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Five-Axis Porcine Stage for Eye Research

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Interim Report for November 2021 to March 2022

Air Force Research Laboratory
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13. SUPPLEMENTARY NOTES

14. ABSTRACT
This report describes the design and operation of a new five-axis goniometric stage for supporting and positioning porcine subjects for studies targeting the *in vivo* eye. It includes detailed engineering drawings and maintenance instructions.

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1 SUMMARY

In vivo eye research requires the exact placement of experimental laser exposures and quantification of the source dosages. A live view of the target area is also advantageous. The sources used in experimental laser research are often large and immobile, requiring articulation of the subject to achieve placement of laser exposures. Therefore, a stage for maneuvering the subject is necessary to articulate them about their corneal apex. The stage must support the maximum weight and size of the subject. It must also be stable and capable of fine adjustments for exact placement of laser exposure. The eye research community has used similar stages for decades with smaller animal species, but there are no similar systems available for larger species such as swine.

2 INTRODUCTION

This report describes the design and operation of a new five-axis goniometric stage for supporting and positioning porcine subjects for studies evaluating the *in vivo* eye and retina response to laser insult. This stage design specifically accommodates unique anatomical features of porcine subjects. It incorporates ideas from previous stage designs over the last 60 years for other species. The design of the stage is based on the weight and size limits of Yucatan mini pigs up to one year of age. A key feature of the stage is accommodating the extended peripheral field of view of the swine eye. The gyratory axes of the stage are roll and horizontal rotation with the addition of X, Y, and Z linear translations. The stage has ±19 degrees of roll and ±40 degrees of rotation. The X (left/right) and Y (forward/reverse) travels are 25 cm with 20.9 cm Z (vertical) travel. The minimum and maximum pupil heights are approximately 97 cm and 118 cm above the floor, respectively. The stage replaces the movements of a Fundus camera, allowing the Fundus camera to be fixed in the experimental setup. The rotational movements revolve about a point in space centered on the apex of the subject's cornea (the pupil plane of the eye). The stage keeps the eye aligned with the optical axis of a fundus camera, maintaining a clear view of the retina. The stage was tested with a 53 kg load to simulate a nominally 1-year-old Yucatan miniature swine (45 kg mean weight) [1] combined with necessary additional veterinary support equipment.

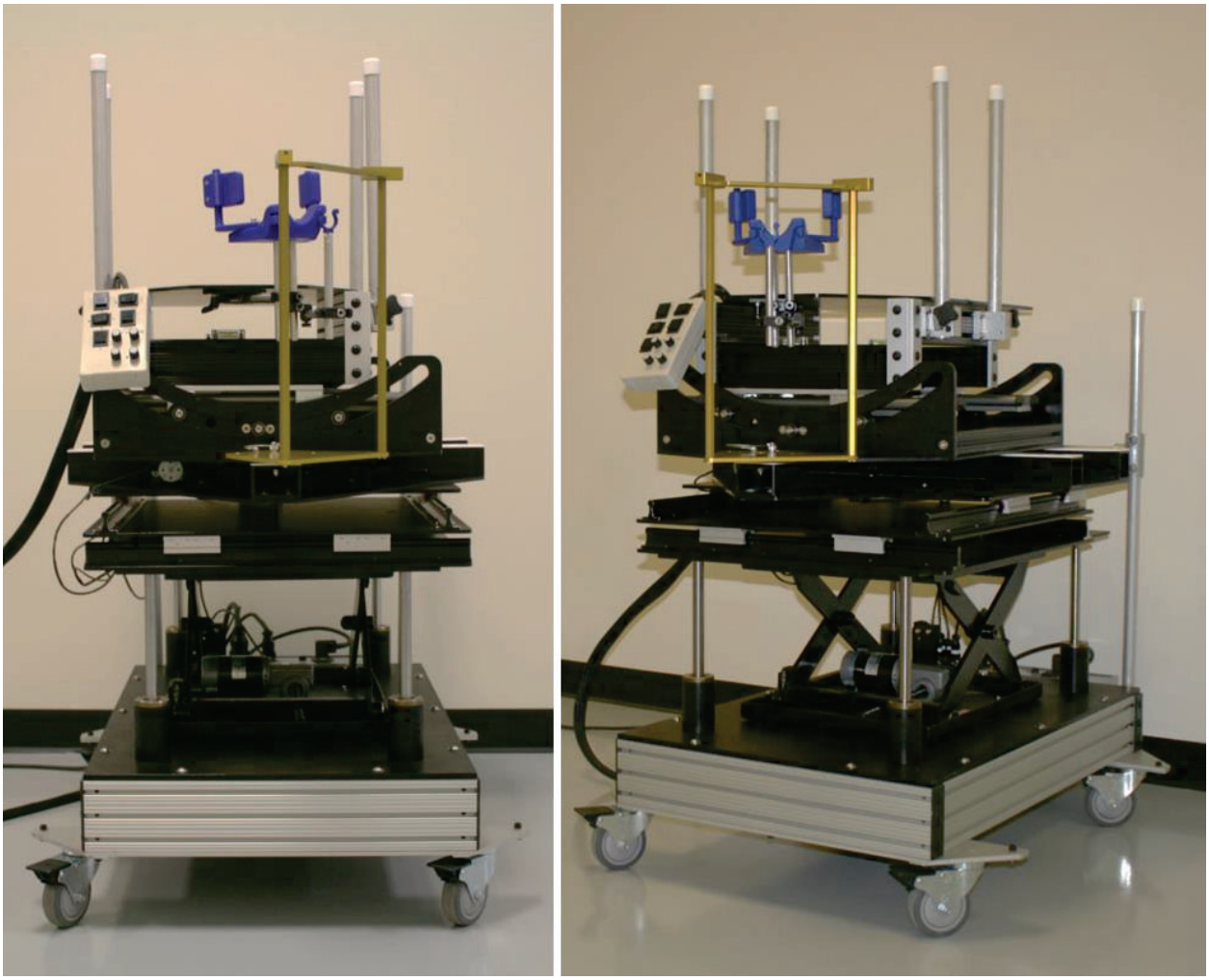

Figure 1. Pictures of assembled stage

3 STAGE DESCRIPTION

The primary use of the stage is to position anesthetized swine subjects during laser exposures of the retina using a fixed beam path and optics. The subject is positioned so that the laser beam passes through the center of the pupil (visual axis) of the eye being exposed. Rotating the eye about the apex of the cornea selects different locations on the retina for exposure. The stage accomplishes this rotation by moving the entire body of the subject through two rotational and three translational axes. By carefully positioning and securing the subject on the stage, the two rotational axes intersect at the center of the pupil.

The stage design, shown as a completed assembly in Figure 1, reproduces the same motions as a Fundus camera. The operator has the ability to place the subject at a point in space such that the intersection of the rotational axes is coincident with the apex of the cornea of the eye to be exposed. The

three linear translation axes enable aligning the subject to an optical train once the subject is properly positioned on the stage. The five stage axes are roll, rotation, X (left / right), Y (forward / reverse), and Z (height). Individual sections of the stage are labeled in Figure 2. All the components of the stage mount to a mobile base. An alignment jig enables proper positioning of the subject. The alignment jig ensures placement of the subject's corneal apex at the point where the two rotational axes coincide by defining two lines that intersect at this point. An enclosure on the back of the mobile base contains all the electronics used to control the stage. The user controls the motion of the stage with a wired remote.

The first (top) section of the stage is the roll axis. The roll axis pans the retina vertically (i.e., superior-inferior). The roll section of the stage includes the ability to select the left or right corneal apex, OS (left eye) or OD (right eye) respectively. Two linear cross slides mounted under the subject platform accomplish this motion. Bubble levels, mounted above the two linear cross slides in both the front and rear of the stage, are included to level the roll section before use. The chin rest assembly at the front of the roll section (blue items seen in Figure 1) sets the corneal height, as defined by the alignment jig. The chin rest is the primary component of the chin rest assembly. Two pairs of rods for moving the subject's head support the chin rest; one pair moves the chin rest up and down, and the other pair moves it forward and backward. The ability to rotate the chin rest left and right also aids alignment. The locking handle for the chin rest rotation is located on the front bottom of the subject platform. The subject platform also slides forward and backward to assist in this alignment. The combination of the chin rest's forward and backward motion, the rotation of the chin rest, raising and lowering the chin rest, the subject platform moving forward and backward, and the two linear cross slides facilitate moving the selected corneal apex (OS or OD) to the rotational axes of the stage. The top section contains all adjustments of the subject that accomplish aligning the subject to the stage. Subject restraint bars are mounted to the side of the subject platform. Using these and padding such as a Hug-U-Vac (Allen Medical Systems Inc.) ensures the subject does not shift during stage movements. Additionally, head stabilizers mounted to the chin rest prevent the subject's head from shifting during stage operation. Note that once the subject is aligned to the stage, the stage itself must be aligned to the optical train with the linear translations.

The second section of the stage is the rotation axis. This axis pans the retina horizontally (nasal-temporal). A vertical line through the center of the axis' pivot point defines the rotation axis. A shoulder bolt installed near the front of the rotation axis defines this pivot point. The alignment jig defines a line that intersects the rotation axis at the height of the roll axis above the subject support. Ball screw actuators drive both the rotational axes. The wired remote controls these actuators. Independent speed controls for each axis are located at the top of the wired remote. Rocker switches on the remote control the direction. Both the switches and speed control knobs are labeled for their respective axes.

The next three axes of the stage are linear translations. The X-axis and Y-axis are combined into one section. The X-axis drives the stage left and right. The Y-axis drives the stage forward and backwards. The Z-axis is the final section and drives the vertical motion of the stage. Ball screw actuators drive all three of these translations. The X-axis and Y-axis share the same speed control. The Z-axis has an independent speed control. These speed controls are at the top of the wired remote. Each axis has a rocker switch on the wired remote that controls its direction. Both the switches and speed control knobs are labeled for their respective axis.

The mobile base, electronics enclosure, wired remoted, and alignment jig support operation and placement of the stage. The mobile base supports the entire stage and allows easy relocation of the stage. It has four locking casters; locking any two will keep it from moving from the desired location. The

mobile base has a set of handlebars mounted at the rear of the stage. In order to prevent potential damage to the translational axes of the stage, do not use the subject restraint bars to push the stage. These look similar to the handlebars but are not designed for positioning or relocating the stage. Use only the handlebars when relocating the stage.

The electronics enclosure contains the support electronics including speed controllers, wired remote connections, fuses, power connection, and main power switch. It is located on the back of the mobile base. The wired remote controls all the translational axes of the stage, both speed and direction. It connects to the electronics enclosure. The alignment jig ensures proper alignment of the subject to the rotational axes of the stage and can be stored at the rear of the mobile base. It mounts in one of two positions depending on whether a left (OS) or right (OD) eye alignment is being executed.

4 DESIGN AND IMPLEMENTATION

The stage design can be viewed as eight distinct units plus an alignment jig. The units are subject support, roll, rotation, Y-axis, X-axis, Z-axis, mobile base, and electronics enclosure with remote. Note: Part numbers for design specific components are labeled following a standardized convention "XXX##" where XXX is the three to five capital letter designation of the unit, and ## is the two-digit part number within the unit. The stage design handles subjects with weights up to 50 kilograms. The subject's retina can be panned +/- 19 degrees vertically (roll) and +/- 40 horizontally (rotation). These axes rotate about the same point in space, which should be coincident with one of the corneal apexes for proper operation of the stage. This point of rotation can be adjusted to any height between 97 cm to 118 cm from the floor with the Z-axis. Additionally, the stage has 25 cm of total travel in both forward/reverse (Y-axis) and left/ right (X-axis) to aid in alignment to an optical system. The mobile base, which has four 4-inch locking castors, supports the entire stage, and allows for easy location stage. The electronics enclosure attaches to the mobile base and houses all the control electronics. The remote connects to the electronics enclosure and enables the operator to control the function of the stage.

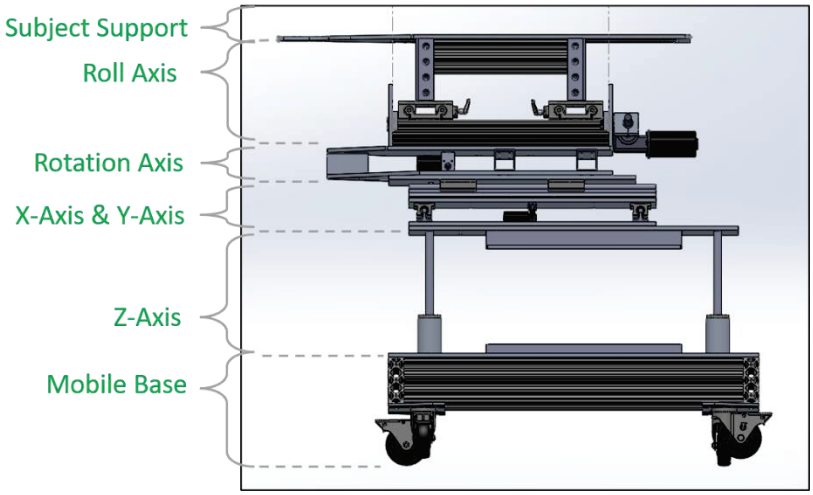

Figure 2. Stage design units

4.1 Subject Support

The subject support unit contains all the adjustments to align the subject's corneal apex to the rotation point of the stage. See figure 3 for the locations of subject support components. The core of the subject support is a box frame constructed from four aluminum extrusions (PSP04). The box frame connects the cross-slide carriages to the subject platform (PSP03). Two bubble levels zero the roll axis before placing the subject on the subject support, attached to the top crossbars of the box frame. The cross slides allow the operator to move the OS or OD corneal apex to the centerline of the roll axis. This is accomplished by releasing the locking levers on the cross slide, moving the subject left or right to the desired position, and locking the levers once again. Sliding the subject platform forward and backward aids in aligning the selected corneal apex to the rotation axis. The chin rest (PSACC02), attached to the subject platform via the chin support rod holder (PSP10) with four ½-inch stainless steel optical posts (Thorlabs Inc.), facilitates forward/backward alignment. The chin rest also moves the subject's corneal apex to the proper height above the subject platform. The chin support rod holder has a rotational adjustment for fine alignment to the rotation axis. Head stabilizers (PSACC04) are connected to the chin rest as well.

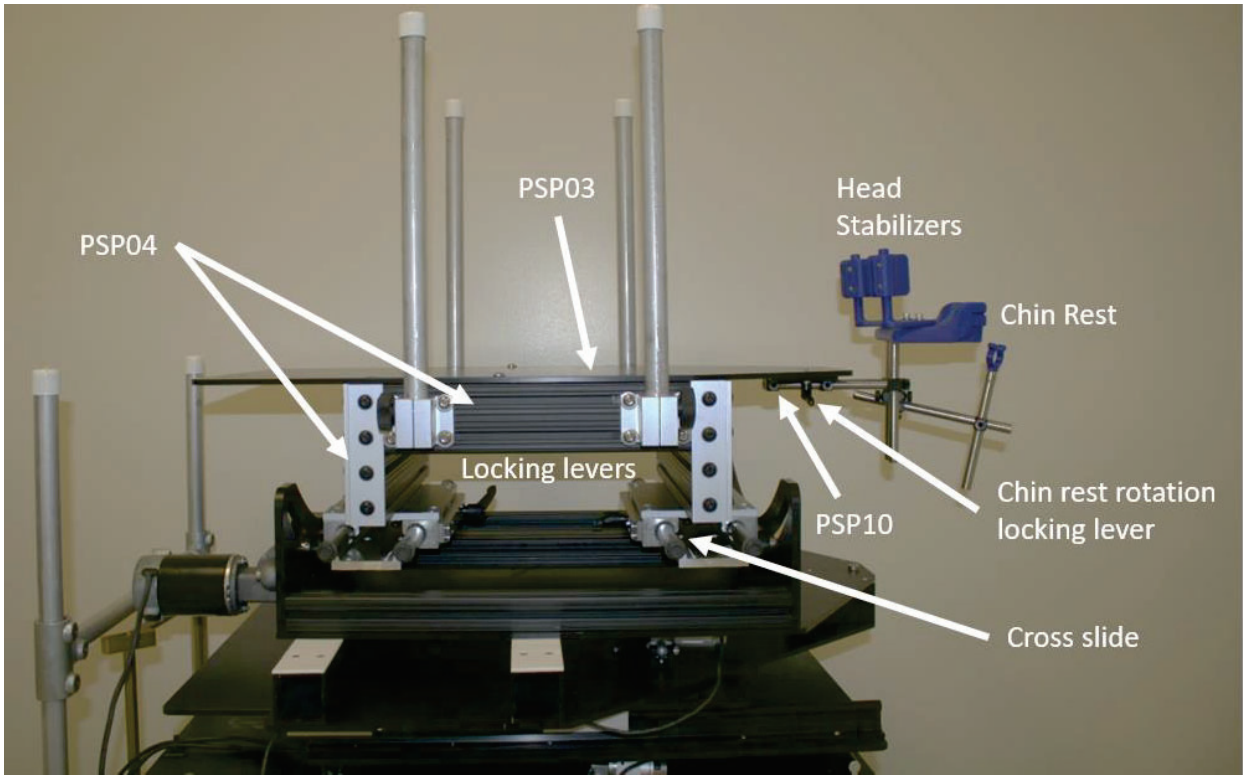

Figure 3. Subject support

4.2 Roll Axis

The roll axis unit controls the vertical panning (superior-inferior) of the retina. Figure 4 illustrates the locations of the roll axis components. The cross slides connect the roll axis to the subject platform via the Arc Connector Bar (PSP02). The Arc Connector Bar connects the two Arc Slides (PSP01) together, forming the movable portion of the roll axis. Three bearings are mounted to each of the Arc Slides. This assembly is contained between the two Arc Tracks (PSP05). The Arc Track Frame Support (PSP06) connects the Arc Tracks together and sets their spacing. The bearings mounted to the Arc Slides ride in the Arc Tracks. The arc described by the Arc Tracks has a radius of 39.37 cm and defines the point of rotation of the roll axis. The motion for the roll axis is driven by a ball screw actuator (Motion Systems Corp. P/N 85152-RH-40-10-ALT.-STD.-B-0.375-DC5) mounted at the rear of the roll axis unit. The actuator pivots on two shoulder screws that connect it to the rear Arc Slide and the rear Arc Track. The ball screw nut of the actuator drives the Arc Track through its range of motion and is connected to the Arc Slide by the Nut Mount Bottom (PSP07) and the Nut Mount Cap (PSP08). A setscrew in the Nut Mount Cap prevents the ball screw nut from rotating in the Nut Mount. The fixed end of the actuator is mounted to the Arc Track via a shoulder screw and the Mount Pedestal (PSP09). The Mount Pedestal is fixed to the Arc Track by a ¼-20 cap screw.

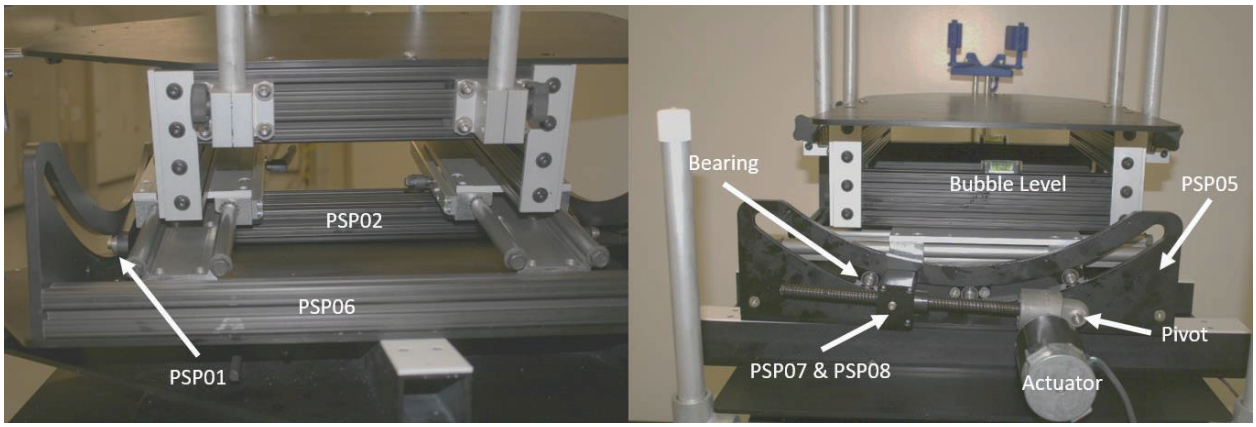

Figure 4. Roll axis

4.3 Rotation Axis

The rotation axis unit controls horizontal panning (nasal-temporal) of the retina. Figure 5 identifies the rotation axis components. The roll axis connects the rotation axis via the Arc Track Frame Supports (PSP06), which connect to the Rotation Top Plate (PSR01). A shoulder screw that attaches to the Rotation Front Support (PSR03) sets the point of rotation. A Teflon bearing surface (Rotation Front Support Bearing PSR04) between the Rotation Top Plate and the Rotation Front Support reduces friction. The entire rotation rides on this and two more Teflon bearing surfaces (Rotation Support Beam Bearing PSR06) mounted on the Rotation Support Beams (PSR05). One of the Rotation Support Beams mounts in the middle of the Rotation Axis assembly and the other at the back of the assembly. The two Rotation Support Beams and the Rotation Front Support mount on the Rotation Bottom Plate (PSR02). A ball screw actuator (Motion Systems Corp. P/N 85616-RH-30-15-ALT.-STD.-B-0.250-DC2) drives the rotation axis. The actuator mounts to the Rotation Bottom Plate via the Actuator Fixed End Mount

(PSR07) and a shoulder screw plus a ¼-20 cap head screw. The actuator's ball screw nut connects to the Rotation Top Plate (PSR01) by the Actuator Nut Mount (PSR08) with a shoulder screw. The Actuator Nut Clamp (PSR09) secures the ball screw nut in the Actuator Nut Mount. Two setscrews keep it from rotating in the Actuator Nut Mount.

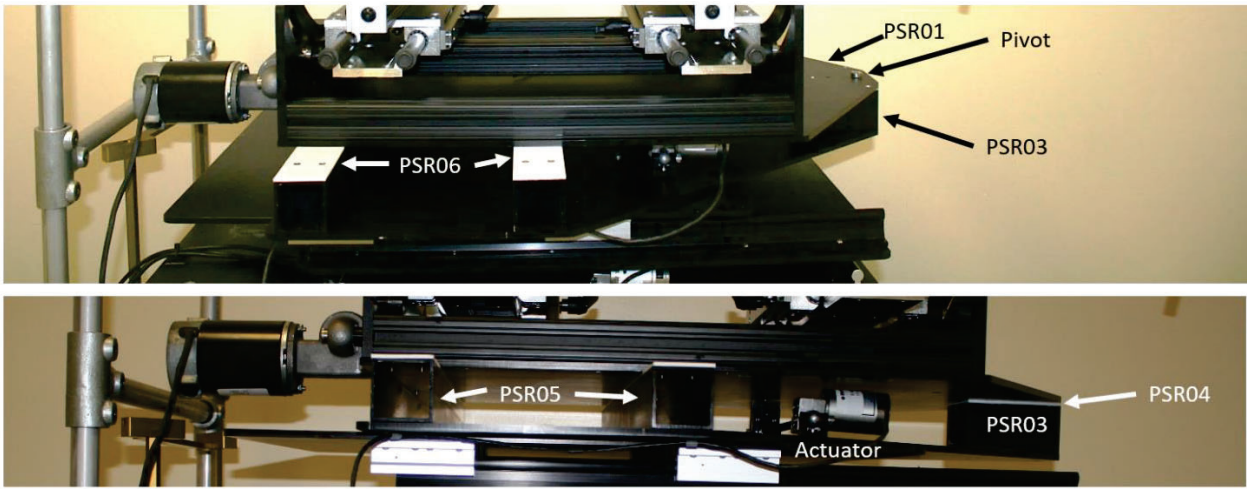

Figure 5. Rotation axis

4.4 X-Axis and Y-Axis

The X-axis and Y-axis units control the left/right and forward/reverse positioning of the stage, respectively. See figure 6 for the X-axis and Y-axis component locations. The Rotation Bottom Plate (PSR02) mounts to the XY Plate Top (PSXY01A) with four bolts. Two configurations for mounting these together allows the combined roll and rotation units to move farther forward if desired. The default position has less overhung load. Both the X-axis and the Y-axis move on a pair of linear rails (McMaster 1049K15) with two mounted linear sleeve bearings (McMaster 6374K342) per rail. The linear rails mount on the XY Plate Middle (PSXY01B) and the XY Plate bottom (PSXY01C). The mounted linear sleeve bearings mount on the XY Plate Top and the XY Plate Middle. The XY Plate Middle is shared between the X and Y assemblies. The same model ball screw actuator (Motion System Corp. P/N 85915-19-10-A-0.187-DC2-RE) drives both the X axis and the Y axis. Both ends of the ball screw actuators connect to the XY plates with Actuator Mounting Brackets (PSXY02). Two 8-32 cap head screws hold the actuators in place. These 8-32 cap screws act as clevis pins. Two 6-32 cap head screws mount each of the four Actuator Mounting Brackets to the XY plates.

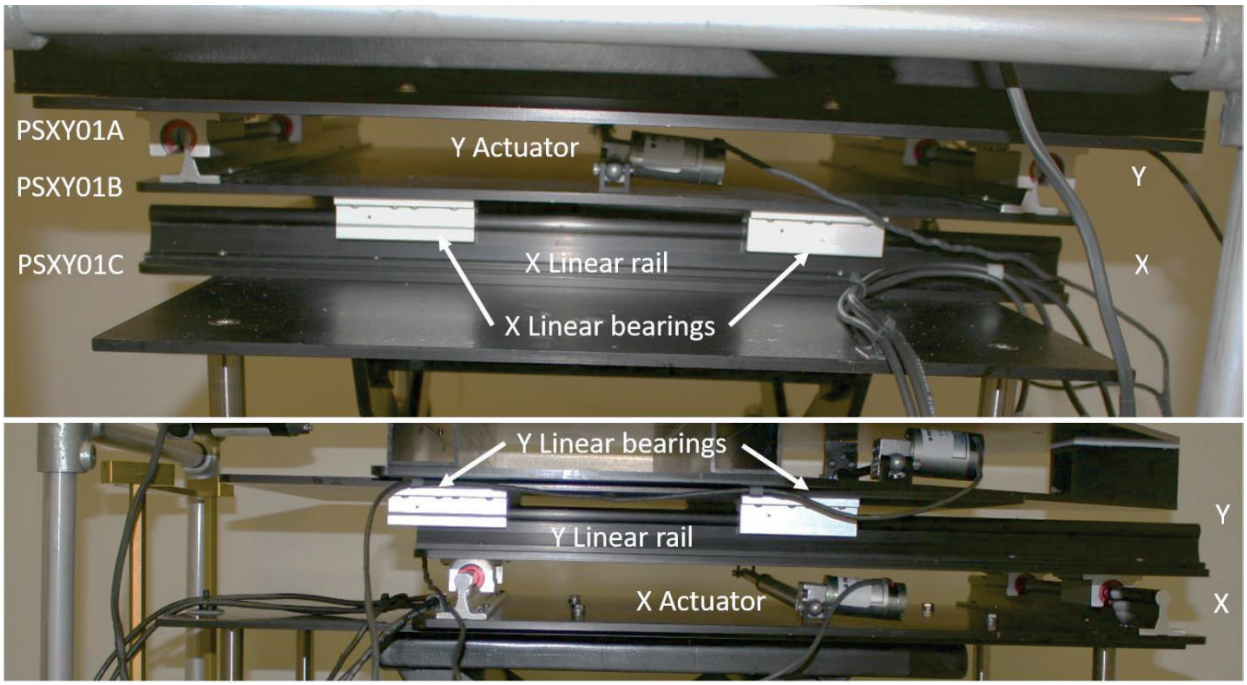

Figure 6. X-axis and Y-axis

4.5 Z-Axis

The Z-axis unit controls the overall height of the stage. Figure 7 diagrams the Z-axis components. The XY Plate Bottom (PSXY01C) attaches the X-axis to the Z-axis via the Top Plate (PSMB02). A motorized scissor lift table (Air Technical Industries MSL-A1519), mounted between the Base Plate (PSMB01) and the Top Plate, accomplishes the Z-axis motion. Four linear motion shafts (McMaster 6649 K 13) stabilize the Z-axis motion. These shafts bolt to the Top Plate at each corner. The shafts insert into four linear ball bearing guides (McMaster 6483K750) mounted in four Linear Bearing Supports (PSMB03) at the corners of the Base Plate. **IMPORTANT:** The linear motion shafts extend below the Castor Supports (PSMB04) when the Z-axis is at the bottom of its travel and will interfere with the castors. The Z-axis must be raised enough to ensure this does not occur when relocating the stage.

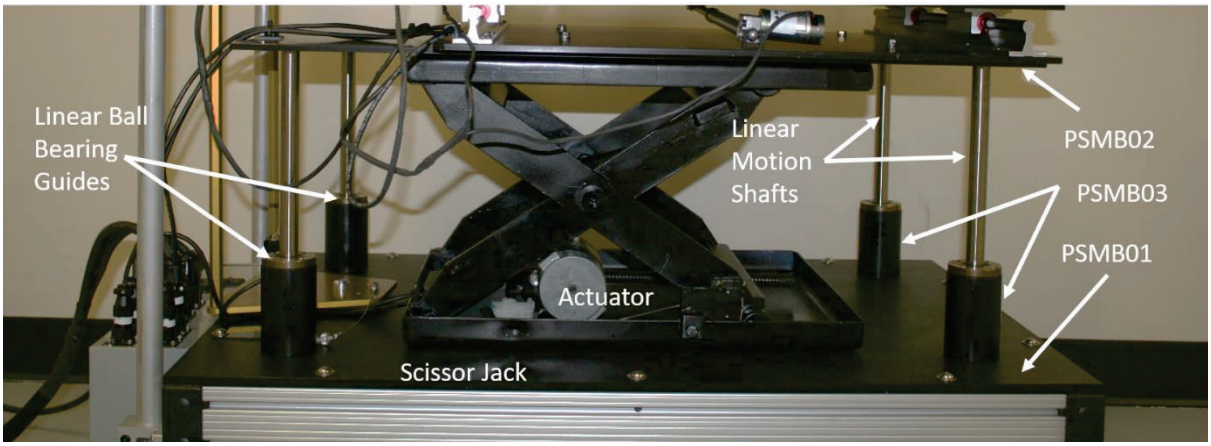

Figure 7. Z-axis

4.6 Mobile Base

The mobile base unit supports the entire stage and provides portability of the stage. Figure 8 shows the location of the Mobile Base components. The Base Plate (PSMB01) integrates the Z-axis unit into the mobile base. Five aluminum extrusions (PSMB005 2 each, PSMB06 2 each, and PSMB07) construct the frame of the mobile base. Two Castor Supports (PSMB04) mount to the bottom of the frame, and four lockable swivel castors (8020 Incorporated 2337) attach to Castor Supports.

Figure 8. Mobile base

4.7 Electronics Enclosure with Wired Remote

The electronics enclosure unit houses the motion controllers, power supply, fuses, and main power switch. It also facilitates the electrical interconnections between the stage axes and the wired remote. The wired remote contains all the direction switches and speed control potentiometers. Electronics Enclosure components are illustrated in figure 9. The stage requires four speed controls. Two of these speed controls, SC1 and SC2 (Dart Controls 13DV2A-TS), operate from 24 volts AC supplied by transformer T1 (Triad Magnetics F-260U). This supply is protected by fuse F3 (5A 250V), labeled 24 VAC on the electronics enclosure. The other two speed controllers, SC3 and SC4 (Dart Controls 15DV2A-TS),

operate from 115 volts AC. These two controllers and T1 connect to the main power via fuses F1 and F2 (6.1A 250V). Switch S1 (Delta Electronics 10C2) controls power for the stage. This switch assembly also houses fuses F1 and F2.

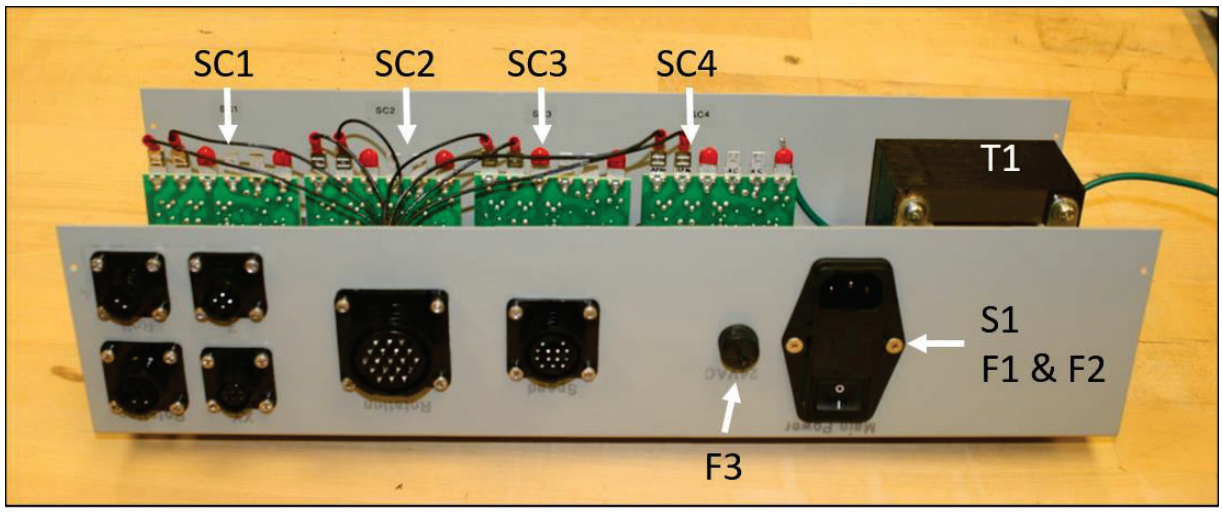

Figure 9 Electronics enclosure

Figure 10 Wired remote

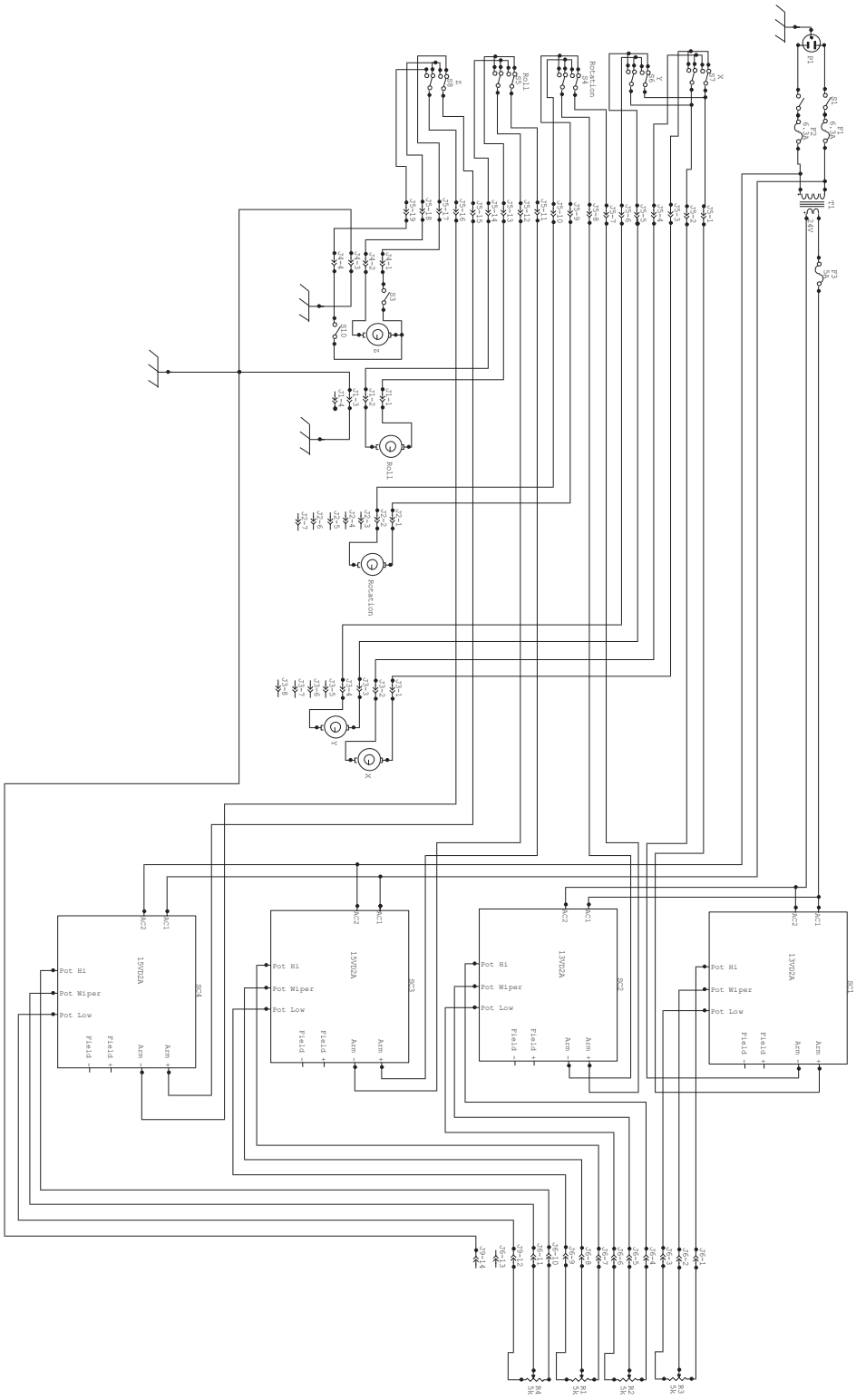

Figure 11 Electrical diagram

5 ALIGNMENT

Alignment of the subject on the stage is crucial to proper operation of the stage. For the stage to perform as designed, the apex of the selected cornea must be placed at the intersection point of both the roll and rotation axes. The alignment jig (see Figure 1) facilitates locating the point in space where these axes intersect. The following procedure describing the necessary steps to place and align the subject properly on the stage.

- Before placing the subject on the stage
    - Level the roll section using the bubble levels mounted below the subject platform (PSP03)
    - Center the X-axis and Y-axis by aligning the edges of X and Y sections
    - Ensure the chin rest rotation adjustment is centered using the chin support rod holder (PSP10)
    - Lock the cross slides beneath the subject platform
- Place the Hug-U-Vac on the subject platform and anything else needed for the subject
- Place the subject on the subject platform (PSP03), aligning their head on the chin rest (PSACC02)
- Place the alignment jig on the front of the stage either on the left or right side based on which eye will be used, OS or OD respectively. Ensure the jig does not interfere with subject monitoring or support equipment (e.g. the intubation tube)
- Adjust the chin rest to roughly set the corneal height to the rotational height of the roll axis
- Slide the subject platform forward or backward so that the subject's cornea aligns to the roll alignment sight (PSAJ03)
- Fine adjust the chin rest height and slide the subject platform with front to back adjustments to align the apex of the cornea to the roll alignment sight
- Install the head stabilizers (PSACC04) on the chin rest, and adjust so the subject's head will be stable during roll axis movements
- Unlock the cross slides
- Slide the subject left and right to align the subject with the rotation axis alignment sight (PSAJ03)
- Lock the cross slides
- Confirm the alignment of the subject's corneal apex with roll and rotation alignment sights
    - Finely adjust the alignment using the chin rest and cross slides
      Note: the closer this alignment is to the ideal position the better the stage will perform during retinal exposures
- Remove the alignment jig
- Place the alignment jig in its storage location at the rear of the mobile base
- Move the stage to the optical setup
- Using the X, Y, and Z controls align the subject to the optical setup

- Lock one or two of the castors so the stage does not move out of alignment
- Confirm the stage is still aligned to the optical setup and readjust as necessary

6 DAILY OPERATIONS

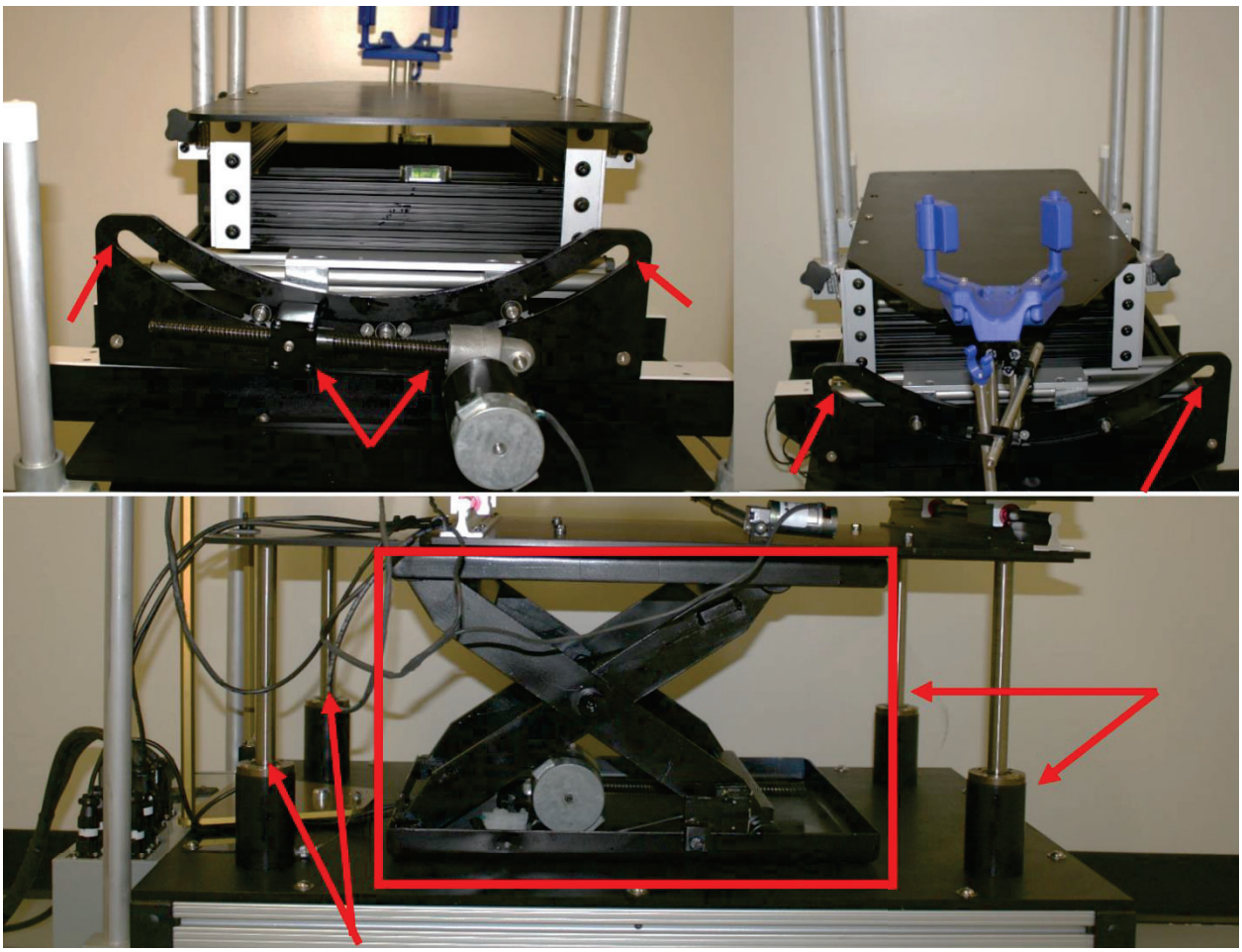

Figure 12: Pinch points.

