EG1311: DESIGN AND MAKE

Team Report

2025-11-12

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REPORT BODY

1 | Project Introduction

Throughout the course, our team was challenged to build a robot capable of navigating a track consisting of a ramp and a bump, as well as throwing a ball over a 30-centimeter wall. This report outlines the journey we undertook to design and construct the robot, detailing the difficulties we encountered and the lessons we learned along the way. It highlights our application of design thinking and demonstrates the knowledge we gained in working with the Arduino microcontroller, various electronic components, CAD modeling tools, and C programming.

1.1 | Identification of required modifications:

After assembling the template project, we pinpointed four critical flaws: a lack of structural rigidity in the main body, insufficient motor power to cross obstacles, poor wheel traction, and the small size that caused it to become stuck on obstacles. To address these issues, we planned corresponding changes: reinforcement of the main body with ice cream sticks, increasing the number of motors, adding anti-slip mats (Figure 1) to the wheel rims to improve traction, and increasing the overall size of the body.

1.2 | Ideation phase:

Our team also identified some features from the requirements that can help us make more educated decisions for the design of our robot, which is presented in the following table:

Table 1 : Robot Design Considerations

Robot feature	Problem	Solution
Wheels	The obstacle has a 3 cm bump	Wheel diameter must be at least 3 times the height of the bump (9cm)
Motors	The motors might not have enough power to turn the wheels	Use two different power sources for the Arduino and the wheels
30x30 centimeter dimension	The robot and its components, especially the catapult must be compacted into a small area	The base must be cut to efficiently use the full available length and width
Height	A taller robot design elevates the center of gravity, decreasing its stability.	Strategically place components to lower center of gravity
Catapult	The catapult might not be strong enough to throw a ball over the wall	Mount the catapult on a vertical mast to increase reach

2 | Initial modifications:

Based on the observations made on the template robot, we started to make early design decisions for our prototype.

2.1 | Lack of motor power and lack of wheel traction:

Problem: Climbing the ramp was challenging due to a lack of wheel friction, causing the robot to slip.

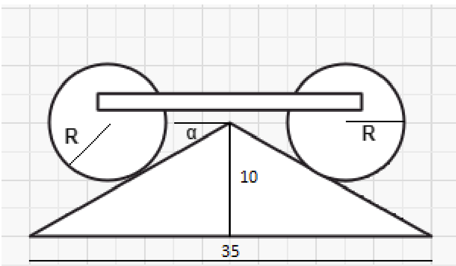
Solution: Prior attempts using the glue gun on the rim of the wheels to increase friction are insufficient. As a result, we attached anti-slip mats to the wheels. Additionally, two extra wheels are installed at the back, creating a 4-wheel configuration that provides the necessary traction and power for the vehicle to traverse the course.

2.2 | Lack of structural stability:

Problem: Cardboard material that is suitable for a small template robot will bend when used for a bigger robot, causing it to veer off course.

Solution: To reinforce our base, we added wooden sticks in a triangular formation. However, this configuration is still not strong enough to support the 7.2V battery set. Therefore, we finally switched to a polypropylene base to increase structural integrity. Combined with the accurately cut acrylic wheels, this configuration ensured that the base is oriented horizontally and prevented the robot from veering off course (Figure 2).

2.3 | Wheel configuration and size of robot:



Problem: We have to ensure that the base doesn't touch the ramp.

Solution: Since the ramp shown in the figure has a base of 35 cm and a height of 10 cm, the angle of inclination can be calculated using:

$$\alpha = \arctan\left(\frac{\text{height of ramp}}{\text{half of base of ramp}}\right) \Rightarrow \alpha \approx 29.75°$$

To find the minimum condition needed to get the robot stuck on the ramp, we need to satisfy:

$$\sin(\alpha) = 2\frac{R}{L}$$

Where L is the distance between the front and rear axles and R is the radius of the wheel we used (5cm).

$$L = 2\frac{R}{\sin(\alpha)} = 2\frac{5}{\sin(29.75)} \approx 20.15$$

By setting the distance between the front and rear wheel axles to approximately 19 cm, which is less than the calculated maximum of 20.15 cm, we ensured the robot would not get stuck. In fact, this calculation was the rationale for the rear motor alignment in the final design (Figure 2). The opposite alignment would have caused the wheelbase to exceed the limit.

3 | Catapult design:

The additional task of having the robot be capable of delivering a ping-pong ball over a 30cm wall was next on the group's list. We first decided to tackle the simplest design, mounting the catapult on a vertical mast. This ultimately was the design we had incorporated into our final design, albeit with several iterations.

3.1 | Designing catapult:

Problem: The catapult can't launch the ball high enough to clear the wall consistently.

Solution: We raised the catapult's initial elevation with ice-cream sticks and lengthened the catapult arm, which produced a higher release point. Because the longer arm lowered angular velocity, we are able to generate greater torque for the same power, as:

$$\text{power} = \text{torque} \times \text{angular velocity}$$

3.2 | Keeping the ball in place:

Problem: Holding the ball in place as the robot traverse the course.

Solution: Initially, we designed the basket as 4 ice cream sticks wrapped with a thin strip of tape (Figure 3). However, the ball kept falling out of the basket whenever the robot hit the bump. Therefore, we used a more stable design with a cardboard box that can fit the entire ping pong ball. Thus, the robot was able to reliably carry the ball without it falling out.

4 | Stability issues:

Towards the final iteration of our robot, one of the major issues discovered was that it is able to clear the course but would tip over when moving backward up the ramp. Through researching, we learnt that stability depended on two aspects: low center of gravity and big base of support.

4.1 | Redistributing weight to shift the center of gravity:

Problem: High center of gravity causing the robot to flip over.

Solution: We strategically placed the 7.2V batteries toward the rear to counterbalance the front motors, effectively shifting the center of gravity backward to prevent flipping. For greater stability, the Arduino and breadboard were mounted low, directly onto the main base, rather than the mast. This configuration lowered the center of gravity, boosting stability.

4.2 | Changing wheel configuration

Problem: Small base of support causing the robot to flip over when reversing on the ramp.

Solution: We initially mounted the motors inward for simplified ultrasonic sensor tuning, but later flipped them outward to improve stability. This crucial modification widened the base of support (the area defined by the wheels' contact points) and shifted the front wheels forward, ensuring the line of gravity consistently passed through the base for successful stabilization.

5 | Wiring and sensor:

Wiring is a very important aspect of our design process. Owing to our logical arrangement of wires, we can prevent them from interfering with the spinning wheels, but still allow for easy debugging and fixes.

5.1 | Position of sensor:

Problem: The low position of the ultrasonic sensor resulted in premature stopping during testing, as it misidentified the ramp's incline as a solid wall obstacle.

Solution: The sensor was repositioned and mounted on top of the mast to ensure accurate wall detection. The primary trade-off was managing the resulting longer, hanging wires that could potentially interfere with the spinning wheels. This require us to have good wire organization

5.2 | Neatness and organization of wires:

Problem: The dense wiring created significant difficulty during debugging and required rewiring whenever an issue arose.

