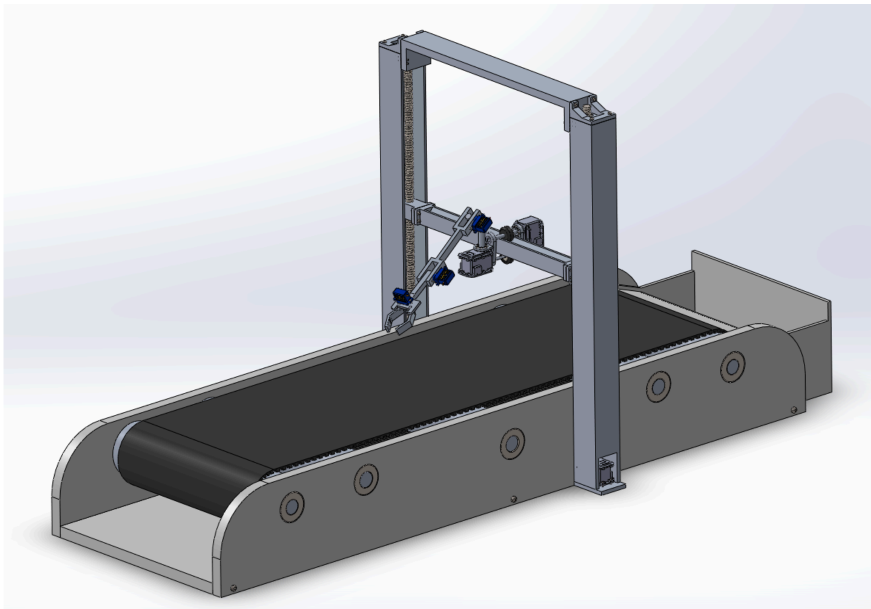
Final Report: CAD Project
Automated Quality Sorting Manipulator



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Abstract

The Automated Quality Sorting Manipulator (AQSM) is a robotic sorting system designed to automate the transfer and separation of components on a manufacturing conveyor. The system combines a conveyor, dual-axis gantry, articulated robotic arm, and motorized gripper to provide the translational and rotational motion required to pick up components and transfer them to a designated collection or reject area.

The final design consists of 29 parts, including custom structural components and commercially available bearings and fasteners. Most structural components use 1060 aluminum alloy, while some components are designed for ABS additive manufacturing to decrease weights and costs. Lead screws provide motion along the vertical axes, while a wheel mechanism provides horizontal movement. The articulated, chain-link arm and gripper provide additional reach and allow components to be picked up and released at distance.

The design was evaluated using computer-aided design and theoretical calculations. The lead screw was calculated to have a helix angle of approximately 3.41° and a transmission efficiency of 22.7%. With an actuator torque of 2.5 N·m, the screw was predicted to produce approximately 1681 N of axial thrust, while the carriage required less than 1 N to accelerate. However, the shallow lead resulted in a predicted linear velocity of approximately 1.94 mm/s at 55 rev/min, making travel speed a significant limitation of the current design. The lead-screw geometry was also found to provide resistance to back-driving under the assumed friction conditions. Improvements to this could be made at further iterations.

The AQSM satisfies the primary design requirements of providing multiple degrees of freedom, powered motion, and component transfer between a conveyor and collection area. Manufacturing considerations were incorporated through the use of machinable materials, additive manufacturing, and commercially available hardware. Since no physical prototype was fabricated and tested, the reported performance values are theoretical predictions. The analysis identifies increased linear speed and transmission efficiency as key areas for future design improvement. Overall, the analysis serves to highlight that the design can be a success with rigorous testing.

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List of Symbols

Symbol	Description	Unit (SI)
D	Major thread diameter	mm
d_m	Mean thread diameter	mm
p	Thread pitch	mm
l	Thread lead	mm
λ	Thread helix angle	degree
μ	Coefficient of friction	dimensionless
η	Transmission efficiency	Dimensionless (out of 100)
T	Torque	N·m
F	Axial force	N
N	Rotational speed	rev/min
v	Linear velocity	mm/s
δ	Positional error or deflection	μm or mm
m	Mass	kg
g	Acceleration due to gravity	m/s^2
r	Radius, or distance to centre of mass	mm
R	Reach, pivot to gripper	mm
a	Linear acceleration	m/s^2
α	Angular acceleration	rad/s^2
J	Mass moment of inertia	$kg \cdot m^2$

1. Introduction and General Background

In modern manufacturing, automated systems focus heavily on reducing labor costs, improving production efficiency, and maintaining consistent product quality. A common task in industrial production is the sorting of manufactured components based on inspection or quality-control criteria. Manual sorting is often repetitive, time-consuming, and extremely susceptible to human error, especially in assembly lines where countless products flow through simultaneously. There is a growing need for robotic systems capable of identifying defective components and ensuring that only viable components are accepted.

To address this need, our team designed an Automated Quality Sorting Manipulator (AQSM), a robotic manipulator capable of transferring components between a conveyor belt and a reject bin. The system combines a dual-axis gantry with an articulated robotic arm and a motorized gripper capable of picking components from the conveyor, transporting them or discarding them if they are defective.

The machine was designed to satisfy project requirements while remaining as manufacturable as possible given common fabrication methods. Most components are made from 1060 aluminum alloy, a common, lightweight, yet strong material, as well as some parts of acrylonitrile butadiene styrene (ABS), a common 3D printable plastic. All fasteners and bearings are also commonly available sizes.

2. Design Goals and Objectives

The design goals and objectives for this project are outlined below. The AQSM must:

1. Transfer components from a conveyor system to a designated collection area or reject bin, so an arm must have sufficient reach.
2. Provide three degrees of freedom, with at least one rotational degree of freedom
3. Utilize electric motors or servo motors for powered motion.
4. Be designed as an assembly containing at least five unique subassemblies, with each subassembly containing at least five unique custom-designed parts.
5. Be manufacturable using common machine shop operations as well as only include commercially available bearings and fasteners whenever practical.

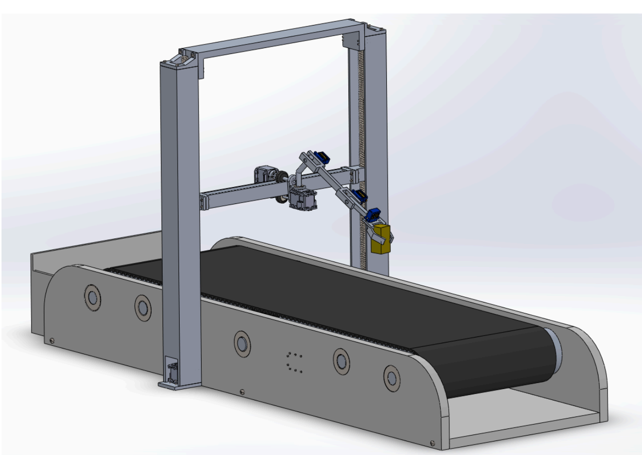

Figure 1: The AQSM picking up a sample component, depicted in yellow, demonstrating its use case.

3. Prior Work

To satisfy the needs of the industry for such a device, there exists few options on the market. Most commonly, these devices are seen in the food industry, and do not involve an articulating arm like the AQSM. These devices are relatively passive. Such as the automatic sorting machine shown below:

Figure 2: Example of Automatic Sorting Machine on Market [1][1]

The Automatic Sorting Machine above completes the task of being able to select components that are deemed of acceptable quality, and lets them pass through to the next conveyor belt below. Although it does not satisfy the same objectives as providing 3 degrees of freedom and being manufacturable using machine shop parts and easily purchasable components, it is able to complete the main objectives outlined for the AQSM.

Figure 3: Example of Automatic Sorting Platform on Market [2][2]

The device shown to the left resembles more similarly the objectives of the AQSM but does not have ease of manufacturability nor satisfies the need to be robust enough to perform in an assembly line. That being said, it still accomplishes the goals, while also having an articulating arm, unlike the Automatic Sorting Machine in Figure 2.

[1] [1]. This image was used from RadioStudio, a machine learning blog. The exact link can be found in the reference section
[2] [2]. Image from Think Robots. Example of a Sorting platform. Link in Reference Section.

4. Concept Development

The idea for the AQSM essentially arose from combining strengths of various industry devices.

Design Concept 1: 3D Printer

Early development of the AQSM looked similar to that of a 3D printer. The wheel on the X-axis as well as the Y-gantry take direct inspiration from 3D printers on the market. This can be seen well below:

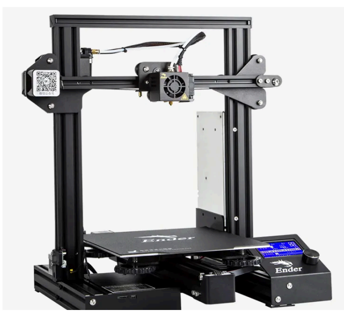

Figure 4: Example 3D Printer: Ender 3 Pro [3][3]

The AQSM differs slightly in structure to a conventional 3D printer. For one, the AQSM does not have a hot-end printing attachment but rather an articulating arm (more to be discussed later) and employs a conveyor instead of a controlled z-axis. The Y-gantry of the AQSM is essentially the same, but the X-axis differs from conventional 3D printing builds as it employs driven wheel motion instead of a belt to move the attachment. Both Y-gantries consist of lead screws to articulate motion in that direction. Although the AQSM uses a dual gantry to ensure that each motor does not exceed its torque limits. The 3D printer provides a key starting point for the design of the AQSM but still did not accomplish all the objectives.

Design Concept 2: Conveyor

Figure 5: Example Of Conveyor Belt [4][4]

The addition of a conveyor into the AQSM allows the machine to be deployed in any industry assembly line. The choice to include one was an obvious choice when considering ways to satisfy the objectives.

Design Choice: AQSM

The final design choice for the AQSM met all the objectives by combining each of the design concepts with an articulating arm. Employing the 3D printer's ideas of y-gantries and x-axis movement allows for extreme and robust articulation, while the conveyor allows for ease of usability. The design for the arm is uninspired, but comes from the need to be able to reach over long distances, so that it can place defective objects as far as the user sees fit.

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[3] [3] This image is from Creality, a 3D printer manufacturer. The link is found in the references.
[4] [4] This image is from IndiaMart, a manufacturing market. The link is found in the references.

5. Theoretical Calculations

In this section, we use known and measured quantities from our assembly to determine some metrics which can be analyzed and interpreted to understand the strengths and features of each part, as well as suggesting possible areas of improvement in subsequent models with a full set of simulation-related data and user testing to learn from.

The calculations (as well as tools such as the motion testing feature in SolidWorks) are predictive; no physical prototype or creation was tested under real-world conditions.

Several assumptions are made to idealize and simplify what can be a very complicated system to model through elementary means with multiple parts in motion.

The coefficient of friction is assumed to be a firm value of 0.20, and this relies on using a steel screw in an 1060-aluminium nut. Published ranges vary depending on exact conditions and empirical date but can be roughly between 0.15 and 0.25, by most engineering databases, so this lies well within this range. This matters since over the range the efficiency can vary by percentages in the double digits.

It is worth mentioning that the thread dialog in SolidWorks says 1-12 but the diameter was overridden to 0.5 in. A quick skim of the component specifications page in SolidWorks confirms that it is a single-start right hand thread. Lastly, actuator performance is contingent on it running at 12V, in line with the values from the MX-28AR datasheet, taken from Robotis's website.

Onto the actual calculations themselves, we converted from inches, as our display was set to IPS and kept like that:

Starting with Equation 1, a standard, well-known expression in engineering for our particular configuration and specific type of screw (one of two common types, the other involves cosine terms instead of tan); unwrapping a single turn of the thread gives a ramp that rises (or drops) 2.117 mm while travelling 35.6 mm around, giving a slope of 3.41°.

$$d_m = D - 0.649519p,\ 12.7 - 0.649519\,(2.117) = 11.325mm\,/\,0.4459in \qquad (1)$$

This is a very shallow ramp, which means that producing a small torque at the screw produces a large force along it, contributing to the axis' strength. It also means the nut advances very little per revolution, which is why the axis is so slow and inertial.

$$\lambda = arctan\,(\frac{l}{\pi d_m}) = arctan\,(\frac{2.117}{35.578}) = 3.41deg\,/\,0.0593rad \qquad (2)$$

Some useful benefits which were not deliberately accounted for but we are accepting with open arms are the fact that the machine does not need holding current between moves, generates no heat while stationary, and will not sag under load if power is lost.

$$\eta = \frac{tan\,\lambda\,(1-\mu\,tan\,\lambda\,)}{tan\,\lambda + \mu} = \frac{tan\,3.41\,(1-0.2\,tan\,3.41\,)}{tan\,3.41 + 0.2} * 100 = 22.7\% \qquad (3)$$

At an assumed friction coefficient of 0.20 for a steel screw in an aluminium nut (according to Engineering Toolbox's database which is one of the most comprehensive ones out there), the transmission is only 22.7% efficient. Slightly over three quarters of the input work is lost as heat in the thread (thermodynamics and the actual required torque is greater than in a frictionless calculation by a factor of more than 4.

This initially looked like a poor result, but friction losses and mechanical advantage both increase as the ramp gets shallower. It is very likely (or plausible) that the two cannot be improved independently.

$$\mu \geq tan\,\lambda,\ satisfies\ 0.0595 \geq 0.0280 \qquad (4)$$

A useful consequence emerges from the same geometry. For the carriage to be pushed back along the axis by an external force, the load's component down the thread ramp would have to overcome friction in the thread.

At 3.41° the ramp is shallow enough that friction always tan λ by a factor of 3.4, so the screw cannot be back-driven. Each linear axis is always able to hold its position comfortably.

$$F = \frac{2\pi\eta T}{l} = \frac{2\pi(0.227)(2.5)}{0.0021167} = 1681N\,/\,378lbf \qquad (5)$$

Rearranging the screw torque relation, the actuator's 2.5 N m develops 1681 N of axial thrust. The carriage requires a figure in the tens to accelerate owing to how it was designed and account for initially varying masses (moving parts were between 1 and 5N).

When trying to understand why this is the case, what sticks out is that the actuator is not enormous, but the lead screw multiplies its torque so heavily that almost any actuator would suffice, so the strength of the motor suddenly goes from being an all-important factor to a nice-to-have.

$$v = \frac{N}{60} l = \frac{55}{60}(2.117) = 1.94 mm\, s^{-1} / 0.0764\, in\, s^{-1} \quad (6)$$

The same shallow helix that produced that margin limits moves at 1.94 mm/s at the actuator's 55 rev/min. A 300 mm traverse therefore takes over two and a half minutes, which can at times become a bigger bottleneck, or limiting factor, than applied load.

Most plausible applications would not have unimaginably high payloads, but if this observation had this been recognised earlier, a coarser or multi-start thread are among the obvious and immediate revisions which could be made.

$$\delta_{res} = \frac{l}{n_{enc}} = \frac{2.117}{4096} = 0.517\ \mu m\ /\ 20.3 \mu in \quad (7)$$

The encoder divides one revolution into 4096 counts, giving a commanded increment of 0.52 µm. The actuator's stated backlash of 0.33° corresponds to 1.94 µm of lost motion at this lead.

$$\delta_b = \frac{\Theta_b}{360} l = \frac{0.33}{360}(2.117) = 1.94\ \mu m\ /\ 76.4 \mu in \quad (8)$$

In practice and upon further examination, compliance in the printed structure and backlash in the thread itself will degrade this further, so 2 µm should be read as an optimistic bound rather than a specification.

$$m_{arm} = 0.62 lb,\ r_{perp, cg} = 4.461 in, T_g = mgr = 0.2812(9.81)(0.1133) = 0.3126\ N\, m \quad (9)$$

We calculated from an assembly mass of 281 g acting at a measured 113.3 mm from the pivot axis, taking solely the perpendicular component. The arm in its current configuration could potentially be at risk of being too long for this actuator, depending on the margin of safety with the SG90’s stall. Depending on the size of the payload, modifications might have to be made further down.

Incrementally, we ensure that every derived value can be used to calculate other unknown quantities and shed some light on the physical features and limitations of our design. The specifications concluded above are consolidated in Section 6, where the final design is described in detail.

6. Design Specifications

6.1 Final Design Description

The device is made of 29 parts. In this section we outline the design specifications of each part and of the final product. This includes the conveyor system, dual gantry structure, horizontal positioning mechanism, articulated robotic arm, and motorized gripper.

The conveyor continuously transports components through the machine, while the gantry moves the robotic arm to the required working area. The arm then provides additional reach and rotational motion, while the gripper interacts directly with the component to pick it up and release it.

This seemingly basic system is versatile without having to be too fancy, enabling it to serve as a functional, solid cog within manufacturing and any tangential, related industries where it can be sensibly deployed.

Table 1: Device Dimensions

Parameter	Metric	Imperial
Length	130.81 cm	51.50 in
Height	64.14 cm	25.25 in
Width	52.07 cm	20.50 in
Weight	31.43 kg	69.30 lbs

The gantry design is inspired by the linear positioning systems commonly used in 3D printers. Two vertical gantries are used to support the moving assembly and distribute the mechanical load. Lead screws provide linear motion along the gantry direction, while the horizontal axis uses driven wheel motion to move the robotic arm from side to side across the conveyor.

Together, the linear and rotational motions provide the system with the degrees of freedom needed to perform the sorting operation.

Table 2: Device Performance Metrics

Parameter	Metric	Imperial
Axial thrust capacity	1681 N	378 lbf
Traverse speed at 55 rev/min	1.94 mm/s	0.0764 in/s
Transmission Efficiency	22.7%	
Commanded Resolution	0.517 μm	20.3 μin
Achievable accuracy	1.94 μm	76.4 μin

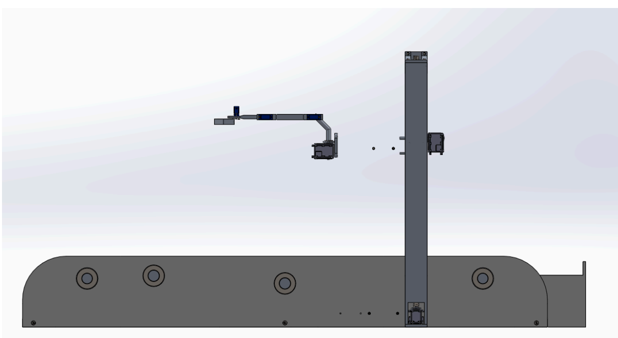


Figure 6: Full Assembly Exploded View (Larger in Appendix)

6.2 Device Parts Design

The theoretical analysis provides additional specifications for the lead-screw system. The modeled lead screw has a shallow helix angle of approximately 3.41°, resulting in a large mechanical advantage. With an actuator torque of 2.5 N·m, the screw is predicted to produce a substantially larger force than what's required to accelerate the carriage (which is well below 1 N).

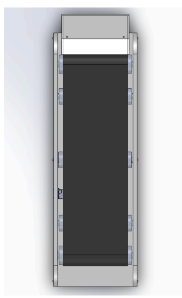
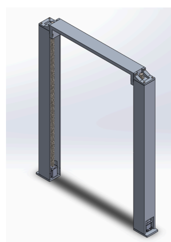
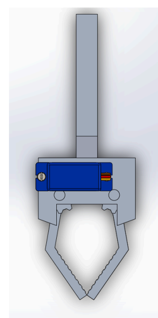
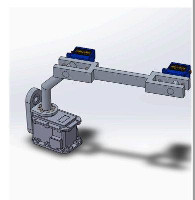
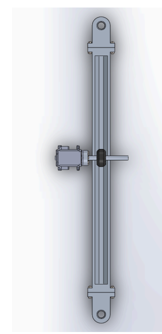
The same geometry results in a predicted linear velocity of approximately 1.94 mm/s at 55 rev/min, showing that the current design provides a high mechanical advantage but sacrifices speed and efficiency.

The shallow helix angle also makes the lead screw effectively non-backdrivable under the assumptions used in the analysis. As a result, the gantry can maintain its position without requiring continuous holding torque from the actuator. However, the low travel speed is a significant limitation of the current design and could be addressed in future design iterations.

Various other parts, such as the side walls and baseplates, were designed with holes in sections to allow for easy assembly and usage of fasteners. In depth drawings of each part are shown in the Appendix. This includes subassemblies and the main assembly at the very end.

Each Subassembly Serves a specific purpose, with their parts working together to accomplish their specific task:

Table 3: Subassembly Objectives.

