SENG 466 PROJECT #2 DESIGN REPORT

MECHANICAL DESIGN

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1 INTRODUCTION

Project 2 of SENG 466: Software for Embedded and Mechatronic Systems course was to design a piano playing robot in conjunction with the Music and ECE Masters Departments at the University of Victoria. The task for this project is to design and build a robotic instrument which can play a piano key at various speeds and for varying lengths of time. The idea of this project is to be a proof of concept for a robot that can play one key and an array of the device could potentially play a full keyboard. The instrument can be preprogrammed to play the note in a desired way. To accomplish this task a support structure was designed and built to support the solenoid mechanism which would play the note. This report will outline the mechanical design involved in the construction of the solenoid and support structure.

2 MECHANICAL DESIGN

The mechanical design of the piano player robot was centered around the solenoid mechanism which would actuate the piano key. An electromechanical solenoid is a transducer device which can produce linear motion from an electrical source. The solenoid consists of an electromagnetically inductive wire wound into a tight coil around a non-magnetic hollow tubing, called the solenoid bobbin, which houses the movable steel slug or armature. The coil must be an insulated wire such that the electric current will flow through the entire length of the wire. The core material or armature must be ferromagnetic such that the magnetic field induced by the coil pulls it into the center of the field and the resulting magnetic flux exists within the armature.

The coil is shaped as such to create a controlled magnetic field within the coil when electric current is applied to the wire. The coils inductance will chance and thereby move the armature in a linear fashion along the axis of the coil such that it sits in the middle of the coil when activated. The mechanical force provided by the armature will be used to actuate the piano key. The force of a solenoid is typically weak over anything other than a short distance which makes it very useful for this application along with its short reaction time. The solenoid is controlled by a relay circuit and Arduino microcontroller. The software design of the microcontroller and the electrical design of the solenoid are discussed at length in Design Report #3.

2.1 BOBBIN DESIGN

The first iteration of the solenoid design involved winding a very small gauge wire around a plastic straw acting as the solenoid bobbin. This was done for testing purposes only and when this design was determined to function at a basic level it was necessary to design and construct a solenoid bobbin which would allow for some versatility in attachment to a support structure which would not be viable with a straw bobbin.

2.1.1 3D PRINTED BOBBIN

A very important aspect of the solenoid bobbin design is that the bobbin thickness must remain as small as possible to ensure the magnetic field from the solenoid is not disrupted. As the 3D printer has restrictions on the diameter of the plastic extruded, the solenoid bobbin cannot be made as thin as desired. The extruder diameter is 0.4mm; however, due to concerns of the strength of the printed solenoid the part was printed with an initial thickness of 0.8mm. This presented no issues in printing and the part came out nicely. The Solidworks part for the first iteration of the solenoid bobbin is seen in Figure 1.

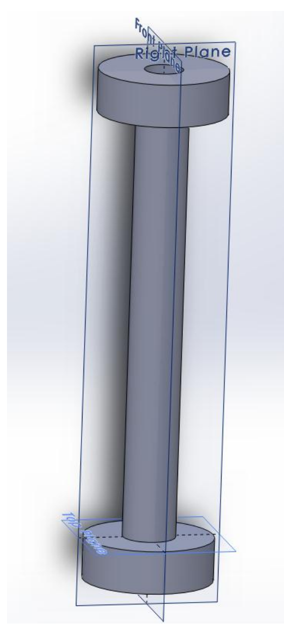


Figure 1: Solenoid Bobbin Version 1

The first version of the bobbin was made to be fairly simple for testing purposes. The bobbin consists of a hollow tube with larger diameter stoppers on either end to hold the wire coil in place. The wire coil was wound on by a drill in order to get a nice tight coil and to allow for faster winding. When removing the bobbin from the drill chuck the part failed and broke at about the halfway point along the grain. This occurred because of the direction of the grain which is horizontal rather than vertical, with respect to Figure 1. This grain direction transpired because of the way the 3D printer prints. The 3D printer takes a Solidworks part and slices it into layers to print, which are printed from the bottom up as seen in Figure 2.

