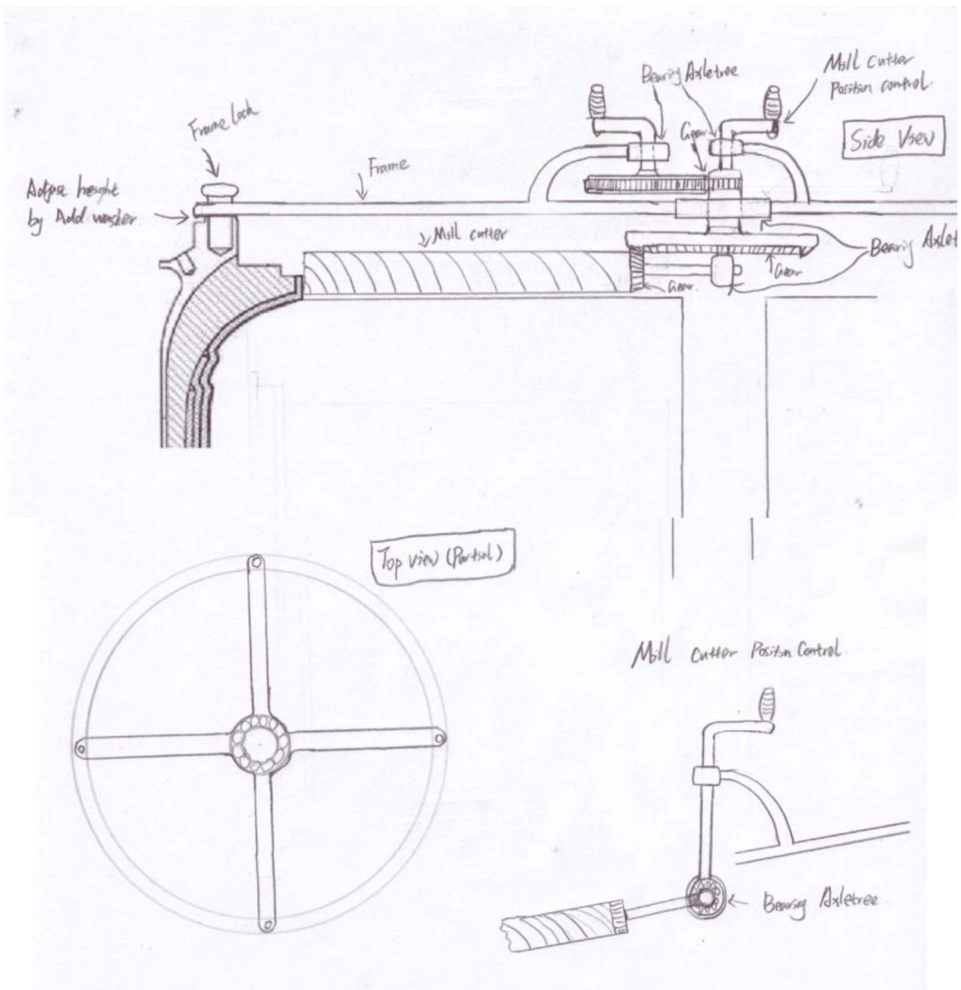


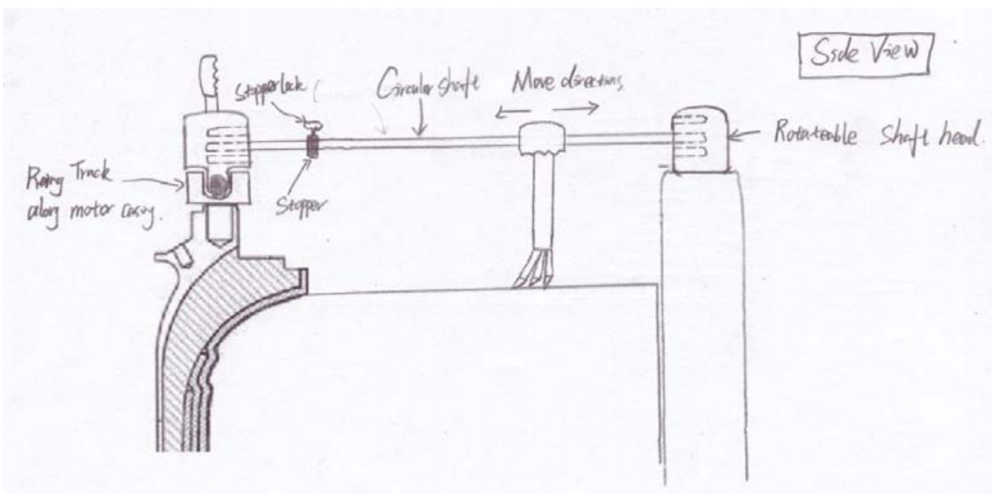
5	Milling Machine Style	Use a mill style blade to take off a small layer at a time using guided circular track. This design would use some sort of a milling/grinding tool to mill/grind away the left over propellent. Use of different size cutters would allow for rough, medium, and finishing cuts. The tool would be moved manually around a track of some sort. An aluminum cylinder of some sort would be used to hold this guide track.

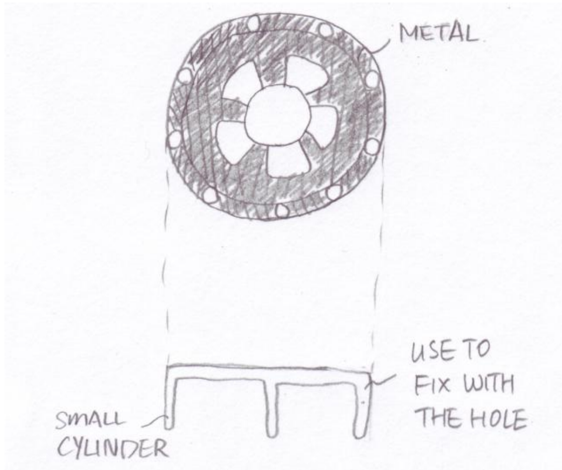
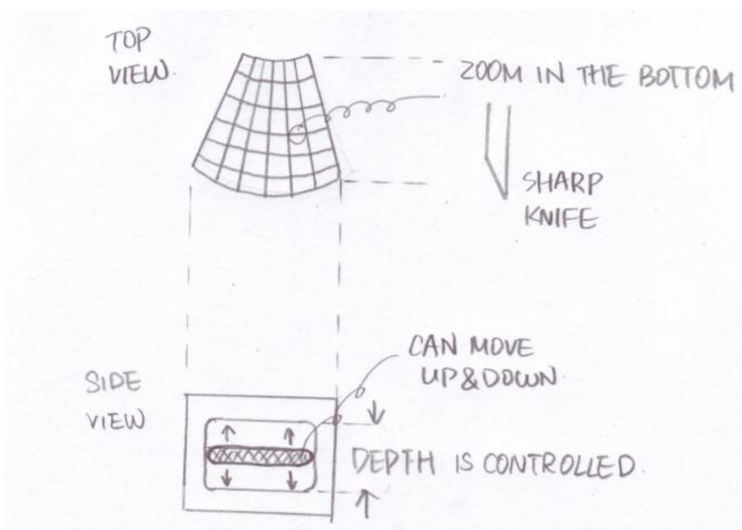
		
6	Wheeled Cart & Turbine Idea	This combines the turbine idea from (1) and the cart with wheels and adjustable neck from (3) This would allow for easy movement of the tool, easy 1 person handling, easy blade switching.

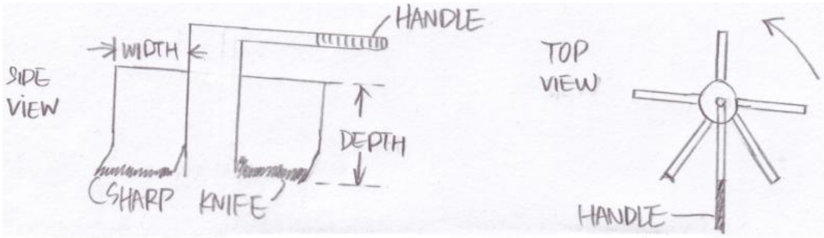
		
7	Vertical Milling Machine Style	Design includes mount which fits into mandrel cavity, shaped exactly as mandrel which has been removed. Create frame to support a face mill blade. The frame is mounted in the mandrel fitting at one end and another end is mounted on the ring track along the rocket casing. The frame can rotated around the mandrel (other end slide along the track.) The mill blade axis is perpendicular to the cutting surface. This device is operated by manpower, which transfers the energy from the handle through bearing system to the face mill blade. Cutting depth is controlled by the moveable blade mounting fixture


Slider
Adjustable Bearing Axletree
Circular shaft
Side view
Ring track along casing
Rotatable Shaft head
Mill cutter
Mandrel mounting
Top view (Partial)
Slider
Shaft lock
ABA lock
Scale on shaft
Shaft lock
Rotatable Shaft head
Adjustable Bearing Axletree

8	Horizontal Milling Machine Style	4 arm frame is attached on the rocket casing hole pattern. The mill blade axis is parallel to the cutting surface, and it can revolve around one end. Involves gear system Cutting depth is controlled by the 4 arm frame. Multiple cutting steps from rough cut to final cut.
		

9	Sliding bar cutter	Round bar; one end connects the mandrel fixture and other end connects to the track fixture. The two end fixture can change bar height by moving between grooves in track (adjustable bar height). Cutting blade can slide on the bar. Multiple blades. Simple design, no gear involved. Overcut prevented by mechanical stop.
		
	10	
Step 1	Protection pattern	Made of metal Use three small cylinders to fix with the hole Use for protect the part which shouldn't be cut Continue use through the whole process

		
Step 2	Chopper	The depth can be controlled Make smaller to Avoid tearing off The knifes are sharp
		
Step 3	Blade cutter	Simple design, Easy to operate After the last step, should be very easy to cut

D3 Screening Process and Selection Criteria

After the creation of the ten preliminary full concepts, shown above in TABLE D II, our team set up a selection process to determine which concepts to continue to pursue and further develop. The first step in this selection process was the screening matrix. The screening matrix used twenty one criteria. These criteria were based on different aspects of the technical requirements, limitations, and constraints. The criteria that were used to screen the ten preliminary full concepts are listed below in TABLE D III, shown below. The selection criteria and a brief description of such are given.

TABLE D III DESCRIPTION OF SELECTION CRITERIA

Selection Criteria	**Description**
Non-Sparking	The material must be non-sparking
Conforms To Geometry	The material must conform to geometry
Adjustable Depth	The design must incorporate a method to control the depth to ensure accuracy
Mounts on Rocket Safely	The concept must mount on the rocket safely
Single Operator Can Use it without Assistance	The concept should be simple enough for a single operator to install and use
Performs all Trimming Operations	The tool should be able to cut the propellant and the EPDM
Mechanical Stop to Control Depth	Depth control must have a way to prevent overcutting
Simple to use (No Advanced Training Required)	Tool must be of simple design so that operators do not need extensive training

Tool Can Cut Cleanly (No tearing)	The cutting tool must be able to cut through both EPDM and propellant properly without damaging the material
Allows for Repeatability	The design must ensure that the cutting process will have always have the same results without variation in depth or quality
Safe Power Method	The power method must conform to the explosive safety requirements
Does not Requires grease, or other liquids	The propellant must not be contaminated by liquids
Under $10,000	The design must be under $10,000
Lightweight	The design should be less than 50 pounds
Small Size	The design should be small enough that one person can use it
Avoids Excess Moving Parts	The design should be simple so that maintenance and cost are reduced and the tool is easy to use
Accurate	The tool should be accurate to prevent over cutting
Requires Little Human Input	The tool should be easy to use and require minimal human input to operate
Easy to Manufacture	The design should avoid excessive manufacturing in order to reduce cost
Durable	The tool should be built so that it will not break
Good Visibility of Progress	The design should allow for good visibility of the cutting process to ensure high accuracy

The ten preliminary full concepts were measured against the selection criteria based on feedback from our client, and our own reasoning. The five designs that were chosen for further analysis were not perfect full designs. They scored high because they had some positive aspects that the team felt are in accordance with what our contacts at Bristol would like to see. Our team liked concept 2 because the design was light and had very good visibility for the cutting procedure. Concept 5 was selected to continue because of the idea of a tool that rides on a track. Concept 7, 8, and 9 were chose for the combination of the track that holds a tool with some method of depth control, and because this track is moveable around the circular frame that would be attached to the rocket interface. Our team took the positive aspects of these five designs and used them in next step of the concept selection process to create full designs.

The five other designs also had some positive ideas which the team will look at, but they were marked low on several other important criteria. After talking to our Bristol contacts, the team discovered that concept 1 would not perform well because the cylinder reduces visibility, and the blade cutting system probably would not work as the material being cut is tougher than was initially thought. Concept 3 was deemed to be to too inaccurate because the design does not locate on the rocket property. Concept 4 was similar to concept 5, but was not selected because it had a few more moving parts and required more human input than concept 5. Concept 6 was a mix of concepts 1 and 3 which was turned down because it was hard to locate, had bad visibility of the process, and was very big and bulky. Lastly, concept 10 was rejected because of its inaccuracy and complexity.

The screening matrix that was used for screening our concepts is shown below in Table D4. Designs that met the criteria were given a 1. Designs that did not meet the criteria were given a -1. Designs that were neutral in that criteria area were given a 0. After all designs were evaluated against the criteria the 1's, -1's, and 0's were added up. Based on the scores that the designs received, the team decided to continue developing the top five designs.