Solution: Our group adopted a system using colored wires to track its corresponding circuit function. This simple technique enabled easy identification of connection problems. Furthermore, masking tape was used to secure all hanging wires to the base, preventing them from stalling the wheels.

5.3 | Modification of wiring for reverse movement:

Problem: The robot required a mechanism to achieve motor reversal.

Solution: We utilized the L293D H-bridge IC to control motor direction.We can reverse the polarity of the voltage applied across the motor's two terminals using the Input pins of the L293D. This polarity difference changes the direction of the motor's spin. Therefore, reverse movement is achieved by simply reversing the logic signal sequence (HIGH/LOW) sent to the corresponding Input pins of the L293D.

6 | Software modification:

In the process of developing our code, we had to face multiple challenges, ranging from hard-coding certain parameters as well as trying to debug the logic of our code. Owing to our consideration for the physical side of our robot, we were able to write code that helps our robot move smoothly throughout the course.

6.1 | Reverse movement of the robot.

Problem: Initially, we controlled the motors by connecting them to different Output legs of the L293D IC. This led to complications when debugging the control code for our motors.

Solution: After redesigning our circuit, we used only two Output legs of the IC to control all of our motors. This change made our code more simple, which is ideal for debugging.

6.2 | Stopping distance of robot:

Problem: The stopping distance must be fine-tuned for the final robot.
Solution: While conducting test runs, we would assign a member to take a close-up video of the robot when it stopped in front of the wall. After many trials and errors, we can determine the ideal distance, allowing our robot to stop between the 5-centimeter mark and the wall.

6.3 | Reliability of the throwing motion:

Problem: The servo's throwing motion was too rushed, causing the ball to be released prematurely and fail to clear the wall.
Solution: To correct this, we introduced a 0.5-second delay between each servo angle change in the code. This delay successfully generated a smoother throwing arc, which guarantees the ball will consistently cross the wall.

7 | Learning points:

Overall, we as a group have come to learn a lot from this project. This was an invaluable experience in learning more about the iterative design process, being a core principle in engineering development, while gaining technical skills in both software and hardware. It allowed us as a group to learn that effective communication is key. Most importantly, it has improved our problem-solving and analytical thinking skills through applying our engineering knowledge to create a robot that can clear an obstacle course.

7.1 | Playing to our strengths

Our team, drawn from Computer Engineering, Electrical Engineering, and Robotics & Machine Intelligence, effectively leveraged its diverse expertise. Computer Engineers specialized in coding, Electrical Engineers handled hardware implementation, and Robotics students led physical design and movement. This clear division of strengths ensured that every team member provided valuable input and relevant solutions for all software and hardware challenges encountered.

7.2 | Facing failure

Throughout this project, time and time again, we are frustrated by the robot not living up to our expectations. We discovered many times that a design we proposed to be functional in thinking did not translate into reality. Even when our robot managed to pass an obstacle, this result was not reproducible, as it would fail on some tries. However, this taught us the importance of perseverance, and our final robot would not have succeeded were it not for the endless iterations and design changes we've made through these failures.

7.3 | Time constraints and time management

Meeting outside of the lab was commonplace in many groups, as it was with ours. However, knowing each other's strengths made it easier to delegate tasks and split up the workload. It enabled each of us to do what we were most efficient at. We also tried to prioritize more significant and crucial tasks first before moving on to more trivial tasks. For example, whenever our robot was experiencing issues during its run, we tried to sort out the problems that would prevent the robot from achieving tasks systematically, analyzing each component's possibility of causing a failure, and taking steps to fix this. This led to an efficient design process whereby no time was wasted.

7.4 | Critical thinking

Being a key factor in engineering design thinking, utilizing a step-by-step analysis contributed to our entire process. Learning how to identify problems, form hypotheses and test out our design was crucial. As mentioned before, we encountered numerous difficulties while developing our robot. As such, we needed to think deeply about each run to identify the underlying causes of these issues. We picked up debugging skills through the process of correcting the robot's movement through the obstacle course, as we needed to constantly check the wiring to identify any faults in the circuits. Overall, our analytical thinking and reasoning skills have improved as a result, becoming better at diagnosing problems and coming up with innovative solutions.

7.5 | Effective communication

As a group, we developed an environment where no idea was a bad idea. Everyone was able to voice out when necessary, and we were also open to feedback and criticism. Since we were from different majors, we gave constructive feedback on the different areas of the robot. For example, when it came to the design and structure of the robot, our Robotics student would provide ideas on how to stabilize and improve the structural integrity of the robot with their area of expertise, which we would all take time to consider. When it came to optimizing code and debugging circuits, Computer Engineering and Electrical Engineering students stepped in to offer possible improvements. This highlights the importance of active listening in communication.

8 | Conclusion

Overall, this module was a great experience and opportunity for the members of the group to further hone our skill sets. We explored practical solutions and picked up valuable skills in engineering and design thinking. Many of us managed to significantly improve our teamwork and communication skills. Through this project, we have been equipped with essential skills and lessons that would serve us well not only in our journey in NUS, but in our professions as well.

REPORT APPENDIX

Appendix I: Figures

Figure 1 : Wheels with anti-slip mats

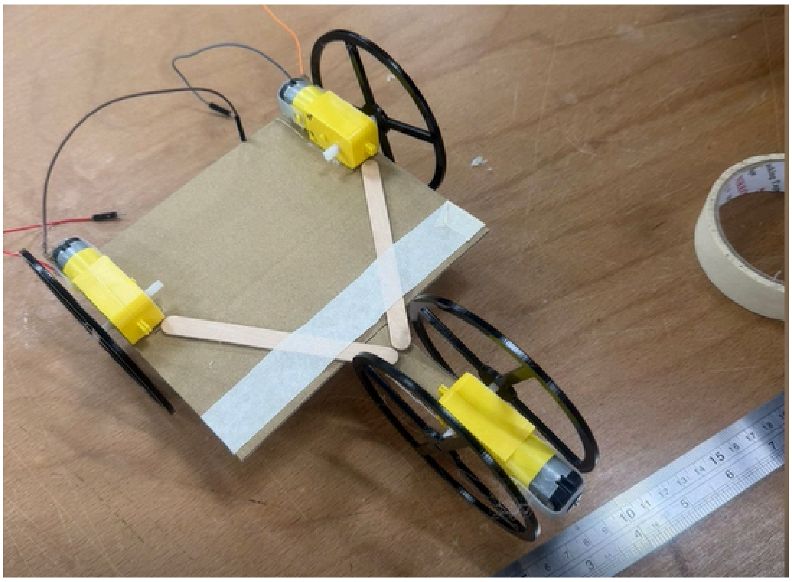


Figure 2 : Base and wheels configuration (bottom)