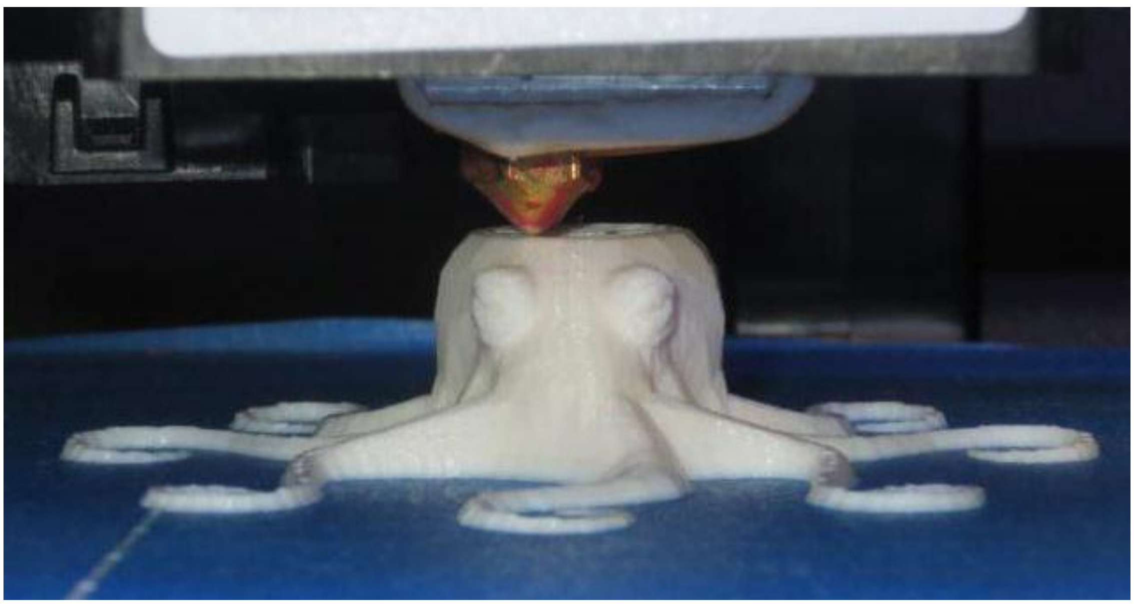


Figure 2: MakerBot Replicator 2 3D Printer

The only orientation that the bobbin may be printed in is the upright orientation as seen in Figure 1, which would print the bobbin in rings that are only bonded together by the heat of the extruder. This is not an ideal grain for this part; however, it is not possible to print the part laying down due to restrictions on the angle of the part with the platform. This angle must be greater than 45° or the extruding plastic will fall to the platform below and will not print the desired shape.

In order to mitigate this failure in the future it was determined that the part could be printed with a slightly thicker wall. The part was printed again with a wall thickness of 1.2mm; however, it was determined that this would not provide much more strength the direction of the grain would continue to be a problem and other designs should be considered.

2.1.2 Aluminum Tubing Bobbin

In order to increase the strength of the bobbin it was determined that a non-magnetic material such as aluminum could also be used. Aluminum tubing with reasonable small wall thickness was found in the lab and preliminary testing was done to determine if the material and thickness would work. The new bobbin material would not be at risk for breaking along its length as the printed part did.

Once it was determined that the aluminum tubing would be a suitable alternative to the printed bobbin, end caps were designed for the tubing to hold the coil into place and also to allow for mounting to the support stand. The end caps can be seen in Figure 3 and Figure 4.

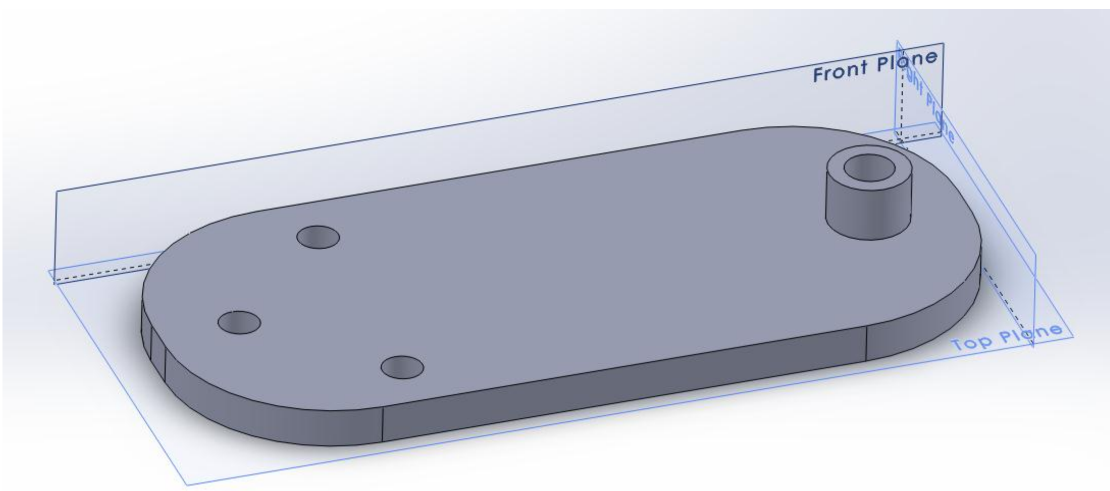


Figure 3: Aluminum Tubing End Cap

The top cap was designed to be mounted to a support structure at the end where the three mounting holes are. The mounting holes were made to be a certain distance from the solenoid to allow for a mounting structure to sit in front of the keyboard piano and reach the solenoid out over the keys.

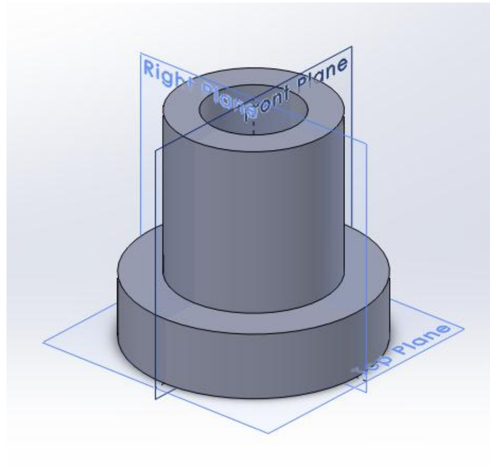


Figure 4: Other End Cap

The other end was designed to be a simple cap to hold the solenoid coil in place. Both end caps were glued to the aluminum tubing to be held into place.

The solenoid was built with the above parts and assembled as seen in Figure 5. The solenoid windings are underneath the black electrical tape which was used to hold everything in place.

