Final Design Report – Group 13.5

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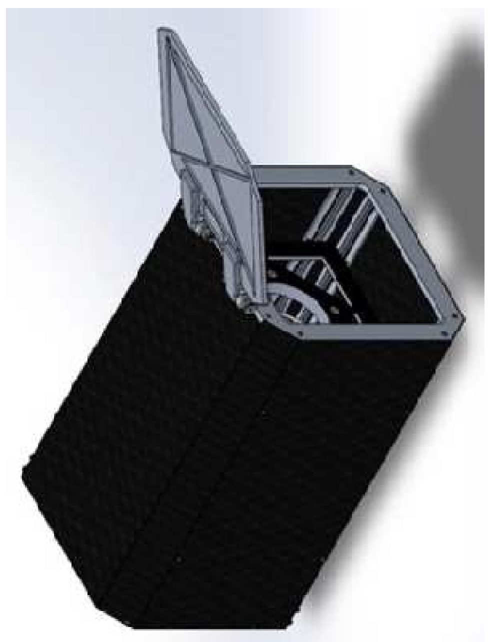

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I. Executive Summary

Sat^3 is a diverse group of engineers with three goals in mind: contributing to the future of space exploration, optimizing the weight of a structurally sound system, and delivering a high-quality product to sell to contractors. These goals are represented in the below Venn-diagram.

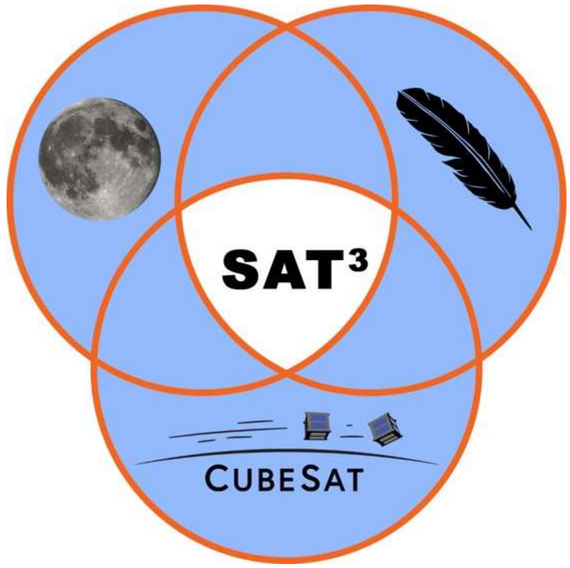


Fig. 1 Venn-Diagram

The product being created is a Canisterized CubeSat Dispenser (CSD). The CSD will be used to capture high-quality photos of space. This will contribute to the goal of Artemis 3: return humans to the lunar surface in 2025. To ensure mission success, an optimal landing site is necessary. CubeSat's accomplish this mission by taking high-resolution photos of the lunar surface landing sites and transmitting the data to Earth. All data can be captured and transmitted from a box as small as 12U. The CubeSat has different subsystems that accomplish this goal: enclosure, door, launcher, ventilation, and communication.

The product created by Sat^3 has unique design features to make it as lightweight as possible. The enclosure is made of hollowed out rails, carbon-fiber sides, and foam to create a structurally sound lightweight design. This design should withstand the structural, vibrational, acoustic, and shock loads that the CSD may encounter. The rails are made of Aluminum 6061, but they were hollowed out to create a lightweight design. The door is opened using a torsion spring to provide force and the impact of the CSD when it launches. The door attaches to the front plate of the enclosure assembly.

The launcher assembly uses a compression spring and connects to the rails to launch the CSD. The spring also attaches to the launcher base plate and pusher plate. This will launch the CubeSat with a speed of 2 m/s or faster. The spring design is a common launching method for CSD's, but Sat^3 integrated foam to dampen the vibration transmitted to the CubeSat. The ventilation subassembly uses an aluminum mesh to prevent debris from contaminating the CSD. A carbon fiber sheet with multiple perforations is laid over the aluminum mesh. Standard CSD's do not have on-board communication or power regulation, but Sat^3 designed a CSD that comes with the communication and power devices. The devices used are an Ibeos EPS, Nanomind A3200, and X-Band Patch and Antenna.

II. Design Revisions Addressing Design Review #2

1. All the screws and bolts are easily accessible. There are no parts interfering with the access to them.
2. Axial force calculations have been done for each type of screw. Based on the center of mass of CSD, the bending force calculations prove that the 6 bolts are enough to fasten the CSD to the payload interference. However, Loctite Ablestick 104 was chosen as a fastener adhesive to prevent any possibility of the unthreading of the screws. One Side plate panel will not use Loctite for adhering the screws to allow unscrewing of the panel for easy accessibility of the CSD interior.
3. The foam has changed material for better outgassing properties. However, the thickness remained 3.175 mm as the tolerances loops for the launcher to rail foam interface are based on it. The foam is ultra-smooth therefore it has low friction. However, Nye Lubricants Synthetic Oil 1001-3PBNP has been chosen as a lubricant if necessary due to its low outgassing properties. But its usage will be decided based on the testing of friction between the CubeSat.
4. Due to the complexity of the door structure, accurate hand calculations were possible. An FEA analysis was run by fixing the door at the latch and at the hinge. A load of 273.566 N was modelled to act on the bottom face of the door. This force was based on the spring force acting on the door. There were multiple stress concentrations, at the latch, the hinges, the elevated surfaces on the edge and the corners of the elevated edges. However, the minimum FOS was determined to be 3.196. Since there is no yielding, the door was determined to be reliable.
5. Linear solenoid was always positioned correctly. The door was slightly opened therefore it looked off position.
6. Wiring has been added.
7. AZ-93 thermal paint has been chosen as the thermal coating. Since it is white it has a high reflectivity of 0.91 and a low absorptance of 0.15.
8. The temperature range was wrongly determined. The correct temperature range of the CPL environment is 4˚F to 130˚F. All the electricals are operable in that temperature range.
9. FEA analysis using the max load of the door and front plate at 4.1 G showed that the rail does not buckle.

III. Team Self-Assessment

For the FDR the team worked together perfectly. Everyone worked on their assigned sections while also being available to discuss and help with other member's sections. Each member of the group put equal effort in ensuring the report is good. Overall, it was felt that the report should score at least 70 out of 72.

IV. Report Gantt Chart

To plan out the workflow for this report, our team created a Gantt Chart (Fig. 1). The Gantt Chart was drafted and presented at our first meeting discussing this report. The Gantt Chart divided the report into tasks and milestones. Milestones were indicated by the red diamond icons. During our initial meeting, we refined the timeline and due dates to work around our goals and availabilities for the next two weeks. The team ensured that the schedule was met, and all the tasks were properly completed comfortably before the deadline.

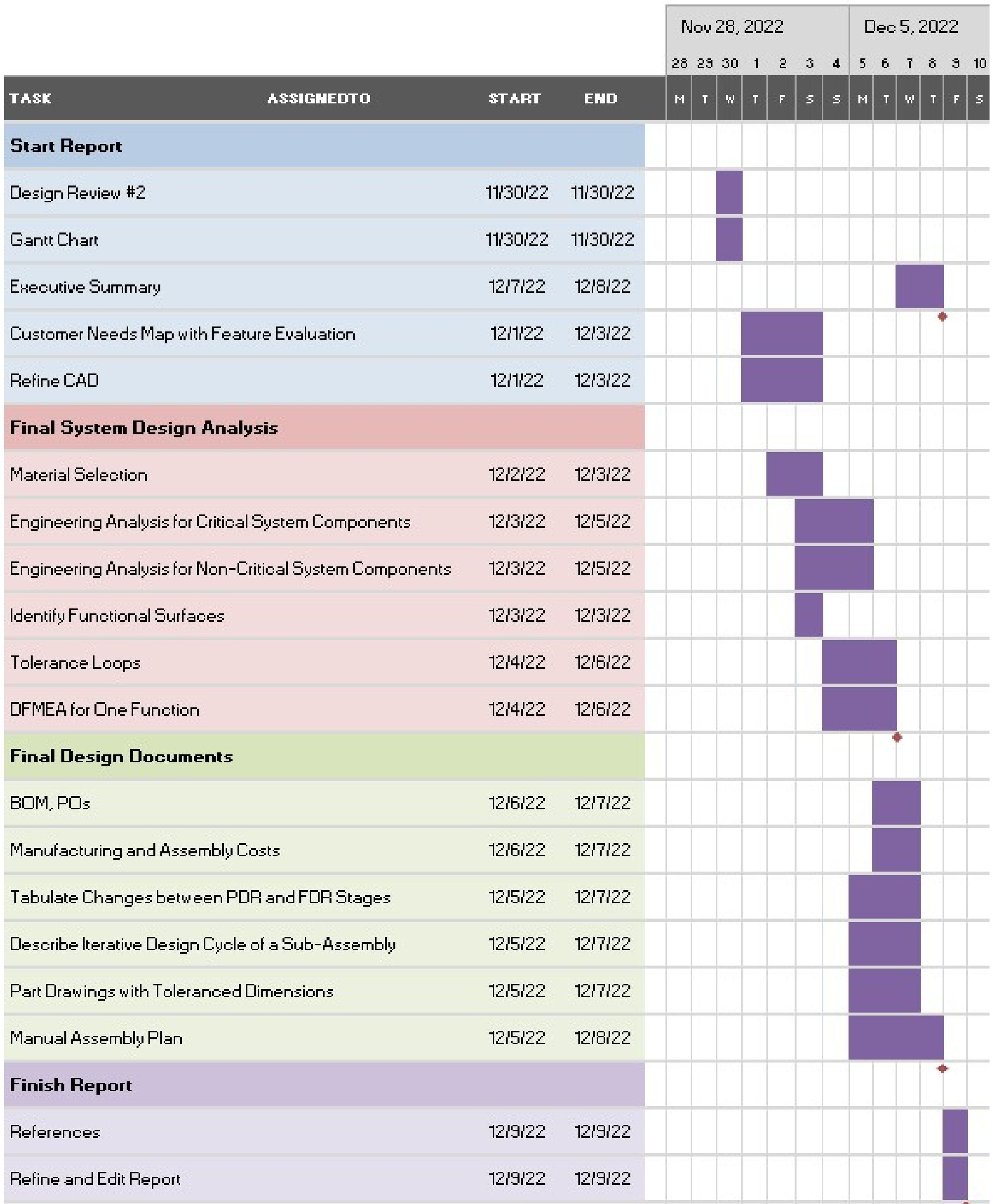


Fig. 2 Group 13.5's Gantt Chart for Final Design Report

V. Customer Needs Maps with Kano Model Feature Evaluation

A. Map of Customer Needs, Quantified Metrics, and Subsystem Features

In a customer needs map, the customer needs, their corresponding quantified metrics, the design's subsystems, and relevant features and parts are connected, visually representing how the subsystems and their feature and parts address and relate to the customer needs.

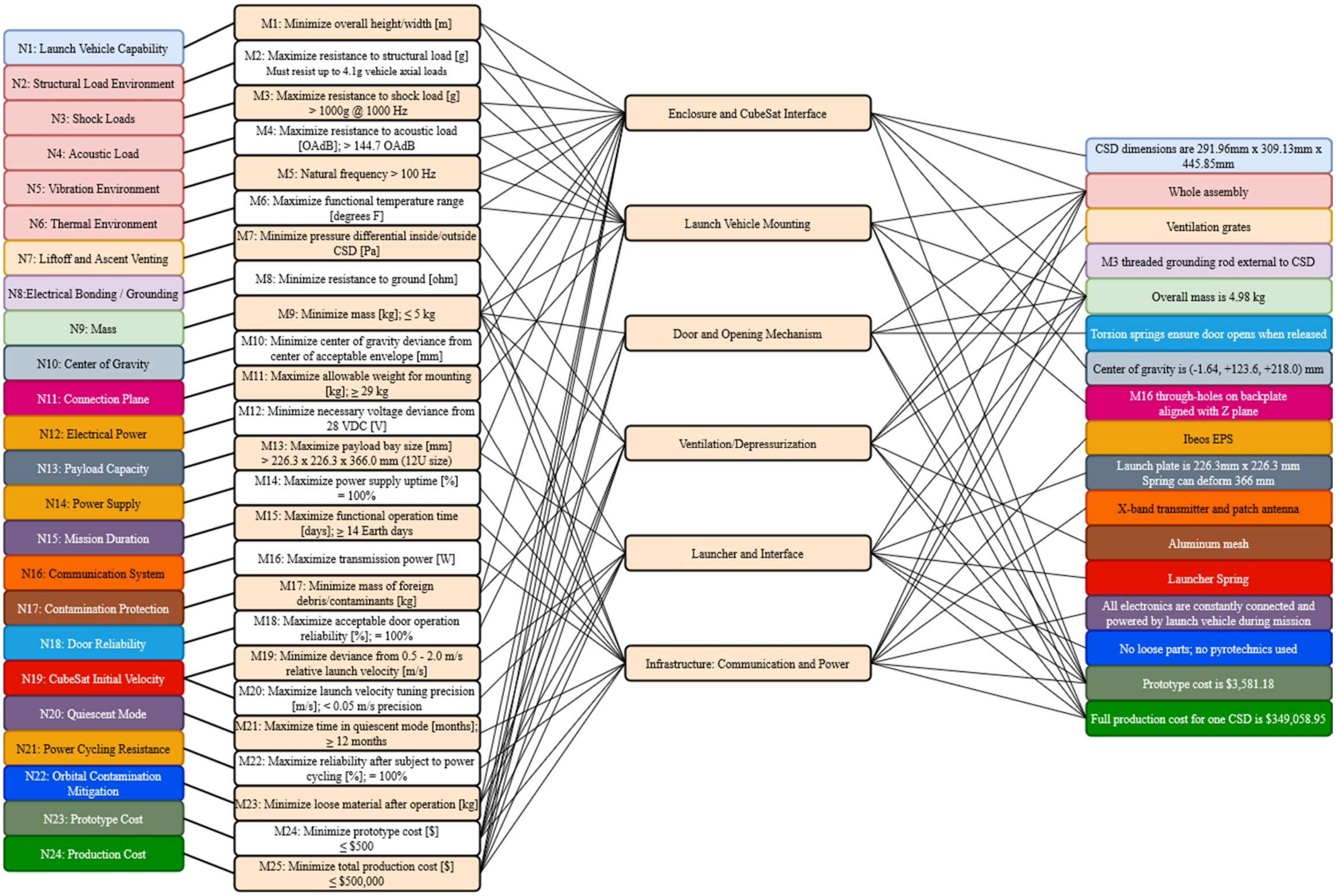


Fig. 3 Group 13.5's Customer Needs to Feature Mapping for Final Design Report

B. Kano Model Feature Evaluation Table

To evaluate how our group's design satisfies the customer's needs, Kano Model thinking was incorporated. This considers the customer's priorities and meanings toward their stated needs and rates how the design features meet the given customer needs. Each customer need is given a Kano designation, which are basic, performance, or attractive. Basic needs are features that are expected in all products and do not increase customer satisfaction. Performance needs are features that can add satisfaction or dissatisfaction in the customer based on the execution. Attractive needs are features that delight customers and do not satisfy them if not present. Each feature listed is given a rating between -5 and +5. "-5" indicates customer disgust. "0" indicates customer neutrality. "+5" indicates customer delight. These ratings are also graphed by customer need in a Kano chart.

Table 1 Kano Table

Customer Need Information			Rating
Customer Need	*Feature*	*Kano Designation*	
N1: Launch Vehicle Capability	CSD dimensions are 291.96mm x 309.13mm x 445.85mm	Basic	+5
N2: Structural Load Environment	Enclosure	Basic	0
N3: Shock Loads	Enclosure	Basic	0
N4: Acoustic Loads	Enclosure	Basic	0
N5: Vibration Environment	Enclosure	Basic	0
N6: Thermal Environment	Enclosure	Basic	0
N7: Liftoff and Ascent Venting	Ventilation grates	Basic	0
N8: Electrical Bonding/Grounding	M3 threaded grounding rod external to CSD	Basic	0
N9: Mass	Overall mass is 4.98 kg	Performance	+5
N10: Center of Gravity	CG = (-1.64, +123.6, +218.0) mm[1]	Basic	0
N11: Connection Plane	M16 through-holes aligned with Z-plane and on backplate	Basic	0
N12: Electrical Power	Ibeos EPS accepts input of 18-42 VDC	Basic	0
N13: Payload Capacity	Launch plate is 226.3mm x 226.3mm. Spring can deform 366mm.	Basic	0
N14: Power Supply	Ibeos EPS capable of continuous operation	Basic	+5
N15: Mission Duration	All electronics are constantly connected and powered by launch vehicle during mission	Basic	+5
N16: Communication System	X-band transmitter and patch antenna	Basic	+5
N17: Contamination Protection	Aluminum mesh	Basic	+2.5
N18: Door Reliability	Torsion Springs	Performance	+5
N19: CubeSat Initial Velocity	Launcher spring	Performance	+5
N20: Quiescent Mode	All electronics are constantly connected and powered by launch vehicle during mission	Basic	0
N21: Power Cycling Resistance	Ibeos EPS can withstand power cycling	Basic	0
N22: Orbital Contamination Mitigation	No loose parts; no pyrotechnics used	Basic	0
N23: Prototype Cost	Prototype cost is $3,581.18	Performance	-5
N24: Production Cost	Production cost is $349,058.95	Performance	+1.5

[1] Coordinates based on those specified in SLS Mission Guide, Figure 6-20, p.79.

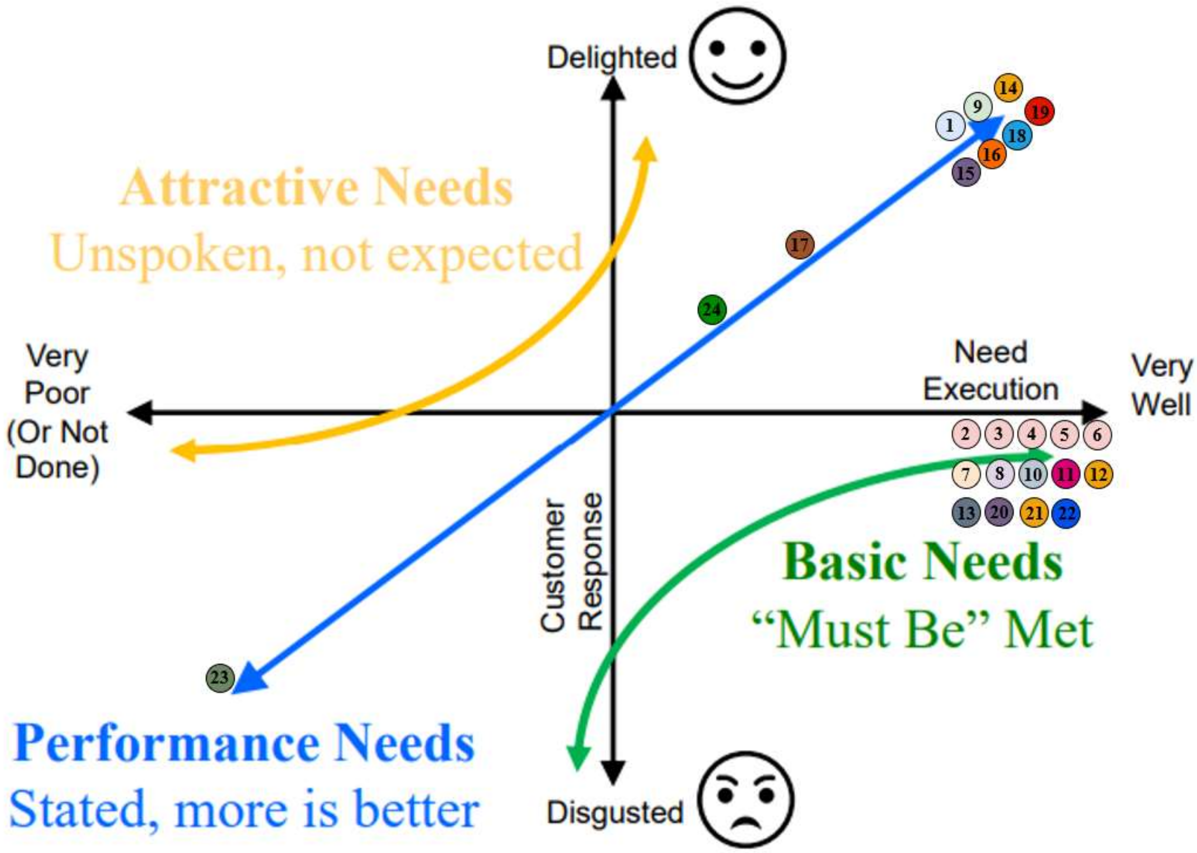


Fig. 4 Kano chart

VI. Bill of Materials, Purchase Order, Vendor Vetting, and Manufacturing and Assembly Costs

A. Vendor Vetting

As McMaster-Carr and other OTS part vendors do not list a shipping price, the shipping prices had to be estimated using the UPS shipping price calculator based on overall dimensions and weight [1]. Additionally, due to a lack of openly listed pricing from many vendors without getting a quote, a conservative estimate of price based on similar items from competitors had to be used. This price estimation had to be performed on the GOMSpace Nanomind A3200, AAC Clyde Pulsar-XTX, Pulsar-XANT, and Ibeos 150 Watt SmallSat EPS. Competitor prices were taken from EnduroSat's website and increased by 5% to account for possible variance.

Vendors were vetted based on a combination of market share, recent business activity, and for spacecraft component vendors, spaceflight heritage. The vetting process of all vendors used is detailed below.

EnduroSat is a Bulgarian aerospace company that specializes in OTS CubeSat equipment [2]. Their components are listed on NASA's SmallSat Institute webpage as a potential vendor for various subsystems that have flight heritage [3]. News of recent office expansions in August 2022 indicates that they are still an active company that can provide these parts at the prices they list [4]. Additionally, the European Investment Bank (EIB) invested 10 million euros in EnduroSat in August 2021 [5].

Specific material properties and parameters (outgassing, wire and coil diameter, etc.) of the foam used on the rail surfaces, the launcher spring, and the carbon fiber used for the enclosure would require custom ordering to attain. Once again, an exact price for these purchases would require getting a quote from the vendors which was not feasible in the timeframe of this report, in addition to wasting the businesses' time. As such, similar parts available OTS were found from other vendors (McMaster-Carr) and used to base a conservative price estimate for custom ordering the parts with desired properties. McMaster-Carr is a commonly used supplier for hardware, materials, and components, among many other things. McMaster-Carr has an A+ rating from the Better Business Bureau [6].

A third vendor, Mouser Electronics, based out of Mansfield, Texas, is used to purchase the limit switch for the door. Mouser Electronics is a company owned by TTI, Inc. and subsequently Berkshire Hathaway. In 2019, they began construction of a new headquarters with one million square feet [7]. More recent news indicates that they are still a very active company that has grown since the construction of their new headquarters [8].

GOMSpace is a publicly traded Danish company that produces CubeSat components. They manufactured a nanosatellite used on the Space-X Transporter-4 mission in early 2022 [9]. Additionally, the specific Nanomind A3200 computer is listed on NASA's SmallSat Institute webpage as an option for state-of-the-art on-board computing systems [3].

AAC Clyde Space is a publicly traded small satellite technology company based out of Sweden. They have various components listed on NASA's SmallSat Institute webpage with flight heritage [3]. They appear to own several subsidiary companies with offices around the world [10]. Their spaceflight heritage across several components is evidence that they are capable of producing the X-band transmitter and antenna specified for this CSD.

Ibeos, formerly known as Cubic Aerospace, is a woman-owned company based out of Virginia, USA that produces space electronics for CubeSat and small satellite applications. Their electric power subsystems (EPS) are listed under NASA's SmallSat Institude webpage [3].

EML 4501 Final Design Full Assembly Bill of Materials

Item No.	DWG Number	Part Description	Material (Individual Custom & Modified OTS Parts)	Qty.
1	EML4501-A-01	Full CSD Assembly	-	1
2	EML4501-A-02	Door Assembly		1
3	EML4501-A-03	Enclosure Assembly		1
4	EML4501-A-04	Launcher Assembly	-	1
5	EML4501-01	Back Plate	Aluminium 6061	1
6	EML4501-02	Rail	Aluminium 6061	8
7	EML4501-03	Front Plate	Aluminium 6061	1
8	EML4501-04	Rail Angle Bracket	Aluminium 6061	4
9	EML4501-05	Ventilation Grate	Carbon Fiber Reinforced Composite	4
10	EML4501-06	Side Plates	Carbon Fiber Reinforced Composite	3
11	EML4501-07	Hinge-Face Side Plate	Carbon Fiber Reinforced Composite	1
12	EML4501-08	Door	Aluminium 6061	1
13	EML4501-09	Spring	Stainless Steel 302	1
14	EML4501-10	Launcher Base Plate	ABS	1
15	EML4501-11	Pusher Plate	ABS	1
16	EML4501-12	Rail Foam	Polyethylene Foam	8
17	EML4501-13	Mesh Filter	Aluminium	4
18	EML4501-OTS-01	316 Stainless Steel Hex Drive Flat Head Screw, 90 Degree Countersink, M3 x 0.50mm Thread, 12mm Long	Stainless Steel 316	16
19	EML4501-OTS-02	316 Stainless Steel Button Head Hex Drive Screws, M3 x 0.5mm Thread, 12mm Long	Stainless Steel 316	8
20	EML4501-OTS-03	18-8 Stainless Steel Shoulder Screw, 10 mm Shoulder Diameter, 50 mm Shoulder Length, M8 x 1.25 mm Thread	Stainless Steel 18-8	2
21	EML4501-OTS-04	18-8 Stainless Steel Nylon-Insert Locknut, M8 x 1.25 mm Thread, 13 mm Wide, 9.5 mm High	Stainless Steel 18-8	2
22	EML4501-OTS-05	Titanium Button Head Hex Drive Screw, M3 x 0.50 mm Thread, 8mm Long	Titanium	52
23	EML4501-OTS-06	Ultra-Low-Profile Socket Head Screw, Alloy Steel, M6 x 1.00 mm Thread, 10 mm Long	Alloy Steel	4
24	EML4501-OTS-07	18-8 Stainless Steel Nylon-Insert Locknut, M6 x 1 mm Thread, 10 mm Wide, 6 mm High	Stainless Steel 18-8	4
25	EML4501-OTS-08	Sealed Linear Solenoid, Intermittent, Pull, 0.5" Stroke	-	1
26	EML4501-OTS-09	Omron Sub-Miniature Roller Limit Switch	-	1
27	EML4501-OTS-10	18-8 Stainless Steel Pan Head Slotted Screws, 1-64 Thread Size, 3/8" Long	Stainless Steel 18-8	2
28	EML4501-OTS-11	Nanomind A3200 On-board Computer	-	1
29	EML4501-OTS-12	Pulsar-XTX X-Band Transmitter	-	1
30	EML4501-OTS-13	Pulsar-XANT X-Band Patch Antenna	-	1
31	EML4501-OTS-14	Aluminum Male-Female Threaded Hex Standoff, 4.5mm Hex, 10mm Long, M2.5 x 0.45 mm Thread	Aluminium	4
32	EML4501-OTS-15	Alloy Steel Socket Head Screw, Black-Oxide, M2.5 x 0.45 mm Thread, 6 mm Long	Alloy Steel	8
33	EML4501-OTS-16	Torsion Spring, 270 Degree Angle, Right-Hand Wound, 0.601" OD	Alloy Steel	2
34	EML4501-OTS-17	Steel Hex Nut, Medium-Strength, Class 8, M2.5 x 0.45 mm Thread	Class 8 Steel	4
35	EML4501-OTS-18	18-8 Stainless Steel Threaded Rod, M3 x 0.5 mm Thread Size, 20 mm Long	Stainless Steel 18-8	1
36	EML4501-OTS-19	Ibeos 150-Watt SmallSat Electrical Power System	-	1

Purchase Order for Full Assembly

REQUEST FOR ITEMS TO BE PURCHASED **Date Requested:** 11/20/2022

1. Purchase Order Number: 1
2. Group requesting item(s): 13.5
3. Account to be charged: MAE Mechanical Design 2
4. Group member issuing PO: Sean Bresney

BOM Part Number	BOM Part Name	Description of item to be purchased:	Part Number	Qty.	Unit	Price	Shipping	Sub Total	Vendor Name	Vendor Address	Vendor City/State/Zip	Vendor Phone Number
EML4501-01	Back Plate	12" W x 48" L x 1.5" T Aluminum 6061 Plate. Back Plate, Front Plate, Rail Angle Brackets, and Door are cut from one plate	89015K95	1	EA	$527.84	$147.95	$675.79	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-03	Front Plate	12" W x 48" L x 1.5" T Aluminum 6061 Plate. Back Plate, Front Plate, Rail Angle Brackets, and Door are cut from one plate	89015K95	###	EA	-	-	-	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-04	Rail Angle Bracket	12" W x 48" L x 1.5" T Aluminum 6061 Plate. Back Plate, Front Plate, Rail Angle Brackets, and Door are	9246K666	###	EA	-	-	-	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-08	Door	12" W x 48" L x 1.5" T Aluminum 6061 Plate. Back Plate, Front Plate, Rail Angle Brackets, and Door are	9246K666	1	EA	-	-	-	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-02	Rail	12" W x 48" L x 0.5" T Aluminum 6061 Plate	9246K495	1	EA	$197.57	$28.30	$225.87	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-05	Ventilation Grates	24" W x 48" L x 1/16" T Carbon Fiber Sheet, Checked, Glossy. Ventilation Grates and Hinge-Face Side Plate are cut from one plate.	8181K29	1	EA	$421.71	$13.34	$435.05	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-07	Hinge-Face Side Plate	24" W x 48" L x 1/16" T Carbon Fiber Sheet, Checked, Glossy. Ventilation Grates and Hinge-Face Side Plate are cut from one plate.	8181K29	1	EA	-	-	-	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-06	Side Plates	24" W x 48" L x 1/16" T Carbon Fiber Sheet, Checked, Glossy.	8181K29	1	EA	$421.71	$13.34	$435.05	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-09	Spring	Custom, Made to Order Spring	1391N235	1	EA	$354.38	$23.61	$377.99	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-10	Launcher Base Plate	ABS Sheet 12" x 12" x 1"	8586K221	1	EA	$59.85	$11.00	$70.85	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-11	Pusher Plate	ABS Sheet 12" x 12" x 1"	8586K221	1	EA	$59.85	$11.00	$70.85	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-12	Rail Foam	24" W x 24" L x 1/16" T Polyethylene Foam	8722K6	1	EA	$5.59	$10.48	$16.07	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-13	Mesh Filter	3' W x 3' L Aluminium Wire Cloth	9227T374	1	EA	$92.68	$12.63	$105.31	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-OTS-01	316 Stainless Steel Hex Drive Flat Head Screw, 90 Degree Countersink, M3 x 0.50mm Thread, 12mm Long.	Box of 100.	93395A207	1	PKG	$15.35	$12.55	$27.90	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-OTS-02	316 Stainless Steel Button Head Hex Drive Screws, M3 x 0.5mm Thread, 12mm Long	Box of 100.	94500A264	1	PKG	$5.24	$12.55	$17.79	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-OTS-03	18-8 Stainless Steel Shoulder Screw, 10 mm Shoulder Diameter, 50 mm Shoulder Length, M8 x 1.25 mm Thread	Individual Pieces.	90265A167	2	EA	$7.60	$11.46	$26.66	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-OTS-04	18-8 Stainless Steel Nylon-Insert Locknut, M8 x 1.25 mm Thread, 13 mm Wide, 9.5 mm High	Box of 10.	93625A114	1	PKG	$5.00	$12.01	$17.01	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-OTS-05	Titanium Button Head Hex Drive Screw, M3 x 0.50 mm Thread, 8mm Long	Individual Pieces.	93625A114	52	EA	$10.57	$14.65	$564.29	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-OTS-06	Ultra-Low-Profile Socket Head Screw, Alloy Steel, M6 x 1.00 mm Thread, 10 mm Long	Individual Pieces.	90358A016	4	EA	$4.18	$10.15	$26.87	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-OTS-07	18-8 Stainless Steel Nylon-Insert Locknut, M6 x 1 mm Thread, 10 mm Wide, 6 mm High	Box of 100.	93625A250	1	PKG	$13.13	$11.46	$24.59	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-OTS-08	Sealed Linear Solenoid, Intermittent, Pull, 0.5" Stroke	Individual Pieces.	69905K113	1	EA	$35.22	$11.46	$46.68	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-OTS-09	Omron Sub-Miniature Roller Limit Switch	Individual Pieces.	D2F-01L2-A1	1	EA	$5.03	$7.99	$13.02	Mouser Electronics	1000 North Main Street	Mansfield, TX 76063	(800) 346 -6873
EML4501-OTS-10	18-8 Stainless Steel Pan Head Slotted Screws, 1-64 Thread Size, 3/8" Long	Box of 50.	91792A168	1	PKG	$9.16	$11.46	$20.62	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-OTS-11	Nanomind A3200 On-board Computer	Individual Pieces.	A3200	1	EA	$4,515.00	$18.74	$4,533.74	GOMSpace	211 North Union Street, Suite 100	Alexandria, VA 22314	(703) 866 - 8742
EML4501-OTS-12	Pulsar-XTX X-Band Transmitter	Individual Pieces.	PULSAR-XTX	1	EA	$31,395.00	$11.46	$31,406.46	AAC Clyde Space	Uppsala Science Park Dag Hammarskjölds väg 48	Uppsala SE-751 83 Sweden	4618560130
EML4501-OTS-13	Pulsar-XANT X-Band Patch Antenna	Individual Pieces.	PULSAR-XANT	1	EA	$4,725.00	$11.74	$4,736.74	AAC Clyde Space	Uppsala Science Park Dag Hammarskjölds väg 48	Uppsala SE-751 83 Sweden	4618560130
EML4501-OTS-14	Aluminum Male-Female Threaded Hex Standoff, 4.5mm Hex, 10mm Long, M2.5 x 0.45 mm Thread	Individual Pieces.	98952A107	4	EA	$1.99	$10.54	$18.50	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-OTS-15	Alloy Steel Socket Head Screw, Black-Oxide, M2.5 x 0.45 mm Thread, 6 mm Long	Box of 50.	91290A101	1	PKG	$11.12	$11.46	$22.58	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-OTS-16	Torsion Spring, 270 Degree Angle, Right-Hand Wound, 0.601" OD	Box of 6.	9271K421	1	PKG	$9.14	$8.57	$17.71	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-OTS-17	Steel Hex Nut, Medium-Strength, Class 8, M2.5 x 0.45 mm Thread	Box of 100.	90592A080	1	PKG	$4.19	$12.63	$16.82	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-OTS-18	18-8 Stainless Steel Threaded Rod, M3 x 0.5 mm Thread Size, 20 mm Long	Box of 10.	93805A631	1	PKG	$10.57	$10.15	$20.72	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-OTS-19	Ibeos 150-Watt SmallSat Electrical Power System	Individual Pieces.	E14-150	1	EA	$3,990.00	$12.48	$4,002.48	Ibeos	12110 Sunset Hills Rd, Ste C4	Reston, VA 20190	(571) 299 - 6977

TOTAL: 47974.01

Deliver to whom: Sean Bresney
Delivery location: Dept of Mech and Aero Eng.
Building B, Room 305

Denotes items to be filled in by preparer.

Purcahse Order for Scaled Production Order

REQUEST FOR ITEMS TO BE PURCHASED

Date Requested: 8/31/2020

1. Purchase Order Number: 1
2. Group requesting item(s): 13.5
3. Account to be charged: MAE Mechanical Design 2
4. Group member issuing PO: Sean Bresney

BOM Part Number	BOM Part Name	Description of item to be purchased:	Part Number	Qty.	Unit	Price	Shipping	Sub Total	Vendor Name	Vendor Address	Vendor City/State/Zip	Vendor Phone Number
EML4501-01	Back Plate	12" W x 48" L x 1.5" T Aluminum 6061 Plate. Back Plate, Front Plate, Rail Angle Brackets, and Door are cut from one plate	9246K666	25	EA	$527.84	$591.80	$2,703.16	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-03	Front Plate	12" W x 48" L x 1.5" T Aluminum 6061 Plate. Back Plate, Front Plate, Rail Angle Brackets, and Door are cut from one plate	9246K666	25	EA	-	-	-	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-04	Rail Angle Bracket	12" W x 48" L x 1.5" T Aluminum 6061 Plate. Back Plate, Front Plate, Rail Angle Brackets, and Door are cut from one plate	9246K666	25	EA	-	-	-	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-08	Door	12" W x 48" L x 1.5" T Aluminum 6061 Plate. Back Plate, Front Plate, Rail Angle Brackets, and Door are cut from one plate	9246K666	25	EA	-	-	-	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-02	Rail	12" W x 48" L x 0.5" T Aluminum 6061 Plate	9246K495	100	EA	$197.57	$113.20	$903.48	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-05	Ventilation Grates	24" W x 48" L x 1/16" T Carbon Fiber Sheet, Checked, Glossy. Ventilation Grates and Hinge-Face Side Plate are cut from one plate.	8181K29	100	EA	$421.71	$53.36	$1,740.20	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-07	Hinge-Face Side Plate	24" W x 48" L x 1/16" T Carbon Fiber Sheet, Checked, Glossy. Ventilation Grates and Hinge-Face Side Plate are cut from one plate.	8181K29	25	EA	-	-	-	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-06	Side Plates	24" W x 48" L x 1/16" T Carbon Fiber Sheet, Checked, Glossy.	8181K29	25	EA	$421.71	$53.36	$1,740.20	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-09	Spring	Custom, Made to Order Spring	1391N235	100	EA	$354.38	$94.44	$1,511.96	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-10	Launcher Base Plate	6" W x 6" L x 3/4" T PEEK Sheet	8504K36	100	EA	$295.55	$44.00	$1,358.20	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-11	Pusher Plate	12" W x 12" L x 3/4" T PEEK Sheet	8504K67	100	EA	$895.62	$57.68	$3,813.20	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-12	Rail Foam	24" W x 24" L x 1/16" T Polyethylene Foam	8722K6	100	EA	$5.59	$41.92	$190.04	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-13	Mesh Filter	3' W x 3' L Aluminium Wire Cloth	9227T374	100	EA	$92.68	$50.52	$572.80	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-OTS-01	316 Stainless Steel Hex Drive Flat Head Screw, 90 Degree Countersink, M3 x 0.50mm Thread, 12mm Long.	Box of 100.	93395A207	20	PKG	$15.35	$50.20	$262.20	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-OTS-02	316 Stainless Steel Button Head Hex Drive Screws, M3 x 0.5mm Thread, 12mm Long	Box of 100.	94500A264	20	PKG	$5.24	$50.20	$221.76	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-OTS-03	18-8 Stainless Steel Shoulder Screw, 10 mm Shoulder Diameter, 50 mm Shoulder Length, M8 x 1.25 mm Thread	Individual Pieces.	90265A167	200	EA	$7.60	$45.84	$244.16	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-OTS-04	18-8 Stainless Steel Nylon-Insert Locknut, M8 x 1.25 mm Thread, 13 mm Wide, 9.5 mm High	Box of 10.	93625A114	20	PKG	$5.00	$48.04	$212.16	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-OTS-05	Titanium Button Head Hex Drive Screw, M3 x 0.50 mm Thread, 8mm Long	Individual Pieces.	93625A114	4160	EA	$10.57	$58.60	$176,119.20	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-OTS-06	Ultra-Low-Profile Socket Head Screw, Alloy Steel, M6 x 1.00 mm Thread, 10 mm Long	Individual Pieces.	90358A016	3200	EA	$4.18	$40.60	$53,666.40	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-OTS-07	18-8 Stainless Steel Nylon-Insert Locknut, M6 x 1 mm Thread, 10 mm Wide, 6 mm High	Box of 100.	93625A250	20	PKG	$13.13	$45.84	$1,233.76	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-OTS-08	Sealed Linear Solenoid, Intermittent, Pull, 0.5" Stroke	Individual Pieces.	69905K113	1200	EA	$35.22	$45.84	$42,309.84	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-OTS-09	Omron Sub-Miniature Roller Limit Switch	Individual Pieces.	D2F-01L2-A1	800	EA	$5.03	$31.96	$16,223.84	Mouser Electronics	1000 North Main Street	Mansfield, TX 76063	(800) 346 -6873
EML4501-OTS-10	18-8 Stainless Steel Pan Head Slotted Screws, 1-64 Thread Size, 3/8" Long	Box of 50.	91792A168	30	PKG	$9.16	$45.84	$1,282.56	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-OTS-11	Nanomind A3200 On-board Computer	Individual Pieces.	A3200	100	EA	$4,515.00	$74.96	$451,574.96	GOMSpace	North Union Street, Suite	Alexandria, VA 22314	(703) 866 - 8742
EML4501-OTS-12	Pulsar-XTX X-Band Transmitter	Individual Pieces.	PULSAR-XTX	100	EA	$31,395.00	$45.84	$3,139,545.84	AAC Clyde Space	Uppsala Science Park Dag Hammarskjölds väg 48	Uppsala, SE-751 83, Sweden	4618560130
EML4501-OTS-13	Pulsar-XANT X-Band Patch Antenna	Individual Pieces.	PULSAR-XANT	100	EA	$4,725.00	$11.74	$472,511.74	AAC Clyde Space	Uppsala Science Park Dag Hammarskjölds väg 48	Uppsala, SE-751 83, Sweden	4618560130
EML4501-OTS-14	Aluminum Male-Female Threaded Hex Standoff, 4.5mm Hex, 10mm Long, M2.5 x 0.45 mm Thread	Individual Pieces.	98952A107	1600	EA	$1.99	$10.54	$3,194.54	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-OTS-15	Alloy Steel Socket Head Screw, Black-Oxide, M2.5 x 0.45 mm Thread, 6 mm Long	Box of 50.	91290A101	20	PKG	$11.12	$11.46	$233.86	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-OTS-16	Torsion Spring, 270 Degree Angle, Right-Hand Wound, 0.601" OD	Box of 6.	9271K421	40	PKG	$9.14	$44.80	$1,641.60	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-OTS-17	Steel Hex Nut, Medium-Strength, Class 8, M2.5 x 0.45 mm Thread	Box of 100.	90592A080	20	PKG	$4.19	$44.21	$512.02	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-OTS-18	18-8 Stainless Steel Threaded Rod, M3 x 0.5 mm Thread Size, 20 mm Long	Box of 10.	93805A631	20	PKG	$10.57	$40.60	$1,008.00	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 - 7000
EML4501-OTS-19	Ibeos 150-Watt SmallSat Electrical Power System	Individual Pieces.	E14-150	100	EA	$3,990.00	$49.92	$399,049.92	Ibeos	2110 Sunset Hills Rd, Ste	Reston, VA 20190	(571) 299 - 6977

TOTAL: $4,775,581.60

Deliver to whom: Sean Bresney
Delivery location: Dept of Mech and Aero Eng.
Building B, Room 305

Denotes items to be filled in by preparer.

EML 4501 Final Design Manufacturing and OTS Costs

Item No.	DWG Number	Material (Individual Custom & Modified OTS Parts)	Qty.	Raw Material Size	Part Volume	Material Removed	Manufacturing Cost	Raw Material Cost	Total Cost	Production Scale Cost
1	EML4501-A-01	-	1							
2	EML4501-A-02		1							
3	EML4501-A-03		1							
4	EML4501-A-04	-	1							
5	EML4501-01	Aluminium 6061	1	$ 3,539.61	$ 303.99	$ 3,235.62	$ 136.42	$ 168.95	$ 305.37	$ 30,536.75
6	EML4501-02	Aluminium 6061	8	$ 4,719.47	$ 346.05	$ 4,373.42	$ 174.94	$ 225.87	$ 400.81	$ 38,076.95
7	EML4501-03	Aluminium 6061	1	$ 3,539.61	$ 170.86	$ 3,368.75	$ 141.05	$ 168.95	$ 310.00	$ 30,999.75
8	EML4501-04	Aluminium 6061	4	$ 589.93	$ 12.46	$ 577.47	$ 23.10	$ 168.95	$ 192.05	$ 15,363.64
9	EML4501-05	Carbon Fiber Reinforced Composite	4	$ 589.94	$ 106.12	$ 483.81	$ 38.70	$ 217.53	$ 256.23	$ 24,341.38
10	EML4501-06	Carbon Fiber Reinforced Composite	3	$ 1,179.87	$ 362.38	$ 817.49	$ 65.40	$ 435.05	$ 500.45	$ 47,542.64
11	EML4501-07	Carbon Fiber Reinforced Composite	1	$ 589.94	$ 118.41	$ 471.52	$ 37.72	$ 217.53	$ 255.25	$ 24,248.47
12	EML4501-08	Aluminium 6061	1	$ 3,539.61	$ 221.20	$ 3,318.41	$ 132.74	$ 168.95	$ 301.68	$ 30,168.35
13	EML4501-09	Stainless Steel 302	1			$ -		$ 377.99	$ 377.99	$ 35,909.05
14	EML4501-10	ABS	1	$ 2,359.74	$ 22.48	$ 2,337.26	$ 46.75	$ 70.85	$ 117.60	$ 10,583.57
15	EML4501-11	ABS	1	$ 2,359.74	$ 56.44	$ 2,303.30	$ 46.07	$ 70.85	$ 116.92	$ 10,522.44
16	EML4501-12	Polyethylene Foam	8					$ 16.07	$ 16.07	$ 1,446.30
17	EML4501-13	Aluminium	4					$ 105.31	$ 105.31	$ 9,477.90
18	EML4501-OTS-01	Stainless Steel 316	16					$ 27.90	$ 27.90	$ 558.00
19	EML4501-OTS-02	Stainless Steel 316	8					$ 17.79	$ 17.79	$ 142.32
20	EML4501-OTS-03	Stainless Steel 18-8	2					$ 26.66	$ 26.66	$ 2,666.00
21	EML4501-OTS-04	Stainless Steel 18-8	2					$ 17.01	$ 17.01	$ 340.20
22	EML4501-OTS-05	Titanium	52					$ 564.29	$ 564.29	$ 56,429.00
23	EML4501-OTS-06	Alloy Steel	4					$ 26.87	$ 26.87	$ 2,687.00
24	EML4501-OTS-07	Stainless Steel 18-8	4					$ 24.59	$ 24.59	$ 98.36
25	EML4501-OTS-08	-	1					$ 46.68	$ 46.68	$ 4,668.00
26	EML4501-OTS-09	-	1					$ 13.02	$ 13.02	$ 1,236.90
27	EML4501-OTS-10	Stainless Steel 18-8	2					$ 20.62	$ 20.62	$ 82.48
28	EML4501-OTS-11	-	1					$ 4,533.74	$ 4,533.74	$ 453,374.00
29	EML4501-OTS-12	-	1					$ 31,406.46	$ 31,406.46	$ 3,140,646.00
30	EML4501-OTS-13	-	1					$ 4,736.74	$ 4,736.74	$ 473,674.00
31	EML4501-OTS-14	Aluminium	4					$ 18.50	$ 18.50	$ 1,850.00
32	EML4501-OTS-15	Alloy Steel	8					$ 22.58	$ 22.58	$ 361.28
33	EML4501-OTS-16	Alloy Steel	2					$ 17.71	$ 17.71	$ 584.43
34	EML4501-OTS-17	Class 8 Steel	4					$ 16.82	$ 16.82	$ 67.28
35	EML4501-OTS-18	Stainless Steel 18-8	1					$ 20.72	$ 20.72	$ 207.20
36	EML4501-OTS-19	-	1					$ 4,002.48	$ 4,002.48	$ 400,248.00
								Total Cost	**$ 48,816.89**	**$ 4,849,137.62**

Labor Costs

Position	Comments	Qty	Total Cost
Engineers	Paid equivalent of 75K f	8	$ 300,000.00
Assemblers	Paid $19/hr for 12.74 h	1	$ 242.06

Production Costs

Production Type	Total Cost
Single Unit	$ 349,058.95
Production Scale (100 u	$ 5,173,343.62
Prototype	$ 3,581.18

VII. Final System Design Analysis

A. Material Selections for Individual Components

Part Description	Material
Full CSD Assembly	-
Back Plate	Aluminum 6061-T6
Rail	Aluminum 6061-T6
Front Plate	Aluminum 6061-T6
Rail Angle Bracket	Aluminum 6061-T6
Ventilation Grate	Carbon Fiber Reinforced Composite
Side Plates	Carbon Fiber Reinforced Composite
Hinge-Face Side Plate	Carbon Fiber Reinforced Composite
Door	Aluminum 6061-T6
Spring	Stainless Steel 302
Launcher Base Plate	ABS Plastic
Pusher Plate	ABS Plastic
Rail Foam	Viton Fluoroelastomer Foam
Mesh Filter	Aluminum
316 Stainless Steel Hex Drive Flat Head Screw, 90 Degree Countersink, M3 x 0.50mm Thread, 12mm Long	Stainless Steel 316
316 Stainless Steel Button Head Hex Drive Screws, M3 x 0.5mm Thread, 12mm Long	Stainless Steel 316
18-8 Stainless Steel Shoulder Screw, 10 mm Shoulder Diameter, 50 mm Shoulder Length, M8 x 1.25 mm Thread	Stainless Steel 18-8
18-8 Stainless Steel Nylon-Insert Locknut, M8 x 1.25 mm Thread, 13 mm Wide, 9.5 mm High	Stainless Steel 18-8
Titanium Button Head Hex Drive Screw, M3 x 0.50 mm Thread, 8mm Long	Titanium
Ultra-Low-Profile Socket Head Screw, Alloy Steel, M6 x 1.00 mm Thread, 10 mm Long	Alloy Steel
18-8 Stainless Steel Nylon-Insert Locknut, M6 x 1 mm Thread, 10 mm Wide, 6 mm High	Stainless Steel 18-8
Sealed Linear Solenoid, Intermittent, Pull, 0.5" Stroke	-
Omron Sub-Miniature Roller Limit Switch	-
18-8 Stainless Steel Pan Head Slotted Screws, 1-64 Thread Size, 3/8" Long	Stainless Steel 18-8
Nanomind A3200 On-board Computer	-
Pulsar-XTX X-Band Transmitter	-
Pulsar-XANT X-Band Patch Antenna	-
Aluminum Male-Female Threaded Hex Standoff, 4.5mm Hex, 10mm Long, M2.5 x 0.45 mm Thread	Aluminium
Alloy Steel Socket Head Screw, Black-Oxide, M2.5 x 0.45 mm Thread, 6 mm Long	Alloy Steel
Torsion Spring, 270 Degree Angle, Right-Hand Wound, 0.601" OD	Alloy Steel
Steel Hex Nut, Medium-Strength, Class 8, M2.5 x 0.45 mm Thread	Class 8 Steel
18-8 Stainless Steel Threaded Rod, M3 x 0.5 mm Thread Size, 20 mm Long	Stainless Steel 18-8
Ibeos 150-Watt SmallSat Electrical Power System	-

B. Changes from PDR to FDR

Table 1. Changes from PDR to FDR

Subsystem	Description of Change
Enclosure	Added thermal paint to carbon fiber plates to better reflect radiation incident on the enclosure
Launcher	Changed material of launcher base plate and launcher pusher plate from PEEK to ABS to reduce cost
Enclosure	Changed material of Foam on the rail from Polyethylene to Viton Fluoroelastomer due to unacceptable outgassing properties

1. Thermal Paint

Thermal paint is commonly used in aerospace systems which are affected by solar radiation. Therefore, it is important to protect the CSD from solar radiation. The main method is to use a thermal coating on the outer surface of the CSD. The CSD is to be coated in a white coating because white has the highest reflectivity of any coating.

AZ-93 manufactured by AZ Technology is a white thermal control coating. This was chosen because it is manufactured specifically for aerospace purposes. Since the carbon-fiber composite is naturally black, this will be necessary for thermal control and protection. It has a thermal emittance of 0.91 and a low solar absorptance of 0.15. This coating is used on the International Space Station, hence it is proved to work in the harsh environment in space [11].

2. Launcher Pusher and Base Plate Material Change

PEEK is a very strong and light plastic; however it is very expensive. From the Preliminary Design report purchase order, it was calculated that the total cost of the PEEK would be $1292.85 for two sheets. Two sheets were required because, due to the complex geometry of the launcher base plate and ejection plate, machining thick sheets were necessary.

However, after Design Review 2, it was found out that the wrong temperature range was considered for the CSD. According to the NASA SLS mission planner guide, the temperature range is 6 ˚F to 130 ˚F. This allowed a wider range of plastics to be used, which will subsequently reduce weight and cost, while maintaining the strength required to hold the CubeSat.

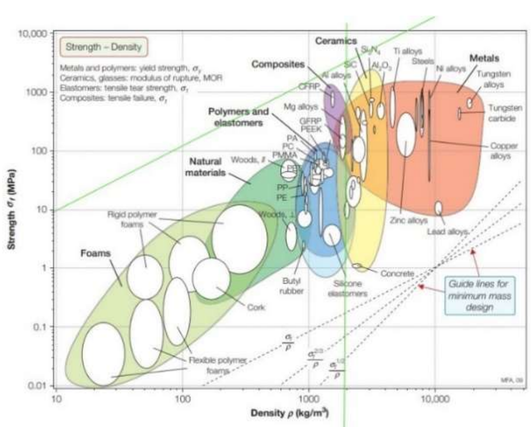


Figure 5: Strength vs Density Ashby Plot

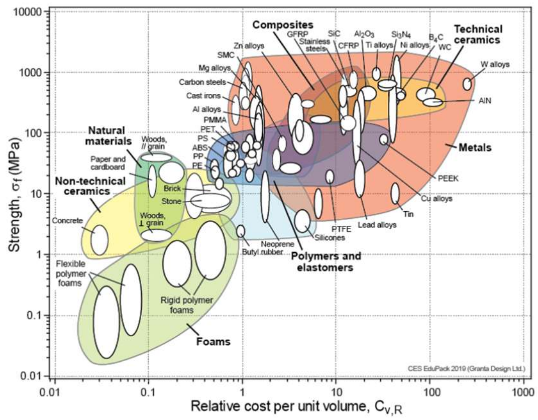


Figure 6: Strength vs Relative Ashby Plot

Both the Ashby plots can be used to find materials which satisfy the designers requirement. The plastics chosen will be both lighter and cheaper than PEEK. PMMA, PEEK, PET, PP, PE and ABS were ranked in order of decreasing strength.

However, one of the most important properties of a plastic for its use is space is its outgassing properties. According to NASA the outgassing requirements to be cleared for space use are total mass loss (TML) less than 1% and collected volatile condensable materials (CVCM) less than 0.1%. NASA has provided an online database where the outgassing properties and their primary use for different plastics can be found. PET and ABS were the only plastics which satisfied the outgassing requirements because there was no data on PMMA and PP, while PE exceeded the CVCM limit.

The advantage of using PET and ABS is that they can be 3D printed, which saves on material wastage since machining a PEEK sheet results in high wastage due to the complex geometry of the parts. From the Ashby plot, the cost of PET and ABS are very similar, while the strengths are 70 MPa and 50 MPa respectively.

$$\sigma_{CS} = \frac{W_{CS}}{A}$$
$$\sigma_{CS} = \frac{25 \times 9.81}{0.01240866} = 0.019\ MPa$$

Since both plastics have significantly higher strength than the maximum stress on the plate the deciding factor will be density since the lighter material is preferred. ABS was significantly less dense with a density of 1020 kg-m^3 compared to 1020 kg-m^3 of PET. Therefore, ABS was selected as the new material for the launch ejector plate and the launcher base plate.

3. Rail Bar Foam Material Change

It was found out that PE has outgassing properties which do not meet NASA outgassing standards, hence the material needed to change. The Ashby plots shows that the foams are classes as rigid polymer foams and flexible polymer foams, therefore the Ashby plot is not a viable analysis tool for choosing the material.

To keep the cost low, it was decided to buy currently available foam sheets instead of getting custom orders from manufacturers. The most important properties for the foam would that it is ultra-smooth and has low outgassing properties.

It was found that Chemical-Resistant Viton® Fluoroelastomer Foam is the best option. It has an operating temperature of -10 to 400 ˚F and the surface is ultra-smooth which is a property which would reduce frictional force on the launcher plate and CubeSat. The outgassing properties fall under NASA's requirements with a TML < 1% and CVCM < 0.1% based off of the NASA outgassing database.

C. Engineering Analysis for Critical Components

1. Door

Several engineering analyses were conducted on the door to ensure the design's viability with respect to the customer metrics. The first analysis done was a bending analysis to ensure the force of the CubeSat being pushed into the door by the spring will not cause the door to fail. Due to the complex loading scenario and cross-section of the door, the study is done using FEA in SolidWorks. Using SolidWorks simulation, maximum and minimum values are found for stress and factor of safety. The door material was previously chosen using Ashby plot analysis as Aluminum 6061-T6 alloy.

The only force acting on the door is a 3D distributed load due to the CubeSat being pushed into the door by the spring. This force is constant since the spring is preloaded when the CubeSat is inserted into the CSD and is the largest force the door is expected to experience. From the spring calculations, at compression the spring exerts a force of 273.556 *N*. The door is held at the bottom by two pins and at the top by a single linear solenoid, both of which can be modelled as hinged supports.

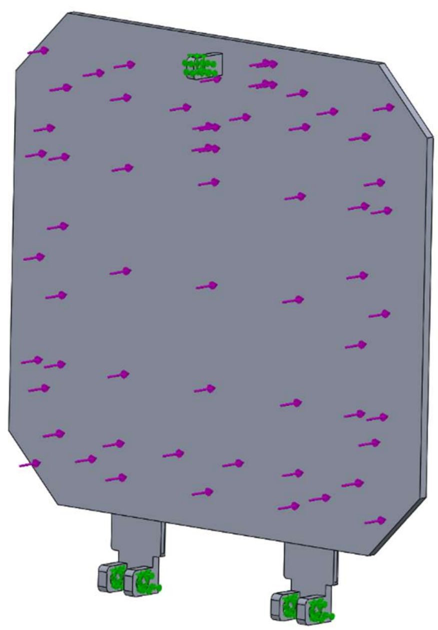


Figure 7: Loading conditions of the door. Hinged supports shown with green arrows at the top and bottom of the door.

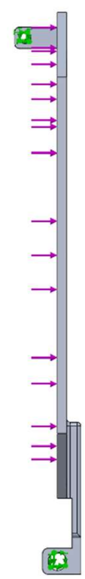


Figure 8: Left side view of the door loading conditions.

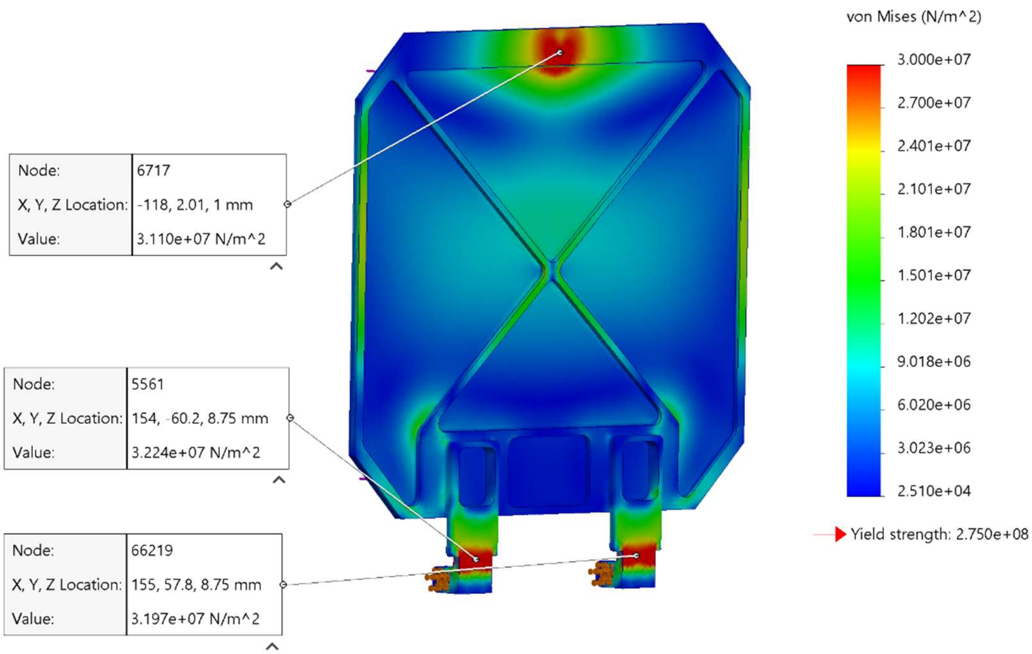


Figure 9: Von Mises Stress plot of the door. Maximum stresses occur in red at the midpoint of the bottom two tabs and behind the slot on the top where the linear solenoid holds the door in place. The greatest stress probed occurred at the left-bottom tab and was $\mathbf{3.197 \times 10^7}$ $\boldsymbol{Pa}$.

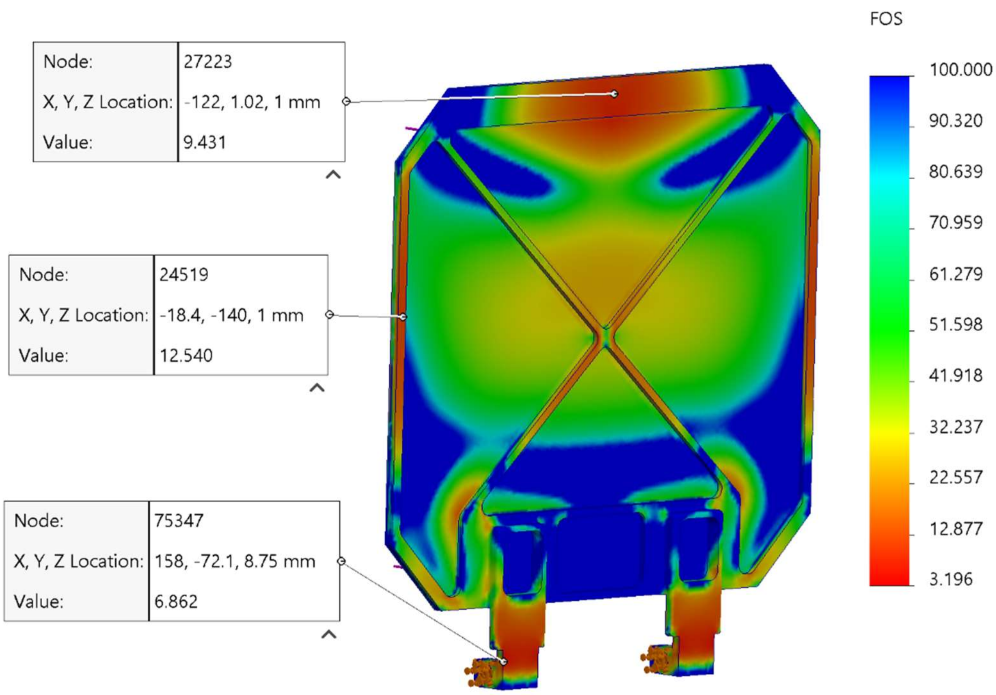


Figure 10: Factor of safety plot for the door. Maximum factor of safety has been manually limited to see differences. Minimum factors of safety were found in the same regions of maximum stress, being the two bottom tabs and behind the top tab. Minimum factor of safety probed was 6.862.

