UtahStateUniversity

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Design Baseline Document

Gimbal for DJI Inspire

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Mechanical & Aerospace
ENGINEERING

CONTENTS

APPENDICES

1 PROBLEM DEFINITION

1.1 OVERVIEW

Our customer needs a way to attach a GoPro HERO4 to a DJI Inspire. It should have at least 2 axes of rotation. It should not interfere with the flight or landing of the drone.

1.2 ENGINEERING REQUIREMENTS

1.2.1 The gimbal shall be capable of at least a 70-degree roll axis.

Source: The DJI Inspire drone is only capable of a roll axis of 35 degrees in either direction. Therefore, in order to keep the camera level with the ground it should be able to move in either direction at least 35 degrees.[1]

Fulfillment Strategy: This requirement will be tested by flying the drone, and seeing it's actual maximum roll. At the angle to the ground which the drone fails to continue flying. That is the maximum angle for the roll of our gimbal, with it being able to roll that angle in both directions from parallel.

1.2.2 The gimbal shall be capable of a pitch angle from pointing the camera straight at the ground to the angle at which the camera is pointing just beneath it.

Source: "The drone should not interfere with the Camera's field of view." (customer requirements)

Fulfillment Strategy: This requirement will be tested by prototyping a gimbal and then calibrating the actuators to stop just below the bottom of the drone's legs while in the flying position.

1.2.3 The gimbal shall weigh no more than 1.44 pounds.

Source: Manufacturer's website states that the gimbal has the ability to take off with 7.71 pounds. The drone itself weighs 6.27 pounds, which includes the propellers and battery. Therefore, our gimbal shall not weigh more than 1.44 pounds so as not to affect the flight of the drone.[1]

Fulfillment Strategy: Test the drone's flying capabilities with different weights attached. Trying to find if 1.44 pounds affects flying, or whether that will just affect maneuverability.

1.2.4 The gimbal shall have a way to mitigate the rolling shutter effect or the rolling shutter effect caused by the vibration of the drone while flying.
Source: Customer Requirements

Fulfillment strategy: Test the drone to see how much vibration is produced while flying, and at what point of vibration the Rolling Shutter effect starts to occur. This will affect the type of dampener we use.

1.2.5 The gimbal must be attached to the drone with a simple connection so the gimbal can be easily removed.
Source: Customer Requirements

Fulfillment Strategy: Test quick attachments among consumers by asking how many bolts is too many. Trying to find which bolt assembly is difficult and not a considered quick, while still securely attaching (no wobble introduced at the bolt assembly.)

1.2.6 The camera shall be easily removable by two bolts at the max, that can be hand tightened, or a similar connection that is easy to remove, but safe.
Source: Customer Requirements

Fulfilment strategy: Test among consumers which is the best way to mount a camera that is easily removed. Produce prototypes, and have consumers select the one that is easiest to attach to the camera.

1.2.7 The gimbal shall be positioned in a way that does not interfere with the Field of View of the camera.
Source: Customer Requirements

Fulfillment Strategy: Create a prototype of the gimbal and then use the camera to test whether the landing gear of the gimbal disrupts the Field of View.

1.2.8 The gimbal shall have a mechanism that can push the button without causing damage.
Source: The customer does not want a broken camera from using this device.

Fulfillment Strategy: test the button, how much force is required for the button sensors to activate. How much force will destroy it. Any mechanism that is designed must provide a force that is within that range.

1.2.9 When the drone is in the landing configuration, the camera shall be no less than 15 mm from the ground.
Source: Customer Requirements

Fulfillment Strategy: Measure the space in between the ground and the bottom of the gimbal attachment on the underside of the drone. the gimbal and camera must be within that space minus 15 millimeters.

1.2.10 The cost of the gimbal shall be 100$ or less.

Source: The price of the drone is roughly 1,999$.[2] The GoPro costs about 240$.[3] We would like our gimbal to cost less than the camera and the drone, so that it is marketable.

Fulfillment Strategy: Keep track of the price of the parts and how much it will be to make them. Research other gimbals with the same functionality as this one. Make sure the prices are similar.

1.2.11 The gimbal shall only use actuators that are common to remote control vehicles.

Source: Customer Requirements

Fulfillment Strategy: Research actuators that are used on remote control vehicles. Only purchase actuators from approved Remote Control Vehicle providers.

1.3 GOALS

1.3.1 The gimbal should have a movable yaw angle of 360 degrees.

Source: The customer said that they need 2 rotational axes. This goal could be achieved by the drone itself (I.E. the drone spinning 360 degrees) or by the gimbal.

Fulfillment Strategy: This goal would be achieved by adding a third axis of rotation to the gimbal.

1.3.2 The gimbal should be sturdy enough to withstand a crash of the drone. Force of weight of drone

Source: Drones run out of batteries or sometimes run into trees. Therefore; the gimbal should be able to safely survive a fall, so that the customer does not need to replace the gimbal every time the drone falls out of the sky.

Fulfillment Strategy: Test the gimbal to see if it can withstand an impact equivalent to the weight of the drone.

2 CONCEPTUAL ANALYSIS

2.1 BACKGROUND RESEARCH

While researching solutions we first split the gimbal into its different subcomponents, and then compiled a list of different solutions for each problem that these subcomponents tacked. We did not limit our research to ways that gimbals had been made before, but instead focused on the fundamental principles need to accomplish each subtask. These categories included vibration dampening, rotation, button pushing, and quick attachments.

For vibration dampening, we searched for ways that vibrations were damped in all sorts of applications. We looked at how things like sound vibrations are dampened[4], how cars reduce vibrations from the road through various types of dampening mechanisms from air compression shocks to more conventional coil spring and leaf spring shocks[5], and things like how the rotors in helicopters are dampened and tried to find various ways to incorporate these dampening ideas into our design[6].

For the different degrees of rotation that we needed in the camera, we looked at not only previous camera designs, but at more fundamental principles to get the rotation that we needed.

For rotation, we looked at previous attempts to rotate a camera in different axes. We looked at other gimbals that had already been produced, and attempted to understand how they achieve the rotation in 3 axes[7] [8]. We found that most gimbals use motors (stepper or actuator) to achieve this rotation. Other ideas that we researched involved using flywheels to control a cube that we could use to point the camera in our desired direction[9].

Attaching quickly to either the camera or the drone is more difficult to define. However, we looked across industries, how are lids secured, as well as what bolts and pins are used to securely attach a number of devices in a way that is considered “quick”.[10] [11]

For the Button Pushing Mechanisms we looked into several different types of servos and pushing mechanisms for large and small-scale applications.[12] [13]

We looked at various types of motors in order to get the precision and size that we need.[14]

2.2 CONCEPTS CONSIDERED

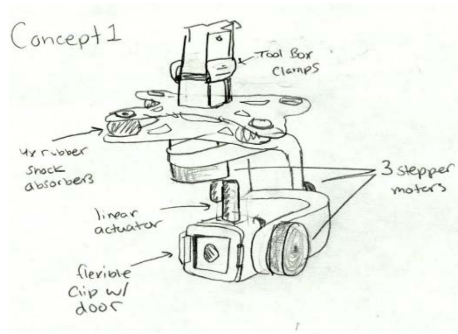

Figure 1. Concept 1

2.2.1 Concept 1: (Classic) This concept uses a 3 axis, gimbal run by three stepper motors, one for each axis of rotation The Rolling Shutter Effect will be solved with an array of rubber ball springs fixed upon two plates near where the drone is attached to the gimbal. The camera will be held be a flexible 3-D printed clip that holds a door in the front of a case holding the camera closed. A small linear actuator attached to the top of the camera frame will press the button. The gimbal will attach to the drone with two clamps similar to those on toolboxes. (Figure 1)

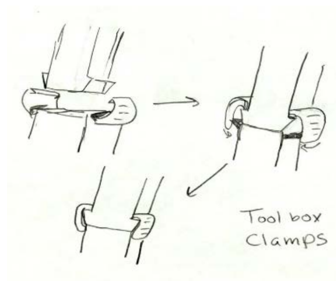

Figure 2. Tool Box Clamps

2.2.1.1 The stepper motors can be controlled to precise angular positions, they will be arranged to get 360-degree yaw rotation, 110-degree pitch rotation, and 300-degree roll rotation.

2.2.1.2 The rubber ball stabilizers will consist of four rubber balls that separate two plates and provide stabilization from the jello effect. These balls provide a correcting force for both lateral and vertical displacement from their equilibrium.

2.2.1.3 The camera holder consists of a rigid frame around the camera that has a small clip on the side that can be pulled open to let the door that holds the camera open.

2.2.1.4 The gimbal will be mounted to the bottom of the drone with semi-permanent screws to hold the top half of the toolbox like quick release mechanism (Figure 2) that will connect to the rest of the gimbal.

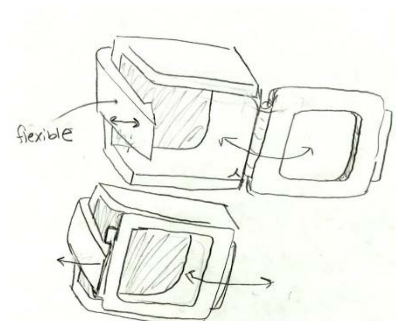

Figure 3. Camera holder

2.2.2 <u>Concept 2: (Rack and Pinion) (Figure 4)</u> This concept uses a rack and pinion track in a semicircle form that the camera rotates inside of for two axis of movement. The camera would sit in a circular cradle that is then rotated by a gear or rack and pinion track. The camera would be attached with two clamps that are fixed to the cradle. The button would be pushed by an electric servo setup above the camera. The entire gimbal would be attached to the drone with a quick-release quarter turn locking mechanism.

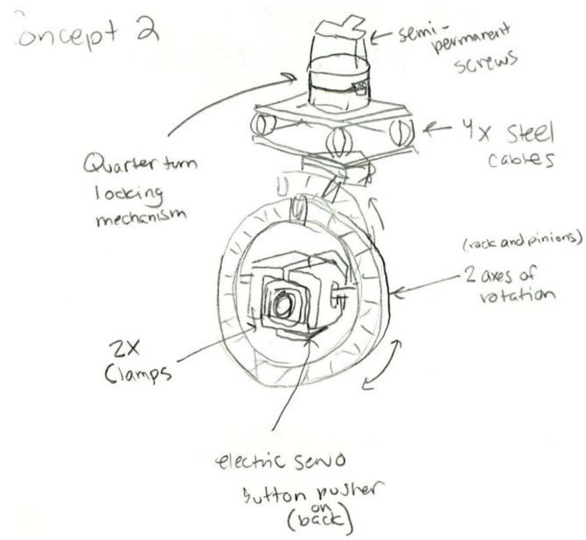

Figure 4. Concept 2

2.2.2.1 The rack and pinion has a full circular track for the rolling axis and a half-circle for the pitch axes. The cradle will be able to turn 360 degrees for the roll and 180 for the pitch.

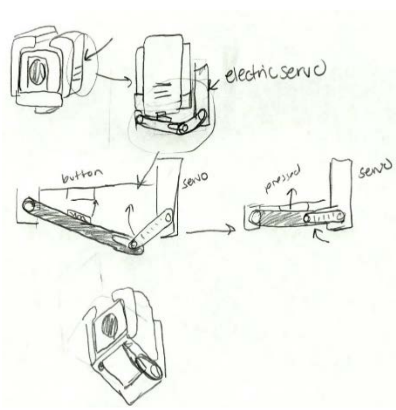

Figure 5. Servo button pushing machine

2.2.2.2 The cable spring mount would use 4 points of cables bent to absorb shock.

2.2.2.3 The camera would be attached to the cradle with two clamps to allow easy insertion and removal.

2.2.2.4 The button of the camera would be pushed by an electric servo setup situated below the camera. (Figure 6)

2.2.2.5 The Gimbal would be attached with a quarter turn locking mechanism for quick release, and semi-permanent screws to the base of the drone itself. (Figure 5)

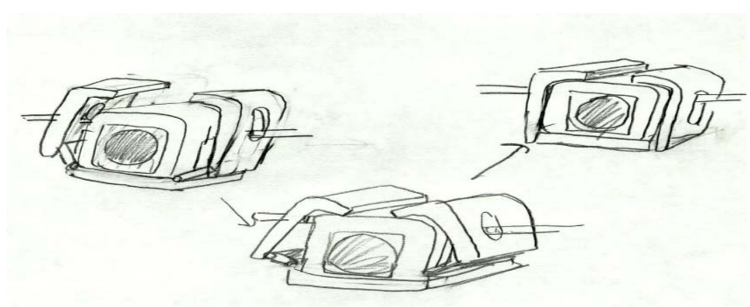
Figure 6. Camera Clamp

2.2.3 Concept 3: (Flywheels) (Figure 7) This concept relies on a set of three flywheels to keep the camera pointed in any direction regardless of what the drone does. These flywheels are run from the battery of the drone. The button of the GoPro is pushed by a linear servo. The camera is held in a slightly larger cube that has a door that slides in a track to hold the GoPro in place. This larger cube is packed with rubber to hold the camera tightly as well as reduce vibrations. Guided rubber bands will be used to absorb most of the vibrations. The arm than holds the camera will be held on by a bolt with a cotter pin.

