Miniaturized Ultraviolet Imager Phase III
– Final Design Review –

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Nomenclature

CAMI: Conjugate Auroral Mapping Imager
DFM: Design for Manufacturing
DFMA: Design for Manufacturing and Assembly
FEA: Finite Element Analysis
FOD: Foreign Object Debris
FUV: Far Ultraviolet
GEVS: Goddard Space Flight Center General Environmental Verification Standard
GOLD: Global-scale Observations of the Limb and Disk, NASA satellite
GSE: Ground Support Equipment ICON: Ionospheric Connection Explorer, NASA satellite
MUVI: Miniaturized Ultraviolet Imager
MUVI I: The first Cal Poly senior project team that contributed to design of the MUVI CubeSat.
MUVI II: The second Cal Poly senior project team that contributed to design of the MUVI CubeSat.
MUVI III: The third and **current** Cal Poly senior project team contributing to design of the MUVI CubeSat.
OGODS: On-Ground Orbital Deployer Simulator
P-POD: Poly-Picosatellite Orbital Deployer
SOW: Scope of work
TIMED: Thermosphere Ionosphere Mesosphere Energetics and Dynamics, NASA satellite
TRL: Technology Readiness Level
TVAC: Thermal Vacuum
UCB SSL: University of California, Berkeley – Space Sciences Laboratory
1U: 1 unit CubeSat standard, approximately 10cm x 10cm x 10cm
2U: 2 unit CubeSat standard, approximately 10cm x 10cm x 22.7cm
PDR: Preliminary Design Review CDR: Critical Design Review FDR: Final Design Review

Acknowledgements

We would like to express our appreciation to our advisor, Cal Poly Professor Dr. Eltahry Elghandour, and main sponsor from UCB SSL, Kodi Rider. Dr. Elghandour pushed us to complete tasks well beyond the minimum requirements and helped us to do so efficiently and on time. Mr. Rider invited us to Berkeley for several design reviews and shared his knowledge from experiences as an engineer for Lockheed Martin and UCB SSL. We would also like to thank Dr. Thomas Immel and Jason Grillo of UCB SSL for their insight and support throughout the design process.

Finally, we are grateful for all the skills that Cal Poly's Department of Mechanical Engineering has provided these past four years. We are sad to be saying goodbye to San Luis Obispo, but eager to share our newly derived engineering expertise in the professional world.

This work was supported by the NASA Science Mission Directorate, Heliophysics Division through contract 80NSSC19K0494.

Abstract

This document details the work to date, June 9, 2020, done by the Cal Poly Mechanical Engineering senior project team, *Miniaturized Ultraviolet Imager: Phase III (MUVI III)*, sponsored by the University of California, Berkeley – Space Sciences Laboratory (UCB SSL). MUVI III is the third senior project team of an ongoing design, MUVI: the prototype of a 2U sized CubeSat intended to capture aurora images in the ionosphere. The first team, MUVI I, finished development of the UV imager. The second team, MUVI II, designed the mirror mounting and deployable door mechanisms.

The goal of MUVI phase III is to design, manufacture, and test MUVI's 2U sized instrumentation frame, Photek UV camera mounting flexure, and ground support test fixture modeled after a P-POD. The instrumentation frame serves as an optical alignment datum, provides structural integrity, and dampens vibrations for the satellite. The instrumentation frame must survive launch and the thermal vacuum of space, have minimal mass, and comply with budgetary needs. Furthermore, the instrumentation frame shall fulfill the 2U size specification as detailed by CubeSat. Using FEA (Finite Element Analysis), the effects of vibrational loads will be modeled and accounted for. During launch, the instruments within the frame will face dynamic motion, risking failure of electronics, mechanical yielding, and overall mission demise. Boundary conditions will be replicated on ground by mimicking the mass of the Photek on the mounting flexure and by inserting the instrumentation frame into a replica P-Pod (Poly-Picosatellite) OGODS (On Ground Orbital Deployer Simulator) before beginning vibration testing.

Once modeling has provided adequate confidence in the design, UCB SSL will manufacture the designed prototype components, and the assembled prototype will undergo vibration testing at Cal Poly. Ultimately, the mission of this project is to qualify the MUVI instrumentation frame for a TRL 6 rating from NASA.

The main body of this document includes an introduction to the project, background information, project objectives, preliminary research and documentation, initial design ideas and concepts, final design, manufacturing plans, design verification plans, sponsor wants and needs, details about project management, Quality Function Development (QFD), and a project Gantt chart.

1 - Introduction

The ionosphere is a layer of Earth's atmosphere at the boundary between Earth and space. Interactions between the lower levels of the atmosphere and the ionosphere are of particular interest to NASA scientists. Three current NASA missions use UV spectrometers to explore these interactions. One of these missions, ICON (Ionospheric Connection Explorer), launched in October, 2019. In future missions, NASA will look to miniaturize similar satellites to lessen launch costs. Miniaturization will help NASA meet two goals: "making space-based observations from multiple vantage points" [**1**] and working toward the use of "low-complexity instruments that demand as little of spacecraft resources as possible while providing required performance" [**1**].

In 2018, Dr. Thomas Immel and Kodi Rider of UCB SSL, along with Dr. Eltahry Elghandour of Cal Poly, San Luis Obispo, received a NASA grant to create miniaturized ultraviolet imaging instrumentation to fit in a CubeSat envelope size. The proposed satellite, MUVI, is intended to be the prototype of an eight-satellite constellation called CAMI (Conjugate Auroral Mapping Imager). To date, MUVI has several completed milestones including completion of the camera, power systems, and deflection mirrors. These items have been finished by two previous Cal Poly, San Luis Obispo senior project teams.

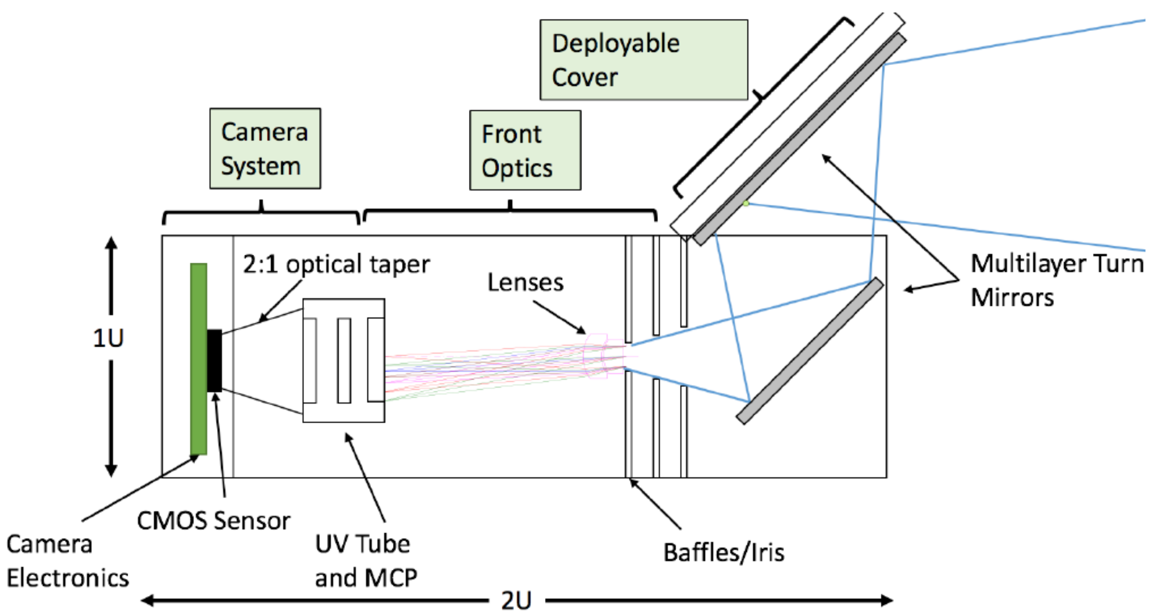


Figure 1.1: Concept layout of components in MUVI [**2**].

The purpose of this project is to design, build, and test the instrumentation frame, Photek (UV imager) flexure mount of the Miniaturized Ultraviolet Imager such that it will meet the specifications of a 2U CubeSat and allow for operation of the FUV (Far Ultraviolet) imaging subsystem in the ionosphere. The structure must survive extreme temperature variations in the vacuum of space as well as withstand the dramatic vibrations of launch. If the final MUVI structural assembly passes vibrational testing, the satellite qualifies as NASA TRL (Technology Readiness Level) 6, at which point it may be considered for launch. Once in space, MUVI will provide UCB SSL and NASA with data on ionospheric weather patterns to be used for a variety of research applications.

MUVI is a follow up mission to ICON that will take advantage of advances in UV imaging technology. These advancements simplify the structure and decrease design, manufacturing, and launch costs. As a constellation of satellites, CAMI will provide ionospheric data from multiple vantage points in space simultaneously. This project, MUVI Phase 3, is the third Cal Poly senior project involving the MUVI CubeSat prototype. The first senior project, MUVI Phase 1, worked on the UV imaging sub-assembly of the CubeSat and designed a 1U structure. The second senior project team, MUVI Phase 2, completed design of the deployable door assembly.

The primary goal for MUVI Phase 3 is to integrate the existing systems into a 2U CubeSat format and thoroughly test the entire assembly to qualify for NASA TRL 6. This project will finish in early June 2020.

The project will be carried out by three senior mechanical engineering undergraduates at Cal Poly, SLO: Bradley Albright, Colin Harrop, and Nicolas Armenta.

> ”We are thankful for the opportunity to contribute to the effort put forward by previous teams by supplying our unique design skills, passion for space science, and ambition to help researchers better understand the ionosphere. We look forward to working more with Mr. Kodi Rider and Dr. Thomas Immel of UCB SSL, the guidance from Mr. Jason Grillo and Dr. Elghandour of Cal Poly, SLO, and the bonding our team will experience over the course of the project.” - Bradley, Colin, and Nicolas (September 2019)

This document contains the Final Design Review (FDR) for the third phase of MUVI and how it relates to the project as a whole. The main body of this document contains background information of the ICON mission preceding the MUVI project, a literature review of similar CubeSats and UV imaging satellites, along with a review of the NASA testing standards the project will need to fulfill. Following the background research, the main objectives of the project are stated. This includes the central problem statement and design specifications. Finally, this document details project management and an overall timeline.

2 - Background Research

2.1 Prior Development of the MUVI Satellite

ICON mission development began in 2013, and launched in October of 2019. A large mission like ICON has numerous technical challenges and a high budget. In 2017 UCB SSL, the primary lead for ICON, sought to miniaturize and reduce the cost of the FUV imaging technology. Taking advantage of recent technological improvements stemming from a general push in the space industry toward miniaturization and simplification, it became possible to scale down the FUV portion to a 2U CubeSat size. A 2018 senior project at Cal Poly was started with the goal of designing and testing the front optics assembly. After the first year, NASA accepted a grant proposal for the MUVI project and further progress was made. As part of the first senior project, a 1U CubeSat structure was designed to house the front optics. In the second year, revisions were made to accommodate the lens and mirror door mechanisms. To integrate the optics and door sub-assemblies, the previously designed 1U structure will be used as a starting point for the 2U design [**3**].

2.2 MUVI and the Ionosphere

The ionosphere is the layer of Earth's atmosphere ranging from 75 to 1000 *km* above Earth's sea level where plasma and solar UV radiation ionize atoms. The collision of electrons or heavier charged particles in the ionosphere sometimes results in UV photon emission and auroras across the globe that are not visible to the eye. The ionosphere also reflects radio waves back to earth [**4**].

Earth weather phenomena in the lower atmosphere interact with that of outer space in the ionosphere. NASA has long known about the influence of weather phenomena in space on the ionosphere, but they have taken a particular interest in better understanding the influence of Earth's weather on the ionosphere [**4**].

UV spectrometry is used to observe UV light densities within the ionosphere that are highly informative to scientists. MUVI includes a FUV imaging payload capable of observing these densities.

2.3 NASA ICON Explorer Mission

The ICON mission has 3 primary science objectives. First, to understand the source of strong variability in the ionosphere. Second, to understand large scale atmospheric waves propagating from the lower atmosphere vertically up to the ionosphere. Third, to understand how solar winds and geomagnetic activity from the earth are connected [**5**]. ICON's FUV imager measures two UV wavelengths to identify regions of disturbed plasma densities. ICON specifically observes UV light emitted by ionized oxygen and nitrogen. The FUV is able to operate day and night and adjusts its gain to compensate for changing light conditions.

The type of data the FUV outputs is classified as level 1 because "calibrated radiances" from the FUV are reported. This raw data is used with other sensors on ICON for the primary science objectives of the mission [**5**].

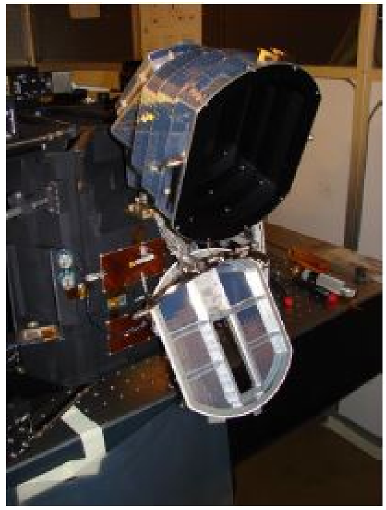


Figure 2.1: ICON FUV Optical Assembly [**4**].

Challenges facing the design of the optical assembly on ICON included its need to survive temperature from -25 to 43°C, to avoid the influence of stray light, and to eliminate contamination by FOD (Foreign Object Debris). Light of similar wavelengths to the wavelengths of interest, in this case 135.6*nm* and 157*nm*, can distort the image; this is known as stray light. For ICON, the biggest source of stray light came from light just outside the field of view [**6**]. The optics on board ICON are extremely sensitive, and any small amount of FOD can distort the image or even render the optical imaging inoperable. According to Mr. Kodi Rider,

> "The ICON instruments are sensitive to both particular and molecular contamination which has resulted in designs that isolate sensitive components from the exterior environment and have strict material usage constraints to ensure minimal loss of instrument throughput and sensitivity" [**7**].

Since MUVI and ICON have similar science objectives, with similar optical equipment, and will experience similar environmental conditions, it is critical in the design process to understand the challenges encountered and solved while designing ICON. Specifically, the control of contamination in the form of outgassing will be a large driver in the overall design of MUVI, especially as it relates to material choices.

2.4 Specifications and Testing

The NASA TRL (Technology Readiness Level) is a measurement system used to assess the maturity and mission readiness of a space bound device. The readiness of a technology to be deployed is determined by evaluating the technology against the parameters of the nine readiness levels. When in the concept phase – napkin drawing phase – a technology is considered TRL 1. As the technology is proven through modeling, prototyping, and testing, its TRL rating increases until its operational readiness is definitely validated through successful mission operation and attains TRL 9. Upon operation of a high fidelity prototype in a relevant environment that demonstrates successful performance – successful on ground space environment tests – a technology is assessed as TRL 6, at which point it can be considered mission ready [**8**].

As part of the initial research to gain a better understanding of general CubeSat design principles, the CubeSat 101 article written by NASA CubeSat Launch Initiative was heavily utilized. This article gave a high-level overview of the factors that go into designing and testing a CubeSat. Discussion of the 2U CubeSat formfactor, the P-POD (Poly-Picosatellite Orbital Deployer) dispenser, and other design considerations like outgassing were a focus [**9**]. This source was a good starting point that gave the team an introductory level of information and pointed to further reading into specific topics. One critical topics is NASA's General Environmental Verification Standard (GEVS) [**10**]. The document lays out clear requirements for the structural strength, the types and duration of vibration testing and thermal vacuum (TVAC) testing. GEVS specifies that both computational analyses, FEA, as well as successful test results are required for an instrument or assembly to be launch ready. A design factor for loading cases of 1.25 was specified in section 2.4 (Structural and Mechanical standards).

2.5 Similar Products and Technology

Satellites employing use of UV spectroscopy are common in the space exploration industry. MUVI is a miniaturized, simplified version of larger NASA heliophysics missions, including GOLD, TIMED, and ICON [**5**][**11**][**12**]. These missions follow the more traditional approach to satellite technology – a larger assembly of several instruments. These satellites are costly to launch and require the better part of a decade to develop. They are expensive to design/manufacture, long development times slow the availability of data, and observations are made from a single vantage point.

Figure 2.2: NASA ICON mounted to a Northrop Grumman Pegasus IV [**13**].

Fortunately for today's researchers, a less daunting alternative to traditional satellites is available: CubeSats. In 1999, professors Jordi Puig-Suari of Cal Poly and Bob Twiggs of Stanford wanted a way for graduate students to have easier access to space data acquisition. Cal Poly and Stanford engineering collaborated to design the first CubeSat, a miniature satellite of several stock configurations that performs simple data probing in low Earth orbit [**14**].

Since then, CubeSats have exploded in popularity for government funded space missions, such as MUVI, and private sector missions. One use case of a CubeSat is Redmond, WA based company Planetary Resources Inc's Arkyd program. The Arkyd program involved series of CubeSats mounted with infrared cameras used to map the solar system for asteroids containing a sufficient mass and concentration of water worth mining in the future [**15**].

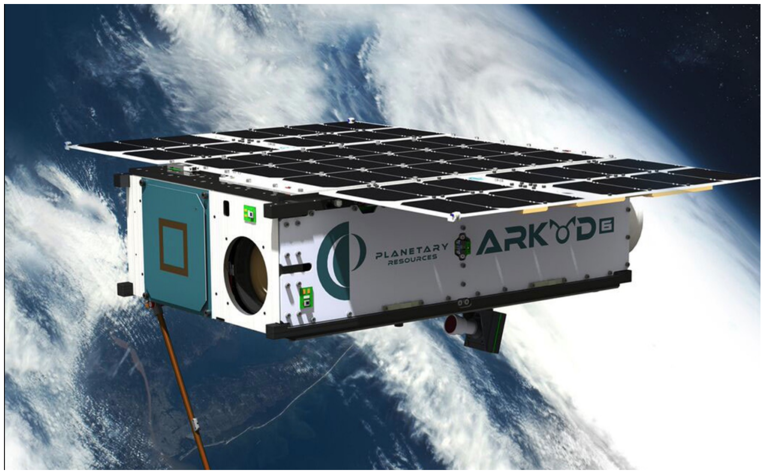


Figure 2.3: Planetary Resources Arkyd-6 Satellite [**15**].

A significant benefit of using a CubeSat instead of a larger satellite is a CubeSat's ability to fit in a rideshare mission on a P-POD. In fall of 2018, SpaceX launched 64 satellites in a single Falcon 9 mission, 49 of which were CubeSats [**16**]. Launching multiple satellites with one rocket is known as a rideshare mission. Once the payload is in orbit, a P-Pod containing the CubeSat propels the satellite outward, into its own orbit. P-PODs are the stock ejection system accompanying the stock size of the CubeSat.

2.6 Patents

Several useful patents were found during the initial brainstorming of this project. There are many patents for CubeSats and their applications, but here are a few significant patents relevant for this scope of work:

Patent No. US9150313B2: Describes the general assembly structure of a CubeSat for a specific avionics package [**17**].

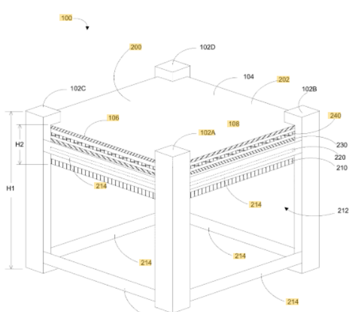


Figure 2.4: CubeSat structure [**17**].

Patent No. US9845166B2: Describes a P-Pod like CubeSat/Nanosat deployment system. Contains ideas for alignment rails, a pneumatic ejector, and a gas reservoir. This is similar to a P-Pod [**18**].

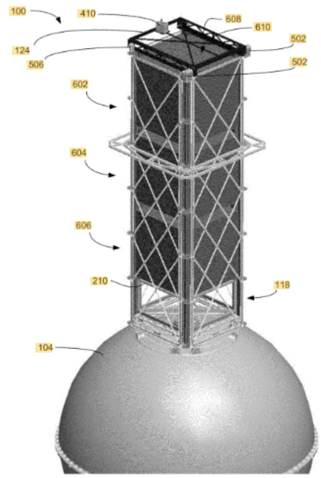


Figure 2.5: Pneumatic CubeSat Payload Deployment System [**18**].

Patent No. US3374702A: Details concept for exploding bolt (MUVI utilizes exploding bolts during deployment). This is similar to other gas sealed propellant mechanisms. This is one of many types of exploding bolts [**19**].

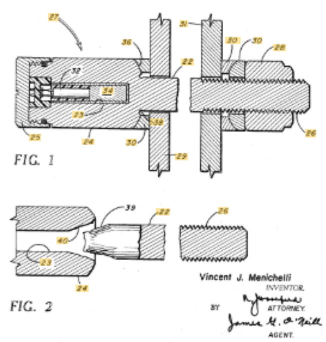


Figure 2.6: Exploding Bolt [**19**].

Patent No. US10315784B2: Describes concept of CubeSat instrumentation frame designed to maximize the allowable volume within envelope size to be dedicated for main payload. Shows drawings of how geometry can be manipulated to provide more storage space [**20**].

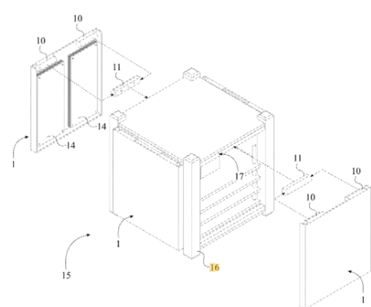


Figure 2.7: Method to increase volume in a CubeSat [**20**].

Patent No. US9862507B2: Illustrates and describes insulation-controlled CubeSat instrumentation frame panels. These panels are lined with fins that can rest flush with the plane of the panel or extend perpendicular with help of torsion springs or similar [**21**].

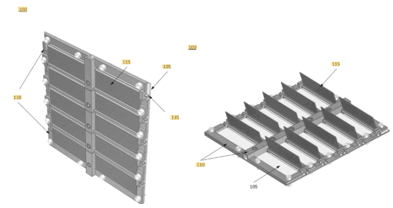


Figure 2.8: CubeSat Thermal Louvers [**21**].

2.7 Flexures

The design of damping flexures capable of carrying the vibrational loads undergone during launch will be integral to the success of MUVI. The critical components–mirrors, camera, etc.–contained within the structure will not have the ability to take loads, so flexures will be used to distribute any loads away from these components. Previously, one senior project team designed flexures to support the mirrors; these can be seen in Figure 4.9. This project team will focus on designing flexures to interface with the outer structure and the previously designed subsystems.

At its most basic, a flexure can be a flat, rectangular piece of metal loaded such that it allows motion in a desired direction but restricts motion in other directions [**22**]. In general, ”flexures are bearings that allow motion by bending load elements such as beams” [**23**]. The basic function of a flexure is ”to provide motion in desired directions, but constraint in other directions” [**23**].

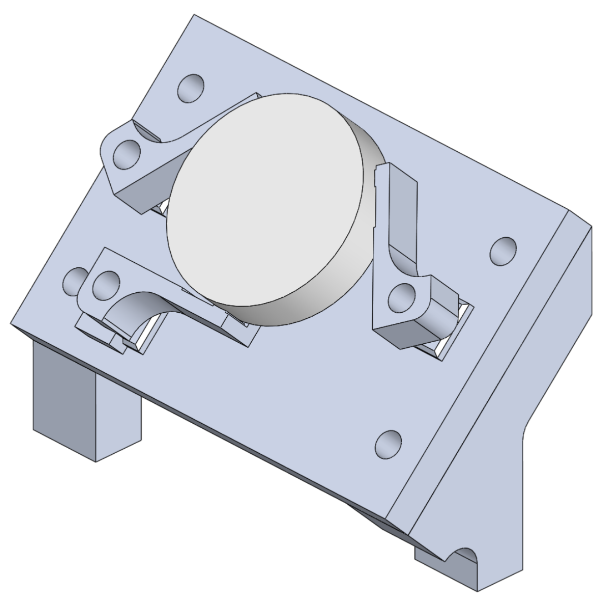


Figure 2.9: MUVI damping-flexure-supported mirror.

3 - Objectives

3.1 Problem Statement

UCB SSL needs an instrumentation frame to integrate the sub-assemblies of MUVI in a 2U CubeSat envelope size. FEA must demonstrate the proposed instrumentation frame's ability to withstand the vibrations of launch before proceeding with manufacturing. The instrumentation frame shall also dampen vibrations resulting in noise to the FUV camera. Once the instrumentation frame is manufactured, it is to undergo vibration simulation while contained in a ground support replica P-POD. The fully assembled satellite must be tested to qualify for a NASA TRL 6 rating.

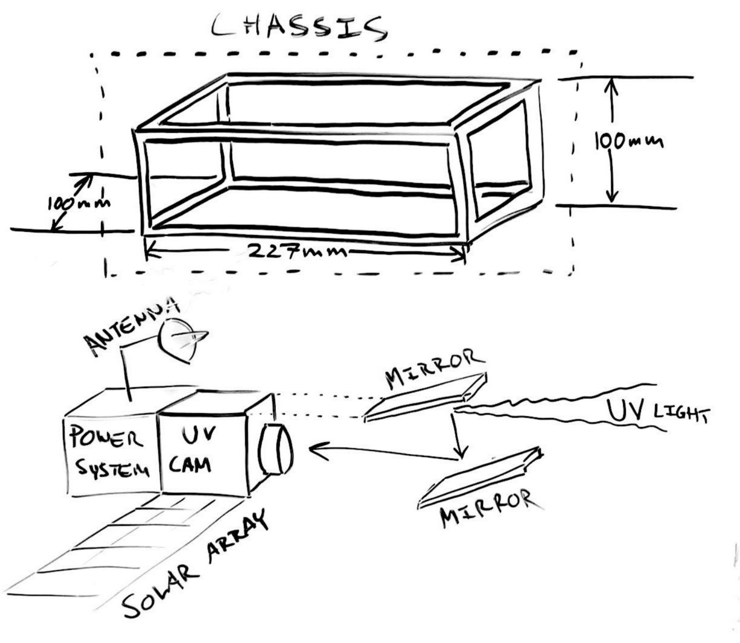


Figure 3.1: Project Scope Boundary Diagram.

3.2 Customer Wants and Needs

The ultimate goal of the project, according to the initial grant proposal, is to produce a prototype UV imager for geospace application with a CMOS (Complementary Metal-Oxide Semiconductor) detector and high spatial resolution with photo counting capability [**1**]. Most subsystems of this prototype imager have been developed to TRL 6 individually, but the outer structure must be completed and the full system must be modeled and tested in order to bring the system as a whole to TRL 6. This requires that the system be tested for adherence to NASA environmental vibrational and TVAC standards, per GEVS. All subsystems must assemble together while adhering to CubeSat 2U specifications. Successful operation of the imager requires the prevention of outgassing or contamination by FOD.

3.3 Quality Function Deployment (QFD) Process

A QFD was used to identify customers, evaluate their needs, and prioritize need-based objectives. For more detail, see the completed QFD House of Quality in Appendix A. The main customers are the following:

Table 3.1: Customers and Customer Needs

Customer	**Needs**
UCB SSL Scientists	Data obtained by observations made by MUVI
NASA	Entire assembly and all subassemblies TRL 6
UCB SSL Machine Shop	Manufacturable design of components
Cal Poly MUVI Senior Project Team	Testable for vibration and TVAC standards
United Launch Alliance	Design meets launch standards and specifications

3.4 Engineering Specifications and Testing

Engineering specifications serve as the evaluation criteria for the project. A complete list of specifications is contained in the QFD in Appendix A. The risk column in the engineering specifications table below estimates how difficult it will be to satisfy a specification, with H standing for high risk, M, standing for medium risk, and L, standing for low risk. The compliance column describes the method to be used to determine whether the design meets specifications, where T stands for testing, A for analysis, and I for inspection.

Table 3.2: Engineering Specifications

Number	Specification	Requirement/Target	Tolerance	Risk	Compliance
1	Size	2U (100mm x 100mm x 227mm)	MAX	M	I
2	Mass	2.66 kg	MAX	L	I
3	TRL	6	N/A	H	T,A
4	TVAC Standards	Refer to [10]	N/A	H	T,A
5	Vibration Standards	Refer to [10]	N/A	H	T,A
6	Allowable Flight Temperature	0ºC to 40ºC	N/A	M	T,A
7	Grease and Debris	No grease or debris	0	H	I
8	Outgassing	No outgassing	0	H	I
9	Survives Exploding Bolt	All instruments operational after exploding bolt	0	M	T
10	Interfacing to Subsystems	All subsystems must properly assemble	0	L	I

3.5 Evaluation Criteria

The evaluation criteria are the tests used to evaluate the specifications listed in Table 3.3.

Table 3.3: Evaluation Criteria for Engineering Specifications

Number	Evaluation Criteria
1	MUVI instrumentation frame meets 2U size configuration specifications
2	The mass of instrumentation sub assemblies will be measured when previous team(s) hand over components in December 2019. The instrumentation frame of the satellite will be designed to accommodate for the required mass.
3	TRL 6 will be earned by testing the functionality of MUVI in a replicated space environment on ground. This includes vibrating the complete assembly to simulate launch, running thermal cycles of 0ºC - 40ºC, and verifying camera operates nominally afterwards.
4	Refer to [**10**]
5	Refer to [**10**]
6	See Specification Numbers 3 and 4
7	Outgassing will not be a stand alone test. Materials will be selected to mitigate risk of outgassing. If there are any outgassing issues, they will arise during thermal vacuum and potentially vibration tests per Specifications 3 and 4.
8	Grease will not be tested for. However, precautions will be taken to ensure there is no grease on satellite components. This includes ultrasonic IPA and/or Acetone baths for metal parts prior to assembly.
9	TBD
10	Self apparent

4 - Concept Design

4.1 Concept Design Process

Note: Section 4 of this report describes only the *concept* designs in the MUVI III project. *Final* design is described in Section 5.

After sufficient background research was completed, the team moved to ideation and brainstorming. The three ideation exercises used were brainstorming, SCAMPER, and brain writing. Brainstorming included writing as many ideas as possible about a specific challenge on sticky notes. SCAMPER, which stands for substitute, combine, adapt, modify, put to another use, eliminate, rearrange, consisted of taking current solutions to design challenges facing MUVI and attempting to adapt them to MUVI's specific needs. Brainwriting required that each team member come up with a list of ideas then pass their list on to a team member to build off of those ideas and add their own. Each of these techniques were employed to come up with creative ideas and to think outside the box. On October 29, 2019, the team produced several concept prototypes of the proposed 2U instrumentation frame and OGODS structures. Although made of simple materials (foam board, pipe cleaners, popsicle sticks, etc.) these models provided the tangible objects illustrating the envelope size of the satellite and OGODS. Additionally, this exercise provided the opportunity to come up with creative solutions and try new concepts without a big time or resource investment. Figure 4.1 below shows the concept model of the 100 x 100 x 227mm 2U instrumentation frame.

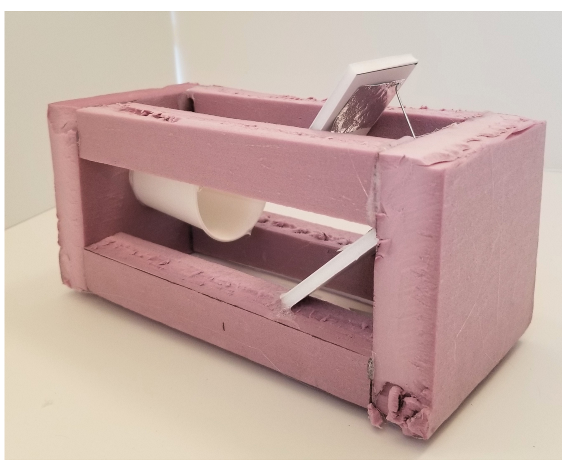
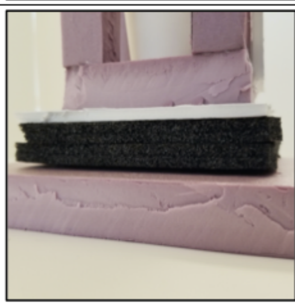
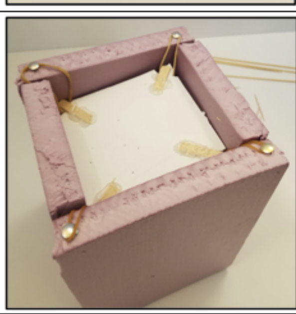


Figure 4.1: Concept Prototype of MUVI Instrumentation Frame.

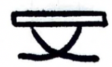
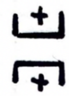
During the concept modeling activity, a big focus was exploring the spring mechanism for the OGODS load plate. In Table 4.1, a picture and explanation of each concept for the spring mechanism is included.

Table 4.1: Concept prototypes of spring mechanism for load plate.

Concept	Description
	Cantilever Beam: Forks were used to represent a leaf spring style spring mechanism. The white foam core represents the load plate and the pink foam represents the back plate of the PPOD.
	Coil Spring: Pipe cleaners were used to represent the idea of a coil spring.
	Magnets: Thumb tacks were used to represent a magnetic repulsive force instead of using a spring force.
	Damping Material: Foam pieces were used to represent the idea of a viscoelastic material that would act as a spring when a force from the CubeSat is applied.
	Spring in tension: Rubber bands attached at the front of the PPOD were used to represent the idea of using a spring in tension instead of compression from the back.

After the developing concepts, some decision matrices were used to compare and contrast each idea against certain criteria for a given function. After narrowing down the design direction, preliminary CAD models were developed for the 2U instrumentation frame, detector-mounting flexures, and OGODS.

Table 4.2: Pugh matrix of top 5 spring ideas.

Ideas / Criteria	Datum: Coil Spring	Cantilever	Rubber Bands	Magnets	Torsion Springs	Foam
						
survive vibration testing	S	+	S	+	S	+
ease of assembly	S	S	–	S	–	+
manufacturing cost	S	–	S	S	S	+
manufacturing feasibility	S	S	S	S	S	S
reliability	S	+	–	+	S	+
works in a vaccum	S	S	S	S	S	–
Σ	0	+1	-2	+2	-1	+3

4.2 2U Instrumentation Frame

The instrumentation frame is the overall structure of the 2U CubeSat. It pieces together the camera, lenses, mirrors, circuit boards, and flexures. The two previous projects have designed their respective subsystems for 1U configurations. This leaves an extra 27 *mm* in the axial direction of the CubeSat for the current team to fit in any extra components. See Figure 4.2 shown below for a visual of the instrumentation frame envelope size.

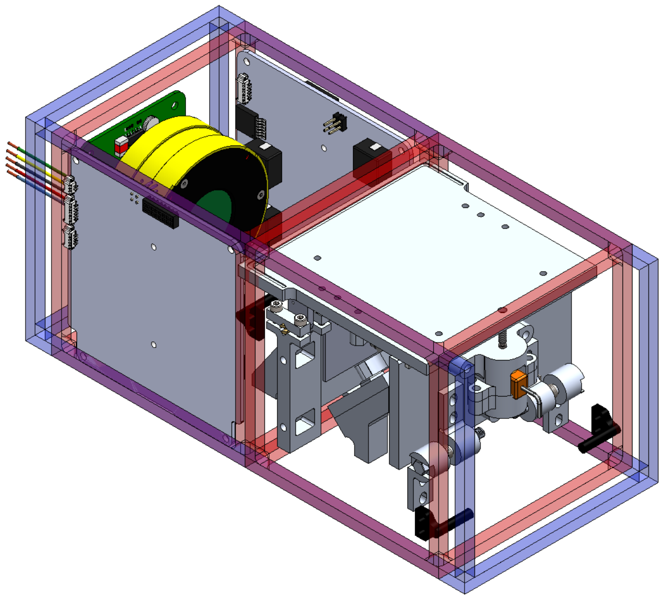


Figure 4.2: CAD showing 2 x 1U envelope size (red) versus full 2U size (blue). This illustrates the extra space the current team has to work with.

Figure 4.2 is missing several key components of the final satellite. First, as this is an optical device, there must be some datum to align camera components. Second, the satellite must be sealed during launch to avoid particulate pollution. The team has developed conceptual CAD including these critical components and is shown below in Figure 4.3.

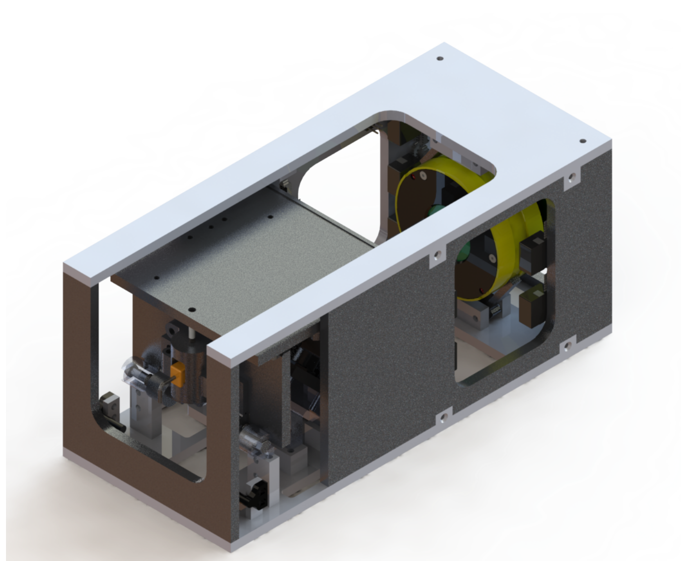


Figure 4.3: CAD render of MUVI with Instrumentation Frame.

One issue the team encountered while designing the structure was modeling the instrumentation frame within the 2U envelope size while allowing room for the mirrors to rotate about their hinges. It is likely that redesigns of the instrumentation will come from this senior project. The team would like to shrink the width of the primary mirror mounting plate. For now, the team must negotiate the size of the mirror mounting plate with respect to the instrumentation frame (As of December 2019)

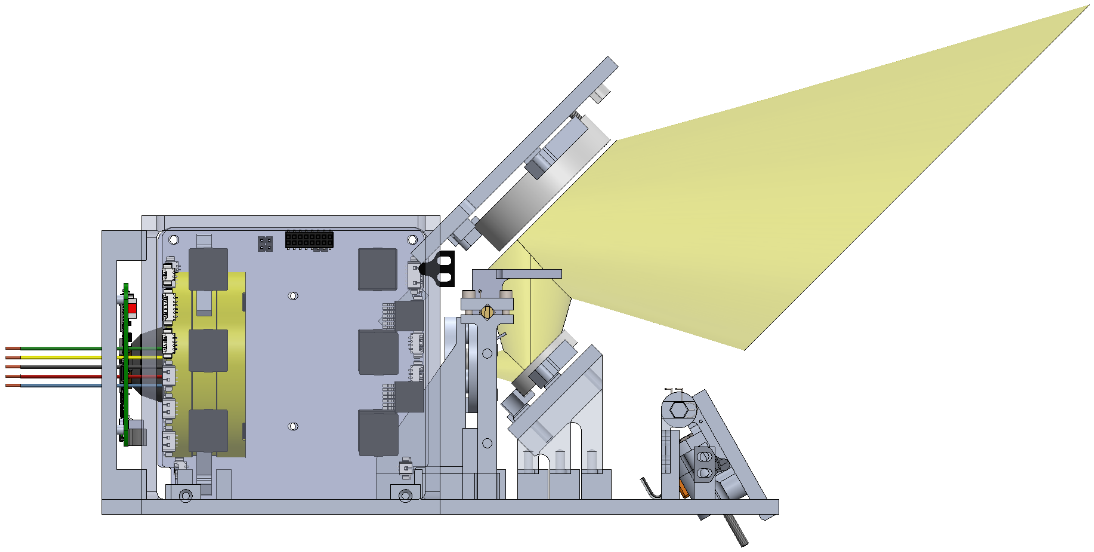


Figure 4.4: Path of light exposure to camera.

The most complete CAD component is the optical array datum plate shown below in Figure 4.5. The datum aligns the camera, lenses, and mirrors such that the light exposure tolerance is maintained. The team plans to reevaluate design for manufacturability after PDR. Although UCB SSL's machine shop has high capabilities, there are many challenges with the proposed design considering that tolerances will be on the order of magnitude of microns.

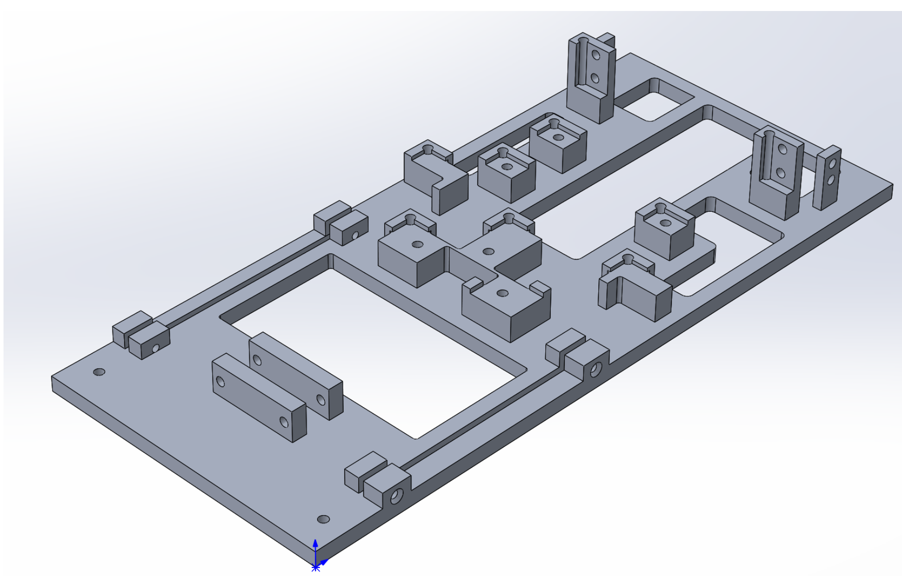


Figure 4.5: Optical Array Datum Plate.

4.3 Satellite Instrumentation Frame (Through CDR)

Note: This section details the Instrumentation Frame design through CDR. The final design of the Instrumentation as of FDR is in the next chapter.

4.3.1 Design Status

As of CDR, the Instrumentation Frame is still a work in progress. The deadline the complete Instrumentation Frame Design, including engineering drawings, FEA, and bill of materials is Friday, February 28, 2020. From there, drawing will be sent to a machine shop for fabrication.

There is extra scrutiny on several aspects of the design. First, there is a tight tolerance on the path of light from mirrors to the focal plane (+/- 0.25 degrees light exposure to Photek). Alignment of optical components will be corrected by Sunday, February 9, 2020. Next, the satellite must adhere to CubeSat regulations on mass. Mass properties will be placed into the CAD model after optical alignment is corrected. Panels have more material than necessary. The overall mass and center of mass can be manipulated via milling pockets in the structural panels. After the general panel shape is finalized, FEA will be used to determine final part geometry. Mass manipulation and FEA (100g static load case and modal analysis) shall be completed by Sunday, February 16, 2020.

The senior project team plans to meet with the sponsor, Kodi Rider, at UCB SSL on Friday, February 14, 2020. The team will present a Critical Design Review presentation tailored to the informational needs of the sponsor. Furthermore, the team and sponsor will review drawings and FEA results. Ideally, drawings will be approved for fabrication at this meeting, but there is time in the calendar for editing and final submission of drawings on Friday, February 28, 2020.

Although the Instrumentation Frame design is a few weeks from completion, there has been significant progress since preliminary design review. This progress is detailed in the remainder of this section.

4.3.2 Instrumentation Frame Design Description

Overall, the Instrumentation Frame consists of seven panels serving as structural support, sealing, and an optical alignment datum of the satellite. Exploded, stowed, and deployed configurations of the integrated satellite are shown below in figures 4.6, 4.7, and 4.8.

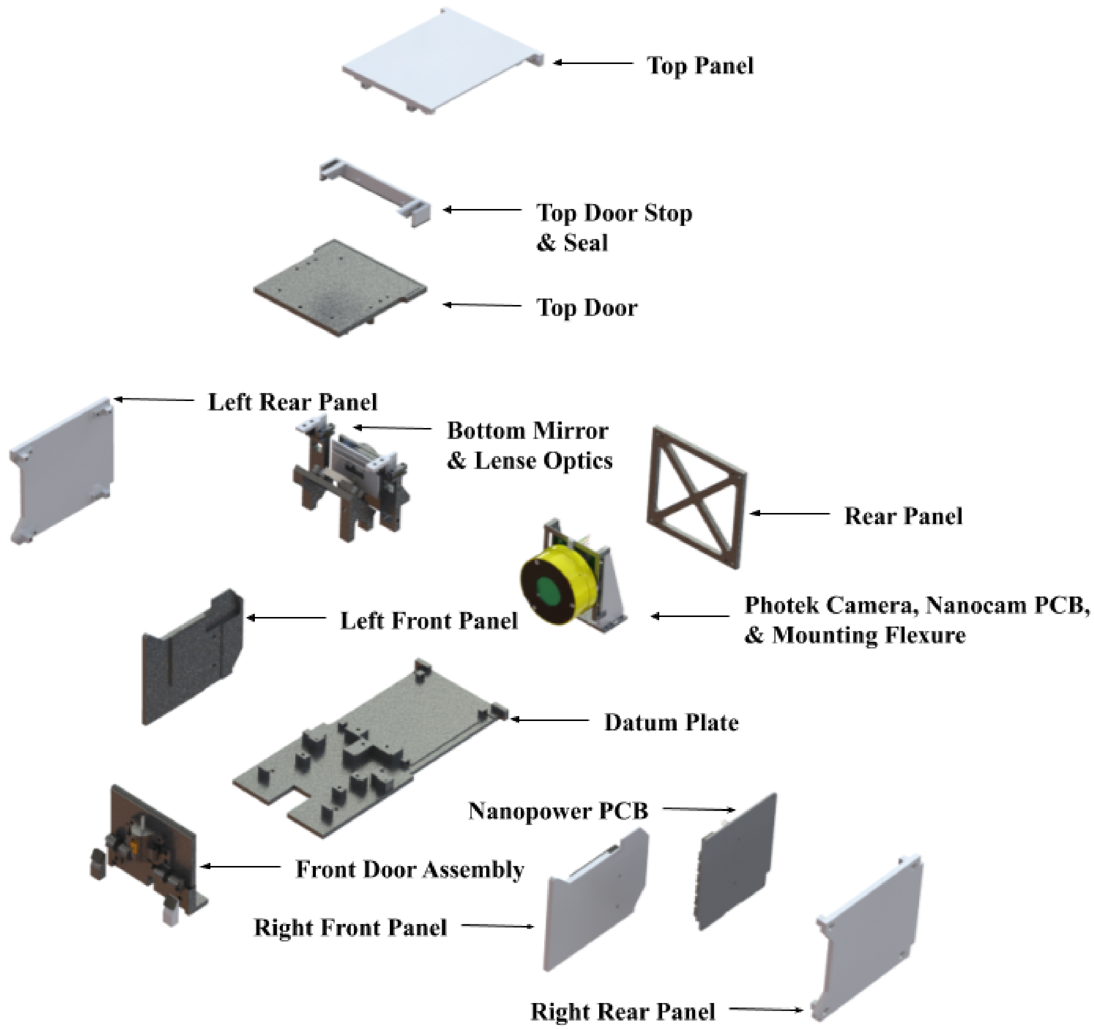


Figure 4.6: Exploded view of the MUVI Satellite with integrated Instrumentation Frame

Each panel in the Instrumentation Frame will be made of 6061 T6 Aluminum. Pending FEA, the panels will have a thickness of 5 *mm*. Panels will be fastened together by 2 to 3 *mm* diameter pins to take shear force and by M2.5 of M3 bolts for compression. Blind holes are to be minimized in attempt to avoid out-gassing.

The satellite has two configurations: stored and deployed. The Instrumentation Frame is designed to seal the instrumentation from external environments in the stowed configuration while minimizing frictional resistance as the top door opens to the deployed configuration. The configurations are shown as follows in 4.7.

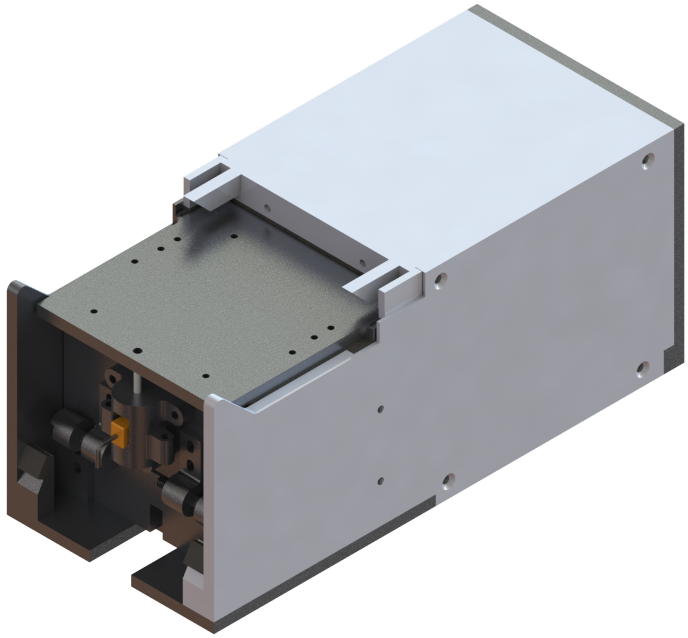


Figure 4.7: Stowed view of the MUVI Satellite with integrated Instrumentation Frame.

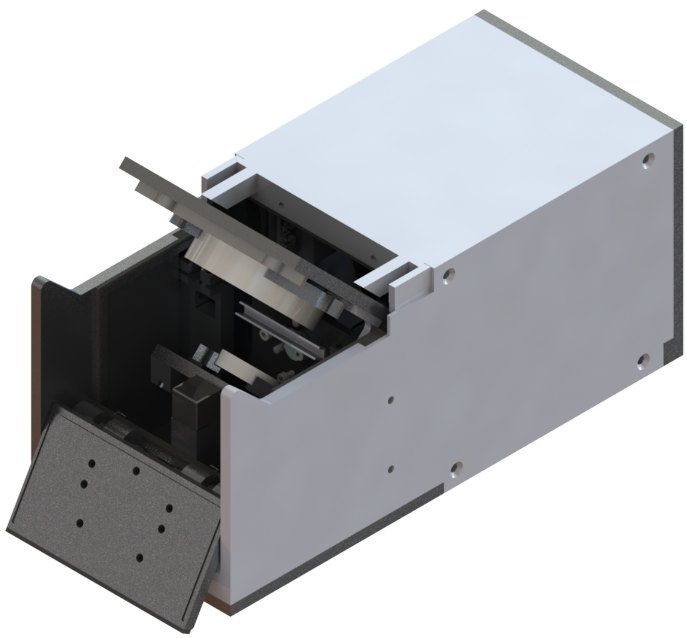


Figure 4.8: Deployed view of the MUVI Satellite with integrated Instrumentation Frame.

In the open configuration, UV light is deflected by mirrors and through lenses to reach the optical plane of the Photek camera. See 4.9 for visual.

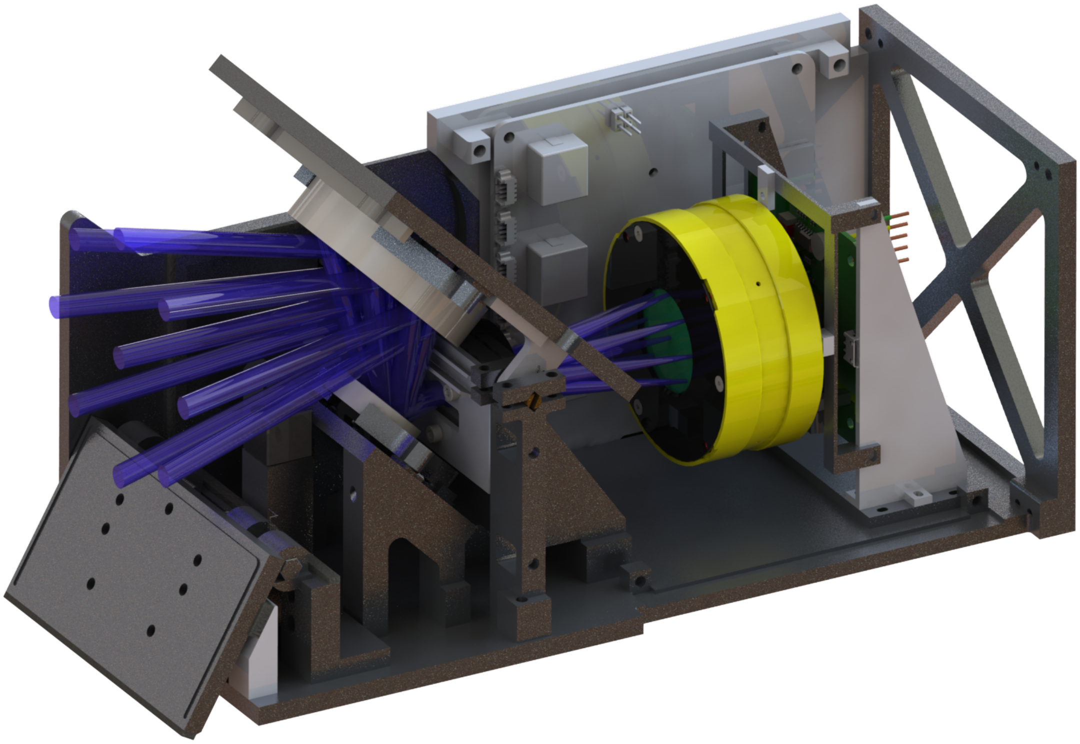


Figure 4.9: Illustration of UV light-path from Aurora to mirror assembly, through optical lens assembly, to Photek.

In the stored configuration, the satellite's mirror doors are closed. Nitrogen floods the interior of the satellite via a Swagelok port. The nitrogen keeps the inside of the satellite clean. Viton strips seal openings in the satellite to prevent pollution from foreign object debris (FOD). The satellite is stored from transportation to launch site through launch and to orbit. The Viton sealing is shown in 4.10.

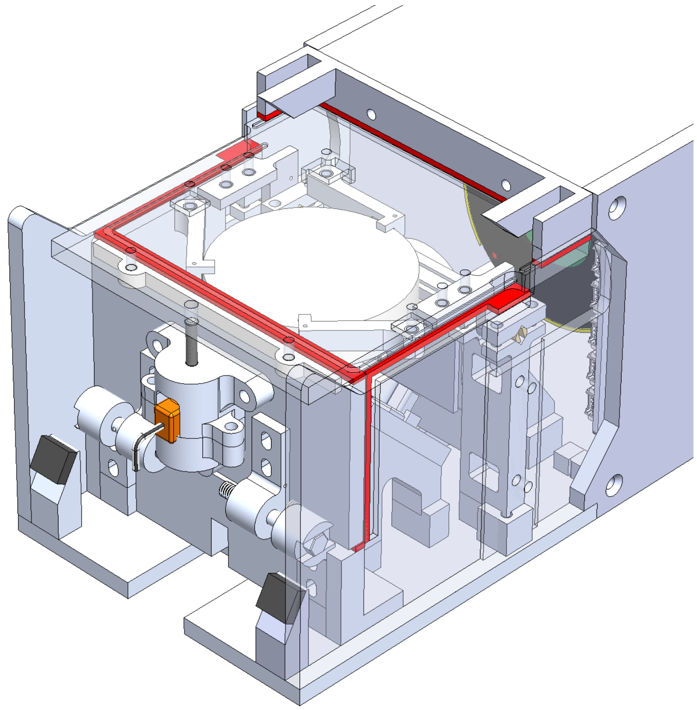


Figure 4.10: Illustration of Viton seal placement. Seals colored red for clarity.

After reaching orbit, current is sent to the Frangibolt on the mirror door sub-assembly. The Frangibolt fractures, allowing for doors to open. This is the deployed configuration. In the deployed configuration, UV light has line of site to the primary deflection mirror (2" mirror on top door). Light deflects to the secondary mirror, lens assembly, and finally to the focal plane of the Photek Camera. A visual of the light path is shown in 4.11.

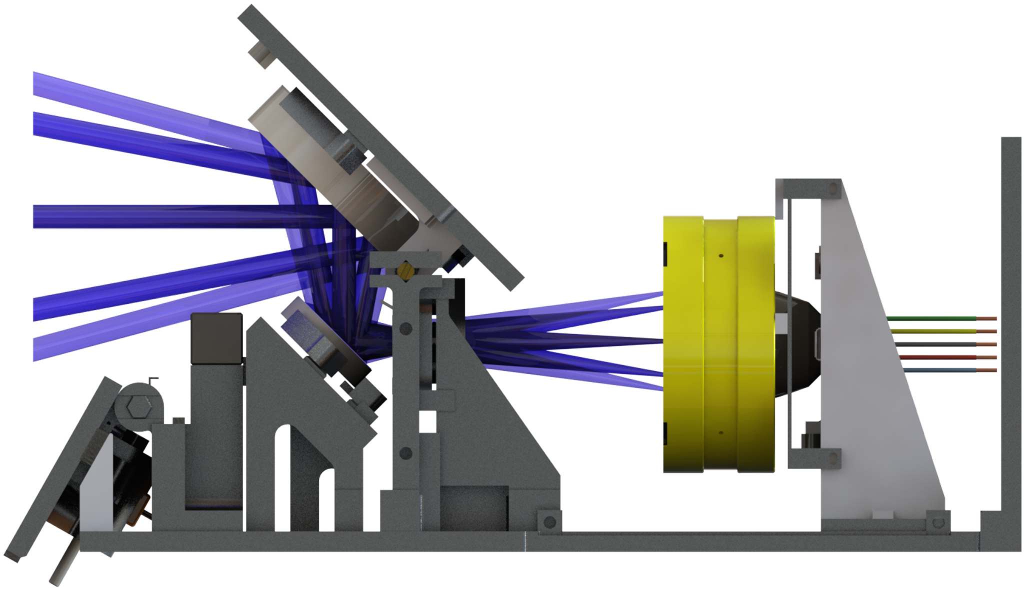


Figure 4.11: Illustration of UV light-path from Aurora to mirror assembly, through optical lens assembly, to Photek.