Subassembly	Conveyor	Y Gantry	Gripper	Rotating Section	X Gantry
Function	Moves sample part under the manipulator to be picked up and moved	Supports the structure of the X gantry, contains lead screw to support vertical movement	Enables the manipulator to pick up components, Uses motor-driven gears to open and close.	Allows links to extend and retract, changing the length of the manipulator arm.	Allows movement along the x axis using a driven wheel, supports manipulator.
Image					

6.3 Powering the Assembly

The AQSM is powered by a combination of electric rotary actuators and multiple mechanical transmission systems which can translate the power into mechanical motion. Instead of relying on one actuator to power the whole machine, the motion is distributed between the gantry positioning system, robotic arm, conveyor, and gripper components, allowing for each subsystem to perform different parts of the overall sorting operation. The motors provide input for rotational mechanics, while the driven wheels, screws, and actuated joints convert this power into the actual motion.

The vertical positioning of the robotic arm is powered by the motors which are connected to the two gantry structures. Each gantry uses a lead screw to convert the out of its actuator into linear movement. When the motor rotates, the corresponding threaded interface moves along the screw axis, causing the corresponding arm assembly to translate. By using two gantries, this allows the structure to be supported from both of its sides instead of putting the total load on a single linear drive. Both of these sides, in implementation, must therefore be synchronized in movement to prevent the overall mechanism from being skewed or binding along its guides.

The horizontal positioning of the arm is powered through a driven-wheel mechanism rather than through a lead screw. The output of the motor transfers into the driven wheel, which then rotates against the supporting surface. This creates linear movement of the carriage across the horizontal axis. Because of this, the robotic arm and gripper assembly can travel laterally across the conveyor while the lead-screw controlled gantries can control the position on the other translational axis. Using separate actuators for both the directions allows for them to be controlled independently.

The arm and gripper utilize the remaining powered motion to allow for the system to successfully interact with items. The arm uses servo actuation at its rotational joint, where the actual rotation changes the angular position of the arm links instead of being converted into linear movement. This allows for the arm to extend and position the gripper closer to the object. The gripper itself is actuated to open and close around items on the conveyor, allowing for grabbing and releasing motions. The overall AQSM machine, therefore, is powered by a combination of lead screw-driven translation, wheel-driven translation, and servo-driven rotation to create coordinated movements needed for sorting.

In actual implementation, the AQSM would require external electrical power supply to provide voltage for the motors and servos it is using. It could be powered from a standard wall outlet through an AC-to-DC power supply, with corresponding DC-DC buck convertors or voltage regulators used to move the supplied voltage down to the different voltages required by each actuator and electronic, allowing for each subassembly to be powered from a common electrical source while receiving their required input voltages. The motor drivers and control electronics would regulate exactly how much power and when each actuator receives power to coordinate the actual movement.

7. Manufacturing, Fabrication & Tolerancing

Throughout the development of the AQSM, manufacturability was taken into consideration. Most of the structural components are made from 1060 aluminum alloy, a lightweight structural material that can be manufactured using common machine-shop processes.Most of the structural parts use 1060 aluminum alloy since it's easy to machine, but a few pieces are made from ABS so they can be 3D printed to cut down on weight and cost. Vertical motion comes from lead screws, and horizontal movement is handled by a wheel mechanism. The chain-link arm and gripper extend the reach further, so parts can be picked up and released from a distance.

There was a degree of trial and error which was not intended but very useful at fine-tuning and honing the process of design without having to run motion studies or check for interference. Parts which were heavily affected and important are the fasteners, servos (and within them, the mounting holes) as well as the arm which governed the degrees of freedom. The simulation and visualization capabilities of SolidWorks proved useful in understanding real-world behaviour giving a machinist a higher degree of confidence.

The gantry structure includes several custom-designed parts, including the main gantry members, mounting plates, brackets, and components associated with the lead screws. These parts are designed to be assembled using standard hardware, making it easier to manufacture or replace individual components without redesigning the entire system. The modular subassemblies are also intended to allow the conveyor, gantry, robotic arm, and gripper to be produced and tested independently before being integrated into the complete machine. The use of lead-screw-driven Y-gantries and the overall modular gantry arrangement are consistent with the existing design description.

Interestingly, the lead screw is a cut thread produced with an inch die, 0.500 in diameter at 12 threads per inch. This is not a very commonly encountered combination since a half-inch die is normally supplied at 13 or 20 threads per inch, so the specified thread requires either custom tooling or a change to a standard pitch. These don't affect function but will need to be considered for manufacture.

Final manufacturing drawings should include all dimensions required to produce each custom component, including overall dimensions, hole sizes and locations, material specifications, thread specifications, and assembly tolerances.

Moving onto the cost-benefit element with regards to how it's powered, we find that the MX-28AR units are approximately two orders of magnitude more expensive than the SG90 servos. This is noteworthy since we established earlier that the minimum torque required for acceleration and setting in motion is far lower than what is being generated.

Particular attention should be given to components that interface with bearings, shafts, lead screws, and other moving parts because their dimensions can directly affect alignment and motion. We found that interference tests done early on flagged hundreds of possible collisions, even after adjusting the settings to make the detection lenient and liberal. Threaded connections for some reason are shown as cosmetic threads with callouts per ISO 6410 rather than modelled helices, something which varies depending on software. Even so, the analysis shows that the design has good potential if it's tested rigorously later on.

Another important manufacturing consideration is the order of the fabrication & assembly of the AQSM. Because the system consists of several smaller components, (conveyor, gantry structures, horizontal drive, articulated arm, and gripper) it would ideally be manufactured and tested as their subassemblies first before integrating all of the components. The aluminum parts could be first cut and machined, followed by the drilling & tapping of mounting holes, while the ABS components would be produced separately through additive manufacturing. Lead screws, motors, shafts, bearings, and other commercial components would then be installed into their subassembles and checked for unrestricted motion & alignment before conjoining the whole system. This would make it easier to identify any manufacturing errors, since a problem with a singular screw, or lack of clearance could be isolated to only one subassembly, making its discovery harder if it were assembled all at once.

Tolerancing is important in manufacturing the AQSM, as there are several interconnected moving parts which depend on proper aligning and fit. Excessive variation at locations including bearings and shafts, lead-screw assemblies, motor mounts, driven wheels, and pivot points of the actual arm could lead to misalignment, unwanted clearance, or binding. Therefore, tighter dimensional control would be most important at these interfaces. However, features which are non-mating can use less restrictive tolerances in order to avoid increase in manufacturing time and cost. For such critical machined interfaces, a tolerance on the order of ±0.002 in (±0.05 mm) would be recommended as an initial target. The parts which are less critically structural can use looser tolerances in order to reduce unnecessary complexity during manufacturing.

Tolerance stack-up must also be considered throughout the assembly. Small variations in dimensions can accumulate through multiple parts of the system such as the gantry, and horizontal positioning system, creating a large positioning error.

8. Conclusion

Overall, the ASQM model uses a conveyor combined with a dual gantry, articulated robotic arm, and motorized gripper to pick up and move a component from the conveyor to a collection or reject area; a process which has commonly been seen across the industrial spaces across sectors such as manufacturing, biotechnology, and hardware, especially coupled with the increasing emphasis on automation and a drive towards autonomous physical systems.

The design also focuses on manufacturability by using common materials, standard hardware, and components that can be produced using conventional manufacturing techniques.

The lead-screw system provides a large mechanical advantage and a predicted axial force much greater than that required to move the carriage. Its shallow thread geometry also makes the lead screw non-backdrivable under the assumptions used in the analysis, allowing the gantry to remain in position when stationary. However, this mechanical advantage is accompanied by a low predicted transmission efficiency.

For a sorting application where cycle time matters, its current speed is on the slower end, and it's probably the most significant limitation of the current design, which might be acceptable for an introductory design engineering class but will almost always be fixed in an industrial-grade engineering assembly line.

The arm analysis uncovers how as the required reach grows, the moment loads at the joints scale up quickly, and the actuator torque and payload capacity are likely to become the limiting factors before the structure itself does.

The AQSM was evaluated through CAD modeling, theoretical calculations, and SolidWorks motion analysis rather than through a manufactured physical prototype. There are also some simplifying assumptions baked into the numbers, like idealized friction coefficients, rigid-body behavior, and neglecting things like manufacturing tolerances, thermal effects, and dynamic loading from starts and stops.

In reality, factors like backlash in the lead screw, deflection in the arm links, and inconsistencies in surface finish would all affect how the system actually performs, and none of these are fully captured in the current analysis, partially due to an evaluation not being immediately useful or even observable at times.

Future work could include manufacturing and physically testing the system, measuring positioning accuracy and backlash, load testing the robotic arm, and evaluating the gantry under actual operating conditions. A coarser or multi-start lead screw could also be considered to increase gantry travel speed.

Together, these subsystems give the manipulator multiple degrees of freedom and a large working envelope, which means it can reach parts across a wide portion of the conveyor rather than being locked into a single pick point. Another possible extension which could be implemented is striving for 6 degrees of freedom, instead of the current 2 translational and 1 rotational DOF that we have gone with; we prized simplicity and functionality over something over aspirational which might look great in principle but fail to hold up in the real world. The tradeoff between mobility and functionality is something really interesting to consider not just here but in engineering more broadly.

An important conclusion from the design process is that maximizing an individual performance metric does not produce a better machine overall. The lead-screw system is an example of this: it produces far more axial force than is necessarily needed to move the carriage, but this mechanical advantage jeopardizes travel speed and efficiency. For an actual system, having additional force beyond what is required does not give much value, while cycle time directly affects how many components the machine can actually process. For the future, development of this machine should focus less on maximizing the available force and should rather focus more on the relationships between torque, lead-screw ;pitch, carriage speed, positioning accuracy, and payload.

Future development should also move from evaluating individual parts of the machine to evaluating the system as a whole. Current calculations only consider idealized behavior, but when in operation, all components would need to coordinate within the same sorting cycle. Another future consideration is how acceleration & deacceleration of the gantry would cause vibration into the arm, and analyzing how increased arm extension could amplify joint moments and structural deflection. Alignment errors may also accumulate between multiple different parts and potentially reduce accuracy of the arm. Future testing would need to not only measure each subsystem's functionality, but also consider the factors listed above to provide a much clearer idea of whether the AQSM could actually become a practical manufacturing mechanism.

Furthermore, the AQSM could expand beyond its current capabilities with the addition of sensors and machine-vision systems to identify specific components, determine whether they should be rejected or not, and grab those items rather than relying on predetermined commands from the user. However, these additions would have to follow mechanical validation rather than compensate for weaknesses in the underlying design. Therefore, before integrating such systems, the AQSM would have to be thoroughly tested and established to be an already reliable and manufacturable device by itself to have a strong foundation. This way, the device could evolve in the future to be a fully autonomous machine.

Experimental validation and further design improvements could help develop the AQSM into a more practical automated component-handling system, accounting for the variances in materials, real-world scenarios, and complex conditions.

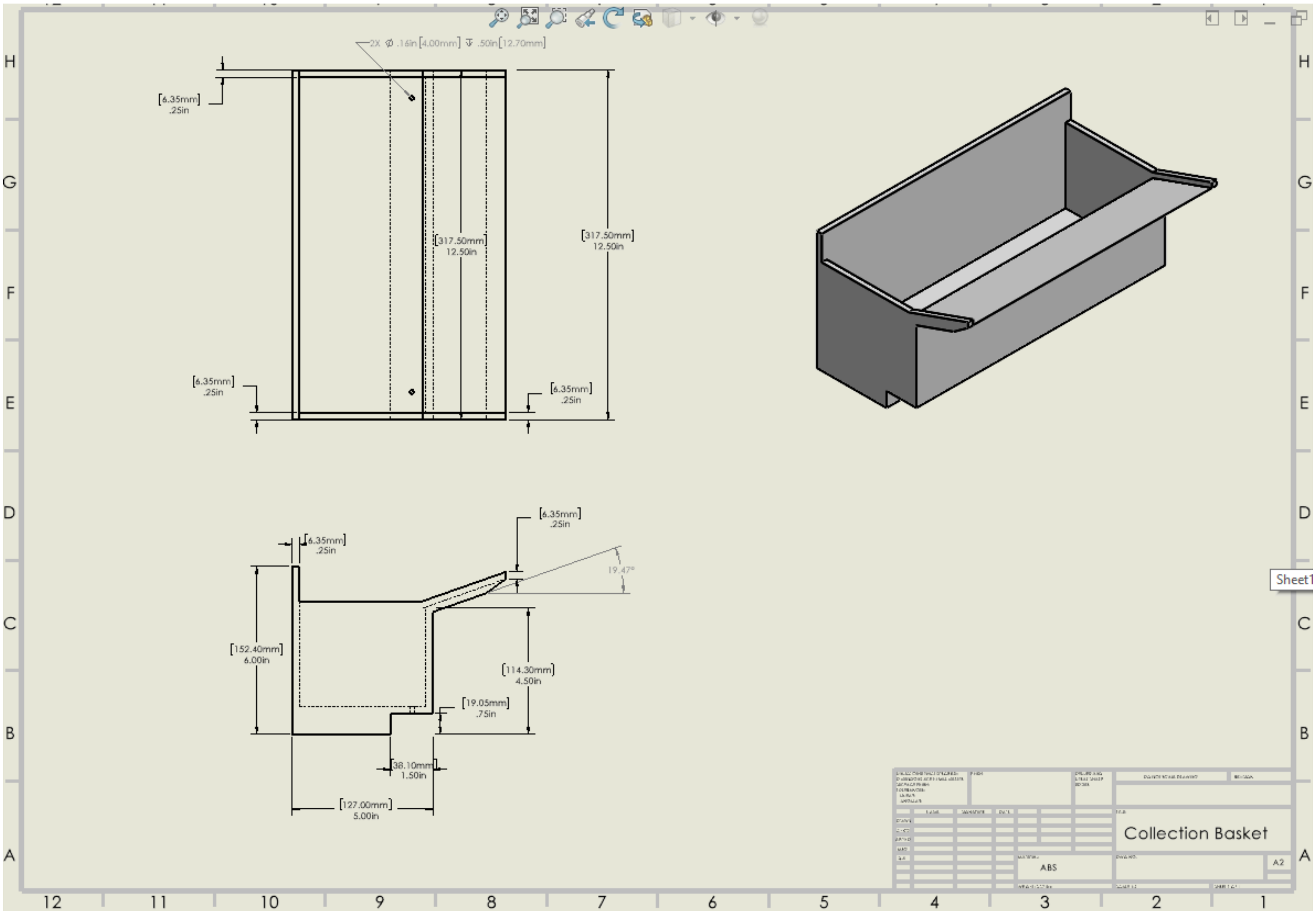
9. References

1. https://radiostud.io/blog/artificial-intelligence/machine-learning-automated-food-quality-inspection/, accessed 8/13/26
2. https://thinkrobotics.com/products/autonomous-ai-sorting-training-platform, accessed 8/13/26
3. https://www.creality.com/products/ender-3-pro-3d-printer, accessed 8/13/26
4. https://www.indiamart.com/proddetail/aluminum-frame-belt-conveyors-12862677191.html, accessed 8/13/26
5. https://www.engineeringtoolbox.com/friction-coefficients-d_778.html#gsc.tab=0, accessed 8/13/26
6. https://www.robotis.us/dynamixel-mx-28ar/, accessed 8/13/26

7. https://www.digikey.com/en/articles/power-supply-design-considerations-for-mains-powered-equipment?utm_source=chatgpt.com, accessed 8/14/26

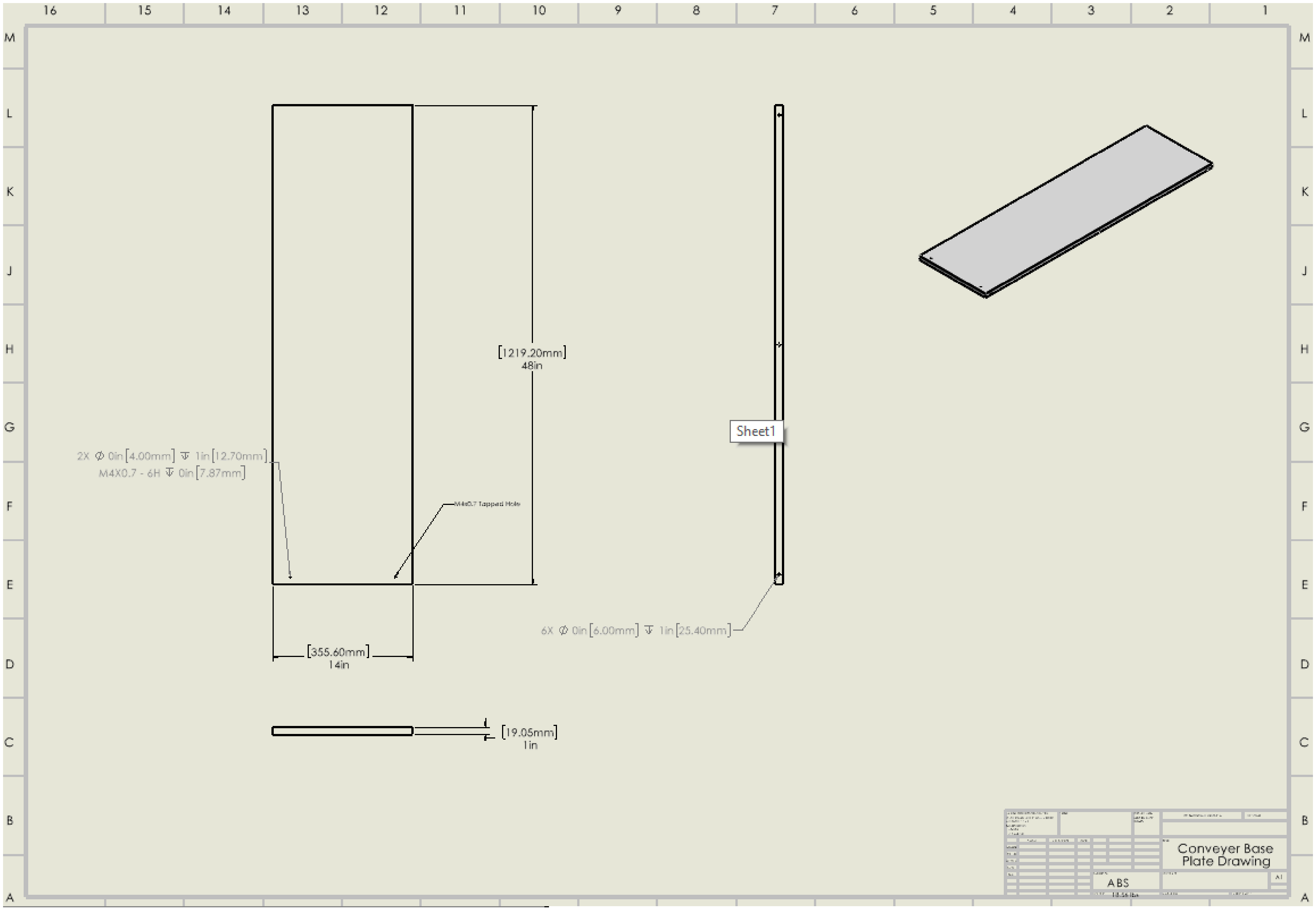
10. Appendix

Shown below are the drawings for the parts, subassemblies, and assemblies. (Material specified in drawing details in corner for easier readability instead of hatching) All drawing files are also within the CAD zip-file in case readability is an issue with the screenshots.