Based on the FEA simulations, the door will not endure any forces during rest and launch that would cause it to fail. The maximum stress predicted is about 9×10^7 less than the yield strength of 6061 aluminum and the minimum factor of safety found is 3.196.

2. Pusher Plate

The pusher plate had several engineering analyses done to ensure it would be capable of enduring the loads present on it during rest and during launch. There analyses include both an FEA stress simulation and an FEA deflection simulation. During rest, the launcher plate will endure significantly less force than during launch, thus, for a worst-case scenario analysis the launching state will be used. During launch, the pusher plate experiences a normal force due to the spring and, as the plate moves along the rails, loses some of the energy from the spring to friction along the four guide feet. The material of the pusher plate is previously chosen as ABS plastic for its high strength to weight ratio, low cost, and it is on the NASA approved list of plastics in space for outgassing. The ABS plastic interfaces with the polyethylene foam rails. The normal force acting on the pusher plate by the foam rails is unknown and cannot be calculated exactly analytically since there is no interference and the CSD will operate in a weightless environment; there is no clear normal force. Thus, thorough laboratory testing is recommended to precisely determine the losses due to friction during launch. For the purposes of the FEA simulation, the normal force will be due to the mass of 61.39 g and acceleration due to gravity at sea level.

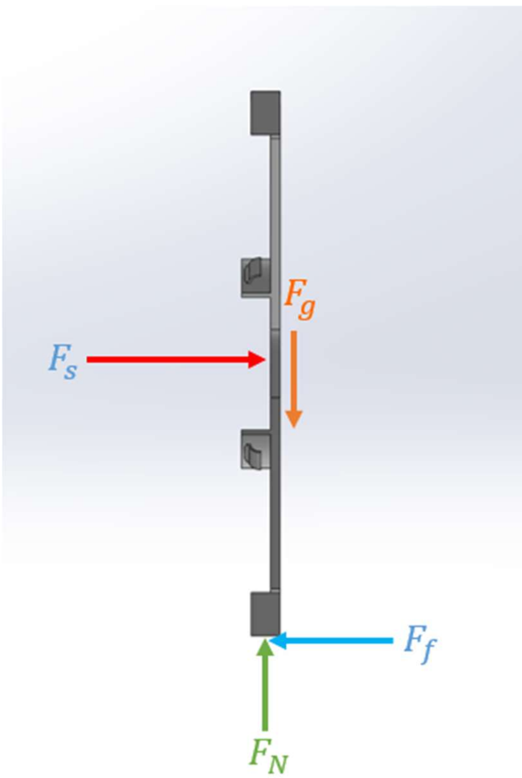


Figure 11: Theoretical forces acting on the pusher plate. Normal force (F_N) is due to the force of gravity (F_g) acting on the mass. The force of the spring is represented by F_S and the force due to friction is F_f.

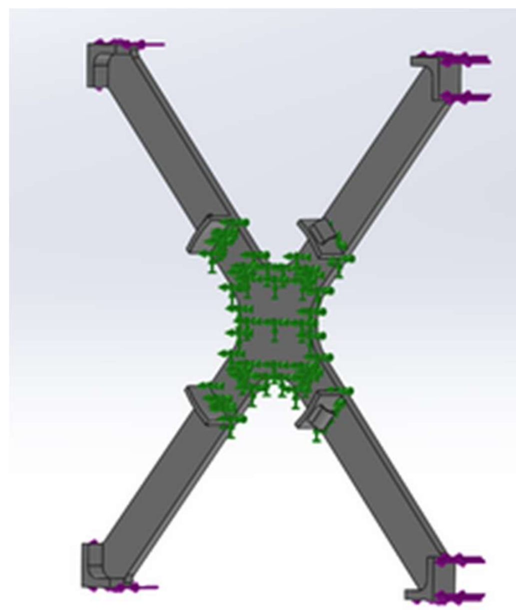


Figure 12: FEA loading of the pusher plate in SolidWorks. Although the theoretical model only has friction acting along the bottom guides, the FEA model has frictional forces on the top as well to more realistically simulate the symmetric frictional forces expected.

The mass of the pusher plate (m_p) is 60.39 g given by SolidWorks, and acceleration due to gravity (g) is 9.81 $\frac{m}{s^2}$.

$$F_N = F_g = m_p g = (60.39g)\left(\frac{1kg}{1000g}\right)\left(9.81\frac{m}{s^2}\right) = 0.602\ N$$

The theoretical coefficient of the two plastics (μ), clean and dry, is 0.2.

$$F_f = \mu F_N = (0.2)(0.602\ N) = 0.120\ N$$

From this friction calculation, the force value for friction is applied parallel to all eight faces of the four guide feet while the center is fixed to represent the spring. Before the FEA simulation is done, simplified theoretical hand calculations for beam deflection are done to validate the FEA. For the hand calculations, the arm of the pusher plate will be modelled as a simple beam.

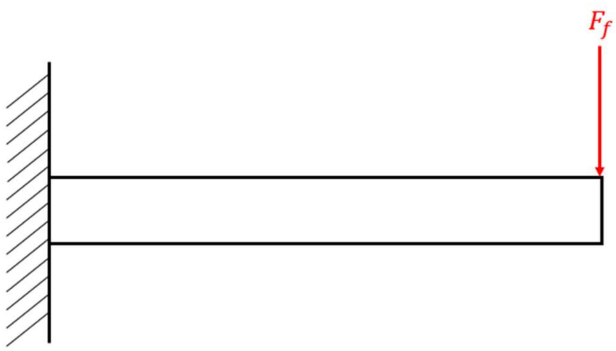


Figure 13: One arm of the pusher plate modelled as a simple beam. The arm is showed fixed on the left end, representing the center of the pusher plate held fixed by the spring.

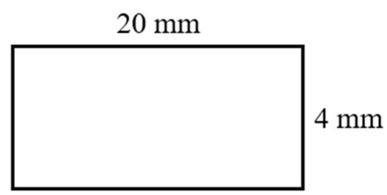


Figure 14: Cross section of the pusher plate arm for finding the moment of inertia.

The moment of inertia, *I*, for a simple rectangular cross section is given as:

$$I = \frac{bh^3}{12} = \frac{(20mm)(4mm)^3}{12} = 106.67\ mm^4 = 1.0667 * 10^{-11}\ m^4$$

The length of the beam, L, is measured in SolidWorks as 92.79 mm and the material of the pusher plate is ABS plastic which has a modulus of elasticity (E) of approximately 2000 MPa. Using the force of friction with these variables allows the theoretical deflection (δ) to be calculated.

$$\delta = \frac{PL^3}{3EI} = \frac{(0.12\ N)(0.0928\ m)^3}{3(2000 * 10^6\ Pa)(1.0667 * 10^{-11}\ m^4)} = 0.0015\ m = 1.5\ mm$$

Based on hand calculations, the pusher plate will not deform excessively during launch of the CubeSat due to frictional forces. This calculation is only a rough estimate, the normal force cannot be found analytically and, thus, the frictional force is not exact. Lab testing of a prototype will provide much more accurate results than that can be found using hand calculations or FEA for this component.

Using these hand calculations as reference values, the FEA simulation is then performed for more accurate results.

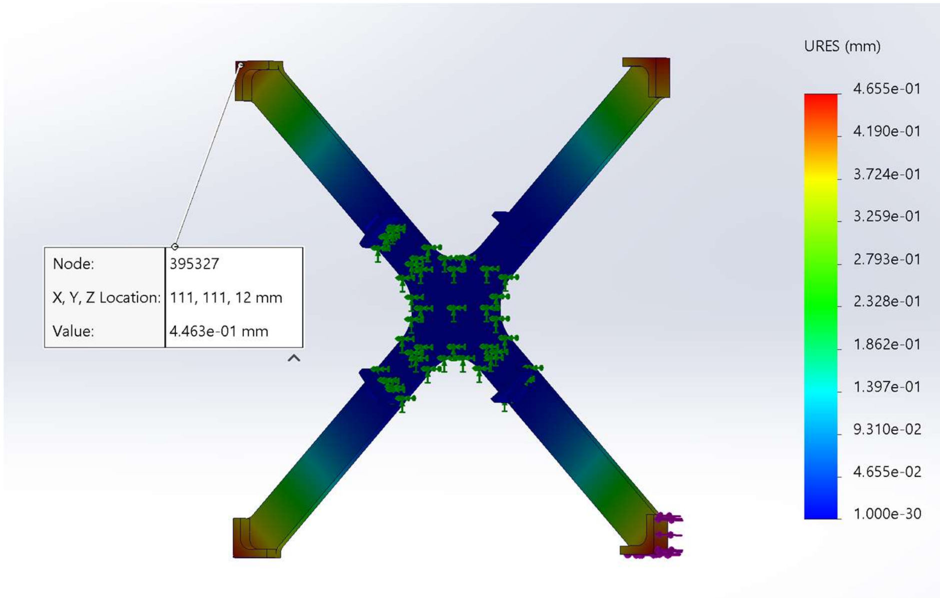


Figure 15: Plot showing maximum deflection of the pusher plate during launch. Maximum deflection occurs at the end of the arms and the maximum value is 0.47 mm

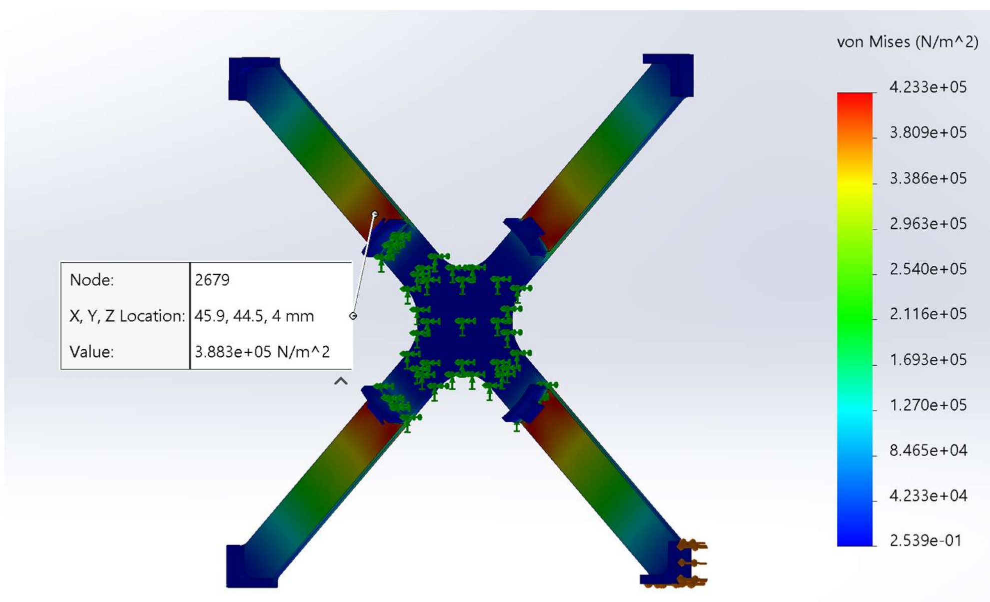


Figure 16: Plot showing stress on the pusher plate during launch. Stress plot shows close to zero stress on the ends of the arms a maximum stress occurring shortly after where the spring is mounted. Maximum stress found is $\boldsymbol{4.233 * 10^5\ Pa}$.

The hand calculations found a maximum deflection of 1.5 mm where SolidWorks shows a maximum deflection of 0.47 mm—roughly a third of the hand calculated value. This can be explained by the simplifications the hand calculations make to make the problem solvable in a concise manner and the SolidWorks data is likely more accurate. Regardless of the method, even with a maximum deflection of 1.5 mm the deflection will not cause problems with this component during launch.

The launcher pusher plate is made of a polymer, ABS. Because the interface between the pusher plate and the rails is critical, it is important to evaluate the thermal expansion of the plate to add the correct tolerances. The complexity of the geometry makes manual calculations difficult, however since it is necessary to consider it an FEA was run on it.

The geometric constraints were set to elastic on the bottom surface to mimic to actual set up of the plate on the spring. The NASA SLS guide states that the maximum ambient temperature will be 130˚F in the CPL, hence all the exposed surfaces were set to that temperature.

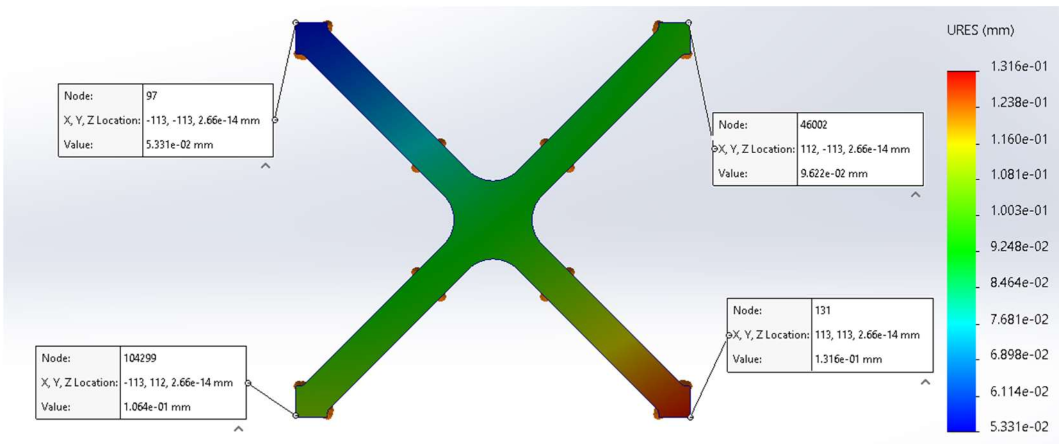


Figure 17: Plot showing the maximum thermal expansion on the pusher plate during maximum ambient temperature. The Deformation at the end of the cross is most important since that is the interface at which the rails meet the plate, and the maximum expansion is 0.316 mm

If the plate expands too much, it will interfere with the rails and prevent launch. Therefore, the average expansion at the cross ends will be calculated.

$$d_{avg} = \frac{0.09622 + 0.05331 + 0.1064 + 0.1316}{4} = 0.097\ mm$$

The average deformation at the 4 points of the cross is 0.097 mm is very small and since the foam will have low friction, it will be negligible.

3. Front plate

Two main statics studies are performed on the front plate: a stress study and a factor of safety study. The only force directly acting on the front plate originates in the spring force during compression. The spring presses on the CubeSat and this force propagates into the door, and then into the front plate at the hinges and slot at the top for the linear solenoid. The front plate's material was previously selected in the PDR as aluminum 6061 using Ashby plots. Due to the complex geometry of the front plate—a result of milling out sections to save weight while remaining structurally sound—hand calculations cannot be completed for this component. Instead, a SolidWorks FEA simulation is ran using the known spring force of 273.556 *N* and the attachment points are modelled as fixed geometry. This is largest force expected to act upon the front plate and is present after the CubeSat is loaded up until launch. Using SolidWorks simulation, the maximum stresses and stress concentrations are found as well as the deflection of the hinges.

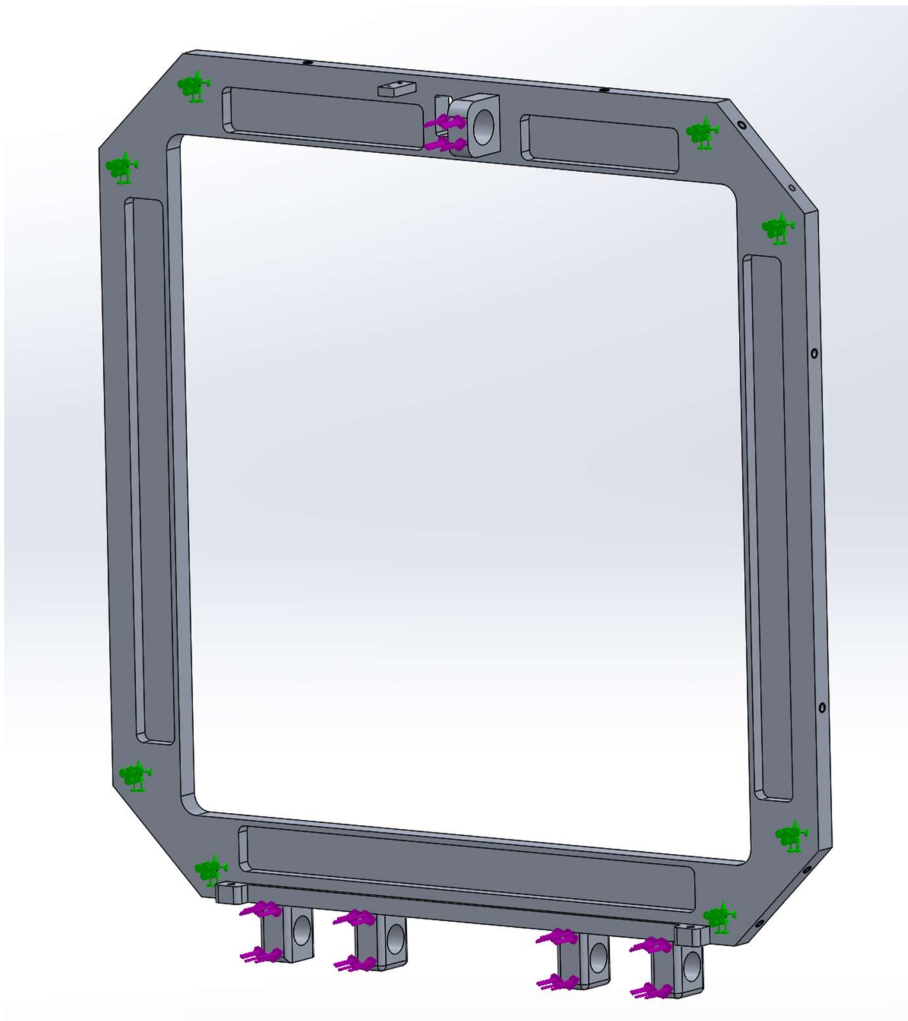


Figure 18: Loading conditions of the front plate. The front plate is fixed at each corner with two screws shown in green. The force due to the door pulling on the front plate from the spring force is equally distributed along the top and bottom.

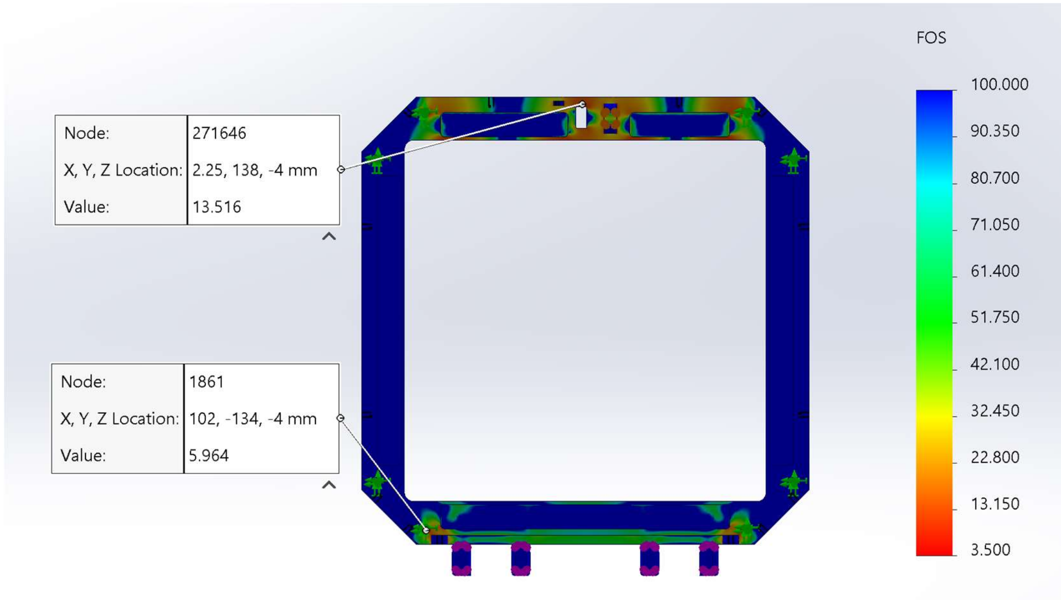


Figure 19: Factor of safety plot for the front plate based on the force due to the spring. Minimum factor of safety found was 5.96 at the bottom of the faceplate as seen in the bottom probe.

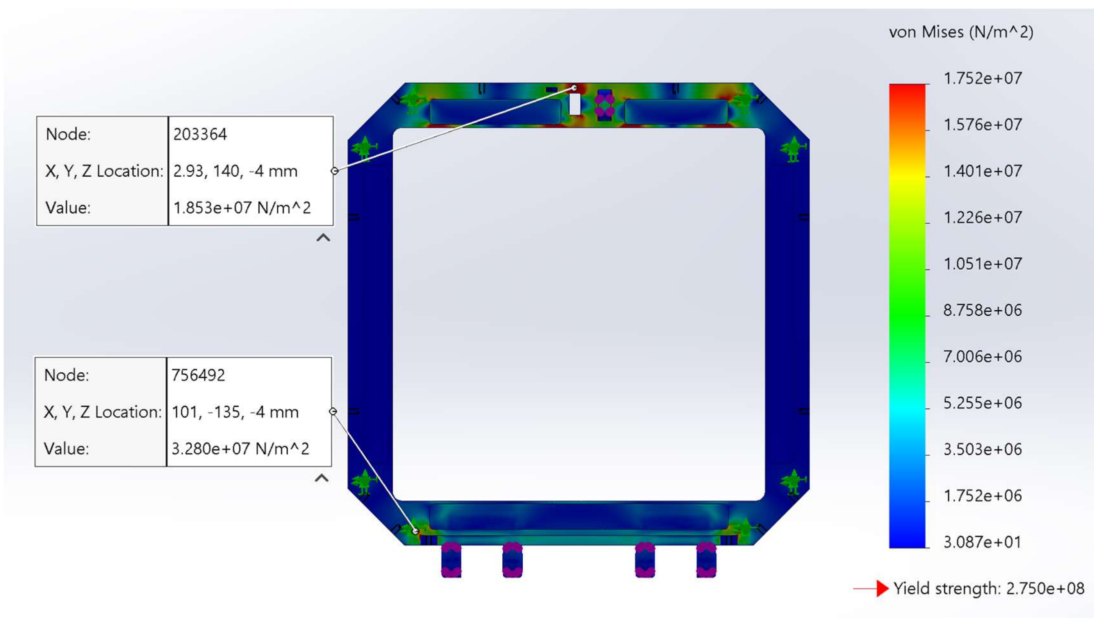


Figure 13: Stress plot for the front plate based on the force due to the spring. Figure 20: Stress plot for the front plate based on the force due to the spring. Maximum stress found was $\mathbf{3.28 * 10^7}$ $\boldsymbol{Pa}$ at the bottom of the plate near the fasteners that attach the front plate to the rails. Stress concentrations are found near all the mounting holes as well as near the slot for the linear solenoid.

Based on the FEA simulations, the front plate will not experience any forces that will cause it to fail. Maximum stress found was $2.06 * 10^7$ Pa, about a third of the yield strength of aluminum 6061-T6 alloy. Additionally, minimum factor of safety was found to be 5.964.

4. Rails

According to the NASA SLS mission planner the CSD will experience a maximum of 4.1 G's [12]. In the axial loading orientation, the maximum force is from the weight of the front plate and door. The worst case scenario is if the whole mass is concentrated on a single rail. The force acting on the rail would be the weight on earth multiplied by 4.1.

$$W_{door} = 4.1 \times 9.81 \times 1.0741272 = 43.202\ N$$

For the buckling analysis, the worst case will be assumed, where the total weight is acting axially on the top face of a single rail, while the rail is fixed on the bottom face and the angle brackets are ignored.

Two simulations were used, a static simulation and a buckling simulation. The static simulation will result in the Factor of Safety data and the Buckling simulation will result in the Buckling Load Factor. The Factor of Safety determines yielding of the beam while the Buckling Load Factor determines buckling of the beam. Since the loading is the same, the lower value determines the first mode of failure.

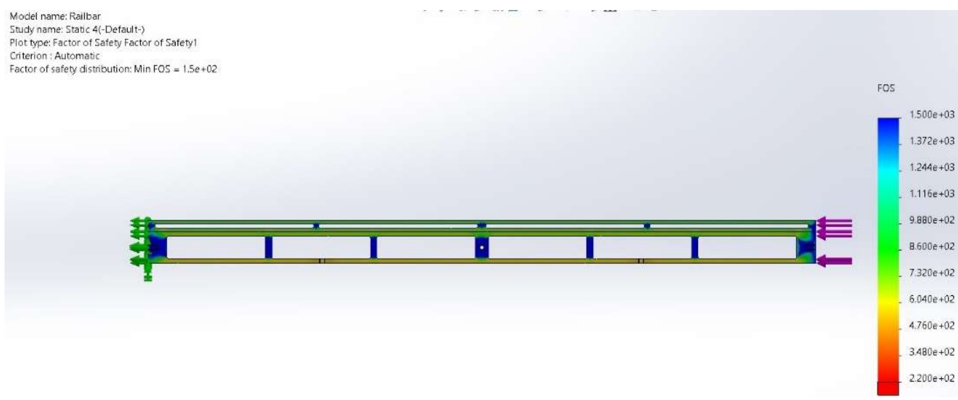


Figure 21: Factor of Safety data from static simulation

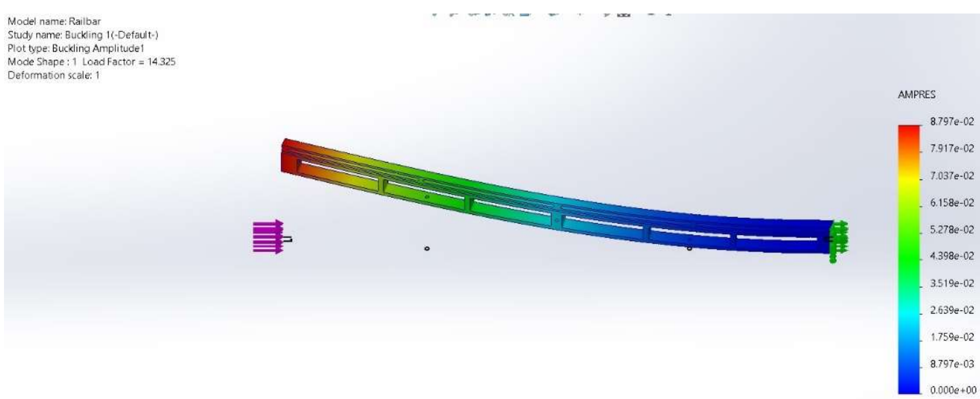


Figure 22: Buckling Ampere data from buckling simulation

The minimum factor of safety is 150. The Buckling Load factor is 14.325. Since both FOS and BLF are greater than 1 during this loading case, it can be proven that there will be no failure in the rails. However, if there are higher loads to be applied, the rail would buckle before it yields.

In reality the weight will approximately be evenly distributed over the 8 rails and the angle brackets will spread the weight more evenly. Therefore, the FOS and BLF will be higher. Also, the rails will be fixed by the front plate and the base plate while also having the angle brackets provide support in the middle of the rail, hence the amplitude of buckling will be negligible.

In the transverse loading condition, the maximum load will occur from the weight of the CubeSat, which will not exceed 25kg. The 8 rails will bear the whole load from the CubeSat. Similar to the axial loading situation, the weight of the CubeSat will be multiplied by 4.1.

$$W_{door} = 4.1 \times 9.81 \times \frac{25}{8} = 125.69\ N$$

For the bending analysis, the rail is fixed on the bottom face and top face (the faces which are at the interface of the face plate and base plate connection).

For the bending analysis, a static simulation will be performed, and it will result in the Factor of Safety and displacement data.

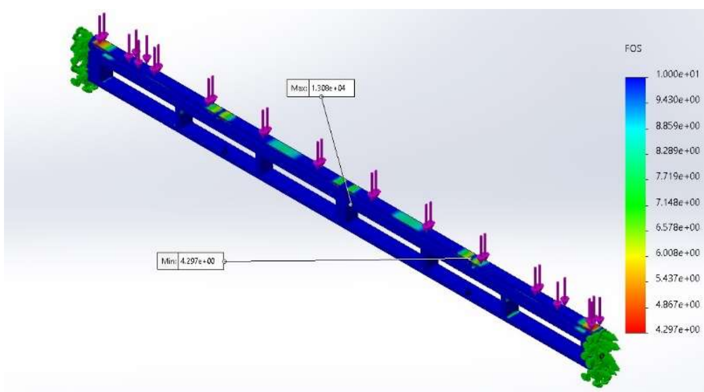


Figure 23: Factor of Safety data from bending simulation

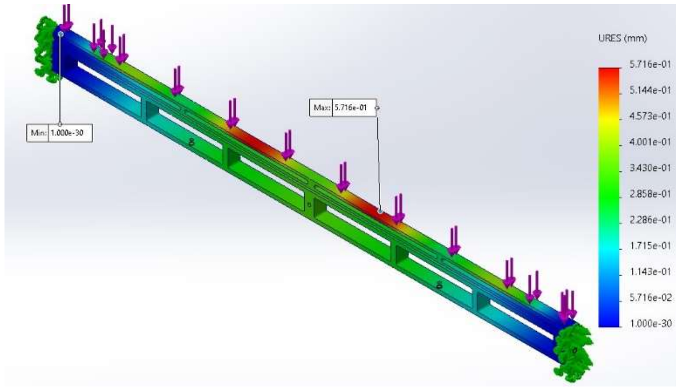


Figure 24: Displacement data from bending simulation

The minimum factor of safety is 4.297. The maximum displacement from the original position is 0.5716 mm. The displacement is very small and will hardly be noticeable by the eye. Also, the FOS is greater than 1, the rail will not fail due to bending. Comparing the axial and transverse loading situations it is also seen that the rail is much stronger when transversally loaded, which is preferred in this application of the rail bar.

To ensure these simulations are valid, the rail can be modelled as a simple beam and hand calculations can be performed to find the maximum bending stress and a factor of safety. To complete these hand calculations some assumptions had to be made. Firstly, the end of the beam is modeled as free which isn't accurate for the design since this end will be connected to the front plate and thus indirectly to the other rails. Second, the support the angle bracket provides is omitted. Additionally, the point of maximum stress concentration is predicted as the thinnest cross-sectional area closest to the fixed face, shown by the dashed lines.

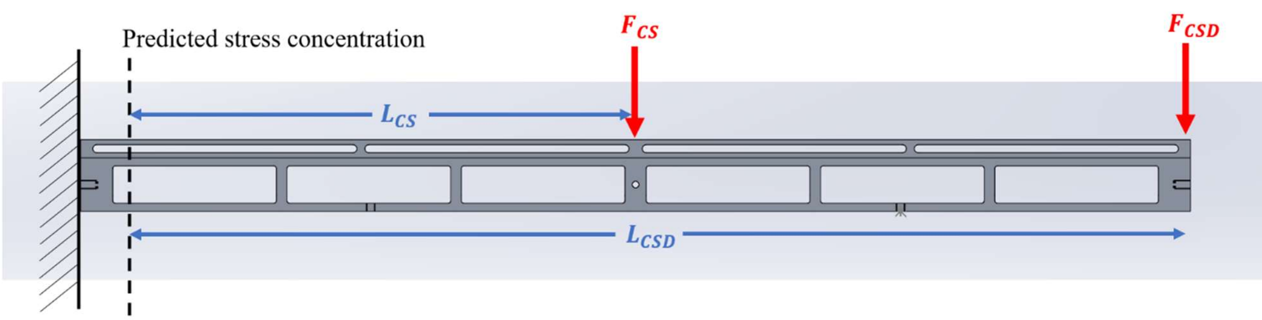


Figure 18: Diagram for the rail modelled as a simple beam. Figure 25: Diagram for the rail modelled as a simple beam. F_{CSD} is the weight of the door and the front plate and F_{CS} is the weight of the CubeSat

Based on the predicted stress concentration region, using the parallel axis theorem the moment of inertia of this cross section can be found.

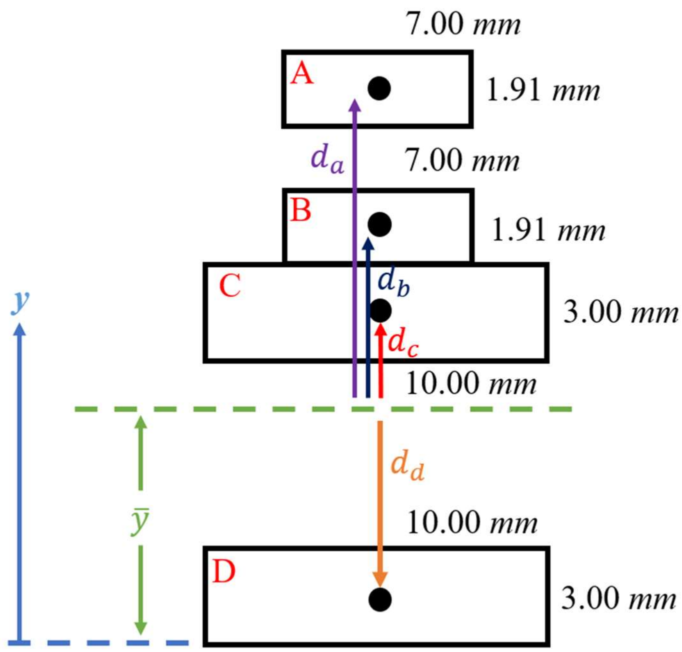


Figure 19: Diagram used for moment of inertia calculations using the parallel axis theorem.Figure 26: Diagram used for moment of inertia calculations using the parallel axis theorem.

$$\bar{y} = \frac{\sum_i \bar{y}A}{\sum_i A}$$

$$I_x = \sum_i (I_i + A_i d_i^2)$$

$$I_i = \frac{1}{12} b_i h_i^3$$

$$I_x = \sum_i \left(\frac{1}{12} b_i h_i^3 + A_i d_i^2\right)$$

Table 2: Intermediate values found to calculate combined moment of inertia using the parallel axis theorem.

Sub-component	$A_i\ (mm^2)$	$\bar{y}\ (mm)$	$\bar{y}A\ (mm^3)$	$d\ (mm)$	$d^2\ (mm^2)$	$I\ (mm^4)$	$I_{xi}\ (mm^4)$
A	13.37	25.875	345.9488	11.739	137.814	4.064	1846.648
B	13.37	20.955	280.1684	6.819	46.504	4.064	625.836
C	30	18.5	555	4.364	19.048	22.500	593.954
D	30	1.5	45	12.635	159.657	22.500	4812.209
Sum	86.74		1226.117				7878.648

$$\bar{y} = 14.14\ mm$$

$$Mass\ of\ Door = m_d = 0.597\ kg$$

$$Mass\ of\ Front\ Plate = m_f = 0.461\ kg$$

$$Mass\ of\ CubeSat\ (MAX) = m_{cs} = 25\ kg$$

$$F_{d+f}(total) = (4.1)\left(9.81\frac{m}{s^2}\right)(0.597\ kg + 0.461\ kg) = 42.58\ N \Rightarrow \frac{42.58\ N}{8\ rails} = 5.32\ N$$

$$F_{CS}(total) = (4.1)\left(9.81\frac{m}{s^2}\right)(25\ kg) = 1005.53\ N \Rightarrow \frac{1005.53\ N}{8\ rails} = 125.69\ N$$

$$M_{CSD} = F_{CSD}L_{CSD} = (5.32\ N)(0.405\ m) = 2.15\ Nm$$

$$M_{CS} = F_{CS}L_{CS} = (125.69\ N)(0.223\ m) = 28.01\ Nm$$

$$M_{total} = M_{CSD} + M_{CS} = 30.16\ Nm$$

$$\sigma_b = \frac{M_{total}y}{I} = \frac{(30.16\ Nm)(0.0127\ m)}{(7.88 * 10^{-9}\ m^4)} = 4.86 * 10^7\ Pa = 48.6\ MPa$$

$$\sigma_{y,tensile} = 276\ MPa$$

$$n = \frac{\sigma_{y,tensile}}{\sigma_b} = \frac{276\ MPa}{48.6\ MPa} = 5.68$$

Based on hand calculations of a simplified beam loading structure, the minimum factor of safety is 5.68

5. Base Plate

The total force exerted on the plate cab be found by taking the sum of the weight of the CubeSat, the weight of the rest of the CSD components and the force exerted by the spring.

$$F = 4.1 \times 9.81 \times (4.14871 + 25) + 273.556 = 1445.95\ N$$

Since the Base Plate is not of uniform thickness and its geometry is not rectangular, manual calculations will be difficult. For the base plate three static simulations will be run. The simulations will have the same force applied but different geometric constrains with first one being fixed on the sides, the second being fixed on the base and the third one being fixed at the point where the screws fix the plate to the interference.

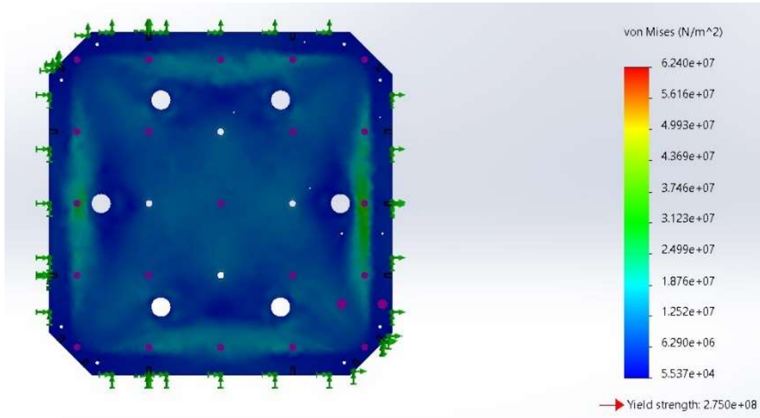


Figure 27: Stress data when fixed on each side (Note: the purple circles are a representation of normal load)

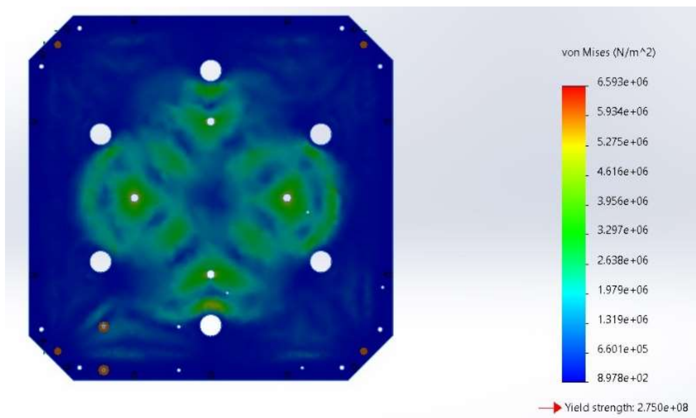


Figure 28: Stress data when fixed on bottom surface

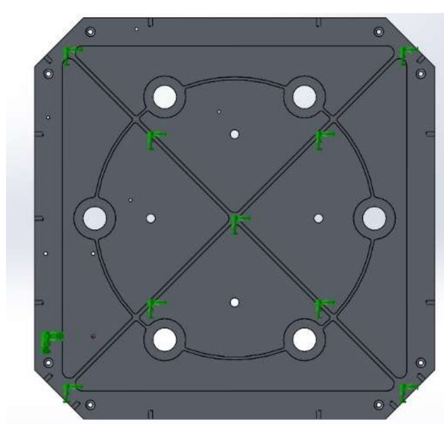


Figure 29: Surface which is fixed for the second simulation

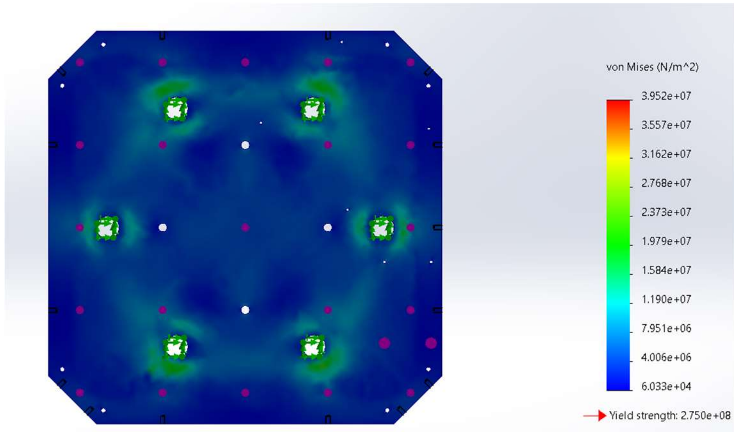


Figure 30: Stress data when fixed at the screw holes

It is seen that from the three simulations, the stresses incurred by the force is at a minimum 1 magnitude less than the yield strength of Al 6061-T6.

6. Spring

An integral part of the CSD's function is based on the spring that imparts a velocity on the CubeSat. Several parameters must be taken into consideration to ensure proper function of the spring whilst optimizing mass and required space. In order to design a spring for this application, the spring's end goal must be clearly outlined. The most stringent requirement for the spring's performance would be getting a resultant velocity of 2.0 m/s when the CubeSat's mass is at its maximal value, that is, the maximum kinetic energy that the spring must impart. The aero design team indicated that exceeding the 2.0 m/s is acceptable and in fact desirable as it reduces their CubeSat's required fuel. Thus, designing for the 2.0 m/s velocity at maximal CubeSat mass will ensure that the velocity customer need will be met.

A simple energy balance between spring potential energy and the requisite kinetic energy of the CubeSat can be used to find the minimum spring constant that must be designed for. Friction cannot be aptly represented without further testing and simulation due to a lack of a known coefficient of friction between polyethylene foam and hard anodized aluminum. Furthermore, the microgravity environment of space when the launcher is intended to function means that there is no clear normal force and thus resultant frictional force to use to reach a proper value for work lost to friction. The lubricated foam rails of the CSD are the only points of contact with the CubeSat when launching, and there will likely be very little normal force on the rails due to the lack of gravity. For these reasons, it will be assumed that there is negligible friction and potential energy can be directly equated to kinetic energy. In the following equation, m is the CubeSat mass in kilograms, v is the exit velocity in meters per second, k is the spring rate in newtons per meter, and x is the spring displacement in meters.

$$\frac{1}{2}mv^2 = \frac{1}{2}kx^2$$

This equation can be simplified and solved for k as a function of m, v, and x. Spring rate k can be solved for using the worst-case mass of 25 kg, 2.0 m/s velocity, and a spring displacement of 0.366 m taken from the length of the CubeSat in the Z direction.

$$k = \frac{mv^2}{x^2} = \frac{(25\ kg)(2.0\ m/s)^2}{(0.366\ m)^2} = 746.514\ N/m$$

Knowing the spring rate lays the groundwork for determining the other parameters of the spring. The inner diameter of the spring D_i was constrained to 102 mm by the cylindrical plastic mounting plate face it mounts to. The material selection of 302 stainless steel indicates a shear modulus G of 69.0 GPa according to Table 10-5 in Shigley's Mechanical Engineering Design. The ultimate tensile strength S_{ut} of a wire with diameter d (mm) can be found as a function of constants A and m determined by the material. For 302 stainless with a wire diameter of 5 to 10 mm, A is 2911 MPa·mm^m and m is 0.478.

$$S_{ut} = \frac{A}{d^m} = \frac{2911\ MPa \cdot mm^{0.478}}{d^{0.478}}$$

Initially, a wire diameter of 10 mm was selected to minimize the spring index C as there is a generally ideal range of $4 \leq C \leq 12$. However, the consequence of exceeding a spring index of 12 does not impact the function of the spring itself, but if springs are packaged in bulk with this high a spring index, they run the risk of tangling. This necessitates individual packaging which increases the price. As the spring is a core part of the CSD, this increased cost is acceptable and thus exceeding C = 12 can be ignored.

$$C = \frac{D_i + d}{d}\ [13] = \frac{102\ mm + 10\ mm}{10\ mm} = 11.2$$

Thus, S_{ut} for d = 10 mm is found as follows:

$$S_{ut} = \frac{2911\ MPa \cdot mm^{0.478}}{(10\ mm)^{0.478}} = 968.372\ MPa$$

The spring rate k is a function of wire diameter d, shear modulus G, mean coil diameter $D = D_i + d$, and number of active coils N_a.

$$k = \frac{d^4 G}{8D^3 N_a}$$

This equation can be rearranged to find N_a given a desired value for k.

$$N_a = \frac{d^4 G}{8D^3 k} = \frac{(10\ mm)^4 (69.0 \times 10^3 N/mm^2)}{8(102 + 10\ mm)^3 (.746514\ N/mm)} = 82.24\ active\ coils$$

N_a's desired range is $3 \leq N_a \leq 15$ due to loss of linearity of spring force from contacting coils. 82.24 active coils are over 5 times beyond the acceptable upper limit of 15, and thus the wire diameter must be revised.

Taking advantage of the removal of the upper limit of spring index, a new wire diameter of d = 6 mm was chosen.

$$S_{ut} = \frac{2911\ MPa \cdot mm^{0.478}}{(6\ mm)^{0.478}} = 1236.192\ MPa$$

$$N_a = \frac{(6\ mm)^4 (69.0 \times 10^3 N/mm^2)}{8(102 + 6\ mm)^3 (.746514\ N/mm)} = 11.887\ active\ coils$$

The new d = 6 mm satisfies the criteria for number of active coils. Now the factor of safety against yielding must be determined. The principal stresses in compression springs are shear stresses. As such, the factor of safety against yielding can be calculated using the shear yield stress S_{sy} and the maximum shear stress due to deflection τ_{max}. S_{sy} can be found as a percentage of the ultimate tensile strength S_{ut}. For 302 stainless, the low (conservative) estimate for shear yield strength is 45% of S_{ut}, thus S_{sy} is 556.286 MPa.

To find the torsional shear stress in the spring, the Bergsträsser factor k_B, spring force being exerted at its deformed position F, mean coil diameter D, and wire diameter d must be known. The Bergsträsser factor is a function of spring index C, thus the new spring index for d = 6 mm must be found.

$$C = \frac{D}{d}\ [13] = \frac{D_i + d}{d} = \frac{102\ mm + 6\ mm}{6\ mm} = 18$$

$$k_B = \frac{4C + 2}{4C - 3}\ [13] = \frac{72 + 2}{72 - 3} = 1.072464$$

The spring force F is found as a product of spring rate k and spring displacement x. It is assumed that the spring displacement will be the length of the CubeSat in the Z direction, 366 mm.

$$F = kx = (746.514\ N/m)(0.366\ m) = 270.640\ N$$

Thus, the maximum shear stress that this spring will undergo is found as follows:

$$\tau_{max} = k_B \frac{8FD}{\pi d^3}\ [13] = (1.072464)\frac{8(270.640\ N)(108\ mm)}{\pi(6\ mm)^3} = 369.56\ N/mm^2 = 369.56\ MPa$$

Given the allowable shear stress S_{sy} of 1236.192 MPa, this configuration would have a factor of safety against yielding as follows:

$$FoS = \frac{S_{sy}}{\tau_{max}} = \frac{1236.192\ MPa}{369.56\ MPa} = 3.345$$

Thus, this configuration has a factor of safety of 3.345. Now, in order to find a free length L_o and solid (fully compressed) length L_s, the number of total coils N_t is needed. For plain, ground ends (such that the spring is aligned as closely axially as possible when pressed between the two plates), N_t is 1 more than the number of active coils N_a. Rounding up to the nearest whole such that N_a = 12, N_t is as follows:

$$N_t = N_a + 1 = 12 + 1 = 13\ coils$$

The solid length for plain, ground ends with d = 6 mm is as follows:

$$L_s = dN_t = (6\ mm)(13\ coils) = 78\ mm$$

As a result, the minimum free length that this spring can have for this application is:

$$L_o = L_s + x = 78\ mm + 366\ mm = 444\ mm$$

Given the relatively high factor of safety and the desire for reduced overall dimensions and subsequently minimal mass, this spring can be redesigned to be more mass efficient whilst still adequately performing its function. As such, a new wire diameter of 5.5 mm was selected.

$$S_{ut} = \frac{2911\ MPa \cdot mm^{0.478}}{(5.5\ mm)^{0.478}} = 1288.691\ MPa$$

$$N_a = \frac{(5.5\ mm)^4(69.0 \times 10^3 N/mm^2)}{8(102 + 5.5\ mm)^3(.746514\ N/mm)} = 8.51\ active\ coils$$

This new, reduced diameter still fulfills the constraints for $3 \leq N_a \leq 15$. Using the new ultimate tensile strength S_{ut} value for this d = 5.5 mm, shear yield strength S_{sy} can once again be found as 45% of S_{ut}.

$$S_{sy} = 0.45 S_{ut} = 0.45(1288.691\ MPa) = 579.911\ MPa$$

Also, N_a can be rounded to 8.5 active coils such that the new k is slightly higher than the original design parameter k.

$$k = \frac{d^4 G}{8D^3 N_a} = \frac{(5.5\ mm)^4(69.0 \times 10^3 N/mm^2)}{8(102 + 5.5\ mm)^3(8.5\ active\ coils)} = 0.747421\ N/mm = 747.421\ N/m$$

Using this adjusted k that would still meet customer needs for velocity, the spring force when compressed by the CubeSat is as follows:

$$F = kx = (747.421\ N/m)(0.366\ m) = 273.556\ N$$

The spring index C and subsequently Bergsträsser factor k_B can be solved for.

$$C = \frac{D_i + d}{d} = \frac{102\ mm + 5.5\ mm}{5.5\ mm} = 19.545$$

$$k_B = \frac{4C + 2}{4C - 3} = \frac{78.182 + 2}{78.182 - 3} = 1.066505$$

Knowing these values, the maximum shear stress τ_{max} can be found.

$$\tau_{max} = k_B \frac{8FD}{\pi d^3} = 1.066505 \frac{8(273.556\ N)(102 + 5.5\ mm)}{\pi(5.5\ mm)^3} = 480.032\ MPa$$

Thus, the factor of safety against yielding for the 5.5 mm wire diameter spring is as follows:

$$FoS = \frac{S_{sy}}{\tau_{max}} = \frac{579.911\ MPa}{480.032\ MPa} = 1.2081$$

This factor of safety is still above 1 and thus would not yield under this compression. Furthermore, spring fatigue can be effectively ignored for this application as the spring will simply undergo one cycle of loading and unloading when the CubeSat is stored and then ejected. Thus, this factor of safety is the overall factor of safety for this spring's mission operation.

Now, free length L_o and solid length L_s can be found if N_t is known.

$$N_t = N_a + 1 = 8.5 + 1 = 9.5\ coils$$

The solid length for plain, ground ends with d = 5.5 mm is as follows:

$$L_s = dN_t = (5.5\ mm)(9.5\ coils) = 52.25\ mm$$

As a result, the minimum free length that this spring can have for this application is:

$$L_o = L_s + x = 52.25\ mm + 366\ mm = 418.25\ mm$$

This new spring is nearly 6% shorter than the previous 6 mm wire diameter, which saves mass in both reduced wire diameter, reduced spring wire length, and reduced necessity for overall dimensions of the CSD itself. Thus, the design was built around a minimal spring free length of 418.25 mm.

7. Full Assembly Resonant Frequency

Vibration in the launch vehicle is transmitted to the CSD through the mounting interface. The launch vehicle guides state that global vehicle motion drives excitations for frequencies up to 100 Hz. For us, this means that vibrational loads are transmitted through the solid mounting interface up to 100 Hz. Given this, the natural frequency of our structure should be outside of 100 Hz.

In order to derive a natural frequency of the CSD, the CSD can be modeled as a cantilever beam. The rigidity of a beam can be derived as a function of the material's elastic modulus E, cross-sectional area A, and length L. The main structural components along the length of the CSD are the aluminum rails and the carbon fiber outer plates (ventilation and sideplates). The rails have a non-constant cross-section and thus the minimum and maximum areas were found to account for both extremes in these calculations. The rails are made of 6061-T6 aluminum with an elastic modulus of 69 GPa, and the carbon fiber specified has an elastic modulus of 452 GPa. The minimum and maximum cross-sectional area of all 8 rails are 6.94128×10^{-4} m^2 and 1.9822×10^{-3} m^2, respectively. The collective cross-sectional area of the carbon fiber plates is 1.3716×10^{-3} m^2. For both materials, the length L is simply the overall length of the CSD, 433.25 mm or 0.43325 m.

$$k = \frac{EA}{L}$$

Additionally, the carbon fiber and aluminum rigidities act together as parallel springs. Equivalent spring rate k_{eq} for parallel springs is simply the sum of the parallel springs' k values.

Table 3: Combined rigidity values for minimum and maximum rail area.

Railbar Area Condition	Railbar Rigidity k_1	Carbon Fiber Rigidity k_2	Resultant Equivalent Rigidity k_{eq}
Min. Area	1.1054×10^8 N/m	1.4310×10^9 N/m	1.5415×10^9 N/m
Max. Area	3.1569×10^8 N/m		1.7466×10^9 N/m

The natural frequency f_n of the structure can be solved as follows, where m is the mass of the combined CSD and 25 kg cubesat (30 kg total).

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}}\ [Hz]$$

Based on these values, the minimum and maximum area natural frequencies were found to be 1160.36 Hz and 1235.16 Hz, respectively. The structure's natural frequencies for both assumptions of area fall far out of the 100 Hz range and thus resonance due to excitation from the launch vehicle interface would not occur. Further testing is required to attain more detailed information on the dynamic response modes of the overall structure.

D. Engineering Analysis for Non-Critical Components

1. *Screws*

For the screws an axial force and bending force calculation can be used to see if the screws can withstand the maximum force applied by the CSD and CubeSat at 4.1 G's. For maximum mass, the CSD will be 5 kg and the CubeSat will be 30 kg.

$$F_T = 4.1 \times 9.81 \times (5 + 25) = 1206.63\ N$$

However, some of the screws will also experience the force from the spring since it stays compressed until the box is open.

$$F_{T,spring} = 4.1 \times 9.81 \times (5 + 25) + 273.556 = 1480.186\ N$$

The maximum axial force can be calculated based on the yield strengths of the screw. This can determine how much force a screw can handle before it yields.

$$\sigma_y = \frac{F_{max}}{A}$$

Where A is the minimum area of the screw, since it will fail at the smallest area first. However, since there are multiple screws with different diameters and yield strength, the force must be calculated for all.

Screw type	Screw Yield Strength	Screw Minimum diameter	Max Force
316 Stainless Steel M3x0.5, 90 degree countersink, Hex Drive	70000 psi	2.272 mm	1956.69 N
316 Stainless Steel M3 x 0.5, Button Head Hex Drive	70000 psi	2.272 mm	1956.69 N
Titanium M3 x 0.50 mm, Button Head Hex Drive	130000 psi	2.272 mm	3633.86 N
Alloy Steel M6 x 1.00 mm, Ultra-Low-Profile Socket Head	140000 psi	4.596 mm	16013.89 N
18-8 Stainless Steel 1-64, Pan Head Slotted	100000 psi	0.0532 in	988.78 N
Black Oxide Steel M2.5 x 0.45, Alloy Steel Socket Head Screw	170000 psi	1.840 mm	3116.68 N
Aluminum Male-Female Threaded Hex Standoff, M2.5 x 0.45	40000 psi	1.840 mm	733.33 N

All the screws except two can withstand the full force of the CSD and the CubeSat during 4.1 Gs. However, it is noted that the 18-8 Stainless Steel 1-64, Pan Head Slotted screw and the Aluminum Male-Female Threaded Hex Standoff screw cannot. This is not a structural issue because the Male-Female Threaded Hex Standoff screw is securing the EPS to the base and the Pan Head Slotted screw is securing the limit switch to the faceplate, hence neither of the two screws will come close to being loaded at that force.

To ensure proper securing of different components, it is necessary that there are enough threads engaged. The general rule of thumb is that at least 1-1.5 screw diameter thread engagement [13]. During the Design Review 1, it was also recommended that there are at least 5 threads engaged.

Screw type	**Connection**	**Diameter**	**Depth of Engagement**	**Number of Threads Engaged**
316 Stainless Steel M3x0.5, 90 degree countersink Hex Drive	Front Plate/Base Plate to Railbar	3 mm	4.26 mm	9
Titanium M3 x 0.50 mm, Button Head Hex Drive	Side Plate to Front Plate/Base Plate	3 mm	6.71 mm	13
Titanium M3 x 0.50 mm, Button Head Hex Drive	Ventilation Grate to Front Plate/Base Plate	3 mm	6.71 mm	13
316 Stainless Steel M3 x 0.5, Button Head Hex Drive	Angle Bracket to Railbar	3 mm	8 mm	16
Titanium M3 x 0.50 mm, Button Head Hex Drive	Computer Unit to Baseplate	3 mm	5.46 mm	11
Aluminum Male-Female Threaded Hex Standoff, M2.5 x 0.45	EPS to Base Plate	1.840 mm	3.85 mm	7

The table only includes screws which are not secured with a bolt. The remaining electrical components and the Launcher Base Plate are secured with screws and nuts. The rule of thumb which was used for nut fastening is that there were at least two threads extending beyond the nut [14]. While the door uses a shoulder screw, to connect to the front plate, the threads are not engaged by the two components as it requires free rotation when the door is unlatched. Instead, the shoulder screw is secured by a nut.

Since the center of mass is known for the CSD, we can assume that is the distance from the base at which the mass is acting. To find the length.

$$l = \sqrt{x^2 + y^2 + z^2}$$

$$l = \sqrt{x^2 + y^2 + z^2} = \sqrt{-11.36^2 + 67.21^2 + 434.34^2} = 439.656\ mm$$

$$M = Wl$$

$$M = 9.81 \times 4.97599 \times 0.439656 = 21.46\ Nm$$

To find the bending stress, the moment of inertia is taken from SolidWorks mass property evaluation.

$$\sigma_x = \frac{My}{I_{xx}}$$

$$\sigma_x = \frac{21.46 \times 0.06721}{0.47990534742} = 3.005\ Pa$$

$$\sigma_y = \frac{My}{I_{yy}}$$

$$\sigma_x = \frac{21.46 \times 0.06721}{0.185} = 7.797\ Pa$$

The bending stress is very low because the CSD is only 5 kg, hence the bolts will not fail due to bending.

It should be noted that Loctite Ablestik 104 will be used as an adhesive for the screws. This is because outgassing is a very important property for the CSD, and this specific Loctite would meet the NASA requirements. Also Henkel states that this Loctite specifically dampens vibrational stress on the screws which would further reduce the possibility of failing.

2. *Launcher base plate*

The launcher base plate is determined to be a non-critical component because its failure would not result in the failure of the CSD. This is because, once the CubeSat is loaded into the CSD the spring is compressed and the door is locked. Hence, if the base plate fails, the spring will remain compressed because the CubeSat cannot move while the door is closed. Hence the CubeSat will still launch.

The design is simple to allow the spring to be secured. It is a hollow cylinder around which the spring is tightly fit, and the base is flat to allow fastening to the enclosure base plate. There are tabs on the top which prevent the spring from sliding out when it is decompressed. The cylinder is hollow, and the flat base is chamfered on the corners to reduce weight.

The material was selected as ABS because polymers were the best lightweight alternative to Aluminum and Carbon Fiber composites. ABS has high strength which resists the loads of the CubeSat. ABS was chosen over other polymers due to its superior outgassing qualities, low cost and easy manufacturability.

3. *Angle Bracket*

The angle bracket is mainly used to provide torsional rigidity for the rails. It also provides structure at the center of the Carbon Fiber side plate. If it fails the CSD will still be completely functional, however the side plates are more likely to fail from shock loads.

The reason it was chosen as Aluminum 6061-T6 was only to keep the CSD enclosure skeleton of the same material to prevent uneven thermal expansion due to different CTE values.

4. Side Plates

The side plates were necessary to prevent contamination and to prevent any direct contact between debris large enough to damage the CubeSat. If it fails, the CSD will still be able to function in terms of deploying the CubeSat, however the x-band patch antenna would be hanging from the cable which would make it susceptible to breaking off, there will be no contamination protection and the electricals may probably fail since the walls provide radiation protection.

The reason they were chosen as carbon-fiber is because a lightweight alternative to aluminum was required while also maintaining the strength. Carbon-Fiber is chosen over materials like PEEK because it has a very low CTE which makes any volume change due temperature negligible.

5. Ventilation Grate and Mesh

To reduce the weight and keep contamination protection of the CSD a mesh system was chosen. This is because a depressurization system would be necessary if the CSD was completely sealed, this would add extra cost and weight to the CSD. Instead, a mesh was used with a perforated plate over it along the 4 chamfered edges. Failure would allow normal functioning of the CSD but there will be no contamination protection and the electricals may probably fail since the walls provide direct some radiation protections

The mesh was chosen to be an aluminum mesh with opening sizes of 73.66 microns, therefore it would prevent debris from entering the enclosure. The aluminum mesh provides no structural stability, therefore a carbon fiber plate, similar to the side plates were fixed over it. Multiple holes are drilled into the plate for weight reduction and to prevent the mesh from being redundant.

6. Rail Foam

The Rail Foam is a non-critical component because its failure would allow function of the CSD, however without it, there would be increased friction between the CubeSat and the rails. This would result in two things, the launch velocity would be reduced, and the CubeSat exterior can get damaged due to friction and vibrations.

The use of foam was integral for two important tasks, vibration mitigation and friction reduction. Therefore, three properties were required, rigid foam, ultra-smooth and low outgassing requirements. The Viton Fluoroelastomer met all those criteria. It was also readily available rather than requiring getting custom quotes from manufacturers.

7. Torsion springs

Torsion springs were determined to be non-critical because its failure would not result in total failure of the system. Since the launcher spring is exerting force on the door through the CubeSat, the door will open regardless of the torsion springs failing or not. However, there will be interference with the door as it may send the CubeSat out of the correct trajectory since it will open slower. The speed calculation can be used to find the speed of the door opening.

The torsional spring is expected to open 180 degrees or π rads, so the torque can be found based on the approximation of conservation of energy. κ is the rotational spring constant, θ is the angular deflection, I is the moment of inertia of the spring, m is the mass of the spring, M is the mass of the door, l is the length of the spring arms, ω is rotational velocity. Since there are two spring the spring energy will be multiplied by 2.

$$2 \times \frac{1}{2}\sqrt{\frac{I}{m}}\theta^2 = \frac{1}{2}(Ml^2)\omega^2$$

$$2\sqrt{\frac{0.00000091}{0.00414428}}\pi^2 = (0.59725 \times 9.81) \times 0.05 \times \omega^2$$

$$\omega = 0.999$$

$$t = \frac{0.999}{\pi} = 3\ s$$

This time is only based of the torsion springs alone. However, there is impulse which will act on the door immediately after it is unlatched therefore, the spring force on the door must be factored in. Since the spring force is significantly larger than the torsional force the speed will be much higher. Also, it must be noted that since it will be in 0 gravity, there will be no resultant weight of the door resisting the rotation.

E. Other Engineering Analyses

1. Thermal Analysis

In order to evaluate the expected heat transfer on the CSD during orbit due to radiation the absorbed radiations with and without the AZ-93 White Thermal Control Coating were compared.