TABLE D IV SCREENING MATRIX

Criteria\Concept	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Non-Sparking	1	1	1	1	1	1	1	1	1	1
Conforms To Geometry	1	1	-1	1	1	-1	0	0	0	1
Adjustable Depth	0	0	-1	-1	-1	-1	1	1	1	1
Mounts onto Rocket Safely	0	1	-1	1	1	-1	1	1	1	1
Single Operator Can Use it without Assistance	0	1	1	0	0	1	1	1	1	1
Performs all Trimming	-1	-1	-1	-1	-1	-1	1	1	-1	-1

Operations										
Mechanical Stop to Control Depth	-1	-1	-1	-1	-1	-1	1	1	1	1
Simple to Use (No Advanced Training Required)	1	1	1	0	0	1	-1	-1	-1	-1
Tool Can Cut Cleanly (No tearing)	-1	-1	-1	1	1	-1	1	1	1	-1
Allows for Repeatability	1	1	-1	1	1	-1	1	1	1	-1
Safe Power Method	1	1	1	1	1	1	1	1	1	1
Does not Require Grease or Other Liquids	1	1	1	0	0	1	1	1	1	1
Under $10,000	0	1	-1	0	0	-1	1	1	1	0
Lightweight	-1	1	-1	0	0	-1	1	-1	1	0
Small Size	-1	1	-1	0	0	-1	1	1	1	-1
Avoids Excess Moving Parts	1	1	0	-1	0	0	-1	-1	0	-1
Accurate	-1	-1	-1	1	1	-1	1	1	-1	-1
Requires Little Human Input	1	1	-1	-1	0	-1	-1	-1	-1	1
Easy to Manufacture	-1	0	-1	0	0	-1	0	-1	0	-1
Durable	1	-1	1	0	0	1	0	-1	-1	-1
Good Visibility of Progress	-1	1	1	0	0	-1	1	1	1	-1
Total	1	9	-6	2	4	-8	12	8	8	-1
Continue Developing	**No**	**Yes**	**No**	**No**	**Yes**	**No**	**Yes**	**Yes**	**Yes**	**No**

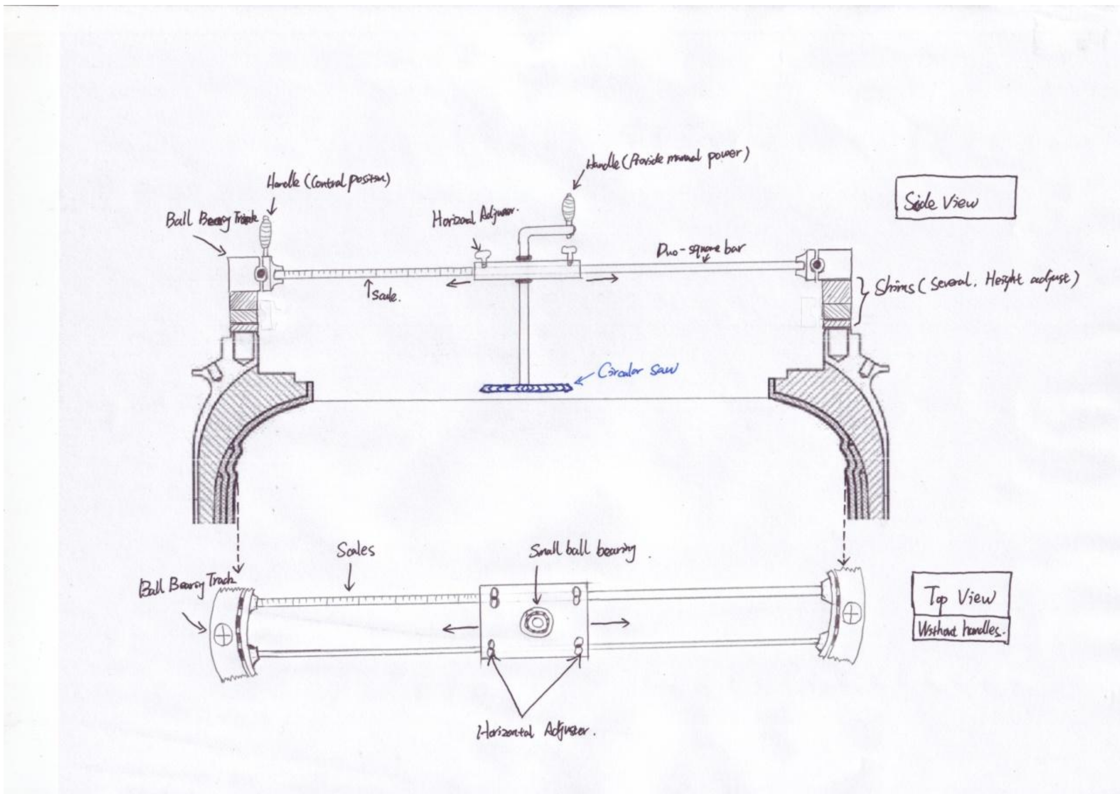
From the screening matrix, our team decided that the best idea for a frame was a small cylinder with some sort of moving track. Our Bristol contacts gave us the idea of using a large commercially available bearing for this purpose. Our team also decided that the best method of tool control would be a track of some sort that can be rotated around via the bearing, because a track is simple and easy to use. Our team also decided that some sort of a rotary tool will be considered for the actual cutting tool. This cutting tool is subject to change, because a properly designed apparatus will be the best solution for whatever cutting tool is selected. The next step for our team is to select a method of depth control and some sort of cutting tool.

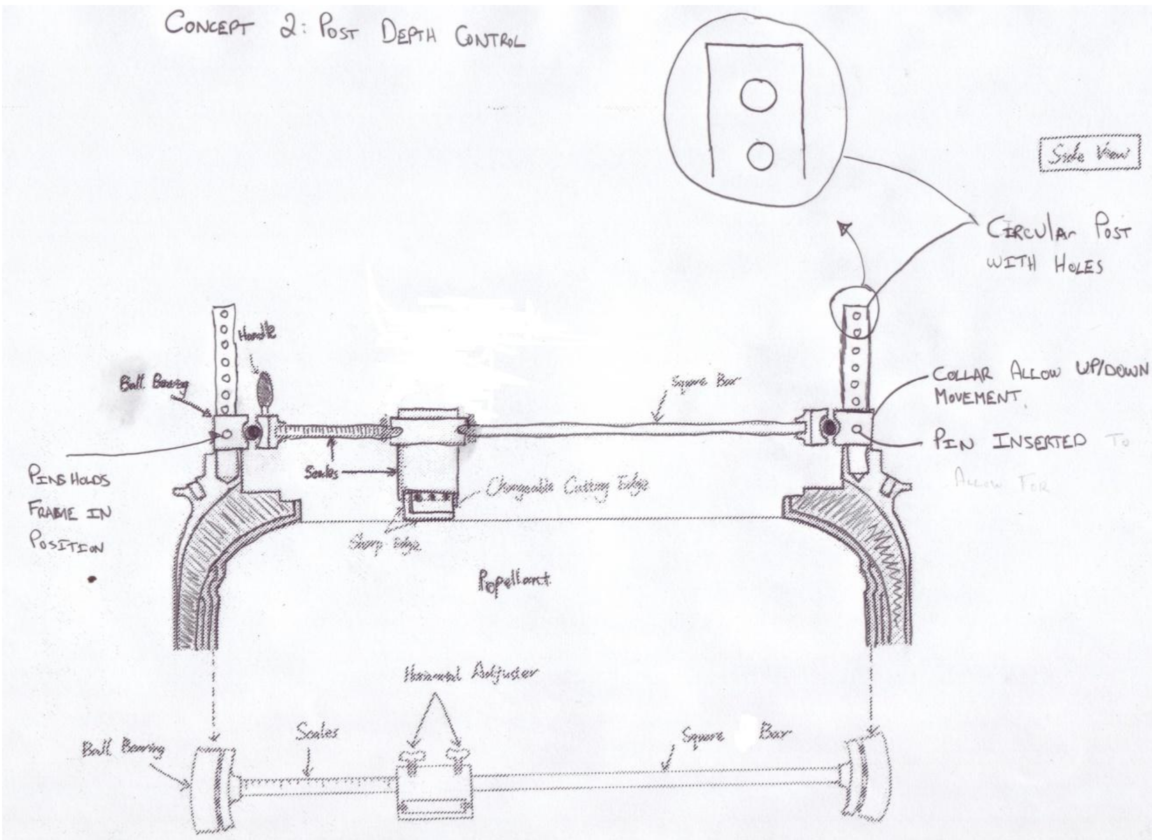
D4 Refined Full Concepts

Following the use of the screening matrix five designs were chosen. These designs showed the most promise in terms of positive ideas and concepts that could be actually be used in a final design. Elements of these designs were incorporated in to the next set of full concepts that were going to be considered. TABLE D Vshows the refined full concepts that were developed as a result of the screening matrix.

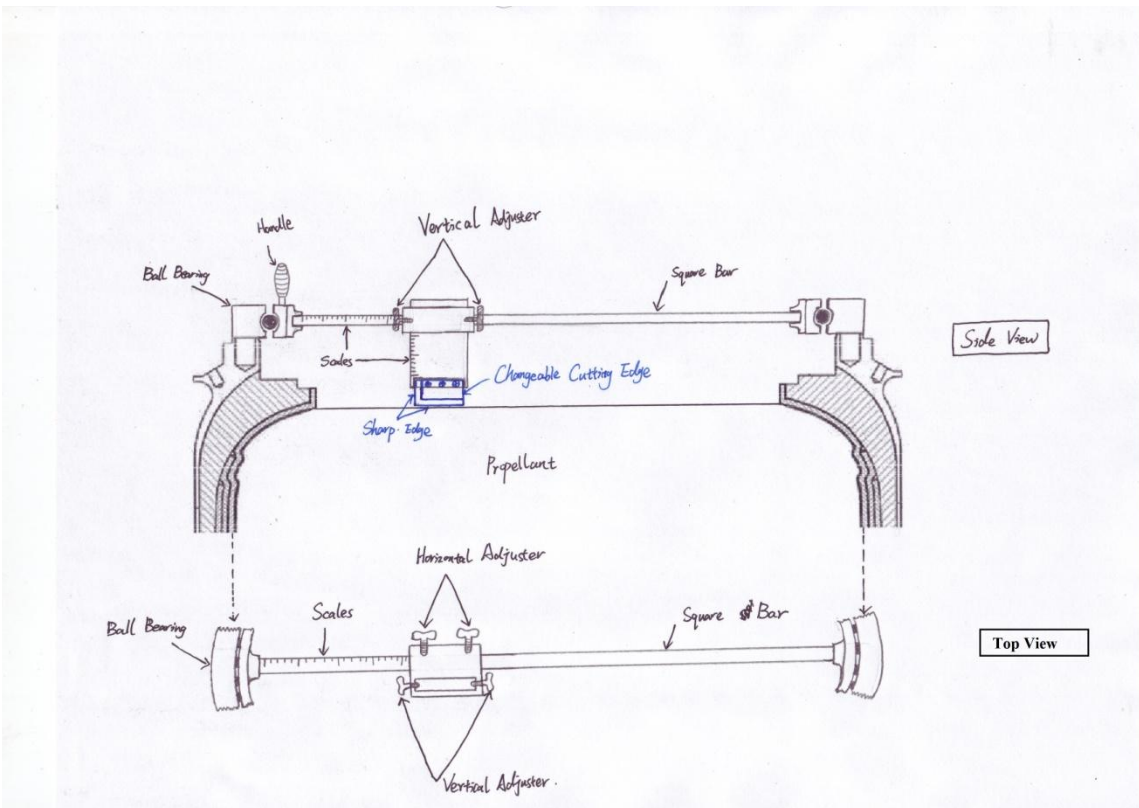
TABLE D V REFINED FULL CONCEPTS

No.	Concept Name	Description
Drawing		
1	Bearing + Track + Shims + cutting tool	Circular Bearing with a track across it and a circular saw cutting tool on the track. The depth is controlled by shims

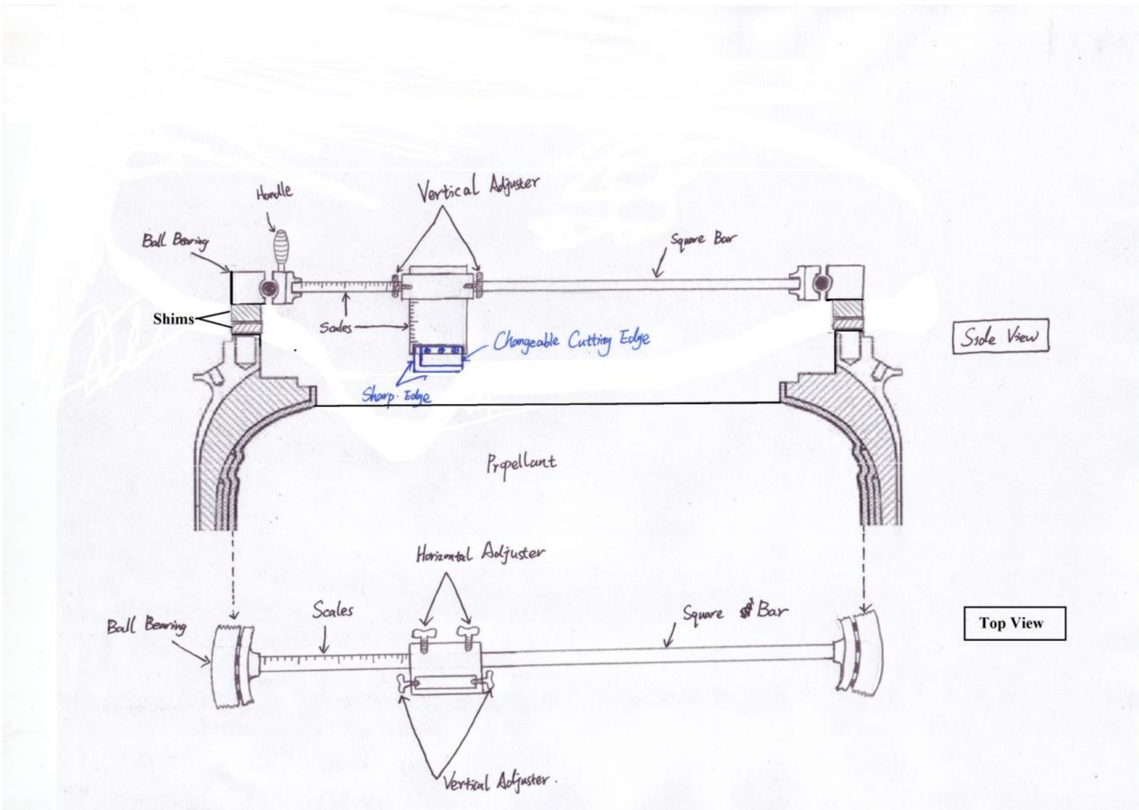


2	Bearing + Track + post depth control + cutting tool	Circular bearing with a track across it and a cutting edge tool attached to a special pin controlled depth control
		

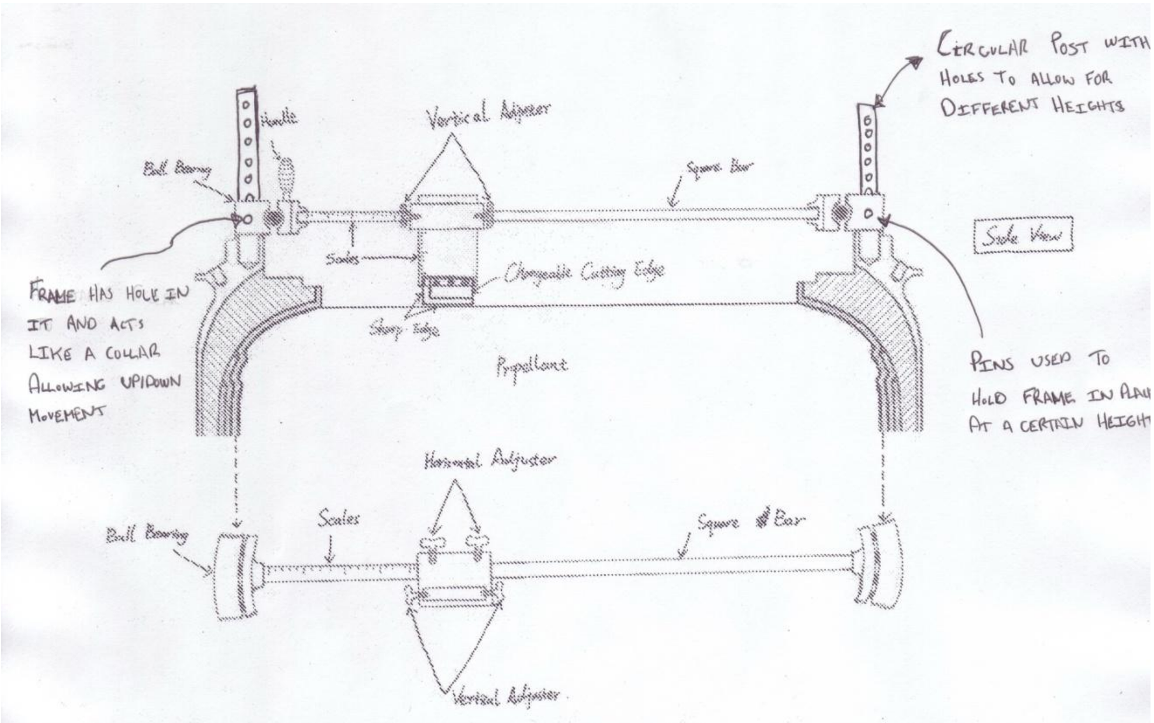
3	Bearing + Track + track mounted depth control + cutting tool	Circular bearing with a track across it and a circular saw cutting tool attached to the track. The depth is controlled by two moving the bearing up and down 2 threaded rods on the outside of the bearing



4	Bearing + Track + shims + track depth control + cutting tool	Same as 3 but with shims depth control



5	Bearing + Track + post depth control + track mounted depth control + cutting tool	Same as 3 but with a post which control the track depth



The five designs shown, above, have the same frame and track but have different methods of controlling the depth of the cutting process. The three different methods of depth control are shims, rod and pin, and tool mounted depth control. The five designs have different combinations of these control methods.