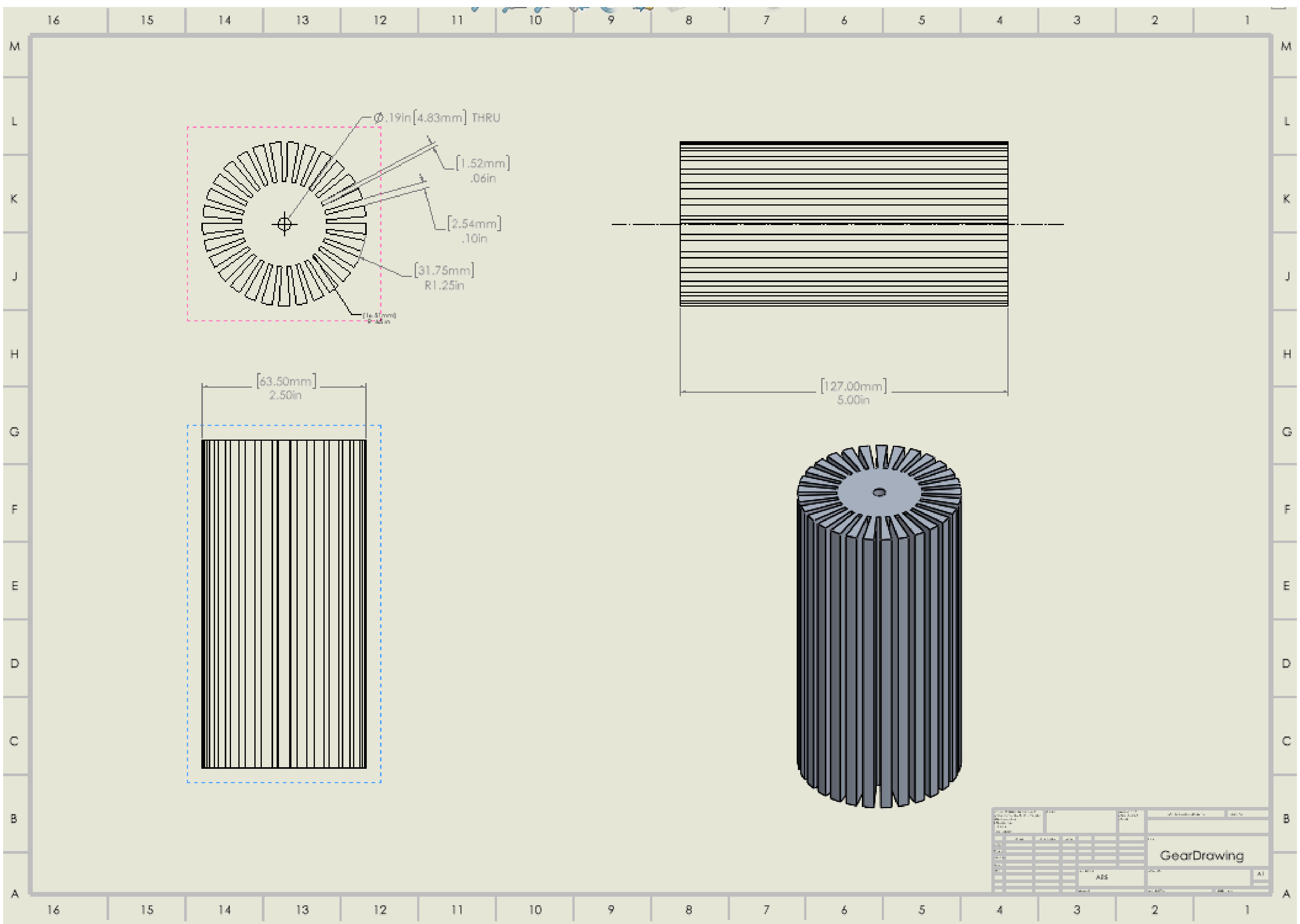
2X ⌀ .16in [4.00mm] ↧ .50in [12.70mm]
[6.35mm] .25in
[317.50mm] 12.50in
[317.50mm] 12.50in
[6.35mm] .25in
[6.35mm] .25in
[6.35mm] .25in
[6.35mm] .25in
19.47°
[152.40mm] 6.00in
[114.30mm] 4.50in
[19.05mm] .75in
[38.10mm] 1.50in
[127.00mm] 5.00in
Collection Basket
ABS
A2
Sheet1

Figure 7: Collection Basket



[1219.20mm]
48in
2X ⌀ 0in [4.00mm] ↧ 1in [12.70mm]
M4X0.7 - 6H ↧ 0in [7.87mm]
M4x0.7 Tapped Hole
[355.60mm]
14in
[19.05mm]
1in
6X ⌀ 0in [6.00mm] ↧ 1in [25.40mm]
Sheet1
Conveyer Base Plate Drawing
ABS
A1

Figure 8: Conveyor Base Plate



Ø.19in[4.83mm] THRU
[1.52mm] .06in
[2.54mm] .10in
[31.75mm] R1.25in
[63.50mm] 2.50in
[127.00mm] 5.00in
GearDrawing
ABS

Figure 9: Gear

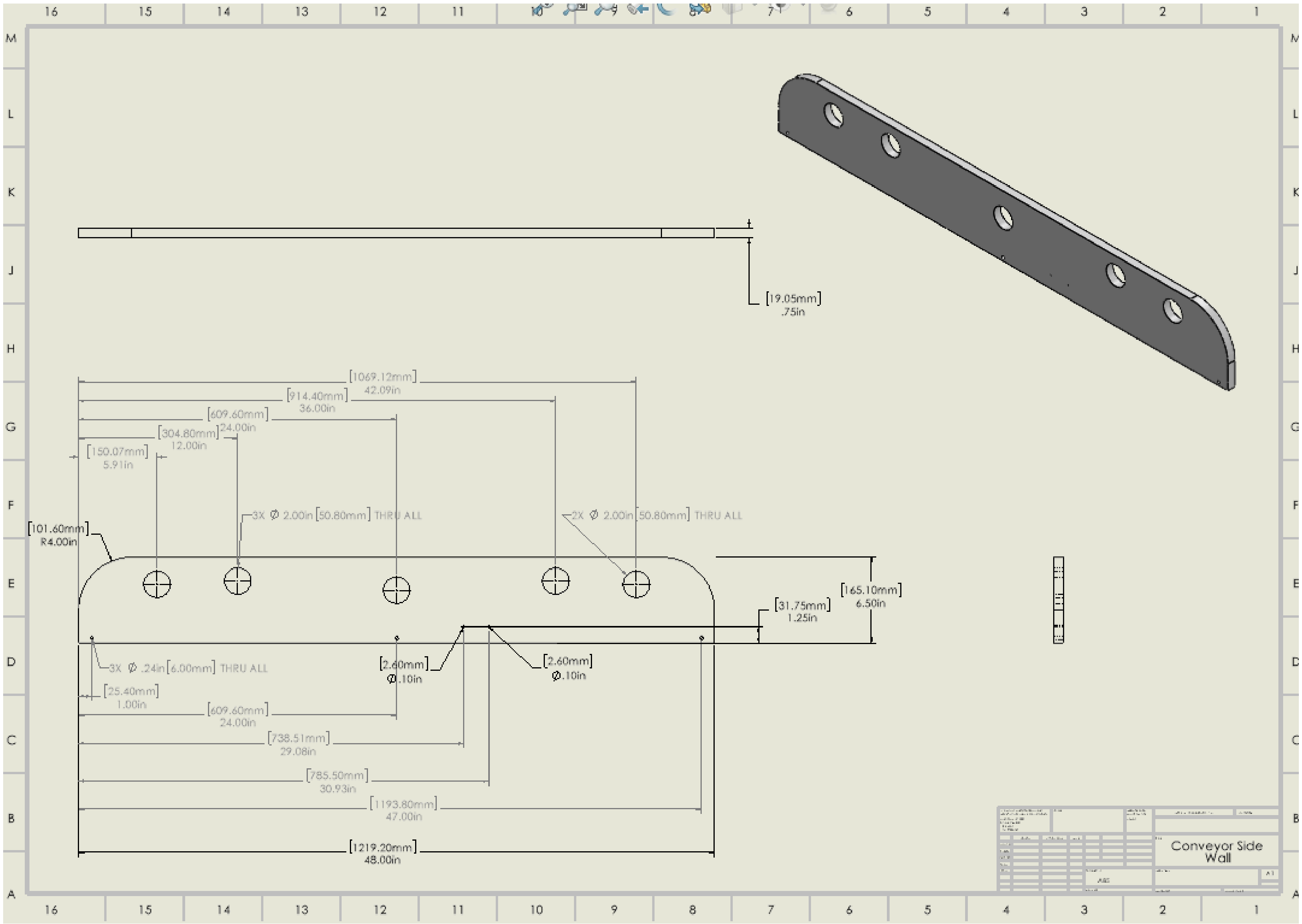

[19.05mm]
.75in
[1069.12mm]
42.09in
[914.40mm]
36.00in
[609.60mm]
24.00in
[304.80mm]
12.00in
[150.07mm]
5.91in
3X Ø 2.00in [50.80mm] THRU ALL
2X Ø 2.00in [50.80mm] THRU ALL
[101.60mm]
R4.00in
[165.10mm]
6.50in
[31.75mm]
1.25in
[2.60mm]
Ø.10in
[2.60mm]
Ø.10in
3X Ø .24in [6.00mm] THRU ALL
[25.40mm]
1.00in
[609.60mm]
24.00in
[738.51mm]
29.08in
[785.50mm]
30.93in
[1193.80mm]
47.00in
[1219.20mm]
48.00in
ABS
Conveyor Side Wall
A1

Figure 10: Conveyor Side Wall

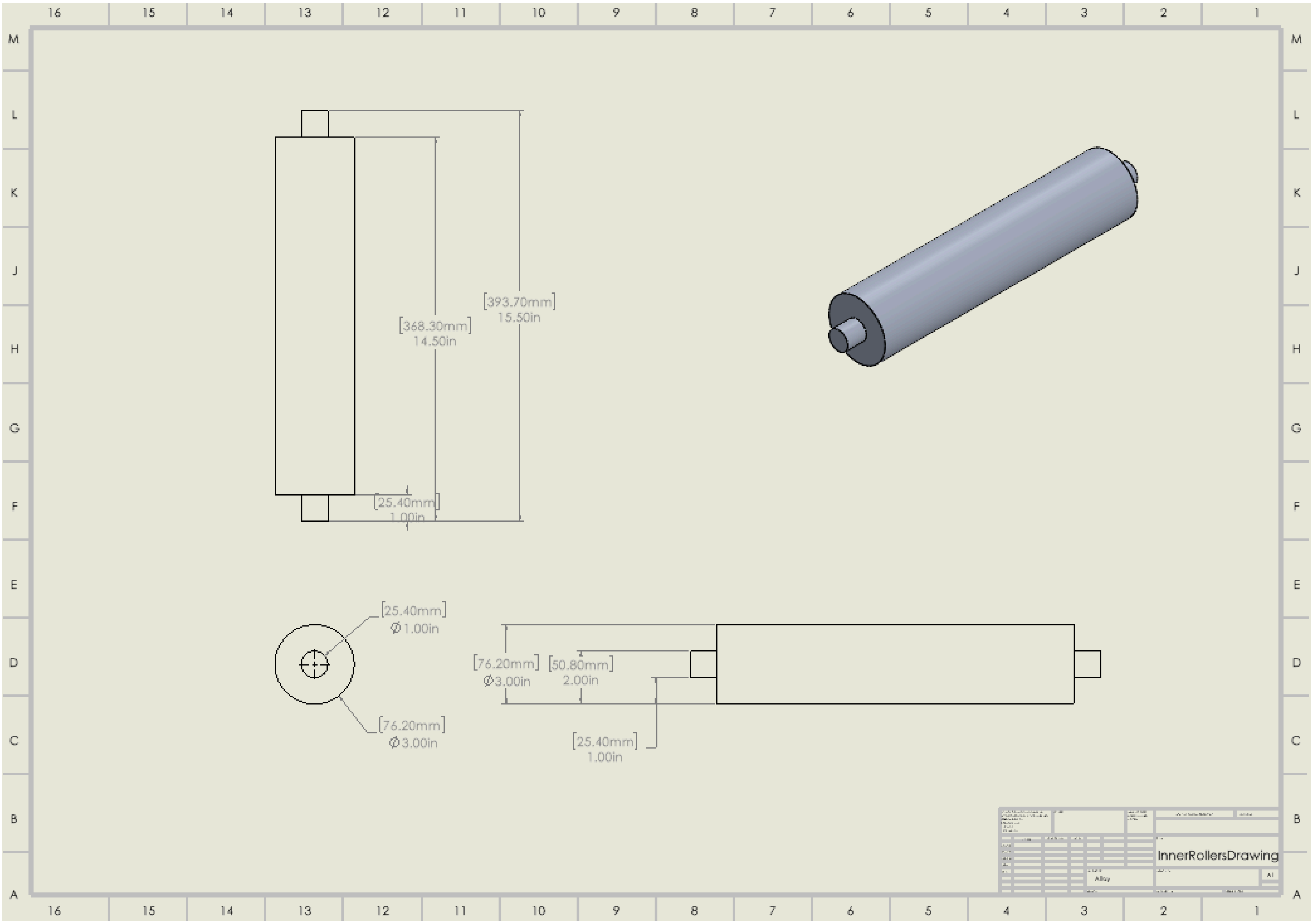
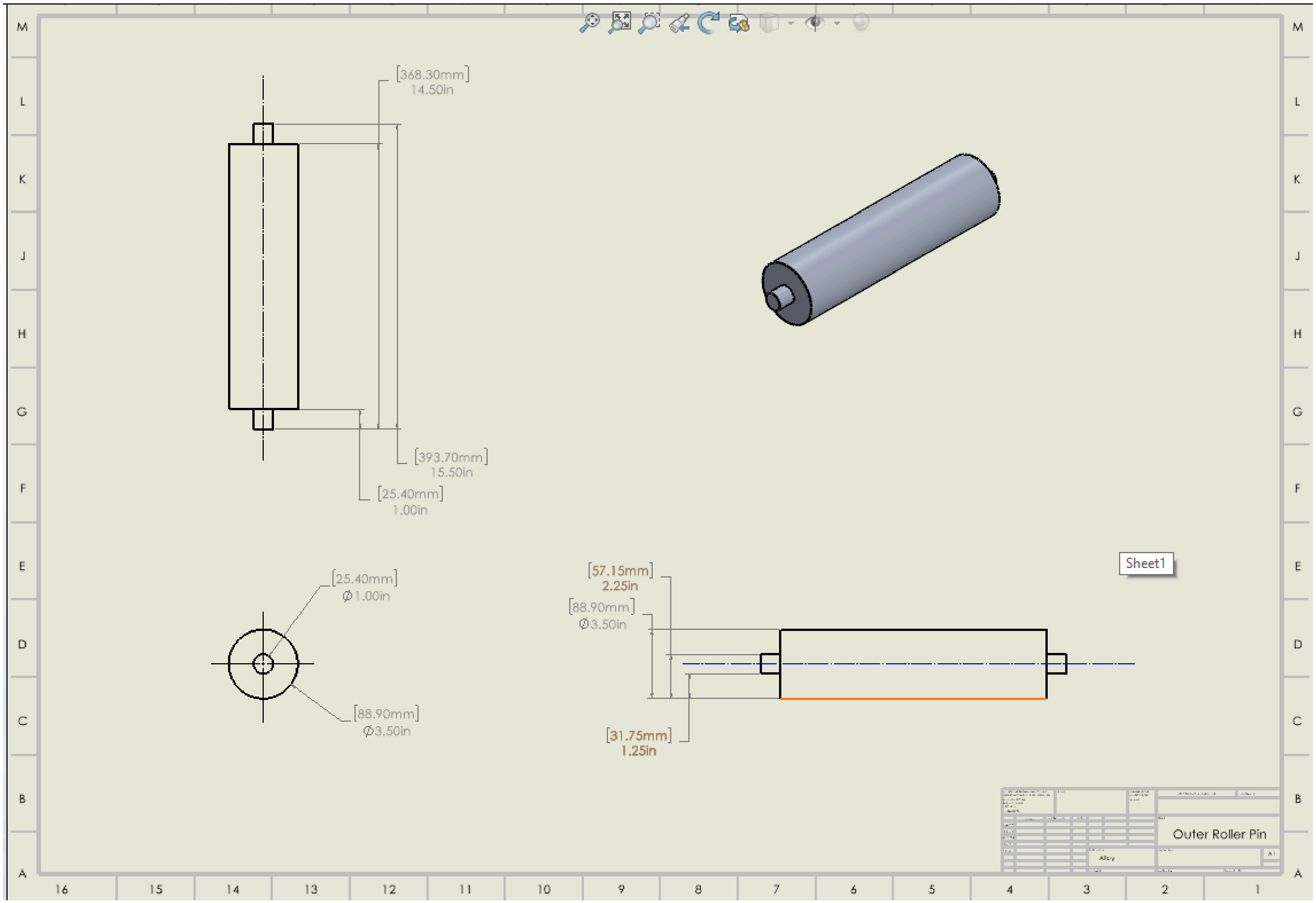
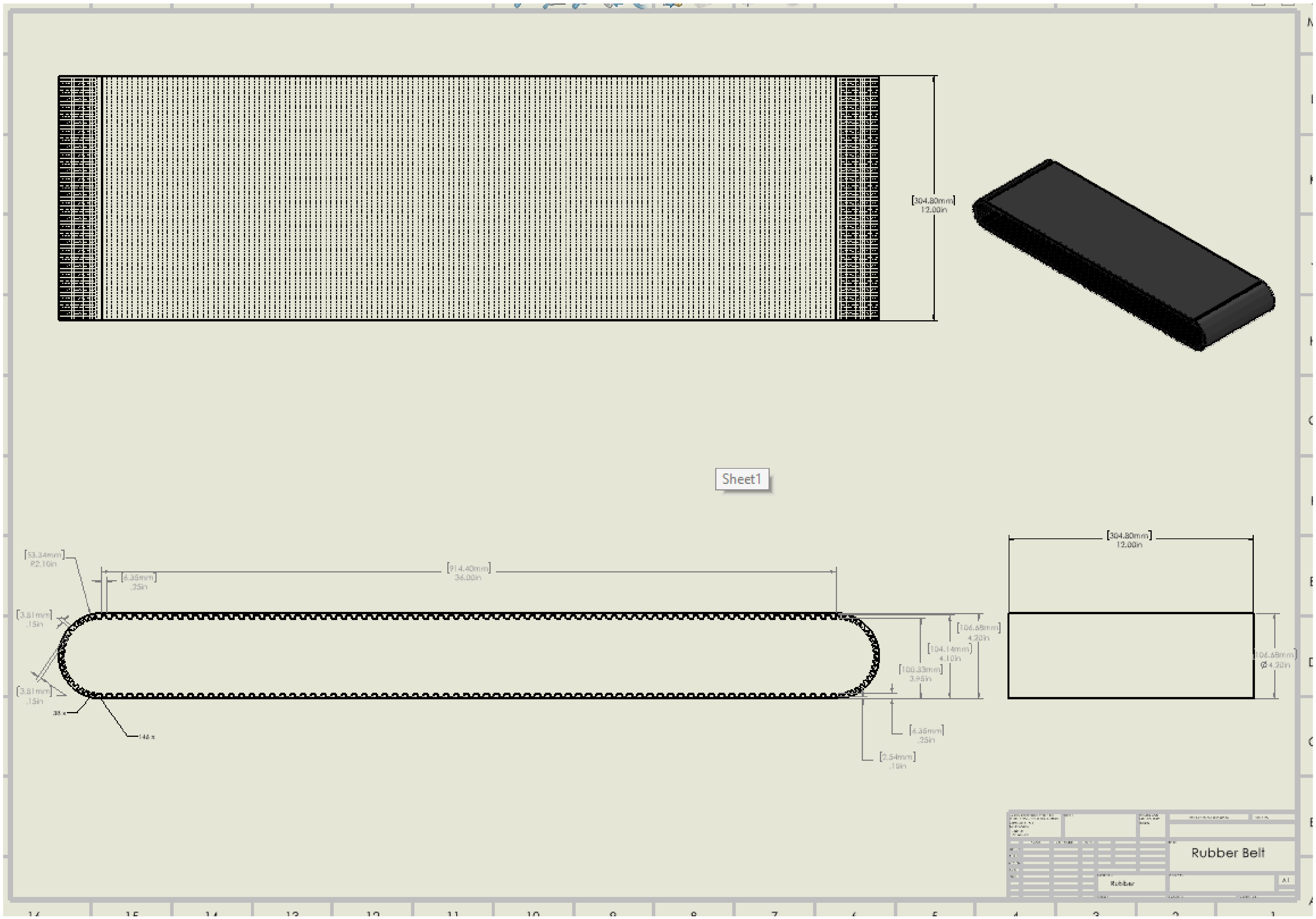

[393.70mm]
15.50in
[368.30mm]
14.50in
[25.40mm]
1.00in
[25.40mm]
Ø1.00in
[76.20mm]
Ø3.00in
[76.20mm]
Ø3.00in
[50.80mm]
2.00in
[25.40mm]
1.00in
InnerRollersDrawing
Alloy
A

Figure 11: Inner Roller



[368.30mm]
14.50in
[393.70mm]
15.50in
[25.40mm]
1.00in
[25.40mm]
Ø1.00in
[88.90mm]
Ø3.50in
[57.15mm]
2.25in
[88.90mm]
Ø3.50in
[31.75mm]
1.25in
Sheet1
Outer Roller Pin

