Final Report: CAD Project
"Quasi-Octopus Robotic Arm Manipulator"

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Abstract

The goal in this project is to utilize the Solidworks computer-aided design (CAD) software to create a robotic manipulator that can be feasibly manufactured. Further, our group added the additional goal of attempting to create a manipulator that, with further development, could be scaled down and implemented into a larger design focused on creating a manipulator that emulates the movement of an octopus tentacle. In order to achieve these overarching goals, a set of seven specific design conditions were set to guide our design process. They were: to create a robotic arm manipulator that possesses a full six degrees of freedom of motion; to develop a design that accurately reflects the total mobility of a ball joint at a macro-level scale in order to satisfy the "tentacle" behavior we wish to replicate; to develop a design that maximizes the range of motion at each joint; to use axial revolution and planar joint rotation exclusively to simplify the design and manufacturing process; to implement the Servo-Motor CAD provided by Professor Edward Gao (developed by Yunbo Wang) as the primary joint actuator; to create a design that can be relatively simply manufactured using basic machining techniques and low-cost 3D printing techniques; and to include a grasping implement at the end of the manipulator to allow for the robotic arm to interact with its surroundings. Our design process took inspiration from existing multi-degree of freedom robots. Our final design consisted of five subassemblies: the grabber, wrist, forearm, stand, and base. Each of these subassemblies consisted of a minimum of five unique components. The proposed manufacturing process uses either commercially available off-the-shelf parts, or custom components that can be fabricated using acrylonitrile butadiene styrene (ABS) thermoplastic 3-D printing. The final analysis of our design revealed that there are several factors that can be optimized in our design in future iterations, including implementing more complex joint configurations, optimizing the design for weight savings, and utilizing more sophisticated manufacturing techniques. Overall, the design our team developed is a strong first step in the iterative challenge we have outlined. There are clear steps to improving the design, but the mechanical abilities of this robotic manipulator satisfy the basic conditions we outlined in our design specifications.

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Introduction

Engineering is a field that is largely defined by the design, development, and production of products and infrastructures. With the dawn of the industrial revolution in the late 18^{th} century, labor has been progressively becoming more and more automated to enhance efficiency in production and manufacturing. Furthermore, automation eliminates human error and labor costs, and technology is much more dependable and predictable. Although it took centuries for humans to develop the infrastructures and tools we have today, the 21^{st} century has seen rapid development in robotics and the production line for materials. In the case of our project, this is seen with the design of our robotic manipulator. Robotic manipulators are mechanical apparatuses that are capable of moving and handling objects precisely with certain degrees of freedom. Degrees of freedom are also considered as axes and correlates to the number of motors within the robot. Six degrees of freedom for a robotic manipulator closely emulate the motion of a human arm, which is why we decided to pursue this amount in our own project.

Before we began creating our robotic manipulator, we did some research on what qualities characterize a manipulator and separate it from other forms of industrial machinery. Robotic manipulation was created to substitute human labor on assembly lines, it was designed to be quicker, more reliable, and far more accurate than a human worker. This inquiry made our group establish reliability and sturdiness as the two hallmarks of our design, because if we made a manipulator that was always reliable, we should in principle have one that can perform at higher speeds without sacrificing precision. Moreover, we wished to develop a proof of concept that can be extrapolated to replicate the joint movement of an octopus tentacle, which possesses one of the highest degrees of mobility of any living creature's extremity. Doing so requires developing a design that prioritizes creating a manipulator that requires relatively small motor housings that can be feasibly scaled down to create a larger, more complex linear array of joints that could replicate the behavior of a real-life octopus.

Design Objectives

Now that we had formed a more concrete idea of what we wanted our manipulator to be able to accomplish, we spent more time evaluating the design objectives. We evaluated what specific goals we wanted our manipulator to satisfy and prepared for the obstacles that we would likely encounter during the design process. The fifty part minimum made us consider what size we would want our final constructor to be. Fifty pieces could be difficult to fit on a smaller manipulator, such as one designed to solder circuit boards or assemble small arrangements of pieces. Moreover, we were worried about what role size would play when using standardized toolbox screws and bolts, would we have the proper components to be able to properly fasten the pieces of the manipulator if we designed one that was either too big or too small. With these concerns in mind, the design goals and objectives for this project are outlined below:

(1) Create a robotic arm manipulator that possesses a full six degrees of freedom of motion.
(2) Develop a design that accurately reflects the total mobility of a ball joint at a macro-level scale in order to satisfy the “tentacle” behavior we wish to replicate.
(3) Develop a design that maximizes the range of motion at each joint.
(4) Use axial revolution and planar joint rotation exclusively to simplify the design and manufacturing process.
(5) Implement the Servo-Motor CAD provided by Professor Edward Gao (developed by Yunbo Wang) as the primary joint actuator.
(6) Create a design that can be relatively simply manufactured using basic machining techniques and low-cost 3D printing techniques.
(7) Include a grasping implement at the end of the manipulator to allow for the robotic arm to interact with its surroundings.

Figure 1: An octopus tentacle, exemplifying the range of motion the project will attempt to replicate at a macro-level scale (image courtesy of StockFood).

Figure 2: A sample 6 degree of freedom robot (image courtesy of Mecademic Robotics).

Prior Work

The development of precision robotics, especially the robotic arm, has been continuously evolving and improving over the last few centuries. While the true implementation of the robotic tools in the automation of tasks did not begin until the dawn of the industrial revolution in the mid-19th century, the true history of robotic implements is much older, stretching back to the Renaissance and the prolific inventor Leonardo da Vinci. In fact, in the late fifteenth century da Vinci developed several humanoid robots with varying degrees of motion, even including programmable controllers and multiple joint extremities[1].

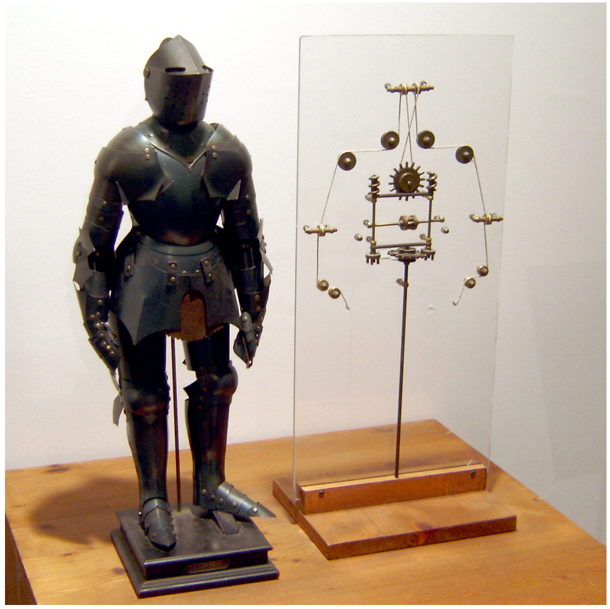


Figure 3: An image of “Leonardo’s Mechanical Knight,” one example of a humanoid automaton developed by Leonardo da Vinci (image courtesy of Wikipedia).

In the centuries following da Vinci’s design, many similar engineering projects were developed, but like their predecessor, none of these designs provided the opportunity for an increase in productivity, and served only as a proof of concept. The first robotic system that marked the beginning of the use of automation in manufacturing and assembly was implemented by General Motors in 1962, used to automate the diecasting process[1]. This development, fueled by the arrival of computer systems, electronics, and transistors, marked the beginning of a boom in the development of robotic manipulators.

In the modern day, robotic arms are the focus of many graduate-level studies in engineering dynamics, control systems, and other fields of engineering and technology. Dr. Veronica Santos, professor of Mechanical and Aerospace Engineering at UCLA, focuses on grasp, manipulation, and hand biomechanics. Examples of robotic manipulators developed in line with Dr. Santos’s research is provided in Figures 4 and 5.

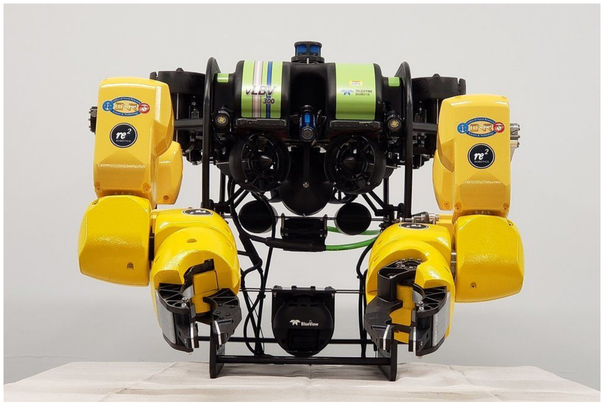


Figure 4: Dexterous underwater robot developed by RE2 Robotics for handling dangerous devices (image courtesy of RE2 Robotics).

Figure 5: Explosive disposal robot developed by Dr. Veronica Santos and her team (image courtesy of Department of Mechanical and Aerospace Engineering at UCLA).

Development in the field of engineering with direct regards to the “tentacle” freedom of movement that we hope to emulate in this project has also been the source of study by a joint team of researchers at Harvard University and Beihang University[3]. This team developed the soft robot (referring to robots that are composed of pliant materials) that demonstrably was able to grip and lift a variety of objects. This project represents a different avenue to achieve the same goal of creating a robotic system that can contort in multiple forms.

Concept

In order to best satisfy the design criteria we outlined, our team decided to use an iterative design process instead of a branched design process. In order to develop the final design, our team worked through each design objective and focused on how we could refine our design to make it better suited to meet the expectations we had created.

The primary objective of our robotic manipulator was to have a full six degrees of freedom. The primary constraint we placed on this design, as described in the design objectives section, was to only use axial revolution and planar rotation to simplify the overall complexity of the design. While there are other joint configurations that would provide greater mobility and decrease the number of parts necessary to achieve the full range of motion, these alternatives existed beyond the constraints of our current manufacturing methods. Benefits and drawbacks to different joint types are provided in the ‘Theory’ section of the paper.

Design Iteration 1

Figure 6 provides a sketch of the first design iteration our team came up with. This design set the basic structure of our final design. The primary takeaways from this iteration was the use of a turntable base and rotating claw as the grasping implement. Potential causes for concern that led us to our second design was the redundancy of freedom of motion in the X-Z plane, which did not recreate the versatility in motion that we hoped to capture in our final product.

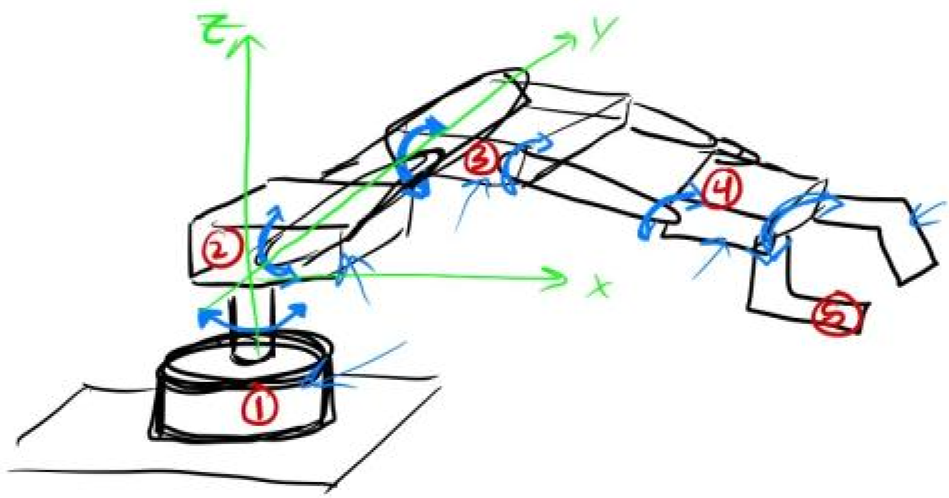


Figure 6: Sketch of the first design iteration for the robotic manipulator.

Design Iteration 2

Figure 7 provides a sketch of our second design iteration. This design utilized the standard six degrees of freedom—motion along the X, Y, and Z axes as well as roll, pitch, and yaw that define rotation about each of these coordinate axes. The benefit to this design was having a design that had the full freedom of movement that we hoped to achieve. Drawbacks to this design, however, were primarily rooted in the difficulty of creating a rack-and-pinion system to convert the rotational motion of the motor into the linear motion necessary for this design. Since one of the design constraints we wanted to design our robotic manipulator to was ease of modeling and manufacturing, we decided to develop a design that would combine elements of our past two design iterations. It was at this point in the design cycle that we decided to implement the constraint of only using rotational and revolution joints, since exclusively utilizing motion that relies on circular (as opposed to rectangular) paths would greatly simplify the design.

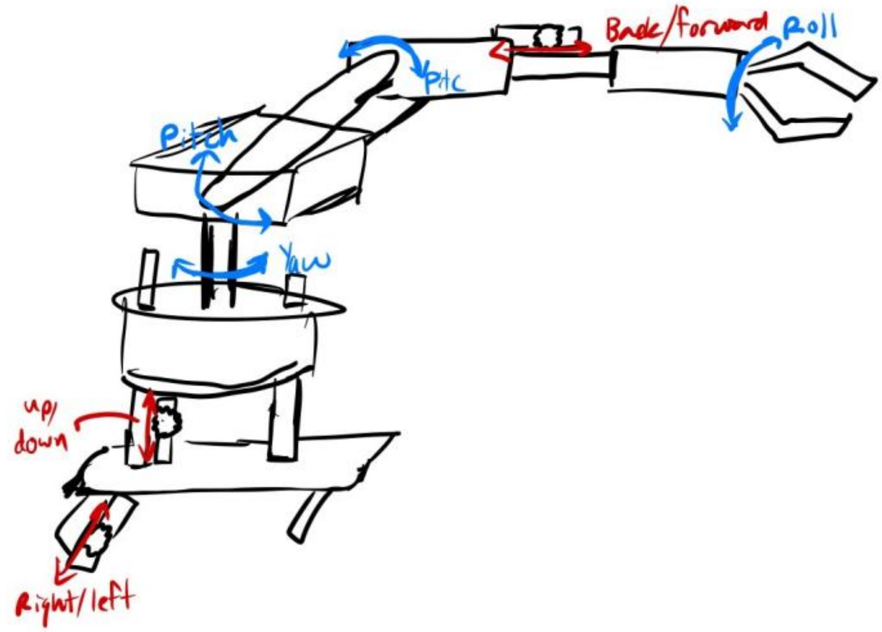


Figure 7: Sketch of the second design iteration for the robotic manipulator.

<u>Design Iteration 3 (Final Design)</u>

The sketch for the final design that we chose to model is shown in Figure 8. As previously stated, this final design combined components of both the first and second design iteration. The first design's simplicity of converting the motion of the motor to the motion of the robotic manipulator was used in combination with the multiple axes included in the second design to create a balanced design that would be both relatively simple to implement motor housing solutions for, as well as possessing the full range of motion that is specified in our design criteria.

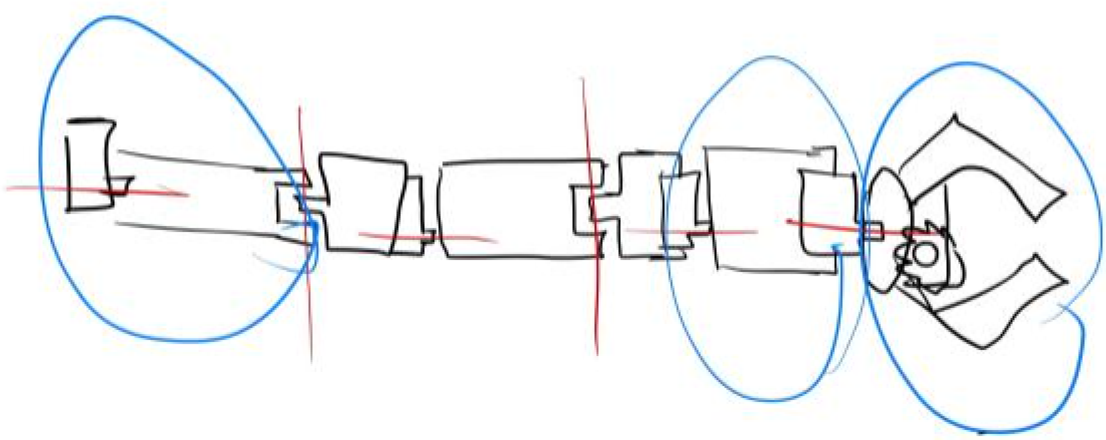


Figure 8: Sketch of the final design iteration for the robotic manipulator.

Theory

Developing a robotic manipulator that possesses a full range of motion requires an understanding of different joint mechanism configurations. In this section, we will discuss several distinct configurations and the limitations that they pose.

Joints that provide a single degree of freedom (either rotational or translational) are the simplest kinds of joints. For the purposes of this project, four single degree of freedom joints were considered. The first kind, as illustrated in Figure 1, is the collinear joint[4]. The collinear joint provides motion along one linear axis. As explained in the 'Concept' portion of this report, the collinear joint can provide added dynamical control to the robotic manipulator, especially if the end goal of the system is to constrain motion of the grasping implement to a specific axis or plane. However, for the scope of this project, the only viable methods of creating linear motion was by either using a rack-and-pinion system to convert rotational motion from a motor to linear motion, or alternatively to use a system of hydraulics to directly actuate motion in the linear direction.

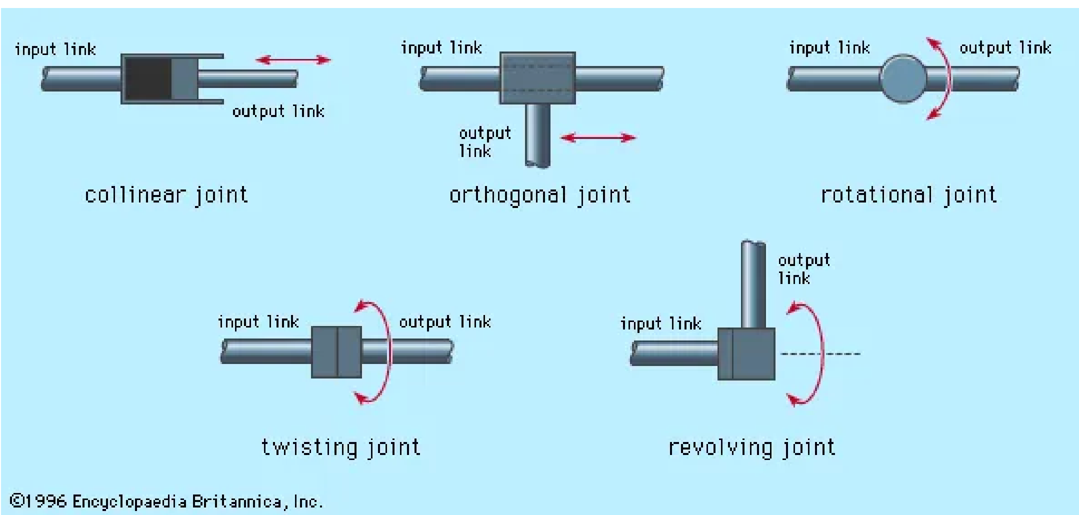


Figure 9: Illustration of different joint mechanisms (image courtesy of Encyclopedia Britannica)

The next two single degree of freedom joints are closely connected: the twisting joint and the revolving joint[4]. Both of these joint configurations rely on directly using rotational motion to create a circularly constrained path within a specific plane. These joints are often used in robotic systems for two reasons. First, there is no mechanical constraint preventing these configurations from accessing their full range of motion (a rotation of 360 degrees), which cannot be said for the other joint configurations. Second, unlike the linear joints, the rotational motion output from a motor can be directly translated to the joint motion without any intermediary system.

The final joint configuration considered within the scope of this project is the rotational joint[4]. Similar to the previous two joint configurations, the rotational joint constrains motion to a circular path within a specific plane. However, unlike the previous configurations, the rotational joint cannot necessarily access its full range of motion due to interference between the two constituent arms, meaning use of these joints can significantly decrease the overall accessible 3-dimensional space for a robotic manipulator.

It is important to note that there are additional joint configurations, namely configurations that are able to access multiple degrees of freedom. The scope of this project was limited to only consider single degree of freedom joint configurations due to the complexity in modeling and manufacturing multiple degrees of freedom joint configurations.

In addition to the various joint configurations, the other aspect of theoretical applications that was considered was the consequence of weight and torque. Torque is a measure of the force that can cause an object to rotate about an axis, considered as an analog to force in a linear reference frame. Specifically, torque is what causes an object to acquire angular acceleration[5]. Designing a robotic manipulator must take into account the effects of weight and torque because these factors define the capabilities of the manipulator, especially its capacity to perform activities and lift heavy objects. Since specific power output numbers were not provided for the motor used in this project, this consideration is open to future refinement. Within the breadth of this project, the mass and dimensions of different components are provided in order for future work to use these data points for further optimization.

Calculations

We first tested the limits of our manipulator by calculating the degree to which each motor on the robot was free to rotate. Some motors could rotate different amounts forwards or backwards so degrees of rotation are signed, with positive signs denoting how many degrees of forward freedom each motor experienced and negative signs denoting freedom of backward movement.

Motor	Min Angle (deg)	Max Angle (deg)	Total Range of Motion (deg)
Base Motor	N/A	360 (Unlimited)	360
Stand Motor	-114	+141	255
Forearm Motors	-103	+103	206
Wrist Motors	N/A	360 (Unlimited)	360
Grabber	-83	+139	222

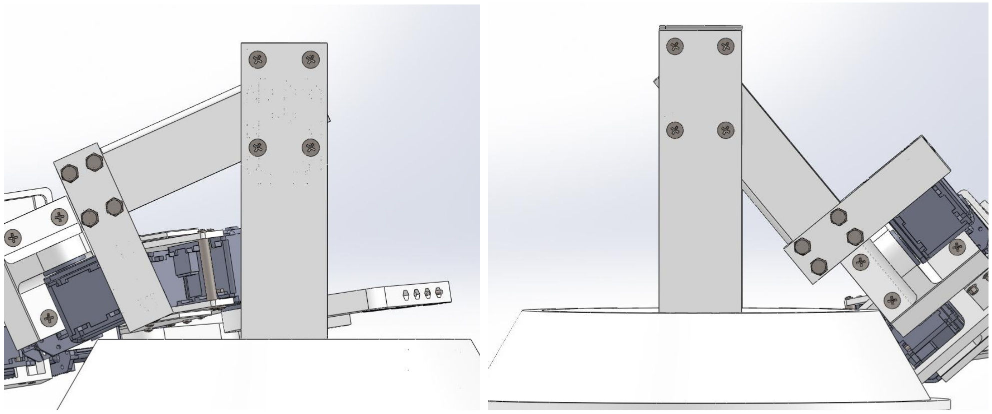


Figure 10 and 11: Illustrating the different degrees of rotation for forward and backward movement.

Next we calculated the amount of vertical and horizontal reach our manipulator had. Vertically the manipulator was 700 mm tall from the bottom of the base to the tip of its claw. Horizontally the manipulator measured 536 mm from the back of the stand to the claw tip.

Lastly, we calculated the total mass of the manipulator by using the equation:
$m(total) = \Sigma\, m(individual)$
The manipulator’s total mass was 3.021 kg.

Specifications

Final Design Description

Our manipulator is made up of 5 components, with each component composed of mainly ABS 3D printed plastic pieces and steel toolbox components. Many pieces are reused across the different components, but each component is made up of at least 5 unique parts. The locations of each component can be found in figure B1, the Full Assembly Drawing in appendix B.

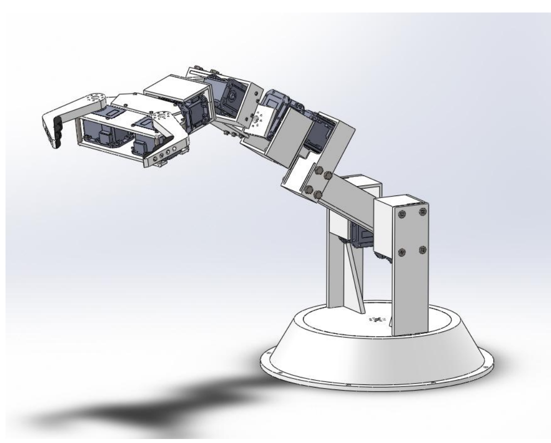


Figure 12: The finished robotic manipulator

The total number of parts, the weight of each part, and each part's respective material is given in the table below.