It is important to maintain awareness of and avoid exposed pinch points between all moving components, pointed to by red arrows and inside the red box in Figure 12.

The following should be done before placing the subject on the stage:

- Level the Roll section using the bubble levels
- Center the chin rest rotation adjustment
- Place Hug-U-Vac on the subject platform
- Center the X-axis

- Center the Y-axis
- Adjust the Rotation-axis to the center of its travel

After stage usage has finished for the day:

- Turn off the power
- Clean all surfaces that have come in contact with the subject
- Remove any saline or other fluids from surfaces and clean these surfaces thoroughly
- Place the alignment jig in its storage location at the rear of the mobile base
- Stow the wired remote on the subject platform

7 MAINTENANCE

Maintenance should be performed every three months, unless otherwise stated, when the stage is in active use. No maintenance is required when the stage is being stored for long periods and not being actively used. Maintenance should be performed when the stage is brought out of storage and put back into active use.

- Inspect wiring and electrical connectors
- Check the operation ball screw actuators and lubricate as necessary with Lucas Oil Red'n'Tacky heavy grease (or equivalent) every 3 months or as needed
- Inspect rotation Teflon bearing surfaces and clean as necessary
- Inspect linear slides and linear bearings
- Inspect the roll-axis' six ball bearings
- Inspect and tighten all fasteners as necessary
- Inspect pivot points and ensure shoulder bolts are tightened properly
- Inspect linear motion shafts and linear ball bearing guides
- Inspect castors and wheel locks
- Check the operation of the scissor jack
- Check the operation of the limit switches on the Z-axis
- Run all axes to ensure they operate freely and both end travel limits work properly
- Center the axes after their operational check
- Clean all surfaces

8 REFERENCES

[1] Bouchard GF, Brown LD, Liu J,Shoemake C, Brocksmith D, Trickey J, Teel A. 7 January 2019. Miniature Swine Book of Normal Data 2019. ©Sinclair Bio Resources, LLC and Sinclair Research, LLC.

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APPENDIX A: MECHANICAL DRAWINGS

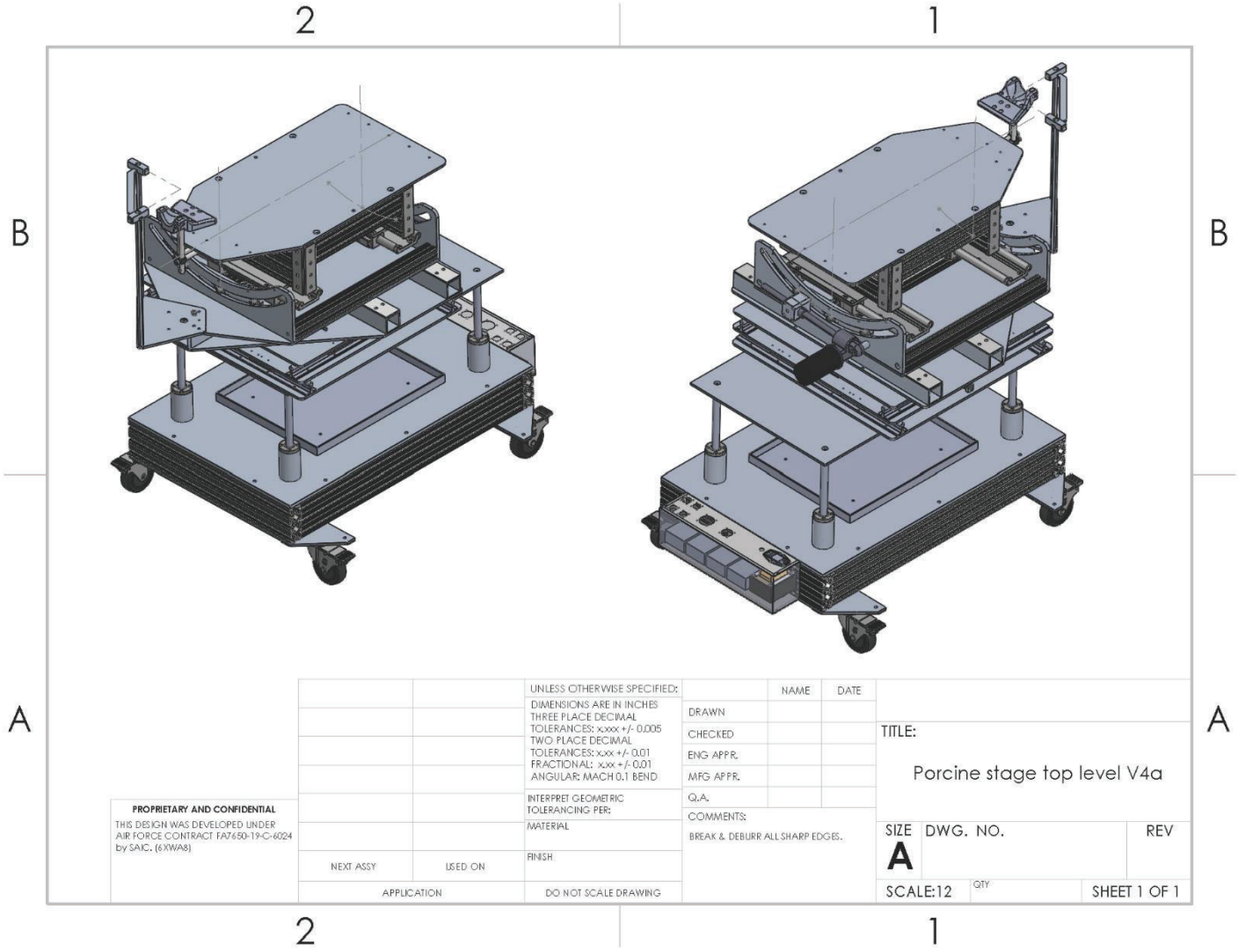

Figure 13: Top Level Porcine Stage Assembly

A.1 Mobile Base

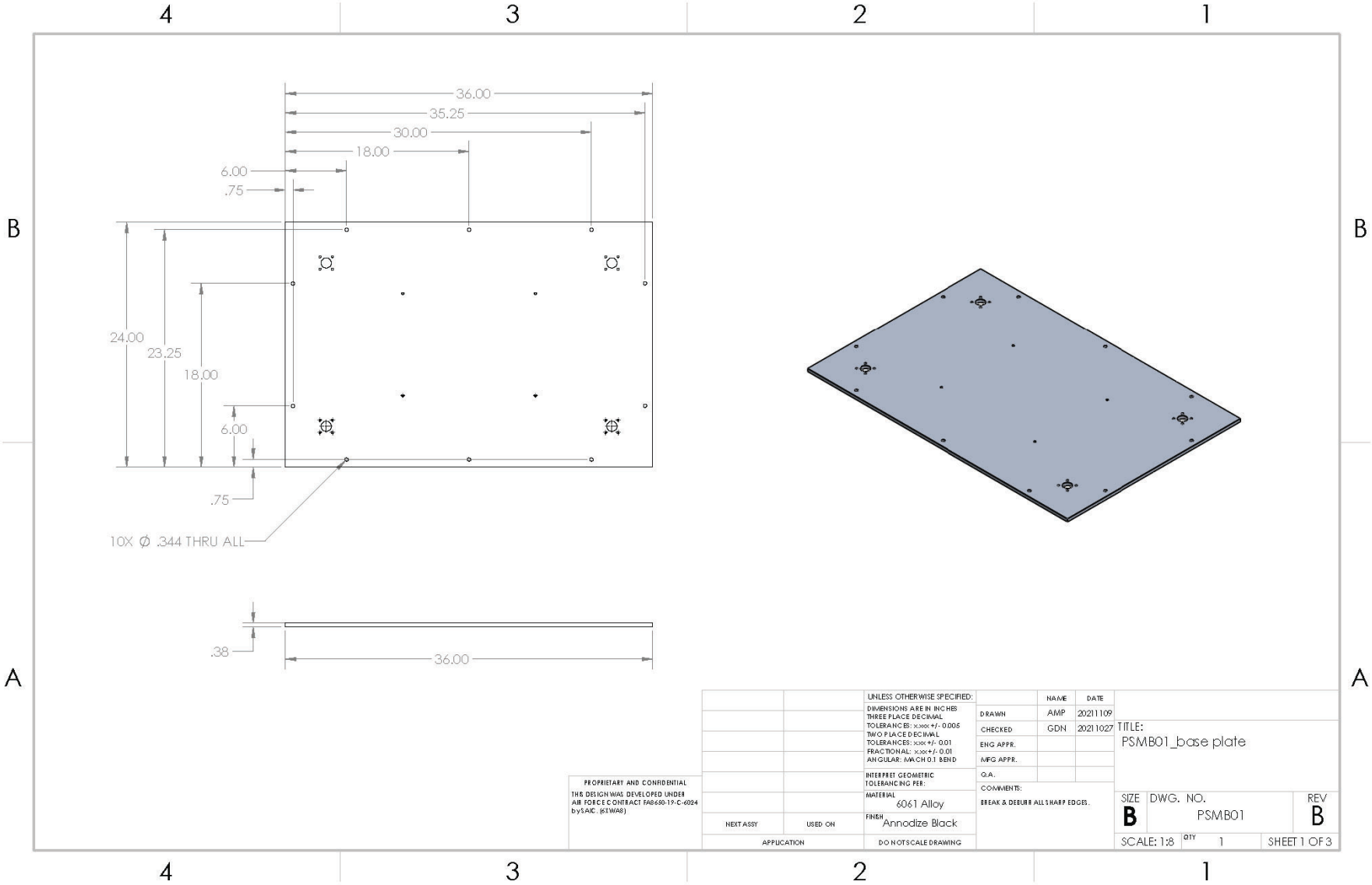

Figure 14: PSMB01_base plate (page 1)

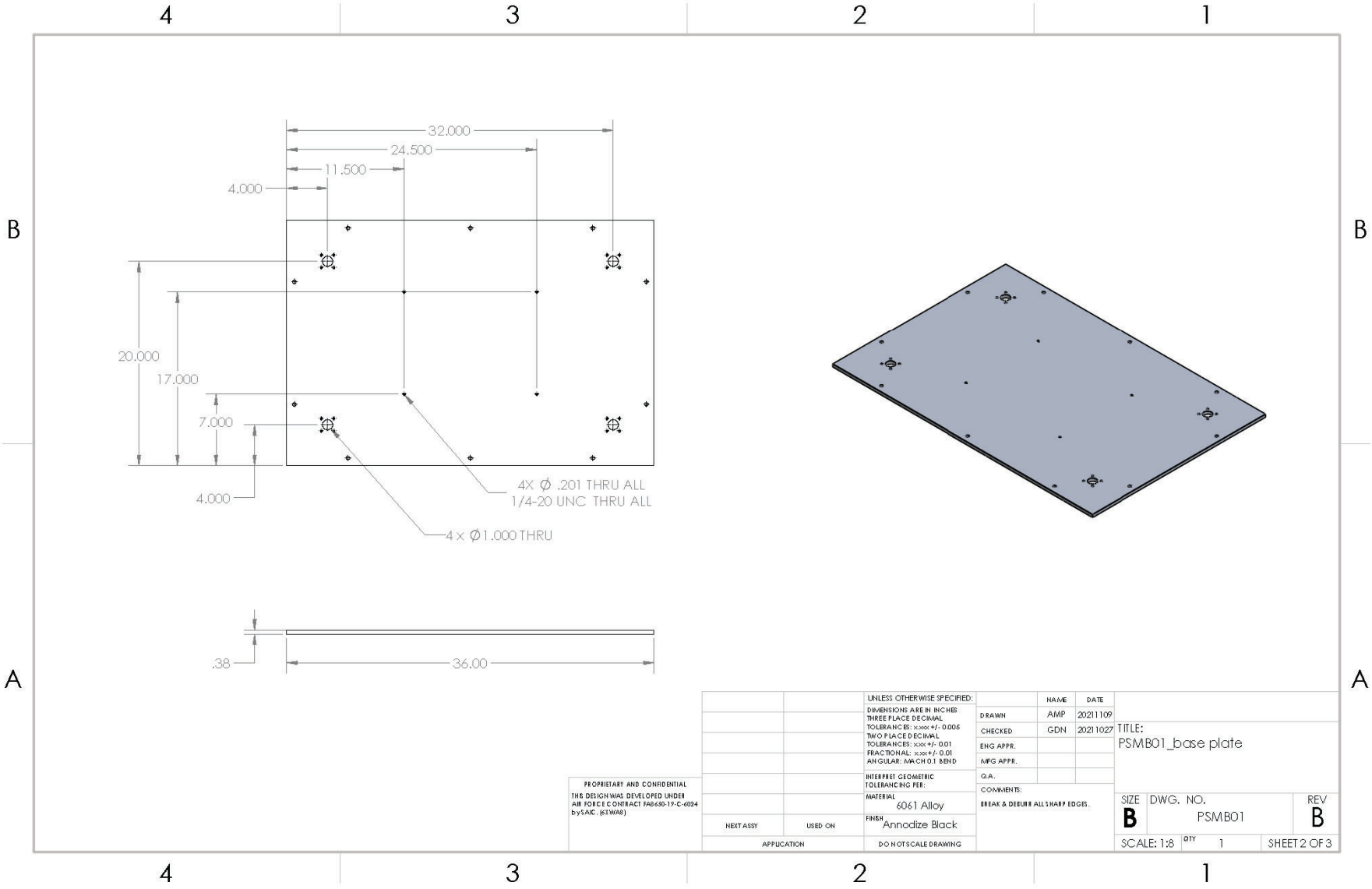

Figure 15: PSMB01_base plate (page 2)

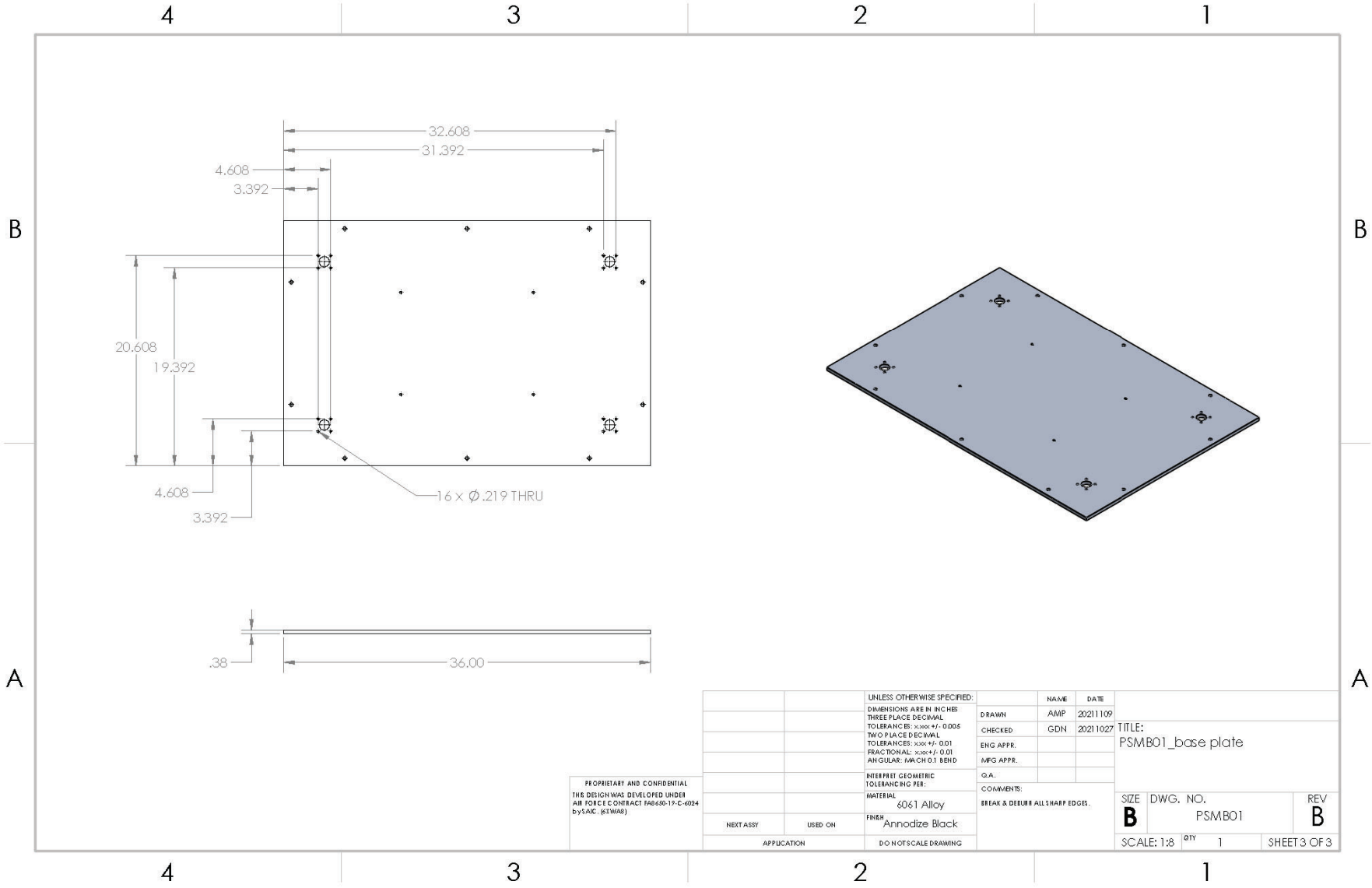

Figure 16: PSMB01_base plate (page 3)

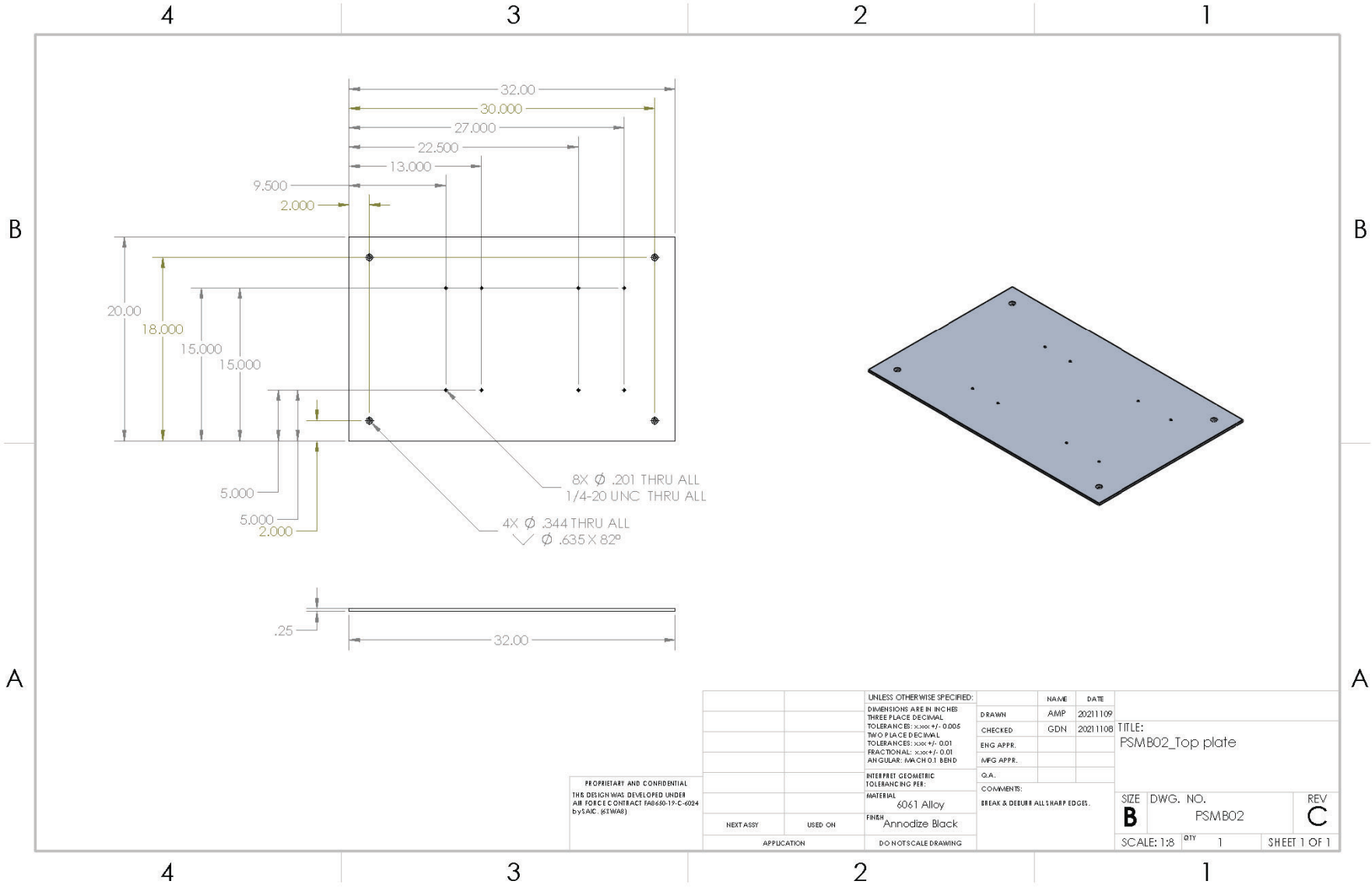

Figure 17: PSMB02_Top plate

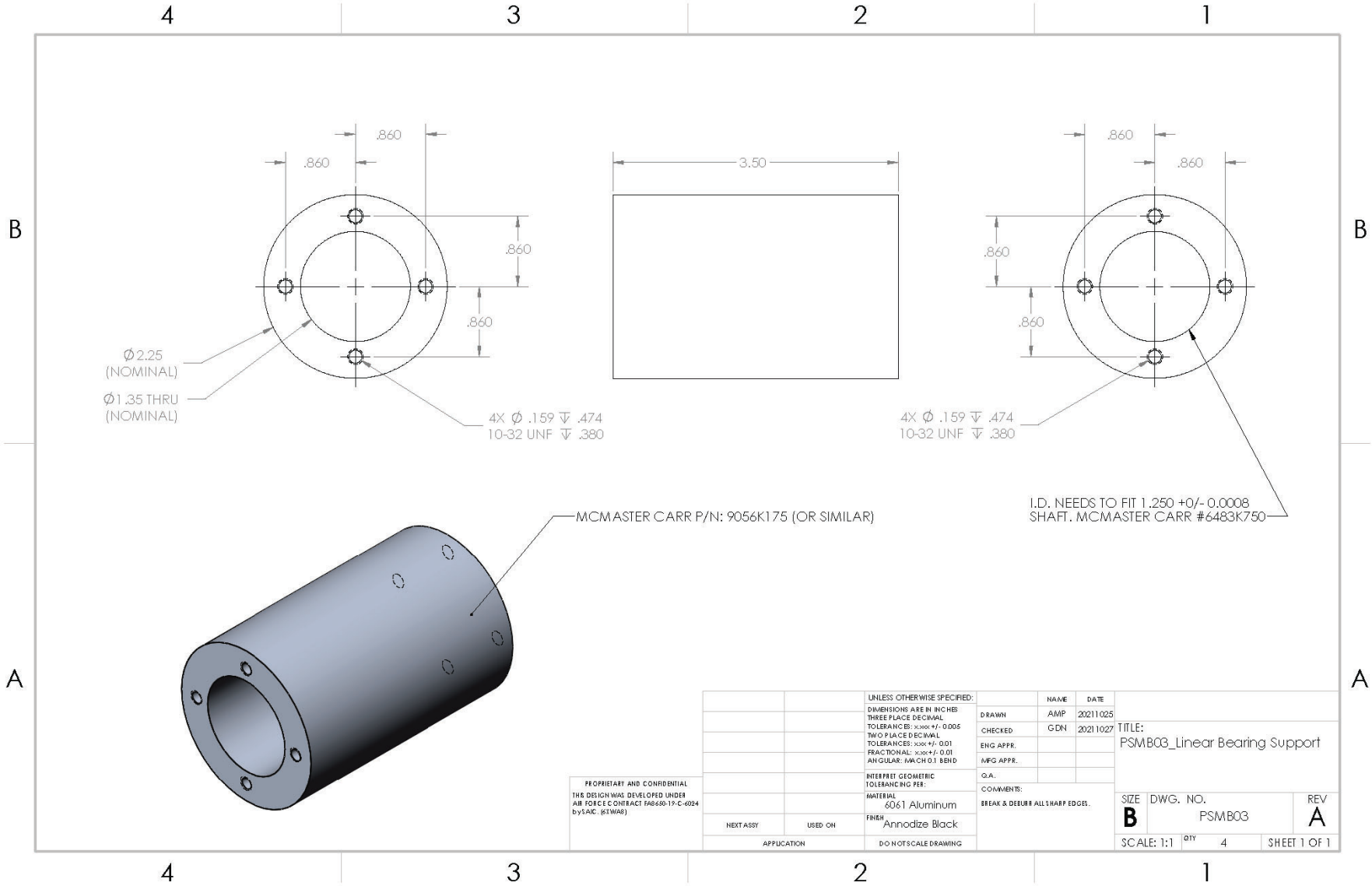

Figure 18: PSMB03_Linear Bearing Support

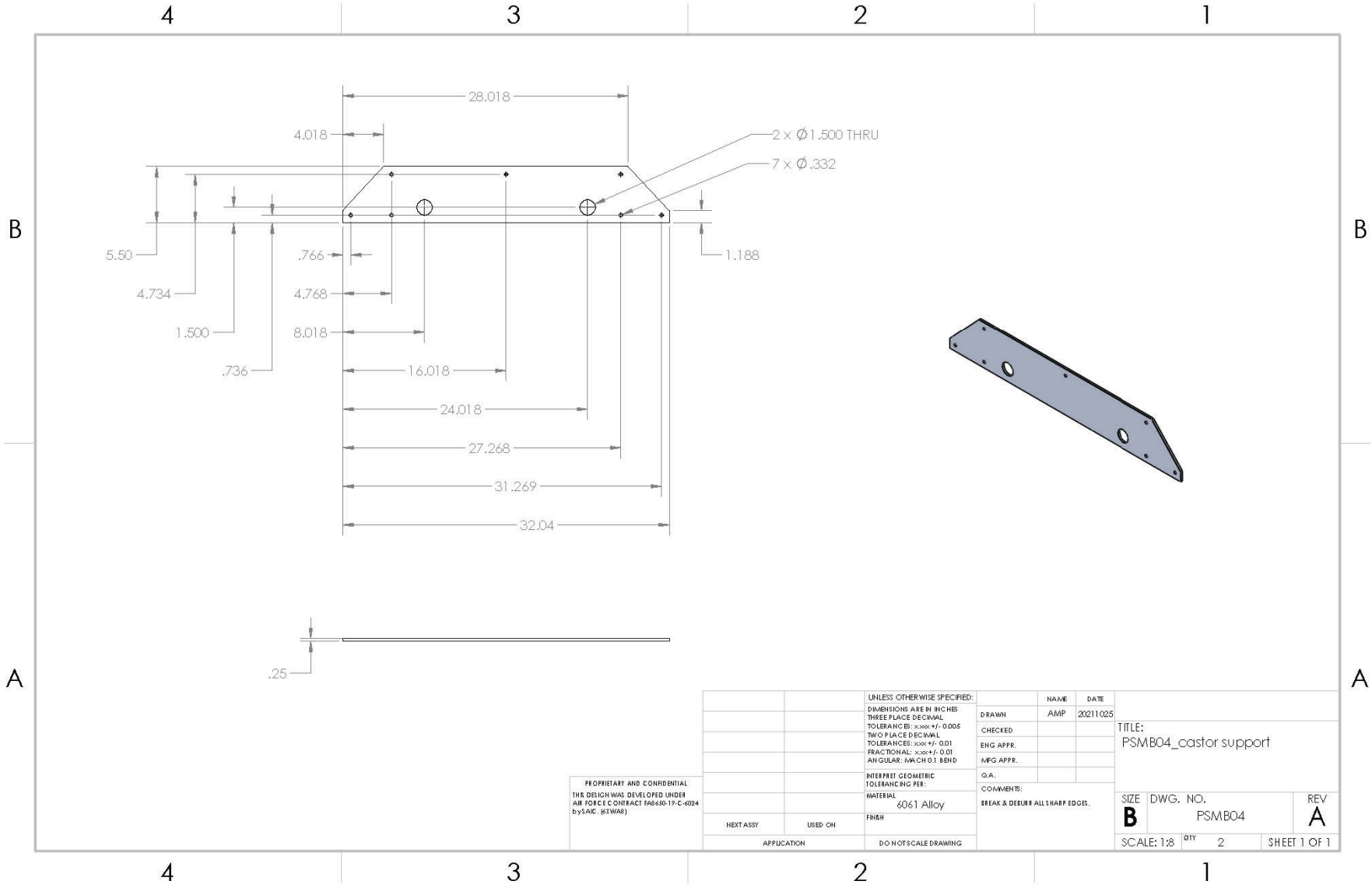

Figure 19: PSMB04_castor support

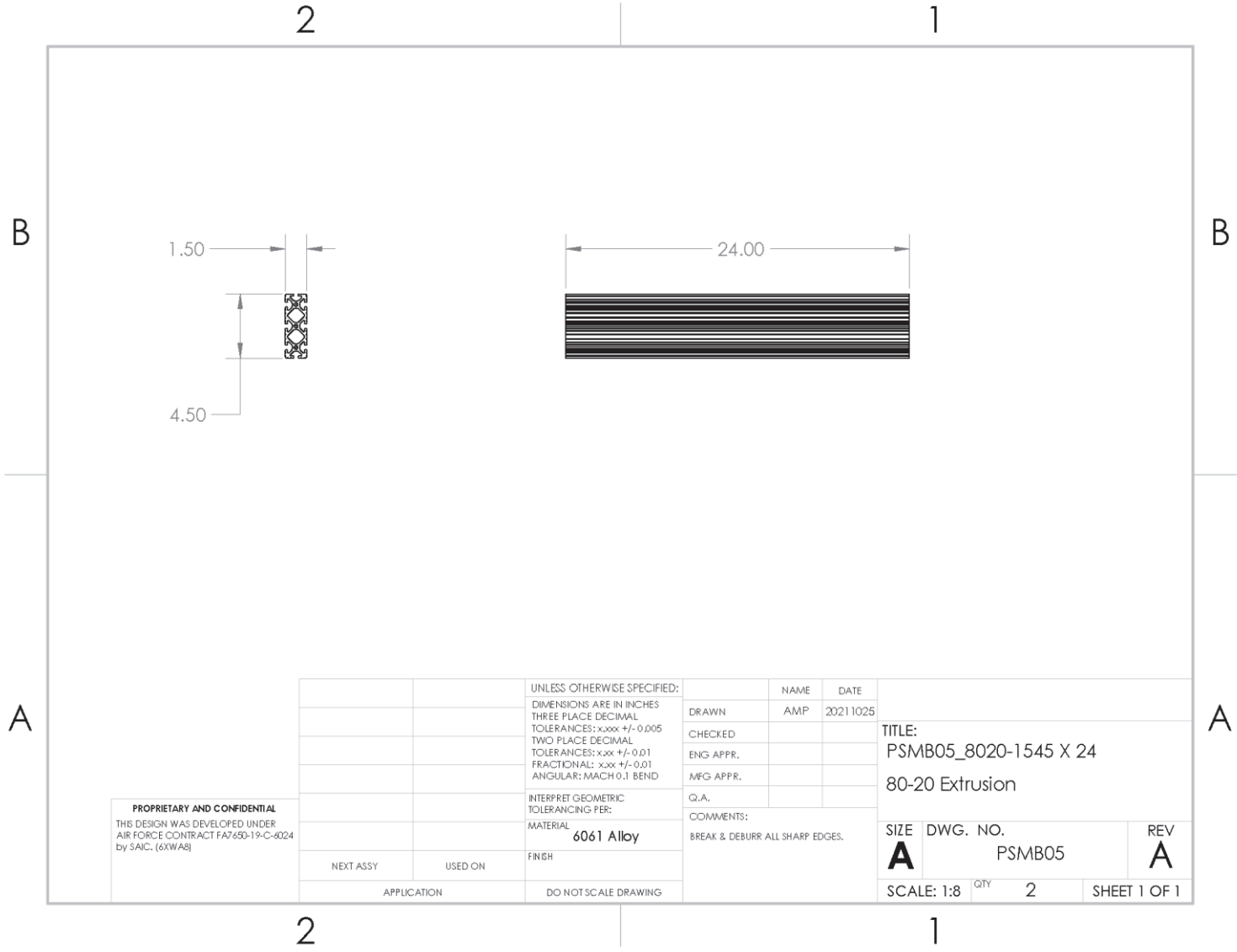

Figure 20: PSMB05_8020-1545 X 24

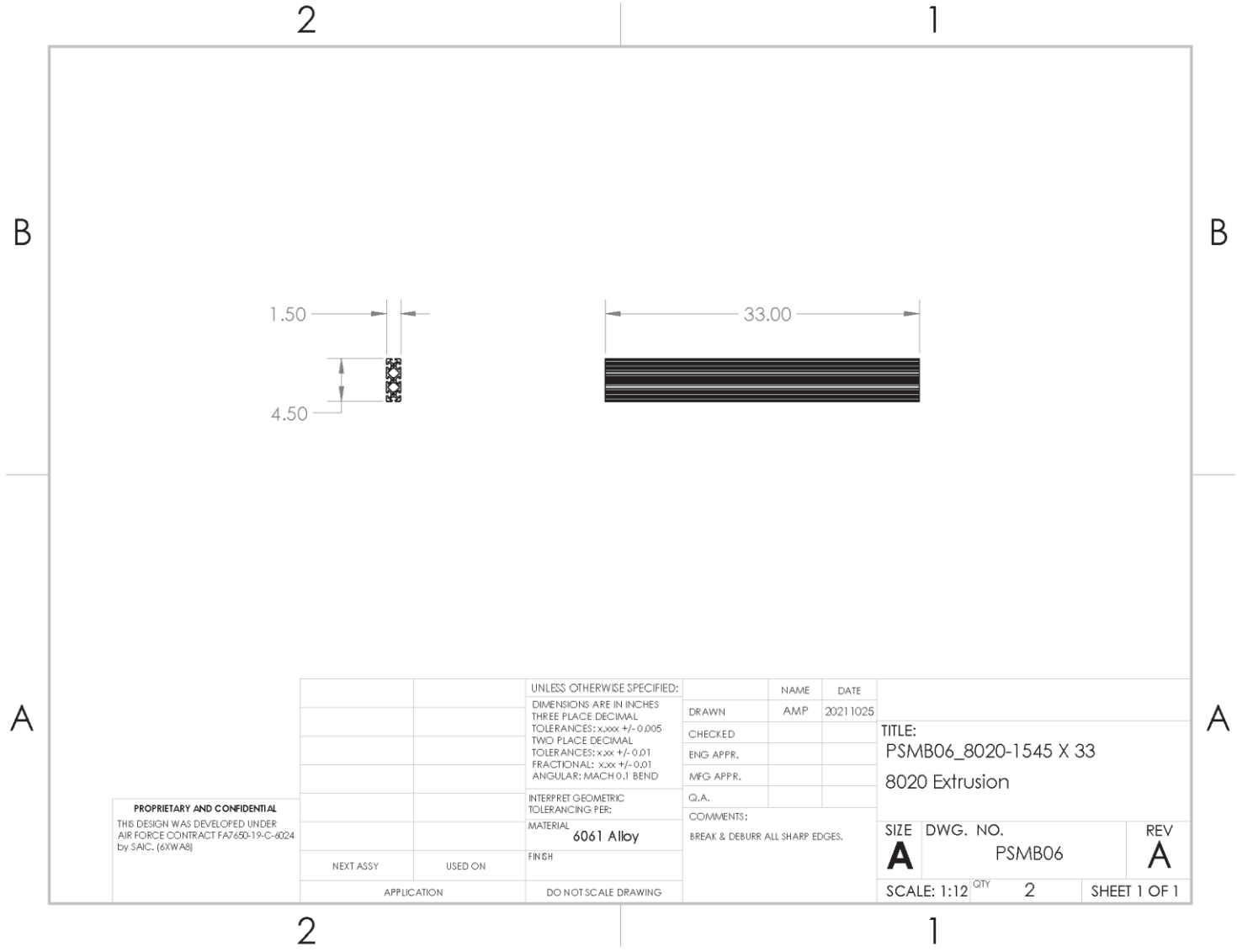

Figure 21: PSMB06_8020-1545 X 33

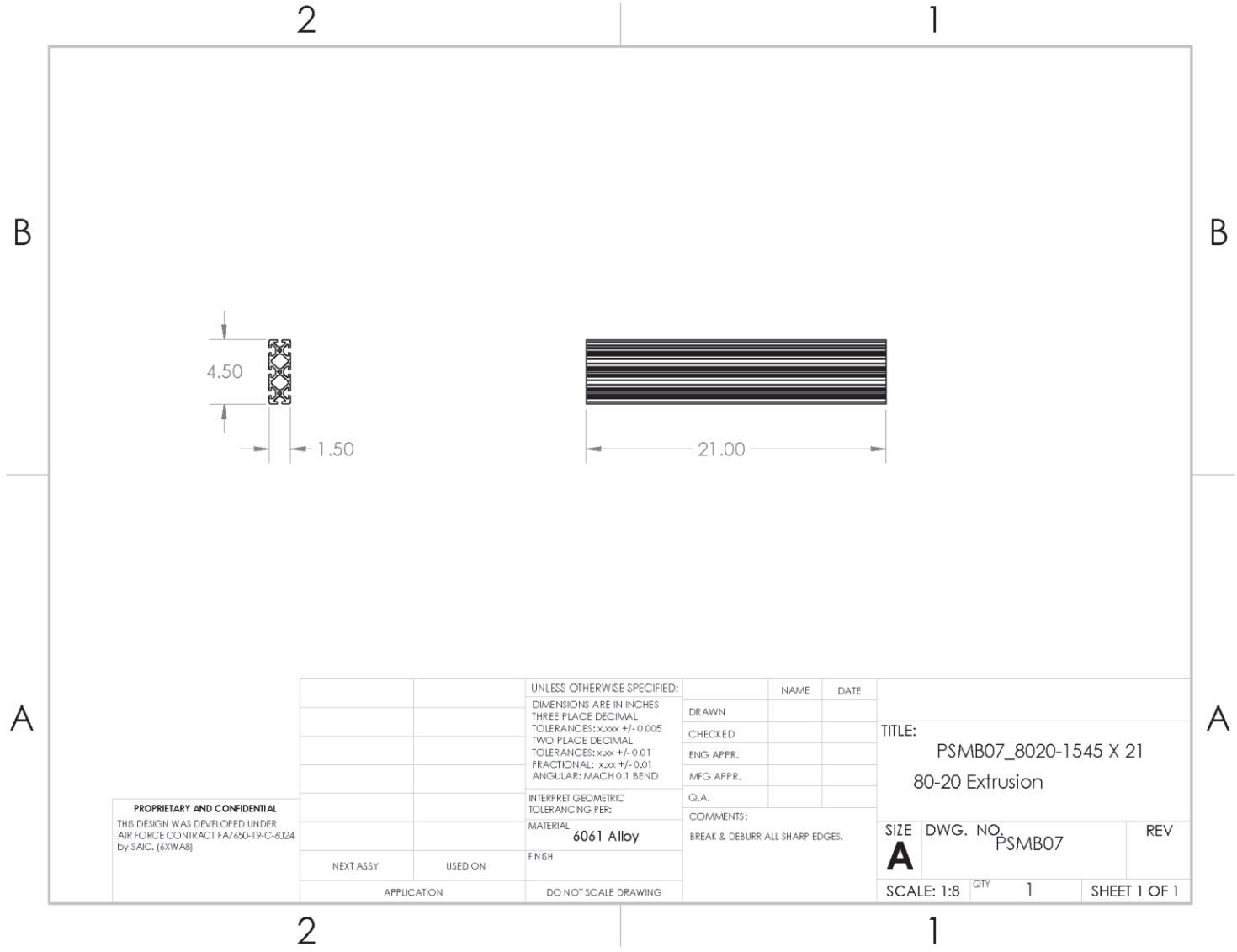

Figure 22: PSMB07_8020-1545 X 21

A.2 X-Y Translation

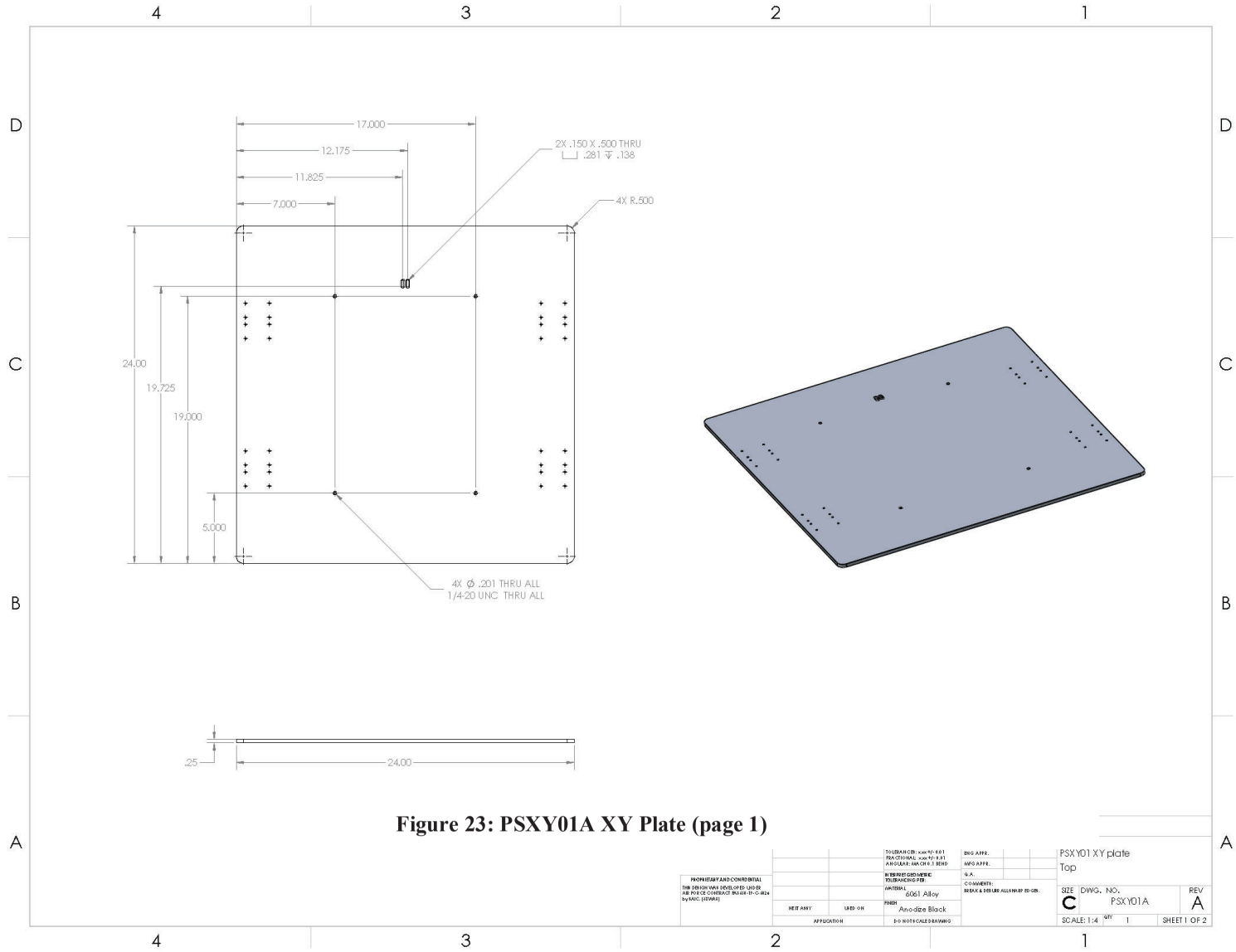

Figure 23: PSXY01A XY Plate (page 1)