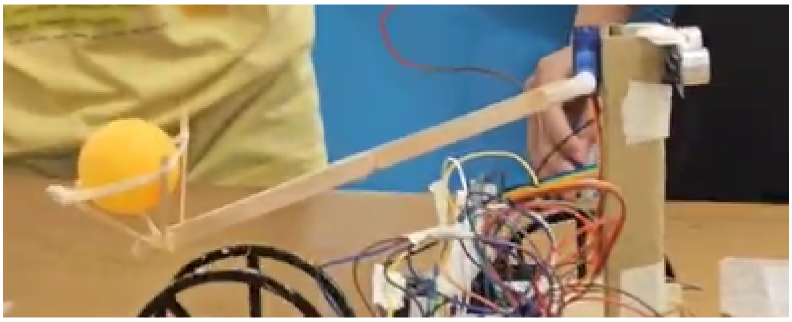
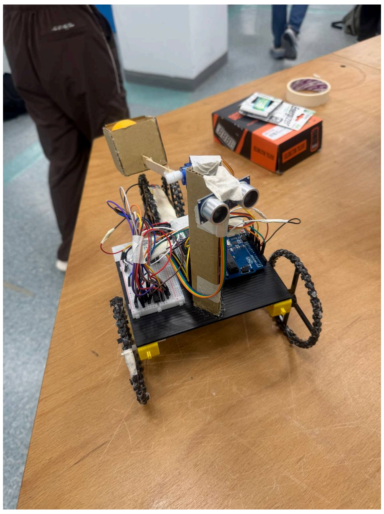
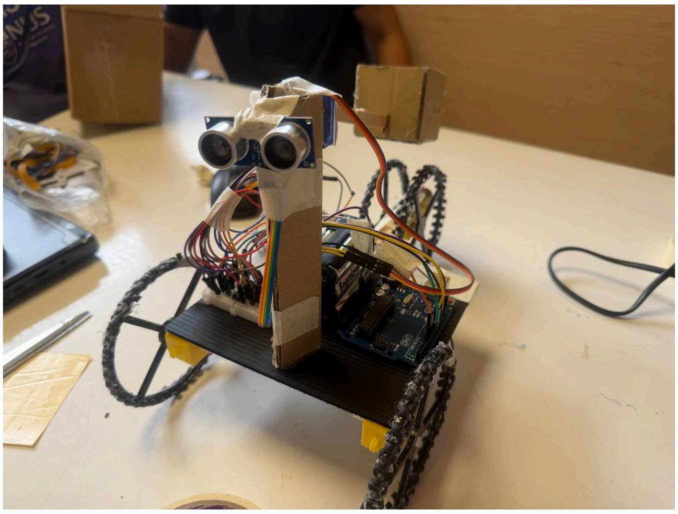