Parts	Number of Part	Material	Weight (grams)
grabber grabber	1	ABS	19.68
motor	9	Engineering Plastic Full Metal Gears	77
wrist motor holder bottom	4	ABS	18.85
wrist motor holder bottom	4	ABS	12.09
wrist hinge plate	2	ABS	16.42
forearm motor holder	2	ABS	53.46
forearm extension	1	ABS	26.62
forearm mounting plate	1	ABS	10.97
forearm extension base	1	ABS	36.81
Stand	1	ABS	229.06
Base	1	ABS	679.83
Base motor bracket	1	ABS	31.69
Bearing Collar	1	ABS	92.56
gripper	2	rubber	2.69
grabber	2	ABS	17.43
frame	2	ABS	16.46
support	6	alloy steel	3.81
bearing ball	23	alloy steel	32.25

Parts (toolbox)	Number of Part	Material	Weight (grams)
Flat Head Screw M4*0.7*13	28	Alloy Steel	0.723
flat head m2*0.4*13	24	alloy steel	0.301
pan cross head m2*0.4*8	40	alloy steel	0.279
hex nut m20*2.5	28	alloy steel	0.143
formed hex screw m5*0.8*14	16	alloy steel	3.25

Figure 13: Parts table

Dimensions and exploded views for each component are given in the Device Parts Design section. Images for each unique non-toolbox part can be found in appendix C.

Powering The Device

The manipulator achieves its 6 degrees of freedom through rotation of 9 different motors, pictured in figure 12. These motors turn in alternating angles to give the manipulator complete mobility in all directions, rotation direction is pictured in figure 13.

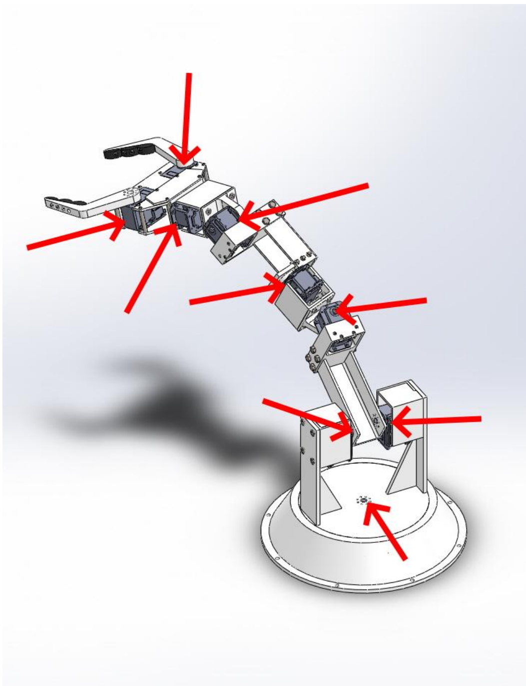


Figure 14: Motor locations

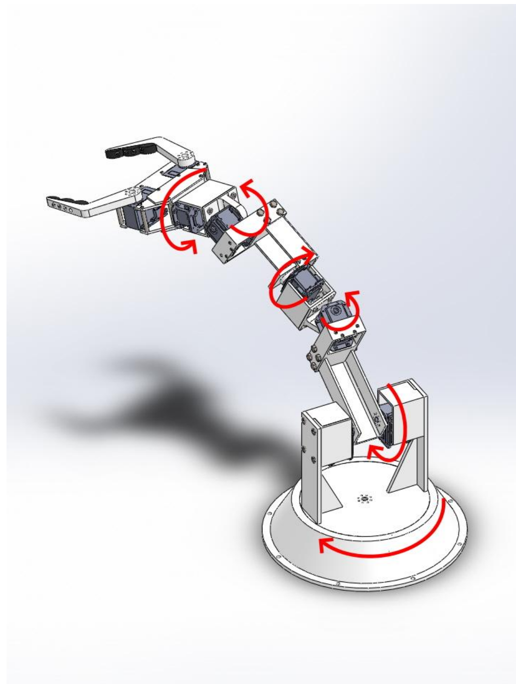


Figure 15: Rotation directions

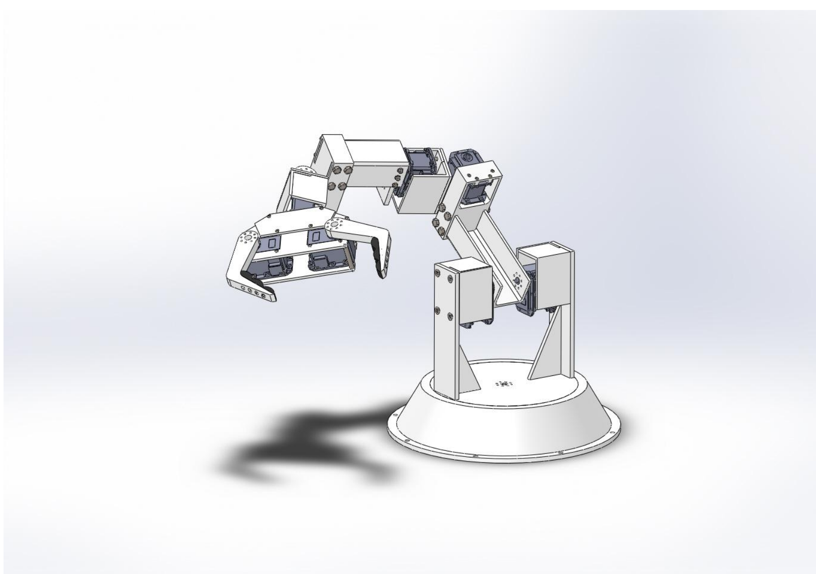


Figure 16: The alternating motor directions give the manipulator it's "tentacle like" mobility

Space for an Arduino to control the motors could be found on the inside of the base or on the base's exterior. Additionally, each motor would be powered by wires that would likely run down the length of arm to the base. To prevent wire tangling, wires would have to be properly managed and bundled after fabrication, and for motors that can spin endlessly without collision (motors in the wrist components) electronic limits would have to be programmed to prevent the wires from wrapping around the arm and causing failure.

<u>Device Parts Design</u>

Grabber Component

The first component we will be discussing is our grabber component, which consists of two grabbers, two grippers, two motors, two frames, a grabber grabber, 6 support beams, 32 Pan cross head screws M2 x 0.4 x 8, and 20 Hex nuts M20 x 2.5. Exact locations of each part can be found in figure B2 in appendix B.

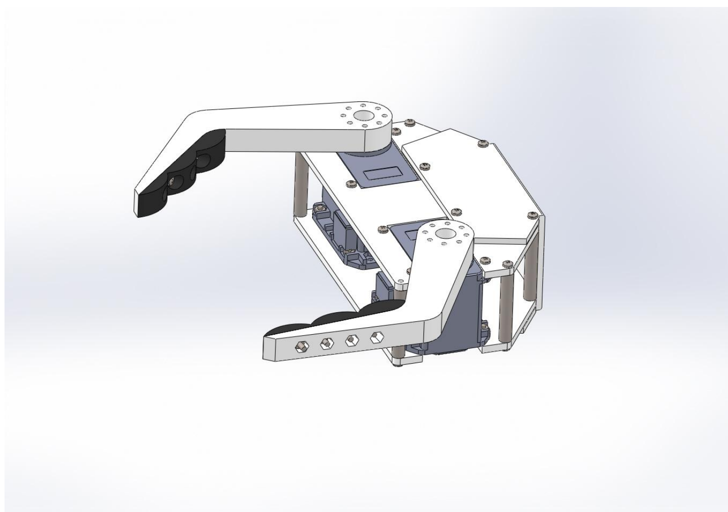


Figure 17: Grabber component

The design of the grabber is fairly straightforward, two motors power their own individual grabber arm which is each fastened with a rubber gripper whose shape and material would in theory help the grabber grip the objects it would be manipulating. The motors are held in place by two frames which are then connected by 6 threaded metal supports. Finally a grabber grabber is fastened to the back of the component so it can be easily attached to the wrist motor. All pieces are fastened with screws that either screw into hex nuts or the threaded supports.

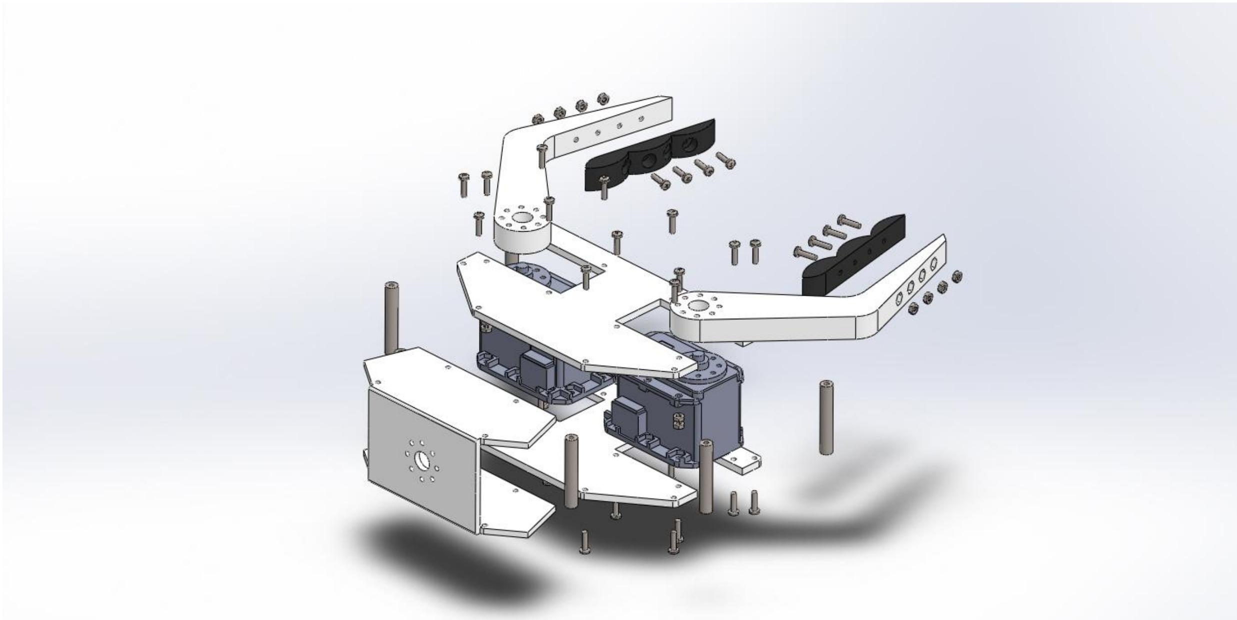


Figure 18: Exploded view of grabber

Wrist Component

The next component in our robot is the wrist of the apparatus. It consists of one wrist hinge plate, one motor, one wrist motor holder, one wrist motor holder bottom, four flat head screw M4 x 0.7 x 13, and an additional four flat head M2 x .04 x 13. Exact locations of each part can be found in figure B3 in appendix B.

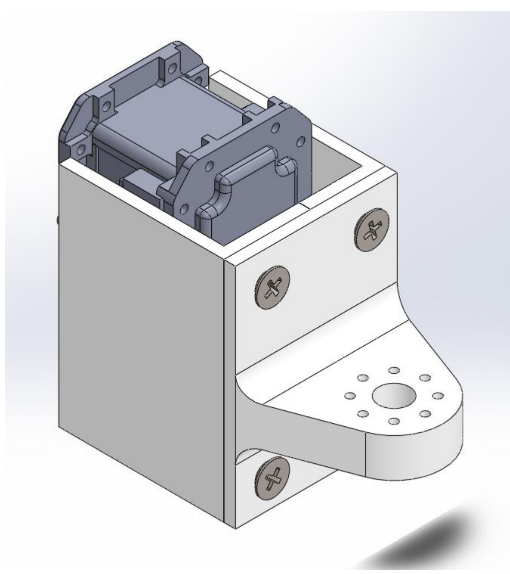


Figure 19: Wrist component

The wrist component is used twice in the final assembly of the robotic manipulator. Once connecting the grabber and forearm, and again while connecting the forearm to the stand. The motor holder and motor holder bottom encase the motor, and are attached by the larger flat head screws to the wrist hinge plate, whose purpose is to provide a site for motor attachment of surrounding components.

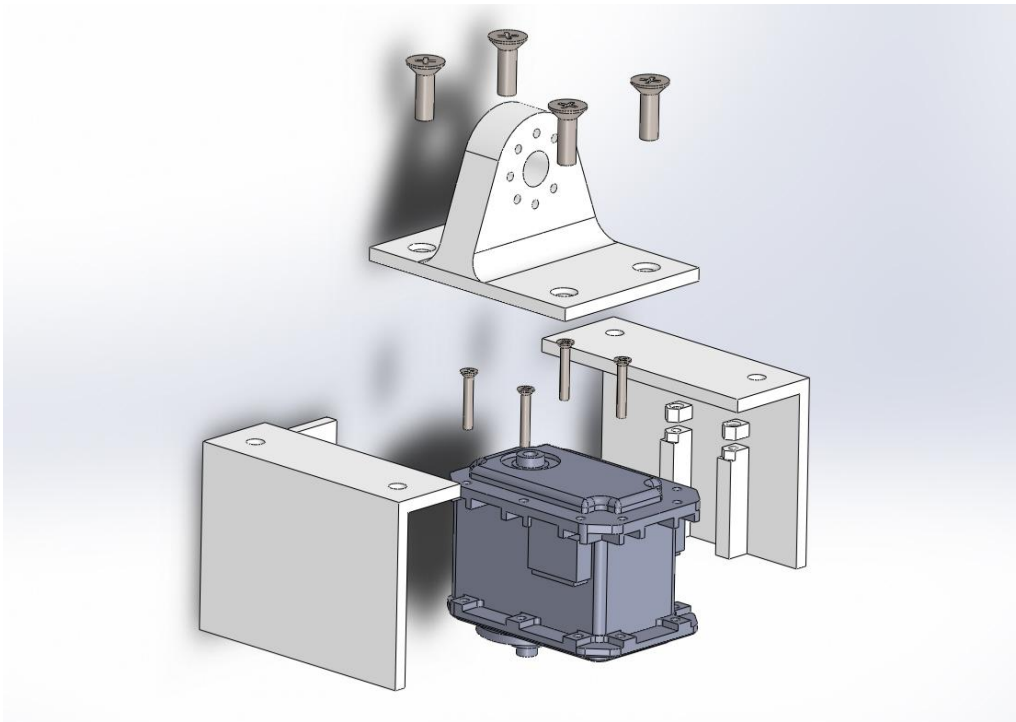


Figure 20: Exploded wrist component

Forearm Component

The middle component of our manipulator is our forearm. It contains one motor, one forearm motor holder, one forearm extension, one forearm mounting plate, 8 formed hex screws M5 x .8 x 14, and 6 hex flange machine screws M3 x 0.5 x 8. Exact locations of each part can be found in figure B4 in appendix B.

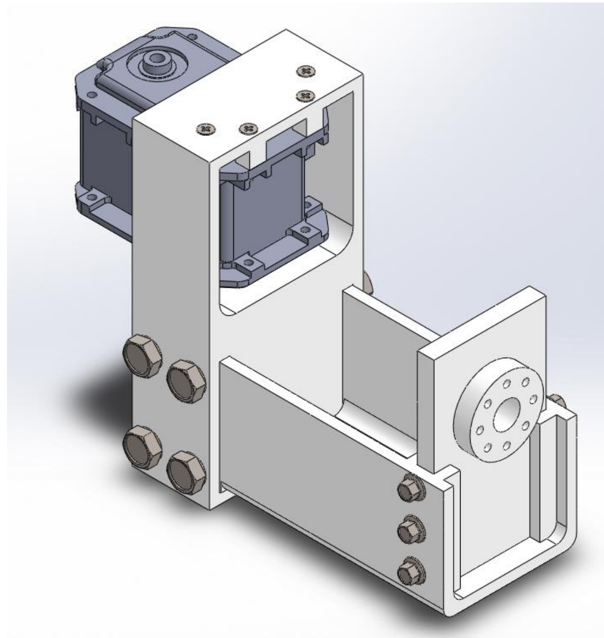


Figure 21: Forearm component

The forearm gives length to the arm of the manipulator and also provides a port that can attach to another wrist component. The forearm is arranged by connecting the ABS plastic pieces using screws and threaded holes inside the forearm motor holder and the forearm mounting plate. However, since creating threaded holes using 3D printed plastic is somewhat unreliable, this component could harbor sites of potential failure.

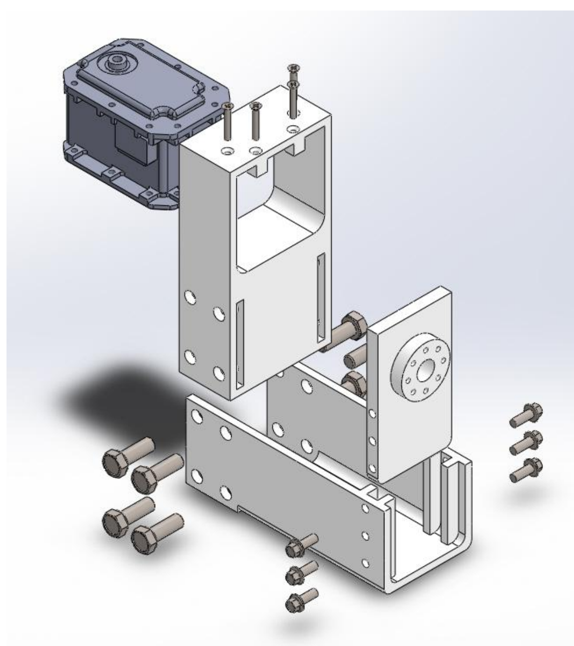


Figure 22: Exploded forearm component

Stand Component

This is the stand for our component, it connects to the base and the second wrist component and spins about the key axis of rotation for the entire robot. It consists of one stand, two wrist motor holders and wrist holder bottoms, one forearm motor holder, one forearm extension base, three motors, 16 flat head screws M4 x 0.7 x 13, 12 flat head screws M2 x 0.4 x 13, and one bearing collar. Exact locations of each part can be found in Figure B5 in appendix B.

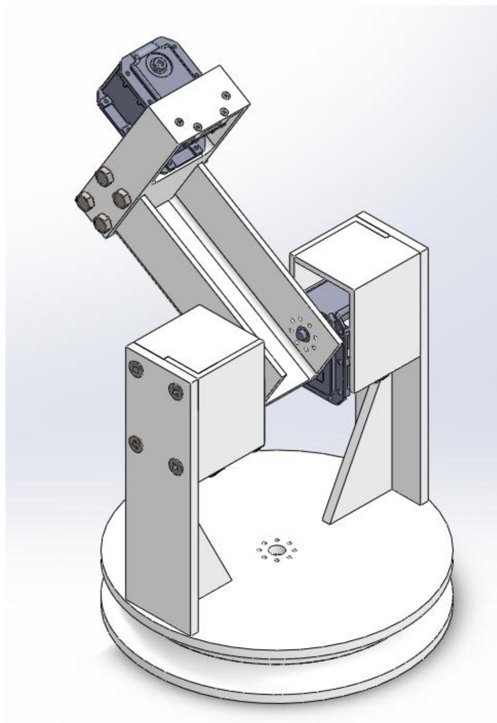


Figure 23: Stand Component

The stand has one motor that spins the connected wrist component, and an additional two motors to spin the entirety of the arm. The extra motor ensures that there will be plenty of power to deal with the load and torque that can be exhibited when the arm is outstretched fully. These two motors attach to half of a modified forearm component, with the normal forearm extension being replaced by a longer arm that mounts from the sides instead of a mounting plate. The stand also has ribs to make sure the load is more supported and below the stand there is a detachable bearing collar so the bearing balls in the base can be easily inserted. Again the bearing collar is attached using threaded plastic which could be a potential cause of stress.

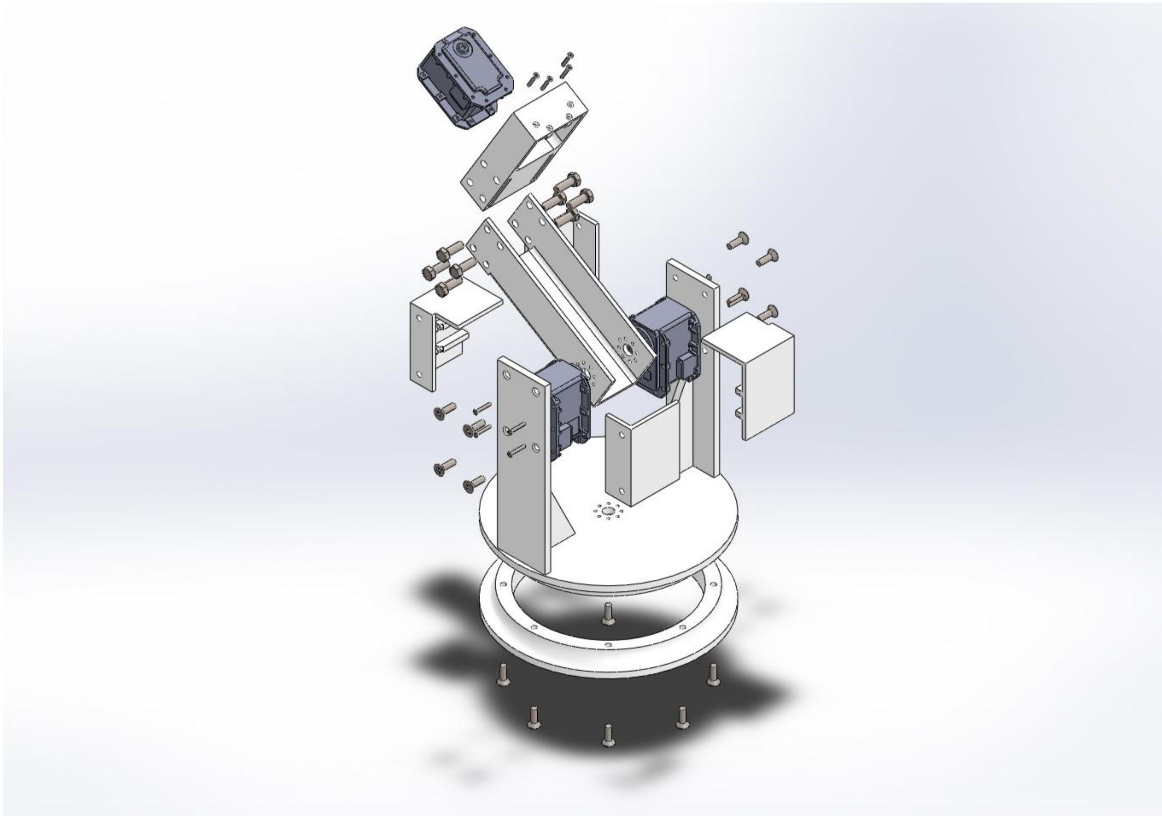


Figure 24: Exploded stand component.

Base Component

The base of our robot, which is the lowest component on the chain, consists of one motor, the base piece, twenty three bearing balls, one base motor bracket, four flathead screws M4 x 0.7 x 13, eight pan cross head M2 x 0.8 x 14 and eight hex nut M5 x 0.8 x 14. Exact locations of each part can be found in figure B6 in appendix B.

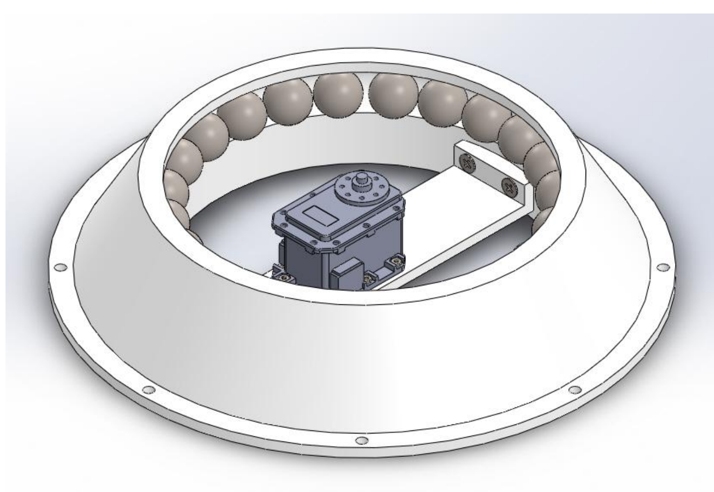


Figure 25: Stand component

The base's main purpose is to act as a solid anchor for the rest of the arm. To accomplish this the base slopes outward and supplies wide and sturdy mounting points along its edge. The base connects to the stand using a ball bearing that allows for the arm to rotate easily, and reduces stress on the base's one central motor. The steel ball bearings can be bought pre-manufactured online and can be inserted easily because of the stand's detachable bearing collar. Lastly, the motor is attached to the base using the base motor bracket which is anchored to the walls using threaded holes. While threaded plastic is always an issue, the screws are large and the holes are deep, so chances of the piece failing is unlikely.