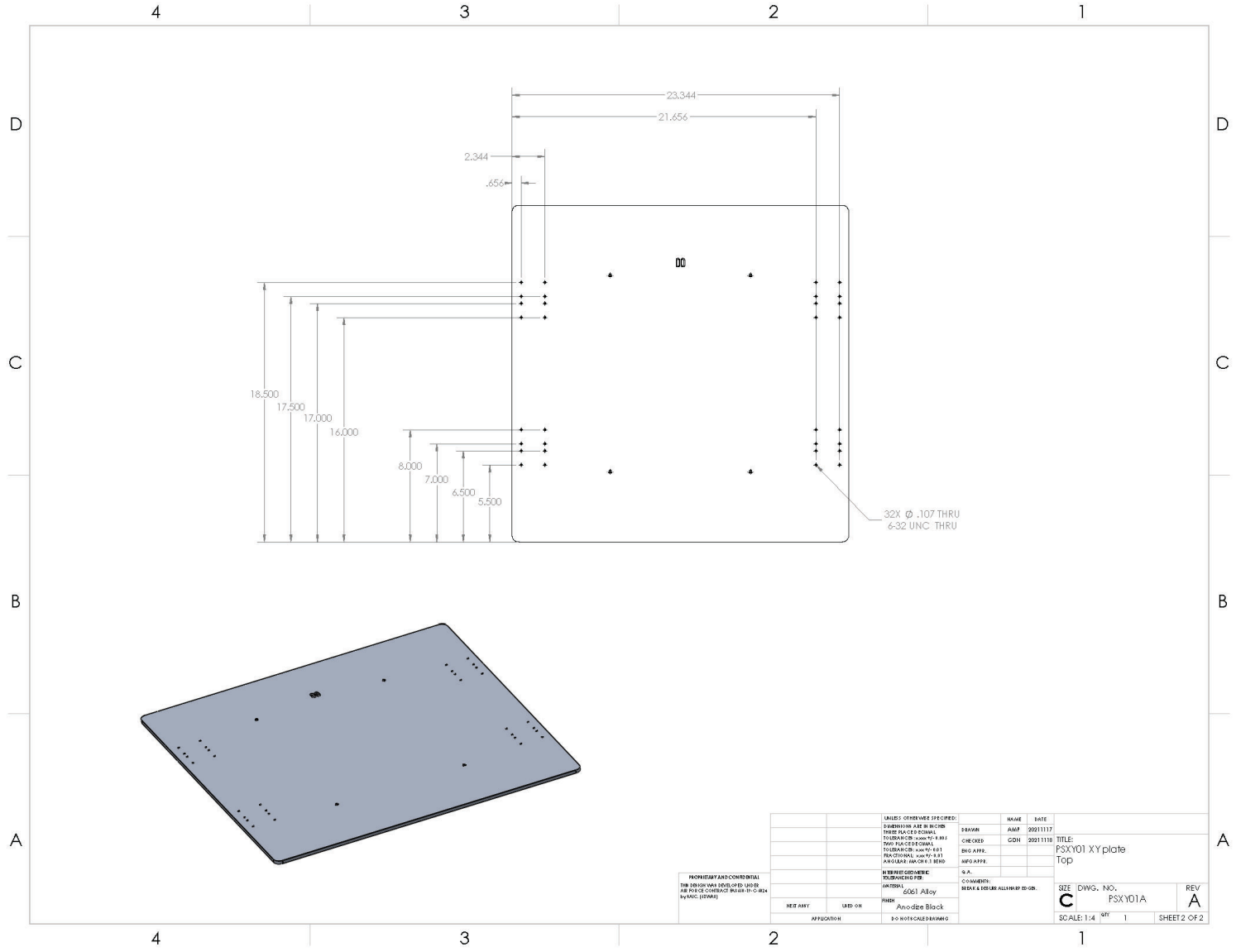

Figure 24: PSXY01A XY Plate (page 2)

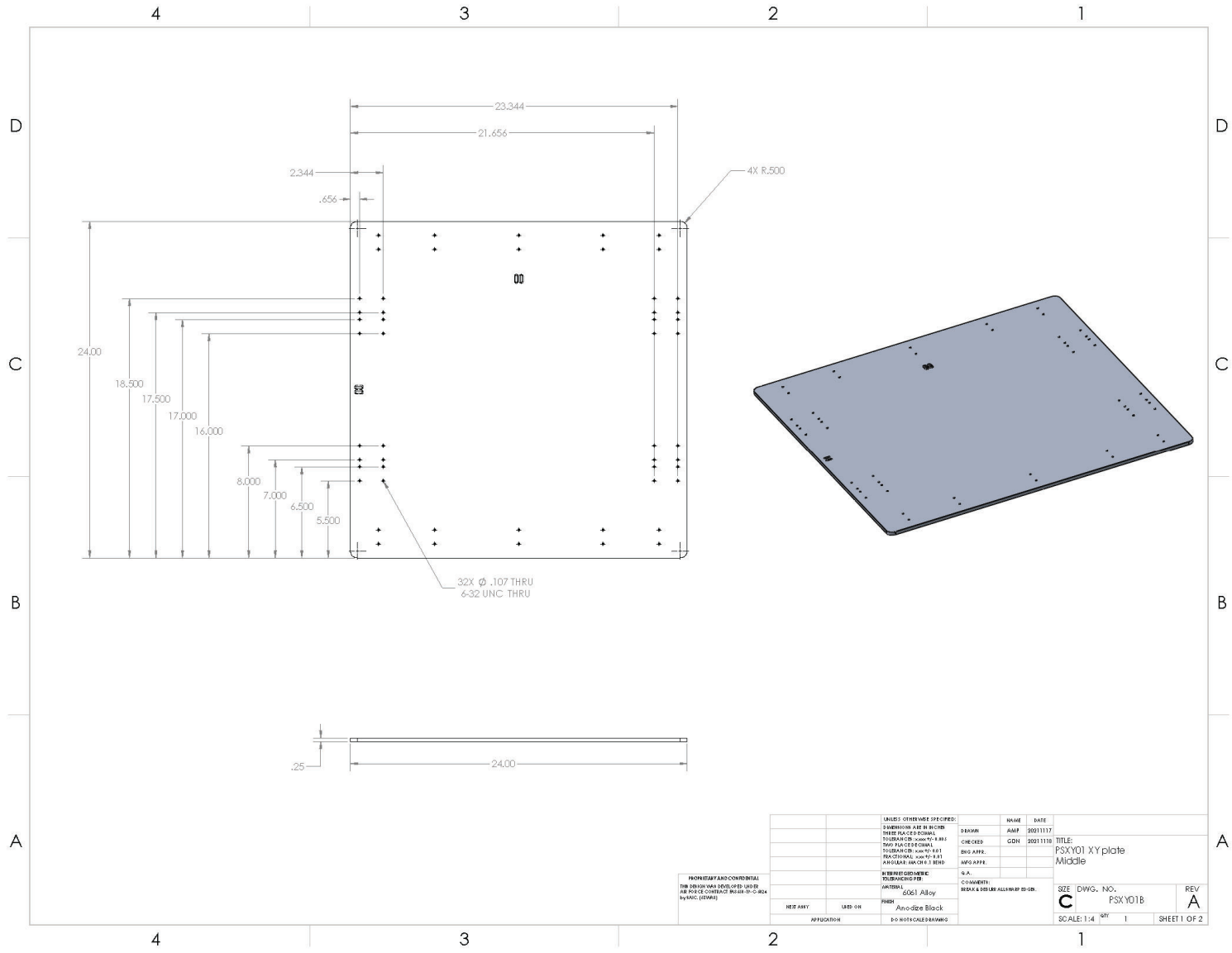

Figure 25: PSXY01B XY Plate (page 1)

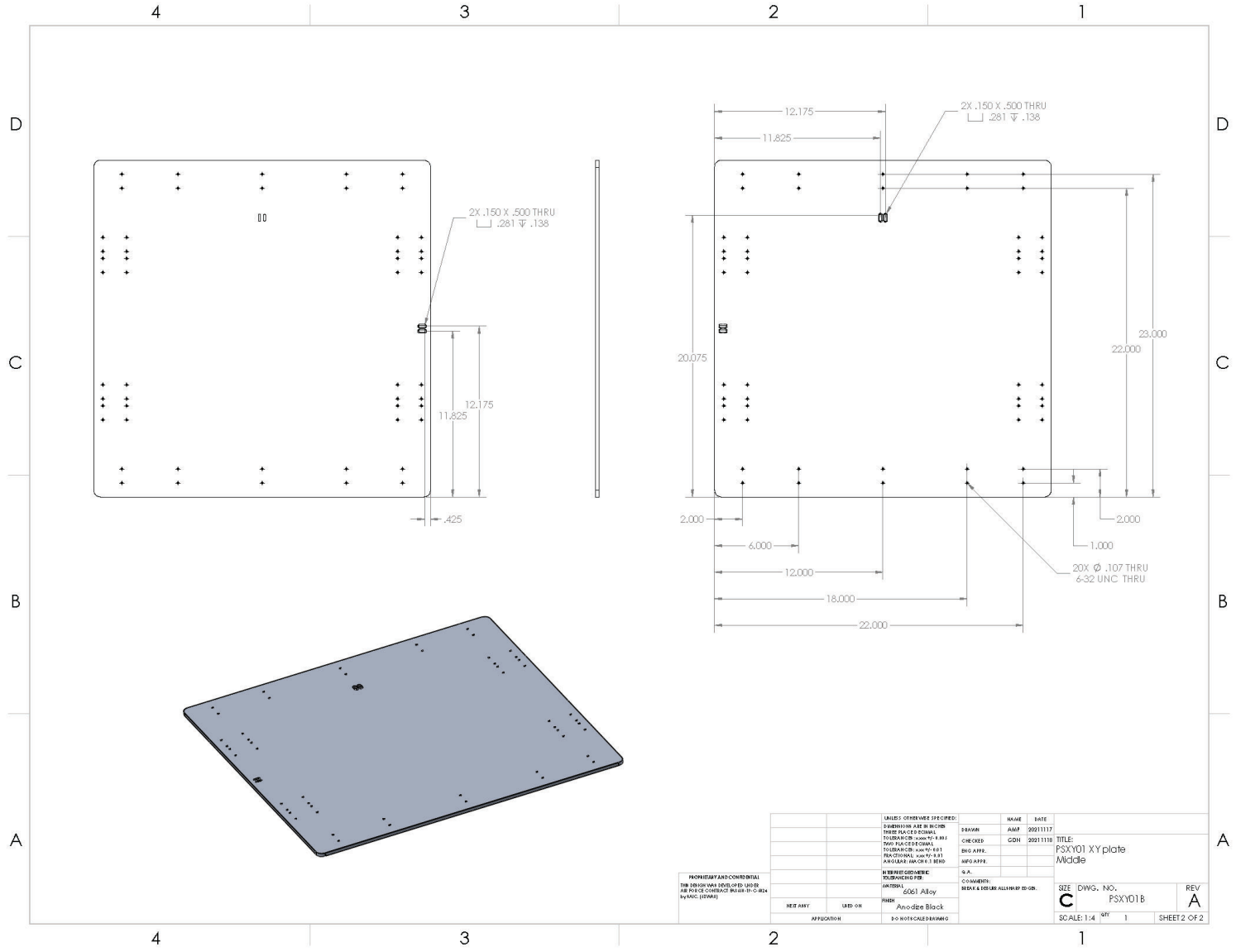

Figure 26: PSXY01B XY Plate (page 2)

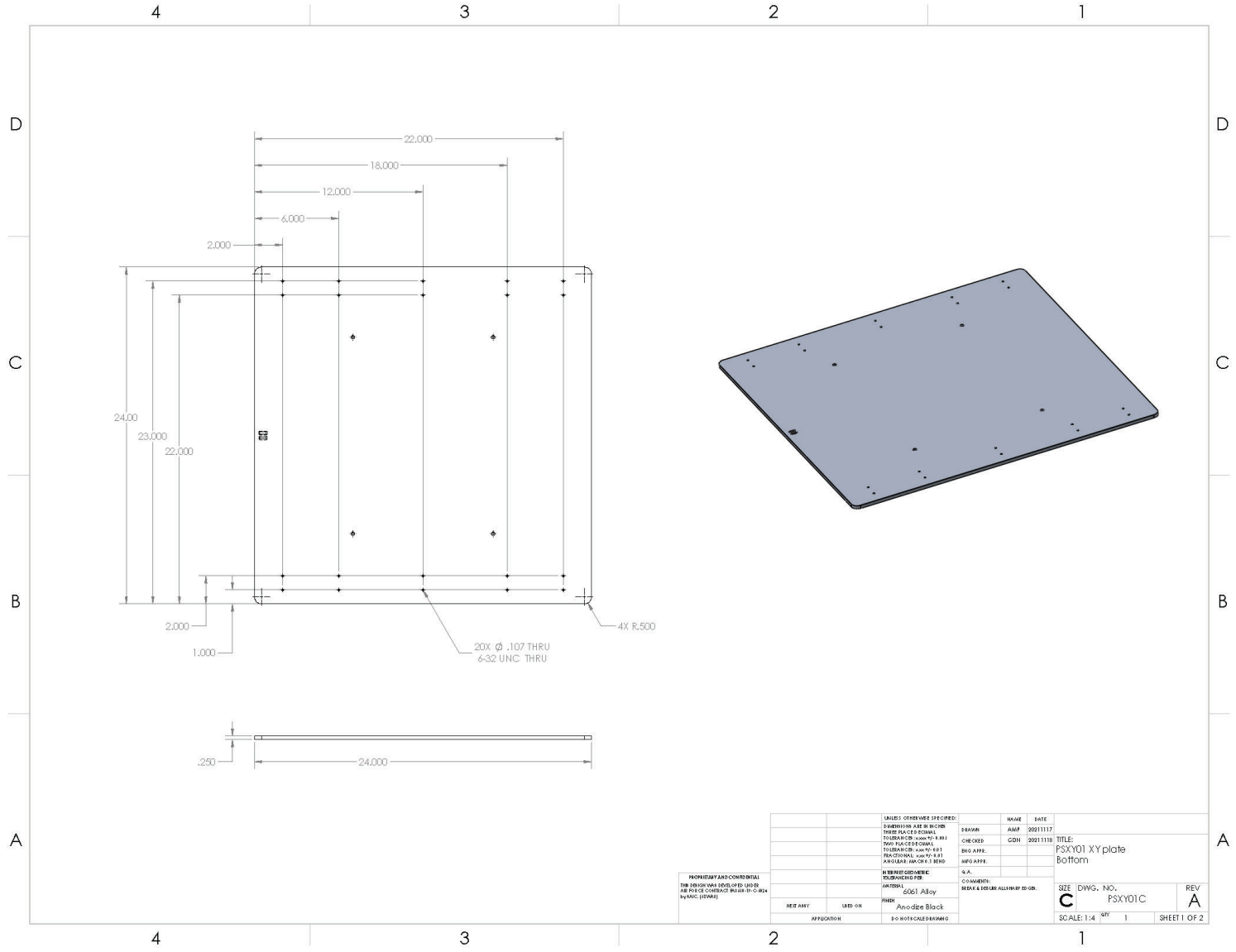

Figure 27: PSXY01C XY Plate (page 1)

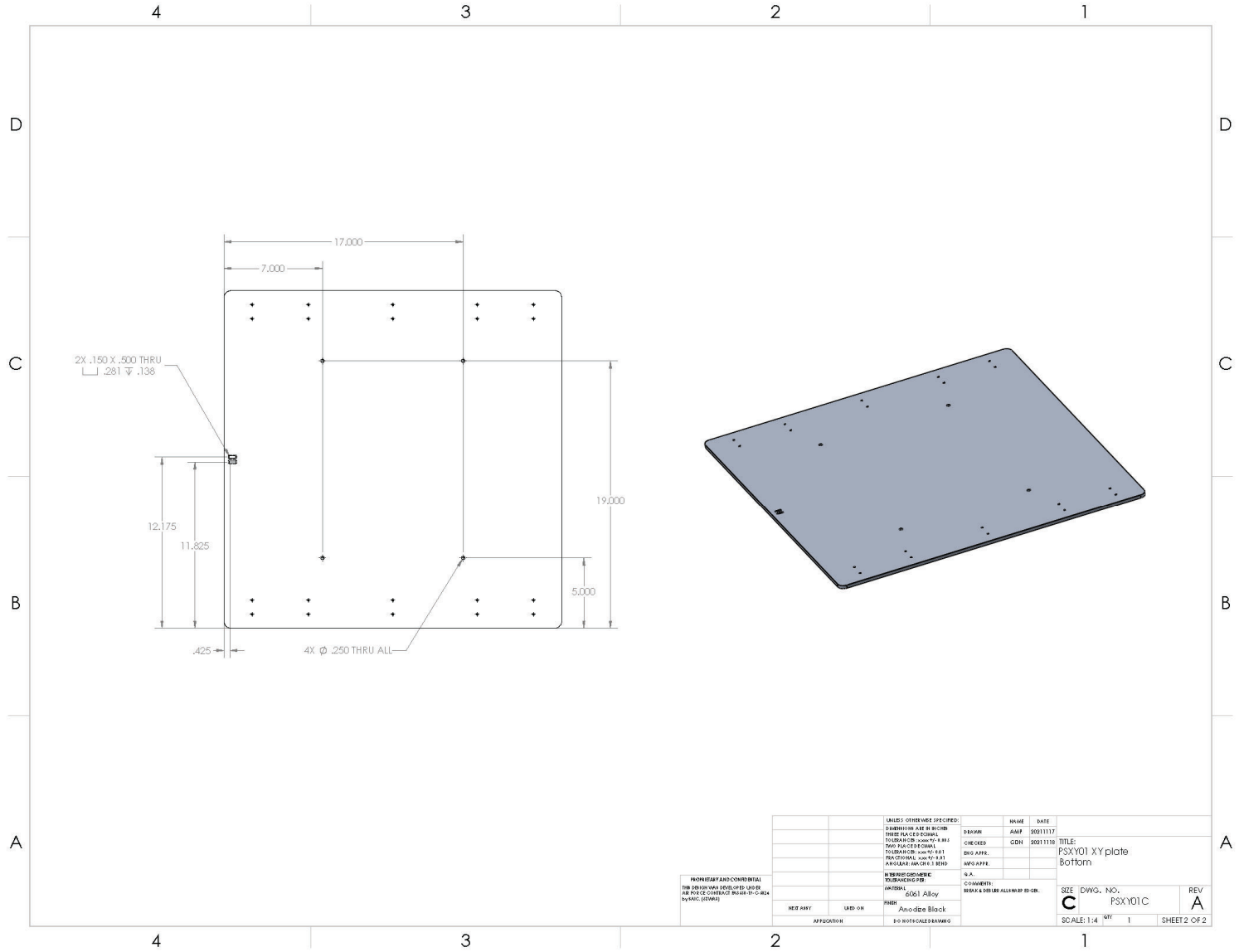

Figure 28: PSXY01C XY Plate (page 2)

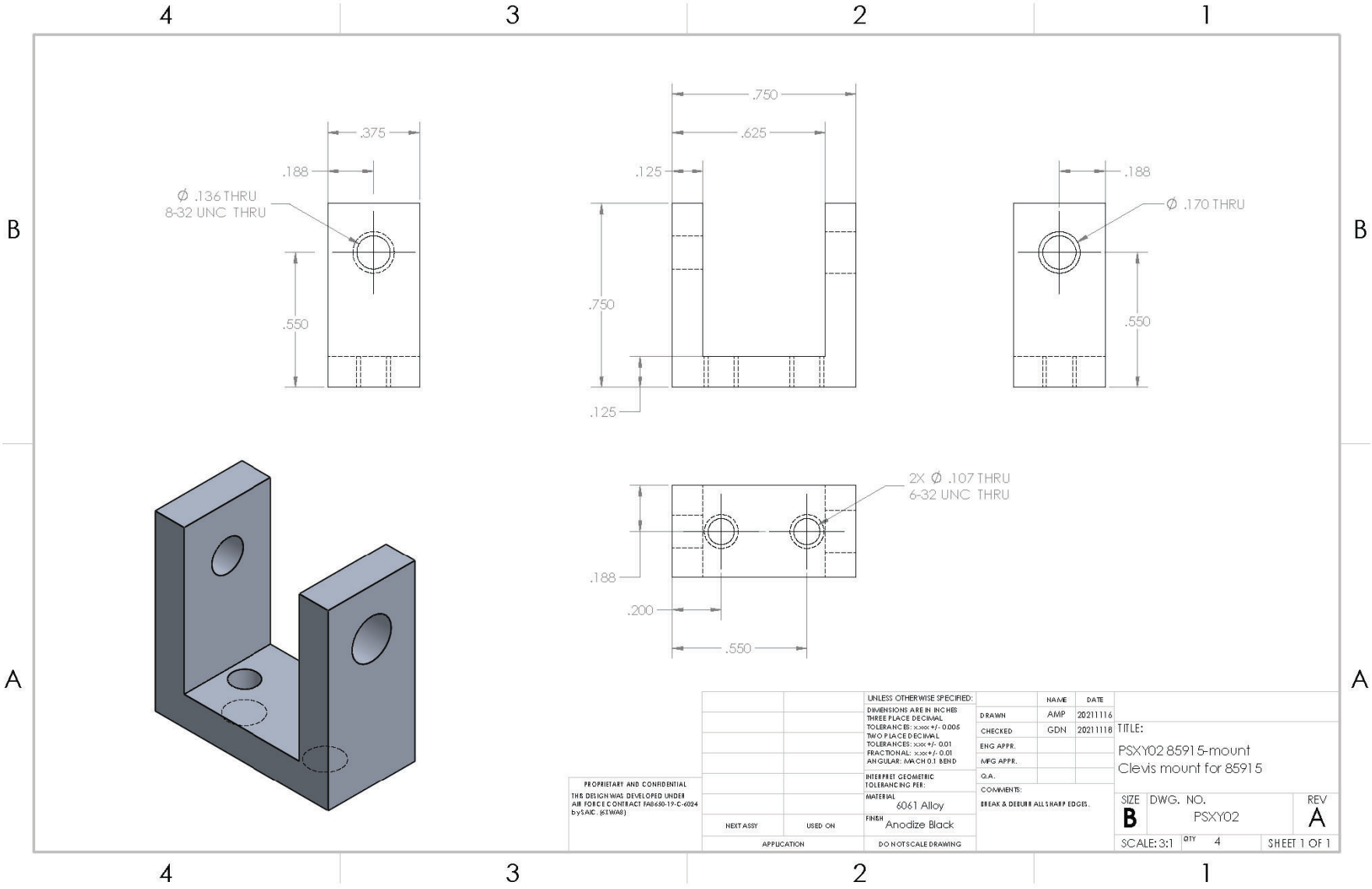

Figure 29: PSXY02 85915-mount

A.3 Rotation Axis

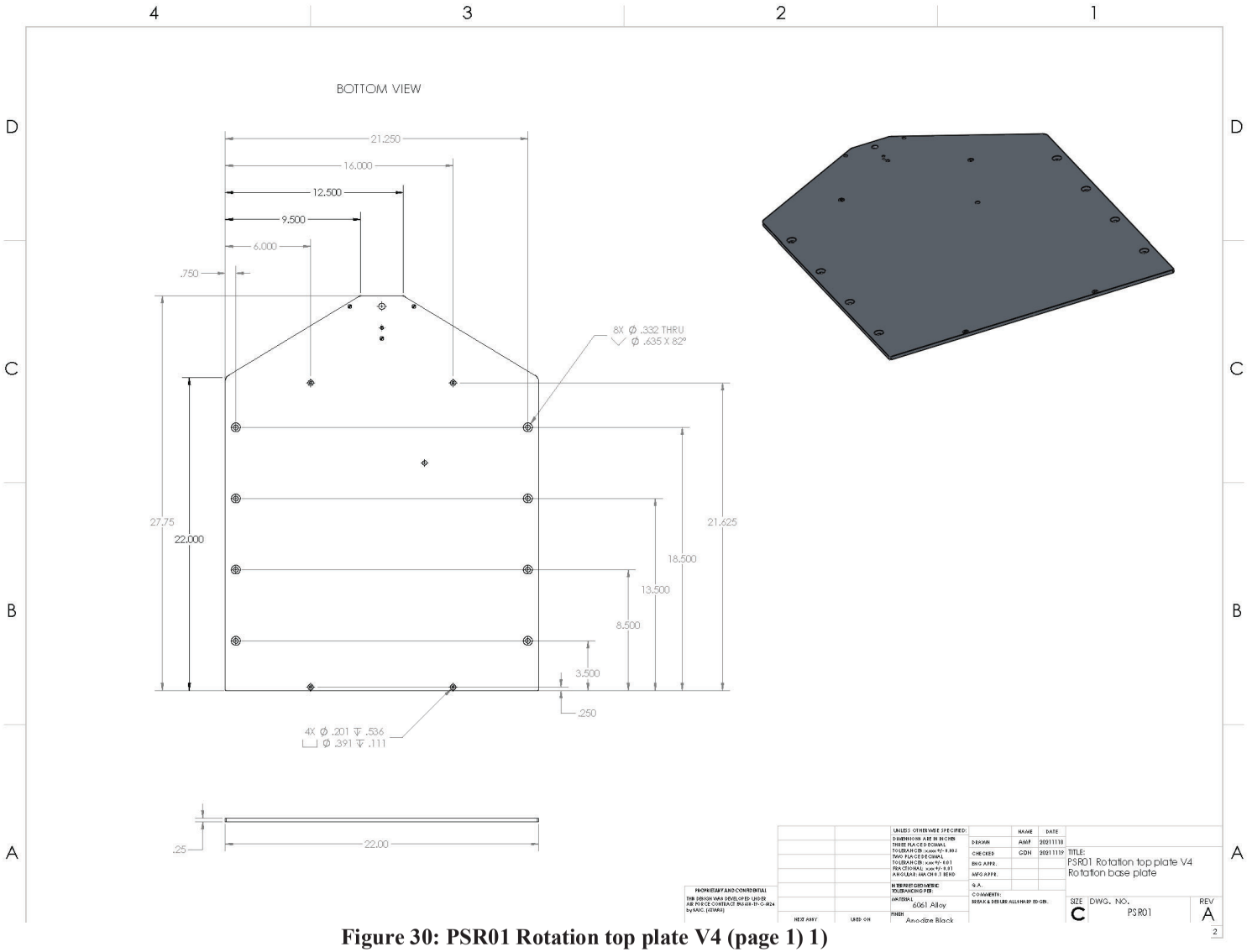

Figure 30: PSR01 Rotation top plate V4 (page 1) 1)

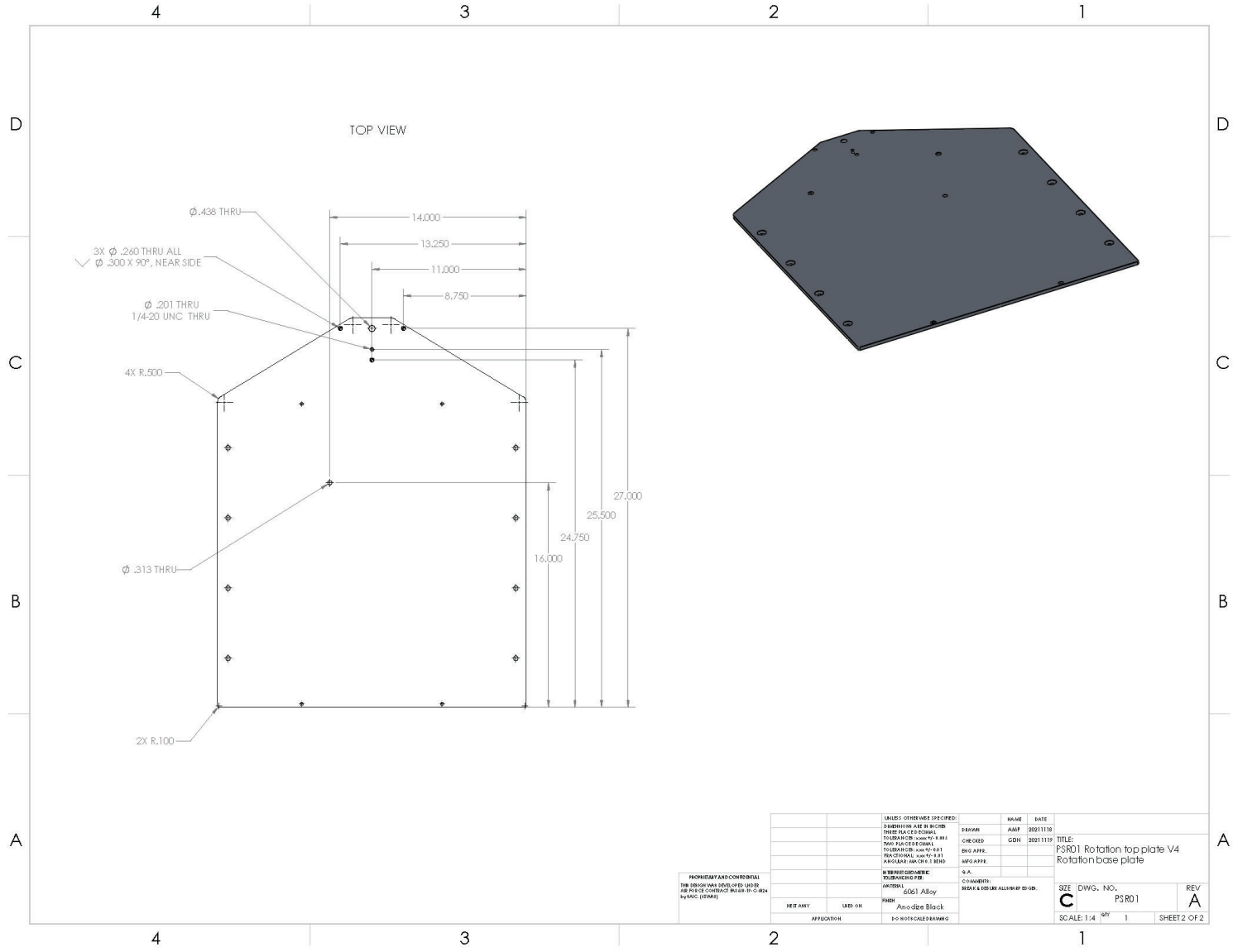

Figure 31: PSR01 Rotation top plate V4 (page 2)

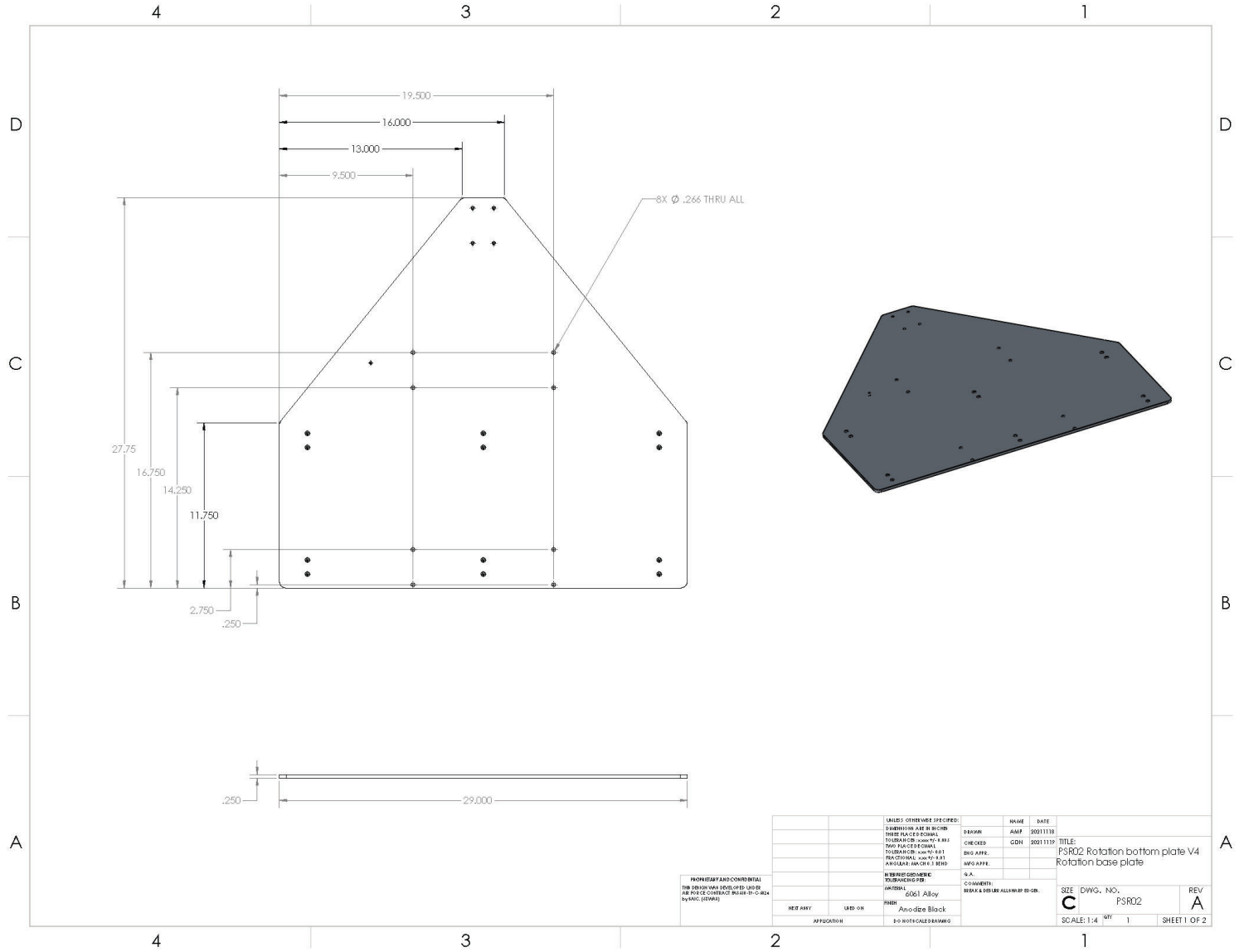

Figure 32: PSR02 Rotation bottom plate V4 (page 1)

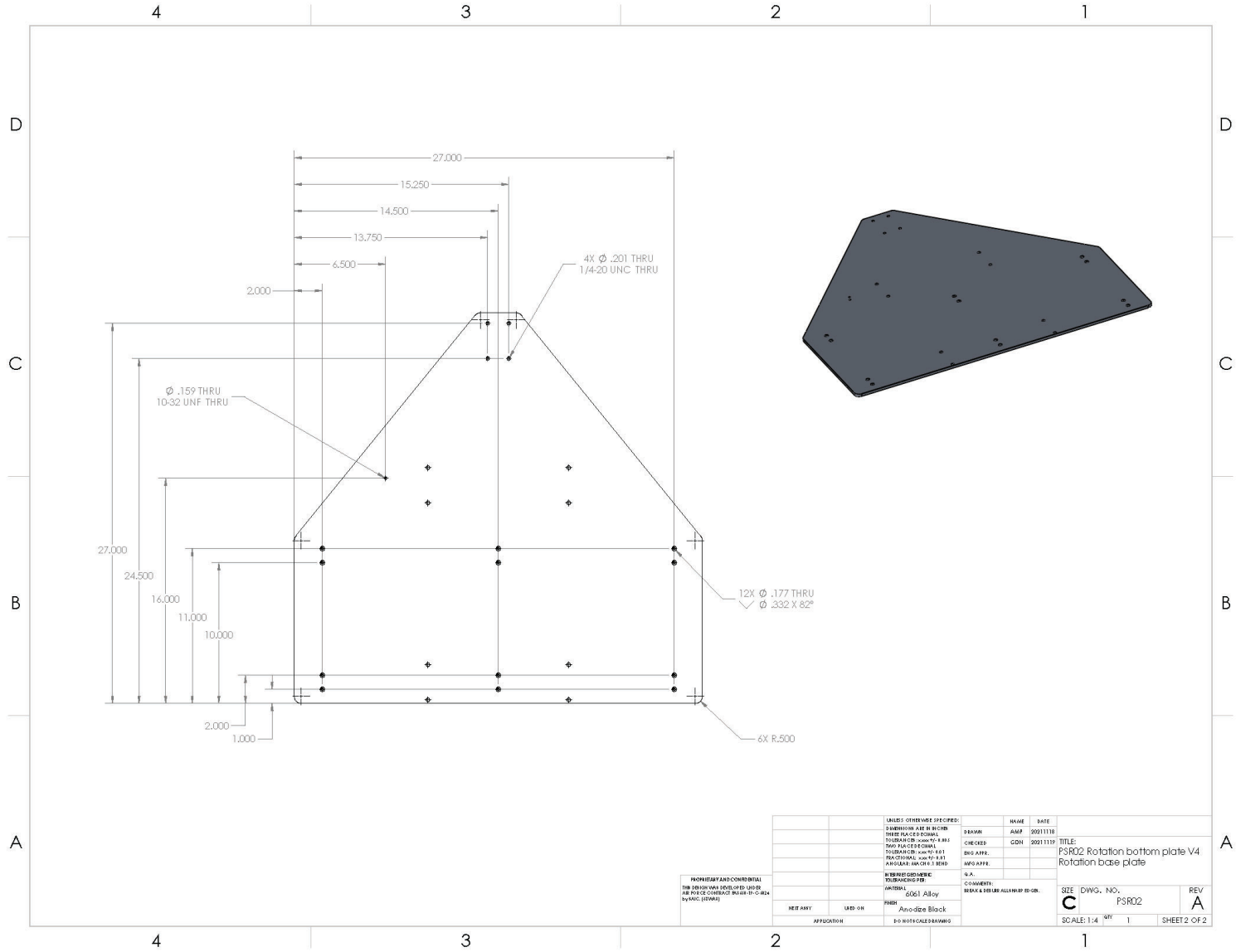

Figure 33: PSR02 Rotation bottom plate V4 (page 2)

