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Level 3 High Powered Rocketry Certification Through Tripoli Rocketry Association

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LEVEL 3 HIGH POWERED ROCKETRY CERTIFICATION THROUGH TRIPOLI ROCKETRY ASSOCIATION

by

Zachary Foster

Capstone submitted in partial fulfillment of the requirements for graduation with

University Honors

with a major in
Mechanical Engineering

in the Department of Mechanical and Aerospace Engineering

Approved:

Capstone Mentor
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UTAH STATE UNIVERSITY
Logan, UT

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Level 3 High Powered Rocketry Certification Through the TRIPOLI Rocketry Association

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This paper aims to give an overview of the Level 3 certification process through the TRIPOLI Rocketry Association. This paper will also give an overview of Zachary Foster's Level 3 Certification submission. The overview of the certification submission will include fin flutter calculations, stability calculations, descent rate calculations, flight simulations, flight results, construction overview, drawing package for the airframe, and pre-flight checklists. The results of fin flutter calculations showed that the minimum flutter speed is 1972 ft/s. The maximum flight velocity is 1309.6 ft/s. The flutter calculation has a total factor of safety of 1.5. The stability calculations show a minimum stability of 2.2 cal and a maximum stability of 4.58 cal. The descent rate calculations show a ground hit velocity of 15.75 ft/s. The flight simulations show a maximum altitude of 14787 ft.

I. Nomenclature

a = local speed of sound
G = shear modulus
P = air pressure
λ = taper ratio
t = fin thickness
C_r = root chord
C_t = tip chord
V_f = flutter velocity
b = semi-span
V_i = maximum flight velocity
T = ambient air temperature
P = air pressure
Cg = center of gravity measured from the nose
Cp = center of pressure measured from the nose
D = diameter
Cal = calibers of stability
V_d = descent rate
D_p = parachute diameter
C_d = coefficient of drag
S_p = parachute area
ρ = air density
m = mass

II. Desing Overview

Zachary Foster's level 3 certification submission was based on a modified rocket design by Mach 1 Rocketry. The level 3 candidate purchased an Alien Interceptor Kit from Mach 1 Rocketry and modified the design better to suit the needs of a level 3 certification. The primary change that the candidate made was the fin geometry. The original fin design used a large complex fin shape that could not be easily modeled in flight simulations or used in fin flutter calculations.

When the candidate did model the original fin design in the simulation software, the candidate noted that the fins also provided insufficient stability for the larger M motor that was being used. The candidate modified the fin design to be a much simpler clipped delta design. The dimensions of the fin are shown in Appendix C, drawing number 20-001-000. After the change was made, the candidate was able to achieve a sufficient amount of stability. The finalized design in the Open Rocket simulation software is shown in Fig. 1.

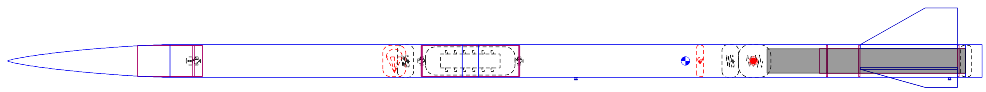


Fig. 1 Rocket design in Open Rocket

III. Fin Flutter

Fin flutter occurs on rockets at high velocities. Flutter occurs due to the vortex shedding off the fin's leading edge, causing oscillations in the fins. If the magnitude of the oscillations becomes too large, the bending stress on the fin could exceed the material's ultimate strength, causing a catastrophic failure in the fin. A catastrophic failure in the fin would cause the fin to detach from the airframe causing the rocket to become unstable. To avoid fin flutter, the candidate uses the flutter boundary equation shown in Eq. (1) to determine the velocity at which the flutter would occur. By ensuring that the flutter speed is greater than the maximum velocity experienced during flight, an airframe failure due to fin failure can be avoided [1].

$$V_f = a\sqrt{\frac{G}{\frac{1.337AR^3P(\lambda+1)}{2(AR+2)(t/c)^3}}} \tag{1}$$

The designed fin geometry, shear modulus for G10 fiberglass, and maximum flight velocity are shown in Table 1.

Table 1 Known constants for the fin geometry and atmospheric conditions

Root Chord (C_r)	12 in.
Tip Chord (C_t)	4 in.
Thickness (t)	0.188 in.
Semi-Span (b)	4.5 in.
Shear Modulus (G)	800,000 psi
Maximum flight Velocity (V_i)	12 ft
Air Pressure at sea level at 68 degrees Fahrenheit (P)	16.1 psi

The first step in calculating the flutter velocity is to calculate the local speed of sound by making a simplifying assumption that the maximum velocity occurs at sea level and the temperature of the air is 68°F. The speed of sound is calculated by using Eq. 2.

$$a = \sqrt{1.4 \times 1716.59 \times (T(°F) + 460)} \tag{2}$$

By using Eq. 2, the local speed of sound is calculated below.

$$a = \sqrt{1.4 \times 1716.59 \times (68 + 460)}$$

$$a = 1126\text{ft/s}$$

The second step to calculating the flutter speed is to calculate the fin area, aspect ratio, and taper ratio. Eq. 2, Eq.v3, and Eq. 4 are the formulas to calculate the aspect ratio, taper ratio, and fin area, respectively.

$$S = \frac{C_r + C_t}{2b} \tag{3}$$

$$AR = \frac{b^2}{S} \tag{4}$$

$$\lambda = \frac{C_t}{C_r} \tag{5}$$

The fin area, aspect ratio, and taper ratio calculations are shown below.

$$S = \frac{12 + 4}{2(4.5)}$$

$$S = 36.0\text{in}^2$$

$$AR = \frac{4.5^2}{36}$$

$$AR = 0.563$$

$$\lambda = \frac{4.5}{12}$$

$$\lambda = 0.333$$

Once all of the necessary values have been calculated, Eq. 1 can be used to calculate the flutter velocity.

$$V_f = 1226\sqrt{\frac{800000}{\frac{1.337(0.563)^3(16.1)(0.333+1)}{2(0.563+2)(0.188/12)^3}}}$$

$$V_f = 1972\text{ft/s}$$

The above calculation indicates that the speed at which fin flutter begins to occur is at 1972 ft/s. Based on preliminary simulations, the maximum velocity experienced during flight is 1292 ft/s. The factor of safety for fin flutter is 1.52. Since the factor of safety is greater than one, this design passes the fin flutter calculations.

IV. Stability Calculations

Because the rocket is passively stabilized with the fins, stabilization calculations must be performed to ensure stability. Stability depends on two factors: center of gravity and center of pressure. By keeping the center of gravity forward of the center of pressure, the rocket will be aerodynamically stable.

A. Center of Gravity

The center of gravity is the location where all of the body force on the rocket act. This can be estimated using design software such as Open Rocket or by assembling the rocket and balancing it on your finger. The balance point on the airframe is the center of gravity. The center of gravity is measured from the nose of the airframe. During the flight, the center of gravity moves forward due to the engine burning and mass leaving the aft of the rocket in the form of thrust. Because the center of gravity is moving forward, the rocket becomes more stable during flight.

B. Center of Pressure

The center of pressure is the location on the airframe where the aerodynamic force on the airframe act. The pressure center can be calculated using a modeling program such as Open Rocket or RASAero II. The center of pressure is also a function of the Mach number, so the center of pressure can move forward, especially during the boost phase of flight.

C. Calibers of Stability

Calibers of stability are determined by the distance between the center of pressure and the center of gravity divided by the diameter of the airframe, as shown in Eq. 6.

$$Cal = \frac{Cg - Cp}{D} \tag{6}$$

For a rocket to be stable, the rocket must have a minimum of one caliper of stability. This will ensure the rocket remains stable with a built-in safety factor. The calipers of stability for this project will be calculated using RASAero II because it has a more accurate algorithm for calculating the center of pressure. The center of pressure location, the center of gravity location, and calibers of stability are shown in Fig. 2.

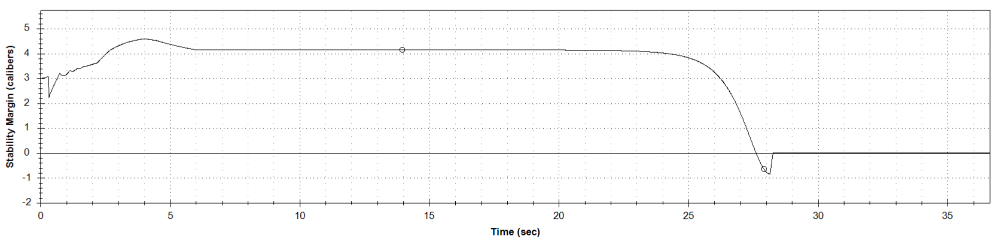


Fig. 2 Calibers of Stability Vs. Time calculated by RASAero II

From Fig. 2, the candidate observed that the minimum calipers of stability during the first 25 seconds of flight is 2.2 calibers. The candidate also noted that the stability decreases after 25 seconds. The decrease in stability is due to the rocket slowing down as it approaches apogee, causing the center of pressure to move forward, making the rocket unstable as it approaches apogee. This is an expected outcome and is not a safety concern since the vertical velocity near apogee is approaching zero, and parachutes are expected to be deployed at apogee. The result of the above analysis is that the airframe is stable and should fly in a safe manner.

V. Descent Rate

Recovery is the most important part of a certification flight because a failed recovery will always result in a failed certification. Because of this, the candidate was required to perform a descent rate calculation. The candidate had several options for parachutes but opted to use a Rocketman Parachutes 48 in. for the drogue and a Rocketman Parachutes 108 in. for the main. These parachutes were chosen for their high drag coefficient of 0.97 and their design. The number of shroud lines was the primary design parameter that led to the Rocketman Parachutes being chosen over other brands. The Rocketman Parachutes only have four shroud lines making it less likely for the parachute to become tangled during the descent. While the candidate was confident that they had correctly sized the parachute according to the manufactures specifications, the candidate used Eq. 7 and Eq. 8 to verify the descent rate of the rocket [2].

$$S_p = \frac{\pi}{4} D^2 \tag{7}$$

$$V_d = \sqrt{\frac{2mg}{S_p \rho C_d}} \tag{8}$$

Table. 2 shows the relevant values for both parachutes to perform this calculation.

Table 2 Physical properties to calculate descent rates under the main and drogue parachutes

C_d (Main)	0.97
C_d (Drogue)	0.97
D (Main)	108 in.
D (Drogue)	48 in.
S_p (Main)	63.62 ft^2
S_p (Drogue)	12.57 ft^2
ρ (15000 ft MSL)	0.001469 slugs/ft^3
ρ (5000 ft MSL)	0.00248 slugs/ft^3
m (After Burnout)	0.59 slugs

The candidate used Eq. 8 to calculate the descent rate for the main.

$$V_d = \sqrt{\frac{2(.59)(32.17)}{63.62(.00248)(.97)}}$$
$$V_d = 15.75 \text{ ft/s}$$

The descent rate of the rocket under the main parachute is 15.75 ft/s. This descent rate is considered to be acceptable because the optimal descent rate under the main parachute for high-powered rocketry is typically under 20 ft/s. The candidate also used Eq. 8 to calculate the descent rate under the drogue.

$$V_d = \sqrt{\frac{2(.59)(32.17)}{12.57(.001469)(.97)}}$$
$$V_d = 46.04 \text{ ft/s}$$

The descent rate of the rocket under the drogue parachute is 46.04 ft/s. The descent rate is considered acceptable because the optimal descent rate for high-powered rocketry under the drogue is between 60 ft/s and 30 ft/s.

VI. Flight Simulations

The candidate used two programs to simulate the flight of the rocket, Open Rocket, and RASAero II. Both of these programs can be downloaded for free on a personal computer. Both of these programs have advantages and disadvantages. Open Rocket is easy to use and has more tools geared toward designing the airframe and its internal components. The program will automatically calculate the center of gravity and center of pressure based on the density of materials chosen and the external dimensions of the airframe. Open Rocket also has a built-in flight simulation function; however, Open Rocket is known to give inaccurate values, especially at high altitudes and speeds. Because of this, the candidate did not rely on Open Rocket for most of the flight simulations and only used them to get a ballpark estimation.

RASAero II is more difficult to use and requires that the operator already knows the external dimensions of the airframe as well as the mass and center of gravity. This program also has a built-in flight simulator that has been proven to give highly accurate flight simulations at high altitudes and speeds. RASAero II uses algorithms backed by experimental wind tunnel data and flight data. Because of this mix of algorithms and experimental data, if the program is properly used, it can result in highly accurate simulations [3].

The candidate decided to use both of these programs in concert in the design phase of the rocket. The candidate first used Open Rocket to design the airframe and get estimated stability and altitude for the design. The candidate then exported the Open Rocket File as a Rocksim file and imported the Rocksim file into RASAero II. This ensured that all the dimensions of the rocket were kept without any error in the translation between the two programs. The candidate then ran the flight simulations under ideal conditions until the launch date was close enough for weather reports to be distributed. Once the candidate had weather reports for the launch day, the candidate would run simulations to get an updated estimate of the maximum altitude. Once launch day arrived and the candidate was at the launch site, they ran a final simulation with the observed weather conditions Fig.3 shows the generated altitude vs. time plot.