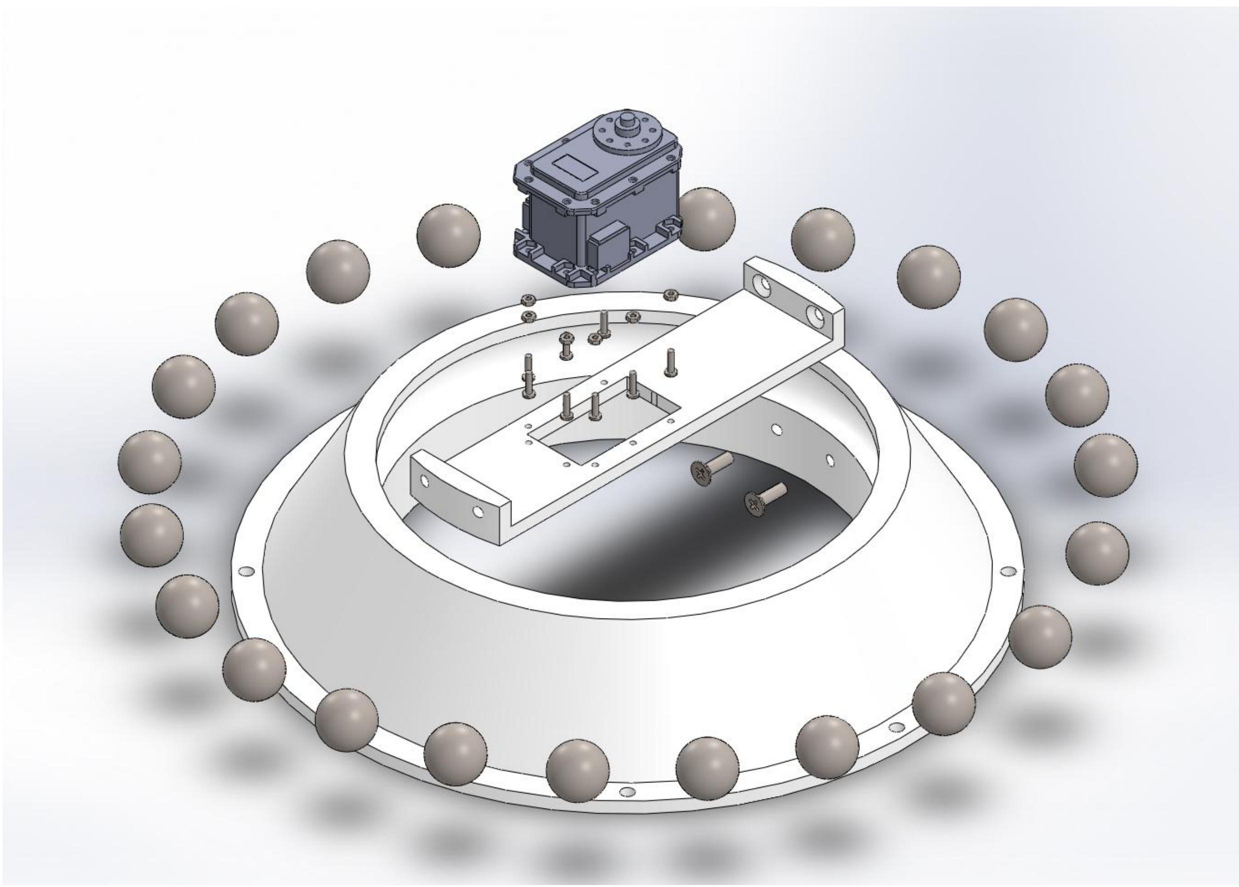


Figure 26: Exploded stand component

Manufacturing

3-D printing was considered as the primary manufacturing method for this robotic manipulator. As described in the 'Specifications' portion of this report, components used in the final assembly of our robotic manipulator are sourced either directly from commercially available parts—namely fasteners and motors—or will be created using 3-D printing technology. The use of 3-D printing technology poses several key challenges in the final development of this robotic manipulator. First, there are several factors that affect all 3-D printing jobs in general that will definitely pose a challenge in the fabrication of our components as well. This includes the relatively weak material properties of the plastics available for 3-D printing (especially when compared to more robust, conventional manufacturing methods that create machined metal components), the cost associated with using additive manufacturing techniques, and the need for post-processing to create more refined final products[6].

Two standards exist in thermoplastic 3-D printing materials, either Polylactic Acid (PLA) Acrylonitrile Butadiene Styrene (ABS). Generally, PLA is stronger and stiffer than ABS, but poor heat-resistance properties means PLA is mostly a hobbyist material. ABS is weaker and less rigid, but also tougher and lighter, making it a better plastic for prototyping applications[7]. For the purposes of our project, we decided that ABS plastic would serve better since the goal of this project is to allow for later iterations to develop more refined designs.

ABS plastic filament can be purchased for around 40 to 75 dollars per kilogram[8]. Using this metric and the mass properties defined in the ‘Specifications’ section of the report, overall material costs for this design should not exceed 150 dollars. Using approximate numbers for electronics and fabrication costs, the total manufactured final design should not exceed 450 dollars.

Conclusion

The purpose of this project was to utilize Solidworks to develop a robotic manipulator. Our team further focused this objective by attempting to create a manipulator that, with further development, could be scaled down and implemented into a larger design focused on creating a manipulator that emulates the movement of an octopus tentacle. Through the development of our model it is evident that there is further room to iterate on our design to create a system that is better suited to achieving this long-term goal. First, an additional design constraint can be added to minimize the arm length between joints in order to create a more compact packaging for the system as a whole. This would allow for a more realistic transition when scaling down. Another point of improvement to consider is implementing higher degrees of freedom joint configurations into the design, as well as different implementations of the single degree of freedom joint configurations to widen the breadth of possible combinations that can be used. Additionally, further research should go into the biological locomotion involved in tentacle movement, and how those techniques compare to the mechanical systems available. On the manufacturing side of the process, further refinement can be achieved by utilizing more advanced machining techniques, such as CNC fabrication. This would allow for the custom housing components to be manufactured from metal alloys, increasing the strength of the parts and consequently of the assembly as a whole. Finally, a significant point of improvement is in the overall weight of the design. The mass properties analysis of our design indicates that there is a high probability that our design can be optimized to save weight, which can decrease the overall fabrication cost as well as make it more efficient in its performance. Overall, the design our team developed is a strong first step in the iterative challenge we have outlined. There are clear steps to improving the design, but the mechanical abilities of this robotic manipulator satisfy the basic conditions we outlined in our design specifications. Namely, the design successfully implemented the full six degrees of freedom, in addition to minimizing complexity, utilizing specific joint geometry, and creating a working grasping implement to allow for the system to interact with its surroundings.

References

Please note that the rights to all images not directly sourced from the Solidworks platform in direct connection to the development of this project are given to their respective owners, but are not directly cited in the 'References' section.

(1) https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4247431/, accessed May 30, 2022.
(2) https://www.mae.ucla.edu/veronica-santos-part-of-team-awarded-3m-in-onr-funding-to-develop-a-dexterous-underwater-robotic-hand-with-tactile-feedback/, accessed May 30, 2022.
(3) https://www.seas.harvard.edu/news/2020/02/tentacle-bot, accessed May 28, 2022.
(4) https://www.britannica.com/technology/joint-robotics, accessed May 29, 2022.
(5) https://www.khanacademy.org/science/physics/torque-angular-momentum/torque-tutorial/a/torque, accessed May 29, 2022.
(6) https://www.stratasys.com/en/stratasysdirect/resources/articles/3d-printing-adoption-challenges, accessed May 30, 2022.
(7) https://markforged.com/resources/blog/pla-abs-nylon, accessed May 30, 2022.
(8) https://www.fusion3design.com/how-much-does-3d-printing-filament-cost, accessed May 30, 2022.