Figure 5: Solenoid Design #1

The first solenoid design was completed and tested to see if the force created by the design was sufficient to actuate a piano key. Unfortunately the gauge of the wire was small enough that it increased the resistance of the solenoid and resulted in too small of a mechanical force when electric current was applied.

In order to overcome the issue of high resistance in the wiring, a larger gauge wire was used. This larger gauge wire also provided a lot more force for less windings. The wire was wound around non-magnetic square tubing and held in place by the mounting structure as seen in the next section of this report.

2.2 MOUNTING STRUCTURE

The mounting structure provided some challenges as the keyboard piano did not supply and mounting places and rather the support structure for the solenoid would have to stay in place on its own or rest underneath the piano.

The first design utilized the weight of the piano to hold the support structure in place with a long thin base platform as seen in Figure 6. The solenoid must be mounted to the stand protruding from the platform by the three mounting holes which lined up with the original design aluminum tubing solenoid.

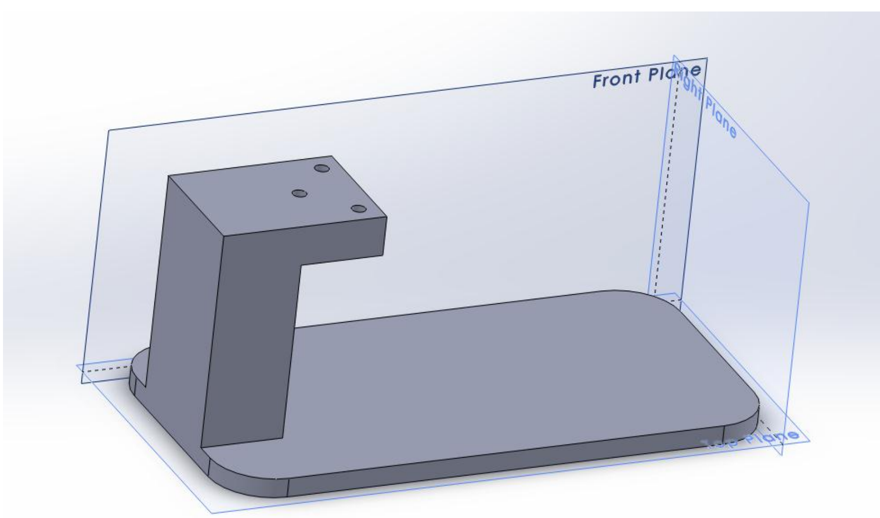


Figure 6: Original Solenoid Stand Design

The issues with printing this part are that the 3D printer cannot print the arm that protrudes 90° from the stand. The only way to print this component is with a raft support structure. This option is available for the 3D printer; however, the generation of the gcode for this part was extremely time consuming and the printer had issues when it came to printing due to the size of the part. Once the original solenoid design was abandoned due to lack of mechanical force, it was determined that a new design would be required for the support structure due to the increased size of the new solenoid.

Due to the issues with the size of objects to be 3D printed, the new design incorporated wood doweling along with some printed parts. A base plate and the cap were printed to fit the wood stand snugly into it and can be seen in Figure 7 and Figure 8 below. The parts were designed as simply as possible so that gcode generation was problem free and allowed for quick printing.