The fused silica optical alignment fiducial cube as seen in 4.12 is used to determine the proper alignment of all the optical components.

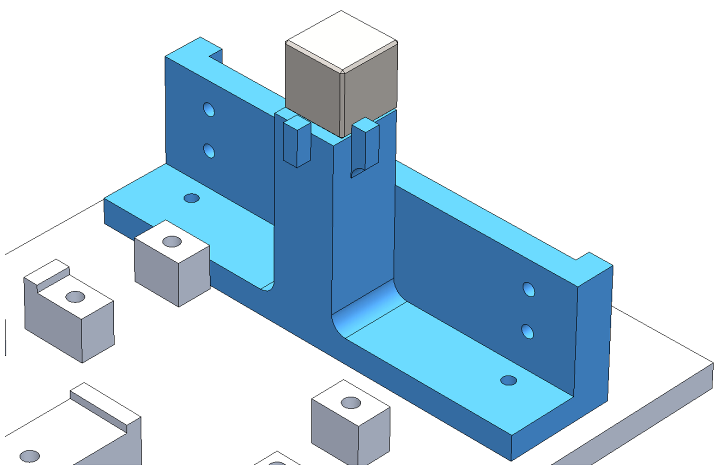


Figure 4.12: Silica Alignment Cube and Bottom Door Mount to Datum Plate.

The tower which the cube sits atop must be of a height such that the upper portion of the cube or about 0.25" is exposed to light, parallel to the datum plate and orthogonal to the laser light used for alignment. Utilizing the cube helps shim optical subassemblies to the correct locations with respect to the datum plate.

Several accommodations remain to be designed by the drawing deadline including [1]Nitrogen purge port, [2]Pins for side and top panels, [3]mouse hole for Frangibolt burn wire, [3]refined Delrin door stops, and [4]PTFE low friction upper door side seal.

As for mass properties, a solution is known, though FEA is needed. Milling out material of different panels can shift the center of mass in any of the *X*, *Y*, or *Z* directions. A concept is shown below in the Rear Panel, 4.13.

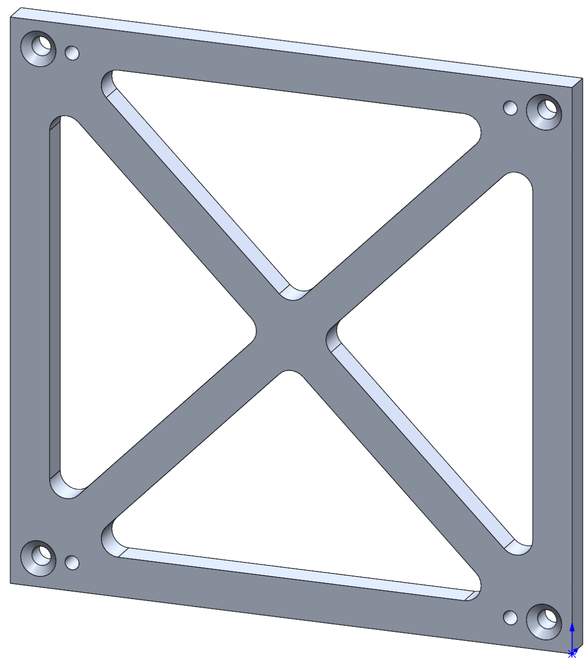


Figure 4.13: Rear Panel of Instrumentation Frame.

Note that the milled slots do not need to go through entire panel. In fact, leaving even 0.5 *mm* of thickness is enough to shed significant mass while maintaining the sealed off interior.

The last seal to be designed is a low friction PTFE used to seal the volume between the top door and front side panels. Locations of this seal are shown below.

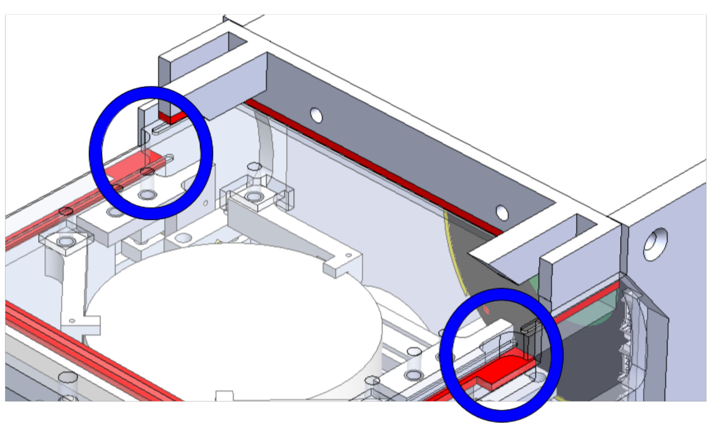


Figure 4.14: The blue circles show the location where low friction PTFE (Teflon) seals must be added to properly seal the top door.

4.4 Flexure Mount

The mirrors and Photek are highly sensitive, mission critical components that cannot take loading. A previous team designed flexures to hold the mirrors, as shown in Figure 2.9. The current team was tasked with designing flexures to attach the Photek to the instrumentation frame. Existing components prevented the flexures from interfacing with the side walls of the frame, so any design needed to interface with the instrumentation frame at the top and bottom plates only.

The mirror flexure design provided one source of inspiration for a potential means of supporting the Photek. A second design that was closely considered was the design of the flexures used to support ICON's detector. Shown in Figure 4.15, this flexure design utilized two large contact areas, as opposed to the three single points of contact used in the mirror flexure design of MUVI.

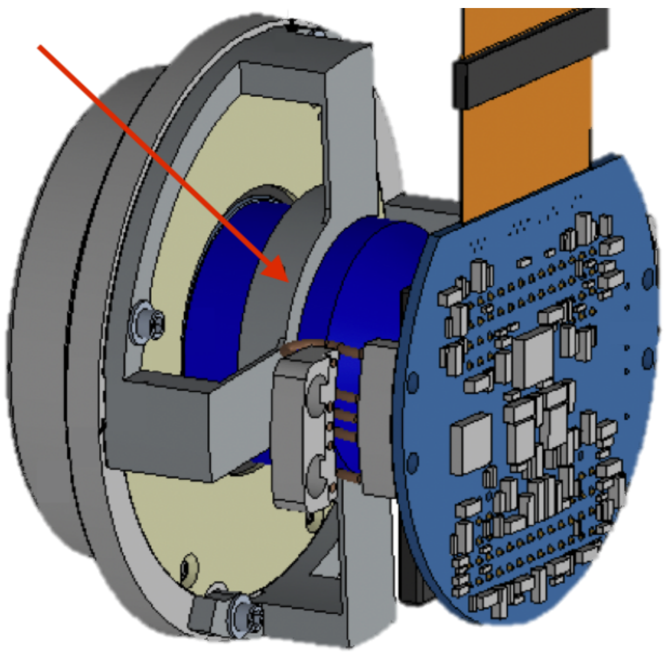


Figure 4.15: Damping Flexure supports for ICON detector.

Five concepts were originally considered for the geometry of the detector flexure assembly. These five concepts are shown in Figure 4.16. The criteria used to weigh each design against the others were maneuverability, ease of assembly, effectiveness at constraining the detector, and the degree to which similar designs had been previously validated.

One concept followed the interfacing strategy used in ICON, but though the reliability of this concept had already been tested by its use in ICON, its potential to over constrain the detector, which cannot be held with too great of stiffness during launch, decreased its appeal. While it scored high in its ease of assembly and previous design validation, its low score in the constraints section proved insurmountable because the constraint of the detector was given the most weight because of how critical it is that the detector not be damaged or shifted during launch. Two concepts were made that used four flexures that each interfaced at a single point; these concepts too had the potential to over constrain the detector's motion and thus were not selected. The two concepts that would utilize three flexures that each interface to the detector at a single point scored the highest. Ease of manufacture for the fourth option, shown in Figure 4.16, proved to be the determining criteria for the originally chosen design.

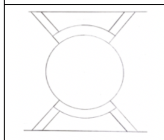
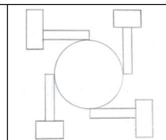
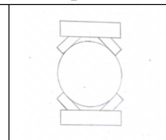
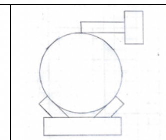
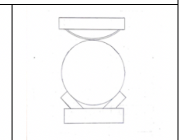
Damping Flexure Weighted Decision Matrix		Options									
											
Criteria	Weighting	Score	Total	Score	Total	Score	Total	Score	Total	Score	Total
Ease of Manufacturing	2	2	4	4	8	5	10	5	10	4	8
Ease of Assembly	4	5	20	3	12	4	16	5	20	5	20
Constraints	5	3	15	2	10	2	10	5	25	5	25
Design Validation	2	5	10	1	2	1	2	1	2	1	2
Total		49		32		38		**57**		55	

Figure 4.16: Weighted Decision Matrix used in determination of best detector flexure geometry.

Once chosen, the flexure concept drawing was turned into concept CAD, shown in Figure 4.17. After originally choosing a design with which to proceed, however, the mirror flexures underwent testing, and the mirrors cracked. It was determined that the mirror flexures were too short and thick, not allowing for absorption of energy before it could reach the mirrors. For that reason, a new design with longer, thinner blades had to be developed. It was also later decided that a mounting apparatus interfacing with only the datum plate should support the Photek. This would prevent any need to tightly tolerance the top plate to ensure alignment of the flexure mount.

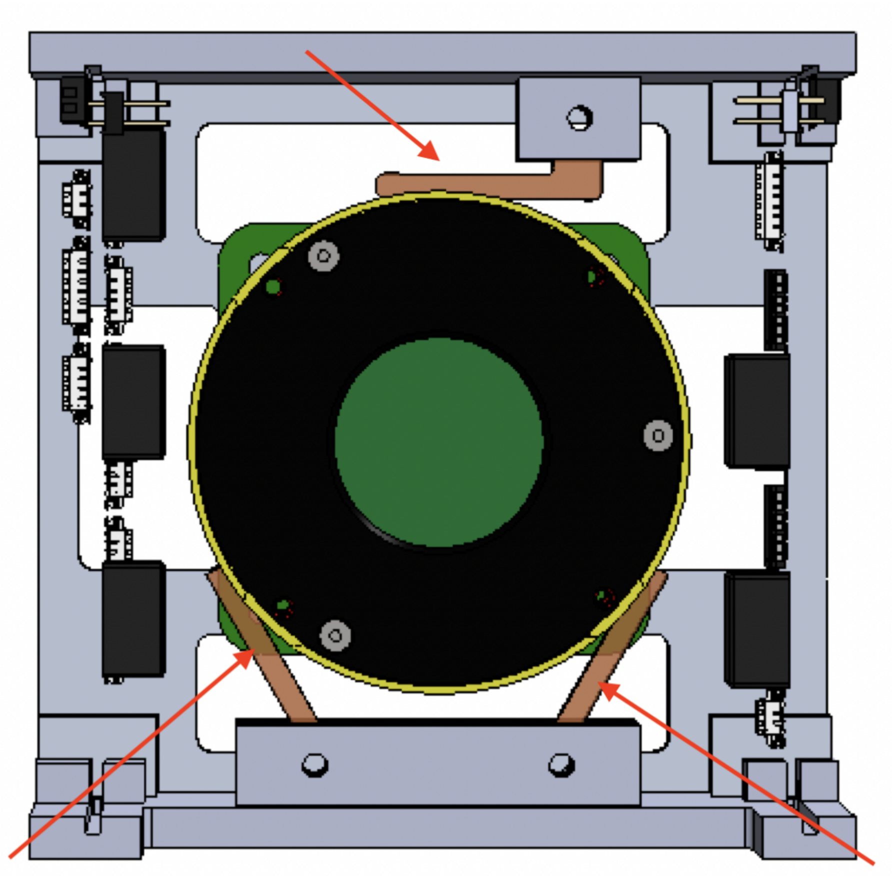


Figure 4.17: Chosen design concept for detector flexures.

4.5 OGODS

The On-Ground Orbital Deployer Simulator (OGODS), is used for holding the CubeSat for on ground vibration testing and validation. During rocket launch, there is severe vibrational loading which is difficult to model analytically and requires extensive real-world testing. The purpose of this project's OGODS design is to be used as Ground Support Equipment, GSE, during vibration testing. The OGODS will be mounted to the shake table located in the Mechanical Engineering Department's Mechanical Vibrations Lab.

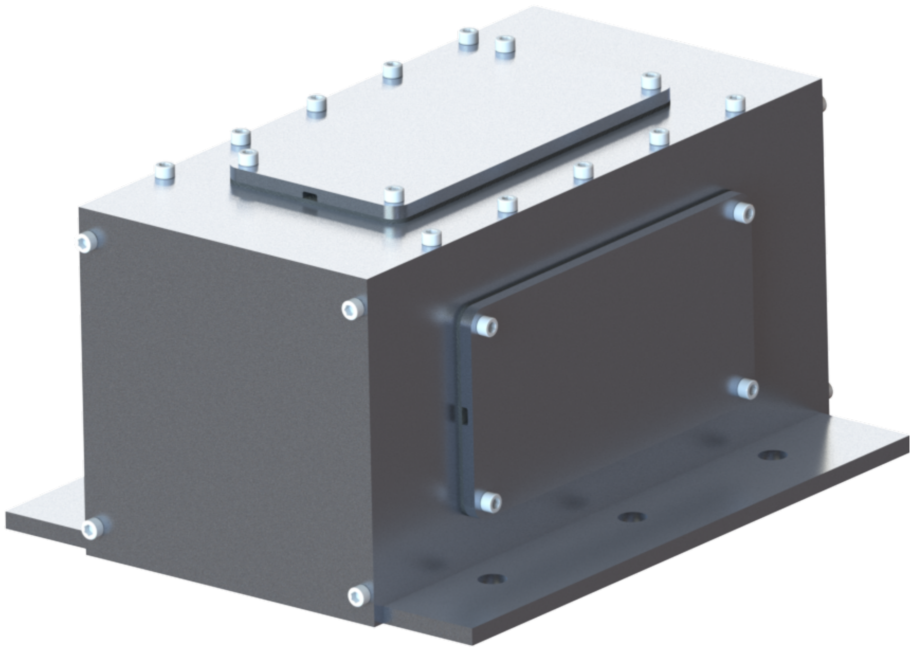


Figure 4.18: CAD render of OGODS test fixture.

This OGODS test fixture is used to replicate the boundary conditions experienced by the satellite as it goes through launch. The standard design for a P-POD is that it has spring plungers that push on a load plate which in turn pushes on the CubeSat. The boundary conditions that must be considered are that the front door is a hard mount, the back panel is spring loaded, and the CubeSat can slide on nearly frictionless rails.

The CubeSat will slide on the rails and push up against the springs at the back, and the front panel will be bolted in place to hold the CubeSat in the OGODS. The geometric constraints of this design are that it must fit a 2U CubeSat which has predefined dimensions, and it must match the bolt pattern of the shake table. The 2U CubeSat design envelope is a 100mm by 100mm and is 227mm long.

MUVI Phase I designed a 1U Test Pod fixture for vibration testing of their optical subassembly. This 2U Test Pod design is a modification of the old design implementing lessons learned from their Test Pod. The biggest issue Jason Grillo mentioned with their design was that the front plate vibrated excessively. To combat this, the front and rear panel are bolted axially instead of in shear. A second lesson learned was to use spring plungers instead of metal standoffs. This is important because replicating the boundary conditions of a real P-POD gives better test results. The third lesson learned was that the OGODS needs access panels so that accelerometers and other test equipment can be added and modified without disassembling the whole OGODS.

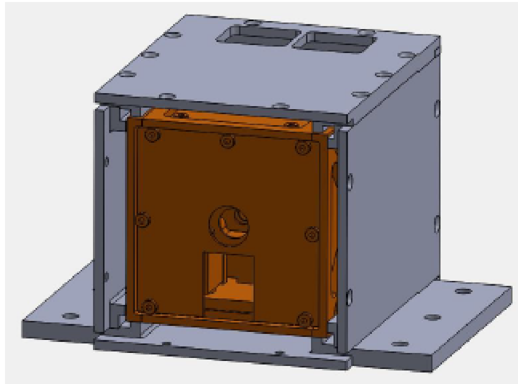


Figure 4.19: Previous senior project's 1U Test Pod.

OGODS will be made out of 6061-T6 aluminum as per the CubeSat design criteria specify [**24**] for orbital deployers. 6000 series aluminum is used for space applications because it is strong and lightweight as well as resistant to cold welding in the vacuum of space. Any aluminum parts that go into space must be anodized to form a protective coating. In the deployer the CubeSat sits rails which require an additional Teflon coating to create a low friction environment so the satellite can easy eject. Additionally, 6061 is relatively inexpensive and easy to machine making it a good choice for this application.

In the ideation phase, springs for the OGODS were a big concern. The team went through several potential spring ideas before choosing the spring plunger. As seen in 4.20 a spring plunger works by threading into the back plate of the OGODS and has a spring-loaded nose. Spring plungers are a standard component used in P-PODs according to CubeSats' design specifications [**24**]. Spring plungers are an off the shelf component with standard thread sizes and known spring force. They can be sourced from McMaster-Carr as part number 8490A792.

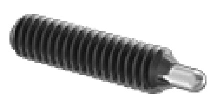


Figure 4.20: Spring Plunger

OGODS will be manufactured using conventional machining processes almost entirely on a CNC mill. During the design process special considerations were made to ensure all parts would be easily machinable. Since this assembly is only used for testing and won't be going into space, the overall weight of the design was not a driving factor. That being said, reducing unnecessary material keeps the overall cost lower. Along the same lines, the tolerances of OGODS can be slightly looser than that of the datum plate. One reason for this is that the way the parts interface does not impact other subassemblies like the CubeSat with the optical sensors would. Another reason that the tolerances can be larger is that the parts fit together with floating fasteners which have tolerances from their manufacturer. The tolerance of the fit between fasteners and the panels is limited to that of the tolerances of the off the shelf bolts. Looser tolerances lower costs and machining time. One final consideration for DFM was using all the same fasteners so only one setup of tooling would be required for all the holes. Reducing the tooling setup time has a big impact on overall manufacturing time and costs.

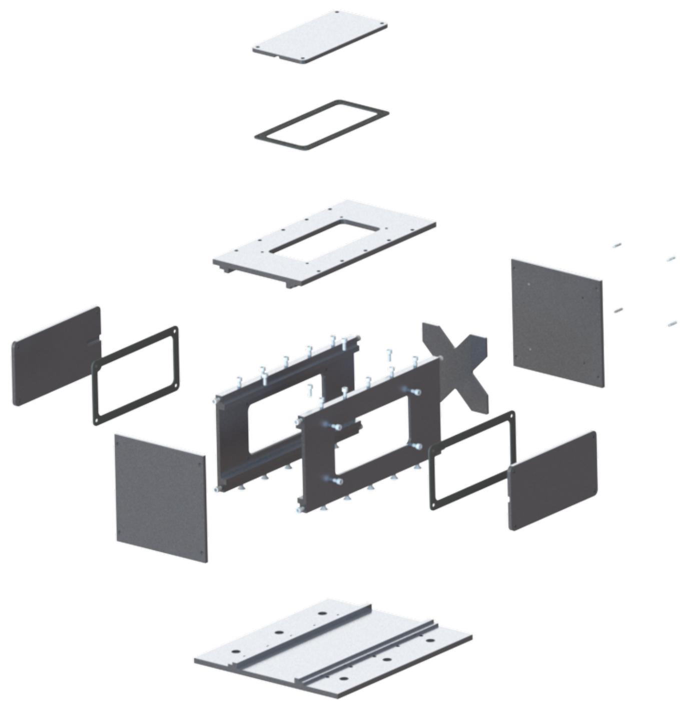


Figure 4.21: CAD render of exploded view of assembly.

Another consideration in the design was how the parts would fit together. Design for assembly is especially important for OGODS because it must be disassembled and reassembled many times for the many vibration tests that will be performed. Cap head screws were chosen for all the exterior fasteners because once loosened with a tool, they are easy to quickly unscrew by hand. Another aspect of design for assembly that was considered was making parts symmetric and using all the same fastener thread sizes, so they are all interchangeable. Reducing the total number of different parts greatly increases the ease of assembly.

4.6 Feasibility

There are two main high risk hazards that must be considered in the overall design of this project as seen in Appendix G, Design Hazards Checklist. First is that the instrumentation frame will undergo extreme acceleration loads during the rocket launch. The second high risk that must be considered is that in space there are extreme environmental conditions. These included very large temperature fluctuations as well as being a vacuum so certain materials could out-gas and release harmful particulates. These hazards will be addressed first in finite element analysis and then in testing. The point of the extensive testing is to replicate as best as possible the environmental factors the frame will experience while being in a controlled lab setting.

One unknown with this project is the door mechanism designed by the previous senior project. That team is still working on the design of the door stops and will not have a finalized design until the end of fall quarter. Right now, the preliminary design assumes the same mounting pattern as the current design. Additionally, the preliminary frame design treats the door backstops as a generic design envelope that the frame must not interfere with. Until the door backstop design is finalized, the current frame design will have this unknown that must be designed around.

5 - Final Design

There are three main assemblies designed in this senior project: the Photek camera flexure, the satellite instrumentation frame, and the On-Ground Orbital Deployer Simulator (OGODS). This section details the finalized design of each assembly.

5.1 Photek Flexure Mounting

5.1.1 Design Description

The Photek flexure mount is the subassembly tasked with mounting, aligning, and protecting the Photek. The mount includes a base plate which bolts to the datum plate and is the only component fastened to any part of the frame. Previous concepts fastened components to the top and bottom of the frame; this strategy was abandoned to eliminate any need for tight tolerances to ensure proper alignment. Two towers support three flexure blades at their respective ends, and standoffs fastened at the center of each blade act as the interface between the flexure mount and the Photek. An exploded view of the subassembly labeling each component can be seen in Figure 5.1.

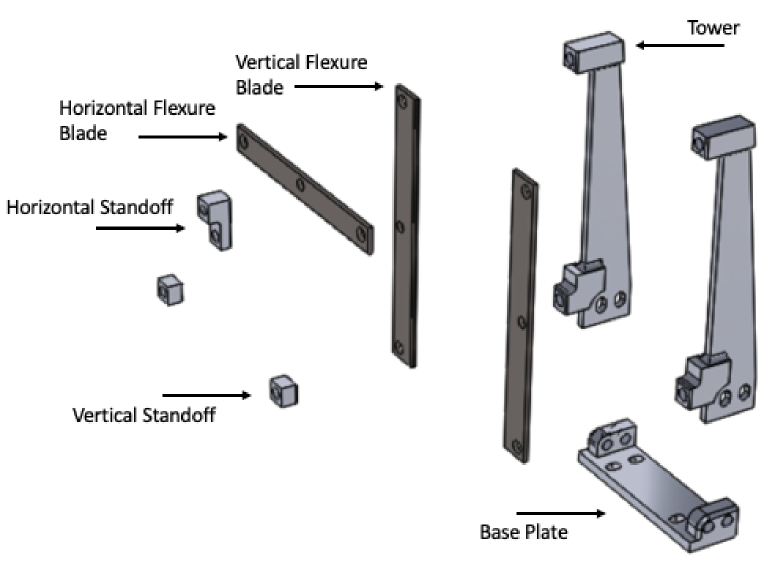


Figure 5.1: Exploded View of Photek flexure mounting

Protecting the Photek from experiencing harmful loads during launch is the primary function of the flexure mount. This function is accomplished with the flexure blades. The blades are designed to elastically deform under vibrations so that energy can be dissipated before reaching the Photek. The blades are made of stock, Grade 5, sheet Titanium. They have a thickness of 0.50 *in*, though blades with thicknesses of 0.40 *in* and 0.64 *in* will be tested as well. Titanium was chosen because its high strength and elastic modulus allow for a thinner design than 6061 Aluminum. The towers are also designed to dissipate energy. Towers and all other flexure mount components are made of 6061 Aluminium because of its high specific strength, ease of machining, and widespread use in space applications.

To facilitate optical alignment without requiring excessively tight tolerances, the flexure mount is designed to allow adjustment of the Photek location in all three principal directions. Adjustment along the longitudinal axis of the satellite can be made at the interface between the base plate and the datum plate. As is shown in Figure 5.2, axially oriented slots through which the base plate is bolted to the datum plate make this possible. Adjustment along this axis is necessary for calibration.

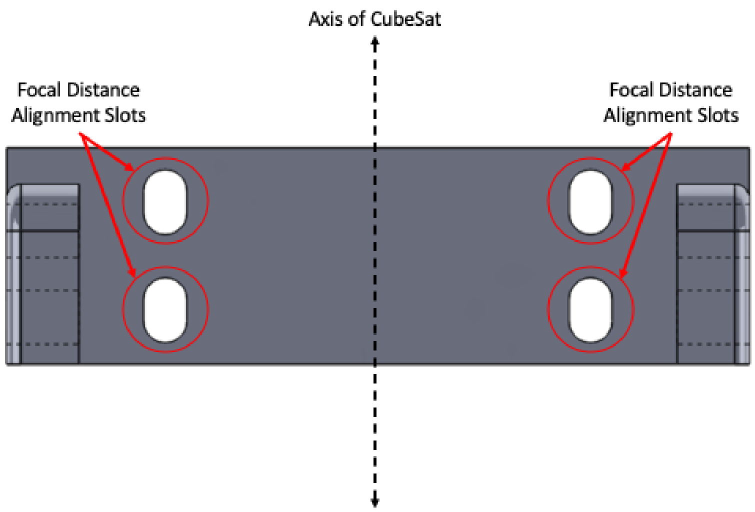


Figure 5.2: Top view of flexure mount base plate highlighting slots through which base plate is bolted to instrumentation frame datum plate.

To ensure proper positioning of the light on the Photek, room for adjustments in the plane normal to the light has been implemented through the design of the towers. As shown in Figure 5.3, clearance has been included between the towers and the side of the base plate. This allows for horizontal adjustment, and shims can be added during assembly to fill this clearance. Also shown in Figure 5.3, the bottom of the towers is designed to be in contact with the datum plate. Slots at the interface between the towers and the base plate, shown in Figure 5.4, allow shims to be placed below the towers to facilitate adjustment of the vertical position of the Photek.

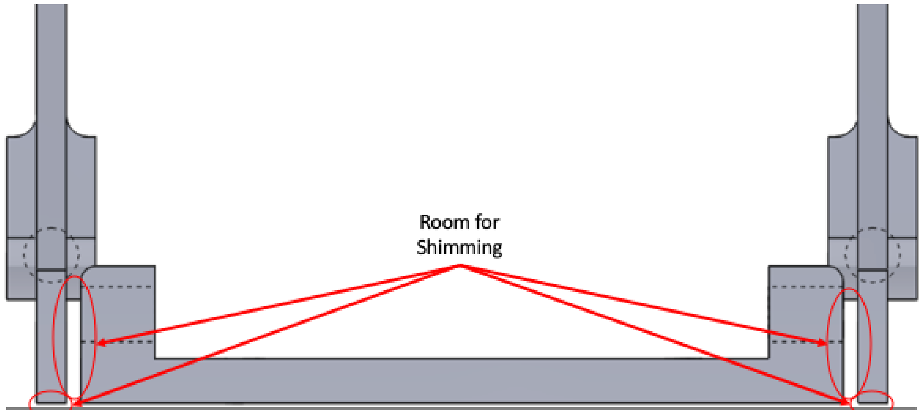


Figure 5.3: Back view of flexure mount base plate and bottom of flexure mount towers highlighting gap between towers and base plate and interface between towers and instrumentation frame datum plate.

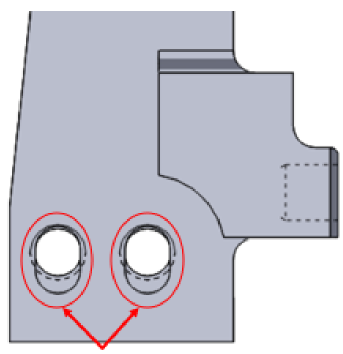


Figure 5.4: Side view of bottom of flexure mount tower highlighting slots through which tower is bolted to flexure mount base plate.

An image of the final design of the assembled Photek flexure mount with the Photek is shown in Figure 5.5.

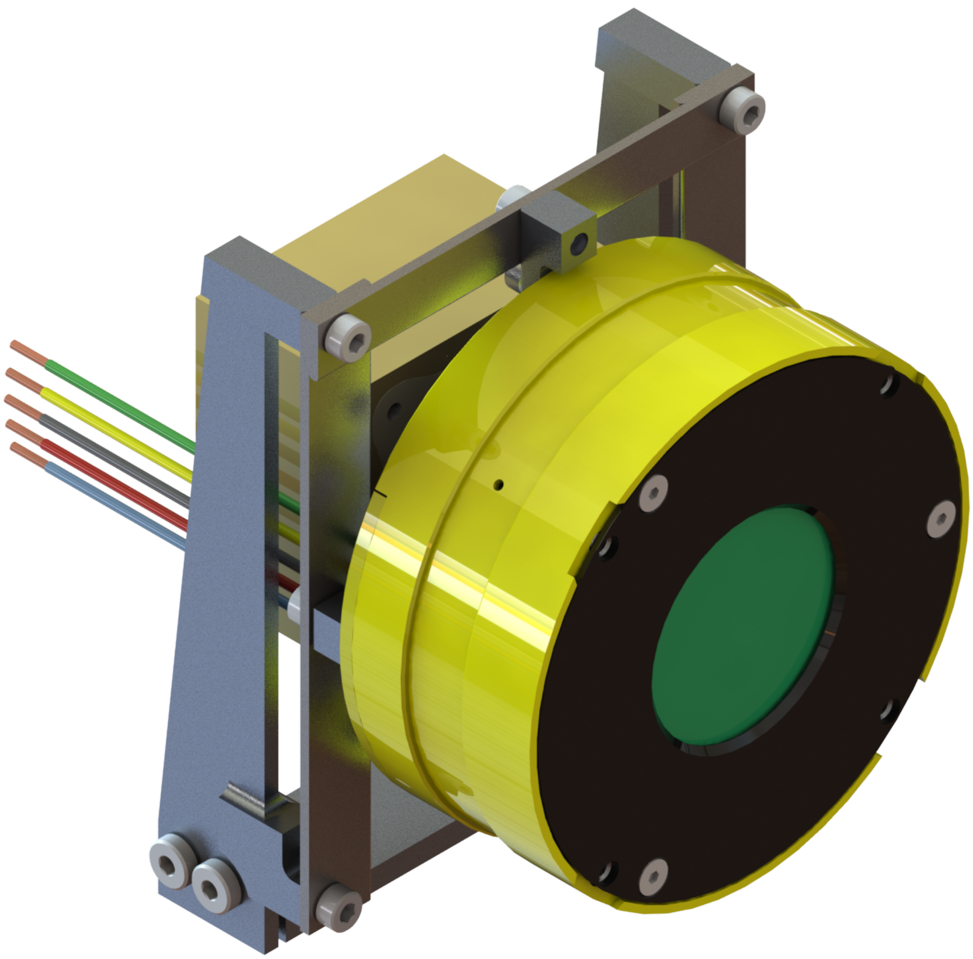


Figure 5.5: Final assembled design of Photek flexure mount holding Photek.

5.1.2 Analysis

Despite the need to design for elastic deformation, plastic deformation in any components of the flexure mount is not acceptable. To size each component as to allow for flexion without yielding, finite element analysis was used. As directed by the sponsor, Kodi Rider, a 100 g force was applied to a mass model of the Photek fastened to the flexure mount. The results, as can be seen in Figure 5.6 showing an axially directed force, Figure 5.7 showing a horizontally directed force, and Figure 5.8 showing a vertically directed force, showed stress concentrations near the interfaces between components that had the potential to cause yield. As a result, the stresses near these interfaces drove the thickness design of the flexures and towers.

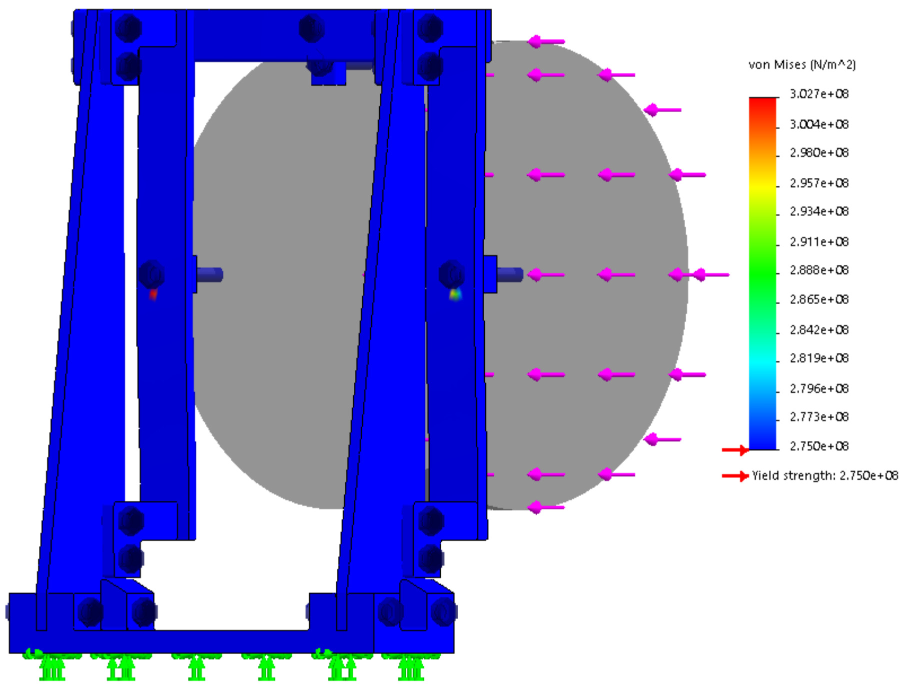


Figure 5.6: FEA model of flexure mount with 100 G static load applied axially to rigid body mass model of Photek.

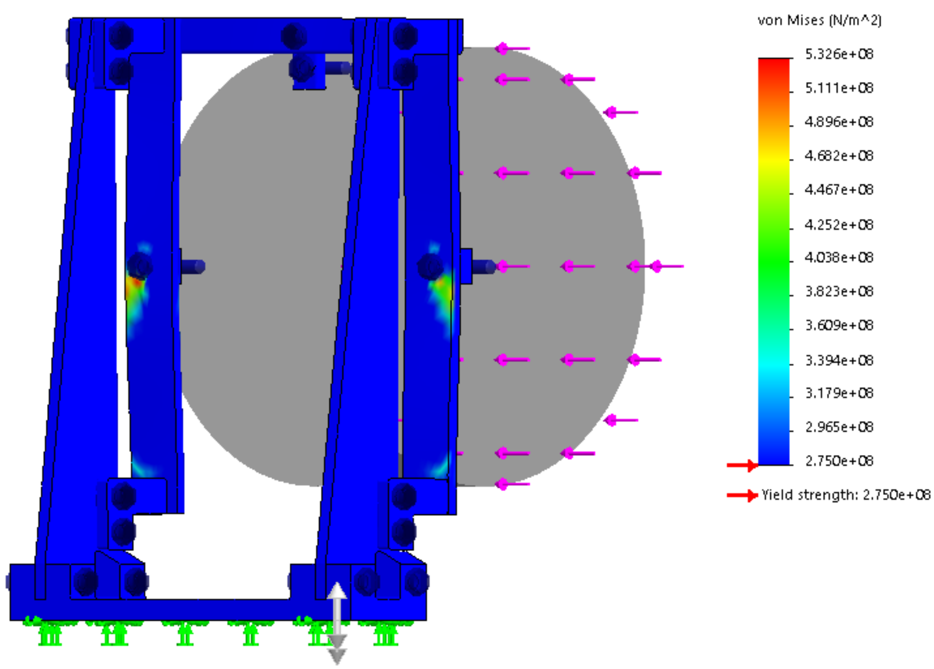


Figure 5.7: FEA model of flexure mount with 100 G static load applied horizontally to rigid body mass model of Photek.

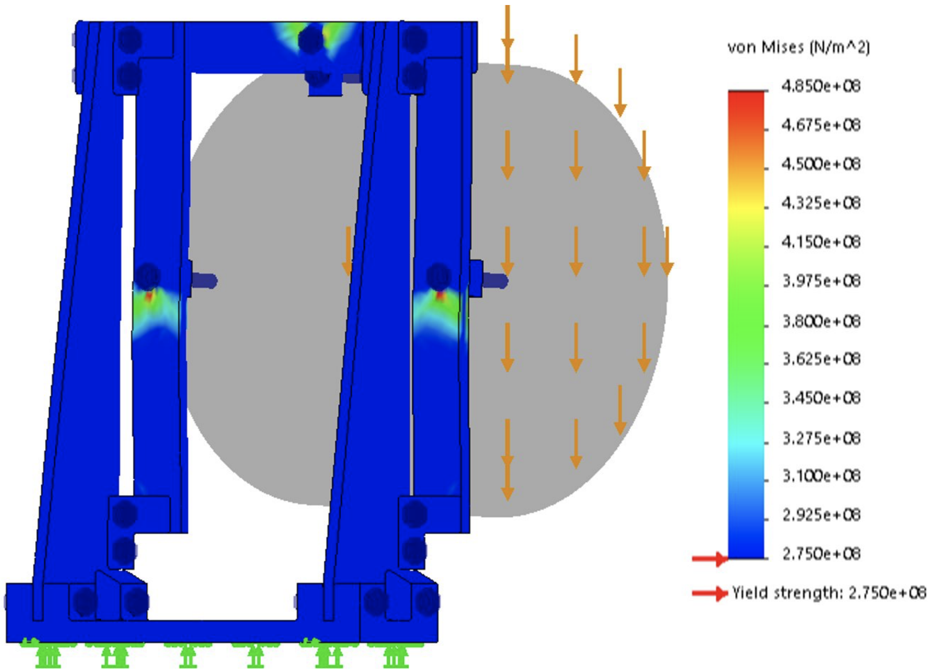


Figure 5.8: FEA model of flexure mount with 100 G static load applied vertically to rigid body mass model of Photek.

5.2 Satellite Instrumentation Frame Final Design

This section details the updates to the Instrumentation Frame design from CDR through FDR. The main updates include geometric changes to shed weight and obtain correct optical alignment, coatings to metal plates, and several small additions like door sensors, nitrogen purge accommodations, and foreign object debris (FOD) filters. Static load cases to validate geometric decisions are also explained in this section.

5.2.1 Shedding Mass

The MUVI satellite has a mass limit of 2.66 *kg* and the center of mass must be within 2 *cm*, horizontally and vertically, of the center longitudinal axis, and within 4.5 *cm* of the geometric center along the longitudinal center axis. To shed mass and control the center of mass, the design of side plates were changed. A CAD render of the final design of MUVI in stowed and deployed configurations can be seen in 5.9 and 5.10, respectively.

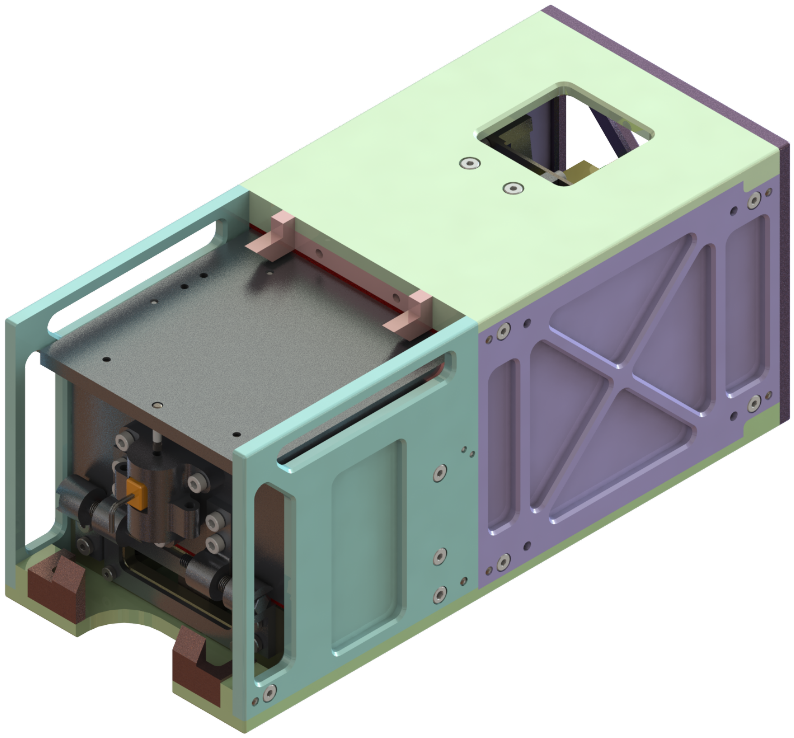


Figure 5.9: Final Design of MUVI showing cut-outs in frame plates, stowed.

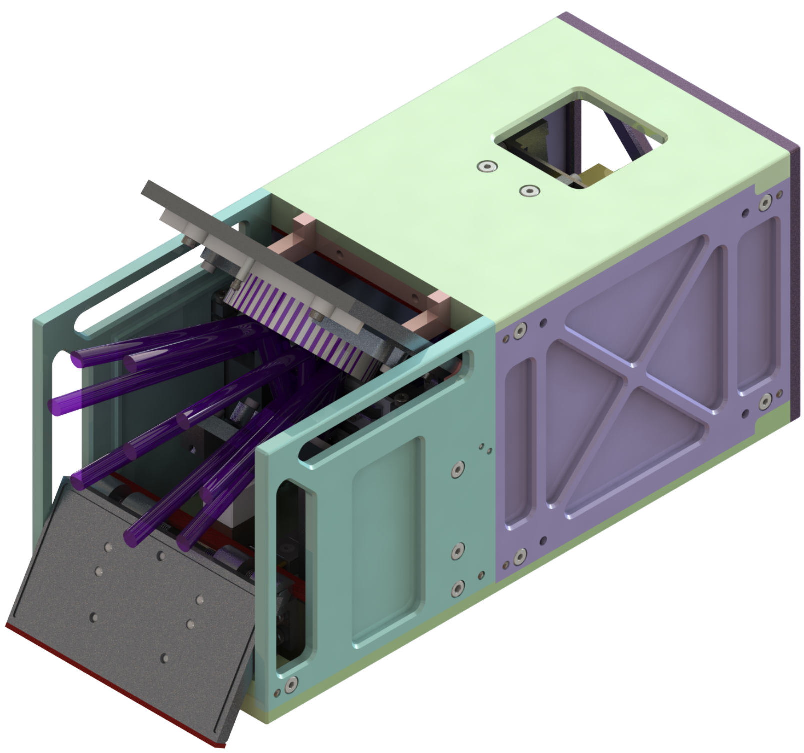


Figure 5.10: Final Design of MUVI showing cut-outs in frame plates, deployed.

Most of the unnecessary mass rested in the side panels. This mass can be shed by milling out pockets on outer faces. Note that the full envelope size of the front side panel is needed for the satellite to fit correctly in a P-POD during launch and OGODS during ground testing.

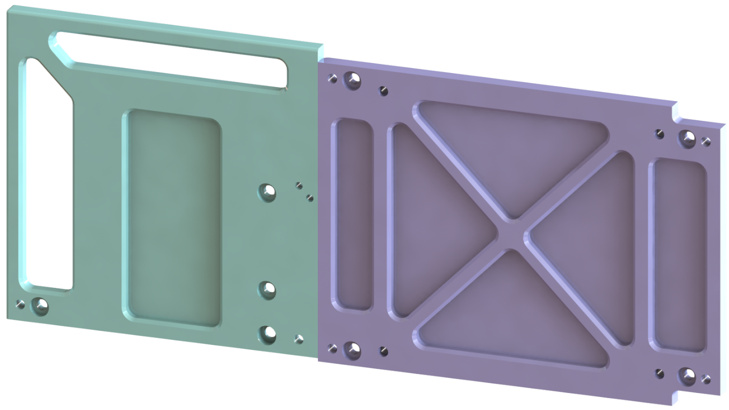


Figure 5.11: Final design of side plates (exterior). Front side plate in green and rear side plate in purple.

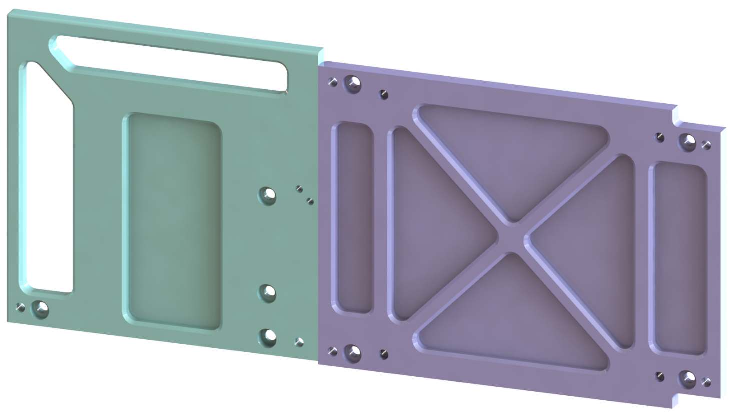


Figure 5.12: Final design of side plates (interior). Front side plate in green and rear side plate in purple.

Mass was also taken from the top plate design, though, not to the extent of the side panels. One addition to the satellite since CDR is a nitrogen purge push-to-connect fitting with a mount, stainless steel mesh filter, and access hole in the top plate. The nitrogen purge port is used to retain a positive pressure during launch and minimize moisture buildup within the walls of the satellite.

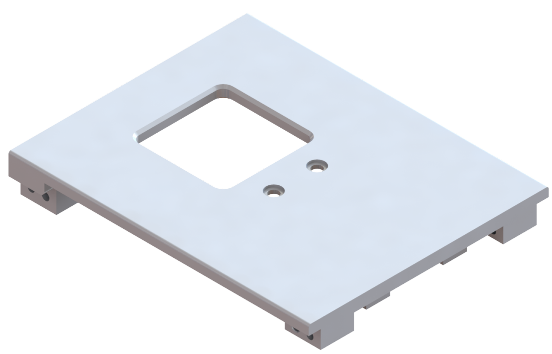


Figure 5.13: Top view of top plate. Note the access hole for nitrogen hose to reach push-to-connect fitting.

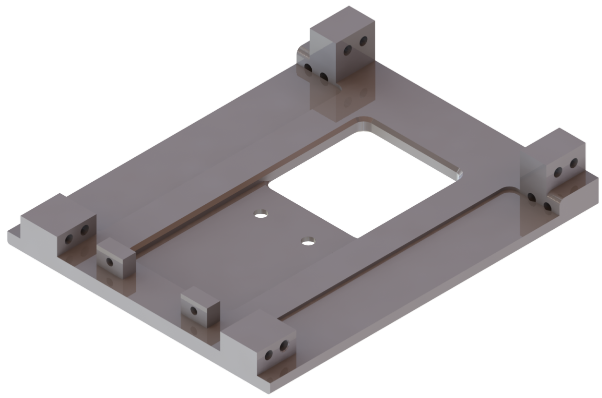


Figure 5.14: Bottom view of top plate

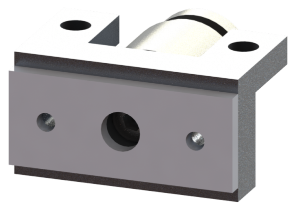


Figure 5.15: Front view of nitrogen purge push-to-connect fitting with mount and stainless steel mesh clamp.

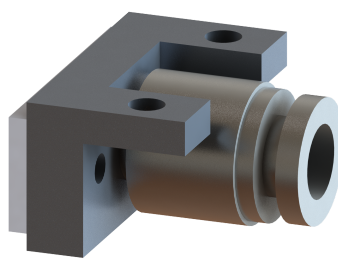


Figure 5.16: Side view of nitrogen purge push-to-connect fitting with mount and stainless steel mesh clamp

The last main additions to the satellite are the Winchester electrical connections mounted to the datum plate and door deployment sensors mounted to front side panels. The purpose of the Winchester Connectors is to connect the Frangibolt burn wire to the satellite computer. The door sensors detect whether the top door has deployed or not after current is sent to the burn wire to fracture the Frangibolt. There are two door sensors for redundancy, one both front side panels.

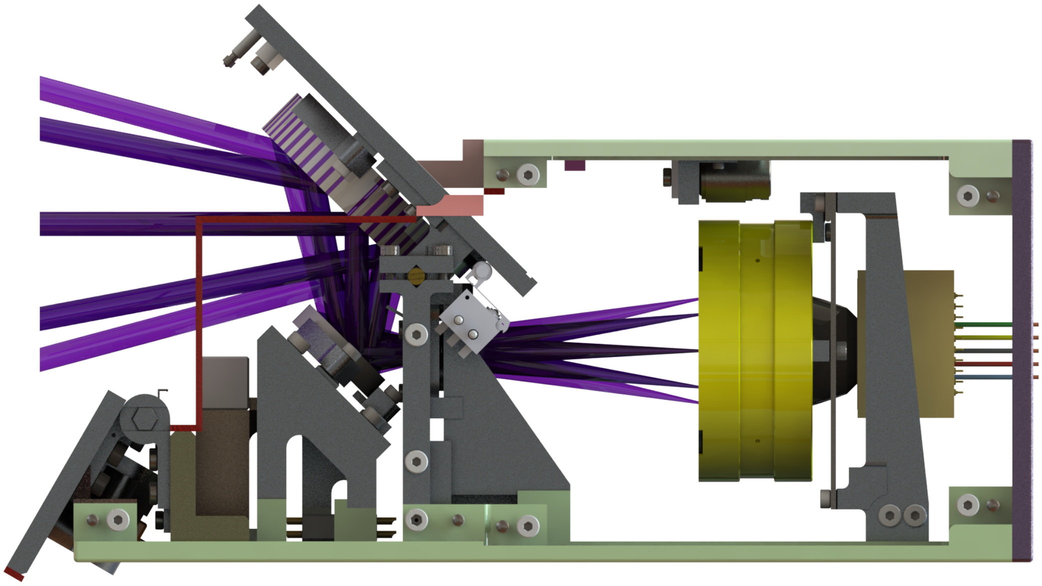


Figure 5.17: Side view of MUVI with side panels removed. Note the Winchester Connectors beneath the lower mirror assembly and the door sensor near the back of the top door.

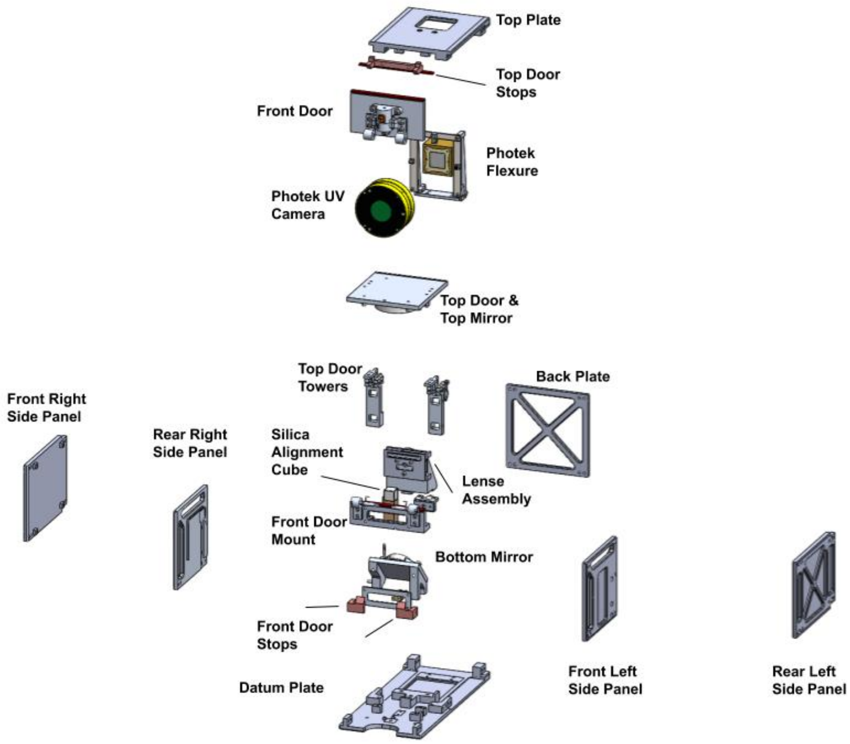


Figure 5.18: Side view of MUVI with side panels removed. Not the Winchester Connectors beneath the lower mirror assembly and the door sensor near the back of the top door.

5.2.2 Instrumentation Frame Analysis

Once the satellite frame met the necessary conditions for both overall mass and location of the center of mass, further analysis was performed. Finite Element Analysis was used for both stress and vibration analysis. Stress analysis of the frame was performed to ensure it would withstand the loads it must endure during launch without yielding or deforming significantly. The vibration analysis was performed to determine the natural frequencies of the structure to be compared when testing is performed.

The first major analysis of the frame was a static loading analysis to determine the strength of the frame. A static 100G load was applied to ensure Instrumentation Frame panels were of adequate thickness. In these studies, roller boundary conditions were applied to the rails of the satellite. All instrumentation components were removed from the assembly and replaced with 100G remote loads. 100G loads were chosen as conservative estimates of loads MUVI may see during launch.

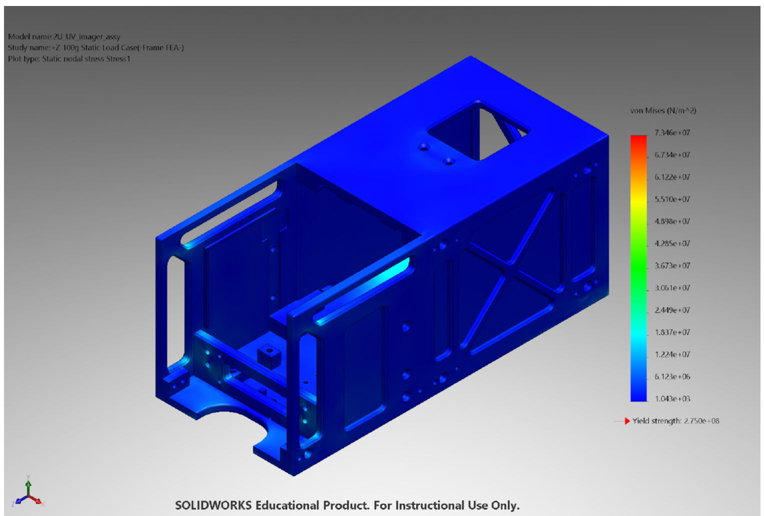


Figure 5.19: Snap shot of +Z 100G load FEA study in SolidWorks.

This study was performed for each of the six principal axis directions +/-X, +/-Y and +/-Z. Even with the very conservative 100G load case, a factor of safety on yielding of 2.67 was obtained and the frame had a maximum deflection under 0.076 *mm*. The frame passed the 100G load case in all directions while meeting mass requirements. The final mass of the complete satellite assembly is 2.54 *kg* as estimated in SolidWorks. This allows an extra 20% of mass to account for discrepancies between the 3D CAD model and the real machined parts as well as other sources of extra mass like the Alodine coatings, Anodization, tapes and adhesives used in assembly.

A summary of the mass properties and FEA results for the Instrumentation Frame can be found in the appendix of this report.

5.3 On-Ground Orbital Deployer Simulator (OGODS)

When CubeSats are launched into space as part of a ride share they sit inside a Poly-Picosatellite Orbital Deployer, or P-POD as it is commonly known. For MUVI's Instrumentation Frame to undergo vibration testing a test fixture replicating the boundary conditions the satellite experiences during launch was required. The On-Ground Orbital Deployer Simulator or OGODS for short was design to meet this need. The OGODS design was inspired by the 1U Test Pod the MUVI Phase I team designed for their senior project. The OGODS was scaled up to meet the 2U size while incorporating lessons learned from the first team. Large access panels for running accelerometers, spring plungers and a load plate to represent the spring loaded boundary condition of a P-POD and fasteners oriented to hold the front and back panels in tension instead of shear were the main improvements made to the original design.

Much of the design remains the same from what was discussed in the concept design chapter (Chapter 4). The main updates and changes from the preliminary to the final design are with regards to DFMA and optimizing the dimensions of certain parts through finite element analysis.

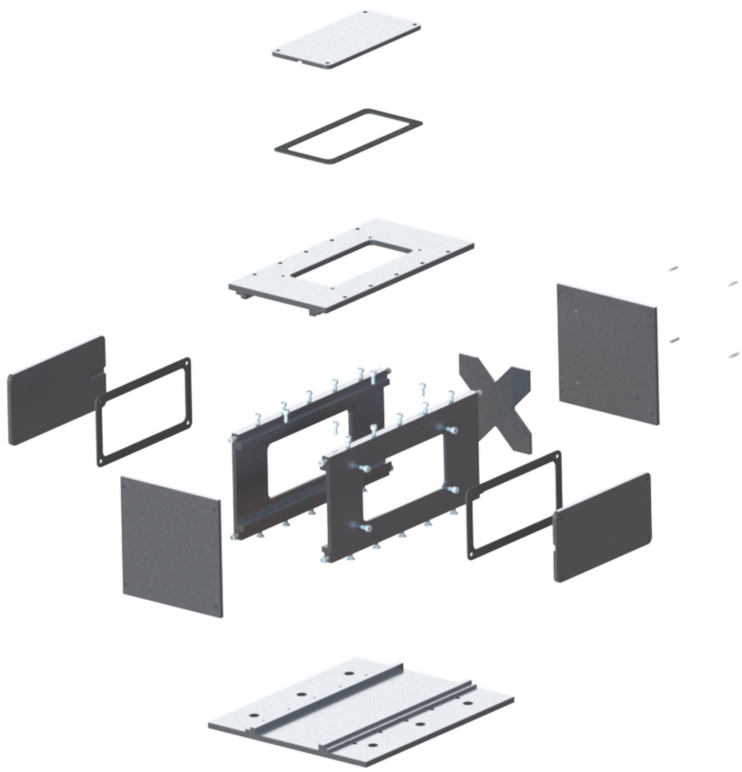


Figure 5.20: Exploded View of OGODS

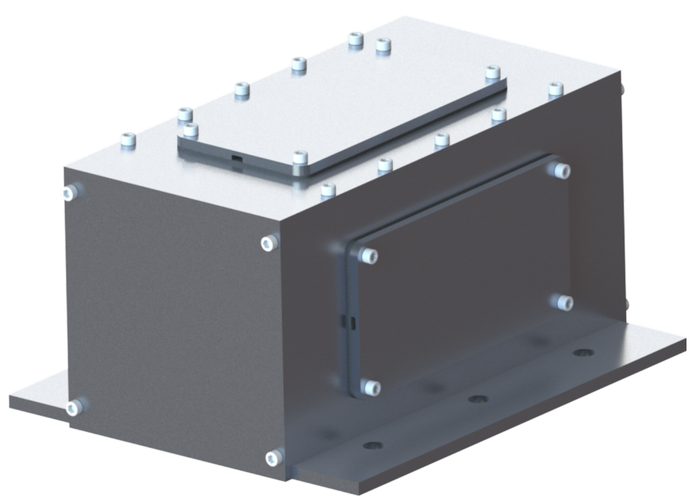


Figure 5.21: Assembled OGODS

5.3.1 Finalized Design

The final design of the OGODS will enclose a 2U CubeSat volume. Some design iterations of the load plate were made for appropriate thickness. Considerations of its effect on vibrational testing were made and the overall size of the load plate was reduced such that it would not interfere with the OGODS rails and introduce erroneous vibrational chatter. Preload spring plungers fill detents on the back of the load plate. This locates the load plate geometrically.