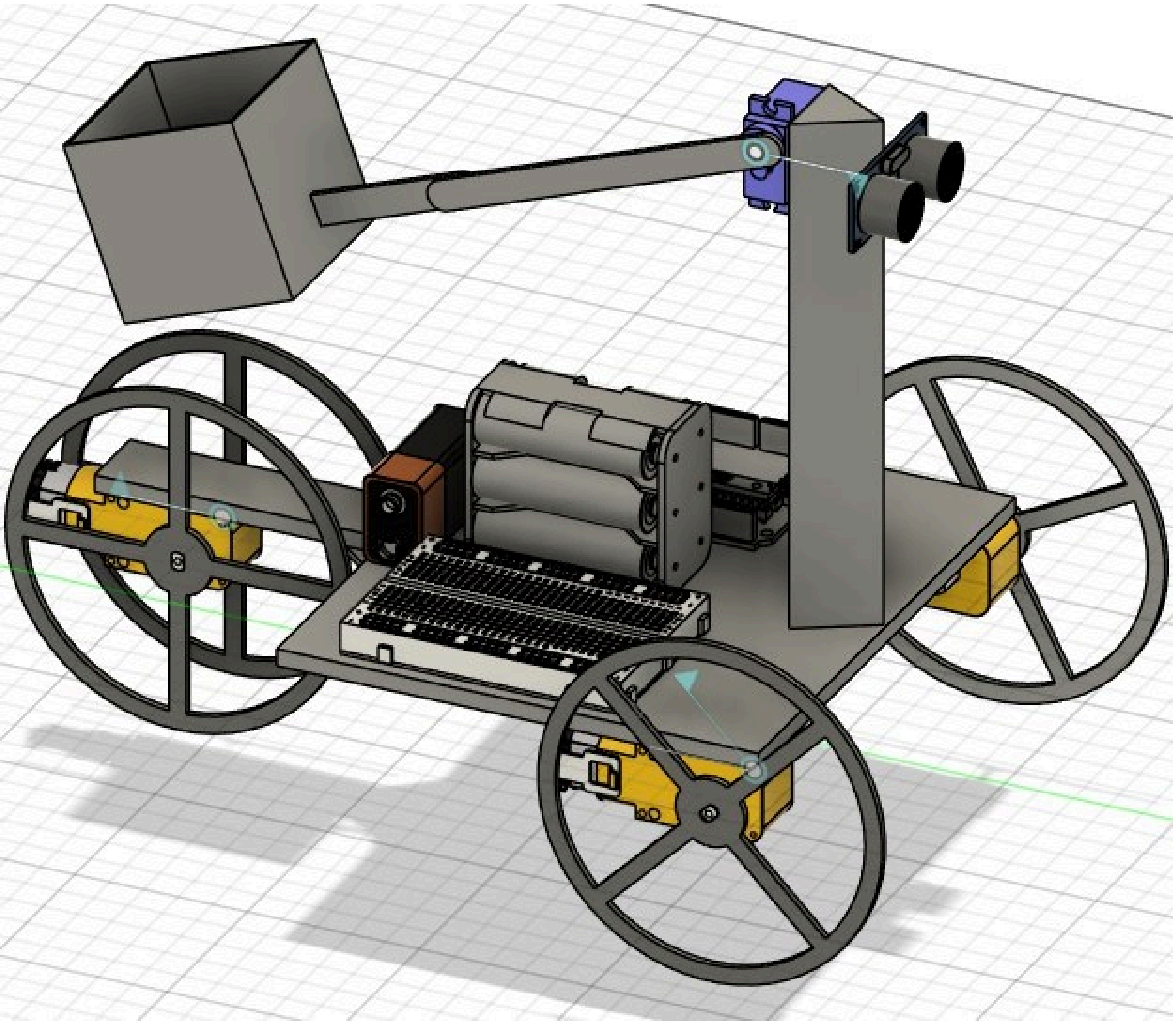
Figure 3 : Previous catapult design

Appendix II: Final iteration of the robot





Appendix III: 3D CAD rendering of final iteration



Appendix IV: Breadboarding and Circuitry Layout

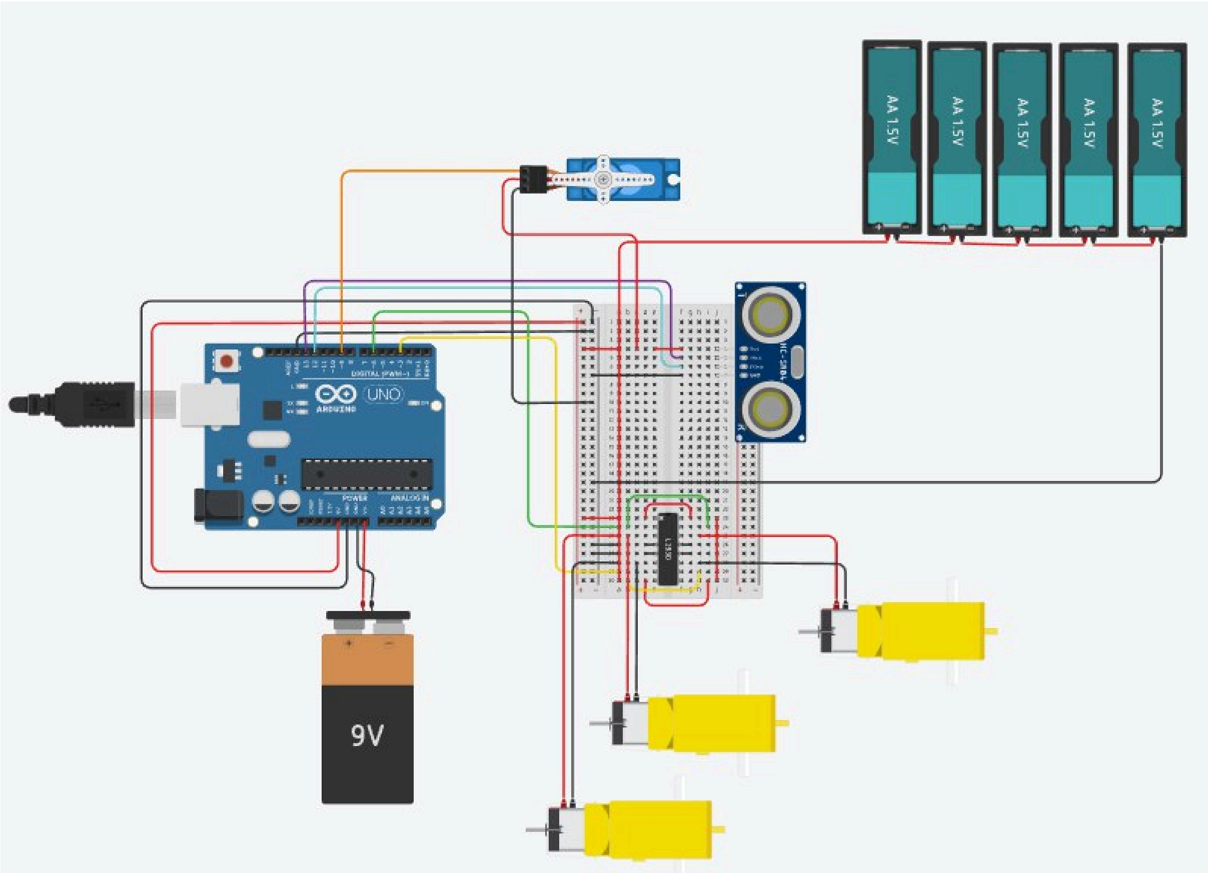


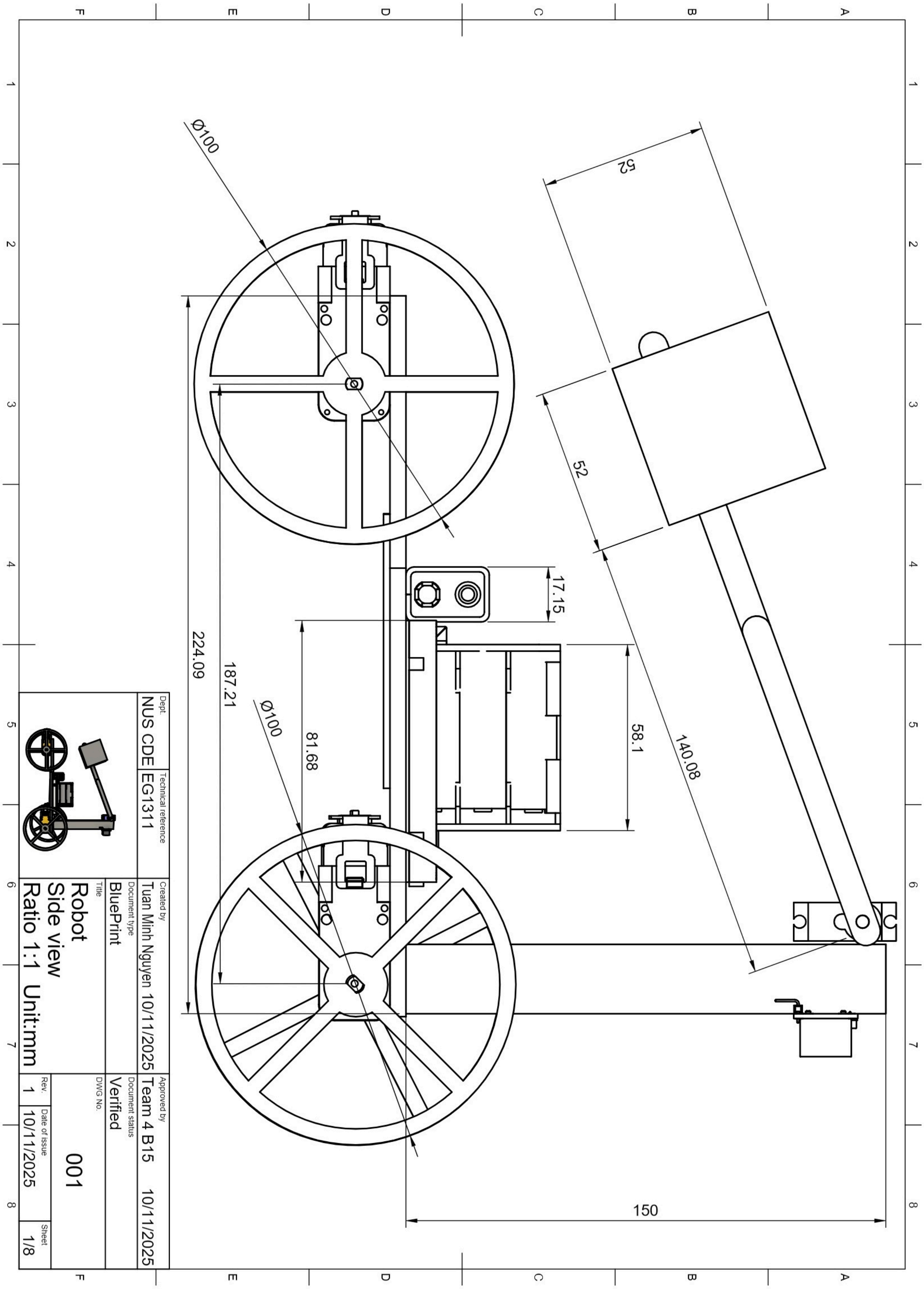
Figure 6 : TinkerCAD circuit diagram (7.2V battery set replaced with 5 1.5V batteries)