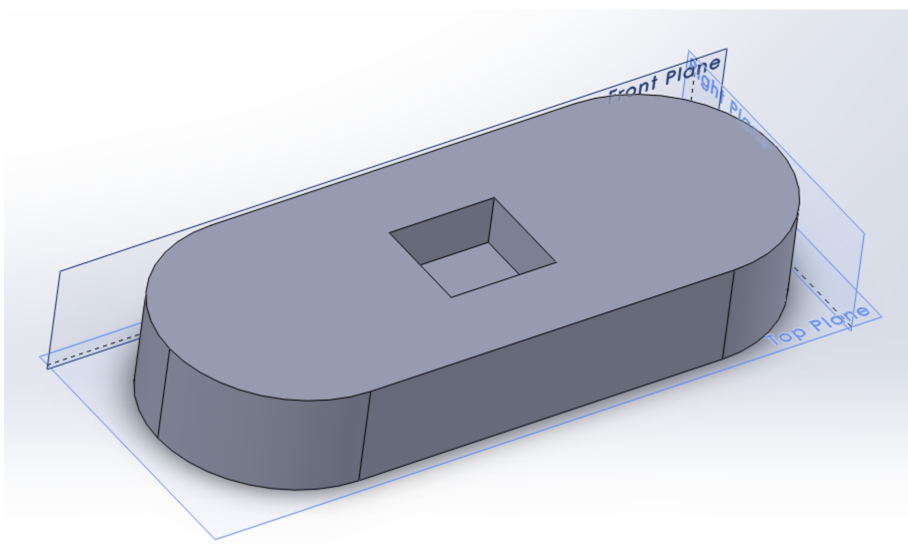


Figure 7: Support Structure Base

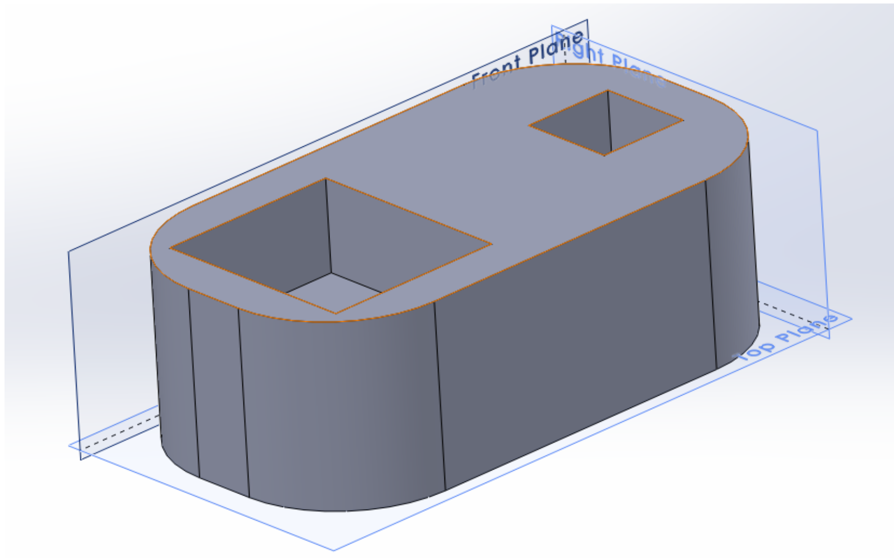


Figure 8: Support Structure Cap

The parts were glued to the wood stand as seen in Figure 9 below. The simplicity of the stand and printed parts allowed for quick construction and a sleek finished project.

Figure 9: Final Setup

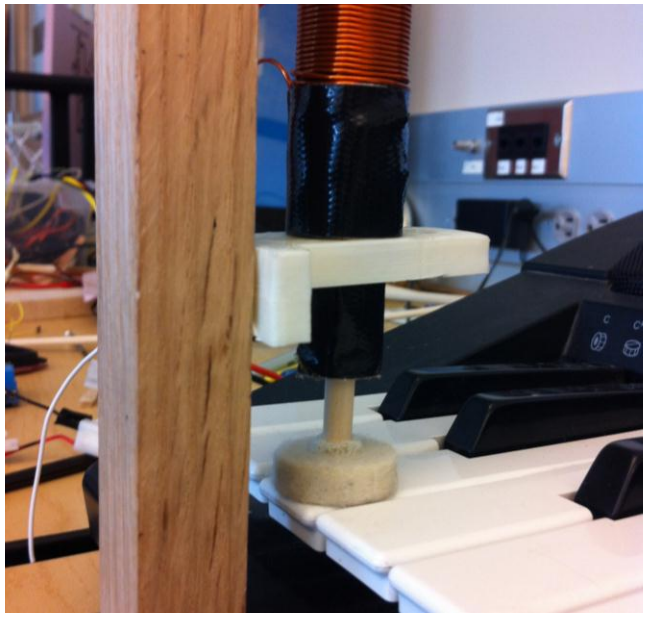


Figure 10: Close-up on Piano Actuation

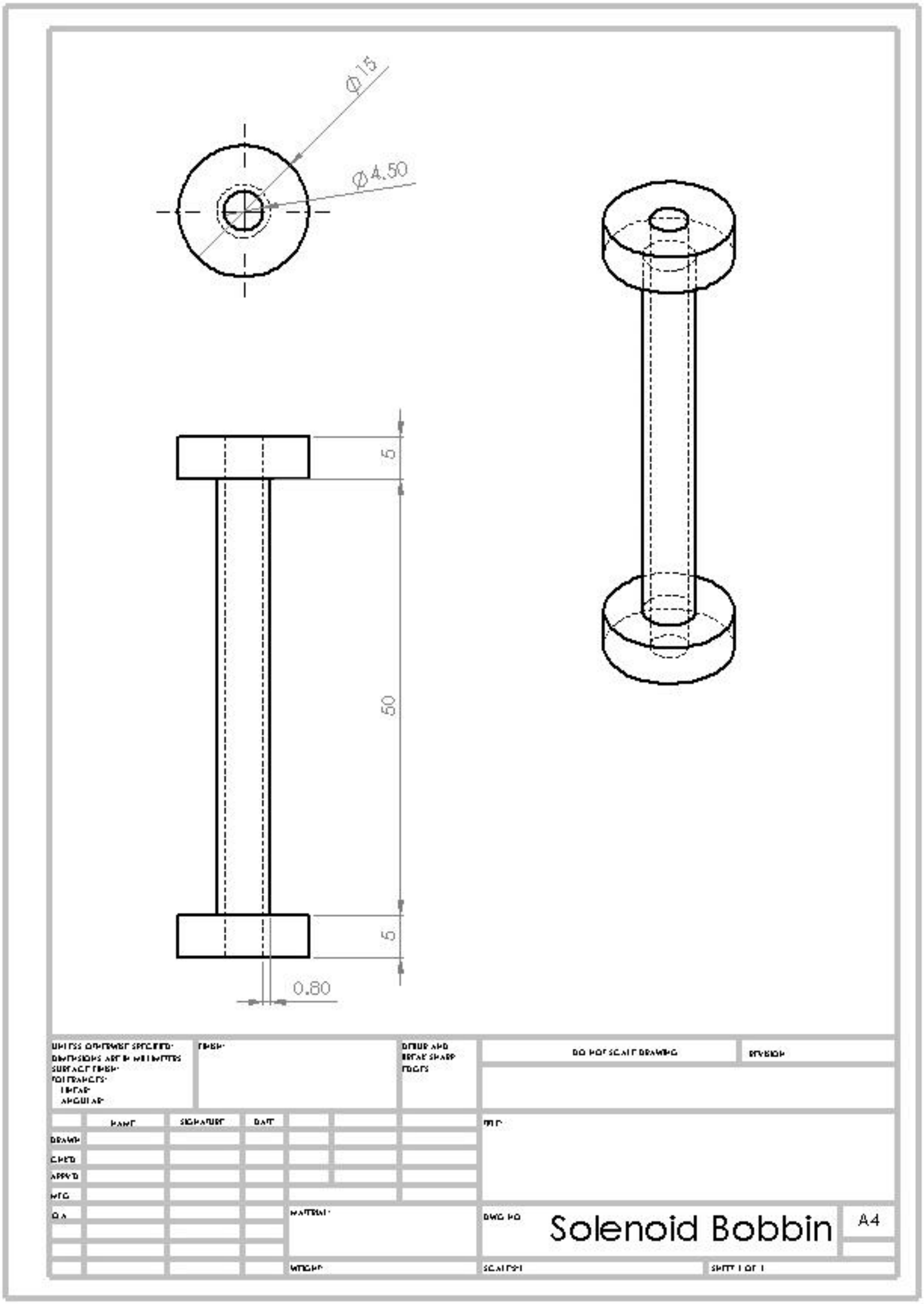
Figure 10 shows a close-up of the piano actuation where a felt puck was glued to the armature. The solenoid is held up against the wood stand with the white printed part which acts as a web to distribute the opposing force of the solenoid amount the top cap and that part.