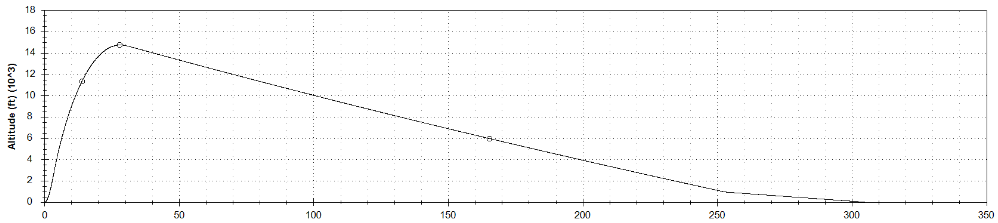


Fig. 3 Altitude Vs. Time calculated by RASAero II

The results of the simulation are shown in Table. 2.

Table 3 Simulated maximum flight values

Apogee	14774 ft
Maximum Acceleration	15.3 Gs
Maximum Velocity	1309.6 ft/s

VII. Flight Results

Once the candidate completed the project, they attempted to launch at the TRIPOLI Idaho Association launch on April 22, 2023. Upon arival at the launch site, the candidate noticed that the cloud cover was about 6000 ft which was too low to launch as per the TRIPOLI Safety Rules. The candidate decided to prep the rocket for launch and wait for a break in the clouds that would allow for a safe launch. The candidate loaded the rocket onto the pad at about 1:00 pm and chose to leave the parachute deployment electronics off to conserve battery. Several small launch windows appeared, and the candidate walked out to the pad to arm the electronics just for the cloud cover to come back once they were safely behind the flight line. The candidate would then walk back out to the pad to turn the electronics off. The candidate repeated the process of turning the electronics on and then back off again due to the changing weather five more times until there was a sufficient break in the clouds to launch. At about 4:15 pm, the Range Safety Officer (RSO) gave approval for the flight and initiated the countdown. The rocket successfully launched and reached apogee without incident. The candidate and other flyers at the launch were able to maintain a line of sight on the rocket during the entire flight. Once apogee was reached, the drogue was deployed and began its descent. Once the rocket descended to 1000 ft, the main was deployed and landed about 50 ft from the flight line. A picture of the rocket on the pad is shown in Fig. 4.

Fig. 4 Rocket on the pad with Zachary Foster standing on the left and Xavier Kipping standing on the right.

The rocket was recovered, and the candidate and the TAP performed a post-flight inspection. After the inspection, it was noted that the drogue parachute had suffered a catastrophic failure and had detached from the rocket during the descent. Despite the failure, the airframe had flown safely and was recovered in a state where the airframe could fly again if handed another motor, and the TAP signed off on the flight. The altitude data recorded by the Raven 4 is shown in Fig. 5. The rocket reached a maximum apogee of 14939 ft, a maximum velocity of 1231 ft/s, and a maximum acceleration of 18.1 Gs.

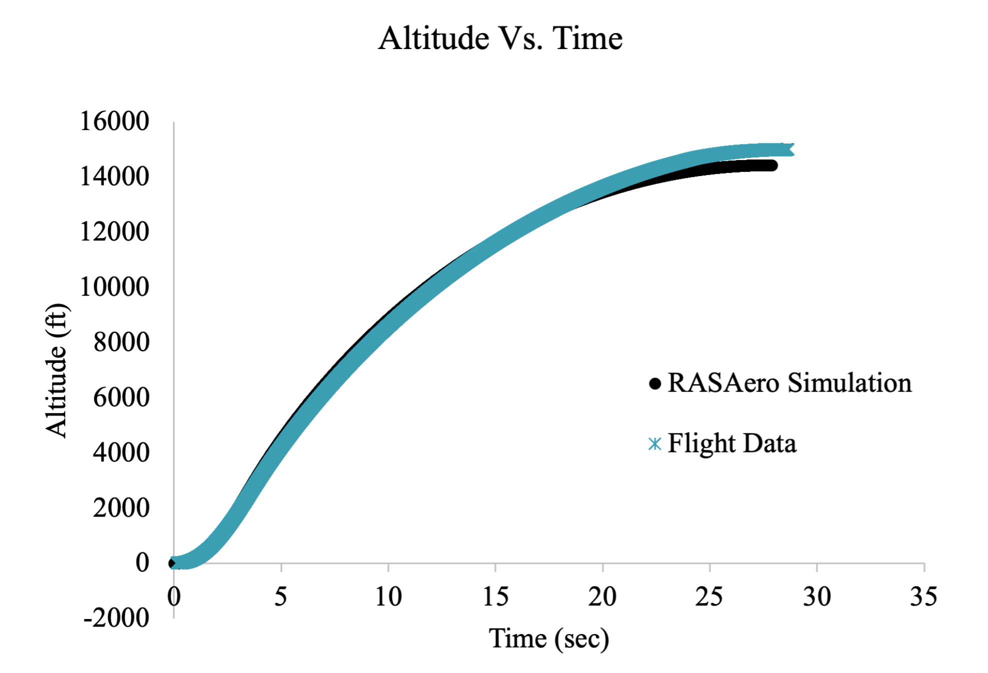


Fig. 5 Altitude Vs. Time with flight data and RASAero II simulation

From the figure, the candidate noticed that the flight data and the simulation from RASAero II are very close to each other. Given the opportunity to develop better simulations, the candidate would attempt to change the skin friction in the simulation to get a more representative value of the airframe for the simulation.

Appendix

A. Construction Overview

Lower Airframe:

- Wash all fiberglass parts to remove mold release
- Prepare centering rings for epoxying onto the motor mount tube
- Sand bonding surfaces with 240 git sandpaper as per epoxy instructions
- Mark the location for the centering rings on the motor tube
- Epoxy kevlar shock cord to motor mount tube under upper centering ring
- Epoxy upper centering ring onto the motor tube
- Epoxy the second centering ring into place
- Dry fit the motor tube into the booster section to ensure a proper fit
- Sand the inside of the booster section where the centering rings will be glued in
- Use a stick to apply epoxy on the inside of the booster section
- Slide the motor tube into the booster section
- Dry fit the aft centering ring to ensure that the motor tube is centered
- Prepare fins for epoxy work
- Epoxy each fin using a fin guide
- Epoxy internal filets.
- Epoxy external filets
- Epoxy aft centering ring
- Epoxy motor retainer onto the motor tube

Upper Airframe:

- Epoxy the nose cone bulkhead into place
- Drill holes into the nose cone and shoulder for removable rivets
- Epoxy the GPS sled into the nose cone shoulder

Electronics Bay

- 3D print the electronics sled using PLA
- Drill access holes in e-bay bulkheads
- Install eyebolts
- Install wiring through e-bay bulkhead
- Install terminal blocks onto bulkheads
- Drill access hole for switch pull-out rod in e-bay wall
- Drill vent holes in the e-bay wall

Additional

- Drill holes on the upper side of the electronics bay for removable rivets
- Drill and tap holes for shear pins in the nose cone shoulder, and booster section
- Drill vent holes in the payload section and booster section
- Install 1515 rail guides
- Install shock chords and parachutes

B. Checklists

Pre-flight checklist:

- Ensure that all fins are securely attached
- Examine shock chord for frayed fibers or burn marks
- Check eye-bolts are securely attached
- tighten all quick links to the shock chord and eye-bolts
- Tape all quick links closed with electrical tape
- Install eye-bolt into motor
- Tighten eye-bolt locking nuts onto the motor
- Install motor into the airframe
- Tighten the motor retainer
- Check parachutes for burn marks or holes
- Fold parachutes
- Wrap parachutes in fireproof blankets
- Ensure parachutes are attached to the shock chord
- Install parachutes into the airframe
- Use a generous amount of fireproof insulation between the parachutes and ejection charges
- Check the rail buttons are firmly attached
- Check the rail buttons are properly aligned
- Install batteries for RRC2+
- Install batteries for Raven 4
- Check continuity on RRC2+, three high pitched beeps
- Check continuity on Raven 4, two high-pitched beeps and two low-pitched beeps
- Install the electronics bay into the coupler
- Tighten bolts for electronics bay
- Wrap electrical tape on exposed threads on the electronics bay
- Prep ejection charges
- Install pull pin turning off electronics
- Tape the pull pin to the side of the rocket to prevent accidental removal
- Install ejection charges
- Install well nuts into payload and electronics bay
- Turn on GPS
- Zip tie GPS sled into the nose cone
- Assemble nose cone
- install well nuts into the nose cone
- Install Shear pins into the payload section and booster section
- Prep igniter
- Tape the igniter to the side of the rocket
- Weigh the rocket
- Locate the center of gravity
- Run sim with current weather conditions, weight, and center of gravity
- Fill out a flight card
- Pass pre-flight inspection with RSO

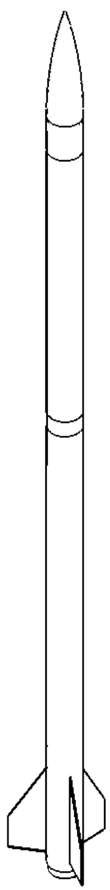
At the pad:

- Obtain pad assignment from RSO
- Install the airframe onto the pad
- Check wind conditions and ensure that the rocket is pointed away from the direction of the wind
- Install igniter into the rocket
- Insure good GPS lock
- Wire igniter to the range box
- Check continuity on the range box, solid high-pitched tone
- Pull the pull pin halfway and listen for Raven 4 to boot up
- Raven 4 will beep battery voltage to the lowest whole number, which must be greater than eight volts
- Raven 4 is working properly if there are two high beeps and two low beeps after the voltage is read

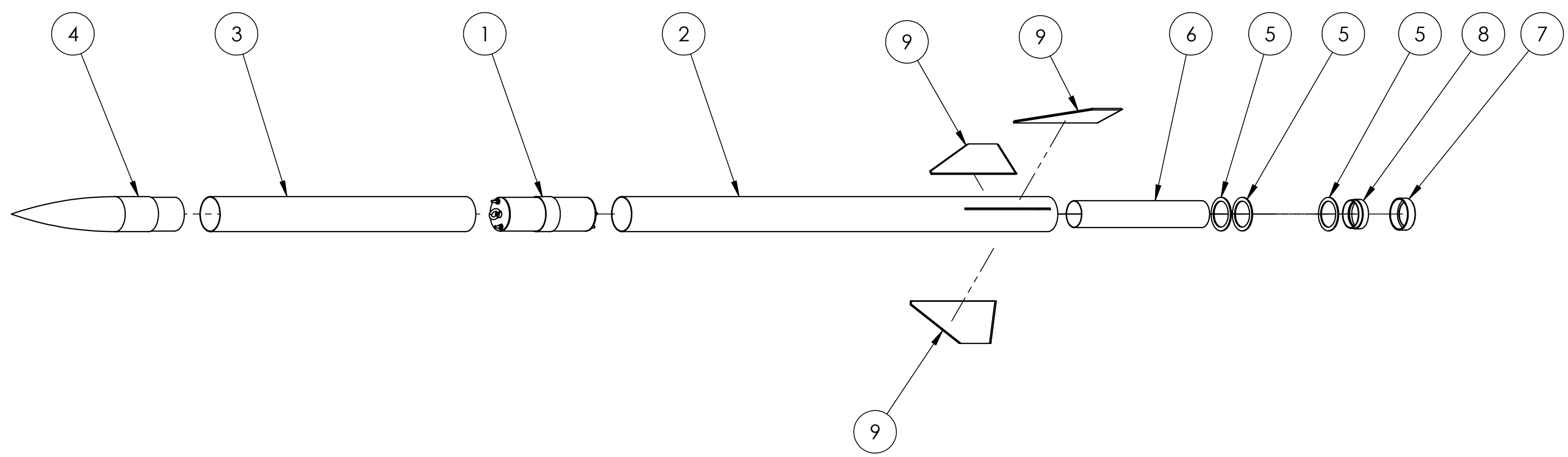
- Pull the pull pin all the way out
- RRC2+ will beep out battery voltage first set of beeps is the one's decimal place, and the second set of beeps is the tenth decimal place
- RRC2+ must read a voltage of at least nine volts
- RRC2+ is working properly if there are three high-pitched beeps after the voltage is read
- If the boot-up sequences are not as explained above, remove the rocket from the pad and follow the electronics user manuals for troubleshooting protocols
- Clear the range
- Initiate count down
- Launch

C. Drawing Package

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	50-002-000	E-BAY ASSEMBLY	1
2	10-001-000	BOOSTER SECTION	1
3	10-002-000	PAYLOAD SECTION	1
4	50-003-000	NOSE CONE ASSEMBLY	1
5	20-004-000	CENTERING RING	3
6	10-003-000	MOTOR TUBE	1
7	30-001-000	MOTOR RETAINER FEMALE	1
8	30-002-000	MOTOR RETAINER MALE	1
9	20-001-000	FIN	3



ISOMETRIC VIEW



SPECIFICATIONS AND TOLERANCES

UNLESS OTHERWISE NOTED
DRAWING ARE CREATED IN ACCORDANCE TO ASME Y14.5-2009

DEFAULT DIMENSIONAL TOLERANCES:
LINEAR DIMENSIONS [inches]: X±.5, X.X±.1, X.XX±.03, X.XXX±.005
ANGULAR DIMENSIONS [degrees]: X±3, X.X±.5, X.XX±.1
MINIMUM SURFACE FINISH: 1000 microinches