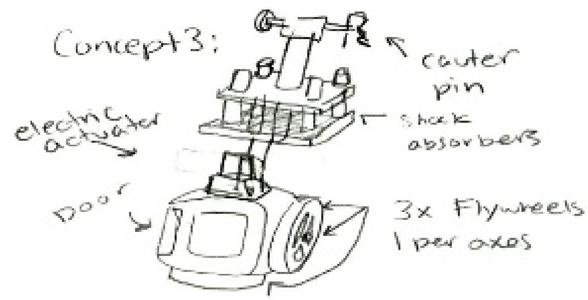

Figure 7. Concept 3

2.2.3.1 A flywheel works by spinning in a certain direction. This axis never changes unless torque is applied to the system. This is used to control the camera by setting the camera at a certain angle and then starting the flywheels. The camera will stay set at this angle.

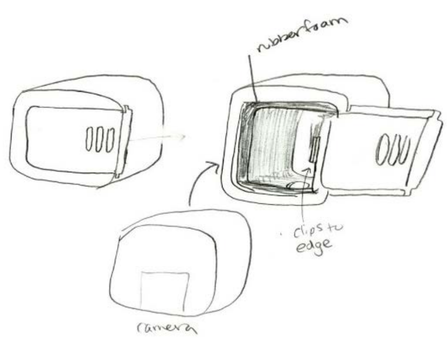

Figure 8. Sliding Door Concept

2.2.3.2 The button of the GoPro will be pushed by an electric actuator.

2.2.3.3 The camera will be held in a case with a sliding door (Figure 9). The door can be quickly closed once the camera is inside. The case will have a hole for the camera and the button. This case will also be lined with rubber, so that the GoPro is kept snug and will not be affected by the vibrations produced by the flywheels.

2.2.3.4 The arm that connects the camera case to the drone will be bolted to the Gimbal Attachment Location on the drone with a bolt, instead of drilling and tapping it will be held in place with a cotter pin. These pins can effectively connect something to something else up to a certain tension, which should not occur in the regular use of this drone.

2.2.3.5 The Rolling shutter effect will be mitigated using guided rubber bands (Figure 8).

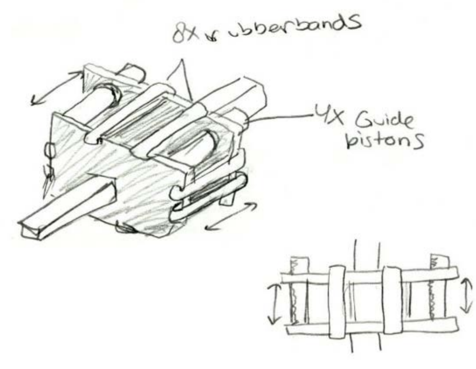

Figure 9. Guided Rubber Band Dampening System

2.3 OPTIONS ANALYSIS

Requirements 1.2.1, 1.2.2, 1.2.3, 1.2.8 are all absolutely critical to the customer. These requirements cannot be affected by any other outside variable. These were given five points since they are most important to the customer. Requirements 1.2.4 and 1.2.7 are all important to the comfort and usability of the customer. The Rolling Shutter Effect can be mitigated in other ways, upping the frame rate of the camera, etc. The FOV can also be changed by cropping the video feed. These were given a four in our matrix. All the requirements that were given a 3 are requirements that are again merely a comfort and ease of use to the customer.

We decided to use the clevis pin and r-clip for the quick release to the drone itself, as it was the best balance of cost and functionality. We went with the classic gimbal design as it proved to be the best overall design in our design matrix as well as the easiest to produce with the least complex parts. We decided to move forward with the sliding door for the camera holding mechanism as it was the least complex to produce, and met all of our requirement. We went with an electric thrust solenoid to push the button to minimize size and weight, and reduce complexity of the design.

Table 1. Decision Matrix

	Weight	Concept 1 (Classic)	Concept 2 (Rack and Pinion)	Concept 3 (Flywheels)
Requirement 1.2.1 (Pitch)	5	3	2	2
Requirement 1.2.2 (Roll)	5	2	3	2
Requirement 1.2.3 (less than 1.44 pounds)	5	2	2	1
Requirement 1.2.4 (Jello Effect)	4	3	3	2
Requirement 1.2.5 (Quick Drone Connection)	3	2	3	2
Requirement 1.2.6 (Quick Camera Connection)	3	2	3	2
Requirement 1.2.7 (FOV)	4	3	2	2
Requirement 1.2.8 (Push the button)	5	2	1	2
Requirement 1.2.9 (15 mm)	3	3	1	1
Requirement 1.2.10(<100$)	2	2	0	0
Requirement 1.2.11 (common actuators)		2	3	2
Goal 1.3.1 (third axis)	2	3	0	2
Goal 1.3.2 (sturdy)	2	3	1	1
Total (optional)		32	24	18

Exceeds = 3 pts
Meets = 2 pts
Questionable = 1 pts
Does Not Meet = 0 pts

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3 SYSTEM OVERVIEW

3.1 PHYSICAL DESCRIPTION

The Gimbal consists of two ABS plates, one with a quick release mechanism, two ABS Arms, and an ABS Camera Case and door, along with a silicone liner in the camera case and 4 silicone shock absorbers, with a thrust solenoid attached to the top of the camera case.

Three stepper motors are bolted in six different places with a low profile steel cap screw, an aluminum flat washer and steel hex nut. The solenoid is fixed with two steel alloy cup point set screws.

The Silicone Dampers are held in the four holes in each of the upper and lower plates. The Gimbal is fixed to the drone with a stainless steel clevis pin and a stainless steel hairpin cotter pin. The door is held in place with a small clip that allows for the door to open with light pressure.

Figure 10. Design Overview

Figure 11. Clevis pin and Hairpin Cotter open

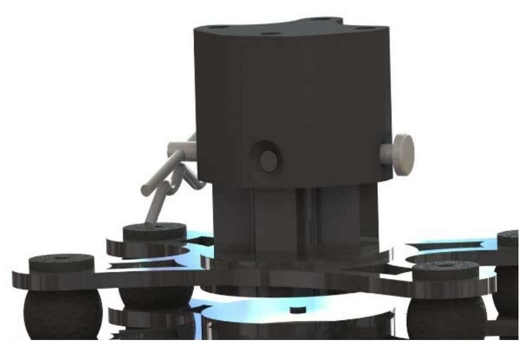


Figure 12. Clevis Pin and Hairpin Cotter engaged

Figure 13. Back Camera Door Open

3.2 FUNCTIONAL DESCRIPTION

Our gimbal uses a 3-axis stepper motor system able to control each axis of rotation. The entire gimbal is attached to an array of rubber ball dampers fixed upon two plates to absorb vibrations and minimize the rolling shutter effect. The camera is inside a case with a rubber lining with a sliding clip on the back for easy removal, and extra vibration dampening. There is a thrust solenoid on top of the camera case that pushes the button down mechanically, due to the nature of these thrust solenoids there will be no damage to the camera button. The stepper motors can be controlled to precise angular positions, they will be arranged to get 360-degree yaw rotation, 110-degree pitch rotation, and 300-degree roll rotation.

4 REFERENCES

[1] http://www.dji.com/inspire-1/info#specs

[2] http://store.dji.com/product/inspire-1-v2?site=brandsite&from=buy_now_bottom

[3] https://www.amazon.com/GoPro-Session-CHDHS-101-Waterproof-Camera/dp/B010H05JMQ

[4] http://ask.metafilter.com/212758/what-material-would-best-dampen-the-noise-and-vibrations-of-a-treadmill

[5] http://www.shox.com/blog/automotive-suspension/different-types-of-shocks-used-on-cars-trucks-and-suvs

[6] http://www.rotorandwing.com/2010/11/01/vibration-identification-minimization/

[7] https://www.youtube.com/watch?v=n_6p-1J551Y

[8] http://smashingdrones.com/how-to-choose-the-best-gimbal-for-your-drone/

[9] http://www.droneflyers.com/understanding-brushless-camera-gimbals/

[10] https://en.wikipedia.org/wiki/Clevis_fastener

[11] https://en.wikipedia.org/wiki/R-clip

[12] https://www.h2wtech.com/article/voice-coil-actuators-vs-solenoids

[13] https://en.wikipedia.org/wiki/Linear_actuator

[14] https://oscarliang.com/servo-brushless-camera-gimbal-fpv-quadcopter/

Appendix A

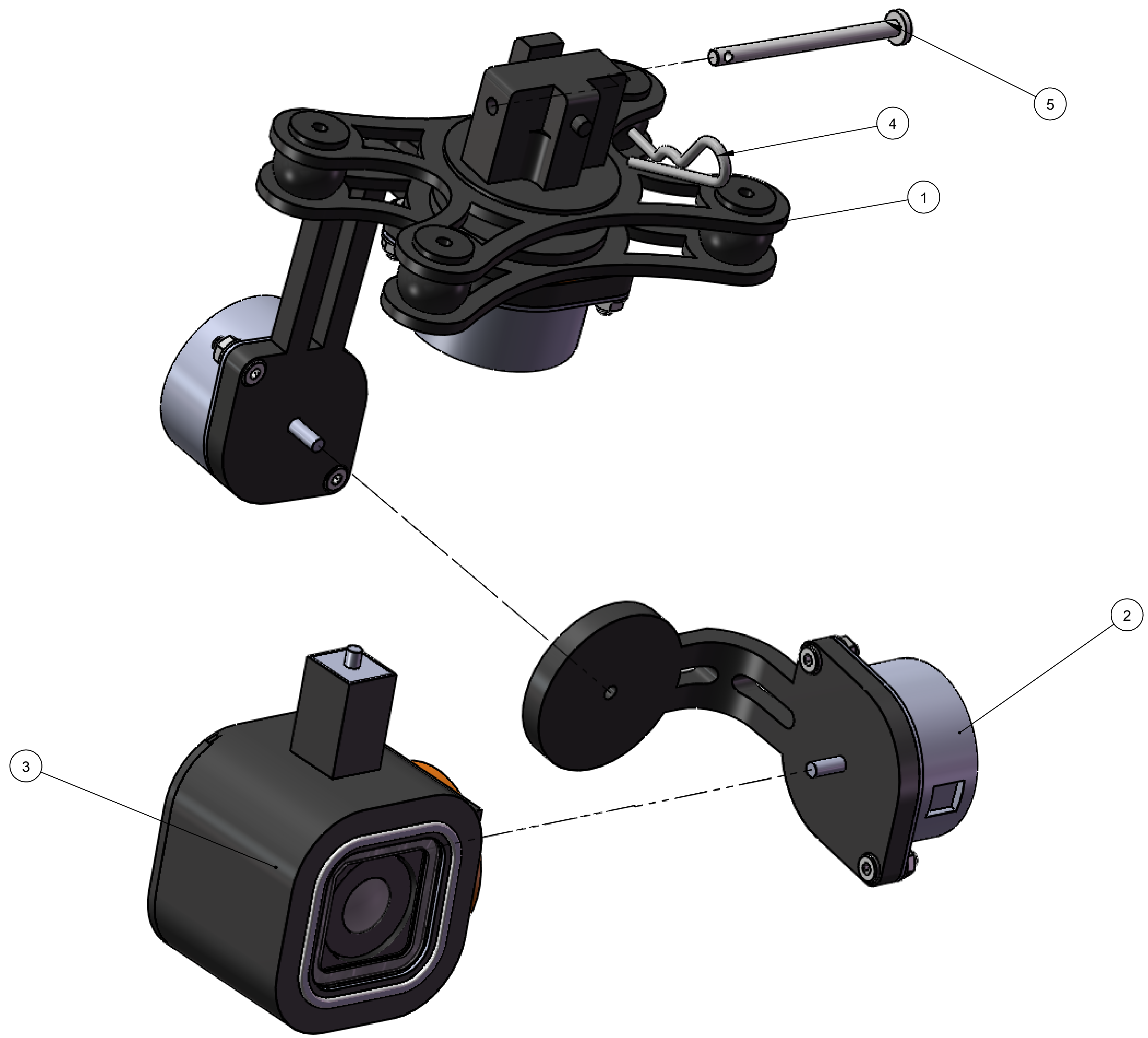
Bill of Materials

Item No.	Part Name/Description	Part Number	Vendor/Manufacturer	Cost Ea.	QTY.	Total
1	STEPPER MOTOR	10551	Spark Fun Electronics	$6.95	3	$20.85
2	TYPE 18-8 SS LOW PROFILE SOCKET CAP SCREW	92855A310	MCMASTER CARR	$2.63 per pack 25	6	$0.64
3	ALUMINUM FLAT WASHER	92334A109	MCMASTER CARR	$9.42 per pack of 10	6	$5.65
4	STEEL HEX NUT	90592A009	MCMASTER CARR	$1.04 per pack of 100	6	$0.07
5	THRUST SOLENOID	2776	Adafruit Industries	$4.95	1	$4.95
6	18-8 STAINLESS STEEL HAIRPIN COTTER PIN	92391A034	MCMASTER CARR	$9.75 per pack of 100	1	$0.10
7	SILICONE RUBBER DAMPERS	Zenmuse Z15-A7 - Rubber Damper	DJI STORE	$3.00 per pack of 3	4	$4.00
8	STAINLESS STEEL CLEVIS PIN	1327K94	MCMASTER CARR	$3.27	1	$3.33