D5 Scoring Matrix and Scoring Criteria

In order to determine which design was the best for our application our team used a scoring matrix. Our scoring matrix used fourteen criteria to determine the top design. These fourteen criteria are based on the technical requirements, limitations, and constraints. The criteria are shown below in TABLE D VI. A brief description of each criterion has also been provided.

TABLE D VI CRITERIA USED IN SCORING MATRIX

Criteria	Description
Safe	The design must follow the explosive safety requirements
Does not Require Changing Parts	The design does not include changing parts which increases the complexity and the time required to do the cutting process
Easy to Use for Single Operator	The concept should be useable by a single operator without requiring large amounts of training
Simple Design	The design should be simple in order to lower cost and make it easier to build, fix, and use
Prevents Overcutting	The design should incorporate some method to prevent overcutting of the propellant and EPDM
Minimal Deflection During Use	The design should locate on the holes provided remain centered during use to ensure high accuracy
Producible within Budget	The design should be producible for less than $10,000
Process Time Decreases	The design should try to reduce the time required to perform the trimming operation
Lightweight	The design must be under 60 pounds so that one person can carry, install, and use it
Compact	The design should be compact allowing for easy carrying, installation, and storage
Easy to Repair	The design should allow for easy removal of parts if it becomes damaged.
Good Visibility	The design must allow for good visibility of the cutting surface and tool to ensure high accuracy
Accurate	The design MUST have very high accuracy for the cutting procedure so that costly mistakes will not occur

Ease of Manufacturing	The design must be fairly easy to manufacture in order to reduce cost

The five designs were scored based on these criteria. A score was given between 0 and 5 depending on how the design would perform for the given criteria. Poor performance received a 0 while excellent performance received a 5. All five designs were scored. The overall score was calculated as a percentage. After performing our scoring analysis, concept 3 was selected for further analysis and design. The scoring matrix that was used is shown below in TABLE D VII.

TABLE D VII SCORING MATRIX AND RESULTS

Criteria\Concept	**1**	**2**	**3**	**4**	**5**
Safe	5	5	5	5	5
Does not Require Changing Parts	1	5	5	5	5
Easy to Use for Single Operator	2	1	4	2	0
Simple Design	4	3	4	4	2
Prevents Overcutting	3	3	4	4	4
Minimal Deflection During Use	5	1	5	5	1
Producible within Budget	5	5	5	5	5
Process Time Decreases	0	1	3	2	1
Lightweight	4	1	3	3	1
Compact	4	1	4	4	1
Easy to Repair	4	1	3	3	1
Good Visibility	5	5	5	5	5
Accurate	2	3	4	5	3
Ease of Manufacturing	4	2	4	3	1
Total	48	37	58	55	35

Score (%)	69	53	83	79	50
Continue	**No**	**No**	**Yes**	**No**	**No**

Concept 1 used shims to control the depth control for the design. A shim is a circular piece of hard rubber or metal with the same bolt pattern as the frame and would mount underneath the frame, to help position the frame at the right height. The main reason that this concept was not chosen was because using the shims add quite a bit of time to the process as the whole tool has to be removed every time to add or remove a shim to get the correct depth. Also, the shims would add material to the design, increasing the cost and the weight.

Concept 2 involved using rods with holes and pins to set the depth of the cutting tool. Our team agreed that this would be very hard to set up with just one person, would add a lot of material to the design, increase the manufacturing and material cost, and make it hard to locate the cutting tool properly. For these reasons concept 2 scored quite low.

Concept 3 was modeled using SolidWorks and is shown in Fig D1. Concept 3 consists of a circular bearing frame which would bolt to the rocket. A track to span the diameter is attached to the turning component of the bearing. A tool is then mounted on the track. This design allows the tool to move longitudinally along the track from one side of the bearing to the other. The component of the bearing which spins allows the tool to cut in a circle. A depth control system is attached to the tool itself which allows the tool to move up and down, cutting the propellant to the correct depth and cutting the EPDM properly.

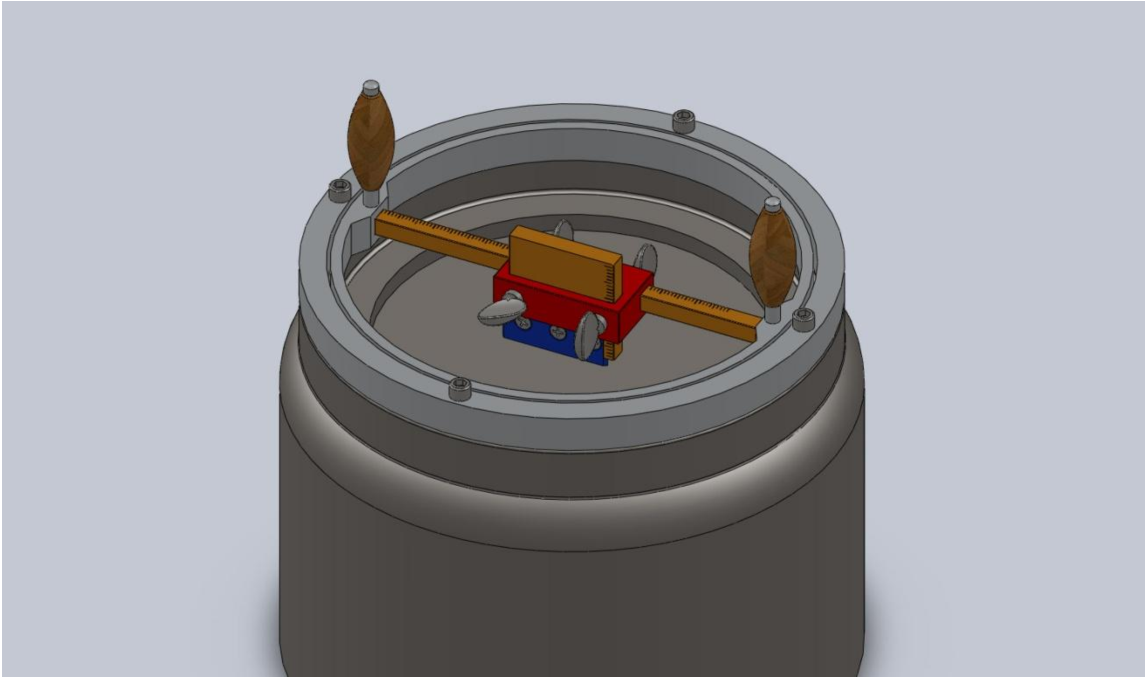


Figure D 1Isometric view SolidWorks drawing for concept 3

Concept 3 consists of the same frame and tool track, but uses a depth control system that is mounted on the tool itself. This means that the frame assembly can be rigidly mounted to the rocket. This makes locating the tool much easier, increasing the overall accuracy of the process. Also, since the depth control is mounted with the tool on the track, the accuracy is increased. This design is also quite simple, has less weight, and is more compact than the other designs. One operator should be able to use the design, as he would only have to attach the frame to the rocket and then adjust the depth of the cutting tool itself in one location, and then operate the tool. Based on these criteria, this design was selected.

Concept 4 had a very close score to concept 3. Concept 4 is very similar to concept 3, with the addition of shims. This design scored slightly lower than concept 3 because the shims will add significant time to the process because the tool has to be removed and then replaced once each shim is in place. The shims also add weight and cost to the design. Shims are one idea that the team will keep in mind, as this is a very simple way to control the depth if a larger range of depth control is needed.

Concept 5 had the poorest score of all five designs. This design was a combination of the rods with pins and the adjustable tool depth. The rods and pins add extra weight to the design, increase the complexity of the tool, and make it harder to accurately locate the tool. The rods and pins also make it much harder for a single person to use the tool. This design is very similar to concept 2 but with the addition of the tool depth control so it has the same negative aspects as concept 2.

D6 Sensitivity Analysis

Our team used a screening matrix, scoring matrix, and the feedback of our contacts at Bristol to come to a consensus on which design to pursue. Table A4 shows the screening matrix with results. Table A7 shows the scoring matrix with results. Our team did not use a weight system to evaluate our requirements as almost all of the criteria were necessary for the design of the tool. The budget and the production time were the only two criteria that were non-crucial. Adding weights to these matrices will not significantly increase or decrease the scores to a point where the selected design concept will change.

D7 Further Research

After selecting the concept that our team had decided to pursue our team did some research in order to find off the shelf parts we could use to build and improve our design. Our team broke down our design into five components/features. These components were the frame, the track, the cutting tool, depth control, and power method. In this section, the search for off the shelf parts that could be used for these components is summarized and explained.

D7.1 Frame

When our team selected this concept for our final design, we also decided to use the suggestion given to us by our clients. They had suggested using an off the shelf commercial bearing as our frame. Our team liked this suggestion because it made our design a lot simpler. After our concept design report, our team began to search for an appropriate bearing that we could use for design.

Our team found that bearings are commonly made out of three materials: stainless steel, aluminum, and ceramic. We also found bearings that were made out of a combination of these materials. Our team rejected the use of stainless steel on the grounds of it is not safe to use because it can spark. One concern that was brought up with regard to the stainless steel bearings was the possibility of someone accidentally hitting the stainless steel part of the bearing with another tool causing a spark. Since one of our technical requirements is that the design must adhere to the explosive safety requirements we could not use a stainless steel bearing.

Our team also considered using a ceramic bearing. This material again presents a different set of challenges. Ceramic is a brittle material so it would be hard to drill through in order to attach to the rocket. A possible solution to this would be to bond the ceramic bearing to an interface plate of some sort which would then be bolted to the rocket motor. This would add some cost the design both for materials and for labor. Also, the mechanical properties of the ceramic may not be optimal for our design. Although these are minor difficulties, our team decided to leave ceramic bearings as a backup in the event that a suitable aluminum bearing could not be found.

Our team then turned our focus to finding an aluminum bearing. Two different types of aluminum bearings were found. The first type that was found was an aluminum Lazy Susan bearing. Two possible distributors of these bearings were found. However, our team decided not to use a Lazy Susan bearing design because the bearing was open, which means that material that is cut can fall into the bearing, damage components of the bearing, and severely decrease the accuracy of the overall device. The other type of bearing that was considered was general commercially available aluminum bearings. These bearings come in all different shapes and sizes. Initially we had trouble finding a bearing greater than 15.5 inches. After some searching, our team found several different bearings that could be used.

Our team opted to use a sealed commercial bearing that is made by Kaydon® Corporation Inc. The part number for the bearing that we have decided to use is JG180XP0. This is a Reali-Slim sealed bearing from the JG series which is double sealed. Our team selected the four-point contact version.

D7.2 Track

After completing our concept design report our team already had a good idea of what we were looking for in terms of a track that the tool holder would slide along. Our team decided to use 1x1 inch aluminum bar for this track. This product was very easy to find which means that it will be quite easy to get.

D7.3 Cutting Tool

Our team looked at several different cutting tools for this design. We decided to look around and see what could possibly be used for cutting the propellant and EPDM. Our initial ideas for a cutting tool were medical bone saw, die grinder tool, custom built pneumatic rotary tool, off the shelf cutting blade or machining tool, and a custom made cutting blade.

The medical bone saw was the first idea that our team came across. This device is small with a cylindrical shape and could be used to cut through different materials. A similar idea to this was the pneumatic die grinder. These two ideas presented several challenges. The first challenge was that the speed of the tool would have to be controlled or else there would be too much friction and the propellant could ignite. The second challenge was mounting a cylindrical device like this in our device. The mounting unit would add a lot of complexity to the design that our team felt was unnecessary.

The third idea was to build a custom pneumatic rotary tool. When our clients gave us a tour of their plant they demonstrated a pneumatic rotary tool that was used to trim smaller rocket motors. We thought about recommending a custom pneumatic rotary tool but this would add a lot of complexity to our design. Also, this would significantly increase the cost of the design.

Our team also looked at off the shelf cutting blades and machining tools. For this we looked at the McMaster-Carr website which showed lots of blades and tool. Some of these off the shelf parts require high speed. Other off the shelf blades and tools would not be useable with our design because they required certain cutting angles or tools that our design did not have.

The last option that our team looked as was designing a custom blade that could be used with our design. Our team decided this would be the best option because this could easily be made by a machining shop. A custom made blade would also allow for us to design it to integrate properly into our design.

D7.4 Depth Control

Our team came up with two different ideas for the depth control the tool. The first idea was to use tightening screws to fasten the cutting tool at the correct depth. These screws would allow for fine adjustments to be made. Also the depth could be changed rapidly without extensive labor. This is the idea that we initially like and presented in our concept design report.

After talking to our clients, they suggested using a rack and pinion gear to control the depth of the tool. Our team thought this would be a good idea so we found an off the shelf rack and pinion gear that would allow us to move the cutting blade up and down with very little trouble.

D7.5 Power Method

Our team looked at different ways to power our design. The first method of power it was pneumatically. Using air we felt that we could power some sort of rotary cutting tool that could be used to cut the propellant and EPDM. Pneumatic tools are a possible solution to using electricity because it will not cause sparks as there is no current. This is still a possibility that our team will suggest as an extra feature.

Our team also looked at finding and using a gear system to turn the moving part of the bearing to make the cutting blade move around the rocket and trim the material.

There were several issues with this approach. The first issue was that it was hard to find off the shelf gears and parts that would fit in with our design. The second issue was that the gears restricted the space and visibility of our design. Lastly this gearing system would also add more complexity to the design and manufacture of the overall design.