Calculated absorbed radiation without reflective coating:

$$G_{abs} = \propto G$$

$$G_{abs} = 0.96 * 1371\ W/m^2$$

$$G_{abs} = 1316.2\ W/m^2$$

$$Q = G_{abs}A$$

$$Q = (1316.2\ W/m^2) * 0.0937\ m^2$$

$$Q = 123.6\ W$$

Calculated absorbed radiation with reflective coating:

$$G_{abs} = \propto G$$

$$G_{abs} = 0.15 * 1371\ W/m^2$$

$$G_{abs} = 205.7\ W/m^2$$

$$Q = G_{abs}A$$

$$Q = (205.7\ W/m^2) * 0.0937\ m^2$$

$$Q = 19.3\ W$$

The use of a reflective coating significantly reduces the amount of incoming heat transfer due to solar radiation

Hand calculations for conduction and convection were too complex to be carried out. Resulting heat transfer and expected temperature values due to conduction and convection are to be determined via lab testing.

F. Iterative Design Cycle

The Launcher subsystem will be chosen to highlight the iterative design process involved up till it converges to the final prototype. The Final assembly in the FDR will be chosen as the prototype.

As with all final products, the first step was research. In this step the problem statement needs to be analyzed. After understanding the requirements and constraints, a blueprint of the steps till the final prototype manufacturing must be laid out. The next step is ideation of the design. In this step as many possible designs that could have been imagined should be sketched. These sketches should include a rough sketch with labels showing the components. Once the sketches have been complete, the team or the person must pick the most feasible design.

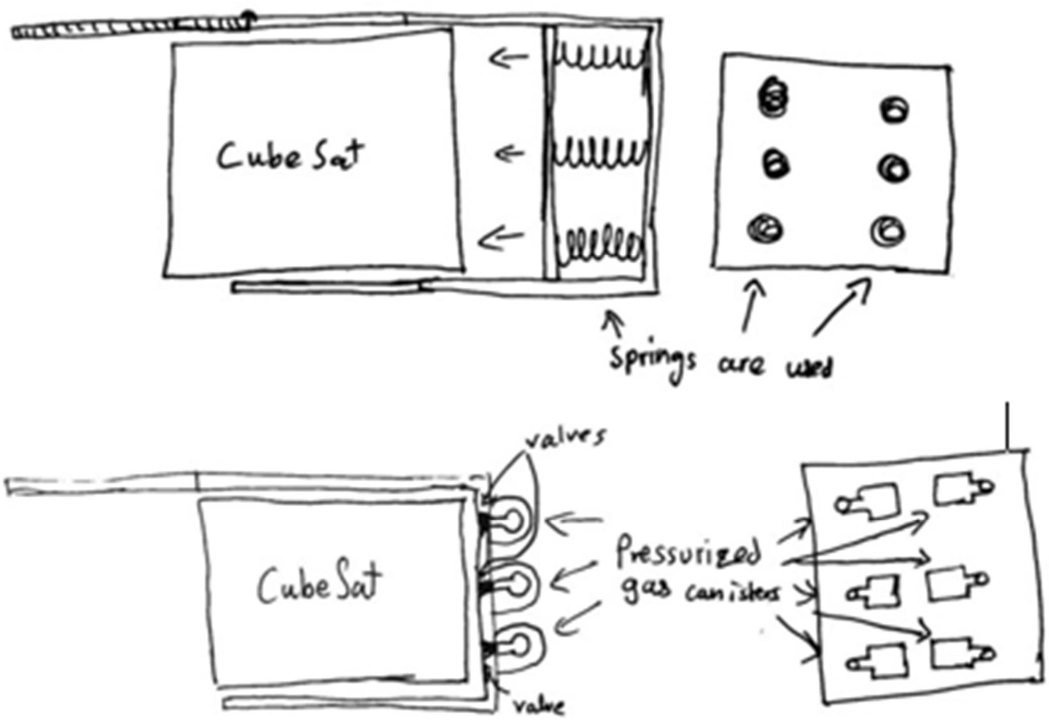


Figure 31 - Final Launcher subsystem designs

From the two final designs, it was decided that the spring launcher was the most viable option due to its simplicity and that it is not dependent on any electrical systems. Once the launcher system was finalized, the initial model was modelled on SolidWorks.

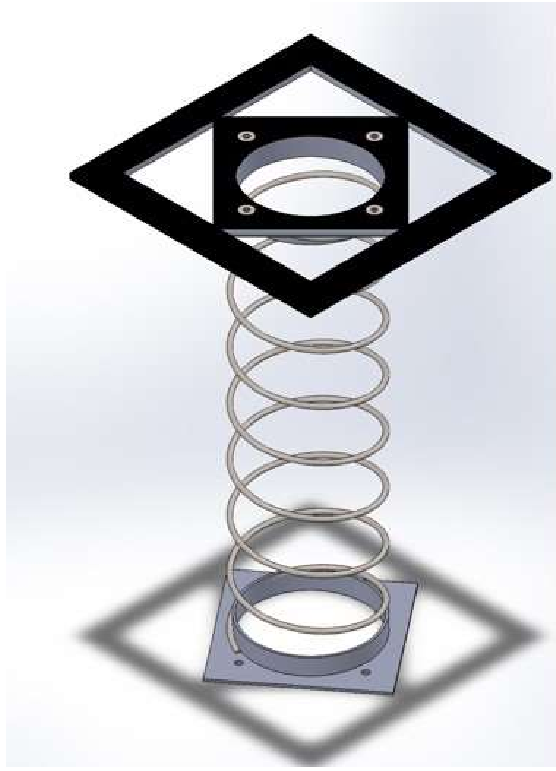


Figure 31 - First Launcher subsystem design

There were four components in this design. It was found out that the CSD was overweight, and the launcher subsystem was significantly heavier than it was expected to be. This was because the launcher upper section consisted of two components, an aluminum pusher plate and another component screwed on the bottom to connect it to the spring. This part was understood to be redundant and if the launcher plate was fully made out of plastic, It could have been manufactured as 1 whole part. Also, there was no element which would prevent the spring from. The next design iteration showed significant change. The lower section of the push plate and the launcher base plate were made out of peek. PEEK was chosen because of its lightweight, low outgassing and high strength.

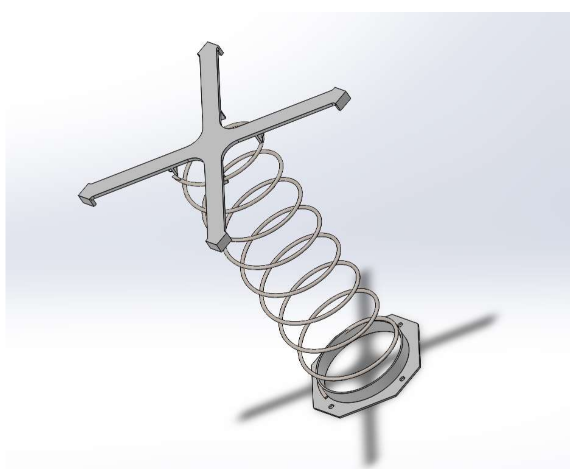


Figure 32 - Second Launcher subsystem design

In this design, the number of components was reduced to three. The upper launch plate was milled out to reduce excess redundant material. It was also selected to be constructed of PEEK and had tabs on the 4 tips and on the surface at which the spring is attached. The tabs prevent the spring from sliding off, it was recommended during Design Review 1. The tabs on the 4 tips reduce bending along their lengths. The base plate remained PEEK. This design was submitted with the PDR.

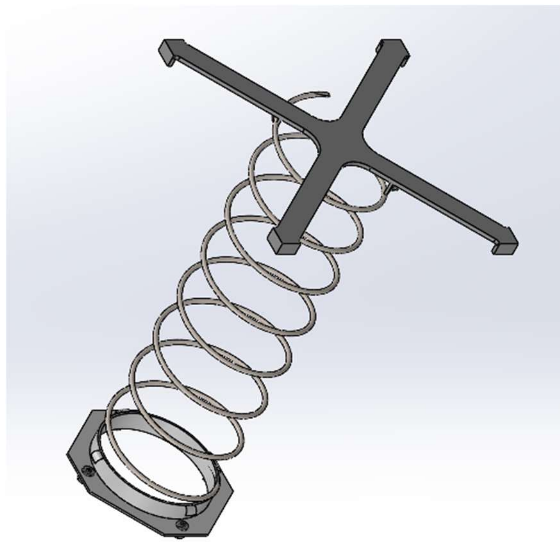


Figure 33 - Final Launcher subsystem design

For the final design few the overall design remained the same, but there were still changes to be addressed. Firstly, the tabs were missing on the launcher base plate. The tabs are integral to prevent the spring from launching out of the CSD along with the CubeSat. The second change was the material change. This was done because it was determined that the minimum temperature was much higher than expected with it being 6˚F instead of -106˚F. This allowed much more room to use cheaper plastics while maintaining enough strength to prevent failure under the expected loading conditions. Hence both the launcher push plate and base plate were changed to ABS. Not only was the material lighter, but it was cheaper and 3D printing allowed cheaper manufacturing costs and less material waste compared to machining out PEEK sheets.

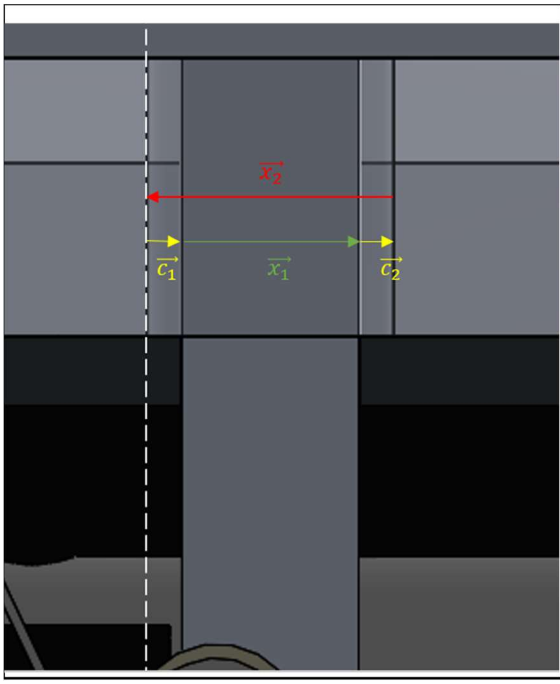
The spring however has remained the same from the PDR. It was chosen as to be made of 302 stainless steels. This is because Stainless Steel springs have very high strength, corrosion resistance and have a wide temperature range for usage.

G. Functional Surfaces

Functional Surface No.	Parts Involved	Location	Significance of Functional Surface
1	Front plate, door	Door latch's fit within the front plate's hole, along the Y-axis	The door latch must be able to fit through the front plate's hole without any resistance or obstruction. This requires clearances.
2	Front plate, door	Door latch's fit within the front plate's hole, along the X-axis	The door latch must be able to fit through the front plate's hole without any resistance or obstruction. This requires clearances.
3	Front plate, door	Hinge features of the front plate and door that make contact when door is fully closed.	If the faces at the hinges of the front plate and door interfere, this will prevent the door from closing flush against the front plate, creating a gap that can let contaminants in.
4	Front plate, door	Hinge features of the front plate and door that align with the fastener	The clearances between the front plate's and door's hinges are important to maintain because it prevents the addition of friction and damage due to rubbing and contact.
5	Door, linear solenoid	Linear solenoid shaft's fit within the hole of the door latch	The linear solenoid's shaft must be able to fit through the latch in order to secure the door in a closed position.
6	Door, linear solenoid	Hole of the door latch's alignment with the linear solenoid shaft's positioning	The position of the door latch's hole must be aligned with the solenoid's shaft to allow the solenoid's shaft to go through the hole without restriction or obstruction.
7	Screw, door	Screw's fit within the hole of the door hinge	In order to have working hinges for the door to rotate about, the screw securing the hinges must be able to fit through the hinge holes easily.
8	Screw, front plate	Screw's fit within the hole of the front door hinge	In order to have working hinges for the door to rotate about, the screw securing the hinges must be able to fit through the hinge holes easily.
9	Hinge-face side plate, front plate	Hole of the hinge-face side plate's alignment with the threaded holes of the front plate	These holes need to be well-aligned in order for the screw to be insert into them properly. If there is no clearance between the diameters, the screw cannot go through both holes.
10	Hinge-face side plate, back plate	Back faces of carbon fiber plate and backplate	If the carbon fiber plate extends too far past the face of the backplate the CSD will not be able to properly mount to the launch vehicle.
11	Spring, launch base plate	Spring's fit along the diameter of the launch base plate	The spring must be able to stay secured on the launch base plate, which necessitates that the spring has a press fit to the plate.
12	Spring, launch plate	Spring's fit at the launch plate tabs	If the interference between the spring and launch plate is not large enough the spring will not be rigidly held in place.
13	Rail foam, launch plate	Launch plate in contact with rail foam	The launch plate and rail foam must maintain contact in order to properly guide the CubeSat out of the CSD. The rail foam and launch plate may interfere, but ideally, they should interfere minimally to prevent additional resistance at launch.

H. Tolerance Loops

Functional Surface 1



Vector Name	Nominal Dimension (mm)	Tolerances		Reference
c_1	1.00	+Δx1	0.2000	See Calculations Below
		-Δx1	0.2000	See Calculations Below
x_1	5.00	+Δx2	0.2000	Manufacturing Process Tolerance
		-Δx2	0.2000	Manufacturing Process Tolerance
c_2	1.00	+Δx3	0.2000	See Calculations Below
		-Δx3	0.2000	See Calculations Below
x_2	7.00	+Δx4	0.2000	Manufacturing Process Tolerance
		-Δx4	0.2000	Manufacturing Process Tolerance
		+Δx5		
		-Δx5		
		+Δx6		
		-Δx6		
		+Δx7		
		-Δx7		
		+Δx8		
		-Δx8		
		+Δx9		
		-Δx9		
		+Δx10		
		-Δx10		
		+Δx11		
		-Δx11		
		+Δx12		
		-Δx12		

Figure 34 Functional Surface 1's Tolerance Loop

The general tolerance loop vector equation for this functional surface is shown below.

$$(\overrightarrow{c_1} \pm \Delta\overrightarrow{c_1}) + (\overrightarrow{x_1} \pm \Delta\overrightarrow{x_1}) + (\overrightarrow{c_2} \pm \Delta\overrightarrow{c_2}) - (\overrightarrow{x_2} \pm \Delta\overrightarrow{x_2}) = 0$$

Resulting calculations when the minimum clearance occurs, and the equal distribution method is applied to the clearances' tolerances:

$$\overrightarrow{c_1}_{min} + (\overrightarrow{x_1} + \Delta\overrightarrow{x_1}) + \overrightarrow{c_2}_{min} - (\overrightarrow{x_2} - \Delta\overrightarrow{x_2}) = 0$$

$$(\overrightarrow{c_1} - \Delta\overrightarrow{c_1}) + (\overrightarrow{c_2} - \Delta\overrightarrow{c_2}) = (\overrightarrow{x_2} - \Delta\overrightarrow{x_2}) - (\overrightarrow{x_1} + \Delta\overrightarrow{x_1})$$

$$-\Delta\overrightarrow{c_1} - \Delta\overrightarrow{c_2} = (\overrightarrow{x_2} - \Delta\overrightarrow{x_2}) - (\overrightarrow{x_1} + \Delta\overrightarrow{x_1}) - \overrightarrow{c_1} - \overrightarrow{c_2}$$

$$\Delta\overrightarrow{c_1} = \Delta\overrightarrow{c_2} = 0.20$$

Resulting calculations when maximum clearance occurs, and the equal distribution method is applied to the clearances' tolerances:

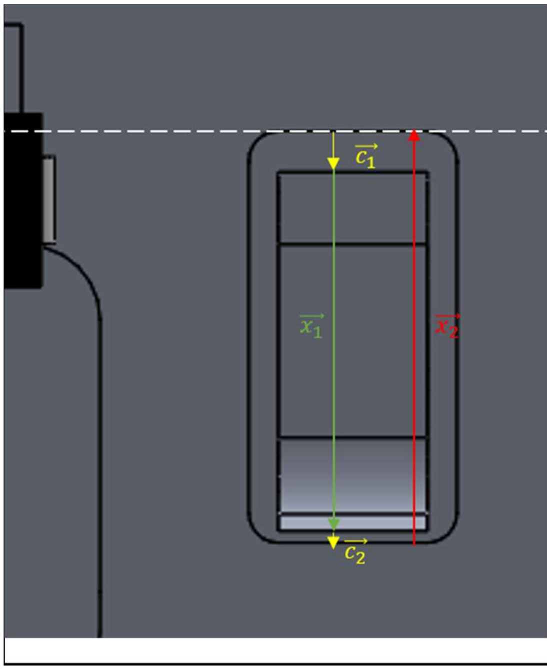
$$\overrightarrow{c_1}_{max} + (\overrightarrow{x_1} + \Delta\overrightarrow{x_1}) + \overrightarrow{c_2}_{max} - (\overrightarrow{x_2} - \Delta\overrightarrow{x_2}) = 0$$

$$(\vec{c_1} + \Delta\vec{c_1}) + (\vec{c_2} + \Delta\vec{c_2}) = (\vec{x_2} + \Delta\vec{x_2}) - (\vec{x_1} - \Delta\vec{x_1})$$

$$\Delta\vec{c_1} + \Delta\vec{c_2} = (\vec{x_2} + \Delta\vec{x_2}) - (\vec{x_1} - \Delta\vec{x_1}) - \vec{c_1} - \vec{c_2}$$

$$\Delta\vec{c_1} = \Delta\vec{c_2} = 0.20$$

Functional Surface 2



Vector Name	Nominal Dimension (mm)	Tolerances		Reference
c_1	1.83	+Δx2	0.2000	See Calculations Below
		-Δx2	0.2000	See Calculations Below
x_1	11.50	+Δx3	0.2000	Manufacturing Process Tolerance
		-Δx3	0.2000	Manufacturing Process Tolerance
c_2	0.50	+Δx4	0.2000	See Calculations Below
		-Δx4	0.2000	See Calculations Below
x_2	13.83	+Δx5	0.2000	Manufacturing Process Tolerance
		-Δx5	0.2000	Manufacturing Process Tolerance
		+Δx6		
		-Δx6		
		+Δx7		
		-Δx7		
		+Δx8		
		-Δx8		
		+Δx9		
		-Δx9		
		+Δx10		
		-Δx10		
		+Δx11		
		-Δx11		
		+Δx12		
		-Δx12		
		+Δx13		
		-Δx13		

Figure 35 Functional Surface 2's Tolerance Loop

The general tolerance loop vector equation for this functional surface is shown below.

$$(\vec{c_1} \pm \Delta\vec{c_1}) + (\vec{x_1} \pm \Delta\vec{x_1}) + (\vec{c_2} \pm \Delta\vec{c_2}) - (\vec{x_2} \pm \Delta\vec{x_2}) = 0$$

Resulting calculations when the minimum clearance occurs, and the equal distribution method is applied to the clearances' tolerances:

$$\vec{c_1}_{min} + (\vec{x_1} + \Delta\vec{x_1}) + \vec{c_2}_{min} - (\vec{x_2} - \Delta\vec{x_2}) = 0$$

$$(\vec{c_1} - \Delta\vec{c_1}) + (\vec{c_2} - \Delta\vec{c_2}) = (\vec{x_2} - \Delta\vec{x_2}) - (\vec{x_1} + \Delta\vec{x_1})$$

$$-\Delta\vec{c_1} - \Delta\vec{c_2} = (\vec{x_2} - \Delta\vec{x_2}) - (\vec{x_1} + \Delta\vec{x_1}) - \vec{c_1} - \vec{c_2}$$

$$\Delta\vec{c_1} = \Delta\vec{c_2} = 0.20$$

Resulting calculations when maximum clearance occurs, and the equal distribution method is applied to the clearances' tolerances:

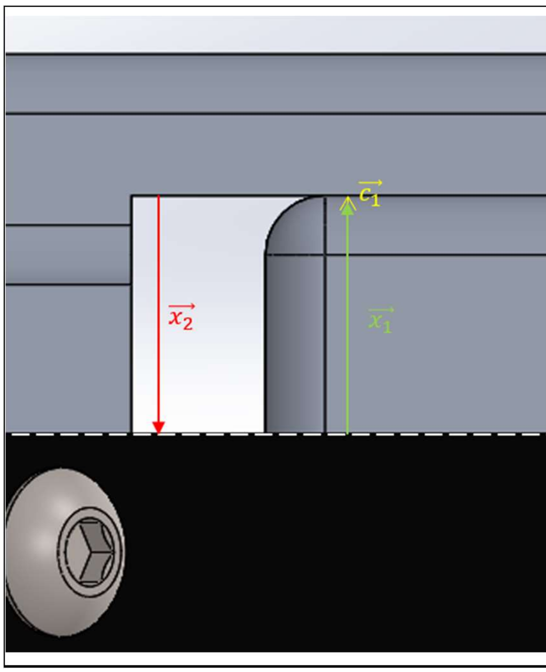
$$\overrightarrow{c_1}_{max} + (\overrightarrow{x_1} + \Delta\overrightarrow{x_1}) + \overrightarrow{c_2}_{max} - (\overrightarrow{x_2} - \Delta\overrightarrow{x_2}) = 0$$

$$(\overrightarrow{c_1} + \Delta\overrightarrow{c_1}) + (\overrightarrow{c_2} + \Delta\overrightarrow{c_2}) = (\overrightarrow{x_2} + \Delta\overrightarrow{x_2}) - (\overrightarrow{x_1} - \Delta\overrightarrow{x_1})$$

$$\Delta\overrightarrow{c_1} + \Delta\overrightarrow{c_2} = (\overrightarrow{x_2} + \Delta\overrightarrow{x_2}) - (\overrightarrow{x_1} - \Delta\overrightarrow{x_1}) - \overrightarrow{c_1} - \overrightarrow{c_2}$$

$$\Delta\overrightarrow{c_1} = \Delta\overrightarrow{c_2} = 0.20$$

Functional Surface 3



Vector Name	Nominal Dimension (mm)	Tolerances		Reference
x_1	8.00	+Δx1	0.00	Manufacturing Process Tolerance
		-Δx1	0.04	Manufacturing Process Tolerance
c_1	0.00	+Δx2	0.08	See Calculations Below
		-Δx2	0.00	See Calculations Below
x_2	8.00	+Δx3	0.04	Manufacturing Process Tolerance
		-Δx3	0.00	Manufacturing Process Tolerance
		+Δx4		
		-Δx4		
		+Δx5		
		-Δx5		
		+Δx6		
		-Δx6		
		+Δx7		
		-Δx7		
		+Δx8		
		-Δx8		
		+Δx9		
		-Δx9		
		+Δx10		
		-Δx10		
		+Δx11		
		-Δx11		
		+Δx12		
		-Δx12		

Figure 36. Functional Surface 3's Tolerance Loop

The general tolerance loop vector equation for this functional surface is shown below:

$$(\overrightarrow{x_1} \pm \Delta\overrightarrow{x_1}) + (\overrightarrow{c_1} \pm \Delta\overrightarrow{c_1}) - (\overrightarrow{x_2} \pm \Delta\overrightarrow{x_2}) = 0$$

For this functional surface, there ideally must be no space between the front plate and the door, so the minimum clearance is designed at 0 mm. Based on the minimum clearance and the equal distribution method, the minimum length of $\overrightarrow{x_2}$ and the maximum length of $\overrightarrow{x_1}$ are calculated:

$$(\overrightarrow{x_1} + \Delta\overrightarrow{x_1}) + \overrightarrow{c_1}_{max} - (\overrightarrow{x_2} + \Delta\overrightarrow{x_2}) = 0$$

$$\Delta\overrightarrow{x_1} + \Delta\overrightarrow{x_2} = \overrightarrow{x_2} - \overrightarrow{x_1} - \overrightarrow{c_1}_{max}$$

$$\Delta\overrightarrow{x_1} = \Delta\overrightarrow{x_2} = 0\ mm$$

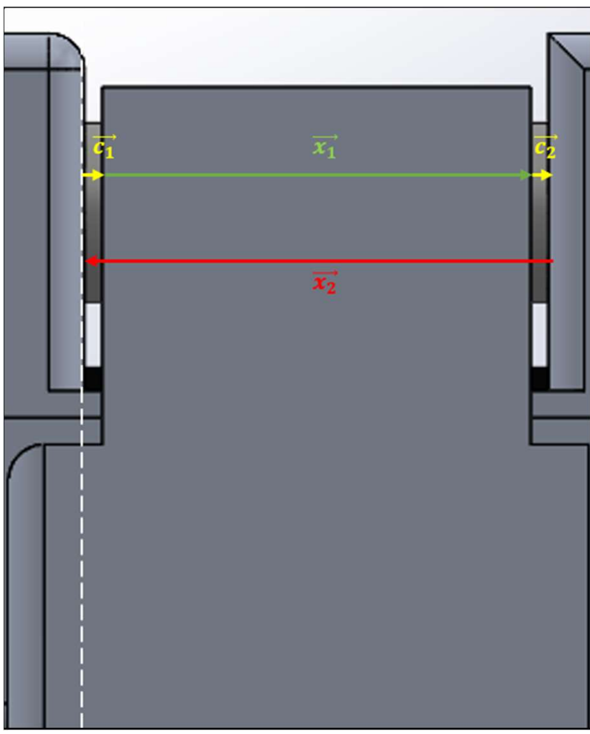
Resulting calculations when maximum clearance occurs:

$$(\overrightarrow{x_1} + \Delta\overrightarrow{x_1}) + \overrightarrow{c_1}_{max} - (\overrightarrow{x_2} - \Delta\overrightarrow{x_2}) = 0$$

$$\overrightarrow{c_1} + \Delta\overrightarrow{c_1} = (\overrightarrow{x_2} + \Delta\overrightarrow{x_2}) - (\overrightarrow{x_1} - \Delta\overrightarrow{x_1})$$

$$\Delta\overrightarrow{c_1} = 0.08\ mm$$

Functional Surface 4



Vector Name	Nominal Dimension	Tolerances		Reference
c_1	1.00	+Δx1	0.20	See Calculations Below
		-Δx1	0.20	See Calculations Below
x_1	24.00	+Δx2	0.20	Manufacturing Process Tolerance
		-Δx2	0.20	Manufacturing Process Tolerance
c_2	1.00	+Δx3	0.20	See Calculations Below
		-Δx3	0.20	See Calculations Below
x_2	26.00	+Δx4	0.20	Manufacturing Process Tolerance
		-Δx4	0.20	Manufacturing Process Tolerance
		+Δx5		
		-Δx5		
		+Δx6		
		-Δx6		
		+Δx7		
		-Δx7		
		+Δx8		
		-Δx8		
		+Δx9		
		-Δx9		
		+Δx10		
		-Δx10		
		+Δx11		
		-Δx11		
		+Δx12		
		-Δx12		

Figure 37 Functional Surface 4's Tolerance Loop

The general tolerance loop vector equation for this functional surface is shown below:

$$(\overrightarrow{c_1} \pm \Delta\overrightarrow{c_1}) + (\overrightarrow{x_1} \pm \Delta\overrightarrow{x_1}) + (\overrightarrow{c_2} \pm \Delta\overrightarrow{c_2}) - (\overrightarrow{x_2} \pm \Delta\overrightarrow{x_2}) = 0$$

Resulting calculations when the minimum clearance occurs, and the equal distribution method is applied to the clearances' tolerances:

$$\overrightarrow{c_1}_{min} + (\overrightarrow{x_1} + \Delta\overrightarrow{x_1}) + \overrightarrow{c_2}_{min} - (\overrightarrow{x_2} - \Delta\overrightarrow{x_2}) = 0$$

$$(\vec{c_1} - \Delta\vec{c_1}) + (\vec{c_2} - \Delta\vec{c_2}) = (\vec{x_2} - \Delta\vec{x_2}) - (\vec{x_1} + \Delta\vec{x_1})$$

$$-\Delta\vec{c_1} - \Delta\vec{c_2} = (\vec{x_2} - \Delta\vec{x_2}) - (\vec{x_1} + \Delta\vec{x_1}) - \vec{c_1} - \vec{c_2}$$

$$\Delta\vec{c_1} = \Delta\vec{c_2} = 0.20$$

Resulting calculations when maximum clearance occurs, and the equal distribution method is applied to the clearances' tolerances:

$$\vec{c_1}_{max} + (\vec{x_1} + \Delta\vec{x_1}) + \vec{c_2}_{max} - (\vec{x_2} - \Delta\vec{x_2}) = 0$$

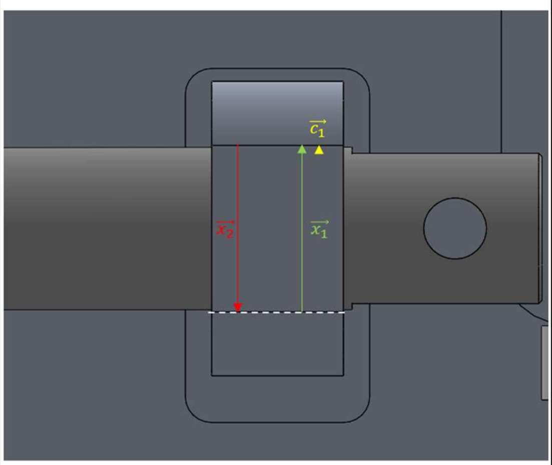
$$(\vec{c_1} + \Delta\vec{c_1}) + (\vec{c_2} + \Delta\vec{c_2}) = (\vec{x_2} + \Delta\vec{x_2}) - (\vec{x_1} - \Delta\vec{x_1})$$

$$\Delta\vec{c_1} + \Delta\vec{c_2} = (\vec{x_2} + \Delta\vec{x_2}) - (\vec{x_1} - \Delta\vec{x_1}) - \vec{c_1} - \vec{c_2}$$

$$\Delta\vec{c_1} = \Delta\vec{c_2} = 0.20$$

Functional Surface 5

Solenoid Shaft and Door Latch Hole



Vector Name	Nominal Dimension (mm)	Tolerances		Reference
x_1	6.350	+Δx1		See Calculations Below
		-Δx1		See Calculations Below
c_1	0.000	+Δx2	0.1778	Tap and Drill Chart
		-Δx2	0.0000	Required by fit type
x_2	6.350	+Δx3		See Calculations Below
		-Δx3		See Calculations Below
		+Δx4		
		-Δx4		
		+Δx5		
		-Δx5		
		+Δx6		
		-Δx6		
		+Δx7		
		-Δx7		
		+Δx8		
		-Δx8		
		+Δx9		
		-Δx9		
		+Δx10		
		-Δx10		
		+Δx11		
		-Δx11		
		+Δx12		
		-Δx12		

Figure 38 Functional Surface 5's Tolerance Loop

The general tolerance loop vector equation for this functional surface is shown below:

$$(\overrightarrow{x_1} \pm \Delta\overrightarrow{x_1}) + (\overrightarrow{c_1} \pm \Delta\overrightarrow{c_1}) - (\overrightarrow{x_2} \pm \Delta\overrightarrow{x_2}) = 0$$

Resulting calculations when minimum clearance occurs:

$$(\overrightarrow{x_1} + \Delta\overrightarrow{x_1}) + \overrightarrow{c_1}_{min} - (\overrightarrow{x_2} - \Delta\overrightarrow{x_2}) = 0$$

$$(\overrightarrow{x_1} - \overrightarrow{x_2}) + (\Delta\overrightarrow{x_1} + \Delta\overrightarrow{x_2}) = -\overrightarrow{c_1}_{min}$$

$$\Delta\overrightarrow{x_1} = \Delta\overrightarrow{x_2} = 0$$

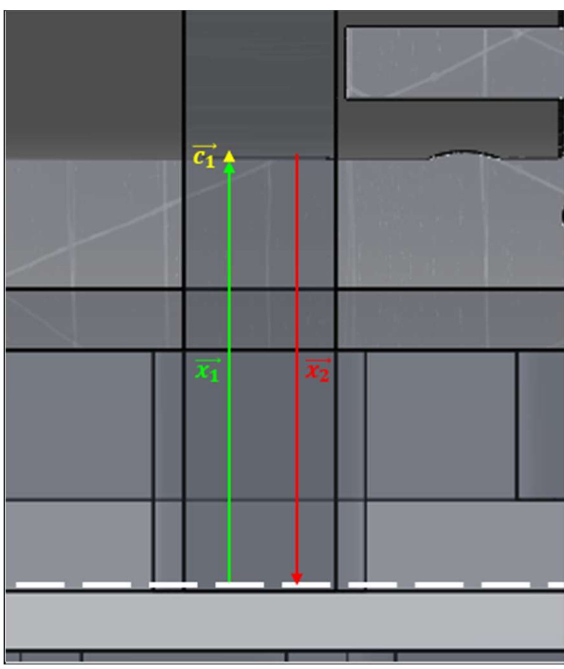
Resulting calculations when maximum clearance occurs:

$$(\overrightarrow{x_1} - \Delta\overrightarrow{x_1}) + \overrightarrow{c_1}_{max} - (\overrightarrow{x_2} + \Delta\overrightarrow{x_2}) = 0$$

$$(\overrightarrow{x_1} - \overrightarrow{x_2}) - (\Delta\overrightarrow{x_1} + \Delta\overrightarrow{x_2}) = -\overrightarrow{c_1}_{max}$$

$$\Delta\overrightarrow{x_1} = \Delta\overrightarrow{x_2} = 0.0889\ mm$$

Functional Surface 6



Vector Name	Nominal Dimension	Tolerances		Reference
x_1	14.360	+Δx1	0.00	Manufacturing Process Tolerance
		-Δx1	0.04	Manufacturing Process Tolerance
c_1	0.000	+Δx2	0.08	See Calculations Below
		-Δx2	0.00	See Calculations Below
x_2	14.360	+Δx3	0.04	Manufacturing Process Tolerance
		-Δx3	0.00	Manufacturing Process Tolerance
		+Δx4		
		-Δx4		
		+Δx5		
		-Δx5		
		+Δx6		
		-Δx6		
		+Δx7		
		-Δx7		
		+Δx8		
		-Δx8		
		+Δx9		
		-Δx9		
		+Δx10		
		-Δx10		
		+Δx11		
		-Δx11		
		+Δx12		
		-Δx12		

Figure 39 Functional Surface 6's Tolerance Loop

The general tolerance loop vector equation for this functional surface is shown below.

$$(\overrightarrow{x_1} \pm \Delta\overrightarrow{x_1}) + (\overrightarrow{c_1} \pm \Delta\overrightarrow{c_1}) - (\overrightarrow{x_2} \pm \Delta\overrightarrow{x_2}) = 0$$

For this functional surface, there ideally must be no space between the front plate and the door, so the minimum clearance is designed at 0 mm. Based on the minimum clearance and the equal distribution method, the minimum length of $\overrightarrow{x_2}$ and the maximum length of $\overrightarrow{x_1}$ are calculated:

$$(\overrightarrow{x_1} + \Delta\overrightarrow{x_1}) + \overrightarrow{c_1}_{max} - (\overrightarrow{x_2} + \Delta\overrightarrow{x_2}) = 0$$

$$\Delta\overrightarrow{x_1} + \Delta\overrightarrow{x_2} = \overrightarrow{x_2} - \overrightarrow{x_1} - \overrightarrow{c_1}_{max}$$

$$\Delta\overrightarrow{x_1} = \Delta\overrightarrow{x_2} = 0\ mm$$

Resulting calculations when maximum clearance occurs:

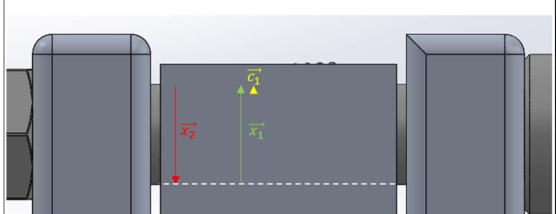
$$(\overrightarrow{x_1} + \Delta\overrightarrow{x_1}) + \overrightarrow{c_1}_{max} - (\overrightarrow{x_2} - \Delta\overrightarrow{x_2}) = 0$$

$$\overrightarrow{c_1} + \Delta\overrightarrow{c_1} = (\overrightarrow{x_2} + \Delta\overrightarrow{x_2}) - (\overrightarrow{x_1} - \Delta\overrightarrow{x_1})$$

$$\Delta\overrightarrow{c_1} = 0.08\ mm$$

Functional Surface 7

Door Mounting Hole and Fastener



Vector Name	Nominal Dimension	Tolerances		Reference
x_1	10.000	+Δx1	0.0000	Provided by Manufacturer
		-Δx1	0.0720	Provided by Manufacturer
c_1	0.000	+Δx2	0.5000	Tap and Drill Chart
		-Δx2	0.0000	Required by fit type
x_2	10.000	+Δx3		See Calculations Below
		-Δx3		See Calculations Below
		+Δx4		
		-Δx4		
		+Δx5		
		-Δx5		
		+Δx6		
		-Δx6		
		+Δx7		
		-Δx7		
		+Δx8		
		-Δx8		
		+Δx9		
		-Δx9		
		+Δx10		
		-Δx10		
		+Δx11		
		-Δx11		
		+Δx12		
		-Δx12		

Figure 40 Functional Surface 7's Tolerance Loop

The general tolerance loop vector equation for this functional surface is shown below:

$$(\overrightarrow{x_1} \pm \Delta\overrightarrow{x_1}) + (\overrightarrow{c_1} \pm \Delta\overrightarrow{c_1}) - (\overrightarrow{x_2} \pm \Delta\overrightarrow{x_2}) = 0$$

Resulting calculations when minimum clearance occurs:

$$(\overrightarrow{x_1} + \Delta\overrightarrow{x_1}) + \overrightarrow{c_1}_{min} - (\overrightarrow{x_2} - \Delta\overrightarrow{x_2}) = 0$$

$$(\overrightarrow{x_1} - \overrightarrow{x_2}) + (\Delta\overrightarrow{x_1} + \Delta\overrightarrow{x_2}) = -\overrightarrow{c_1}_{min}$$

$$\Delta\overrightarrow{x_1} = \Delta\overrightarrow{x_2} = 0$$

Resulting calculations when maximum clearance occurs:

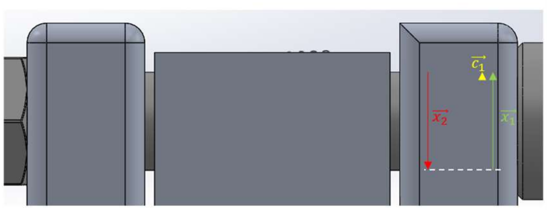
$$(\overrightarrow{x_1} - \Delta\overrightarrow{x_1}) + \overrightarrow{c_1}_{max} - (\overrightarrow{x_2} + \Delta\overrightarrow{x_2}) = 0$$

$$(\overrightarrow{x_1} - \overrightarrow{x_2}) - (\Delta\overrightarrow{x_1} + \Delta\overrightarrow{x_2}) = -\overrightarrow{c_1}_{max}$$

$$\Delta\overrightarrow{x_1} = \Delta\overrightarrow{x_2} = 0.286\ mm$$

Functional Surface 8

Front Panel Hinge and Fastener



Vector Name	Nominal Dimension	Tolerances		Reference
x_1	10.000	+Δx1	0.0000	Provided by Manufacturer
		-Δx1	0.0720	Provided by Manufacturer
c_1	0.000	+Δx2	0.5000	Tap and Drill Chart
		-Δx2	0.0000	Required by fit type
x_2	10.000	+Δx3		See Calculations Below
		-Δx3		See Calculations Below
		+Δx4		
		-Δx4		
		+Δx5		
		-Δx5		
		+Δx6		
		-Δx6		
		+Δx7		
		-Δx7		
		+Δx8		
		-Δx8		
		+Δx9		
		-Δx9		
		+Δx10		
		-Δx10		
		+Δx11		
		-Δx11		
		+Δx12		
		-Δx12		

Figure 41 Functional Surface 8's Tolerance Loop

The general tolerance loop vector equation for this functional surface is shown below:

$$(\overrightarrow{x_1} \pm \Delta\overrightarrow{x_1}) + (\overrightarrow{c_1} \pm \Delta\overrightarrow{c_1}) - (\overrightarrow{x_2} \pm \Delta\overrightarrow{x_2}) = 0$$

Resulting calculations when minimum clearance occurs:

$$(\overrightarrow{x_1} + \Delta\overrightarrow{x_1}) + \overrightarrow{c_1}_{min} - (\overrightarrow{x_2} - \Delta\overrightarrow{x_2}) = 0$$

$$(\vec{x_1} - \vec{x_2}) + (\Delta\vec{x_1} + \Delta\vec{x_2}) = -\vec{c_1}_{min}$$

$$\Delta\vec{x_1} = \Delta\vec{x_2} = 0$$

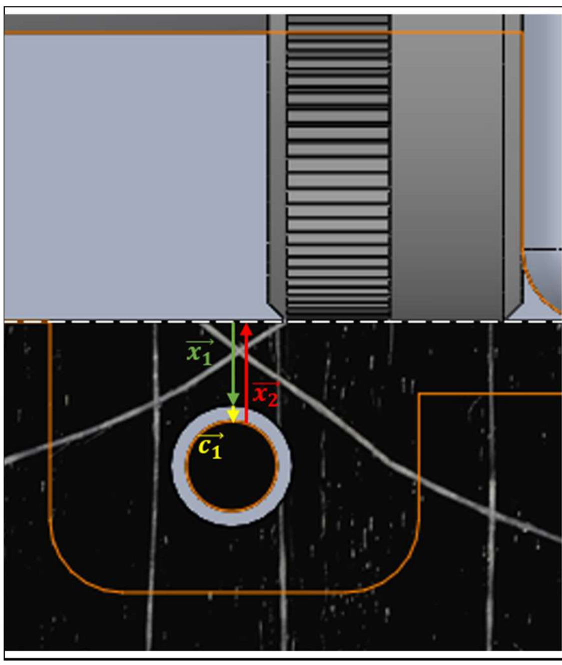
Resulting calculations when maximum clearance occurs:

$$(\vec{x_1} - \Delta\vec{x_1}) + \vec{c_1}_{max} - (\vec{x_2} + \Delta\vec{x_2}) = 0$$

$$(\vec{x_1} - \vec{x_2}) - (\Delta\vec{x_1} + \Delta\vec{x_2}) = -\vec{c_1}_{max}$$

$$\Delta\vec{x_1} = \Delta\vec{x_2} = 0.286\ mm$$

Functional Surface 9



Vector Name	Nominal Dimension	Tolerances		Reference
x_1	2.300	+Δx1	0.10	Manufacturing Process Tolerance
		-Δx1	0.10	Manufacturing Process Tolerance
c_1	0.450	+Δx2	0.20	See Calculations Below
		-Δx2	0.20	See Calculations Below
x_2	2.750	+Δx3	0.10	Manufacturing Process Tolerance
		-Δx3	0.10	Manufacturing Process Tolerance
		+Δx4		
		-Δx4		
		+Δx5		
		-Δx5		
		+Δx6		
		-Δx6		
		+Δx7		
		-Δx7		
		+Δx8		
		-Δx8		
		+Δx9		
		-Δx9		
		+Δx10		
		-Δx10		
		+Δx11		
		-Δx11		
		+Δx12		
		-Δx12		

Figure 42 Functional Surface 9's Tolerance Loop

The general tolerance loop vector equation for this functional surface is shown below.

$$(\vec{x_1} \pm \Delta\vec{x_1}) + (\vec{c_1} \pm \Delta\vec{c_1}) - (\vec{x_2} \pm \Delta\vec{x_2}) = 0$$

Resulting calculations when minimum clearance occurs:

$$(\vec{x_1} + \Delta\vec{x_1}) + \vec{c_1}_{max} - (\vec{x_2} + \Delta\vec{x_2}) = 0$$

$$\vec{c_1} - \Delta\vec{c_1} = (\vec{x_2} - \Delta\vec{x_2}) - (\vec{x_1} + \Delta\vec{x_1})$$

$$\Delta\vec{c_1} = 0.20\ mm$$

Resulting calculations when maximum clearance occurs:

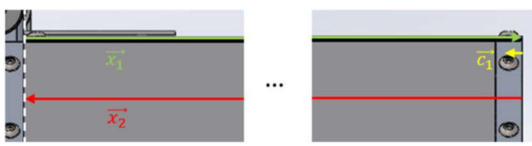
$$(\vec{x_1} + \Delta\vec{x_1}) + \vec{c_1}_{max} - (\vec{x_2} - \Delta\vec{x_2}) = 0$$

$$\vec{c_1} + \Delta\vec{c_1} = (\vec{x_2} + \Delta\vec{x_2}) - (\vec{x_1} - \Delta\vec{x_1})$$

$$\Delta\vec{c_1} = 0.20\ mm$$

Functional Surface 10

Carbon Fiber Plate and Back Plate



Vector Name	Nominal Dimension	Tolerances		Reference
x_1	425.250	+Δx1	0.0500	Manufacturing Process Tolerance
		-Δx1	0.0500	Manufacturing Process Tolerance
c_1	0.000	+Δx2		See Calculations Below
		-Δx2		See Calculations Below
x_2	425.250	+Δx3	0.0500	Manufacturing Process Tolerance
		-Δx3	0.0500	Manufacturing Process Tolerance
		+Δx4		
		-Δx4		
		+Δx5		
		-Δx5		
		+Δx6		
		-Δx6		
		+Δx7		
		-Δx7		
		+Δx8		
		-Δx8		
		+Δx9		
		-Δx9		
		+Δx10		
		-Δx10		
		+Δx11		
		-Δx11		
		+Δx12		
		-Δx12		

Figure 43 Functional Surface 10's Tolerance Loop

The general tolerance loop vector equation for this functional surface is shown below:

$$(\vec{x_1} \pm \Delta\vec{x_1}) - (\vec{c_1} \pm \Delta\vec{c_1}) - (\vec{x_2} \pm \Delta\vec{x_2}) = 0$$

Resulting calculations when minimum clearance occurs:

$$(\vec{x_1}_{min}) - (\vec{c_1} - \Delta\vec{c_1}) - (\vec{x_2}_{max}) = 0$$

$$\Delta\vec{c_1} = \vec{x_2}_{max} - \vec{x_1}_{min} + \vec{c_1}$$

$$\Delta\vec{c_1} = 0.1\ mm$$

Resulting calculations when maximum clearance occurs:

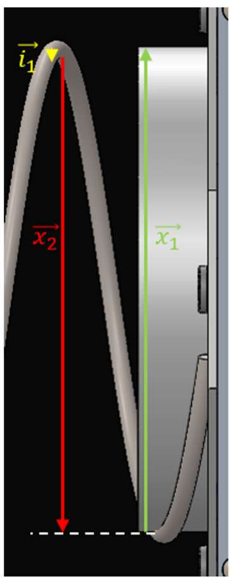
$$(\vec{x_1}_{\ max}) - (\vec{c_1} + \Delta\vec{c_1}) - (\vec{x_2}_{min}) = 0$$

$$\Delta\vec{c_1} = \vec{x_1}_{max} - \vec{x_2}_{\ min} - \vec{c_1}$$

$$\Delta\vec{c_1} = 0.1\ mm$$

Functional Surface 11

Launcher Baseplate and Spring



Vector Name	Nominal Dimension	Tolerances		Reference
x_1	104.000	+Δx1	0.5000	Manufacturing Process Tolerance
		-Δx1	0.5000	Manufacturing Process Tolerance
i_1	2.000	+Δx2		See Calculations Below
		-Δx2		See Calculations Below
x_2	102.000	+Δx3	1.0000	Manufacturing Process Tolerance
		-Δx3	1.0000	Manufacturing Process Tolerance
		+Δx4		
		-Δx4		
		+Δx5		
		-Δx5		
		+Δx6		
		-Δx6		
		+Δx7		
		-Δx7		
		+Δx8		
		-Δx8		
		+Δx9		
		-Δx9		
		+Δx10		
		-Δx10		
		+Δx11		
		-Δx11		
		+Δx12		
		-Δx12		

Figure 44 Functional Surface 11's Tolerance Loop

The general tolerance loop vector equation for this functional surface is shown below:

$$(\vec{x_1} \pm \Delta\vec{x_1}) - (\vec{\iota_1} \pm \Delta\vec{\iota_1}) - (\vec{x_2} \pm \Delta\vec{x_2}) = 0$$

Resulting calculations when minimum interference occurs:

$$(\vec{x_1}_{\ min}) - (\vec{\iota_1} - \Delta\vec{\iota}) - (\vec{x_2}_{max}) = 0$$

$$\Delta\vec{\iota_1} = \vec{x_2}_{max} - \vec{x_1}_{\ min} + \vec{\iota_1}$$

$$\Delta\vec{\iota_1} = 1.5\ mm$$

Resulting calculations when maximum interference occurs:

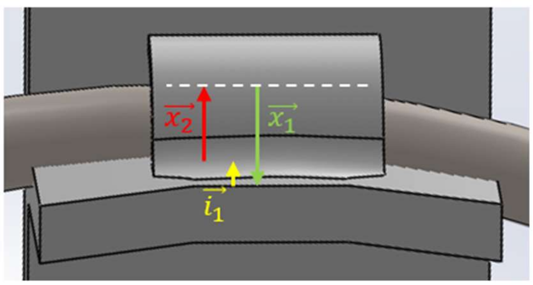
$$(\overrightarrow{x_1}_{\,max}) - (\overrightarrow{\iota_1} + \Delta\vec{\iota}) - (\overrightarrow{x_2}_{min}) = 0$$

$$\Delta\overrightarrow{\iota_1} = \overrightarrow{x_1}_{max} - \overrightarrow{x_2}_{\,min} - \overrightarrow{\iota_1}$$

$$\Delta\overrightarrow{\iota_1} = 1.5\ mm$$

Functional Surface 12

Spring and Launchplate



Vector Name	Nominal Dimension	Tolerances		Reference
x_1	6.000	+Δx1	0.0000	Provided by Manufacturer
		-Δx1	0.0000	Provided by Manufacturer
i_1	1.500	+Δx2		See Calculations Below
		-Δx2		See Calculations Below
x_2	4.500	+Δx3	0.0500	Manufacturing Process Tolerance
		-Δx3	0.0500	Manufacturing Process Tolerance
		+Δx4		
		-Δx4		
		+Δx5		
		-Δx5		
		+Δx6		
		-Δx6		
		+Δx7		
		-Δx7		
		+Δx8		
		-Δx8		
		+Δx9		
		-Δx9		
		+Δx10		
		-Δx10		
		+Δx11		
		-Δx11		
		+Δx12		
		-Δx12		

Figure 45 Functional Surface 12's Tolerance Loop

The general tolerance loop vector equation for this functional surface is shown below:

$$(\overrightarrow{x_1} \pm \Delta\overrightarrow{x_1}) - (\overrightarrow{\iota_1} \pm \Delta\overrightarrow{\iota_1}) - (\overrightarrow{x_2} \pm \Delta\overrightarrow{x_2}) = 0$$

Resulting calculations when minimum interference occurs:

$$(\overrightarrow{x_1}_{\,min}) - (\overrightarrow{\iota_1} - \Delta\vec{\iota}) - (\overrightarrow{x_2}_{max}) = 0$$

$$\Delta\overrightarrow{\iota_1} = \overrightarrow{x_2}_{max} - \overrightarrow{x_1}_{\,min} + \overrightarrow{\iota_1}$$

$$\Delta\overrightarrow{\iota_1} = 0.05\ mm$$

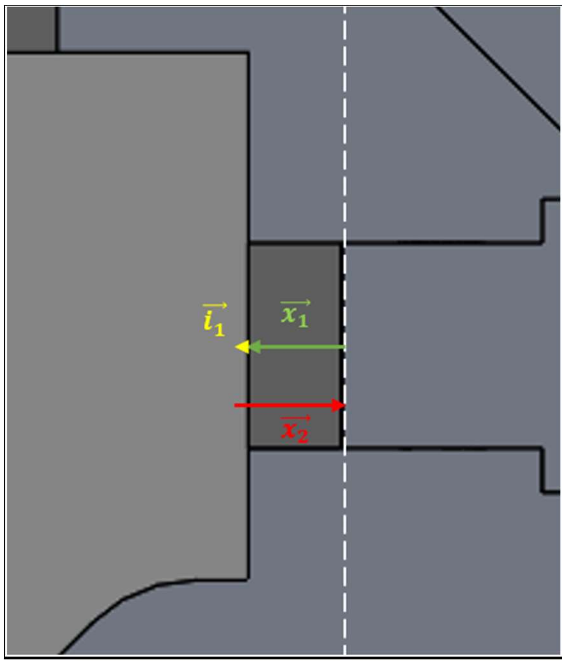
Resulting calculations when maximum interference occurs:

$$(\overrightarrow{x_1}_{\,max}) - (\overrightarrow{\iota_1} + \Delta\vec{\iota}) - (\overrightarrow{x_2}_{min}) = 0$$

$$\Delta\vec{i_1} = \vec{x_1}_{max} - \vec{x_2}_{min} - \vec{i_1}$$

$$\Delta\vec{i_1} = 0.05\ mm$$

Functional Surface 13



Vector Name	Nominal Dimension	Tolerances		Reference
x_1	3.180	+Δx1	0.1524	Manufacturing Process Tolerance
		-Δx1	0.0400	Manufacturing Process Tolerance
i_1	0.000	+Δx2	0.1924	See Calculations Below
		-Δx2	0.0000	See Calculations Below
x_2	3.180	+Δx3	0.1524	McMaster-Carr
		-Δx3	0.1524	McMaster-Carr
		+Δx4		
		-Δx4		
		+Δx5		
		-Δx5		
		+Δx6		
		-Δx6		
		+Δx7		
		-Δx7		
		+Δx8		
		-Δx8		
		+Δx9		
		-Δx9		
		+Δx10		
		-Δx10		
		+Δx11		
		-Δx11		
		+Δx12		
		-Δx12		

Figure 46 Functional Surface 13's Tolerance Loop

The general tolerance loop vector equation for this functional surface is shown below:

$$(\vec{x_1} \pm \Delta\vec{x_1}) + (\vec{i_1} \pm \Delta\vec{i_1}) - (\vec{x_2} \pm \Delta\vec{x_2}) = 0$$

For this functional surface, there ideally must be no interference between the foam and the launch plate, so the minimum interference is designed at 0 mm. Based on the minimum interference, the maximum length of $\vec{x_1}$ is calculated:

$$(\vec{x_1} + \Delta\vec{x_1}) + \vec{i_1}_{min} - (\vec{x_2} - \Delta\vec{x_2}) = 0$$

$$\vec{x_1} + \Delta\vec{x_1} = (\vec{x_2} - \Delta\vec{x_2}) - \vec{i_1}_{min}$$

$$\Delta\vec{x_1} = 0.1524\ mm$$

Resulting calculations when maximum interference occurs:

$$(\overrightarrow{x_1}_{max}) - (\overrightarrow{\iota_1} + \Delta\vec{\iota}) - (\overrightarrow{x_2}_{min}) = 0$$

$$\Delta\overrightarrow{\iota_1} = \overrightarrow{x_1}_{max} - \overrightarrow{x_2}_{min} - \overrightarrow{\iota_1}$$

$$\Delta\overrightarrow{\iota_1} = 0.1924\ mm$$

I. Design Failure Modes and Effects Analysis (DFMEA)

DFMEA (Design Failure Modes & Effects Analysis) is a widely used technique that applies a methodical approach for identifying risks that could potentially lead to failure. The failure modes are the anti-functions, or the requirements that are not being met. These are ranked on a scale of 1-10, using the severity chart. Then, the potential causes are ranked on a scale of 1-10 using the occurrence chart. These are the defined mechanisms of failure for the function. Finally, the likelihood of detection is ranked on a scale of 1-10 using the detection chart. This column is important because failure that cannot be detected presents more risk than an easily preventable one. By multiplying the S, O, and D columns together, the Risk Priority Number (RPN) is found. The row with the highest RPN value will be considered for lowering occurrence on causes and lowering detection on specific test improvements. Additionally, columns with a severity rating of 9 or 10 must be eliminated. Finally, recommended actions are given in order to lower the risk of failure on the specified function of the product.

In this case, DFMEA was performed on the door and opening mechanism. Iterations of it were done as early as possible to avoid design flaws that could have been missed. Specifically, the DFMEA was performed on the door and opening mechanism subsystem, on the function of opening the door. Below is the resulting DFMEA table with calculated RPN.

Function	Potential Failure Mode	Potential Effects of Failure	S	Potential Cause of Failure	O	Current Process Controls	D	RPN	Recommended Action (s)
Open door	CubeSat lock unlaches prematurely	CubeSat is lost before reaching launch point	10	Broken latch	2	Warning labels	9	180	Identify early risks
	Linear solenoid fails to move; door opens too slowly	CubeSat does not launch	8	Limit switch signal cannot reach CSD	3	User manuals	5	120	
	Door alters launch angle	CubeSat launched at different angle	7	Torsion spring compressed improperly	4	User manuals	5	140	

The DFMEA should result in actions which bring high risk items to a lower risk. The appropriate actions in this case are to perform run-time sensor diagnostics, which could reveal line shorts and component faults. Hardware redundancy could also be implemented for items with critical-safe requirements.