9	CUSTOM ABS TOP PLATE	1327K94, 8712K199	MCMASTER CARR	$3.33	1	$3.33
10	CUSTOM ABS BOTTOM PLATE	8712K248	MCMASTER CARR	$5.90	1	$5.90
11	CUSTOM ABS TOP ARM	8712K208	MCMASTER CARR	$3.08	1	$3.08
12	CUSTOM ABS BOTTOM ARM	8712K208	MCMASTER CARR	(Included with cost of top arm)	1	$0.00
13	CUSTOM ABS CAMERA CARRYING CASE	8712K199	MCMASTER CARR	$20.56	1	$20.56
14	CUSTOM ABS SLIDING DOOR	8586K161	MCMASTER CARR	$3.33	1	$3.33
15	ALLOY STEEL CUP POINT SET SCREW	91390A087	MCMASTER CARR	$3.01	2	$6.02
16	INTERNAL RUBBER DAMPER	1460N14	MCMASTER CARR	$10.36	1	$10.36
					TOTAL	$92.17

Appendix B

Drawing Package



ITEM NO.	QTY.	PART/ASSEMBLY NUMBER	PART/ASSEMBLY NAME
1	1	MAE-A-0004	UPPER ASSEMBLY
2	1	MAE-A-0003	LOWER ASSEMBLY
3	1	MAE-A-0001	CAMERA CARRIER ASSEMBLY
4	1	92375A100	HAIRPIN COTTER PIN
5	1	92390A095	CLEVIS PIN

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UtahState University

PROJECT GIMBAL	
	DRAFTED BY: MICRO TIGER
PART/ASSEM NAME: FINAL ASSEMBLY	CHECKED BY: JACKSON GRAHAM
PART/ASSEM NUMBER: MAE-A-1	APPROVED BY: JACKSON GRAHAM
MATERIAL: N/A	DATE APPROVED: 4/28/2017
FINISH: N/A	SHEET SCALE: 1:5 — SHEET NUMBER: 1 of 1

SPECIFICATIONS AND TOLERANCES

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

DEFAULT DIMENSIONAL TOLERANCES:
LINEAR DIMENSIONS [mm]: 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: 25 micrometers

ITEM NO.	QTY.	PART/ASSEMBLY NUMBER	PART/ASSEMBLY NAME
1	2	10551	STEPPER MOTOR
2	4	90592A009	HEX NUT
3	4	92334A109	FLAT WASHER
4	4	92855A130	SOCKET CAP SCREW
5	1	MAE-P-0002	UPPER ARM
6	1	MAE-P-0004	BOTTOM PLATE
7	4	MAE-P-0009	SHOCK ABSORBER
8	1	MAE-P-0007	TOP PLATE

SPECIFICATIONS AND TOLERANCES		
	Mechanical & Aerospace ENGINEERING UtahState University	PROJECT GIMBAL
		DRAFTED BY: MICRO TIGER
UNLESS OTHERWISE NOTED DRAWING ARE CREATED IN ACCORDANCE TO ASME Y14.5-2009	PART/ASSEM NAME: UPPER ASSEMBLY	CHECKED BY: JACKSON GRAHAM
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	MATERIAL: N/A	DATE APPROVED: 4/28/2017
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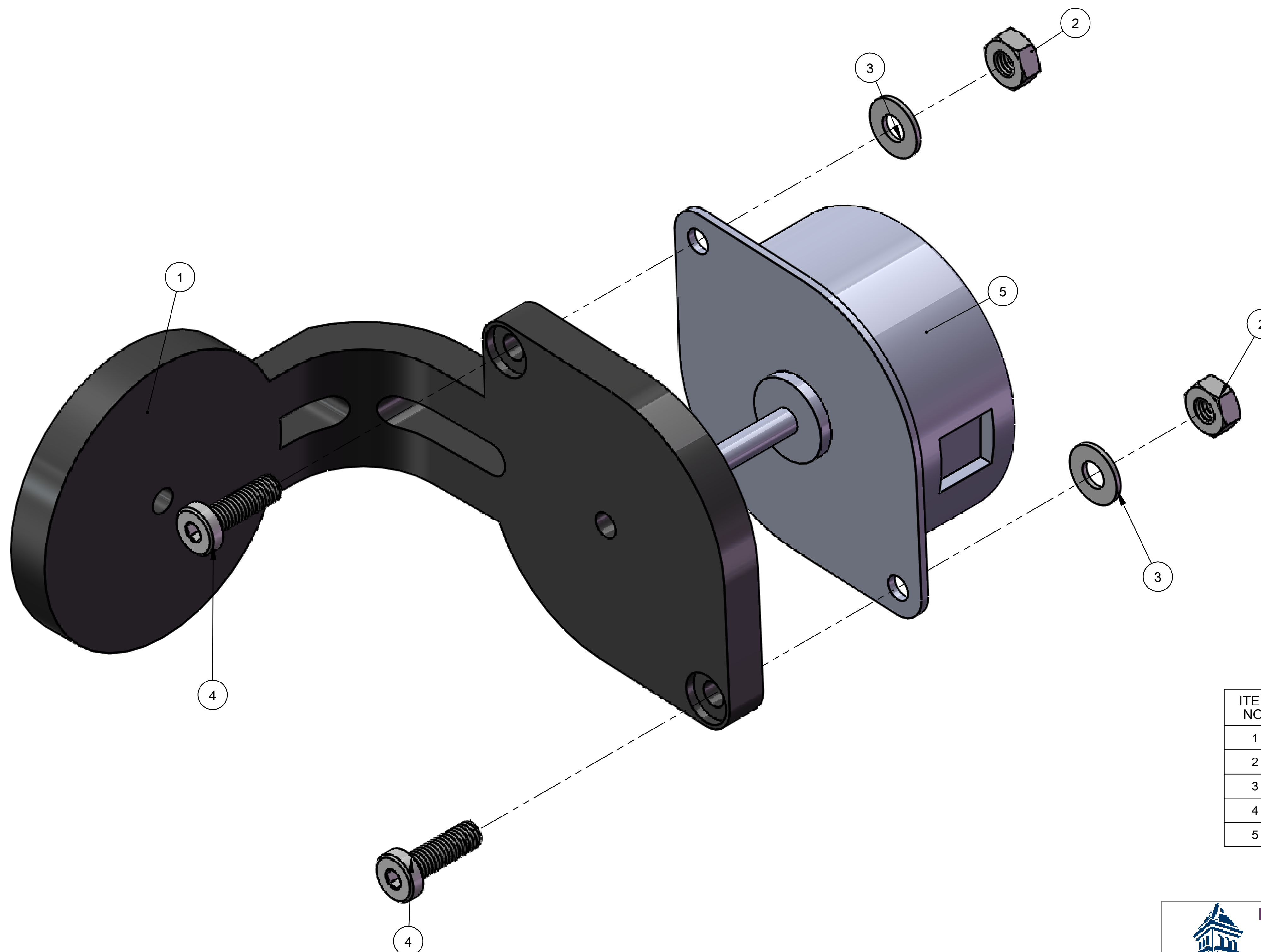

ITEM NO.	QTY.	PART/ASSEMBLY NUMBER	PART/ASSEMBLY NAME
1	1	MAE-P-0001	BOTTOM ARM
2	2	90592A009	HEX NUT
3	2	92334A109	FLAT WASHER
4	2	92855A130	SOCKET CAP SCREW
5	1	10551	STEPPER MOTOR

Mechanical & Aerospace ENGINEERING
UtahState University

PROJECT GIMBAL	DRAFTED BY: MICRO TIGER
PART/ASSEM NAME: LOWER ASSEMBLY	CHECKED BY: JACKSON GRAHAM
PART/ASSEM NUMBER: MAE-A-0003	APPROVED BY: JACKSON GRAHAM
MATERIAL: N/A	DATE APPROVED: 4/28/2017
FINISH: N/A	SHEET SCALE: 1:2 — SHEET NUMBER: 1 of 1

SPECIFICATIONS AND TOLERANCES

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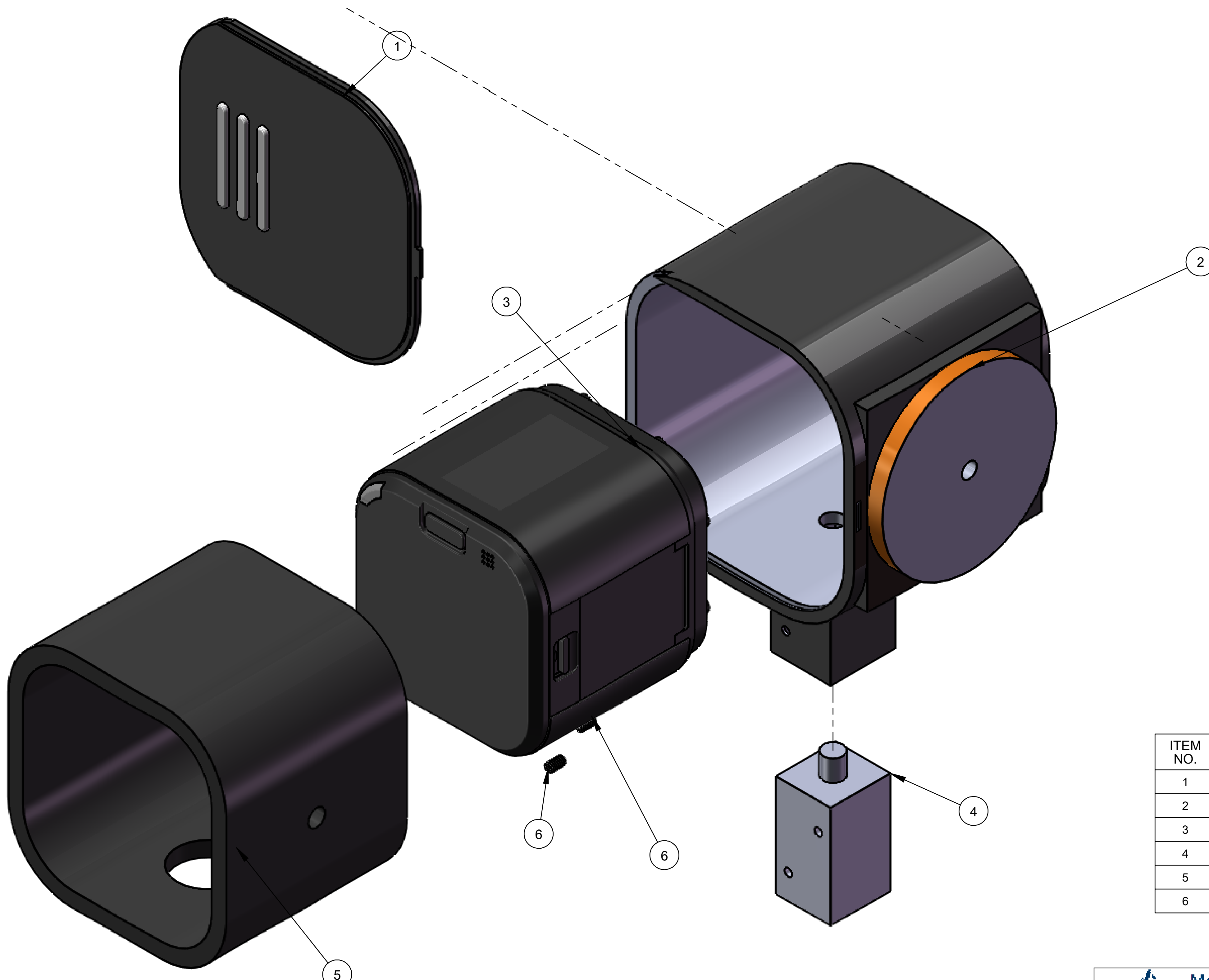
DEFAULT DIMENSIONAL TOLERANCES:
LINEAR DIMENSIONS [mm]: X±.5, X.X±.1, X.XX±.03, X.XXX±.005
ANGULAR DIMENSIONS [degrees]: X±3, X.X±.5, X.XX±.1
MINIMUM SURFACE FINISH: 25 micrometers