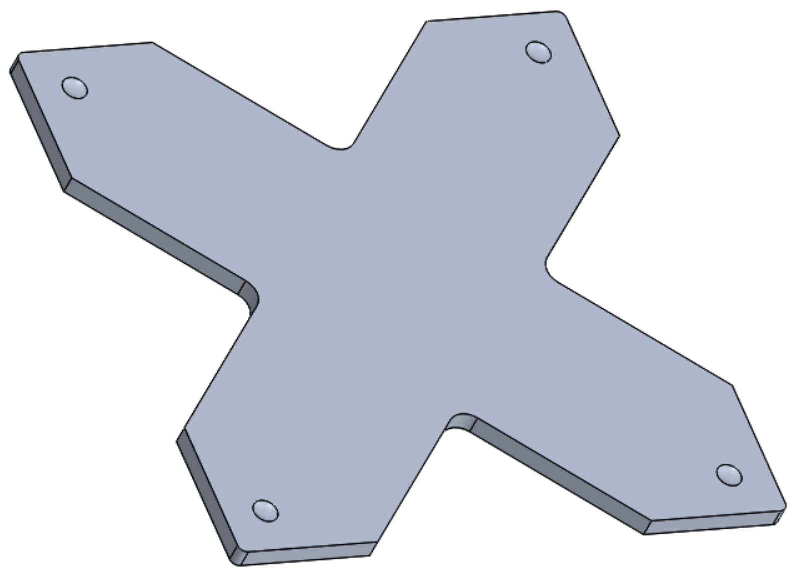


Figure 5.22: OGODS's Load Plate showing detents

The bolt pattern on the base plate of the OGODS is designed to fasten to the shaker tables in Cal Poly's Mechanical Engineering Department Vibration Lab. The shake tables have a 3" on center square bolt pattern that use 3/8" bolts for mounting. The holes in the base plate are slightly oversized to allow for some adjustability during assembly and mounting to the table. A viscoelastic material, Viton, will be used between the base plate of the OGODS and the mounting platform of the shake table. The Viton will be cut out to match the bottom surface geometry of the base plate to damp out any chatter between the table and base plate. Viton will also be used for the gaskets on the side and top accessibility panels. Viton was chosen for its damping properties.

5.3.2 OGODS Analysis

After the general shape of the load plate was finalized, finite element analysis was performed to determine the optimal thickness for a static load case. The load plate was tested under a 100 *G* static loading from the instrument onto the load plate. This was to simulate a worst case peak loading that might occur. The first run was made with a 0.3168" thick plate. This thickness was determined to far exceed what was required for the strength of the part. For the second run a 1/8" plate was tested, another standard thickness. The results of the test was that 1/8" was within our factors of safety and no further tests were required.

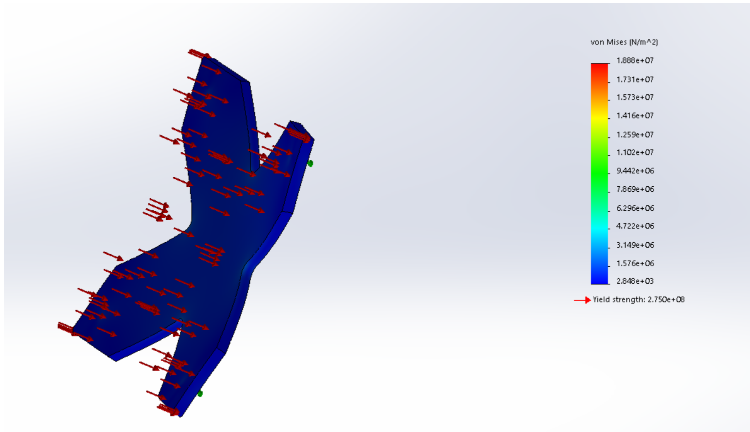


Figure 5.23: Static loading analysis of the load plate

As seen in figure 5.23, the maximum stress seen by the 1/8" thick load plate was 18 *MPa*, well under the yield strength of 6061 T6 aluminum: 275 *MPa*. Deflection of the plate was also evaluated and it was analyzed that the max deflection is 7 microns. It would be possible to go thinner, but 1/8" 6061 is stock thickness, and the thinnest possible part is not needed, what is important is that it will not yield under extreme vibrational loads.

A vibration study was performed to determine the natural frequencies. It is important for the OGODS and the frame to have different natural frequencies because if they were close together there would be a coupling of frequencies and severe damage could occur when the pair resonate. Ensuring each has different natural frequencies helps to reduce any issues with damage due to resonance of the structure.

A simplified model of the OGODS was created to reduce computation time in FEA. The assembly of parts was consolidated into a single solid model part, bolt holes were removed, and the access panels were eliminated. Using the simplified model, a frequency study within the SolidWorks Simulation package was performed. The first three modes were determined to be 1796 Hz, 1882 *Hz*, and 1920 *Hz*. These all fall within the upper range of frequencies the OGODS will experience during testing. The range of frequencies for testing is 5Hz - 2kHz.

Next, a dynamic frequency analysis was performed. A random vibration analysis using the input curve from NASA GEVS section 2.4 was applied to the OGODS in all three directions separately. The output of the random vibration analysis is a plot of the Amplitude Spectral Density on the y-axis against the frequency on the x-axis. On the OGODS simplified model two "sensors" were placed; one on the top and one near the top on the front panel. These sensors allowed for data to be captured at those specific locations. This was done to represent where accelerometers will be placed during testing. 5.24 shows the response of the x-axis from the random vibration analysis.

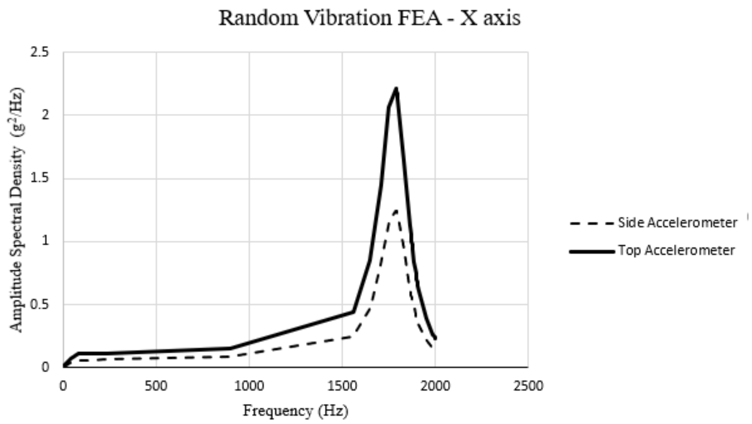


Figure 5.24: Random Vibration simulation for Z axis of OGODS

5.4 Cost Analysis

The cost analysis for this project is broken into three main categories; manufacturing costs of the OGODS, frame and flexure, purchased part, and miscellaneous costs such as travel. Some parts of this project are not included in the cost analysis because the components were already on hand. For example, the Photek Image Intensifier is already in the possession of UCB SSL from a previous project. The Photek is a very expensive part of the optical instrument and not factored into the overall costs. The cost analysis also excludes costs associated with the work of the MUVI Phase I and MUVI Phase II. The door assembly and the lens assembly are significant subassemblies each with their own costs, but not part of the cost breakdown for this project. It should also be noted that the OGODS can be reused for future 2U CubeSat projects that require on ground vibration testing.

5.4.1 Manufacturing Costs

This section breaks down the cost associated with manufacturing all components for this project. As seen in Table 5.1 it is split into three sections; the costs for OGODS, the Frame and Flexure assemblies and the Flexure Blades separately. The design for the OGODS was completed first so a quote from E&S Machining was obtained while design work was continued on the frame and flexure. The frame and flexure components were manufactured by Tridecs Corporation. The original plan was to water jet the flexure blades in house in the Cal Poly Mustang 60 machine shop. Due to COVID-19, we were not able to use the machine shop so a quote from Big Blue Saw water cutting was sourced. It is important to note that these figures do not include the anodization and alodine coating required for the aluminum machined parts of the frame and the flexure as well as the Tiodize for the titanium flexure blades. Manufacturing delays due to COVID-19 meant that at the time of this report, quotes for anodization and chemical coating have not be obtained yet.

Table 5.1: Manufacturing Costs

Item	Component or Part	Vendor	Total Price ($)
Manufacturing	OGODS	E&S Machining	$3,301.15
	Frame and Flexure	Tridecs Corp.	$13,259.02
	Flexure Blades	Big Blue Saw	$150.00
		TOTAL:	**$16,710.17**

5.4.2 Purchased Parts Cost

This section breaks down the costs associated with all the purchased parts required for assembly and testing of the entire instrument frame assembly as well as the OGODS test fixture. Most of the purchased parts are the fasteners, helical inserts and dowel pins used in assembly. Other parts of note are the door switches, Winchester Connector, adhesives and sealing material, and the specialized tools required for installing helical inserts.

Table 5.2: Purchased Parts Cost

Vendor	Part Number	Description	Qty	Unit Cost	Total Cost	Use
McMaster-Carr	8476a41	#6-32 Spring Plunger	4	$5.62	$22.48	OGODS
McMaster-Carr	92210a194	#8-32 1/2" Countersunk screws	1	$5.51	$5.51	OGODS
McMaster-Carr	92196a194	#8-32 1/2" Cap Head Screws	1	$6.24	$6.24	OGODS
McMaster-Carr	92196a192	#8-32 3/8" Cap Head Screws	1	$5.93	$5.93	OGODS
McMaster-Carr	92141a009	#8 Washer	1	$2.07	$2.07	OGODS
McMaster-Carr	90666a103	M3 x 0.5mm, 6mm long socket	1	$8.35	$8.35	Flexure+Frame
McMaster-Carr	92290a056	M2.5 x 0.45mm, 6mm socket	1	$2.33	$2.33	Flexure
McMaster-Carr	92290a060	M2.5 x 0.45mm, 10mm socket	1	$5.67	$5.67	Flexure
McMaster-Carr	92290a058	M2.5 x 0.45mm, 8mm socket	1	$2.83	$2.83	Flexure
McMaster-Carr	93235a311	M3, 6mm long vented socket	1	$6.72	$6.72	Flexure
McMaster-Carr	93914a060	M3, 3mm long helicoil	3	$9.85	$29.55	Flexure+Frame
McMaster-Carr	93914a077	M3, 4.5mm long helicoil	5	$10.35	$51.75	Flexure+Frame
McMaster-Carr	93914a009	M2.5, 2.5mm long helicoil	1	$7.53	$7.53	Flexure
McMaster-Carr	93914A026	M2.5, 3.8mm long helicoil	2	$7.92	$15.84	Flexure
McMaster-Carr	93914A043	M2.5, 5mm long helicoil	1	$8.96	$8.96	Flexure+Frame
SMC	KQG2S07-32	N2 Push to Conect	1	$18.15	$18.15	Frame
McMaster-Carr	92715T71	N2 Filter Dutch Woven Mesh	1	$17.27	$17.27	Frame
McMaster-Carr	90666a105	M3, 10mm socket head	1	$9.19	$9.19	Frame
McMaster-Carr	93235a312	M3, 8mm socket head vented	1	$8.40	$8.40	Frame
McMaster-Carr	93235a315	M3, 16mm Socket head Vented	3	$4.48	$13.44	Frame
McMaster-Carr	91595A108	Pins (M3, 10mm, rounded)	1	$15.10	$15.10	Frame
McMaster-Carr	90666a104	M3 x 0.5mm, 8mm socket head	1	$8.40	$8.40	Frame
McMaster-Carr	92290a161	M4 x 0.7mm, 18mm socket hea	1	$7.28	$7.28	Frame
McMaster-Carr	92855a842	M2.5 x 0.45mm, 6mm socket	1	$12.81	$12.81	Frame
McMaster-Carr	91223a411	M3, 5mm ultra low profile sock	2	$4.06	$8.12	Frame
McMaster-Carr	90585a120	#2-56 3/8" long, flat head	1	$8.91	$8.91	Frame
McMaster-Carr	92290a017	M2 x 0.4, 10mm socket head	1	$4.88	$4.88	Frame
McMaster-Carr	93914a094	M3, 6mm long helicoil	4	$10.93	$43.72	Frame
McMaster-Carr	93914a145	M4, 8mm helicoil	1	$8.38	$8.38	Frame
McMaster-Carr	96246a018	#2-56 helicoil	1	$7.92	$7.92	Frame
McMaster-Carr	96246A200	#10-32 Helicoil, 0.19" length	1	$7.53	$7.53	Frame
Olander	1084-2EN050	M2, 5mm helicoil	4		$0.00	Frame
Omron Electronics	D2JW-01K21	Door Switch	2	$8.32	$16.64	Frame
Winchester	JF2S	Winchester Connecteor	1	$11.38	$11.38	Frame
McMaster-Carr	86075K32	1/16" Viton Sheet per sq. ft.	2	$62.26	$124.52	Frame
McMaster-Carr	1063T13	1/16" PTFE sheet 6" x 6"	1	$14.79	$14.79	Frame
Ellsworth	EA 9394	50ml Epoxy for staking fastener	2	$35.38	$70.76	Frame
McMaster-Carr	92955a206	Helicoil Insertion Tool, M2 x 0.	1	$117.60	$117.60	Installation Tool
McMaster-Carr	90261a185	Prong Break-Off Tool, M2 x 0.4	1	$163.56	$163.56	Installation Tool
McMaster-Carr	90261A161	Helicoil Inertion Tool, #10-32	1	$91.01	$91.01	Installation Tool
McMaster-Carr	92955A109	Prong Break Off Tool, #10-32	1	$70.84	$70.84	Installation Tool
McMaster-Carr	90261A140	Helicoil Inertion Tool, #2-56	1	$56.33	$56.33	Installation Tool
McMaster-Carr	92955A101	Prong Break Off Tool, #2-56	1	$70.84	$70.84	Installation Tool
			TOTAL:		$1,189.53	

5.4.3 Miscellaneous Costs

The only other expense associated with this project was for travel to visit Space Sciences Lab in Berkeley, CA. During these visits we gave our Preliminary and Critical Design Reviews (PDR and CDR) to Kodi Rider and Dr. Thomas Immel.

Table 5.3: Miscellaneous Costs

Category	Description	Amount	Price per Trip ($)	Total Price ($)
Travel	Visit UCB SSL for design reviews	2	$110.00	$220.00
			TOTAL	$220.00

5.4.4 Total Costs

This section breaks down the total costs for the entire project based on category.

Table 5.4: Total Costs

Category	Amount
Manufacturing	$16,710.17
Purchased Parts	$1,189.53
Travel	$220.00
TOTAL	$18,119.70

5.5 Safety

Neither he satellite nor OGODS designs have any major safety concerns regarding risk to operators or users. There are no moving components or rotating parts in the designs that include speeds or forces compromising safety. That being said the design will undergo sustained vibrations and experience high accelerations. Our main concern with regards to safety revolve around the potential for danger during vibration testing. A few different steps are being taken to mitigate any potential hazards. First, thorough analysis of the designs with regards to vibration has been conducted. Second, personal protective equipment including safety glasses and will be worn when tests are conducted. The tests will be conducted in the vibration lab on equipment MUVI III has been trained on and tests will not be conducted when other students are present, reducing the risk to others. The shaker table in the vibes lab is loud and hearing protection such as ear plugs should be worn to protect the users hearing.

The frame including the flexures are unique components and therefore more extensive analysis was conducted before the design was finalized. The OGODS was inspired by an existing design that had already been manufactured and successfully used in vibration testing. Since the OGODS is based on an existing design there is less of a concern regarding durability.

A Failure Modes and Effects Analysis was conducted to review our design. We reviewed any potential failure modes and addressed all that we could within the design. Most of the failure modes listed were accounted for in the design and analysis. Some failure modes are due to user error and mitigated by providing thorough documentation on proper assembly and use. Within the appendices the FMEA as well as assembly instructions and testing procedure documents can be found.

6 - Manufacturing Plan

There are three main assemblies to be manufactured for this project. The first is the instrumentation frame, the second is the flexure assembly and the third is the OGODS. Originally some components were to be manufactured in the Cal Poly Mustang 60 machine shop but due to COVID-19 the team switched to fully sourcing components. The following chapter outlines procurement and manufacturing of components as well as the assembly documentation.

6.1 Procurement

When outsourcing the manufacturing of the components, the procurement of the stock metal is included in the price. The materials that were procured externally included sheets of Viton and PTFE for seals and gaskets as well as all fasteners, helicoils, dowel pins and spring plungers for assembly. The Bill of Materials for all required parts is found in Appendix E.

6.2 Manufacturing

Before determining manufacturing processes, the materials to be used had to determined. The main considerations in determining the materials used were cost, environmental factors, manufacturability and ability to be used in space applications. Almost all components will be made out of 6061 T6 aluminum. This material was selected for numerous reasons including machinability, cost, ease of procurement and the fact that it is tried and tested to work well in space. The instrumentation frame will be in the vacuum of space so outgassing properties drove material selection. Outgassing was not a concern for metal, more so for sealing and damping materials. Viton, a damping polymer with low outgassing will be used to seal and dampen vibrations at door interfaces. In other applications where the door needs a seal to slide, PTFE, another low outgassing polymer, will be used.

After determining the materials to be used in manufacturing of the instrumentation frame, flexure and OGODS, the team generated the manufacturing processes. Factors such as material choice, project timeline and budget all pointed to CNC machining as the proper manufacturing process to use for most components. The flexure blades are the one exception to this. They are made from titanium and very thin, allowing for water-jet processing. The other notable exception is the manufacturing process for the Viton door seals. The Viton material comes in large sheets that will be cut to size using a computer-controlled die cutting machine.

In the design process the principles of Design for Manufacturing and Assembly (DFMA) were used extensively. A notable example of DFMA in this project is the symmetry of the instrumentation frame and OGODS. To save on assembly time, shims were used to keep machining time down. Shimming also allows for calibration of optical components after fabrication. OGODS uses only one type of fastener and frame fasteners were kept consistent where possible. We also employed the philosophy of *the best part is no part*.

One difficulty MUVI III faced with DFM was designing an instrumentation frame accommodating the design decisions made by MUVI I and MUVI II. At first glance the datum plate designed by MUVI III may appear to be one part with many unnecessary stilts rising up to the lens and door assemblies built by MUVI I and MUVI II respectively. At the request of UCB SSL, such risers are included in the datum plate to avoid redesigning previously fabricated parts. Essentially, there is a part number system and budget to adhere to. Similar strange features like the datum plate risers can be seen on other panels of the satellite.

Figure 6.1 shows a snapshot of the side panel of the OGODS used to demonstrate DFMA principles. The part is symmetric about two axes making it easier to assemble. All the holes are 8-32", including the holes for the access panel. This makes assembly easier since only one bolt is needed for the entire assembly. The overall thickness can be made from a standard sheet thickness without the need for excessive machining. The pocket's corners can be made with standard end mill radii. Both of these design decisions were made with DFM in mind.

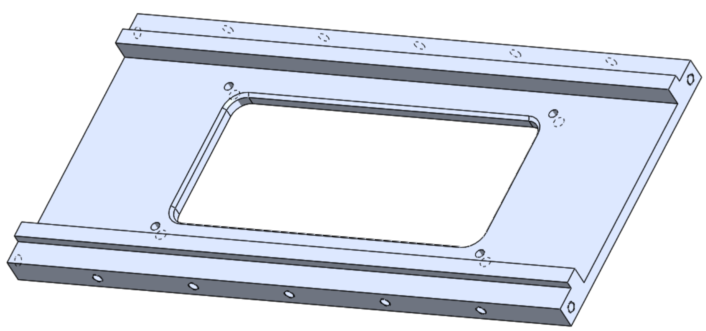


Figure 6.1: OGODS Side Panel

After metal components are manufactured by the machine shop at SSL the aluminum must be anodized. The instrumentation frame will be exposed to harsh environments in space so a protective type II Black Anodization will be included on all parts of the frame [**25**]. The anodization is a protective coating for the metal and is non-conductive. Certain areas of the instrumentation frame will need to be masked off such as joints and fastener holes. The OGODS will also require some anodization. The rails that the CubeSat slide on will need a protective, low-friction anodization with PTFE [**26**]. Since the OGODS is just on ground test equipment it does not need complete anodization like the instrumentation frame does.

All manufactured components were outsourced for this project. A detailed breakdown of cost can be found in chapter 5.4 and the Bill of Materials in Appendix E. Due to delays in manufacturing due to COVID-19 there is remaining fabrication to be made before assembly. Once all the parts reach net shape, they will be anodized as per MIL-A-8625 TYPE II CLASS 2. The anodization will protect the exposed metal while the black coating reduces stray light interfering with the optical components. An Alodine coating is applied instead of the anodization at mating instances. The Alodine chem film coasting is per MIL-DTL-5541, CL3 (Yellow). Detailed anodization and Alodine drawings are included in the drawing package in Appendix D.

6.3 Assembly

Careful planning and order of operation is critical to successful assembly of both the instrumentation frame and OGODS. DFA (Design for Assembly) was a focus accompanying DFM. Assembly must allow for calibration of optical geometry once the Photek is installed. Shims can be used to adjust positions of lens and mirror assemblies in the x and y directions. The flexure mounts for the Photek assembly have slots allowing for position adjustments in all three principal directions.

There are a few subassemblies that will be assembled outside of the CubeSat before being assembled on the instrumentation frame. The door and mirror subassemblies, the lens mount, the Photek mount and the electrical systems will all be assembled separately first. Then these subsystems will be connected to the datum plate followed by side, back, and top panels. The side panels are split in two pieces so that the rear part of the side panel can be removed and allow for access to the internals of the instrumentation frame. Once everything is in place, on ground optical alignment can take place to get the final position of all critical optical components. The optical alignment will be conducted using a laser and optical alignment cube. The satellite will be mounted into Jason Grillo's manipulator assembly for final alignment of all optical components.

Viton and PTFE components will be attached to side panels prior to attaching door assemblies and side panels. The seals will be placed using an adhesive that is rated for space use. The back panel has large cutouts to reduce the overall weight. Outgassing rated tape will cover the holes.

Detailed assembly instructions for the flexure subassembly and the instrumentation frame are included as an appendix.

7 - New Project Scope

7.1 Changes to Project Scope

The COVID-19 pandemic began prior to manufacturing and testing, forcing major changes to the project scope. Rather than testing in person, detailed assembly and vibration testing procedures were written. Final design verification will be completed by future MUVI project members.

7.2 Design Verification Plan

There are multiple tests that need to be conducted for the instrumentation frame to meet NASA's TRL level 6. The main tests that will be conducted to verify NASA TRL 6 will be vibration and TVAC testing. This chapter, the Design Verification Plan, will indicate each specification defined in appendix B, the Quality Function Deployment.

7.2.1 Optical Instrument Alignment Test Plan

Before any tests on the instrument frame itself can be conducted, all the parts that go into the optical instrument must be tested to verify alignment. This will require some specialized equipment at UCB SSL. The instrumentation frame will be loaded into Jason Grillo's on ground Manipulator. In the manipulator the instrument will be able to move with four degrees of freedom. It can translate and rotate about the X and Y axes. While in the Manipulator, a laser will be shown on to the top mirror, reflected on the bottom mirror and through the lens into the Photek and to the detector. All components have adjustability by use of shims so each component will be adjusted independently until the laser light reaches the sensor as expected. Once the instrumentation frame and all the optical parts are successfully aligned then we can move to vibration testing.

7.2.2 Vibration Test Plan

The vibration test is the main focus of the testing phase for our project. The vibration testing will be conducted in the Mechanical Engineering Department Vibration Laboratory. The vibes lab has two shake tables, one horizontal and one vertical. Each test we do will be conducted on both shake tables. The tests we will conduct include a low-level sine sweep to find natural frequencies, low-level random vibration profile, full-level random vibration and finally another low-level sine sweep to check for any changes.

The vibration test specifications are specified in NASA GEVS for prototype qualifications. We will repeat tests for both horizontal and vertical shake tables. For each test we will place accelerometers on the OGODS, the door of the instrument, the Photek mass model, and on the instrumentation frame.

7.2.3 Post Vibration Optical Alignment Test

After all vibration tests are conducted, the instrument must remain in its specified 0.25° tolerance for the light entering. To verify the instrument meets this specification the team will again mount the frame into the Manipulator and run the same tests as in the pre-vibration test optical alignment.

8 - Project Management

8.1 Project Phases

The overall design process of MUVI Phase III roughly aligns with the quarter system of Cal Poly, SLO.

Fall 2019: Project background research, CAD design of OGODS, preliminary design of frame and flexure.

Winter 2020: Final design of all components. Detailed analysis of components to meet strength and weight requirements. Drawing package for all parts requiring outsourced manufacturing. Development of assembly and test procedures.

Spring 2020: Complete assembly and test procedures. Complete final report and all documentation required to continue this project.

8.2 Key Deliverables

Item	**Due Date**
Preliminary Design Review	11/15/2019
Complete detailed design for 2-U OGODS	12/12/2019
Generate drawings for 2U OGODS	12/12/2019
Complete structure and detector flexure preliminary design	12/12/2019
Complete design and analysis of frame and flexure	02/07/2020
Critical Design Review	02/07/2020
Complete frame and flexure drawing package	03/07/2020
Complete assembly and test procedures	05/01/2020
Complete virtual expo website	05/29/2020
Final Design Review	06/05/2020
Submit research paper to SPIE conference	07/29/2020

8.3 Unique Design Challenges and Techniques

Due to the nature of this project being a continuation of existing senior projects, new parts had to work with existing assemblies. The design work was mostly integrating the existing designs of sub-assemblies into the envelope of a 2U CubeSat. While the design is relatively straight forward, there was need for special consideration during the analysis and validation of the design. FEA was utilized for modeling launch vibration loads. Testing was a primary focus of this senior project. Specifically, the design of fixtures to represent the P-POD dispenser for the satellite to mount to the vibes table.

8.4 Next Steps

At the completion of the designs of the instrumentation frame, flexure mount, and OGODS, manufacturing orders were submitted. At the conclusion of the MUVI Phase III, only manufacturing of the OGODS parts has been completed. Completion of manufacturing, assembly, and testing are the most immediate next steps for the project sponsors, Kodi Rider and Jason Grillo. The satellite as a whole has many more tasks to complete. Most notably are: redesign of the mirror flexures, completion of the design of the door stops, inclusion of thermal equipment, and design of the third unit for power and communication.

9 - Conclusion

MUVI III has designed and analyzed the Instrumentation Frame, Photek Camera Flexure Mount, and On Ground Orbital Deployer Simulator for the ongoing MUVI project. Due to schedule changes in the midst of COVID-19, testing plans were written but execution was postponed. There are several tasks to tackle before NASA TRL 6 is obtained; mainly, vibration and TVAC testing. One unique aspect about the components designed by MUVI III is the minimalist approach. There is sufficient volume within the envelope size of the Instrumentation Frame and around the Photek Camera Flexure to include thermal controls and computer electronics. Furthermore, OGODS is somewhat modular in that it can be changed from 2U to 3U by extending length in the longitudinal direction.

Overall, it was unfortunate that validation of the design through physical testing could not be performed but the groundwork is set for future MUVI project members to pick up where MUVI III left off and get the satellite into the ionosphere.

Bibliography

[1] T. Immel, K. Rider, et. al. “MUVI Grant Proposal” 2018. Addison-Wesley, Reading, Massachusetts, 1993.

[2] K. Rider, “UCB UV Imager Instrument” Senior project proposal, September 2019.

[3] J. Grillo, T. Hajjar, and B. Hill, “UV Imager Application for a Cube Satellite” Senior Project. Available: https://digitalcommons.calpoly.edu/mesp/465/. [Accessed: 17-Oct-2019]

[4] “The Earth’s Ionosphere,” Tracking Solar Flares. [Online]. Available: http://solar-center.stanford.edu/SID/activities/ionosphere.html. [Accessed: 17-Oct-2019].

[5] T. Immel et. al., “The Ionospheric Connection Explorer Mission: Mission Goals and Design”, Space Science Reviews, v 214, n 1, February 1, 2018

[6] S. Menda et. al. “The Far Ultra-Violet Imager on the Icon Mission”, Space Science Reviews, v 212, n 1-2, pp 655-696, October 1, 2017

[7] K. Rider, “ICON: Where Earth’s weather meets space weather” IEEE Aerospace Conference Proceedings, v 2015-June, June 5, 2015

[8] B. Dunbar, “Technology Readiness Level,” NASA, 06-May-2015. [Online]. Available: https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html. [Accessed: 18-Oct-2019].

[9] “CubeSat 101: Basic Concepts and Processes for First-Time CubeSat Developers” NASA CubeSat Launch Initiative, October 2017 [Online]. Available: https://www.nasa.gov/sites/default/files/atoms/files/nasa_csli_cubesat_101_508.pdf [Accessed: 17-Oct-2019]

[10] NASA General Environmental Verification Standards. NASA Goddard Space Flight Center Standard 7000A, 22-Apr.-2019

[11] “History of the CubeSat,” Space Daily, 23-Aug-2016. [Online]. Available: http://www.spacedaily.com/reports/History_of_the_CubeSat_999.html. [Accessed: 17-Oct-2019]

[12] “Medium-Class Explorers (MIDEX) Missions in Development”, [Online], Available: https://explorers.gsfc.nasa.gov/midex.html. [Accessed: Oct.16, 2019].

[13] S. Potter, “NASA to Broadcast Launch of Mission to Study the Frontier of Space” Oct. 1, 2019 [Online], Available: https://www.nasa.gov/press-release/nasa-to-broadcast-launch-of-mission-to-study-the-frontier-of-space|. [Accessed: Oct.13, 2019].

[14] “History of the CubeSat,” Space Daily, 23-Aug-2016. [Online]. Available: http://www.spacedaily.com/reports/History_of_the_CubeSat_999.html. [Accessed: Oct.11, 2019].

[15] Arkyd-6, Planetary Resources, [Online], Available: https://www.planetaryresources.com/missions/arkyd-6/ [Accessed: Oct.15, 2019].

[16] “SpaceX launches 64 satellites at once”, Dec. 3, 2018 [Online]. Available: https://phys.org/news/2018-12-spacex-satellites.html. [Accessed: Oct. 17, 2019].

[17] J. Puig-Suari, A. Williams, “CubeSat system, method and apparatus,” U.S. Patent 9150313B2, Oct. 29, 2012.

[18] A. London, B. Gerber-Siff, “Pneumatic CubeSat payload deployment system utilizing launch vehicle tank pressure,” U.S. Patent 9845166B2, June 1, 2015.

[19] J. Menichelli, “Explosive bolt,” U.S. Patent 3374702A, March 26, 1968.

[20] M. Leonard, “System for increasing storage volume of a CubeSat,” U.S. Patent 10315784B2, June 11, 2019.

[21] A. Evans, “CubeSat form factor thermal control louvers,” U.S. Patent 9862507B2, January 9, 2018.

[22] F. A. Seelig, ”Flexural Pivots for Space Applications”, [Online], Available: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19690002472.pdf. [Accessed: Nov. 5, 2019].

[23] T. Marcel, ”Flexures”, 2012, [Online], Available: http://web.mit.edu/mact/www/Blog/BlogIndex.html. [Accessed: Nov. 5, 2019].

[24] CubeSat Design Specifications Revision 13, April 2015, [Online], Available: https://static1.squarespace.com/static/5418c831e4b0fa4ecac1bacd/t/56e9b62337013b6c063a655a/1458157095454/cds_rev13_final2.pdf. [Accessed: Nov 11, 2019].

[25] US Military Detail Specifications, ”CHEMICAL CONVERSION COATINGS ON ALUMINUM AND ALUMINUM ALLOYS,” MIL-DTL-5541F, July 2006

[26] US Military Specification, ”Aluminum Oxide Coatings, Lubricative, For Aluminum and Aluminum Alloys,” MIL-A-63576A, Dec. 1985

Appendices

A - Quality Function Deployment House of Quality

Correlations	
Positive	+
Negative	–
No Correlation	

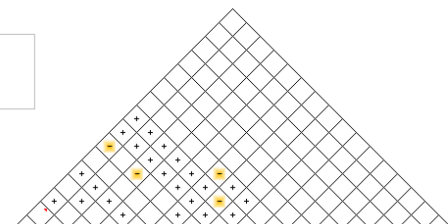
Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

QFD House of Quality

Project: MUVI, Group 74

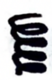
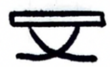
Revision Date: 10.17.19

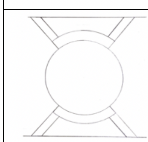
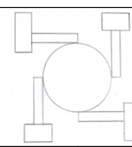
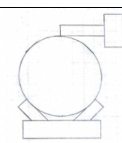


WHO: Customers									Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	NOW: Curr. Products		
									Direction of Improvement	▼	◇	◇	◇	◇	▲	▼	◇	▼	▼									
Row #	Weight Chart	Relative Weight	UCB/SSL (Thomas, Kodi, etc.)	UCB Machine Shop	NASA	Testing Team (Brad, Colin & Nico)	ULA (Launch Provider)	Maximum Relationship	HOW: Engineering Specifications (Tests) / WHAT: Customer Requirements (Needs/Wants)	FEA - Vibrations	FEA - Thermal	Environmental Vibration Simulation of Full Assembly	Environmental TVAC Simulation of Full Assembly	Post Environmental Simulation instrumentation check	Prototype Manufacturing	Weight	Geometry	Interaction Between components	Cost							Our Current Product	NASA Heliophysics Missions (ICON, TIMED, GOLD)	Row #
1	I	4%	10	1	10	2	2	9	TRL 6	●	●	●	●	●	●	▽	▽	●	○							0	5	1
2	I	4%	10	1	10	2	5	9	Thermal Vacuum Pass – max/min temp, thermal expansion, rate of heating/cooling	○	●	○	●	●	▽	○	○	●	○							0	5	2
3	I	4%	10	1	10	2	5	9	Vibration Pass – simulate launch orientation	●	○	●	○	●	▽	▽	▽	●	○							0	5	3
4	III	7%	10	5	10	10	5	9	Fit into 2U Size Requiremen	○	○	○	○	○	▽	●	●	●	○							0	1	4
5	II	5%	9	1	10	10	5	9	Survive launch – Delta 5	●	●	●	●	●	▽	●	●	●	○							0	1	5
6	III	7%	8	10	8	8	10	9	Material Weight – Max weight of MUVI is 7 kg, for P-Pod	●	●	●	●	●	▽	●	●	●	●							0	1	6
7	III	6%	10	7	10	5	4		Material Thermal Properties	○	●	○	●	●	▽	○	○	●	●							0	5	
8	I	4%	10	1	10	2	1	9	Prevent unwanted UV light pollution	○	○	○	○	●	○	○	●	○	○							0	5	7
9	I	4%	10	1	10	2	1	9	Prevent outgasing	○	○	●	●	●	●	○	○	●	○							0	5	8
10	I	4%	10	1	10	2	3	9	No Grease – use helicoils/te	○	○	▽	▽	●	●	●	●	●	○							0	5	9
11	I	4%	10	1	10	2	1	9	Cannot interfere with RF sy:	○	○	▽	▽	●	○	○	●	●	○							0	5	10
12	II	5%	2	7	2	10	10	9	Safe for launch install – deb	○	○	●	●	●	●	▽	●	●	○							0	3	11
13	II	5%	5	5	5	10	5	9	DFA	○	○	●	●	●	●	●	●	●	○							0	1	12
14	II	5%	10	1	10	10	1	9	Survive Exploding Bolt	●	●	●	●	●	○	○	●	●	○							0	3	13
15	III	7%	7	10	5	10	1	9	Due June 13th. 2020	●	●	●	●	●	●	○	●	●	●							0	5	14
16	II	6%	10	5	10	5	1	9	Survival in Ionosphere	○	○	○	▽	▽	○	○	●	●	○							0	5	15
17	III	7%	10	5	10	10	1		Interface to Instrumentatior	●	●	●	●	●	●	▽	●	●	○							0	5	
18	III	7%	10	10	7	7	3		Project Documentation	●	●	●	●	●	●	●	●	●	●							0	5	
19	II	4%	10	1	10	5	1	9	Minimize Cost	○	○	▽	▽	▽	●	●	●	●	●							0	1	16

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	UCH: Target Values	Survives vibration modeling	Survives thermal variation modeling	Survives vibration simulation	Survives thermal variation	Operates properly after simulations	Fully manufacturable	Mass (7kg Max)	Meets 2U sepcification	Components fit together	Cost significantly less than ICON						
	Max Relationship	9	9	9	9	9	9	9	9	9	9						
	Technical Importance Rating	584	623	646	673	778	519	505	757	878	498	0	0	0	0	0	0
	Relative Weight	9%	10%	10%	10%	12%	8%	8%	12%	14%	8%	0%	0%	0%	0%	0%	0%
Curr. Products	Our Current Product																
	NASA Heliophysics Missions (ICON, TIMED, GOLD)	5	5	5	5	5	3	0	0	5	0						
	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

B - Decision Matrices

Ideas / Criteria	Datum: Coil Spring	Cantilever	Rubber Bands	Magnets	Torsion Springs	Foam
						
survive vibration testing	S	+	S	+	S	+
ease of assembly	S	S	–	S	–	+
manufacturing cost	S	–	S	S	S	+
manufacturing feasibility	S	S	S	S	S	S
reliability	S	+	–	+	S	+
works in a vaccum	S	S	S	S	S	–
Σ	0	+1	-2	+2	-1	+3

Damping Flexure Weighted Decision Matrix		Options									
											
Criteria	Weighting	Score	Total	Score	Total	Score	Total	Score	Total	Score	Total
Ease of Manufacturing	2	2	4	4	8	5	10	5	10	4	8
Ease of Assembly	4	5	20	3	12	4	16	5	20	5	20
Constraints	5	3	15	2	10	2	10	5	25	5	25
Design Validation	2	5	10	1	2	1	2	1	2	1	2
Total		49		32		38		**57**		55	

C - Bill of Materials

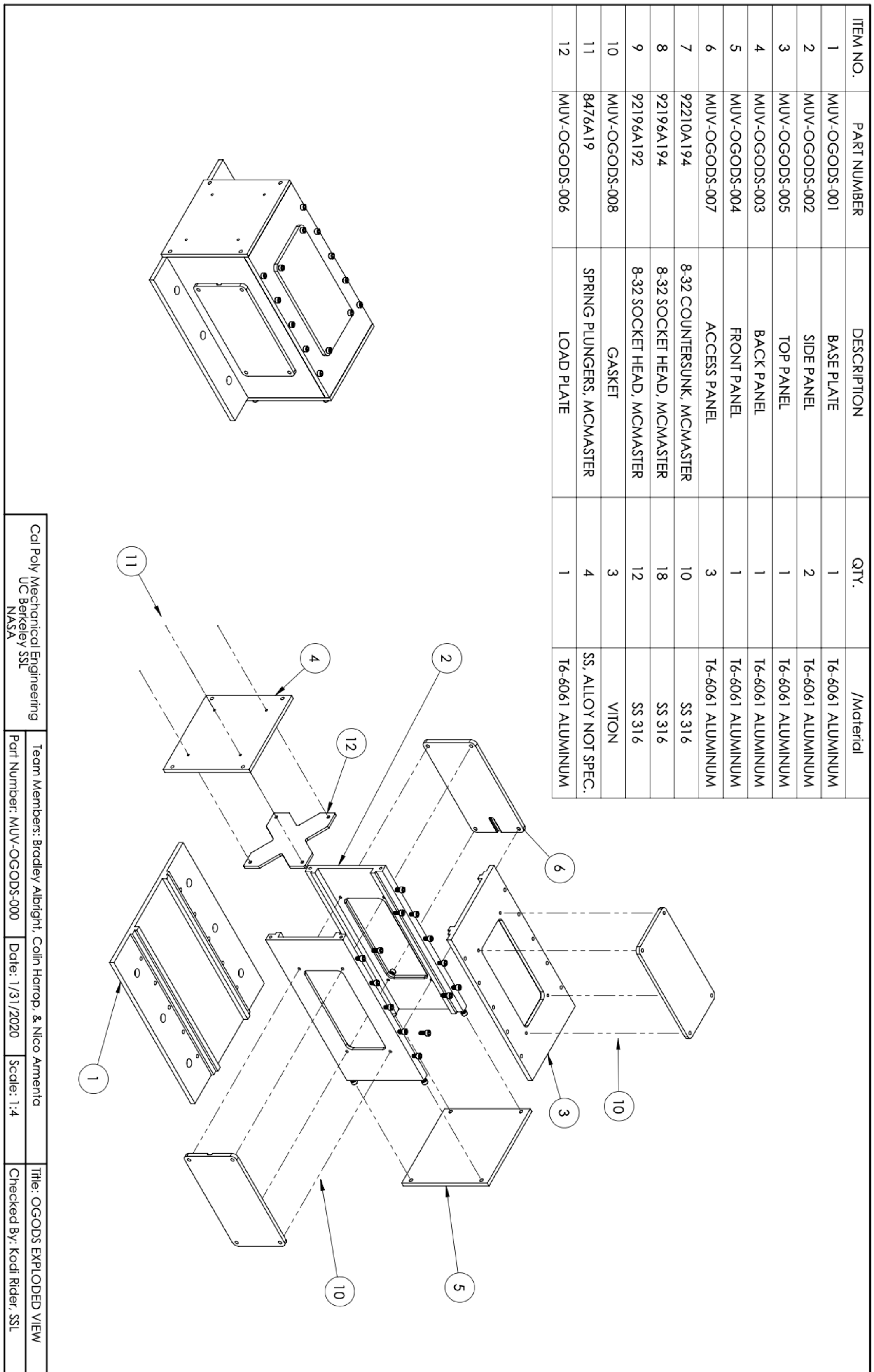
Subsystem	Part No.	Description	Qty.	Source
FRAME	MUV-F-101	Datum Plate	1	Machined
	MUV-F-102	Rear Plate	1	Machined
	MUV-F-103	Front Right Plate	1	Machined
	MUV-F-104	Rear Right Plate	1	Machined
	MUV-F105	Front Left Plate	1	Machined
	MUV-F106	Rear Left Plate	1	Machined
	MUV-F107	Front Door Mount	1	Machined
	MUV-F108	Top Plate	1	Machined
	MUV-F109	Alignment Cube Tower	1	Machined
	MUV-F-110	Inlet N2 Filter Clamp	1	Machined
	MUV-F-111	Exit N2 Filter Clamp	1	Machined
	MUV-F-112	N2 Push-To-Connect Mount	1	Machined
	MUV-F116	Silica Alignment Cube	1	N/A
	MUV-F117	N2 Inlet Filter	1	McMaster-Carr
	MUV-F118	N2 Exit Filter	1	McMaster-Carr
	MUV-F-119	PTFE Door Seal	2	McMaster-Carr
	MUV-F120	Viton Side Seal	2	McMaster-Carr
	MUV-F121	Viton Front Door Bottom Seal	1	McMaster-Carr
	MUV-F122	Viton Front Door Top Seal	1	McMaster-Carr
	MUV-F123	Viton Top Door Rear Seal	1	McMaster-Carr
	MUV-F130	Top Mirror Mass Model	1	Machined
	MUV-F131	Bottom Mirror mass model	1	Machined
	KQG2S07-32	N2 Push to Conect	1	SMC
	92715T71	N2 Filter Dutch Woven Mesh	1	McMaster-Carr
	90666a105	M3, 10mm socket head	1	McMaster-Carr
	93235a312	M3, 8mm socket head vented	1	McMaster-Carr
	93235a315	M3, 16mm Socket head Vented	3	McMaster-Carr
	91595A108	Pins (M3, 10mm, rounded)	1	McMaster-Carr
	90666a104	M3 x 0.5mm, 8mm socket head	1	McMaster-Carr
	92290a161	M4 x 0.7mm, 18mm socket head	1	McMaster-Carr
	92855a842	M2.5 x 0.45mm, 6mm socket	1	McMaster-Carr
	91223a411	M3, 5mm ultra low profile socket	2	McMaster-Carr
	90585a120	#2-56 3/8" long, flat head	1	McMaster-Carr
	92290a017	M2 x 0.4, 10mm socket head	1	McMaster-Carr
	93914a094	M3, 6mm long helicoil	4	McMaster-Carr
	93914a145	M4, 8mm helicoil	1	McMaster-Carr
	96246a018	#2-56 helicoil	1	McMaster-Carr
	96246A200	#10-32 Helicoil, 0.19" length	1	McMaster-Carr
	1084-2EN050	M2, 5mm helicoil	4	Olander
	D2JW-01K21	Door Switch	2	Omron Electronics
	JF2S	Winchester Connecteor	1	Winchester
	1063T13	1/16" PTFE sheet 6" x 6"	1	McMaster-Carr
	EA 9394	50ml Epoxy for staking fasteners	2	Ellsworth

Subsystem	Part Number	Description	Qty.	Source
PHOTEK FLEXURE	MUV-FLEX-001	Base Plate	1	Machined
	MUV-FLEX-002	Tower	2	Machined
	MUV-FLEX-003	Horizontal Photek Standoff	1	Machined
	MUV-FLEX-004	Vertical Photek Standoff	2	Machined
	MUV-FLEXBLADE-1	Vertical Flexure .040"	2	Water Jet
	MUV-FLEXBLADE-2	Vertical Flexure .050"	2	Water Jet
	MUV-FLEXBLADE-3	Vertical Flexure .063"	2	Water Jet
	MUV-FLEXBLADE-4	Horizontal Flexure .040"	1	Water Jet
	MUV-FLEXBLADE-5	Horizontal Flexure .050"	1	Water Jet
	MUV-FLEXBLADE-6	Horizontal Flexure .063"	1	Water Jet
	90666a103	M3 x 0.5mm, 6mm socket	1	McMaster-Carr
	92290a056	M2.5 x 0.45mm, 6mm socket	1	McMaster-Carr
	92290a060	M2.5 x 0.45mm, 10mm socket	1	McMaster-Carr
	92290a058	M2.5 x 0.45mm, 8mm socket	1	McMaster-Carr
	93235a311	M3, 6mm long vented socket	1	McMaster-Carr
	93914a060	M3, 3mm long helicoil	3	McMaster-Carr
	93914a077	M3, 4.5mm long helicoil	5	McMaster-Carr
	93914a009	M2.5, 2.5mm long helicoil	1	McMaster-Carr
	93914A026	M2.5, 3.8mm long helicoil	2	McMaster-Carr
	93914A043	M2.5, 5mm long helicoil	1	McMaster-Carr

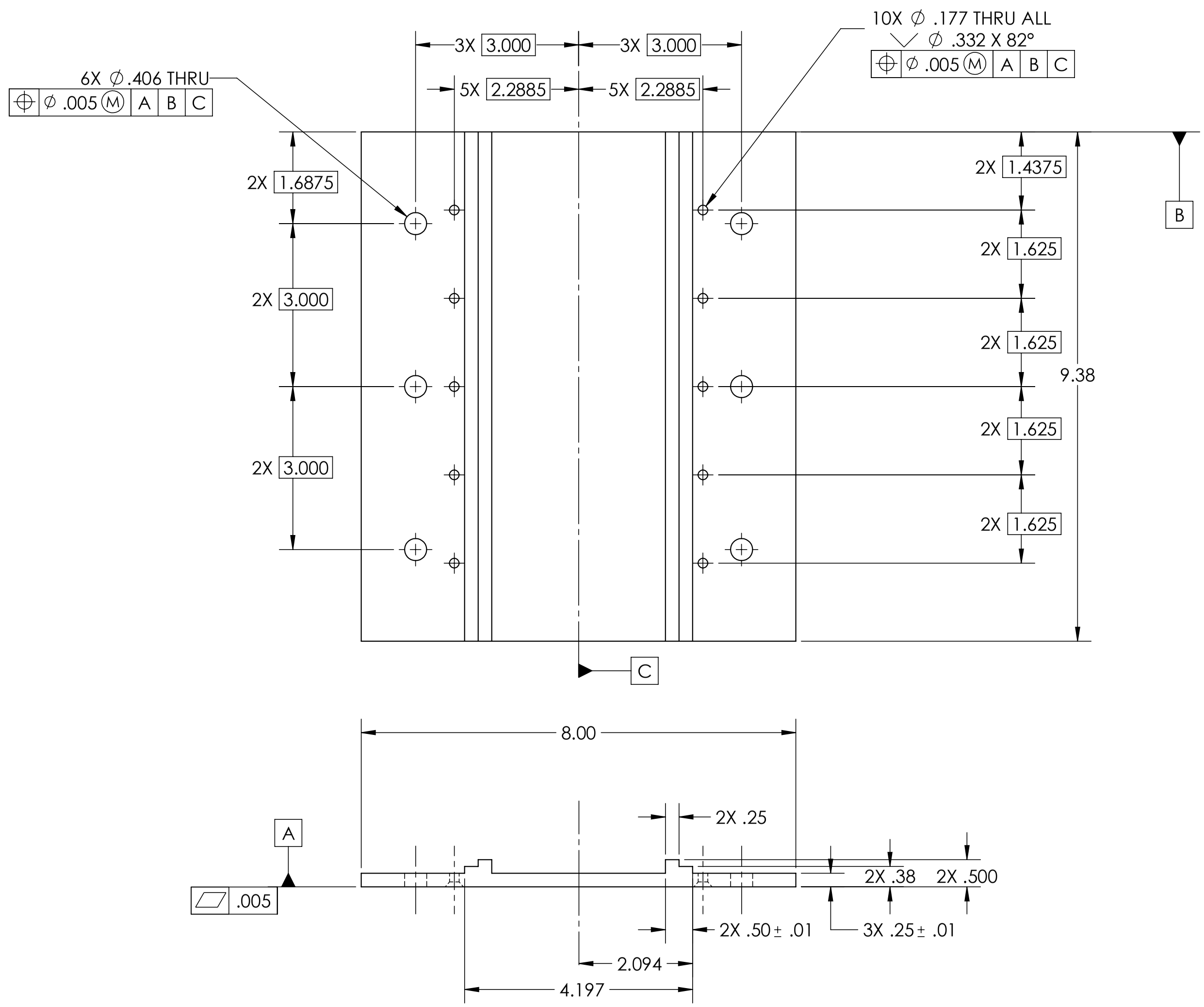
Subsystem	Part Number	Description	Qty.	Source
OGODS	MUV-OGODS-001	Base Plate	1	Machined
	MUV-OGODS-002	Side Panel	2	Machined
	MUV-OGODS-003	Back Panel	1	Machined
	MUV-OGODS-004	Front Panel	1	Machined
	MUV-OGODS-005	Top Panel	1	Machined
	MUV-OGODS-006	Load Plate	1	Machined
	MUV-OGODS-007	Access panel	3	Machined
	MUV-OGODS-008	Viton Gasket	3	McMaster-Carr
	8476a41	#6-32 Spring Plunger	4	McMaster-Carr
	92210a194	#8-32 1/2" Countersunk	1	McMaster-Carr
	92196a194	#8-32 1/2" Cap Head	1	McMaster-Carr
	92196a192	#8-32 3/8" Cap Head	1	McMaster-Carr
	92141a009	#8 Washer	1	McMaster-Carr

Subsystem	Part Number	Description	Qty.	Source
Installation Tools	92955a206	Helicoil Insertion Tool, M2 x 0.4	1	McMaster-Carr
	90261a185	Prong Break-Off Tool, M2 x 0.4	1	McMaster-Carr
	90261A161	Helicoil Inertion Tool, #10-32	1	McMaster-Carr
	92955A109	Prong Break Off Tool, #10-32	1	McMaster-Carr
	90261A140	Helicoil Inertion Tool, #2-56	1	McMaster-Carr
	92955A101	Prong Break Off Tool, #2-56	1	McMaster-Carr

D - Drawing Package

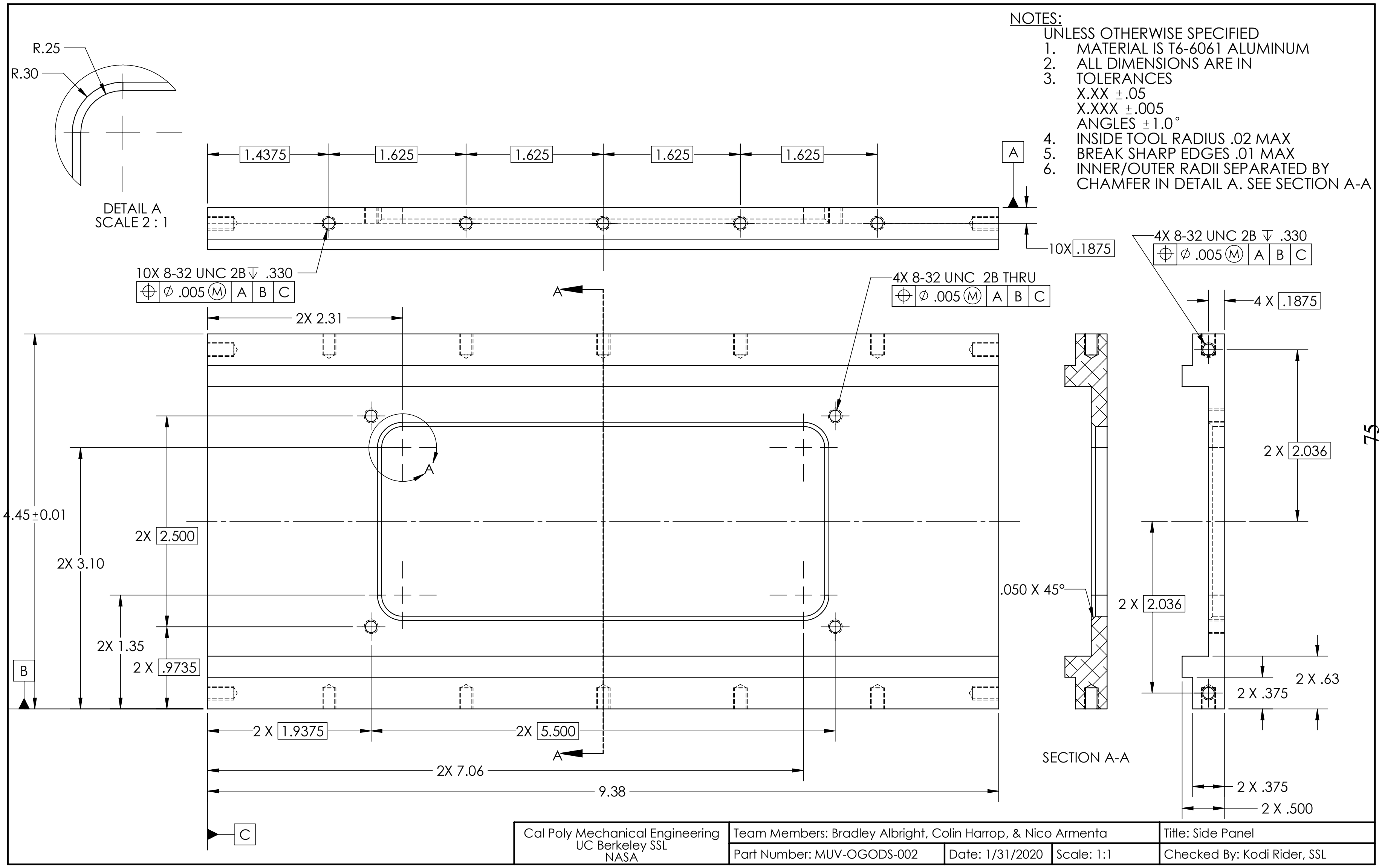


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.	/Material
1	MUV-OGODS-001	BASE PLATE	1	T6-6061 ALUMINUM
2	MUV-OGODS-002	SIDE PANEL	2	T6-6061 ALUMINUM
3	MUV-OGODS-005	TOP PANEL	1	T6-6061 ALUMINUM
4	MUV-OGODS-003	BACK PANEL	1	T6-6061 ALUMINUM
5	MUV-OGODS-004	FRONT PANEL	1	T6-6061 ALUMINUM
6	MUV-OGODS-007	ACCESS PANEL	3	T6-6061 ALUMINUM
7	92210A194	8-32 COUNTERSUNK, MCMASTER	10	SS 316
8	92196A194	8-32 SOCKET HEAD, MCMASTER	18	SS 316
9	92196A192	8-32 SOCKET HEAD, MCMASTER	12	SS 316
10	MUV-OGODS-008	GASKET	3	VITON
11	8476A19	SPRING PLUNGERS, MCMASTER	4	SS, ALLOY NOT SPEC.
12	MUV-OGODS-006	LOAD PLATE	1	T6-6061 ALUMINUM