Effect	Criteria: Severity of Effect on Product (Customer Effect)	Rank
Failure to Meet Safety and/or Regulatory Requirements	Potential failure mode affects safe vehicle operation and/or involves noncompliance with government regulation without warning.	10
	Potential failure mode affects safe vehicle operation and/or involves noncompliance with government regulation with warning.	9
Loss or Degradation of Primary Function	Loss of primary function (vehicle inoperable, does not affect safe vehicle operation).	8
	Degradation of primary function (vehicle operable, but at reduced level of performance).	7
Loss or Degradation of Secondary Function	Loss of secondary function (vehicle operable, but comfort / convenience functions inoperable).	6
	Degradation of secondary function (vehicle operable, but comfort / convenience functions at reduced level of performance).	5
Annoyance	Appearance or Audible Noise, vehicle operable, item does not conform and noticed by most customers (> 75%).	4
	Appearance or Audible Noise, vehicle operable, item does not conform and noticed by many customers (50%).	3
	Appearance or Audible Noise, vehicle operable, item does not conform and noticed by discriminating customers (< 25%).	2
No Effect	No discernible effect.	1

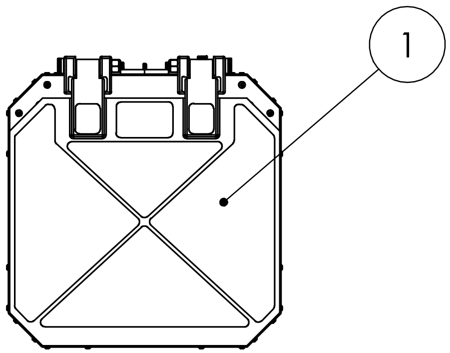
Likelihood of Failure	Criteria: Occurrence of Cause (Design life/reliability of item/vehicle)	Criteria: Occurrence of Cause (Incidents per items/vehicles)	Rank
Very High	New technology/new design with no history.	≥ 100 per thousand ≥ 1 in 10	10
High	Failure is inevitable with new design, new application, or change in duty cycle/operating conditions.	50 per thousand 1 in 20	9
	Failure is likely with new design, new application, or change in duty cycle/operating conditions.	20 per thousand 1 in 50	8
	Failure is uncertain with new design, new application, or change in duty cycle/operating conditions.	10 per thousand 1 in 100	7
Moderate	Frequent failures associated with similar designs or in design simulation and testing.	2 per thousand 1 in 500	6
	Occasional failures associated with similar designs or in design simulation and testing.	.5 per thousand 1 in 2000	5
	Isolated failures associated with similar design or in design simulation and testing.	.1 per thousand 1 in 10,000	4
Low	Only isolated failures associated with almost identical design or in design simulation and testing.	.01 per thousand 1 in 100,000	3
	No observed failures associated with almost identical design or in design simulation and testing.	≤.001 per thousand 1 in 1,000,000	2
Very Low	Failure is eliminated through preventative control.	Failure is eliminated through preventive control.	1

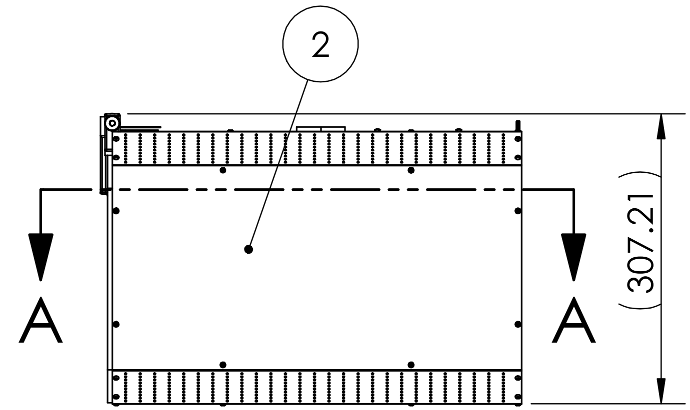
Opportunity for Detection	Criteria: Likelihood of Detection by Design Control	Rank	Likelihood of Detection
No detection opportunity	No current design control; Cannot detect or is not analyzed.	10	Absolute Uncertainty
Not likely to detect at any stage	Design analysis/detection controls have a weak detection capability; Virtual Analysis (e.g., CAE, FEA, etc.) is **not correlated** to expected actual operating conditions.	9	Very Remote
Post Design Freeze and prior to launch	Product verification/validation after design freeze and prior to launch with **pass/fail** testing (Sub-system or system testing with acceptance criteria such as ride & handling, shipping evaluation, etc.)	8	Remote
	Product verification/validation after design freeze and prior to launch with **test to failure** testing (Sub-system or system testing until failure occurs, testing of system interactions, etc.)	7	Very Low
	Product verification/validation after design freeze and prior to launch with **degradation** testing (Sub-system or system testing after durability test, e.g., function check).	6	Low
Prior to Design Freeze	Product validation (reliability testing, development or validation tests) prior to design freeze using **pass/fail** testing (e.g., acceptance criteria for performance, function checks, etc.)	5	Moderately
	Product validation (reliability testing, development or validation tests) prior to design freeze using **test to failure** (e.g., until leaks, yields, cracks, etc.).	4	Moderately High
	Product validation (reliability testing, development or validation tests) prior to design freeze using **degradation** testing (e.g., data trends, before/after values, etc.)	3	High
Virtual Analysis - Correlated	Design analysis/detection controls have strong detection capability. Virtual Analysis (e.g., CAE, FEA, etc.) is **highly correlated** with actual and/or expected operating conditions prior to design freeze.	2	Very High
Detection Not Applicable: Failure Prevention	Failure cause or failure mode cannot occur because it is fully prevented through design solutions (e.g. proven design standard, best practice or common material, etc.)	1	Amost Certain

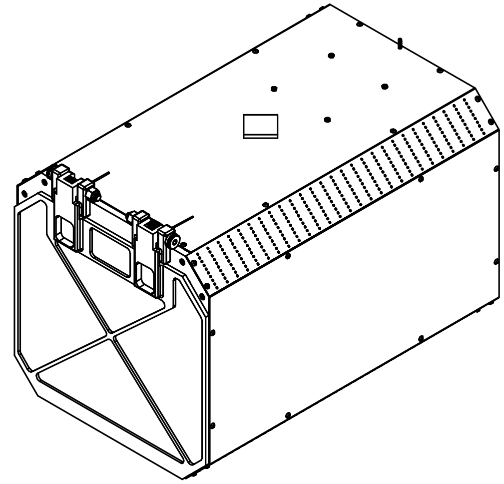
Reprinted from Potential Failure Mode and Effects Analysis (FMEA) 4th Edition, 2008 Manual

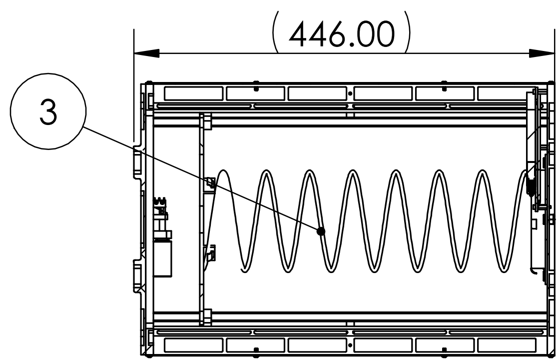
VIII. Complete Part Drawings

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	EML4501-A-02	Door Assembly	1
2	EML4501-A-03	Enclosure	1
3	EML4501-A-04	LauncherAssy	1









SECTION A-A

1. DIMS IN MM

UF Herbert Wertheim College of Engineering
Department of Mechanical & Aerospace Engineering
UNIVERSITY of FLORIDA

EML4502: MECHANICAL DESIGN 3

TEAM: Group 13.5

PART NAME: CSD

PART NUMBER: EML4501-A-01 **Rev:**

MATERIAL: **FINISH:**

DESIGN ENGINEER:

DESIGN APPROVAL:

MANUFACTURING APPROVAL:

STANDARD DIMENSIONAL TOLERANCES:

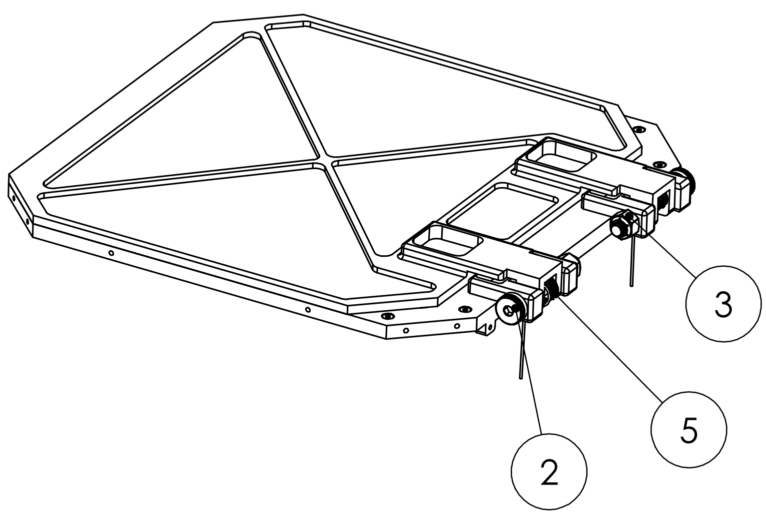
LINEAR [mm]		ANGULAR [degrees]	
X.X:	±**1**	**X:**	±**3**
X.XX:	±**.1**	**X.X:**	±**.5**
X.XXX:	±**.05**	**X.XX:**	±**.1**

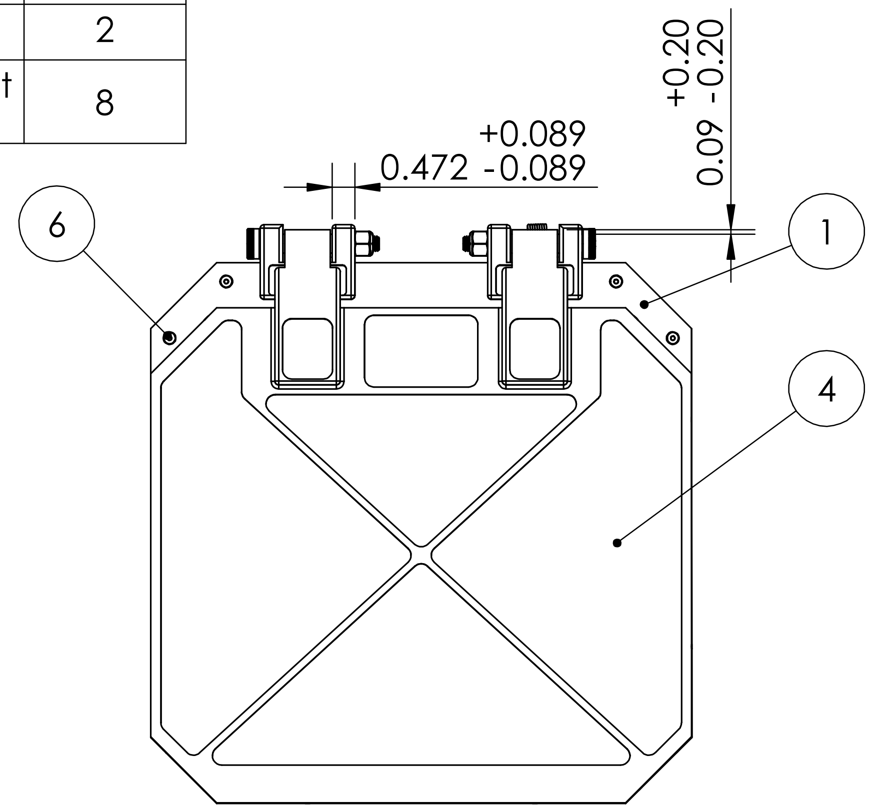
MAXIMUM SURFACE FINISH: .004 in Ra

PART LOCATION:

SHEET SCALE: 1:8 **SHEET NUMBER: 1 of 1**

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	EML4501-03	Front Plate	1
2	90265A167	18-8 Stainless Steel Shoulder Screw	2
3	93625A114	18-8 Stainless Steel Nylon-Insert Locknut	2
4	EML4501-08	Door	1
5	9271K421	Torsion Spring	2
6	93395A207	316 Stainless Steel Hex Drive Flat Head Screw	8





1. DIMS IN MM

UF Herbert Wertheim College of Engineering
Department of Mechanical & Aerospace Engineering
UNIVERSITY of FLORIDA

EML4502: MECHANICAL DESIGN 3

TEAM: Group 13.5	**PART NAME: Door Assembly**
PART NUMBER: EML4501-A-02	**Rev:**
MATERIAL:	**FINISH:**
DESIGN ENGINEER:	
DESIGN APPROVAL:	
MANUFACTURING APPROVAL:	

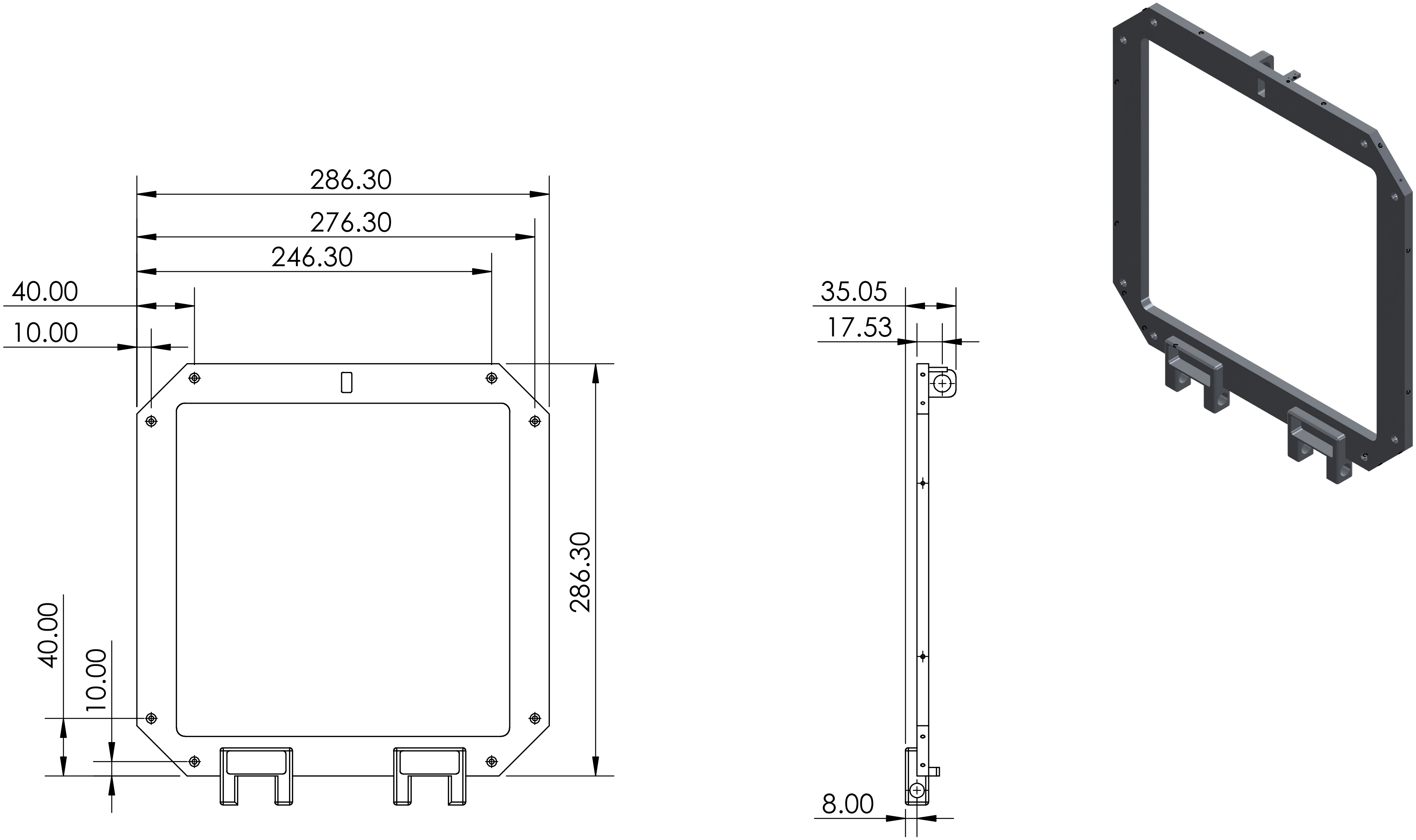
STANDARD DIMENSIONAL TOLERANCES:

LINEAR [mm]		ANGULAR [degrees]	
X.X:	±**1**	**X:**	±**3**
X.XX:	±**.1**	**X.X:**	±**.5**
X.XXX:	±**.05**	**X.XX:**	±**.1**

MAXIMUM SURFACE FINISH: .004 in Ra

PART LOCATION:

SHEET SCALE: 1:4 **SHEET NUMBER: 1 of 1**



1. DIMS IN MM
2. BREAK ALL EDGES

Herbert Wertheim College of Engineering
Department of Mechanical & Aerospace Engineering
UNIVERSITY of FLORIDA

EML4502: MECHANICAL DESIGN 3

TEAM: GROUP 13.5	PART NAME: Frontplate
PART NUMBER: EML4501-03	Rev:
MATERIAL: Aluminium 6061	FINISH:
DESIGN ENGINEER: Bresney,Sean P	
DESIGN APPROVAL:	
MANUFACTURING APPROVAL:	

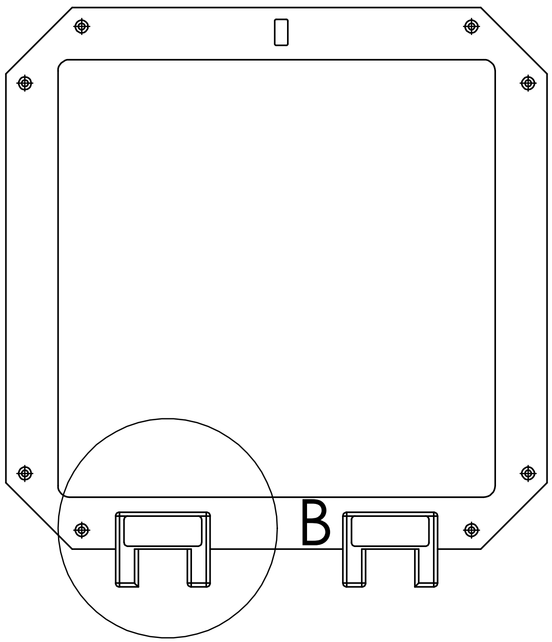
STANDARD DIMENSIONAL TOLERANCES:

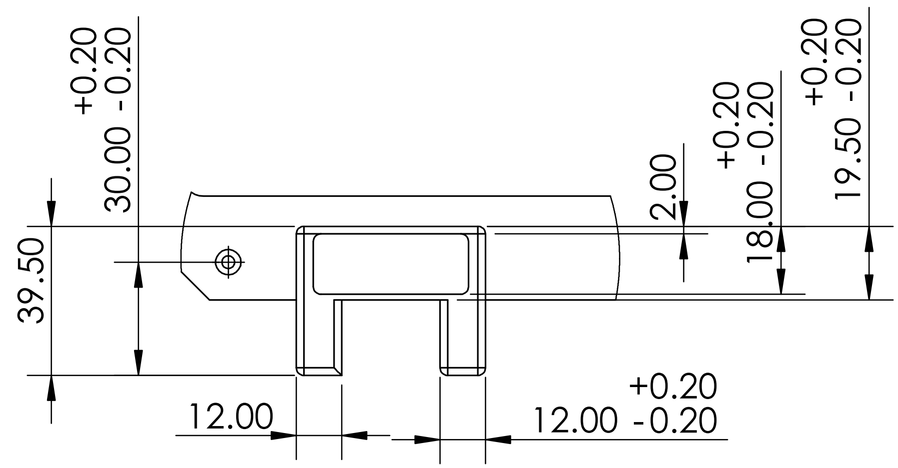
LINEAR [mm]		ANGULAR [degrees]	
X.X:	±**1**	**X:**	±**3**
X.XX:	±**.1**	**X.X:**	±**.5**
X.XXX:	±**.05**	**X.XX:**	±**.1**

MAXIMUM SURFACE FINISH: .004 in Ra

PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\Frontplate.SLDPRT

SHEET SCALE: 1:4 **SHEET NUMBER: 1 of 2**





DETAIL B

SCALE 1 : 2

1. DIMS IN MM
2. BREAK ALL EDGES

UF Herbert Wertheim College of Engineering
Department of Mechanical & Aerospace Engineering
UNIVERSITY of FLORIDA

EML4502: MECHANICAL DESIGN 3

TEAM: GROUP 13.5	**PART NAME:** Frontplate
PART NUMBER: EML4501-03	**Rev:**
MATERIAL: Aluminium 6061	**FINISH:**
DESIGN ENGINEER: Bresney,Sean P	
DESIGN APPROVAL:	
MANUFACTURING APPROVAL:	

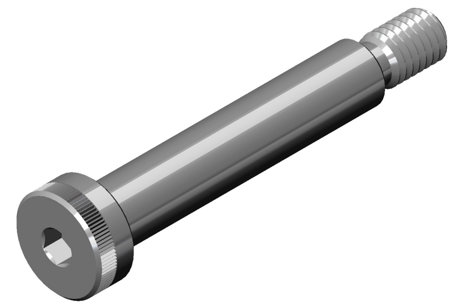
STANDARD DIMENSIONAL TOLERANCES:

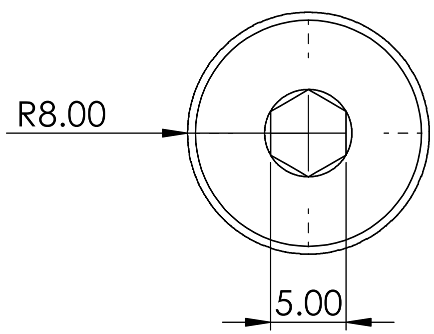
LINEAR [mm]		ANGULAR [degrees]	
X.X:	±**1**	**X:**	±**3**
X.XX:	±**.1**	**X.X:**	±**.5**
X.XXX:	±**.05**	**X.XX:**	±**.1**

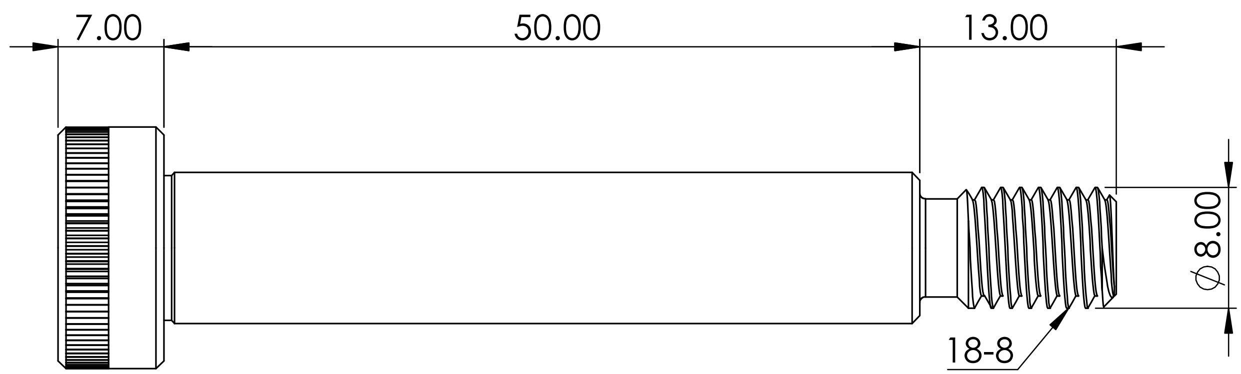
MAXIMUM SURFACE FINISH: .004 in Ra

PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\Frontplate.SLDPRT

SHEET SCALE: 1:4 **SHEET NUMBER:** 2 of 2





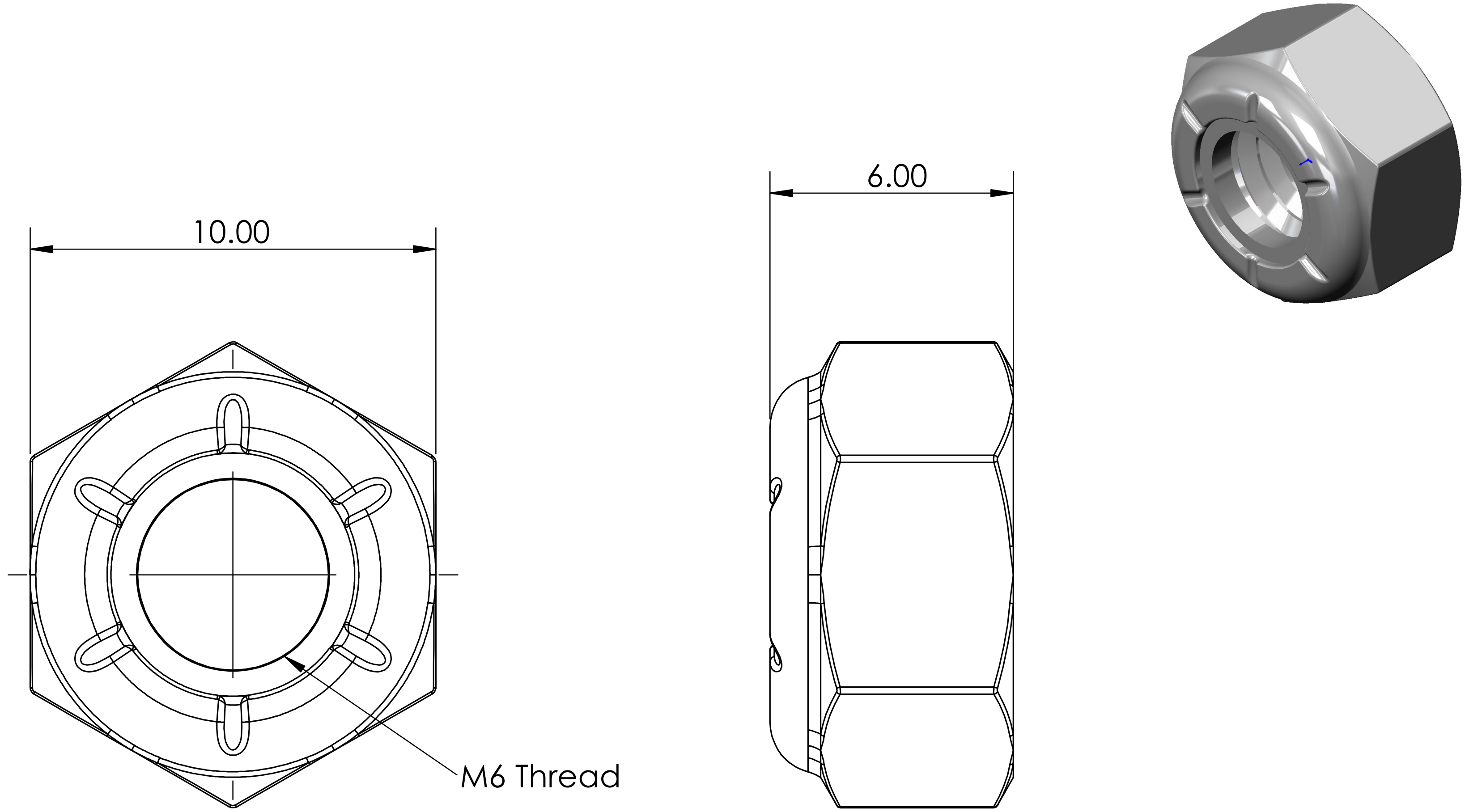


1. DIMS IN MM

UF Herbert Wertheim College of Engineering, Department of Mechanical & Aerospace Engineering, UNIVERSITY of FLORIDA	***EML4502: MECHANICAL DESIGN 3***	**TEAM: Group 13.5**	**PART NAME:** 18-8 Stainless Steel Shoulder Screw
		PART NUMBER: EML4501-OTS-03	**Rev:**
STANDARD DIMENSIONAL TOLERANCES:		**MATERIAL: 18-8 Stainless Steel**	**FINISH:**
LINEAR [mm]	ANGULAR [degrees]	**DESIGN ENGINEER: Sun, Tessa**	
X.X: ±**1**	**X:** ±**3**		
X.XX: ±**.1**	**X.X:** ±**.5**	**DESIGN APPROVAL:**	
X.XXX: ±**.05**	**X.XX:** ±**.1**		
MAXIMUM SURFACE FINISH: .004 in Ra		**MANUFACTURING APPROVAL:**	

PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\OTS parts\90265A167_18-8 Stainless Steel Shoulder Screw.SLDPRT

SHEET SCALE: 1:1 **SHEET NUMBER: 1 of 1**

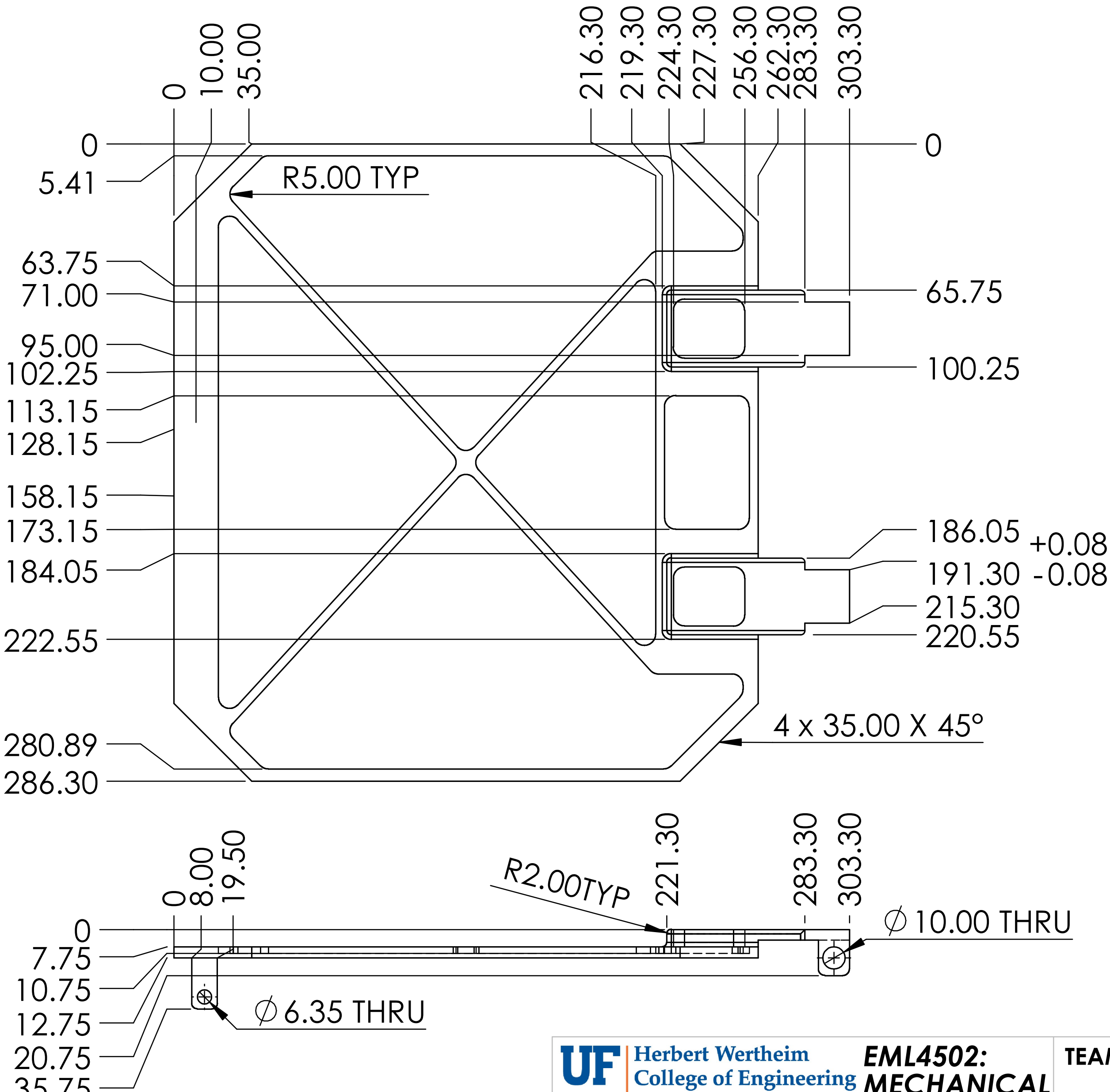


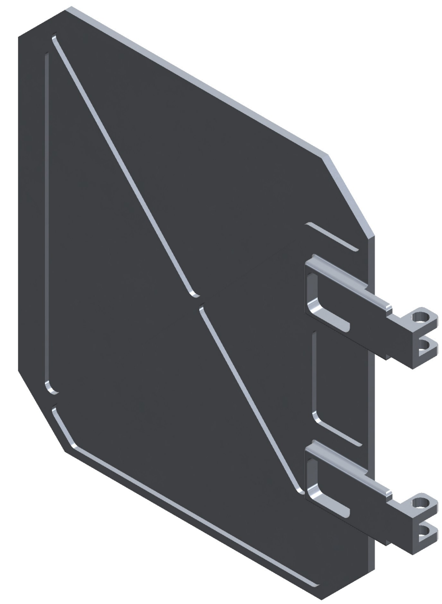
1. DIMS IN MM

UF Herbert Wertheim College of Engineering Department of Mechanical & Aerospace Engineering UNIVERSITY of FLORIDA	***EML4502: MECHANICAL DESIGN 3***	**TEAM: Group 13.5**	**PART NAME:** **18-8 Stainless Steel Nylon-Insert**
		PART NUMBER: EML4501-OTS-07	**Rev:**
STANDARD DIMENSIONAL TOLERANCES:		**MATERIAL: 18-8 Stainless Steel**	**FINISH:**
LINEAR [mm]	ANGULAR [degrees]	**DESIGN ENGINEER: Sun, Tessa**	
X.X: ±1	**X: ±3**		
X.XX: ±.1	**X.X: ±.5**	**DESIGN APPROVAL:**	
X.XXX: ±.05	**X.XX: ±.1**		
MAXIMUM SURFACE FINISH: .004 in Ra		**MANUFACTURING APPROVAL:**	

PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\OTS parts\93625A250_18-8 Stainless Steel Nylon-Insert Locknut.SLDPRT

SHEET SCALE: 4:1 **SHEET NUMBER: 1 of 1**





1. DIMS IN MM
2. BREAK ALL EDGES

UF Herbert Wertheim College of Engineering
Department of Mechanical & Aerospace Engineering
UNIVERSITY of FLORIDA

EML4502: MECHANICAL DESIGN 3

TEAM: GROUP 13.5

PART NAME: DOOR

PART NUMBER: EML4501-08 **Rev: A**

MATERIAL: ALUMINUM 6061 **FINISH:**

DESIGN ENGINEER: BRESNEY,SEAN P

DESIGN APPROVAL:SUN, TESSA

MANUFACTURING APPROVAL:TIPNIS, VARUN

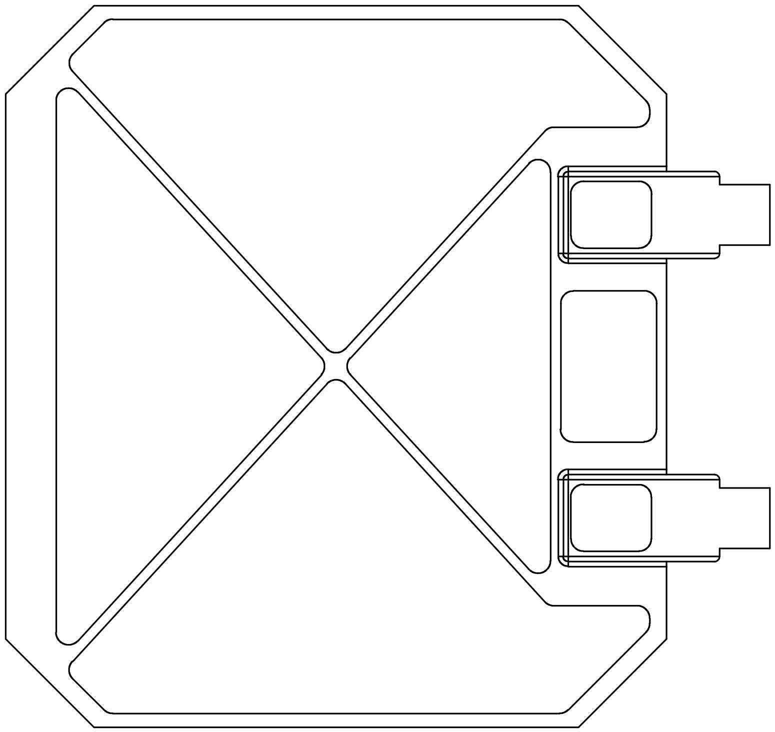
STANDARD DIMENSIONAL TOLERANCES:

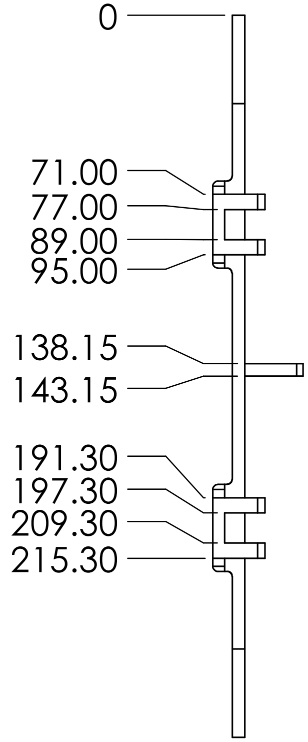
LINEAR [mm]		ANGULAR [degrees]	
X.X:	**±1**	**X:**	**±3**
X.XX:	**±.1**	**X.X:**	**±.5**
X.XXX:	**±.05**	**X.XX:**	**±.1**

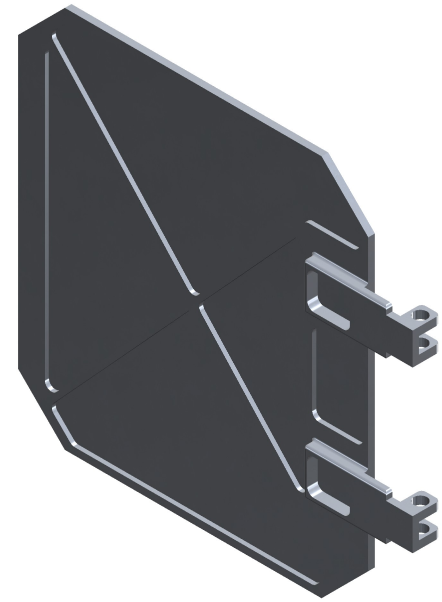
MAXIMUM SURFACE FINISH: .004 in Ra

PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\Door 2.0.SLDPRT

SHEET SCALE: 1:4 **SHEET NUMBER: 1 of 2**







UF Herbert Wertheim College of Engineering
Department of Mechanical & Aerospace Engineering
UNIVERSITY of FLORIDA

EML4502: MECHANICAL DESIGN 3

STANDARD DIMENSIONAL TOLERANCES:

LINEAR [mm]		ANGULAR [degrees]	
X.X:	±**1**	**X:**	±**3**
X.XX:	±**.1**	**X.X:**	±**.5**
X.XXX:	±**.05**	**X.XX:**	±**.1**

MAXIMUM SURFACE FINISH: .004 in Ra

TEAM:

PART NAME: Door

PART NUMBER: EML4502-22-11-26010 **Rev:**

MATERIAL: **FINISH:**

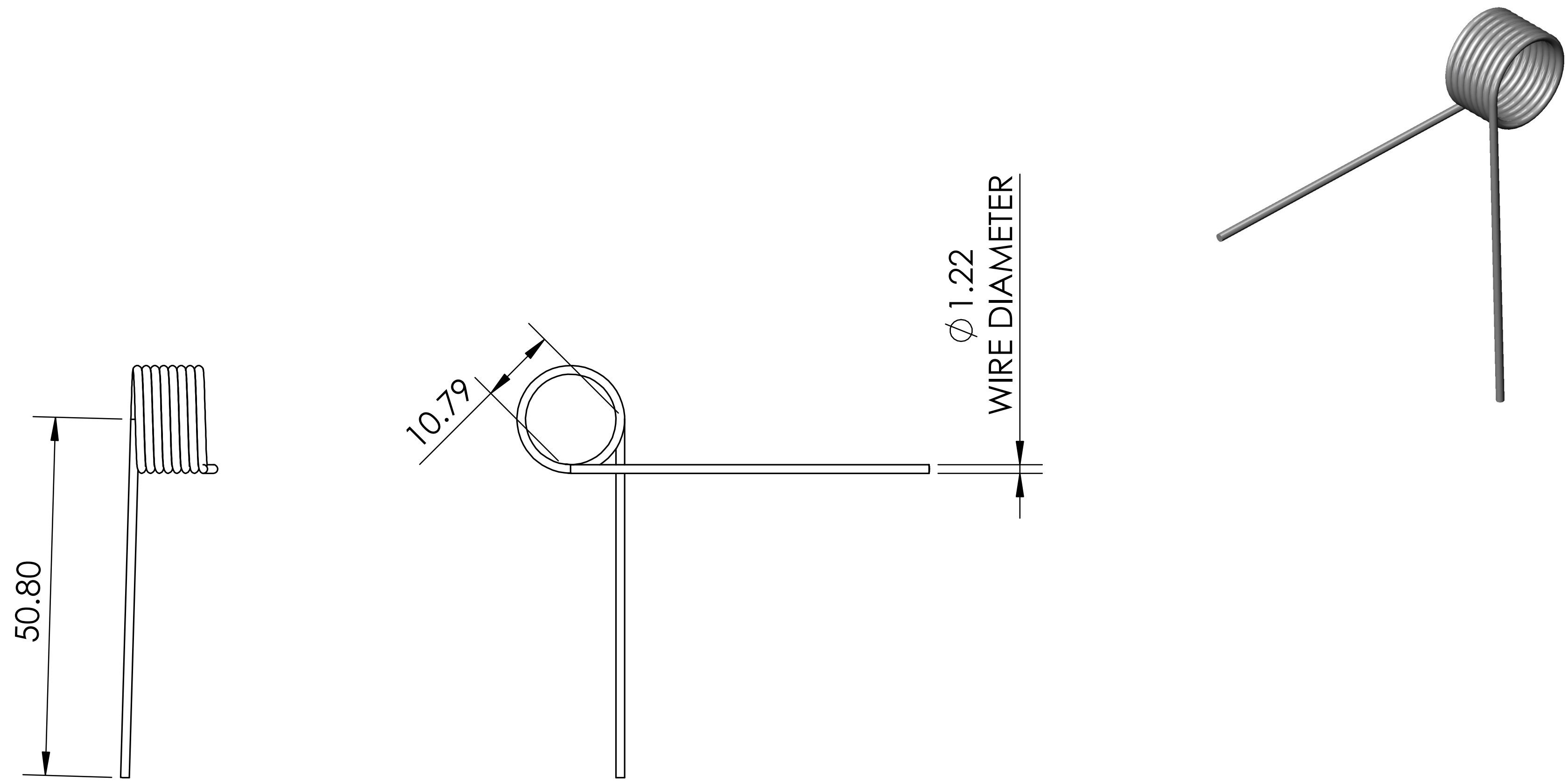
DESIGN ENGINEER: Bresney,Sean P

DESIGN APPROVAL:

MANUFACTURING APPROVAL:

PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\Door 2.0.SLDPRT

SHEET SCALE: 1:4 **SHEET NUMBER: 2 of 2**



1. DIMS IN MM

UF Herbert Wertheim College of Engineering *Department of Mechanical & Aerospace Engineering* UNIVERSITY *of* FLORIDA	***EML4502: MECHANICAL DESIGN 3***	**TEAM: GROUP 13.5**
		PART NAME: TORSION SPRING
		PART NUMBER: EML4501-OTS-16
		Rev:

STANDARD DIMENSIONAL TOLERANCES:

LINEAR [mm]		ANGULAR [degrees]	
X.X:	**±1**	**X:**	**±3**
X.XX:	**±.1**	**X.X:**	**±.5**
X.XXX:	**±.05**	**X.XX:**	**±.1**

MAXIMUM SURFACE FINISH: .004 in Ra

MATERIAL: Music-Wire Steel

FINISH:

DESIGN ENGINEER: Bresney,Sean P

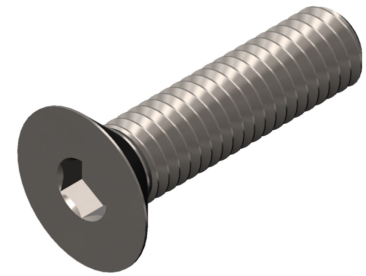
DESIGN APPROVAL:

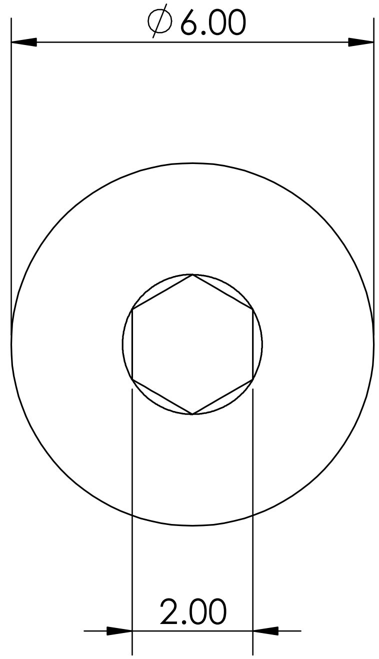
MANUFACTURING APPROVAL:

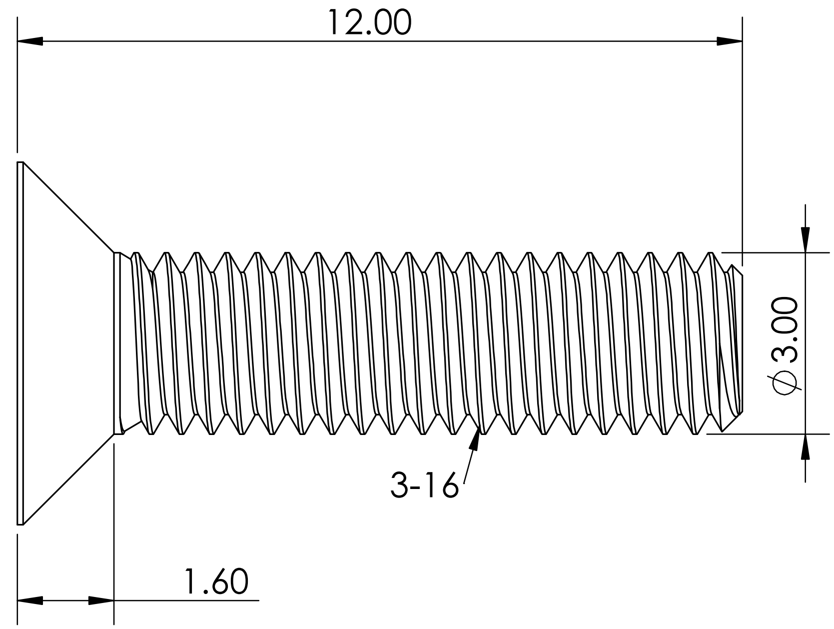
PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\9271K421_Torsion Spring.SLDPRT

SHEET SCALE: 1:1

SHEET NUMBER: 1 of 1







1. DIMS IN MM
2. BREAK ALL EDGES

UF Herbert Wertheim College of Engineering, Department of Mechanical & Aerospace Engineering, UNIVERSITY of FLORIDA	***EML4502: MECHANICAL DESIGN 3***	**TEAM:** **GROUP 13.5**	**PART NAME:** **316 Stainless Steel Hex Drive**
		PART NUMBER: EML4501-OTS-01	**Rev:**
		MATERIAL: 316 Stainless Steel	**FINISH:**
		DESIGN ENGINEER: Bresney,Sean P	
		DESIGN APPROVAL:	
		MANUFACTURING APPROVAL:	

STANDARD DIMENSIONAL TOLERANCES:

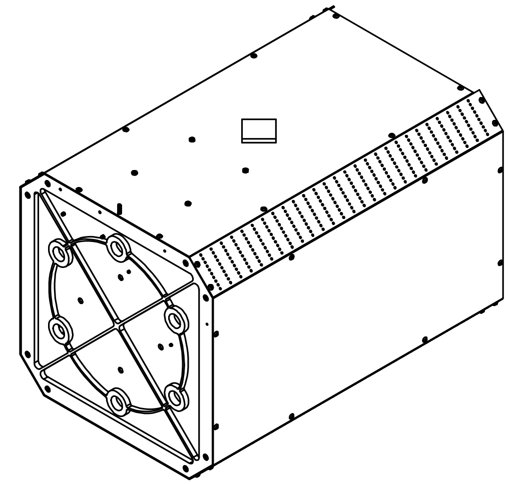
LINEAR [mm]		ANGULAR [degrees]	
X.X:	**±1**	**X:**	**±3**
X.XX:	**±.1**	**X.X:**	**±.5**
X.XXX:	**±.05**	**X.XX:**	**±.1**

MAXIMUM SURFACE FINISH: .004 in Ra

PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\93395A207_316 Stainless Steel Hex Drive Flat Head Screw.SLDPRT

SHEET SCALE: 4:1 **SHEET NUMBER: 1 of 1**

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	EML4501-01	Back Plate	1
2	EML4501-02	Rail Bar	8
3	EML4501-04	Rail Bar Angle Bracket	4
4	EML4501-05	Ventilation Grate	4
5	93395A207	316 Stainless Steel Hex Drive Flat Head Screw	16
6	94500A264	316 Stainless Steel Button Head Hex Drive	8
7	EML4501-06	Side Plates	3
8	90944A112	Titanium Button Head Hex Drive Screw	52
9	EML4501-07	Hinge Face Side Plates	1
10	69905K11	Sealed Linear Solenoid	1
11	D2F_01L2_A1	Omron Sub-Miniature Roller Limit Switch	1
12	91792A168	18-8 Stainless Steel Pan Head Slotted Screws	2
13	EML4501-OTS-11	NanoMind A3200 - Computer	1
14	EML4501-OTS-12	PULSAR-XANT Xband Patch	1
15	EML4501-12	Rail Foam	8
16	9238T723	Lightweight-Particle-Filtering Wire Cloth	4
17	98952A107	Aluminum Male-Female Threaded Hex Standoff	4
18	91290A101	Black-Oxide Alloy Steel Socket Head Screw	8
19	90592A080	Steel Hex Nut	4
20	93805A631	18-8 Stainless Steel Threaded Rod	1
21	EML4501-OTS-19	Ibeos EPS	1
22	EML4501-OTS-13	PULSAR-XTX Xband Transmitter	1



1. DIMS IN MM

UF Herbert Wertheim College of Engineering
Department of Mechanical & Aerospace Engineering
UNIVERSITY of FLORIDA

EML4502: MECHANICAL DESIGN 3

STANDARD DIMENSIONAL TOLERANCES:

LINEAR [mm]		ANGULAR [degrees]	
X.X:	$\pm$**1**	**X:**	$\pm$**3**
X.XX:	$\pm$**.1**	**X.X:**	$\pm$**.5**
X.XXX:	$\pm$**.05**	**X.XX:**	$\pm$**.1**

MAXIMUM SURFACE FINISH: .004 in Ra

TEAM: Group 13.5

PART NAME: Enclosure

PART NUMBER: EML4501-A-03

Rev:

MATERIAL:

FINISH:

DESIGN ENGINEER:

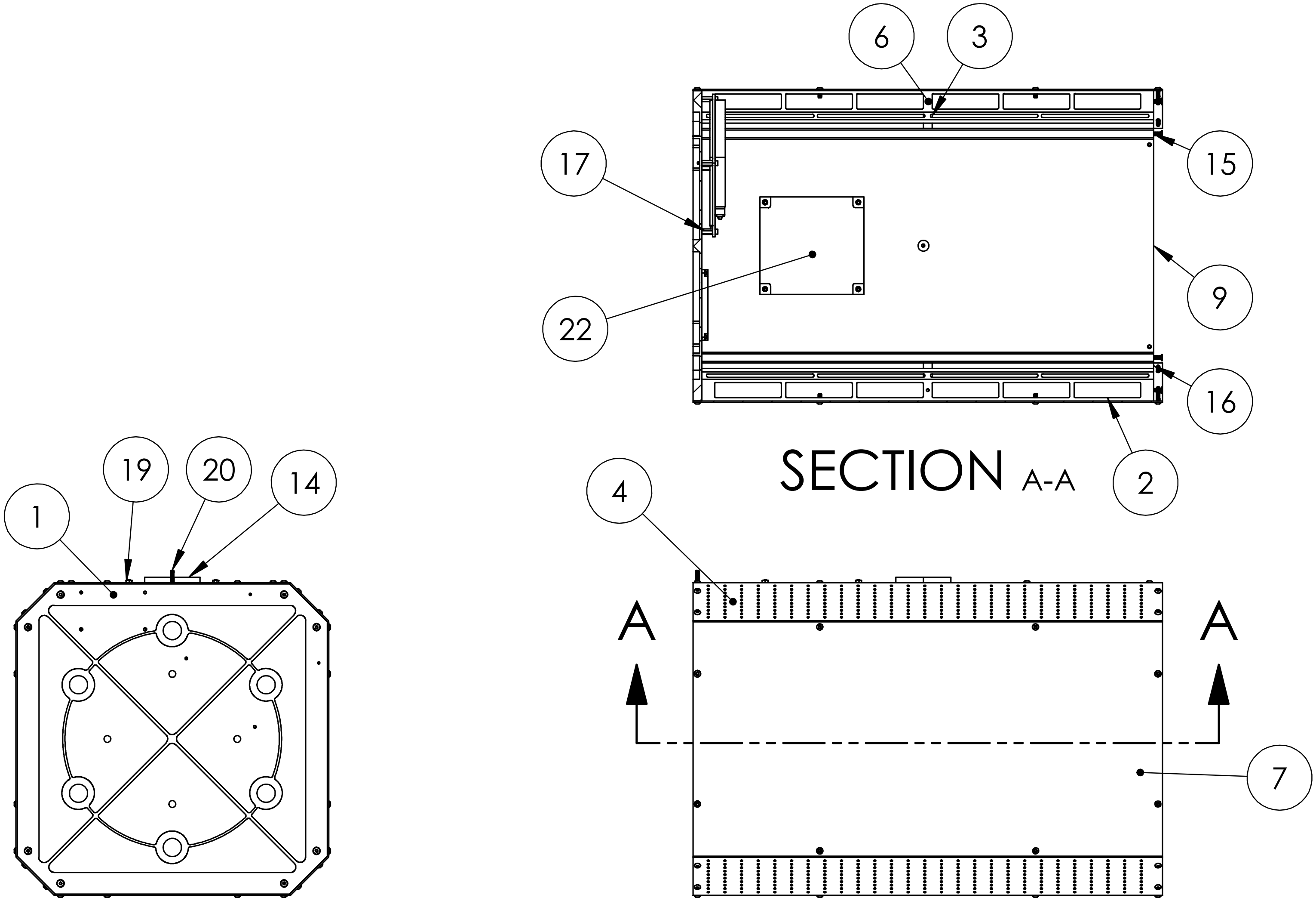
DESIGN APPROVAL:

MANUFACTURING APPROVAL:

PART LOCATION:

SHEET SCALE: 1:8

SHEET NUMBER: 1 of 3



UF Herbert Wertheim College of Engineering Department of Mechanical & Aerospace Engineering UNIVERSITY of FLORIDA	**EML4502: MECHANICAL DESIGN 3**	**TEAM:** GROUP 13.5
		PART NAME: Enclosure
		PART NUMBER: EML4501-A-03
		Rev:
		MATERIAL:
		FINISH:
STANDARD DIMENSIONAL TOLERANCES:		**DESIGN ENGINEER:**
		DESIGN APPROVAL:
		MANUFACTURING APPROVAL:

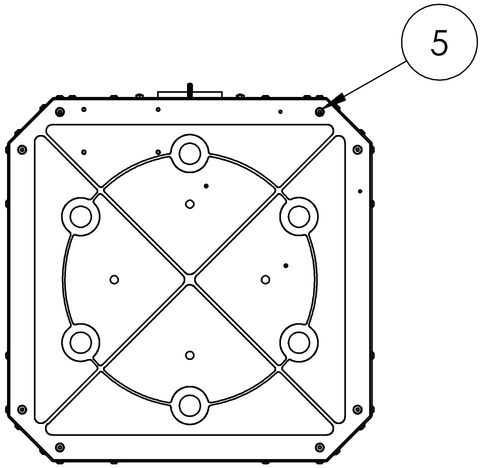
STANDARD DIMENSIONAL TOLERANCES:

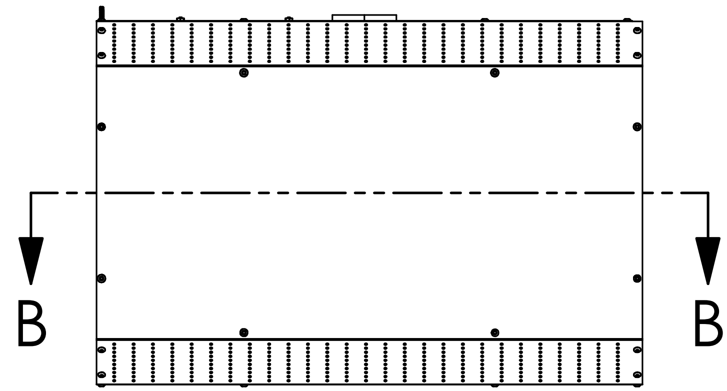
LINEAR [mm]		ANGULAR [degrees]	
X.X:	±**1**	**X:**	±**3**
X.XX:	±**.1**	**X.X:**	±**.5**
X.XXX:	±**.05**	**X.XX:**	±**.1**

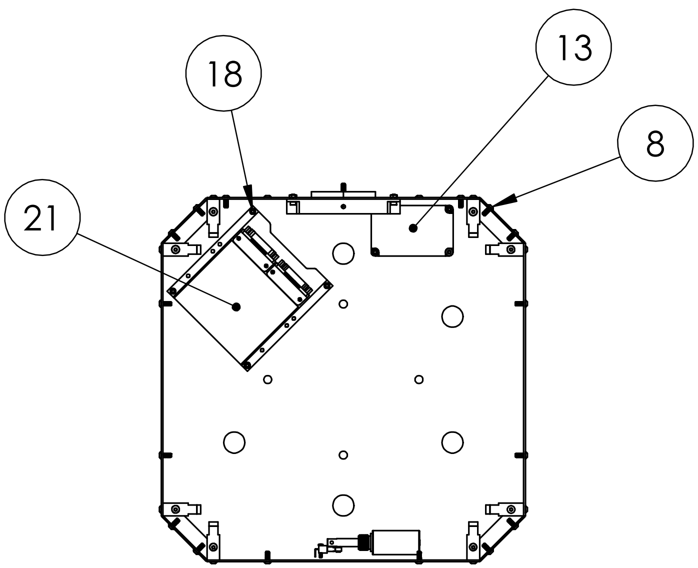
MAXIMUM SURFACE FINISH: .004 in Ra

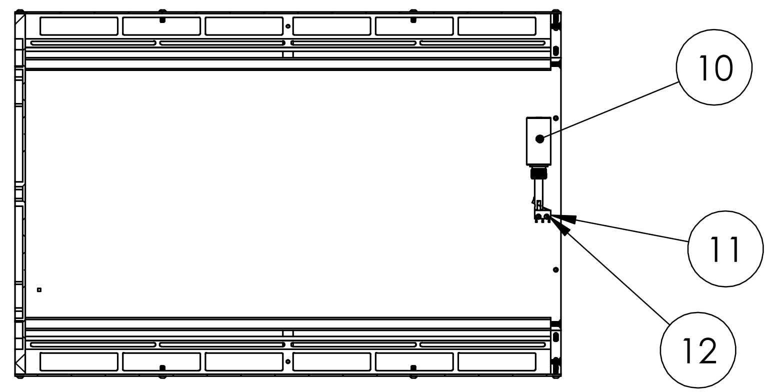
PART LOCATION:

SHEET SCALE: 1:6









SECTION B-B

UF Herbert Wertheim College of Engineering
Department of Mechanical & Aerospace Engineering
UNIVERSITY of FLORIDA

EML4502: MECHANICAL DESIGN 3

TEAM: **GROUP 13.5**

PART NAME: **Enclosure**

PART NUMBER: EML4501-A-03 **Rev:**

MATERIAL: **FINISH:**

DESIGN ENGINEER:

DESIGN APPROVAL:

MANUFACTURING APPROVAL:

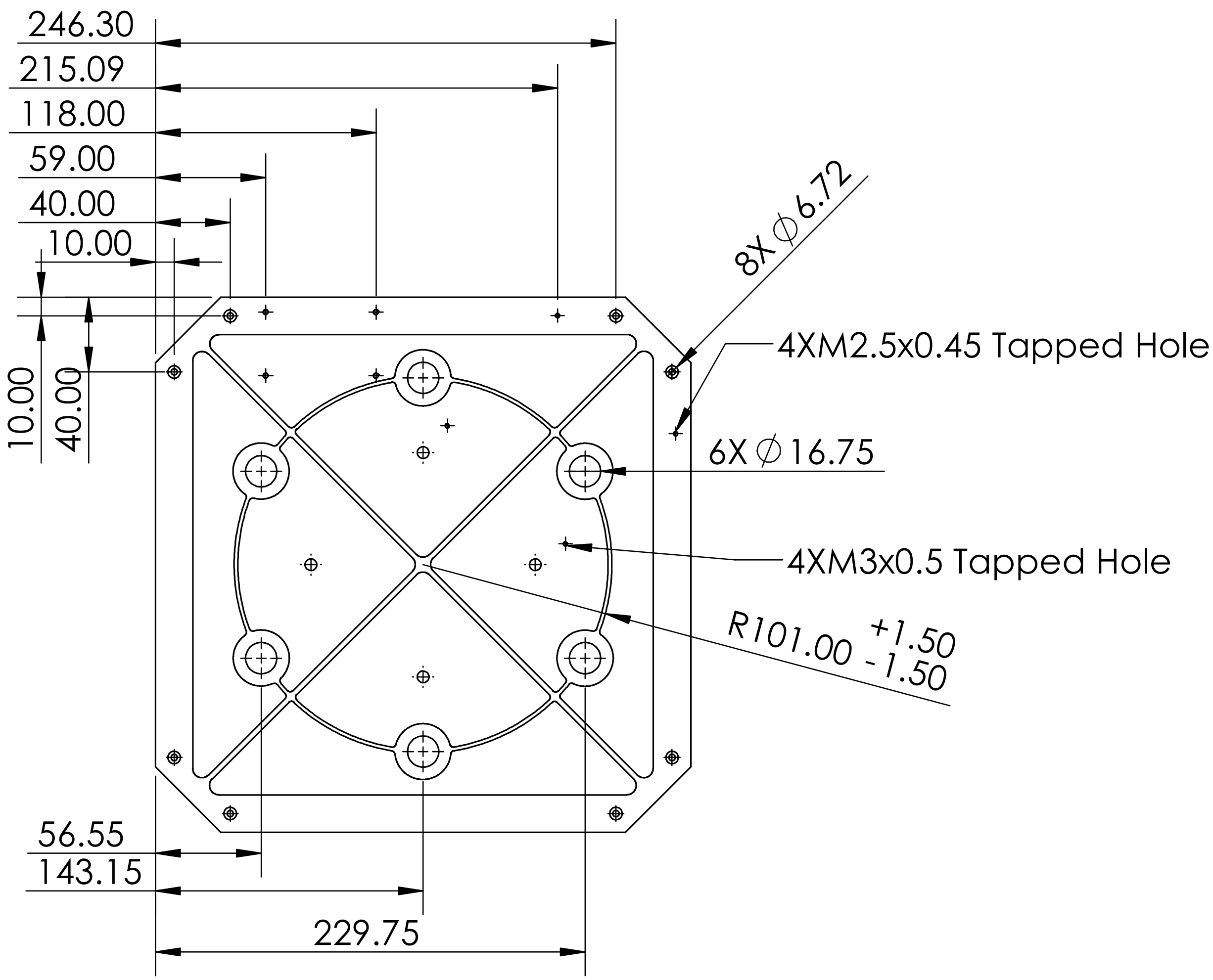
STANDARD DIMENSIONAL TOLERANCES:

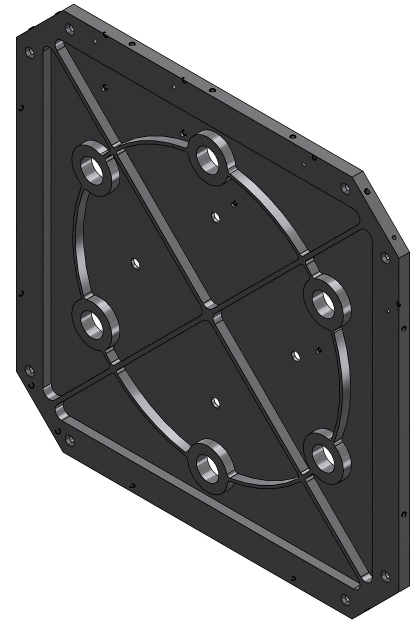
LINEAR [mm]		ANGULAR [degrees]	
X.X:	±**1**	**X:**	±**3**
X.XX:	±**.1**	**X.X:**	±**.5**
X.XXX:	±**.05**	**X.XX:**	±**.1**

MAXIMUM SURFACE FINISH: .004 in Ra

PART LOCATION:

SHEET SCALE: 1:6 **SHEET NUMBER: 3 of 3**





1. DIMS IN MM
2. BREAK ALL EDGES

UF Herbert Wertheim College of Engineering
Department of Mechanical & Aerospace Engineering
UNIVERSITY of FLORIDA

EML4502: MECHANICAL DESIGN 3

TEAM: **GROUP 13.5**

PART NAME: **Backplate**

PART NUMBER: EML4501-01 **Rev:**

MATERIAL: Aluminium 6061 **FINISH:**

DESIGN ENGINEER: Bresney,Sean P

DESIGN APPROVAL:

MANUFACTURING APPROVAL:

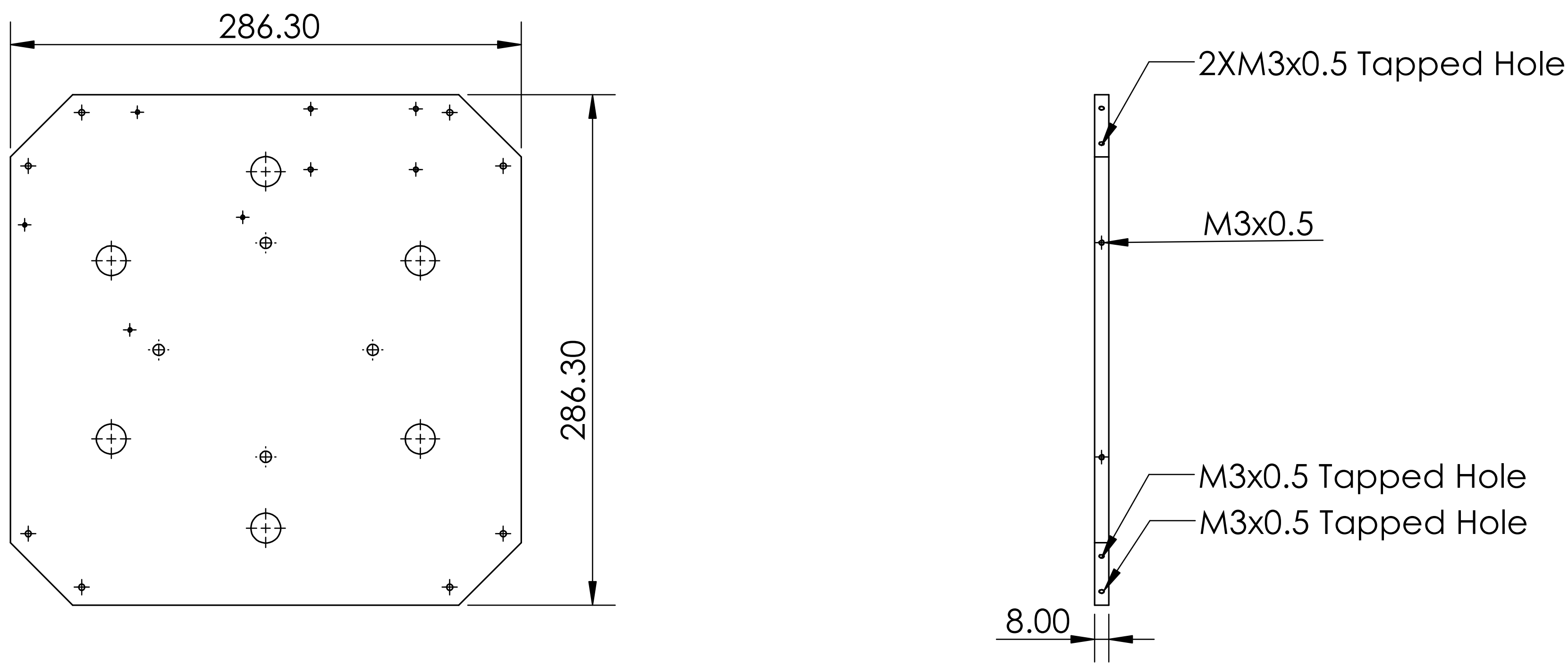
STANDARD DIMENSIONAL TOLERANCES:

LINEAR [mm]		ANGULAR [degrees]	
X.X:	±**1**	**X:**	±**3**
X.XX:	±**.1**	**X.X:**	±**.5**
X.XXX:	±**.05**	**X.XX:**	±**.1**

MAXIMUM SURFACE FINISH: .004 in Ra

PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\Backplate.SLDPRT

SHEET SCALE: 1:4 **SHEET NUMBER: 1 of 2**



UF Herbert Wertheim College of Engineering
Department of Mechanical & Aerospace Engineering
UNIVERSITY of FLORIDA

EML4502: MECHANICAL DESIGN 3

TEAM: **GROUP 13.5**

PART NAME: **Backplate**

PART NUMBER: EML4502-22-11-26010 **Rev:**

MATERIAL: Aluminium 6061 **FINISH:**

DESIGN ENGINEER: Bresney,Sean P

DESIGN APPROVAL:

MANUFACTURING APPROVAL:

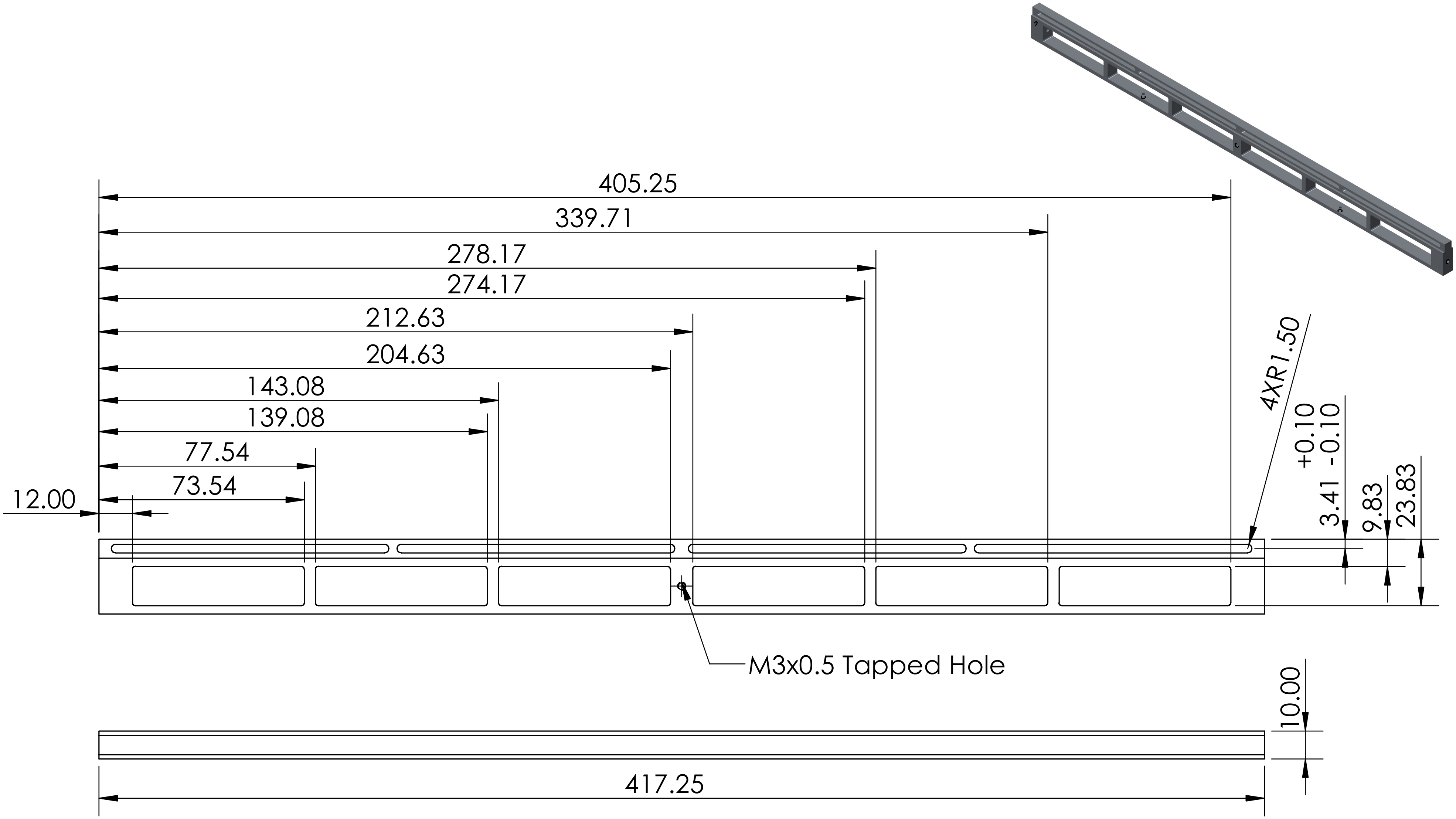
STANDARD DIMENSIONAL TOLERANCES:

LINEAR [mm]		ANGULAR [degrees]	
X.X:	±**1**	**X:**	±**3**
X.XX:	±**.1**	**X.X:**	±**.5**
X.XXX:	±**.05**	**X.XX:**	±**.1**

MAXIMUM SURFACE FINISH: .004 in Ra

PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\Backplate.SLDPRT

SHEET SCALE: 1:4 **SHEET NUMBER: 2 of 2**

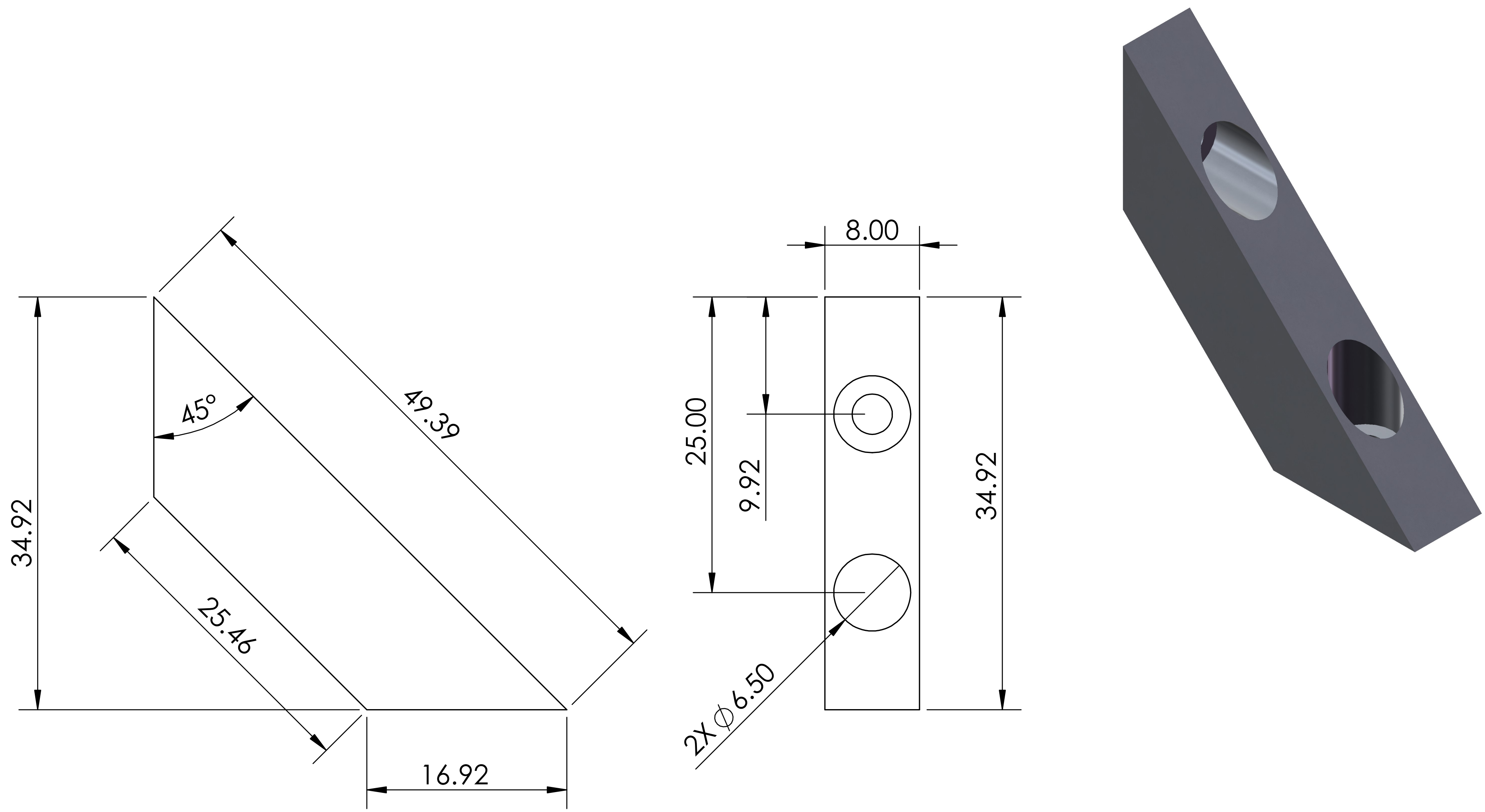


1. DIMS IN MM
2. BREAK ALL EDGES

UF Herbert Wertheim College of Engineering Department of Mechanical & Aerospace Engineering UNIVERSITY of FLORIDA	***EML4502: MECHANICAL DESIGN 3***	**TEAM:** **GROUP 13.5**	**PART NAME:** **Railbar**
		PART NUMBER: EML4501-02	**Rev:**
STANDARD DIMENSIONAL TOLERANCES: LINEAR [mm] ANGULAR [degrees] **X.X:** ±**1** **X:** ±**3** **X.XX:** ±**.1** **X.X:** ±**.5** **X.XXX:** ±**.05** **X.XX:** ±**.1** MAXIMUM SURFACE FINISH: .004 in Ra		**MATERIAL: Aluminium 6061**	**FINISH:**
		DESIGN ENGINEER: Bresney,Sean P	
		DESIGN APPROVAL:	
		MANUFACTURING APPROVAL:	

PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\Railbar.SLDPRT

SHEET SCALE: 1:4 **SHEET NUMBER: 1 of 1**



1. DIMS IN MM
2. BREAK ALL EDGES

UF Herbert Wertheim College of Engineering
Department of Mechanical & Aerospace Engineering
UNIVERSITY of FLORIDA

EML4502: MECHANICAL DESIGN 3

TEAM: **GROUP 13.5**

PART NAME: **RAILBAR ANGLE BRACKET**

PART NUMBER: EML4501-04 **Rev:**

MATERIAL: Aluminium 6061 **FINISH: AS MACHINED**

DESIGN ENGINEER: Sun, Tessa

DESIGN APPROVAL:

MANUFACTURING APPROVAL:

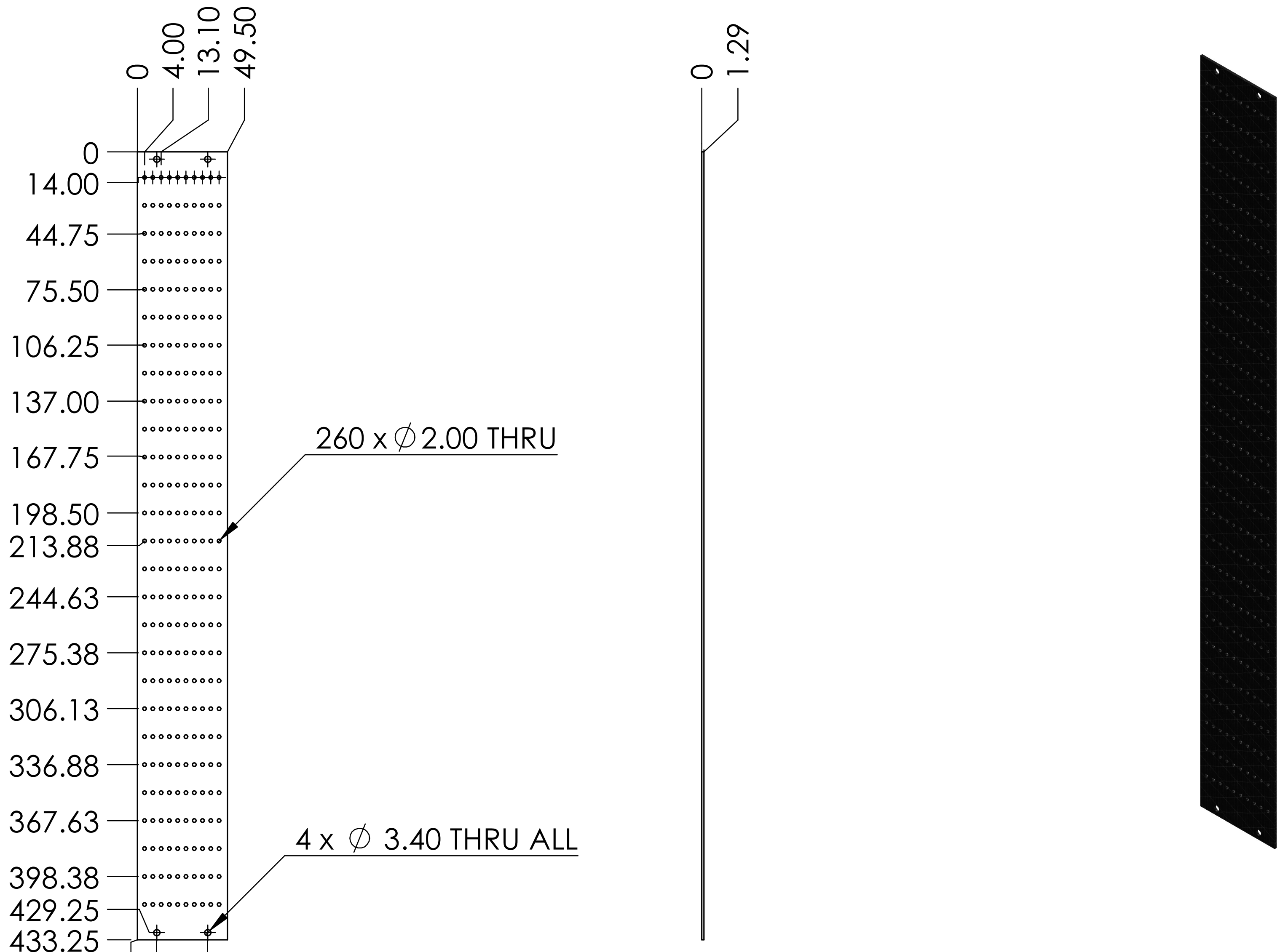
STANDARD DIMENSIONAL TOLERANCES:

LINEAR [mm]		ANGULAR [degrees]	
X.X:	**±1**	**X:**	**±3**
X.XX:	**±.1**	**X.X:**	**±.5**
X.XXX:	**±.05**	**X.XX:**	**±.1**

MAXIMUM SURFACE FINISH: .004 in Ra

PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\railbar angle bracket.SLDPRT

SHEET SCALE: 2:1 **SHEET NUMBER: 1 of 1**

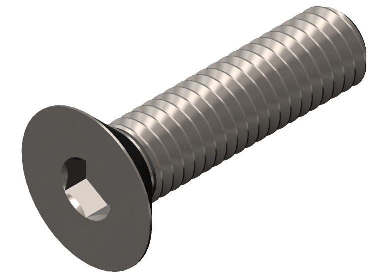


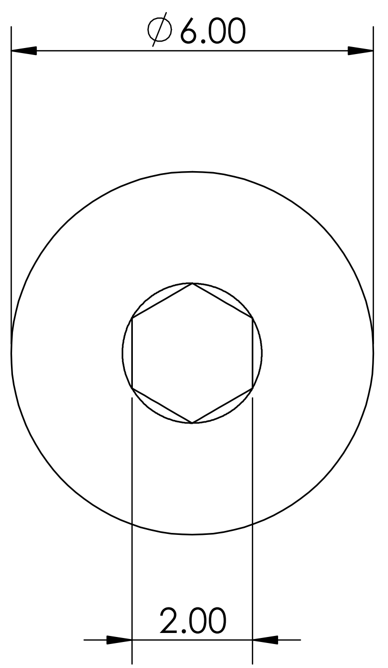
1. DIMS IN MM

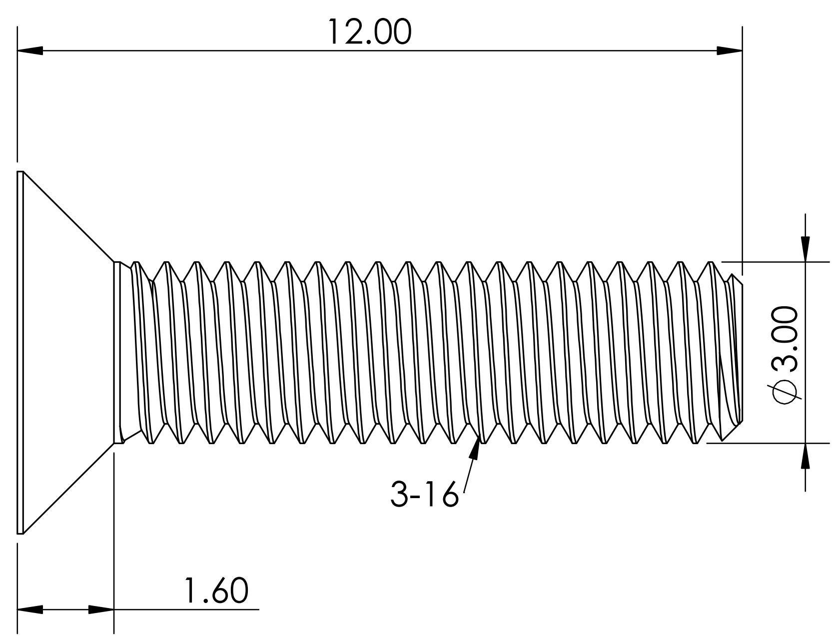
UF Herbert Wertheim College of Engineering Department of Mechanical & Aerospace Engineering UNIVERSITY of FLORIDA ***EML4502: MECHANICAL DESIGN 3***	**TEAM: Group 13.5**	**PART NAME: VENTILATION GRATE**
STANDARD DIMENSIONAL TOLERANCES: LINEAR [mm] ANGULAR [degrees] **X.X: ±1** **X: ±3** **X.XX: ±.1** **X.X: ±.5** **X.XXX: ±.05** **X.XX: ±.1** MAXIMUM SURFACE FINISH: .004 in Ra	**PART NUMBER: EML4501-05**	**Rev:**
	MATERIAL: **Carbon Fiber Reinforced Composite**	**FINISH:**
	DESIGN ENGINEER: Crouch,Christopher R	
	DESIGN APPROVAL: Sun, Tessa	
	MANUFACTURING APPROVAL: Bresney, Sean	

PART LOCATION: **C:\EML4501\PDR CAD\Group 13.5\VentilationGrate.SLDPRT**

SHEET SCALE: 1:4 **SHEET NUMBER: 1 of 1**







1. DIMS IN MM
2. BREAK ALL EDGES

UF Herbert Wertheim College of Engineering
Department of Mechanical & Aerospace Engineering
UNIVERSITY *of* FLORIDA

EML4502: MECHANICAL DESIGN 3

TEAM: GROUP 13.5

PART NAME: 316 Stainless Steel Hex Drive

PART NUMBER: EML4501-OTS-01 **Rev:**

MATERIAL: 316 Stainless Steel **FINISH:**

DESIGN ENGINEER: Bresney,Sean P

DESIGN APPROVAL:

MANUFACTURING APPROVAL:

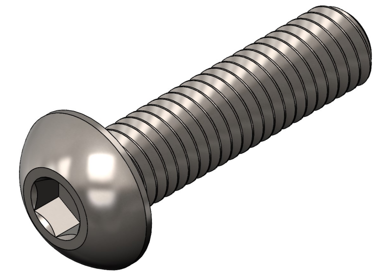
STANDARD DIMENSIONAL TOLERANCES:

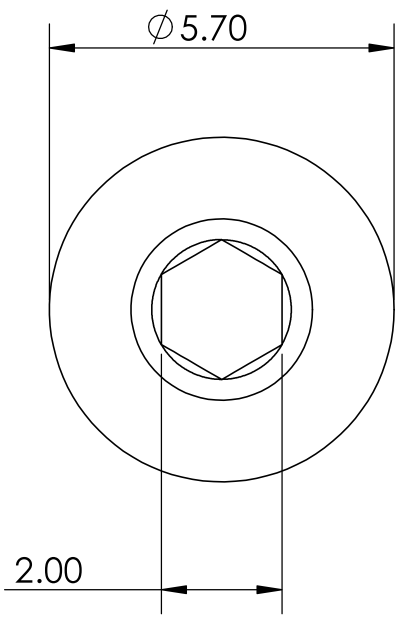
LINEAR [mm]		ANGULAR [degrees]	
X.X:	±**1**	**X:**	±**3**
X.XX:	±**.1**	**X.X:**	±**.5**
X.XXX:	±**.05**	**X.XX:**	±**.1**

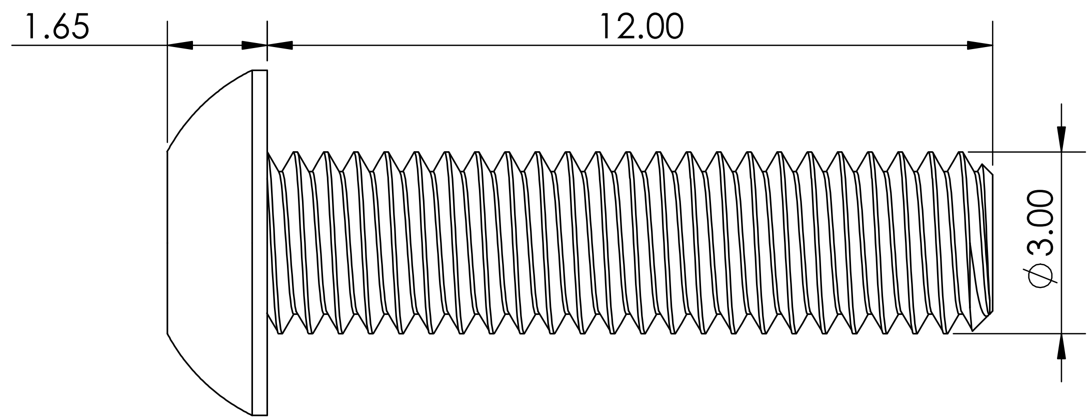
MAXIMUM SURFACE FINISH: .004 in Ra

PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\93395A207_316 Stainless Steel Hex Drive Flat Head Screw.SLDPRT

SHEET SCALE: 4:1 **SHEET NUMBER:** 1 of 1





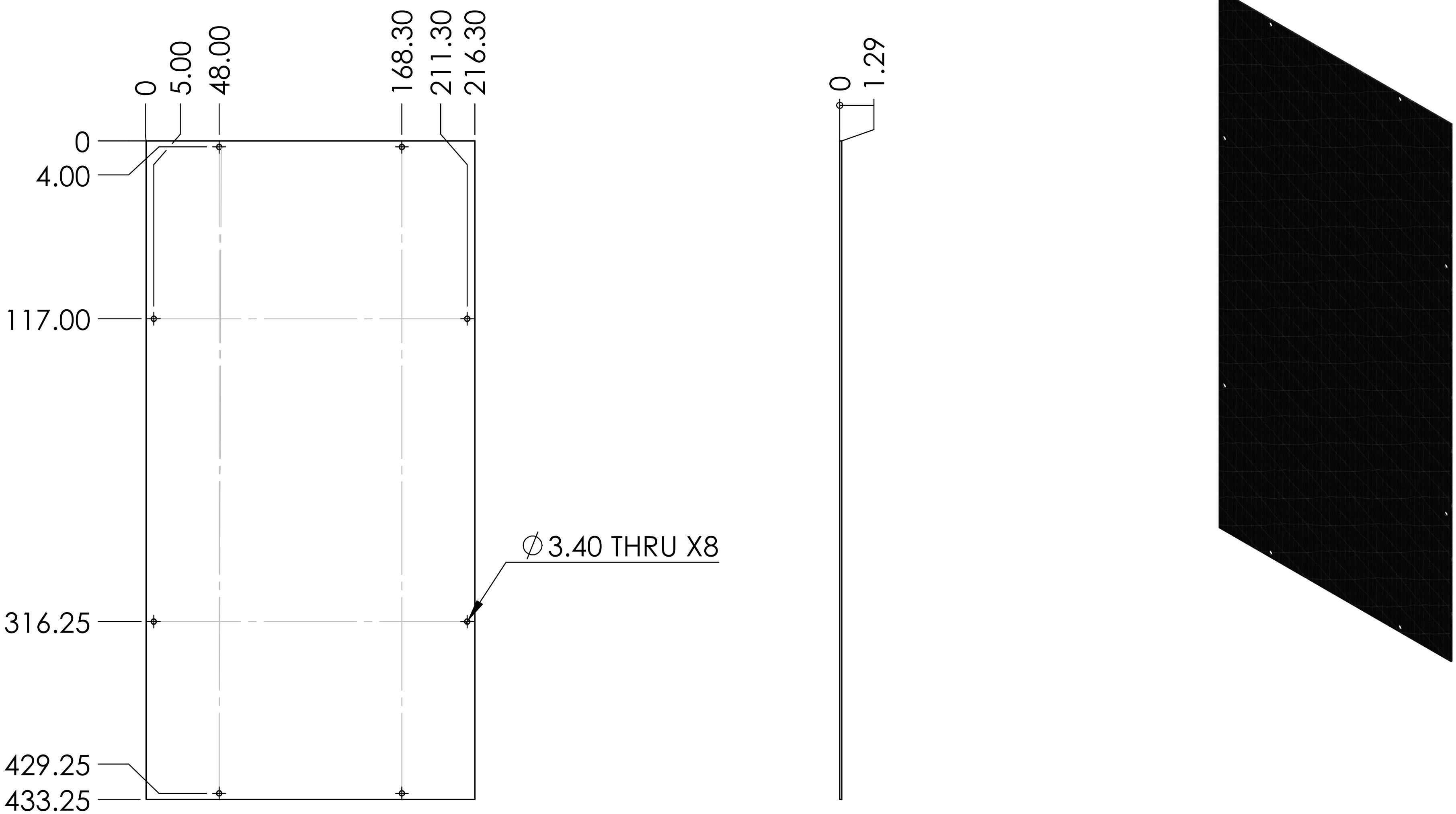


1. DIMS IN MM
2. BREAK ALL EDGES

UF Herbert Wertheim College of Engineering, Department of Mechanical & Aerospace Engineering, UNIVERSITY of FLORIDA	***EML4502: MECHANICAL DESIGN 3***	**TEAM:** GROUP 13.5	**PART NAME:** 316 Stainless Steel Button Head Hex
STANDARD DIMENSIONAL TOLERANCES:		**PART NUMBER:** EML4501-OTS-02	**Rev:**
LINEAR [mm]	ANGULAR [degrees]	**MATERIAL:** 316 Stainless Steel	**FINISH:**
X.X: ±1	**X:** ±3	**DESIGN ENGINEER:** Bresney,Sean P	
X.XX: ±.1	**X.X:** ±.5	**DESIGN APPROVAL:**	
X.XXX: ±.05	**X.XX:** ±.1	**MANUFACTURING APPROVAL:**	
MAXIMUM SURFACE FINISH: .004 in Ra			

PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\94500A264_316 Stainless Steel Button Head Hex Drive Screws.SLDPRT

SHEET SCALE: 4:1 **SHEET NUMBER:** 1 of 1



1. DIMS IN MM
2. BREAK ALL EDGES

UF Herbert Wertheim College of Engineering
Department of Mechanical & Aerospace Engineering
UNIVERSITY of FLORIDA

EML4502: MECHANICAL DESIGN 3

TEAM: Group 13.5

PART NAME: SIDE PLATES

PART NUMBER: EML4501-06

Rev:

MATERIAL: Carbon Fiber Reinforced Composite

FINISH:

STANDARD DIMENSIONAL TOLERANCES:

LINEAR [mm]		ANGULAR [degrees]	
X.X:	**±1**	**X:**	**±3**
X.XX:	**±.1**	**X.X:**	**±.5**
X.XXX:	**±.05**	**X.XX:**	**±.1**

MAXIMUM SURFACE FINISH: .004 in Ra

DESIGN ENGINEER: Bresney,Sean P

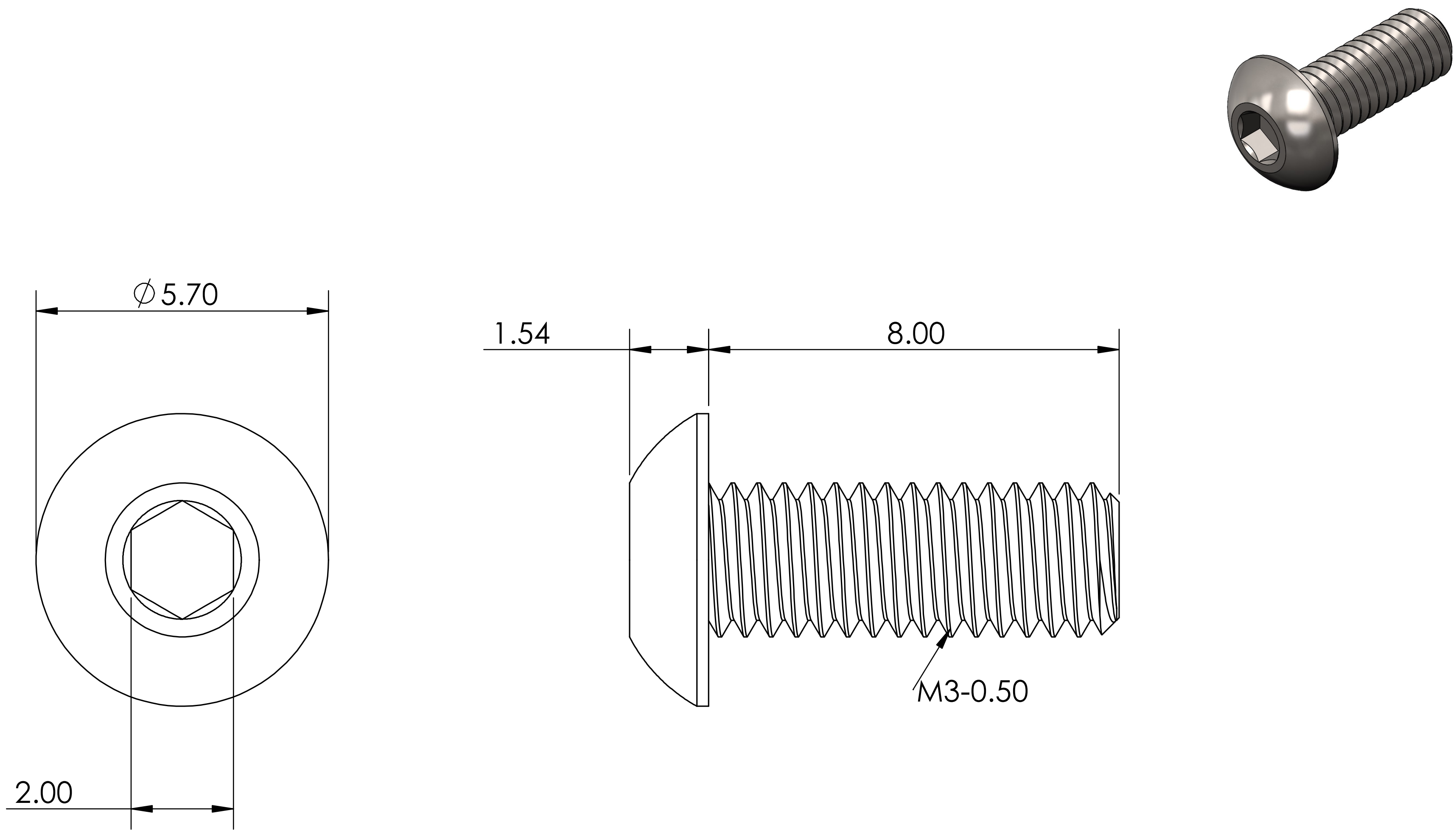
DESIGN APPROVAL: Sun, Tessa

MANUFACTURING APPROVAL: Bresney,Sean P

PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\SidePlates.SLDPRT

SHEET SCALE: 1:4

SHEET NUMBER: 1 of 1



1. DIMS IN MM
2. BREAK ALL EDGES

UF Herbert Wertheim College of Engineering
Department of Mechanical & Aerospace Engineering
UNIVERSITY of FLORIDA

EML4502: MECHANICAL DESIGN 3

TEAM: GROUP 13.5

PART NAME: Titanium Button Head Hex

PART NUMBER: EML4501-OTS-05 **Rev:**

MATERIAL: Grade 5 Titanium **FINISH:**

DESIGN ENGINEER: Bresney,Sean P

DESIGN APPROVAL:

MANUFACTURING APPROVAL:

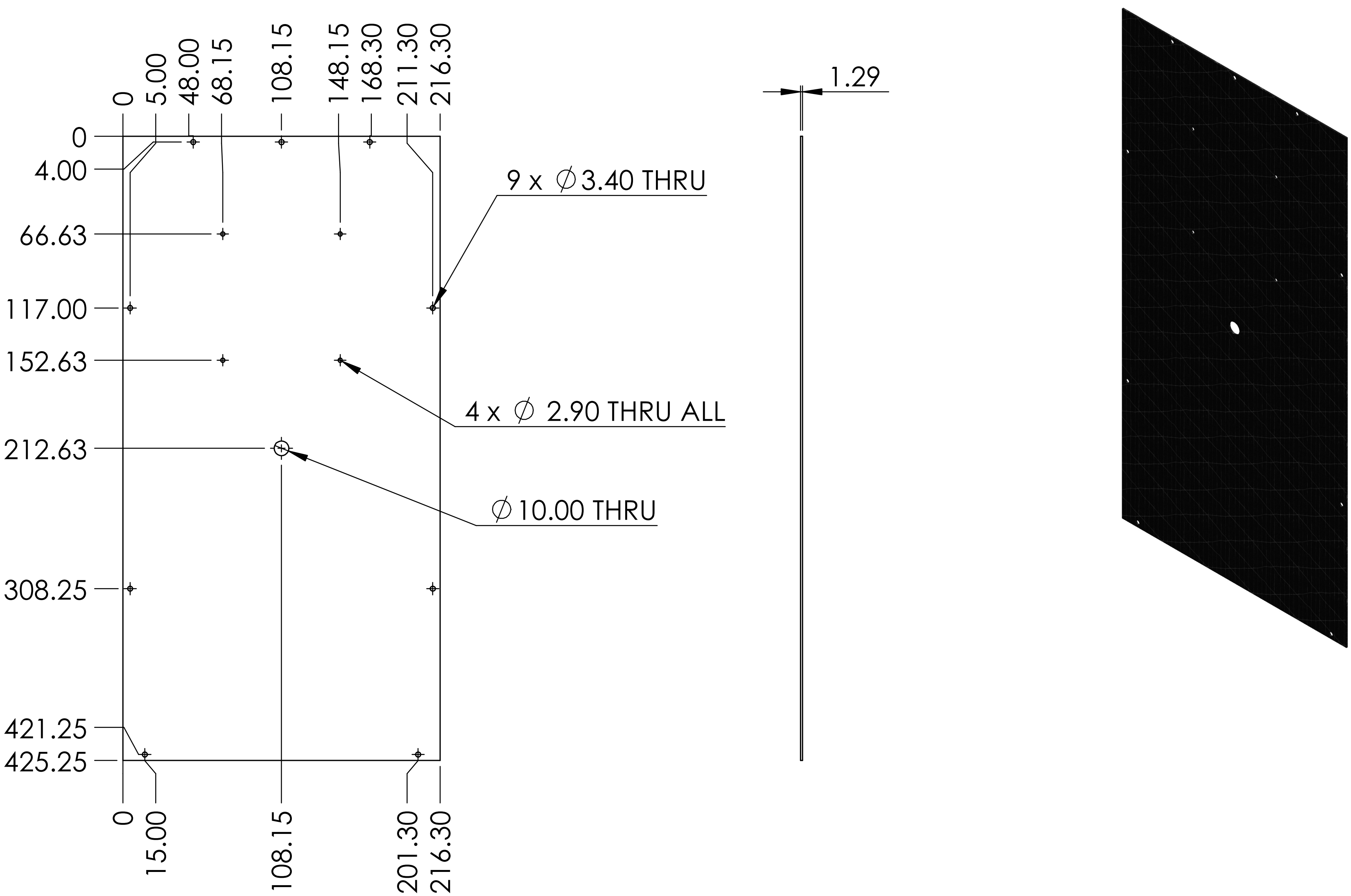
STANDARD DIMENSIONAL TOLERANCES:

LINEAR [mm]		ANGULAR [degrees]	
X.X:	**±1**	**X:**	**±3**
X.XX:	**±.1**	**X.X:**	**±.5**
X.XXX:	**±.05**	**X.XX:**	**±.1**

MAXIMUM SURFACE FINISH: .004 in Ra

PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\90944A112_Titanium Button Head Hex Drive Screw.SLDPRT

SHEET SCALE: 4:1 **SHEET NUMBER:** 1 of 1



1. DIMS IN MM
2. BREAK ALL EDGES

UF Herbert Wertheim College of Engineering
Department of Mechanical & Aerospace Engineering
UNIVERSITY of FLORIDA

EML4502: MECHANICAL DESIGN 3

TEAM: Group 13.5

PART NAME: Hinge Face Side Plates

PART NUMBER: EML4501-07

Rev:

MATERIAL: Carbon Fiber Reinforced Composite

FINISH:

STANDARD DIMENSIONAL TOLERANCES:

LINEAR [mm]		ANGULAR [degrees]	
X.X:	±**1**	**X:**	±**3**
X.XX:	±**.1**	**X.X:**	±**.5**
X.XXX:	±**.05**	**X.XX:**	±**.1**

MAXIMUM SURFACE FINISH: .004 in Ra

DESIGN ENGINEER: Bresney,Sean P

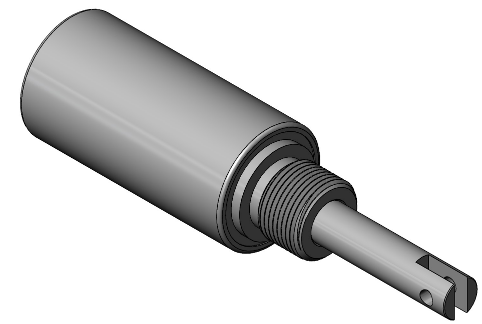
DESIGN APPROVAL: Sun, Tessa

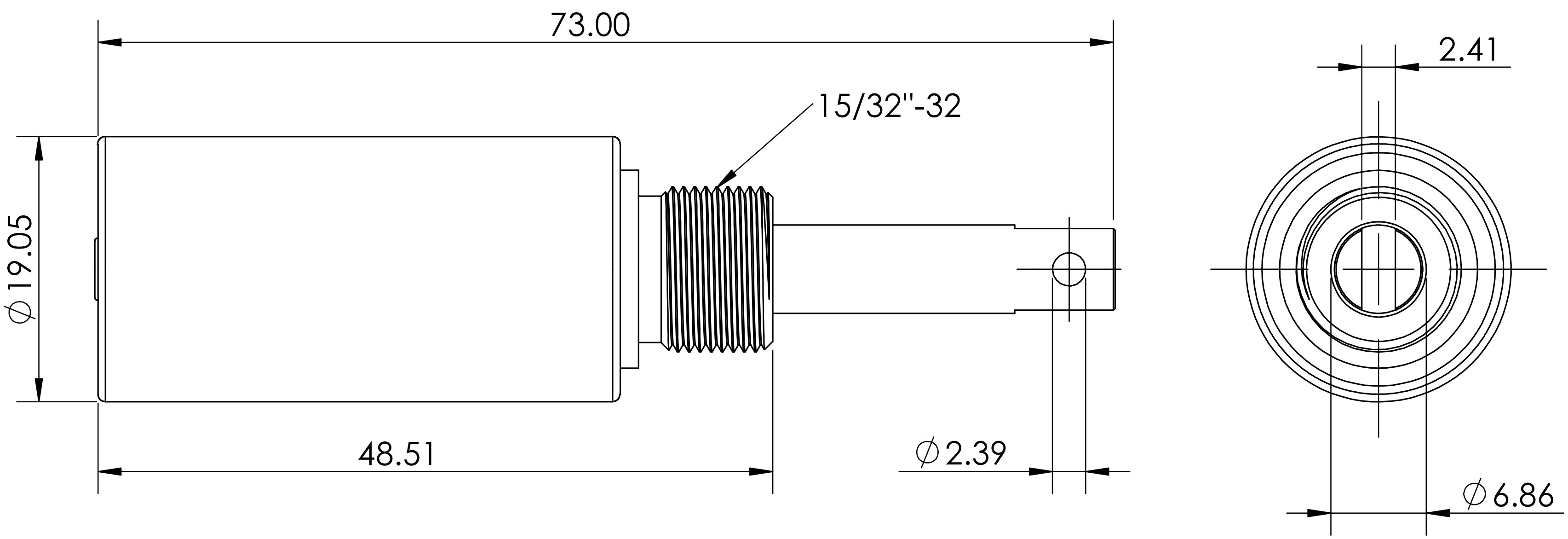
MANUFACTURING APPROVAL: Tipnis, Varun

PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\hinge face SidePlates.SLDPRT

SHEET SCALE: 1:4

SHEET NUMBER: 1 of 1





1. DIMS IN MM

UF Herbert Wertheim College of Engineering
Department of Mechanical & Aerospace Engineering
UNIVERSITY of FLORIDA

EML4502: MECHANICAL DESIGN 3

TEAM: GROUP 13.5

PART NAME: Sealed Linear Solenoid

PART NUMBER: EML4501-OTS-08

Rev:

STANDARD DIMENSIONAL TOLERANCES:

LINEAR [mm]		ANGULAR [degrees]	
X.X:	±**1**	**X:**	±**3**
X.XX:	±**.1**	**X.X:**	±**.5**
X.XXX:	±**.05**	**X.XX:**	±**.1**

MAXIMUM SURFACE FINISH: .004 in Ra

MATERIAL:

FINISH:

DESIGN ENGINEER: Bresney,Sean P

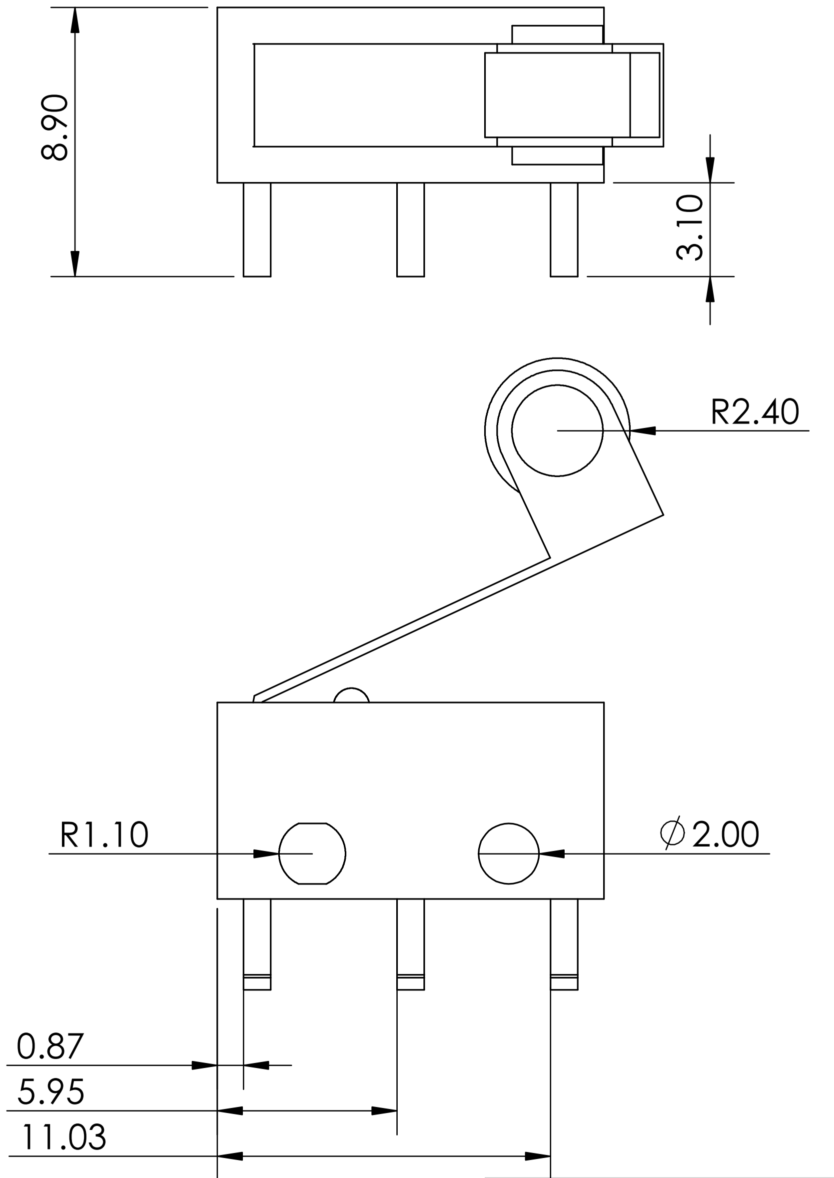
DESIGN APPROVAL:

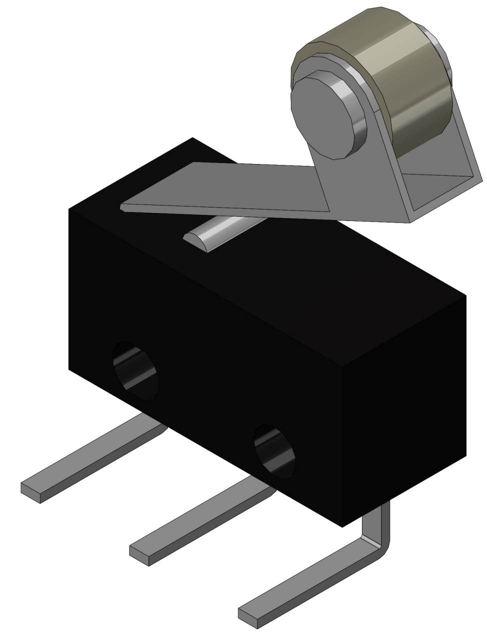
MANUFACTURING APPROVAL:

PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\69905K11_Sealed Linear Solenoid.SLDPRT

SHEET SCALE: 1:1

SHEET NUMBER: 1 of 1





1. DIMS IN MM
2. BREAK ALL EDGES

UF Herbert Wertheim College of Engineering
Department of Mechanical & Aerospace Engineering
UNIVERSITY of FLORIDA

EML4502: MECHANICAL DESIGN 3

TEAM: GROUP 13.5	**PART NAME:** Omron Sub-Miniature Roller Limit Switch
PART NUMBER: EML4501-OTS-09	**Rev:**
MATERIAL:	**FINISH:**
DESIGN ENGINEER:	
DESIGN APPROVAL:	
MANUFACTURING APPROVAL:	

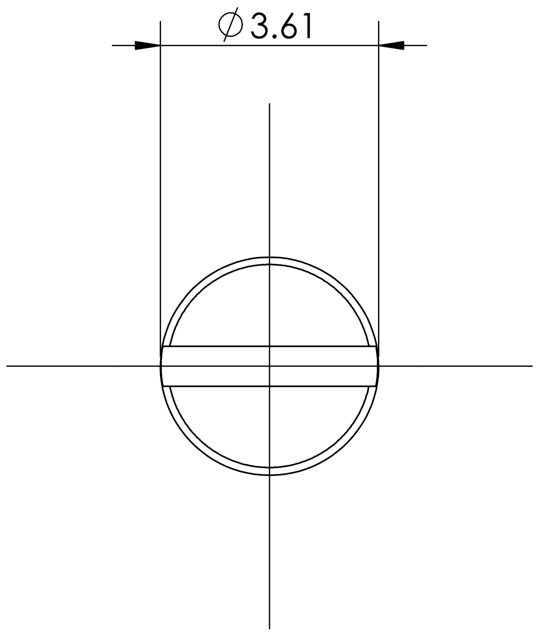
STANDARD DIMENSIONAL TOLERANCES:

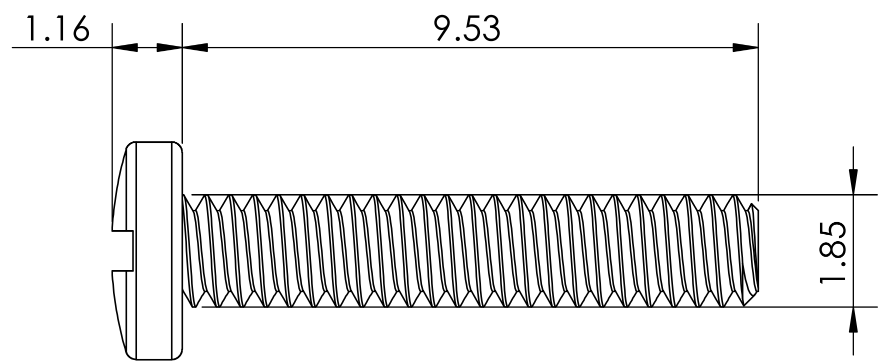
LINEAR [mm]		ANGULAR [degrees]	
X.X:	±**1**	**X:**	±**3**
X.XX:	±**.1**	**X.X:**	±**.5**
X.XXX:	±**.05**	**X.XX:**	±**.1**

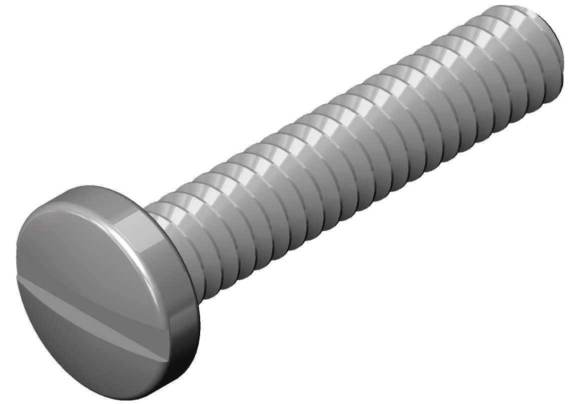
MAXIMUM SURFACE FINISH: .004 in Ra

PART LOCATION:

SHEET SCALE: 2:1 **SHEET NUMBER: 1 of 1**







1. DIMS IN MM

UF Herbert Wertheim College of Engineering
Department of Mechanical & Aerospace Engineering
UNIVERSITY *of* FLORIDA

EML4502: MECHANICAL DESIGN 3

STANDARD DIMENSIONAL TOLERANCES:

LINEAR [mm]		ANGULAR [degrees]	
X.X:	**±1**	**X:**	**±3**
X.XX:	**±.1**	**X.X:**	**±.5**
X.XXX:	**±.05**	**X.XX:**	**±.1**

MAXIMUM SURFACE FINISH: .004 in Ra

TEAM: Group 13.5

PART NAME: 18-8 Stainless Steel Pan Head

PART NUMBER: EML-OTS-10 **Rev:**

MATERIAL: 18-8 Stainless Steel **FINISH:**

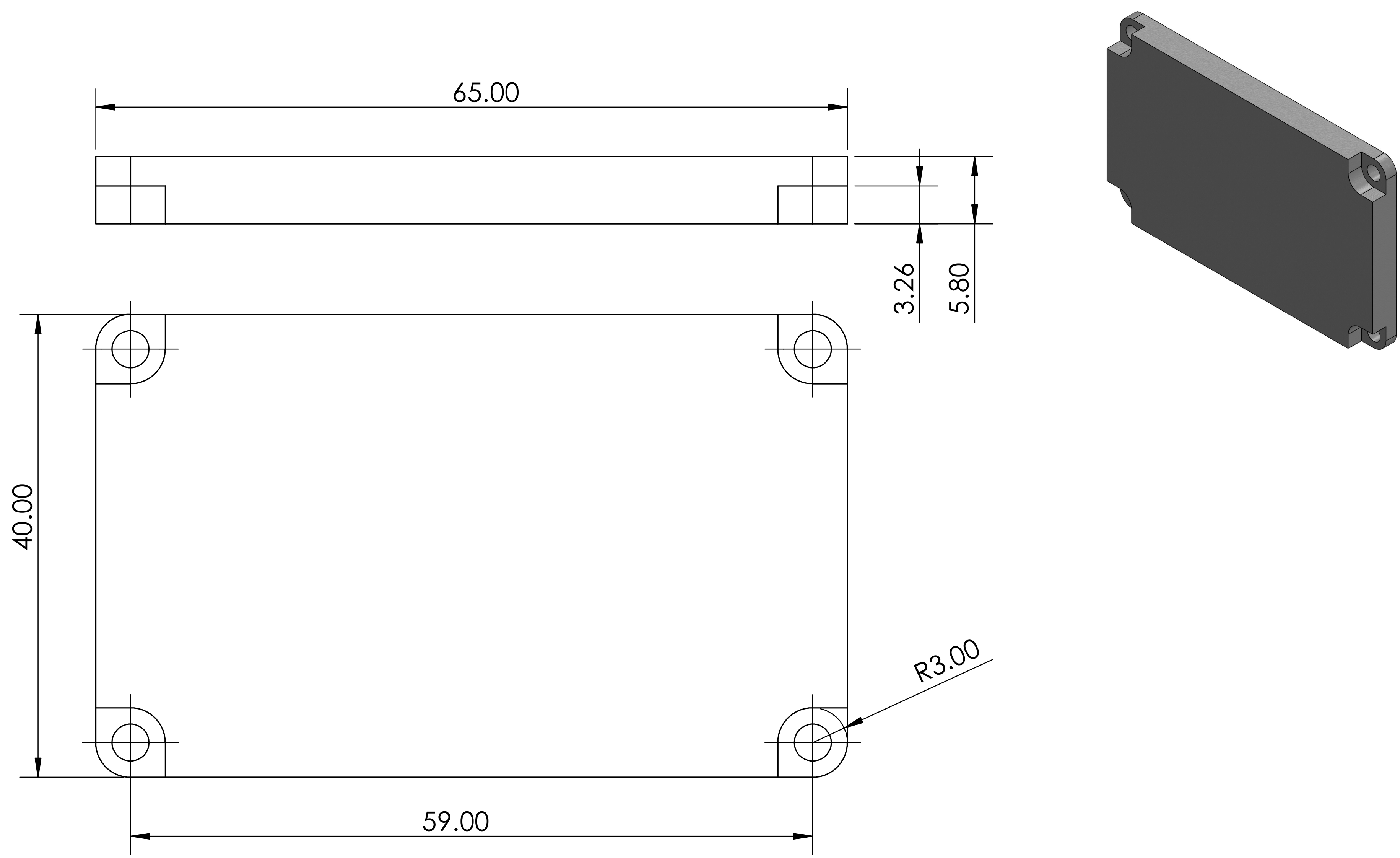
DESIGN ENGINEER: Sun, Tessa

DESIGN APPROVAL:

MANUFACTURING APPROVAL:

PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\OTS parts\91792A168_18-8 Stainless Steel Pan Head Slotted Screws.SLDPRT

SHEET SCALE: 8:1 **SHEET NUMBER: 1 of 1**

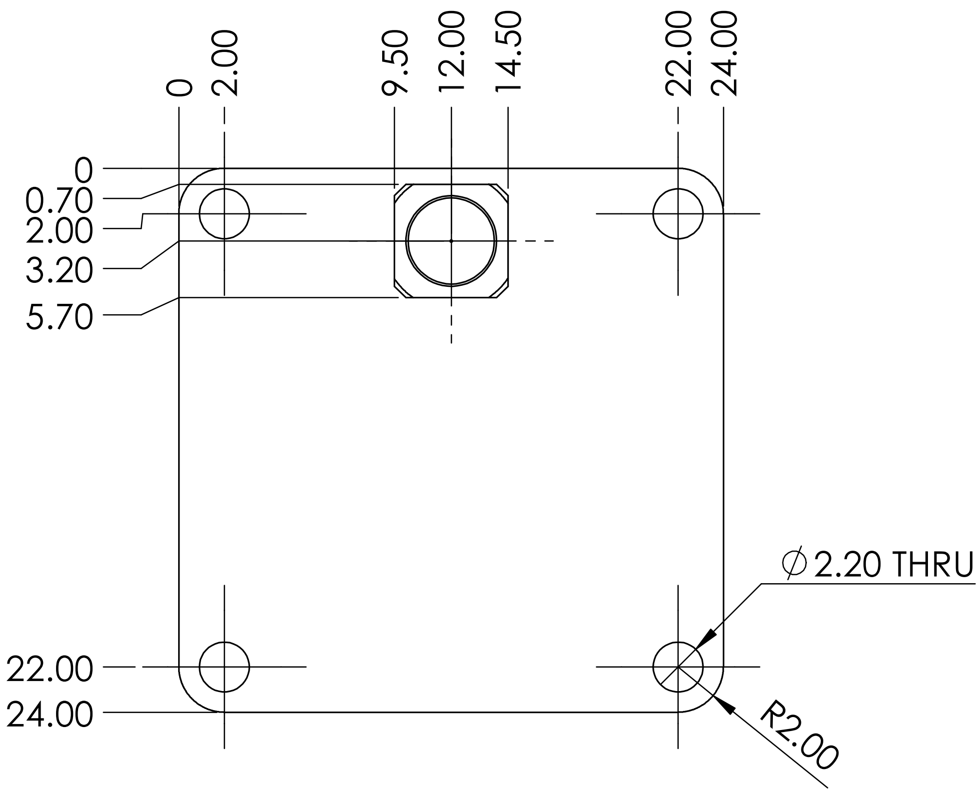


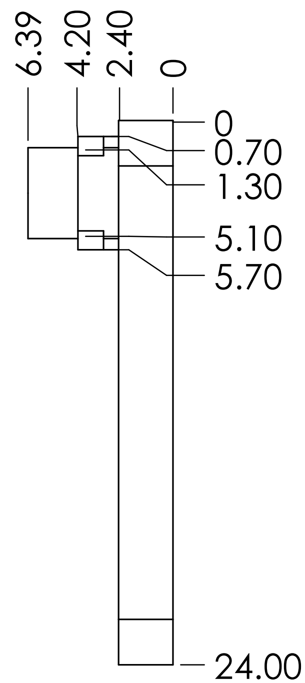
1. DIMS IN MM
2. BREAK ALL EDGES

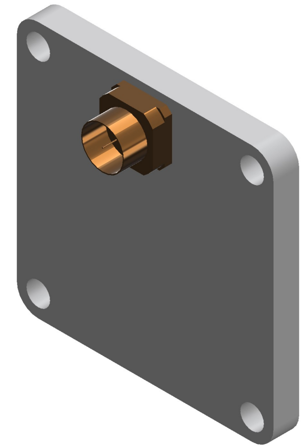
UF Herbert Wertheim College of Engineering, Department of Mechanical & Aerospace Engineering, UNIVERSITY of FLORIDA	*EML4502: MECHANICAL DESIGN 3*	TEAM: GROUP 13.5	PART NAME: NanoMind A3200 - Computer
		PART NUMBER: EML4501-OTS-09	Rev:
STANDARD DIMENSIONAL TOLERANCES:		MATERIAL:	FINISH:
LINEAR [mm]	ANGULAR [degrees]	DESIGN ENGINEER: Tipnis,Varun	
X.X: ±1	X: ±3	DESIGN APPROVAL:	
X.XX: ±.1	X.X: ±.5	MANUFACTURING APPROVAL:	
X.XXX: ±.05	X.XX: ±.1		
MAXIMUM SURFACE FINISH: .004 in Ra			

PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\OTS parts\NanoMind A3200 - Computer.SLDPRT

SHEET SCALE: 2:1 SHEET NUMBER: 1 of 1





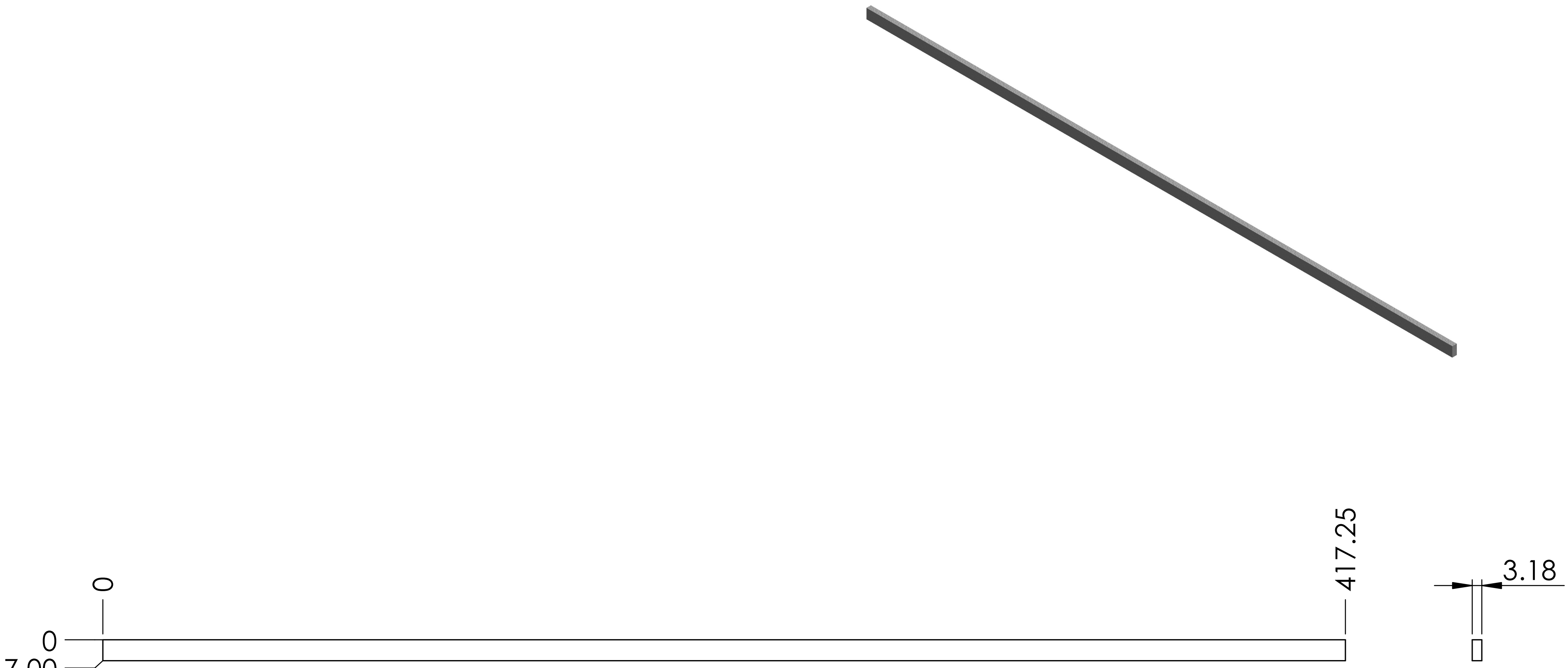


1. DIMS IN MM

UF Herbert Wertheim College of Engineering Department of Mechanical & Aerospace Engineering UNIVERSITY of FLORIDA	***EML4502: MECHANICAL DESIGN 3***	**TEAM: Group 13.5**	**PART NAME:** **X-Band Chip**
		PART NUMBER: EML4501-OTS-12	**Rev:**
STANDARD DIMENSIONAL TOLERANCES: LINEAR [mm] ANGULAR [degrees] **X.X: ±1** **X: ±3** **X.XX: ±.1** **X.X: ±.5** **X.XXX: ±.05** **X.XX: ±.1** MAXIMUM SURFACE FINISH: .004 in Ra		**MATERIAL:**	**FINISH:**
		DESIGN ENGINEER: Tipnis,Varun	
		DESIGN APPROVAL:	
		MANUFACTURING APPROVAL:	

PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\xband chip.SLDPRT

SHEET SCALE: 2:1 **SHEET NUMBER: 1 of 1**



1. DIMS IN MM
2. BREAK ALL EDGES

UF Herbert Wertheim College of Engineering
Department of Mechanical & Aerospace Engineering
UNIVERSITY of FLORIDA

EML4502: MECHANICAL DESIGN 3

TEAM: Group 13.5	PART NAME: Rail Foam
PART NUMBER: EML4501-12	Rev:
MATERIAL: Polyethylene Foam	FINISH:
DESIGN ENGINEER: Bresney,Sean P	
DESIGN APPROVAL: Tipnis, Varun	
MANUFACTURING APPROVAL: Sun, Tessa	

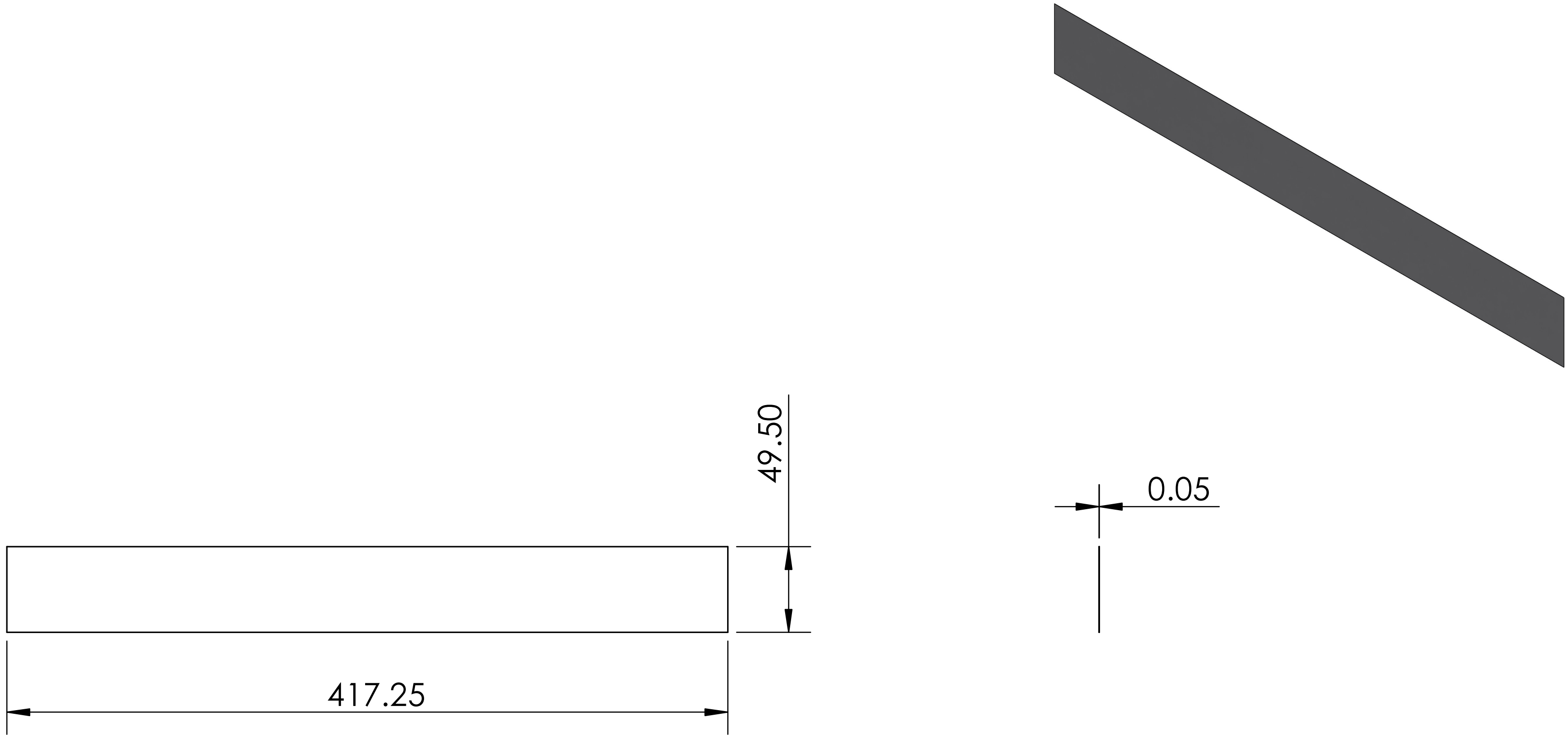
STANDARD DIMENSIONAL TOLERANCES:

LINEAR [mm]		ANGULAR [degrees]	
X.X:	±1	X:	±3
X.XX:	±.1	X.X:	±.5
X.XXX:	±.05	X.XX:	±.1

MAXIMUM SURFACE FINISH: .004 in Ra

PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\RailFoam.SLDPRT

SHEET SCALE: 1:4 SHEET NUMBER: 1 of 1



1. DIMS IN MM
2. BREAK ALL EDGES

UF Herbert Wertheim College of Engineering
Department of Mechanical & Aerospace Engineering
UNIVERSITY of FLORIDA

EML4502: MECHANICAL DESIGN 3

TEAM: **GROUP 13.5**

PART NAME: **Mesh Filter**

PART NUMBER: EML4501-13 **Rev:**

MATERIAL: 316 Stainless Steel **FINISH:**

DESIGN ENGINEER: Tipnis,Varun

DESIGN APPROVAL:

MANUFACTURING APPROVAL:

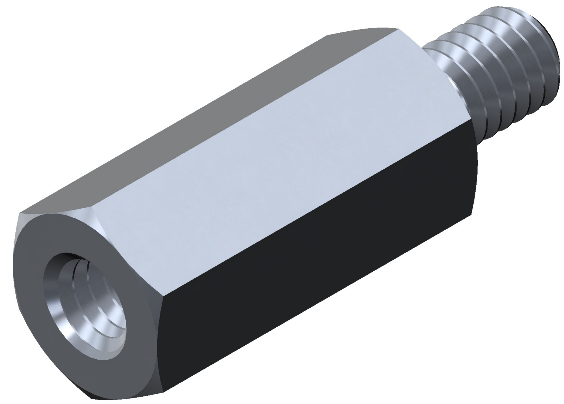
STANDARD DIMENSIONAL TOLERANCES:

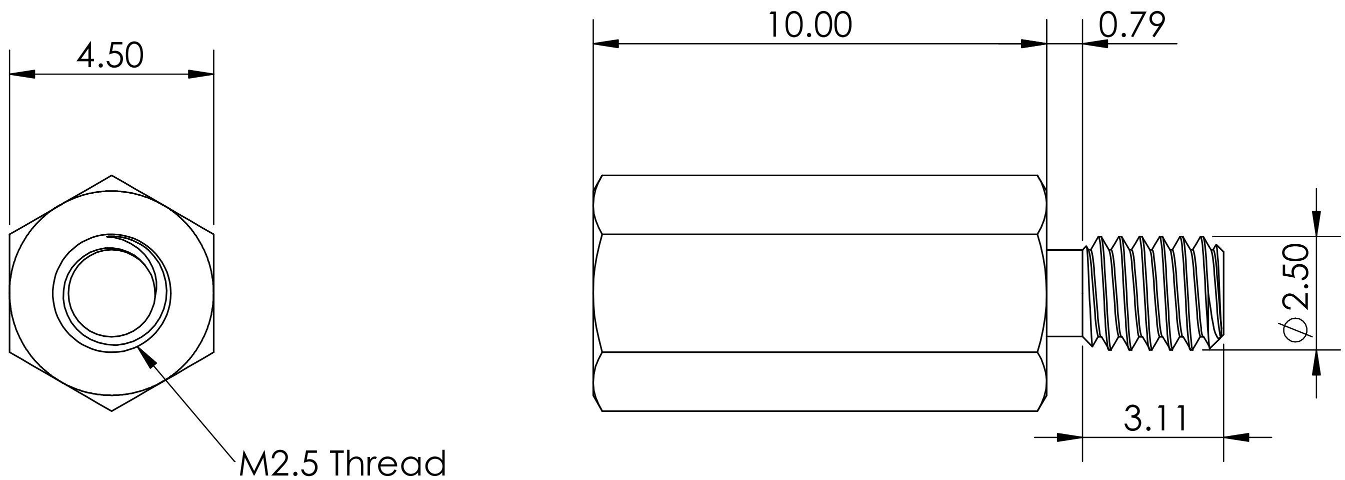
LINEAR [mm]		ANGULAR [degrees]	
X.X:	±**1**	**X:**	±**3**
X.XX:	±**.1**	**X.X:**	±**.5**
X.XXX:	±**.05**	**X.XX:**	±**.1**

MAXIMUM SURFACE FINISH: .004 in Ra

PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\Aluminum_mesh.SLDPRT

SHEET SCALE: 1:4 **SHEET NUMBER: 1 of 1**



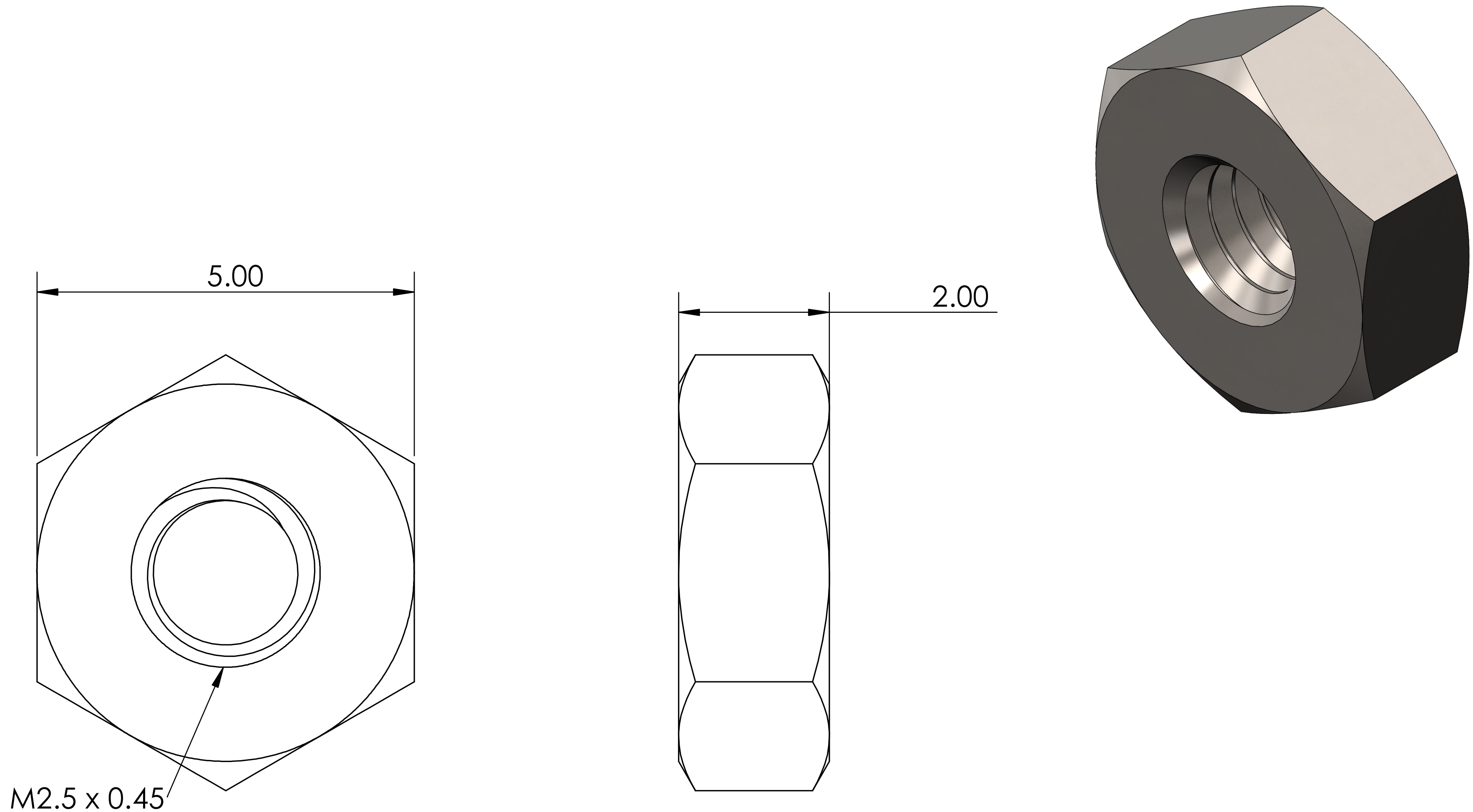


1. DIMS IN MM

UF Herbert Wertheim College of Engineering, Department of Mechanical & Aerospace Engineering, UNIVERSITY of FLORIDA	***EML4502: MECHANICAL DESIGN 3***	**TEAM: Group 13.5**	**PART NAME:** Aluminum Male-Female Threaded
		PART NUMBER: EML4501-OTS-14	**Rev:**
STANDARD DIMENSIONAL TOLERANCES: LINEAR [mm] ANGULAR [degrees] **X.X: ±1** **X: ±3** **X.XX: ±.1** **X.X: ±.5** **X.XXX: ±.05** **X.XX: ±.1** MAXIMUM SURFACE FINISH: .004 in Ra		**MATERIAL: Aluminum**	**FINISH:**
		DESIGN ENGINEER: Sun, Tessa	
		DESIGN APPROVAL:	
		MANUFACTURING APPROVAL:	

PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\OTS parts\98952A107_Aluminum Male-Female Threaded Hex Standoff.SLDPRT

SHEET SCALE: 4:1 **SHEET NUMBER: 1 of 1**

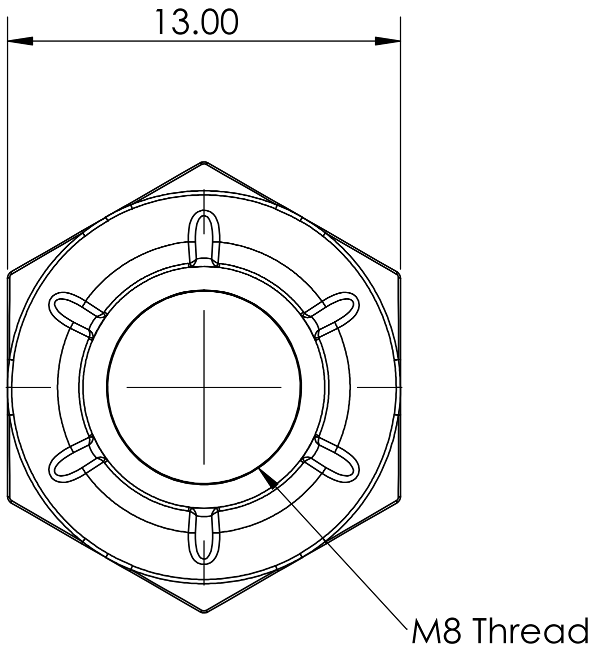


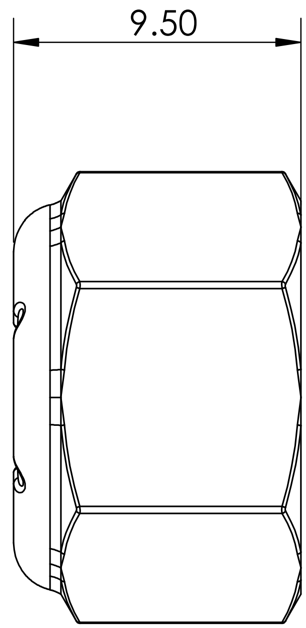
1. DIMS IN MM

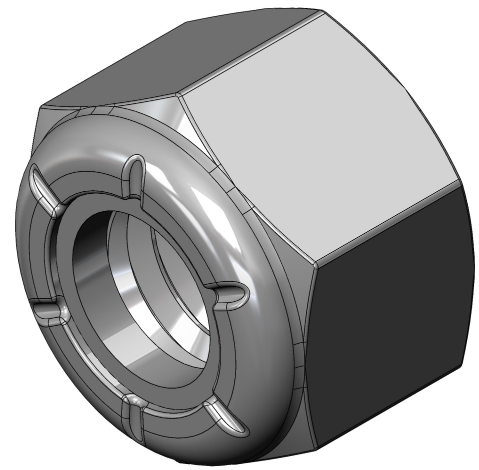
Herbert Wertheim College of Engineering, Department of Mechanical & Aerospace Engineering, UNIVERSITY of FLORIDA	***EML4502: MECHANICAL DESIGN 3***	**TEAM:** **GROUP 13.5**	**PART NAME:** **Steel Hex Nut**
		PART NUMBER: EML4501-OTS-17	**Rev:**
STANDARD DIMENSIONAL TOLERANCES:		**MATERIAL: Steel**	**FINISH:**
LINEAR [mm]	ANGULAR [degrees]	**DESIGN ENGINEER: Sun, Tessa**	
X.X: ±**1**	**X:** ±**3**	**DESIGN APPROVAL:**	
X.XX: ±**.1**	**X.X:** ±**.5**		
X.XXX: ±**.05**	**X.XX:** ±**.1**	**MANUFACTURING APPROVAL:**	
MAXIMUM SURFACE FINISH: .004 in Ra			

PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\OTS parts\90592A080_Steel Hex Nut.SLDPRT

SHEET SCALE: 12:1 **SHEET NUMBER: 1 of 1**





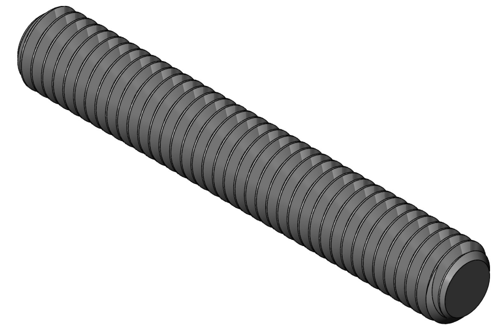


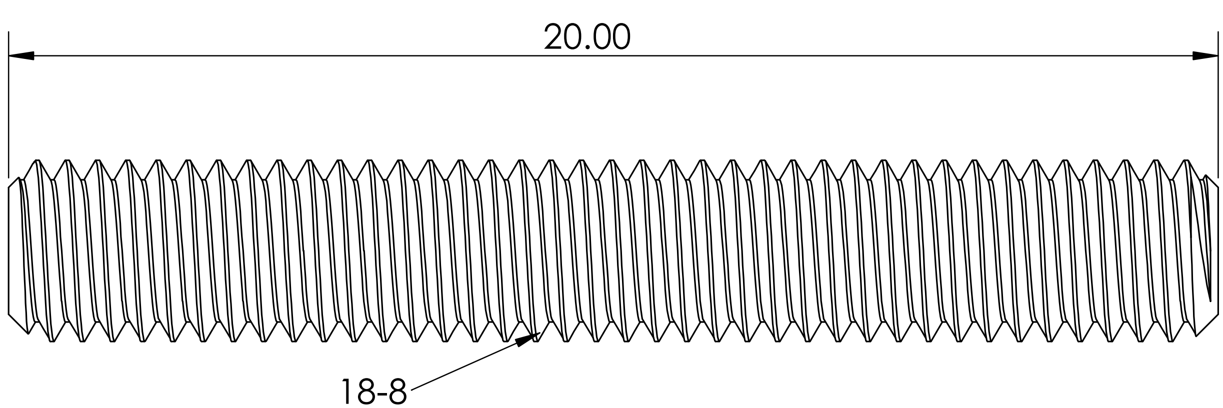
1. DIMS IN MM

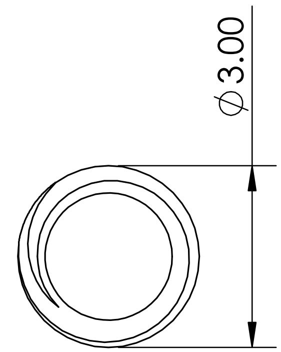
UF Herbert Wertheim College of Engineering, Department of Mechanical & Aerospace Engineering, UNIVERSITY of FLORIDA	***EML4502: MECHANICAL DESIGN 3***	**TEAM: Group 13.5**	**PART NAME: 18-8 Stainless Steel Nylon-Insert**
		PART NUMBER: EML4501-OTS-04	**Rev:**
STANDARD DIMENSIONAL TOLERANCES: LINEAR [mm] **X.X:** ±**1** **X.XX:** ±**.1** **X.XXX:** ±**.05** ANGULAR [degrees] **X:** ±**3** **X.X:** ±**.5** **X.XX:** ±**.1** MAXIMUM SURFACE FINISH: .004 in Ra		**MATERIAL: 18-8 Stainless Steel**	**FINISH:**
		DESIGN ENGINEER: Sun, Tessa	
		DESIGN APPROVAL:	
		MANUFACTURING APPROVAL:	

PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\OTS parts\93625A114_18-8 Stainless Steel Nylon-Insert Locknut.SLDPRT

SHEET SCALE: 4:1 **SHEET NUMBER: 1 of 1**





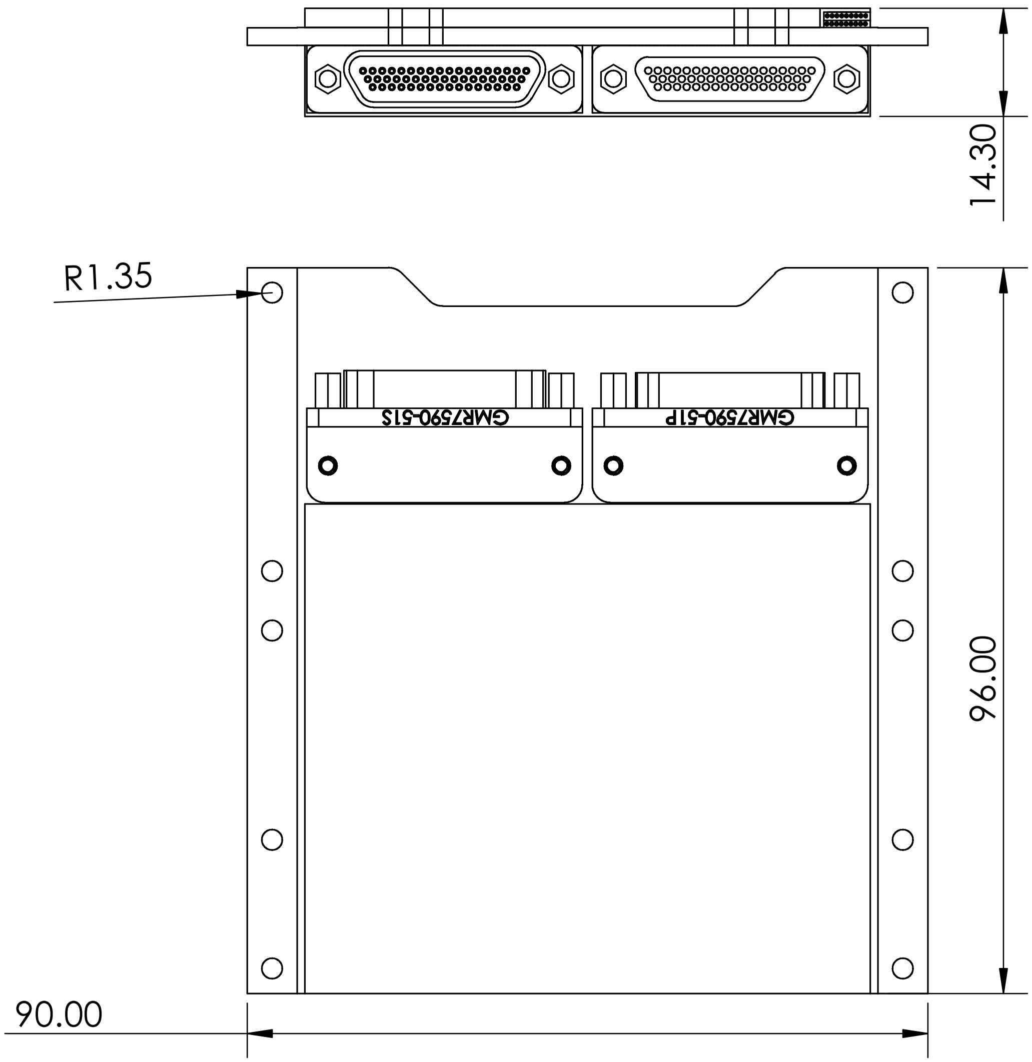


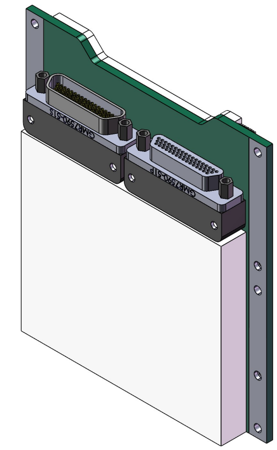
1. DIMS IN MM
2. BREAK ALL EDGES

UF Herbert Wertheim College of Engineering, Department of Mechanical & Aerospace Engineering, UNIVERSITY of FLORIDA	***EML4502: MECHANICAL DESIGN 3***	**TEAM:** GROUP 13.5	**PART NAME:** 18-8 Stainless Steel Threaded Rod
		PART NUMBER: EML4501-OTS-18	**Rev:**
STANDARD DIMENSIONAL TOLERANCES: LINEAR [mm] ANGULAR [degrees]		**MATERIAL: 18-8 Stainless Steel**	**FINISH:**
X.X: ±**1**	**X:** ±**3**	**DESIGN ENGINEER: Bresney,Sean P**	
X.XX: ±**.1**	**X.X:** ±**.5**	**DESIGN APPROVAL:**	
X.XXX: ±**.05**	**X.XX:** ±**.1**	**MANUFACTURING APPROVAL:**	
MAXIMUM SURFACE FINISH: .004 in Ra			

PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\93805A631_18-8 Stainless Steel Threaded Rod.SLDPRT

SHEET SCALE: 4:1 **SHEET NUMBER: 1 of 1**





1. DIMS IN MM

UF Herbert Wertheim College of Engineering
Department of Mechanical & Aerospace Engineering
UNIVERSITY of FLORIDA

EML4502: MECHANICAL DESIGN 3

TEAM: GROUP 13.5

PART NAME: Ibeos 150-Watt

PART NUMBER: EML4501-OTS-19

Rev:

MATERIAL:

FINISH:

DESIGN ENGINEER: Bresney,Sean P

DESIGN APPROVAL:

MANUFACTURING APPROVAL:

STANDARD DIMENSIONAL TOLERANCES:

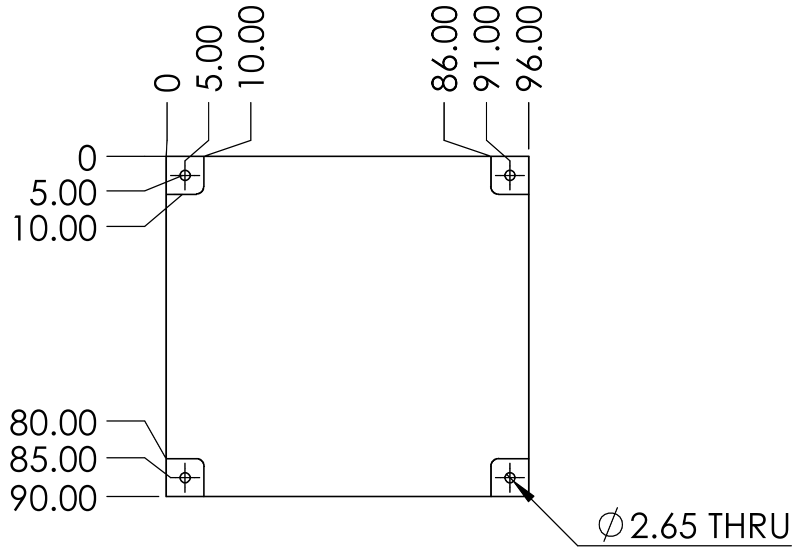
LINEAR [mm]		ANGULAR [degrees]	
X.X:	±**1**	**X:**	±**3**
X.XX:	±**.1**	**X.X:**	±**.5**
X.XXX:	±**.05**	**X.XX:**	±**.1**

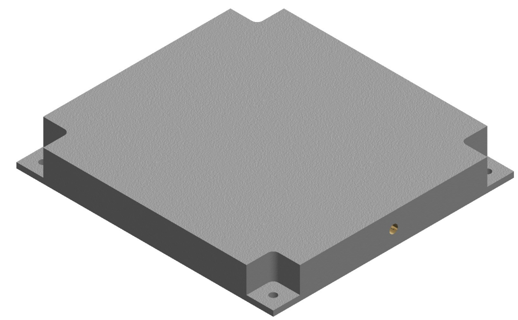
MAXIMUM SURFACE FINISH: .004 in Ra

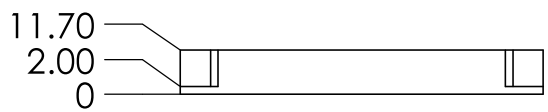
PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\Ibeos_EPS.SLDPRT

SHEET SCALE: 1:2

SHEET NUMBER: 1 of 1







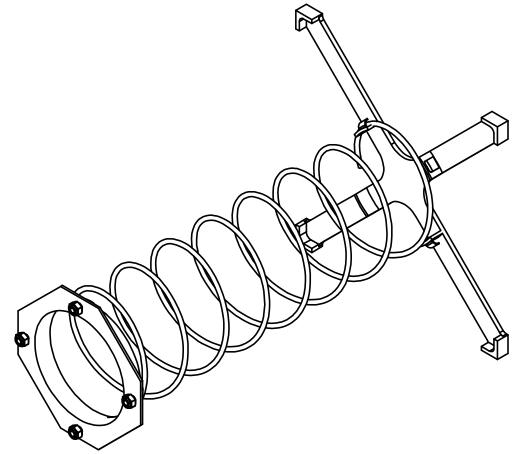
1. DIMS IN MM

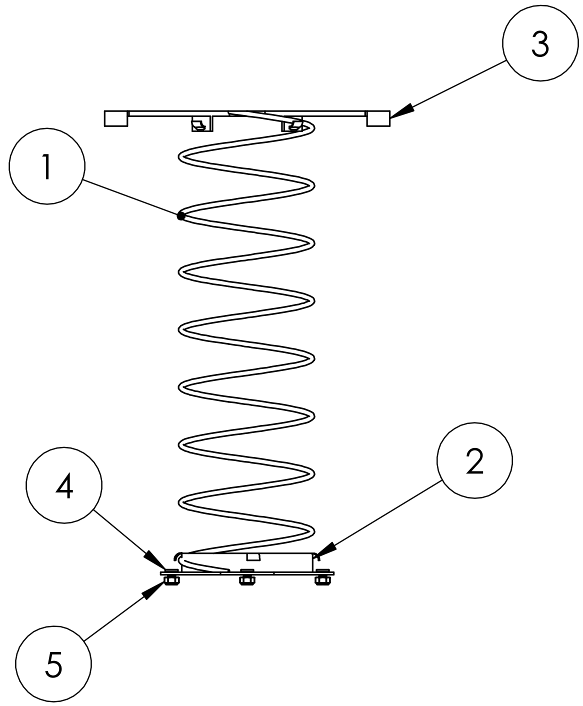
UF Herbert Wertheim College of Engineering Department of Mechanical & Aerospace Engineering UNIVERSITY of FLORIDA	***EML4502: MECHANICAL DESIGN 3***	**TEAM: Group 13.5**	**PART NAME: PULSAR-XTX xband transmitter**
		PART NUMBER: EML4501-OTS-13	**Rev:**
STANDARD DIMENSIONAL TOLERANCES: LINEAR [mm] ANGULAR [degrees] **X.X: ±1** **X: ±3** **X.XX: ±.1** **X.X: ±.5** **X.XXX: ±.05** **X.XX: ±.1** MAXIMUM SURFACE FINISH: .004 in Ra		**MATERIAL:**	**FINISH:**
		DESIGN ENGINEER: Tipnis,Varun	
		DESIGN APPROVAL:	
		MANUFACTURING APPROVAL:	

PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\OTS parts\PULSAR-XTX xband transmitter.SLDPRT

SHEET SCALE: 1:2 **SHEET NUMBER: 1 of 1**

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	EML4501-09	Spring	1
2	EML4501-10	Launcher Plate Base	1
3	EML4501-11	X-Launch Plate	1
4	90358A016	Ultra-Low-Profile Socket Head Screw	4
5	93625A250	18-8 Stainless Steel Nylon-Insert Locknut	4





1. DIMS IN MM

UF Herbert Wertheim College of Engineering
Department of Mechanical & Aerospace Engineering
UNIVERSITY of FLORIDA

EML4502: MECHANICAL DESIGN 3

TEAM: Group 13.5

PART NAME: LAUNCHER ASSEMBLY

PART NUMBER: EML4501-A-04 **Rev:**

MATERIAL: **FINISH:**

DESIGN ENGINEER:

DESIGN APPROVAL:

MANUFACTURING APPROVAL:

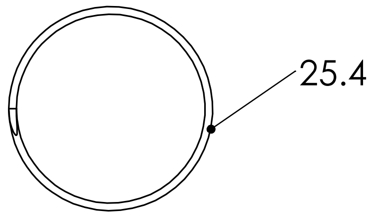
STANDARD DIMENSIONAL TOLERANCES:

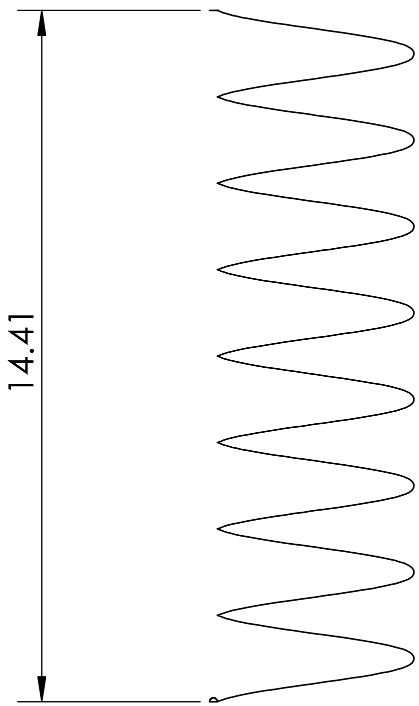
LINEAR [mm]		ANGULAR [degrees]	
X.X:	±**1**	**X:**	±**3**
X.XX:	±**.1**	**X.X:**	±**.5**
X.XXX:	±**.05**	**X.XX:**	±**.1**

MAXIMUM SURFACE FINISH: .004 in Ra

PART LOCATION:

SHEET SCALE: 1:6 **SHEET NUMBER: 1 of 1**



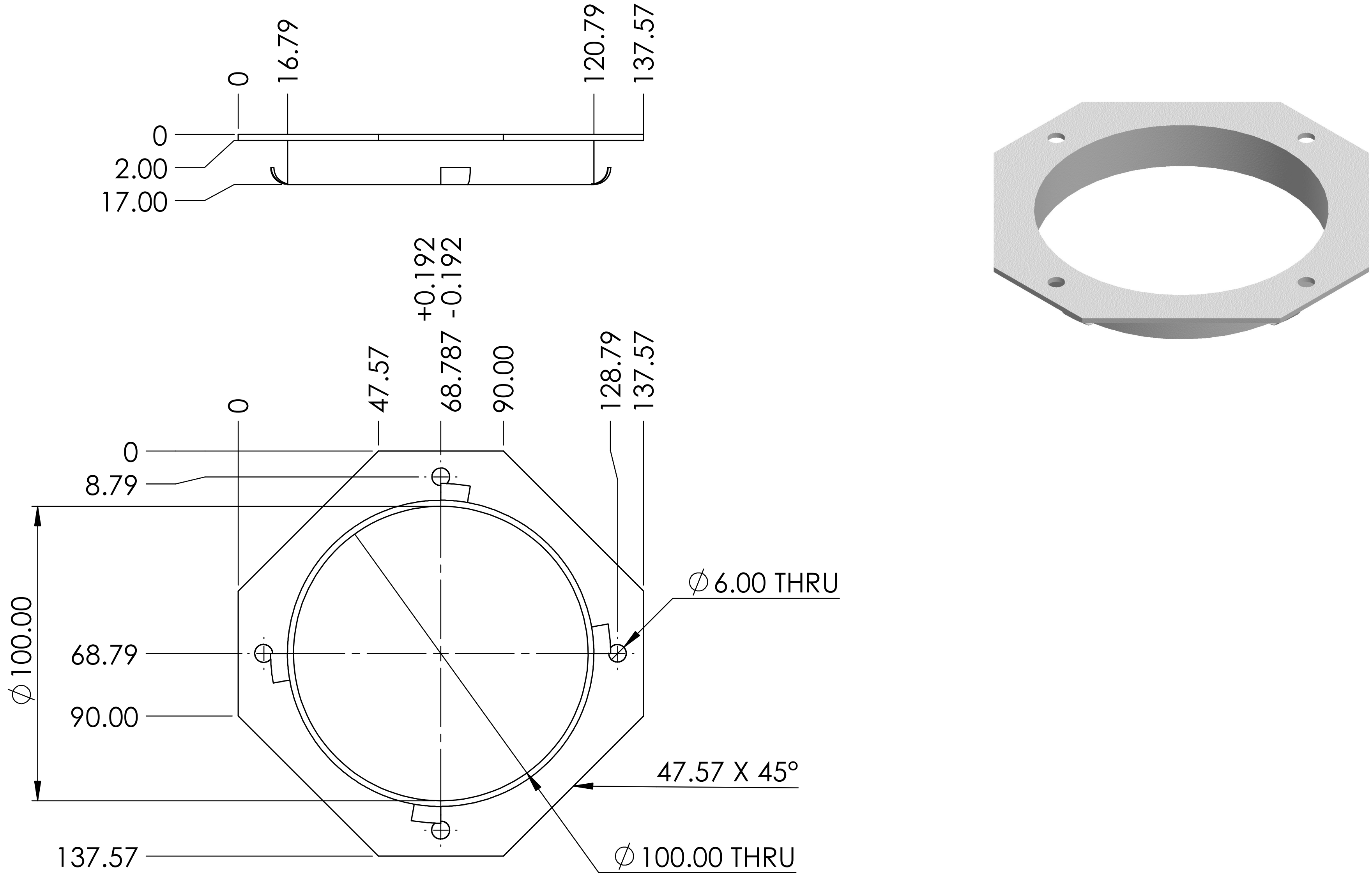


1. DIMS IN MM
2. BREAK ALL EDGES

UF Herbert Wertheim College of Engineering Department of Mechanical & Aerospace Engineering UNIVERSITY of FLORIDA	***EML4502: MECHANICAL DESIGN 3***	**TEAM:** **GROUP 13.4**	**PART NAME:** **Spring**
		PART NUMBER: EML4501-09	**Rev:**
STANDARD DIMENSIONAL TOLERANCES: LINEAR [mm] ANGULAR [degrees] **X.X: ±1** **X: ±3** **X.XX: ±.1** **X.X: ±.5** **X.XXX: ±.05** **X.XX: ±.1** MAXIMUM SURFACE FINISH: .004 in Ra		**MATERIAL: STAINLESS STEEL 302**	**FINISH:**
		DESIGN ENGINEER: Tipnis,Varun	
		DESIGN APPROVAL:	
		MANUFACTURING APPROVAL:	

PART LOCATION: **C:\EML4501\PDR CAD\Group 13.5\Spring.SLDPRT**

SHEET SCALE: 1:8 **SHEET NUMBER: 1 of 1**

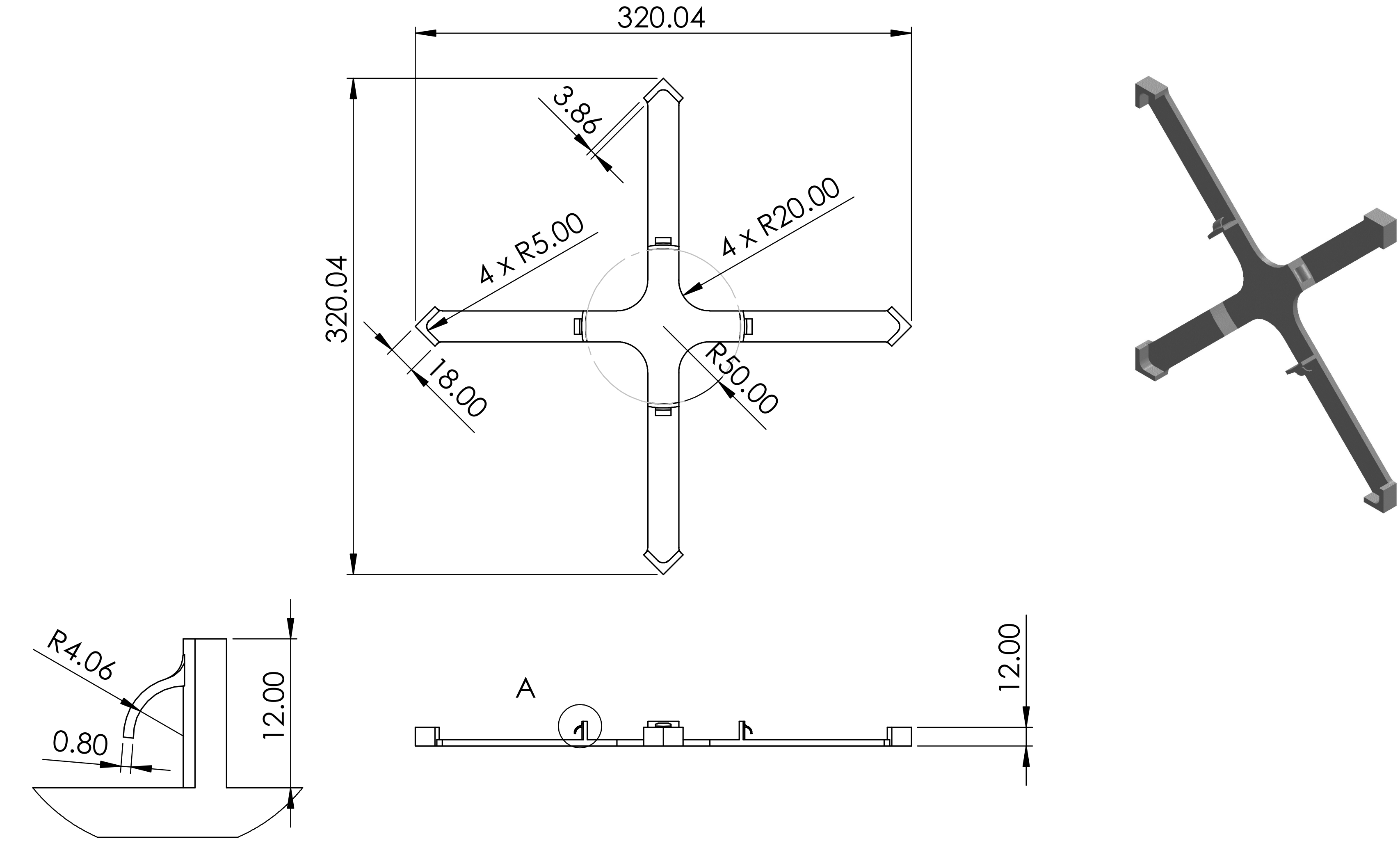


1. DIMS IN MM
2. BREAK ALL EDGES

UF Herbert Wertheim College of Engineering Department of Mechanical & Aerospace Engineering UNIVERSITY of FLORIDA	***EML4502: MECHANICAL DESIGN 3***	**TEAM:** Group 13.5	**PART NAME:** Launcher Base Plate
		PART NUMBER: EML4501-10	**Rev:**
STANDARD DIMENSIONAL TOLERANCES: LINEAR [mm] ANGULAR [degrees] **X.X:** ±**1** **X:** ±**3** **X.XX:** ±**.1** **X.X:** ±**.5** **X.XXX:** ±**.05** **X.XX:** ±**.1** MAXIMUM SURFACE FINISH: .004 in Ra		**MATERIAL:** ABS PLASTIC	**FINISH:**
		DESIGN ENGINEER: Tipnis,Varun	
		DESIGN APPROVAL: Bresney, Sean	
		MANUFACTURING APPROVAL: Sun, Tessa	

PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\launcher plate base.SLDPRT

SHEET SCALE: 1:2 **SHEET NUMBER:** 1 of 1



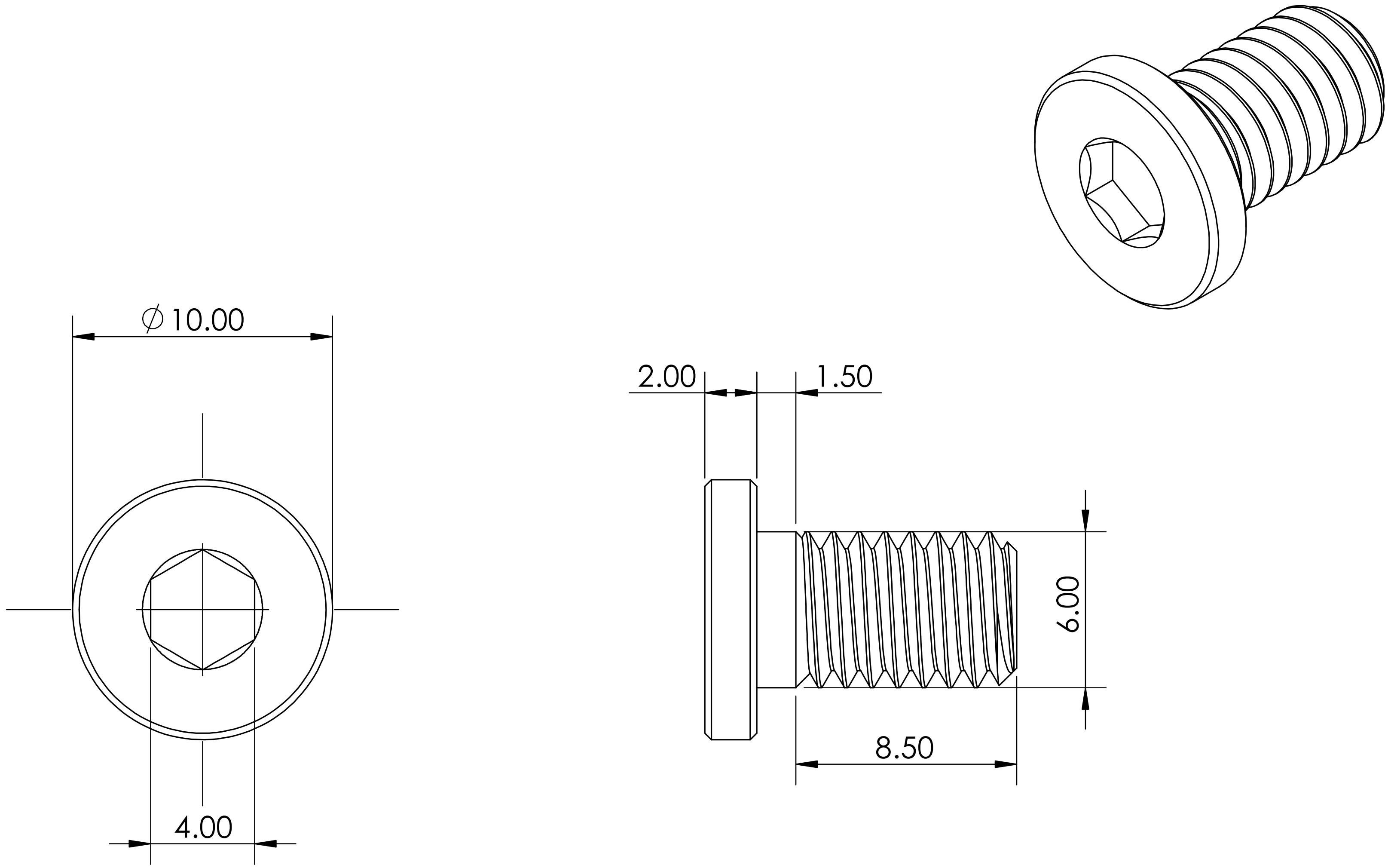
DETAIL A
SCALE 2 : 1

1. DIMS IN MM

UF Herbert Wertheim College of Engineering, Department of Mechanical & Aerospace Engineering, UNIVERSITY of FLORIDA	***EML4502: MECHANICAL DESIGN 3***	**TEAM: Group 13.5**	**PART NAME: X-LaunchPlate**
		PART NUMBER: EML4501-11	**Rev:**
STANDARD DIMENSIONAL TOLERANCES:		**MATERIAL: ABS**	**FINISH:**
LINEAR [mm]	ANGULAR [degrees]	**DESIGN ENGINEER: Bresney,Sean P**	
X.X: ±**1**	**X:** ±**3**		
X.XX: ±**.1**	**X.X:** ±**.5**	**DESIGN APPROVAL: Sun, Tessa**	
X.XXX: ±**.05**	**X.XX:** ±**.1**		
MAXIMUM SURFACE FINISH: .004 in Ra		**MANUFACTURING APPROVAL:Crouch, Christopher**	

PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\X-LaunchPlate.SLDPRT

SHEET SCALE: 1:4 **SHEET NUMBER: 1 of 1**

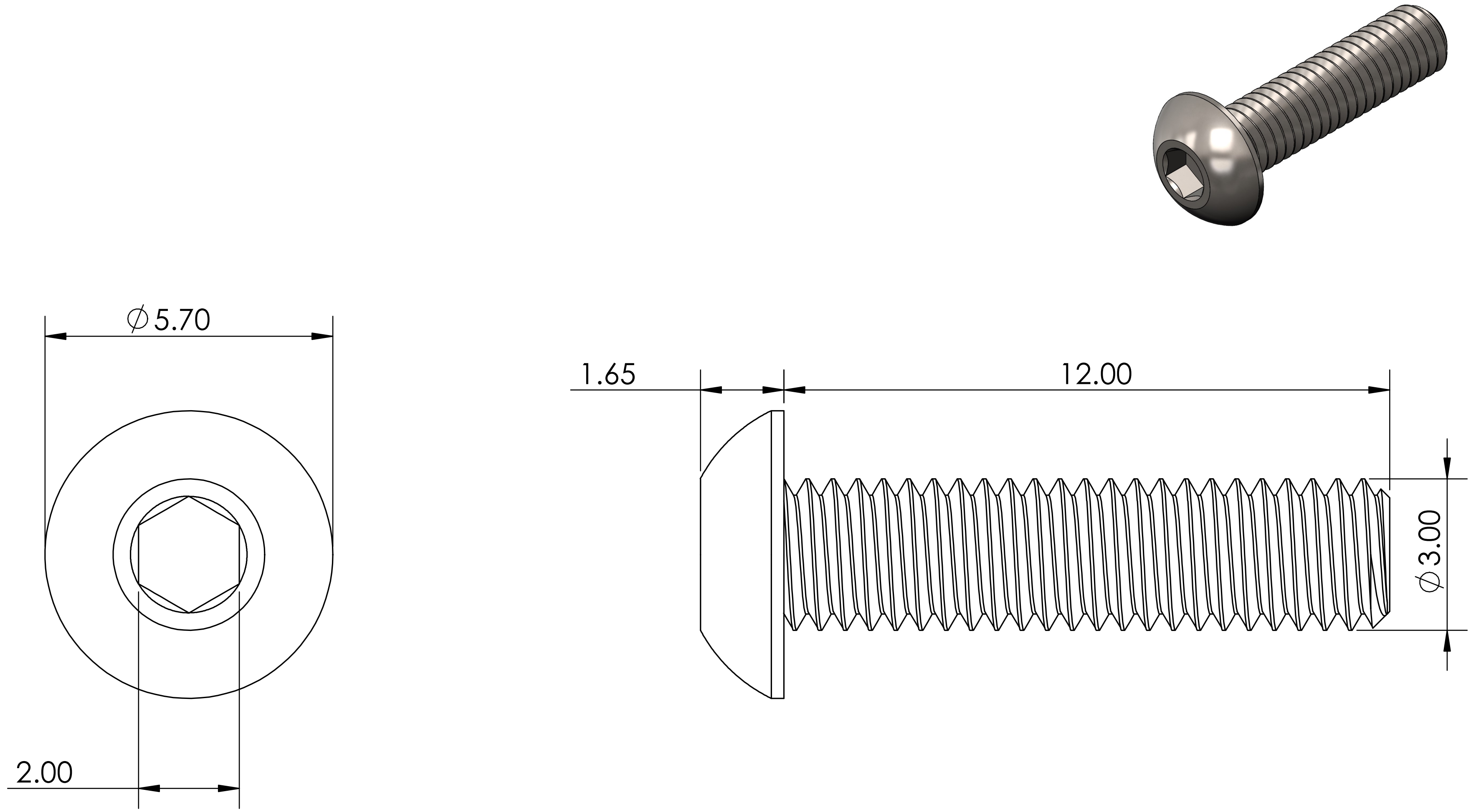


1. DIMS IN MM

UF Herbert Wertheim College of Engineering, Department of Mechanical & Aerospace Engineering, UNIVERSITY of FLORIDA	***EML4502: MECHANICAL DESIGN 3***	**TEAM: Group 13.5**	**PART NAME:** Socket Head Screw
		PART NUMBER: EML4501-OTS-6	**Rev:**
STANDARD DIMENSIONAL TOLERANCES:		**MATERIAL: Alloy Steel**	**FINISH:**
LINEAR [mm]	ANGULAR [degrees]	**DESIGN ENGINEER: Sun, Tessa**	
X.X: ±**1**	**X:** ±**3**		
X.XX: ±**.1**	**X.X:** ±**.5**	**DESIGN APPROVAL:**	
X.XXX: ±**.05**	**X.XX:** ±**.1**		
MAXIMUM SURFACE FINISH: .004 in Ra		**MANUFACTURING APPROVAL:**	

PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\OTS parts\90358A016_Ultra-Low-Profile Socket Head Screw.SLDPRT

SHEET SCALE: 4:1 **SHEET NUMBER: 1 of 1**



1. DIMS IN MM
2. BREAK ALL EDGES

UF Herbert Wertheim College of Engineering
Department of Mechanical & Aerospace Engineering
UNIVERSITY of FLORIDA

EML4502: MECHANICAL DESIGN 3

TEAM: GROUP 13.5

PART NAME: 316 Stainless Steel Button Head Hex

PART NUMBER: EML4501-OTS-02 **Rev:**

MATERIAL: 316 Stainless Steel **FINISH:**

DESIGN ENGINEER: Bresney,Sean P

DESIGN APPROVAL:

MANUFACTURING APPROVAL:

STANDARD DIMENSIONAL TOLERANCES:

LINEAR [mm]		ANGULAR [degrees]	
X.X:	±**1**	**X:**	±**3**
X.XX:	±**.1**	**X.X:**	±**.5**
X.XXX:	±**.05**	**X.XX:**	±**.1**

MAXIMUM SURFACE FINISH: .004 in Ra

PART LOCATION: C:\EML4501\PDR CAD\Group 13.5\94500A264_316 Stainless Steel Button Head Hex Drive Screws.SLDPRT

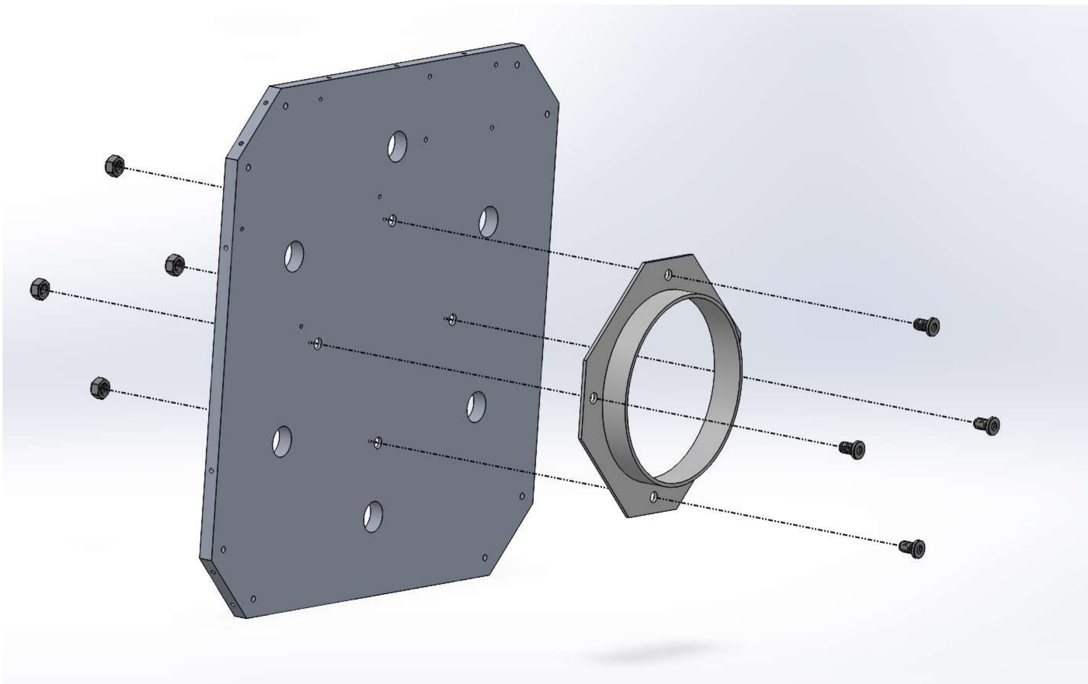
SHEET SCALE: 4:1 **SHEET NUMBER:** 1 of 1

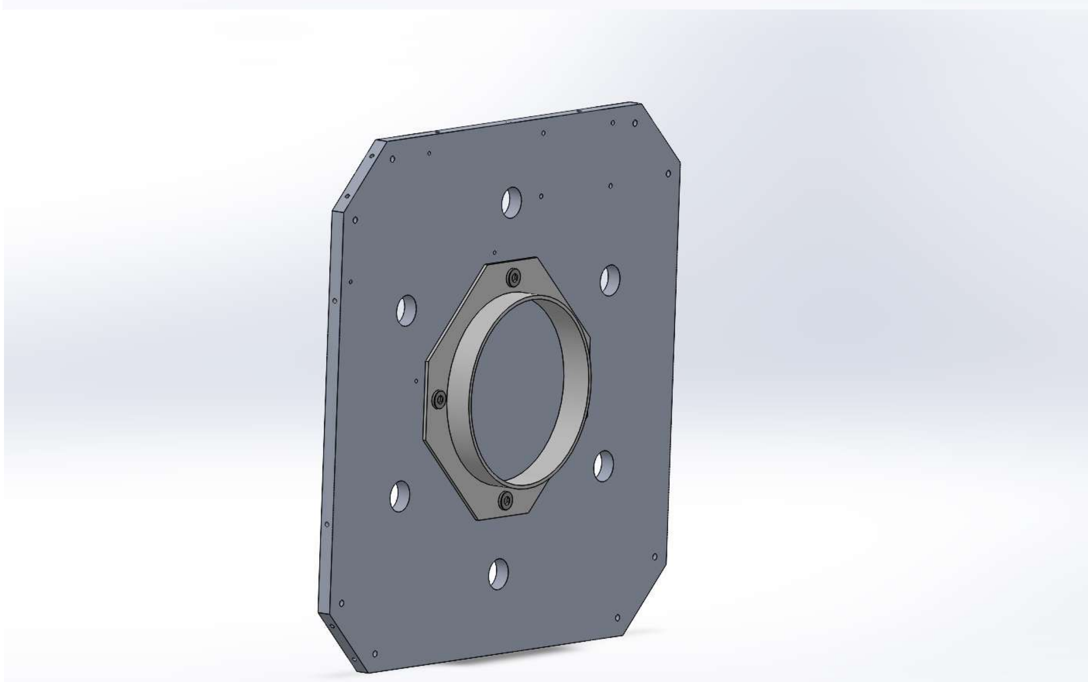
IX. Assembly Procedure

A. Manual Assembly Plan

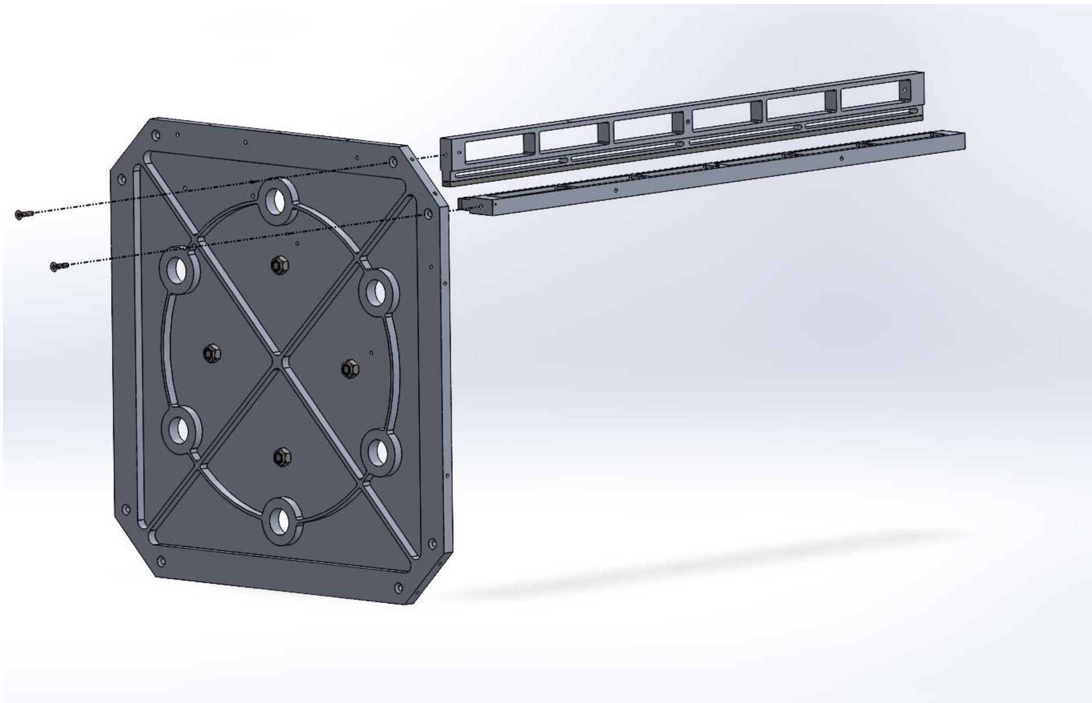
Below is a detailed assembly procedure manual for assembling our CSD design. It provides step-by-step instructions with visual diagrams on how the CSD should be assembled. Any photos marked with an asterisk (*) to the side or below have some installed components hidden from view for ease of viewing the relevant assembly steps.