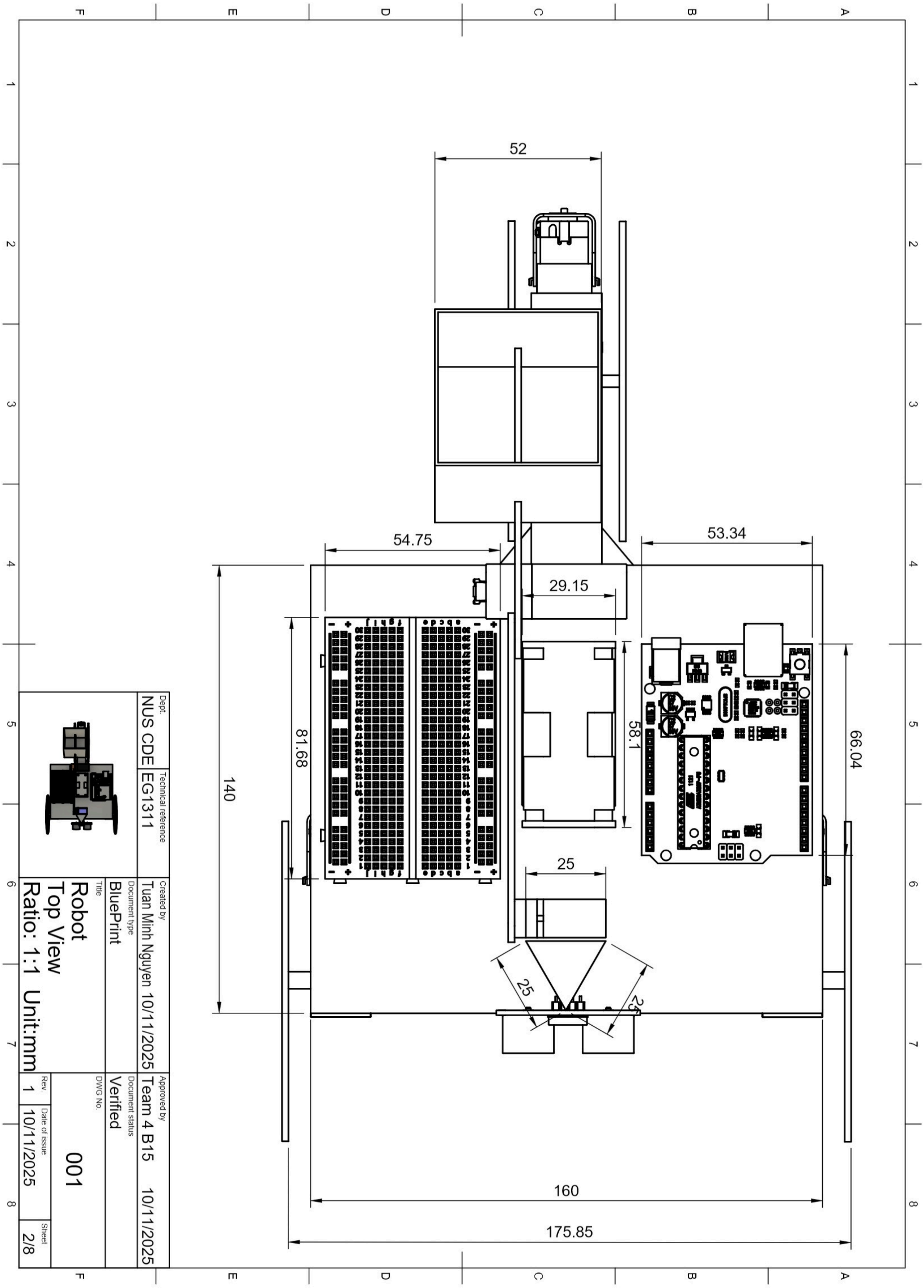
Appendix V: Arduino Code

```
#include <Servo.h>

const int TRIG_PIN   = 13;
const int ECHO_PIN   = 12;
const int MOTOR_PIN1 = 6;
const int MOTOR_PIN2 = 3;

const float SPEED_OF_SOUND = 0.0345f;
const unsigned long PULSE_TIMEOUT_US = 30000UL;

Servo myServo;

void setup() {
  pinMode(MOTOR_PIN1, OUTPUT);
  pinMode(MOTOR_PIN2, OUTPUT);

  pinMode(TRIG_PIN, OUTPUT);
```

```
  pinMode(ECHO_PIN, INPUT);
  digitalWrite(TRIG_PIN, LOW);

  Serial.begin(9600);

  myServo.attach(9);
  myServo.write(130);
}

void loop() {
  digitalWrite(TRIG_PIN, LOW);  delayMicroseconds(2);
  digitalWrite(TRIG_PIN, HIGH); delayMicroseconds(10);
  digitalWrite(TRIG_PIN, LOW);

  unsigned long us = pulseIn(ECHO_PIN, HIGH, PULSE_TIMEOUT_US);
  if (us == 0) {
    moveForward();
    delay(10);
    return;
  }

  float cm = (us * SPEED_OF_SOUND) / 2.0f;
  Serial.println(cm);

  if (cm < 13.0f) {

    stopMotors();
    activateServo();
    moveBackward();
    delay(10000);
    stopMotors();
    delay(5000000);
  } else {
    moveForward();
  }

  delay(10);
}
void moveForward()  { digitalWrite(MOTOR_PIN1, HIGH); digitalWrite(MOTOR_PIN2,
LOW);  }
void moveBackward() { digitalWrite(MOTOR_PIN1, LOW);  digitalWrite(MOTOR_PIN2,
HIGH); }
void stopMotors()   { digitalWrite(MOTOR_PIN1, LOW);  digitalWrite(MOTOR_PIN2,
LOW);  }

void activateServo() {
  myServo.write(10);   delay(500);
  myServo.write(130);  delay(500);
}
```