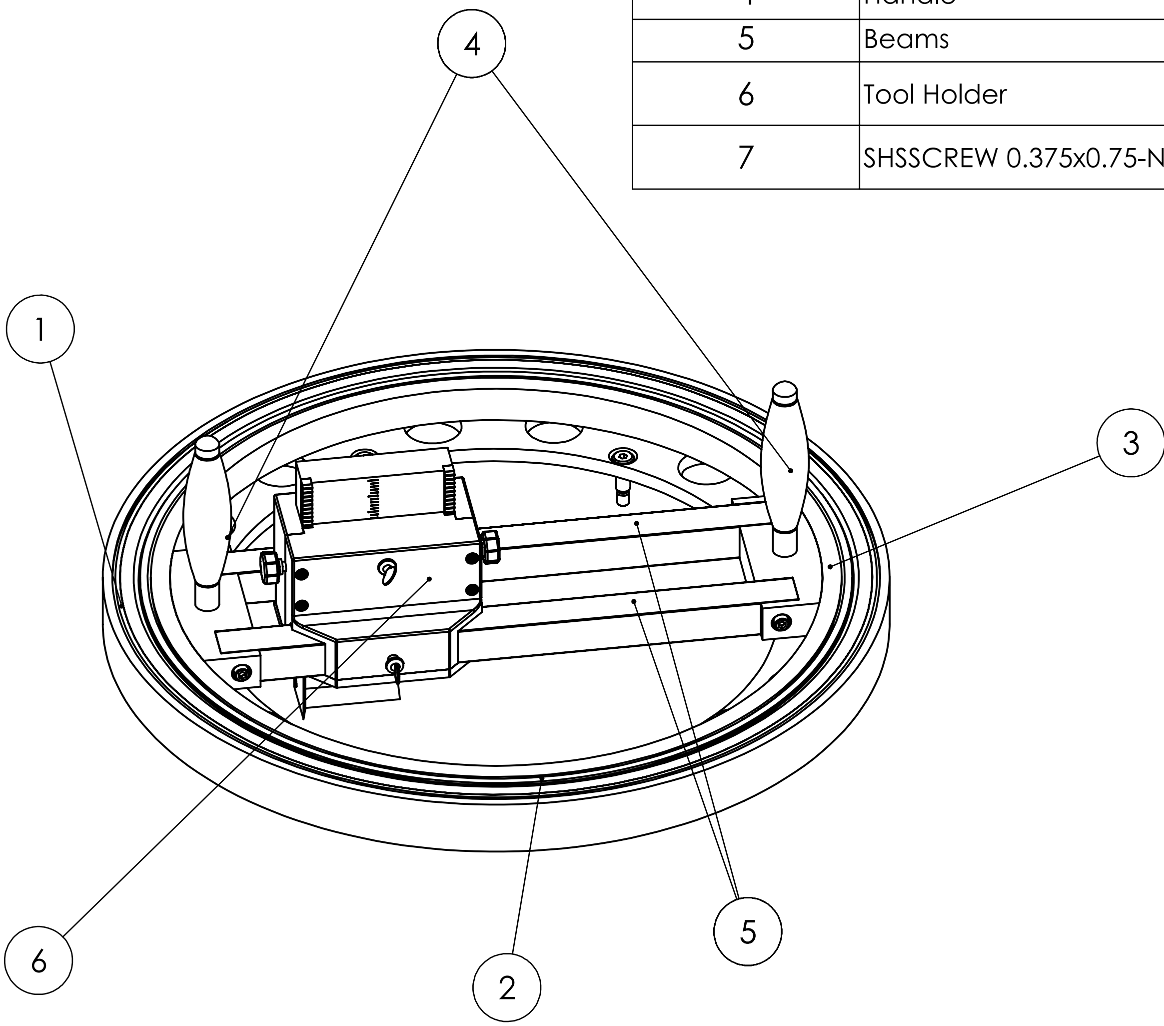
The last option that our team considered was using manual power. This would involve the operator using their own physical strength to turn the moving part of the bearing and force the blade to cut through the material this way. Our team believes that with the right blade design this method of powering the device would work best. For this reason our team selected this method to power our design.

D7.6 Summary

In summary, our team looked at several different off the shelf parts for each component of the design. For the purpose of this design, components were chosen that adhered to the technical requirements, limitations, and constraints.

Appendix E: Part Drawings

ITEM NO.	NAMPART NUMBERE	DESCRIPTION	QTY
1	Rocket to Bearing Interface		1
2	SW3dPS-JG180XP0	Commercial Bearing	1
3	Inner Ring Assembly		1
4	Handle	Commercially Avaliable	2
5	Beams	With Teflon Coating	2
6	Tool Holder		1
7	SHSSCREW 0.375x0.75-N		7



TITLE:
Trimming Tool Full Assembly

Nihka Propellant Liner Trimming Tool

Bristol Aerospace

INTERPRET GEOMETRIC TOLERANCING PER:		NAME	DATE	
DO NOT SCALE DRAWING	DRAWN	NS	10/11/2011	
MATERIAL	CHECKED			
FINISH	NUMBER			

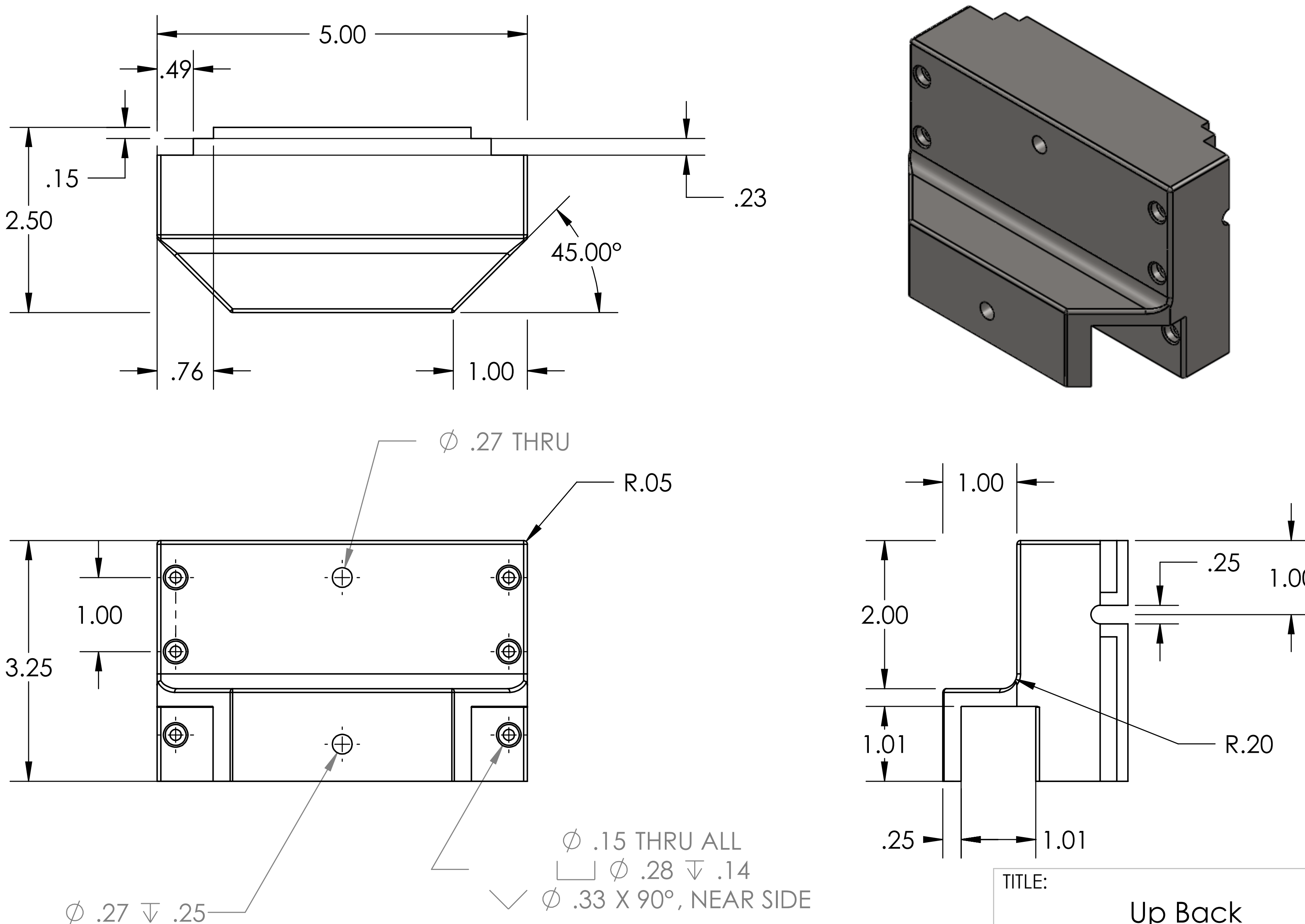
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

MECH 4860
Engineering Design

SIZE	DWG. NO.	REV
A	1 OF 19	

SCALE: 1:5	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1



TITLE:

Up Back

Nihka Propellant Liner Trimming Tool

Bristol Aerospace

MECH 4860
Engineering Design

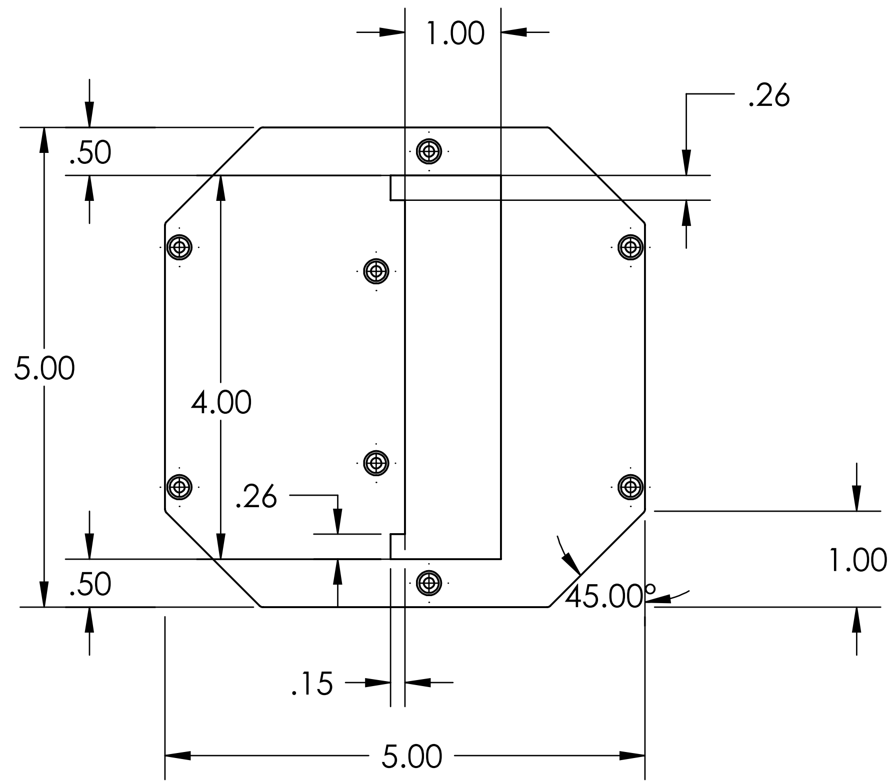
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

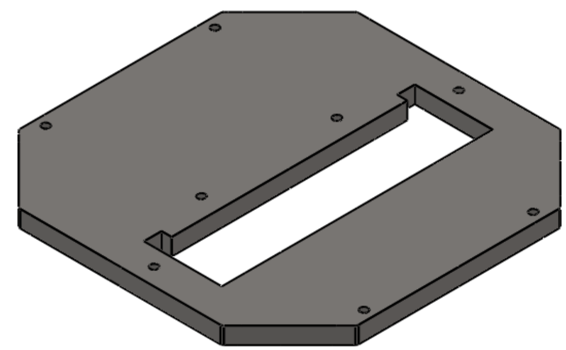
INTERPRET GEOMETRIC TOLERANCING PER:		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	NS	10/11/2011
MATERIAL	CHECKED		
FINISH	NUMBER		

SIZE A | DWG. NO. 10 OF 19 | REV

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

5 4 3 2 1





TITLE:

Bottom

Nihka Propellant Liner Trimming Tool

Bristol Aerospace

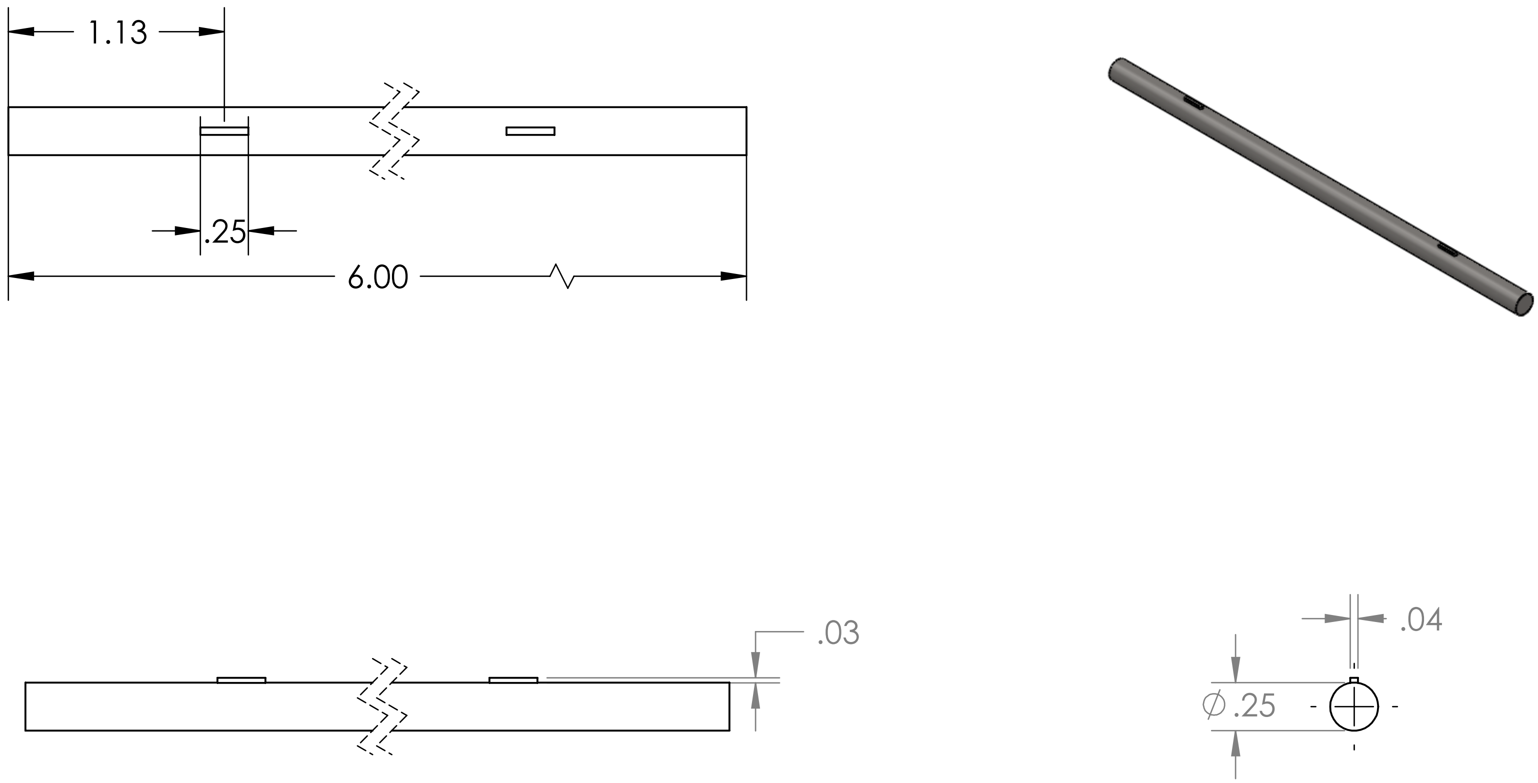
MECH 4860
Engineering Design

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

INTERPRET GEOMETRIC TOLERANCING PER:		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	NS	10/11/2011
MATERIAL	CHECKED		
FINISH	NUMBER		