Mechanical & Aerospace ENGINEERING
UtahState University

DRAFTED BY: ZACHARY FOSTER
DRAFTED DATE:1/17/2023
DATE APPROVED:
SHEET SCALE: 1:14
SHEET NUMBER: 1 of 2

PROJECT:
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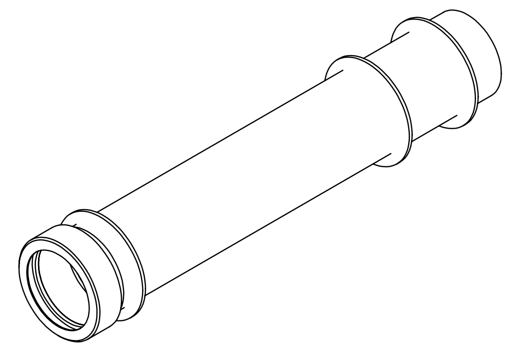
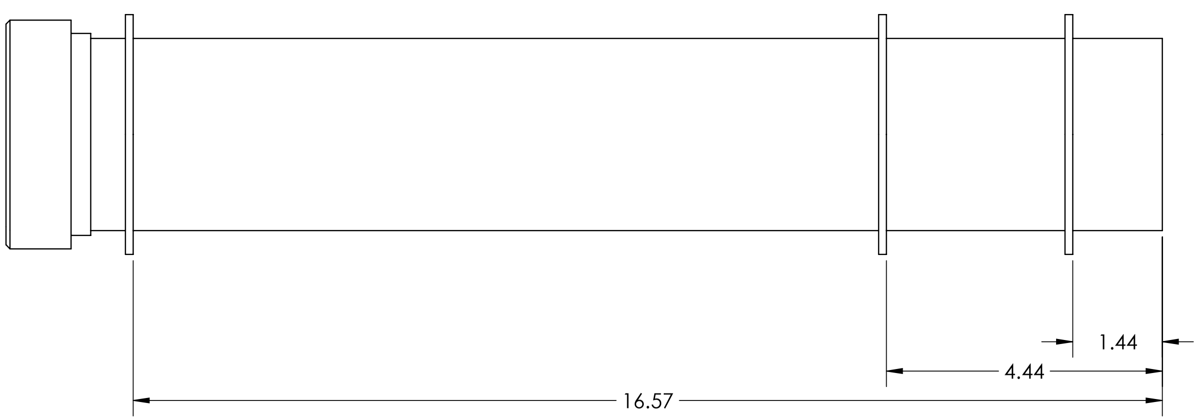
PART/ASSEM NAME: AILEN INTERCEPTER ASSEMBLY
PART/ASSEM NUMBER: 50-001-000
NEXT ASSEM NUMBER:
MATERIAL:
FINISH:



ISOMETRIC
VIEW
SCALE 1 : 4



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ANGULAR DIMENSIONS [degrees]: X±3, X.X±.5, X.XX±.1
MINIMUM SURFACE FINISH: 1000 microinches

Mechanical & Aerospace ENGINEERING
UtahState University

DRAFTED BY: ZACHARY FOSTER		PROJECT: AILEN INTERCEPTER
DRAFTED DATE:1/17/2023		PART/ASSEM NAME: MOTOR TUBE ASSEMBLY
DATE APPROVED:		PART/ASSEM NUMBER: 50-001-001
SHEET SCALE: 1:2	SHEET NUMBER: 2 of 2	NEXT ASSEM NUMBER:
		MATERIAL:
		FINISH:

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
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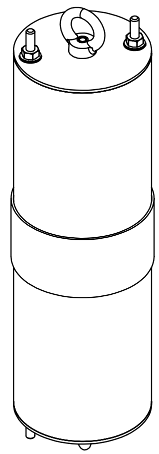
2	10-005-000	SWITCH BAND	1
3	20-002-000	STEPPED BULKHEAD	2
4	30-006-000	M6 EYE NUT	2
5	30-007-000	M6 PAN HEAD SCREW	2
6	30-008-000	M6 WASHER	2
7	60-002-000	RAVEN 4 ELECTRONICS SLED	1
8	60-001-000	RRC2+ ELECTRONICS SLED	1
9	30-003-000	1/4"-20 THREADED ROD	2
10	30-005-000	1/4" WASHER	6
11	30-004-000	1/4"-20 NUT	10



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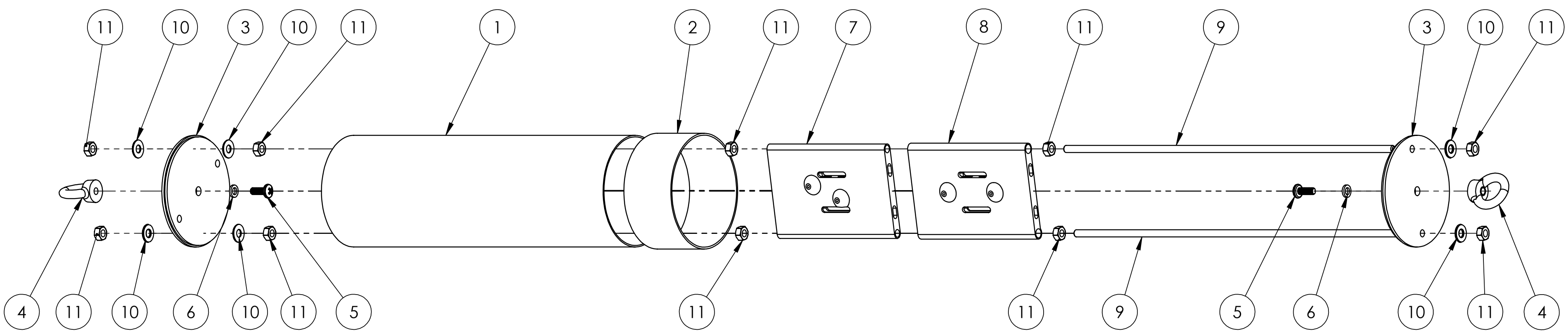

Mechanical & Aerospace ENGINEERING
UtahState University

PROJECT:	
PART/ASSEM NAME: E-BAY ASSEMBLY	
DRAFTED BY: ZACHARY FOSTER	PART/ASSEM NUMBER: 50-002-000
DRAFTED DATE:1/17/2023	NEXT ASSEM NUMBER: NA
DATE APPROVED: NA	MATERIAL: NA
SHEET SCALE: 1:3.5 SHEET NUMBER: 1 of 1	FINISH: NA

SPECIFICATIONS AND TOLERANCES

UNLESS OTHERWISE NOTED
DRAWING ARE CREATED IN ACCORDANCE TO ASME Y14.5-2009

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MINIMUM SURFACE FINISH: 1000 microinches

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
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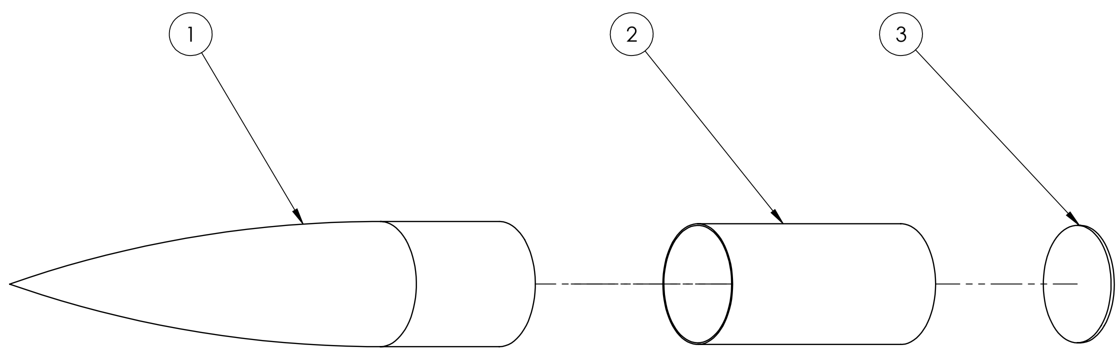
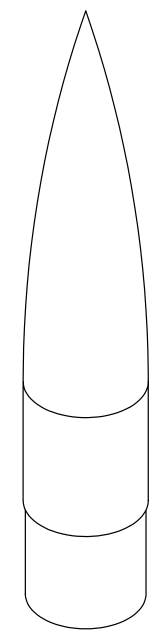
3	20-003-000	BULKHEAD	1





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Mechanical & Aerospace ENGINEERING
UtahState University

PROJECT:

PART/ASSEM NAME: NOSE CONE ASSEMBLY

DRAFTED BY: ZACHARY FOSTER

PART/ASSEM NUMBER: 50-003-000

DRAFTED DATE:1/17/2023

NEXT ASSEM NUMBER:

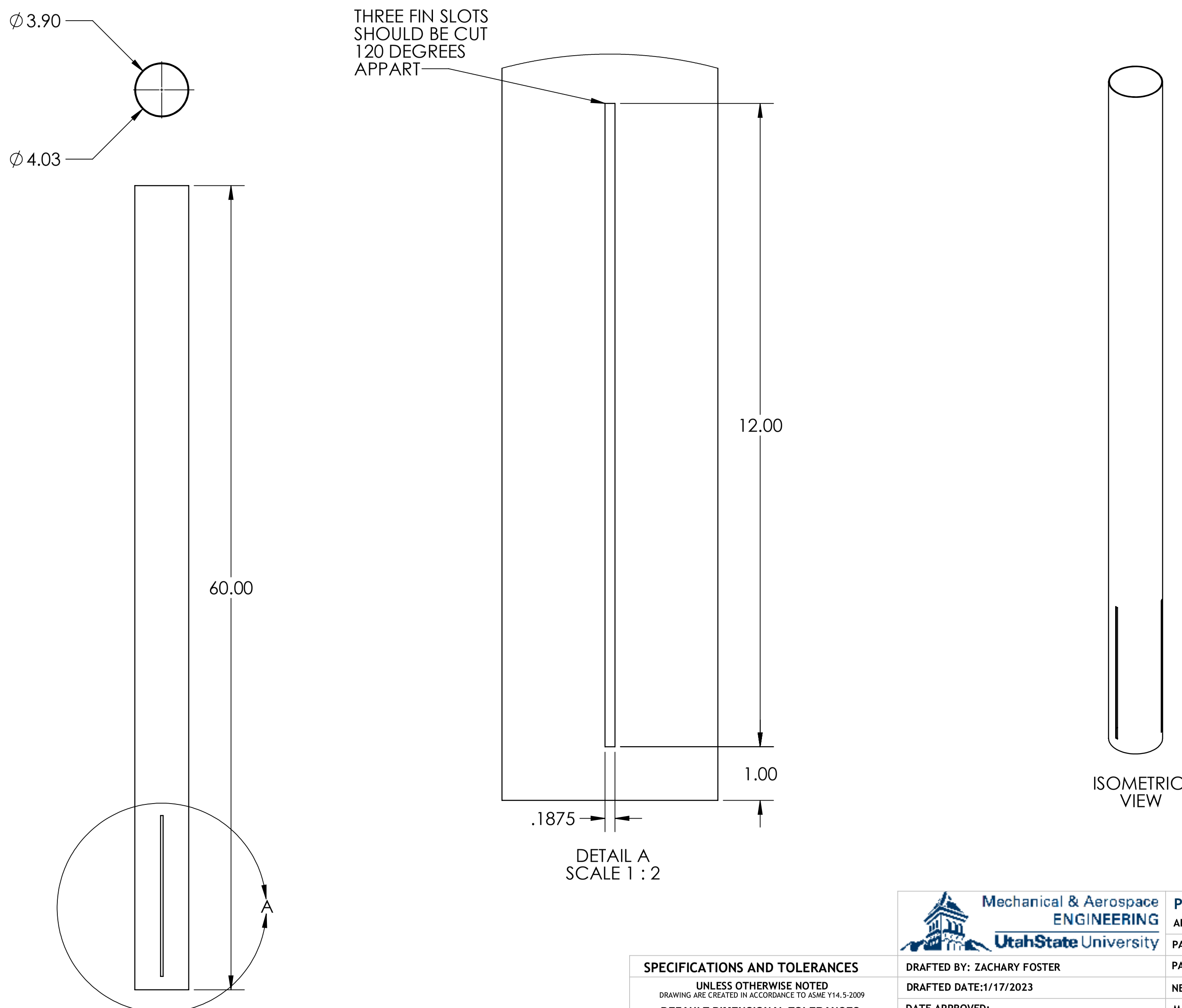
DATE APPROVED:

MATERIAL:

SHEET SCALE: 1:4

SHEET NUMBER: 1 of 1

FINISH:



SPECIFICATIONS AND TOLERANCES

UNLESS OTHERWISE NOTED
DRAWING ARE CREATED IN ACCORDANCE TO ASME Y14.5-2009

DEFAULT DIMENSIONAL TOLERANCES:
LINEAR DIMENSIONS [inches]: X±.5, X.X±.1, X.XX±.03, X.XXX±.005
ANGULAR DIMENSIONS [degrees]: X±3, X.X±.5, X.XX±.1
MINIMUM SURFACE FINISH: 1000 microinches