Appendix VI: Blueprints

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Approved by
Team 4 B15 10/11/2025
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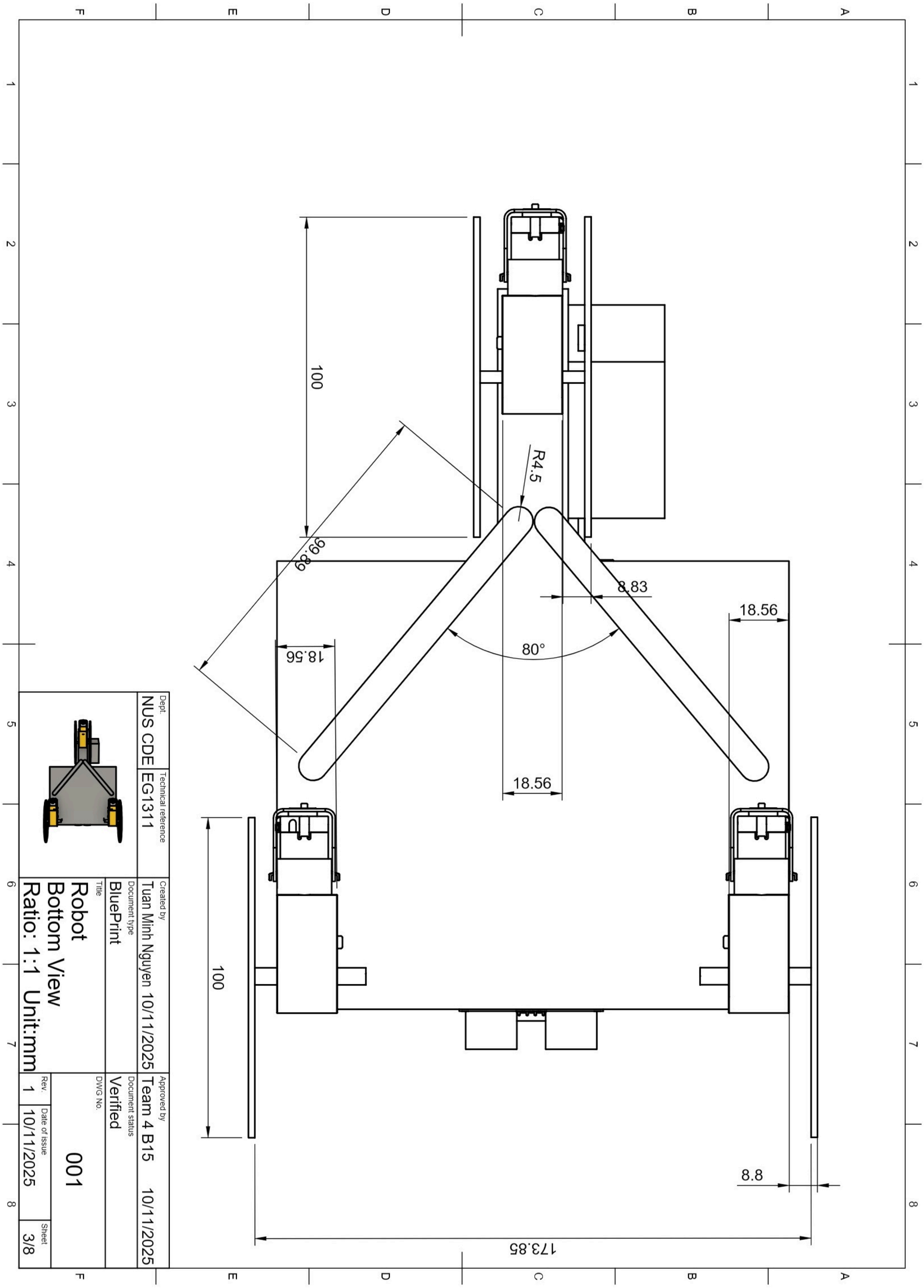
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