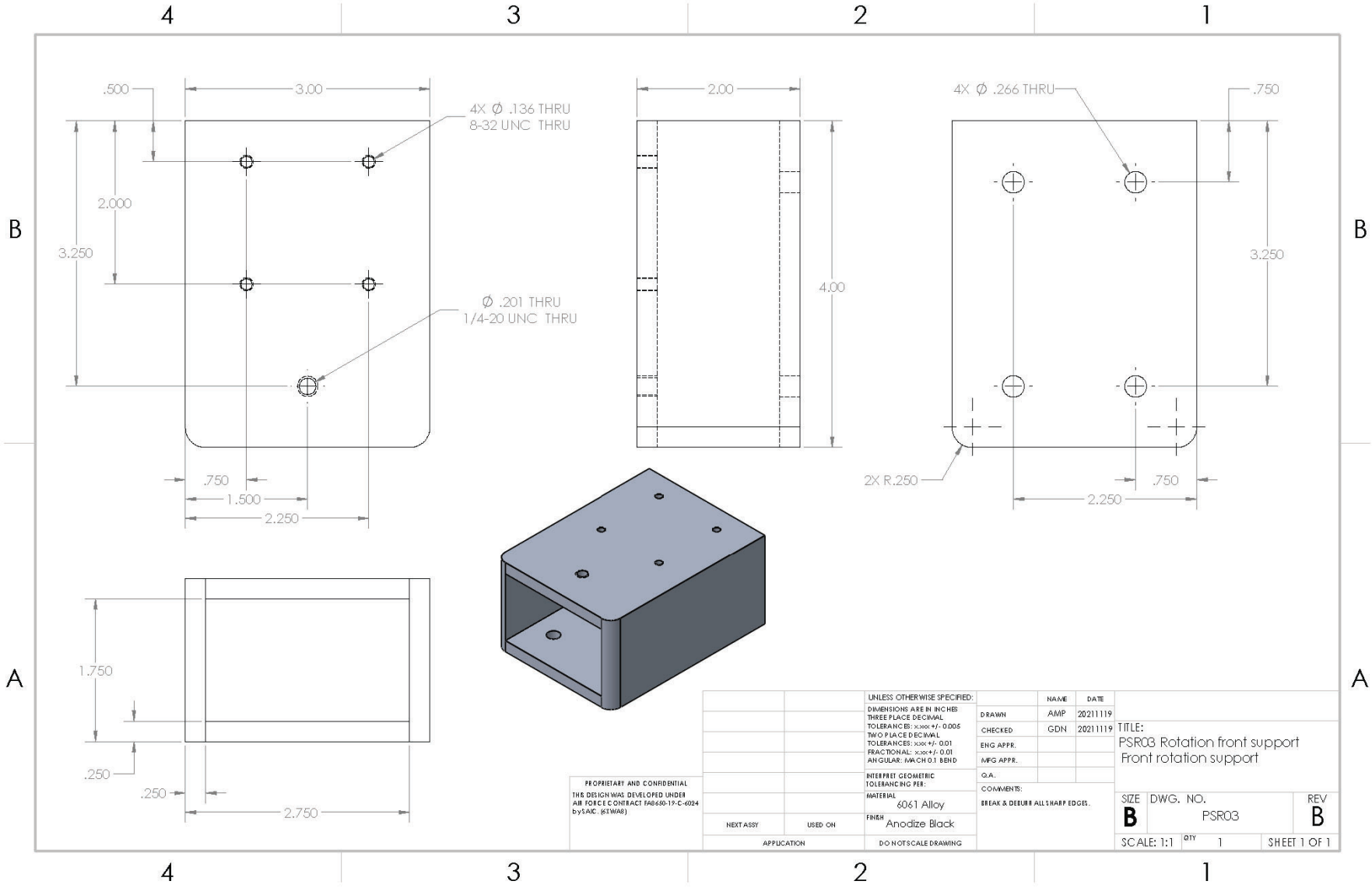

Figure 34: PSR03 Rotation front support

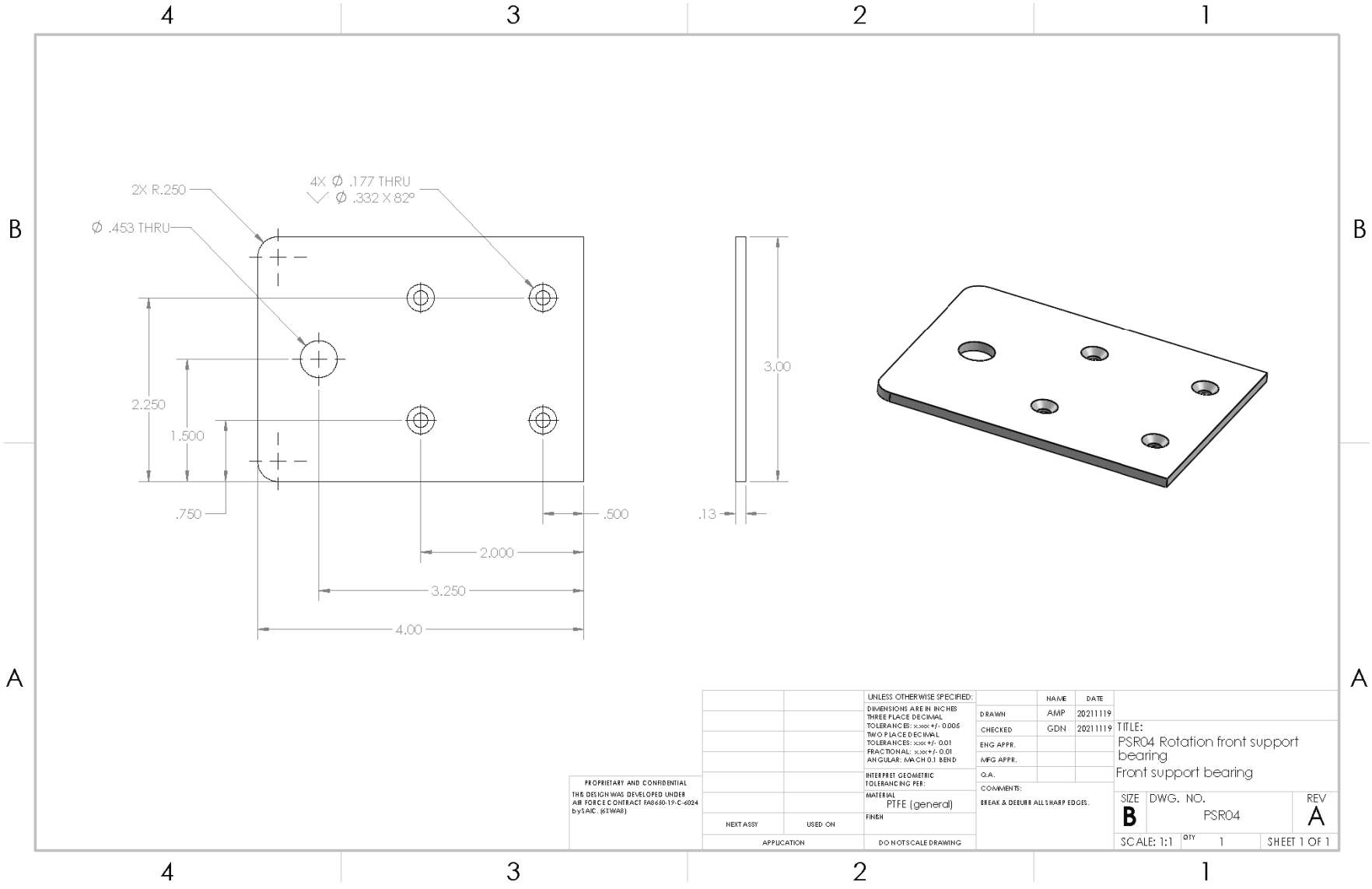

Figure 35: PSR04 Rotation front support bearing

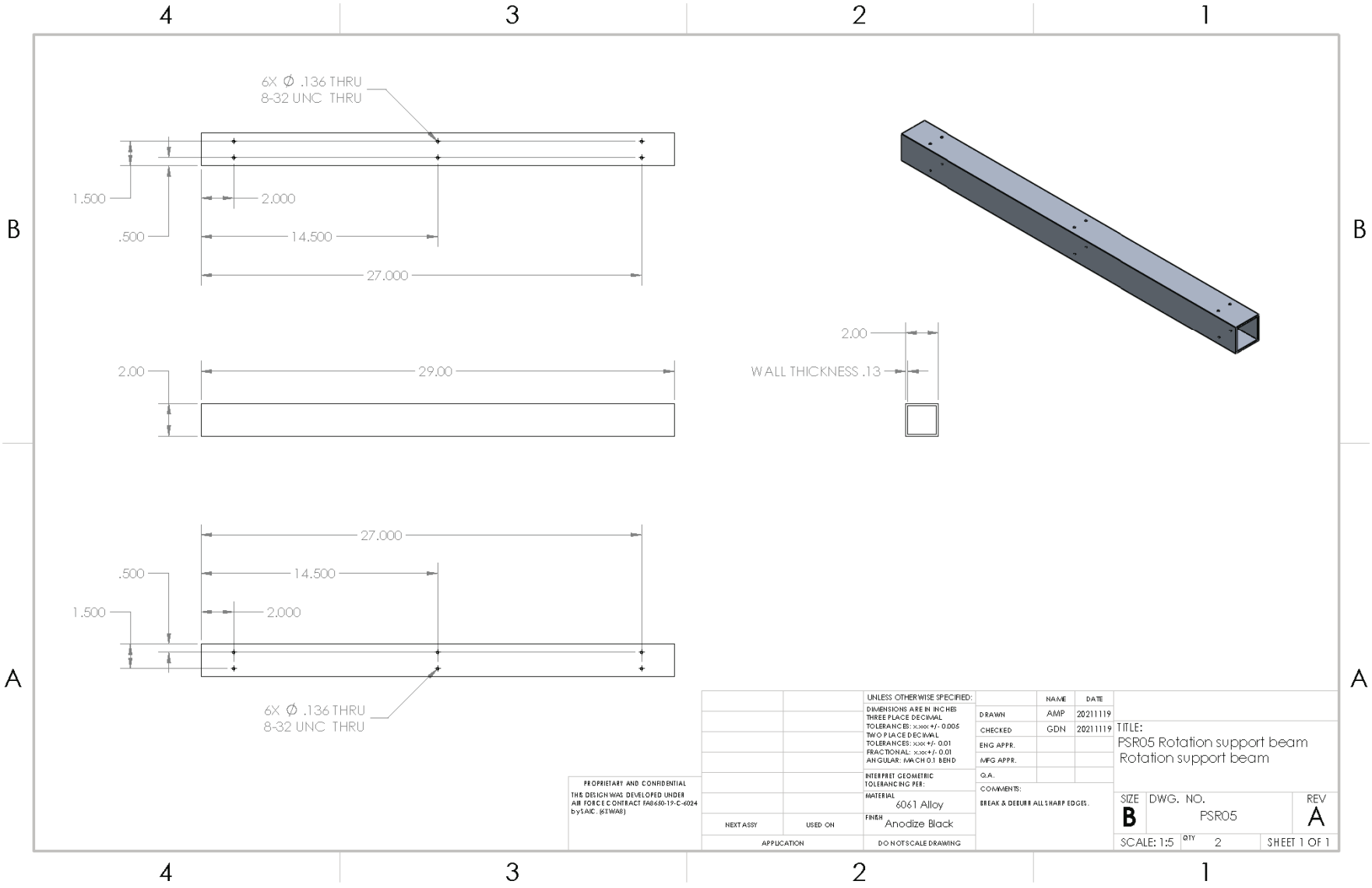

Figure 36: PSR05 Rotation support beam

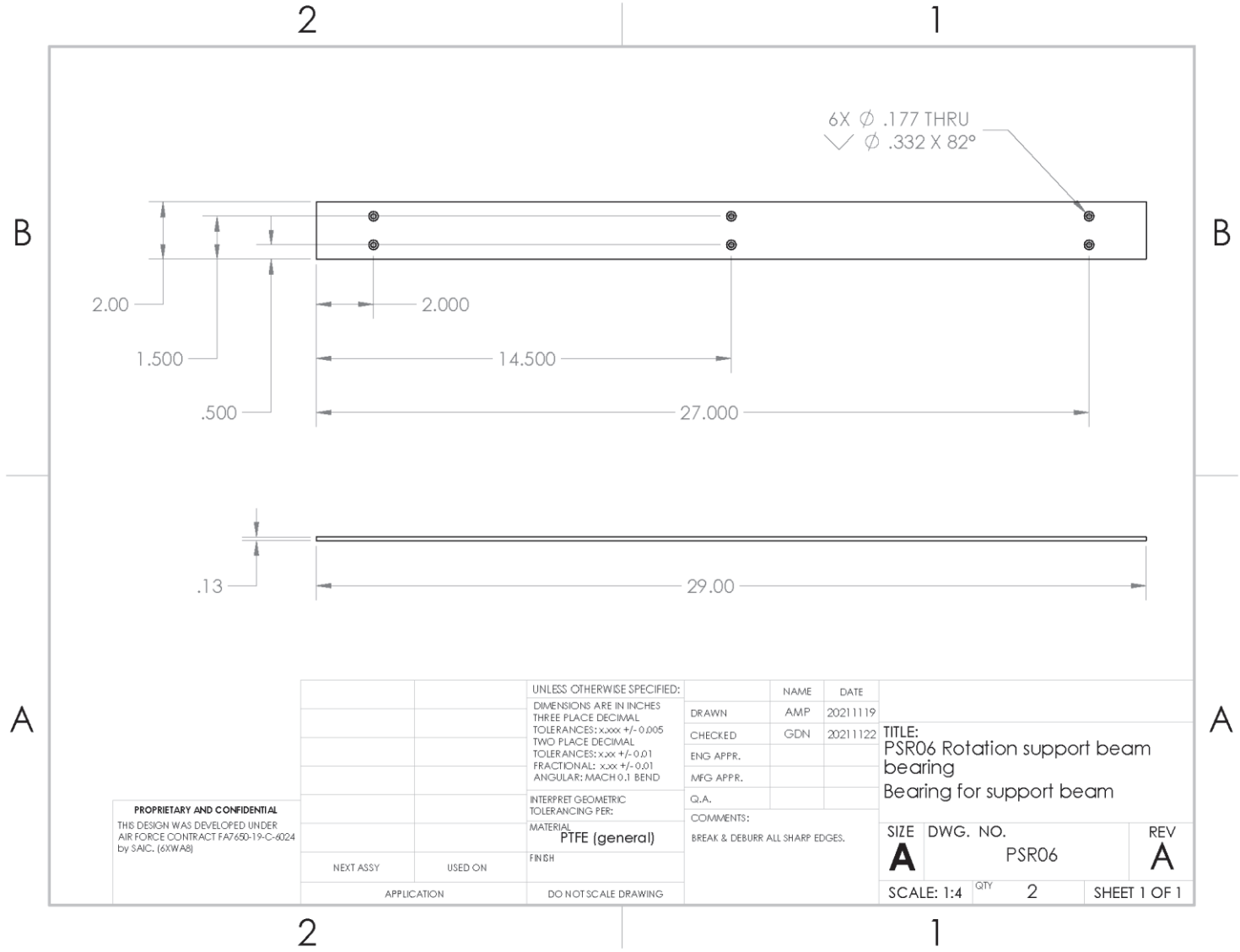

Figure 37: PSR06 Rotation support beam bearing

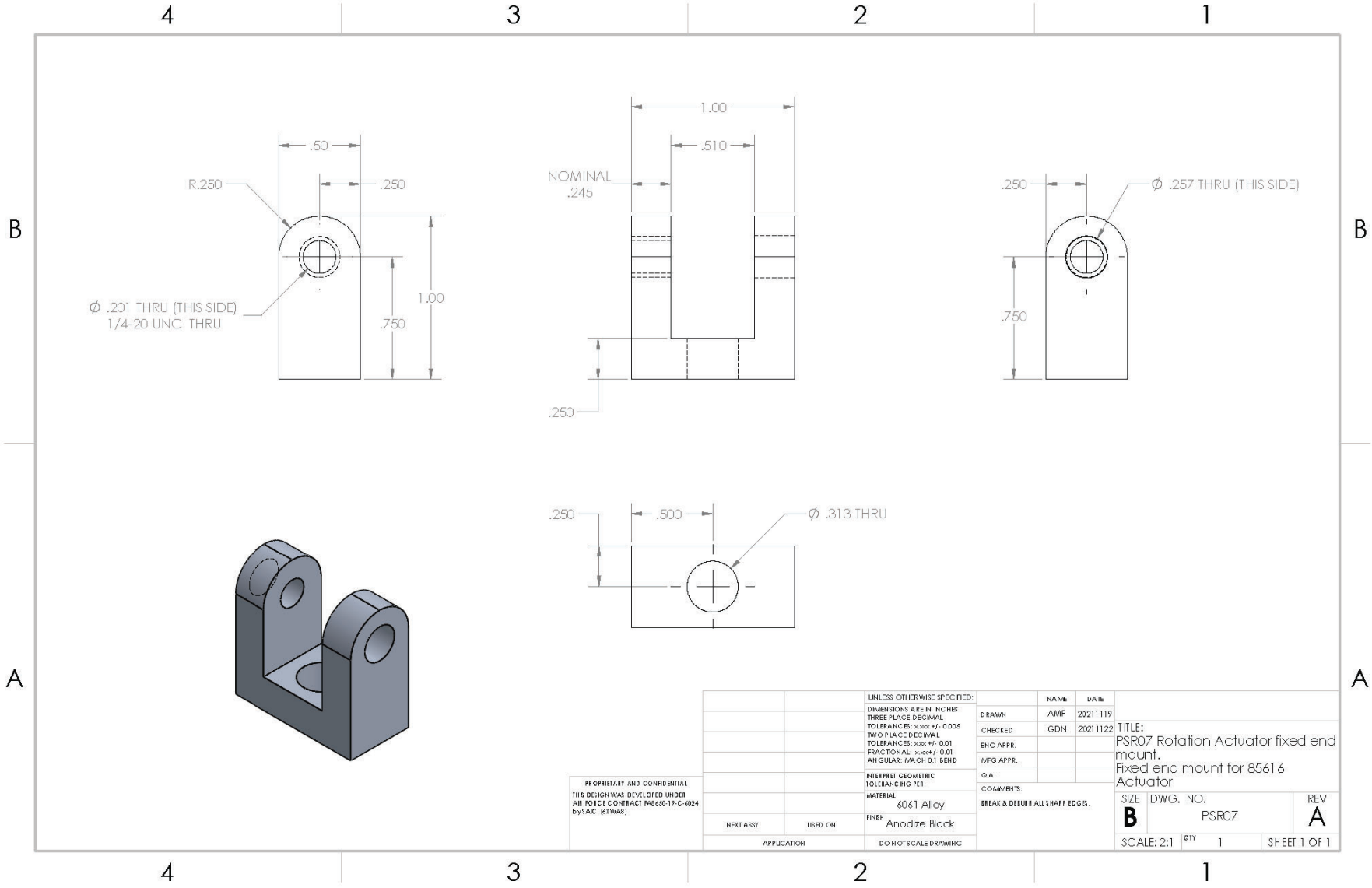

Figure 38: PSR07 Rotation Actuator fixed end mount

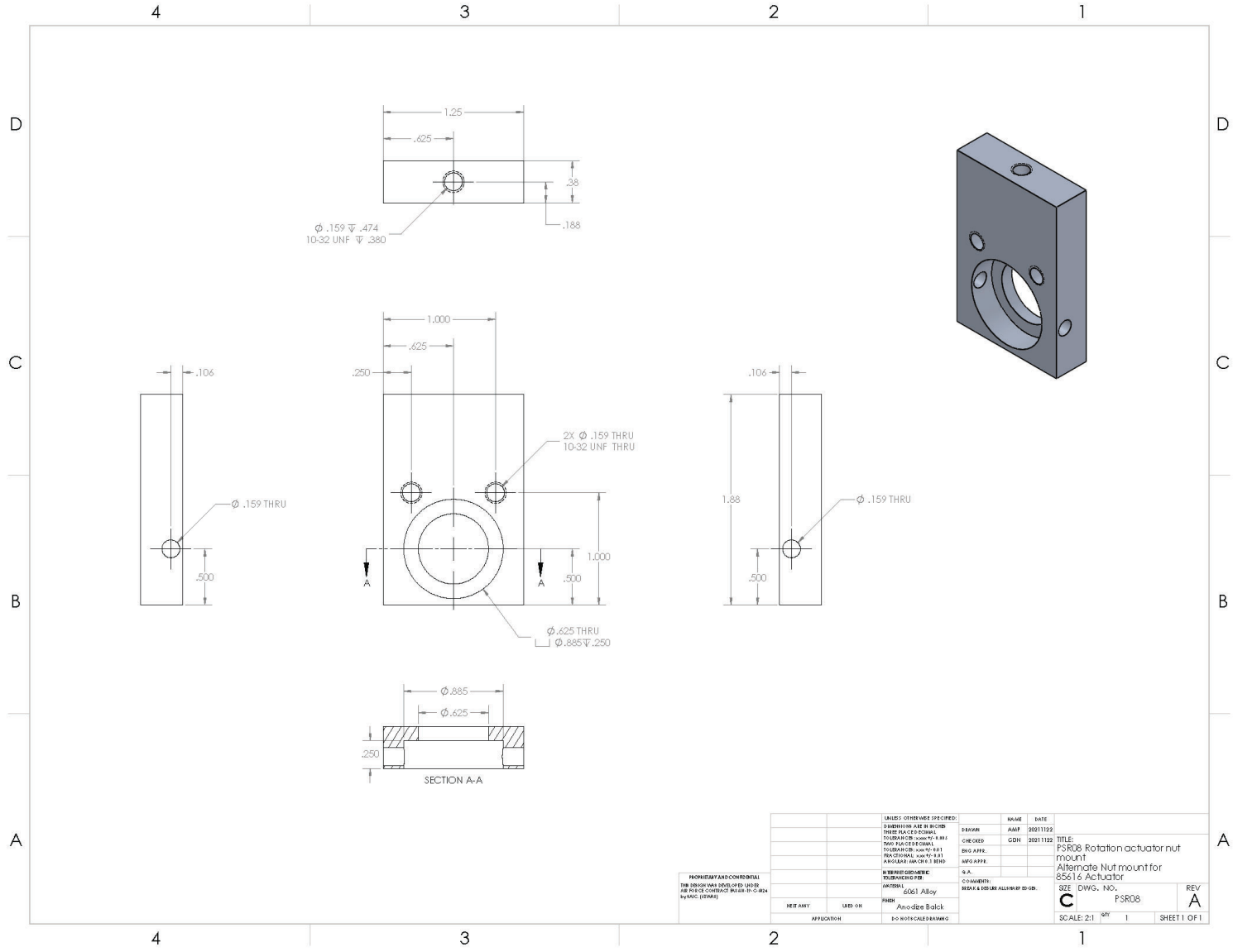

Figure 39: PSR08 Rotation actuator nut mount

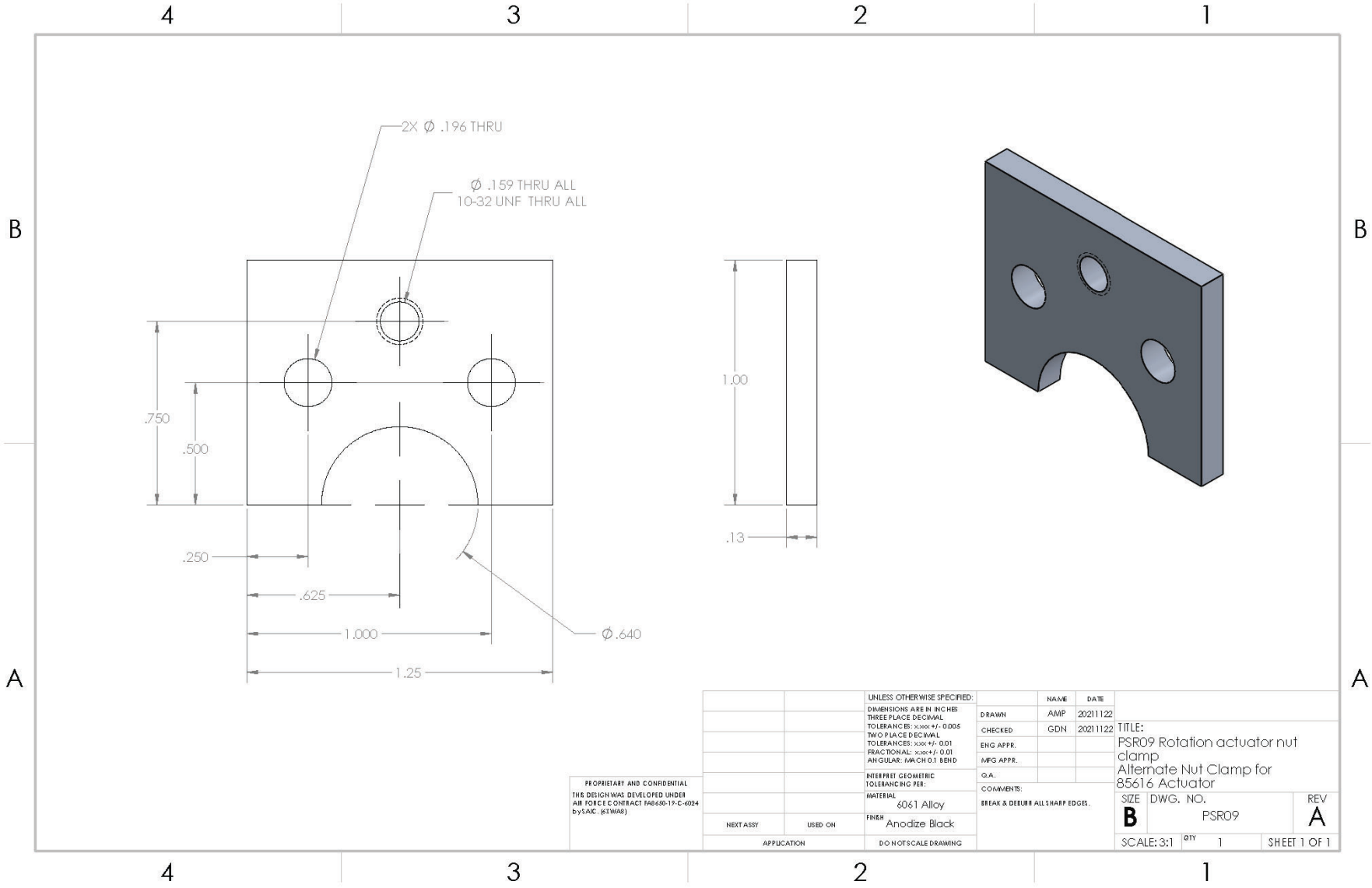

Figure 40: PSR09 Rotation actuator nut clamp

A.4 Roll Axis

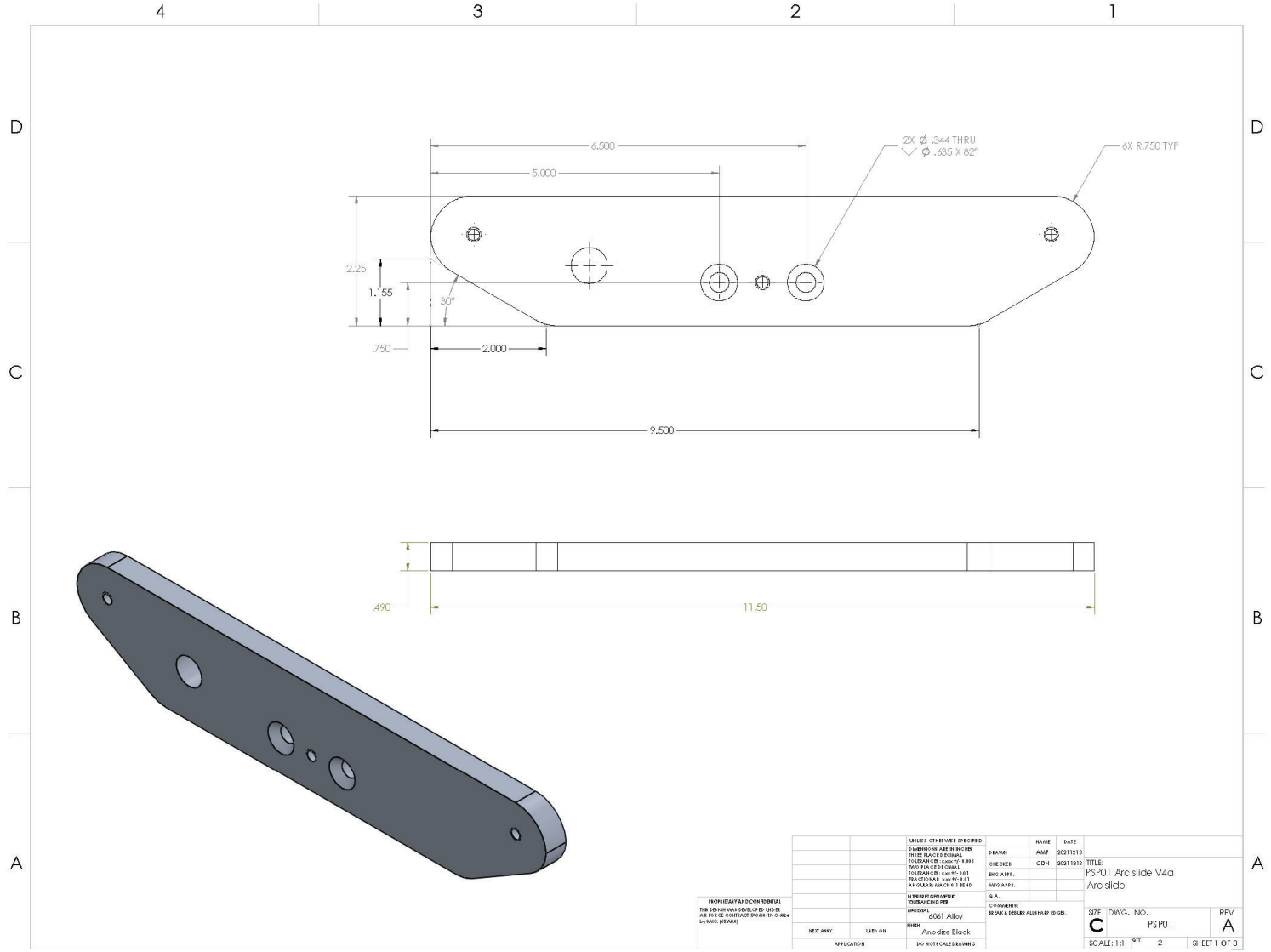

Figure 41: PSP01 Arc slide V4a (page 1)

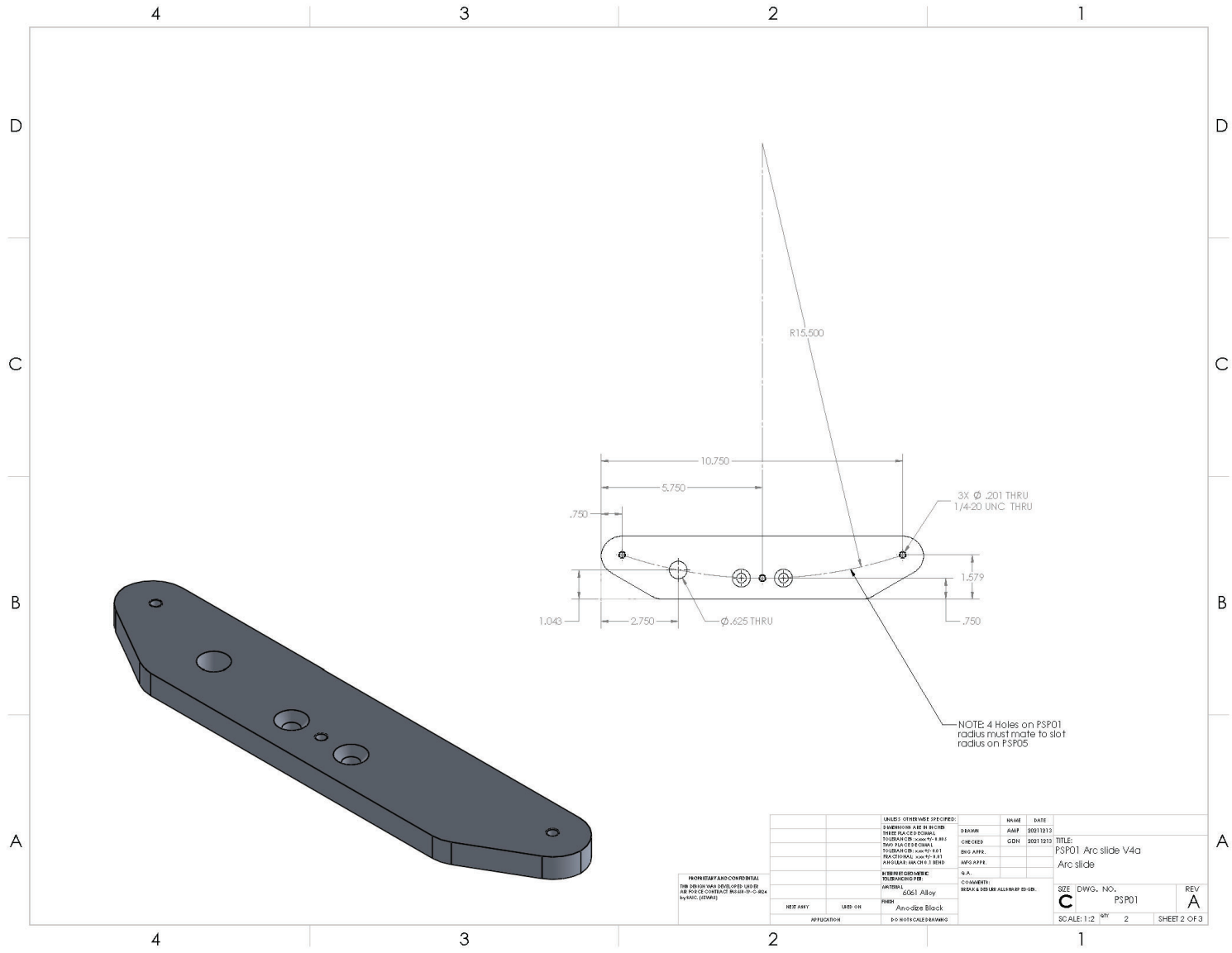

Figure 42: PSP01 Arc slide V4a (page 2)

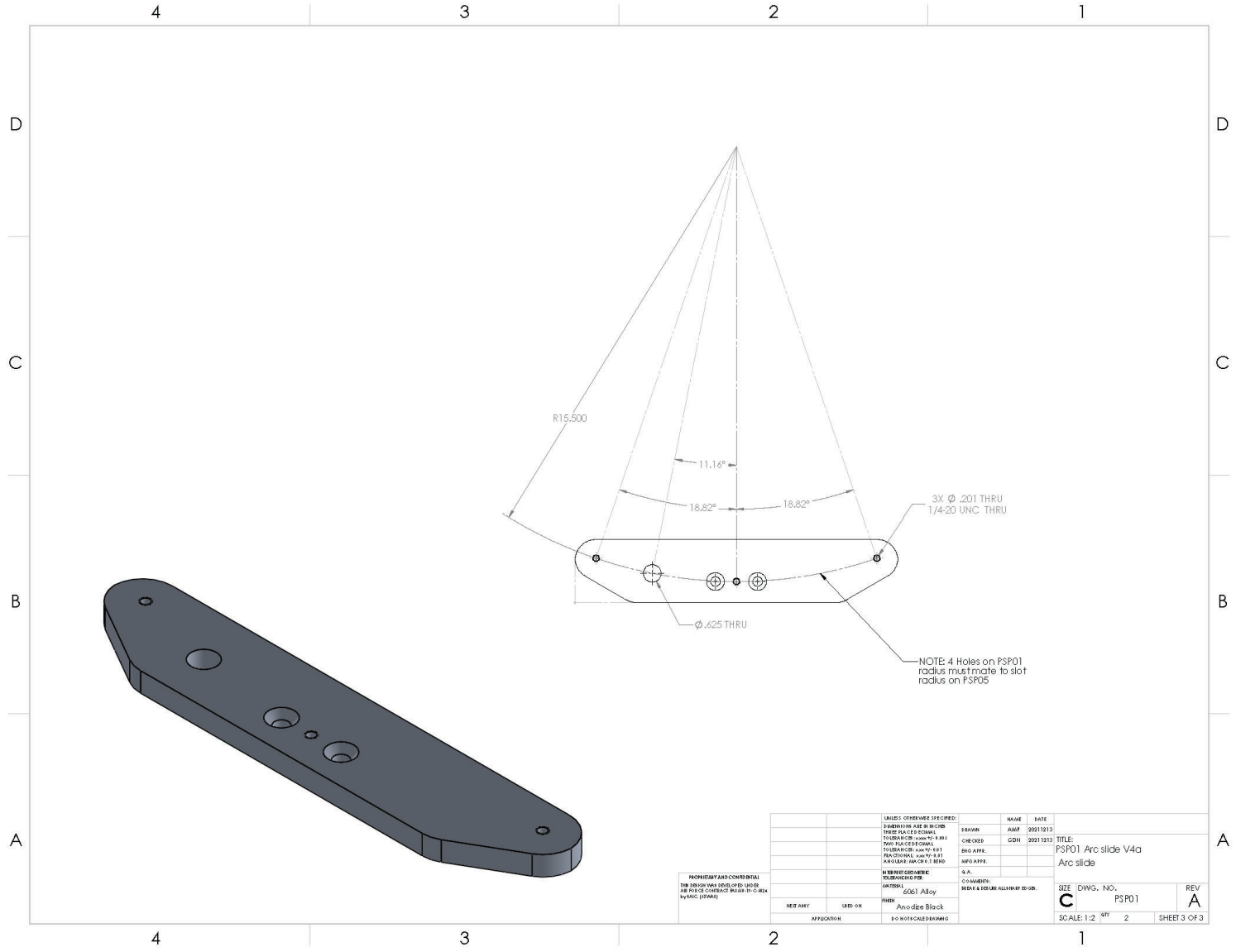

Figure 43: PSP01 Arc slide V4a (page 3)

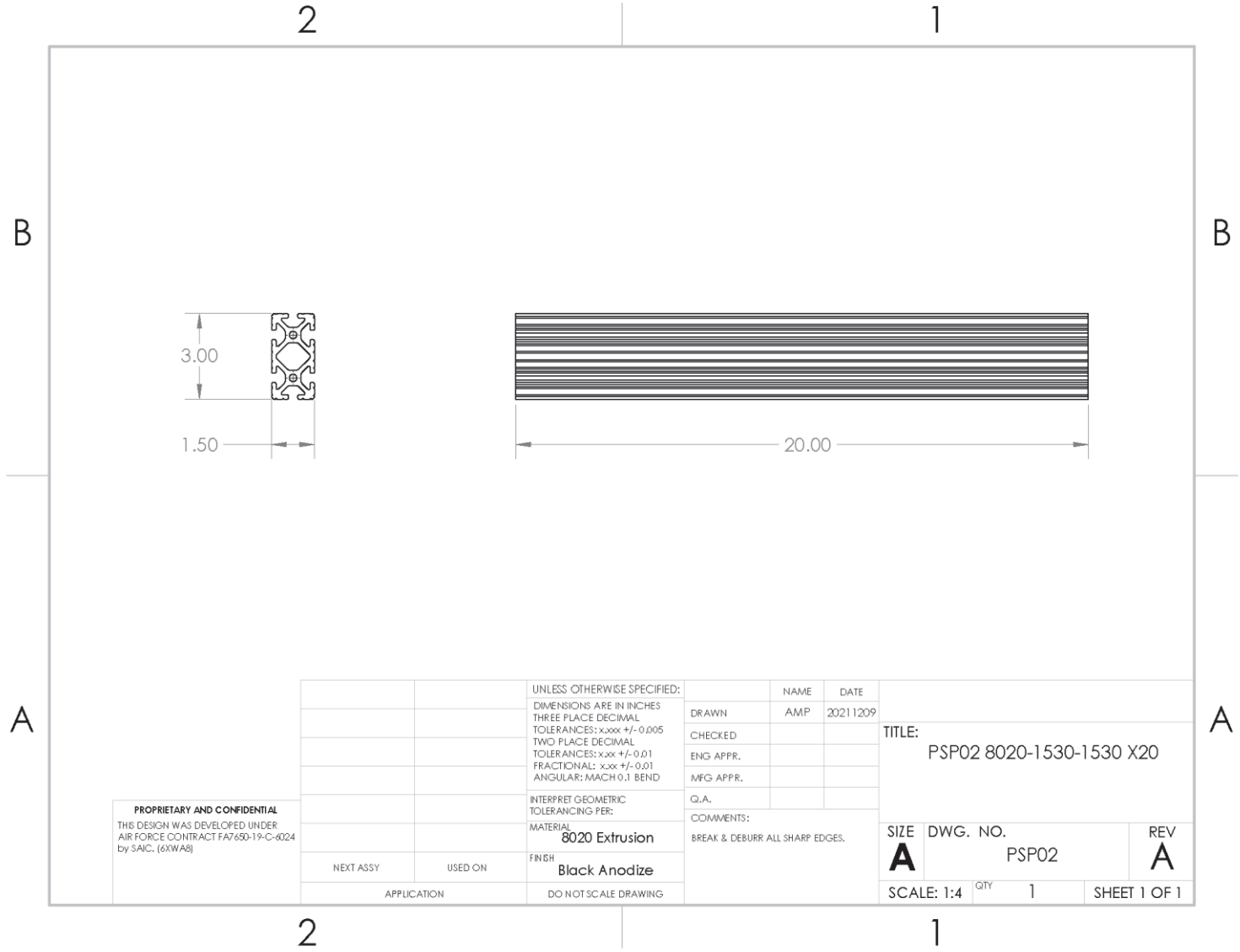

Figure 44: PSP02 8020-1530-1530 X 20

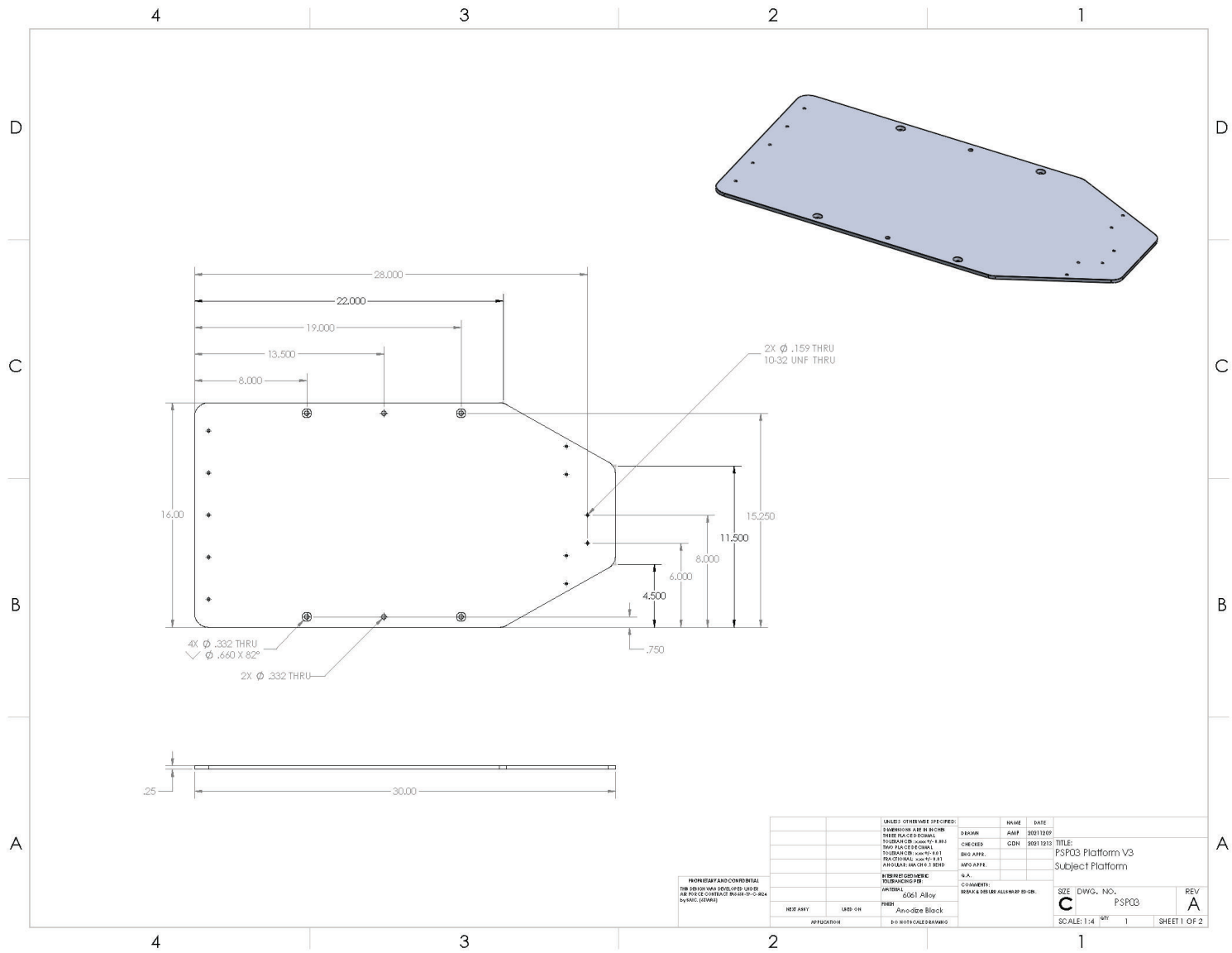

Figure 45: PSP03 Platform V3 (page 1)

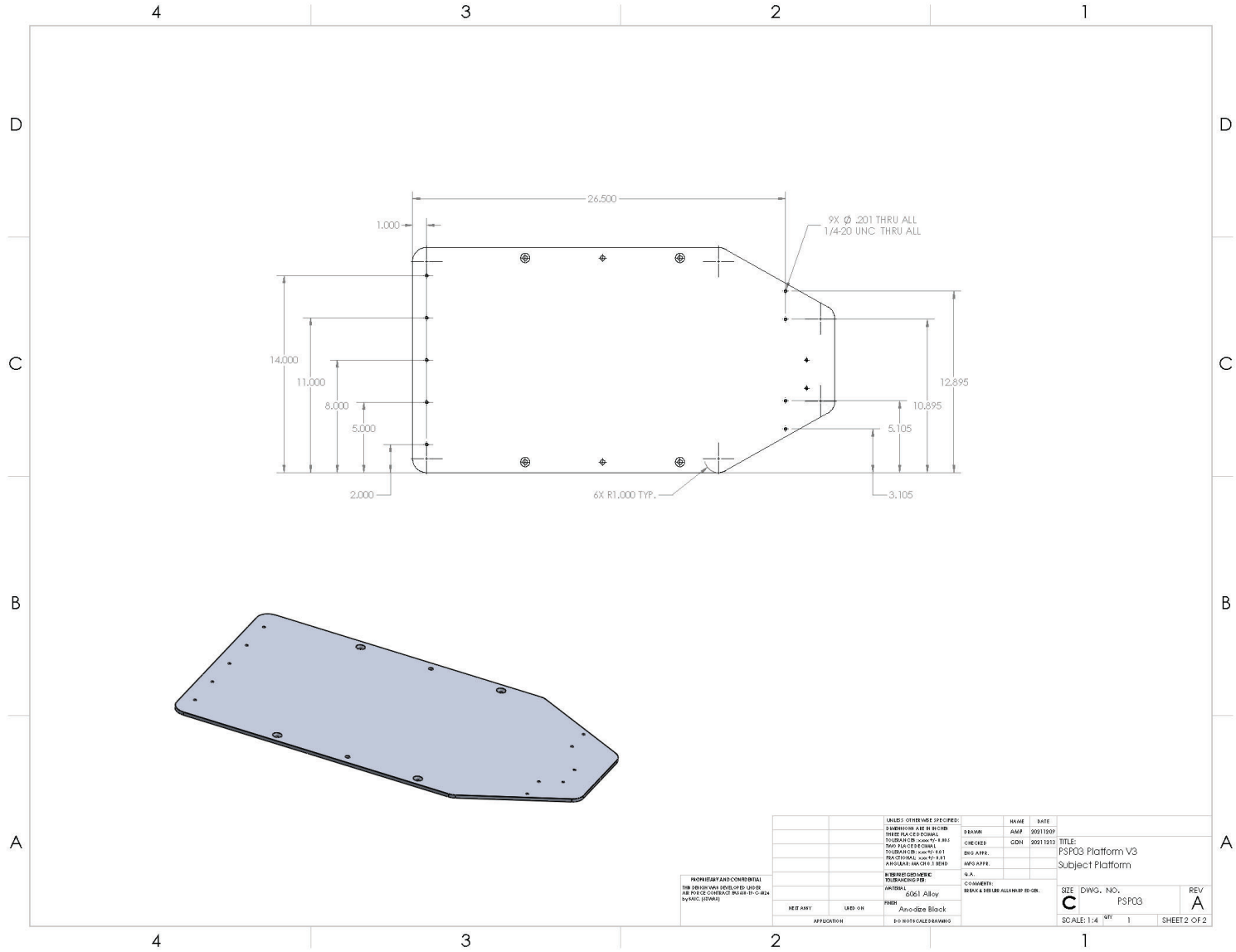

Figure 46: PSP03 Platform V3 (page 2)