Appendix

Appendix A: Parts Drawings

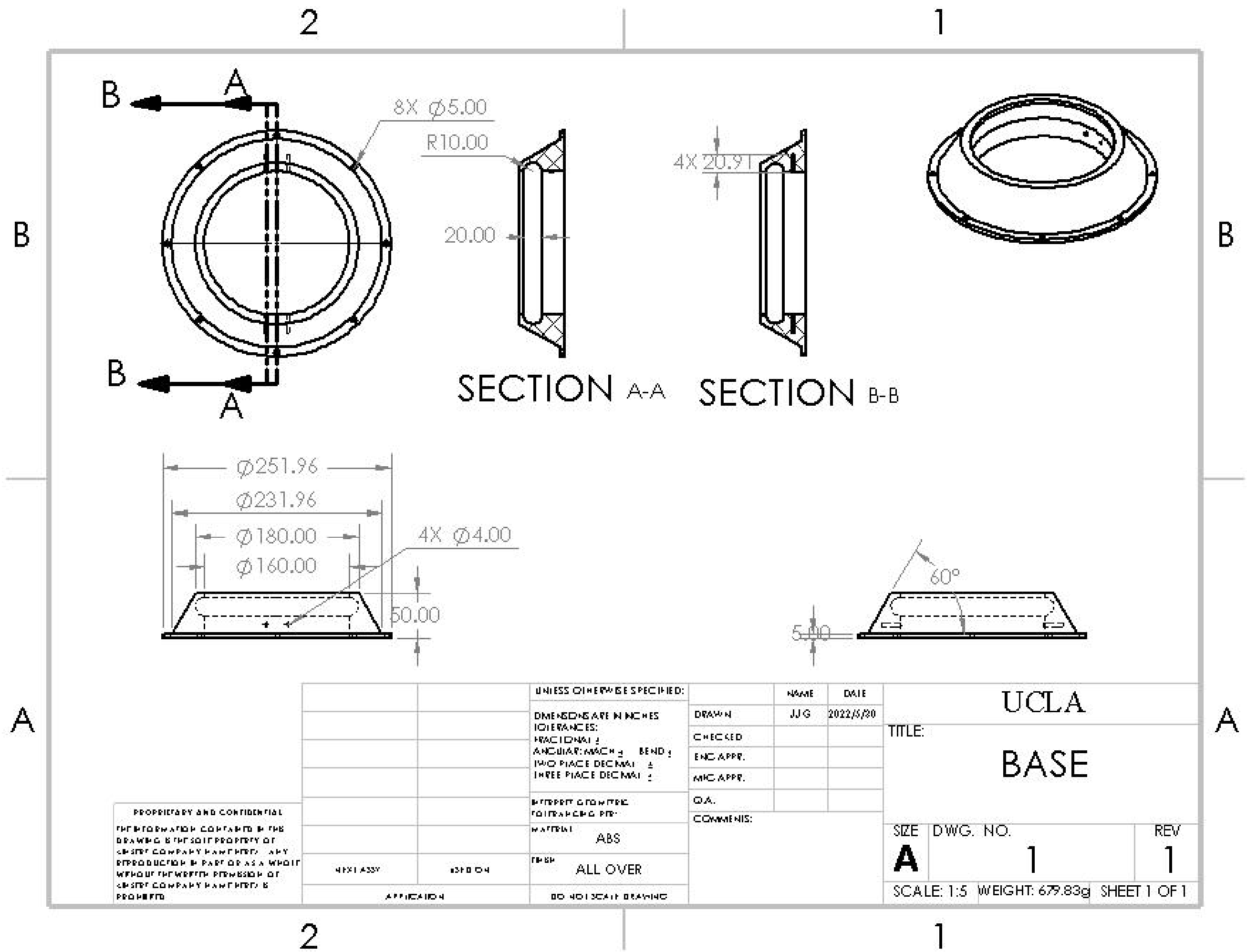


Figure A1: Base Drawing

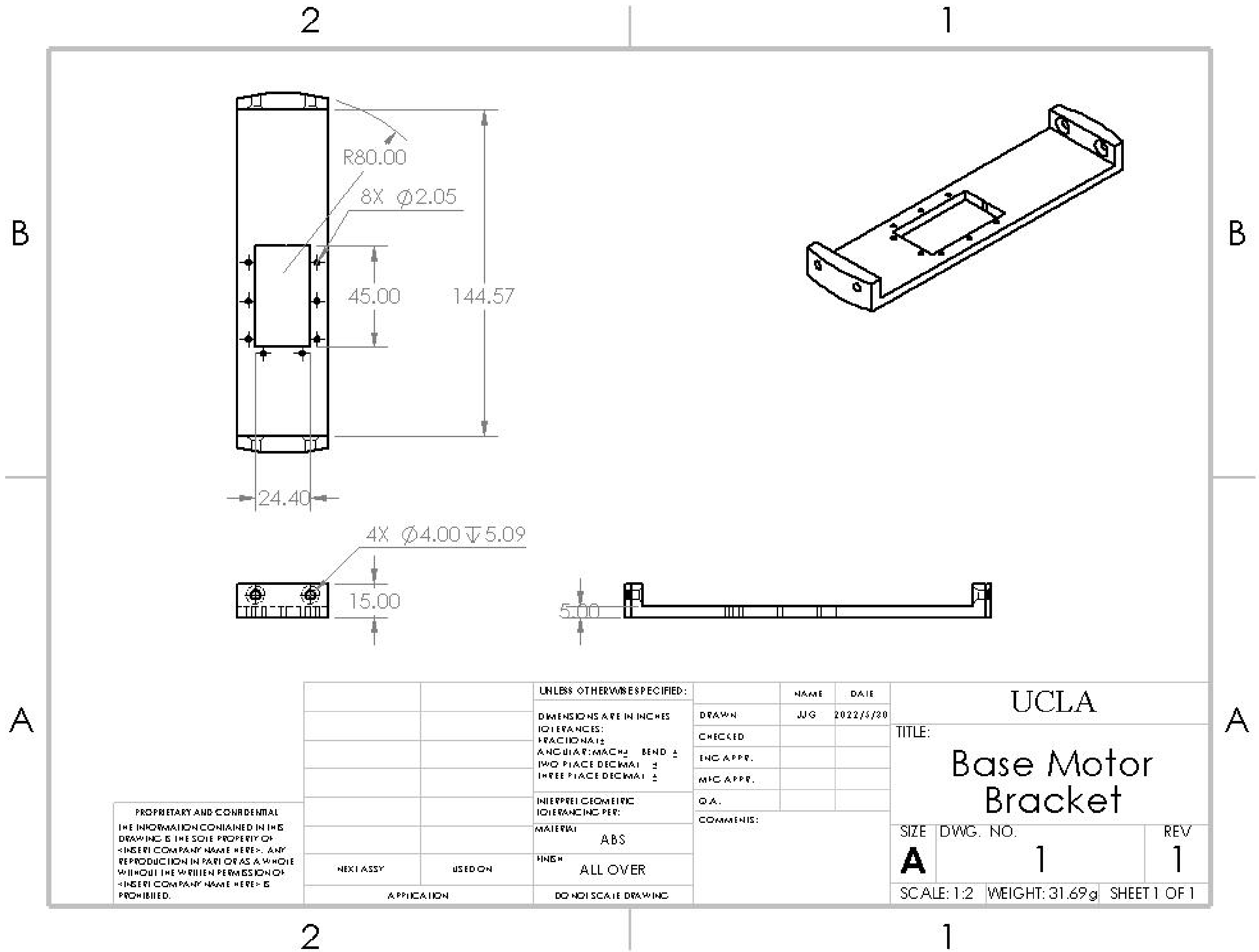


Figure A2: Base Motor Bracket Drawing

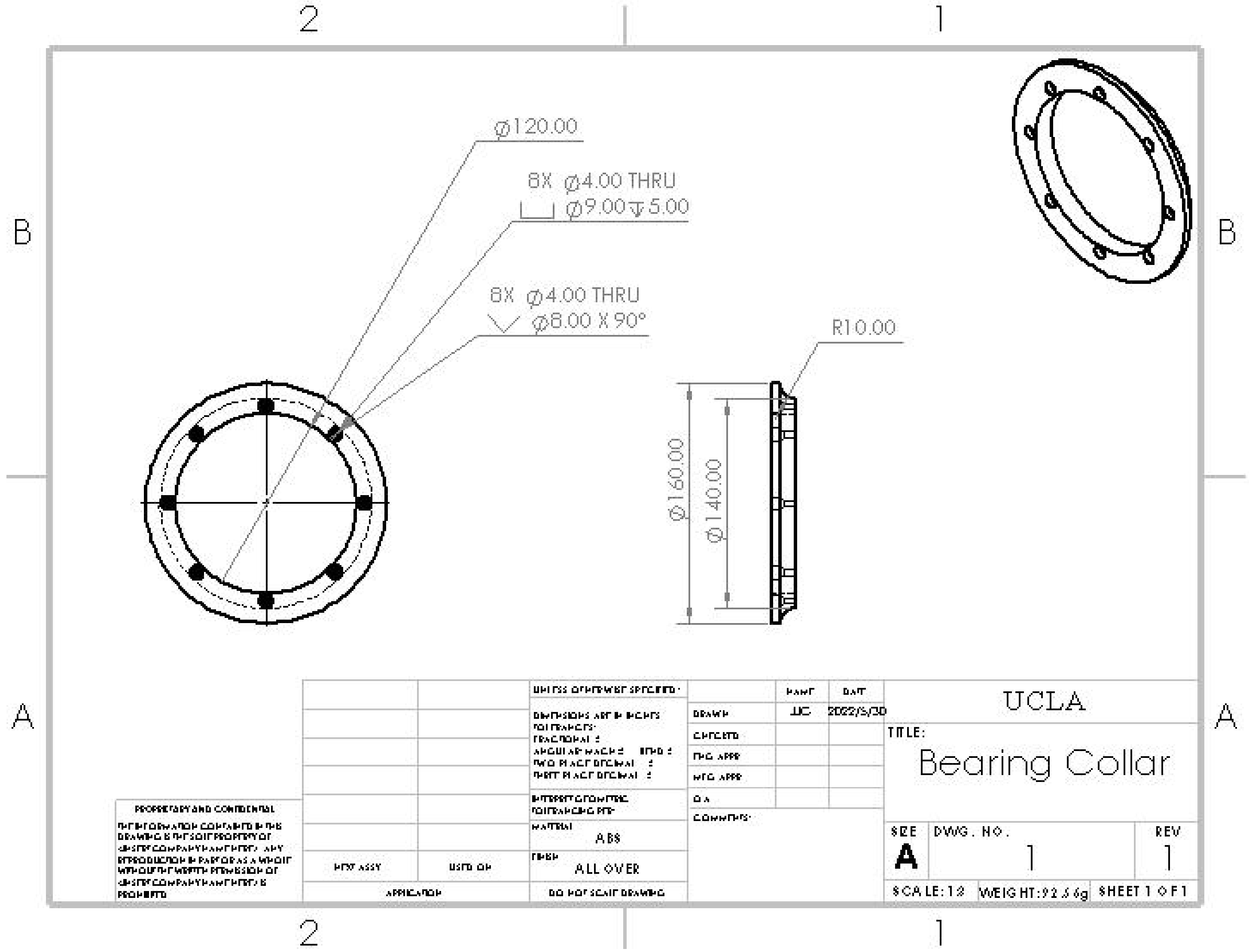


Figure A3: Bearing Collar Drawing

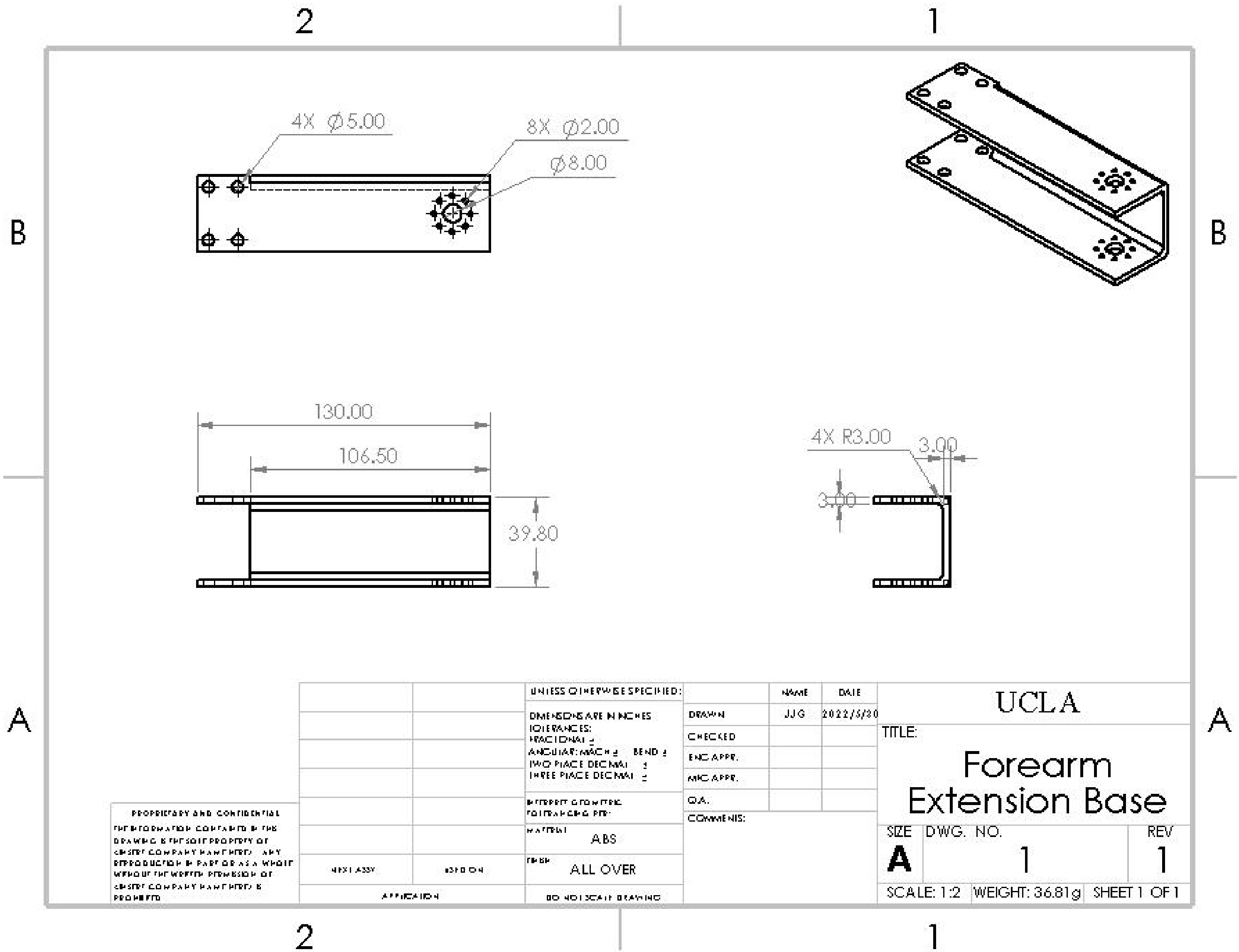


Figure A4: Forearm Extension Base Drawing

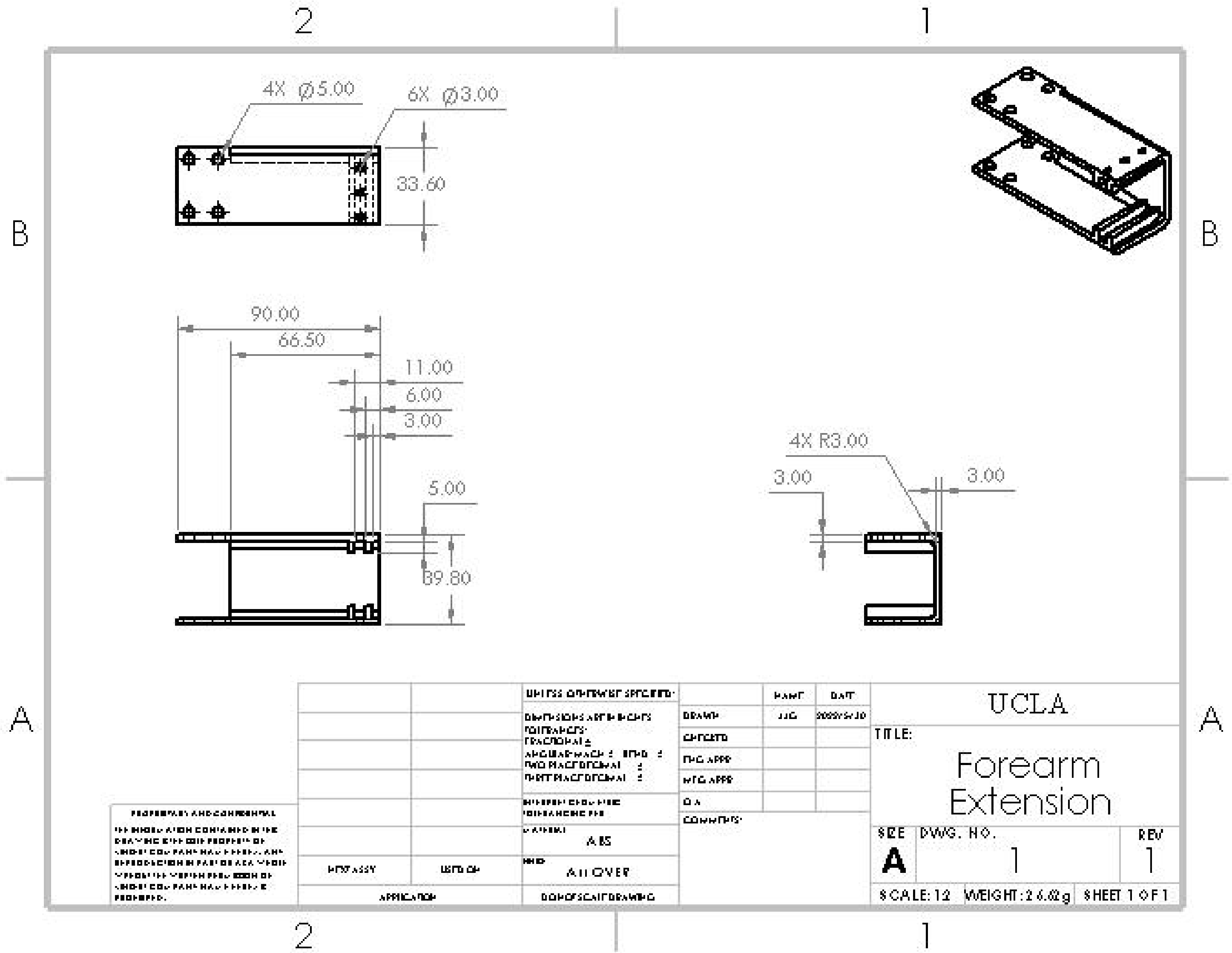


Figure A5: Forearm Extension Drawing

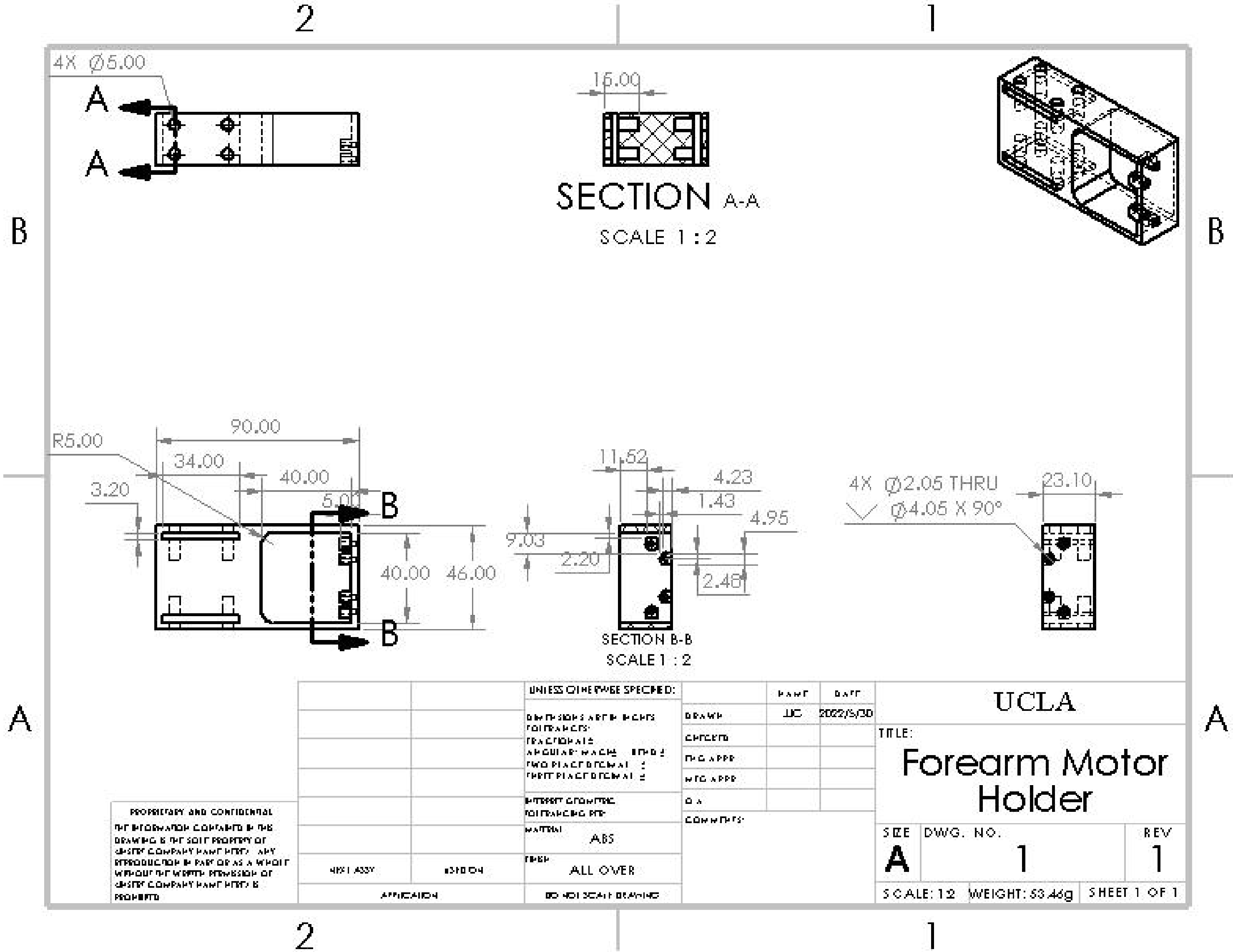


Figure A6: Forearm Motor Holder Drawing

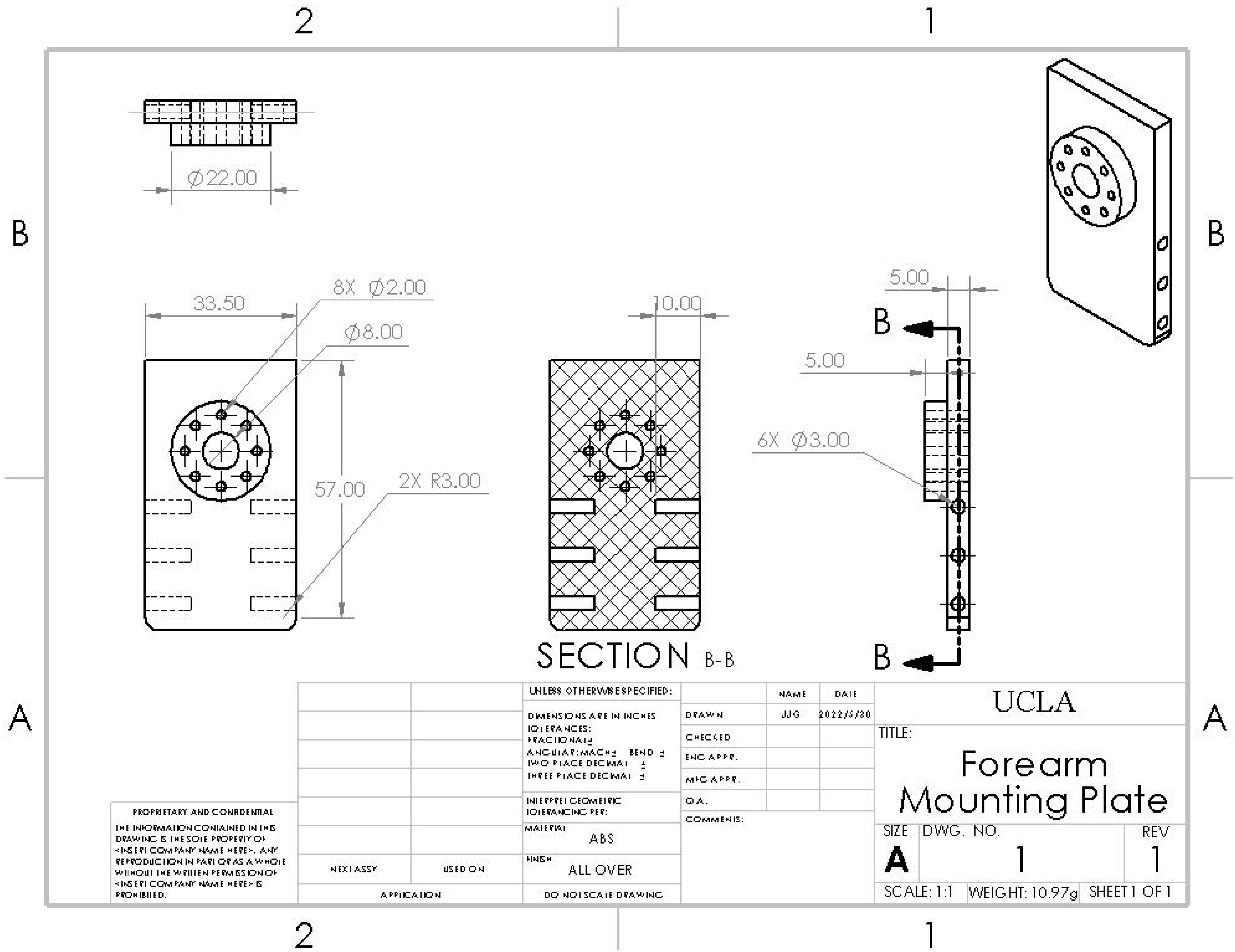


Figure A7: Forearm Mounting Plate Drawing

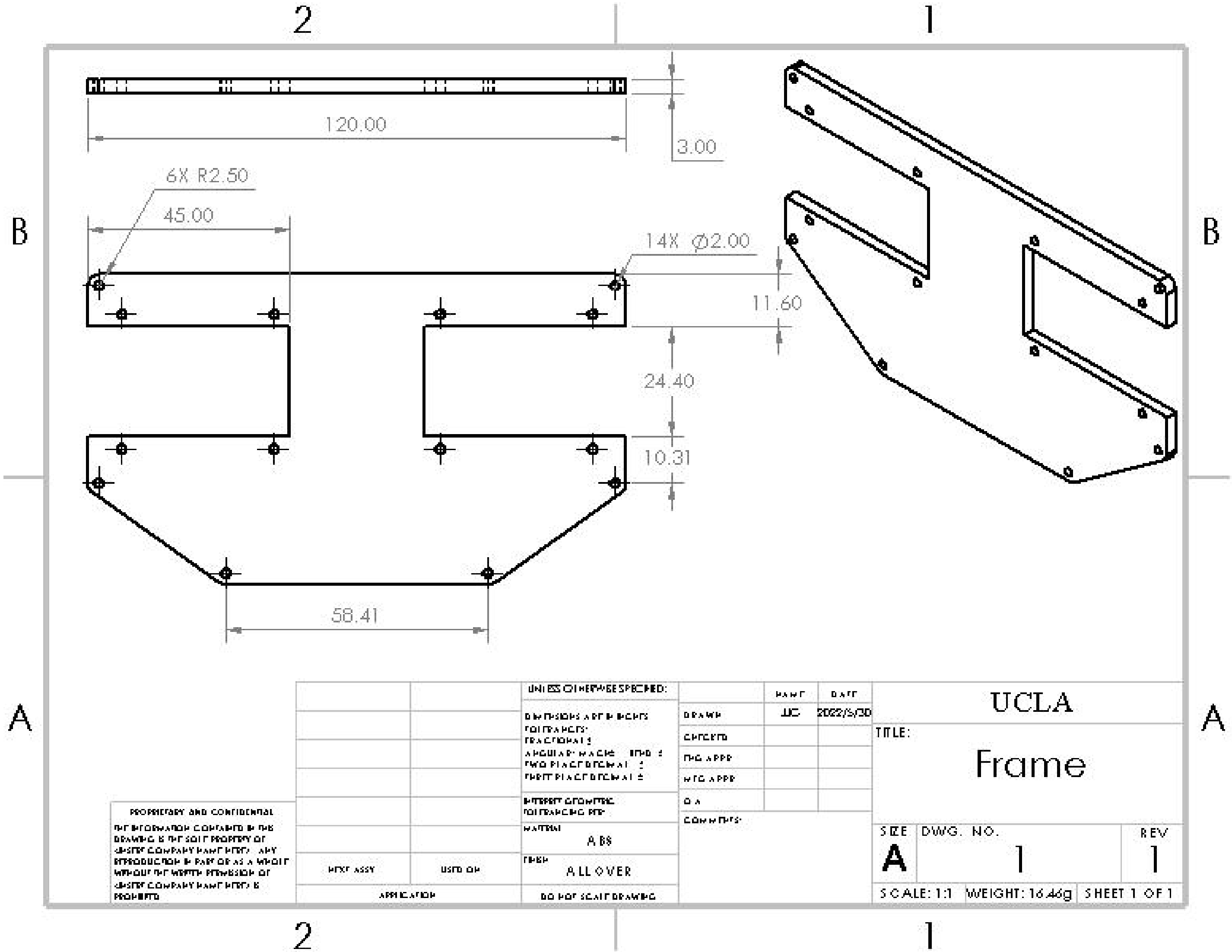


Figure A8: Frame Drawing

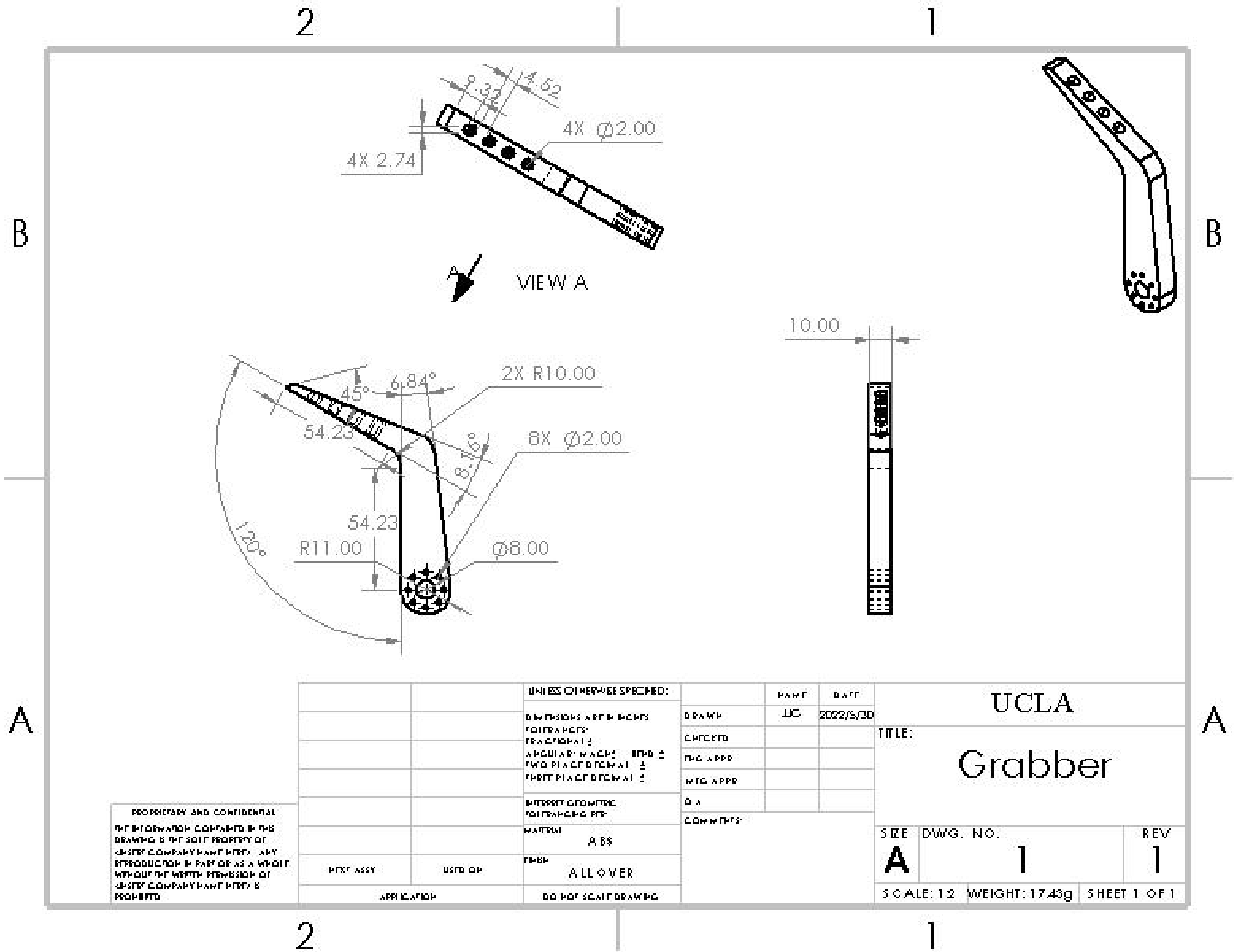


Figure A9: Grabber Drawing

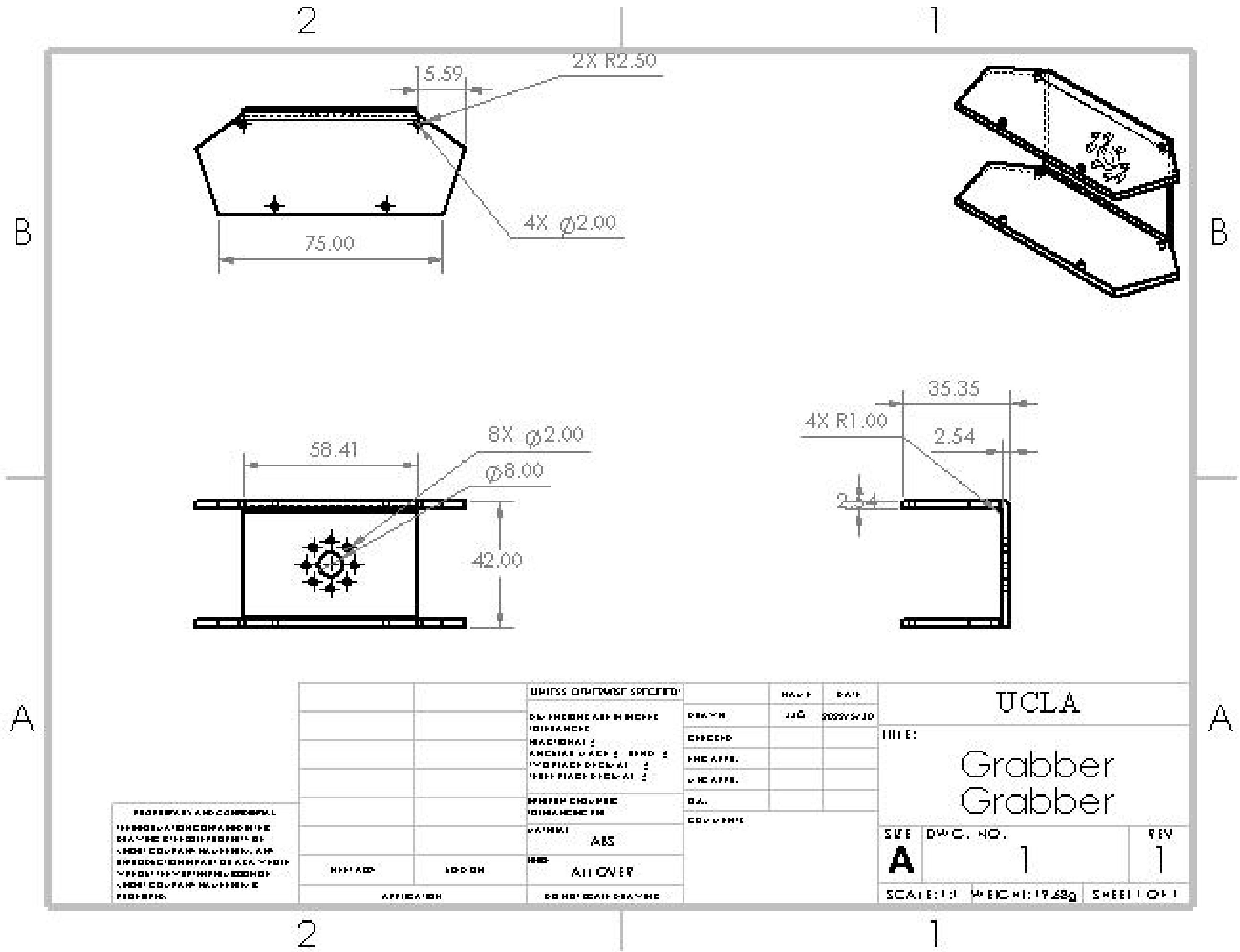


Figure A10: Grabber Grabber Drawing

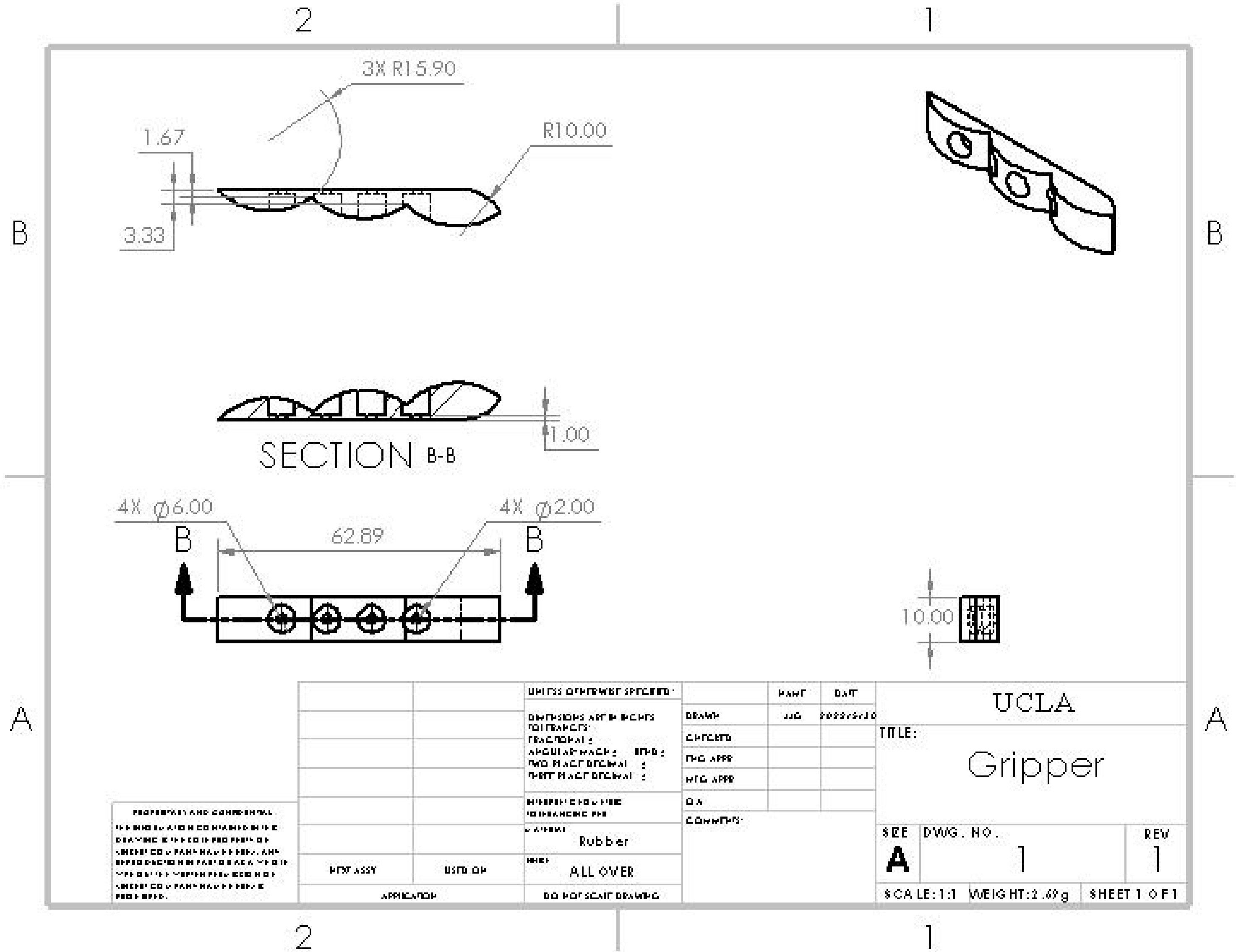


Figure A11: Gripper Drawing

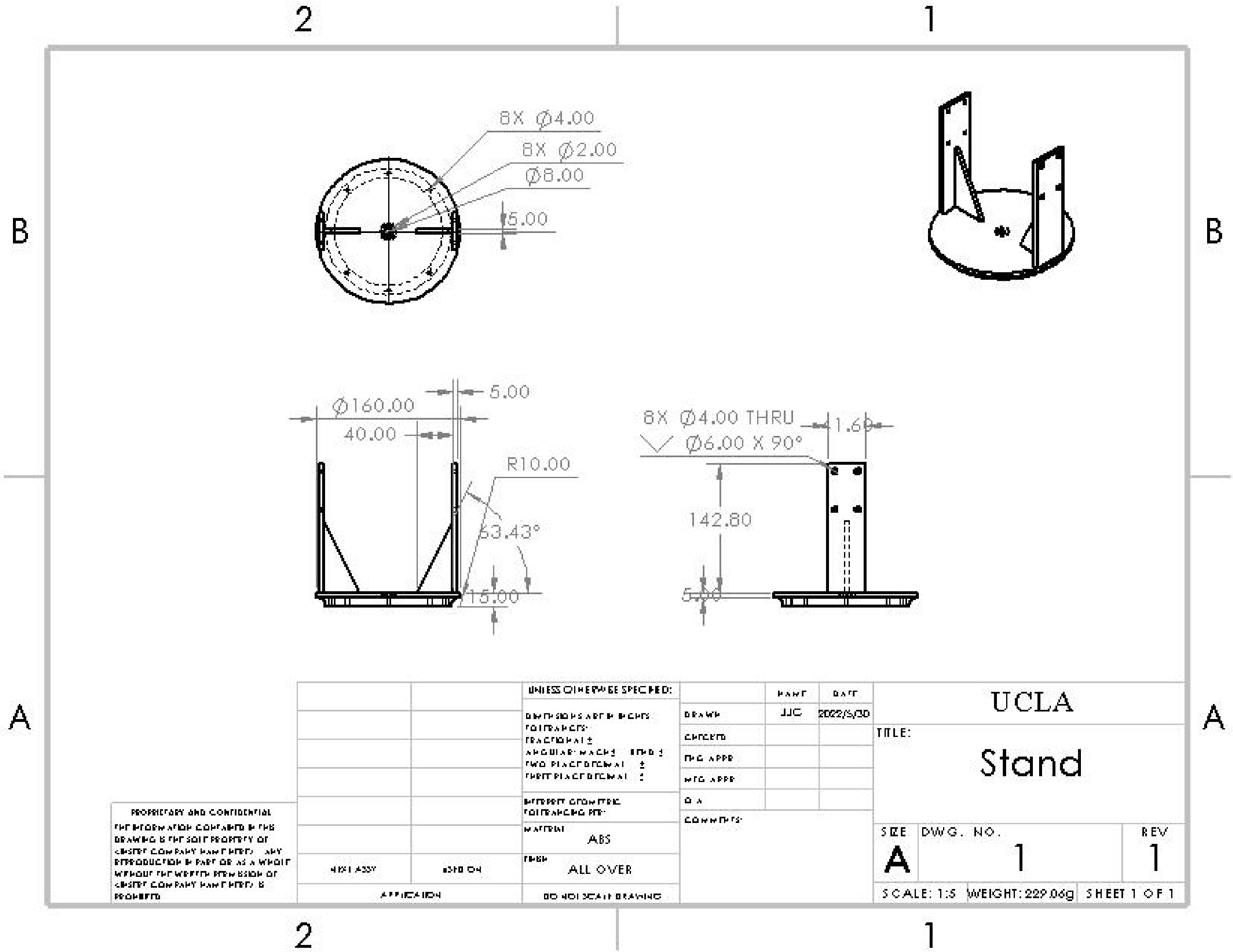


Figure A12: Stand Drawing

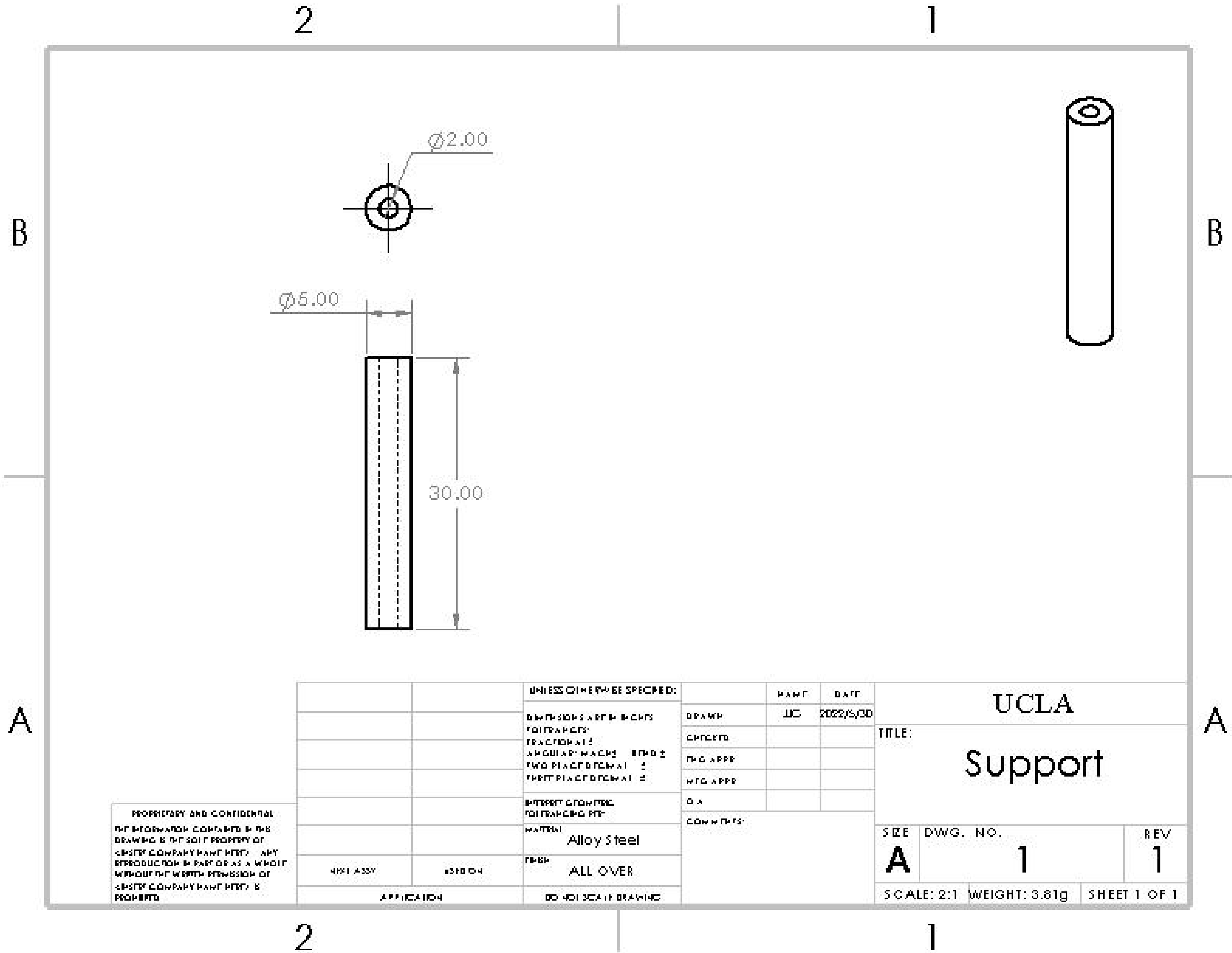


Figure A13: Support Drawing