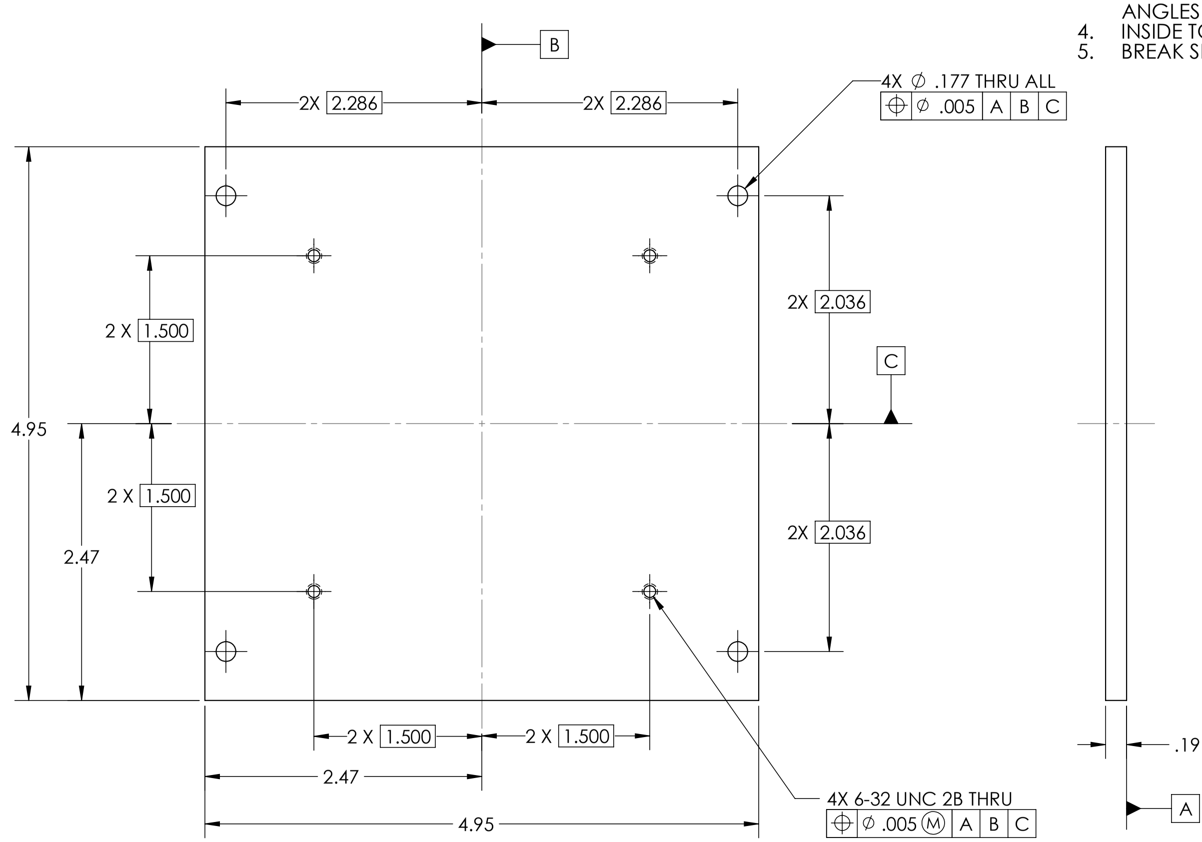
NOTES:
UNLESS OTHERWISE SPECIFIED
1. MATERIAL IS T6-6061 ALUMINUM
2. ALL DIMENSIONS ARE IN
3. TOLERANCES
X.XX ± .05
X.XXX ± .005
ANGLES ± 1.0°
4. INSIDE TOOL RADIUS .02 MAX
5. BREAK SHARP EDGES .01 MAX

Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: OGODS Base Plate
	Part Number: MUV-OGODS-001	Date: 1/31/2020	Scale: 1:2	Checked By: Kodi Rider, SSL

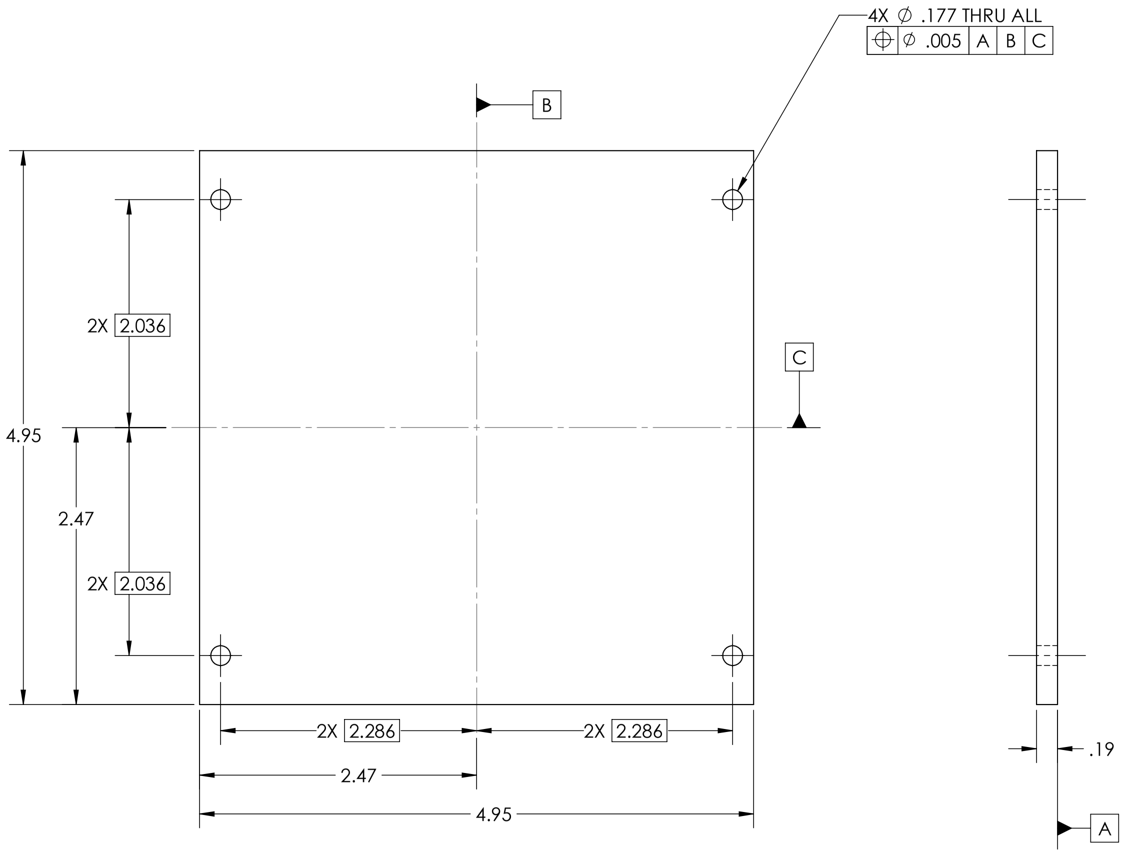

NOTES:
UNLESS OTHERWISE SPECIFIED
1. MATERIAL IS T6-6061 ALUMINUM
2. ALL DIMENSIONS ARE IN
3. TOLERANCES
X.XX ±.05
X.XXX ±.005
ANGLES ±1.0°
4. INSIDE TOOL RADIUS .02 MAX
5. BREAK SHARP EDGES .01 MAX
6. INNER/OUTER RADII SEPARATED BY CHAMFER IN DETAIL A. SEE SECTION A-A
R.25
R.30
DETAIL A
SCALE 2 : 1
1.4375
1.625
1.625
1.625
1.625
A
10X .1875
10X 8-32 UNC 2B ↧ .330
⌖ ∅ .005 Ⓜ A B C
4X 8-32 UNC 2B THRU
⌖ ∅ .005 Ⓜ A B C
4X 8-32 UNC 2B ↧ .330
⌖ ∅ .005 Ⓜ A B C
4 X .1875
2X 2.31
4.45±0.01
2X 2.500
2X 3.10
2X 1.35
2 X .9735
B
2 X 1.9375
2X 5.500
2X 7.06
9.38
C
.050 X 45°
SECTION A-A
2 X 2.036
2 X 2.036
2 X .63
2 X .375
2 X .375
2 X .500
Cal Poly Mechanical Engineering
UC Berkeley SSL
NASA
Team Members: Bradley Albright, Colin Harrop, & Nico Armenta
Title: Side Panel
Part Number: MUV-OGODS-002
Date: 1/31/2020
Scale: 1:1
Checked By: Kodi Rider, SSL

NOTES:

UNLESS OTHERWISE SPECIFIED
1. MATERIAL IS T6-6061 ALUMINUM
2. ALL DIMENSIONS ARE IN
3. TOLERANCES
   X.XX ±.05
   X.XXX ±.005
   ANGLES ±1.0°
4. INSIDE TOOL RADIUS .02 MAX
5. BREAK SHARP EDGES .01 MAX

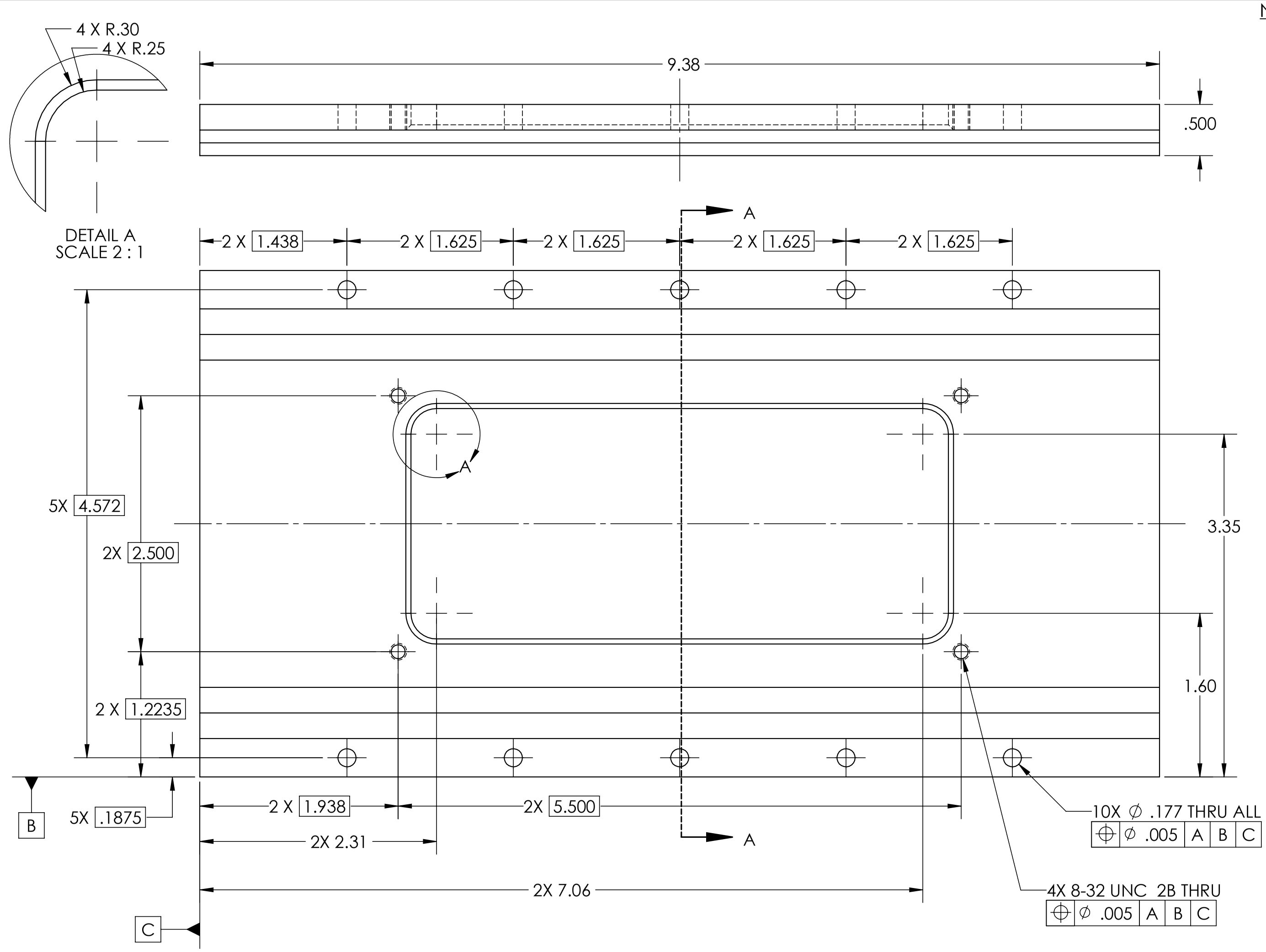


Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Back Panel
	Part Number: MUV-OGODS-003	Date: 1/31/2020	Scale: 1:1	Checked By: Kodi Rider, SSL

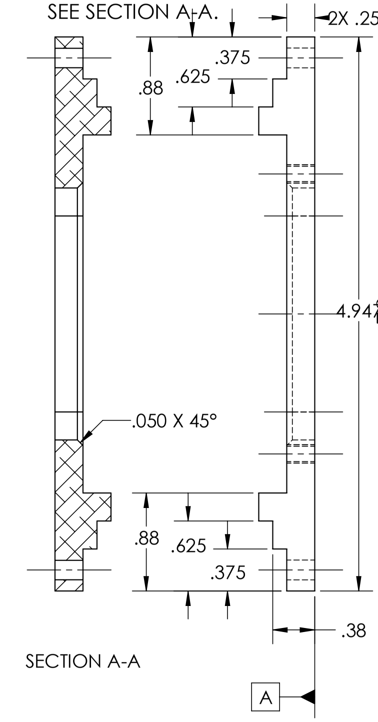


NOTES:
UNLESS OTHERWISE SPECIFIED
1. MATERIAL IS T6-6061 ALUMINUM
2. ALL DIMENSIONS ARE IN
3. TOLERANCES
X.XX ±.05
X.XXX ±.005
ANGLES ±1.0°
4. INSIDE TOOL RADIUS .02 MAX
5. BREAK SHARP EDGES .01 MAX

Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Front Panel
	Part Number: MUV-OGODS-004	Date: 1/31/2020	Scale: 1:1	Checked By: Kodi Rider, SSL



NOTES:
UNLESS OTHERWISE SPECIFIED
1. MATERIAL IS T6-6061 ALUMINUM
2. ALL DIMENSIONS ARE IN
3. TOLERANCES
X.XX ±.05
X.XXX ±.005
ANGLES ±1.0°
4. INSIDE TOOL RADIUS .02 MAX
5. BREAK SHARP EDGES .01 MAX
6. SEE CAD FOR SLOT DIMS
7. INNER/OUTER RADII IN DETAIL A SEPARATED BY CHAMFER. SEE SECTION A-A.



SECTION A-A

Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Top Panel
	Part Number: MUV-OGODS-005	Date: 1/31/2020	Scale: 1:1	Checked By: Kodi Rider, SSL

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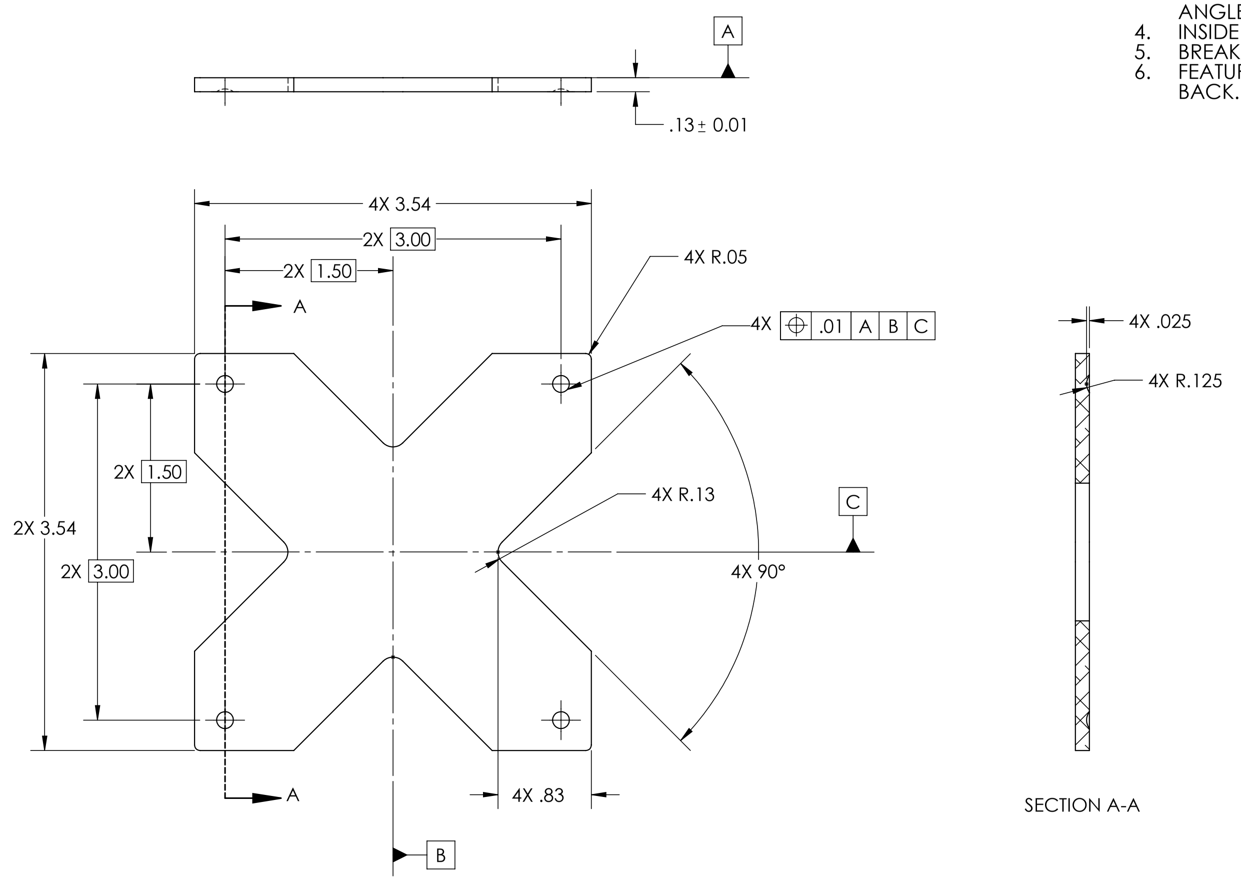
NOTES:
UNLESS OTHERWISE SPECIFIED
1. MATERIAL IS T6-6061 ALUMINUM
2. ALL DIMENSIONS ARE IN
3. TOLERANCES
X.XX ±.05
X.XXX ±.005
ANGLES ±1.0°
4. INSIDE TOOL RADIUS .02 MAX
5. BREAK SHARP EDGES .01 MAX
6. FEATURE IN A-A IS DETENT FROM BACK. SEE CAD.

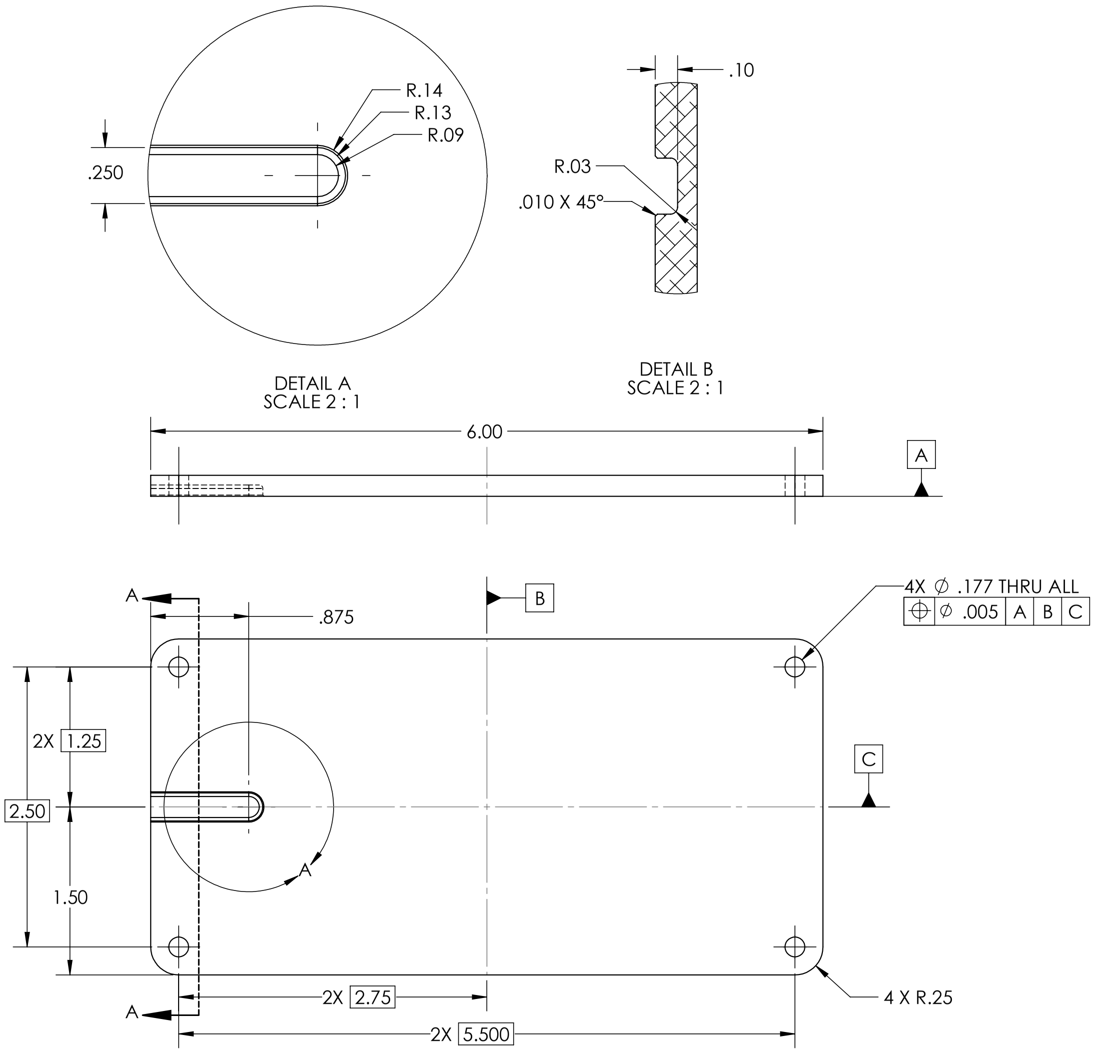


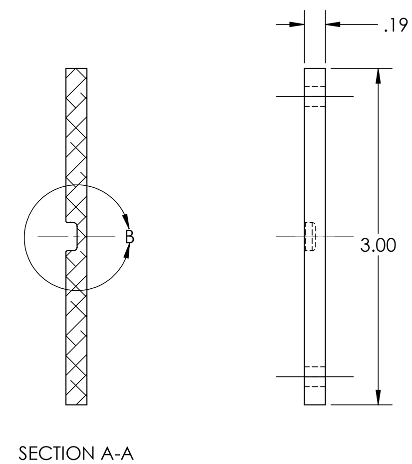
Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta		Title: Load Plate
	Part Number: MUV-OGODS-006	Date: 1/31/2020	Scale: 1:1	Checked By: Kodi Rider, SSL

NOTES:

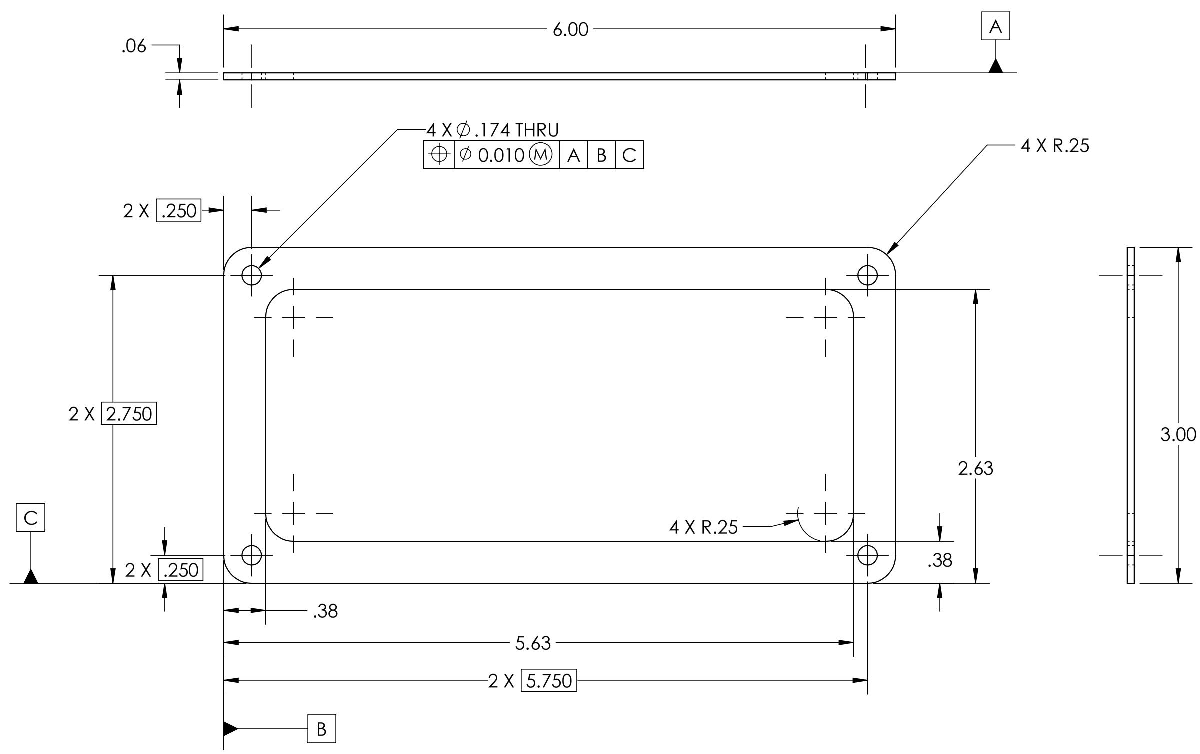
UNLESS OTHERWISE SPECIFIED

1. MATERIAL IS T6-6061 ALUMINUM
2. ALL DIMENSIONS ARE IN
3. TOLERANCES
   X.XX ±.05
   X.XXX ±.005
   ANGLES ±1.0°
4. INSIDE TOOL RADIUS .02 MAX
5. BREAK SHARP EDGES .01 MAX





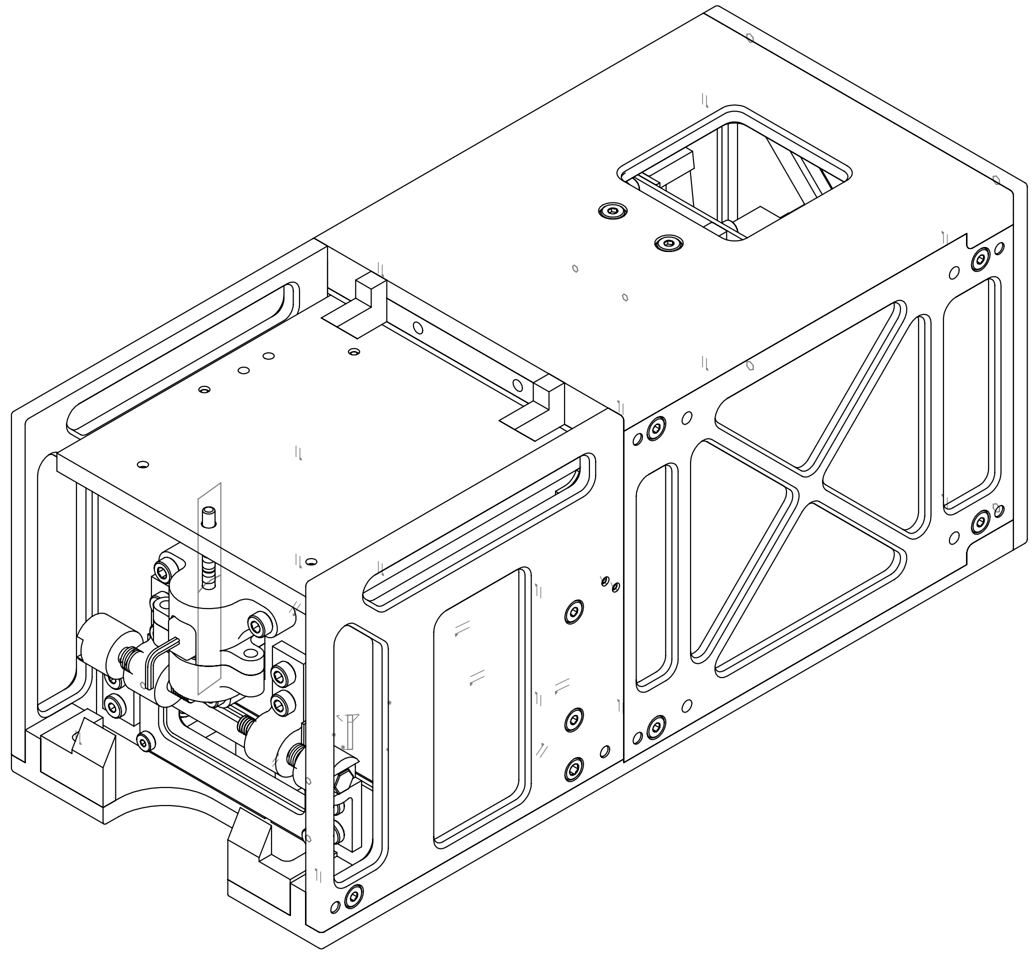
Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Access Panel
	Part Number: MUV-OGODS-007	Date: 1/31/2020	Scale: 1:1	Checked By: Kodi Rider, SSL



NOTES:
UNLESS OTHERWISE SPECIFIED
1. MATERIAL: VITON
MCMASTER PN. 86075K72
2. ALL DIMENSIONS ARE IN
3. TOLERANCES
X.XX ±.05
X.XXX ±.005
ANGLES ±1.0°
4. INSIDE TOOL RADIUS .02 MAX
5. BREAK SHARP EDGES .01 MAX

Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: GASKET
	Part Number: MUV-OGODS-008	Date: 1/31/2020	Scale: 1:1	Checked By: Kodi Rider, SSL

PART NO.	NAME	QTY.
MUV-F101	DATUM PLATE	1
MUV-F102	REAR PLATE	1
MUV-F103	FRONT RIGHT PLATE	1
MUV-F104	REAR RIGHT PLATE	1
MUV-F105	FRONT LEFT PLATE	1
MUV-F106	REAR LEFT PLATE	1
MUV-F107	FRONT DOOR MOUNT	1
MUV-F108	TOP PLATE	1
MUV-F109	ALIGNMENT CUBE TOWER	1
MUV-F110	INLET N2 FILTER CLAMP	1
MUV-F111	EXIT N2 FILTER CLAMP	1
MUV-F112	N2 PUSH-TO-CONNECT MOUNT	1
MUV-F130	TOP MIRROR MASS MODEL	1
MUV-F131	BOTTOM MIRROR MASS MODEL	1



NOTES, UNLESS OTHERWISE SPECIFIED:

1. DIMENSIONS IN INCHES
2. HOLE CALLOUTS IN METRIC
3. ALL MATERIAL: ALUMINUM 6061-T6 PER AMS 4027 AND AMS 4150
4. BREAK EXTERNAL EDGES .01 MAX
5. INSIDE TOOL RADIUS .02 MAX
6. TOLERANCES
   X.XX ±.05
   X.XXX±.005
   ANGLES ±1°
6. INSTALL HELICAL COIL INSERT PER NASM33537. REMOVE TANG.

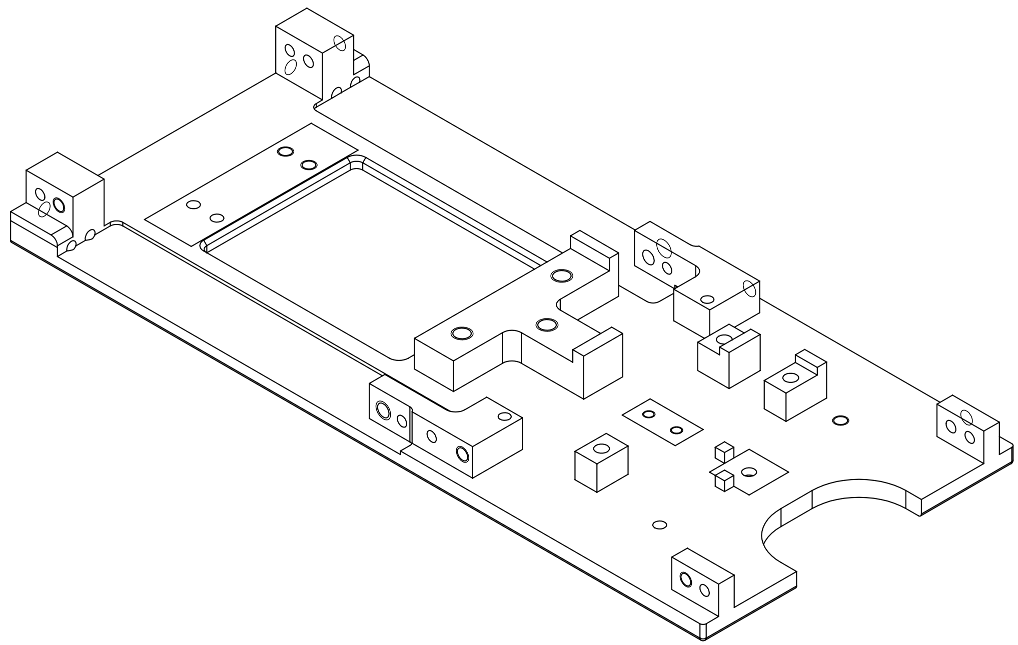
Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Instrumentation Frame
	Part Number: MUV-F-100	Date: 03/10/2020	Scale: 1:2	Checked By: Kodi Rider, SSL

NOTES:

1. ANODIZE ALL MACHINED PARTS PER MIL-A-8625 TYPE II CLASS 2, EXCEPT WHERE NOTED PER NOTE 2. COLOR SHALL APPROXIMATE FED-STD-595 NO. 37038 (LUSTERLESS/MATTE BLACK). CAUTION: USE ONLY AN ORGANIC BLACK DYE. PRIOR TO ANODIZING, GRIT BLAST SURFACE TO BE ANODZED, USE NO. 50 ALUMINUM OXIDE GRIT. DO NOT USE GLASS BEADS. SEAL WITH NICKEL ACETATE. HELICOIL INTERTS, ALL THREADED HOLES, COUNTERBORE HOLES, AND DOWEL PIN HOLES SHALL BE FREE ANODIZE.

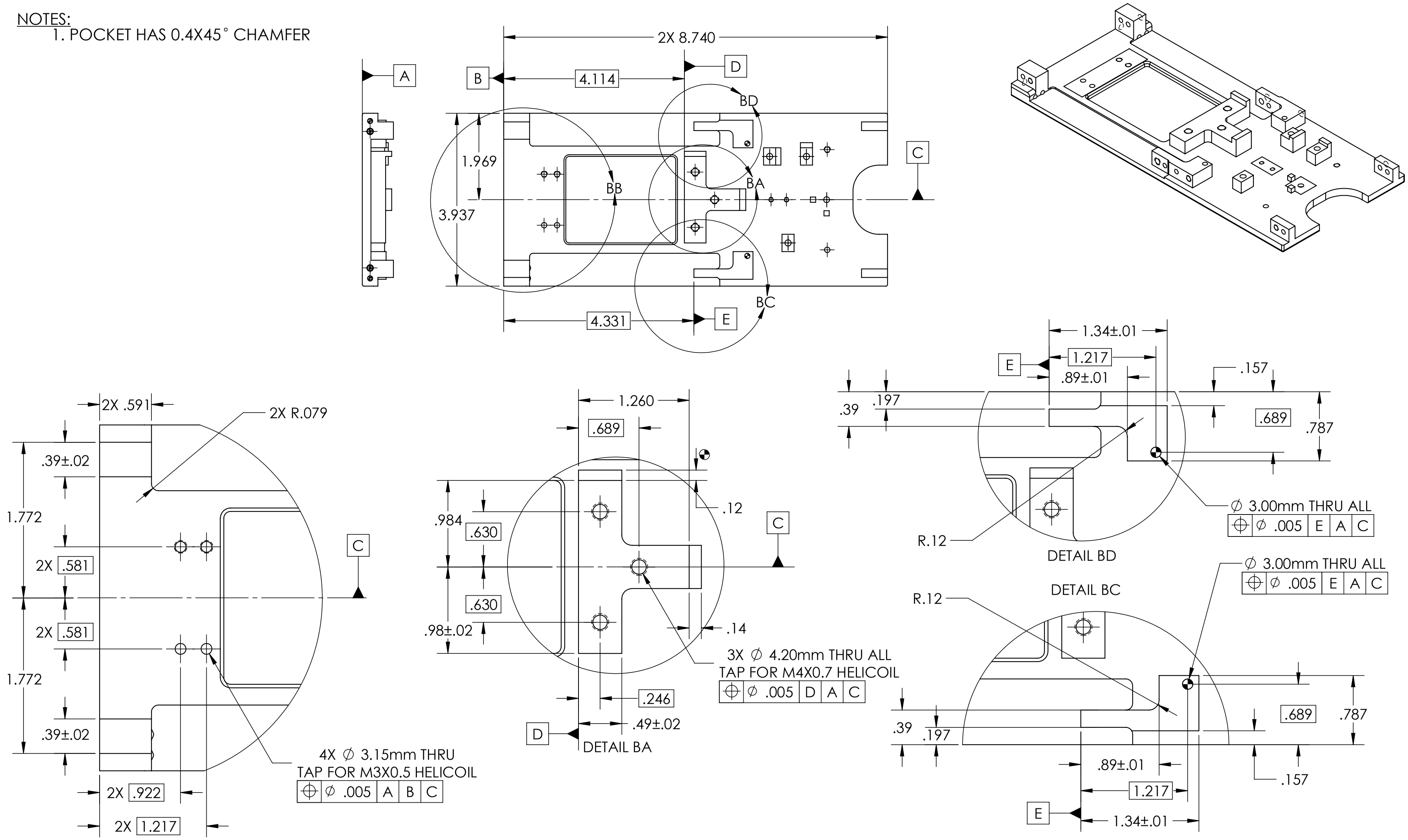
2. MASK INDICATED SURFACE AND/OR DIMENSIONED AREA BEFORE THE ANODIZATION PROCESS. SURFACE MUST REMAIN FREE OF ANODIZE.

3. CHEM-FILM PER MIL-DTL-5541, CL3 (YELLOW). SEE DETAIL ON SHEET 5



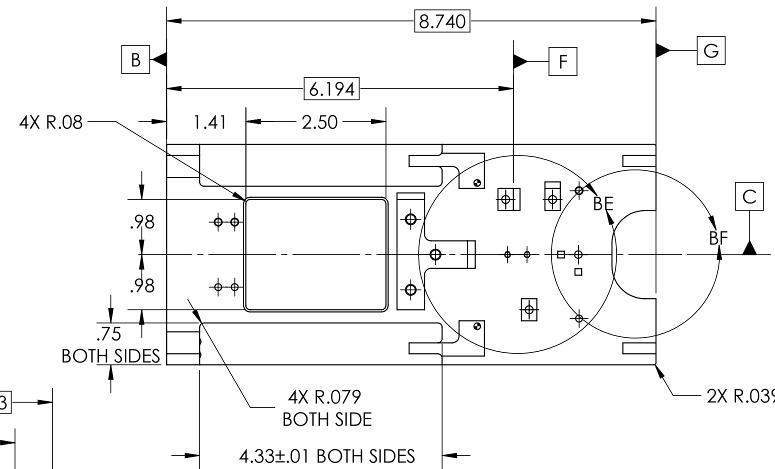
Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Datum Plate - Page 1 of 5
	Part Number: MUV-F-101	Date: 04/25/2020	Scale: 1:1	Checked By: Kodi Rider, SSL

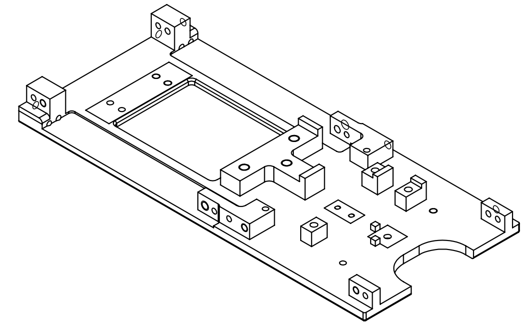
NOTES:
1. POCKET HAS 0.4X45° CHAMFER

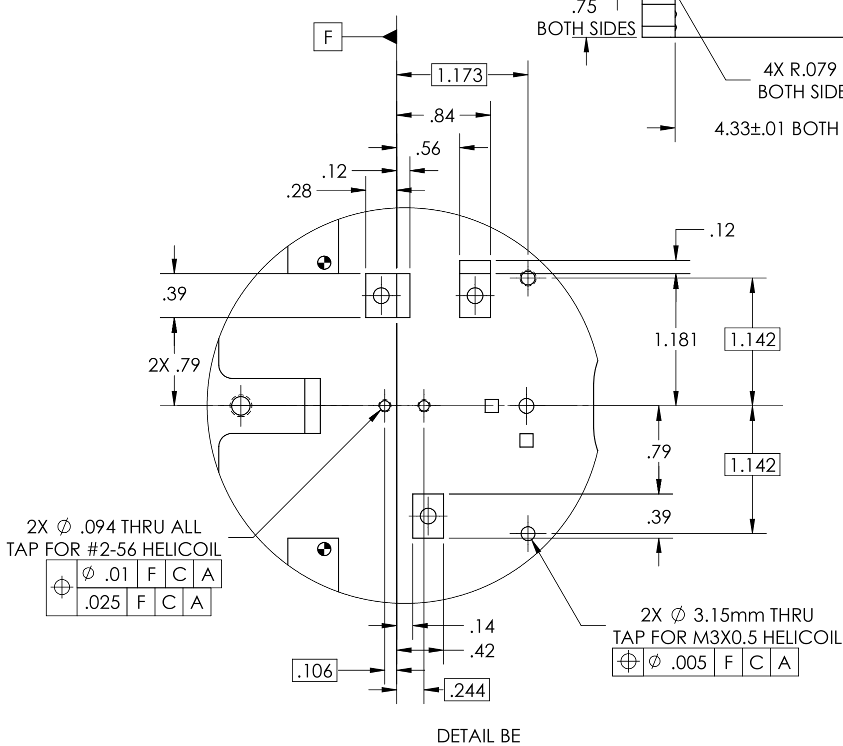


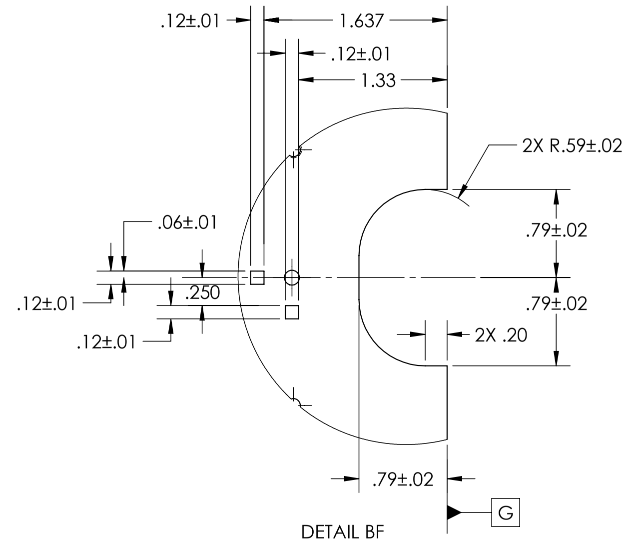
Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta		Title: Datum Plate - Page 2 of 5
	Part Number: MUV-F-101	Date: 03/10/2020 Scale: 1:2	Checked By: Kodi Rider, SSL

NOTES:
1. POCKET HAS 0.4X45° CHAMFER









Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta		Title: Datum Plate - Page 3 of 5
	Part Number: MUV-F-101	Date: 03/10/2020 Scale: 1:2	Checked By: Kodi Rider, SSL

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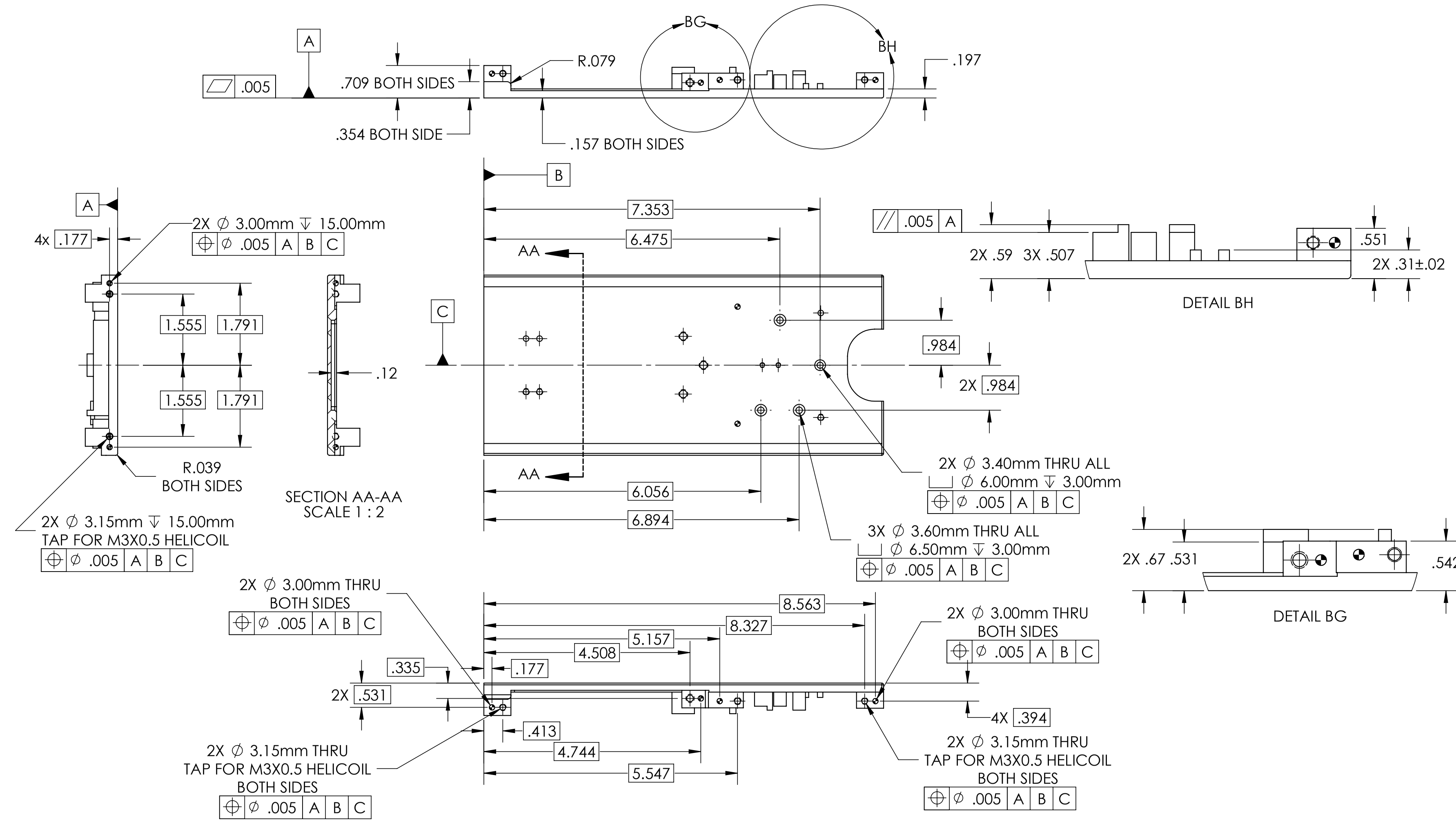

Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta		Title: Datum Plate - Page 4 of 5
	Part Number: MUV-F-101	Date: 03/10/2020 Scale: 1:2	Checked By: Kodi Rider, SSL

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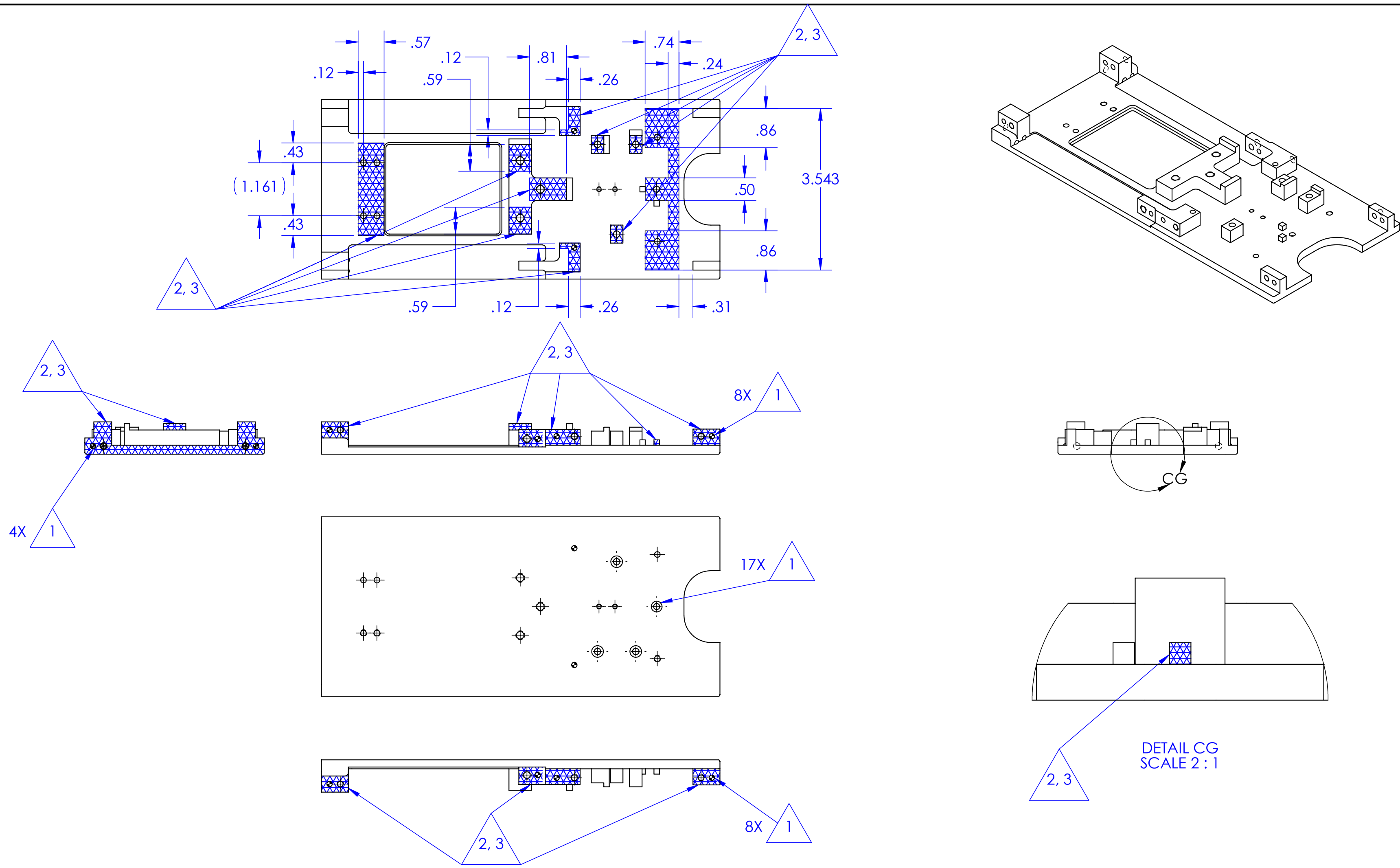


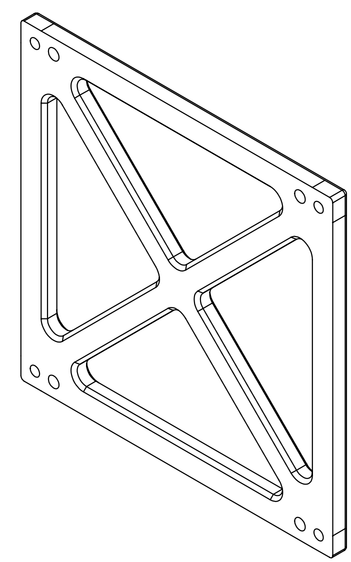
Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Datum Plate - Anodizing - 5/5
	Part Number: MUV-F-101	Date: 04/25/2020	Scale: 1:2	Checked By: Kodi Rider, SSL

NOTES:

1. ANODIZE ALL MACHINED PARTS PER MIL-A-8625 TYPE II CLASS 2, EXCEPT WHERE NOTED PER NOTE 2. COLOR SHALL APPROXIMATE FED-STD-595 NO. 37038 (LUSTERLESS/MATTE BLACK). CAUTION: USE ONLY AN ORGANIC BLACK DYE. PRIOR TO ANODIZING, GRIT BLAST SURFACE TO BE ANODZED, USE NO. 50 ALUMINUM OXIDE GRIT. DO NOT USE GLASS BEADS. SEAL WITH NICKEL ACETATE. HELICOIL INTERTS, ALL THREADED HOLES, COUNTERBORE HOLES, AND DOWEL PIN HOLES SHALL BE FREE ANODIZE.

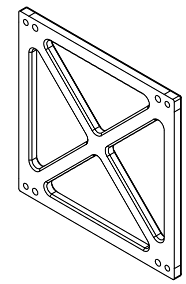
2. MASK INDICATED SURFACE AND/OR DIMENSIONED AREA BEFORE THE ANODIZATION PROCESS. SURFACE MUST REMAIN FREE OF ANODIZE.

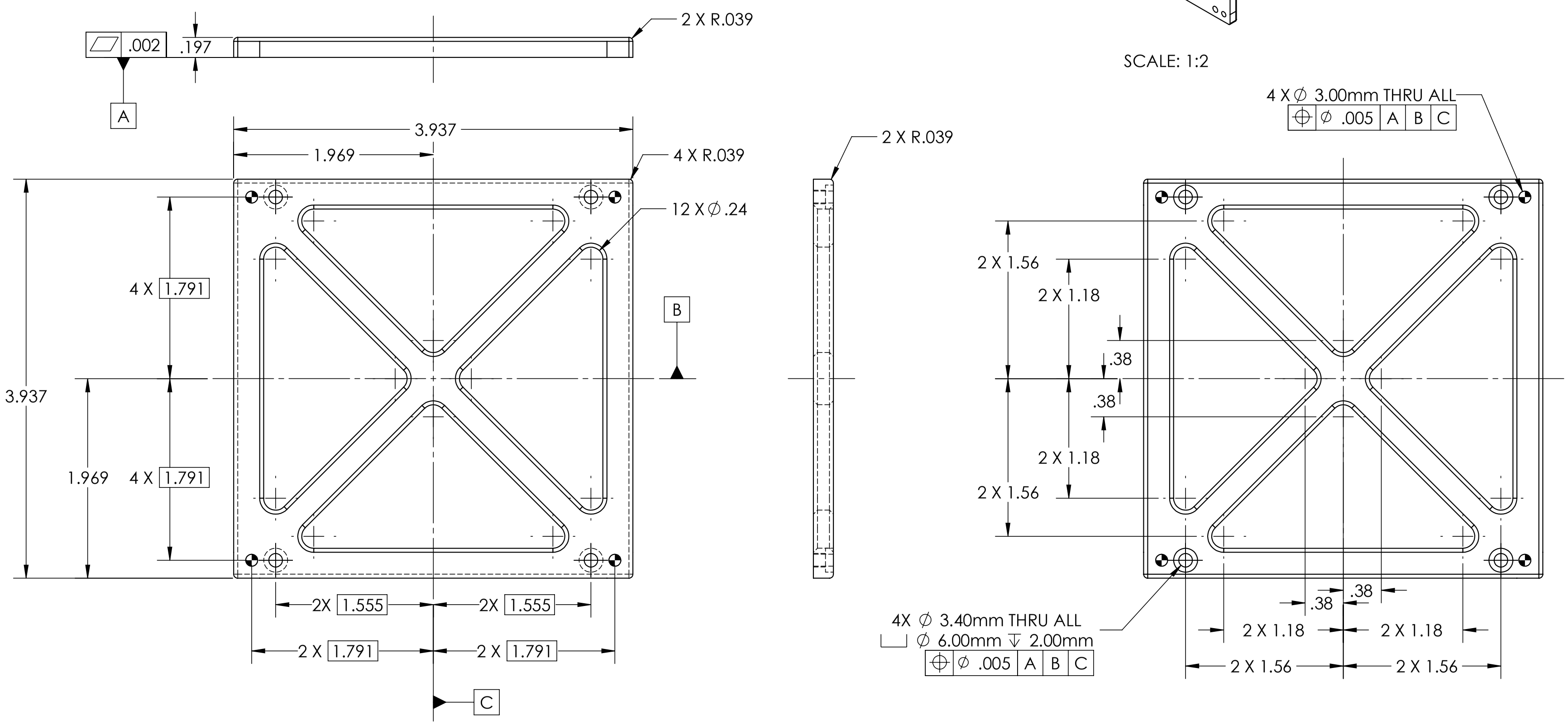
3. CHEM-FILM PER MIL-DTL-5541, CL3 (YELLOW). SEE DETAIL ON SHEET 3



Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Rear Plate - Page 1 of 3
	Part Number: MUV-F-102	Date: 03/10/2020	Scale: 1:1	Checked By: Kodi Rider, SSL

NOTES:
1. THE 4X TRIANGULAR CUT-OUTS HAVE 0.04 X 45.0° CHAMFERS ALL AROUND ON FRONT & BACK FACES


SCALE: 1:2



Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Rear Plate - 2/3
	Part Number: MUV-F-102	Date: 03/10/2020	Scale: 1:1	Checked By: Kodi Rider, SSL

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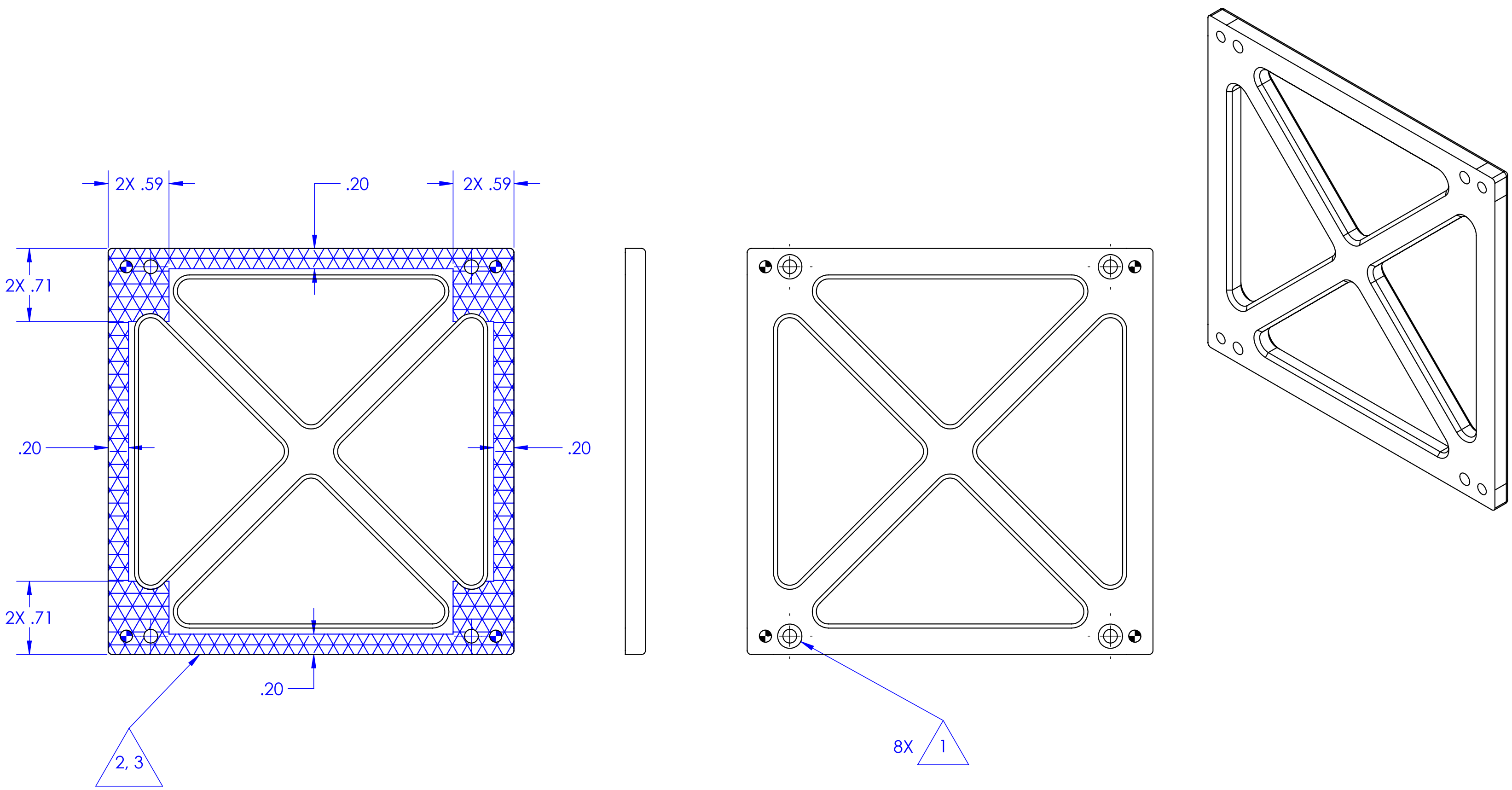


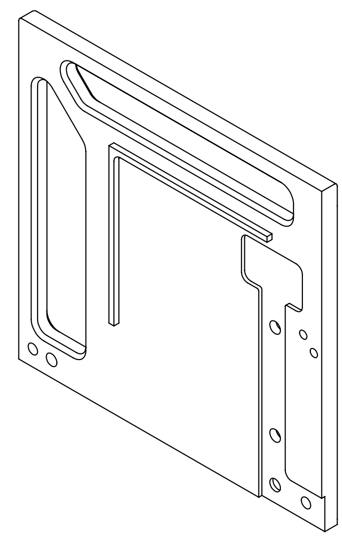
Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Rear Plate - Anodize - 3/3
	Part Number: MUV-F-102	Date: 04/26/2020	Scale: 1:1	Checked By: Kodi Rider, SSL

NOTES:

1. ANODIZE ALL MACHINED PARTS PER MIL-A-8625 TYPE II CLASS 2, EXCEPT WHERE NOTED PER NOTE 2. COLOR SHALL APPROXIMATE FED-STD-595 NO. 37038 (LUSTERLESS/MATTE BLACK). CAUTION: USE ONLY AN ORGANIC BLACK DYE. PRIOR TO ANODIZING, GRIT BLAST SURFACE TO BE ANODZED, USE NO. 50 ALUMINUM OXIDE GRIT. DO NOT USE GLASS BEADS. SEAL WITH NICKEL ACETATE. HELICOIL INTERTS, ALL THREADED HOLES, COUNTERBORE HOLES, AND DOWEL PIN HOLES SHALL BE FREE ANODIZE.