ITEM NO.	QTY.	PART/ASSEMBLY NUMBER	PART/ASSEMBLY NAME
1	1	MAE-P-0002	CAMERA DOOR
2	1	MAE-P-0005	CAMERA CASE
3	1	MAE-P-0010	GOPRO HERO 4
4	1	MAE-P-0010	THRUST SOLENOID
5	1	MAE-P-0011	RUBBER INSULATOR
6	2	91390A087	SET SCREW

SPECIFICATIONS AND TOLERANCES

UNLESS OTHERWISE NOTED
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DEFAULT DIMENSIONAL TOLERANCES:
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MINIMUM SURFACE FINISH: 25 micrometers

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UtahState University

PROJECT GIMBAL	
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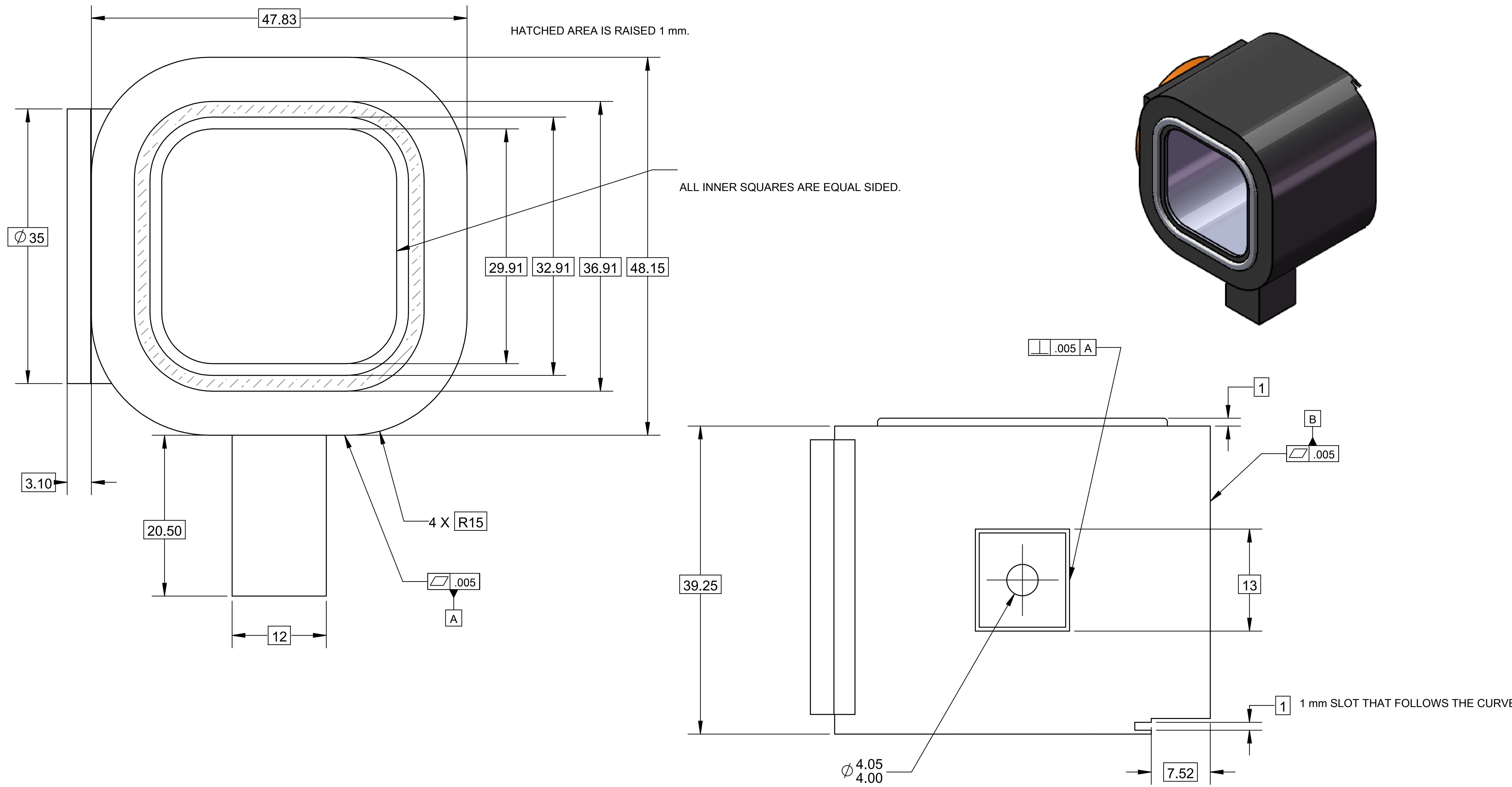
PART/ASSEM NUMBER: MAE-A-0001	APPROVED BY: JACKSON GRAHAM
MATERIAL: N/A	DATE APPROVED: 4/28/2017
FINISH: N/A	SHEET SCALE: 1:5 — SHEET NUMBER: 1 of 1



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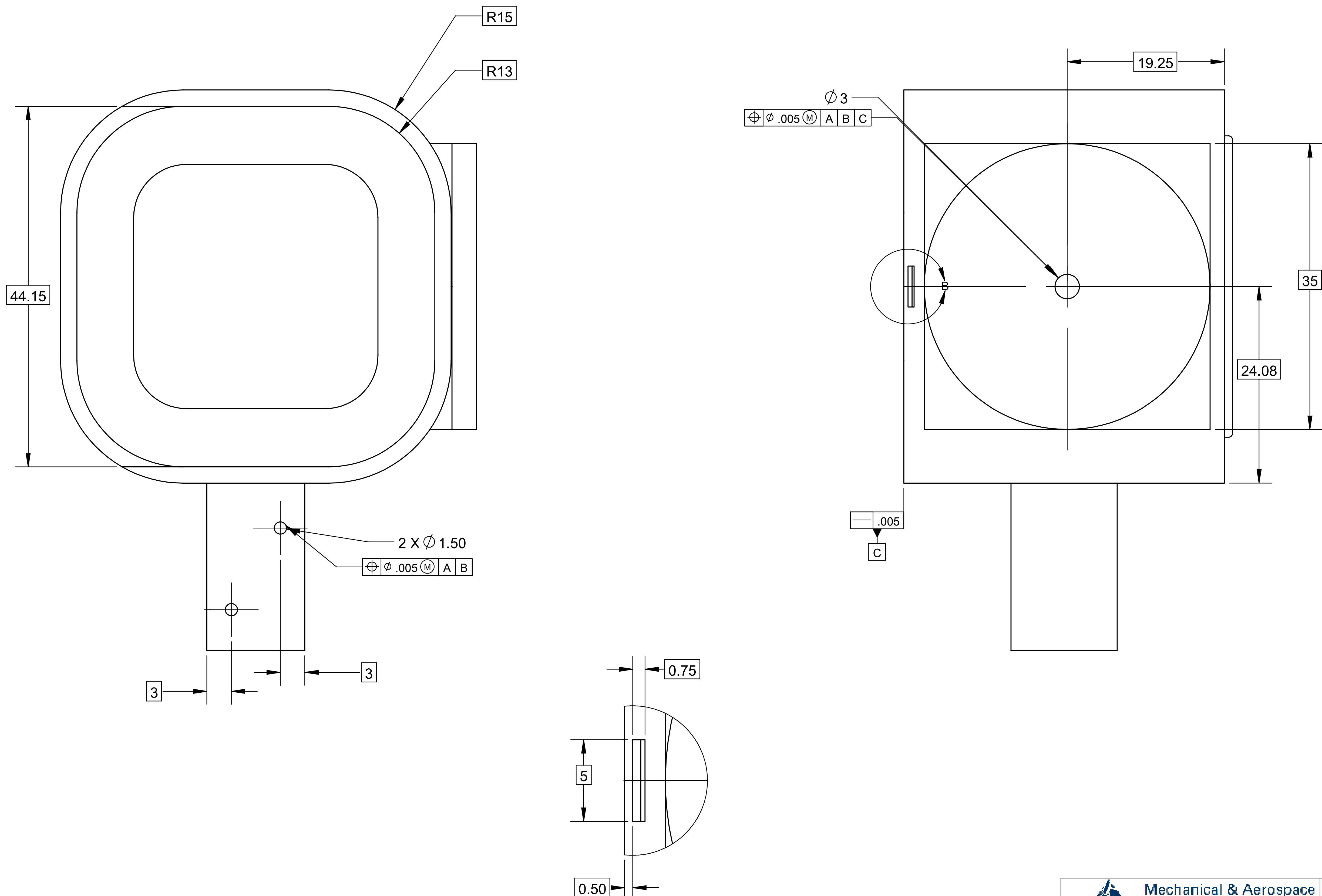
	Mechanical & Aerospace ENGINEERING UtahState University	PROJECT GIMBAL
		DRAFTED BY: MATHESON PRICE
SPECIFICATIONS AND TOLERANCES	PART/ASSEM NAME: CAMERA CASE	CHECKED BY: JACKSON GRAHAM
UNLESS OTHERWISE NOTED DRAWING ARE CREATED IN ACCORDANCE TO ASME Y14.5-2009	PART/ASSEM NUMBER: MAE-P-0004	APPROVED BY: JACKSON GRAHAM
DEFAULT DIMENSIONAL TOLERANCES: LINEAR DIMENSIONS [mm]: 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: 25 micrometers	MATERIAL: ABS	DATE APPROVED: 4/28/2017
	FINISH: XXXXXX	SHEET SCALE: 1:1 — SHEET NUMBER: 1 of 2