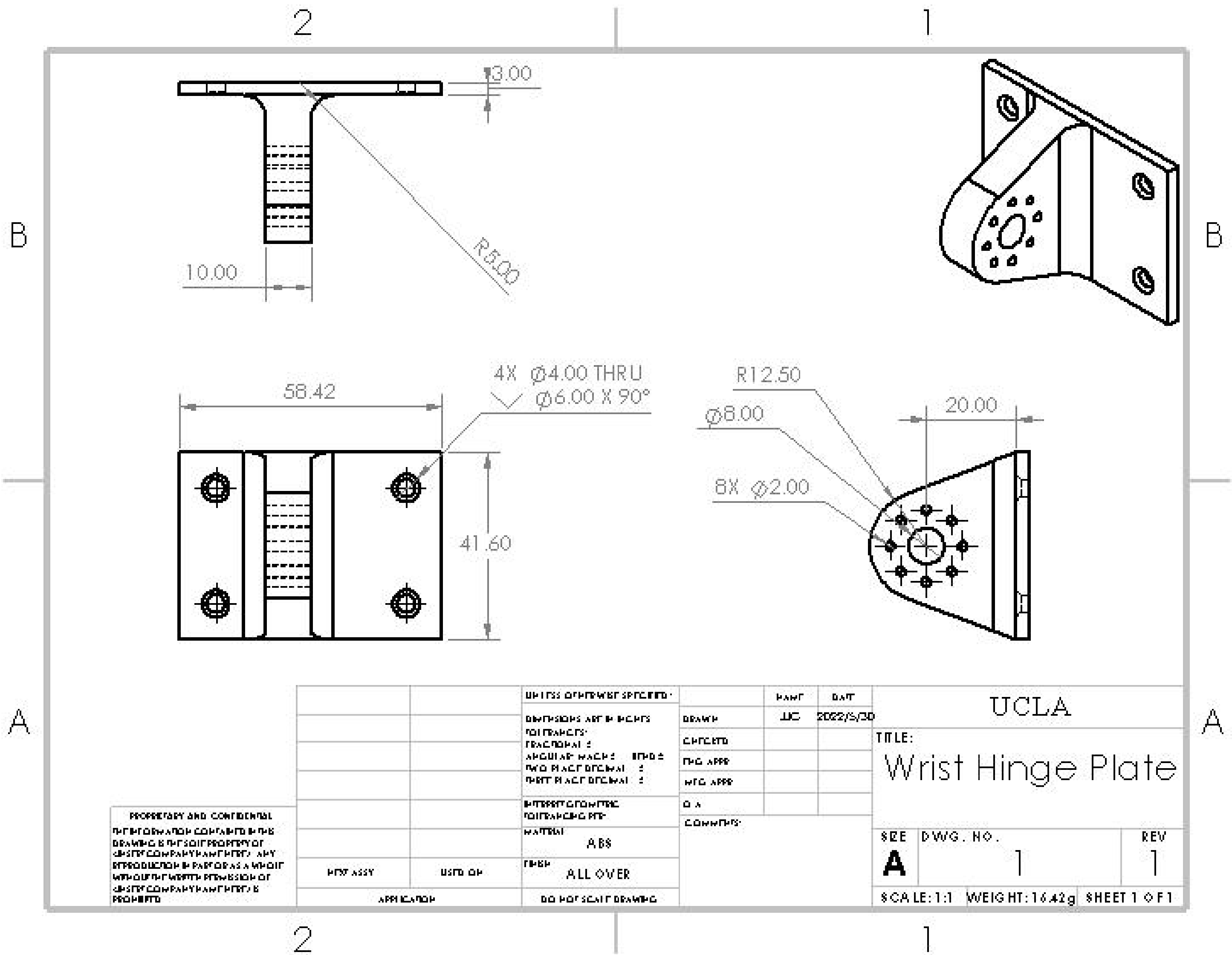


Figure A14: Wrist Hinge Plate Drawing

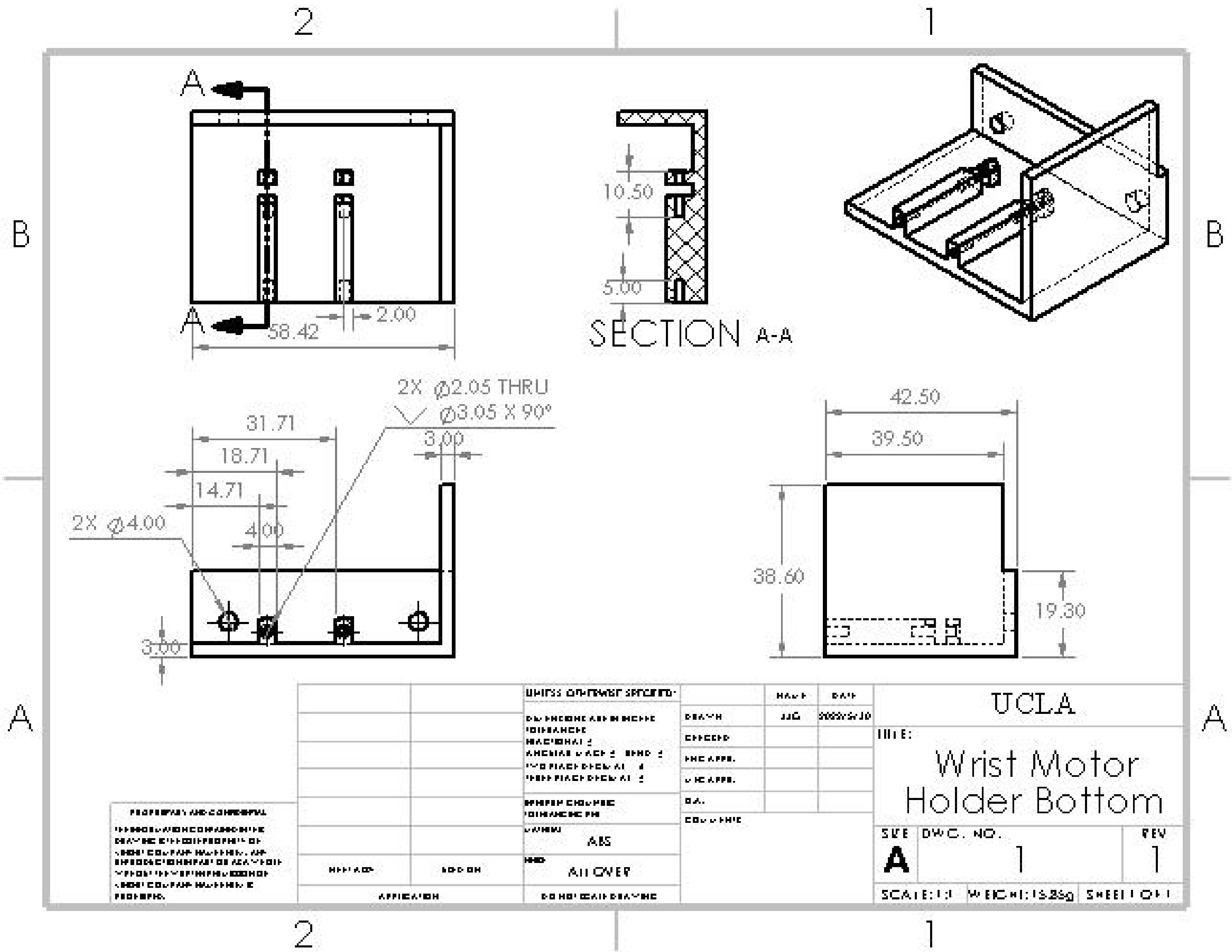


Figure A15: Wrist Motor Holder Bottom Drawing

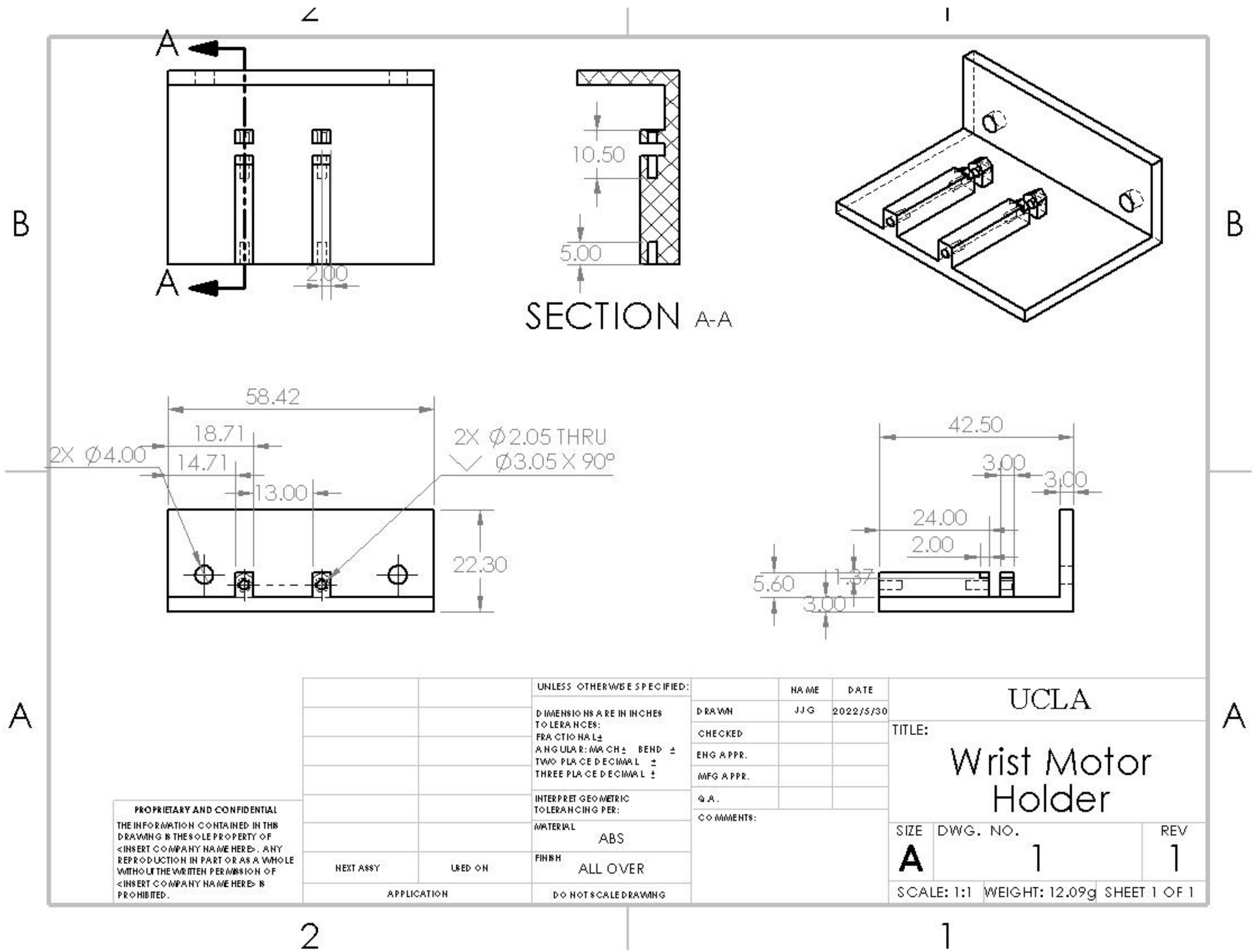
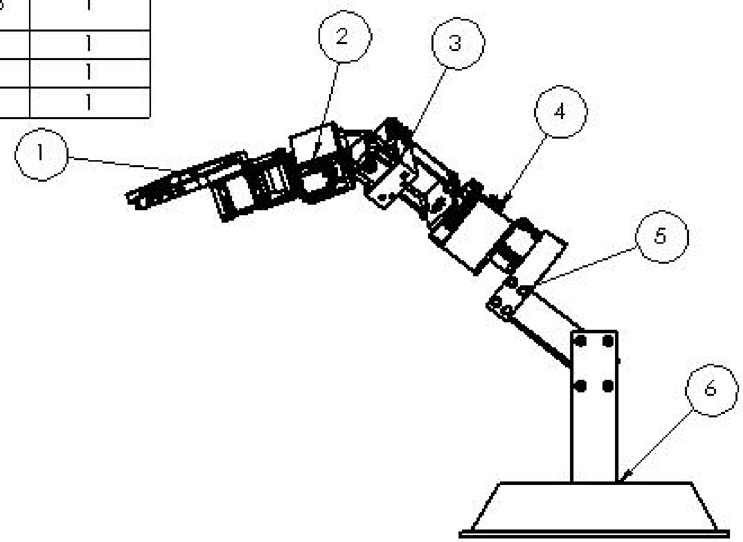


Figure A16: Wrist Motor Holder Drawing

Appendix B: Subassembly Drawings

ITEM NO.	PART NO.	DESCRIPTION	QTY.
1	1	GRABBER SUBASSMB	1
2	2	WRIST SUBASSMB	1
3	3	FOREARM SUBASSMB	1
4	4	ELBOW SUBASSMB	1
5	5	BICEP SUBASSMB	1
6	6	BAS SUBASSMB	1



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ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

UCLA

TITLE: Full Assembly

SIZE A DWG. NO. 1 REV 1

SCALE: 1:5 SHEET 1 OF 1

APPLICATION

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Figure B1: Full Assembly Drawing

ITEM NO	PART NO	DESCIPTION	QTY.
1	1	FRAME	2
2	2	GRABBER	2
3	3	GRIPPER	2
4	4	MOTOR	2
5	5	SUPPORT	6
6	6	PAN CROSS HEAD M2*0.4*8	32
7	7	HEX NUT M2*0.4*8	20
8	8	GRABBER GRABBER	1

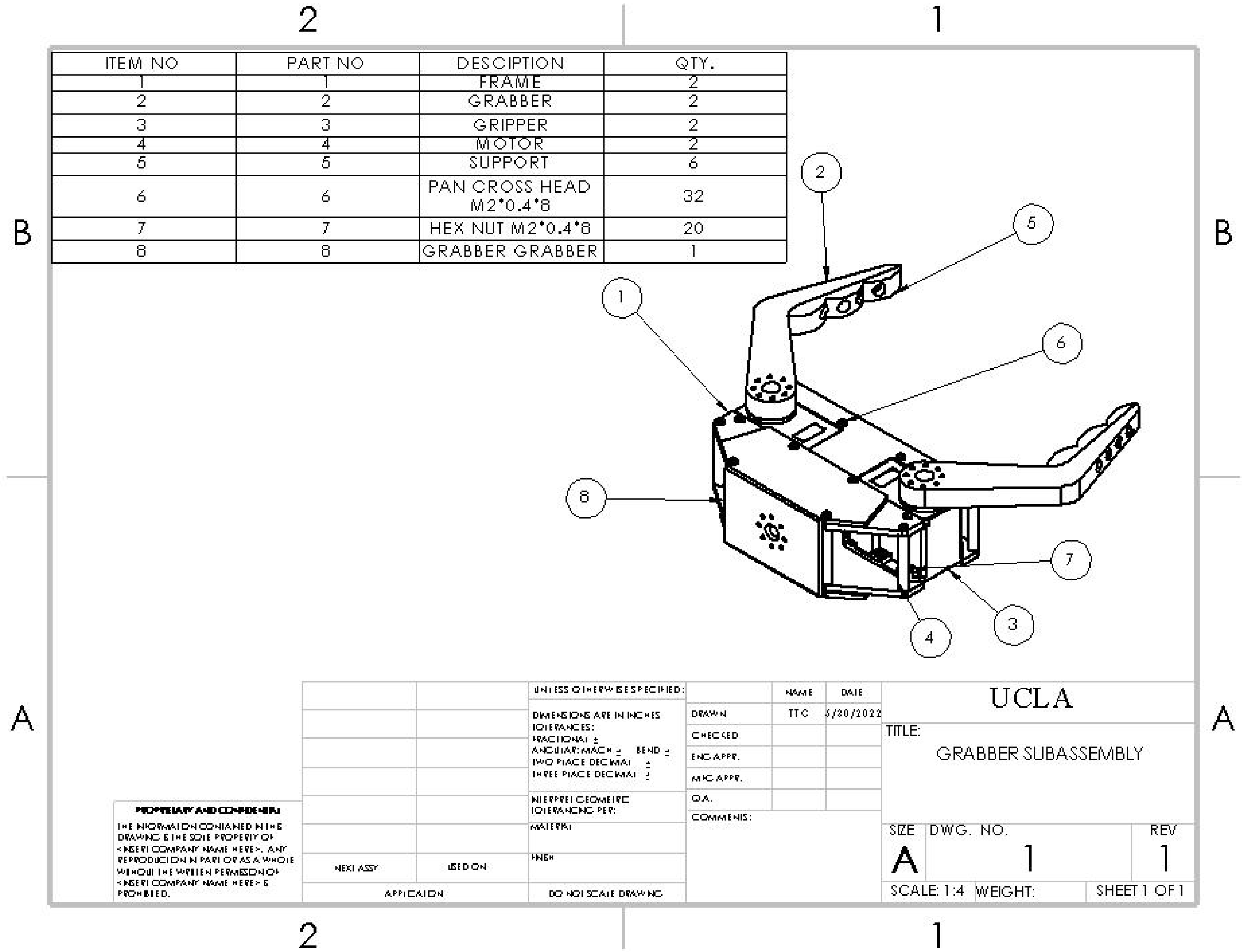
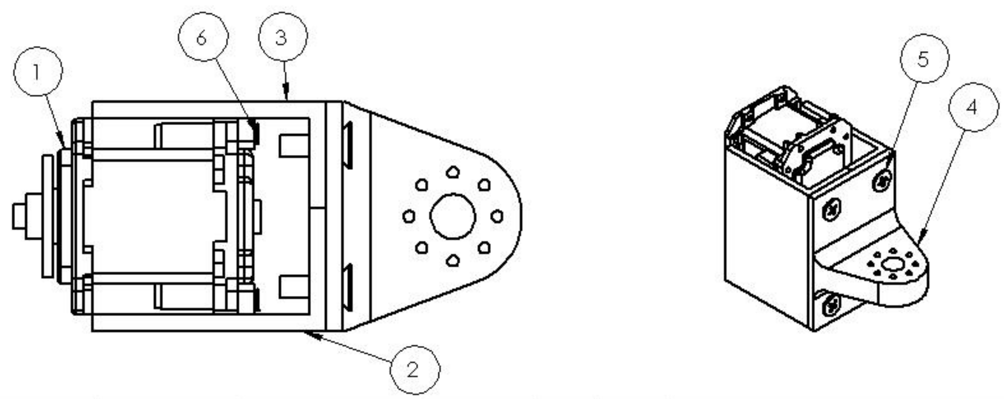