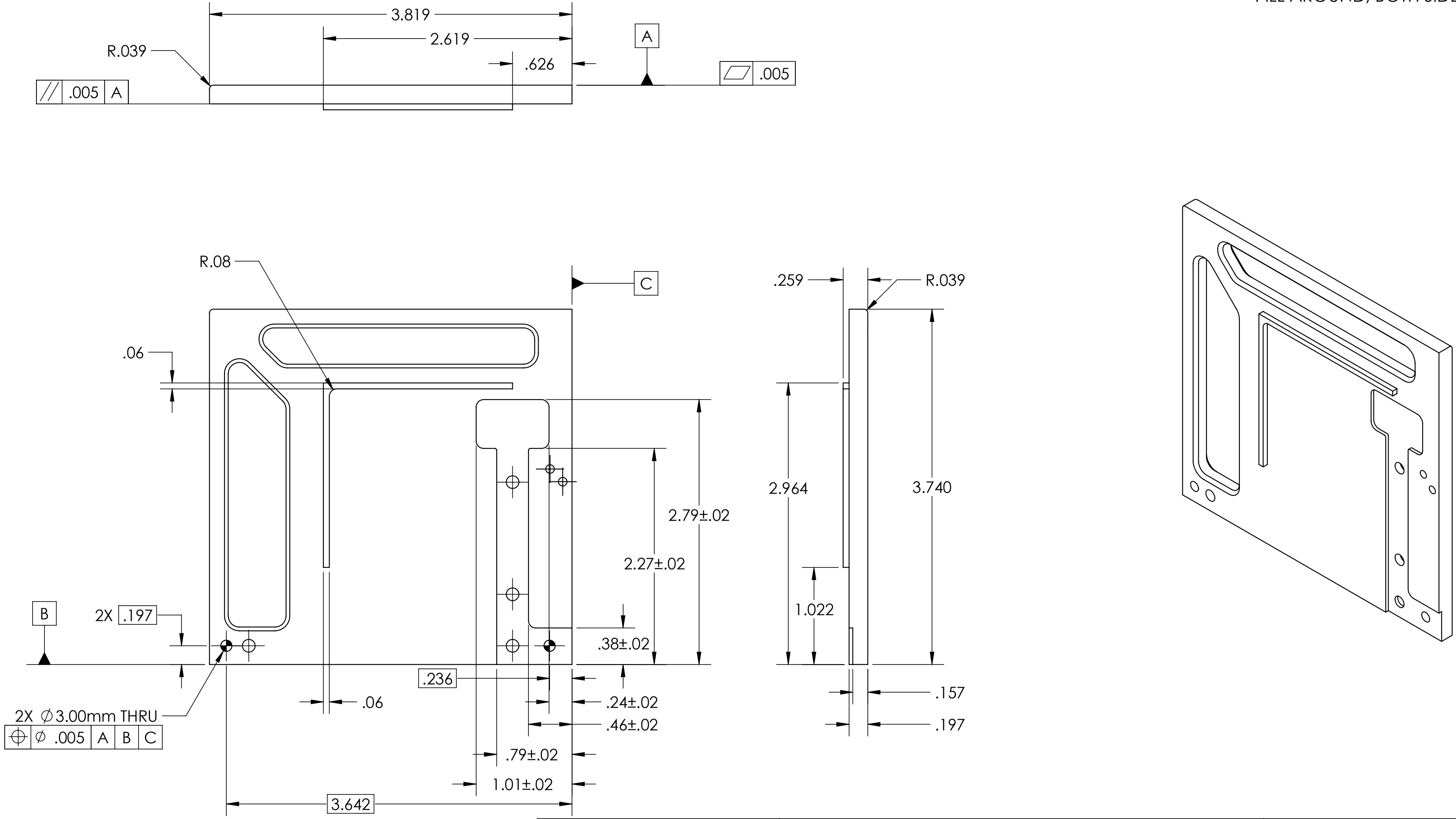
2. MASK INDICATED SURFACE AND/OR DIMENSIONED AREA BEFORE THE ANODIZATION PROCESS. SURFACE MUST REMAIN FREE OF ANODIZE.

3. CHEM-FILM PER MIL-DTL-5541, CL3 (YELLOW). SEE DETAIL ON SHEET 4



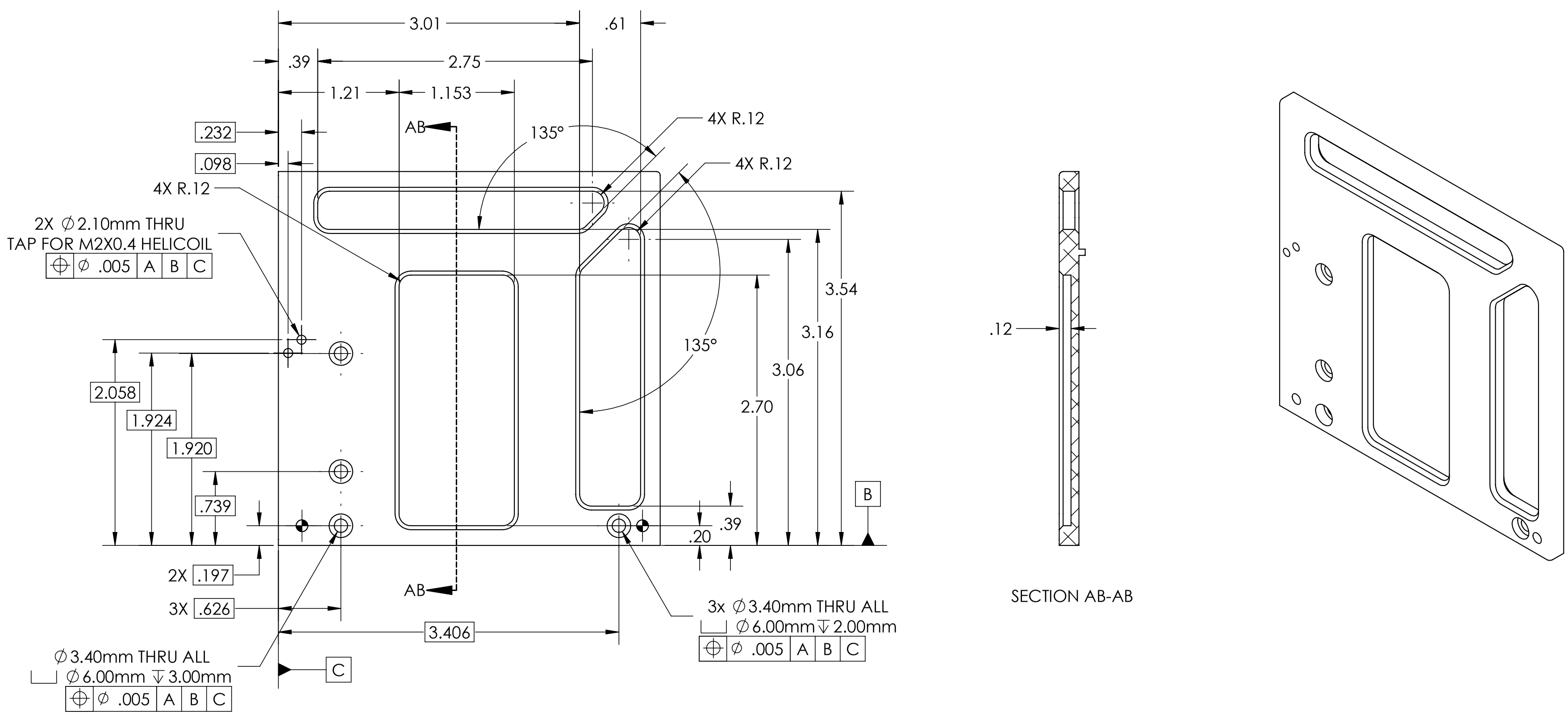
Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Front Right Plate - Pg. 1/4
	Part Number: MUV-F-103	Date: 04/26/2020	Scale: 1:1	Checked By: Kodi Rider, SSL

NOTES:
1. THE 2 CUT-OUTS HAVE A 0.04 X 45.0° CHAMFER ALL AROUND, BOTH SIDES

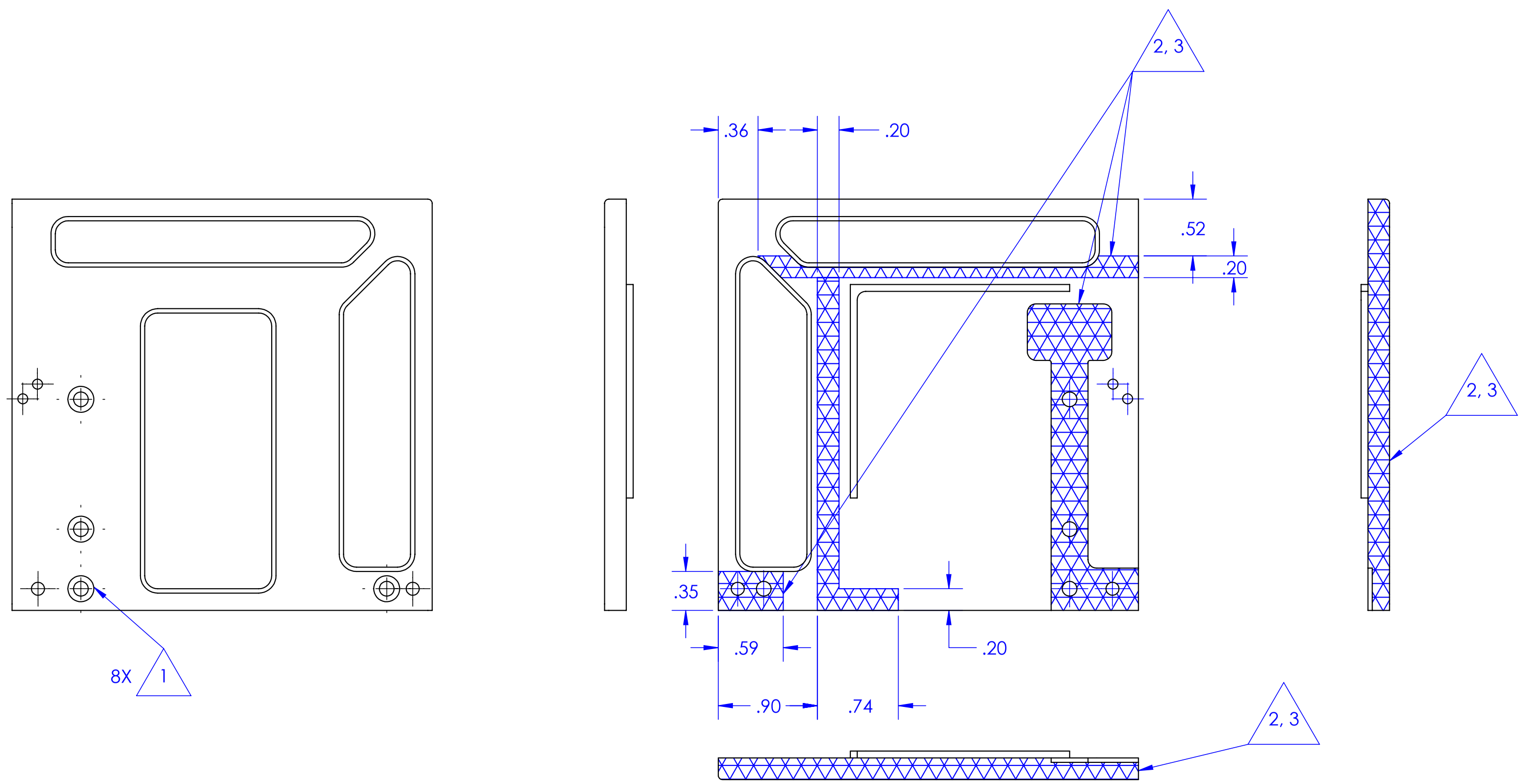


Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Front Right Plate - Pg. 2/4
	Part Number: MUV-F-103	Date: 03/10/2020	Scale: 1:1	Checked By: Kodi Rider, SSL

NOTES:
1. THE TWO CUT-OUTS AND RECTANGULAR POCKET HAVE A 0.04 X 45.0° CHAMFER ALL AROUND, BOTH SIDES



Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Front Right Plate - Pg. 3/4
	Part Number: MUV-F-103	Date: 03/10/2020	Scale: 1:1	Checked By: Kodi Rider, SSL



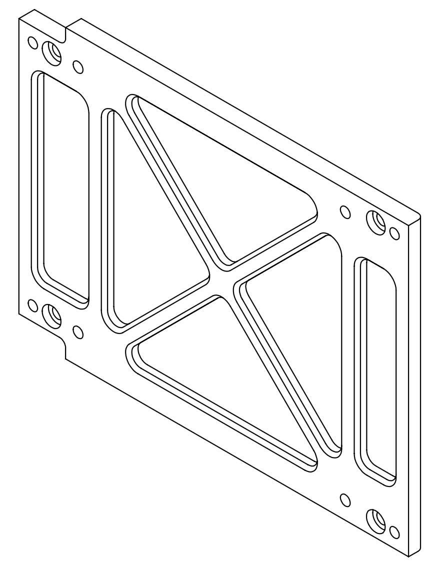
Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Front Right Plate - Anodize -4/4
	Part Number: MUV-F-103	Date: 04/26/2020	Scale: 1:1	Checked By: Kodi Rider, SSL

NOTES:

1. ANODIZE ALL MACHINED PARTS PER MIL-A-8625 TYPE II CLASS 2, EXCEPT WHERE NOTED PER NOTE 2. COLOR SHALL APPROXIMATE FED-STD-595 NO. 37038 (LUSTERLESS/MATTE BLACK). CAUTION: USE ONLY AN ORGANIC BLACK DYE. PRIOR TO ANODIZING, GRIT BLAST SURFACE TO BE ANODZED, USE NO. 50 ALUMINUM OXIDE GRIT. DO NOT USE GLASS BEADS. SEAL WITH NICKEL ACETATE. HELICOIL INTERTS, ALL THREADED HOLES, COUNTERBORE HOLES, AND DOWEL PIN HOLES SHALL BE FREE ANODIZE.

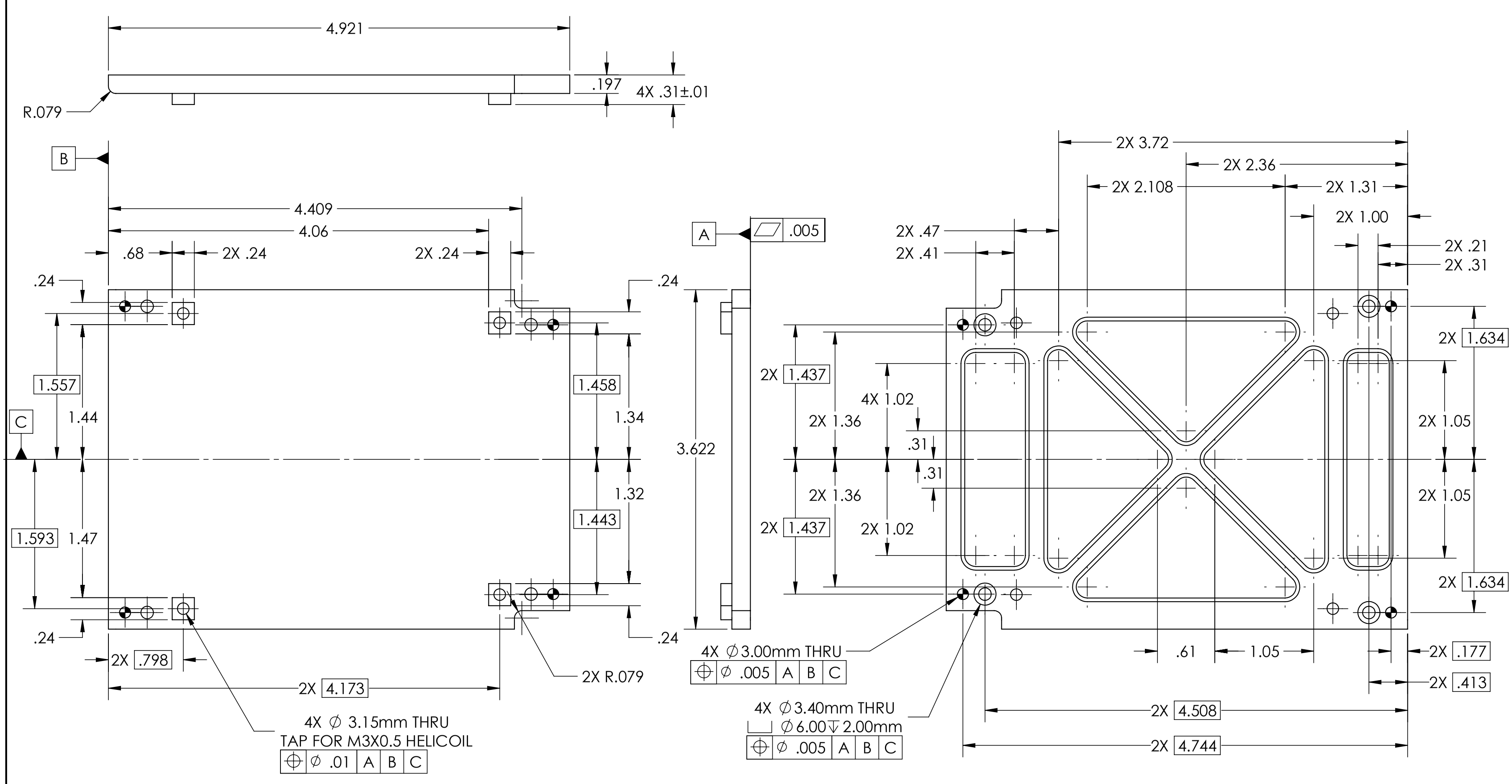
2. MASK INDICATED SURFACE AND/OR DIMENSIONED AREA BEFORE THE ANODIZATION PROCESS. SURFACE MUST REMAIN FREE OF ANODIZE.

3. CHEM-FILM PER MIL-DTL-5541, CL3 (YELLOW). SEE DETAIL ON SHEET 3

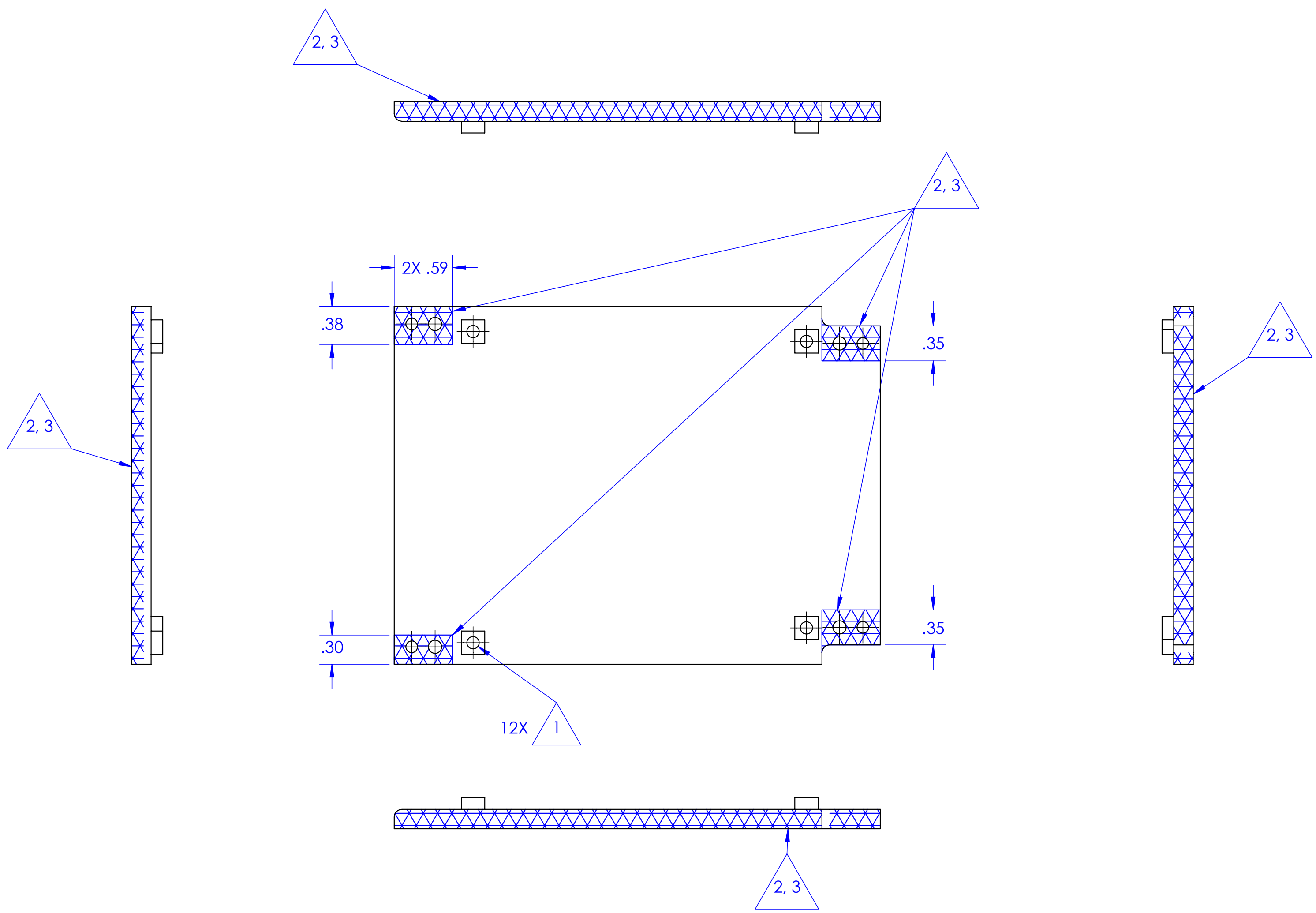


Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta		Title: Rear Right Plate - 1/3
	Part Number: MUV-F-104	Date: 04/27/2020 Scale: 1:1	Checked By: Kodi Rider, SSL

NOTES:
1. THE FOUR TRIANGULAR AND TWO RECTANGULARCUT-OUTS HAVE 0.04 X 45.0° CHAMFERS ALL AROUND



Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Rear Right Plate - 2/3
	Part Number: MUV-F-104	Date: 03/10/2020	Scale: 1:1	Checked By: Kodi Rider, SSL



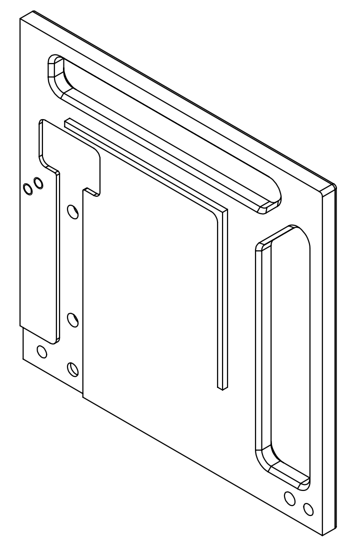
Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Rear Right Plate - Anodize - 3/3
	Part Number: MUV-F-104	Date: 04/27/2020	Scale: 1:1	Checked By: Kodi Rider, SSL

NOTES:

1. ANODIZE ALL MACHINED PARTS PER MIL-A-8625 TYPE II CLASS 2, EXCEPT WHERE NOTED PER NOTE 2. COLOR SHALL APPROXIMATE FED-STD-595 NO. 37038 (LUSTERLESS/MATTE BLACK). CAUTION: USE ONLY AN ORGANIC BLACK DYE. PRIOR TO ANODIZING, GRIT BLAST SURFACE TO BE ANODZED, USE NO. 50 ALUMINUM OXIDE GRIT. DO NOT USE GLASS BEADS. SEAL WITH NICKEL ACETATE. HELICOIL INTERTS, ALL THREADED HOLES, COUNTERBORE HOLES, AND DOWEL PIN HOLES SHALL BE FREE ANODIZE.

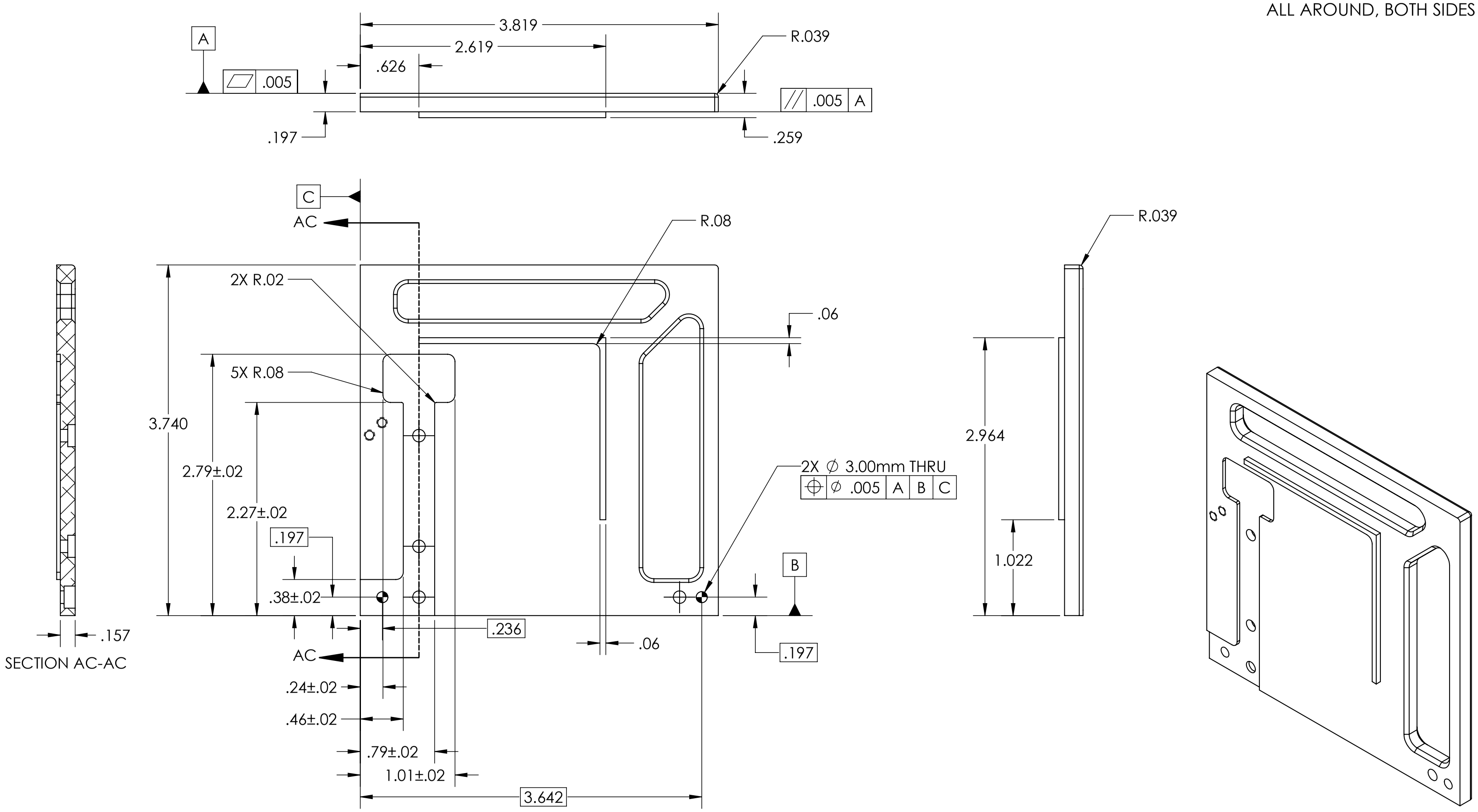
2. MASK INDICATED SURFACE AND/OR DIMENSIONED AREA BEFORE THE ANODIZATION PROCESS. SURFACE MUST REMAIN FREE OF ANODIZE.

3. CHEM-FILM PER MIL-DTL-5541, CL3 (YELLOW). SEE DETAIL ON SHEET 4



Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Front Left Plate - Page 1/4
	Part Number: MUV-F-105	Date: 04/27/2020	Scale: 1:1	Checked By: Kodi Rider, SSL

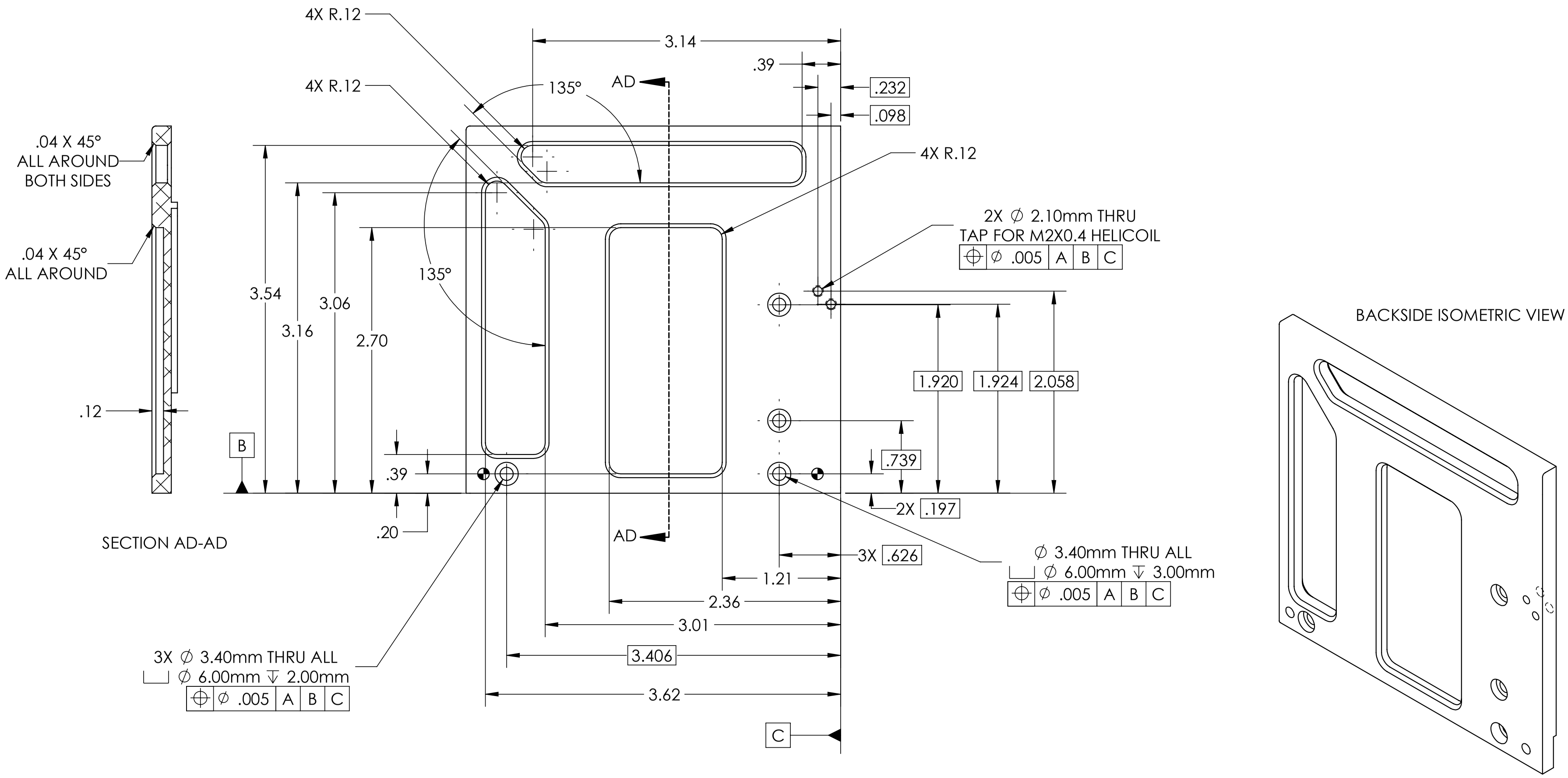
NOTES:
1. THE 2 CUT-OUTS HAVE A 0.04 X 45.0° CHAMFER ALL AROUND, BOTH SIDES



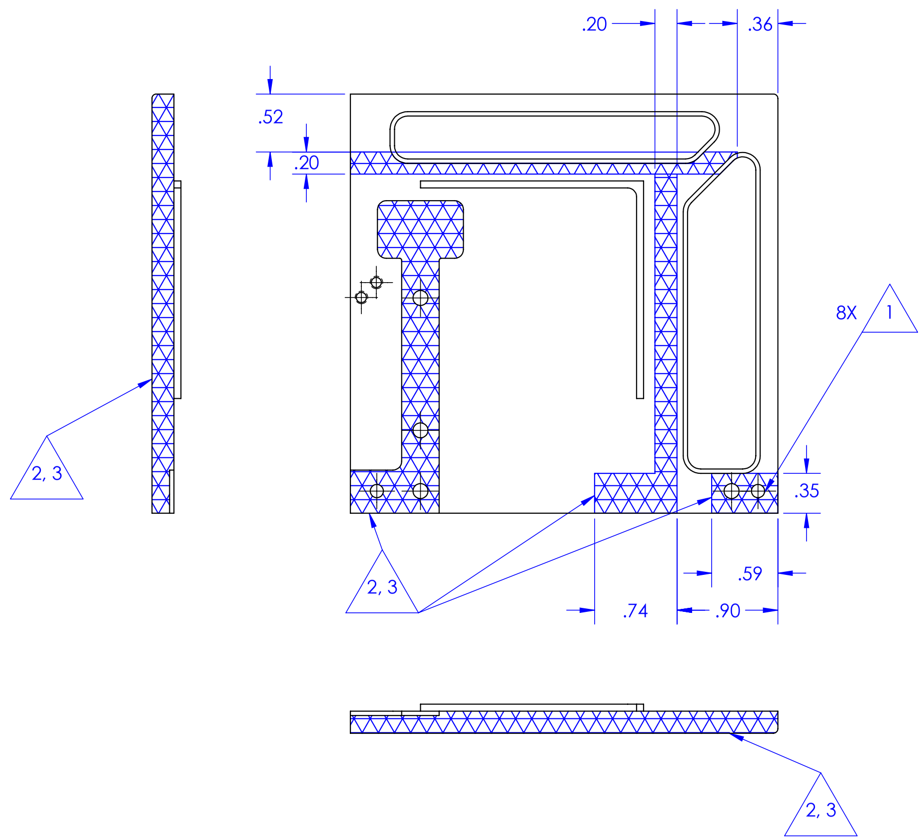
Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Front Left Plate - Page 2/4
	Part Number: MUV-F-105	Date: 03/10/2020	Scale: 1:1	Checked By: Kodi Rider, SSL

SOLIDWORKS Educational Product. For Instructional Use Only.

NOTES:
1. THE 2 CUT-OUTS HAVE A 0.04 X 45.0° CHAMFER ALL AROUND, BOTH SIDES



Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta	Title: Front Left Plate - Page 3/4
	Part Number: MUV-F-105 | Date: 03/10/2020 | Scale: 1:1	Checked By: Kodi Rider, SSL



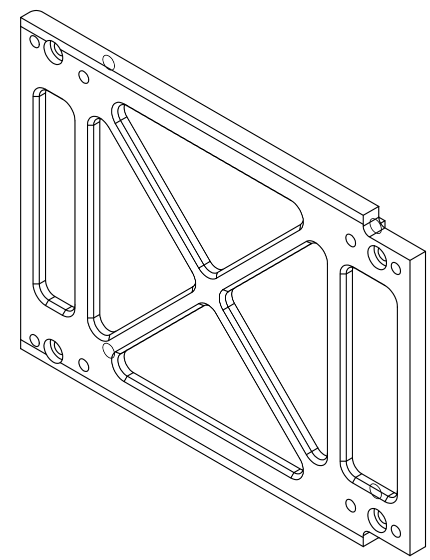
Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta		Title: Front Left Plate - Page 4/4
	Part Number: MUV-F-105	Date: 04/27/2020 Scale: 1:1	Checked By: Kodi Rider, SSL

NOTES:

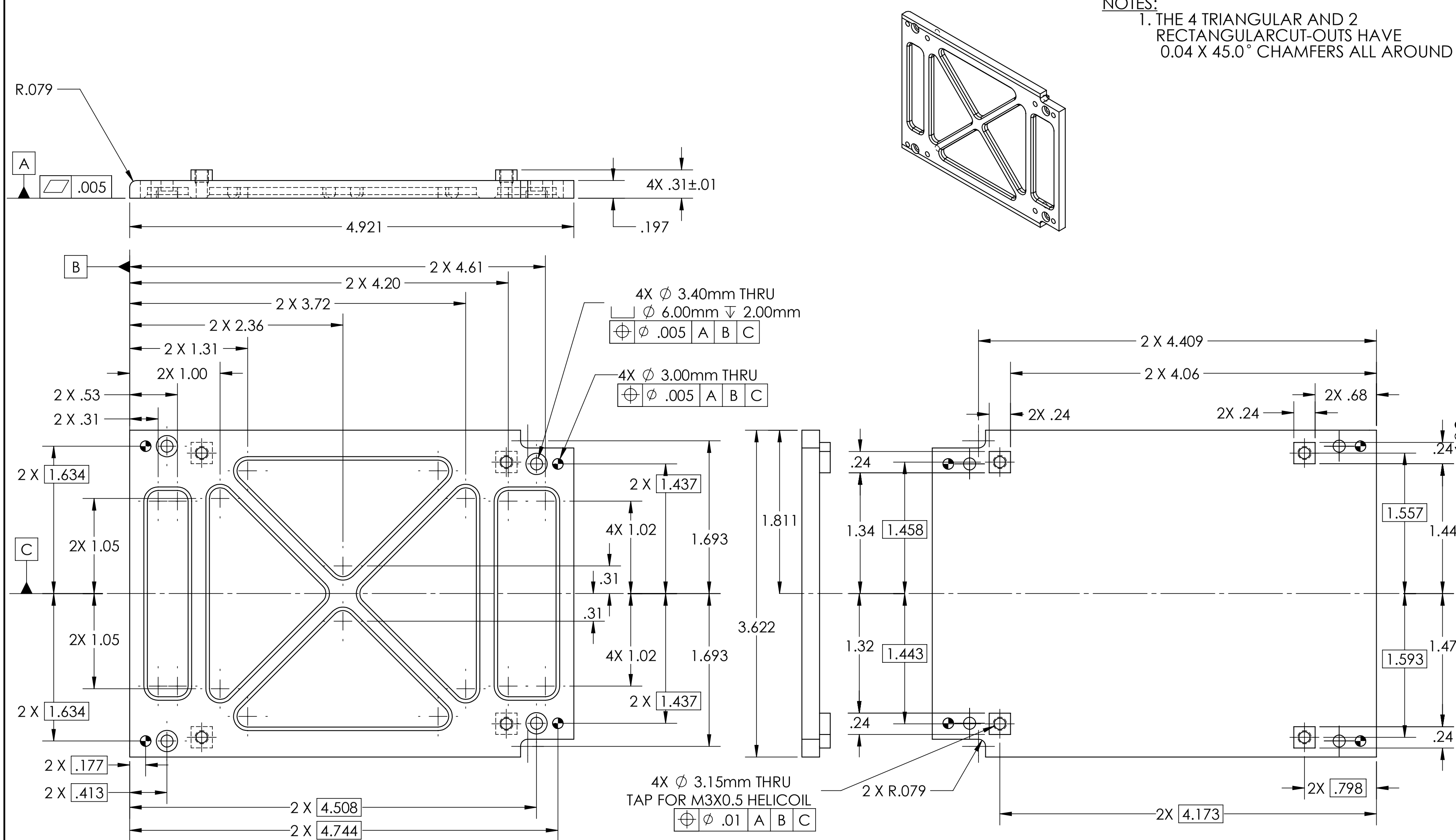
1. ANODIZE ALL MACHINED PARTS PER MIL-A-8625 TYPE II CLASS 2, EXCEPT WHERE NOTED PER NOTE 2. COLOR SHALL APPROXIMATE FED-STD-595 NO. 37038 (LUSTERLESS/MATTE BLACK). CAUTION: USE ONLY AN ORGANIC BLACK DYE. PRIOR TO ANODIZING, GRIT BLAST SURFACE TO BE ANODZED, USE NO. 50 ALUMINUM OXIDE GRIT. DO NOT USE GLASS BEADS. SEAL WITH NICKEL ACETATE. HELICOIL INTERTS, ALL THREADED HOLES, COUNTERBORE HOLES, AND DOWEL PIN HOLES SHALL BE FREE ANODIZE.

2. MASK INDICATED SURFACE AND/OR DIMENSIONED AREA BEFORE THE ANODIZATION PROCESS. SURFACE MUST REMAIN FREE OF ANODIZE.

3. CHEM-FILM PER MIL-DTL-5541, CL3 (YELLOW). SEE DETAIL ON SHEET 3

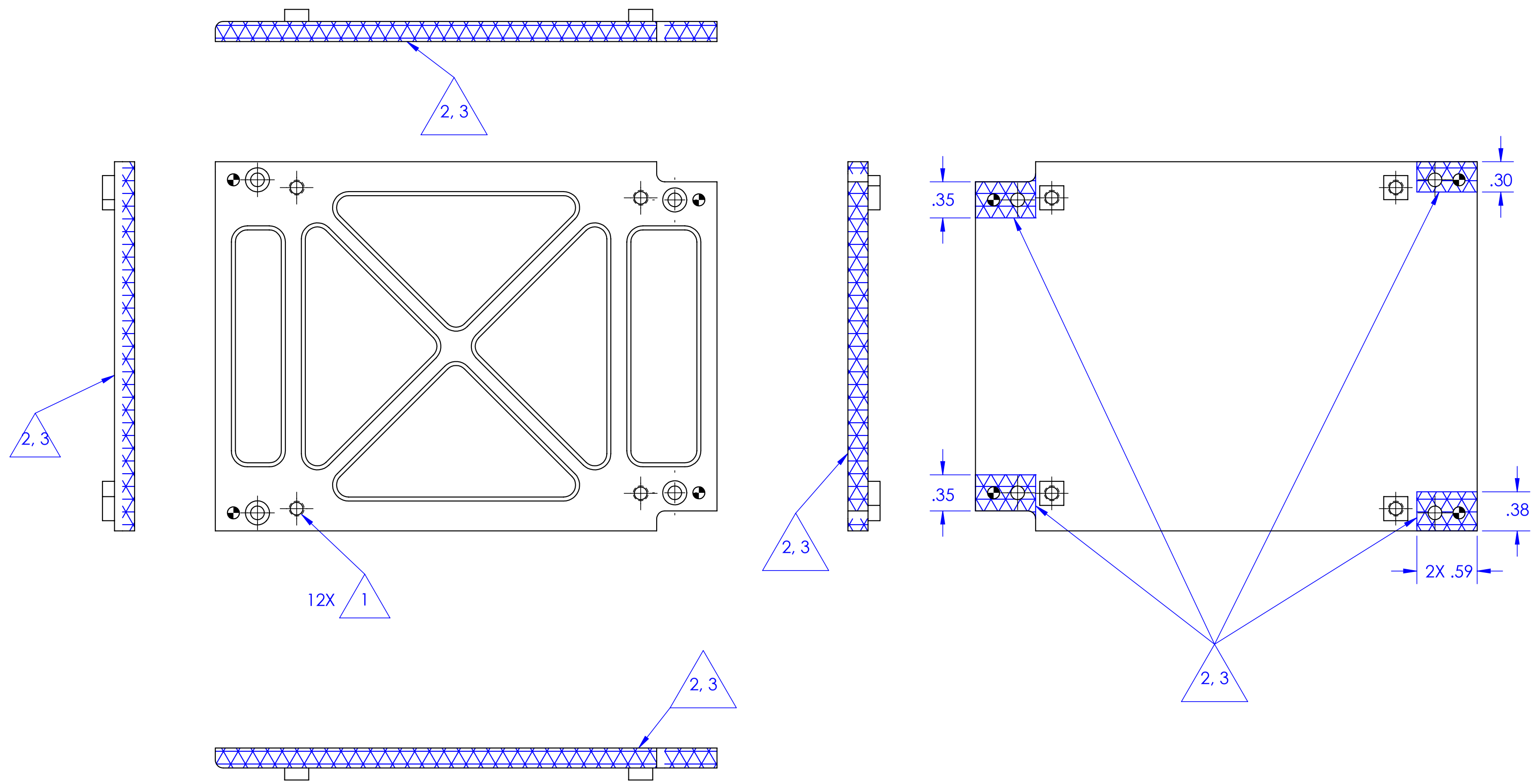


Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Rear Left Plate - Page 1/3
	Part Number: MUV-F-106	Date: 04/27/2020	Scale: 1:1	Checked By: Kodi Rider, SSL



NOTES:
1. THE 4 TRIANGULAR AND 2 RECTANGULARCUT-OUTS HAVE 0.04 X 45.0° CHAMFERS ALL AROUND

Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Rear Left Plate - 2/3
	Part Number: MUV-F-106	Date: 03/10/2020	Scale: 1:1	Checked By: Kodi Rider, SSL



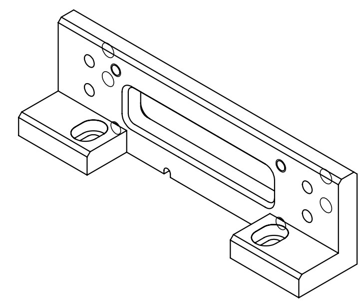
Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta		Title: Rear Left Plate - Anodize - 3/3
	Part Number: MUV-F-106	Date: 04/27/2020 · Scale: 1:1	Checked By: Kodi Rider, SSL

NOTES:

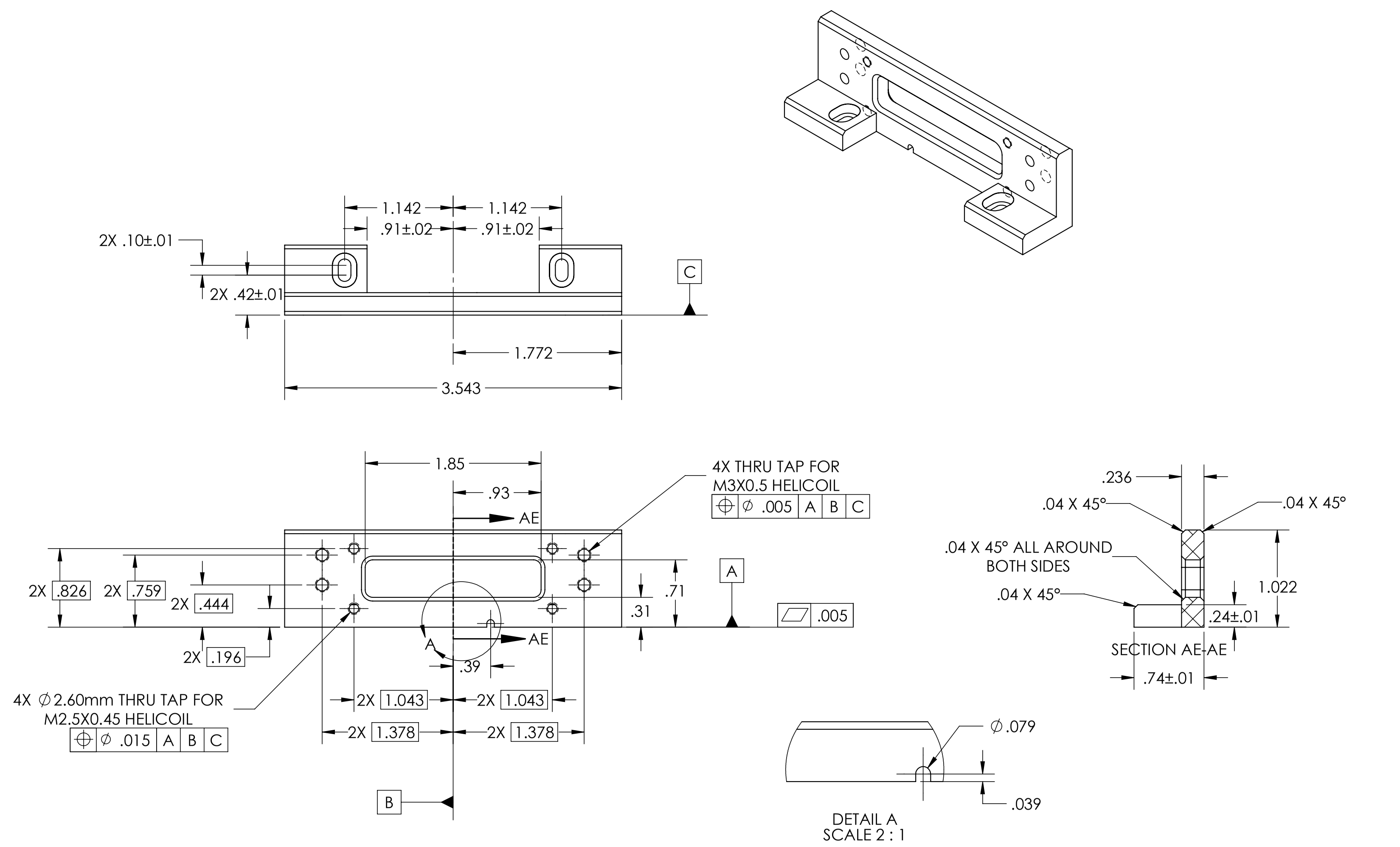
1. ANODIZE ALL MACHINED PARTS PER MIL-A-8625 TYPE II CLASS 2, EXCEPT WHERE NOTED PER NOTE 2. COLOR SHALL APPROXIMATE FED-STD-595 NO. 37038 (LUSTERLESS/MATTE BLACK). CAUTION: USE ONLY AN ORGANIC BLACK DYE. PRIOR TO ANODIZING, GRIT BLAST SURFACE TO BE ANODZED, USE NO. 50 ALUMINUM OXIDE GRIT. DO NOT USE GLASS BEADS. SEAL WITH NICKEL ACETATE. HELICOIL INTERTS, ALL THREADED HOLES, COUNTERBORE HOLES, AND DOWEL PIN HOLES SHALL BE FREE ANODIZE.