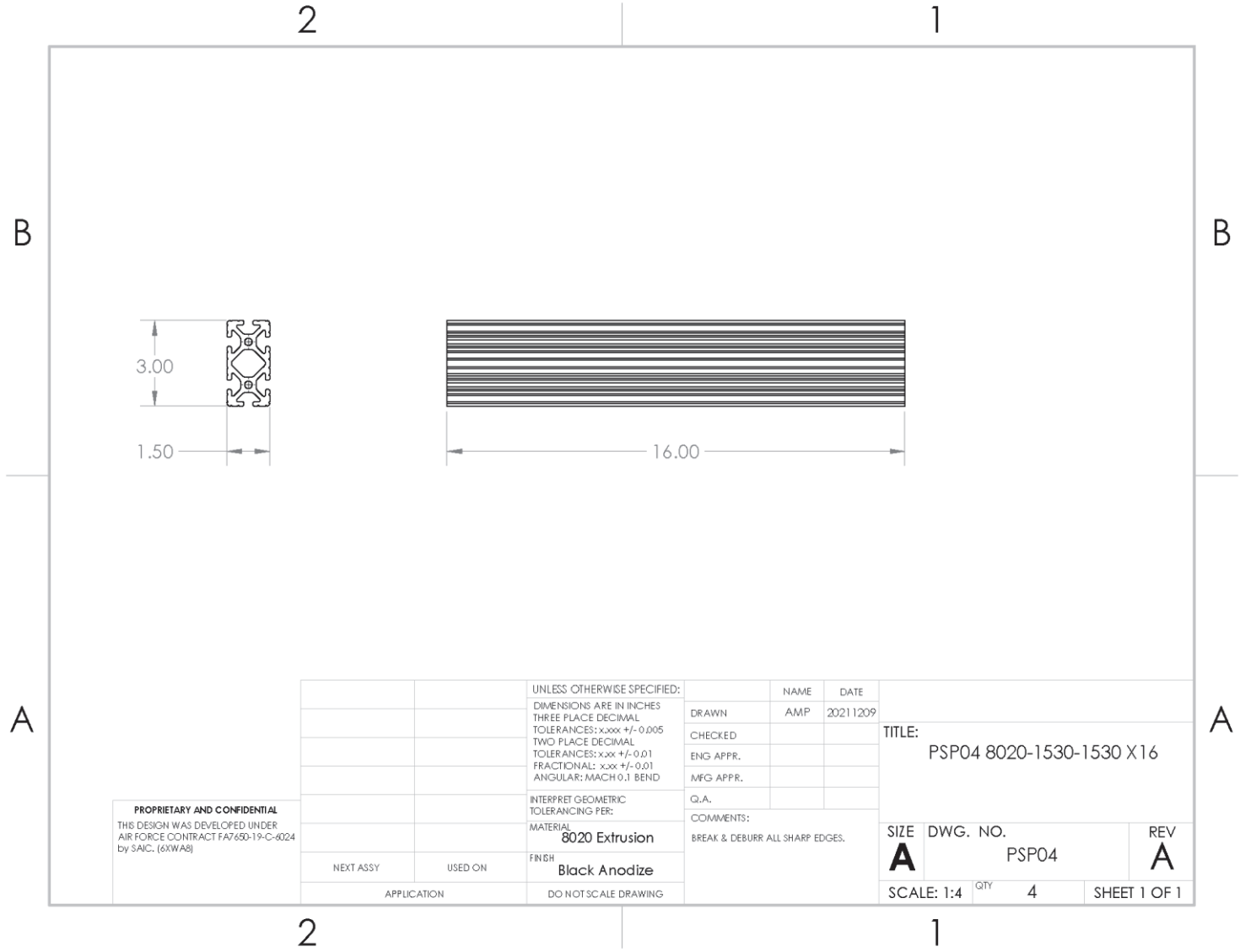

Figure 47: PSP04 8020-1530-1530 X 16

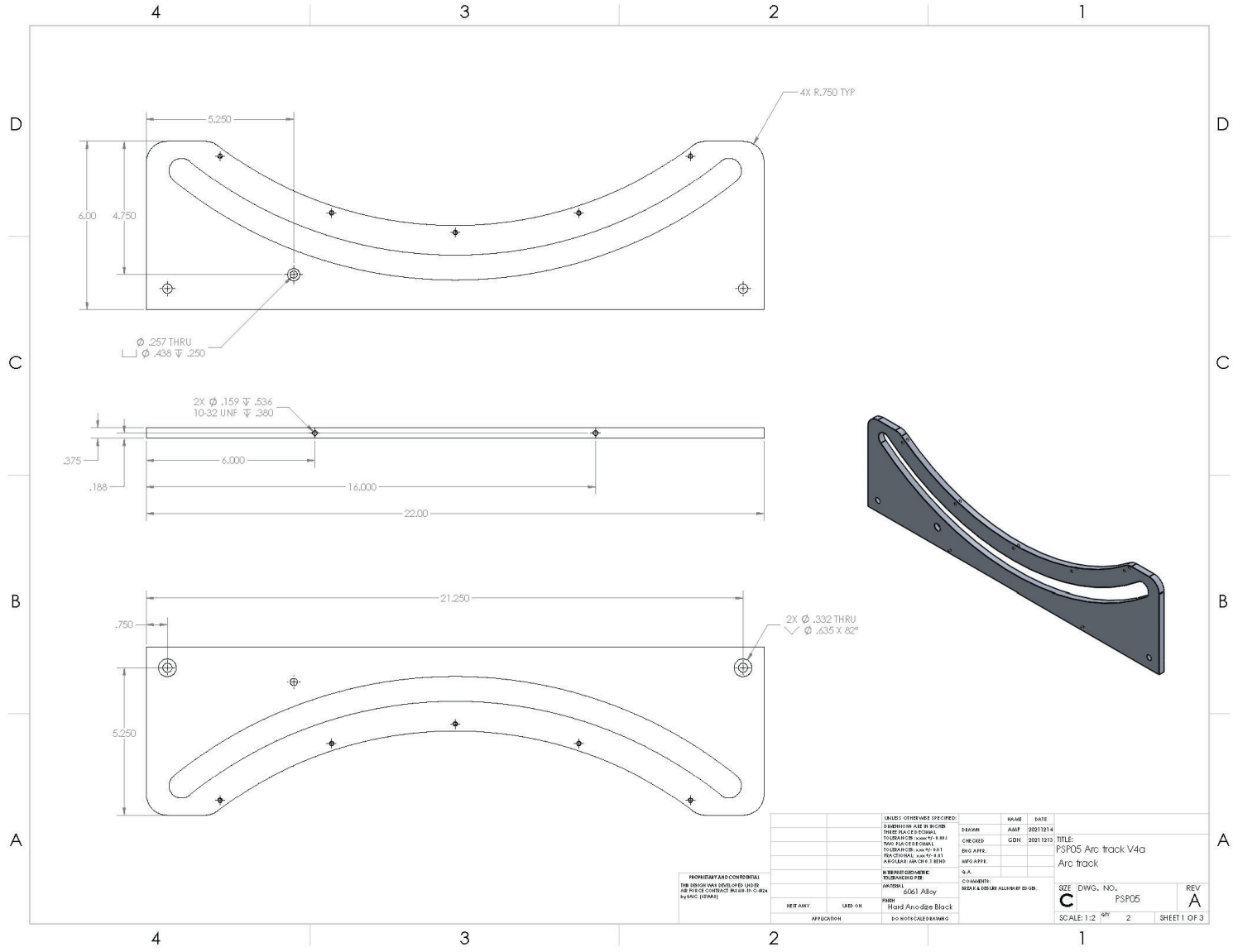

Figure 48: PSP05 Arc track V4a (page 1)

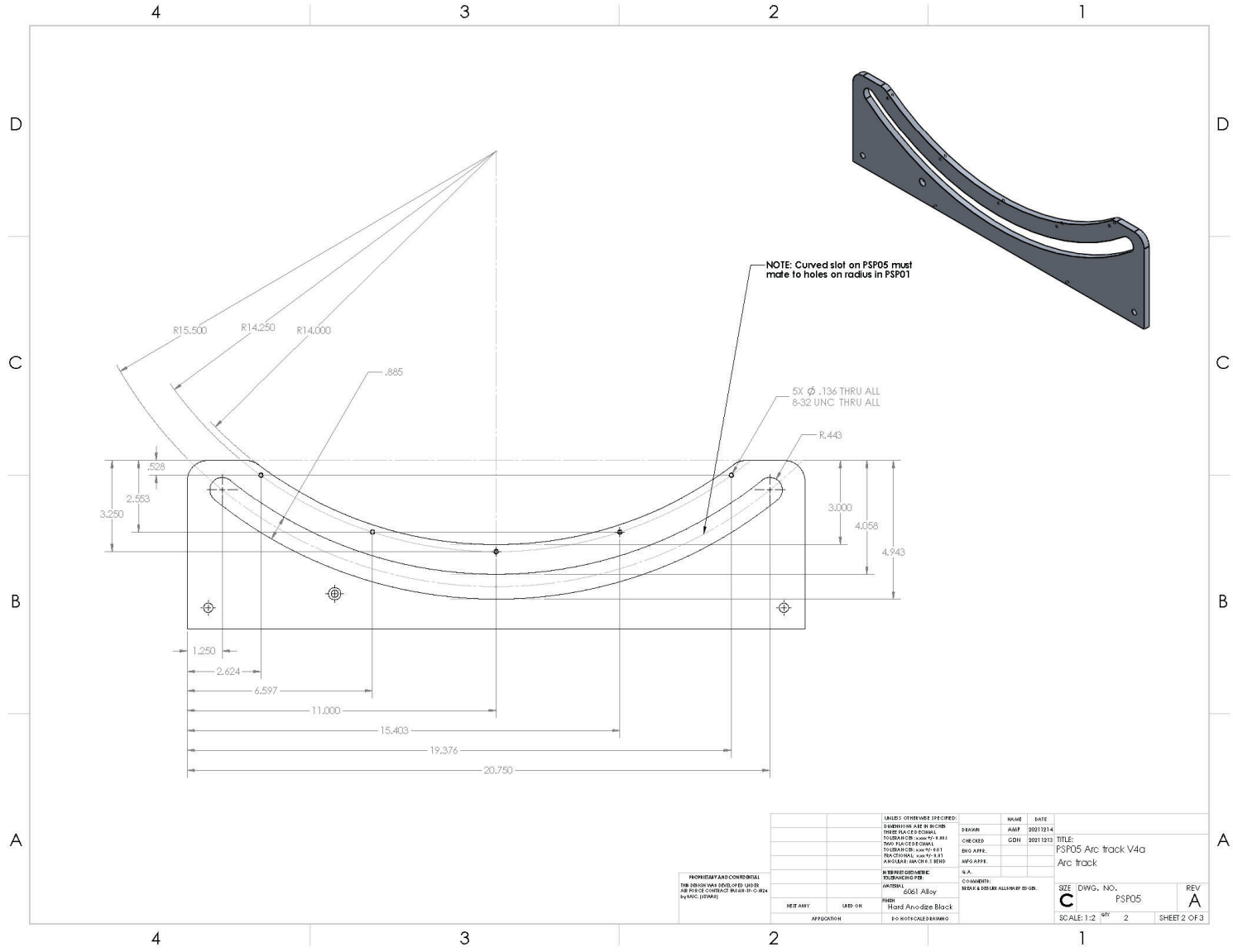

Figure 49: PSP05 Arc track V4a (page 2)

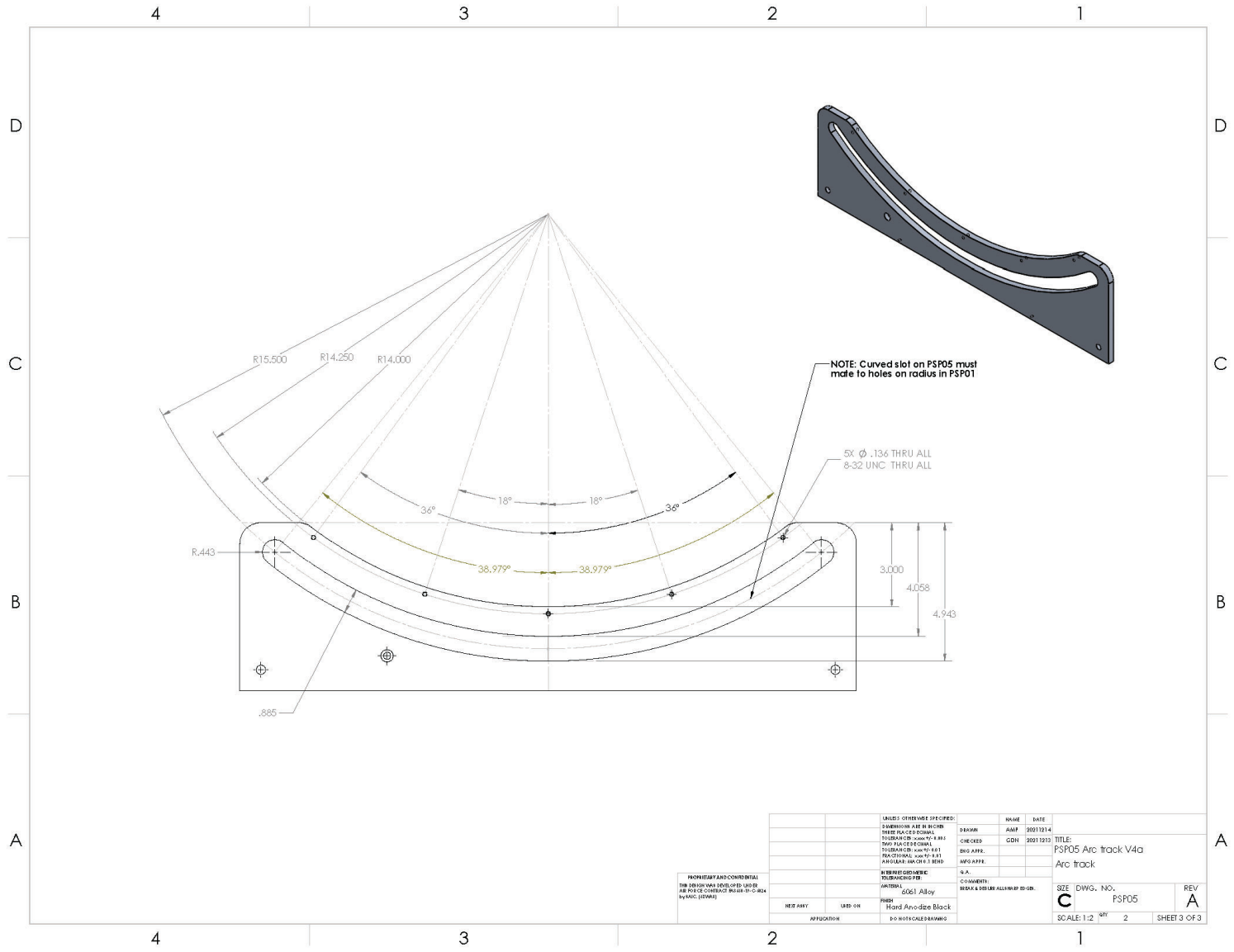

Figure 50: PSP05 Arc track V4a (page 3)

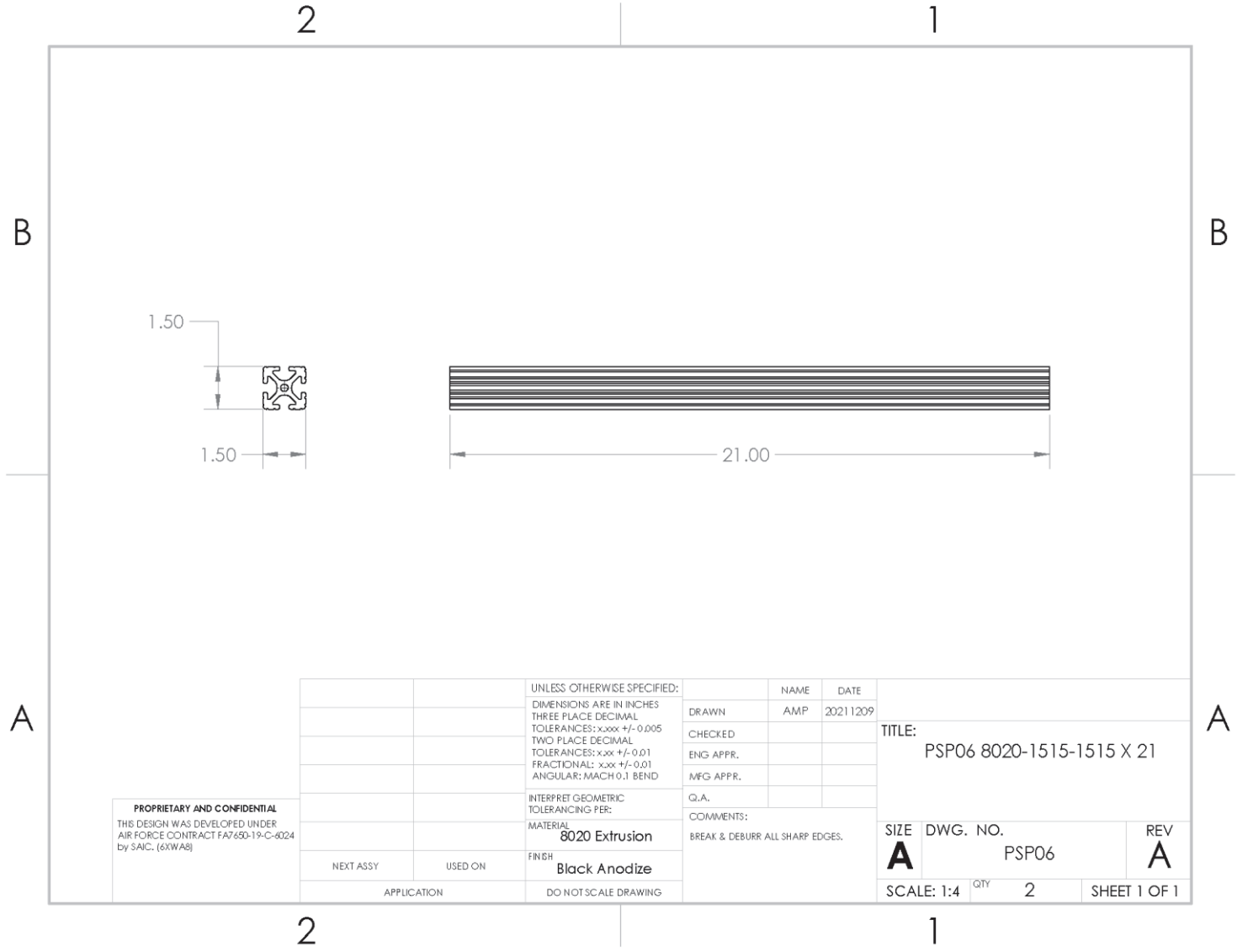

Figure 51: PSP06 8020-1515-1515 X 21

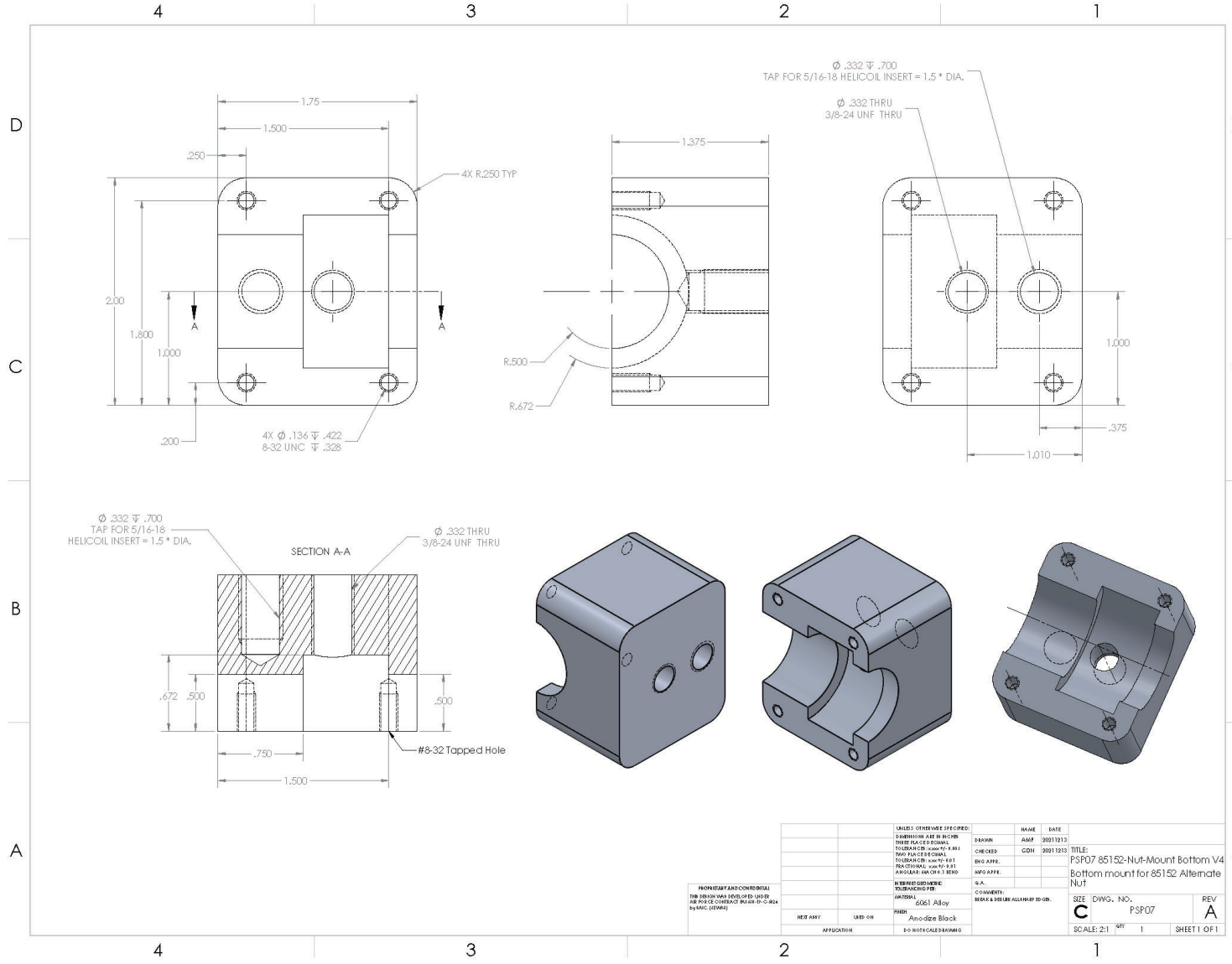

Figure 52: PSP07 85152-Nut-Mount Bottom V4

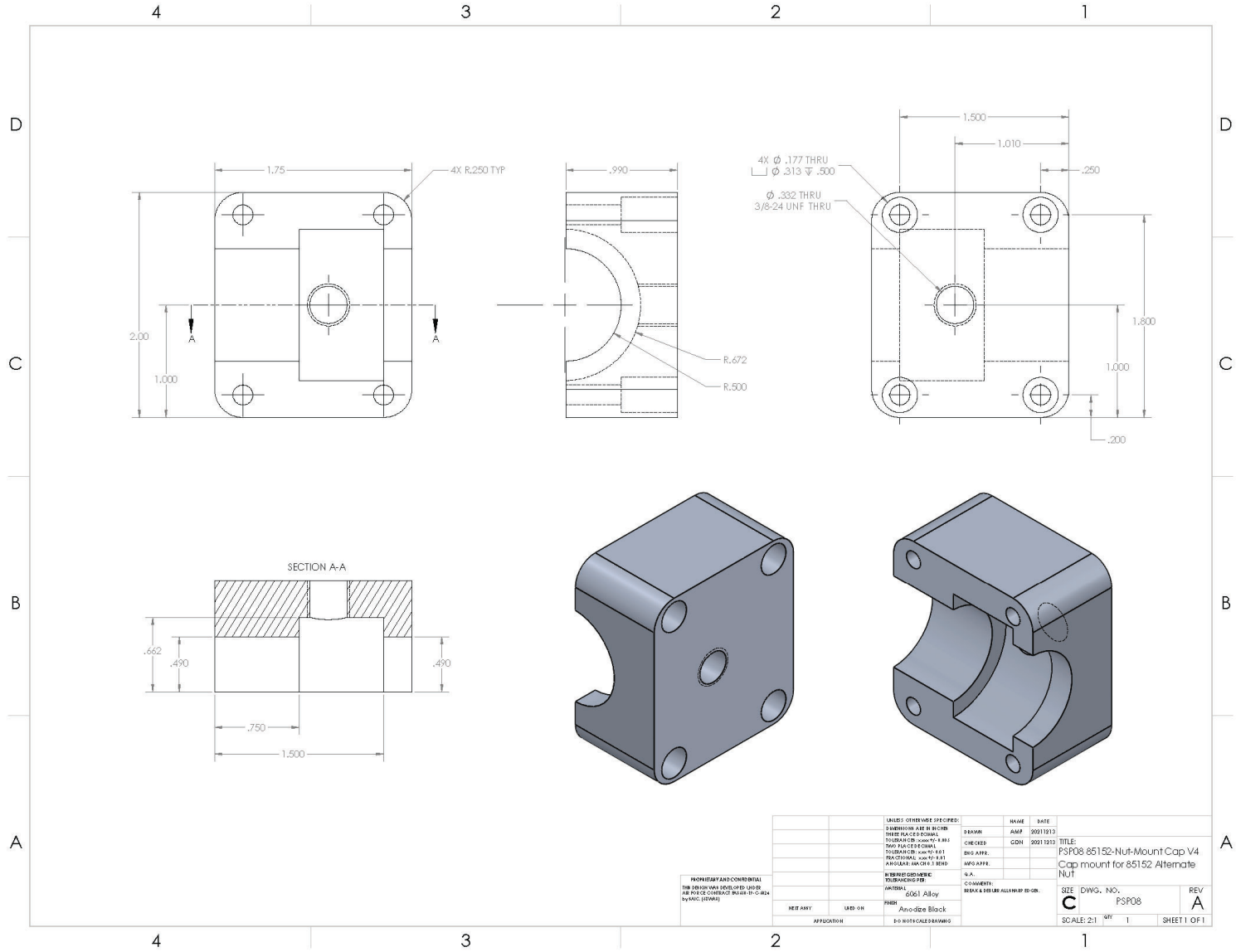

Figure 53: PSP08 85152-Nut-Mount Cap V4

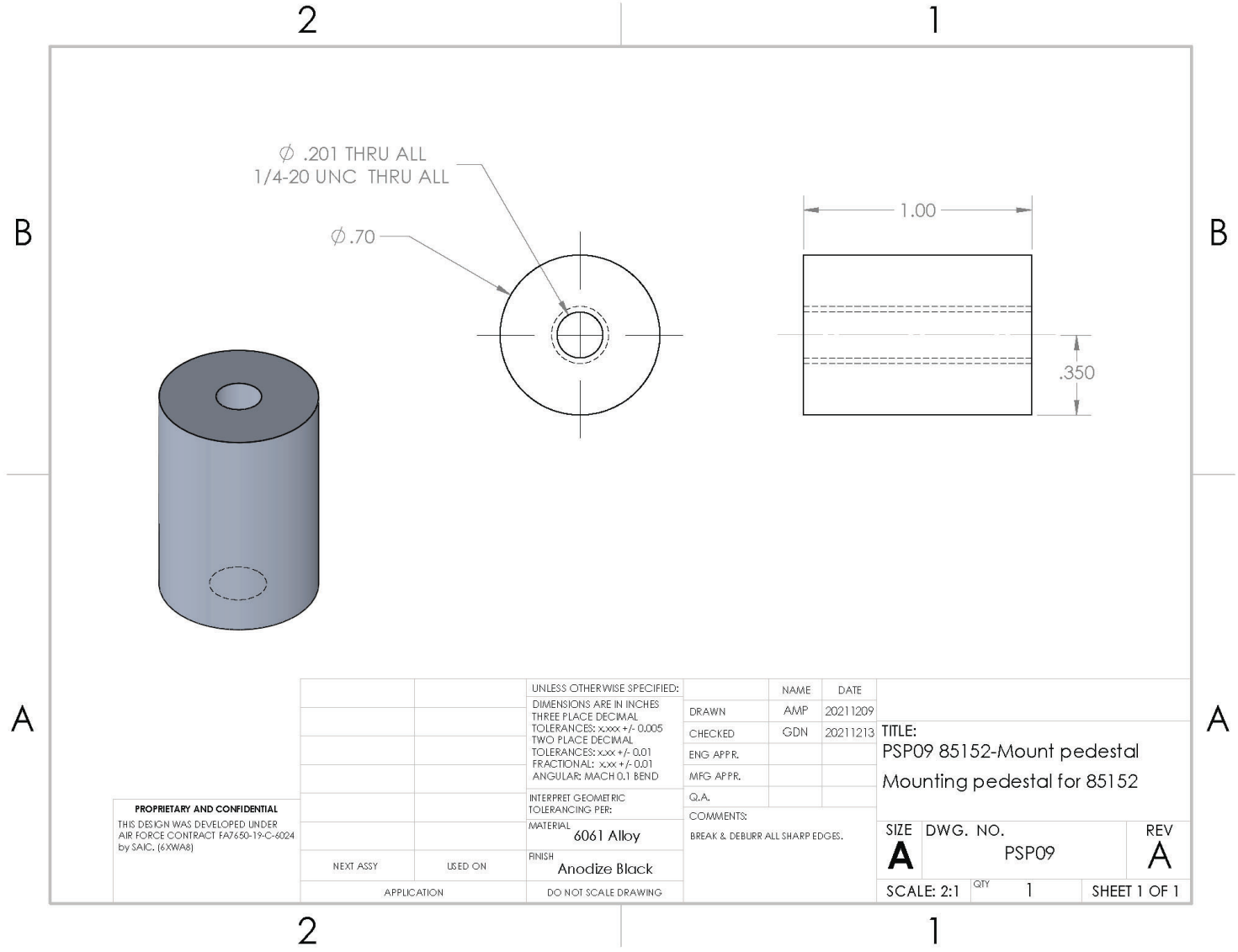

Figure 54: PSP09 85152-Mount pedestal

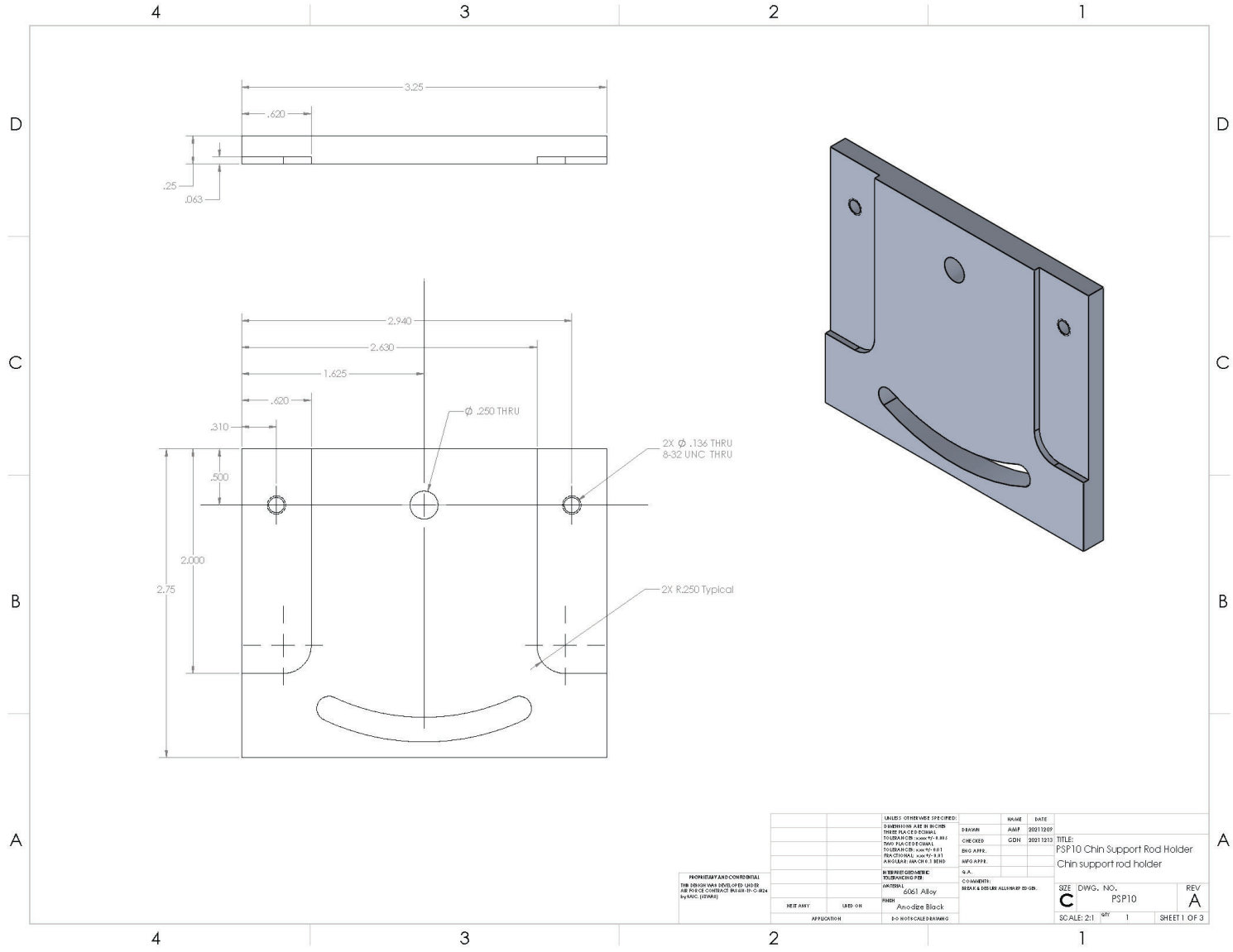

Figure 55: PSP10 Chin Support Rod Holder (page 1)

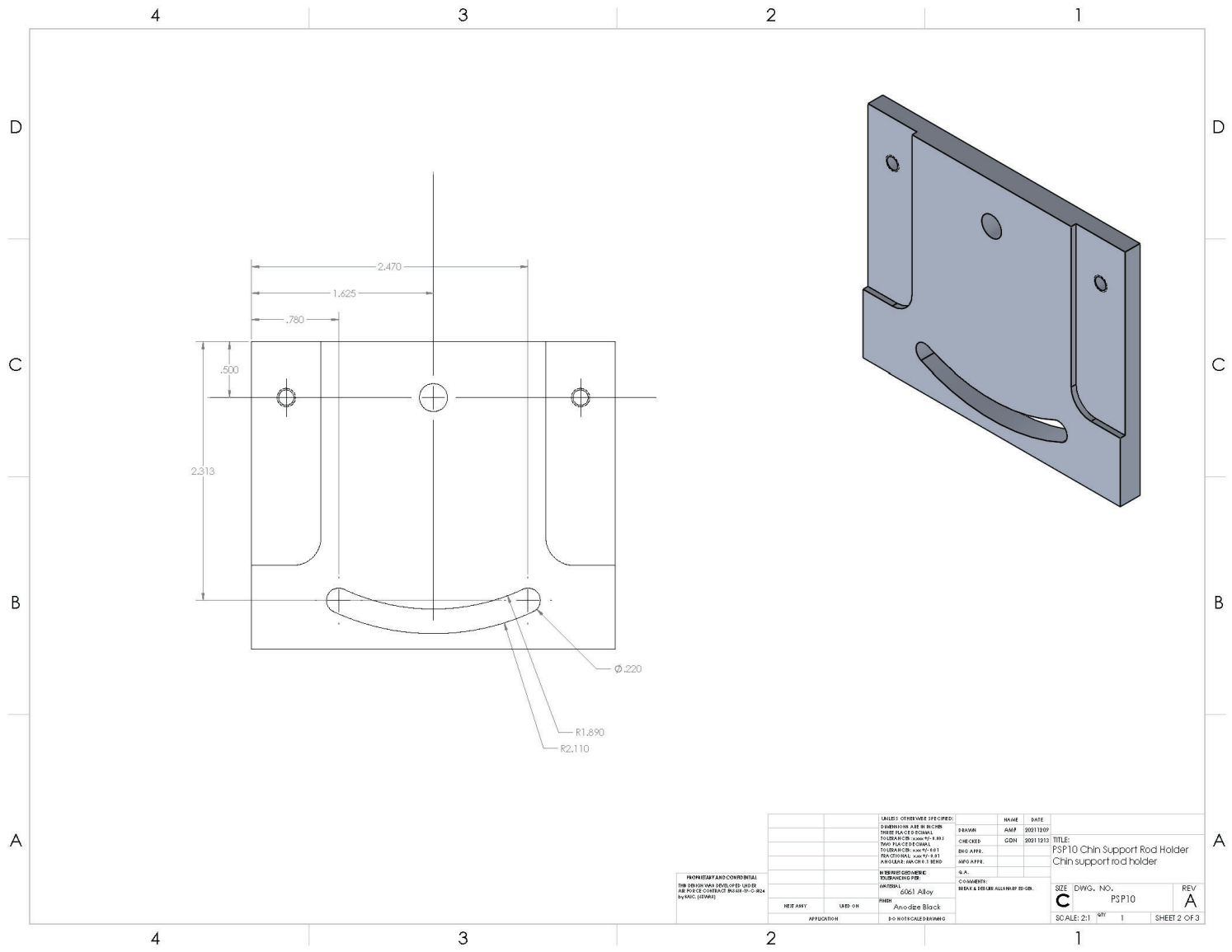

Figure 56: PSP10 Chin Support Rod Holder (page 2)

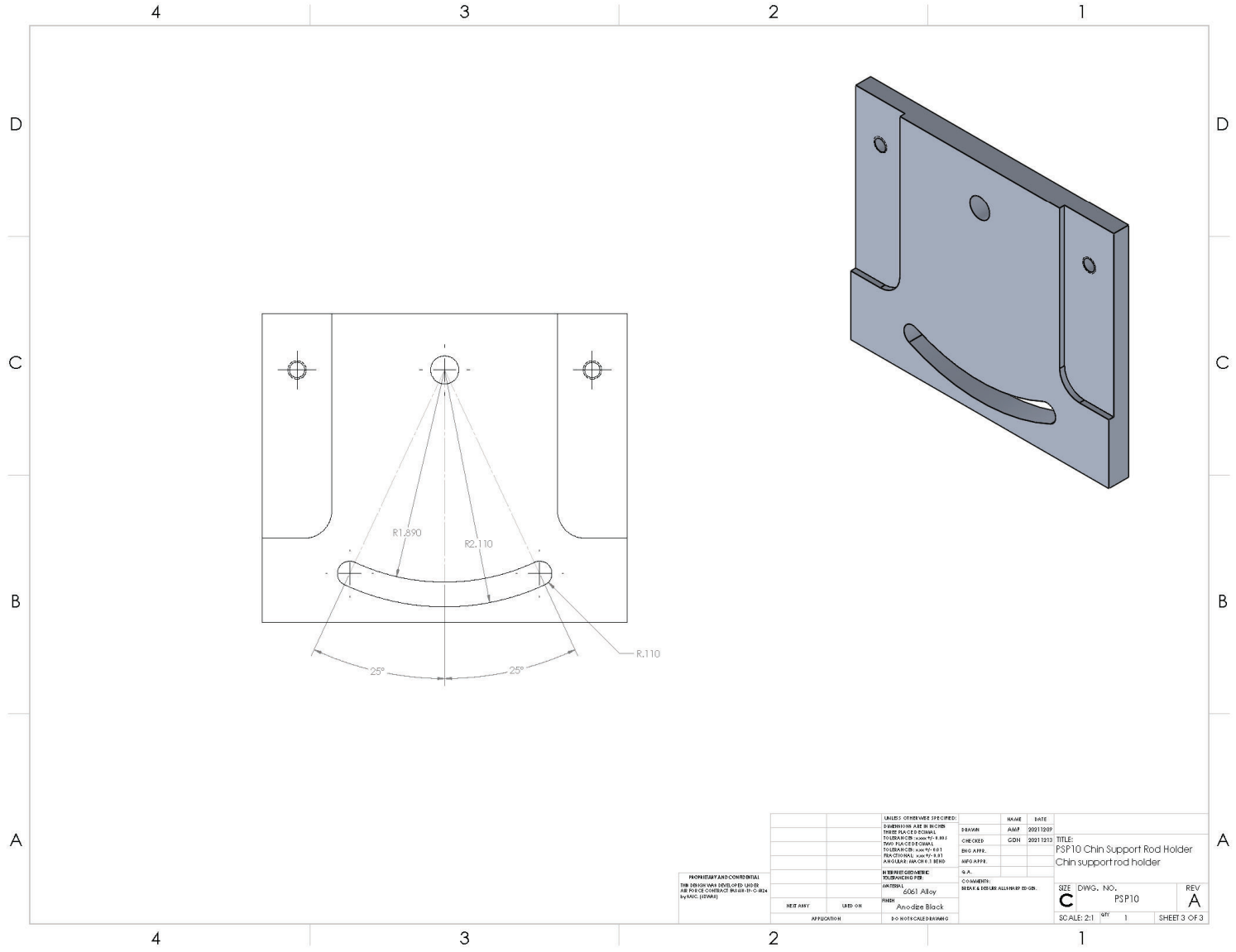

Figure 57: PSP10 Chin Support Rod Holder (page 3)