Figure B2: Grabber Subassembly

ITEM NO.	PART NO.	DESCRIPTION	QTY.
1	1	MOTOR	1
2	2	WRIST MOTOR HOLDER	1
3	3	WRIST MOTOR HOLDER BOTTOM	1
4	4	WRITST HINGE PLATE	1
5	5	FLAT HEAD SCREW M4*0.7*13	4
6	6	FLAT HEAD SCREW M2*0.4*13	4



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TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
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DRAWN	TC	5/30/2022
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ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

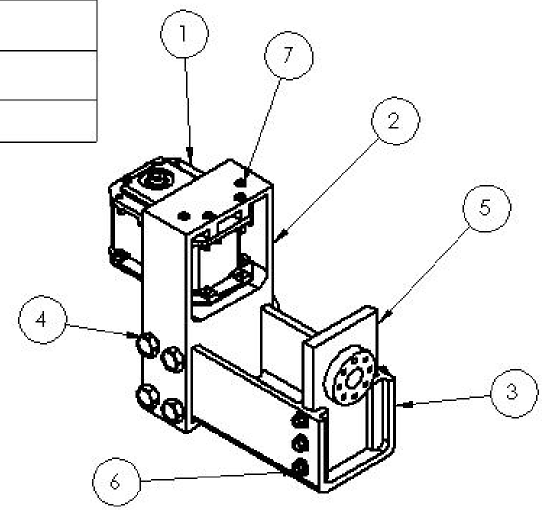
UCLA

TITLE: WRIST SUBASSEMBLY

SIZE A | DWG. NO. 1 | REV 1
SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1

Figure B3: Wrist Subassembly

ITEM NO.	PART NO.	DESCRIPTION	QTY.
1	1	MOTOR	1
2	2	FOREARM MOTOR HOLDER	1
3	3	FOREARM EXTENSION	1
4	4	FORMED HEX SCREW M5*0.8*8	8
5	5	FOREARM MOUNTING PLATE	1
6	6	HEX FLANGE MACHINE M3*0.5*8	6
7	7	FLAT HEAD SCREW M2*0.4*13	4



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ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
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CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

UCLA

TITLE:

FOREARM SUBASSEMBLY

SIZE	DWG. NO.	REV
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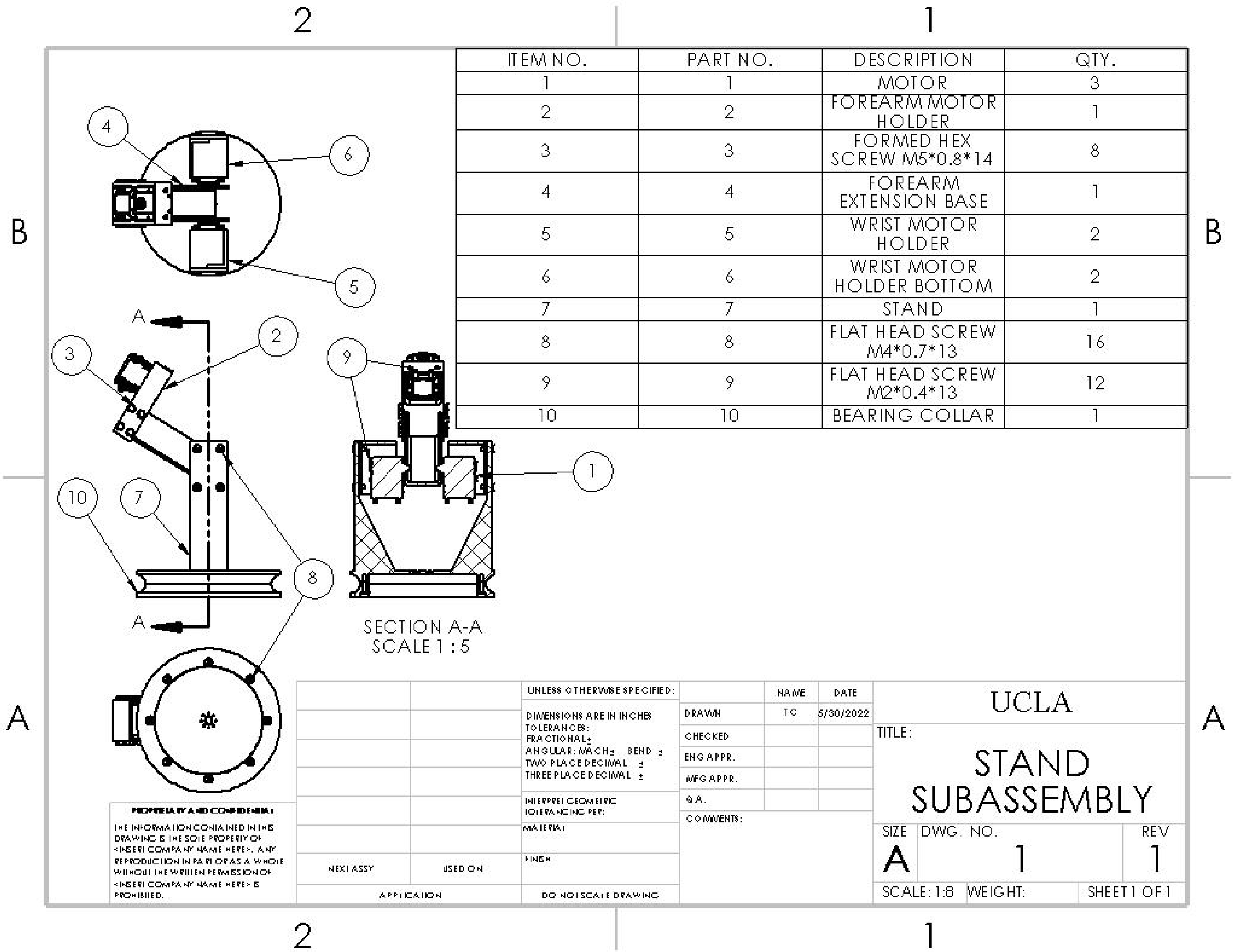
SCALE: 1:2 WEIGHT: SHEET 1 OF 1

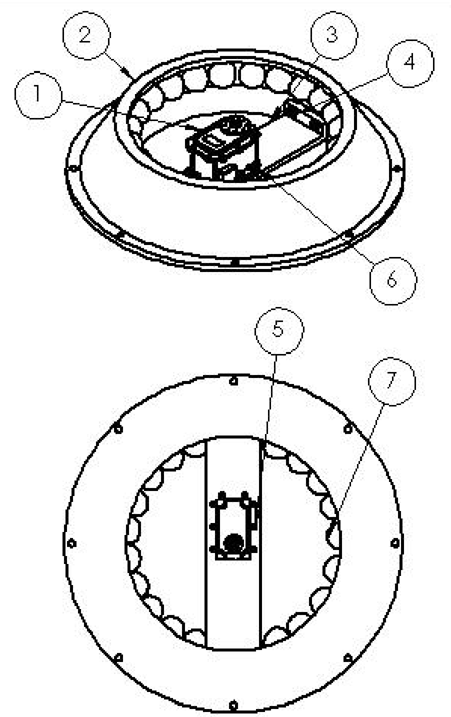
Figure B4: Forearm Subassembly



ITEM NO.	PART NO.	DESCRIPTION	QTY.
1	1	MOTOR	3
2	2	FOREARM MOTOR HOLDER	1
3	3	FORMED HEX SCREW M5*0.8*14	8
4	4	FOREARM EXTENSION BASE	1
5	5	WRIST MOTOR HOLDER	2
6	6	WRIST MOTOR HOLDER BOTTOM	2
7	7	STAND	1
8	8	FLAT HEAD SCREW M4*0.7*13	16
9	9	FLAT HEAD SCREW M2*0.4*13	12
10	10	BEARING COLLAR	1

Figure B5: Stand Subassembly

PART NO.	ITEM NO.	DESCRIPTION	QTY.
1	1	MOTOR	1
2	2	BASE	1
3	3	BASE MOTOR BRACKET	1
4	4	FLAT HEAD SCREW M4*0.7*13	4
5	5	PAN CROSS HEAD M2*0.4*8	8
6	6	HEX NUT M5*0.8*14	8
7	7	BALL BEARING	23



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UCLA
TITLE:
BASE SUBASSEMBLY
SIZE A | DWG. NO. 1 | REV 1
SCALE: 1:4 | WEIGHT: | SHEET 1 OF 1