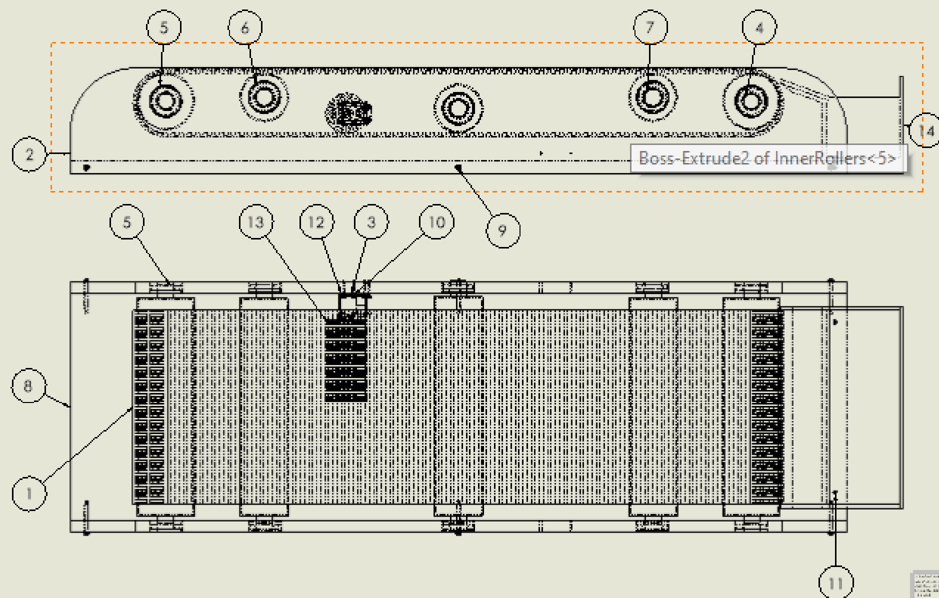
Figure 12: Outer Roller



[304.80mm]
12.00in
Sheet1
[53.34mm]
R2.10in
[6.35mm]
.25in
[914.40mm]
36.00in
[3.81mm]
.15in
[3.81mm]
.15in
38 x
146 x
[106.68mm]
4.20in
[104.14mm]
4.10in
[100.33mm]
3.95in
[6.35mm]
.25in
[2.54mm]
.10in
[304.80mm]
12.00in
[106.68mm]
Ø4.20in
Rubber Belt
Rubber

Figure 13: Rubber Belt

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1	RubberBelt	1
2	2	ConveyorSideWall	1
3	3	ConveyorSideWall	1
4	4	OuterEdgeRoller	2
5	5	AFBMA 24.2.7 - 15TB032 - 8,SI,NC,8	4
6	6	AFBMA 24.2.5 - 17TB030 - 12,SI,NC,12	6
7	7	InnerRollers	3
8	8	ConveyerBasePlate	1
9	9	B18.6.7M - M5 x 0.8 x 50 Slotted PHMS --50N	6
10	10	B18.6.7M - M2 x 0.4 x 20 Indented HHMS --20N	8
11	11	B18.6.7M - M3.5 x 0.6 x 16 Indented HHMS --16N	2
12	12	Motor (1)	1
13	13	Gear	1
14	14	CollectionBasket	1



Conveyor Assembly

Figure 14: Conveyor Subassembly

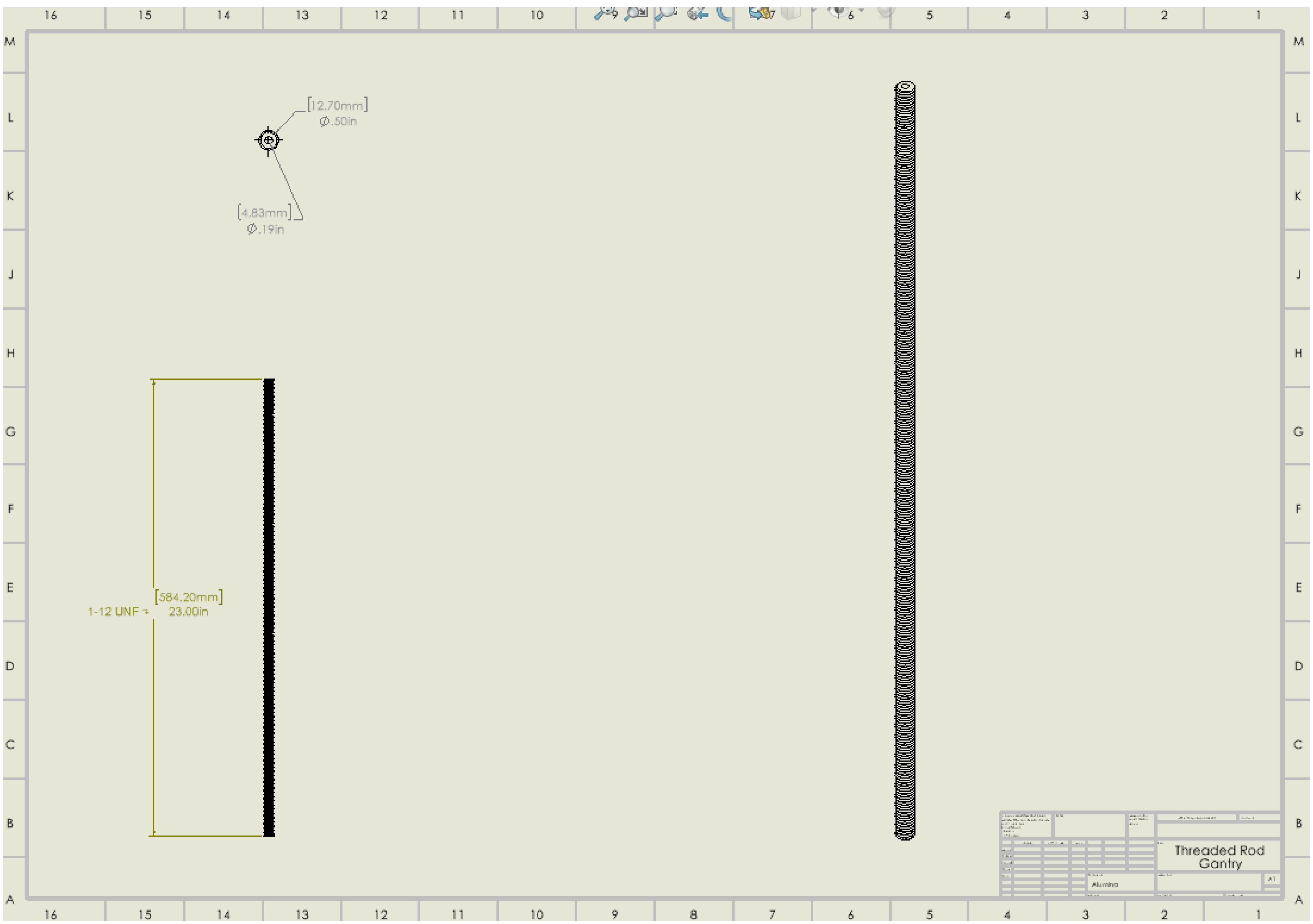
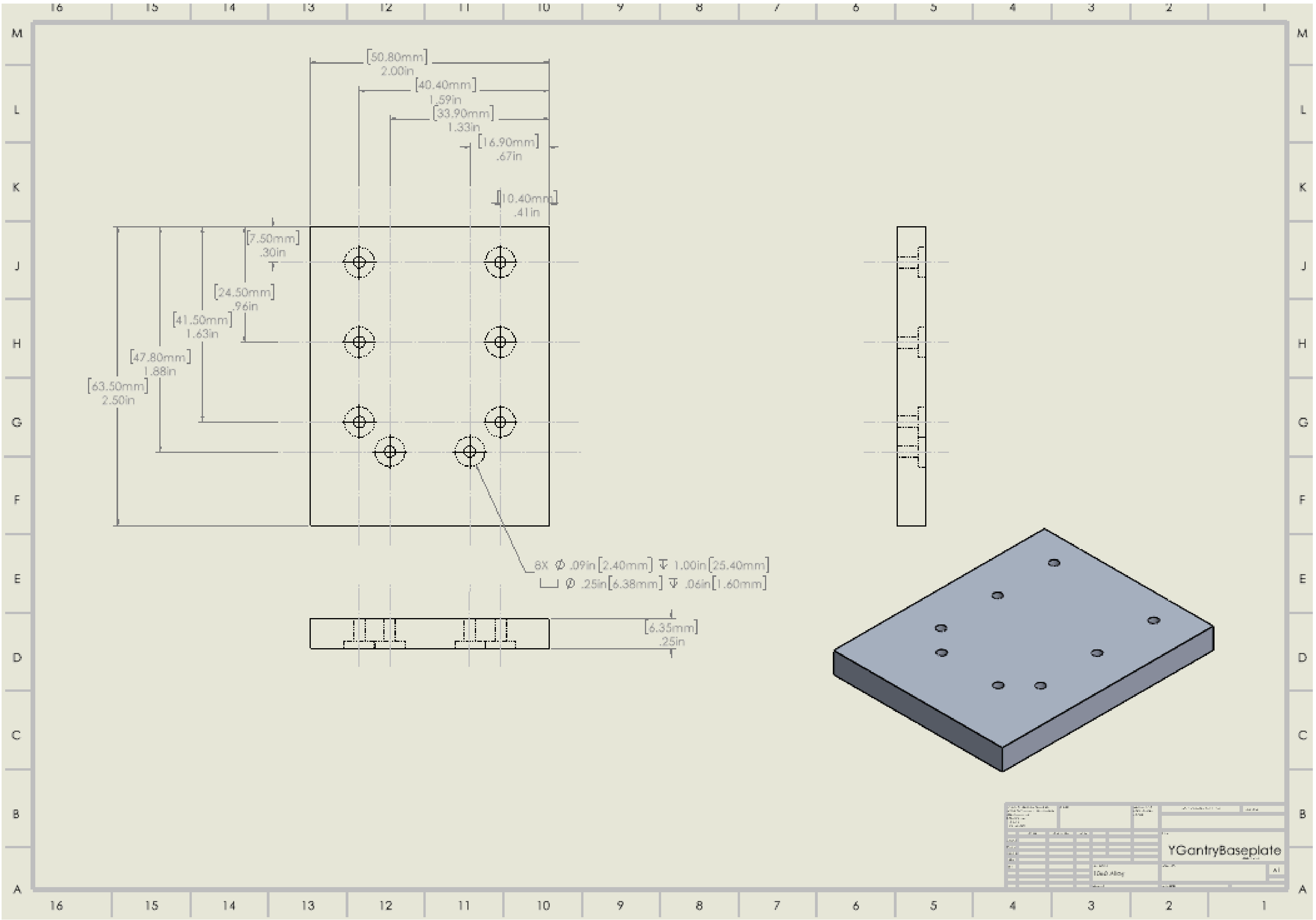
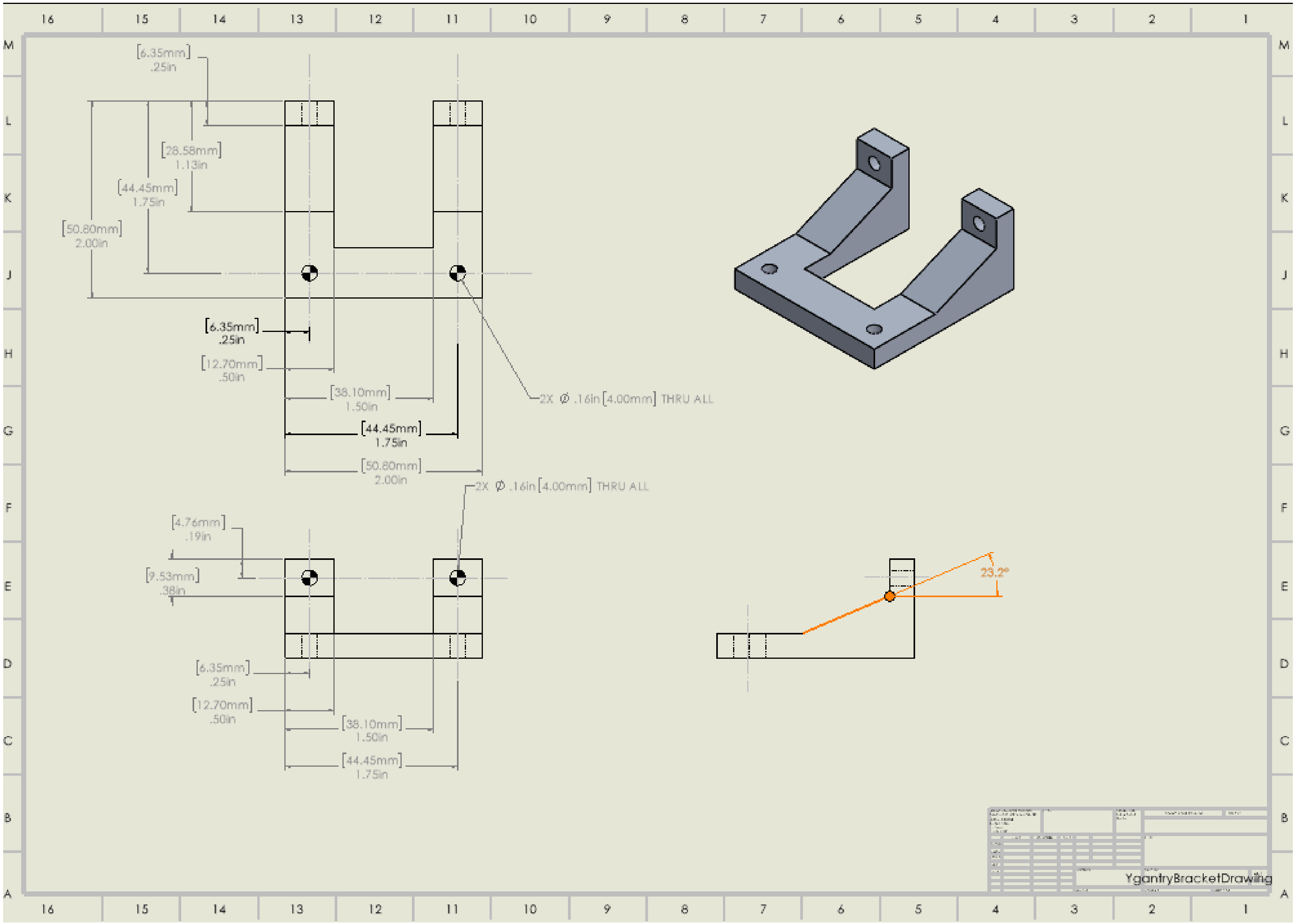

[12.70mm]
⌀.50in
[4.83mm]
⌀.19in
1-12 UNF
[584.20mm]
23.00in
Threaded Rod Gantry
Alumina
A1

Figure 15: Threaded Rod Gantry



[50.80mm] 2.00in
[40.40mm] 1.59in
[33.90mm] 1.33in
[16.90mm] .67in
[10.40mm] .41in
[7.50mm] .30in
[24.50mm] .96in
[41.50mm] 1.63in
[47.80mm] 1.88in
[63.50mm] 2.50in
8X Ø .09in[2.40mm] ↧ 1.00in[25.40mm]
⌴ Ø .25in[6.38mm] ↧ .06in[1.60mm]
[6.35mm] .25in
YGantryBaseplate
A1

Figure 16: YGantry Base Plate



[6.35mm]
.25in
[28.58mm]
1.13in
[44.45mm]
1.75in
[50.80mm]
2.00in
[6.35mm]
.25in
[12.70mm]
.50in
[38.10mm]
1.50in
[44.45mm]
1.75in
[50.80mm]
2.00in
2X Ø .16in [4.00mm] THRU ALL
2X Ø .16in [4.00mm] THRU ALL
[4.76mm]
.19in
[9.53mm]
.38in
[6.35mm]
.25in
[12.70mm]
.50in
[38.10mm]
1.50in
[44.45mm]
1.75in
23.2°
YgantryBracketDrawing

Figure 17 Y Gantry Bracket

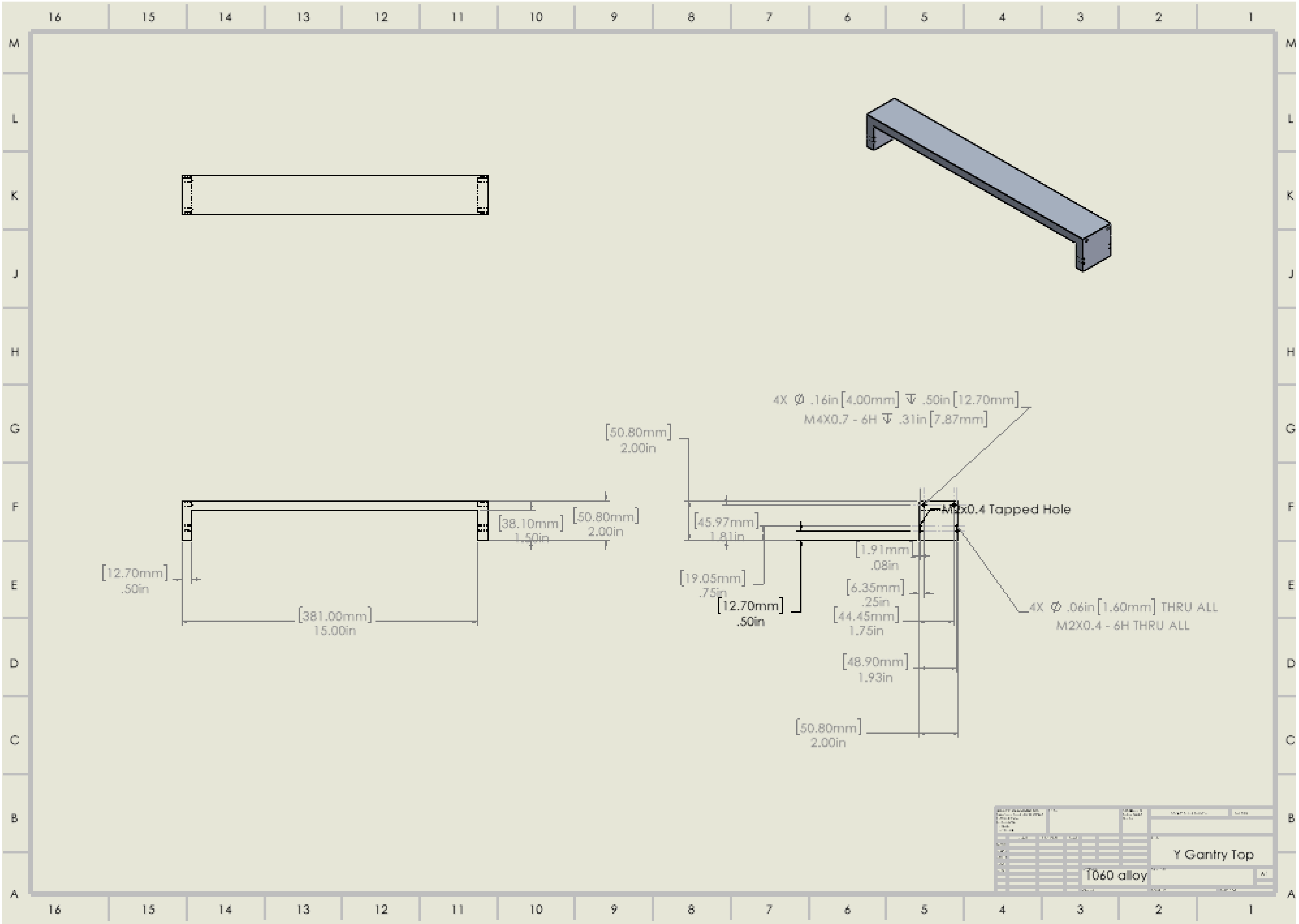

4X ∅ .16in [4.00mm] ↧ .50in [12.70mm]
M4X0.7 - 6H ↧ .31in [7.87mm]
M2x0.4 Tapped Hole
4X ∅ .06in [1.60mm] THRU ALL
M2X0.4 - 6H THRU ALL
[50.80mm] 2.00in
[38.10mm] 1.50in
[45.97mm] 1.81in
[1.91mm] .08in
[19.05mm] .75in
[12.70mm] .50in
[6.35mm] .25in
[44.45mm] 1.75in
[48.90mm] 1.93in
[381.00mm] 15.00in
Y Gantry Top
1060 alloy