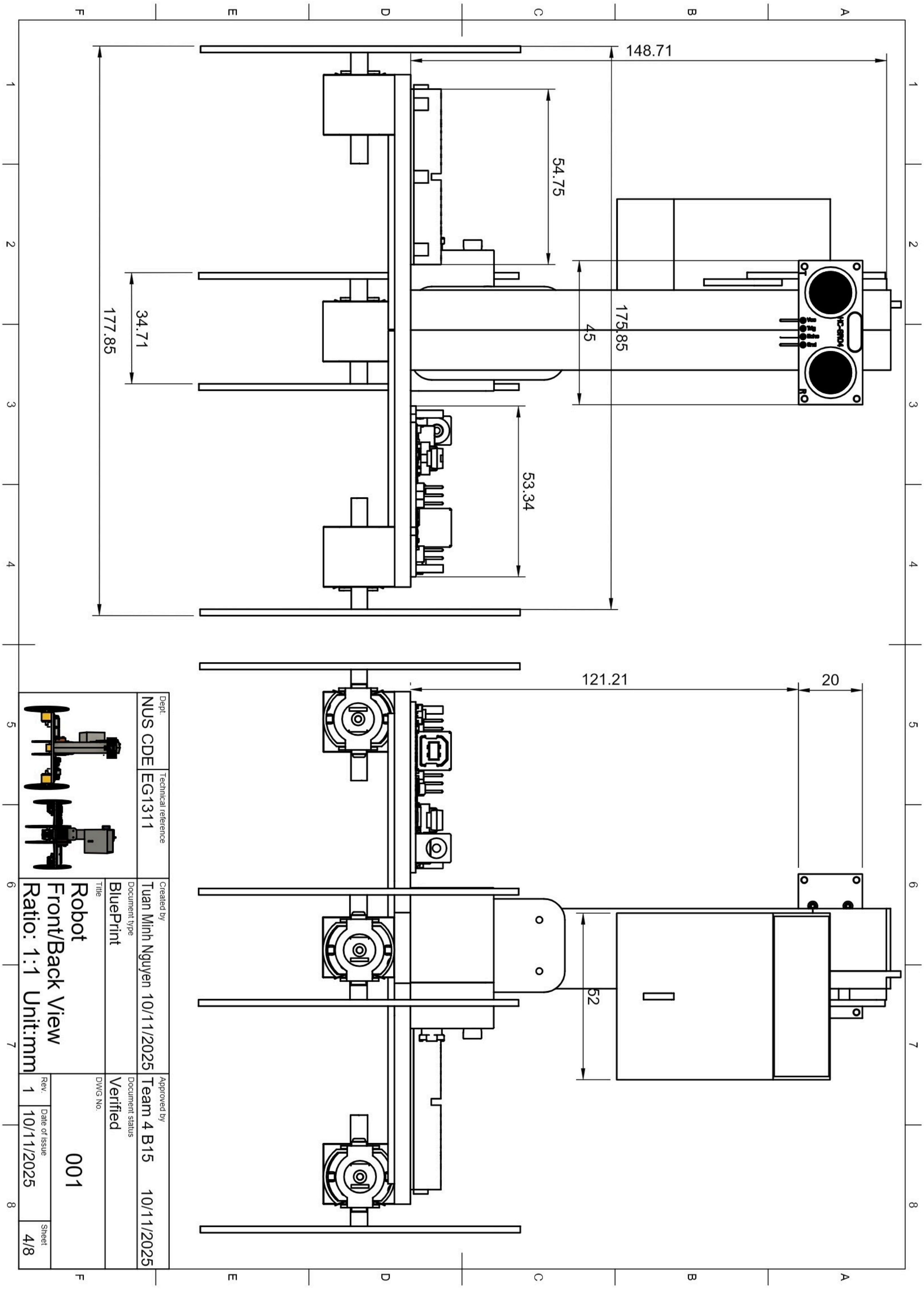
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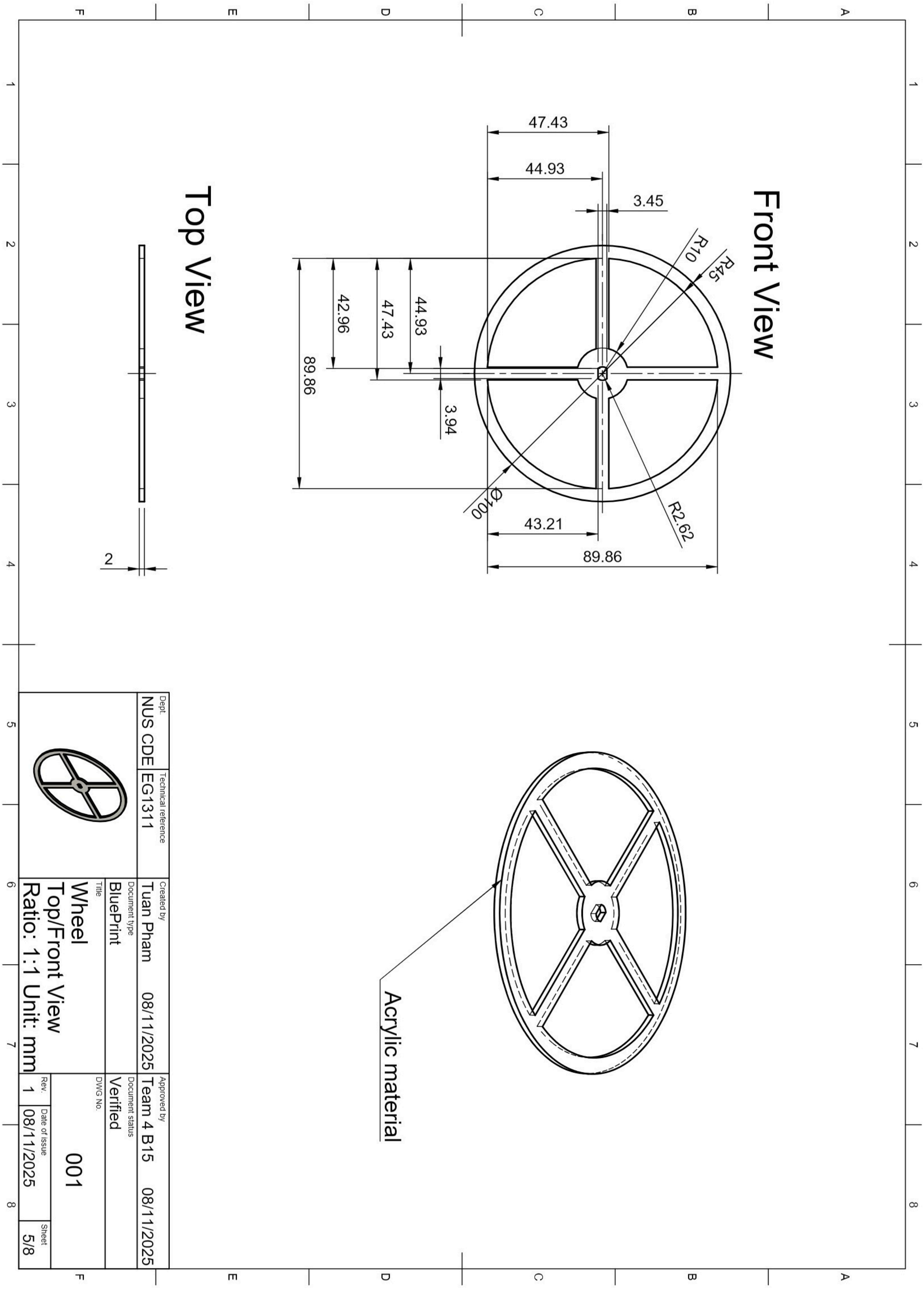
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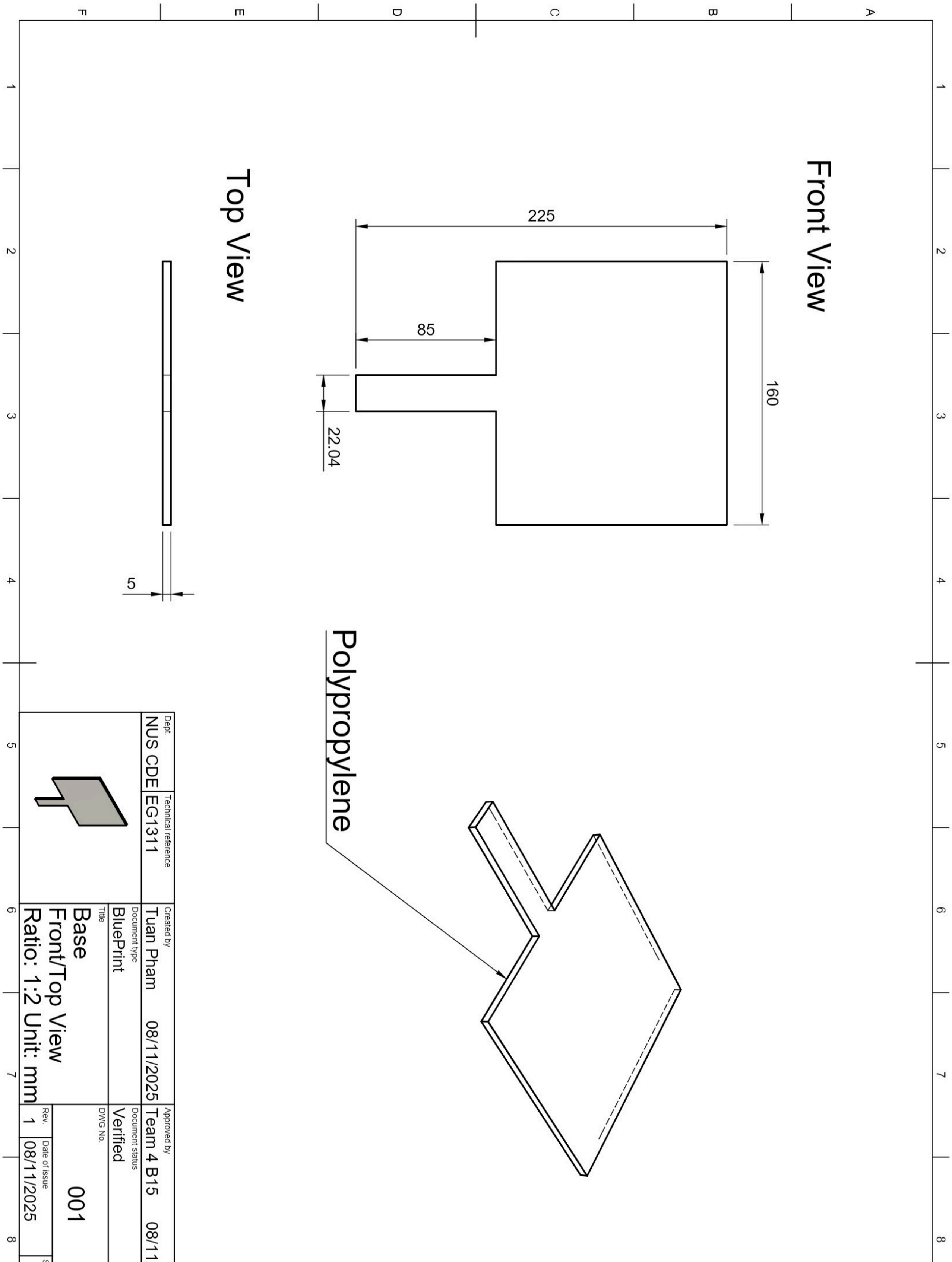