3 Conclusion and Recommendations

The aim of this project was to design and build a self-actuated piano playing robot. Due to time constraints the robot designed was only proof of concept and can be applied on a larger stage with an array of solenoids. This report discussed the issues which arose in the design and building of this robot. Due to changes in the solenoid deign, two stands were designed both with unique designs. The solenoid bobbin design was iterative as the first printed design was found to be too weak to support the coil. Overall the mechanical design was pretty straight forward and only required changes due to restrictions in the manufacturing process.

A sleeker and more accurate design could have been obtained if the stand was designed with aluminum parts however due to time constraints it was found to be better to used materials available in the lab and the 3D printer.

APPENDIX A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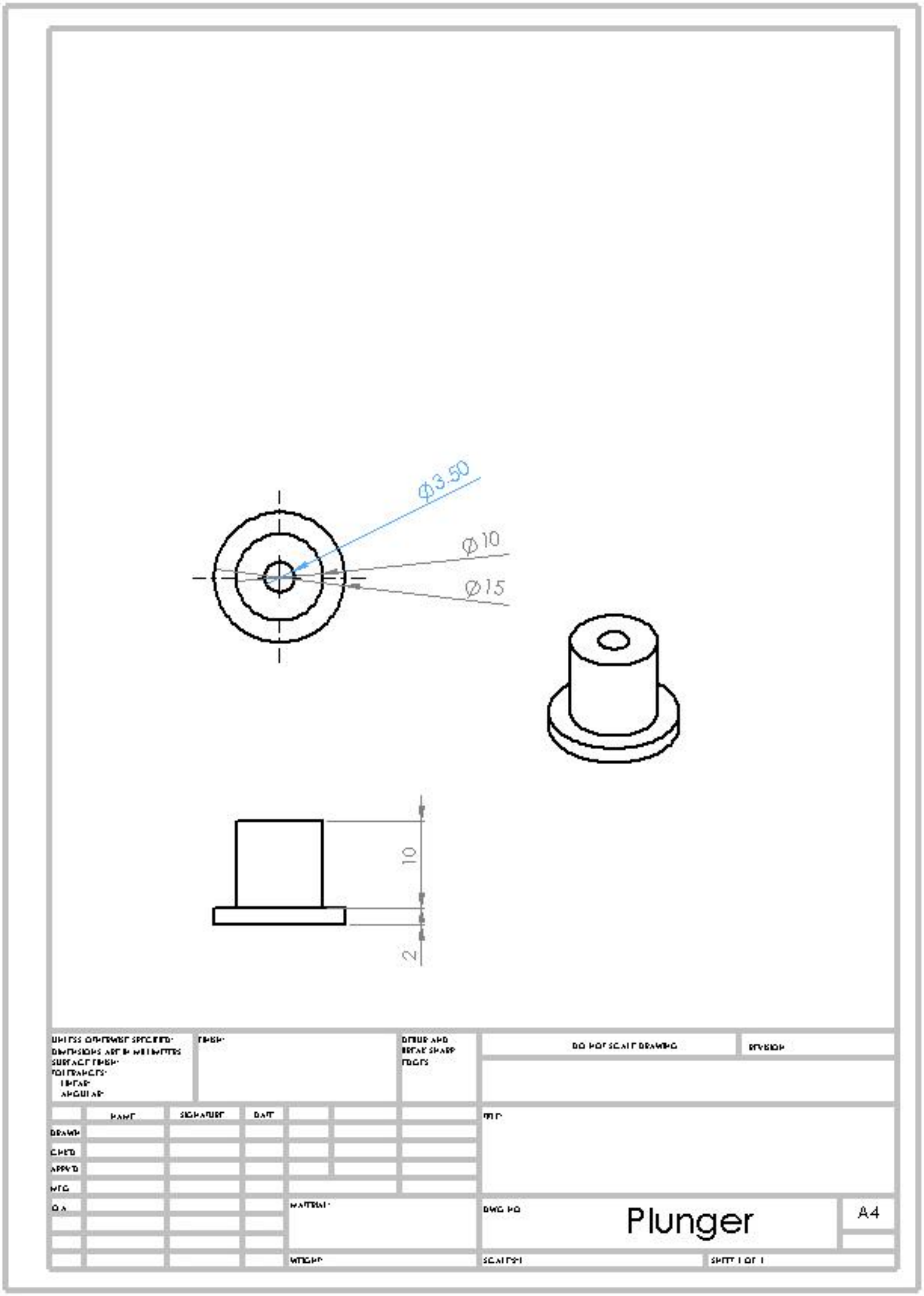