2. MASK INDICATED SURFACE AND/OR DIMENSIONED AREA BEFORE THE ANODIZATION PROCESS. SURFACE MUST REMAIN FREE OF ANODIZE.

3. CHEM-FILM PER MIL-DTL-5541, CL3 (YELLOW). SEE DETAIL ON SHEET 3



Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta		Title: Front Door Mount - 1/3
	Part Number: MUV-F-107	Date: 04/28/2020 / Scale: 1:1	Checked By: Kodi Rider, SSL



Cal Poly Mechanical Engineering
UC Berkeley SSL
NASA

Team Members: Bradley Albright, Colin Harrop, & Nico Armenta

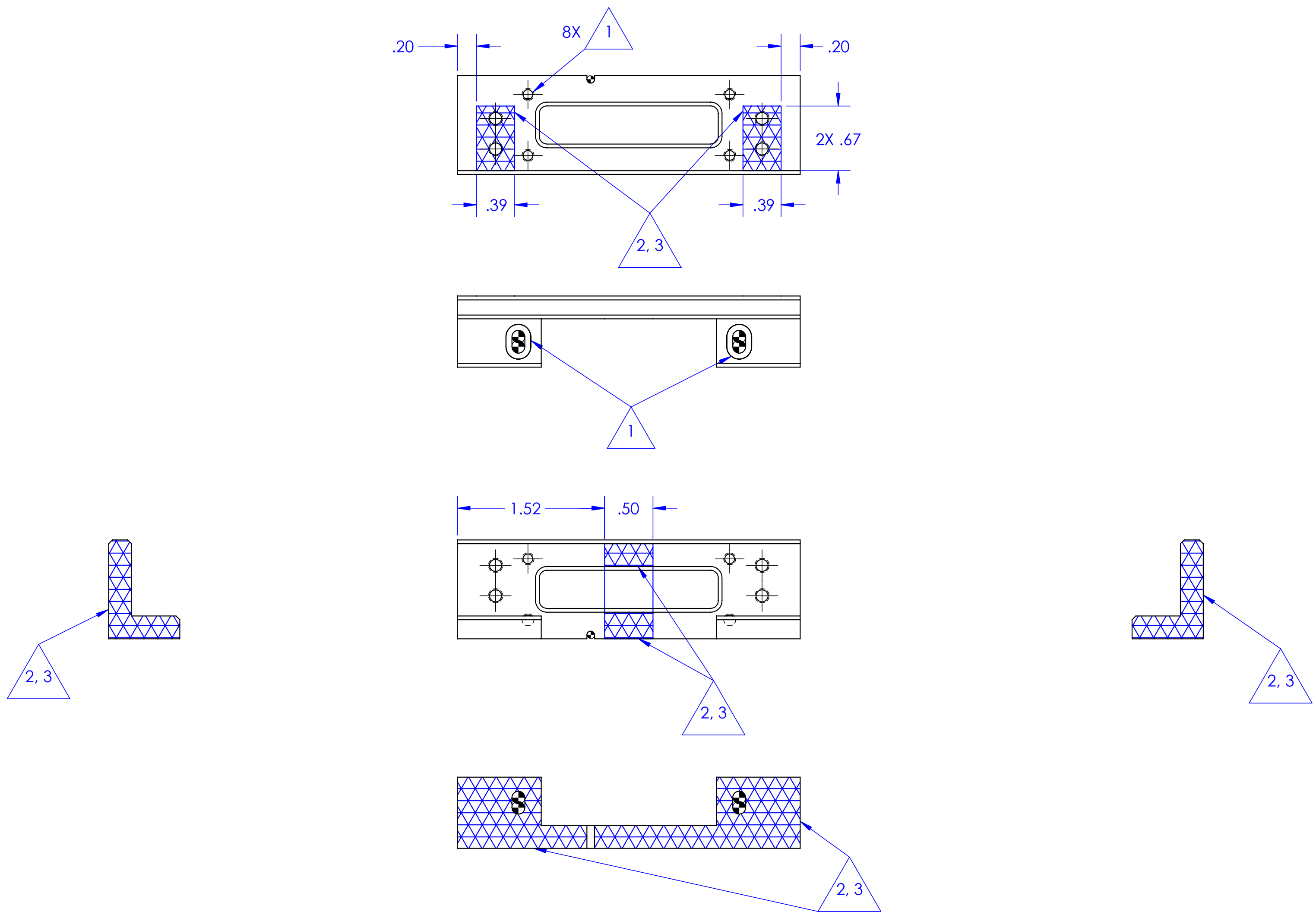
Title: Front Door Mount - 2/3

Part Number: MUV-F-107

Date: 03/10/2020

Scale: 1:1

Checked By: Kodi Rider, SSL



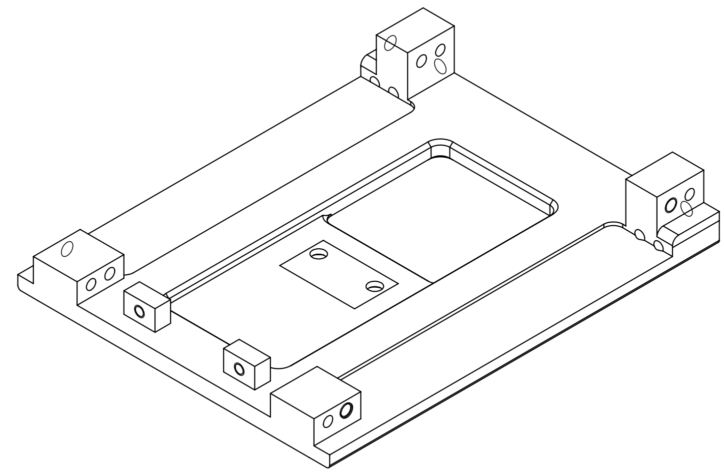
Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Front Door Mount - Anodize -3/3
	Part Number: MUV-F-107	Date: 04/28/2020	Scale: 1:1	Checked By: Kodi Rider, SSL

NOTES:

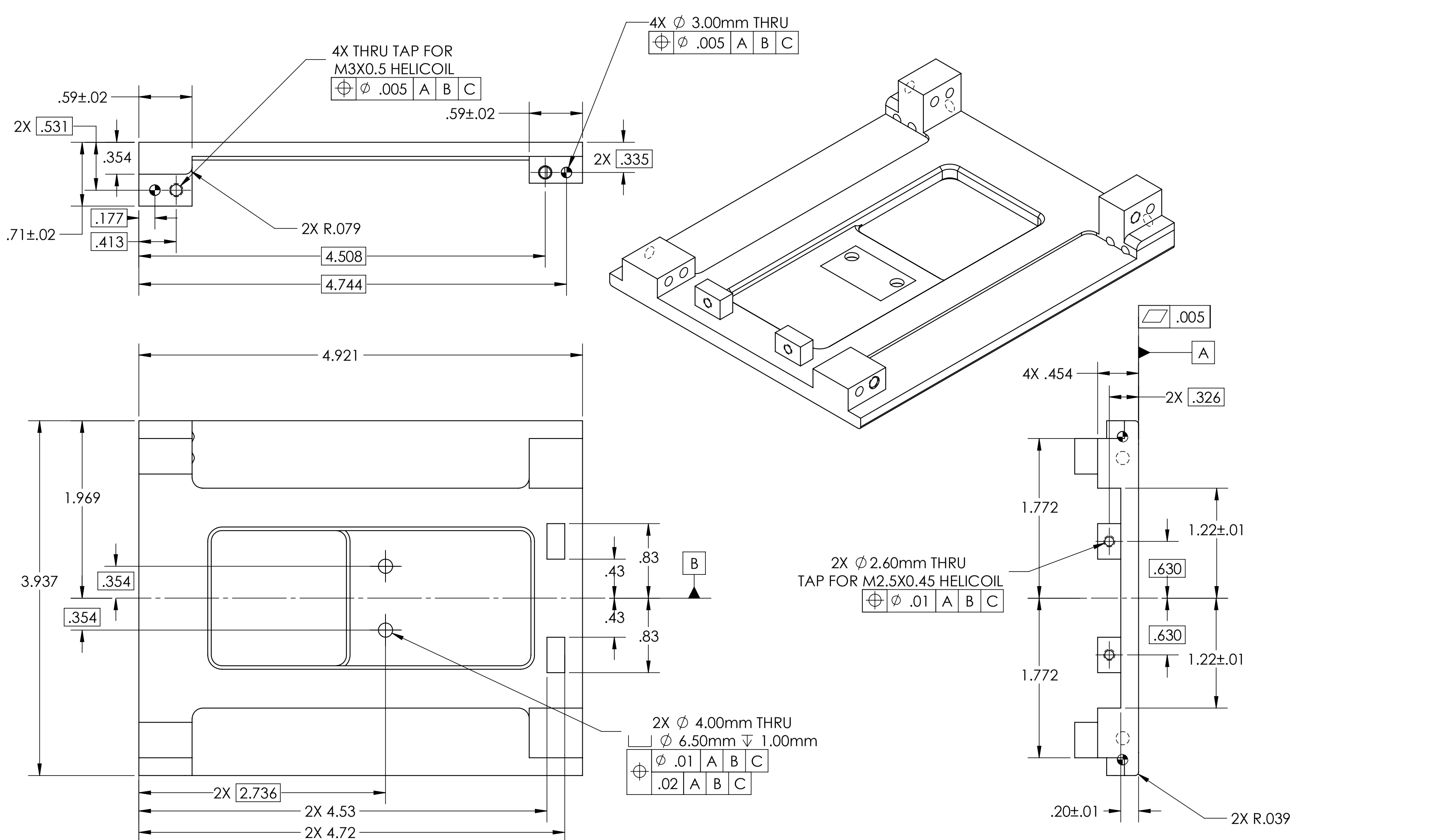
1. ANODIZE ALL MACHINED PARTS PER MIL-A-8625 TYPE II CLASS 2, EXCEPT WHERE NOTED PER NOTE 2. COLOR SHALL APPROXIMATE FED-STD-595 NO. 37038 (LUSTERLESS/MATTE BLACK). CAUTION: USE ONLY AN ORGANIC BLACK DYE. PRIOR TO ANODIZING, GRIT BLAST SURFACE TO BE ANODZED, USE NO. 50 ALUMINUM OXIDE GRIT. DO NOT USE GLASS BEADS. SEAL WITH NICKEL ACETATE. HELICOIL INTERTS, ALL THREADED HOLES, COUNTERBORE HOLES, AND DOWEL PIN HOLES SHALL BE FREE ANODIZE.

2. MASK INDICATED SURFACE AND/OR DIMENSIONED AREA BEFORE THE ANODIZATION PROCESS. SURFACE MUST REMAIN FREE OF ANODIZE.

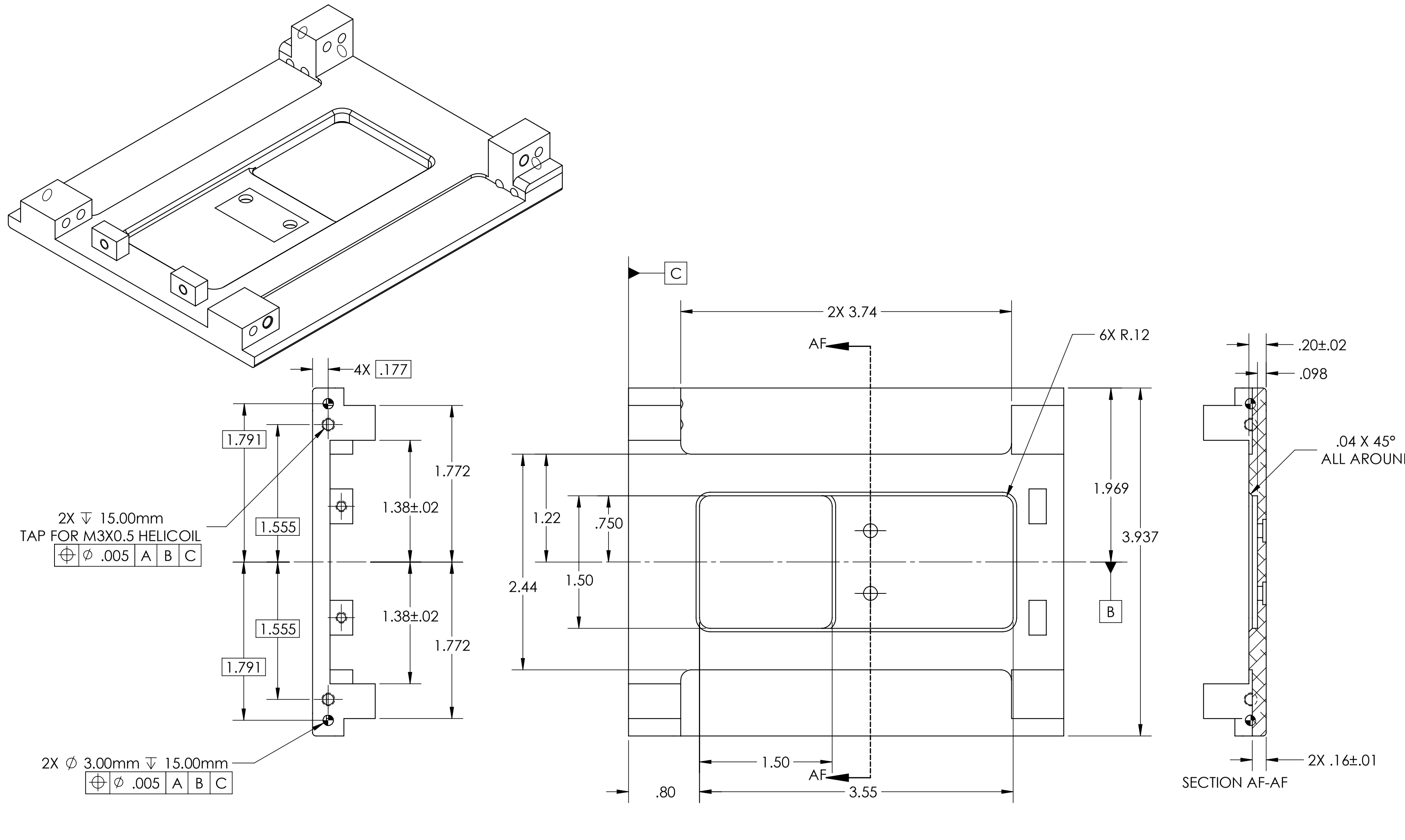
3. CHEM-FILM PER MIL-DTL-5541, CL3 (YELLOW). SEE DETAIL ON SHEET 4



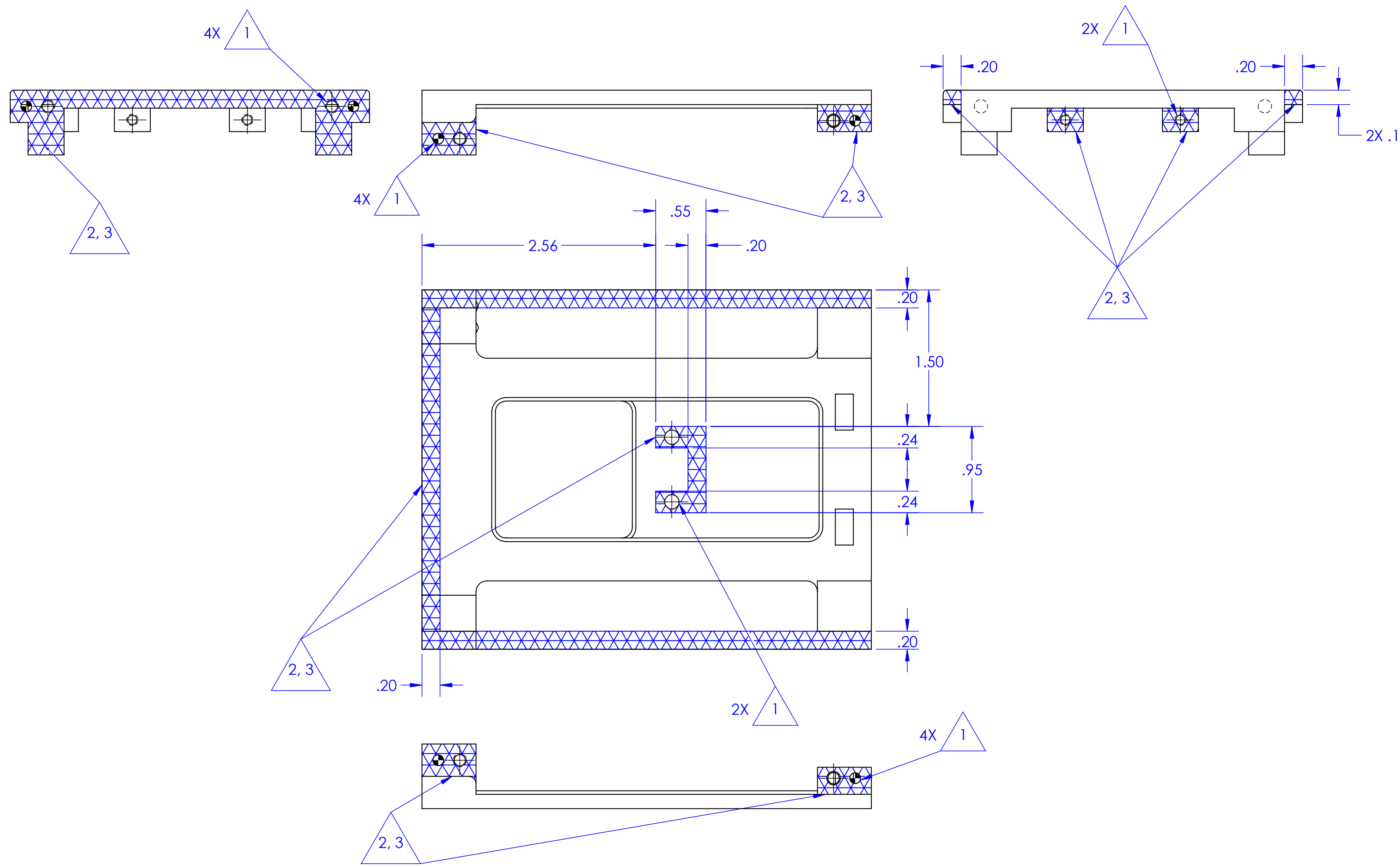
Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Top Plate - Page 1/4
	Part Number: MUV-F-108	Date: 04/29/2020	Scale: 1:1	Checked By: Kodi Rider, SSL



Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Top Plate - Page 2/4
	Part Number: MUV-F-108	Date: 03/10/2020	Scale: 1:1	Checked By: Kodi Rider, SSL



Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Top Plate - Page 3/4
	Part Number: MUV-F-108	Date: 03/10/2020	Scale: 1:1	Checked By: Kodi Rider, SSL



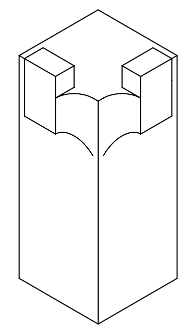
Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta	Title: Top Plate - Anodize - 4/4
	Part Number: MUV-F-108 | Date: 04/29/2020 | Scale: 1:1	Checked By: Kodi Rider, SSL

NOTES:

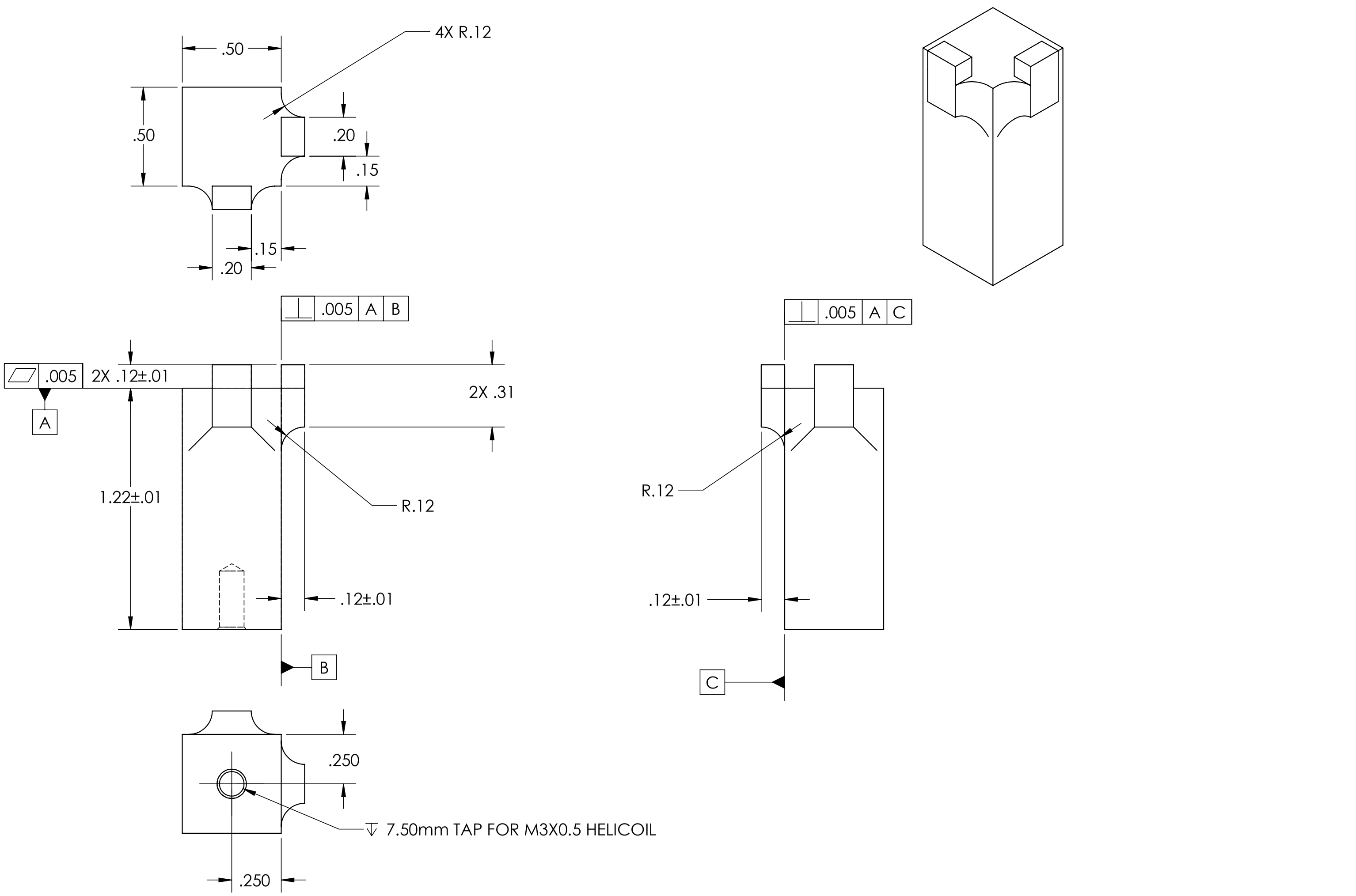
1. ANODIZE ALL MACHINED PARTS PER MIL-A-8625 TYPE II CLASS 2, EXCEPT WHERE NOTED PER NOTE 2. COLOR SHALL APPROXIMATE FED-STD-595 NO. 37038 (LUSTERLESS/MATTE BLACK). CAUTION: USE ONLY AN ORGANIC BLACK DYE. PRIOR TO ANODIZING, GRIT BLAST SURFACE TO BE ANODZED, USE NO. 50 ALUMINUM OXIDE GRIT. DO NOT USE GLASS BEADS. SEAL WITH NICKEL ACETATE. HELICOIL INTERTS, ALL THREADED HOLES, COUNTERBORE HOLES, AND DOWEL PIN HOLES SHALL BE FREE ANODIZE.

2. MASK INDICATED SURFACE AND/OR DIMENSIONED AREA BEFORE THE ANODIZATION PROCESS. SURFACE MUST REMAIN FREE OF ANODIZE.

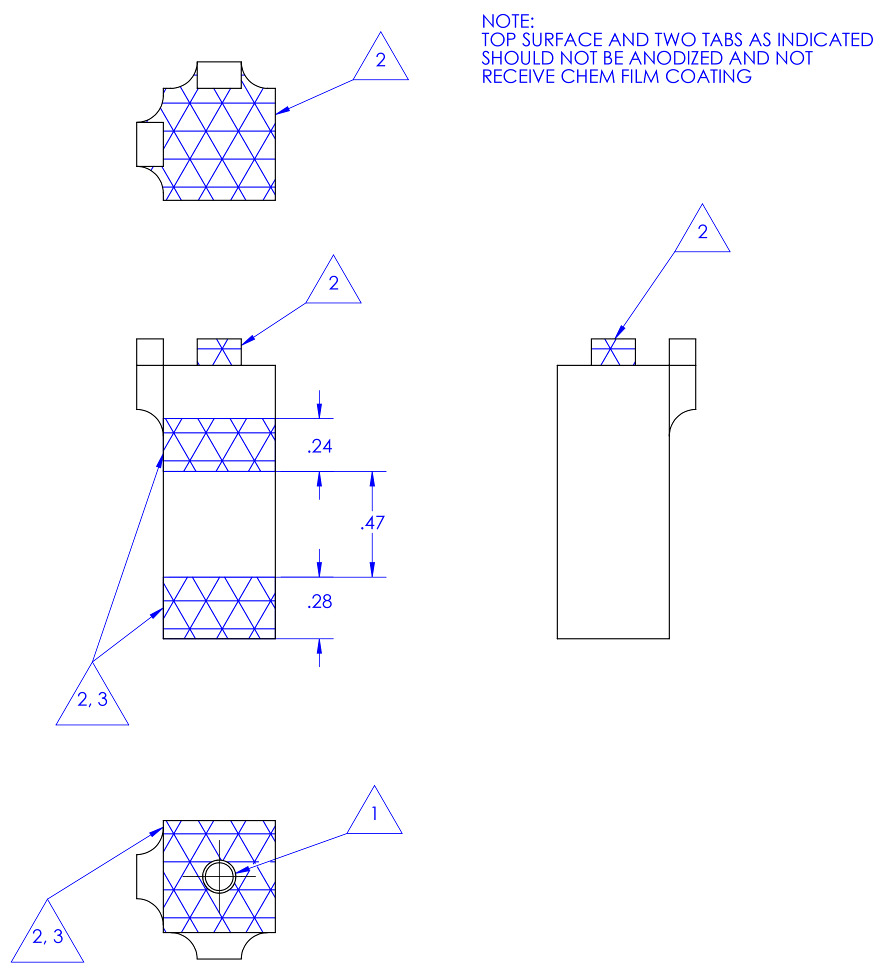
3. CHEM-FILM PER MIL-DTL-5541, CL3 (YELLOW). SEE DETAIL ON SHEET 3



Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Alignment Cube Tower - 1/3
	Part Number: MUV-F-109	Date: 04/29/2020	Scale: 2:1	Checked By: Kodi Rider, SSL



Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Alignment Cube Tower - 2/3
	Part Number: MUV-F-109	Date: 03/10/2020	Scale: 2:1	Checked By: Kodi Rider, SSL



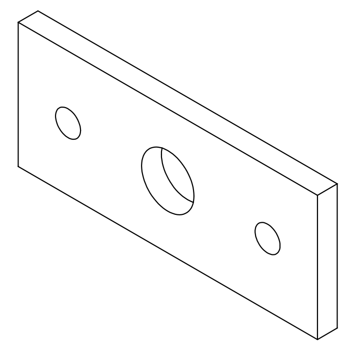
Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Cube Tower - Anodize - 3/3
	Part Number: MUV-F-109	Date: 04/29/2020	Scale: 2:1	Checked By: Kodi Rider, SSL

NOTES:

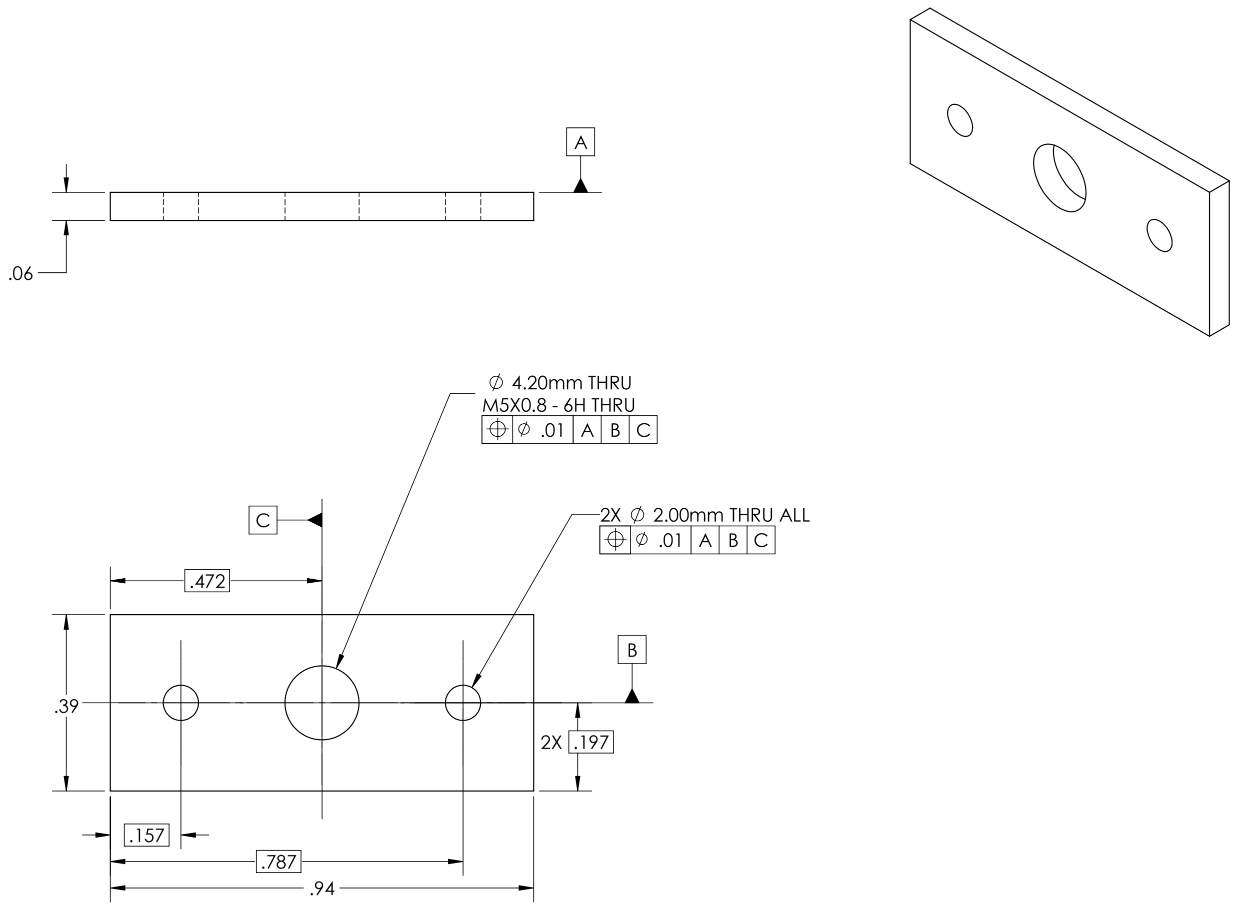
1. ANODIZE ALL MACHINED PARTS PER MIL-A-8625 TYPE II CLASS 2, EXCEPT WHERE NOTED PER NOTE 2. COLOR SHALL APPROXIMATE FED-STD-595 NO. 37038 (LUSTERLESS/MATTE BLACK). CAUTION: USE ONLY AN ORGANIC BLACK DYE. PRIOR TO ANODIZING, GRIT BLAST SURFACE TO BE ANODZED, USE NO. 50 ALUMINUM OXIDE GRIT. DO NOT USE GLASS BEADS. SEAL WITH NICKEL ACETATE. HELICOIL INTERTS, ALL THREADED HOLES, COUNTERBORE HOLES, AND DOWEL PIN HOLES SHALL BE FREE ANODIZE.

2. MASK INDICATED SURFACE AND/OR DIMENSIONED AREA BEFORE THE ANODIZATION PROCESS. SURFACE MUST REMAIN FREE OF ANODIZE.

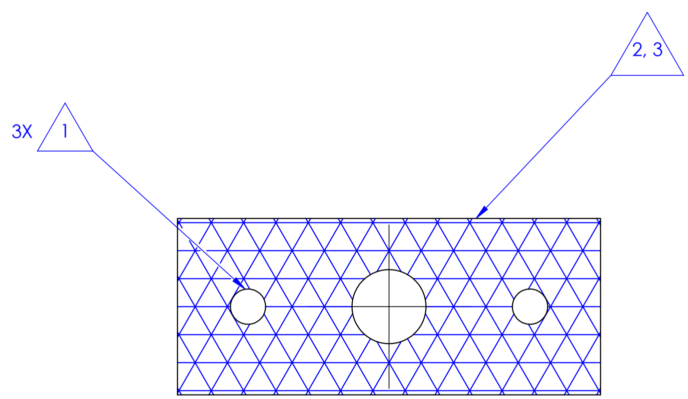
3. CHEM-FILM PER MIL-DTL-5541, CL3 (YELLOW). SEE DETAIL ON SHEET 3



Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Inlet N2 Filter Clamp - 1/3
	Part Number: MUV-F-110	Date: 05/01/2020	Scale: 4:1	Checked By: Kodi Rider, SSL



Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Inlet N2 Filter Clamp - 2/3
	Part Number: MUV-F-110	Date: 03/10/2020	Scale: 4:1	Checked By: Kodi Rider, SSL



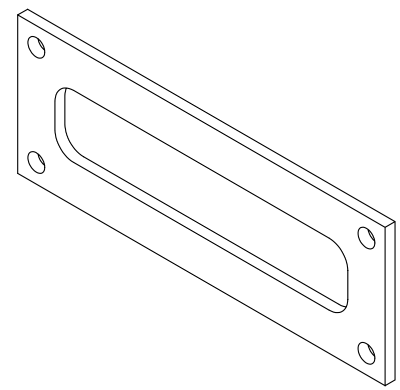
Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Inlet N2 Clamp - Anodize - 3/3
	Part Number: MUV-F-110	Date: 05/01/2020	Scale: 4:1	Checked By: Kodi Rider, SSL

NOTES:

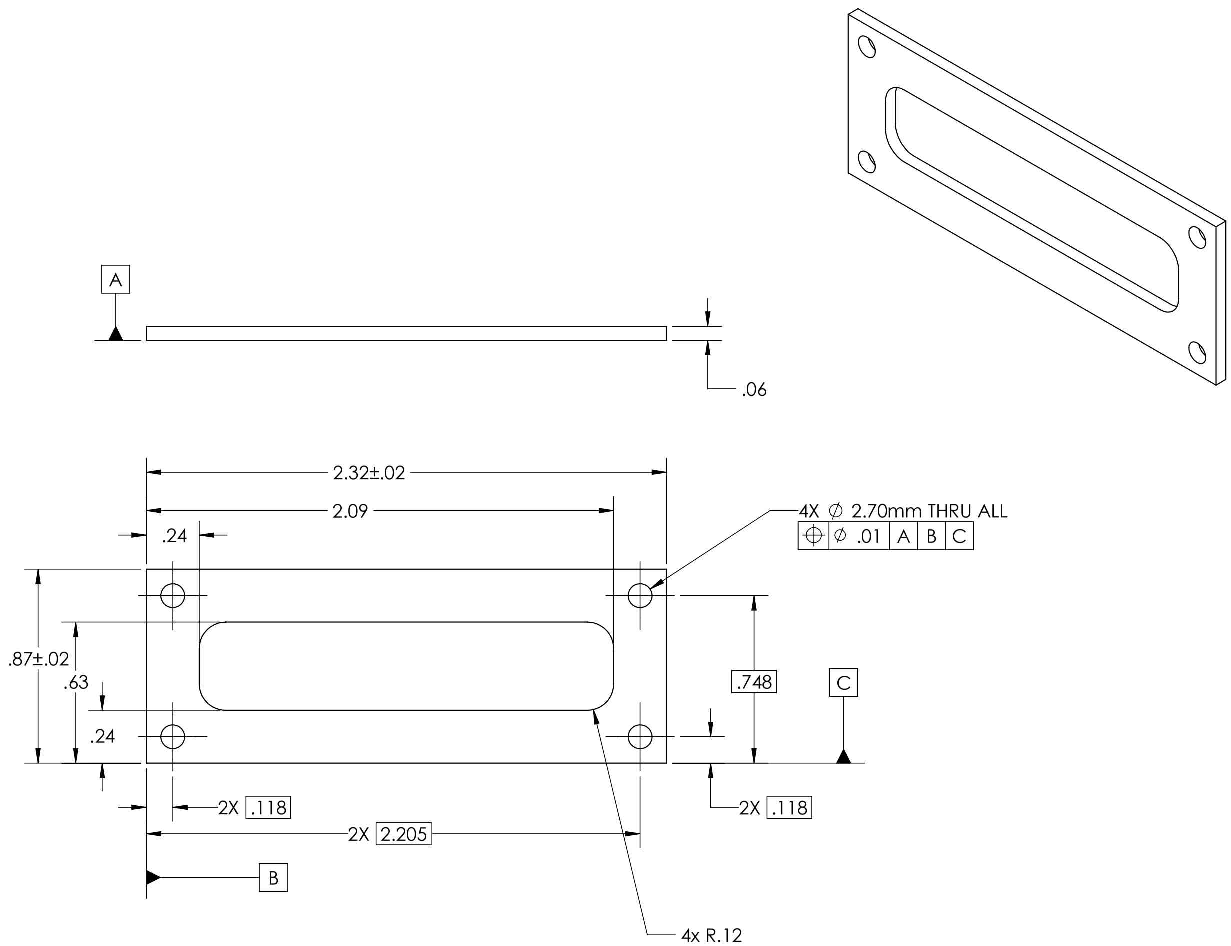
1. ANODIZE ALL MACHINED PARTS PER MIL-A-8625 TYPE II CLASS 2, EXCEPT WHERE NOTED PER NOTE 2. COLOR SHALL APPROXIMATE FED-STD-595 NO. 37038 (LUSTERLESS/MATTE BLACK). CAUTION: USE ONLY AN ORGANIC BLACK DYE. PRIOR TO ANODIZING, GRIT BLAST SURFACE TO BE ANODZED, USE NO. 50 ALUMINUM OXIDE GRIT. DO NOT USE GLASS BEADS. SEAL WITH NICKEL ACETATE. HELICOIL INTERTS, ALL THREADED HOLES, COUNTERBORE HOLES, AND DOWEL PIN HOLES SHALL BE FREE ANODIZE.

2. MASK INDICATED SURFACE AND/OR DIMENSIONED AREA BEFORE THE ANODIZATION PROCESS. SURFACE MUST REMAIN FREE OF ANODIZE.

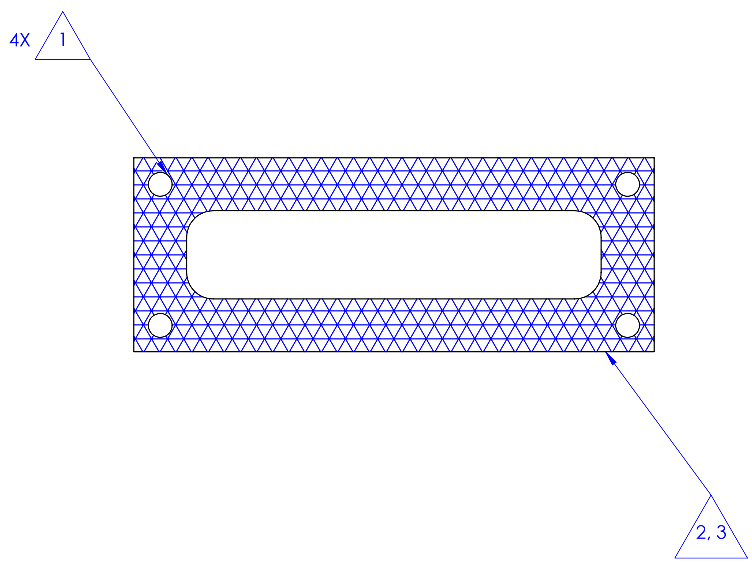
3. CHEM-FILM PER MIL-DTL-5541, CL3 (YELLOW). SEE DETAIL ON SHEET 3



Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Exit N2 Filter Clamp - 1/3
	Part Number: MUV-F-111	Date: 05/01/2020	Scale: 2:1	Checked By: Kodi Rider, SSL



Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Exit N2 Filter Clamp - 2/3
	Part Number: MUV-F-111	Date: 03/10/2020	Scale: 2:1	Checked By: Kodi Rider, SSL



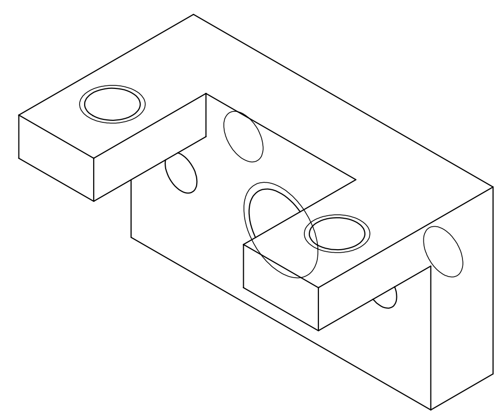
Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Exit N2 Clamp - Anodize - 3/3
	Part Number: MUV-F-111	Date: 05/01/2020	Scale: 2:1	Checked By: Kodi Rider, SSL

NOTES:

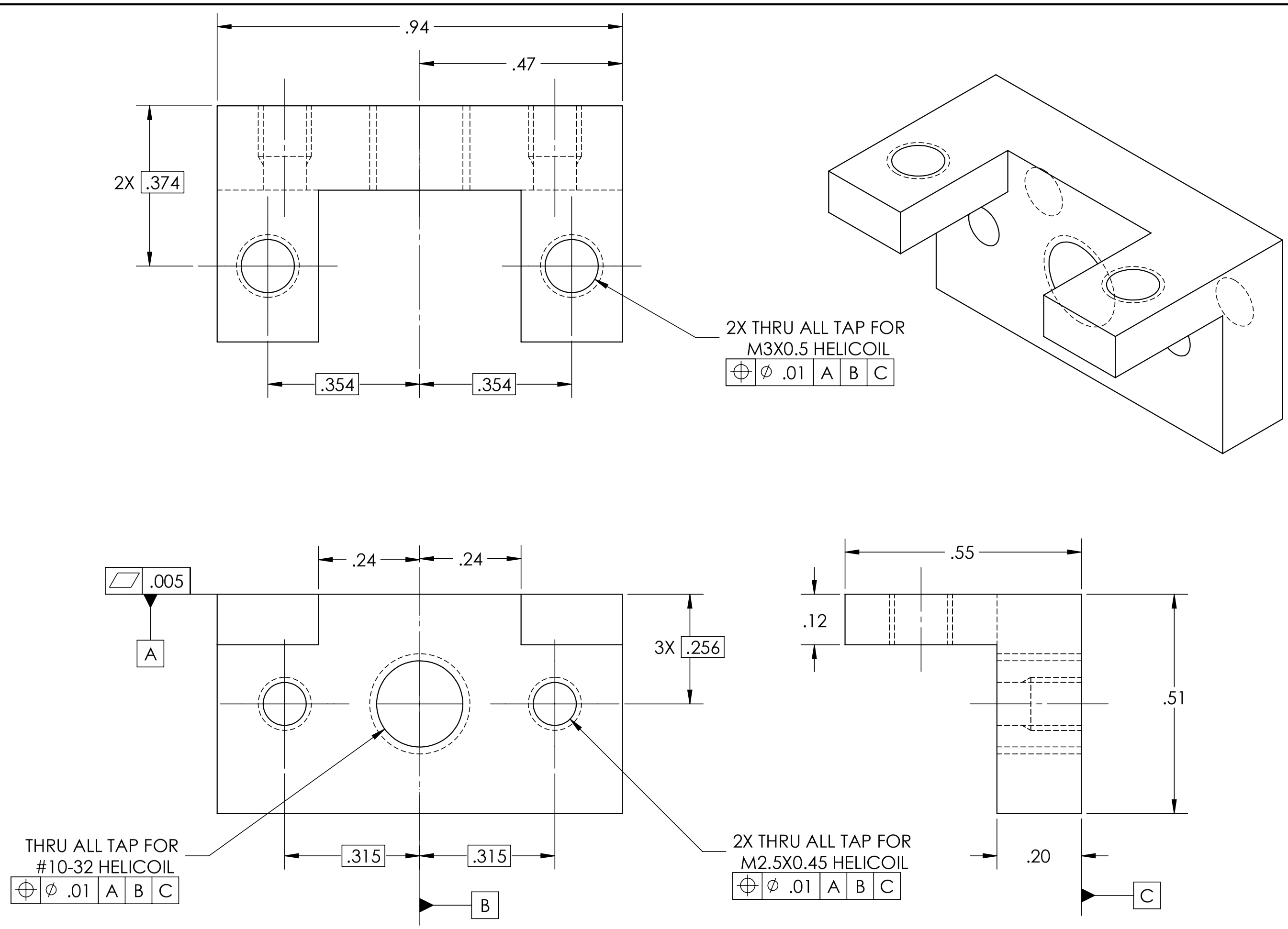
1. ANODIZE ALL MACHINED PARTS PER MIL-A-8625 TYPE II CLASS 2, EXCEPT WHERE NOTED PER NOTE 2. COLOR SHALL APPROXIMATE FED-STD-595 NO. 37038 (LUSTERLESS/MATTE BLACK). CAUTION: USE ONLY AN ORGANIC BLACK DYE. PRIOR TO ANODIZING, GRIT BLAST SURFACE TO BE ANODZED, USE NO. 50 ALUMINUM OXIDE GRIT. DO NOT USE GLASS BEADS. SEAL WITH NICKEL ACETATE. HELICOIL INTERTS, ALL THREADED HOLES, COUNTERBORE HOLES, AND DOWEL PIN HOLES SHALL BE FREE ANODIZE.

2. MASK INDICATED SURFACE AND/OR DIMENSIONED AREA BEFORE THE ANODIZATION PROCESS. SURFACE MUST REMAIN FREE OF ANODIZE.

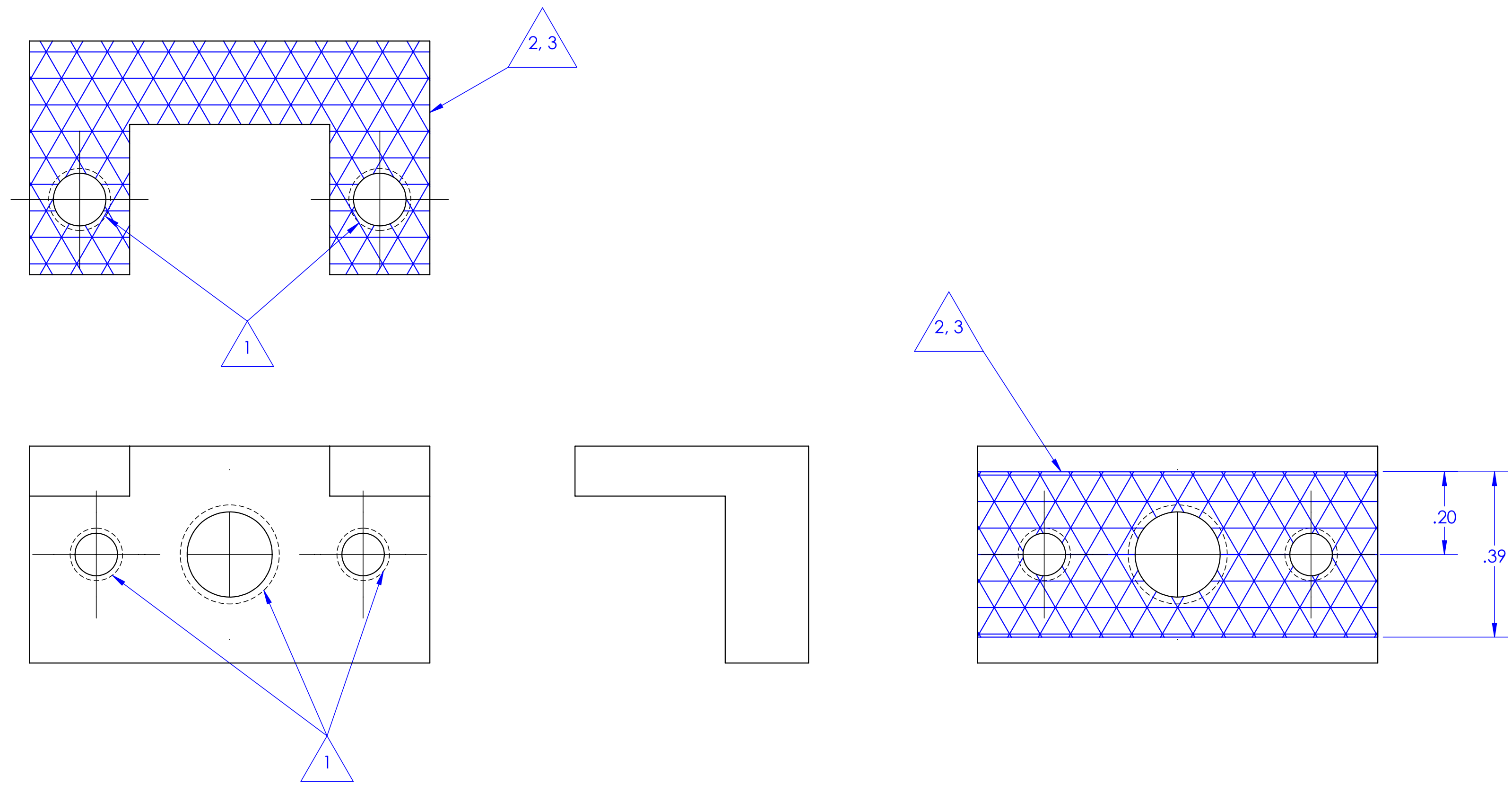
3. CHEM-FILM PER MIL-DTL-5541, CL3 (YELLOW). SEE DETAIL ON SHEET 3



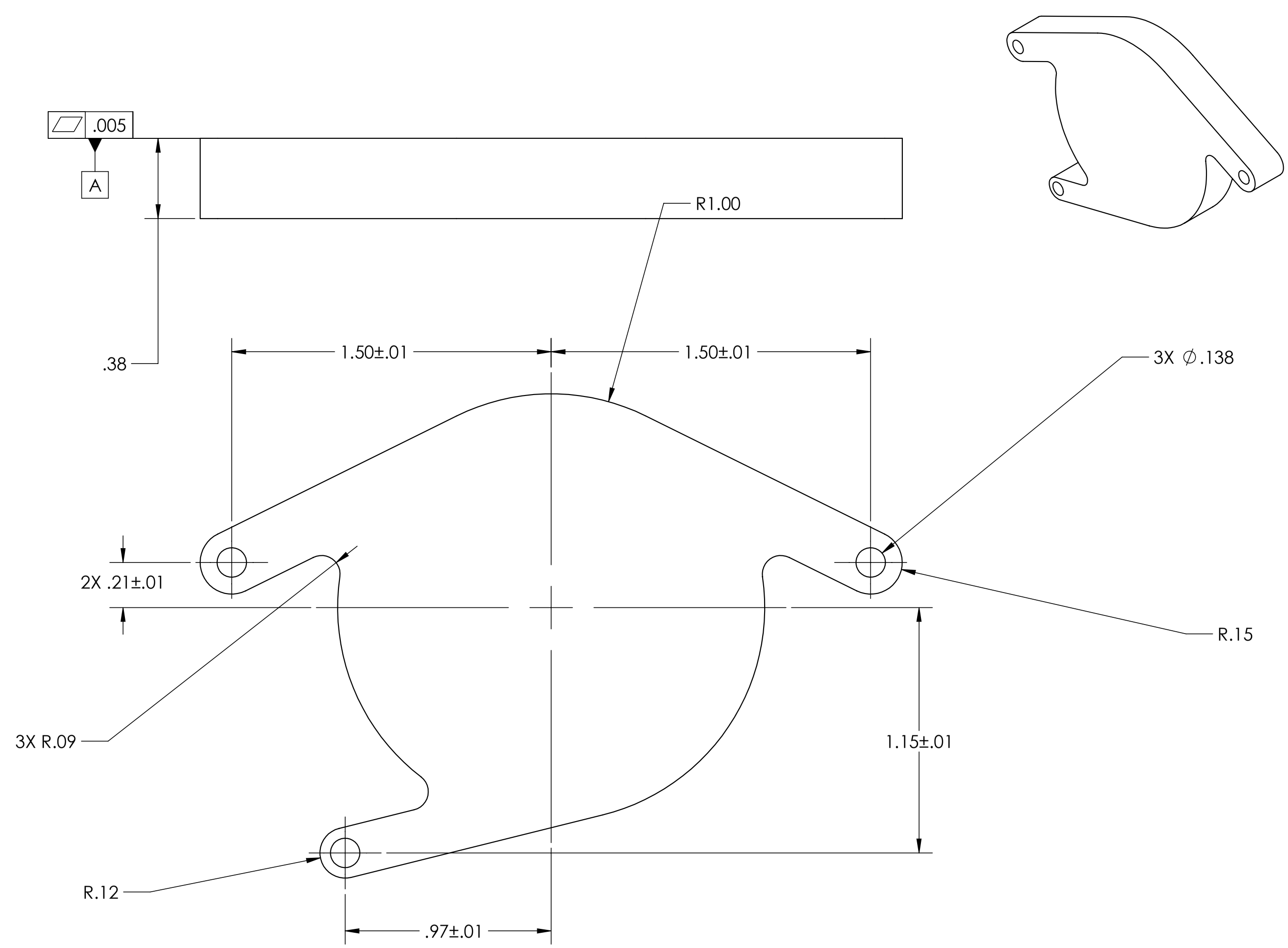
Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta		Title: N2 Push-to-Connect Mount - 1/3
	Part Number: MUV-F-112	Date: 04/29/2020 Scale: 4:1	Checked By: Kodi Rider, SSL



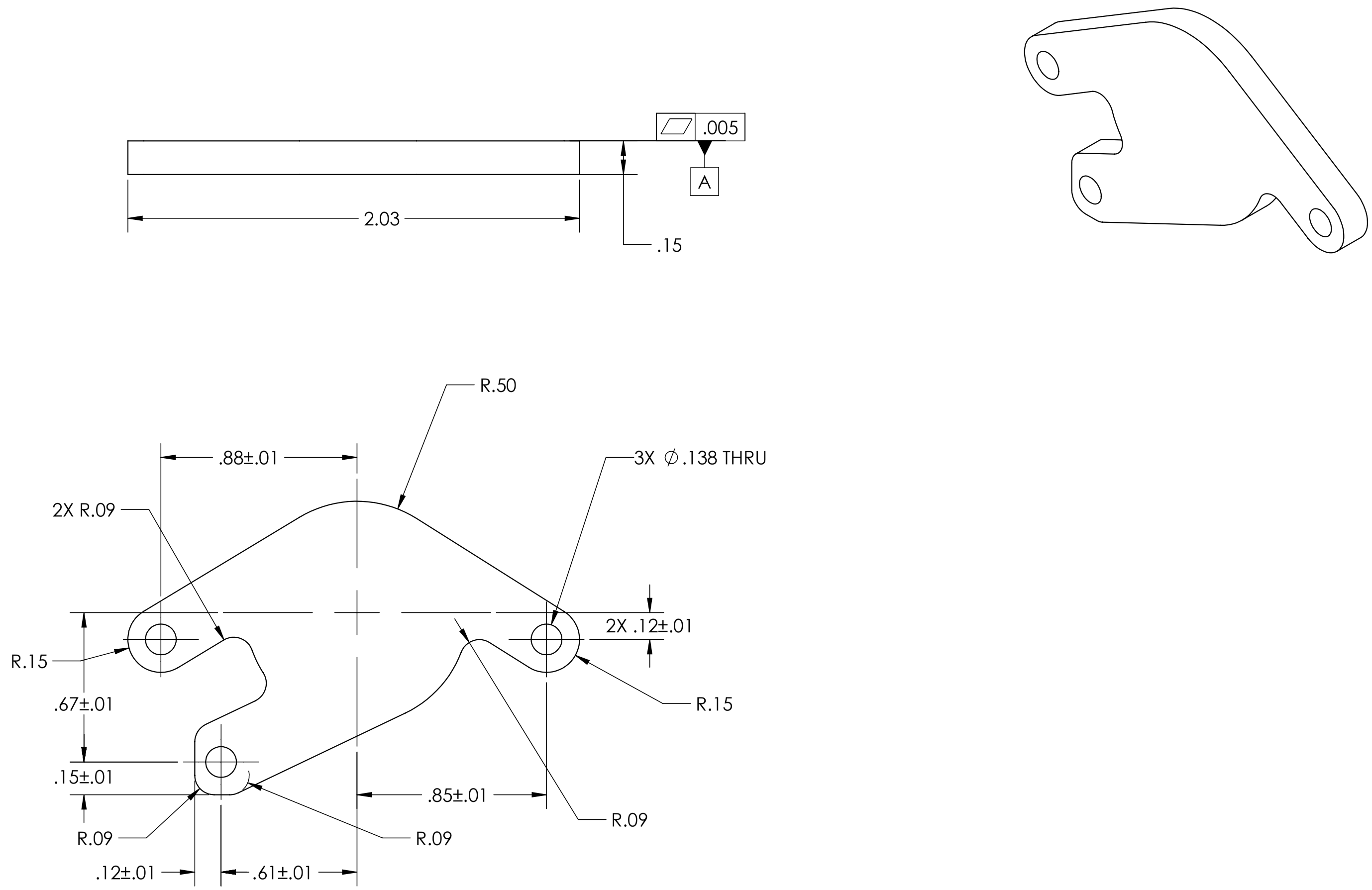
Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: N2 Push-to-Connect Mount - 2/3
	Part Number: MUV-F-112	Date: 03/10/2020	Scale: 4:1	Checked By: Kodi Rider, SSL



Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: N2 Mount - Anodize - 3/3
	Part Number: MUV-F-112	Date: 04/29/2020	Scale: 4:1	Checked By: Kodi Rider, SSL



Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Top Mirror Mass Model
	Part Number: MUV-F-130	Date: 03/10/2020	Scale: 2:1	Checked By: Kodi Rider, SSL

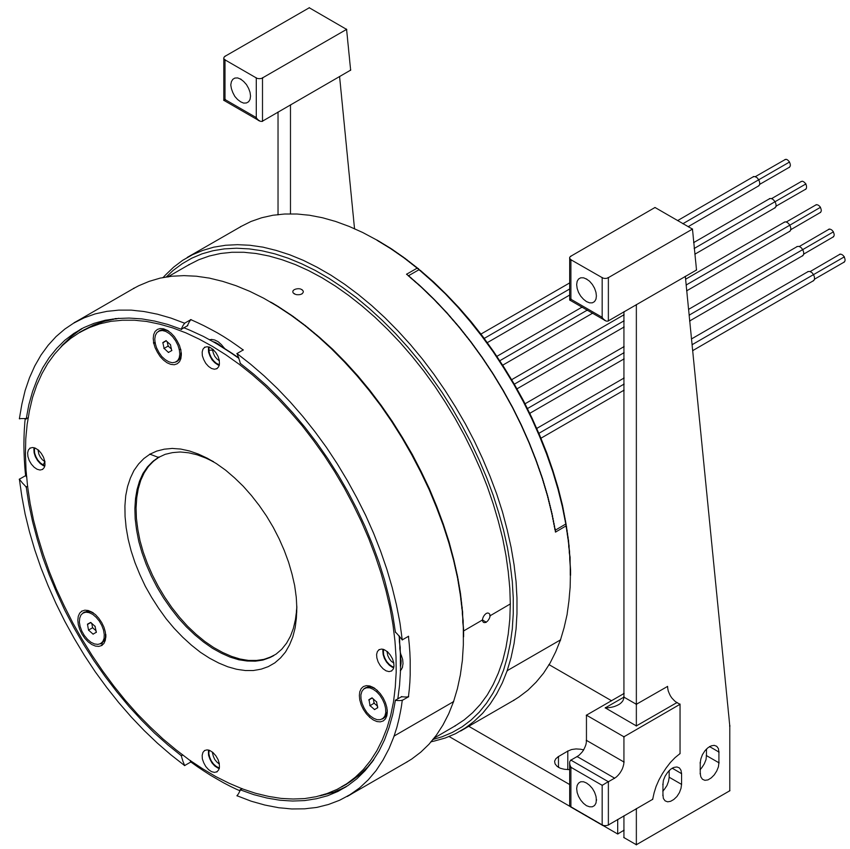


Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Bottom Mirror Mass Model
	Part Number: MUV-F-131	Date: 03/10/2020	Scale: 2:1	Checked By: Kodi Rider, SSL

