# PRACTICE OF MECHANICAL ENGINEERING

## FINAL　REPORT

### Group 25, G


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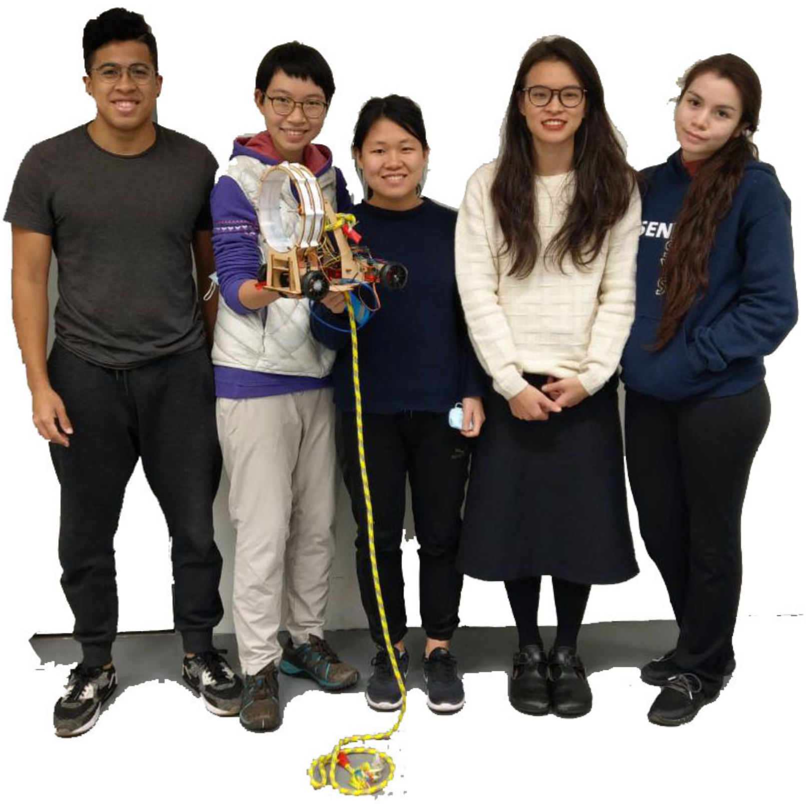
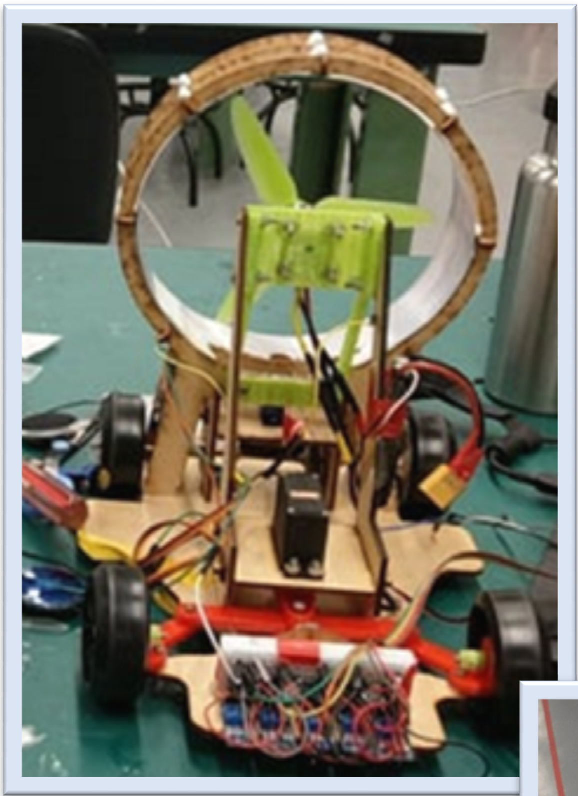
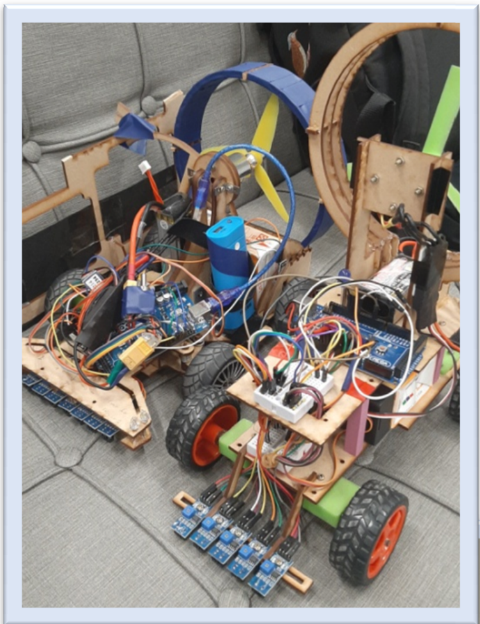


化軍 黄子瑜 林育萱 簡靜 艾安妮





Upper left- modified midterm car

Upper right-New final car

Middle left-the two cars of group G

Middle right-the midterm car(the can car)

Bottom-the group photo of group G

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# Section One -Introduction

Chapter 1 Preface

# Chapter 1 Preface

It is part of the academic learning process to simulate a real world situation. The course of Practice of Mechanical Engineering is one that gives the student the opportunity to grasp what it is to work as a team of future engineers, into developing a product that meets the expectations of, in this case, the professors. It takes team work, community, responsibility, but most importantly, competence to succeed in this course. This is the course that will test our acquired abilities throughout our engineering training, the course that will test our commitment to our craft. Competence is not limited to the knowledge we acquired throughout the years, competence is how we combine our knowledge with our values.

In the sections to come, the design process of our project, along with its specifications and its task will be detailed, including the experiences of each group member in aiding for the success of the collective. Without much further ado, we present our project and our very own first-hand experience into the real engineering world.

## 1.1 Introduction of the group

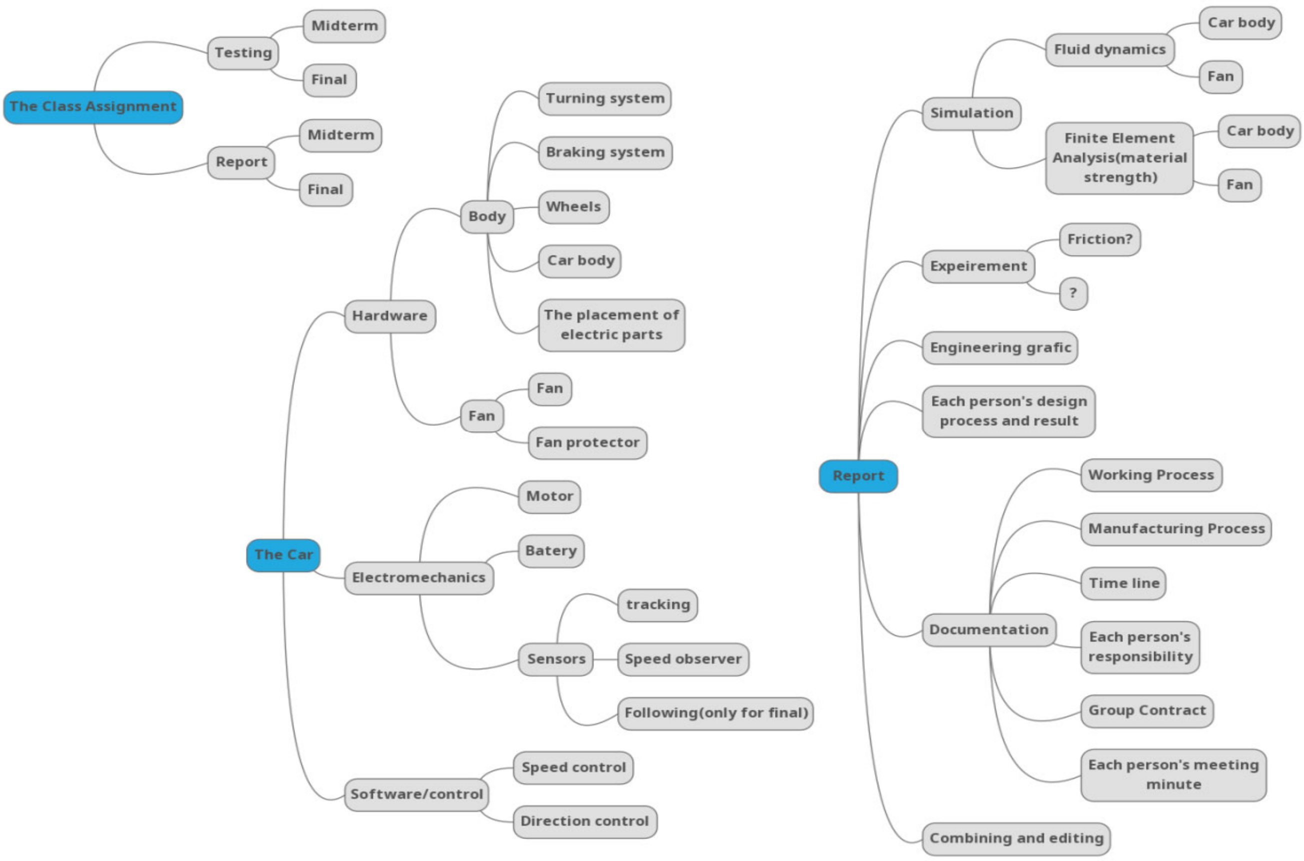
The team consists of 5 group members. The team captain is Christine Lin(林育萱). She is in charge of the overall structure of the car. As the overseer of the entire project, she supervises the work of other team members and helping as needed. Her specific work includes, but is not limited to, the design of the breaking system and CFD models. The vice-captain is Huang Tzu Yu (黃子瑜). She is responsible for the overall automated performance and in charge of the main programming code and the data acquisition, while also helping with the structural integrity of the car. Her role is not limited to data acquisition and interpretation, but also helping the structural integrity of the car. Directly working with the data provided by Huang Tzu Yu, is Lloyd Perkins (任軍). He is in charge of the electromechanical design of the car. His responsibilities include control of the motors for the propulsion, braking, and turning systems; and monitoring the circuitry of the car. Ola Chien(簡秀芳) is responsible for the airfoil design of the blades for the propulsion system of the car. She is in charge of overseeing the overall aerodynamics of the blades, carefully designing a fan that would give the most efficient performance. Finally, Johanny Alvarado(艾安妮), is in charge of the computer aided design of the car as well as the design of the turning system. Alvarado, alongside Team Captain Lin, works together in the design, manufacturing, and assembly of the car structure.

Each team member's role was chosen according to his or hers abilities. Our success depends on not only on our individual work, but also in our ability to work our ideas together. While each team member had his or hers individual job, each one of us actively supported one another, giving help as necessary.

## 1.2 Discussion and Design Process

The initial discussion stages consisted of us working out the various responsibilities and our design approach. It was stated that there should be as less improvisation as possible, and limit "design on the fly." By the third meeting, all team members had already laid out their plan and methodology. It was asked that the planning be as thorough as possible in order to satisfy our condition of limiting improvisation. This implies that during the initial meetings, the propulsion system, the turning system, and the braking system were outlined by each responsible group member. The outline was presented in the group meetings, and each group member presented their particular plan and an alternative for comparison. The design features will be presented in the following section.

## 1.3 Mind Map




In the beginning of the semester, this mind map was drawn to visualize the tasks and their relations of this project. The dividing of the job was also based on this figure.

## 1.4 Main Design Features

The three systems of the car must work in synergy to reach the goal. It is the work of the designer to take this into consideration in the design process. Firstly, the structure was made taking into consideration all the mechanical and electrical components needed to operate the car and its systems. The propulsion system features a 3D printed fan, on a suitable shroud. The fan is driven by a brushless DC motor, which is controlled with an electronic speed controller and an Arduino board. The turning system is based on the Ackerman mechanism. The mechanism is a 3D printed linkage, with the input link being driven by a high torque servo motor. Which is controlled with the aid of infrared sensors and the Arduino board.Lastly, the braking system, which consists of a smooth brake and sharper brake. A servo motor drives the braking pad against a surface which is connected to the back wheels. There are two surfaces, high friction and low friction, with the former corresponding to sharp braking.

## 1.5 Team Contract

**Ground Rules:**

1. Deadlines must be met on time, it is encouraged to finish work before the given deadline.
2. Every member should be punctual at meetings.
3. Meetings will be held every Friday afternoon at 1:20 p.m.
4. Group chat should be only used for project related discussions. Each member is encouraged to remain active and keep good communication, with the exception of emergencies. Failure to remain active and engaged will result in a penalty.
5. Group members are encouraged to ask for help in times of trouble.
6. Group members should keep track of money spent on components, which are to be agreed upon by all group members.
7. Group members should document their processes in detail.
8. The report will be written in English.
9. Discussion will be carried out in a respectful manner, no offensive comments will be tolerated. Any aggressive behaviors will result in penalties.
10. Report: each member should document their process in passive, objective writing styles.

**Penalty**

Penalties are separated into three categories:

1. Mild: Compensation in the form of reparations.
2. Serious: Point deduction in the peer review report.
3. Grave: Offender's name will not appear in the final report, automatically receiving the lowest score in the peer review. This action will be notified to the instructors prior to being executed.

**Goals**

- Each group member will aim towards the best score possible, A+.
- Each group member will give their best towards this learning experience.

- It is also expected, as is common in the professional environment, to reduce expenses while maximizing quality.
- Budget for the whole car including process: 5000 NTD

# Section Two -Midterm Car

Chapter 2 Performance Requirement

Chapter 3 System Design,

Chapter 4 Overall Examination

# Chapter 2 Performance Requirement

## 2.1 Race Tracks and Rules

1. The runway is 14.4 meters long and 60 centimeters wide. The total testing time is 5 minutes with the car automatically tracking the line and powered by air force.
2. If the car runs out of the runway during testing, it has to go back to the starting point and start again, the stop watch would not stop during the period.
3. Track the center line of the runway.
4. If the speed requirement is not met at the first part of the runway, the car needs to start again from the beginning. If the speed requirement is not met at the second part of the runway, it can continue finishing the remaining parts.
5. When car enters the pause area, operators can adjust the position of the car, but cannot change or repair any parts.
6. The performance evaluation was based on the speed detector installed every 30 centimeters.
7. After finish the runway, the car can start from the beginning and starts again. The higher grade in the two would be the midterm grade.

Figure 2.1 shows the requirement of midterm exam and the speed-position curve.

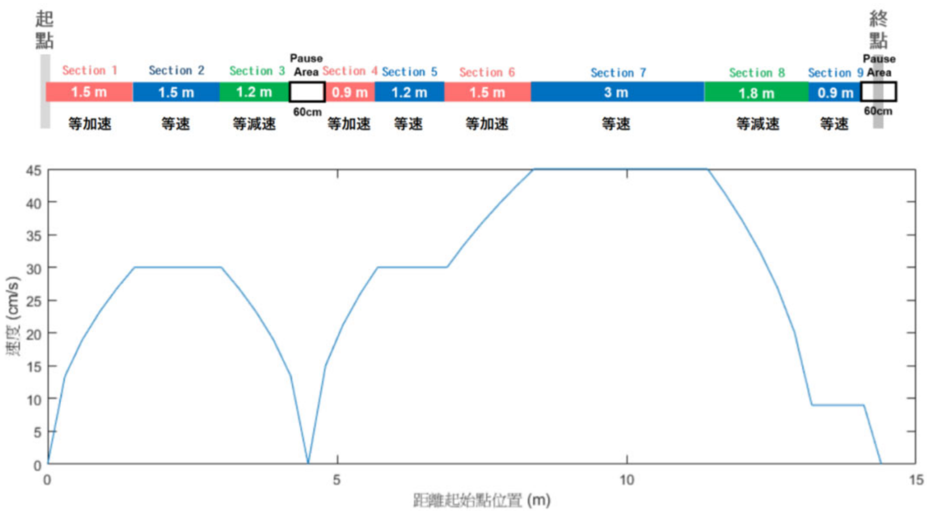



Figure 2.1 speed curve for midterm tests

## 2.3 Performance Requirements

1. Automatic line tracking is required
2. The fan cover is required for protection.
3. The braking method is not limited
4. The electrical system should be assembly by group members.
5. The total cost of the car should be under 3000 NT dollars.
6. All the components should have receipt or proof during manufacturing. Out sourcing is not allowed.
7. The size of the car should be under A4 size, a 250ml juice box should be placed on the car. There should be a black board for speed detection.

## 2.4 Relevance and Interdependence

To meet the requirements, each part of the car governs its own function but also needs to cooperate together.

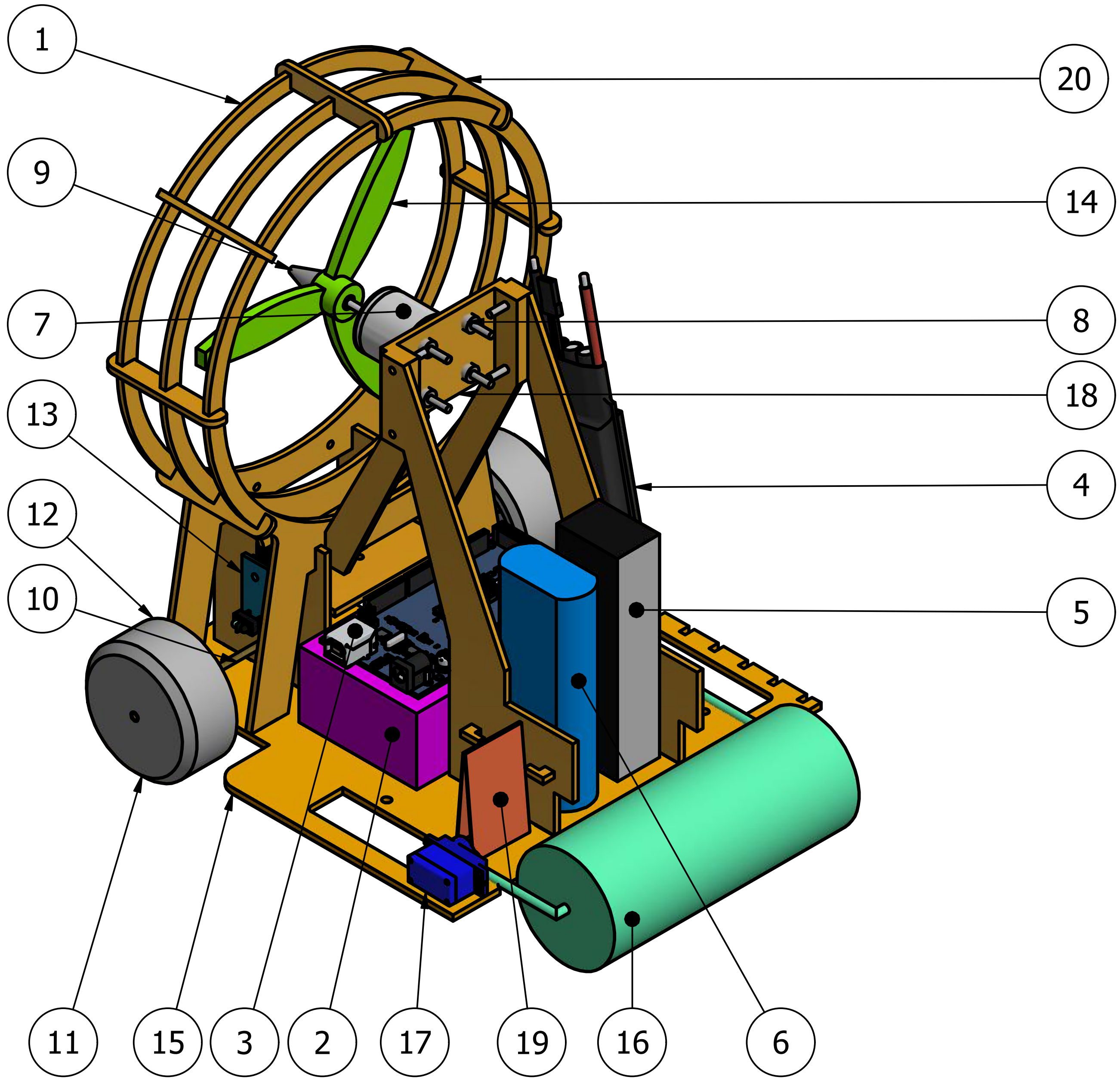
1. Structure: reliable while minimize the air drag.
2. Wheels: Can go in straight line by itself.
3. Turning: Short reaction time, small and precise direction adjustment.
4. Braking: Can make the car decelerate at constant rate.
5. Fan: Can provide enough thrust.
6. Software: Control and combine each parts with minimized errors.

To facilitate efficient turning, wheels and control parts needs to be collaborate together closely. The system relies on both systems to work coherently. The wheel needs to move promptly to compensate the deviation; the sensors need to send signals correctly in times of needed.

To combine the whole car, the structural part needs to keep communicating with the design of sensor, motor, and fan systems. Knowing the needs of the electronics parts, where and how to locate the components, is important for the structure to modify the design and help the group to successfully complete the tasks.

# <u>Chapter 3 System Design,</u>

## 3.0 Engineering Drawing




| PARTS LIST | | |
|---|---|---|
| ITEM | QTY | PART NUMBER |
| 1 | 1 | Fan Cover |
| 2 | 1 | Drink |
| 3 | 1 | Arduino |
| 4 | 1 | SkywalkerHobbywing |
| 5 | 1 | Battery |
| 6 | 1 | Power Bank |
| 7 | 1 | Brushless Motor |
| 8 | 8 | M3x18 Screw |
| 9 | 1 | Fan Fastener |
| 10 | 1 | Wheel Tube |
| 11 | 2 | Wheel |
| 12 | 1 | Encoder Plate |
| 13 | 1 | Encoder |
| 14 | 1 | Fan |
| 15 | 1 | Platform |
| 16 | 1 | Can |
| 17 | 1 | Servo Motor |
| 18 | 1 | Motor Holder |
| 19 | 1 | Brake |
| 20 | 7 | Fan Connector |

| | | | | | | |
|---|---|---|---|---|---|---|
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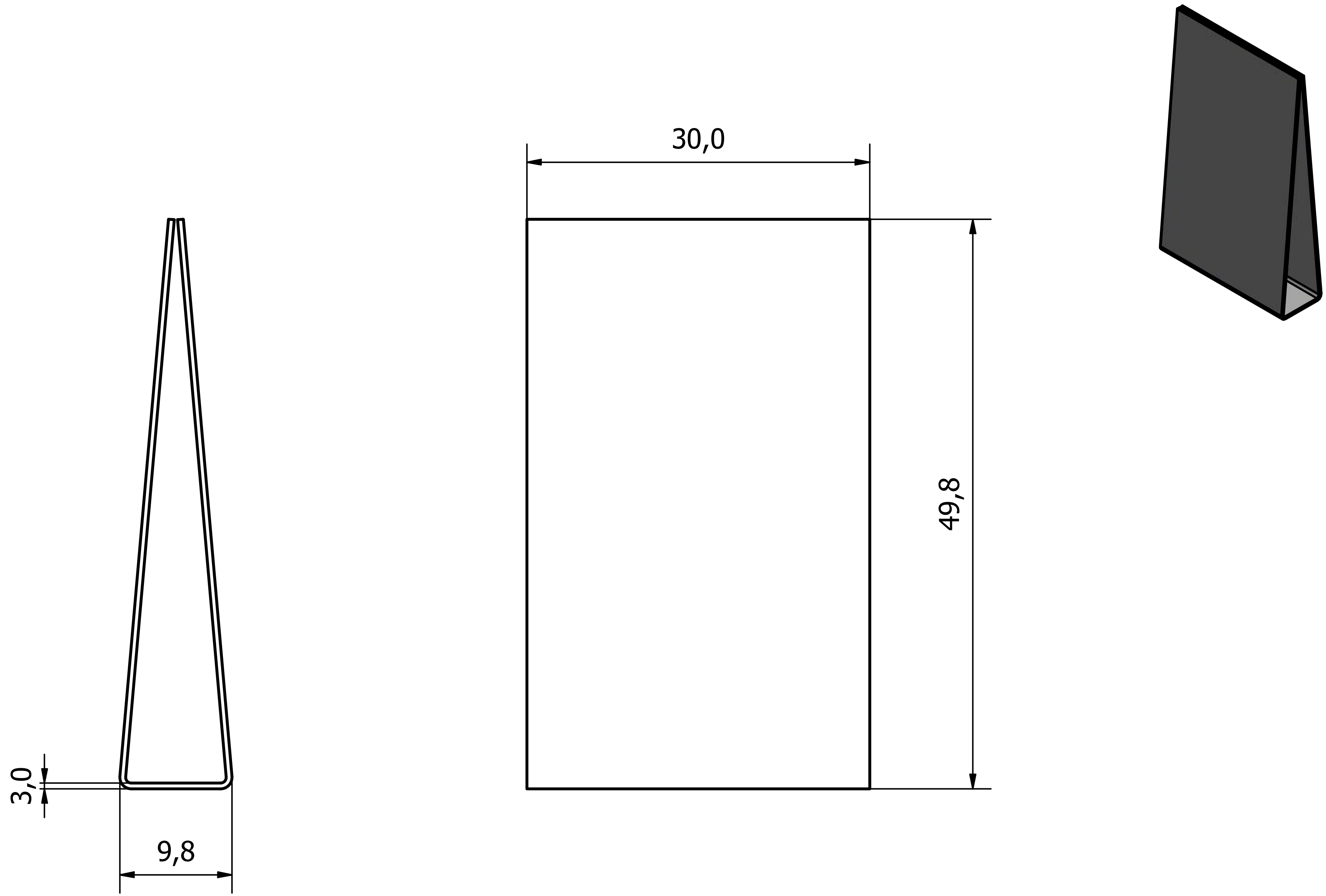
| Author | Johanny Alvarado | Sheet No. | 1 | Midterm Car | Scale | 1:2.5 |




| | | | | | | |
|---|---|---|---|---|---|---|
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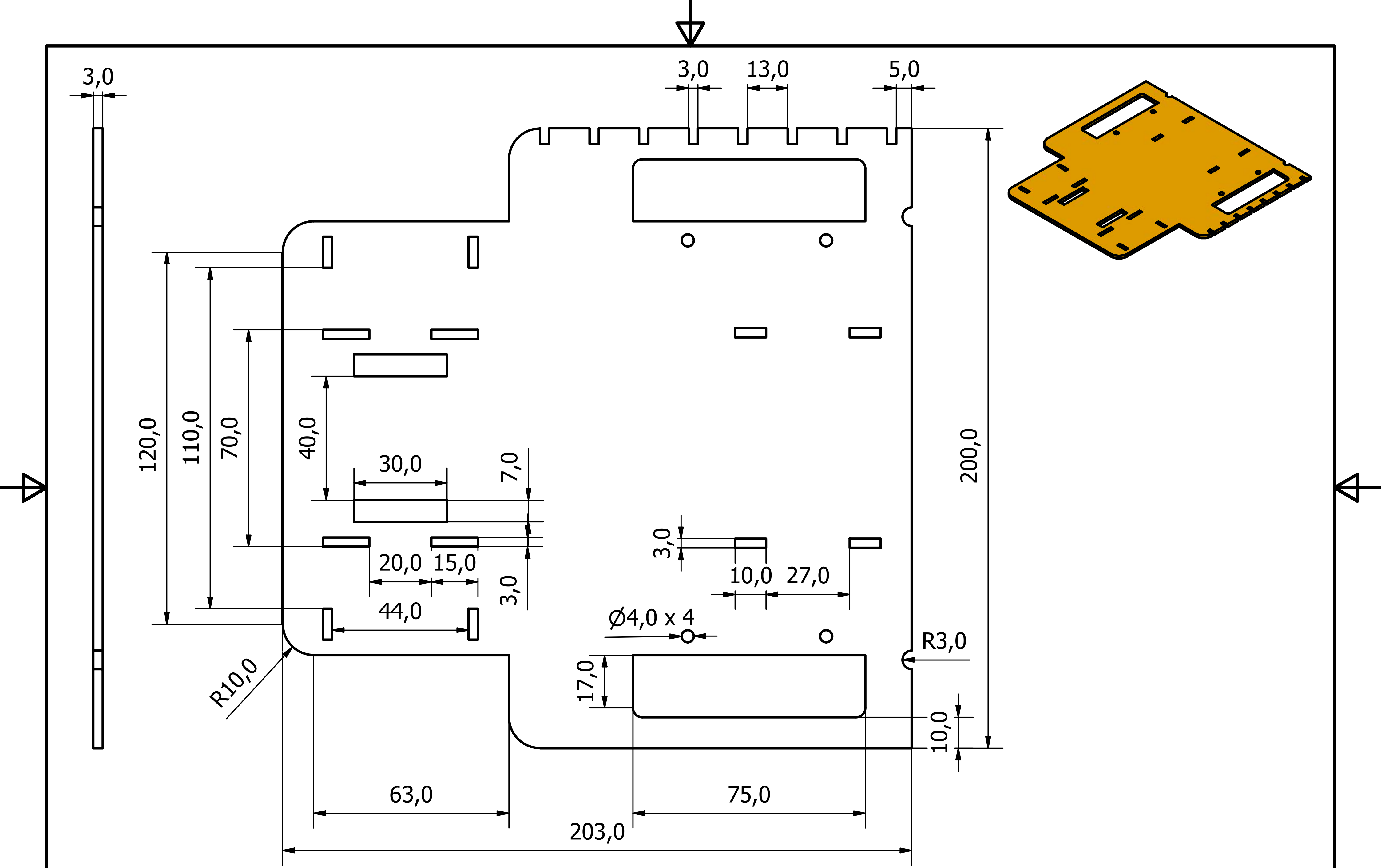


| | | | | | | |
|---|---|---|---|---|---|---|
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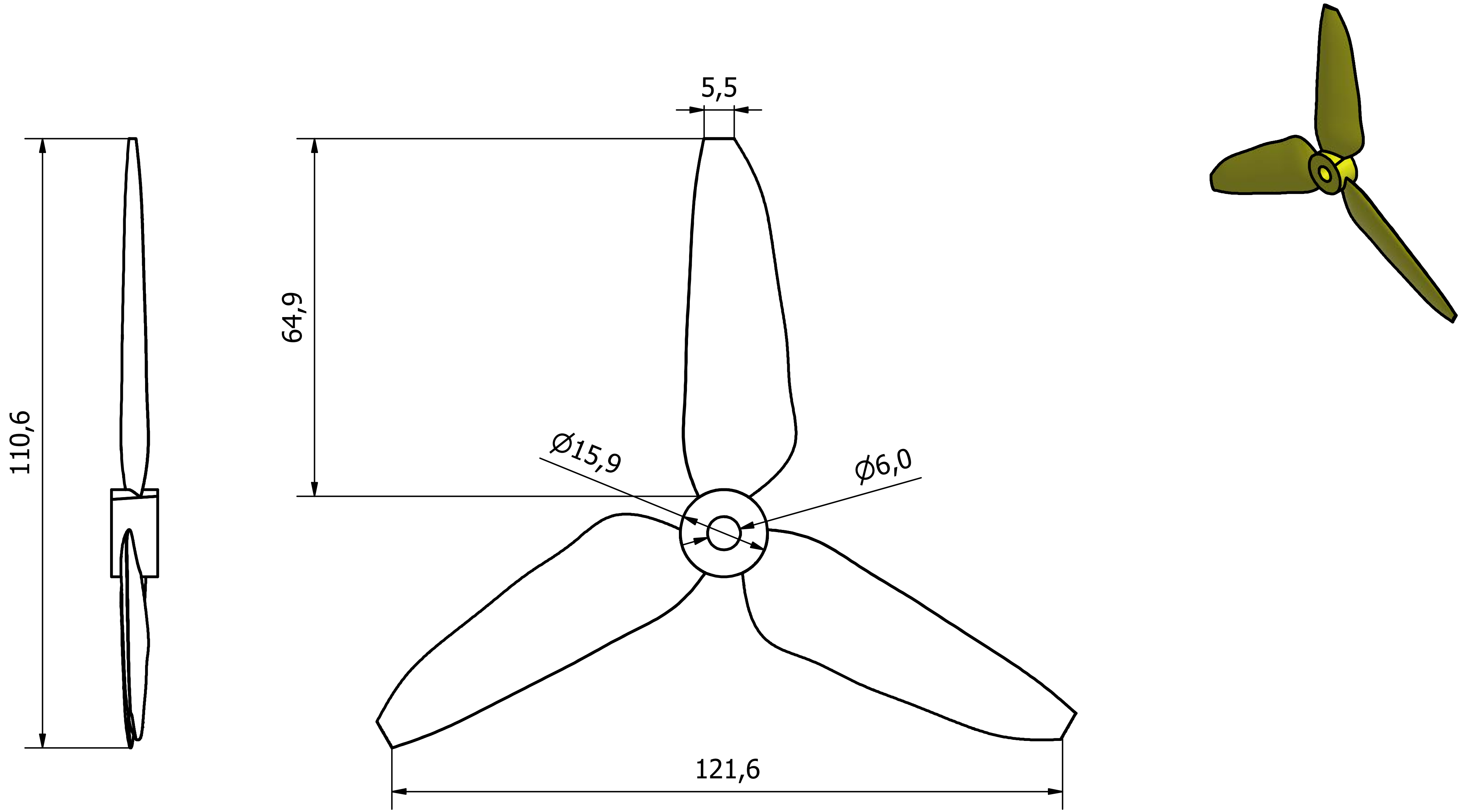


| | | | | | | | |
|---|---|---|---|---|---|---|---|
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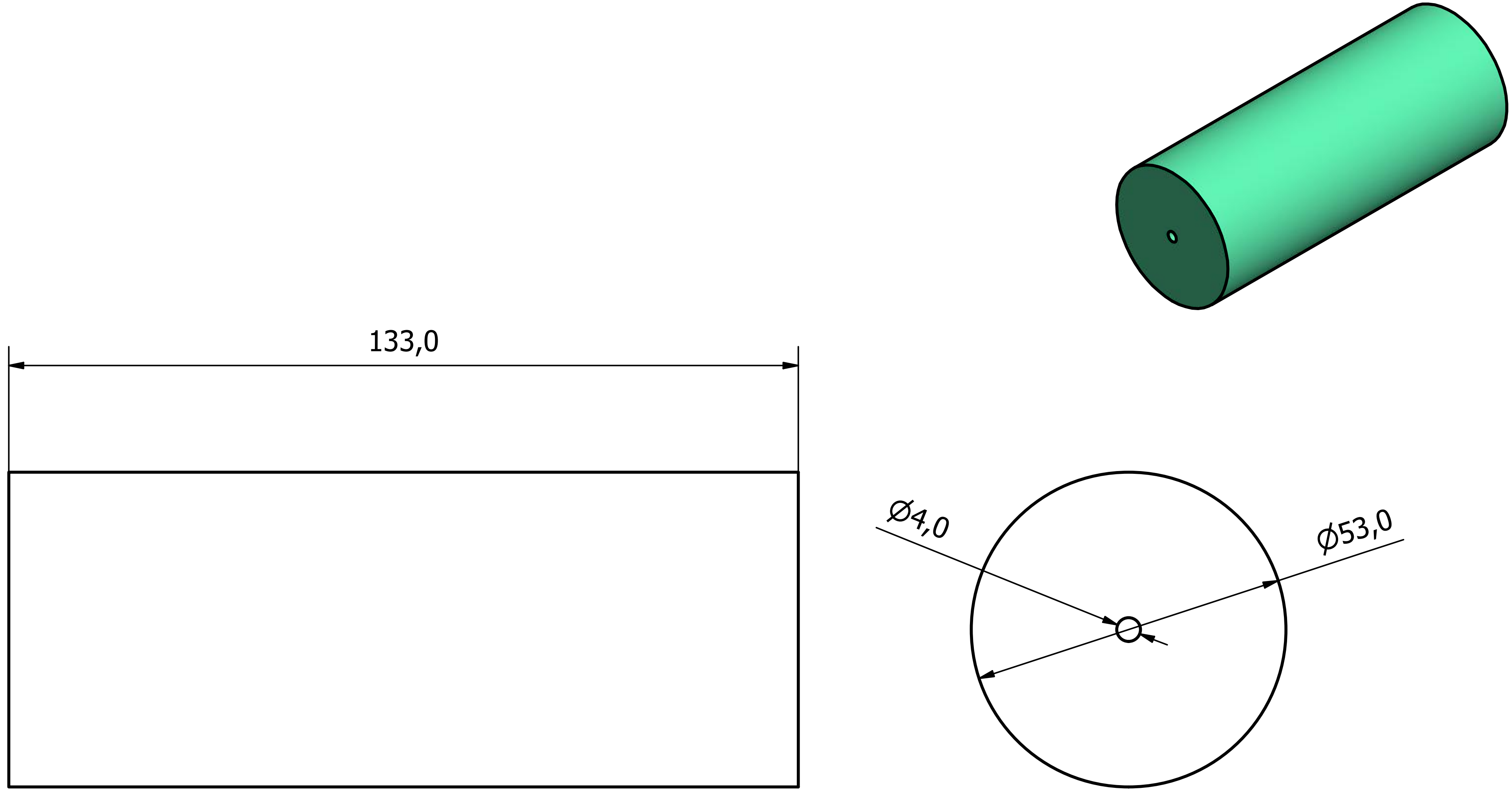


| | | | | | | | |
|---|---|---|---|---|---|---|---|
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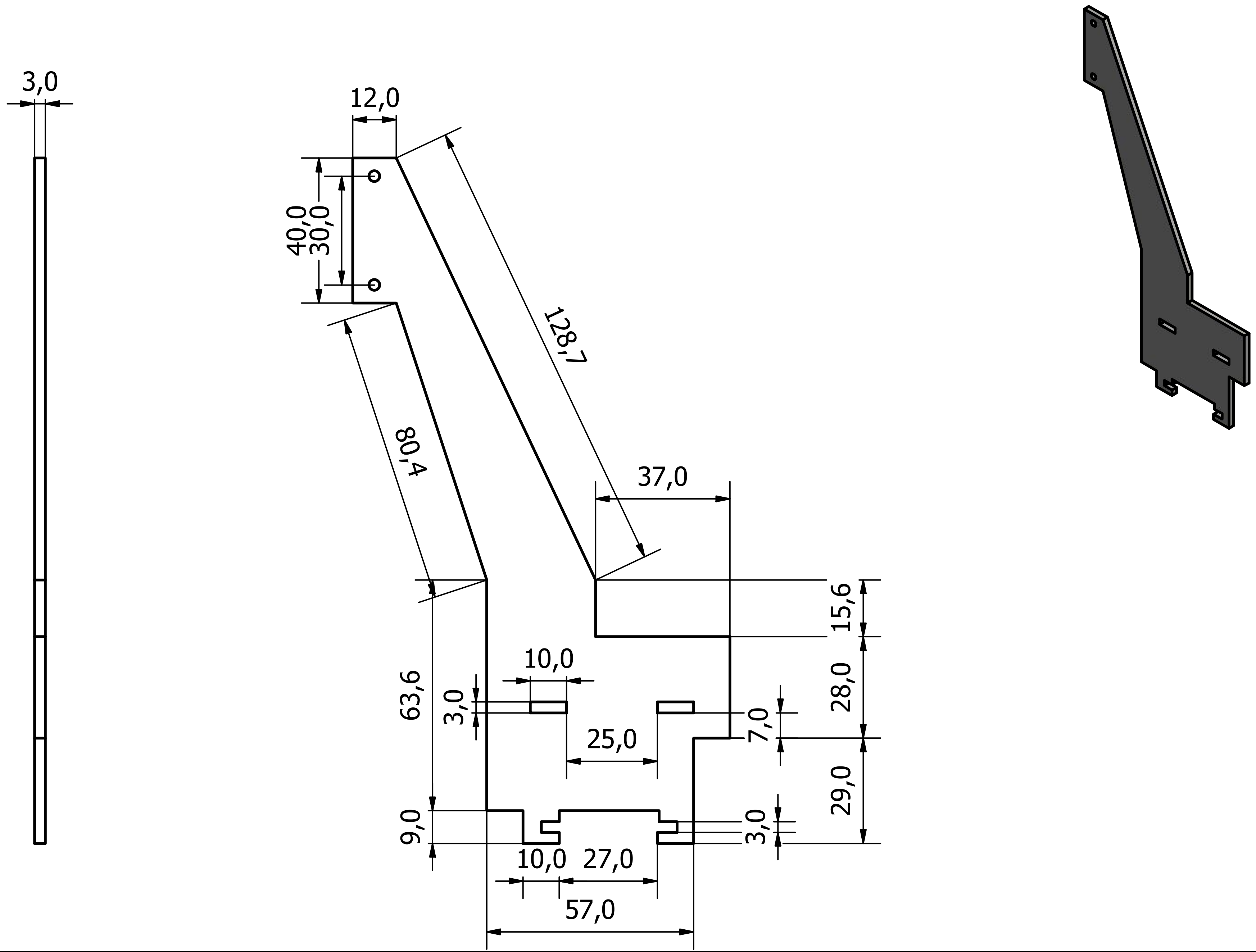
| Author | Johanny Alvarado | Sheet No. | 5 | Can Wheel | | Scale | 1:1 |

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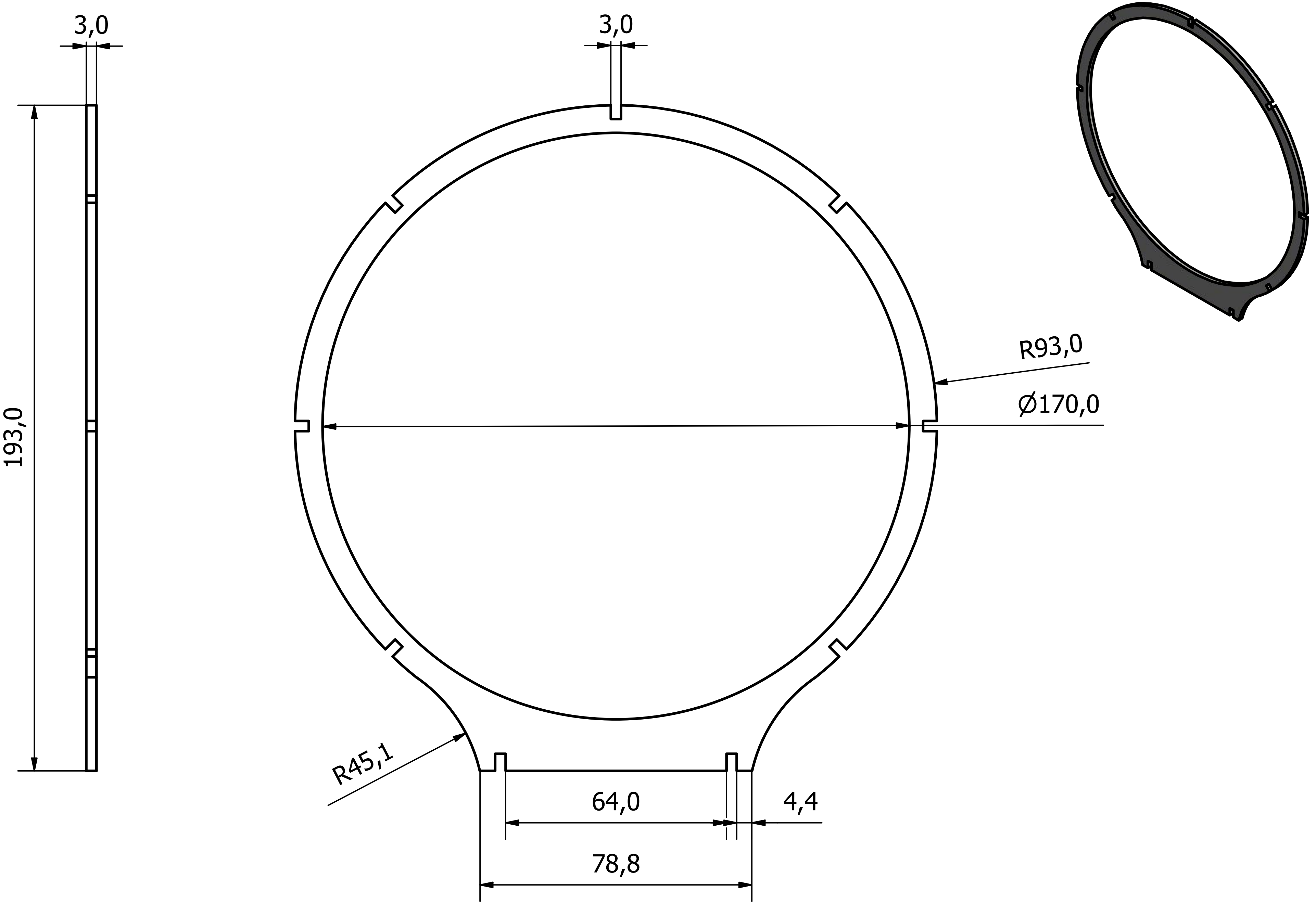
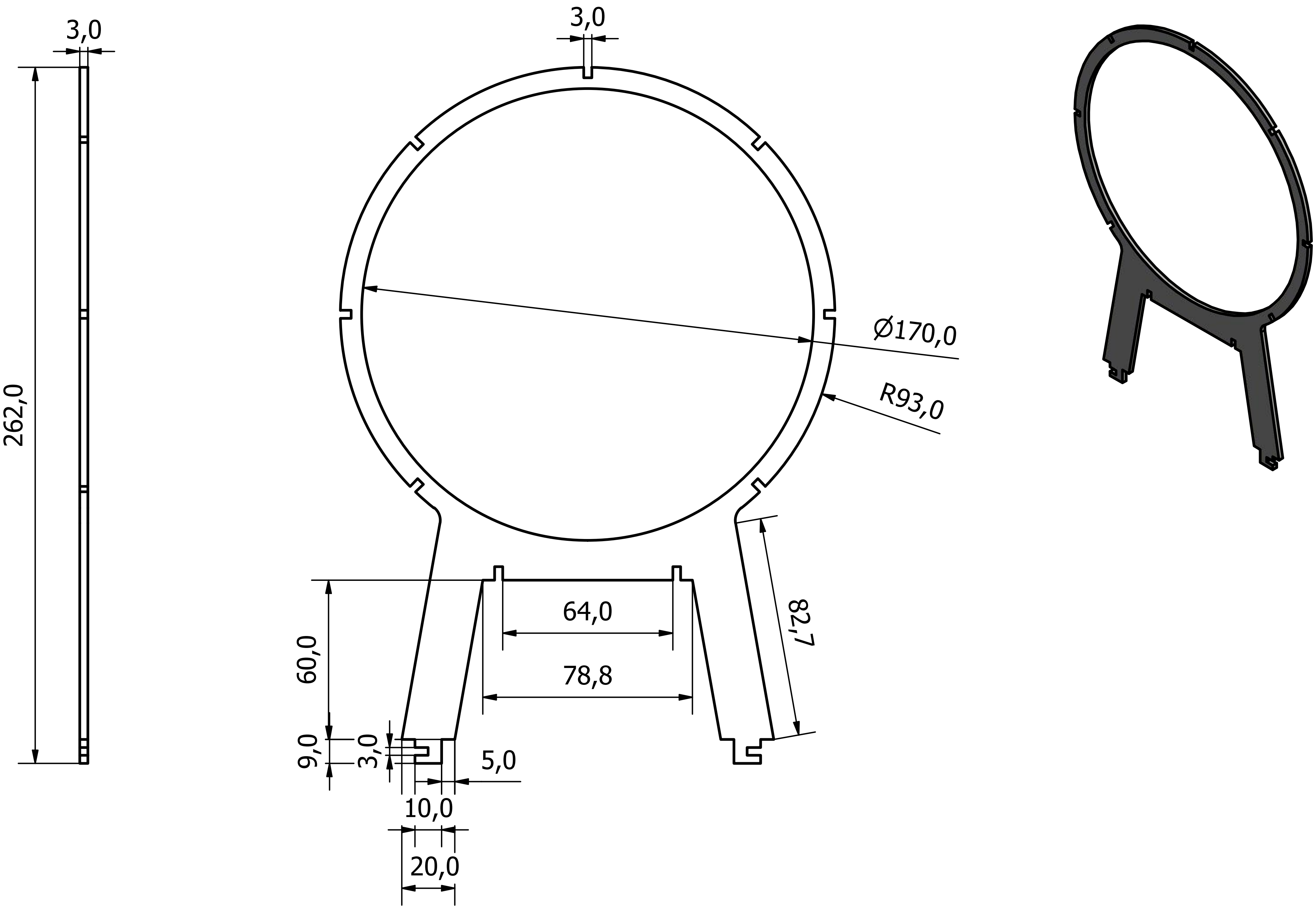
| Author | Johanny Alvarado | Sheet No. | 6 | Column | Scale | 1:1.5 |




| | | | | | | |
|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Title | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 7 | Fan Cover 2 | Scale | 1:1.5 |

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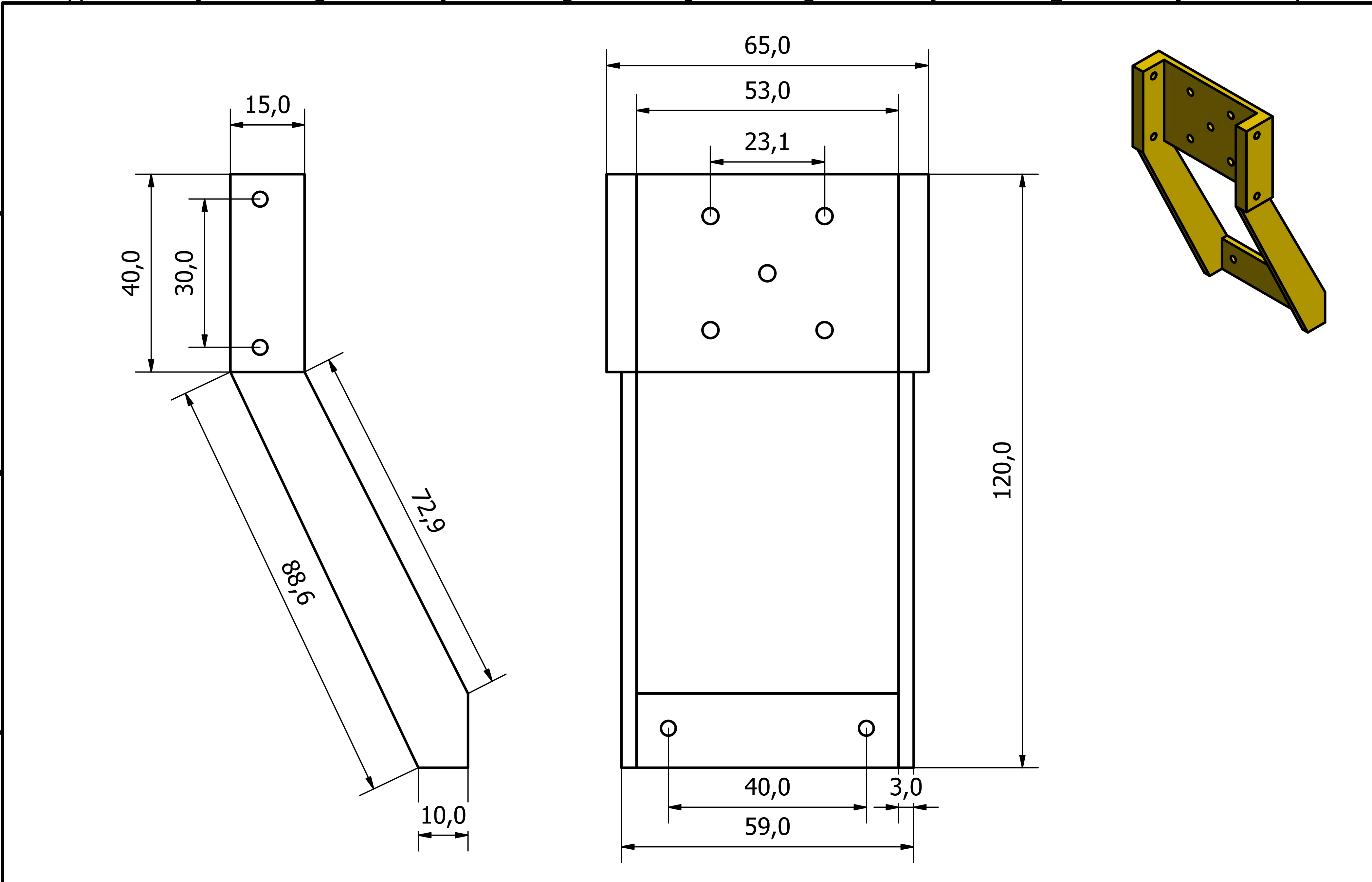
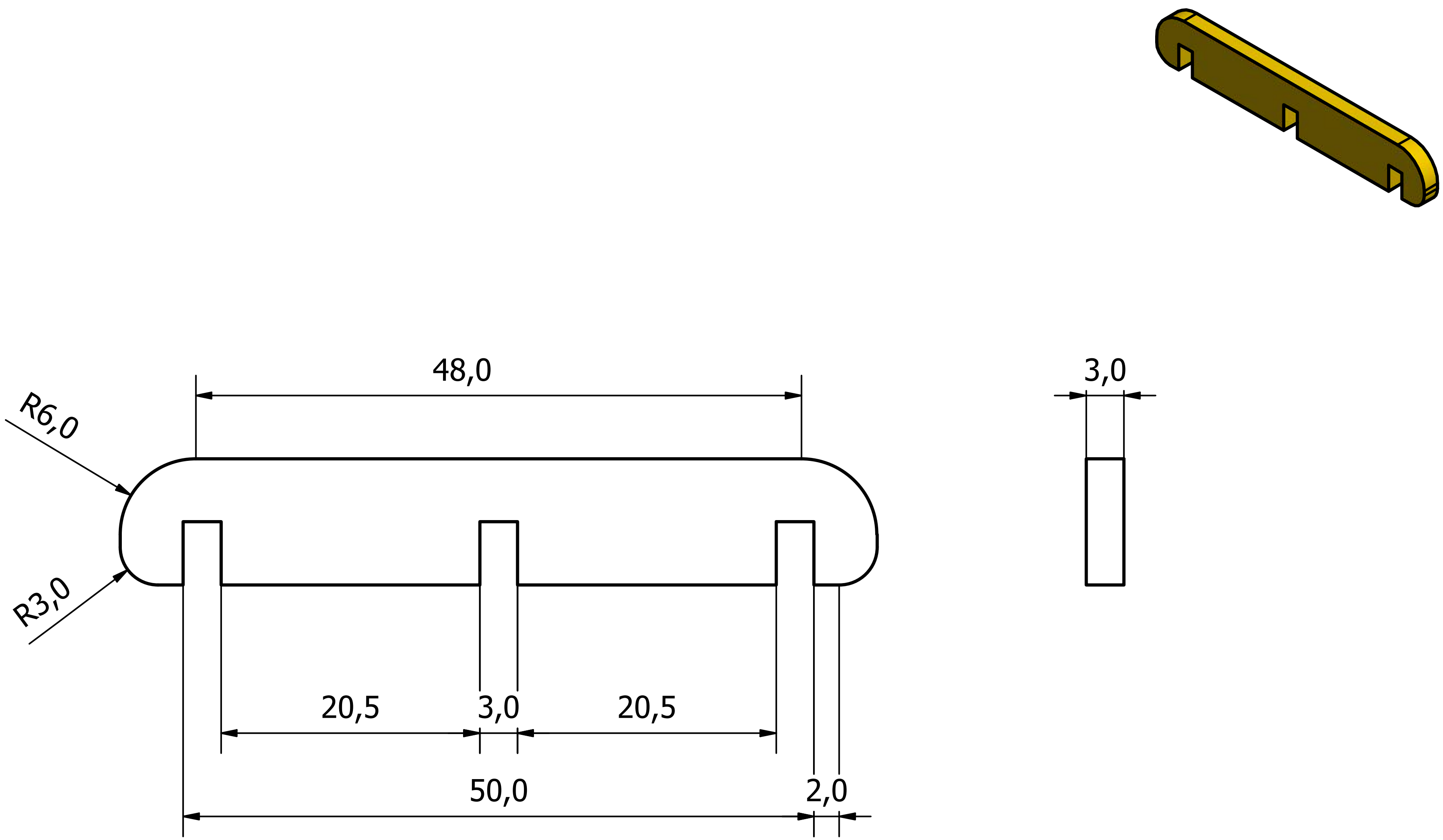



| | | | | | | |
|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Title | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 9 | Motor Holder | Scale | 1:1 |




| | | | | | | |
|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Title | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 10 | Fan Connector | Scale | 2:1 |

## 3.1 Overall Structure

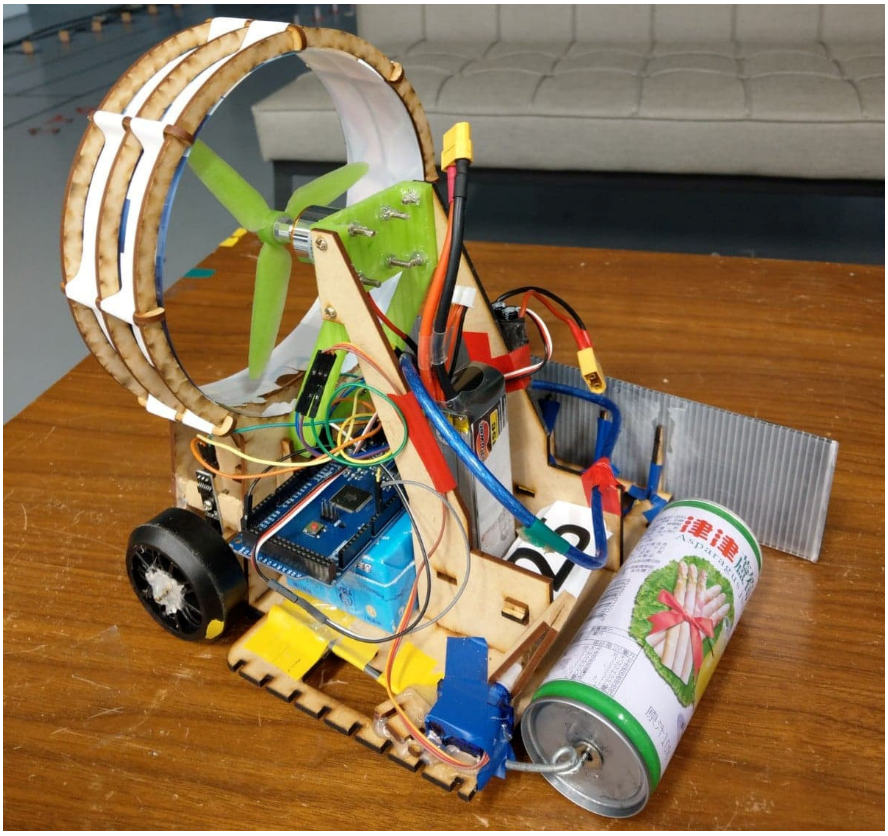


Figure 3.1 overall structure of the midterm car

Performance Requirement

The overall structure aims to support all components, including a fan, motors and other electronic components. Considering the roughness of the track and targeting speed, the platform and supporting structures are designed to be steady and high stiffness. Supporting the car to move in a steady and controllable way is the main goal for the overall structure.