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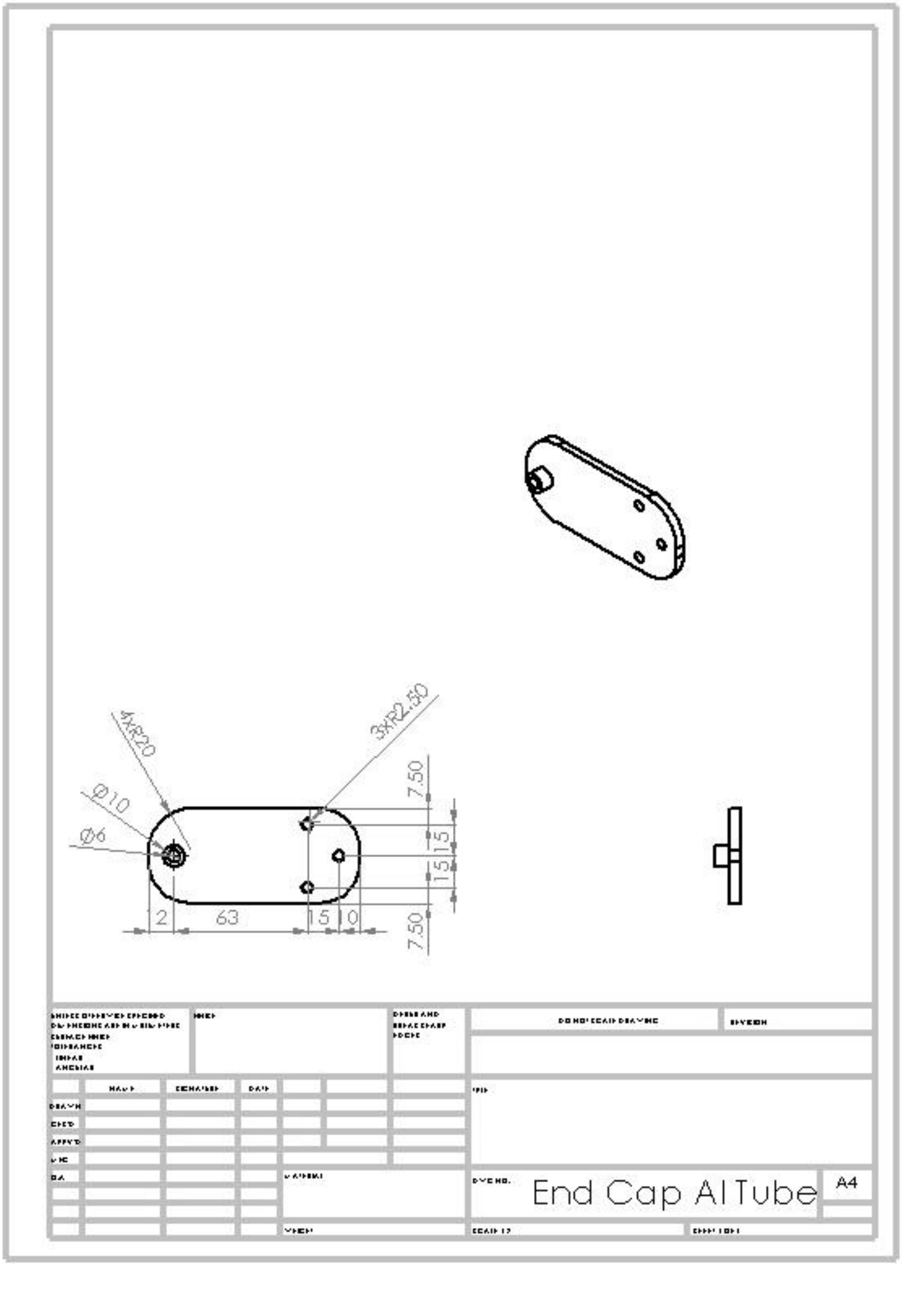
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