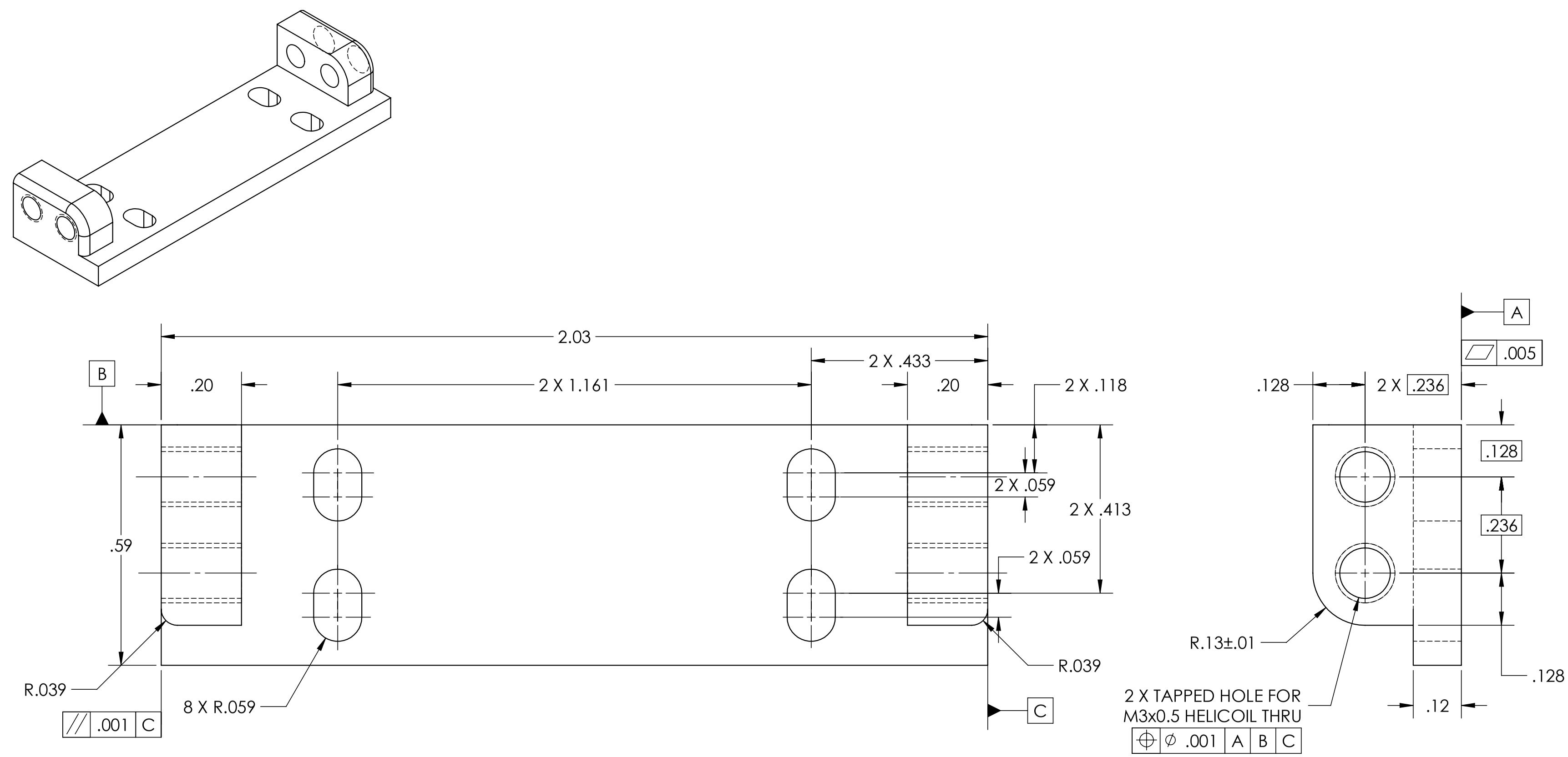
PART NO.	NAME	QTY.
MUV-FLEX-001	BASE PLATE	1
MUV-FLEX-002	TOWER	2
MUV-FLEX-003	HORIZONTAL STANDOFF	1
MUV-FLEX-004	VERTICAL STANDOFF	2

NOTES:
UNLESS OTHERWISE SPECIFIED

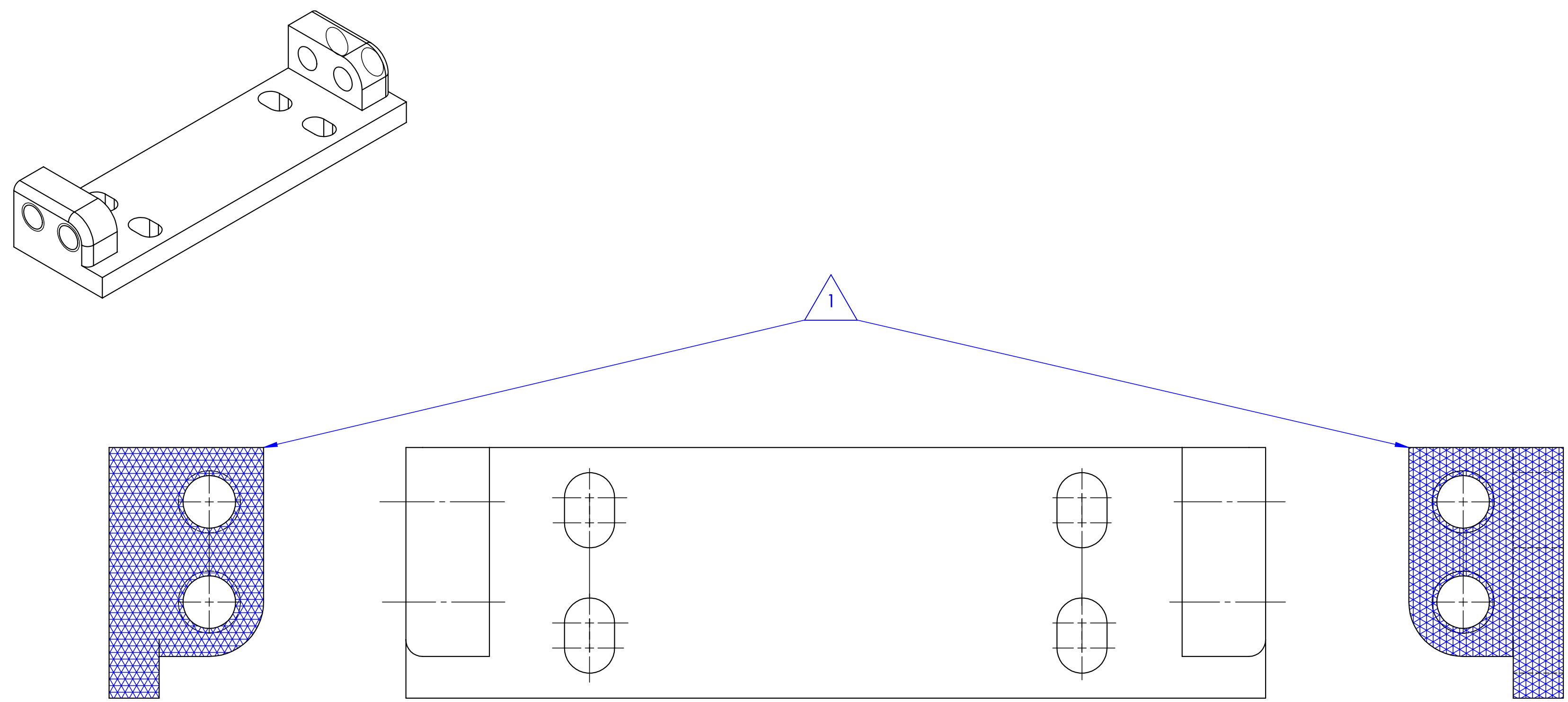
1. ANODIZE ALL MACHINED PARTS PER MIL-A-8625 TYPE II CLASS 2. EXCEPT WHERE NOTED PER NOTE 2. COLOR SHALL APPROXIMATE FED-STD-595 NO. 37038 (LUSTERLESS/MATTE BLACK). CAUTION: USE ONLY AN ORGANIC BLACK DYE. PRIOR TO ANODIZING, GRIT BLAST SURFACE TO BE ANODIZED. USE NO. 50 ALUMINUM OXIDE GRIT. DO NOT USE GLASS BEADS. SEAL WITH NICKEL ACETATE. HELICOIL INSERTS, COUNTERBOR HOLES AND SLOTS, AND DOWEL PIN HOLES SHALL BE FREE OF ANODIZE.
2. MASK INDICATED SURFCE AND/OR DIMENSIONED AREA BEFORE THE ANODIZATION PROCESS. SURFACE MUST REMAIN FREE OF ANODIZE.
3. MATERIAL IS T6-6061 ALUMINUM
4. ALL DIMENSIONS ARE IN
5. TOLERANCES
   X.XX ±.02
   X.XXX ±.005
   ANGLES ±1.0°
6. INSIDE TOOL RADIUS .02 MAX
7. BREAK SHARP EDGES .01 MAX



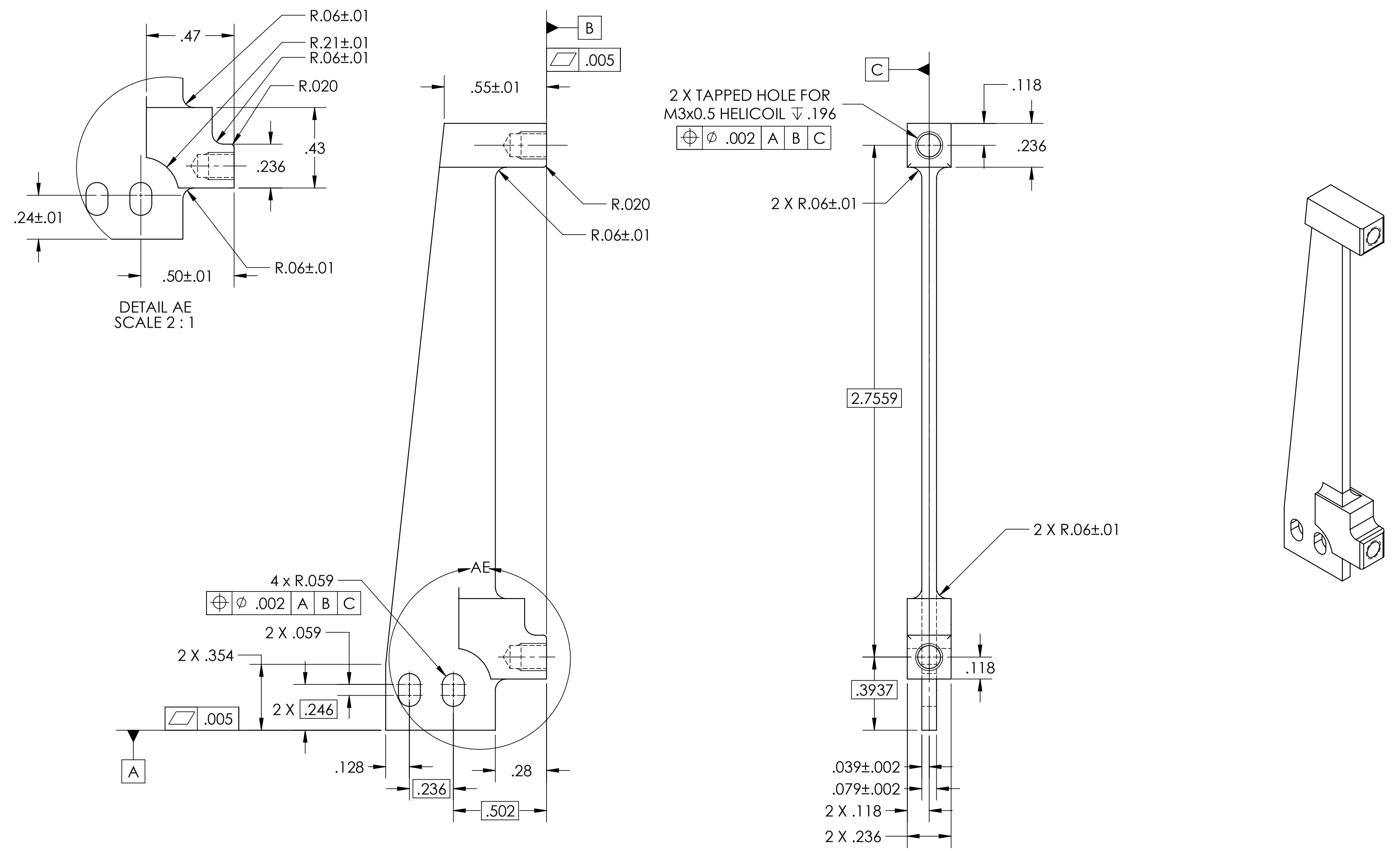
Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Flexure Sub-Assembly
	Part Number: MUV-FLEX-000	Date: 3/17/2020	Scale: 2:1	Checked By: Kodi Rider, SSL



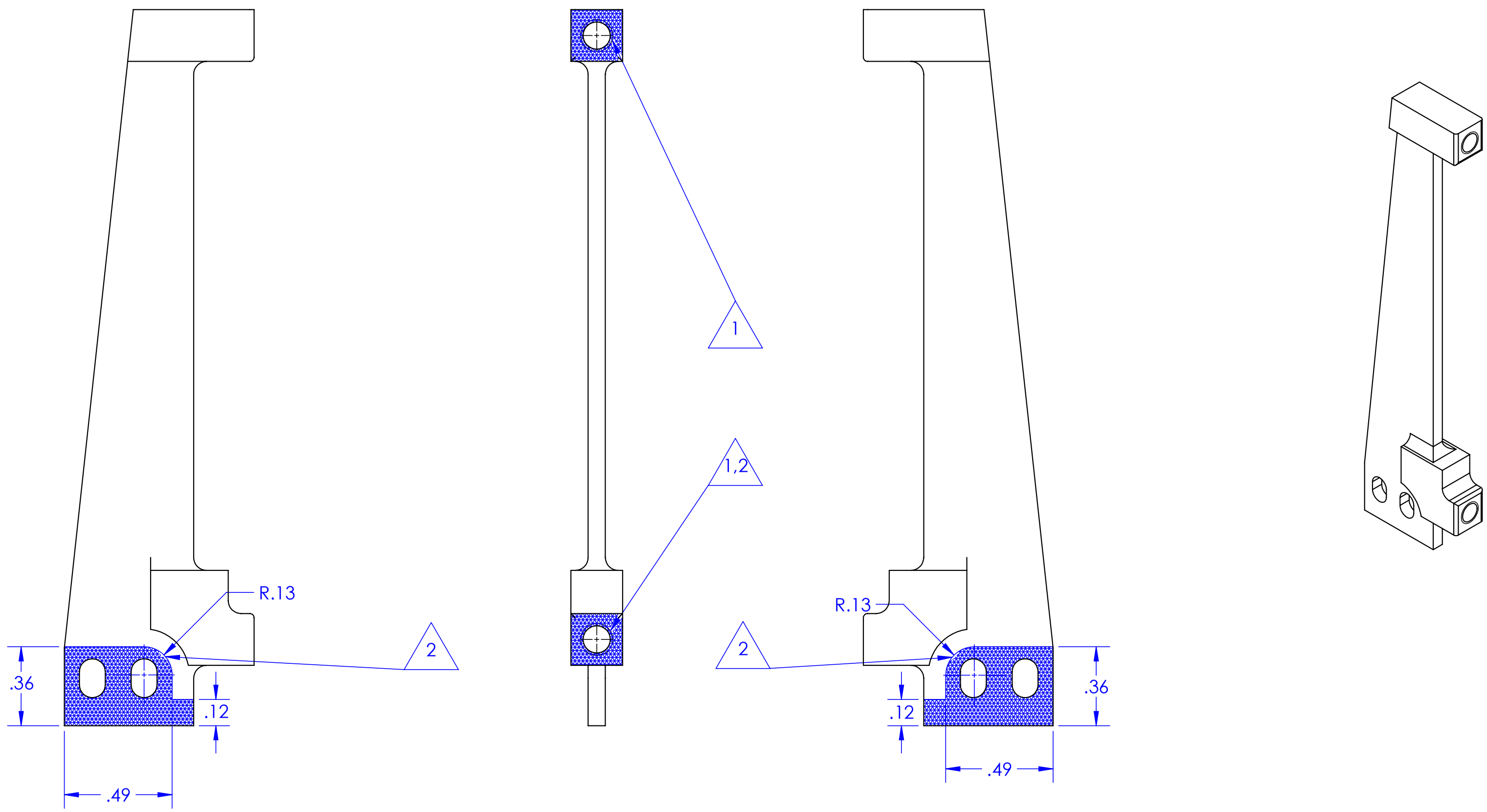
Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: BASE PLATE
	Part Number: MUV-FLEX-001	Date: 3/17/2020	Scale: 4:1	Checked By: Kodi Rider, SSL



Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: BASE PLATE
	Part Number: MUV-FLEX-001	Date: 3/17/2020	Scale: 4:1	Checked By: Kodi Rider, SSL

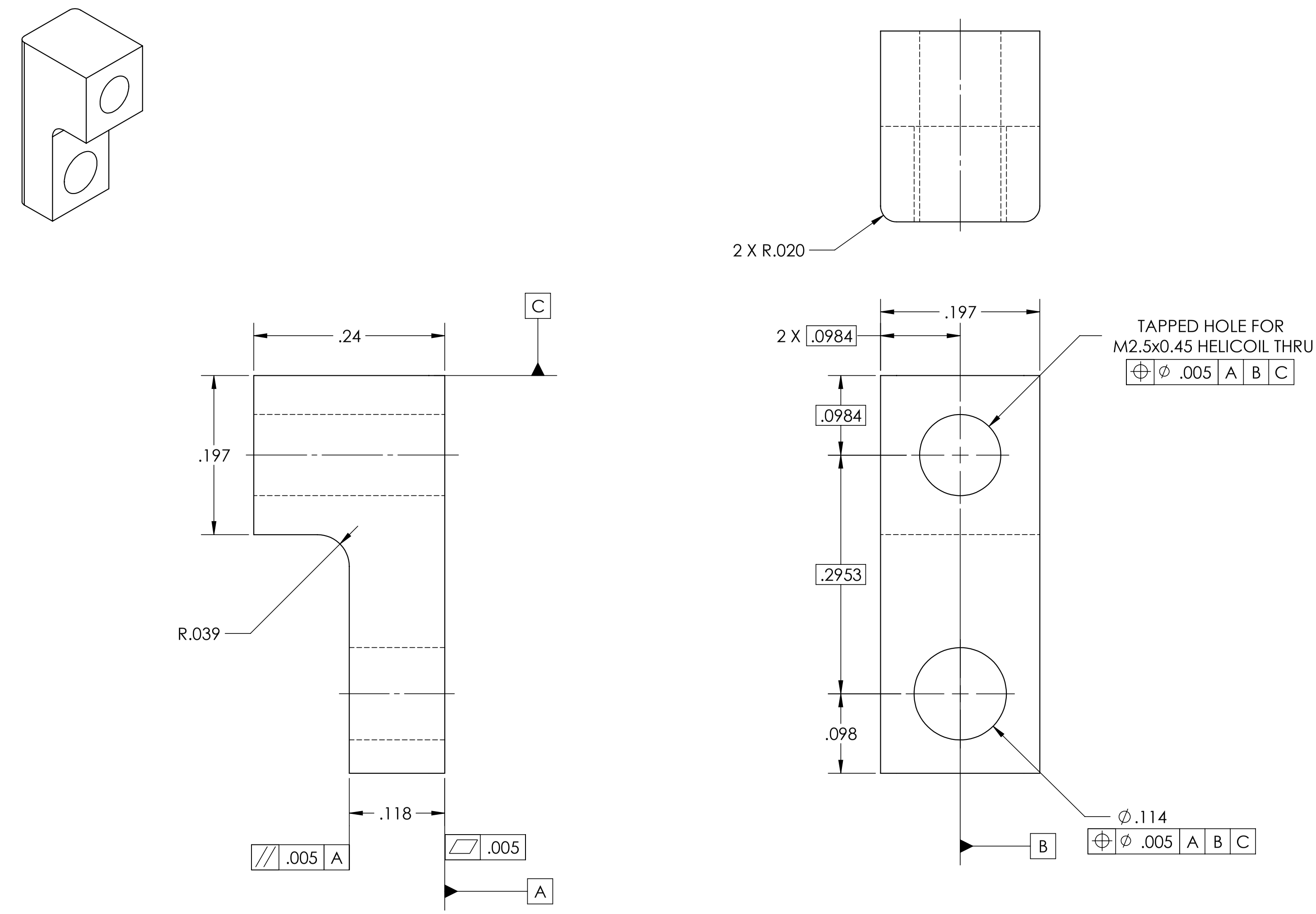


Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: TOWER
	Part Number: MUV-FLEX-002	Date: 3/17/2020	Scale: 2:1	Checked By: Kodi Rider, SSL

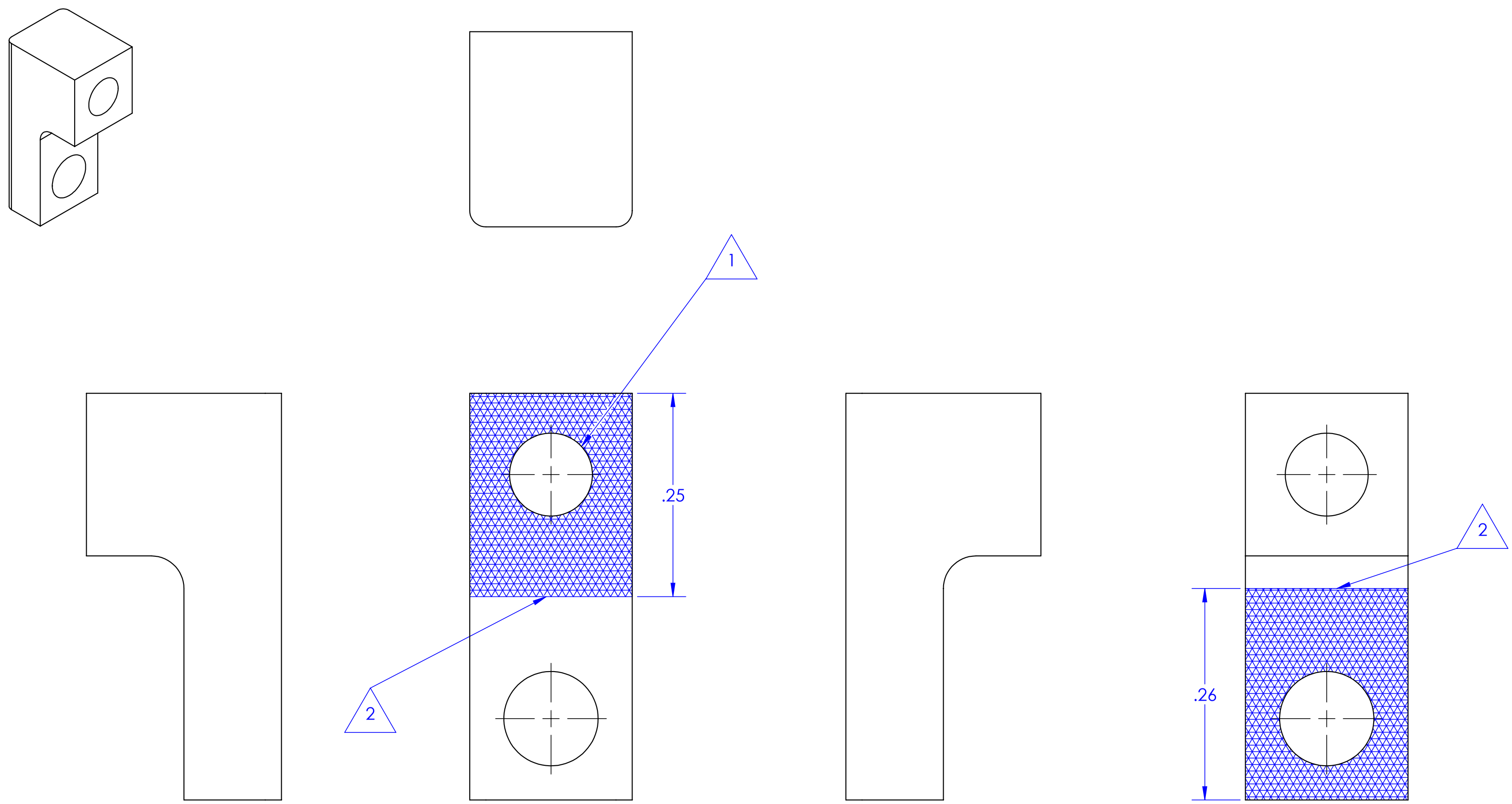


Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: TOWER
	Part Number: MUV-FLEX-002	Date: 3/17/2020	Scale: 2:1	Checked By: Kodi Rider, SSL

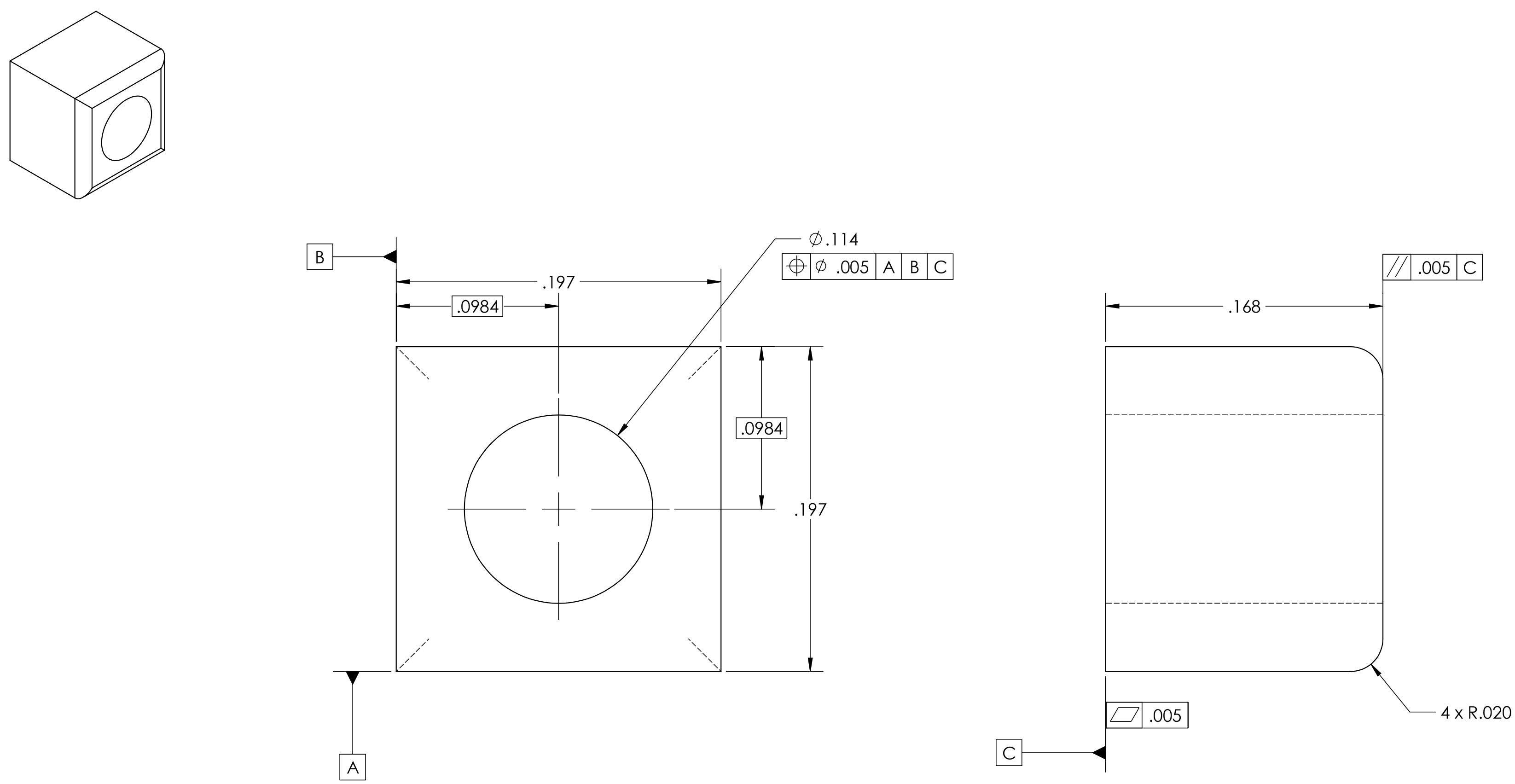
SOLIDWORKS Educational Product. For Instructional Use Only.



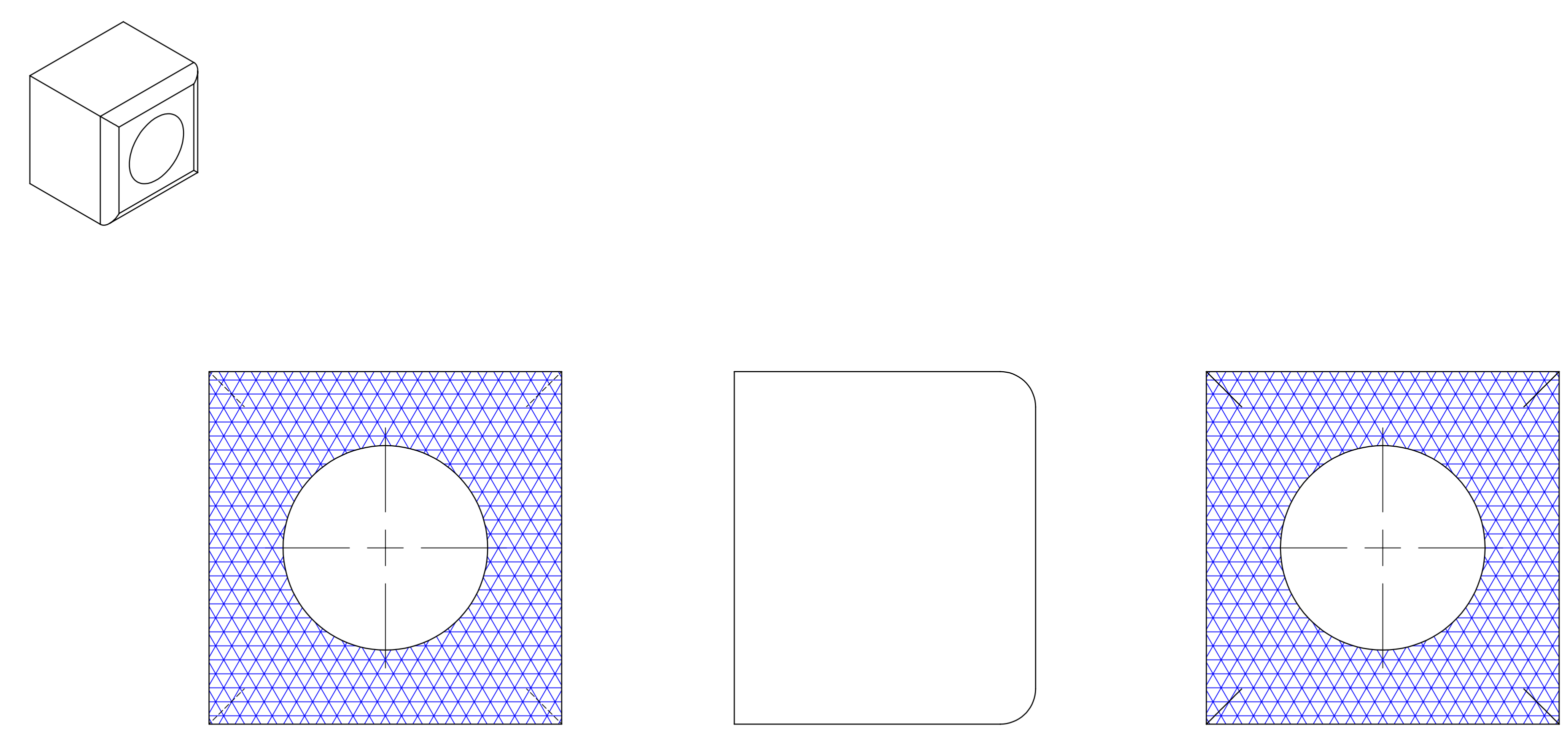
Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: HORIZONTAL STANDOFF
	Part Number: MUV-FLEX-003	Date: 3/17/2020	Scale: 4:1	Checked By: Kodi Rider, SSL



Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: HORIZONTAL STANDOFF
	Part Number: MUV-FLEX-003	Date: 3/17/2020	Scale: 4:1	Checked By: Kodi Rider, SSL

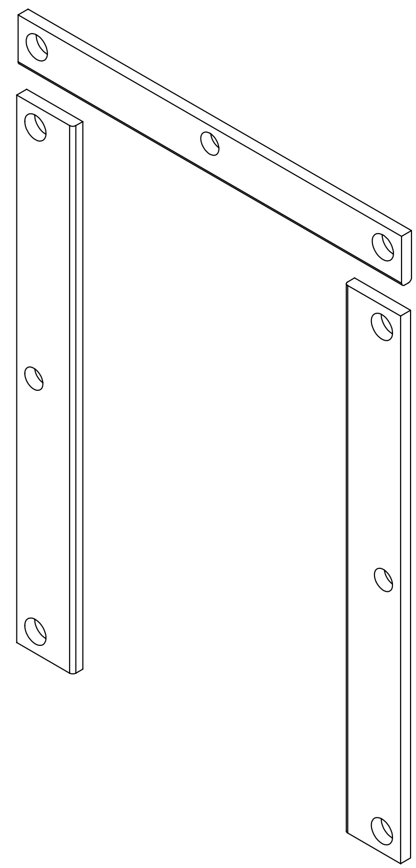


Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: VERTICAL STANDOFF
	Part Number: MUV-FLEX-004	Date: 3/17/2020	Scale: 4:1	Checked By: Kodi Rider, SSL



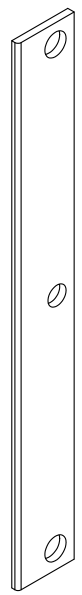
Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: VERTICAL STANDOFF
	Part Number: MUV-FLEX-004	Date: 3/17/2020	Scale: 4:1	Checked By: Kodi Rider, SSL

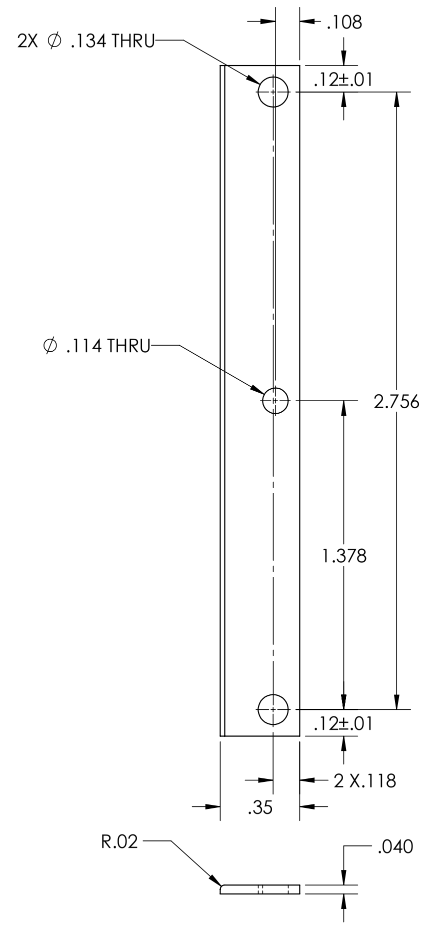
PART NO.	NAME	QTY.
MUV-FLEXBLADE-001	VERTICAL FLEXURE BLADE .040	2
MUV-FLEXBLADE-002	VERTICAL FLEXURE BLADE .050	2
MUV-FLEXBLADE-003	VERTICAL FLEXURE BLADE .063	2
MUV-FLEXBLADE-004	HORIZONTAL FLEXURE BLADE .040	1
MUV-FLEXBLADE-005	HORIZONTAL FLEXURE BLADE .050	1
MUV-FLEXBLADE-006	HORIZONTAL FLEXURE BLADE .063	1



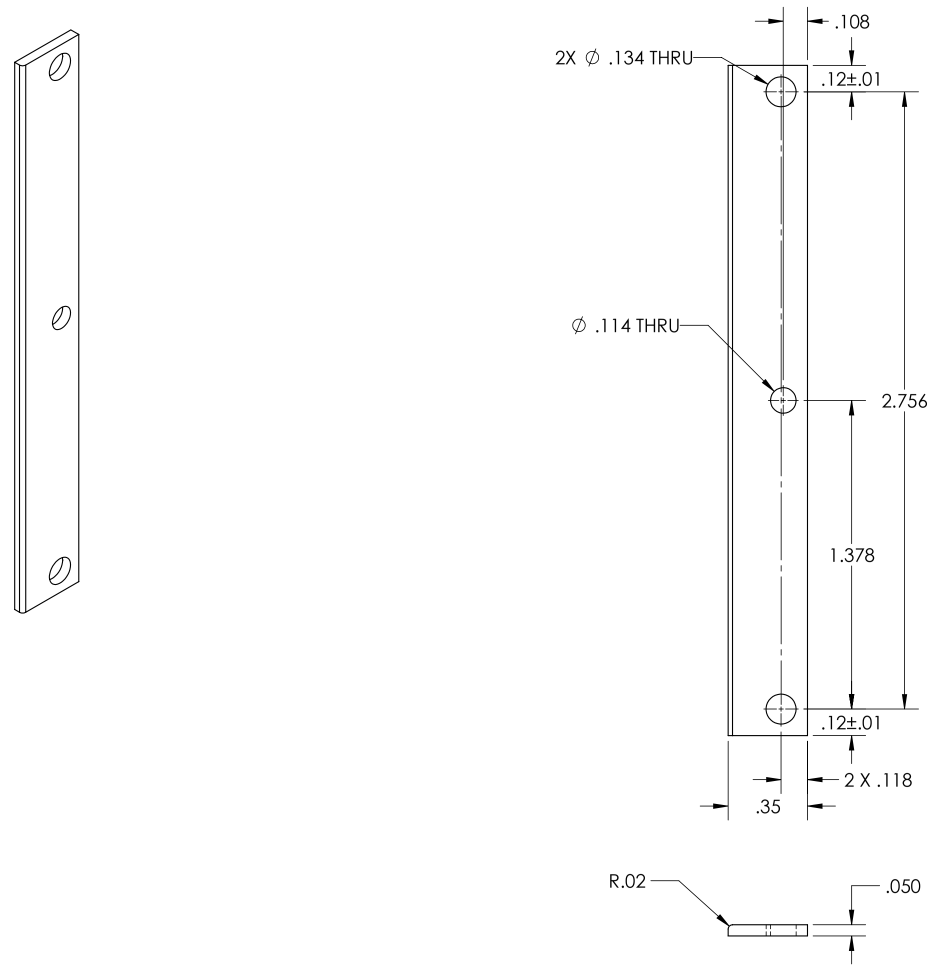
NOTES:
UNLESS OTHERWISE SPECIFIED
1. MATERIAL IS 6Al-4V TITANIUM
2. FINISH: TITANIUM ANODIZA OR TIODIZE IAW AMS-2488, TYPE II
3. ALL DIMENSIONS ARE IN
4. TOLERANCES
   X.XX ±.02
   X.XXX ±.005
   ANGLES ±1.0°
5. INSIDE TOOL RADIUS .02 MAX
6. BREAK SHARP EDGES .01 MAX

Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: Flexure Blades
	Part Number: MUV-FLEXBLADE-000	Date: 4/23/2020	Scale: 2:1	Checked By: Kodi Rider, SSL

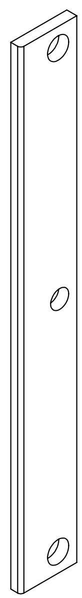


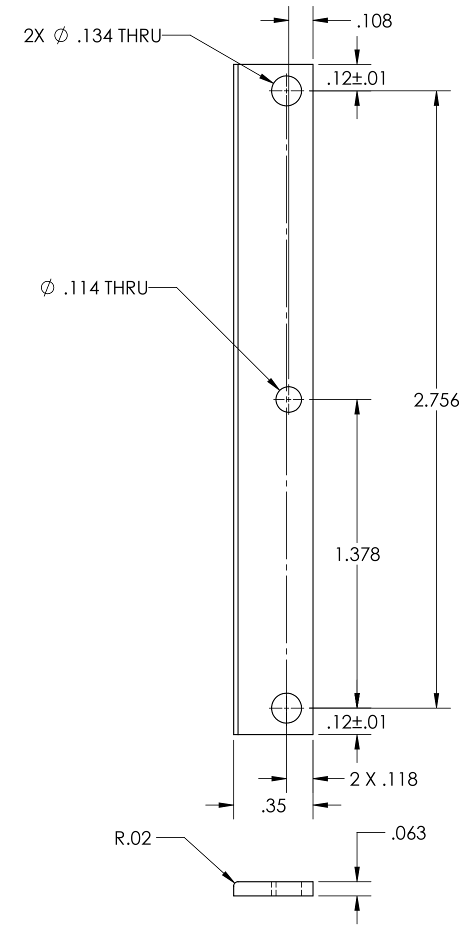


Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: VERTICAL FLEXURE BLADE
	Part Number: MUV-FLEXBLADE-001	Date: 4/22/2020	Scale: 2:1	Checked By: Kodi Rider, SSL

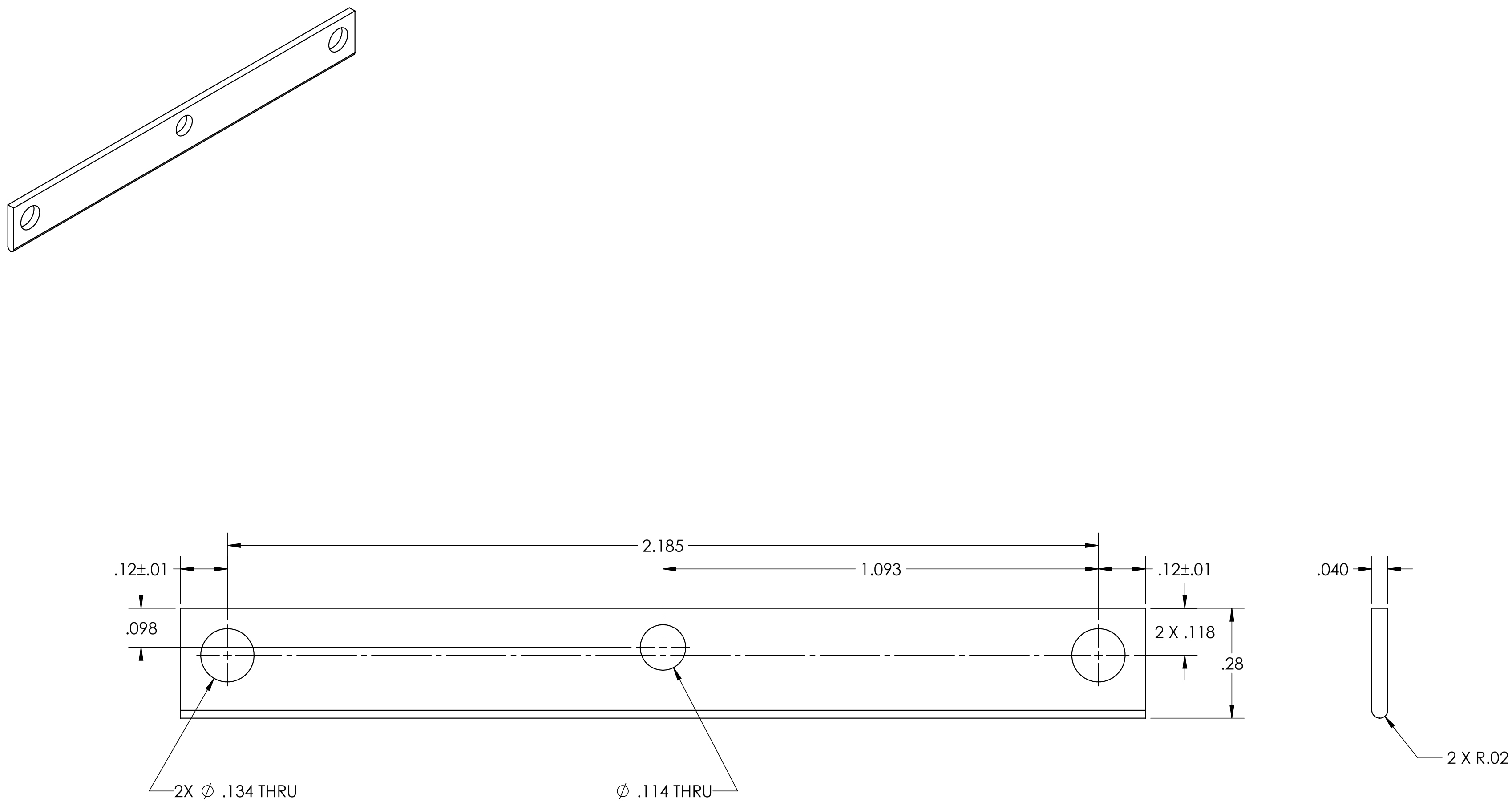


Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: VERTICAL FLEXURE BLADE
	Part Number: MUV-FLEXBLADE-002	Date: 4/22/2020	Scale: 2:1	Checked By: Kodi Rider, SSL

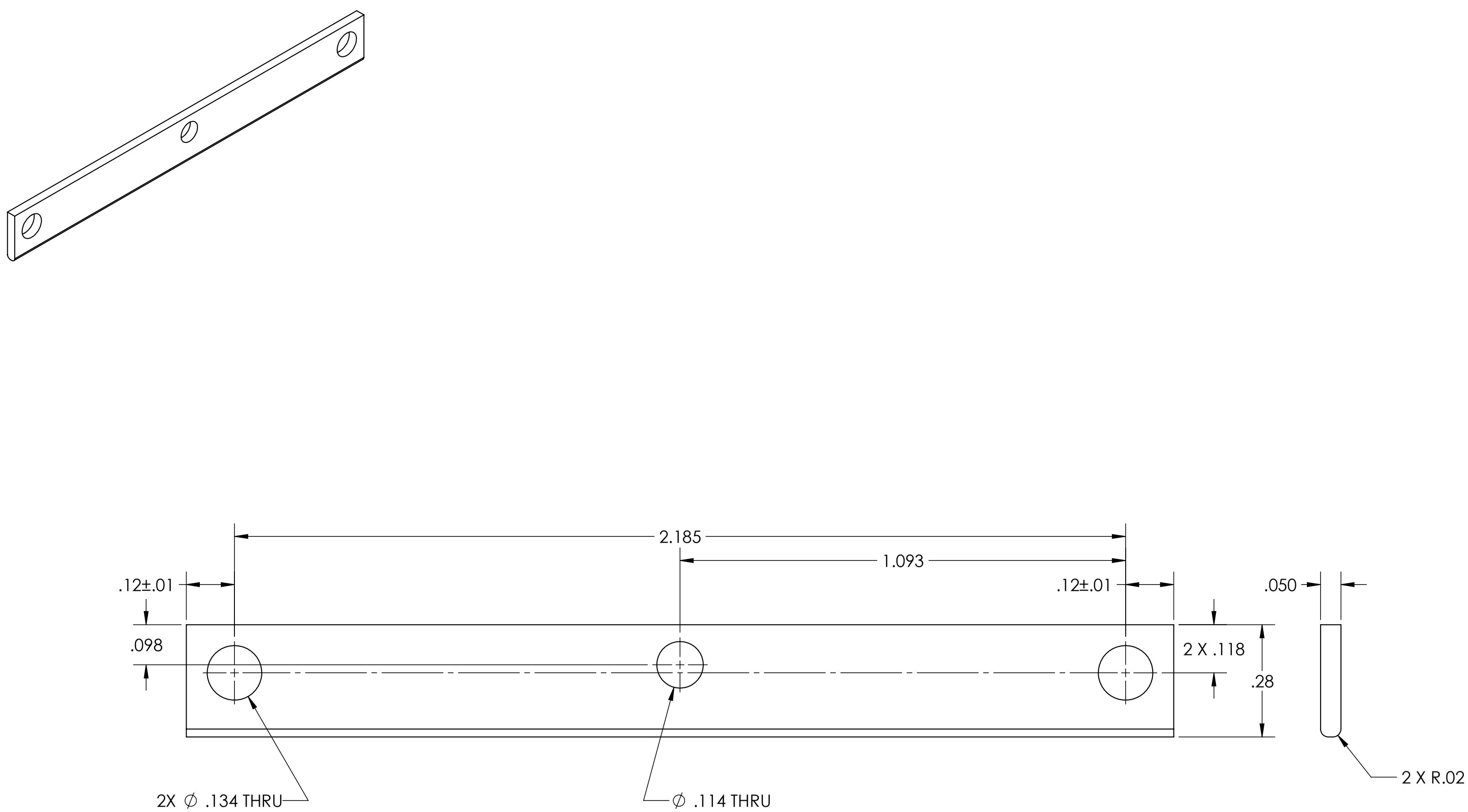




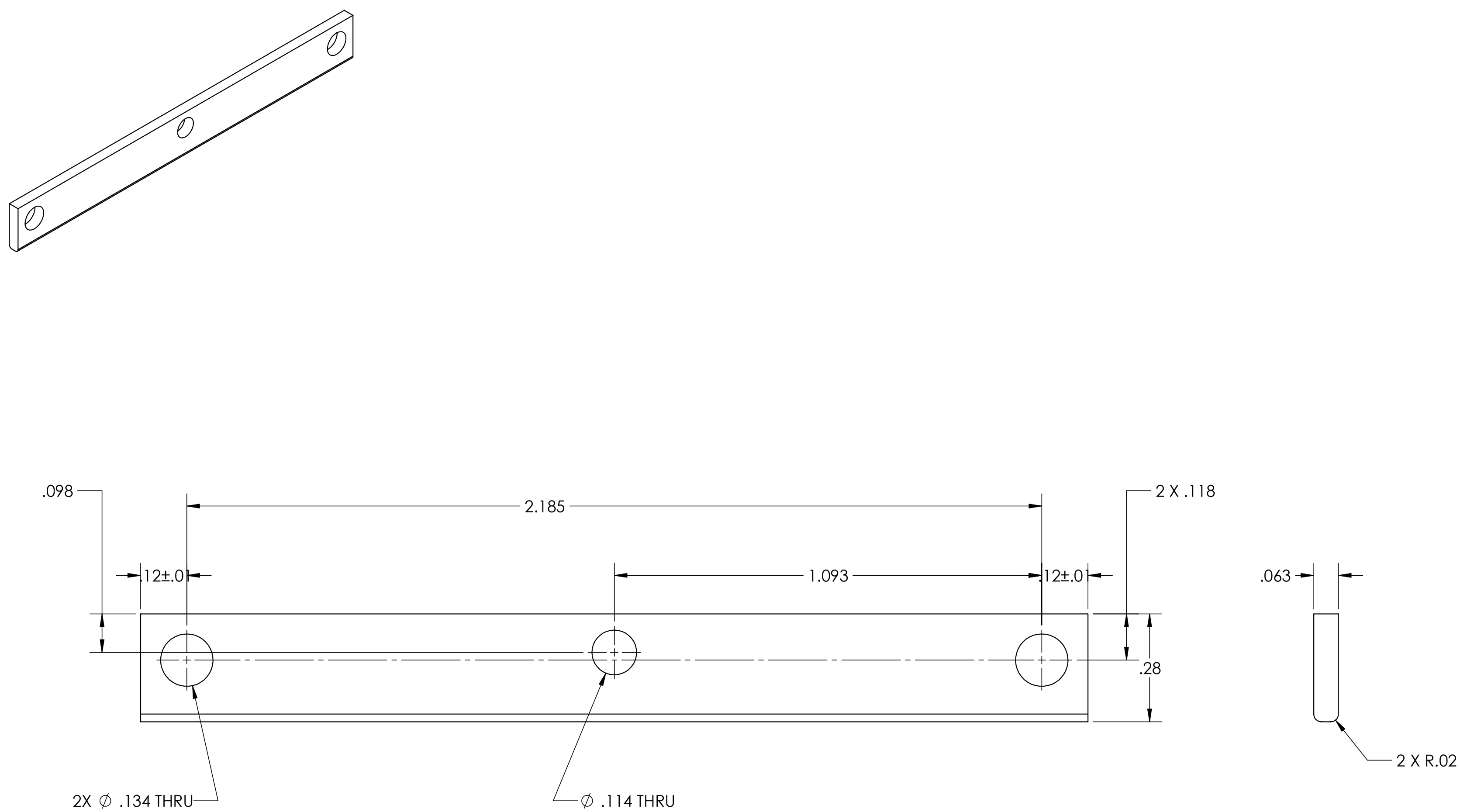
Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: VERTICAL FLEXURE BLADE
	Part Number: MUV-FLEXBLADE-003	Date: 4/22/2020	Scale: 2:1	Checked By: Kodi Rider, SSL



Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: HORIZONTAL FLEXURE BLADE
	Part Number: MUV-FLEXBLADE-004	Date: 4/22/2020	Scale: 4:1	Checked By: Kodi Rider, SSL



Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: HORIZONTAL FLEXURE BLADE
	Part Number: MUV-FLEXBLADE-005	Date: 4/22/2020	Scale: 4:1	Checked By: Kodi Rider, SSL



Cal Poly Mechanical Engineering UC Berkeley SSL NASA	Team Members: Bradley Albright, Colin Harrop, & Nico Armenta			Title: HORIZONTAL FLEXURE BLADE
	Part Number: MUV-FLEXBLADE-006	Date: 4/22/2020	Scale: 4:1	Checked By: Kodi Rider, SSL

E- Budget

Table 9.1: Purchased Parts

Vendor	Part Number	Description	Qty	Unit Cost	Total Cost	Use
McMaster-Carr	8476a41	#6-32 Spring Plunger	4	$5.62	$22.48	OGODS
McMaster-Carr	92210a194	#8-32 1/2" Countersunk screws	1	$5.51	$5.51	OGODS
McMaster-Carr	92196a194	#8-32 1/2" Cap Head Screws	1	$6.24	$6.24	OGODS
McMaster-Carr	92196a192	#8-32 3/8" Cap Head Screws	1	$5.93	$5.93	OGODS
McMaster-Carr	92141a009	#8 Washer	1	$2.07	$2.07	OGODS
McMaster-Carr	90666a103	M3 x 0.5mm, 6mm long socket	1	$8.35	$8.35	Flexure+Frame
McMaster-Carr	92290a056	M2.5 x 0.45mm, 6mm socket	1	$2.33	$2.33	Flexure
McMaster-Carr	92290a060	M2.5 x 0.45mm, 10mm socket	1	$5.67	$5.67	Flexure
McMaster-Carr	92290a058	M2.5 x 0.45mm, 8mm socket	1	$2.83	$2.83	Flexure
McMaster-Carr	93235a311	M3, 6mm long vented socket	1	$6.72	$6.72	Flexure
McMaster-Carr	93914a060	M3, 3mm long helicoil	3	$9.85	$29.55	Flexure+Frame
McMaster-Carr	93914a077	M3, 4.5mm long helicoil	5	$10.35	$51.75	Flexure+Frame
McMaster-Carr	93914a009	M2.5, 2.5mm long helicoil	1	$7.53	$7.53	Flexure
McMaster-Carr	93914A026	M2.5, 3.8mm long helicoil	2	$7.92	$15.84	Flexure
McMaster-Carr	93914A043	M2.5, 5mm long helicoil	1	$8.96	$8.96	Flexure+Frame
SMC	KQG2S07-32	N2 Push to Conect	1	$18.15	$18.15	Frame
McMaster-Carr	92715T71	N2 Filter Dutch Woven Mesh	1	$17.27	$17.27	Frame
McMaster-Carr	90666a105	M3, 10mm socket head	1	$9.19	$9.19	Frame
McMaster-Carr	93235a312	M3, 8mm socket head vented	1	$8.40	$8.40	Frame
McMaster-Carr	93235a315	M3, 16mm Socket head Vented	3	$4.48	$13.44	Frame
McMaster-Carr	91595A108	Pins (M3, 10mm, rounded)	1	$15.10	$15.10	Frame
McMaster-Carr	90666a104	M3 x 0.5mm, 8mm socket head	1	$8.40	$8.40	Frame
McMaster-Carr	92290a161	M4 x 0.7mm, 18mm socket hea	1	$7.28	$7.28	Frame
McMaster-Carr	92855a842	M2.5 x 0.45mm, 6mm socket	1	$12.81	$12.81	Frame
McMaster-Carr	91223a411	M3, 5mm ultra low profile sock	2	$4.06	$8.12	Frame
McMaster-Carr	90585a120	#2-56 3/8" long, flat head	1	$8.91	$8.91	Frame
McMaster-Carr	92290a017	M2 x 0.4, 10mm socket head	1	$4.88	$4.88	Frame
McMaster-Carr	93914a094	M3, 6mm long helicoil	4	$10.93	$43.72	Frame
McMaster-Carr	93914a145	M4, 8mm helicoil	1	$8.38	$8.38	Frame
McMaster-Carr	96246a018	#2-56 helicoil	1	$7.92	$7.92	Frame
McMaster-Carr	96246A200	#10-32 Helicoil, 0.19" length	1	$7.53	$7.53	Frame
Olander	1084-2EN050	M2, 5mm helicoil	4		$0.00	Frame
Omron Electronics	D2JW-01K21	Door Switch	2	$8.32	$16.64	Frame
Winchester	JF2S	Winchester Connecteor	1	$11.38	$11.38	Frame
McMaster-Carr	86075K32	1/16" Viton Sheet per sq. ft.	2	$62.26	$124.52	Frame
McMaster-Carr	1063T13	1/16" PTFE sheet 6" x 6"	1	$14.79	$14.79	Frame
Ellsworth	EA 9394	50ml Epoxy for staking fastener	2	$35.38	$70.76	Frame
McMaster-Carr	92955a206	Helicoil Insertion Tool, M2 x 0.	1	$117.60	$117.60	Installation Tool
McMaster-Carr	90261a185	Prong Break-Off Tool, M2 x 0.4	1	$163.56	$163.56	Installation Tool
McMaster-Carr	90261A161	Helicoil Inertion Tool, #10-32	1	$91.01	$91.01	Installation Tool
McMaster-Carr	92955A109	Prong Break Off Tool, #10-32	1	$70.84	$70.84	Installation Tool
McMaster-Carr	90261A140	Helicoil Inertion Tool, #2-56	1	$56.33	$56.33	Installation Tool
McMaster-Carr	92955A101	Prong Break Off Tool, #2-56	1	$70.84	$70.84	Installation Tool
			TOTAL:		$1,189.53	

Table 9.2: Manufacturing Costs

Item	Component or Part	Vendor	Total Price ($)
Manufacturing	OGODS	E&S Machining	$3,301.15
	Frame and Flexure	Tridecs Corp.	$13,259.02
	Flexure Blades	Big Blue Saw	$150.00
		TOTAL:	**$16,710.17**

Table 9.3: Miscellaneous Costs

Category	Description	Amount	Price per Trip ($)	Total Price ($)
Travel	Visit UCB SSL for design reviews	2	$110.00	$220.00
			TOTAL	**$220.00**

Table 9.4: Total Costs

Category	Amount
Manufacturing	$16,710.17
Purchased Parts	$1,189.53
Travel	$220.00
TOTAL	**$18,119.70**

F - Failure Modes and Effects Analysis

												Action Results
System / Function	Potential Failure Mode	Potential Effects of the Failure Mode	Severity	Potential Causes of the Failure Mode	Current Preventative Activities	Occurence	Current Detection Activities	Detection	Priority	Recommended Action(s)	Responsibility & Target Completion Date	Actions Taken
Frame/Protect Optics	Foreign object debris	1. outgassing 2. optics break 3. Data is incorrect	9	Lack of seal "Dirty assembly conditions"	Design sealing system Practice clean lab procedures	5	Analyze data gathered by optics, compare to anticipated data, look for anomolies	3	##	- Assemble in clean environment - Design seal system	Brad & N/A	None
						2			0			None
Frame/Align Optics	Doesn't allow door to open	misaligned optics unable to collect data	9	Interfering members	SolidWorks interference detection	4	Sw interference detection	1	36	- Pereform interference detection	Brad & CDR	None
	improper assembly	misaligned optics	9	Poor assy procedure	Scrutinize details in assembly procedure	3	Kodi	2	54	- Write assembly procedure	Team & around CDR	None
	Frame yields	misaligned optics	9	Not enough material	FEA	1	Visible yeild	3	27	- FEA	Brad & CDR	None
Flexure/Allow Vibration	overcon-strained	misaligned optics, detector breaks	9	Design not thought through	Consult professors to review constraint status	1	Assy not aligning correctly	2	18	- Design for 3 points of contact	Nico & CRD	None
Flexure/align detector	mount yields	misaligned optics	9	Not enough material	FEA	1	Visible yeild	2	18	- FEA	Nico & CRD	None
Flexure/mount to frame	doesn't properly mount	detector slips	9	Poor fastener decision	Evaluate the pros and cons of each fastener option	3	Assy not aligning correctly	2	54	- Compare different mounting methods	Nico & CRD	None

Flexure/mount to detector	doesn't properly mount	detector slips	9	Poor fastener decision	Evaluate the pros and cons of each fastener option	3	Assy not aligning correctly	2	54	- select adequate mounting mechanism / fasteners	Brad/Nico & CDR	None
PPOD/allows access to internals	cant access inside	take apart the ppod to adjust	4	No designed	design it	1	Can't access inside	1	4	- Design access	Colin & pre winter break	None
PPOD/securely mounted to shake table	gets loose	fly off the table	9	Not fastened properly	FEA to ensure structural integrity	3	Torque wrench fasteners	2	54	- Assy procedure	Colin & CDR	None
PPOD/represent BC	Not a good test	Misleading data	9	Poor design	Model P-pod after real P-pod	2	Is our P-pod correctly mimicing a real one?	2		- Research real p-pods, compare to ours	Colin & winter break	None

G - Design Hazards Checklist

DESIGN HAZARD CHECKLIST

Team: MUVI, Team 74 **Advisor**: Dr. Elghandour **Date**: 2/4/2020

Y	N	
☐	⦸	1. Will the system include hazardous revolving, running, rolling, or mixing actions?
☐	⦸	2. Will the system include hazardous reciprocating, shearing, punching, pressing, squeezing, drawing, or cutting actions?
⦸	☐	3. Will any part of the design undergo high accelerations/decelerations?
☐	⦸	4. Will the system have any large (>5 kg) moving masses or large (>250 N) forces?
☐	⦸	5. Could the system produce a projectile?
☐	⦸	6. Could the system fall (due to gravity), creating injury?
☐	⦸	7. Will a user be exposed to overhanging weights as part of the design?
☐	⦸	8. Will the system have any burrs, sharp edges, shear points, or pinch points?
☐	⦸	9. Will any part of the electrical systems not be grounded?
☐	⦸	10. Will there be any large batteries (over 30 V)?
☐	⦸	11. Will there be any exposed electrical connections in the system (over 40 V)?
☐	⦸	12. Will there be any stored energy in the system such as flywheels, hanging weights or pressurized fluids/gases?
☐	⦸	13. Will there be any explosive or flammable liquids, gases, or small particle fuel as part of the system?
☐	⦸	14. Will the user be required to exert any abnormal effort or experience any abnormal physical posture during the use of the design?
☐	⦸	15. Will there be any materials known to be hazardous to humans involved in either the design or its manufacturing?
☐	⦸	16. Could the system generate high levels (>90 dBA) of noise?
⦸	☐	17. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, or cold/high temperatures, during normal use?
☐	⦸	18. Is it possible for the system to be used in an unsafe manner?
☐	⦸	19. For powered systems, is there an emergency stop button?
☐	⦸	20. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

For any "Y" responses, add (1) a complete description, (2) a list of corrective actions to be taken, and (3) date to be completed on the reverse side.