SIZE	DWG. NO.	REV
A	11 OF 19	
SCALE: 1:2	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1



TITLE:

Shaft with Keys

Nihka Propellant Liner Trimming Tool

Bristol Aerospace

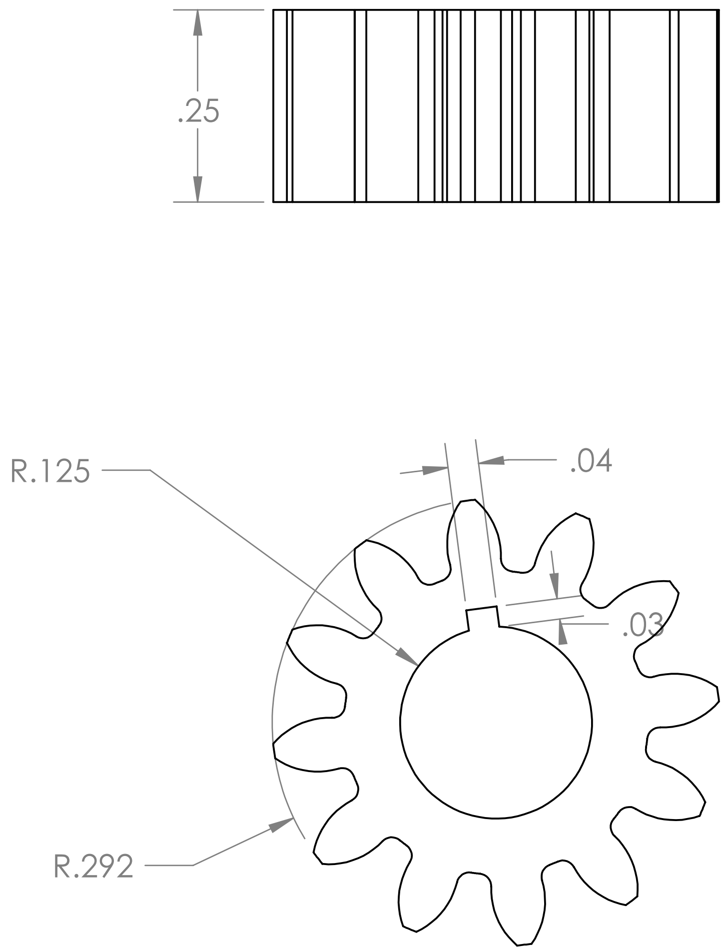
MECH 4860
Engineering Design

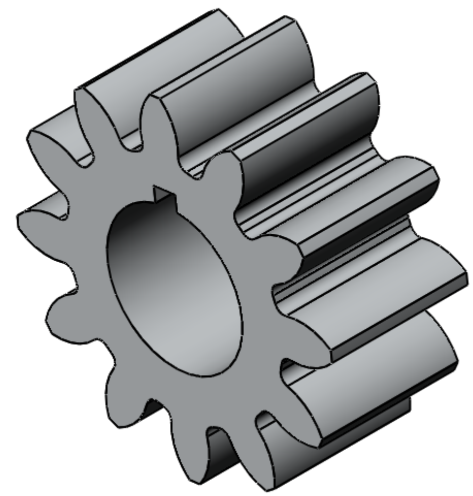
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

INTERPRET GEOMETRIC TOLERANCING PER:		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	NS	10/11/2011
MATERIAL	CHECKED		
FINISH	NUMBER		

SIZE	DWG. NO.	REV
A	12 OF 19	
SCALE: 1:2	WEIGHT:	SHEET 1 OF 1

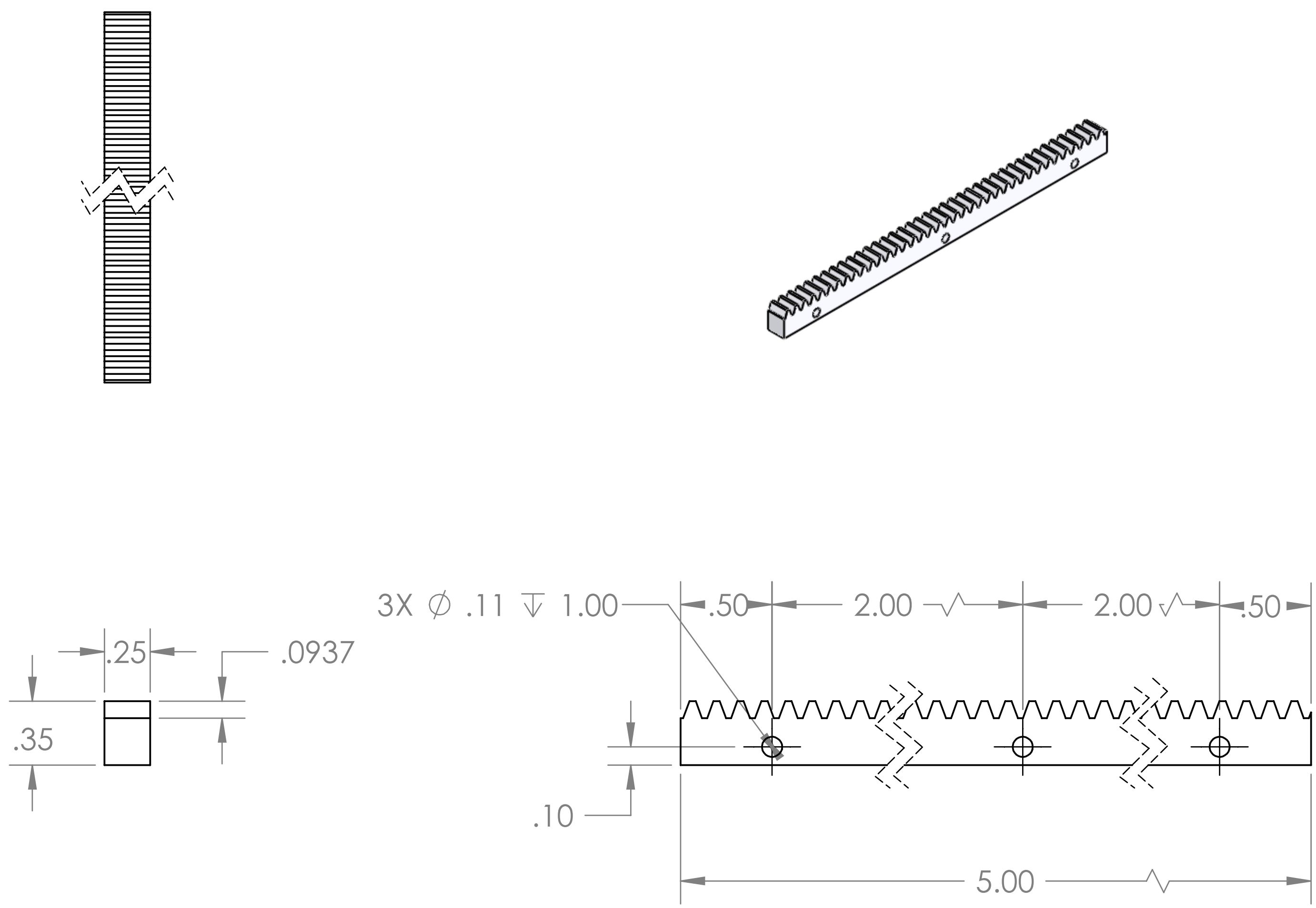
5 4 3 2 1





MECH 4860 Engineering Design	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ±0° 30' TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002	Bristol Aerospace				TITLE: RushGears_FA2412 Key Way Nihka Propellant Liner Trimming Tool	
		INTERPRET GEOMETRIC TOLERANCING PER:		NAME	DATE	SIZE A	DWG. NO. 13 OF 19	REV
		DO NOT SCALE DRAWING	DRAWN	NS	10/11/2011		
		MATERIAL	CHECKED				
		FINISH	NUMBER			SCALE: 4:1	WEIGHT: SHEET 1 OF 1

5 4 3 2 1



TITLE:

RushGears_TR24AL-2 5in

Nihka Propellant Liner Trimming Tool

Bristol Aerospace

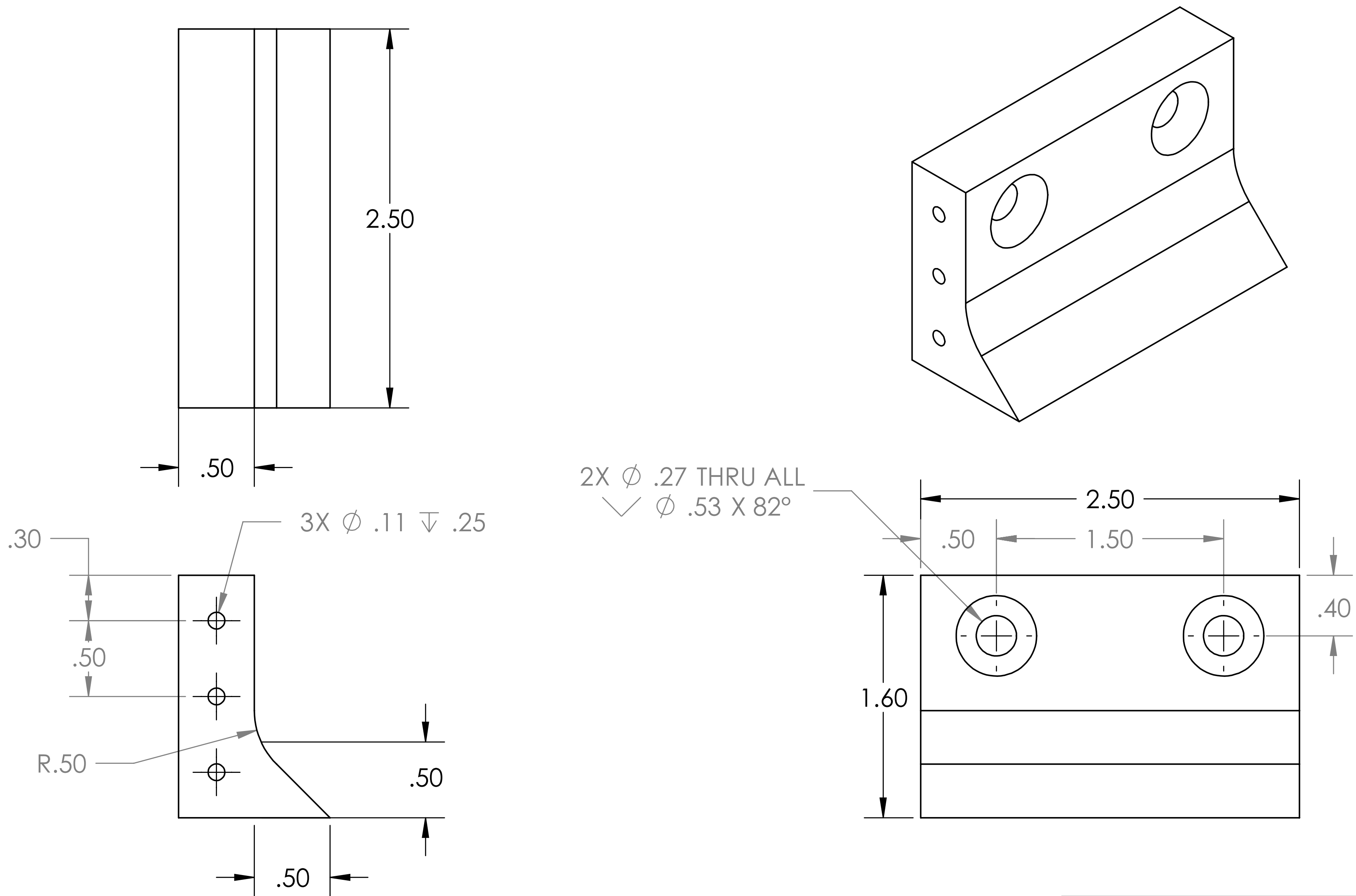
MECH 4860
Engineering Design

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

INTERPRET GEOMETRIC TOLERANCING PER:		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	NS	10/11/2011
MATERIAL	CHECKED		
FINISH	NUMBER		

SIZE	DWG. NO.	REV
A	14 OF 19	
SCALE: 1:2	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1



TITLE:

Cutting Edge Propellant A

Nihka Propellant Liner Trimming Tool

Bristol Aerospace

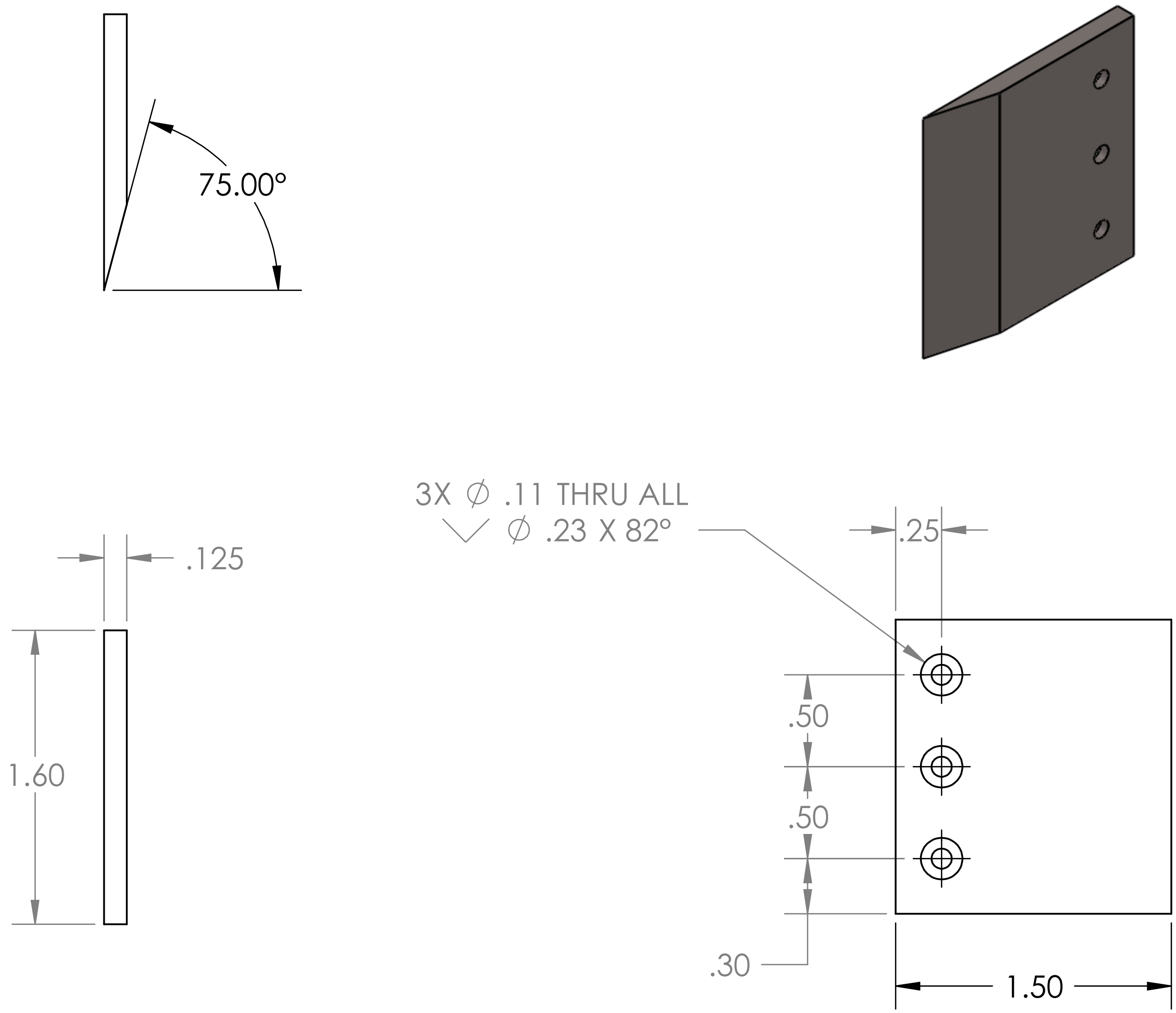
MECH 4860
Engineering Design

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

INTERPRET GEOMETRIC TOLERANCING PER:		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	NS	10/11/2011
MATERIAL	CHECKED		
FINISH	NUMBER		