DETAIL B
SCALE 4 : 1

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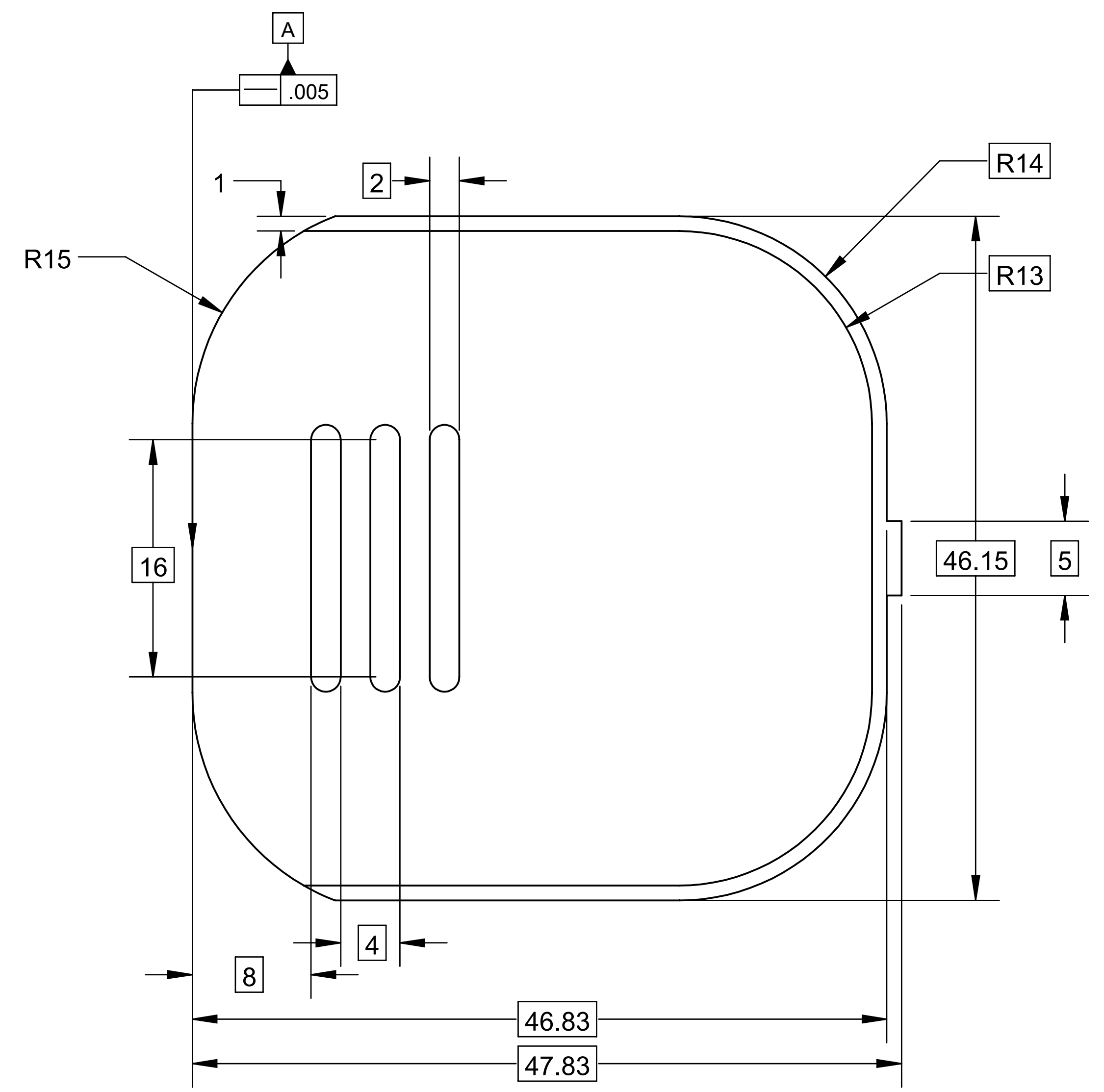
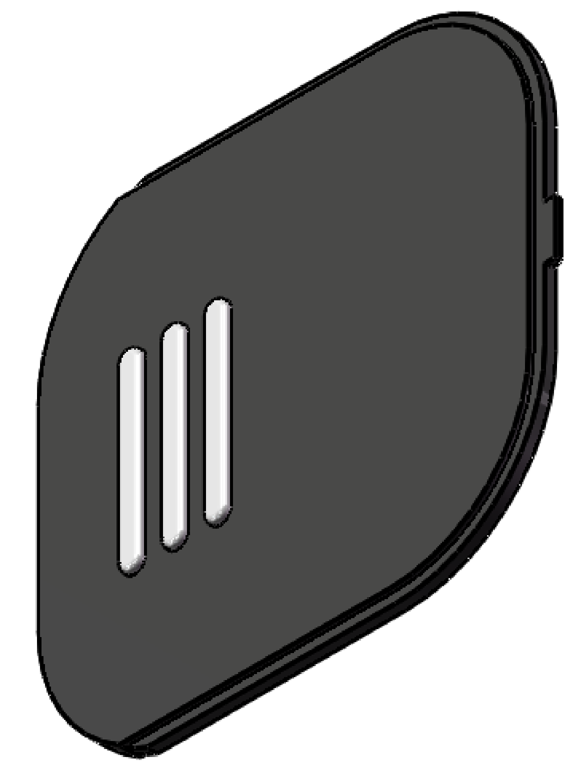
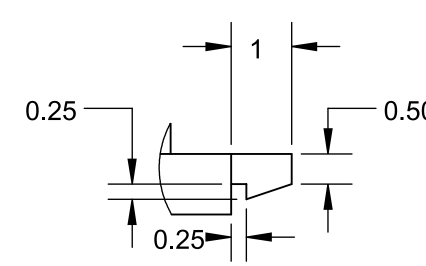
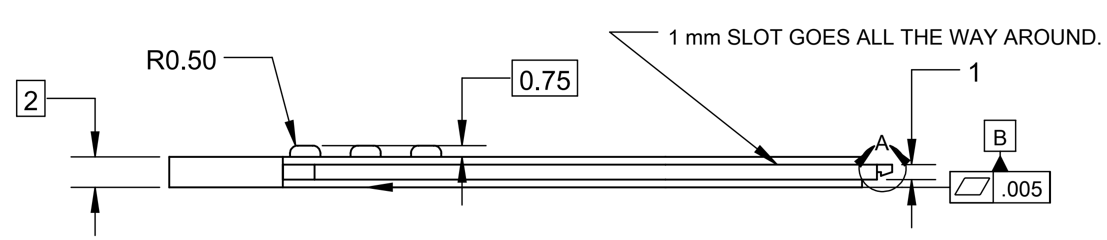
SPECIFICATIONS AND TOLERANCES	Mechanical & Aerospace ENGINEERING UtahState University	PROJECT GIMBAL
		DRAFTED BY: MATHESON PRICE
UNLESS OTHERWISE NOTED DRAWING ARE CREATED IN ACCORDANCE TO ASME Y14.5-2009	PART/ASSEM NAME: CAMERA CASE	CHECKED BY: JACKSON GRAHAM
	PART/ASSEM NUMBER: MAE-P-0004	APPROVED BY: JACKSON GRAHAM
DEFAULT DIMENSIONAL TOLERANCES: LINEAR DIMENSIONS [mm]: 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: 25 micrometers	MATERIAL: ABS	DATE APPROVED: 4/28/2017
	FINISH: XXXXXX	SHEET SCALE: 1:1 SHEET NUMBER: 2 of 2