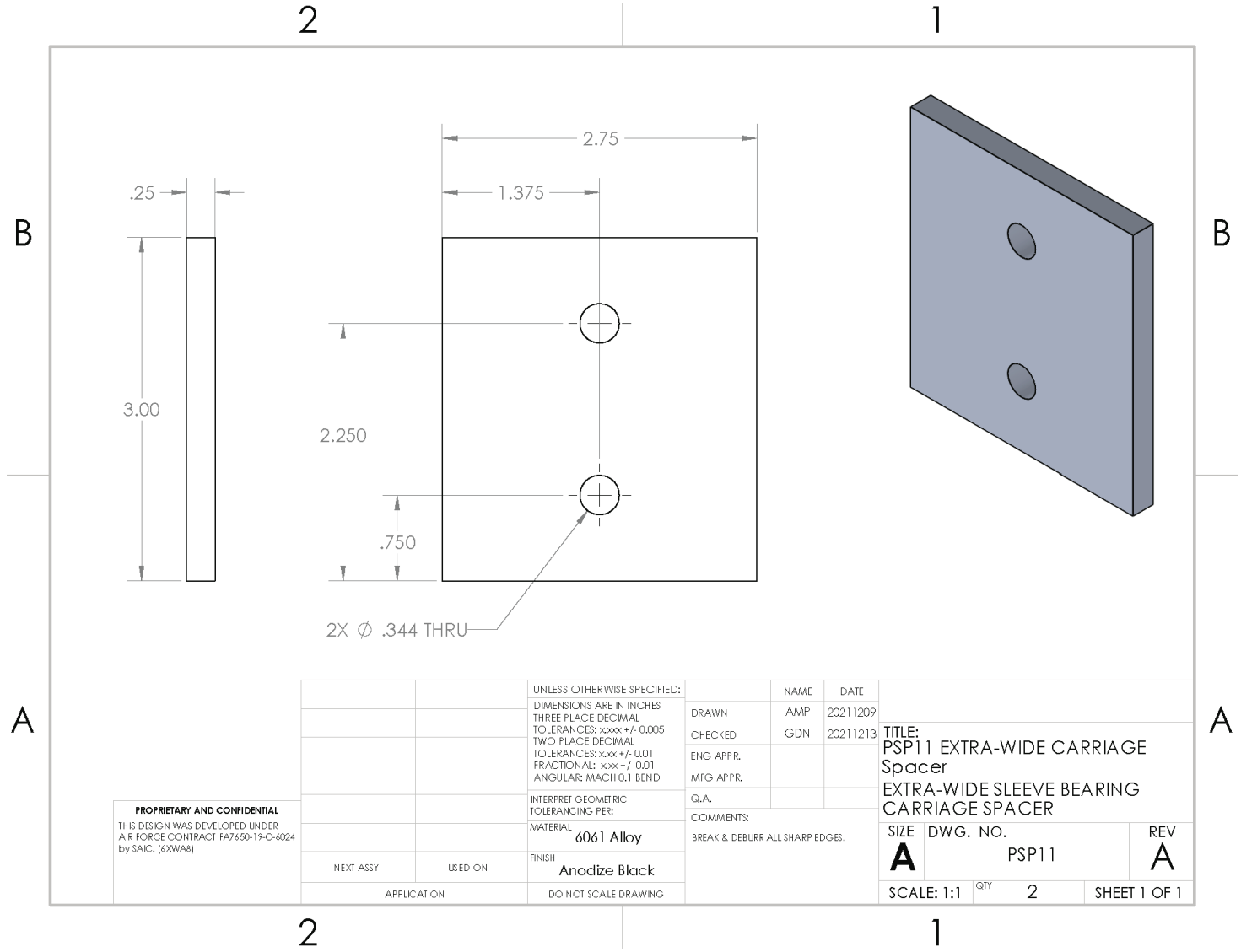

Figure 58: PSP11 EXTRA-WIDE CARRIAGE Spacer

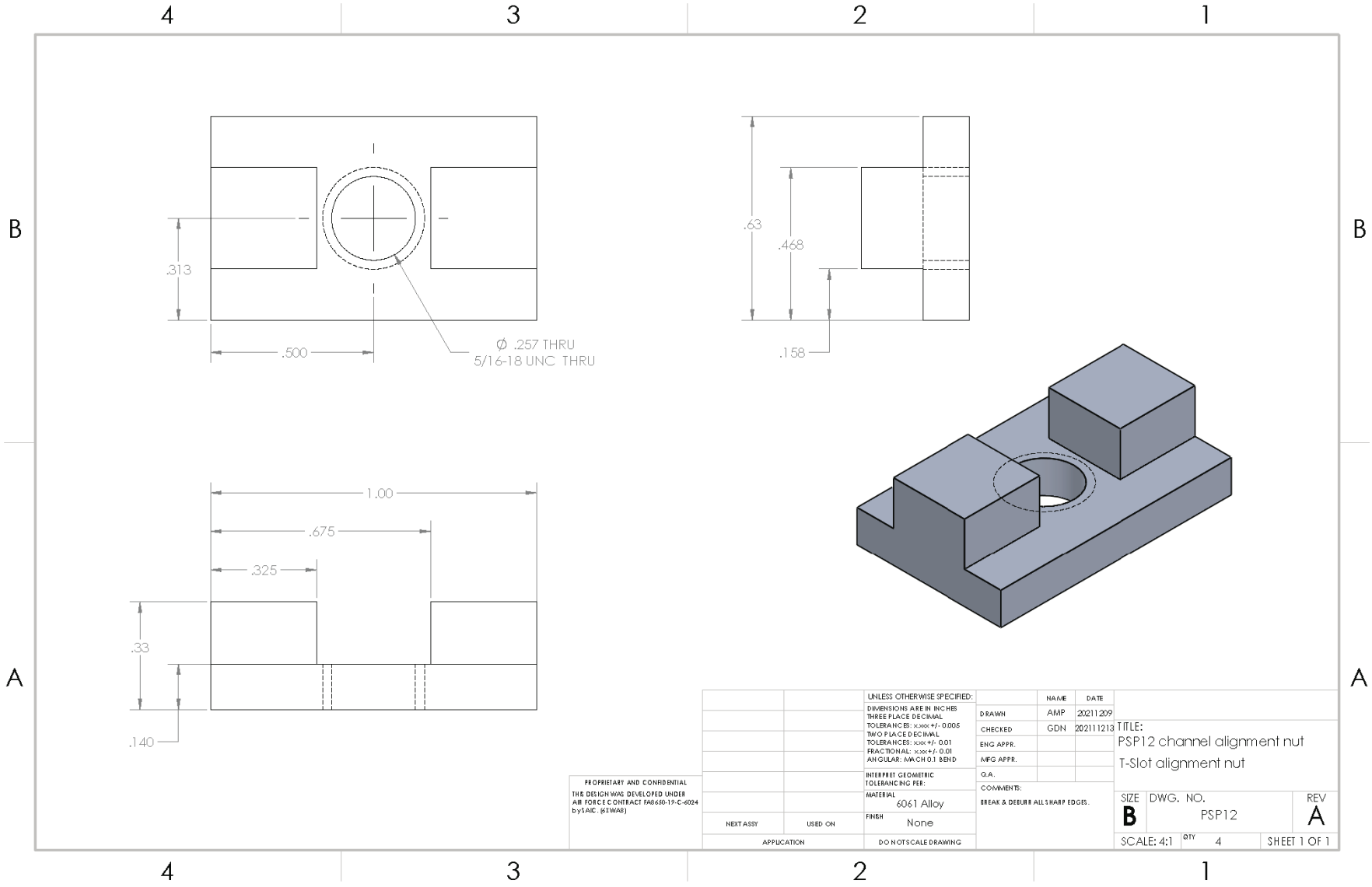

Figure 59: PSP12 channel alignment nut

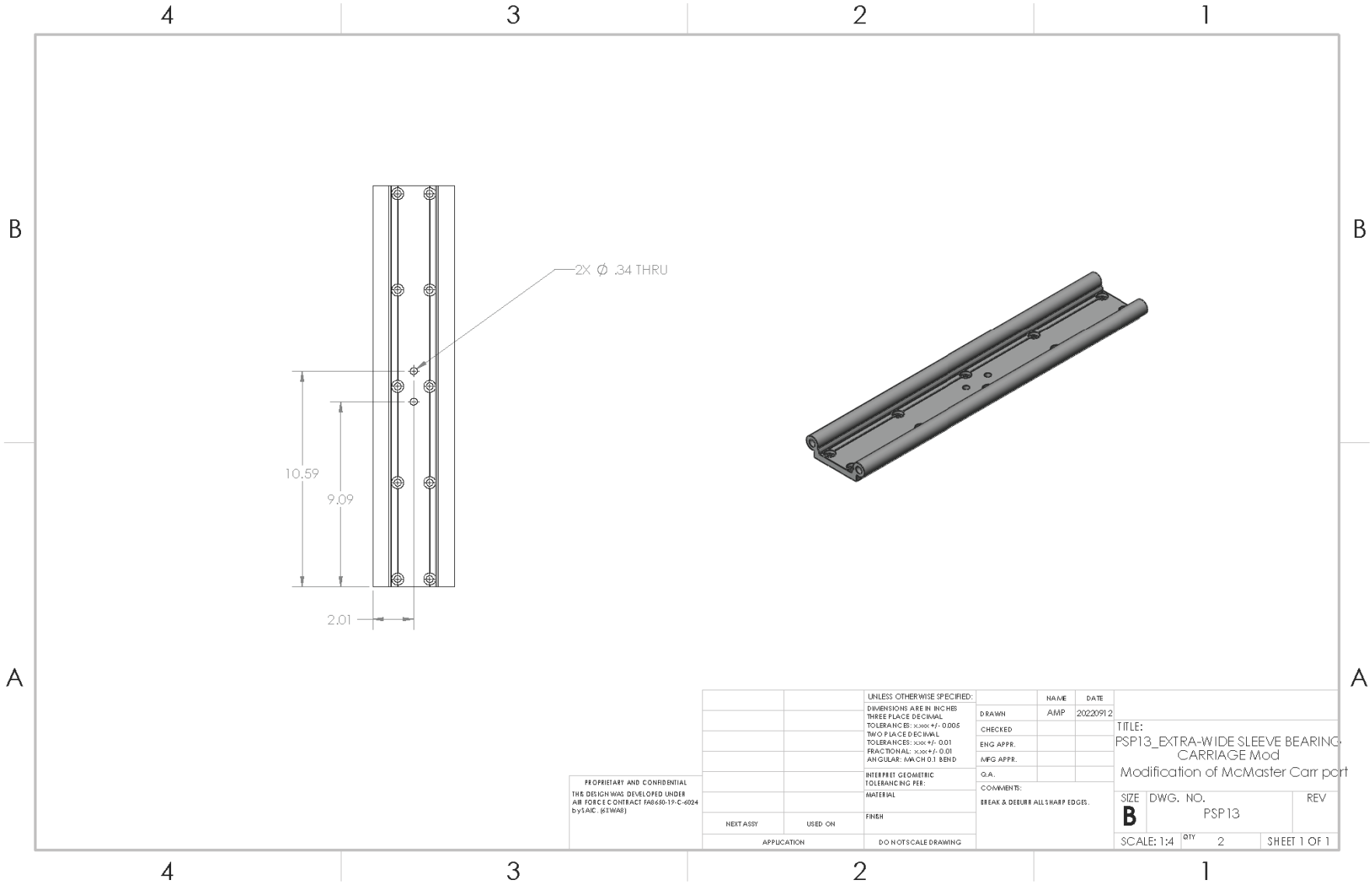

Figure 60: PSP13 Extra-Wide Sleeve Bearing Carriage Mod a

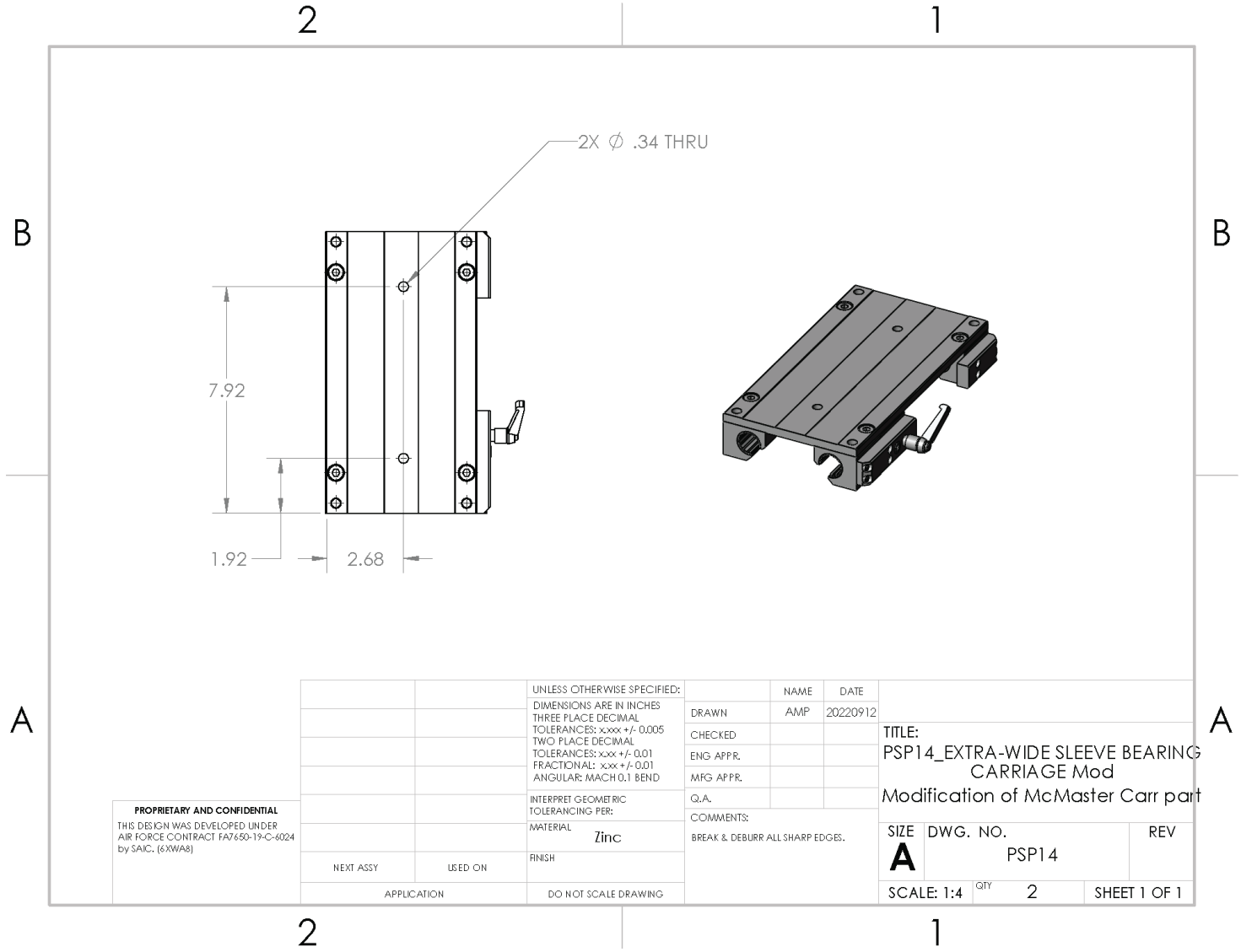

Figure 61: PSP14 Extra-Wide Sleeve Bearing Carriage Mod b

A.5 Alignment Jig

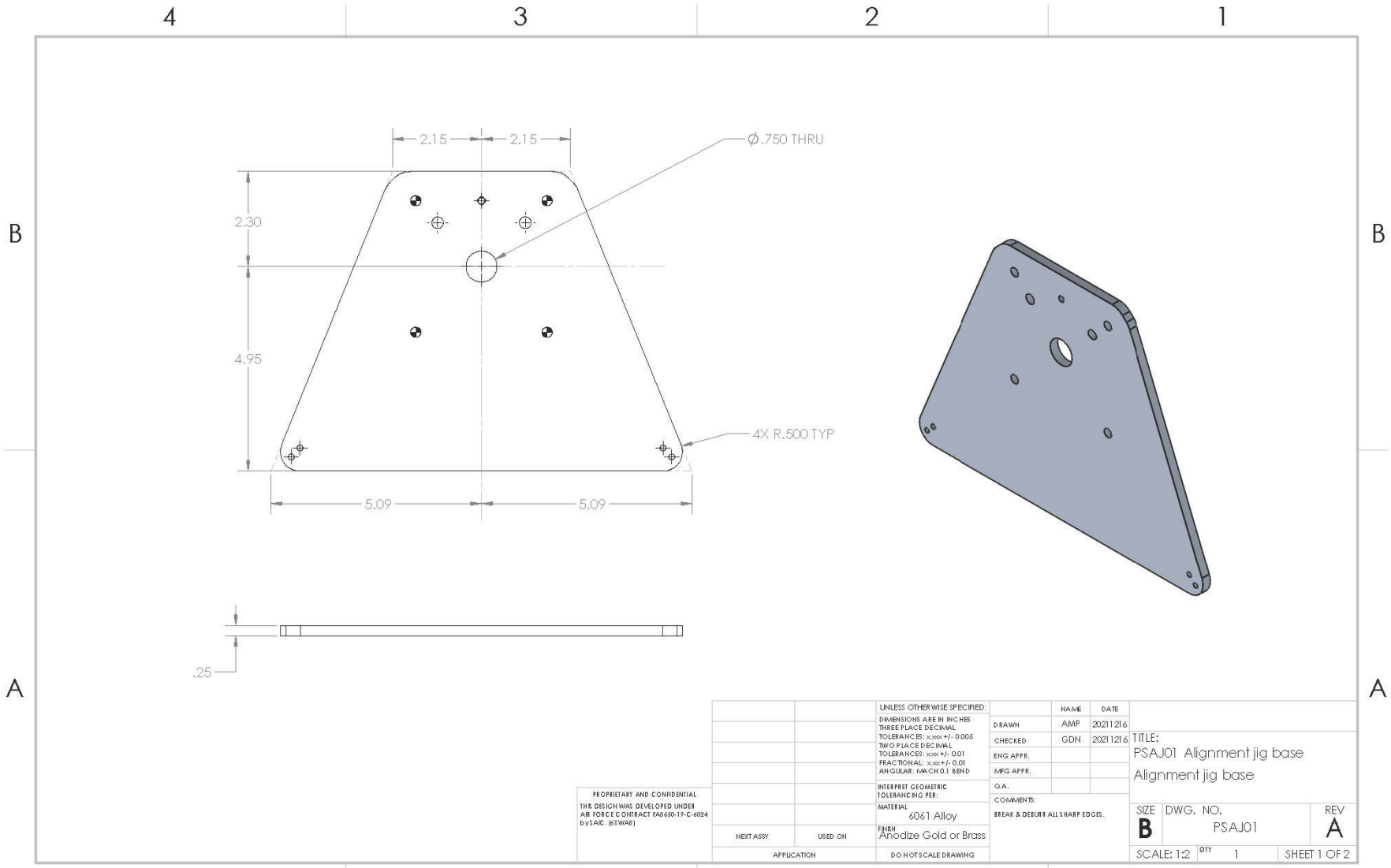

Figure 62: PSAJ01 Alignment jig base (page 1)

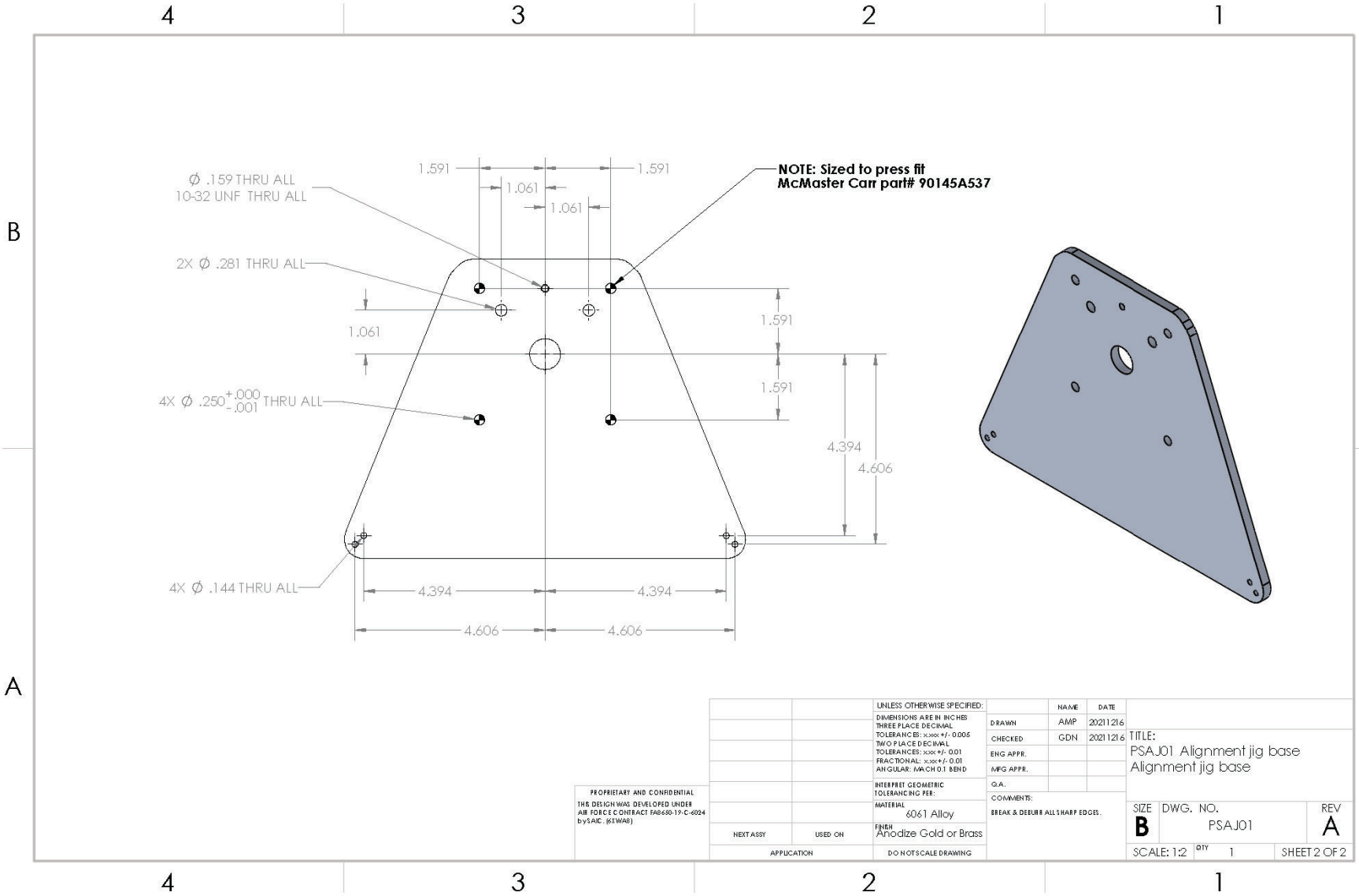

Figure 63: PSAJ01 Alignment jig base (page 2)