Mechanical & Aerospace ENGINEERING
UtahState University

DRAFTED BY: ZACHARY FOSTER		**PROJECT:** AILEN INTERCEPTER
DRAFTED DATE:1/17/2023		PART/ASSEM NAME: BOOSTER SECTION
DATE APPROVED:		PART/ASSEM NUMBER: 10-001-000
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		MATERIAL: G12 FIBERGLASS
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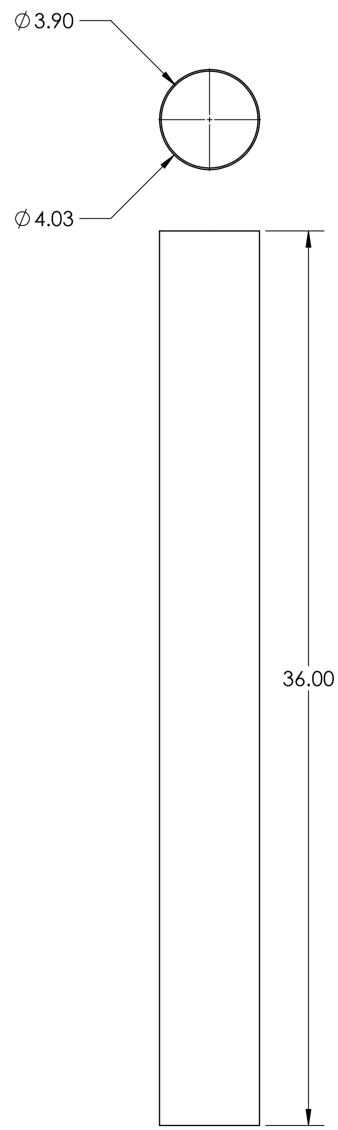
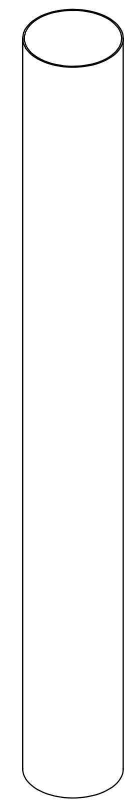
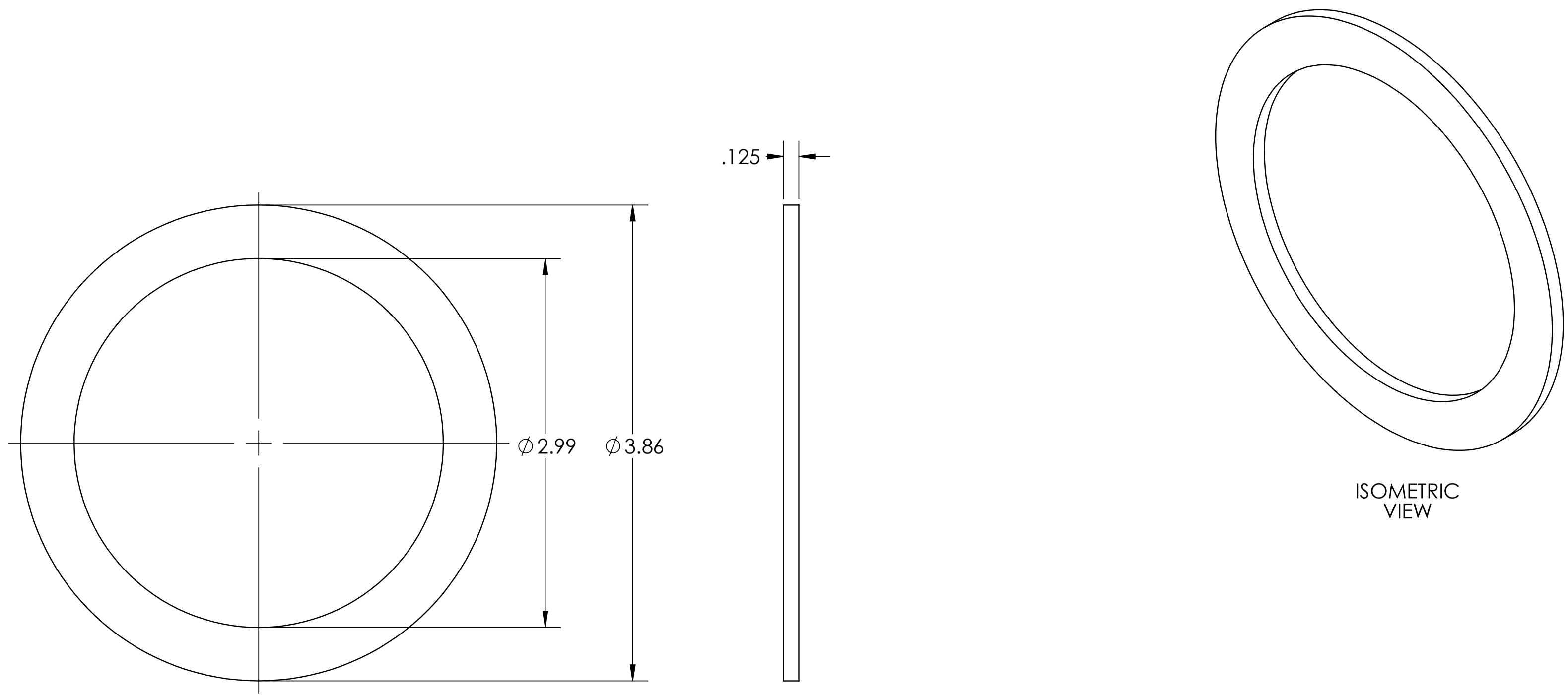




ISOMETRIC VIEW

SPECIFICATIONS AND TOLERANCES	Mechanical & Aerospace ENGINEERING UtahState University	PROJECT: AILEN INTERCEPTER
UNLESS OTHERWISE NOTED DRAWING ARE CREATED IN ACCORDANCE TO ASME Y14.5-2009		PART/ASSEM NAME: PAYLOAD SECTION
DEFAULT DIMENSIONAL TOLERANCES: LINEAR DIMENSIONS [inches]: X±.5, X.X±.1, X.XX±.03, X.XXX±.005 ANGULAR DIMENSIONS [degrees]: X±3, X.X±.5, X.XX±.1 MINIMUM SURFACE FINISH: 1000 microinches	DRAFTED BY: ZACHARY FOSTER	PART/ASSEM NUMBER: 10-002-000
	DRAFTED DATE:1/17/2023	NEXT ASSEM NUMBER:
	DATE APPROVED:	MATERIAL: G12 FIBERGLASS
	SHEET SCALE: 1:5 / SHEET NUMBER: 1 of 1	FINISH: N/A



SPECIFICATIONS AND TOLERANCES
UNLESS OTHERWISE NOTED DRAWING ARE CREATED IN ACCORDANCE TO ASME Y14.5-2009 **DEFAULT DIMENSIONAL TOLERANCES:** LINEAR DIMENSIONS [inches]: X±.5, X.X±.1, X.XX±.03, X.XXX±.005 ANGULAR DIMENSIONS [degrees]: X±3, X.X±.5, X.XX±.1 MINIMUM SURFACE FINISH: 1000 microinches

Mechanical & Aerospace ENGINEERING UtahState University		PROJECT: AILEN INTERCEPTER
		PART/ASSEM NAME: CENTERING RING
DRAFTED BY: ZACHARY FOSTER		PART/ASSEM NUMBER: 20-001-000
DRAFTED DATE:1/17/2023		NEXT ASSEM NUMBER:
DATE APPROVED:		MATERIAL: G10 FIBERGLASS
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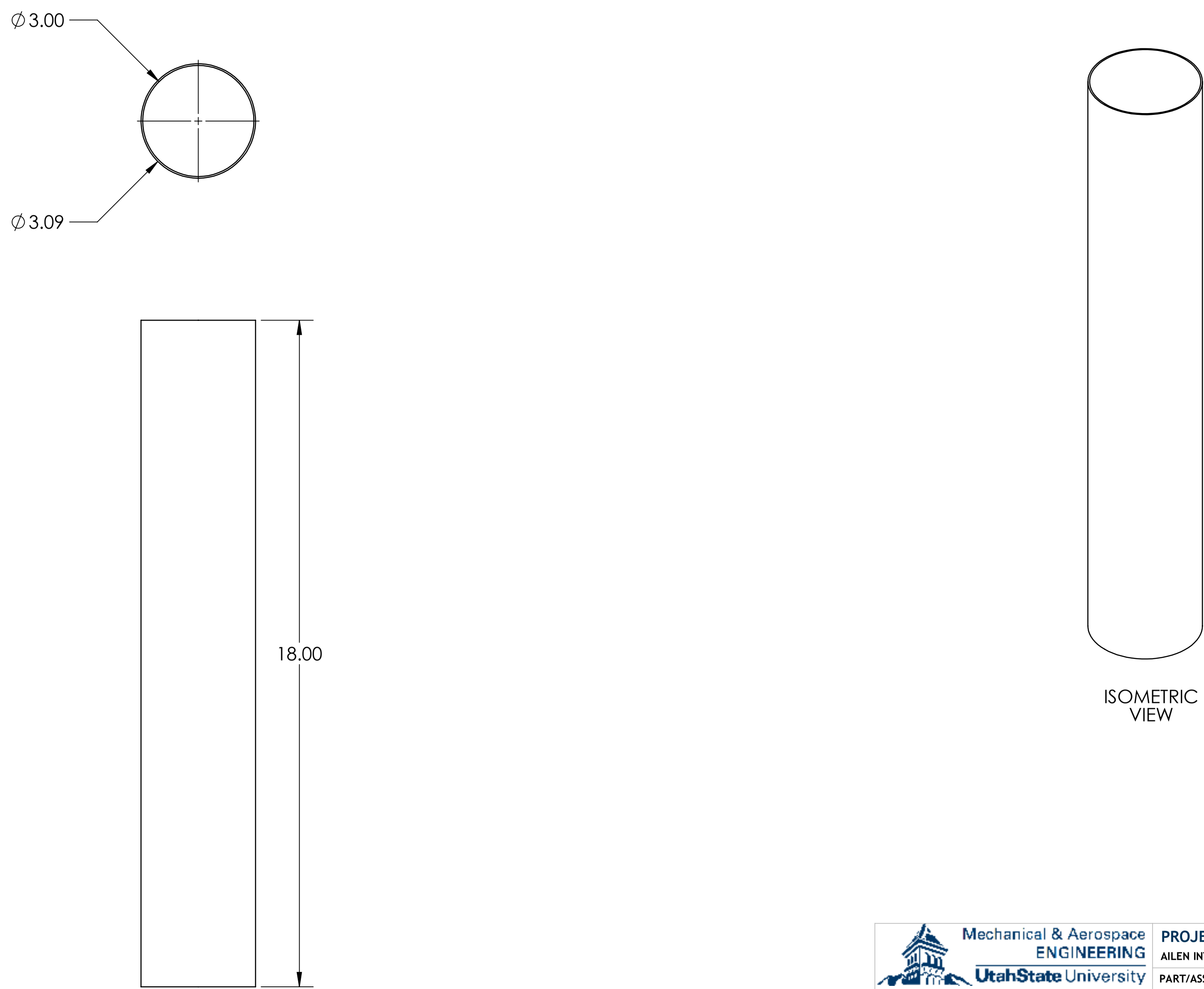

SPECIFICATIONS AND TOLERANCES

UNLESS OTHERWISE NOTED
DRAWING ARE CREATED IN ACCORDANCE TO ASME Y14.5-2009

DEFAULT DIMENSIONAL TOLERANCES:
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ANGULAR DIMENSIONS [degrees]: X±3, X.X±.5, X.XX±.1
MINIMUM SURFACE FINISH: 1000 microinches