Prototype and Concept

1. Platform

Considering designing the braking system with an axle originally, the team decided to place the platform beneath the axle. The benefits of a low-platform design are stability and more space on the platform. What's more, the space of the platform needs to be arranged smartly, not only to accommodate every manufactured part and electronic component but also remain balance of the weight distribution. Even though the final breaking system is not the original design with the axle, the platform locates quite low to ensure the advantages of a low-platform design.

2. Motors Supports

Three motors are used for propelling the fan, braking system, and turning system, one for each system. Since the two servos use for braking and turning system already possess screw holes and a corresponding surface, the team aims for a supporting platform that holds the servos downward, so that the turning head can be in contact with the turning and braking system.

Out team chose a brushless DC motor to propel the fan, hanged in the middle of the fan cover. To have the least influence on streamline and flow friction, the support is designed to be parallel with the driving direction. Consequently, the contact surface with the airflow can be minimized. Another feature to consider is which side to support the DC motor. To propel the car, the fan turns and the wind flows in the opposite direction of the driving motion of the car. Thrust is, thus, generated and pushes the car forward. To reduce vortex or unsteady flows and avoid energy losses, the brushless DC motor support is designed in front of the fan. In this case, the air flows, generated by the fan, do not encounter any obstacles and can flow freely.

3. Fan Cover

Fan Cover can be separated into three different kinds of design: nozzle, diffuser, or simple tunnel, this last being without cross-sectional area changing. Due to the cross section area contraction or expansion, the flow speed increases and decreases. From the thrust equation

$$\mathrm{F} = \dot{m}_e v_e - \dot{m}_i v_i + (P_e - P_i)\mathrm{A} \qquad (3.1)$$

where F is the thrust, $\dot{m}_e$ and $\dot{m}_i$ are the mass flow rate at the exit and the inlet, respectively; $v_e$ and $v_i$ are symbols for the flow speed at the exit and the inlet; $P_e$ and $P_i$ are the pressure at the exit and the inlet and A is the cross-sectional area.

Assume ambient airflow can be neglected and the pressure difference between inlet and outlet is small, the thrust increases with a bigger exit flow velocity. Therefore, a nozzle design would provide a bigger thrust.

However, considering the manufacturing difficulty and the track requirements, speed is not the first priority. To be able to control the car with precise speeds and acceleration rates are more important. Furthermore, adding a layer on fan cover becomes complicated with area changes. Therefore, weighing the pros and cons of a nozzle and normal tunnel design, our team reached a consensus that much time should not be invested on a complicated fan cover design and settled down on the simple version.

Table 3.1 Different fan cover comparisons

| Fan Cover Types | Advantages | Disadvantages |
|---|---|---|
| Nozzle | Bigger Thrust | Difficult to manufacture<br>Unsteady flow may appear |
| Normal Tunnel | Easy to manufacture<br>Stead flow | No additional thrust |

<u>Working Principle</u>

The overall structure needs to combine different systems together, including braking, turning systems, and the fan. Since our final design utilizes a can to make the car go straight. This solution also helps us save some space in the front since there is no need for the sensor system and wiring.

The supports for the DC brushless motor are separated into two parts. The first part connects the bottom of the fan cover; the second one stretches to the front and is fixed at the platform. Furthermore, the second part of the DC motor support acts as the holder of the drink, the mandatory component as the car driver. The figure below shows the final assembly of the car.

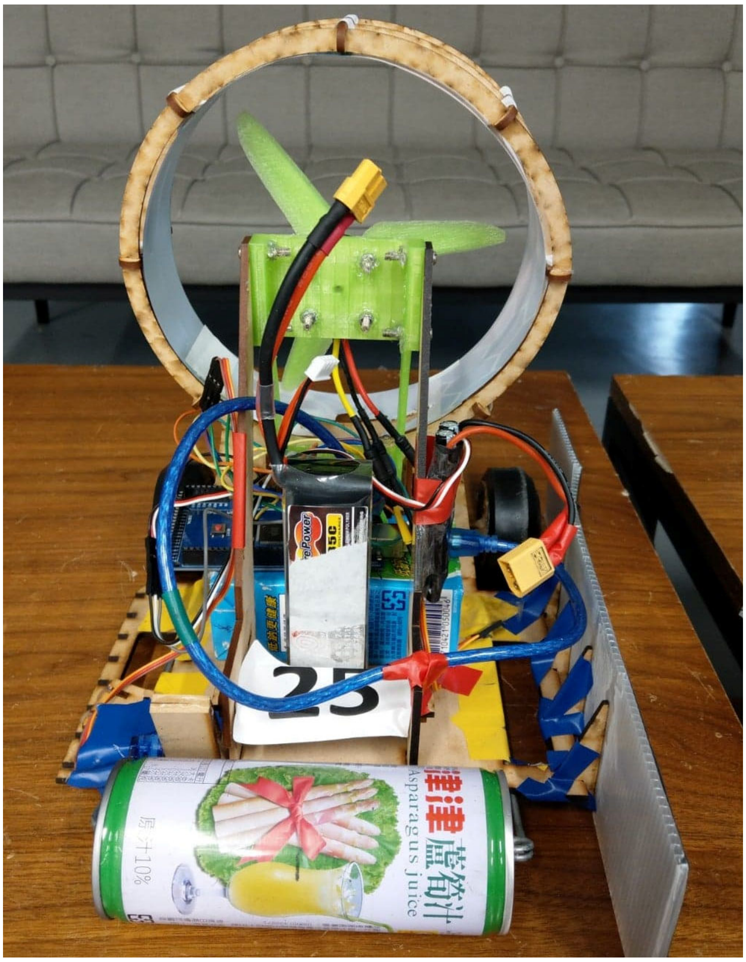



Figure 3.2 final assembly of the midterm car

Problems Encountered

The main issues occurred were related with the space in the front platform. At first, the drink lied on the platform, with the longer side pointing to the front. With this structure, the team had difficulties fitting the turning system.

Modification

Several ways were proposed and tested to accommodate the Ackerman system to the car body. Eventually, the team changed the way to place the drink. For the current version, the drink lies horizontally, giving more space to the front, so that both Ackerman system and sensors have enough space.

## 3.2 Turning Mechanism

Performance Requirement

Since the midterm track is a straight line, the car aims to go as straight as possible. Most of the group addresses this requirement by combining the sensor system and the turning mechanism. However, our group has found a more straight-forward approach.

Can Design

With the midterm testing approaching, the sensors, coding, and mechanical turning systems still showed some problems and instability. To start tuning the speed control faster, our group came up with a brilliant design, which is capable of going in a straight line, combining the turning and line tracking functions.

One group member was inspired by an asparagus can. Its lengthy body was capable of following a straight line if it was well located. Our team examined the straight performance of the can first and decided to incorporate it into our original system and substituted the turning and sensor system simultaneously.

Problems Encountered

The main issue of this design system was the starting position. Since we were able to readjust our car at the pausing area, our car could stay in the track in the first session without big issues. In contrast, the starting position at session two of the track was more critical.

The second issue observed while testing was that due to the large surface area of the can, our car was more susceptible to the ground particles. During testing, we discovered that some tiny particles hindered the car from proceeding with its normal speed, resulting in instability of its velocity. The car surface was mostly dirty after many testing, verifying our guess that the ground particles interfered with the can.

<u>Modification</u>

To be able to stay in the whole track and terminate at the end, our group made a “starting board” for the person responsible for readjusting the car at the pausing area. The “starting board” aligned the starting line and the front of the can. After some practice, our member was able to place the can with the right angle and position repeatedly. The car might diverge slightly in session 2 but most of the time, the divergence was acceptable.

To cope with the second issue, we cleaned the surface of the can regularly and particularly before the midterm test. Our group also swept the floor before testing and checked for the particles during the 1 minute checking time before the formal test. With these efforts, our midterm performance was satisfying, which is more elaborated in chapter 4.

## 3.3 Breaking Mechanism

<u>Performance Requirement</u>

To meet the track requirements, a braking system aims to reach the targeting deceleration rates and to stop at the pausing and termination areas.

<u>Concept</u>

1. Front braking system or back braking system

Front braking system makes the whole car easier to tip over, as the car needs to stop abruptly. Installing a braking system at the back wheels gives the biggest advantage – stability. Even though the racing track is flat, the surface roughness still needs be taken considered. Therefore, we have agreed on putting the braking system at the rear wheels. On the other hand, it would also give space to the turning system, decided to be placed in the front.

2. Caliper Break or Breaking Plate Design


Figure 3.3 Caliper brake of the car[9]

Our initial thought is based on the braking system of a bike, also called caliper break. When the car is set to decelerate, the braking rubber touches the wheels and stops the rotating motion with friction. However, the disadvantage of this design is that two rear wheels need to be stopped at the same time. To be able to synchronize two wheels is difficult in the sense of manufacturing and controlling. If two rear wheels decelerate at different time, the car will turn in an unpredictable way, increasing the instability. Hence, our team moved on to the “breaking plate design”.

To address the asynchronous problem, our team decided to install a breaking plate on the axle, which connects the two rear wheels. When braking is triggered, the braking rubber touches the plate and causes friction to stop the rotation. In this case, since the axle, wheels and the braking plate are rotating together, slowing down the motion of plate can result in braking without the unsynchronized problem.

3. Harsh and smooth braking systems

Since the tasks of racing tracks include different acceleration rates, one pause and termination at the end, the team decides to build up a braking system, consisting of both harsh and smooth brakes. To develop a model of two different braking effects, the team improved the original design by adding two braking plates with diverse surface materials. One braking plate does not undergo a further manufactured process, the original surface of the material used; the other one is added another layer of rubber. The following figure shows the sketch of our design.

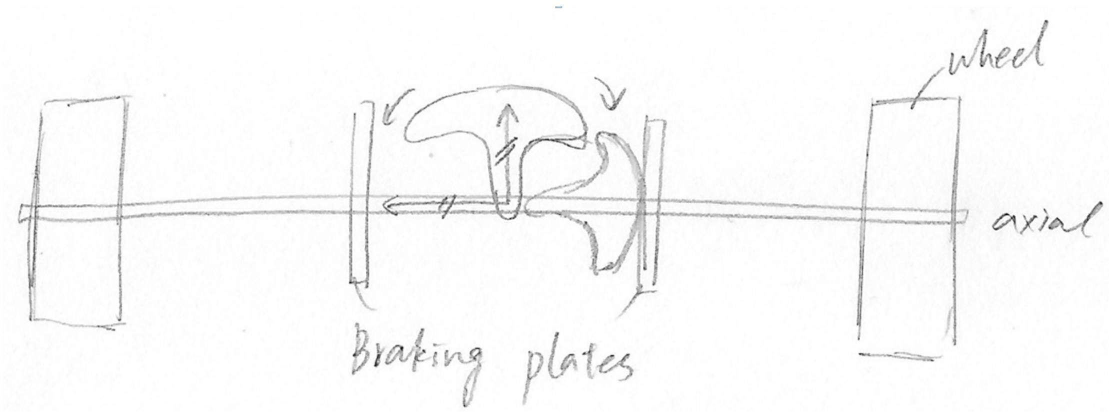



Figure 3.4Sketch of the first design

Working Principle

Our design results in an anchor-shaped braking rubber, powered by a servo (more details are available at the electronics part). The braking piece will turn clockwise for a smooth brake; counterclockwise for a harsh break. When in contact with the braking plates, rotating synchronously with the wheels, the braking piece causes friction to slow down the motion. After several testing, the team is satisfied with the performance of the system and believes that by adjusting the power output of the propelling system and the action of braking system, we are able to reach the track requirements.

Besides the electrical parts of the braking system, the rest is manufactured by fiberboard. Laser cutting gives a precise dimension, contributing to the success of our braking system. To increase the contact surface, ensuring a reliable breaking effect, two pieces of anchor-shaped braking pieces are pasted together. With a double thickness of fiberboard, 6mm thickness, our breaking system works under the command of braking orders. The picture below shows the finished parts of the braking system.

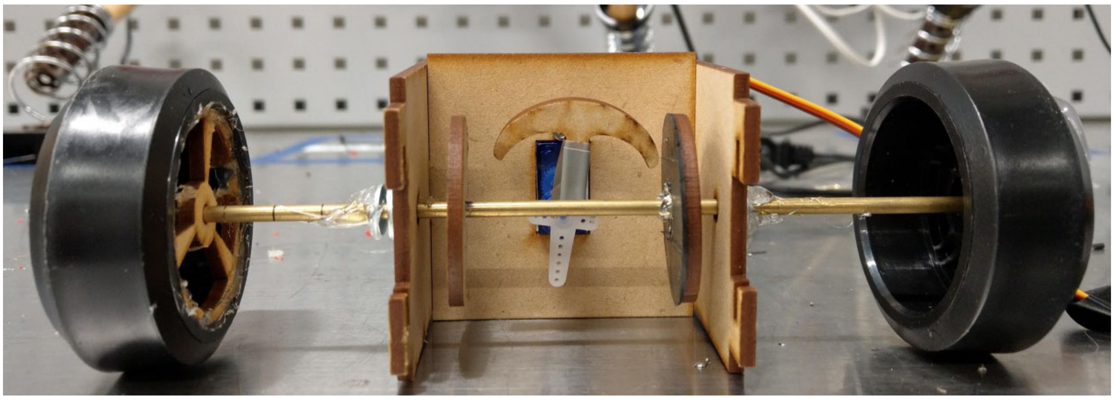


Figure 3.5 manufactured first braking system

Problems Encountered

Thanks to the precise measurements and a careful design, our first finished breaking system showed effective breaking performance. However some problems are discovered:

1. After several testing and moving the cars back and forth, the braking plates fell off.
2. Due to the manufacturing error, the plate was not perfectly perpendicular to the axle. The braking plate leaned back and forth while the car was running. Therefore, the braking effect was not uniform.

Modification

To address the first problem, more hot glue was used to ensure a fixed and stable contact with the axle. The second problem was related to the deceleration part of the midterm test. Since the requirement was to precisely control the decreasing speed, the unstable breaking effect of the system made it dependent of luck, whether we would reach the velocity requirement.

Therefore, our team moved on to the second design of the braking system.

Second Design

After our group changed the turning system and line tracking system to a can, the second design of the braking system was added at the front desk by enforcing a friction force on the rotating can. When the car was supposed to break, a breaking stick would lower down and touched the surface of the can. Since there was a large surface of the can, the second braking system did not require a sophisticated measurement and our group finished the design in less than one hour.

The second design comprises a small servo was pasted right behind the can, with a breaking stick attached to it. Since there was enough space in the front desk, a rather wide breaking stick was made to ensure efficient contact surface. After testing the angle of contacting the can, the new design allowed us to reach the desired deceleration rate and to stop at the designed pausing and termination areas.

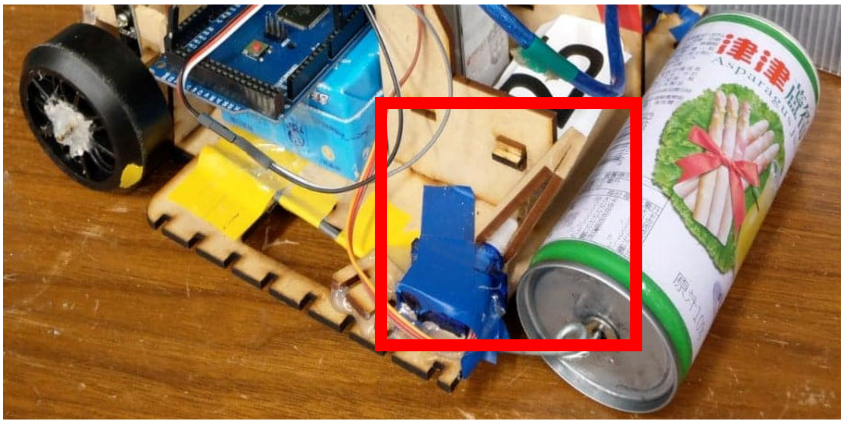



Figure 3.6The final manufactured second breaking system

## 3.4 Fan Design

<u>Performance Requirement</u>

To propel the car, the following design properties must be taken into consideration.

1. High thrust and high efficiency

The car is meant to use a fan to drive airflow as the propelling force in order to move forward. Therefore, the thrust of the fan needs to be sufficient to overcome the friction between the wheel and the floor. The fan is controlled by a brushless motor, with high driving efficiency, enabling the car to reach expected performances even at a lower motor speed. The benefits are reducing the circuit burden and increasing the overall efficiency.

2. Stable thrust

When the vehicle moves forward, the infrared sensor reads the signal to follow the track. If the thrust is unstable, the car structure will not drive forward steadily, affecting the tracking effectiveness. To meet the requirements of the track, where the targeting speeds are different in each section, the stability of the thrust is an important factor in order to drive at a constant speed. Furthermore, the stable thrust can effectively avoid excessive vibration of the car, which may lead to instability and loose parts.

Design guide

1. Number of blades
   a. Odd or even

      The overall efficiency of odd-numbered blades is higher than that of even-numbered blades. Even-numbered blades are arranged in a symmetrical manner, making difficult to balance the fan. Furthermore, the fan with even-numbered blades generates more resonance at high speed. Drawbacks of long-term resonance are material fatigue and, eventually, the blade breaks.

   b. Moment of inertia

      A higher moment of inertia leads to more power consumption. Even though, a greater number of blades and a larger area produce a greater thrust, the bigger mass needs to be considered as it increases the moment of inertia.

   c. Blade spacing

      The small spacing with a large number of blades can cause airflow disturbance, increasing the friction and reducing fan efficiency. However, the large spacing of the blades increases the pressure loss and reduces the wind pressure. Based on the above three points, the group chose three-leaf and five-leaf fans to compare their performance.

2. Fan size

In general, a bigger diameter produces a higher thrust. Since the diameter of 3Dprinting is limited to 160mm, and the stress that the PLA material can withstands needs to be considered, it was decided to make a fan diameter of 150 mm and to increase the fan strength by choosing the appropriate ratio of the airfoil to chord length.

Working Principle

Among them, in the case that the blade and the fluid in the flow field have relative motion, and there is an angle difference, and the fluid flows through the upper and lower surfaces of the blade, due to the different shapes of the upper and lower surfaces, it will result in different fluid velocities. When the angle of attack is positive, the velocity above the wing will be greater than the one below. The difference in upper and lower speeds results in a difference in upper and lower pressures, which in turn produces Lift.

According to the Bernoulli's equation, the relationship between pressure and speed is [3]：

$$p + \frac{1}{2}\rho v^2 = constant \qquad (3,2)$$

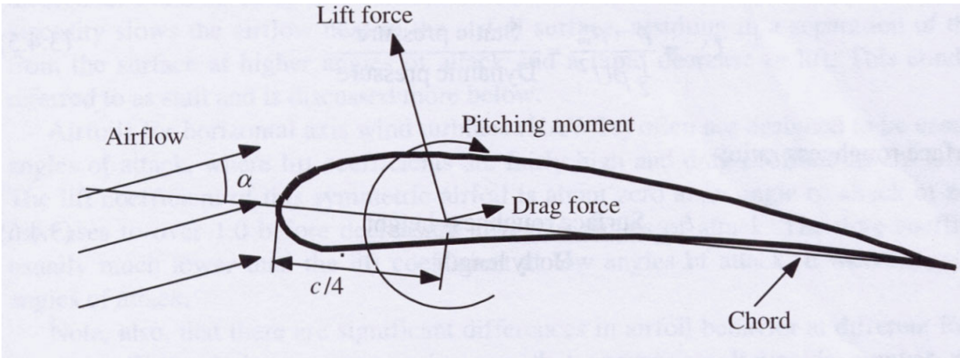



Figure 3.7 Drag and Lift forces on stationary airfoil [2]

Blade Design

1. Airfoil

Table 3.2 Design parameters and environmental factors

| | | | |
|---|---|---|---|
| Temperature. T | 20℃ | Fan diameter. D | 150mm |
| motor speed. ω | 8000rpm | chord distance. c | 3-17.5mm |
| car speed. v | 2m/s | Air viscosity.ν [7] | $1.516\times 10^{-5} m^2/s$ |
| Blade diameter. D | 135mm | Central diameter. d | 25mm |

The relative speed V of the motor and air can be calculated from the motor speed ω and the vehicle speed v

$$V(r) = \sqrt{(wr)^2 + v^2} \qquad (3.3)$$

Reynolds number formula

$$Re(r) = \frac{Vc}{\nu} \qquad (3.4)$$

It can be calculated that when the radius is 35mm, Re=74310. Based on the paper [4], in the environment of Reynold number stays between 5000 to 10000, a fan design with a thinner and sharp leading edge and trailing edgeis more suitable. Therefore, S9037, which meets the above ideas, was initially selected as the fan airfoil. However, the airfoil is thin and has sharp points that were beyond the capabilities of the 3Dprinter. The printing results were highly error-prone. Therefore, the NACA2418,which has a thicker airfoil shape, was re-selected. In this way, not only is manufacturing more precise, but the blade strength is also higher.

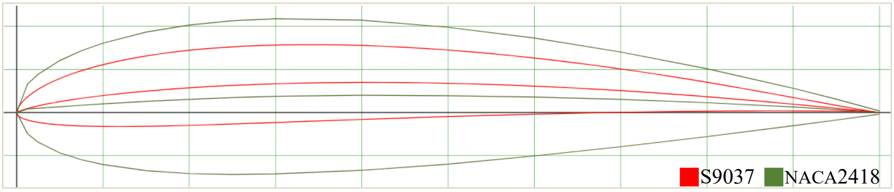



Figure 3.8 Comparison of the shape of S9037 and NACA2418[4]

2. Chord distance

There are many ways to design the chord length distribution. Looking at the reports of the previous two years, most of them use straight-line distribution or use Excel to grab available data points and then reuse the polynomial trend line. We refer to the data of chord length radius ratio of UIUC Propeller Data Site. Based on the fan radius and expected forward speed, the following is selected. Kyosho.9x6, Thin electric.9x6 and Gwssf.10x8 are selected as the design basis. [5] The Kyosho.9x6 is difficult to manufacture because its chord length to radius ratio is too small. Therefore, Thin electric.9x6 and Gwssf.10x8 with a larger chord length were changed to test and compare the thrust efficiency.

3. Attack angle

Relation between rotation angle and speed：

$$\text{rotation angle} = \text{attack angle} + \tan^{-1}\left(\frac{\text{Inlet velocity}}{\text{Section radius} \times \text{motor speed}}\right) \quad (3.5)$$

Table 3.3Design parameters and environmental factors

| | | | |
|---|---|---|---|
| Temperature. T | 20℃ | Fan diameter. D | 150mm |
| motor speed. ω | 8000rpm | chord distance. c | 3-17.5mm |
| car speed. v | 2m/s | Air viscosity.ν [6] | $1.516\times 10^{-5} m^2/s$ |
| Blade diameter. D | 135mm | Central diameter. d | 25mm |

From the previous calculation, when the radius is 35mm, Re=74310, and then from the Airfoil Tools website, the relationship between the lift-drag ratio and the angle of attack can be obtained [5]. It can be seen that the lift-drag ratio of NACA2418 is almost the same as just above 0, while the S9037 angle of attack is 7~10 degrees, such that the lift-to-drag ratio is the largest, so the angle of attack is designed from 10 degrees as the initial condition.

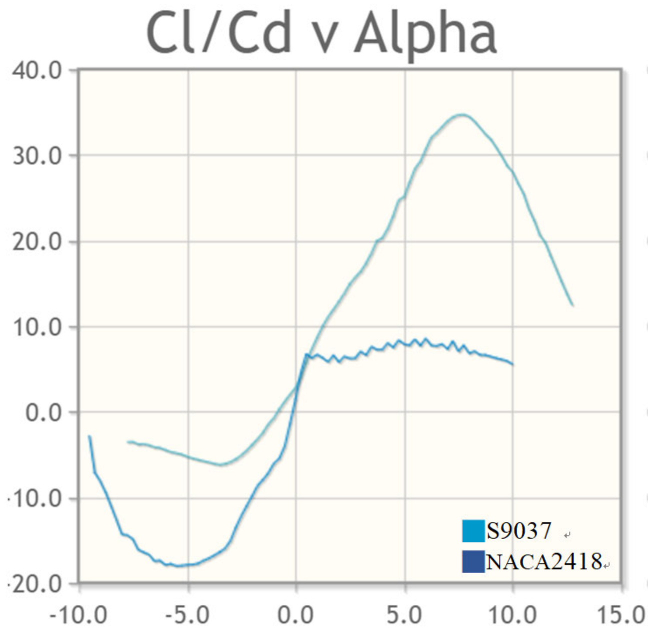



Figure 3.9 The lift-drag ratio and the angle of attack of S9037 and NACA2418 is at Re = 50000, [6]

Table 3.4 data of each section, r = distance from section to axle (mm), c = chord length (mm), θ = angle of rotation (deg)

| Section | r | c | θ | Section | r | c | θ |
|---|---|---|---|---|---|---|---|
| 1 | 11.25 | 8.175 | 20.63227 | 10 | 45 | 17.325 | 10.46962 |
| 2 | 15 | 9.375 | 17.30891 | 11 | 48.75 | 16.875 | 10.20331 |
| 3 | 18.75 | 10.875 | 15.27918 | 12 | 52.5 | 16.05 | 9.974926 |
| 4 | 22.5 | 12.525 | 13.91398 | 13 | 56.25 | 15 | 9.776919 |
| 5 | 26.25 | 14.1 | 12.9339 | 14 | 60 | 13.575 | 9.603608 |
| 6 | 30 | 15.375 | 12.19651 | 15 | 63.75 | 11.925 | 9.450647 |
| 7 | 33.75 | 16.425 | 11.62177 | 16 | 67.5 | 9.975 | 9.314653 |
| 8 | 37.5 | 17.1 | 11.16131 | 17 | 71.25 | 6.675 | 9.192951 |
| 9 | 41.25 | 17.4 | 10.78416 | 18 | 75 | 3.3 | 9.083403 |

Fan drawing

Inventor was the initial drawing software, but there were some limitations. It couldn’t assemble the parts together in the desired fashion. The results are shown below.

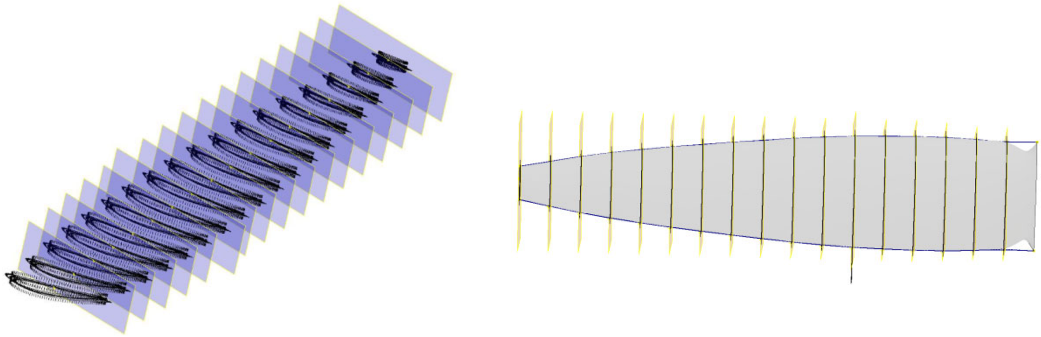


Figure 3.10 The left picture is before mixing; the right side is after mixing.

Solidworks proves to be a more suitable software for our design requirements. However, the reasons for the hybrid problem in Inventor may be: (1) After in putting the data points in each sketch, they are connected by a cloud, but not every time the initial point and the endpoint are connected into a closed curve; (2) The data points obtained from the Airfoil website are too many, and some overlap, which makes the contour of the cloud line to be too convoluted.

Fan Versions

After taking the above considerations into account, we have pre-selected 5 airfoil designs for the control group to choose the most suitable fan.

1. First Version

The purpose of the first version was for familiarization. Looking at the final reports of previous models for this project, it was decided to first simulate Group25'sfan. The first version of the fan was produced as shown below. The airfoil is NACA4412, and the chord length distribution directly refers to the design method of commercial fans, with the maximum chord length at 0.3R. 8]

The fan, made by 3D printer Kingssel, has a lot of unevenness on the edges and most noticeably on the surface. We used glue as a finishing varnish: first, a file was used to polish the surface protrusions, followed by sandpapers for fine processing. Finally, glue was applied throughout the piece. This process can remove surface unevenness, by filling on small gaps in the surface of the fan. In result, we obtain a smoother rotation.

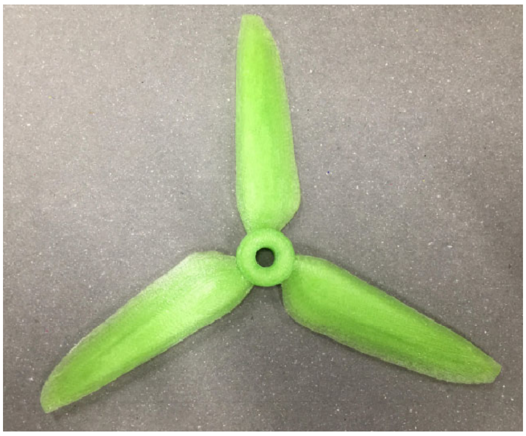


Figure 3.11 the first version of fan

2. Second Version

Taking the low Reynolds number environment for consideration, we selected the wing type S9037, whose chord length is based on the Kyosho.9x6 data in the UIUC Propeller Data Site. It can be observed from the following images that the tip of the fan blade is incomplete, and there are more obvious strip marks on the edge of the blade. The manufacturing limitations of the 3D printer were ignored. If the airfoil is too thin, the chord length radius ratio is small, and the tip and edge slope are too large. This will increase the manufacturing error. It was difficult to completely remove from the support material, and even some areas were not printed at all.

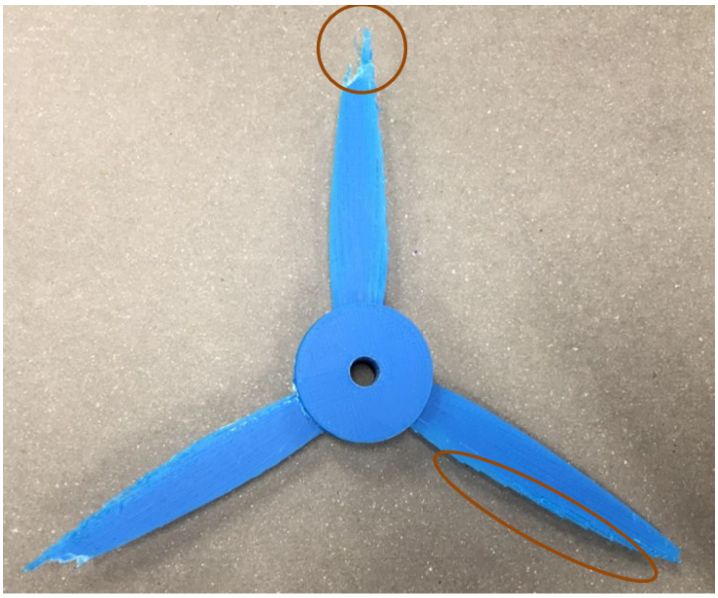


Fig 3.12 second version of the fan

3.Third and fourth Versions

The NACA2418 is selected as the new airfoil. In addition to being suitable forlow Reynolds numbers, we also considered its thinness. The chord length ratio is based on the thin electric.9x6 data in the UIUC Propeller Data Site. The chord length ratio is larger and the fan blades are wider and thicker. The angle of attack of the third edition is 10 °, and the test results are much higher than those of the first edition. In the fourth edition, the angle of attack was changed to 15 °, and the overall chord length was slightly increased, also making the blades thicker at the base, which in turn prevents breaking and produces more thrust.

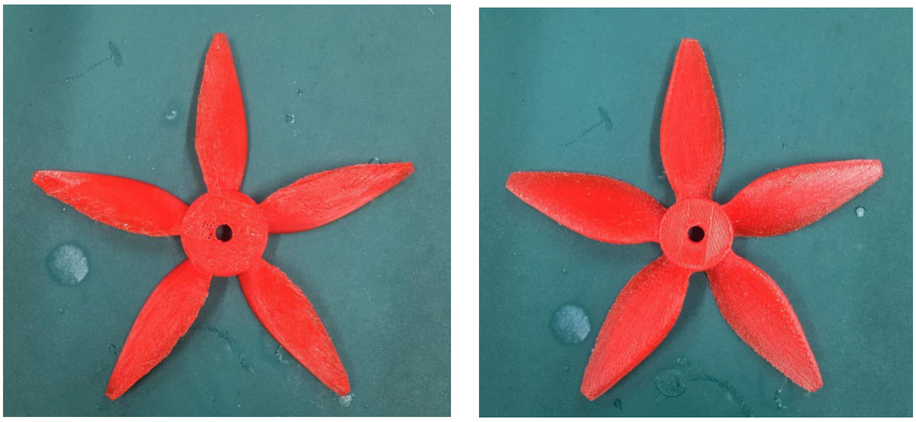


Figure 3.13 third and fourth version of the fan

4.FifthVersion

Use Gwssf.10x8 chord length ratio data instead. The reason is that Gwssf.10x8 does not need to adjust each chord length ratio to meet the requirements of this group. The root joint area is large enough, and the tail area is large enough. The motor body can be pushed without too much motor speed. In addition, the unit movement of the z-axis stepper motor of the 3D printer is found to be 0.02mm, so when printing the fan, the layer is specifically adjusted to a multiple of 0.02 to increase the manufacturing accuracy. The result is shown in the following figure.

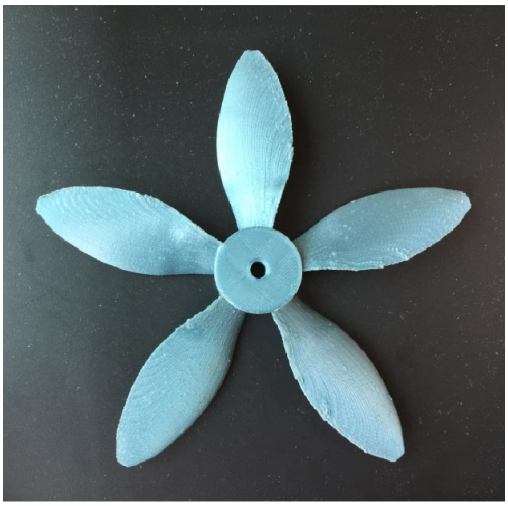


Figure 3.14 fifth version of the fan

Finally, through actual experimentation, it was found that the first version of the fan is the most suitable of the preselected versions. After installing the first version of the fan, the car runs smoothly and the noise of the fan rotation is small. The characteristics of each version of the fan will be analyzed later by Ansys simulation.

## 3.5 Electromechanical System

Performance requirement

The performance requirement for the actuating system of the car consists of three sections, braking, turning and propulsion systems.

1. Braking System

The braking system consists of an individual standard servo motor, model: Tower Pro SG 90. It will rotate counter-clockwise for an abrupt break and will rotate clockwise for a smoother brake, as is deemed necessary by the installed sensors, to satisfy the speed modulation requirements of the track. Before deciding on this model, there was some controversy as to which model to use. It was proposed to use the high torque Tower Pro MG996r. After some consultation and later experimentation, that for adequate performance, the Tower Pro SG 90 servo model was deemed enough. It was concluded that the Mg996r model would provide extra weight and cost. The extra weight would require the propulsion system to generate more thrust to drive the car and to generate this thrust, there would be more power consumption. For reducing the speed, a reduction in the speed of the brushless DC motor, along with the aid of the braking system is needed. This servo motor has a speed of 0.1 sec/60deg, and a torque of 1.8 kg.

2. Turning System

To satisfy the necessary torque to steer the car and all of its components, a servo motor with a higher power rating was used. The model is the Tower Pro MG996r. It is a standard servo, working on the same principle. It has a higher speed than the servo motor for braking, about 0.17 sec/60 deg; and a torque several times higher, at about 9.5kg for the same voltage, 4.8 V. Upon detected deviation by the sensors, or upon detecting lack of available track, the servo will rotate accordingly. This servomotor works as the driving input of the Ackerman mechanisms installed on the car to turn. This is a joint operation.

3. Propulsion System

Because the fan requires a long time to propel the car with a heavy load, it is necessary to choose a motor with high torque, high speed, and high power. Therefore, we have chosen a brushless motor without carbon brush friction. The motor has less friction of carbon brushes. The temperature rises smaller and the motor also produces less noise and operates smoothly. Therefore, the efficiency is improved, corresponding to our needs. A brushless DC motor with a Kv rating of 2300 was first used in the system. The Kv rating of a brushless motor is the ratio of the motor's unloaded rpm, meaning without any external resistance, to the peak voltage on the wires connected to the coils. Considering our 11.1 V Li-po battery, the maximum velocity of this BLDC is about 25,530 rpm. The following figures show the standard servo motor (SG90), torque servo motor (MG996r), and the Li-po battery.


Figure 3.15The battery used[7]

Prototype and Concept

These systems are controlled via an Arduino controller and its interface. The Arduino model employed for the project is the Arduino Mega board. Its larger amount of pins gives way for more comfortable wiring for the project. Both servo motors are connected through their corresponding signal wire. With the appropriate input value at its code, which will then send a pulse width modulated signal. The pulse duration then provides voltage for the duration necessary to achieve the desired position. Regarding the brushless DC motor, when controlling it via Arduino, the servo libraries are referenced, such that syntax when dealing with a servo motor is similar to the BLDC. It must be noted that the input for the servo motor is a position, whereas the input for the BLDC is velocity. To control the BLDC, an electronic speed controller is used alongside the Arduino board. The ESC controls the speed by activating the appropriate MOSFETs to create the magnetic fields in which the BLDC runs. The ESC employed in the project is the Skywalker ESC 40A, with a linear converter, which can provide up to 210rpm for a 2 pole brushless motor.

Due to safety concerns, it was decided to power the equipment with 2 independent power sources are employed. For the propulsion system, a 3 cell lithium polymerase battery, with 11.1 V is used. The model used is of the brand Desire Power with a capacity of up to 2400mAh. The LiPo battery is not to be connected to Arduino to avoid shorting or overcharging. There is an inherent danger in the use of LiPobatteries, hence, the most straightforward approach was employed. To power the servo motors, the Arduino, and the sensors, a standard 9V battery is used, connected to the Arduino's power jack. The figure below shows the Electronic Speed Controller.


Figure 3.16The ESC used[8]

Working Principle

To control the speed of the motor, an electronic speed controller is necessary. Skywalker ESC 40A, with a linear converter, is the model used for this project. It can be closely compared to its switching converter counterpart. The importance of this comparison arises when considering the power source for the BLDC. The power supply was chosen to be a LiPo battery. In contrast with the alternative option, the NiMH, LiPo batteries have a much higher energy density and can discharge current at a much higher rate. When compared with NiMH batteries, LiPo batteries can make BLDC run at full potential if needed. The biggest downside to LiPo batteries is its inherent danger. They must be treated with proper care, mishandling could be harmful and in some cases, could result in death. Hence, we decided to separate the supply for the BLDC motor from the rest of the components. An ESC with a switching converter could have allowed us to run the entire car on one power supply. It was decided not to navigate this route. Our decision was made due to the following observations: we wanted to reduce the risk factor as much as possible to zero, less wiring, and boards on the structure of the car. We have maintained that decision. The 40A version of the ESC was about 30 NTD more expensive than its 30A counterpart. While its performance was similar, we wanted to maintain the performance standards as we did with the power supply and the BLDC. After some testing accidents, the ESC was replaced by a 30A one. The performance stayed similar.

For the remaining motors, servo motors were the primary option. Due to their high torque, they were necessary for our mechanical design of the braking system. SG90 model provides enough torque to perform this task. It requires 5V as most servo motors do. For the turning system, besides a servo motor, a stepper motor was considered. Even though it was faster than a servo, it would require additional electronics to run. A high torque servo motor was chosen for this task. This decision has remained unchanged. All the aforementioned motors are controlled with the Arduino Mega Board and powered with a 5V power bank. The alternative for powering the system was a standard 9V battery due to its size. The power bank, albeit a smaller voltage, has a bigger power rating, and hence it was chosen. It weighs the same as the 9V battery, the car design still provides the space for the power bank and it can also provide larger currents in a smaller period than the 9V battery.

Problems Encountered

The first issue to overcome is the selection of the adequate electromechanical components, namely, a brushless DC motor, position control motors, control board, and its adequate power source. The propulsion system needed a motor that could rotate at sufficiently high speeds. The brushless DC motor to be employed on this project has a Kv rating of 2300. The Kv number of a brushless motor represents the speed of the motor increased by several rpm for every increase of several volts. The higher the KV number, the faster the motor speed; the torque is thus smaller, and the current consumption is smaller. Kv rating can then be multiplied by a voltage to find its unloaded rpm. There is a remark on torque because the actual torque would depend on the gearbox of the motor. After testing, the 2300 Kv number of the DC motor has higher rotational speed than the track requires. What needed to meet the requirement is a DC motor with less speed but higher torque.

Modification

The immediate complication from the motors was the speed of the turning system servo motor. At sufficiently high velocities, the speed of the servo motor is not enough to realign the car. The solution was not to change the motor but rearrange the configurations of the infrared sensors to compensate for this problem. Besides this complication, all motors are working as expected.

Our team reconsidered the choice of different standards of brushless motor. Our fan possesses a large area and a large resistance. Therefore, compared with a high-speed motor, a motor with a larger torque is preferred to make the operation smoother. For the control part, since the battery voltage will drop gradually through operation, the motor speed will also decrease accordingly. To ensure the motor runs at a stable speed, control the voltage drop of the battery is particularly important. As a result, we have changed to a brushless motor with a low KV number to increase the torque. Reducing the consumption of load current and minimizing the battery voltage drop, to help achieve stable speed control. The 1400KV brushless motor is paired with an 11.7V lithium battery and the maximum speed is 16380rpm. Compared to the 2000KV, the 1400KV brushless motor is sufficient for the task requirements. The torque is enough to drive the fan and the battery is sufficient to provide a stable voltage continuously.

## 3.6 Sensor System

**Performance Requirement**

The requirements of the control part for this project include the following:

1. Speed control of the car to meet the speed requirements,
2. Direction control to follow the line on the ground.

**Prototype and Concept**

The connected hardware components include a brushless DC motor for the fan and two servo motors for braking and turning systems. The sensor system consists of five infrared sensors to detect the car direction and one extra sensor for the encoder to record the speed and distance. The concept of the design is to simplify the main code and use separate functions for each job. That way, the code is easily readable, and adding modification would be easier.

**Principles of Coding**

The main code comprises four parts: global variable announcement, setup function, main loop function, and all the other called functions. In the setup function, we set the pin for each component and initialize the motors. In the main loop, we put the functions in the right order and repeat it every second. The functions called in the main loop will be discussed in the following sections.

In the main loop, the following orders are executed: process the data collected with Encoder(), return the required velocity with the function getFutureSpeed(), and generate the command for motors based on the distance.

Afterward, the direction of the car was obtained by the function Infrared() and processed by the function value() to convert to the error value. This value was then used to generate the command for the turning servo, by the function get PID().

**<u>Working Principles of components</u>**

1. Encoder:

Encoder aims to record the distance and speed of the car and makes the respective control, based on the condition. Between absolute and incremental encoders, the incremental encoder was chosen since the tasks did not require the precise position of the encoder. Secondly, the incremental encoder is much simpler for our purpose.

Judged from the previous reports, infrared sensors were chosen for detection devices. Since infrared sensors were already used for position detection, using the same sensor could save time and effort. Moreover, infrared sensors are simple to control and can record motions in short reaction times.

To gain the speed and position of the car, the function attachinterrupt() was used to record the times when signals are detected. The data was written in an SD card, which can be extracted from excel. Using this simple system, the team can compare car velocities and the requirements easily. A plate-shaped fiberboard with many slots is attached to one of the back wheels and turns simultaneously. The infrared sensor detects each time when the slot on the encoder plate passing.

Table 3.5 Comparison between absolute and incremental encoder

| | Incremental Encoder | Absolute Encoder |
|---|---|---|
| Advantage | · Simple structure<br>· Easily made<br>· Simpler processing code | · Fewer chances of detection errors<br>· Noises would not affect the overall data |
| Disadvantage | · Error accumulation | · Harder to make |

2. Speed regulation:

The group decided that the best way to regulate the car speed was by trial and error. (see table3.6) Thus, the method of speed control was simply changing the variables. The speed and distance data, collected by the encoder, was saved in an SD card during testing. After testing, the team collected the data from the SD card, input it into a prepared excel file, and compared the curve with the speed requirements. To tune the car speed to the required velocities at different sessions, two arrays called motorC[] and brakeC[] were constructed, controlling the value output to the brushless dc motor and the braking servo respectively. Each element in the array controlled the motion of the motors in a 20-centimeter section. Through modifying the outputs from the dc motor and the braking servo, the team aimed to reach the same curve as the track requirements.

Table 3.6 Comparison between two method of speed control

| | Trial and error | Automatic control |
|---|---|---|
| Advantage | · Simple code<br>· Easy to operate<br>· Save time | · Easily meet different requirements once the system is fully developed |
| Disadvantage | · Cannot reaction to changed conditions | · May require more testing<br>· Difficult to adjust variables. |

3. Method of direction detection

For the midterm exam, since the car only needs to track a straight line, the Infrared sensor should suffice. Furthermore, the speed of the car is relatively fast. As a result, a slower processing time of the computer vision may make it harder to react promptly.

Table 3.7 Comparison between two method of line tracking

| | Infrared sensor | Computer Vision |
|---|---|---|
| Advantage | · Lower cost<br>· Faster processing time<br>· Simpler components | · Many different processing methods to choose from<br>· Amore advanced algorithm to deal with complicate situations<br>· Detect a wider range |

| | | |
|---|---|---|
| Disadvantage | · Only detect the line beneath the car<br>· Harder to exclude noise | · A more complicated setup<br>· The calculation speed is slower |

4. Infrared sensors

To detect the car position, to modify the direction, and to track the line on the ground, five encoders were used. The output data of all the sensors were converted to binary numbers, with each encoder as a digit. Thus, the detection data could be converted to integer numbers from 0 to 31 for future processing.

In the value() function, the numbers from the encoder are converted to error values, based on the deviation from the main track. Some signals are classified as noises and if-else statements were used for these cases.

5. Turning Command:

To control the direction, a command for the turning servo is given based on the detected error, calculated by the infrared sensors.

**Problems encountered**

1. The threshold of the infrared sensor:

Originally, the digital infrared sensors were used for both the direction detection and the encoder. However, the sensors on the figure showed insufficient performances during testing. The problem was that the infrared sensors could not distinguish the black line and the intrinsic color on the ground. The threshold of the original sensor could not be adjusted. Hence, it is necessary to find a suitable sensor to finish the tasks.

2. The design of the encoder plate:

The encoder plate was designed to have 15 slots around 360 degrees, but it was useless in testing. The infrared sensor has a specific detection region. If the space was too small, the infrared sensor failed to detect the space, and thus cannot record the motion of the plate. Based on testing, 3 slots around 360 degrees is the best option because it has enough space for each slot to ensure correct detection from the infrared sensor. Also, due to the high rotating speed, three times per round is sufficient for our speed recording purpose.

3. The direction control algorithm

When testing at a lower speed, the encoder and the turning system performed well and could track the line on the runway closely. However, when testing at a higher speed, the detection noise and the imperfect front wheels, combined with the slow reaction time, would cause the car to run off the track.

4. The open-loop control approach failed to tackle power instability

Among testing, it is found that the energy level of the battery and the consistency of power supply highly affect the performance of the fan. The original open-loop control is unable to reject the effect of the situation.

5. The occasionally failed initiation of the car

The successfully starting of the car depends on several factors: the power level of the battery, the friction of the wheel axle, and the inclination of the ground. The starting part cannot use the same control logic as the other part, for its lack of velocity. The original concept was to give the car an initial velocity by a higher duty cycle at the beginning. However, the set duty and period were sometimes not enough to start the car, and sometimes too high that the speed at the first sensor exceeds the desired region.

**Modification**

1. The threshold of the infrared sensor:

The digital infrared sensor was changed into digital and analog sensors (figure x). The new sensors can output both digital and analog signals. The digital output was preferred owing to its simplicity of processing data. The new sensors are screwed on a bar, which enables the team to adjust the threshold of the sensor. After adjusting the threshold, the sensor can read the position successfully.

2. The design of the encoder plate:

The comparison of the three-generation of encoders is in figure x. The final version has only three slots on the encoder plate. With a larger space, it lowers the chance of misdetection.

3. The direction control algorithm

To solve the problem, the whole infrared sensors and control systems are taken off. The new car design was with a very straight wheel, thus thoroughly avoid the line tracking problem.

4. The open-loop control approach failed to tackle power instability

Eventually, closed-loop control was complemented. The new system control would automatically adjust the duty cycle of the motor based on the current position and the current speed, to reach the target speed requirements.

5. The occasionally failed initiation of the car

A new approach is designed to solve the problem. By giving the motor a slowly increasing duty cycle at the beginning, and stopping when the encoder detects the first signal, it can give the car a smooth start, and also avoid failing the first sensor.

# Chapter 4 Overall Examination

## 4.1 Mechanical Parts

The most distinguished design of our car structure is the asparagus can design. The creative idea not only enables us to start testing earlier and also to reach the race track requirement. Even though, sometimes the car runs out of the track during testing, the chance is small enough so that we can be confident before and during testing. Moreover, our car stands out from others with its special design and shows high enough competence throughout the challenges.

## 4.2 Electromechanical Parts

The performance during the midterm was acceptable. No electrical issues throughout the entire testing. Power was sufficient, nothing got disconnected. Besides some precision control issues, where some of our speed values deviated from the given velocities, overall performance was great. For the final test, the base scheme for the design should not be changed, as the current design is already acceptable. However, it must be remarked that in the midterm we didn't have a turning system. It wasn't that it was not made, it wasn't implemented due to manufacturing issues. It will be fully implemented for the final.

## 4.3 Software Control

The performance of the car in the midterm test was similar to that during testing. When it was at its best performance, the score could reach above eighty. However, the car sometimes missed one or two sensors in the first section and only obtained a score of sixty. The reason for this fluctuating performance behavior was the lack of accuracy of speed controlling. After some discussion and evaluation of the time given for the midterm test, our group agreed that the instability was acceptable and our group stopped from further enhancing the reliability in the last 24 hours before midterm testing.

To have a higher chance of success, the group member practiced several times each role and duty during the midterm test to have the best efficiency and to obtain as many chances as possible.

In the midterm test, with four or five runs, sometimes running out of the track or stopping at the low speed session, the car successfully reached the expected grade of 83.

## 4.4 Performance Examination

4.4 Performance

| Mid-term Evaluation Performance | | | | |
|---|---|---|---|---|
| Performance Factors | Excellent | Very Good | Fair | Notes |
| 1. QUALITY OF WORK – Completion; accuracy; general performance. | | ● | | We believe we did a good job with the completion of our car and meeting all the requirements, therefore our work was of very good quality. |
| 2.FIRST PART OF THE TRACK – In general, during test. | ● | | | All points for this part were achieved, the control part was perfect and the car behaved accordingly. |
| 3. SECOND PART OF THE TRACK – In general, during test. | | | ● | More than half the points were obtained in this part since it was more challenging and the code would have required more improvement to achieve it. |
| 4. ON-SITE TEAM WORK | ● | | | All teammates did their job as previously accorded between all members. There were no last minutes changes and a good teamwork was achieved. |
| 5. SPEED CONTROL | | | ● | As mentioned before, the speed control was mostly very good. |
| 6. STRUCTURE | | ● | | |
| 7. DRIVING STRAIGHT | | | ● | Since we did not included a |

| | | | | |
|---|---|---|---|---|
| | | | | line tracking system, for the last part of the track the car would derail mainly due to imperfections in the track, However, it never went out of the track. |
| 8. BRAKING | ● | | | |
| 9. PROBLEM SOLVING | ● | | | Problems were resolved in a creative and efficient manner. |
| OVERALL EVALUATION | | ● | | Even though we did not get the highest score, the results were as expected and our goals were met. |

DEFINITION OF RATINGS

FAIR: A rating of fair means that the group's performance with respect to the factor under consideration no more than meets and occasionally falls below acceptable standards.

VERY GOOD: A rating of good means that the group's performance with respect to the factor under consideration meets acceptable standards.

EXCELLENT: A rating of excellent means that the employee's performance with respect to the factor under consideration consistently meets and occasionally exceeds acceptable standards.

# Section Three -Final Car

# Chapter 5 Performance Requirement

## 5.1 Race Tracks and Rules

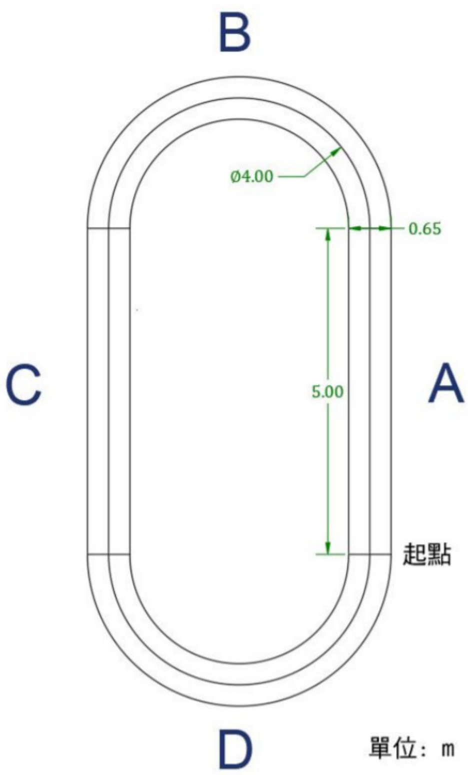



Figure 5.1The midterm track

The track is as shown in Figure 5.1. The length of the straightsection (A & C) is 5 meters, and the radius of the curved section (B & D) is 4 meters. The total length of the track in one round is 22.57 meters. The grades depend on four factors: Line tracking, finishing three rounds, car following, car overtaking, and the average speed. The points are given based on the extent of achievement.

## 5.2 Performance Requirements

Based on the grading system and the task, the performance requirements, and the priority are listed out. The demands on the hardware and software to meet the requirements are also discussed

1) Tracking the line with good precision. Eliminate the chances that the car runs out

accidentally, or develops a system to go back if it happens.
2) A higher average speed. The average speed point is easier to get then the following distance. Hence, it is prioritized.
3) A smaller following distance: accurate encoder documenting or ultrasonic detecting. Precise speed control also relates to a good car-following distance.
4) Avoid collision during overtaking.

To meet the requirements, there are some demands for the hardware.

1) Stability. The hardware should have a similar behavior whenever given the same command.
2) Reliability. The mechanism and components should be sturdy and cannot be broken easily.
3) Precision.For the turning mechanism, in particular, the response to the command should be precise to be able to perform small turning degrees for smoother control.

## 5.3 Relevance and Interdependence

Speed: to the fastest speed needed, 50 cm/s, the following requirements have to be reached: enough fan thrust, less friction in wheels, the structural integrity of the car body( for eliminating vibrating), and the short converging time of line tracking.

Stable line tracking: to track line, the following requirements have to be reached: minimum noises and errors from the infrared sensors, a fast reaction time, a minimum tolerance in the turning mechanism and the wheels, and a reliable algorithm.