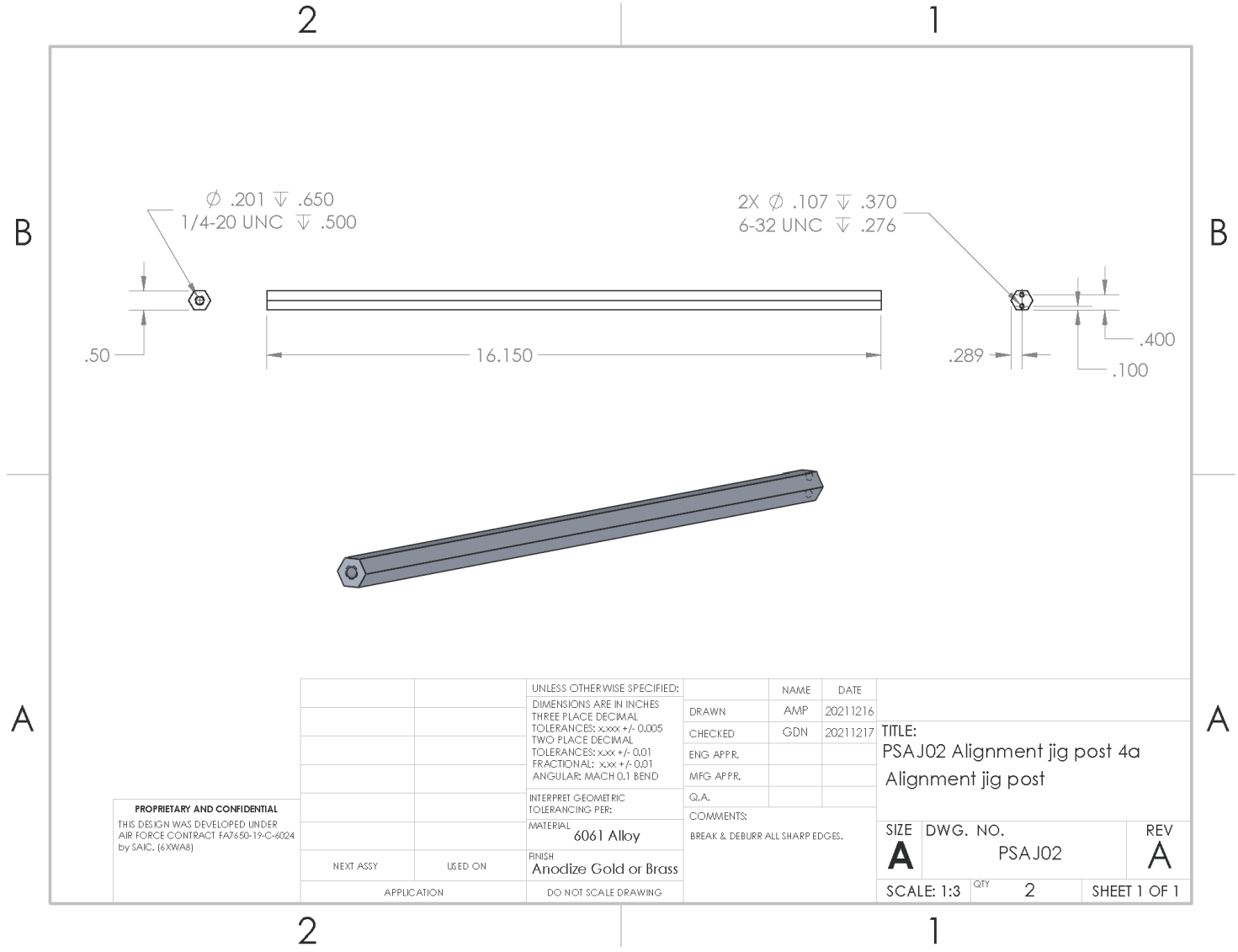

Figure 64: PSAJ02 Alignment jig post 4a

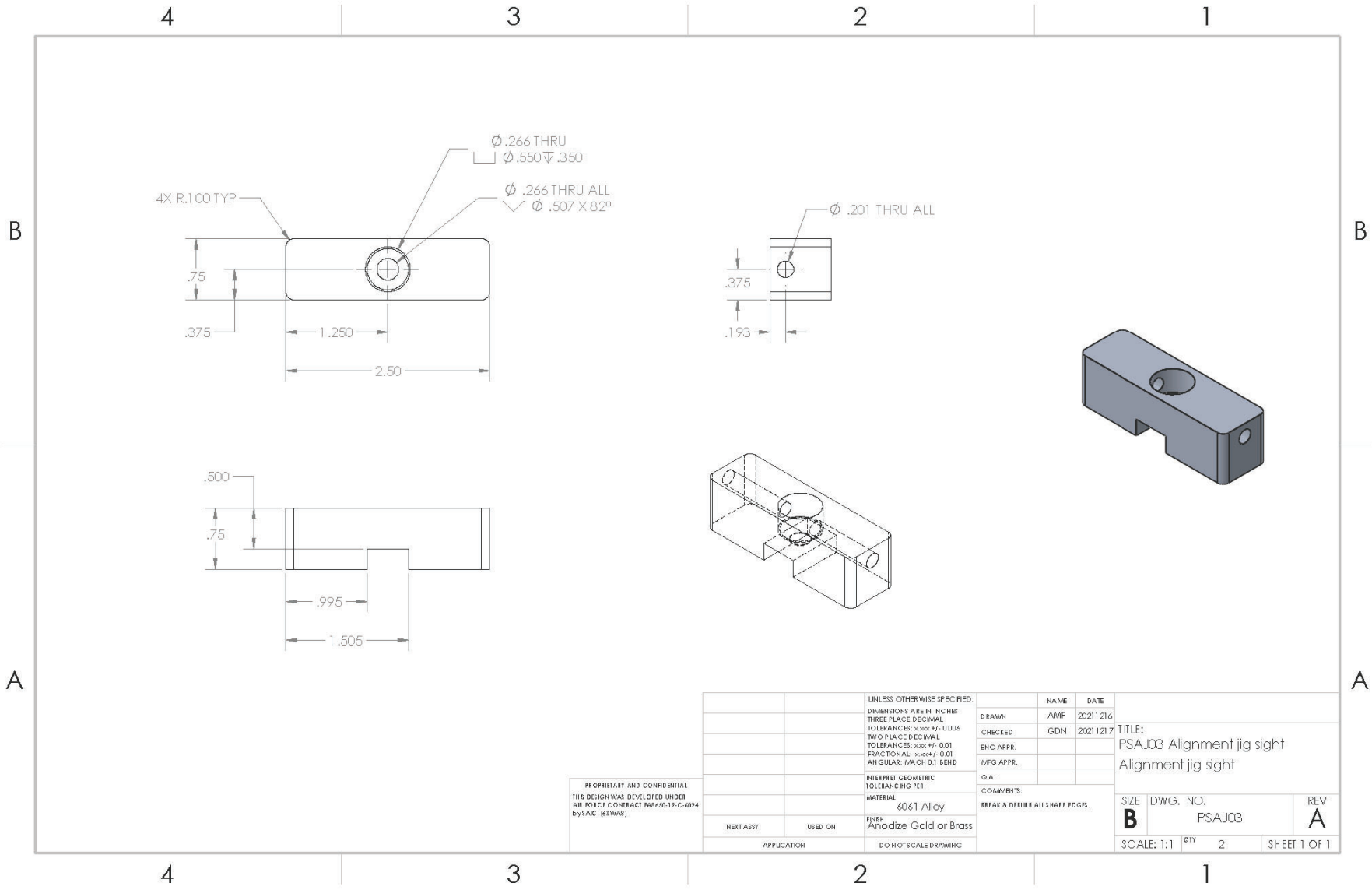

Figure 65: PSAJ03 Alignment jig sight

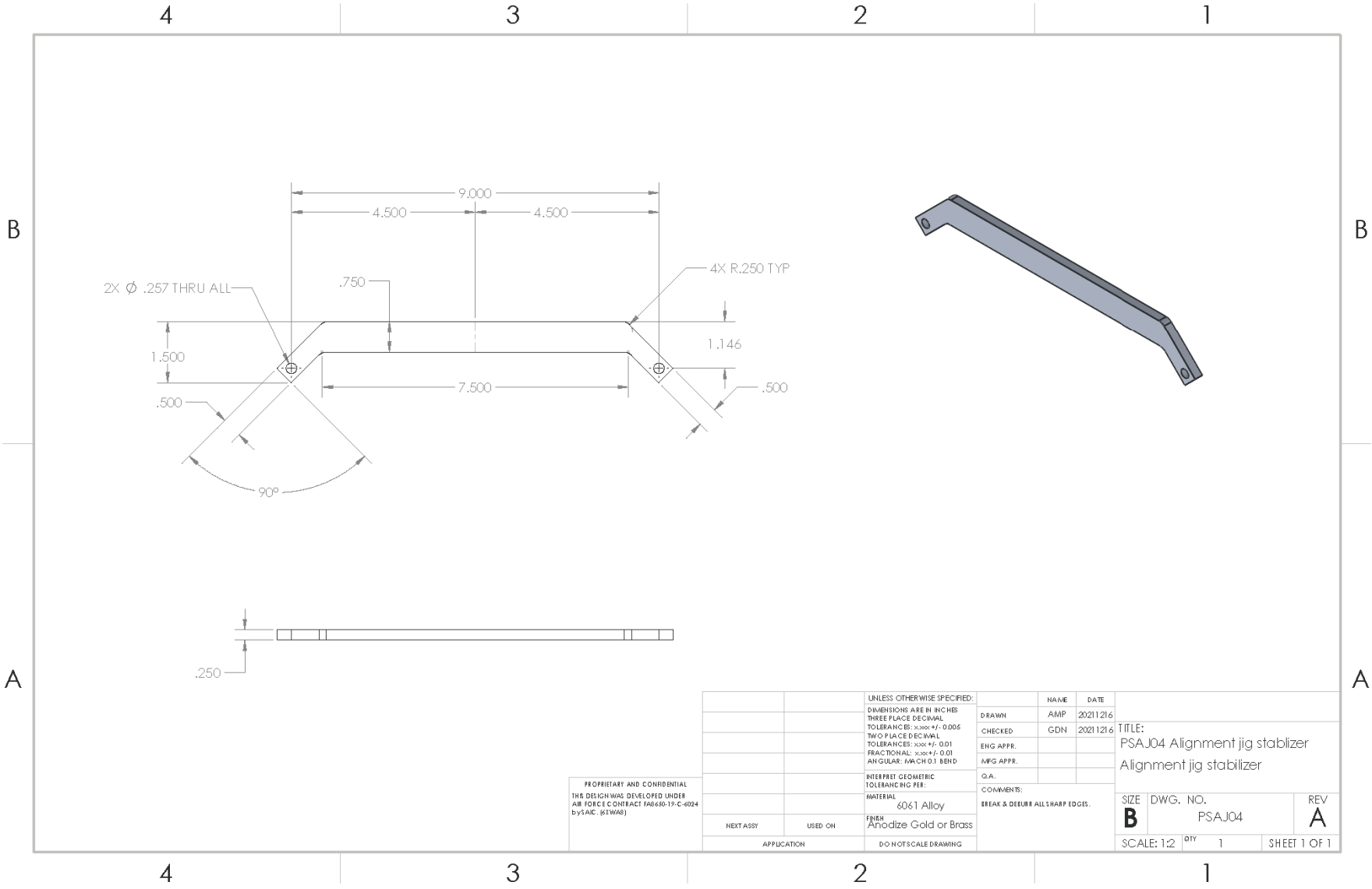

Figure 66: PSAJ04 Alignment jig stabilizer

A.6 Accessories

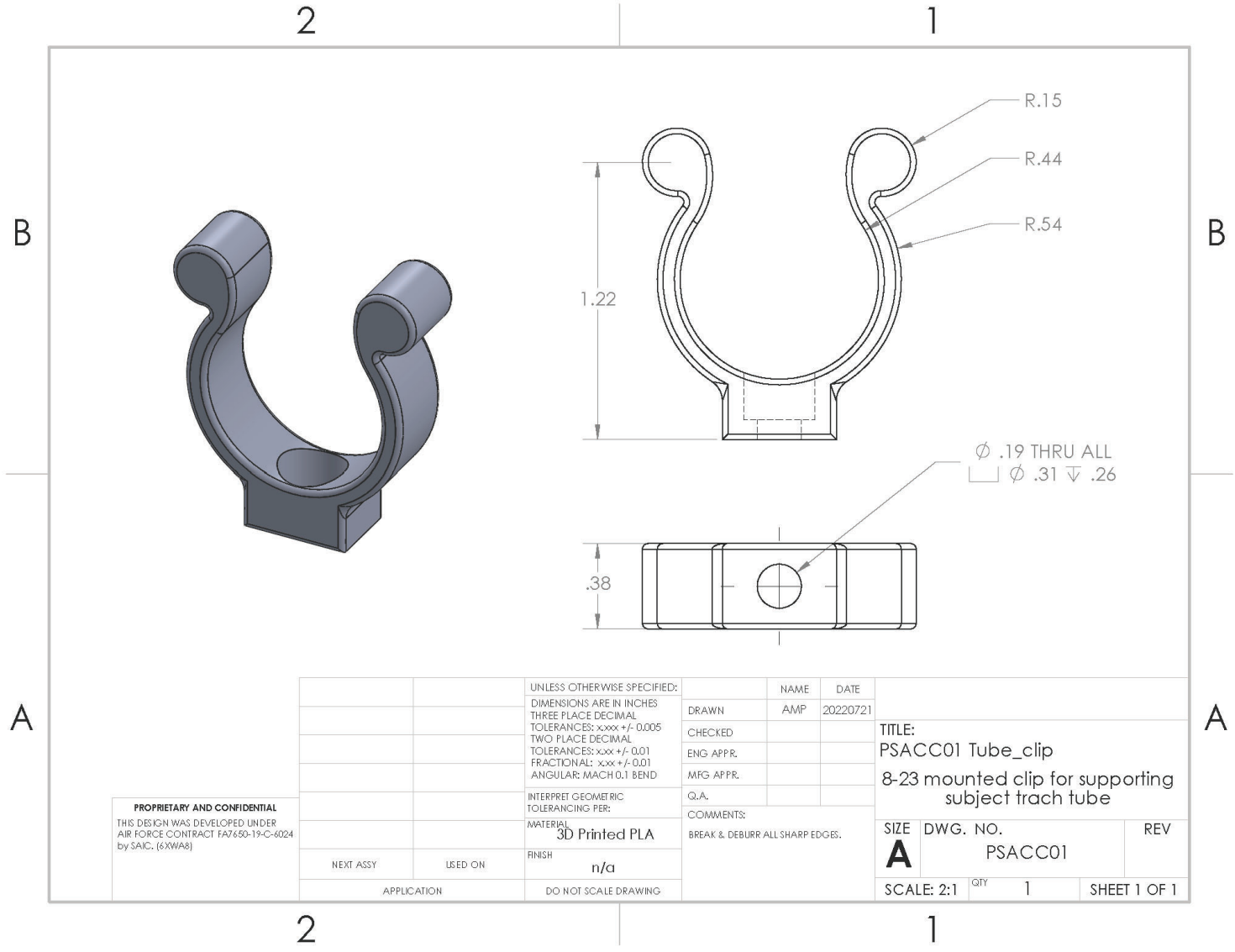

Figure 67: PSACC01 Tube Clip

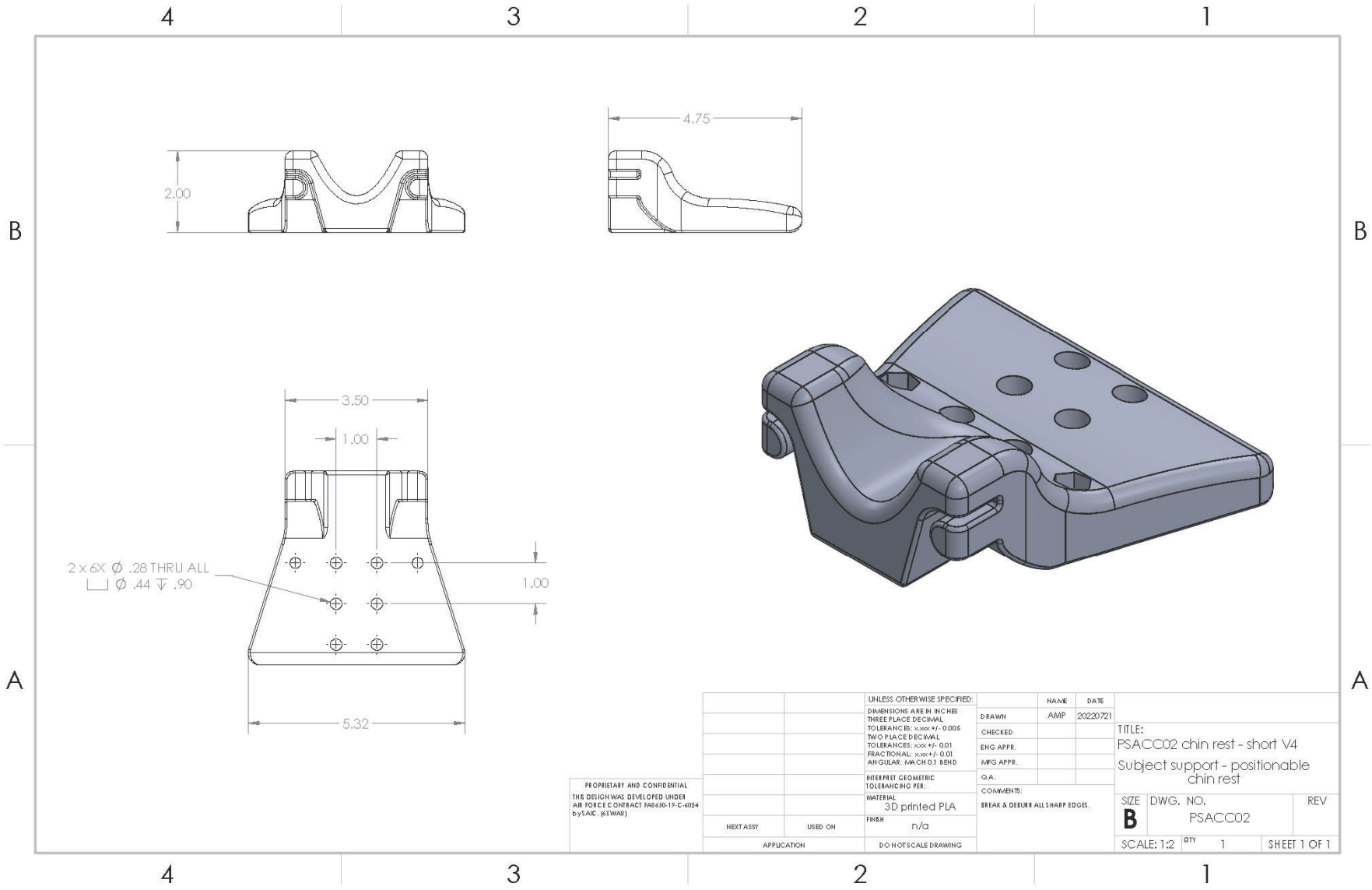

Figure 68: PSACC02 chin rest - short V4

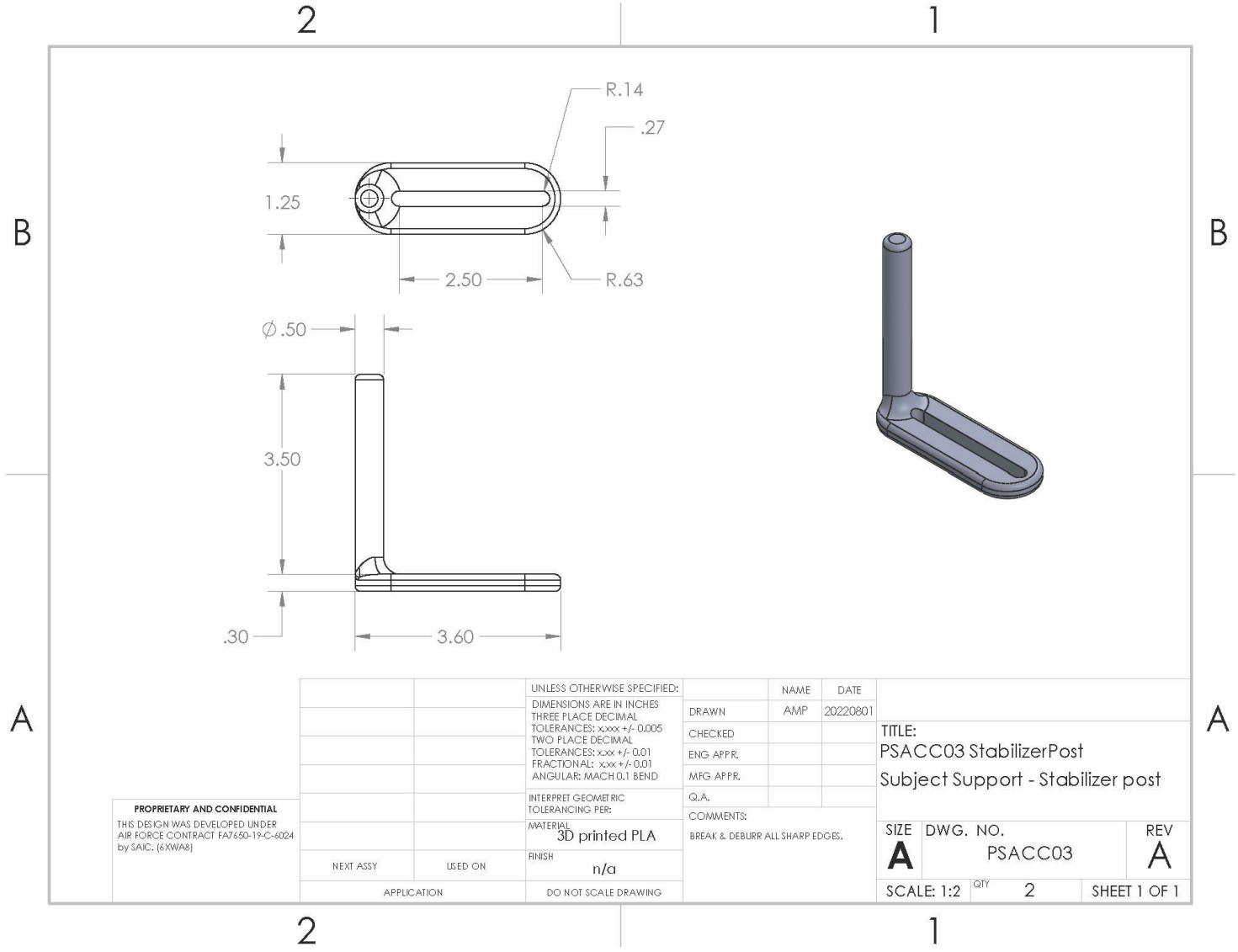

Figure 69: PSACC 03 Stabilizer Post

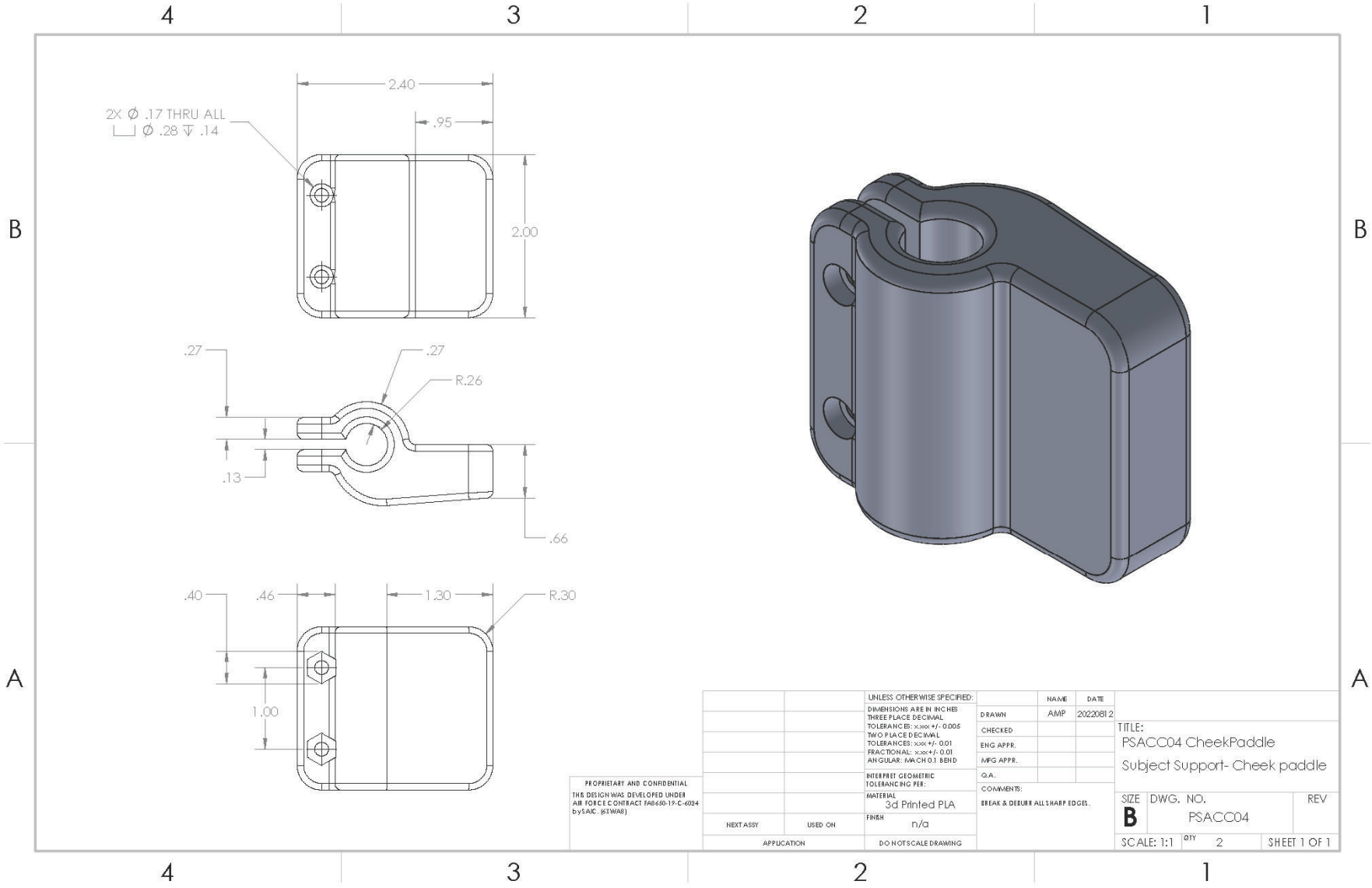

Figure 70: PSACC04 Cheek Paddle

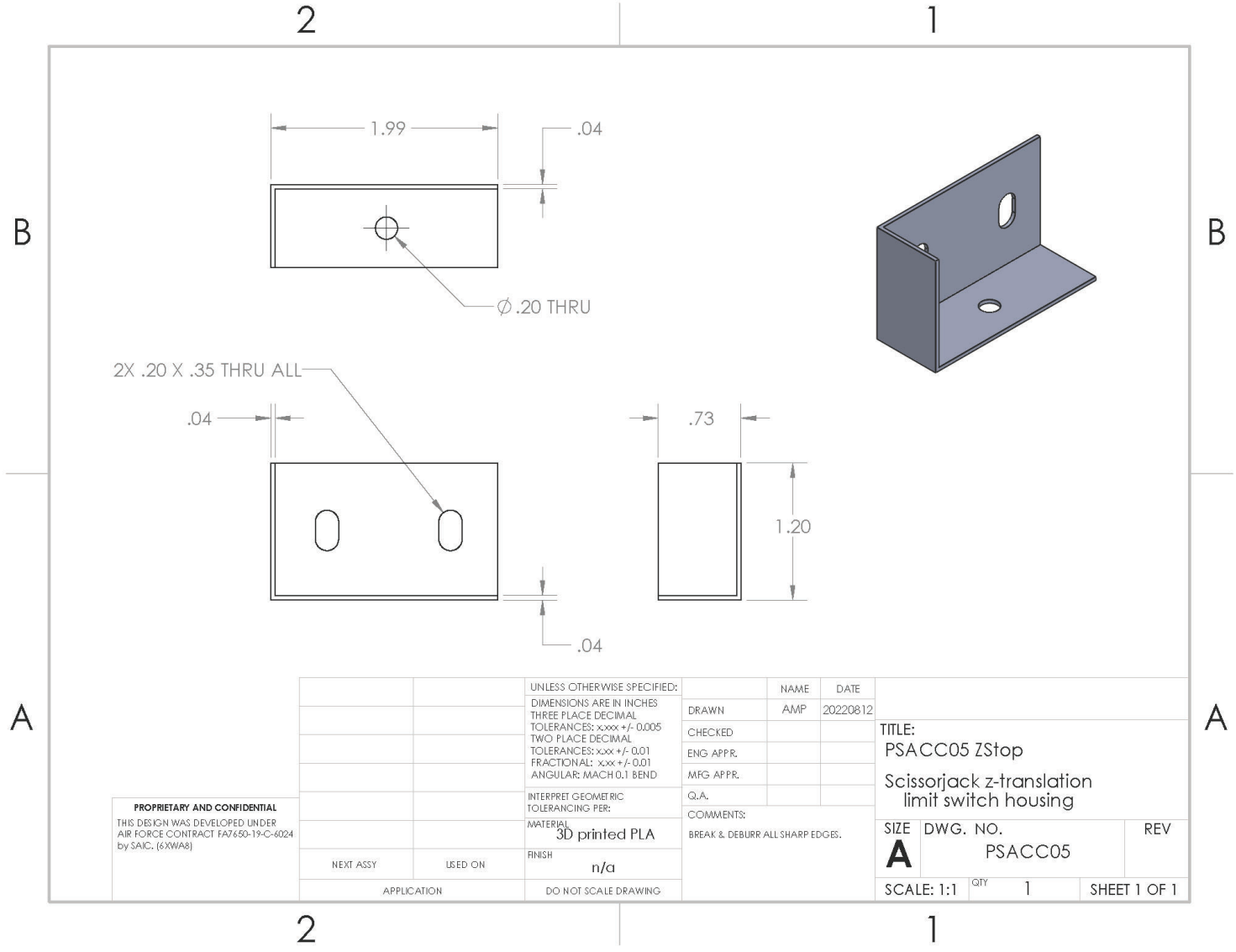

Figure 71: PSACC05 Z-stop

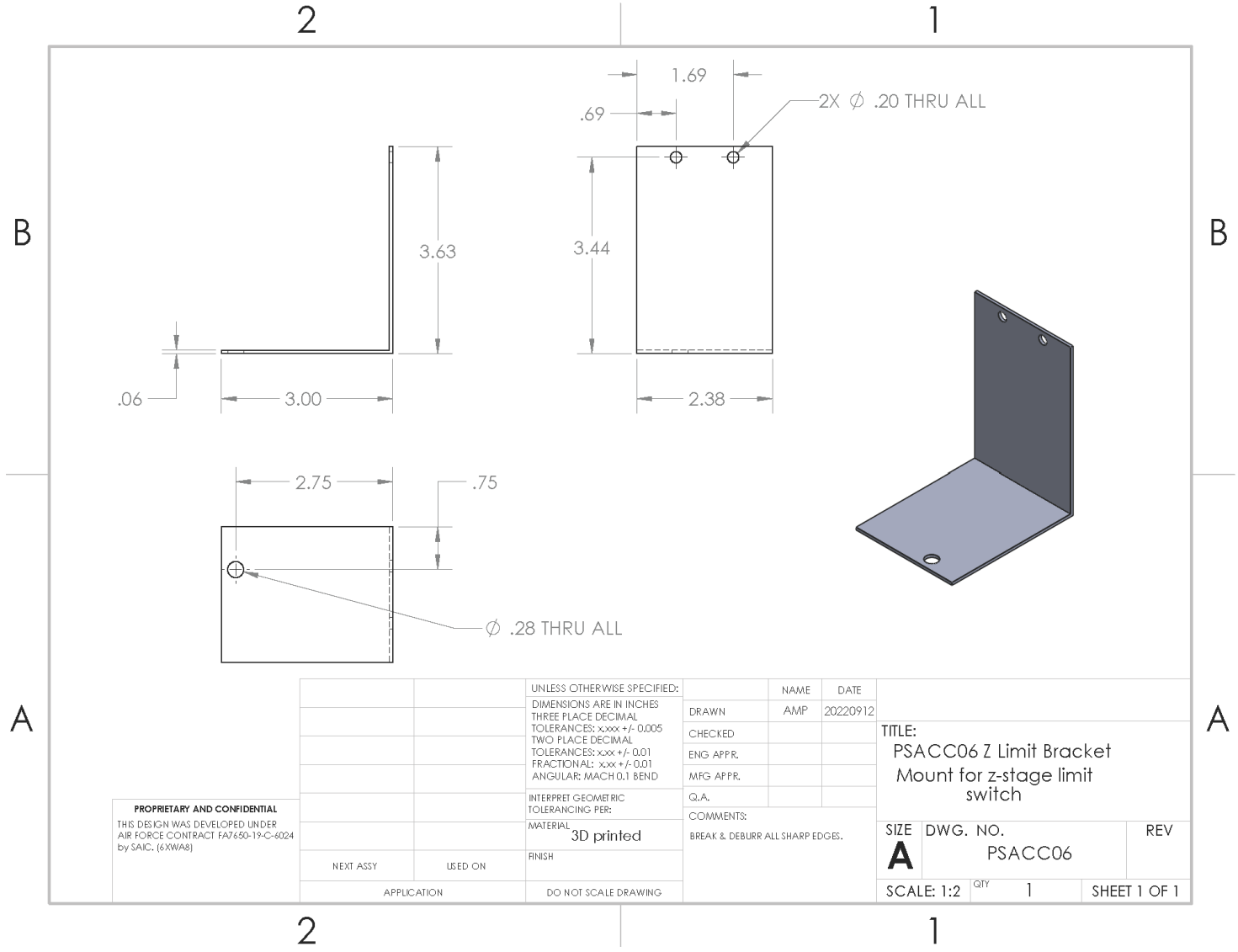

Figure 72: PSACC06 Z Limit Bracket

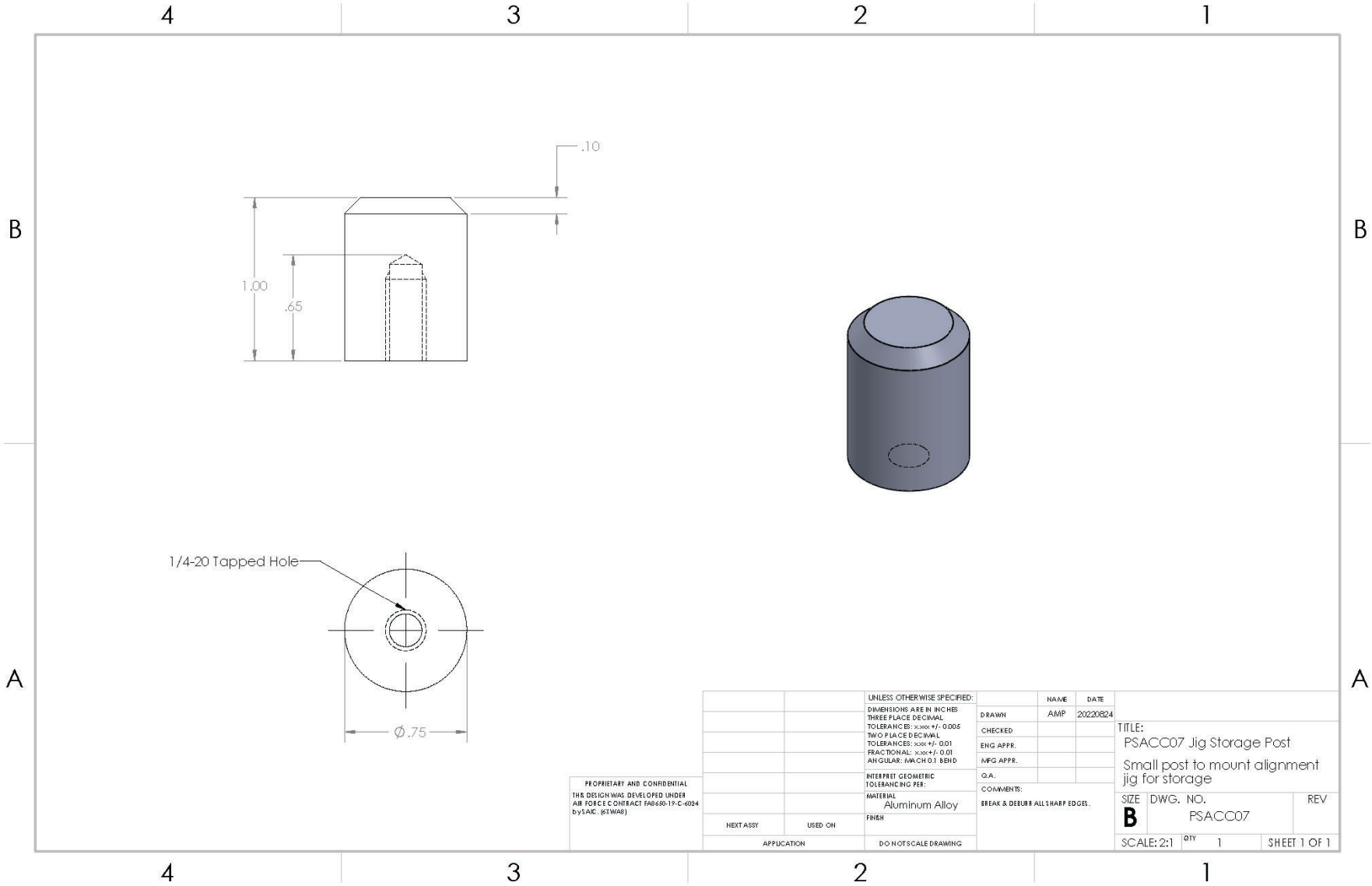

Figure 73: PSACC07 Jig Storage Post

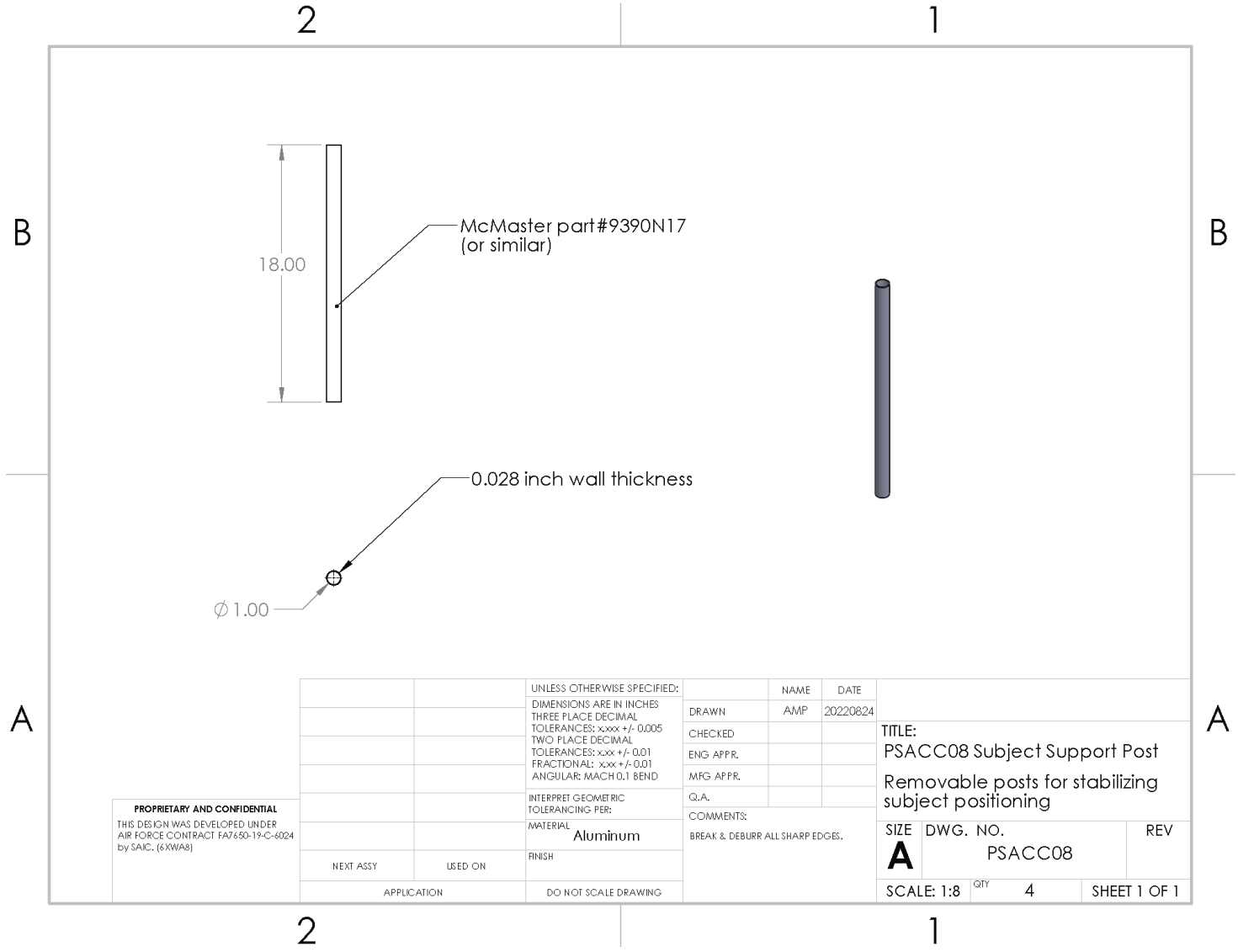

Figure 74: PSACC08 Subject Support Post

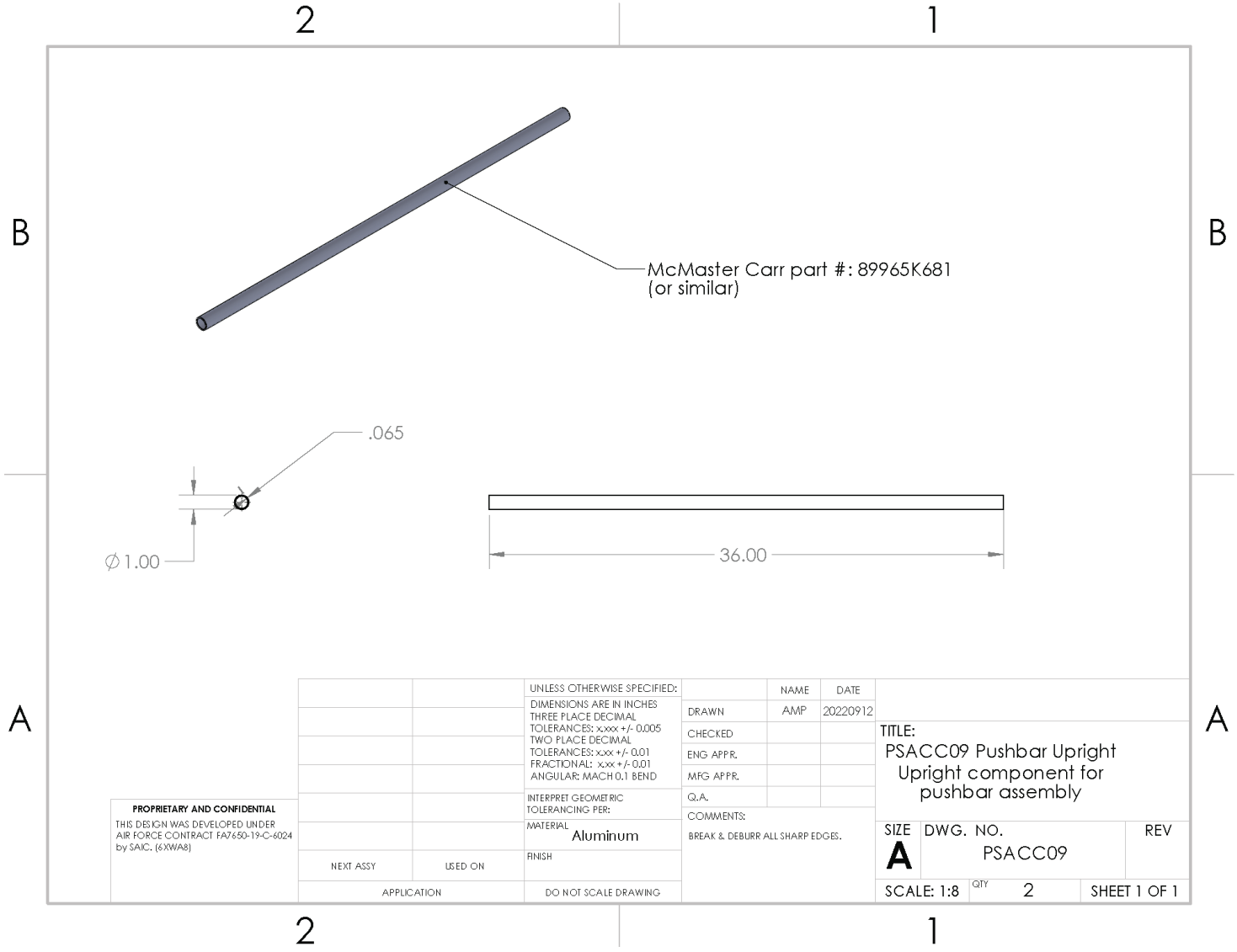

Figure 75: PSACC09 Pushbar Upright

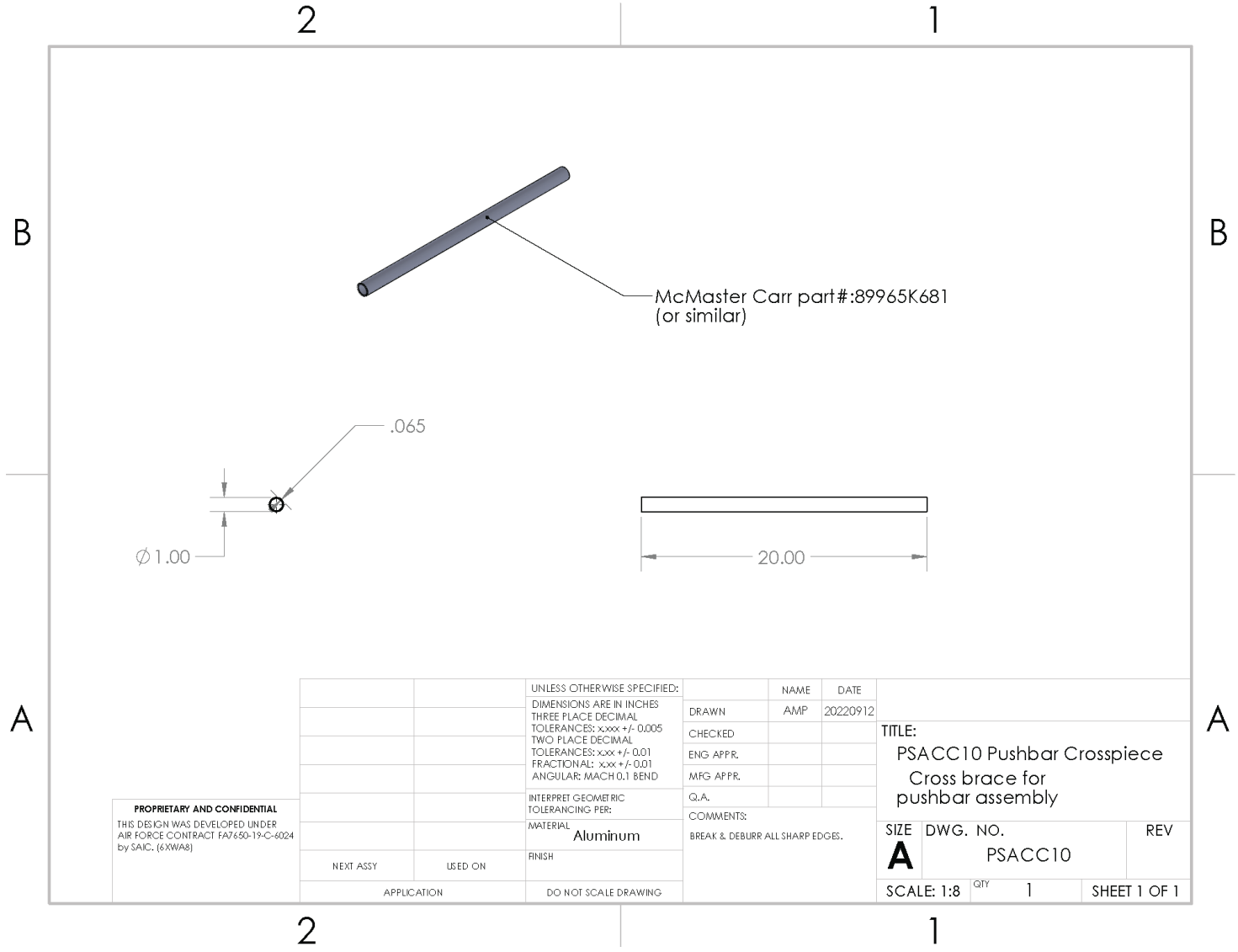

Figure 76: PSACC10 Pushbar Crosspiece

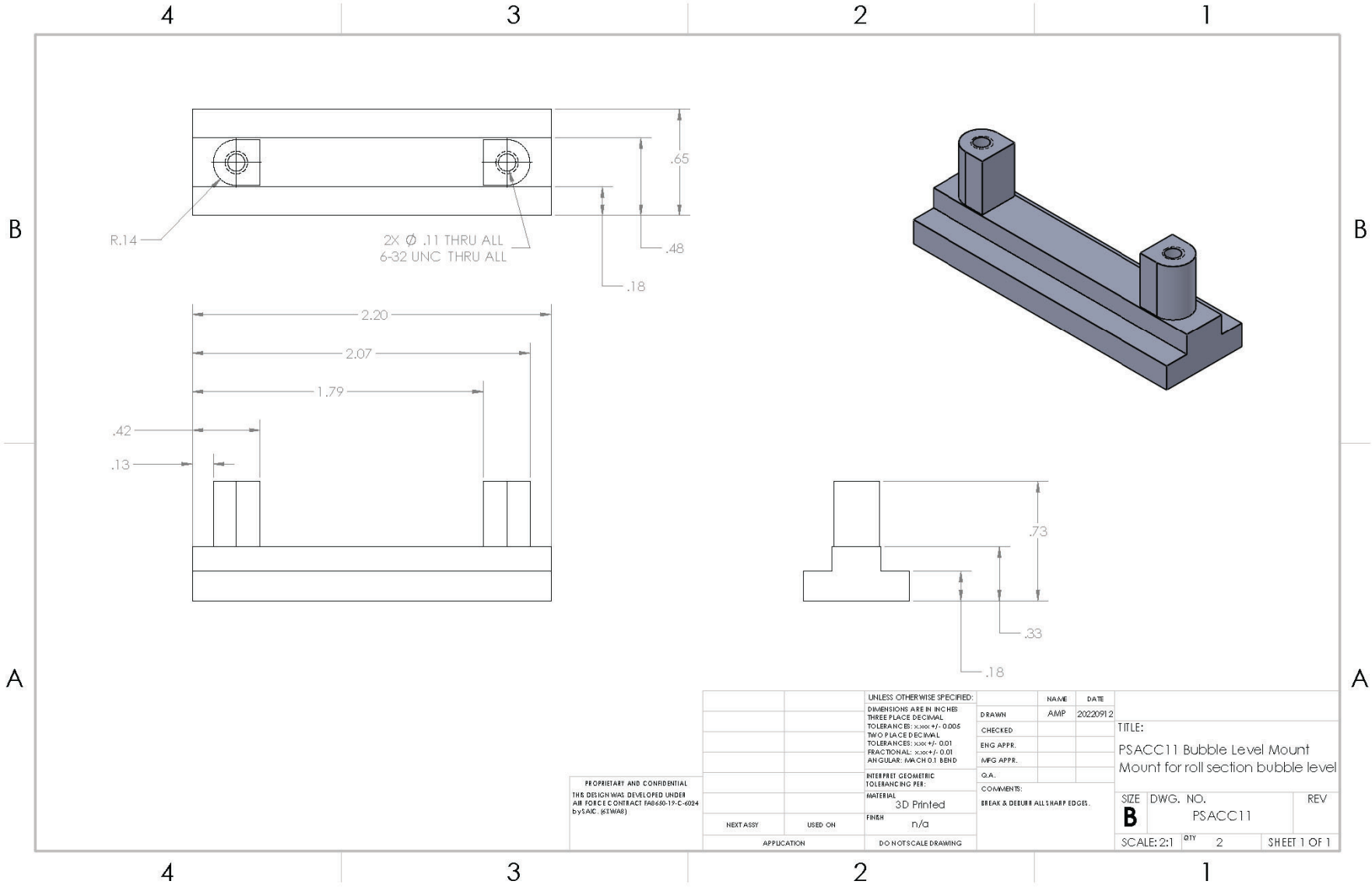

Figure 77: PSACC11 Bubble Level Mount

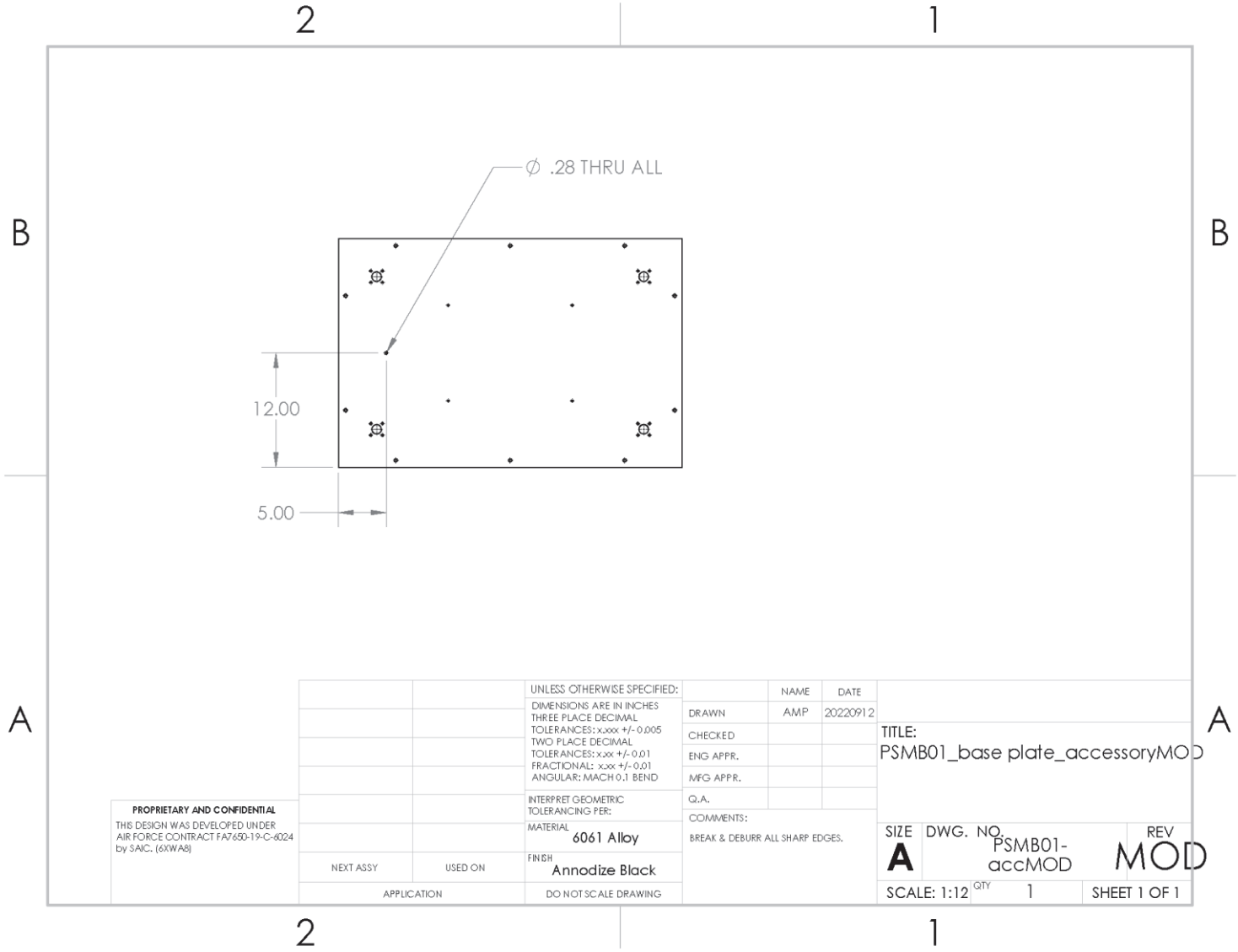

Figure 78: PSMB01 Base Plate - Accessory Mod

A.7 Electrical

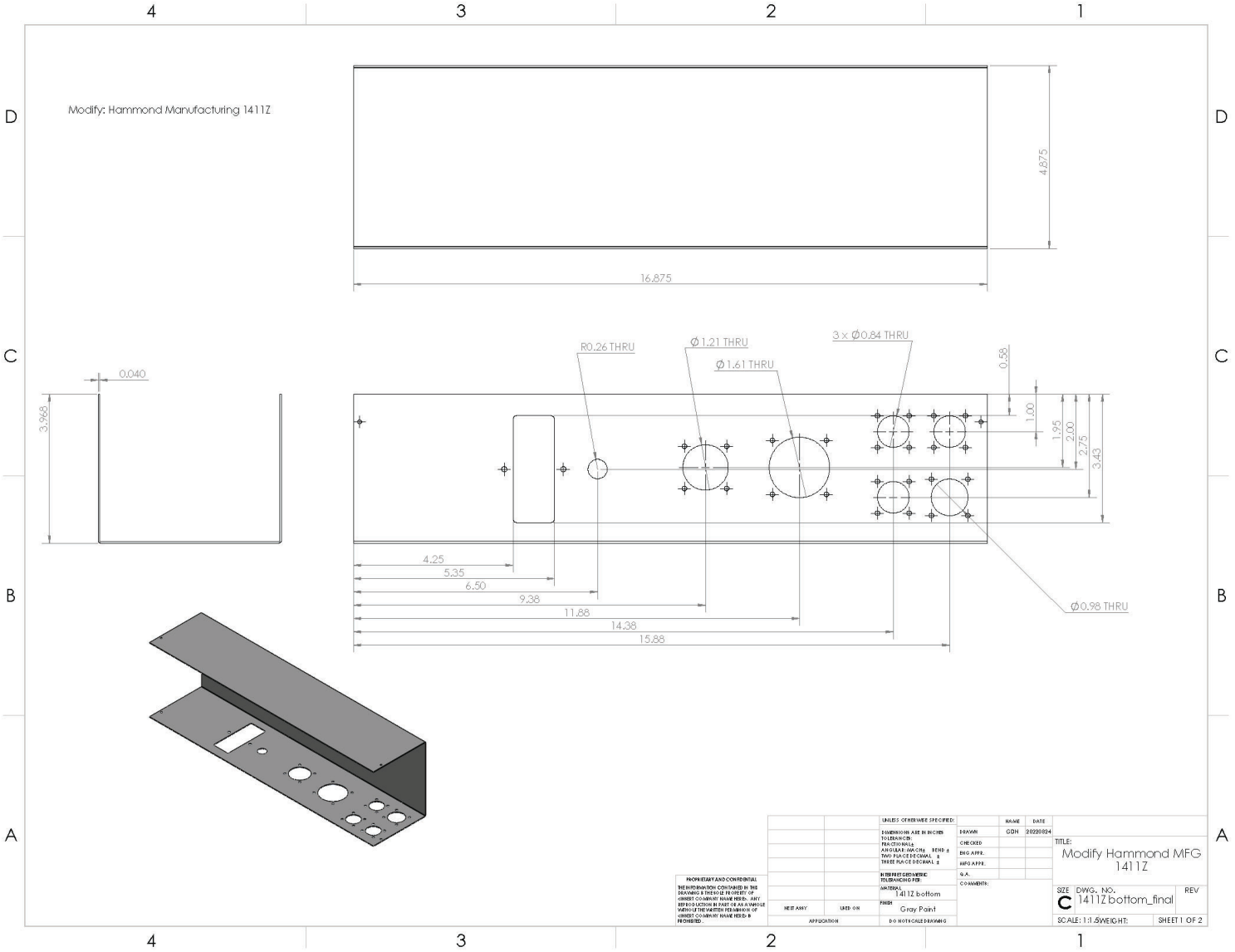

Figure 79: Hammond MFG 1411Z – Mod (page 1)

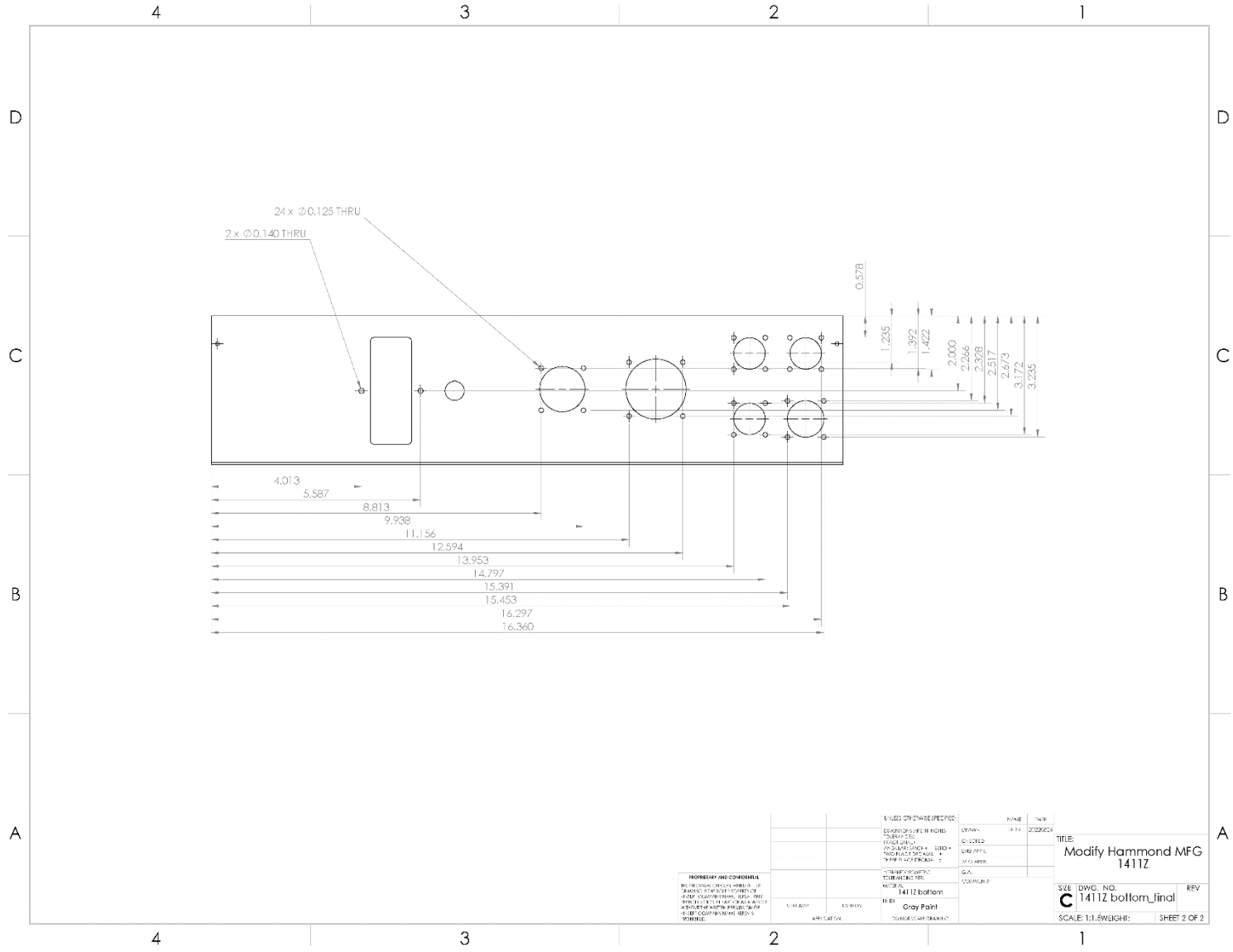

Figure 80: Hammond MFG 1411Z – Mod (page 2)