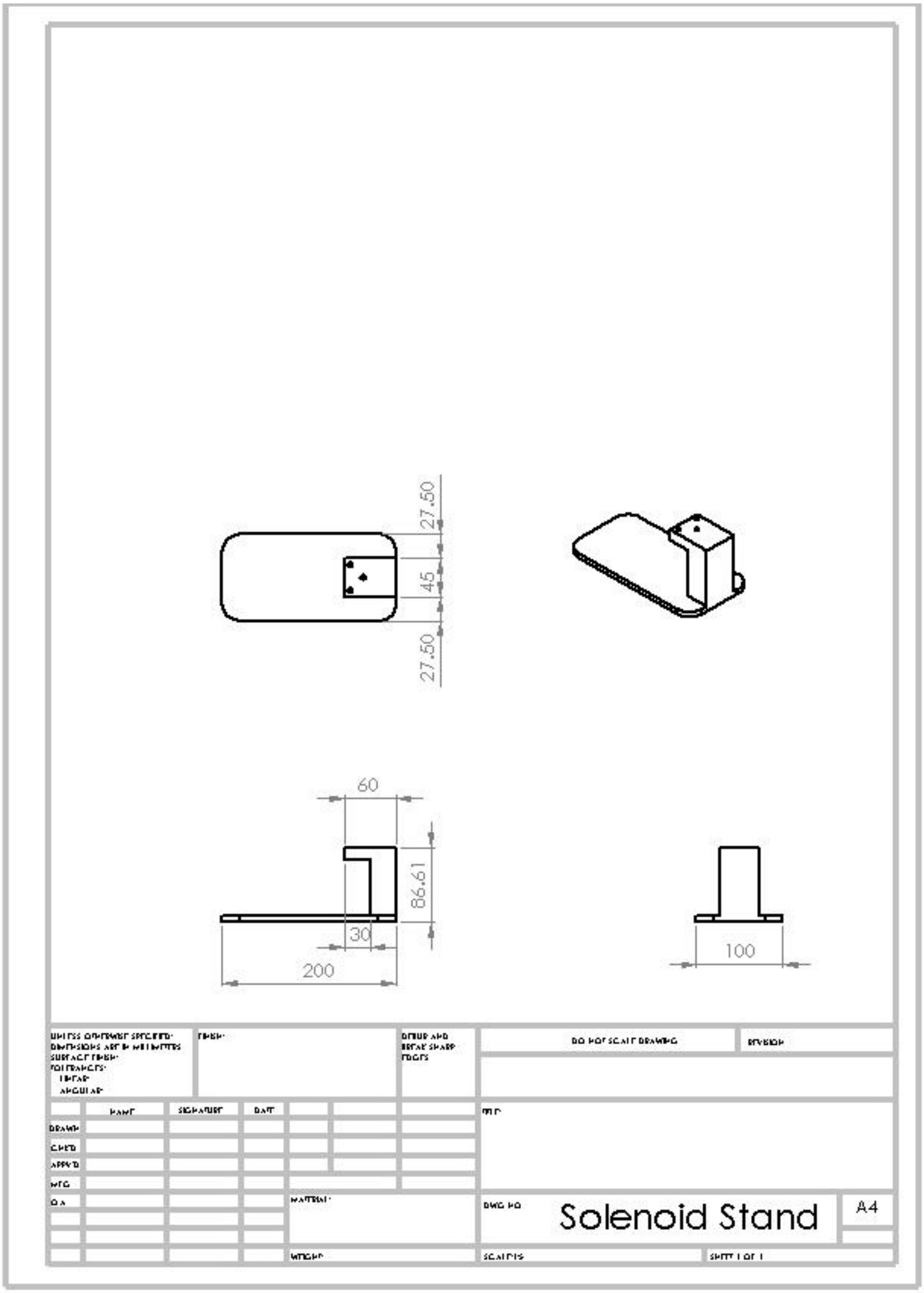
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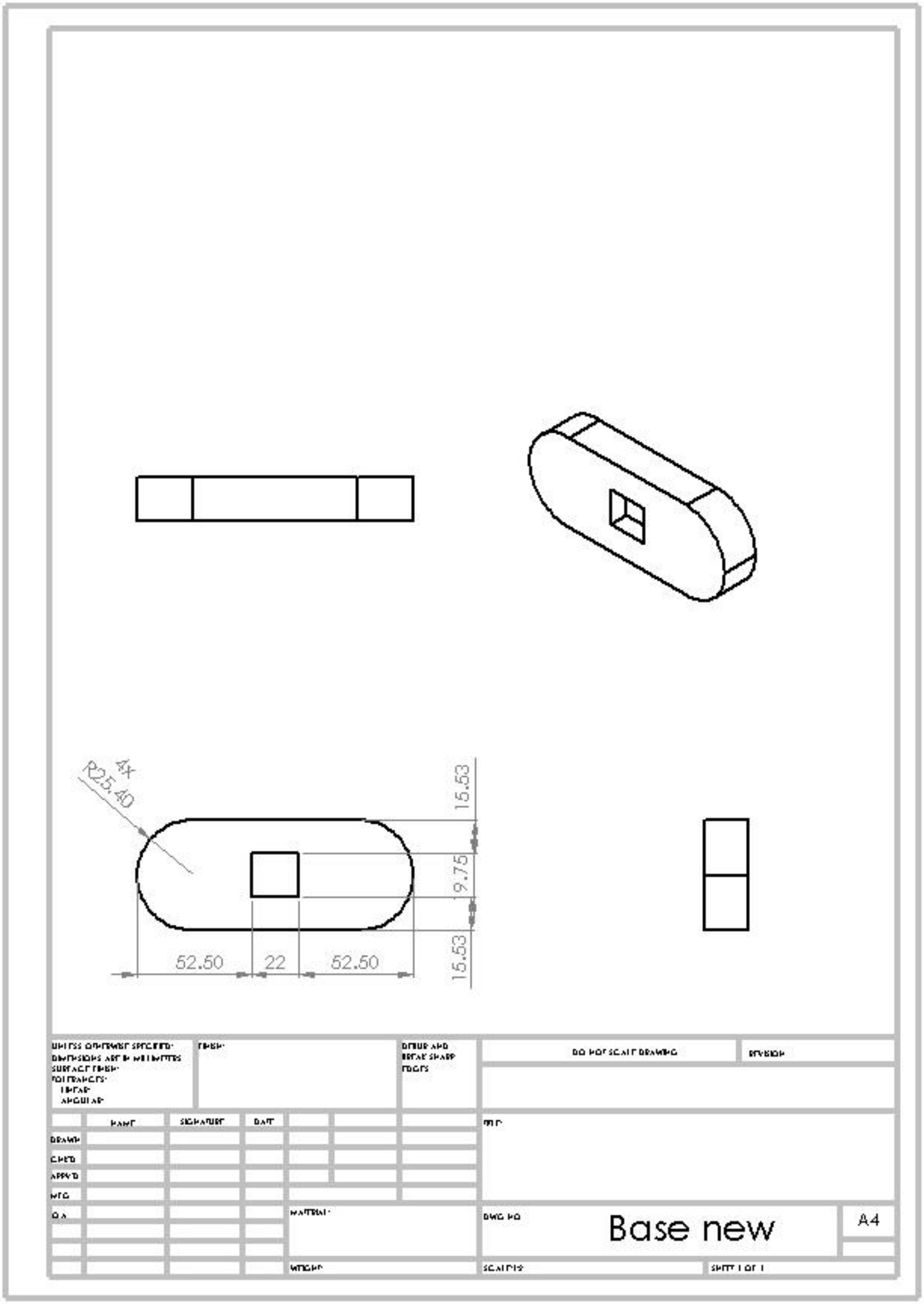