# Chapter 6 System Design

## 6.1 Modified midterm car

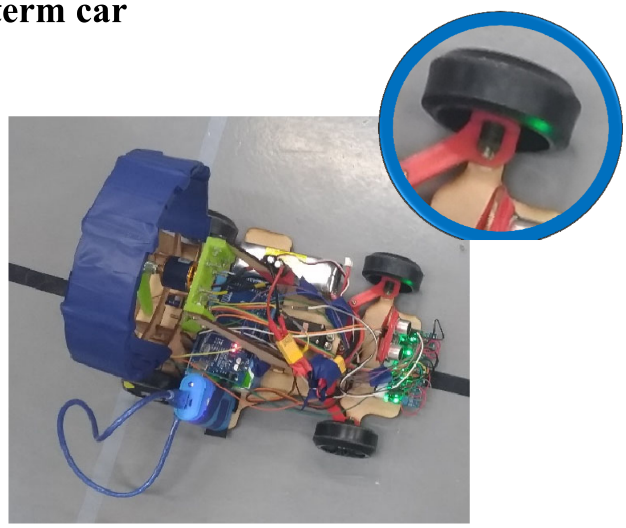
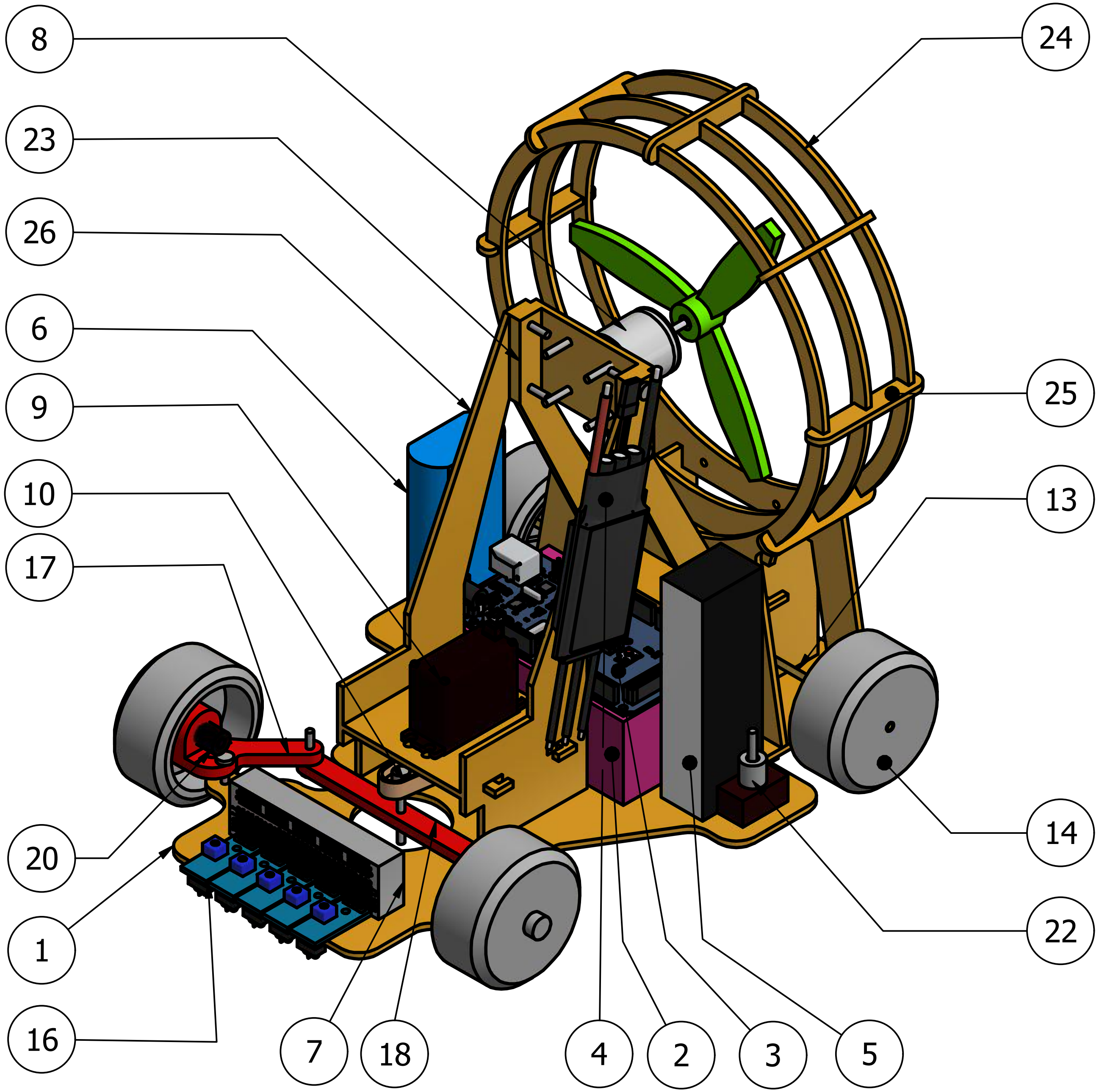


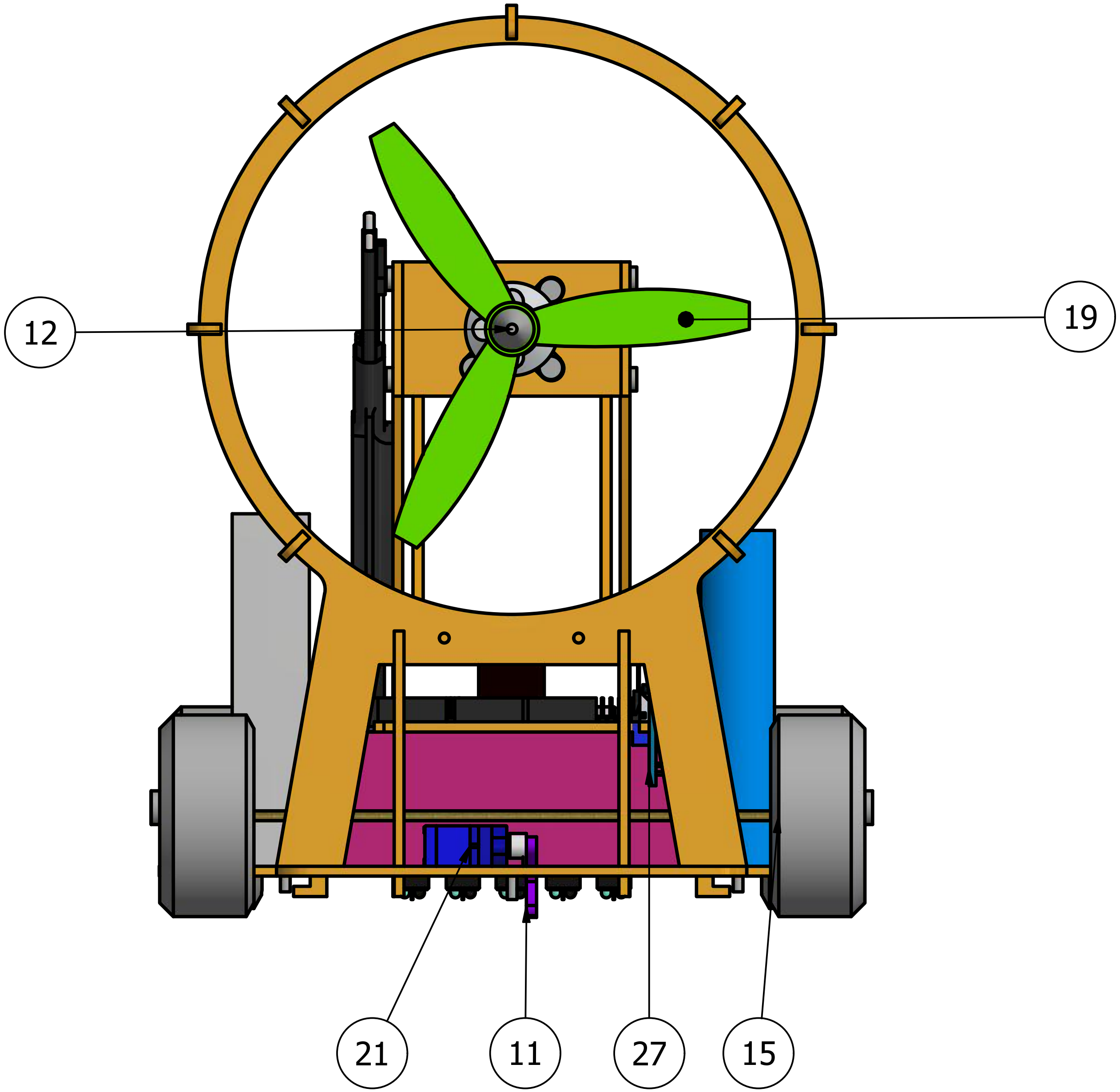
Figure 6.1, 6.2The figures of modified midterm car

### 6.1.1 Engineering drawing



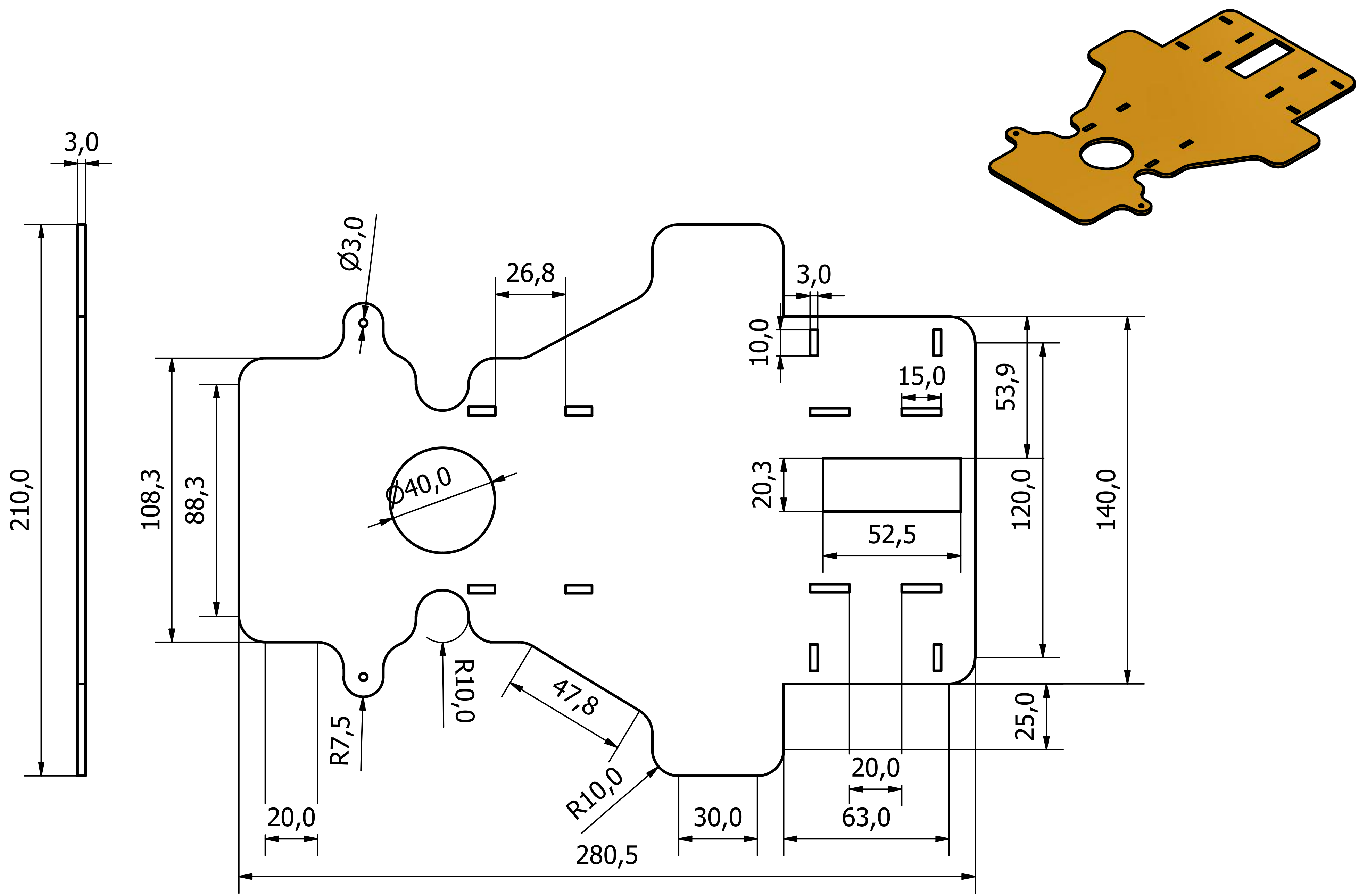

| ITEM | QTY | PART NUMBER |
|---|---|---|
| 1 | 1 | Platform |
| 2 | 1 | Drink |
| 3 | 1 | Arduino |
| 4 | 1 | SkywalkerHobbywing |
| 5 | 1 | Battery |
| 6 | 1 | Power Bank |
| 7 | 1 | Breadboard |
| 8 | 1 | Brushless Motor |
| 9 | 1 | Servo Motor |
| 10 | 1 | ServoMotor Link |
| 11 | 1 | Brake |
| 12 | 1 | Fan Fastener |
| 13 | 1 | Wheel Tube |
| 14 | 4 | Wheel |
| 15 | 1 | Encoder Plate |
| 16 | 5 | Sensor |
| 17 | 1 | Wheel Joint |
| 18 | 1 | Turning Bar |
| 19 | 1 | Fan |
| 20 | 2 | Nut |
| 21 | 1 | Small Servo Motor |
| 22 | 1 | Switch |
| 23 | 1 | Motor Holder |
| 24 | 1 | Fan Cover |
| 25 | 1 | Fan Connector |
| 26 | 1 | Column |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Title | | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 1 | Modified Car | | Scale | 1:2.5 |

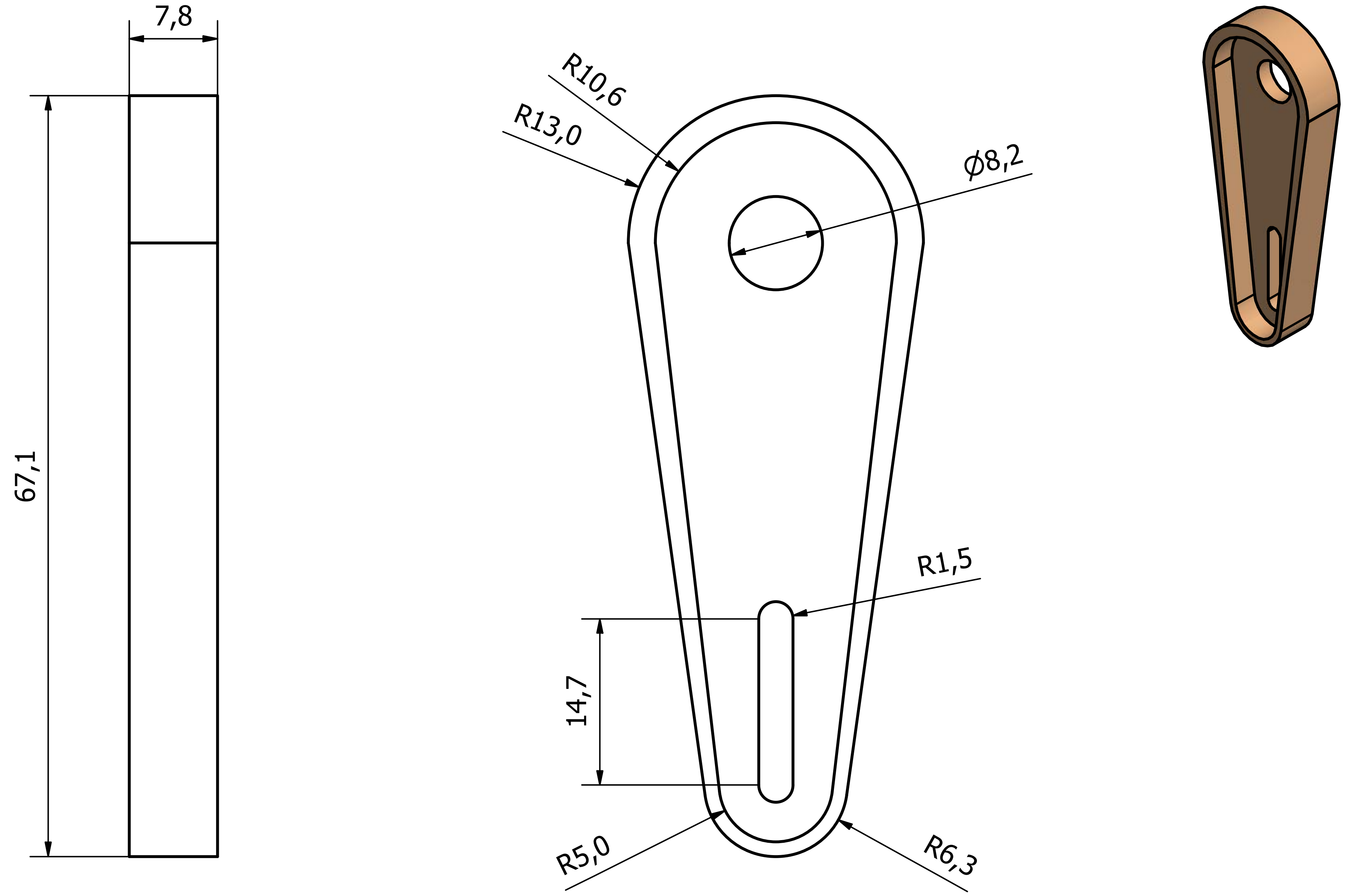



| ITEM | QTY | PART NUMBER |
|---|---|---|
| 1 | 1 | Platform |
| 2 | 1 | Drink |
| 3 | 1 | Arduino |
| 4 | 1 | SkywalkerHobbywing |
| 5 | 1 | Battery |
| 6 | 1 | Power Bank |
| 7 | 1 | Breadboard |
| 8 | 1 | Brushless Motor |
| 9 | 1 | Servo Motor |
| 10 | 1 | ServoMotor Link |
| 11 | 1 | Brake |
| 12 | 1 | Fan Fastener |
| 13 | 1 | Wheel Tube |
| 14 | 4 | Wheel |
| 15 | 1 | Encoder Plate |
| 17 | 1 | Wheel Joint |
| 18 | 1 | Turning Bar |
| 19 | 1 | Fan |
| 20 | 2 | Nut |
| 21 | 1 | Small Servo Motor |
| 22 | 1 | Switch |
| 23 | 1 | Motor Holder |
| 24 | 1 | Fan Cover |
| 25 | 1 | Fan Connector |
| 26 | 1 | Column |
| 27 | 1 | Encoder |

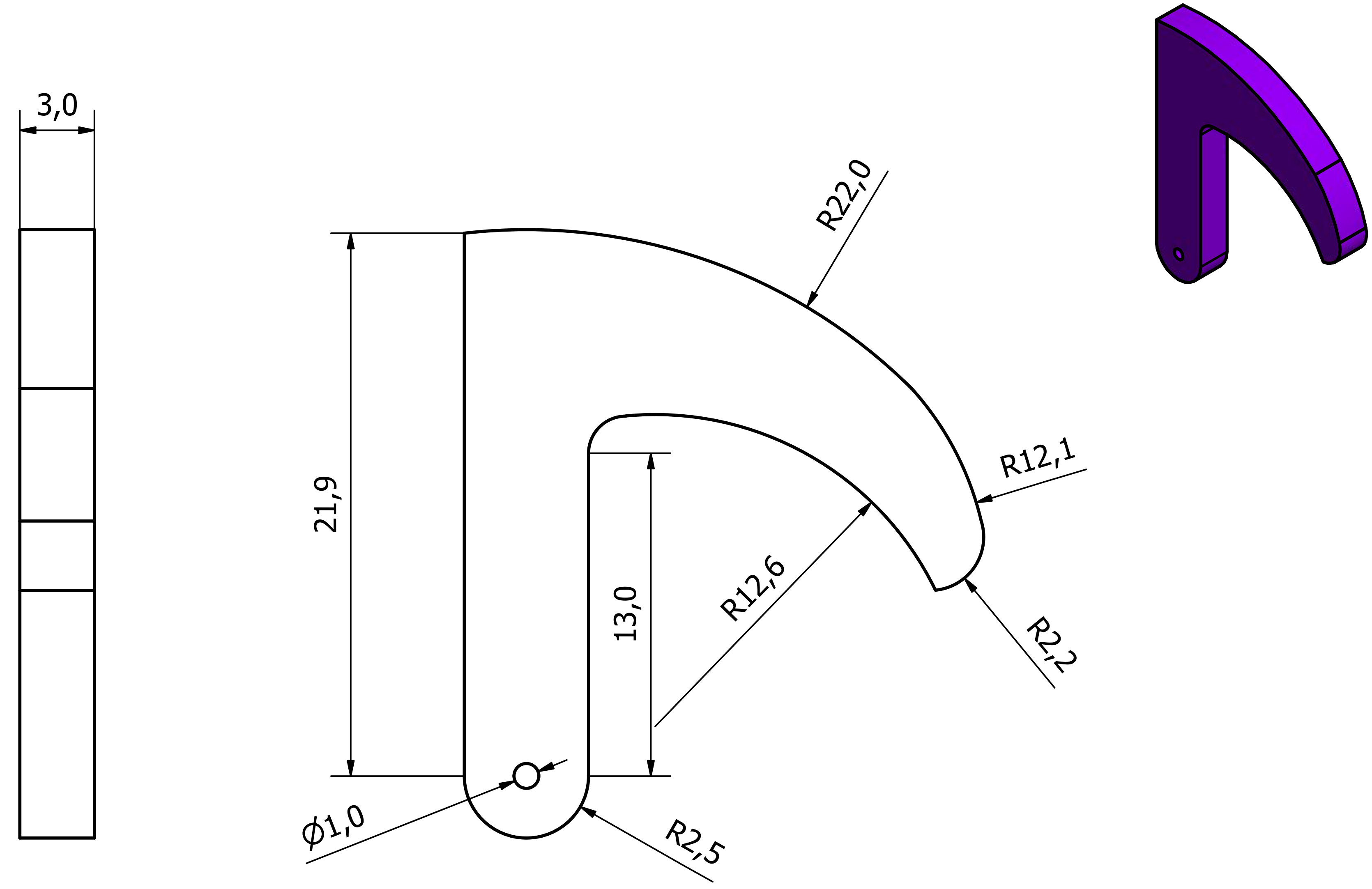
| | | | | | | |
|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Title | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 2 | Modified Car | Scale | 1:2 |



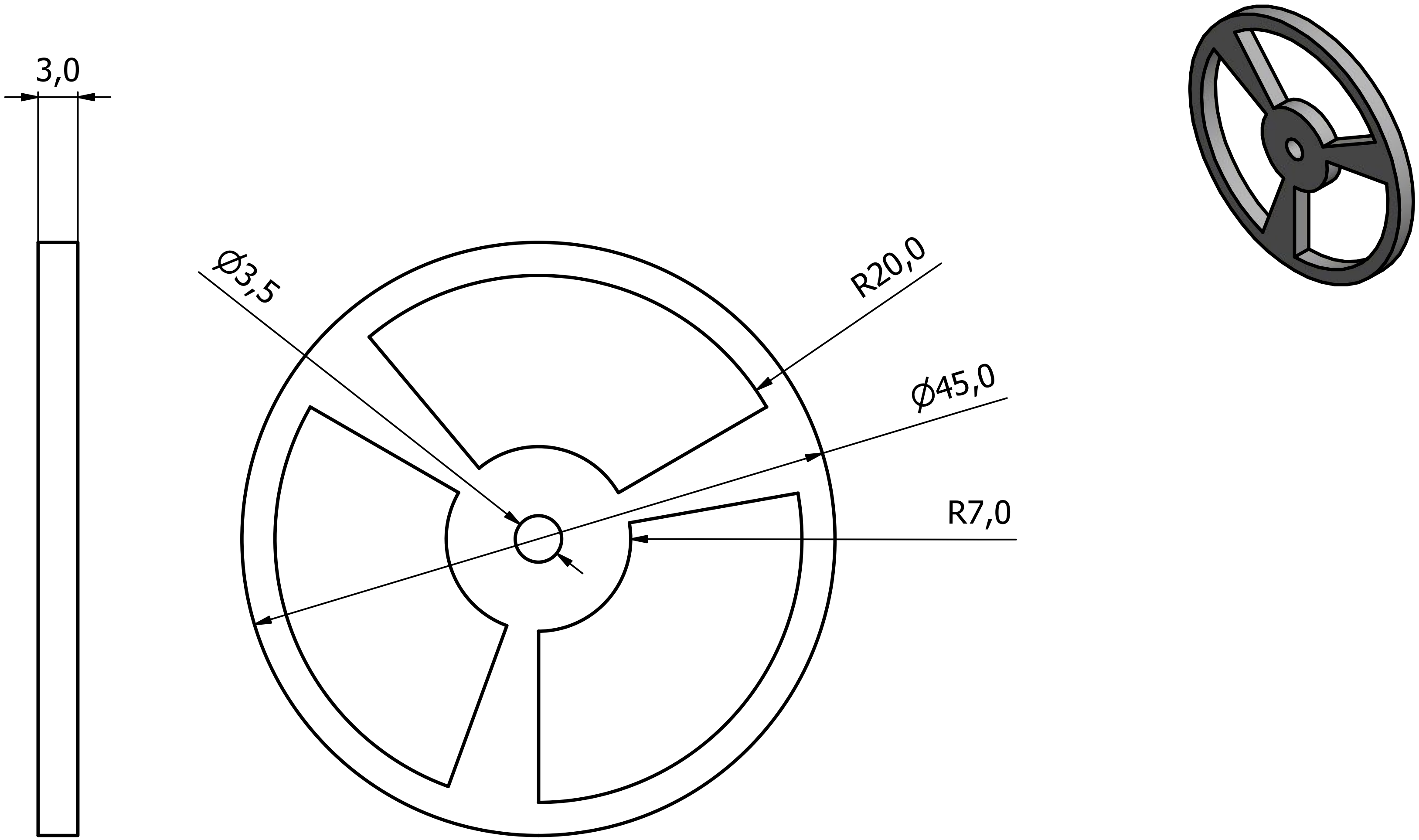

| | | | | | | |
|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Title | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 3 | Platform | Scale | 1:2 |



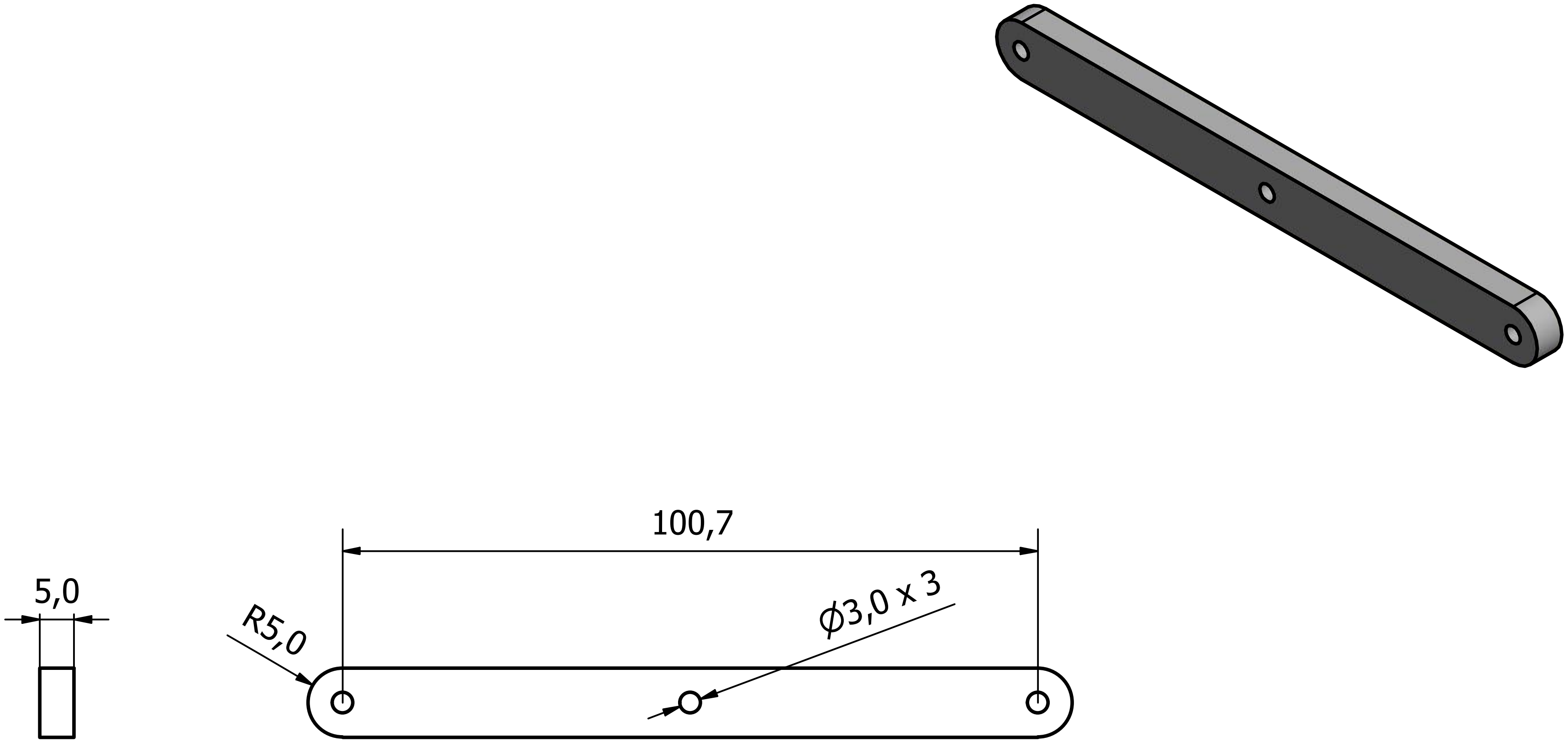

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Title | | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 4 | ServoMotor Link | | Scale | 2:1 |



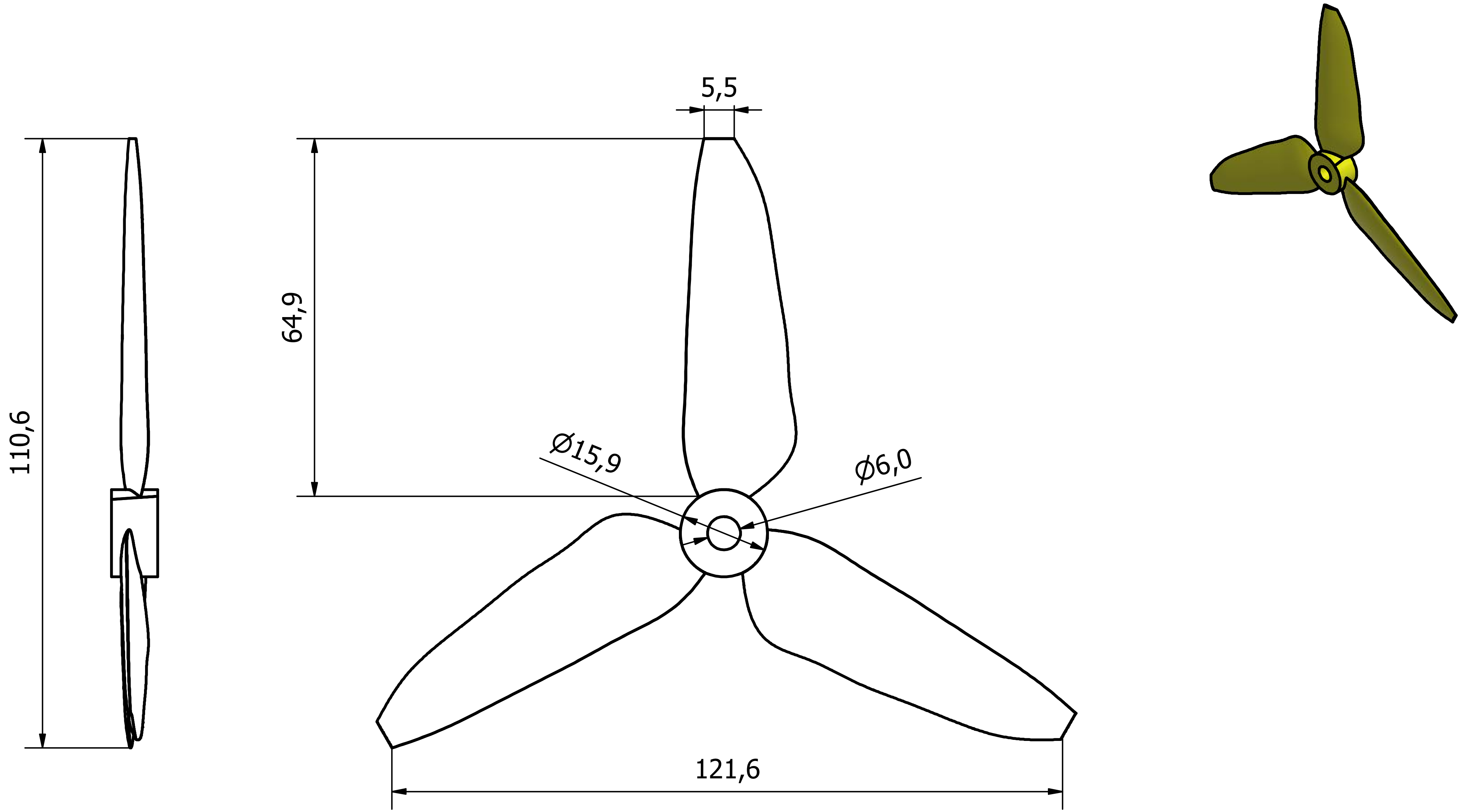

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Title | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 5 | Brake | Scale | 4:1 |



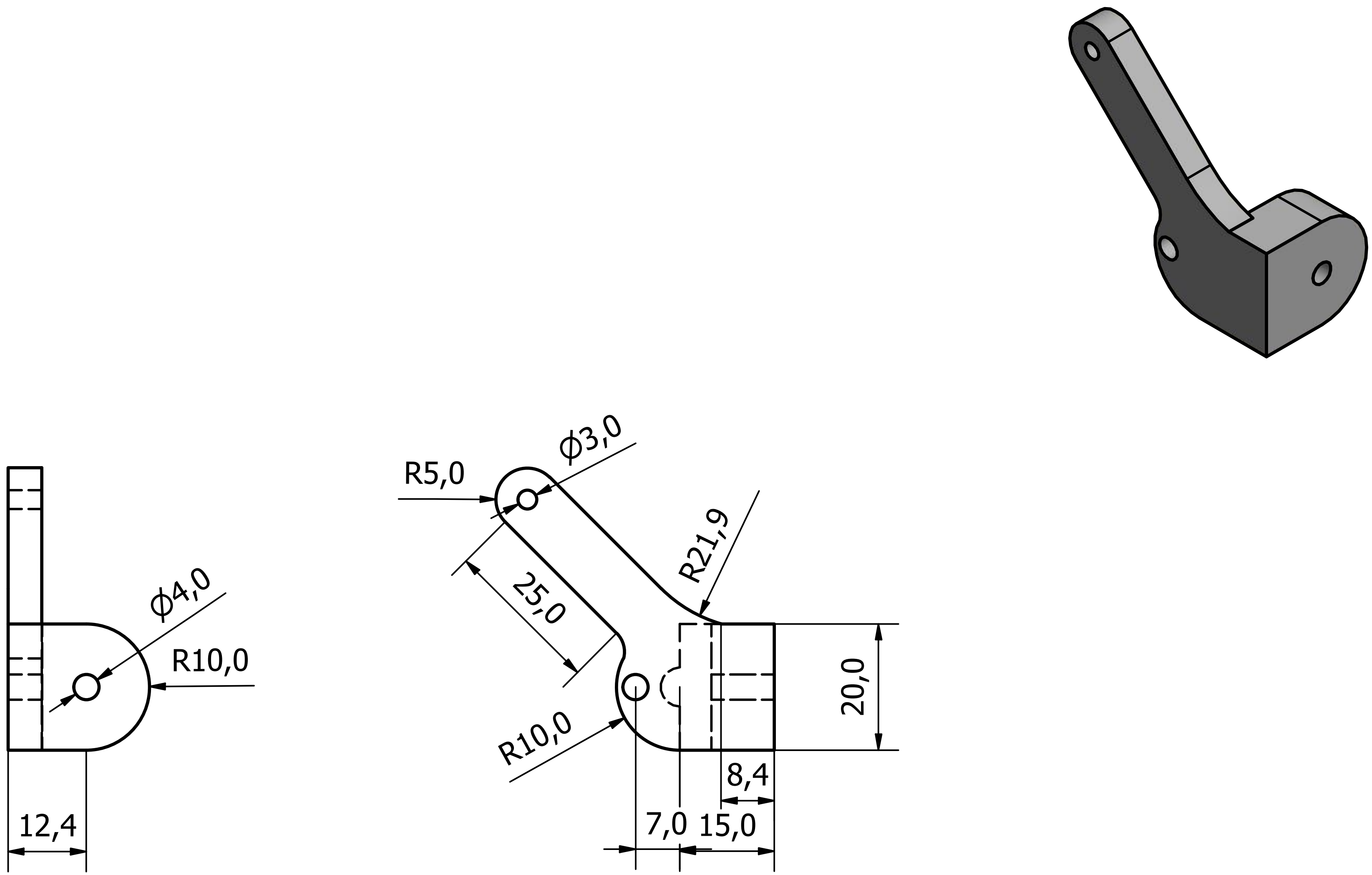

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Title | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 6 | encoder plate | Scale | 2:1 |



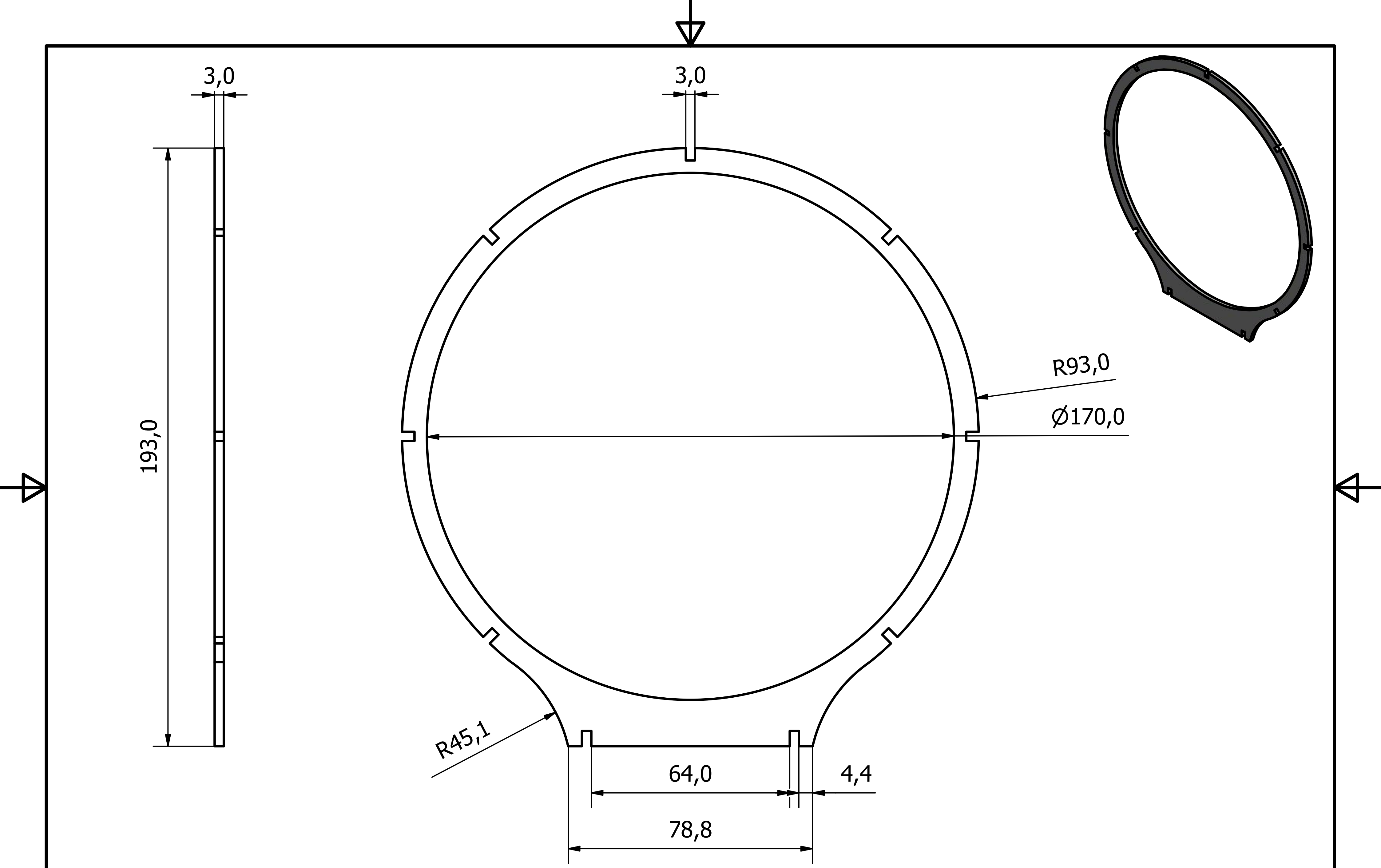

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Title | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 7 | Turning Bar | Scale | 1:1 |



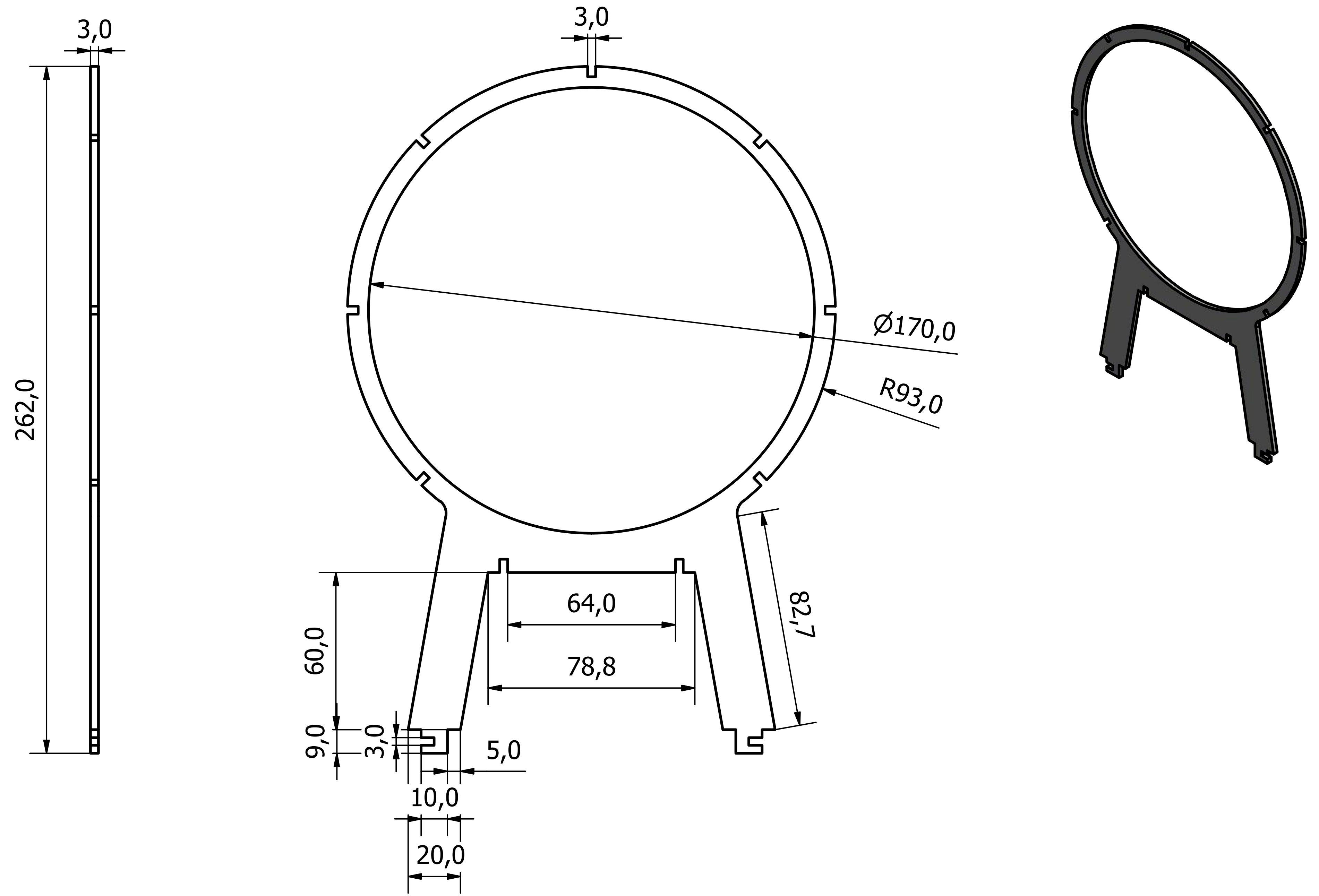

| | | | | | | |
|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Title | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 8 | Fan | Scale | 1:1 |



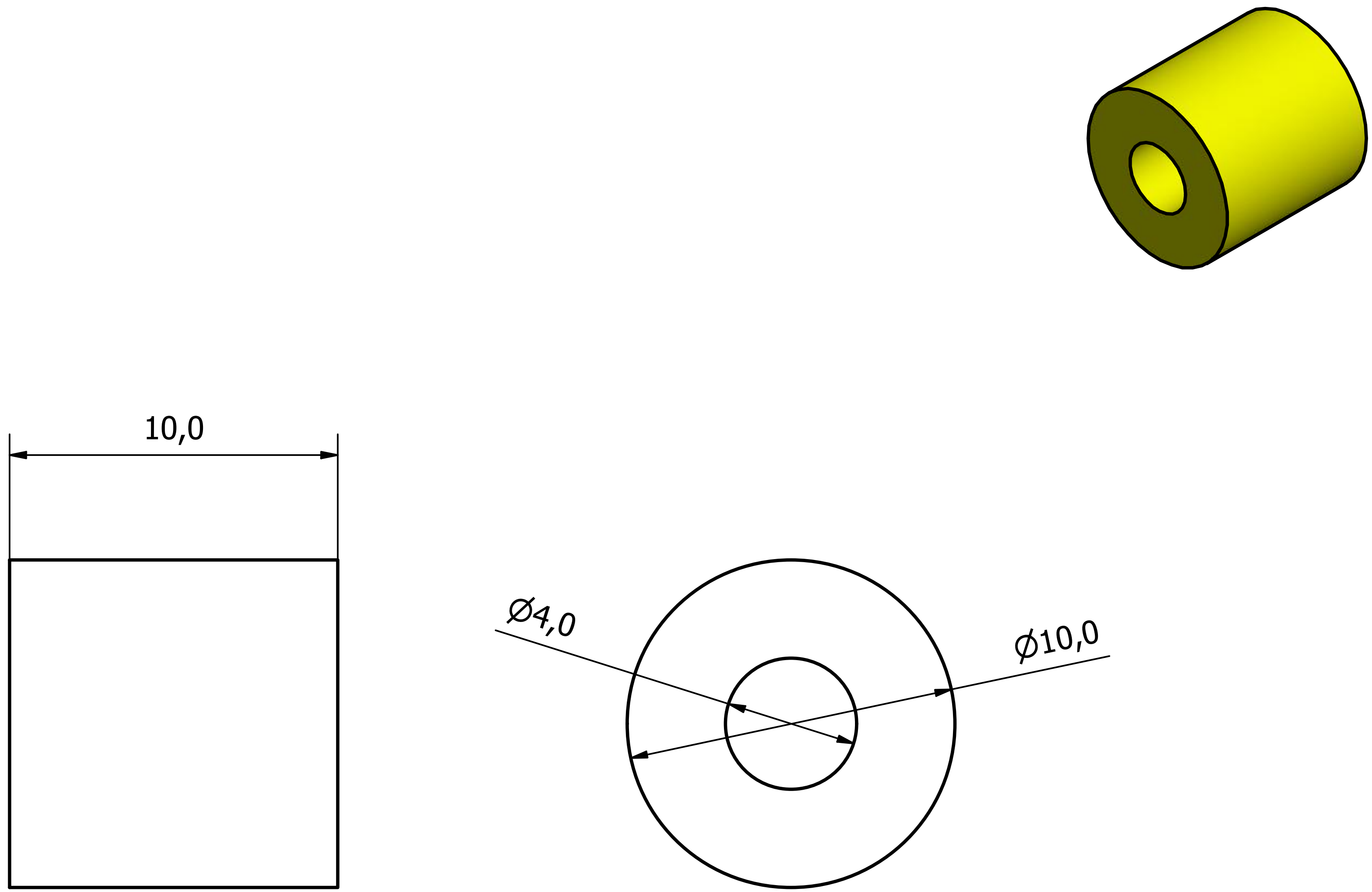

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Title | | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 9 | Wheel Joint | | Scale | 1:1 |



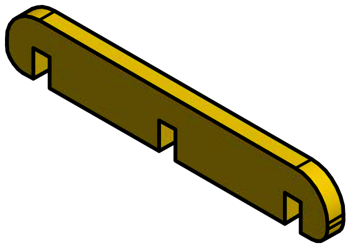

| | | | | | | |
|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Title | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 10 | Fan Cover 2 | Scale | 1:1.5 |

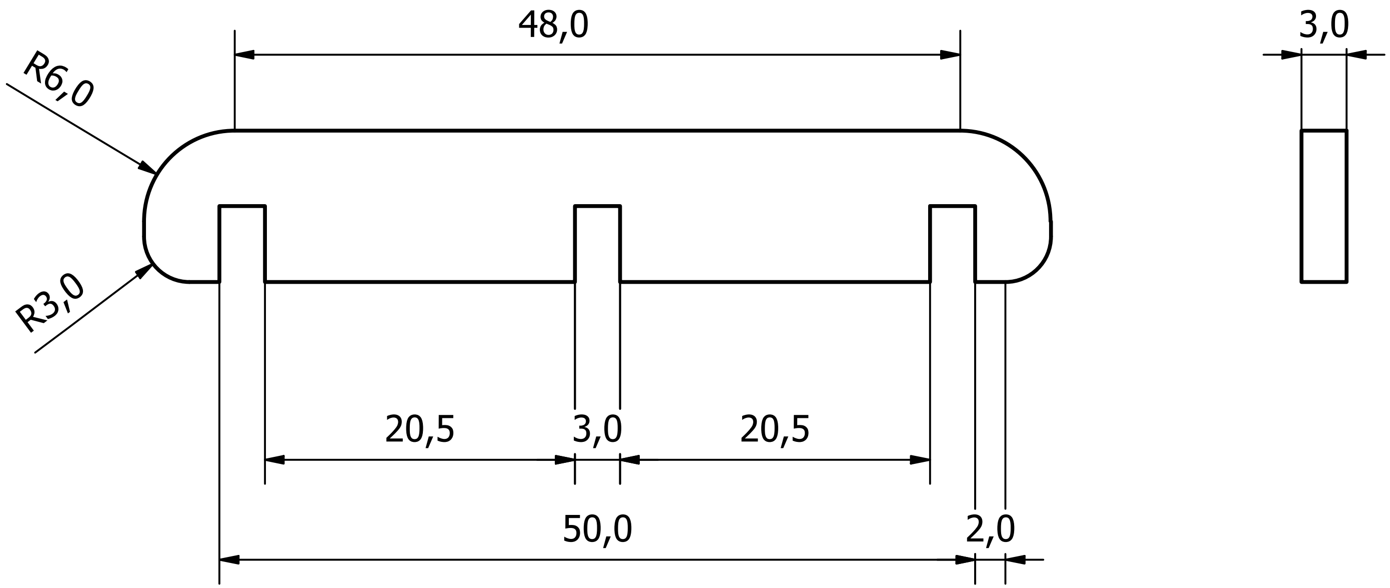



| | | | | | | |
|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Title | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 11 | Fan Cover 1 | Scale | 1:2 |

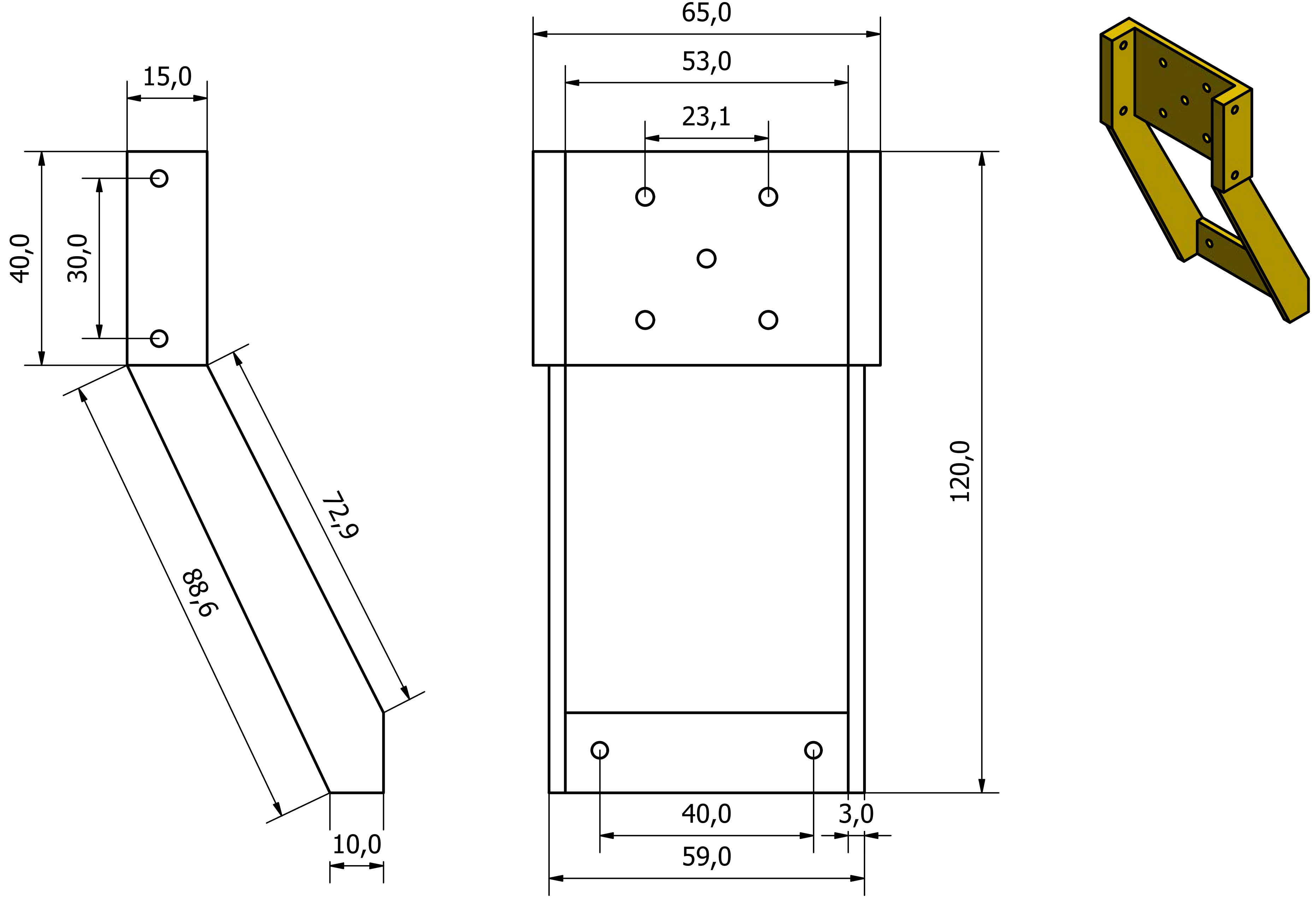



| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Title | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 12 | Nut | Scale | 5:1 |

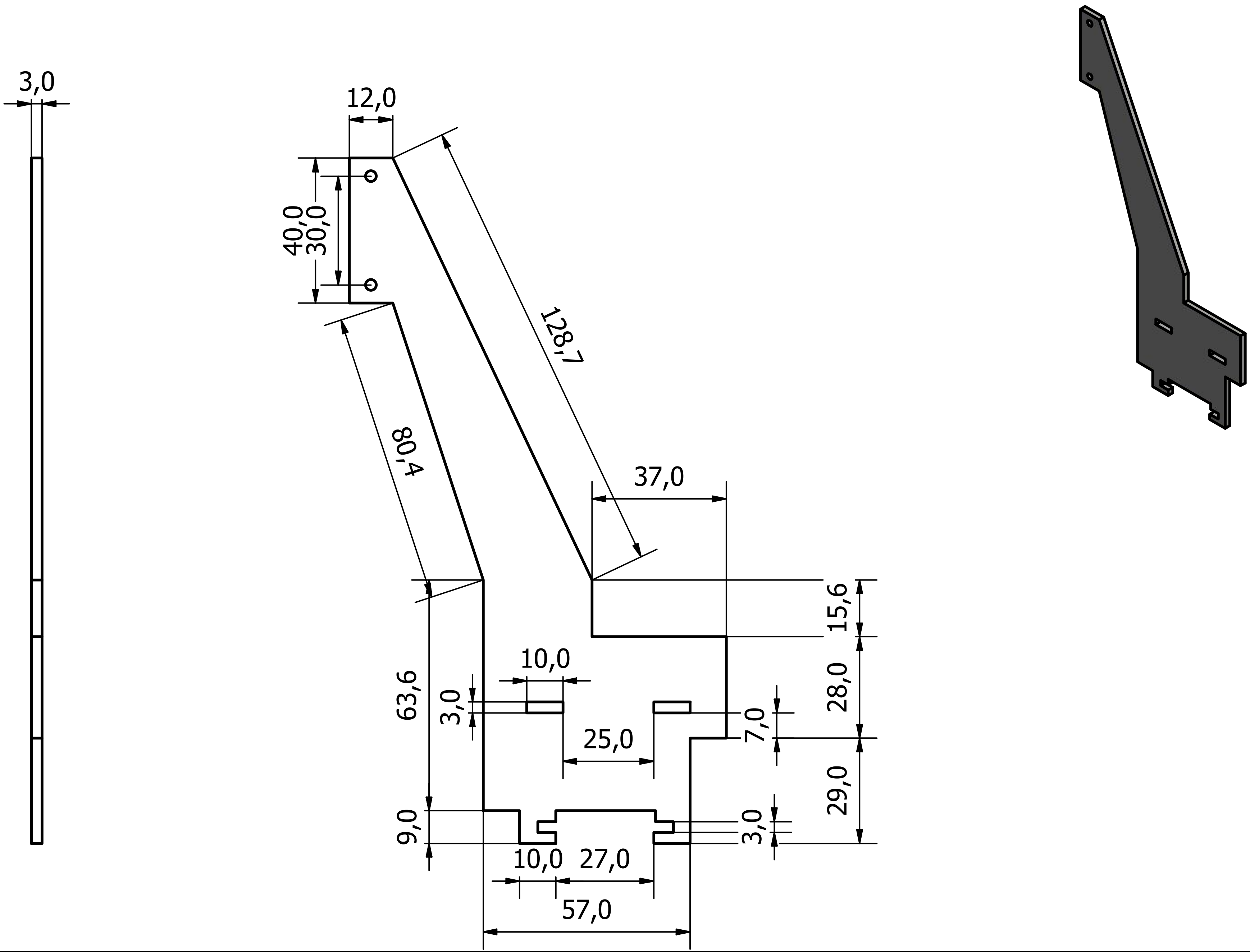





| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Title | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 13 | Fan Connector | Scale | 2:1 |




| | | | | | | |
|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Title | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 14 | Motor Holder | Scale | 1:1 |




| Team | Cheap Sony | Group | 25 - G | Title | Unit | mm |
|---|---|---|---|---|---|---|
| Author | Johanny Alvarado | Sheet No. | 15 | Column | Scale | 1:1.5 |

### 6.1.2 Overall Structure Design

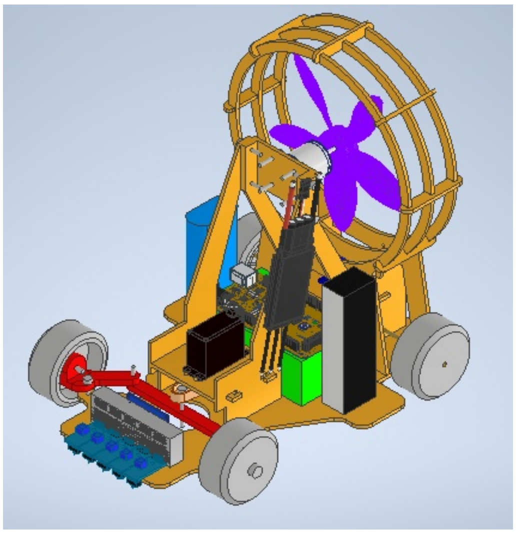


Figure 6.3 Original car model assembly figure

After the mid-term test, we returned to our original model in order to correct the deficiencies. The result is the car model shown in Figure 6.3. The fan structure was reinforced with tape for stability and minimizing drag. The original platform was also modified in order to avoid contact between the platform and the turning mechanism. We used Velcro to fasten the battery and power bank to the platform to avoid them falling from the platform while the car was moving.