Figure B6: Base Subassembly

Appendix C: Part Photos

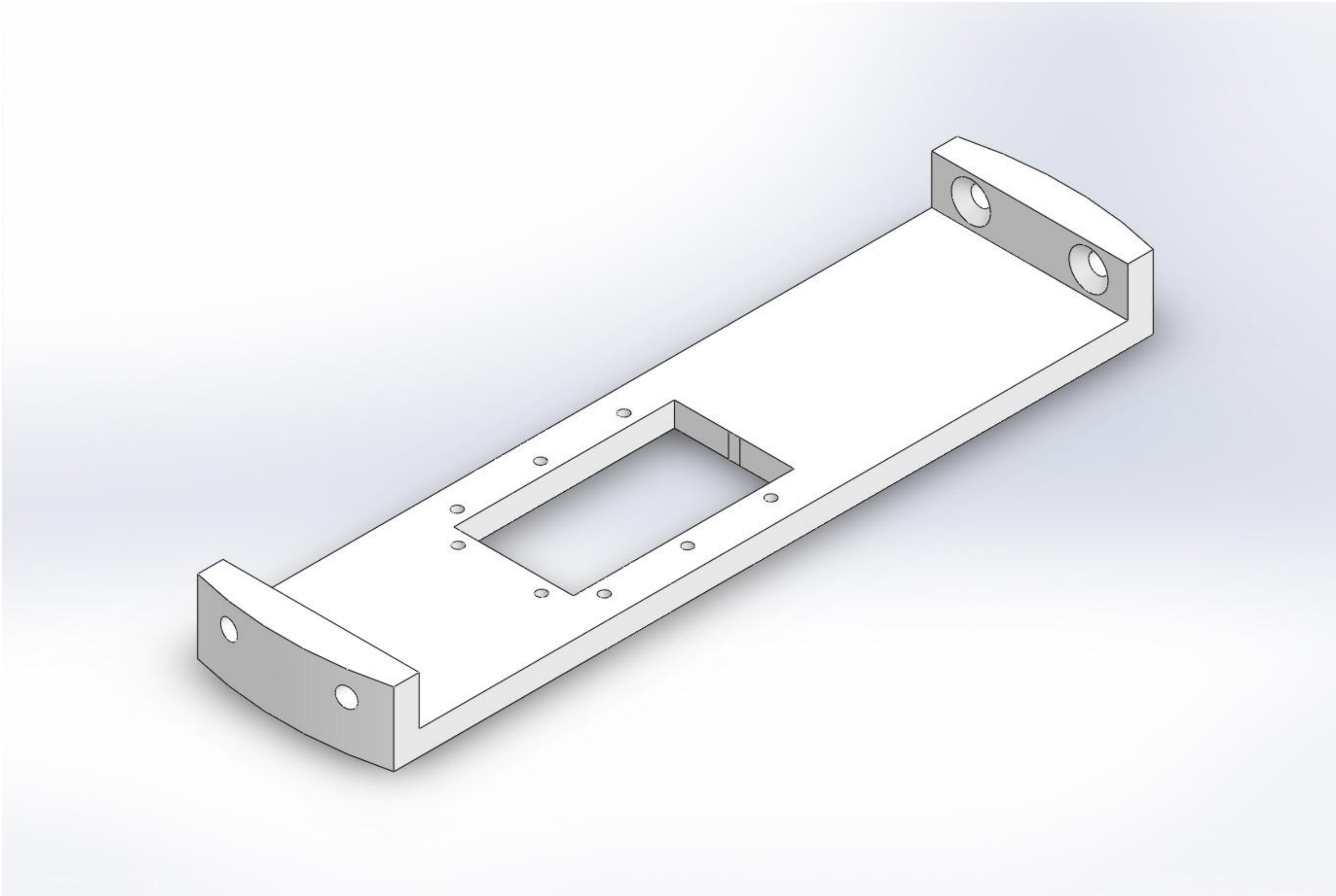

Figure C1: Base Motor Bracket

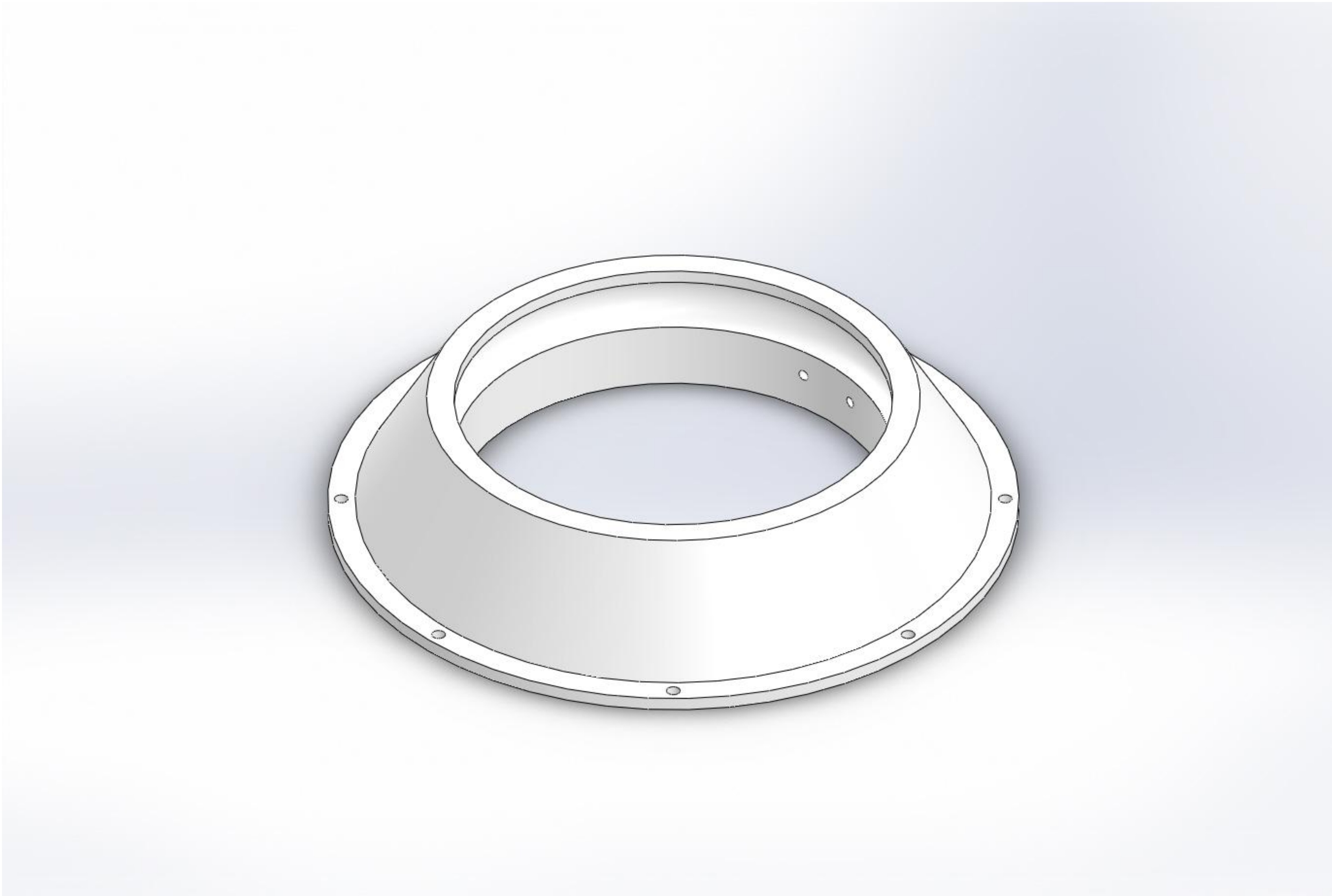

Figure C2: Base

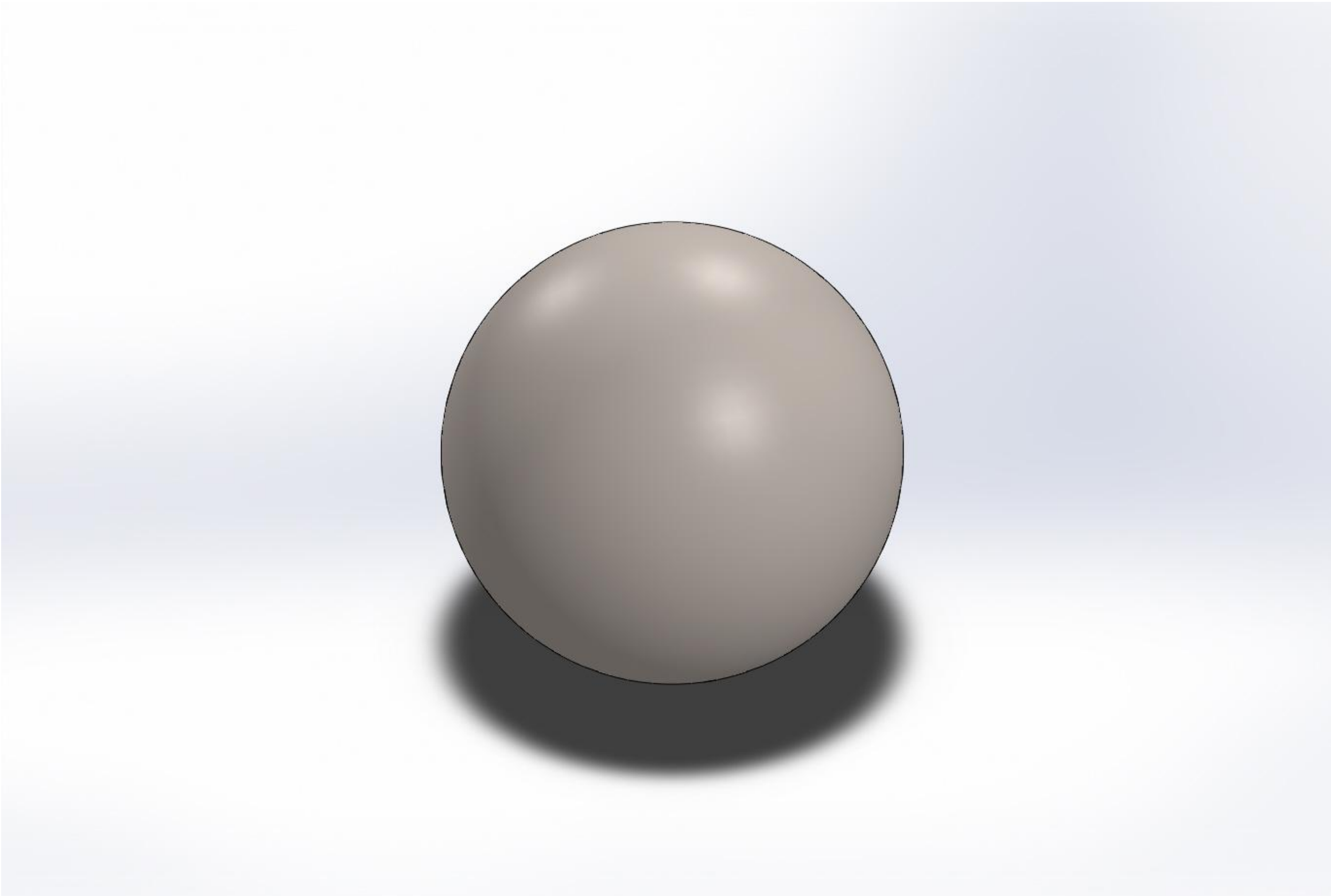
Figure C3: Ball Bearing

Figure C4: Bearing Collar

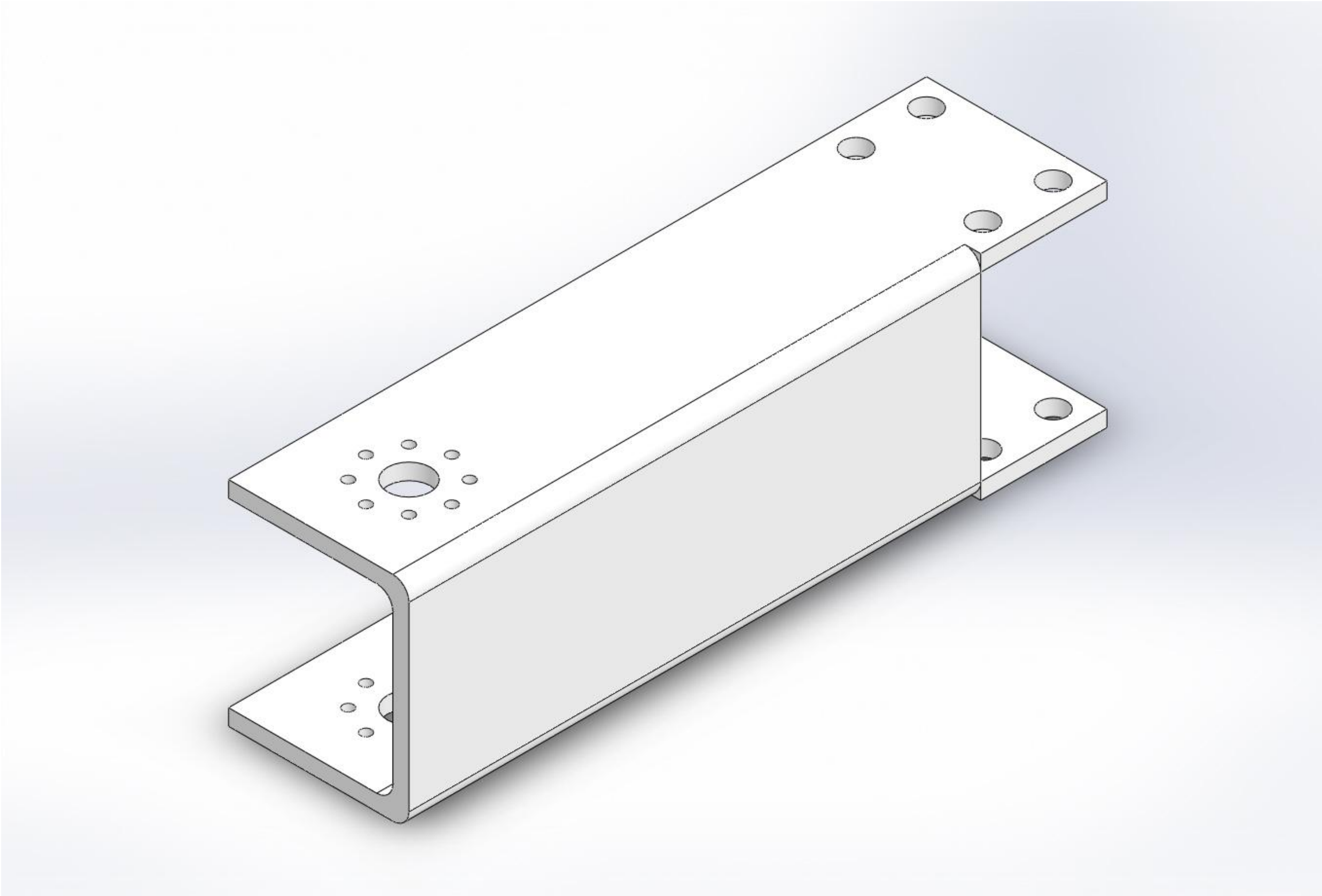

Figure C5: Forearm Extension Base

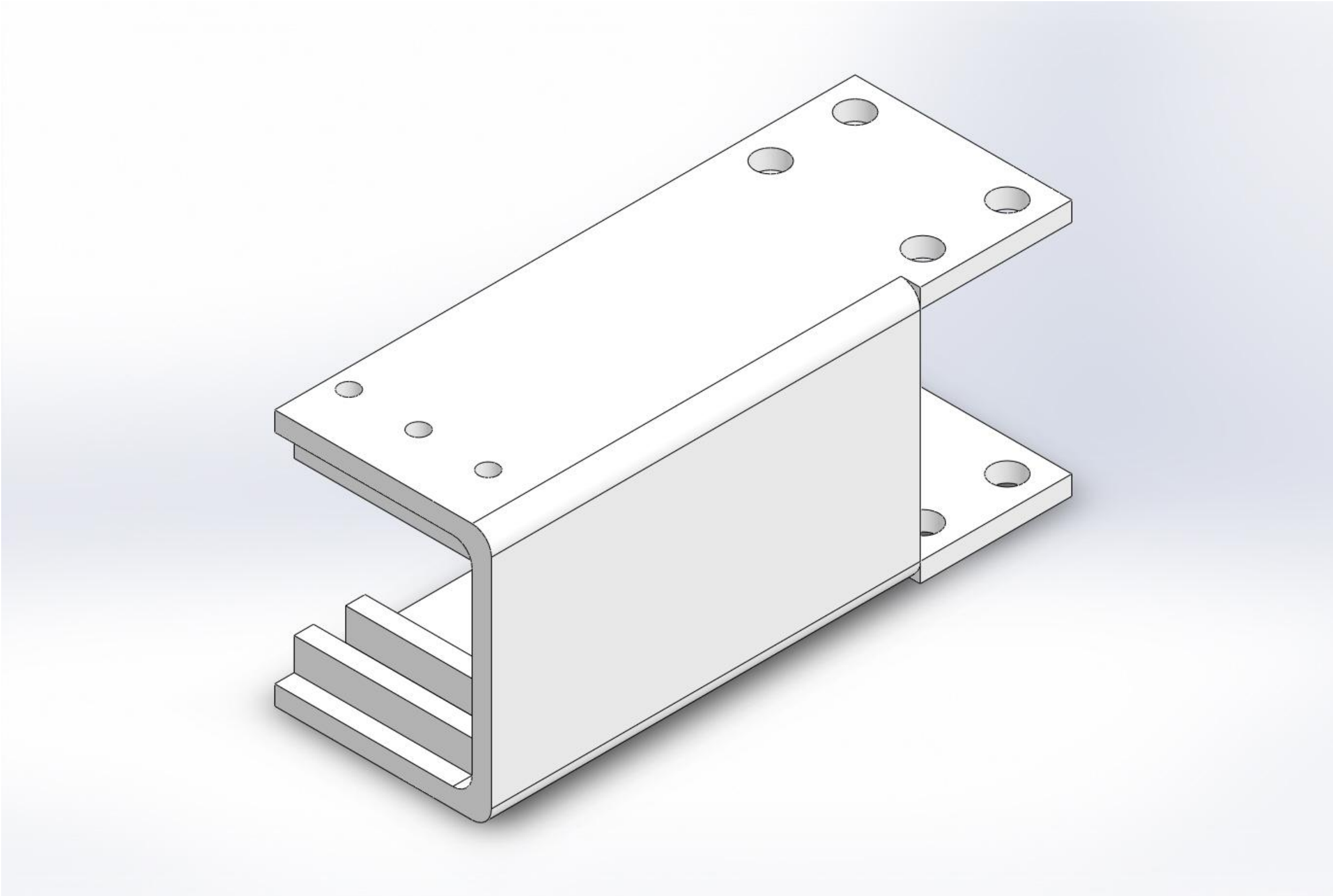

Figure C6: Forearm Extension

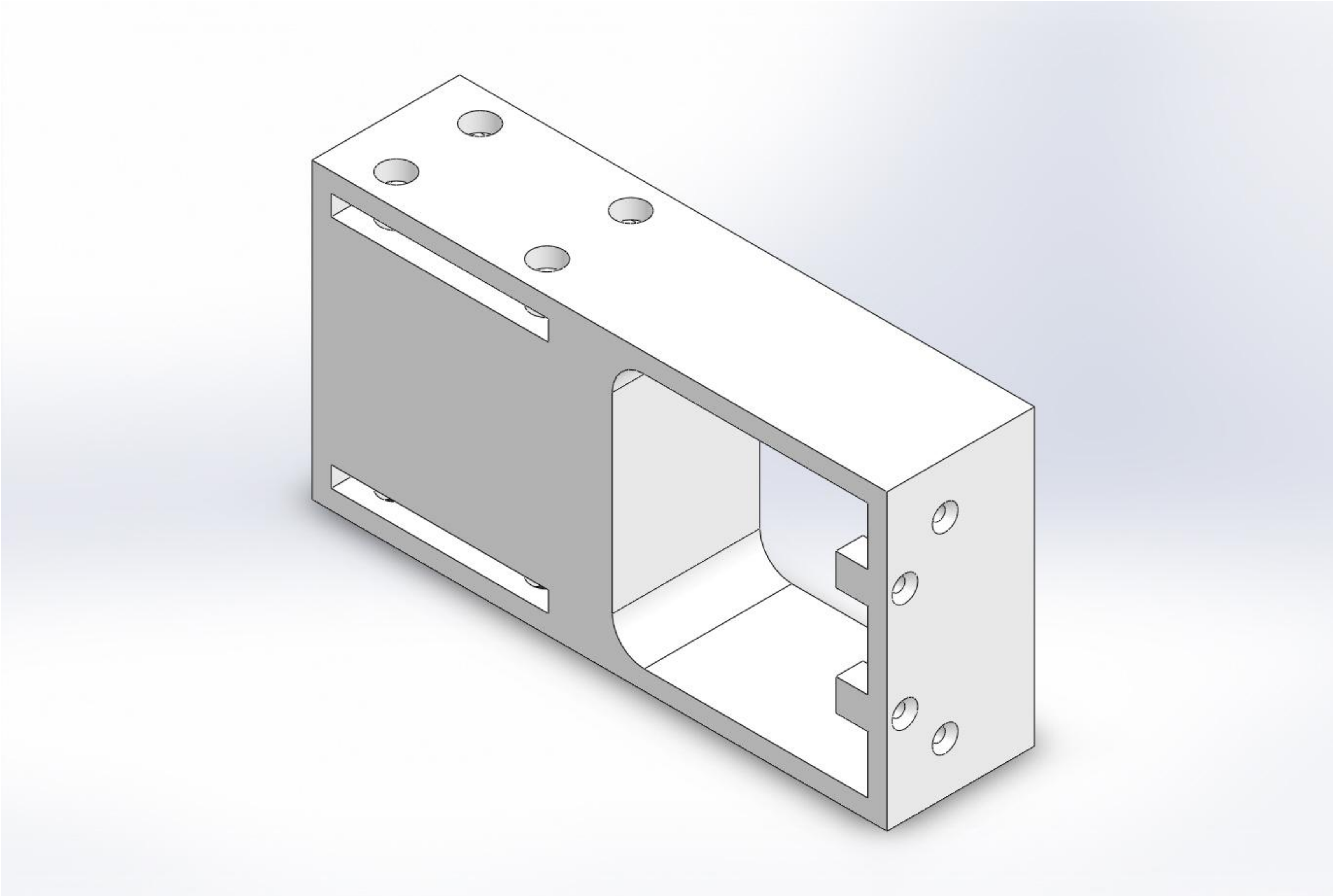

Figure C7: Forearm Motor Holder

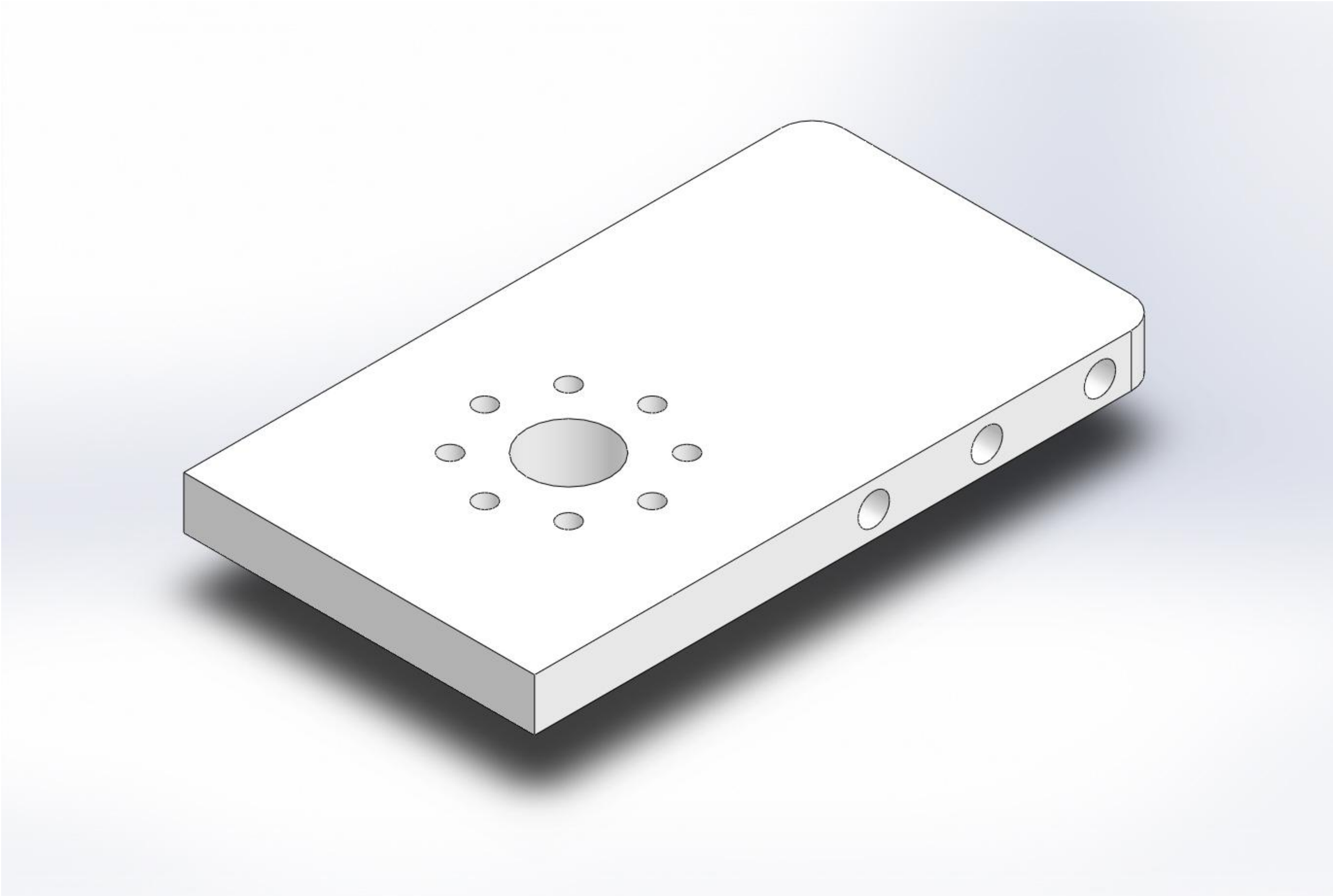

Figure C8: Forearm Mounting Plate

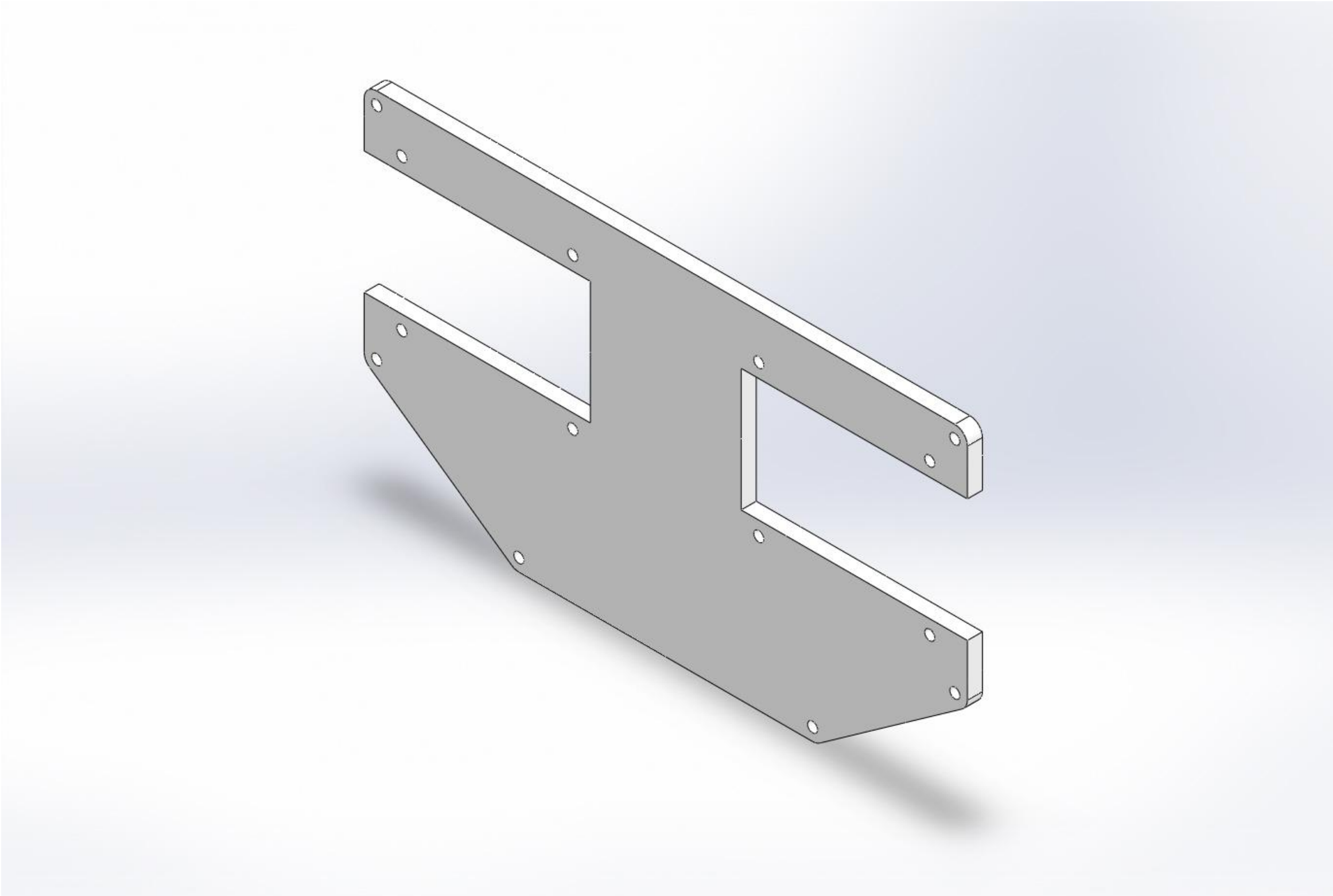