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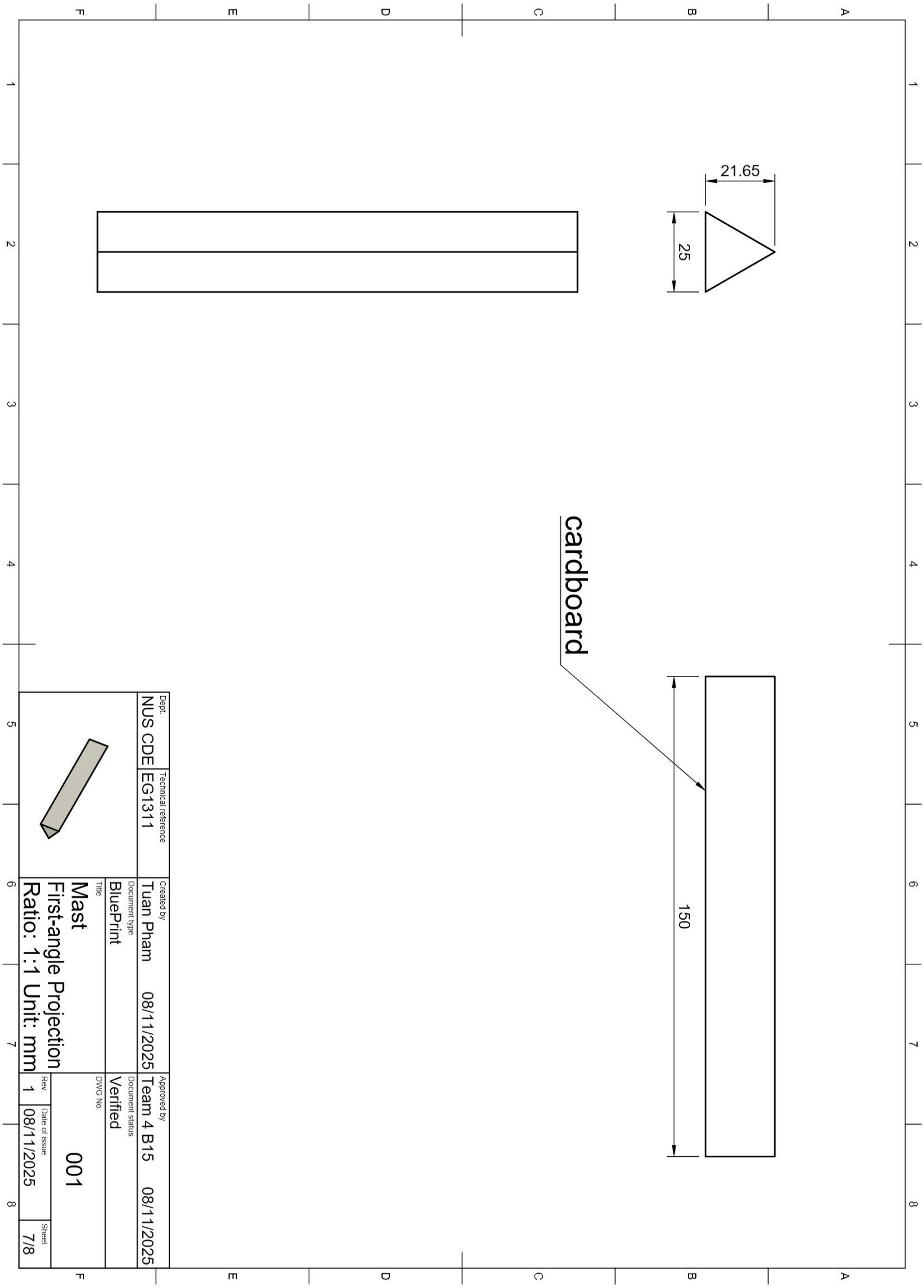
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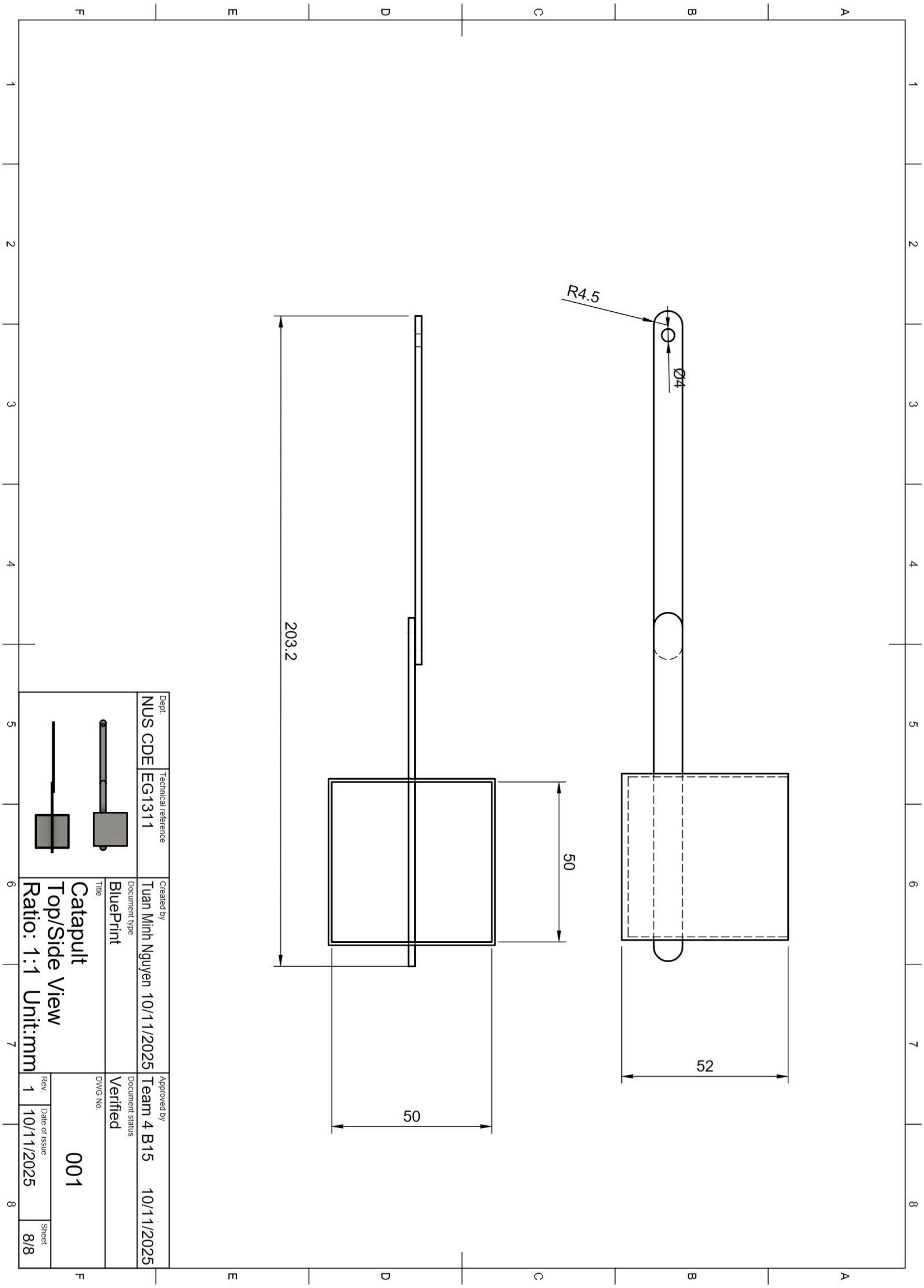
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