The main issue of our original model was that the turning mechanism would get stuck because we were using generic nuts to fasten the wheels to the Ackerman mechanism; when running the car, one wheel would fasten and get stuck do to torque produced by the spinning of the wheel, while the other wheel would de-fasten causing the car to derail due to lack of symmetry. This issue was fixed by using 3D-printed nuts, shown in the zoomed part of Figure 6.2. In just one week, we were able to finish the mid-term track with this model using an improved code. But, we do not regret the decision we made for our mid-term car, since we were able to test our car before the thoroughly before the test, completed our mid-term goals, and got the ideas to effectively improve our original model. Then, we proceeded to change the code to achieve the requirements for the final test. However, due to other issues on our mechanism, we opted for working on a new model. The fan structure was still not as sturdy as we wanted it and the vibration of the car caused the other screws and nuts in the car to fall constantly during testing, which would require adjusting after every test.

### 6.1.3 Electromechanical System

The alternate car is the originally designed car from section 3.5. After clearing the manufacturing issues, the original design worked as intended. The infrared sensors to be used for line tracking capabilities were the TCRT-5000 infrared sensors in a 5 sensor configuration. It emits an infrared signal, which will bounce back and the receptor of the sensor can then send this information to the Arduino. Upon reaching black tape, no light will bounce back to the sensor, and the pin mode will be set to LOW, instead of HIGH which is when some infrared light bounces back. The sensibility of these sensors can be adjusted thanks to a potentiometer that is embedded in the sensor. In addition to changing its turning system motor, the data acquisition method to overtake other cars waschosen. The original idea was to use a configuration of ultrasonic sensors. The most standard model when working with Arduino is normally the HC-SR04 sensor. By itself, it offers remarkable non-contact range detection. The sensor uses sonars to determine a distance. It has four pins: voltage pin, ground pin, and two transmitter pins, namely trig and echo. The trig pin sends a high-frequency sound, which will then bounce back from an object, and the other pin, echo, will send a signal back to the Arduino. The time it takes between the transmission and reception of the signal can then be used to calculate the distance to an object. Note that the velocity of sound through air is known. The duration of the signal is divided by two and multiplied by 0.0343 to obtain the distance in centimeters.

Experimentation was done to know the accuracy of the sensor. Without any other component working alongside the sensor, i.e. only the sensor, the Arduino, and its power supply, the sensor measured distance accurately. The serial monitor of the Arduino IDE displayed the distance between the sensor and a flat surface. The sensor measured any change of distance remarkably fast. A brushless DC motor was connected to the Arduino. If an object reaches a certain distance, the motor will stop. There was practically no noticeable delay between the proximity of the flat surface to the stoppage time of the motor. However, the sensor was discarded from the final design. Upon testing with the car assembly, there was a noticeable delay. While this issue was closely related to the delay implementation on our Arduino code, changing our delay parameters would affect the performance of other crucial components such as the encoder. Therefore, we migrated towards another alternative, i.e. the use of a Bluetooth module to share encoder information between the two cars, this way both Arduinos would know the current position of the other car. Below we provide the diagram of the car.

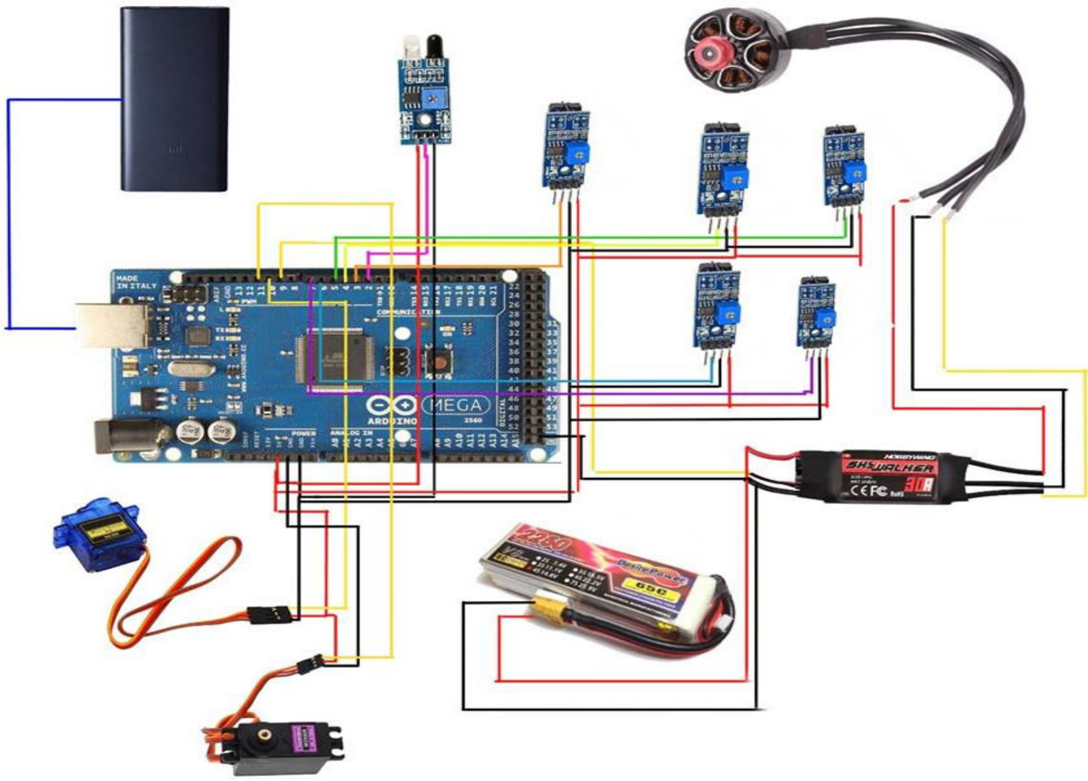



Figure 6.4Circuit diagram of the revised midterm car

### 6.1.4 System Control

The control systems of the car were divided into three sections: line tracking, speed control, and car avoidance.

The line tracking algorithm works in tandem with the Ackerman system, a five infrared sensor configuration, and its corresponding servo motor. The main logic of the algorithm was divided into three different functions. The first ones are the infrared sensor configurations. There are a total of 10 different states, which will each give a value for the error. If the middle IR sensor is directly on top of the black tape, it will be a zero error state. If the leftmost or rightmost sensor is on the black tape, it will be a negative 4 error or positive 4 error respectively. This means that the range of error goes from negative four to positive four, depending on which sensors are on the black tape, for a total of 8 states. The two remaining states belong to either all sensors are detecting black tape, or no sensor is on the black tape. The second function is the actual brains of the operation. A PID algorithm was fitted into the Arduino code. Depending on each value of error, and selected gains for the PID values, the servo motor will then do the control effort necessary to keep the error to zero. Upon some PID tuning, it was noticeable that perhaps just PD was enough. The final function is then depending on what value does the PID algorithm yields, what should the servo motor do in return.

For speed control, an IR sensor and encoder was used. This will count the rotations of the back wheel. Already knowing the dimensions of the back wheel will then allow us to calculate the distance traveled, given how Arduino can count time. In contrary to the midterm, the velocity was to be set constant.

For car overtaking, the original idea was to use two ultrasonic sensor configurations, one in the front and one on the left side. Upon a traveled distance, as measured by the encoder, the car will switch “lanes” and once the ultrasonic sensor on the left detected more than the distance between the two cars, the car would merge back to the original “lane.” This idea was not put into the testing stage since our group and the other group agreed on the Bluetooth method, which will be detailed in the second final car design.

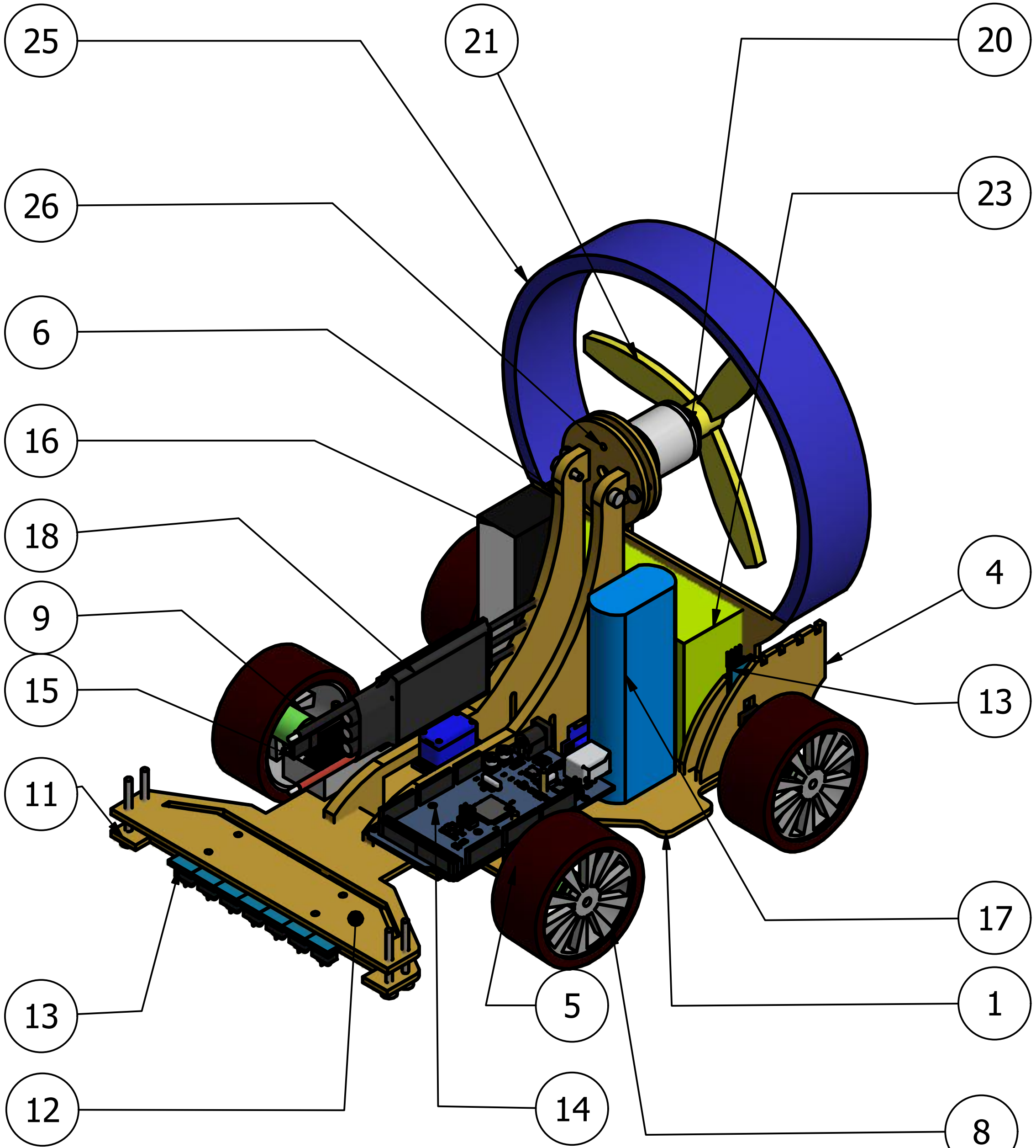
### 6.1.5 Analysis of System

The performance is adequate for all the requirements of the final test. The speed of the car is higher enough, while still retain tracking ability. The precision of the turning system is lacking, making the car unable to control the direction use subtle degree changes. However, due to the robustness of the control algorithm, the care can track the line, though the oscillation is pronounced. However, there is a fatal flaw in the speed control. To avoid running out of the track, the car slows down automatically whenever all the infrared sensors are not detecting. This approach works very well in itself, but when running with the other car, the ever-changing speed increases the difficulty of the car following in aconstant distance. It is the main reason that this car is not chosen for the final test.

## 6.2 Second car

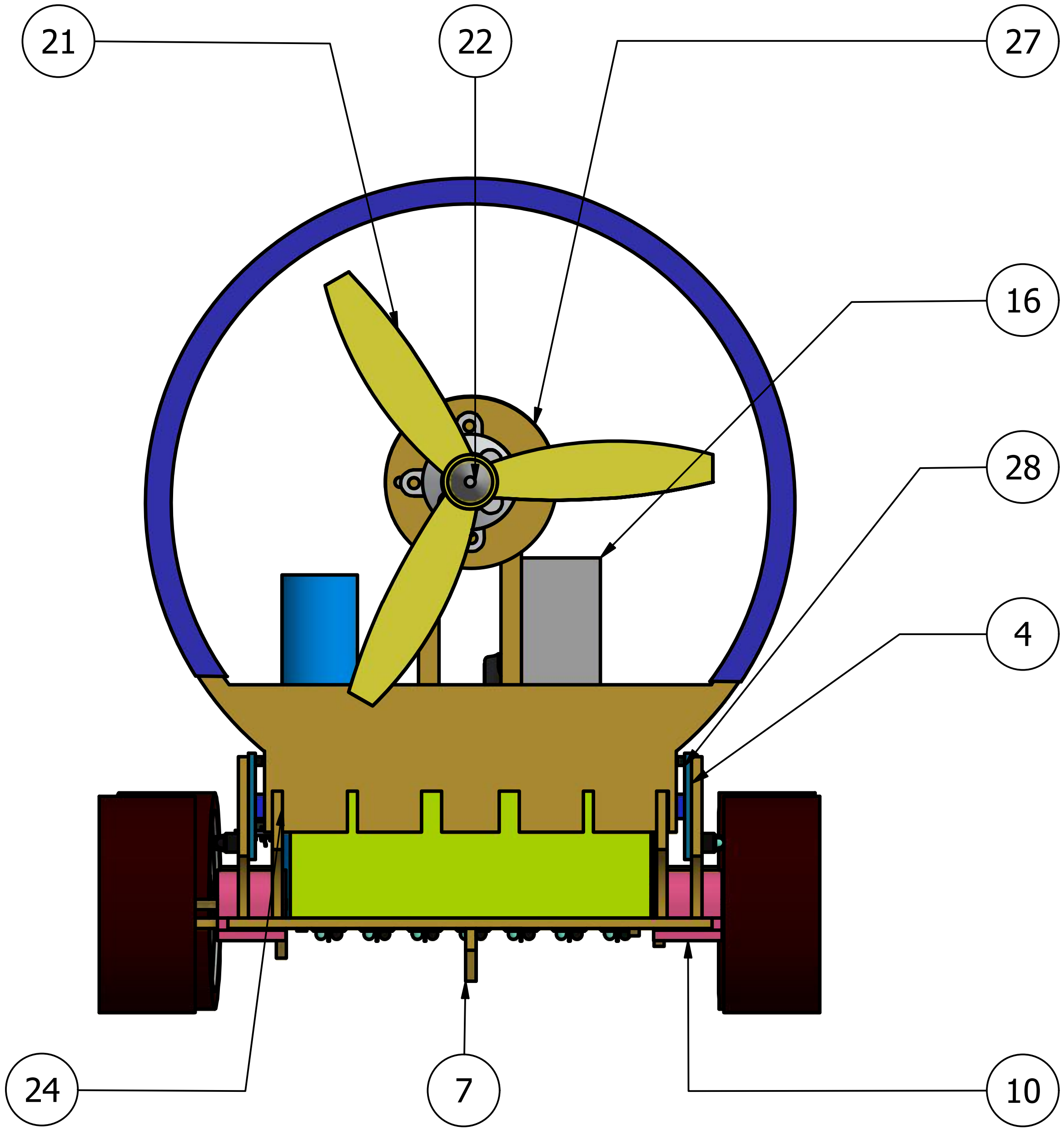

Figure 6.5 The second car, and also the car used for the final test

### 6.2.1 Engineering drawing



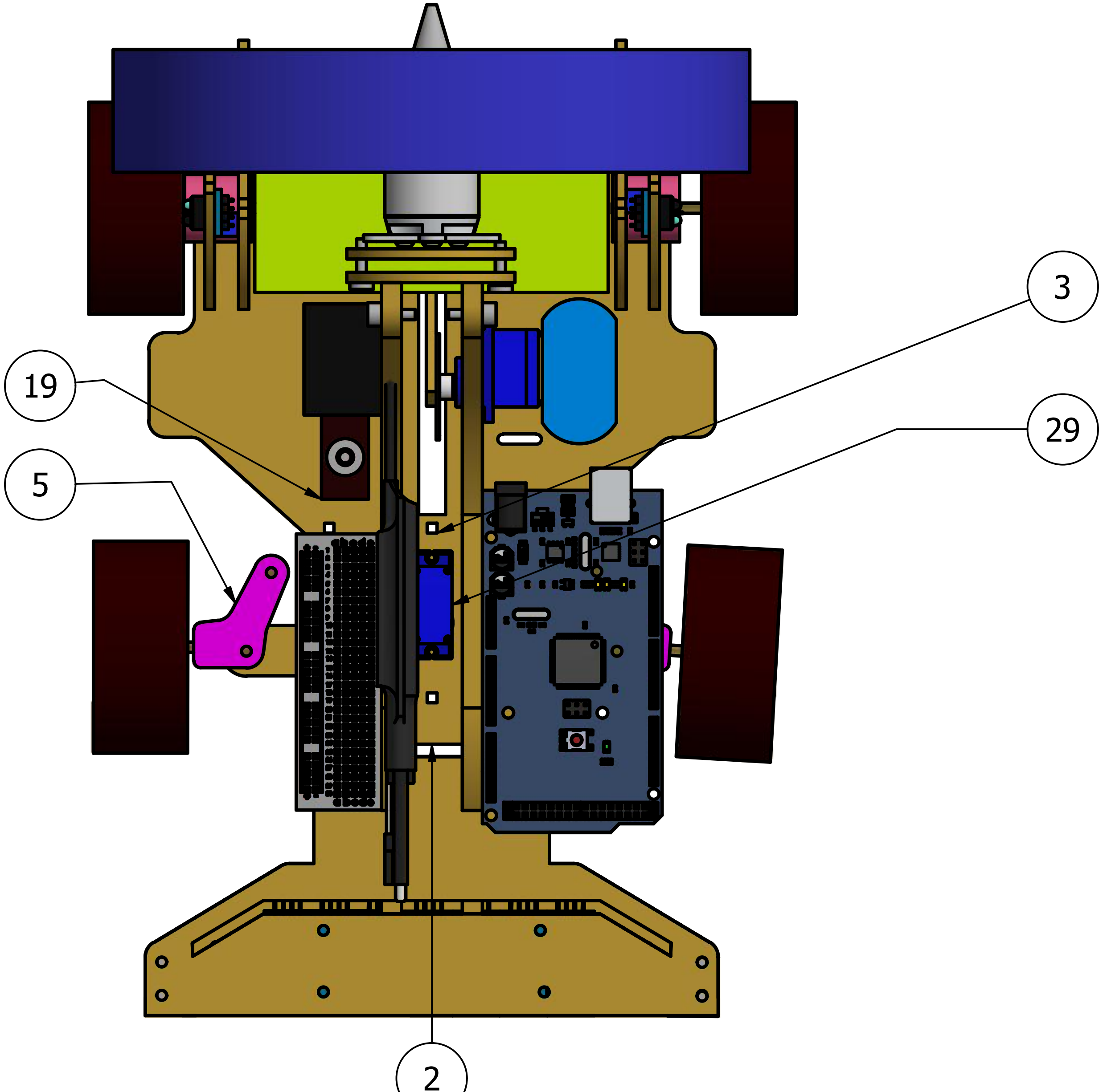

| ITEM | QTY | PART NUMBER |
|---|---|---|
| 1 | 1 | Main Platform |
| 2 | 2 | Front Column |
| 3 | 1 | ServoMotor Holder |
| 4 | 2 | Back Column |
| 5 | 1 | Turning Link |
| 6 | 2 | Structure |
| 7 | 1 | Brake |
| 8 | 4 | Wheel |
| 9 | 4 | Bearing |
| 10 | 2 | Connector |
| 11 | 1 | Sensor holder |
| 12 | 1 | Sensor Top |
| 13 | 9 | Sensor TCRT5000 |
| 14 | 1 | Arduino |
| 15 | 1 | Breadboard |
| 16 | 1 | Battery |
| 17 | 1 | Power Bank |
| 18 | 1 | SkywalkerHobbywing |
| 19 | 1 | Switch |
| 20 | 1 | Brushless Motor |
| 21 | 1 | Fan |
| 22 | 1 | Fan Fastener |
| 23 | 1 | Drink |
| 24 | 2 | Cover Holder |
| 25 | 3 | Fan Cover |
| 26 | 1 | Motor Base |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Title | | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 1 | Final Car | | Scale | 1:3 |



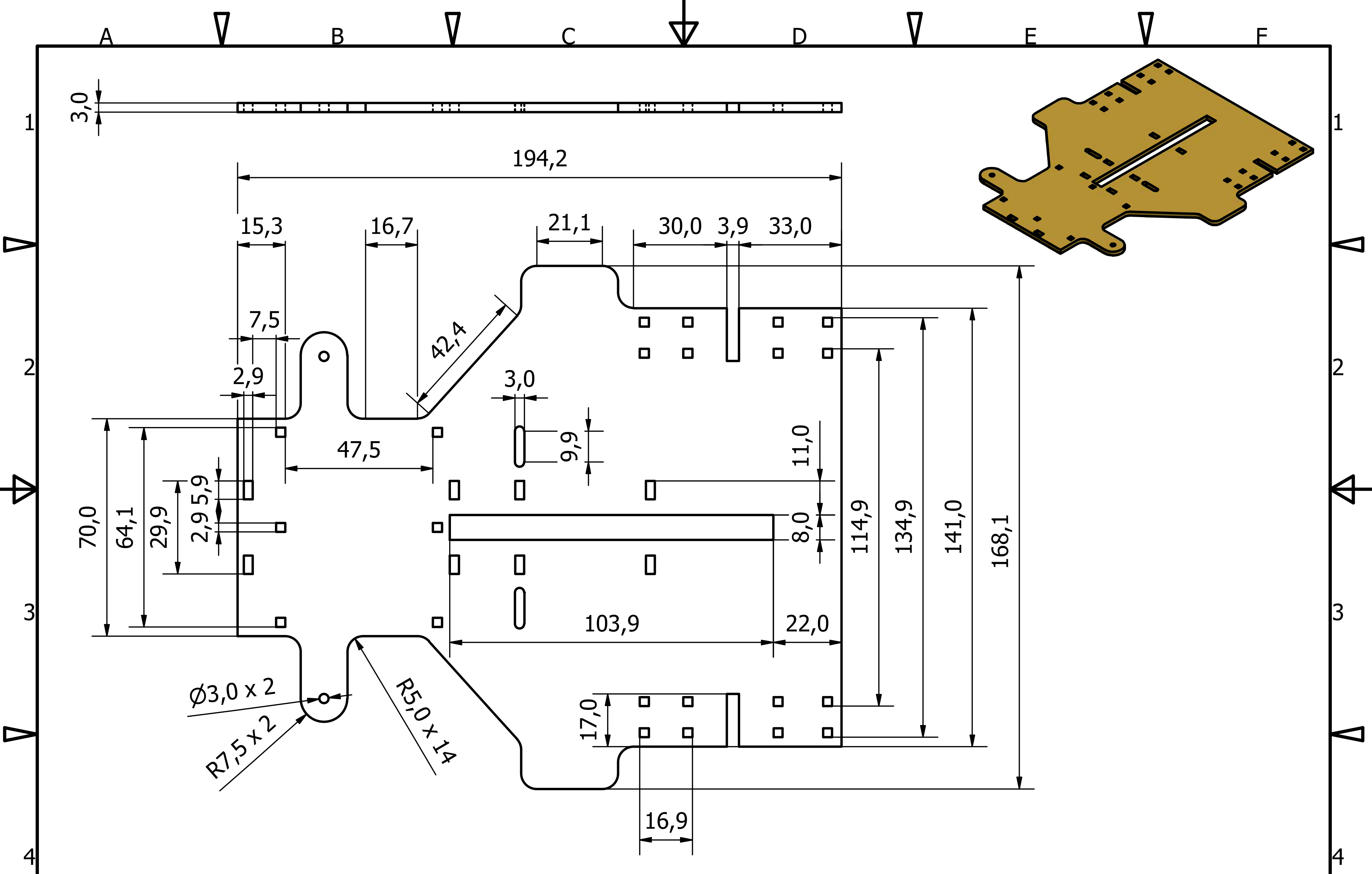

| ITEM | QTY | PART NUMBER |
|---|---|---|
| 1 | 1 | Main Platform |
| 2 | 2 | Front Column |
| 3 | 1 | ServoMotor Holder |
| 4 | 2 | Back Column |
| 5 | 1 | Turning Link |
| 6 | 2 | Structure |
| 7 | 1 | Brake |
| 8 | 4 | Wheel |
| 10 | 2 | Connector |
| 12 | 1 | Sensor Top |
| 13 | 9 | Sensor TCRT5000 |
| 14 | 1 | Arduino |
| 15 | 1 | Breadboard |
| 16 | 1 | Battery |
| 17 | 1 | Power Bank |
| 18 | 1 | SkywalkerHobbywing |
| 19 | 1 | Switch |
| 20 | 1 | Brushless Motor |
| 21 | 1 | Fan |
| 22 | 1 | Fan Fastener |
| 23 | 1 | Drink |
| 24 | 2 | Cover Holder |
| 25 | 3 | Fan Cover |
| 26 | 1 | Motor Base |
| 27 | 1 | Motor Holder |
| 28 | 2 | Encoder |

| | | | | | | |
|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Title | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 2 | Final Car | Scale | 1:2 |

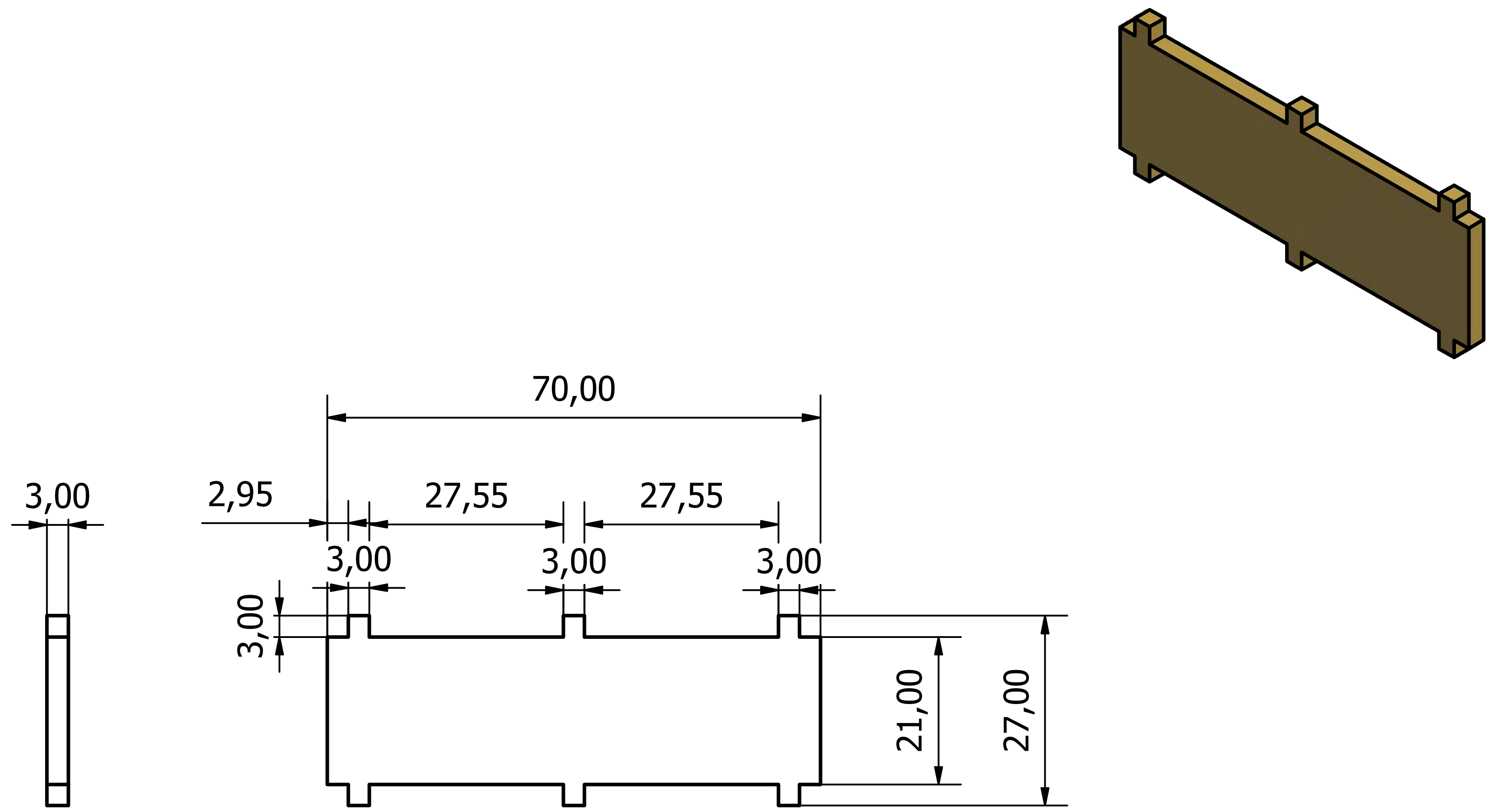



| ITEM | QTY | PART NUMBER |
|---|---|---|
| 1 | 1 | Main Platform |
| 2 | 2 | Front Column |
| 3 | 1 | ServoMotor Holder |
| 4 | 2 | Back Column |
| 5 | 1 | Turning Link |
| 6 | 2 | Structure |
| 7 | 1 | Brake |
| 8 | 4 | Wheel |
| 10 | 2 | Connector |
| 12 | 1 | Sensor Top |
| 13 | 9 | Sensor TCRT5000 |
| 14 | 1 | Arduino |
| 15 | 1 | Breadboard |
| 16 | 1 | Battery |
| 17 | 1 | Power Bank |
| 18 | 1 | SkywalkerHobbywing |
| 19 | 1 | Switch |
| 20 | 1 | Brushless Motor |
| 21 | 1 | Fan |
| 22 | 1 | Fan Fastener |
| 23 | 1 | Drink |
| 24 | 2 | Cover Holder |
| 25 | 3 | Fan Cover |
| 26 | 1 | Motor Base |
| 27 | 1 | Motor Holder |
| 29 | 1 | ServoMotor |

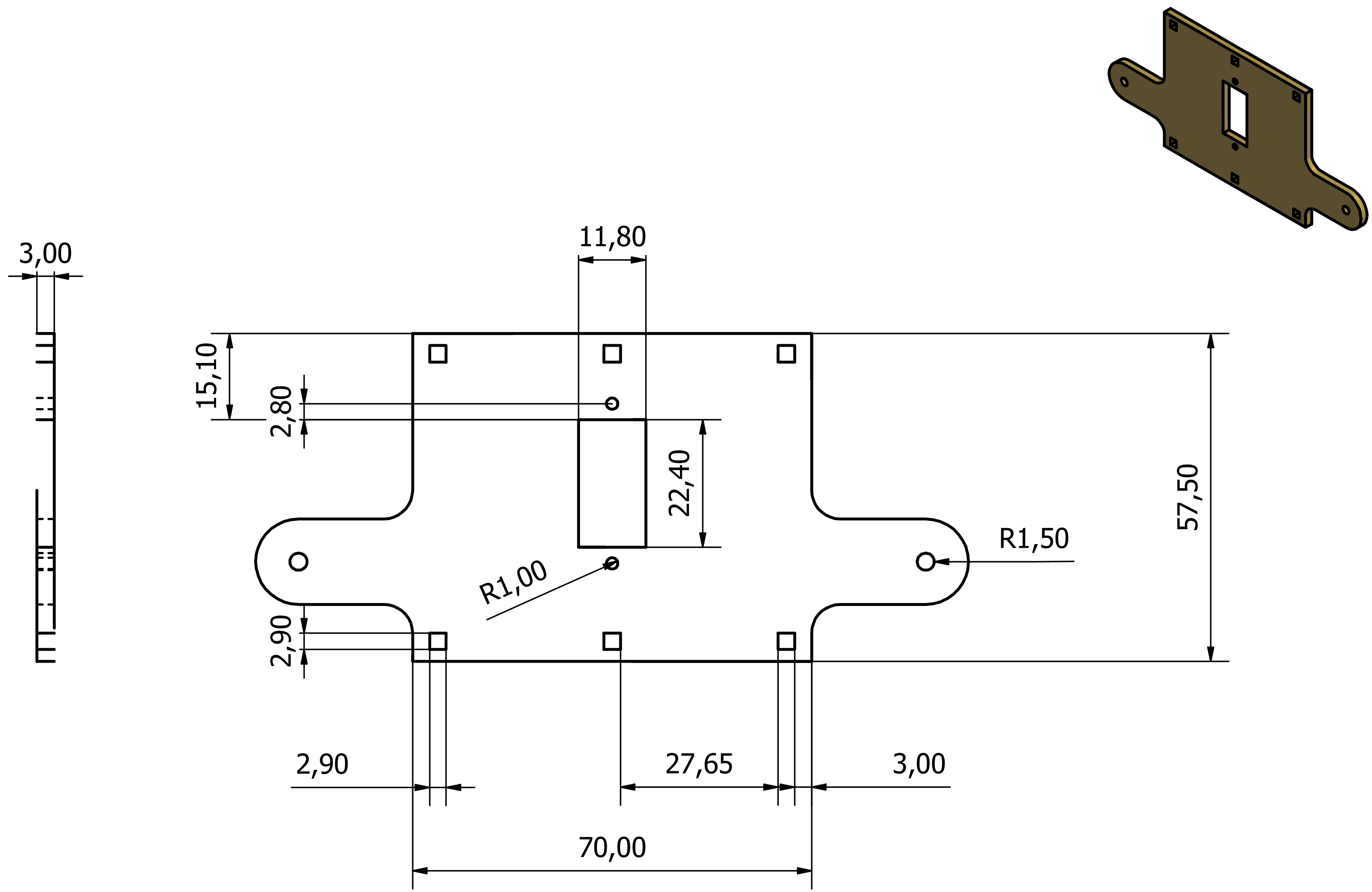
| Team | Cheap Sony | Group | 25 - G | Title | Unit | mm |
|---|---|---|---|---|---|---|
| Author | Johanny Alvarado | Sheet No. | 3 | Final Car | Scale | 1:2 |



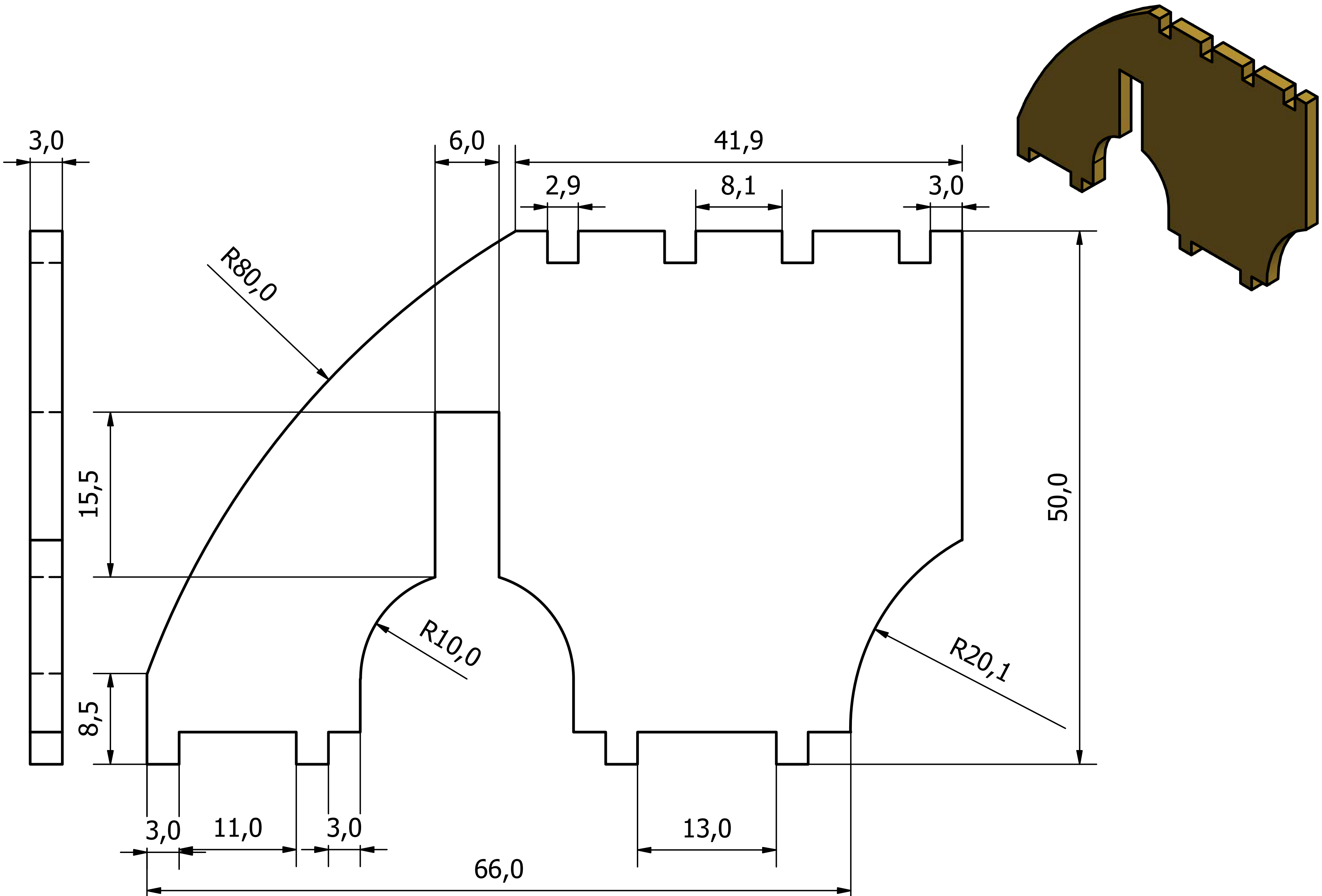

| Team | Cheap Sony | Group | 25 - G | Part Name | Unit | mm |
|---|---|---|---|---|---|---|
| Author | Johanny Alvarado | Sheet No. | 1 | Main Platform | Scale | 1:1.5 |



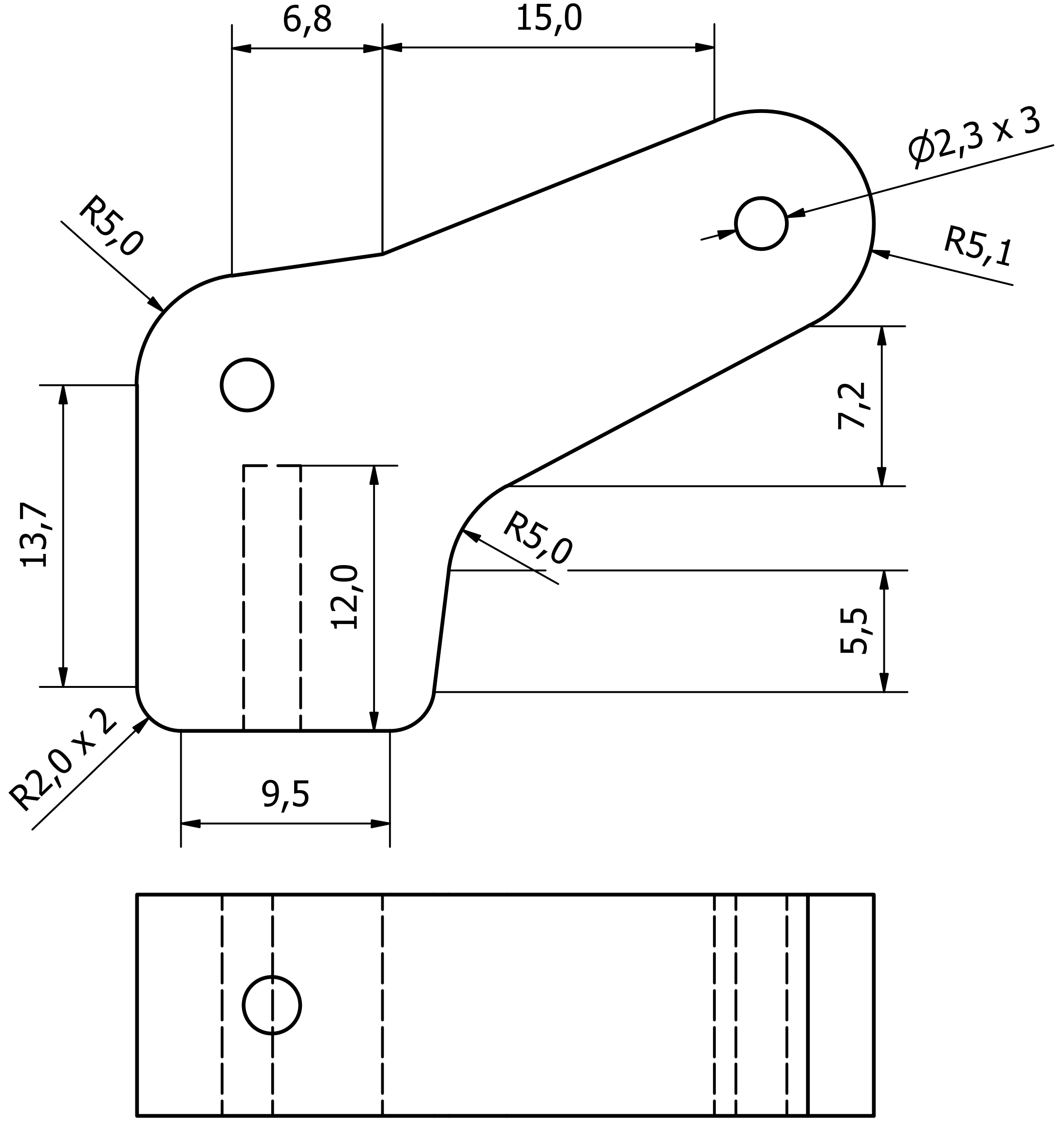

| Team | Cheap Sony | Group | 25 - G | Part Name | Unit | mm |
|---|---|---|---|---|---|---|
| Author | Johanny Alvarado | Sheet No. | 2 | Front Column | Scale | 1:1 |

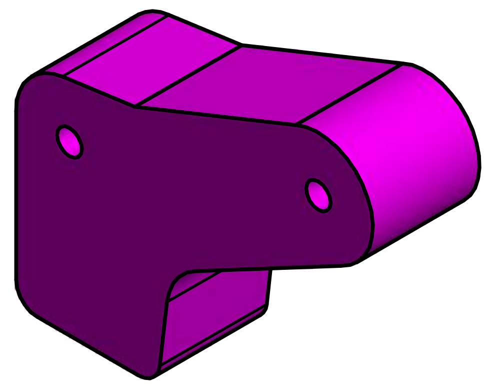



| | | | | | | |
|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Part Name | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 3 | ServoMotor Holder | Scale | 1:1 |

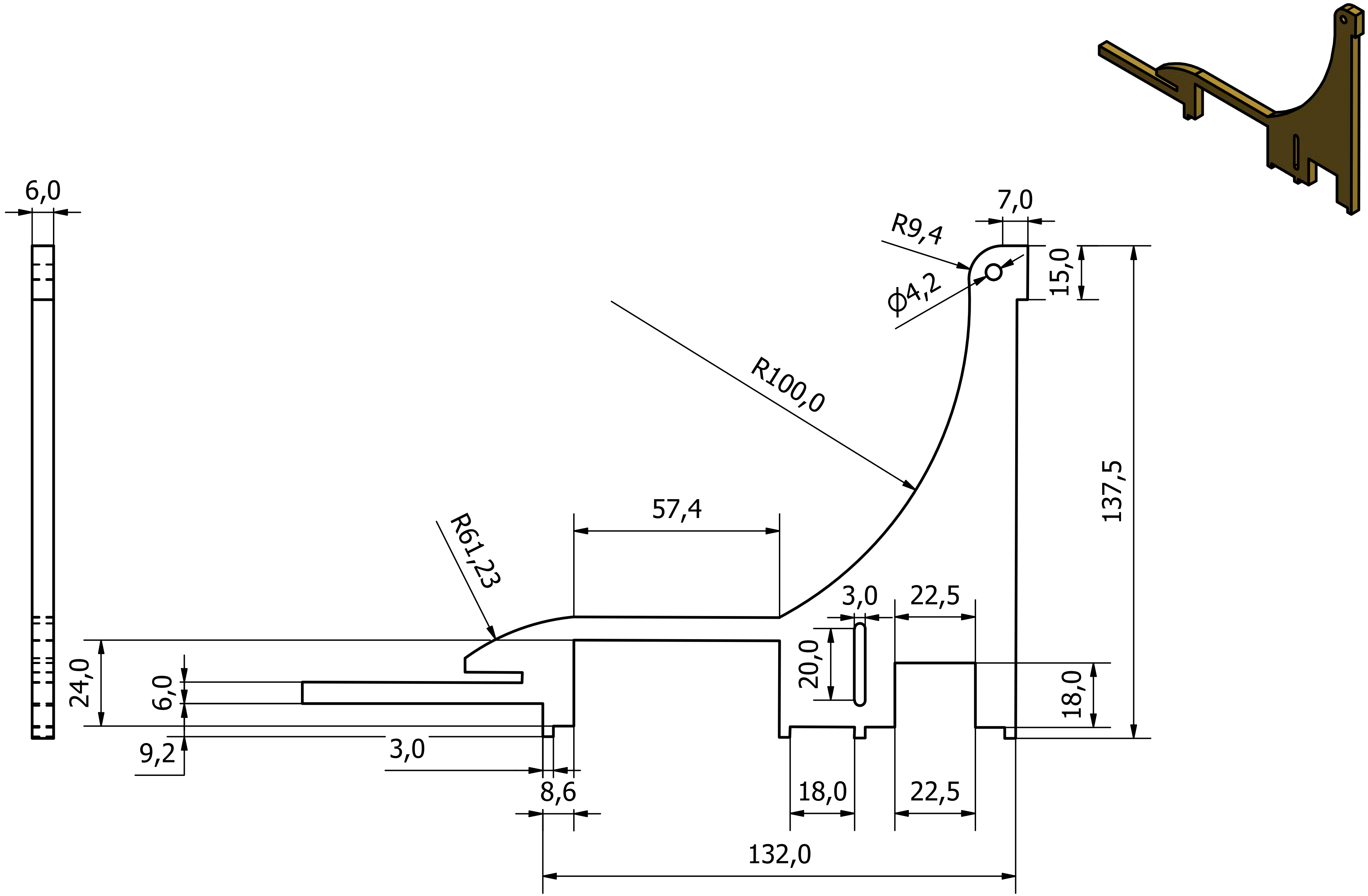



| | | | | | | |
|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Part Name | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 4 | Back Column | Scale | 2:1 |

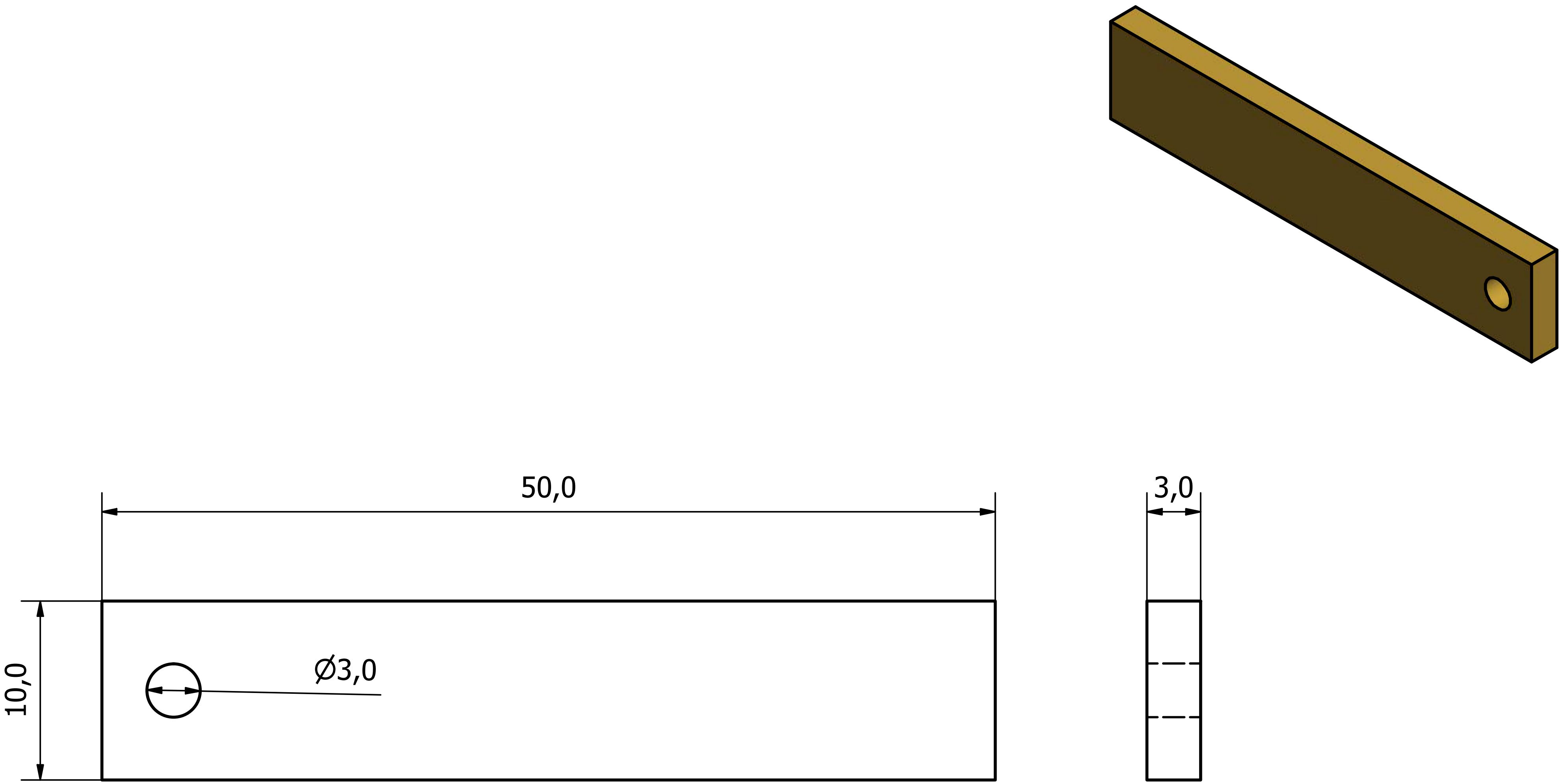


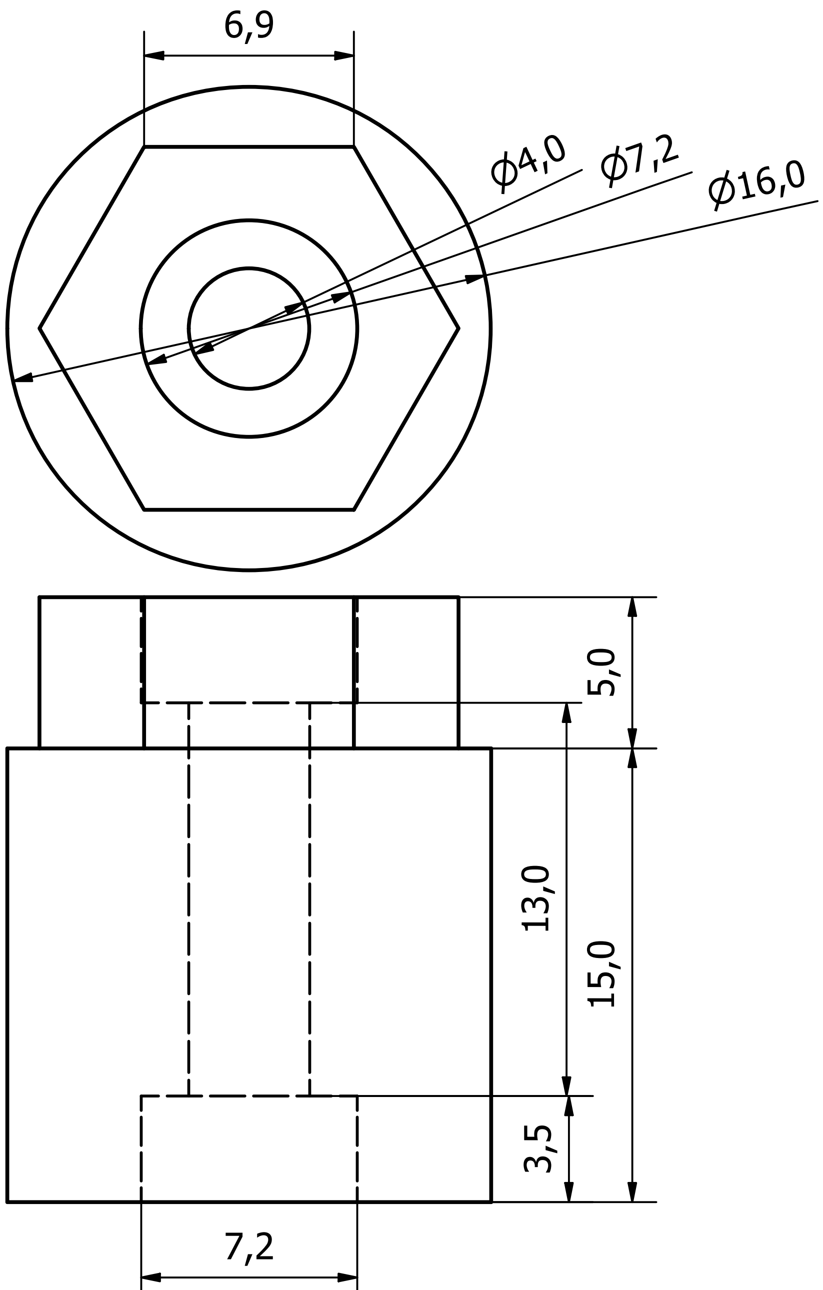
| Team | Cheap Sony | Group | 25 - G | Part Name | Unit | mm |
|---|---|---|---|---|---|---|
| Author | Johanny Alvarado | Sheet No. | 5 | Turning Link | Scale | 3:1 |

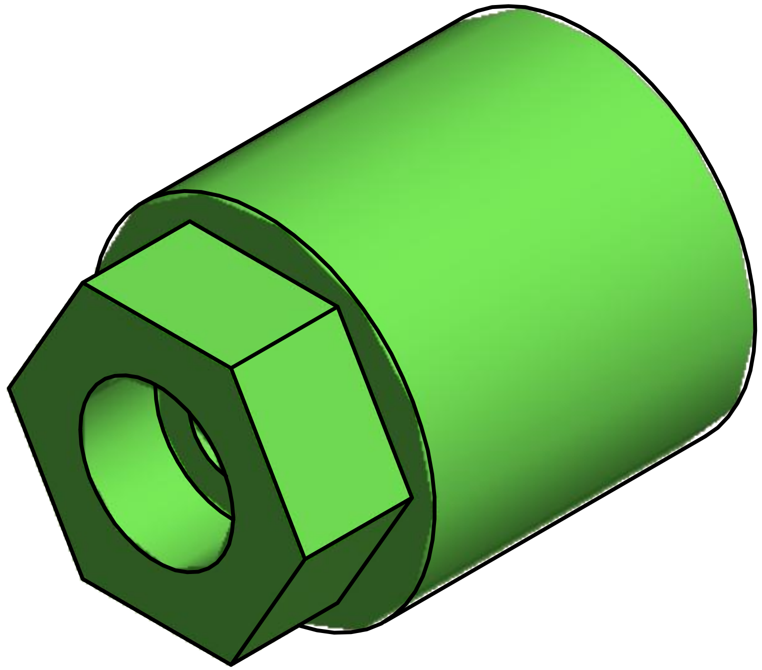



| Team | Cheap Sony | Group | 25 - G | Part Name | Unit | mm |
|---|---|---|---|---|---|---|
| Author | Johanny Alvarado | Sheet No. | 6 | Structure | Scale | 1:1.5 |

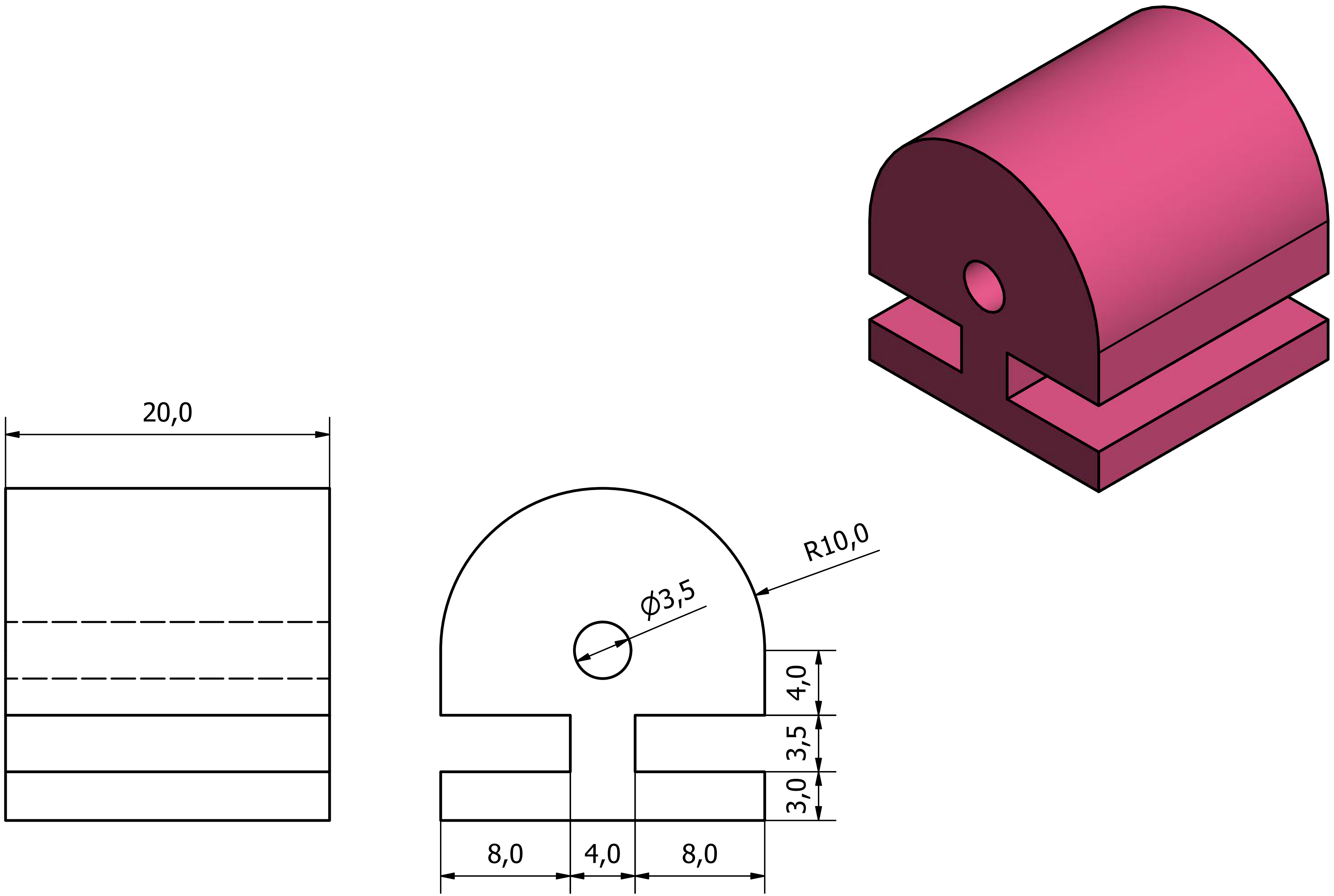



| | | | | | | |
|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Part Name | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 7 | Brake | Scale | 3:1 |