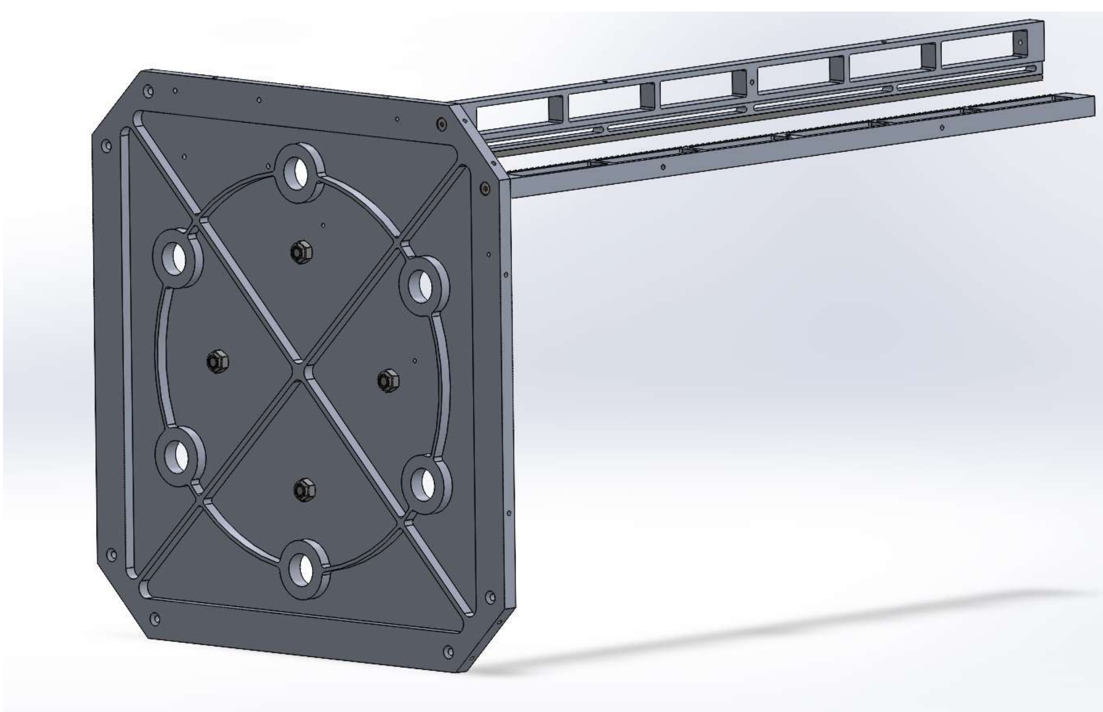
Step 1: Install Back Plate (x1) onto Launcher Base Plate (x1) using M6x1.00mm Socket Head Screw (x4) and M6x1mm Lock Nut (x4).



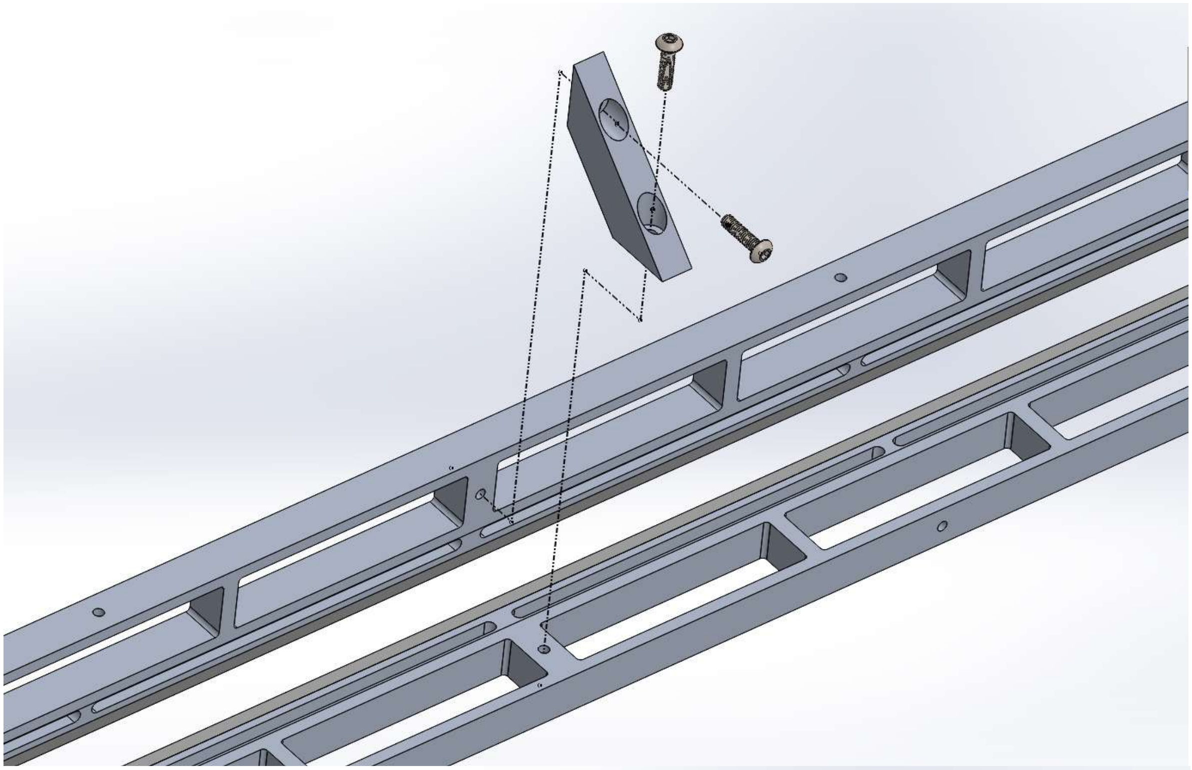


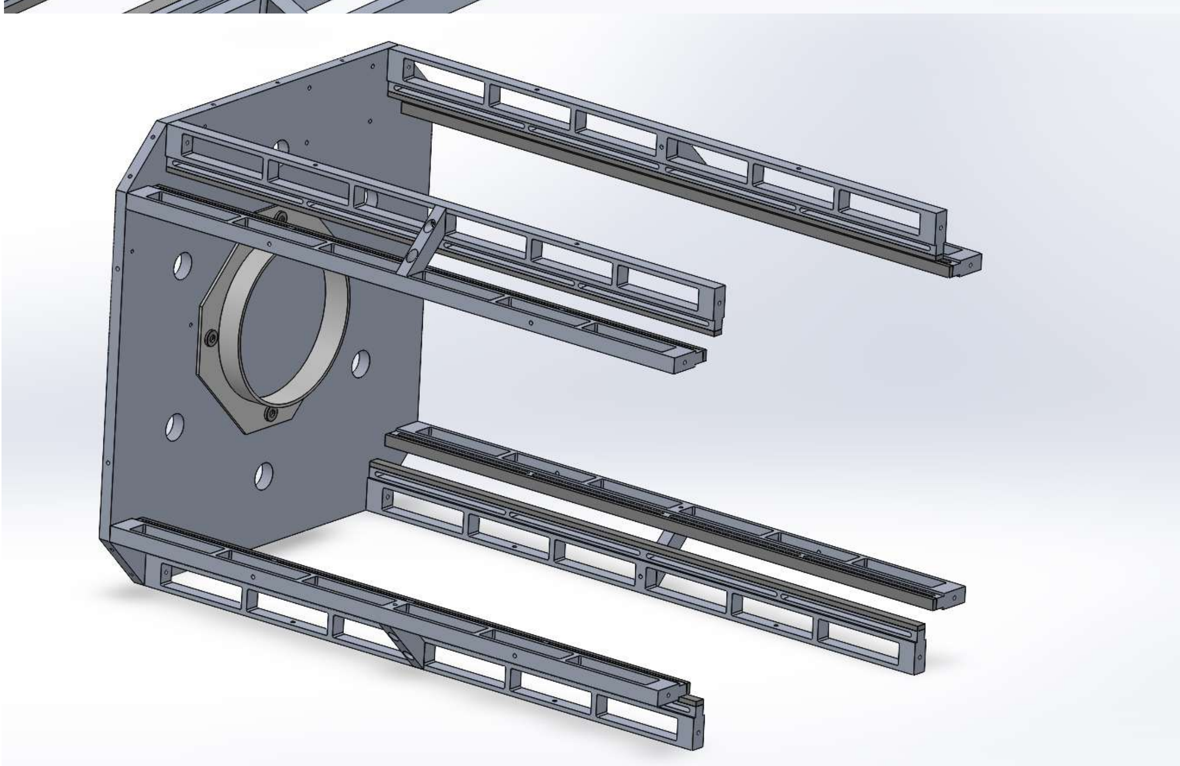
Step 2: Install Rail (EML4501-02) (x8) onto Back Plate using M3x0.5mm Hex Drive Flat Head Screw (x8)



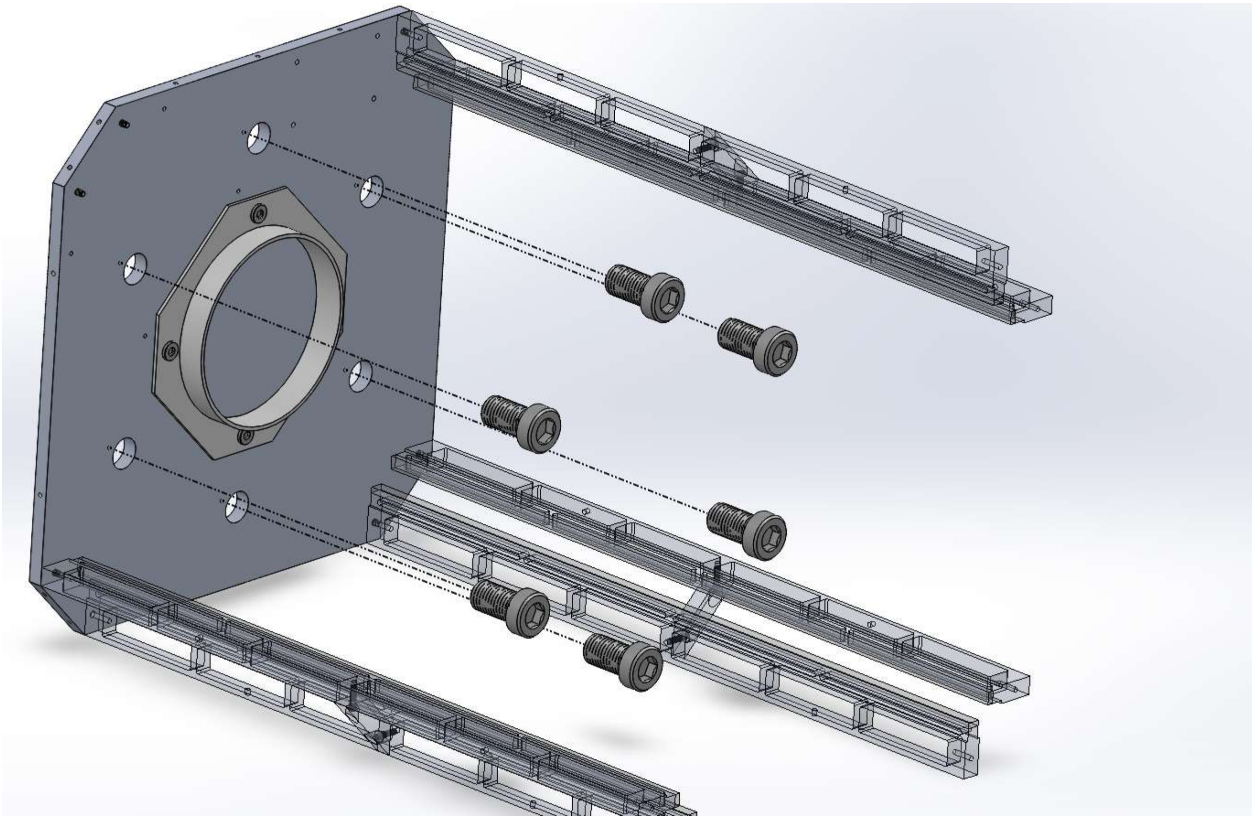


<u>Step 3:</u> Install Rail Angle Bracket (x4) between Rails using M3x0.5mm Screw (x8).





<u>Step 4:</u> Mount Back Plate (x1) onto launch vehicle using M16 Screw (x6)



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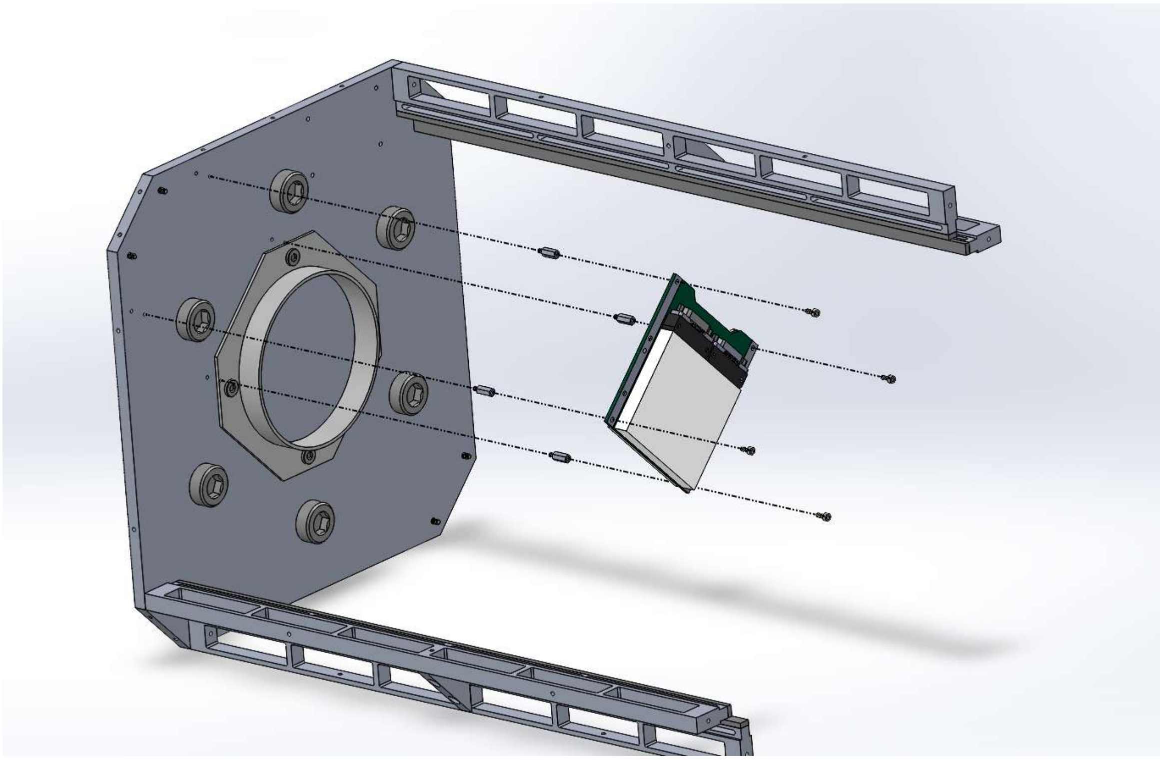
<u>Step 5:</u> Install Ibeos EPS (x1) onto Back Plate using M2.5x0.45mm Standoffs (x4) and M2.5x0.45mm Socket Head Screw (x4).



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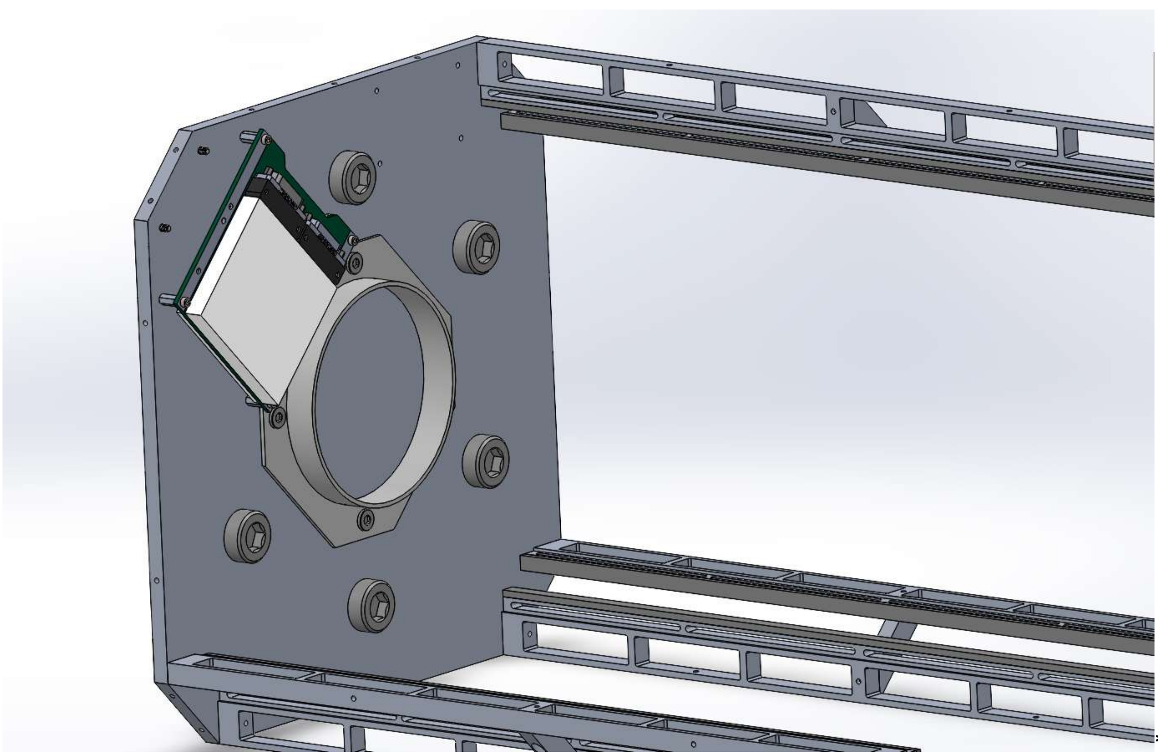

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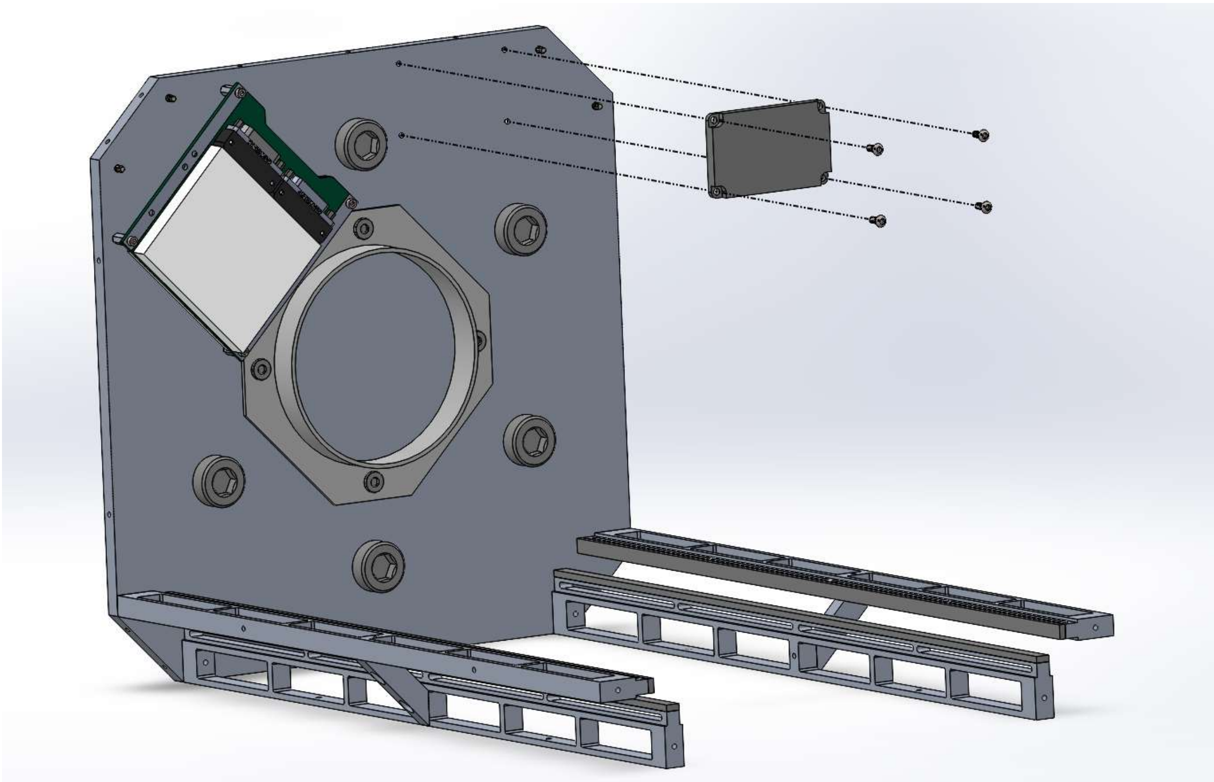
Step 6: Install Nanomind A3200 (x1) onto Back Plate using M3 Button Head Hex Drive Screw (x4).



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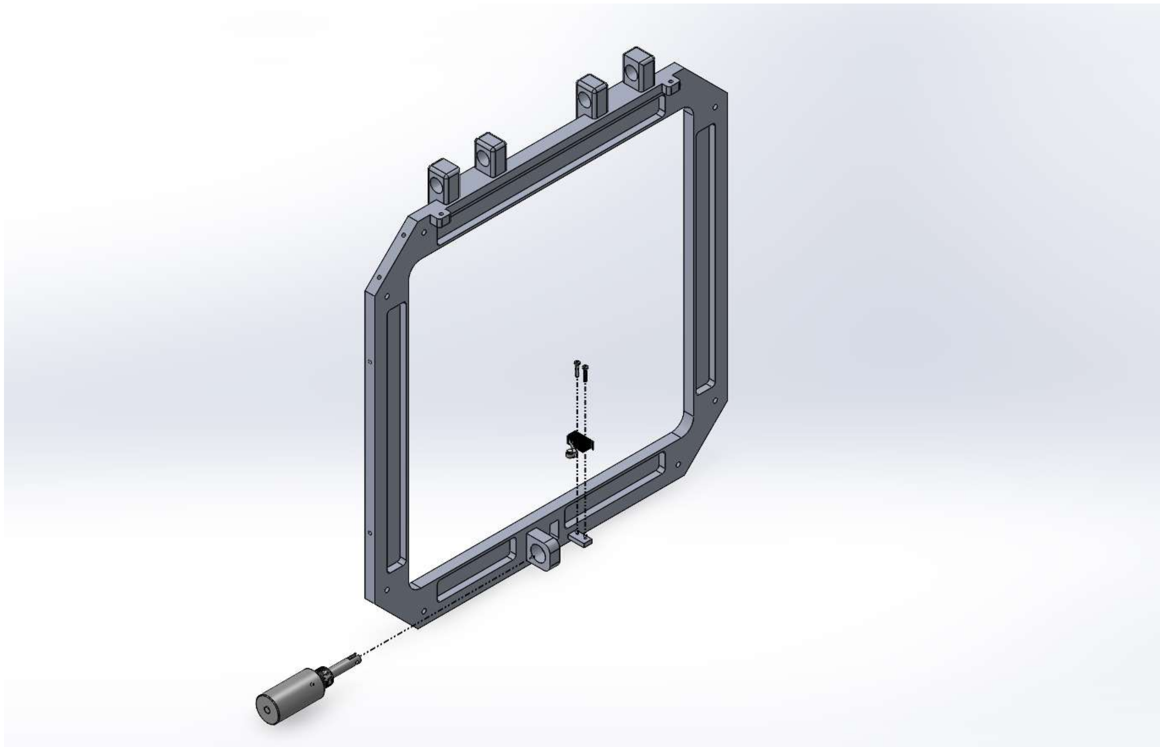
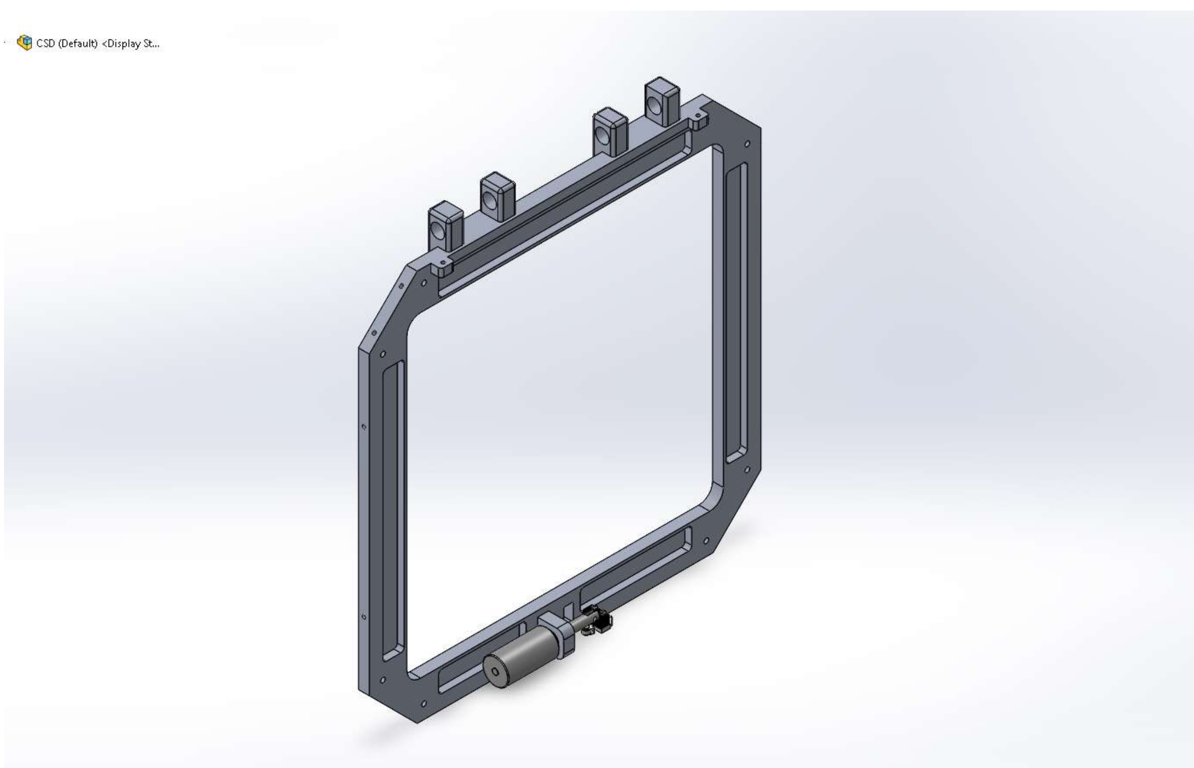
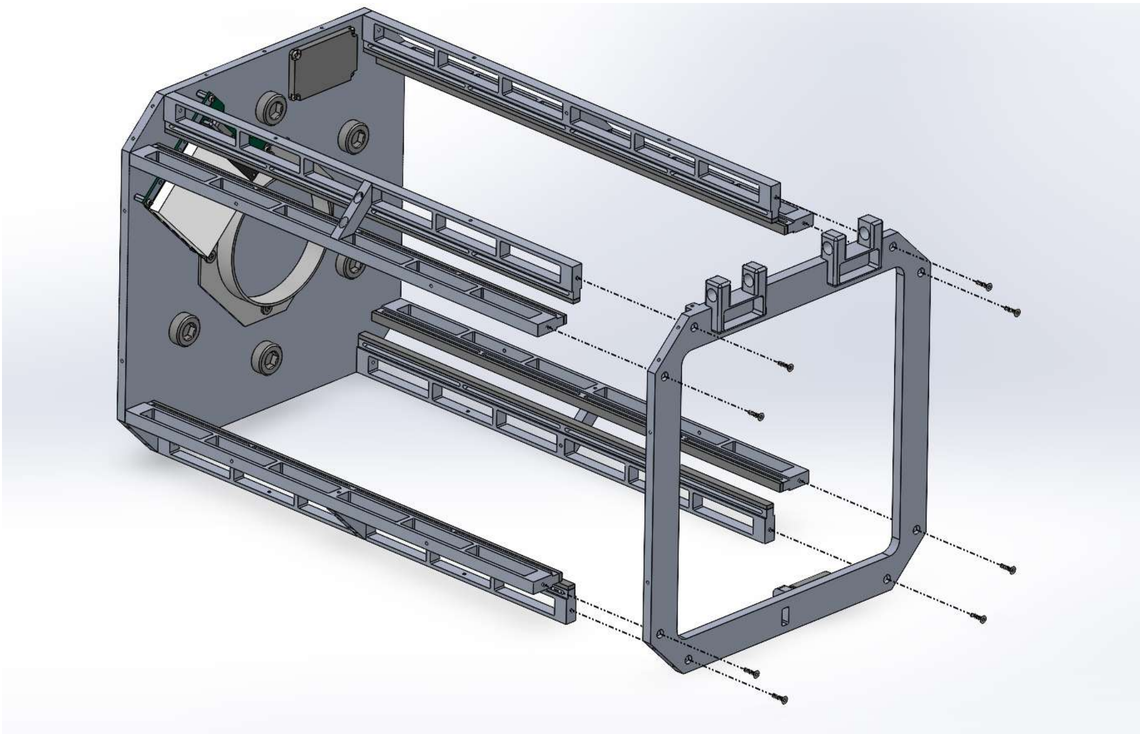
Step 7: Separate from previously assembled components, install Linear Solenoid (x1) on Front Plate (x1). Install Omron Limit Switch (x1) on Front Plate (x1) using 1-64x3/8” Screw (x2).

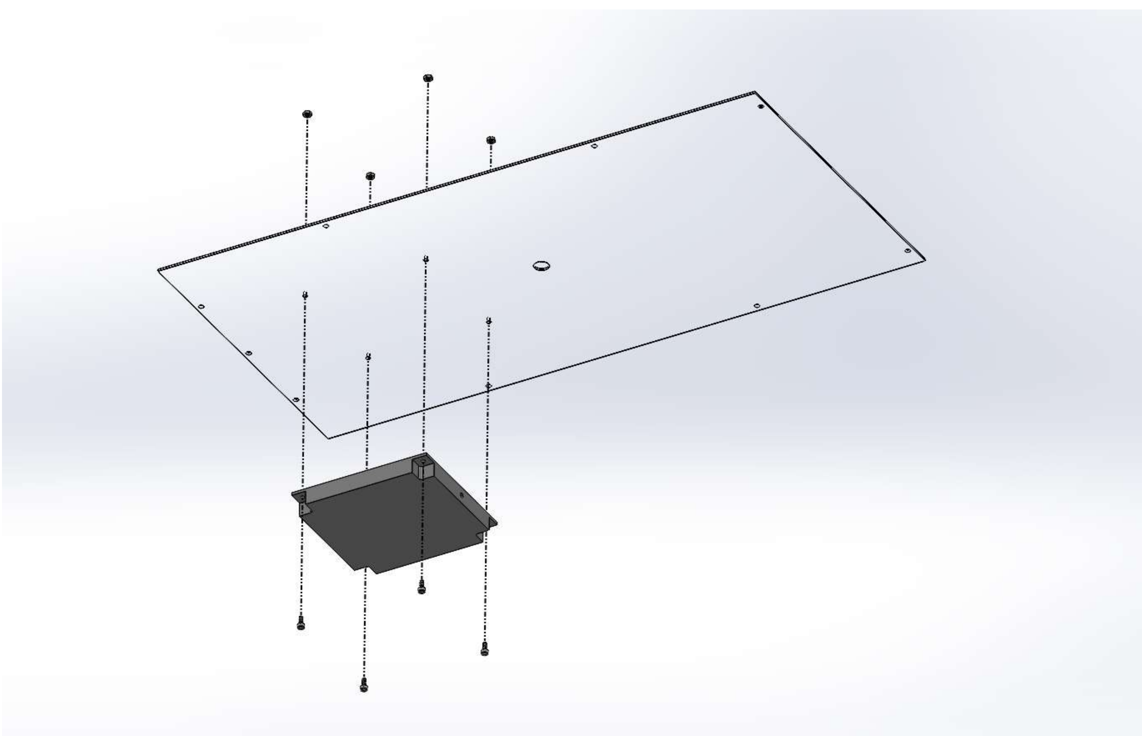




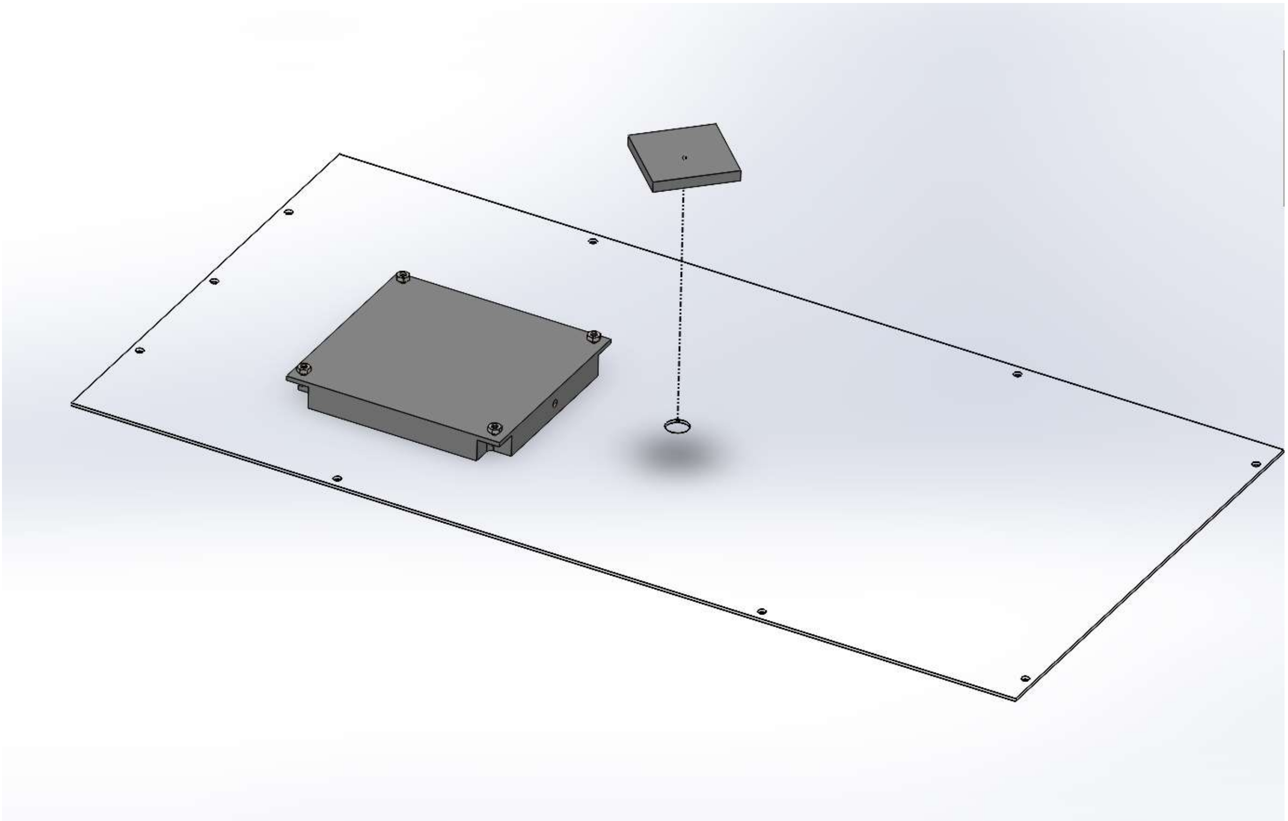
Step 8: Install Front Plate onto Rails using M3 Countersunk Screws (x8).



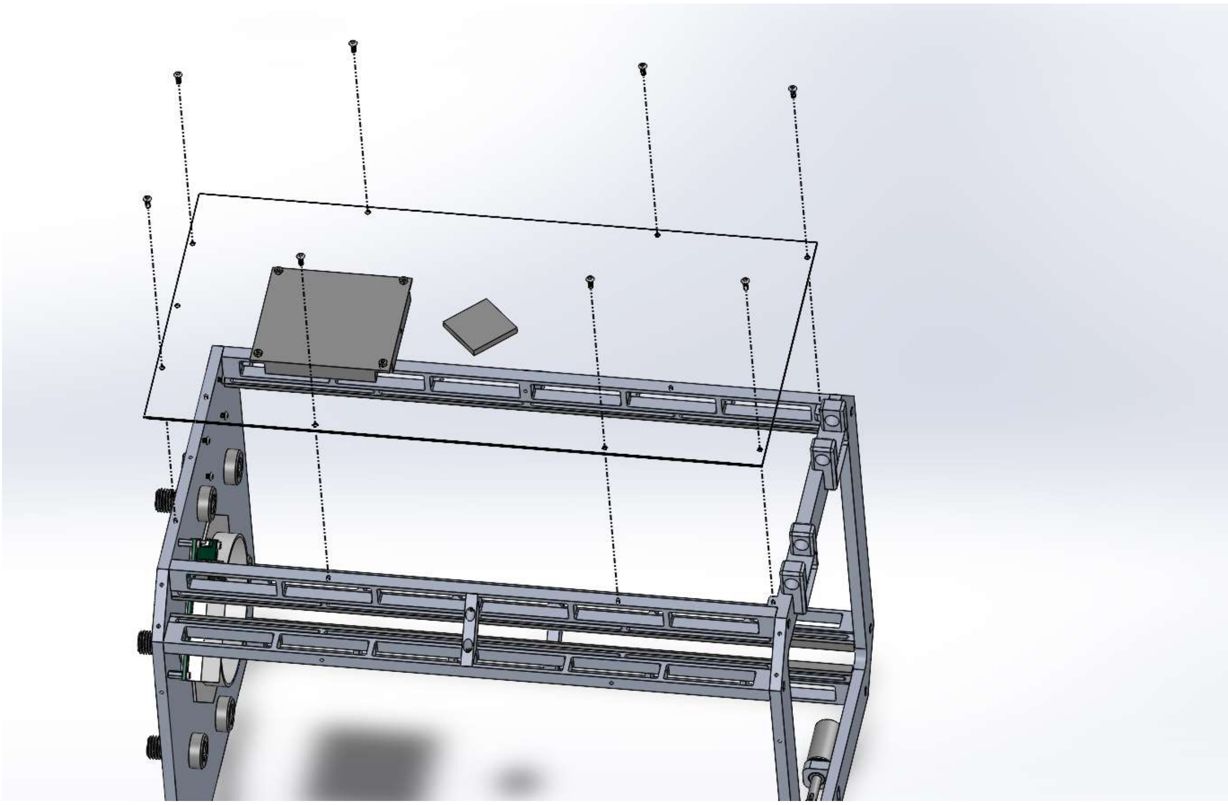
Step 9: Separate from previously assembled components, mount X-Band Transmitter (x1) to Hinge-Face Side Plate (x1) using M2.5x0.45 Head Screw (x4) and Hex Nut (x4).

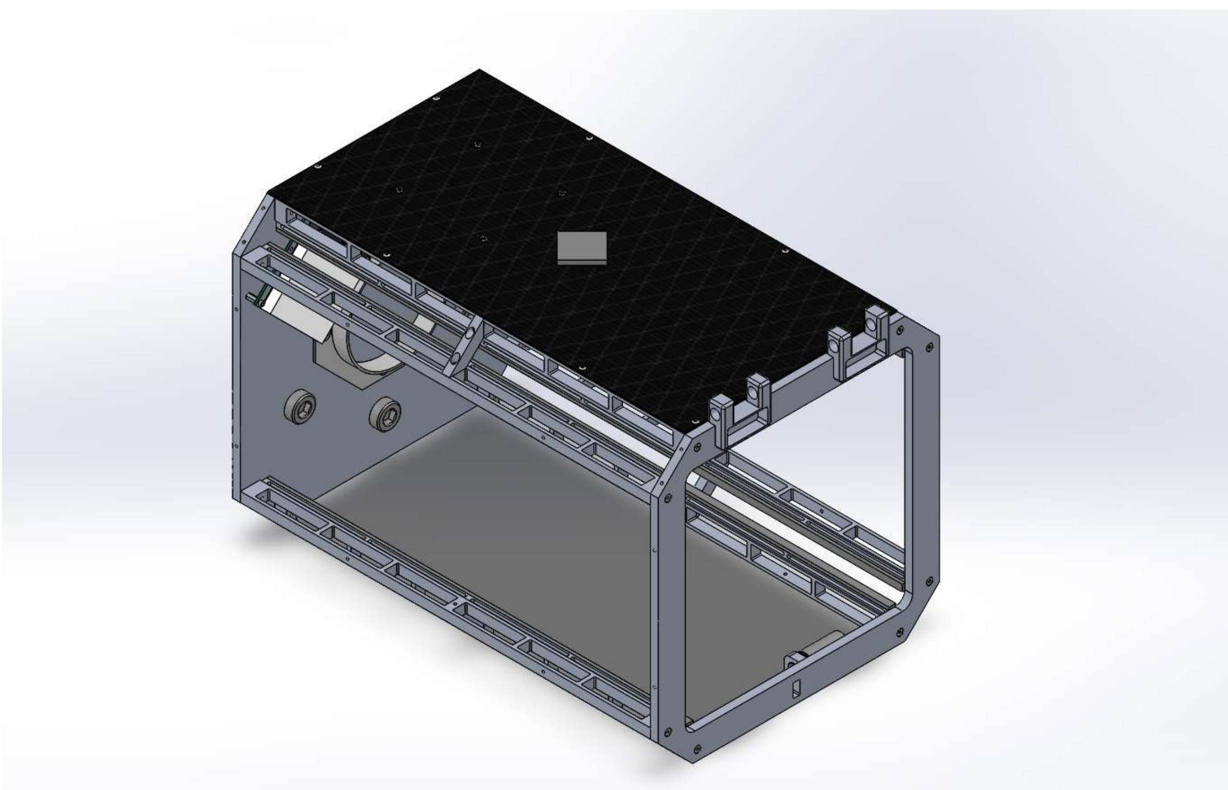


Step 10: Mount X-Band Patch Antenna (x1) to Hinge-Face Side Plate (x1) with an adhesive.

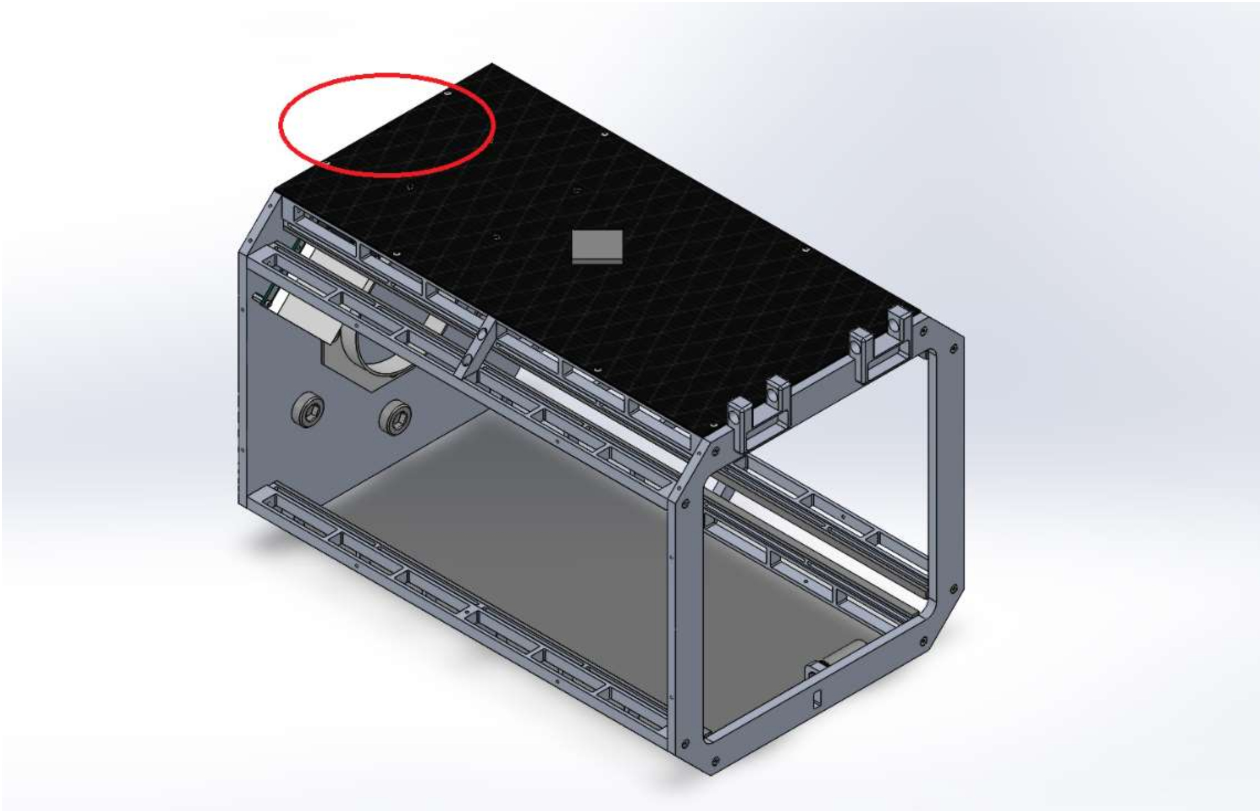


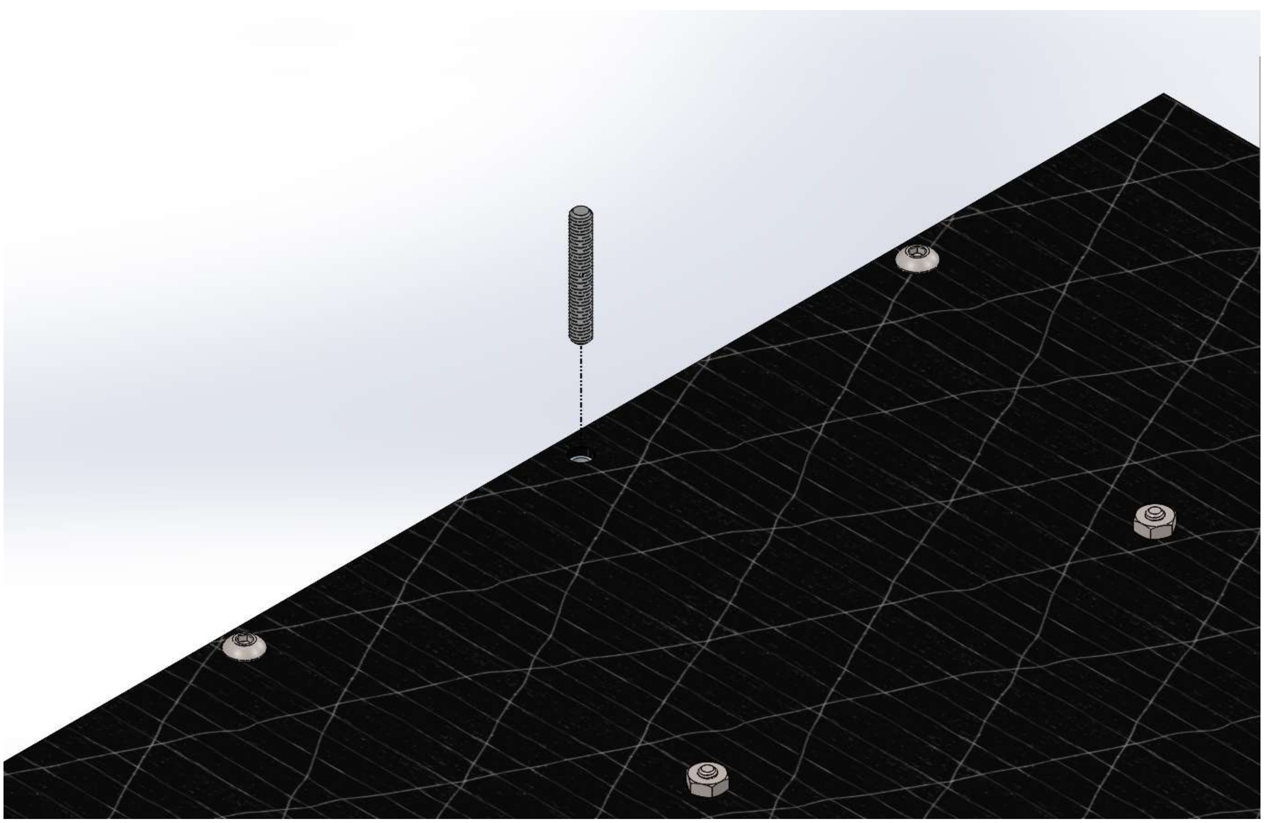
Step 11: Mount Hinge-Face Side Plate (x1) to Rail, Base Plate, and Front Plate using M3 Button Head Hex Drive Screws (x8).

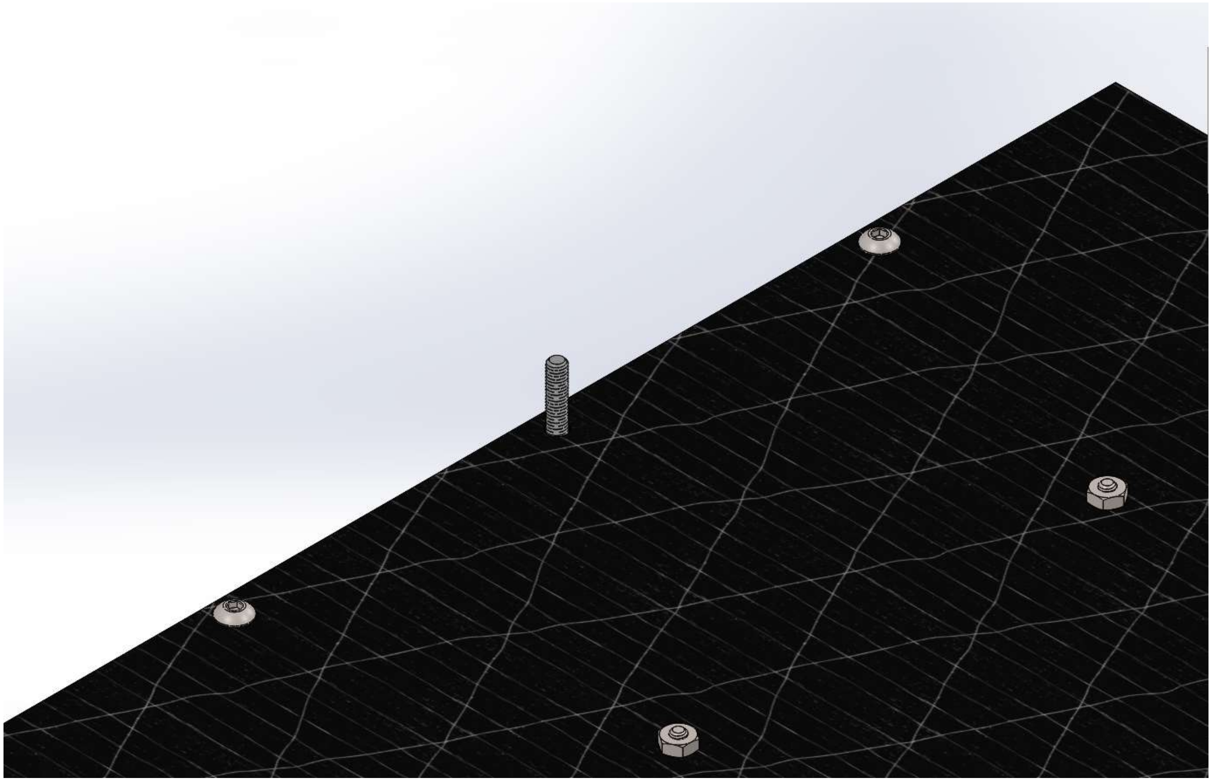




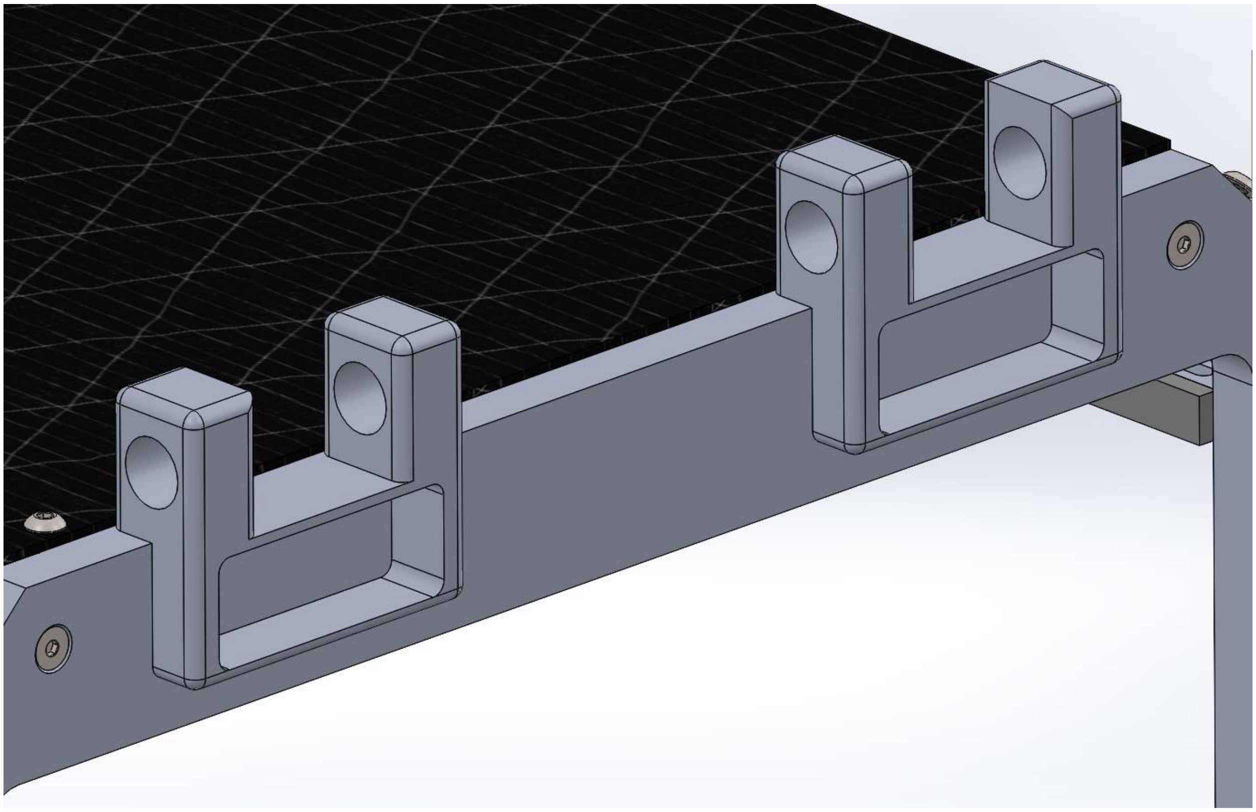
Step 12: Install Threaded Grounding Rod (x1) into Base Plate.

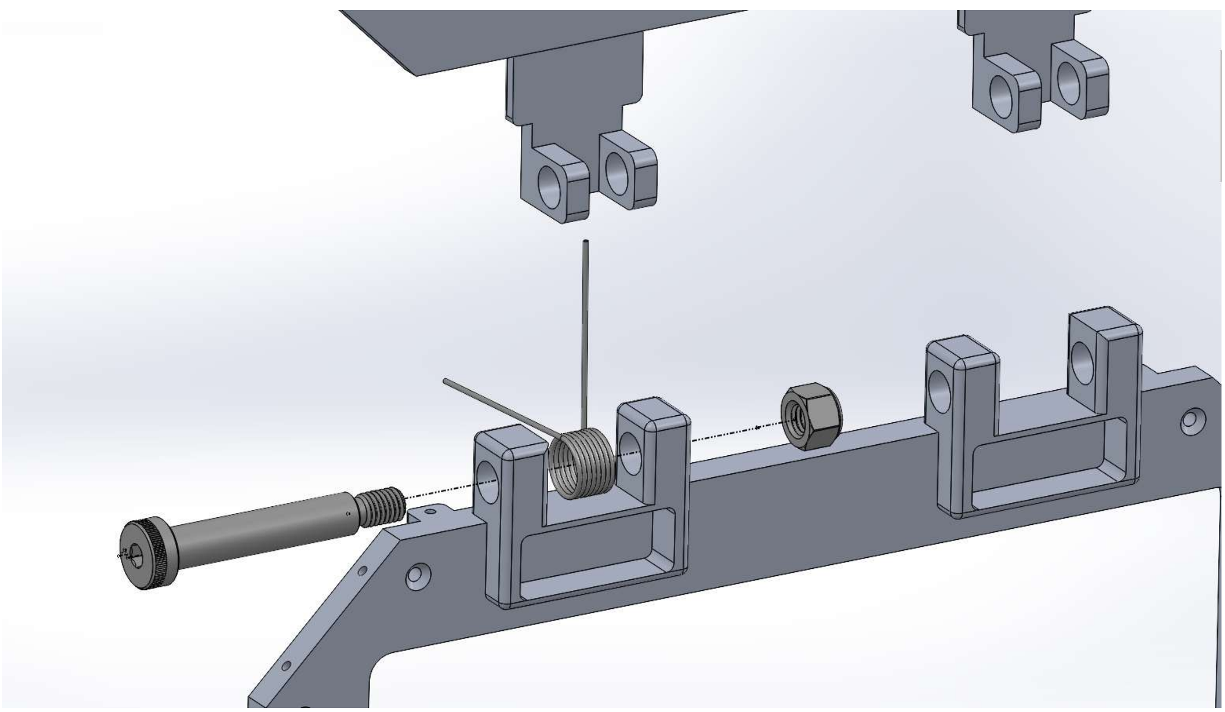






Step 13: Assemble hinges on Door using 10mm Stainless Shoulder Screw (x2), M8x2.5 Locknut (x2), and Torsion Spring (x2).