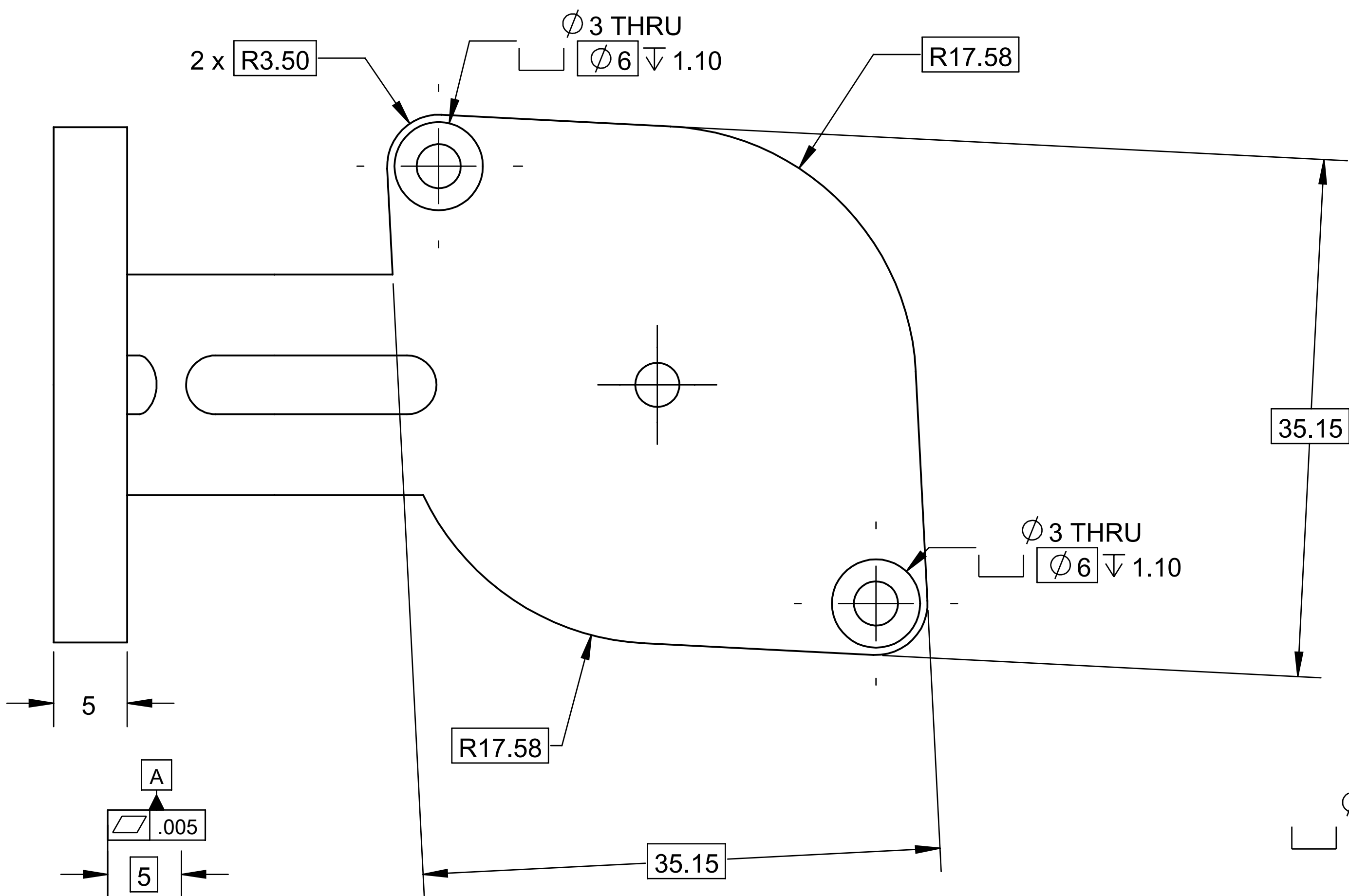


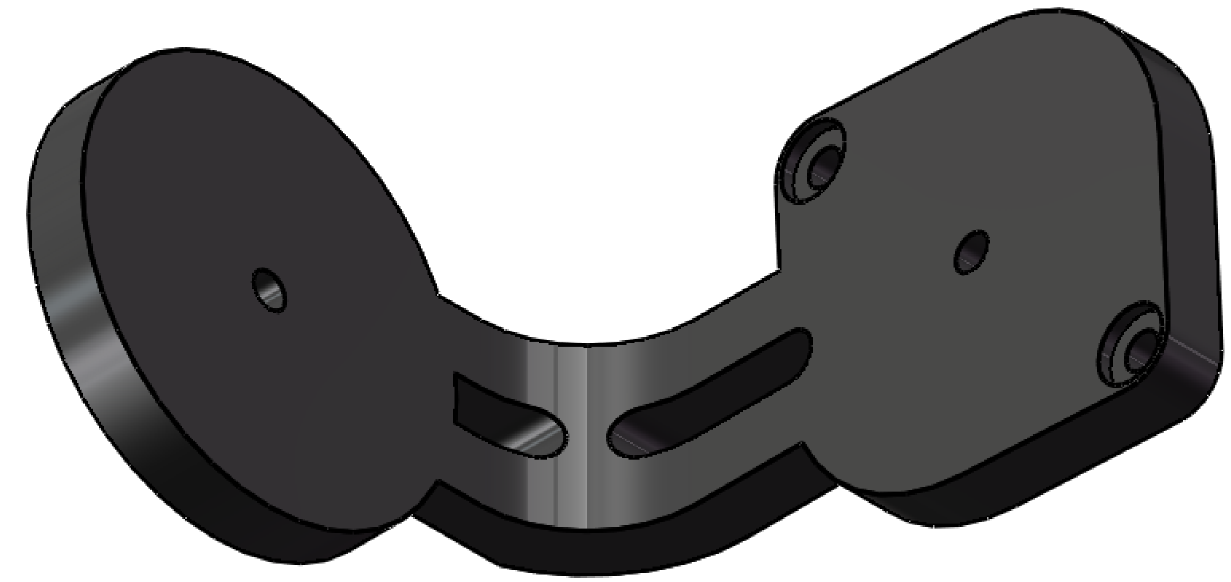


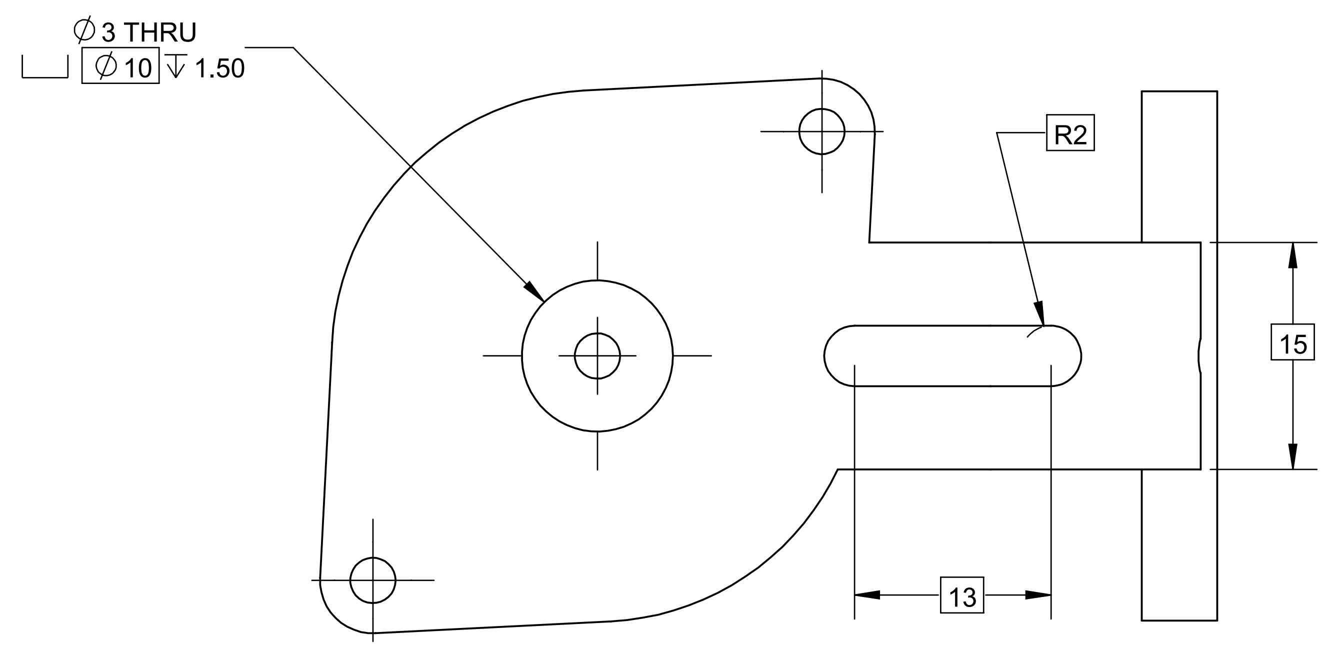
DETAIL A
SCALE 8 : 1

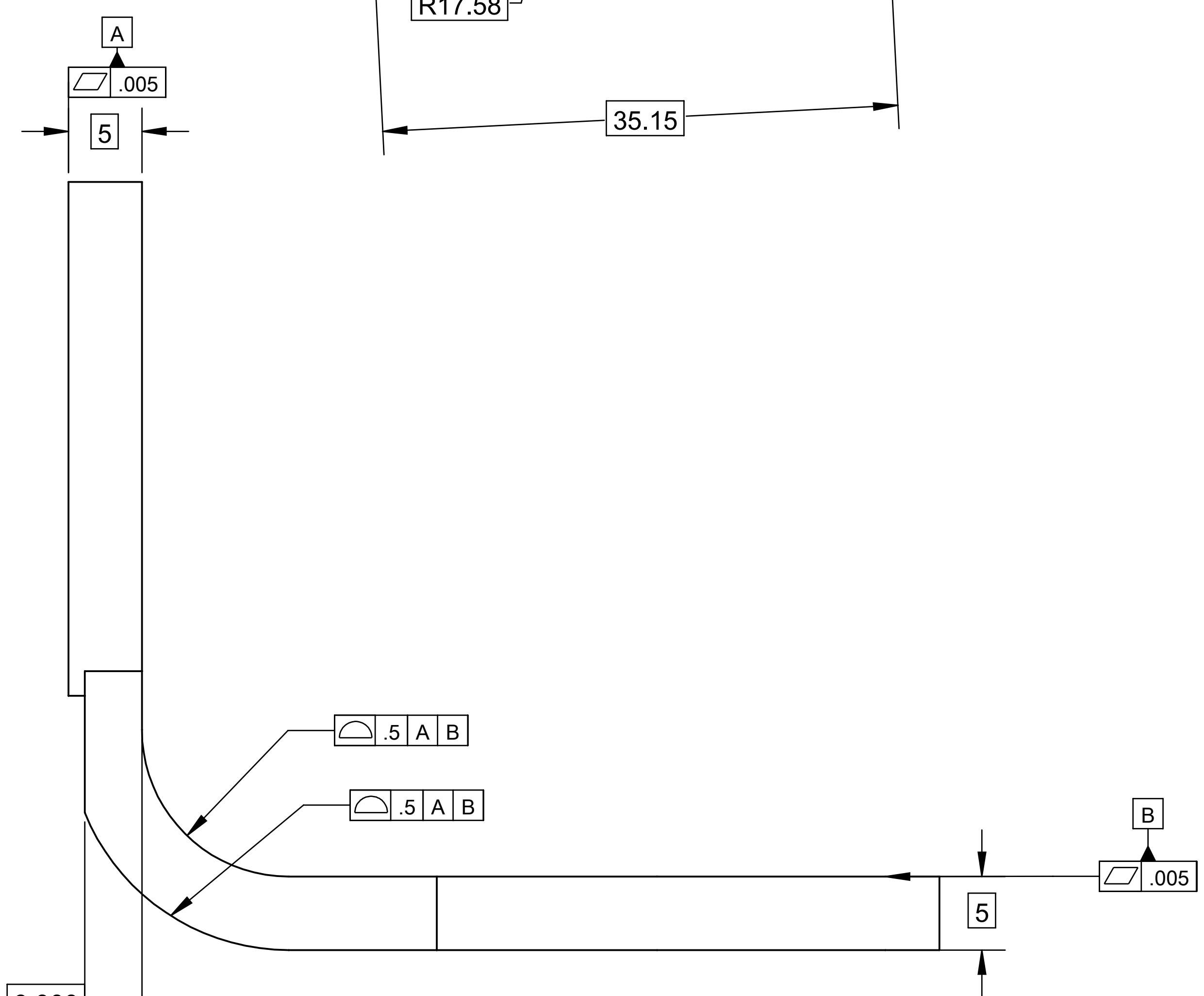


	Mechanical & Aerospace ENGINEERING UtahState University	PROJECT GIMBAL
		DRAFTED BY: MATHESON PRICE
SPECIFICATIONS AND TOLERANCES	PART/ASSEM NAME: CAMERA DOOR	CHECKED BY: GRAHAM JACKSON
UNLESS OTHERWISE NOTED DRAWING ARE CREATED IN ACCORDANCE TO ASME Y14.5-2009	PART/ASSEM NUMBER: MAE-P-0002	APPROVED BY: GRAHAM JACKSON
DEFAULT DIMENSIONAL TOLERANCES: LINEAR DIMENSIONS [mm]: 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: 25 micrometers	MATERIAL: ABS	DATE APPROVED: 4/28/2017
	FINISH: XXXXXX	SHEET SCALE: 2:1 — SHEET NUMBER: 1 of 1









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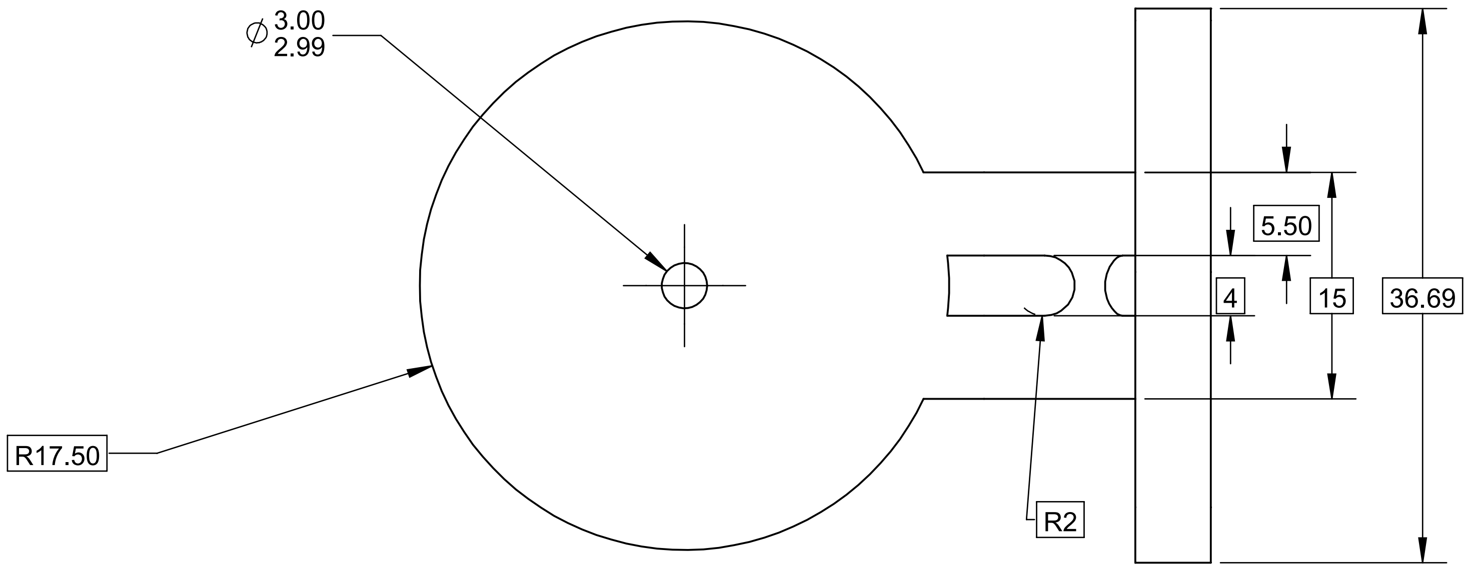
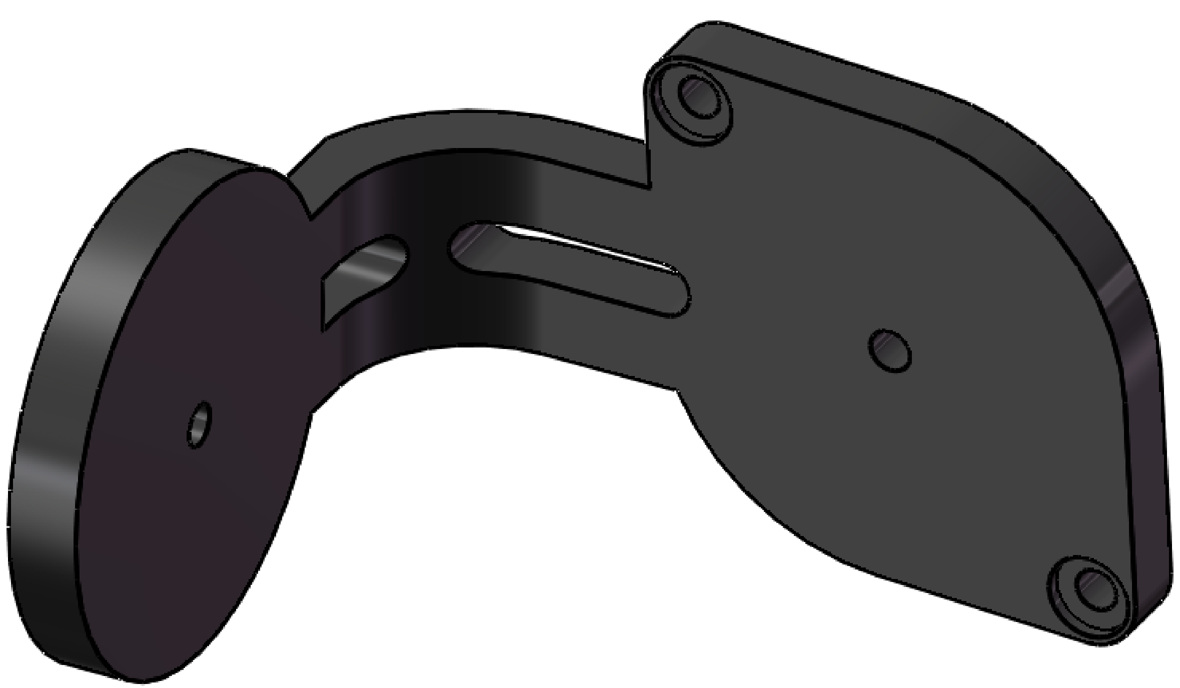
SPECIFICATIONS AND TOLERANCES	Mechanical & Aerospace ENGINEERING Utah State University	PROJECT GIMBAL
		DRAFTED BY: REED THURBER
UNLESS OTHERWISE NOTED DRAWING ARE CREATED IN ACCORDANCE TO ASME Y14.5-2009 DEFAULT DIMENSIONAL TOLERANCES: LINEAR DIMENSIONS [mm]: X±.5, X.X±.1, X.XX±.03, X.XXX±.005 ANGULAR DIMENSIONS [degrees]: X±3, X.X±.5, X.XX±.1 MINIMUM SURFACE FINISH: 25 micrometers	PART/ASSEM NAME: BOTTOM ARM	CHECKED BY: JACKSON GRAHAM
	PART/ASSEM NUMBER: MAE-P-0001	APPROVED BY: JACKSON GRAHAM
	MATERIAL: ABS	DATE APPROVED: 4/28/2017
	FINISH: XXXXXX	SHEET SCALE: 1:1 | SHEET NUMBER: 1 of 2