Description of Hazard	**Planned Corrective Action**	**Planned Date**	**Actual Date**
The system will undergo high accelerations when launched into space	The system will undergo rigorous vibration testing to ensure its structural stability in the face of the accelerations it will experience	April, 2020	
The system will be required to survive temperature fluctuations from about 0 °C to 40 °C	Each subsystem will undergo testing after the entire system is heated to 40 °C and after the entire system is cooled to 0 °C to ensure that every subsystem can properly function after exposure to temperature fluctuations	April 2020	

H - Design Verification Plan

Senior Project DVP&R													
Date: 2/4/2020		Team: 74 - MUVI	Sponsor: UCB SSL			Description of System: Instrumentation Frame					DVP&R Engineer: Colin Harrop		
TEST PLAN										TEST REPORT			
Item No	Specification #	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	SAMPLES		TIMING		TEST RESULTS			NOTES
						Quantity	Type	Start date	Finish date	Test Result	Quantity Pass	Quantity Fail	
1	1	Overall mass < 2.66kg. Test by putting fully assembled system on a scale	<2.66 kg	Colin	FP	1	Sys	4/7/2020					
2	2	Vibration Testing, vertical and horizontal shake table	Sine Sweep and random vibration, both low level and full level. Optical insturments must remain aligned after vibes test	Colin	FP	1	Sys	4/14/2020					
3													
4													
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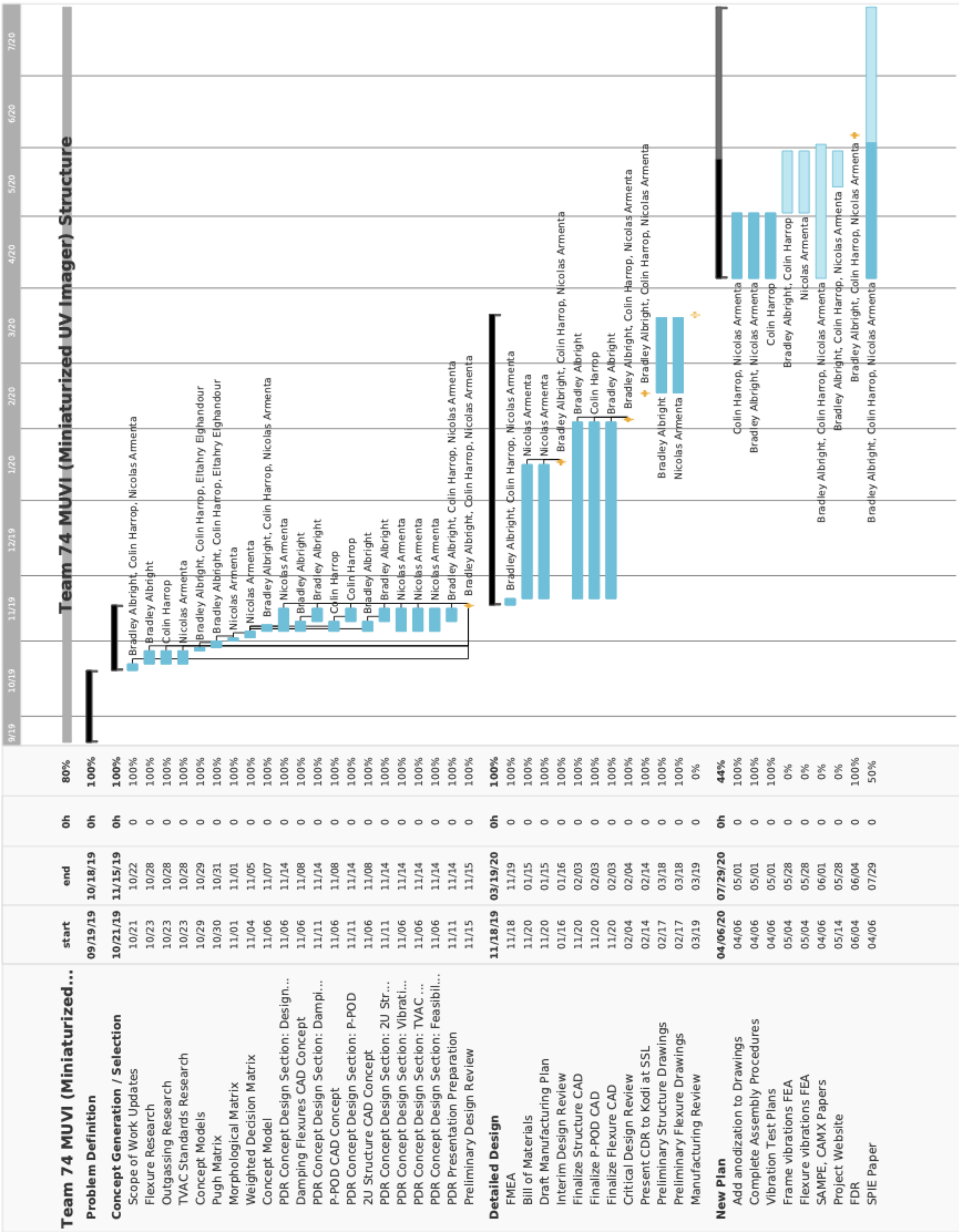
I - Project Gantt Chart

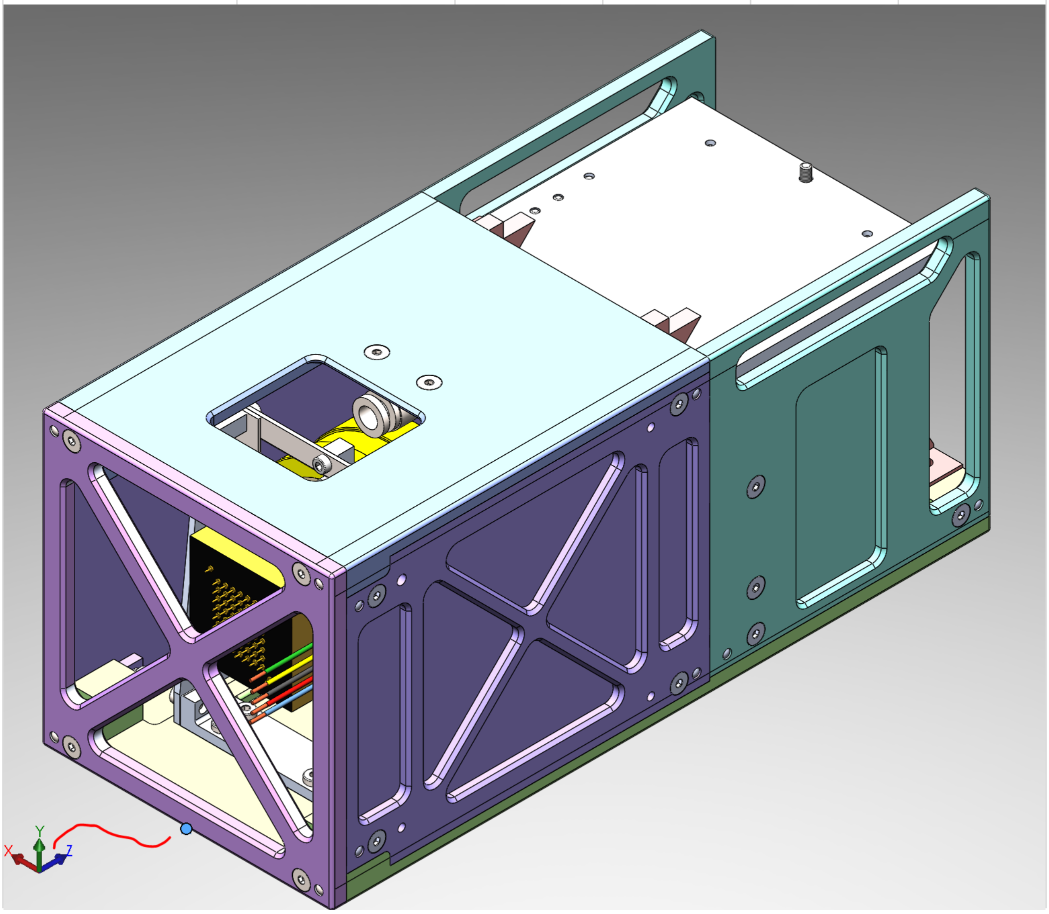


J - Instrumentation Frame 100G Static FEA

Part/Subassy (include fasteners)	Mass [*g*]	X [*mm*]	Y [*mm*]	Z [*mm*]	100G Load [*N*]
Optics (Lenses)	78.11	1.40	37.19	133.90	76.63
Left NanoPower	127.39	41.13	49.99	68.03	124.97
Top Door (hinge,mirror, flexure)	179.77	-0.22	80.20	170.80	176.35
Towers (including side bolts)	35.81	0.00	48.51	145.71	35.13
Lower mirror mount	69.94	1.80	36.51	168.54	68.61
Front Door, hinges and fringibolt	105.27	0.00	50.98	205.53	103.27
Datum Plate	304.76	0.32	3.61	117.61	298.97
Back Plate	58.78	0.00	50.00	2.51	57.66
Top Plate	142.87	0.00	96.80	67.62	140.16
Rear Left Side Panel	101.79	47.98	49.98	58.56	99.86
Front Left Side Panel	82.64	47.71	51.44	174.23	81.07
Front door mount ("L" bracket)	45.04	-0.01	15.61	199.39	44.18
Cube and tower	19.31	-0.16	25.71	191.60	18.94
Door Seals	5.93	0.00	66.65	176.48	5.82
Top door bumper	4.28	0.00	92.28	130.38	4.20
Front Door bumpers	4.27	0.00	10.92	222.35	4.19
Photek	320.00	-0.20	50.00	64.52	313.92
CMOS detector	64.00	0.00	51.61	30.00	62.78
Photek flexure	40.23	0.00	36.81	38.61	39.47
Front right side panel	82.64	-47.71	51.44	174.23	99.86
Rear Right Side Panel	101.79	-49.98	49.98	68.56	15.93
nitrogen boi	16.24	0.00	91.59	75.45	15.93
Right NanoPower	125.30	-40.93	49.99	68.05	122.92
Winchester connector	3.15	0.00	8.20	163.98	3.09
	Mass [*kg*]	X [*mm*]	Y [*mm*]	Z [*mm*]	100G Load [*N*]
Stowed Total (Expected)	2.543	2.40	47.20	108.66	2.495
Deployed Total (Expected)	2.543	2.39	46.91	108.01	2.495

	Mass [kg]	X [mm]	Y [mm]	Z [mm]	100G Load [N]
Stowed Total (Expected)	2.543	2.40	47.20	108.66	2.495
Deployed Total (Expected)	2.543	2.39	46.91	108.01	2.495

Updated:	03.01.20, 3PM, Brad
CAD Rev:	Integrated_P3V2_Rev_02.29.20_9pm

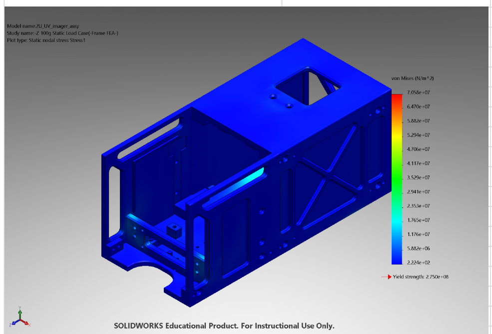


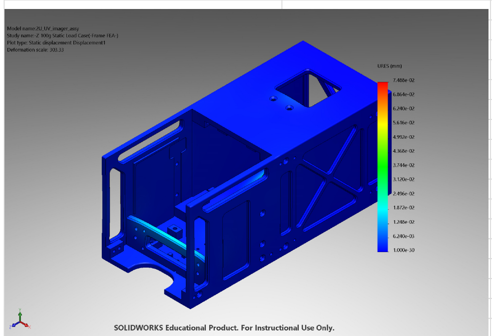
Negative Z FEA Study

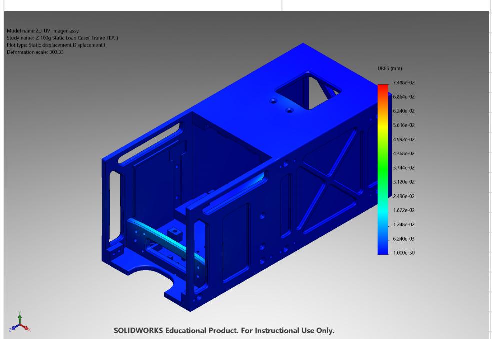
Loads	
Load Desctiption	Direction
Remote loads of (981 m/s2)*(subassembly mass)	Negative Z
Gravity defined as 981 m/s2	Negative Z

Fixures	
Fixure Type	Surface
Fixed Geometry	Rear face of rear plate
Slider	All longitudinal edges, 6.5*mm* inward

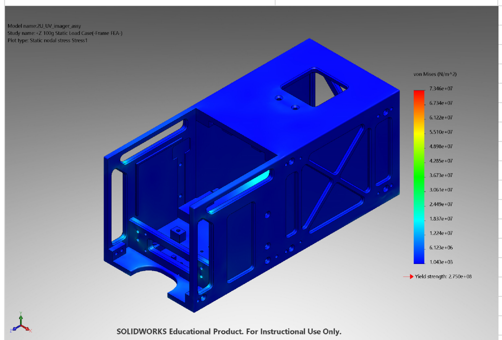
Results		
Aluminum Yield Stress	2.75E+08	*N/mm2*
MUVI Frame Max von Misis Yield Stress	7.06E+07	*N/mm2*
Max Deflection	0.075	*mm*
Max Elastic Strain	6.07E-04	

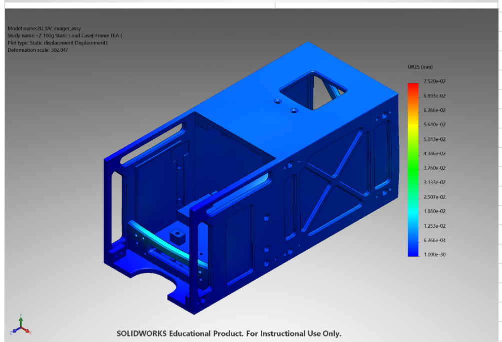


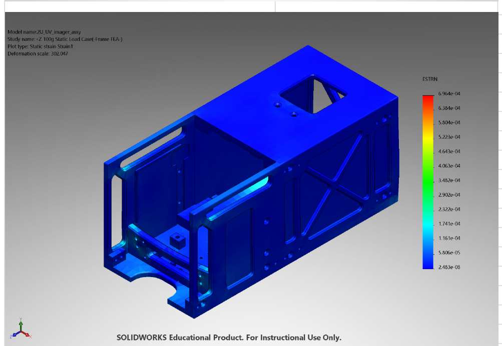




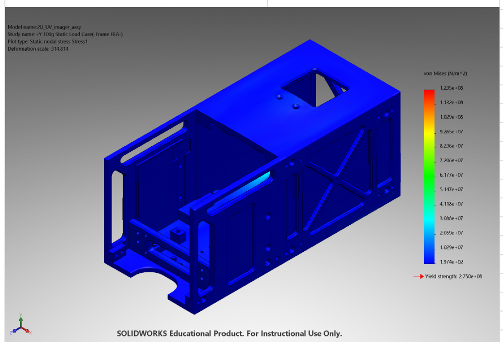
Positive Z		
Loads		
Load Desctiption	Direction	
Remote loads of (981 m/s2)*(subassembly mass)	Positive Z	
Gravity defined as 981 m/s2	Positive Z	
Fixures		
Fixure Type	Surface	
Fixed Geometry	Front face datum plate & font side plates	
Slider	All longitudinal edges, 6.5*mm* inward	
Results		
Aluminum Yield Stress	2.75E+08	*N/mm2*
MUVI Frame Max von Misis Yield Stress	7.35E+07	*N/mm2*
Max Deflection	0.0752	*mm*
Max Elastic Strain	6.96E-04	

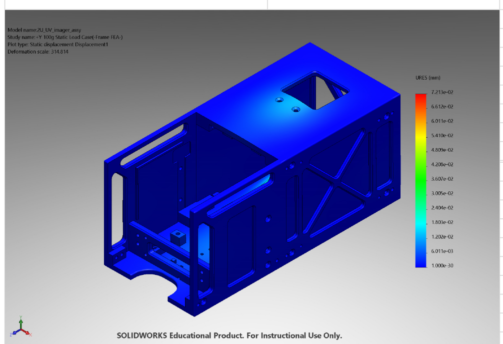


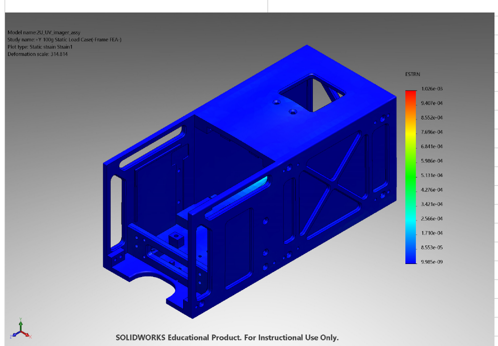




Positive Y		
Loads		
Load Desctiption	Direction	
Remote loads of (981 m/s2)*(subassembly mass)	Positive Y	
Gravity defined as 981 m/s2	Positive Y	
Fixures		
Fixure Type	Surface	
Fixed Geometry	Top plate & top rails of front/rear side plates	
Slider	Side faces of datum, side, & top plates	
Results		
Aluminum Yield Stress	2.75E+08	*N/mm2*
MUVI Frame Max von Misis Yield Stress	1.24E+08	*N/mm2*
Max Deflection	0.07213	*mm*
Max Elastic Strain	1.03E-03	





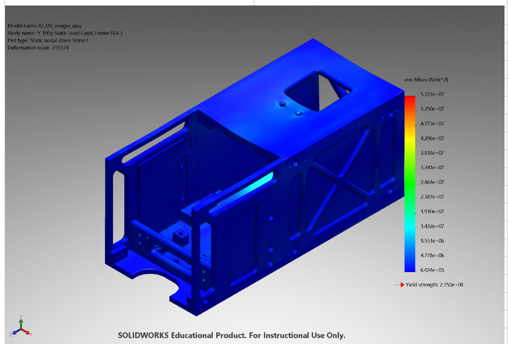


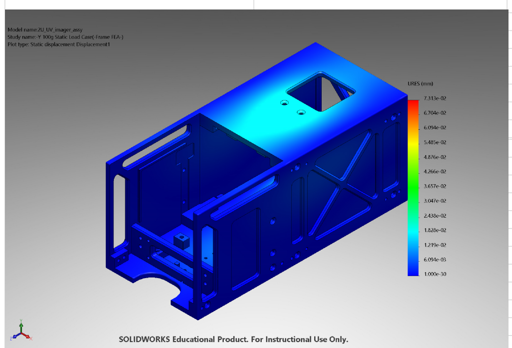
Negative Y	

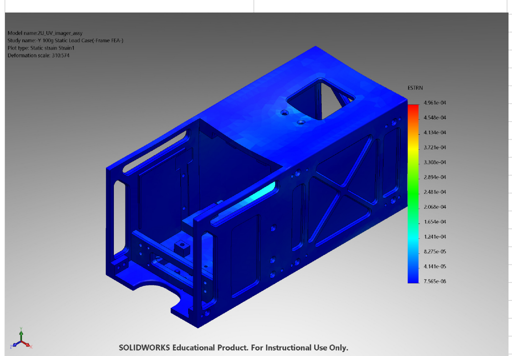
Loads	
Load Desctiption	Direction
Remote loads of (981 m/s2)*(subassembly mass)	Negative Y
Gravity defined as 981 m/s2	Negative Y

Fixures	
Fixure Type	Surface
Fixed Geometry	Datum plate & bottom rails of front/rear side plates
Slider	Side faces of datum, side, & top plates

Results		
Aluminum Yield Stress	2.75E+08	*N/mm2*
MUVI Frame Max von Misis Yield Stress	5.73E+07	*N/mm2*
Max Deflection	0.07313	*mm*
Max Elastic Strain	4.96E-04	





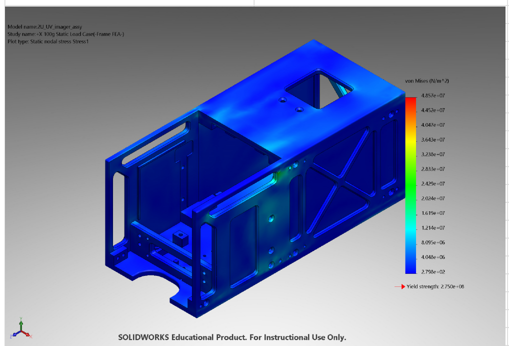


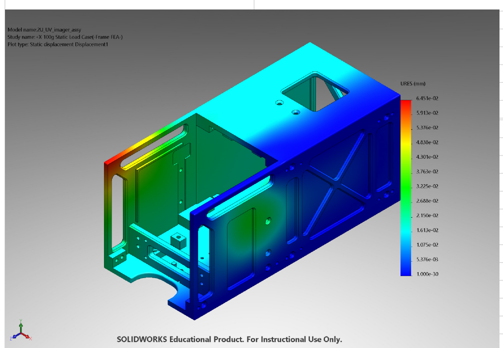
Positive X

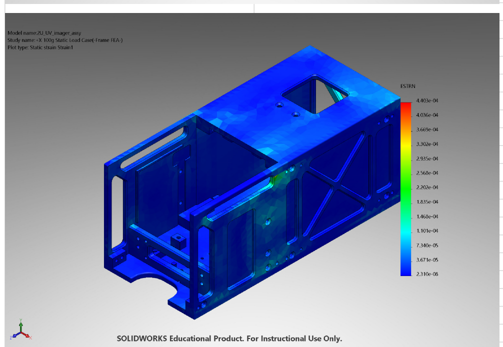
Loads	
Load Desctiption	Direction
Remote loads of (981 m/s2)*(subassembly mass)	Positive X
Gravity defined as 981 m/s2	Positive X

Fixures	
Fixure Type	Surface
Fixed Geometry	Left side plates & left side of datum/top plates
Slider	Front & rear faces

Results		
Aluminum Yield Stress	2.75E+08	*N/mm2*
MUVI Frame Max von Misis Yield Stress	4.86E+07	*N/mm2*
Max Deflection	0.06451	*mm*
Max Elastic Strain	4.40E-04	







K - Flexure Mount Assembly Procedure

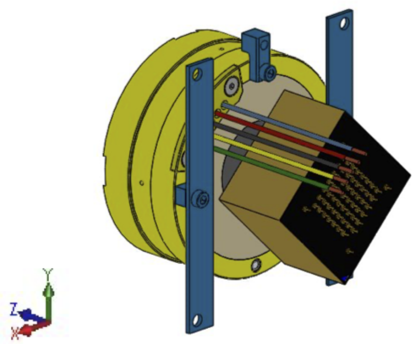
The following pages detail the procedure for assembling the Photek mounting flexure assembly, prior to integrated MUVI assembly and vibration testing.

MUVI PHASE III - FLEXURE MOUNT ASSEMBLY PROCEDURE
AUTHORS: BRADLEY ALBRIGHT, NICO ARMENTA, COLIN HARROP
REVISED: 04-21-20

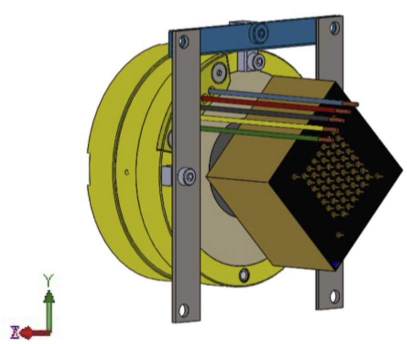
This document details the procedure for assembly of the MUVI PHOTEK Flexure Mount and its attachment to the Datum Plate

Step 1
Fasten Vertical PHOTEK Standoffs and Vertical Flexure Blades to either side of the PHOTEK Tube and Horizontal PHOTEK Standoff to the top of the PHOTEK Tube
Fasteners used:

- For vertical components: 2X M2.5 x .45 mm Thread, 10 mm Long Socket Head Screw [92290A060]
- For horizontal component: 1X M2.5 x .45 mm Thread, 8 mm Long Socket Head Screw [92290A058]



Step 2
Fasten Horizontal Flexure Blade to Horizontal PHOTEK Standoff
Fastener used: 1X M2.5 x .45 mm Thread, 6 mm Long Socket Head Screw [92290A056]



MUVI PHASE III - FLEXURE MOUNT ASSEMBLY PROCEDURE
AUTHORS: BRADLEY ALBRIGHT, NICO ARMENTA, COLIN HARROP
REVISED: 06-04-20

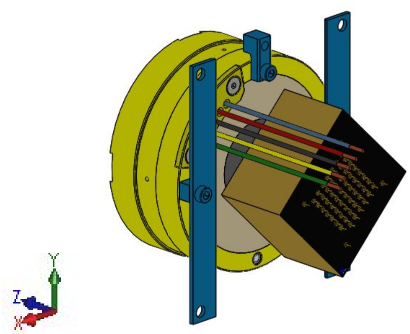
This document details the procedure for assembly of the MUVI PHOTEK Flexure Mount and its attachment to the Datum Plate

Step 1

Fasten Vertical PHOTEK Standoffs and Vertical Flexure Blades to either side of the PHOTEK Tube and Horizontal PHOTEK Standoff to the top of the PHOTEK Tube

Fasteners used:

- For vertical components:
    - 2X M2.5 x .45 mm Thread, 10 mm Long Socket Head Screw [92290A060]
    - Helicoil used: 1X M2.5, 5mm long [93914A043]
- For horizontal component:
    - 1X M2.5 x .45 mm Thread, 8 mm Long Socket Head Screw [92290A058]
    - Helicoil used: 1X M2.5, 3.8mm long [93914A026]

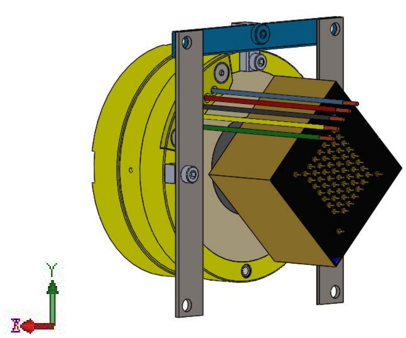


Step 2

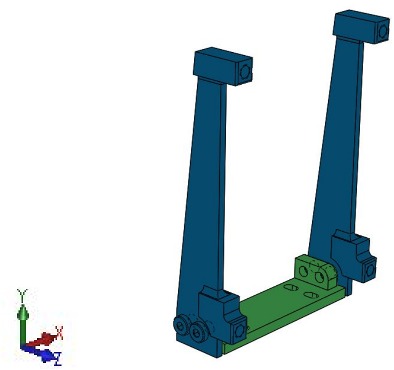
Fasten Horizontal Flexure Blade to Horizontal PHOTEK Standoff

Fastener used: 1X M2.5 x .45 mm Thread, 6 mm Long Socket Head Screw [92290A056]

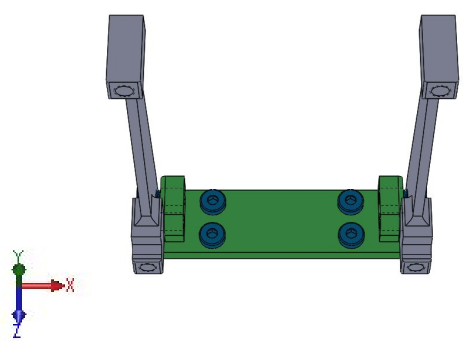
Helicoil used: 1X M2.5, 2.5mm long [93914a009]



Step 3
Fasten Flexure Mount Towers to either side of the Flexure Mount Base Plate. Use shims between the interfacing surfaces on either side of the Flexure Mount Base Plate to assume preliminary Flexure Mount Tower positions, ensuring that the centers of the holes on either Flexure Mount Tower are positioned with a 55.5 mm horizontal distance apart
Fasteners used: 4X M3 x .5 mm Thread, 6 mm Long, Low Profile, Socket Head Screw [90666A103]
Helicoil used: 4X M3, 3mm long [93914a060]

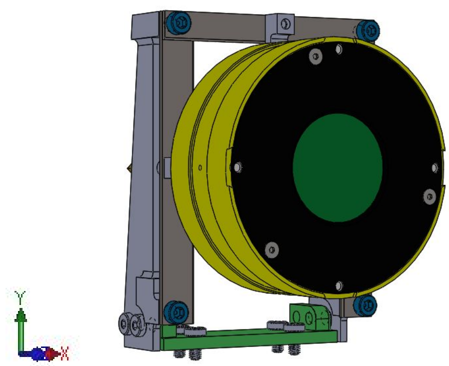


Step 4
Fasten the Flexure Mount Base Plate to the Datum Plate in a preliminary position along the axis of the Datum Plate.
Fasteners used: 4X M3 x .5 mm Thread, 6 mm Long, Low Profile, Socket Head Screw [90666A103]
Helicoil used: 4X M3, 3mm long [93914a060]



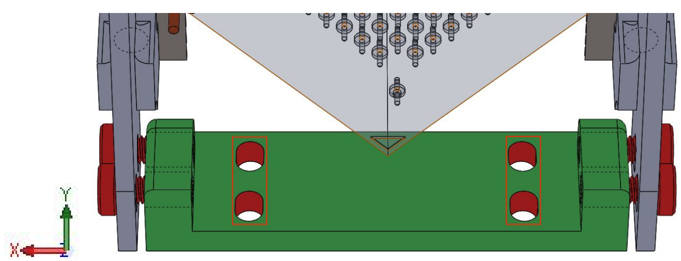
Step 5

Fasten the Vertical and Horizontal Flexure Blades to the Flexure Mount Towers
Fasteners used: 4X M3 x 0.5 mm Thread, 8 mm Long, Vented Socket Head Screw [93235A312]
Helicoil used: 4X M3, 4.5mm long [93914a077]

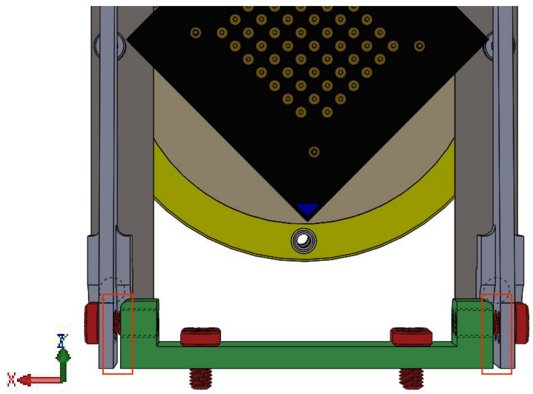


Step 6-A

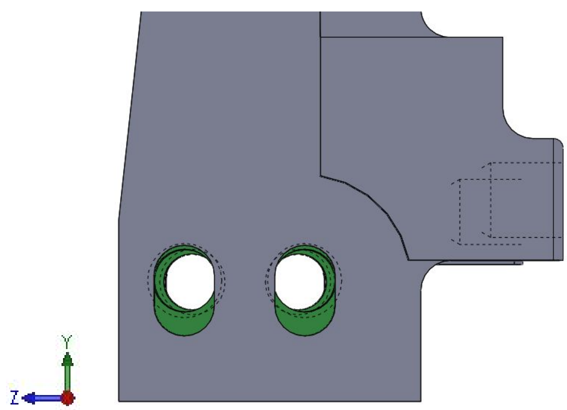
Once assembled in a preliminary position, the position of the PHOTEK Flexure Mount must be tuned to allow for proper focusing of light on the Detector. Slots on the Flexure Mount Base Plate oriented along the axis of the MUVI Frame allow for adjustment of the PHOTEK toward or away from the Lens.



Step 6-B
Clearance between the Flexure Mount Towers and the Flexure Mount Base Plate allow shimming to adjust the horizontal location of the PHOTEK



Step 6-C
Slots on the Flexure Mount Towers oriented vertically allow shimming under the Flexure Mount Towers to adjust the vertical location of the PHOTEK.



L - Instrumentation Frame Assembly Procedure

The following pages detail the procedure for assembling MUVI prior to vibration testing.

MUVI PHASE III - INTEGRATED 2U ASSEMBLY PROCEDURE
AUTHORS: BRADLEY ALBRIGHT, NICO ARMENTA, COLIN HARROP
REVISED: 05/05/20

This document details the procedure for assembly of the MUVI 2U satellite frame with all integrated subsystems.

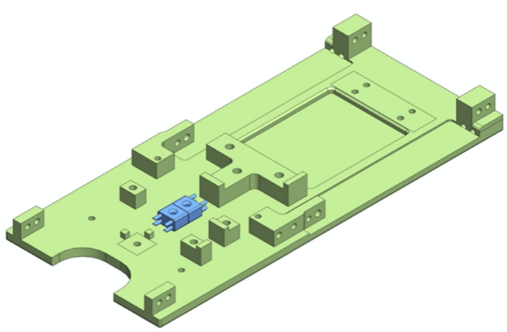
Unless Otherwise Specified

Preload Calculator

Fastener	Standard	Strength Class	Friction Conditions		Proof Load %	Preload [*N-m*]
M2.0	ISO 4762	A2-70	Steel/Steel	Dry	90	0.25
M2.5	DIN 9122	A2-70	Steel/Steel	Dry	90	0.45
M3.0	ISO 4762	A2-70	Steel/Steel	Dry	90	0.83

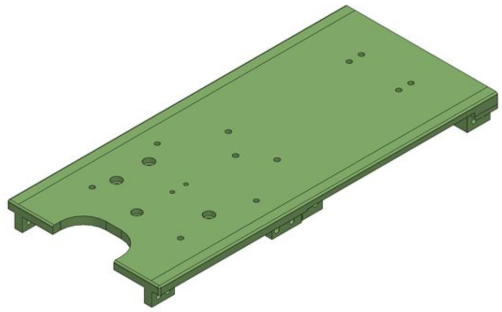
Notes:
- *DIN 912 is a modified version of ISO 4762*
- *ISO 4762 produces an error when using the calculator for M2.5*

Step 1
Fasten Winchester connectors to datum plate
Fasteners: 2X #2-56 3/8" Flat Head (90585A120)
Helicoils: 2X #2-56 (96246A018)



Step 2
Attach viton atop front door mount using kapton tape

Step 3
Flip over datum plate

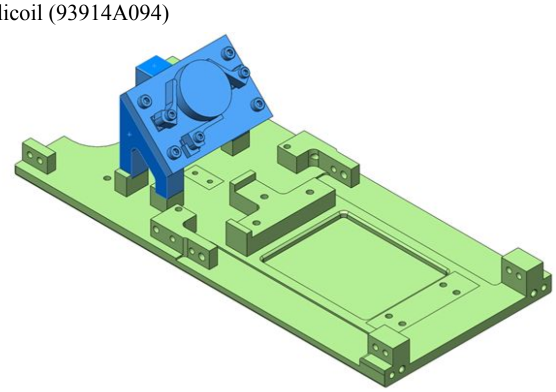


Step 4
Fasten [1]bottom mirror subassembly and [2]silica alignment cube assembly to datum plate. Flip back over.
Fasteners:

- 3X M3, 16mm Socket head Vented for bottom mirror assembly (93235A315)
- 1X M3 8mm socket head vented for silica alignment cube tower (93235A312)

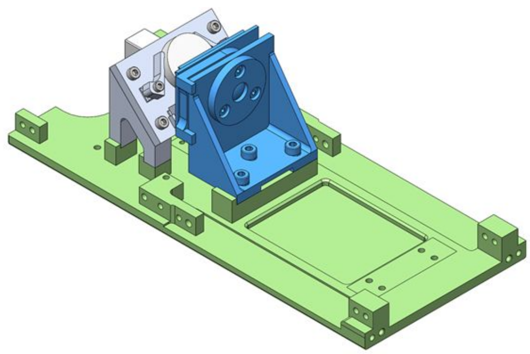
Helicoils:

- 4X M3, 6mm helicoil (93914A094)

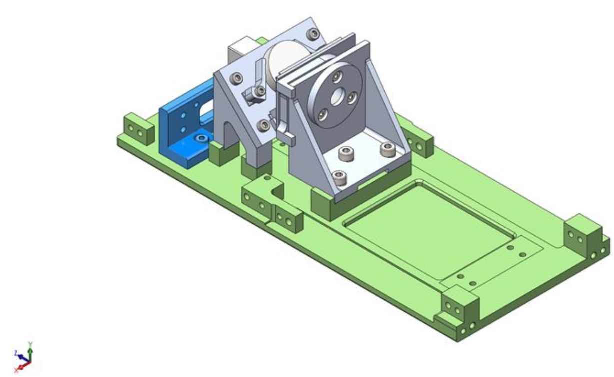


Step 5
Fasten and shim lense assembly to datum plate
Fasteners: 3X M4 x 0.7, 18mm long socket head (92290A161)
Helicoils: 3X M4, 8mm long helicoil (93914A145)

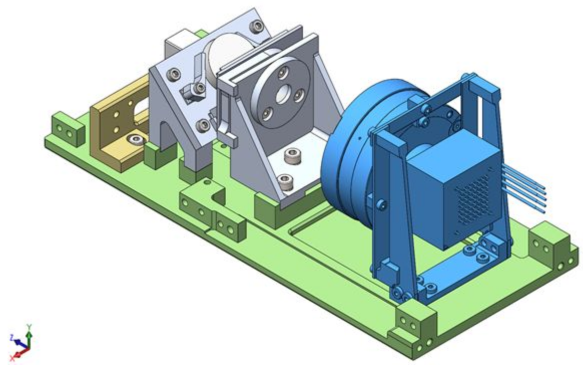
3



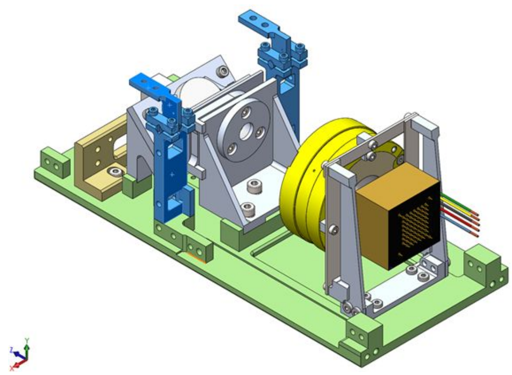
Step 6
Loosely fasten front door mount to datum plate (torque down after front side panels attached)
Note: SS mesh must be fastened to front door mount prior to installation on datum plate
Secure steel mesh down with N2 Exit Filter Clamp (MUV-F-111)
 Fasteners: 4X M2.5 x 0.45mm, 6mm socket head (92855A842)
 Helicoils: 4X M2.5, 5mm long helicoil (93914A043)
Fasten Front Door Mount to Datum Plate
 Fasteners: 2X M3 x 0.5mm, 8mm long low profile socket head (90666A104)
 Helicoils: 2X M3, 4.5mm long helicoil (93914A077)



Step 7
Fasten/shim camera and flexure assembly to datum plate
Note: This step is also called out in the Flexure Mount Assembly Procedures
Fasteners: 4X M3 x .5 mm Thread, 6 mm Long, Low Profile, Socket Head Screw (90666A103)
Helicoils: 4X M3, 3mm long helicoil (93914A060)



Step 8
Pin top door towers to datum plate
Fasteners: 2X Dowel Pin, 3 mm Diameter, 14 mm Long (91595A112)

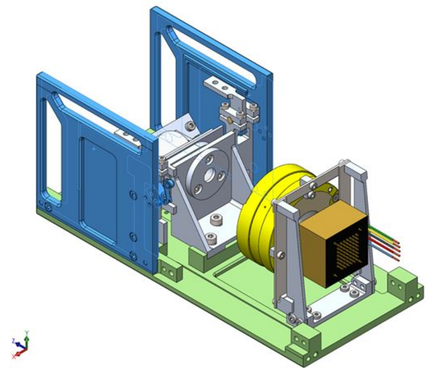


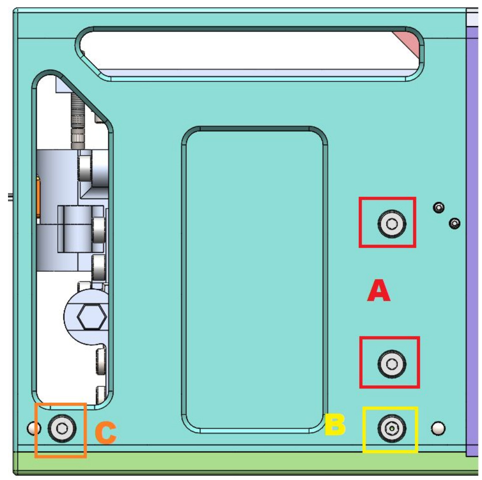
Step 9
Fasten front side panels to datum plate & towers (Note: Door switch and side viton seals already attached to side plates).
Fasteners:

- 6X M3 x 0.5mm, 10mm low profile socket head (90666A105)
- 4X Dowel Pin, M3-10mm, rounded (91595A108)
- 2X M3 8mm socket head vented (93235A312)

Helicoils:

- 4X M3, 3mm long helicoil (93914A060), red boxed fasteners in picture
- 2X M3, 4.5mm long helicoil (93914A077), orange boxed fastener
- 2X M3, 6mm long helicoil (93914A094), yellow boxed fastener

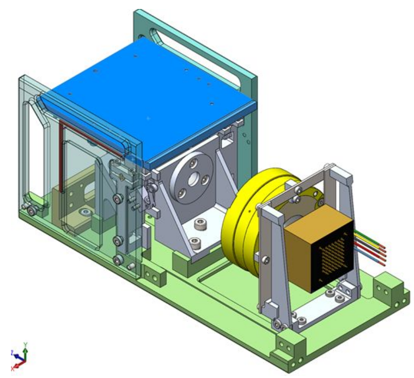




Step 10
Step 10 & 11 are performed somewhat simultaneously. When installing the top door, torsion springs will force the door open. Hold down the top door while installing front door prior to torquing down frangibolt nut.

Torque down front door mount & fasten top door to towers hinges. Top door rests on side plate viton seals. When installing the top door, the springs will force the door open.
Notes:
- PTFE seal already attached to door
- Fasteners & helicoils belong to MUVI Phase II BOM

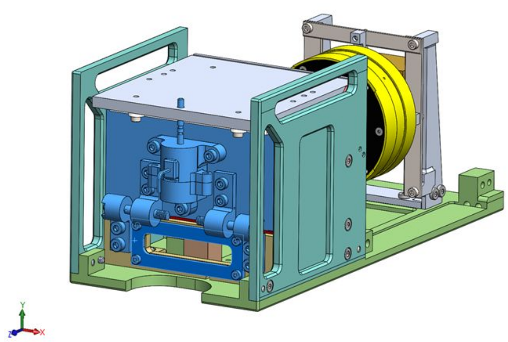
Fasteners: 4X M2.5 x 0.45 mm Thread, 8 mm Long (92290A058)
Helicoils: 4X M2.5, 5mm long helicoil (93914A043)



Step 11
Fasten front door assembly to front door mount and thread frangibolt to top door.
Fasteners:

- 4X M3 x 0.5mm, 8mm long low profile socket head (90666A104)
    - Installation torque: 0.35 *N-m* (50 *oz-in*)
    - Max allowable running torque: 0.14 *N-m* (20 *oz-in*) (Frangibolt Torque Spec)
- 2X Nut corresponding to ICON-FUV-MEC-695(frangibolt)

Helicoils: 4X M3, 4.5mm long helicoil (93914A077)

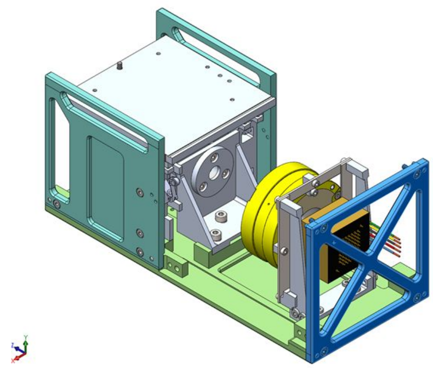


Step 12
Fasten rear panel (X-panel) to datum plate
Fasteners:

- 2X Dowel Pin, M3-10mm, rounded (91595A108)
- 2X M3 x 0.5mm, 10mm low profile socket head (90666A105)

Helicoils: 2X M3, 6mm long helicoil (93914A094)

7

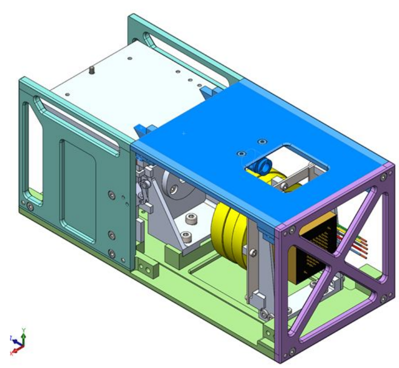


Step 13
Fasten top panel to rear panel
Note: N_2 inlet, top bumper, & viton sealing already attached to top panel

N2 Installation:
N2 Push to Connect (KQG2S07-32) threads with 10-32 helical inset (96246A200) into N2 Mount (MUV-F-112) and is fastened to the Top Panel
Fasteners: 2X M3 x 0.5mm, 5mm Ultra low profile socket head (91223A411)
Helicoil: 2X M3, 3mm long helicoil (93914A060)

Top Panel Installation:
Fasteners:
- 2X Dowel Pin, M3-10mm, rounded (91595A108)
- 2X M3 x 0.5mm, 10mm low profile socket head (90666A105)

Helicoils: 2X M3, 6mm long helicoil (93914A094)



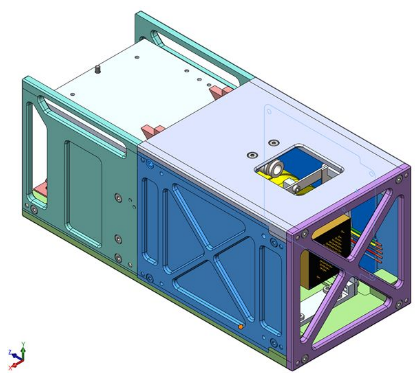
Step 14
Fasten side plates to datum & top plates
Note: PCB's and door switches already fastened to side plates

Door Switch installation on both side panels:
- 2X M2, 10mm long socket head bolt (92290A017)
- 2X M2, 5mm long helicoil (1084-2EN050)

PCB Installation:
- Install 4 spacers between standoff and board
- 4X M3 x 0.5mm, 5mm long low profile socket head (90666A103)
- 4X M3, 4.5mm long helicoil (93914A077)

Fasteners (each side):
- 4X Dowel Pin, M3-10mm, rounded (91595A108)
- 4X M3 x 0.5mm, 10mm low profile socket head (90666A105)

Helicoils:
- 3X M3, 6mm long (93914A094)
- 1X M3, 4.5mm long (93914A077) in lower front corner



M - Vibration Testing Procedure

The following pages detail the procedure for future MUVI project members to perform vibration testing on MUVI and OGODS to evaluate the effectiveness of viscoelastic materials, like Viton, to lower damping time.

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MUVI Instrumentation Frame Vibration Testing Procedures

Objective:
This document specifies step-by-step instructions to perform vibration testing on the MUVI 2U frame with integrated instrumentation. The purpose of physical vibration testing is to experimentally verify that the MUVI design adheres to NASA TRL 6 standards.

Tools and Equipment:

- Accelerometers (1X control mounted to OGODS Base Plate, 2X variable mounted to MUVI components)
- Accelerometer adhesive: kapton tape + Petro Wax
- 2U MUVI Frame with integrated instrumentation
- 2U OGODS
- Shake Table mounting bolts
- PPE: Eye & ear protection

Reference Documentation
NASA-GSFC-STD-7000, *General Environmental Verification Standard,* Section 2.4

Test Summary
Vibration testing for MUVI involved placing accelerometers at various locations on the MUVI & OGODS assemblies and subjecting components to vibrations via a shake table. A control accelerometer will be placed on the OGODS load plate and a variable accelerometer will be placed on the MUVI top door for every test. For the first half of the tests, an accelerometer will be placed on the PHOTEK mass model, Configuration 1. For the remaining half, the accelerometer will be moved to the top plate of the instrumentation frame, Configuration 2. In each configuration, the following tests will be performed in all 6 principal axis directions:

- Sine Signature Test
- Random Vibration Test (at -18, -12, -6, and 0 dB)

The sine signature test will be repeated after the random vibration tests to ensure fundamental frequencies did not change during random vibration.

Test Procedures for X axis

1. Bolt OGODS to shake table oriented in the X-axis
2. Record location and sensitivity of accelerometers used in experiment (See Appendix for visuals)

Component	Accelerometer Location	Model	Serial Number	Sensitivity (mV/g)
PHOTEK Mass Model	Front Face Center (lens side)			
MUVI Top Door	Front Center (Use for test 1 only)			
Instrument Frame Top Plate	Bottom Center in front of N2 port (Use for test 2 only)			
OGODS – Load Plate	Top, left, center			

3. Mount accelerometers to internal locations and route wires out through back plate or top plate
4. Tape accelerometer wires to prevent movement
5. Install into the OGODS and route accelerometer wires through access panel reliefs

6. Sine Signature test
    a. Set or verify the following
        i. *G Input level*
        ii. *5-2000Hz*
    b. Perform sine sweep
    c. Generate response plots (frequency vs amplitude) to assess fundamental frequencies
7. Random Vibration test
    a. Set or verify the following
        i. Accelerometer signals reading
        ii. Accelerometer sensitivity correctly set
        iii. Random profile as specified in GEVS correctly input
        iv. Test duration correctly input
        v. Input abort and alarm limits
    b. Perform random test at each level for at least 15 seconds each
        i. -18 dB, -12 dB, -6 dB continuously observing control and response accelerometers for anomalies.
        ii. Full (0 dB) input test
    c. Generate control and response spectral plots
    d. Verify base input levels were within random testing tolerances
    e. Visually inspect OGODS and instrument frame for any physical damage, yield of components and backed out fasteners.
8. Post-Random Sine Sweep test
    a. Follow procedure step 6 to assess if fundamental frequencies changed during random input test.
9. Overlay and compare pre and post random vibration sine sweep test plots. Verify the difference is within specified limits.

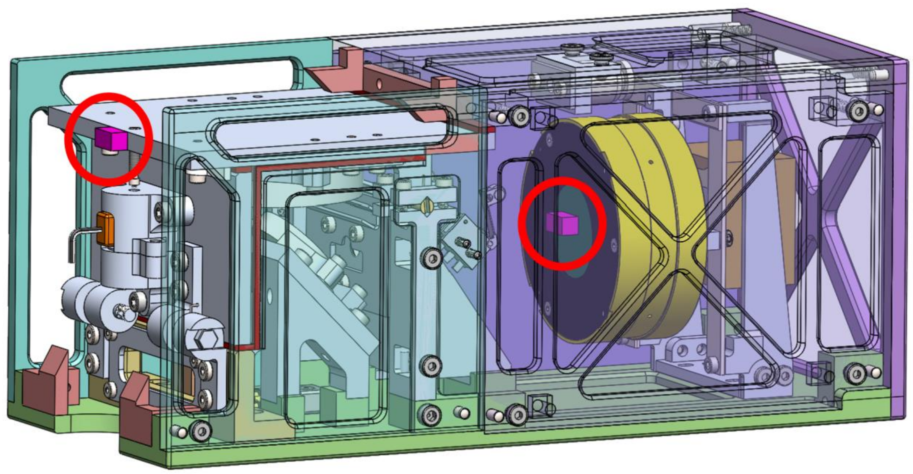
Test Procedures for Y axis

10. Unbolt and reorient OGODS in the Y-axis on the shake table. Make sure not to remove the instrument frame from the OGODS to maintain that the boundary conditions are consistent between tests.
11. Repeats steps 2 through 9 for Y axis

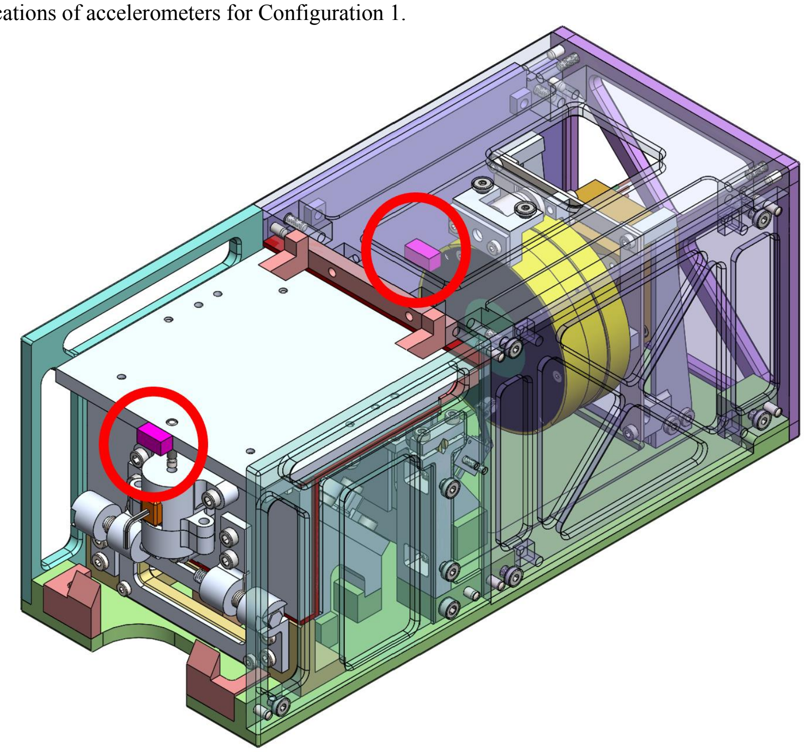
Test Procedures for Z axis

12. Remove OGODS from horizontal shake table and mount to vertical shake table for Z axis testing
13. Repeat steps 2 through 9 for Z axis testing

Appendix



A. Locations of accelerometers for Configuration 1.



B. Locations of accelerometers for Configuration 2.