SIZE	DWG. NO.	REV
A	15 OF 19	
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1



TITLE:

Cutting Edge Propellant B

Nihka Propellant Liner Trimming Tool

Bristol Aerospace

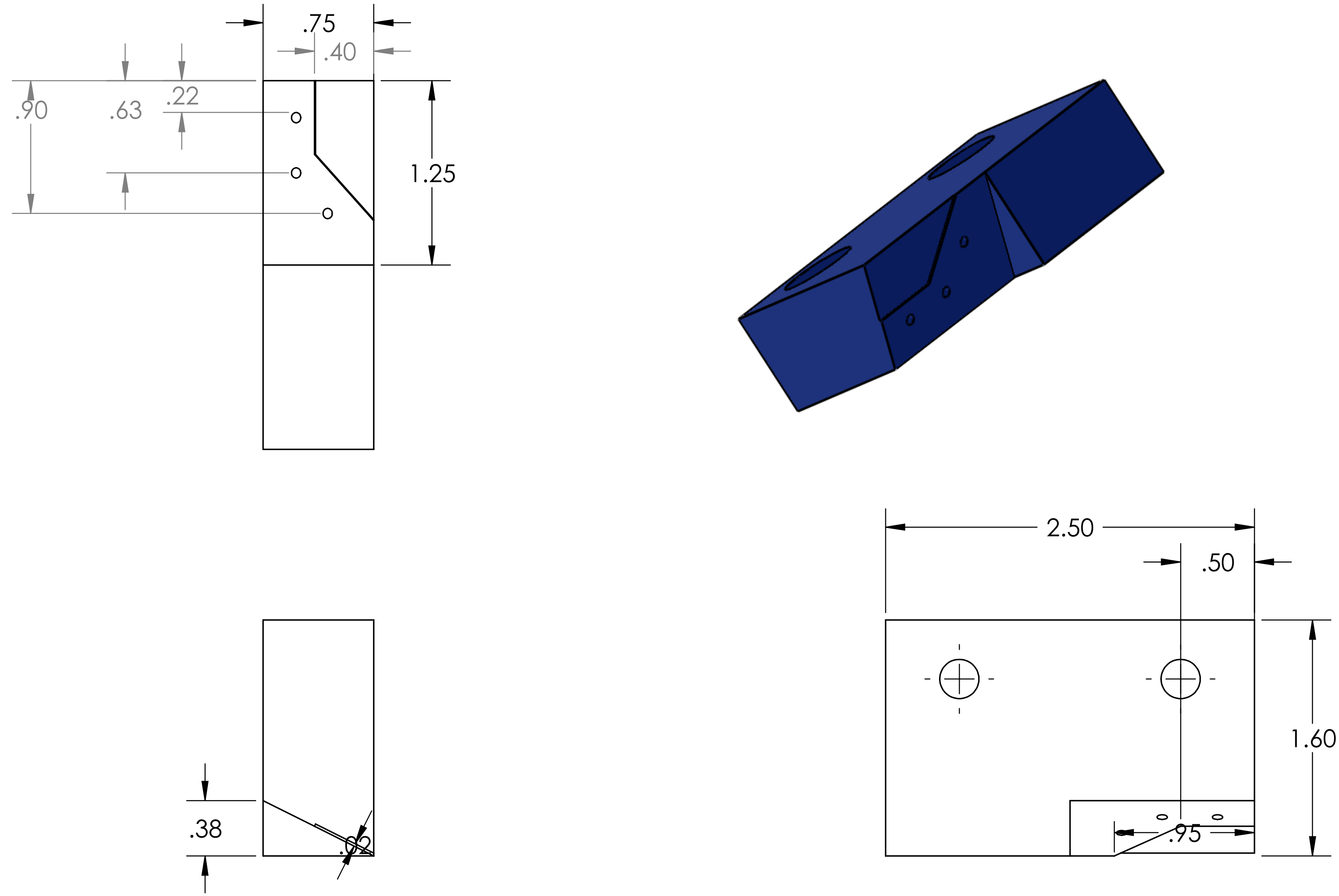
MECH 4860
Engineering Design

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

INTERPRET GEOMETRIC TOLERANCING PER:		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	NS	10/11/2011
MATERIAL	CHECKED		
FINISH	NUMBER		

SIZE	DWG. NO.	REV
A	16 OF 19	
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1



TITLE:

Cutting Edge EPDM

Nihka Propellant Liner Trimming Tool

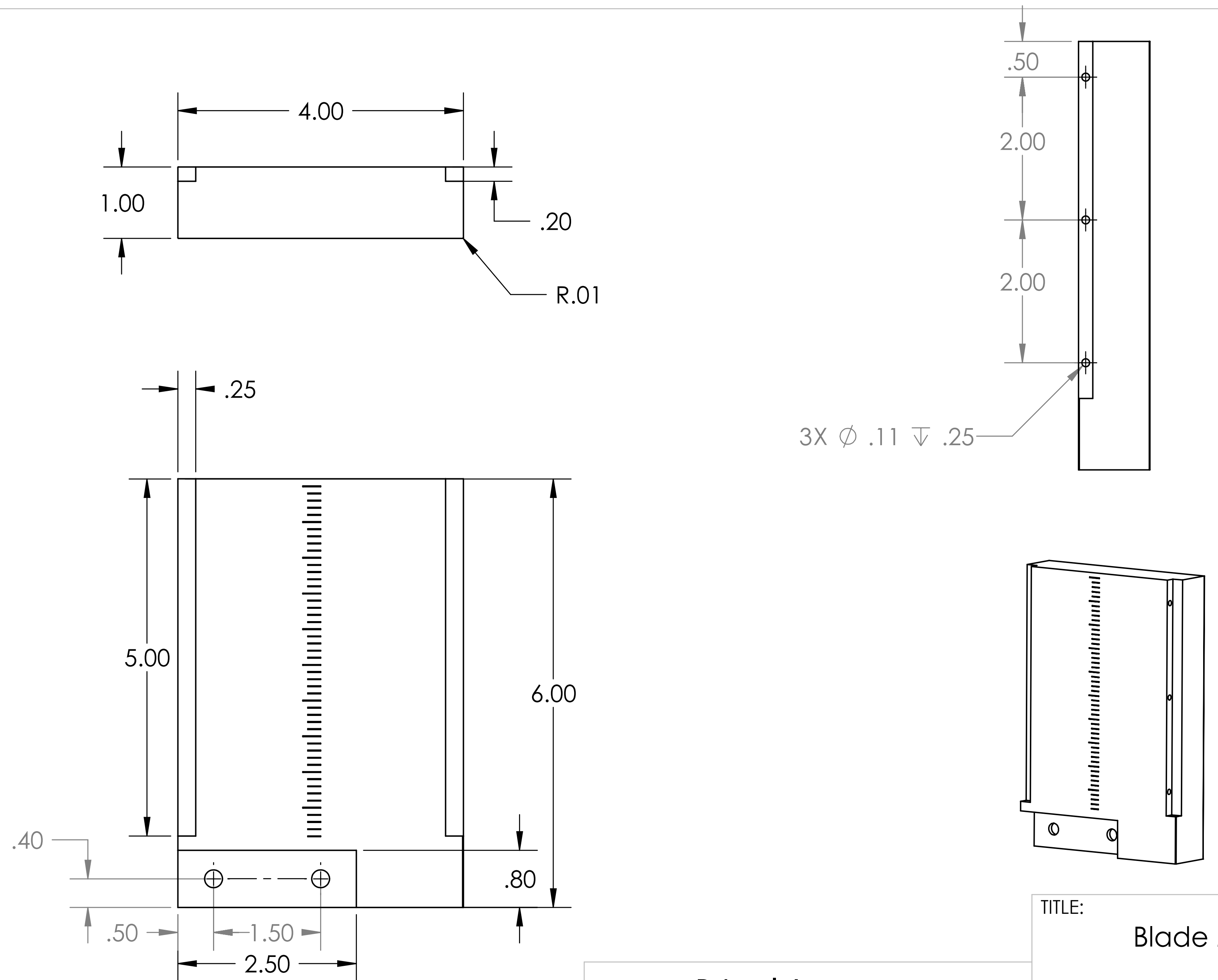
Bristol Aerospace

MECH 4860
Engineering Design

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

		NAME	DATE
INTERPRET GEOMETRIC TOLERANCING PER:			
DO NOT SCALE DRAWING	DRAWN	NS	10/11/2011
MATERIAL	CHECKED		
FINISH	NUMBER		

SIZE	DWG. NO.	REV
A	17 OF 19	
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1



TITLE: Blade Mount				
Nihka Propellant Liner Trimming Tool				
SIZE A	DWG. NO. 18 OF 19		REV	
SCALE: 1:2	WEIGHT:		SHEET 1 OF 1	

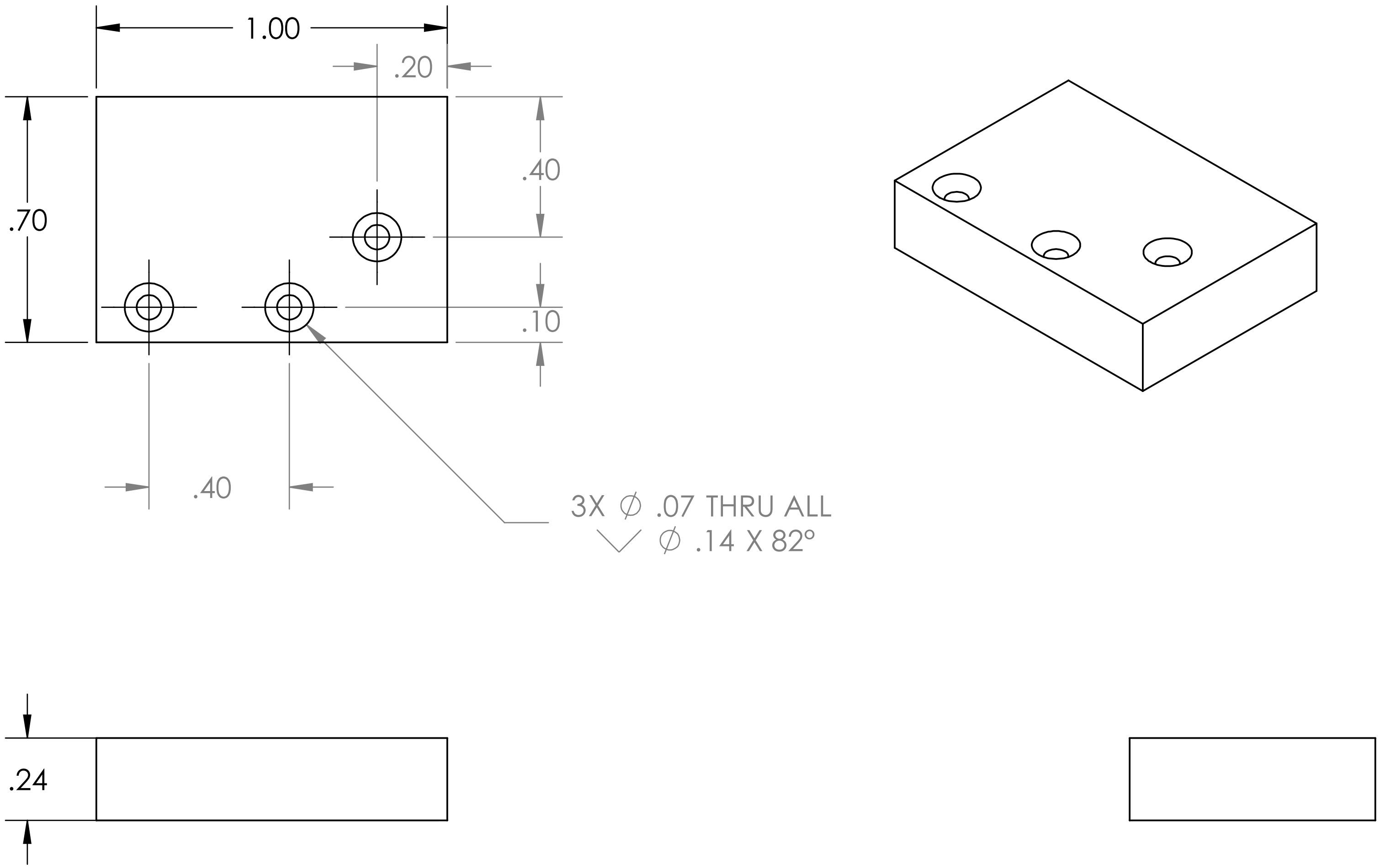
Bristol Aerospace

INTERPRET GEOMETRIC TOLERANCING PER:		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	NS	10/11/2011
MATERIAL	CHECKED		
FINISH	NUMBER		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

MECH 4860 Engineering Design

5 4 3 2 1



TITLE:

Blade Holder

Nihka Propellant Liner Trimming Tool

Bristol Aerospace

MECH 4860
Engineering Design

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

INTERPRET GEOMETRIC TOLERANCING PER:

DO NOT SCALE DRAWING

MATERIAL

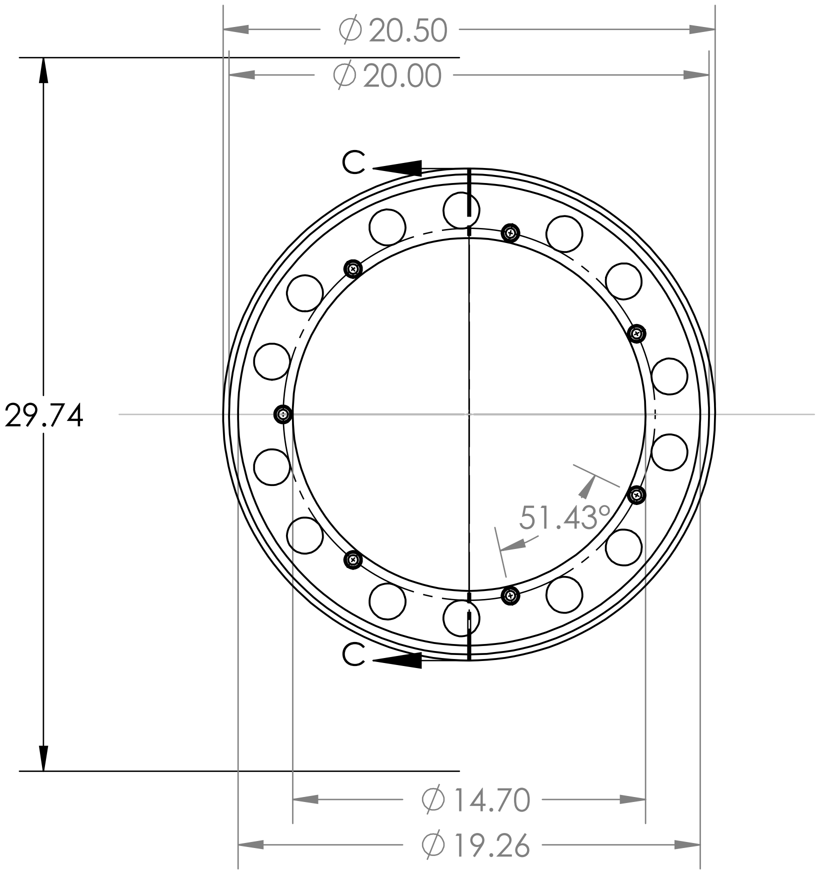
FINISH

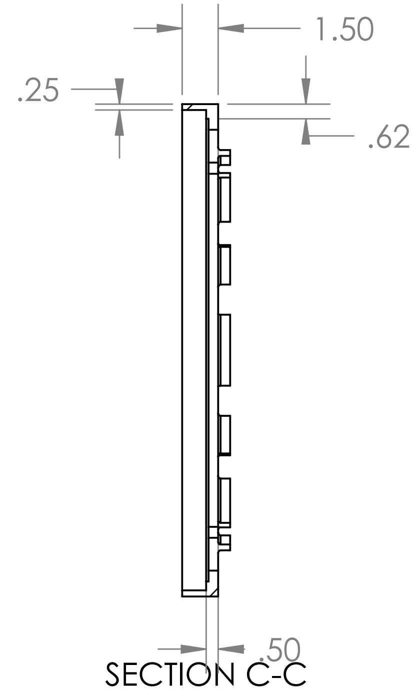
	NAME	DATE
DRAWN	NS	10/11/2011
CHECKED		
NUMBER		

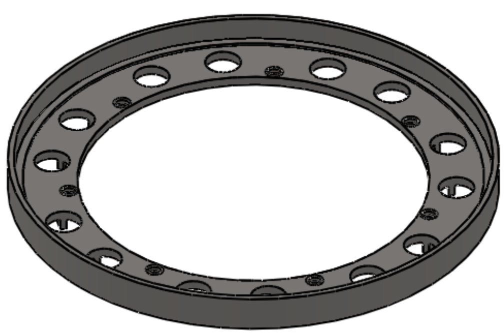
SIZE A | DWG. NO. **19 OF 19** | REV

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

5 4 3 2 1







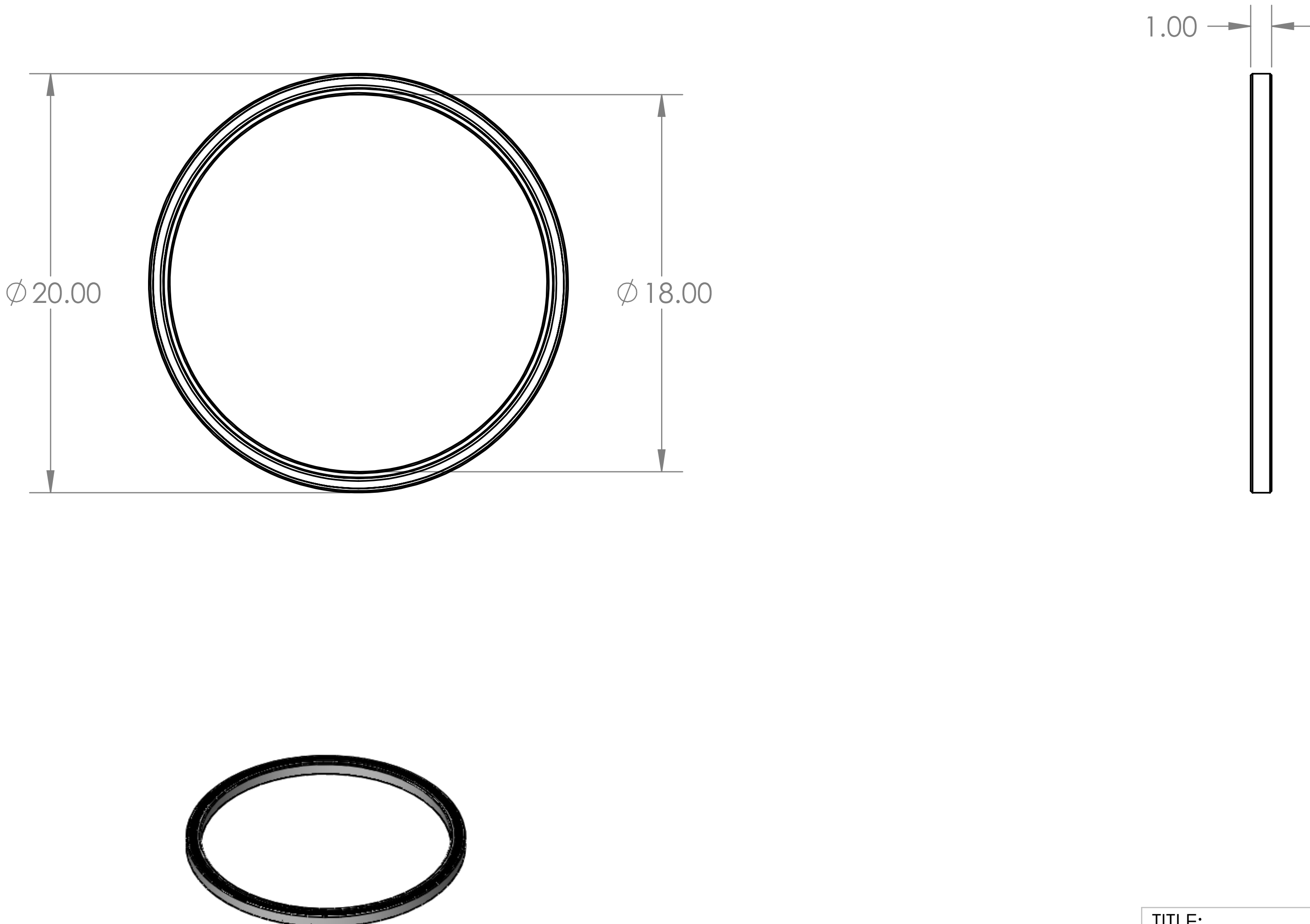
MECH 4860 Engineering Design	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ±0° 30' TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002	Bristol Aerospace		
		INTERPRET GEOMETRIC TOLERANCING PER:	NAME	DATE
		DO NOT SCALE DRAWING — DRAWN	NS	10/11/2011
		MATERIAL — CHECKED		
		FINISH — NUMBER		

TITLE:
Rocket to Bearing Interface

Nihka Propellant Liner Trimming Tool

SIZE	DWG. NO.	REV
A	2 OF 19	
SCALE: 1:8	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1



TITLE:

Bearing SW3dPS-JG180XP0

Nihka Propellant Liner Trimming Tool

Bristol Aerospace

MECH 4860
Engineering Design

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

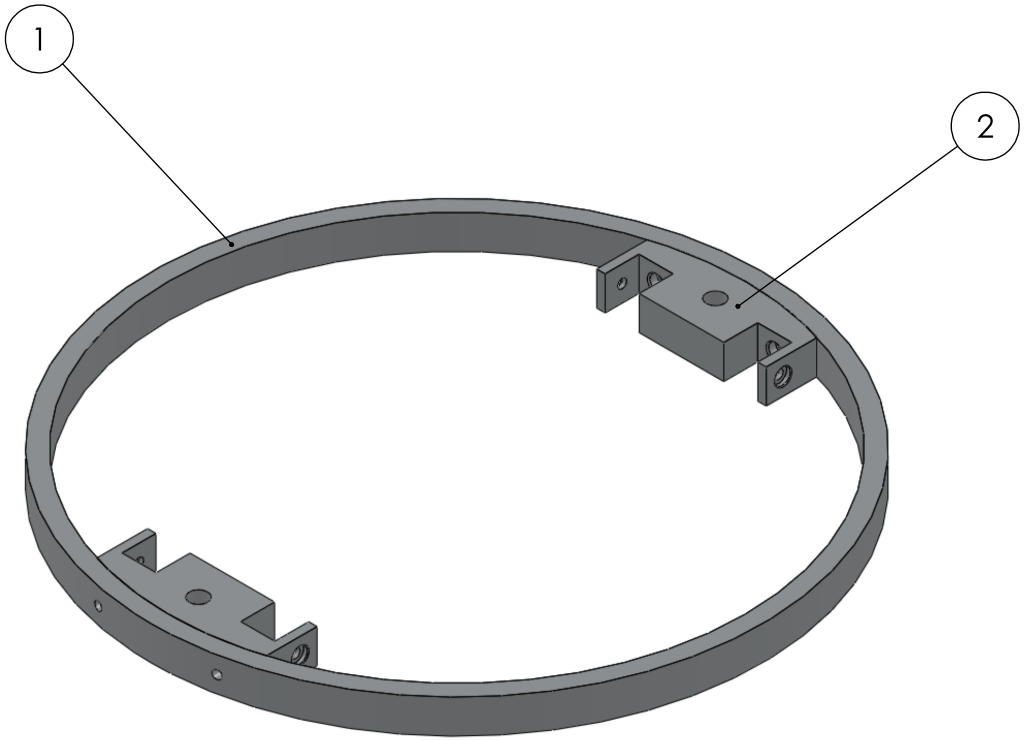
INTERPRET GEOMETRIC TOLERANCING PER:		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	NS	10/11/2011
MATERIAL	CHECKED		
FINISH	NUMBER		

SIZE	DWG. NO.	REV
A	3 OF 19	

SCALE: 1:12 WEIGHT: SHEET 1 OF 1

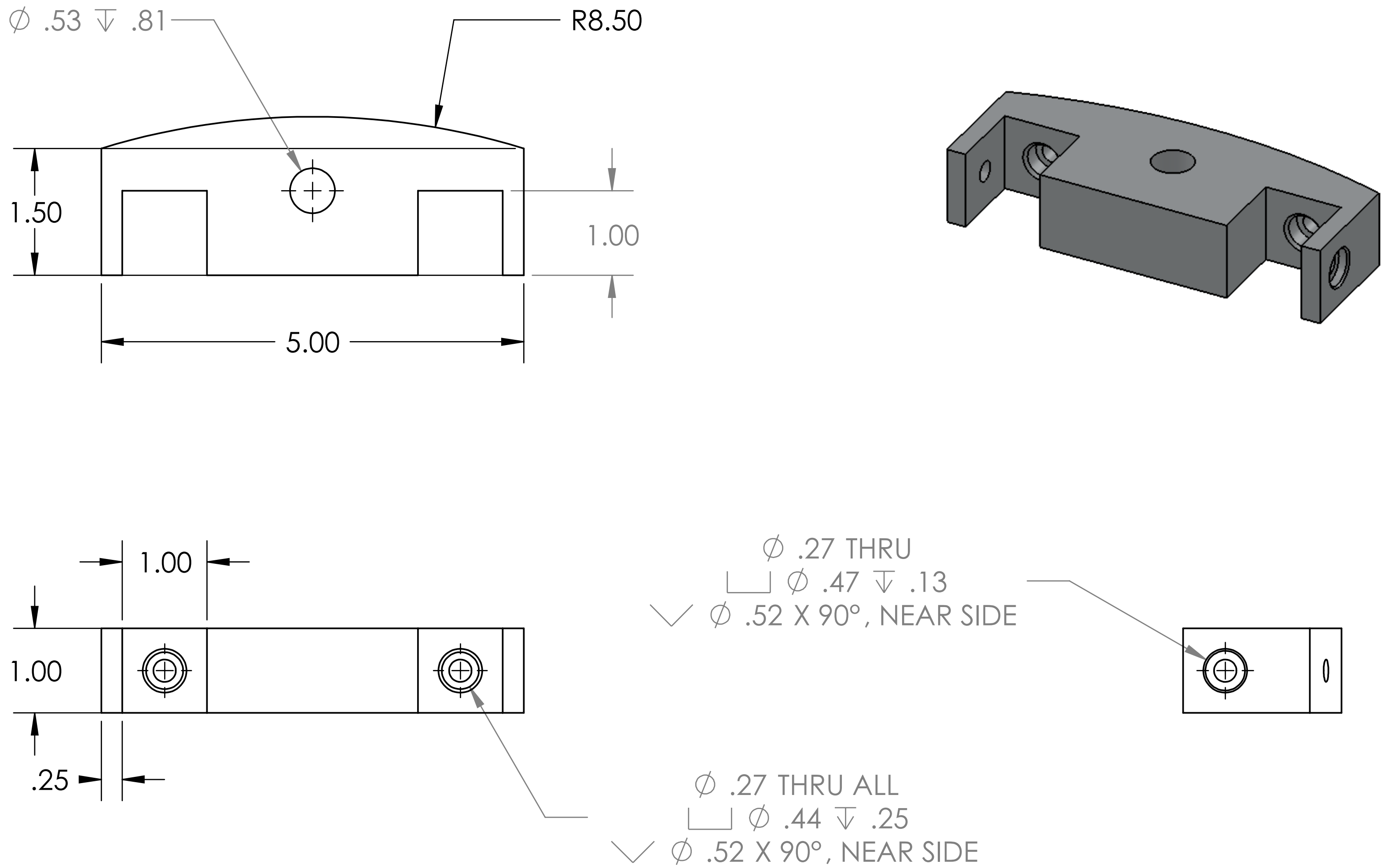
5 4 3 2 1

DET NO	NAME	DESCRIPTION	NO. REQ'D
1	Inner Ring		1
2	Beam to Ring Interface		2



MECH 4860 Engineering Design	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ±0° 30' TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002	Bristol Aerospace			TITLE: Inner Ring Assembly — Nihka Propellant Liner Trimming Tool
		INTERPRET GEOMETRIC TOLERANCING PER:	NAME	DATE	SIZE A — DWG. NO. 4 OF 19 — REV
		DO NOT SCALE DRAWING — DRAWN	NS	10/11/2011	
		MATERIAL — CHECKED			
		FINISH — NUMBER			SCALE:1:4 — WEIGHT: — SHEET 1 OF 1