Figure C9: Frame

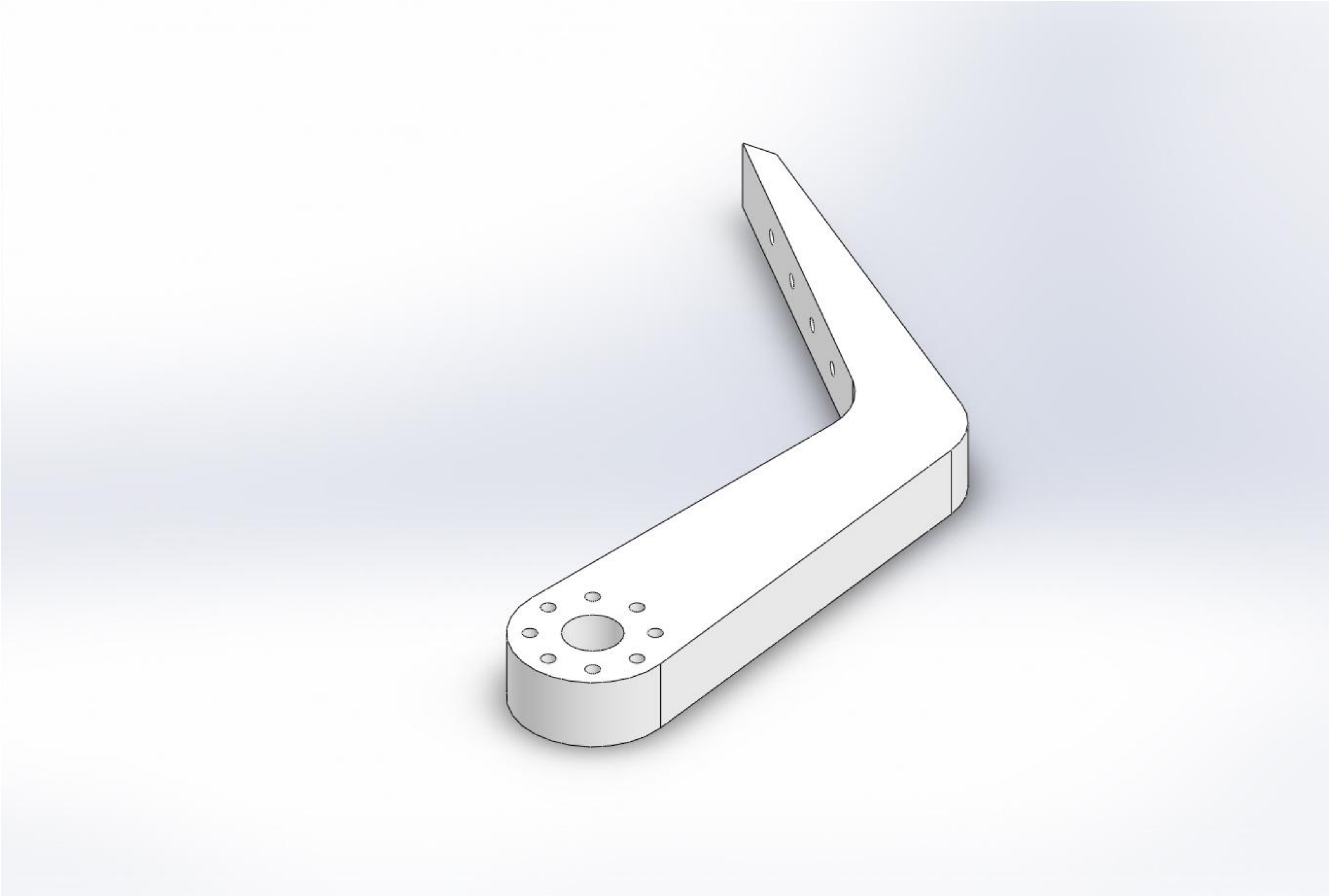

Figure C10: Grabber

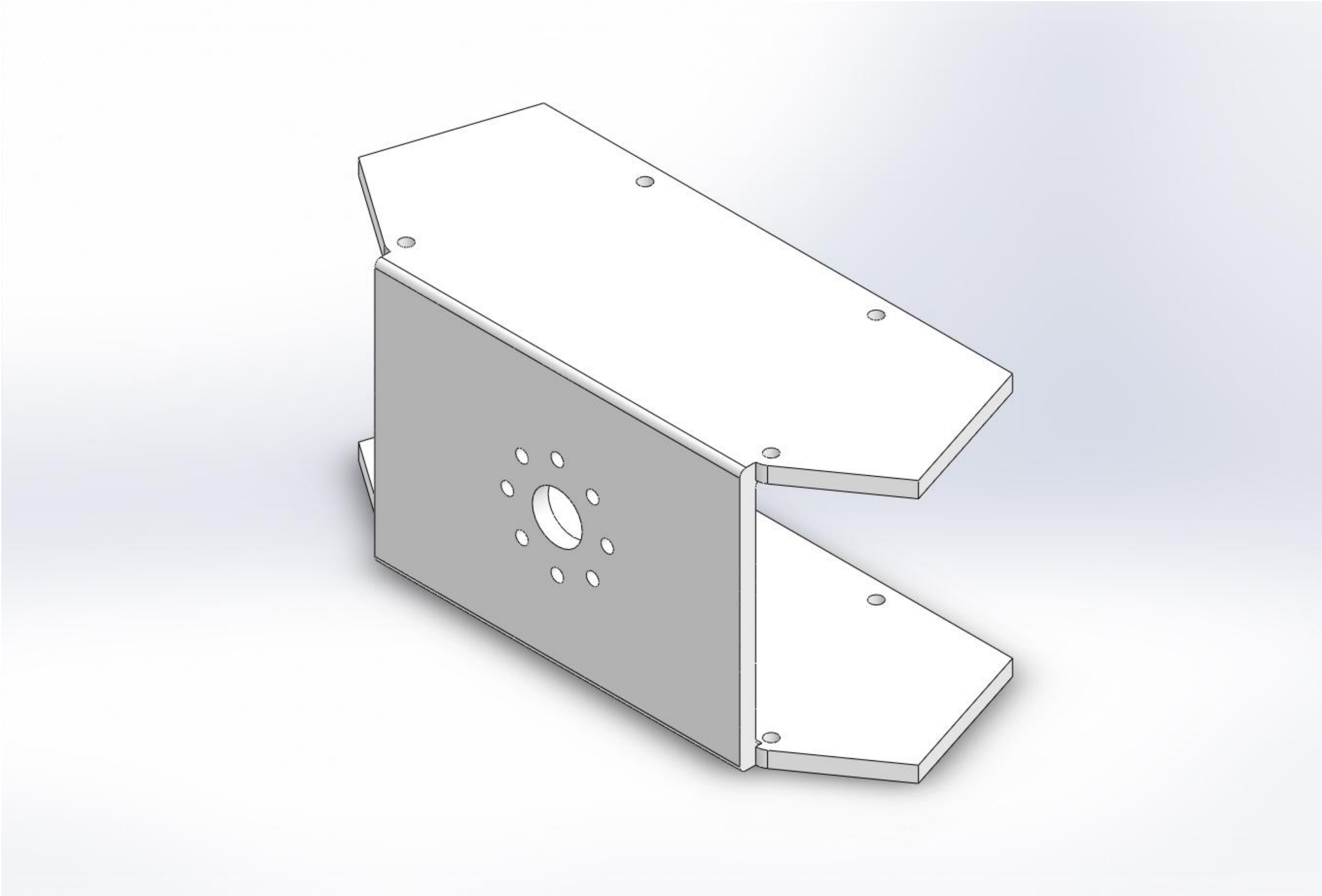

Figure C11: Grabber Grabber

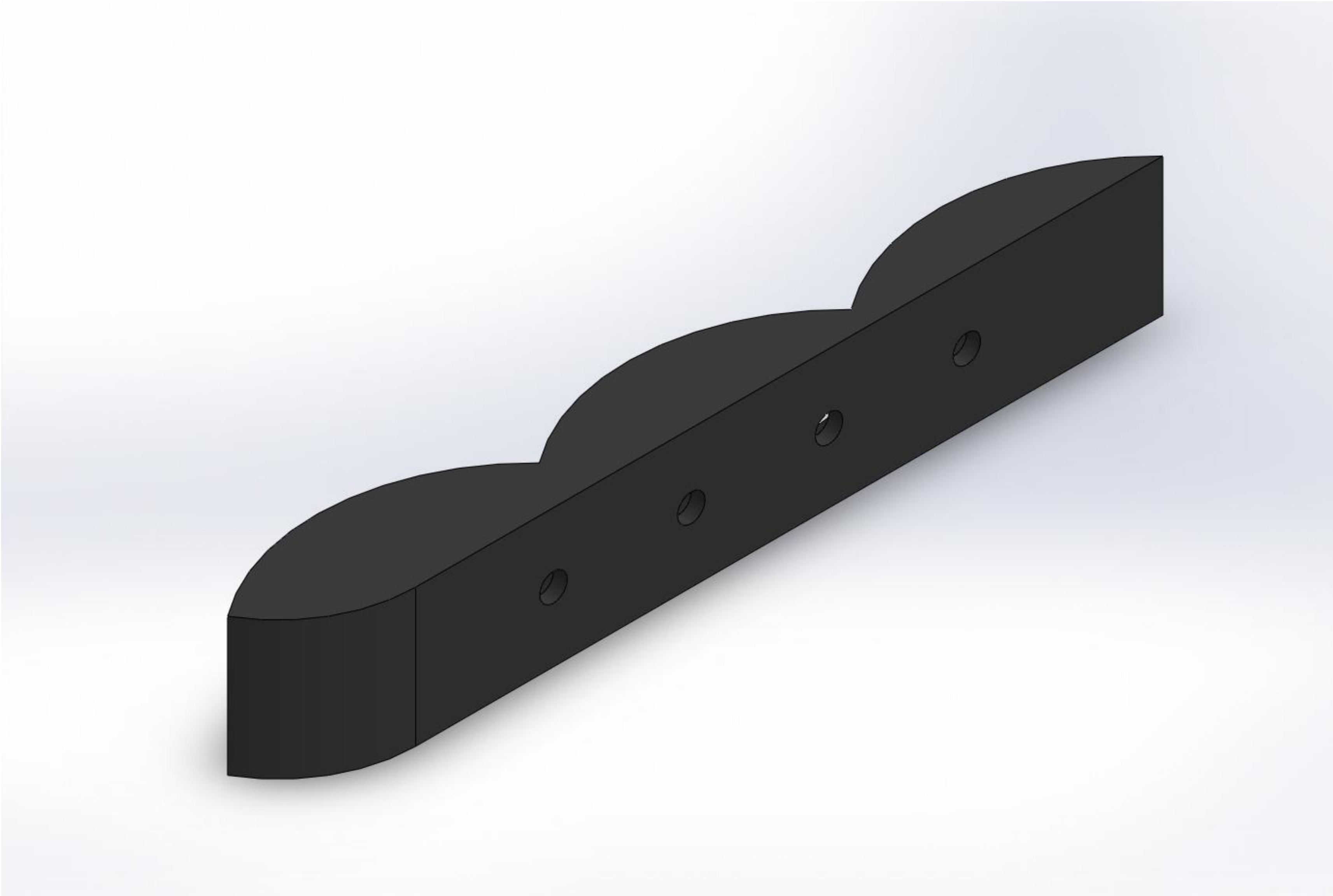

Figure C12: Gripper

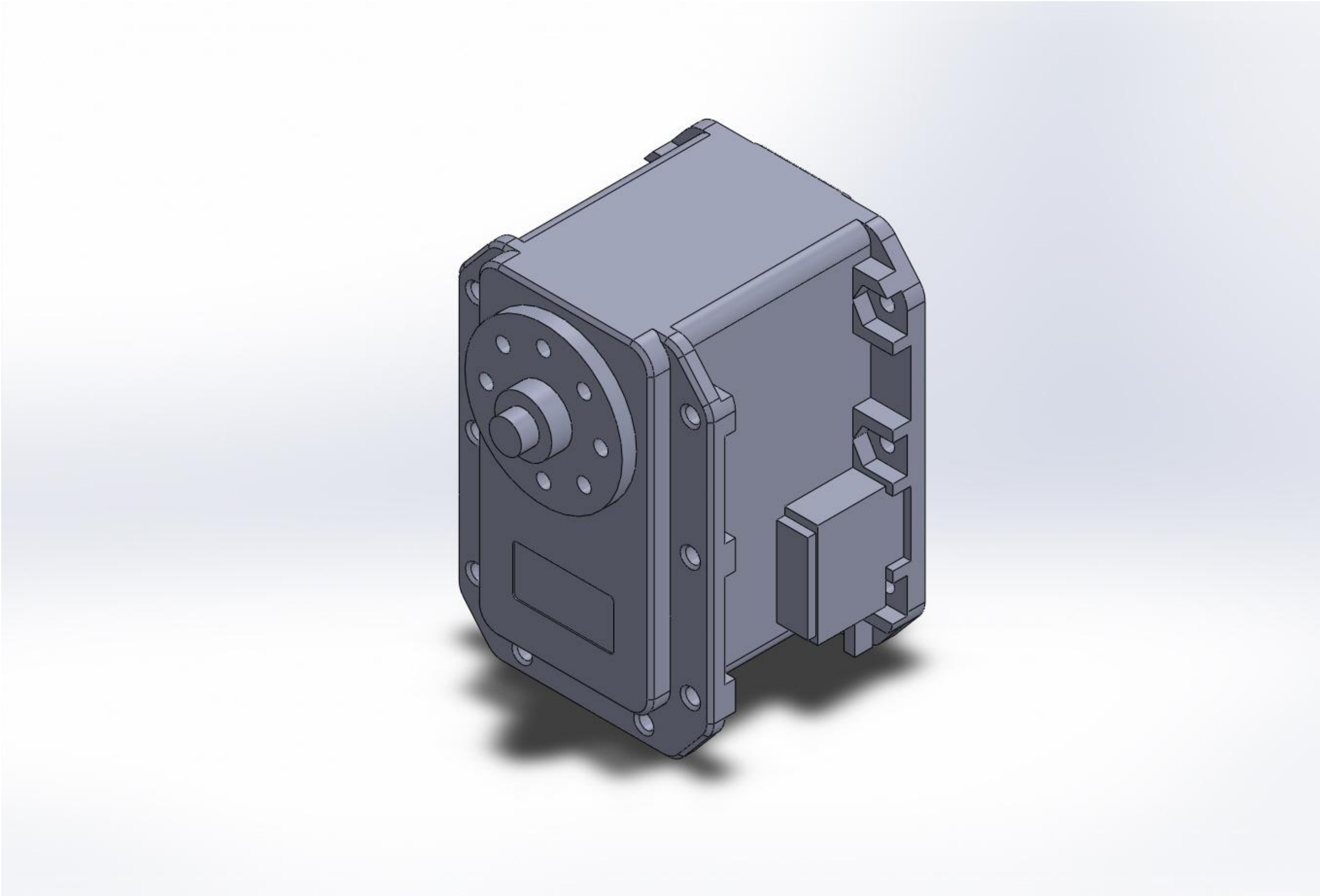

Figure C13: Motor

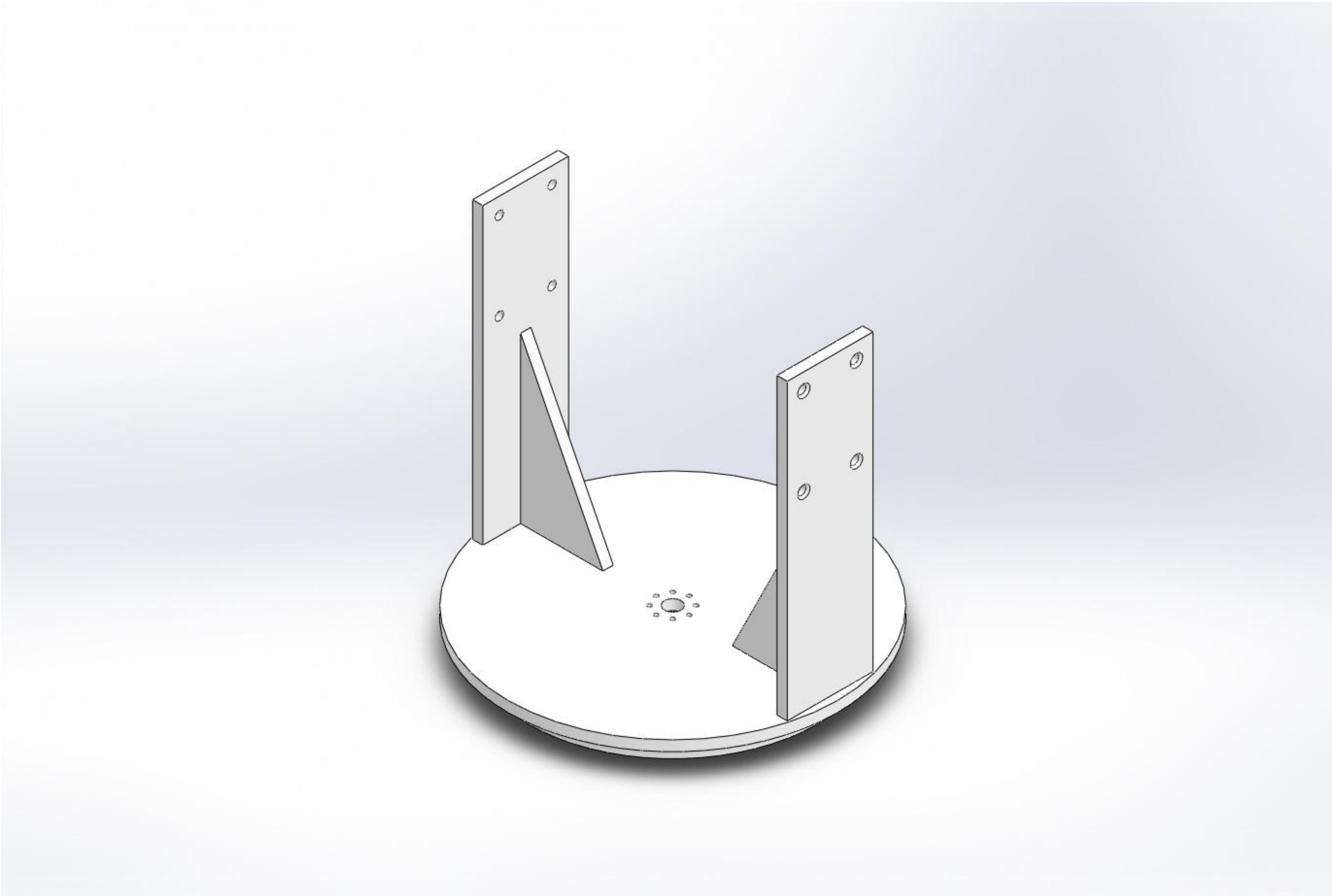

Figure C14: Stand

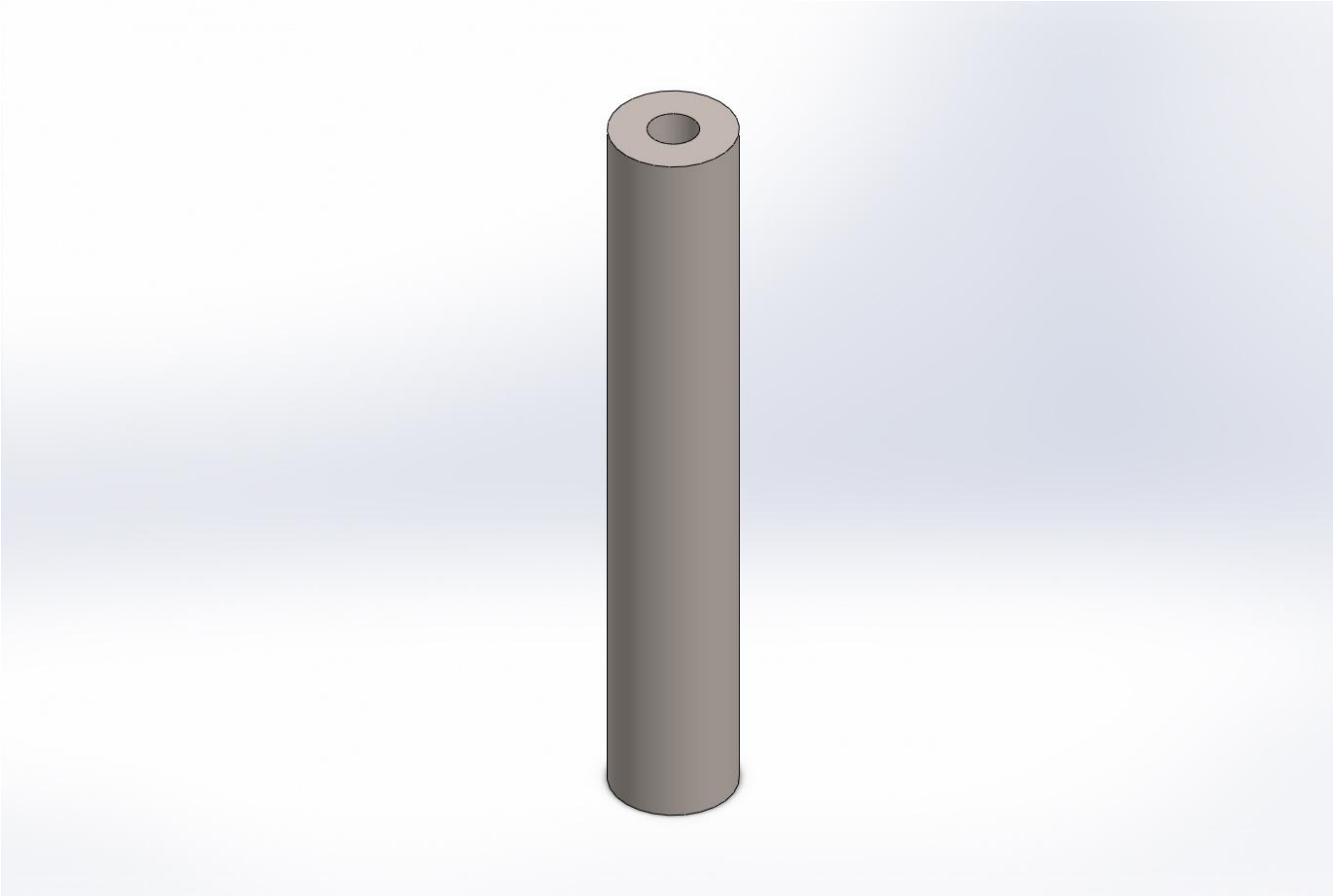

Figure C15: Support

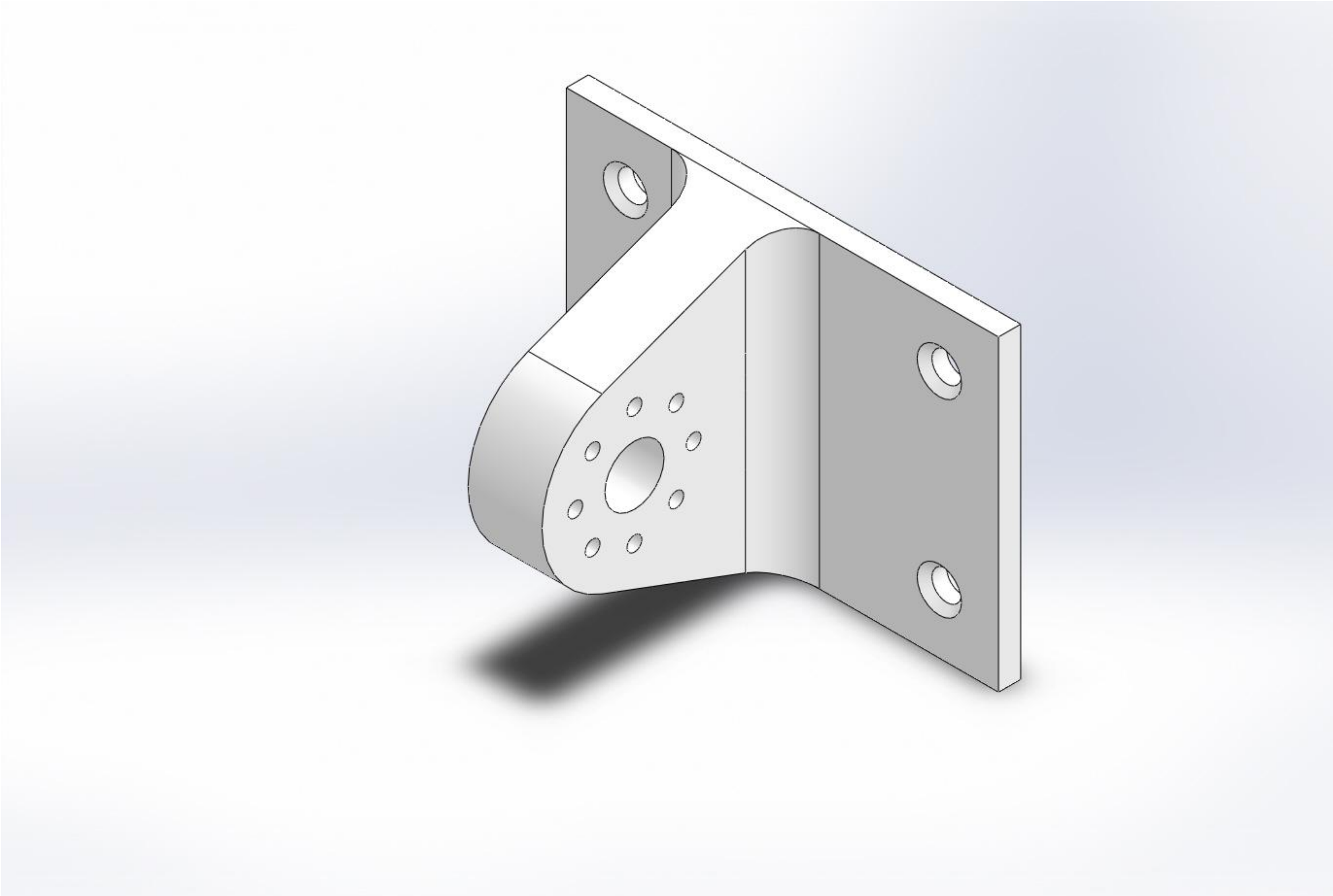

Figure C16: Wrist Mount Holder

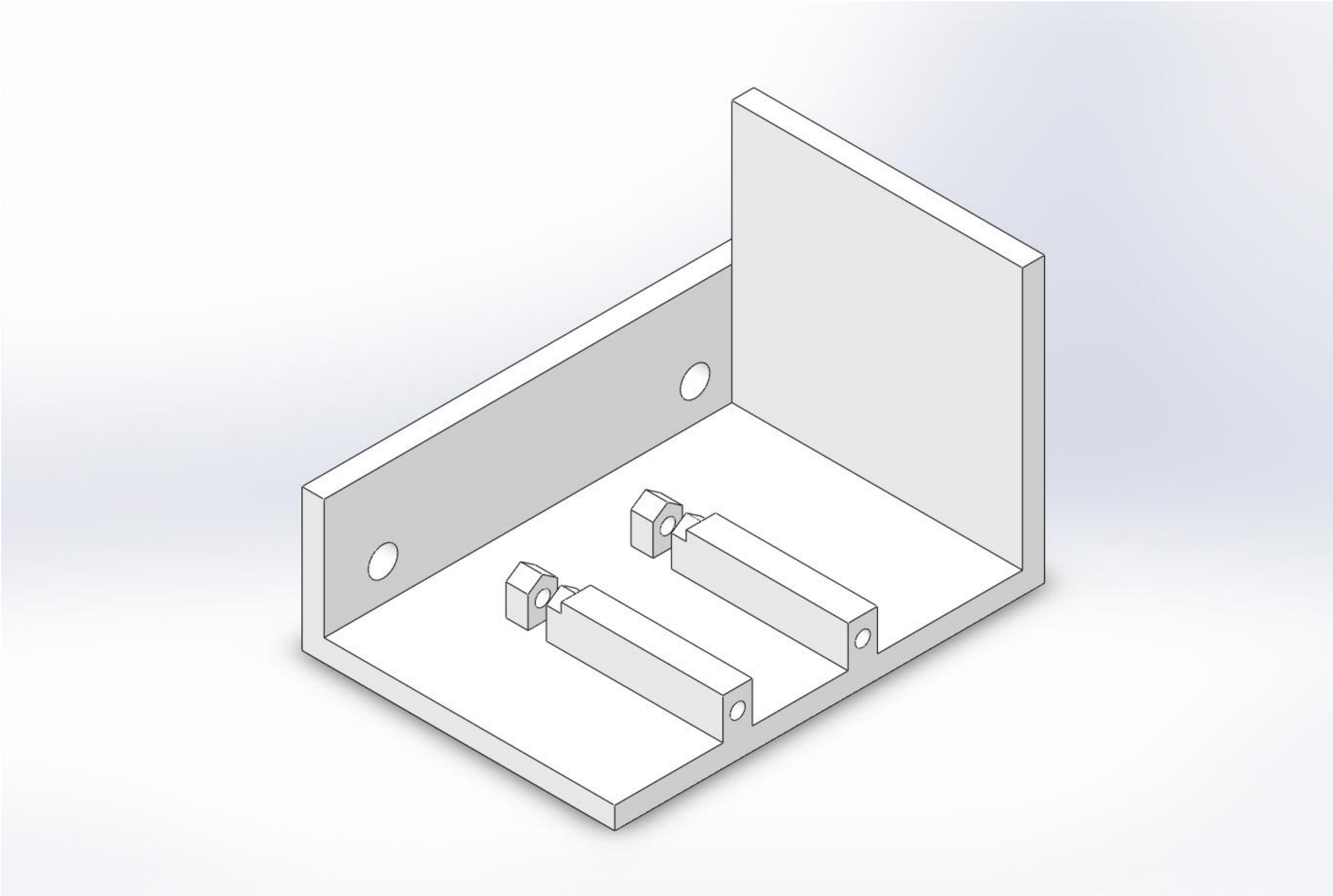

Figure C17: Wrist Motor Holder Bottom

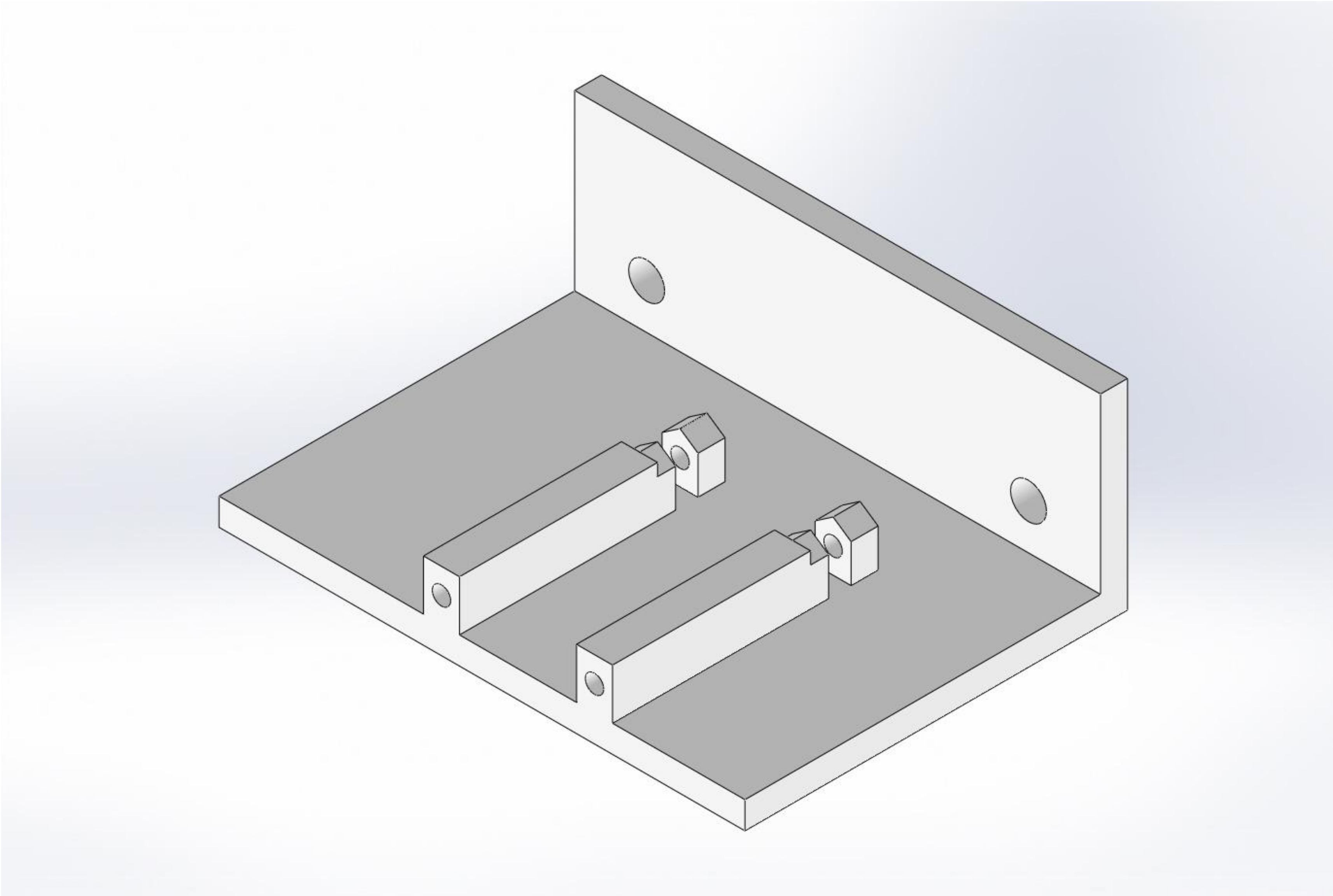

Figure C18: Wrist Motor Holder