Figure 18: Y Gantry Top

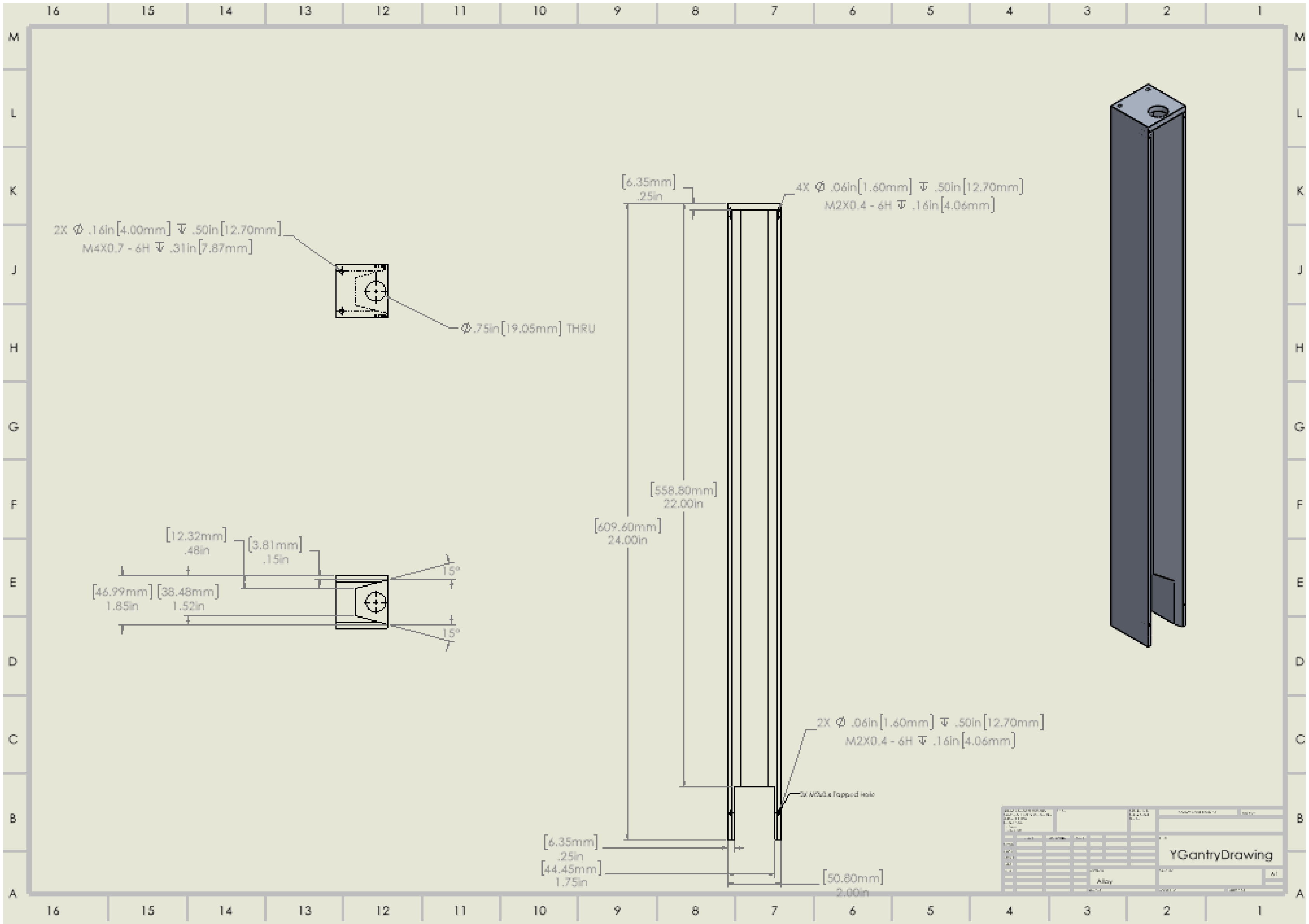
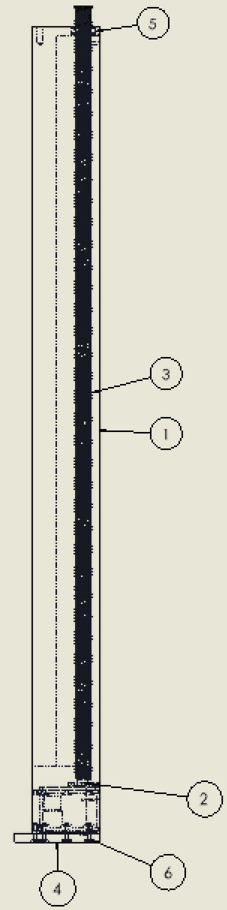
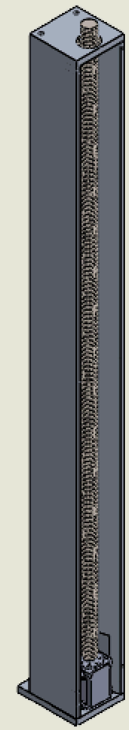

2X Ø .16in [4.00mm] ⊽ .50in [12.70mm]
M4X0.7 - 6H ⊽ .31in [7.87mm]
Ø .75in [19.05mm] THRU
[12.32mm]
.48in
[3.81mm]
.15in
[46.99mm]
1.85in
[38.48mm]
1.52in
15°
15°
[6.35mm]
.25in
4X Ø .06in [1.60mm] ⊽ .50in [12.70mm]
M2X0.4 - 6H ⊽ .16in [4.06mm]
[558.80mm]
22.00in
[609.60mm]
24.00in
2X Ø .06in [1.60mm] ⊽ .50in [12.70mm]
M2X0.4 - 6H ⊽ .16in [4.06mm]
[6.35mm]
.25in
[44.45mm]
1.75in
[50.80mm]
2.00in
YGantryDrawing
Alloy

Figure 19: Y Gantry

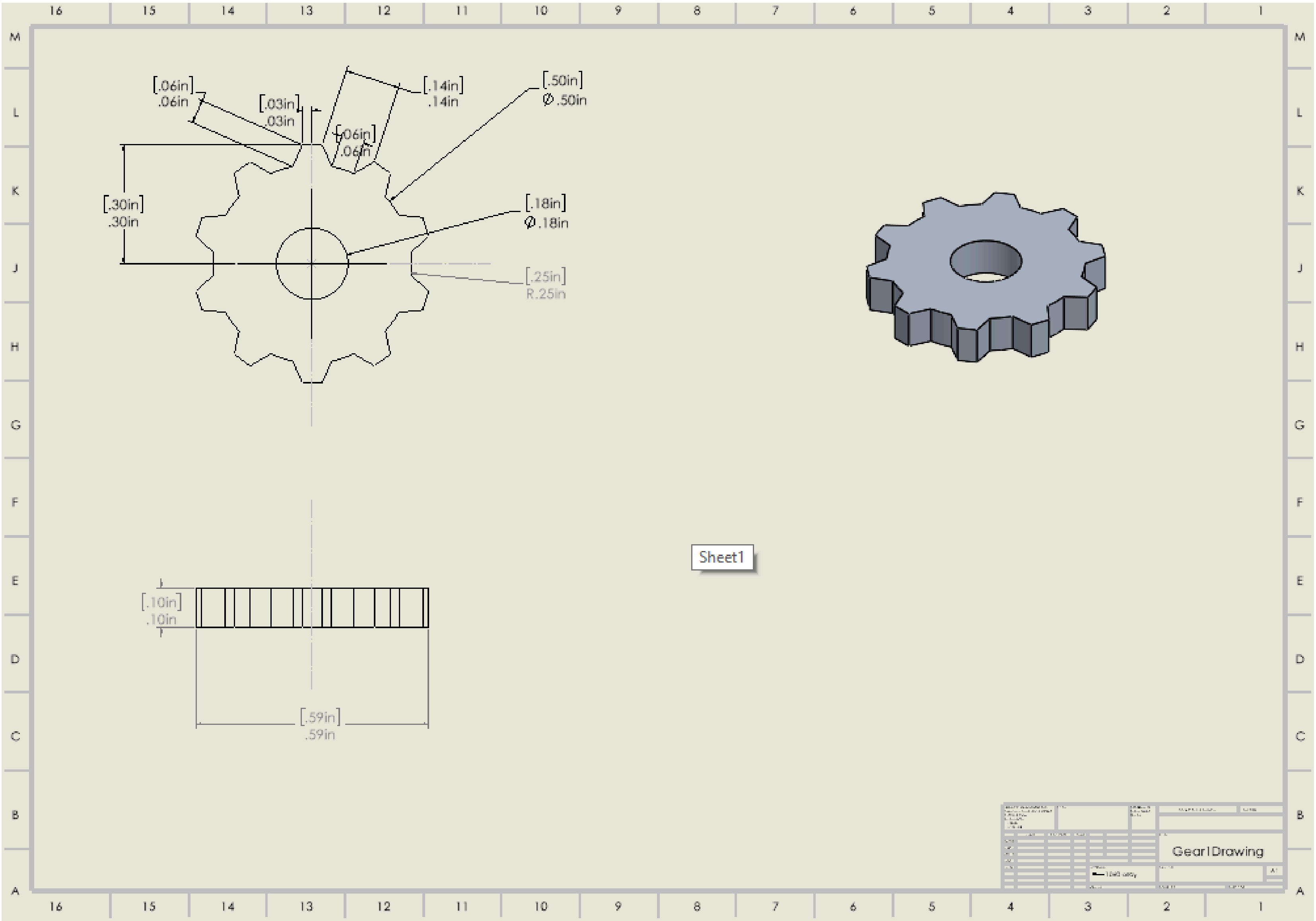
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1	YGantry	1
2	2	Motor (1)	1
3	3	ThreadedRodGantry	1
4	4	YGantryBaseplate	1
5	5	AFBMA 12.2 - 0.2500 - 0.7500 - 0.2188 - 8,SI,NC,8	1
6	6	B18.6.7M - M2 x 0.4 x 13 Indented HHMS --13N	8





YGantryAssemblyDrawing

Figure 20: Y Gantry Subassembly



[.06in] .06in
[.03in] .03in
[.14in] .14in
[.06in] .06in
[.50in] Ø.50in
[.30in] .30in
[.18in] Ø.18in
[.25in] R.25in
[.10in] .10in
[.59in] .59in
Sheet1
Gear1Drawing

Figure 21: Gear 1

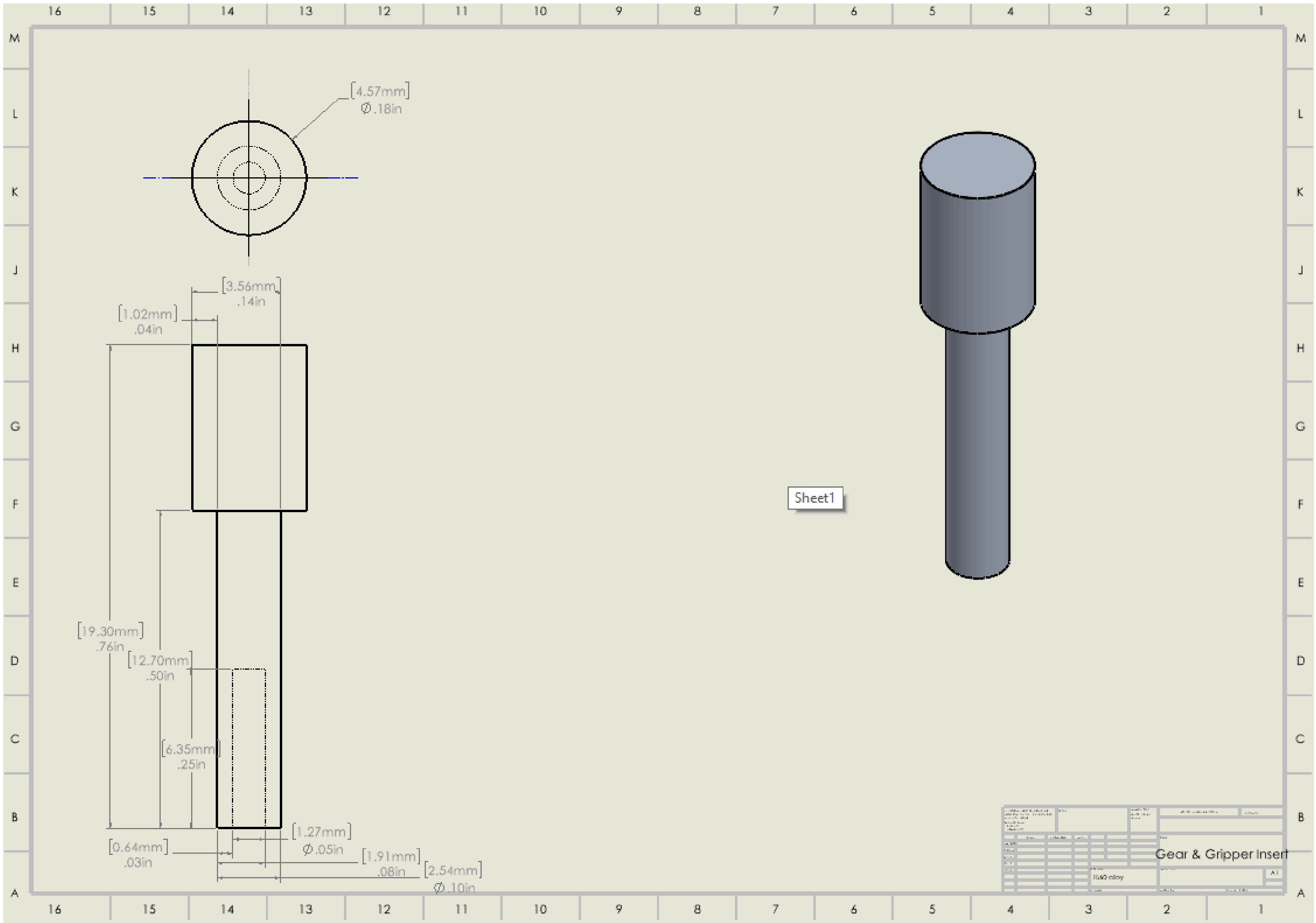

[4.57mm]
Ø.18in
[3.56mm]
.14in
[1.02mm]
.04in
[19.30mm]
.76in
[12.70mm]
.50in
[6.35mm]
.25in
[1.27mm]
Ø.05in
[0.64mm]
.03in
[1.91mm]
.08in
[2.54mm]
Ø.10in
Sheet1
Gear & Gripper Insert

Figure 22: Gear + Gripper Insert

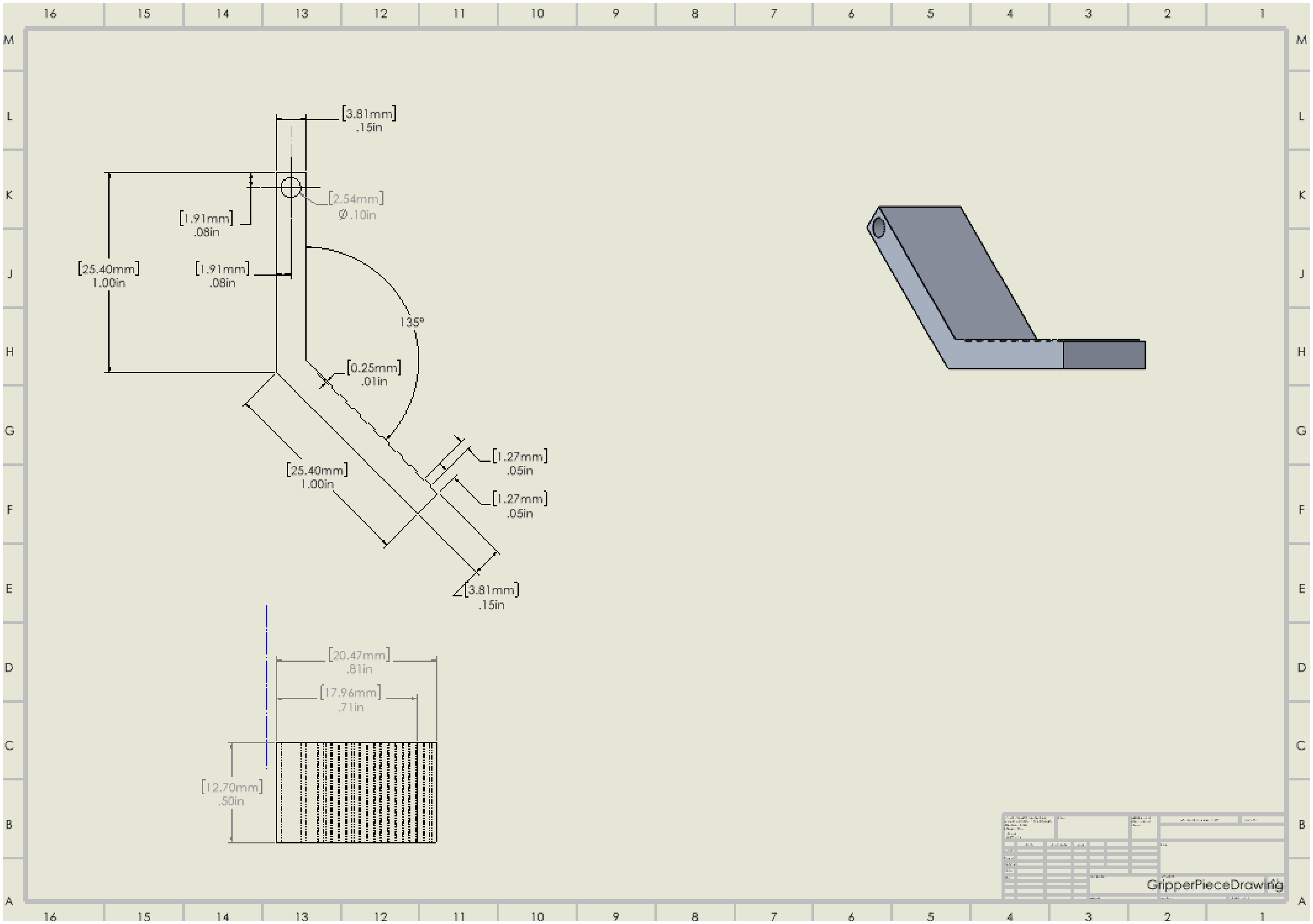
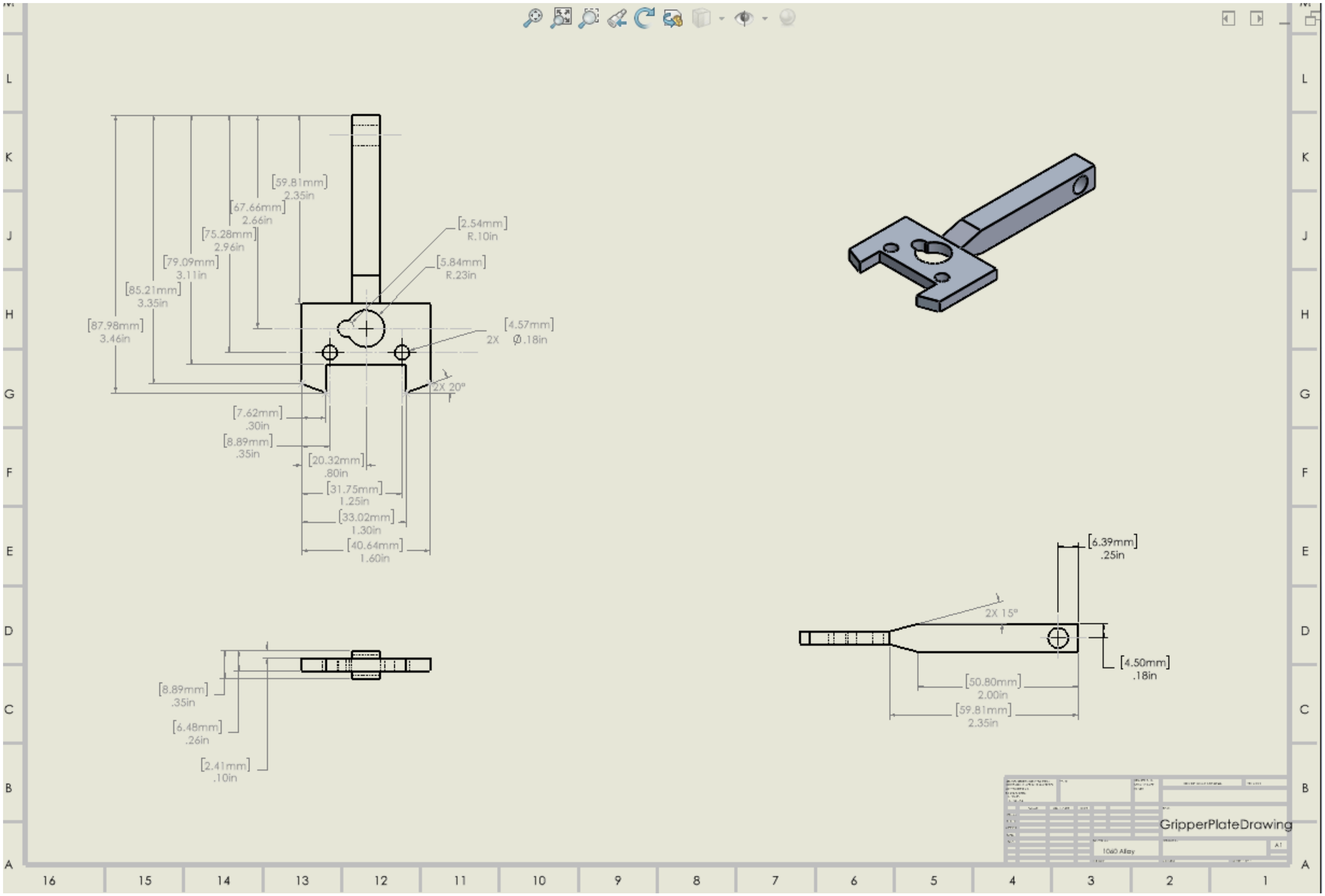