Mechanical & Aerospace ENGINEERING
UtahState University

DRAFTED BY: ZACHARY FOSTER	PROJECT: AILEN INTERCEPTER
DRAFTED DATE:1/17/2023	PART/ASSEM NAME: MOTOR TUBE
DATE APPROVED:	PART/ASSEM NUMBER: 10-003-000
SHEET SCALE: 1:3	NEXT ASSEM NUMBER:
SHEET NUMBER: 1 of 1	MATERIAL: G12 FIBERGLASS
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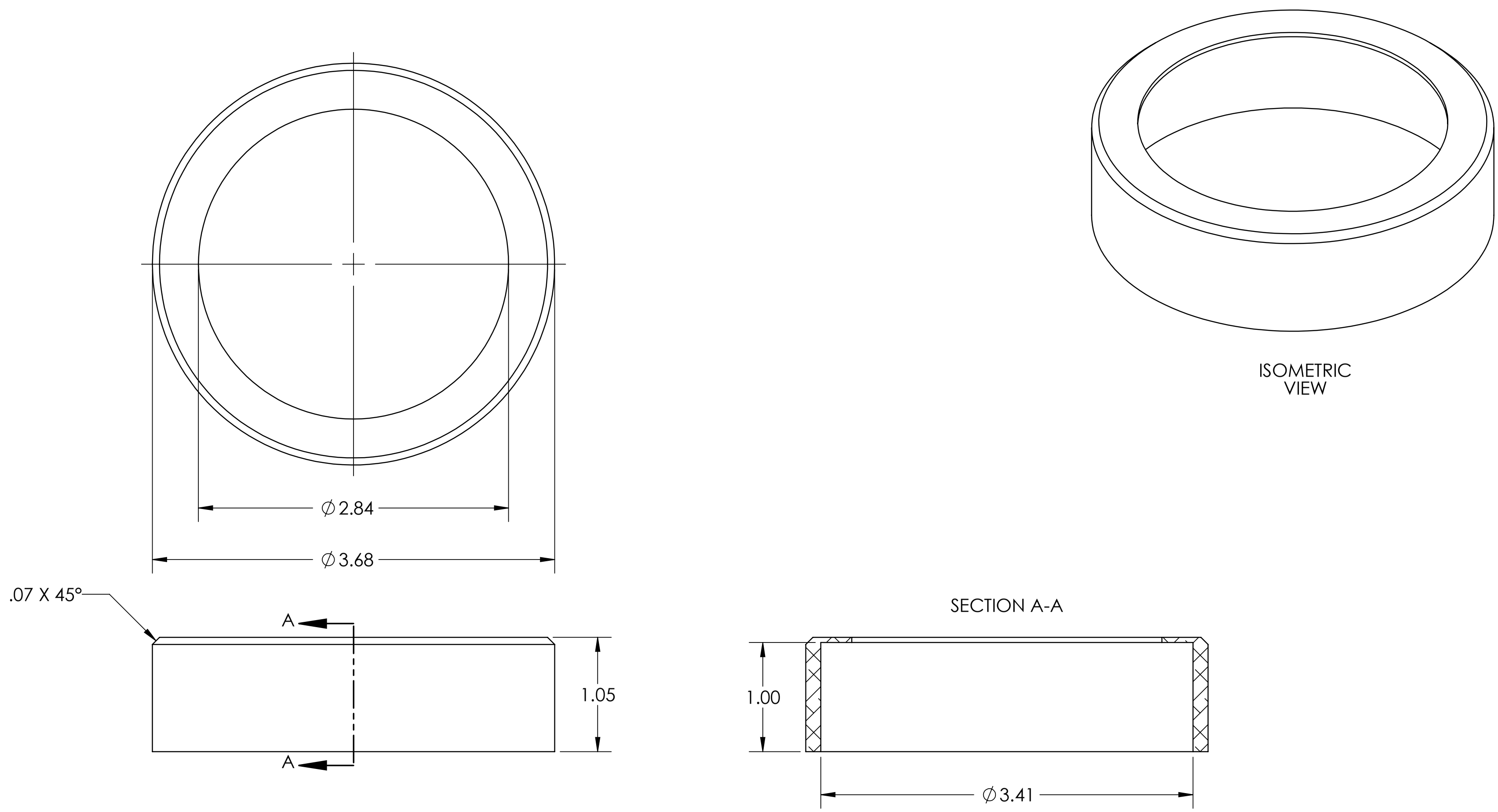
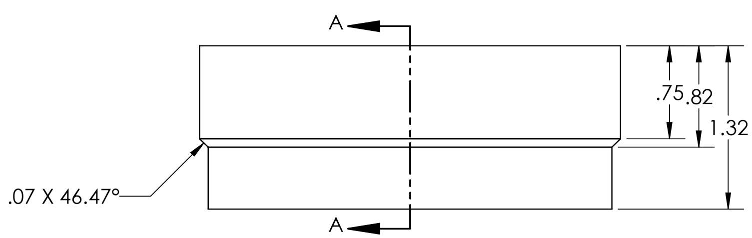


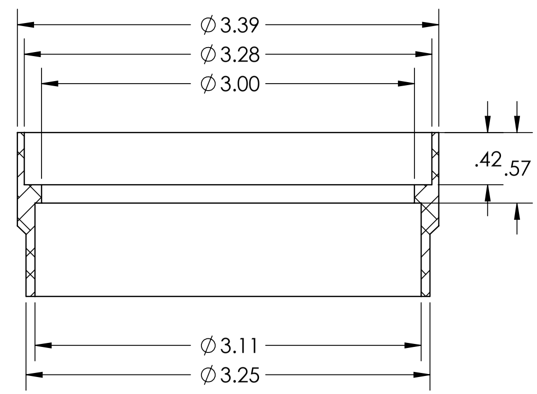
Mechanical & Aerospace ENGINEERING UtahState University	PROJECT: AILEN INTERSEPTER
	PART/ASSEM NAME: MOTOR RETAINER FEMALE
DRAFTED BY: ZACHARY FOSTER	PART/ASSEM NUMBER: 30-001-000
DRAFTED DATE:1/17/2023	NEXT ASSEM NUMBER:
DATE APPROVED:	MATERIAL: 6061-T6 ALUMINUM
SHEET SCALE: 1:1 SHEET NUMBER: 1 of 1	FINISH: N/A

SPECIFICATIONS AND TOLERANCES

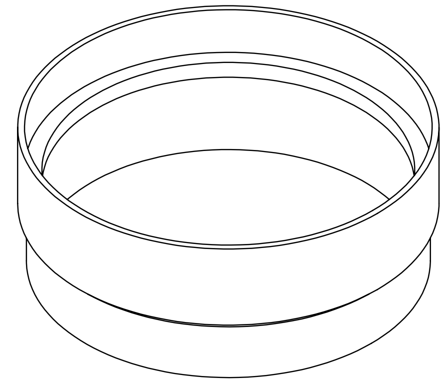
UNLESS OTHERWISE NOTED
DRAWING ARE CREATED IN ACCORDANCE TO ASME Y14.5-2009

DEFAULT DIMENSIONAL TOLERANCES:
LINEAR DIMENSIONS [inches]: X±.5, X.X±.1, X.XX±.03, X.XXX±.005
ANGULAR DIMENSIONS [degrees]: X±3, X.X±.5, X.XX±.1
MINIMUM SURFACE FINISH: 1000 microinches





SECTION A-A



ISOMETRIC VIEW

SPECIFICATIONS AND TOLERANCES

UNLESS OTHERWISE NOTED
DRAWING ARE CREATED IN ACCORDANCE TO ASME Y14.5-2009

DEFAULT DIMENSIONAL TOLERANCES:
LINEAR DIMENSIONS [inches]: X±.5, X.X±.1, X.XX±.03, X.XXX±.005
ANGULAR DIMENSIONS [degrees]: X±3, X.X±.5, X.XX±.1
MINIMUM SURFACE FINISH: 1000 microinches

Mechanical & Aerospace ENGINEERING
UtahState University

DRAFTED BY: ZACHARY FOSTER	PROJECT: AILEN INTERCEPTER
DRAFTED DATE:1/17/2023	PART/ASSEM NAME: MOTOR RETAINER MALE
DATE APPROVED:	PART/ASSEM NUMBER: 30-002-000
SHEET SCALE: 1:1	NEXT ASSEM NUMBER:
SHEET NUMBER: 1 of 1	MATERIAL: 6061-T6 ALUMINUM
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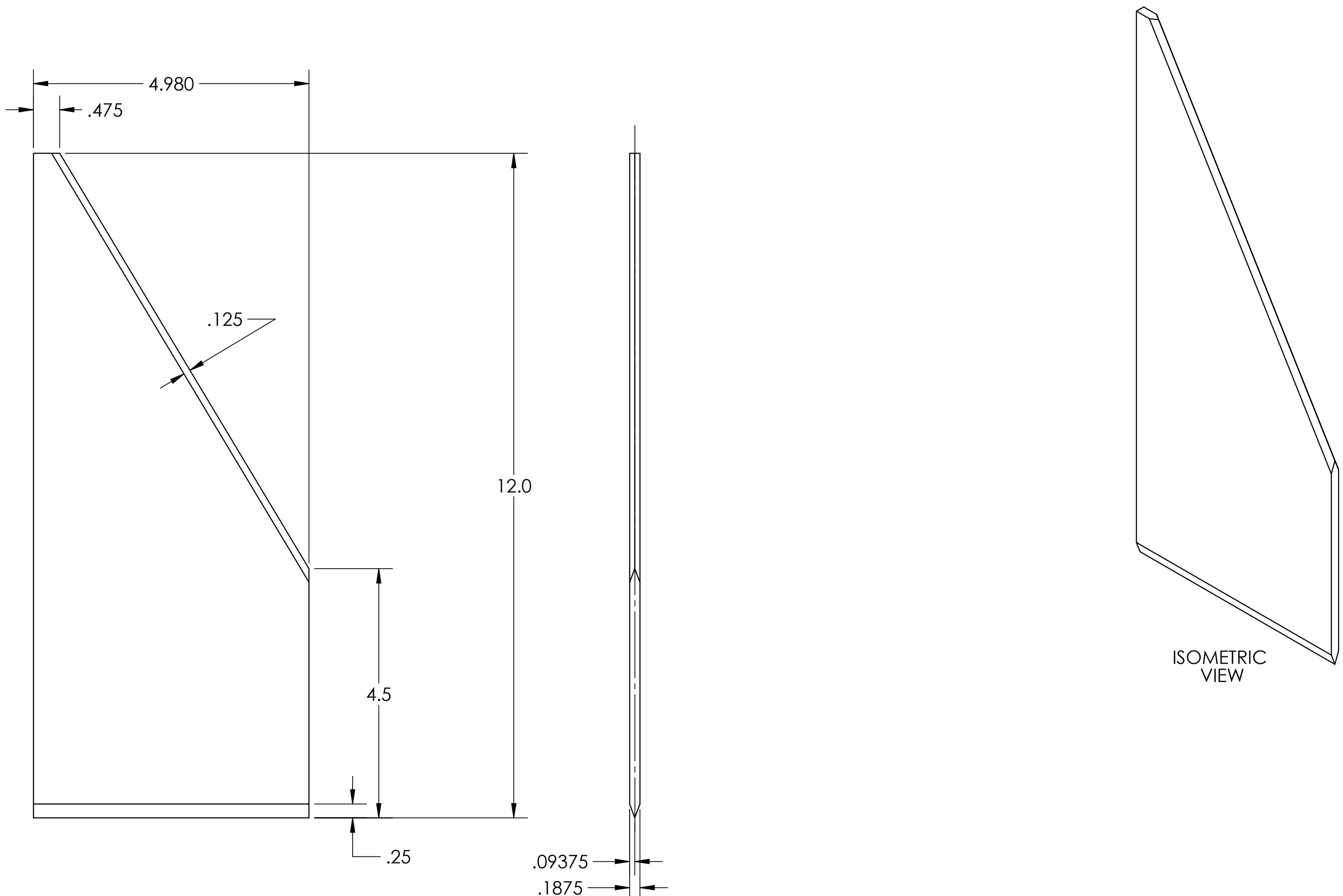

SPECIFICATIONS AND TOLERANCES

UNLESS OTHERWISE NOTED
DRAWING ARE CREATED IN ACCORDANCE TO ASME Y14.5-2009

DEFAULT DIMENSIONAL TOLERANCES:
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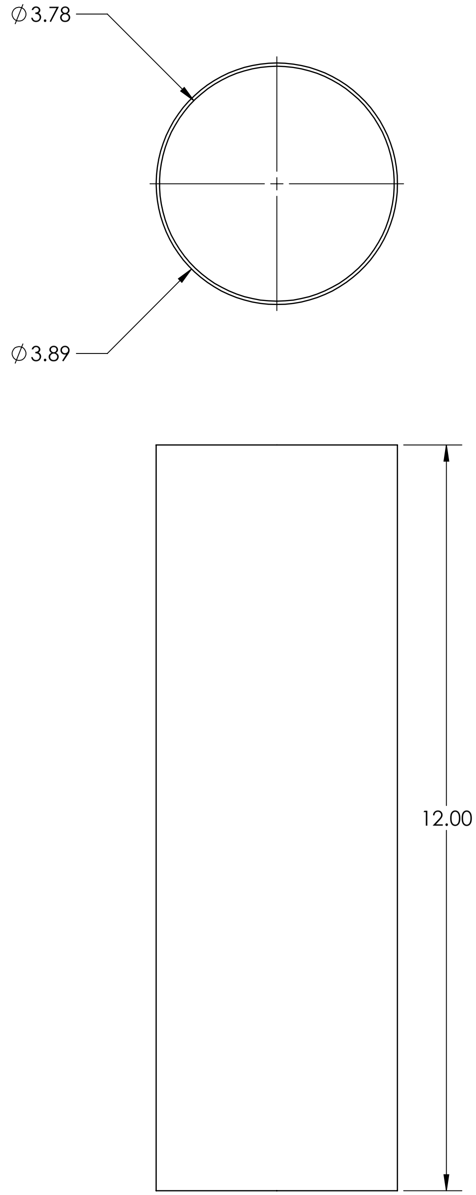
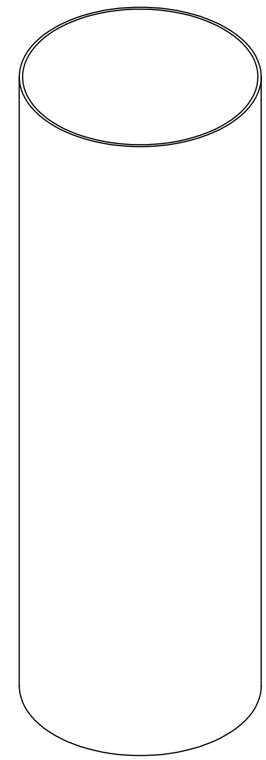
ANGULAR DIMENSIONS [degrees]: X±3, X.X±.5, X.XX±.1
MINIMUM SURFACE FINISH: 1000 microinches