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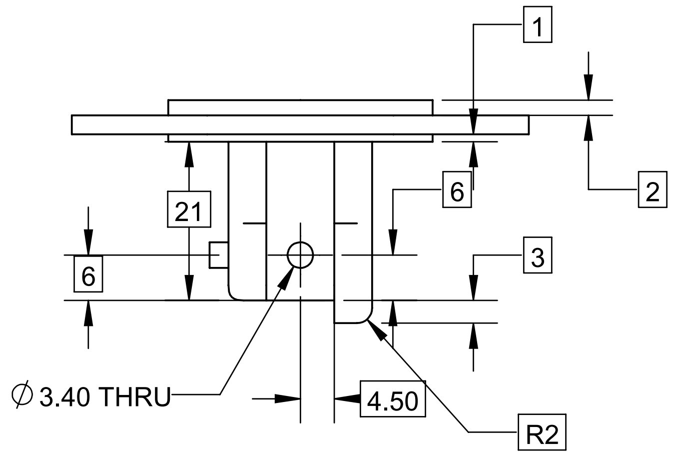
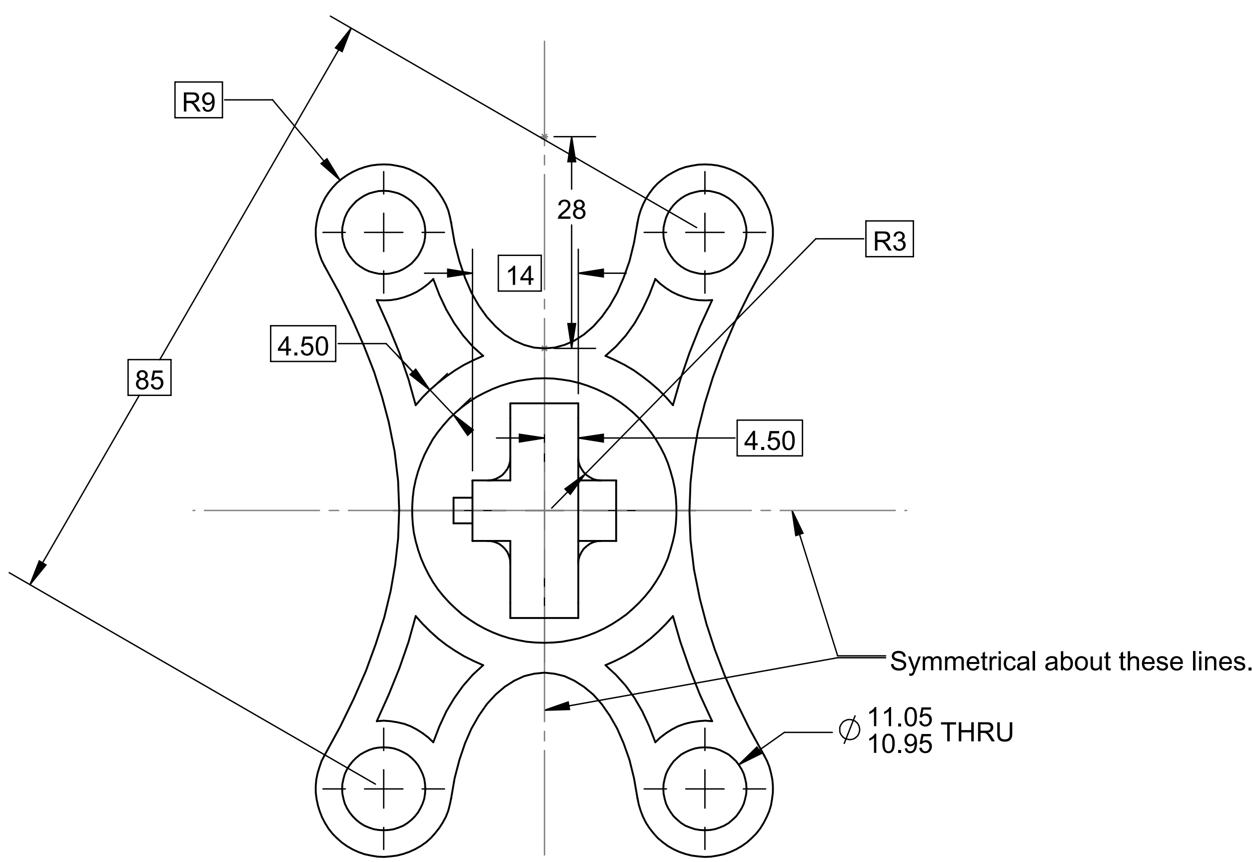
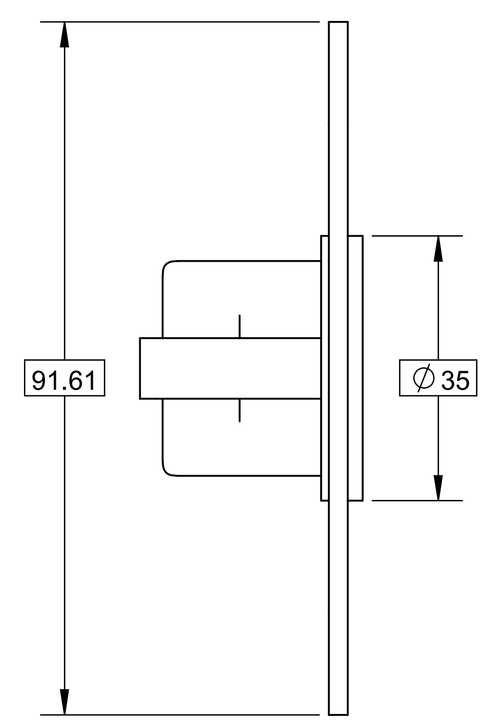
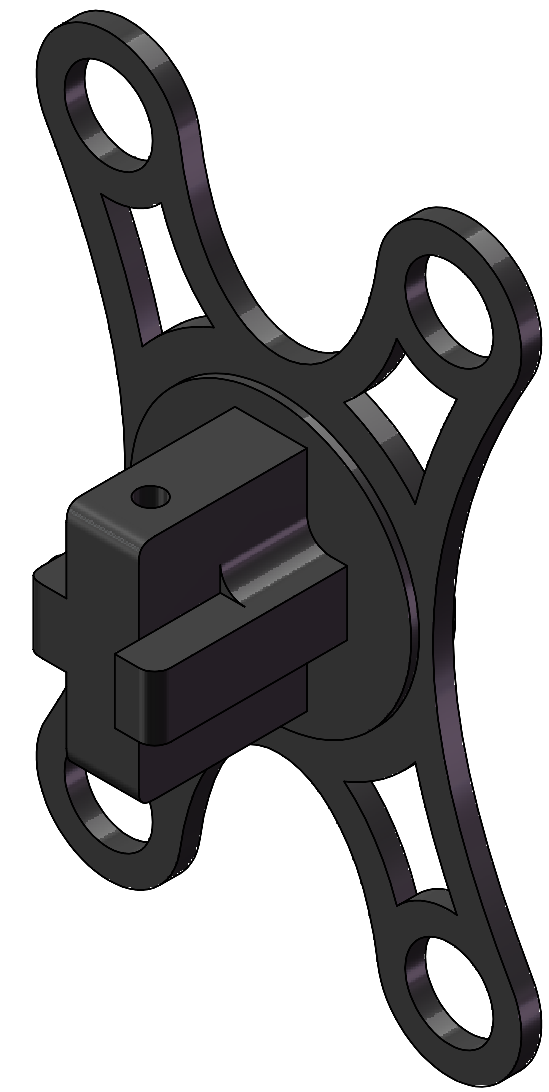
SPECIFICATIONS AND TOLERANCES	
UNLESS OTHERWISE NOTED DRAWING ARE CREATED IN ACCORDANCE TO ASME Y14.5-2009 DEFAULT DIMENSIONAL TOLERANCES: LINEAR DIMENSIONS [mm]: X±.5, X.X±.1, X.XX±.03, X.XXX±.005 ANGULAR DIMENSIONS [degrees]: X±3, X.X±.5, X.XX±.1 MINIMUM SURFACE FINISH: 25 micrometers	

Mechanical & Aerospace ENGINEERING UtahState University	PROJECT GIMBAL
	DRAFTED BY: REED THURBER
PART/ASSEM NAME: BOTTOM ARM	CHECKED BY: JACKSON GRAHAM
PART/ASSEM NUMBER: MAE-P-0001	APPROVED BY: JACKSON GRAHAM
MATERIAL: ABS	DATE APPROVED: 4/28/2017
FINISH: XXXXXX	SHEET SCALE: 1:1 | SHEET NUMBER: 2 of 2









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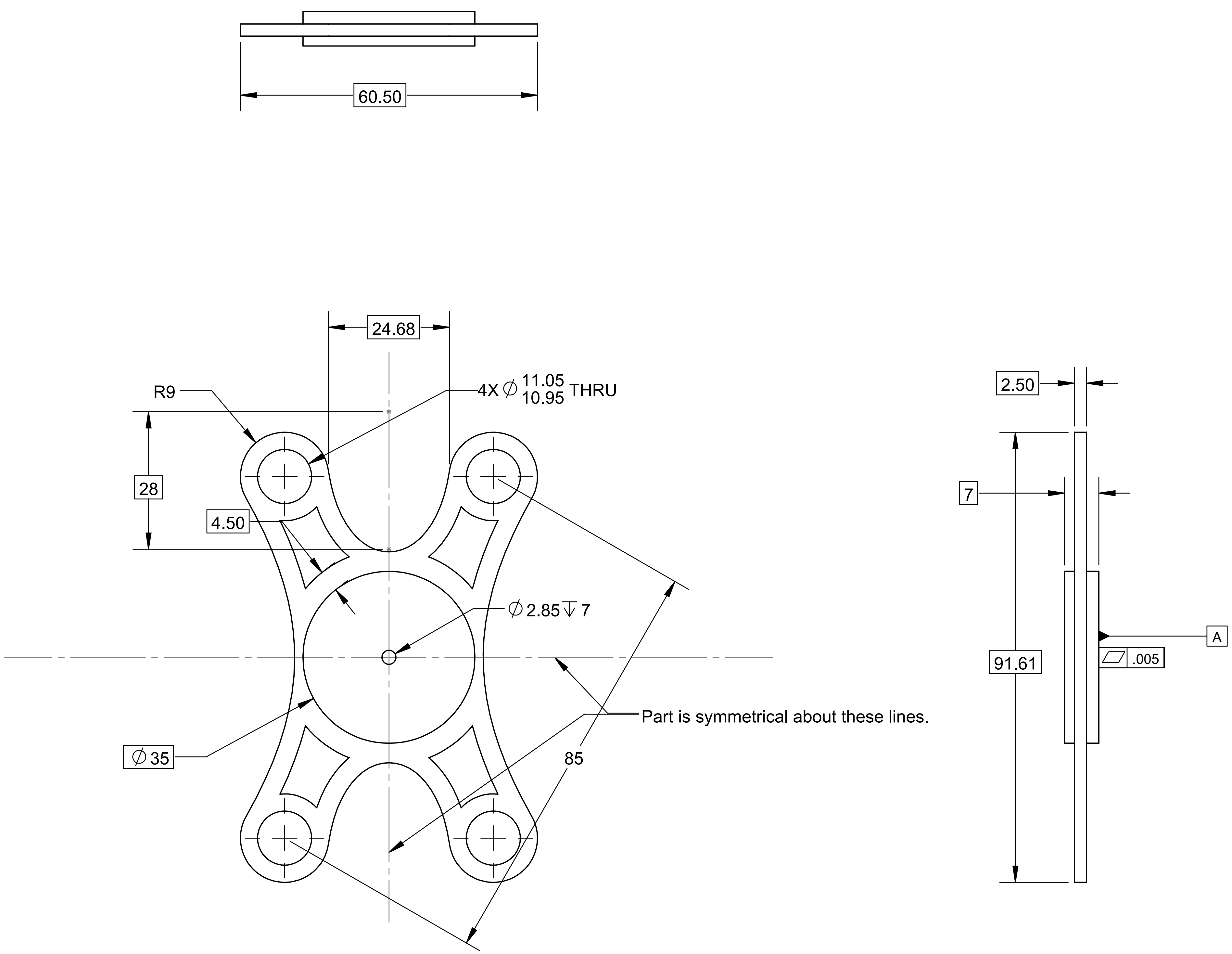
SPECIFICATIONS AND TOLERANCES	Mechanical & Aerospace ENGINEERING UtahState University	PROJECT GIMBAL
		DRAFTED BY: MATHESON PRICE
UNLESS OTHERWISE NOTED DRAWING ARE CREATED IN ACCORDANCE TO ASME Y14.5-2009	PART/ASSEM NAME: TOP PLATE	CHECKED BY: JACKSON GRAHAM
	PART/ASSEM NUMBER: MAE-P-0007	APPROVED BY: JACKSON GRAHAM
DEFAULT DIMENSIONAL TOLERANCES: LINEAR DIMENSIONS [mm]: 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: 25 micrometers	MATERIAL: ABS	DATE APPROVED: 4/28/2017
	FINISH: XXXXXX	SHEET SCALE: 1:1 — SHEET NUMBER: 1 of 1