5 4 3 2 1



TITLE:

Beam to Ring Interface

Nihka Propellant Liner Trimming Tool

Bristol Aerospace

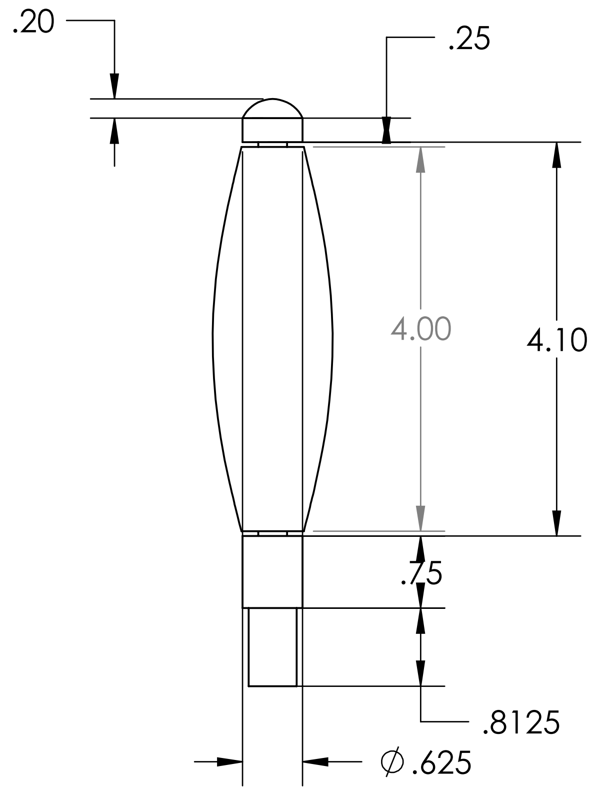
MECH 4860
Engineering Design

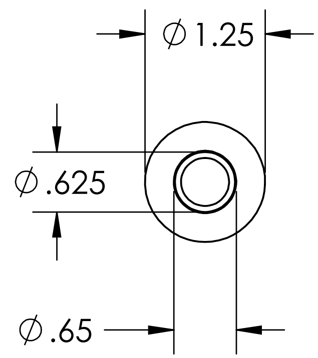
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

INTERPRET GEOMETRIC TOLERANCING PER:		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	NS	10/11/2011
MATERIAL	CHECKED		
FINISH	NUMBER		

SIZE	DWG. NO.	REV
A	5 OF 19	
SCALE: 1:2	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1



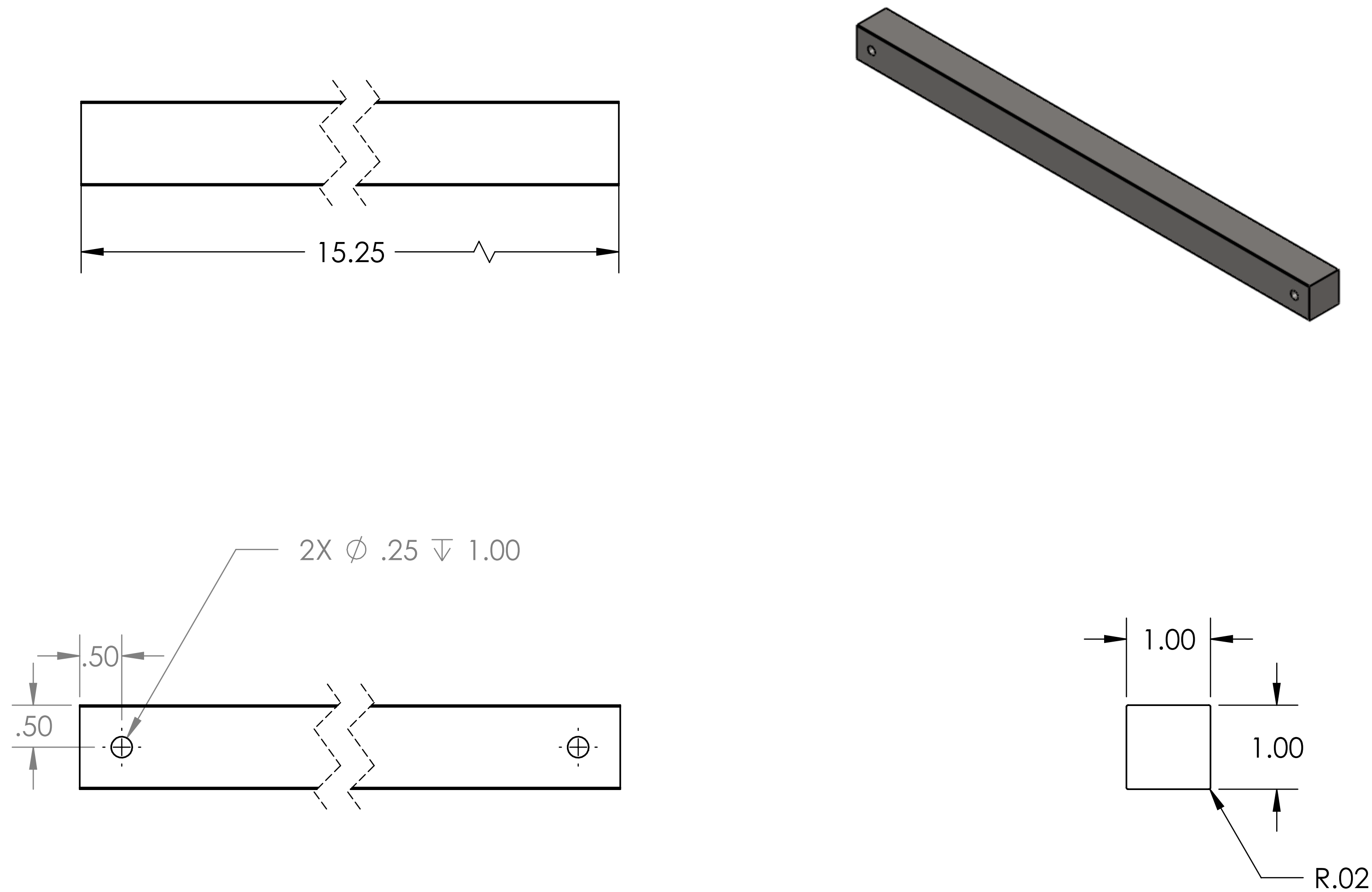


TITLE: Handle				
Nihka Propellant Liner Trimming Tool				
Bristol Aerospace				
INTERPRET GEOMETRIC TOLERANCING PER:		NAME	DATE	
DO NOT SCALE DRAWING	DRAWN	NS	10/11/2011	
MATERIAL	CHECKED			
FINISH	NUMBER			
SIZE A	DWG. NO. 6 OF 19			REV
SCALE: 1:2	WEIGHT:		SHEET 1 OF 1	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

MECH 4860
Engineering Design

5 4 3 2 1



TITLE:

Beam

Nihka Propellant Liner Trimming Tool

Bristol Aerospace

MECH 4860
Engineering Design

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

INTERPRET GEOMETRIC TOLERANCING PER:

DO NOT SCALE DRAWING

		NAME	DATE
	DRAWN	NS	10/11/2011
MATERIAL	CHECKED		
FINISH	NUMBER		

SIZE A

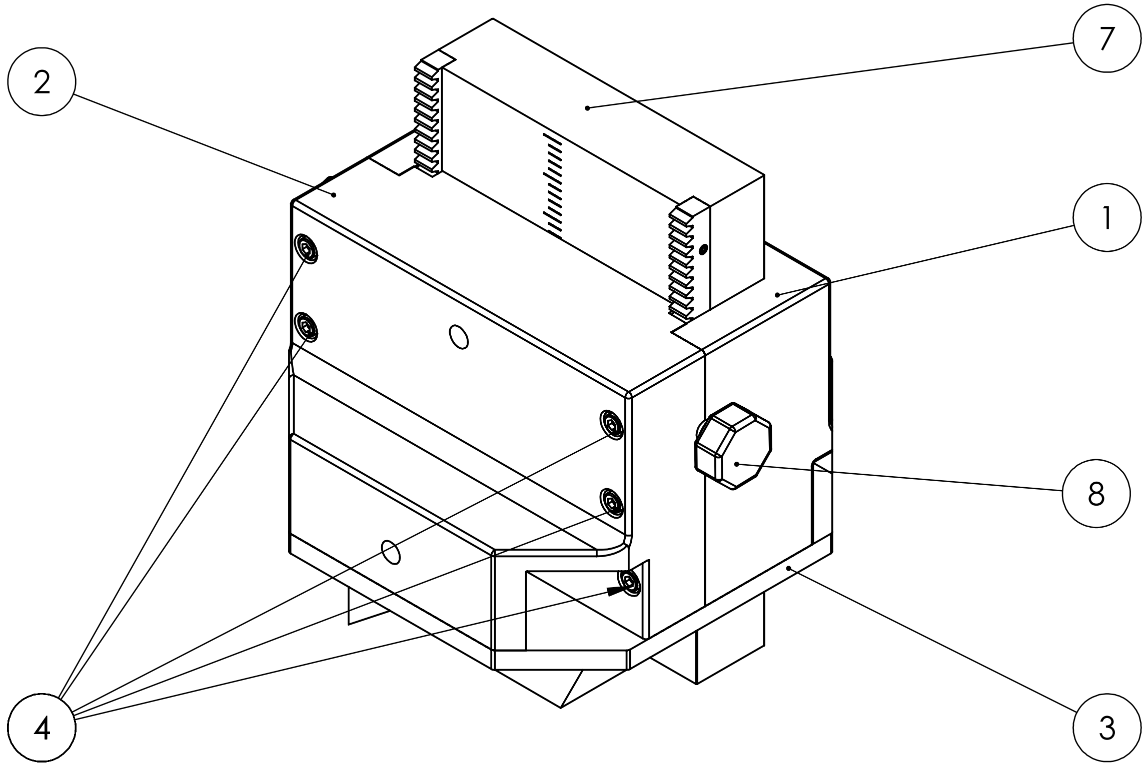
DWG. NO. 7 OF 19

REV

SCALE: 1:4 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Up Front		1
2	Up Back		1
3	Bottom		1
4	HX-SHCS 0.138-32x1.75x0.75-N	Socket Head Cap Screw	6
5	HX-SHCS 0.099-48x0.5x0.5-N	Socket Head Cap Screw	8
6	Pinion Assembly	Commercially Avaliable	1
7	Vertical Slider Assembly		1
8	Knobs	Commercially Avaliable	2



TITLE:
Tool Holder
Nihka Propellant Liner Trimming Tool

Bristol Aerospace

MECH 4860
Engineering Design

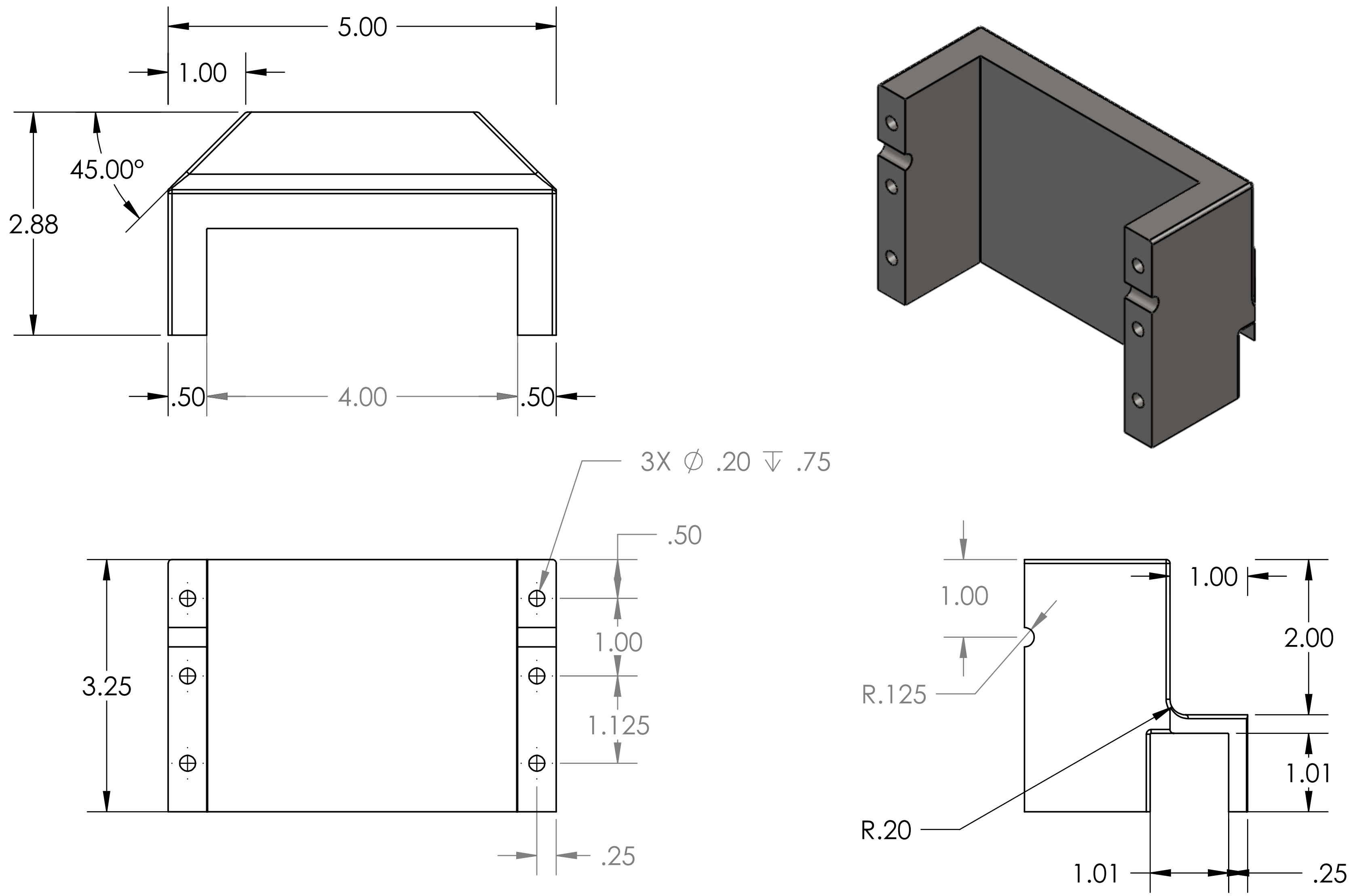
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

INTERPRET GEOMETRIC TOLERANCING PER:		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	NS	10/11/2011
MATERIAL	CHECKED		
FINISH	NUMBER		

SIZE A | DWG. NO. 8 OF 19 | REV

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

5 4 3 2 1



TITLE:

Up Front

Nihka Propellant Liner Trimming Tool

Bristol Aerospace

MECH 4860
Engineering Design

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

INTERPRET GEOMETRIC TOLERANCING PER:		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	NS	10/11/2011
MATERIAL	CHECKED		
FINISH	NUMBER		

SIZE	DWG. NO.	REV
A	9 OF 19	
SCALE: 1:2	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1