Mechanical & Aerospace ENGINEERING
UtahState University

		PROJECT: AILEN INTERCEPTER
		PART/ASSEM NAME: FIN
DRAFTED BY: ZACHARY FOSTER		PART/ASSEM NUMBER: 20-001-000
DRAFTED DATE:1/17/2023		NEXT ASSEM NUMBER:
DATE APPROVED:		MATERIAL: G10 FIBERGLASS
SHEET SCALE: 1:2	SHEET NUMBER: 1 of 1	FINISH: N/A





ISOMETRIC
VIEW

Mechanical & Aerospace ENGINEERING
UtahState University

SPECIFICATIONS AND TOLERANCES	DRAFTED BY: ZACHARY FOSTER	PROJECT: AILEN INTERCEPTER
UNLESS OTHERWISE NOTED DRAWING ARE CREATED IN ACCORDANCE TO ASME Y14.5-2009	DRAFTED DATE:1/17/2023	PART/ASSEM NAME: E-BAY COUPLER
DEFAULT DIMENSIONAL TOLERANCES: LINEAR DIMENSIONS [inches]: X±.5, X.X±.1, X.XX±.03, X.XXX±.005 ANGULAR DIMENSIONS [degrees]: X±3, X.X±.5, X.XX±.1 MINIMUM SURFACE FINISH: 1000 microinches	DATE APPROVED:	PART/ASSEM NUMBER: 10-004-000
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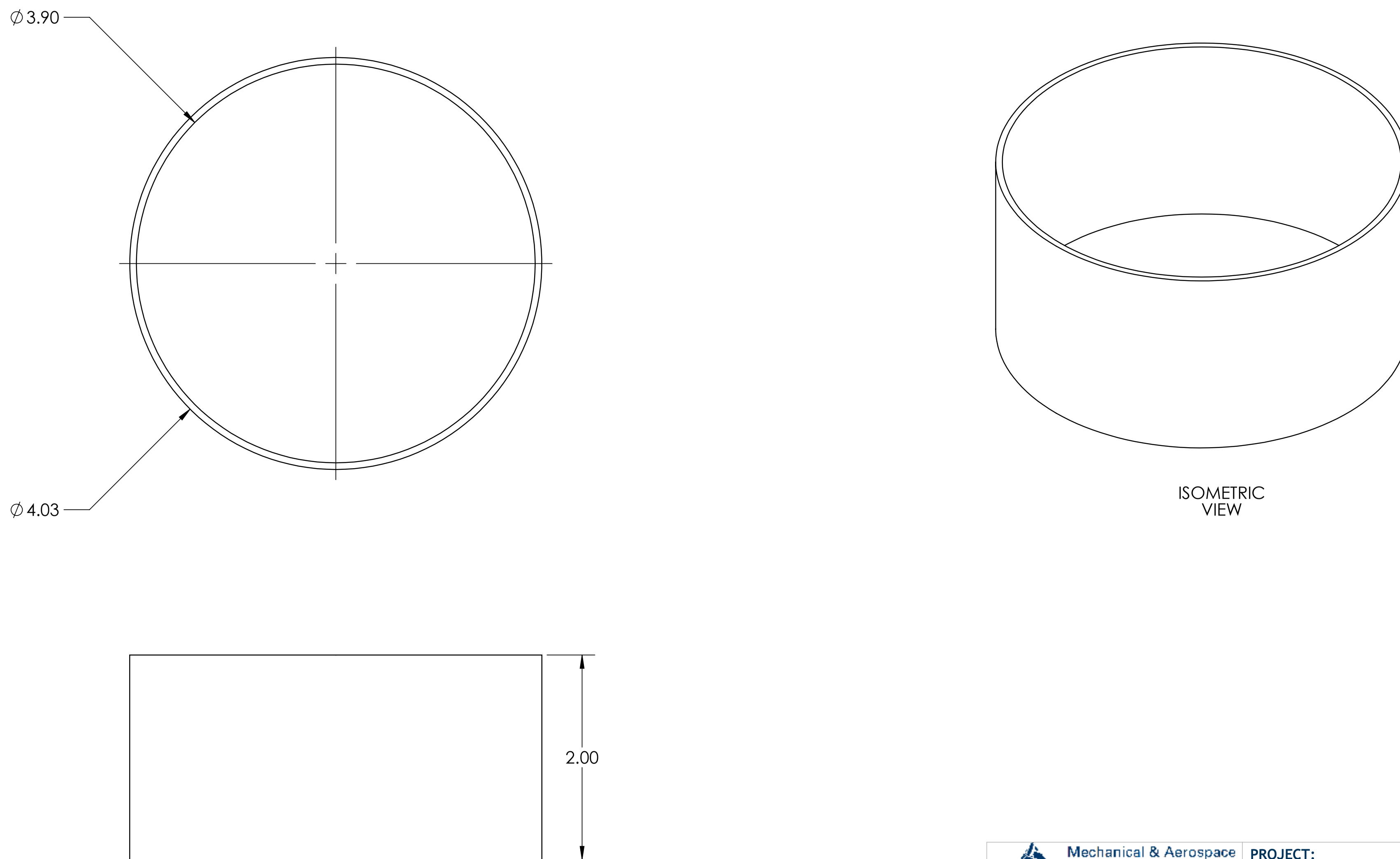

Mechanical & Aerospace ENGINEERING Utah State University	PROJECT: AILEN INTERCEPTER
	PART/ASSEM NAME: SWITCH BAND
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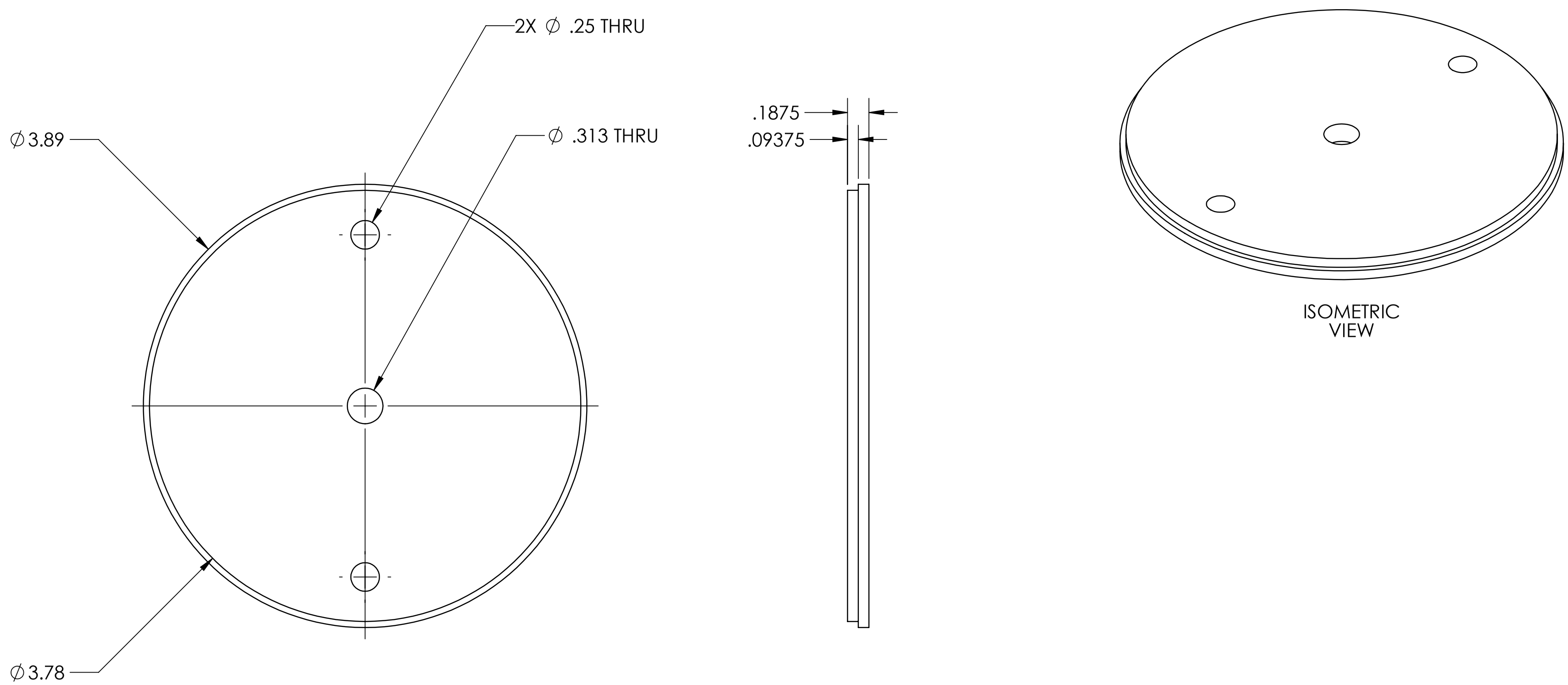
DRAFTED DATE:1/17/2023	NEXT ASSEM NUMBER:
DATE APPROVED:	MATERIAL: G12 FIBERGLASS
SHEET SCALE: 1:1 — SHEET NUMBER: 1 of 1	FINISH: N/A

SPECIFICATIONS AND TOLERANCES

UNLESS OTHERWISE NOTED
DRAWING ARE CREATED IN ACCORDANCE TO ASME Y14.5-2009

DEFAULT DIMENSIONAL TOLERANCES:
LINEAR DIMENSIONS [inches]: X±.5, X.X±.1, X.XX±.03, X.XXX±.005
ANGULAR DIMENSIONS [degrees]: X±3, X.X±.5, X.XX±.1
MINIMUM SURFACE FINISH: 1000 microinches



SPECIFICATIONS AND TOLERANCES

UNLESS OTHERWISE NOTED
DRAWING ARE CREATED IN ACCORDANCE TO ASME Y14.5-2009

DEFAULT DIMENSIONAL TOLERANCES:
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ANGULAR DIMENSIONS [degrees]: X±3, X.X±.5, X.XX±.1
MINIMUM SURFACE FINISH: 1000 microinches

Mechanical & Aerospace ENGINEERING
UtahState University

DRAFTED BY: ZACHARY FOSTER		PROJECT: AILEN INTERCEPTER
DRAFTED DATE:1/17/2023		PART/ASSEM NAME: STEPPED BULKHEAD
DATE APPROVED:		PART/ASSEM NUMBER: 20-002-000
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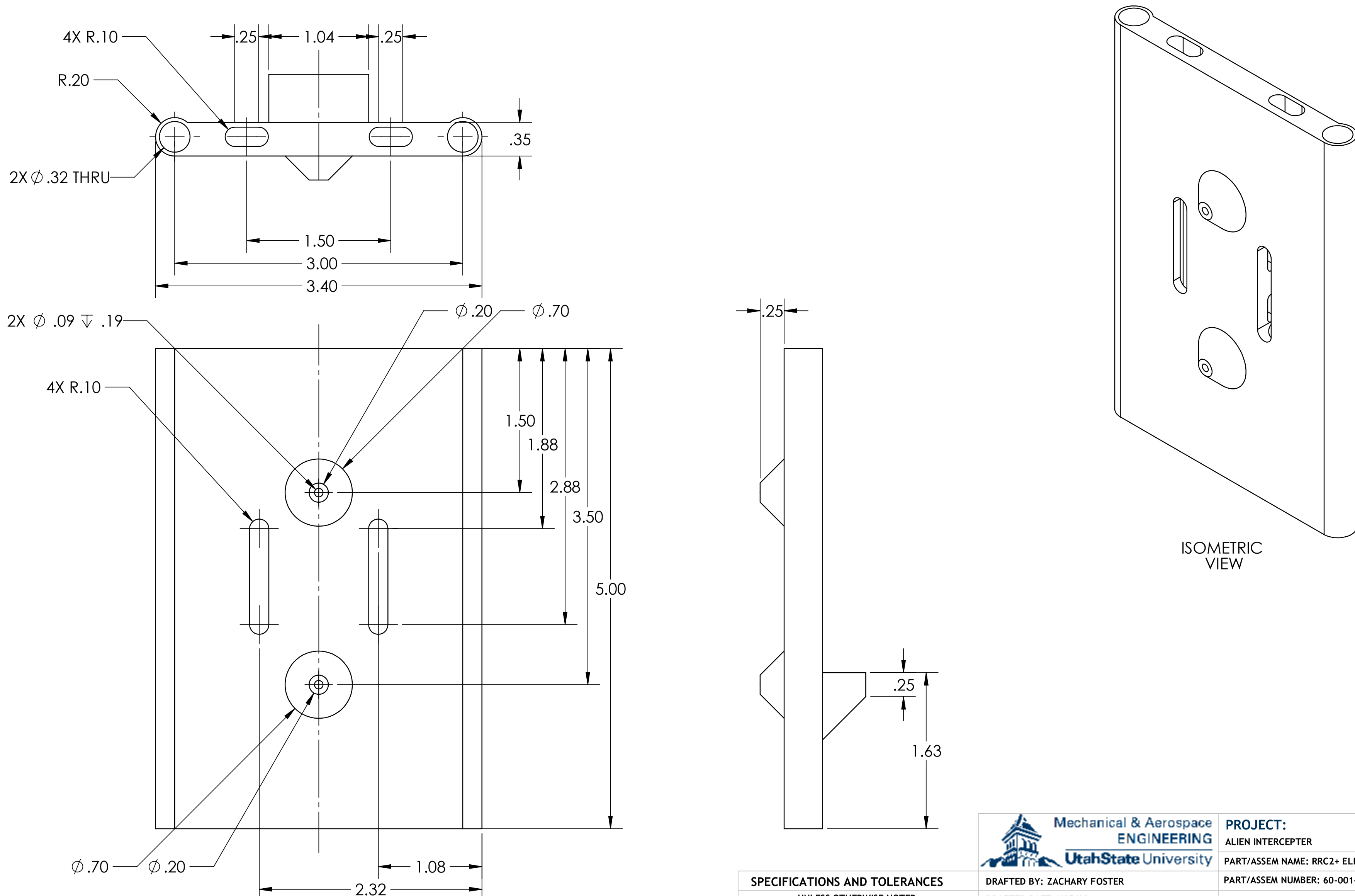