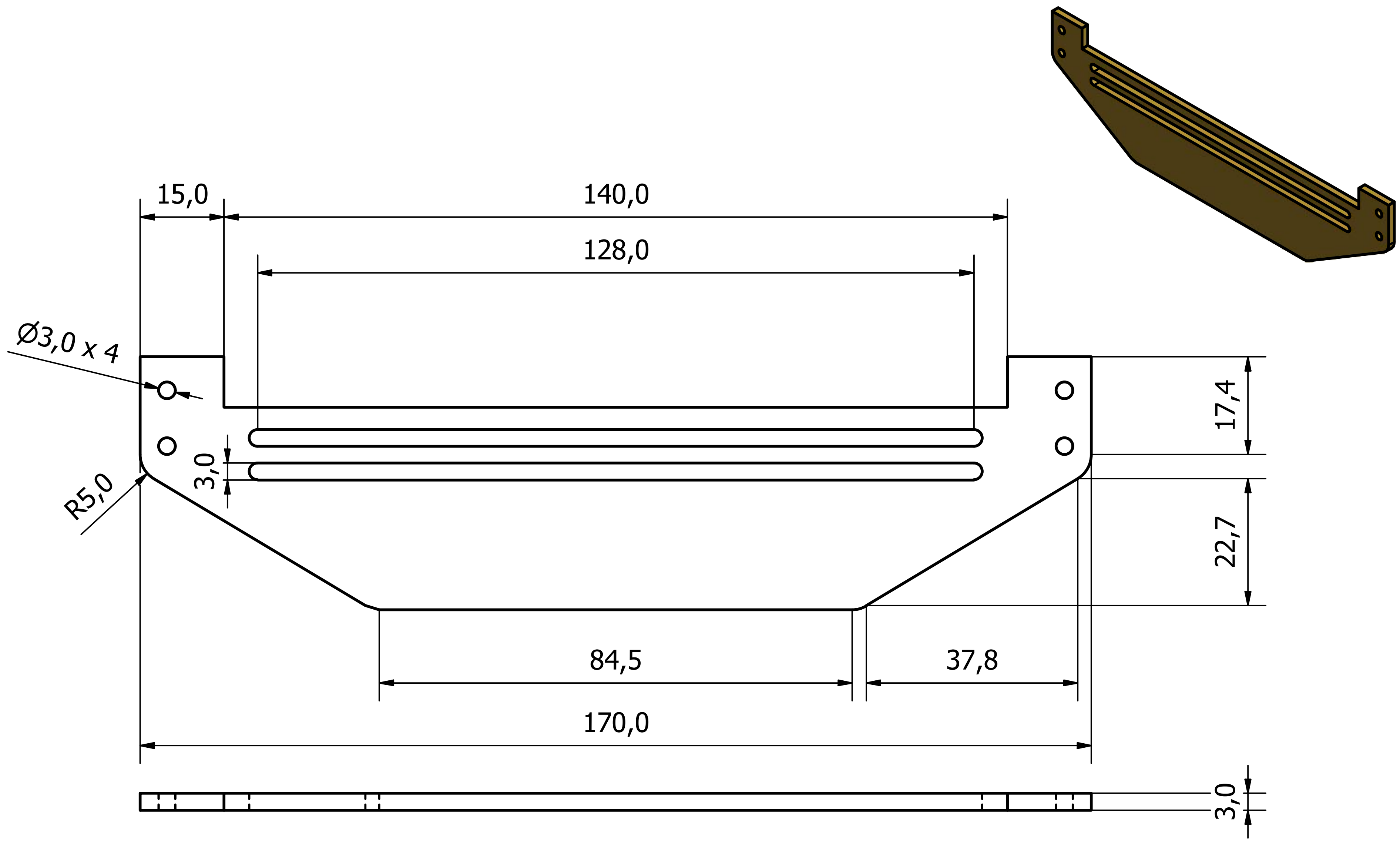


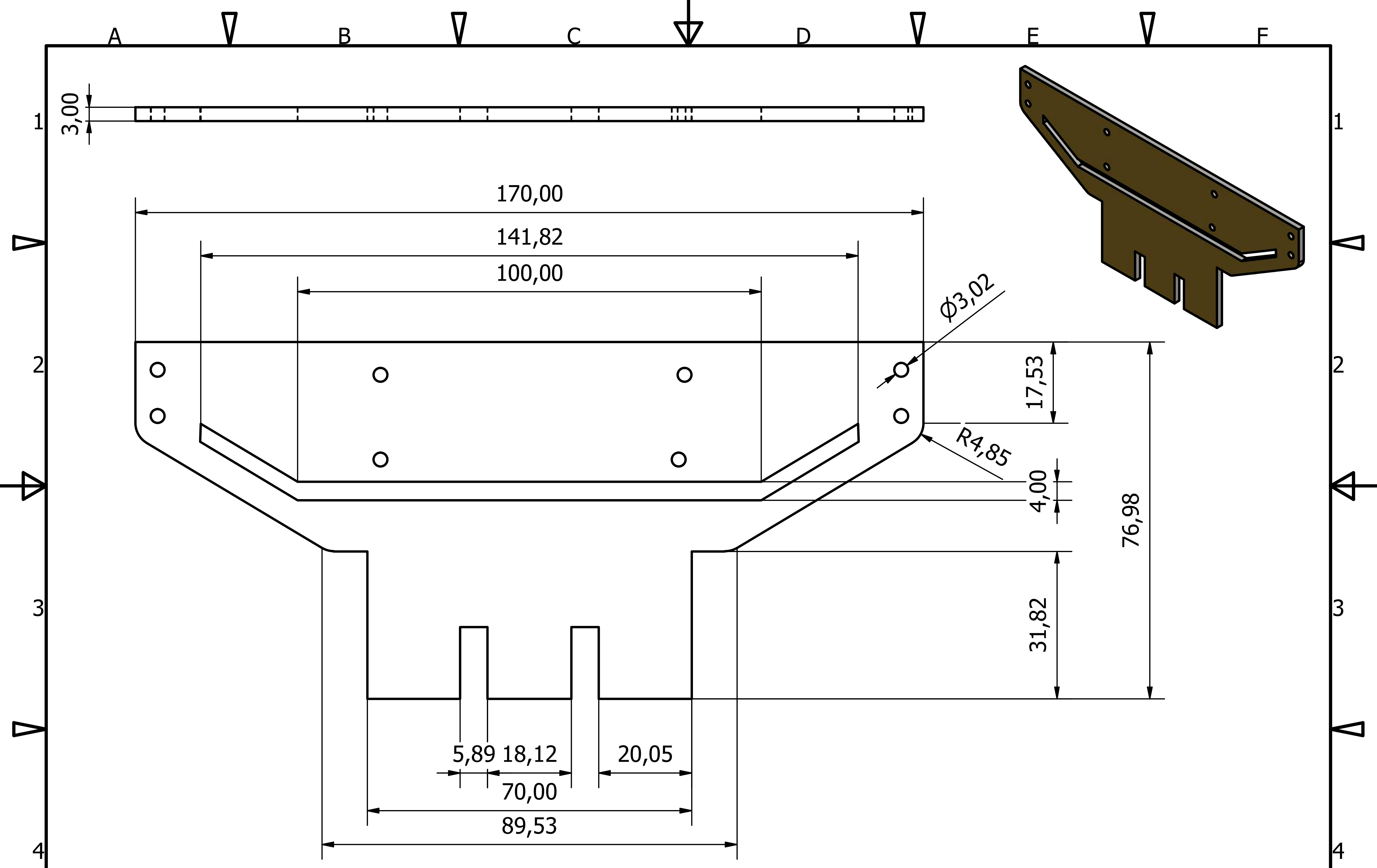
| | | | | | | |
|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Part Name | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 8 | Bearing | Scale | 4:1 |



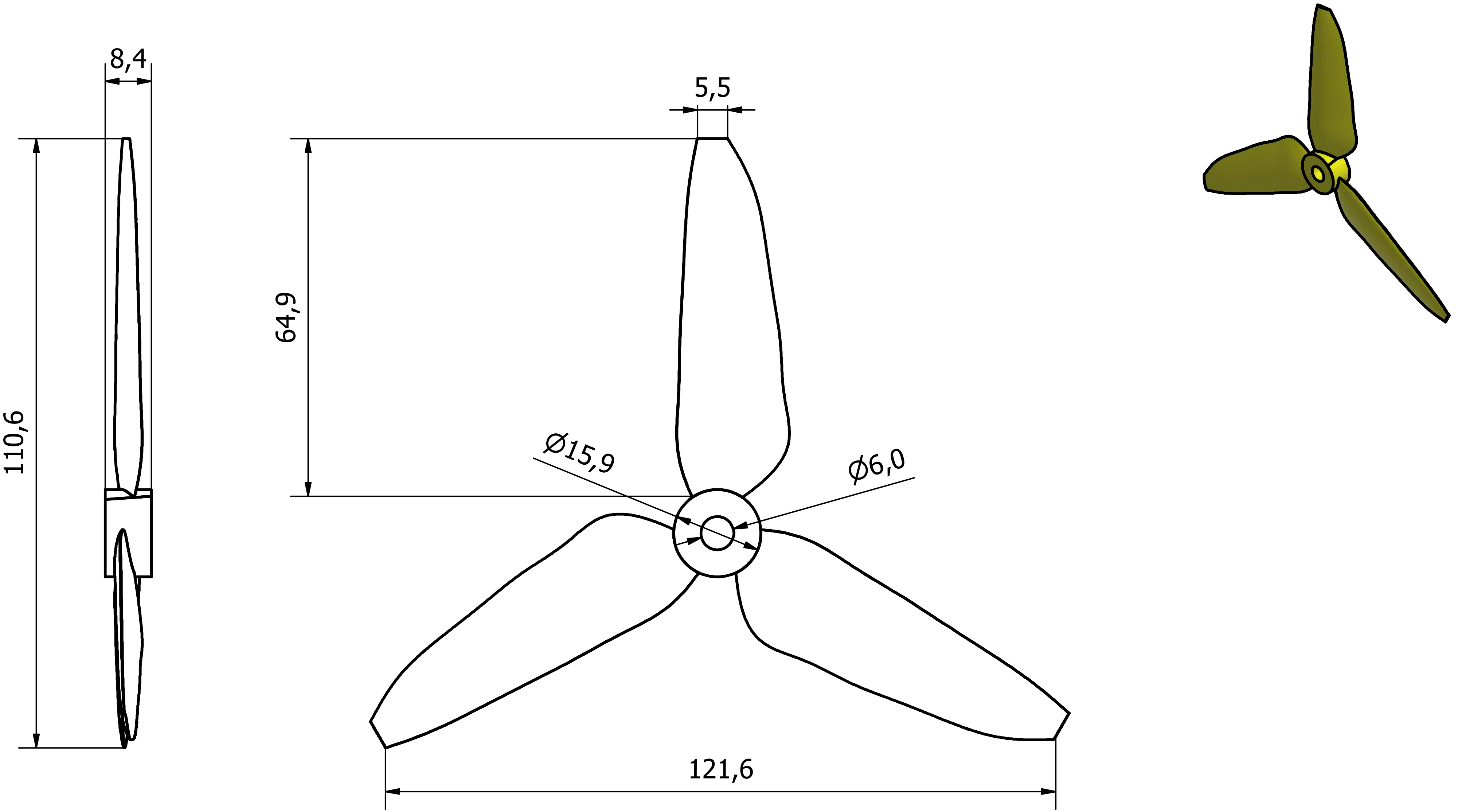

| | | | | | | |
|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Part Name | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 9 | Connector | Scale | 3:1 |



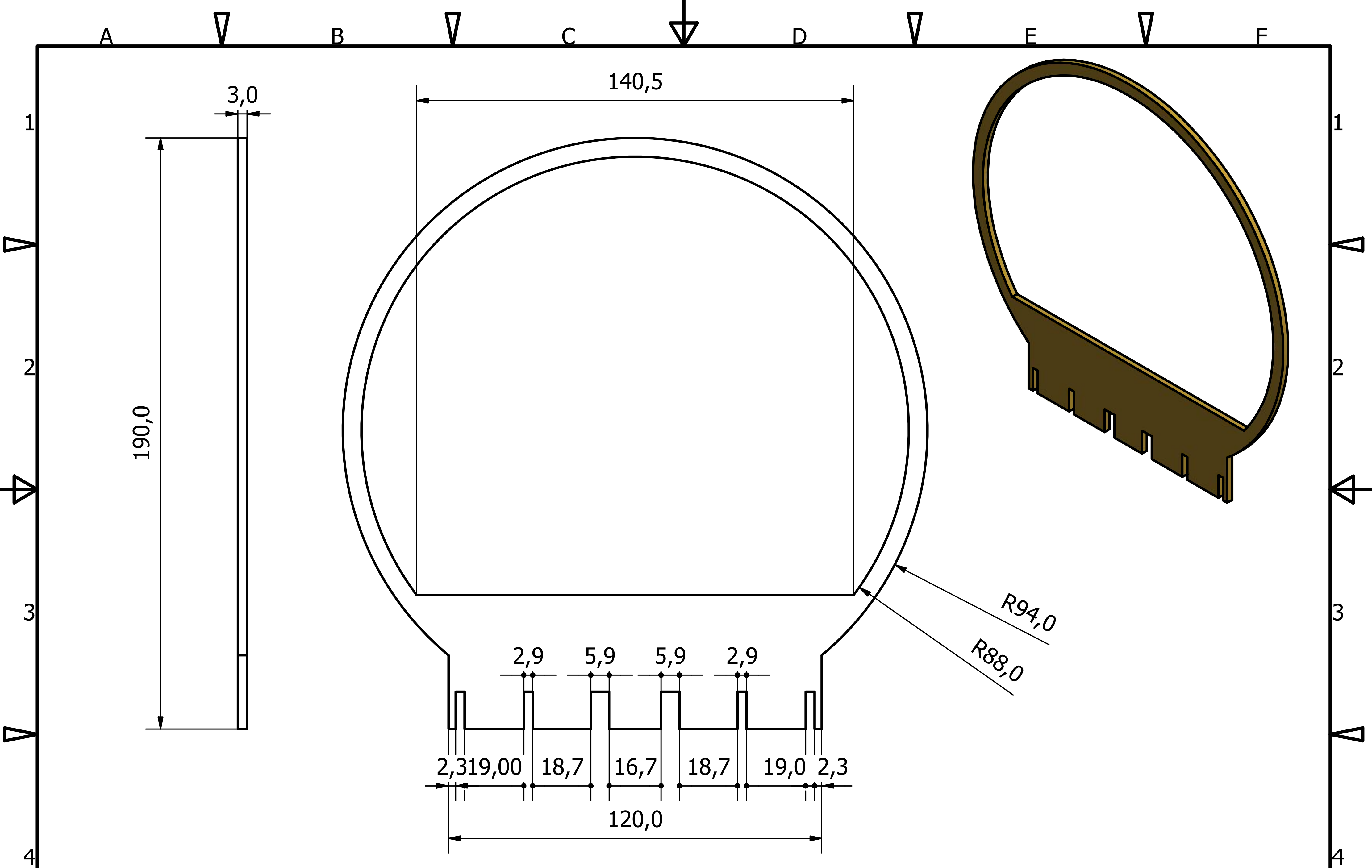

| | | | | | | |
|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Part Name | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 10 | Sensor Holder | Scale | 1:1 |



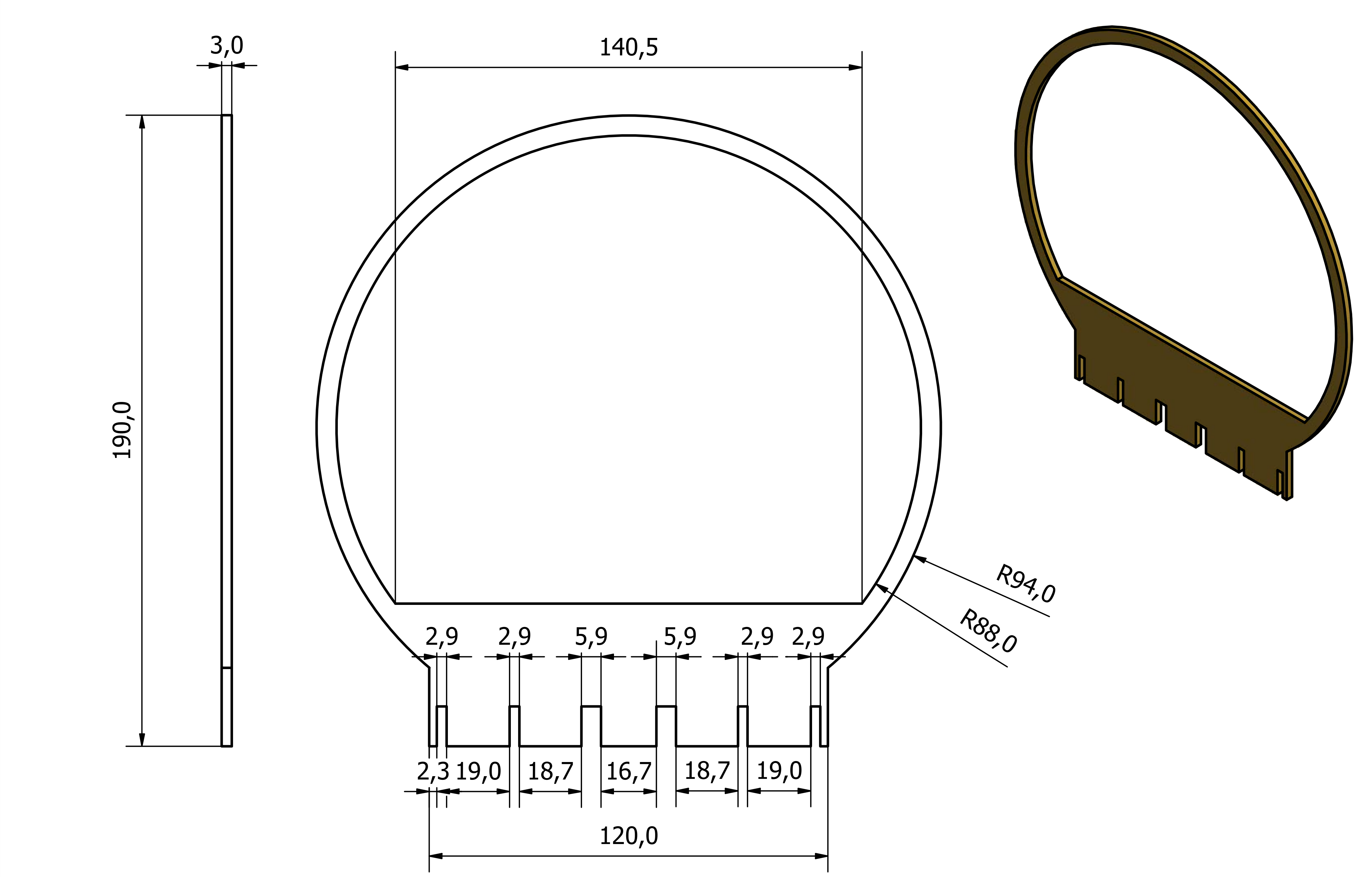

| | | | | | | |
|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Part Name | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 11 | Sensor Top | Scale | 1:1 |



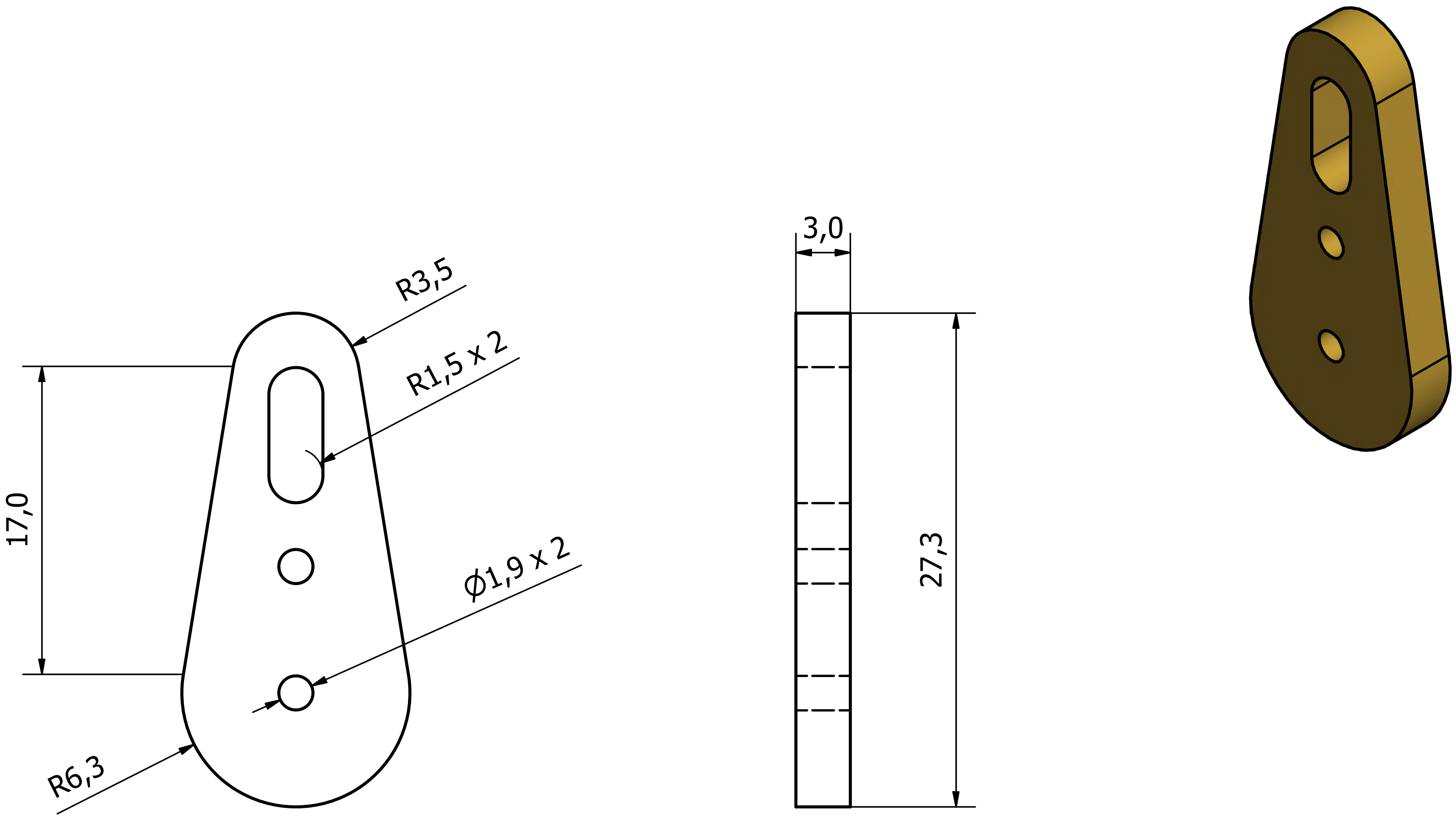

| | | | | | | |
|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Part Name | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 12 | Fan | Scale | 1:1 |



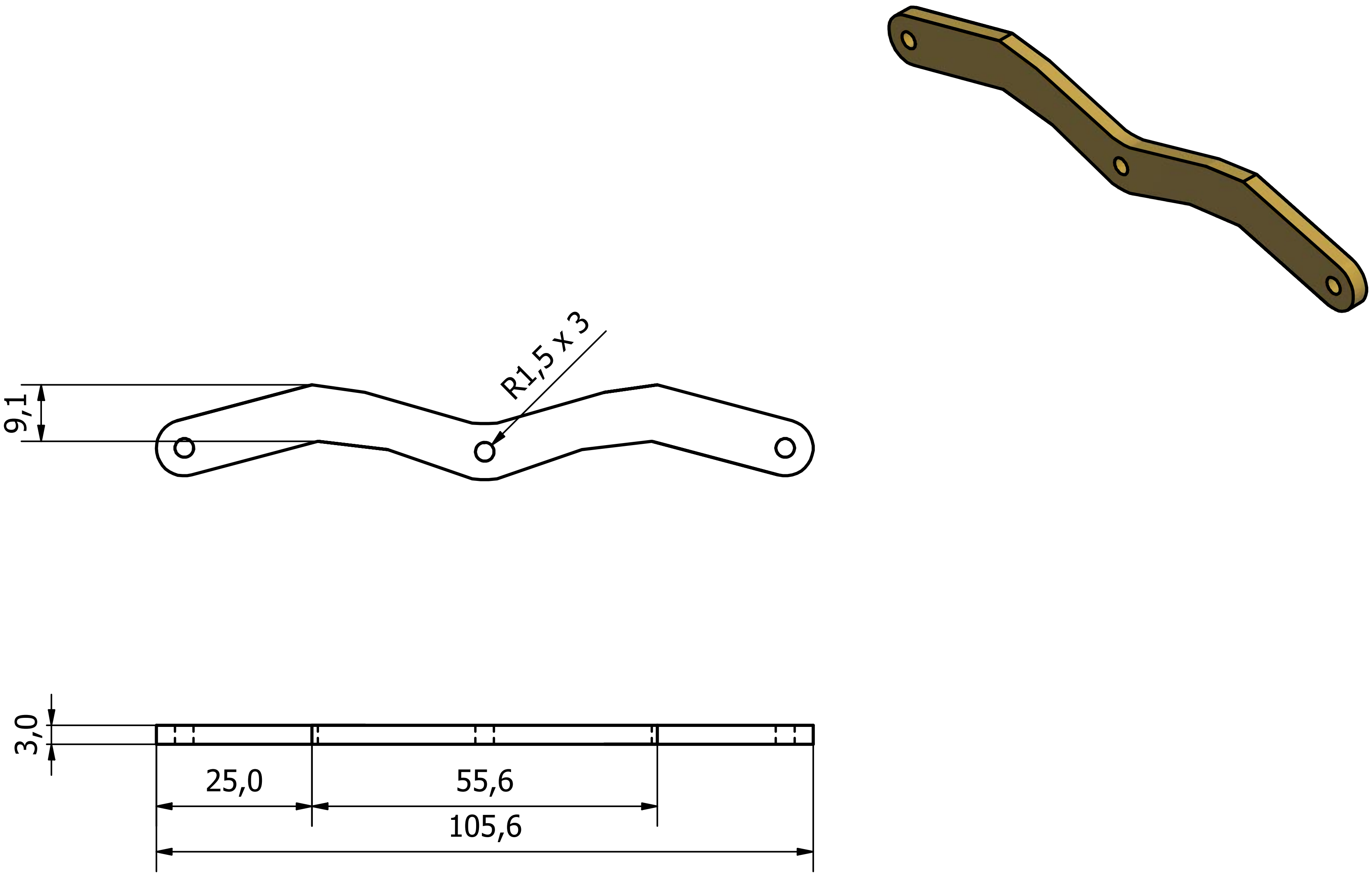

| Team | Cheap Sony | Group | 25 - G | Part Name | Unit | mm |
|---|---|---|---|---|---|---|
| Author | Johanny Alvarado | Sheet No. | 13 | Fan Cover 1 | Scale | 1:1.5 |



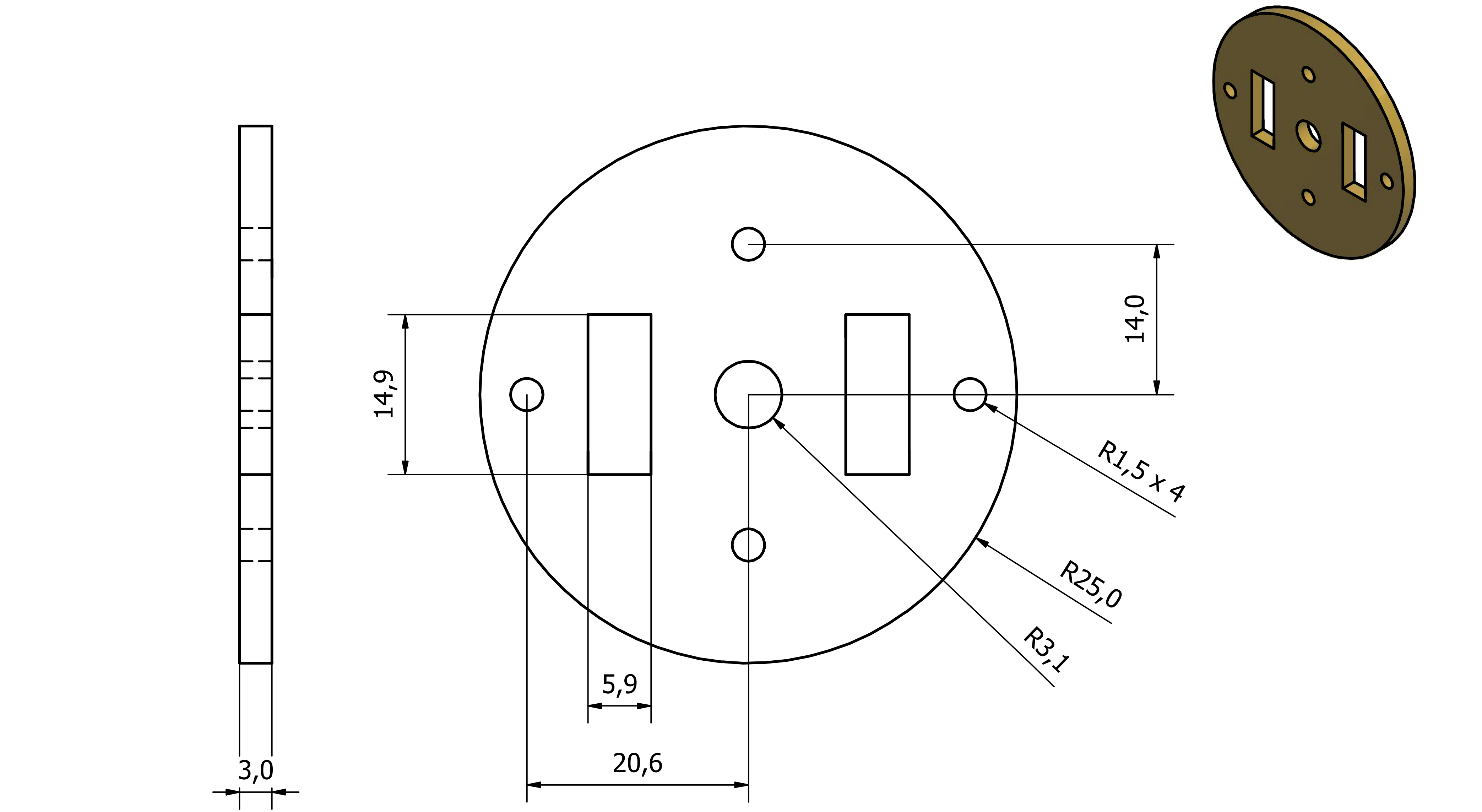

| | | | | | | |
|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Part Name | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 14 | Fan Cover 2 - 4 | Scale | |



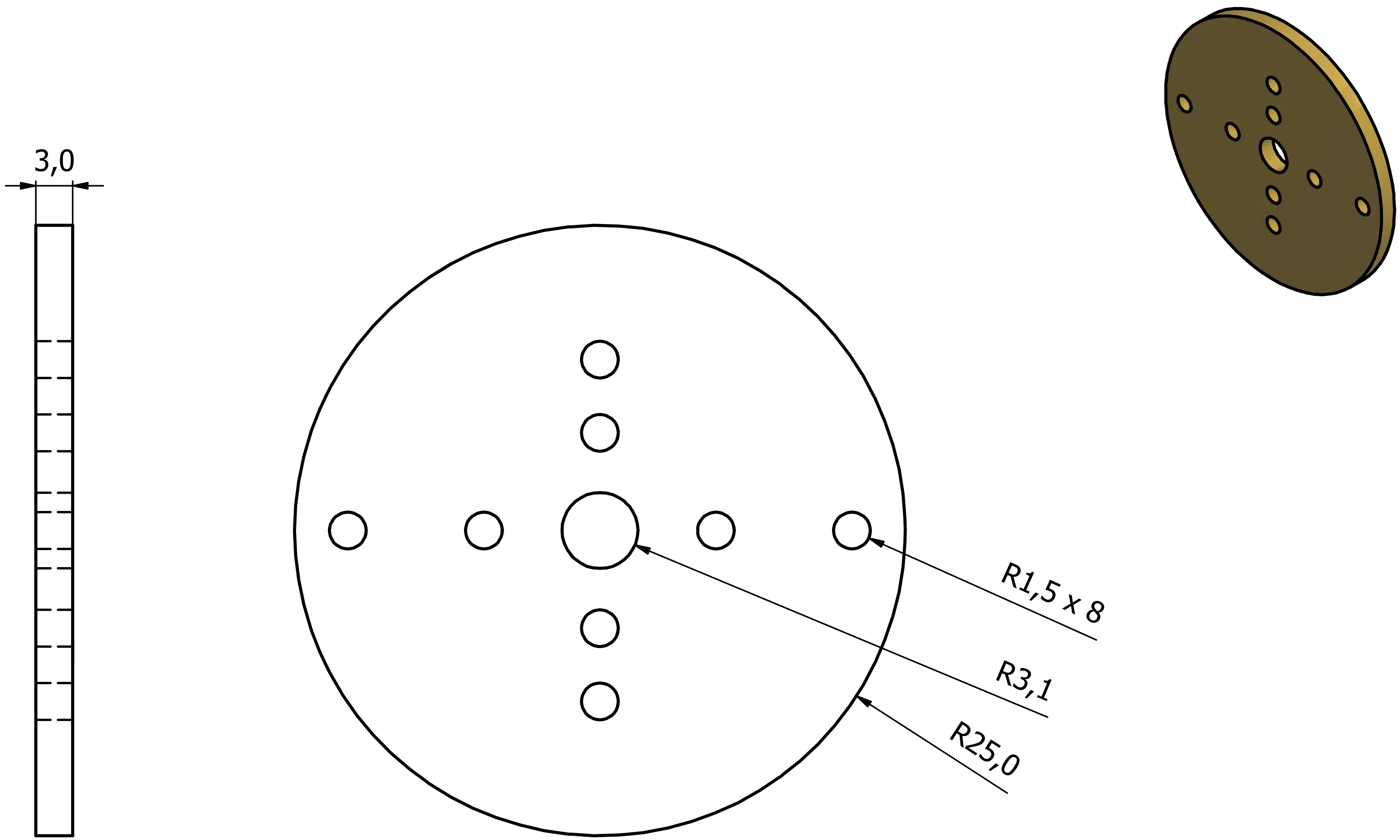

| Team | Cheap Sony | Group | 25 - G | Part Name | Unit | mm |
|---|---|---|---|---|---|---|
| Author | Johanny Alvarado | Sheet No. | 15 | Turning ServoLink | Scale | 3:1 |



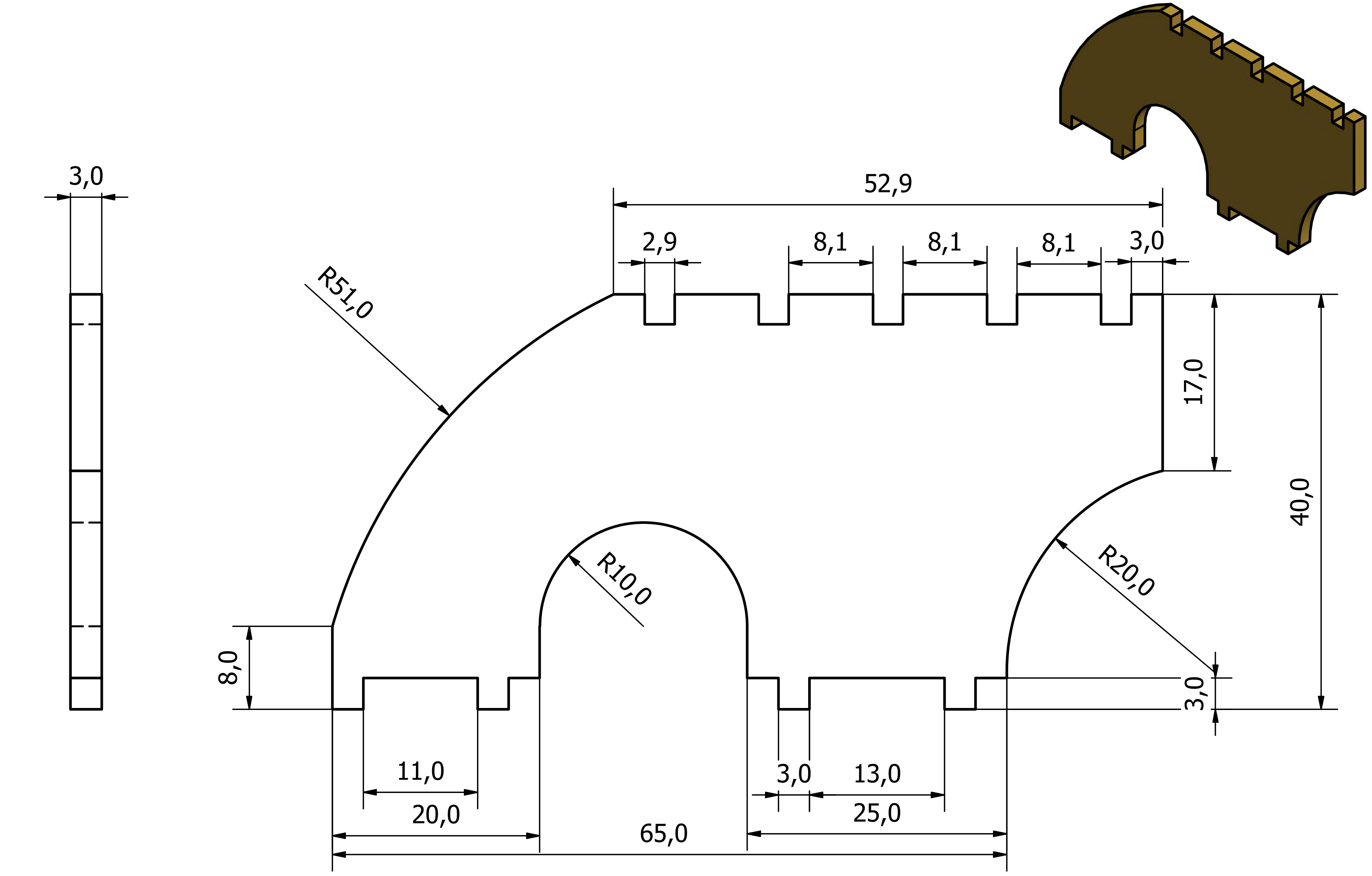

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Part Name | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 16 | Turning Bar | Scale | 1:1 |




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Part Name | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 17 | Motor Base | Scale | 2:1 |




| | | | | | | |
|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Part Name | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 18 | Motor Holder | Scale | 2:1 |




| | | | | | | |
|---|---|---|---|---|---|---|
| Team | Cheap Sony | Group | 25 - G | Part Name | Unit | mm |
| Author | Johanny Alvarado | Sheet No. | 19 | Cover Holder | Scale | 2:1 |

### 6.2.2 Overall Structure Design

Considering several problems faced by the previous car and based on these issues,a new mechanism, more suitable for the final test, is redesigned. Among them, the expectations for the final car are as follows: (1) The overall body structure is stable and simple, sturdy, and that no parts would fall off under operation; (2) The friction of the car body is minimized, especially at the axle at the wheel; (3) When the brushless motor is started, the vibration of the car body is small, particularly at the fan motor bracket; (4) The tolerance of the steering mechanism is small and stable., with a flexible connecting rod. Based on the above indicators, the team categorized the design choices for various parts of the assembly, with the final product shown in the following figure 6.6.

Figure 6.6 Overall configuration

Key points: tight-fitting links, low chassis, keel frame

The car body can be divided into a front car system, a mid-section system, and a rear car system, and are mainly connected by a tight-fitting plate. This not only greatly reduce the gap between components, reduce vibration, but also reduce the complexity of the assembly and disassembly process.

The front vehicle system includes a tracking device, a steering system, and front wheels. Place the infrared sensor under the forefront of the car body to ensure that the position of the black line is sensed at the first time to control the direction of travel; the steering system is placed on the front wheels to control the front wheels and guide the direction of the rear wheels.

The mid-section includes a fan frame and keel, brakes, and a 250mL aluminum foil drink. The brake device is placed in the middle of the car's body to avoid unevenness of the friction on the car caused by the front and rear friction forces during braking. The keel runs through the whole car, connecting the tracking device, protecting the steering and braking system, and finally used as a fan frame. The integrated design embedded in the bottom plate reduces the trivial gap of the rods, making the whole car more stable and firm.

The rear vehicle system includes the propulsion system, a fan cover, an encoder, and rear wheels. The propulsion system, that is, the fan, is placed at the end of the car body so that the obstruction of the fan outlet streamline is minimized, and the car is pushed more efficiently. We made a hole at the bottom of the fan cover, placed a rear axle retainer, and then connect the rear wheel, which greatly saves device space.

Additionally, the foundation of the whole car: the bottom plate is specially designed to be lower than the plane formed by the four axles, so that the design of the low chassis makes the center of gravity of the whole car lower and the grip improved so that the whole car is stable and easy to control; the vertical position of the fan is also because of the downforce, to reduce the torque caused by the fan thrust on the car body.

B. Various designs

1. Wheelset

(1) Selection of the number of wheels

We compared three wheels versus four wheels. The three-wheel steering system is simple, only the motor is directly connected to the wheels, but it is less stable when cornering and it can easily tip to the side; the Ackerman system used by the four-wheel steering system is more complicated, difficult to manufacture, but easier to use repeatedly, such that it is also relatively stable. It should be able to remain stable when performing the necessary maneuvers to overtake other cars.

(2) Tire selection

As with the mid-term, commercially available tires are more accurate in size than self-made tires. Hence, we also bought commercially available tires. The specifications are standardized; after determining the size, designing a suitable coupling will be a much simpler task. The difference is that compared to the midterm car, which had hard wheels, this time rubber tires were used. Rubber tires have a higher friction coefficient and will prevent the car from slipping.

(3) Coupling system

The hex coupling (六角聯軸器) is designed to connect the wheels. Each hex coupling has a bearing on the front and back, which minimizes the friction when the tire rotates. The front axle is directly connected to the steering system, and the rear axle is connected to the car’s body with a rear axle shaft retainer(後輪固定器).

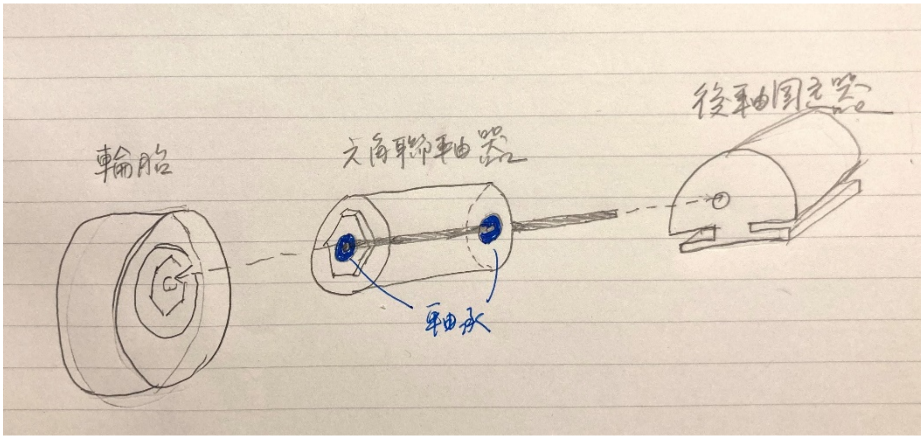



Figure 6.7 Coupling system

1. Fan motor bracket, keel

Originally, only a simple motor bracket is used. Although the bracket mechanism has been improved, the motor still vibrates significantly during operation, which affects the overall operating efficiency. Therefore, we combined the fan motor bracket with the keel to create a stable spine through the entire vehicle, which greatly improved the stability of the entire vehicle and reduced vehicle body vibration.

Figure 6.8 Left: motor bracket of midterm car

Figure 6.9 Right: motor bracket andkeel of the final car

## 1. Turning System

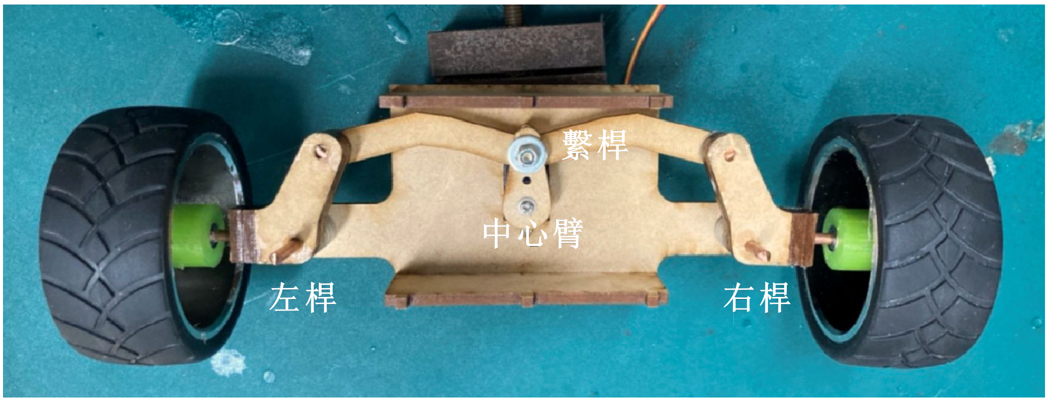
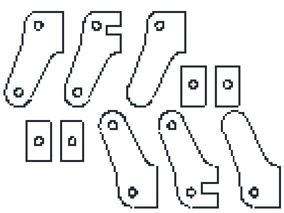



Figure 6.10 Turning System

The steering system design focuses on reducing clearance and increasing stability. It was originally planned to manufacture each rod with a 3D printing machine. However, due to the large error in 3D printing, it was changed to the Ray-cut method to assemble the steering rods.



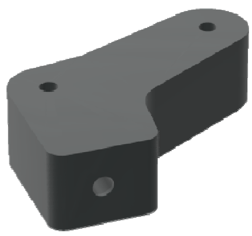


Figure 6.11 Left: laser cutting left lever

Figure 6.12 Right: 3D printing left lever

As shown inFigure 6.13, unlike the previous car, where screws were used to connect the rods and the axles, the new design model solves the problems encountered in the previous car, wherethe screws would tighten or loosenwhen turning. Therefore, the car will use aluminum rods with a diameter of 3mm. The length can also be adjusted freely. Besides, A small circle with an inner diameter of 2.98mm is used as a nut for the aluminum rod to avoid loosening in a tight fit.

We considered using springs as suspension from the turning mechanism to the body.However, springs proved to be rather hard to adjust. In the end, shims were preferred and chosen.

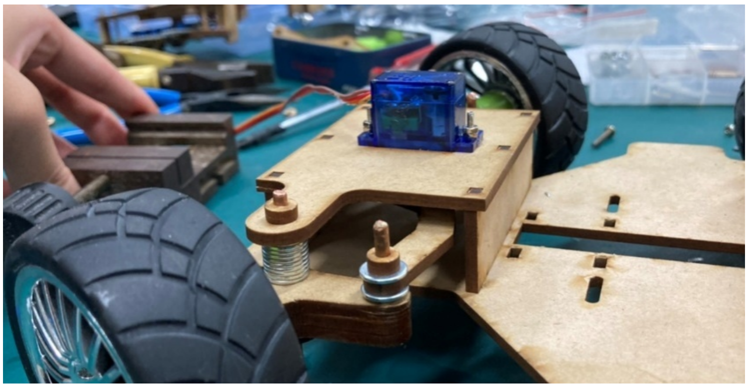


Figure 6.13 Turning System Details

### 6.2.3 Manufacturing

1. Materials

To choose the most suitable material for car structures, two materials: fiberboard and 3D-printing material, PLA, are compared. To construct a sturdy structure,the static stiffness (靜剛性) and dynamic stiffness (動剛性) of the materials are taken into consideration.

Static stiffness is defined as the ability of the material to sustain applied static forces. For instance, if one beam bends easily under a small static force, the structure demonstrates low static stiffness. For our car, there will be friction force from the ground and other reacting forces. A high static stiffness helps the car complete the task smoothly. [10]

Dynamic stiffness is associated with the natural resonant frequency, stating the frequency at which the car vibrates along with the variable frequency of the force. The higher the natural frequency, the higher the material possesses dynamic stiffness. The equations of natural frequency and dynamic stiffness are

$$\mathrm{W_n} = \sqrt{\frac{k}{m}} \ and \ k_d = \frac{f_0}{a} = M\sqrt{(w_n^2 - w^2)^2 + 4\varepsilon^2 w^2} \qquad (6.1)$$

where k is the value of static stiffness, m is the mass and $\mathrm{W_n}$symbolizesthe amplitude of vibration. Although it requires experimentation to determine the static and dynamic stability of the two materials, our team makes some simple assumptions based on our observation and compares other factors of the materials. [10]

Table 6.1 Comparison of different material

| Material | Fiberboard | PLA |
|---|---|---|
| Processing Method | Laser Cutting | 3D Printing |
| Weight | Heavier | Lighter |
| Processing time | Short | Much |
| Precision | Higher | Lower precision, more tolerance |
| Static stiffness | Higher | Lower |

After considering all factors, the team has decided to build the car mainly with fiberboard, to have high static stiffness and stable structure. Only some parts with irregular shapes or connections are 3D- printed.

2. Joint

Table 6.2 Comparison of latch, screw and interference fit

| | Property |
|---|---|
| Latch | Simple, easy to assemble, and lightweight. It is easy to have gaps and make the mechanism lose and vibrate. |
| Screw | Assembly is time-consuming and heavy. It is easy to loosen due to vibration when the car body travels or the motor starts. |
| Rubber screw | Once installed, it is difficult to disassemble. Hardly loose. |
| Interference fit | Easy to assemble and lightweight. If it is assembled and disassembled many times, the tight fit will fail, but once installed, it can reduce a large number of rooms. |

For the midterm, since most of the structure is manufactured with fiberboard, our team decided to use latches as our main joint option. Only the pairings of the DC motor utilizes screws.

For the final car, we changed the main joint design to an interference fit. The connection between the center arm of the steering mechanism and the tie rod uses a rubber screw to ensure that it is not loosened, and it also eliminates the need to disassemble the mechanism for maintenance and also causes tight fitting. This pairing method results in a stable car, where vibration has little effect onthe structure, and no parts loosen itself automatically during testing. Furthermore, the vibration of the car structure issignificantly smaller than that of the midterm vehicle.

3. Manufacturing method

(1) Fan manufacturing

Table 6.3 Possible fan materials and manufacturing methods

| Material | Aluminum Sheet | ABS |
| --- | --- | --- |
| Method | CNC | 3D Printing |
| Advantage | Strong structure, high toughness, not easy to fatigue. | Easy to obtain and cheap. |
| Disadvantage | High cost and difficult to manufacture. | The strength is weak, it is not easy to separate from the support material, and the accuracy is limited. |

After discussion, considering the cost and the need for repeated printing attempts in the manufacture of fans, it was still decided to use the 3D printing machine Kingssel of the implementation center. However, after repeated attempts, we were still not able to obtain a fan of accurate size. We had to prepare the drawings in advance to the already known factors. For example, if the center axis of the fan will be printed smaller than the ideal size, increase the diameter of the center axis of the design slightly.

After pre-adjusting parameters, as explained above, we got almost ideal results. For example, the density of the support material is adjusted to 40%, so that the whole piece can be pulled down without being too hard; adjust the Layer to 0.08, which is a z-axis stepper motor multiples of unit movement amount (0.02) to reduce the dead angle of the printing process; when printing, make the windward side up, so that the surface is smooth without removing the support material. After printing, the support material is removed with clamps, followed by rough processing with files, fine processing with sandpaper, and finally a layer of white glue is applied to the surface, to not only fill the fine gaps but also make the surface smoother.

(2) Car body manufacturing

All are laser-cut with fiberboard and the cut pieces are assembled.

### 6.2.4 Electromechanical System

For the final exam, a completely new structure was built, with new electrical components. Not much changed in comparison to the original midterm car discussed above. It possessed a different servo motor for the turning system. The SG90, the same one for the braking system, worked just fine for the turning system. Not only was it cheaper, but it also felt more responsive and had higher sensitivity than the MG996 servo motor from the original midterm car.

In addition to changing its turning system motor, the data acquisition method to overtake other cars was to be chosen. The original idea was to use a configuration of ultrasonic sensors. The most standard model when working with Arduino is normally the HC-SR04 sensor. By itself, it offers remarkable non-contact range detection. The sensor uses sonars to determine a distance. It has four pins: voltage pin, ground pin, and two transmitter pins, namely trig and echo. The trig pin sends a high-frequency sound, which will then bounce back from an object, and the other pin, echo, will send a signal back to the Arduino. The time it takes between the transmission and reception of the signal can then be used to calculate the distance to an object. Note that the velocity of sound through air is known. The duration of the signal is divided by two and multiplied by 0.0343 to obtain the distance in centimeters.

Experimentation was done to know the accuracy of the sensor. Without any other component working alongside the sensor, i.e. only the sensor, the Arduino, and its power supply, the sensor measured distance accurately. The serial monitor of the Arduino IDE displayed the distance between the sensor and a flat surface. The sensor measured any change of distance remarkably fast. A brushless DC motor was connected to the Arduino. If an object reaches a certain distance, the motor will stop. There was practically no noticeable delay between the proximity of the flat surface to the stoppage time of the motor. However, the sensor was discarded from the final design. Upon testing with the car assembly, there was a noticeable delay. While this issue was closely related to the delay implementation on our Arduino code, changing our delay parameters would affect the performance of other crucial components such as the encoder. Therefore, we migrated towards another alternative, i.e. the use of a Bluetooth module to share encoder information between the two cars, this way both Arduinos would know the current position of the other car.

Below, we provide the wiring diagram for the final exam car. Colors other than red or black are signal cables. Red stands for voltage, black for ground. The power bank has a blue cable.

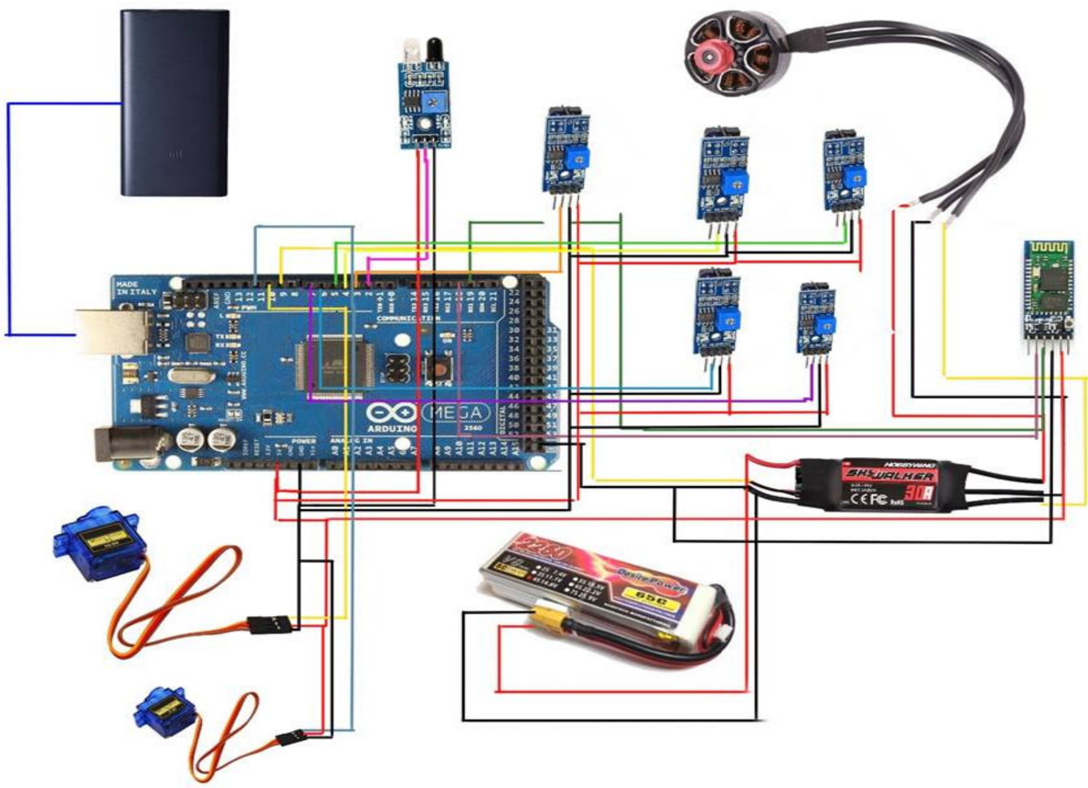


Figure 6.14 Circuit diagram for the final car.

### 6.2.5 System Control

1. **Prototype and Concept.**

   Judging from the performance requirement (Chapter5.2), the means to meet the requirement are considered. For the two additional tasks in final-- overtaking and car following, the different approaches are listed and discussed.