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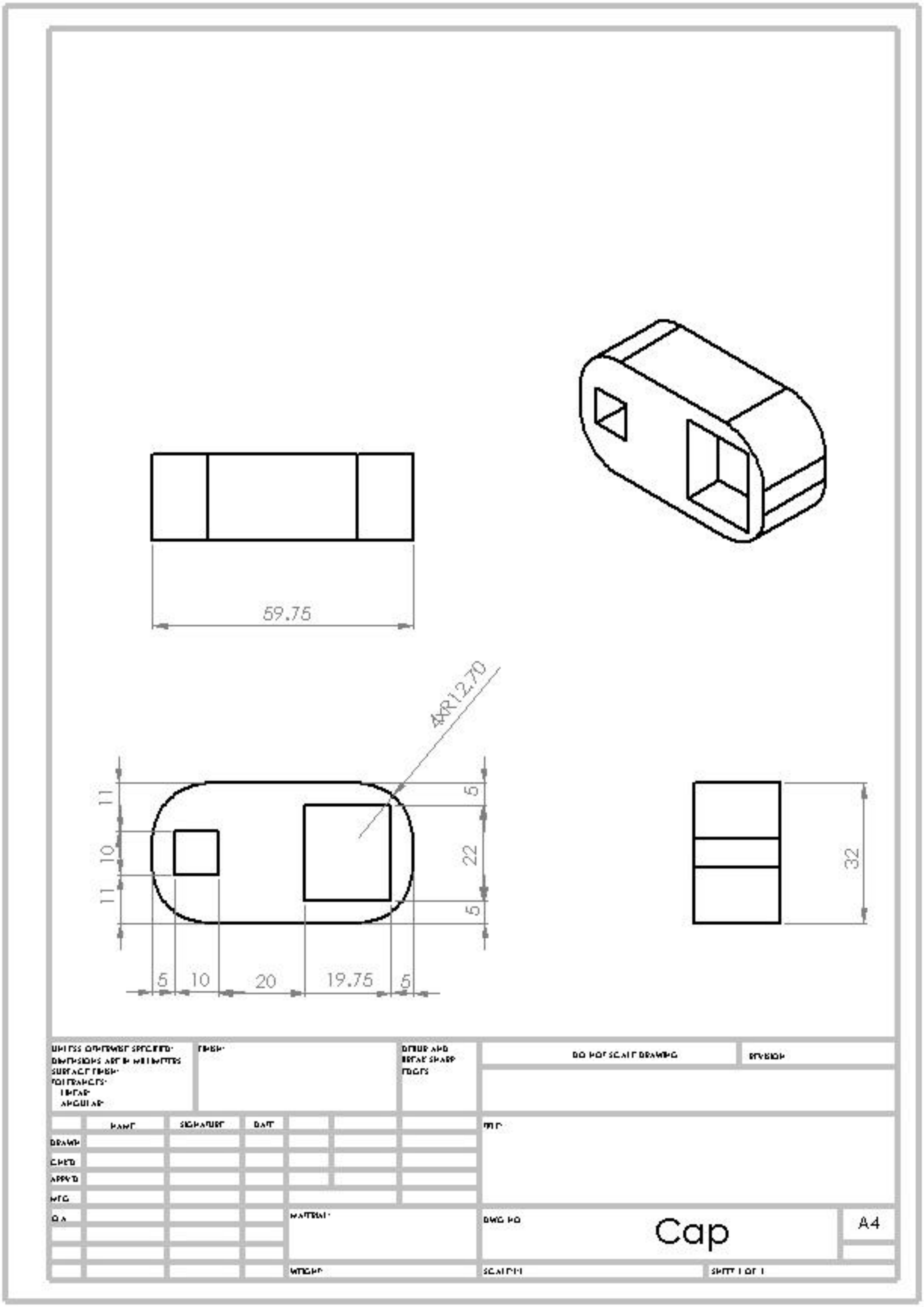
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