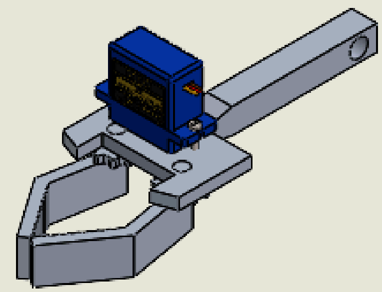
Figure 23: Gripper Piece

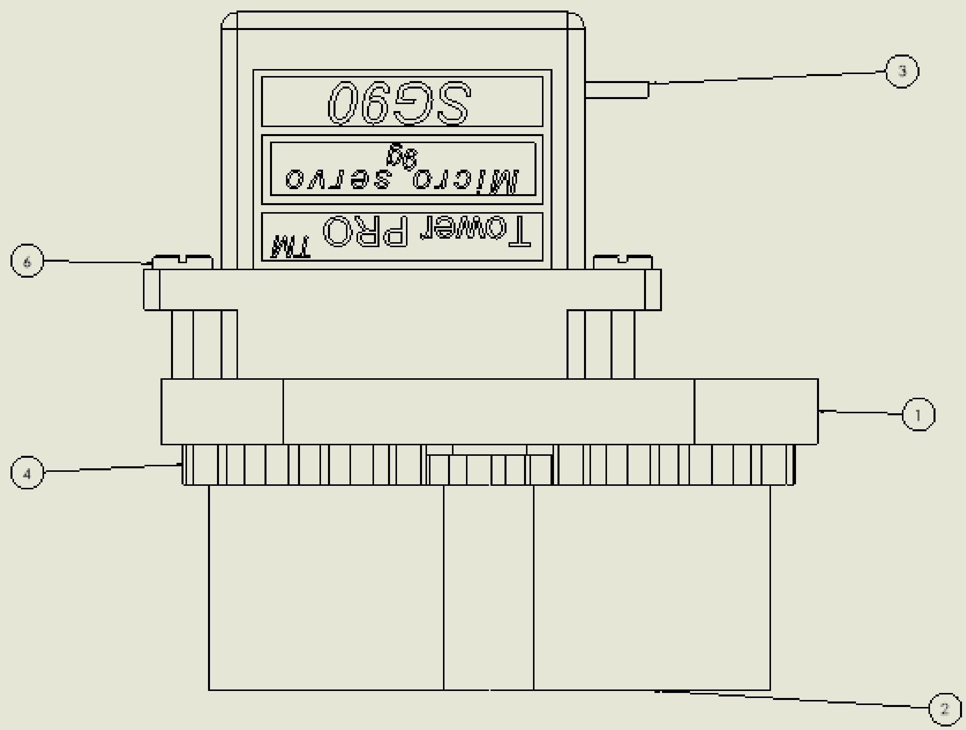


[59.81mm]
2.35in
[67.66mm]
2.66in
[75.28mm]
2.96in
[79.09mm]
3.11in
[85.21mm]
3.35in
[87.98mm]
3.46in
[2.54mm]
R.10in
[5.84mm]
R.23in
[4.57mm]
2X Ø.18in
2X 20°
[7.62mm]
.30in
[8.89mm]
.35in
[20.32mm]
.80in
[31.75mm]
1.25in
[33.02mm]
1.30in
[40.64mm]
1.60in
[8.89mm]
.35in
[6.48mm]
.26in
[2.41mm]
.10in
[6.39mm]
.25in
2X 15°
[4.50mm]
.18in
[50.80mm]
2.00in
[59.81mm]
2.35in
1060 Alloy
GripperPlateDrawing

Figure 24: Gripper Plate

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1	GripperPlate	1
2	2	GripperPiece	2
3	3	SG90	1
4	4	Gear1	3
5	5	GearandGripperInsert	2
6	6	SL-BHMS-MINI 0.0551-85x0.4x0.22-N	2





GripperAssemblyDrawing

Figure 25: Gripper Subassembly

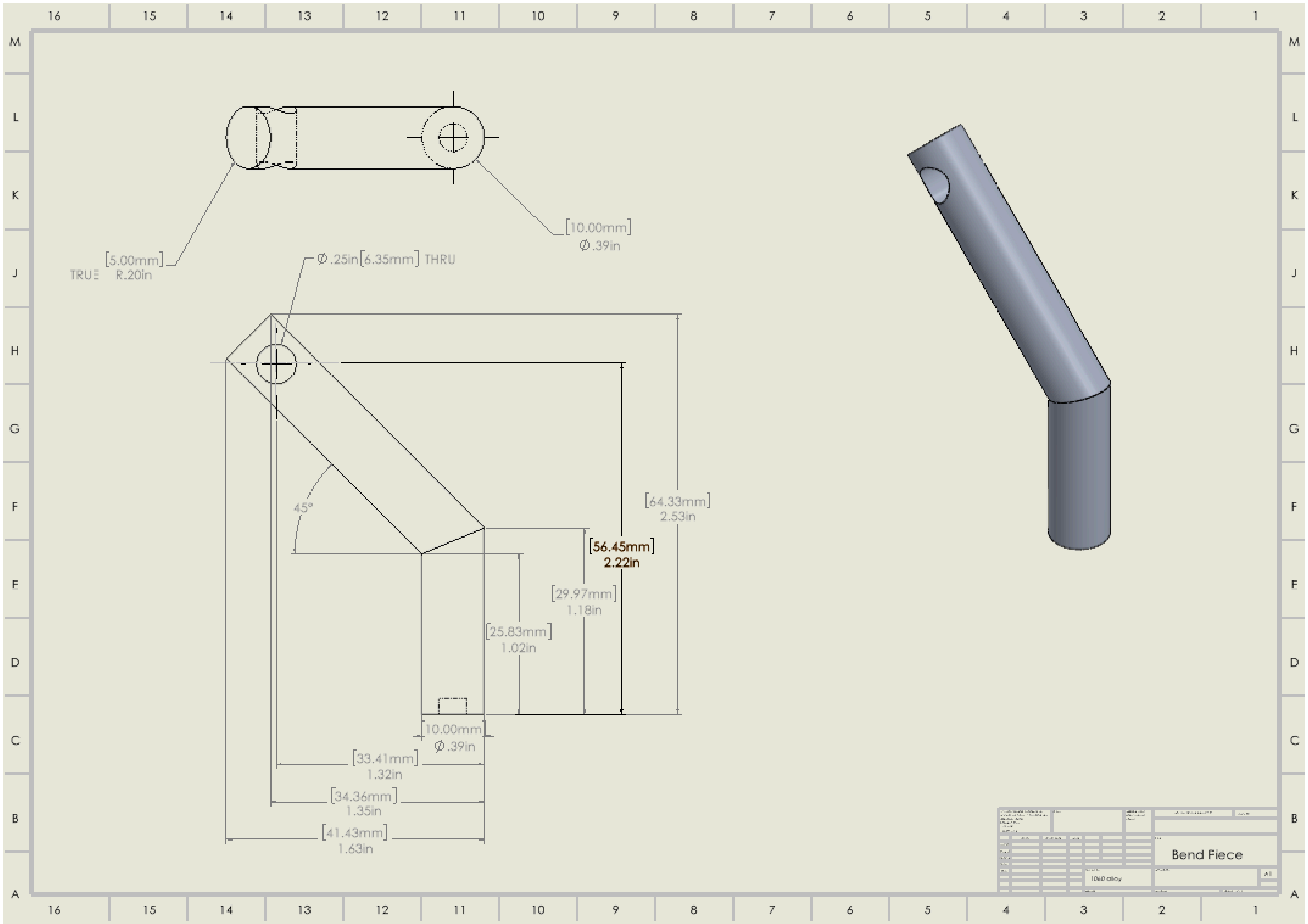


Figure 26: Bend Piece

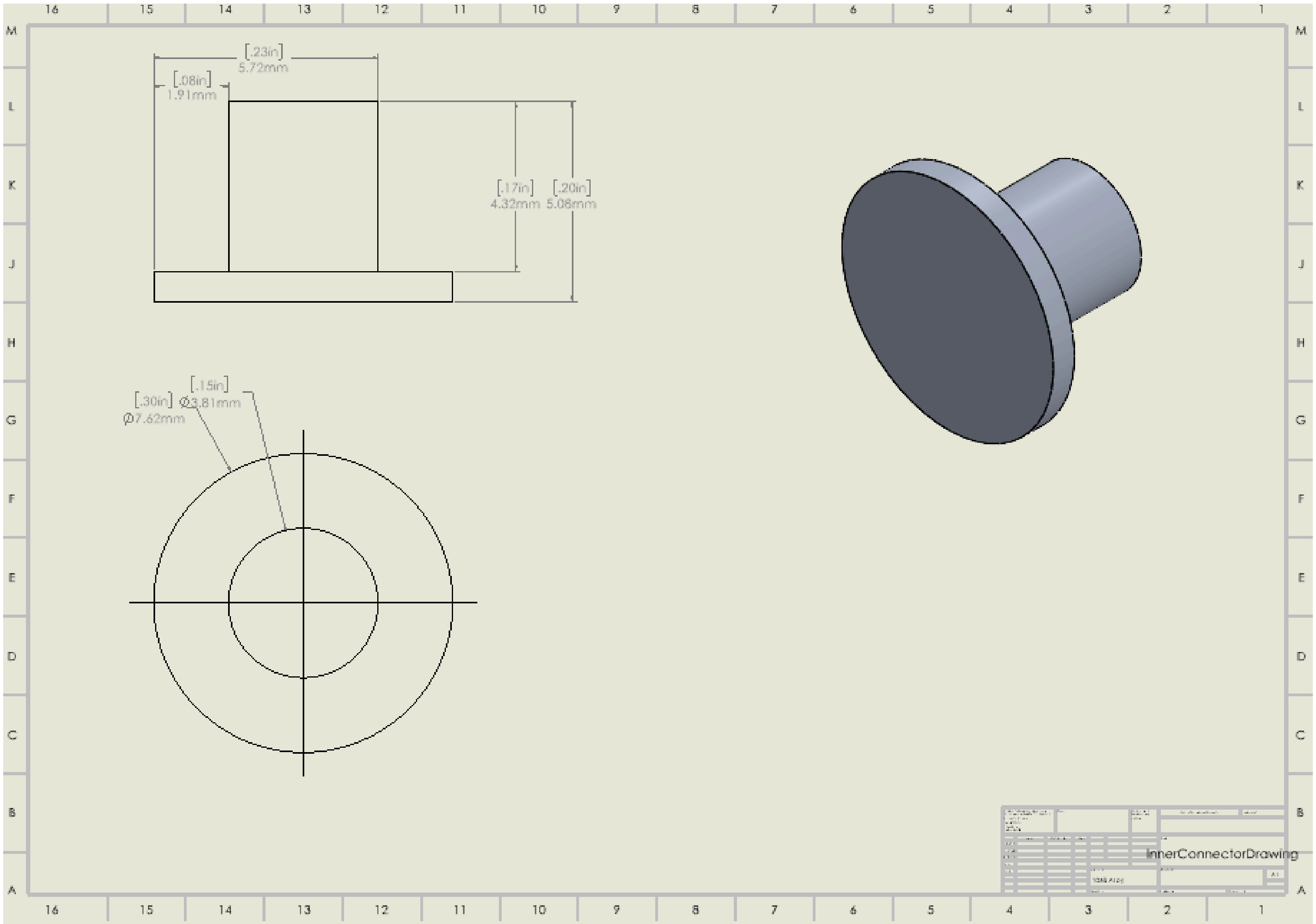

[.23in]
5.72mm
[.08in]
1.91mm
[.17in]
4.32mm
[.20in]
5.08mm
[.15in]
Ø3.81mm
[.30in]
Ø7.62mm
InnerConnectorDrawing

Figure 27: Inner Connector

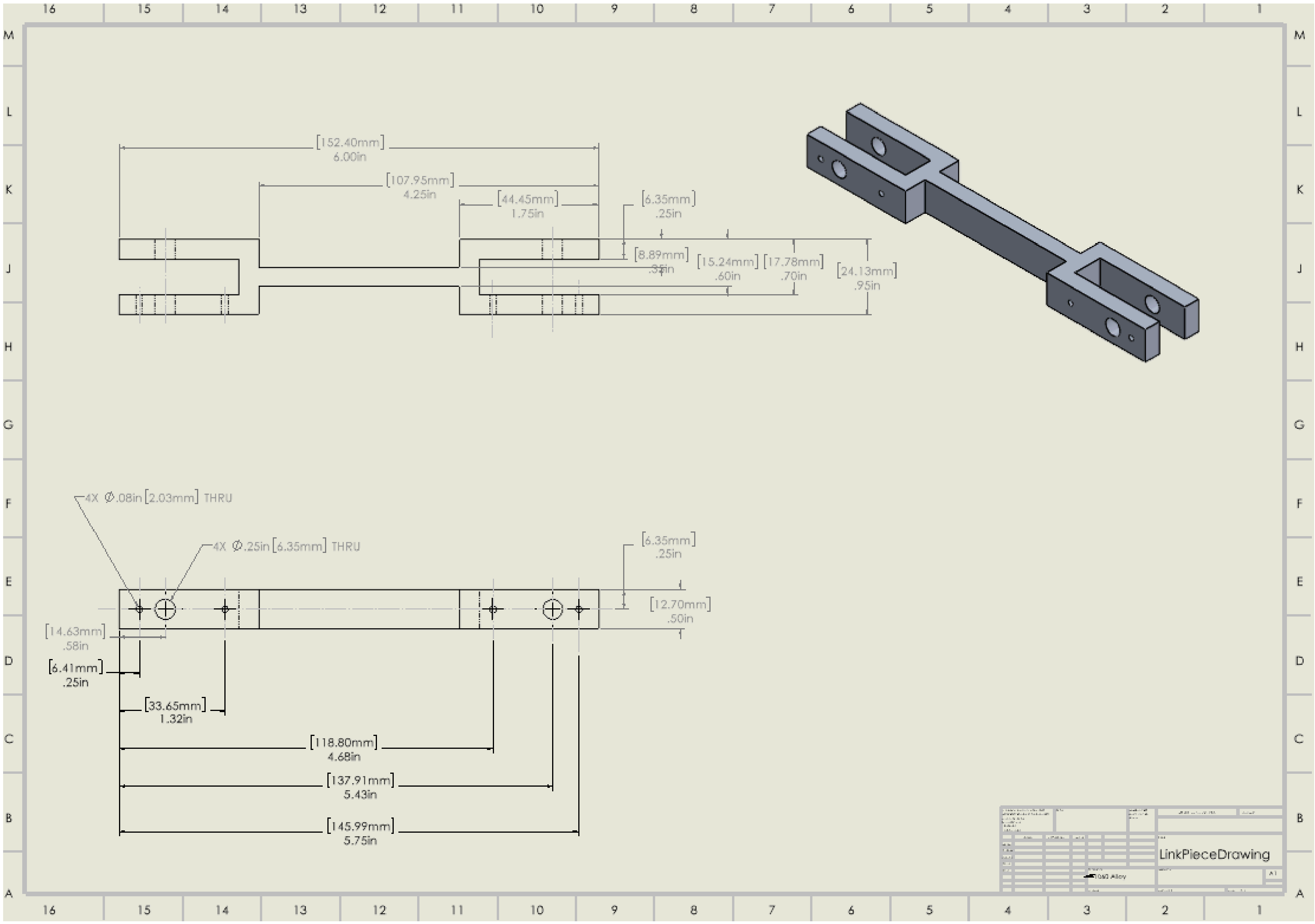
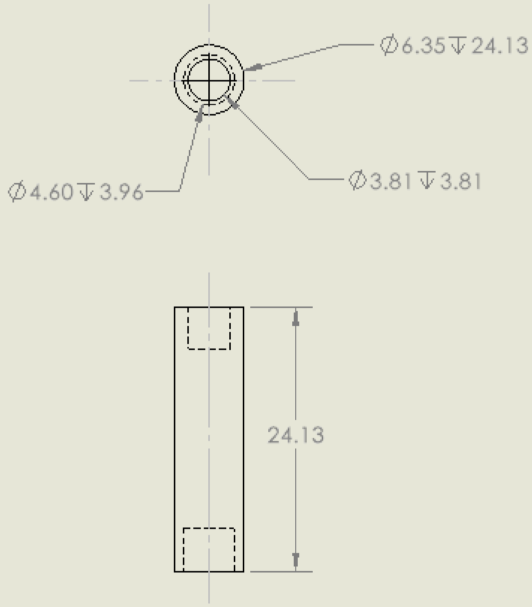
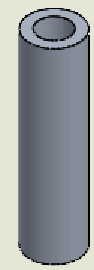

[152.40mm] 6.00in
[107.95mm] 4.25in
[44.45mm] 1.75in
[6.35mm] .25in
[8.89mm] .35in
[15.24mm] .60in
[17.78mm] .70in
[24.13mm] .95in
4X Ø.08in [2.03mm] THRU
4X Ø.25in [6.35mm] THRU
[6.35mm] .25in
[12.70mm] .50in
[14.63mm] .58in
[6.41mm] .25in
[33.65mm] 1.32in
[118.80mm] 4.68in
[137.91mm] 5.43in
[145.99mm] 5.75in
1060 Alloy
LinkPieceDrawing

Figure 28: Link Piece





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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: 1060 alloy

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

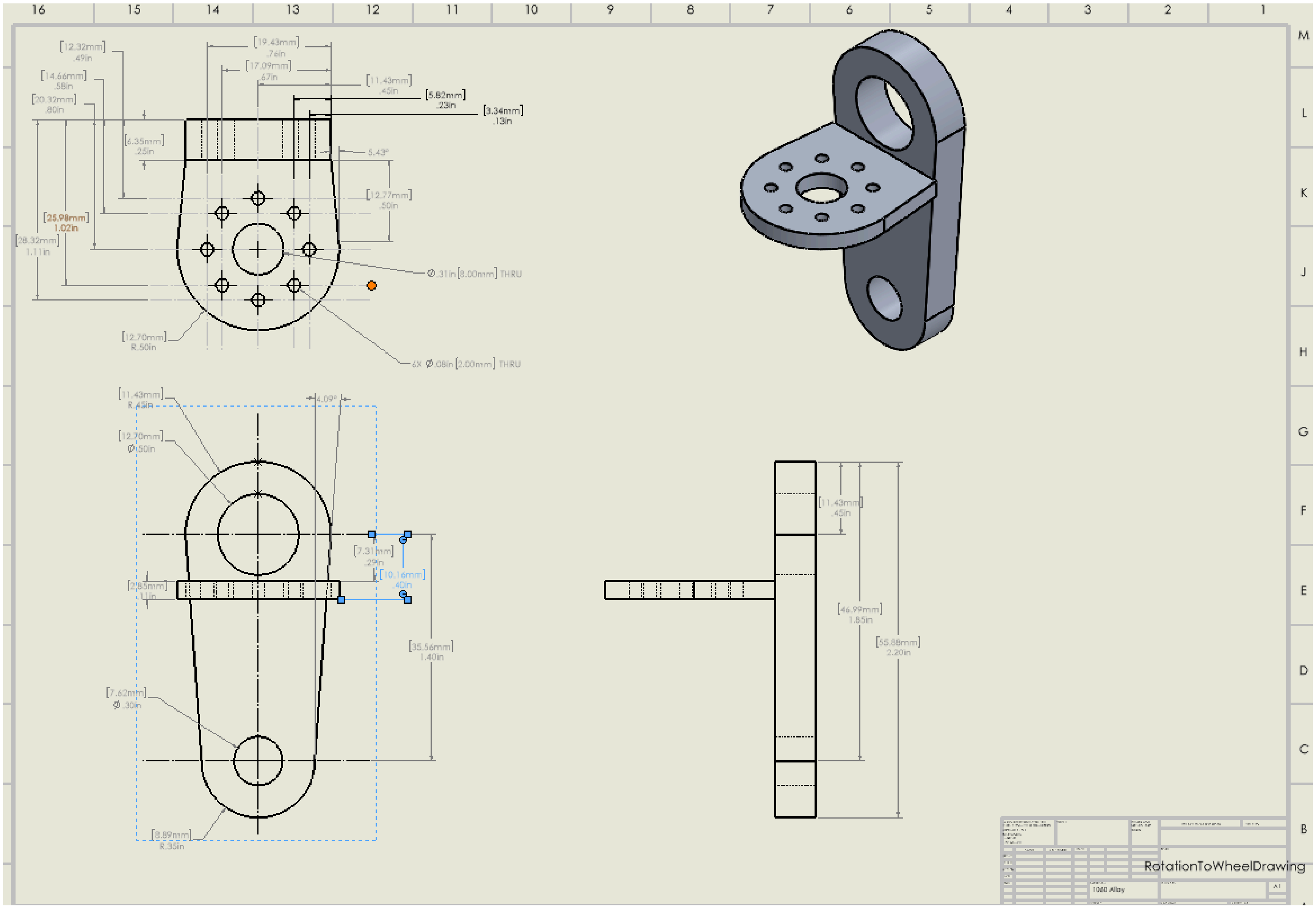
COMMENTS:

TITLE:
OuterConnectorDrawing

SIZE	DWG. NO.	REV
A		

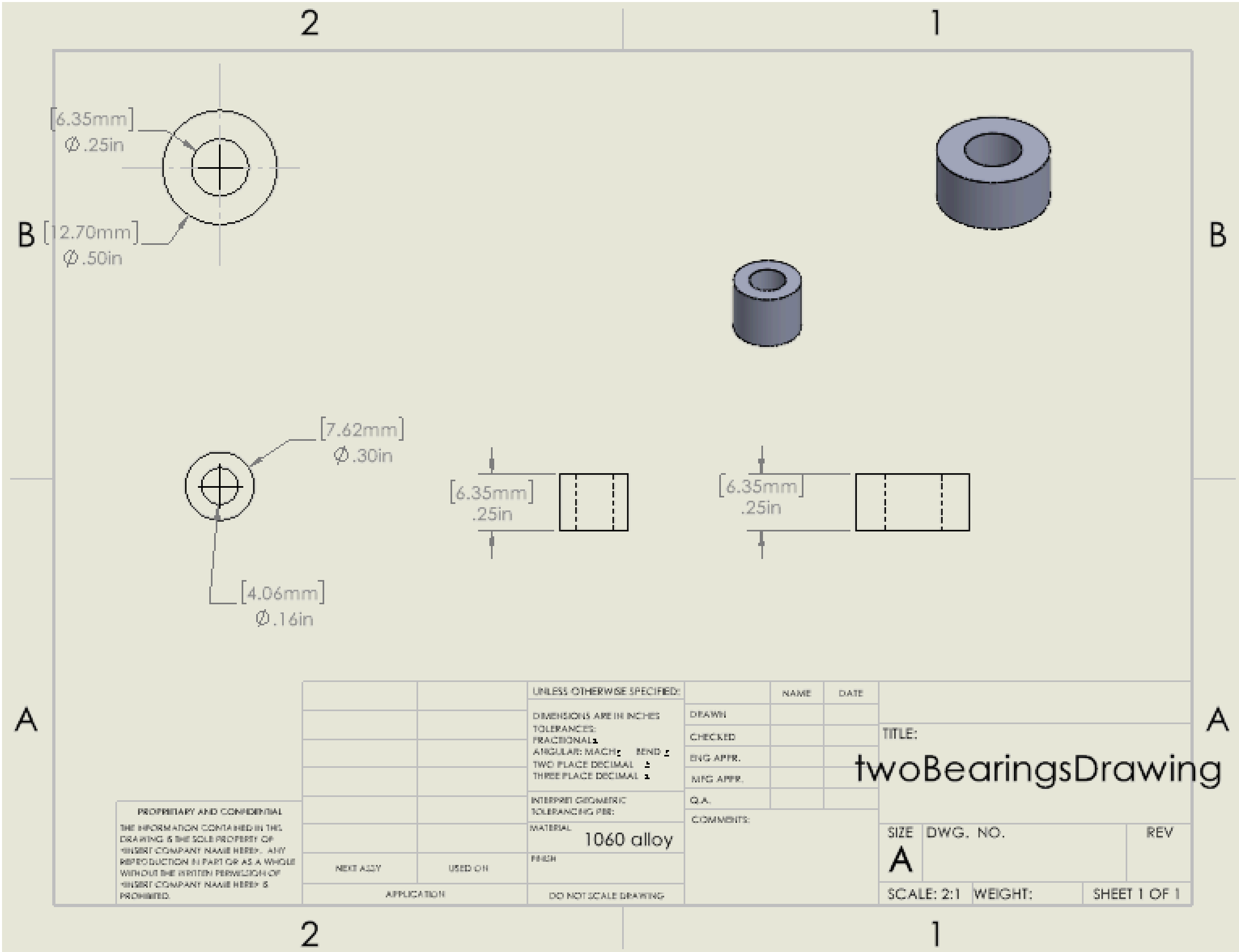
SCALE: 2:1 WEIGHT: SHEET 1 OF 1

Figure 29: Outer Connector Drawing



[19.43mm] .76in
[17.09mm] .67in
[12.32mm] .49in
[14.66mm] .58in
[20.32mm] .80in
[11.43mm] .45in
[5.82mm] .23in
[3.34mm] .13in
[6.35mm] .25in
5.43°
[12.77mm] .50in
[25.98mm] 1.02in
[28.32mm] 1.11in
Ø .31in [8.00mm] THRU
[12.70mm] R.50in
6X Ø .08in [2.00mm] THRU
[11.43mm] R.45in
4.09°
[12.70mm] Ø.50in
[7.31mm] .29in
[10.16mm] .40in
[2.85mm] .11in
[35.56mm] 1.40in
[7.62mm] Ø .30in
[8.89mm] R.35in
[11.43mm] .45in
[46.99mm] 1.85in
[55.88mm] 2.20in
RotationToWheelDrawing
1060 Alloy

Figure 30: Rotation to Wheel



2
1
B
A
[6.35mm]
Ø.25in
[12.70mm]
Ø.50in
[7.62mm]
Ø.30in
[4.06mm]
Ø.16in
[6.35mm]
.25in
[6.35mm]
.25in
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USED ON
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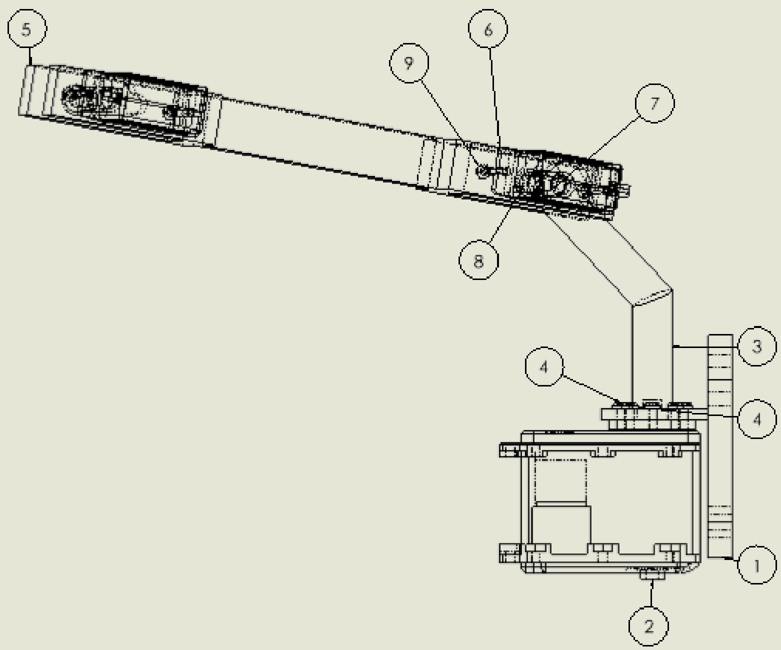
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
1060 alloy
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
twoBearingsDrawing
SIZE
A
DWG. NO.
REV
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1

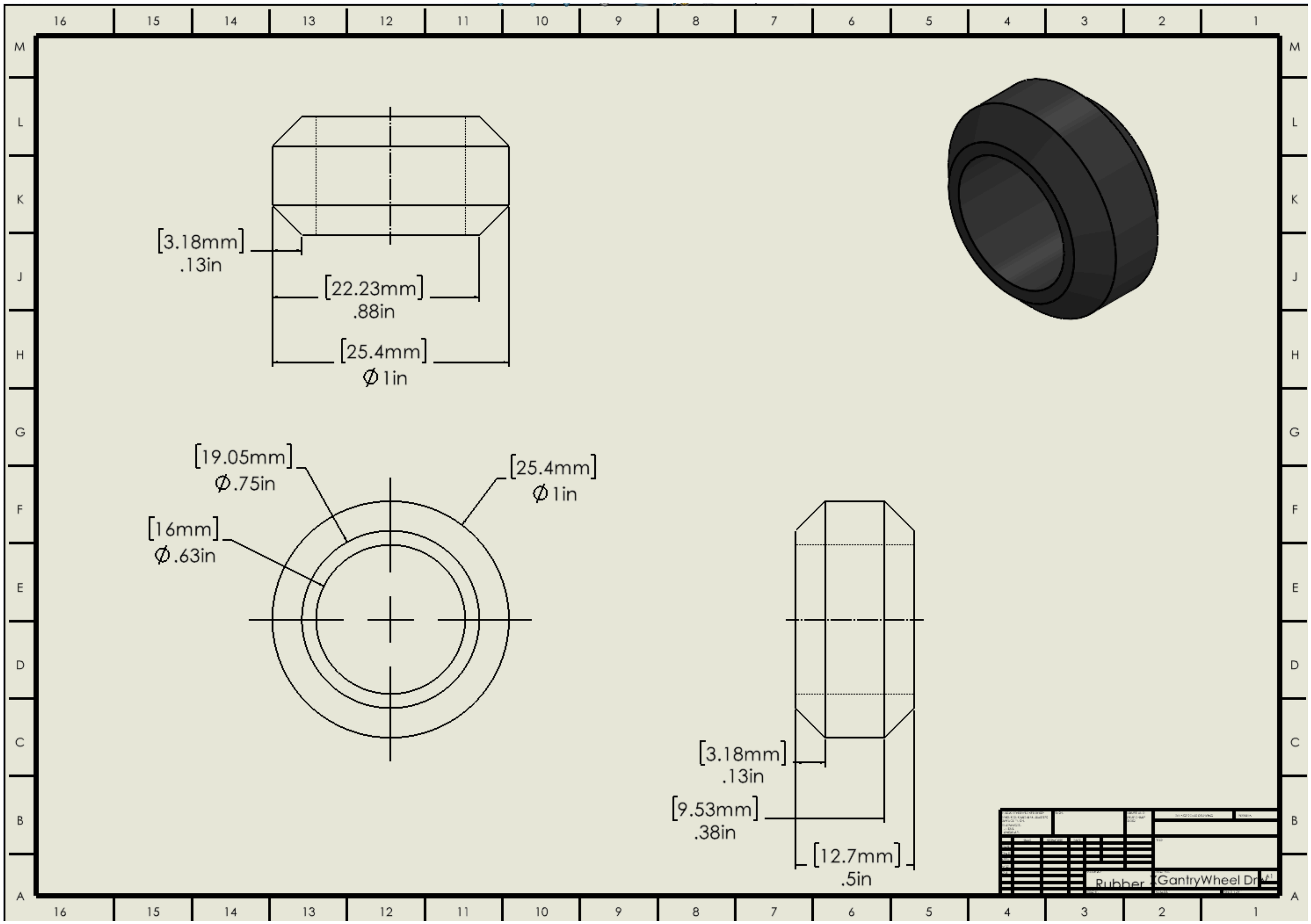
Figure 31: Two Bearings

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1	RotationToWheel	1
2	2	Motor (1)	1
3	3	BendPiece	1
4	4	B18.6.7M - M2 x 0.4 x 5 Slotted PHMS --5N	8
5	5	LinkPiece	1
6	6	SG90	2
7	7	OuterConnector	2
8	8	InnerConnector	2
9	9	SL-BHMS-MINI 0.0551-85x0.6x0.22-N	4
10	10	twoBearings	1



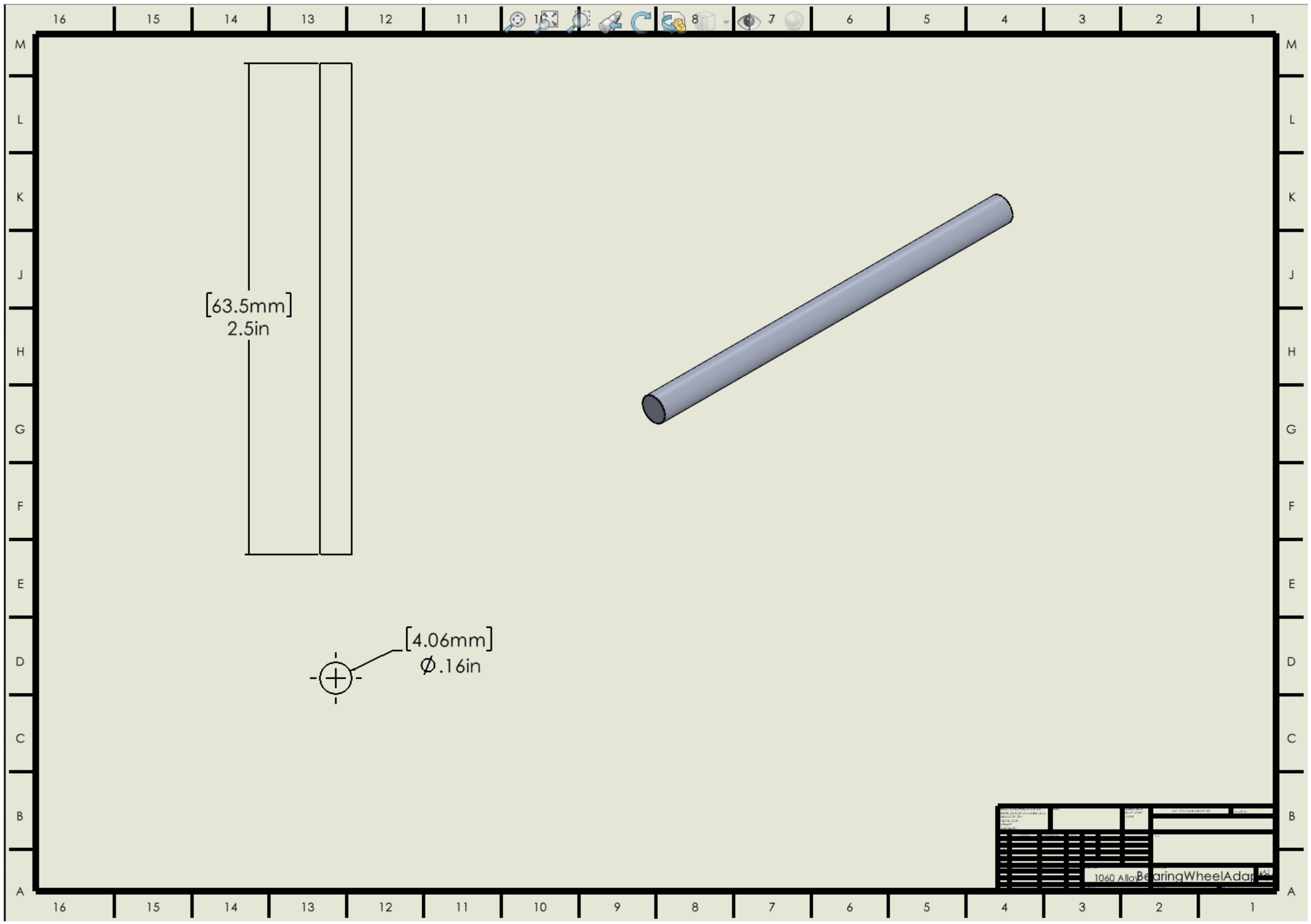
RotatingSectionDrawing

Figure 32: Rotating Section Subassembly



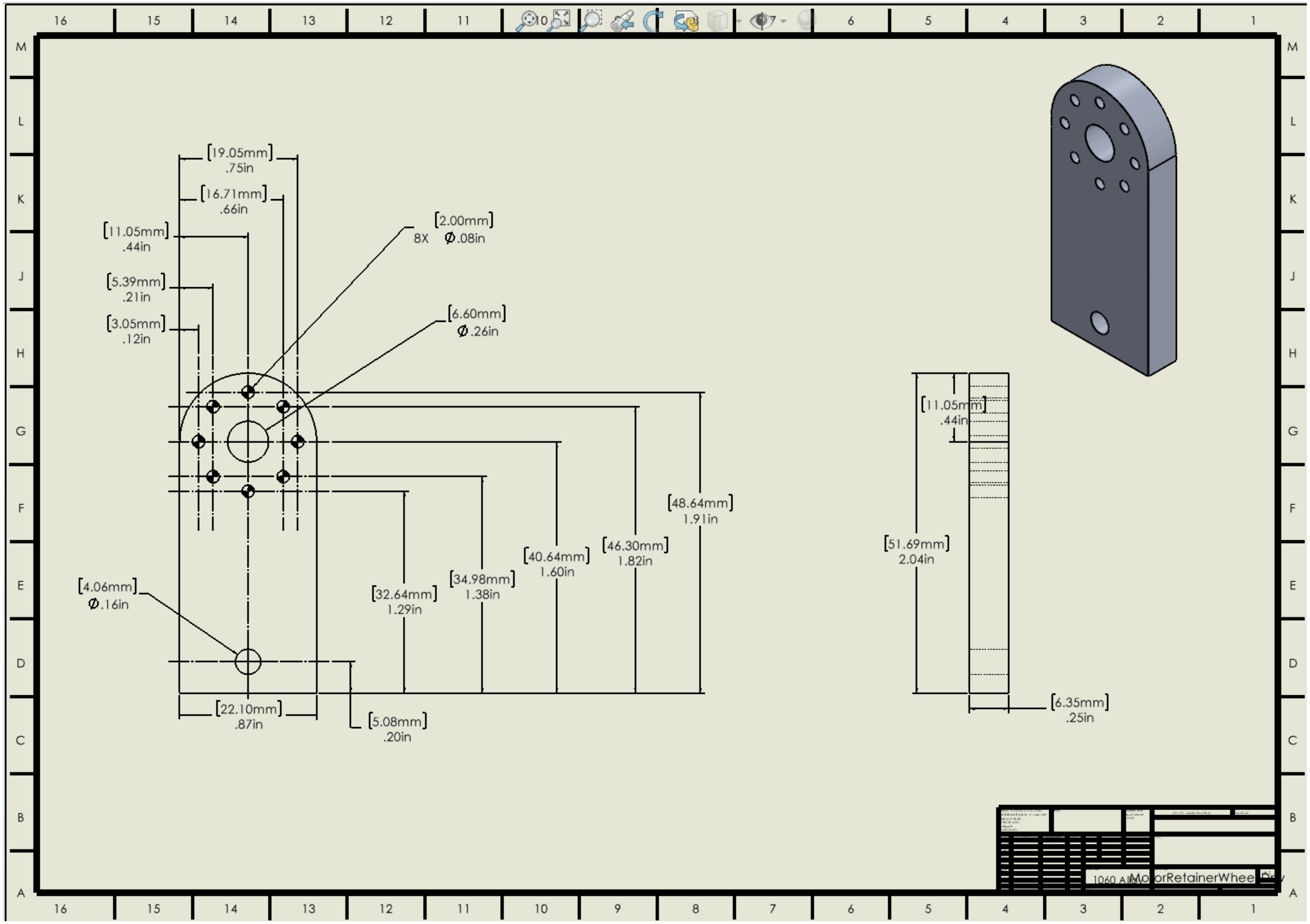
[3.18mm]
.13in
[22.23mm]
.88in
[25.4mm]
Ø1in
[19.05mm]
Ø.75in
[25.4mm]
Ø1in
[16mm]
Ø.63in
[3.18mm]
.13in
[9.53mm]
.38in
[12.7mm]
.5in
Rubber
GantryWheel Drw