Following methods:

Table 6.4 Comparison of different following methods

| | Advantages | Disadvantages |
|---|---|---|
| Ultrasonic sensor | ◦ Easy implemented<br>◦ Can measure accurate distance<br>◦ has a fast response | ◦ Harder to detect at the curved track.<br>◦ time delay in the algorithm slows down the response<br>◦ Harder to overtake without means of communication. |
| Encoder and Bluetooth | ◦ Comparatively easy operation once the hardware was set up<br>◦ The most precise one on distance judgment.<br>◦ Can achieve smooth control since the position data is smooth and continuous. | ◦ The encoders need calibration for two cars to have the same scale.<br>◦ The Bluetooth may disconnect when the distance is too long. |
| Computer vision | ◦ Can collect the most information.<br>◦ Can handle the most complicated situation and can tackle almost all situations if designed. | ◦ The higher cost of camera and raspberry pi.<br>◦ Heavier computational task, longer operation time.<br>◦ More complicated software needed. |

The ultrasonic sensors were chosen for it is simpler in handling the data from the encoder, and it is advantageous in overtaking and Curved track.

Overtaking methods:

Table 6.5 Comparison of different tracking methods

| | Advantage | Disadvantage |
|---|---|---|
| Curved track | ◦ The inner and outer track has nature difference in length | ◦ Harder to decide the distance and turning angle<br>◦ Harder to go back to centerline |

| | | |
|---|---|---|
| Straight track | ◦ Simpler operation(going out and going back can use the same method)<br>◦ Easier to achieve higher speed in a straight track | ◦ Need more turning angle than at the curved track |

To overtake at a straight track was decided upon in the end.

<u>Overall design concept:</u>

Our control design focuses on a simple, clear, and straight forward logic. Starting with the simplest method, and gradually implement the software when the situation arose. This approach keeps the readability of the software and lessens the efforts needed for debugging.

**2. Working Principle**

<u>The logic of car following</u>

For simplicity, the car being followed is called car A, and the other car is called car B in the upcomingcontext. Since our car is being followed, the car discussed in this report is car A. The roles are decided based on the features and advantages of the cars.

During the run, car A sendsposition data to car B every 0.5 seconds, andcar B controls its speed and displacement based on the data and its current speed.

When the cars are about to overtake and change position, car B changes the desired distance in its software from positive to a negative number. It will then automatically drives ahead of car A and become the leading car. When car B overtakes back, the desired distance is again changed back to positive.

<u>The logic of overtaking</u>

At times of overtaking, car A goes out of the track and tracks the outer line instead. After car B change the relative position between two cars, car A goes back to the centerline.

<u>The deciding of the roles</u>

After some cooperation with the other group, our car is determined to be car A, and the car from the other group is car B,due to the different features of the cars. Car A has seven infrared sensors implemented in the front, while car B has only five. The more sensors lead to a wider coverage area. Thus, car A can track the line more smoothly and stable, less likely to run out of the track. On the other hand, car B controls the speed using a continuous approach, while car A only uses three-speed sections to control speed. Thus, when considering the additional information on the position of the other car, car B is more capable of performing a smoother speed control.

The structure of the software control

There are four parts in the main code: (1)global variable announcement, (2)setup function, (3)main loop function, and (4)all the other called functions.

```
void loop() {//a concept of counter: the control c
 //speed---------------------------------------
 if (counter == 4){
  Encoder();
  Bluetooth();
  speedControl();
  counter = 0;
  }
  else counter++;

 //direction-----------------------------------
 Infrared();
 PID();
 Turn();
 delay(50);//we should decide the delay time so ta
}
```

In the main loop, the functions called are separated into two sections, speed and direction control, each has a different time delay. For the shorter reaction speed in line-tracking, the direction control delay is set to 50 milliseconds. On the other hand, since the speed of brushless DC motor cannot be changed so fast, and the precision limit of the encoder(about 5 centimeters), the speed control has a time delay of 250 milliseconds, which means the functions are called every four times the main loop repeats.

The detail of each functions

void Encoder():

The built-in function attachinterrupt()is used to count the number of times and the moment when the infrared sensors on the encoder are triggered, and the time moment of which. With this information, this function calculates the information of distance and velocity.

void Bluetooth()

Based on the discussion above, car A is responsible for sending out information, while car B receives it. Therefore, for car A, this function simply sends out the current position to car B (in cm). The Bluetooth module can only send integer within 8 bits(0-255) when the team member tested it. Thus, the distance data is first made to be the remainder of 256 before sent out to the other car. The data is sent every two times this function called, which means a 500 milliseconds time delay. Based on the testing results, the sending frequency should be lower than the receiving frequency,to preventaccumulation and cause receiving delay.

Speed control:

The speed control was done with simple if-else statements. Apart from the current speed, it also depends on the current position of the car, in order to set the different speed at each section as desiredfor overtaking.

void Infrared()

The midterm version considered the situation that multi-sensors were triggered at the same time. Some new sensors with better quality are bought, and the chances of misread are lower.

For the final, the function is changed to an if-else statement. If more than one sensor is on, the one closest to the center decides the error number. The new algorithm deals with the detection noise and enhances tracking performance.

The total sensor number is added from 5 to 7. The two additional ones are on the same side (left) for the curved part of the track.

```
void PID(){
  P = error;
  I = I + error;
  D = error-olderror;
  PIDvalue = (Kp*P) + (Ki*I) + (Kd*D);
  if (PIDvalue>10) PIDvalue=10;
  else if(PIDvalue<-19)PIDvalue=-19;
}
```

void PID(): calculate the PID value for servo motor command.

```
float Kp = 6;
float Ki = 0;
float Kd = 6;//4;
```

Observation in tuning the PID controller: with a higher proportional gain, the reaction is sufficient at the curved place but causes oscillation.With a higher derivative gain, the signals converge faster but cause high-speed oscillation.

void Turn(): control the servo motor for turning based on the PID value and the position when performing overtaking.

**3. Problem encountered**

1) Line tracking stability was low since the car doesnot have a turning system in the midterm.The line tracking hardware and software were newly developed after the midterm. Five sensors were initially installed, But the performance was not good enough. It would occasionally move to one side and made all the infrared sensors leave the track.
2) The different curvature of the straight and curved track. If the turning setting is the same in both regions, the car will be tracking the line in the curved region with only the 2 leftmost sensors.Because when the center one detects, it will go straight, but the new neutral position is curved. When this occurs, the car is likely to go off the track.
3) The encoder is not precise, and cannot get a definite point when the track turns to curve.
4) A small encoder difference between two cars leads to the changing following distance between two cars.

**4. Modification**

1) Make the same error as the previous error if all the sensors are not detecting.
2) Different center points for a different region.
3) Discard the method of a different neutral position. Instead, add two more sensors on the left of the original sensors. This way, when the car is on the curved region, there are still one or two spare sensors on the left.
4) Multiply the distance of one car by a coefficient.

### 6.2.6 Analysis of System

The tracking performance is not only satisfying but also shows high reliability. The car motion is smooth and the oscillation is minimized. The chance that the car runs out of track by itself is less than one-tenth, from the observation during testing. The speed control still lacks precision and the speed would slightly change within a bounded region. However, since the car does not control the following distance but being followed, the speed control already sufficed. The car can track the line smoothly and follow the curve swiftly. On top of that, the car is reliable and performs similarly repeatedly, making it suitable for performing overtaking. In conclusion, the car is capable of completing the final test without big issues and concerns.

# Chapter 7 Overall Examination

## 7.1 Mechanical Parts

During testing, the final car shows good integrity and stability. The fan turns smoothly and produces little noise pollution. Even when the duty cycle increases and the thrust as well, the car structure shows unrecognizable vibration. When the fan is on, the car runs smoothly without noticeable friction. Furthermore, the turning system of our car also functions stably and smoothly, while driving on the curve. Furthermore, our car goes off the main track when performing overtaking when the other car accelerates or decelerates. The well designed and manufactured turningmechanism is the key to a successsmooth and swift turning and moving off the main track. Durning testing, our car rarely leaves off the track when overtaking, showing good reliability of both the mechanical parts and control parts.

## 7.2 Electromechanical Parts

The implementation of the SG90 servo worked perfectly. It was more responsive than the original alternative, the high torque MG996r. There were no power surges or electrical faults. The electromechanical design worked perfectly. There were some issues regarding the partnered car, and analyzing the mistakes of that car is beyond the scope of this report. Also since the distance control, albeit having some issues, it accomplishes its task and it allowed us to have an acceptable grade.

## 7.3 Software Control

The software of the car is very reliable. The simplicity of the code makes it very easy to troubleshoot. Few revisions are needed, and malfunctioning rarely occurs.

## 7.4 Performance Examination

The final test score is 80 points, whereas the expectation is 90-95 points. The following section discusses the reasons for the deviation and reflection.

First, the code of maintaining the following distance is mostly in the other car, which means the performance of our car only needs to be predictable and stable. Because of the complicated tasks, the other car has a higher rate of malfunctioning.

The occasional failure is decided to be acceptable, for the testing time is 10 minutes, and the two cars only require two and a half minutes to finish three rounds. In the four or five chances, one successful performance can secure a 90 points grade.

Second, the tasks of following and overtaking are completed two weeks before the final test. During the remaining time, the group members aim to decrease the following distance to increase the final score. However, since more groups were using the track inYoulin, the efficiency dropped significantly, which leads to a less reliable new version of the controlling software.

The third is the ambiguous definition of rules. It is stated on the rule that “除風扇產生之風力外，不得以其它動力驅動車輛(如前車拉後車、後車推前車等)，但允許兩車偶有擦撞。”. The group member presumed that the rare and accidental collisions are acceptable and did not change the code when testing. However, during the final test, the TA judged that the situation is “推撞” and thus not acceptable. The ambiguous definitionofthe rule made the groups revise the code during the 10 minutes testing time, and failed in finishing the three rounds.

# Section Four
# -System Analysis

# Chapter 8 Simulation

## 8.1 Computational Fluid Dynamics Simulation

1. Geometry

Space Claim is a 3D modeling software to create, edit, or repair geometry. There are several formats, suitable for importing files into Space Claim before meshing, including STEP, IGS, X_T. These files differ from their operating speed of importing and exporting data and the integrity of the files. Since meshing plays a significant role in solving the computational fluid analysis, ensuring the completeness of the object is the priority. Therefore, X_T file is chosen before starting drawing the rotary fluid zone and flow passage. The table below compares the performance of different file types.

Table 8.1 comparison of different file types

| File Type | Importing speed | Exporting speed | Model completeness |
|---|---|---|---|
| X_T | Faster | Faster | Fully complete |
| STEP | Slower | Slower | Contain surface error |
| IGS | Slower | Slower | Partially complete |

<u>Simulation system</u>

Since the fan is rotating in the air, the simulation zone can be separated into two parts: moving reference frame (MRF Zone) and stationary cell zone. During the simulation, the MRF zone will be given an angular velocity, related to the rotating force of the fan. The stationary cell zone is not moving, presenting the passageway of the simulating fluid. [11]


Figure 8.2 scheme of the simulation

To transform the scheme in Space Claim, first draw a circle, diameter 150mm, for the rotary fluid region. Pull it for thickness 25mm. The thinner the thickness is, the simulation result is closer to reality. However, if the surface of the MRF zone is too close to the fan surface, meshing will be difficult. Weighing both two factors and some try and error, a thickness of 25 mm is chosen.

Draw another circle with diameter 200 mm, for fluid passage. Unfortunately, this is a mistake that results in an unreal simulation result. Even though our team has built a fan cover around the fan, the cover does not act as a pipe but more like a support. Therefore, a larger stationary (cell) zone would be more reasonable for our car fan simulation. However, due to some technical issues, we did not redo the simulation. As a result, when examining the simulation result, the mistake is taken into consideration and what can be expected in reality.

Use Boolean operation to remove interference, both for fluid passage and rotary fluid region. This functionality, referred to as Boolean operations, is very important for advanced 3D modeling in both architectural and mechanical design. We cover the three Boolean operations of union, subtract, and intersect. The functionality of each can be represented by two overlapping circles (representing two solid or fluid), as shown in the figure below. [12]

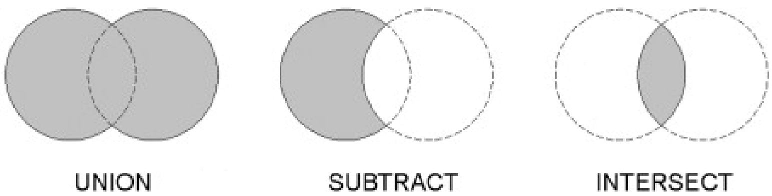



Figure 8.3 Boolean operation[12]

Since we are simulating the airflow, the solid blade is deleted at the end. Only the MRF zone and stationary cell zone are left and are named as fluid. Last, move the twofluid bodies into a component and use the “share” setting in shared topology imprint and merge all bodies in the components and transfers the result to ANSYS as a multi-body part. [13]

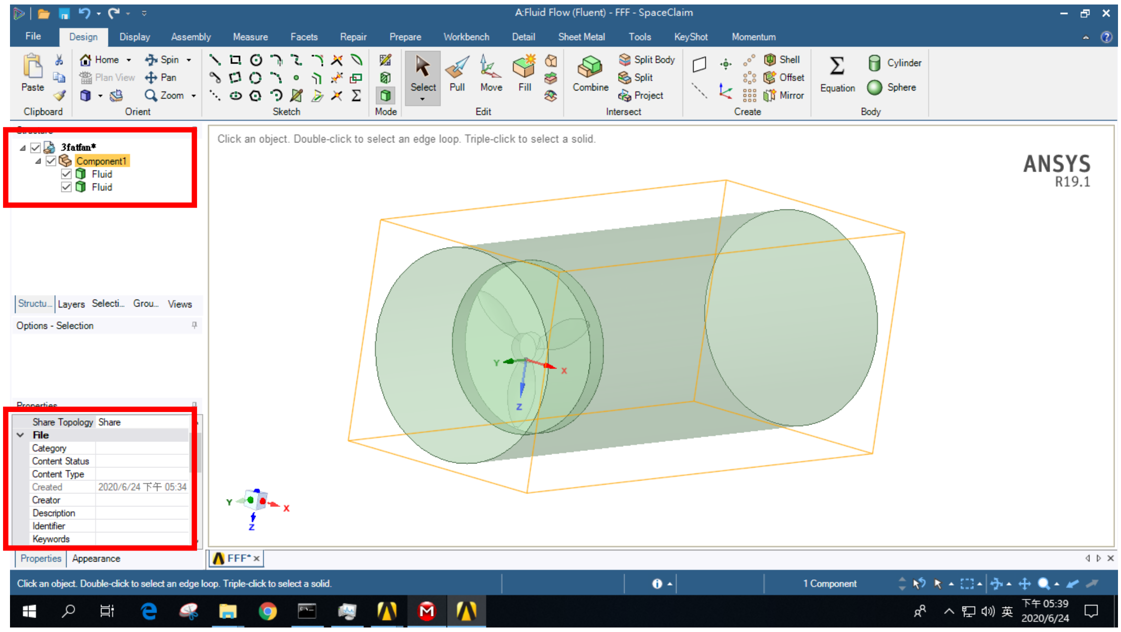


Figure 8.3 Edited geometry

2. Meshing

Close Space Claim and start edit Mesh Cell. Before creating meshing, it is important to first check the unit and change the property of geometry into fluid. (The default mode seems to be solid.) Afterward, two different Meshes are created.

Body sizing

Body sizing is created for the passage flow (Stationary cell zone), to be able to stimulate the airflow at the upstream and downstream. At the setting, element size is set at 2 mm, and Capture Curvature is changed to “Yes”. Since this part is not directly in contact with the fan blade, where small meshes need to be created at the fan tip, the mesh size does not have to be too small. Capture Curvature needs to be changed to “Yes” so that the mesh will be generated with the same curvature for fluent flow.

Face sizing

Select the surface of the blade and insert a face sizing with element size 1 mm. The element size of the blade surface is critical of whether the meshing will succeed. If the CAD drawing contains extra edges or gaps, these errors need to be repaired in Space Claim. Otherwise, meshing is likely to fail. Capture Curvature is also turned on.

After finishing meshing, use “Create Name Selection” to name inlet and outlet at the upstream and downstream of the stationary zone. Use face selector to create a name selection for blade; use body selector to name the MRF zone.

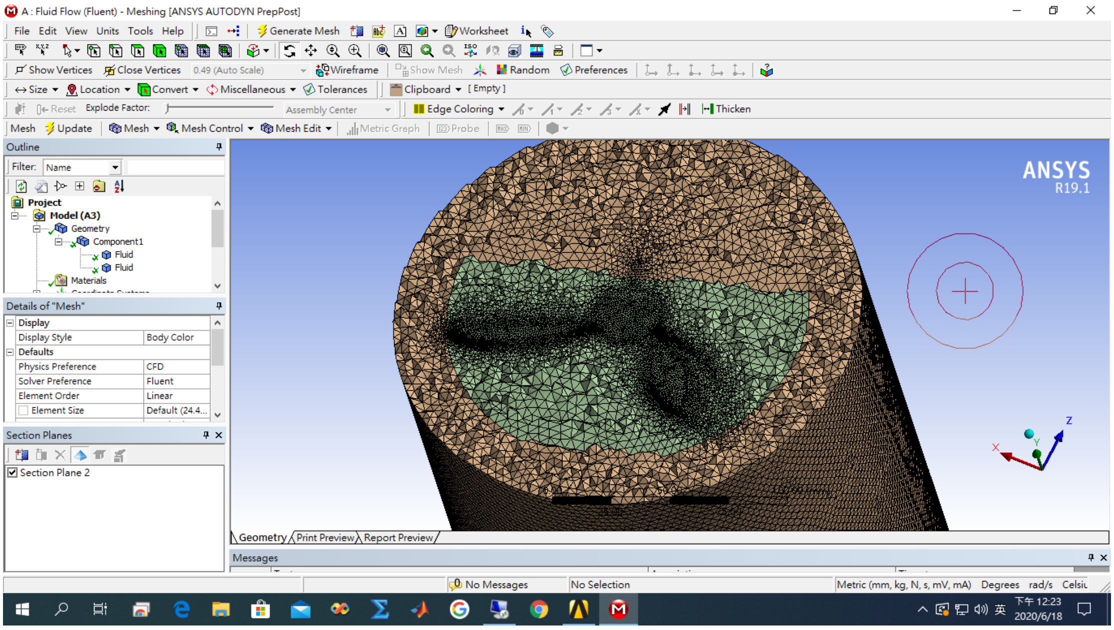



Figure 8.4 The meshing result

3. Set up

There are many details and options when setting up the simulation. The following screenshots illustrate the important ones. To build up models, there are several options to choosefrom Viscous Model. Some common models for solving turbulence are listed below to discuss their pros and cons.

<u>K-epsilon</u>

K-epsilon is the baseline two-transport-equation model solving for kinetic energy k and turbulent dissipation ε. Turbulent dissipation is the rate at which velocity fluctuations dissipate.

<u>K-omega</u>

K-omega is a two-transport-equation model solving for kinetic energy k and turbulent frequency ω. This model allows for a more accurate near-wall treatment with an automatic switch from a wall function to a low-Reynolds number formulation based on grid spacing.

<u>Shear Stress Transport</u>

Shear Stress Transport (SST) accounts for the transport of turbulent shear stress and gives highly accurate predictions of the onset and the amount of flow separation under adverse pressure gradients.

The key to choosing the right model is to understand its strengths, weaknesses, and definitions. Eventually, K-epsilon is chosen since it is easy to implement and valid for fully turbulent flows. It is also suitable for initial iterations, initial screening of alternative designs, and parametric studies. [14]

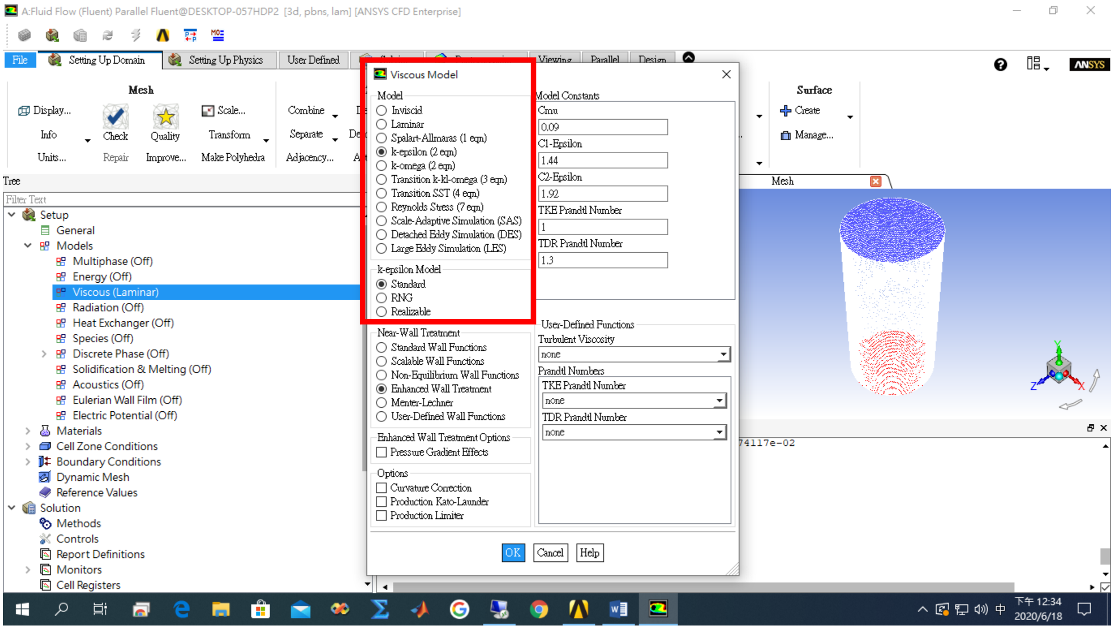



Figure 8.5 Viscous Model – k-epsilon

## Cell Zone condition

Edit on the MRF zone and click on Frame Motion and set the rotational Velocity. Unfortunately, our team did not measure the angular speed of our fan during the experiment hour. Therefore, 2000 rpm is an estimated value of our fan.

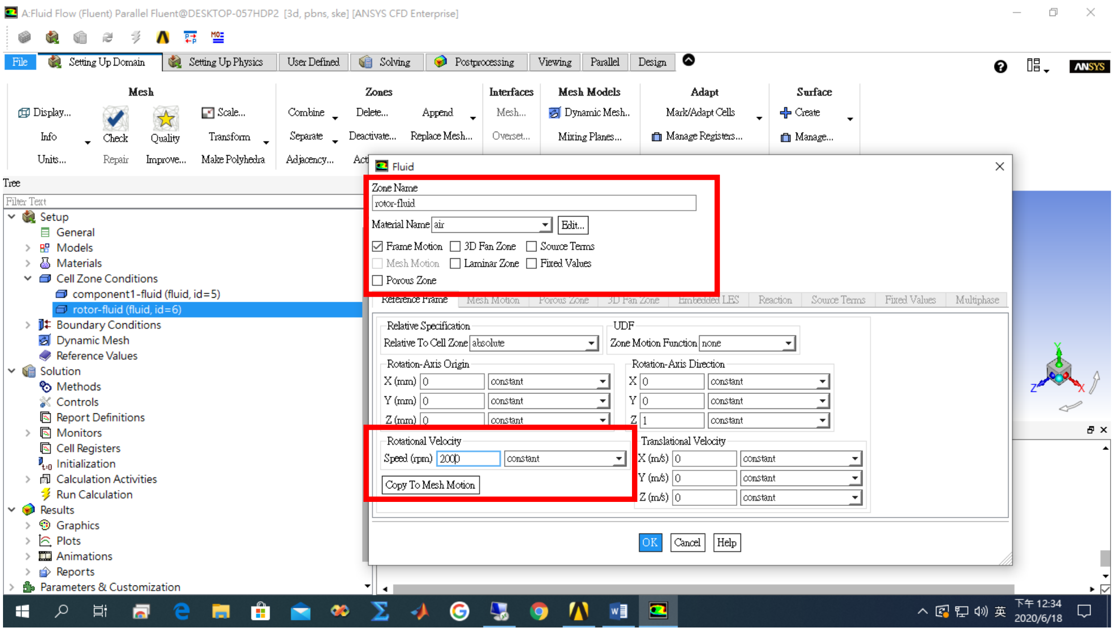



Figure 8.6 Set up for the cell-zone condition

## Boundary Conditions

Three boundary conditions are given. The first two are the pressure at the inlet and outlet. The last one is the wall motion, changed to moving wall and rotational.

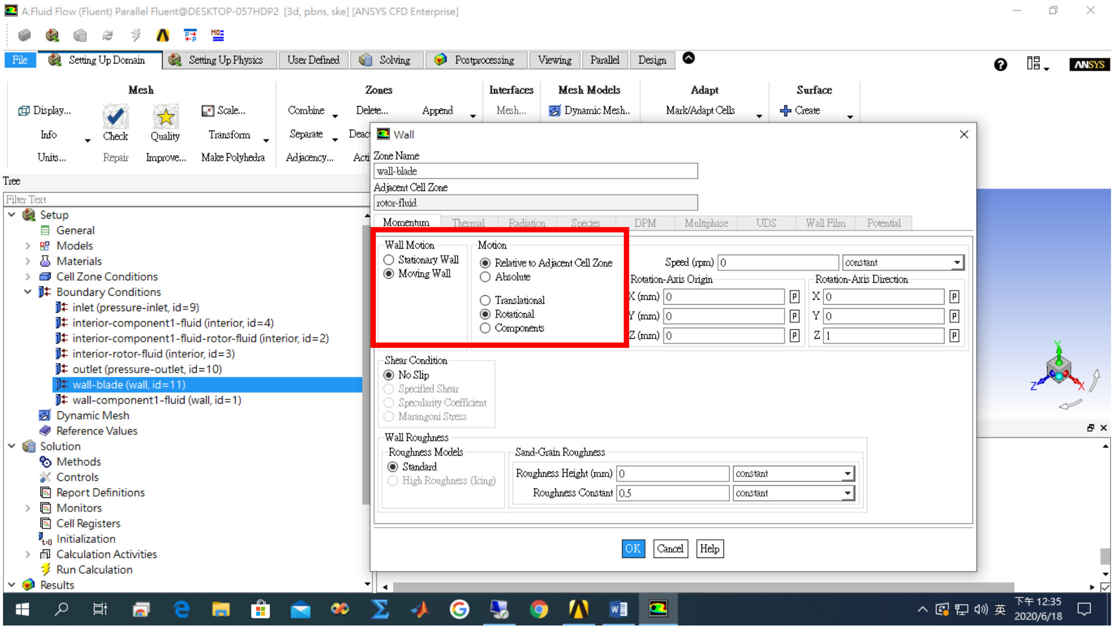


Figure 8.7 Boundary condition set up

## Run Calculation

Set the maximum number of iteration and start to calculate after all the settings. When it finishes, check the residuals of the model to verify that it has reached a steady-state.

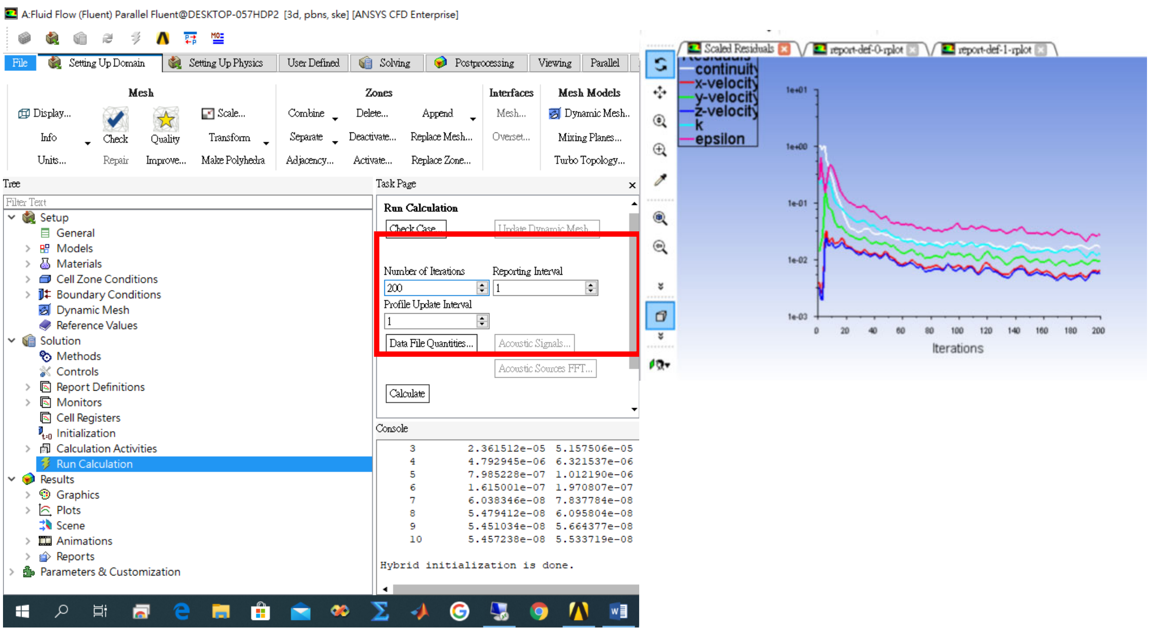


Figure 8.8 Set up for running simulation

## 4. Results and Discussion

The following figures are the static pressure at the fan surface. It is clear to see that the left corner curving fan tip undergoes the highest pressure and the back and the edge of the fan experience rather low pressure. This echoes to the theory discussed in the previous chapter of the fan prototype: one side of the fan is the pressure side and the other one is the suction side. The simulation result shows the pressure differences, verifying the theory.

One question raised according to the simulation result is that why is the pressure distribution of the fan asymmetric. The design of the fan blade is identical and both the MRF zone and stationary zone are also symmetric. Therefore, the fan blades are assumed to experience the same force and give symmetric pressure distribution. The possible answer to this issue is the simulation setup. Since there are several models to choose and even more settings in each model, our setting for this simulation might not be the most ideal one and thus give an undesirable simulation result.

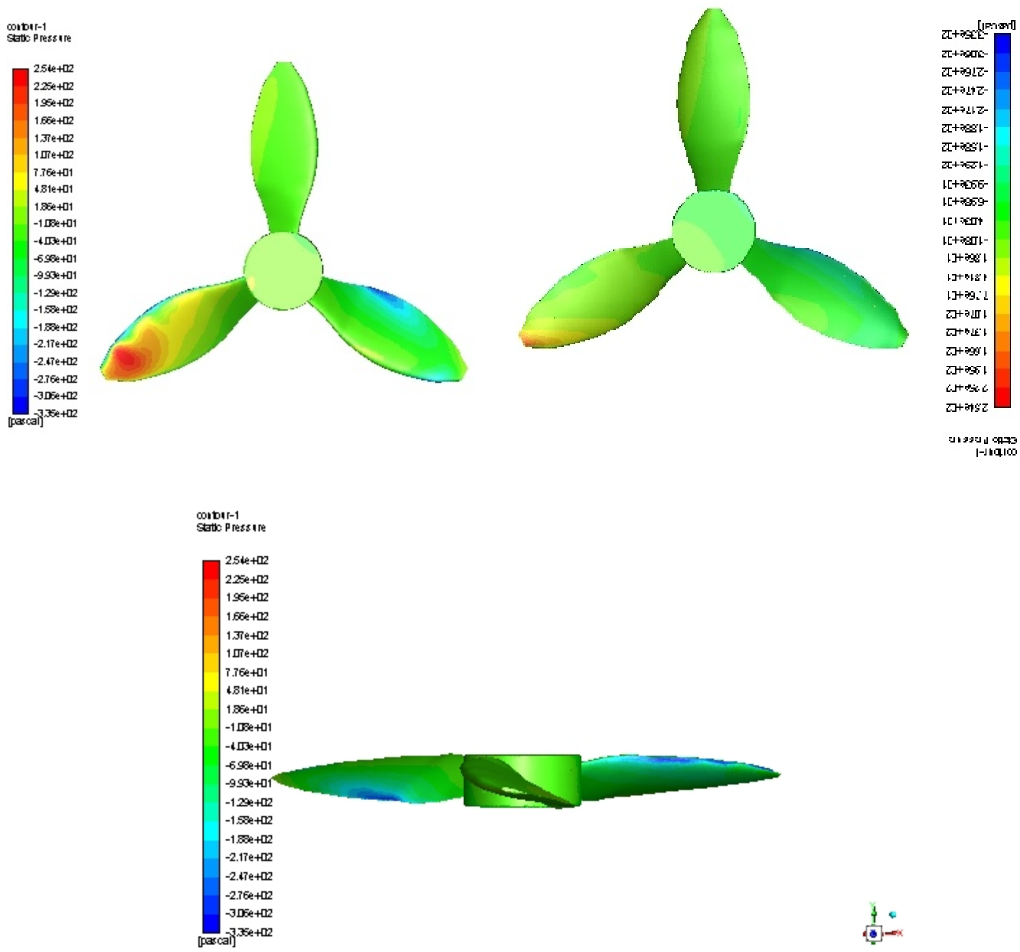



Figure 8.9-11 Static pressure distribution of the fan

Besides the static surface pressure, further analysis of the velocity vector field is analyzed. From the figure below, it is clear to see that a vortex is generated behind the fan, with a higher velocity vector. However, since the size and shape of the passage flow (stationary zone) is chosen wrong, this may lead to the result of a stronger vortex. Therefore, if the simulation is conducted with a bigger stationary zone, a more uniform velocity vector profile is expected. Nevertheless, the form of the vortex still presents a challenge for car following. Since our car is being followed, the vortex generated by the fan will increase the difficulty of car following, meaning that the driving control system for the other car will need to cope with unstable disturbance.

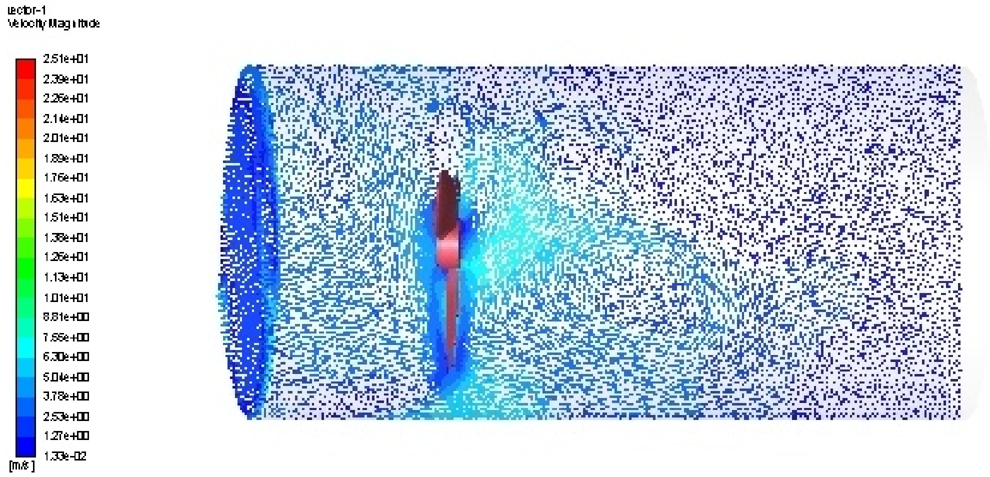



Figure 8.12 Velocity vector flow

## 8.2 Finite Elements Analysis

To evaluate the mechanical properties of different fan designs, the stress distribution of the fan with a centrifugal force was simulated. The following parts present the simulation analysis and comparisons.

**Model setup**

The simulation was done with Abaqus. Since the fan is axially symmetrical, the simulation was done in cyclic symmetry boundary conditions to save the simulation time. Boundary conditions are given as displacement equals zero at the center axial; the load was given as rotational body force. The figure below shows the force distribution during the simulation.

Two different fan shapes were simulated, both are five-blade fans.

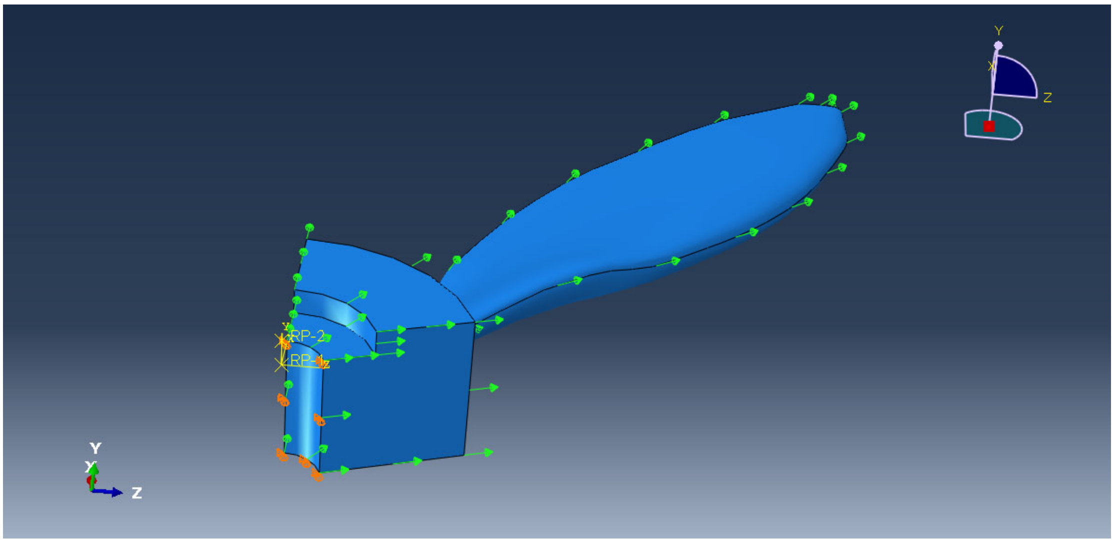



Figure 8.13 the boundary condition and the load of the model

**Simulation results**

Both fans have higher stress on the blade near the center, which is expected because the part, closer to the center, experiences a higher centrifugal force due to its shorter distance. The analysis results show that Fan1 has higher overall stress then fan 2, particularly at the part where the blade attaches to the axial. The main reason may be the lack of chamfer in fan 1. In both simulation and reality, sharp edges are prone to stress concentration. The situation can be improved if a chamfer is added in the future version of fans. Besides, fan2 is thicker than fan 1, meaning that although it has a higher weight, it also possesses more material to support it.

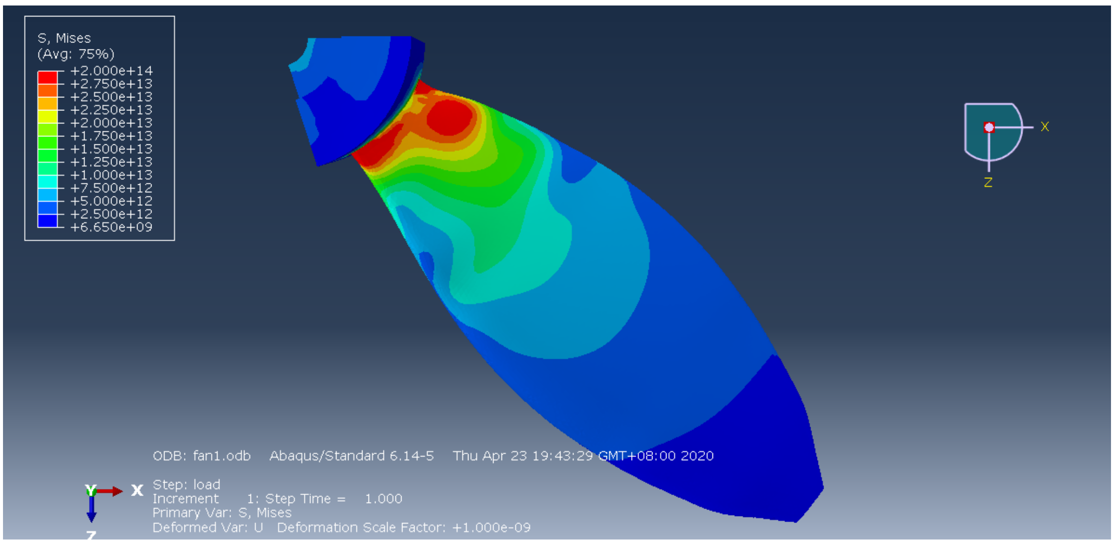



Figure 8.14 the back side of fan 1

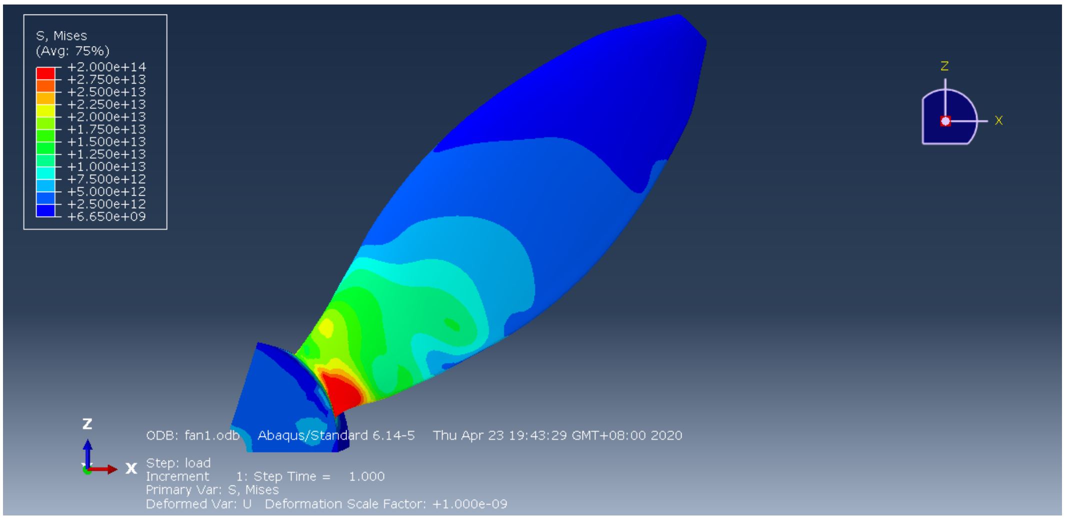



Figure 8.15 the front side of fan1

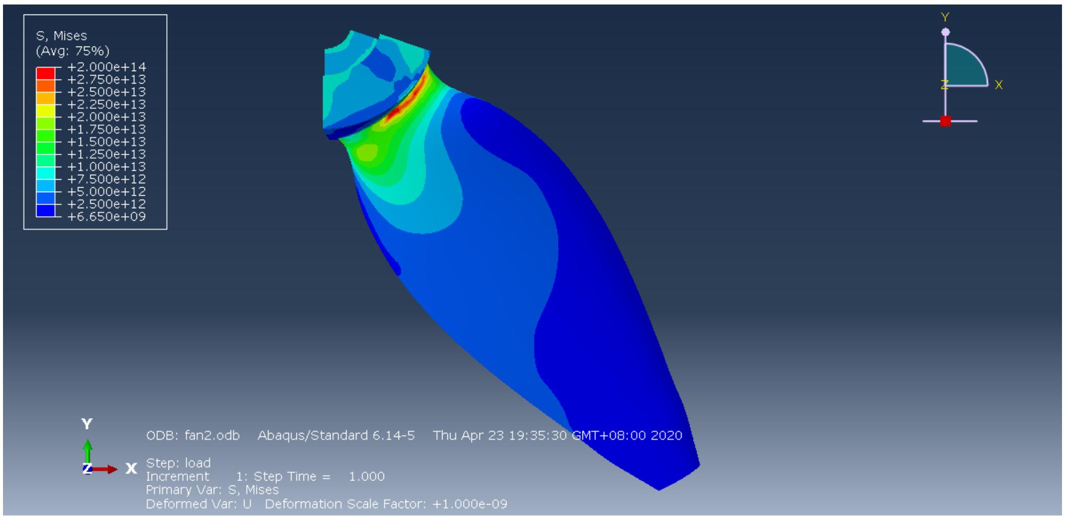



Figure 8.16 the backside of fan2

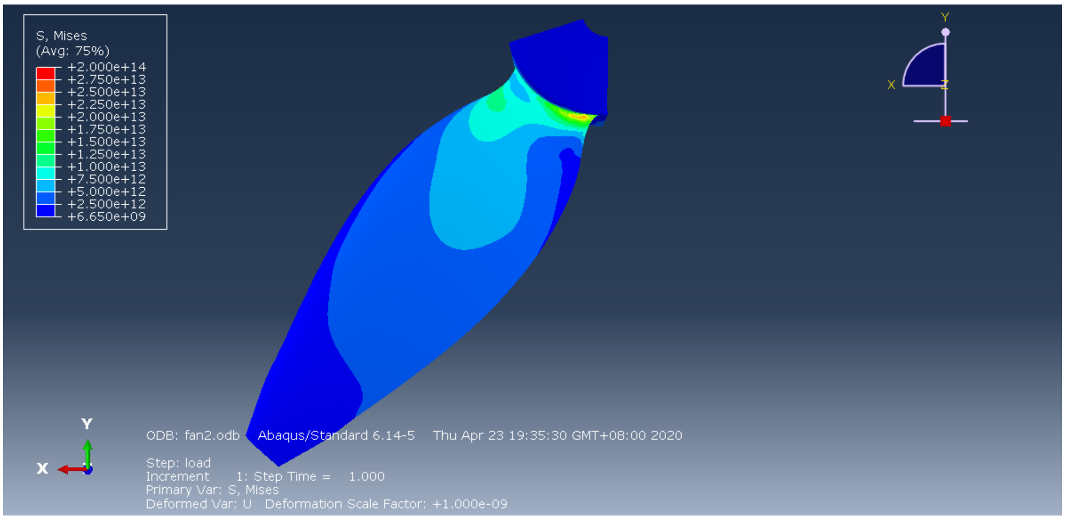



Figure 8.17 front side of fan2

Comparing the whole fan of fan 1 and fan 2, part of the axial of fan 2 helps to sustain the centrifugal force more because the connection area between the blade and axial is larger. On the other hand, the deformation of the axial of fan 1 is small. Since both fans experience the same force if the axial undergoes a smaller deformation the blade connection will share more portion of sustaining the stress and experience higher stress.

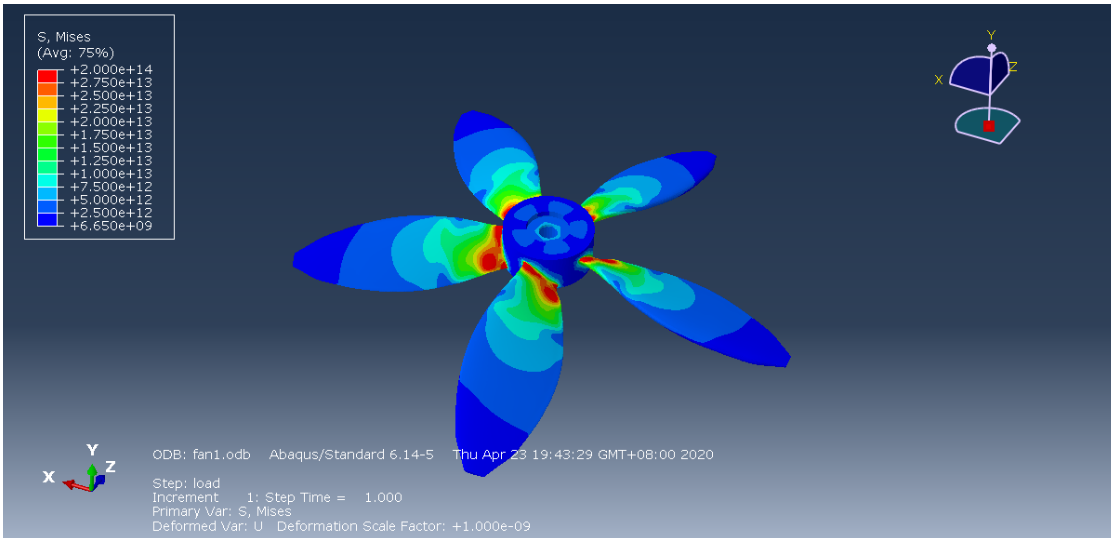



Figure 8.18 Overall view of fan 1

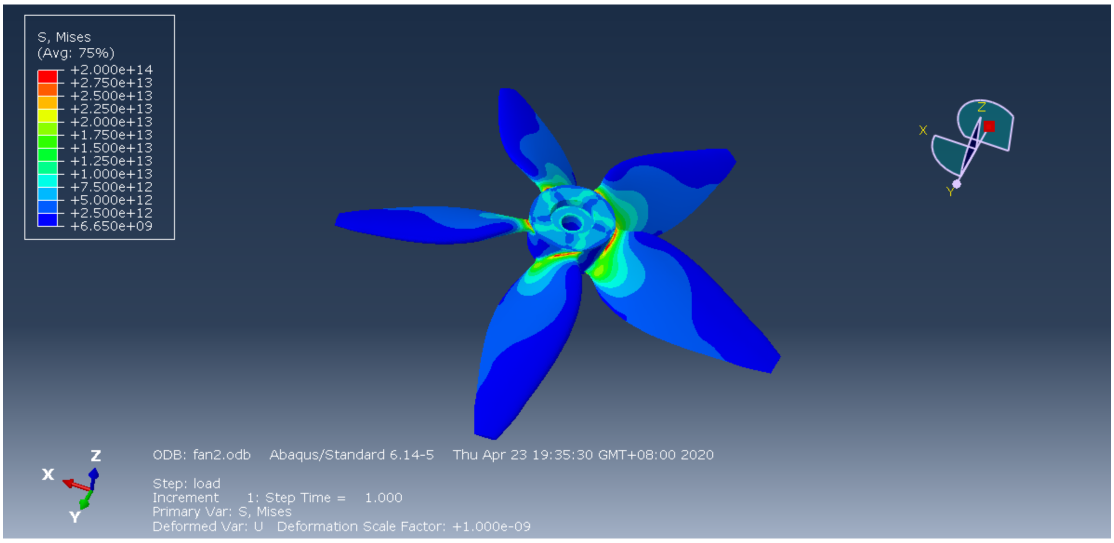



Figure 8.19 overall view of fan 2

In the figures below, the meshed part is the original shape, and the colored part is the deformed result after simulation. Comparing the results of fan1 and fan2, fan 1 shows a larger deformation in the blade. The higher deformation rate may contribute to larger stress. The result can also be explained that the center of mass does not lie on the line between the center of the fan and the roots of fan blades.

However, the deformation may not be a problem in reality. When operating the fan in the air, there is air drag on the fan, providing force from the other direction. Therefore, the deformation from the air drag may offset that from the centrifugal force.

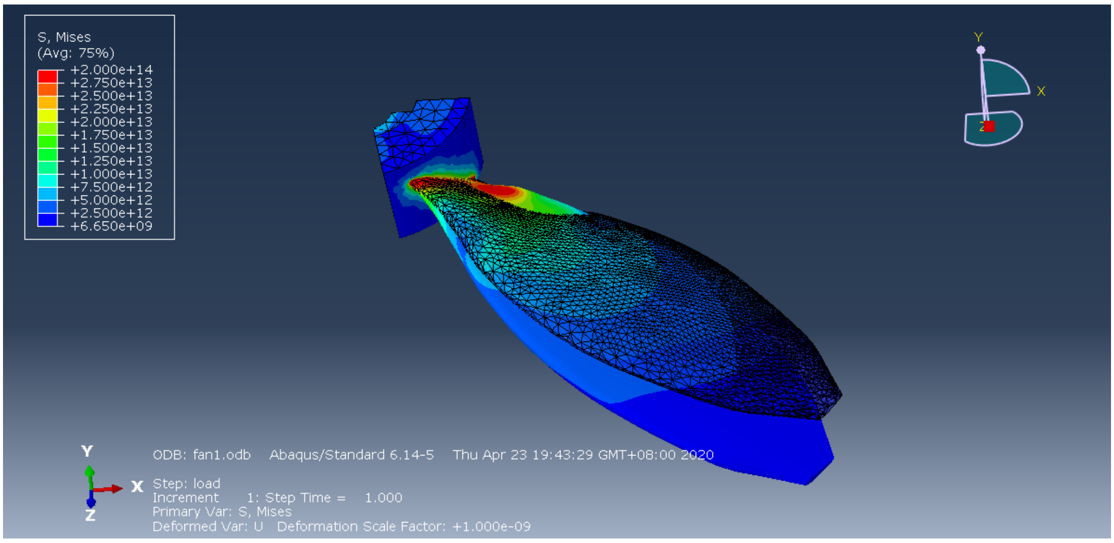



Figure 8.20 Fan 1 deformation

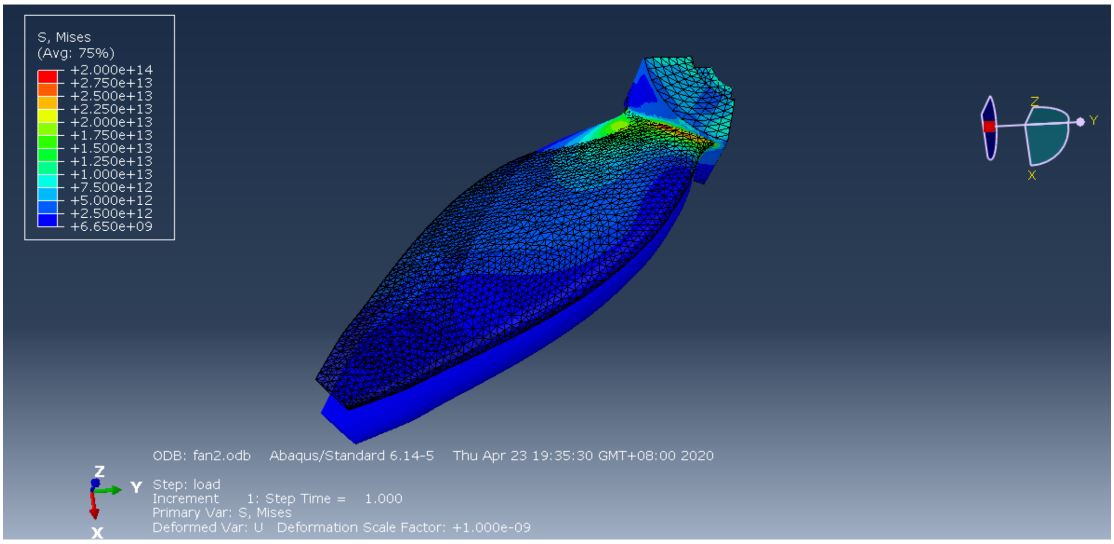



Figure 8.21 Fan 2 deformation

## Conclusion

Due to the complexity of solid and fluid interaction, the simulation is conducted without air. Although the real situation is different from our assumption, this simulation still sheds some light on some possible ways to improve the fan designs in the future.

## Simulation of Midterm Car Motor Supporting Structure

The structure of the motor holder is designed with two parts: fiberboard structure at the front, 3D printed part at the back, connecting the motor and the fan cover. To find out the structural reliability of the design, Finite Element Analysis (FEA) simulation was made to observe the deformation situations under forces.

In the analysis, two boundary conditions were set: one at the car base, displacement equals zero, and the other at the part connected to the motor, where displacement was given. The boundary condition is set as the following: the plate connecting to the motor is fixed in the z-direction, and given displacement in the y-direction. The z-direction has movement freedom.

The simulation results show that the 3D printed part undergoes deformations mostly from stretching forces, while the fiberboard part experiences compression forces. The fan cover structure is rather sturdy, only the two motor holder parts undergo larger deformations. Judging from the simulation results and the finished prototype, we can safely conclude here that the main structure of the car is strong enough.

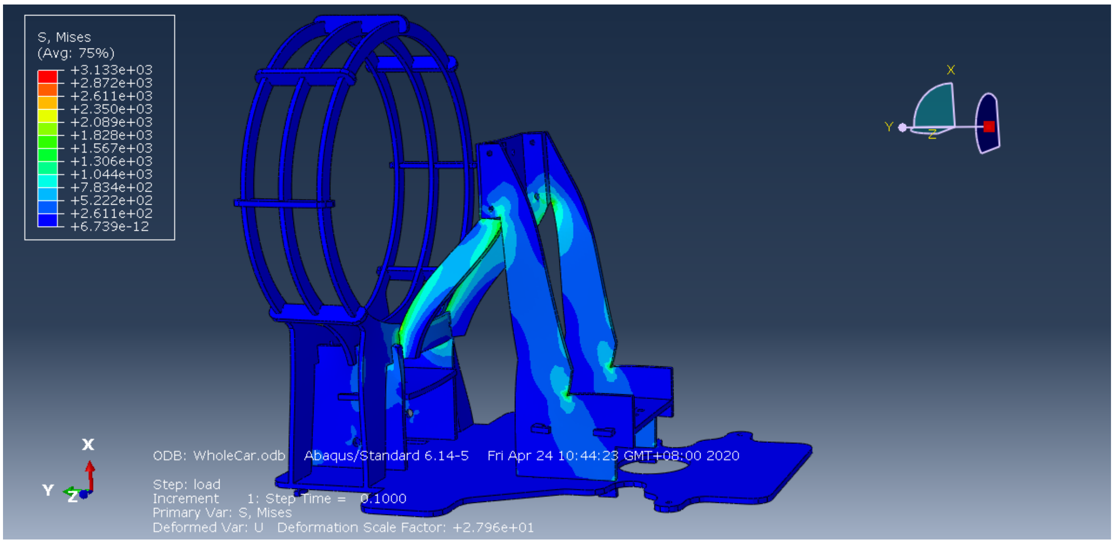



Figure 8.22 the deformation of motor holder with car base and fan cover

Simulation of the keel of the final car

The keel of the car undergoes the highest force. To evaluate the design of the keel, finite elements analysis was performed.

The boundary condition and the force applied are shown in the following figure. The part of the keel facing downwards and contacting the car base was set to have contact with little shells that have fixed positions. The vertical slot on the keel is the place that fixed the keel to the base by cornered steels. The boundary condition was set to be fixed in all degrees of freedom. The upper part of the keel, connecting to the motor, was applied with horizontal force to simulate the thrust. Since there are four keels in total supporting the motor, the z-direction freedom of this part is fixed.