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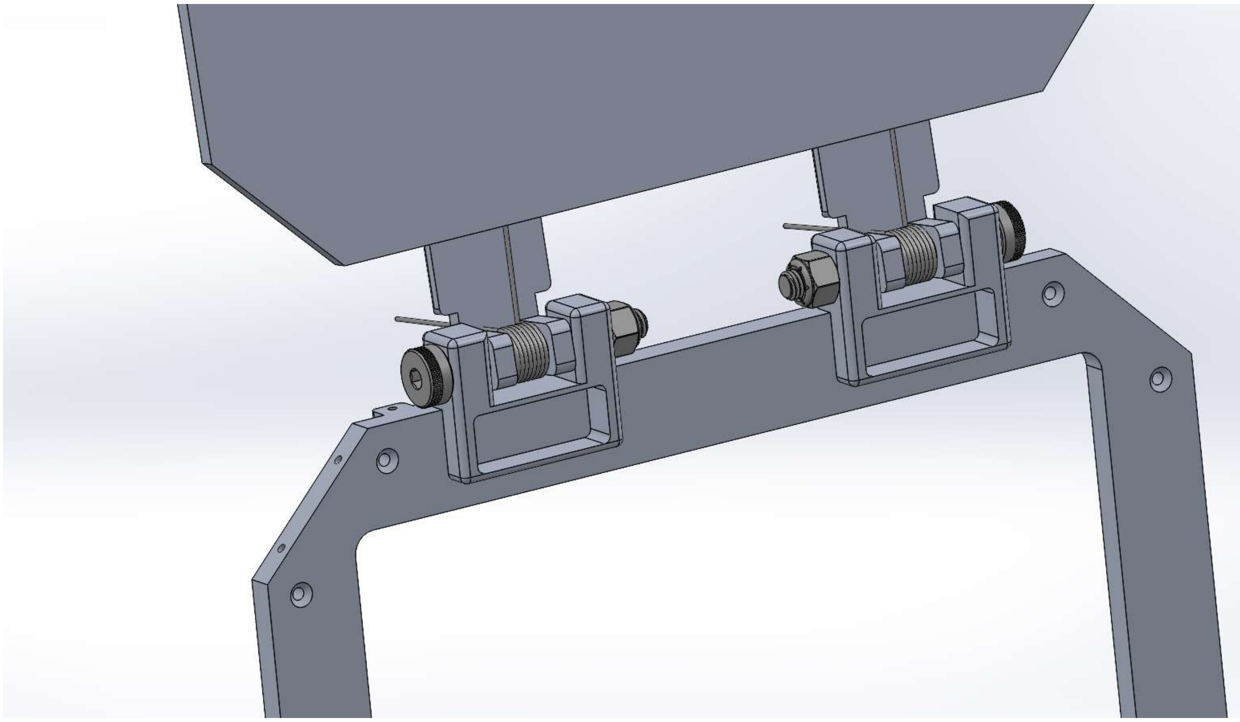

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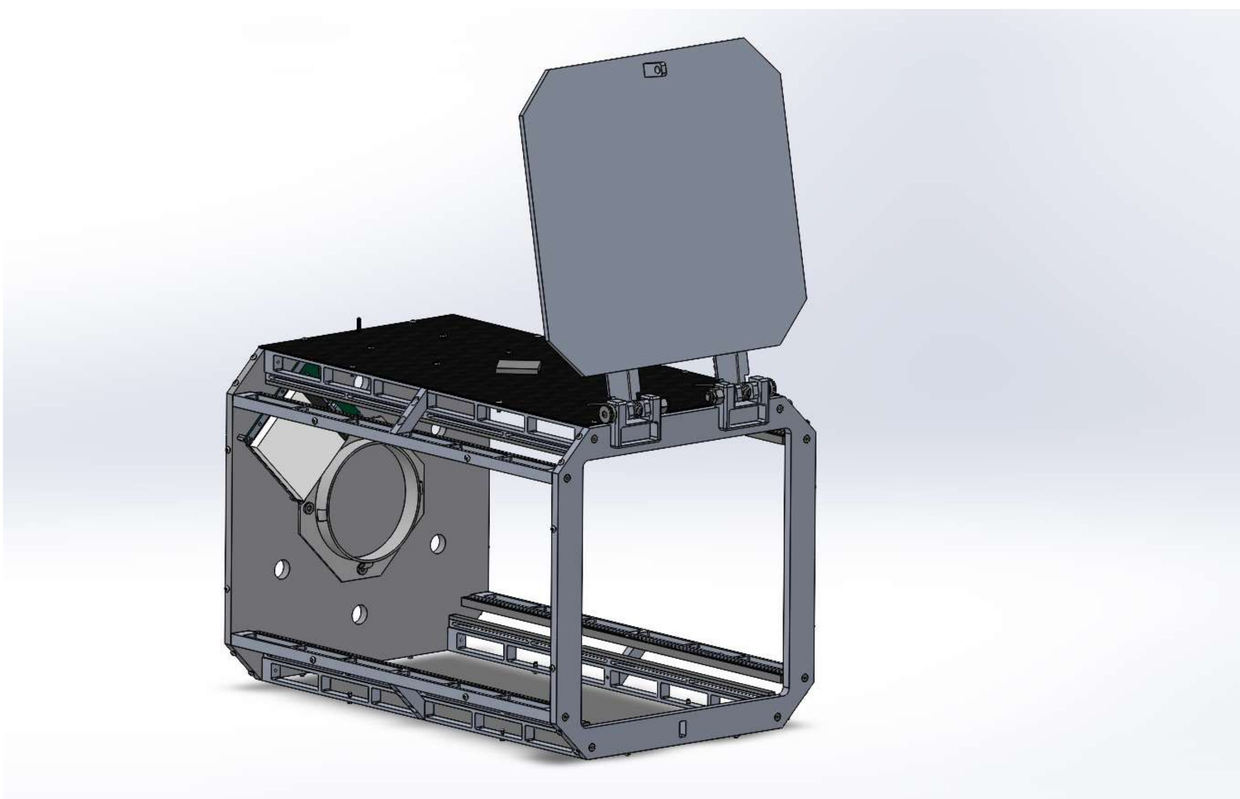
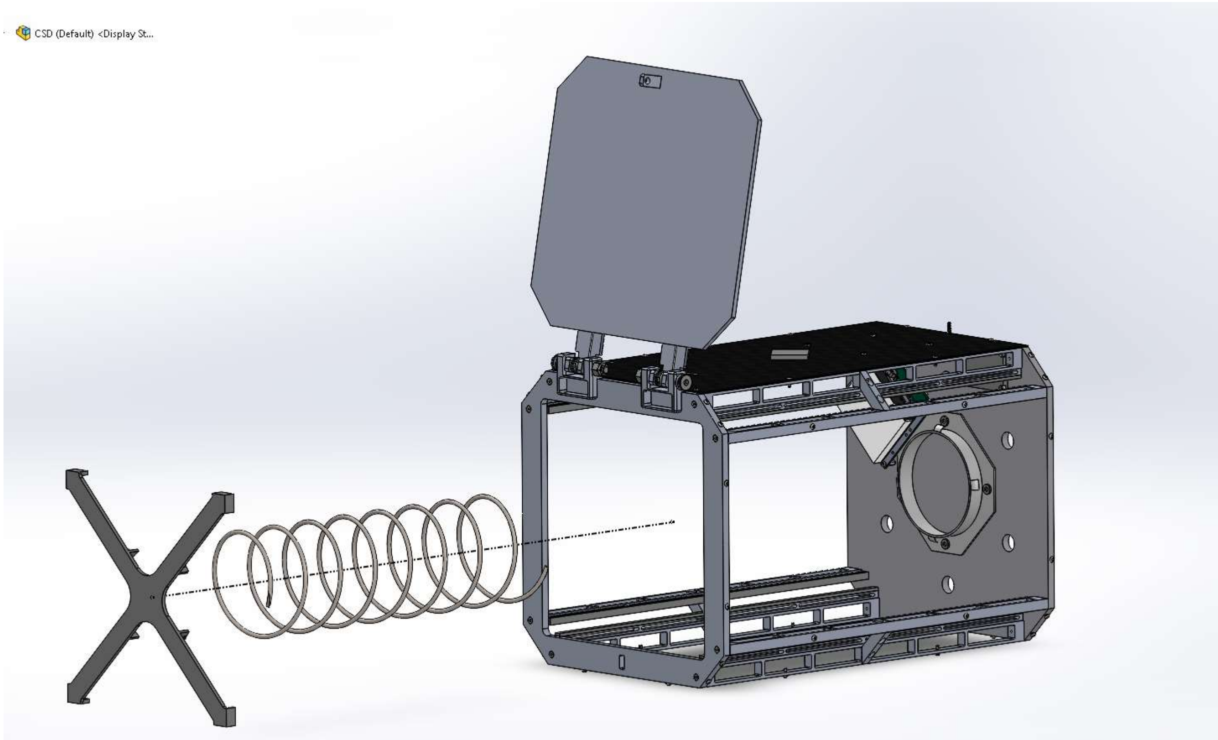
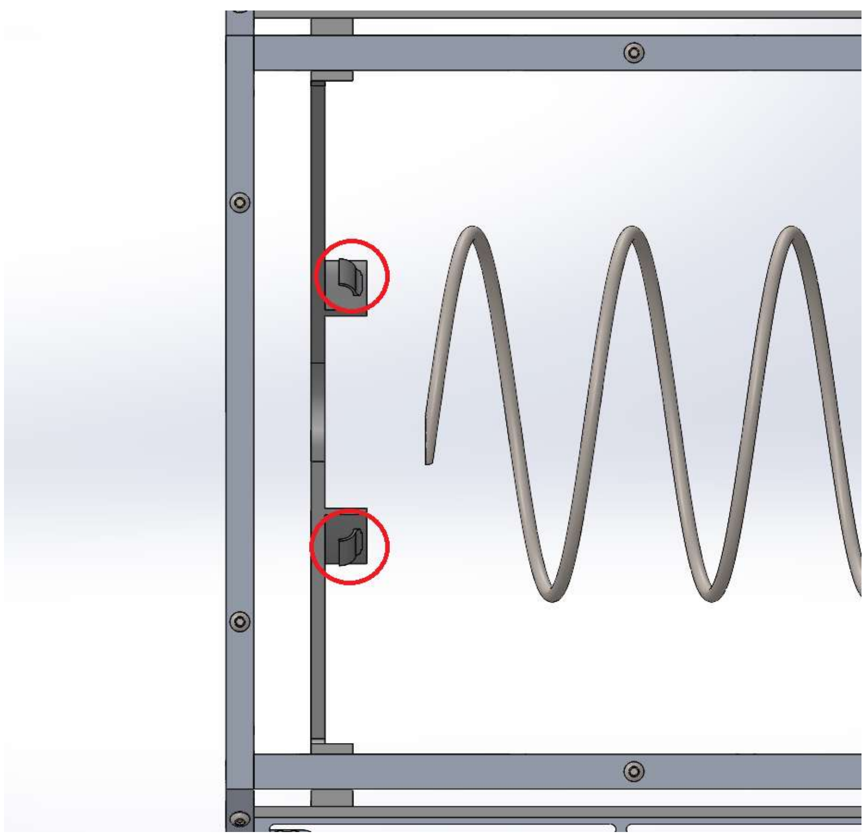
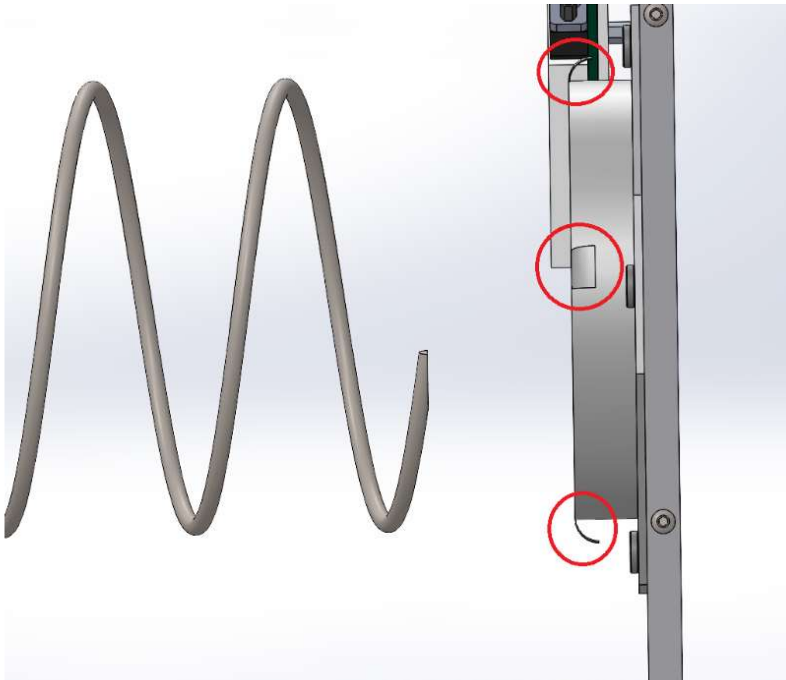


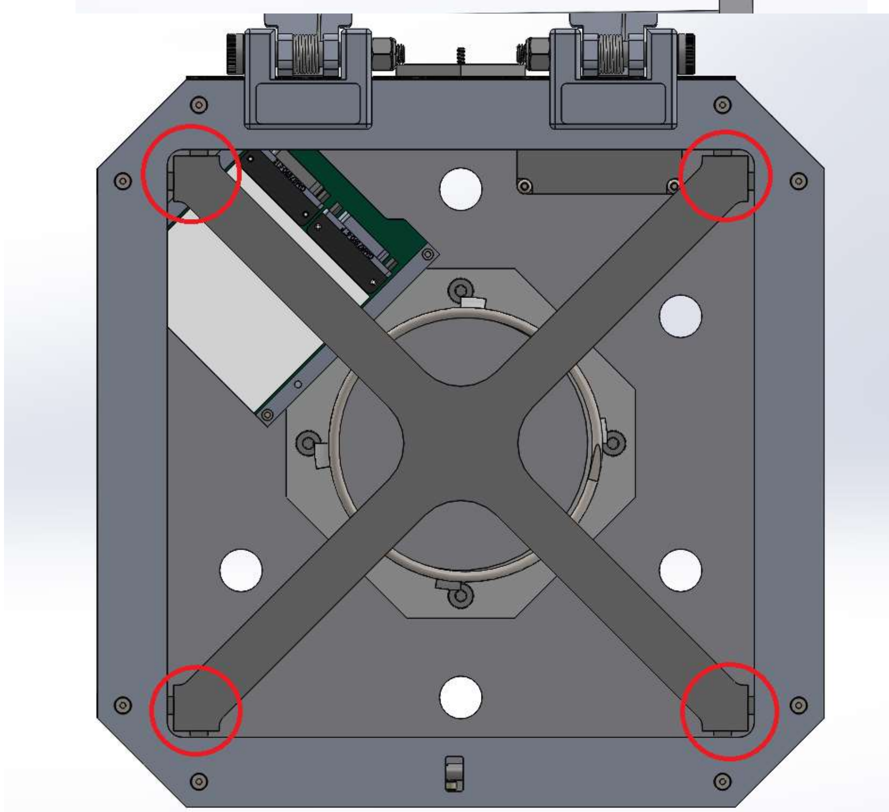
<u>Step 14:</u> Attach Spring (x1) to Pusher Plate (x1) using tab features.



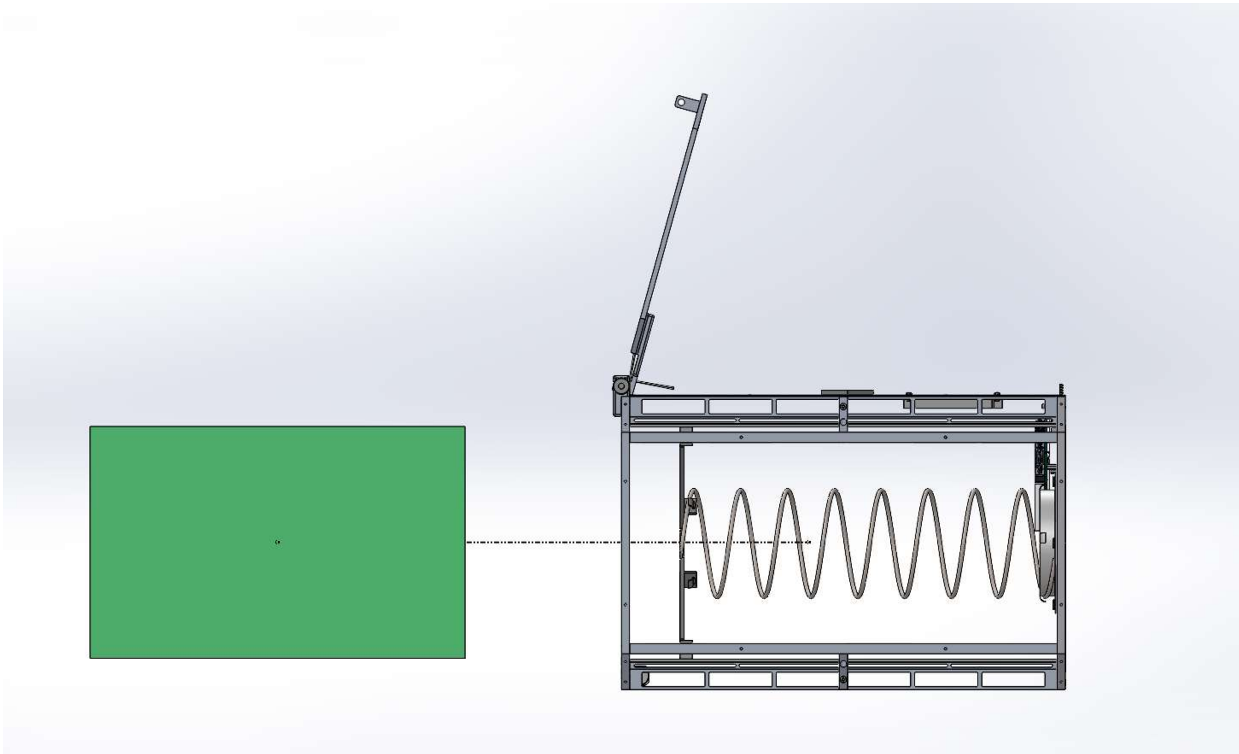


Step 15: Attach Spring to Launcher Base Plate (x1) using tab features. Ensure alignment of Pusher Plate with Rails.

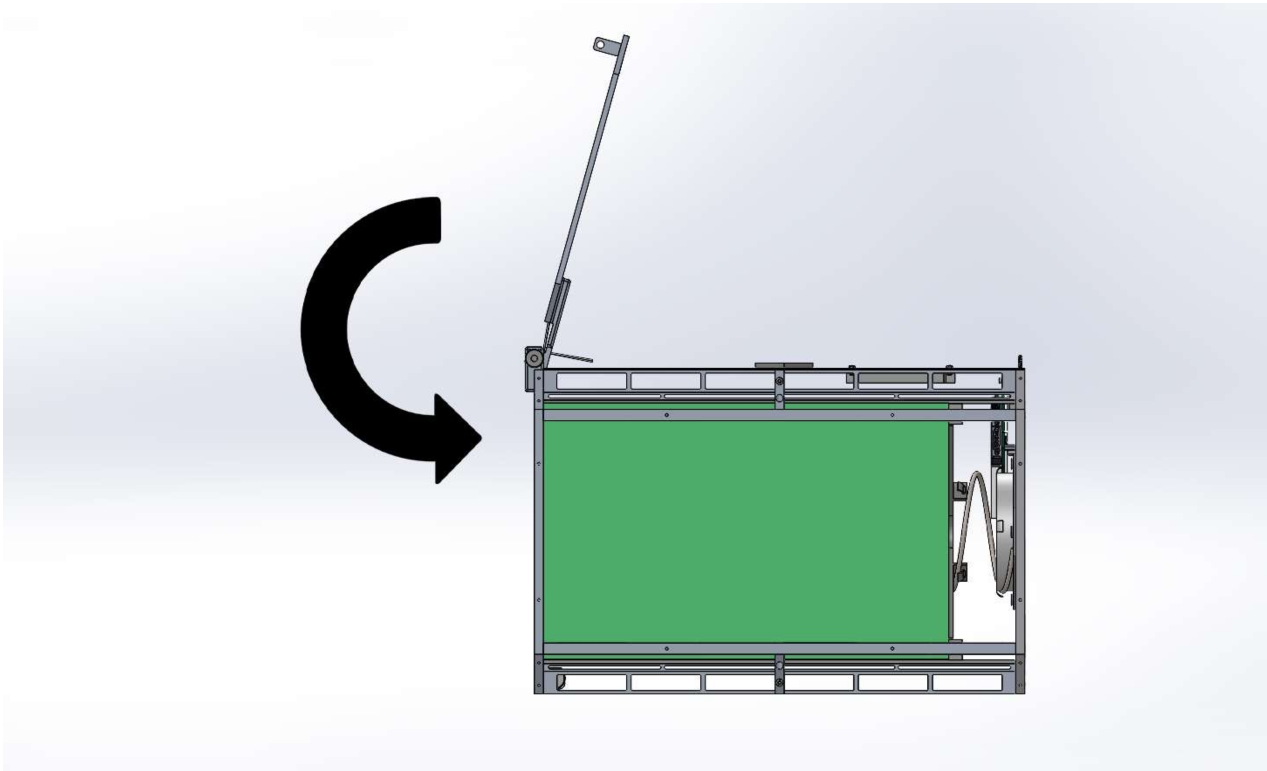


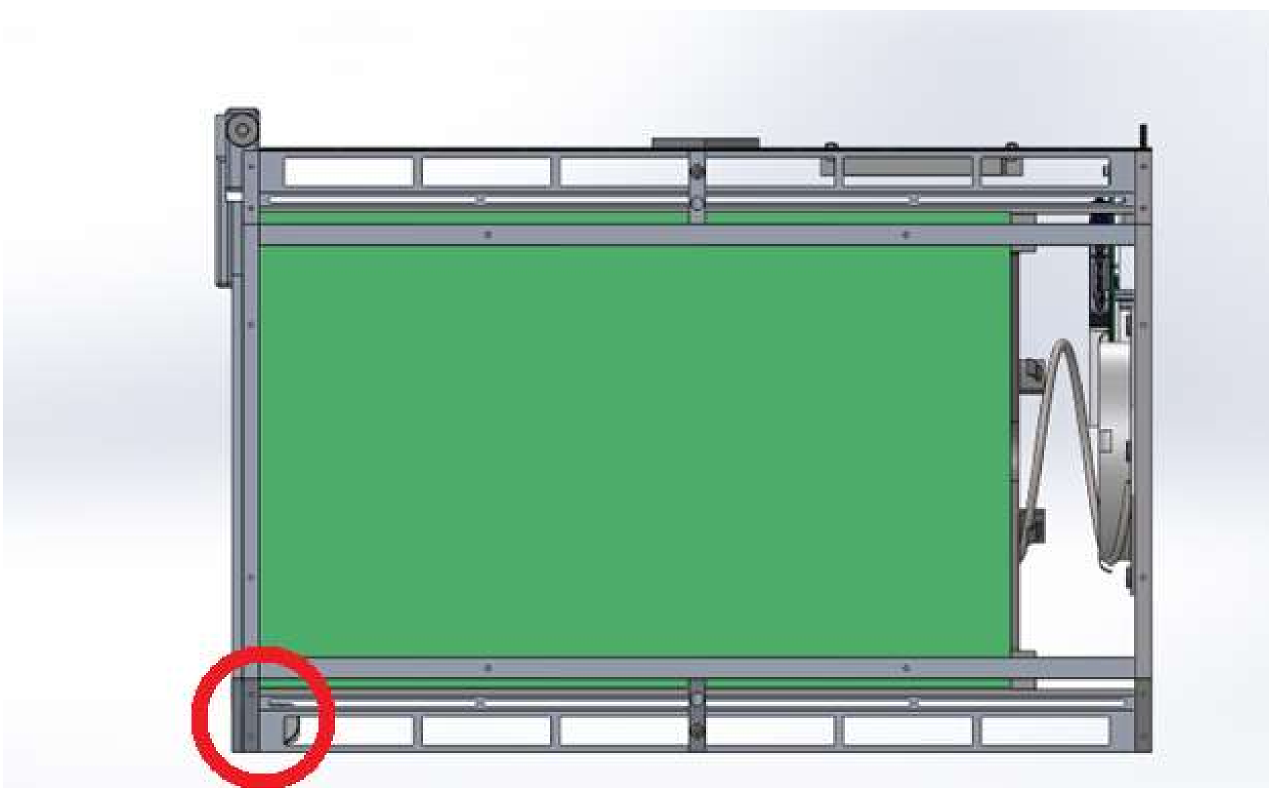


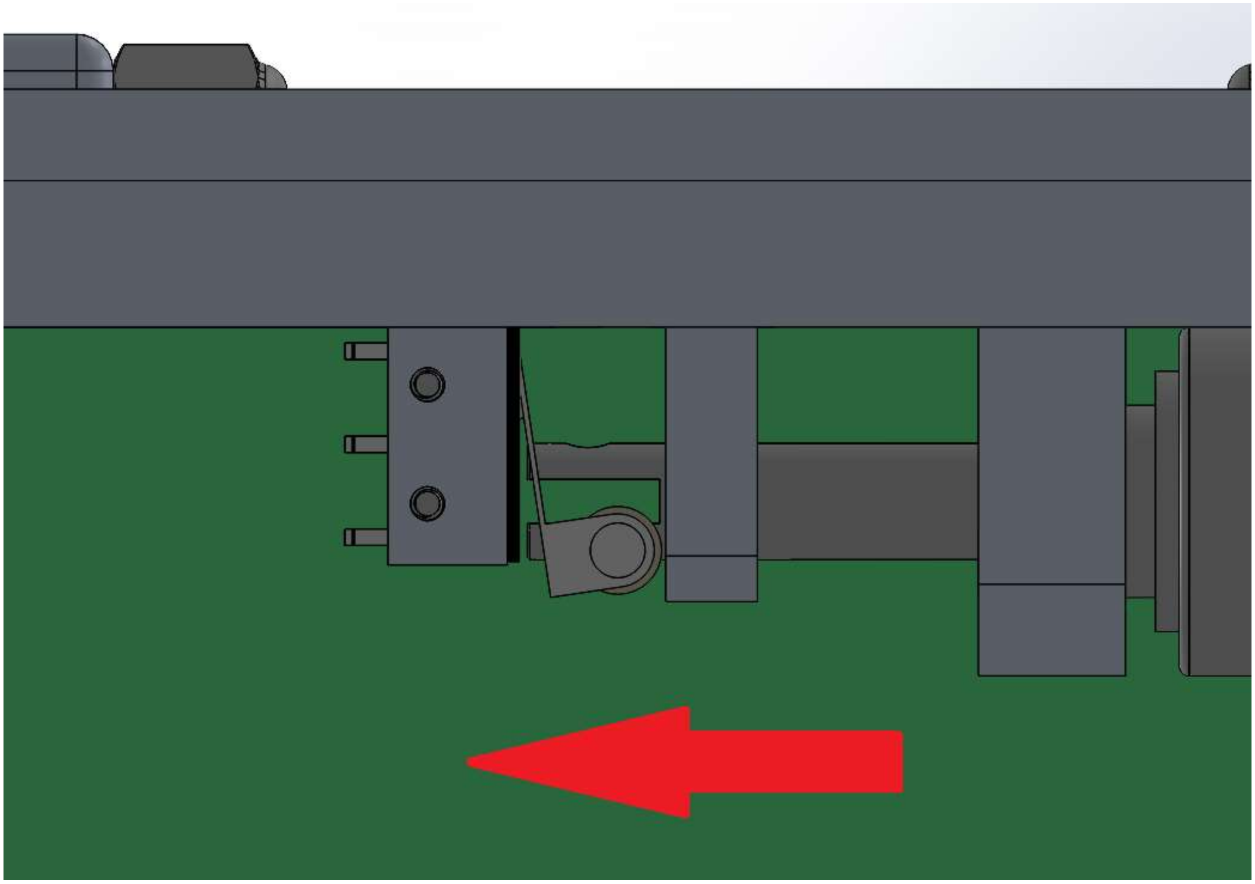
Step 16: Insert CubeSat (x1) into CSD.

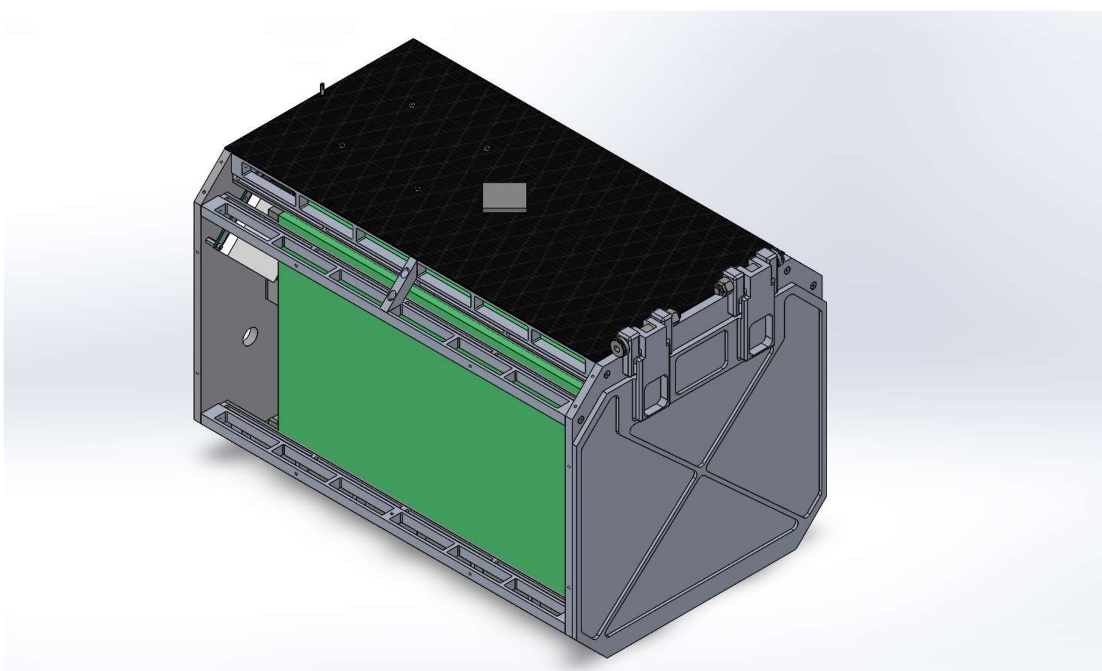


Step 17: Close Door and pull Linear Solenoid pin to secure door in place and close Omron Limit Switch.

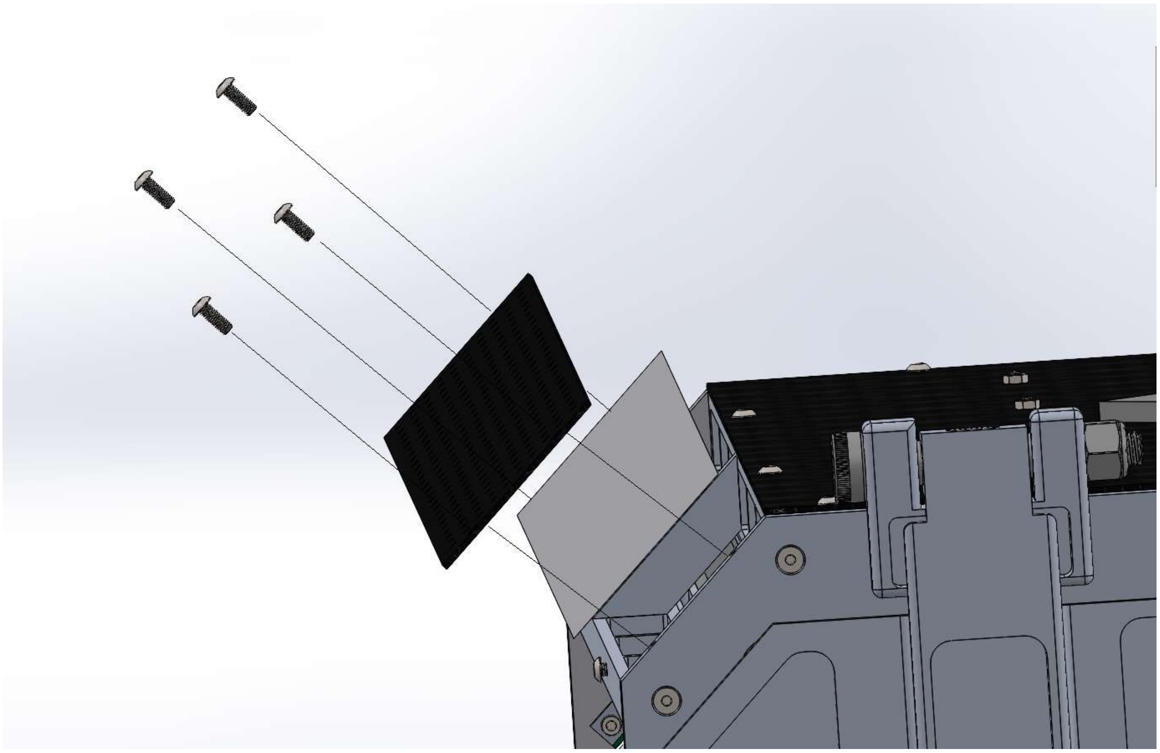


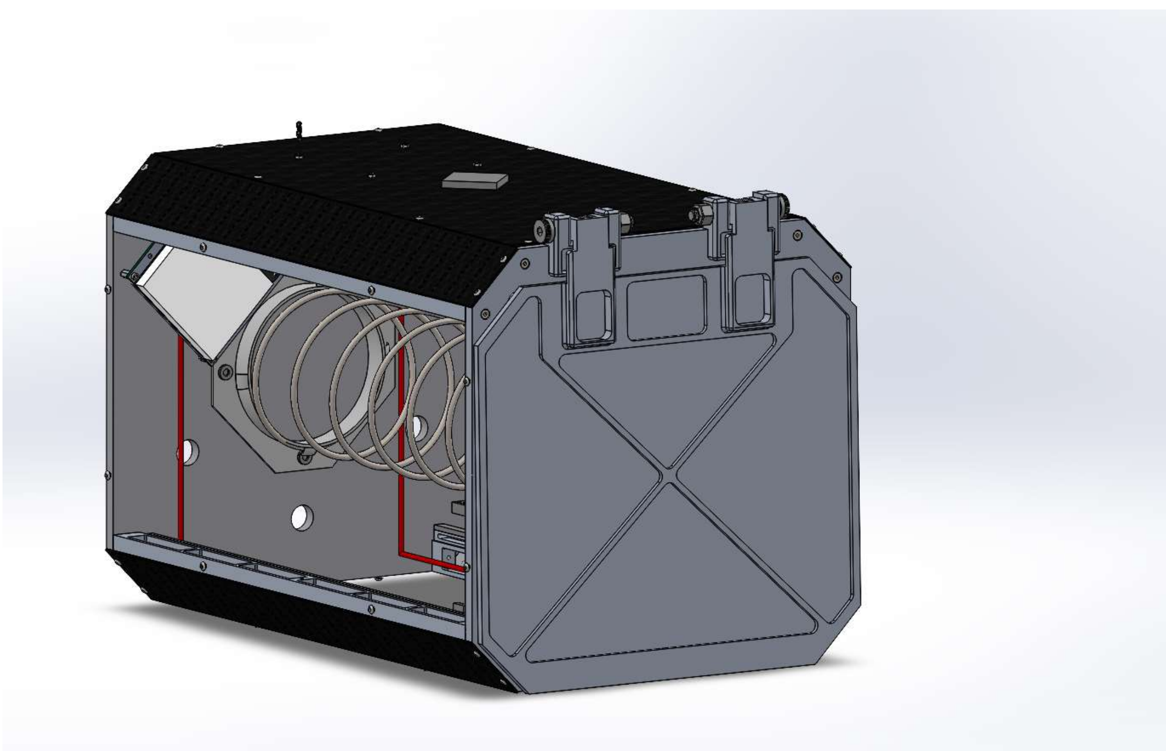




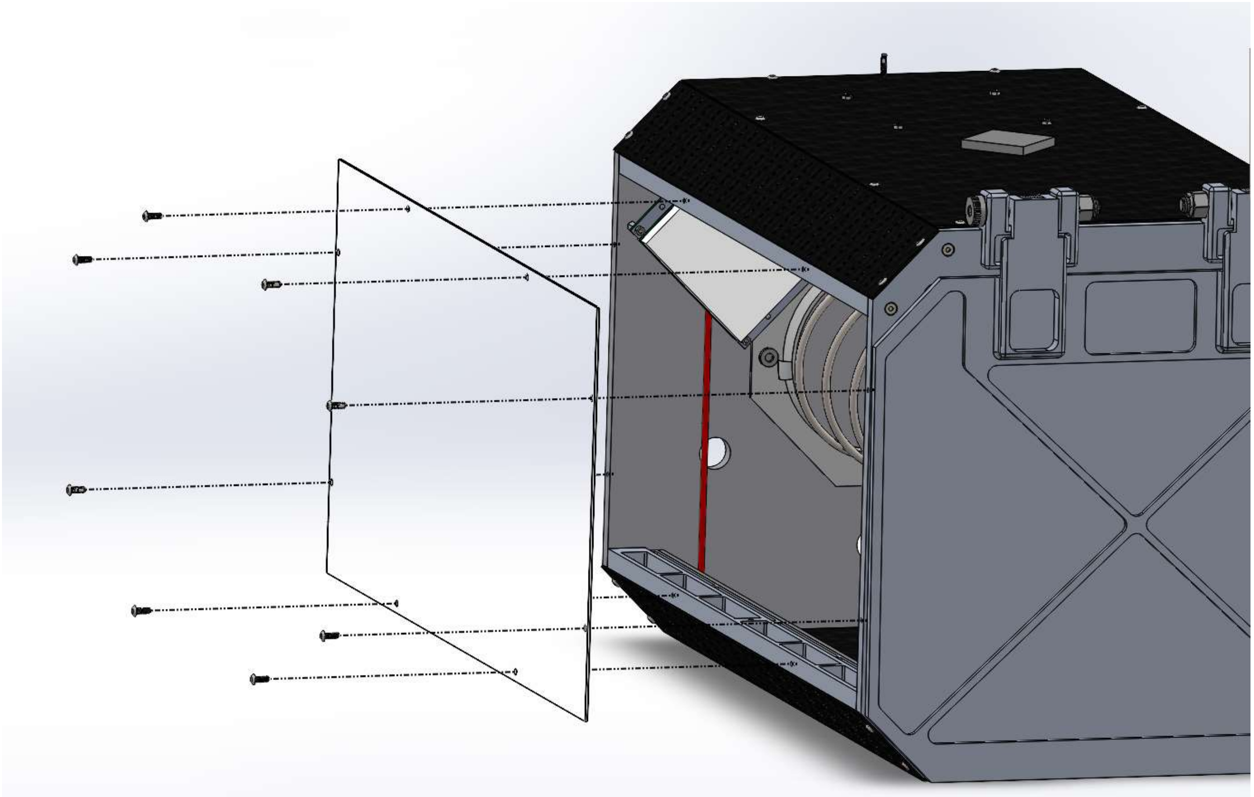


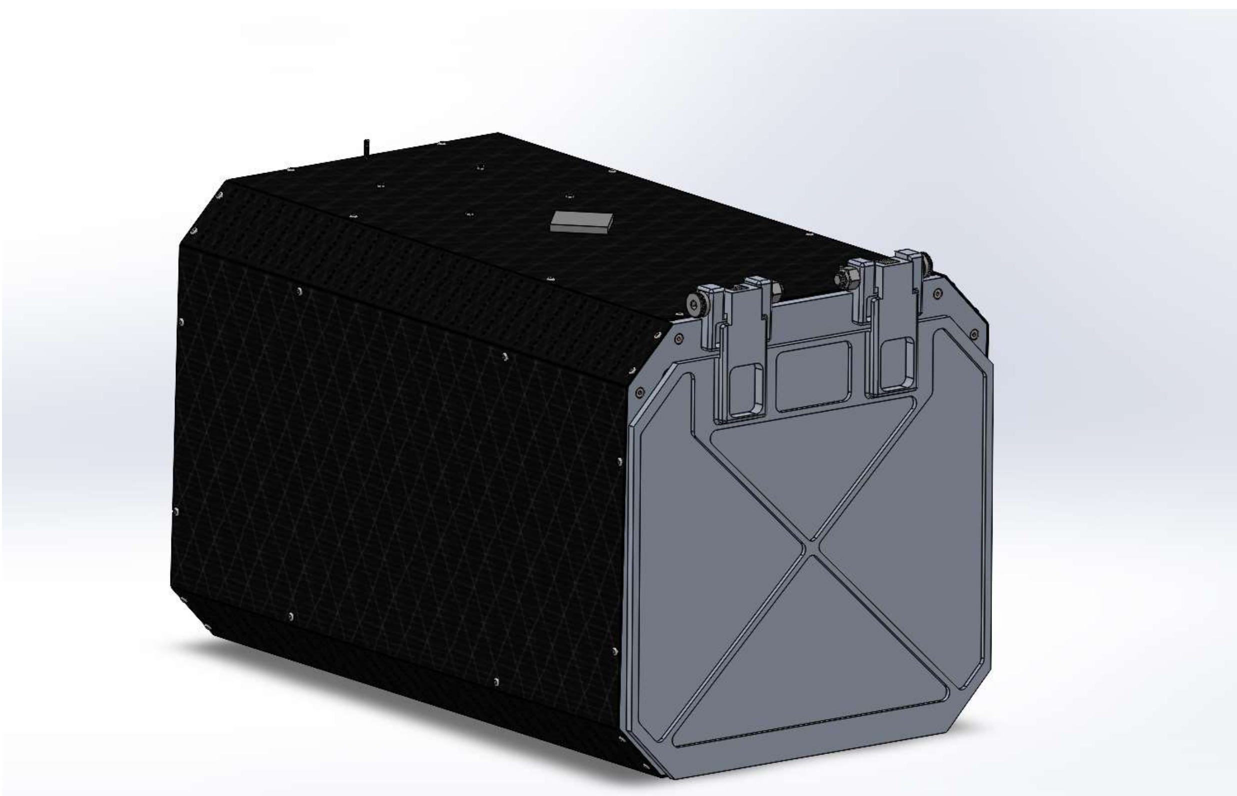
Step 18: Align Aluminum Mesh (x4) with holes up to Ventilation Grate (x4) and install aligned pieces onto Frontplate and Backplate chamfered surfaces (at each corner) using M3 Button Head Hex Drive Screws (x16).





Step 19: Install remaining Side Plates (x3) onto exposed Rails using M3 Button Head Hex Drive Screws (x24).





B. Manual Handling and Insertion Times

Utilizing the Boothroyd and Dewhurst Manual Handling and Insertion Times, every step of the full system's assembly is given a process time, based on the type of process, α and β angles, and conditions of the step.

Step #	Task	H/I Process	α	β	$\alpha + \beta$ Sum	H/I Code	Process Time	Justification
1	Handle Base Plate	H	360	0	360	(0,2)	1.88	
2	Handle Launcher Base	H	360	0	360	(0,2)	1.88	
3	Handle Head Screw	H	180	0	180	(0,1)	1.43	
4	Insert Head Screw into Base Plate and Launcher Base	I				(0,2)	2.50	
5	Handle Head Screw	H	180	0	180	(0,1)	1.43	
6	Insert Head Screw into Base Plate and Launcher Base	I				(0,2)	2.50	
7	Handle Head Screw	H	180	0	180	(0,1)	1.43	
8	Insert Head Screw into Base Plate and Launcher Base	I				(0,2)	2.50	
9	Handle Head Screw	H	180	0	180	(0,1)	1.43	
10	Insert Head Screw into Base Plate and Launcher Base	I				(0,2)	2.50	
11	Handle Locknut	H	180	0	180	(0,1)	1.43	
12	Insert Locknut onto End of Head Screw	I				(0,2)	2.50	
13	Handle Locknut	H	180	0	180	(0,1)	1.43	
14	Insert Locknut onto End of Head Screw	I				(0,2)	2.50	
15	Handle Locknut	H	180	0	180	(0,1)	1.43	
16	Insert Locknut onto End of Head Screw	I				(0,2)	2.50	
17	Handle Locknut	H	180	0	180	(0,1)	1.43	
18	Insert Locknut onto End of Head Screw	I				(0,2)	2.50	
19	Handle Rail Bar	H	360	0		(1,1)	1.8	
20	Handle Rail Foam	H	360	180	540	(2,7)	3.38	Adhesive applied on foam and rail bar contact surface
21	Insert Rail Foam onto Rail Bar	I				(1,1)	5.00	Adhesive applied on foam and rail bar contact surface
22	Handle Rail Bar	H	360	0		(1,1)	1.8	
23	Handle Rail Foam	H	360	180	540	(2,7)	3.38	Adhesive applied on foam and rail bar contact surface
24	Insert Rail Foam onto Rail Bar	I				(1,1)	5.00	Adhesive applied on foam and rail bar contact surface
25	Handle Rail Bar	H	360	0		(1,1)	1.8	
26	Handle Rail Foam	H	360	180	540	(2,7)	3.38	Adhesive applied on foam and rail bar contact surface
27	Insert Rail Foam onto Rail Bar	I				(1,1)	5	Adhesive applied on foam and rail bar contact surface
28	Handle Rail Bar	H	360	0		(1,1)	1.8	

29	Handle Rail Foam	H	360	180	540	(2,7)	3.38	Adhesive applied on foam and rail bar contact surface
30	Insert Rail Foam onto Rail Bar	I				(1,1)	5	Adhesive applied on foam and rail bar contact surface
31	Handle Rail Bar	H	360	0		(1,1)	1.8	
32	Handle Rail Foam	H	360	180	540	(2,7)	3.38	Adhesive applied on foam and rail bar contact surface
33	Insert Rail Foam onto Rail Bar	I				(1,1)	5	Adhesive applied on foam and rail bar contact surface
34	Handle Rail Bar	H	360	0		(1,1)	1.8	
35	Handle Rail Foam	H	360	180	540	(2,7)	3.38	Adhesive applied on foam and rail bar contact surface
36	Insert Rail Foam onto Rail Bar	I				(1,1)	5	Adhesive applied on foam and rail bar contact surface
37	Handle Rail Bar	H	360	0		(1,1)	1.8	
38	Handle Rail Foam	H	360	180	540	(2,7)	3.38	Adhesive applied on foam and rail bar contact surface
39	Insert Rail Foam onto Rail Bar	I				(1,1)	5	Adhesive applied on foam and rail bar contact surface
40	Handle Rail Bar	H	360	0		(1,1)	1.8	
41	Handle Rail Foam	H	360	180	540	(2,7)	3.38	Adhesive applied on foam and rail bar contact surface
42	Insert Rail Foam onto Rail Bar	I				(1,1)	5	Adhesive applied on foam and rail bar contact surface
43	Handle Rail Bar	H	360	0		(1,1)	1.8	
44	Handle Head Screw	H	180	0	180	(0,1)	1.43	
45	Insert Head Screw into Base Plate and Rail Bar	I				(0,2)	2.5	
46	Handle Rail Bar	H	360	0		(1,1)	1.8	
47	Handle Head Screw	H	180	0	180	(0,1)	1.43	
48	Insert Head Screw into Base Plate and Rail Bar	I				(0,2)	2.5	
49	Handle Rail Bar	H	360	0		(1,1)	1.8	
50	Handle Head Screw	H	180	0	180	(0,1)	1.43	
51	Insert Head Screw into Base Plate and Rail Bar	I				(0,2)	2.5	
52	Handle Rail Bar	H	360	0		(1,1)	1.8	
53	Handle Head Screw	H	180	0	180	(0,1)	1.43	
54	Insert Head Screw into Base Plate and Rail Bar	I				(0,2)	2.5	
55	Handle Rail Bar	H	360	0		(1,1)	1.8	
56	Handle Head Screw	H	180	0	180	(0,1)	1.43	
57	Insert Head Screw into Base Plate and Rail Bar	I				(0,2)	2.5	
58	Handle Rail Bar	H	360	0		(1,1)	1.8	
59	Handle Head Screw	H	180	0	180	(0,1)	1.43	
60	Insert Head Screw into Base Plate and Rail Bar	I				(0,2)	2.5	

61	Handle Rail Bar	H	360	0		(1,1)	1.8	
62	Handle Head Screw	H	180	0	180	(0,1)	1.43	
63	Insert Head Screw into Base Plate and Rail Bar	I				(0,2)	2.5	
64	Handle Rail Bar	H	360	0		(1,1)	1.8	
65	Handle Head Screw	H	180	0	180	(0,1)	1.43	
66	Insert Head Screw into Base Plate and Rail Bar	I				(0,2)	2.5	
67	Handle Angle Bracket	H	360	180	540	(2,1)	2.1	
68	Handle Head Screw	H	180	0	180	(0,1)	1.43	
69	Insert Head Screw into Angle Bracket and Head Screw	I				(0,2)	2.5	
70	Handle Head Screw	H	180	0	180	(0,1)	1.43	
71	Insert Head Screw into Angle Bracket and Head Screw	I				(0,2)	2.5	
72	Handle Angle Bracket	H	360	180	540	(2,1)	2.1	
73	Handle Head Screw	H	180	0	180	(0,1)	1.43	
74	Insert Head Screw into Angle Bracket and Head Screw	I				(0,2)	2.5	
75	Handle Head Screw	H	180	0	180	(0,1)	1.43	
76	Insert Head Screw into Angle Bracket and Head Screw	I				(0,2)	2.5	
77	Handle Angle Bracket	H	360	180	540	(2,1)	2.1	
78	Handle Head Screw	H	180	0	180	(0,1)	1.43	
79	Insert Head Screw into Angle Bracket and Head Screw	I				(0,2)	2.5	
	Handle Head Screw	H	180	0	180	(0,1)	1.43	
	Insert Head Screw into Angle Bracket and Head Screw	I				(0,2)	2.5	
	Handle Angle Bracket	H	360	180	540	(2,1)	2.1	
	Handle Head Screw	H	180	0	180	(0,1)	1.43	
	Insert Head Screw into Angle Bracket and Head Screw	I				(0,2)	2.5	
	Handle Head Screw	H	180	0	180	(0,1)	1.43	
	Insert Head Screw into Angle Bracket and Head Screw	I				(0,2)	2.5	
	Handle Partial CSD Assembly	H	360	90	450	(2,2)	2.55	
80	Handle Head Screw	H	180	0	180	(0,1)	1.43	
81	Insert Head Screw into Base Plate and Launch Vehicle	I				(0,2)	2.5	
82	Handle Head Screw	H	180	0	180	(0,1)	1.43	
83	Insert Head Screw into	I				(0,2)	2.5	

	Base Plate and Launch Vehicle							
84	Handle Head Screw	H	180	0	180	(0,1)	1.43	
85	Insert Head Screw into Base Plate and Launch Vehicle	I				(0,2)	2.5	
86	Handle Head Screw	H	180	0	180	(0,1)	1.43	
87	Insert Head Screw into Base Plate and Launch Vehicle	I				(0,2)	2.5	
88	Handle Head Screw	H	180	0	180	(0,1)	1.43	
89	Insert Head Screw into Base Plate and Launch Vehicle	I				(0,2)	2.5	
90	Handle Head Screw	H	180	0	180	(0,1)	1.43	
91	Insert Head Screw into Base Plate and Launch Vehicle	I				(0,2)	2.5	
92	Handle Ibeos EPS	H	360	0	360	(1,6)	2.57	
93	Handle Head Screw	H	180	0	180	(0,1)	1.43	
94	Insert Head Screw into Ibeos EPS	I				(0,2)	2.5	
95	Handle Standoff	H	180	0	180	(0,1)	1.43	
96	Insert Standoff onto Head Screw	I				(0,2)	2.5	
97	Handle Head Screw	H	180	0	180	(0,1)	1.43	
98	Insert Head Screw into Ibeos EPS	I				(0,2)	2.5	
99	Handle Standoff	H	180	0	180	(0,1)	1.43	
100	Insert Standoff onto Head Screw	I				(0,2)	2.5	
101	Handle Head Screw	H	180	0	180	(0,1)	1.43	
102	Insert Head Screw into Ibeos EPS	I				(0,2)	2.5	
103	Handle Standoff	H	180	0	180	(0,1)	1.43	
104	Insert Standoff onto Head Screw	I				(0,2)	2.5	
105	Handle Head Screw	H	180	0	180	(0,1)	1.43	
106	Insert Head Screw into Ibeos EPS	I				(0,2)	2.5	
107	Handle Standoff	H	180	0	180	(0,1)	1.43	
108	Insert Standoff onto Head Screw	I				(0,2)	2.5	
109	Insert Head Screw into Base Plate	I				(0,2)	2.5	
110	Insert Head Screw into Base Plate	I				(0,2)	2.5	
111	Insert Head Screw into Base Plate	I				(0,2)	2.5	
112	Insert Head Screw into Base Plate	I				(0,2)	2.5	
113	Handle Nanomind A3200	H	360	180	540	(2,3)	2.36	
114	Handle Hex Head	H	180	0	180	(0,1)	1.43	

	Screw							
115	Insert Hex Head Screw into Nanomind A3200 and Base Plate	I				(0,2)	2.5	
116	Handle Hex Head Screw	H	180	0	180	(0,1)	1.43	
117	Insert Hex Head Screw into Nanomind A3200 and Base Plate	I				(0,2)	2.5	
118	Handle Hex Head Screw	H	180	0	180	(0,1)	1.43	
119	Insert Hex Head Screw into Nanomind A3200 and Base Plate	I				(0,2)	2.5	
120	Handle Hex Head Screw	H	180	0	180	(0,1)	1.43	
121	Insert Hex Head Screw into Nanomind A3200 and Base Plate	I				(0,2)	2.5	
122	Handle Front Plate	H	360	0	360	(1,5)	2.25	
123	Handle Linear Solenoid	H	180	0	180	(1,2)	2.25	
124	Insert Linear Solenoid into Front Plate	I				(1,2)	5	
125	Handle Omron Limit Switch	H	360	0	360	(1,4)	2.55	
126	Handle Head Screw	H	180	0	180	(0,1)	1.43	
127	Insert Head Screw into Omron Limit Switch and Front Plate	I				(0,2)	2.5	
128	Handle Head Screw	H	180	0	180	(0,1)	1.43	
129	Insert Head Screw into Omron Limit Switch and Front Plate	I				(0,2)	2.5	
130	Handle Front Plate	H	360	0	360			
131	Handle Flat Head Screw	H	180	0	180	(0,1)	1.43	
132	Insert Screw into Front Plate and Rail Bar	I				(0,2)	2.5	
133	Handle Flat Head Screw	H	180	0	180	(0,1)	1.43	
134	Insert Screw into Front Plate and Rail Bar	I				(0,2)	2.5	
135	Handle Flat Head Screw	H	180	0	180	(0,1)	1.43	
136	Insert Screw into Front Plate and Rail Bar	I				(0,2)	2.5	
137	Handle Flat Head Screw	H	180	0	180	(0,1)	1.43	
138	Insert Screw into Front Plate and Rail Bar	I				(0,2)	2.5	
139	Handle Flat Head Screw	H	180	0	180	(0,1)	1.43	
140	Insert Screw into Front Plate and Rail Bar	I				(0,2)	2.5	

141	Handle Flat Head Screw	H	180	0	180	(0,1)	1.43	
142	Insert Screw into Front Plate and Rail Bar	I				(0,2)	2.5	
143	Handle Flat Head Screw	H	180	0	180	(0,1)	1.43	
144	Insert Screw into Front Plate and Rail Bar	I				(0,2)	2.5	
145	Handle Flat Head Screw	H	180	0	180	(0,1)	1.43	
146	Insert Screw into Front Plate and Rail Bar	I				(0,2)	2.5	
148	Handle Wiring	H	360	180	540	(4,4)	5.6	
149	Insert Wires onto Solenoid and Limit Switch	I				(4,3)	7.5	
151	Handle Hinge-Face Side Plate	H	360	0	360	(1,4)	2.55	
152	Handle X-Band Transmitter	H	360	0	360	(1,4)	2.55	
153	Handle Socket Head Screw	H	180	0	180	(0,1)	1.43	
154	Insert Socket Head Screw	I				(0,2)	2.5	
155	Handle Socket Head Screw	H	180	0	180	(0,1)	1.43	
156	Insert Socket Head Screw	I				(0,2)	2.5	
157	Handle Socket Head Screw	H	180	0	180	(0,1)	1.43	
158	Insert Socket Head Screw	I				(0,2)	2.5	
159	Handle Socket Head Screw	H	180	0	180	(0,1)	1.43	
160	Insert Socket Head Screw	I				(0,2)	2.5	
161	Handle Hex Nut	H	180	0	180	(0,1)	1.43	
162	Insert Hex Nut onto Socket Head Screw	I				(0,2)	2.5	
163	Handle Hex Nut	H	180	0	180	(0,1)	1.43	
164	Insert Hex Nut onto Socket Head Screw	I				(0,2)	2.5	
165	Handle Hex Nut	H	180	0	180	(0,1)	1.43	
166	Insert Hex Nut onto Socket Head Screw	I				(0,2)	2.5	
167	Handle Hex Nut	H	180	0	180	(0,1)	1.43	
168	Insert Hex Nut onto Socket Head Screw	I				(0,2)	2.5	
169	Handle Patch Antenna	H	360	0	360	(7,4)	7.1	Sticky adhesive
170	Insert Patch Antenna on Side Plate	I				(1,3)	6	Sticky adhesive
171	Handle Wiring	H	360	180	540	(4,1)	6.85	
172	Insert Wiring to X-Band Transmitter and Patch Antenna	I				(3,5)	7	

173	Handle Hinged-Face Side Plate	H	360	0	360	(1,4)	2.55	
174	Handle Button Head Screw	H	180	0	180	(0,1)	1.43	
175	Insert Button Head Screw into Hinged-Face Side Plate and Front Plate	I				(0,2)	2.5	
176	Handle Button Head Screw	H	180	0	180	(0,1)	1.43	
177	Insert Button Head Screw into Hinged-Face Side Plate and Front Plate	I				(0,2)	2.5	
178	Handle Button Head Screw	H	180	0	180	(0,1)	1.43	
179	Insert Button Head Screw into Hinged-Face Side Plate and Back Plate	I				(0,2)	2.5	
180	Handle Button Head Screw	H	180	0	180	(0,1)	1.43	
181	Insert Button Head Screw into Hinged-Face Side Plate and Back Plate	I				(0,2)	2.5	
182	Handle Button Head Screw	H	180	0	180	(0,1)	1.43	
183	Insert Button Head Screw into Hinged-Face Side Plate and Rail Bar	I				(0,2)	2.5	
184	Handle Button Head Screw	H	180	0	180	(0,1)	1.43	
185	Insert Button Head Screw into Hinged-Face Side Plate and Rail Bar	I				(0,2)	2.5	
186	Handle Button Head Screw	H	180	0	180	(0,1)	1.43	
187	Insert Button Head Screw into Hinged-Face Side Plate and Rail Bar	I				(0,2)	2.5	
188	Handle Button Head Screw	H	180	0	180	(0,1)	1.43	
189	Insert Button Head Screw into Hinged-Face Side Plate and Rail Bar	I				(0,2)	2.5	
190	Handle Wiring	H	360	0	360	(8,7)	8.6	Working around rail bars and plates
191	Insert Wiring to X-Band Transmitter and Ibeos EPS	I				(2,3)	7.5	Working around rail bars and plates

192	Handle Wire	H	360	0	360	(8,7)	8.6	Working around rail bars and plates
193	Insert Wiring to X-Band Transmitter and Nanomind A3200	I				(2,3)	7.5	Working around rail bars and plates
194	Handle Threaded Grounding Rod	H	180	0	180	(0,8)	2.45	
195	Insert Threaded Grounding Rod into Base Plate	I				(0,3)	3.50	Rod has no place to grip properly in threading it into CSD
196	Handle Door	H	360	0	360	(1,4)	2.55	
197	Handle Torsion Spring	H	180	0	180	(1,2)	2.25	
198	Insert Torsion Spring into Door's Hinge Space	I				(1,2)	5.00	
199	Handle Shoulder Screw	H	180	0	180	(0,1)	1.43	
200	Insert Shoulder Screw into Door's Hinge and Torsion Spring	I				(0,2)	2.50	
201	Handle Locknut	H	180	0	180	(0,1)	1.43	
202	Insert Locknut onto Shoulder Screw	I				(0,2)	2.50	
203	Handle Torsion Spring	H	180	0	180	(1,2)	2.25	
204	Insert Torsion Spring into Door's Hinge Space	I				(1,2)	5.00	
205	Handle Shoulder Screw	H	180	0	180	(0,1)	1.43	
206	Insert Shoulder Screw into Door's Hinge and Torsion Spring	I				(0,2)	2.5o	
207	Handle Locknut	H	180	0	180	(0,1)	1.43	
208	Insert Locknut onto Shoulder Screw	I				(0,2)	2.5o	
209	Handle Launcher Plate	H	360	0	360	(1,4)	2.55	
210	Handle Launcher Spring	H	180	0	180	(1,2)	2.25	
211	Insert Launcher Spring to Launch Plate	I				(1,2)	5.00	
212	Insert Spring to Launcher Base Plate	I				(1,2)	5.00	
213	Handle CubeSat	H	360	360	720	(9,7)	5.00	Mass is 24kg
214	Insert CubeSat in CSD	I				(9,2)	5.00	Mass is 24kg
215	Handle Door to Closed Position	H	360	0	360	(1,4)	2.55	
216	Handle Solenoid Shaft	H	360	360	720	(3,8)	3.34	Solenoid shaft is small and without grip
217	Insert Solenoid Shaft Out	I				(1,0)	4	Solenoid shaft is small and without grip
218	Handle Wiring Between CubeSat and Electronics on Z-Face	H	360	0	360	(8,7)	8.6	There is some obstruction of space from other parts
219	Insert Wiring Between	I				(2,3)	7.5	There is some obstruction of

	CubeSat and Electronics on Z-Face							space from other parts
220	Handle Aluminum Mesh	H	180	180	360	(2,9)	3.38	
221	Insert Aluminum Mesh to Align with Ventilation Grate	I				(1,1)	5	
222	Handle Aluminum Mesh and Ventilation Grate	H	360	0	360	(1,4)	2.55	
223	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
224	Insert Hex Drive Screw into Ventilation Grate, Aluminum Mesh, and Front Plate	I				(0,2)	2.5	
225	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
226	Insert Hex Drive Screw into Ventilation Grate, Aluminum Mesh, and Front Plate	I				(0,2)	2.5	
227	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
228	Insert Hex Drive Screw into Ventilation Grate, Aluminum Mesh, and Back Plate	I				(0,2)	2.5	
229	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
230	Insert Hex Drive Screw into Ventilation Grate, Aluminum Mesh, and Back Plate	I				(0,2)	2.5	
231	Handle Aluminum Mesh	H	360	0	360	(1,4)	2.55	
232	Insert Aluminum Mesh to Align with Ventilation Grate	H	180	0	180	(0,1)	1.43	
233	Handle Aluminum Mesh and Ventilation Grate	I				(0,2)	2.5	
234	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
235	Insert Hex Drive Screw into Ventilation Grate, Aluminum Mesh, and Front Plate	I				(0,2)	2.5	
236	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
237	Insert Hex Drive Screw into Ventilation Grate, Aluminum Mesh, and Front Plate	I				(0,2)	2.5	
238	Handle Hex Drive	H	180	0	180	(0,1)	1.43	

	Screw							
239	Insert Hex Drive Screw into Ventilation Grate, Aluminum Mesh, and Back Plate	I				(0,2)	2.5	
240	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
241	Insert Hex Drive Screw into Ventilation Grate, Aluminum Mesh, and Back Plate	I				(0,2)	2.5	
242	Handle Aluminum Mesh	H	360	0	360	(1,4)	2.55	
243	Insert Aluminum Mesh to Align with Ventilation Grate	H	180	0	180	(0,1)	1.43	
244	Handle Aluminum Mesh and Ventilation Grate	I				(0,2)	2.5	
245	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
246	Insert Hex Drive Screw into Ventilation Grate, Aluminum Mesh, and Front Plate	I				(0,2)	2.5	
247	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
248	Insert Hex Drive Screw into Ventilation Grate, Aluminum Mesh, and Front Plate	I				(0,2)	2.5	
249	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
250	Insert Hex Drive Screw into Ventilation Grate, Aluminum Mesh, and Back Plate	I				(0,2)	2.5	
251	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
252	Insert Hex Drive Screw into Ventilation Grate, Aluminum Mesh, and Back Plate	I				(0,2)	2.5	
253	Handle Aluminum Mesh	H	360	0	360	(1,4)	2.55	
254	Insert Aluminum Mesh to Align with Ventilation Grate	H	180	0	180	(0,1)	1.43	
255	Handle Aluminum Mesh and Ventilation Grate	I				(0,2)	2.5	
256	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
257	Insert Hex Drive Screw into Ventilation	I				(0,2)	2.5	

	Grate, Aluminum Mesh, and Front Plate							
258	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
259	Insert Hex Drive Screw into Ventilation Grate, Aluminum Mesh, and Front Plate	I				(0,2)	2.5	
260	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
261	Insert Hex Drive Screw into Ventilation Grate, Aluminum Mesh, and Back Plate	I				(0,2)	2.5	
262	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
263	Insert Hex Drive Screw into Ventilation Grate, Aluminum Mesh, and Back Plate	I				(0,2)	2.5	
264	Handle Side Plate	H	360	0	360	(1,4)	2.55	
265	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
266	Insert Hex Drive Screw into Side Plate and Rail Bar	I				(0,2)	2.5	
267	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
268	Insert Hex Drive Screw into Side Plate and Rail Bar	I				(0,2)	2.5	
269	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
270	Insert Hex Drive Screw into Side Plate and Rail Bar	I				(0,2)	2.5	
271	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
272	Insert Hex Drive Screw into Side Plate and Rail Bar	I				(0,2)	2.5	
273	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
274	Insert Hex Drive Screw into Side Plate and Rail Bar	I				(0,2)	2.5	
275	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
276	Insert Hex Drive Screw into Side Plate and Rail Bar	I				(0,2)	2.5	
277	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
278	Insert Hex Drive Screw into Side Plate	I				(0,2)	2.5	

	and Rail Bar							
279	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
260	Insert Hex Drive Screw into Side Plate and Rail Bar	I				(0,2)	2.5	
281	Handle Side Plate	H	360	0	360	(1,4)	2.55	
282	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
283	Insert Hex Drive Screw into Side Plate and Rail Bar	I				(0,2)	2.5	
284	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
285	Insert Hex Drive Screw into Side Plate and Rail Bar	I				(0,2)	2.5	
286	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
287	Insert Hex Drive Screw into Side Plate and Rail Bar	I				(0,2)	2.5	
288	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
289	Insert Hex Drive Screw into Side Plate and Rail Bar	I				(0,2)	2.5	
290	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
291	Insert Hex Drive Screw into Side Plate and Rail Bar	I				(0,2)	2.5	
292	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
293	Insert Hex Drive Screw into Side Plate and Rail Bar	I				(0,2)	2.5	
294	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
295	Insert Hex Drive Screw into Side Plate and Rail Bar	I				(0,2)	2.5	
296	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
297	Insert Hex Drive Screw into Side Plate and Rail Bar	I				(0,2)	2.5	
298	Handle Side Plate	H	360	0	360	(1,4)	2.55	
299	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
300	Insert Hex Drive Screw into Side Plate and Rail Bar	I				(0,2)	2.5	
301	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	

302	Insert Hex Drive Screw into Side Plate and Rail Bar	I				(0,2)	2.5	
303	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
304	Insert Hex Drive Screw into Side Plate and Rail Bar	I				(0,2)	2.5	
305	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
306	Insert Hex Drive Screw into Side Plate and Rail Bar	I				(0,2)	2.5	
307	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
308	Insert Hex Drive Screw into Side Plate and Rail Bar	I				(0,2)	2.5	
309	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
310	Insert Hex Drive Screw into Side Plate and Rail Bar	I				(0,2)	2.5	
311	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
312	Insert Hex Drive Screw into Side Plate and Rail Bar	I				(0,2)	2.5	
313	Handle Hex Drive Screw	H	180	0	180	(0,1)	1.43	
314	Insert Hex Drive Screw into Side Plate and Rail Bar	I				(0,2)	2.5	
						TOTAL TIME	***764.4 s***	

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