Figure 33: X Gantry Wheel



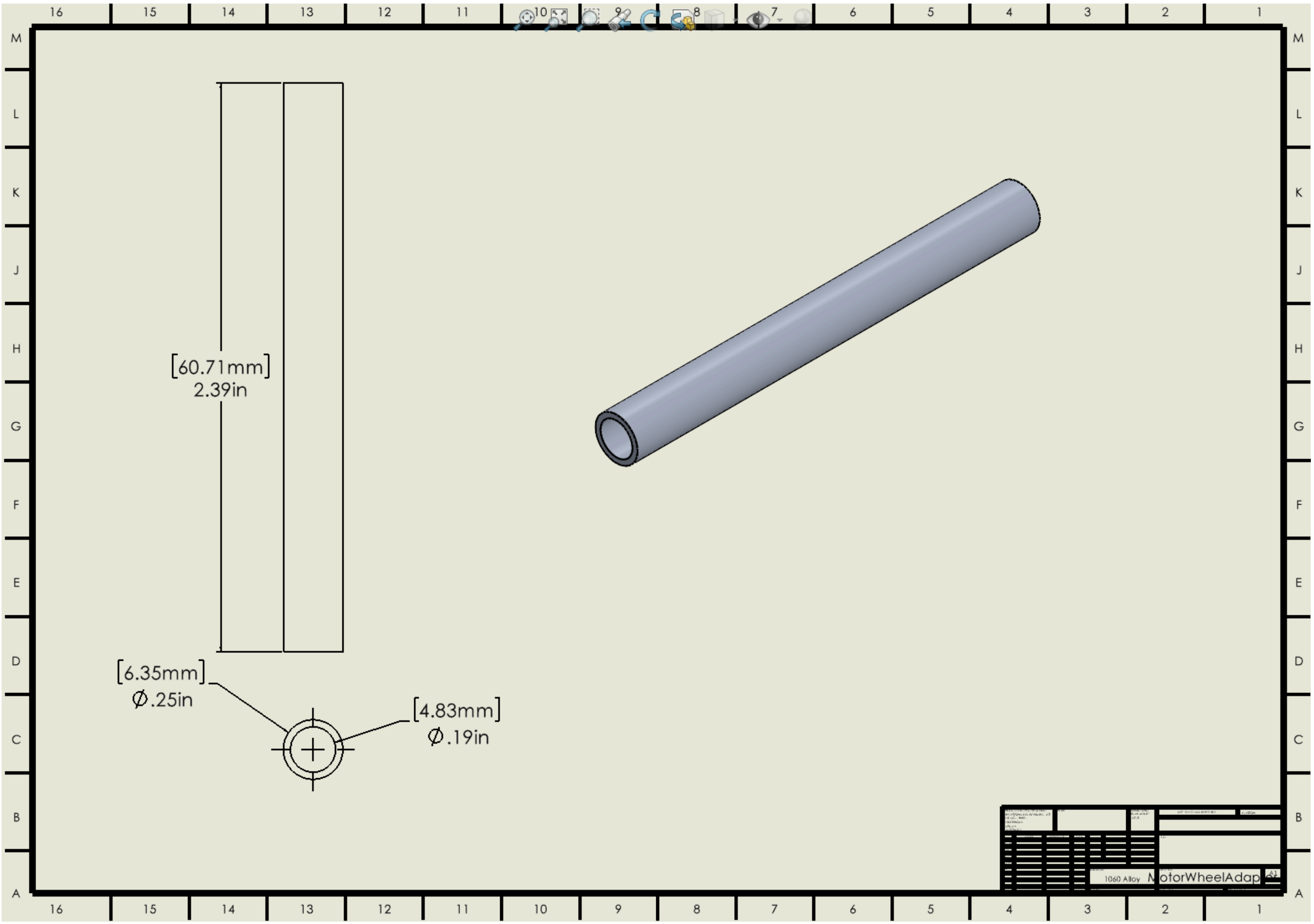
[63.5mm]
2.5in
[4.06mm]
Ø.16in
1060 Alloy
BearingWheelAdap

Figure 34: Bearing Wheel Adapter



[19.05mm] .75in
[16.71mm] .66in
[11.05mm] .44in
[5.39mm] .21in
[3.05mm] .12in
8X [2.00mm] Ø.08in
[6.60mm] Ø.26in
[4.06mm] Ø.16in
[22.10mm] .87in
[5.08mm] .20in
[32.64mm] 1.29in
[34.98mm] 1.38in
[40.64mm] 1.60in
[46.30mm] 1.82in
[48.64mm] 1.91in
[11.05mm] .44in
[51.69mm] 2.04in
[6.35mm] .25in
1060 Alloy
MotorRetainerWheel

Figure 35: Motor Retainer Wheel



[60.71mm]
2.39in
[6.35mm]
Ø.25in
[4.83mm]
Ø.19in
1060 Alloy
MotorWheelAdapter

Figure 36: Motor Wheel Adapter

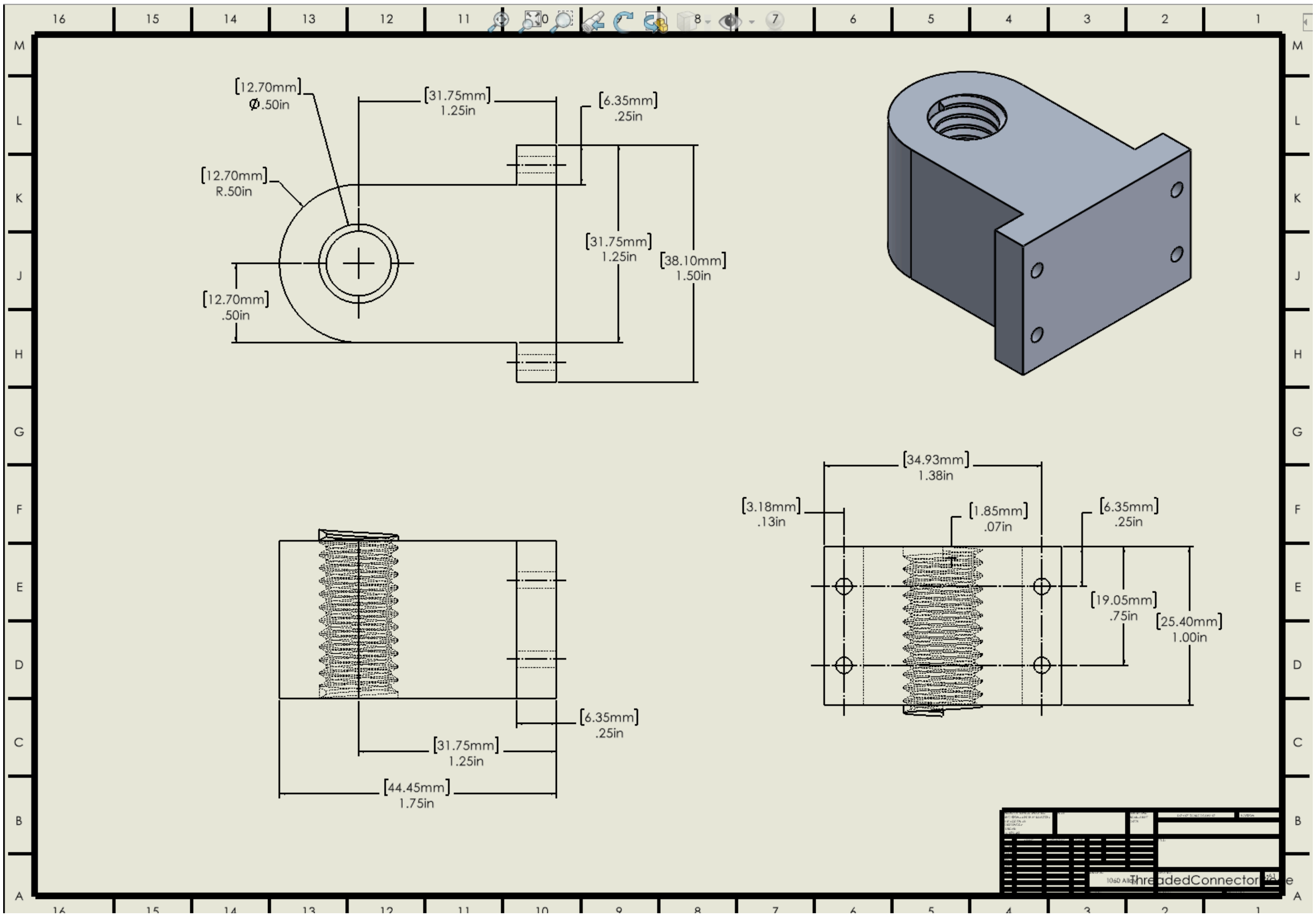
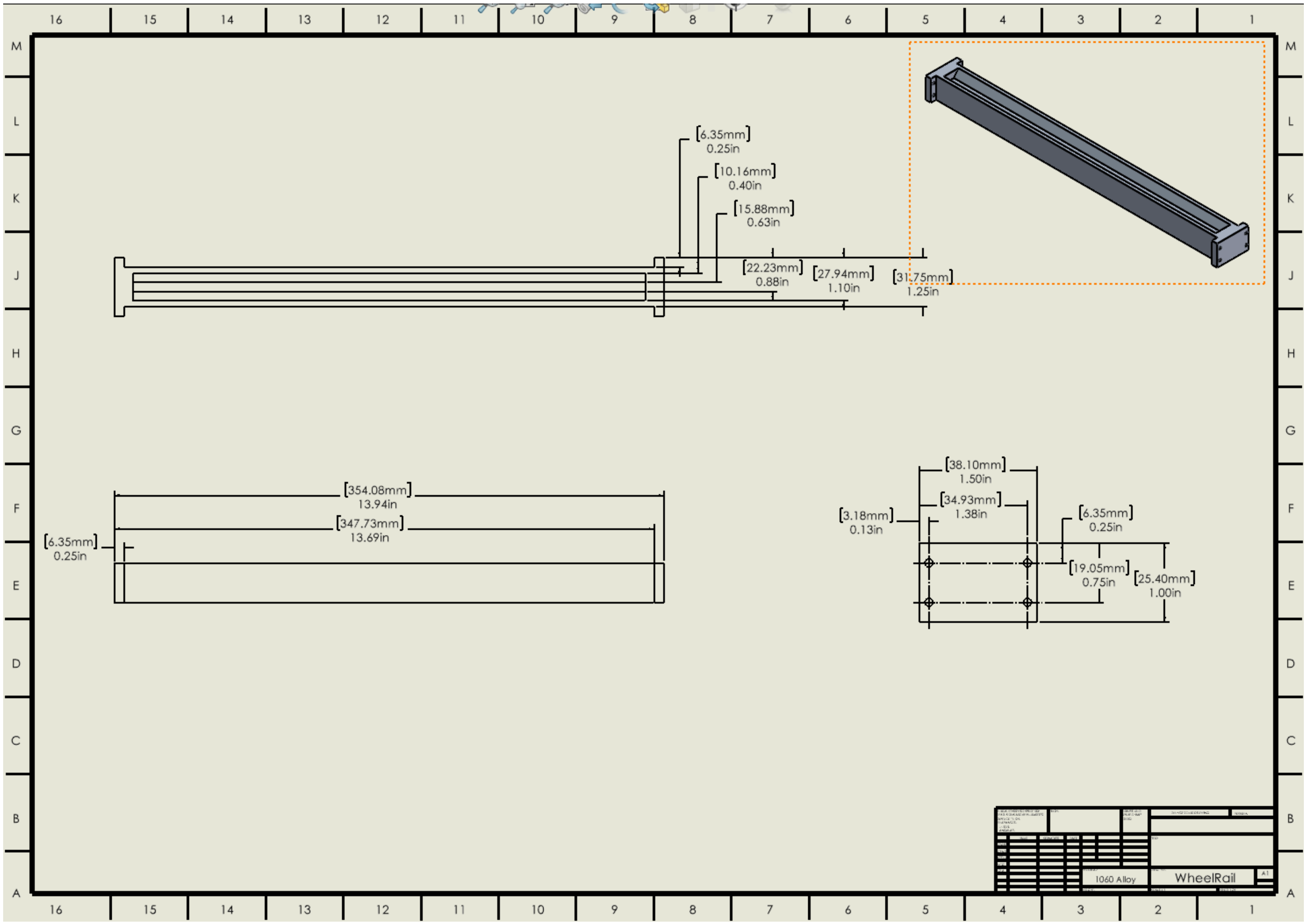

[12.70mm] Ø.50in
[31.75mm] 1.25in
[6.35mm] .25in
[12.70mm] R.50in
[31.75mm] 1.25in
[38.10mm] 1.50in
[12.70mm] .50in
[34.93mm] 1.38in
[3.18mm] .13in
[1.85mm] .07in
[6.35mm] .25in
[19.05mm] .75in
[25.40mm] 1.00in
[6.35mm] .25in
[31.75mm] 1.25in
[44.45mm] 1.75in

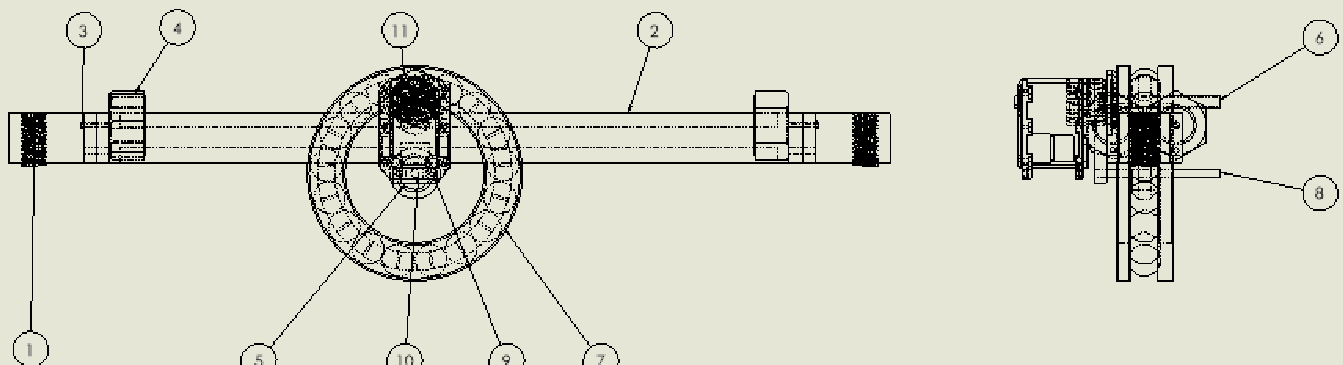
Figure 37: Threaded Connector Piece



[6.35mm] 0.25in
[10.16mm] 0.40in
[15.88mm] 0.63in
[22.23mm] 0.88in
[27.94mm] 1.10in
[31.75mm] 1.25in
[354.08mm] 13.94in
[347.73mm] 13.69in
[6.35mm] 0.25in
[38.10mm] 1.50in
[34.93mm] 1.38in
[3.18mm] 0.13in
[6.35mm] 0.25in
[19.05mm] 0.75in
[25.40mm] 1.00in
1060 Alloy
WheelRail

Figure 38: Wheel Rail

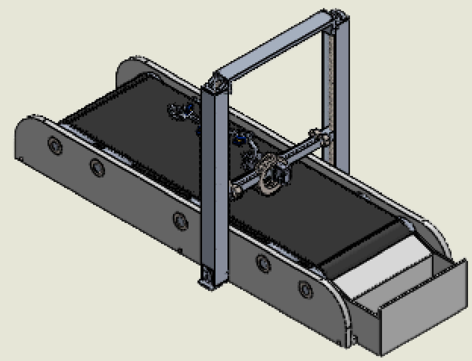
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1	ThreadedConnectorPiece	2
2	2	WheelRail	1
3	3	B18.6.7M - M2 x 0.4 x 13 Indented HHMS --13N	4
4	4	B18.2.4.1M - Hex nut, Style 1, M20 x 2.5 --W-N	4
6	6	XGantryWheel	1
6	6	MotorWheelAdapter	1
7	7	thrust ball bearing2_68_am	1
8	8	BearingWheelAdapter	1
9	9	Motor (1)	1
10	10	MotorRetainerWheel	1
11	11	pan head tapping screw_am	8

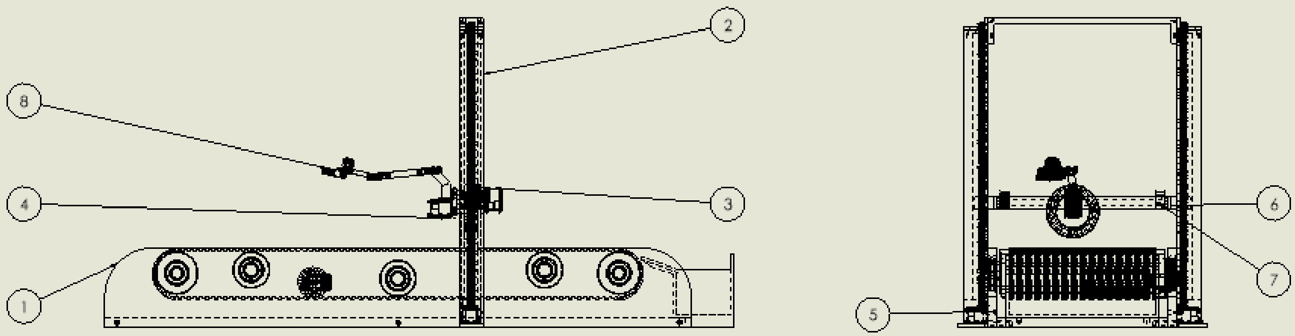


XgantryAssembly

Figure 39: XGantry Assembly

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1	Conveyer Assembly	1
2	2	YGantryBothSides	1
3	3	XgantryAssembly	1
4	4	RotatingSection	1
5	5	B18.6.7M - M2.5 x 0.45 x 25 Type I Cross Recessed PHMS --25N	4
6	6	B18.6.7M - M2.5 x 0.45 x 16 Indented HHMS --16N	4
7	7	B18.2.4.1M - Hex nut, Style 1, M2.5 x 0.45 --D-N	4
8	8	GripperAssembly	1





FullAssemblyDrawing

Figure 40: Full Assembly

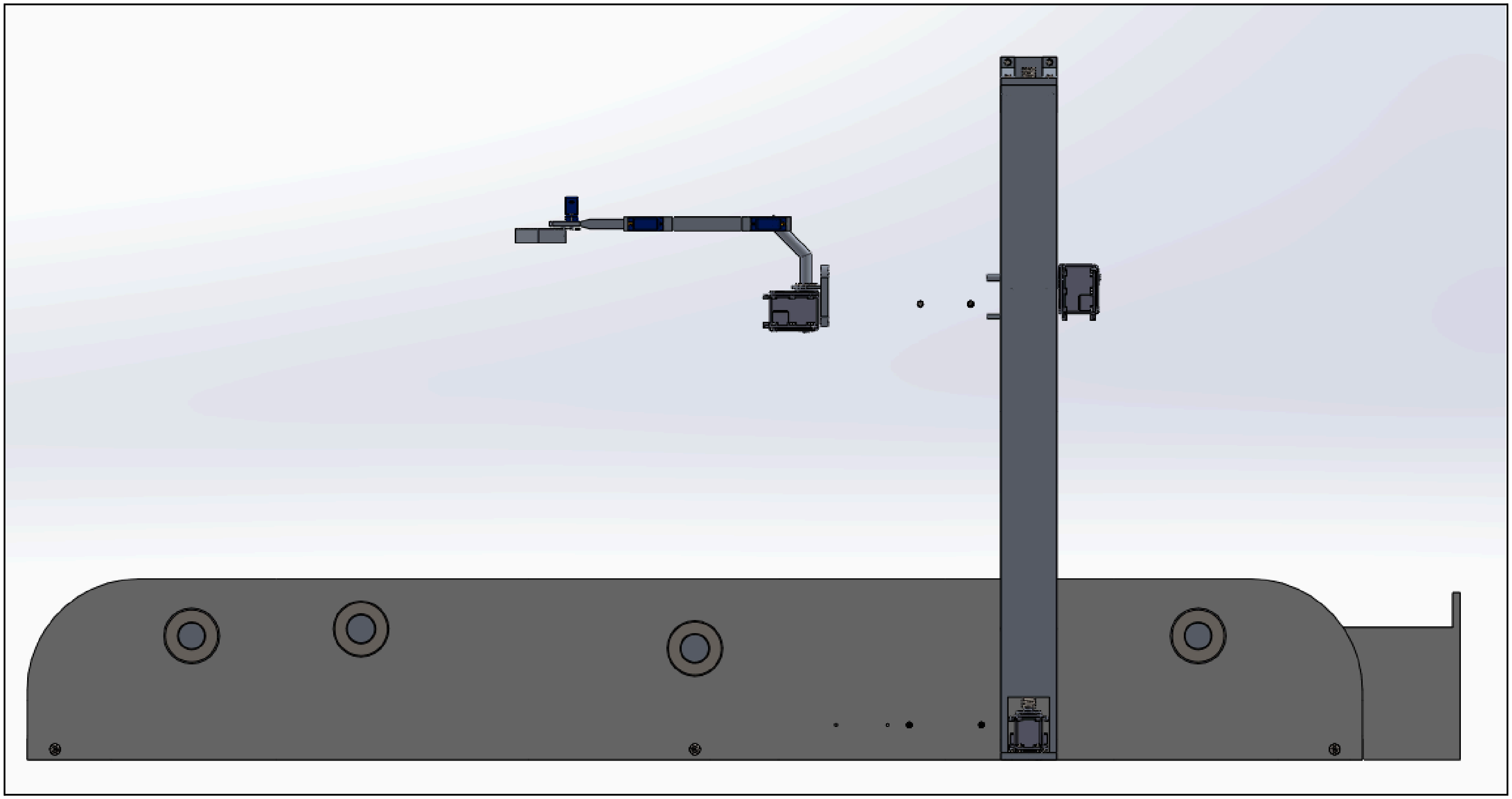


Figure 41: Exploded View