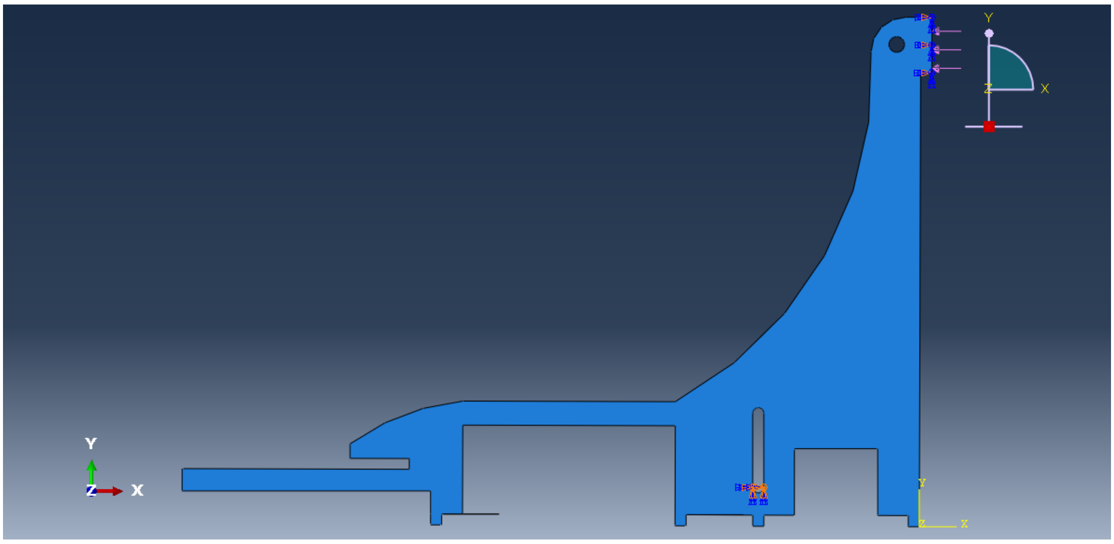



Figure 8.23 the set up of keel

The simulation results are shown in the following figure. The distortion is amplified by the software for visualization. It shows that the part facing the motor undergoes tension stress, while the other direction undergoes compression stress. The superiority of the design is clear: the curved back can provide sufficient support for the motor holder while having a little movement freedom in the x-direction. This small freedom makes the strain and stress distribute averagely to the whole structure, instead of concentrating on the corners.

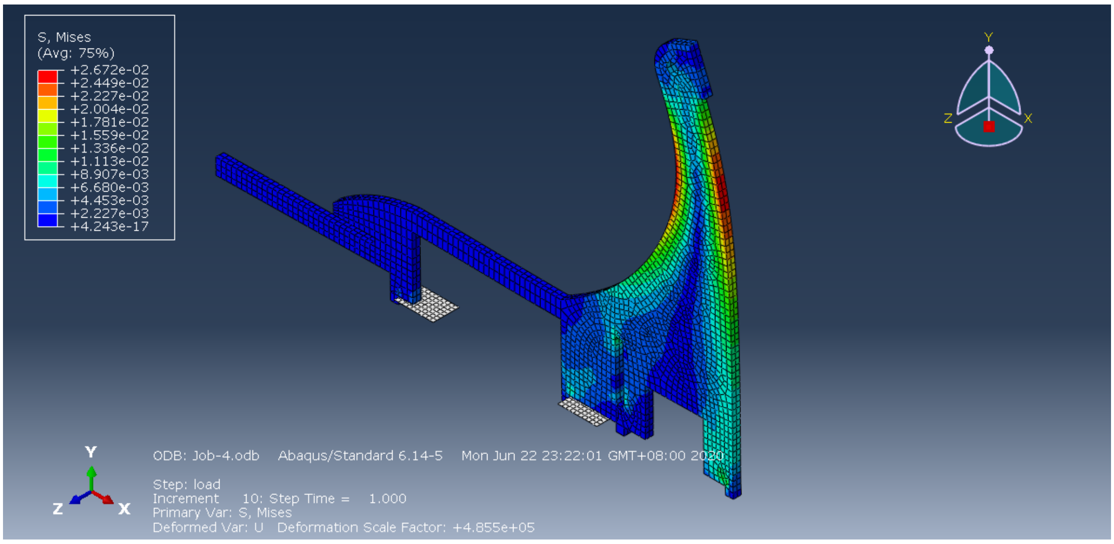



Figure 8.24 The deformation of the keel with applied horizontal force

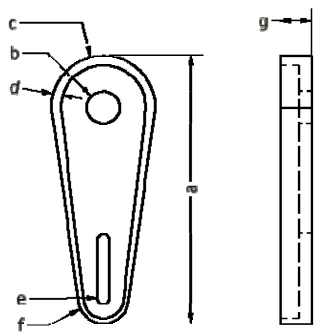
# Chapter 9 Experiment

## 9.1 Tolerance

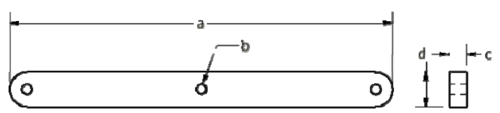
To examine the manufacturing error of each component of the car, each component, made by 3D printing or laser cutting, is measured and compared with the ideal size.

Modified midterm car: 3D printed parts with Kingssel 3D printer

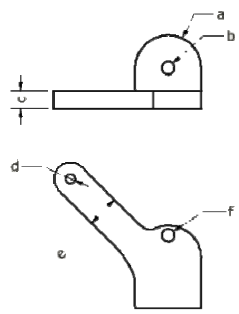
| Ackerman Main Link | | | |
|---|---|---|---|
| No. | Original (mm) | Measured (mm) | Error (%) |
| a | 67 | 66.8 | 0.30 |
| b | Ø8.2 | Ø8.1 | 1.22 |
| c | R13 | R12.9 | 0.77 |
| d | 2.3 | 2.1 | 8.70 |
| e | R1.5 | R1.25 | 16.67 |
| f | R6.2 | R6.0 | 3.23 |
| g | 7.8 | 7.9 | -1.28 |



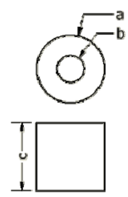

| Ackerman Center Link | | | |
|---|---|---|---|
| No. | Original (mm) | Measured (mm) | Error (%) |
| a | 110 | 114 | -3.64 |
| b | Ø3 | Ø2.5 | 16.67 |
| c | 5 | 4.9 | 2.00 |
| d | 10 | 12 | -20.00 |



| Ackerman Side Link | | | |
|---|---|---|---|
| No. | Original (mm) | Measured (mm) | Error (%) |
| a | R10 | R9.8 | 2.00 |
| b | Ø4 | Ø3.9 | 2.50 |
| c | 5.4 | 5.0 | 7.41 |
| d | Ø3 | Ø3.0 | 0.00 |
| e | 10 | 10.1 | -1.00 |
| f | Ø4 | Ø4.0 | 0.00 |



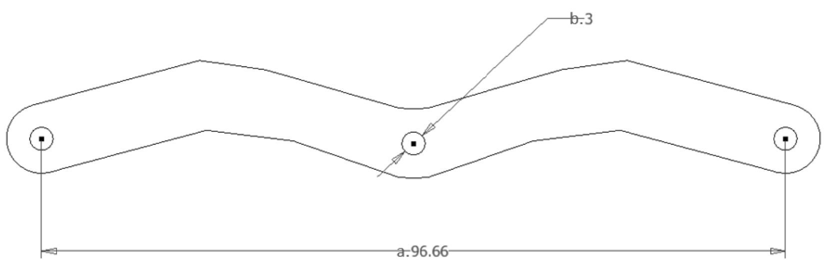

| Wheel-Ackerman Nut | | | |
|---|---|---|---|
| No. | Original (mm) | Measured (mm) | Error (%) |
| a | Ø10 | Ø9.8 | 2.00 |
| b | Ø4 | Ø3.7 | 7.50 |
| c | 10 | 9.8 | 2.00 |




Final Car

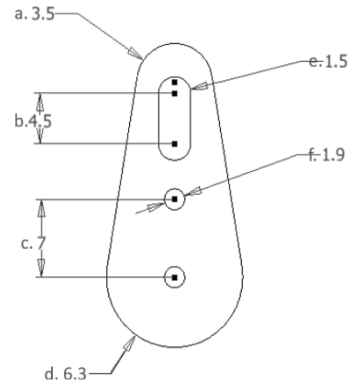
a. Laser Cutting: Beambox with layer height 0.08mm and fill density 40%.

Tie Rod of Turning System




| No. | Ideal size (mm) | #1 | #2 | #3 | Error(%) |
|---|---|---|---|---|---|
| a | 96.66 | 96.35 | 96.34 | 96.35 | 0.32416 |
| b | 3 | 3.06 | 3.06 | 3.07 | -2.11111 |

| Center Arm of Turning System | | | | | |
|---|---|---|---|---|---|
| No. | Ideal size | #1 | #2 | #3 | Error(%) |
| a | 3.5 | 3.6 | 3.58 | 3.59 | -2.57143 |
| b | 4.5 | 4.5 | 4.4 | 4.4 | 1.481481 |
| c | 7 | 7.1 | 7.0 | 7.0 | -0.47619 |
| d | 6.3 | 6.28 | 6.26 | 6.28 | 0.42328 |
| e | 1.5 | 1.50 | 1.52 | 1.51 | -0.66667 |
| f | 1.9 | 1.89 | 1.89 | 1.89 | 0.526 |

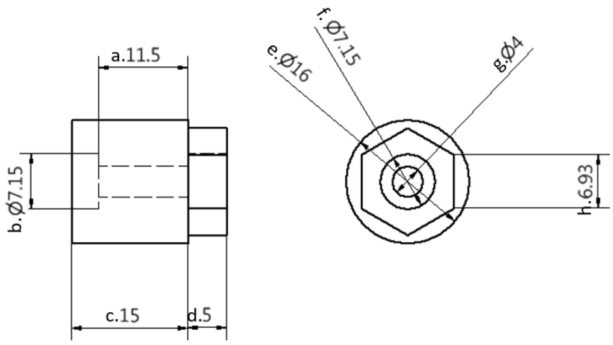



The sources of laser cutting manufacturing errors are the following:

1. The fiberboard is put inside the machine without holders. Hence, the position may change during manufacturing.
2. Within a manufacturing process, the fiberboard may not lay completely flat, resulting in the varying distance between the part and focus point, resulting in the difference of cutting width.
3. Among different manufacturing processes, the conditional difference of the machine, such as the height of the laser source, or the calibrating error is also possible resources for producing errors.
4. The laser cutter is constantly used, which may result in the overheat of the machine.

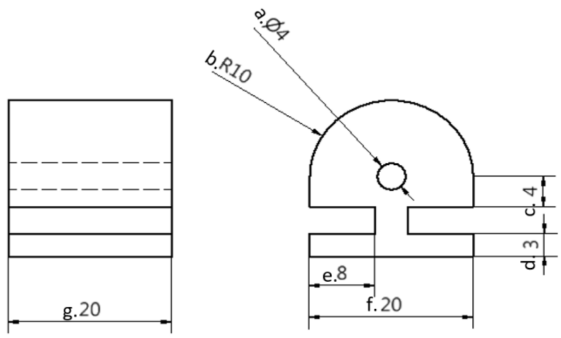
b. 3D Printing: Kingssel with Power 90% and speed11%.

Hex Coupling




| No. | Ideal size (mm) | #1 | #2 | #3 | Error(%) |
|---|---|---|---|---|---|
| a | 11.5 | 11.7 | 11.7 | 11.71 | -1.76812 |
| b | 7.15 | 7.15 | 7.15 | 7.14 | 0.04662 |
| c | 15 | 15.21 | 15.20 | 15.21 | -1.37778 |
| d | 5 | 5 | 4.99 | 4.99 | 0.133333 |
| e | 16 | 16.03 | 16.05 | 16.05 | -0.27083 |
| f | 7.15 | 7.15 | 7.15 | 7.15 | 0 |
| g | 4 | 3.99 | 4 | 3.98 | 0.25 |
| h | 6.93 | 6.95 | 6.96 | 6.96 | -0.3848 |

Rear Axle Shaft Retainer




| No. | Ideal size (mm) | #1 | #2 | #3 | Error(%) |
|---|---|---|---|---|---|
| a | 4 | 4 | 4 | 4 | -2.33333 |
| b | 10 | 10.2 | 10.3 | 10.2 | -3.58333 |
| c | 4 | 4.15 | 4.14 | 4.14 | -7.77778 |
| d | 3 | 3.2 | 3.2 | 3.3 | 2.416667 |
| e | 8 | 7.8 | 7.82 | 7.8 | -0.71667 |
| f | 20 | 20.14 | 20.16 | 20.13 | -0.06667 |
| g | 20 | 20 | 20.02 | 20.02 | -2.33333 |

The sources of 3D printing manufacturing errors are the following:

1. When converting the format of the drawings to .stl file, the model is layered, and complicated shapes are simplified to many two dimensional figures. These figures are layered up and form the manufactured part. However, during the converting and simplifying process, some of the geometrical features are lost. For example, a circle may be simplified to a polygon. This is one possible reason to cause a manufacturing error.
2. The lack of regular maintenance and the frequently used machine may lead to the imprecision of positioning and temperature.

<u>Conclusion:</u>

Comparing the results of laser cutting and 3D printing, it is obvious that the laser cutting has higher precision, and the errors are more consistent. On the other hand, the errors of 3D printed parts have inconsistent errors. It can be accurate sometimes, but it can also have an error of up to 7.78%.

## 9.2 Drag Force

Objective

Measure the upstream and downstream flow speed of the car with the fan turned off. Apply the control volume theory to estimate the drag force.

Theory

To estimate hydrodynamic force, a control volume is defined to describe the flow around an object. Neglecting the lateral velocity component in the studied area, the flow is assumed to be one-dimensional. After measuring velocity distributions, the drag per unit width on the object can be calculated. [15] For a fixed volume system, the momentum flux across the boundary is

$$\sum \vec{F} = \frac{d}{dt}\int \rho V dV + \oint \rho V(V \cdot n) dA \qquad (9.2.1)[15]$$

Lab procedures

1. Measure the height of car (H) and room temperature (repeat under different duty values); place the car in position and add some obstacles in front of it.
2. Turn on the wind tunnel and tune the duty to 30%.
3. Measure the flow speed at up- and downstream of the car with an interval of 4 cm, with the fan off. Aim the hotwire anemometer perpendicular to the streamline and use the average value for 20 seconds and record the flow speed.

Data Analysis and Discussions

1. Airflow distribution

To visualize our data result, the measured flow speed is plotted against the height, where the data is measured. The figures below show how the airflow varies across the height from 4 centimeters to 36 centimeters, with the fan motor off.

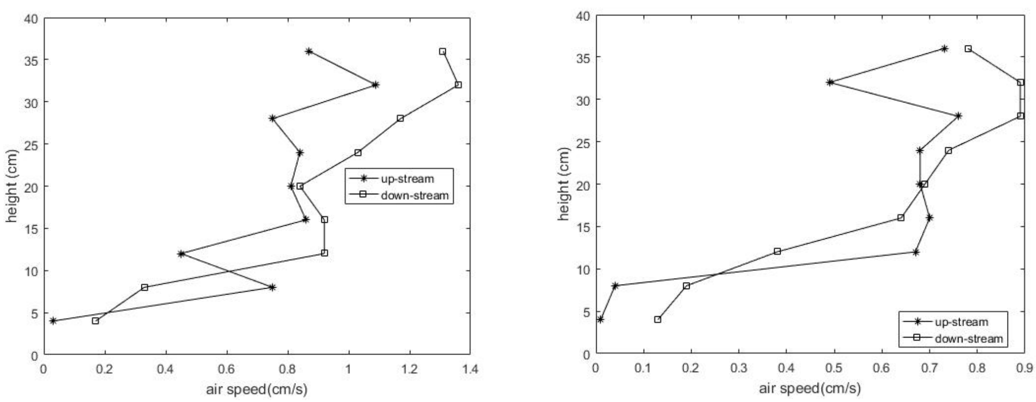



Figure 9.1 the upstream and downstream flow speed of the two cars

To calculate the drag of the car, the formula is written as

$$D = \int \rho({U_u}^2 - {U_d}^2)dA \qquad (9.2.2)[15]$$

where $\rho$ is density, $U_u$ is the upstream airflow velocity and $U_d$ is the downstream airflow velocity. $dA$is defined as the cross-sectional area that captures the fluid with the mathematical equation

$$dA = dy * w$$

wheredy is the interval of measuring height and w is the width of the car. At room temperature, the air density is 1.24 kg/m$^3$; and the width is around 18 centimeters long at the cross-section. Summing all the measured data from the experiment, the drag force of the car can be calculated.

However, taking a closer look at the data from the previous figures, the downstream velocity exceeds the upstream velocity, which means that the pressure differences dominate the flow distribution of the system. This phenomenon can also be explained by the car structure. The bottom of the car is stacked with many mechanisms and electrical components, forming an obstacle and, thus, the downstream velocity is smaller than the upstream ones. However, as the measuring height increases, the car structure has fewer mechanical structures. In fact, only a fan and a fan shroud are at the top. The airflow can go through space without any difficulties. The volume decrease may also cause the effect of a nozzle and increase the flow speed.

## 9.3 Fan Thrust

Objective

Operate the smoke generation facility to observe the flow lines and measure the flow distribution. Apply the actuator disk theory to calculate the fan thrust.

Theory

Actuator Disk theory illustrates a model of a propeller or a helicopter rotor. From picture 1, the mass flow rate remains constant in each section. Therefore, when the flow speed is decreased due to the turbine's extraction, the upstream tube has a smaller area than that of downstream. These relations can be expressed in the formulas

$$\rho A_\infty U_\infty = \rho A_d U_d = \rho A_w U_w \qquad (9.2.3)[16]$$

$$\frac{1}{2}\rho_\infty {U_\infty}^2 + P_\infty + \rho_\infty g h_\infty = \frac{1}{2}\rho_w {U_w}^2 + P_w + \rho_w g h_w \qquad (9.2.4)[16]$$

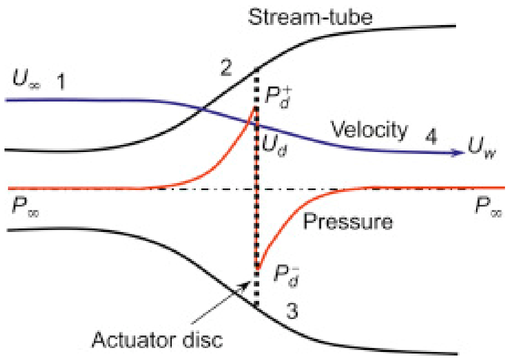



Figure 9.2 Actuator disk theory[17]

Procedures

1. Close the door first and turn on the fan to duty 30%. Measure the background flow at W1, W2, W3. Calculate the background flow as $U_\infty=(U_{w1}+U_{w2}+U_{w3})/3$
2. Turn on the smoke generation facility andturn off the light. Make sure the green laser light aims toward the center.
3. Turn on the fan power supply. Set the duty cycle of the motor to 30.
4. Estimate the inlet and outlet throat area through the visualized streamline. Measure 5 equally spaced points at the inlet throat area and three points at the outlet. Read the value after a 20-second average.

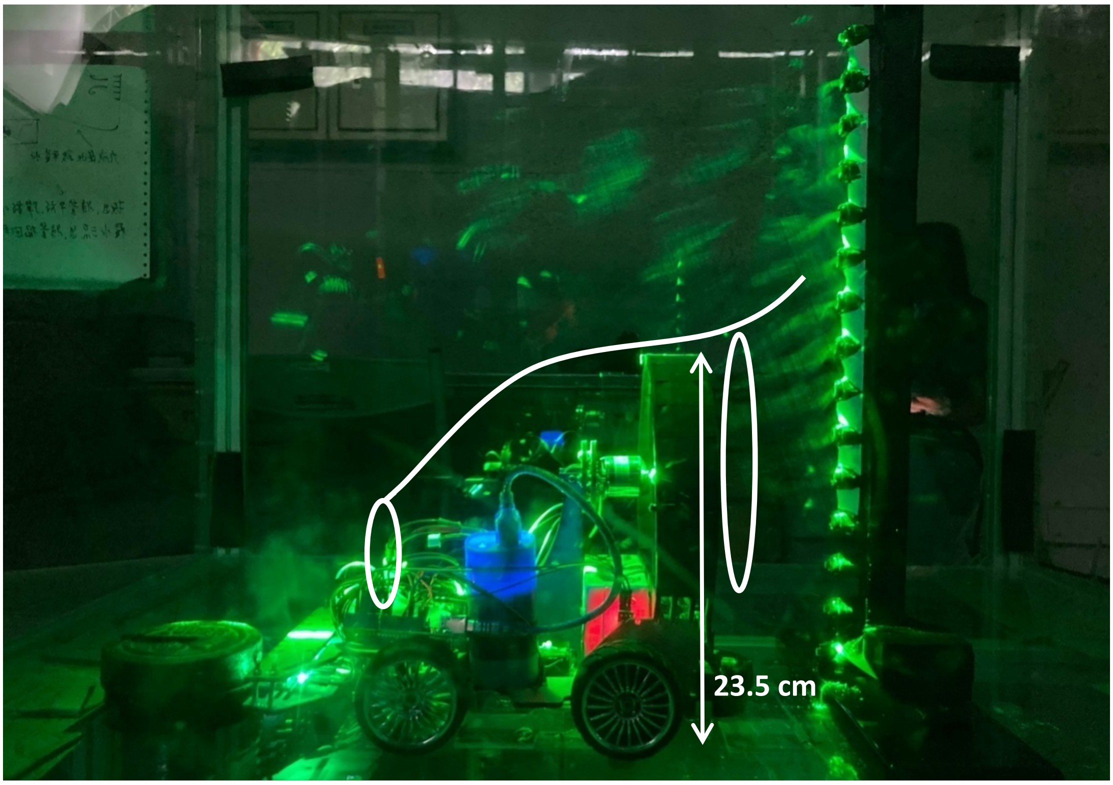



Figure 9.3 Experiment with airflow visualization

## Data Analysis and Discussion

While measuring the background flow speed, we noticed the difference between closing the door and leaving it open. The table below presents the collected data.

Table 9.2 Background flow measurement

| | Door Closed | Door Opened |
|---|---|---|
| Right point (cm/s) | 0.39 | 1.31 |
| Middle point (cm/s) | 0.89 | 1.06 |
| Left point (cm/s) | 0.81 | 1.19 |
| Average (cm/s) | 0.68 | 1.186 |

The table below is the data from the inlet and outlet throat areas and the calculated average speed.

Table 9.2 the data from the inlet and outlet throat areas and the calculated average speed

| Measuring location | Inlet throat area | Outlet throat area |
|---|---|---|
| Data 1 (m/s) | 0.044 | 5.204 |
| Data 2 (m/s) | 0.554 | 4.01 |
| Data 3 (m/s) | 0.324 | 3.294 |
| Data 4 (m/s) | 0.214 | |
| Average flow speed (m/s) | 0.284 | 4.17 |

The inlet and outlet throat area are estimatedthrougha photo with the height of the car as the scale. The height of the car is 23.5 centimeters; the estimated radius of the inlet throat area is 7.83 centimeter and the estimated radius of the outlet throat area is 3.91 centimeters. The throat areas are calculated

$$A_{inlet} = \pi r^2 = \pi \times 0.0783^2 = 0.0193\ (m^2)$$
$$A_{outlet} = \pi r^2 = \pi \times 0.0391^2 = 0.0048\ (m^2)$$

Using the average upstream, downstream velocity, throat areas, the volume flow rate is obtained. Based on the conservation of mass and assume no change of density, the results should not differ much. Volume flow rate is calculated as

$$\mathrm{Q = Area \times average\ flow\ speed = A \times u}$$

The radius of our fan is 6.5 centimeters.

$$A_{disk} = \pi r^2 = \pi \times 0.065^2 = 0.0133 (mm^2)$$

From the actual disk theory, the flow speed at the fan equals the average of the upstream and downstream velocity.

$$u_{disk} = \frac{1}{2} \times (u_{out} + u_{in}) \qquad (9.2.5)[16]$$

The volume flow rate is calculated as

$$\mathrm{Q} = A_{disk} \times u_{disk} = 0.0133 \times 2.227 = 0.0296 (m^3/s)$$

The fan thrust can be derived from actuator disk theory,

$$\mathrm{T} = A_{disk}(P_2 - P_1) \quad and \quad P_2 - P_1 = \frac{1}{2}\rho(u_{out}{}^2 - u_{in}{}^2) \qquad (9.2.6)[16]$$

$$\mathrm{T} = \frac{1}{2} A_{disk} \rho (u_{out}{}^2 - u_{in}{}^2)$$

where T is the thrust, $A_{disk}$ is the rotational area of our fan, $\rho$ is the air density, $u_{out}$ is the average of the downstream velocity; $u_{in}$ is the average of the upstream velocity.

The thrust is, thus, calculated

$$\mathrm{T} = \frac{1}{2} \times 0.0133 \times 1.24 \times (4.17^2 - 0.284^2) = 1.4\ (N)$$

## 9.4 Net Thrust

Objective

Apply the control volume concept to describe the system and use Bernoulli's equation to calculate the net thrust of the fan propelled car.

Theory

Bernoulli equation is an approximate relation between pressure, velocity, and elevation, andis valid in regions of steady, incompressible flow where net frictional forces are negligible. Itis an approximate equation that is valid only in inviscid regions of flow where net viscousforces are negligibly small compared to inertial, gravitational, or pressure forces. Suchregions occur outside of boundary layers and wake. [18] The governing equation can be written as

$$\int \frac{dP}{\rho} + \frac{V^2}{2} + gz = const \qquad (9.4.1)[18]$$

where P is pressure, $\rho$ and V are the density and velocity of the flow, g is the gravitational acceleration and z is the height change between inlet and outlet. For incompressible flow, the formula is simplified as

$$\frac{P}{\rho} + \frac{V^2}{2} + gz = const \qquad (9.4.2)[18]$$

Based on Bernoulli's equation, the thrust can be described as

$$\mathrm{T} = A_{cv}(P_d - P_u) = \frac{1}{2} A_{cv}\rho\left({U_d}^2 - {U_u}^2\right) \qquad (9.4.3)[18]$$

where $A_{cv}$ is the defined control volume, $P_d$ is the downstream pressure, $P_u$ is the upstream pressure, $\rho$ is the density of the fluid, and $U_d$ and $U_u$ are the downstream and upstream airflow velocity respectively.

Lab Procedure

1. Place the car in the center of the flow passage and add some obstacles in front of it to prevent sliding from flow speed.
2. Turn on the fan to duty 30%. Turn on the propeller fan of the car, the duty cycle of the fan speed control is set at 30. Measure the flow speed at up- and downstream of the car with an interval of 4 cm. Aim the hotwire anemometer perpendicular to the streamline and use the average value for 20 seconds and record the flow speed.

Data Analysis and Discussions

With the effect of a fan, the downstream flow speed is much larger than that of upstream flow. The control volume is defined as a rectangular area with 36 cm high and 18 cm wide. When the height exceeds 36 cm, the effect of fan flow is small enough to be neglected, verified by the figure below. Therefore, it is reasonable to gain data below 36 cm to calculate net thrust. the width of the control volume is the width of the car.

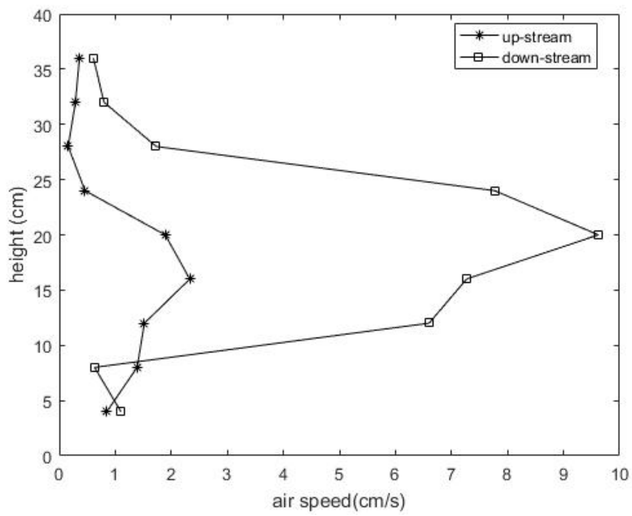



Figure 9.4 upstream and downstream flow speed measurement

From the previous formula, the net thrust of the system is calculated as

$$T = \frac{1}{2} \times 0.18 \times 0.04 \times 1.24 \times (254.9 - 14.41) = 1.07(\mathrm{N})$$

Since it is the net thrust of the system, both propulsion force and drag force are included. Therefore, deducted by the fan thrust obtained from actual disk theory, the drag force can be calculated.

$$\mathrm{Drag} = \mathrm{Fan\ thrust} - \mathrm{Net\ thrust} = 1.4 - 1.07 = 0.33(\mathrm{N})$$

## 9.5 Noise test

Objective

Use a sound level meter to test the noise generated by our fan. Compare the noise detected at the different duty cycles and compare the result with a decibel table in daily life.

Theory

A sound level meter is used for acoustic (sound that travels through the air) measurements. It is commonly a hand-held instrument with a microphone. The best type of microphone for sound level meters is the condenser microphone, which combines precision with stability and reliability. The diaphragm of the microphone responds to changes in air pressure caused by sound waves. [19]

Procedure

1. Download an app that has the function of a sound meter.
2. Find a quiet place to minimize the noise influence from the environment and place the car facing a wall.
3. Turn on the power supply of the car and set the duty cycle to 11.
4. Record the average noise detected from the app and increase the duty cycle to 16, 21, 26, 31, 36.

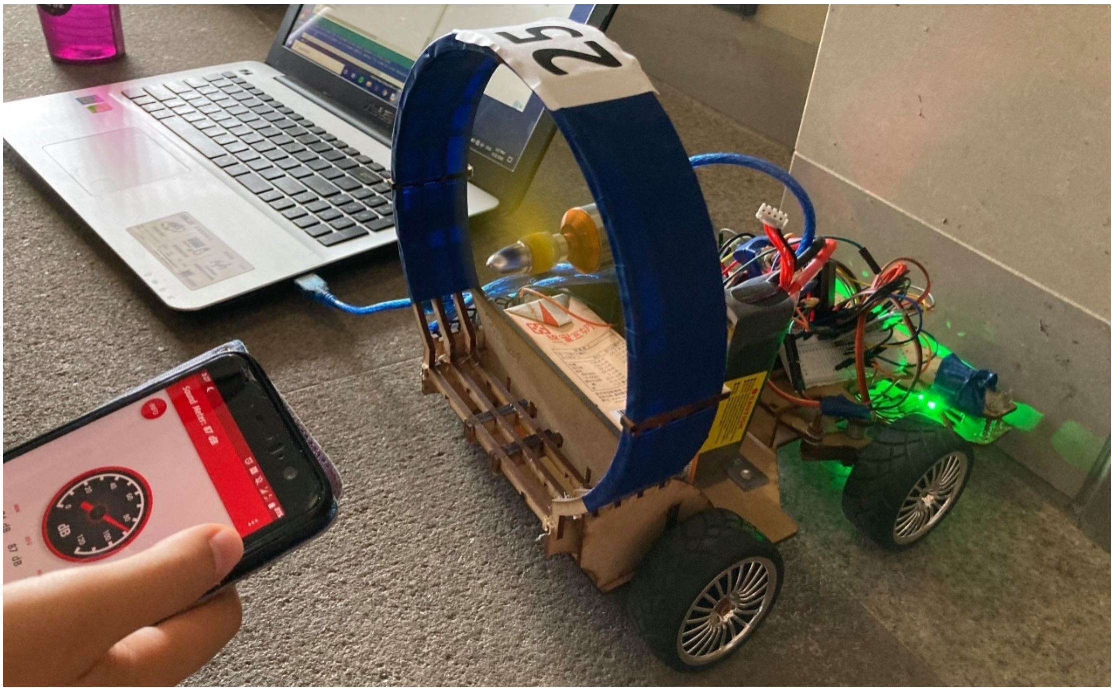


Figure 9.5 Experiment setup

Data Analysis

The figure below shows the data points of increasing the duty cycle and the detected noise. Since a sound meter app was used during the experiment, the sound testing might not be as sensitive as a real one, which might be one reason why the detected noise saturates at the end.

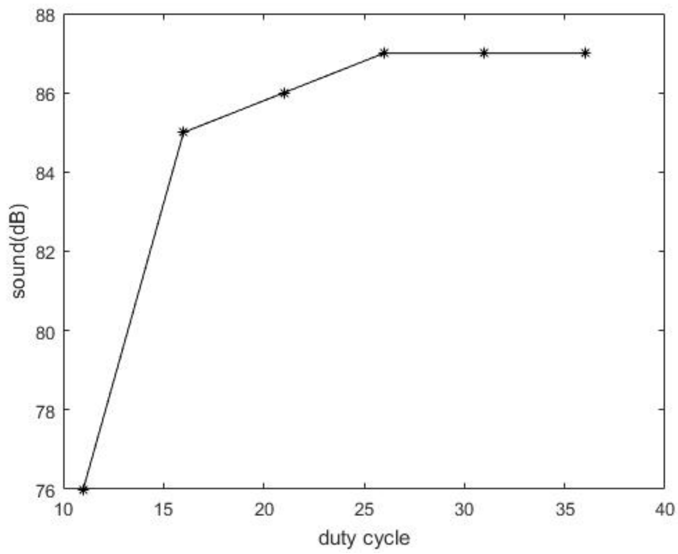



Figure 9.6 Sound test experimental data

The data shows that the detected noise saturates at 87 dB even though the duty cycle keeps increasing. Therefore, through the whole testing process, our car probably generates the noise at this level, which falls in the region of Busy Hotel Lobby and

Subway. However, this test does not include environmental noises in Yonglin. During the busy hours before testing, several groups are testing their cars and students normally do not lower down their voices when discussing. Some students may have jeopardized their health by exceeding the permitted exposure hours of the decibel level.

| dB Level | Examples | Permitted Exposure (Hours per Day) |
|---|---|---|
| 10 | Breathing | |
| 20 | Whisper | |
| 30 | Library | |
| 50 | Quiet Office | |
| 60 | Conversational Speech, Electric shaver | |
| 65 | Piano Practice | |
| 70 | Noisy Restaurant | |
| 75 | Alarm Clock | |
| 80 | Vacuum Cleaner | |
| 85 | Garbage Disposal / Busy Hotel Lobby | |
| 90 | Tractor / Subway | 8 |
| 100 | Blender, Factory Noise | 2 |
| 105 | Motorcycle, Orchestra | 1 |
| 110 | Power Saw, Heavy Truck, Power Mower | 0.5 |
| 115 | Uncomfortable Feeling Starts | 0.25 |
| 120 | Disco / Loud Bar Music / Shotgun | 0 |
| 130 | Cymbal Crash, Air Raid Siren | 0 |
| 140 | Rock Concert Front Row / Jet | 0 |
| 150 | Chest begins to vibrate | 0 |
| 160 | Eardrum bursts | 0 |
| 190 | Loudest Possible Sound | 0 |

Figure 9.7 Decibel table[20]

## 9.6 Friction test

**Objective**

Obtain the friction coefficient of the wheels and compare its value amongst the two cars made. Both static and dynamic friction tests were conducted. This serves as a reflection of the quality of the manufacturing of both cars, including the selection of bearings, wheels, and pasting methods.

**Working Principle**

Static Friction

Consider a solid body resting on a slope, as is pictured in the following image.

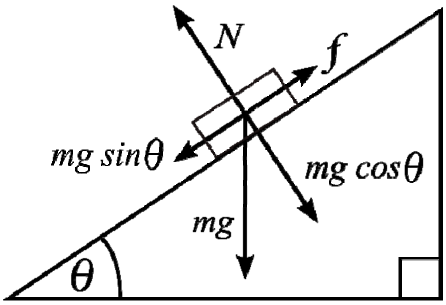



Figure 9.8 the free body diagram

A normal force is defined as $N = mgsin\ (\theta)$, where m denotes the mass and g denotes gravitational acceleration constant. The friction force is defined as $F_f = mgcos(\theta)\mu s$, where $\mu s$ is the static friction coefficient. Summation of the forces yields:

$$mgsi(\theta) = mgcos(\theta)\mu s \qquad (9.6.1)$$

$$\mu s = \frac{sin\theta}{cos\theta} \qquad (9.6.2)$$

$$\mu s = tan\theta \qquad (9.6.3)$$

The formulas show that static friction is solely dependent on our experimental angles.

Dynamic Friction

To obtain the dynamic friction coefficient, therigid body slides down the slope, travels a distance $L_w$ through the slope, and afterward travels a distance L through the horizontal axis. Applying conservation principles, we equate the potential energy from a height h to the work done by the distance traveled through the slope and the horizontal section, w stands for the width of the car.

$$mgh = \mu_d[mgwcos\theta + mgL] \qquad (9.6.4)$$

$$h = \mu_d(L_w * cos\theta + L) \qquad (9.6.5)$$

**Procedure**

We did different tests to obtain different values for static friction and dynamic friction. (Note there is rolling, tipping and sliding). All obtained experimental results are to be recorded at least five times per testing subject.

Static Friction

1. Place the car on a wooden board, perpendicular to the side which is to be elevated.
2. Incline the wooden board until the car rolls forward.
3. Record the angle on inclination θ.

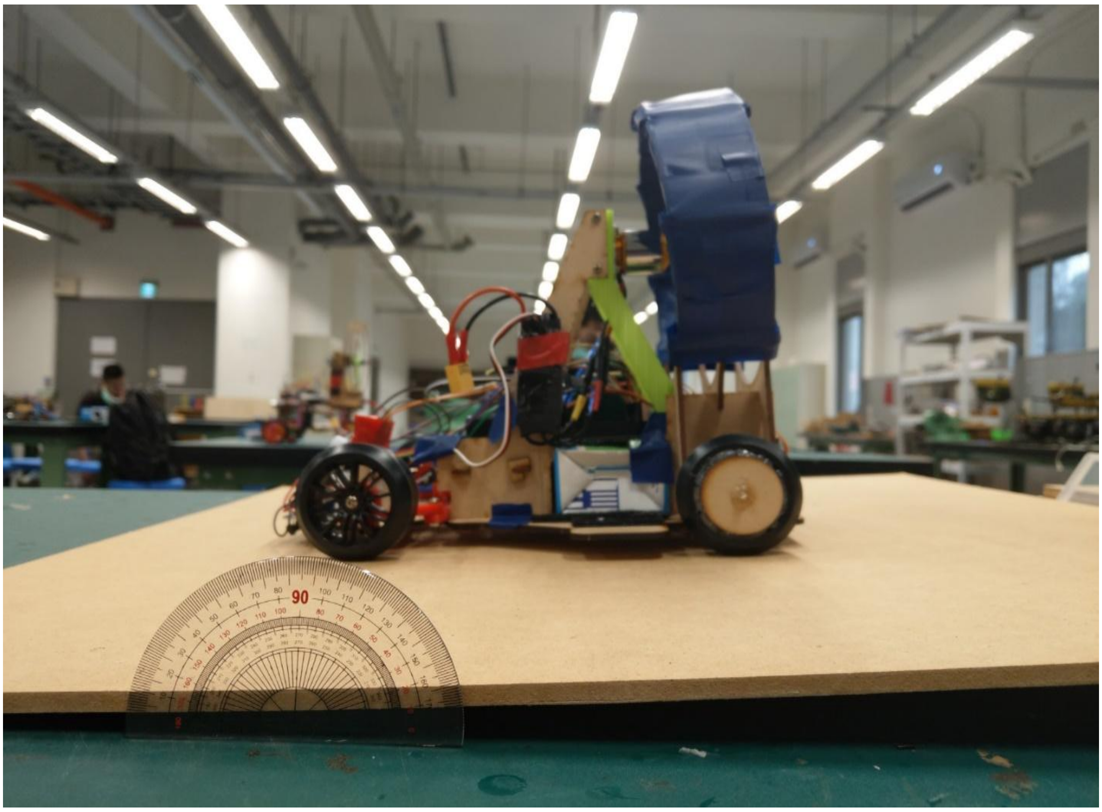


Figure 9.9 Static friction experimental setup

Dynamic Friction

1. Set an inclined surface.
2. Measure the height and angle between the inclined surface and the horizontal.
3. Measure the length $L_w$of the inclined surface.
4. Set the car at the top of the surface and let the car fall on its own.
5. Record the distance traveled L.

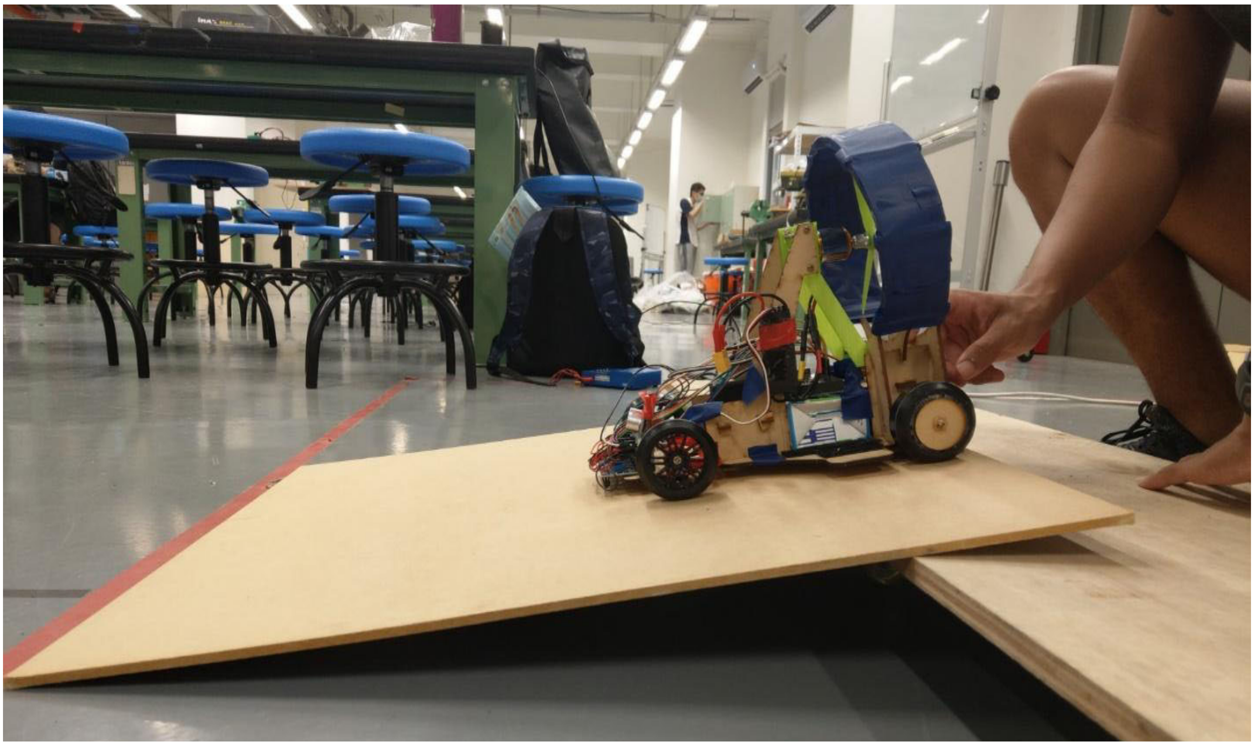


Figure 9.10 dynamic friction experimental setup

Data Analysis

For the dynamic friction test, $L_w$was measured 38.5cm, height h was 8cm, and θ=12°. The following tables present the experimental data of front rolling, side sliding, and the rolling distance of dynamic friction force.

Table 9.3 Table for Sony 1.0.

| | 1st attempt | 2nd attempt | 3rd attempt | 4th attempt | 5th attempt |
|---|---|---|---|---|---|
| Front Rolling | 5° | 5° | 5° | 5° | 5° |
| Side Sliding | 26° | 22° | 22° | 20° | 25° |
| Dynamic Friction | 85.5cm | 84.4cm | 87cm | 89cm | 86.5cm |

Table 9.4 Table for Sony 2.0.

| | 1st attempt | 2nd attempt | 3rd attempt | 4th attempt | 5th attempt |
|---|---|---|---|---|---|
| Front Rolling | 4° | 3° | 3.5° | 4° | 4° |
| Side Sliding | 45° | 47° | 46° | 44° | 45° |
| Dynamic Friction | 416cm | 398cm | 385cm | 398cm | 393cm |

The front rolling test for Sony 1.0gives the internal friction of the wheel, that is, the friction between the wheel and its axle. Using an average value for $\theta$ of $5^o$, the obtained $\mu_{sf} = 0.08$. The side sliding test gives the friction coefficient of the contact between the wheel and the plywood surface. Using an average value for $\theta$ of $23^o$, we can obtain a $\mu_{ss}0.42$. The dynamic friction test gives the dynamic friction coefficient of the wheel contact with its axle. Using an average traveled length L of 86.48cm, $\mu_d = 0.0644$.

The same approach can be used to obtain values for Sony 2.0. The following table compares the two cars. Note that the width of both cars is the same.

Table 9.5 comparison of two cars

| | **Sony 1.0** | **Sony 2.0** |
|---|---|---|
| $\boldsymbol{\mu_{sf}}$ | 0.08 | 0.06 |
| $\boldsymbol{\mu_{ss}}$ | 0.42 | 1.56 |
| $\boldsymbol{\mu_d}$ | 0.06 | 0.02 |

The major differences between the two cars are the following: the much higher $\mu_{ss}$in Sony 2.0 is desirable. It greatly reduces the car's proneness to skidding. This is particularly important in low friction coefficient surfaces, such as a wetted surface. The much lower $\mu_d$ and $\mu_{sf}$ for Sony2.0 are a reflection of a better matching between the wheel and its axle. It is important to know that the matching method for Sony 2.0 were bearings, whereas the matching method for Sony1.0 had immediate contact between the wheel and the axle. Bearings are used to reduce this friction. Note also that since weight is unrelated to the friction according to our relations found above, the traveled distance between the two cars is much higher for Sony2.0 and it is completely unrelated to its weight, but due to its better matching method.

### 9.7 Center of Gravity test

Objective

Apply conservation of torque to evaluate the height of the center of gravity of our car, to see whether it meets our design goals.

Working Principle

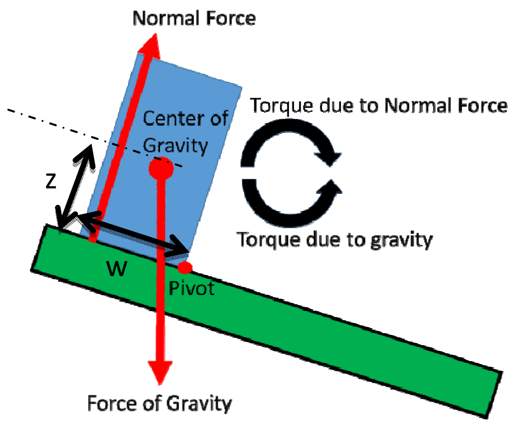



Figure 9.11 Free body diagram of tipping [21]

Applying conservation equations for torque, we obtain the following expression:

$$mg * \frac{w}{2} cos\theta = mgzsin\theta$$

$$z = \frac{w}{2} cot\theta$$

where mg is the force of gravity of the object, w is the width and z is the height of the center of gravity. Therefore, an expression for the center of gravity is obtained, solely dependent on measured values.

Procedure

1. Place the car parallel to the side of the board that is to be elevated.
2. Place an extra wooden board to the side of the car to prevent it from sliding.
3. Record the angle when the upper part of the wheels leaves the surface of the fiberboard. (when tipping happens)

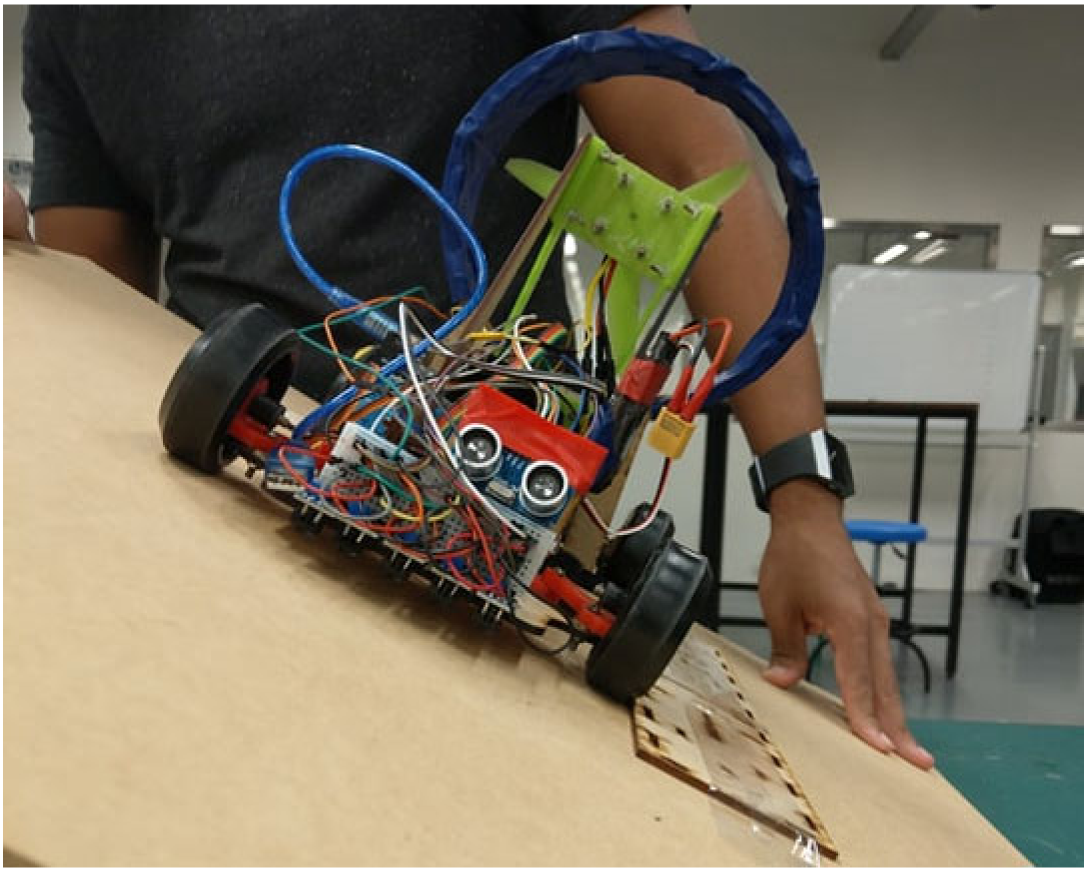


Figure 9.12 Experimental setup of the center of gravity

Data Analysis

The tables below present the experimental data and also the calculated height of the center of gravity (C.G.).

Table 9.6 the tipping angle and the calculated height of C.G

| | 1st attempt | 2nd attempt | 3rd attempt | 4th attempt | 5th attempt |
|---|---|---|---|---|---|
| Sony 1.0 | 62º | 60º | 60º | 60º | 61º |
| Sony 2.0 | 59º | 59º | 59º | 55º | 55º |

| | Sony 1.0 | Sony 2.0 |
|---|---|---|
| Height of C.G. (cm) | 5.21 | 5.91 |

Since the heights of both cars are all around 23 centimeters, the center of gravity is low enough to keep the car stable while driving, which is one of the main design goals to have high stability.

## 9.8 Acceleration and constant speed test

Objective

To observe how fast will the car accelerate from a dead stop to a constant velocity, observe any fluctuations on the constant velocity, and determine why the velocity is not constant at some points.

Working Principle

Using a camera and a track with a tape measure for length visualization, we can see how fast does the car move through the trajectory. Grabbing different points of distance versus time, we will be able to obtain a relationship between both, and observing the points on the path in which acceleration or deceleration occurs.

Lab Procedure

1. Set the tape measure parallel to the track.
2. Place a tick on the edge of the car, as a guide to pinpoint the marks on the tape measure.
3. Start the car at a certain fan duty cycle.
4. As the car starts, videotape the car's trajectory. (Top view recording)
5. Repeat with duty cycle equals to 16 and 18. (The magnitude of the duty cycle is limited due to how good the video can showcase the tape measure.)
6. Record multiple data points and make a graph.
7.

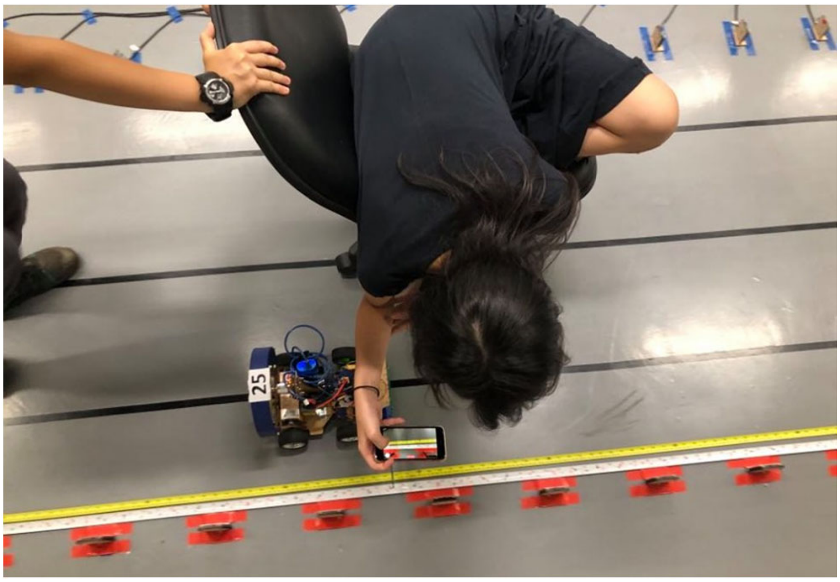


Figure 9.13 Videotaping of the car's trajectory

Figure 9.14 Videotaping of the car's trajectory-2

Data Analysis

It is expected for the distance versus time graph to have a certain rise at the beginning, and then achieve a fully horizontal behavior towards the remainder of the trajectory. The resulting graph shows the speed curve of the car when the fan duty is set to 16.

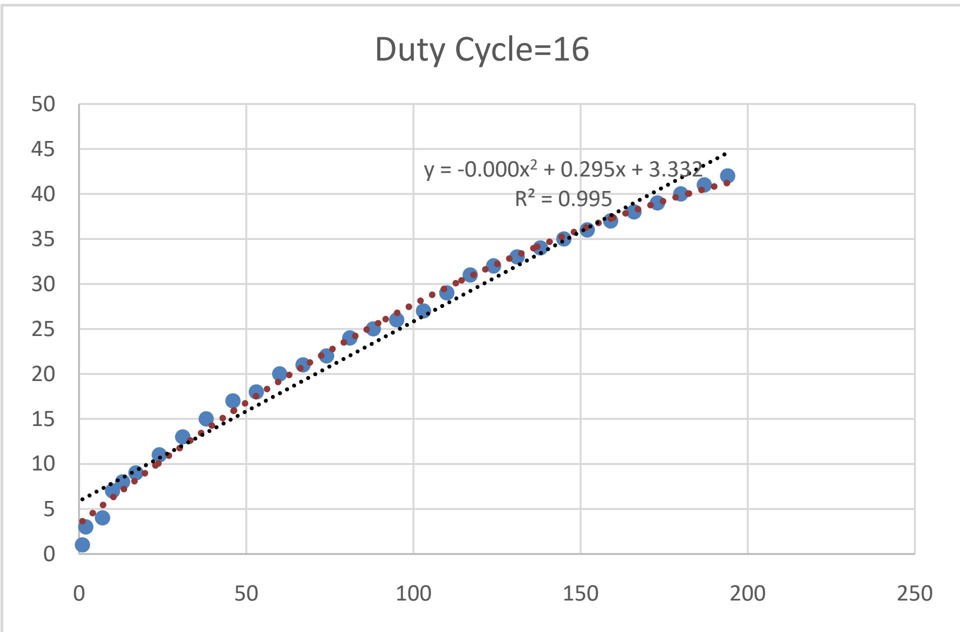



Figure 9.15 Distance versus Time.

From the figure, the distance traveled is plotted versus time as the blue dots.The black dots are linear regression, representing velocity and the orange dots are a polynomial regression of second degree, which can give the changes in acceleration. As shown from the regression results, the polynomial regression gives a very small acceleration rate. The figure below shows the experimental result of the duty cycle equals 18.

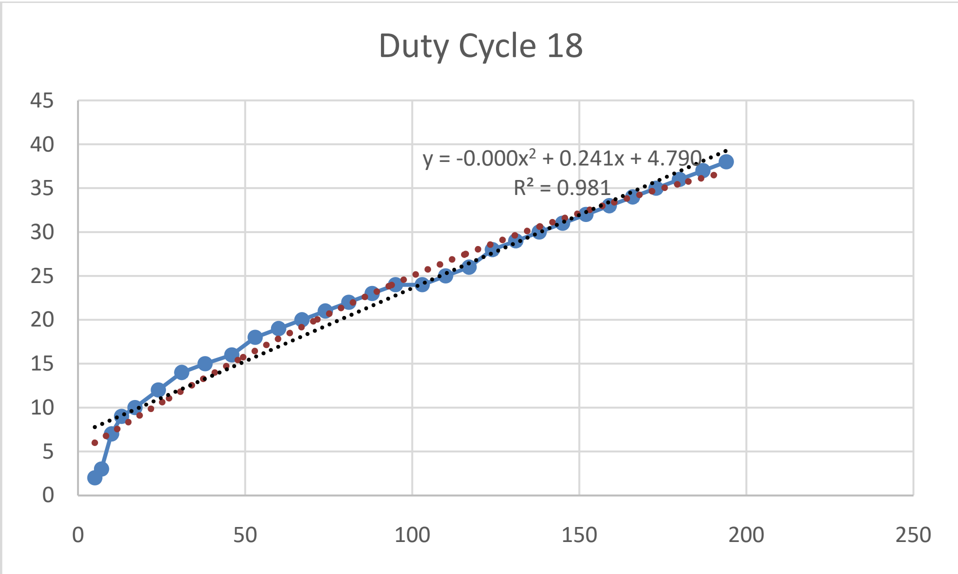



Figure 9.16The duty cycle of 18.

Fig. 3 uses the same color coloring as figure 2. Small changes in acceleration are noted, not so many differences compared to the result with a duty cycle of 16. Due to the restriction of the experimental design, the change in the duty cycle does not influence the collected data significantly. Therefore, in Figures 2 and 3, similar results with a small acceleration rate are obtained.

Since the braking system was not acting its part, the car was supposed to accelerate, under the prediction that the propulsion force was bigger than the frictional forces. Some possible reasons are discussed below.

Firstly, we used a line tracking code such that the car could travel in a straight line. Whenever the car readjusted its trajectory, the linearity of its path was affected, such that there were dips in velocity. Secondly, other reasons for dips in velocity can be attributed to oscillations in the current supplied to the car. The current issue would be solved by adding a switching converter. However, such precision was not required for the final test and,thus, this idea was deemed unnecessary. Some manufacturing issues could also playa part.Vibrations could damage the trajectory of the car, and irregularities at the couplings of the wheels could also influence the car performance. Last but not least, deriving data points from the video can attribute to error.

In summary, even though there are several factors to cause errors in data analysis, the behavior of the curves show an acceptable and sturdy design for the task at hand.

## 9.9 Propulsion test

Objective

To observe how much thrust the fan-produced on different fan duty cycles and compare it to the results of the fan thrust experiment of the wind tunnel.