SPECIFICATIONS AND TOLERANCES

UNLESS OTHERWISE NOTED
DRAWING ARE CREATED IN ACCORDANCE TO ASME Y14.5-2009

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ANGULAR DIMENSIONS [degrees]: X±3, X.X±.5, X.XX±.1
MINIMUM SURFACE FINISH: 1000 microinches

Mechanical & Aerospace ENGINEERING
UtahState University

DRAFTED BY: ZACHARY FOSTER		PROJECT: ALIEN INTERCEPTER
		PART/ASSEM NAME: RRC2+ ELECTRONICS SLED
DRAFTED DATE:4/25/23		PART/ASSEM NUMBER: 60-001-000
DATE APPROVED:		NEXT ASSEM NUMBER:
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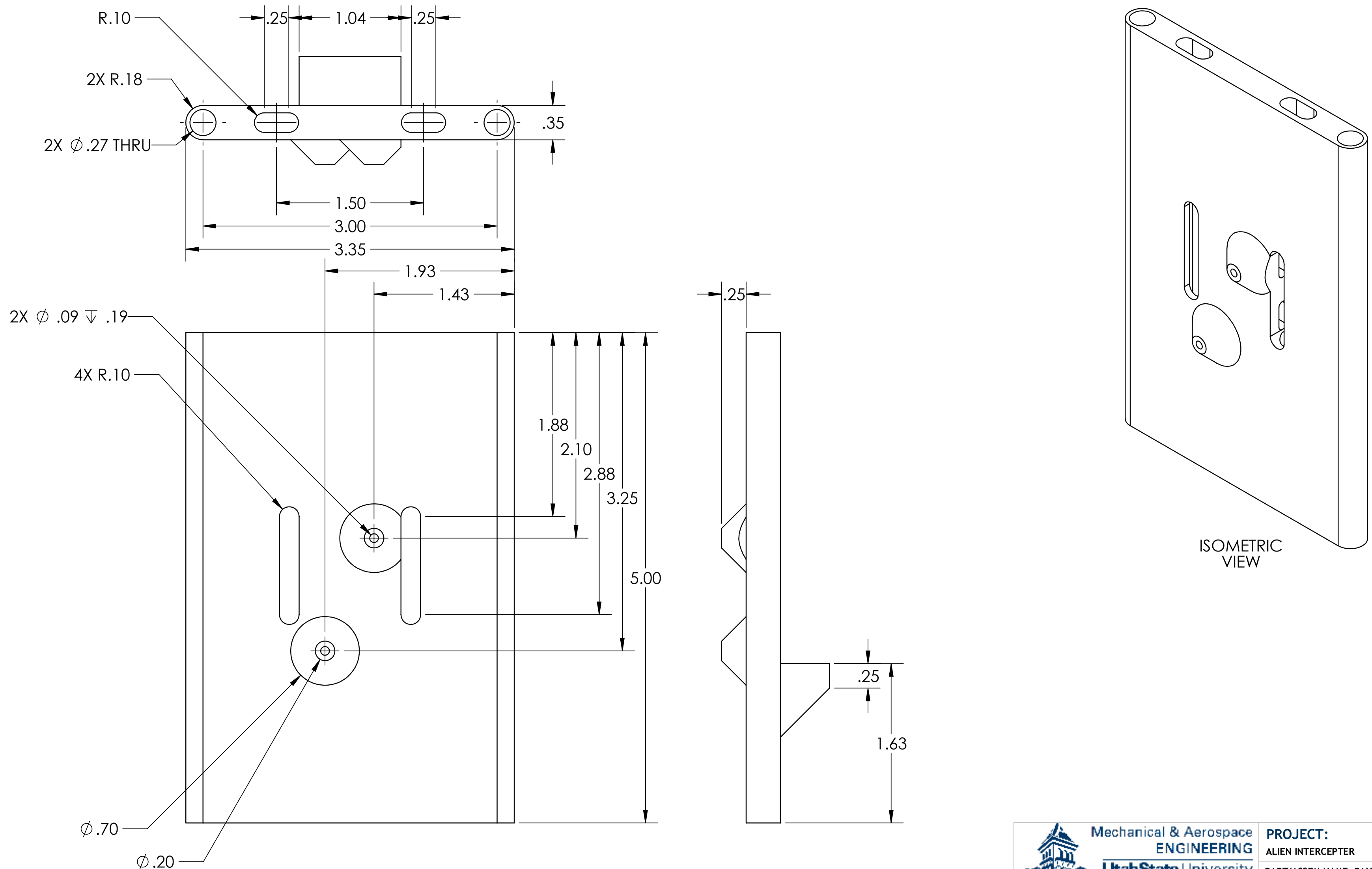
SHEET SCALE: 1:1	SHEET NUMBER: 1 of 1	FINISH: NA



SPECIFICATIONS AND TOLERANCES

UNLESS OTHERWISE NOTED
DRAWING ARE CREATED IN ACCORDANCE TO ASME Y14.5-2009

DEFAULT DIMENSIONAL TOLERANCES:
LINEAR DIMENSIONS [inches]: X±.5, X.X±.1, X.XX±.03, X.XXX±.005
ANGULAR DIMENSIONS [degrees]: X±3, X.X±.5, X.XX±.1
MINIMUM SURFACE FINISH: 1000 microinches

Mechanical & Aerospace ENGINEERING
UtahState University

		PROJECT: ALIEN INTERCEPTER
		PART/ASSEM NAME: RAVEN 4 ELECTRONICS SLED
DRAFTED BY: ZACHARY FOSTER		PART/ASSEM NUMBER: 60-002-000
DRAFTED DATE:4/25/23		NEXT ASSEM NUMBER:
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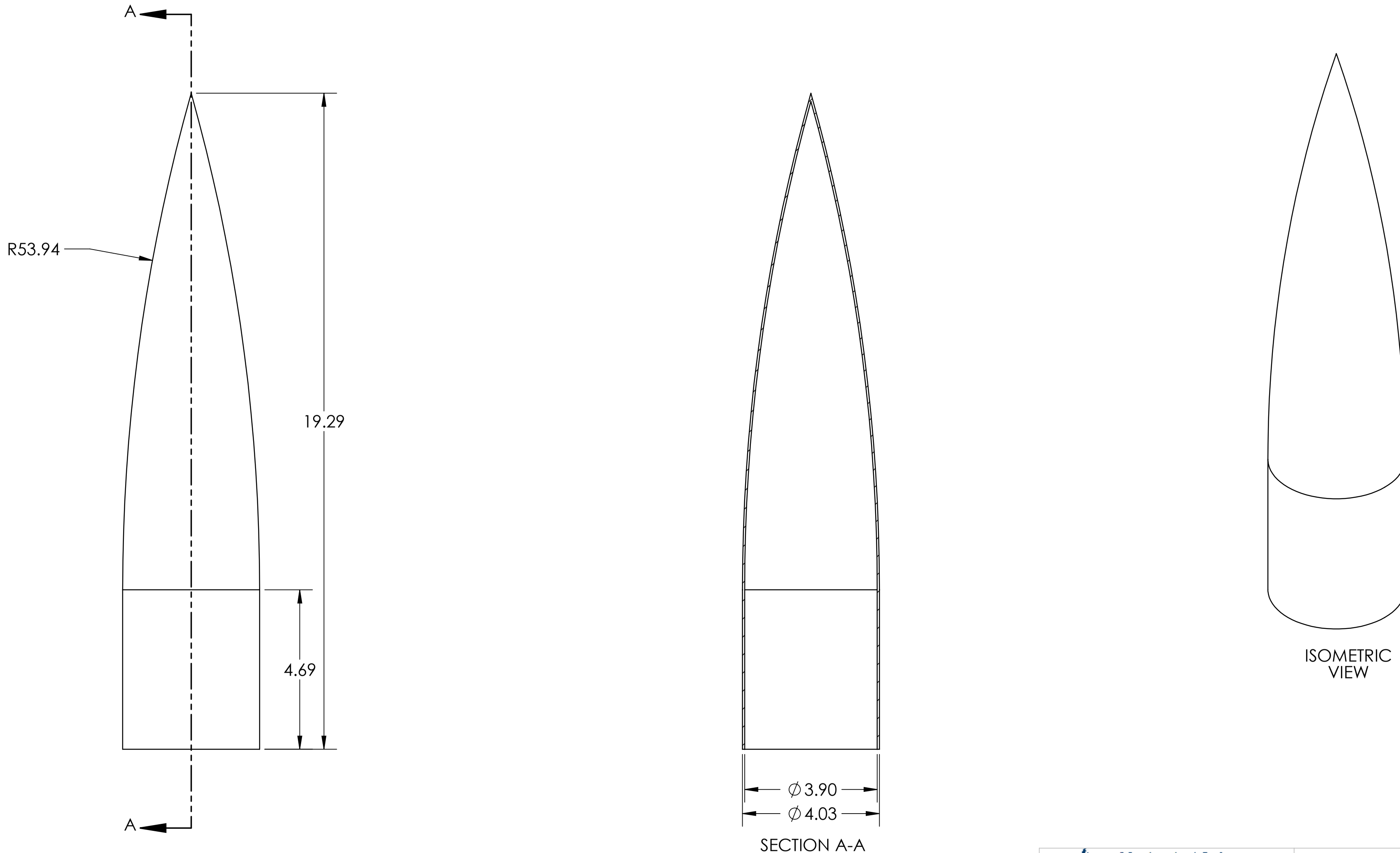

SPECIFICATIONS AND TOLERANCES

UNLESS OTHERWISE NOTED
DRAWING ARE CREATED IN ACCORDANCE TO ASME Y14.5-2009

DEFAULT DIMENSIONAL TOLERANCES:
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ANGULAR DIMENSIONS [degrees]: X±3, X.X±.5, X.XX±.1
MINIMUM SURFACE FINISH: 1000 microinches

Mechanical & Aerospace ENGINEERING
UtahState University

PROJECT:
AILEN INTERCEPTER

DRAFTED BY: ZACHARY FOSTER	PART/ASSEM NAME: NOSE CONE
DRAFTED DATE:1/17/2023	PART/ASSEM NUMBER: 10-005-000
DATE APPROVED:	NEXT ASSEM NUMBER:
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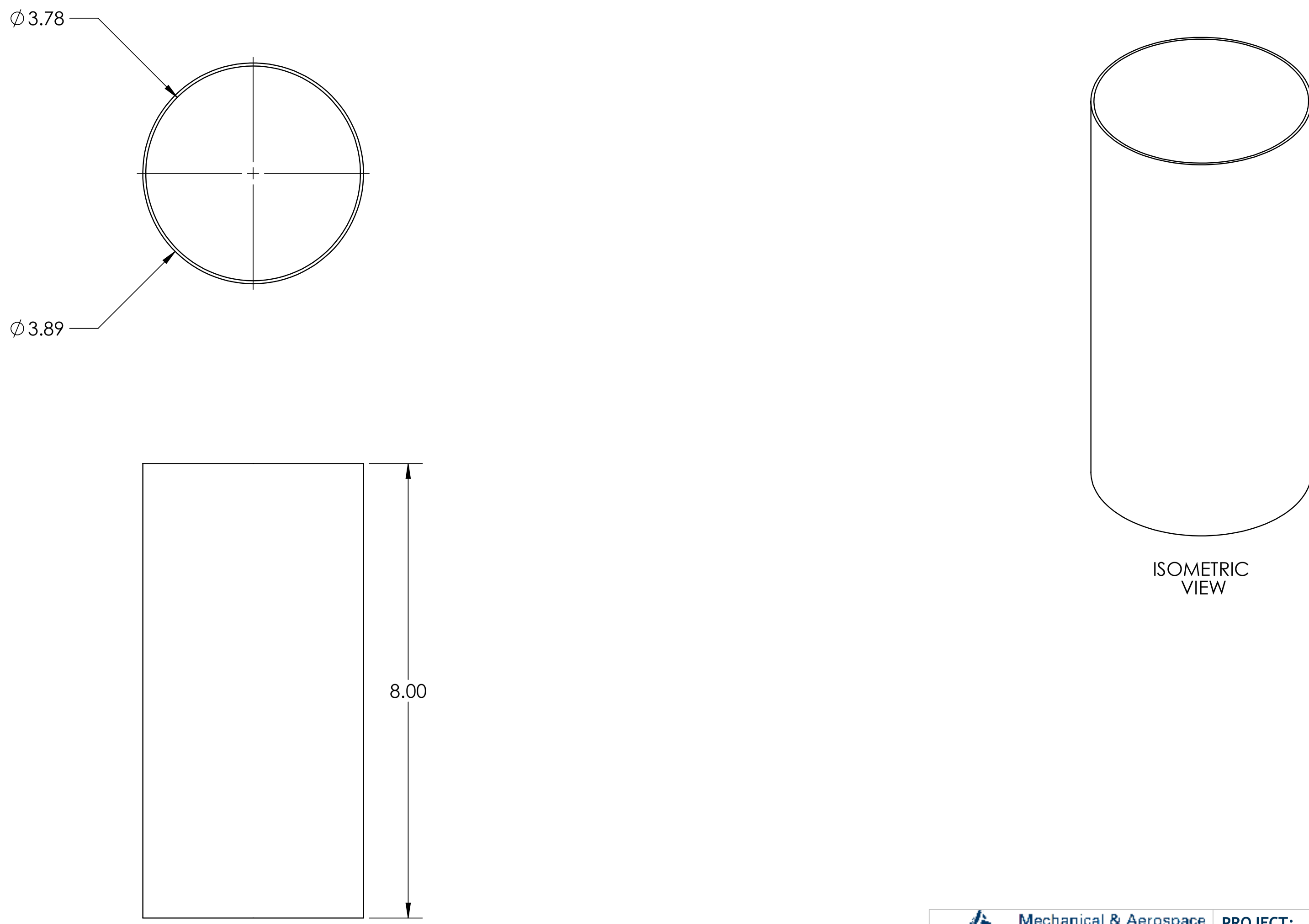