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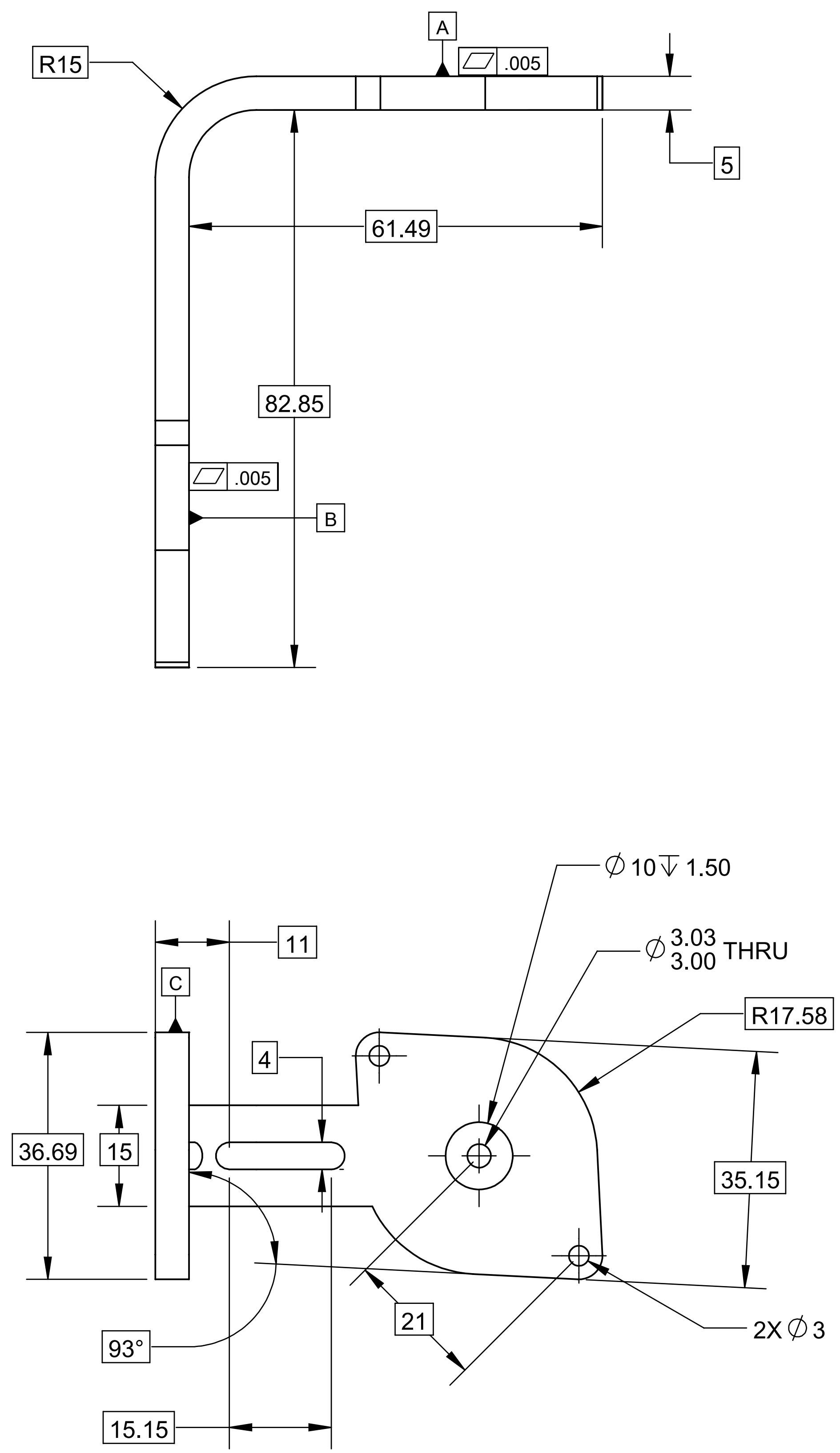
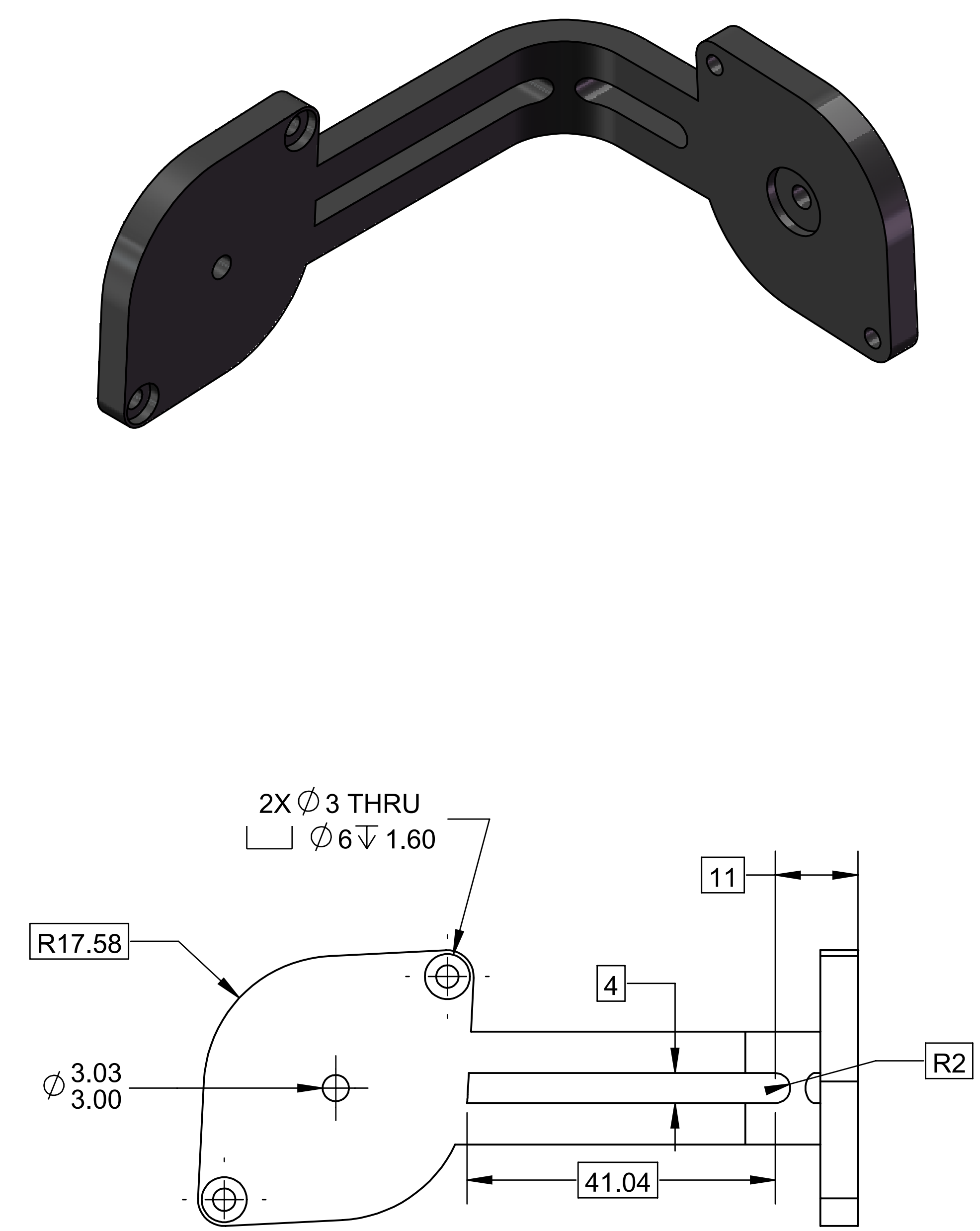
	Mechanical & Aerospace ENGINEERING UtahState University	PROJECT GIMBAL
		DRAFTED BY: REED THURBER
SPECIFICATIONS AND TOLERANCES	PART/ASSEM NAME: BOTTOM PLATE	CHECKED BY: JACKSON GRAHAM
UNLESS OTHERWISE NOTED DRAWING ARE CREATED IN ACCORDANCE TO ASME Y14.5-2009	PART/ASSEM NUMBER: MAE-P-0004	APPROVED BY: JACKSON GRAHAM
DEFAULT DIMENSIONAL TOLERANCES: LINEAR DIMENSIONS [mm]: 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: 25 micrometers	MATERIAL: ABS	DATE APPROVED: 4/27/2017
	FINISH: XXXXXX	SHEET SCALE: 1:1	SHEET NUMBER: 1 of 1





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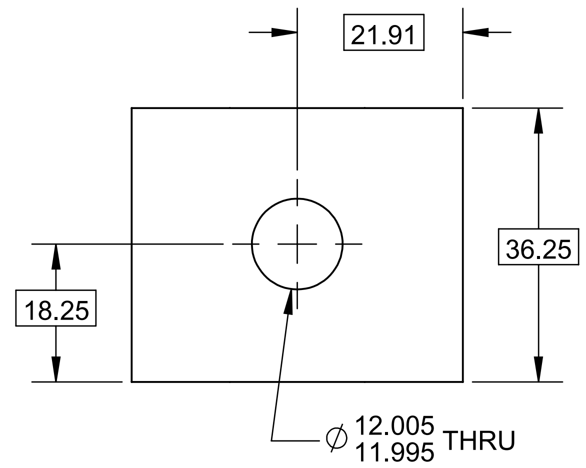
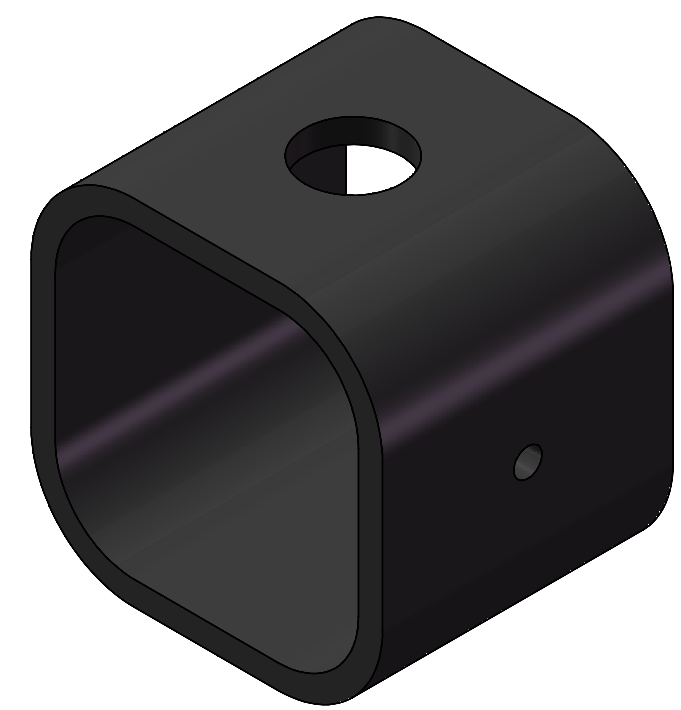
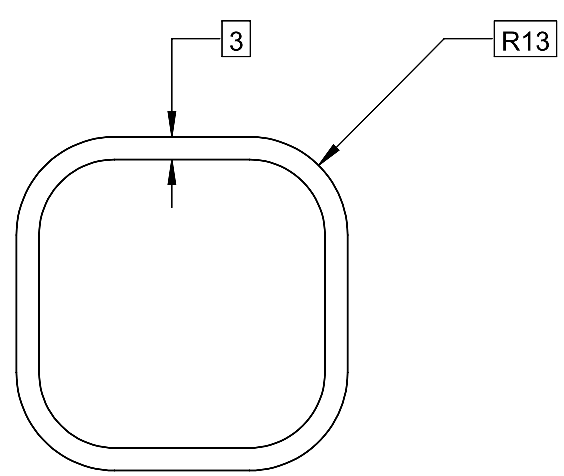
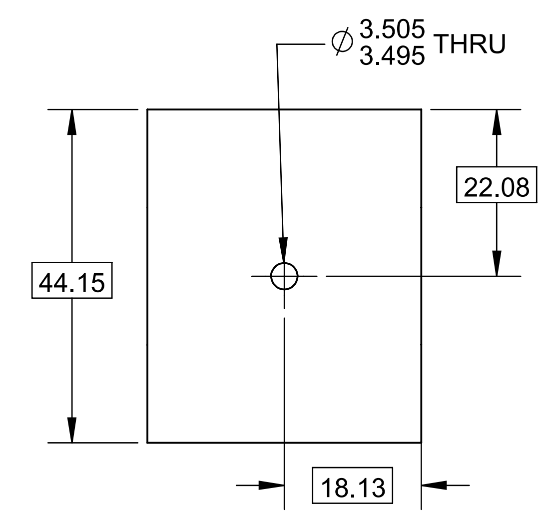
UtahState University

SPECIFICATIONS AND TOLERANCES	PART/ASSEM NAME: UPPER ARM	PROJECT GIMBAL
		DRAFTED BY: JAMES COSGROVE
		CHECKED BY: JACKSON GRAHAM
UNLESS OTHERWISE NOTED DRAWING ARE CREATED IN ACCORDANCE TO ASME Y14.5-2009	PART/ASSEM NUMBER: MAE-P-0004	APPROVED BY: JACKSON GRAHAM
DEFAULT DIMENSIONAL TOLERANCES: LINEAR DIMENSIONS [mm]: 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: 25 micrometers	MATERIAL: ABS	DATE APPROVED: 4/28/2017
	FINISH: XXXXXX	SHEET SCALE: 1:2 — SHEET NUMBER: 1 of 1









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SPECIFICATIONS AND TOLERANCES	Mechanical & Aerospace ENGINEERING UtahState University	PROJECT GIMBAL
		DRAFTED BY: JAMES COSGROVE
UNLESS OTHERWISE NOTED DRAWING ARE CREATED IN ACCORDANCE TO ASME Y14.5-2009	PART/ASSEM NAME: RUBBER INSERT	CHECKED BY: JACKSON GRAHAM
	PART/ASSEM NUMBER: MAE-P-0011	APPROVED BY: JACKSON GRAHAM
DEFAULT DIMENSIONAL TOLERANCES: LINEAR DIMENSIONS [mm]: 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: 25 micrometers	MATERIAL: NEOPRENE	DATE APPROVED: 4/28/2017
	FINISH: N/A	SHEET SCALE: 1:1 / SHEET NUMBER: 1 of 1