Working Principle

A weight scale can be used to measure how much force is being exerted upon it. By multiplying the displayed value of the scale by the gravitational acceleration constant, we can obtain in Newton, the force exerted on the scale. This obtained force is the thrust.

$$T = m \times g \qquad (9.9.1)$$

where T is the thrust of the fan, m is the measured value of the electronic scale and g is the acceleration force constant.

Lab Procedure

1. Tape an electronic scale to a firm, vertical surface.
2. Place the car perpendicular to the scale, press it against the scale.
3. Tare the scale, such that the displayed value is zero.
4. Start the fan, wait for the displayed value to stabilize.
5. Record the weight.
6. Repeat the experiment with different fan duty cycles.

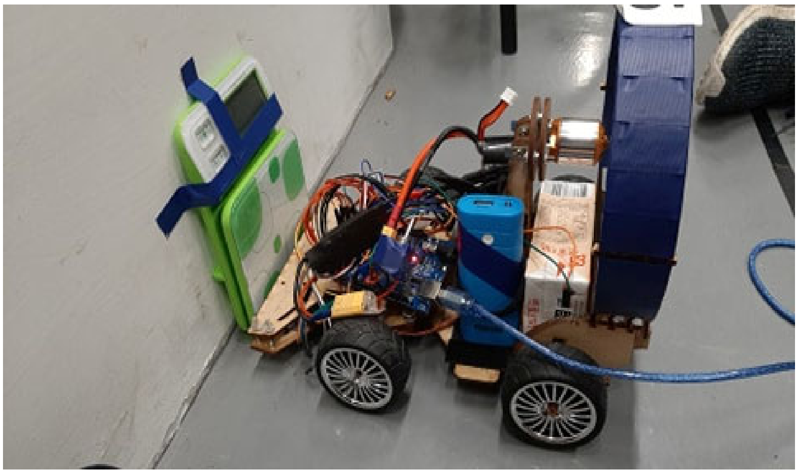


Figure 9.16 Experimental setup.

Data Analysis

Table 9.7 Duty cycle versus recorded weight.

| | | | | | | |
|---|---|---|---|---|---|---|
| **Duty Cycle** | 11 | 16 | 21 | 26 | 31 | 36 |
| **Weight (g)** | 25 | 33 | 51 | 74 | 91 | 110 |

Plotting the data obtained from the experiment, we obtain the following graph.

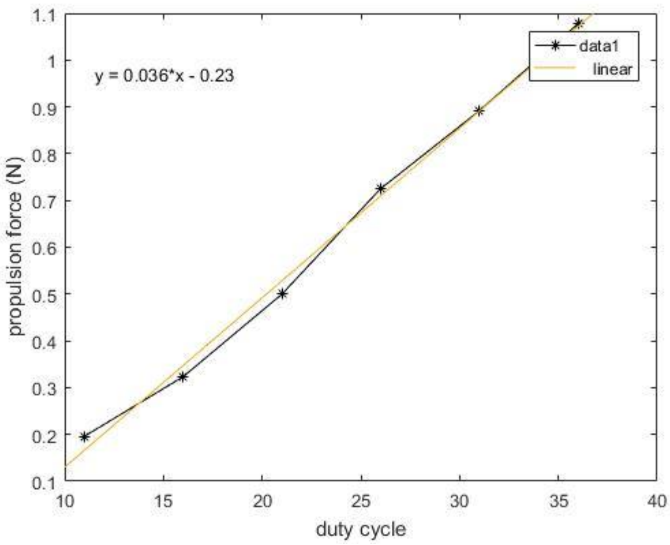



Figure 9.17 Duty Cycle vs. Propulsion Force

As expected, as the duty cycle increases, the propulsion force also increases. The data gives a linear relationship

$$\mathrm{T} = 0.036 \times \text{duty cycle} - 0.23$$

The graph is not entirely linear due to some reasons. For example, the current provided either to the motor or to the Arduino board fluctuates.

Compare to the result from the thrust experiment, which obtains a fan thrust of 1.4 N and a net thrust of the whole system 1.093 N, the propulsion force test gives a similar value 0.9 N at the duty cycle equals 30. Therefore, we can safely conclude here that the net thrust of the whole system is around 1 N, verifying by the fan thrust experiment and the propulsion force test.

## 9.10 Motion analysis

**Objective**

To obtain the theoretical acceleration of the car and to observe whether the obtained acceleration at the specific fan duty is similar to the one obtained at the acceleration experiment.

**Analysis**

Applying Newton's second law, considering the propulsion forces and friction forces, we obtain the following equation:

$$F_p - F_f = ma \qquad (9.10.1)$$

$$F_p - \mu_d mg = ma \qquad (9.10.2)$$

$$a = \frac{F_p - mg\mu_d}{m} \qquad (9.10.3)$$

From experiments, the propulsion forces at duty cycle 16 and 18 are 0.32N and 0.4N respectively. The dynamic friction coefficient was measured to be 0.02, and the mass of the car is of 0.9kg. Therefore, the acceleration at duty 16 and 18 can be calculated as

$$a_{16} = \frac{0.32 - 0.02 \times 0.9 \times 9.8}{0.9} = 0.1596 \ (\mathrm{m}/s^2)$$

$$a_{18} = \frac{0.4 - 0.02 \times 0.9 \times 9.8}{0.9} = 0.2485 \ (\mathrm{m}/s^2)$$

The result is compared with that of the acceleration experiment displayed in prior sections. These accelerations are bigger than what can be observed on the graphs from the acceleration test. Since there are several possible errors during the accelerationtest experiment, the acceleration rates obtained from the motion analysis is more reliable. In the acceleration test, the way that the car is tracked is one possible source of error. As also mentioned before, the fact that it doesn't go in a perfectly straight line also affects it. Power surges or a not so constant current supply will also affect the results. In conclusion, we believe the car should have a small acceleration instead of a constant speed in the accelerating experiment.

# Chapter 10 Comprehensive discussion

## 10.1 Discussion

Simulation

Even though the computational fluid dynamic analysis (CFD) and finite element (FEM) analysis are implemented with the same input, the angular velocity of the fan, these two simulations consider different factors and, hence, the results give different fan performances. In the FEM analysis, the pressure concentration is higher in the center; however, in the CFD analysis, the pressure distribution is higher at the blade tips.

In the CFD analysis, the fan is considered as walls and its material is not taken into consideration. On the other hand, in the FEM analysis, the simulation considers the material effect and calculates its deformation and pressure distribution based on the weight of the fan. The airflow is the focus of CFD simulation but in FEM analysis, airflow is ignored. As a result, FEM performs the fan without the influence of airflow.

The real situation is a combination of CFD and FEM analysis. Since the fan is quite light, the influence of airflow should dominate. The influence of airflow plays a more significant flow. Therefore, we can conclude here that the pressure should concentrate on the blade tips, in reality, judging from the influence of two analysis methods.

Experiment

We have conducted many experiments to analyze our car. Some important features of our car are manifested and listed below.

1. Low dynamic friction

From the dynamic friction test, the final possesses a tiny dynamic friction coefficient of 0.2. This result showcases the benefits of using two bearings of each car. With a smaller dynamic frictional force, the car does not only run more smoothly, but the fan duty can also reduce so that less noise is generated during testing.

2. Low noise pollution

Even though we did not have the chance to measure the noise generated by the cars from other groups, during the preparation time before final testing, some other cars produce a significantly larger noise. Therefore, we believe that thanks to the smooth fan surface and the tight structure assembly, our car produces noise pollution as small as possible.

3. Low center of gravity (C.G.)

Most of the structure of our car is stacked in the lower part. Therefore, it is not surprising to gain the height of the center of gravity equals to 5 centimeters during the experiment. A low C.G. contributes to the steadiness of car performance. When performing car following and overtaking, some collisions might happen unpredictably. Therefore, our car aims to remain its speed and direction under these disturbances and the design of low CG achieves the goal.

4. Fan curve

The fan curve depicts the various points that the fan can operate. It indicates the amount of a single flow rate (CFM) will provide a given total static pressure, dependent on the connected ducted system. Our design goal is to operate our fans in the stable region. The stable region is the area on the fan curve where there is a single CFM value for every pressure value. In the unstable region, a pressure value can have multiple CFM values, which will cause the fan system to surge. Furthermore, The stable region has little change in CFM for large changes in total pressure. [22]

Unfortunately, we did not perform more experiments under different duty cycles. It is, thus, difficult to relate our fan performance to the fan curve. Since thrust is proportional to pressure differences, discussed in the fan thrust experiment, we expect that the pressure differences under different duty cycle will show a sub linear relationship with mass flow rate, so does the thrust.

# Section Five
# -Working Process and Discussion

# Chapter 11 Work Division and Process

## 11.1 Kantte Chart

Before midterm

| Date | | | 3/6 | 3/13 | 3/20 | 3/27 | 4/3 | 4/10 | 4/17 | 4/24 | 5/1 | 5/8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Category | Job | Person in charge | W1 | W2 | W3 | W4 | W5 | W6 | W7 | W8 | W9 | W10 |
| Structure | Overall design | Johanny, Christine | | | | | | | | | | |
| | Turning system | Johanny | | | | | | | | | | |
| | Braking system | Christine | | | | | | | | | | |
| | Fan cover & motor holder | Christine, Tzuyu | | | | | | | | | | |
| Control | Main program | Tzuyu | | | | | | | | | | |
| | Motors control | Lloyd | | | | | | | | | | |
| | Sensor data processing | Tzuyu | | | | | | | | | | |
| Electro components | Motor testing | Lloyd | | | | | | | | | | |
| | Sensor testing | Tzuyu | | | | | | | | | | |
| Fan | Fan design | Ola | | | | | | | | | | |
| Integrated testing | | All | | | | | | | | | | |
| Experiement | Designer | Christine | | | | | | | | | | |
| | Performer | All | | | | | | | | | | |
| Simulation | Finite element analysis | Tzuyu | | | | | | | | | | |
| Report | Structure | Christine, Johanny | | | | | | | | | | |
| | Control | Lloyd, Tzuyu | | | | | | | | | | |
| | Fan design | Ola | | | | | | | | | | |
| | Editor | Christine | | | | | | | | | | |

After midterm

| Date | | | 5/15 | 5/22 | 5/29 | 6/5 | 6/12 | 6/19 | 6/26 |
|---|---|---|---|---|---|---|---|---|---|
| Category | Job | Person in charge | W11 | W12 | W13 | W14 | W15 | W16 | W17 |
| Structure | Midterm car revision | Johanny | | | | | | | |
| | New car designing | Ola | | | | | | | |
| | New car manufacturing | Ola, Tzuyu | | | | | | | |
| Control | Main program writing | Tzuyu | | | | | | | |
| | | Lloyd | | | | | | | |
| | Testing and revising | Tzuyu | | | | | | | |
| Electro components | Sensor testing | Tzuyu | | | | | | | |
| Experiement | Designer | Christine | | | | | | | |
| | Performer | All | | | | | | | |
| Simulation | Finite element analysis | Tzuyu | | | | | | | |
| | CFD | Christine | | | | | | | |
| Report | Writer | All | | | | | | | |
| | Editor | Christine | | | | | | | |

## 11.2 Work Division and Execution

At the beginning of this project, we distributed each member's work based on our strengths and interests. During our weekly meeting, each group member reported on what they have accomplished in the last week. Even though the group members are the experts in the fields assigned, it is still necessary to share the issues they encounter. Therefore, other group members can ask for help from friends or senior students they know. After the group meeting, things to do be done before the next meeting are also discussed so that the whole team stays on the track of reaching the final goal.

At the second half of the semester, we worked with the other team to discuss how to collaborate on car following and overtaking. In general, the discussion and teamwork went smoothly and both teams dedicated themselves with aiming for the best performance. Since car following and overtaking relies on the control system, both team's control parts cooperate tightly. The only shame of the teamwork is that the other group members are not used to speak English. Therefore, the international students in our group cannot participate as much as possible.

The most important attitude of execution is that each team member is willing to give help and put into effort when needed. Even though all of us have our own studies, when it comes to this car project, we are not individuals but a united team. For instances, even though one to two team members are responsible of the car structures, after group meetings, all of us stay and help assembly. Before the midterm test, all group members take part of testing and tuning to meet the targeted speed. Instead of defining each person's responsibility clearly, assisting each other contributes to our overall success of this course.

## 11.3 Meeting Minutes

### A.4 Meeting Minutes

Date: 2020-03-11

Place: 綜合學開204

Time: 3:30-6:00 p.m.

Member: all

Meeting minute documented by: Christine

Group name:

1. A star is born 0 vote
2. Korean fish 0 vote
3. Angle of music 3 votes (first round)
4. Cheap sony 2 votes (first round)

Final vote for option 3,4: 2 against 3.

**Group name: Cheap Sony**

**Group leader: Christine**

**Vice leader: 子瑜(TY)**

Timeline:

Deadline Assignment Notes

**4/10 Friday a car that runs** (sensor, fan, structure)

**5/08 Mid test and clinic**

**6/19 Final Test**

**6/22 Finish Report** Each member finishes their own part before noon.

**6/26 Final Report**

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Structure:

1. Turning: servo motor, 阿克曼轉向
2. Breaking system: bike (check the previous group), a servo turns a stick to causefriction to a turning wheel.
3. Fans should be screwed and fastened. Other electronic devices can be taped.
4. Find a space for a drink. Cup holder?
5. Control team will tell the structure team the components to put on the car on03/20.
6. Fan size should be given on 03/20.

Control:

1. TY is responsible for sensor
2. Lloyd is responsible for actuator
3. 996 Servo, high torque for harsh breaks; little blue servo, small torque for gentlebreaks.

4. h bridge, brushless dc motor
5. Infrared sensors several
Fan:
1. Create first prototype for testing
2. Keep revising
Things to be done before next meeting:
Control: all the things needed to put on the car, buy the components needed
Structure: Do a design without measurement (find wheels)
Fan: Find the desire airfoil for the first prototype with measurements
**Bring the electronics, batteries, ask if we can borrow a car**
**In front of B01, P5, where we can store our car and parts**

Date: 2020/3/20
Place: 普通204
Time: 13:30- 15:30
Members: all
Meeting minute documented by: TY
59
Things to be done before this meeting:
Control: all the things needed to put on the car, buy the components neededStructure: Do a design without measurement (find wheels) (It was done byvery briefly)
Fan: Find the desire airfoil for the first prototype with measurements
**Bring the electronics, batteries, ask if we can borrow a car**
**Above are what we should do before this meeting**
Things to discuss:
1. Each person's progress since last week
2. From control part: things that we need to put on the car
3. From Structure part: we would like to know which electrical parts are tobe placed together or at least close by.
4. The safety concern of handling Lithium-ion battery (I heard one group'sbattery exploded last year… we need to use it correctly and safely)
5. About the fee of purchasing, do we pay the split total amount in theend?->split it at the end
6. 風罩
Structure: ellipse shape, a cover over the car body, wheels bought. try to not block theair flow when designing the car body.

Things to put on the car body:
infrared sensors 3-5 pieces, 1-2 cm from the floor
At least 2 ultrasound sensors for the final, leave the space first.
One extra infrared sensors for encoder at the back wheel
Arduino mega
A battery+esc
half of bread board (or a whole)
Brushless motor (the fan fastener is now kept by Johanny?)
MG996R for the turning system
Braking system at the back, use sg90 servo motor.
Plastic cover of the fan would be inside the structure
Power: ideal case: one lithium ion battery
less ideal: one lithium ion battery+ a 9V
worst case: one lithium ion battery+ 9V + power band …
60
What we need to do before next meeting:
TY: test the best distance of infrared sensor from the floor. Finish the inrared trackingcode. Get some fuses
Lloyd: test the dc motor, try to control it. Test the battery, esc& voltage regulator.
Johanny: look for 3d models of the components we use, look for(design?) the turning system. Get the drink
Christine: Design the braking system
Ola: 確認風罩, change the dimension of the hole. Maybe make a new fan.

Date: 2020-03-27
Place: 永齡
Time: 14:30
Meeting begins at 1:52 pm. The group starts by informing about their process up to themeeting time. Christine shows the main structure of the fan to the group. The front partis yet to be designed. Tze Yu proceeds to inform about the arduino code for the sensor.Testings for the code will be done by next week. Ola informs about a new fan bladedesign. ANSYS analysis is yet to be done. Johanny proceeds to show the 3D model ofthe car, specifically the front wheels, which are meant to be for steering. Lloydproceeds to inform the group that some adapters are needed in order to connect theelectrical components.
Meeting Minute 03/31

Place: 永麟
Things accomplished:
Control: infrared sensor tested, bldc tested, discussed a more detailed code structure.
Fan: made a new fan, decided a new airfoil type for future fans.
Structure- turning: revised the car base for the turning system. Produced the firstversion turning system.
Structure- braking& motor: designed the juice box holder and motor holder.
next meeting: finish assembly

**Date: 2020-04-07**
**Place:** 永齡
**Tasks finished before the meeting**
**Structure:**
TY modified the fan support and encoder
Christine: made the connector to the axis (3D printing results do not fit)
Johanny: front platform finished, including servo platform and ackerman.
Lloyd: Searched how to perform tests safely
Ola: three types of fan (three leaves, five leaves, and thin and fat.)
**Things to discuss**
**Test and Trials**
How to make it stop?Lloyd: arduino board will keep turning and turning.
Solution: RUN after the car.
Report
Component used
Design process as detail and technical as possible
Tests
Simulation if possible
Meeting minutes
Everybody should send the file to **Christine** 22 of April before 10 a.m.
Include: Design process, comparison, and final versio
**Johanny**will do the engineering drawing

Date: 2020-04-10
Location: 永齡
TY will finish the coding and every group member can help testing for parameters.
Christine: design the platform and turning servo holder.
Johanny: Improve the front wheel
Lloyd: work on the main code. test the speed, if we can reach the highest speed
Ola: improve the fan performance. Change the dimension of the motor holder,
TY: adjust the threshold of each infrared sensor for the direction detection.
Today we did: assembly the car (again
Establish the speed recording system and teach it to everyone.
Test the bldc highest speed, 100 duty( it's really fast
Test the hard brake with the lowest speed of the bldc( it feels slow enough
What to achieve before hand in the report
turning system done, able to go straight.
Speed control done, may not fit the curve, but we should be able to reach the highest speed, lowest speed, and highest acceleration.
Finite element analysis if possible

Meeting Minutes 2020-04-15
Place: 永齡
At the present date, the turning system was tested along with a revision of the fansupport and the servo support. TY informs she has modified the threshold for the IRsensors to correctly output the right position. Ola proceeded to present a new model forthe fan. Unfortunately, the 3D printer was not working as expected. Production of thenew fan design is delayed. More involved testing should begin starting the date of thismeeting. The tests to be done: constant speed test, acceleration and deceleration test,and finally, the line tracking system, which will combine the performance of thepropulsion system, turning system, and the braking system. Once the tests are done, thegroup can proceed to tune the car to meet the performance requirements stated by theproject supervisors. For future meetings, things that should improve include theorientation of the Ackerman mechanism. Due to assembly problems, the car presentsdifficulty on maintaining a straight line. To fix this issue, it was recommended to reducethe constraints on the left wheel.

Date: 2020-4-17
Place: 永齡
Things done today: Adjust the threshold or infrared sensor again. Checked that theturning system and infrared sensor worked fine together.Fixed the encoder. Now the car can track the runway in a low fan duty cycle.
Checked the receipt.
For midterm report, use table for comparing different design choices.
Dead line for the midterm report: Wed, 18:00

Date: 2020-5-01
Place: 永齡
Progress: reaches nine green light during testing
Prpblem: starting is unstable. Sometimes, the car got stuck.

Things discussed for testing

1. TY will buy a new brushless motor.
2. Find a new power bank as backup.
3. Two extra fans are printed just in case.
4. Everybody figured out the time to come for testing.

Discussion: how we can improve the final report

Date: 2020-5-8
Place: 永齡
Conclusion: For the midterm test: excellence!
Things we need to do for the later: redesign the car: specifically:
Switch job: Christine will be in charge of cfd simulation experiments. Christine will arrange and search for the experiments and the other groups will help.
Things to buy: a switch, ultra-sonic sensors, blue tooth module control if necessary, another battery if necessary.

Next meeting time: Wednesday 3:20 p.m.
What to do before the meeting
TY and Lloyd: do some researches from the previous reports about car following and

plan the structure of the code. Plan what to buy.
Johanny: Start the drawing for the midterm car
Christine and Johanny: will use the turning code to test the ackerman system.
Christine: design and do research about the experiment
Ola: redesign a new structure for the final car and TY will help her.
Arrange a meeting with the other group. Friday 1: 20 p.m. appointment set.

Discussion: Why does our battery voltage fluctuate that much? Buy a switching converter. It can also be combined with an esc. (more expensive)

Date: 2020-5-13
Place: 永齡
Things finished before this week's meeting
Lloyd: worked with Johanny and made sure the turning system works. Some problems such as big tolerance appear. Tested the curvature on the ground, which has a smaller curvature. The car could not track the small curvature but it is still possible for a bigger one.
TY: Did research on how to realize the performance requirement for the final test. Started constructing the main code.
Ola: Built up a new structure. Made a new car. Some size needs to be corrected.
Chrisitne: Did research on experiments to be included in the final report. (TY can help with the speed test to use Python to analyze videos.)

Discussion(Things to discuss with the other group during for final test)

1. Big concern that we are not sure whether the sensors work under high speed. (to be discussed on Friday with the other group, we should also discuss what speed we aim for the final testing.)
2. Discuss bluetooth module and how to surpass the car.(超車)
3. In what conditions should we help the other group. If one group is struggling, the other group should help.
4. Control part is closely related and will cooperate closely.

Things to do:
Christine: Review the lecture about experiment. Make plans for the experiment, when

to do it and decide on which car.
Lloyd: Do some tests on the ultrasonic sensor and do research how to keep the voltage stable. He wants to come on the weekend for more testing. (bring the car home is another solution if the space is not opened)
TY: After Friday discussion, TY will do some research on Bluetooth and try to implement PID control approach. Start working on the main code.
Ola: Improve the design of the new structure.

Date: 2020-6-04
Place: 永齡
What we did this week
Lloyd: finish the code started PID controller, put on the new infrared seneors, expensive! It does help the performance, connected to the encoder. Speed control is ready.
TY: Speed control and line tracking. Two sensors added. The performacne is steady and reliable. Start working on Bluetooth with the other group. The cars are communicating their positions and adjusting their speeds accordingly. Some details can be improved.
Christine: Tried with Ansys and figured out that starting simulation with stl file is not working.
Ola: Print another fan, send Johanny engineering file for the car
Johanny: Start working the report

Things to discuss
Final Report: What each team member is responsible in completing the report
When the experiment will be conducted
Punishment for missing group deadline will pay 100 NTD more for the bill

# Chapter 12 Feedback and Recommendation

**Lloyd (任軍)**

The Capstone course has been one the most enjoyable courses in the Mechanical Engineering program. Having said that, many students will not share the same opinion as me. I will try to keep it brief. Personally, I feel that this course only tested my capability of learning new things, instead of the application of my engineering knowledge as taught by my professors throughout the years. I will speak from a personal standpoint. I was in charge of the electromechanical design of the car as well as some coding. While the programming course of my second year was particularly helpful, everything else that I applied in the development of this project was through my own investigation. Besides the obvious recommendations that were given at the lectures, everything else was self-learned. While I am particularly glad with the performance of my group at both the midterm and the final, I can understand that other groups might not have done a good job. This is not because they are lazy, but because there is a huge limiting factor in the development of this project. Not everyone has a good programming background, not everyone has much experience with Arduino. In the other hand, for other groups, this was their nth Arduino project. These groups have a clear advantage over everyone else.  Most importantly, those that already have experience with these sort of projects will try and pair up amongst themselves, leaving the novices to their own. Don't get me wrong, this was an enrichening experience, and it also gave me an opportunity to have a first-hand experience into a branch of engineering that has always caught my attention; but I do have to say that the Capstone course does need to take into consideration that the most challenging parts about this course, are mostly self-learned. And for those groups whose background is limited, the Capstone course will prove to be a harrowing experience.

**Johanny(艾安妮)**

Overall, the class offers a unique, valuable experience for future engineers. The experience is an opportunity for each to showcase their individual specific talents while learning how to work with other people as a team. I valued this aspect of the experience very much. I believe our group had a perfect balance on specific talents; from the first day, everyone knew what they wanted to work on based on their specific interests and abilities and nobody's desired job clashed with somebody else's desired job. That said, I am very happy with our team work and what we achieved throughout the semester. However, this does not happen in every group and the experience could be even more challenging. Even though it is enriching to develop new skills, I believed that improving the ones we have is just as important, and sometimes even more. There is a lot of value in knowing a little about everything, but to know more about a specific task or topic has even more value. Of course, if you know a lot about different tasks and topics is even better. I did not learn much about using Arduino, but I practiced and improved my CAD skills. I have a special interest in computer-aided design and I was very happy to be in charge of this part during the project. However, I faced new challenges with making the CAD model come to life and make it work. It is very challenging to take into account all variables when designing a piece; there are so many factors that make a tangible piece different from the desired piece you design, mostly tolerance and friction. 0.001 mm can make a big difference that can result is too much or too little friction. Something I learned at the end of this semester in another course would have helped me with this and I believe this could be a problem in this course. I do not feel like we obtained the skills and knowledge required for this project in the courses we took in the previous semesters at NTU, they are all self-learned either at the time of the project or, in some cases, before due to individual interest. I understand there was a lot of information from previous years (most of it in Chinese), but I would like for the course to provide more guidance and resources for students to develop these new skills. It would be nice to have a professor, certain days at a certain time (rotating) at yonglin checking what the groups are doing and giving some feedback, like a supervisor, but without the pressure of grading.

**Chrisitne(林育萱)**

Writing my feedback and thought on this course is a relief since I am glad that my team has overcome some difficulties and accomplished the tasks eventually. Speaking frankly, this course was not as tough as I thought thanks to my teammates who dedicated themselves with this project. At the first half of the semester, I reviewed engineering drawing, which I have not touched after the mandatory course in the first year, 工程圖學. Even though the car I built is not in very good shape, it is still a cool experience to achieve things that I find it rather difficult before. The second half of the semester, I was mainly struggling with ANSYS simulation. The most frustrating experiences were solving the error messages. Simulation is different with coding. The error messages are quite ambiguous that makes debugging difficult and stressful. It is a shame that I could not finish more simulations to compare different versions of our fans. The result is also not very satisfying. However, I appreciate this tough experience and hope I can improve my skills in the future. One main thing that this course illustrates me is that I am not good at hand-on tasks (From the previous years of studying I already feel it, though.) After this course, I am more certain at my strengths and weakness and have a better vision of what my future research or working directions is like.

One thing that I would like to recommend about this course is to change the topic. Making a fan-propelled car is not much fun because it is standardized from the precious years. Even though we do have the choice to make our own designs, copying what the previous students do is the most efficient way to pass the course because every year, students receive a more difficult task. To be able to focus on the new requirements, it is not about being creative but more importantly to learn from the past experiences to save time. To me, it is a pity that students cannot run their imagination widely to meet the performance requirements.

Last comment on this course, much credit to my group members who helped me to graduate this year so that I can technically only study three years at NTU and GRADUATE!

**Ola(簡秀芳)**

意外和外國人同組的我，先是遇到溝通的困難。儘管有時用著英文急著去說還是無法傳達精準令人沮喪，然而更大的困難還是使用著不同語言背後截然不同的價值觀。因為不同的價值觀，好難達成共識。然而經過種種混亂，同伴智慧的溝通，終究還是完成了。

從學期初摸索著風扇設計、閱讀上一屆甚至上上一屆的報告，花了好多時間，終於做出風扇，卻還是不曉得到底哪一個風扇比較好，調整再調整以為風扇越來越優，卻在學期接近一半的時候機構完成開始測試，才發現最初的風扇最好。當時是確定了風扇可以用，效果也不錯，但走出實作中心的時候覺得很迷惘，不知道自己之前在做啥，還是不曉得為什麼著風扇最好，什麼是好，怎麼樣的風扇才適合這台車子，為什麼這個風扇噪音最小，車子開起來最平滑。

我們期中的車子是車輪是津津蘆筍汁那台，這在期中拯救了大家，但無法在期末使用。因為很怕控制組的同學期末會因為時間不足而很辛苦，我期中後改做機構，用著拙劣的繪圖技巧一邊求助學長姐，總算還是在短時間內生出還算穩固的機構。其中有非常想哭的時刻，因為自己一人弄、不厲害又有時間壓力，然而後來很神奇地，這些痛苦想哭，都在伙伴的幫忙下通通變成其他正向的東西，除了借助他的能力之外，有人一起做錯再做對，一邊動手動腦也一邊聊天，像是有魔法一樣就是沒那麼辛苦了，甚至有點開心。這樣的過程讓我深深地感受到同儕的重要，也發現一種新的努力方式。

覺得可以改善的地方是，小組的人數，五個人太多了，沒那麼積極的人無法真正的參與其中，非常可惜，也因為一個人可以做完的事情分成兩人，反而效率更差，以這學期課程的要求，或許一組三人就夠了，這樣大家都容易進入狀況也好達成共識，能更專注於實務本身。也覺得分組可以打亂抽籤(按照學號的話，還是依照高中跟入學方式排的)，這樣對於轉輔系生、非大三生比較公平。

另外我認為要有每組必須參加的診斷或是諮詢，除了專業的疑惑、卡住無法

突破的之外，也會給在自己組別默默努力的人很大的幫助。

或許能有風扇有關的競賽。學期前半前面研究了很久風扇，但發現其實不用改弦長扭角都一樣甚至翼型亂用，好像馬達開大一點車子，即使噪音很大但都還是會跑。因為感覺風扇好壞不那麼重要，會有花很多時間但隊友不太理解你在幹啥的情況發生(雖然真的學會很多東西)。

修課前一直被修過的人嚇，搞控制後面會很想死、會住在實作中心、做夢會夢到啟動車子的嗶嗶聲，去年大約這個時候我好像也真的抱著因為氣動車身心疲倦而哭泣的同學，安慰他們。然而，這學期即便有嚴峻時刻，很感謝辛苦改造課程的老師助教，我們沒有再熬過夜了！總的而言我也非常喜歡這門課，動起來感覺很好，不再只是閉門讀書，與人交流的感覺很好，我也發現自己原來還算是個有用的人。

還記得有一次滴三秒膠到一個小小的東西很容易弄到手，我說，我來犧牲！結果子瑜跟我說，不用有人要犧牲啦！然後我們兩個很小心很小心的一起弄好了。不知為啥覺得很感動。雖然感覺要再繼續改善這門課很麻煩，而且總會有人不滿意，但希望這門課能夠變得更好，好到即使辛苦，也沒有人認為自己是犧牲了些什麼的。

Tz(黃子瑜)

我是大四才修這門課的，修之前被很多朋友警告: 大家都得睡在實作，絕對不要負責程式控制，組員一定要好好找……等等。修完這門課後回頭看看，其實許多都滿有道理的。

睡在實作這方面，這學期這樣的情形好像比較少發生。或許是這學期教授們有將難易度調整得更為適中吧。這方面，很感謝教授們的安排。學期初在研究這門課的任務時，就認為是一些只要努力，至少能達成部分的程度。實際上做下來也是如此。期中時稍微比較狼狽，因為一開始大家都什麼都不會，一切都要重頭學起，連馬達怎麼控制都不知道。這個時候幸好有很多前屆的報告可以參考，使我們少走了很多彎路。花了很多時間不斷升級硬體或軟體後，終於能夠達成部分的期中需求，並得到 83 這個還算滿意的分數。

期末部分，則是一直都十分順利。因為有了其中的經驗，期末新增加的部分實際上不算太難達成，只是在嘗試控制邏輯上花了一些時間。然而，一切非常順利的結果卻是在實際測試時只拿到 80 分，比期望的低了十五分。在這個過程中，我覺得學習到很多執行計畫與程式控制的邏輯與經驗。不斷修改的同時，也逐漸體到其中的樂趣。

至於程式控制，雖然負責這部分的人是最有可能需要測試前睡實作的，但我認為也是最具挑戰性也最有趣的部分。硬體的部分，因為我們的測試其實對硬體的要求不高，限制相對寬鬆，而且一旦做完也不太需要很多修改。但程式的優化是沒有盡頭的。一開始要提升性能，性能達到要求以後又得提升穩定與可靠程度。不斷改程式，並看著車子的表現越來越好，這個過程非常有成就感。

組員部分，我覺得碰到的人都很不錯，也有交到好友。雖然我們在期中時有一點不愉快，也因為種種原因導致報告遲交，但整體而言我還是很高興能夠和這些同學一起修完機械系最特別的這門課。

接下來是關於課程的建議，首先因為實作的課有上下兩個學期，因此我建議上學期的課改成 1 到 2 人一組的模式。這樣的情形下，可以讓每個同學都接觸到實做的每一個部分。有些同學如果上下學期都是做硬體，可能到畢業也還不會寫 arduino code。而如果下學期有個組別完全沒有做過控制的人，這組可能會非常辛苦。此外，因為買個人都只擅長單一領域，不了解全局也會造成合作上的困難。因此如果以 1-2 人一組的模式規劃上學期的課程，就可以讓每個人都學到更多，也更有參與感。至於工程師很重要的團隊合作，則可以在下半學期的課程中學到。而上半學期了解了所有的設計面向，也能讓大家在下半學期合作時，更了解自己的專長，與不是自己負責部分的內容。

另一項建議則是課程內容。希望能舉辦機器人擂台賽，或是氣動船競賽，或是潛水比賽等更有趣的內容。個人非常希望能夠參加機器人擂台賽，讓不同組別的機器人破壞彼此。如此熱血的題目一定能讓更多人投注在其中。

最後，謝謝教授們辛苦規劃課程和改報告，助教們辛苦架設場地與回答同學問題。肯定還有能改善的地方，但我覺得這是很棒的一門課。

# Appendix

A.1 BOM table

A.2 Code

A.3 Reference

# Appendix

## A.1 BOM table

| Items | Quantity | Unit price | Total price | Source |
|---|---|---|---|---|
| Fiberboard | 3 | 25 | 75 | 實作中心 |
| Bearing 3*7*3 | 8 | 23 | 184 | 添榮五金行 |
| Copper rod 3mm*1m | 1 | 70 | 70 | 銅成五金行 |
| Corner iron1” | 4 | 5 | 20 | 萬見隆五金 |
| Rubber nut M3 | 1 | 2 | 2 | 添榮五金行 |
| Tires | 1 set | 400 | 420 | 吉華科技 |
| Arduino Mega | 1 | 157 | 0 | 合作組出借 |
| Jump wire | 1 set | 60 | 60 | 今華電子 |
| Power bank DC5V 2.5A | 1 | 160 | 0 | 同學贈送 |
| ESC Skywalker 40A | 1 | 330 | 330 | 露天拍賣 |
| Breadboard | 1 | 12 | 12 | 今華電子 |
| Servo motorSG90 | 2 | 70 | 140 | 今華電子 |
| Bluetooth ModuleHC-05 | 1 | 270 | 270 | 今華電子 |
| Resistance 1k & 2k | 2 | 4 | 8 | 今華電子 |
| Infrared sensor TCRT5000 | 9 | 45 | 405 | 今華電子 |
| Switch SW 2P 10A | 1 | 15 | 15 | 今華電子 |
| Lithium polymer battery 11.1V 2250mAh 35C-70C | 1 | 629 | 629 | 露天拍賣 |
| Brushless motor XXD A2217 KV2300/4T | 1 | 250 | 250 | 露天拍賣 |
| **Total** | **2890 NTD** | | | |

## A.2 Code

Midterm car

```
#include <SPI.h>
#include <SD.h>
#include <Servo.h>

Servo ESC;
Servo servo; //brake;

const byte irEncoder = 2;//notice only certain pins can be use as attachinturrupt:2,3,18,19,20,21 for mega

//Encoder
volatile long encoder0Pos = 0;
volatile long newPos = 0;
volatile long oldPos = 0;
volatile unsigned long  newTime = 0;
volatile unsigned long  oldTime = 0;
volatile float velocity;
volatile float oldVelocity;
volatile float distance;
volatile float acceleration;//the 4th sensor number is higher then the regulation by 2 for control reason. The last two and the additional one also are adjusted
float givenSpeed[100] = {13,12.95,12.95, 18.82, 23.15, 27, 28, 28, 28, 27, 27, 27, 25, 23.15, 21, 16,13,1,1,1,1,1,1,1,1,1,1};//this is the given condition by professors
float givenSpeed2[100] = {15,14.49,21.04,24.89,28.51,
                           29,29,29,30.45,
33.5,35.71,39.66,42.41,44.68,
45,45,45,45,45,
45,45,45,45,44.54,
41.2,37.04,32.35,26.83,19.70,16,
                       16,16,16,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0};
volatile float gVelocity;

```

```
//for controlling components
int brakeCommand = 0;//!!!!!
float motorCommand = 0;
int turningCommand = 0;
int sensorNumber = 0;
int tt = 0;
int countOfPart = 0;
////////////////////////////////////////////////////////////////////////////////
void setup(){
 pinMode(irEncoder,INPUT);

// Serial.begin(9600);

//motors setup
  ESC.attach(9,1000,2000);
  servo.attach(11,1000,2000);
  servo.write(70);//the center position is 60
  ESC.write(60);
  delay(1000);
  ESC.write(0);
  delay(3000);
//this is the initial push
  int NuMbEr = 15;
  ESC.write(NuMbEr);
  attachInterrupt(digitalPinToInterrupt(irEncoder), doEncoder, RISING);
 while((tt != 77)&& (NuMbEr <40)){
  ESC.write(NuMbEr);
  NuMbEr += 1;
  delay(300);
 }
 ESC.write(10);


}

///////////////////////////////////////////////////////////////////////////////
```

```
void loop() {
 if (gVelocity == 1 && countOfPart == 0){
    countOfPart++;
    setup2();
 }

 delay(500);
}

void doEncoder(){//count the number of marks past
    encoder0Pos++;
    if (encoder0Pos == 2)tt = 77;
    newTime = millis();
    distance = encoder0Pos*6.28;
    float tInterval = (newTime - oldTime);
    velocity = 6.28/(tInterval/1000);

    int sensorNumber = ceil(distance/30);
    gVelocity = givenSpeed[sensorNumber];
    if (sensorNumber >=17){
      ESC.write(0);//
    }
//    else if (gVelocity == 98){
//      //ESC.write(18);
//    }
//    else if(gVelocity ==100){
//      ESC.write(0);
//    }
    else if (velocity < (gVelocity-2)){
         ESC.write(16);
    }
    else if (gVelocity == 0){
      ESC.write(0);
      servo.write (100);
     }
     else if ((velocity > (gVelocity+2)) && sensorNumber>2){
       ESC.write (0);
     }
```

```
        else ESC.write(10);//這裡原本是
        //Serial.println(velocity);
        if ((sensorNumber >13)&&(velocity > gVelocity+1)){
          servo.write (100);
        }

        oldTime =newTime;
}

void setup2(){
  detachInterrupt(digitalPinToInterrupt(2));
  ESC.write(0);
  delay(10000);
  pinMode(irEncoder,INPUT);
  encoder0Pos = 0;
  newPos = 0;
  oldPos = 0;
  oldTime = newTime;
  servo.write(70);//the center position is 60
  tt = 0;

//this is the initial push
  int NuMbEr = 15;
  ESC.write(NuMbEr);
  attachInterrupt(digitalPinToInterrupt(irEncoder), doEncoder2, RISING);
   while((tt != 77)&& (NuMbEr <40)){
    ESC.write(NuMbEr);
    NuMbEr += 1;
    delay(400);
   }
  ESC.write(10);
}
void doEncoder2(){//count the number of marks past
    encoder0Pos++;
    if (encoder0Pos == 2)tt = 77;
    newTime = millis();
    distance = encoder0Pos*6.28;
    float tInterval = (newTime - oldTime);
```

```
      velocity = 6.28/(tInterval/1000);

      int sensorNumber = ceil(distance/30);
      gVelocity = givenSpeed2[sensorNumber];
//    if (gVelocity == 99){
//      ESC.write(25);//
//    }
//    else if (gVelocity == 98){
//      ESC.write(22);
//    }
//    else if(gVelocity ==100){
//      ESC.write(0);
//    }
      if (velocity < (gVelocity)){
           ESC.write(16);
      }
      else if (gVelocity == 0){
        ESC.write(0);
        servo.write (100);
      }
      else if (((velocity > 22)&& (velocity > (gVelocity))) && sensorNumber>2){
        ESC.write (0);
      }
      else ESC.write(10);//這裡原本是
      //Serial.println(velocity);

      oldTime =newTime;
}
```

## Revised midterm car

```
#include <SPI.h>
#include <SD.h>
#include <Servo.h>
File myFile;
Servo ESC;
Servo servo; //brake;
```

```
Servo servot; //turning;
int x;


//infrared sensors
const byte ir1 = 3;//infrard #one//不能用1
const byte ir2 = 4;
const byte ir3 = 5;
const byte ir4 = 6;
const byte ir5 = 7;
const byte irEncoder = 2;//notice only certain pins can be use as attachinturrupt:2,3,18,19,20,21 for mega
byte irr1;//infrared read 1//it's the left most sensor
byte irr2;
byte irr3;
byte irr4;
byte irr5;
byte irrEncoder;
byte Read = 0;//read position data from infrared
byte oldRead[10]; //Read_Queue
byte Infrared_history = 0;//????????????????????????????????????????????

//Turning PID Value---------------------------------------------------------

float error;
float oldError[10]; //error_queue
byte error_history = 0;
byte delay_time = 1000;
float integral = 0, derivative;//?????????????????
float Kp, Ki, Kd;
byte error_zero = 0;
byte error_low = 12;//need adjustments
byte error_medium = 18;
byte error_high = 25;

//Encoder
volatile long encoder0Pos = 0;
long newPos = 0;
```

```
long oldPos = 0;
unsigned long newTime = 0;
unsigned long oldTime = 0;
float velocity;
float oldVelocity;
float distance;
float acceleration;
float currentSpeed = 0;//this is the given condition by professors
float futureSpeed = 0;//this is also
//for controlling components
int brakeCommand = 0;//!!!!!
int brakeC[100] = {0,0,0,1,1,1,2,2,2,3};//brake range:???
int motorCommand = 0;
int motorC[100] = {1,1,1,1,1,1,1,1,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,

                   0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,  };//the command data from our trails   range:0-10
int turningCommand = 0;
float controlUnite = 20;

//SD module




/////////////////////////////////////////////////////////////////////////////////
//

////////////////////////////////////////////////////////////////////////////////
void setup()
{
 //pins for infrared and encoder
 pinMode(ir1,INPUT);
 pinMode(ir2,INPUT);
 pinMode(ir3,INPUT);
```

```
 pinMode(ir4,INPUT);
 pinMode(ir5,INPUT);
 pinMode(irEncoder,INPUT);

 //the function to count encoder. Can interrupt the main loop any time it get the signal
 Serial.begin(9600);

//motors setup
  ESC.attach(9,1000,2000);
  servo.attach(11,1000,2000);
  servot.attach(10,1000,2000);
  ESC.write(180);
  delay(1000);
  ESC.write(0);
  delay(3000);
//

//??adjust later
 if (!SD.begin(53)) {
    Serial.println("initialization failed!");
    while (1);
  }
  SD.remove("data.txt");

 }

 ///////////////////////////////////////////////////////////////////////////////
 void loop() {
  //speed
  Encoder();//v
  speedControl();
  BLDC();
  turn();
  infra();
 }
 void doEncoder(){//count the number of marks past
```

```
        encoder0Pos++;
        myFile = SD.open("data.txt", FILE_WRITE);
        float a = encoder0Pos;
        myFile.print(a);
        myFile.print("\t");
        myFile.println(millis());
        myFile.close();
    }
    void Encoder(){
      newPos = encoder0Pos;
      newTime = millis();
      velocity = (newPos-oldPos) * 1000 /(newTime-oldTime);//!!!!!!!!!!!change 1000 into another constant(related to the wheel diameter and marks per round

      distance = newPos*6.28319;//
      acceleration = (velocity- oldVelocity)/ (newTime-oldTime);//is it needed? or just use the delay?
      Serial.print (distance);
      Serial.print ("\t");
      Serial.println (velocity);

      //myFile = SD.open("testtt.txt", FILE_WRITE);
      //myFile.print(newTime);
      //myFile.print("\t");
      //myFile.println(newPos);
      //myFile.close();


      oldPos = newPos;
      oldVelocity = velocity;
      oldTime = newTime;
    }
    void getFutureSpeed(){

    }
    void speedControl(){
       int currentPos = distance/controlUnite;
       motorCommand = motorC[currentPos];
```

```
  brakeCommand = brakeC[currentPos];
  }
void BLDC(){
  int value = (motorCommand)*18;
  ESC.write(value);
}
void infra(){
  irr1 = digitalRead(ir1);
  irr2 = digitalRead(ir2);
  irr3 = digitalRead(ir3);
  irr4 = digitalRead(ir4);
  irr5 = digitalRead(ir5);
  Serial.println(irr1);
  Serial.println(irr5);

}
void turn(){
   if(irr1==LOW&&irr5==LOW){
    servot.write(94);
  }
  else if(irr1==HIGH&&irr5==LOW){
    servot.write(80);

  }
  else if(irr2==HIGH&&irr4==LOW){
    servot.write(84);
  }
  else if(irr1==LOW&&irr5==HIGH){
    servot.write(108);
  }
  else if(irr2==LOW&&irr4==HIGH){
    servot.write(104);
  }
  else{
    servot.write(94);

  }
  delay(10);
```

```
}

void Brake(){
    int value = (brakeCommand)*30;
    servo.write(20);
}
```

Final car

```
#include <SPI.h>
#include <Servo.h>
#include  <SoftwareSerial.h>
Servo ESC;
Servo servob; //brake;
Servo servot; //turning;

SoftwareSerial BTSerial(10, 11);
//infrared sensors
const byte ir1 = 3;//infrard #one//不能用1//it's the left most sensor
const byte ir2 = 4;
const byte ir3 = 5;
const byte ir4 = 6;
const byte ir5 = 7;
const byte ir6 = 12;
const byte ir7 = 13;
const byte irEncoder = 2;//notice only certain pins can be use as attachintu
rrupt:2,3,18,19,20,21 for mega
byte irr1;//infrared read 1
byte irr2;
byte irr3;
byte irr4;
byte irr5;
byte irr6;
byte irr7;
byte irrEncoder;
byte Read = 0;//read position data from infrared
```

```

float error;
byte error_zero = 0;
byte error_low = 1.5;//need adjustments
byte error_medium = 2;
byte error_high = 2.7;
byte error_extra = 3.3;

//PID
float olderror =0;
float P,I,D;
int PIDvalue = 0;
float Kp = 6;
float Ki = 0;
float Kd = 6;//4;

//Encoder
volatile long encoder0Pos = -16;
long newPos = -16;
long oldPos = -16;

//unsigned long newTime = 0;
//unsigned long oldTime = 0;
volatile unsigned long  newTime = 0;
volatile unsigned long  oldTime = 0;
volatile unsigned long timediff = 0;
volatile float velocity;
//float velocity;
float oldVelocity;
float distance = -80;
float unit_dist = 6.863;

int counter = 4;
int counter2 = 1;
int chauCar =0;

//超車
int leave =0;
```

```
unsigned long  leaveTime = 0;
int firstTime = 0;
int goBack = 0;

int ESCcommand = 0;

int x = 0;
int otherDist = 0;
int start =0;
//int Around = 225;//no, it is in fact half round XD
int Around = 225;

int times =0;
////////////////////////////////////////////////////////////////////////////////
void setup()
{
 //pins for infrared and encoder
 pinMode(ir1,INPUT);
 pinMode(ir2,INPUT);
 pinMode(ir3,INPUT);
 pinMode(ir4,INPUT);
 pinMode(ir5,INPUT);
 pinMode(ir6,INPUT);
 pinMode(ir7,INPUT);
 pinMode(irEncoder,INPUT);
  BTSerial.begin(38400);

 attachInterrupt(digitalPinToInterrupt(irEncoder), doEncoder, RISING);////rising: voltage change from low to high/

 Serial.begin(9600);


//motors setup
  ESC.attach(9,1000,2000);
//  servob.attach(11,1000,2000);//this is for braking
    servot.attach(8,1000,2000);
```

```
  servot.write(90);
  ESC.write(60);
  delay(1000);
  ESC.write(0);
  delay(2000);
  int n = 0;
  int initializer = 100;
while (n<10){
  BTSerial.write(initializer);
  n++;
  delay (500);
  }
//  ESC.write(28);
//  delay(500);

}

////////////////////////////////////////////////////////////////////////////////
void loop() {//a concept of counter: the control of direction and speed can be in different delay
 //speed-------------------------------------------------
 if (counter == 4){
  Encoder();
  Bluetooth();
  speedControl();
  counter = 0;
  }
  else counter++;
 //direction---------------------------------------------
 Infrared();
 PID();
 Turn();
 delay(50);//we should decide the delay time so tahat it can get reasonable result. maybe I should buy the plate? If the time is too short, the velocity calculation should be changed
}

```

```
void doEncoder(){//count the number of marks past
    encoder0Pos++;
    newTime = millis();
    timediff = newTime - oldTime;
}

void Encoder(){
 newPos = encoder0Pos;

 if (newPos% 225<97)unit_dist = 5.155;
 else unit_dist = 5.368;
 distance = distance +(newPos - oldPos)* unit_dist;//cm

 velocity = (newPos-oldPos) * unit_dist *1000 /(newTime-oldTime);//

// Serial.print (newPos);
// Serial.print ("\t");
// Serial.println (distance);

 oldPos = newPos;
 oldTime = newTime;

}

void Bluetooth(){
//     if (BTSerial.available()){
//     x =BTSerial.read();
//     while(x<otherDist-128)x+=256;
//     otherDist = x;
//     Serial.print(distance);
//     Serial.println(x);
//     }
//
if (counter2 ==1){
  x = distance;
  if (x<0)x = 50;
  else {
    x = x%256;
```

```
  }
BTSerial.write(x);
Serial.print(x);
Serial.print("\t");
Serial.println(newPos);
counter2 =0;}
else counter2 ++;
}


void speedControl(){
//  if (velocity>40)ESC.write(15);
//  else if (velocity<35)ESC.write(26);
//  else ESC.write(20);
if (start <7){
  ESCcommand = 28;
  start++;
}
else if (newPos >218+Around &&newPos <260+Around){
  if (velocity>32)ESCcommand =12;
  else if (velocity<27)ESCcommand = 16;
  else ESCcommand = 16;
}
else if (newPos >Around*3+68 &&newPos <Around*3+115){
  if (velocity>32)ESCcommand =12;
  else if (velocity<22)ESCcommand = 16;
  else ESCcommand = 14;
}
else {
  if (velocity>50)ESCcommand =11;
  else if (velocity<40)ESCcommand =21;
  else if(velocity <45)ESCcommand = 15;
  else ESCcommand = 13;
}
  ESC.write(ESCcommand);
  }

void Infrared() { //Convert the read data to a certain value
```

```
    olderror = error;
    irr1 = digitalRead(ir1);
    irr2 = digitalRead(ir2);
    irr3 = digitalRead(ir3);
    irr4 = digitalRead(ir4);
    irr5 = digitalRead(ir5);
    irr6 = digitalRead(ir6);
    irr7 = digitalRead(ir7);
    if( irr5 == HIGH )error = 0;
    else if ( irr4 == HIGH )error = -error_low;
    else if ( irr6 == HIGH )error = error_low;
    else if ( irr3 == HIGH )error = -error_medium;
    else if ( irr7 == HIGH )error = error_medium;
    else if ( irr2 == HIGH )error = -error_high;
    else if ( irr1 == HIGH )error = -error_extra;
    else {error = olderror; leave++;}
  }

  void PID(){
    P = error;
    I = I + error;
    D = error-olderror;
    PIDvalue = (Kp*P) + (Ki*I) + (Kd*D);
    if (PIDvalue>10) PIDvalue=10;
    else if(PIDvalue<-19)PIDvalue=-19;
  }


  void Turn(){//more control to be added(combine with the encoder, change of middle value(more like tuning
    if (times == 0 &&newPos >198+Around){
    if (newPos >198+Around &&chauCar ==0){//to go out
      servot.write(115);
      if (firstTime ==0){leaveTime =millis(); firstTime++;}
      if (millis() >leaveTime+700){chauCar=1;error = error_zero;goBack=1;}
    }
    else if(goBack ==1){//to go straight
```

```
        if ( irr7 == HIGH || irr6 == HIGH ){servot.write(60);delay(700);goBack =0;firstTime = 0;chauCar =2;}
    }
    else if (newPos>235+Around &&chauCar ==2){//to go back
        servot.write(70);
        if (firstTime ==0){leaveTime =millis(); firstTime++;}
        if (millis() >leaveTime+800){chauCar=3;error = error_zero;goBack=2;}
    }
    else if(goBack==2 ){//to go back
        if ( irr2 == HIGH || irr1 == HIGH ){servot.write(125);delay(1100);error = error_zero;goBack =0;firstTime =0;chauCar =0;times =1;}
    }

        else servot.write(90+PIDvalue);
    }
    /////////////////////////////////////////////////////////////////////////////////////////////////////////////
    else if(times ==1&& newPos >198+Around*2){
   if (newPos >198+Around*2 &&chauCar ==0){//to go out
        servot.write(115);
        if (firstTime ==0){leaveTime =millis(); firstTime++;}
        if (millis() >leaveTime+700){chauCar=1;error = error_zero;goBack=1;}
    }
    else if(goBack ==1){//to go straight
        if ( irr7 == HIGH || irr6 == HIGH ){servot.write(60);delay(700);goBack =0;firstTime = 0;chauCar =2;}
    }
    else if (newPos>235+Around*2 &&chauCar ==2){//to go back
        servot.write(70);
        if (firstTime ==0){leaveTime =millis(); firstTime++;}
        if (millis() >leaveTime+800){chauCar=3;error = error_zero;goBack=2;}
    }
    else if(goBack==2 ){//to go back
        if ( irr2 == HIGH || irr1 == HIGH ){servot.write(125);delay(1100);error = error_zero;goBack =3;chauCar =10;times =2;}
    }
        else servot.write(90+PIDvalue);}

```

```
    else servot.write(90+PIDvalue);
}
```

## A.3 Reference


[1] https://www.sefiles.net/merchant/823/images/site/caliper_brake_600w.jpg

[2]http://dlearn.ncue.edu.tw/base/10001/course/10078922/content/C12_BriefNotes_Bernoulli%20Equations.pdf

[3] http://airfoiltools.com/airfoil/details?airfoil=naca2418-il

[4] Airfoiltools.com. (2020). Airfoil Tools.
http://airfoiltools.com/compare/index

[5]UIUC Propeller Data Site.
https://m-selig.ae.illinois.edu/props/volume-1/propDB-volume-1.html#Graupner

[6]"Viscosity of Air, Dynamic and Kinematic", Engineers Edge.
https://www.engineersedge.com/physics/viscosity_of_air_dynamic_and_kinematic_14483.htm

[7]chapter3 battery figure
https://www.google.com/url?sa=i&url=https%3A%2F%2Fgoods.ruten.com.tw%2Fitem%2Fshow%3F21546097611125&psig=AOvVaw1KBtxd9kI37MAyzQ6exPL_&ust=1593159193949000&source=images&cd=vfe&ved=0CA0QjhxqFwoTCPir5tDCnOoCFQAAAAAdAAAAABAI

[8]chapter 3 ESC figure
https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.robotistan.com%2F80a-esc-brushless-motor-driver&psig=AOvVaw2dk4feQeOzbbB6I7iUadaE&ust=1593159453475000&source=images&cd=vfe&ved=0CA0QjhxqFwoTCPjD0tHDnOoCFQAAAAAdAAAAABAJ

[9]caliper_brake
https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.trekbikessouthcarolina.com%2Fabout%2Fbasic-bicycle-anatomy-101-brake-systems-pg437.htm&psig=AOvVaw1B1DdlAfEUcWw6PG6it-PE&ust=1593230922772000&source=images&cd=vfe&ved=0CA0QjhxqFwoTCJDzrO3NnuoCFQAAAAAdAAAAABAD

[10]
https://books.google.com.tw/books?id=twEAAAAAMBAJ&pg=PA76&lpg=PA76&dq=A+high+static+stiffness+helps+the+car+complete+the+task+smoothly&source=bl&ots

=NY9vrkWACN&sig=ACfU3U3XqairWaJPCZqZfZ9fQ-rV_cNNJQ&hl=zh-TW&sa=X&ved=2ahUKEwjuvJWs057qAhWFKqYKHRXSCkAQ6AEwDXoECAwQAQ#v=onepage&q=A%20high%20static%20stiffness%20helps%20the%20car%20complete%20the%20task%20smoothly&f=false
session 9.2~9.4
[11]Moving Reference Frame for Computational Fluid Dynamics
https://www.symscape.com/blog/moving-reference-frame-for-cfd
[12]Boolean Operation
https://www.sciencedirect.com/topics/engineering/boolean-operation
[13]Shared topology in ANSYS
http://help.spaceclaim.com/dsm/4.0/en/Content/ANSYS_SharedTopology.htm
[14]CFD models
https://www.researchgate.net/post/What_is_the_difference_between_k_epsilon_and_k_omega_models_in_CFD_and_how_does_it_affect_flow_in_a_shell_and_tube_heat_exchanger
[15] https://en.wikipedia.org/wiki/Drag_equation
[16] Actuator Disc
https://www.sciencedirect.com/topics/engineering/actuator-disc
[17] Actual Disk Theory,
Figurehttps://ars.els-cdn.com/content/image/3-s2.0-B9780081009758000035-f03-01-9780081009758.jpg?_
[18] BERNOULLI AND ENERGY EQUATIONS
http://dlearn.ncue.edu.tw/base/10001/course/10078922/content/C12_BriefNotes_Bernoulli%20Equations.pdf
[19] Noise
https://www.researchgate.net/figure/Free-body-diagram-of-the-car-as-the-car-moves-along-the-circular-track-with-the-minimum_fig5_41822987
[20] Decibel table figure
https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.pinterest.com%2Fpin%2F849984129649503022%2F&psig=AOvVaw2zc5fn5dLYTs0y3f3qL6DH&ust=1593235315661000&source=images&cd=vfe&ved=0CA0QjhxqFwoTCPDZjZrenuoCFQAAAAAdAAAAABAD
[21]
https://openoregon.pressbooks.pub/app/uploads/sites/42/2018/08/Equilibrium-body.png
[22]
http://curta.dlinkddns.com/html_tutoring/PE/HVAC_Equipment_Systems/fancurve.htm