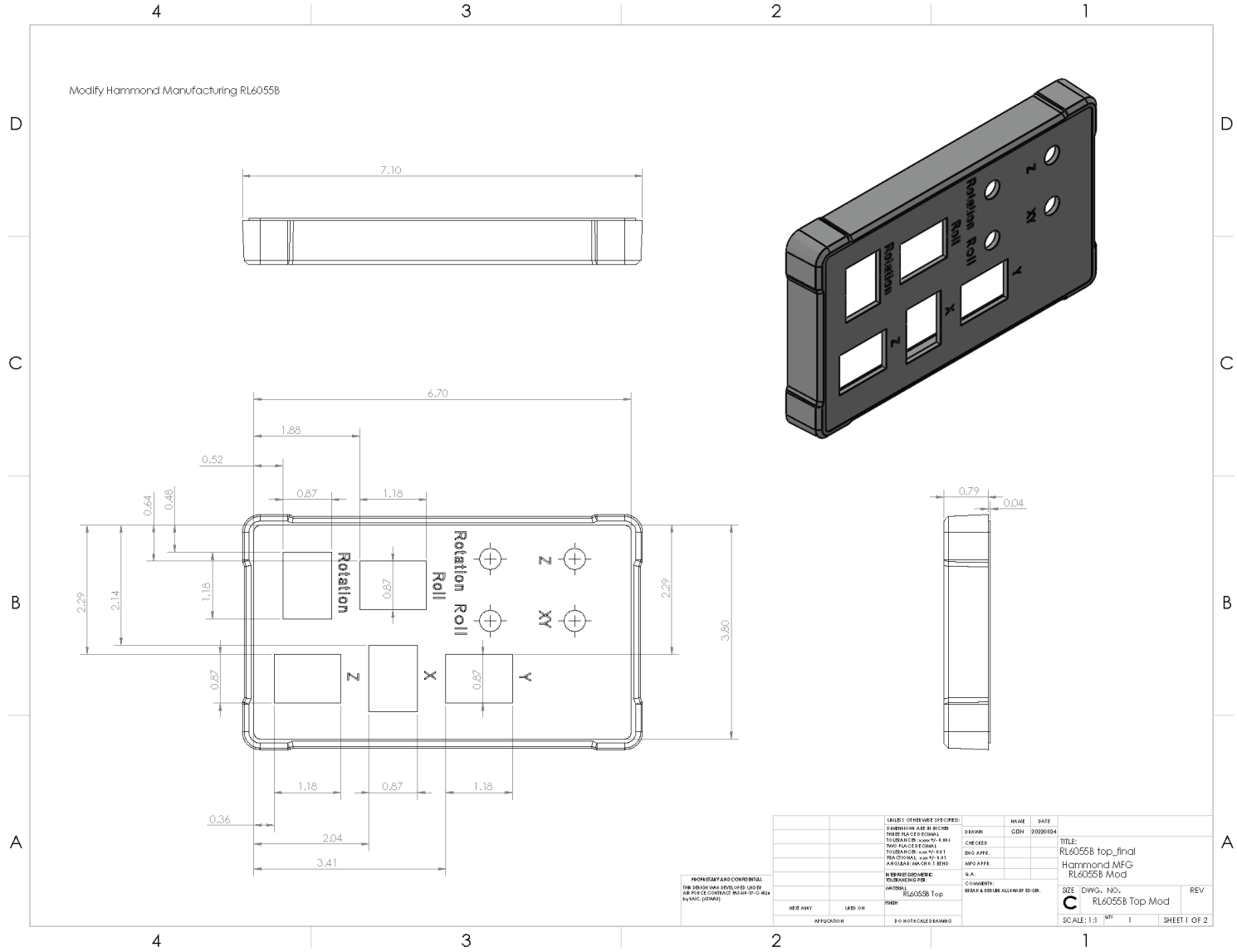

Figure 81: RL6055 top – mod (page 1)

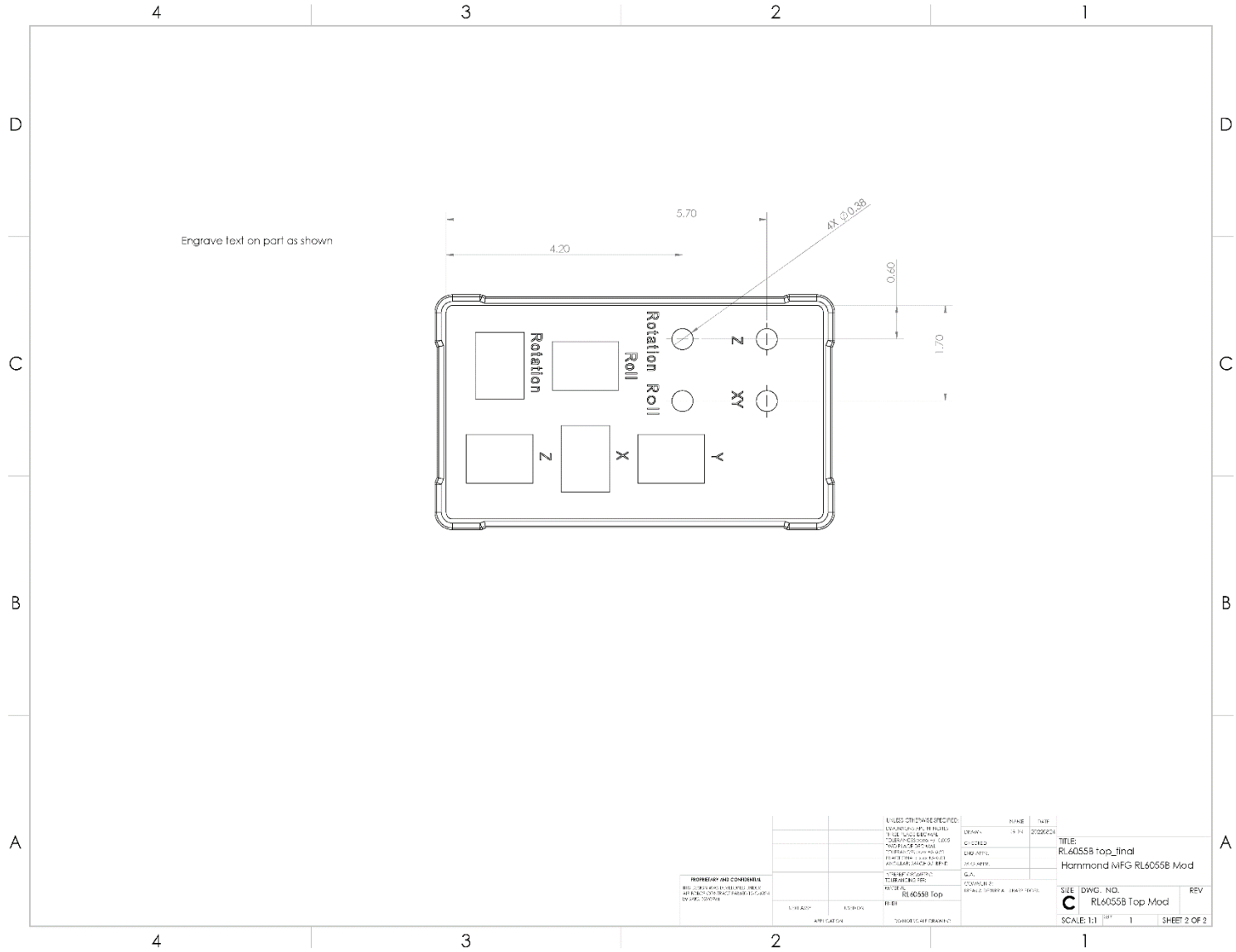

Figure 82: RL6055 top – mod (page 2)

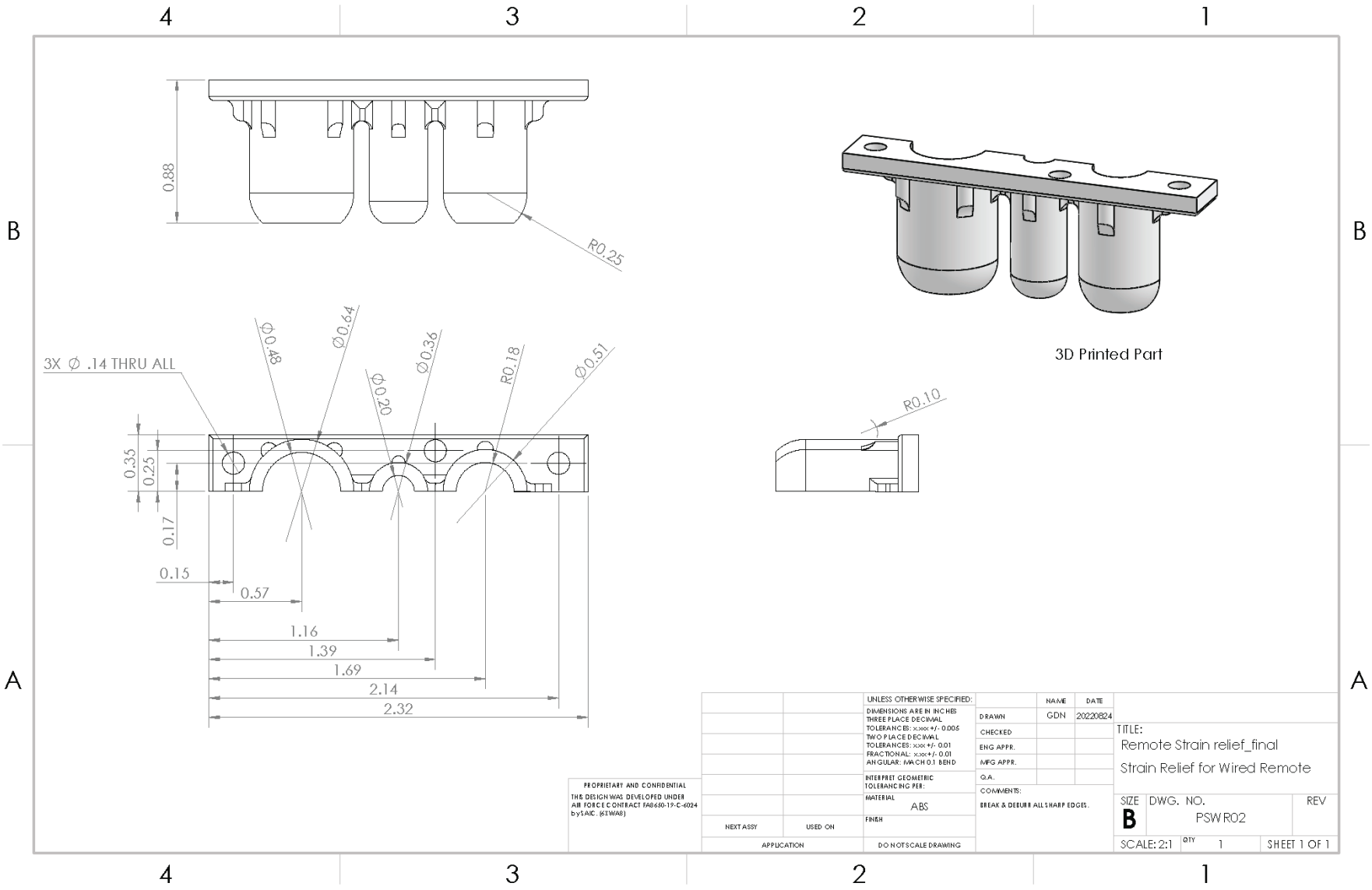

Figure 83: Remote Strain Relief a

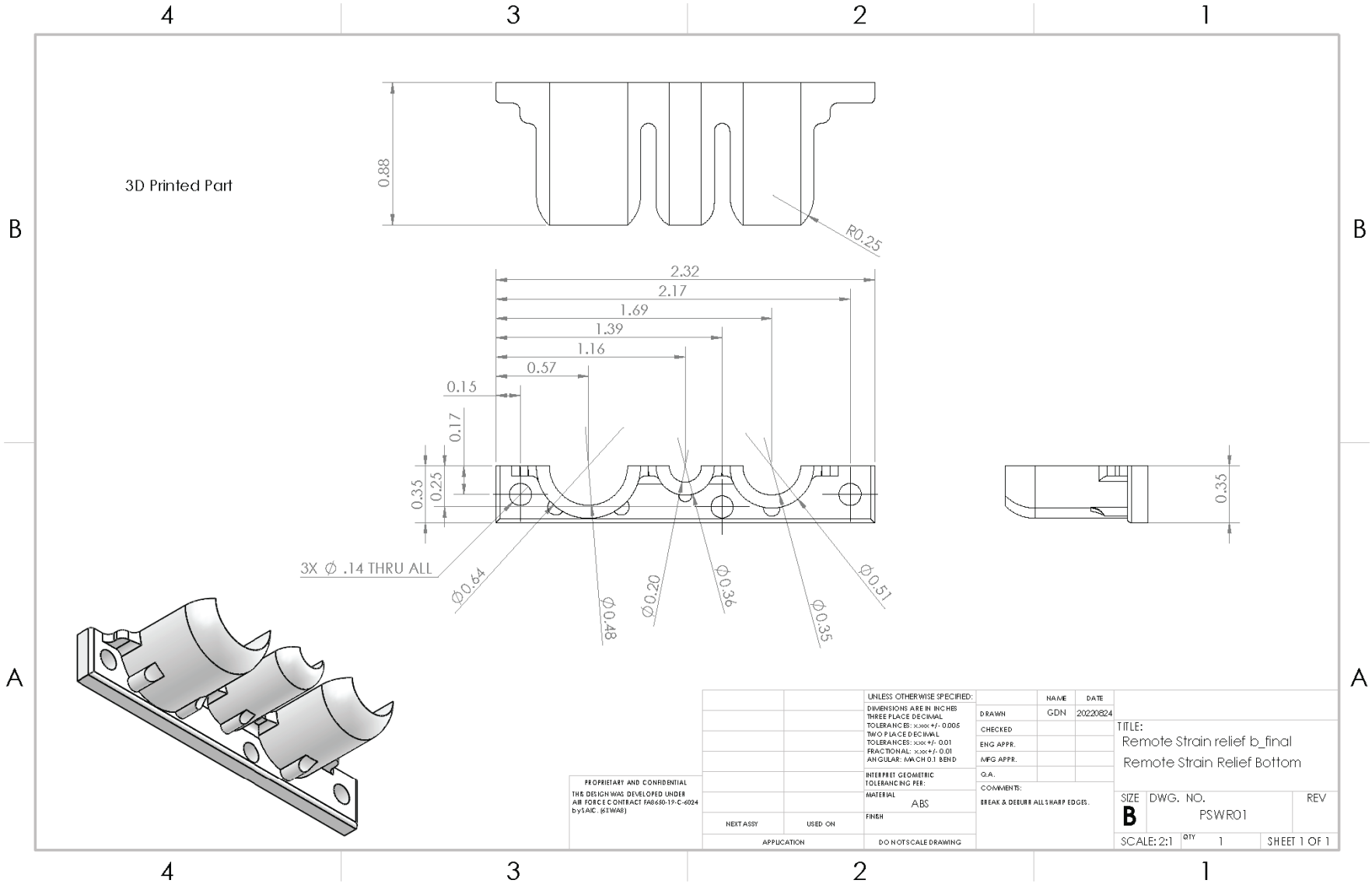

Figure 84: Remote Strain Relief b

APPENDIX B: PARTS LIST

B.1 Mobile Base

Subassembly	Part	Source	Part Number	Description	QTY	NOTES:
Mobile Base	8020 kit:	Shepherd Controls	-	pre cut 8020 frame, fasteners, and wheels/ mounts	1	
(Mobile Base)	castors	Shepherd Controls	2337			
(Mobile Base)	castor support	Shepherd Controls	PSMB04			
(Mobile Base)	8020 frame	Shepherd Controls	PSMB05, PSMB06, PSMB07			
(Mobile Base)	hardware	Shepherd Controls	-			
Mobile Base	Base Plate	ITM	PSMB01		1	
Mobile Base	Scissor Jack	Air Technical	MSL-A1519	15" x 19", capacity 250lbs, variable speed, limit switches	1	
Mobile Base	Top Plate	ITM	PSMB02		1	
Mobile Base	Tapped Linear Motion Shaft	McMaster	6649K13	Tapped on Both Ends, 52100 Alloy Steel, 3/4" Diameter, 12" Long	4	
Mobile Base	Linear Bearing Suport	ITM	PSMB03		4	
Mobile Base	Flange- Mounted Linear Ball Bearing	McMaster	6483K750	with Round Housing, 3-1/8" x 2-3/16" x 2-3/16" Overall	4	
Mobile Base	Linear Bearing Support --> Flange Hardware	McMaster	92196A269	10-32 Thread Size, 1/2" Long, 18-8 Stainless Steel Socket Head Screw	32	100pk
Mobile Base	Scissor Jack Mounting Hardware (top + bottom)	(in house)	(in house)	1/4"-20 SS Cap Head	8	

Mobile Base	**(HARDWARE SELECTION)**					
Mobile Base	Base Plate Mounting 8020 Nut (includes washers)	McMaster	47065T145	5/16"-18 8020 slot nut SS	10	4pk x 3
Mobile Base	Base Plate Mounting Bolts (if no washer)	McMaster	92949A581	5/16"-18 Thread Size, 3/4" Long, 18-8 Stainless Steel Button Head Hex Drive Screw	10	25pk

Mobile Base	Base Plate Mounting Bolts (if with washer)	McMaster	92949A583	5/16"-18 Thread Size, 7/8" Long, 18-8 Stainless Steel Button Head Hex Drive Screw	10	
Mobile Base	Linear Bearing Support + Top Plate bolt	McMaster	91099A482	82 Degree Countersink, 5/16"-18 Thread, 3/4" Long, Undercut, Passivated 18-8 Stainless Steel Phillips Flat Head Screw	4	25pk

*ITM - Innovation, Technology, Machinery (www.itm-texas.com)

B.2 X-Y Translation

Subassembly	Part	Source	Part Number	Description	QTY	NOTES:
X-Y	Mounted Linear Sleeve Bearing	McMaster	6374K342	for Support Rail Shafts, 0.0015" Clearance, 3-1/2" Length	8	
X-Y	One-Piece Support Rail Shaft	McMaster	1049K15	Ceramic-Coated 6063 Aluminum, 1/2" Diameter, 24" Long	4	
X-Y	XY Plate - Top	ITM	PSXY01A		1	
X-Y	XY Plate - Middle	ITM	PSXY01B		1	
X-Y	XY Plate - Bottom	ITM	PSXY01C		1	
X-Y	Linear Actuator	Motion Systems Cp.	85915	40lb capacity	2	
X-Y	Actuator Body and Rod Mounting Bracket	ITM	PSXY02		4	

X-Y	**(HARDWARE SELECTION)**					
X-Y	X Carriage Mount Hardware	McMaster	92949A149	6-32 Thread Size, 7/16" Long, 18-8 Stainless Steel Button Head Hex Drive Screw	32	100pk D
X-Y	Y Carriage Mount Hardware	McMaster	(92949A149)	6-32 Thread Size, 7/16" Long, 18-8 Stainless Steel Button Head Hex Drive Screw	32	pkD
X-Y	X Rail Mount Hardware	McMaster	(92949A149)	6-32 Thread Size, 7/16" Long, 18-8 Stainless Steel Button Head Hex Drive Screw	10	pkD
X-Y	Y Rail Mount Hardware	McMaster	(92949A149)	6-32 Thread Size, 7/16" Long, 18-8 Stainless Steel Button Head Hex Drive Screw	10	pkD
X-Y	Actuator Bracket Mounting cap head	McMaster	92196A144	6-32 Thread Size, 1/4" Long, 18-8 Stainless Steel Socket Head Screw	8	100pk
X-Y	Actuator Bracket Mounting button head	McMaster	92949A144	6-32 Thread Size, 1/4" Long, 18-8 Stainless Steel Button Head Hex Drive Screw	8	100pk
X-Y	Actuator Bracket Mounting Pin	McMaster	92196A198	8-32 Thread Size, 7/8" Long, 18-8 Stainless Steel Socket Head Screw	4	100pk E

X-Y	Actuator Bracket Mounting Pin washer	McMaster	92141A009	for Number 8 Screw Size, 0.172" ID, 0.375" OD, 18-8 Stainless Steel Washer	4	100pk
X-Y	Actuator mounting shims A	McMaster	94773A708	for Shortening 3/16" Diameter Screw Shoulder, 0.02" Thick	1	10pk
X-Y	Actuator mounting shims B	McMaster	94773A739	for Shortening 3/16" Diameter Screw Shoulder, 0.03" Thick	1	10pk
X-Y	Actuator mounting shims C	McMaster	94773A768	for Shortening 3/16" Diameter Screw Shoulder, 0.06" Thick	1	5pk
X-Y	Actuator mounting shims D	McMaster	94773A608	for Shortening 3/16" Diameter Screw Shoulder, 0.005" Thick	1	10pk

B.3 Rotation Axis

Subassembly	Part	Source	Part Number	Description	QTY	NOTES:
Rotation	Top Plate	ITM	PSR01		1	
Rotation	Bottom Plate	ITM	PSR02		1	
Rotation	Front Support (FS)	ITM	PSR03		1	
Rotation	FS Bearing	ITM	PSR04		1	
Rotation	Support Beam (SB)	ITM	PSR05		2	
Rotation	SB Bearing	ITM	PSR06		2	
Rotation	Actuator Fixed End Mount	ITM	PSR07		1	
Rotation	Actuator Nut Mount	ITM	PSR08		1	
Rotation	Actuator Nut Clamp	ITM	PSR09		1	
Rotation	Linear Actuator	Motion Systems Cp	85616	100lb capacity	1	
Rotation	Oil-Embedded Bronze Sleeve Bearing	McMaster	6391K126	for 1/4" Shaft Diameter and 5/16" Housing ID, 1/4" Long	2	
Rotation	18-8 Stainless Steel Low-Profile Precision Shoulder Screw	McMaster	90337A193	Socket Drive, 1/4" Shoulder Diameter, 1/4" Shoulder Length, 10-32 Thread	2	
Rotation	Oil-Embedded Bronze Sleeve Bearing	McMaster	6391K876	for 3/8" Shaft Diameter, for 7/16" Housing ID, 3/8" Long	1	
Rotation	18-8 Stainless Steel Shoulder Screw	McMaster	97832A274	3/8" Shoulder Diameter, 3/8" Shoulder Length, 1/4"-20 Thread Size	1	

Rotation	**(HARDWARE SELECTION)**					
Rotation	FS bottom hardware (1/2in long)	McMaster	92949A537	1/4"-20 Thread Size, 1/2" Long, 18-8 Stainless Steel Button Head Hex Drive Screw	4	50 pk H
Rotation	FS bottom hardware washers	McMaster	92141A029	for 1/4" Screw Size, 0.281" ID, 0.625" OD, 18-8 Stainless Steel Washer	4	100 pk G
Rotation	FS --> FS Bearing hardware (3/8in)	McMaster	91099A260	82 Degree Countersink, 8-32 Thread, 3/8" Long, Undercut, Passivated 18-8 Stainless Steel Phillips Flat Head Screw	4	100pk C

Rotation	SB bottom hardware (3/8in)	McMaster	(91099A260)	83 Degree Countersink, 8-32 Thread, 3/8" Long, Undercut, Passivated 18-8 Stainless Steel Phillips Flat Head Screw	20	pk C
Rotation	SB --> SB Bearing hardware (1/4in, accept 3/8)	McMaster	(91099A260)	84 Degree Countersink, 8-32 Thread, 3/8" Long, Undercut, Passivated 18-8 Stainless Steel Phillips Flat Head Screw	20	pk C
Rotation	Actuator Nut Mount + Clamp attachment	McMaster	92196A271	10-32 Thread Size, 5/8" Long, 18-8 Stainless Steel Socket Head Screw	2	100 pk
Rotation	Actuator Nut Mount + Clamp washer	McMaster	92141A011	for Number 10 Screw Size, 0.203" ID, 0.438" OD, 18-8 Stainless Steel Washer	2	100 pk
Rotation	Actuator Nut Mount Set Screw	McMaster	92845A335	18-8 Stainless Steel, 10-32 Thread, 3/8" Long, Extended-Tip Set Screw	2	25 pk
Rotation	Actuator Bracket Mounting Pin	(in house)	(in house)	1/4-20 x 1"+ cap or button	1	
Rotation	Actuator Bracket Mounting Pin washer	(in house)	(in house)	1/4-20 hole	1	
Rotation	Shoulder screw shims (actuator)	McMaster	91017A464	for Lengthening 5/16" Diameter Screw Shoulder, 0.005" Thick, 316 Stainless Steel Shims	1	
Rotation	Shoulder screw shims (front rotation)	McMaster	91017A456	for Lengthening 1/4" Diameter Screw Shoulder, 0.005" Thick, 316 Stainless Steel Shims	1	

B.4 Roll Axis

Subassembly	Part	Source	Part Number	Description	QTY	NOTES:
Arc	Arc Slide	ITM	PSP01		2	
Arc	8020 Arc Connector Bar (1.5" x 3") x 20"	Shepherd	PSP02		1	
Arc	Precision Shoulder Screw	McMaster	94035A307		6	
Arc	Permanently Lubricated Ball Bearing	McMaster	2342K185		6	
Arc	8020 Arc Slide and Connector Bar attachment hardware	McMaster	91099A482	82 Degree Countersink, 5/16"-18 Thread, 3/4" Long, Undercut, Passivated 18-8 Stainless Steel Phillips Flat Head Screw	4	25pk A
Roll	Subject Platform	ITM	PSP03		1	
Roll	8020 Platform Support Frame (1.5" x 3") x 16"	Shepherd	PSP04		4	
Roll	Extra-Wide Sleeve Bearing Carriage 500mm	McMaster	6109K62 - MOD	500mm	2	
Roll	Extra-Wide Sleeve Bearing Carriage 500mm (machining)	(in house)	PSP13		2	
Roll	Extra-Wide Sleeve Bearing Carriage (car)	McMaster	6109K265 - MOD		2	
Roll	Extra-Wide Sleeve Bearing Carriage (car) (machining)	(in house)	PSP14		2	
Roll	8020 4 Hole Strap Connector (includes fasteners)	McMaster	47065T261	T-Slotted Framing, Surface Bracket, 6" Long for 1.5" High Single Rail (Silver)	8	
Roll	Arc Track - black hard anodize	ITM	PSP05		2	
Roll	8020 Arc Track Frame Support (1.5" x 1.5") x 21"	Shepherd	PSP06		2	
Roll	Bronze Bearing for Actuator Rod Shoulder Screw	McMaster	6391K736	Oil-Embedded Bronze Sleeve Bearing for 1/2" Shaft Diameter, for 5/8" Housing ID, 5/16" Long	1	

Roll	Linear Actuator	Motion Systems Corp	85152-RH-40-10-ALT-STD-B-0_375-DC5	500lb capacity	1	
Roll	Actuator Nut Mount (Bottom)	ITM	PSP07		1	
Roll	Actuator Nut Mount (Cap)	ITM	PSP08		1	
Roll	Actuator Rod Mount Pedistal	ITM	PSP09		1	
Roll	Actuator Nut Mount Set Screw	McMaster	95289A164	Extra-Long Extended-Tip Set Screw, 3/8"-24 Thread Size, 3/4" Long	2	
Roll	Actuator Nut Mount Shoulder Screw	McMaster	97832A147	18-8 Stainless Steel Shoulder Screw, 1/2" Shoulder Diameter, 1" Shoulder Length, 5/16"-18 Thread Size	1	
Roll	Actuator Nut Mount connector	McMaster	(92196A198)	8-32 Thread Size, 7/8" Long, 18-8 Stainless Steel Socket Head Screw	4	pk E
Roll	Actuator Rod Mount Shoulder Screw	McMaster	97832A280	18-8 Stainless Steel Shoulder Screw, 3/8" Shoulder Diameter, 1" Shoulder Length, 1/4"-20 Thread Size	1	
Roll	Actuator Rod Motion Arc Bushing	McMaster	98042A452	Press-Fit Drill Bushing, 0.5156" ID, 3/4" OD, 1/2" Long	1	
Roll	Horizontal Surface Mount Tube Level	McMaster	3338A22	Horizontal-Surface-Mount Tubular Level	2	
Roll	8020 4 corner braces (includes hardware)	McMaster	47065T312	Black Corner Bracket, 3" Long for 1-1/2" High Rail T-Slotted Framing	4	
Roll	Subject Platform to OS/OD Sliders Hardware	McMaster	92949A581	5/16"-18 Thread Size,3/4" Long button	4	25pk
Roll	Arc Frame to OS/OD Sliders Hardware	McMaster	92949A582	5/16"-18 Thread Size, 1" Long Button	4	25pk
Roll	Extra Wide Carriage Spacers	ITM	PSP11		2	
Roll	Channel alignment nut	ITM	PSP12		4	

Roll	**(HARDWARE SELECTION)**					
Roll	8020 Arc Track Frame Support + Arc Track Hardware	McMaster	(91099A481)	5/16"-18 x 3/4 SS flathead	4	pk A

Roll	Subject Platform Mounting Screws - floating	McMaster	91771A580	82 Degree Countersink, 5/16"-18 Thread, 5/8" Long, Undercut, Passivated 18-8 Stainless Steel Phillips Flat Head Screw	4	25pk
Roll	Subject Platform Mounting Screws - locking	McMaster	92949A580	5/16"-18 Thread Size, 5/8" Long, 18-8 Stainless Steel Button Head Hex Drive Screw	2	25pk
Roll	splash skirt fasteners?	(in house)	(in house)	8 32 caphead, how long?	10	
Roll	actuator nut clamp hardware	(in house)	(in house)	8 32 caphead, how long?	4	
Roll	actuator rod end bushing connector	(in house)	(in house)	1/4 20 cap head	1	
Roll	8020 Nut for rail and carrier mounting	McMaster	47065T145	5/16"-18 8020 slot nut SS	8	4pk x 2
Roll	7-16 - 20 tap	(in house)	(in house)	Use on carriage ends	1	
Roll	large flange bolt for OD/OS carriage slide stop	McMaster	92316A341	Flanged Hex Head, 7/16"-20 Thread Size, 1" Long, Black-Phosphate Grade 8 Steel Screws	8	

B.5 Subassembly Connections

Subassembly	Part	Source	Part Number	Description	QTY	NOTES:
Mobile Base --> X-Y	MB Top Plate to X-Y Bottom	McMaster	(in house)	1/4-20 socket head cap screw, 1/2"	4	
Mobile Base --> X-Y	MB Top Plate to X-Y Bottom Washer	McMaster	(92141A029)	for 1/4" Screw Size, 0.281" ID, 0.625" OD, 18-8 Stainless Steel Washer	4	pk G
X-Y --> Rotation	X-Y Top Plate to Rotation Bottom Plate	McMaster	(92949A537)	1/4"-20 Thread Size, 1/2" Long, 18-8 Stainless Steel Button Head Hex Drive Screw	4	pk H
Rotation --> Pitch	R Top Plate to Arc track smile	McMaster	92949A265	10-32 Thread Size, 1/2" Long, 18-8 Stainless Steel Button Head Hex Drive Screw	4	100pk
Rotation --> Pitch	R Top Plate to 8020 frame	McMaster	(91099A481)	5/16 18 countersunk screw to locknuts	8	pkA ?

B.6 Accessories

Subassembly	Part	Source	Part Number	Description	QTY	NOTES:
Alignment Jig	Attachment thumb screw tether	McMaster	90312A325	Eye-to Eye, Coated, 3/64" Diameter, 8" Length, Galvanized Steel Lanyard - Not for Lifting	1	
Alignment Jig	Jig baseplate	ITM	PSAJ01		1	
Alignment Jig	Jig post	ITM	PSAJ02		2	
Alignment Jig	Jig sight	ITM	PSAJ03		2	
Alignment Jig	Jig stabilizer bar	ITM	PSAJ04		1	
Alignment Jig	attachment thumb screw	McMaster	92421A537	1/4"-20 Thread Size, 1/2" Long, Brass Flared-Collar Knurled-Head Thumb Screws	1	10pk
Alignment Jig	Dowel pins for mounting alignment	McMaster	90145A537	1/4" Diameter, 1/2" Long, 18-8 Stainless Steel Dowel Pin	4	10pk
Alignment Jig	small post for component storage mount	In House	--	3/4 inch dia. 1 inch height, 1/4-20 tap on bottom	1	
Alignment Jig	Post to mobile base plate attachment screw	In House	--	1/4-20 screw	1	
Alignment Jig - Acc	Jig storage post	In House	PSACC07	(turned from stock aluminum)		

Roll - chin	Chin support rod holder	ITM	PSP10		1	
Roll - chin	90 degree post mount	ThorLabs	RA360	Parallel Clamp for Ø1/2" Posts, #8 Counterbore and 3/16" Hex	2	
Roll - chin	Chin rest rotation shoulder screw	McMaster	93691A280	1/4" Shoulder Diameter, 1/4" Shoulder Length, 10-32 Thread, 18-8 Stainless Steel Precision Shoulder Screw with Certification	1	
Roll - chin	chin rest rotation adjustment handle	McMaster	60655K24	BLACK - Zinc Adjustable- Position Handle, with Stainless Steel 10-32 Threaded 9/16" Long Stud, 1-3/16" Projection	1	
Roll - chin	chin rest rotation adjustment washer	McMaster	92141A011	Number 10 Screw Size, 0.203" ID, 0.438" OD, 18-8 Stainless Steel Washer	1	100 pk
Roll - chin	Chin rest post	ThorLabs	TR6	Ø1/2" Optical Post, SS, 8-32 Setscrew, 1/4"-20 Tap, L = 6"	4	

Roll - chin	Chin rest post 90 angle end mount	ThorLabs	RA180	Right-Angle End Clamp for Ø1/2" Posts, 1/4"-20 Stud and 3/16" Hex	2
Roll - chin	Trach Tube Clip	In House	PSACC01	3D printed	1
Roll - chin	Chin Rest v4	In House	PSACC02	3D printed	1
Roll - chin	Stabilizer Post	In House	PSACC03	3D printed	2
Roll - chin	Cheek Paddle	In House	PSACC04	3D printed	2

MB - push bars	8020 Post mounting brackets (includes hardware)	McMaster	47065T44	Silver Rail-to-Tube Holder for 3" High Double/Quad Rail	2
MB - push bars	1" OD tubing	McMaster	89965K681	6ft length, 1" OD, 0.065" Wall Thickness, General Purpose Aluminum Tubing	2
MB - push bars	Push bar upright	In House	PSACC09	cut to length from McMaster 1"OD tubing 89965K681	2
MB - push bars	Push bar crosspiece	In House	PSACC10	cut to length from McMaster 1"OD tubing 89965K681	1
MB - push bars	Pipe fittings - T	Grainger	30LX02	1" ID T-shaped pipe fitting	2
MB - maintenance	Actuator lubrication grease	AdvaceAuto	10574	Red'n'Tacky #2 Grease (1lb)	1

Roll - subject	8020 Subject restraint posts	McMaster	9390N17, PSACC08	6ft length, 1" OD, 0.028" Wall Thickness, General Purpose Aluminum Tubing	2	
Roll - subject	8020 Post mounting brackets (includes hardware)	McMaster	47065T44	Silver Rail-to-Tube Holder for 3" High Double/Quad Rail	4	
Roll - subject	quick release handles	McMaster	6305K51	Plastic Adjustable-Position Handle, with 1/4"-20 Threaded 1-1/4" Long Stud, 1-3/8" Projection	4	
Roll - subject	knobs	McMaster	2454K66	Four-Arm Comfort-Grip Knob, 1/4"-20 Threaded Stud, 1-3/4" Diameter Head	4	
Roll - subject	Subject Restraint post caps	McMaster	3504T43	Food Industry Round Caps for 1" OD	1	pk of 25
Roll - subject	Bubble Level	McMaster	3338A22	Horizontal-Surface-Mount Tubular Level	2	
Roll - subject	Bubble Level mount	In House	PSACC11	3D printed	4	

Electronic Accessory	Limit switch mount - z-stop	In House	PSACC05	3D printed	1
Electronic Accessory	Limit switch mounting bracket	In House	PSACC06	Fabricated	1
Electronic Accessory	Electronics enclosure	In House	1411Z Bottom Mod	Part modification - CNC cutout	1
Electronic Accessory	Remote box	In House	RL6055B w1 151103	Part modification - CNC cutout	1
Electronic Accessory	Strain Relief a	In House	PSWR02	3D printed	1
Electronic Accessory	Strain Relief b	In House	PSWR01	3D printed	1

B.7 Electrical

Subassembly	Part	Source	Part Number	Description	QTY	NOTES:
XY and Rotation	Drive for XY and Rotation Actuators	Dart Controls	13DV2A-TS	13DV2A-TS - 12/24VAC Small Dual Voltage SCR Control 2.0 DC Amps with onboard three position terminal strip	2	
Pitch	Drive for Pitch Actuator	Dart Controls	15DV2A-TS	15DV2A-TS 120/240VAC Small Dual Voltage SCR Control, 2.0 DC Amps with onboard three position terminal strip	1	
All	Switch	Digi-Key	679-1182-ND	APEM Inc. 2647LH/2A212000L0 SEALED IP56 DPDT (ON)-OFF-(ON) Rocker Switch DPDT 10A (DC) Panel Mount, Snap-In	5	
All	Cable for speed control potentiometers to remote	Digi-Key	2389-CF881.05.12-ND	CF881.05.12 Igus CABLE 12COND 20AWG BLK SHD	10	
All	Cable for speed control to remote	Digi-Key	2389-CF881.05.18-ND	CF881.05.18 Igus CABLE 18COND 20AWG BLK SHD	10	
All	Cable for motors	Digi-Key	2389-CF880-05-03-ND	CF880-05-03 Igus CABLE 3COND 20 AWG BLACK	50	
XY and Rotation	Actuator power	Digi-Key	237-1950-ND	F-260U Triad Magnetics PWR XFMR LAMINATED 144VA CHAS MT	1	
All	Main power switch / Main fuse	Digi-Key	603-1262-ND	10C2 Delta Electronics PWR ENT MOD RCPT IEC320-C14 PNL	1	
Remote	Remote box	Digi-Key	HM1081-ND	RL6055 Hammond Manufacturing BOX ABS GRAY 7.118"L X 4.218"W	1	
XY and Rotation	24 VAC power fuse holder	Digi-Key	732-11380-ND	696211001102 Würth Elektronik SHOCKSAFE FUSEHOLDERS - PANEL	1	
XY and Rotation	24 VAC power fuse	Digi-Key	507-1545-ND	5ET 5-R Bel Fuse Inc. FUSE GLASS 5A 250VAC 5X20MM	3	
All	120 VAC and 24 VAC distribution	Digi-Key	WM5778-ND	WM5778-ND0387600106 Molex CONN BARRIER STRIP 6CIRC 0.375"	2	
All	120 VAC and 24 VAC distribution blocks	Digi-Key	WM4244-ND	0387236502 Molex JUMPER BARRIER BLK 2POS SPADE	10	

Z and Pitch	Connector for Z and Pitch panel mount	Allied Electronics	70083005	206430-1 Circular Plastic Connector Plug Assembly Sz11 Panel Mount Rev Sex 4 Position	2
Z and Pitch	Connector for Z and Pitch cable end	Allied Electronics	70083004	206429-1 Circular Plastic Connector Plug Assembly Sz11 Free Hang Reverse Sex 4 Position	2
Remote	Connector for speed control to Remote cable end	Allied Electronics	70083006	206044-1 Circular Plastic Connector Plug Assembly Sz17 Free Hang Rev Sex 14 Position	1
Remote	Connector for speed control to Remote panel mount	Allied Electronics	70083007	206043-1 Circular Plastic Connector Plug Assembly Sz17 Panel Mount Rev Sex 14 Position	1
Remote	Connector for direction control panel mount	Allied Electronics	70087405	211773-1 Connector Housing CPC Receptacle 19 Pos. Sz. 23 Series 1 Panel Mnt Rev Sex	1
Remote	Connector for direction control cable end	Allied Electronics	70087406	211772-1 Connector Housing CPC Plug Assy 19 Pos. Sz. 23 Series 1 Free Hang Rev Sex	1
Rotation	Connector for Rotation cable end	Allied Electronics	70087239	211400-1 Circular Plastic Connector Plug Assembly Sz13 Free Hang Rev Sex 7 Position	1
Rotation	Connector for Rotation panel mount	Allied Electronics	70087237	211398-1 Connector Housing CPC Receptacle 7 Pos Sz. 13 Series 1 Panel Mount Rev Sex	1
XY	Connector for XY panel mount	Allied Electronics	70082959	206433-1 Connector Housing CPC Recept. Assy 8 Pos. Sz 11 Series 2 Panel Mnt Rev Sex	1
XY	Connector for XY cable end	Allied Electronics	70082955	206434-1 Connector Housing CPC Plug Assy 8 Pos. Sz. 11 Series 2 Free Hang Rev Sex	1
All	Pins for XY connector	Allied Electronics	70083291	66506-9 AMPLIMITE HDP-20 pin crimp contact 20 DF HDP20 Series	16

All	Sockets for XY Connector	Allied Electronics	70083292	66504-9 Socket Contact Size 20 Gold Plating Crimp 2 A 20-24 AWG AMP Series	16
All	Pins for Pitch, Rotation, and Z	Allied Electronics	70042260	1-66400-0 Type III+ Contact Pin 24-20AWG Bright Tin Plating Crimp CPC Series 1	50
All	Sockets for Pitch, Rotation, and Z	Allied Electronics	70994272	66399-1 Type III+ Series Female Crimp Contact for use with Type III + Series Connector	50
Control Box	Control box housing	Digi-Key	HM333-ND	1411Z BOX ALUM GRAY 16.980"L X 5.010"W	1
Z	Junction Box	Digi-Key	HM1968-ND	1590YBK BOX ALUM BLACK 3.622"L X 3.622"W	1
Z	Strain relief	Digi-Key	2081-96571.1-ND	96571.1 CABLE GLAND 7-11MM M16 POLYAMIDE	2
Remote	Strain relief	Digi-Key	1722-1461-ND	GC2000-ACABLE GLAND 3.5-6.5MM PG7 POLY	4
Z and Pitch	Back shell	Digi-Key	A32515-ND	1-206062-4 CONN BACKSHELL W/CLAMP SZ 11	2
Rotation	Back shell	Digi-Key	A106559-ND	206966-9 CONN BACKSHELL W/CLAMP SZ 13 BLK	1
Remote	Back shell	Digi-Key	A135696-ND	213904-4CONN BACKSHELL W/CLAMP SZ 17 BLK	1
Remote	Back shell	Digi-Key	A111988-ND	1-206138-0 CONN CABLE CLAMP SZ 23 1 3/8-18	1
XY	Back shell	Digi-Key	A32518-ND	206358-5 CONN BACKSHELL W/CLAMP SZ 11 BLK	1
Z	Cable	Digi-Key	2389-CF880.05.04-ND	CF880.05.04 CABLE 4COND 20AWG BLACK 1=1FT	10
Remote		McMaster	60955K61	Comfort-Grip Plastic Indicating Knob for Round Shafts, 5/8" Diameter 9/16" High Head	4

All		McMaster	2735K23	Moisture-Seal Heat-Shrink Semi-Rigid Tubing 4 Feet Long, 0.43" ID Before Shrinking, Black	1
All		McMaster	2735K141	Moisture-Seal Heat-Shrink Semi-Rigid Tubing 1/2 Feet Long, 0.7" ID Before Shrinking, Black	1
All	Main Power fuse	Digi-Key	507-1215-ND	5HT 6.3-R Bel Fuse Inc. FUSE CERAMIC 6.3A 250VAC 5X20MM	5