SPECIFICATIONS AND TOLERANCES

UNLESS OTHERWISE NOTED
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DEFAULT DIMENSIONAL TOLERANCES:
LINEAR DIMENSIONS [inches]: X±.5, X.X±.1, X.XX±.03, X.XXX±.005
ANGULAR DIMENSIONS [degrees]: X±3, X.X±.5, X.XX±.1
MINIMUM SURFACE FINISH: 1000 microinches

Mechanical & Aerospace ENGINEERING
UtahState University

DRAFTED BY: ZACHARY FOSTER	PROJECT: AILEN INTERCEPTER
DRAFTED DATE:1/17/2023	PART/ASSEM NAME: NOSE CONE COUPLER
DATE APPROVED:	PART/ASSEM NUMBER: 10-006-000
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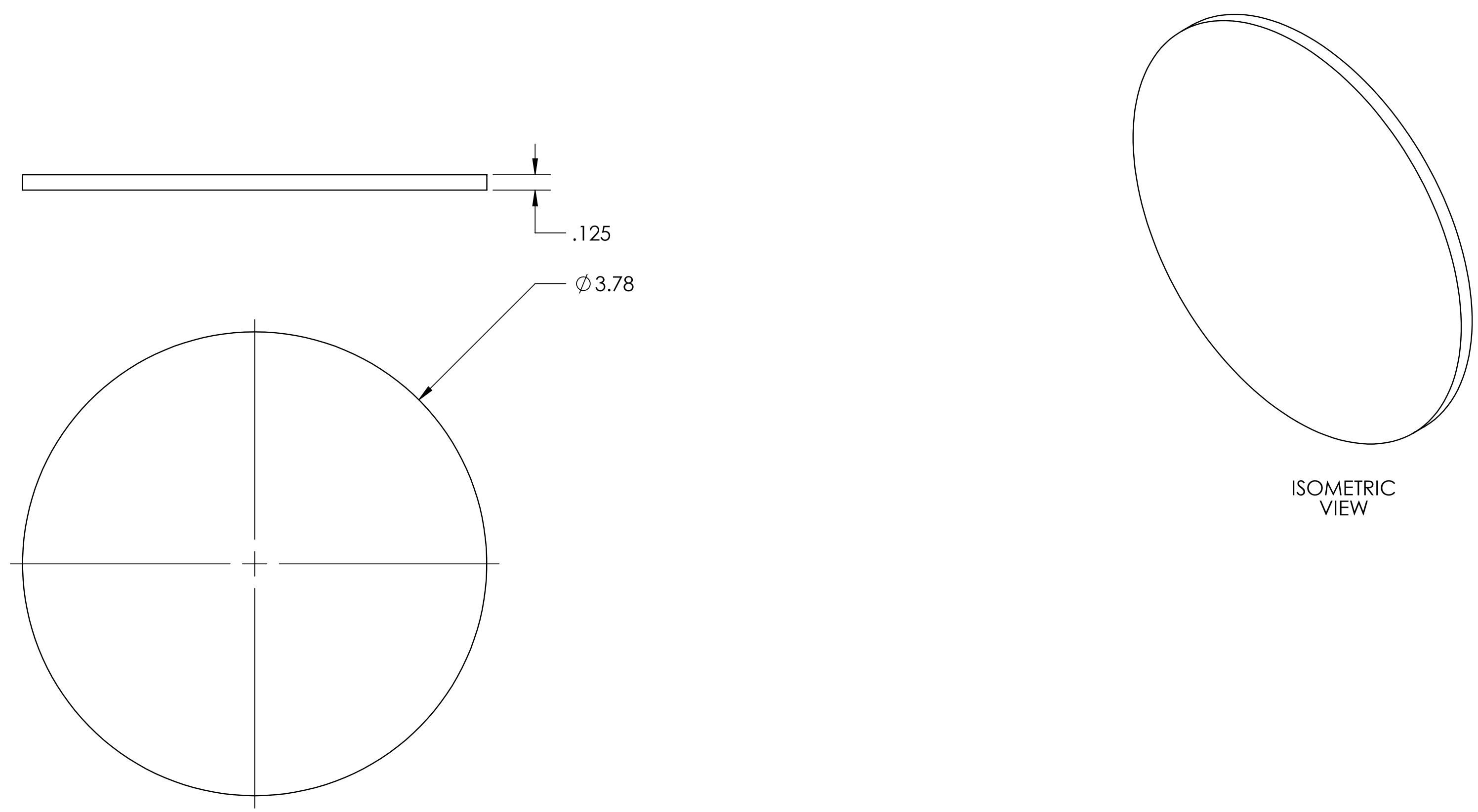

SPECIFICATIONS AND TOLERANCES

UNLESS OTHERWISE NOTED
DRAWING ARE CREATED IN ACCORDANCE TO ASME Y14.5-2009

DEFAULT DIMENSIONAL TOLERANCES:
LINEAR DIMENSIONS [inches]: X±.5, X.X±.1, X.XX±.03, X.XXX±.005
ANGULAR DIMENSIONS [degrees]: X±3, X.X±.5, X.XX±.1
MINIMUM SURFACE FINISH: 1000 microinches

Mechanical & Aerospace ENGINEERING
UtahState University

DRAFTED BY: ZACHARY FOSTER	PROJECT: AILEN INTERCEPTER
DRAFTED DATE:1/17/2023	PART/ASSEM NAME: COUPLER BULKHEAD
DATE APPROVED:	PART/ASSEM NUMBER: 20-003-000
SHEET SCALE: 1:1 / SHEET NUMBER: 1 of 1	NEXT ASSEM NUMBER:
	MATERIAL: G10 FIBERGLASS
	FINISH: N/A

Reflective Writing

While obtaining my level 3 certification through the TRIPOLI Rocketry Association, I learned a lot of valuable skills and lessons that can easily be transferred into industry.

During the design process, I learned the importance of iterative design and to remember that just because you finished designing a part doesn't mean the procedure is done. Several times, I was close to the end of the design process and realized that I needed to redesign several subcomponents of the assembly because I didn't quite meet a design requirement. This process was frustrating at first because I felt that the design wasn't close to being finished, and there wasn't an excellent measurable metric to show how much work I had put into the design. But after twenty-plus design iterations, I realized that my plan was significantly better than the one I had started with. The airframe was much more robust and had a higher resistance to failure in compression; the fins had a ridged construction design that could withstand high static aero-loading and high aerodynamic loading. The flight envelope of the airframe was also much more aggressive and allowed for high Mach flights and launching in high winds.

During the approval process, I learned the importance of being able to take criticism on something I designed. As part of the Level 3 certification process, you are required to get approval from two mentors who also have a Level 3 certification. During this part of the process, I became discouraged because my mentors were picking apart my entire design and finding every flaw in my plan. After I got my preliminary design report back, the document had massive amounts of red and black ink. I later found out my design was being picked apart, not because the overall design was terrible, but because they had to dig into the plan's details even to find anything wrong with it. At the time, however, it felt like a personal attack on my intelligence and competence as an engineer. After arranging a meeting with my mentors, we walked through the document and addressed their concerns with the design. After that meeting, I realized they were not trying to tear down my work but genuinely wanted to see my design improve.

During the construction phase of the airframe, I learned that not everything turns out as good as the drawing on the computer. Many late nights were spent trying to fix mistakes in the construction that I had made. Epoxy got into places I hadn't expected that required countless hours of sanding, or fiberglass tubes had accidentally vacuumed themselves together, making it almost impossible to separate the two pieces. Toward the end of the construction phase, I finally learned to accept that I had designed critical components with high safety factors for a reason. Not everything needed to be perfect, nor did everything match the computer drawing perfectly.

During the flight portion of the airframe, I learned once again that some things were outside my control. The weather on launch day was not cooperating, and after a 4:30 am wake-up call and a 5-hour drive, I just wanted to launch and go home. I assembled the rocket and prepared the airframe for launch. The launch preparations were completed by 11:00 am, but the cloud cover prevented me from launching. At this point, my TAP and I were beginning to think that a launch window would never appear and I would have to wait for the next launch a month later. I decided to put the rocket on the pad anyway and leave the electronics disarmed until I was ready to launch. The only problem with this plan is that the GPS tracker I used did not have an on-off switch, and the GPS would have to remain on the entire time. This was concerning because I didn't know how long the battery would last, and if the rocket launched without a GPS tracker, it could be impossible to recover err the missile. I kept the rocket on the pad for three and a half hours, waiting for a window to appear. During this time were several breaks in the clouds, so I ran out to the pad, which was over a quarter mile away, and armed the electronics just for the gap in the clouds to disappear again. This pattern of arming and disarming the electronics happened six times in 3 hours. Around 4:00 pm, there was a significant break in the clouds, and I ran out to arm the electronics for the final time. The RSO approved the flight, initiated the count, and launched the rocket.

The rocket flew beautifully, and for the first time, I felt that my hard work, blood, sweat, and tears had all been worth it. The rocket descended under the parachute and landed about 50 ft from my car, which was impressive considering I had to walk 2 miles to recover my level 2 certification rocket. After the recovery, I attempted to pull data off the GPS and flight altimeters only to discover that the maximum data log time for the GPS was two and a half hours. This meant I had over two hours of GPS data of the rocket sitting on the pad and zero data from the actual flight. Once again, my impatience had come back to bite me. While my perseverance had been rewarded with a successful flight and certification, my lack of patience had resulted in me not getting the desired flight data to validate the other sensors I had on board.

Throughout the project, there was a common theme of my perfectionism and lack of patience causing problems. Toward the end of the project, I felt that I had experienced a lot of personal growth, especially concerning my perfectionism. Toward the end of the project, I worked hard to do the very best that I could do given the circumstances and tried not to let the little things get to me as much. However, I think that my patients still have a long way to go, which is pretty apparent, especially when I was trying to launch.

Overall I think that his project has allowed me to use my technical skills, but more importantly, it allowed me to observe and reflect on my soft skills that seem to be lacking compared to other things.

Acknowledgements

I want to thank my two TAP members, Greg Spohn and Kip Daugirdas. This project would not have been possible without them, and their knowledge proved invaluable. I would also like to thank Xavier Kipping for his help with the GPS Tracking and for being tall enough to pull the electronic pin. I would also like to thank my two faculty advisers, Jackson Graham and Joel Ellsworth. Their advice on this project has made the process go smoothly.

Biography of the Author

Zachary Foster is studying Mechanical Engineering with an emphasis in Aerospace and a minor in Unmanned Aerial Systems. During Zachary's time at Utah State University, he joined the High Powered Rocketry Club and completed several projects. Most notably, Zachary worked on a two-stage altitude world record attempt. During this project, the rocket reached a maximum altitude of 50K ft, breaking the previous record by 10K ft. Unfortunately, the booster section of the rocket suffered a parachute deployment failure, and the booster was never recovered, resulting in an unofficial world record. Zachary restarted the Spaceport America Competition Team at Utah State and plans to compete in the 2023 Spaceport America Cup in June. After graduation, Zachary is planing to pursue a Master of Science in Mechanical Engineering at Utah State University. Zachary will be doing his thesis research on Morphing Supersonic Aircraft through USU's AeroLab under Dr. Douglas Hunsaker. Zachary hopes to go on working at an aerospace company designing control systems for unmanned aircraft.

References

[1] Howard, Z., "How To Calculate Fin Flutter Speed," Peak of Flight, 1(291), pp. 1-6.
[2] Manfredo, J., "Properly Sizing Parachutes for Your Rockets," Peak of Flight, 1(149), pp. 2-7.
[3] Rogers, C., Cooper, D.,2019, "Rogers Aeroscience RASAero II Aerodynamic Analysis and Flight Simulation Program," Rogers Aeroscience, Lancaster, California.